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## THE EFFECTIVENESS OF RANDOM MFSK FREQUENCY-HOPPING ECCM RADIOS AGAINST WORST-CASE PARTIAL-BAND NOISE JAMMING

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FINAL REPORT

AUGUST 1986

PREPARED FOR U.S. ARMY RESEARCH OFFICE

> CONTRACT CAAG29-85-C-0021

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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available real-time information on relative powers of signal, noise, and jamming. These include adaptive gain control, clipping, hard-decision, and selfnormalizing (nonparametric) schemes. It is shown that a simple, self-normalizing receiver, using no jamming state information or measurements, can perform nearly as well as one using a priori values of received noise-plus-jamming powers for adaptive gain control. It is also demonstrated that a hard-decision receiver (majority logic decoding of the L repetitions) achieves an ECCM effect and is viable if the SNR is high. Although the BER varies with jammer power in much the same way as for conventional FH/MFSK (given the parameters M, L, and the unjammed SNR), including a diversity gain for high SNR, FH/RMFSK in general is more vulnerable to WCPBNJ for M greater than 2. Therefore, it is concluded that implementation of effective diversity schemes is feasible, and that for a binary system the additional complexity of random hopping can be assessed to the additional protection gained against follow-on jamming.

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THE EFFECTIVENESS OF RANDOM MFSK FREQUENCY HOPPING ECCM RADIOS AGAINST WORST-CASE PARTIAL-BAND NOISE JAMMING

#### 1.0 INTRODUCTION

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. . The purpose of this study is to provide the Army a direct comparison of the uncoded bit error rate (BER) performance of several receiver anti-jam processing schemes with varying degrees of implementation complexity, under the same conditions of system noise and jamming. In this manner the engineering cost of complex anti-jam receiver designs can be weighed against their effectiveness, as illustrated in Figure 1.0-1. In what follows we discuss the issues surrounding the work and summarize our effort.

#### 1.1 BACKGROUND

In the Electronic Warfare (EW) environment, where a "battle" is waged between the communicating party and the party that is engaged in the pursuit of disrupting the communicator's link, strategy plays an important and fundamental role for the opposing parties. To the communicating party, the opponent's Electronic Support Measures (ESM) and Electronic Counter~ measures (ECM) pose as threats. ESM involves essentially activities for spectrum surveillance and direction finding by passive means, whereas ECM involves activities for the purpose of victimizing the communicator's link. Jamming is an active measure of accomplishing ECM objectives. It is, therefore,





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easy to recognize that fixed-frequency radios are very much vulnerable to ESM and ECM attacks. Communication systems that are designed to counter or mitigate the effects of ESM or ECM attacks are termed Electronic Countercountermeasures (ECCM) radios, or jam-resistant communication systems.

In principle, there exist many different schemes which can provide the communicator with jam-resistant radio capabilities; Direct Sequence (DS) spread-spectrum and Frequency-Hopping (FH) spread-spectrum systems are two generic schemes. While the DS/SS system requires phase coherence over the system's wide operational bandwidth in its implementation, the FH/SS system does not. The fact that most of the tactical ECCM radios are of FH/SS type is based not only on this reason, but also on the fact that the attainable "processing gain" is achieved with less complexity and cost.

#### 1.1.1 Jamming Strategy Against Frequency-Hopping Radios

ECCM radio designs are based on the desire to suppress the total jamming power by an amount equal to the processing gain, defined as the ratio of FH system bandwidth to the receiver noise bandwidth. The difference between the processing gain in dB and the SNR in dB required for traffic demodulation is the (anti-jam) margin that the communicator can use to tolerate an excess of jammer power over signal power at the system front end. The intelligent jammer, however, does not spread his power over the entire system bandwidth, so that the definition and effects of processing gain will not apply.

The jammer may employ a partial-band noise jamming strategy, in which the available jammer power is placed in a fraction  $(\gamma)$  of the radio

1-3

system bandwidth, as illustrated in Figure 1.1-1. Assuming that total power is fixed, there is an optimum value of  $\gamma$  which achieves the most effective tradeoff of the probability of jamming and the probability of error when jammed, thus achieving a maximum overall error rate for the given amount of jammer power.

The jammer may, if it is feasible, concentrate his power further if he can intercept the hopping signal in real time and immediately broadcast a strong burst of noise in the frequencies near the signal (follow-on jamming). This type of jamming can be successful against FH systems in which a conventional narrowband communications signal is slowly hopped by simple translation in frequency.

#### 1.1.2 ECCM Waveforms

Along with using hopped signals, the communicator can exercise an additional degree of freedom by employing a low energy density waveform to minimize interceptions by a potential jammer. Such a waveform is FH/MFSK using a number of hops per symbol (L), a kind of repetition code or diversity [5] to permit transmission at lower power and/or to combat fading. The conventional form of FH/MFSK is illustrated in Figure 1.1-2; once a symbol has been chosen for a given interval  $T_s$ , a conventional MFSK signal is generated and randomly hopped (translated) L times at a rate  $R_H = L/T_s = 1/\tau$ before a new symbol is keyed. Because the M possible symbol frequencies are adjacent, this waveform is vulnerable to follow-on repeat jamming, unless the hopping rate can be made very high.

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FIGURE 1.1-1 THERMAL NOISE AND PARTIAL-BAND NOISE JAMMING MODEL



FIGURE 1.1-2 TYPICAL L HOPS/SYMBOL FH/MFSK WAVEFORM PATTERN

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If the individual symbol frequencies of the MFSK symbol are assigned randomly on a per hop basis, as illustrated in Figure 1.1-3, then repeat jamming is less likely to produce an error since the symbol frequencies (at RF) are no longer adjacent [6,7]. (We shall refer to this waveform as FH/RMFSK with L hops per symbol.) It has been shown [6] that, for the special case of one hop/bit binary systems (M=2) and very little system or thermal noise ( $E_b/N_0 = 30$  dB), the two forms of FH/BFSK achieve the same performance in optimum partial-band noise jamming. This suggests that the random MFSK waveform will perhaps be a better choice for L > 1 and M > 2, although it has not been established as a fact that its performance in partial-band noise is always equal to that of the conventional system, while offering additional protection against follow-on jamming.

The FH/RMFSK implementation is more complex, and the study in this report will permit the cost of this additional complexity to be weighed against its performance, compared to that of the more conventional FH/MFSK as calculated by LAI [1].

#### 1.1.3 <u>Motivation for the Proposed Random Hopping</u>

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As we have stated above, the proposed FH/RMFSK waveform is less vulnerable to follow-on or repeat jamming than is a conventional FH/MFSK systems with M contiguous signalling frequencies. In addition, the FH/RMFSK waveform is less vulnerable to tone jamming, since the randomized selection of the M frequencies reduces the amount of structure in the signal. This makes it

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FIGURE 1.1-3 TYPICAL L HOPS/SYMBOL FH/RMFSK WAVEFORM PATTERN
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much more difficult for a tone jammer to implement an optimum jamming strategy consisting of one jamming tone per M-ary symbol: the lack of structure in the hopping gives the jammer no features to exploit to insure a tone hits the symbol; thus the jammer is forced to divide his available power up into more tones, resulting in a lessened effect on the communications link when it hops into a jammed slot.

Therefore, the motivation for considering the use of FH/RMFSK as an LPI anti-jam communications system design is based upon a desire to lessen or reduce vulnerability to certain more sophisticated jamming threats, such as follow-on jamming and tone jamming. However, before the system can be considered a viable design candidate, its performance under the less sophisticated jamming, namely partial-band noise jamming, must be known.

# 1.1.4 <u>Rationale for the Exact Analysis of FH/MFSK System Performance</u> <u>In Partial-Band Noise Jamming</u>

It is known that the advantage of an M-ary orthogonal modulation system rests on the fact that the scheme requires less energy per data bit transmission than other available modulation schemes. Cost-effective implementation (efficient non-coherent detection) is another reason in selecting M-ary FSK waveforms by designers of ECCM radios. Recently, Hughes Aircraft Company has conducted studies for U.S. Army CECOM on feasibility of AJ/LPI ECCM techniques, employing L-hops per symbol FH/MFSK [8].

Exact knowledge of performance measures and vulnerability of L-hops per symbol FH/MFSK SS systems has not been available until recently,

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and that of FH/RMFSK is yet to be determined. Workers in this field previously held the view that M-ary system performance measures could be estimated once the performance measures of the binary systems are available. This view was based on the conventional wisdom of applying the "union bound". As is well known, once we know the binary system performance, that of the M-ary system can be approximated by the union bound given by

$$P_{M}(e;E_{s}) \leq (M-1) P_{2}(e;E_{s})$$
 (1.1-1)

where  $P_2(e;E_s)$  is the probability of error for the binary system, using any pair of symbols from the set  $\{s_1(t), s_2(t), \ldots, s_M(t)\}$ , and  $P_M(e;E_s)$ is the M-ary system probability of error, where  $E_s$  is the symbol energy. The workers have also invoked the well-known relationship between the bit error probability and the symbol (K-bit word) error probability for the M-ary orthogonal system. That is,

$$P_{b}(e;E_{b}) = \frac{M}{2(M-1)} P_{M}(e;E_{s}).$$
 (1.1-2)

where  $P_b(e;E_b)$  denotes bit error probability and  $E_b$  is the energy per bit. By putting equation (1.1-1) into equation (1.1-2), we obtain the "union bound"based approximate-performance measure of the bit error probability of an MFSK systems, given by

$$P_{b}(e;E_{b}) \leq \frac{M}{2} P_{2}(e;E_{s}) = 2^{K-1} P_{2}(e;KE_{b})$$
 (1.1-3)

where

$$K = \log_2 M.$$
 (1.1-4)

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с. . In principle, one can use equation (1.1-3) to assess the performance of an M-ary orthogonal system. Our discovery, however, did not support this generality when the communication channel is of the non-exponential type. In an attempt to obtain an approximate performance measure of 2-hops per symbol FH/MFSK system under partial-band noise jamming environment for M=4, 8, 16, and 32, we have used equation (1.1-3) in applying the binary results, as shown in Figures 1.1-4 to 1.1-6, to three different receiver schemes. A surprising result is that as M is increased, bit error probability as given by the union bound is worsened for all three receivers! Interpretation of this result is that one needs to expend more energy per bit in the higher-order-message-alphabet orthogonal system, a result that is not supportable even on the basis of intuition; and is, indeed, contrary to the exact results shown in the figures.

The above paragraph is to point out that the "union bound" cannot be used when one considers non-Gaussian channels such as partial-band noise, as experienced by a FH/MFSK system. These channels are inverse linear channels, and they do not allow the union bounding techniques to be applicable in assessing M-ary system performances. Thus, one can conclude that exact analysis is necessary.

1.1.5 Extension of Uncoded Error Analysis to Coded Performance

While error-control coding is quite likely to be used by the communicator to counter any jamming effects, the analysis of total system performance may be usefully divided into two parts: uncoded performance and



FIGURE 1.1-4 COMPARISON OF THE EXACT ANALYSES WITH THE UNION BOUNDS FOR THE SQUARE-LAW LINEAR COMBINING RECEIVER



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FIGURE 1.1-5 COMPARISON OF THE EXACT ANALYSES WITH THE UNION BOUNDS FOR THE AGC RECEIVER



FIGURE 1.1-8 COMPARISON OF EXACT ANALYSES WITH THE UNION BOUNDS FOR THE CLIPPER RECEIVER

enhanced performance using coding. For comparison studies of anti-jam demodulation schemes such as we are proposing, it is sufficient to consider uncoded performance, since the coded system performance is proportional to the uncoded.

For example, for code words using n channel symbols the probability of word error for a bounded-distance decoding algorithm is [9]

$$P_{W} = \sum_{i=t+1}^{n} {\binom{n}{i}} P_{S}^{i} (1 - P_{S})^{n-i}$$
(1.1-5)

where  $P_s$  is the uncoded performance in terms of symbol errors and t is the number of correctable errors. This word error probability can be translated into an equivalent information bit error probability by a formula appropriate to the particular coding and decoding algorithms.

#### 1.2 ECCM PROCESSING

Once the FH/MFSK or FH/RMFSK waveform has been dehopped at the intended receiver, the L hops constituting the MFSK symbol can be combined in several ways. It has been shown [10] that the conventional method of summing up the (non-coherent) L hop energies, although effective against fading, produces a BER which increases with L against optimum partial-band noise jamming. Therefore, a number of non-linear combining schemes have been studied, based on weighting the dehopped and envelope-detected hops in some fashion to discriminate against those hops which have been jammed [1, 11, 12].

Using these nonlinear combining schemes it has been shown for FH/MFSK that the use of L > 1 hops per symbol can be understood as providing a kind of diversity improvement against the jamming, depending on the system noise level.

It has not been determined how a FH/RMFSK waveform with L hops per symbol will perform against optimum partial-band noise, whether using conventional or nonlinear soft-decision combining of the hops.\*

### 1.2.1 <u>Examples of Receiver Effectiveness Computations for FH/MFSK</u>

Under contract to the Office of Naval Research, LAI has studied in great detail the uncoded performances of frequency hopped BFSK and MFSK communication systems under optimum partial-band noise jamming [1, 10, 11, 13, 14, 15]. The focus of these efforts has been to determine both the optimum partial-band jamming strategy and the most effective anti-jam receiver processing schemes for this type of modulation, using exact analyses which include the system's thermal noise. One of the chief results of our work has been the discovery that conclusions drawn from previous, approximate studies neglecting thermal noise are not strictly valid. It had been commonly asserted that the use of multiple hops per symbol in FH/MFSK systems provides a diversity gain improvement against optimum partial-band jamming in much the same way that it does against the effect of fading on the signal. We have been able to show that this improvement does not exist for the conventional (linear combining) receiver, and we have demonstrated quantitatively

<sup>\*</sup>In a recent paper [16], FH/RMFSK performance with L hops per symbol has been shown for a receiver using hard decisions. The binary hard-decision case was also analyzed in [17].

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that a limited improvement holds for certain nonlinear hop combining receiver processing schemes ("metrics"), as a function of the system's thermal noise.

A generic model of FH/MFSK square-law receivers is given in Figure 1.2-1. Among the processing schemes, represented by the function  $f_k(\cdot)$  in the figure prior to the accumulation of soft decision statistics  $\{z_m\}$ , are those listed in Table 1.2-1. The performance of the conventional, linear combining receiver in optimum partial-band noise jamming was calculated directly and compared to that of the three nonlinear combining receivers. For the calculation, the bit error probabilities were expressed by

$$P_{b}(e) = \sum_{\ell=0}^{L} p_{\ell} P_{b}(e|\ell),$$
 (1.2-1)

where  $p_2$  is the probability that 2 out of L hops constituting a given symbol are jammed, and  $P_b(e|2)$  is the bit error probability given that 2 hops are jammed. For conventional FH/MFSK, we have assumed that

$$\mathbf{p}_{\mathfrak{L}} = \begin{pmatrix} L \\ \mathfrak{L} \end{pmatrix} \gamma^{\mathfrak{L}} (1-\gamma)^{\mathbf{L}-\mathfrak{L}}$$
(1.2-2)

based on all of the M symbol frequency slots being jammed on a given hop, with probability  $\gamma$  (the fraction of the system bandwidth which is jammed), or none of them being jammed, with the probability 1- $\gamma$ .

For each receiver type and values of  $E_b/N_0$  and  $E_b/N_J$ , the maximum bit error probability was found as a function of  $\gamma$ , the partial-band jamming





### TABLE 1.2-1

### DESCRIPTIONS OF THE RECEIVERS

RECEIVER TYPE	SPECIFICATION OF z <sub>ik</sub> =f <sub>k</sub> (x <sub>ik</sub> ), i=1,2,,M	REMARKS
LINEAR COMBINING RECEIVER	z <sub>ik</sub> = x <sub>ik</sub>	Direct Connection (Linear Combining)
CLIPPER RECEIVER	z <sub>ik</sub> { x <sub>ik</sub> , x <sub>ik</sub> < n n, x <sub>ik</sub> > n	Soft Limiter (Nonlinear Combining)
AGC RECEIVER	$z_{ik} = x_{ik} / \sigma_k^2$ $\sigma_k^2 = \begin{cases} \sigma_N^2, \text{ if not jammed} \\ \sigma_N^2 + \sigma_J^2, \text{ if jammed} \\ (\sigma_k^2 = \text{measured}) \end{cases}$	Adaptive Gain Control (Nonlinear Combining)
SELF-NORMALIZING RECEIVER	$z_{ik} = \frac{x_{ik}}{\sum_{i=1}^{M} x_{ik}}$	Practical Realization of AGC Using In-Band Measurements

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fraction. These calculations revealed significant differences among the receiver types in the optimum value of  $\gamma$  as well as in the bit error probability. For example, in Figure 1.2-2, we show that for M=8 that the jammer's optimum  $\gamma$  is much more sensitive to the value of L, the number of hops per MFSK symbol, for the AGC receiver than for the clipper receiver. Therefore the jammer must have more accurate information on the modulation parameters in order to be as effective as possible against the AGC receiver.

Another typical result is the comparison shown in Figure 1.2-3, also for M=8, and for L=2 hops per symbol. We see that the (ideal) AGC form of ECCM receiver processing is significantly better at combatting the effects of the jamming, and that the clipper receiver also improves the BER, but not as much.

Figure 1.2-4 shows the effect of increasing  $E_b/N_0$  so as to provide a lower bit error probability in the absence of jamming for the AGC receiver with M=4 and L as a paramter. We see that under these conditions, the optimum choice of L includes higher values of the number of hops per symbol before increased noncoherent combining loss dominates and forces a choice of a lower value of L.

Figure 1.2-5 illustrates the performance as  $E_b/N_0 \rightarrow \infty$ , i.e. no thermal noise, for FH/BFSK (i.e. M=2). We see that in the absence of thermal noise, the optimum value of L increases without limit as  $E_b/N_J$  increases. A similar result holds for the case of M>2.



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FIGURE 1.2-2 OPTIMUM JAMMING FRACTION (Y) VS. NUMBER OF HOPS/SYMBOL (L) FOR THE AGC AND CLIPPER FH/MFSK (M=8) RECEIVERS WHEN  $E_b/N_0 = 9.09$  dB WITH  $E_b/N_J$  AS A PARAMETER (FOR 10<sup>-5</sup> ERROR RATE WITHOUT JAMMING)



FIGURE 1.2-3 OPTIMUM PARTIAL-BAND NOISE JAMMING PERFORMANCE OF FH/MFSK (M= 8) SQUARE-LAW COMBINING RECEIVERS FOR L=2 HOPS/SYMBOL WHEN  $E_b/N_0$ =9.09 dB (FOR IDEAL MFSK (M=8) CURVE THE ABSCISSA READS  $E_b/N_0$ )



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FIGURE 1.2-4 OPTIMUM JAMMING PERFORMANCE OF THE AGC FH/MFSK (M=4) RECEIVER WHEN  $E_b/N_0 = 13.16$  dB WITH THE NUMBER OF HOPS/SYMBOL (L) AS A PARAMETER (FOR IDEAL MFSK (M=4) CURVE THE ABSCISSA READS  $E_b/N_0$ )



FIGURE 1.2-5 OPTIMUM JAMMING PERFORMANCE OF THE AGC RECEIVER FOR BFSK/FH WITH THE NUMBER OF HOPS/BIT (L) AS A PARAMETER WHEN THERMAL NOISE IS ABSENT (FOR IDEAL BFSK CURVE THE ABSCISSA READS E /N )

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Our exact calculations permit the construction of composite curves such as illustrated in Figure 1.2-6, in which the performance of the AGC receiver processing scheme for FH/BFSK (M=2) is shown for the optimum L values at different thermal noise levels. It is seen that for  $E_b/N_0 > 15$  dB, the use of the proper number of hops per bit enables the communication systems to recover the performance of unjammed BFSK to within 3 dB of SNR. The results for  $E_b/N_0 < 15$  dB are very sensitive to thermal noise, and had not been predicted by other workers, who ignored thermal noise.

#### 1.2.2 Impact of Random FH/MFSK (FH/RMFSK) on Analysis

Evaluation of the BER performance of ECCM receiver processing schemes becomes significantly more complex for M>2 and L>1 when the MFSK symbol frequency assignments are not contiguous but each randomly chosen to be anywhere in the hopping band. The complexity consists in there being many more jamming events than those reflected in equation (1.2-1), since now on each hop there can be from 0 to M of the dehopped symbol frequency slots jammed on a given hop (rather than 0 or M). The probability of bit error expression accordingly must be generalized, giving

$$P(e) = \sum_{\ell_1=0}^{L} \sum_{\ell_2=0}^{L} \cdots \sum_{\ell_M=0}^{L} Pr(\ell_1, \ell_2, \dots, \ell_M) P(e|\ell_1, \ell_2, \dots, \ell_M) (1.2-3)$$

in which the number of jammed hops in each symbol channel is explicitly enumerated and accounted for in the conditional probability of error calculations.



FIGURE 1.2-6 PROBABILITY OF BIT ERROR VS. E<sub>b</sub>/N<sub>j</sub> FOR AGC FH/BFSK RECEIVER USING OPTIMUM NUMBER (L) OF HOPS/BIT, FOR DIFFERENT VALUES OF E<sub>b</sub>/N<sub>0</sub> IN WORST-CASE PARTIAL-BAND NOISE JAMMING

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From equation (1.2-3) it is apparent that up to  $(L + 1)^{M}$ jamming events may be distinguished, if it can be assumed that the symbol decision is affected only by the total numbers of jammed hops  $\{l_m\}$  in the M dehopped channels, rather than by the individual hop patterns. The sheer number of events can therefore become the major factor influencing the magnitude of the receiver effectiveness evaluation task in terms of computational effort. LAI has had experience in the computation of similar expressions in the connection with the evaluation of tone jamming effects on FH/MFSK systems [1].

#### 1.3 SUMMARY OF REPORT

In this section, we will first give a general description of the work. We then summarize the report organization and major findings.

### 1.3.1 General Description of Work and Approach.

In Sections 1.1 and 1.2 we discussed the fundamental issues concerning ECCM systems and ECCM processing. Now, we treat the more specific ECCM system which we have studied, namely FH/RMFSK in the presence of partialband noise jamming.

1.3.1.1 Receiver models studied.

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A generic soft-decision receiver structure for an FH/RMFSK waveform is shown in Figure 1.3-1. The incoming waveform is dehopped by mixing it separately with M hopping local oscillators controlled by replicas of the M possible hopping sequences available for transmission by the transmitter.



FIGURE 1.3-1 SOFT-DECISION RECEIVER FOR FH/RMFSK

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Thermal noise with power spectral density  $N_0$  is present over the entire bandwidth W. A fraction,  $\gamma$ , of the band is jammed by bandlimited white Gaussian noise of power spectral density  $N_J/\gamma$ , where  $N_J \triangleq J/W$  with J being the total jammer power. The jamming fraction,  $\gamma$ , is constrained to the range  $0 < \gamma \leq 1$ .

The relation between the jammed bandwidth  $\gamma W$  and the FH/RMFSK waveform is illustrated in Figure 1.3-2. On any given hop, anywhere from 0 to M of the possible signalling frequencies may have hopped into the jammed portion of the band; thus a multitude of jamming events may occur. Let the L hops for a given symbol be referred to individually by the index k (k = 1, 2,...,L). The jamming events for the kth hop can be described in terms of which of the M symbol frequencies are jammed, and which are not. In general there are 2<sup>M</sup> possibilities for a given hop, which we may specify by the indicator vector

$$\underline{\nabla}_{k} = (\nabla_{1k}, \nabla_{2k}, \dots, \nabla_{Mk}) \tag{1.3-1}$$

where

For the L hops comprising a symbol, there are  $2^{ML}$  possible jamming events, and these can be specified individually by the M × L indicator matrix  $[v] \equiv [v_{mk}]$ .



FIGURE 1.3-2 PARTIAL-BAND JAMMING OF FH/RMFSK

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Each dehopped channel, corresponding to one of the M possible symbols, is then passed through a bandpass filter of width B Hz and the filter output is envelope detected. The output of each linear envelope detector is subjected to a function  $f(\cdot)$ ; the form of this function defines the particular receiver structure.\* Table 1.3-1 gives the forms of  $f(\cdot)$  for the several receiver structures we include in the study. The modified envelopes are sampled once per hop and the samples in each channel are summed over the L hops comprising a symbol. The largest of these sums is selected and the index identifying the channel in which it occurred is outputted as the symbol decision.

As an alternative to the soft-decision receiver scheme described above, we may also consider the hard-decision receiver structure which is shown in Figure 1.3-3. The processing in this hard-decision receiver is identical with the soft-decision receiver up to the outputs of the samplers. In the hard-decision receiver, unlike the soft-decision receiver, the samples are not summed; rather, a symbol decision is made each hopping interval, giving a sequence of L decisions. These L decisions may be considered as a noise-corrupted received code-word in an M-ary repetition code wherein the transmitted symbol is repeated L times; thus the sequence is fed into an L-hop M-ary repetition code decoder which delivers the final decision as to which symbol was transmitted.

1.3.1.2 Jamming model and measure of effectiveness.

The partial-band noise jamming model was shown in Figure 1.1-2.

\*As long as  $f(\cdot)$  is a memoryless transformation, the order of applying  $f(\cdot)$  and the sampling may be interchanged without altering the receiver's performance.

# TABLE 1.3-1 RECEIVER PROCESSING FUNCTIONS STUDIED

RECEIVER TYPE	۴(۰)
Square-Law Linear Combining	$f(x_i) = x_i^2$
Square-Law with Clipper	$f(x_i) = \begin{cases} x_i^2, & x_i < \sqrt{\eta} \\ \eta, & x_i \ge \sqrt{\eta} \end{cases}$
Square-Law AGC	$f(x_i) = x_i^2 / \sigma_i^2$
Self-normalizing receiver	$f(x_{j}) = \frac{x_{1}^{2}}{\sum_{j=1}^{M} x_{j}^{2}}$



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FIGURE 1.3-3 HARD-DECISION RECEIVER FOR FH/RMFSK

The measure of the effectiveness of the jammer is the degradation of the communicator's bit error probability inflicted by the presence of the jamming. Since the bit error probability  $P_b(e)$  will depend upon the jamming event, we must average the error probability over the jamming events. Thus, the measure of effectiveness of the jamming is

$$P_{b}(e; E_{b}/N_{0}, E_{b}/N_{J}, \gamma, M, L) = \sum_{[v]} P_{b}(e; E_{b}/N_{0}, E_{b}/N_{J}, \gamma, M, L|[v]) \pi_{L}[v]$$
  
where  $\pi_{L}[v]$  is the probability of jamming event [v] occurring over the L hops  
of the M-ary symbol. Thus the required analysis may be divided into two parts:  
determination of  $\pi_{L}[v]$  and determination of  $P_{b}(e; E_{b}/N_{0}, E_{b}/N_{J}, \gamma, M,$   
 $L|[v]$ ). These two parts can then be combined to perform the final optimization,

namely finding the receiver performance under the optimum jamming fraction  $\gamma$ , max P<sub>b</sub>(e;  $\gamma$ ).

1.3.1.3 Organization of report.

In Section 2 we address parts of the analysis considered preliminary or containing aspects common to the several receiver types. This material includes enumeration of jamming events and analysis of their probabilities, as well as an analysis of the hard-decision receiver.

Sections 3 to 6 are devoted, respectively, to analysis and numerical results for the worst-case partial-band noise jamming error performances of FH/RMFSK using the linear combining receiver, the adaptive gain control (AGC) type receivers, the clipper receiver, and the self-normalizing receiver.

Section 7 first provides analysis and results for the performance of FH/RMFSK in follow-on noise jamming, then comparisons of RMFSK receivers S)

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with regard to their overall relative error performance, their performances in both RMFSK and MFSK, and their success in using diversity (multiple hops per symbol) to mitigate jamming effects.

Section 8 considers issues related to implementation of the FH/RMFSK receivers, including a discussion of possible measurement approaches to support the ECCM weighting schemes, and an assessment of the effect of using practical measurements (instead of <u>a priori</u> information) on the system performance. Conclusions and recommendations growing out of our study are included in Section 8 also.

1.3.2 Summary of Findings.

Here we only briefly cite the more significant findings from our study; more detailed information is contained throughout the report.

The overall significance of the work we have accomplished may be described as follows: For the first time, the expected performance of an FH/RMFSK system using L hops per symbol and soft decisions, in both thermal noise and worst-case partial-band jamming noise, has been derived and calculated. Moreover, we have demonstrated through direct analysis and calculation of bit error rate (BER) that the performances of certain practical soft-decision ECCM receivers (using no <u>a priori</u> or side information) are quite acceptable, being very close to those for idealized receivers (using <u>a priori</u> information on received noise and jamming conditions). While we have shown that the hard-decision receiver does implement a form of ECCM processing (not previously shown) against PBNJ in the most simple manner, it cannot be

considered a viable alternative unless the system's unjammed SNR is quite high.

Specifically, we find that:

(a) Generally random frequency hopping MFSK is more vulnerable to partial-band noise jamming than is conventional FH/MFSK for M>2 and L>1. However, for certain diversity weighting schemes the increased vulnerability is small enough to justify saying that the two hopping systems achieve comparable performance for M=2 or 4. For one combining scheme studied, the self-normalizing receiver, FH/RMFSK performs better than FH/MFSK for M=2.

(b) A diversity effect for L hops/symbol is observed for RMFSK using nonlinear hop combining, in the same manner as for MFSK and subject to the same condition that thermal noise is relatively small.

(c) Using optimum diversity values, if thermal noise is negligible  $(E_b/N_0 \ge 20 \text{ dB})$ , FH/RMFSK with ideal nonlinear combining can exhibit a nearly exponential dependence upon  $E_b/N_J$ , as opposed to an inverse linear one for no diversity; the jamming then is limited to inflicting about a 4 dB loss in system performance. However, this effect is very sensitive to the amount of thermal noise present, since the jammed BER cannot be better than the unjammed error, and the use of diversity tends to degrade the no-jamming performance due to noncoherent combining losses.

(d) Simple nonlinear combining receivers can duplicate the ideal receiver optimum diversity performance with about a one-dB loss when  $E_b/N_0^>$   $E_b/N_J$ ; the hard decision receiver can approach to within 2 dB with a sufficient-ly high  $E_b/N_0$ .

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### 2.0 PRELIMINARY ANALYSES

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The general approach to be followed in obtaining the probability of error for the multi-hops/symbol FH/RMFSK communications system under partial band noise jamming is to expand the total probability of error in terms of individual jamming events:

where P(e|jamming event) is the probability of error conditioned upon the occurrence of a particular jamming event. In Section 2.1, we consider a general formulation for this conditional probability, and in Section 2.2 the jamming events and their probabilities are developed. The computational procedures necessary for efficient evaluation of the error probability are discussed in Section 2.3. These analyses and procedures are applied to specific receiver structures beginning in Section 3.

#### 2.1 CONDITIONAL PROBABILITY OF ERROR

The generic form of the receiver to be analyzed for reception of FH/RMFSK is shown in Figure 2.1-1. In effect it is an M-channel receiver with IF frequencies  $f_1, f_2, \ldots, f_M$ ; M pseudorandom sequence generators, assumed to be in synchronism with the transmitter, command the frequency synthesizers used to tune the M channels to B-Hz wide frequency slots, one of which will be occupied by signal energy on a given hop. The message information is



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conveyed through selection of the (randomly-shifted) IF (symbol) frequency for transmission of signal energy. In order to determine at which symbol frequency the signal is present, each of the IF waveforms  $r_1(t), r_2(t), \ldots, r_M(t)$ is first subjected to envelope detection, then sampled before processing through memoryless, possibly nonlinear devices with transfer functions  $f(\cdot)$ . The outputs of these devices are the per-hop decision statistics  $\{z_{mk}\}$ , which are accumulated to form the final decision statistics

$$z_{m} = \sum_{k=1}^{L} z_{mk}$$
,  $m = 1, 2, ..., M$ . (2.1-1)

In the following subsections, we formulate the probability of error associated with the decision performed by the FH/RMFSK receiver, conditioned upon the possible jamming events.

#### 2.1.1 Assumed Signals, Noise and Jamming.

After dehopping, the received signal is assumed equally likely to be present in any one of the M channels for the entire symbol period  $T_s = L\tau$ , where  $\tau$  is the hop period and L is the number of hops per MFSK symbol. Without loss of generality, we assume that the signal with power S is in channel 1, or

 $s(t) = \sqrt{2S} \cos(\omega_1 t + \theta_k), \ (k-1)\tau < t \le k\tau, \ k = 1, 2, \dots, L, \qquad (2.1-2)$ where  $\theta_k$  is an arbitrary carrier phase and  $\omega_1 = 2\pi f_1$ .

Thermal noise is considered also to be present in each channel, and is assumed to be zero-mean narrowband Gaussian noise with variance  $\sigma_N^2 = N_0 B$ , where  $N_0/2$  is the (two-sided) noise power spectral density and B is the bandwidth of each channel. Thus for no jamming the samples of the M envelope detector outputs on the kth hop are the variables

$$x_{1k} = \left[ \left( \sqrt{2S} \cos \theta_{k} + \eta_{c1k} \right)^{2} + \left( \sqrt{2S} \sin \theta_{k} + \eta_{s1k} \right)^{2} \right]^{2}$$
(2.1-3a)

and

$$x_{mk} = (n_{cmk}^2 + n_{smk}^2)^{\frac{1}{2}}, m = 2, 3, ..., M,$$
 (2.1-3b)

where  $n_{cmk}$ ,  $n_{smk}$ , m = 1, 2, ..., M; k = 1, 2, ..., L, are the independent noise quadrature components in the channels at the sample times  $t_k = k\tau$ , with  $E(n_{cmk}^2) = E(n_{smk}^2) = \sigma_N^2 = N_0 B$ , for all m, k. (2.1-4)

Because the MFSK symbol slots are hopped independently, none, some, or all of the dehopped channels can be jammed on an individual hop. The possible combinations of such events and their probabilities are discussed in Section 2.2.

When jamming noise is present in a channel, it is assumed to be zero-mean narrowband Gaussian noise with variance  $\sigma_J^2 = N_J B/\gamma$ , where  $N_J/2$ is the (two-sided) noise power spectral density averaged over the system bandwidth; and  $\gamma$  is the fraction of this bandwidth which is jammed. That is,

$$N_{j} = \frac{J}{W} , \qquad (2.1-5)$$

where J is the total jammer power and W is the system bandwidth. When the channels are jammed on the k-th hop, the combination of jamming and thermal noise produces the detector output samples

$$x_{1k} = \left[ \left( \sqrt{2S} \cos \theta_{k} + n_{c1k} + j_{c1k} \right)^{2} + \left( \sqrt{2S} \sin \theta_{k} + n_{s1k} + j_{s1k} \right)^{2} \right]^{\frac{1}{2}} \quad (2.1-6a)$$

$$x_{mk} = \left[ \left( n_{cmk} + j_{cmk} \right)^{2} + \left( n_{smk} + j_{smk} \right)^{2} \right]^{\frac{1}{2}}, \quad m = 2, 3, \dots, M, \quad (2.1-6b)$$

where  $j_{cmk}$ ,  $j_{smk}$ , i = 1, 2, ..., M; k = 1, 2, ..., L, are the independent jamming noise quadrature components in the channels at the sample times, with

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$$E(j_{cmk}^{2}) = E(j_{smk}^{2}) = \sigma_{J}^{2} = N_{J}B/\gamma, \text{ for all } m, k, \qquad (2.1-7)$$

and  $\gamma$  is the fraction of the system bandwidth which is jammed.

In a summary way, we can express the detector output samples by

$$x_{1k} = \sigma_{1k} \left[ \left( \sqrt{\frac{2S}{\sigma_{1k}^2}} \cos \theta_k + \mu_{c1k} \right)^2 + \left( \sqrt{\frac{2S}{\sigma_{1k}^2}} \sin \theta_k + \mu_{s1k} \right)^2 \right]^{\frac{1}{2}}$$
(2.1-8a)

$$x_{mk} = \sigma_{mk} (\mu_{cmk}^2 + \mu_{smk}^2)^{\frac{1}{2}}, m = 2, 3, ..., M,$$
 (2.1-8b)

where  $\mu_{cmk}$  and  $\mu_{smk}$  are independent, unit-variance, zero-mean Gaussian random variables, and for channel m on hop k,

$$\sigma_{mk}^{2} = \begin{cases} \sigma_{N}^{2} = N_{0}B, & \text{unjammed} \\ \sigma_{\overline{I}}^{2} = \sigma_{N}^{2} + \sigma_{\overline{J}}^{2} = (N_{0} + N_{J}/\gamma)B, & \text{jammed} \end{cases}$$
(2.1-9a)

or, more compactly,

$$\sigma_{mk}^{2} = \sigma_{N}^{2} + v_{mk} \sigma_{J}^{2}$$
 (2.1-9b)

In this last equation  $v_{mk} = 1$  if channel m is jammed on hop k, and  $v_{mk} = 0$ if not. Thus  $x_1$  is  $\sigma_{1k}$  times a Rician random variable with SNR

$$\rho_k = S/\sigma_{1k}^2$$
, (2.1-10)

and  $x_{mk}$ , m > 1, is  $\sigma_{mk}$  times a Rayleigh random variable.

### 2.1.2 <u>Conditional Error Probability Formulation</u>

Assuming equally likely M-ary symbols, we may write the conditional symbol error probability as

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$$P_{s}(e|[v]) = P_{s}(e|[v],m_{1} \text{ transmitted})$$
(2.1-11)

in which  $[\nu]$  is a matrix describing the jamming event for L hops, with elements  $\nu_{mk}$ 

For M a power of two  $(M=2^K)$ , the conditional bit error probability is obtained from the conditional symbol error probability using the relation

$$P_{b}(e|[v]) = \frac{M/2}{M-1} P_{s}(e|[v]). \qquad (2.1-12)$$

Since for M > 2 there are many error events but only one correct decision, it is convenient to write the conditional symbol error probability in terms of the probability of a correct decision as

$$P_{s}(e|[v]) = 1 - P_{s}(c|m_{1},[v])$$
  
= 1-Pr{z<sub>2</sub> < z<sub>1</sub>, z<sub>3</sub> < z<sub>1</sub>,...,z<sub>M</sub> < z<sub>1</sub>}. (2.1-13)

In terms of the pdf's for the statistics, this becomes

$$P_{s}(e|[\nu]) = 1 - \int_{0}^{\infty} d\beta_{1} \int_{0}^{\beta_{1}} d\beta_{2} \dots \int_{0}^{\beta_{1}} d\beta_{M} p_{\underline{Z}}(\beta_{1},\beta_{2},\dots,\beta_{M}|[\nu]); \quad (2.1-14)$$

if the decision statistics are independent, then

$$P_{s}(e|[v]) = 1 - \int_{0}^{\infty} d\beta \, p_{z_{1}}(\beta|[v]) \, \prod_{m=2}^{M} \, \int_{0}^{\beta} \, d\alpha_{m} \, p_{z_{m}}(\alpha_{m}|[v]). \quad (2.1-15)$$

For certain receiver structures, the probability distributions of the individual channel statistics  $\{z_m\}$  are mutually independent. This relationship causes the conditional probability of error to depend only on the number of hops jammed in each of the M channels, rather than on specific patterns, and greatly reduces the number of distinguishable jamming events.

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### 2.2 ENUMERATION OF DISTINGUISHABLE JAMMING EVENTS

Examination of the conditional error probability expression reveals that the same conditional error will occur for several different values of the fundamental jamming event matrix, [v]. Therefore, in terms of error probability, there is a number of <u>distinguishable</u> jamming events which is smaller than the 2<sup>ML</sup> possible values of the [v] matrix. It is important to identify and enumerate these distinguishable jamming events in order to take advantage of the savings in computation which will result.

In this section we first identify and enumerate the distinguishable jamming events, then investigate methods for calculating their probabilities.

### 2.2.1 <u>Definition of Distinguishable Jamming Events</u>.

The conditional error probability, as shown in Section 2.1, is a function of given values of the [v] matrix elements  $v_{mk}$ , where m=1 to M (the number of MFSK channels) and k=1 to L (the number of hops per symbol). Often this function can be written

$$P(e|[v]) = P(e|v_{11}, v_{12}, \dots, v_{1L}; \dots; v_{M1}, \dots, v_{ML})$$
  
=  $f\left(\sum_{k=1}^{L} v_{1k}, \sum_{k=1}^{L} v_{2k}, \dots, \sum_{k=1}^{L} v_{mk}\right).$  (2.2-1)

Thus, if we define the row sums

$${}^{\ell}m \stackrel{\Delta}{=} \sum_{k=1}^{L} {}^{\nu}mk, \qquad (2.2-2)$$

the conditional P(e) is a function only of these sums, which are to be interpreted as the number of hops jammed in the respective channels. This fact can be expressed by the relation

$$P(e|[v]) = f(\ell_1, \ell_2, \ell_3, ..., \ell_M)$$
  
=  $f(\ell_1)$ , (2.2-3)

where  $\underline{\mathtt{\ell}}_{\underline{}}$  is the vector of  $\mathtt{\ell}_{\underline{}}$  components.

Since each  $\ell_m$  can take integer values from 0 to L, there (L+1)<sup>M</sup> possible jamming events described by the vector  $\underline{\ell}$ . This is a considerable savings in numbers of jamming events, as illustrated by Table 2.2-1.

## TABLE 2.2-1 NUMBER OF JAMMING EVENTS

M	L	$\#\{[v] events, 2^{ML}\}$	$\#\{\underline{\&} \text{ events}, (L+1)^M\}$
2	1	4	4
	2	16	9
	3	64	16
	4	256	25
4	1	16	16
	2	256	81
	3	4,096	256
	4	65,536	625
8	1	256	256
•	2	65,536	6.561
	3	16.777.216	65,536
	Ĩ,	4,294,967,296	390,625

#### 2.2.2 <u>Smallest Set of Distinguishable Jamming Events</u>.

A further reduction in the number of distinguishable jamming events

<sup>\*</sup>An exception to this condition results for an ECCM processing scheme studied in Section 4.
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results from noticing that permutation of the non-signal channel quantities  $\binom{\ell_2}{2}$  to  $\binom{\ell}{M}$  does not affect the conditional P(e). That is,

$$f(\underline{\ell}) = f(\ell_1, \ell_2, \ell_3, \dots, \ell_M)$$
  
=  $f(\ell_1, \ell_M, \ell_3, \ell_4, \dots, \ell_2)$  (2.2-4)  
=  $f(\ell_1, \ell_5, \ell_M-1, \ell_2, \dots, \ell_3)$   
= ... etc.

Thus we can restrict our attention to just one permutation of the set of values  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$ . A convenient way to represent the permutations is the ordered set of numbers

$$\underline{\ell}^{\ell} \stackrel{\text{\tiny $\&$}}{=} \{ \ell_1, \ell_2, \ell_3, \dots, \ell_M : \ell_2 \leq \ell_3 < \dots \leq \ell_M \}.$$
(2.2-5)

There are, from Appendix B.3, .

$$\sum_{\ell_1=0}^{L} \sum_{\ell_{M}=0}^{M} \sum_{\ell_{M-1}=0}^{\ell_{M}} \cdots \sum_{\ell_{3}=0}^{\ell_{4}} \sum_{\ell_{2}=0}^{\ell_{3}} = (L+1)\binom{M-1+L}{M-1}$$
(2.2-6)

such ordered  $\underline{x}$  vectors, which represent the minimum number of distinguishable events. Example values are given in Table 2.2-2.

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MINIMUM	NUMBER	OF DISTINGUISHABLE	EVENTS
<u>M</u>	L 	$\#\{\underline{\mathfrak{l}} events\}$	
2	1 2 3 4	4 9 16 25	
4	1 2 3 4	8 30 80 175	
8	1 2 3 4	16 108 480 1,650	

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Each of the distinguishable jamming events represents a certain number of events with identical jamming effects. The number of  $\underline{\mathscr{R}}$  vectors thereby represented by a particular ordered vector  $\underline{\mathscr{R}}_{i}$  is

$$#(\underline{p} \leftrightarrow \underline{p}_{1}) = \begin{pmatrix} M-1 \\ n_{0}, n_{1}, \dots, n_{L} \end{pmatrix}$$
(2.2-7a)  
$$= \frac{(M-1)!}{n_{0}! n_{1}! \dots n_{L}!}$$
(2.2-7b)

where

$$n_{\ell}$$
 = number of  $\ell_{m}$  which equal  $\ell$ ;  $\ell=0,1,\ldots,L$ ;  $m > 1$ 

and we have

$$\sum_{\ell=0}^{L} n_{\ell} = M-1.$$
 (2.2-7d)

For example, for M=8 and L=6, the number of jamming event vectors  $\underline{\ell}$  represented by the ordered vector  $\underline{\ell}' = (\ell_1; 0, 0, 2, 3, 3, 4, 5)$  is

$$\binom{7}{2,0,1,2,1,1,0} = \frac{7!}{2!0!1!2!1!1!0!} = 1260.$$
(2.2-8)

As a check on this enumeration, we find that the total number of  $\underline{\ell}$  jamming events is given by

$$#(\underline{\hat{x}}) = \sum_{\hat{x}_{1}=0}^{L} \sum_{\hat{x}_{M}=0}^{L} \sum_{\hat{x}_{M}=0}^{\hat{x}_{M}} \sum_{\hat{x}_{3}=0}^{\hat{x}_{4}} \sum_{\hat{x}_{2}=0}^{\hat{x}_{3}} \binom{M-1}{n_{0}, n_{1}, \dots, n_{L}}$$

$$= (L+1) \sum_{\hat{x}_{M}=0}^{L} \dots \sum_{\hat{x}_{2}=0}^{\hat{x}_{3}} \binom{M-1}{n_{0}, n_{1}, \dots, n_{L}} ...$$

$$(2.2-9)$$

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It can be shown (see Appendix B) that the summation in (2.2-9) is equal to  $(L+1)^{M-1}$ . Thus the total number of  $\frac{2}{2}$  vectors computed by (2.2-9) is  $(L+1)^{M}$ , which agrees with our previous enumeration.

#### 2.2.3 Jamming Event Probabilities, Single Hop.

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Given a jamming event described by the vector  $\underline{\ell}$ , what is the probability of the event under the random hopping scheme and partial-band noise jamming? To find this answer, we first consider the case of one hop per MFSK symbol, or L=1.

The jammer spectrum is assumed to be flat, with one-sided power spectral density  $J/\gamma W$ , where  $\gamma$  is the fraction of the system bandwidth occupied by the jammer. There are N=W/B possible symbol frequency slots, and it is assumed that M of these slots are assigned randomly to the MFSK symbol on each hop. At the same time the number of slots containing jamming power is

$$q \stackrel{\triangle}{=} \gamma N,$$
 (2.2-10)

assumed to be an integer. That is,  $\gamma = q/N$ , with q an integer.

The probability that n of the M symbol slots are jammed on a given hop is

$$\pi_{n} = \frac{q}{N} \cdot \frac{q-1}{N-1} \cdots \frac{q-n+1}{N-n+1} \cdot \frac{N-q}{N-n} \cdots \frac{N-q-M+n+1}{N-M+1}$$
$$= \frac{\binom{N-M}{q-n}}{\binom{N}{q}}, \ n=0,1,2,\ldots,\min(q,M).$$
(2.2-11)

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Note that the probability  $\pi_{n}$  is valid for several different jamming events since

$$n_{k} = \sum_{m=1}^{M} v_{mk}$$
 (2.2-12)

on the k-th hop. In fact there are  $\binom{M}{n}$  jamming events for L=1 which have probability  $\pi_n$  . Thus

$$\sum_{n=0}^{L} \begin{pmatrix} M \\ n \end{pmatrix} \pi_{n} = 1, \qquad (2.2-13)$$

as required.

In terms of distinguishable jamming events, we differentiate between whether the signal channel is jammed ( $v_{1k} = 1$ ) or not ( $v_{1k} = 0$ ), and describe single-hop jamming events by the pair of numbers ( $v_{1k}$ , $r_k$ ) with

$$\mathbf{r}_{k} \stackrel{\text{\tiny def}}{=} \sum_{m=2}^{n} \mathbf{v}_{mk} , \qquad (2.2-14)$$

the number of non-signal channels jammed. We have

$$\Pr\{\nu_{1k}, r_{k}\} = \pi(\nu_{1k} + r_{k}) \equiv \pi_{n}, n = \nu_{1k} + r_{k}$$
(2.2-15)

and

$$\sum_{\nu_{1k}=0}^{-} \sum_{r_{k}=0}^{\mu-1} {\binom{M-1}{r_{k}}} \pi(\nu_{1k} + r_{k}) = 1.$$
(2.2-16)

### 2.2.4 Jamming Event Probabilities For Multiple Hops, Characteristic Function Method.

 $\sum_{i=1}^{n}$ 

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For L > 1 hops per symbol, as discussed in Sections 2.2.1 and and 2.2.2, the distinguishable jamming events are described by the vectors  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$ . We note that

$$\underline{\ell} = \sum_{k=1}^{L} \underline{\nu}_{k}$$
(2.2-17)

where  $\underline{v}_k = (v_{1k}, v_{2k}, \dots, v_{mk})$  is the vector whose elements are the k-th column of the matrix [v] of fundamental jamming events. Since the hopping pattern is assumed to be independent from hop to hop, we may treat  $\underline{k}$  as the sum of identically distributed discrete random vectors, and find the probabilities of the  $\underline{k}$  jamming events from the characteristic function of the  $\underline{v}$  jamming events.

The characteristic function of any one of the random vectors  $\underline{\nu}_k$  is given by

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For example, for M=2 and 4 the characteristic functions for one hop are

$$\phi_{\underline{\nu}}(\underline{\mu};2) = \pi_0 + \pi_1 e^{j\mu_1} + \pi_1 e^{j\mu_2} + \pi_2 e^{j\mu_1 + j\mu_2}$$
(2.2-19)

and

$$\Phi_{\underline{\nu}}(\underline{\mu}; 4) = \pi_{0} + \pi_{1}e^{j\mu_{1}} + \pi_{1}e^{j\mu_{2}} + \pi_{1}e^{j\mu_{3}} + \pi_{1}e^{j\mu_{4}}$$

$$+ \pi_{2}e^{j\mu_{1}+j\mu_{2}} + \pi_{2}e^{j\mu_{1}+j\mu_{3}} + \pi_{2}e^{j\mu_{1}+j\mu_{4}}$$

$$+ \pi_{2}e^{j\mu_{2}+j\mu_{3}} + \pi_{2}e^{j\mu_{2}+j\mu_{4}} + \pi_{2}e^{j\mu_{3}+j\mu_{4}}$$

$$+ \pi_{3}e^{j\mu_{1}+j\mu_{2}+j\mu_{3}} + \pi_{3}e^{j\mu_{1}+j\mu_{2}+j\mu_{4}}$$

$$+ \pi_{3}e^{j\mu_{1}+j\mu_{3}+j\mu_{4}} + \pi_{3}e^{j\mu_{2}+j\mu_{3}+j\mu_{4}}$$

$$+ \pi_{4}e^{j\mu_{1}+j\mu_{2}+j\mu_{3}+j\mu_{4}}$$

$$(2.2-20)$$

In this characteristic function, there are  $2^{M}$  terms, one for each of one events described by  $\underline{v}_{k}$ .

The characteristic function for  $\underline{\ell}$  is simply that of  $\underline{\nu}_k,$  raised to the L-th power:

$$\Phi_{\underline{\lambda}}(\underline{\mu};\mathbf{M}) = \left[\Phi_{\underline{\nu}}(\underline{\mu};\mathbf{M})\right]^{\mathsf{L}}.$$
(2.2-21)

For example, for M=2,

$$\phi_{\underline{\mu}}(\underline{\mu};2) = \left[\phi_{\underline{\nu}}(\underline{\mu};2)\right]^{L}$$

$$= \sum \begin{pmatrix} L \\ n_{0},n_{1},n_{2},n_{3} \end{pmatrix} \pi_{0}^{n_{0}} \pi_{1}^{n_{1}+n_{2}} \pi_{2}^{n_{3}}$$

$$(2.2-22a)$$

$$\times \exp\{j(n_{1}+n_{3})\mu_{1}+j(n_{2}+n_{3})\mu_{2}\},$$

where the summation is over all  $(n_0, n_1, n_2, n_3)$  such that

$$\sum_{q=0}^{2^{M}-1} n_{q} = L .$$
 (2.2-22b)

The discrete probability density function (pdf) for  $\underline{\ell}$  is the inverse Fourier transform of  $\phi_{\underline{\ell}}(\underline{\mu};M)$ . Again, for M=2, the pdf  $p(\underline{\ell};M,L)$  for  $\underline{\ell}$  is

$$p(\underline{\imath};2,L) = \sum \begin{pmatrix} L \\ n_0, n_1, n_2, n_3 \end{pmatrix} \pi_0^{n_0} \pi_1^{n_1+n_2} \pi_2^{n_3} \times \delta(n_1+n_3-\imath_1) \delta(n_2+n_3-\imath_2), \qquad (2.2-23)$$

which can be used to find the individual <u>\*</u> vector probabilities

$$\Pr\{\underline{\ell}; 2, L\} = \sum_{n=0}^{L} \begin{pmatrix} L \\ n, L - \ell_2 - n, L - \ell_1 - n, \ell_1 + \ell_2 + n - L \end{pmatrix} \times \pi_0^n \pi_1^{2L - \ell_1 - \ell_2 - 2n} \pi_2^{\ell_1 + \ell_2 - L + n}$$
(2.2-24)

In (2.2-24) it is realized that the combinatorial factor is zero if any of its parameters is negative. As an example for L=3 and M=2,

$$\Pr\{\ell_{1} = 1, \ell_{2} = 2; 2, 3\}$$

$$= \begin{pmatrix} 3 \\ 0, 1, 2, 0 \end{pmatrix} \pi_{1}^{3} + \begin{pmatrix} 3 \\ 1, 0, 1, 1 \end{pmatrix} \pi_{0} \pi_{1} \pi_{2}$$

$$= 3\pi_{1}^{3} + 6\pi_{0} \pi_{1} \pi_{2} . \qquad (2.2-25)$$

An aid to checking our calculations is the fact that each  $\underline{\&}$  event corresponds to

$$\begin{pmatrix} \mathsf{L} \\ \mathfrak{x}_1 \end{pmatrix} \begin{pmatrix} \mathsf{L} \\ \mathfrak{x}_2 \end{pmatrix} \cdots \begin{pmatrix} \mathsf{L} \\ \mathfrak{x}_{\mathsf{M}} \end{pmatrix}$$
(2.2-26)

[v] matrix events. In (2.2-25) therefore, there are  $\binom{3}{1}\binom{3}{2} = 9$  terms.

A complete table of M=2 jamming event probabilities for L=1 to 4 is given in Table 2.2-3, and an equation for computing these probabilities for M=4 is included as Table 2.2-4.

2.2.5 Jamming Event Probabilities For Multiple Hops, Convolution Method.

Since  $\underline{\mathscr{X}}$  is the sum of L independent random event vectors  $\underline{v}_k$ , the pdf for  $\underline{\mathscr{X}}$  is the L-fold convolution of the pdf for  $\underline{v}_k$ :

$$P(\underline{2};M,L) = P(\underline{v}_{1};M)*P(\underline{v}_{2};M)*...*P(\underline{v}_{L};M), \qquad (2.2-27)$$

or

$$\Pr\{\underline{\ell}; \mathbf{M}, \mathbf{L}\} = \sum_{\underline{\nu}} \sum_{\underline{1}} \frac{\sum_{\underline{\nu}} \cdots \sum_{\underline{\nu}}}{\sum_{\underline{\nu}} \sum_{\underline{\nu}} \sum_{\underline{\nu}} \sum_{\underline{\nu}}} \Pr\{\underline{\nu}_{\underline{1}}; \mathbf{M}\} \cdots \Pr\{\underline{\nu}_{\underline{L}}; \mathbf{M}\} \delta(\underline{\ell} - \sum_{k=1}^{\underline{L}} \underline{\nu}_{k}).$$
(2.2-28)

Figure 2.2-1 illustrates a programming approach for calculating this equation indirectly.

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### TABLE 2.2-3

JAMMING EVENT PROBABILITIES FOR M=2, L=1 TO 4

l	<u>L=1</u>	<u>L=2</u>	<u>L=3</u>	<u>L=4</u>
0,0	" 0 <sup></sup>	πc <sup>2</sup>	π0 <sup>3</sup>	πσ <sup>μ</sup>
0,1	<b>"</b> 1	2=0=1	$3\pi 0^2 \pi 1$	4π <sub>0</sub> <sup>3</sup> π1
1,0	۳1	2 <sub>7</sub> <sup>7</sup> 1	$3\pi_0^2\pi_1$	$4\pi_0^3\pi_1$
1,1	<sup>π</sup> 2	$2\pi_0\pi_2 + 2\pi_1^2$	$3\pi_0^2\pi_2 + 6\pi_0\pi_1^2$	$4\pi_0^3\pi_2 + 12\pi_0^2\pi_1^2$
0,2		π1 <sup>2</sup>	3 <sup>π</sup> 0 <sup>π</sup> 1 <sup>2</sup>	6π0 <sup>2</sup> π1 <sup>2</sup>
1,2		2 <sub>71</sub> 72	$5\pi_0\pi_1\pi_2 + 3\pi_1^3$	$12\pi_0^2\pi_1\pi_2 + 12\pi_0\pi_1^3$
2,0		π1 <sup>2</sup>	3 " 0 " 1 2	6π <sub>0</sub> <sup>2</sup> π <sub>1</sub> <sup>2</sup>
2,1		27172	$5\pi_0\pi_1\pi_2 + 3\pi_1^3$	$12\pi_0^2\pi_1\pi_2 + 12\pi_0\pi_1^3$
2,2		"2 <sup>2</sup>	$3\pi_0\pi_2^2 + 5\pi_1^2\pi_2$	$6\pi_0^2 \pi_2^2 + 24\pi_0 \pi_1^2 \pi_2 + 6\pi_1^4$
0,3			п	4π <sub>0</sub> π <sub>1</sub> <sup>3</sup>
1,3			371 <sup>2</sup> 72	$12\pi_0\pi_1^2\pi_2 + 4\pi_1^4$
2,3			3° 1 72 <sup>2</sup>	$12\pi_0\pi_1\pi_2^2$ + $12\pi_1^3\pi_2$
3,0			π1 <sup>3</sup>	4π <sub>0</sub> π <sub>1</sub> 3
3,1			3π <sub>1</sub> <sup>2</sup> π <sub>2</sub>	$12\pi_0 n_1^2 \pi_2 + 4\pi_1^4$
3,2			3 <sub>71</sub> <sub>2</sub> <sup>2</sup>	$12\pi_0\pi_1\pi_2^2 + 12\pi_1^3\pi_2$
3,3			π2 3	$4\pi_0\pi_2^3 + 12\pi_1^{2\pi_2^2}$
0,4				<sup>π</sup> 1 <sup>4</sup>
1,4				4 π <sub>1</sub> 3 π <sub>2</sub>
2,4				би1 <sup>2</sup> т 2 <sup>2</sup>
3,4				4m1m2 <sup>3</sup>
4,0	1			π <u>i</u>
4.1				$4\pi_1^3\pi_2$
4,2				$6\pi_1^2\pi_2^2$
4,3				$4\pi_1\pi_2^3$
4,4				π <sub>2</sub> 4

$$\Pr(\underline{\ell}) = \sum_{n=0}^{L} (n, L-\underline{\ell}_{2}-n, L-\underline{\ell}_{1}-n, \underline{\ell}_{1}+\underline{\ell}_{2}+n-L) \pi_{0}^{n} \pi_{1}^{2L-\underline{\ell}_{1}-\underline{\ell}_{2}-n} \pi_{2}^{\underline{\ell}_{1}+\underline{\ell}_{2}+n-L}$$

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PROBABILITIES OF  $\underline{g}$  JAMMING EVENTS FOR M =

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**TABLE 2.2-4** 

 $\Pr\left\{\underline{z}\ ;\ 4,\ L\ \right\} = \sum_{n_0=0}^{L}\sum_{n_1=1}^{L}\cdots \sum_{n_15=0}^{L}\frac{1}{n_0!n_1!}\cdots \frac{1!}{n_15!}\pi_0^{n_0}\pi_1^{n_1+n_2+n_4+n_8}\pi_2^{n_3+n_5+n_6+n_9+n_10+n_{12}}\pi_3^{n_7+n_{11}+n_{13}+n_{14}}\pi_4^{n_{15}}\pi_1^{n_{1$ 

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Input: M, L,  $\pi_0$  to  $\pi_M$ Initialize all  $Pr\{ \underline{\ell} \} = 0$  $\bar{I}_1 = 0$  to  $2^{M} - 1$  $v_{m1} = mth \ bit \ of \ I_1, \ m \approx 1 \ to \ M$  $w_1 = \sum_{m} v_{ml}$  $\overline{I}_2 = 0$  to  $2^M - 1$  $\overline{v}_{m2} = m$ th bit of  $I_2$ , r = 1 to M  $w_2 = \sum_{m} v_{m2}$  $I_{L} = 0 \text{ to } 2^{M} - 1$  $v_{ml}$  = mth bit of  $I_{L}$ , m = 1 to M  $w_L = \sum_m u_{mL}$  $u_{\rm m} = \sum_{\rm k} u_{\rm mk}$ , m = 1 to M  $J(z) = \sum_{m} \dot{z}_{m} L^{m-1}$ skip if any ²<sub>m</sub>>²<sub>m+1</sub>, m = 2 to M-1 Increment  $Pr(\underline{x}) = Pr(I(\underline{x}))$ to get ordered vector output by  $-(w_1) - (w_2) \dots - (w_l)$ 

FIGURE 2.2-1 PROGRAM STRUCTURE FOR CALCULATING JAMMING EVENT PROBABILITIES INDIRECTLY

This can also be done iteratively, using the fact that

$$\Pr\{\underline{v}; M, L\} = \sum_{\underline{\alpha}} \sum_{\underline{\nu}} \Pr\{\underline{\alpha}; M, L-1\} \Pr\{\underline{\nu}_{\underline{i}}; M\} \delta(\underline{v} - \underline{\alpha} - \underline{\nu}_{\underline{i}})$$
$$= \sum_{\underline{\nu}_{\underline{i}}} \Pr\{\underline{v} - \underline{\nu}_{\underline{i}}; M, L-1\} \Pr\{\underline{\nu}_{\underline{i}}; M\}.$$
(2.2-29)

To accomplish the vector additions needed for the convolution, we may encode the M x 1 vectors  $\underline{\ell}$  and  $\underline{\nu}_{1}$  into a number using the form

$$I(\underline{x}) = x_{1} + bx_{2} + b^{2}x_{3} + \dots + b^{M-1}x_{M}, \qquad (2.2-30a)$$

where  $b \ge L$  is an integer base number, supporting the relationship

$$I\left(\underline{\mathfrak{k}}_{1} + \underline{\mathfrak{k}}_{2}\right) = I\left(\underline{\mathfrak{k}}_{1}\right) + I\left(\underline{\mathfrak{k}}_{2}\right). \qquad (2.2-30b)$$

In this manner the convolution in (2.2-29) can be done using

$$\Pr\{\underline{\varrho}; \mathsf{M}, \mathsf{L}\} = \sum_{\mathbf{I}(\underline{\omega})} \sum_{\mathbf{I}(\underline{\omega})} \Pr\{\mathbf{I}(\underline{\omega}); \mathsf{M}, \mathsf{L}-1\} \Pr\{\mathbf{I}(\underline{\omega}); \mathsf{M}\} \times \delta[\mathbf{I}(\underline{\varrho}) - \mathbf{I}(\underline{\omega}) - \mathbf{I}(\underline{\omega})],$$

$$= \sum_{\mathbf{I}(\underline{\omega})} \Pr\{\mathbf{I}(\underline{\varrho}) - \mathbf{I}(\underline{\omega}); \mathsf{M}, \mathsf{L}-1\} \Pr\{\mathbf{I}(\underline{\omega}); \mathsf{M}\}.$$
(2.2-31)

2.3 TOTAL PROBABILITY OF ERROR

In terms of the conditional probability of symbol error, given a jamming event defined by the vector  $\underline{k}$ , and the probabilities of the jamming events, we now can write the total probability of error as

$$P_{s}(e) = \sum_{\underline{\ell}} Pr\{\underline{\ell}\} P_{s}(e|\underline{\ell})$$
$$= \sum_{\underline{\ell}} \left( n_{0}, n_{1}, \dots, n_{L} \right) Pr\{\underline{\ell}\} P_{s}(e|\underline{\ell}). \qquad (2.3-1)$$

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This formulation utilizes the fact that  $\underline{\ell}$  vectors formed by permutations of the nonsignal channel elements  $\{\ell_m, m>1\}$  of the ordered  $\underline{\ell}$  vector are equiprobable, and that the conditional error probability is the same for each permutation.

#### 2.4 FH/RMFSK HARD DECISION ANALYSIS

In addition to studying the performance of L hops/symbols soft decision receivers for various FH/RMFSK combining schemes, we shall calculate the performance when L M-ary hard decisions are combined to produce a final symbol decision. This configuration is in itself a form of ECCM processing, as will be shown in later sections.

#### 2.4.1 Formulation of Error Probability.

Under an M-ary hard decision approach, shown previously as Figure 1.3-3, on the kth hop the decision variables  $\{z_{mk}\}$  are compared to find the largest; the signal is assumed to be present in the channel with the largest decision variable. The per hop or "hard" symbol decision can be thought of as selecting one of M vectors  $\{\underline{D}_1, \underline{D}_2, \dots, \underline{D}_M\}$ , where

$$\underline{D}_{m} = (D_{1m}, D_{2m}, \dots, D_{Mm})$$
(2.4-1a)  
$$D_{im} = \begin{cases} 1, & i=m \\ 0, & i\neq m \end{cases}$$
(2.4-1b)

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The hard symbol decision on the kth hop then can be expressed as the vector

$$\underline{\mathbf{d}}_{\mathbf{k}} = (\mathbf{d}_{1\mathbf{k}}, \mathbf{d}_{2\mathbf{k}}, \dots, \mathbf{d}_{\mathbf{M}\mathbf{k}}) \stackrel{\Delta}{=} \underline{\mathbf{D}}_{\mathbf{m}} \star$$
(2.4-2a)

where m\* is chosen such that

$$z_{m \star k} = \max_{m} (z_{mk}).$$
 (2.4-2b)

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The components of the per-hop decision vector  $\underline{d}_k$  are accumulated over the L hops of the symbol to produce the final, discrete decision variables

$$d_m = \sum_{k=1}^{L} d_{mk}; m = 1, 2, ..., M;$$
 (2.4-3a)

or, in vector notation, the final discrete-valued decision vector

$$\underline{\mathbf{d}} = \sum_{k=1}^{L} \underline{\mathbf{d}}_{k} . \tag{2.4-3b}$$

The error probability can be formulated as

 $P_s(e) = 1 - P_s(correct decision = C)$ 

$$= 1 - \sum_{\underline{\ell}} P_{s}(C|\underline{\ell}) Pr{\underline{\ell}}$$

$$= 1 - \sum_{\underline{\ell}} Pr{\underline{\ell}} \sum_{n \in \Omega_{c}} Pr{\underline{d} = \underline{n}|\underline{\ell}}, \qquad (2.4-4)$$

where  $\underline{\mathfrak{L}} = (\mathfrak{l}_1, \mathfrak{l}_2, \dots, \mathfrak{l}_M)$  describes the jamming events, and  $\Omega_c$  is the set of decision vectors which produce a correct decision.

Since the components of <u>d</u> are discrete-valued, there exists the possibility of a tie between the signal channel's final decision variable value and that of one or more non-signal channels. Thus the error expression (2.4-4) should be modified to

$$P_{s}(e) = 1 - \sum_{\underline{\ell}} \Pr{\{\underline{\ell}\}} \sum_{\underline{n} \in \Omega_{c}} h(\underline{n}) \Pr{\{\underline{d} = \underline{n} | \underline{\ell}\}}, \qquad (2.4-5a)$$

where  $h(\underline{n}) = (\#channels equal to maximum)^{-1}$ , (2.4-5b) assuming that a randomized decision is made when there is a tie. For example, if three channels (including the signal channel) are equal to the maximum value, then  $h(\underline{n}) = 1/3$ .

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### 2.4.2 <u>Explicit Form of Error Probability</u>.

Interchanging the summations in the probability of a correct symbol decision gives

$$P_{s}(c) = \sum_{\underline{n} \in \Omega_{c}} h(\underline{n}) \sum_{\underline{\ell}} Pr\{\underline{\ell}\} Pr\{\underline{d} = \underline{n} | \underline{\ell}\} . \qquad (2.4-6)$$

Now, since the jamming event vector  $\underline{\ell}$  is related to the jamming event matrix [v] by

$$\frac{2}{k} = \sum_{k=1}^{L} \frac{v_k}{k}, \qquad (2.4-7)$$

where  $\underline{\psi}_k$  is the kth column of  $[\psi]$ , the summation over  $\underline{\ell}$  can be replaced by

$$\sum_{\underline{\nu}_{1}} \sum_{\underline{\nu}_{2}} \dots \sum_{\underline{\nu}_{L}} \Pr\{[\nu]\} \Pr\{\underline{d} = \underline{n} | [\nu]\}$$

$$= \sum_{\underline{\nu}_{1}} \Pr\{\underline{\nu}_{1}\} \sum_{\underline{\nu}_{2}} \Pr\{\underline{\nu}_{2}\} \dots \sum_{\underline{\nu}_{L}} \Pr\{\underline{u}_{L}\} \Pr\{\underline{d} = \underline{n} | \underline{\nu}_{1}, \underline{\nu}_{2}, \dots, \underline{\nu}_{L}\}. \quad (2.4-8)$$

In this expression we use the fact that the  $\{\underline{v}_k\}$  are statistically independent. It is also true that the individual hop decisions  $\{\underline{d}_k\}$  are independent, so we can expand (2.4-8) further to obtain

$$\sum_{\underline{\nu}_{1}} \Pr\{\underline{\nu}_{1}\} \Pr\{\underline{d}_{1} | \underline{\nu}_{1}\} \sum_{\underline{\nu}_{2}} \Pr\{\underline{d}_{2} | \underline{\nu}_{2}\}$$

$$\dots \sum_{\underline{\nu}_{L}} \Pr\{\underline{\nu}_{L}\} \Pr\{\underline{d}_{L} | \underline{\nu}_{L}\} \delta(\sum_{k} \underline{d}_{k}, \underline{n}) , \qquad (2.4-9)$$

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where  $\delta(\underline{a},\underline{b})$  is a vector version of the Kronecker delta function:

$$\delta(\underline{a},\underline{b}) \stackrel{\Delta}{=} \begin{cases} 1 & \text{if } \underline{a} = \underline{b} \\ 0 & \text{if } \underline{a} \neq \underline{b} \end{cases} .$$
 (2.4-10)

Recognizing that the sums over the individual  $\{\underline{\nu}_k\}$  are simply averages, we can write

$$P_{s}(e) = 1 - \sum_{\underline{n} \in \Omega_{c}} h(n) \operatorname{Pr}\{\underline{d}_{1}\} \operatorname{Pr}\{\underline{d}_{2}\} \dots \operatorname{Pr}\{\underline{d}_{L}\} \mathfrak{s}(\underline{d},\underline{n}), \quad (2.4-11)$$

where  $\Pr{\{\frac{d}{k}\}}$  for the kth hop is the average of the (discrete) probability distribution for the hop decision over the jamming events for the kth hop,  $\frac{v}{k}$ . Assuming without loss of generality that the first channel is the signal channel, these averages are

$$Pr\{\underline{d}_{k} = D_{1}\} \equiv p = 1 - P_{s}(e;\gamma, \frac{1}{L} \cdot \frac{E_{s}}{N_{0}}, \frac{1}{L} \cdot \frac{E_{s}}{N_{J}}, L=1) \triangleq 1 - P_{1} \quad (2.4-12a)$$

$$Pr\{\underline{d}_{k} = \underline{D}_{m}\} \equiv q = (1-p)/(M-1)$$

$$= P_{1}/(M-1), m \ge 2. \quad (2.4-12b)$$

Finally, using the function

$$H(\underline{n}) = \begin{cases} 1 & \text{if } \underline{n} \in \Omega_{c} \\ 0 & \text{if } \underline{n} \in \Omega_{c}' \end{cases}$$
(2.4-13)

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as a "mask" for the correct decisions, we can write (2.4-11) more explicitly as

$$P_{s}(e) = 1 - \sum_{\substack{n_{1}=0 \ n_{2}=0 \ \dots n_{M}=0}}^{L} \sum_{\substack{n_{1}=0 \ \dots n_{M}=0}}^{L} H(\underline{n})h(\underline{n}) \begin{pmatrix} n_{1}, n_{2}, \dots, n_{M} \end{pmatrix} p^{n_{1}}q^{L-n_{1}}$$

$$= 1 - \sum_{\substack{n_{1}=0 \ n_{2}=0 \ \dots n_{M}=0}}^{L} \sum_{\substack{n_{1}=0 \ n_{2}=0}}^{n_{1}} \dots \sum_{\substack{n_{M}=0 \ n_{M}=0}}^{n_{1}} h(\underline{n}) \begin{pmatrix} n_{1}, n_{2}, \dots, n_{M} \end{pmatrix} p^{n_{1}}q^{L-n_{1}}\delta(\underline{\Sigma} n_{1}, L).$$

$$(2.4-14)$$

2.4.2.1 Special case: L = 2.

2.4.2.2 Special case: L = 3.

For L = 2, (2.4-14) reduces to

$$P_{s}(e;\gamma,\frac{E_{s}}{N_{0}},\frac{E_{s}}{N_{J}},L=2) = 1 - p^{2} - (M-1)pq$$

$$= 1 - p^{2} - p P_{1} = P_{1}$$

$$= P_{s}(e;\gamma,\frac{1}{2}\frac{E_{s}}{N_{0}},\frac{1}{2}\frac{E_{s}}{N_{J}},L=1); \qquad (2.4-15)$$

that is, the hard decision receiver is uniformly 3 dB worse for L = 2 than for L = 1, for any value of M.

For L = 3, (2.4-14) reduces to  

$$P_{s}(e;_{Y}, \frac{E_{s}}{N_{0}}, \frac{E_{s}}{N_{J}}, L=3) = \frac{1}{M-1} P_{1}^{2}(2M - 1 - MP_{1}),$$
 (2.4-16a)

with

$$P_1 = P_s(e; r, \frac{1}{3} \frac{E_s}{N_0}, \frac{1}{3} \frac{E_s}{N_0}, L=1).$$
 (2.4-16b)

2.4.2.3 Special case: L = 4.  
For L = 4, (2.4-14) reduces to  

$$P_{s}(e;_{Y}, \frac{E_{s}}{N_{0}}, \frac{E_{s}}{N_{J}}, L = 3) = \frac{1}{M-1}P_{1}^{2}\left[3 + \frac{P_{1}}{M-1}(3M^{2}-9M+4) - 2M \cdot \frac{M-2}{M-1}P_{1}^{2}\right]$$
(2.4-17a)

with

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$$P_1 = P_s(e; \gamma, \frac{1}{4} \frac{E_s}{N_0}, \frac{1}{4} \frac{E_s}{N_J}, L=1).$$
 (2.4-17b)

Note that for M = 2, (2.4-16a) and (2.4-17a) both give  $P_s = P_1^2(3-2P_1)$ ; this implies that the L = 4 hard decision performance is uniformly 10  $\log_{10}(\frac{4}{3}) = 1.25$  dB worse than that for L = 3 when M = 2.

2.4.2.4 Special case: M = 2.

For M = 2, (2.3-14) reduces to

$$P_{b}(e) = \begin{cases} 1 - \sum_{n_{1}=\frac{L}{2}+1}^{L} {\binom{L}{n_{1}}} p^{n_{1}} q^{L-n_{1}} - \frac{1}{2} {\binom{L}{L/2}} p^{L/2} q^{L/2}, L \text{ even} \\ & n_{1}=\frac{L}{2}+1 \\ 1 - \sum_{n_{1}=(L+1)/2}^{L} {\binom{L}{n_{1}}} p^{n_{1}} q^{L-n_{1}}, L \text{ odd.} \end{cases}$$
(2.4-18)

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#### 3.0 FH/RMFSK PERFORMANCE USING SQUARE-LAW LINEAR COMBINING RECEIVER

In this section we consider the case of the generic receiver shown in Figure 2.2-1 when the envelope samples are processed using the function

$$f(x_{mk}) = x_{mk}^2 \equiv z_{mk}.$$
 (3.0-1)

That is, the decision statistics  $\{z_m\}$  are the unweighted linear combinations or sums of samples of the squared envelopes in each channel over multiple (L) hops. For non-hopping systems, this receiver is known to give good performance when the signal is subject to Rayleigh fading, L being the order of diversity which can be chosen to optimize performance for a given SNR.

#### 3.1 ERROR PROBABILITY ANALYSIS

In Section 2.2 it was shown that the envelope samples  $\{x_{mk}\}$  are  $\sigma_{mk}$  times a Rician random variable for the signal channel (m=1) and  $\sigma_{mk}$  times a Rayleigh random variable for the non-signal channels (m>1), where the value of  $\sigma_{mk}$  depends upon whether the channel is jammed or not. Therefore, for the square-law linear combining FH/RMFSK receiver, the hop decision statistics, which are the squares of the envelope samples, are  $\sigma_{mk}^2$  times chi-squared random variables with two degrees of freedom. For the signal channel the noncentrality parameter is

$$\lambda_{k} = 2\rho_{k} = 2S/\sigma_{1k}^{2} . \qquad (3.1-1)$$

The probability density function (pdf) for the signal channel samples is

$$p_{Z_{1k}}(\alpha; \sigma_{1k}, \sigma_{1k}^{2}) = \frac{1}{2\sigma_{1k}^{2}} \exp\left(-\rho_{k} - \frac{\alpha}{2\sigma_{2k}^{2}}\right) I_{0}(\sqrt{2\sigma_{k}\alpha/\sigma_{1k}^{2}}), \quad (3.1-2)$$

while that for the non-signal channel samples is

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$$p_{z_{mk}}(\alpha;\sigma_{mk}^2) = \frac{1}{2\sigma_{mk}^2} \exp\left\{-\frac{\alpha}{2\sigma_{mk}^2}\right\}, m>1.$$
(3.1-3)

### 3.1.1 <u>Distribution of the Decision Statistics</u>.

The accumulated decision statistics {  $\boldsymbol{z}_m$  } can be expressed as

$$z_{1} = \sum_{k=1}^{L} \sigma_{1k}^{2} \chi^{2}(2; \lambda_{k})$$
(3.1-4a)

and

$$z_{m} = \sum_{k=1}^{L} \sigma_{mk}^{2} \chi^{2}(2)$$
 (3.1-4b)

where  $\chi^2(n)$  denotes a chi-squared random variable with n degrees of freedom and  $\chi^2(n;\lambda)$  denotes a noncentral chi-squared random variable with n degrees of freedom and a noncentrality parameter  $\lambda$ . It is well known that sums of equally weighted chi-squared variables yield chi-squared variables:

$$\sum_{k=1}^{L} \chi^{2}(n_{k};\lambda_{k}) = \chi^{2}\left(\sum_{k=1}^{L} n_{k}; \sum_{k=1}^{L} \lambda_{k}\right).$$
(3.1-5)

This fact can be applied to (3.1-4) by recalling that for a given jamming event,  $\ell_m$  out of L hops in a given channel are jammed. Thus

$$z_{1} = \sigma_{N}^{2} \chi^{2} [2(L-\ell_{1}); 2(L-\ell_{1})S/\sigma_{N}^{2}] + \sigma_{T}^{2} \chi^{2} (2\ell_{1}; 2\ell_{1}S/\sigma_{T}^{2}) (3.1-6a)$$

and

$$z_m = \sigma_N^2 \chi^2 [2(L-\ell_m)] + \sigma_T^2 \gamma^2 (2\ell_m), m > 2.$$
 (3.1-6b)

In Appendix A it is shown that the pdf for the normalized variable  $u_1 = z_1/z_N^2$  is

$$p_{\chi}^{2}(\alpha; 2L, 2Lp_{N})$$
  $\hat{\ell}_{1} = 0;$  (3.1-7a)

$$p_{u_1}(\alpha) = \begin{cases} \frac{1}{K} p_{\chi^2}(\alpha/K; 2L, 2L\rho_T), & \ell_1 = L; \end{cases}$$
 (3.1-7b)

$$\left(\sum_{n=0}^{\infty} c_{n} p_{\chi^{2}}[\alpha; 2L + 2n, 2(L-\ell_{1})\rho_{N}], (3.1-7c)\right) = 0 < \ell_{1} < L;$$

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$$\rho_{N} \equiv S/\sigma_{N}^{2}, \rho_{T} \equiv S/\sigma_{T}^{2}, K \equiv \sigma_{T}^{2}/\sigma_{N}^{2}$$
 (3.1-7d)

and where

$$c_{n} = e^{-\ell_{1}\rho_{T}} \left(\frac{K-1}{K}\right)^{n} \left(\frac{1}{K}\right)^{\ell_{1}} \mathcal{L}_{n}^{\ell_{1}-1} \left[-\frac{-\ell_{1}\rho_{T}}{K-1}\right], \quad \ell_{1} \geq 1.$$
(3.1-7e)

In (3.1-7e), the function  $\mathcal{L}_{n}^{a}(x)$  is the generalized Laguerre polynomial.

For the non-signal channels, substitution of  $\rho_N = \rho_T = 0$  in (3.1-7) yields, for  $u_m = z_m / \sigma_N^2$  (m >1),

$$p_{\chi^2}(\alpha; 2L), \quad \ell_m = 0;$$
 (3.1-8a)

$$p_{u}(\alpha) = \begin{cases} p_{\chi^{2}}(\alpha;2L), & p_{m} = 0; \\ \frac{1}{K} p_{\chi^{2}}(\alpha/K;2L), & p_{m} = L; \\ \infty & (3.1-8b) \end{cases}$$

$$\prod_{n=0}^{\infty} b_n P_{\chi^2}(\alpha; 2L+2n), \ 0 < \ell_m < L; \qquad (3.1-8c)$$

where

$$b_{n} = \left(\frac{K-1}{K}\right)^{n} \quad \left(\frac{1}{K}\right)^{\ell} \quad \left(\frac{n+\ell_{m}-1}{n}\right) \quad .$$
(3.1-8d)

In (3.1-7) and (3.1-8) the chi-squared pdf's are, for 2n degrees of freedom,

$$p_{\chi^{2}(\alpha;2n,2p)} = \frac{1}{2} \exp\left\{-\frac{\alpha}{2} - p\right\} \left(\frac{\alpha}{2p}\right)^{(n-1)/2} I_{n-1}(\sqrt{2p\alpha})$$
 (3.1-9a)

$$= \frac{1}{2} e^{-\frac{1}{2}/2} (\frac{1}{2})^{n-1} / r(n), \ \alpha = 0 \qquad (3.1-9b)$$

where  $I_m(x)$  is the modified Bessel function of the first kind and order m and  $\Gamma(\cdot)$  is the gamma function.

### 3.1.2 Formulation of the Conditional Error Probability.

From Section 2.2, the conditional symbol error probability is

$$P_{s}(e|[v]) = P_{s}(e|\ell_{1},\ell_{2},...,\ell_{M})$$

$$= 1 - Pr\{z_{2} < z_{1}, z_{3} < z_{1},...,z_{M} < z_{1}|\underline{\ell}\}$$

$$= 1 - Pr\{u_{2} < u_{1}, u_{3} < u_{1},...,u_{m} < u_{1}|\underline{\ell}\}$$

$$= 1 - \int_{0}^{\infty} d \alpha P_{u_{1}}(\alpha) \prod_{m=2}^{M} \int_{0}^{\alpha} d\beta_{m} P_{u_{m}}(\beta_{m}). \quad (3.1-10)$$

From (3.1-8) and (3.1-9),

$$(1 - \Gamma(L;\alpha/2)/\Gamma(L), \ell_m = 0;$$
 (3.1-11a)

$$F_{L}(\alpha; \ell_{m}) \oint_{0}^{\alpha} d\beta_{m} p_{u_{m}}(\beta_{m}) = \begin{cases} 1 - \Gamma(L; \alpha/2K)/\Gamma(L), \ell_{m} = L; \\ \sum_{m=1}^{\infty} (3.1-11b) \end{cases}$$

$$\left( \begin{array}{c} 1 - \sum_{n=0}^{\infty} b_n r(L+n;\alpha/2)/r(L+n), \quad (3.1-11c) \\ 0 < \ell_m < L; \end{array} \right)$$

where  $\Gamma(n;t)$  is the incomplete gamma function,

$$\Gamma(n;t) = \int_{t}^{\infty} dx \ e^{-x} \ x^{n-1} = \Gamma(n) \ e^{-t} \ \sum_{r=0}^{n-1} \ \frac{t^{r}}{r!} \ . \tag{3.1-12}$$

Formally, (3.1-10) can be written

$$P_{s}(e|\underline{2}) = 1 - \int_{0}^{\infty} d\alpha p_{u_{1}}(\alpha) [F_{L}(\alpha; 0)]^{n_{0}} [F_{L}(\alpha; 1)]^{n_{1}} \dots [F_{L}(\alpha; L)]^{n_{L}}, (3.1-13a)$$

where  $n_i$  is the number of non-signal channels with  $\ell_m$ =i, and it is true that

 $n_0 + n_1 + \ldots + n_1 = M - 1$ . (3.1-13b)

### 3.1.3 <u>Powers of Non-Signal Channel Probabilities</u>.

We now show that the probabilities  $F_{L}(\alpha; \mathfrak{a}_{m})$  in the general expression (3.1-13a) can be written in terms of power series.

For  $\ell_m = 0$ , from (3.1-11) and (3.1-12)

$$[F_{L}(\alpha; 0)]^{n_{0}} = \begin{bmatrix} -\alpha/2 & L-1 & \frac{\alpha}{2} \\ 1 - e & \sum_{r=0}^{L-1} & \frac{(\alpha/2)^{r}}{r!} \end{bmatrix}^{n_{0}}$$

$$= \sum_{r_0=0}^{n_0} {\binom{n_0}{r_0}} (-1)^{r_0} e^{-r_0 \alpha/2} \left[ \sum_{r=0}^{L-1} \frac{(\alpha/2)^r}{r!} \right]^{r_0}$$

$$= \sum_{\substack{r=0\\0}}^{n} \binom{n}{r_{0}} \binom{(-1)^{n}}{r_{0}} e^{-r_{0}\alpha/2} \sum_{\substack{k_{0}=0\\k_{0}=0}}^{r_{0}(L-1)} \frac{C(k_{0}, r_{0})}{k_{0}!} \binom{\alpha}{2}^{k_{0}}, \quad (3.1-14)$$

where the coefficients  $C(k_0, r_0)$  are [1, Appendix 4A] the functions

$$C(0, r) = 1$$

$$C(k, r) = \frac{1}{k} \sum_{n=1}^{\min(k, L-1)} {\binom{k}{n}} [(r+1)n - k] C(k - n, r),$$

$$(3.1-15b)$$

$$k > 0, L \ge 2.$$

For example, when L = 2 the coefficients are simply

$$C(k, r) = (r+1-k) C(k-1, r)$$
  
=  $r!/(r-k)!$  (3.1-16a)

so that the series raised to the  $\mathbf{r}_{\!\Omega}$  power is

$$\sum_{k_0=0}^{r_0} \frac{r_0!}{k_0!(r_0-k_0)!} \left(\frac{\alpha}{2}\right)^{k_0} = (1+\alpha/2)^{r_0}$$
(3.1-16b)

as required.

Similarly, for  $\ell_m = L$ , we find that

$$\left[F_{L}(\alpha;L)\right]^{n_{L}} = \sum_{r_{L}=0}^{n_{L}} {\binom{n_{L}}{r_{L}}} (-1)^{r_{L}} e^{-\frac{r_{L}\alpha/2K}{k_{L}=0}} \frac{r_{L}(L-1)}{k_{L}} \frac{C(k_{L},r_{L})}{k_{L}!} \left(\frac{\alpha}{2K}\right)^{k_{L}}, \quad (3.1-17)$$

using the same C(k, r) function as for  $\boldsymbol{\ell}_m{=}0$  .

For  $0 < z_M < L$ ,  $L \ge 2$ , the evaluation of the probability is more challenging, but does indeed reduce to a closed form. The development begins by recognizing that  $\infty = n + i - 1$ 

$$F_{L}(\alpha; \lambda_{m}) = 1 - e^{-\alpha/2} \sum_{n=0}^{\infty} b_{n} \sum_{r=0}^{n+L-1} \frac{(\alpha/2)^{r}}{r!}$$

$$= 1 - e^{-\alpha/2} \sum_{r=0}^{L-1} \frac{(\alpha/2)^{r}}{r!} - e^{-\alpha/2} \sum_{n=0}^{\infty} b_{n+1} \sum_{r=0}^{n} \frac{(\alpha/2)^{r+L}}{(r+L)!}$$
(3.1-18)
where  $b_{n}$  is defined by (3.1-8d). The double summation in the last term can be

manipulated in the following way:

$$\sum_{n=0}^{\infty} b_{n+1} \sum_{r=0}^{n} \frac{(\alpha/2)^{r+L}}{(r+L)!} = \sum_{n=0}^{\infty} \sum_{r=0}^{\infty} b_{n+r+1} \frac{(\alpha/2)^{r+L}}{(r+L)!}$$
$$= \kappa^{-2} \sum_{r=0}^{\infty} \left(\frac{\kappa-1}{\kappa}\right)^{r+1} \frac{(\alpha/2)^{r+L}}{(r+L)!} {r+2 \choose k-1} {}_{2}F_{1}(r+k+1,1;r+2;\frac{\kappa-1}{\kappa}).$$
(3.1-19)

The hypergeometric function can be transformed using [2, Eq. 15.3.5] to obtain

on the summation were zero, the summation would be a Taylor's series:

$$\sum_{n=0}^{\infty} \frac{a^{n}}{n!} \frac{n!}{(n+L-\ell)!} \frac{1}{1} F_{1}(n+1;n+L-\ell+1;b)$$

$$= \frac{1}{(L-\ell)!} \sum_{n=0}^{\infty} \frac{a^{n}}{n!} \left[ \frac{d^{n}}{dx^{n}} \frac{1}{1} F_{1}(1;L-\ell+1;x) \right]^{x} = b$$

$$= \left[ e^{a+b} - \sum_{n=0}^{L-\ell-1} \frac{(a+b)^{n}}{n!} \right] \frac{1}{(a+b)!} \cdot (3.1-23b)$$
(3.1-23b)

therefore, (3.1-22) is seen to be

$$e^{\alpha/2} - \sum_{n=0}^{L-\ell-1} \frac{(\alpha/2)^n}{n!} - \sum_{n=0}^{\ell-1} \left(\frac{1}{K}\right)^n \frac{(\alpha/2)^{n+L-\ell}}{n!} \frac{d^n}{dx^n} x^{\ell-L} \left[ e^x - \sum_{r=0}^{L-\ell-1} \frac{x^r}{r!} \right] \left| \begin{array}{c} x^{r} (K-1)\alpha/2K \\ . \\ . \\ (3.1-24) \end{array} \right|^{k}$$

Now, substituting (3.1-24) into (3.1-21) and the resulting expression into (3.1-18) gives

$$F_{L}(x; \ell) = 1 - e^{-\alpha/2} \left[ \sum_{r=0}^{L-1} \frac{(\alpha/2)}{r!} + \sum_{r=0}^{\infty} \frac{(\alpha/2)^{r+L}}{(r+L)!} \right] + e^{-\alpha/2} \left[ (3.1-24) \right] = 0 + e^{-\alpha/2} \left[ (3.1-24) \right] = 1 - e^{-\alpha/2} \left\{ \sum_{n=0}^{L-\ell-1} \frac{(\alpha/2)^{n}}{n!} + \left(\frac{\alpha}{2}\right)^{L-\ell} \sum_{n=0}^{\ell-1} \frac{(\alpha/2K)^{n}}{n!} \frac{d^{n}}{dx^{n}} \times^{\ell-L} \left[ e^{X} - \sum_{r=0}^{L-\ell-1} \frac{x^{r}}{r!} \right] \right|^{X=(K-1)\alpha/2K} \right\}$$

$$= 1 - e^{-\alpha/2} \left\{ \sum_{n=0}^{L-\ell-1} \frac{(\alpha/2)^{n}}{n!} \left[ 1 - \left(\frac{K}{K-1}\right)^{L-\ell-n} \sum_{r=0}^{\ell-1} \frac{(L-\ell+r-n-1)}{r} \frac{(-1)^{r}}{(K-1)^{r}} \right] \right\}$$
$$-e^{-\alpha/2K} \left(\frac{K}{K-1}\right)^{L-\ell} \sum_{n=0}^{\ell-1} \frac{(\alpha/2K)^{n}}{n!} \sum_{r=0}^{\ell-1-n} \binom{L-\ell+r-1}{r} \binom{(-1)^{r}}{K-1}. \quad (3.1-25)$$

For example, if L = 2 and  $\ell = 1$ ,

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$$F_{2}(\alpha; 1) = 1 - e^{-\alpha/2} \left\{ 1 - \frac{K}{K-1} \right\} - e^{-\alpha/2K} \left( \frac{K}{K-1} \right)$$
$$= 1 - \frac{1}{K-1} \left\{ K e^{-\alpha/2K} - e^{-\alpha/2} \right\}.$$
(3.1-26)

By direct algebraic calculation of (3.1-25), it can be shown that  $F_{L}(\alpha, \ell)$  is of the form

$$F_{L}(\alpha; \ell) = 1 - \frac{1}{(K-1)^{L-1}} \left\{ e^{-\alpha/2K} f_{1}(\alpha; \ell, L) + e^{-\alpha/2}f_{2}(\alpha; \ell, L) \right\}, \quad (3.1-27)$$

where  $f_1(\alpha;\ \ell,\ L)$  and  $f_2(\alpha;\ \ell,\ L)$  are the polynomials given in Table 3.1-1. Therefore

$$[F_{L}(\alpha; \ell)]^{n} \ell = \sum_{r_{\ell}=0}^{n} {n \choose r} \left[ \frac{-1}{(K-1)^{L-1}} \right]^{r_{\ell}}$$
$$\cdot \left[ e^{-\alpha/2K} f_{1}(\alpha; \ell, L) + e^{-\alpha/2} f_{2}(\alpha; \ell, L) \right]^{r_{\ell}}$$

L	£	f <sub>1</sub> (a;l,L)	f <sub>2</sub> (α;ℓ,L)
1	0	0	1
:	1	1	0
2	0	0	$(K-1)(1+\alpha/2)$
	1	к	-1
	2	(K-1)(1+a/2K)	0
3	0	0	$(K-1)^2(1+\alpha/2+\alpha^2/8)$
	1	κ <sup>2</sup>	- [2K-1+(K-1)a/2]
	2	K(K-2)+(K-1)α/2	1
	3	$(K-1)^{2} \left[ 1 + \alpha/2K + \alpha^{2}/8K^{2} \right]$	0
4	0	0	$(K-1)^{3}(1+\alpha/2+\alpha^{2}/8+\alpha^{3}/48)$
	1	к <sup>3</sup> - [зк	$^{2}$ -3K+1+(2K <sup>2</sup> -3K+1) $\alpha$ /2+(K-1) $^{2}\alpha^{2}$ /8
	2	κ <sup>3</sup> -3κ <sup>2</sup> +κ(κ-1)α/2	3K-1+(K-1)α/2
	3	к <sup>3</sup> -3К <sup>2</sup> +3К	-1
		+(K <sup>2</sup> -3K+2)a/2 +(K-1) <sup>2</sup> a <sup>2</sup> /8K	
	4	$(K-1)^{3}(1+\alpha/2K+\alpha^{2}/8K^{2}+\alpha^{3}/48K^{3})$	0

TABLE 3.1-1 POLYNOMIALS FOR  $F_{L}(\alpha; \ell)$ 

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$$= \sum_{r_{\ell}=0}^{n_{\ell}} {n_{\ell} \choose r_{\ell}} \left[ \frac{-1}{(K-1)^{L-1}} \right]^{r_{\ell}} \sum_{k_{\ell}=0}^{r_{\ell}} {r_{\ell} \choose k_{\ell}} e^{-(r_{\ell}-k_{\ell})\alpha/2K-k_{\ell}\alpha/2}$$

 $\cdot [f_{1}(\alpha; \ell, L)] \stackrel{r_{\ell}-k_{\ell}}{[f_{2}(\alpha; \ell, L)]} (3.1-28)$ 

and the powers of the polynomials can be expressed as a higher order polynomial:

$$[f_1]^{r_{\ell}-k_{\ell}}[f_2]^{k_{\ell}} = \sum_{p_{\ell}=0}^{P} d(p_{\ell}) (\alpha/2)^{p_{\ell}}. \qquad (3.1-29)$$

The coefficients d(p) are given in Table 3.1-2 for L up to 4.

#### 3.1.4 Expectation Over Signal Channel PDF.

Substitution of the powers of the non-signal channel probabilities into the conditional probability of symbol error equation yields the lengthy expression given in Table 3.1-3. The remaining analysis requires obtaining the expectation

$$\int_{0}^{\infty} d\alpha \, p_{u_{1}}(\alpha) \, e^{-a_{0} \alpha/2} (\alpha/2)^{b_{0}} = E_{u} \left\{ e^{-au_{1}/2} \left( \frac{u_{1}}{2} \right)^{b_{0}} \right\} , \qquad (3.1-30)$$

where  $a_0$  and  $b_0$  are given in Table 3.1-3. From (3.1-7a), when the signal channel is not jammed  $(a_1 = 0)$ , the pdf  $p_{u_1}(\alpha)$  is a straightforward noncentral chi-squared pdf, and the expectation is

$$\int_{0}^{\infty} d_{\alpha} p_{\chi^{2}}(\alpha; 2L, 2L^{p}_{N}) e^{-a_{0}\alpha/2} (\alpha/2)^{b_{0}}$$

TABLE 3.1-2 COEFFICIENTS FOR EQUATION (3.1-29)

L	l	P = max p	d(p)
2	1	0	$\kappa^{r_1-k_1}(-1)^{k_1}$
3	1	k <sub>1</sub>	$(\kappa^{2})^{r_{1}-k_{1}}(-1)^{k_{1}}\binom{k_{1}}{p}(2\kappa-1)^{k_{1}-p}(\kappa-1)^{p}$
3	2	r2 - k2	$\binom{r_2 - k_2}{p} [K(K-2)]^{r_2 - k_2 - p} (K-1)^{p}$
4	1	2k <sub>1</sub>	$(K^3)^{r_1-k_1}(-1)^{k_1}(3K^2-3K+1)^{k_1} \cdot g(p)$
			where $g(0) = 1$ , $g(1) = k_1 \cdot \frac{2K^2 - 3K + 1}{3K^2 - 3K + 1}$ $g(n) = \frac{1}{n} \left( (k_1 + 1 - n) \cdot \frac{2K^2 - 3K + 1}{3K^2 - 3K + 1} \cdot g(n - 1) + [2(k_1 + 1) - n] \frac{(K - 1)^2/2}{3K^2 - 3K + 1} \cdot g(n - 2) \right), n \ge 2$
4	2	r <sub>2</sub>	$\kappa^{2r_{2}-2k_{2}-p} (K-1)^{p} \qquad \sum_{q = \max(0, p-r_{2}+k_{2})}^{\min(p, k_{2})} {\binom{r_{2}-k_{2}}{p-q}\binom{k_{2}}{q}}$
			• (К-З) <sup>r</sup> 2 <sup>-k</sup> 2 <sup>-р+q</sup> (ЗК-1) <sup>k</sup> 2 <sup>-q</sup> К <sup>q</sup>
4	3	2(r <sub>3</sub> -k <sub>3</sub> )	(-1) <sup>k</sup> <sub>3</sub> (K <sup>3</sup> -3K <sup>2</sup> +3K) <sup>r<sub>3</sub>-k<sub>3</sub> g(p)</sup>
			where $g(0) = 1$ , $g(1) = (r_3 - k_3) \cdot \frac{K^2 - 3K + 2}{K^3 - 3K^2 + 3K}$ $g(n) = \frac{1}{n} \left\{ (r_3 - k_3 + 1 - n) \cdot \frac{K^2 - 3K + 2}{K^3 - 3K^2 + 3K} \cdot g(n - 1) + \left[ 2(r_3 - k_3 + 1) - n \right] \cdot \frac{(K - 1)^2 / 2K}{K^3 - 3K^2 + 3K} \cdot g(n - 2) \right\}$ , $n \ge 2$

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		(k <sup>r</sup> , r <sup>L</sup> )					
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	PROBABI -1 <sub>i</sub> F <sub>L</sub> (°	$\left( r_{L}^{n} \right)^{(-)}$	( 1	<sup>P</sup> -1 -1 -1 -1			
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	or cond n1	(k <sub>0</sub> ,r <sub>0</sub> ) k <sub>0</sub> !	$= C \begin{pmatrix} r_1 \\ k_1 \end{pmatrix}$		po	r <sub>e</sub> -k K	
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	EXPRE: ) ] <sup>n</sup> 0 ( F	$1)^{r_0}\sum_{k_0}^{r_0}$	-1 (K-1)	-1 (K-1)	e-a <sub>0</sub> α/2	+ × =1	
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$$= \int_{0}^{\infty} d_{\alpha} e^{-L\rho_{N}-(1+a_{0})\alpha/2} \left(\frac{\alpha}{2L\rho_{N}}\right)^{(L-1)/2} I_{L-1}\left(\sqrt{2L\rho_{N}\alpha}\right) \left(\frac{\alpha}{2}\right)^{b_{0}}$$

$$= \exp\left(\frac{-L\rho_{N}a_{0}}{1+a_{0}}\right)(1+a_{0})^{-b_{0}-L}$$

$$\int_{0}^{\infty} dx e^{-L\rho_{N}/(1+a_{0})-x/2} \left[\frac{x}{2L\rho_{N}/(1+a_{0})}\right]^{(L-1)/2} I_{L-1}\left(\sqrt{\frac{2L\rho_{N}x}{1+a_{0}}}\right) \left(\frac{x}{2}\right)^{b_{0}}$$

$$= \exp\left(\frac{-L\rho_{N}a_{0}}{1+a_{0}}\right) (1+a_{0})^{-b_{0}-L} \cdot E\left[\left(\frac{x}{2}\right)^{b_{0}}\right], \qquad (3.1-31)$$

where x is distributed as a noncentral chi-squared random variable with 2L degrees of freedom and noncentral parameter  $2L\rho_N/(1+a_0)$ . The moments needed are

$$E\left[\left(\frac{x}{2}\right)^{b_0}\right] = b_0! \mathcal{L}_{b_0}^{L-1}\left(-\frac{L_{p_N}}{1+a_0}\right)$$
(3.1-32a)

$$= \sum_{r=0}^{b_0} {\binom{b_0 + L - 1}{b_0 - r}} {\binom{L \rho_N}{1 + a_0}} \frac{1}{r!} b_0! \qquad (3.1 - 32b)$$

where  $\mathcal{L}_{n}^{a}(x)$  is the generalized Laguerre polynomial. Thus for the case of

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 $\ell_1 = 0$ , the integral in (3.1-30) becomes the quantity

$$\exp\left(-\frac{L_{\rho_{N}}^{a_{0}}}{1+a_{0}}\right) = \frac{b_{0}!}{(1+a_{0})^{b_{0}+L}} \mathcal{L}_{b_{0}}^{L-1}\left(-\frac{L_{\rho_{N}}}{1+a_{0}}\right).$$
(3.1-33)

In a similar way, when all the hops in the signal channel are jammed  $(l_1 = L)$ , the integral in (3.1-30) becomes

$$\exp\left(-\frac{L_{P_{T}}Ka_{0}}{1+Ka_{0}}\right) \frac{K^{b_{0}}b_{0}!}{(1+Ka_{0})^{b_{0}+L}} \quad \mathcal{L}_{b_{0}}^{L-1}\left(-\frac{L_{P_{T}}}{1+Ka_{0}}\right).$$
(3.1-34)

Now, when the signal channel is jammed, but not on every hop  $(0 < \ell_1 < L)$ , the channel pdf is a series of weighted noncentral chi-squared pdf's, as shown previously in (3.1-7c). This expectation (3.1-30) yields

$$\exp\left[-\frac{(L-\ell_{1})\rho_{N}a_{0}}{1+a_{0}}\right]\sum_{n=0}^{\infty}c_{n}\frac{b_{0}!}{(1+a_{0})^{b_{0}+L+n}}\mathcal{L}_{b_{0}}^{L+n-1}\left[-\frac{(L-\ell_{1})\rho_{N}}{1+a_{0}}\right], (3.1-35)$$

where the weights  $\{c_n\}$  are

$$c_{n} = e^{-\ell_{1} \rho_{T}} \left( \frac{K-1}{K} \right)^{n} \kappa^{-\ell_{1}} \mathcal{L}_{n}^{\ell_{1}-1} \left[ - \frac{\ell_{1} \rho_{T}}{K-1} \right].$$
(3.1-36)

In order to reduce (3.1-35) to a finite summation, it is necessary to seek an identity for

$$\sum_{n=0}^{\infty} A^{n} \mathcal{L}_{n}^{a}(x) \mathcal{L}_{r}^{n+k}(y).$$
(3.1-37)

To accomplish this objective, we note that [3, eq. 8.970.1]

$$\mathcal{L}_{r}^{n+k}(y) \stackrel{\Delta}{=} \frac{1}{r!} e^{y} y^{-n-k} \frac{d^{r}}{dy^{r}} (e^{-y} y^{r+n+k}); \qquad (3.1-38)$$

substituting in (3.1-37) yields the development

 $\frac{1}{r!} e^{y} y^{-k} \sum_{n=0}^{\infty} \left(\frac{A}{y}\right)^{n} \mathcal{L}_{n}^{a}(x) \frac{d^{r}}{dy^{r}} (e^{-y} y^{r+n+k})$   $= \frac{e^{y} y^{-k}}{r!} \frac{\partial^{r}}{\partial z^{r}} \left[e^{-z} z^{r+k} \sum_{n=0}^{\infty} \left(\frac{Az}{y}\right)^{n} \mathcal{L}_{n}^{a}(x)\right]^{|z=y|}$   $= \frac{e^{y} y^{-k}}{r!} \sum_{q=0}^{r} \left(\frac{r}{q}\right) \frac{\partial^{r-q}}{\partial z^{r-q}} (e^{-z} z^{r+k}) \frac{\partial^{q}}{\partial z^{q}} \left[\sum_{n=0}^{\infty} \left(\frac{Az}{y}\right)^{n} \mathcal{L}_{n}^{a}(x)\right]^{|z=y|}$   $= e^{y} y^{-k} \sum_{q=0}^{r} \frac{1}{q!} e^{-z} z^{k+q} \mathcal{L}_{r-q}^{k+q}(z) \sum_{n=q}^{\infty} \left(\frac{A}{y}\right)^{n} \frac{n!}{(n-q)!} z^{n-q} \mathcal{L}_{n}^{a}(x) |\sum_{n=q}^{z=y|} (3.1-39)$ 

The second summation, when manipulated, gives the result

$$\left(\frac{A}{y}\right)^{q} \sum_{n=0}^{\infty} \frac{(n+q)!}{n!} \left(\frac{Az}{y}\right)^{n} \mathcal{L}_{n+q}^{a}(x)$$

$$= \left(\frac{A}{y}\right)^{q} \sum_{n=0}^{\infty} \left(\frac{Az}{y}\right)^{n} \frac{(n+q+a)!}{n! a!} {}_{1}F_{1}(-n-q; a+1; x)$$

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$$= \left(\frac{A}{y}\right)^{q} e^{X} \sum_{n=0}^{\infty} \left(\frac{Az}{y}\right)^{n} \frac{(n+q+a)!}{n! a!} {}_{1}F_{1}(n+q+a+1; a+1; -x)$$

$$= \left(\frac{A}{y}\right)^{q} e^{X} \sum_{n=0}^{\infty} \left(\frac{Az}{y}\right)^{n} \frac{1}{n!} \sum_{m=0}^{\infty} \frac{(-x)^{m}}{m!} \frac{(n+q+a+m)!}{(a+m)!}$$

$$= \left(\frac{A}{y}\right)^{q} e^{X} \sum_{m=0}^{\infty} \frac{(-x)^{m}}{m!} \frac{(q+a+m)!}{(a+m)!} (1 - Az/y)^{-q-a-m-1}$$

$$= \left(\frac{A}{z}\right)^{q} e^{X} \frac{(q+a)!}{a!} (1 - Az/y)^{-q-a-1} {}_{1}F_{1}(q+a+1; a+1; \frac{-x}{1 - Az/y})$$

$$= \left(\frac{A}{z}\right)^{q} \frac{\exp(\frac{-Axz}{y-Az})}{a!} - a! \ell^{a} \left(\frac{xy}{z}\right)$$

$$= \left(\frac{A}{y}\right)^{q} \frac{\exp\left(\frac{TAZ}{y-AZ}\right)}{\left(1-Az/y\right)^{q+a+1}} q! \mathcal{L}_{q}^{a}\left(\frac{xy}{y-Az}\right) . \qquad (3.1-40)$$

After substitution in (3.1-39), we find that

$$\sum_{n=0}^{\infty} A^{n} \mathcal{L}_{n}^{a}(x) \mathcal{L}_{r}^{n+k}(y)$$

$$= \frac{1}{(1-A)^{a+1}} \exp\left(\frac{-Ax}{1-A}\right) \sum_{q=0}^{r} \left(\frac{A}{1-A}\right)^{q} \mathcal{L}_{r-q}^{k+q}(y) \mathcal{L}_{q}^{a}\left(\frac{x}{1-A}\right).$$
(3.1-41)

And, substituting appropriately, the desired expectation (3.1-35) becomes

$$\exp\left[-\frac{(L-\ell_{1})\rho_{N}a_{0}}{1+a_{0}}-\frac{\ell_{1}\rho_{T}Ka_{0}}{1+Ka_{0}}\right]\frac{b_{0}!}{(1+a_{0})^{b_{0}+L-\ell_{1}}(1+Ka_{0})^{\ell_{1}}}$$

$$\sum_{q=0}^{C_0} \left(\frac{K-1}{1+Ka_0}\right)^q \mathcal{L}_{b_0-q}^{q+L-1} \left[-\frac{(L-\ell_1)\rho_N}{1+a_0}\right] \mathcal{L}_q^{\ell_1-1} \left[-\frac{\ell_1\rho_T}{K-1} \cdot \frac{K(1+a_0)}{1+Ka_0}\right] .$$
(3.1-42)

3.1.5 Special case: L=1 and M=2.  
For L=1 and M=2 the FH/RMFSK total error probability is
$$\frac{-\rho_N}{(K+1)} = \frac{-\rho_T}{2}$$

$$P(e) = \pi_0 \cdot \frac{1}{2} e^{-\rho N/2} + \pi_1 \cdot e^{-\rho N/(K+1)} + \pi_2 \cdot \frac{1}{2} e^{-\rho T/2} \quad (3.1-43a)$$

where

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$$\rho_{\rm N} = E_{\rm b}/N_{\rm 0}$$
,  $\rho_{\rm T} = E_{\rm b}/N_{\rm T}$ ; (3.1-43b)

and 
$$K = \sigma_T^2 / \sigma_N^2 = \rho_N / \rho_T$$
. (3.1-43c)

### 3.2 NUMERICAL RESULTS

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#### 3.2.1 Soft-Decision Receiver.

Numerical results were obtained using two computational methods. In regions where the series converge rapidly enough, the form given in Table 3.1-3 and equation (3.1-42) was used for the computations. However, the presence of the term  $(K-1)^{L}$  in the denominator of several terms causes difficulty when K is nearly equal to 1. In these cases, and on other occasions when round-off errors became excessive, the computations were performed by direct numerical integration of (3.1-10) using the densities (3.1-7) and (3.1-8) and the identity

$$1 - \int_{0}^{\infty} d\alpha p(\alpha) g(\alpha) \equiv \int_{0}^{\infty} d\alpha p(\alpha) [1-g(\alpha)] \qquad (3.2-1)$$

which holds for all density functions  $p(\alpha)$  for which  $p(\alpha) \equiv 0$  if  $\alpha < 0$ , and hence by the properties of a p.d.f.

$$\int_{0}^{\infty} d_{\alpha} p(\alpha) = 1. \qquad (3.2-2)$$

Then (3.2-1) follows immediately from the fact that integration is a linear operation. The form on the right-hand side of (3.2-1) has the computational advantage that only the integrand need be computed to high accuracy, rather than the integral. For example, if  $P_s(e) \approx 10^{-5}$  and we desire 4 significant digits in the answer, than the integral on the left-hand side must be computed numerically to 8-digit accuracy (e.g. 0.9999xxxx) in order to leave 4 non-zero

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correct digits after subtracting from 1. But if we use the form on the right-hand side of (3.2-1) we could demand only 4-place relative accuracy from the numerical integration; the burden of many-place accuracy is placed only on the function  $g(\cdot)$ , which is usually much simpler and faster to compute then the overall integral. A listing of the computer program is given in Appendix D.

In Figures 3.2-1 through 3.2-4 we show the bit error probability as a function of bit energy-to-jamming density ratio with jamming fraction  $\gamma$ as a parameter for the case of M=2 (binary FSK) and L=1,2,3, and 4 hops per symbol (bit), respectively. In these figures the ratio of the bit energy to thermal noise density is set at 13.3525 dB, which corresponds to a bit error probability of 10<sup>-5</sup> for one hop per bit in the absence of jamming. We note that for a given  $E_b/N_J$  ratio there is an optimum value of  $\gamma$  which maximizes the jammer's effectiveness. Furthermore, an incorrect choice of  $\gamma$  by the jammer can reduce the effectiveness (as measured by the communicator's bit error probability) by possibly as much as two orders of magnitude.

Figure 3.2-5 shows the envelopes of the curves in Figures 3.2-1 through 3.2-4, which represent the performance of the square-law combining receiver in worst-case partial-band noise jamming. We note that increasing L, the number of hops per bit, consistently degrades the performance. This implies that the noncoherent combining loss dominates over any diversity gain effects.

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FOR SQUARE-LAW COMBINING RECEIVER WITH M=2 AND L=2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 13.3525$  dB (FOR  $10^{-5}$  BER WITH-OUT JAMMING WHEN L=1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER



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Similar results for the case of M=4 are shown in Figures 3.2-6 through 3.2-9 for L=1,2,3, and 4 hops/symbol, respectively. Again we note that the jammer must carefully choose the proper partial-band fraction or risk reducing his effectiveness by more than an order of magnitude. We also observe that full-band jamming ( $\gamma$ =1.0) is not optimum until the jamming becomes very strong, i.e.  $E_{\rm b}/N_{\rm l} < 0$  dB.

Figure 3.2-10 shows the envelope of the curves in Figures 3.2-6 through 3.2-9, which gives the performance in worst-case partial-band noise jamming. We note that increasing the number of hops per symbol consistently degrades the performance of the 4-ary system, just as it does for the binary system.

Finally, Figure 3.2-11 shows the worst-case partial-band noise jamming performance of the square-law receiver for L=1 hop/symbol and M=2,4, and 8. We observe that for strong jamming increasing M from 2 to 4 provides a very small performance improvement; but further increase to M=8 degrades the performance. This behavior is similar to that of a block-hopping system in tone jamming [1, Section 8].

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2400 HOPPING SLOTS, AND  $E_b/N_0 = 10.606573$  dB (FOR  $10^{-5}$ BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER



FIGURE 3.2-7 BIT ERROR PROBABILITY VS. BIT ENERGY TO JAMMING DENSITY RATIO FOR SQUARE-LAW COMBINING RECEIVER WITH M = 4 AND L = 2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 10.606573$  dB (FOR  $10^{-5}$ BER WITH-JAMMING WHEN L = 1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER



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FIGURE 3.2-9 BIT ERROR PROBABILITY VS. BIT ENERGY TO JAMMING DENSITY RATIO FOR SQUARE-LAW COMBINING RECEIVER WITH M = 4 AND L = 4 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 10.606573$  dB (FOR  $10^{-5}$ BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION Y AS A PARAMETER



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#### 3.2.2 Hard-Decision Receiver

In this subsection we apply the explicit form of the error probability expression (2.4-14) to evaluate the symbol error probability,  $P_s(e)$ , for a square-law receiver with hard decisions. We consider M-ary cases of M=2,4, and 8 with L values (hops per symbol) ranging from one through five. The worstcase or maximum probability of error is obtained by computing  $P_s(e)$  upon varying the number of noise jammed hopping slots q, for an FH/RMFSK system comprised of 2400 hopping slots; i.e. a partial-band noise jamming (PBNJ) model.

We first present plots of numerical results for P(e) versus the variable  $E_b/N_J$  with thermal noise  $(E_b/N_0)$  as a parameter. Practical values of  $E_b/N_0$  were chosen for which the probability of error becomes  $10^{-5}$  in the absence of jamming. These values are: 13.35247, 10.60657, and 9.09401 dB for M-ary signalling alphabets of M=2, 4, and 8 respectively. Corresponding performance plots are shown in Figures 3.2-12 to 3.2-14.

A comprehensive view of Figure 3.2-12 (M=2) reveals that all five of the L error curves could be grouped into three  $E_b/N_J$  regions of relative jamming strength: (1) below 11 dB (strong), (2) 11 dB to 28 dB (medium), and (3) beyond 28 dB (weak). Within the strong jamming region, we see a consistent P(e) L-curve ordering of 4,5,2,3,1 and a 4,2,5,3,1 ranking in the weak region. The region defined as medium strength jamming exhibits "cross-overs" of the various L P(e) curves. Similarly, for M=4 (Figure 3.2-13) and M=8 (Figure 3.2-14) this same three-region behavior exists as follows:





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Relative Jamming Region of  $E_b/N_1$  (dB) Values

M	Strong	Medium	Weak
4	< 4	4 to 32	> 32
8	< 6	6 to 38	> 38

The ranking of the L P(e) curves for both M=4 and M $\approx$ 8 in the strong jamming region is 5,4,3,2,1 while for weak jamming a 5,4,2,3,1 ordering is observed.

It is plain to see that for the most part no diversity improvement is realized by the communicator with the exception of a portion of the L=3 P(e)curve in medium jamming for M=2 and M=4. This general behavior can be attributed to the dominance of the noncoherent combining loss existing for the stated thermal noise levels.

A somewhat different trend is noticed when the effect of thermal noise is minimized. Figures 3.2-15 through 3.2-17 show P(e) results for M=2,4, and 8 respectively at  $E_b/N_0$  levels of 20 dB. Clearly, the regions of strong and weak jamming are now quite discernable with a smaller crossover region (medium jamming) existing among the L P(e) curves. However, we do notice a ranking in the weak jamming areas that differs from those of the  $10^{-5}$  parameter  $E_b/N_0$  curves previously presented. Here it is easily seen that the hard-decision receiver is uniformly 3 dB better for L=1 than for L=2 as described by (2.4-15) for any value of M. Also, a form of diversity improvement is realized as L becomes greater than 2 for all M-ary cases at  $E_b/N_1$  values of more than about 12 dB.



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The case of M=2 is an exception to this trend for L=3 and L=4 as explained in subsection 2.4.2.3 where L=4 is shown to be 1.25 dB worse than that for L=3.

Thus we conclude that when thermal noise is minimized, a form of diversity improvement does exist in all M cases for  $E_b/N_J$  values greater than around 12 dB for L>2 hops per symbol.

We now determine the optimum number of jammed slots ( $\textbf{Q}_{\text{max}}$ ) which yields the maximum probability of error for a given value of  $E_{\rm b}/N_{\rm i}$ . Figures 3.2-18 to 3.2-20 show such plots for case of M=2,4, and 8 with L values ranging from one to five. It is seen that in all cases a definite ascending order of the L  $Q_{max}$  curves exists for increasing  $E_b/N_J$  values as is to be expected for worst-case jamming calculations. For example, in Figure 3.2-18 (M=2) we see that at a 30 dB  $E_b/N_J$  value, the  $Q_{max}$  value is 2 for L=1 and over 200 for L=5. Also in Figure 3.2-18 we note the "plateau" effect for all the curves at  $Q_{max}$ equal to 2400. Now the breakpoint at which each individual L-curve falls off from the "plateau" represents that  $E_b/N_1$  value for which full-band jamming (y=1.0) will not cause maximum probability of error. We can also characterize each L-curve behavior of Figure 3.2-18 as per three definite regions with respect to the "slope" of each curve. These regions, in terms of  $Q_{max}$  values, are: (1) 2400 to about 900, (2) 900 down to approximately 20, and (3) below 20. Note that distinguishable breaks in the curves below 20 are due to the smaller quantized values of Q becoming more discernable for the lower values of the logarithmic  $Q_{max}$  scale.

With regard to Figures 3.2-19 (M=4) and 3.3-20 (M=8), we see an asymptotic merging of the L-curves within the region of approximately  $Q_{max} = 800$  to 2400. Below a  $Q_{max}$  of about 800 we have two more noticeable regions







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similar to those in Figure 3.2-18. Additionally, we see that this asymptotic merging has yet to reach a full-band value of  $Q_{max}=2400$  for the minimum  $E_b/N_J$  value utilized in the calculations. Further computations (not shown) for lower values of  $E_b/N_J$  reveal the following points at which the L=1 curve breaks from the  $Q_{max}=2400$  ( $\gamma=1.0$ ) value: M=4 at -149.0 dB, M=8 at -150.0 dB. Hence, in these cases, full-band jamming would only be optimum for a very large amount of available jamming power.

A final point of interest is shown in Figure 3.2-21 with respect to minimization of the thermal noise component. Here we see that for the binary (M=2) case, increasing the  $E_b/N_0$  value over that used in Figure 3.2-18 causes the L=5 curve to move around 10 dB ( $E_b/N_0$ ) lower while the L=1 curve decreases only about 1 dB.

The results indicate that the hard symbol decision receiver can be considered an ECCM receiver (for sufficiently high  $E_b/N_0$ ), while the linear combining receiver cannot. Therefore, it is not diversity as such that yields an ECCM effect, but the combining technique. Hard decisions ( $\circ$  form of repetition coding) in effect limit the jamming effects on a given hop to that hop, whereas with linear combining a single, strongly jammed hop can dominate the soft decision.



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#### 4.0 FH/RMFSK PERFORMANCE USING SQUARE-LAW AGC RECEIVER

In this section we consider the case of the generic receiver shown in Figure 2.2-1 when the envelope samples are processed using the function

$$f(x_{mk}) = x_{mk}^2 \cdot w_{mk} = z_{mk}$$
 (4.0-1)

That is, the decision statistics  $\{z_m\}$  are weighted sums of samples of the squared envelope in each channel over multiple (L) hops.

For conventional FH/MFSK, where the symbol frequency slots are hopped together, it was assumed in [1] that all the slots are jammed or all the slots are not jammed on a given hop, and the weights were taken to be

$$w_{mk} = 1/\sigma_k^2 = \begin{cases} 1/\sigma_N^2 , \text{ hop not jammed} \\ 1/\sigma_T^2 , \text{ hop jammed.} \end{cases}$$
(4.0-2)

This weighting or normalization scheme was predicated on use of a separate channel, or perhaps a look-ahead scheme, to measure the noise power (perfectly) on each hop. The effect of the weighting is to de-emphasize the jammed hops in the summations

$$z_{\rm m} = \sum_{k=1}^{L} z_{\rm mk}$$
, (4.0-3)

and therefore to mitigate the effect of the jamming on the symbol decision.

For FH/RMFSK, in general the different symbol frequency slots are independently jammed or not jammed when the system bandwidth contains power from a partial-band noise jammer. In Section 4.1, we discuss several normalization schemes of the AGC (adaptive gain control) type. The performances of two of these schemes are analyzed in Sections 4.2 and 4.3. We also consider the effect of hard-limiting the hop statistics  $\{z_{mk}\}$  prior to combining.

## 4.1 POSSIBLE AGC WEIGHTING SCHEMES FOR FH/RMFSK

The squared envelope samples in the M receiver channels on a given hop are weighted chi-squared random variables:

$$x_{1k}^{2} \sim \sigma_{1k}^{2} \quad x^{2}(2; \lambda_{1k} = 2S/\sigma_{1k}^{2})$$

$$= (\sigma_{N}^{2} + v_{1k} \sigma_{J}^{2}) x^{2}[2; 2S/(\sigma_{N}^{2} + v_{1k}\sigma_{J}^{2})]$$

$$(4.1-1a)$$

in the signal channel, and

$$x_{mk}^{2} \sim \sigma_{mk}^{2} \chi^{2}(2) = (\sigma_{N}^{2} + v_{mk}\sigma_{J}^{2}) \chi^{2}(2), m > 1,$$
 (4.1-1b)

in the non-signal channels, where

$$v_{mk} \stackrel{a}{=} \begin{cases} 1, \text{ channel } m \text{ jammed on hop } k \\ 0, \text{ channel } m \text{ not jammed on hop } k. \end{cases}$$
 (4.1-2)

We shall consider three approaches to AGC normalization, as illustrated in Figure 4.1-1:

(a) Measurement of noise power in the M de-hopped channels on each hop and normalization (division) by the average received noise power (variance) in these channels.

(b) Individual measurement and normalization of each of the M channels on each hop.

(c) Normalization of the M channels by the same amount, depending on whether one or more of the channels are jammed, or none are jammed.

#### 4.1.1 Average AGC Scheme.

An ideal measurement of average noise power in the M channels would yield the weights



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Weighting schemes:

(a) Average AGC approach:

$$w_{mk} = \left[ \frac{1}{2} E \left\{ \sum_{m=1}^{M} x^2_{mk} - S \right\} \right]^{-1} \left[ \frac{1}{M} \sum_{m=1}^{M} \sigma_{mk}^2 \right]^{-1} w_k$$

wmk = ( 0 mk ) IQUUEUD. (b) Individual-

 $\left(\sigma_{N}^{2}\right)$ 

 $\left(\sigma_{T}^{2}\right)^{-1}$ (c) Any-channel-jammed AGC approach:  $w_{mk} = w_{k} =$ 

no channels jammed

one or more channels jammed

FIGURE 4.1-1 POSSIBLE AGC NORMALIZATION SCHEMES

$$w_{mk} \equiv w_{k} = \left(\frac{1}{M}\sum_{m=1}^{M}q_{mk}^{2}\right)^{-1}$$
$$= \left(\sigma_{N}^{2} + \sigma_{J}^{2}\sum_{m=1}^{M}v_{mk}/M\right)^{-1}.$$
(4.1-3)

There are M possible values to these weights. After normalization, the  $\{z_{mk}\}$  become

$$z_{1k} \sim w_k \sigma_{1k}^2 \chi^2(2;2S/\sigma_{1k}^2)$$
 (4.1-4a)

$$z_{mk} \sim w_k \sigma_{mk}^2 \chi^2(2), m > 1.$$
 (4.1-4b)

The effective weights  $W_k \equiv w_k \sigma_{mk}^2$  on the chi-squared variables in a given channel can take 2(M-1) values. Therefore the decision statistics for this normalization scheme have the form

$$z_{m} \sim \sum_{k=1}^{L} W_{k} \chi^{2}(2; \lambda_{mk}).$$
 (4.1-5)

The distribution of sums of non-equally weighted chi-squared random variables is extremely difficult to compute. For this reason, it is not feasible to consider calculation of the error performance using such a weighting scheme.

#### 4.1.2 Individual Channel AGC Scheme.

Ideal measurements of noise power in each of the M channels would yield the weights

$$w_{mk} = (\sigma_{mk}^2)^{-1}$$
 (4.1-6)

and the decision statistics

$$z_{1} = \sum_{k=1}^{L} x^{2}(2;\lambda_{1k}) = x^{2}(2L;\lambda_{1})$$
(4.1-7a)

in the signal channel, where

$$\lambda_{1} = \sum_{k=1}^{L} \lambda_{1k} = (L - \ell_{1}) \cdot 2S / \sigma_{N}^{2} + \ell_{1} \cdot 2S / \sigma_{T}^{2} , \qquad (4.1-7b)$$

and in the non-signal channels,

$$z_{m} = \sum_{k=1}^{L} \chi^{2}(2) = \chi^{2}(2L).$$
 (4.1-7c)

Thus whatever else the merits of this normalization scheme may be, it yields decision statistics which are purely chi-squared random variables with 2L degrees of freedom. In fact, from (4.1-7) we observe that the discernable jamming events are characterized solely by the number of hops jammed in the signal channel,  $\ell_1$ .

## 4.1.3 Any-Channel-Jammed AGC Scheme.

This scheme takes the approach that if any of the channels on a given hop is jammed, then all the channels are normalized by  $\sigma_T^2 = \sigma_N^2 + \sigma_J^2$ ; otherwise they are all normalized by  $\sigma_N^2$ . Expressed mathematically, the weights are

$$W_{mk} \equiv W_{k} = \begin{cases} (\sigma_{N}^{2})^{-1}, \sum_{m=1}^{M} v_{mk} = 0 \\ (\sigma_{1}^{2})^{-1}, \text{ otherwise.} \end{cases}$$
 (4.1-8)

The result of this approach is that the hop statistics fall into three categories:

(a) channel not jammed, normalized by  $\sigma_{\rm N}^2$ (b) channel not jammed, normalized by  $\sigma_{\rm T}^2$ (c) channel jammed, normalized by  $\sigma_{\rm T}^2$ .

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If we define  $\iota_0$  as the number of hops on which at least one of the channels is jammed, we find that in channel m (m=1,2,...,M) there would be

- \* (L- $\ell_0)$  hops with noise power  $\sigma_N^2$  normalized by  $\sigma_N^2$
- \* ( ${\tt l}_0-{\tt l}_m)$  hops with noise power  $\sigma_N^2$  normalized by  $\sigma_T^2$

\*  $\ell_m$  hops with noise power  $\sigma_T^2$  normalized by  $\sigma_T^2$ .

Therefore, for a given  $\ell_0$  and jamming event vector  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$ , the decision statistics would have the following distributions:

$$z_{1} \sim \chi^{2} [2(L-\ell_{0}); 2(L-\ell_{0})S/\sigma_{N}^{2}] + (\sigma_{N}^{2}/\sigma_{T}^{2})\chi^{2} [2(\ell_{0}-\ell_{1}); 2(\ell_{0}-\ell_{1})S/\sigma_{N}^{2}] + \chi^{2} [2\ell_{1}; 2\ell_{1}S/\sigma_{T}^{2}] = \chi^{2} [2(L+\ell_{1}-\ell_{0}); 2(L-\ell_{0})S/\sigma_{N}^{2} + 2\ell_{1}S/\sigma_{T}^{2}] + K^{-1}\chi^{2} [2(\ell_{0}-\ell_{1}); 2(\ell_{0}-\ell_{1})S/\sigma_{N}^{2}], \ell_{1} \neq \ell_{0};$$
(4.1-9a)

and

$$z_{m} \sim \chi^{2}[2(L-\ell_{0})] + (\sigma_{N}^{2}/\sigma_{T}^{2})\chi^{2}[2(\ell_{0}-\ell_{m})] + \chi^{2}(2\ell_{m})$$
  
=  $\chi^{2}[2(L+\ell_{m}-\ell_{0})] + K^{-1}\chi^{2}[2(\ell_{0}-\ell_{m})], m > 1; \ell_{m} \neq \ell_{0}.$  (4.1-9b)

When  $\ell_m = \ell_0$  the case of noise power  $\sigma_N^2$  normalized by  $\sigma_T^2$  does not occur and the distributions are:

$$z_1 \sim \chi^2 [2L; 2(L-\ell_0)S/\sigma_N^2 + 2\ell_0S/\sigma_T^2], \ \ell_1 = \ell_0;$$
 (4.1-9c)

and

$$z_{\rm m} \sim \chi^2(2L), \ \ell_{\rm m} = \ell_0.$$
 (4.1-9d)

As in Section 3, we use  $K \triangleq \sigma_T^2/\sigma_N^2 > 1$ . We see from (4.1-9) that the decision statistics are in general sums of two unequally weighted chi-squared random variables. Analysis of this distribution is difficult but has been accomplished previously, in Section 3. There is the additional complexity, however, that the jamming events now must be described by an additional parameter:  $\ell_0$ , the number of hops with at least one channel jammed. This task can be achieved as shown below.

4.2 ANALYSIS OF FH/RMFSK PERFORMANCE USING INDIVIDUAL CHANNEL AGC SCHEME Now we obtain the probability of bit error for the FH/RMFSK receiver using the individual channel AGC normalization scheme.

## 4.2.1 <u>Conditional Probability Of Error.</u>

The probability of a symbol error, given a jamming event described by  $\underline{\alpha} = (\alpha_1, \alpha_2, \dots, \alpha_M)$ , is  $P_s(e|\underline{\alpha}) = 1 - P_s(C|\underline{\alpha})$   $= 1 - \int_0^{\infty} d\alpha P_{z_1}(\alpha) \prod_{m=2}^{M} \int_0^{\alpha} d\beta_m P_{z_m}(\beta_m). \qquad (4.2-1)$ 

From (4.1-7) we observe that the non-signal channel decision statistics  $\{z_m, m>1\}$  are identically distributed as chi-squared random variables with 2L degrees of freedom. Thus

$$\int_{0}^{\alpha} d\beta_{m} P_{Z_{m}}(\beta_{m}) = \int_{0}^{\alpha} d\epsilon P_{Z_{2}}(\beta), \quad m = 2, 3, ..., M$$

$$= 1 - \frac{\Gamma(L; \alpha/2)}{\Gamma(L)} \qquad (4.2-2a)$$

$$= 1 - e^{-\alpha/2} \sum_{r=0}^{L-1} \frac{(\alpha/2)^{r}}{r!}, \qquad (4.2-2b)$$

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$$P_{s}(C|_{\underline{\lambda},\alpha}) \stackrel{\Delta}{=} \prod_{m=2}^{M} \int_{0}^{\alpha} d\beta_{m} P_{Z_{m}}(\beta_{m}) = \left[ 1 - e^{-\alpha/2} \sum_{r=0}^{L-1} \frac{(\alpha/2)^{r}}{r!} \right]^{M-1}$$
$$= \sum_{k=0}^{M-1} {\binom{M-1}{k}} (-1)^{k} e^{-k\alpha/2} \left[ \sum_{r=0}^{L-1} \frac{(\alpha/2)^{r}}{r!} \right]^{k} . \qquad (4.2-3)$$

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From Section 3, equation (3.1-14), we find that

$$P_{s}(C|\underline{x},\alpha) = \sum_{k=0}^{M-1} {\binom{M-1}{k}} (-1)^{k} e^{-k\alpha/2} \sum_{r=0}^{k(L-1)} \frac{c(r,k)}{r!} \left(\frac{\alpha}{2}\right)^{r}, \qquad (4.2-4a)$$

where

$$C(0,k) = 1$$
  

$$C(r,k) = \frac{1}{r} \sum_{n=1}^{\min(r,l-1)} {r \choose n} [(k+1)n - r] C(r-n,k), \qquad (4.2-4b)$$
  

$$r>0, L \ge 2.$$

Substitution in (4.2-1) yields

$$P_{s}(e|\underline{\ell}) = 1 - \sum_{k=0}^{M-1} {\binom{M-1}{k}} (-1)^{k} \sum_{p=0}^{k(L-1)} \frac{C(r,k)}{r!} \int_{0}^{\infty} d\alpha P_{z_{1}}(\alpha) e^{-k\alpha/2} (\alpha/2)^{r}.$$
(4.2-5)

From (4.1-7) and (3.1-9) the pdf for  $z_1$  is

$$p_{z_{1}}(\alpha) = \frac{1}{2} e^{-(\alpha + \lambda_{1})/2} \left(\frac{\alpha}{\lambda_{1}}\right)^{(L-1)/2} I_{L-1}\left(\sqrt{\alpha \lambda_{1}}\right) , \qquad (4.2-6)$$

with  $\lambda_1$  = 2(L- $\ell_1)\rho_N$  +  $2\ell_1\rho_T$  . Thus the required integral in (4.2-5) is

$$\left(\frac{1}{1+k}\right)^{r+L} \int_{0}^{\infty} dx \left(\frac{x}{2}\right)^{r} exp\left(-\frac{k\lambda_{1}/2}{k+1}\right) p_{\chi^{2}}\left(x; 2L, \lambda = \frac{\lambda_{1}}{1+k}\right)$$

$$= \left(\frac{1}{1+k}\right)^{r+L} exp\left(-\frac{k\lambda_{1}/2}{k+1}\right) r! \qquad \pounds_{r}^{L-1}\left(\frac{\lambda_{1}/2}{k+1}\right),$$

$$(4.2-7)$$

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giving the error probability

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$$P_{s}(e|\underline{x}) = \sum_{k=1}^{M-1} {\binom{M-1}{k}} \frac{(-1)^{k+1}}{(1+k)^{L}} \sum_{r=0}^{k(L-1)} \frac{C(r,k)}{(1+k)^{r}} \exp\left(-\frac{k\lambda_{1}/2}{k+1}\right) \mathcal{L}_{r}^{L-1}\left(\frac{-\lambda_{1}/2}{1+k}\right)$$
(4.2-8)  
=  $P_{s}(e|\underline{x}_{1})$ .

# 4.2.2 <u>Total Error Probability</u>.

Since the symbol error probability depends only on whether the signal channel is jammed, the total <u>bit</u> error probability is

$$P_{b}(e) = \sum_{\ell_{1}=0}^{L} {\binom{L}{\ell_{1}} \gamma^{\ell_{1}} (1-\gamma)^{L-\ell_{1}} \frac{M/2}{M-1} P_{s}(e|\ell_{1}), \qquad (4.2-9a)$$

where

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$$Y = \Pr\{\text{channel 1 jammed on hop k}\}.$$
(4.2-9b)

Noting that (4.2-8) and (4.2-9) are mathematically identical to equations (4-26) in [1], we observe that MFSK and RMFSK give equivalent PBNJ performances for individual channel AGC normalization.

### 4.3 ANALYSIS OF FH/RMFSK PERFORMANCE USING ANY-CHANNEL-JAMMED AGC SCHEME

In what follows we find the probability of bit error for the FH/RMFSK receiver using the any-channel-jammed AGC normalization scheme (ACJ).

#### 4.3.1 <u>Conditional Probability Of Error</u>.

The probability of a symbol error, given the jamming event  $(x_0, \underline{x})$ , is

$$P_{s}(e \mid \ell_{0}, \underline{\ell}) = 1 - P_{s}(C \mid \ell_{0}, \underline{\ell})$$

$$= 1 - \int_{0}^{\infty} d\alpha \quad P_{z_{1}}(\alpha; \ell_{0}, \ell_{1}) \prod_{m=2}^{M} \int_{0}^{\alpha} d\beta_{m} P_{z_{m}}(\beta_{m}; \ell_{0}, \ell_{m}). \quad (4.3-1)$$
Since 
$$P_{s}(C | \ell_{0}, \underline{\ell}) = Pr\{z_{2} < z_{1}, z_{3} < z_{1}, \dots, z_{M} < z_{1}\}$$
  
=  $Pr\{Kz_{2} < Kz_{1}, Kz_{3} < Kz_{1}, \dots, Kz_{M} < Kz_{1}\}$ , (4.3-2)

we may analyze the error probability using the statistics  $\{u_m\}$  instead of  $\{z_m\}$ where  $u_1 \equiv Kz_1 = \chi^2 [2(\ell_0 - \ell_1); 2(\ell_0 - \ell_1)\rho_N] + K\chi^2 [2(L + \ell_1 - \ell_0); 2(L - \ell_0)\rho_N + 2\ell_1\rho_T]$  (4.3-3a)

and

$$u_{m} \equiv Kz_{m} = \chi^{2} \left[ 2 \left( \ell_{0} - \ell_{m} \right) \right] + K \cdot \chi^{2} \left[ 2 \left( L + \ell_{m} - \ell_{0} \right) \right] \quad m > 1.$$
(4.3-3b)

From Appendix A, the pdf's of these random variables are as follows: for the signal channel,

$$(F_{\chi^{2}}(\alpha; 2L, 2L\rho_{N}), \ell_{0}-\ell_{1} = L$$
 (4.3-4a)

$$p_{u_1}(\alpha) = \begin{cases} \frac{1}{K} p_{\chi}^2 [\alpha/K; 2L, 2(L-\ell_0)\rho_N + 2\ell\rho_T], \ \ell_0 - \ell_1 = 0; \\ \infty \end{cases} (4.3-4b)$$

$$\left\{\sum_{n=0}^{\infty} c_{n} p_{\chi^{2}}[\alpha; 2L+2n, 2(\ell_{0}-\ell_{1})\rho_{N}], 0 < \ell_{0}-\ell_{1} < L; \right\}$$
(4.3-4c)

where

$$c_{n} = e^{-(L-\ell_{0})\rho} N^{-\ell_{1}\rho} T \left(\frac{K-1}{K}\right)^{n} \left(\frac{1}{K}\right)^{L-\ell_{0}+\ell_{1}} \mathcal{L}_{n}^{L-\ell_{0}+\ell_{1}-1} \left[\frac{-(L-\ell_{0})\rho}{K-1}\right] \cdot (4.3-4d)$$

For the nonsignal channels (m>1),

$$p_{\chi^2}(\alpha; 2L), \ \ell_0 - \ell_m = L$$
 (4.3-5a)

$$p_{u_{m}}(\alpha) = \left\{ \frac{1}{K} p_{\chi^{2}}(\alpha/K; 2L), \ell_{0} - \ell_{m} = 0 \right.$$
 (4.3.5b)

$$\left(\sum_{n=0}^{\infty} b_n p_{\chi^2}(\alpha; 2L+2n), \quad 0 < \ell_0 - \ell_m < L \right)$$
 (4.3-5c)

using the coefficients

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$$\mathbf{b}_{n} = \left(\frac{K-1}{K}\right)^{n} \left(\frac{1}{K}\right)^{L-\ell_{0}+\ell_{m}} \binom{n+L-\ell_{0}+\ell_{m}-1}{n}$$

$$(4.3-5d)$$

The symbol error probability expression for the  $\{u_m\}$  statistics is (4.3-1) with the subscripts  $\{u_m\}$  instead of  $\{z_m\}$ , m=1,2,...,M.

4.3.1.1 Formulations of nonsignal channel probabilities

Since the nonsignal channel pdf's are identical except for the parameters  $\{\ell_m\}$ , the number of hops jammed in the individual channels. we may express the product

$$\frac{M}{\prod_{m=2}^{M}} \int_{0}^{\alpha} d\beta_{m} P_{u_{m}}(\beta_{m}; \ell_{0}, \ell_{m}) \frac{M}{m=2} Pr\{u_{m} < \alpha\}$$
(4.3-6)

in terms of the numbers of channels with certain combinations of  $\iota_0$  and the  $\{\iota_m\}$ . The probabilities needed are

$$(1 - \Gamma(L;\alpha/2)/\Gamma(L), \ell_0 - \ell_m = L$$
 (4.3-7a)

$$\Pr\{u_{m}<\alpha\} = \left\{ 1 - \Gamma(L;\alpha/2K)/\Gamma(L), \ \ell_{0}-\ell_{m} = 0 \right\}$$
(4.3-7b)

$$\left(1 - \sum_{n=0}^{\infty} b_{n} \Gamma(L+n;\alpha/2) / \Gamma(L+n), 0 < \ell_{0} - \ell_{m} < L. \right)$$
(4.3-7c)

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Upon comparing (4.3-7) with (3.1-11), we observe that

$$\Pr\{u_{m}<\alpha\} \equiv F_{L}(\alpha;L-\ell_{0}+\ell_{m}).$$
(4.3-8)

Thus we can write the product in (4.3-6) as

$$\prod_{m=2}^{m} \Pr\{u_{m} < \alpha\} = \left[F_{L}(\alpha; 0)\right]^{n_{0}} \left[F_{L}(\alpha; 1)\right]^{n_{1}} \cdots \left[F_{L}(\alpha; L)\right]^{n_{L}}$$
(4.3-9)

where

$$n_i \stackrel{\Delta}{=} #$$
 (channels with L- $\ell_0 + \ell_m = i$ .), (4.3-10)

and  $[F_{L}(\alpha;p)]^{n_{p}}$  is given by (3.1-14), (3.1-17), and (3.1-28).

# 4.3.1.2 Formulation of symbol error probability in terms of previous results (Section 3).

If we denote the conditional probability of symbol error for the square-law linear combining FH/RMFSK receiver studied in Section 3 by

$$P_{s}(e;\rho_{N},\rho_{T}|\underline{r})_{LC}$$
, (4.3-11)

we can by analogy express the conditional probability of symbol error for the anychannel-jammed AGC receiver as

$$P_{s}(e;\rho_{N},\rho_{T}|\ell_{0},\underline{\ell})_{ACJ} = P_{s}(e;\rho_{N},\rho_{T}|\underline{\nu})_{LC} \qquad (4.3-12a)$$

where

$$\rho_{T}^{*} = \begin{cases} \frac{\ell_{1}\rho_{T}^{*} + (L-\ell_{0})\rho_{N}}{L-\ell_{0}+\ell_{1}}, & \ell_{0}-\ell_{1} \neq L \\ \rho_{T}^{*}, & \ell_{0}-\ell_{1} \end{cases}$$
(4.3-12b)

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$$\underline{\mathbf{v}} \stackrel{\triangle}{=} (\mathbf{L} - \boldsymbol{\ell}_0 + \boldsymbol{\ell}_1, \mathbf{L} - \boldsymbol{\ell}_0 + \boldsymbol{\ell}_2, \dots, \mathbf{L} - \boldsymbol{\ell}_0 + \boldsymbol{\ell}_{\mathsf{M}}). \tag{4.3-13}$$

#### 4.3.2

### Enumeration and Probabilities for Jamming Events.

The enumeration of jamming events, and their probabilities, has already been accomplished in Section 2.2 for the situation in which the jamming event is sufficiently described by the vector  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$ . Now our task is to develop for use in (4.3-12) the conditional probabilities  $Pr\{\ell_0 | \underline{\ell}\}$ for the parameter  $\ell_0$ , the number of hops on which at least one channel is jammed, given the vector  $\underline{\ell}$ .

The enumeration technique treated in Section 2.2 recognized the arbitrariness of the channel numbers m for m>1 (nonsignal channels) by assuming that the calculations will generate the partially ordered  $\underline{x}$  vector

$$\underline{\mathfrak{a}} = \{ (\mathfrak{a}_1, \mathfrak{a}_2, \dots, \mathfrak{a}_M) : \mathfrak{a}_2 \leq \mathfrak{a}_3 \leq \dots \leq \mathfrak{a}_M \} .$$

$$(4.3-14)$$

Thus, with this ordering the range of  $\mathbf{t}_0$  is

$$\ell_{\mathbf{X}} \stackrel{\Delta}{=} \max(\ell_1, \dots, \ell_M) \leq \ell_0 \leq \min(\mathbf{L}, \ell_1 + \ell_2 + \dots + \ell_M).$$
(4.3-15)

The number of elementary or [v]-matrix jamming events characterized by a given  $\underline{\ell}$  or  $\underline{\ell}$  vector is

$$\#([v] \rightarrow \underline{\ell}) = \binom{L}{\ell_1} \binom{L}{\ell_2} \cdots \binom{L}{\ell_M} = \prod_{m=1}^{M} \binom{L}{\ell_m}, \qquad (4.3-16)$$

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and each  $\frac{\ell}{2}$  vector represents

$$\begin{pmatrix} M-1 \\ n_0, n_1, \dots, n_L \end{pmatrix}, \quad n_k = \#(\mathfrak{L}_m = k), m > 1$$

$$(4.3-17)$$

*l* vectors. Thus

$$\sum_{\underline{a}} \begin{pmatrix} M-1 \\ n_0, n_1, \dots, n_L \end{pmatrix} Pr\{\underline{a}^*; M, L\} = 1.$$
(4.3-18)

Now for jamming events specified by  $\mathfrak{L}_0$  as well as  $\underline{\mathfrak{L}}$ , the number of elementary jamming events thus specified can be shown to be

$$#([v] \rightarrow \ell_0, \underline{\ell}) \quad \begin{pmatrix} L \\ \ell_0 \end{pmatrix} \sum_{r=0}^{\ell_0 - \ell_X} \begin{pmatrix} \ell_0 \\ r \end{pmatrix} \quad (-1)^r \prod_{m=1}^{M} \begin{pmatrix} \ell_0^{-r} \\ \ell_m \end{pmatrix}.$$

$$(4.3-19)$$

For example, if  $\ell_0 = \ell_x = \max(\ell_m)$ , there are

$$\begin{pmatrix} L \\ \mathfrak{L}_0 \end{pmatrix} \stackrel{M}{\underset{m=1}{\longrightarrow}} \begin{pmatrix} \mathfrak{L}_0 \\ \mathfrak{L}_m \end{pmatrix}$$
 (4.3-20)

[v] events. Summation of (4.3-19) over the values of  $\ell_0$  given by (4.3-15) can be shown numerically to give (4.3-16). (See Appendix B.4.)

What is needed for evaluation of the ACJ total probability of error are the probabilities of the jamming events  $(\mathfrak{L}_0, \underline{\mathfrak{L}})$  and the number of  $(\mathfrak{L}_0, \underline{\mathfrak{L}})$  events represented by the ordered version. Since  $(\mathfrak{L}_0, \underline{\mathfrak{L}})$  is a subset of  $\underline{\mathfrak{L}}$  for any  $\underline{\mathfrak{L}}$ , and permutations of the nonsignal channel elements of  $\underline{\mathfrak{L}}$  do not affect  $\mathfrak{L}_0$ , it is reasonable that (4.3-17) gives the required number. This fact is confirmed

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by the consideration that

$$\Pr\left\{\underline{\ell}; M, L\right\} = \sum_{\ell_0} \Pr\{\underline{\ell}; \ell_0; M, L\}$$
(4.3-21)

which can be substituted in (4.3-18) to show that  $Pr\{\mathfrak{x}_0, \underline{\mathfrak{k}}\}$  must be multiplied by (4.3-17).

The probability of the event  $(\ell_0, \underline{\ell})$  is derived in the following manner:

$$\Pr\{\underline{\ell}, \ell_{0}\} = \begin{pmatrix} L \\ \ell_{0} \end{pmatrix} \Pr\{\underline{\nu_{1}} + \underline{\nu_{2}} + \dots + \underline{\nu}_{\ell_{0}} = \underline{\ell}, \underline{\nu_{1}} \neq \underline{0}, \underline{\nu_{2}} \neq \underline{0}, \dots, \\ \underline{\nu}_{\ell_{0}} \neq \underline{0}, \underline{\nu}_{\ell_{0}} + 1 = \underline{0}, \dots, \underline{\nu}_{L} = \underline{0}\}$$
$$= \begin{pmatrix} L \\ \ell_{0} \end{pmatrix} \pi_{0}^{L-\ell} \Pr\{\underline{\nu_{1}} + \underline{\nu_{2}} + \dots + \underline{\nu}_{\ell_{0}} = \underline{\ell}, \underline{\nu_{1}} \neq 0, \dots, \underline{\nu}_{\ell_{0}} \neq 0\}$$
(4.3-22)

The probability required in (4.3-22) can be computed using the convolutional method described in Section 2.2.5, modified to give

$$\Pr\left\{\underbrace{\nu_{1}+\nu_{2}+\ldots+\nu_{\ell_{0}}}_{\underline{\nu}_{1}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\sum_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\sum_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{\ell_{0}}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{1}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{\underline{\nu}_{2}}\right\}}_{\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}\geq\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{2},\underbrace{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\geq\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{2},\underbrace{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{2},\underbrace{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{2}\in\underline{\nu}_{2}}\cdots\underbrace{\Pr\left\{\underbrace{\nu}_{2},\underbrace{\nu}_{2}\in\underline{\nu}_{2}\\\underline{\nu}_{2}\\\underline{\nu}_{2}\in\underline{\nu}_{$$

This method is useful for M tending to be large; for M=2, it is simpler to recognize that (2.2-24), repeated here as

$$\Pr\left\{\underline{\ell};2,L\right\} = \sum_{n=0}^{L} \begin{pmatrix} L \\ n,L-\ell_{2}-n,L-\ell_{1}-n,\ell_{1}+\ell_{2}+n-L \end{pmatrix} \times \pi_{0}^{n} \pi_{1}^{2L-\ell_{1}-\ell_{2}-2n} \pi_{2}^{\ell_{1}+\ell_{2}-L+n}, \qquad (4.3-24)$$

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is the sum of  $Pr\{\underline{\ell}, \ell_0; 2, L\}$  over  $\ell_0$ , with  $n \equiv L-\ell_0$ . Therefore,

$$\Pr\{\underline{\ell}, \ell_0; 2, L\} = \begin{pmatrix} L \\ L - \ell_0, \ell_0 - \ell_2, \ell_0 - \ell_1, \ell_1 + \ell_2 - \ell_0 \end{pmatrix} \xrightarrow{2\ell_0 - \ell_1 - \ell_2}{\pi_1} \xrightarrow{\ell_1 + \ell_2 - \ell_0} (4.3-25)$$

For M=4, we recognize the same principle in the equation given in Table 2.2-4 for  $Pr{\underline{l};4,L}$  to give the  $Pr{\underline{l}_0,\underline{l};4,L}$  equation shown in Table 4.3-1.

TABLE 4.3-1 PROBABILITIES OF  $(v_0, \frac{p}{2})$  JAMMING EVENTS FOR M = 4

CONSTRAINTS: 
$$n_1 + n_3 + n_5 + n_7 + n_9 + n_{11} + n_{13} + n_{15} = {}^{R}_1$$
  
 $n_2 + n_3 + n_6 + n_7 + n_{10} + n_{11} + n_{14} + n_{15} = {}^{R}_2$   
 $n_4 + n_5 + n_6 + n_7 + n_{12} + n_{13} + n_{14} + n_{15} = {}^{R}_3$   
 $n_8 + n_9 + n_{10} + n_{11} + n_{12} + n_{13} + n_{14} + n_{15} = {}^{R}_4$   
 $15$   
 $\sum_{i=1}^{15} n_i = {}^{R}_0$ 

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### 4.4 NUMERICAL RESULTS

In this section we present numerical results for the performance of the individual-channel AGC receiver and the any channel-jammed (ACJ) AGC receiver.

### 4.4.1 <u>Numerical Results for Individual-Channel AGC Receiver</u>

The numerical computations for the performance of the individualchannel AGC receiver were performed using (4.2-8) and (4.2-9). In this particular case, no unusual computational difficulties are encountered in the computations. A listing of the computer program is given in Appendix E.

Figures 4.4-1 through 4.4-4 show the performance of binary (M=2) RMFSK/FH with L=1,2,3, and 4 hops/bit, respectively with the jamming fraction  $\gamma=q/N$  as a parameter. We observe that the choice of jamming fraction is critical to the effective operation of the jammer. This is similar to the behavior of the square-law combining receiver. However, unlike the square-law combining receiver, the optimum jamming fraction against the individual-channel AGC receiver is  $\gamma=1.0$  over a wider range of  $E_b/N_J$ , especially for higher values of L, the number of hops/bit.

Figure 4.4-5 compares the worst-case jamming performance of binary RMFSK/FH as L varies. We observe that over the range of about  $E_b/N_J=8$  dB to  $E_b/N_J=39$  dB, the optimum choice for the communicator is L=2 or 3 hops/bit. However, outside this range L=1 is optimum. In no case does increasing L beyond 3 hops/bit improve the performance.

Figures 4.4-6 through 4.4-9 show the performance of RMFSK/FH when M=4 and L=1,2,3, and 4, respectively. Again, the importance to the jammer of



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2400 HOPPING SLOTS, AND  $E_b/N_0 = 13.352471 \text{ dB}$  (FOR  $10^{-5}$  BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION Y AS A PARAMETER





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FIGURE 4.4-6 BIT ERROR PROBABILITY VS. BIT ENERGY TO JAMMING DENSITY RATIO FOR INDIVIDUAL CHANNEL AGC RECEIVER WITH M = 4 AND L = 2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 10.606573$  dB (FOR  $10^{-5}$  BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER



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INDIVIDUAL CHANNEL AGC RECEIVER WITH M = 4 AND L = 2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 10.606573$  dB (FOR  $10^{-5}$  BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER





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the correct selection of  $\gamma$  stands out clearly. Figure 4.4-10 compares the performance of 4-ary RMFSK/FH in worst-case partial-band noise jamming as L varies. We see that for  $E_b/N_J$  in the range of about 7 to 36 dB, L=2 or 3 is optimum; elsewhere, L=1 is optimum.

Figures 4.4-11 through 4.4-14 show the curves for M=8 with  $\gamma$  as a parameter and L=1,2,3, and 4, respectively. Figure 4.4-15 shows performance for M=8 with L as a parameter in worst-case partial-band noise jamming. Again, from about  $E_b/N_J$ =5 dB to 35 dB the optimum L is 2 or 3, but elsewhere L=1 is optimum.

Two important conclusions can be drawn from these curves:

- The correct choice of fraction  $\gamma$  is critical for the jammer;
- The communicator can obtain only a small benefit by using multiple hops/symbol, and then only over a limited range of jamming conditions.

### 4.4.2 Numerical Results for Any-Channel-Jammed AGC (ACJ-AGC) Receiver

The numerical computations for the performance of the ACJ-AGC receiver required the use of two alternative forms. We used (4.3-12) for the computations, in conjunction with the computational techniques discussed in Section 3.3. The switch-over criteria for choosing between series and numerical integration were determined empirically. A listing of the computer program for numerical computations is given in Appendix F and a listing of the program which produced the plots is given in Appendix G. This latter program is typical of the plotting programs for all receivers; for sake of brevity only this one version of the plot program is included in our report.





2400 HOPPING SLOTS, AND  $E_L/N_0 = 9.094011$  dB (FOR  $10^{-5}$  BER WITH-OUT JAMMING WHEN L = 1) WITH JAMMING FRACTION Y AS A PARAMETER



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AS A PARAMETER IN PRESENCE OF WORST-CASE PARTIAL-BAND NOISE JAMMING

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. / . . . Figures 4.4-16 through 4.4-19 show the performance of the ACJ-AGC receiver with M=2 for L=1,2,3, and 4 hops/bit, respectively. Figure 4.4-20 summarizes the performance in worst-case partial-band noise jamming with L as a parameter. Again, we find a limited range, roughly 10 dB  $\leq E_b/N_J \leq 35$  dB, where the optimum diversity is L=2 or 3 hops per bit; elsewhere L=1 is optimum.

Figures 4.4-21 through 4.4-24 show the performance of the ACJ-AGC receiver with M=4 for L=1,2,3, and 4 hops/symbol, respectively. These curves show the same general behavior as those for the other receivers. Figure 4.4-25 shows the performance in worst-case partial-band noise jamming with L as a parameter. Again, we find a limited range where L=2 or 3 is optimum, but elsewhere L=1 is optimum.

Finally, Figures 4.4-26 and 4.4-27 show the performance for M=8 and L=1 and 2, respectively. Because of the large computer time required, L>2 was not considered for M=8. Figure 4.4-28 summarizes performance in worst-case partial-band noise jamming. Again, there is a region where diversity (L=2) offers some advantage.

In summary, a small amount of diversity (L=2 or 3) is of meaningful benefit to RMFSK/FH over a limited range of signal-to-jamming ratios. However, outside this range no diversity (L=1) gives better performance. In some cases, e.g. Figure 4.4-20 for M=2, the penalty for using L=3 in the absence of jamming is nearly the same as the benefit of using L=3 when  $E_b/N_d=25$  dB.





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FIGURE 4.4-17 BIT ERROR PROBABILITY VS. BIT ENERGY TO JAMMING DENSITY RATIO FOR ANY-CHANNEL-JAMMED AGC RECEIVER WITH M=2 AND L=2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 13.352471$  dB (FOR 10<sup>-5</sup> BER WITH-OUT JAMMING WHEN L=1) WITH JAMMING FRACTION  $\gamma$  AS A PARAMETER



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#### 5.0 FH/RMFSK PERFORMANCE USING CLIPPER RECEIVER

We now undertake analysis of a third type of ECCM receiver for FH/RMFSK, in which the effect of jamming on the symbol decision is reduced by soft-limiting or clipping the per-hop symbol decision variables  $\{z_{m_k}; m=1,2,\ldots,M; k=1,2,\ldots,L\}$ . The receiver structure is diagrammed in Figure 5.0-1. In each of the M dehopped symbol channels, the square-law envelope detector samples are clipped at some level n prior to summing to perform the symbol decision. Because the contribution of a jammed hop to the decision variables is at most n, no matter how strong the jammer noise power, it is expected that an improved performance will result. The clipping threshold n is to be chosen to minimize the error probability when there is no jamming.

In previous analyses of the clipper receiver (for conventional FH/MFSK) we had employed a numerical convolution technique to obtain the distributions of the decision variables. Here we shall obtain the needed probability density functions (pdf's) directly, through analysis.

#### 5.1 DISTRIBUTIONS OF THE DECISION VARIABLES

We first discuss the general form for the pdf of the sum of clipped square-law envelope detector samples, then apply this form to nonsignal and signal channels.

#### 5.1.1 General Form of the pdf.

If the input to a clipper with clipping level  $\eta$  has the pdf  $f_1(x), x \ge 0$ , then the output has the pdf

$$p_{1}(x) = \begin{cases} f_{1}(x) + q \delta(x-n) & 0 \le x \le n \\ 0, \text{ otherwise;} \end{cases}$$
(5.1-1a)



FIGURE 5.0-1 SOFT-DECISION FH/RMFSK RECEIVER WITH CLIPPERS

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$$q = Pr\{input > n\} = \int_{n}^{\infty} d\alpha f_{1}(\alpha)$$
 (5.1-1b)

This fact is illustrated by figure 5.1-1.

Now, since individual hops are jammed independently and in any combination, we introduce the notations

$$q_0 = Pr\{one \ sample > n \mid not \ jammed\}$$
 (5.1-2b)

$$q_1 = Pr\{one \ sample > n \mid jammed\}.$$
 (5.1-2c)

Note that it is sufficient to specify only l, the number of hops jammed; the order in which the jamming occurs does not affect the sum. Using this notation, the pdf for a single clipped envelope sample is

$$p_1(x;0) = f_1(x;0) + q_0 \delta(x-\eta)$$
, hop not jammed; (5.1-3a)

$$p_1(x;1) = f_1(x;1) + q_1 \delta(x-\eta)$$
, hop jammed; (5.1-3b)

and it is understood that the pdf is zero outside the interval  $0 \le x \le n$ .

For  ${\boldsymbol{\ell}}$  hops jammed, the pdf of the sum of L clipped samples can be

expressed as the convolution

$$\underbrace{P_1(x;0)*P_1(x;0)*\ldots*P_1(x;0)*P_1(x;1)*\ldotsP_1(x;1)}_{(5.1-4)}$$

L-l pdf's  $\ell$  pdf's Thus we have the following general expressions for the sum's pdf for L=2 to 4:





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(b) pdf after clipping

FIGURE 5.1-1 EFFECTS OF CLIPPING ON pdf

$$p_{2}(x;0) = f_{2}(x;0) + q_{2}^{2} \delta(x-2n)$$
 ,  $0 \le x \le 2n$ ;

where

$$f_{2}(x;0) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;0)f_{1}(w;0), & 0 \le x \le n; \\ \int_{x-n}^{n} dw f_{1}(x-w;0)f_{1}(w;0) & (5.1-5b) \\ &+ 2q_{0}f_{1}(x-n;0), & n \le x \le 2n. \end{cases}$$

(5.1-5a)

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$$p_2(x;1) = f_2(x;1) + q_0q_1 \delta(x-2n) , 0 \le x \le 2n; \qquad (5.1-6a)$$

where

$$f_{2}(x;1) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;1)f_{1}(w;0) , & 0 \le x \le \eta ; \\ \int_{0}^{\eta} dw f_{1}(x-w;1)f_{1}(w;0) & (5.1-6b) \\ x-\eta & + q_{0}f_{1}(x-\eta;1) + q_{1}f_{1}(x-\eta;0), & \eta \le x \le 2\eta . \end{cases}$$

$$p_2(x;2) = f_2(x;2) + q_{10}^2(x-2\eta), \quad 0 \le x \le 2\eta;$$
 (5.1-7a)

where

$$f_{2}(x;2) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;1) f_{1}(w;1) , & 0 \le x \le n; \\ \int_{0}^{n} dw f_{1}(x-w;1) f_{1}(w;1) & (5.1-7b) \\ x-n & + 2q_{1}f_{1}(x-n;1) , & n \le x \le 2n. \end{cases}$$

$$p_3(x;0) = f_3(x;0) + q_0^3 \delta(x-3_n), \quad 0 \le x \le 3_n;$$
 (5.1-8a)

where

$$f_{3}(x;0) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;0) f_{2}(w;0) , & 0 \leq x < n; \\ \int_{0}^{x} dw f_{1}(x-w;0) f_{2}(w;0) \\ x-n \\ & + q_{0}f_{2}(x-n;0) , & n \leq x < 2n; \end{cases}$$
(5.1-8b)

and

$$f_{3}(x;0) = \begin{cases} \int_{x-n}^{2n} dw f_{1}(x-w;0)f_{2}(w;0) \\ x-n \\ +q_{0}f_{2}(x-n;0) \\ +q_{0}^{2}f_{1}(x-2n;0) , 2n \le x \le 3n \end{cases}$$
(5.1-8c)

$$p_{3}(x;1) = f_{3}(x;1) + q_{0}^{2}q_{15}(x-3_{n}), \quad 0_{\xi}x_{\xi}3_{n}; \quad (5.1-9a)$$

where

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$$f_{3}(x;1) = \begin{cases} \int_{0}^{X} dw f_{1}(x-w;1) f_{2}(w;0), & 0 \le x \le n \\ \int_{0}^{X} dw f_{1}(x-w;1) f_{2}(w;0) \\ x-n \\ & + q_{1}f_{2}(x-n;0), & n \le x \le 2n \\ & & (5.1-9b) \\ \int_{X-n}^{2n} dw f_{1}(x-w;1) f_{2}(w;0) \\ & + q_{1}f_{2}(x-n;0) \\ & + q_{0}^{2}f_{1}(x-2n;1) , & 2n \le x \le 3n \end{cases}.$$

$$p_3(x;2) = f_3(x;2) + q_0 q_1^2 \delta(x-3n), \quad 0 \le x \le 3n;$$
 (5.1-10a)

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$$f_{3}(x;2) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;0)f_{2}(w;2) , & 0 \le x \le n; \\ \int_{0}^{x} dw f_{1}(x-w;0)f_{2}(w;2) \\ & + q_{0}f_{2}(x-n;2) , & n \le x \le 2n; \\ & + q_{0}f_{2}(x-n;2) , & n \le x \le 2n; \end{cases}$$
(5.1-10b)  
$$\int_{x-n}^{2n} dw f_{1}(x-w;0)f_{2}(w;2) \\ & + q_{0}f_{2}(x-n;2) \\ & + q_{1}^{2}f_{1}(x-2n;0) , & 2n \le x \le 3n. \end{cases}$$

$$p_3(x;3) = f_3(x;3) + q_1^3 \delta(x-3\eta), \quad 0 < x < 3\eta$$
;

where

$$f_{3}(x;3) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;1)f_{2}(w;2) , & 0 \le x \le n; \\ \int_{0}^{x} dw f_{1}(x-w;1)f_{2}(w;2) \\ x-n & + q_{1}f_{2}(x-n;2) , & n \le x \le 2n; \end{cases}$$
(5.1-11b)  
$$\int_{x-n}^{2n} dw f_{1}(x-w;1)f_{2}(w;2) \\ x-n & + q_{1}f_{2}(x-n;2) \\ + q_{1}^{2}f_{1}(x-2n;1) , & 2_{n} \le x \ge 3n. \end{cases}$$

(5.1-11a)

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$$p_{1}(x;0) = f_{4}(x;0) + q_{0}^{4}\delta(x-4n), \quad 0 \le x \le 4n; \quad (5.1-12a)$$

$$F_{4}(x;0) = \begin{cases} \int_{0}^{X} dw f_{1}(x-w;0)f_{3}(w;0) , & 0 \le x \le n; \\ \int_{0}^{X} dw f_{1}(x-w;0)f_{3}(w;0) \\ x-n \\ & + q_{0}f_{3}(x-n;0), & n \le x \le 3n \\ & \int_{0}^{3n} dw f_{1}(x-w;0)f_{3}(w;0) \\ x-n \\ & + q_{0}f_{3}(x-n;0) \\ & + q_{0}^{3}f_{1}(x-3n;0) , & 3n \le x \le 4n. \end{cases}$$
(5.1-12b)

$$(5.1-13b) = \begin{cases} x \\ \int_{x-n}^{x} dw f_1(x-w;1)f_3(w;0) \\ + q_1f_3(x-n;0) , & n \le x \le 3n; \\ \int_{x-n}^{3n} dw f_1(x-w;1)f_3(w;0) \\ + q_1f_3(x-n;0) \\ + q_0^2f_1(x-3n;1) , & n \le x \le 4n. \end{cases}$$

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$$p_4(x;2) = f_4(x;2) + q_0^2 q_1^2 \delta(x-4n), \quad 0 \le x \le 4n;$$
 (5.1-14a)

where

$$f_{4}(x;2) = \begin{cases} \int_{0}^{x} dw f_{2}(x-w;2)f_{2}(w;0) , & 0 \le x \le 2n; \\ \int_{0}^{2n} dw f_{2}(x-w;2)f_{2}(w;0) & , & (5.1-14b) \\ x-2n & \\ & + q_{0}^{2}f_{2}(x-2n;2) \\ & + q_{1}^{2}f_{2}(x-2n;0), & 2n \le x \le 4n. \end{cases}$$

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$$p_4(x;3) = f_4(x;3) + q_0 q_1^3 \delta(x-4\eta)$$
,  $0 \le x \le 4\eta$ ; (5.1-15a)

where

$$f_{\mu}(x;3) = \begin{cases} \int_{0}^{x} dw \ f_{1}(x-w;0)f_{3}(w;3) \ , \ 0 \le x \le n; \\ \int_{0}^{x} dw \ f_{1}(x-w;0)f_{3}(w;3) \\ x-n \\ + \ q_{0}f_{3}(x-n;3), \ n \le x \le 3n; \\ \int_{0}^{3n} dw \ f_{1}(x-w;0)f_{3}(w;3) \\ x-n \\ + \ q_{0}f_{3}(x-n;3) \\ + \ q_{1}^{2}f_{1}(x-3n;0) \ , \ 3n \le x \le 4n. \end{cases}$$
(5.1-15b)

 $p_4(x;4) = f_4(x;4) + q_1^4 \delta(x-4\eta)$ ,  $0 \le x \le 4\eta$ ;

$$f_{4}(x;4) = \begin{cases} \int_{0}^{x} dw f_{1}(x-w;1)f_{3}(w;3) , 0 \le x \le \eta; \\ \int_{0}^{x} dw f_{1}(x-w;1)f_{3}(w;3) \\ x-\eta \\ + q_{1}f_{3}(x-\eta;3) , \eta \le x \le 3\eta; \end{cases}$$
(5.1-16b)  
$$\int_{x-\eta}^{3\eta} dw f_{1}(x-w;1)f_{3}(w;3) \\ x-\eta \\ + q_{1}f_{3}(x-\eta;3) \\ + q_{1}^{3}f_{1}(x-3\eta;1) , 3\eta \le x \le 4\eta. \end{cases}$$

#### 5.1.2 <u>Non-Signal Channel pdf</u>.

Assuming without loss of generality that the received signal power S is present in the first (m=1) of M dehopped symbol frequency channels, the remaining channels (m=2,3,...,M) contain only background noise and possibly jamming noise. The samples of the square-law envelope detectors in these channels are independent chi-squared random variables with two degrees of freedom, multiplied by  $\sigma_{mk}^2$ , where

$$\sigma_{mk}^{2} = \begin{cases} \sigma_{N}^{2} = N_{0}B, \text{ hop not jammed} \\ \sigma_{T}^{2} = (N_{0} + N_{J}/\gamma)B, \text{ hop jammed.} \end{cases}$$
(5.1-17)

Consequently, the pdf of the unclipped samples is

$$f_{1}(x) = \frac{1}{2\sigma^{2}mk} e^{-x/2\sigma^{2}mk}, \quad x \ge 0;$$

$$= \begin{cases} a e^{-ax}, \quad x \ge 0, \text{ hop not jammed}; \\ b e^{-bx}, \quad x \ge 0, \text{ hop jammed}; \end{cases}$$
(5.1-18a)

using

$$a \equiv 1/2\sigma_N^2$$
,  $b \equiv 1/2\sigma_T^2$ . (5.1-18b)

Also, we have from (5.1-2b and c)

$$q_0 = e^{-a_\eta}, q_1 = e^{-b_\eta}.$$
 (5.1-19)

In order to distinguish the non-signal channel pdf's from that of the signal channel, we adopt the notation

$$g_{1}(x; \ell) = f_{1}(x; \ell, S=0)$$
 (5.1-20)

for the non-delta function part of the pdf of the sum of L clipped samples when  $\ell$  hops in that channel are jammed. Thus we have for channels {m:m>2}, the sum pdf

$$p_{Z_{m}}(x) = \begin{cases} g_{L}(x;\ell_{m}) + (q_{0})^{L-\ell_{m}} (q_{1})^{\ell_{m}} \delta(x-L_{n}), & 0 \leq x \leq L_{n}; \\ 0, & \text{otherwise.} \end{cases}$$
(5.1-21)

Substituting (5.1-18) in the general convolutional formulas in Section 5.1.1 yields the pdf's listed in Table 5.1-1 for L=1 to 3. TABLE 5.1-1 NON-SIGNAL CHANNEL PROBABILITY DENSITY FUNCTIONS, L = 1 TO 3

	8	p <sub>zm</sub> (x; ℓ)
,t	0	ae <sup>-ax</sup> + e <sup>-an</sup> $\delta(x-n)$ , $0 \le x \le n$ ; 0, otherwise. $a \equiv 1/2\sigma_N^2$
	1	$be^{-ax} + e^{-bn} \delta(x-n), 0 \le x \le n; 0, \text{ otherwise.} b \equiv 1/2a_T^2$
2	0	a <sup>2</sup> xe <sup>-ax</sup> , 0 < x < n; [2a + a <sup>2</sup> (2n-x)]e <sup>-ax</sup> + e <sup>-2an</sup> \delta(x-2n), n < x < 2n; 0, otherwise
	1	$\frac{ab}{a-b} (e^{-bx}-e^{-ax}), \ 0_{\leq}x < n; \ \frac{a^2}{a-b} e^{-bn-a(x-n)} \frac{b^2}{-a-b} e^{-an-b(x-n)} + e^{-(a+b)n_{\delta}(x-2n)}, \ n_{\leq}x < 2n; 0, \ otherwise$
	5	same as for $\ell = 0$ , but with a replaced by b
m	0	$\begin{split} & \frac{1}{2}a^{3}x^{2}e^{-ax}, \ 0 \le x < n; \\ & a^{2}[\frac{1}{2}an^{2} + (3+an)(x-n) - a(x-n)^{2}] e^{-ax}, \ n \le x < 2n \\ & a[3+3an+\frac{1}{2}a^{2}n^{2} - a(3+an)(x-2n) + \frac{1}{2}a^{2}(x-2n)^{2}] e^{-ax} + e^{-3an} \delta(x-3n), \ 2n \le x \le 3n. \end{split}$
		$\frac{a^{2}b}{(a-b)^{2}} \left\{ e^{-bx} - e^{-ax} [1+(a-b)x] \right\}, 0 \le x < n; 0, x > 3n, x < 0;$ $\frac{a}{a-b} e^{-a(x-n)} \left\{ a \left[ \frac{b}{a-b} + a(x-n) \right] e^{-bn} + b \left[ \frac{a}{a-b} - (2+a_{n}) + a(x-n) \right] e^{-a_{n}} \left\{ - \frac{2ab^{2}}{(a-b)^{2}} e^{-a_{n} - b(x-n)} \right\}, \frac{a}{n \le x < 2n}$
		$\frac{a^{2}}{a-b}e^{-(a+b)n-a(x-2n)}\left[\frac{2a-3b}{a-b}+a_{n-a(x-2n)}\right]+\frac{b^{3}}{(a-b)^{2}}e^{-2a_{n}-b(x-2n)}+e^{-(2a+b)n}\delta(x-3n), 2n_{2}+2n^{2}$
	2	same as for $l = 1$ , but with a and b exchanged
	m	same as for $\ell = 0$ , but with a replaced by b

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In the conditional probability of error expression,

$$P_{s}(e|\ell,L) = 1 - E_{z_{1}} \left( \frac{M}{m=2} Pr\{z_{m} < z_{1} | \ell,L\} \right), \qquad (5.1-22)$$

the cumulative distribution function for the non-signal channels is needed, written

$$G_{L}(x; \ell) \stackrel{\Delta}{=} \Pr\{z_{m} \leq x \mid \ell, L\}.$$
(5.1-23)

This function is given in Table 5.1-2 for L=1 to 3.

#### 5.1.3 Signal Channel pdf .

The samples of the square-law envelope detector in the signal channel are independent noncentral chi-squared random variables with two degrees of freedom, multiplied by  $\sigma_{1k}^2$ , and with noncentrality parameters

$$\lambda_{k} = 2S/\sigma_{1k}^{2} = \begin{cases} 2S/\sigma_{N}^{2} = 2\rho_{N}, \text{ hop not jammed} \\ 2S/\sigma_{T}^{2} = 2\rho_{T}, \text{ hop jammed.} \end{cases}$$
(5.1-24)

Consequently the pdf of the unclipped samples is

$$f_{1}(x) = \frac{1}{2\sigma_{1k}^{2}} e^{-(x+2S)/2\sigma_{1k}^{2}} I_{0}(\sqrt{2Sx/\sigma_{1k}^{2}})$$

$$= \begin{cases} a \ e^{-a(x+2S)} I_{0}(2a\sqrt{2Sx}), \ x \ge 0, \ hop \ not \ jammed; \\ b \ e^{-b(x+2S)} I_{0}(2b\sqrt{2Sx}), \ x \ge 0, \ hop \ jammed; \end{cases} (5.1-25)$$

where a and b are given by (5.1-18b). To distinguish the signal case from the non-signal case, the q<sub>0</sub> and q<sub>1</sub> defined by (5.1-2) will be written in the upper case; the values are

<b></b> 1	r	$G_{L}(x; \ell) = Pr(z_{m} \leq x \ell, L), m \geq 2$	
P=4	0	$1-e^{-ax}$ , $0 \le x \le n$ ; $1, x \ge n$ . $a \equiv 1/20\frac{2}{N}$	
	1	$1-e^{-bx}$ , $0 \le x < n; 1, x \ge n$ . $b \equiv 1/20\frac{2}{T}$	
64	0	1-e <sup>-ax</sup> (1+ax), 0 < x < n; 1-e <sup>-ax</sup> [1+a(2n-x)], n < x < 2n; 1, x > 2n .	
	1	$1 - \frac{1}{a-b} [ae^{-bx} - be^{-ax}],  0 \le x < n;  1 - \frac{1}{a-b} [ae^{-bn-a}(x-n) - be^{-an-b}(x-n)],  n \le x < 2$	; 1, x <sub>2</sub> 2 <sub>n</sub> .
	2	$1-e^{-bx}(1+bx)$ , $0 \le x < n$ ; $1-e^{-bx}[1+b(2n-x)]$ , $n \le x < 2n$ ; $1, x \ge 2n$	
m	0	$1-e^{-ax}(1+ax+\frac{1}{2}a^2x^2), 0 \le x < n; 1-e^{-ax}[1+a_n+\frac{1}{2}a^2n^2+a(1+a_n)(x-n)-a^2(x-n)^2], n$	x < 2n;
	:	1-e <sup>-ax</sup> [1+2an <sup>41</sup> <sub>2</sub> a <sup>2</sup> n <sup>2</sup> -a(2+an)(x-2n)+ <sup>1</sup> <sub>2</sub> a <sup>2</sup> (x-2n) <sup>2</sup> ], 2n < 3n; 1, x > 3n .	
	1	$1 - \frac{a^2}{(a-b)}e^{-bx} + \frac{b}{a-b}e^{-ax}\left[\frac{2a-b}{a-b}+ax\right],  0 \le x < r_1;$	
		$1-e^{-a(x-\eta)} \left\{ e^{-b\eta} \left[ \frac{a^2}{(a-b)^2} + \frac{a^2}{a-b} (x-\eta) \right] + e^{-a\eta} \left[ \frac{b^2}{(a-b)^2} + \frac{ab}{a-b} (x-2\eta) \right] \right\} + \frac{2ab}{(a-b)^2}$	-an-b(x-n), η <sub>-</sub> x<2n;
		$1-e^{-(a+b)n-a(x-2n)}\left[\frac{a(1+a_n)}{a-b}-\frac{ab}{(a-b)^2}-\frac{a^2}{a-b}(x-2n)\right]-\frac{b^2}{(a-b)^2}e^{-2a_n-b(x-2n)}$	2n <sup>c</sup> x<3n; 1, x <sub>2</sub> 3n .
	2	same as for $\&$ = 1, but with a and b exchanged	
	с	same as for $l = 0$ , but with a replaced by b	

TABLE 5.1-2 NON-SIGNAL CHANNEL CUMULATIVE DISTRIBUTION FUNCTIONS, L=1 TO 3

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$$Q_0 = \Pr\{z_{1k} \ge n \mid \text{not jammed}\}\$$
  
= Q (2 $\sqrt{aS}, \sqrt{2a_n}$ ) (5.1-26a)

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$$Q_{1} = \Pr\{z_{1k} > n | jammed\}$$
  
= Q (2\sqrt{bS}, \sqrt{2bn}), (5.1-26b)

where Q(x,y) is Marcum's Q-function.

For the sum of clipped samples, the pdf is

$$p_{z_1}(x) = \begin{cases} f_{L}(x;\ell_1) + (Q_0)^{L-\ell} (Q_1)^{\ell_1} \delta(x-L_n), & 0 \le x \le L_n; \\ 0, & \text{otherwise.} \end{cases}$$
(5.1-27)

Substituting (5.1-25) in the general convolutional formulas in Section 5.1.1 yields the pdf's listed in Table 5.1-3 for L=1, 2 and Table 5.1-4 for L=3.

#### 5.2 ERROR PROBABILITY FORMULATION

Having the pdf's for the FH/RMFSK clip-and-sum decision variables  $\{z_m\}$ , we can formulate the probability of error.

#### 5.2.1 <u>Conditional Probability of Error</u>.

The probability of symbol error, conditioned on the jamming event  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$  where  $\ell_m$  is the number of hops jammed (out of L hops) in channel m, can be expressed as parametric in n, the clipping threshold, by

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p <sub>z1</sub> (x x, L)	$ae^{-a(x+2S)} I_0 \left( 2a \sqrt{2xS} \right) + Q_0^{\delta}(x-n), 0 \le x \le n. \qquad a = 1/2\sigma_N^2, \ Q_0 = Q\left( 2\sqrt{aS}, \sqrt{2an} \right)$	$be^{-b(x+2S)} I_0 \left( 2b\sqrt{2xS} \right) + Q_1^{\delta}(x-n),  0 \le x \le n, \qquad b \equiv 1/2\sigma_N^2,  Q_1 = Q\left( 2\sqrt{bS}, \sqrt{2bn} \right)$	$v_{2a}\sqrt{x/5} e^{-a(x+4S)} I_1(4a\sqrt{5x}), 0 \le x < r_1; 0, x > 2n, x < 0;$	$2aQ_{0}e^{-a(x-n+2S)}I_{0}(2a\sqrt{2S(x-n)}) + a^{2}e^{-a(x+4S)}\int_{x-n}^{n}dw I_{0}(2a\sqrt{2Sw})I_{0}(2a\sqrt{2S(x-w)})$	+ $Q_0^2 \delta(\mathbf{x}-2n)$ , $n \leq \mathbf{x} \leq 2n$ .	$abe^{-bx-2(a+b)S} \int_{\Omega}^{X} dw e^{-(a-b)w} I_0 \left(2a\sqrt{2Sw}\right) I_0 \left(2b\sqrt{2S(x-w)}\right), 0 \le x < n; 0, x > 2n, x < 0;$	$bq_0e^{-b(x-n+2S)}I_0(2b\sqrt{2S(x-n)}) + aq_1e^{-a(x-n+2S)}I_0(2a\sqrt{2S(x-n)})$	+ $abe^{-bx-2(a+b)S}\int_{x-n}^{n} dw e^{-(a-b)w I_0} \left(2a\sqrt{2Sw}\right)I_0\left(2b\sqrt{2S(x-w)}\right) + Q_0Q_1\delta(x-2n)$ , $n \le x \le 2n$ .	same as for $\ell = 0$ , but with a replaced by b and $Q_0$ replaced by $Q_1$ .
ઝ	0	1	0			1			2
_ <b>_</b>	-		5						

TABLE 5.1-3 SIGNAL CHANNEL PROBABILITY DENSITY FUNCTIONS, L = 1,2

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TABLE 5.1-4 SIGNAL CHANNEL PROBABILITY DENSITY FUNCTIONS, L = 3

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L : 
$$P_{21}(x_{1,2}, L)$$
3 0 
$$(ax/65) e^{-a(x+65)} I_{2}(2a\sqrt{65x}), 0 \le x \le n_{1}, 0, x \ge 3n, x \le 0;$$
3 a00 
$$(x-n)/5 e^{-a(x-n+45)} I_{1}(4a\sqrt{5(x-n)}) + y_{2}2e^{-a(x+65)} \int_{x-n}^{n} dx \sqrt{x/5} I_{1}(4a\sqrt{5x}) I_{0}(2a\sqrt{25(x-n)}))$$
+ a3  $e^{-a(x+65)} \int_{x}^{n} dx I_{0}(2a\sqrt{25(x-1)}) + y_{2}2e^{-a(x+65)} \int_{x-n}^{n} dx I_{0}(2a\sqrt{25(x-2)}), n \le x \le 2;$ 
3 a00  $e^{-a(x-2n+25)} I_{0}(2a\sqrt{25(x-2)}) \int_{x-n}^{n} dx I_{0}(2a\sqrt{25(x-1)}) + 00 \le (x-3n)$ 
+ a3  $e^{-a(x+65)} \int_{x-n}^{2n} dx I_{0}(2a\sqrt{25(x-1)}) I_{0}(2a\sqrt{25(x-2)}) + 00 \le (x-3n)$ 
+ a3  $e^{-a(x+65)} \int_{x-n}^{2n} dx I_{0}(2a\sqrt{25(x-1)}) I_{0}(2a\sqrt{25(x-1)}) + 00 \le (x-3n)$ 
+ a3  $e^{-a(x-65)} \int_{x-n}^{2n} dx I_{0}(2a\sqrt{25(x-1)}) I_{0}(2a\sqrt{25(x-2)}), n \le x \le 3n,$ 
1  $y_{ab} e^{-bx-2(2a+b)5} \int_{0}^{2n} dx e^{-(a-b)} \sqrt{x/5} I_{0}(2b\sqrt{25(x-1)}) I_{1}(4a\sqrt{5x}), 0 \le x \le n \le 3n, x \le 0;$ 
 $y_{a0} I_{1}\sqrt{(x-n)/5} e^{-a(x-n+45)} I_{1}(4a\sqrt{5(x-1)}) + y_{ab} e^{-bx-(2a+b)25} \int_{x-n}^{n} dx I_{0}(2a\sqrt{25(x-1)}) e^{-(a-b)w}$ 
+  $2abQ_{0} e^{-b(x-1)-(a+b)25} \int_{0}^{x} dw e^{-(a-b)w} I_{0}(2a\sqrt{25w}) I_{0}(2a\sqrt{25(x-1)}) e^{-(a-b)w}$ 
+  $a^{2}U e^{-bx-(2a+b)25} \int_{x-n}^{n} dw I_{0}(2a\sqrt{25(x-1)}) I_{1}(2a\sqrt{25(x-1)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-b(x-2n+25)} I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-b(x-2n+25)} I_{0}(2a\sqrt{25(x-2n)}) I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-b(x-2n+25)} I_{0}(2a\sqrt{25(x-2n)}) I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2a\sqrt{25(x-w)}) I_{0}^{-n} dx I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2a\sqrt{25(x-w)}) I_{0}^{-n} dx I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2a\sqrt{25(x-w)}) I_{0}^{-n} dx I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2b\sqrt{25(x-w)}) I_{0}^{-n} dx I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2b\sqrt{25(x-w)}) I_{0}^{-n} dx I_{0}(2a\sqrt{25(x-2n)}) e^{-(a-b)w}$ 
+  $a^{2}U_{0} e^{-bx+an-(a+b)25} \int_{x-n}^{2n} dw I_{0}(2b\sqrt{2$ 

 $P_{s}(e;n|L,\underline{\ell}) = 1 - Pr\{C \equiv correct \ decision;n|L,\underline{\ell}\}.$ (5.2-1)

Since there is clipping, there is a finite probability that one or more of the  $\{z_m\}$  are equal to L. Thus an appropriate formulation, assuming a randomized decision rule, is

$$Pr\{C;n|L,\underline{\imath}\} = \sum_{p=0}^{M} Pr\{C \text{ and } (p \text{ channels } = L_n);n|L,\underline{\imath}\}$$

$$= \sum_{p=0}^{M} Pr\{C \text{ and } (p \text{ channels=L}_n, \text{ including signal channel});n|L,\underline{\imath}\}$$

$$= Pr\{C \text{ and no channels=L}_n;n|L,\underline{\imath}\}$$

$$+ \sum_{p=0}^{M-1} Pr\{C \text{ and } (\text{signal channel=L}_n) \text{ and } (p \text{ non-signal channels=L}_n);$$

$$n|L,\underline{\imath}\}.$$
(5.2-2)

The first term in (5.2-2) is

$$\int_{0}^{L_{n}} dx f_{L}(x; \ell_{1}) \prod_{m=2}^{M} G_{L}(x; \ell_{m}) , \qquad (5.2-3)$$

where  $f_{L}(x; \iota_{1})$  is the non-delta function part of the signal channel's pdf, and  $G_{L}(x; \iota_{m})$ , m>2, is the cumulative distribution function for the non-signal channels. (We assume without loss of generality that the signal channel is the first one, i.e., m=1.) The sum in (5.2-2) can be expanded as

$$\begin{split} \sum_{p=0}^{M-1} &\Pr\{C;_{n} \mid (z_{1}=L_{n}) \text{ and } (p \text{ non-signal channels}=L_{n}); L, \underline{\ell} \} \\ & \quad \cdot \Pr\{p \text{ non-signal channels}=L_{n} \mid L, \ell_{2}, \dots, \ell_{m} \} \cdot \\ & \quad \cdot \Pr\{z_{1}=L_{n} \mid L, \ell_{1} \} \\ & \quad = \sum_{p=0}^{M-1} \frac{1}{p+1} \Pr\{p \text{ non-signal channels}=L_{n} \mid L, \ell_{2}, \dots, \ell_{M} \} \cdot \Pr_{1L}(\ell_{1}), \quad (5.2.4a) \end{split}$$

and we use 
$$P_{1L}(\hat{z}_1) \stackrel{\Delta}{=} Q_0^{L-\hat{z}_1} Q_1^{\hat{z}_1}$$
. (5.2-4b)

Using a similar notation, the probability of a non-signal channel's being equal to  $L_{n}$ , i.e.,  $z_{m}=L_{n}$  for  $m \ge 2$ , is

$$P_{2L}(\hat{x}_{m}) \stackrel{\Delta}{=} q_{0}^{\ell_{m}} q_{1}^{\ell_{m}} = e^{-(L-\ell_{m})a_{n}-\ell_{m}b_{n}} . \qquad (5.2-5)$$

Now, there are  $\binom{M-1}{p}$  ways for p of the M-1 non-signal channels to be selected as either  $z_m = L_n$  or  $z_m < L_n$ . However, it is necessary to account for the fact that these channels may have different numbers of hops jammed,  $\hat{x}_m$ . Let

$$v_{m} = \begin{cases} 1 & \text{if } z_{m} = L_{n} \\ 0 & \text{if } z_{m} < L_{n}; \end{cases}$$
(5.2-6)

using this indicator variable, and the vector

$$\underline{\mathbf{v}} = (\mathbf{v}_2, \mathbf{v}_1, \dots, \mathbf{v}_M), \qquad (5.2-7)$$

we can write

 $\Pr\{p \text{ non-signal channels} = L_n | L, \ell_2, \dots, \ell_M \}$ 

$$= \sum_{\underline{\nu}} \prod_{m=2}^{M} \left\{ \nu_m P_{2L}(\ell_m) + (1-\nu_m) \left[ 1-P_{2L}(\ell_m) \right] \right\} \cdot \delta\left( \sum_{m} \nu_m, p \right)$$
(5.2-8a)

where

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$$\delta(\mathbf{n},\mathbf{p}) \stackrel{\Delta}{=} \begin{cases} 1, \quad \mathbf{p} = \mathbf{n} \\ 0, \quad \mathbf{p} \neq \mathbf{n}. \end{cases}$$
(5.2-8b)

For example, if all the non-signal channels have the same number of jammed hops,  $\ell_m = \ell$ , then (5.2-8a) is evaluated as

$$\begin{bmatrix} P_{2L}(\ell) \end{bmatrix}^{p} \begin{bmatrix} 1 - P_{2L}(\ell) \end{bmatrix}^{m-1-p} \sum_{\underline{\nu}} \delta(\sum_{m} \nu_{m}, p)$$

$$= \binom{M-1}{p} \begin{bmatrix} P_{2L}(\ell) \end{bmatrix}^{p} \begin{bmatrix} 1 - P_{2L}(\ell) \end{bmatrix}^{-1-p}.$$
(5.2-9)

Substituting (5.2-8) and (5.2-3) into the error expression results in

$$P_{s}(e;n|L,\underline{\ell}) = 1 - \int_{0}^{Ln} dx f_{L}(x;\ell_{1}) \prod_{m=2}^{M} G_{L}(x;\ell_{m})$$
(5.2-10)  
-  $P_{1L}(\ell_{1}) \sum_{p=0}^{M-1} \frac{1}{1+p} \sum_{\underline{\nu}} \prod_{m=2}^{M} \{\nu_{m}P_{2L}(\ell_{m}) + (1-\nu_{m})[1-P_{2L}(\ell_{m})]\} \delta(\sum_{m} \nu_{m}, P) \}$ 

5.2.1.1 Special case: L=1 (one hop/symbol). For L=1, we have

$$f_1(x; \ell_1) = c_1 e^{-c_1(x+2s)} I_0(2c_1\sqrt{2Sx});$$
 (5.2-11)

using

$$c_{m} = \begin{cases} a & \text{if } \ell_{m} = 0 \\ b & \text{if } \ell_{m} = 1; \end{cases}$$
(5.2-12)

$$P_{21}(\ell_m) = e^{-C}m^n$$
; (5.2-13)

and

$$\prod_{m=2}^{M} G_{L}(x; \ell_{m}) = \prod_{m=2}^{M} (1 - e^{-C_{m}x})$$

$$= (1 - e^{-ax})^{n_{0}} (1 - e^{-bx})^{M-1-n_{0}}$$

$$= \sum_{k=0}^{n_{0}} \sum_{r=0}^{M-1-n_{0}} {n_{0} \choose k} {M-1-n_{0} \choose r} (-1)^{k+r} e^{-(ka+rb)x}$$
(5.2-14a)

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$$n_0 \stackrel{\Delta}{=} \#(\hat{k}_m = 0, m \ge 2),$$
 (5.2-14b)

that is,  $n_0$  is the number of unjammed, non-signal channels. Substituting in the error expression (5.2-10) results in

$$P_{s}(e;n|1,\underline{i}) = \sum_{\substack{k=0 \ k+r > 0}}^{n_{0}} \sum_{\substack{r=0 \ k+r > 0}}^{M-1-n_{0}} {n_{0} \choose k} {M-1-n_{0} \choose r} (-1)^{k+r+1} \\ \cdot \int_{0}^{n} dx c_{1} e^{-2c_{1}S-(c_{1}+ka+rb)x} I_{0}(2c_{1}\sqrt{Sx}) + Q_{\underline{i}_{1}} \\ - Q_{\underline{i}_{1}} \sum_{p=0}^{M-1} \frac{1}{1+p} \sum_{\underline{v}} \prod_{m=2}^{M} \left| (2v_{m}-1) e^{-c_{m}n} + 1-v_{m} \right| \delta(\sum_{m} v_{m},p). \quad (5.2-15)$$

The integral equals

$$\frac{c_{1}}{c_{1}+ka+rb} \exp \left\{ \frac{-(ka+rb)2c_{1}S}{c_{1}+ka+rb} \right\} \left[ 1 - Q\left(\sqrt{\frac{4c_{1}^{2}S}{c_{1}+ka+rb}}, \sqrt{2(c_{1}+ka+rb)n}\right) \right].$$
(5.2-16)

Also, since  $\boldsymbol{\epsilon}_{m}$  = 0 or 1 when L = 1, the last term can be written

$$- Q(2\sqrt{c_{1}S},\sqrt{2c_{1}n}) \sum_{p=0}^{M-1} \frac{1}{1+p} \sum_{p_{0}=p_{min}}^{p_{max}} {n_{0} \choose p_{0}} {M-1-n_{0} \choose p-p_{0}} e^{-p_{0}(a-b)n-pbn} \times (1-e^{-an})^{n_{0}-p_{0}} (1-e^{-bn})^{M-1-n_{0}-(p-p_{0})}, \quad (5.2-17)$$

where

$$p_{min} = max[0,p-(M-1-n_0)], p_{max} = min(p,n_0).$$
 (5.2-1)

(5.2-18

For example, if M=2, (5.2-15) becomes, since  $n_0 = 0$  or 1  $(n_0 \equiv 1-\ell_2)$ ,

$$P_{b}(e;n|1,\underline{x}) = \underline{x}_{2} \cdot \frac{c_{1}}{c_{1}+b} \exp\left\{\frac{-2bc_{1}S}{c_{1}+b}\right\} \left[1 - 0\left(\sqrt{\frac{4c_{1}^{2}S}{c_{1}+b}}, \sqrt{2(c_{1}+b)n}\right)\right] + (1-\underline{x}_{2}) \cdot \frac{c_{1}}{c_{1}+a} \exp\left\{\frac{-2ac_{1}S}{c_{1}+a}\right\} \left[1 - 0\left(\sqrt{\frac{4c_{1}^{2}S}{c_{1}+a}}, \sqrt{2(c_{1}+a)n}\right)\right] - 0\left(2\sqrt{c_{1}S}, \sqrt{2c_{1}n}\right) \left[\underline{x}_{2} \cdot \left[1 - e^{-bn} + \frac{1}{2}e^{-bn}\right] + (1-\underline{x}_{2}) \cdot \left[1 - e^{-an} + \frac{1}{2}e^{-an}\right]\right] + 0\left(2\sqrt{c_{1}S}, \sqrt{2c_{1}n}\right)$$

5.2.1.2 Special case:  $\underline{\ell} = \underline{0}$  (no jamming).

For this case, we substitute  $\underline{\ell} = \underline{0}$  in (5.2-10) to get

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$$P_{s}(e;n|L,\underline{0}) = 1 - \int_{0}^{Ln} dx f_{L}(x;0) \left[G_{L}(x;0)\right]^{M-1} - Q_{0}^{L} \sum_{p=0}^{M-1} \frac{1}{1+p} {M-1 \choose p} e^{-Lpan} \left(1 - e^{-Lan}\right)^{M-1-p}$$
(5.2-19a)  
$$\frac{M-1}{\sum_{p=0}^{M-1} M-1} \sum_{k=1}^{M-1} {L^{n} \choose p} e^{-Lpan} \left(1 - e^{-Lan}\right)^{M-1-p}$$

$$= \sum_{k=1}^{L} {\binom{M-1}{k}} (-1)^{k+1} \int_{0}^{L} dx f_{L}(x;0) \left[ 1 - G_{L}(x;0) \right]^{k} + Q_{0}^{L} + Q_{0}^{L} - Q_{0}^{L} \cdot \frac{e^{La\eta}}{M} \left[ 1 - (1 - e^{-La\eta})^{M} \right].$$
(5.2-19b)

Now,  $1-G_{L}(x;0)$  in the integral has the form (see Tables 5.1-3 and 5.1-4)

$$1-G_{L}(x;0) = \begin{cases} 1, & x<0; \\ e^{-ax} h_{r}(x-rn), & rn \leq x < (r+1)n, r=0,1,2,...,L-1; \\ 0, & x > Ln; \end{cases}$$
(5.2-20)

where  $h_r(x)$  is an (L-1) degree polynomial. Using this form, the integral in (5.2-19) becomes

$$\sum_{r=0}^{L-1} \int_{rn}^{(r+1)n} dx f_{L}(x;0) [h_{r}(x-rn)]^{k} - kax$$

$$= \sum_{r=0}^{L-1} \int_{0}^{n} dx f_{L}(x+rn;0) [h_{r}(x)]^{k} e^{-ka(x+rn)} . \qquad (5.2-21)$$

Noting also from Tables 5.1-5 and 5.1-6 that the signal channel pdf can be written

$$f_{L}(x;0) = e^{-ax} v_{r}(x-rn), r=0,1,...,L-1,$$
 (5.2-2)

we further manipulate (5.2-21) to obtain

$$\sum_{r=0}^{L-1} e^{-(k+1)ra} \int_{0}^{n} dx \ e^{-(k+1)ax} \ v_{r}(x) [h_{r}(x)]^{k}.$$
 (5.2-2)

For example, if L=1, then  $h_0(x) \equiv 1$  and  $v_0(x) = a e^{-2aS} I_0(2a\sqrt{2Sx})$ , giving for (5.2-23) the value

$$\frac{1}{1+k} \exp\left(-\frac{2kaS}{k+1}\right) \left[1-Q\left(\sqrt{\frac{4aS}{1+k}}, \sqrt{2a(k+1)n}\right)\right]$$
(5.2-24)

and

$$P_{s}(e;n|1,\underline{0}) = \sum_{k=1}^{M-1} {\binom{M-1}{k}} \frac{(-1)^{k+1}}{k+1} \exp\left\{\frac{-2kaS}{1+k}\right\} \left[1 - Q\left(\sqrt{\frac{4aS}{1+k}}, \sqrt{2a(k+1)n}\right)\right].$$
  
+  $Q_{0} - Q_{0} \frac{e^{an}}{M} \left[1 - (1 - e^{-an})^{M}\right].$  (5.2-23)

#### 5.2.2 <u>Total Probability of Error</u>.

For a given number of hops/symbol, L, the total symbol probability of error is

$$P_{s}(e;n,L) = \sum_{\underline{\ell}} Pr{\underline{\ell}} P_{s}(e;n|L,\underline{\ell}); \qquad (5.2-26)$$

the bit error probability is

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$$P_b(e;n,L) = \frac{M/2}{M-1} P_s(e;n,L).$$
 (5.2-27)

5.2.2.1 Choice of clipping threshold.

The procedure we have adopted for choosing n, the clipping threshold, is the following: choose n to minimize the error probability when there is no jamming. That is,

$$n^* : \min_{n} P_s(e;n|L,0).$$
 (5.2-28)

Differentiation of the error expression (5.2-19a) gives an equation for the optimum n thus defined. This equation may be written

$$-f_{L}(L_{n};0) (1 - e^{-La_{n}})^{M-1}$$

$$+ \sum_{r=1}^{L-1} \int_{0}^{n} dx \frac{\partial}{\partial n} \left\{ f_{L}(x+rn;0) \left[ G_{L}(x+rn;0) \right]^{M-1} \right\}$$

$$+ L Q_{0}^{L-1} f_{1}(n;0) \frac{e^{La_{n}}}{M} \left[ 1 - (1 - e^{-La_{n}})^{M} \right]$$

$$- Q_{0}^{L} \frac{La e^{La_{n}}}{M} \left\{ 1 - (1 - e^{-La_{n}})^{M} - Me^{-La_{n}}(1 - e^{-La_{n}})^{M-1} \right\}$$
(5.2-29)

For L=1, the second term is zero and the equation can be put in the form

$$\frac{e^{an}}{M} \left[ Q_0^{a} - f_1^{(n;0)} \right] \left[ \left[ 1 + (M-1)e^{-an} \right] (1-e^{-an})^{M-1} - 1 \right]; \quad (5.2-30)$$

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this partial derivative with respect to n is negative, indicating the error decreases as n increases, indefinitely. Thus for L=1 the optimum threshold is infinite (no clipping):

$$\eta^{*}(L=1) \rightarrow \infty .$$
 (5.2-31)

For L>1, it is not feasible to find the optimum threshold by differentiation; it must be done numerically.

5.2.2.2 Total error for L=1.

Since the optimum threshold for L=1 is  $n^* \rightarrow \infty$ , we may express the total error probability by using (5.2-15) to obtain

$$P_{b}(e;L=1) = \frac{M/2}{M-1} \sum_{\underline{k}} Pr\{\underline{k}\} \sum_{k=0}^{n_{0}} \sum_{r=0}^{M-1-n_{0}} {n_{0} \choose k} {M-1-n_{0} \choose k} (-1)^{k+r+1}$$

$$k+r>0$$

$$k+r>0$$

$$\cdot \frac{c_1}{c_1 + ka + rb} \exp \left\{ \frac{-(ka + rb)2c_1S}{c_1 + ka + rb} \right\}, \quad (5.2-32a)$$

(5.2-32b)

where  $c_1 = (1-\ell_1)a + \ell_1b$ 

$$n_0 = M-1 - \sum_{m=2}^{M} a_m$$
 (5.2-32c)

and

This, of course, gives exactly the same performance as the other receiver processing schemes for L=1.

\* The last factor in (5.2-30) can be recognized as the quantity -  $\sum_{m=2}^{M} {\binom{M}{m}} (1 - e^{-a_n})^{n-m} e^{-ma_n} < 0$ . The second factor is always positive since  $aQ_0 = f_1(n;0) + exp\{-a(2S+n)\} \sum_{k>1} a(2S/n)^k I_k(2a\sqrt{Sn})$ .

#### 5.3 NUMERICAL RESULTS

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In this section we present some numerical results for the clipper receiver's performance. These results are less voluminous than those obtained for other receivers because of the extremely long computer run times for the clipper equations.\*

Two stages of computation are required for the clipper receiver. First, the optimum clipping level in the absence of jamming,  $n_0/\sigma_N^2,$  must be found by a numerical search. Then this value must be used in computing the jammed performance. Whenever L, M, or  $E_b/N_0$  changes the optimum clipping level must be recomputed.

The many numerical integrations required to evaluate (5.2-10) using the forms for  $f_1(x; l_1)$  from Tables 5.1-3 and 5.1-4 and for  $G_1(x; l)$  from Table 5.1-2 result in very lengthy computations. Consider, for example, the case of M=4, L=2, in which the numerical integrations which are required have the structure

$$1 - \left[ \int f_1 g + \int (f_2 + \int f_3) g \right], \quad \ell_1 = 0 \text{ or } \ell_1 = 2$$
 (5.3-1a)

$$1 - \left[ \int f_1 \int f_2 g + \int (f_3 + \int f_4) g \right], \quad \ell_1 = 1$$
 (5.3-1b)

where g is a function of  $\ell_2$ . Each conditional error probability involves one or two double integrations which must be evaluated numerically to sufficient accuracy as to leave several significant digits after subtracting from 1. This subtractive cancellation problem is especially severe for high  $E_b/N_d$  when P(e) is small.

For L=3 the situation is even worse, for the numerical integrations take the forms

\*It has been noted that for L=1 and any M value, the clipper receiver with optimum threshold is merely a conventional receiver, since that threshold is infinite for L>1. Thus the results computed previously for L=1 apply to this Section as well. 5-27

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$$1 - \left\{ \int f_{1}g + \int [f_{1} + \int f_{2} + \int (f_{3}\int f_{4})]g + \int [f_{5} + \int f_{6} + \int (f_{7}\int f_{8})]g \right\},$$
  
$$\ell_{1} = 0 \text{ or } \ell_{1} = 3 \qquad (5.3-2a)$$

$$1 - \left\{ \int (\int f_{1})g + \int [f_{2} + \int f_{3} + \int f_{4} + \int f_{5}(\int f_{6})]g + \int [f_{7} + \int f_{8} + \int f_{9} + \int f_{10}(\int f_{11})]g \right\}, \ \ell_{1} = 1 \text{ or } \ell_{1} = 2 \quad (5.3-2b)$$

which results in a worst-case of 2 one-dimensional integrations, 5 two-dimensional integrations, and 2 three-dimensional integrations to be performed numerically. The inner-most integrals must be evaluated to very high precision in order to evaluate the outer integrals to sufficient precision so as to reduce subtractive cancellation to acceptable levels. The result is a very slow computer program.

Under these conditions, the available computational facilities (a PDP-11/44 minicomputer) restricted the number of performance curves we were able to generate.

#### 5.3.1 The Optimum Threshold Setting .

The optimum clipping threshold  $n_0$  is defined as the level n which minimizes the bit error probability in the absence of jamming. This is accomplished by the first part of the computer programs for calculating the performance in partial-band noise jamming. The thresholds are normalized by the thermal noise density; thus we actually find  $n_0/2\sigma_N^2$ . The optimum thresholds found by the computer programs given in appendices H (for M=2, L=2), I (for M=4, L=2), and J (for M=2 or 4, L=3) are given in Table 5.3-1.

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TABLE	5.3	-1
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		M	
L	$(E_{b}/N_{0} = 13.35247 \text{ dB})$	$(E_{b}/N_{0} = 10.60657 \text{ dB})$	$(E_{b}/N_{0} = 9.09401 \text{ dB})$
2	10.20	10.55	10.89
3	7.91	8.15	

OPTIMUM NORMALIZED CLIPPING THRESHOLD  $\eta_0/2\sigma_N^2$ 

We note that in terms of signal power  $n_0 = (1.89S, 1.83S, 1.79S)$ for L=2 and M=(2,4,8);  $n_0 = (2.19S, 2.13S)$  for L=3 and M=(2,4). The threshold is almost a function only of S, L, and M.

#### 5.3.2 Probability of Bit Error.

For M=2 and L=2, the computations using the program given in Appendix H were sufficiently rapid to permit obtaining a full set of curves for jamming fractions from  $\gamma = 0.001$  through  $\gamma = 1.0$ , as shown in Figure 5.3-1.

For M=4 and L=2, the computations were much slower, due to the increased number of jamming events and the need to compute products of the function  $G_L(x)$ . Therefore, the program in Appendix I was used to search for the optimum value of  $\gamma$  for each value of  $E_b/N_J$ . To aid the speed of the search, we used the <u>a priori</u> knowledge that  $\gamma_{opt} = 1/N$  where N is the number of hopping slots when  $E_b/N_J$  is very high, and that  $\gamma_{opt}$  increases as  $E_b/N_J$  decreases. Thus the computations started at  $E_b/N_J = 50$  dB and decreased (in rather large steps to conserve computer time) to 0 dB. The result is the curve of  $P_b(e)$  vs.  $E_b/N_J$  in worst-case partial-band noise jamming as shown for M=4 in Figure 5.3-2. We see that M=4 FH/RMFSK is about 2 dB better than M=2 FH/RMFSK in strong jamming.

Selected runs for M=8 and L=2 with  $E_b/N_0=9.09$  dB were made in order to examine the dependence of the worst-case jamming performance upon M. These runs yielded the threshold shown in Table 5.3-1 and the following points for  $\gamma=0.01$ :  $[E_b/N_J, P(e)] = [15, 8.963(-4)], [20, 4.680(-4)], [22.5, 2.604(-4)], [25, 1.286(-4)], [\infty, 3.91(-5)].$  From these points, a curve for  $\gamma=0.01$  was constructed, and the inflection point was taken to be a point on the worst-case jamming curve. This point, estimated as the 22.5 dB point given above, is shown on Figure 5.3-2.

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Although the program given in Appendix J contains code to compute  $P_b(e)$  as well as  $n_0/2\sigma_N^2$ , excessive run time (nearly 8 hours to obtain just  $n_0/2\sigma_N^2$ ), prevented us from allowing it to run to completion to obtain performance curves for the case L=3 hops per symbol.



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### 6.0 FH/RMFSK PERFORMANCE USING SQUARE-LAW SELF-NORMALIZING RECEIVER

The ECCM weighting schemes which make the (ideal) AGC and clipper soft-decision receivers for FH/MFSK and FH/RMFSK work depend upon <u>a priori</u> knowledge of system parameters, or else real-time measurements. (The feasibility of these measurements is discussed in a later section.) It is evident that the clipper strategy, which requires setting an SNR-dependent threshold, would be easier to implement than the AGC receiver, which requires detection of which hops are jammed and knowledge or measurement of thermal noise and jamming noise levels. Meanwhile we have seen that the hard-decision receiver accomplishes a form of ECCM protection, much in the manner of the clipper receiver - the jammed hops are prevented from dominating the decision. If there is sufficient SNR, one might well choose then to employ the hard-decision scheme, since it does not require any <u>a priori</u> knowledge or measurements.

In this section we consider soft-decision weighting schemes which are not predicated on using signal or noise parameters. In particular, we find the FH/RMFSK performance of a "self-normalizing" receiver in partial-band noise jamming.

#### 6.1 THE SELF-NORMALIZATION SCHEME

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The general FH/RMFSK soft-decision receiver shown in Figure 2.2-1 is rendered what we call the "self-normalizing" (SNORM) receiver by use of the weighting function

$$z_{mk} = f(x_{mk}) = \frac{x_{1nk}^2}{x_{1k}^2 + x_{2k}^2 + \dots + x_{Mk}^2}$$
 (6.1-1)

That is, on each hop (indexed by k, k=1,2,...,L), the squared envelope samples in each channel (m=1,2,..,M) are normalized (divided) by their sum. In this manner, hops which are jammed in one or more MFSK slots can be expected to be weighted less than unjammed hops.

Thus the decision variables for the SNORM receiver are

$$z_{m} = \sum_{k=1}^{L} z_{mk}$$
$$= \sum_{k=1}^{L} w_{k} x_{mk}^{2}$$
(6.1-2a)

where

$$w_{k} = \left(\sum_{m=1}^{M} x_{mk}^{2}\right)^{-1}$$
 (6.1-2b)

### 6.1.1 <u>Single-hop</u> <u>Distribution</u> of Decision Variables.

With the FH/RMFSK hopping scheme, any, none, or all of the channels can be jammed on a particular hop. Using  $u_{mk} \equiv x_{mk}^2$  for the square-law envelope samples and

> a =  $1/2\sigma_N^2$ b =  $1/2\sigma_T^2$ , (6.1-3)

for a general one-hop jamming event, we can write (assuming the signal is in channel 1)

$$P_{u_1}(\alpha;c_1) = c_1 e^{-c_1 \alpha - \rho_1} I_0(2\sqrt{\rho_1 c_1 \alpha}), \alpha > 0; \qquad (6.1-4a)$$

and

$$P_{u_m}(\alpha; c_m) = c_m e^{-c_m \alpha}, m=2,...,M; \alpha > 0;$$
 (0.1-3b)

where

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$$c_m = \begin{cases} a, channel not jammed \\ b, channel jammed, m=1,2,...,M. \end{cases}$$
 (6.1-4c)

Thus the joint pdf for the square-law envelope detector samples is, conditioned on the jamming,

$$p_{\underline{u}}(\alpha_1,\ldots,\alpha_M|c_1,\ldots,c_M) = c_1c_2\ldots c_M \exp\left\{-\rho_1 - \sum_{m=1}^M c_m\alpha_m\right\} l_0(2\sqrt{c_1c_1\alpha_1}),$$
  
$$\alpha_m \ge 0. \qquad (6.1-5)$$

By a change of variables,

$$u_{1} = \xi z_{1}$$

$$u_{1}+u_{2} = \xi(z_{1}+z_{2})$$

$$\sum_{i=1}^{k} u_{i} = \xi \sum_{i=1}^{k} z_{i}$$
(6.1-6)

$$u_1 + u_2 + \cdots + u_M = \xi,$$

we can express the joint pdf of  $\{z_1, z_2, \dots, z_{M-1}\}$  by, using  $\underline{c} \approx (c_1, c_2, \dots, c_M)$ ,

$$\mathbf{p}_{\underline{z}}(\alpha_{1},\alpha_{2},\ldots,\alpha_{M-1}|\underline{c}) = \int_{0}^{\infty} d\xi \ \xi^{M-1} \mathbf{p}_{\underline{u}} \left[ \xi \alpha_{1},\xi \alpha_{2},\ldots,\xi \alpha_{M-1},\xi - \sum_{m=1}^{M-1} \xi \alpha_{m} \right]$$

$$c_{1}c_{2}...c_{M} e^{-\rho_{1}} \int_{0}^{\infty} d\xi \xi^{M-1} exp \left\{ -\xi \left[ c_{M} + \sum_{m=1}^{M-1} (c_{m}-c_{M}) \alpha_{m} \right] \right\} \times I_{0}(2\sqrt{\rho_{1}c_{1}\xi\alpha_{1}})$$

$$= \frac{(M-1)! e^{-p_1} \prod c_m}{\left[c_M + \sum_{m=1}^{M-1} (c_m - c_M)_{\alpha_m}\right]^M} {}_{1}F_1\left[M;1; \frac{c_1^{\rho_1 \alpha_1}}{c_M + \sum_{m=1}^{M-1} (c_m - c_M)_{\alpha_m}}\right]. \quad (6.1-7)$$

In this development we used equations 6.643.2 and 9.220.2 from [3];  ${}_{1}F_{1}(a;b,x)$  is the confluent hypergeometric function.

Note that  $\alpha_{M}$  does not appear in (6.1-7). This occurrence is due to the fact that there are now only M-1 <u>dependent</u> random variables; the value of the Mth channel variable is completely determined by the others. This fact can be made explicit by writing (using all variables)

$$p_{\underline{z}}(\alpha_1, \alpha_2, \dots, \alpha_M | \underline{c}) = p_{\underline{z}}(\alpha_1, \alpha_2, \dots, \alpha_{M-1} | \underline{c}) \quad \delta\left(\sum_{m=1}^M \alpha_m - 1\right). \quad (6.1-8)$$

Also, we note that the domains of these variables are interdependent:

$$0 \le z_m \le 1$$
  
 $0 \le z_i + z_j \le 1$  (all pairs)  
 $0 \le z_i + z_j + z_k \le 1$  (all triples) (6.1-9)

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$$0 \le z_1 + z_2 + \dots + z_{M-1} \le 1$$
  
 $\sum_{m=1}^{M} z_m \equiv 1.$ 

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This interdependence of finite domains makes analysis and computation difficult, as will be seen below.

6.1.2 <u>Alternate Forms</u>.

By using the identity

$${}_{1}F_{1}(M;1;x) = e^{X}{}_{1}F_{1}(1-M;1;-x)$$
  
=  $e^{X} \mathcal{L}_{M-1}(-x)$ , (6.1-10)

where  $\mathcal{L}_{n}(x)$  is the Laguerre polynomial, we realize that the joint pdf given in (6.1-7) has the form of an exponential times an (M-1)-degree polynomial in  $x(\underline{\alpha})$ , divided by an M-degree polynomial in  $y(\underline{\alpha})$ :

$$p_{\underline{z}}(\underline{\alpha}|\underline{c}) = \frac{\text{const} \cdot e^{x(\underline{\alpha})} \mathcal{L}_{M-1}[-x(\underline{\alpha})]}{\left[y(\underline{\alpha})\right]^{M}} \quad \delta(\sum_{m} \alpha_{m} - 1)$$
(6.1-11a)

where

$$x(\underline{\alpha}) = c_1 c_1 \alpha_1 / y(\underline{\alpha})$$
(6.1-11b)

$$y(\alpha) = c_{M} + \sum_{m=1}^{M-1} (c_{m} - c_{M}) \alpha_{m}$$
 (6.1-11c)

and

const = 
$$(M-1)!e^{-\rho_1} \prod_{m=1}^{M} c_m.$$
 (6.1-11d)

A somewhat simpler form results from recognizing that [3,

equation 8.970.1]

$$\mathcal{L}_{M-1}(x) = \frac{1}{(M-1)!} e^{x} \frac{d^{M-1}}{dx^{M-1}} \left[ e^{-x} x^{M-1} \right].$$
(6.1-12)

Applying this relation results in

$$\mathbf{p}_{\underline{z}}(\underline{\alpha}|\underline{c}) = \frac{\prod_{m} c_{m}}{\left[\sum_{m} c_{m} \alpha_{m}\right]^{M}} e^{-c_{1}} \frac{M-1}{\partial \rho_{1}} \left( \rho_{1}^{M-1} e^{\rho_{1} \mathbf{x}(\underline{\alpha})} \right) \delta(\sum_{m} \alpha_{m}-1). \qquad (6.1-13)$$

6.1.2.1 Special case: M=2 (binary).

The various general expressions for the joint pdf reduce to the following ones for M=2:

$$p_{\underline{z}}(\alpha_{1}, \alpha_{2} | c_{1}, c_{2}) = \frac{c_{1}c_{2}e^{-\rho_{1}}}{(c_{1}\alpha_{1} + c_{2}\alpha_{2})^{2}} - 1^{F_{1}(2;1; \frac{c_{1}\rho_{1}\alpha_{1}}{c_{1}\alpha_{1} + c_{2}\alpha_{2}}) \delta(\alpha_{1} + \alpha_{2}-1)}$$
(6.1-14a)  
$$= \frac{c_{1}c_{2}e^{-\rho_{1}}}{\left[c_{2} + (c_{1}-c_{2})\alpha_{1}\right]^{2}} \exp\left\{\frac{c_{1}\rho_{1}\alpha_{1}}{c_{2} + (c_{1}-c_{2})\alpha_{1}}\right\} \left[1 + \frac{c_{1}\rho_{1}\alpha_{1}}{c_{2} + (c_{1}-c_{2})\alpha_{1}}\right] \delta(\alpha_{1}+\alpha_{2}-1)$$
(6.1-14b)

$$=\frac{c_{1}c_{2}e^{-c_{1}}}{\left[c_{2}+(c_{1}-c_{2})\alpha_{1}\right]^{2}} \quad \frac{\partial}{\partial c_{1}}\left[c_{1}\exp\left\{\frac{c_{1}c_{1}\alpha_{1}}{c_{2}+(c_{1}-c_{2})\alpha_{1}}\right\}\right]\delta(\alpha_{1}+\alpha_{2}-1) \quad (6.1-14c)$$

with

$$0 \le \alpha_1 \le 1, \quad 0 \le \alpha_2 = 1 - \alpha_1 \le 1.$$
 (6.1-14d)

6.1.2.2 Special case: no jamming.

For no jamming,  $c_1 = c_2 = \dots = c_M$  (also true for all channels jammed), the general pdf reduces to

$$p_{\underline{Z}}(\underline{\alpha} | c_1 = c_2 = \dots = c_M) = (M-1)! e^{-\rho_1} {}_{1}F_1(M; 1; \rho_1 \alpha_1) \delta(\sum_{m} \alpha_m - 1)$$
(6.1-15a)

= (M-1): 
$$e^{-\rho_1 + \rho_1 \alpha_1} \mathcal{L}_{M-1}(-\rho_1 \alpha_1) \delta(\sum_{m \alpha_m} \alpha_m - 1)$$
 (6.1-15b)

$$= e^{-\rho_1} \frac{\partial^{M-1}}{\partial \rho_1} \left\{ \begin{array}{c} M-1 \\ \rho_1 \end{array} e^{\rho_1 \alpha_1} \right\} \delta(\sum_{m \alpha_m} \alpha_m - 1).$$
 (6.1-15c)

### 6.1.3 <u>Conditional pdf's for M=2</u>.

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We now show the explicit expressions for the decision variable for the binary case; there is only one decision variable  $z \equiv z_1$  since  $z_2 \equiv 1 - z_1$ . 6.1.3.1 Single hop/bit case (L=1).

As far as computation of error probabilities is concerned, the L=1 case of the SNORM receiver pdf's is not needed since the normalization does not affect the outcome of the decision; we know in advance that the result will be the same as if no normalization were employed. However, to go on to the L=2 case, we need the L=1 pdf's.

Using  $K \stackrel{\ell}{=} \sigma_T^2 / \sigma_N^2$  as in previous analyses, the pdf's conditioned on the possible jamming events  $\underline{v} = (v_1, v_2)$  are as follows:

$$p_{1}[z|\underline{v} = (0,0)] = e^{-\rho_{N}} F_{1}(2;1;\rho_{N}z)$$
(6.1-16a)

$$= e^{-\rho_N + \rho_N z} (1 + \rho_N z) . \qquad (6.1 - 16b)$$

$$p_{1}[z]_{\underline{v}}=(0,1)] = \frac{Ke^{-v_{N}}}{[1+(K-1)z]^{2}} - 1^{F_{1}}(2;1;\frac{Kv_{N}z}{1+(K-1)z})$$
(6.1-17a)

$$= \frac{Ke^{-\rho}N}{\left[1 + (K-1)z\right]^2} \exp\left[\frac{K_{\rho}N^2}{1 + (K-1)z}\right] \left(1 + \frac{K_{\rho}N^2}{1 + (K-1)z}\right) (6.1-17t)$$

$$p_{1}[z|\underline{v}=(1,0)] = \frac{Ke^{-\rho}T}{[K-(K-1)z]^{2}} \mathbf{1}^{F_{1}}(2;1;\frac{\rho}{K-(K-1)z})$$
(6.1-18a)

$$= \frac{Ke^{-\rho}T}{\left[K - (K-1)z\right]^{2}} \exp\left[\frac{\rho T^{2}}{K - (K-1)z}\right] \left(1 + \frac{\rho T^{2}}{K - (K-1)z}\right) (6.1-1\varepsilon b)$$

$$p_{1}[z| \ge (1,1)] = e^{-\rho_{T}} F_{1}(2;1;\rho_{T}z)$$
 (6.1-19a)

$$= e^{-\rho_T + \rho_T z} (1 + \rho_T z) . \qquad (6.1-19b)$$

For all of these expressions, the domain of z is  $0 \le z \le 1$ . Note that when there is no signal  $(\rho_N = \rho_T = 0)$ , the variable z is uniformly distributed when both channels have the same noise power.

6.1.3.2 Two hops/bit case (L=2).

To obtain the pdf for L=2, it is necessary to convolve the expressions (6.1-16) to (6.1-19) with each other for the jamming events  $\underline{x} = \underline{v}_1 + \underline{v}_2$ . The general form of the convolution is

$$p_{2}(z|\underline{l} = \underline{v}_{1} + \underline{v}_{2}) = \int_{\max(0, z-1)}^{\min(1, z)} dv p_{1}(z-v|\underline{v}_{1})p_{1}(v|\underline{v}_{2}), 0 \le z \le 2.$$
(6.1-2)

There are ten distinguishable jamming events, two for  $\underline{\ell}=(1,1)$  and one each for other  $\underline{\ell}$ . For three of these ten cases, the convolution shown in (6.1-20) can be performed analytically without too much difficulty; the cases are the ones in which both channels are jammed or not jammed on a given hop:  $\underline{\ell}=(0,0)$ ,  $(1,1)^*$ , (2,2). For these cases, the pdf for one hop can be written

$$p_1(z) = e^{-\rho_1} \frac{\partial}{\partial \rho_1} \rho_1 e^{\rho_1 z} , \quad 0 \le z \le 1$$
 (6.1-2)

The convolution then takes the form

$$p_{2}(z|\rho_{1},\rho_{2}) = e^{-\rho_{1}-\rho_{2}} \frac{\partial^{2}}{\partial\rho_{1}\partial\rho_{2}} \rho_{1}\rho_{2} \int_{\max(0,z-1)}^{\min(1,z)} dv e^{\rho_{1}(z-v)+\rho_{2}v} \\ = e^{-\rho_{1}-\rho_{2}} \frac{\partial^{2}}{\partial\rho_{1}\partial\rho_{2}} \frac{\rho_{2}\rho_{1}}{\rho_{2}-\rho_{1}} \cdot \begin{cases} e^{\rho_{2}z} e^{\rho_{1}z}, & 0 \le z \le 1 \\ e^{2+\rho_{1}(z-1)} e^{\rho_{1}+\rho_{2}(z-1)} \\ e^{-e}, & 1 \le z \le 2. \end{cases}$$
(6.1-2)

\*i.e., the case of  $\underline{2}$  = (1,1) where  $\underline{v}_1$  = (1,1) and  $\underline{v}_2$  = (0,0) or vice versa.

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Carrying out the partial differentiations results in

$$P_{2}(z|\rho_{1},\rho_{2}) = \frac{e^{-\rho_{1}-\rho_{2}}}{(\rho_{1}-\rho_{2})^{3}} \left\{ e^{\rho_{1}z} \left[ -2\rho_{1}\rho_{2} + \rho_{1}^{2}(\rho_{1}-\rho_{2})z \right] \right\}$$
(6.1-23a)

$$+ e^{\rho_2 z} \left[ 2\rho_1 \rho_2 + \rho_2^2 (\rho_1 - \rho_2) z \right], \ \rho_1 \neq \rho_2, 0 \le z \le 1;$$
  
=  $e^{-2\rho + \rho z} z(1 + \rho z + \rho^2 z^2/6), \ \rho_1 = \rho_2 = \rho, \ 0 \le z \le 1;$  (6.1-23b)

$$= \frac{1}{(\rho_1 - \rho_2)^5} \left\{ e^{\rho_2(z-2)} \left[ -2\rho_1\rho_2 + \rho_1^2(\rho_1 - \rho_2) + \rho_2(\rho_1 - \rho_2)(\rho_1^2 - \rho_1\rho_2 - \rho_2)(z-1) \right] \right\}$$

$$+ e^{\rho_{1}(z-2)} \left[ 2\rho_{1}\rho_{2} + \rho_{2}^{2}(\rho_{1}-\rho_{2}) + \rho_{1}(\rho_{1}-\rho_{2})(\rho_{2}^{2}-\rho_{1}\rho_{2}-\rho_{1})(z-1) \right] \right]$$

$$+ \rho_{1}(\rho_{1}-\rho_{2})(\rho_{2}^{2}-\rho_{1}\rho_{2}-\rho_{1})(z-1) \right] \left[ 1 < z \leq 2, \ \rho_{1}\neq\rho_{2} \right] (6.1-23c)$$

$$= e^{-2\rho+\rho z} \left[ 1 + \rho + \rho^{2}/6 - (1-\rho^{2}/2)(z-1) - \rho(1+\rho/2)(z-1)^{2} - (\rho^{2}/6)(z-1)^{3} \right], \ \rho_{1}=\rho_{2}=\rho, \ 1 < z \leq 2.$$

$$(6.1-23d)$$

This expression is applied to the pertinent jamming events using the following table:

£1	ρ1	P2	
0	۶N	۶N	
1	۴N	۲٩	(6.1-24)
2	۲٩	۰T۰	•

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The other seven cases must be handled by numerical convolution. (We have found an analytical expression, but it is no easier to compute than the convolutions.)

6.1.4 <u>Conditional pdf's for M=4</u>.

The system analysis for M>2 becomes very difficult, as we now demonstrate for M=4.

6.1.<sup>4</sup>.1 Single hop/symbol case (L=1).

For M=4 and L=1 there are sixteen possible jamming events, described by the vector  $\underline{v} = (v_1, v_2, v_3, v_4)$ , where  $v_m = 1$  if the mth symbol frequency slot is jammed, and  $v_m = 0$  if not. These events give rise to the conditional pdf

$$p(\underline{z}|\underline{v}) = \frac{6\mu_1}{[y(\underline{z})]^4} e^{-\rho_1^{+\mu}2^{\rho_1^{-\mu}2^{-\mu_2^{-\mu$$

where

$$\mathcal{L}_{3}(-u) = 1 + 3u + \frac{3}{2}u^{2} + \frac{1}{6}u^{3}$$
(6.1-25b)

and the parameters  $\mu_1, \mu_2$ , and  $\rho_1$  and the polynomials  $y(\underline{z})$  are listed in Table 6.1-1. Since  $z_4 \equiv 1-z_1^{-z_2^{-z_3}}$ , it does not appear in the pdf. We note that  $z_1$ always appears in the conditional pdf, while  $z_2$  and  $z_3$  may or may not appear.

It is understood that the domain of values for the variables is  $(z_1, z_2, z_3) \in \Omega_{4,1}$ , where  $\Omega_{4,1}$  is the volume

 $\Omega_{4,1}^{\Omega_{4,1}^{L}} \begin{cases} 0 \leq z_{i} \leq 1, i = 1,2,3; \\ 0 \leq z_{i} + z_{j} \leq 1, all pairs; \\ 0 \leq z_{1} + z_{2} + z_{3} \leq 1. \end{cases}$  (6.1-26)

	L=1 PROBABILITY DENSITIES FOR M=4								
	V1 V2V3V4	Pl	μı	μ2	y(z)				
A	0000		1	1	1				
В	0001		κ <sup>3</sup>		$1 + (K-1) (z_1 + z_2 + z_3)$				
С	0010		к <sup>3</sup>		K - (K-1)z <sub>3</sub>				
D	0011	<sup>р</sup> N	κ <sup>2</sup>		$1 + (K-1) (z_1 + z_2)$				
E	0100		к <sup>3</sup>	к	K - (K-1)z <sub>2</sub>				
F	0101		κ <sup>2</sup>		$1 + (K-1) (z_1 + z_3)$				
G	0110		к <sup>2</sup>		K - (K-1) (z <sub>2</sub> +z <sub>3</sub> )				
н	0111		к		$1 + (K-1)z_1$				
I	1000		к <sup>3</sup>		$K - (K-1)z_1$				
J	1001		κ <sup>2</sup>		$1 + (K-1) (z_2 + z_3)$				
к	1010		κ <sup>2</sup>		$K - (K-1) (z_1 + z_3)$				
L	1011		к		$1 + (K-1)z_2$				
м	1100	۲	κ <sup>2</sup>	1	$K - (K-1) (z_1 + z_2)$				
N	1101		к		$1 + (K-1)z_3$				
0	1110		К		$K - (K-1) (z_1 + z_2 + z_3)$				
P	1111		1		1				

TABLE 6.1-1

Form:

$$p_{1}(\underline{z}|\underline{v}) = \frac{6\mu_{1}}{[y(\underline{z})]^{4}} e^{-\rho_{1} + \frac{\mu_{2}}{2}\rho_{1}z_{1}/y(\underline{z})} \mathcal{L}_{3}(-\mu_{2}\rho_{1}z_{1}/y(\underline{z}))$$
$$\mathcal{L}_{3}(-\mu) = 1 + 3\mu + \frac{3}{2}\mu^{2} + \frac{1}{6}\mu^{3}$$
$$\underline{z} = (z_{1}, z_{2}, z_{3}) \in \Omega_{4}, 1$$
$$z_{4} = 1 - z_{1} - z_{2} - z_{3}$$

The domain  $\Omega_{4,1}$  may also be described as the volume included by the planes  $z_1=0$ ,  $z_2=0$ ,  $z_3=0$ , and  $z_1+z_2+z_3=1$ , as illustrated by Figure 6.1-1. It is obvious from the mutual constraints among the variables that they are statistically dependent.

6.1.4.2 Two hop/symbol case (L=2).

Since the four SNORM variables are dependent, we cannot analyze the M=4, L=2 case by finding the two-sample distributions of the separate channels as we did for other receivers. The convolution must be done in three dimensions (M-1 dimensions for the general case). The concept for doing this is unusual, but can be visualized. Figure 6.1-2 illustrates the fact that multi-dimensional convolution of two pdf's involves integration over the volume which is the intersection of the domains of the pdf's. In Figure 6.1-2(b), the simple case when the point  $(z_1, z_2, z_3)$  lies inside the domain of  $p_1(z)$  is shown; this yields a rectangular-sided volume. If  $(z_1, z_2, z_3)$  lies outside the domain of  $p_1(z)$ , the intersection is much more complicated.

By careful study we have determined that the pdf for the SNORM receiver's decision variables for M=4 and L=2 has the general form

$$p_{2}(\underline{z}|\underline{x} = \underline{v}_{1} + \underline{v}_{2}) = \int_{A_{1}}^{B_{1}} \int_{A_{2}}^{B_{2}} dv_{2} \int_{A_{3}}^{B_{3}} dv_{3} p_{1}(\underline{v}|\underline{v}_{1})p_{1}(\underline{z}-\underline{v}|\underline{v}_{2}), \quad (6.1-27a)$$

where

$$A_{1} = \max (0, z_{1}-1)$$

$$B_{1} = \min (1, z_{1})$$

$$A_{2} = \max (0, z_{1}+z_{2}-v_{1}-1)$$

$$B_{2} = \min (1-v_{1}, z_{2})$$

$$A_{3} = \max (0, z_{1}+z_{2}+z_{3}-v_{1}-v_{2}-1)$$

$$B_{3} = \min (1-v_{1}-v_{2}, z_{3}).$$
(6.1-27b)



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 $\iiint d\underline{v} \ p_{a}(\underline{v})p_{b}(\underline{z}\underline{-v})$  $V(\underline{v}) \cap V(\underline{z}-\underline{v})$ 

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(b) three-dimensional convolution

FIGURE 6.1-2 TWO- AND THREE-DIMENSIONAL CONVOLUTIONS

Now, since there are sixteen cases of  $p_1(\underline{z}|\underline{v})$  for L=1, there are  $(16)^2 = 256$  cases for L=2. However since the numbering of symbol channels is arbitrary, there can be considered to be fewer, distinguishable jamming events. These are fully enumerated in Section 6.2. What we wish to note here is that if neither of the densities in (6.1-27) contains  $v_3$ , the integral can be simplified to

$$p_{2}(\underline{z}|\underline{x}) = \int_{A_{1}}^{B_{1}} dv_{1} \int_{A_{2}}^{B_{2}} dv_{2} p_{1}(\underline{v}|v_{1}) p_{1}(\underline{z}-\underline{v}|v_{2}) (B_{3}-A_{3})$$
(6.1-28a)

where

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$$B_{3} - A_{3} = \min (1 - v_{1} - v_{2}, v_{3}) - \max(0, z_{1} + z_{2} + z_{3} - v_{1} - v_{2} - 1)$$
  
$$= \frac{1}{2} \left\{ 2 - z_{1} - z_{2} - |1 - v_{1} - v_{2} - z_{3}| - |z_{1} + z_{2} + z_{3} - v_{1} - v_{2} - 1| \right\}.$$
 (6.1-28b)

If neither pdf in (6.1-27) contains  $v_2$  or  $v_3$ , the integral can be further simplified to

$$p_{2}(\underline{z}|\underline{k}) = \int_{A_{1}}^{B_{1}} dv_{1} p_{1}(v_{1}|\underline{y}_{1})p_{1} (z_{1}-v_{1}|\underline{y}_{2}) \int_{A_{2}}^{B_{2}} dv_{2} (B_{3}-A_{3}), \qquad (6.1-29)$$

where

$$\int_{P_2}^{P_2} dv_2 (B_3 - A_3) = \frac{1}{2} (2 - z_1 - z_2) (B_2 - A_2)$$

$$- \frac{1}{4} \left\{ (B_2 + v_1 + z_3 - 1) | B_2 + v_1 + z_3 - 1 | \\ - (A_2 + v_1 + z_3 - 1) | A_2 + v_1 + z_3 - 1 | \\ + (B_2 + v_1 + 1 - z_1 - z_2 - z_3) | B_2 + v_1 + 1 - z_1 - z_2 - z_3 | \\ - (A_2 + v_1 + 1 - z_1 - z_2 - z_3) | A_2 + v_1 + 1 - z_1 - z_2 - z_3 | \\ \right\}, \qquad (6.1 - 30)$$

since

$$\int_{A}^{B} dx |x-a| = \int_{A}^{B} dx |a-x| = \frac{1}{2} (B-a)|B-a| - \frac{1}{2} (A-a)|A-a|. \quad (6.1-3)$$

Now, if  $v_3$  is in the integrand of (6.1-27) but  $v_2$  is not, we simply "switch labels" on  $v_2$  and  $v_3$  to get (6.1-28) with  $v_3$  replacing  $v_2$ .

### 6.2 JAMMING EVENTS AND ERROR PROBABILITY FOR L=2

We now extend the conditional distribution analysis in the last section to obtain the BER for the FH/RMFSK SNORM receiver under partial-band noise jamming. Since the jammed error for L=1 is the same for other receivers, we proceed to the case of L=2.

### 6.2.1 Jamming Events and Probabilities for M=2.

For L=2 and M=2 there are 2<sup>ML</sup>=16 elementary jamming events. As mentioned previously, for the SNORM receiver, only ten of these events are distinguishable in terms of jamming effects. These are listed in Table 6.2-1, along with the single-hop events which produce them and the probabilities of the L=2 events.

The error event, assuming the signal is in channel 1, is  $z_1 < z_2 = 2-z_1$ . Thus

$$P_{b}(e;\gamma) = Pr\{z_{1}<1\} = \sum_{\underline{\ell}} Pr\{\underline{\ell}\} Pr\{z_{1}<1|\underline{\ell}\}. \qquad (6.2-1)$$

The conditional error probabilities in (6.2-1) are calculated by integrating the pdf's shown previously in equation (6.1-23) or the convolution

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TABLE 6.2-1

# events £ Probability  $\underline{v}_1$ <u>v</u>2 0,0 0,0 0,0  $\pi_0^2$ 1 0,1 0,1 0,0 2  $2\pi_0\pi_1$ 0,2 0.1  $\pi_{1}^{2}$ 0.1 1 1,0 0,0 1,0 2  $2\pi_0\pi_1$ 0,0 1,1 1,1 2 **2**π<sub>0</sub>π<sub>2</sub> 0,1 1,0 2  $2\pi_1^2$ 1,2 0,1 1,1 2  $2\pi_{1}\pi_{2}$ 2,0 1,0  $\pi_{1}^{2}$ 1,0 1 2,1 1,0 1,1 2  $2\pi_1\pi_2$ 2,2  $\pi_{2}^{2}$ 1,1 1,1 1 Totals: 1 16 1 1 1

$$\pi_{0} = \frac{\binom{N-2}{q}}{\binom{N}{q}} = \frac{(N-q)(N-q-1)}{N(N-1)} , \pi_{1} = \frac{\binom{N-2}{q-1}}{\binom{N}{q}} = \frac{q(N-q)}{N(N-1)} , \pi_{2} = \frac{\binom{N-2}{q-2}}{\binom{N}{q}} = \frac{q(q-1)}{N(N-1)}$$

$$p_{2}(z|\underline{y}=\underline{y}_{2}+\underline{y}_{2}) = \int_{\max(0,z-1)}^{\min(1,z)} dv \ p_{1}(v|\underline{y}_{1}) \ p_{1}(z-v|\underline{y}_{2})$$

JAMMING EVENTS AND PROBABILITIES FOR M=2, L=2

of the pdf's in equations (6.1-16) to (6.1-19). The result is

$$\begin{split} P_{b}(e;\gamma) &= \pi_{0}^{2} \cdot \frac{1}{2} e^{-\rho_{N}} (1+\rho_{N}/3) \\ &+ 2\pi_{0}\pi_{1} \int_{0}^{1} dv (1-v) e^{-\rho_{N}^{V}} p_{1}(v|0,1) \\ &+ \pi_{1}^{2} \int_{0}^{1} dv p_{1}(v|0,1) \cdot \frac{K(1-v)}{v+K(1-v)} exp \left\{ \frac{-\rho_{N}^{V}}{v+K(1-v)} \right\} \\ &+ 2\pi_{0}\pi_{1} \int_{0}^{1} dv (1-v) e^{-\rho_{N}^{V}} p_{1}(v|1,0) \\ &+ 2\pi_{0}\pi_{2} \frac{1}{(\rho_{N}-\rho_{T})^{3}} \left\{ e^{-\rho_{T}} \left[ \rho_{N}(\rho_{N}-\rho_{T}) - (\rho_{N}+\rho_{T}) \right] \right\} \\ &+ e^{-\rho_{N}} \left[ \rho_{T}(\rho_{N}-\rho_{T}) + (\rho_{N}+\rho_{T}) \right] \right\} \\ &+ 2\pi_{1}^{2} \int_{0}^{1} dv p_{1}(v|0,1) \cdot \frac{1-v}{Kv+1-v} exp \left\{ \frac{-K\rho_{T}v}{Kv+1-v} \right\} \\ &+ 2\pi_{1}\pi_{2} \int_{0}^{1} dv (1-v) e^{-\rho_{T}^{V}} p_{1}(v|0,1) \\ &+ \pi_{1}^{2} \int_{0}^{1} dv (1-v) e^{-\rho_{T}^{V}} p_{1}(v|1,0) \\ &+ 2\pi_{1}\pi_{2} \int_{0}^{1} dv (1-v) e^{-\rho_{T}^{V}} p_{1}(v|1,0) \\ &+ \pi_{2}^{2} \cdot \frac{1}{2} e^{-\rho_{T}} (1+\rho_{T}/3). \end{split}$$

(6.2-2)

In this expression we have used the fact that

$$\int_{0}^{1} dz \int_{0}^{\min(1,z)} dv \, p_{1}(v|\underline{y}_{1}) \, p_{1}(z-v|\underline{y}_{2})$$

$$= \int_{0}^{1} dz \int_{0}^{z} dv \, p_{1}(v|\underline{y}_{1}) \, p_{1}(z-v|\underline{y}_{2})$$

$$= \int_{0}^{1} dv \, p_{1}(v|\underline{y}_{1}) \int_{0}^{1-v} dz \, p_{1}(z|\underline{y}_{2}) \, . \qquad (6.2-3)$$

Also, the parameters K,  $\rho_{\mbox{N}},$  and  $\rho_{\mbox{T}}$  are

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$$K = \frac{\sigma_{T}^{2}}{\sigma_{N}^{2}} , \rho_{N} = \frac{1}{2} \cdot \frac{E_{b}}{N_{0}} , \rho_{T} = \frac{1}{2} \cdot \frac{E_{b}}{N_{T}} . \qquad (6.2-4)$$

### 6.2.2 Jamming Events and Probabilities for M=4.

For L=2 and M=4, there are 256 elementary jamming events, which can be represented by 47 distinguishable events. These are listed in Table 6.2-2, along with their probabilities of occurrence. The joint pdf of the decision variables, given the representative jamming event shown in the table, is the convolution (6.1-27) with the single-hop pdf's selected from Table 6.1-1 as indicated.

The error event for M=4 and L=2 is the complement of the condition for a correct symbol decision, so that the conditional error probability is

$$P_{s}(e|\underline{v}) = 1 - Pr\{z_{1} > z_{2}, z_{1} > z_{3}, z_{1} > z_{4} = 2 - z_{1} - z_{2} - z_{3}|\underline{v}\}$$
  
= 1 - Pr\{z\_{1} > z\_{2}, z\_{1} > z\_{3}, 2z\_{1} > 2 - z\_{2} - z\_{3}|\underline{v}\} (6.2-5a)

$$= 1 - P_{s}(C|\underline{k}).$$
 (6.2-5b)

£	cases*	# even	ts prob.	<u>٤</u>	cases*	# events	prob
0000	A+A	1	<b></b> "0 <sup>2</sup>	1220	F+N	6	<b>6</b> π2τ3
0100	A+E	6	<b>6</b> π <sub>0</sub> π <sub>1</sub>	1221	H+N	6	<b>6</b> π3 <sup>2</sup>
0110	A+G	6	6π0 <sup>π</sup> 2		G+P	6	- 6π2π4
	C+E	6	6111 <sup>2</sup>	1222	H+P	2	21314
0111	A+H	2	2 <sub>1013</sub>				•
	C+F	6	<b>6</b> π <sub>1</sub> π <sub>2</sub>	2000	1+I	1	π1 <sup>2</sup>
0200	E+E	3	3 <sub>π1</sub> <sup>2</sup>	2100	I+M	6	<b>6</b> $\pi_1$ <b><math>\pi_2</math></b>
0210	E+G	12	12 m 1 m 2	2110	I+N	6	<b>6π</b> 1 <b>π</b> 3
0211	E÷H	6	<b>6</b> π1π3		К+М .	6	6 <sub>72</sub> 2
	F+G	6	<b>6</b> π2 <sup>2</sup>	2111	I+P	2	- 2π1π4
0220	G+G	3	3π2 <sup>2</sup>		K+N	6	<b>6</b> $\pi_2$ <b></b> $\pi_3$
0221	G+H	6	<b>6</b> π2π3	2200	M+M	3	3 <sub>72</sub> 2
0220	H+K	1	<b>7</b> 3 <sup>2</sup>	2210	M+N	12	<b>12</b> π <sub>2</sub> π <sub>3</sub>
				2211	M+P	6	<b>6</b> π2π4
1000	A+I	2	2 <sub>10</sub> 1		L+N	6	6 <b>π</b> ₃²
1 1 0 0	A+M	6	<b>6</b> π <sub>0</sub> π <sub>2</sub>	2220	N+N	3	<b>3</b> = 3 <sup>2</sup>
	E+1	6	6π1 <sup>2</sup>	2221	N+P	6	6 <u>≘</u> 3≖4
1 1 1 0	A+N	6	<b>6</b> π <sub>0</sub> π <sub>3</sub>	2222	<b>P+</b> P	1	π4 2
	G+I	6	<b>6</b> π1π2		Totals:	256	1
	C+M	12	12 <sub>112</sub>				
1 1 1 1	A+P	2	2 <i>m</i> 0 <i>m</i> 4	*cases (A-	P): See T	able 6.1	-1
	H+1	2	2π <sub>1</sub> π <sub>3</sub>	(N	/N ~ 1\/N	[]	- 21
	C+N	6	6m1m3	10 # <u>(N-q)</u> N	(N-1)(N-	(N-3)	<u>1-3</u> )
	F+K	6	6π2 <sup>2</sup>				
1200	E+M	6	<b>6</b> π <sub>1</sub> π <sub>2</sub>	$\pi_1 = \frac{q_1(N-1)}{N(1)}$	<u>q) (N-q-1)</u> N-1) (N-2(	(N-g-2) N-3)	
1210	E+N	12	12 = 1 = 3				
	G+M	12	12 <sup>π</sup> 2 <sup>2</sup>	$\pi_2 = \frac{q(q-1)}{N(N)}$	<u>)(N-q)(N-</u> -1)(N-2)(	$\frac{q-1}{N-3}$	
1211	G+N	12	12n.m3		,, ,,	•	
	E+P	6	<b>6π</b> ]π4	$\pi_3 = \frac{\mathbf{q}}{\mathbf{n}_3} \left( \frac{\mathbf{q}}{\mathbf{q}} \right)$	$\frac{1}{q-2}$	<u></u>	
	H+M	6	<b>6</b> π2π3	· n(n-	1)(n-2)(N	- 3 )	
				$\pi_{4} = \frac{q}{N(N-1)}$	1)(q-2)(c 1)(N-2)(N	(-3)	

# TABLE 6.2-2JAMMING EVENTS AND PROBABILITIES FOR M=4, L=2

From this expression we observe that the probability of a correct symbol decision is obtained from the joint pdf of  $(z_1, z_2, z_3)$  by integrating it over the volume  $\omega_c$  implied in (6.2-5):

$$P_{s}(C|\underline{\ell}) = \iint_{\Omega_{c}} \int dz_{1} dz_{2} dz_{3} \quad P_{2}(\underline{z} | \underline{\ell}).$$
(6.2-6)

As illustrated in Figure 6.2-1, the volume  $\Omega_c$  may be described as that enclosed by the planes  $z_2=0$ ,  $z_3=0$ ,  $2z_1+z_2+z_3=2$ ,  $z_1+z_2+z_3=2$ ,  $z_1=z_2$ , and  $z_1=z_3$ . Thus

$$P_{s}(C|\underline{x}) = \int_{A_{4}}^{B_{4}} dz_{1} \int_{A_{5}}^{B_{5}} dz_{2} \int_{A_{6}}^{B_{6}} dz_{3} p_{2}(\underline{z} | \underline{x}), \qquad (6.2-7a)$$

where

$$A_{4} = 1/2, B_{4} = 2$$

$$A_{5} = \max(0, 2-3z_{1})$$

$$B_{5} = \min(z_{1}, 2-z_{1})$$

$$A_{6} = \max(0, 2-2z_{1}-z_{2})$$

$$B_{6} = \min(z_{1}, 2-z_{1}-z_{2}).$$
(6.2-7b)



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points:  $(z_1, z_2, z_3)$ A: (2/3, 2/3, 0) D: (1, 0, 1)B: (1/2, 1/2, 1/2) E: (2/3, 2/3, 2/3)C: (2/3, 0, 2/3) F: (1, 1, 0)

FIGURE 6.2-1 VOLUME OF INTEGRATION FOR CORRECT SYMBOL DECISION, M=4, L=2

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6.3 AN ALTERNATE APPROACH FOR M=2 AND L=3 HOPS/SYMBOL

In order to obtain a more computationally tractable form for the performance of the self-normalizing receiver in partial-band noise jamming, we may proceed as follows. The probability of a symbol error is

$$Pr(e) = Pr\{z<3/2\}$$

$$= E_{\underline{\nu}} \{ \Pr\{z < 3/2 | \underline{\nu} \} \}$$

$$= E_{\underline{\nu}} \{ \int_{0}^{3/2} p_{3}(z | \underline{\nu}) dz \}$$
(6.3-1)

where  $p_3(z | \underline{v})$  is the probability density function conditioned on jamming event  $\underline{v}$ .

If we interchange the order of integration with respect to  $\zeta$  and expectation with respect to  $\underline{v}$  in (6.3-1), we obtain

$$Pr(e) = \int_0^{3/2} E_{\underline{v}}\{p_3(\zeta | \underline{v})\} d\zeta. \qquad (6.3-2)$$

The expectation in (6.3-2) may be written as

$$p_{3}(\zeta) \stackrel{\triangleq}{=} E_{\underline{\nu}} \{ p_{3}(\zeta | \underline{\nu}) \}$$

$$= E_{\underline{\nu}} \{ p_{1}(\zeta | \underline{\nu}) * p_{2}(\zeta | \underline{\nu}) \}$$

$$= p_{1}(\zeta) * p_{2}(\zeta)$$
(6.3-3)

where the operator \* denotes convolution and

$$P_{1}(\zeta) \stackrel{\Delta}{=} E_{\underline{\nu}_{1}}\{P_{1}(\zeta | \underline{\nu}_{1})\}$$
(6.3-4)

with  $\underline{\nu}_1$  being the first column of the event matrix  $\underline{\nu}$  and

$$\mathbf{p}_{2}(\zeta) \stackrel{\text{\tiny def}}{=} \mathbf{E}_{\underline{\nu}_{2}}\{\mathbf{p}_{2}(\zeta | \underline{\nu}_{2})\}$$
(6.3-5)

with  $\underline{\nu}_2$  being the last two columns of the matrix  $\underline{\nu}$ . The expectation in (6.3-4) is given by

$$p_1(\zeta) = \pi_0 p_{00}(\zeta) + \pi_1 p_{01}(\zeta) + \pi_1 p_{10}(\zeta) + \pi_2 p_{11}(\zeta)$$
(6.3-6)

where the  $p_{ij}(z) \triangleq p_1[z|v = (i,j)]$  are given by (6.1-16)-(6.1-19) and the event probabilities  $\pi_0$ ,  $\pi_1$ , and  $\pi_2$  are given by Table 6.2-1.

The density  $p_2(z)$  from (6.3-5) contains 10 terms, as discussed in Section 6.1.3.2. Analytical results for three of these cases are given by (6.1-23) and (6.1-24).

By performing the convolution (6.3-3) using (6.3-6) and (6.1-23), we obtain a form containing the sum of seven numerical convolutions. However, each convolution involves a reasonably well-behaved integrand. Overall, the computational effort is also lightened by the reduction in total terms due to splitting up the 3-hop jamming events into 1-hop events in (6.3-6) and 2-hop events in (6.3-5) for which, at least in part, analytical results are available. This is the method implemented by the computer program given in Appendix L.

### 6.4 NUMERICAL RESULTS

The numerical computations for the self-normalizing receiver suffer difficulties similar to those encountered for the clipper receiver, namely a multitude of multiple-dimensional numerical integrations. For the case of M=2 and L=2, from (6.2-2) and (6.1-16), we have the simplest case to compute, consisting of 7 one-dimensional integrals. For the case of M=2 and L=3, we must do 5 two-dimensional numerical integrations and 2 three-dimensional numerical integrations to obtain a value of  $P_b(e)$  for given  $E_b/N_0$ ,  $E_b/N_J$ , and  $\gamma$ . For the case of M=4 and L=2, we are faced with numerical integrations in five or six dimensions over non-standard regions (see, for example, Figure 6.2-1 for the region of integration of the outermost 3 dimensions).

At the computational throughput rate of the PDP-11/44 computer available for the computations, the CPU time to obtain results for even M=4 and L=2 are estimated to run to many months, or even years. Hence, we restrict our numerical computations to M=2 and L=2 and 3. For L=2, the speed of computation was sufficiently high to permit the full set of curves for  $\gamma = 0.001$ to  $\gamma = 1.0$ , to be computed using the program in Appendix K. Figure 6.4-1 shows the performance as a function of  $E_b/N_J$  when  $E_b/N_0 = 13.35247$  dB, which corresponds to  $P_b(e) = 10^{-5}$  for ideal MFSK with M=2. We note in Figure 6.4-1 that there is a clustering of the cross-over around  $E_b/N_J = 16$  dB.

If  $E_b/N_0$  is increased to 20 dB, the performance curves shown in Figure 6.4-2 are obtained. In this figure we observe that many of the curves exhibit a breakpoint at which the direction of curvature changes. Clearly, the self-normalizing receiver departs considerably from the ideal receiver under certain ranges of operating conditions. The exact mechanisms which come into play to explain this behavior are not totally clear, but it appears to be the

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FIGURE 6.4-1 PERFORMANCE OF SELF-NORMALIZING RECEIVER FOR FH/RMFSK WITH M=2, L=2 HOPS/SYMBOL, 2400 HOPPING SLOTS, AND  $E_b/N_0 = 13.35247$  dB (FOR  $P_b(e)=10^{-5}$  IN THE ABSENCE OF JAMMING WHEN L=1)



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interaction of several different effects, with the switch-over from thermalnoise-limited operation to partial-band-jamming-limited operation playing a significant role. The importance of this switch-over is supported by the lack of apparent breakpoints in the curves for very small  $\gamma$  ( $\gamma = 0.001$ , 0.002) and very large  $\gamma$  ( $\gamma = 0.5$ , 1.0); these are the cases in which the one-slot-jammed jamming event predominates and the shape of the curves reflects essentially the performance conditioned on the dominant event.\*

For the case of L=3 hops, the reduced speed of computation dictated that we search for the optimum jamming fraction at each  $E_b/N_J$  rather than run full curves for the various values of  $\gamma$ . Again, we started at  $\gamma = 1/2400$  for  $E_b/N_J = 50$  dB to speed the search, and then stepped to a lower value of  $E_b/N_J$ . The computer program in Appendix L was used to obtain the results presented in Figure 6.4-3 for M=2, L=3.

Finally, Figure 6.4-4 compares the performances of the selfnormalizing receiver as L, the number of hops per symbol, varies. As we have observed with the other receivers, there is a limited range of  $E_b/N_J$ over which a "diversity" effect is achieved. For example, L=3 outperforms L=2 for 17 dB <  $E_b/N_J$  < 29 dB. However, in the thermal-noise-limited region and in the strong-jamming region (where  $\gamma = 1.0$  is the worst-case jamming), the noncoherent combining loss dominates and L=1 is optimum.

<sup>\*</sup> For further discussion, see Section 7.3.3.5.



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AND  $E_b/N_0 = 13.35247$  dB WITH NUMBER OF HOPS/SYMBOL AS A PARAMETER

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### 7.0 <u>COMPARISONS OF RECEIVER PERFORMANCES</u>

The information we have generated separately on the performances of the various FH/RMFSK receivers in Sections 3-6 can now be compared to learn which ECCM processing scheme is most effective in worst-case partialband noise jamming. However, since the random MFSK waveform is specifically designed to counter follow-on jamming, we first develop the performances of these receiver processing schemes in follow-on jamming, both for conventional hopping and for random hopping.

7.1 RECEIVER PERFORMANCES IN FOLLOW-ON NOISE JAMMING

### 7.1.1 Formulation of Follow-on Jamming Analysis: Simple Jammer.

Under follow-on noise jamming (FNJ), it is assumed that on each hop, the jammer places his available power, J watts, in a relatively narrow band centered on the signal's hop frequency. If this band is at least 2(M-1) + 1 slots wide, then the jammer is guaranteed to jam all M slots of conventional FH/MFSK on every hop\*. The hop SNR for FNJ therefore is

$${}^{\rho}_{T} = \frac{S}{\sigma_{N}^{2} + \sigma_{J}^{2}} = \frac{E_{h}}{N_{0} + N_{J} / \gamma_{r}} = \frac{\log_{2} M}{L} \cdot \frac{E_{b}}{N_{0} + N_{J} / \gamma_{r}}$$
(7.1-1a)

where the jammer spectral density  $N_J$  is defined over the entire hopping system bandwidth,  $N_J = J/W$ , and therefore the effective jamming fraction is

$$Y_{r} = \frac{W_{J}}{W} \ge \frac{2M-1}{N} \quad . \tag{7.1-1b}$$

In terms of the jamming events indexed by the vector  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$ , where  $\ell_m$  is the number of hops jammed in symbol frequency

<sup>\*</sup>In Section 7.1.2, we consider an "advanced" FNJ which excludes jamming from the signal slot.

channel m, for repeat jamming we have

$$\ell_{\pm} = L.$$
 (7.1-2)

The values of the other  $\{\mathfrak{k}_m\}$  depend on the hopping scheme.

7.1.2 Formulation of FNJ Analysis: Advanced Jammer.

The FNJ can avoid helping the communicator by not putting any jammer power in the signal slot. Assuming that this measure is taken, the hop SNR is  $\rho_N$  in the signal slot. For maximum effectiveness against FH/MFSK, we also assume that the jammer places half its power in each of the two slots on either side of the intercepted signal, as illustrated in Figure 7.1-1. Thus  $\ell_1 = 0$ , and for a single hop, for FH/MFSK,

$$Pr\{1 \text{ nonsignal slot jammed}\} = \frac{2}{M}$$

$$Pr\{2 \text{ nonsignal slots jammed}\} = 1 - \frac{2}{M}.$$

$$(7.1-3a)$$

For random hopping and advanced FNJ,

$$Pr\{0 \text{ nonsignal slots jammed}\} = \frac{(N-M)(N-M-1)}{(N-1)(N-2)}$$

$$Pr\{1 \text{ nonsignal slot jammed}\} = 2 \frac{(N-M)(M-1)}{(N-1)(N-2)}$$

$$Pr\{2 \text{ nonsignal slots jammed}\} = \frac{(M-1)(M-2)}{(N-1)(N-2)}.$$

$$(7.1-3b)$$

### 7.1.3 Performance of Conventional FH/MFSK in FNJ.

For conventional FH/MFSK, the M symbol frequency slots are contiguous at RF on each hop. Under simple FNJ, therefore, all M slots are jammed on each hop. That is,

$$\ell_2 = \ell_3 = \cdots = \ell_M = L.$$
 (7.1-4)

The error probability for the system then is

$$P_b(e;\gamma_r) = \frac{M/2}{M-1} P_s(e;\gamma_r | \ell_m = L, all m).$$
 (7.1-5)







(b) "Advanced" follow-on jammer.

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For the several receiver processing schemes we have the results using  $\rho_T$  given in (7.1-1),

$$P_b(e;\gamma_r) = probability of error for broadband jamming (\gamma=1),with  $E_b/N_J$  replaced by  $E_b/N_J + 10 \log_{10} \gamma_r$ .  
(7.1-6)$$

Thus the error curves for rollow-on jamming,  $P_b(e)$  vs.  $E_b/N_J$  with  $E_b/N_0$  = constant, are those for full-band jamming, but moved to the right by -10  $\log_{10} \gamma_r$  dB.

Figure 7.1-2 illustrates the performance of conventionally-hopped FH/MFSK in follow-on noise jamming, assuming the follow-on jammer's bandwidth guarantees jamming of all M slots of the symbol. For example, if there are 2400 hopping slots and the jammer occupies 100 slots, then  $\gamma_r = 100/2400 = -13.8$  dB, so that the effective  $E_b/N_J$  shown in the figure runs from about 14 dB to 64 dB. Something like 25 dB  $E_b/N_J$  gives an error rate of  $10^{-2}$  for L = 1.

For the advanced FNJ, the effect on FH/MFSK is to produce the symbol error rate

$$P_{s} = \frac{2}{M} P_{s}(e|\ell_{2}=L;\ell_{m}=0,m\neq 2) + (1 - \frac{2}{M}) P_{s}(e|\ell_{2}=\ell_{3}=L;\ell_{m}=0,m\neq 2,3); \qquad (7.1-7a)$$
  
$$Y_{n} = 2/N. \qquad (7.1-7b)$$

with

Figure 7.1-3 illustrates the jammed BER for this case for M=2, 4, and 8. It is quite clear the the follow-on capability gives the jammer a tremendous advantage against FH/MFSK.

### 7.1.4 Performance of FH/RMFSK in Follow-on Jamming.

The FH/RMFSK hopping scheme is designed to defeat FNJ by making it difficult for the jammer to jam the nonsignal slots; the nonsignal slots are distributed randomly in the hopping band. The simple follow-on jammer



FIGURE 7.1-2 FOLLOW-ON JAMMING PERFORMANCE OF LCR AND ACJ-AGC RECEIVERS FOR FH/MFSK WITH L=1,2,6 AND M=2,32 WHEN  $E_b/N_0$  YIELDS A  $10^{-5}$  BER FOR L=1


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can very likely help the receiver by placing more RF power into the signal's slot.

For M<<N, that is, for a very wide hopping band compared to the symbol bandwidth, the effect of FNJ on FH/RMFSK is approximately to guarantee that

$$\ell_1 = L$$
  
 $\ell_2 = \ell_3 = \cdots = \ell_M = 0.$  (7.1-8)

This has two effects. First, the per-hop SNR  $\rho_T$  is decreased since additional noise is inserted in the signal channel by the jammer. Second, the scaling of the square-law envelope samples increases for the same reason. Since the average value of a single sample is

$$E\{z_{1k}\} = 2(\sigma_T^2 + S),$$
  

$$E\{z_{mk}\} = 2\sigma_N^2, \quad m \ge 2, \quad (7.1-9)$$

on the whole we anticipate that repeat jamming will increase the probability that the receiver will make a correct decision.

7.1.4.1 Soft-decision receivers.

For the various soft-decision receivers studied, under simple FNJ the decision variables are described as follows:

Linear combining (conventional) receiver

$$z_{1} = \sigma_{T}^{2} \chi^{2} (2L; 2L_{P_{T}})$$

$$z_{m} = \sigma_{N}^{2} \chi^{2} (2L), \quad m \ge 2. \quad (7.1-10)$$

AGC - individual channel normalization receiver (IC)

$$z_1 = \chi^2(2L; 2L_{P_T})$$
  
 $z_m = \chi^2(2L), m \ge 2.$  (7.1-11)

AGC - any channel jammed normalization receiver (ACJ)

$$z_{1} = \chi^{2}(2L, 2L_{P_{T}})$$

$$z_{m} = \frac{\sigma_{N}^{2}}{\sigma_{T}^{2}} \chi^{2}(2L), \quad m \ge 2. \quad (7.1-12)$$

Clipper receiver

$$z_{1} = \sum_{k=1}^{L} \left[\sigma_{T}^{2} \chi^{2}(2; 2\rho_{T})\right] \text{clip at } \eta$$

$$z_{m} = \sum_{k=1}^{L} \left[\sigma_{N}^{2} \chi^{2}(2)\right] \text{clip at } \eta. \qquad (7.1-13)$$

Since multiplication of all channels by a constant factor does not affect the error probability, we observe that the conventional and AGC-ACJ receivers will achieve the same performance in FNJ:

$$P_{b}(e; \gamma_{r})_{ACJ} = \frac{M/2}{M-1} \sum_{k=1}^{M-1} {\binom{M-1}{k}} \frac{(1)^{k+1}}{(1+kK)^{L}} \exp \left\{ -\frac{kKL_{\rho_{T}}}{1+kK} \right\}$$

$$\times \sum_{r=0}^{k(L-1)} C(k,r) \left( \frac{K}{1+kK} \right)^{r} \mathcal{L}_{r}^{L-1} \left( \frac{-L_{\rho_{T}}}{1+kK} \right), \qquad (7.1-14a)$$

where

$$K \stackrel{\Delta}{=} \sigma_{\overline{1}}^{2} / \sigma_{N}^{2}, \qquad (7.1-14b)$$

$$C(k,r) = \frac{1}{r} \sum_{n=1}^{\min(r,L-1)} {\binom{r}{n} \left[ (k+1)n-r \right] C(k,r-n)}, \qquad (7.1-14c)$$

$$C(k,0) = 1,$$

and  $\mathcal{L}_{r}^{L-1}(\cdot)$  denotes the generalized Laguerre polynomial of degree r with parameter L-1.

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The performance for the AGC receiver with individual channel normalization is the same as given by (7.1-14), but with K=1.

$$P_{b}(e;\gamma_{r}) = P_{b}(e;\gamma_{r})_{ACJ}$$
 (7.1-15)

The performance of the clipper receiver in follow-on jamming and FH/RMFSK is

$$P_{b}(e;\gamma_{r})_{C} = 1 - \int_{0}^{L_{\eta} \star} dx f_{L}(x;L) \left[ G_{L}(x;0) \right]^{M-1} - \left[ Q(\sqrt{2\rho_{T}},\sqrt{\eta^{\star}/\sigma_{T}^{2}}) \right]^{L} \frac{e^{L_{\eta} \star/2\sigma_{N}^{2}}}{M} \left[ 1 - \left( 1 - e^{-L_{\eta} \star/2\sigma_{N}^{2}} \right)^{M} \right],$$
(7.1-16)

where  $n^*$  is the optimum clipping threshold. For L=1, this threshold is infinite, causing the clipper receiver to have the same performance as the ACJ receiver under follow-on jamming for that case.

Figure 7.1-4 illustrates the performance of the randomly-hopped FH/RMFSK receivers against simple FNJ for L=1. We observe that the error probability is maximized for a particular value of  $\gamma_{r}E_{b}/N_{J}$ ; for the binary case, this value is slightly greater than 0 dB, while for M=4 and M=8, it is approximately -2.5 dB and -4.0 dB, respectively, for the assumed values of  $E_{b}/N_{0}$  (chosen to achieve 10<sup>-5</sup> error rate without jamming). It is interesting to note that for very strong jamming (to the left of the maximum error), the error rate increases with M as does the maximum error. Using the example of the last subsection, a 10<sup>-2</sup> error rate is achieved for an  $E_{b}/N_{J}$  of about 17 dB for  $\gamma_{r} \approx -14$  dB, an 8 dB improvement over conventional hopping.



FOR L=1 HOP/SYMBOL AND M=2,4,8 WHEN  $E_b/N_0$  YIELDS A  $10^{-5}$  BER WITHOUT JAMMING

Figure 7.1-5 demonstrates that the same critical jammer power effect is observed for L=2, but at different values (approximately 3 dB higher), so that the jammer must know L in order to be effective. It is also evident from this figure that the maximum error rate is decreased by increasing L to 2.

For the advanced FNJ described above, using RMFSK hopping, there is only a slight chance of jamming the symbol on a given hop. The possible jamming events for a single hop are the vectors

$$\frac{v_{k}}{k} = (0, v_{2k}, v_{3k}, \dots, v_{MK})$$
(7.1-17)

with probabilities

Pr{r nonsignal slots jammed}

$$= -r = \frac{\binom{N-M}{2-r}}{\binom{N-1}{2}} \binom{M-1}{r}.$$
(7.1-18)

For M=2 the result is

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$$P_{b}(e) = \sum_{k=0}^{L} {\binom{L}{k} \left(\frac{2}{N-1}\right)^{k} \left(1 - \frac{2}{N-1}\right)^{L-k} P_{b}(e \mid l_{1}=0, l_{2}=k).$$
(7.1-19a)

$$= P_{b}(e | \ell_{1} = \ell_{2} = 0) + \frac{2L}{N-1} P_{b}(e | \ell_{1} = 0, \ell_{2} = 1), N-1 > 2. \quad (7.1-19b)$$

Thus the FH/RMFSK hopping scheme achieves very nearly the unjammed error performance of MFSK when the follow-on noise jammer is configured against FH/MFSK. As (7.1-19b) shows, for L=1 and M=2 the unjammed error rate is increased by, at most, 2/(N-1); this quantity equals  $8.3 \times 10^{-4}$  for N=2400, and  $7.8 \times 10^{-3}$  for N=256. For L=1, Figure 7.1-3 shows the performance of FH/RMFSK much improved over FH/MFSK in advanced FNJ.



An exception to Figure 7.1-3 for FH/RMFSK is the IC-AGC receiver, for which the "advanced" FNJ is completely nullified. The jammer in this case is "too smart," because the IC-AGC receiver is vulnerable to jamming only if the signal channel is jammed. This statement also holds for the case of conventional MFSK hopping if individual-channel normalization is employed.

7.1.4.2 Hard-decision receiver.

Performance of the hard-decision receiver in simple follow-on noise jamming is depected in Figures 7.1-6 through 7.1-8 for values of M=2, 4, and 8 respectively. The parameter  $E_b/N_0$  was chosen to yield a  $10^{-5}$  BER in the absence of jamming per respective M value for L=1 hop per symbol. It is clearly seen in each of the L P(e) curves that as the jammer power is increased below that  $E_b/N_J$  value to cause maximum P(e), a decrease in P(e) takes place. Hence, for strong jamming the jammer is actually aiding the communicator by the addition of energy to the noncoherent FSK signal slot. We also have a diversity improvement for L>3 hops per symbol in the strong jamming regions. Conversely, for weak jamming (beyond  $E_b/N_1 \approx 20$  dB) no diversity improvement is realized for L>2 hops per symbol due to the dominance of the noncoherent combining loss existing for the stated thermal noise  $(E_b/N_0)$  values. Therefore, in order to be effective (maximum P(e)), the jammer must maintain  $E_{\rm b}/N_{\rm J}$  to within small ranges. For example, to ensure a minimum P(e) of  $10^{-2}$  for M=2 and L=1 (Figure 7.1-4),  $E_{h}/N_{1}$  must be held to values ranging from 4 to 14 dB.

The effects of decreased thermal noise levels  $(E_b/N_0 = 20 \text{ dB})$ for cases of M=2, 4, and 8 are illustrated in Figures 7.1-9 through 7.1-11 respectively. Here we observe all of the L P(e) curves exhibiting a





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FIGURE 7.1-10 PERFORMANCE OF HARD-DECISION FH/RMFSK RECEIVER IN SIMPLE FNJ VS. EFFECTIVE  $E_b/N_J$  FOR M=4 AND  $E_b/N_0$  = 20 dB



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"parabolic" type of behavior, i.e. steeply defined strong and weak jamming regions. Thus, the jammer appears to have quite a narrow window of  $E_b/N_J$  values to work within for attaining a maximum effect.

7.2

#### COMPARISONS OF FH/RMFSK RECEIVER PERFORMANCES IN WORST-CASE PARTIAL-BAND NOISE JAMMING (WCPBNJ)

It is understood that the motivation for using the proposed FH/RMFSK waveform is that it is less vulnerable to follow-on noise jamming (FNJ) or repeat noise jamming than is a conventional FH/MFSK block-hopping system. RMFSK is effective in that the FNJ is not able to place jamming power in the unused symbol frequency slots as is the case for MFSK where the M signalling frequencies are adjacent. At the FH/MFSK or FH/RMFSK receiver, the L hops comprising the MFSK symbol can be combined in a number of ways. Certain types of nonlinear combining soft-decision schemes, which weight the detected hops in some form to discriminate against jammed hops, are employed. Previous results [1] have shown that conventional FH/MFSK system performance with L-hop diversity in WCPBNJ is improved by nonlinear combining techniques. This study has addressed FH/RMFSK system performance in the less sophisticated, yet more pervasive, ECM tactic of PBNJ - a basic jamming threat which is inevitably encountered in an EW scenario. In Sections 3 through 6 it has been demonstrated that nonlinear combining yields improved RMFSK performance in this type of jamming.

In what follows, we compare performances of the different types of ECCM receivers for FH/RMFSK signals in the WCPBNJ environment. In Section 7.3 we also compare FH/MFSK and FH/RMFSK receiver performances in WCPBNJ, and in Section 7.4 consider the different effects of the RMFSK diversity combining

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techniques studied. Unless stated otherwise, we note that all  $E_b/N_0$  values utilized in performance plots are chosen so as to yield a  $10^{-5}$  BER in the absence of jamming when L=1 hop per symbol.

Comparisons among the different FH/RMFSK receivers analyzed are provided by Figures 7.2-1 and 7.2-2 for M=2 and  $E_b/N_0 = 13.35$  dB, and by Figures 7.2-3 and 7.2-4 for M=4 at  $E_b/N_0 = 10.61$  dB. The enormous amount of computer time required to obtain performance results for the clipper receiver at L=3 and the SNORM receiver for M=4 is beyond the scope of this study. Therefore, in some figures for comparison, these receivers are not represented. Explanations of the difficulties involved in such calculations were presented in the numerical results of Section 5 (clipper receiver) and Section 6 (SNORM receiver).

We can develop a performance ranking for these receivers with their respective parameter sets (M,L values) by assessing performances in the regions of strong, moderate, and weak jamming. These arbitrary regions are taken to mean the following: (1) strong jamming - usually full-band jamming with  $E_b/N_J$  values less than about 4 to 8 dB, (2) weak jamming - region of very small  $\gamma$  values with  $E_b/N_J$  usually greater than 35 to 40 dB, and (3) moderate jamming - area between strong and weak jamming.

For the case of M=2, L=2 (Figure 7.2-1), we find receiver performances asymptotically approaching two groups in the strong jamming region. These are (1) lower P(e): IC-AGC, ACJ-AGC, clipper, and SNORM; (2) higher P(e): hard-decision (HD), and square-law linear combining receiver (LCR). We observe that the first group is more effective due to their nonlinear weighting (normalization) schemes. In the second group, we have the LCR

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which provides no weighting and the HD receiver which is ineffective for L=2 because it is subject to the possibility of a tie (for L even) in the final quantized decision variable values. In strong jamming, all receivers are experiencing full-band jamming at high power levels and discriminating against a jammed hop is not done by any receiver since all hops are jammed. It is only when the optimum  $\gamma$  values begin to fall below full-band jamming that we realize the performance improvement of the nonlinear combining techniques. In the moderate jamming region, we see a sub-division among the receivers which we termed "effective" for strong jamming: (a) "ideal" receivers (AGC) and (b) "practical" receivers (clipper, SNORM). In this region we notice performance results for the nonlinear combining types remaining within about 1 dB of each other up until around the point where  $E_b/N_1 > E_b/N_0$ . That is, where thermal noise becomes more dominant than jamming noise. At these values, the SNORM and clipper receiver performances begin to degrade relative to the AGC types, yet still remain superior to the square-law LCR. We note the AGC receivers as maintaining a continuous and graceful transition in this moderate jamming region with the IC-AGC showing a slightly better performance. The worse performance for the ACJ-AGC is due to an imbalancing effect of the ACJ normalization scheme in which all receiver channels are inversely weighted by the largest of all the M channel noise powers. In contrast, the IC-AGC receiver normalizes each channel separately and thereby "balances" or "equalizes" the received noise powers.

The performance "breakaway" for  $N_0 > N_J$  for the clipper and SNORM receivers reflects the dominance of the "unbalanced symbol" error mechanism

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as Y becomes smaller; jamming in more than one M-ary channel becomes unlikely. In the case of the clipper, the receiver tends to limit the unbalancing contribution to the sum without affecting the signal channel sum. But for the SNORM receiver, any input noise power unbalance due to one channel being jammed reduces the signal channel sum. This is because the SNORM normalization weight is inversely proportional to the <u>total</u> noise power (i.e. sum of all M channels) measurement on a given hop without recognition of which individual channels are jammed.

In the weak or no jamming region, all receivers suffer degradation due to the noncoherent combining loss (NCL) when L>1. As  $E_b/N_J$  approaches 50 dB (practically no jamming), the different performances of the receivers in the Gaussian channel are evident. All receivers suffer degradation relative to the L=1 result (P(e) = 10<sup>-5</sup>) due to the NCL as Figure 7.2-1 demonstrates. We see that the SNORM and HD receivers are subject to higher NCL due, respectively, to inefficient combining and to the possibility of "tie votes" for M=2 and L=2, with the HD receiver being more severely affected because of its use of only two levels of quantization in the soft-decision.

Figure 7.2-2 compares receiver performances for the parameter set M=2, L=3. For strong jamming, we see a change in two groupings recognized for the case M=2, L=2. The HD receiver is now more effective than the square-law LCR, and provides a significant improvement in strong jamming. We attribute this to the fact that no ties exist in the majority logic decoding when L is odd. But in the weak or no jamming region the HD performance is worse than

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LCR due to quantization noise effects. We likewise note that in moderate jamming, the SNORM performance has improved somewhat over the results for M=2, L=2. It is reasoned that for L=3, the multiple unbalancing effects predominant for decreasing  $\gamma$  values begin to become less probable. Performance rankings in the thermal-noise-limited region for SNORM remain unchanged from the case of M=2, L=2.

The effect of an increase in alphabet size (M=4) can be discerned from Figures 7.2-3 and 7.2-4. Wf  $_{J''}$  ice that the parameter set M=4, L=2 (Figure 7.2-3) appears similar to the M=2, L=2 set where two distinct groupings are present in moderate jamming with the nonlinear combining soft-decision receiver group yielding superior performance. Considering the moderate jamming region to be from  $E_{b}/N_{J} = 5$  to 39 dB, we observe that the clipper and ACJ-AGC receivers trade rankings around the regional midpoint of 22 dB; the clipper receiver showing  $\leq 1$  dB better performance over the range of 5 to 17 dB. However, in strong jamming we find the clipper's performance degrading to the point of being the overall worst performer at  $E_{b}/N_{J} = 0$  dB. For the HD receiver, we find a worse performance than for M=2, L=2 because there are now two more channels allowing for the possibility of more tie decisions on the output decision variables.

In the case of M=4, L=3 (Figure 7.2-4), receiver performances appear similar to the behavior exhibited by the parameter set M=2, L=3 in that two distinguishable groups are presented. These are the AGC types (better performances) versus the square-law LCR and HD receivers. Throughout most of the strong and moderate jamming regions (2 to 35 dB), it is noticed that the ACJ-AGC performance is up to 2 dB worse than the IC-AGC; this again

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being due to the unbalancing effect of the normalization weighting scheme of the ACJ-AGC receiver. The difference between the two AGC performances for M=4 is larger than for M=2 (see Section 7.3 for more discussion of this phenomenon). As for the HD receiver, it proves to be better than the HD cases for L=2 yet exhibits poorer performance than HD for M=2, L=3. Although there are no output decision variable ties for L=3, the HD receiver with more channels will now suffer increased quantization effects in approximating the LCR.

With regard to receiver performances in little thermal noise, Figure 7.2-5 depicts performance results of three candidates (IC-AGC, ACJ-AGC, SNORM) for the parameter set M=2, L=2 at  $E_b/N_0 = 20$  dB. These receivers represent the previously shown most ideal performers (AGC types) and the more realizable SNORM receiver. The HD receiver, although a relatively simple ECCM diversity technique in practice, is not included in this comparative set due to the "tie" decision factor when L=2.

We observe for full-band jamming that the IC-AGC and ACJ-AGC receivers yield equivalent performances with the SNORM showing a slightly higher BER. Such behavior for the AGC receivers is to be expected in full-band jamming where a Gaussian channel performance is realized and discrimination against a jammed hop is nonexistent. But as  $\gamma$  becomes less than full-band, it is seen that the AGC receiver curves maintain the same negative slope for increasing  $E_b/N_J$  with the ACJ-AGC staying about 1 dB worse than the IC-AGC, this inferior performance being due to the previously described imbalancing effect of the ACJ-AGC normalization mechanism. For the SNORM receiver, we see its performance with respect to the AGC receivers as being: (1) about 0.5 dB

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worse in full-band jamming, (2) less than 1 dB better for  $\gamma < 1$  (at  $E_b/N_J \sim 10$  dB) up until  $E_b/N_J > E_b/N_0$ , and (3) more than either ACJ-AGC or IC-AGC from about 20 dB to the point where P(e) =  $10^{-5}$  is reached.

An empirical explanation of this phenomenon is obtained by comparing Figure 7.2-6 (IC-AGC) with Figure 7.2-7 (SNORM). These figures show each receiver's individual performance at  $E_b/N_0 = 20$  dB for ten different values of  $\gamma$  ranging from  $\gamma=0.001$  to  $\gamma=1.0$  or full-band jamming. We note for the AGC receiver (Figure 7.2-6) that  $\gamma=0.001$  and 0.002 curves produce P(e) <  $10^{-5}$ and thus do not appear on the performance plots. Upon observing the eight remaining  $\gamma$ -curves in these AGC plots, we see each of these P(e) curves contributing the same smooth behavior toward producing an optimum  $\gamma$ -curve result which is a straight line for  $\gamma < 1.0$ , that is, a slope equal to  $A/(E_b/N_J)^2$  where A is some constant defining the inverse-linear relationship existing between  $\gamma$  and available jamming power when  $E_b/N_0 = 20$  dB.

However, for the SNORM case we find performance curves for  $\gamma=0.005$  through  $\gamma=0.2$  exhibiting behavior resulting in an optimum  $\gamma$ -curve which is not constant; over these  $\gamma$  ranges the SNORM performance is superior to the IC-AGC receiver. The upper envelope of the curves at first is proportional to  $(E_b/N_J)^{-2}$ , then transitions to a dependence on  $(E_b/N_J)^{-1}$ . For infinite  $E_b/N_0$ , from [21] we expect the SNORM and IC-AGC BER's to be proportional to  $(E_b/N_J)^{-2}$  indefinitely; for L=3 and MFSK the SNORM in [21] is shown to be dependent on  $(E_b/N_J)^{-2}$  for no thermal noise, but the AGC is dependent on  $(E_b/N_J)^{-3}$ , as shown in Figure 7.2-8, taken from [21]. Therefore, the better performance of SNORM for high SNR is not to be expected in all cases of M and L. (See Section 7.3.3.5 for further discussion on the SNORM performance.)



FIGURE 7.2-6 BIT ERROR PROBABILITY VS. BIT ENERGY TO JAMMING NOISE DENSITY RATIO FOR IC-AGC RECEIVER IN WORST-CASE PARTIAL-BAND NOISE FOR M=2, L=2 AT  $E_b/N_0 = 20$  dB



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#### 7.3 COMPARISONS OF FH/RMFSK AND FH/MFSK

Having compared the performances of the various FH/RMFSK receivers in worst-case partial-band noise jamming (WCPBNJ), we now consider the differences in performance to be expected between the random hopping MFSK system studied in this report (FH/RMFSK) and the conventional (adjacent or contiguous) hopping MFSK system (FH/MFSK) studied, for example, in [1].

7.3.1 <u>The M=2</u>, <u>L=1 Case</u>

It was found by Blanchard [6] that for M=2 and L=1 the two systems yield the same performance, at least for the  $E_b/N_0$  = 30 dB case he studied, with the differences in possible jamming events accounted for by different optimum values of  $\gamma$ , the fraction of the system bandwidth which is jammed. (Typically, for high  $E_b/N_J$  the RMFSK  $\gamma_{opt}$  was found to be half that for MFSK.) Figure 7.3-1 displays the cases Blanchard considered, except that we use  $E_b/N_0$  = 13.35 dB, corresponding to a 10<sup>-5</sup> BER with no jamming. Our results indicate that the two systems do indeed perform the same for M=2 and L=1, except for certain differences for weak jamming (high  $E_b/N_J$ ). What is the significance of the differences we observe in these computed results?

Curve A in Figure 7.3-1 is from [1] and represents the quantity

$$\max_{D < \gamma \leq 1} \left[ \frac{1}{2} (1 - \gamma) e^{-E_{b}/2N_{0}} + \frac{1}{2} \gamma e^{-E_{b}/2N_{T}} \right], \qquad (7.3-1a)$$

where

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$$\frac{E_{b}}{N_{T}} = \frac{\frac{E_{b}}{N_{0}} \cdot \frac{\gamma E_{b}}{N_{J}}}{\frac{E_{b}}{N_{0}} + \frac{\gamma E_{b}}{N_{J}}} .$$
(7.3-1b)



In this formulation for the binary case it is assumed that both slots are either jammed (with probability  $\gamma$ ) or unjammed (with probability  $1-\gamma$ ).

Curve B represents the quantity

$$\max_{1 \le q \le N} \left[ \frac{1}{2} p_0 e^{-E_b/2N_0} + \frac{1}{2} p_1 e^{-E_b/2N_T} \right],$$
(7.3-2a)

where

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$$p_1 = 1 - q/N = 1 - p_0$$
 (7.3-2b)

This formulation assumes that  $\gamma = q/N$  is quantized - a discrete number (q) of the total number slots (N) are jammed, with the minimum  $\gamma$  equal to 1/N. It further assumes that the system is FH/RMFSK with IC-AGC processing; a more explicit form of the error expression is

$$P(e;q) = (\pi_0 + \pi_1) \cdot \frac{1}{2} e^{-E_b/2N_0} + (\pi_1 + \pi_2) \cdot \frac{1}{2} e^{-E_b/2N_T}, \qquad (7.3-3)$$

where

$$\pi_r = \text{prob. that } r \text{ slots are jammed},$$
 (7.3-4a)

and

$$\pi_0 = \frac{N-q}{N} \cdot \frac{N-q-1}{N-1}$$
(7.3-4b)

$$\pi_1 = \frac{N-q}{N_1} \cdot \frac{q}{N-1}$$
(7.3-4c)

$$\pi_2 = \frac{q}{N} \cdot \frac{q-1}{N-1}$$
 (7.3-4d)

Because of the individual channel normalization, the conditional BER depends only on whether the signal channel is jammed. Thus here are only two terms, with weights  $p_0 = \pi_0 + \pi_1$  and  $p_1 = \pi_1 + \pi_2$ .

Now, the only difference between (7.3-2) and (7.3-1) is the quantization and minimum value of  $\gamma = \frac{q}{N}$ . Therefore in Figure 7.3-1 we identify curve B also with binary FH/MFSK, even though q = 1 violates the assumption that both channels are together jammed or unjammed.

Curve C in Figure 7.3-1 represents the quantity

$$\max_{1 \le q \le N} \left[ \pi_0 \cdot \frac{1}{2} e^{-E_b/2N_0} + \pi_1 \cdot e^{-(E_b/N_0)/(K+1)} + \pi_2 \cdot \frac{1}{2} e^{-E_b/2N_T} \right], \quad (7.3-5a)$$

where

$$K = \sigma_{T}^{2}/\sigma_{N}^{2} = (E_{b}/N_{0})/(E_{b}/N_{T}). \qquad (7.3-5b)$$

This is the BER for all the FH/RMFSK receivers except the IC-AGC, and allows for only one of the two channels to be jammed.

Thus, in general, our results agree with Blanchard's conclusion that FH/RMFSK performs the same as FH/MFSK for M=2 and L=1, neglecting small asymptotic differences connected with assumptions on the quantization and minimum value of  $\gamma$ . Now we consider whether his conjecture that the two hopping systems perform the same for M>2 and L=1 is correct, and how the comparison is affected by L>1. In what follows, we shall use the fact that the IC-AGC FH/RMFSK receiver performs essentially the same as the AGC FH/MFSK receiver.

7.3.2 L=1 with Alphabet Size Varied.

In order to compare RMFSK and MFSK for L=1 and M>1, it is sufficient to consider Figures 7.3-2 and 7.3-3.

In Figure 7.3-2 the performances of the FH/MFSK and the IC-AGC FH/RMFSK receivers are shown for L=1 and M=2,4,8. The values of  $E_b/N_0$  used were chosen



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to give each example a  $10^{-5}$  BER under no jamming. We observe from these results that for these systems the BER decreases as the alphabet size M increases, the conventional interpretation of which is that an "M-ary coding gain" is at work. This is the phenomenon usually observed for MFSK systems in the Gaussian interference channel.

In Figure 7.3-3 the same parameters are used as in Figure 7.3-2, but now the receivers are the FH/RMFSK receivers (except IC-AGC), which have identical performance for L=1. For these receivers we find that for strong jamming the system performance does not consistently improve as M increases, but instead improves very slightly for M=4 and degrades for M=8. Clearly this is the result of the increased probability, as M increases, of the most damaging jamming event: jamming power in a non-signal slot but not in the signal slot. Since the M=2 performances in the two figures are virtually the same, we conclude that FH/RMFSK is consistently more vulnerable to WCPBNJ than is FH/MFSK for M>2. The difference is about 3 dB for M=4 and 5 to 6 dB for M=8.

When the jamming is weak, we expect the relative performances for different M to approach the usual non-jammed behavior, and this is observable in Figure 7.3-3 for  $E_b/N_1 > 34$  dB.

7.3.3 Cases Where L>1 Hop/Symbol

Since the various FH/RMFSK receivers and their FH/MFSK counterparts begin to exhibit different performances when diversity is used (L>1), it is necessary to consider them separately. Most of the FH/MFSK results are taken
from [1]; however, when convenient we shall continue to utilize the fact that IC-AGC FH/RMFSK receiver performs essentially the same as the AGC FH/MFSK receiver.

7.3.3.1 Linear Combining Receiver.

We begin by comparing the performance of the square-law linear combining receiver for both FH/RMFSK and RH/MFSK signalling strategies. Figures 7.3-4 and 7.3-5 show these performances for M=2, L=2 and M=4, L=2 respectively. In usth figures, it is apparent that MFSK is superior to RMFSK, ignoring the effects of the different minimum  $\gamma$  value used in the computations. This vulnerability of RMFSK can be attributed to what we term the "unbalancing" error mechanism inherent in partial-band jamming of RMFSK. Specifically, the random placement of M-ary slots over the hopping bandwidth W allows more chance for a jamming hit than does a block-hopping MFSK signal where it is assumed that either all M slots will be jammed or unjammed. This probability increases for greater values of M as evidenced by Figure 7.3-5.

7.3.3.2 AGC receivers.

Comparisons for L>1 among the AGC-type nonlinear combining receiers are exhibited in Figures 7.3-6 to 7.3-9. Recalling that RMFSK and MFSK hopping systems perform virtually the same for M=2 and L=1, it is instructive to observe in Figures 7.3-6 and 7.3-7 that the system performances differ by about 1 dB when L=2 or L=3. The approximately 3 dB difference noted for M=4 and L=1 continues to hold for M=4 and L=2 or 3, as shown in Figures 7.3-8 and 7.3-9.

7.3.3.3 Clipper receiver.

A very interesting consideration is brought to light by Figure 7.3-1 which shows the clipper receiver's FH/RMFSK performance for L=2 and several values of M. It was found analytically in Section 5 that the optimum clipping





FIGURE 7.3-5 COMPARISON OF SQUARE-LAW LINEAR COMBINING RECEIVERS FOR FH/MFSK AND FH/RMFSK WITH M=4 AND L=2 HOPS/SYMBOL WHEN  $E_b/N_0 = 10.60657$  dB



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FIGURE 7.3-7 COMPARISON OF AGC RECEIVERS FOR FH/MFSK AND FH/RMFSK WITH M=2 AND L=3 HOPS/SYMBOL WHEN  $E_b/N_0$  = 13.35247 dB





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FIGURE 7.3-9 COMPARISON OF AGC RECEIVERS FOR FH/MFSK AND FH/RMFSK WITH M=4 AND L=3 HOPS/SYMBOL WHEN  $E_b/N_0 = 10.60657 \text{ dB}$ 



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threshold for L=1 is infinite (no clipping), whereas numerically it was determined that a finite threshold is optimum for L>1. Consequently, the L=1 "clipper" receiver is not a clipping receiver at all but one identical in operation to all the other RMFSK receivers for L=1 except IC-AGC, and its FH/RMFSK performance tends to get worse for increasing M as demonstrated previously in Figure 7.3.3. However, for L=2 we observe from Figure 7.3-10 that the clipper is performing in a manner similar to the IC-AGC, in that increasing M from 2 to 4 reduces the BER; however further increase to M=8 degrades performance. The reason for this similarity in behavior is that the clipper receiver, like the IC-AGC, operates to limit jamming input to the soft decision on an individual channel basis. The clipper is in this sense a crude version of the IC-AGC; but for higher values of M the losses become significant and the performance trend resembles the other RMFSK receivers more than the IC-AGC receiver. We then would expect clipping to be advantageous against jamming for L=1 as well; but the threshold was optimized for no jamming in order to avoid requiring the receiver to know or measure jamming parameters. If the threshold were jamming-dependent, the clipper receiver might follow the IC-AGC more closely for higher M. The tendency of the clipper receiver to "emulate" the IC-AGC was observed earlier in Figure 7.2-3, where we see that this tendency is more pronounced for strong jamming.

7.3.3.4 Hard-decision receiver.

Now if the clipper receiver can be thought of as a crude version of the IC-AGC, the hard-decision (HD) receiver can be considered a crude version of the ACJ-AGC because both act to limit or de-emphasize the entire set of M channels on a jammed hop, rather than operating on the channels separately.

Thus we observe in Figure 7.3-11 the tendency for the HD receiver's BER to increase with M (after M>4) in strong jamming, just like the ACJ-AGC receiver's BER, and thereby to yield a worse performance for RMFSK than for MFSK. In weak or no jamming, the HD's BER for L>1 gets worse for increasing M (unlike the other, soft-decision receivers) because noncoherent combining losses are in effect amplified by the quantization the HD uses.

7.3.3.5 Self-normalizing receiver.

In the previous examples, we have observed a consistent trend for RMFSK hopping to yield no better--and sometimes worse--performance than conventional MFSK hopping. This was explained as being due to the possibility of jamming being present in a non-signal channel but not in the signal channel for RMFSK but not for MFSK. It is also true that using RMFSK there can be jamming only in the signal channel, which tends to favor a correct decision. Apparently, using the LCR, AGC, clipper, and HD receivers, the jamming of one channel has a net effect of degrading the system performance for L>1.

Now, we consider the comparison of RMFSK with MFSK using the self-normalizing receiver, and will see an exception to the trend previously observed. Figure 7.3-12 displays the SNORM error performances for FH/RMFSK and RH/MFSK in WCPBNJ for M=L=2 and  $E_b/N_0 = 13.35$  dB and 20 dB. We see that the BER for RMFSK is better than for MFSK. This behavior seems to be connected with the jamming events in which both channels are either jammed or unjammed on a given hop, rather than those for which only one channel is jammed. This statement is supported by the fact that (1) the curves are roughly parallel for moderate-to-weak jamming (the portion of



FIGURE 7.3-11 ERROR PERFORMANCE FOR HARD SYMBOL DECISION FH/RMFSK RECEIVER IN WORST-CA: PARTIAL-BAND NOISE JAMMING WHEN L=3 HOPS/SYMBOL; M=2,4,8; AND  $E_b/N_0$  GIVE: 10<sup>-5</sup> ERROR WITHOUT JAMMING WHEN L=1



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the curve proportional to  $e^{-E_b/N_J}$ , and (2) the MFSK receiver is subject only to those particular jamming events, by assumption. The advantage of RMFSK, according to this interpretation, then lies in the smaller probability of both channels being jammed on a given hop.

Now if M were increased to M=4 or M=8, it would be expected that the effects of jamming in one channel only would tend to increase the RMFSK error, since then a damaging effect would be M-1 times as likely as a helping effect.

On the other hand, the improvement of the RMFSK error over that of MFSK can be explained in terms of how the SNORM receiver processes the jamming events for which only one channel is jammed, in contrast to the way the other RMFSK receivers process the events. When only the non-signal channel is jammed the hop statistics are (K =  $\sigma_T^2/\sigma_N^2 \gg 1$ )

$$z_{1k} = \frac{\chi^2(2,2\rho_N)}{\chi^2(2,2\rho_N) + K\chi^2(2)} \to 0$$
 (7.3-6a)

$$z_{2k} = \frac{K\chi^2(2)}{\chi^2(2,2\rho_N) + K\chi^2(2)} \rightarrow 1.$$
 (7.3-6b)

But when only the signal channel is jammed,

$$z_{1k} = \frac{K_{\chi^2}(2, 2\rho_T)}{K_{\chi^2}(2, 2\rho_T) + \chi^2(2)} \rightarrow 1$$
 (7.3-7a)

$$z_{2k} = \frac{\chi^2(2)}{K\chi^2(2,2\rho_T) + \chi^2(2)} \neq 0.$$
 (7.3-7b)

That is, the SNORM per-hop processing is nearly equivalent to a hard symbol decision; the signal channel suppresses the nonsignal channel when the signal is jammed, but if the nonsignal channel is jammed, it is awarded a value of at most 1. Thus the receiver de-emphasizes jammed hops while at the same time distinguishing between "good" and "bad" jammed hops. The

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IC-AGC receiver, by contrast, penalizes the channel being jammed by normalizing its noise to the same variance as the other channel; this has the effect of suppressing the jammed channel when only one is jammed. This is a good thing to do when the non-signal channel is jammed; but it is not beneficial when the signal channel is jammed.

According to this second interpretation of the results the SNORM performance for RMFSK is better because it makes good use of the "favorable" jamming events, which do not occur for MFSK. However, we still would expect the RMFSK performance to degrade for higher M under this interpretation.

#### 7.4 COMPARISON OF RECEIVER DIVERSITY EFFECTS

The FH/RMFSK receivers we have studied are distinguished by their methods of combining the L hops transmitted per MFSK symbol. The objective of the diversity transmission is to spread the signal on a symbol basis, making it less likely that the symbol is jammed for the entirety of its duration. The L pieces of the symbol transmission are then sequentially acquired noncoherently and accumulated after weighting or otherwise processing them individually. Since the combining is done noncoherently, the performance of the system without jamming or with full-band jamming (Gaussian channel) necessarily is degraded from that using one hop with same signal energy. However, when the system bandwidth is jammed partially, giving rise to a type of non-Gaussian interference channel, the system performance is improved using diversity, provided that the hop processing in some fashion limits or discriminates against those hops which are jammed.

The conventional diversity receiver for MFSK, which we have termed the linear combining square-law receiver (LCR), is known to be effective against signal fading, that is, when there exists a random-amplitude signal in a Gaussian channel. But against partial-band noise jamming (PBNJ), the LCR is not effective since jammed hops are not de-emphasized. Figure 7.4-1 illustrates for M=2 that LCR performance degrades in proportion to L.

One view of the individual-channel adaptive gain control receiver (IC-AGC), which normalizes each square-law detector sample by its <u>a priori</u> noise variance, is that it in effect renders the non-Gaussian PBNJ interference into a Gaussian interference with unit variance in each MFSK slot. The residual



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effect of the jamming after normalization is to reduce the SNR in the MFSK signal channel or slot by an amount which depends upon the random event of that channel's being jammed on  $\ell_1$  of the L hops. Because the amount of reduction is inversely proportional to  $\gamma$ , the fraction of the system bandwidth which is jammed, while the probability of jamming is directly proportional to  $\gamma$ , there exists an optimum value of  $\gamma$  which maximizes the system error probability as a function of available jamming power; generally  $\gamma_{opt} = const_1/(E_b/N_J) = const_2 \cdot J$ , that is, the optimum value of  $\gamma$  is directly proportional to jamming power, and for sufficient jammer power full-band jamming ( $\gamma$ =1) is optimum.

It is possible to reason without analysis that the IC-AGC receiver performs better than the LCR because, while the two receivers are subject to the same SNR degradation, the IC-AGC in effect "matches" the accumulator structure (soft-decision) to the channel. However, it is difficult to predict how any improvement would depend upon L, and whether an optimum value of L exists. Thus the analysis and computations of IC-AGC performance have been quite revealing. For example, Figure 7.4-2 shows that there is a tendency for increasing L to improve the IC-AGC performance for increasing  $E_b/N_J$ , but this tendency is by no means uniform for the value of  $E_b/N_0$  shown. Figure 7.4-3 shows the IC-AGC performance which would be obtained if the best value of L were always used. This figure reveals that the effectiveness of the diversity depends on the degree of thermal noise present; when  $N_0$  is not negligible, increasing L eventually gives rice to noncoherent combining losses which overcome the gains from diversity.





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It is important to keep in mind that the performance in jamming can never be better than that without jamming, and that without jamming the best performance is for L=1. Therefore "optimum diversity" values may increase with  $E_b/N_J$ , but must eventually decrease again to L=1 as  $E_b/N_J \rightarrow \infty$  (no jamming). However, as the figure demonstrates, for a desired performance of, say  $10^{-5}$ , the optimum diversity value can be greater than one if the unjammed error is much smaller.

Examples of diversity effects for the "any channel jammed" receiver (ACJ) and the self-normalizing receiver are given by Figures 7.4-4 and 7.4-5. We observe that these receivers, in that their normalization techniques "approximate" that of the IC-AGC, achieve similar diversity gain effects.

Two of the receivers studied, the clipper and hard-symbol decision (HD) receivers, do not utilize normalization as such, yet accomplish a diversity gain effect by limiting the "contamination" that a jammed hop may bring to the symbol decision. It has noted previously that the clipper receiver's performance generally is close to that of the ACJ for stronger jamming, but that the HD receiver is considerably worse for the same amount of thermal noise. However, as Figure 7.4-6 shows, even this very simple HD approach can be considered effective in the diversity sense when thermal noise is low.





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FIGURE 7.4-6 OPTIMUM DIVERSITY PERFORMANCE OF HARD DECISION RECEIVER FOR FH/RMFSK WITH M=2

#### 8.0 ECCM RECEIVER IMPLEMENTATION STUDIES

In the previous sections, we analyzed the BER performance of various ECCM receiver processing schemes for uncoded FH/RMFSK radio systems in the presence of worst-case partial-band noise jamming (PBNJ).

Our objective has been to provide a comparison of these different systems, which vary extensively in their implementation complexities. These results will enable the ECCM system designer to weigh the engineering cost requirements of a particular receiver design versus the anti-jam effectiveness. Toward this end, we now explore practical issues related to the implementation of these different processing schemes along with an assessment of implementation effects.

#### 3.1 IMPLEMENTATION ISSUES AND CONCEPTS

All receivers suppress the total noise jamming power by an amount equivalent to the system processing gain, defined as the ratio of the jammer bandwidth to the receiver bandwidth. Hopping the signal forces the jammer to spread its power over a wide bandwidth, but the jammer can maximize its effectiveness by selecting an optimum bandwidth, which is a certain fraction ( $\gamma$ ) of the total hopping system bandwidth (W). This results in a BER which tends to be an inverse linear function of  $E_b/N_J$ , so that more than 40 dB of  $E_b/N_J$  is required to obtain BER's less than 10<sup>-4</sup>. ECCM FH/MFSK and FH/MFSK systems counter this effect by using multiple hops per symbol, with the L hops per symbol combined at the receiver as in diversity transmission schemes.

We have demonstrated that effective jammer suppression is obtained by incorporating a nonlinear function in each M-ary channel prior to combining. The improvement in BER performance is realized by the fact that within a PBNJ environment, the nonlinear techniques (clipper, AGC, hard-decision, SNORM) mitigate the tendency of a jammed hop to dominate the symbol decision. Of these nonlinear

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techniques we have studied, it was assumed that certain <u>a priori</u> information or perfect measurements are available to the clipper (SNR threshold) and AGC (noise powers) schemes; no such measuring tactics are necessary for the harddecision or SNORM receivers. In what follows, we investigate the practicalities concerning the implementation and impact of non-ideal noise power measurements and threshold settings.

#### 8.1.1 ECCM Receiver Information Requirements

In Table 8.1-1 we summarize the ECCM techniques used by the various receivers we have studied, including the information necessary for their implementation. The square-law linear combining receiver is presented as a base-line for comparison with the other, nonlinear combining types. Our specific interest here is to address the feasibility of implementation.

In the table, the nonlinear combining receivers are classified according to whether their anti-jam measures operate on a per-symbol basis (across all M channels) or on a per-channel basis. The per-symbol ECCM receivers include the ACJ-AGC, the hard-decision, and the SNORM receivers. Of these, the ACJ-AGC is seen as the only type utilizing <u>a priori</u> information on the received noise (thermal plus jamming), since it weights all channels on a given hop by

$$w_{mk} = w_{k} = \begin{cases} (\sigma_{N}^{2})^{-1}, \text{ no channels jammed on hop k} \\ (\sigma_{N}^{2})^{-2}, \text{ any channel jammed on hop k} \end{cases}$$

$$\begin{bmatrix} \max_{m} \left( \frac{2}{mk} \right) \end{bmatrix}^{-1}.$$
(8.1-1)

TABLE 8.1-1 SUMMARY OF ECCM TECHNIQUES FOR THE RECEIVERS STUDIED

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RECEIVER(S) EXTENT OF HOP WEIGHTING

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INFORMATION	REQUIRED

None

None

Max{o<sup>2</sup>mk} m

Scale Down Jammed Hops (Normalize Max Variance to 1)

Any-Channel-Jammed AGC (ACJ-AGC)

Per-Symbol

TECHNIQUE
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None

Linear Combining

 $\sigma_N^2$  and  $E_b/N_0$  (t.) Set Value of n) a<sup>ر</sup> م علام None None (Normalize All Variances to 1) Scale Down Jammed Hops (Normalize Channel Sum to 1) Scale Down Jammed Channels Limit Each Channel to Max Value of n Limit Hops to One Vote Hard-Symbol Decision Self-Normalizing (SNORM)

\*Notes: (1) Hops numbered by k (k=1,2,...,L) and channels numbered by m (m=1,2,...,M)

Clipper

Per-Channel

- (2)  $\sigma_{mk}^2$  is the <u>a</u> priori variance of the total noise present in channel m at time k
- be interpreted as knowing whether a channel is jammed (IC-AGC) or a symbol is jammed (ACJ-AGC) (3) Since  $\sigma_{mk}^{2}$  is assumed to be either  $\sigma_{N}^{2}$  (unjammed) or  $\sigma_{T}^{2}$  (jammed), "information required" may

Therefore, the information required is  $w_k^{-1} = \max_{m} (\sigma_{mk}^2)$ , which involves knowing  $\sigma_N^2, \sigma_T^2$ , and whether any of the M channels is jammed. As a minimum, the ACJ receiver needs to know the  $\frac{\text{ratio}}{m} \max(\sigma_{mk}^2)/\sigma_N^2$ , since the operation of the receiver is unaffected if unjammed hops are left-alone (weight = 1) and jammed hops are reduced by the factor  $\sigma_N^2/\sigma_T^2$ .

The hard-decision receiver is classified as a per-symbol ECCM receiver because, as we have observed in previous sections, its operation in effect limits each symbol piece (hop) to one vote in the M-ary majority logic decision, no matter how strongly a hop may have been jammed. Its operation does not require any <u>a priori</u> information or measurement.

The SNORM receiver derives its per-symbol weights from the M square-law envelope detector samples themselves:

$$w_{k} = \left(\sum_{m} x_{mk}^{2}\right)^{-1}$$
 (8.1-2)

Therefore, it does not require <u>a priori</u> information or additional measurements in its operation.

The per-channel ECCM receivers include the IC-AGC and the clipper receivers, and both utilize <u>a priori</u> information. The IC-AGC weights each channel sample by the inverse of its <u>a priori</u> noise variance:

$$w_{mk} = (\sigma_{mk}^2)^{-1}$$
 (8.1-3)

In this manner, all channels on all hops are normalized to have unit noise variance; any channels which are jammed  $(\sigma_{mk}^2 = \sigma_T^2)$  are therefore suppressed. This technique involves knowing  $\sigma_N^2$ ,  $\sigma_T^2$ , and the jamming state or condition

of each channel. Alternately, the ratios  $\sigma_{mk}^2/\sigma_N^2$  are needed, as a minimum.

The clipper receiver achieves an ECCM effect by "containing" any jammed channels; their contribution to the soft-decision sums cannot be any larger than the clipping threshold (n), no matter how strongly jammed. In order to set the threshold, both  $\sigma_N^2$  and  $E_b/N_0$  <u>a priori</u> values are needed since  $n = n(\sigma_N^2, E_b/N_0)$  is chosen to minimize the error without jamming.

With respect to the additional receiver complexity required to develop information needed by the suppression technique, only the AGC schemes (jamming decision and normalization weights) and clipper (SNR levels) receivers need be addressed.

#### 8.1.2 Measurement Approaches.

Implementation of the two AGC schemes requires differentiation between two zero-mean bandpass Gaussian noise processes with different variances which determine a jammed/unjammed channel state. In addition, to be useful as a quantity for a normalization weight in an AGC scheme, our measurement (noise-power estimate) must reflect as closely as possible in real-time the actual system state of the measured channel. This leads us to consider factors in both time and frequency domain representations of our measuring technique, i.e. the accuracy or quality of a band-limited channel noise-power measurement.

It is assumed throughout the measurement process that the data measures are sample records from a continuous stationary random process. Letting x(t) be a single sample time history record from a zero-mean stationary (ergodic) Gaussian random process  $\{x(t)\}$ , the mean-square value (variance) of  $\{x(t)\}$  can be estimated by time-averaging over a finite time interval  $\tau$  as

$$\hat{\sigma}_{X}^{2} = \frac{1}{\tau} \int_{0}^{\tau} x^{2}(t) dt$$
 (8.1-4)

with the true mean-square value being

$$\sigma_{\mathbf{x}}^2 = \mathbf{E} \left[ \mathbf{x}^2(\mathbf{t}) \right]$$
 (8.1-5)

and is independent of t since  $\{x(t)\}$  is stationary. Now the expected value of the estimate of  $\sigma_x^2$  is

$$E[\hat{\sigma}_{X}^{2}] = \frac{1}{\tau} \int_{0}^{\tau} E[x^{2}(t)] dt = \frac{1}{\tau} \int_{0}^{\tau} \sigma_{X}^{2} dt = \sigma_{X}^{2}. \qquad (8.1-6)$$

Thus,  $\hat{\sigma}_{\textbf{X}}^2$  is an unbiased estimate of  $\sigma_{\textbf{X}}^2,$  independent of  $\tau.$ 

Regarding the quality of measurement, it is shown [19, p. 176] that the variance of a mean-square value estimate of band-limited white Gaussian noise with zero mean is

$$\operatorname{Var}[\hat{\sigma}_{X}^{2}] \simeq \frac{\sigma_{X}^{2}}{B_{T}}$$
 (8.1-7)

Hence, we clearly see the inverse relationship of accuracy of our measurement to the measured channel time-bandwidth product; that is, for  $B_T \rightarrow \infty$  we would realize a "perfect" noise measurement.

8.1.2.1 A look-ahead measurement scheme.

Since the optimum power estimator uses a square-law detector [18] one could obtain a workable noise-power estimate by measuring the next slot to be hopped into by all M-ary channels; such a "look-ahead" scheme is illustrated in Figures 8.1-1 and 8.1-2.

Figure 8.1-1 shows the first part of the scheme in which we obtain the look-ahead receiver samples. Here we allow the receiver channel codesynchronized PN sequence generators to be delayed by one hop period  $(\tau)$  in relationship to the respective measurement channel synchronization. In this manner we obtain the look-ahead samples at hop time k for use with



FIGURE 8.1-1 ACQUISITION OF JAMMING STATE DATA BY A "LOOK-AHEAD" SCHEME

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the usual communicator receiver samples to be gathered at time k+1. We note that the look-ahead samples are assumed to be values of either  $\sigma_N^2$  or  $\sigma_T^2$  and that any type of spectral interference from other hoppers in the network is nonexistent. Also, this first part (Figure 8.1-1) of the look-ahead operation is the same for both IC- and ACJ-AGC receiver types.

In Figure 8.1-2 we show the use of the M-channel look-ahead measurements to derive the proper normalization weights. Thus, at time k+1 we obtain the following variables for accumulating in the L-hop diversity combining state for each of the M channels:

$$z_{mk} = x_{mk}^{2} \cdot \left[ \max_{m} \left( \hat{\sigma}_{mk}^{2} \right) \right]^{-1}, \text{ for ACJ}$$
(8.1-8)

$$z_{mk} = x_{mk}^2 \cdot (\hat{\sigma}_{mk}^2)^{-1}$$
, for IC. (8.1-9)

Additionally, the weight computation network could incorporate a multi-hop/multi-channel processing stage (see Figure 8.1-3) to determine jamming state information (JSI) based upon multiple look-ahead measurements. Should the channel be jammed, we then have a one-sample estimate of the noise plus jamming power  $\hat{\sigma}_{1}^{2}$ . If unjammed, we obtain  $\hat{\sigma}_{N}^{2}$  which is a one-sample measure of the channel's thermal noise power. The additional processing envisions each channel estimate  $\hat{\sigma}_{N}^{2}$  as going into a smoothing operation, which would then output the improved  $\sigma_{N}^{2}$  and  $\sigma_{1}^{2}$  estimates. These values in turn are fed back to the jammed/unjammed decision blocks in the form of the detection threshold. The use of multiple-hop/multiple-channel measurements improves the quality of the noise power estimates by increasing the BT product in (8.1-7). Details involved in both the jamming state detection and data smoothing of estimates are discussed later in this section.



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8.1.2.2 In-band measurement schemes.

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One in-band measurement scheme assumes that  $\hat{\sigma}_N^2$  and  $\hat{\sigma}_T^2$  are to be measured between signal transmission times over the frequency-hopping bandwidth W. That is, a measurement process takes place during the communications "link idle" state, enabling the gathering of measurement samples over many hop periods. This procedure avoids the system complexity required by the lookahead scheme, and is subject to the same caveats regarding stationarity of the noise (thermal, background, and jamming) environment across the hopping system bandwidth, as well as the corruption of purely noise estimates by the activity of other communications users during measurement intervals.

Receiver frame synchronization information or message preamble data could be used to decide when to cease or start taking measurement data samples. In concept, these measurements would enable high quality estimates of  $\sigma_N^2$  and  $\sigma_T^2$  to be developed, and/or perhaps even a stored estimate of the received noise power as a function of frequency.

Now, in order to detect the presence of jamming or to set the clipper's optimized threshold, we require knowledge of the received (average) thermal noise power  $\sigma_N^2 = N_0 B$ , where  $N_0$  is the noise density in watts per hertz, assumed to be independent of frequency, and B is the channel bandwidth. In concept, an independent channel noise-power measurement system could be used to take several simultaneous measurements uniformly distributed within the thermal-noise-only (unjammed) portion of the hopping band W. The arithmetic average of these measurements would then be the estimate  $\hat{\sigma}_N^2$ . Assuming that  $\sigma_N^2$  varies slowly, if at all, we would continuously correct the long-term moving average of  $\hat{\sigma}_N^2$ ;

that is, a type of smoothing operation in which the processing scheme uses all measurements between times 0 and T to estimate the state of a system at a time t, where 0<t<T. This smoothed estimate of  $\sigma_N^2$  over the time interval 0 and T can be denoted by  $\underline{\sigma}_N^2(t|T)$ . Specifically, we envision a fixed-lag smoother in which a running smoothing solution lags the most recent measurement by a constant time delay  $\Delta$  and is denoted as  $\hat{\sigma}_N^2(T-\Delta|T)$ . A reasonable value of  $\Delta$  would be equal to the time for one symbol transmission.

Figure 8.1-4 illustrates a conceptual in-band measurement approach for the AGC type FH/RMFSK receivers. There are two modes: (a) between signal transmissions and (b) during signal transmissions. Between transmissions, the receiver continues to operate its synthesizers, detectors, and samplers to gather data for estimates of  $\sigma_N^2$  and  $\sigma_T^2$ , as mentioned above. During transmissions, jamming detection at the channel level (threshold  $n_{ch}$ ) or symbol level (threshold  $n_{sym}$ ) would furnish jamming state information (JSI) for selection of AGC weights, using thresholds based on the estimates of  $\sigma_N^2$ and  $\sigma_T^2$ . Possibly the samples received during transmissions could be used also for the variance estimation by feeding back the symbol decision to identify the channel with the signal, as suggested in the diagram.

With respect to the clipper receiver, Figure 8.1-5 depicts a scheme for setting the optimized clipping threshold  $n_0$ . Toward this end, we need to obtain a current estimate of the clipper receiver's SNR. Similar to the previously described two-mode in-band noise-power measurement concept for the AGC receivers, an individual channel measurement system would likewise be used to estimate the received signal power S. Several measurements would be taken



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of the received signal plus thermal noise within the unjammed portion of the hopping band W, using symbol decision feedback to identify the signal channel. The arithmetic average of these measurements forms an estimate of signal plus noise power,  $\hat{P}_{sn}$ . This estimate could also be refined by a fixed-lag (per-symbol) smoothing operation. Hence, we would obtain

$$\hat{\rho}_{N} = \frac{\hat{S}}{\hat{\sigma}_{N}^{2}} = \frac{\hat{P}_{Sn}}{\hat{\sigma}_{N}^{2}} - 1 = \frac{K}{L} \cdot \frac{\widehat{E}_{b}}{N_{0}} , \qquad (8.1-10)$$

the signal-to-noise ratio for a given hop dwell time, to be updated on a per-symbol basis.

Table 5.3-1 showed a summary of the clipper receiver values of  $n_0$  for a given L, M, and  $E_b/N_0$ . Note that these numeric values were obtained only for values of  $E_b/N_0$  such that  $P_b(e) = 10^{-5}$  for two MFSK systems in the absence of jamming. We point out that, in practice, new values of  $n_0$  need to be computed for each different value of  $E_b/N_0$ . Therefore the actual clipper receiver would require that matrices of  $n_0$  values be stored in a read-only memory (ROM) look-up table.

#### 8.1.3 Jamming State Decisions.

Implementation of a jamming state decision scheme would be based upon the following assumptions: (1) that a look-ahead or in-band measurement scheme is utilized, and (2) that the noise power estimates of  $\hat{\sigma}_N^2$  and  $\hat{\sigma}_T^2$ are readily available in time. Ultimately, the criterion for making a jammed/ unjammed state detection is predicated upon a single observation (per channel) or a multiple observation (per symbol). The ACJ-AGC receiver requires detection of a jammed symbol hop whereas the IC-AGC requires detection of jamming in each of the M channels on each hop.

In both the symbol and the channel cases, the problem is one of deciding between Gaussian noise with variance  $\sigma_N^2$  and Gaussian noise with variance  $\sigma_1^2$ . Due to the lack of <u>a priori</u> jamming probabilities ( $\gamma$ ) or cost functions, we utilize the Neyman-Pearson criterion as our hypothesis testing technique. Its test objective is to maximize the probability of detection (P<sub>D</sub>) for a given probability of false alarm ( $\alpha$ ) and is accomplished by employing a likelihood ratio test.

8.1.3.1 Jammed channel detection.

A basic problem in determining a jammed/unjammed state with an individual channel look-ahead scheme is in accounting for the signal itself. Recalling that the look-ahead measurement channel is one hop period "ahead" of the normal receiver channel, the situation can arise in which the measurement channel is actually the present signal channel. However, we first analyze the case for a measured channel without a signal present.

Using the narrowband Gaussian process representation for the channel samples, the hypotheses to be considered are

$$H_{0}: p(\underline{n}_{c}, \underline{n}_{s}) = \frac{1}{2\pi\sigma_{N}^{2}} \exp\left\{-\frac{n_{c}^{2}+n_{s}^{2}}{2\sigma_{N}^{2}}\right\}$$
(3.1-11)

$$H_{1}: p(\underline{n}_{c}, \underline{n}_{s}) = \frac{1}{2\pi\sigma_{T}^{2}} \exp\left\{-\frac{n_{c}^{2}+n_{s}^{2}}{2\sigma_{T}^{2}}\right\}$$
(8.1-12)

where  $H_0$  is the unjammed case and  $H_1$  is the jammed case. For the likelihood ratio we obtain

$$\Lambda = \frac{\sigma_{N}^{2}}{\sigma_{T}^{2}} \exp \left\{ -\frac{(n_{c}^{2}+n_{s}^{2})}{2} \left( \frac{1}{\sigma_{T}^{2}} - \frac{1}{\sigma_{N}^{2}} \right) \right\}$$
(8.1-13)

and in comparing the log-likelihood function to a threshold we have

$$\log \Lambda = \log \left(\frac{\sigma_N^2}{\sigma_T^2}\right) + \frac{\chi^2}{2} \left(\frac{\sigma_T^2 - \sigma_N^2}{\sigma_N^2 \sigma_T^2}\right) \stackrel{H_1}{\underset{H_0}{\gtrless}} \eta \qquad (8.1-14)$$

where  $x^2 = n_c^2 + n_s^2$  is our estimated look-ahead noise-power measurement or sample test statistic for a single channel.

The value of  $x^2$  to decide that jamming is present (H  $_1\ {\rm true})$  is

$$\mathbf{x}^{2} \geq \frac{2\sigma_{N}^{2}\sigma_{1}^{2}}{\sigma_{T}^{2}-\sigma_{N}^{2}} \left[ n - \log\left(\frac{\sigma_{1}^{2}}{\sigma_{N}^{2}}\right) \right] = n_{ch}, \sigma_{T}^{2} > \sigma_{N}^{2} . \qquad (8.1-15)$$

For the false alarm probability we have

$$P_{FA} = Pr \left\{ x^{2} > \eta_{ch} | H_0 \right\} = \alpha = e^{-\eta_{ch}/2\sigma_N^2}$$
 (8.1-16)

Similarly, the probability of detection is

$$P_{\rm D} = e^{-n_{\rm C}h/2\sigma_{\rm T}^2}$$
(8.1-17)

with a receiver operating characteristic for our jamming detector given by

$$P_{D} = \left[\alpha\right]^{\sigma_{N}^{2}/\sigma_{T}^{2}} = \left[\alpha\right]^{1/K}.$$
(8.1-18)

Now in the case of the look-ahead channel sampling a signal channel slot, these samples  $(x^2)$  are independent noncentral chi-squared random variables with two degrees of freedom, multiplied by the total channel noise power  $\sigma_{ch}^2$ , and with noncentrality parameters

$$\lambda = 2S/\sigma_{ch}^{2} = \begin{cases} 2S/\sigma_{N}^{2} = 2\rho_{N}, \text{ hop unjammed} \\ 2S/\sigma_{T}^{2} = 2\rho_{T}, \text{ hop jammed.} \end{cases}$$
(8.1-19)

Therefore, the pdf of a given sample  $u=x^2$  is

$$f_{sig}(u) = \frac{1}{2\sigma_{ch}^{2}} e^{-(u+2S)/2\sigma_{ch}^{2}} I_{0}(\sqrt{2Su/\sigma_{ch}^{2}}) \qquad (8.1-20a)$$

$$= \begin{cases} (1/2\sigma_{N}^{2}) e^{-(u+2S)/2\sigma_{N}^{2}} I_{0}(\sqrt{2Su/\sigma_{N}^{2}}), & u \ge 0, \text{ hop unjammed} \\ (1/2\sigma_{T}^{2}) e^{-(u+2S)/2\sigma_{T}^{2}} I_{0}(\sqrt{2Su/\sigma_{T}^{2}}), & u \ge 0, \text{ hop jammed} \end{cases}$$

where S signifies power in the signal itself. Consequently, the probability of a false alarm and the probability of detection can be written as

$$P_{FA} = Q(\sqrt{2\rho_N}, \sqrt{\eta_{ch}/\sigma_N^2})$$
(8.1-21)

$$P_{D} = Q\left(\sqrt{2\rho_{T}}, \sqrt{\eta_{ch}/\sigma_{T}^{2}}\right)$$
(8.1-22)

where Q(x,y) is Marcum's Q-function.

8.1.3.2 Jammed symbol detection.

In the jammed M-ary symbol detection case, we have the two hypotheses of: (1) no channel is jammed, and (2) any of the M channels is jammed, i.e. ACJ. Hence, the situation is one of multiple alternative hypothesis testing given as

$$H_0: \sigma_m^2 = \sigma_N^2, \quad m = 1, 2, \dots, M;$$

$$(8.1-23)$$

$$H_1: \sigma_m^2 = \sigma_T^2, \quad 2^{M}-1 \text{ possible combinations of jammed channels;}$$

where  $\sigma_{\rm m}^2$  is a parameter in the likelihood function of the measurement samples which is written as

$$p(\underline{n}_{c},\underline{n}_{s}) = \prod_{m} \left(\frac{1}{2\pi\sigma_{m}^{2}}\right) e^{-x_{m}^{2}/2\sigma_{m}^{2}}.$$
 (8.1-24)

As in the jammed channel detection case, we require a current estimate of  $\sigma_N^2$  obtained from a look-ahead or in-band noise-power measurement scheme. Furthermore, an estimate of SNR ( $\hat{\rho}_N$ ) is also needed for threshold determination when accounting for the signal itself being detected in a look-ahead scheme.

Since there are many alternatives to  $H_0$  as expressed by (8.1-23), we consider the simplified test of whether the sum of the channel samples exceeds a threshold.

For the case of the signal being present in one of the channels, the sum of the samples  $(u_m = x_m^2)$  is distributed as, with no jamming,

$$\sum_{m=1}^{M} u_m = \sigma_N^2 \chi^2 (2M, 2\rho_N)$$
(8.1-25)

i.e., a non-central chi-squared variable with 2M degrees of freedom, non-central parameter  $2\rho_N$ , and weighted by the current est mate of  $\sigma_N^2$ . In the noise-only case, the distribution of the summed decision variables is a central chi-squared distribution, written as

$$\sum_{m=1}^{M} u_m = \sigma_N^2 \chi^2(2M) . \qquad (8.1-26)$$

A scheme that may provide a workable jammed symbol detection when a signal slot can be jammed is realized by discarding the maximum of the  $u_m$ variables which results in the distributional assumption

$$\sum_{m=1}^{M-1} u_m - u_{max} = \sigma_{NX}^2 (2M-2). \qquad (8.1-27)$$

Note that the distribution of (8.1-27) is written as a central chi-square distribution which assumes that the signal itself is always stronger than the jamming. That is, the presence of weak jamming can easily be detected in the absence of the now discarded stronger signal. Should the jamming be strong, we have a situation in which the signal channel is included in the left-over sum. However, this is an acceptable scenario because the signal channel power will help in deciding if a jammed symbol condition exists.

The probability of a false alarm for this scheme is obtained by applying the methodology to formulate the non-signal channel probabilities for ACJ-AGC receivers as discussed in Section 4.3. Specifically, the probability of the sum of the non-signal channel measurement samples being less than the normalized symbol threshold on a given hop is written as

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$$\Pr\left\{\sum_{m} u_{m} < \frac{r_{sym}}{\sigma_{N}^{2}}\right\} = 1 - \frac{\Gamma(2M-2; r_{sym}/2\sigma_{N}^{2})}{\Gamma(2M-2)} . \qquad (8.1-28)$$

Hence, the probability of a false-alarm for jammed symbol detection is simply

$$P_{FA(sym)} = \frac{\Gamma(2M-2;n_{sym}/2\sigma_N^2)}{\Gamma(2M-2)} . \qquad (8.1-29)$$

Another method to implement jammed symbol detection in the presence of a signal would utilize a combination of the individual channel jammed detector outputs. For example, in the case of M=4 we can employ the combinatorial logic of any two individual channel detectors' outputs "ANDed" to produce a symbol jamming decision from the six possible combinations. The detection of the "any channel jammed" condition will be the logic variable

$$J_{symbol} = (J_1 \cdot J_2) + (J_1 \cdot J_3) + (J_1 \cdot J_4) + (J_2 \cdot J_3) + (J_2 \cdot J_4) + (J_3 \cdot J_4)$$
(8.1-30)

where it is assumed that detection of the signal itself has triggered the decision of a jammed channel  $(J_i)$  for a particular channel. Thus, we are able to realize a jammed symbol detection when a signal is present. For the case of any M we have the overall false alarm probability (when no signal is present)

$$P_{FA(sym)} = \sum_{n=2}^{M} {\binom{M}{n}} P_{FA(CH)}^{n} (1 - P_{FA(CH)})^{M-n}$$
(8.1-31)

which simplifies to

$$P_{FA(sym)} \approx {\binom{M}{2}} P_{FA(CH)}^2$$
 (8.1-32)

as the overall false-alarm rate for a jammed symbol detection.

#### 8.2 ASSESSMENT OF IMPLEMENTATION EFFECTS

In this second part of our implementation studies, we investigate the effects of the previously discussed implementation schemes on the performance of the ECCM receivers. We demonstrate the necessary adjustments involved in reformulating the probability of error expressions which are now conditioned on estimated (measured) parameters instead of assumed "perfect" measurement quantities. Our objective is to assess the "return on the investment" realized by resorting to the complex measurement schemes needed to implement the AGC receivers, which for ideal measurements achieve the best ECCCM receiver performances in worst-case PBNJ. That is, we seek to answer the question, "Will practical implementations of the AGC receivers continue to outperform the simple SNORM and hard-decision receivers, which require no measurement?"

#### 8.2.1 <u>Methodology for Direct Assessment</u>.

Analyses of the error performance of the implementated AGC schemes are extremely difficult for the following reasons. First, we must account for the measured (estimated) quantities  $\hat{\sigma}_N^2$  and  $\hat{\sigma}_T^2$  as random variables imbedded in the probability of error expressions. Second, the effect of errors in the JSI decisions upon the P(e) expressions must also be considered. Previous analytical results in this report were derived on the assumption that perfect measurements were obtained for  $\sigma_N^2$  and  $\sigma_T^2$ ; this provided a lower bound on the error performance to be realized in practice. This ideal total error probability can be expressed

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$$P(e) = P(e; Y, E_b/N_0, E_b/N_1, L, M; \sigma_N^2, \sigma_T^2, S)$$
actual parameters
parameters assumed by
receivers
$$(8.2-1)$$

and can be written as

$$P(e) = \sum Pr\{[v_j]\} P_b(e|[v_j]),$$
 (8.2-2)

where [v] is a matrix describing the jamming event (see Section 2.2) over the L-hop diversity. The above expressions must now be restated as,

$$P(e) \equiv P(e; \gamma, E_b/N_0, E_b/N_J, L, M; \hat{\sigma}_N^2, \hat{\sigma}_T^2, \hat{S})$$
 (8.2-3)

$$P(e) = \sum Pr\{\{v\}, [\hat{v}]\} P(e|[v], [\hat{v}])$$
(8.2-4)

in accounting for  $\hat{\sigma}_N^2,\;\hat{\sigma}_T^2,\;\hat{S},\;as$  well as estimates in JSI.

For example, in the ideal situation the IC-AGC receiver decision variables are

$$z_{m} = \sum_{k=1}^{L} z_{mk}; m=1,2,...,M;$$
 (8.2-5a)

where each  $z_{mk}^{}$  is the square-law envelope detector sample  $x_{mk}^{2}$  multiplied by the weight

$$w_{mk} = \begin{cases} 1/\sigma_N^2 , \text{ channel m not jammed on hop k} \\ \\ 1/\sigma_T^2 , \text{ channel m jammed on hop k.} \end{cases}$$
(8.2-5b)

This ideal normalization results in the  $\{z_{mk}\}$  being all unscaled chi-square random variables, as discussed in Section 4.

Now if the <u>a priori</u> quantities  $\sigma_N^2$  and  $\sigma_T^2$  are not available and the jamming condition of the channels is not known, we must use estimates  $\hat{\sigma}_N^2$  and  $\hat{\sigma}_T^2$ , and also decide whether the channel is jammed. This results in the weights

$$\hat{w}_{mk} = \begin{cases} (\hat{\sigma}_{N}^{2})^{-1} (1 - P_{Fm}) + (\hat{\sigma}_{T}^{2})^{-1} P_{Fm} = W_{0}, \text{ not jammed}; \\ (\hat{\sigma}_{N}^{2})^{-1} (1 - P_{Dm}) + (\hat{\sigma}_{T}^{2})^{-1} P_{Dm} = W_{1}, \text{ jammed}; \end{cases}$$
(8.2-6)

where  $P_{Fm}$  and  $P_{Dm}$  are per-channel jamming false alarm and detection probabilities. In this description, it is assumed that the variance estimates are developed from look-ahead or in-band measurement data prior to the symbol being processed, and that the channel jamming decision is based on a one-hop look-ahead scheme. In the absence of signals in the look-ahead channels,

$$\mathsf{P}_{\mathsf{Fm}} = \mathsf{P}_{\mathsf{F}}(\hat{\sigma}_{\mathsf{N}}^{2}, \hat{\sigma}_{\mathsf{T}}^{2}; \sigma_{\mathsf{N}}^{2}, \sigma_{\mathsf{T}}^{2}) \text{ and } \mathsf{P}_{\mathsf{Dm}} = \mathsf{P}_{\mathsf{D}}(\hat{\sigma}_{\mathsf{N}}^{2}, \hat{\sigma}_{\mathsf{T}}^{2}; \sigma_{\mathsf{N}}^{2}, \sigma_{\mathsf{T}}^{2});$$

that is, these probabilities are the same for each of the M symbol channels.

Thus, after accumulating the L hops, the decision statistics are, conditioned on jamming events and measurements,

$$z_{1} = W_{0}\sigma_{N}^{2}\chi^{2}[2(L-\ell_{1});2(L-\ell_{1})\sigma_{N}] + W_{1}\sigma_{T}^{2}\chi^{2}[2\ell_{1};2\ell_{1}\sigma_{T}]; \qquad (8.2-7a)$$

$$z_{m} = W_{0}\sigma_{N}^{2}\chi^{2} [2(L-\ell_{m})] + W_{1}\sigma_{T}^{2}\chi^{2}(2\ell_{M}), m>1;$$
 (8.2-7b)

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where  $\underline{\ell} = (\ell_1, \ell_2, \dots, \ell_M)$  is the jamming event vector of the number of hops jammed in each channel. Recall now that the linear combining receiver (LCR) has the normalized decision statistics

$$u_{1} = z_{1}/\sigma_{N}^{2} = \chi^{2}[2(L-\ell_{1});2(L-\ell_{1})\rho_{N}] + K\chi^{2}[2\ell_{1};2\ell_{1}\rho_{T}]; \qquad (8.2-8a)$$

$$u_m = z_m / \sigma_N^2 = \chi^2 [2(L-\ell_m)] + K_{\chi^2} (2\ell_m), m>1;$$
 (8.2-8b)

where  $K = \sigma_T^2/\sigma_N^2$ . We therefore recognize that, conditioned on the measurements, the implemented IC-AGC receiver's BER will have the same functional form as the LCR's with the new K value

$$K' = \frac{\sigma_T^2 W_1}{\sigma_N^2 W_0} = \frac{\sigma_T^2}{\sigma_N^2} \cdot \frac{\hat{\sigma}_T^2 (1 - P_D) + \hat{\sigma}_N P_D}{\hat{\sigma}_T^2 (1 - P_F) + \hat{\sigma}_N^2 P_F}.$$
(8.2-9)

Evaluation of the effect of the measurements and JSI decisions then involves numerically averaging the LCR error probability (with K replaced by (8.2-9)) over the distributions of  $\hat{\sigma}_{N}^{2}$  and  $\hat{\sigma}_{T}^{2}$ .

#### 8.2.2 In Search of an Upper Bound: Simplified Measurement Models.

Equations (8.2-7) to (8.2-9) reveal that the implemented IC-AGC receiver statistics more or less tend toward those of the ineffective LCR, depending on the quality of the measurements. This fact underscores the important role of the <u>a priori</u> information utilized by the AGC receivers in

their superior performance. We can take the position that the ideal AGC performances calculated in this report represent a lower bound on achievable BER, though perhaps not the lowest bound, and then seek an upper bound instead of attempting the arduous and time-consuming direct analysis of implemented systems. Such an upper bound, if sufficiently tight, would be suitable for comparison with the BER results for the receivers not employing a priori information.

How shall we obtain an upper bound? Since the performance degradation associated with the receiver implementations is related to the quality of the measurements, we realize that any bound would be directly identified with a particular measurement approach, and parametric in the features of that approach (such as number of samples taken). We fully anticipate, for example, that an upper bound on the implemented system's BER would decrease as the number of samples used in the measurement increases. Therefore, it is reasonable to consider possible implementations utilizing <u>one sample</u> as candidates for systems whose performances represent an upper bound on what is achievable in the same manner as the ideal systems represent a lower bound.

For the ACJ-AGC FH/MFSK receiver, we consider the simplified version that we call the "practical ACJ" (PACJ) receiver. Since the ideal ACJ receiver uses the weights  $w_k = (\max_{m} \sigma_{mk}^2)^{-1}$ , we stipulate that the PACJ uses the weights

$$w_k = (\max_{m} x_{mk}^2).$$
 (8.2-10)

<sup>\*</sup>In Section 7 it was observed that the SNORM receiver can outperform the AGC receivers in some, limited circumstances.

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This approach in effect utilizes the received square-law envelope detector samples themselves as (one sample) measurements of the noise power in each channel, and thus is a form of in-band measurement which is very simple indeed compared to schemes discussed in Section 8.1.

We note in passing that this PACJ receiver is related to the hard-decision receiver in the following way: the HD decision statistics  $\{z_{mk}\}$  are the PACJ decision statistics after being subjected to a two-level quantization. That is,

$$z_{HD} = \begin{cases} 1, & z_{PACJ} \ge 1 \\ 0, & z_{PACJ} \le 1. \end{cases}$$
 (8.2-11)

For the IC-AGC receiver, we postulate that a one-hop look-ahead implementation yields one detector sample in each of the M channels just prior to the actual symbol's occupancy of those channels.\* Since the ideal IC-AGC uses the weights  $w_{mk} = (\sigma_{mk}^2)^{-1}$ , we can treat the look ahead samples  $\{v_{mk}\}$ as one-sample estimates of noise power and specify the "practical IC" (PIC) weights

$$w_{mik} = (v_{mk})^{-1}$$
 (8.2-12)

In what follows, we evaluate each of these practical receivers for the case of M=2, L=2 in order to compare them with their respective ideal receivers. We also can consider the SNORM and hard-decision receivers as

<sup>\*</sup>Alternatively, the hopping and symbol rates could be reduced by one-half in order to sample the channel first, then receive the transmission; look-ahead is avoided in this way, at the expense of data rates.

"practical" AGC implementations, and will continue to exhibit their BER results for comparison purposes.

8.2.3 Example Evaluations of Practical AGC Receivers .

We now find the error probabilities for the PACJ and PIC receivers for M=2 and L=2.

8.2.3.1 Analysis of the PACJ receiver.

The PACJ receiver for M=2 is diagrammed in Figure 8.2-1. The decision statistics are

$$z_{m} = \sum_{k=1}^{L} \frac{x_{mk}^{2}}{\max(x_{mk}^{2})}, m = 1,2.$$
 (8.2-13)

In Appendix C it is shown that this receiver for L=2 and FH/RMFSK has the bit error probability

$$P_{b}(e) = 2 \int_{0}^{1} dx f(x)G(x) + G^{2}(1) \qquad (8.2-14a)$$

where K =  $\sigma_T^2/\sigma_N^2$  and

$$f(x) = \pi_0 \frac{1}{(x+1)^2} \exp \left\{ -\frac{\rho_N x}{(x+1)} \right\} \left[ 1 + \frac{\rho_N}{x+1} \right]$$
  
+  $\pi_1 \frac{K}{(Kx+1)^2} \exp \left\{ -\frac{K\rho_T x}{(Kx+1)} \right\} \left[ 1 + \frac{\rho_T}{Kx+1} \right]$   
+  $\pi_1 \frac{K}{(x+K)^2} \exp \left\{ -\frac{\rho_N x}{(x+K)} \right\} \left[ 1 + \frac{K\rho_N}{x+K} \right]$   
+  $\pi_2 \frac{1}{(x+1)^2} \exp \left\{ -\frac{\rho_T x}{(x+1)} \right\} \left[ 1 + \frac{\rho_T}{x+1} \right].$  (8.2-14b)

and

$$G(x) = \pi_0 \frac{x}{x+1} e^{-\rho_N/(1+x)} + \pi_2 \frac{x}{x+1} e^{-\rho_T/(1+x)} + \pi_1 \frac{Kx}{Kx+1} e^{-\rho_N/(1+Kx)} + \pi_1 \frac{x}{x+K} e^{-K\rho_T/(x+K)}. \quad (8.2-14c)$$



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Numerical results for the L=2 PACJ binary receiver are shown for  $E_b/N_0 = 13.35$  dB and 20 dB, respectively, in Figures 8.2-2 and 8.2-3. There is no difference between these results and those of the SNORM receiver that can be discerned from the figures - a close look at the data reveals a slight difference except for  $\gamma$ =1 (full-band jamming), for which analysis shows that the two receivers yield identical performance for the M=2, L=2 case.

8.2.3.2 Analysis of the PIC receiver.

The PIC receiver for M=2 is diagrammed in Figure 8.2-4. The decision statistics are

$$z_{m} = \sum_{k=1}^{L} \frac{u_{mk}}{v_{mk}}$$
, m=1,2; (8.2-15)

where the  $\{u_{mk}\}$  are the usual receiver samples and the  $\{v_{mk}\}$  are look-ahead samples. These look-ahead samples are assumed to have the same noise powers as their corresponding "usual" samples, and not to have a signal present.

In Appendix C it is shown that the L=2 FH/RMFSK or FH/MFSK PIC receiver error probability in partial-band noise jamming is given by

$$P_{b}(e) = (1-\gamma)^{2} P_{b}(e|_{\rho_{1}}=\rho_{2}=E_{b}/2N_{0})$$
  
+ 2\gamma(1-\gamma)P\_{b}(e|\_{\rho\_{1}}=E\_{b}/2N\_{0},\rho\_{2}=E\_{b}/2N\_{T})  
+ \gamma^{2}P\_{b}(e|\_{\rho\_{1}}=\rho\_{2}=E\_{b}/2N\_{T}), \qquad (8.2-16a)

where  $\gamma$  is the jamming fraction and

$$P_{b}(e|\rho_{1},\rho_{2}) = \int_{0}^{1} du \int_{0}^{1} dv e^{-\rho_{1}u-\rho_{2}v} (1+\rho_{1}-\rho_{2}u)(1+\rho_{2}-\rho_{2}v) \\ \times \frac{uv}{u+v} \left[ 2 + \frac{uv}{u+v} \ln(\frac{u+v}{uv} - 1) \right]. \quad (8.2-16b)$$





NOISE JAMMING FOR M=2, L=2, AND  $E_b/N_0 = 20 \text{ dB}$ 



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Numerical results for the L=2 PIC binary receiver reveal that it performs very poorly. For example, for full-band noise jamming the BER varies with  $E_b/N_J$  as shown in Figure 8.2-5. We note that for high  $E_b/N_J$ (practically no jamming) the error probability is greater than  $10^{-4}$  even for thermal noise so small that  $E_b/N_0 = 40$  dB. Evidently the predictably poor quality of the one-sample estimate of noise variance is especially damaging when using it in the denominator of the ratios taken in (8.2-15).

With slightly more effort, we find that if the PIC receiver uses <u>two</u> look-ahead noise samples, summed to obtain a better variance estimate, the performance improves considerably. The decision statistics for this version of the PIC receiver are

$$z_{m} = \sum_{k=1}^{L} \frac{u_{mk}}{v_{mk1}^{+}v_{mk2}}$$
, m=1,2. (8.2-17)

Using the same analytical approach as in Appendix C, but with the sum of the look-ahead variables being  $\sigma_{mk}^2 x^2(4)$  distributed, we find that the conditional P(e) for M=2 and L=2 is

$$P_{b}(e|\rho_{1},\rho_{2}) = 4 \int_{0}^{1} du \int_{0}^{1} dv (1-u)(1-v) exp\{-\rho_{1}(1-u)-\rho_{2}(1-v)\}$$

$$\times [1+2\rho_{1}^{2}u + \rho_{1}^{2} u^{2}/2] [1+2\rho_{2}^{2}v + \rho_{2}v^{2}/2]$$

$$\times g(\frac{u}{1-u} + \frac{v}{1-v}), \qquad (8.2-18a)$$



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where

$$g(x) = \frac{12}{(x+2)^4} \ln(x+1) + \frac{2(x^2+7x+4)}{(x+1)(x+2)^3} . \qquad (8.2-18b)$$

Numerical results for full-band jamming are shown in Figure 8.2-6. For  $E_b/N_0 = 13.35$  dB, there is not much of an improvement, but for 20 dB and higher  $E_b/N_0$ , there is about a decade improvement over the asymptotic BER obtained using a one-sample noise estimate. Clearly as more look-ahead samples are used, the PIC receiver will act more like the IC-AGC. However, if more measurements are taken, the likelihood increases that the measurement will suffer from changes in the assumed noise environment over the measurement time. Perhaps with the RMFSK hopping scheme it is possible to gather noise samples from adjacent (unused) hopping slots in addition to (or in place of) using a look-ahead approach.

#### 8.3 CONCLUSIONS AND RECOMMENDATIONS

Having considered practical implementations of ECCM receivers for FH/RMFSK in worst-case partial-band noise jamming (WCPBNJ), we are able to conclude our study with some "lessons learned," from which we also can recommend further studies.

#### 8.3.1 Knowledge Gained from Study.

8.3.1.1 Ideal receiver performances.

The ideal receiver performances obtained in Sections 3-6 and compared in Section 7 show for the first time what the expected performance of random frequency-hopping MFSK is in WCPBNJ when L hops per symbol soft decisions are

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used and thermal noise is not neglected. We have learned that per-channel adaptive normalization, such as envisioned using the IC-AGC receiver weighting scheme, is effective in countering the jamming effects which are most damaging to the RMFSK performance: jamming power in non-signal symbol frequency channels and not in the signal channel. The IG-AGC scheme controls the channel gains in such a way as to equalize the <u>a priori</u> noise powers in the channels, in effect forcing the non-Gaussian input noise process to be a Gaussian process. The jamming then only affects the error through the reduction of relative signal power when jammed signal hops are normalized, and RMFSK using this scheme performs the same as the conventional MFSK hopping.

We have learned also that per-symbol adaptive normalization, typified by the ACJ-AGC receiver's weighting scheme, is effective in countering WCPBNJ, though not as effective as per-channel normalization. The per-symbol operation equalizes the <u>maximum</u> of the M channels' <u>a priori</u> noise powers to a constant value, but does not affect the <u>relative</u> powers among the M channels, so that to a certain extent the RMFSK system, unlike MFSK, is still subject to noise power imbalances on each hop and therefore is more vulnerable than MFSK. However, the per-symbol normalization does prevent jammed hops from dominating the soft-decision, and therefore achieves an ECCM or anti-jam diversity effect.

The per-channel and per-symbol AGC schemes perform the same for no jamming, and the performance achieved is sensitive to the amount of thermal and/or background noise present at the receiver, expressed relatively in our

study by the ratio  $E_b/N_0$ . For any finite  $E_b/N_0$  value, the receiver performances for weak or no jamming degrade in proportion to L, the number of hops/symbol, due to noncoherent combining losses. It cannot be emphasized too strongly that thermal noise should always be included in any study, because different implementations of the ideal receiver combining schemes in general are subject to different noncoherent combining losses plus any losses due to quantization effects. The ideal AGC performances we have obtained provide a lower bound on achievable performance in the sense that errorless noise power measurements are assumed.

8.3.1.2 Practical receiver performances.

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К. С The several "practical" FH/RMFSK receiver combining schemes we have studied may be classified as implementations of either per-channel (IC-AGC) or per-symbol (ACJ-AGC) ideal schemes.

The clipper receiver implements a per-channel ECCM scheme and thus to a certain extent achieves a performance in WCPBNJ whose parametric behavior follows that of the IC-AGC. However, its best clipping threshold value is parametric in received signal and thermal noise powers and in L. In our study we have calculated performances assuming that these powers are known <u>a priori</u>; it is expected that estimation of the correct threshold will degrade its performance. But if we can assume that a reasonably good estimate of unjammed SNR is available, the clipper receiver appears to be a viable candidate for a practical ECCM receiver.

It was shown that direct implementation of the IC-AGC using auxiliary noise power measurements has the potential for approaching the IC-AGC performance, but only if certain assumptions are made: (a) the receiver complexity can be further advanced economically to include the required noise power measurements (as many as possible per channel); (b) the noise processes

being measured are relatively stationary during the time of measurement and not subject to corruption from the signal or other signals. These assumptions are quite restrictive, so that we would choose to implement another, simpler scheme if its performance is satisfactory.

The per-symbol receiver ECCM schemes studied include the selfnormalizing receiver (SNORM) and the so-called "practical ACJ" (PACJ). These receiver implementations are very simple, requiring only operations using the usual received envelope samples in the M symbol frequency channels. Somewhat surprisingly, these two schemes perform very well (nearly identically for M=2 and L=2), even better than the supposedly best ideal IC-AGC receiver under certain limited circumstances. Therefore, if the receivers using <u>a priori</u> noise and jamming information tend to represent a lower bound on system performance, and the small-sample size "practical" receivers, an upper bound--then we have observed a situation when lower and upper bounds converge to agree upon a predicted performance result. The implications are that we may regard the easily-calculated IC-AGC performance as representative of achievable system performance, with perhaps a slight implementation loss of a few dB when the simple practical receivers are employed, and when the system noise without jamming is small (high  $E_b/N_0$ ).

8.3.1.3 RMFSK vs MFSK.

We have found that for smaller alphabet sizes (M=2 or 4), the error performance of FH/RMFSK in worst-case PBNJ is comparable to that of the conventional FH/MFSK, when appropriate receiver processing is employed, to the extent that we state that the price to be paid for the additional RMFSK system

complexity can be assessed against the threat of follow-on noise jamming. That is, if follow-on jamming is not considered a threat, MFSK should be used; but if it is a threat, RMFSK is an effective counter-countermeasure that also works satisfactorily in the worst-case partial-band noise jamming environment.

8.3.2 <u>Recommendations</u>.

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With the perspective gained from our study we make the following recommendations for further research.

(a) Derivation of system error performances using the PACJ and similar "nonparametric" ECCM receivers; it is conjectured that analysis would yield BER expressions for M>2 that are more feasible for computation than those for the clipper and self-normalizing receivers we have studied.

(b) Analysis of FH/RMFSK performance under multi-tone jamming; it has been asserted that FH/RMFSK "precludes" systematic tone jamming, but what, in quantitative terms, is its vulnerability to tone jamming, relative to FH/MFSK?

(c) Analysis of mutual interference effects in an FH/RMFSK system; these are considered to be more numerous than for FH/MFSK, and possibly more damaging - a more intricate setup for multiple users may be necessary to avoid mutual interference. このないないないない 御御をからたいない ないない ないない たいたい たいかい ひょうしょう しょうしょう ちょうちょう たいていていたい

#### APPENDIX A

## PROBABILITY DENSITY FUNCTIONS FOR SOFT DECISION RECEIVER STATISTICS

For soft decision receivers with multiple hops per symbol, the M decision statistics are of the form

$$z_{m} = \sigma_{1m}^{2} \chi^{2}(v_{1m}; \lambda_{1m}) + \sigma_{2m}^{2} \chi^{2}(v_{2m}; \lambda_{2m}), \qquad (A-1)$$

where  $\chi^2(\nu; \lambda)$  denotes a noncentral chi-squared random variable with  $\nu$  degrees of freedom and noncentrality parameter  $\lambda$ , and  $\sigma_{1m}^2$  and  $\sigma_{2m}^2$  are different scalings. For the cases to be studied we can also write

$$u_m = z_m / \sigma_{1m}^2 = \chi^2 (2L - 2\ell_m; \lambda_{1m}) + K_m \chi^2 (2\ell_m; \lambda_{2m}),$$
 (A-2)

since  $v_{1m}^+v_{2m}^- = 2L$ , twice the number of hops per symbol, and  $v_{2m}^- = 2l_m^+$ , twice the number of jammed hops for symbol channel m. Also, without loss of generality we designate the first (m = 1) channel as the one containing the transmitted signal, and the others (m > 2) as containing noise only. Thus

$$\lambda_{11} = 2(L - \ell_1) S/\sigma_{11}^2, \ \lambda_{21} = 2\ell_1 S/\sigma_{21}^2$$
(A-3a)

and

$$\lambda_{1m} = \lambda_{2m} = 0, m \ge 2.$$
 (A-3b)

Previously it has been shown [1, Appendix 2E] that the probability density function (pdf) for  $u_m$  given by (A-2) is  $p_u(\alpha; \ell_m, \lambda_{1m}, \lambda_{2m}, K_m)$ , where

$$P_{u}(\alpha; \ell, \lambda_{1}, \lambda_{2}, K) = \frac{K^{-\ell}}{2} \exp\left(-\frac{\lambda_{1}+\lambda_{2}+\alpha}{2}\right) \sum_{k=0}^{\infty} \sum_{r=0}^{\infty} \frac{\left(\frac{\lambda_{1}}{2}\right)^{k} \left(\frac{\lambda_{2}}{2K}\right)^{r} \left(\frac{\alpha}{2}\right)^{k+r+L-1}}{k! r! (k+r+L-1)!} \times {}_{1}F_{1}(r+\ell; k+r+L; \frac{K-1}{K} - \frac{\alpha}{2}), \qquad (A-4)$$

where  ${}_{1}F_{1}(a; b; x)$  is the confluent hypergeometric function. The computation of this expression is very time consuming; in this Appendix we consider alternative expressions that can be computed more quickly, or perhaps be amenable to approximations.

By expanding the confluent hypergeometric function in its series form,

$${}_{1}F_{1}\left(r+\ell; k+r+L; \frac{K-1}{K} \frac{\alpha}{2}\right) \qquad (A-5)$$

$$= \sum_{n=0}^{\infty} \left(\frac{K-1}{K} \cdot \frac{\alpha}{2}\right)^{n} \frac{1}{n!} \frac{(r+\ell)_{n}}{(k+r+L)_{n}},$$

$$(a)_{n} = \Gamma(a+n)/\Gamma(a), \qquad (A-6)$$

with

and summing over the index k, we obtain the expression

$$p_{u}(\alpha) = \frac{K^{-2}}{2} \exp\left(-\frac{\lambda_{1}+\lambda_{2}+\alpha}{2}\right) \sum_{n=0}^{\infty} \left(\frac{K-1}{K}\right)^{n} \frac{1}{n!}$$

$$\times \sum_{r=0}^{\infty} \frac{\left(\frac{\lambda_{2}}{2K}\right)^{r}}{r!} (r+2)_{n} \left(\frac{\alpha}{\lambda_{1}}\right)^{(r+n+L-1)/2} I_{r+m+L-1}(\sqrt{\alpha\lambda_{1}}) \quad (A-7)$$

This form is based on recognizing the series for  $I_{r+n+L-1}(x)$ , the modified Bessel function of the first kind of order r+n+L-1:

$$I_{r+n+L-1}(x) = \sum_{k=0}^{\infty} \frac{(x/2)^{2k+r+n+L-1}}{k! (k+r+n+L-1)!}$$
 (A-8)

Further, we recognize that

$$\left(\frac{\alpha}{\lambda_1}\right)^{(q-1)/2} I_{q-1}(\sqrt{\alpha\lambda_1}) = 2e^{(\alpha+\lambda_1)/2}p_{\chi^2}(\alpha; 2q, \lambda_1),$$
 (A-9)

where  $p_{\chi^2}(\alpha; \upsilon, \lambda)$  is the pdf for a noncentral chi-squared random variable with  $\upsilon$  degrees of freedom and noncentrality parameter  $\lambda$ . This allows us to write

$$p_{u}(\alpha) = \kappa^{-\ell} e^{-\lambda_{2}/2} \sum_{n=0}^{\infty} \frac{\left(\frac{\kappa-1}{\kappa}\right)^{n}}{n!} \sum_{r=0}^{\infty} \frac{\left(\frac{\lambda_{2}}{2\kappa}\right)^{r}}{r!} (r+\ell)_{n}$$

$$\times p_{\chi^{2}}(\alpha; 2r+2n+2L; \lambda_{1})$$
(A-10)

Now we concentrate on the summation over the indices r and n.

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$$\sum_{n=0}^{\infty} \sum_{r=0}^{\infty} f(n, r) g(n + r)$$
  
=  $\sum_{n=0}^{\infty} g(n) \sum_{r=0}^{n} f(n-r, r),$  (A-11)

we can express the pdf in the form

$$p_{u}(\alpha) = \sum_{n=0}^{\infty} c_{n} p_{\chi^{2}}(\alpha; 2L+2n, \lambda_{1}),$$
 (A-12)

where

$$c_n = e^{-\lambda_2/2} \left(\frac{K-1}{K}\right)^n \frac{1}{K^2} \sum_{r=0}^n \frac{\left(\frac{\lambda_2/2}{K-1}\right)^r}{r!} \frac{(r+\ell)_{n-r}}{(n-r)!}$$
 (A-13)

Now,

$$\frac{(r+\ell)_{n-r}}{(n-r)!} = \frac{(r+\ell+n-r-1)!}{(r+\ell-1)!(n-r)!}$$
$$= \binom{n+\ell-1}{n-r};$$
(A-14)

and

$$\sum_{r=0}^{n} {\binom{n+a}{n-r}} \frac{(-x)^r}{r!} = \mathcal{L}_n^a(x), \qquad (A-15)$$

with  $\mathcal{L}_{n}^{a}(x)$  the generalized Laguerre polynomial. Thus,

$$c_{n} = e^{-\lambda_{2}/2} \left(\frac{K-1}{K}\right)^{n} \quad \frac{1}{K^{\ell}} \mathcal{L}_{n}^{\ell-1} \left[-\frac{\lambda_{2}/2}{K-1}\right] \qquad (A-1.6)$$

Since (A-12) is a pdf, it must integrate over lpha to unity. This

requires that

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$$\sum_{n=0}^{\infty} c_n = 1.$$
 (A-17)

In fact, this is so, since [3, eq. 8.975.1]

$$\sum_{n=0}^{\infty} b^{n} \mathcal{L}_{n}^{a}(x) = (1-b)^{-a-1} \exp\left\{\frac{bx}{b-1}\right\}$$
$$= K^{\ell} e^{\lambda_{2}/2}. \qquad (A-18)$$

#### Approximation

The expression (A-12) for the pdf is in the form of a series of weighted chi-squared pdf's. This suggests an approximation based on truncating the series:

$$p_{u}(\alpha) \approx \sum_{n=0}^{N} c_{n} p_{\chi^{2}}(\alpha; 2L+2n, \lambda_{1}) / \sum_{n=0}^{N} c_{n}.$$
 (A-19)

Since, even for  $\lambda_2 = 0$ ,

$$\frac{c_{n+1}}{c_n} = \frac{1}{n} \left( \frac{\frac{K-1}{K}}{\frac{1}{1+1/n}} \cdot \frac{\frac{1+\ell/n}{1+(\ell-1)/n}}{\frac{1+\ell/n}{1+(\ell-1)/n}} \right) \xrightarrow{\left( \frac{K-1}{K} \right)}_{n} < \frac{1}{n}, \qquad (A-20)$$

the truncation is feasible but, depending on the value of K, the convergence of the weights  $\{c_n\}$  is slow.

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#### APPENDIX B

COMBINATORIAL RELATIONS FOR JAMMING EVENT ENUMERATION

8.1 NUMBERS OF ORDERED VECTORS

We define

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$$(L+1)S_{M}(L) \stackrel{\Delta}{=} \#\{\underline{\ell} : \underline{\ell} : \underline{\ell} : (\ell_{1}; \ell_{2} \le \ell_{3} \le \dots \le \ell_{M})\}$$
  
=  $(L-1)\sum_{\ell_{M}=0}^{L} \sum_{\ell_{M}-1=0}^{\ell_{M}} \dots \sum_{\ell_{2}=0}^{\ell_{3}} (1)$ . (B.1-1)

By direct manipulation,

$$S_{2}(L) = \sum_{\ell_{2}=0}^{L} 1 = L+1 = \binom{L+1}{1}$$
 (B.1-2)

$$S_{3}(L) = \sum_{\ell_{3}=0}^{L} \sum_{\ell_{2}=0}^{\ell_{3}} 1 = \sum_{\ell_{3}=0}^{L} S_{2}(\ell_{3})$$
$$= \sum_{\ell_{3}=0}^{L} \binom{\ell_{3}+1}{1} = \binom{L+2}{2}, \qquad (B.1-3)$$

using [3, equation 0.151.1]. Assuming that

$$S_{M}(L) = \begin{pmatrix} L+M-1 \\ M-1 \end{pmatrix}, \qquad (B.1-4)$$

we find that

$$S_{M+1}(L) = \sum_{\ell_{M+1}=0}^{L} S_{M}(\ell_{M+1})$$
  
= 
$$\sum_{\ell_{M+1}=0}^{L} {\binom{\ell_{M+1}+M-1}{M-1}} = {\binom{L+M}{M}}.$$
 (B.1-5)

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Thus (B.1-4) is proved by induction.

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#### B.2 NUMBERS OF PARTITIONED ORDERED VECTORS

We define  $R_M(L;n)$  as  $(L+1)^{-1}$  times the number of ordered vectors  $\underline{\mathfrak{L}}'$  such that there are exactly n partitions of the components  $(\mathfrak{L}_2 \leq \mathfrak{L}_3 \leq \ldots \leq \mathfrak{L}_M)$ such that the  $\mathfrak{L}_m$  in the partition are equal. For example,

$$R_{M}(L;1) = \sum_{\ell_{M}=0}^{L} \sum_{\ell_{M-1}=0}^{\ell_{M}} \dots \sum_{\ell_{2}=0}^{\ell_{3}} U(\ell_{2} = \ell_{3} = \ell_{4} = \dots = \ell_{M})$$
$$= \sum_{\ell_{M}=0}^{L} 1 = (L+1), \qquad (B.2-1)$$

where  $U(\cdot)$  is 1 if the relation in the argument is true and zero otherwise.  $R_M(L;1)$  is the number of ordered vectors where the components are all equal. For two partitions, there are many cases, but they all produce the sum

$$R_{M}(L;2) = \sum_{r_{2}=1}^{L} \sum_{r_{1}=0}^{r_{2}-1} 1 = \sum_{r_{2}=0}^{L} r_{2} = {L+1 \choose 2}, \qquad (B.2-2)$$

from [3, equation 0.121.1]. We find that

$$R_{M}(L;n) = \sum_{r_{n}=0}^{L} R_{M-1}(r_{n}-1; n-1).$$
 (B.2-3)

Asserting that

$$R_{M}(L;n) = \begin{pmatrix} L+1\\ n \end{pmatrix} \equiv R(L;n)$$
 (B.2-4)

and substituting (B.2-4) in (B.2-3) establishes this relation by inductive proof.

#### B.3 TOTAL NUMBER OF VECTORS REPRESENTED BY ORDERED VECTORS

Since there are

$$\begin{pmatrix} M - 1 \\ n_0, n_1, \dots, n_L \end{pmatrix}$$
(B.3-1)

 $\underline{\&}$  vectors represented by each  $\underline{\&}$ ' vector (see Section 2.2), the total number of vectors represented is (L+1) times the summation

$$\sum_{\ell_{\mathsf{M}}=0}^{\mathsf{L}}\sum_{\ell_{\mathsf{M}-1}=0}^{\ell_{\mathsf{M}}}\cdots\sum_{\ell_{2}=0}^{\ell_{3}} \binom{\mathsf{M}-1}{\mathsf{n}_{0}, \mathsf{n}_{1},\cdots, \mathsf{n}_{L}} \stackrel{\Delta}{=} \mathsf{T}_{\mathsf{M}}(\mathsf{L}).$$
(B.3-2)

Using the partitioning relations, we can write

$$T_{M}(L) = \sum_{n=1}^{M-1} {\binom{M-1}{n_{0}, n_{1}, \cdots, n_{L}}} \times {\binom{number of partitioned \underline{a}'}{which produce n_{0}, n_{1}, \cdots, n_{L}}}$$
$$= \sum_{n=1}^{M-1} R(L;n) \sum_{partitions} {\binom{M-1}{q_{1}, q_{2}, \cdots, q_{n}}} \cdot {\binom{n}{r_{1}r_{2}, \cdots, r_{M-1}}},$$
(B.3-3)

where

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$$q_k \stackrel{\text{\tiny def}}{=}$$
 number of equal l's in partition k (B.3-4a)

$$r_s \stackrel{\text{\tiny{lag}}}{=} number of q_k equal to s.$$
 (B.3-4b)

Thus

$$T_{2}(L) = \sum_{n=1}^{l} R(L;n) \sum_{part.} {\binom{1}{q_{1}, q_{2}, \dots, q_{n}} \binom{n}{r_{1}}} = L+1, \quad (B.3-5)$$

B-3

and

$$T_{3}(L) = \sum_{n=1}^{2} R(L;n) \sum_{\text{part.}} {\binom{2}{q_{1}, q_{2}, \dots, q_{n}}} {\binom{n}{r_{1}, r_{2}}} \\ = {\binom{L+1}{1}} {\binom{2}{2}} {\binom{1}{1}} + {\binom{L+1}{2}} {\binom{2}{1, 1}} {\binom{2}{2, 0}} \\ = L+1+2{\binom{L+1}{2}} = (L+1)^{2}$$
(B.3-6)

(B.3-7

Calculations show that

$$T_4(L) = (L+1)^3$$
  
 $T_5(L) = (L+1)^4$   
and  $T_6(L) = (L+1)^5$ .

It can be shown [4, p. 106] that

$$T_{M}(L) = (L + 1)^{M-1}$$
,

giving the total of  $(L + 1)^{M}$   $\underline{\ell}$  vectors.

B.4 NUMBERS OF ACJ-AGC JAMMING EVENTS

From Section 4, the jamming events are described by the vector  $\underline{\ell}$  and the number of hops with at least one channel jammed,  $\ell_0$ .

B.4.1 Number of  $\{\ell_0, \ell\}$  events

For a given  $\ell_0$  and  $\underline{\ell}$ , the number of events may be counted directly using

$$\#(\ell_0,\underline{\ell}) = \binom{\mathsf{L}}{\ell_0} \sum_{\underline{\nu}_1 > \underline{0}} \dots \sum_{\underline{\nu}_{\ell_0} > \underline{0}} \delta(\mathbf{\Sigma}_{k=1} \ \underline{\nu}_k,\underline{\ell}). \tag{B.4-1}$$

Previously we have established that the number of  $\underline{\mathfrak{L}}$  vectors for n hops is

$$\mathcal{S}(\mathbf{n}) \stackrel{\Delta}{=} \sum_{\underline{\mathcal{V}}_{1}} \cdots \sum_{\underline{\mathcal{V}}_{n}} \delta(\frac{\mathbf{n}}{\mathbf{k}}, \underline{\mathcal{V}}_{\mathbf{k}}, \underline{\mathcal{L}}) \prod_{m=1}^{M} \binom{\mathbf{n}}{\mathbf{\ell}_{m}}$$
(B.4-2)

Note that this quantity is zero for  $n < \ell_x = \max_m \ell_m$ . For notational convenience, let the sum in (B.4-1) be represented as

$$S(\ell_0) = \sum_{[\nu:\ell_0] > 0} \delta(\cdot, \cdot) \equiv (\text{sum over all } [\nu] \text{ with } \ell_0 \text{ non-zero columns}$$
and M rows). (B.4-3)

Then we find that

$$\sum_{[\nu:\ell_0]>0} = \sum_{[\nu:\ell_0]} - \sum_{[\nu:\ell_0]} (at least one zero column of [\nu:\ell_0]), (B.4-4a)$$

or

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$$S(\ell_0) = S(\ell_0) - (sums with at least one zero column).$$
 (B.4-4b)

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Now, a sum with exactly n non-zero columns of [v] is equivalent to S(n), so that

$$S(\ell_0) = \mathcal{S}(\ell_0) - \sum_{n=1}^{\ell_0} {\ell_0 \choose n} S(\ell_0 - n). \qquad (B.4-5)$$

For example,

$$S(1) = S(1) - S(0) = S(1) - S(0)$$
 (B.4-6a)

$$S(2) = S(2) - 2S(1) - S(0)$$
  
=  $S(2) - 2S(1) + S(0)$  (B.4-6b)

$$S(3) = S(3) - 3S(2) - 3S(1) - S(0)$$
  
= S(3) - 3S(2) - 3S(1) - S(0). (B.4-6c)

From these examples we conjecture that

$$S(n) = \sum_{k=0}^{n} {\binom{n}{k}} (-1)^{k} S(n-k);$$
 (B.4-7)

substitution of (B.4-7) into (B.4-5) for  $\ell_0=n+1$  leads to an inductive proof. Therefore, we obtain the result

$$#(\mathfrak{l}_{0},\underline{\mathfrak{k}}) = S(\mathfrak{l}_{0})$$

$$= \begin{pmatrix} L \\ \mathfrak{l}_{0} \end{pmatrix} \sum_{r=0}^{\mathfrak{l}_{0}} \begin{pmatrix} \mathfrak{l}_{0} \\ r \end{pmatrix} (-1)^{r} \prod_{m=1}^{M} \begin{pmatrix} \mathfrak{l}_{0}-r \\ \mathfrak{l}_{m} \end{pmatrix} \qquad (B.4-8a)$$

$$= \begin{pmatrix} L \\ \mathfrak{l}_{0} \end{pmatrix} \sum_{r=0}^{\mathfrak{l}_{0}-\mathfrak{l}_{X}} \begin{pmatrix} \mathfrak{l}_{0} \\ r \end{pmatrix} (-1)^{r} \prod_{m=1}^{M} \begin{pmatrix} \mathfrak{l}_{0}-r \\ \mathfrak{l}_{m} \end{pmatrix}, \qquad (B.4-8b)$$

since terms of the sum are zero for r >  $l_0-l_x$ .

### B.4.2 <u>Summation over 20</u> events

We now demonstrate that summation of (B.4-8a) over  $\ell_0$  gives the total number of  $\underline{\ell}$  vectors. We use the fact that

$$\binom{\mathfrak{l}_0-\mathbf{r}}{\mathbf{k}} = \frac{1}{\mathbf{k}!} \quad \frac{\partial^{\mathbf{k}}}{\partial \mathbf{x}^{\mathbf{k}}} \quad (1+\mathbf{x})^{\mathfrak{l}_0-\mathbf{r}} \quad \left| \begin{array}{c} \mathbf{x}=0\\ \mathbf{x}=0 \end{array} \right| . \tag{B.4-9}$$

Substituting this M times (once for each  $\boldsymbol{\ell}_m = \boldsymbol{k}$  ) yields

$$\sum_{\ell_0=0}^{L} S(\ell_0) = \left\{ \left( \prod_{m=1}^{M} \frac{1}{\ell_m!} - \frac{\partial^{\ell_m}}{\partial x_m^{\ell_m}} \right) \sum_{\ell_0=0}^{L} \left( \begin{pmatrix} L \\ \ell_0 \end{pmatrix} \sum_{r=0}^{\ell_0} \left( \begin{pmatrix} \ell_0 \\ r \end{pmatrix} \right) (-1)^r \right\} \right\}$$
$$\cdot \left[ \prod (1+x_m) \right]^{\ell_0-r} \right\}$$

$$= \left\{ \prod_{m=1}^{M} \frac{1}{\ell_m!} \frac{1}{2\kappa_m!} \frac{\partial^{\ell_m}}{\partial x_m!} (1+x_m)^{L} \right\}^{\frac{K=0}{m}} = \prod_{m=1}^{M} {L \choose \ell_m} . \quad (B.4-10)$$

### B.4.3 <u>Summation over 2 events</u>

The number of  $i_0$  events can be found by summing (B.4-8a) over all possible  $\underline{i}$  vectors. This is found to be

$$\#(\mathfrak{L}_{0}) = \begin{pmatrix} L \\ \mathfrak{L}_{0} \end{pmatrix} \sum_{r=0}^{\mathfrak{L}_{0}} \begin{pmatrix} \mathfrak{L}_{0} \\ r \end{pmatrix} (-1)^{r} \sum_{\underline{\mathfrak{L}}} \prod_{m=1}^{M} \begin{pmatrix} \mathfrak{L}_{0} - r \\ \mathfrak{L}_{m} \end{pmatrix}$$
$$= \begin{pmatrix} L \\ \mathfrak{L}_{0} \end{pmatrix} \sum_{r=0}^{\mathfrak{L}_{0}} \begin{pmatrix} \mathfrak{L}_{0} \\ r \end{pmatrix} (-1)^{r} (\mathfrak{L}_{0} - r + 1)^{M}. \qquad (B.4-11)$$

For example,

$$\#(\ell_0=0) = 1$$
 (B.4-12)

$$\#(\mathfrak{L}_0=1) = L(2^{M}-1)$$
 (B.4-13)

$$\#(\ell_0=2) = \binom{L}{2} (3^{M} - 2 \cdot 2^{M} + 1)$$
 (B.4-14)

$$\#(l_0=L) = (L+1)^M - L \cdot L^M + {\binom{L}{2}} (L-1)^M + \dots$$
 (B.4-15)

#### APPENDIX C

### DERIVATION OF ERROR RATE EXPRESSIONS FOR "PRACTICAL ACJ" AND "PRACTICAL IC" RECEIVERS

### C.1 JOINT PDF FOR ONE PAIR OF SAMPLES (PACJ).

The error expression will be obtained for M=2 and L=2. For a single pair of square-law envelope detector samples the joint pdf is

$$P_0(x_1, x_2) = c_1 c_2 e^{-c_1 x_1 - c_2 x_2 - \rho_1} I_0(2 \sqrt{\rho_1 c_1 x_1}), \qquad (C.1-1a)$$

where

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$$c_{i} = \begin{cases} 1/2\sigma_{N}^{2}, \text{ channel unjammed;} \\ 1/2\sigma_{T}^{2}, \text{ channel jammed,} \end{cases}$$
(C.1-1b)

and the signal is assumed to be in channel 1. The normalized variables  $(z_1, z_2)$  resulting from this pair have the pdf

$$p_1(z_1, z_2) = p_a(z_1, z_2; x_1 > x_2) + p_b(z_1, z_2; x_1 < x_2).$$
 (C.1-2)

Now, when  $x_1 > x_2$ ,  $z_1$  is made equal to 1 and  $z_2 = x_2/x_1$ ; thus

$$p_{a}(z_{1}, z_{2}; x_{1} > x_{2}) = \delta(z_{1} - 1) \int_{0}^{\infty} d\zeta \zeta p_{0}(\zeta, \zeta z_{2}), \quad 0 \le z_{2} \le 1.$$
 (C.1-3)

Similarly, when  $x_2 < x_1$ ,

$$P_{b}(z_{1}, z_{2}; x_{1} < x_{2}) = \delta(z_{2} - 1) \int_{0}^{\infty} d\zeta \zeta P_{0}(\zeta z_{1}, \zeta), \quad 0 \leq z_{1} \leq 1.$$
 (C.1-4)

The result is that  $z_1$  and  $z_2$ , a single pair of normalized variables, have the joint pdf (conditioned on the possible jamming events) given by

$$p_{1}(z_{1}, z_{2}; c_{1}, c_{2}) = \frac{c_{1}c_{2}}{(c_{1}z_{1}+c_{2}z_{2})^{2}} \exp \left\{ -\frac{c_{2}z_{2}c_{1}}{c_{1}z_{1}+c_{2}z_{2}} \right\} \left[ 1 + \frac{c_{1}c_{1}z_{1}}{c_{1}z_{1}+c_{2}z_{2}} \right] \times \left[ \delta(z_{1}-1) + \delta(z_{2}-1) \right], \quad 0 \le z_{1}, z_{2} \le 1.$$
(C.1-5)

By direct integration it may be shown that

$$\Pr\{z_1 < z_2\} = \frac{c_1}{c_1 + c_2} \exp\left(-\frac{\rho_1 c_2}{c_1 + c_2}\right)$$
(C.1-6a)

and that

$$\Pr\{z_1 > z_2\} = 1 - \Pr\{z_1 < z_2\};$$
 (C.1-6t

thus the pdf integrates to unity as required.

Taking into account the four possible jamming events, the unconditional pdf may be written using

$$f(z_{1}, z_{2}) = \pi_{0} \cdot \frac{1}{(z_{1}^{+} z_{2})^{2}} \exp\left\{-\frac{\wp_{N} z_{2}}{z_{1}^{+} z_{2}}\right\} \left[1 + \frac{\wp_{N} z_{1}}{z_{1}^{+} z_{2}}\right]$$

$$+ \pi_{1} \cdot \frac{\kappa}{(z_{1}^{+} \kappa z_{2})^{2}} \exp\left\{-\frac{\kappa_{\wp_{T}} z_{2}}{z_{1}^{+} \kappa z_{2}}\right\} \left[1 + \frac{\wp_{T} z_{1}}{z_{1}^{+} \kappa z_{2}}\right]$$

$$+ \pi_{1} \cdot \frac{\kappa}{(\kappa z_{1}^{+} z_{2})^{2}} \exp\left\{-\frac{\wp_{N} z_{2}}{\kappa z_{1}^{+} z_{2}}\right\} \left[1 + \frac{\wp_{N} \kappa z_{1}}{\kappa z_{1}^{+} z_{2}}\right]$$

$$+ \pi_{2} \cdot \frac{1}{(z_{1}^{+} z_{2})^{2}} \exp\left\{-\frac{\wp_{T} z_{2}}{z_{1}^{+} z_{2}}\right\} \left[1 + \frac{\wp_{T} z_{1}}{z_{1}^{+} z_{2}}\right];$$

$$0 \leq z_{1}, z_{2} \leq 1. \quad (C.1-7)$$

With this function the unconditioned pdf becomes

$$p_1(z_1, z_2) = f(z_1, z_2) [\delta(z_1 - 1) + \delta(z_2 - 1)].$$
 (C.1-8)

C.2 JOINT PDF FOR SUMS OF TWO SAMPLES (PACJ).

Using convolution, the joint pdf for L=2 is

$$p_{2}(z_{1},z_{2}) = \int_{0}^{\min(1,z_{1})} \int_{0}^{\min(1,z_{2})} dv_{2} p_{1}(v_{1},v_{2})p_{1}(z_{1}-v_{1},z_{2}-v_{2}), \quad (C.2-1)$$

$$\max(0,z_{1}-1) \max(0,z_{2}-1)$$
which reduces to

which reduces to

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$$p_{2}(z_{1}, z_{2}) = \delta(z_{1}-2) \int_{0}^{0} \frac{dv_{2}}{dv_{2}} f(1, v_{2})f(1, z_{2}-v_{2}) \\ \max(0, z_{2}-1) \\ + 2f(1, z_{2}-1)f(z_{1}-1, 1)u(z_{2}-1)u(z_{1}-1)$$

+ 
$$\delta(z_2-2) \int_{dv_1}^{min(1,z_1)} f(v_1,1)f(z_1-v_1,1),$$
 (C.2-2)  
max(0,z\_1-1)  
 $0 \le z_1, z_2 \le 2.$ 

C.3 ERROR PROBABILITY FOR L=2 (PACJ).

The error probability is, using (C.2-2),

$$P(e) = Pr\{z_{2} > z_{1}\} = 2 \int_{1}^{2} dz_{2} \int_{1}^{z_{2}} dz_{1}f(1, z_{2} - 1)f(z_{1} - 1, 1) + \int_{0}^{1} dz_{2} \int_{0}^{z_{2}} dv_{1}f(v_{1}, 1)f(z_{1} - v_{1}, 1) + \int_{1}^{2} dz_{2} \int_{z_{2} - 1}^{1} dv_{1}f(v_{1}, 1)f(z_{1} - v_{1}, 1).$$
(C.3-1)

C-3

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Manipulation of the integrals yields

$$P(e) = 2 \int_{0}^{1} dx f(1,x) \int_{0}^{x} dy f(y,1)$$
  
+  $\int_{0}^{1} dx \int_{0}^{x} dy f(y,1) f(x-y,1)$   
+  $\int_{0}^{1} dx \int_{x}^{1} dy f(y,1) f(x+1-y,1)$  (C.3-2)  
=  $2 \int_{0}^{1} dx f(1,x) G(x)$   
+  $\int_{0}^{1} dy f(y,1) G(1-y)$   
+  $\int_{0}^{1} dy f(y,1) [G(1) - G(1-y)]$  (C.3-3)  
=  $2 \int_{0}^{1} dx f(1,x) G(x) + G^{2}(1),$  (C.3-4)

where G(x) is defined as

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$$G(x) \stackrel{\Delta}{=} \int_{0}^{X} du f(u,1) \qquad (C.3-5)$$

$$= \pi_{0} \cdot \frac{x}{1+x} \exp \left\{ -\frac{\rho_{N}}{1+x} \right\}$$

$$+ \pi_{1} \cdot \frac{x}{K+x} \exp \left\{ -\frac{K\rho_{T}}{K+x} \right\}$$

$$+ \pi_{1} \cdot \frac{Kx}{1+Kx} \exp \left\{ -\frac{\rho_{N}}{1+Kx} \right\}$$

$$+ \pi_{2} \cdot \frac{x}{1+x} \exp \left\{ -\frac{\rho_{T}}{1+x} \right\}. \qquad (C.3-6)$$

Analytically it can be shown that, for  $\pi_0 = 1$  (no jamming) or  $\pi_2 = 1$  (full-band jamming), the P(e) equals

$$P(e) = \frac{1}{2} e^{-\rho} (1+\rho/3), \qquad (C.3-7)$$

where  $\rho = \frac{1}{2} \frac{E_b}{N_0}$  for  $\pi_0 = 1$  and  $\rho = \frac{1}{2} \frac{E_b}{N_T}$  for  $\pi_2 = 1$ . This is precisely the same performance obtained by the self-normalizing receiver in Section 5, for the same conditions.

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C.4

JOINT PDF FOR ONE PAIR OF SAMPLES (PIC).

The joint pdf of the usual and the look-ahead receiver square-law envelope detector samples is

$$p_{0}(u_{1}, u_{2}, v_{1}, v_{2}) = c_{1}^{2}c_{2}^{2}e^{-c_{1}(u_{1}+v_{1})-c_{2}(u_{2}+v_{2})}I_{0}(2\sqrt{\rho_{1}c_{1}u_{1}}), \quad (C.4-1)$$

where the constants are defined in (C.1-1b). The normalized variables are  $z_{1k} = u_1/v_1$  and  $z_{2k} = u_2/v_2$ , with the joint pdf

$$p_{z1k,z2k}(\alpha,\beta) = \int_{0}^{\infty} dv_{1} \int_{0}^{\infty} dv_{2} v_{1}v_{2}p_{0}(v_{1}\alpha,v_{2}\beta,v_{1},v_{2})$$
$$= \frac{1}{(1+\beta)^{2}} \cdot \frac{1}{(1+\alpha)^{2}} \cdot \exp\left\{-\frac{\rho_{1}}{1+\alpha}\right\} \left[1 + \frac{\rho_{1}\alpha}{1+\alpha}\right] \qquad (C.4-2a)$$

$$= p_1(\beta;0) p_1(\alpha;\rho_1); \quad \alpha,\beta > 0.$$
 (C.4-2b)

That is, the normalized variables are independent. Note that the jamming conditions are present only in the SNR,  $\rho_1$ .

C.5 CDF FOR SUM OF TWO NON-SIGNAL VARIABLES (PIC).

Since the two channels are independent, we may first derive the probability that the non-signal sum  $z_2$  is greater than the signal channel sum  $z_1$ , given a specific value of  $z_1$ , then later average over  $z_1$  to get the error probability. Formally,

$$\Pr\left(z_{2}>z_{1}|z_{1}=\alpha\right) = 1 - F_{2}(\alpha), \qquad (C.5-1)$$

C-6

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where  $F_2(\alpha)$  is the cumulative distribution function for  $z_2$ . This function is found to be

$$F_{2}(\alpha) = \Pr \left\{ z_{2} = z_{21} + z_{22} \le \alpha \right\}$$

$$= \int_{0}^{\alpha} \frac{dx}{(1+x)^{2}} \int_{0}^{\alpha - x} \frac{dy}{(1+y)^{2}}$$

$$= \int_{0}^{\alpha} \frac{dx}{(1+x)^{2}} \left[ 1 - \frac{1}{\alpha - x + 1} \right]$$

$$= \frac{\alpha}{1+\alpha} - \int_{0}^{\alpha} \frac{dx}{(1+x)^{2}} \cdot \frac{1}{(\alpha - x + 1)} \quad . \quad (C.5-2)$$

Using a partial-fraction expansion results in

$$\Pr \{z_{2} > z_{1} | z_{1} = \alpha\} = \frac{1}{(\alpha + 2)^{2}} \left\{ \int_{0}^{\alpha} dx \frac{x + 3 + \alpha}{(1 + x)^{2}} + \int_{0}^{\alpha} \frac{dx}{1 + \alpha - x} \right\} + \frac{1}{1 + \alpha}$$
$$= \frac{2}{(\alpha + 2)^{2}} [\alpha + 2 + \ln(\alpha + 1)].$$
(C.5-3)

C.6 ERROR PROBABILITY FOR L=2 (PIC).

The pdf for  $z_1$  is the convolution

$$p_{z1}(\alpha) = p_{1}(\alpha;\rho_{1}) * p_{1}(\alpha;\rho_{2})$$
  
= 
$$\int_{0}^{\alpha} dx p_{1}(x;\rho_{1}) p_{1}(\alpha-x;\rho_{2}) , \alpha > 0.$$
 (C.6-1)

and the second state of the second state of the

Thus the error probability is, conditioned on  $\rho_1$  and  $\rho_2$ ,

$$P_{b}(e|\rho_{1},\rho_{2}) = 2 \int_{0}^{\infty} d\alpha \frac{\alpha + 2 + ln(\alpha + 1)}{(\alpha + 2)^{2}} \int_{0}^{\alpha} dx p_{1}(x;\rho_{1})p_{1}(\alpha - x;\rho_{2})$$
$$= 2 \int_{0}^{\infty} d\alpha \int_{0}^{\infty} dx p_{1}(\alpha;\rho_{1})p_{1}(x;\rho_{2}) \cdot \frac{\alpha + x + 2 + ln(\alpha + x + 1)}{(\alpha + x + 2)^{2}} \quad (C.6-2)$$

Transforming the integration variables by

$$u = \frac{1}{1+\alpha}$$
,  $v = \frac{1}{1+x}$  (C.6-3)

results in the expression

$$P_{b}(e|\rho_{1},\rho_{2}) = 2 \int_{0}^{1} du \int_{0}^{1} dv e^{-\rho_{1}u-\rho_{2}v} (1+\rho_{1}-\rho_{1}u)(1+\rho_{2}-\rho_{2}v) \\ \times \left(\frac{uv}{u+v}\right)^{2} \left[\frac{u+v}{uv} + \ell_{n}\left(\frac{u+v}{uv} - 1\right)\right].$$
(C.6-4)

Averaging over the jamming events (the number of hops jammed in the signal channel) yields the total error

$$P_{b}(e) = (1-\gamma)^{2} P_{b}(e|_{p_{1}=p_{2}=E_{b}/2N_{0}})$$

$$+ 2\gamma(1-\gamma) P_{b}(e|_{p_{1}=E_{b}/2N_{0}},_{p_{2}=E_{b}/2N_{T}})$$

$$+ \gamma^{2}P_{b}(e|_{p_{1}=p_{2}=E_{b}/2N_{T}}). \qquad (C.6-5)$$

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#### APPENDIX D

### COMPUTER PROGRAM FOR SQUARE-LAW LINEAR COMBINING RECEIVER

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the square-law linear combining receiver for FH/RMFSK.

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57 88 88 8888888	P-11 F( F5KN1HE 568 569 577 772 772 773 771 773 776 777 778 777 778	3. FTN: 11 3. FTN: 11 3. 5 5 5 5 5 5 5 7 40 5 7 42 7 42 7 42 7 42 5 7 42 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	7 V4.0-1 09:41:35 16-Jul-86 Page 3 / /F77/TR:BLOCKS/WR READ(4) MMIN, LLIN, EBNOIN, NSL IN, GAMIN IF(MMIN.NE.MM. OR. LLIN.NE.LL .OR. EBNOIN.NE.DEBNOL(10) .OR. GAMIN.NE.GAMMA.OR. NSLIN.NE.NSLOTS) STOP 'FILE SYNC ERROR OR CORRUPTED FILE' JJ=0 OPEK(UNIT=6,FILE='FOROO6.DAT',STATUS='OLD',FORM='FORMATTED', ACCESS='APPEND') JJ=JJ+I JJ=JJ+I JJ=JJ+I JJ=JJ+I STOP (4,END=742) DBS.R(JJ), PRLOG(JJ) NRITE(6.666) DBS.R(JJ), PRLOG(JJ) NRITE(6.666) DBS.R(JJ), PRLOG(JJ) NRITE(6.666) DBS.R(JJ), PRLOG(JJ) READ(4,END=742) DBS.R(JJ), PRLOG(JJ) READ(4,END=742) DBS.R(JJ), PRLOG(JJ) STOP 760 CLOSE(UNIT=4) CLOSE(UNIT=6) GOTO 755 STING FILE, THIS IS THE FIRST TIME: CREATE FILE MEADER RECORD
55555 55555 D-3		C 750 755 735 3939 3939 3939 5 AND CI	JJ=1 OPEK(UMIT=4,FILE=FNAME,STATUS='NEW',FORM='UNFORMATTEU') WRITE(4) MM,LL,DEBMOL(IO),MSLOTS,GAMMA CLOSE(UNIT=4) NRITE(GMAME,735) MM,LL,IGOU? FORMATT'EV',11,11,11,14,4,',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,44,4',0AT') FORMATT'EV',11,11,11,11,44,4',0AT') FORMATT'EV',11,11,11,11,44,4',0AT') FORMATT'EV',11,11,11,11,11,11,11,11,10,11,11,11,11,
8888 88888 8888	190 1995 1995 1996 1996 1996 100 100 100 100 100 100 100 100 100 10	3938 3938 5 777 601 601	CONTINUE WRITE(5,393R) FORMATT' CREATIME EVENT FILE') CALL GENPIE(LL,MM,WO,MSLOTS,GOOD,MATRIX,MLOW,MINC,MUP,PIE, D.1DSUB,NUSED) OPEN(UNIT=3,FILE=BANME,STATUS='MEW',FORM='UNFORMATTED') WRITE(3) D.1DSUB,NUSED,GOOD CLOSE(UNIT=3) IF(.MOT.GOOD) GOTO 7C0 D0 6600 13-3J,NJ FORMAT('13-1) POGRESS MESSAGE TO TI: WRITE(5,601) 1J FORMAT('13-1)*OBINC DEBNJ=STARI+(1J-1)*OBINC
86888	06 02 06 <b>0</b>		IF(MM.LE.4) THEN HIGH=DEBMJ.GE.15.DO ELSE HIGH=DEBNJ.GT.30.DO END IF

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PDP-11 FO	RTRAN-7 .FTN;13	7 <b>v4</b> .0-1 1 /F77/TI	09:41:35 3:BLOCKS/WR	16-Jul-86	Page 4	
0109 0110		DBSJR(1J)=DEBN. R=10_D0**(DEBN.	) (00.01/1			
1110		RHOTS=GAMMA*R*I	BNO/ (GAMMA+R+	FEBMO)		
0112		RHOT=K*RHOTS/FI	-			
J	EVALUA	VTE THE PROBABJI	11Y			
0113		CALL PSUBE(RHON	N, RHOT, LL, MM, F	PESM.D. IDS	UB, MUSED, PRERR, IPSUB)	
0114		PE=NORBIT*PESM	-			
0115		OPEN(UNIT=6.FII	LE= 'FOR006. DA1	r . STATUS= "	DLD' FORM= 'FORMATTED'	
		ACCESS= A	PEND')			
0116		MRITE(6,666) DI	SJR(IJ) .PE			
0117		CLOSE(UNIT=6)				
0118	666	FORMAT(1X, F7.3	5X,1P012.5)			
0119		PRLOG( 1J) * DLOG	10(PE)			
0120		OPEN(UNIT=4,FII	E=FNAME STATU	15= 10LD . ACI	CESS='APPEND',	
	~	FORM= "UNFI	DRMATTED <sup>1</sup> )	•		
0121		WRITE(4) DBSJR(	(1)), PRLOG(1)	6		
0122		CLOSE(UNIT=4)	•			
0123	<b>00</b> 9	CONTINUE				
0124		OPEN(UNIT=4,FII	E=FNAME, STATU	IS= 'NEW' , FOI	WH='UNFORMATTED')	
0125		<b>MRITE(4) MM, LL</b>	DEBNOL ( TO) . NS	SLOTS, GAMMA	DBSJR, PRLOG	
0126		CLOSE(UNIT=4)		•		
0127	200	CONTINUE				
0128	800	CONTINUE				
0129	8	CONTINUE				
0130		STOP PLEASE PL	JRGE DATA FILE	ŝ		
0131		ENU				

OD01         SUBROUTINE GET(NA, START, DBJNC)           C002         INFLICIT DOUBLE PECISION(A-H, Q-2)           C003         CUMARCTER-9 FIELD, BLANKO           C003         CUMARCTER-9 FIELD, BLANKO           C003         CONON / JIPUTS/D EROLOGI, LLIST(A), MSLOTS, GANLST(A)           C003         CONON / JIPUTS/D EROLOGI, LLIST(A), MSLOTS, GANLST(A)           C004         STANKO, M., MG           C005         CONON / JIPUTS/D EROLOGI, JI, LIST(A), MSLOTS, GANLST(A)           C006         DIAL BLANKO           C007         MALTEL, STSTEPPODARLIV MEEDED ARE IN SHARED STORAGE N           C007         MALTALLISTS TENPODARLIV MEEDE ARE IN SHARED STORAGE N           C007         MALTALLASTS TENPODARLIV MEEDE ARE IN SHARED STORAGE N           C007         MALTALLASTS TENPODARLIV MEEDE ARE IN SHARED STORAGE N           C0003         STALALANCY           D003         TORAT (E, ANO)           D014         Z           C0012         MALTEL, STANBOL (K) [2]: ·, S)           D014         Z           C0012         MALTEL, MANY EB/NO? [1]: ·, S)           D013         TORAT(E, ANN)           D014         Z           D015         TORAT(C, S)           D015         TORAT(C, S)           D014         Z <th>F SKN</th> <th></th> <th></th> <th></th> <th></th> <th>13 /F77/TR:BLOCKS/MR</th> <th></th>	F SKN					13 /F77/TR:BLOCKS/MR	
CINTERACTIVE INPUT OF PARAMETERS FOR RUN           C002         INFERACTIVE INPUT OF PARAMETERS FOR RUN           C003         CUMMARTIEN-9FIELD.BLANK9           C004         JINUTSJ DERPODARILY MEEDE ARE IN SHARED STORAGE W           C005         COMMAN / JINUTSJ DERPODARILY MEEDE ARE IN SHARED STORAGE W           C0001         COMMAN / JINUTSJ DERPODARILY MEEDE ARE IN SHARED STORAGE W           C0003         COMMAN / JINUTSJ DERPODARILY MEEDE ARE IN SHARED STORAGE W           C0004         SISTASTENPODARILY MEEDE ARE IN SHARED STORAGE W           C0005         DATA BLANKOV           C0001         MATA BLANKOV           C0011         FORMATI (JINUTS) DERAFORMED (K) [2]: ·,\$)           D0112         COMMAT (JINUTS) DERAFOR (K) [2]: ·,\$)           D0112         DATA BLANKOV           D0112         DATA BLANKOV           D0112         PORMATI (F) AN MANY EB/NO? [1]: ·,\$)           D0112         DATA BLANKOV           D0112         DATA BLANKOV           D0112         DATA BLANKOV           D0113         TERANCS           D0113         TERANCS           D0113         TERANCS           D0114         TERANCS           D0115         TERANCS           D0115         TERANCS           <	õ	L	SUBROUTINE GET(N.J., START, DBINC)	0048	24	FORMAT(15)	
CO02         IMPLICIT DOUBLE PRECISION(A.H., O-Z)           C003         COMMANTTREPS FIELD.BLANNES           C003         COMMANTTREPS FIELD.BLANNES           C003         COMMANTTREPS FIELD.BLANNES           C004         SIZE           C005         COMMANTTREPS FIELD.BLANNES           C006         COMMANTTREPS FIELD.BLANNES           C007         COMMANTTREPS FIELD.BLANNES           C007         COMMANTTRES           C007         COMMANTTRES           C008         COMMANTTRES           C001         SIREC           D011         FIREC           D012         FIREC           FIREC         FIREC           D012         FIREC           D013         FIREC           FIREC         FIREC           D013         FIREC           D013         FIREC		LINI JUL	RACTIVE INPUT OF PARAMETERS FOR RUN	1000 1000 1000	52	JF (NSLDTS.EQ.0) %SLDTS=2400 MRTTE(5,26)	
0003         COMMANCTERPS FIELD, BELANNEG           0003         COMMANCTERPS FIELD, BELANNEG           0005         COMMON FJIZF, TREUDE ANE IN SHARED STORAGE W           0005         COMMON FJIZF, TREUDE ANE IN SHARED STORAGE W           0005         COMMON FJIZF, TREUDE ANE IN SHARED STORAGE W           0006         DATA BLANNE()           0007         STERAUT LISTS TEMPONATILY NEEDED ANE IN SHARED STORAGE W           0008         DATA BLANNE()           0013         REAUCT STORAGE ANE STORAGE W           0011         THE LARGE CONVECUTION MORKING ARRAYS           00112         NAMED STORAGE ANE STORAGE W           00112         REAUS, SJN           00112         REAUS, SSTENDOL (K) [2]: ',S)           00112         REAUS, SSTENDOL           0012         REAUS, SSTENDOL           0013         REAUS, SSTENDOL	202	J	IMPLICIT DOUBLE PRECISION(A-H,0~Z)	1900	<b>5</b> 6	FORMAT(* HOW MANY GAMMA? [IN]: *.\$) READ(5.3)NG	
ODOS         COMMON /SIZE/ MO, NL, MG           C THE LLARE CONVEUTION MERLING ARRAYS         NARAYS           C THE LLARE CONVEUTION MERLING ARRAYS         NARAYS           C THE LLARE CONVEUTION MERLING ARRAYS         NARAYS           C THE LLARE CONVEUTION MERLING (31), DSNR(5, 4)         DATA BLANKY/           DODD         DATA BLANKY/         STARAYS           C THE LLARE CONVEUTION MERLING (31), DSNR(5, 4)         DATA BLANKY/           DODD         DATA BLANKY/         STARAYS           DODD         DATA BLANKY/         STARAYS           DODD         DATA BLANKY/         NARAYS           DODD         DATA BLANKY/         STARAYS           DODD         DATA BLANKY/         NARAYS           DODD         DATA BLANKY/         NARAYS           DODD         DATA PLAN         NARAYS           DODD         DATA PLAN         NARY           DODD         DATA PLAN         NARY           DODD         THEN         NARY           DODD         THEN         NARY           DODD         THEN         NARY           DODD         THAN         NARY           DODD         THEN         NARY           DODD         THEN         NARY <td>őğ</td> <td></td> <td>CHARACTER+9 FIELD,BLANK9 COMMON /inPUTS/ DEBNOL(5).LLIST(4).NSLOTS.GANLST(31).K.MM</td> <td>0054 0054</td> <td></td> <td>IF(MG.ÉQ.O)NG=10 DO 31 1M=1 MG</td> <td></td>	őğ		CHARACTER+9 FIELD,BLANK9 COMMON /inPUTS/ DEBNOL(5).LLIST(4).NSLOTS.GANLST(31).K.MM	0054 0054		IF(MG.ÉQ.O)NG=10 DO 31 1M=1 MG	
C THE LARGE CONVELUTION MARLIN RELEUE MAR IN SHAVELD STORAGE W C THE LARGE CONVELUTION UNRELING MARIANS CODOR 32 RUTE(5,33) CODOR 33 FORMAT(* BITS/SYMBOL (K) [2]: •,\$) CODOR 53 FORMAT(12) CODOR 53 FORMAT(12) CODOR 54 FORMAT(12) CODOR 56 FORMAT(12) CODOR 56 FORMAT(5,5) M.CO CODOR 56 FORMAT(7, MON MANY L? [4]: •,\$) FORMAT(7) HOW MANY L? [4]: •,\$) FORMAT(7) HOW MANY L? [4]: •,\$) FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 56 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$) CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$] CODOR 57 FORMAT(7) HOW MANY L? [4]: •,\$] CODOR 50	<b>XO5</b>		COMMON /SIZE/ NO.NL.NG	0055	28	MRIFE(5,29) IN, DG(IN)	
0006 COMECY /SHARE/ DG(31), DSNA(5, 4) 0013 32 REIR(5, 33) 0013 11 REIR(5, 33) 0014 2 FORMAT(1' BITS/SYMBOL (K) [2]: •, \$) 0015 11 REIR(5, 2) 0015 11 REIR(5, 2) 0010 11 REIR(1, 1, 1) 0010 11 REIR(1, 1) 0010			ILI LISIS TEMPUMANILT MEEUEU ANE IN SHAKLU STURAGE WITH ARGE CONVCLUTION MORKING ARRAYS	0056 0057	62	FORMAT(' GUUDNA(',I2,') [',1PD8.1,']: ',\$) READ(5 30)GAMM ST(1M)	
0000       32       WHITE GLANKAVY       Y         0011       WHITE GLANKAVY       Y         0012       WHITE GLANKAVY       Y         0013       WHITE GLANKAY       Y         0013       WHITE GLANKAY       Y         0013       WHITE GLANKAY       Y         0013       WHITE GLANKAY       Y         0014       Z       FORMATI' HON MANY EB/NO? [1]: •, \$)         0015       J       FORMATI' HON MANY EB/NO? [1]: •, \$)         0016       J       FORMATI' HON MANY EB/NO? [1]: •, \$)         0015       J       FORMATI' HON MANY EB/NO? [1]: •, \$)         0016       J       FORMATIZ'         0017       J       J         0018       DO-OLOO       DO-OLOO         0022       GO-OLOO       DO-OLOO         0023       HOI JF       J         0023       GUO-OLOO       J         0033       GUO-OLOO       J         0033	89		COMPON /SHARE/ DG(31), DSNR(5,4)	0058	30	FORMAT(015.8)	
0009         33         FORMATI' BITS/SYMBOL (K) [2]: ',5)           0011         NETE(5.0)K=2         NETE(5.0)K=2           0012         NETE(5.0)K=2         NETE(5.2)           0013         NETE(5.2)         NETE(5.2)           0014         Z         FORMAT(12)           0015         3         FORMAT(12)           0016         3         FORMAT(12)           0015         3         FORMAT(12)           0016         3         FORMAT(12)           0018         NG         EQ.0)NO=1           0019         NG         FORMAT(12)           0019         NG         E.           0017         NG         EQ.0)NO=1           0002         E.         NG           0002         NG         NG           0002         NG         NG           0002         NG         NG           002         NG         NG           002	ŝ	32	UAIA BLARKY/ '/ '/ WAIA BLARKY/ '/ WAIA BLARKY/ '/ '/ WAIA BLARKY/ '/ '/ WAIA BLARKY/ '/ '/ WAIA BLARKY/ '/ '/	0059	1	IF(GAMLST(IN).EQ.0.DO)GAMLST(IN)=DG(IN) CONTIMUE	
OUTU         FKAN(S, S) MK           0011         FF(K.ES.O)K=2           0012         FF(K.ES.O)K=2           0013         FF(K.ES.O)K=2           0014         FF(MATT' HOW MANY EB/NO? [1]: ',S)           0015         FF(MATT' HOW MANY EB/NO? [1]: ',S)           0016         FF(MC.EQ.D)MO=1           0017         FF(MC.EQ.D)MO=1           0018         FF(MC.EQ.D)MO=1           0019         FF(MC.EQ.D)MO=1           0019         FF(MC.EQ.D)MO=1           0019         FF(MC.EQ.D)MO=1           0019         FF(MC.EQ.D)MO=1           0022         FONDATT(2)           0023         FONDATT(2)           0024         MTHE(S,S) IN, DO           0025         FONDATT(2)           0027         ELSE           0028         FONDATT(2)           0027         FONDATT(2)           0028         FONDATT(2)           0029         FONDATT(2)           0023         FONDATT(2)           0023         FONDATT(2)           0023         FONDATT(2)           0023         FONDATT(2)           0023         FONDATT(2)           0023         FONDATT(2)	8	33	FORMAT(' BITS/SYMBOL (K) [2]: ',S)	0061	38	WR1TE(5,39)	
0012 WETE(5,2) 0014 Z FORMAT(12) 0016 3 FORMAT(12) 0016 3 FORMAT(12) 0015 FORMAT(12) 0017 FORMAT(12) 0018 FORMAT(12) 0019 FORMAT(12) 0019 FORMAT(12) 0019 FORMAT(12) 0021 ELSE 0022 BOD FORMAT(12,1) F,F9.6,'1:',5) 0023 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0025 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0025 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0025 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0026 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0027 ELSE 0028 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0028 FORMAT(12,6) ELAMC(1,12,1) F,F9.6,'1:',5) 0028 FORMAT(12,6) FIELD 0028 FORMAT(12,6) FIELD 0029 FORMAT(12,6) FIELD 0029 FORMAT(12,6) FIELD 0029 FORMAT(15,6) FIELD 0020 FORMAT(15,6) FIELD 0020 FORMAT(15,6) FIELD 0020 FORMAT(15,6) FIELD 0021 FORMAT(15,6) FIELD 0022 FORMAT(15,6) FIELD 0023 FORMAT(15,16) FIELD 0020 FIELD 0023 FORMAT(15,16) FIELD 0023 FORMAT(15,16) FIELD 0023 FORMAT(15,16) FIELD 0023 FORMAT(15,16) FIELD 0023 FORMAT(15,16) FIELD 0023 FORMAT(15,16) FIELD 0023 FIELD 0024 FIELD 0025 FORMAT(15,16) FIELD 0025 FIELD 0026 FIELD 0027 FIELD 0027 FIELD 0027 FIELD 0027 FIELD 0027 FIELD 0027 FIELD 0028 FIELD 0028 FIELD 0029 FIELD 0028 FIELD 0029 FIELD 0029 FIELD 0020 FIEL			READ(5,3)K IF(K FA D)Y=2	0062	<del>6</del> 6	FORMAT(' HOW MANY EB/NJ? []]: '.\$) DEAD(E 24 EDD_201 E) '.	
0013       1       MKITE(5,2)         0016       3       FORMAT(12)         0016       3       FORMAT(12)         0016       3       FORMAT(12)         0011       7       FORMAT(12)         0012       FORMAT(12)       FORMAT(12)         0013       FORMAT(12)       FORMAT(12)         0014       7       FORMAT(12)         0015       FORMAT(12)       FORMAT(12)         0016       FORMAT(12)       FORMAT(12)         0017       FORMAT(12)       FORMAT(12)         0021       FORMAT(12)       FORMAT(14,K)         0022       FORMAT(14,K)       FORMAT(14,K)         0023       FORMAT(14, ES,5) N, DO       FORMAT(14,K)         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO         0025       FORMAT(16, ES,5) N, DO       FORMAT(16, ES,5) N, DO	21			0064	34	FORMAT(13)	
0015       FORMAT(12)       FORMAT(12)         0011       FORMAT(12)       FORMAT(12)         0012       FORMAT(12)       FORMAT(12)         0013       FORMAT(12)       FORMAT(12)         0014       FORMAT(12)       FORMAT(12)         0015       FORMAT(12)       FORMAT(12)         0019       FC(K.LE.4)       THEN         0021       FORMAT(12)       FORMAT(12)         0022       END F       FORMAT(12)         0023       FORMAT(12)       FORMAT(12)         0025       FORMAT(12)       FORMAT(12)         0025       FORMAT(12)       FORMAT(12)         0026       FORMAT(12)       FORMAT(12)         0027       FORMAT(12)       FORMAT(12)         0028       FORMAT(12)       FORMAT(13)         0029       FORMAT(12)       FORMAT(13)         0021       FORMAT(12)       FORMAT(13)         0022       FORMAT(12)       FORMAT(13)         0023       FORMAT(13)       FORMAT(13)         0023       FORMAT(13)       FORMAT(13)         0023       FORMAT(13)       FORMAT(13)         0023       FORMAT(13)       FORMAT(14)         0023       FORM				0065		IF(NJ.EO.O) NJ=1	
0016 3 F(K.LE.4) THEN 0019 F(K.LE.4) THEN 0022 B0 7 IN=1,M0 0022 B0 5 F(K.LE.4) THEN 0023 ELSE 00=0.D0 0025 5 F(R.LE.4) F(K.LE.4) 0025 6 F(R.LD.5) F(K.LE.4) 0026 F(R.LD.6) F(R.LD.6) 0026 F(R.LD.6) F(R.LD.6) 0027 6 F(R.LD.6) F(R.LD.6) 0028 F(F.ELD.60.8LAMK9) THEN 0029 F(F.ELD.60.8LAMK9) THEN 0029 F(F.ELD.60.8LAMK9) THEN 0021 F(F.ELD.60.8LAMK9) THEN 0023 F(F.ELD.60.8LAMK9) THEN 0033 F(F.ELD.60.8LAMK9) THEN 0033 F(F.ELD.60.8LAMK9) THEN 0033 F(F.ELD.60.8LAMK9) THEN 0033 F(F.ELD.60.8LAMK9) THEN 0033 F(F.ELD.60.8LAMK9) THEN 0034 F(F.ELD.60.8LAMK9) THEN 0035 F(F.ELD.60.8LAMK9) THEN 0044 F(F.ELD.60.0)LLIST(IN).EN 0045 F(F.ELD.60.0)LLIST(IN).EN 004		7	FURDIAI( HOW MANY EB/NU? [I]: ',5) Deadire 2) mo	0066 2067		IF(HJ.LT.O .OR. NJ.GT.126) GOTO 32	
C017 [F(M0.EQ.0)M0=1 0019 [F(K.LE.4) THEN 0020 D0-D5MR(IN.K) 0021 ELSE 0025 ELSE 000-0.D0 ELSE D0-0.D0 END FF 0025 FND FF(LLD.ED.ED.M0(*,12,') [',F9.6,']: ',5) END FF 0026 FND FF(LD.ED.BLANK9) [',F9.6,']: ',5) END FF 0027 END FF 0028 ELSE 0021 FF(FLLD.ED.BLANK9) THEN 0028 ELSE 0021 FF(FLLD.ED.BLANK9) THEN 0029 ELSE 0021 FF(FLLD.ED.BLANK9) THEN 0029 ELSE 0021 FF(FLLD.ED.BLANK9) THEN 0021 FF(FLLD.ED.BLANK9) THEN 0023 ELSE 0021 FF(FLLD.ED.BLANK9) THEN 0023 ELSE 0023 ELSE 0023 ELSE 0023 END FF 0023 ELSE 0023 END FF 0023 ELSE 0023 ELSE	16	Ē	FORMAT(12)	0068	<b>6</b>	MALIE(5,41) FARMAT(* STARTING VALUE FAR ERVIT (AR) FA ]. * *)	5
0019         DU// IM=1,00           0021         DD-DSMR(IN,K)           0022         ELSE           0023         ELSE           0024         MITE(5,5)IN,00           0025         END IF           0026         D0-0.00           0027         END IF           0028         END IF           0027         END IF           0028         END IF           0027         END IF           0028         END IF           0029         ERMOS(5)ELELD           0021         ERMOS(IN)=DD           0022         ERMOS(IN)=DD           0023         EF(FIELD-EO_BLANK9) THEN           0023         ERMOS(IN)=DD           0023         EFADIS-6)FIELD           0033         ESBODC(IN)=DD           0033         ESBODC(IN)=DD           0033         END IF	<u>[</u> ]		IF(MO.EQ.0)MO=1	0069	!	READ(5,42,ERR=40) START	-
0021         Diversion finance           0023         ELSE         Diveo.DO           0024         MITE(5,5)IN,DO         ELSE           0025         5         FND IF         Diveo.DO           0026         FND IF         ERMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0027         6         FORMAT(A)         ERMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0028         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0029         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0029         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0033         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0033         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0033         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0033         ERADIS, 6) FILLD         DOMOR (10, ER/MO(*,12,*) [*,F9.6,*1]: *,5)           0033         END FIRE(S, 19, IN, IN         DOMOR (10, ER/MO(*,12,*) [*,F1],*,*)	R		00 / 14=1,00 TE/Y IE A) THEN	0020	42	FORMAT(F6.3)	
0021 ELSE 0023 BO0-0.D0 0024 A MITE(5,5)IN,D0 0025 5 FORMAT(* E&/MO(*,12,') [',F9.6,']: ',5) 0026 FORMAT(A9) 0027 6 FORMAT(A9) 1F(FIELD.EC0.BLANK9) THEN 0028 EFAD(5,6)FIELD 0029 DESMOL(IN)=D0 0029 ELSE 0031 DECODE(9,61,FIELD)DEBMOL(IN) FORMAT(F9.6) 0033 EISE 0033 END IF 0033 END IF 0033 END IF 0033 END IF 0033 END IF 0033 EAD(5,9)NL 16(NLE0.0)NL-4 0030 B WITE(5,19)IN,IN 0041 19 PEAD(5,9)NL,IN 0041 19 PEAD(5,9)NL,IN 0042 23 MRITE(5,19)IN,IN 0044 21 CONTINUE 0046 23 FORMAT(* L(',11), [',11,']: ',5) 0046 23 FORMAT(* CONTINUE 0041 19 PEAD(5,2)HLIST(IN).EN 0045 23 MRITE(5,2) 0046 23 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0047 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0047 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0047 FORMAT(* CONTE 0047 FORMAT(* CONTE 0046 20 FORMAT(* CONTE 0047 FORMAT(* CONTE 0047 FORMAT(* CONTE 0047 FORMAT(* CONTE 0046 FORMAT(* CONTE 0047 FORMAT(* FORMAT(* CONTE 0047 FORMAT(* CONTE 0047 FORMAT(* FORMAT(* FORMAT(* CONTE 0047 FORMAT(* FORMAT(* CONTE 0047 FORMAT(* FORMAT(* FORMAT(* CONTE 0047 FORMAT(* FORMAT(* FORMAT(* FORMAT(* CONTE 0047 FORMAT(* FORMAT(	28		DO=DSMRf IN_K)	0072	35	JP(MJ.EU.I) KEIUKN LRTTF/S 3K)	
0022         DD=0.DO           0023         4         WITE(5,5)1N,DO           0025         5         FORMAT(' E&/MO(',12,') [',F9.6,'1: ',5)           0025         5         FORMAT(A)           0027         6         FEMO(5,5)1N,DO           0027         6         FORMAT(A)           0028         FEMO(5,6)FIELD         DO=0.DO           0029         FEMO(5,6)FIELD         DO=0.DO           0029         FEMO(1N)=DO         DO           0029         FERO(5,6)FIELD         DO=0.DO           0029         FERO(7,1N)=DO         DO           0031         DECODE(9,61,FIELD)DEBMOLIN)         DO           0032         ELSE         DOMAT(F9.6)           0033         END IF         DO           0033         END IF         DO           0033         END IF         DO           0034         Z         COMITINE           0035         I6         FORMAT(F9.6)           0035         I6         MITE(5,16)           0035         I6         FORMAT(F9.6)           0035         I6         FORMAT(F9.6)           0036         I6         FORMAT(F9.6)           0037	21		ELSE	0073	38	FORMAT(' DB INCREMENT FOR EB/NJ [5,]: '.5)	
0023 4 MRITE(5,5)IN,00 0025 5 FORMAT(A9) 0026 READ(5,6)FIELD 0027 6 FORMAT(A9) 16(FIELD.E0.BLANK9) THEN 0028 IF(FIELD.E0.BLANK9) THEN 0029 DEBNOL(IN)=D0 0030 DEENOL(IN)=D0 0033 61 FF(ELD.E0.BLANK9) THEN 0033 61 FF(ELD.E0.BLANK9) THEN 0033 DECODE(9,61,FIELD)DEBNOL(IN) FORMAT(F9.6) 0033 E1SE 0033 FORMAT(F9.6) 0034 7 CONTINUE 0035 15 FORMAT(F9.6) 0035 16 FORMAT(F9.6) 16 FORMAT(F9.6) 0035 16 FORMAT(F9.6) 0035 16 FORMAT(F9.6) 16 FORMAT(F9.6) 0035 16 FORMAT(F9.6) 16 FORMAT(F9.6) 0035 16 FORMAT(F9.6) 17 (N.EQ.0)NL=4 0036 18 MRITE(5,16) 0040 18 MRITE(5,19)IN,IN 0041 19 FEAN(5,3)NL 17 (LLIST(IN).E0.0)LLIST(IN)=IN 0041 19 FEAN(5,23) 0046 23 FORMAT(' L(',11,') [',11,']: ',5) 0046 23 FORMAT(' L(',11,') [',11,']: ',5) 0047 17 FORMAT(' FORMAT(' FORMAT(' L(',11,') [',11,']: ',5) 0047 18 FORMAT(' FORMAT(' FORMAT(' FORMAT(' FORMAT(' L(',11,') [',11,']: ',5) 0047 19 FORMAT(' FOR	22		D0=0.D0	0074	5	READ(5,37,ERR=35) DBINC	
0025       5       FORMATI(A)       FORMATI(A)         0026       READ(5,6)FIELD       FORMAT(A)         0028       IF(FIELD.EO.BLANK9) THEN         0029       DEBNOL(IN)=DO         0021       FORMAT(A)         0023       IF(FIELD.EO.BLANK9) THEN         0023       DEGNOL(IN)=DO         0031       DECODE(9,61,FIELD)DEBNOL(IN)         0033       DECODE(9,61,FIELD)DEBNOL(IN)         0033       FORMAT(F9.6)         0034       CONTINUE         0035       IS         0037       FORMAT(F9.6)         0033       FORMAT(F9.6)         0034       CONTINUE         0035       IS         0037       FORMAT(F9.6)         0038       IF(ML.EQ.0)ML=4         0039       IF(ML.EQ.0)ML=4         0031       IF(ML.EQ.0)ML=4         0033       IF(ML.EQ.0)ML=4         0034       IF(ML.EQ.0)ML=4         0035       IF(ML.EQ.0)ML=4         0036       IF(ML.EQ.0)ML=4         0037       IF(ML.EQ.0)ML=4         0038       IF(ML.EQ.0)ML=4         0039       IF(ML.EQ.0)ML=4         0039       IF(ML.EQ.0)ML=4         0031	32	4	ERU IF MRITE(5.5) IN . DO	00/5 9700	3/	FORMAT(F6.3) Teinbluc en n'indlwc_e	
00256         READ(5,6)FIELD           0027         6         FERMATI(A9)           0028         FF(FIELD.EO.BLANK9) THEN           0029         DESNOL(IN)=DO           0021         DESNOL(IN)=DO           0023         ELSE           0023         DECODE(9,61,FIELD)DEBNOL(IN)           0033         DECODE(9,61,FIELD)DEBNOL(IN)           0033         DECODE(9,61,FIELD)DEBNOL(IN)           0033         FORMAT(F9.6)           0033         FORMAT(F9.6)           0033         FORMAT(F9.6)           0033         FORMAT(F9.6)           0033         FORMAT(F9.6)           0034         CONTINUE           0035         FORMAT(F9.6)           0035         FORMAT(F9.6)           0037         FORMAT(F9.6)           0037         FORMAT(F9.6)           0037         FORMAT(F9.6)           0038         FORMAT(F1.6)           0037         FORMAT(F1.6)           0038         FORMAT(F1.1)           0039         FORMAT(F1.1)           0041         FONAT(F1.1)           0041         FOLS.2)LILIST(IN).EO.0)LLIST(IN)=IN           0045         CONATIONE           FAIN(5.2)	25	5	FORMAT(' EB/WO(',I2,') [',F9.6,']: ',\$)	0077		r vormeret. Return	
0028         IF(FIELD.E0.BLANK9)         THEN           0029         ELSE         DECODE(9,61,FIELD)DEBNOL(IN)           0031         DECODE(9,61,FIELD)DEBNOL(IN)           0033         END IF         FORMAT(F9.6)           0033         FORMAT(F9.6)         END IF           0034         Z         CONTINC           0035         END IF         END IF           0035         END IF         CONTINUE           0035         IS         END IF           0036         IS         FORMAT(' HOW MANY L? [4]: 'S)           0037         READ(5,3)NL         IN.1N           0039         IS         FORMAT(' HOW MANY L? [4]: 'S)           0040         IS         IS         IS           0041         IS         FORMAT(' L' 'II),')         IS	26	ų	READ(5,6)FIELD Fromatiaq)	0078		END	
0029         DESNOL(IN)=DO           0031         ELSE           0032         61           0033         50           0033         FORMAT(F9.6)           0033         7           0033         FORMAT(F9.6)           0033         15           0033         51           61         FORMAT(F9.6)           0033         7           0033         15           0034         7           0035         15           80         16           0035         16           6         6           0035         16           7         CONTINC           0035         15           8         17           0035         16           16         FORMAT(' HOW MANY L? F4]: •,\$)           0036         16           8         17           0037         REAO(5,3) ML           0038         16           17         1.1,•1           0039         18           16         10           0041         19           19         FORMAT(' HOW IN.EQ.O)LLIST(IN)=IN	82	•	IF(FIELD.ED.BLANK9) THEN				
OD31         DECODE(9,61,FIELD)DEBMOL(IN)           0032         61         FORMAT(F9.6)           0033         7         CONTINUE           0035         15         MRITE(5.16)           0035         15         MRITE(5.16)           0035         15         MRITE(5.16)           0036         16         FORMAT('HOM MANY L? F4]: ',S)           0036         16         FORMAT('HOM MANY L? F4]: ',S)           0037         16         MANY L? F4]: ',S)           0038         16         FORMAT('HOM MANY L? F4]: ',S)           0039         16         MRITE(5,19) MANY L? F4]: ',S)           0039         16         MANY L? F4]: ',S)           0031         FFANC, FOUNLAG         MANY L? F4]: ',S)           0033         16         MANY L? F4]: ',S)           0033         17         MANY MAN           0041         19         FORMAT('L, L(',II),')           0042         21         MAN, MAN           0043         19         FALLIST(IN).EQ.O)LLIST(IN)=IN           0044         21         CONTINUE           0045         22         MRITE(5,23)           0046         23         MANY MAN           0046	50		DEBNOL (IN)=D0				
0032         61         FORMAT(F9.6)           0033         7         CONTINUE           0035         15         MRITE(5.16)           0035         15         MRITE(5.16)           0035         16         FORMAT(F9.6)           0035         15         MRITE(5.16)           0036         16         FORMAT(F9.6)           0037         16         MANY L? F41: '.S)           0038         16         FORMAT(F1.40)           0039         16         MANY L? F41: '.S)           0039         16         MANY L? F41: '.S)           0039         16         MANY L? F41: '.S)           0041         19         FAILESTINI           0041         19         FAILESTINI           0041         19         FAULSTINI           0042         11         FLLISTINI           0043         21         MANTU           0044         21         CONTINUE           0045         22         MANTU           0045         22         MANTU           0045         21         MANTU           0046         23         FAULS           0046         23         FAUNE SLOTS <td>វត្ត</td> <td></td> <td>DECODE(9.61.FIELD)DEBNOL(IN)</td> <td></td> <td></td> <td></td> <td></td>	វត្ត		DECODE(9.61.FIELD)DEBNOL(IN)				
0033 7 CWTINUE 0035 15 FORMAT(5,16) 0035 16 FORMAT(1 HOW MANY L? [4]: •,\$) 0037 READ(5,3)ML 0038 16 FORMAT(1 HOW MANY L? [4]: •,\$) 0038 16 ML.EQ.0)ML=4 0039 18 MRITE(5,19)MLIA 0040 18 MRITE(5,19)MLIA 0041 19 FORMAT(1 L(1,11,1) [•,11,1]: •,\$) 0040 18 MRITE(5,19)MLIA 0041 19 FORMAT(1 L(1,11,1) [•,11,1]: •,\$) 0042 21 MRITE(5,23) 0046 23 FRITE(5,23) 0046 23 FRITE(5,23) 0046 23 FRITE(5,23) 0046 23 FRITE(5,23) 0046 23 FRITE(5,23) 0046 23 FRITE(5,23) 0046 24 MRITE(5,23) 0046 24 MRITE(5,23) 0047 24 MRITE(5,23) 00047 24 MRITE(5,2	22	61	FORMAT(F9.6)				
0035 I5 MRTE(5.16) 0036 I6 FORMAT(' HOW MANY L? F4]: .,5) 0038 IF(ML:EQ.(5.3)ML 0038 IF(ML:EQ.0)ML=4 0039 I8 WRTE(5.19)IN,IN 0040 I8 WRTE(5,19)IN,IN 0041 19 FORMAT(' L(',II,') [',II,']: ',5) 0042 IF(LLIST(IN).EQ.0)LLIST(IN)=IN 0043 Z1 F(LLIST(IN).EQ.0)LLIST(IN)=IN 0046 Z3 KRTE(5,23) 0046 Z3 FORMAT(' HOPPING SLGTS? [24001: ',5) 0046 Z3 REANC 52MNSIONS	38	7	ENU IF CONTINUE	•			
0036 16 FORMAT(' HOW MANY L? F4]: .,5) 0037 READ(5,3)ML 0038 1F(ML:EQ.O)ML=4 0039 16 (ML:EQ.O)ML=4 0040 18 WRITE(5,19)1N,1N 0041 19 FORMAT(' L(',11,') [',11,']: ',5) 0042 21 N=1,0L 0043 21 F(LLIST(IN).EQ.O)LLIST(IN)=IM 0046 23 KRITE(5,23) 0046 23 KRITE(5,23) 0046 23 FAMAT(' HOPPING SLGTS? [24001: ',5) 0046 23 REAMAT(' HOPPING SLGTS? [24001: ',5)	35	15	MRITE(5,16)				
0038       IF(ML.EQ.0)ML=4         0038       IF(ML.EQ.0)ML=4         0040       I8       WRITE(5,19)IN,IN         0041       19       FORMAT(' L(',II,') [',II,']: ',S)         0042       READ(5,3)LLIST(IN)       I.         0043       IF(LLIST(IN).EQ.0)LLIST(IN)=IN       0043         0043       IF(LLIST(IN).EQ.0)LLIST(IN)=IN       0044         0045       22       KRITE(5,23)         0046       23       FORMAT(' L(ST(IN).EQ.0)LLIST(IN)=IN         0045       22       KRITE(5,23)         0046       23       FANK5 ASINSI ONS	36	16	FORMAT(' HOW MANY L? [4]: ' <b>,5</b> ] Beanle sing				
0039 60 21 IN-1, ML 0040 18 WRITE(5,19) IN, IN 0041 19 FORMAT(' L(',11,') [',11,']: ',5) 0042 READ(5,3)LLIST(IN) 0043 21 F(LLIST(IN).EQ.0)LLIST(IN)=IN 0045 23 FORMAT(' HOPPING SLGTS? [24001: ',5) 0046 23 FORMAT(' HOPPING SLGTS? [24001: ',5) 0047 21 READ(' ADMYSION')	38		rcAU(0,0)NL=4 IF(NL.EQ.0)NL=4				
0041 19 FORMAT(' L(',11,') [',11,']:',\$) 0042 19 FORMAT(' L(',11,') [',11,']:',\$) 0043 1F(LL157(1N).EQ.0)LL15T(1N)=1N 0044 21 CONTINUE 0046 23 RGITE(5,23) 0046 23 FORMAT('HOPPING SLGTS? [24001: ',\$) 0047 24NNS10TS	ŝ	9	CO 21 IN-1, ML				
0042 READ(5,3)LLIŠT(IN)	;;	9 <b>6</b> 1	FORMAT(' _ L(', ]].') [', ]].'S				
0043 IF(LLIST(IN).EQ.0)LLIST(IN)=IN 0044 21 CONTINUE 0045 22 MRITE(5,23) 0046 23 FORMAT(* HOPPING SLGTS? [24001: *,5) 0047 PARAT(* ZAINSIONS	<b>4</b> 2		READ(5,3)LLIST(IN)				
0045 22 WRITE(5,23) 0046 23 FORMAT(* HOPPING SLGTS? [2400]: •,\$) 0047 PARAT(* AUNKI DITS	- 	16	IF(LLIST(IN).EQ.0)LLIST(IN)=IN CONTIMIE				
0046 23 FORMAT(* HOPPING SLGTS? [24001: *,\$) DD47 READ/5: 241MS1.DTS	12	22	WITE(5,23)				
	<b>4</b> 6 47	23	FORMAT(* HOPPING SLGTS? [2400]: • <b>.\$</b> ) Read(5,24)nSL0TS				

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		KML SKNINSCIMS
1000	SUBROUTINE PSUBE(RHON,RHOT,LL,M,PE,D,IDSUB,NUSED,PRERR,IPSUB) C C COMPUTE UNCONDITIONAL ERROR PROBABILITY	0033 0034 0035 0035
0002 0003 0005 0005	L IMPLICIT DOUBLE PRECISION(A-H,0-Z) INTEGER JAM(8),LUP(8),JSUB(8) LOGICAL*1 GO,NONE,STORE LOGICAL TRASH1, TRASH2, HIGH	000 000 000 000 000 000 000 000 000 00
9000 2000 2000	C WE DO WANT TO STORE ZERO ELEMENTS OF THE DENSITY FUNCTION, C SINCE IT SAVES TIME TO AVOID REPEATING THE UNDERFLOWS VIRTUAL PRERR(625), IPSUB(625) COMMON /REGION/ HIGH COMMON /REGION/ HIGH COMMON /RESET/ TRASH1, TRASH2 COMMON /SHAREZ/ LOW(8), LINC(8)	0040 0041 C SUM U 0043 C SUM U 0043 198 0045 198
0012 0013 0016 0017 0017 0018	PE-0.DO NPS-0.DO NPS-0.JAM1=-1 DO 199 I1=0.LL JAM(1)=11 ITER=1 ITER=1 100 DO 101 [=ITER+1,M	0047 197 0049 199 0050
0020 0020 0020	C OUTERMOST NONSIGNAL LOOP ALMAYS STARTS FROM O, BUT C THE OTHERS START FROM THE CURRENT VALUE OF THE C NEXT OUTER MORE LOOP TO PRODUCE THE SORTED EVENTS C IF(I.GT.2) THEN JAM(I)=JAM(I-I) ELSE	
0024 0025 0027 0027 0027 0027	JAMIL]=U END IF 101 ECONTINE IF(JAMI.NE.JAM(1)) THEN C UPDATE TEST VALUE FOR NEXT TIME, AND JAMI=JAM(1) TRASH1=.TRUE.	
0029 0030 0031 0032	CALL EVENT(LL,M,JAM,PIE,D,IDSUB,NUSED) C BYPASS CONDITIONAL ERROR PROBABILITY CALCULATION IF EVENT C PROBABILITY IS ZERO. THIS SAVES MUCH TIME IF(PIE.EO.O.DO)GOTO 198 C STORE AS ELEMENT OF A SPARSE ARRAY TO SAVE MEMORY C EVEN THOUGH WE STORE ZEROS, THE SORTIMG OF SUBSCRIPTS C CUTS OUT MANY ELEMENTS. C CUTS OUT MANY ELEMENTS. C TRY TO FIND COMIN.LUM,LUM,LUM,JSUB) C TRY TO FIND COMIN.LUM,LUM,LUM,SUB) C TRY TO FIND COMINTONAL ERROR PROBABILITY IN STORED ARRAY C TRY TO FIND CONCITIONAL ERROR PROBABILITY IN STORED ARRAY C TRY TO FIND CONCUTTIONAL ERROR PROBABILITY IN STORED ARRAY	

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-11 SKNI	FORTRAI H8. FTN;	+-77 V4.0-1 ;13 /F77/	09:42:05 TR:BLOCKS/WR	16-Ju1-86	Page 8
~		IF ( NONE ) THEN			
		IF(HIGH) TH	ie n		
5		CALI. PSEL	I ( JAM. EL . M. RHC	M.RHOT. PROB)	
s		ELSE			
~		CALL PSET	.2( JAM. LL. M. RHO	M. RHOT , PROB)	
80		END IF			
	: ں	AND SAVE IT FO	R POSSIBLE FUT	URE RE-USE	
•		CALL PUTING	PROB. PRERR. IPS	UB. NPS. 625. 15U	B.KODE.STORE)
0		IF (KODE. NE.	0) STOP 2		
_		END IF			
	C SUM	UP UNCONDITIONA	IL ERROR PROBAB	ILITY	
~		DE*PE+P1E*PR0	8		
~	198	DO 197 1=2.M			
-		[TER=M+2-1			
<u>س</u>		JAM(ITER)=JAM	I( ITER)+1		
9		IF ( JAM( I TER).	LE.LL) GOTO 10	0	
~	197	CONTINUE	•		
<b>6</b> 0	199	CONTINUE			
•		RETURN			
0		END			

Page 9 C IMPLICIT DOUBLE PRECISION(A-H.O-Z) LOGICAL\*1 STORE,NONE DIMENSION JAN(8),LUP(8) VIRTUAL D(625),IDSU8(625) COMPON /SHAREZ/LOU(8),LIMC(8) DATA STORE/FALSE/ C SET UP ARRAY DESCRIPTION D(0:LL...,0:LL) WITH M DIMENSIONS C C SUBROUTINE TO LOOK UP EVENT PROBABILITY FROM STORED ARRAY C COMPUTE LINEAR EQUIVALENT SUBSCRIPT FOR JAMMING EVENT C COMPUTE LOCNIM, LON, LUP, JAM, ISUB) C LOCK UP THE VALUE, GET 0.DO IF NOT THERE CALL LOOKUP(PIE, D, IDSUB, NUSED, 625, ISUB, STORE, NOME) SUBROUTINE EVENT(LL,M.JAM,PIE,D,IDSUB,NUSED) 16-Jul-86 1 09:42:09 /F77/TR:BLOCKS/NR PO 1 1=1,M LUP(1)+LL CONTINUE PDP-11 FORTRAN-77 V4.0-1 RMFSKN1H8.FTN;13 RE TURN END 8000 1100 0012 0013 0014 8

Page 10

16-Jul-86 999 CONTINUE C FORM COLUMN SUMS AND COMPUTE P(EVENT) C INITIALIZE MATRIX-INGER LOOP CALL MLINIT(MATRIX,MLOW,LL,MM) D0 102 1=1,LL INORK(J)=INORK(J)+MATRIX(I,J) CALL PRIHOP(I, MM, NQ, NSLOTS, A) | 09:42:12 /F77/TR:BLOCKS/MR JAMMING EVENT VECTOR DO 102 J=1 MM THORK(J)=0 D0 100 J=1,MM K=K+MATRIX(1,J) P=1.D0 D0 101 1=1,LL K=0 D0 95 J-1,MM D0 95 J-1,LL MLD(I,J)=0 MLD(I,J)=1 MLNC(I,J)=1 MLNC(I,J)=1 MLNC(I,J)=1 D0 98 J-1,MM LOMMRX(I)=0 LUMMRX(I)=LL P=P\*PIE(K) PIE(I)=A PDP-11 FORTRAN-77 V4.0-1 RMFSKN1H8.FTN;13 CONTINUE CONTINUE CONTINUE CONTINUE CONTINUE C FORM 8 8 ŝ g 103 8000 8000 8000 8000 8000 0027 0038 0040 0040 0005 000 0037

D-6

Paq	(TORE)	IY FOR 1F	벌벌		ED E IS SE .	X 1984				
09:42:18 16-Ju1-96 7/18:BLOCKS/MR	PUTIN(CIN,C,ICSUB,NUSE,NMAX,K,IERR,S	NSERTS AN ELEMENT INTO A SPARSE ARR M-ZERO ELEMENTS ARE KEPT IN STORAGE IS .TRUE.	I'ON VALUE CIN IS STORED AS C(K) MHER Ay Icsub is used to keep track of th Corresponding entries in C. Egers are used to accomodate large For the sparse array C.	TORE ISION C,CIN UB(MMAX),C(MMAX) CIN,C,ICSUB,NUSE,MMAX,K,IERR,STORE)	LEMENT TO STORE CH MON-ZERO VALUES ARE ACTUALLY STOR CH MON-ZERO VALUES ARE ACTUALLY STOR Y ARRAY FOR ACTUAL SUBSCRIPT VALUES ELEMENTS OF C CURRENTLY OCCUPIED ARRAY C URN CODE, O IF MO ERROR OR 1 IF THER URN CODE, O IF MO ERROR OR 1 IF THER LABLE IN C O STORE ZEROES EXPLICITLY, ELSE .FAL O STORE ZEROES EXPLICITLY, ELSE .FAL O STORE ZEROES EXPLICITLY, ELSE .FAL D THE SUBSCRIPT K IS FOUND IN ICSUB, IS DELETED BY SHIFTING DOWNMARD ALL LEMENTS OF THE ARRAY	T H. FRENCH DATE: 11 JANUAR	UBLE PRECISION(A-H,0-2) UB(MMAX),C(MMAX) Tore	0T0 5 . DO) 60T030 C)60T0 20 USE	.WE.K) GOTO 10	MHAX) 6010 20 -k
TRAN-77 V4.0-1 FTN:13 /F7	SUBROUTINE	THIS SUBROUTINE I HHICH ONLY THE MO THE SWITCH STORE	THE DOUBLE PRECIS THE AUXILIARY ARR SUBSCRIPTS OF THE LONG (4-BYTE) IMT SUBSCRIPT VALUES	USAGE: USAGE: 000BLE PREC VIRTUAL ICS CALL PUTIM	MARKE CIN = VALUE OF E CIN = VALUE OF E CIN = ARRAY IN WHI ICSUB = AURILIAR NUSE = NUMBER OF MAX = SIZE OF A MAX = SIZE OF A MAX = CIN = A NO ROOM AVAI ROTE = IF CIN=O AVAI THE ELEMENT FOLLOWIMG E	PROGRAMMER: ROBER	IMPLICIT DO VIRTUAL ICS LOGICAL*1 S IEPB-A	IEKA=0 IF(STORE) G IF(CIN.E0.0 IF(NUSE.EQ. D0 10 1=1.N	IF(ICSUB(I) C(I)=CIN RETURN CONTINUE	IF(NUSE.LT.) IERR=1 RETURN NUSE=NUSE+1 ICSUB(NUSE) C/MISE)_FTN
11 FOR KNIHG.	۴.			ບບົບບບບບັ		ບບົບ	د	ĥ	0[	20
Page 11			STORE , NONE)	ERR,STORE) 0)						
נו 16-Jul-B6 Page II מ		THEN	RK, IMORK, I SUB) 1. MUSED,625, I SUB, STORE , NONE)	NUSED,625,ISUB,IERR,STORE) MANY EVENTS' MUP,MINC,LL,MV,GO)						
RAN-77 VA.O-1 09:42:12 16-Jul-B6 Page 11 TN:13 /F77/TR:BLOCKS/WR	CORT MONSIGNAL CHANNELS	U0 103 1=2,551 00 103 J=1+1,991 IF(FUORK(J).LT.FUORK(L)) THEN ITEMP=IMORK(I) TUDORT(I)	INDUCK(J)=TTEMP(J) INDUCK(J)=TTEMP END IF CALL LOCKN(MM,LUMMRK,LUPMRK,IMORK,ISUB) CALL LOCKN(MM,LOMMRK,LUPMRK,IMORK,ISUB,STORE,NONE)	CULL PUTIN(DOUT_D.IDSUB.MUSED,625,ISUB,IERR,STORE) IF(IER.R.C.) STOP 'TOO MANY EVENTS' TERATE MATRIX-INDEX LOOP CALL NLITER(MATRIX,MLOM,MUP,MINC,LL,MV,GO) IF(GO) GOTO 999 BFTIDM	ENO CM					
II FORTRAN-77 V4.0-1 09:42:12 16-Jul-B6 Page II SKNIHB.FTN:13 /F77/TR:BLOCKS/WR	C SORT NONSIGNAL CHANNELS	13 DO 103 1=C,TMT-1 13 DO 103 J=1+1,MM 14 IF(IMORK(J) LT.IMORK(I)) THEN 5 IFEMP=IMORK(I) 6 ILORK(2)	<ul> <li>INCR(J)=ITEMP</li> <li>INCR(J)=ITEMP</li> <li>END IF</li> <li>END IF</li> <li>CONTINUE</li> <li>CALL LOCH(NM.LUPMRK, LUPMRK, INORK, ISUB)</li> <li>CALL LOCKUP(DOUT, D, IDSUB, NUSED, 625, ISUB, STORE, NONE)</li> </ul>	CALL PUTINE DOUT, D. IDSUB, NUSED, 625, ISUB, IERR, STORE) IF(IERR.E.O) STOP 'TOO MANY EVENTS' CITERATE MATRIX-INDEX LOOP SCALL MLTRER(MATRIX, MLOM, MUP, MINC, LL, MV, GO) BIG(G) 60TO 999 7 7						

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09:42:1R 16-Jul-86 Page BLOCKS/MR 16-Jul-86 Page HENT AND BUMP COUNT OF ENTRIES USED 1 1.1)	13 DETECTION TO ALL DETECTION DETECTION DETECTION DE LOCAS MAR RMF SKNIHB.FTN;13 /F77/TR:BLOCKS/MR 0001 SUBROUTINE LOOKUP(COUT,C,ICSUB,N,IMMAX,K,STORE,NO C	C THIS SUBROUTINE RETRIEVES AN ELEMENT OF A SPARSE ARRAY C HAS BEEN STORED COMPACTLY BY STORING OMLY NOM-ZERO ELE	C THE ANALY IN TUDBLE PRECISION.	C UNAVAL ICSUB(NMAX), C(NMAX) C VIELOBICAL*I STORE, NONE C DOUBLE PRECISION COUT C CALL LOOKUP(COUT,C,ICSUB,M,NMAX,K,STORE,NONE)	C WHERE C COUT = VALUE OF C(K) (OUTPUT FROM SUBROUTIME) C C = ARRAY USED TO STORE MON-ZERO ELEMENTS C ICSUB = AUXILIARY ARRAY TO STORE ACTUAL SUBSCRIP C N = NUMBER OF ELEMENTS OF C CURRENTLY IN USE	C NMAX = SIZE OF C K = SUBSCRIPT OF SPARSE ARAY TO LOOK UP C STORE = .TRUE. IF ZEROES NOT STORED OR ZEROES SI C NOME = .FALSE. IF ZEROES NOT STORED OR ZEROES SI C NOME = .FALSE. IF ZEROES NOT STORED AND THE ELEW C .TRUE. IF ZEROES ARE STORED AND THE ELEW C NOT FOUND (OUTPUT QUANTITY)	C C programmer: Robert H. French C date: Il Jamuary 1984	0002 [ IMPLICIT DOUBLE PRECISION(A-H, 0-Z) 0003 VIRTUAL ICSUB(MMAX), C(MMAX) 0004 LOGICAL*I STORE, HONE 0006 MONE = FAISE	0006 D0 10 1=1,N 0007 IF(ICSU8(I),NE.K)60T0 10 0008 COUT=C(I)	0009 RETURN 0010 10 CONTINUE 0011 IF(STORE) THEN 0012 NOME=.TRUE. 0013 ELSE
	3:42:18 15-Jul-86 rage .0CXS/MR	() GOTO 50	HENT AND BUMP COUNT OF ENTRIES USED	11)						

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Labor Lab

DD-11 RMF SKH	FORTRAN-77 V4.0-1 09:42:23 16-Jul-86 Page 15 IHB.FTN;13 /F77/TR:BLOCKS/WR	PDP-1] FI RMFSKNJH	0RTRAN-77 V4.0-1 09:42:26 16-Jul-86 Page 16 18.FTN;13 /F77/TR:BLOCKS/MR
100	SUBROUTINE LOCM(NDIM,ILON,IUP,ISUB,LIMEAR)	1000	SUBROUTINE MLINIT(LMAT,LLOW,LMAXC,LMAXR)
	C THIS SUBROUTINE COMPUTES THE EDUIVALENT LINEAR SUBSCRIPT FOR C A MULTIDIMENSIONAL ARRAY OF NDIM DIMENSIONS C		C C THIS SUBROUTINE INITIALIZES A "MATRIX DO-LOOP" STRUCTURE C DEFINED BY THE FOLLOWING PSEUDO-FORTRAN CODE: C DO TOO TMATYI J)=LLOW(1.1), LIP(1.1), LINC(1.1)
	C IF THE ARRAY A IS DEFINED AS C DIMENSION A(1.OM(1):IUP(1),ILOM(NDIM):IUP(NDIM)) C AND ISUB(1),ISUB(NDIM) IS A SET OF SUBSCRIPTS FOR A, C THEN THIS SUBROUTINE RETURNS IN LINEAR THE OFFSET FROM THE C RIEN OF A TO THE ELEMENT A(ISUB(1),ISUB(NDIM)), ASSUMING		C DO 100 LMAT(LMAXC,1)=LLOW(LMAXC,1),LUP(LMAXC,1),LINC(LMAXC,1) C DO 100 LMAT(1,2)=LLOW(LMAXC,1),LUP(LMAXC,1),LINC(LMAXC,1) C D0 100 LMAT(1,2)=LLOW(1,2),LUP(1,2),LINC(1,2)
	C USAGE:		C DO 100 LMAT(LMAXC, 2)=LLOM(LMAXC, 2), LUP(LMAXC, 2), LINC(LMAXC, 2) C DO 100 LMAT(1,LMAXR)=LLOM(1,LMAXR), LUP(1,LMAXR), LINC(1,LMAXR)
	C DIMENSION ILLOWINDIM, JUPINDIM, ISOBGINDIM) C DATA ILDWIOWER TIMITS OF defined subscripts of array/ C DATA IUP/upper Timits of defined subscripts of array/ CST ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS C CALL LOCK(NDIM, ILOW, IUP, ISUB, LINEAR)		C C C C C C C C C C C C C C C C C C C
	C WHERE C NDIM = NUMBER OF DIMENSIONS THE ARRAY HAS		C (STATEMENTS IN RANGE OF LOOP) C :
	C ILDM = ARRAY OF LOWER SUBSCRIPT BOUNDS C TUP = ARRAY OF UPPER SUBSCRIPT BOUNDS		C 100 CONTINUE
	C ISUB = ARRAY CONTAINING SUBSCRIPT FOR WHICH LOCATION IS L TO BE COMPUTED C LINEAR = RETURNED VALUE OF OFFEET INTO ARRAY IN MEMORY		C THE COMPANION ROUTINE MILITER HANDLES THE LOOP CONTROL AT THE CONTINUE STATEMENT IN THE ABOVE STRUCTURE
	C C PROGRAMMER: ROBERT H. FRENCH C DATE: 11 JANUARY 1984		C USAGE: C USAGE: C DIMENSION LMAT(LMAXC,LMAXR),LLOM(LMAXC,LMAXR),LUP(LMAXC,LMAXR) C DIMENSION LINC(LMAXC,LMAXR),
0002 0004 0005	C DIMENSION ILOW(NDIM),IUP(NDIM),ISUB(NDIM) LINEAR=O DO IO IEI,INDIM-1 J=NDIM-I+I		C (INITIALIZE MATRIX LLOW TO STARTING VALUES OF THE MESTED LOOPS) C (INITIALIZE MATRIX LUP TO STOPING VALUES OF THE MESTED LOOPS) C (INITIALIZE MATRIX LINC TO INCREMENTS OF THE LOOPS) C CALL MLINIT(LMAT,LLOM,LMAXC,LMAXR) C 100 CONTINUE
0000 0008	LINEARFLINEAR+LINEAR+LISUBIJ)=LLUWUJ))=(IUP'U-I)-ILUW(J-I)+I) 10 CONTINUE LINEAR-LINEAR+ISUB(1)-ILOW(1)		C : (STATEMENTS IN RANGE OF LOOPS) C .
0100	RETURN		C CALL MLJTER(LMAT,LLOW,LUP,LINC,LMAXC,LMAXR,GD) C IF(GD)GOTO 100
			C WHERE C LMAT = ARRAY FOR STORAGE OF LOOP INDICES. LMAT(1,1) IS THE C UNT = OUTER-MOST LOOP; LMAT(LMAXC,LMAXR), THE INNER-MOST LOOP. C LLOW = ARRAY FOR STORAGE OF LOOP STARTING VALUES, IN SAME
			C SEQUENCE AS LMAT C LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME C SFINIFACE AS IMAT
			C LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME C SEQUENCE AS LMAT C MAX - MIMAENCE AS LMAT
			C 60 = LOGICAL VARIABLE, TRUE, IF JUMP BACK TO BEGINNING OF C 60 = LOGICAL VARIABLE, TRUE, IF JUMP BACK TO BEGINNING OF C STATEMENTS IN THE RANGE OF THE LOOP SHOULD OCCUR, C .FALSE. OTHERWISE (1.E. OUTER-MOST LOOP TERMINATED)

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C SEE DETAILED COMMENTS IN S
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 PDP-11
 FORTRAM-77
 V4.0-1
 09:42:56
 16-Jui-86
 Page

 RMFSKNIH8.FTN:13
 /F77/TR:BLOCKS/MR
 /F77/TR:BLOCKS/MR
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 PROGRAMMER: ROBERT H. FRENCH
 DATE:
 10 MARCH
 1986

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 PROGRAMMER: ROBERT H. FRENCH
 DATE:
 10 MARCH
 1986

 C
 DO02
 DIMENSION LMAT(LMAXC,LMAXR),LLOM(LMAXC,LMAXR)
 0003
 DO1
 M=1,LMAXR

 D003
 D0
 M=1,LMAXR
 0006
 1 M=1,LMAXR
 0000

 0000
 LMAT(M,M)
 CUNTINUE
 0000
 RETURN
 0000

 0003
 DO
 M=1,LMAXC
 DO
 RETURN
 0000

Page 19 16-Jul-86 SUBROUTINE PRIHOP(KJAM,KM,KQ,KN,AIN) L 09:42:31 /F77/TR:BLOCKS/WR PDP-11 FORTRAN-77 V4.0-1 RMFSKNIH8.FTN;13 100

C THIS SUBROUTINE COMPUTES THE EVENT PROBABILITY FOR ALL C POSSIBLE JAMMING PATTERNS MITH NOM-ZERO PROBABILITY FOR C L=1 HOP/SYMBOL FOR NWESK/FH IN PBNJ C

2003

IMAX=MAXO(KPMAX,LPMAX,JPMAX) PROG=1.DO

Q=KQ

DIFFNQ=KN-KQ

EN=KN DO 100 LOOP=0, IMAX

F=L00P

IF(LODP.LE.KPMAX) PRDD=PROD#(Q-F) IF(LODP.LE.JPMAX) PROD=PROD/(EN-F) IF(LOOP.LE.LPMAX) PROD=PROD#(DIFFNQ-F) CONTINUE Alm=PROD Retury Edd

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D-11

C INITIALIZE SHARED CONSTANTS C INITIALIZE SHARED CONSTANTS IMPLICIT DOUBLE PRECISION (A-H, 0-Z) COMMON /SHARE/ DG(31),DSWR(5,4) COMMON /SHARE/ LON(8),LINC(8) C DEFAULT LISTS FOR INFRACTIVE PARAMETER IMPUTS C ARE SHARED WITH LARGE MORE REGARAYS SINCE THEY DATA D6 / .001D0. .002D0, .005D0, DATA D5MR /13.3524700, 12.3133D0, 10.04443D0, 0.D0, 0.D0, DATA D5MR /13.3524700, 12.3133D0, 10.04443D0, 0.D0, 0.D0, DATA D5MR /13.3524700, 12.3133D0, 10.09443D0, 0.D0, 0.D0, DATA D5MR /11.355700, 7.1996D0, 6.069646D0, 0.D0, 0.D0, DATA LUN MEEDED CONSTANT ARAYS AND SCALARS DATA LOW POLLINC/8\*1/ Page 20 16-Jul-86 /F77/TR:BLOCKS/WR PDP-11 FORTRAN-77 V4.0-1 RMF5KN1H8.FTN;13 2 0000 **100** 2000 800 800 6000 0000

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ANJ=2.DOPINNJPRHON ASHIFT=DMAXI(AJ,ANJ) C SUBTRACT 1 FOR BENEFIT OF RAPID CHI-SQUARE DENSITY CALCULATION MJ=NJ-1 Page 21 IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL PGRAND, DGAU2O DIRENSION MORK(75), STACK(75), SAVE(75) INTEGER NCHAN(0:6) INTEGER NCHAN(0:6) INTEGER NCHAN(0:6) COMMON /PARMS/ BIGK, LL AJ = NOMCENTRAL PARAMETER FOR NOM-JAMMED HOPS ANJ = NOMCENTRAL PARAMETER FOR NOM-JAMMED HOPS ANJ = NUMBER OF NOM-JAMMED HOPS NNJ = NUMBER OF NOM-JAMMED HOPS COMMON /PULPAR/ AJ, ANJ, NNJ COMMON /PULPAR/ AJ, ANJ, NJ, NNJ COMMON /JAMCHT/ MCHAN CALL DLG-S15(PERAMD, ASHIFT, TAIL) CALL ADQUAD(0., ASHIFT, BODY, DGAUZO, PERAMD, 1.0-10, IF(KODE. NE. 0) THEN WRITE(5.3) KODE MRITE(5.3) KODE COUNT NUMBER OF NON-SIGNAL CHANNELS WITH L HOPS JANMED JSUB - JAMMING EVENT VECTOR LL - NUMBER OF HOPS/SYMBOL MM - ALPHABET SIZE PROB - RESULTING CONDITIONAL ERROR PROBABILITY SUBROUTINE PSELI(JSUB,LLL, MM, RHON, RHOT, PROB) C RANDOM MESK/F/ IN PARTIAL BAND TONE JAMMING C GIVEN A JAMMING EVENT 16-Jul-86 I 09:42:35 /F77/TR:BLOCKS/WR I SUB=JSUB(I) NCHAN(ISUB)=NCHAN(ISUB)+1 BIGK=RHON/RHOT NJ=JSUB(1) A.J=2.D0=N.J=RHOT DO 1 I=0,LL NCHAN(1)=0 CONTINUE DO 2 I=2,MM I-DNN=DNN (N-11=()W PDP-11 FORTRAN-77 V4.0-1 RMFSKN1H8.FTN;13 / CONTINUE -1 ~ m ß 00000 ບບບ  $\cup \cup \cup \cup$ 002 000 003 003 003 003 C908 0009 0012 0012 0013 0013 0014 0015 0013 0019 0020 0022 0023 0023 0025 0025 0025 0028 0030 0031 0032 0033 0033 0033 <u></u>

PDP-11 FOR RMFSKN1HB.	FTN;	.77 V4.0-1 09:42:38 16-Ju)-86 13 /F77/TR:BLOCK5/WR	Paqe 22
J000		DOUBLE PRECISION FUNCTION PGRAND(BETA)	
	INTEL	RAND FUNCTION	
, 0003 0003		JMPLICIT DOUBLE PRECISIOM(A-H,O-Z) LOGICAL TRASH1. TRASH2	
0004	~	VIRTUAL PUJV(2053), PUJT(2053), IPUJT(2053), FLT(8191),	
0005		INTEGER MCHAM(0:5)	
000		COMMON /RESET/ IRASHI, TRASH2	
ູ ເມ		A) = NONCENTRAL PARAMETER FOR JAMMED HOPS	
		ANJ = MUNICENIKAL PANAMELIEK FOR MON-JANNED HOPS NJ = NUMBER OF JANNED HOPS NJ = NUMBER OF JANNED HOPS	
0003 0000		COMMON / VUIDER OF NON-JOHNED TOUS COMMON /VUIDER/ AJ, ANJ, NJ, NJ SECTEDACUI) THEM	
J J		TRASH THE SIGNAL CHANNEL DENSITY TABLES	
0011	-	D0 1 1=1,2053 PUIV(1)=0.D0	
6100		00 2 1-1,2053	
0015	N	PULI(1)=0.00 00 3 1=1.2053	
0016	m	PU 1([)≈0 TP4543- E41 E	
0018		END IF	
5100		JF(TRASH2) THEN Thasy the mon signa. Cuannel newsity tables	
0020 ,		DO 4 1+1,8191	
0021 0023	4	FLV(1)=0.00	
0023	ŝ	FLT(1)=0.00	
0024 0025	ų	D0 6 j=1,8191	
0026	•	TRASH2=.FALSE.	
0028 0028		END JF PROD=1, DO	
0029		00 10 1=0,LL	
0030		IF (NCHAM(I).NE.O) THEN ISUB=IHASH(BETA,B191)	
20032	۶	JSUB=15UB 1=ELT(15UB)	
0034	Ŋ	IT=IFLT(ISUB)	
0035 C		IF(T.EO.O.DO .AND. IT.EQ.O) THEN NOT FOUND. COMPUTE IT AND ENTER INTO TABLE	
0036 0037		X=FL(BETA,I) FLV(ISUB)=X	
8600 8600		FLT(ISUB)=BETA JFLT(ISUB)=I+1	

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PDP-	11 FORTRA UNIHB.FTN	-77 V4.0-1 09:42:38 16-Jul-86 Page 23 13 /F77/TR:BLOCKS/WR	PDP-11 FORTR/ RMFSKNIH8.FTI	AN-77 V4.0-1 09:42:46 16-Jul-86 Page 24 V;13 /F77/TR:BLOCKS/MR
0040	Ĺ	ELSE IF(T.NE.BETA .OR. IT.NE.1+1) THEN	000	DOUBLE PRECISION FUNCTION PUL(Y)
0041	.,	ISUBEISUBEI	0003	DIMENSION WORK(75), STACK(75), SAVE(75)
0042		IF(ISUB.GT.8191) ISUB=ISUB-8191	0004	EXTERNAL DGXVI, PUIG
0043		IF(ISUB.NL.JSUB) IHEN	ŝ	LUTRUM /PULUM/ TT Al - WANTERTIAN ARBAURTED FAN JANNERD HADE
		EU CC ED 20	<b>ب ر</b>	AJ = MUNCENTRAL PARAMETER FOR JUNTEU MUPS Anii = Mincentral dadameted fod mum_lammeri Mups
	ų	HASH TABLE OVERFLOW, MUST COMPUTE, CAN NOT STORE	ں ر	NJ = NUMBER OF JAMMED HOPS
0046	,	X=FL(BETA,I)	J	NNJ = NUMBER OF MON-JAMMED HOPS
0047			9000	COMPION /PUIPAR/ AJ, ANJ, NJ, NNJ
8100	ر	ELSE IF(I.EQ.BEIA .AND. !!.EQ.I+I) INEN Cot iti	/000	CUTPTUM / PARTAS/ BIGK, LL TF(Y.IF.D.DO) THEN
0049	د	X=FLV(ISUB)	6000	PU1=0.00
0020		ENO IF	0010	RETURN
0051		PROD=PROD=DXI(X,MCHAN(I))	0011	
0052	:		C NJ C NJ	HAS ALKEADY HAD I SUBIRACTED FOR RAPID CHI-SQUARE EVALUATION Termine i ann uimeitiittee
200	07	CUNIINCE TSUR-TUASU/BETA POES)	J 7100	JELINU.MEI. AMU. NU.ME.LE-JJ IMEN UF MIST FONVOLVE TUO MOMEPRIDAL CHI_SOUADE DENSITIES
0055			0013	Y=Y
0056	0E	T=PUIT(ISUB)	0014	CALL ADQUA2(0.,Y,VALUE,DGXVI,PUIG,1.D-10,WORK,STACK,
0057		I F= IPUIT ( I SUB)		SAVE, 75, KODE)
0058	I	IF(T.EQ.9.D0 .AND. IT.EQ.0) THEN	C015	IF(KODE.NE.O) THEN
	J	NOT FOUND, COMPUTE IT AND ENTER INTO TABLE	4700	WKLIE(5,1) KOUE Prommatt' Dii Anning Edding Kone-1 12)
		T=POL(DCIA) PHIV(TCIR)=Y	, 100 0018	STOP FATAL FREDRY CARON: NUCE , 12)
398 898 13		PUIT(ISUB)=BETA	6100	END IF
0062		IPUIT(ISUB)=NJ+2	0020	PU1=VALUE/81GK
0063	ť	ELSE IF(T.ME.BETA .OR. IT.ME.NJ+2) THEN	0021	ELSE AND MAKE AND AND MANAGEMPANAN ANI PANANG AGAINTYU
0064	ى	AUT THIS ENTRY, TRY NEX! Isuratisticati	<u>ں</u> ر	WE (MLT MAVE UME MOMULEMIKAL CHI-SUUAKE UENSIIY WITH 2411 DEGREES OF FREEDOM
0065		IF(1208.61.2053) 1SUB=1SUB=2053	0022	IF(NJ.EQ1) THEN
0066		IF(ISUB.ME.JSUB) THEN	J	ALL HOPS UNJAMMED
0067		60T0 30 First	0023	CALL CHISQE(Y,LL-1,AMJ,F,KODE) FISE TETREN FO TI_1) THEN
2000		LLSL HASH TABLE OVERELONED	ך געני	ALL HOPS JAMMED
6900	•	Y≠PU1(BETA)	0025	CALL CHISQE(Y/BIGK,LL-1,AJ,F,KODE)
0020		END IF	0026	F=F/BIGK
0071	ł	ELSE IF(T.EQ.BETA .AND. IT.EO.NJ+2) THEN	0027	END IF
0072		eur 11: Y≖PUIY(ISUB)	0029	WRITE(5.111) KODE
0073		ENG IF	0030 111	FORMAT(' BESSEL FUNCTION ERROR CODE = ', II)
0074		PGRAND=Y*(1.DO-PROD)	0031	STOP FATAL ERROR'
0075		RETURN Card	2600	END IF
		CNU	\$E00	
			0035 0036	RETURN EMD

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Page	

1 09:42:49 /F77/TR:BLOCKS/WR

PDP-11 FORTRAN-77 V4.0-1 RMFSKNIH8.FTN;13 //

**100** 

C INNER INTEGRAND FUNCTION

000 0003

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:-77 V4.0-1 09:42:49 16-Ju1-86 Page 2 13 /F77/TR:BLOCKS/WR	5 PDP-11 RMFSKNI	FORTRAN-77 V4.0-1 09:42:51 16-Jul-86 [HB.FTN;13 /F77/TR:BLOCKS/WR
DOUBLE PRECISION FUNCTION PUIG(X)	1000	DOUBLE PRECISION FUNCTION FL(ALPHA,L)
R INTEGRAND FUNCTION		C C MONSIGNAL CHANNEL CUNULATIVE DISTRIBUTION
IMPLICIT DOUBLE PRECISION(A-H, 0-2)	0002	C IMPLICIT MAURLE PREFISION(A.H 0.2)
COMMON /PUICOM/ YY	0003	COMMON /PARMS/ BIGK, LL
AN = MUNICENTRAL PARAMETER END MUNICENTRAL Anj = Municentral Parameter end municamen unde	0004	IF(L.NE.O.AND.L.NE.LL) THEN
NJ = NUMBER OF JAMMED HOPS	0006	N=(BJ6K-1.)/BJ6K B161 AC-N AC/B16K
NNJ = NUMBER OF NON-JANNED HOPS	000	ARG=L*BIGLOG+AIPHA/2
COPPON /PUIPAR/ AJ, ANJ, NJ, NNJ Commany /Padme/ Bick is	0008	START=DEXP(-ARG)
CUTTO (MISOF(X/ATCM ALL STAND))	6000	FL1=L-1
IF(KODE.NE.0) THEN		D0 100 M=0,150
WRITE(5,1) KODE	200	15/N 50 A) THEM
FORMAT(' BESSEL FUNCTION ERROR CODE: ',12)	0013	JI (M.EY.U) INCH PART=J DN
STOP 'FATAL IN JUMPED HOP DENSITY.	0014	TERM=DIEXP(ALPHA/2.00_START_I1_1)
ERU EF Call Chisne(yv_y mm) ami e9 kone)	0015	SUM=TERM
IF(KODE.NE.O) THEN	4100	
MRITE(5,1) KODE	0018	TAXIEFARIAK*(ENAFL])/EN TEDNEDADIANIEVD/ALDUA/2 NO CTADI II
STOP 'FATAL IN UNJAMMED HOP DENSITY'	0019	DUMMY=SUM+TERM DUMMY=SUM+TERM
ENU IF Dille=E1±E2	0020	SUM=DUBMY
rutb*ri_r/	0021	END IF
AL UNA	0022 0022	IF(DABS(TERM).LE.1.D-11*DABS(SUM)) 60T(
	0024	TVV - CUMITING STAP 'FI SUM ATA MANERER'
	0025	ELSE
	0026	IF(L.EQ.O) THEN
	002/	A=ALPHA/2.00
	0028	ELSE IF(L.EQ.LL) THEN
	0030	A#ALPHA/(2.DO#BIGK) FND TF
	1600	START=DEXP(-A)
	0032	SUM=DIEXP(A, START, LL-1)
	1000	
	0034	125 FL=1.00-SUM
	0036	KE TUKR END

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Page 28		YF FREEDOM																		
16-Ju1-86	1 <b>,</b> K00E)	OR EVEN DEGREES (	=2*K+2	-H.O-Z)														0*(X+A))*BESSEL		
09:42:56 7/TR:BLOCKS/MR	CHI SQE ( X , N , A , DEN	SQUARE DENSITY F	FREEDOM (M) IS M	UBLE PRECISION(A		(B,N,BESSEL,KODE	O) RETURN		0) THEN	(N/2.D0)		) THEN	8		6			OWER*DEXP(B-0.50		
RAN-77 V4.0-1 TN;13 /F7	SUBROUTINE	NON-CENTRAL CHI-	DEGREES OF	IMPLICIT DO	B=DSQRT(X*A	CALL DXBESI	JF(KODE.NE.)	R=X/A	IF (R.NE.O.D	POWER=R**	ELSE	IF(N.NE.O	POMER=0	ELSE	POWER=1	END IF	END IF	DEN=0.500*P	RETURN	END
PDP-11 FORT RMFSKN1H8.F	, 1000			0002	0003	0004	0005	0006	000	8000	6000	00100	0011	0012	0013	0014	0015	0016	0017	0018
Page 27																				
16-Ju1-85	EXP(X,START,IUP)	OUBLE PRECISION)	н,0-2)																	
09:42:55 77/TR:BLOCKS/WR	CISION FUNCTION DI	ENTIAL FUNCTION (D	OUBLE PRECISION(A-		D) RETURN	, 1UP		K/F	P+TERM											
RTRAN-77 V4.0-1 .FTN;13 /F:	DOUBLE PREV	INCOMPLETE EXPON	IMPLICIT DU TERM=START	DIEXP=TERM	IF( IUP.EQ.	D0 100 I*1	F=1	TERM=TERM=	DIEXP=DIEX	100 CONTINUE	RETURN	END								
PDP-11 FOM RMFSKNIHB.	1000		0003 0003	000	0005	9000	0007	0003	6000	0010	0011	0012								

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SUBROUTIME ADQUA2(XL,XU,Y,OR,F,TOL,MORK,STACK,SAYE,N,KODE) C ADAPTIVE QUADRATURE ALGORITHM C XL - LOMER LIMIT OF INTEGRAL (IN) XU - UPPER LIMIT OF INTEGRAL (IN) 7 - VALUE OF INTEGRAL (OUT) C QR - MAME OF A OUMAATURE RULE SUBROUTIME (IN) C QR - MAME OF A OUMAATURE RULE SUBROUTIME (IN) C QR - MAME OF A OUMAATURE RULE SUBROUTIME (IN) C QR - MAME OF A OUMAATURE RULE SUBROUTIME (IN) C CALL QR(XL,XU,F,Y) C F - NAME OF FUNCTION TO BE INTEGRATED (IN) C CALL QR(XL,XU,F,Y) C CAL CRANC OF SIZE M (IN) C CAL ERROR ARRAY OF SIZE M, MUST MOT BE C SAVE THIRD MORK ARRAY OF SIZE M, MUST MOT MOT C SAVE ARAY Page 29 1 -- WORK ARRAYS TOO SMALL 2 -- EPS DIVIDED TO ZERO, EITHEN 4SKING FOR TOO TIGHT A TOLERANCE OR ROUND-OFF PREVENTS ATTAINING REQUIRED ACCURACY H. FRENCH, 14 AUGUST 1984 16-Jul-86 IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL F DIMENSION MORK(N),STACK(N),SAVE(N) CALL OR(A,XM,F,P1) CALL OR(XM,B,F,P2) IF(DABS(T-P1-P2).LE.EPS) 60T0 20 | 09:42:58 /F77/TR:BLOCKS/WR IF(NPTS.GT.N) THEN KODE=1 Return CALL OR(XL,XU,F,T) SAVE(1)=T B=WORK(NPTS) (M=(A+B)\*0.5D0 WORK (NPTS) = XM EPS=EPS/2.00 NPTS=1 EPS=TOL STACK(1)=EPS KODE=0 Y=0.00 NORK(1)=XU I+ST 9\*ST 9 PDP-11 FORTRAN-77 V4.0-1 RMFSKN1H8.FTN:13 END IF J=XT C SPLIT ÷ ្ឋ 000 ပပ 0019 0020 0021 0023 0023 0024 0025 1000

-11 FORTRAM-77 V4 SKN1148. FTN:113 SKN1148. FTN:113 SKN1148. FTN:113 SKN1148. FTN:113 SKN1148. FTN:113 STAC1	.0-1 09:42:58 16-Ju1-86 /F77/TR:BLOCXS/WR	PS.EQ.0.DO) THEN EE=2 URN (NPTS)=EPS (NPTS)=P2 (NPTS)=P2 (NPTS)=P2 1+P2 1+P2 1+P2 1+P2 1+P2 1+P2 1+P2 1+
	P-11 FORTRAN-77 V4.0- SKNIH8.FTN;13	If (EPS.)           RETURI           B           RETURI           SAVE(NP)           RETOR           RETOR

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PDP-11 FOR RMFSKNIH8.	(TRAN-77 V4.0-1 .FIN:13 /F77/	09:43:01 /TR:BLOCKS/MR	16-Ju1-86	Page 31	
0001	FUNCTION IMAS	SH(BETA, ISIZE)			
، <b>ن ر</b>	AD HOC HASHING FUNC	TION			
0005	IMPLICIT DOUE	BLE PRECISION(A	-H,0-Z)		
0003	IF(BETA.LT.1.	DO) THEN			
1000	IF(BETA.GT.	.0.500) THEN			
0005	B=1.00/(	(1.01D0-BETA)			
9000	ELSE				
0007	B=50.004	+1.5D0/(BETA+0.	01100)		
0008	END IF				
6000	ELSE				
0010	B=10000.DC	)*(BETA-DINT(BE	TA*1000.00)/1000.0	0)+187.00	
1100	END IF				
0012	B=B*23.DO				
0013	SIZE=ISIZE				
0014	I=DM00( R+0.5[	00,SIZE)+0.500			
0015	I HASH= I + I				
0016	RETURN				
0017	END				

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16-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL REF .: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4 16-Ju1-86 IMPLICIT DOUBLE PRECISJOM (A-H,O-Z) DIMENSION X(8), W(8) DATA X/ 0.09501250983763744018500, 0.4580167765723738634200, 0.4580167765722738634200, 0.51785724440264374844700, 0.5178762440264374844700, 0.75540440835500303389500, 0.75540440835500303389500, 0.75540440835500303389500, 0.75540440835500303389500, 0.75540440835500303389500, 0.7554044025503373257607800, 0.18945061045505849529500 / 0.18945061045505849529500, 0.18945061045505849529500, 0.18945061045505849529500, 0.18915651393500253818900, 0.18915651393500253818900, 0.09515851168749273481000, 0.09515851168749273481000, 0.09515851168749273481000, 0.09515851168749273481000, 0.0951585239384789285300, 0.0951585239384789286300, 0.002155245941175409485200 / ANSWER=0.DO BMAD2=(B-A)/2.DO BPAD2=(B-A)/2.DO DO 10 1=1,8 C=x(1)\*PMAD2 Y1=BPAD2+C Y2=BPAD2+C ANSWER=ANSWER+W(1)\*(F(Y1)+F(Y2)) CONTINUE AMSWER=ANSWER+BMAD2 RETURN EMD SUBHOUTINE DG16(A,B,F,ANSNER) 1 09:43:03 /F77/TR:BLGCKS/WR R. H. FRENCH, 28 FEBRUARY 1986 PDP-11 FORTRAN-77 V4.0-1 RMFSKN1H8.FTN;13 5 2 ں ں S ں 1000 0003 005

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16-Jul-86

16-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL REF .: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25. 0.14959598881657673208100, 0.12462897125553387205200, 0.09515851168249278481000, 0.052253523938647892863D0, 0.027152459411754094852D0 / IMPLICIT DOUBLE PRECISION (A-H,0-Z) DIMENSION X(8), W(8) DATA X/ 0.095012509837637440185D0, 0.281603550779258913230D0, 0.458016777657227386342D0, 0.94457502307323257607800. 0.98940093499164993259600 0.18945061045506849628500. 0.18260341504492358886700 0.16915651939500253818900, 0.61787624440264374844700 0.755404408355003033895D0 0.865631202387831743880D0 ANSWER=ANSWER+W(I)\*(F(Y1)+F(Y2)) CONTINUE ANSWER=ANSWER+BMAQ2 RETURN END SUBROUTINE DGXVI(A,B,F,ANSWER) 09:43:06 /F77/TR:BLOCKS/MR R. H. FRENCH, 28 FEBRUARY 1986 BMA02\*(B-A)/2.00 BPA02\*(B+A)/2.00 D0 10 1=1,8 C=X(1)\*BMA02 ANSWER=0.DO Y1=8PA02+C Y2=8PA02-C PDP-11 FORTRAN-77 44.0-1 RMFSKN1H8.FTN:13 DATA N/ 2 ပပ 0000 0000 0000 0000 0011 0012 0013 0014 0015 0015 0015 0015 0015 888 0005 8 D-18



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F SKN	H8.FTN;13 /F77/TR:BLOCKS/WR	RMF SK NI	H8.FTN;]	.3 /F77/TR:BLOCKS/MR
	C FIRST, RESET INDICES OF ALL LOOPS WITHIN ONE JUST "ICRATED	0079 0080 0081	555	AO=RO+RI/BIGK 180=KO+KL 1F11 KAPS, GT_D) THEN
5285	1000 D0 25 1=NSUB+1,LOOPS 100EX(1)=0 25 CONTINUE	0083 0083 0084 0083	Ş	D0 60 1=1,1M1 D0 60 1=1,1M1 An-An+INDEX(3*1-1)+(1MDEX(3*1-2)-1MDEX(3*1-1))/B)G B0=B0+ENDEX(3*1-1)+(1MDEX(3*1-2)-1MDEX(3*1-1))/B)G
	C SECOND, PERFORM FRONT-OF-LOOP CODE FOR EACH LOOP FROM ITERATED C LOOP ON IMMARD	C800 9800 9800	ອ ບ	Curvitave De JF PART=GRAL ( AD, JB0, JSUB( ] )
g	Second			100 A TERM TO THE OVERALL SUM
55	TRRP=MOD(1,3) C MAP 1.2.3 INTO 2: 4.5.6 INTO 2: ETC. FOR NESTING LEVEL	0089 0089		P*00=C0EF0*C0(K3)*C0EFL*C0EFKL ]f(L00P5.6T.0) THEW
51	NEST=(1+2)/3 IF(IRKF.EQ.LOOPR) THEM	0600 1600		D0 70 ]=1,LM1 PROD=PROD*COEFR(1)*COEFK(1)*COEFP(1)
52	C WE ARE ITERATING AN R-LOOP IF(IMDEX(I).EQ.O) THEN	0093	ğ	CONTINUE ENC IF
	C FIRST TIME THROUGH: C (A) INITIALIZE THE COEFFICIENT	0094 0095		PROUSEPROUSEPAKI Sume Sume PROD
3 3 3	COEFR(MEST)=1.DO ELSE		- 	TERATE THE LOOPS
	C NOT FIRST TIME THROUGH: C UPDATE THE COEFFICIENT	9600	ပ	1F(LOOPS.GT.0) THEN
65	COEFR(MEST)=-(COEFR(NEST)/FKIL1)* 5	8600 8600		DO 80 MSUB=LOOPS,1,-1 INDEX(MSUB)=IMDEX(MSUB)+1
26	END IF C SET UP VARIABLE UPPER LIMITS FOR THE ASSOCIATED	0100		IF(INDEX(MSUB).LE.INDUP(MSUB)) THEN GOTO 1000
5	C K 100P	0101	8	END IF CONTINUE
88	ELSE IF (TRP.EQ.LODPY) THEN		۔ ب ن	NITERMOST VARIARIE-MEST JOON REACHED IIS URDER JOHIT
59	C WE ARE TERKAING A R LUOP IF(INDEX(I).EQ.O) THEN			IONE WITH THE VARIABLE-NEST LOOPS
	C FIRST TIME THROUGH: C INITIALIZE THE COEFFICIENT	6010	، ر	END IF
22	COEFK(MEST)=1.DO ELSE		۔ د د	TERATE THE NORMAL DO LOOPS
1	C NOT FIRST TIME THROUGH: C UPDATE THE COFFFICTENT	0104	ر و00	CONTINUE
72	COEFK(NEST)=COEFK(NEST)+ 5 COEFK(NEST)=COEFK(I=1)+I.DO)/INDEX(I))	0105 0106	7000 8000	CONTINUE CONTINUE
۲ ; ۲	END IF C SET UP UPPER LIMIT FOR THE ASSOCIATED P LOOP	01080108	0006	CCM11MUE PROB=1.DO-SUM PROB=1.DO-SUM
22	ELSE IF [RRP.EQ.LOOPP] THEN LISE IF [RRP.EQ.LOOPP] THEN LISE AFTERATIVE A DAGE	0110		END Service
77	COEFP(NEST)=DEF(LL,NEST,INDEX(I-2),INDEX(I-1),INDEX(I),BIGK) END IF TO CONTINUE			
8/1				
	C DO THE INTEGRAL C			

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G(1)=K\*COEF1
BK1=BIGK-1.DO
CCEF2=0.5D0\*BK1\*BK1/DENOM
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CEF2=6(N-1)
CCEF2=0.5D0\*CF Page 39 5UMQ=SUMQ+DBINCO(IR-K,IP-19)+DBINCO(K,10) +DXI(BK3,IR-K-1P)+DXI(TK1,K)+DXI(BASE,1Q) ELSE FF(LL.EQ.3) THEN IF(MEST.EQ.1) THEN DEE=DX1(81GM+81GK,IR-K)\*DBINCO(K,IP)\* DX1(2:D0-81GK-1.D0,K-IP)\*DX1(81GK-1.D0,IP) TF(MOO(K,2).EQ.1) DEE=-DEE ELSE IF(MEST.ED.2) THEN DEE=DBINCO(IR-K,IP)\*DX1(B1GK\*(B1GK-2.D0),IR-K-IP)\* DX1(B1GK-1.D0,IP) 0EE=SUM0=0X1(BIGK,IR+IR-K-K-IP)=0X1(BIGK-1.00,IP) ELSE IFINEST.EQ.3) THEN G(0)=1.00 DOUBLE PRECISION FUNCTION DEE(LL, MEST, IR, K, IP, BIGK) ELSE (F(.LL.EQ.4) THEN IF(NEST.EQ.1) THEN DENOM=3.D0+BIGK+BIGK-3.D0+BIGK+1.D0 COEF1=(2.D0+BIGK+BIGK-3.D0+BIGK+1.D0)/DENOM G(0)=1.D0 DÊNOM=0'XI(81GK,3)-3.00=81GK+81GK+3.00=81GK COEF1=(81GK+81GK-3.00=81GK+2.00)/0ENOM G(1)=(1R=K)\*COEF1 BK1=81GK-1.00 DEE=DX((BIGK,3\*(IR-K))\*DX((DENOM,K)\*G(IP) IF(MOD(K,2).Eq.]) DEE=-DEE ELSE IF(NEST.ED 2) THEN 16-Jul-86 IMPLICIT DOUPLE PRICISION(A-H,O-Z) DIMEMSION 6(0:8) IF(LL.EG.2) THEN IF(MEST.EQ.1) THEN DEE=DX1(BIGK,IR-K) IF(MOD(K,2).EG.1) DEE=-DEE THE FUNCTION O(P) FOR 'BNJ/RMFSK ILOM=MAX0(0, IP-IR+K) BK3=BIGK-3.00 TK1=3.00+BIGK-1.00 BASE=BK3+BIGK/TK1 09:43:24 /F77/TR:BLOCKS/WR DO 42 IQ=1LON,1UP IUP=MINO( IP ,K) SUNG=0.DO CONTINUE CONTINUE PDP-11 FORTRAN-77 V4.0-1 RMFSKNIH8.FTN;13 / END IF ENO IF -¥ 4  $\cup \cup \cup$ 0002 0003 0005 0006 0006 0008 0000 0010 0010 0013 0015 0017 0019 0019 0019 0020 0021 0038 0041 0041 0041 0042 0045 0045 0045 0045 0012 000

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COEF 2=0.5D0+BK1+BK1/{BIGK+DENOM}

(2+(IR-K+1)-N)+COEF2+G(N-2))/N 16-Jul-96 G(N)=((IR-K+1-N)+COEF1+G(N-1)+ . 09:43:24 /F77/TR:BLOCKS/WR DO 43 N=2, IP POP-IL FORTRAN-77 V4.0-1 RMFSKNIH8.FTN:13 0049 0051 0051 0053 0053 0053 0055 0047 0048

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ALLERA
PCP-11	FCRTRAM-77 V4.0-] 09:43:33 16-Jul-86 VIH8.FTM;13 /F77/TR:BLOCKS/WR	Page 41	PDP-11 FOR RMFSKN1H8.1	TRAN-77 V4.0-1 09:43:35 16-Jul-86 Page 42 FTN:13 /F77/TR:BLOCKS/WR
1000	FUNCTION ICAPP(LL, NEST, IR, K)		0001	DOUBLE PRECISION FUNCTION GRAL(A0, 180, L1)
	C COMPUTE UPPER SUMMATION LIMIT PL			THE INKER INTEGRAL FOR COMDITIONAL ERROR PROBABILITY
2000	L IF(LL.LE.2) THEN		0005	IMPLICIT MOUBLE PRECISION (A-H.O-Z)
0003	ICAPP=0		0003	COMMON /RRRCOM/ RHOT, RHON
100	ELSE IF(LL.EQ.3) THEN		0004	COMMON /PARMS/ BIGK, LL
002 2002	IFINEST.EQ.I) THEN		5000	
9000	ICAPP=K		9000	IF(LI.GT.O .AND. LI.LT.LL) THEN
/000	ELSE JF(MESL.EQ.2) THEN TEADD-TP V		/000	BK]=B1(6K+1.D0 BACE-BK1//1_00+BICK+A0)
	ILATE IAAK			DAJE BAL/(I)ADIGA-AU) ADC1=(I.1_I.1ADIGA-AU)
	ELSE TE(TL_EO.4) THEN		0010	AR2=_L1*RHAT*RIGK/(1_DA+RIGK*AD)
1100	IF(MEST_E0.1) THEN		0011	ARG2=AR2=A1/0K1
0012	ICAPP=2*K		0012	POWER*1.DO
0013	ELSE IF(NEST.EQ.2) THEN		0013	SUM=0.00
0014	ICAPP=IR		0014	D0 100 1Q=0,180
0015	ELSE IF(NEST.20.3) THEN		0015	IF(IQ.GT.O) POWER+POWER+BASE
0016	ICAPP=2*(IR-K)		0016	PM=DSQRT(POWER)
/100			/100	SUM=GNLGPM(IQ+LL-1, 190-IQ, AKGI, PM) = GNLGPM(LI-1, 10, AKGZ, PM)+
0018	END IF		0018	
6100	KE LUKN		6100	F=1.00 60 110 1-1 100
0200	END		0200	00 110 1≤1,160 E≠E≮(1/A1)
			0021	
			0023	F=(F/DXT(A1_11_11_1))/DXT(1_100+B16X*A0_11)
			0024	GRAL = SUMPFFDEXP((ARG)+AR2)*A0)
			0025	ELSE IF(L1.EQ.0) THEN
			0026	ARG]=+LL*RHOM/A1
			0027	START=DEXP(ARG1=AO-LL=DLOG(A1))
			BZDY	
			6200	SIAKIESIAKIF(I/AI)
			0000	LUU LUMIINUC Chai_Chirdhii 1 100 And Fiadii
			1001	BIAL SCHLOFTILL-1,100,4461,51441)
			0033	A2=1.00+816K=A0
			0034	ARG1=-LL+RHOT/A2
			0035	BASE=BIGK/A2
			9036	START=DEXP(ARG1*B1GK*A0-LL*DLOG(A2))
			0037	D0 300 I=1,180
			8600	START=START=(1*BASE)
			6500	300 CUMIIAUE Coal-Carrentii I too adri cyadti
				UNAL FURGATI(LL-1, IDU, MAGI, SIMAI) End te
				RETURN
			600	END

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		л,	34 	300 200 200 200 200 200 200 200 200 200	P-11 FORTR SXHIHB.FT	2	, C (	22222222222222222222222222222222222222
ê	1.44 77 V4.( N;13	000871	NERAL IZED WEIGHTING	IMPLI TERMAI TERMAI 10 10 10 10 10 10 10 10 10 10 10 10 10	14.17 V4.1	SUBRO	MPUTE J.C.	DIMEGIA INTEG DIMEGIA DIMEG
	)-1 / <i>F77/T</i> R	E PRECISIO	LAGUERRE FACTOR (T	CIT DOUBLE DBINCO(N+I. ERM ERM EQ.0) 6070 0 M=1,N -TERM*((X/I UN+TERM 4 SUM 4 SUM	0-1 /F77/TR	UTINE JCPM	.P. MILLER	CIT DOUBLE ER R 1.00 C(0:K) 0.1.10 0.1.10 0.1.10 0.0.11 100(K,LM1) 00 100(K,LM1) 00 100(K,LM1) 00 00 00 00 00 00 00 00 00 00 00 00 00
X	09:43:40 :BLOCKS/WR	N FUNCTION	POLYNOMIAL: Defer th	PRECISION ALFA,N)*PRI 200 H)*((N-H+1.	09:43:42 :BLOCKS/NR	FIC, KMAX, R.	COEFF ICIEI	PRECISION MAX) TURN 1.D0)+N-K)+
	16-Ju1-	GNLGPM( IA	S WITH PRE E INEVITAB	(A-H, J-Z) Enul .D0)/(IALF	16-Jul-	(IMI)	NTS DIVIDE	(A-H,0-Z) *C(K-N)
	96 26	LFA,N,X,PF	MULTIPLIC	( ( [₩•₩:	<b>9</b> 8-		id by Ki	
	Page 4	(TNM3)	ATION BY MS)		Page 4			
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# APPENDIX E COMPUTER PROGRAM FOR INDIVIDUAL CHANNEL ADAPTIVE GAIN CONTROL RECEIVER

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the individual channel adaptive gain control receiver for FH/RMFSK.



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11-909	FORTRAN-	77 V4.0-1 08	1:32:51	16-Jul-R6	Page 3	1-404	I FORTR	AN-77 V4.0-1 08:33:0	ي ب
ICAGC.F	1N;22	/F /// IK:BU	OCKS/#K			ICAN	(W) 22	/F/// IK:BLUUKS/	ž
0066		TRASH2=. TRUE.				1000	•	SUBROUTINE GET(NJ, START	, DBINC
0067		DEBNJ=START+(1J-1)	+DBINC				: ب ب		-
		HIGH=DEBNJ.GE.15.U	2				≍ بر	MIEKAULIYE JUPUL UP PAKAMET	
5000		DETO DOOP DEBUT	2			cuno	,	THOU TELE POLISI E BOEFICE	л е / <del>л</del> о
		R*IU.UUTS=CAMMA*P*FRMD	), UU) )// 6.44444-8+1	FIRMO)				CHARACTER=9 FIFLD_BLANK	
0072		RHOT=K+RHOTS/FLL				1000		COMMON / INPUTS/ DEBMON (	5).417
	C EVALU	ATE THE PROBABILITY				0005		COMMON /SIZE/ NO.ML.NG	
0073		CALL PSUBE (RHON, RH	TULLING	AMMA, PESYM)		000		DIMENSION DG(31), DSMR(	5.4)
0074		PE=WORBIT=PESYM	•			000		DATA DG / .00100, .0020	8
0075		<b>JRITE(6,666) DBSJR</b>	R( [ J) , PE					\$ .0100°, .0200	<u>8</u>
0076	999	FORMAT(IX, F7.3, 5X.	IPD12.5)					5 .100, .200.	<u>G</u>
0077		PRLOG(1.3) = DL0G10(P)	E)			9000		DATA DSNR /13.3524700.	12.313
0078		OPEN(UNIT=4 FILE=FI	-NAME STATU	S= OLD', ACCESS='	APPEND'			10.60657200,	9.62
	5	FORM= "UNFORMA	(TTED')		•			5.0940109-0	8.169
6200	•	MRITE(4) DBSJR(1J)	. PRLOG(1J	_				\$ 8.0783500	7.199
0800		CLOSE (UNIT=4)				6000		DATA BLANK9/'	-
0081	<b>8</b>	CONTINUE				0010	32	WRITE(5,33)	
0082		OPEN(UNIT=4,FILE=F	CNAME, STATU	IS= NEN' , FORM= 'U	VFORMATTED • )	1100	33	FORMAT( BITS/SYMBOL (K	[2]
0083		MRITE(4) MM.LL.DEB	3NOL ( IO) . NSI	LOTS, GAMMA, DBSJK	1, PRL06	0012		READ(5,3)K	1 1
0084		CLOSE (UNIT=4)		•		0013		IF(K.EQ.0)K=2	
0085	200	CONTINUE				0014		X++2=144	
9990	808	CONTINUE				0015	-	MR11E(5,2)	
1 0087	006	CONTINUE		į		0016	2	FORMAT (* HOH MANY EB/HO	? [L]:
8800 3		STOP "PLEASE PURGE	E DATA FILE	2.		/100		KEAU(5,5)NU	
6800		END				0018	•••	FORMAT(12)	
						6700		17(NU.CU.URUEL	
						0200			
						1200		JF(K.LE.4) /MEN	
						2200		DO=DSNK(IN,K)	
						0023		ELSE	
						0024		00=0.00	
						0025	•	ENO IF LUITE/E ENTE DO	
							<b>*</b> .	#KI (E(3,3/14,UV)	
						1200 8600	n	FUKTAI( EB/NU(',12,' DEAN/S SIFTEID	
						0030	ų	REAULUSULI ALLU FromAT/AD)	
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P-11 FORTRAN-77 V4.0-1 08:33:05 16-Jul-86 Page 4 :AGC.FTN:22 /F77/TR:BLOCKS/MR	01 SUBROUTINE GET(NJ,START,DBINC) C	Č INTERACTIVE INPUT OF PARAMETERS FOR RUN	02IMPLICIT DOUBLE PRECISION(A-H,O-Z) N3CHARACTER+9 FIFID_BLAMEQ	COMMON / INPUTS/ DEBNOL (5), LLIST(4), NSLOTS, GAMLST(31), K, PM	DOS DIMENSION DE(31), DSWR(5,4)	07 DATA DG / .00100, .00200, .00500, \$ .0100, .0200, .0500,	06 DATA DSMR /13.3524700, 12.313300, 10.944300, 0.50, 0.50,	10.00 0.00 0.00 0.00 0.00 0.00 0.00 0.0	09 DATA BLANK9/' '''''''''''''''''''''''''''''''''''	10 32 WRITE(5,33)	111 33 FURNATI('BLIS/SYTHBUL (K) [ZJ:',3) 112 READ(5,3)K	113 IF(K.EQ.0)K=2	]]4 . MM=2**K 15 1 . MDTTFL5 2)	16 2 FORMAT( HON MANY EB/MO? [1]: ',S)	117 READ(5,3)NO		20 DO 7 IN=1,MO	22] IF(K.LE.4) THEN 22 DA-DADATA K		124 D0=0.00	25 ENO IF	226 4 WRITE(5,5)IN,DO 23 5 Endwart' FRAMA(1,12,1)['Eq.6,1].1.6)	28 READ(5,6) FIELD	29 6 FORMAT(A9)	)30 IF(FIELD.EQ.BLANK9) THEN 131 DFRMOL(TN)=DD	132 ELSE	33 DECODE(9,61,FIELD)DEBMOL(1M)	134 OL FURNALLES.OJ	136 7 CONTINUE	137 15 WRITE(5,16) 230 16 EADWATP HAW 12 [A]. 1 €)	100 10 FONDATI INVERTIALI LI [1]. , JJ. , JJ. , J. , J. , J. , J. , J.		MI 00 21 IN=1,ML	AZ IB MATC(⊃,19/14,17,1)[',1].'S) Bas to FORMATC' (',1,1)[',1].'S)	M4 READ(5,3)LLISTIN)
82	8		88	88	38	8	8		8	88	38	8	85	88	88	38	8	88	38	88	88	88	38	8	88	88	88	38	88	88	38	38	88	38	88

0045 0046 0046			
0046 740		IF(LLIST(IN).E0.0)LLIST(IN)=?N	8
0047	21	CONTINUE	
	22	urite(5.23)	
0048	ŝ	FORMAT(* HOPPING SLOTS? [2400]: '_\$)	
6100		READ(5, 24) NSLOTS	8
050	24	FORMAT(IS)	8
0051		IF (MSLOTS.EQ.Q) NSLOTS=2400	8
0053	25	MRITE(5.26)	8
0053	3	FORMAT(' HOW MANY GAMMA? [10]: '.5)	8
0054		READ(5,3)MG	
0055		IF (NG.EO.O) MG=10	8
0056		DO 31 1N=1 NG	8
0057	28	MRTTE(5, 20) IN. DG( IN)	6
<b>MAR</b>	2	FORMAT(' CAMMA(' 12 ') [' 1008 ] ']' ' \$)	8
0050	;	READ(S. 30) GAM ST( 10)	88
00ED	ЗР.	FORMAT(D15_8)	8
000	3	TFIGAMESTIN, FO. D. DOIGAMESTIN)=DGIN)	
0062	3		
0063	189	WITE(5.39)	
0064	Ē	FORMAT(* HOM MANY EB/NJ? []]: '.S)	
0065		READ(5.34.ERR=38) NJ	
9900	R	FORMAT(I3)	
0067		IF(NJ.EQ.0) NJ=1	
8900		IF(NJ.LT.O .OR. MJ.GT.126) 60TO 32	
6900	9	MRITE(5,41)	
000	[#	FORMAT(' STARTING VALUE FOR EB/RJ (DB) [0.]: '.5)	
0071		READ(5,42,ERR=40) START	
2/00	<b>4</b> 2	FORMAT(F6.3)	
0073		IF(NJ.EQ.I) RETURN	
0074	35	MRITE(5,36)	
0075	98	FORMAT(" DB INCREMENT FOR EB/NJ [5.]: ",\$)	
0076		READ(5,37,ERR=35) DBINC	
0077	37	FORMAT(F6.3)	
0078		IF(DBINC.EQ.O.) DBINC=5.	
6/00		RETURN	
080		END	

 $\mathcal{A}(\mathbf{r})$ 

Page 6						Q.LL)) THEN	,LL-L1)*PECON				
16-Ju1-86	,LL,M,GAMMA,PE)	<b>BILITY</b>	H-H, 0-Z)		*L1*RHOT	).0.00 .AND. L1.E	XWM.L1)+DX1(0H6				
08:33:15 7/TR:BLOCKS/MR	PSUBE (RHON, RHCT,	DMAL ERROR PROBA	UBLE PRECISION(A		LL-L1)+RHOM+2.DO	.DO.OR. (DMG.EQ	NCO(LL.L] *DX1(6				
FRAN-77 V4.0-1 22 /F7	SUBROUTINE	COMPUTE UNCONDITI	IMPLICIT 00 PE=0.00	0HG=1,00-6A	AL M=2.00+(	IF (CMG.NE.O	PE=PE+DBI	ENC IF	LOO CONTINUE	RETURN	END
-11 FOR		ມບັບ	20	<b>1</b>	c up	⊳ a	2	0.	-	5	m

	3e B			
	<u>A</u>	(x		
	Ju]-86	s(IALFA,N,		-Z) (ALFA+M)))
	22 16-1	TON GENLAG	IALS	10.(A-H,0- H+1.D0)/(1
**	08:33: /TR:BLOCKS	sion funct	RE POLYNOM	010 200 (X/M)+{(N- (X/M)+(N-
	V4.0-1 /F77	UBLE PRECT	ZED LAGUER	2.111 DOU 4.1511 DOU 4.158M CO 1.00 M-1, N 4.1500 M-1, N 4.500 H-1, N 4.500 H-1, N 1.00 M-1, N 1.100 H-1,
	0RTRAN-77	8	C GENERALI	
	PDP-11 FI	1000		000 0006 0006 0011 0011 0011 0011 0012
2448 2				
	7			
	Page			
***	-86			ALL' )*C(IR-K)
	16-Jul	L, PE)	<b>BILITY</b>	((A-H,0-Z) (LL) ANY TOO SM CIENT ()) ())
	08:33:17 t:BLOCKS/W	(ALAH, MI, I	RROR PROB	PRECISIO (MM-FK)/F) (MM-FK)/F) (MM-FK)/F) (FK1 /FK1 /FK1 /FK1 /FK1 /FK1 /FK1 /FK1 /
	0-1 / <i>FT7/</i> TB	UTINE PSLI	DITIONAL	CTT DOUBLE 5510% C(0::U D0 0 K=1,MM-1 0 K=1,MM-1 1:=-POMER1* *(LL-1) *(LL-1) *(LL-1) *(LL-1) *(LL-1) *(LL-1) *(LL-1) *(LL-1) 0.00 0.00 0.R=0; K( 0.00 0.R=0; K( 1:R)*Y/DX SUMR+TERM MUE *(LL-1, *(LL-1) *(LL-1
	RAN-77 V4. 2	Subro	UNPUTE CON	Implify           Premert
*	DP-11 FORT	یں آو	0 0 L	2000 2000 2000 2000 2000 2000 2000 200
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APPENDIX F COMPUTER PROGRAM FOR NUMERICAL COMPUTATIONS FOR THE ANY-CHANNEL-JAMMED ADAPTIVE GAIN CONTROL RECEIVER

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the any-channel-jammed adaptive gain control receiver for FH/RMFSK.



PDP-11 ACJA6C	FORTRAN-77 V4.0-1 16:57:23 15-Jul-86 Page 1 .FTN;36 /F77/TR:BLOCKS/WR	PDP-11 FOR	RAN-77 V4.0-1 16:57:23 15-Jui-86 Page 2 36 /F77/TR:BLOCKS/WR
1000	PPOGRAM CRWHOP C C THIS PROGRAM COMPUTES THE ERROR PROBABILITY FOR RANDOM M-ARY C FXX/FH WITH MULTIPLE HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND	0034 0035 0036	<pre>MRITE(5 733) FNAME 33 FORMAT(' WORKING ON FILE ', A13) 0PEN(UNIT=4, FILE=FNAME, STATUS='0LD', FORM='UNFORMATTED', \$ ERR=750]</pre>
	C MOISE JANNIMG USING THE ANY-CHANNEL-JANNED AGC RECEIVER C analysis: L. E. Miller, R. H. French C Proceans P. N. French		AVE AN EXISTING FILE, READ TO SEE HOW FAR WE GOT BEFORE
	C V 5.1.0 - COMPUTATIONS ONLY	0037 <sup>1</sup> 1 0038	00 READ(4) MMIN, LLIN, EBMDIN, NSLIN, GAMIN If(MMIN.HE.MM. OR. LLIN.NE.LL.OR. EBMDIN.NE.DEBMOL(10) 5 .OR. GAMIN.NE.GAMMA. OR. MSLIN.NE.NSLOTS)
800 800 800 800 800 800 800 800 800 800	C IMPLICIT DOUBLE PRECISION(A-H,O-Z) PARAMETER (LJ=126) CHARACTER+13 FNAME, GNAME	0039 0040 00410 7	5 STOP 'FILE SYNC ERADR OR CORRUPTED FILE' 3.3=0 40 3.3=.3.41 READ(4,END=742) 1985.3R(3.3), PRLOG(3.3)
800	LUGICAL*1 KANAT, KANAC LOGICAL*1 GOOD DIMENSION MATRIX(4,8),MLOM(4,8),MUP(4,8),MIMC(4,8),	0042 0043 0044	60T0 740 42 CLOSE(UNIT=4) 60T0 755
8000 6000	* KEAL*4 PRLOG(LJ),085JR(LJ) VIRTUAL A(100),1ASUB(100),C(625),ICSUB(625) VIRTUAL D(675),TUSUB(100),C(625),ICSUB(625)		O EXISTING FILE, THIS IS THE FIRST TIME: Create file Header Record
1100	C SAVED DENSITY VALIDITY FLAGS COMMON /RESET/ TRASH1, TRASH2 C COMMON /INPUTS/ PASSES PARAMETERS OF THE RUN	0045 7 0046 0047	50 JJ=1 OFEN(UNIT=4,FILE=FNAME,STATUS=*NEW*,FORM=*UNFORMATTED*) MRITE(4) MM.LL.DEBMON(10).MSLOTS.GAMMA
0012 0013 0014	COMMON /INPUTS/ DEBMOL(5),LLIST(4),NSLOTS,GAMLST(31),K,MM C COMMON /SIZE/ PASSES MUBBERS OF PARAMETERS COMMON /SIZE/ MO,ML,MG COMMON /PARMS/ BIGK_LL	0048 0049 0050 7 0051	CLOSE(UNIT=4)
0015 0017 0018 0018	C DISABLE ERROR MESSAGES FOR 'FILE NOT FOUND' CONDITION CALL ERRSET(29, TRUE., FALSE., TRUE., FALSE., 15) CALL GET(NJ,START,DBINC) BITS-K WORDITE(.500MM/(MM-1.DO)	0052 0053 0054 0056	<pre>% Control of the second s</pre>
0050 0021 0022 0022	DU 900 IL=1,ML LL=LLIST(IL) FLL=LL DO 800 10=1,MO FRWGTO POMAT/FERMO(770,700 A0)	0026 C C C C C C	GOTO 777 F FILE FOR EVENT PROBABILITIES DOES NOT EXIST, ALCULATE THEM AND CREATE A FILE.
0024 0025 0026 0027 0027	RHOM=B175-REDNFL(10)/10.00) RHOM=B175-REDNFL(10)/10.00) 100017=DEBND1(10) D0 700 16=1,NG GAMMAASTT(16)	0050 39 0058 39 0060 39	70 CONTINUE 88 FORMAT(* CREATING EVENT FILE*) CALL GENPIE(LL,MM, NQ, NSLOTS, 6000, MATRIX, MLOM, MINC, MUP, PIE,
	C OPEN DATA FILE	0062 0062	<pre>b DEW(UNIT*3,FILE=GNAME,STATUS='NEW',FORM='UNFORMATTED') NRITE(3) D, IDSUB,NUSED,6000</pre>
0029 0030 0031 0033 0033	IGOUT=GAMMA*1000_D0+0.5D0 KRITE(FWAME,730) MM.LL,100UT,160UT 730 FORMAT(*1,11,12,2,14,4,10AT') WRITE(6,776) MM.LL,DEBWOL(10),6AMMA 776 FORMAT(*M±,12,5X,'L=',12,5X,'EB/W0=',FB.4,5X,	0063 0066 0066 0067 0067 0067 0067 0067	CLUDELUNIT=3)           77         IF(.WOT.6000) GDTO 700           00         600         IJ-31,MJ           IVE         PROGRESS         MESSAGE TO T1:           MATTE(5.601)         JJ         01
	5 '644444'', IPDIO.3		

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	15-Ju1-86	KC)	FOR RUN	-H. 0-7)		LIST(4), NSL0TS, 6	ARE IN SHARED ST	AVS	5,4)		1: ' <b>.</b> ')					(c. :[								Fo 6 '1' • 6)	اهو ا ومنتاه				JN)				(5.				(5.		-4		(5.1.100	
	16:57:36 /TR:BLOCKS/WR	ET(NJ, START, DBJ	OF PARMETERS	RLE PRECISION(A	FIELD, BLANK9	TS/ DEBNOL(5),L	ORARILY WEEDED	ION MORKING ARR	E/ DG(31), DSMR(		S/SYMBOL (K) [2	•	2		1000 LD (000 L)	MANT EB/NU? [I		0=1		HEN	(u.		2	,00 B/MDC: 72 -1 C.	LD		BLANK9) THEN	<b>2</b>	1, FTELD) DEBNOL (	6)			. MANY L? [1]: '		[-]	_ <b>a</b>	('.11.') <b>/4</b> 7: '	ST(IN)	.EQ.0)LLIST(IN)		PING SLOTS? [24	LOTS
	-77 V4.0-1 /F77.	SUBROUTINE G	ERACTIVE INPUT	THE LETT BOIL	CHARACTER*9	DdWI/ NOMMOD	ULT LISTS TEMP	LARGE CONVOLUT	CUTTON / SHAK	UNIA BLANKY	FORMAT( BIT	READ(5,3)K	IF(K.EQ.0)K=		ECONATE (5,2)	PUKMAI ( HUW DEADIS 2140	FORMAT(12)	IF (NO.EQ.O)M	ON I=NI 2 DO	IF(K.LE.4) I	ELSE	00-0-00	END IF	FLANDITE (5,5) IN	READ(5.6)FIE	FORMAT(A9)	IF(FIELD.EQ.	UEBNUL ( IN): FI SE	DECODE(9.6	FORMAT (F9.	END IF	LUMIINUE	FORMAT( HOW	READ(5,3)NL	IF (NL.EQ.0)N	TOL INTER 101	FORMAT( L	READ(5,3)LLI	IF(LLIST(IN)	LUNITELS 23)	FORMAT( HOP	READ(5,24)NS
	FORTRAN FTN;36	د		J			C DEFA	C THE		32	; R					~	~	•					•	47 L	n	9				61	٠	15	16			10	96	Ì	į	22	38	ı
R)	PDP-11 ACJAGC.	1000		000	2000		200		88		500	0100	1100	0012	0013	4100 4100	0016	0017	0018	0010	0021	0022	0023	0024 0025	0026	0027	0028	6200	0031	0032	6633 6633	1037 1037 1037	0036	0037	0038	6500		0042	0043		C046	0047
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	16:57:23 R:BLOCKS/MR		J-1)*DBINC	LJ/10.00)	S/FLL		M, XHUI, LL, F	Ŧ	BSJR(1J),PE	3,5X,1PD12.5)	DI F=FNAMF STU	ORMATTED )	RL06(			ILE=FNAME,ST	· 'UEBRUL( IU)			NIDEC DATA C												•										
	.0-1 /F77/1	42=. TRUE.	<b>J=START+(</b> 2(1J)=DEBN	.00**(0EB) 5=241414424	BITS+RHC	HE PROBABI	PSUBE( KH	ORBIT+PES	E(6,666) (	AT(1X,F7.	INIT - ULO	FORM- UNI	E(4) DBSJ	E(UNIT=4)	TNUE	(UNIT=4 F			INUE	INUE IDEFACE 1	LENSE																					
	AN-77 VA. 5	TRAS	DEBN	R=10	RHOT	ALWATE TI	۲ ۲	PE=W	HR I TI		DEN		IL I W	CL 0SI	C CONT			0 CONT	0 CONT			}																				
	POP-11 FORTRU ACJAGC.FTN;34	0068	0069 0070	1/00	0073	C EV	6004	0075	0076	0077 66i	0/00 0170		080	0081	0082 60	0083	0084 0005	0086	0087 800	06 8800 F		3																				

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1 EADIDAM-27 VA A 1 15.62.46 16.1.1-86 0.000 6	I FURTHAN-// V4.U-1 L0:2/149 12-UUI-00 Fage 0 (.FTN;36 /F77/TR:BLOCKS/MR	SUBROUTIME PSUBE(RHOM,RHOT,LL,M,BITS, \$ PE,D,IDSUB,MUSED,PRERR,IPSUB,EBMJ) C	C COMPUTE UNCONDITIONAL ERROR PROBABILITY	MPLICIT DOUBLE PRECISION(A-H,O-Z)	LOGICAL TRASHI, TRASH2	VIRTUAL PRERR(625),IPSUB(625) VIRTUAL D(625),IDSUB(625)	COMMON /RESET/ TRASHI, TRASH2	Pt=0.00 00 199 LTHJ=0,LL	JAMIL(0)=LTHJ . FLAG TO MAKE SURE TRASH1 IS TRUKE FOR FLRST TIME AROUND	(JW(1)=-1	00 199 11=0,LTHJ JAML(1)=11	ITER=1 100 D0 101 [=TTED+1 M		C OUTERMOST MONSIGMAL LOOP ALMAYS STARTS FROM 0, C DIMERC FROM THE CERRENT VALUE OF MEXT MUTER MODE 1000 1MDEX	C UTILING THE COMPLET PARTY OF MAN UNLEY THE LOU THEY	IF([.6T.2] THEN .3444 / 1)=.3446 / 1_1		JAML(i)=U END JF	101 CONTINUE Call Event(LL,M,Jami, PIE,D,IDSUB,NUSED) Isterf fon MN, Eattn Jon	C TRANSFORM TO EQUIVALENT LINEAR RECEIVER COMDITIONAL PROBABILIT	C RHOTIO=RHOTI	IF(JAML(O)-JAML(I).NE.LL) THEN PHOTT=PHOM+(JAM (1)+(PHOT_PHOM))/(II_JAMT(O)+JAMT(1))		I CH3 I CH3	JF(RHOT10.ME.RHCT1) TRASH2=.TRUE.		UG5 CONTINUE	IF(JAM1.ME.JAM(1)) TRASH1=.TRUE. UCK=RHOM/RHOT	IF(RHOTL.ME.RHON) THEW EBNJJ=LL*RHOM*RHOTL/(BITS*(RHOTL-RHOM))	ELSE EBNJJ=LL*RHOW/BJTS	END IF
1 000	ACJAG	0001		0003 0003	0004	888 898	000		0010	0011	0013 0013	0014	100			0016	0018	0020	0021	C700	0024	0025	0027	9200 9200	0030	6032	0034	0035 0036	0037 0038	0040	0041
9	C aber				;	<b>(</b> 2)							( <b>5.</b> :[.(																		
20 6.1	48-1 n(		3		•	3.1, <sup>1</sup> 7: ',	(11)00	( 11 ) P() = (	(5.,	Ì		32	(DB) [0			7.4.1.4.2	· · · · ·														
	-61 6	00	· . :(ɛɹ ¿			11 1PD6	100 CT ( 10)		? [126]:			26) 60T0	FOR EB/N			DR FR/MJ		400													
20,02,01	t:BLOCKS/N	NSLOTS=24	IN GAMAN	~	)(II))	M( • 12 • ) 28)6AML ST(			WY EB/NJ7	38) NJ	•126	. NJ.GT.12	THE VALUE	(0) START	TURN	REMENT FC	35) DBINC	DBINC=0.													
	/F77/TR	I5) ITS.Eq.0) .26)	MI NOH .	(0.0) NG=3	29) IN.D	30, ERR=2	015.8)	1. (ML) IC. E	, 39) • HOW MA	34 . ERR=3	13) (0.0) NJ=	T.0 .0R.	STARTI	42,ERR=4 F6 31	Q.1) RET	; 36) • DR IMC	37 , ERR=3	ro.3) C.Eq.0.)													
	-// <b>/4</b> .0-	FORMAT( IF(NSLO MRITE(5	FURMAT (	IF(NG.E)	INTE(5	FORMAT( READ(5,	FORMAT	CONTINU	FORMAT(	READ(5	IF(NJ.E	IF(N).L	FORMAT (	READ(5,	IF(NJ.E	HRITE(5 FORMAT(	READ(5	IF(0BIN	RE TURN END												
	FURIKAN-	2 <b>4</b> 25	26		28	53	30	31	80 80 80 80	; ;	ŧ,	U <b>V</b>	4	42	ŧ :	SS &	3 1	31													
	ACJAGC.	0048 0049 0050	0051	0053	0055	0056 0057	2058 2058	0000	0062	0063	0064 0065	0066 N067	0068	0069	0071	۲ 0072 ۲	0074	0076 0076	0077 0078												
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15-Jul-86

C EMPIRICAL SWITCH-OVER POINT FOR COMPUTATIONAL METHOD C TO AVOID ROWND-OFF AND TRUNCATION ERRORS IF(EBNJI.GT.31.6. OR. EBNJ.GE.40.DO .OR. \$ (RHOM.GE.30.DO.AND.EBNJ.GE.25.DO) \$ .OK. UCK.LT.1.01DO) THEM CALL PSEL1(JAM,LL,M,RHOM,RHOT1,UCK,PROB) ELSE CALL PSEL2(JAM,LL,M,RHOM,RHOT1,UCK,PROB) TRASH1=.TRUE. FRASH1=.TRUE. END IF END IF PE=PEPROB\*PIE 190 D0 195 1=2,M ITER=H+2-1 JAML(ITER)-JAML(ITER)+1 IF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 END FF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAML(ITER).LE.LTHJ) GOTO 100 IFF(JAMLE) RETURN 16:57:45 /F77/TR:BLGCKS/MR PDP-11 FOPTRAN-77 V4.0-1 ACJAGC.FTN;36 **00**42

CORTRAM-77 V4.0-1 16:57:51 15-Jul-86 Page 9 :TN;36 /F77/TR:BLOCKS/WR	SUBROUTIME EVENT(LL,M,JAML,PIE,D,IDSUB,MUSED) C subroutime to look up event probability from stored Array	C IMPLICIT DOUBLE PRECISION(A-H,O-Z) LOGICAL*1 STORE,NOME DIMENSION JAML(9),LUP(9) VIRTUAL D(625),IDSUB(625)	DIMENSION LON(9) DATA STORE/.FALSE./, LON/9*0/ C SET UP ARRAY DESCRIPTION D(0:LL,,0:LL) WITH M+1 DIMENSIONS D0 1 1=1,M+1 LUP(1)=LL	1 CONTINUE C COMPUTE LINEAR EQUIVALENT SUBSCRIPT FOR JAMMING EVENT CALL LOCH(H-1,LOW,LUP,JAMM,ISUB) C TOWN UP THE VALUE EST O. NO IS MAT THEOF	CALL LOOKUP(PIE, D, IDSUB, NUSED, 625, ISUB, STORE, MOME) RETURN
FORTRAN FTN;36	c SuBF	u	C SET		
PDP-11 ACJAGC.	1000	0002 0004 0005	0006 0008 0008	0010	0012 0013

	ge 12														
	A.			ITRIES USED											
	-Jul-96			ount of Ei											
	:00 15 S/MR		0 50	ND BUMP C											
	16:58: 7/TR:BLOCK	JSE	.EQ.K) GOT(	element a	JSE-1 508(1+1)										
	· V4.0-1 /F77	0 40 i=1,ML	F(ICSUB(I). ONTINUE LETURN	THE ZERDED	CSUB(1)=1C3	JUNI JUUE RUSE=RUSE-1 LETURN MD									
	FORTRAN-77 FTN;36	8	8 . 	C REMOVE	<u>.</u>										
	PDP-11 ACJAGC.	0021	0023 0024 0025		0026 0027 0028	0030 0031 0032									
₿¥.	1														
	Page 1	EI R, STORE)	ar 7ay for Rage If	NHERE DF THE	RGE	ŝ	STORED LUES	THERE IS	.FALSE. CSUB, THEN D ALL	ANUARY 1,54					
	1-86	, MMAX, K, I	A SPARSE PT IN STO	D AS C(K)	IN C.	L JFRR ST	ACTUALLY SCRIPT VA	R OR 1 IF	TLY, ELSE DUND IN I 6 DOWNMAR	ATE: 11 J	_				
	15-Ju	CSUB, NUSE	AENT INTO IS ARE KEI	IS STORE	5 ENTRIES 0 TO ACCO	NX) ISF IMMAX	AE ALUES ARE CTUAL SUB	F NO EPRO	S EXPLICI PT K IS F Y SHIFTIN E ARRAY	Ő	N(A-H,0-Z AX)		6		
	16:58:00 R:BLOCKS/W	IN(CIN.C.IC	RTS AN ELEN IERO ELEMEN' . TRUE.	I VALUE CIN	RRESPONDING RS ARE USEI	LE ON C, CIN MMAX), C(MN LIC: ICSUB M	IENT TO STOO NON-ZERO VI RRAY FOR A	I CODE, O II	STORE ZERDE THE SUBSCRI DELETED B THIS OF THI	I. FRENCH	LE PRECISIO Innax),c(nn le	) 5 () 60T030 50T0 20	.K) 60T0 1	X) G0T0 20	
×.	1.0-1 /F77/1	TOUTINE PUT	NTTLE INSE THE NON-2 I STORE IS	PRECISION	TE) INTEGE	ICAL*1 STOR ILE PRECISI UAL ICSUB( PHTINICIN	UE OF ELEN IN WHICH	IZE OF ARRI ROR RETURN	TRUE. TO SIN=0 AND T CIN=0 AND T ELEMENT IS OWING ELEP	R: ROBERT F	LICIT DOUBL TUAL ICSUB( CAL+1 STOR	STORE) GOT( SIN.EO.O.DC UDSE.EO.O)E	ICCUB(I).ME	rinie Husellinnu Hei	JRN E=NUSE+1 JB(NUSE)=K JSE)=C1N JRN
222 2	teran-77 v4 1;36	SUBR	THIS SUBRC WHICH ONLY THE SWITCH	THE DOUBLE	SUBSCRIPT LONG (4-B) SUBSCRIPT	USAGE : LOGI COUE VIRT	NHERE CIN = VAL C = ARRAL ICSUB = A		SE = . Note: IF ( The Foul	PROGRAMME	IMPI VIR LOGJ		RETU	CON IFL	
	PDP-11 FOF ACJAGC.FTN	1000		ى ر د	,000			, L <b>L L</b>			0002 0003 0004	0006 0007 0008 5	0010 0011 0012	0013 1( 0014 1( 0015	0016 0017 0018 0019 0020

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FORTRAN-77 V4.0-1 16:58:05 15-Jul-86 Page 14 FTN;36 /F77/TR:8LOCKS/MR	SUBROUTINE LOCM(NDIM, ILGM, IUP, ISUB, LINEAR)	C THIS SUBROUTINE COMPUTES THE EQUIVALENT LIMEAR SUBSCRIPT FOR C A MULTIDIHENSIONAL ARRAY OF NOIM DIMENSIONS	C IF THE ARRAY A IS DEFIMED AS DIMENSION A(ILOW(1):IUP(1),,ILOM(MDIM):IUP(MDIM)) AND ISUB(1),,ISUB(MDIM) IS A SET OF SUBSCRIPTS FOR A, AND ISUB(1),,ISUB(MDIM) IS A SET OF SUBSCRIPTS FOR A, C THEN THIS SUBROUTIME RETURNS IN LIMEAR THE OFFSET FROM THE C ORIGIM OF A TO THE ELEMENT A(ISUB(1),,ISUB(MDIM)), ASSUMIME C USAGE: C USAGE: DIMENSION ILOW(MDIM),IUP(MDIM),ISUB(NDIM) C DATA ILOW/IOMEN TIMITS OF DEFINED SUBSCRIPTS OF Array/ DATA IUP/WODE TIMITS OF DEFINED SUBSCRIPTS OF Array/	CSET ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS CALL LOCN(NDIM,ILON,IUP,ISUB,LINEAR) C WHERE NDIM = NUMBER OF DIMENSIONS THE ARRAY HAS ILON = ARRAY OF LOWER SUBSCRIPT BOUNDS ILON = ARRAY OF UPPER SUBSCRIPT BOUNDS IUP = ARRAY OF UPPER SUBSCRIPT BOUNDS C ISUB = ARRAY OF UPPER SUBSCRIPT FOR MHICH LOCATION IS ISUB = ARRAY COMPUTED C LINEAR = RETURNED VALUE OF OFFSET INTO ARRAY IN MEMORY	C PROGRAMMER: ROBERT H. FRENCH DATE: 11 JAMUARY 1984 C DIMENSION ILOW(NDIM), IUP(NDIM), ISUE(NDIM) LINEAR=0 DO 10 I=1,NDIM-1 J=NDIM-1+1 LINEAR=(LINEAR+(ISUB(J)-ILOM(J)))+(IUP(J-1)-ILOM(J-1)+1) LINEAR=(LINEAR+ISUB(1)-ILOM(J)))+(IUP(J-1)-ILOM(J-1)+1) RETURN END END
PDP-11 ACJAGC.	1000				000 000 000 000 000 000 000 00 00 00 00
PDP-11 FORTRAN-77 V4.0-1 16:58:03 15-Ju1-86 Page 13 ACJMGC.FTN;36 /F77/TR:BLOCKS/MR	0001 SUBROUTINE LOOKUP(COUT,C,ICSUB,N,MAX,K,STORE,NOME)	Č THIS SUBROUTIME RETRIEVES AN ELEMENT OF A SPARSE ARRAY MHICH C has been stored compactly by storing only non-zero elements. C	C THE ARRAY IS DOUBLE PRECISION. C USAGE: C USAGE: C USAGE: C DOUBLE PRECISION CONT C LOGICAL*1 STORE, MONE C DOUBLE PRECISION COUT C CALL LOOKUP(COUT,C,ICSUB,N,MMAX,K,STORE,NOME) C ANERE C CALL LOOKUP(COUT,C,ICSUB,N,MMAX,K,STORE,NOME) C MHERE C COUT = VALUE OF C(K) (OUTPUT FROM SUBROUTINE) C COUT = VALUE OF C(K) (OUTPUT FROM SUBROUTINE) C COUT = VALUE OF C(K) (OUTPUT FROM SUBROUTINE) C ICSUB = AUXILIARY ARRAY TO STORE ACTUAL SUBSCRIPTS	C M = NUMBER OF ELEMENTS OF C CURRENTLY IN USE MAXX = SIZE OF C C K = SUBSCRIPT OF SPARSE ARRAY TO LOOK UP C STORE = .TRUE. IF ZEROES STORED EXPLICITLY, ELSE .FALSE. C NOME = .FALSE. IF ZEROES NOT STORED ON ZEROES STORED AND C .TRUE. IF ZEROES ARE STORED AND THE ELEMENT IS NOT FOUND (OUTPUT QUANTITY) C PROGRAMMER: ROBERT H. FRENCH	C DATE: 11 JANUARY 1984 C INFLICT DOUBLE PRECISION(A-H,O-Z) VIRTUAL ICSUB(MAXX),C(MAXX) 0005 VIRTUAL ICSUB(MAXX),C(MAXX) 0005 VIRTUAL ICSUB(MAXX),C(MAX) 0006 VIRTUAL ICSUB(MAXX),C(MAX) 0006 VIRTUAL ICSUB(MAXX),C(MAX) 0006 VIRTUAL ICSUB(MAXX),C(MAX) 0007 10 10 10 10 10 10 10 10 10 10 10 10 10

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 PDP-11
 FORTRAM-77
 V4.0-1
 16:58:07
 15-Jul-86
 Page 15

 ACJAGG. FTN; 36
 /F77/TR: BLOCKS/MR
 /F77/TR: BLOCKS/MR
 /F77/TR: BLOCKS/MR
 PAge 15

 0001
 SUBROUTINE PRIHOP(KJMM, KM, KM, KM, AIN)
 SUBROUTINE COMPUTES THE EVENT PROBABILITY FOR ALL
 POSSIBLE JAMMING PATTERNS WITH MOM-ZERO PROBABILITY FOR ALL
 POD

 0002
 IMPLICIT DOUBLE PRECISIOM (A-H, O-2)
 MIN-0.20
 POD
 POD

 0003
 IMPLICIT DOUBLE PRECISIOM (A-H, O-2)
 MIN-0.20
 POD
 POD

 0003
 IMPLICIT DOUBLE PRECISIOM (A-H, O-2)
 MIN-0.20
 POD
 POD

 0003
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
 MIN-0.20
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 0003
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
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 0003
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
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 0004
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
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 0003
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
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 0003
 IPPLICIT DOUBLE PRECISIOM (A-H, O-2)
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PDP-11 FORTRAN ACJAGC.FTN;36	4-77 Y4.0-1 16:58:13 15-Ju1-86 Page 19 /F77/TR:BLOCKS/WR	POP-11 FORTR ACJAGC.FTN;3	W-7/ V4.0-1 16:58:22 15-Jul-86 Page 20 5 /F77/TR:BLOCKS/WR
0043	IF(ISUB.NE.JSUB) THEN	1600	DOUBLE PRECISION FUNCTION PUL(Y)
0044	6070 20	2000	IMPLICIT DOUBLE PRECISION (A-H,0-Z)
0045	ELSE	0003	DIMENSION WORK(75), STACK(75), SAVE(75)
U	HASH TABLE OVERFLON, MUST COMPUTE, CAN NOT STORE	1000	EXTERNAL DGXVI, PUIG
0046	X=FL(BETA, I)	0005	COMMON /PUICON/ YY
1400		ہ د	AJ = RUNCLRIKAL PAKAMELEK FUK UMMELU HUYS
8400	ELSE IF(T.EQ.BETA .AND. IT.EQ.I+I) THEN	ن <b>د</b>	ANJ = NURCENIKAL PARAMETER FOR NON-JAMMED MOPS v1 = NUMBER AF MAMER UNDE
י יייי		، ر	NJ = NUTBEK UP JUTTEJ NOPS
0040	X=FLV(2006)	, me	MAL F HURDER UF NUR-WATTLU HUPS Fremene /Disidad/a) and ki kki
0500	CRU IF PRON-PROVINCYTY WAIRWITY	2000	CUTION / FULTON/ NUS ANUS NUS NUS COMMON / DABAC/ BICY II
	FRUDFRUDFUL(A, MCMMM(1))		LUTTION / FAMILY DIGN, LL
	ERU IF CONTINEE		
0054	TXIB=THASH(RETA, 2053)	0010	RETURN
0055	JS08=1SU8	1100	
0056 30	T=PU1T(ISUB)	CWC	HAS ALREADY HAD I SUBTRACTED FOR RAPID CHI-SQUARE EVALUATION
0057	IT=1PU1T(1508)	0012	JF(NJ.NE1 .AND. NJ.NE.LL-1) THEN
0058	IF(T.EQ.C.DO .AND. IT.EQ.O) THEN	ں	WE MUST CONVOLVE THO NONCENTRAL CHI-SQUARE DENSITIES
J	NOT FOUND, COMPUTE IT AND ENTER INTO TABLE	0013	Y9=Y
0059	Y=PU1(BETA)	0014	CALL ADQUA2(0.,Y,VALUE,DGXVI,PUIG,1.D-10,MORK,STACK,
0060	A=(BOSI)AIDA		\$ SAVE, 75, KODE)
0061	PUIT(ISUB)=BETA	0015	IF(KODE.NE.O) THEN
0062	IPUIT(ISUB)=NJ+2	0016	MRITE(5,1) KODE
£900 F	ELSE IF(T.ME.BETA .OR. IT.ME.M.)+2) THEN	0017	I FORMAT(' PUI ADQUAZ ERROR: KOGE=', I2)
ں -	NOT THES ENTRY, TRY NEXT	0018	STOP 'FATAL ERROR'
		6100	
5900 .	IF(ISUB.61.2053) ISUB=ISUB-2053	6700	Li Li Li Stature (Stature Stature Stat
0000	IF (ISUB. ME. JSUB) THEM	J 1700	LLSE
/900		د	NE UNLI MAYE UNE UNULGRINAL UNI-SQUAKE VENSIII MIIN 2"LL Defets de edetana
, .	LEUG MAGH TARI F ANFORT ANEN	0027	DECORES OF FALLOWS
0069	Y=P(1) ( RFTA)		ALL MOPS IN JAMPHED
020		0023	CALL CHISOE(Y_LLL-1_ANJ_F_KODE)
1/00	ELSE IF(T.EQ.BETA .AND. IT.EQ.NJ+2) THEN	0024	ELSE IF(NJ.EQ.LL-1) THEN
U	60T 1T!	J	ALL HOPS JAMMED
0672	Y=PUIV(ISUB)	0025	CALL_CHISQE(Y/BIGK,LL-1,AJ,F,KODE)
0073	END IF	0026	F=F/81GX
0074	PSRAND=Y*(1.D0-PROD)	0027	
0075	RETURN	0028	IF(KODE.ME.O) THEN
0075		0029	WALTE(5,111) KODE
		0030	I FUNNAI(* DESSEL FUNCTIUN EKKUK UUUE = ',11) STAD "FATAL FDORD"
		0032	EMD IF
		0033	PUl*F
		0034	END IF
		CEUU 2000	KLIUKN E ND
		000	END

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1-77 V4.0-1 16:58:27 15-Ju1-86 /F77/TR:8LOCXS/WR	DOUBLE PRECISION FUNCTION FLFALPHA,L) IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /PARNS/ BIGK, LL IF(L.NE.O.AND.L.NE.LL) THEN R=(BIGK-L)/BIGK BIGLOG-BLOGE(BIGK)	ARG-L+BIGLOG-ALPHA/2. START-DEXP(-ARG) FL1=L-1 D0 100 N=0,100 EN=N IF(N.EQ.0) THEN PART=1.D0 TENN=DIEXP(ALPHA/2.D0,START,LL-1)	SUM=TERM ELSE Part=part*r*(Em+FL1)/En Part=part*diexp(alpha/2.do,start,LL+H-1) Dumy=sum+term Sum=dumy Fnd tf	IF(DABS(TERN).LE.1.D-11*DABS(SUM)) GOTO 125 CONTINUE STOP 'FL SUM DID NOT CONVERGE' ELSE IF(L.EQ.0) THEN A-ALPHA/2.GO ELSE IF(L.EQ.LL) THEN	A=ALPHA/(2.DO*BIGK) END IF START=DEXP(-A) SUM=DIEXP(A,START,LL-1) END IF FL=1.DO-SUM RETURN END
1 FORTRAN				180	125
PDP-1 ACJAG	8002 8003 000 8003 8003 8003 8006 8003 8003	000 00110 00110 00110 00110 00110 001110 00110 00110 00110 00110 00110	0012 0013 0013 0013 0013 0013 0013 0013	0022 0023 0026 0026 0026 0027 0028	003 003 003 003 003 003 003 003 003 003
Page 21	500				
15-Ju)-86 ל	A PUIG(X) 4(A-H,O-Z) FER FOR JANNED HOPS FER FOR NON-JANNED H HOPS	WED HOPS NJ, MNJ F1,KODE) DM ERROR CODE: ',12) DD BENSTTY'	,F2,KODE) ) HOP DEMSITY'		
16:58:24 /TR:BLOCXS/M	SION FUNCTICN BLE PRECISION ON/ YY NTRAL PARAMET MTRAL PARAMET R OF JAMMED 1	R OF NON-JAN AR/ AJ, ANJ, IS/ BIGK, LL X/BIGK, NJ, AJ, X/BIGK, NJ, AJ, X/BIGK, NJ, AJ, X/DE KODE KODE L IN JAMMED I	YY-X,NNJ,ANJ, ) THEN KODE IL IN UNJANGE		
77 V4.0-1 /F77	DOUBLE PRECI IMPLICIT DOU COMMON /FUIG AJ = MONCE ANJ = MONCE NJ = MUMBE	MNJ = NUME COMMON /PULP COMMON /PARM CALL CHISQE( IF(KOOC.ME.O MRITE(5,1) FORMAT(' B STCP 'FATA	END IF CALL CHISQE( F(KOOE.NE.C MRITE(5,1) STOP 'FATA END IF PUIG-ET#F7	END	
FORTRAN- FTN;36	<u>د</u> د د د	r C			
PDP-11 ACJAGC.	000 0003 0003	000 000 000 000 000 000 000 000 000 00	0012 0013 0015 0016 0015 0017 0017	0013	

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PDP-11 FORTRAN- ACJAGC.FTN;36	-77 Y4.0-1 16:58:30 /F77/TR:BLOCKS/MR	15-Jul-R6	Page 23	POP-I1 FO ACJAGC.FT	RTRAN-77 V4.0-1 16:58:32 15-J 1;36 /F77/TR:BLOCKS/MR	Jul-86 Pa
1000	DOUBLE PRECISION FUNCTION	DIEXP(X,START, IUP)		1000	SUBROUTINE CHISQE(X,M,A,DEN,KODE	(1
2000	IMPLICIT DOUBLE PRECISION(	A-H,0-Z)				
0003	1ERM=START				NON-CENTRAL CHI-SQUARE DENSITY FOR EV	<b>JEN DEGREES OF FREE</b>
1000	DIEXP=TERM			J	DEGREES OF FREEDOM (M) IS M=2*N+	ç.
0005	IF( TUP.EQ.O) RETURN			5		
9000	DC 100 1=1.10P			0002	IMPLICIT DOUBLE PRECISION(A-H,O-	·Z)
0007	F=]			0003	B=DSQRT(X*A)	
0008	TERG=TERG=X/F			1000	CALL DXBESI(B.N.BESSEL.KODE)	
6000	DIEXP=DIEXP+TERM			005	IF (KODE.NE.O) RETURN	
0010 100	CONTINUE			0006	R=X/A	
1100	RETURN			0001	IF(R.NE.O.DO) THEN	
0012	END			8000	PONER=R**(N/2.DO)	
				6000	ELSE	
				0010	IF(N.NE.O) THEN	
				1100	POMER=0.DO	
				0012	ELSE	
				0013	POMER=1.00	
				0014	END IF	
				0015	END IF	
				0016	DEN=0.500*PONER*DEXP(B-0.500*(X+	A) ]*BESSEL
				0017	RETURN	:
				0018	END	

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SUBROUTINE ADQUA2(XL,XU,Y,OR,F,TOL,MORK,STACK,SAVE,N,KODE) C ADAPTIVE OUMBATURE ALGORITHM XL - LOWER LIMIT OF INTEGRAL (IN) Y - UALUE OF INTEGRAL (IN) Y - VALUE OF INTEGRAL (IN) C R - NWEE OF A QUADATURE RULE SUBROUTINE (IN) C R - NWEE OF A QUADATURE RULE SUBROUTINE (IN) C R - NWEE OF A QUADATURE RULE SUBROUTINE (IN) C R - NWEE OF A QUADATURE RULE SUBROUTINE (IN) C R - NWEE OF A QUADATURE RULE SUBROUTINE (IN) C CALLING SEQUENCE ONCK - MORK ARRAY OF SIZE N, MUST NOT BE C MORK - MORK ARRAY OF SIZE N, MUST NOT BE C SAVE ARRAY SS MORK (IN) C STACK - SECOND WORK ARRAY OF SIZE N, MUST NOT BE C SAVE ARRAY SS WORK (IN) C N - SIZE OF WORK ARRAY OF SIZE N, MUST NOT BE C SAVE - THIRD WORK ARRAY OF SIZE N, MUST NOT BE C ONE - ERROR INDICATOR (OUT) C O - NO ERROR (OUT) Page 25 L -- NORK ARRAYS TOO SMALL
 Z -- EPS DIVIDED TO ZERO, EITHER ASKIMG FOR TOO TIGHT A TOLERANCE OR ROUND-OFF PREVENTS
 R. H. FREMCH, 14 AUGUST 1984 15-Jul-86 EPS=TOL STACK(1)=EPS CALL OR(XL,XU,F,T) SAVE(1)=T SAVE(1)=T SAVE(1)=T SAVE(1)=T CALL OR(X,XM,F,P1) CALL OR(XM,SM,F,P2) IF(DABS(T-P1-P2).LE.EPS) 60T0 20 T IT IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL F DIMENSION MORK(N),STACK(N),SAVE(N) L 16:58:33 /F77/TR:BLOCKS/WR IF(NPTS.GT.N) THEN RETURN END IF MORK(NPTS)=XM EPS=EPS/2.DO I+ST GM=ST GM HORK (1) = XU PDP-11 FORTRAN-77 V4.0-1 ACJAGC.FTN;36 K00E=1 KODE=0 IPTS=1 Y=0.00 A=XL C SPLIT 2 uυ 00000 0019 0020 0021 0022 0023 0024 0023 **i**000

1 16:58:33 /F77/TR:BLOCKS/WR IF(EPS.EQ.0.DO) THEN KODE=2 Return End IF Stack(NPTS)=EPS T=P] A=B If(mpts.eq.o) return Goto 10 End EPS=STACK(NPTS) T=SAVE(NPTS) NP fS=NPTS-1 SAVE(MPTS)=P2 60T0 10 C FINISHED A PIECE 20 Y=Y+P1+P2 PDP-11 FORTRAN-77 V4.0-1 ACJAGC.FTN;36 0036 0036 0038 0040 0040 0040 0040 0040

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15-Jul-86

FORTRAM-77 V4.0-1 16:58:38 15-Ju1-86 .FTN;36 /F77/TR:BLOCKS/WR	SUBROUTINE DGI6(A,B,F,ANSMER)	C 16-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL	ČREF.: ABRANOMITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4 C	Č R. H. FREMCH, 28 FEBRUARY 1986 C	IMPLICIT DOUBLE PRECISION (A-H, 0-Z) DIMENSION X(8), N(8)	DATA X/0.09501250983763744018500, C 281603550376376956801323000	\$ 0.458016777657227386342D0,	\$ U.\$L/8/0244402643/4844/UU, \$ 0.75540440835500303389500.	5 0.86563120238783174388000 6 0.04647507307373257567800	0.98940033499164993259600	DATA W/ 0.18945061045506849628500.	0 . 1000052313995018900 . 0 . 0 . 169165133950052318900 . 0 . 0 . 18959598881657673708100 .	\$ 0.12462897125553387205200, \$ 0.09515851168249278481000.	\$ 0.06225352333864789286300, \$ 0.02715245941175409485200 /	ANSWER=0.DO	BMA02=(8-A)/2.D0 BPA02-(8-A)/2.D0		C=X(1)*BPAQ2 Y1=BPAQ2+C	Y2-BPA02-C	ANSMEX=ANSMEX+W(I)=(F(TI)+F(TZ)) In finale	ANSWER-ANSWER-BWAD2	RETURK END	
PDP-11 ACJAGC	1000				0003 0003	000					0005				9000	0003	800 800	0100	0012	0013	0015	0016 0017	
15-Jul-86 Pæge 27		A-H,0-Z)		(0110		ETA*1000.D0)/1000.D0)+187.D0																	
-11 FORTRAN-77 V4.0-1 16:58:36 16C.FTN;36 /F77/TR:BLOCKS/MR	C AD LOC LASHING FINCTION	C AU THUL THANHING FUNLITUM	IF(BETA.GT.0.500) THEN R=1 DO/(1 0100-RFTA)	ELSE ELSE BESC DN+1 SIN//RETA+0	END IF	B=100000.D0+(BETA-DINT(B)	8=8*23.00	3 51.24 51.24 1 = mm/m/ R+0.500 51.25) +0.500	IHASH=I+1	END													
PDP.	1000	00	888	885	888	100	88	000	888	38			F	-1	5								

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11 FORTRAM-77 V4.0-1 16:58:46 15-Jul-86 Page 34 6C.FTN;36 /F77/TR:BLOCKS/MR	555 AO=RC+RL/BIGK 180-KC+RL/BIGK 180-KC+KL 16(LOOPS.GT.O) THEN D0 60 1=1,LM1 AO=AD=INDEX(3+1-1)+(INDEX(3+1-2)-INDEX(3+1-1))/BIGK 180-180-180-180EX(3+1))+(INDEX(3+1-2)-INDEX(3+1-1))/BIGK 180-16-1100EX(3+1) 60 CONTINUE END 1F PART=GRAL(AO,180,JSUB(1)) C	C ADD A TEPH TO THE OVERALL SUM PROD-COEFG-CO(K0)=COEFL+COEFL IF(LOOPS.GT.O) THEM DO 70 1=1_LM PROD-FORD=COFFO=CO(K0)=COEFL+COEFK(1)=COEFP(1) TO FORD=PROD=COFFO=CO(K0)=COEFFK(1)=COEFF	
PDP- ACJA	0079 2080 2083 2083 2089 2089 2089 2089 2089 2089 2089 2089	0099 0099 0099 0099 0099 0099 0099 009	
FORTRAM-77 V4.O-1 16:58:46 15-Jul-86 Page 33 .FTW;36 /F77/TR:BLOCKS/WR	C FIRST, RESET INDICES OF ALL LOOPS MITHIN ONE JUST ITERATED C 1000 D0 25 1-NSUB+1,LOOPS INDEX(1)=0 25 CONTINUE C SECOND, PERFORM FRONT-OF-LOOP CODE FOR EACH LOOP FROM ITERATED C LOOP ON INMARD	<pre>00 30 1=MSUB_LOOPS IRKP=MOU[1,3) MV 12.2,3 INTD 1; 4.5,6 INTD 2; ETC. FOM MESTIME LEVEL IF(INE F0.LOOPS) THEM IF(INE F0.LOOPS) THEM IF(INE F0.LOOPS) THEM IF(INE F0.LOOP) THEM IF(INE F0.LOOP) THEM F1ST TYME TOWOLS: (A) INTTALIZE THE COEFFICIENT OFFICE IF(INE F1)=1.00 ELCE OFFICENTIALIZE NOT FIRST TYME TOWOLS: (A) INTTALIZE THE COEFFICIENT OFFICENTIALIZE NOT FIRST THE TOWOLS: (A) INTTALIZE THE COEFFICIENT COEFFICIENT OFFICENTIALIZE NOT FIRST THE TOWOLS: (A) INTTALIZE THE COEFFICIENT COEFFIC</pre>	C C DO THE INTEGRAI
PDP-11 ACJAGC	0055 0056 0056	8500 65000 6500 6500 6500 6500 6500 6500 6500 6500 6500 6500	

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DO 43 N=2.1P G(N)=[[IR\_K+1\_N)\*CDEF]\*G(N=1)+ [2\*[IR\_K+1]\_N)\*CDEF2\*G[N-2))/M COMTINUE DEE=DXI(DENON,JR-K)+6(JP) JF(MOD(K,2).Eq.1) DEE=-DEE END JF 16:58:59 /F77/TR:BLOCKS/WR PDP-11 FORTRAN-77 V4.0-1 ACJAGC.FTN:36 END JF Return END 9 0043 0049 0050 0051 0053 0054 0055 0055 6(N)=((K+1-N)+COEF1+6(N-1) + (2+K+2-N)+COEF2+6(N-2))/N Page 35 SUMQ=SUMQ+DB1NCO(IR-K,1P-10)\*DB1NCO(K,1Q) \*DX1(BK3,IR-K-1P)\*DX1(TK1,K)\*DX1(BASE,1Q) ELSE IF(LL.Eq.3) THEN IF(NEST.EQ.1) THEN DEE=DXI(BIGK\*BIGK,IR-K)\*DBINCO(K,IP)\* DXI(2.00\*BIGK-1.00,K-IP)\*DXI(BIGK-1.00,IP) IF(MOD(K,2):EQ.1) DEE=DEE ELSE IF(MEST.E0.2) THEN DEE=DBINCO(IR-K,IP)\*DXI(BIGK\*(BIGK-2.D0),IR-K-IP)\* DXI(BIGK-1.00,IP) DEE=SUMQ\*DX1(BIGK,IR+IR-K-K-IP)\*DX1(BIGK-1.D0,IP) ELSE IF(MEST.EQ.3) THEM 6(0)=1.D0 DOUBLE PRECISION FUNCTION DEE(LL, NEST, IR, K, IP, BIGK) ELSE IF(LL.EQ.4) THEN IF(MEST.EQ.1) THEN DEMOM=3.DO\*BIGK+8IGK-3.DO\*BIGK+1.DO COEF1=(2.DO\*BIGK\*8IGK-3.DO\*BIGK+1.DO)/DENOM DEMOM=DX1(BIGK .3)-3.DOPRIGK\*BIGK+3.DOPBIGK COEF1=(BIGK+BIGK-3.DOPBI,GK+2.DO)/DEMOM G(1)=(IR-K)\*COEF1 BK1=BIGK-1.DO DEE=DX1(BIGK,3+(IR-K))\*DX1(DEMOM,K)+G(IP) IF(MOD(K,2).EQ.1) DEE\*-DEE ELSE IF(MEST.EQ.2) THEN IUP=MIMO(IP,K) ILOMHMXD(O,IP-IR+K) 15-Jul-86 COEF2=0.5D0=BK1+BK1/(B1GK+DENOM) [MPLICIT DOUBLE PRECISION(A-H,0-2) DIMENSION 6(0:8) IF(LL.50) 6(0:8) IF(LL.50) 6(0:2) IF(MST.50.1) THEN IF(MST.50.1) THEN IF(MOD(K,2).50,1) DEE=-DEE END IF COEF2=0.500+BK1+BK1/DEMON THE FUNCTION D(P) FOR PBNJ/RMFSK . 16:58:59 /F77/TR:BLOCKS/MR TK1=3.D0+BIGK-1.D0 BASE=BK3\*BIGK/TK1 DO 42 IQ=ILON.IUP BK3=B1GK-3.00 BK1-BIGK-1.00 DO 41 N=2, IP G(1)=K\*COEF1 G(0)=1.D0 SUMQ=0.00 CONTINUE CONTINUE PDP-11 FORTRAN-77 V4.0-1 END IF 4 ACJAGC.FTN; 36 42 0006 6000 0100 0012 0013 0017 0018 0019 0038 0040 0041 0041 0043 0043 0045 0045 0045 2000 0015 0016 0200 000 F-19

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RTRAM-77 V4.O-1 16:59:10 15-Jul-86 Page 38 N:36 /F77/TR:8LOCKS/MR	DOUBLE PRECISION FUNCTION GAM (AQ.180-11)	THE INNER INTEGRAL FOR CONDITIONAL FRAME PORABILITY	INDI TOTT AVIIBLE ANTARETAL /	COMMON /RRRCCOM/ RHOT_RHOM	COMMON /PACHS/ BIGK, LL	IF(L1.GT.O. AMD II (T II) THEW	BK1=B16K-1.00	BASE=BK1/(1.D0+B16K*A0)	ARGI=(L1-L1)*RHON/AI	AN2"=LI"NNU!TB16K/([.60+8]6K*AU) 2023-2034-21/by3		SUM-0.00	D0 100 10-0.180	IF(IQ.GT.O) POWER=POWER=BASE	PM=DSQRT(POWER)	SUM-GNLGPM(IQ+LL-1, 180-10, ARG1, PM)+GN, GPM(L1-1, 10, ARG2, PM)+SIM			UU IIU [*],[80 F=F*(1/A1)	110 CONTINUE	F=(F/DXI(A1,LL-L1))/DX1(1.00+B16K*A0.11)	GRAL=SUMPF*DEXP((ARG1+AR2)+AD)	ELSE JF(LLLEQ.O) THEN	ANG1=+LL*RADM*/AL START=AFYP(APC1+AA_1+AngAc/a1)/	D0 200 I=1.180	START=START*(I/AL)		GRAL = GRULGPW(LL-1, IRO, ARG1, START)	ELSE JFILL.EU.LI) THEN 33-1 Prighteraan	ARGI=-LLARHOT/A2	BASE=BIGK/A2	START=DEXP(ARG1+BIGK+AO-LL+DLOG(A2))	UU JUU JEJ,IBU STADT-STADT+(1+DASS1)	300 CONTINUE	GRAL=GWLGPM(LL-1, 180, ARG1, START)		RETURN END
PDP-11 FO	0001	uυ	U U U	0003	0004	500	000	8000	6000		0012	0013	<b>D014</b>	0015	0016	2017	018	610	021 021	022	023	024 2024	5200	027	028	020	030	150		934	035	036	038	60 60	090	22	
Page 37																																					
15-Jul-86																																					
FORTRAN-77 V4.0-1 16:59:08 .FTN:36 /F77/TR:BLOCKS/MR	FUNCTION ICAPP(LL,NEST,IR,K)	C COMPUTE UPPER SUMMATION LIMIT PL	L IF(LL.LE.2) THEN	ICAPPHO ELSE TEVIL EQ 2) THEY	IF(NEST.EQ.1) THEN	ICAPP=K	LLSE JF(NESI.EQ.Z) THEN TEADD-TD Y	END IF	ELSE IF(LL.EQ.4) THEN	IF (NEST.EQ.1) THEN	ICAPP=2*K	ELSE IF(REST.EQ.2) THEN TSTOR_ID	10477=14 5155 75/4557 50 3/ ***54	ELSE IT(MES!.EU.3) IHEN Ifådd=9+(ID V)		END IF	RETURN	END																			
PDP-11 ACJAG(	1000		0002	8000 1000	5000	900		500	0100	1100				0016	2100	0018	6100	0020	F-	-2(	0																

	PUT-11 FUN KAN-// V4.0-1 15:9:17 15-Jul-86 ACJAGC.FTN;36 /F77/TR:BLOCKS/MR	0001 SUBROUTINE JCPMF(C,KMAX,R,LM1)	C COMPUTE J.C.P. MILLER COEFFICIENTS DIVIDED BY K! C	0002 INPLICIT DOUBLE PRECISION(A-H,0-Z) 0003 INTEGER R	DODA DIMENSION C(O:KMAX)	0006 IF(LM1.EQ.O) RETURN	000/ D0 100 K=1,KMAX	0009 MINP=MIND(K_, MI)	0010 BC=1.00	0011 D0 90 N=1, MUP	0012 BC=8C*((K-N+1.00)/N) 0013 CUM-CUM-AC*/(0.1 00)+# v)+r/v w)	0014 90 CONTINUE	0015 C(K)=SUM/K	0016 100 CONTINUE	001/ FAC=1.00	0018 DO IIO K=1,KMAX DOTO FAC-EACEV	0020 CIK) /FAC	0021 110 CONTINUE	0022 RETURN
	rade Jy	REMUL)	ATION BY OWS)																
16 1.1 06	00-INC-CT	MLGPM( IALFA, N, X, F	NITH PREMULTIPLIC INEVITABLE OVERFL	(J-0,H-	NL		0)/( IA! FA+M) ) )												
31.03-31 1.0	/F77/TR:BLOCKS/MR	E PRECISION FUNCTION G	LAGUERRE POLYNOMJALS FACTOR (TC DEFER THE	CIT DOUBLE PRECISION(A	)BINCO(N+IALFA_N)*PREM FRM	EQ.0) 60T0 200	J FFL_N -TERM+((X/M)+(/N-M+]_D	M+TERM											
10AN 77 VA (	1;36	DOUBLE	GENERAL IZED A NEIGHTING	IMPLIC	TERM=1 SIM=11	IF(N.E		SUM=SU	100 CONTIN	200 GNLGP	EMD EMD	2							
000 11 C.00	ACJAGC.FTN	J 1000	ں <i>ت</i> ر	0002 C	0003	0005	000 000	0008	6000		0012 0012								

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PDP-11 ACJAGC.	FORTRAM-77 V4.0-1 16:59:20 15-Jui-86 Page 41 FTN;36 /F77/TR:BLOCKS/WR	PDP-11 FORTRA ACJAGC.FTN;36	W-77 V4.0-1 16:59:20 55 16:59:20 55 16:59:20 55 16:59:20 55 16:59:20 55 16:59:20 55 16:50	15-Jul-86 Page 42
1000	SUBROUTINE MLINIT(LMAT,LLOW,LMAXC,LMAXR) C THIS SUBROUTINE INITIALIZES A "MATRIX DO-LOOP" STRUCTURE C DEFINED BY THE FOLLOWING PSEUDO-FORTRAN CODE: DO LOO LMAT(1,1)=LLOW(1,1),LUP(1,1),LIMC(1,1) C DO LOO LMAT(L,2)=LLOW(1,2),LUP(1,2),LUP(L,2),LUP(L,2)	1 CCC 0000000000000000000000000000000000	AGRAMMER: ROBERT H. FRENCH DIMENSION LMAT(LMAXC,LMAXR), DO 1 N-1,LMAXR DO 1 H-1,LMAXR DO 1 H-1,LMAXC CONTINUE RETURK END	DATE: 10 MARCH 1986 LLOW(LMAXR)
	DO 100 LMAT(LMAXC,2)=LLOW(LMAXC,2),LUP(LMAXC,2),LINC(LMAXC,2) DO 100 LMAT(1,LMAXR)=LLOW(1,LMAXR),LUP(1,LMAXR),LINC(1,LMAXR) DO 100 LMAT(1,LMAXR)=LLOW(LMAXC,LMAXR),LUP(LMAXC,LMAXR), C D 100 LMAT(LMAXC,LMAXR)=LLOW(LMAXC,LMAXR),LUP(LMAXC,LMAXR), C (STATEMENTS IN RAMGE OF LOOP)	PDP-11 FORTR ACJAGC.FTW;3 0001 C	AM-77 V4.0-1 5 /F77/TR:BLOCXS/MR 5 /F77/TR:BLOCXS/MR 8UBROUTIME MLITER(LMAT,LLOM, 50 ITERATION LOGIC FOR A "MATRIX	15-Jul-86 Page 43 LUP,LINC,LMAXR,GO) . DO-LOOP"
-	C 100 CONTINUE : C THE COMPANION ROUTINE MLITER HAMDLES THE LOOP CONTROL AT THE C CONTINUE STATEMENT IN THE ABOVE STRUCTURE		E DETAILED COMMENTS IN SUBROUTIN RAMETER DEFINITIONS OGRAMMER: ROBERT N. FRENCH DATE: 10 MARCH 1986	E MLINIT FOR USAGE AND
20	C UDARSE: LOGECAL*1 GO DIMENSION LMAT(LMAXC,LMAXR),LLOW(LMAXC,LMAXR),LUP(LMAXC,LMAXR) DIMENSION LINC(LMAXC,LMAXR) C INITIALIZE MATRIX LLOW TO STARTIMG VALUES OF THE MESTED LOOPS) C INITIALIZE MATRIX LUO TO STORING VALUES OF THE MESTED LOOPS) C INITIALIZE MATRIX LUP TO STORING VALUES OF THE MESTED LOOPS) C INITIALIZE MATRIX LUP TO STORING VALUES OF THE LOOPS) C CALL MLINIT(LMAT,LLOW,LMAXC,LMAXR) IOO CONTINUE IOO CONTINUE C (STATEMENTS IN RANGE OF LOOPS)	0010 0000 0000 0000 0000 0000 0000 000	LOGICAL+1 GO DIMENSION LMAT(LMAXC,LMAXR), DIMENSION LIMC(LMAXC,LMAXR), GO=_TRUE. DO IDO MOX=1,LMAXR NSUB=LMAXR+1-MDX DO 100 HDX=1,LMAXC MSUB=LMAXC+1-MDX DO 100 HDX=1,LMAXC MSUB=LMAXC+1-MDX LMAT(MSUB,MSUB).GE.O.AMD IFf((LINC(MSUB,MSUB).GE.O.AMD	LLDW(LMAXC,LMAXR),LUP(LMAXC,LMAXR) LDW(LMAXC,LMAXR),LUP(LMAXC,LMAXR)
	CALL MLITER(LMAT,LLOM,LUP,LINC,LMAXC,LMAXR,GO) IF(60)60T0 100 CMERE LMAT = ARRAY FOR STORAGE OF LOOP INDICES. LMAT(1,1) IS THE OUTER-MOST LOOP: LMAT(LMAXC,LMAXR), THE IMMER-MOST LOOP. CLUM = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME SEQUENCE AS LMAT CLUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME SEQUENCE AS LMAT LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LMAT LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME	0012 0013 0014 0015 0015 0015	CLINC(MSUB, NSUB) .LT.0.AND.LI RETURN LMAT(MSUB, NSUB)=LLON(MSUB, NSI CONTINUE 60FALSE. RETURN END	ure) ure)
	ATTENT TO A CONTRACT AND A CONTRACTOR FOR A CONTRACTOR			

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APPENDIX G

### COMPUTER PROGRAM FOR

### PLOTTING GRAPHICAL RESULTS

#### FOR THE

#### ANY-CHANNEL-JAMMED ADAPTIVE GAIN CONTROL RECEIVER

The following pages contain the source code listing for the FORTRAN-77 program used to produce the plotted graphical results for the any-channel-jammed adaptive gain control receiver for FH/RMFSK. The program makes use of the Hewlett-Packard Industry Standard Plotting Package (ISPP) to drive an HP-7470A plotter.

With minor modifications in annotations and file names, this program will serve to plot results for all other receivers. For brevity, the other versions of the plotting program are not included in this report.

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PDP-11 ACJAGCI	FORTRAW-77 V4.O-1 10:47:21 17-Jul-86 Page 1 .FTH:10 /F77/TR:BLOCKS/WR	PDP-11 FORTR ACJAGCP.FTN;	AN-77 V4.0-1 10:47:21 17-Ju1-86 Page 2 19 /F77/TR:BLOCKS/NR
1000	PROGRAM RNHOPP C THIS PROGRAM PLOTS THE ERROR PROBABILITY FOR RANDOM M-ARY C FSK/FH WITH MULTIPLE HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND C NOISE JAMMING	0031 0032 0033 0033 0033 0033	RTEMP=LL CALL WUNBER(999.,999.,0.15,RTEMP,270.,-1) CALL SYNBOL(7.25,-2.5,0.14,'E',270.,1) CALL SYNBOL(7.215,999.,0.09,'b',270.,1)
	C C ANALYSIS: L. E. MILLER, R. H. FRENCH C PROGRAM: R. H. FRENCH C	500 920 920 920 920 920 920 920 920 920 9	CALL SYMBOL (7.25,999.,0.09, 0, 270.,1) CALL SYMBOL (7.25,999.,0.09, 0, 270.,1) RTEMP=DEBNOL (10)
	C V 3.0.0 - PLOTS	0039 0040 0041	CALL WUNGER(999.,999.,01.44,RTEMP.270.,6) CALL SYNBOL(999.,999.,0.14,' dB',270.,3) RTEMP=MSLOTS CALL WHADREDT 7, 2, 5, 0, 14, DTEMD 210, 21)
2000	PARAMETER (NJ=126)	0043 0043 0043	CALL SYNBOL (999, 9999, 0.14, SLOTS, 270, 6) CALL SYNBOL (999, 9999, 0.14, SLOTS, 270, 6) CALL SYNBOL (6.75, -2.5,0.14, ACJ-AGC, 270, 7)
	PAGARFIEK (NJZ=NG+2) Real & Pride(NJZ),DBSJR(NJZ),RTENP Charatterij Famili	0045 0045	DUTL TIMO DUTO 16-1,06 GUMPATEANE 7(16)
0003	C COMMON /INPUTS/ PASSES PARAMETERS OF THE RUN COMMON /INPUTS/ DEBNOL(5),LLIST(4),NSLOTS,	0048 J	IGOUT=GAMMA*1000.00+0.500 54 AATA ETVE
	T FOMMAN /SIZE/ DASSES MUMBERS OF DARMETERS	5	
800	COPPOR / SIZE/ NO.ML.NG	0049 0050 73	<pre>MRITE(FNAME,730) MM.LL.100UT,160UT 0 F00MAT('A',11,11,12.2,14.4,'.DAT') 0 F00MAT('A',11,11,12.2,14.4,'.DAT')</pre>
	CALL 62 1 PRLOG(NJ+1)=-5.	TCnn	VERIUNITES ILEET NOTE, SIAIUSE ULU , FOUNTEU
0012 0013	PRL 06(NJ+2)=0.625 085JR(NJ+1)=0.	0052 24	62010750 D WRITE(5,741) FNAME
0014	DBS.R(NJ+2)=-10. CALL SETUP(KONF)	0054 74 0055	I FORMAT(1X,A13) STOP 'FILE WOT FOUND'
100		0056 75	D READ(4) MMIN,LLIN,DEBMOJ,ISLOTS,GAMMAI,
100			Principal (N)
0019 0020	D0 500 T0+1, M0 1000T=DE8MOL (10)	005/ 2012	ST PERMUNE THE JUKE LELIN THE LE UKE DEBNUL THE JEENUL (10) S. OR. ISLOTS NE NSLOTS OR. GANNAL NE GANNA) THEN
	C DRAM THE BOX	0059 0059 0060	WKLIELS,/4LJ FROME STOP 'FILE CONTERTS ERROR' End i
0021	CALL SLON CALL PLOT(1.25,6.0,-3)		TERPOLATE TO EDGE OF THE GRAPH
5200 W	LALL LUGALATIUU., PRUGABILITY OF BIL ERRAN. 5 LEM(*PROBABILITY OF BIT ERRAN.), 805.,5) Call ATISTO 0 "RIT ERREY ID. JAMMING NEMSTIR 3.410 (AR)'	0061 0062	DO 790 I=1,WJ MPTC=1
1 700	LEN(BIT ENERGY TO JUNNING DENSITY RATIO (48)'), 52700.10.)	0063 0063	IF PRLOG(I).GE5.) GOTO 790 DY=PRLOG(I)-PRLOG(I-1)
0025	C COMPLETE THE BOX CALL AXISI(8.,0.,-1,0,5.,270.,0.,10.) CALL AXISI(8.,0.,-1,0,5.,270.,0.,10.)	0065 0066 0066	DX=DBGSJR(I)=DBSJR(I=1) PART=(-5.)=PRLOG(I=1) S1.ABE=(PV.AN)
070n	C ANNOTATE M, L, EB/NG	0068	DBS.R(I)=DBS.R(I-1)+SLOPE+PART
0023	CALL SYMBOL(7.5,-2.5,0.14,'M=',270.,2) RIEMPHM	0069	PRL06(T)=-5.
6203	CALL MUMBER(999.,999.,0.14, RTEMP,Z70.,-1) CALL SYMBOL(999.,999.,0.14, L=',270.,4)	6/ T200	0 COMTINUE

G-2

0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, CONTINUE WRITE(5,16) FORWAT(\* HOW MANY L? [1]: ',5) FORWAT(\* HOW MANY L? [1]: ',5) READ(5,3)ML IF(ML.EQ.0)ML=1 DO 21 1M=1,ML WRITE(5,19)1N FORMAT(\* L(',11,') [4]: ',5) 15

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# APPENDIX H COMPUTER PROGRAM FOR CLIPPER RECEIVER WITH M=2 AND L=2

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the clipper receiver for the case of M=2 and L=2 with the jamming fraction  $\gamma=q/N$  as a parameter.

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1 13:12:43 16-Jul-86 /F77/WK

PDP-11 FORTRAN-77 V4.0-1 CLIP2HOP.FTN:14 /

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	C STORE AS ELEMENT OF A SPARSE ARRAY TO SAVE MEMORY	0001	SUBROUTINE GENPIE (MM, MQ, MSLOTS, GOOD, A, IASUB, C, ICSUB,
	C EVEN THOUGH WE STORE ZEROS, THE SORTIMG OF SUBSCRIPTS F cits ont many fifthents		\$ D, IOSUB, MUSED)
0042	Cart LOCM(M.LOW_LUP.JSUB.ISUB)		C SUBROUTINE TO GENERATE EVENT PROBABILITIES
	C TRY TO FIND CONDITIONAL ERROR PROBABILITY IN STORED ARRAY		
0043	CALL LOOKUP(PROB, PRERR, IPSUB, MPS, 625, ISUB, STORE, NOME)	0002	IMPLICIT DOUBLE PRECISION (A-H, n-Z)
	C IF IT IS NOT THERE, WE MUST COMPUTE IT	0003	LOGICAL*1 60,602,STORE,NOME,6000
0044	IF ( #ONE ) THEN	000	DIMENSION LUP2(4) , LUP3(4)
500	CALL PSEL(JSUB,M, PROB) r Ann caur it com Anceire r curing of nee	9003 2000	DIMENSION IUPA(4)
0046	V THU JAYE II VAN FUJIDLE FUINKE KE-UJE Pail Diitim/DDAR DBEDD IDCHR HDV 695 TCHR KANE VINCE)	2000	DITENSION JURU(4)
1047	TELY OF ME ON STOD 2	000	VIDENJUM LVIALT) VIDTHAI ATTON TACHRITON) FLAJK) TEQHRLADK)
0048			
	C SUM LP UNCONDITIONAL ERROR PROBABILITY	6000	DIMENSION 1(4).11(4).111(4)
6006	PE=PE+PIE*PROB		C SHARED STORAGE FOR COMMONLY MEEDED CONSTANT ARRAYS
	C ITERATE THE VECTOR-INDEX LOOP	0010	COMMON /SHAREZ/ LOW(4),LINC(4)
0050	101 CALL VLITER(JAM,LOW,LUP,LINC,M,GO)		C SHARED STORATE FOR: (1) IMPUT DEFAULT LISTS.
0051	IF(60) 6010 100		C (2) CONDITIONAL PROB GEN., AND
2600		1100	C (3) EVENT PROB. GEN. THESE ARE MON-OVERLAPPING USAGES.
5000		1100	CUMMOW /SHARE/ LUP2,LUP3,LUPD,LI,MUSEA,MUSEC,IERR, [SUB2,SUB1,[SUB2,AIM,L,I],II,MI,AOUT,
		0.000	S CIN, COUT, DOUT, DIN
	FORTRAN-77 V4.0-1 13:12:55 16-Jul-86 Page R	2100	DATA 1100/100/ AATA 1100/1241/
-5	04. "LIN' 14 / L'//WW	0014	UARA IURA/9*1/ GATA IRP1/4*1/
1000	SUBROUTINE EVENT(M.JAM.PIE.D.IDSUB.NUSED)		C STORE*.FALSE. => DON'T STORE ZERO ELEMENTS OF SPARSE ARRAY.
	υ	0015	STORE*.FALSE.
	C SUBROUTIME TO LOOK UP EVENT PROBABILITY FROM STORED ARRAY	0016	6000=.TRUE.
0000	L THADITETT AVVIDIE DOEFTETAWIA U D 7)	001/00	9999 IF(NU.LE.U) INEN COND- Cal CE
	Incitationocc factoration(n=11,0+2) Incitation Trade Mark	0100	DETIDN
000	DIMENSION _ DAMA _ 1 1904	0000	AL TURN
000	VIRTIAL D(625) TDSIR(625)	0021	D0 80 11±1 MM
9000	COMMON /SHAREZ/ LOW(4).LINC(4)	0022	1UPD(11)*2
0001	DATA STORE/ FALSE /	0023	80 CONTINUE
	C SET UP ARRAY DESCRIPTION D(0:LL,,0:LL) WITH M DIMENSIONS		C JAMMING PATTERN W/NON-ZERO PROBABILITY ON PER-HOP BASIS
8000	00 1 [*] M	0024	NUSEA=0
6000	[UP(I)=2		C INITIALIZE VECTOR-INDEX LOOP
0100	I COWTINUE	0025	CALL VLINIT(I,LOW,MM)
	U UUMPULE LINEAK EQUIVALENI SUBSUKIPI PUK JAMPIMG EVENI Pati i Arman i Rijija Jam Tridi	9200	90 CONTINUE
1100	C I ADM HO THE VALUE AND I JUN JUND)	/700	CALL LUCH(TH,LUM,JUPA,J.JSUB) Call DR1406/1 AM NO NCIATC ATH)
0012	U LUUM UF THE VALUE, BET U.DU IF NUT THEKE Pait Indexip(dif D Insue mised) 625 Isur Stoof Momen	0028	CALL PKINUP(1,PHF,NU,M,NALUIS,AIN) Cali phitin/aim a tachr micfa tinn tchr fedd ctnof)
0013	RETURN	0030	IF/IFRR. WE ONSTRY 3
0014	END		C ITERATE VECTOR-INDEX LOOP
		0031	CALL VLITER(1,LOW,LUP1,LINC,MM,GO)
		0032	IF(60) 6010 90 C COMDITATION CLARTC HEDE FIGET CAON A 14TA D
			C CUMPUTATION STAKES REAL, FIKST CUFT A EATU U. F STARF ARRAYS ARE A(D-1) D-1D-1) AND D(D-1 D-1
			C THE COPYING MUST BE DOME ON BASIS OF EQUIVALENT LINEAR
			C SUBSCRIPTS RATHER THAN A SIMPLE MOVE OPERATION.
		6600	NUSED=0

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FORTRAN-77 V4.0-1 13:13:06 16-Jul-86 Page 11 P.FTN;14 /F77/WR	SUBROUTINE PUTIN(CIN,C,ICSUB,MUSE,MMAX,K,IERR,STORE) C	C THIS SUBROUTINE INSERTS AN ELEMENT INTO A SPARSE ARRAY FOR C MHICH ONLY THE NON-ZERO ELEMENTS ARE KEPT IN STORAGE IF	C THE SMITCH STOKE IS TRUE.	C THE DOUBLE PRECISION VALUE CIN IS STORED AS C(K) WHERE C THE AUXILIARY ARRAY ICSUB IS USED TO KEEP TRACK OF THE	C SUBSCRIPTS OF THE CORRESPONDING ENTRIES IN C.	C USAGE:	C LOGICAL#I STORE C DOURIE PRECISION FITM	C VIRTUAL ICSUB(NMAX), C(MMAX)	L CALL PUTIN(CIN,C,ICSUB,NUSE,NMAX,K,IERR,STORE) C WHERE	C CIN = VALUE OF ELEMENT TO STORE	C. C. = AKKAY IN WHICH NON-ZERO VALUES ARE ACTUALLY STORED C. TCSIR = ANYIIIADY ADDAY ECD ACTUAL CURSCRIPT VALUES	C NUSE = NUMBER OF ELEMENTS OF C CURRENTLY OCCUPIED	C IMMAX = SIZE OF ARRAY C C TEDD = EDDAD DETTIDU CANE O IT UN FRANCO ON 3 IT FUELD	C NO ROOM AVAILABLE IN C	C STORE = .TRUE. TO STORE ZEROES EXPLICITLY, ELSE .FALSE.	C TOLE & CUT OF AND THE SUBSUCT IN IS FOUND IN ICSUB, THEN C THE ELEMENT IS DELETED BY SHIFTING DOMINIARD ALL	C FOLLOWING ELEMENTS OF THE ARRAY	C PROGRAMMER: ROBERT H. FRENCH DATE: 11 JANUARY 1984	C IMPLICIT DOUBLE DEFITION(A.W A.7)	VIRTUAL ICSUB(MMAX), C(MMAX)	LOGICAL*1 STORE	IF(STORE) GOTO 5	IF(CIN.EQ.0.00) 6010 30 5 IF(NUSE.E0.0)6010 20	DO 10 1=1, NUSE	IF(ICSUB(I).ME.K) GOTO 10 C/1)=C7W	RETURN	10 CONTINUE IF(NUSE.LT.NMAX) 60T0 20	IERR=I CONTRACT	20 NUSE=NUSE+1	ICSUB(NUSE)=K C(NUSE)×CIN	RETURN	
PDP-11 F CLIP2HOP	1000			,															0005	0003	000 000	9000	0008 0008	6000	1100	0012	0014 I	0015 0016	2 200	8100 6100	0020	
FORTRAN-77 V4.0-1 13:12:58 16-Jul-86 Page 10 PP.FTN;14 / /F77/WR	C INITIALIZE VECTOR-INDEX LOOP CALL VLINIT(1,LOM,PM)	99 CONTINUE Call LOCN(MM,LOW,IUPA,I,ISUBI) Call LOCN(MM,LOW,TUPD,TISUBI)	CALL LOOKUP(AOUT,A,IASUB,MUSEA,IIOO,ISUBI,STORE,NOME) CALL POINTA/AOUT,A,IASUB,MUSEA,IIOO,ISUBI,STORE,NOME)	C ITERATE VECTORIANCIALIZATION AUGEU-4023,13402,1EKK,31KKE) C ITERATE VECTOREX LOOP	I CONCOLORISTICAL LUNC, MA BU)	C L-I CUNVOLUTIONS ARE REEDED DO 9998 I1=1.1	C SET UP VECTOR-LOOP UPPER LIMITS FOR THIS CONVOLUTION	9 DO 125 RM=1,001 LUP2(MN)=61	125 LUP3(MM)=L1+1	MUSEC=0 Call VINTTTI DU MM)	98 CONTINUE	CALL VLINIT(II,LON,MM)	C LOOK UP ELEMENTS AND PERFORM ONE TERM OF THE CONVOLUTION	CALL LOCK(MM, LOW, IUPA, 1, ISUB])	CALL LUCKI(TT),LUM, JUTU, JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ	21 COMPTINIE 21 COMPTINIE	CALL LOCN(MM, LOW, IUPD, III, ISUB3)	CALL LOOKUP(AOUT,A, IASUB,NUSEA, IIOO, ISUBI, STORE, NOME) CALL I OMMUPDIANTE D TRANE WISED 625 TSUB2 STORE WOME)	CALL LOOKUP(COUT, C, ICSUB, NUSEC, 625, ISUB3, STORE, NONE)	CIN=COUT+AOUT*DOUT Call DHTTW/CTW C TCSUB MISEC 525 ISUB2 IEBD FT2015	F(IER.ME.O) STOP 4	CALL VLITER(II,LON,LUP2,LINC,MM,602) IF(EA2) EATO 07	CALL VLITER(I,LOW,LUPI,LINC,MM,GO)	LP(GU) GOTO 98 C COPY C TO D IN SORTED PODER END MEYT ITEDATION	NUSED=0	CALL VLINIT(II,LOM,MM) 96 CONTIMUE	CALL LOCH (MM, LOW, TUPD, II, ISUB)	CALL LOOKUP(COUT,C,ICSUB,MUSEC,625,ISUB,STORE,MOME) DIN=COUT	CALL PUTIN(DIM,D,IDSUB,MUSED,625,ISUB,IERR,STORE) Istreed we ol stop 6	CALL VLITER(11,LOW,LUP3,LINC,MM,GO)	ITTEU/ EUI/ 90 9998 CONTINUE BETINDE	END
POP-11 CL IP2H	0034	0035 0036 0037	0038		INO O	0042		0047	0045	900 900 242	0048	0049		c 0051	0023 0023	0054	0056	0057 0058	0059	990	0062	0063	0065	9 <b>9</b> 00	0067	8900 0069	0200	1/00 0072	0073 0074	0075	0078 0078	0079

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I FORTRAN-77 V4.0-1 13:13:10 16-Jul-86 Page 13 10P.FTN;14 /F77/WR	SUBROUTINE LOOKUP(COUT,C,ICSUB,N,MMAX,K,STORE,MONE)	C THIS SUBROUTINE RETRIEVES AN ELEMENT OF A SPARSE ARRAY WHICH C HAS BEEN STORED COMPACTLY BY STORING ONLY NON-ZERO ELEMENTS.	C THE ARRAY IS DOUBLE PRECISION.	C USAGE:	C VIRTUAL ICSUB(MMAX), CIMMAX) C LOGICAL+1 STORE, NOME C DOUBLE PRECISIOM COU'I	C CALL LOOKUP(COUT,C,ICSUB,M,MHAX,K,STORE,MONE) C MHERF	C COUT = VALUE OF C(K) (OUTPUT FROM SUBROUTINE) C C = ARRAY USED TO STORE MON-ZERO ELEMENTS C ICSUB = AUXILIARY ARRAY TO STOPE ACTUAL SUBSCRIPTS C N = MIMPRE OF ELEMENTS OF C CURRENTLY IN USE	C MAX = 51ZE OF C C K = SUBSCRIPT OF SPARSE ARRAY TO LOOK UP C STORE = .TRUE. IF ZERDES STORED EXPLICITLY. ELSE .FALSE. C NONE = .FALSE. IF ZERDES MOT STORED OR ZERDES STORED AND	C ELEMENT IS FOUND IN THE STORED ARRAY C TRUE. IF ZEROES ARE STORED AND THE ELEMENT IS NOT FOUND (OUTPUT QUANTITY)	C PROGRAMMER: ROBERT H. FRENCH C DATE: 11 JANUARY 1984	L IMPLICIT DOUBLE PRECISION(A-H,D-Z) VIRTUAL ICSUB(MMAX),C(MMAX) LOGICAL*I STORE, MONE	D0 10 1=1,N IF(ICSUB(I).ME.K)GOTO 10 CONTECTI)	IO CONTINUE IC CONTINUE	IT STORE TRUE. NOME - TRUE.	COUT=0. END IF
PDF-11 CLIP2H	1000										0002 0003 0004 0004	000 0000 0000	6000 6000	0013	0015
-86 Page 12				OF ENTRIES USED											
13:13:06 16-Jul-i MR	ISE	.EQ.K) GOTO 50		D ELEMENT AND BUMP COUNT I	, MUSE - 1   ICSUB( [+1)   1)							·			
-77 V4.0-1 1 /F77/	DO 40 I=1,MU	J=1 IF(ICSUB(I) CONTINUE	RETURN	re the zeroe	D0 60 1=J ICSUB(I)= C(I)=C(I+	CONTINUE MIISE = MIISE	RE TURN END								

1       13:13:12       16-Jul         /F77/wR       13:13:12       16-Jul         IME LOCN(NDIM, ILOM, IUP, ISUB       100, 100, 1508         ME COMPUTES THE EQUIVALENT       100, 110, 110, 110	1 13:13:12 16-Jul-86 Page 14 PDP-11 FORTRAN-77 V4.O-1 13:13:14 /F77/wR iwf incruting time in the apt 0001 SUBROUTIME VLANIT(LVEC_LLDW.	WE COMPUTES THE EQUIVALENT LINEAR SUBSCRIPT FOR       C       THIS SUBROUTINE INITIALIZES A "VE         JOMAL ARRAY OF NDIM DIMENSIONS       DO INO LVEC(1)=LLOM(1).LUPOF       C       DO INO LVEC(1)=LLOM(2).LUPOF         A IS DEFINED AS       DO INO LVEC(1)=LLOM(2).LUPOF       C       DO INO LVEC(2)=LLOM(2).LUPOF         A IS DEFINED AS       DO INO LVEC(2)=LLOM(2).LUPOF       C       DO INO LVEC(2)=LLOM(2).LUPOF         ON A(LLOM(1): LUP(1), ILOM(NDIM): LUP(NDIM))       C       DO INO LVEC(2)=LLOM(2).LUPOF         ON A(LLOM(1): LUP(1), ILOM(NDIM): LUP(NDIM))       C       DO INO LVEC(2)=LLOM(2).LUPOF         ON A(LLOM(1): LUP(1), ILOM(NDIM): LUP(NDIM))       C       DO INO LVEC(2)=LLOM(2).LUPOF         ON A(LLOMIN) IS A SET OF SUBSCRIPTS FOR A,       C       DO INO LVEC(2)=LLOM(2).LUPOF         CONTINE RETURNS IN LINEAR THE OFFSET FROM THE       C       DO INO LVEC(LINAX)=LLOM(LINAX)         CONTINE RETURNS IN LINEAR THE OFFSET FROM THE       C       DO INO LVEC(LINAX)=LLOM(LINAX)         CONTINE RETURNS IN LINEAR THE OFFSET FROM THE       C       DO INO LVEC(LINAX)=LLOM(LINAX)         CONTINE RETURNS IN LINEAR THE OFFSET FROM THE       C       DO INO LVEC(LINAX)=LLOM(LINAX)         CONTINE RETURNS IN LINEAR       C       DO INO LVEC(LINAX)=LLOM(LINAX)	CM ILOW(NDIM), IUP(NDIM), ISUB(NDIM)       CM ILOW(NDIM), IUP(NDIM), ISUB(NDIM)         OW/lower limits of defined subscripts of array/       CM ILOW(NDIM), IUP(NDIM), ISUB(NDIM)         OW/lower limits of defined subscripts of array/       CONTINUE STATEMENT IN THE ABOVE S         ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS       C CONTINUE STATEMENT IN THE ABOVE S         CM NDIM, ILOW, IUP, ISUB.LINEAR)       C CONTINUE STATEMENT IN THE ABOVE S         ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS       C CONTINUE STATEMENT IN THE ABOVE S         CM NDIM, ILOW, JUP, ISUB.LINEAR)       C CONTINUE STATEMENT IN THE ABOVE S         MUMBER OF DIMENSIONS THE ARRAY HAS       C USAGE:         ARRAY OF UPERE SUBSCRIPT BOUNDS       C INITIALIZE ARRAY LUP TO STARTIN         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LUP TO STARTIN         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LUP TO STARTIN         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LUP TO STARTIN         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LUP TO STARTINCLIFICALLUM, IUP TO STARTINC         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LINT TO STARTINCLIFE         ARRAY OF UPERE SUBSCRIPT FOR WHICH LOCATION IS       C INITIALIZE ARRAY LINT TO STARTINCLIFE         ARRAY OF UPERE       C OPERE         ARRAY OF UPERE       C INI	OBERT H. FREHCH       . (STATEMENTS IN RAMGE OF . (STATEMENTS IN RAMGE OF . (STATEMENTS IN RAMGE OF . DAWLARY 1984         I. JANUJARY 1984       . (STATEMENTS IN RAMGE OF . DAWLARY 1984         ON ILOW(NDIM), IUP(NDIM), ISUB(NDIM)       . (STATEMENTS IN RAMGE OF . DAWLARY 1984         ON ILOW(NDIM), IUP(NDIM), ISUB(NDIM)       . (STATEMENTS IN RAMGE OF . DAWLARY 1984         ON ILOW(NDIM), IUP(NDIM), ISUB(NDIM)       . (LOW - STORAGE OF LO . DOP . DIM-1        DIM-1      DIM-1<	C PROGRAMMER: ROBERT H. FRENCH
0     0     1 <td>FORTRAN-77 OP "FTN "14 Si</td> <td>C THIS SUE C THIS SUE C THIS SUE C THE / C THE / C THE / C THE FIRS</td> <td></td> <td></td> <td></td>	FORTRAN-77 OP "FTN "14 Si	C THIS SUE C THIS SUE C THIS SUE C THE / C THE / C THE / C THE FIRS			

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1 FORTRAN-77 V4.0-1 13:13:18 16-Ju1-86 Pa HOP.FTN:14 /F77/WR	SUBROUTINE PRIHOP(1,KM,KQ,KM,AIN)	C THIS SUBROUTINE COMPUTES THE EVENT PROBABILITY FOR ALL	C POSSIBLE JAMMING PATTERNS MITH MON-ZERO PROBABILITY FOR C L=1 MOP/SYMBOL FOR RMFSK/FH IN PGNJ C	IMPLICIT DOUBLE PRECISION (A-H,O-Z) DIMENSION 1(4)	NJANTEU DO 1 K=1,KM KJANTEXJANTI(K)	L CUMIANCE C IF THIS IS AN IMPOSSIBLE CASE, RETURN WITH RESULT = 0.0 If(Xiam GT Mimnikon KMI) dethion	KPMAX=KJAM-1 PMAX=KM-KJAM-1	JPPAARM-1 Imax-max0(kpmax,Lpmax,Jpmax) Prode: Dri	Q=KQ DIFFMQ=KN-KQ	EN=KN D0 100 L00P=0, IMAX F=1 00P	IF(LOOP.LE.KPMAX) PROD=PROD+(Q-F) IF(LOOP.LE.JPMAX) PROD=PROD/(EW-F)	IF(LOOP.LE.LPMAX) PROD-PROD*(DIFFNQ-F) 100 CONTIMUE AIM=PROD	RETURN
PDP-1 CL IP2	1000			0003 0003 0003 0003 0003			0108	0014	0015		0020	0022 0023 0024	0025 0026
11 FORTRAN-77 V4.0-1 13:13:16 16-Jul-86 Page 16 2HOP.FTW;14 /F77/WR	SUBROUTINE VLITER(LVEC,LLON,LUP,LINC,LMAX,GO)	C LOOP ITERATION LOGIC FOR A "VECTOR DO-LOOP"	C SEE DETAILED COMMENTS IN SUBROUTINE VLIMIT FOR USAGE AND C PARAMETER DEFINITIONS	C C PROGRAMMER: ROBERT H. FRENCH C DATE: IL JANUJARY 1984	C LOGICAL*1 GO DIMENSION LVEC(LMAX),LLOW(LMAX),LUP(LMAX),LINC(LMAX) GO= TRUIF	DO IOO NDX=1,LMAX NSUB=LMAX+1_KDX	LVEC(NSUB)=LVEC(NSUB)+LINC(NSUB) IF((LINC(NSUB)=GE.O.AND.LVEC(NSUB).LE.LUP(NSUB)) C.D.(LINC(NSUB)=GE.O.AND.LVEC(NSUB).LE.LUP(NSUB))	LUCCURSUB)=LLOM(NSUE) 100 CONTINUE	GO=.FALSE. RETURN				
PDP- CLIP	1000				000 0000 8000	5000	6000 0000	0100 5000	001200	З Н-9	9		

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F FORTRAN-77 V4.O-1 13:13:23 16-Jul-86 Page 19 40P.FTN;14 /F77/WR	SUBROUTINE PSEL(JSUB,MM,PROB) C RANDOM MESK/FH IN PARTIAL BAND MOISE JAMMIMG, C GIVEN A JAMMING EVENT, WITH CLIPPER RECEIVER C JSUB - JAMMING EVENT VECTOR MM - ALPHABET SIZE MM - ALPHABET SIZE MM - ALPHABET SIZE	<ul> <li>IMPLICIT DOUBLE PRECISION(A-H, 0-2)</li> <li>DIMENSIOM JSUB(MM), MORK(30), STACK(30), HEAP(30)</li> <li>EXTERNAL DG16, PGRAMD</li> <li>INTEGER MCMMN(0:3)</li> <li>EXTERNAL DG16, PGRAMD</li> <li>EXTERNAL DG17, RHOM2, RHOM4, RHOTH, RHOTH</li> <li>EXTERNAL PLONE, RHOM8, RHOM4, RHOTH</li> <li>EXTERNAL PG10, PARSE</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, PARSE</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, PARSE</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, PARSE</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> <li>EXTERNAL PG10, RHOTS, RHOM4, RHOTH</li> </ul>	KSUB-KSUB-JSUB(I) 6 CONTINC C SET UP VALUES MHICH MILL REMAIN IF THIS IS THE NOTHIMG-JAMMED CASE 00-0(2.00-05QRT(RHOMH),D5QRT(2.DO+TAU)) 01-1.D0 1ALK-0.D0 C IF ANYTHING IS JAMMED, SET UP JAMMING-RELATED QUANTITIES 15(KSUB.ME.0) THEN BIGK-RHOM/RHOT 81GK-RHOM/RHOT AMB-BIGK/BKI	BABE1_DO/BK1 TAUKZ=TAU/BIGK TAUKZ=TAUZ/BIEK Q1=Q(2.DO*DSQRT(RHOTH),DSQRT(2.DO*TAUK)) END IF C C COUNT MUMBER OF MONSIGNAL CHANNELS WITH Lm HOPS JAMMED	C DO 10 1-0.2 NCHAM(1)=0 10 CONTINUE DO 11 1-2.MM XSUBB-JSUBB(1) NCHAM(KSUB)=MCHAM(KSUB)+1 11 CONTINUE JANSC=JSUB(1) CONTINUE C DO THE CONTINUOUS PART OF THE DEMSITY IN SECTIONS
PDP-11 CL 1P2F	1000	0002 0005 0005 0006 0007 0007 0000 0000 0011 0000 0010 001	0014 0015 0016 0017 0019 0019 0020 0020 0020	0022 0023 0024 0026 0026	0027 0028 0030 0031 0033 0034
-11 FORTRAM-77 V4.0-1 13:13:20 16-Jul-86 Page 18 P2HOP.FTN;14 /F77/WR	I     BLOCK DATA       C     IMITIALIZE SWARED CONSTANTS       Z     IMPLICIT DOUBLE PRECISION (A-H, 0-Z)       D     COMMON /SWARE/ DG(10), DSMR(3,4)       C     COMMON /SWARE/ LOW(4), LINC(4)       A     COMMON /MTS/ X(8), W(8)       C     COMMON /MTS/ X(8), W(8)       C     C       C     MEIGHTS AND ABSCISSAS FOR 16-POINT GAUSSIAN QUADRATURE	C DATA X/ 0.0950125096376374018500, 0.28160355077925891323000, 0.28160355077925891323000, 0.27654040835500303399500, 0.0554040835500303399500, 0.0554040835500303399500, 0.0544505030732225760780, 0.0994505030732225760780, 0.182603499164965386800, 0.182661399550023499164902238886700, 0.18266139955002349628500, 0.18266139955002388165700, 0.12462897125553387202500,	5         0.09515851168249278481000,           5         0.06225352393864789286300,           5         0.06225352393864789286300,           6         0.06225352393864789286300,           7         0.062715245941175409485200,           6         0.062715245941175409485200,           7         0.02715245941175409485200,           7         0.0271524584115409485200,           7         0.0271524584115409485200,           7         0.0271545464671184         PARAMETER INPUTS           7         0.027174104         PARAMETER INPUTS           8         DATA D6, 0.00100, 0.00200, 0.0500,         SIORA, RE           8         DATA D6, 0.00100, 0.0200, 0.0500,         SIOR, 0.0500,           8         0.0100, 0.2000, 0.0500,         SIOR, 0.0500,           9         DATA D6, 1.2.313300, 10.9444300,         D.9444300,	S         10.60657200, 9.628400, 8.3324800,           S         9.0940100, 8.169000, 6.97199500,           S         9.0940100, 8.169000, 6.97199500,           C         FREQUENTLY MEEDED CONSTANT ARRAYS AND SCALARS           D         DATA LON/4+0/, LINC/4*1/           I         END	
55	8 8888	8 8	В 8 H_10	88	
			N-10		

PDP-11 FORTRAN-77 V4.0-1 13:13:30 16-Jul-86 Page 22 CLIP2HOP.FTN;14 /F77/WR	D001       SUBROUTINE ADQUAD(XL,XU,Y,QR,F,TOL,MOKK,STACK,HEAP,M,KODE)         C       ADAPTIVE QUADRATURE ALGORITHM         C       XL - LOWER LIMIT OF INTEGRAL (IN)         C       XL - UNPER LIMIT OF INTEGRAL (IN)         C       XL - VALUE OF INTEGRAL (IN)         C       QR - NUME OF A QUADRATINE RULE SUBROUTINE (IN)         C       QR - NUME OF A QUADRATINE RULE SUBROUTINE (IN)         C       QR - NUME OF FUNCTION TO BE INTEGRATED (IN)         C       F - NUME OF FUNCTION TO BE INTEGRATED (IN)         C       CALL QR(XL,XU,F,Y)         C       F - NUME OF FUNCTION TO BE INTEGRATED (IN)         C       CALL OR (XL,XU,F,Y)         C       F - NUME OF FUNCTION TO BE INTEGRATED (IN)         C       F - NUME OF FUNCTION TO BE INTEGRATED (IN)         C       F - NUME OF SIZE M (IN)         C       F - NUME ARANY OF SIZE M (IN)         C       F - NUME ARANY OF SIZE M (IN)         C       SIME ARRAY OF SIZE M (IN)         C       SIME ARANY OF SIZE M (IN)         C       SMORY ARANY OF S	C HEAP- THIRD WORK ARRAY OF SIZE N, DISTINCT FROM BOTH WORK AND STACK C N - SIZE OF WORK AND STACK; MAX, NO. OF BISECTIONS (IN) C KODE - ERROR INDICATOR (OUT) C 0 MO ERROR C 1 WORK ARRAYS TOO SMALL C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 1 MORK ARRAYS TOO SWALL C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 7 MORK ARRAYS TOO SWALL C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 7 MORK ARRAYS TOO SWALL C 2 EPS DIVIDED TO ZERO, EITHER ASKING FOR TOO C 2 FOR TOULED TO ZERO, EITHER ASKING FOR TOO C 7 MORK ARRAYS TOO SWALL	0002       IMPLICIT DOUBLE PRECISION(A-H, D-Z)         0003       EXTERNAL F         0005       DIMENSION MORK(N), STACK(N), HEAP(N)         0005       VIEL         0006       VIEL         0007       NORK(1)=XU         0008       VIEL         0007       VIEL         0008       VIEL         0009       VIEL         00009       VIEL         00010       VIEL         0011       NPTS=1         0012       STACK(1)=XU         0013       NPTS=1         0014       NPTS=1         0015       A=XL         0016       ONLL         0011       NPTS=1         0012       STACK(1)=XU         0013       NPTS=1         0014       NPTS=1         0015       VIEL         0016       ONLL         0017       NPTS=1         0018       STACK(1)=YU         0019       NPTS=1         0011       NPTS=1         0012       NPTS=1         0013       NPTS=1         0014       NPTS<1         0015       STACK(1)=YU <t< th=""></t<>
\$AN-77 V4.O-1 13:13:23 16-Jul-86 Page 20 Y;14 /F77/WR	PCOMT-0.DO DO 13 ISECT=1,2 XL=(ISECT=1,2+TAU XU=ISECT=1)+TAU XU=ISECT=1)+TAU XU=ISECT=1)+TAU STACK,HEAP,30,KODE CALL TEST2(KODE,10) PCONT=PCONT+CHUNK 13 CONTINUE 13 CONTINUE 14 TIE PART OF THE DENSITY CALL TIES(JSUB,MM,PTIE)	JT THEM TOGETHER PROB=1.DO-PCOMT-PTIE RETURN END *1.14 /F77/MR *1.14 /F77/MR	DOUBLE PRECISION FUNCTION PERAMD(BETA) IMPLICIT DOUBLE PRECISION(A-H,O-2) IMPLICIT DOUBLE PRECISION(A-H,O-2) IMPLICIT DOUBLE PRECISION(A-H,O-2) IMPLICIT DOUBLE PRECISION(A-H,O-2) COMMON /SUCANN/ JANSC COMMON /DENPAR/ BILAN, RUN, TAUZ, TAUK, TAUK2 COMMON /DENPAR/ BILAN, RUNG, RHOMH, RHOT2, RHOM4, RHOT4, ROMMON /DUES/ QO, Q1 PROD=1.DO DO 10 1=0.2 IF(NCHAN(I).ME.0) THEN LJAM=1 NELLIN COMTINE LJAM=JANSC CONTINE LJAM=JANSC CONTINE LJAM=JANSC RETURN RETURN END
POP-11 FORTE CLIP2HOP.FTA	0035 0036 0038 0046 0046 0046 0046 0046 0046 0046 004	C PL 0045 0045 0046 0046 0046 PDP-11 F03TTA F171PP.FTMP	-11 -11

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0001       SUBROUTINE ADQUAZ(XL,XU,Y,QR,F,TOL,MOCK,STACK,HEAP,M,KODE)         C ADAPTIVE QUARAATURE ALGORITHM       XL - LONER LIMIT OF INTEGNAL (IN)         C XL - LONER LIMIT OF INTEGNAL (IN)       XL - LONER LIMIT OF INTEGNAL (IN)         C XL - LONER LIMIT OF INTEGNAL (IN)       XL - LONER LIMIT OF INTEGNAL (IN)         C XL - LONER LIMIT OF INTEGNAL (IN)       XL - LONER LIMIT OF INTEGNAL (IN)         C XL - UPPER LIMIT OF INTEGNAL (IN)       XL - LONER LIMIT OF INTEGNAL (IN)         C XL - UPPER LIMIT OF INTEGNAL (IN)       XL - LONER LIMIT OF INTEGNAL (IN)         C R - MWE OF A CALARATORE RULE SUBROUTINE (IN)       NITH (ALLING SOURCE         C R - MWE OF FUNCTION TO BE INTEGNATED (IN)       NIST NOT BE         C TOL - EEROR TOLEAMORE FOR FIML ANSWER (IN)       NIST NOT BE         C STACK - SECON MORK ARRAY OF SIZE M, NIST NOT BE       STACK         STACK - SECON MORK ARRAY OF SIZE M, DISTINCT FROM BOTH WORK AND STACK       N SIZE OF MORK AND STACK; MAX. NO. OF BISECTIONS (IN)         MOR - EEROR NOCK ARRAY OF SIZE M, DISTINCT FROM BOTH WORK AND       STACK         C OCE - EEROR NOCK ARRAY OF SIZE M, DISTINCT FROM BOTH WORK AND       STACK         MORK - AND STACK; MAX. NO. OF BISECTIONS (IN)       0 NO EROR         C OCE - EEROR NOCK ARRAY OF SIZE M, DISTINCT FROM BOTH WORK       0 NO EROR         C OCE - EEROR NOCK ARRAY OF SIZE M, OLIVOLOFF PREVENTS       1 EOS DAUL	0002         IMPLICIT DOUBLE PRECISION(A-H, O-Z)           0003         EXTERNAL F           0005         EXTERNAL F           0006         VIENAL F           0005         FXTERNAL F           0006         VIENAL F           0006         VIENAL F           0006         VIENAL F           0007         MOK(I)=XU           0008         VIENAL F           0010         VIENAL F           0011         MOK(I)=XU           0012         VIENAL F           0013         MOK(I)=XU           0014         MOK(I)=XU           0012         MOK(I)=XU           0013         MOK(I)=XU           0014         MOK(I)=XU           0012         MOK(I)=XU           0013         MOK(I)=XU           0014         MOK(I)=XU           0015         MOK(I)=XU           0016         MOK(I)=XU           0017         MOK(I)=XU           0018         MOK(I)=XU           0019         MOS(A, MOS)           0011         MOS(A, MOS)           0012         MOS(A, MOS)           0013         MOS(A, MOS)           0014 <td< th=""></td<>
IF(EPS.EQ.0.DO) THEN KODE=2 RETURN END IF STACK(MPTS)=EPS GOTD 10 C FINISHED A PIECE 20 Y=FP1AP2 T=HEAP(NPTS) NPTS-RPTS-1 NPTS-1	
	IF (FPS. EQ. 0.00) THEM     THE (FPS. EQ. 0.00) THEM     SUBROUTHER     ADVACZ(XL, VLV, CR, F, TOL, VOOR, STACCA, HEAP, A, KODE)       KODE F     FOD F     CAL     CAL     FOD F     FOD F       KOD F     FOD F     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       STACK (MPTS)=EPS     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       STACK (MPTS)=EPS     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       STACK (MPTS)=EPS     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       STACK (MPTS)=EPS     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       C FINISHED A FIEL     CAL     CORRES LIMITY OF INTEGRAL (IN)     FOD A       STACK (MPTS)=EPS     CAL     CORRES CAL     CAL     FOD A       F = AME OF FIEL     CAL     FOL A     FOL A     FOL A       C = FINISHED A FOR A     CAL     FOL A     FOL A     FOL A       C = AME OF CALCUERT CAL     CAL     FOL A     FOL A     FOL A       C = MARE OF FOR ADD A     CAL     FOL A     FOL A     FOL A       C = AME OF CALCUERT CAL     CAL     FOL A     FOL A     FOL A       C = MARE OF FOL A     CAL     FOL A     FOL A     FOL A       C = MARE OF FOL A     CAL     FOL A     FOL A

H-12

H24110	EDRTRAN-77 V4.0-1 13:13:34 90.FTN;14 /F77/MR	16-Ju]-86	Page 25	PDP-11 FOR CLIP2HOP.F	TRAN-77 V4.0-1 13:13:37 16-Jul-86 Page 26 TN;14 /F77/WR	9
0028 0028	IF(EPS.EQ.0.00) THEN KONE=2			1000	SUBROUTINE DG16(A,B,F,ANSMER)	
0000	RETURN END I				16-POINT GAUSSIAN INTEGRATION OVER AZBITRARY INTERVAL	
	STACK(MPTS)=EPS EATD JD			J J J J J J J J J J J J J J J J J J J	REF.: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4	
	C FINISHED A PIECE			י <u>ה</u> ר	R. H. FREMCH, 28 FEBRUARY 1906	
20032 20032	EPSESTATE FSESTATE (NPTS)			0002	IMPLICIT DOUBLE PRECISION (A-M,0-Z)	
888 888				1000	CUTTON / #12/ A(6) .#(8) ANSHER=0.DO	
	IF(MPTS.EQ.O) RETURN				BMAD2=(B-A)/2.DO BPAD2=(B+A)/2.DO	
85	G0T0 10 Euro			0007		
ŝ				5000	C=K(L)=COMMUC Y1=BPAQ2+C	
				00100	Y2=8PA02-C Ancuep=ancuep44/17)={ffy1}_fffy3)}	
				0012 10		
				0013	ANSWEREANSWEREBANAO2	
				0015	RE JUKN EMD	
				PDP-11 FOR CLIP2H0P.FI	TRAN-77 V4.0-1 13:13:38 16-Jul-86 Page 27 TM;14 /F77/WR	5
				1000	SUBROUTINE DEXVI(A,B,F,AMSMER)	
				50	16-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL	
					REF.: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4	
					R. H. FRENCH, 28 FEBRUARY 1986	
				0002	IMPLICIT DOUBLE PRECISION (A-H.O-Z)	
				000	CUTTOR / MIS/ A(B) + MIB) ANSHER=0.50	
				0002 MUVE	BMAQ2=(B-A)/2.DO BBAQ2-(B+A)/2.DO	
				2000	00 10 1=1,8	
				8000 6000	C=X(I)*8MMAO2 Y1=8PAO2+C	
				0100	Y2=8PA02-C	
				0011	ANSHER=ANSHER+U(1)*(F(Y1)+F(Y2)) CONTINIE	
				0013	ANNER - ANSWER + BHAO2	
				0015 0015	KE JUKN END	

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8200 6200 1E00 1E00 1E00 1E00

H-13

age 28 PDP-11 FORTRAN-77 V4.0-1 13:13:43 16-Jul-86 Page 3 CLIP2HOP.FTN;14 /F77/WR	0001 DOUBLE PRECISION FUNCTION PZI(Y)	C SIGNAL CHANNEL P.D.F. WITH CHANGE OF VARIABLE Y=AX	102         0002         IMPLICIT DOUBLE PRECISION (A-H, 0-Z)           102         0003         DIMENSION MORC(30), STACC(30), HEAP(30)           0004         LOGICAL+1 REG1 REG2         REG2           0005         EXTERNAL DEXVI, F20, F21, F22         P21, F22           0005         EXTERNAL DEXVI, F20, F21, F22         R005, 101, 102           0005         COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102         0007           0007         COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102         100           0005         COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102         100           0007         COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102         100           0008         COMMON /PARNEN/ RIGH, RHOT, RHOT, RHOT2, RHOT2, RHOT4, RHOT4         102	S         RHOMB, RHOTH, RHOTH           age 29         0009         COPPON /QUES/ Q0, Q1           0010         COPPON /XCON/ XCON         001           0011         COPPON /XCON/ XXX, XXXX         001           0012         XXX=Y         0012           0013         COPPON /OUTER/ XXX, XXXX         0012           0013         IF(LJAM.GE.1) THEN         0013           0013         IF(LJAM.GE.1) THEN         0013	ALL NUMBER ', I5) 0015 VK-XXX 0015 VK-XXX 0017 VYR=(Y-TAU2)/BIGK 0018 END IF END IF 0019 REG1=Y.GE.0.D0 .AND. Y.LT.TAU 0020 REG2=Y.GE.TAU .AND. Y.LT.TAU2	C THO HOPS PER SYMBOL C 2000 6010 (2100, 2200, 2300), LJAM+1	C MO CUPS JANNED	0022       2100       IF (REG1)       THEN         0023       BARG1=DSGRT(RHOMB+Y)       0025         0025       CALL       DX8T(2100)         0026       CALL       DX8T(2100)         0026       CALL       DX8T(2100)         0026       CALL       DX8T(2100)         0026       CALL       DX8T(2100)         0027       ELSE       F(REG2)         0029       CALL       DX8T(RHOMH+(Y-TAU))         0029       CALL       DX8T(2101)         0029       D0=0       CALL         0029       CALL       DX8T(RHOM+(Y-TAU))         0029       CALL       DX8T(2101)         0029       D0=0       CALL         0030       CALL       DX8T(Z101)         0031       PART=2.00°400°EEXP(BARG1-YTAU-RHOM)+BI         0032       CALL       DX8T(Z101)         0033       CALL       DX8T(Z101)         0033       CALL       DX8T(Z101)         0033       CALL       DX8T(Z101)         0033       CALL       DX8T(Z101)         0034       CALL       DX8T(Z101)         0035       CALL       DX8T(Z101)         036       CA
PDP-11 FORTRAN-77 V4.O-1 13:13:40 16-Jul-96 CLIP2HOP.FTN;14 /F77/MR	0001 SUBROUTIME TEST(1D)	C TEST RETURN CODE FROM BESSEL FUNCTION	C 0002 C IMPLICIT DOUBLE PRECISION(A-M,O-Z) 0003 COMMON /LOCALS/ BARGI, BARGZ, BI, BZ, KODE, 101, 1 1F(KODE.Eq.O) RETURN 0005 I F(KODE.Eq.O) RETURN 0006 I FOMMAT(' BESSEL FUNCTION CODE * ',I2,' FROM CALL N 0007 STOP 'FATAL ERROR' 0008 END	PDP-11 FORTRAM-77 V4.0-1 13:13:42 16-Jul-86 Pa CLIP2HOP.FTN;14 /F77/MR 0001 SUBROUTIME TEST2(KODE,10) C TEST DETIBUL FONE EDAM ADMIANDIAS	0002 IF(KODE.EQ.0) RETURN 0003 WRITE(5,1) KODE, ID 0004 I FORMAT(' ADAPTIVE INTEGRATOR CODE = ',I2,' FROM CA 5006 END 0006 END			

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V4.0-1 13:13:50 16-Jul-86 Page 32 /F77/WR	OUBLE PRECISION FUNCTION GL(Y)	GMAL CHANNEL CUMULATIVE DISTRIBUTION FUNCTION ITH CHANNE OF VARIABLE Y-AX	Welicit Double Precision (A-H.O-Z) DGicat*i Regi. Reg2. Reg3	OMMON /OEMPAR/ BIGK, AAB, BAB, LJAM, Tau: Taus, Taus, Tauk, Tair2	E61=Y.GE.O.DO .AND. Y.LT.TAU E62=Y.GE.TAU .AND. Y.LT.TAUZ	FLLUMI.61.U) THEN YK=Y/BIGK	YTX=(Y-TAU)/BIGK YTX2=(Y-TAU2)/BIGK MD T2	NO HOPS PER STHBOL	0T0 (2100, 2200, 2300), LJMH-1	NG HOPS JANNED	F(REG1) THEN	GL=].DO-(].DO+Y)*DEXP(-Y) .cc re/scco\ Twew	LSE IF(REGZ) PREM GL=1.00-(1.00+RN2-Y)+DEXP(-Y) LEE TRUPS THEM	LSE IT.1.30.1002/ INLIN LSE LSE	Gi=0.00 M0 JF	010 9000	ONE HOP JANNED	F{REG]) THEN Ci≡i nn_AAR+DFYP/_YK\+RAR+DFYP/_Y)	LSE IFLREG2) THEN LSE IFLREG2) THEN CL-21 NARAPHARITAN TANK VLABAPHARVD(TANK TAN VV)	bert.UU-MAD-UEANT (AU-TAUA-T)70000-UEANT (AMA-TAU-TA) LISE IF (Y. GE.TAU2) THEN ci-i		61 = 0.00 No 17 2010 2000			
ORTRAN-7 .FTN;14	י –   	001 10 10 10	J	6				00	5000 5000	ບບເ	2100					J	، ر. ر	, 2200							
PDP-11 F CLIP2HOP	1000	·	0003 0003	1000	5000 5000 5000	/000 0000	<b>6</b> 00		0012		0013	0014	5100 9100	0018	0200	0022		0023 0023	0025	002) 0023	0026	0030			
Page 31			.D-9,WORK,STACK,				164		1,1.D-9,WORK,STACK,								К-RH0T2)			BIGK	2,1.0-9,WORK,STACK,				
-Jul-86			XVI,F21,1				8/18+(10H)	NU-RHON) #8	R, DGXVI, F2								KP (BARG1-Y			-RHOT)+B1/	R, DGXVI, F2				
n-77 V4.0-1 13:13:43 16 l4 /F77/WR	ONE HOP JANNED	IF(REG1) THEN	ALUM=TK+KRUM+KRUI CALL ADQUA2(0.00,Y,ANSNER,DK t head formd)	CALL TEST2(KOD, 2200)	ELSE IF(REG2) THEN BARGI=DSQRT(RHOT4+YTK)	101=0 CALL DXBT(2201)	PART=00+DEXP{BARG]-YK+TAUK-} BARG]=DSORT(RHOM4+(Y-TAU))	101-0 CALL DXBT(2202) PART=PART+Q1+DEXP(BARG1-Y+T/	XCON=YK+RHON-RHOT Call Adqua2(Y-Tau, Tau, ANSME)	5 CALL TEST2(K00, 2202) CALL TEST2(K00, 2202)	PZ1=PART+ANSNER/BJGK ELSE	P21=0.00	ENU 1F GOTO 9000	THO HOPS JANNED	IF(REG1) THEN BARG1=DSQRT(RHOT8+YK)	101=1 CALL DIRT(2300)	PZ1=0.500=050RT(Y/RHONH)+DE	ELSE IF(REG2) THEN RADCI=NCADT/2HDT4+VTV)	101=0	CALL UXB1(23U1) PART=2,00+01+0EXP(BARG1-YTK- ************************************	CALL ADQUAZ(Y-TAU, TAU, ANSHE)	S HEAP, 30, K00) CALL TEST2(K00, 2300) P71_PADT+ANKUED// RICH+BICK)	ELSE PTITUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUTUT	END IF CONTINUE DETIDAN	END
L FORTRAU HOP . FTN; 1	υu	ر 2200	-	•						~ 1			Ĺ	ارد	<b>2300</b>		•					-		0006	
PDP-11		0000	1 NO	E NOO	5900	600 800 800	600 1900	10023 0023	0054	0056	8822 8822 H	58 8 1	0001		0062 0063	1900 1900	0066	0067	6900 900		8073 0073	0074	0076	0079 0079	0081

13:56 16-Jul-86 Page	WCTION F21(U) SMAL CHANNEL DENSITY, L=2, LJAM=1 :ISIOM(A-H,0-Z) :ISIOM(A-H,0-Z) :AAB, BAB, LJAM AAB, BAB, LJAM AAB, BAB, LJAM AAB, BAB, LJAM AAB, AND AB, AND	-XCOM-U+U/BIGK)+81*B2	3:58 16-Jul-86 Page NT) NS, ARGUMENTS AND RESULTS IN COMM NS, ARGUMENTS AND RESULTS IN COMM ISTON(A-H,0-Z) L. BARG2, B1, B2, KODE, TO1, TO2 L. BARG2, B1, B2, KODE, TO1, TO2 2.82,KODE)
11 FORTRAN-77 V4.0-1 13: 2HOP.FTN;14 /F77/WR	DOUBLE PRECISION FL C INTEGRAND FUNCTION FOR SI C INTEGRAND FUNCTION FOR SI INPLICIT DOUBLE PRE COMPON /LOCALS/ BAR COMPON /LOCALS/ BAR RHO COMPON /PARDEN/ RHO SCOMPON /QUES/ QO, Q COMPON /AUTEN/ XXX, BARG1=DSQRT(RHOT4=( IN)=0 IN)=0	CALL BPROD(2210) F21=DEXP(BARG1+BARG RETURN END	II FORTRAM-77 V4.0-1 13: PHOP.FTN:14 /F77/MR SUBROUTIME BPRCOO(ID C COMPUTE TWO BESSEL FUNCTIO C COMPUTE TWO BESSEL FUNCTIO C COMPON /LOCALS/ BARE C CALL DXBT(IDENT) C CALL DXBT(IDENT) C CALL TEST(IDENT) E ND E ND
13 PDP		4 0013 0014 0014 0015 0015	- 001 2003 2003 2004 2008 2009 2009 2009 2009 2009 2009 2009
6 Page 3		Page 3	ITY, L=2, LJAM=0 22 10T2, RHOM4, RHOT4, RHOTH , KODE, IOL, 102
i0 16-Jul-8	р(-тк) к)=bExP(-тк)	5 16-Jul-8( ON F20(U)	CHAINNEL DENIS) ON(A-H, O-2) ABB, BAB, LJAM, U2, TAUK, TAUK, TAUK, TAUK, TAUK HOT, RHORT, RH HOT, RHORT, RI BARG2, B1, B2, V)) U)) ON)*B1*B2
-77 V4.0-1 13:13:5	THO HOPS JAMMEL If (REG1) THEN GL =1.00-(1.00+YK)*DEX ELSE IF (REG2) THEN GL =1.00-(1.00+TAUK2-Y ELSE IF (Y.GE.TAU2) THEN GL =1.00 GL =1.00 GL =0.00 ELSE GL =0.00 END IF GOTTIMUE RETURN END	77 V4.0-1 13:13:5 /F77/WK DOCIBLE PRECISION FUNCTI	AND FUNCTION FOR SIGNAL INPLICIT DOUBLE PRECISI COMMON /DENPAR/ BIGK, A COMMON /DENPAR/ BIGK, A COMMON /DENPAR/ RHOM, R HOMB, COMMON /LOCALS/ BARGI, COMMON /OUTER/ XXX, XXX BARGI=DSQRT(RHOM4*U) BARG2=DSQRT(RHOM4*U) BARG2=DSQRT(RHOM4*U) BARG2=DSQRT(RHOM4*U) BARG2=DSQRT(RHOM4*U) CALL BPROD(2110) CALL BPROD(2110) F20=DEXP(BARG1+BARG2-XCC RETURN END
PDP-11 FORTRAN- CLIP2HOP.FTN;14	0033 0035 0045 0045 0045 0045 0045 0045	PUP-11 FORTRAM	C INTEG 0002 0005 0005 0005 0005 00014 00016 0005 00016 0005 0005 0005 0005 00

77 V4.0-1 77 V4.0-1 13:13:56 16-Ju1-86 777/MR BOUBLE PRECISION FUNCTION F21(U) RAND FUNCTION FOR SIGMAL CHANNEL DENSIT IMPLICIT DOUBLE PRECISION(A-H,0-2) COMMON /DENMALS/ BURG, AMB, BAUB, LJAM, COMMON /DENMALS/ BURG, AMB, BAUB, LJAM, COMMON /DENMAL BIGK, AMB, BAUB, LJAM, COMMON /PARDEN/ BURA, RHOT, RHOM2, RHOM4, RI COMMON /PARDEN/ BURA, RHOT, RHOM4, RI COMMON /PARDEN/ RHOM4, RHOTB, RHOM4, RI COMMON /OUTER/ XXX, XXXK BARG1-DSQRT(RHOT4*(XXX, XXXK BARG1-DSQRT(RHOT4*(XXX, U/BIGK)) 101-0 102-0 CALL BPROO(2210) F21-DEXP(BARG1+BARG2-XCOM-U+U/BIGK)*B1* RETURN RETURN	Page 36
77 V4.0-1 77 V4.0-1 777/WR 13:13:56 777/WR 13:13:56 DOUBLE PRECISION FUNCTION RAND FUNCTION FOR SIGNAL CA THE PRECISION COMMON /DENPARE BIGK, AUB TAU2 COMMON /DENPARE BIGK, AUB TAU2 COMMON /DENPARE BIGK, AUB TAU2 TAU2 COMMON /DENPARE BIGK, AUB RHOWB, RHO RHOWB, RHO RHOWB, RHOMB, RHO COMMON /OUTER/ XXX, XXXK BARG1=DSQRT(RHOT4=(XXXK-U/ 101=0 102	16-Ju1-86
77 V4.0-1 /F77, DOUBLE PRECIS RAND FUNCTION INPLICT DOUG COMMON /DEMPA COMMON /DEMPA COMON /DEMPA COMMON /DEMPA COMMON /DEMPA COMON /DEMPA COM	13:13:58 MR
	7 W.O-1 /F77/1
2HOP.FTN:14	11 FORTRAN-77 240P.FTN;14

Page 36		RESULTS IN COMMON
10-Jul-86		ARGUMENTS AND I
.FTN:14 /F77/MR	SUBROUTINE BPROD(IDENT)	C COMPUTE THO BESSEL FUNCTIONS
IP2H0P	10	

I FORTRAN-77 V4.0-1 I3:14:02 16-Jul-86 Page 39 HOP.FT%;14 /F77/NR	SUBROUTINE TIES(JSUB,MM, PTIE)	C COMPUTE PROBABILITY OF CORRECT DECISION GIVEN THAT C SEVERAL SATURATED CHANNELS ARE TIED	C IMPLICIT DOUBLE PRECISION(A-H,O-2) DIMENSION JSUB(M), LLOM(7), LIMC(7), LUP(7), MU(7),	DECICAL = 2 60 COMMON / DENPAR/ BIEK, AAB, BAB, LUM,	S TAUR, TAUR, TAUR, TAUR, TAUR, CONNON, PARDEM, RHOT4, CONNON /PARDEM/RHOM, RHOT, RHONZ, RHOMA, RHOT4, C DANNON JAURTS DUCAU DUCTU	C MUMBER OF NON-SIGNAL CHANNELS, WINUT, WINUTH	MMU+#M-1 PTIE=0.00	CUEO-DEXP(-TAU) CUEI-DEXP(-TAUX) DI	PIL=0AI(40,5-0508(1))=UAI(41,5508(1)) DO 10 1=2,000 P24 M(1)=D74 Cife 0, 2-35184(1)\+51x1(Cife 1,518(1))	10 CONTINUE C SET UP VECTOR LOOP PARAMETERS	00 20 1=1,00-1			C START LOOP ON THE TIE EVENTS	CALL VINIT(NU,LLCN,MH-1)	D0 40 1=1, HH-1	MUSIMENUS(IN+NU(I))	FRAC=1.DO/(1.DO+NUSUM)	PRUD=1.00 D0 50 H=2.00	IF(MU(M-1), EQ.1) THEN	PROO=PROD*P2LM(M) ELSE	PROD=PROD*(1.D0-P2LM(M))	E ND 1F SO CONTINUE	PTIE=FRAC*PROD+PTIE CALL_VLITER(NU_LLUP_LLUP_LINC_NH-1,GO)	IF(GU) GUIU 3U PTIE=PTIE=PLL
PDP-11 CL1P2H0	1000		<b>00</b> 02 0003	0004	9000	0007	800 800	0010 0011 0011	0013 0013	0015	0016	0018	0200	1700	0022	0024	0025 0026	0027	0028 0029	0030	0031	603	0034 0035	0036 0037	66 <b>00</b>
Page 37		, LJAN=2		M4, RHD14, 101, 102						Page 38					101, 102										
-Jul-86	(i)	DENSITY, L=2.	-Z) LJAM, TAUK2	NZ, RHOTZ, RH Honh, Rhoth 1, b2, Kode, 1		-		82		-Jul-86				-z)	1, 82, KODE,										
4	2	UNNEL	- H			IGK)	•	<b>•</b> ₿]+		16	1			0.H-J	ש קיא איג	Ĵ.									
' V4.0-1 13:13:59 16 /F77/WR	OUBLE PRECISION FUNCTION F22	ND FUNCTION FOR SIGNAL CHANNEL	INPLICIT DOUBLE PRECISION(A-H,0- COPPON /DENPAR/ BIGK, AAB, BAB, TAU, TAUZ, TAUX, TAUX,	COMPON / PARDEN/ RHON, RHOT, RHO RHONB, RHONB, RHOTB, R OMMON /LOCALS/ BARG1, BARG2, 3	COMPON /QUES/ QO, Q1 COMPON /XCOM/ XCON MANNA /XUTEP/ YYY YYYY	ARG1=DSQRT(RHOT4+U/B1GK) ARG2=DSQRT(RHOT4+U/B1GK) ARG2=DSQRT(RHOT4+(XXXK-U/B1GK)	01-0	ALL BPROD(2310) 22=DEXP(BARG1+BARG2-XCON)+81+ 22=DEXP(BARG1+BARG2-XCON)+81+	ie i ukin Indi	V4.0-1 13:14:01 16	/F77/MR	JUBROUTIME DXBT(ID)	BEST AND TEST RETURN CODE	WPLICIT DOUBLE PRECISION(A-H,O	COMMON /LOCALS/ BARG1, BARG2, B	ALL TEST(ID)	teturn Ng								

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<u>and the contraction of the cont</u>

Page 41	RH014 .	
RTRAN-77 V4.0-1 13:14:08 16-Ju1-86 FTN;14 /F77/WR SUBROUTIME SETTAU(MM,PEOD) SEARCH FOR OPTIMUM THRESHOLD IN ABSENCE OF JAMMING	IMPLICIT DOUBLE PRECISION(A-H, 0-Z) EXTERNAL PUMJAN COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, COMMON /PARDEN/ RHON, RHONZ, RHONZ, RHONZ, RHOMA, COMMON /QUES/ QO, QI LJAM=0 LJAM=0 COMMON /QUES/ QO, QI LJAM=0 COMMON /QUES/ QO, QI LJAM=0 COMMON /QUES/ QO, QI LJAM=0 COMMON /QUES/ QO, QI COMMON /QUES/ QO, QI CUESS=1.0500*4-9.900*2+36.300 ELSE IF(MM.EQ.8) THEN GUESS=15.DO ELSE IF(MM.MM, PEMIN, TAUOPT, 1.DO, GUESS, 0.DO, CALL MINSER(PUMJAM, PEMIN, TAUOPT, 1.DO, GUESS, 0.DO,	\$ TAU=TAU001 TAU=TAU001 TAU2=TAU001 FECO=PEMIM RETURN END
P0P-11 F0 CLIP2H0P. 0001	6000 60000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000	0018 0019 0020 0021 0021
-11 FORTRAM-77 V4.0-1 13:14:07 16-Jul-86 Page 40 P2HOP.FTN;14 /F77/MR 1 DOUBLE PRECISION FUNCTION PUNJAM(ETA) C FUNCTION FOR UNJAMMED P(E) FOR OPT. THRESHOLD SEANCH	<ul> <li>MOTE: IMEN JANNING EVENT IS (0,0,,0), THE VARIABLES BIGK, AMB, RAM, TAUK, AMD TAUK2 ARE NOT USED IN THE COMPUTATIONS, AND HENCE DO NOT MEED USED IN THE COMPUTATIONS, AND HENCE DO NOT MEED TO BE SET UP BEFORE CALLING PSEL FROM THIS FUNCTION</li> <li>IMPLICIT DOUBLE PRECISION(A-H,0-2) DIMENSION ADJAN(4)</li> <li>IMPLICIT DOUBLE PRECISION(A,H,0-2) DIMENSION ADJAN(4)</li> <li>COMMON /INPUTS/ DEBNOL(3), NSLOTS, GAMLST(10), K, MM COMMON /INPUTS/ DEBNOL(3), NSLOTS, GAMLST(10), K, MM</li> <li>MATA MOJAWA(4)</li> <li>DATA MOJAWA(4)</li> <li>COMMON / INPUTS/ DEBNOL(3), NSLOTS, GAMLST(10), K, MM</li> <li>AUZ=TAU+ETA</li> <li>TAUZ=TAU+ETA</li> <li>TAUZ=TAU+ETA</li> <li>TAUZ=TAU+ETA</li> <li>CULL PSEL(NOJAM, MM, P)</li> <li>PUNJAMP</li> <li>PUNJAMP</li> <li>PUNJAMP</li> </ul>	
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PDF-11 CLIP2HO	FORTRAN-77 V4.O-1 13:14:10 16-Jul-86 Page 42 P.FTN;14 /FT7/WR	ГИТ-11 ГИЛИКИМ // V9.U-1 / 13:14:10 16-JU1-86 Раде СЦПР2НОР.FTN;14 /FT7/ИК
1000	SUBROUTINE MINSER(F, FMIN, XMIN, STEP, GUESS, BLIM, ULIM, TOL)	
	C C Search for minimum of F(x) over the interval blim <= x <= ULIM	
	C C TROUBLE MAY OCCUR IF F(X) HAS MULTIPLE LOCAL MIMIMA WITHIN THE C SEARCH INTERVAL OR IF THE FUNCTION IS VERY STEEP AND STEP IS C TOO BIG.	0022 IF(F2.6E.F1) 60T0 200 CNo. STEP AGAIN 0023 F0=F1 0024 F1=F2
	C F HIN = NAME OF FUNCTION TO BE MINIMIZED C FMIN = MINIMUM VALUE OF F(X) OVER INTERVAL	0025 X=X+DX 0026 GOTO 100 C MIN MAY BE AT AN ENDPOINT. CUT STEP SIZE AND TRY AGAIN
	C ZMIN = VALUE OF X FOR WHICH FMIN OCCURS C STEP = INITIAL STEP SIZE FOR SEARCH	C IF INCREMENT NOT TOO SWALL. 0027 110 IF(DABS(DX).LE.TEST) 60TO 120
	C GUESS = INITIAL GUESS AT XMIN, BLIM <= GUESS <= ULIM C BLIM = LOWER LIMIT OF SEARCH INTERVAL	0028 X=X+DX 0029 F0=F1
	C ULIM = UPPER LIMIT OF SEARCH INTERVAL C TOL = TOLERANCE ON XMIN; SEARCH STOPS WHEN DX < TOL	0030 115 DX+DX/10.D0 0031 F1=(X+DX)
	C C NOTE: F MUST BE A DOUBLE PRECISION FUNCTION OF ONE C DOUBLE PRECISION ARGUMENT. ANY PARAMETERS CAN BE PASSED C FROM THE CALLER VIA A COMMON BLOCK.	UUSC BUID JUU C MIN MUST BE AT THE ENDPOINT (OR MITHIM MINIMUM DX THEREOF) 0033 120 If(X2.LE.BLIM) GOTO 122 C MIN AT X=ULIM)
	C C PROGRAMMER: ROBERT H. FRENCH DATE: 17 MARCH 1986	0034 XMIN=ULIM 0035 I21 FMIN=F(XMIN)
005	C IMPLICIT DOUBLE PRECISION(A-H,O-Z)	0036 RETURN MIN AT BLIN 2003 C MIN AT BLIN
38	A BUC255 SIMAX=DABS(X_BLIM)	0038 121 60T0 121
£8	SUMAA.=UAUS(UL.FF-K) DX=DMINI(STEP,SUMAX)	U HAVE PASSED MIN. IS IT LOCATED CLOSELY EMOUGH YET? 0039 2001 If (DABS(DX), LE, TEST) 6010 300
200	TEST=TOL 10 F0=F(X)	C NO, CUT STEP SIZE AND TRY AGAIN
88	$F_1=F(X+DX)$	C DONE!
010	C ARE WE GOING IN THE RIGHT DIRECTION? Teves.le foi coto ind	C_SIMCE FO >= F1 & F2>= F1 AND ABS(DX) <mir. 200="" call="" dx,="" emimment<="" f1="" oaa1="" td="" the=""></mir.>
	C NO, SWITCH DIRECTION	0042 XMIN-X+DX
110	DX=-DX Fl=f1x+DX)	ODA3 RETURN DDAA FMD
013	IF(F1.LE.FO) 60T0 100 C fift we mit be crose to a mit at v-filece co mit	
	C STEP SIZE AND TRY AGAIN	
14	DX=DX/10.DO JE/DARS/DY/ GE TECT) GOTO 10	
2	C CLOSE ENOUGH AT GUESS	
016	IZ XMIN=X FMIN=FO	
810	KEIUKH C NNA GOING RIGHT DIRECTION. KEEP GOING UNTIL PAST MINIMUM	
	C BY ONE SIEP. C	
610	Č 100 X2*X+DX+DX C HAVE WE REACHED EMD POINT?	
720	IF(X2.GT.ULIM .OR. X2.LT.BLIM) GOTO 110	

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## APPENDIX I COMPUTER PROGRAM FOR

## CLIPPER RECEIVER FOR M=4 AND L=2

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the clipper receiver for the case of M=4 and L=2 with a numerical search for the worst-case jamming fraction. By increasing the array A to 256 elements and the arrays C and D to 6561 elements each, and changing the array size parameters to calls to PUTIN and LOOKUP, the program may also be used for the case M=8, L=2.



PDP-11 FORTRAN-77 V4.0-1 14:03:25 16-Ju1-86 Page 2 CLIPL2M4A.FTW;2 /F77/WR	C C HAVE AN EXISTING FILE, READ TO SEE HOM FAR WE GOT BEFORE C Do34 1300 READ(4) AMIN, EBMOIM, NSLIM, TAU, TAU2, PEOO C WE HAVE READ A VALUE OF TAU, SO WE MON'T NEED TO RECOMPUTE C IT UNTIL EITHER EB/MO, MM, OR LL CHAMGES	0035 DOTAUM. FALSE. 0036 JJ-0 0037 740 JJ-JJ+1 0038 READ(4,EMD=742) D6SJR(JJ), PRLOG(JJ), QOPT(JJ) 0039 GOTO 740 0040 742 CLOSE(UMIT=4) 0041 C f MD EXISTING EVE TURE 65 AND FALOG(JJ), QOPT(JJ)	CREATE FILE MEADER RECORD CREATE FILE MEADER RECORD C CREATE FILE MEADER RECORD C C C C C C C C C C C C C C C C C C C	0043 IF(D0TAU) THEN 0045 757 KURTE(5,757) 0045 757 FORMAT('SETTING THRESHOLD') 0046 CALL SETTAU(MM,PEOU) 0047 DOTAU=.FALSE 0049 MRTTE(5,1991) MM, TAU 0049 MRTTE(5,1991) MM, TAU 0049 MRTTE(5,1991) MM, TAU 0050 1991 FORMAT('M=',12,'L=2 OPT THRES = ',1PD15.8) 0051 END IF	0052 0PEN(UNIT=4,FILE=FNUME,STATUS='NEW',FNBM='UNFORMATTED') 0053 MRTTE(4) MM.DEBMOL(IO),MSLOTS,TAU,TAU2,PEOO 0054 CLOST(UNIT=4) 0055 755 D0 600 13-JJ,MJ 0055 IF(1J.GE.3) THEM 0057 IF(1J.GE.3) THEM 0057 IF(1D,GE.0) THOM-1 0058 IF(1D,GE.0) THOM-1	0059 0-0007(1J-1) 107-1 0060 10-0 0061 ELSE 0-000-1 0062 100-1 0063 0-100 0064 10-1 0066 END IF 0067 10-1 0068 601 FORMAT(1-1)-1 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0068 601 FORMAT(1-1)-1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
-11 FORTRAM-77 V4.0-1 14:03:25 16-Jul-86 Page 1 PL2MAA.FTN:2 /F77/MR	PROGRAM CLPRAW C THIS PROGRAM CLPRAW C FISK/FW WITH 2 HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND C FSK/FW WITH 2 HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND C MOISE JWHNIG BY MUMERICAL INTEGRATION FOR THE CLIPPER RECEIVER C ANALYSIS: L. E. MILLER, R. M. FRENCH C ANALYSIS: L. E. MILLER, R. M. FRENCH C PROGRAM: R. H. FRENCH	C V 2.1.0 - COMPUTATIONS ONLY C IMPLICIT DOUBLE PRECISION(A-H,O-Z) PARAMETER (LJ=51) CHARACTER+1 7 FWJRE, GNAME LOGICAL DOTAU, TEST LOGICAL+1 GOOD	REAL *4 PRLOG(LJ), DBSJR(LJ), QOPT(LJ) VIRTUAL A(100), IASUB(100), C(625), ICSUB(625) VIRTUAL D(625), 1DSUB(625), PRERR(625), IPSUB(625) VIRTUAL PESAV(2400) C COMMON /INPUTS/ PASSES PARAMETERS OF THE RUN C COMMON /INPUTS/ DEBMOL(3], NSLOTS, K, MM C COMMON /SIZE/ PASSES MUMBERS OF PARAMETERS	COMMON /DEINVAR/ BICK, AMB, BAB, LJAM, TAU, TAUZ, TAUK, TAUK2 COMMON /PARDEM/ RHOM, RIDT DATA FES, NO, BLAMK /'Y', 'W', ' ', CALL ERRSE(15, TRUEFALSE., TRUEFALSE.,15) CALL GET(N.J, START, DBINC) SLOTS-NSLOTS MARBITS - SDOMMA/(MM-1.DO)	DOTAU*.TRUE. DOTAU*.TRUE. EBMO-10.00+*(DEBMOL(10)/10.Dn) RHON*K*EBMO/2.DO IOGUT=DEBMOL(10) C C OPEN DATA FILE	<pre>C IGOUT=GAWWA*!000.D0+0.5D0 MRITE(FMAME.730) MM.100UT 730 FORMAT('COJ'.11.'2',12.2.'.DAT') MRITE(6,776) MM.DEBMOL(IQ) 776 FORMAT('LCLIPPET RECEIVER, OPTIMUM GAWWA RESULIS'/ 775 FORMAT('LCLIPPET RECEIVER, OPTIMUM GAWWA RESULIS'/ 73 5 5%, "Pe'1.5%, "L=2'.5%, "EB/MO=', FB.4//' EB/MJ (dB)', 8 5%, "Pe'1.5%, "L=2'.5%, "EB/MO=', FB.4//' EB/MJ (dB)', 73 FORMAT(' MORKING ON ', AI3) 73 FORMAT(' MORVING ON ', AI3) 73 FORMAT(' FORMAT(' FORMAT(' MORVING ON ', AI3) 73 FORMAT(' MORVING ON ', AI3) 73 FORMAT(' F</pre>

FORTRAM-77 V4.0-1 14:03:25 16-Jul-86 Page 3 4A.FTN;2 /F77/WR	DBSJR(IJ)=DEBNJ D0 602 IJ0=1,2400 602 PESAV(IJ0)=0.00	R=10.00=TUEBW//10.00) C PRIME THE ALGORITHM WITH DUMMY OLD VALUES OF P(E) P1=0.00 P2=0.00	709 GAMAGAOSIOTS MRITE(GMARE,735) MA, IQ	/35 FORMAT('EO'.II.'2'.I4.4'.'DAT') OPEN(UNIT=3,FILE=GRUME,STATUS='OLD',FORM='UNFORMATTED', S READONLY,ERR=770) MDITELE 2030)	3939 FORMELT, 2503) 3939 FORMELT, FILE BEANTS D. TREND MIETS COND	NCAU 3) U, 10508, MUSEU, 4000 CLOSE (MIT*=3) 6070 777	C IF FILE FOR EVENT PROBABILITIES DOES NOT EXIST, CALCULATE THEM C AND CREATE A FILE.	770 CONTINUE MRTTE(5.3938)	3938 FORMAT(' CREATING EVENT FILE')	S DITUTION NUCLO SUCCESS SUCCE	UPEN (UNITES) FILE "SWORE, STATUS" ALM "FUNCTE" UNFUNDATIEU") MRTE(3) D. [DSUB, NUSED, 6000	CLUSE(UMIT=3) 777 IF(.MOT.GOOD) 60T0 700	RHOTS=GANNUA*R*EBMO/(GANNUA*R+EBMO) Rhot=K*RhotS/2, do	C EVALUATE THE PROBABILITY CALL PSUBE(MM, PESYM, D, IDSUB, MUSED, PRERR, EPSUB, PEOO, \$ PESAV, 10)	P3=PESYM TF(P3_GT_P2ANDT0_1T_R4G_DT4)_THEN	C KEEP ON GOING, WE ARE NOT PAST THE WAXIMUM		APPARATION OF TOTAL STATE	ELSE DMMY-TMMXYTD1 02 03)	EPS-0.00100-0011,112,212) TEST=(DABS(P1-P2).LE.EPS .AND. DABS(P1-P3).LE.EPS .AND.	\$ DABS(P2-P3).LE.EPS) IF( TEST .OR. IDQ.EQ.1 \$ OR (1 MOTTEST) AND ID FO MSIDTSVY THEW	C WE ARE DONE WHEN ALL 3 ARE CLOSE TOGETHER OR WHEN DO-1 C OR WHEN WE REACHED FULL-BAMD JAMMING AND P(E) IS STILL INCREASING POPT-PNAX
PDP-11 CLIPL2M	0070 1700 0072	600 9074	200 9200 9200	6/00 6/00	0081	0083 0083 1	1	0085 U086	0087	80 I-(	6960 3	7600 1600	0098 800	0095	0096 0097	9600	6600	01010	0103	0105	0107	0108

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-11 FORTRAM-77 V4.0-1 14:03:25 16-Jul-86 Page 4 PL2M4A.FTN;2 /F77/WR	9 JF(P2.GT.P3) THEN C THE OPTIMUM MUST BE THE MIDDLE POINT OF THE 3	0 00PT(1J)=q-DQ 1 F 00PT(1J)=(0,0,0) 00PT(1J)=1,00	C TACTERI NUMBER TAUT THAT THE UNTER TAUT TO AND THAT TAUT TAUT	I CN3	C THE OPTIMUM IS FULL-BAND JAMMING	5 QOPT(IJ)=MSLOTS P END IF	3 60T0 665 5 61 cc	C BLASE CONTED SUFFICIENTLY ACCURATELY. CUT DO AND TRY AGAI		1. #= 100/2	] [J≠100 P2≠P1	P1=0.00	()=()+()() 10-10-10-10-10-10-10-10-10-10-10-10-10-1	5 G0T0 709	END IF END IF	665 PE=#UORB17*P0PT	WRITE(6,666) DBSJR(1J), PE,00PT(1J)	boo FUMMAI(IX,F/.3,5X,JPDI2.5,5X,JPDI2.5) PRLOG(IJ)=0LOG10(PF)	OPEN(UNIT 4, FILE FRAME, STATUS= OLD' , ACCESS= 'APPEND',	\$ FORM='UNFORMATTED') WRITE(4) D8SJR(13), PREAG(13), ONPT(13)	CTOSE(UNIT=4)	) 600 COMTIANE D APENGINITA-8 FILE-EMANE STATICMELY EADWMUKCADMATTERY)	WRITE(4) MM,2, DEBNOL(10), MSLOTS, DRSDR, PRLOG, QOPT	CLOSE(UNIT=4) WRITF(6_276) MMLDFRMML(ID)	D0 689 1J=1, NJ	WRITE(5,666) DBSJR(1J),10.**PRLOC(1J),00PT(1J) 689 CONTINUE	MRITE(6,688) TAU	688 FORMAT(//// OPTIMUM THRESHOLD FOR ABOVE IS ETA/SIGMA**2 *',	200 CONTINUE	BOD CONTINUE 900 CONTINUE	STOP O FMD
C 11.	010	0110	110			0110	0116		0120	0125	0124	0125	0126	0128	0129	0131	0132	0134	0135	0136	0137	BETO	0140	0141	0143	0145	0146	0147	0148	0149	0151

1 FORTRAN-77 V4.0-1 14:03:51 16-Jul-86 Page 6 2M4A.FTN;2 /F77/WR	SUBROUTINE PSUBE(M, PE, 0, IDSUB, MUSED, PRERR, IPSUB, PEOD,		L CUTTUIE UNCOMUTTIONAL ERROR PROBABILITY C	IMPLICIT DOUBLE PRECISION(A-H, 0-Z)	INIEGEK WAN(4),LUP(4),JSUB(4) LOGICAL*1 GO.WOME_STORE	VIRTUAL PRERR(625), IPSUB(625)	VIKIUAL DE625), IDSUB(625) Virtiai pesav(2400)	COMMON /SHARE2/ LON(4) _LINC(4)	COMMON /DEMPAR/ BICK, AAB, BAB, LJAM,	COMPON / PARDEN/ RHON, RHOT INUK, INUK,	DATA STORE/.TRUE./	IF(PESAY(IQ).ME.0.DD) THEN	PE=PESATTIQ) DETION	END IF	PE=0.00		00 I0 I=1,M	JSUB(I)=0	10 CONTINUE	C THE ALL-ZERO JANNING EVENY P(E) IS AVAILABLE FROM THE SEARCH FOR	CALL LOCA(M.LOW_LUP.JSIR. 1518)	CALL PUTIN(PEOO, PRERR, IPSUB, NPS, 625, ISUB, KODE, STORE)	IF(KURE.ME.U) STOP "PRERR FULL" JAM]=-1	C START VECTOR-INDEXED LOOP ON JUMPING FVENTS	CALL YLINIT(JAM,LOW,M)	ICO CUMITNUE IF(JAMI_NE_JAM(J)) THEN	C UPDATE TEST VALUE FOR NEXT TIME, AND	(T)WW(=TWW)	EMU IF Call FVENTEM JAM DIE D Inche Whichni	C BYPASS CONDITIONAL ERROR PROBABILITY CALCULATION IF EVENT	C PROBABILITY IS ZERO. THIS SAVES MUCH TIME.	IF(PIE.EU.UU)6010 101 C SINCE JAMMING PROBABILITIFS DEPEND ANY	C HAVING JAM (I) HOPS JAMMED AND NOT THE ARRANGEMENT OF THE	C CHANNELS, WE CAN SORT THE NON-SIGNAL CHANNELS INTO ASCENDING	C CONDITIONAL ERROR PROMARII ITIES MUTEN MUMBER OF DISTINCT C CONDITIONAL ERROr PROMARII ITIES WATCH MIST BE CAVED TO AVOID	C RECOMPUTING THEM UNNECESSARILY.	DO III [*1, M .Sturk(T)×.JAM(7)	111 CONTINUE
PDP-1 CL 1PL	000			6005 6005	88	500	800	0008	6000	0010	1100	2012		0015	9016	6198		0200	0021		0022	0023 0023	0025		0026 0025	0028		6200	0031		, cuo	2500					0034	0035
Page 5																															[ <b>K</b> <sup>*</sup> . :]				()			
6 16-Jul-86	,DBINC)	ERS FOR RUN	CM(A-H,0-Z)	9 3) .mslots.k.mn		~ ~		) [2]: ' <b>.S</b> )				(11 (: . <b>.</b> 2)					() [, [6], 6], ()		-	-		VOL ( IN )				(21]: <b>, </b> 5)			() 60T0 32	COD [D/H] (D0) [CO	LUK COLINA LUB) 100	50.00			R E8/NJ [-1.0]: ',		-1.D0	
14:03:4 #	I(N.), START	JF PARAMET	E PRECISI	( DEBNOL (	Ŷ	USNR(3,4		'SMBOL (K				MNT EB/MU				S	NO( 12.			0		FIELD) DEBI				ANY EB/NJ	38) NJ	5	. NJ.GT.51	The Using	AD) START	DO) START		I UKU	CREMENT FC	35) DBINC	DO) DBINC-	
,01 /F77/N	outine gei	VE INPUT (	ICIT DOUBL	ALIEKTY FI	ON /SIZE/	um /Shuke/ Biankg/*	E(5,33)	NT( - BITS/	(5.3)K .Eq.0)K=2	Ť	E(5,2)		VT(12)	-01 (0.0) NO=		STAKLIN, K) Start Sith D		5,6)FIELD	AT(A9)	NOL (IN)=D		.00E(9,61, MAT(FQ 6)	IF The second	INUE Secondo	(5.39)	N NOH . )11	5, 34 , ERR=	. FD. 0) N.	LT.0 .08	[(5,41) T/' CTADT	5.42.FRR=	ART. EQ. 0.	T(F6.3)	(5,36) KE	T( DB IN	5,37,ERR=. T/E6 2)	INC. EQ. 0.1	z
FRAN-77 V4 TN;2	SUBR	INTERACTI	L L L		Neuo:	DATA	IL I M		IF(K.			PURT PURT	FORM	IF(M	88		FORM	READ	FORMU	050	ELSE		END		IN ITE	FORMA	READ(	IF(N.)	IF(N.)	LIR I TE	READ	IF(S)	FORMA	MAITE	FORMA	FIDMA	IF(08	RETUR
11 FORT	J	ن ر	•				32	E		•		v	en)			4	n i		9			61	:	-	38	<b>6</b> E	ac.	5	:	9	7		42	35	36	15	\$	
PDP	1000		000	000	5000		000	6000		0012		0015	0016	6100		0200	1200 1-	22004	6200	0025	0026	0028	0029		2600	0033	100 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	8036	0037	8200	900	100		1400	0045		0048	0050

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-1 14:03:51 16-Jul-86 Page 7 /F77/WR	0.2) GOTO 199 - 1-2,M-1 - J=r+1,M B(J).LT.JSUB(I)) THEN P=JSUB(I) (J)=JTEMP (J)=JTEMP UE UE	HENT OF A SPARSE ARRAY TO SAVE HENORY WE STORE ZEROS, THE SORTING OF SUBSCRIPTS In Elements. Ocm(m.LOM.LUP.JSUB.ISUB) Ocm(m.LOM.LUP.JSUB.ISUB) COMUTTIOMAL ERRON PROBABILITY IN STOREO ARRAY OCWUPTROB.PRERR, IPSJB, MPS, 625, ISUB, STORE, MOME) THERE, WE MUST COMPUTE IT	PSEL(JSUB,M,PROB) E IT FOR POSSIBLF FUTURE RE-USE PUTIN(PROB,PRERA,IPSUB,MPS,625,ISUB,KODE,STORE) ODE.ME.O) STOP 2 01TIOMAL ERROR PROBABILITY PIE*PROB VECTOR-IMDEX LOOP LITER(JAM.LUP,LIMC,M,EO) GOTO 100
M-77 V4.0-1 1:2 /F77/	IF(M.EQ.2) GO DO 110 I=2,M- DO 120 J=[+1] IF(JSUB(J).LT JSUB(J)=JSUB JSUB(J)=JSU JSUB(J)=JSU JSUB(J)=JTE END F CONTIMUE CONTIMUE CONTIMUE	DRE AS ELEMENT OF CALL LOCHOMILE STOR S OUT MANY ELEME CALL LOCHOMIL T IS NOT THERE. IT IS NOT THERE.	CALL PSEL(J CALL PSEL(J CALL PUTIN( CALL PUTIN( CALL PUTIN( IF(KODE.ME. END IF END IF END IF CALL VLITER(J RATE THE VECTOR- CALL VLITER(J RETURN END
PDP-11 FORTRA CLIPL2M&A.FTN	0036 0037 0037 0040 0041 0041 0041 0041 0042 0042 0043 0043 0043 0043 0043 0043	C CUT C EVE C CUT C CUT C TRY D049 C IF	0050 0051 0054 0054 0055 0055 0055 0055

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PDP-11   CLIPL2M	CORTRAN-77 V4.0-1 1 1A.FTN;2 /F77/WR	4:03:57	16-Ju1-86	Page 8
1000	C SUBROUTINE EVENT(I	M.JMM.PIE,O	, TOSUB, NUSED)	
	č subroutine to look up ei c	VENT PROBAB	ILITY FROM STORED ARR	<b>LAY</b>
2000	IMPLICIT DOUBLE PI	RECISION(A-	H. 0-Z)	
£000	LOGICAL*1 STORE, M	Defe		
<b>100</b>	DIMENSION JAM(4)	LUP(4)		
0005	VIRTUAL D(625), ID	SUB( 625)		
9000	COMMON / SHAREZ/ LO	DN(4) LINC(	<b>4</b> )	
000	DATA STORE/ FALSE		•	
	C SET UP ARRAY DESCRIPTION	DIO:LL	O:LL) WITH M DIMENS	SIONS
8000	DO 1 1=1.M			
6000	LUP(1)=2			
0010	1 CONTINUE			
	C COMPUTE LINEAR EQUIVALEN	VT SUBSCRIP	T FOR JANNING EVENT	
1100	CALL LOCN (M. LON. LI	PLIAN ISIN		
	C LOOK UP THE VALUE. GET (	DO IF NOT	THERE	
0012	CALL LOOKUP(PIE_D.	TDSUR MUSE	0.625 TSUB STORE WONE	-
5100	RETURN			-
0014	END			

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PDP-11 FORTRAN-77 V4.0-1 14:03:59 16-Jul-86 Page 9 CLIPLZMAA.FTN:2 /F77/MR	0001 SUBROUTIME GENPIE (MM, MQ, MSL DTS, GOOD, A, IASUB, C, ICSUB,	C         IMPLICIT DOUBLE PRECISION (A-H, D-Z)           0002         IMPLICIT DOUBLE PRECISION (A-H, D-Z)           0003         LOGICAL*I 60, 602, STORE, MONE, 6000           0004         DIMENSION LUP2(4), LUP3(4)           0005         DIMENSION LUP2(4), LUP3(4)           0006         DIMENSION LUP2(4), COP3(4)           0006         DIMENSION LUP2(4), COP3(4)	0007         Differencies         Differencies <thdiferencies< th=""> <thdifferencies< th=""></thdifferencies<></thdiferencies<>	C SHARED STORAGE FOR COMMARY NEEDED CONSTANT ARRAYS 0010 COMMON /SHARE2/ LON(4),LINC(4) C SHARED STORAFE FOR: C (1) INPUT DEFAULT LISTS, C (2) CONDITIONAL PROB GEN., AND C (3) EVENT PROB. GEN. THESE ARE NON-DVERLAPPING USAGES.	0011 COMPON /SWARE/ LUP2,LUP3,TUP0,L1,MUSEA,MUSEC,TERR, 5 TSUB,TSUB1,TSUB2,AIR,L1,11,111,NN,AGUT, 0012 DATA 1100/100/ 0013 DATA 1100/100/ 0014 DATA LUP1/4=1/ 0014 C STORE=.FALSE. => DOW'T STORE ZERO ELEMENTS OF SPARSE ARRAY.	D015         STORE=.FALSE.         0           0016         6.000=.TRUE.         0           0017         9999         1F(MQ.LE.O)           0018         6.000=.FALSE.         0           0019         RETURN         0           0010         FALSE.         0           0011         9999         1F(MQ.LE.O)         1HEN           0012         9500=.FALSE.         0         0           0019         RETURN         0         0           0021         END IF         0         0           0021         100 80 L1=1,MM         0         0           0022         1UPD(L1)=2         0         0         0	0023 80 CONTINUE C.JANNING PATTERN W/NON-ZERO PROBABILITY ON PER-HOP BASIS C.JANNING PATTERN W/NON-ZERO PROBABILITY ON PER-HOP BASIS 0024 UNISEA=0 CO25 CALL VLINIT(FLON,MN) 0025 90 CONTINE 0025 90 CONTINE CALL VLINITA I TSUR	COLL COLL FORTHOP (1, MG, MG, MG, SIGTS, ASTM) 0028 CALL PUTIN(ATL, A, ASUB, MUSEA, 1100, ISUB, IERR, STORE) 1 [( 1ERATE VECTOR-IMDEX LOOP 0031 CALL VLITER [1, LON, LUP1, LINC, WM, SD) 0032 COMPUTATION STARTS HERE. FIRST COPY A INTO D. C COMPUTATION STARTS HERE. FIRST COPY A INTO D. C THE COPTING MUST BE DONE ON BASIS OF EQUIVALENT LINEAR C SINCE ARRAYS ARE A(0.1, 0.1,, 0.1) AND D(0.1, 0.1, 0.1) C THE COPTING MUST BE DONE ON BASIS OF EQUIVALENT LINEAR C SUBSERPTOPTS ARTHAN A SUMPLE MOVE OPERATION.

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001     Subordire Loordon, Low, Jun, Jick, Jick,Jick, Jick, Jick,Jick, Jick, Jick, Jick, Jick, Jick, Jick,	PDP-1	1 FORTR 2MAA.FTI		CL IPL 2N	4A.FTN;2 /F77/wR
Christ Sementie Commits for Given Second Free Sementie Fried Second Free Sementies Free Free Sementes Free Sementies Free Sementies Free Sementies Free Sementies Fr	1000		SUBROUTIME LOCM(NDIM, ILOW, IUP, ISUB, LINEAR)	1000	SUBROUTIME VLINIT(LVEC, LLOW, LMAX)
If The Markow AT Difference AL     If The Markow AT Difference AL     If The Markow AT Difference AL       If The Markow AT Difference AL     If The Markow AT Difference AL     If The Markow AT Difference AL       If The Markow AT Difference AL     If The Markow AT Difference AL     If The Markow AT Difference AL       If The Markow AT Difference AL     If The Markow AT Difference AL     If The Markow AT Difference AL       If The Markow AT Difference AL     If The Markow AT Difference AL     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT     If The Markow AT       If The Markow AT     If The Markow AT </td <td></td> <td></td> <td>IS SUBROUTINE COMPUTES THE EQUIVALENT LINEAR SUBSCRIPT FOR MULTIDIMENSIONAL ARRAY OF NDIM DIMENSIONS</td> <td></td> <td>C THIS SUBROUTIME INITIALIZES A "VECTOR DO-LEOP" STRUCTURE C DEFINED BY THE FOLLOWING PSEUDO-FORTRAN CODE: D DO LUCCYJALIONIY (1997) 1100/11</td>			IS SUBROUTINE COMPUTES THE EQUIVALENT LINEAR SUBSCRIPT FOR MULTIDIMENSIONAL ARRAY OF NDIM DIMENSIONS		C THIS SUBROUTIME INITIALIZES A "VECTOR DO-LEOP" STRUCTURE C DEFINED BY THE FOLLOWING PSEUDO-FORTRAN CODE: D DO LUCCYJALIONIY (1997) 1100/11
An Fraction Contract     Dio Luccionali (1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1			THE ARRAY A IS DEFINED AS DIRENSTON AT IT OM(1)-THP/S) IT OM(NDIM)-THP/NDIM))		C D0 100 LVEC(1)-LLOW(1),LUP(2),LINC(1) C D0 100 LVEC(2)-LLOW(2),LUP(2),LINC(2)
000000000000000000000000000000000000		SEES!	D ISUB(1)ISUB(NDIM) IS A SET OF SUBSCRIPTS FOR A. EN THIS SUBROUTINE RETURNS IN LINEAR THE OFFSET FROM THE IGIN OF A TO THE ELEMENT A(ISUB(1),ISUB(NDIM)), ASSUMING		C DO 100 LVEC(LMAX)=LLUM(LMAX),LUP(LMAX),LINC(LMAX)
Contribute Statement latter of defined suscripts of array, instructions, limbic site of defined suscripts of array, internations, limbic site of defined site (ope site site, internations, limbic site, limbic site			LE FIRST SUBSCRIPT VARIES MOST RAFIOLT. Age:		C (STATEMENTS IN RANGE OF LOOP) C 100 CONTINUE
Metric         Cont. Locking for metric         Coct. Locking for metric <thcocking for="" metric<="" th=""></thcocking>		, u u u u u	DIMENSION ILOW(MDIM), [UP(MDIM), ISUB(NDIM) DATA ILOW/lower limits of defined subscripts of array/ DATA IUP/upper limits of defined subscripts of array/ SET ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS		C C THE COMPANION ROUTINE VLITER HANDLES THE LOOP CONTROL AT THE C CONTINUE STATEMENT IN THE ABOVE STRUCTURE
Image: Standard Standa		5 000	CALL LOCM(MDIM,ILON,IUP,ISUB,LIWEAR) ERE		C USAGE: C LOGICAL*1 GO F DIMENSION LOFF(IMAY) I JULII MAY) I JURII MAY)
1       C       INTE: 11.00000       CONTINUE       CLIL VLITEVEC,LLOW,LWUX)         0000       UNTE: 11.00000       CONTINUE       CLIL VLITEVEC,LLOW,LUW,LOOS)         0000       UNTE: 11.00000       CULL VLITEVEC,LLOW,LUW,LOOS)       CLIL VLITEVEC,LLOW,LUW,LOOS)         0000       UNTE: 11.00000       CULL VLITEVEC,LLOW,LUW,LOOS)       CLIL VLITEVEC,LLOW,LUW,LOOS)         0000       UNTE: 11.00000       CULL VLITEVEC,LLOW,LUW,LOOS)       CLIL VLITEVEC,LLOW,LUW,LOOS)         0000       UNTE: 11.00000       CULL VLITEVEC,LLOW,LUW,LOS)       CLIL VLITEVEC,LLOW,LUW,LOS)         0000       UNTE: 10.00000       ULERAND       CLIL VLITEVEC,LLOW,LUW,LOS)         0000       UNTERAND       CLIL VLITEVEC,LLOW,LUW,LOS)       CLIL VLITERENES         0000       UNTERAND       CLIL VLITERENES       CLIL VLITERENES       CLIL VLITERENES         0000       UNTERAND       CLIL VLITERENES       CLIL VLITERENES       CLIL VLITERENES       CLIL VLITERENES         0000       UNTERAND       CONTINUE       CLIL VLITERENES       CLIL VLITERENES       CLIL VLITERENES       CLIL VLITERENES         0000       UNTERAND       CONTINUE       CLIL VLITERENES			MULH = NAMBER OF UTHENSLOWS THE AKKAY FAS 11.0M = ARRAY OF LOMER SUBSCRIPT BOUNDS 11.0P = ARRAY OF LOPER SUBSCRIPT BOUNDS 15.0B = ARRAY CONTAINING SUBSCRIPT FOR WHICH LOCATION IS		C (INITIALIZE ARRAY LUN TO STARTING VALUES OF THE MESTED LOOPS) C (INITIALIZE ARRAY LUP TO STARTING VALUES OF THE MESTED LOOPS) C (INITIALIZE ARRAY LUP TO STOPING VALUES OF THE MESTED LOOPS) C (INITIALIZE ARRAY LINC TO INCREMENTS OF THE LOOPS)
Conserver:       Conserver:       Call VLTER(LVC.LL0W.LUP.LIW.L0P.LIW.L00)         DATE:       1.11.JAWUARY 1994       Call VLTER(LVC.LL0W.LUP.LUP.LIW.L00)         DATE:       1.11.AWUARY 1994       Call VLTER(LVC.LL0W.LUP.LUP.LUP.LUP.LUM.L00)         DO00       DIMENSION LOW(DIM), JUP(WEIM), JUP(WEIM), JUP(WEIM), JUP(WEIM), JUP(WEIM), TECIMMER-MOS       Call VLTER(LVC.LL0W.LUP.LUP.LUP.LUP.LUM.L00)         DO01       DIMENSION LOW(DIM), JUP(WEIM), JUP	I-8	<i>د د</i> د	TO BE COMPUTED LINEAR = RETURNED VALUE OF OFFSET INTO ARRAY IN MEMORY		C CALL VLINIT(LVEC, LLON, LMAX) C 100 CONTINUE
0002     UNKESTON ILOM(NOIN), IUP (NCIN), ISUB(NOIN)     UTEL ARRAY FOR STORAGE OF LOOP STARTING VALUES, INEARAD       0003     US     US     ARRAY FOR STORAGE OF LOOP STARTING VALUES, STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J)))*(IUP(J-1)-11CM(J-1)+1)       0003     US     US     STORAGE OF LOOP STARTING VALUES, STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J)))*(IUP(J-1)-11CM(J-1)+1)       0003     US     US     STORAGE OF LOOP STARTING VALUES, STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J))       0003     US     US     STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J)))*(IUP(J-1)-11CM(J-1)+1)       0003     US     US     STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J))       0003     US     US     STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J))       0003     US     US     STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(J))       0003     US     US     STORAGE OF LOOP STARTING VALUES, INEARA-ISUB(1)-1LOM(L))       0003     US     US     US     US       0003     US		ງດີ 2000 ເ	OGRAMMER: ROBERT H. FRENCH		C . (STATEMENTS IN RANGE OF LOOPS)
0002     DIFER-HOST LONE     UVEC     ARRAY FOR STORAGE OF LOOP IMDICES. LVEC(1)       0003     DI PLANO     DI FELANOT LONE, LVEC(1,MAX), THE INVER-HOST LOOP; LVEC(1,MAX), THE INVER-HOST LOOP FINAL VALUES, IN SEQUENCE AS LVEC       0003     DI PLANOF LINEAR+ISUB(1)-ILON(1)     DI PLANOF FICTORAGE OF LOOP FINAL VALUES, IN SEQUENCE AS LVEC       0003     LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SEQUENCE AS LVEC     ENCORTINUE       0003     LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SEQUENCE AS LVEC     ENCORTINUE       0003     LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SECONAL OF LOOP FINAL VALUES, IN SECONAL OF STORAGE OF LOOP FINAL VALUES, IN SECONAL OF LOOP FINAL VALUES, IN SECONAL OF STORAGE OF LOOP		ں ر	DATE: 11 JUNUARY 1984		C IF(60)6070 100
0007       10       CONTINUE       C       LUP = ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN STORAGE OF LOOP FIMAL VALUES, IN S SQUENCE AS LVEC         0009       RETURN       RETURN       SEQUENCE AS LVEC       E         0000       RETURN       E       ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN S SQUENCE AS LVEC       E         0000       RETURN       E       ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN S SQUENCE AS LVEC       E         0000       RETURN       E       ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN S SQUENCE AS LVEC       E         0010       END       ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN S SQUENCE AS LVEC       E       E         0010       E       ARRAY FOR AS LVEC       DE       ARRAY FOR AS LVEC       D         0010       E       ARRAY FOR AS LVEC       D       ARRAY FOR AS LVEC       D         0010       E       ARRAY FOR AS LVEC       D       ARRAY FOR AS LVEC       D         001       N=1, ARRAY FOR AS LVEC       D       ARRAY FOR AS LVEC       D       ARGE AF LOOP FIMAL AND         0003       D       N=1, ARRAY FOR AS LOOP FIMAL AND       D       ARTAR       D       ARTAR         0004       E       C       C       C       C       C       D       ARTAR	000 000 000 000 000 000 000 000 000 00	,	DIMENSION ILOW(NDIM),IUP(NCIM),ISUB(NDIM) LINEAR=0 Do 10 1=1,NDIM-1 J=NDIM-1+1 LINEAR=(LINEAR+(ISUB(J)-1LOM(J)))+(IUP(J-1)-1LOM(J-1)+1)	,	C WHERE C LVEC = ARRAY FOR STORAGE OF LOOP INDICES. LVEC(1) IS THE C LVEC = ARRAY FOR STORAGE OF LOOP INDICES. LVEC(1) IS THE C LLOW = ARRAY FOR STORAGE OF LOOP STARTIMG VALUES, IN SAME C LLOW = ARRAY FOR STORAGE OF LOOP STARTIMG VALUES, IN SAME
0010     END     EQUENCE AS LVEC       011     ENX > NUMBER OF LOOPS MESTED       011     EALSE OTHERNISE IN THE RANGE OF THE LOOP SHOULD O       011     STATEMENTS IN THE RANGE OF THE LOOP SHOULD O       011     FALSE OTHERNISE (I.E. OUTER-MOST LOOP TERM       011     DO02     DIMENSION LVEC(LMMX), LLON(LMMX)       0003     DO1     N=1, LMX       0005     I     LVEC(N)=LLON(N)       0005     I     CONTINUE	000	10	CONTINUE Linear+Linear+Isub(1)-ilon(1) Return		C LUP = ARRAY FOR STORAGE OF LOOP FINAL VALUES, IN SAME C SEQUENCE AS LVEC C LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME
C PROCRAMMER: ROBERT H, FRENCH DATE: 11 JANUA C DIMENSIÓN LVEC(LMAX), LLOW(LMAX) 0003 00 1 H=1,LMAX 0004 LVEC(N)=LLOW(N) 0005 1 COMTINUE 0005 RETURN 0007 EXD	0010		END		C SEQUENCE AS LVEC C LWAX * NUMBER OF LOOPS MESTED C GO * LOGICAL VARIABLE . TRUE. IF JUMP BACK TO BEGINNIMG OF C STATEMENTS IN THE RANGE OF THE LOOP SHOULD OCCUR.
C 0002 DIMENSION LVEC(LMAX),LLOW(LMAX) 0003 D0 1 N=1,LMAX 0006 1 COMTINUS 0005 1 COMTINUS 0007 EXD					C PROGRAMMER: ROBERT H. FRENCH DATE: 11 JANUARY 1984
				0003 0004 0005 0005 0005 0005	C DIMENSION LVEC(LMAX),LLOW(LMAX) DO 1 N=1,LMAX LVEC(N)=LLOW(N) 1 CONTINUS RETURN FWD

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PDF-11	FORTRAM-77 V4.O-1 14:04:16 16-Ju1-86 Page M4A.FTN;2 /F77/WR	16	53
1000	SUBROUTIME VLITER(LYEC, LLON, LUP, LINC, LMAX, 60)		ğ
	C LOOP ITERATION LOGIC FOR A "VECTOR DO-LOOP"		
	C C SEE DETAILED COMMENTS IN SUBROUTINE VLINIT FOR USAGE AND C PARAMETER DEFINITIONS		
	C C PROGRAMMER: ROBERT H. FREWCH C DATE: 11 JANUARY 1984		888
0005	LOGICAL+1 60 Dimension (Versimary) (Indianary) (Indianary)		888
000	60- TRUE.		38
9002 0002	DO 100 MDX=1,LMAX NSIRB-LMAX+1_MDX		Š
000	LVEC(NSUB) =LVEC(NSUB)+LINC(NSUB)		38
8000	IF((LINC(#SUB), GE.O.AND.LVEC(#SUB), LE.LUP(#SUB))		88
6000	• .uk.(LINL(NOUB).LI.U.ANU.LVEL(NOUB).LE.LUP(NOUB)) LVEC(NSUB) *LLON(NSUB)	KEIUKN	88
00100	100 CONTINUE		8
1100	60e.FALSE. BETINH		83
0013	END		88
I-9			85
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PDP-11 FO CLIPL2M4A	RTRAN-3	77 V4.0-1 14: /F77/WR	:0 <b>4</b> :18	16-Jul-86	Page 17	
0001		SUBROUTINE PRIHOP(1	, KM, KQ, KN	(KEV*		
	POSSIE POSSIE L=1 HG	SUBROUTINE COMPUTES BLE JAMMING PATTERNS DP/SYNBOL FOR IMFSK/	THE EVENT S WITH NON FH IN PBN	PROBABILITY FOR ALL -ZERO PROBABILITY FO	. 55	
0003 0003		IMPLICIT DOUBLE PRE DIMENSION 1(4)	CISION (A	-H <b>-</b> O-Z)		
5000		XIM-0 XJAM-0 DO 1 X-1.XM				
6000		KJAM=KJAM+I(K) CONTINUE				
с 	IF THI	IS IS AN IMPOSSIBLE	CASE, RET	URH WITH RESULT = 0.	0	
00100		IF (KJAM.GT.MINO(KQ, KPNAX=KJAM-1	,KM)) RETU	KN .		
0011		LPNAX=KM-KJAM-1 JPNAX=KM-1				
0013		IMAX=MAX0(KPMAX_LPM Pron=1 do	NX, JPHAX)			
0015		Q=KQ				
100						
0019 0019		00 100 L00P=0,1MAX F=L00P				
0020		IF(LOOP.LE.KPMAX) P IF(LOOP.LE.XPMAX) P	#00-PR00+	(Q-F) (FM_F)		
0022	8	IF(LOOP.LE.LPMAX) P	R00-PR00-	(DIFFMQ-F)		
0025 0025 0026	3	AIN=PROD RETURN END				

	age 22 VP.,N.,KODE) STACK (1N)
	Tack, Her F
	-Jul-B6 TOL, MORK, S ADUTINE (IN MER (IN) MER (IN) MER (IN) MOL OF BISE MOL OF BISE MOLOF PRI RACY P(N) P(N) 20
	0 16 , Y, QR, F L (1N) L (1N
	14:04:3 14:04:3 14:04:3 14:04:3 14:04:4 10:00000(xL,xU) 10:000000000 10:00000000000 10:0000000000
	7 V4.0-1 /F) SUBROUTINE / VE DUADRATUE / LOUER LIMIT UPPER LIMIT UPPER LIMIT VALUE OF IN VALUE OF IN V
	RTRAN-7 L FTR:2 ALAPTI ALAPTI ALAPTI ALAPTI KUDE -
<u> EX</u>	P0-111 F0 CLIPL2MAA 0001 00015 00000000
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R.	-86 1-86 10,1.0-8,40 10,1.0-8,40 10,1.0-8,40
<b>X</b>	16-Ju ktobe) ktobe) 16-Ju 16-Ju 16-Ju 16-Ju
	I4:04:23 NU XU,CHUWK,DE ACK,MEAP,30,DE ACK,MEAP,30,DE ACK,MEAP,30,DE HE DENSITY HE DENSITY HE DENSITY HE DENSITY 14:04.27 R 14:04.27 R 14:04.27 R 14:04.27 NONSC 00.01 1(X,NCHAN(I) 1(X,NCHAN(I)
18	(-1 //F7//// /////////////////////////////
	S CALL TAK-77 V4. S CALL S CALL S CALL S CALL TAM-77 V4. TAM-77 V4. TAM-77 V4. S COMM S COMM S CALL TEN S CALL TEN S CALL TEN S CALL S CALL S CALL TEN S CALL S
SS SS	PDP-111 FORT CLIPL-2MAJ.F CUIPL-11 FORT 0038 0038 0045 0045 0045 0044 0044 0005 0005 000
	I-11

1001-04 <u>3060 60 57 60 5</u>

FORTRAM-77 V4.0-1 14:04:33 16-Jul-86 Page 24 MA.FTM:2 /F77/WR	SUBROUTINE ADOUAZ(XL,XU,Y,QR,F,TOK,WORK,STACK,HEAP,A,KODE) ADAPTIVE QUADAATURE ALGORITHM C ALAPTIVE QUADAATURE ALGORITHM C AL - UPPER LIMIT OF INTEGAAL (IN) Y - VALUE OF INTEGAAL (IN) Y - VALUE OF INTEGAAL (IN) C R - NAME OF A QUADRATURE RULE SUBROUTINE (IN) D - NAME OF TA QUADRATURE RULE SUBROUTINE (IN) C R - NAME OF A QUADRATURE RULE SUBROUTINE (IN) D - NAME OF TA QUADRATURE RULE SUBROUTINE (IN) C R - NAME OF A QUADRATURE RULE SUBROUTINE (IN) D - NAME OF TAULTING SEQUENCE CALL QR(XL,XU,F,Y) F - NAME OF TAUL ANSARTED (IN) C - ERROR TOLERANCE FON FINAL ANSARTED (IN) C - ERROR TOLERANCE FON FINAL ANSART (IN) C - STACK - SECOND HORK AND STACK; MAX. NO. OF BISECTIONS (IN) C - NORK AND STACK AND STACK AND STACK C - NORK AND STACK AND STACK AND STAC	IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL F DIMENSION MORK(N),STACK(N),MEAP(N) DIMENSION MORK(N),STACK(N),MEAP(N) DIMENSION MORK(N),STACK(N),MEAP(N) DIMENSION MORK(N),STACK(N),MEAP(N) COLL QR(XL,XU,F,T) MEAP(1)=T ACM(1)=T ACM(1)=T ACM(1)=T ACM(1)=FPS DID B=MORK(NPTS) DID FF MORTS = MORK(NPTS) DID FF MORTS = MORK(NPTS) DIS FPS=FPS/22.DO
PD6-11 CLIPL2	1000	0003 0004 0005 0006 0001 0001 0011 0011 0011 0012 0013 0013
Page 23		

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TRAN-77 V4.O-1 14:04:36 16-Jul-86 Page 26 FTN:2 /F77/WR	SUBROUTINE DG16(A,B,F,ANSWER) 16-POINT GAUSSIAM INTEGRATION OVER ARBITRARY INTERVAL REF.: ABRANGWITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4 R. H. FRENCH, 28 FEBRUARY 1966 IMPLICIT DOUBLE PAECISION (A-H,0-2) COMMON VITS/X(8),M(8) ANSACE (B-A)/2.00 BMAQE (B-A)/2.00 BMAC (A-A)/2.00 BMAQE (B-A)/2.00 BMAQE (B-A)/2.00 BMAQE (B-A)/2.00 BMAQE (B-A)/2.00 BMAQE (B-A)/2.00 BMAC (A-A)/2.00 BMAQE (B-A)/2.00 BMAQE (A-A)/2.00 BMAQE (B-A)/2.00 BMAQE (A-A)/2.00 BMAQE (A-A)/2.00 BMAQE (A-A)/2.00 BMAC (	FTN;2 / FT7/MR SUBROUTIME DGXV1(A,B,F,AMSHER) SUBROUTIME DGXV1(A,B,F,AMSHER) 16-POINT GAUSSIAM INTEGRATION OVER ARBITRARY INTERVAL REF.: ABRAMOMITZ & STEGUM, EQ. 25.4.30 AND TABLE 25.4 R. H. FRENCH, 28 FEBRUARY 1986 IMPLICIT DOUBLE PRECISIOM (A-H,O-Z) COMMOM /MTS/ X(B),M(B) MISHER = 0.00 BPA02=(B-A)/2.D0 BPA02=(DA)/2.D0 BPA02=(DA)/2.D0 BPA02=(DA)/2.D0 BPA02=(DA)/2.D0 BPA02=(DA)	
PDP-11 -08 CLIPL2MMA.	6000 600 6000 6	CLIPELATE CLIPELATE CLIPELATE CODE 00005 000000	cinn
Page 25			
16-Ju1-86			
FORTRAN-77 V4.0-1 14:04:33 14A.FTN:2 /F77/NR	IF(EPS.EQ.0.D0) THEN KODE=2 RETURN END IF STACK(MPTS)=EPS GOTO 10 C FINISHED A PIECE 20 Y=Y+1+P2 T=HEAP(MPTS) NETS-MPTS-1 AB IF(MPTS.EQ.0) RETURN GOTO 10 END END		
PDP-11 CL 1PL2	8200 9030 9030 9030 9030 9030 9030 90000 90000 90000 90000 90000 90000 9000000	10	

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 FORTRAM-77
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 14:04:4C
 16-Jul-A6
 Page 28

 CLIPL2MAA.FTN;2
 /F77/MR
 14:04:4C
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 0001
 SUBROUTIME TEST(ID)
 SUBROUTIME TEST(ID)
 Page 28

 0001
 SUBROUTIME TEST(ID)
 C
 TEST RETURM CODE FROM BESSEL FUNCTIOM

 0002
 C
 TREVIEW CODE FROM BESSEL FUNCTIOM
 0.02

 0003
 TOPPLICIT DOUBLE PRECISIOM(A-H, 0-2)
 COPAGE, BARG2, BI, B2, KODE, 101, 102

 0003
 TOPPLICIT DOUBLE PRECISIOM(A-H, 0-2)
 COPAGE, 101, 102

 0004
 TOPOLECIO DOUBLE PRECISIOM(A-H, 0-2)
 COPAGE, 101, 102

 0005
 TPPLICIT DOUBLE PRECISIOM(A-H, 0-2)
 E000, 100, 100

 0006
 TFROM /LOCE.ED
 PLODE.ED
 COPAGE FUNCTION

 0000
 TFROM /LOCE.ID
 TOP 'FARLE ENDOR'
 TOP

 0000
 STOP 'FATLE ENDOR'
 TOP
 'TAL ENDOR'

PDP-11 FORTRAN-77 V4.0-1 14:04:41 16-Jul-B6 Page 29 CLIPL2N4A.FTN;2 /F77/MR 0001 SUBROUTINE TEST2(KODE,ID) C TEST RETURN CODE FROM ADQUAD/ADQUA2 C TEST RETURN CODE FROM ADQUAD/ADQUA2 0002 IF(KODE.EQ.0) RETURN 0003 1 FORMAT(' ADAPTIVE INTEGRATOR CODE = ',I2, 0005 5 TOP 'FATAL ERROR' 005 = ',I2, 0005 END

(Y 40.0-1)         (Y 40.0-1)         (Y 40.0-1)         (Y 40.0-1)         (Y 40.0-1)         (Y 10.0-1)         (Y 10.0	]4:04:43 ]5-Ju]-86 Page 3] R	P JAMMED		+RHOT	0.00,Y,ANSHER,D6XVI,F21,1.0-9,WORK,STACK, MEAP 20 KOD)	0.2200)		HER 4 . D0+RHOT≠YTK )		0]) / babei _vv.taiw_bhnt)+81 /b1ev	4 _ DO#RHOMP (Y - TAU) )		02) *DFXP{BARG1_Y+TAU_RHON)*B1	+RHOT	Y-TAU, TAU, ANSWER, DGXVI, F21, J. D-9, WORK, STACK,	HE.AP, 30, K00) AD, 22021	MER/BICK					8.00+RH01+YK)		43U) 3007(2   100+4/1244044)+105120(18486)+144-2   100+84407)		THEN A DOADHATAVTVI	4.00-KM1-1KJ	01)	(*DEXP{BARG1~TIK_RHOI)=B1/B1GK DeRHOT	Y-TAU, TAU, ANSWER, DGXVI, F22, 1.0-9, WORK, STACK,	HEAP, 30, KOD) (N) 2300)	WER/(BIGK+BIGK)		
1       W. DJ.       14:04:43       16-Jul-165       Page 30       CUPL2DAAFTW2         7       W. DJ.       7:77/MR       CUPL2DAAFTW2       DOUBLE FREETSION FUNCTION P21(Y)       2200         000BLE FREETSION FUNCTION P21(Y)       000BLE FREETSION FUNCTION P21(Y)       2200       2200         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       2200         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       2000         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       2000         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       2000         019BLTITU DOUBLE FREETSION (A-H, 0-2)       0004       0004         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       0004         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       0004         019BLTITU DOUBLE FREETSION FUNCTION P21(Y)       0004       0004         019BLTITUT DOUBLE FREETSION FUNCTION P21(Y)       0004       0004 <td< th=""><th>7 V4.0-1 /F77/w</th><th>ONE HD</th><th>HENDERS THEN</th><th>XCON=YK+RHON</th><th>CALL ADQUA2(</th><th>CALL TEST2(K</th><th>PZ1=ANSWER/B</th><th>ELSE JF (KE62) BARG1=DSORT(</th><th>101-0</th><th>CALL DXBT(22 DADT_COMPEYE</th><th>BARG1=DSQRT(</th><th>0-101</th><th>CALL DXBT(22 PART=PART+D1</th><th>X CON= YK+RHON</th><th>CALL ADOUA2(</th><th>CALL TESTOCK</th><th>PZ1=PART+ANS</th><th>PZ1=0.00</th><th>END IF</th><th></th><th></th><th>JF(REGI) THEN BARG1=DSORT(</th><th>10]=1</th><th>P71=0 500+0</th><th>[8]+</th><th>ELSE IF(REG2)</th><th>101=10</th><th>CALL DXB7(2:</th><th>PART=2.00=0] XCOM=YK+2.00</th><th>CALL ADRUAZ</th><th>CALL TESTOCH</th><th>PZ1=PART+AN</th><th>- PZ1=0.00</th><th>END IF CONTINUE</th></td<>	7 V4.0-1 /F77/w	ONE HD	HENDERS THEN	XCON=YK+RHON	CALL ADQUA2(	CALL TEST2(K	PZ1=ANSWER/B	ELSE JF (KE62) BARG1=DSORT(	101-0	CALL DXBT(22 DADT_COMPEYE	BARG1=DSQRT(	0-101	CALL DXBT(22 PART=PART+D1	X CON= YK+RHON	CALL ADOUA2(	CALL TESTOCK	PZ1=PART+ANS	PZ1=0.00	END IF			JF(REGI) THEN BARG1=DSORT(	10]=1	P71=0 500+0	[8]+	ELSE IF(REG2)	101=10	CALL DXB7(2:	PART=2.00=0] XCOM=YK+2.00	CALL ADRUAZ	CALL TESTOCH	PZ1=PART+AN	- PZ1=0.00	END IF CONTINUE
Y w. 0-1         JA:04:43         J6-Jul-B6         Page 30         CIP           /F77/MR         SIGML CMANNEL P.D.F. WITH CMANGE OF VARIABLE Y=AX         0000           DUBLE PRECISION FUNCTION P21(Y)         SIGML CMANNEL P.D.F. WITH CMANGE OF VARIABLE Y=AX         0000           SIGML CMANNEL P.D.F. WITH CMANGE OF VARIABLE Y=AX         0000         0001           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0003           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0003           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0003           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0004           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0004           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0043           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0003           DIRFNSION MAGG(30), KEAP(30)         CONC. (1)         0003 <td>-11 FORTRAN-7 L2M4A.FTN;2</td> <td>υu</td> <td>ر ۲<b>۵</b>۳</td> <td>0077</td> <td>•</td> <td>•</td> <td>-</td> <td></td> <td></td> <td>_</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>•</td> <td></td> <td>_</td> <td>_</td> <td><u>ں</u>ر</td> <td>ن د د</td> <td>2300</td> <td></td> <td></td> <td></td> <td>~ ~</td> <td></td> <td></td> <td></td> <td></td> <td>~</td> <td></td> <td></td> <td>0006</td>	-11 FORTRAN-7 L2M4A.FTN;2	υu	ر ۲ <b>۵</b> ۳	0077	•	•	-			_						•		_	_	<u>ں</u> ر	ن د د	2300				~ ~					~			0006
<pre>7 Yet.G-1 14:04:43 16-Jul-96 Page 30</pre>	623		٤	38	8	8	88	88	8	88	38	8	88	8	8	8	88	38	88	3	2	88	88	38	\$	88	58	8	88	88	2	881	58	22
<pre>7 WA.O-1 14:04:43 16-Jul-86 /FT7/WR DOUBLE PRECISIOM FUNCTION P21(Y) SIGML_CUMMEL P.D.F. WITH CHANGE OF VARIABLE Y= SIGML_CUMMEL P.D.F. WITH CHANGE OF VARIABLE Y= IMPLICIT DOUBLE PRECISIOM (A-H,0-2) DIMENSIOM MORK(30), STAC(30), HEAP(30) LOGICAL*1 REGI, FEGZ EXTENDED (A-H,0-2) DIMENSIOM MORK(30), STAC(30), HEAP(30) LOGICAL*1 REGI, FEGZ EXTENDED (A-H,0-2) DIMENSIOM MORK(30), STAC(30), HEAP(30) LOGICAL*1 REGI, EREZ EXTENDED (A-H,0-2) DIMENSIOM MORK(30), STAC(30), HEAP(30) LOGICAL*1 REGI, EREZ EXTENDED (A-H,0-2) DIMENSIOM MORK(30), STAC(30), HEAP(30) COMMON /DUTES/ 00, 01 COMMON /DUTES/ 00, 11 COMMON /DUTES/ 00, 01 COMMON /DUTES/ 00, 11 COMMON /DUTES/ 00, 01 COMMON /DUTES/ 00, 11 COMMON /DUTES/ 00, 11 COMMON /DUTES/ 00, 11 MO HOPS PER SYMBOL MO HOPS DER SYMBOL</pre>	Page 30		AX				102																		D+RHON) +B1					HORK , STACK ,	•			
<pre>7 WA.0-1 14:04:43 16-Ju)-1 7 WA.0-1 /F77/MR DOUBLE PRECISIOM FUNCTION PZ1(Y) SIGMAL CHANNEL P.D.F. WITH CHANGE 0 SIGMAL CHANNEL P.D.F. WITH CHANGE 0 IMPLICIT BOUBLE PRECISIOM (A-H, 0-2) DIMENSIOM MOK(30), STACK(30), HEAP LOBICAL*1 REE1, REE2 EXTERNAL DGXVI, F20, F21, F22 COMMON /DENPAR/ BIGK, AMB, BAB, LJAA COMMON /DUTEK/ XXX, XXXX TXE=(Y-TAU2)/BIGK TK2=(Y-TAU2)/BIGK TM0 HOPS PER SYMBOL ROD (2100, 2200, 2300), LJAM+1 MO HOPS PER SYMBOL ROD (2100, 2200, 2300), LJAM+1 REE2=Y.GE. JU JAMB, RHON TK2=(Y-TAU2)/BIGK TK2 TM0 HOPS PER SYMBOL TM0 HOPS PER SYMBOL TM0 HOPS PER SYMBOL TM0 HOPS PER SYMBOL TM0 TXX, XXX TK=TAU TAU2 TM0 HOPS PER SYMBOL TM0 HOPS</pre>	8		F VARJABLE Y=		(30)		2, KODE, IOI,																		0(BARG1-Y-2.00	1			<b>34)*</b> 81	1, F20, 1, 0-9, 1				
<pre>7 WA.Q-1 /FT7/WR 14:04:43 /FT7/WR 14:04:43 SIGWAL CWANNEL P.D.F. WI SIGWAL CWANNEL P.D.F. WI IMPLICIT DOUBLE PRECISIO DIMENSION MORK(30), STAG LOGICAL*1 REGI, REG COMMON /LOCALS/ BARGI, B COMMON /LOCALS/ BARGI, B B REGI-Y.GE.TAU. AND. Y.I REGZ-Y.GE.TAU. AND. Y.I REGZ-Y.GE.TAU. AND. Y.I REGZ-Y.GE.TAU. AND. Y.I REGZ-Y.GE.THU AND. V.I REGZ-Y.GE.THU AND. V.I REGZ-Y.GE.THU AND. Y.I REGZ-Y.GE.THUN AND. Y.I REGZ-Y.GE.THU AND. Y.I REGZ-Y.GE THER REG COMMY AND. Y.I REGZ-Y.GE THER REG COMMON COMPACE REG FERENCE REG COMPACE REG FERENCE REG COMPACE REG COMPAC</pre>	16-Jul-8	(Y)IZ9 H	TH CHANGE D	M (A-H 0-7)	X(30), HEAP	533	MR62, 81, 8	IB, BAB, LJAU	IC, INUK, IA								T.TAU	F. TAU2		1+446.1			•Y)		Y/RHON)+DEXP		*(Y-TAU))		G1-Y+TAU-RH(	ANSHER DGXV	(00			
<pre>/ V4.0-1 /F77/ /F77/ /F77/ F10008LE PRECIS SIGMAL CHANNE EXTERNAL CHANNE EXTERNAL DOUB DIMENSION HOR COMMON /DENPA COMMON /DENPA COMMON /DENPA COMMON /DUTES COMMON /DUTES CALL TEST PATAR CALL ADQUA CALL TEST PATAR CALL COMMON CALL TEST PATAR CALL COMMON CALL COMMON C</pre>	14:04:43 MR	ION FUNCTIO	L P.D.F. WI	DE DEFLISIO	K(30), STAC	1, REG2 1 E20 E21	S/ BARGI, B	R/ BICK, N	INU INU INU	<b>00</b> . 01	V YYY YYY		THEN		/BIGK	121/BIGK	N. Y. I.	J . AND. Y.I.	SYMBOL	2200, 2300)	OPS JANNED		N ∑(8.DO*RHOW		2100) DSORT(2.00*	) THEN	T(4.D0*RHON	(1014	00+DEXP(BAR	D#RHON 2(Y-TAU.TAU	HEAP . 30 . K	(KOU, 2100) NSWER		
	7 44.0-1 /F77/	DOUBLE PRECIS	SIGNAL CHANNE	THE TELE	DIMENSION NOR	LOGICAL*1 REG	COMMON /LOCAL	COMMON /DENPA	COMMON / PARDE	COMON /QUES/	COMPON /XCON/	XXX=Y	IF(LJAN.GE.1)	XXXK=Y/BIG	TK=XXXK VTK=f Y_TAU	YTK2=(Y-TA	END IF Regi=Y.GE.O.L	REG2=Y.GE.TAI	TNO HOPS PER	6010 (2100, 2	¥ ¥		BARG1=DSOR	[-10]	CALL DXBT(	ELSE IF (REG2	BARGI=DSQR	CALL DXBT(:	PART=2.00+1	XCON=Y+2.D		CALL TESTZ PZ]=PAR7+A	ELSE P71=0.00	ENG IF
	E SE			-																														

Page 33		Page 34	n-Hund		(01, 102			
77 V4.0-1 14:04:50 16-Ju1-86 /F77/wR	ELSE IF(REG2) THEN GL=1.00-(1.00+TAUK2-YK)*DEXP(-YK) ELSE IF(Y.GE.TAU2) THEN GL=1.00 ELSE GL=1.00 ELSE GL=0.00 END IF END IF	continue Return End 7 V4.O-1 - 14:04:54 16-Jul-86	DOUBLE PRECISION FUNCTION F20(U) AND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=2,	IMPLICIT DOUBLE PRECISION(A-H,O-Z) Common /Denpar/ Bigk, AAB, Bab, LJAM,	TAUL, TAU2, TAUK, TAUK2 COMMON /PARDEN/ RHON, RHOT COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, I COMMON /QUES/ Q0, Q1 COMMON /XCOM/ XCOM COMMON /XCOM/ XCOM BARG1=DSCRT(4.D0+RHOM*(XXX-U)) BARG1=DSCRT(4.D0+RHOM*(XXX-U)) 101=0 102=0	CALL BPROD(2110) F20=DEXP(BARG1+BARG2-XCOM)+B1+B2 RTTURM	2	
P-11 FORTRAN- IPL2MAA.FTN;2	8869333	9000 9000 85 11 FORTRAN-: 19L2M4A.FTN;2	DI C C INTEGN	85 2	<b>メ</b> ビルブロクローク	v) ag u) a	٥	
40	000000000	568 20	ŏ	88	888888888888888888888888888888888888888	888	3	
Page 32	NOITS						JK−TAU-YK}	
16-Jul-86	GL(Y) DISTRIBUTION FUNC AX (A-H, O-Z) BAB, LJAM,	TAU2	[+140]		) XP(-Y)		8+0EKP(-Y) (-Y)+BAB+DEXP(TA	
14:04:50 77/NR	CISION FUNCTION WEL CUMULATIVE T E OF VARIABLE Y- DUBLE PRECISION POR/ BIGK, AMS, PAR/ BIGK, AMS,	1.00 .4MD. Y.LT. AND. Y.LT. O) THEN U)/BIGK AU2)/BIGK	r synbol 2200, 2300), L	HOPS JANNED	ER 1.00+Y)+DEXP(-Y 2) THEN 1.00+TAU2-Y)+DE E.TAU2) THEN	HOP JAMMED	en Ng+dekp(-yk)+bad 2) Then Ng+dekp(Tau-taur 6. Tau2) Then 6. Tau2) Then	HOPS JAMMED
AN-77 V4.0-1 N:2 /F:	DOUBLE PREC DN-SIGNAL CHANN MITH CHANG MPLICIT DC LOGICAL*1 F COMMON /DE)	REG1=Y.GE.( REG2=Y.GE.) IF(LJAM.GT, YK=Y/BIGK YTK=(Y-TA YTK2=(Y-TA END IF	TWO HOPS PE 60T0 (2100,	2	IF(REG1) TH GL=1.DO-( GL=1.DO-( ELSE IF(REG GL=1.DO-( ELSE IF(Y.G GL=1.DO ELSE IF(Y.G GOTO 9000	OBE	IF (REG1) TH GL = 1, DO-A GL = 1, DO-A ELSE IF (REG GL = 1, DO ELSE GL = 1, DO ELSE GL = 0, DO END IF	TNC
1 FORTRU 244A.FTI	2 6000		300 S00 S	000	2100	ບບບ	2200	ບບບ
P0P-1	1000 0000 0000 0000 0000	0000 0000 0000 0000 0000 0000 0000 0000 0000	0012		5100 100 100 100 100 100 100 100 100 100		0023 0024 0025 0027 0027 0028 0028 0028 0028 0030 0028	

С 2300 IF(REG1) ТНЕМ GL+1.DO-(1.DO+YK)+DEXP(-YK)

> 0034 0034

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with

-11 FORTRAM-77 V4.0-1 14:04:58 16-Jul-86 Page 3 PL2M4A.FTN;2 /F77/WR	DOUBLE PRECISION FUNCTION F22(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=2, LJAN+2	<pre>L IMPLICIT DOUBLE PRECISION(A-H, 0-Z) COPPION / DENPAR/ BIGK, ANB, GAB, LJAM, TAU, TAUZ, TAUK, TAUK, COPPION / PARDEN/ RHON, RHOT COPPION / LOCALS/ BANG2, B1, B2, KODE, IO1, IO2 COPPION / YOUES/ 00, Q1 COPPION / YOUES/ 00, Q1 COPPION / YOUES/ 00, Q1 COPPION / YOUTER/ XXX, XXXX BARG2=D5QRT(4.DD=RHOT=(XXXK-U/BIGK)) 101=0 102=0 102=0 102=0 CALL BPROD(2310) F22=0EXP(BARG1+BARG2-XCON)=B1=B2 RETURN END</pre>	-11 FORTRAM-77 V4.0-1 14:05:00 16-JU1-B6 Page 30 JL2M4A.FTM;2 /F77/WR L SUBROUTIME DXBT(ID) C CALL DXBESI AND TEST RETURN CODE	C IMPLICIT GOUBLE PRECISION(A-H,0-Z) COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 COLL DXBESI(BARG1,101,B1,KODE) CALL TEST(ID) RETURN FOD
23	8		60 11 000	888888
-11 FURTRAN-77 V4.0-1 14:04:55 16-Ju1-86 Page 35 PL2M4A.FTN:2 /F77/WR	1 DOUBLE PRECISION FUNCTION F21(U) C INTEGRAMD FUNCTION FOR SIGNAL CHANNEL DEMSITY, L*2, LJAM*1	IMPLICIT DOUBLE PRECISION(A-H, 0-7)         3       COMMON /LOCALS/ BARGI, BARGI, BARG, BI, 82, KODE, 101, 102         4       S         5       COMMON /LOCALS/ BARGI, BARGI, BARG, LJAM,         5       COMMON /LOCALS/ BARGI, BARGI, LJAM,         5       COMMON /LOCALS/ BARGI, BARGI, LJAM,         6       TAU, TAUZ, TAUX, TAUX2         7       TAU, TAUZ2         7       TAU, TAUZ2         7       TAU, TAUX2         6       COMMON /PARDEW/ RHOT         7       COMMON /PARDEW/ RHOT         7       COMMON /VCUSS/ QO, QI         7       COMMON /XCON/ XXX, XXXX         8       BARGI-BOSRT(4.DOM-RHOT=(XXXK-U/BIGK))         101=0       102=0         102=0       102=0         6       COMMON /OUTER/ XXX, VXXK         8       COMMON /OUTER/ XXX, VXXK         9       BARGI-BOSRT(4.DOM-RHOT=(XXXK-U/BIGK))         101=0       102=0         102=0       102=0         102=0       CALL BARGI-BARG2-XCOM-U+U/BIGK)*BI*BI         8       FULM         8       COMMON /CONCELLAR/ KXXK-U/BIGK)*BI*BI         8       END         7       COM-U+U/VISIGK)*BI*BI         8       FULM </th <th>-11 FORTRAM-77 V4.O-1 14:04:57 16-Jul-86 Page 36 PL2MAA.Fin,2 /F77/MR 1 SUBROUTIME BPRODO(IDEMT) C COMPUTE TWO BESSEL FUNCTIONS, ARGUMENTS AND RESULTS IN COMMON</th> <th>C IMPLICIT DOUBLE PRECISION(A-H,0-Z) COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 CALL DXBF(IDENT) CALL DXBFS(IDENT) CALL TEST(IDENT) 7 7 8 8 8 8 9 10 10 10 10 10 10 10 10 10 10</th>	-11 FORTRAM-77 V4.O-1 14:04:57 16-Jul-86 Page 36 PL2MAA.Fin,2 /F77/MR 1 SUBROUTIME BPRODO(IDEMT) C COMPUTE TWO BESSEL FUNCTIONS, ARGUMENTS AND RESULTS IN COMMON	C IMPLICIT DOUBLE PRECISION(A-H,0-Z) COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 CALL DXBF(IDENT) CALL DXBFS(IDENT) CALL TEST(IDENT) 7 7 8 8 8 8 9 10 10 10 10 10 10 10 10 10 10
PDP- CL JP	[000	0000 0000 0000 0000 0000 0000 0000 0000 0000	1-17	000 000 000 000 000 000 000 000 000 00

PDP-J1 FORTRAN-77 V4.0-1 14:05:06 16-Jul-86 Fage CLIPL2MA.FTN:2 /F77/WR	0001 DCUBLE PRECISION FUNCTION PUNJAM(ETA) C	C FUNCTION FOR UNJAMMED P(E) FOR OPT. THRESHOLD SEARCH C WOTE: WHEN JAMMING EVENT IS (0,0,,0). THE VARIABLE C BIGK, AND, BAB, TAUX. AND TAUX2 ARE NOT C BIGK, AND THE TAMMITATIONSC	C COLD IN THE CONTRICT ON CONTRICT OF CONTRICT	0004 DIMENSION MOJAN(A) 0004 COMMON /INFUTS/ DEBNOX (3) MSLDTS, K , MM	0005 COMMON /DEMPAR/ BIGK, AAB, FAB, LUAM, \$ 7AU. TAUR, TAUR?	0006 DATA MOJEM/0,0,0,0,0/	0008 TAUETA	0010 CALL PSEL (NO.IM, M, P)	0011 PUNJAMEP 0012 RETURN	0013 END	PDF-11 FORTRAN-77 V4.0-1 14:05:07 16-Ju1-86 Page CLIPL2M44.FTW;2 /F77/WR	0001 SUBROUTINE SETTAU(MM, PEOD)	C SEARCH FOR OPTIMUM THRESHOLD IN ABSEMCE OF JAMMING	0002 IMPLICIT DOUBLE PRECISION(A.H.,0-Z)	0004 EXTERNAL PUNJAM 0004 COMMON /DENPAR/ BIGK, AAB, BAB, LJAM,	S TAU, TAUZ, TAUX, TAUX 0005 COMMON /PARDEN/ RHOT. RHOT	0006 COMMON /QUES/ QO, Q1	C GUESS BASED ON QUADRATIC CURVE FIT	0008 JF(MM.EQ.2) THEN 0009 GUESS=0.92500+4_8.47500+2+32.4500	0010 ELSE 1F(MM.E0.4) THEN	0011 GUESS=1.0500+4-9.3500+2+34.500 0012 ELSE IF(MM.E0.8) THEN	0013 GUESS=1.100+4-9.900*2+36.300	0014 ELSE 0015 GUESS=15.00	0016 END JF 2017 Call Minser/Pinijan Pentn takopt 1.00 Guess 0.00.	50.00,0.0100)	0018 TAUETAUOPT DD19 TAU2ETAU4TAU	002G PE00=PEMIN
RTRAN-77 V4.0-1 14:05:01 16-Jul-86 Page 39 .FTN;2 /FT7/WR	SUBROUTIME TIES(JSUB, MM, PTIE)	COMPUTE PRUBABILITY OF CORRECT DECISION GIVEN THAT SEVERAL SATURATED CHANNELS ARE TIED THALITCIT INNIMI E DOFCTCTIMUA_H 0.2)	DIMENSION JSUB(MM), LLOW(7), LINC(7), LUP(7), MU(7),	LOGICAL+1 CO COMMON /DEMPAR/ BICK, AAB, BAB, LJAM,	S TAUCH TAUZ, TAUK, TAUK2 COMMON /PARDEN/ 94000 PHOT		UPDER OF MON-SLOWALL CRANNELS MNU-MA-SLOWALL CRANNELS ATT 2 020	PILEBU.UC CUEOBDEXP(-TAU)	CUE1=DEXP(-TAUK) PlL=DX1(Q0_2-JSUB(1))+DX1(Q1,JSUB(1))	D0 10 1=2,4M P2LM(1)=DX1(CUE0,2-JSUB(1))+DX1(CUE1,JSUB(1))	10 CONTINUE LET UP VECTOR LOOP PARAMETERS	D0 20 I-1 <b>1,101-</b> 1	LIX([])=0 LIX([])=1	LUP(I)-1 - 20 CONTINUE	PTIE=0.00 TART LOOP CM THE TIE EVENTS	CALL VLINIT(NU,LLON,MM-1) 20 RHISIM=0	D0 40 1=1, MM-1 MICC M-MICC 1	40 CONTINUE	FRAC=1.00/(1.00+WUSUM) PROD=1.00	D0 50 M=2,4M	IF(NU(N-I).EQ.I) THEN PROD=PP2IM(N)	ELSE	PROD=PROD={[.UU-PZLM(")]	50 CONTINUE DTTE-EDAC+DDMA-DTIF	CALL VLITER (NU,LLOW,LUP,LINC, MM-1,60)	IF(60) 60T0 30 PTIF=PTIF+PT	RETURN

כר וערא 11-c0a	FORTRAM-77 V4.0-1 14:05:10 16-Jul-86 Page 42 M4A.FTN;2 /F77/WR	PDP-11 FORTRAN-77 V4.0-1 14:05:10 15-Ju1-86 Page 43 CLIPL2M4A.FTN;2 /F77/WR
1000	SUBROUTTINE MINSER(F,FMIN, XMIN, STEP, GUESS, BLIM, ULIM, TOL)	C ALL DK
	C SEARCH FOR MINIMUM OF F(X) OVER THE INTERVAL BLIM <= X <= ULIM	COZI IDS FZHFIZZ) C PAST MIN?
	Č TROUBLE MAY OCCUR JF F(X) HAS MULTIPLE LOCAL MINIMA WITHIN THE C search interval or if the function is very steep and step is C too big.	0022 IFTE-SEE-FL) 5010 200 CM0, STEP AGAIN 0023 F0=F1 0024 F1=F2
	C F = NAME OF FUNCTION TO BE MINIMIZED	0025 X=X+DX 0026 6010 100
	C FNIN = MINIMUM VALUE OF F(X) OVER INTERVAL C ZNIN * VALUE OF X FOR MHICH FMIN OCCURS	C MIN MAY BE AT AN ENDPOINT. CUT STEP SIZE AND TRY AGAIN C IF INCREMENT NOT TOO SMALL.
	C BUEN # INTITIAL SIEP SIZE FOR SEARCH C GUESS # INTITIAL GUESS AT XNIN, BLIM <= GUESS <= ULIM	002/ 110 IF(DABS(DX).LE.TEST) 60T0 120 0028 X=X+DX
	C BLIM = LUMEN LIMIT OF SEARCH INTERVAL C ULIM = UPPER LIMIT OF SEARCH INTERVAL C TOL = TOLERANCE ON XMIN: SEARCH STOPS WHEN DX < TOL	0029 F0=F1 0030 115 DX=DX/10.D0 6031 F1=F(X+DX)
	C C MOTE: F MUST BE A DOUBLE PRECISION FUNCTION OF ONE DOUBLE PRECISION C ARGUMENT. ANY PARAMETERS CAN BE PASSED FROM THE CALLER VIA	0032 GOTO 100 C NIN MUST BE AT THE ENDPOINT (OR WITHIN MINIMUM DX THEREOF) 0033 120 IF(XX.LE.BLIN) GOTO 122 C MIN AT VAILUTE.
	C PROGRAMMER: ROBERT H. FRENCH DATE: 17 MARCH 1986	0634 XMIN-ULIM 0635 121 FMIN-F(XMIN)
2003 1	C IMPLICIT DOUBLE PRECISION(A-H,O-Z)	0036 RETURN C MIN AT BLIM
8 8 19	X=GUESS CLMAXFEADE(Y BI 141)	0037 122 XMIN=BLIM
500		C HAVE PASSED MIN. IS IT LOCATED CLOSELY ENOUGH YET?
6000 0000	DX=DHINL(STEP,SLMAX,SUMAX) TEST=TOL	0039 ZOO IF(DABS(DX).LE.TEST) 60TO 300 C MO, CUT STEP SIZE AND TRY AGAIN
808 808	IO FO=F(X) FI=F(X+DX)	0040 6010 115 C DOME!
	C ARE WE GOING IN THE RIGHT DIRECTION?	C SINCE FO >= FI 4, F2>= FI AND ABS(DX) CMIN. DX, CALL FI THE MIN.
0100	IF(FLLEFFO) GOTO IOO C NO, SWITCH DIRECTION	0041 300 FMIN=F1 0042 XMIN=X+DX
0011 0012	DX=-DX Fl=f(X+DX)	DOM3 RETURN DOM4 FND
0013	IF(FI.LE.FO) GOTO 100 C FICE DE MART BE FIDGE TO A MIN AT Y-ENECS CO ANT	
	C STEP SIZE AND TRY AGAIN	
0014 0015	DX=DX/10.DO IF(DABS(DX).GE.TEST) 6010 10	
9100	C CLOSE EMOUGH AT GUESS 12 XMIN+X	
0017 2018	FMIN=FO RETURN	
	C WW GOING RIGHT DIRECTION. C KEEP GOING UNTIL PAST MINANUM BY ONE STEP.	
6100	LO X2=K+DX+DX LOO X2=K+DX+DX C HAVE NE REACHED END POINT? IF(X2.GT.ULIM .OR. X2.LT.BLIM) GOTO 110	
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## J. S. LEE ASSOCIATES, INC.

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#### APPENDIX J

### COMPUTER PROGRAM FOR CLIPPER RECEIVER WITH L=3 HOPS/SYMBOL

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the clipper receiver when L=3 hops/symbol, using a numerical search for the worst-case jamming fractions. If M>4 the sizes of the arrays used in computing event probabilities must be increased and the corresponding array-size parameters in calls to PUTIN and LOOKUP changed accordingly.

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PICE MANNER FOR PARTY IN THE FROM PROBABILITY FOR RANDOM M-ART FSKFFM MITH 3 HOPE/STIT THE FROM PROBABILITY FOR RANDOM M-ART FSKFFM MITH 3 HOPE/STIT THE FROM FESTING FOR THE CLIPPER RECEIVER MODES JANNER FIN MIERT CALABILITY FOR RANDOM M-ART FSKFFM MITH 3 HOPE/STIT MIERT CALABILITY FOR RANDOM M-ART FSKFFM MITH 3 HOPE/STIT MIERT CALABILITY FOR RANDOM M-ART FORDAMETER (LJ-LI) DEVICTOR 100MLE PRECISION(A-H, D-2) POLICIT DONAL PERSING ONLY DEVICATIONS ONLY THE LIGE (LOUDING CALABILITY FOR RANDOM M-ART FORDAMETER (LJ-LI) DEVICATIONS ONLY THE LIGE (LOUDING PRECISION (A-H, D-2) CHARTER (LJ-LI) DEVICATIONS ONLY THE LIGE (LOUDING PRECISION (A-H, D-2) CHARTER (LJ-LI) DEVICATIONS ONLY THE LIGE (LOUDING PRECISION (A-H, D-2) CHARTER (LJ-LI) DEVICATIONS ONLY THE LIGE (LOUDING PRECISION (A-H, D-2) DEVICATIONS ONLY THE LIFE (LICE (L) (A) (A) (A) (A) (A) (A) (A) (A) (A) (A			
C 4000.TS15: L. E. NILLER, R. H. FRENCH     0003       C 1000.EL FRENCH:     N. FRENCH       F 3.1.0 - COPPUTATIONS DULY     0003       DP0.LICIT DOUBLE PRECISION(A+H, D-2)     0003       P0.LICIT DOUBLE PRECISION(A+H, D-2)     0004       COMMETTEN L'A-113     0007       CUALACITER-113: FNMEL     0007       DISCULAL-2     00007       DISCULAL-2     00007 </td <td></td> <td>PROGRAM CLIPJR S PROGRAM COMPUTES THE ERROR PROBABILITY FOR RANDOM M-ARY JFH WITH 3 HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND SE JUMMING BY NUMERICAL INTEGRATION FOR THE CLIPPER RECEIVER ) BETWEEN-CONDITIONAL-PROB. RESTART CAPABILITY</td> <td>5600</td>		PROGRAM CLIPJR S PROGRAM COMPUTES THE ERROR PROBABILITY FOR RANDOM M-ARY JFH WITH 3 HOPS/BIT IN THE PRESENCE OF PARTIAL-BAND SE JUMMING BY NUMERICAL INTEGRATION FOR THE CLIPPER RECEIVER ) BETWEEN-CONDITIONAL-PROB. RESTART CAPABILITY	5600
C V 3.1.0 - COPPUTATIONS ONLY       003         IMPLICIT DUBLE PRECISION(A-H, 0-2)       003         PROMETTER: 1 YE, NO, RELY, BLANK       003         CUMARTER: 1 FEWER, LUD, ID, SESREL, 10, 10, 150       003         CUMARTER: 1 FEWER, SUMER       003         CUMARTER: 1 FEWER, SUMER       004         CUMARTER: 1 FEWER, SUMER       004         CUBICAL DONU, TEST       0057(12)         CUBICAL SCODE, ISSURISCOD, ICCES), ISSURISCOD, ICCES), ISSURISCOD, ICCES), ISSURISCOD, ICCES), ISSURISCOD, ICCES), ISSURISCOD, ICCES), ISSURISCOD, ISSURISCOD, ISSURISCOD, ISSURISCOD, ISSURISCOD, ISSURISCO, ISSURISCES)       004         VIRTULA, ALTON, IASURI, DON, ICCES), ISSURISCES)       004         VIRTULA, ALTON, IASURISCO, FARRERS, IRES, INSURISCO, ISSURISCES)       004         COMMON / VIRTULA, ALTON, IASURISCOF       004         VIRTULA, ALTON, IASURISCOF       004         COMMON / STIER, MON       BAR, JUM, AMER, AND	C PRO	LYSIS: L. E. MILLER, R. H. FRENCH Gram: R. H. French	200
IMPLICIT DOUBLE PRECISION(A-H, 0-2)         003           IMPLICIT DOUBLE PRECISION(A-H, 0-2)         003           CUMANTERT (L_0-11)         CREME           CUMANTERT (L_0-11)         COPTICUL)           COMMANTERT (L_0-11)         COPTICUL)           COMMANTERT (L_0-11)         COPTICUL)           COMMANTERT (L_0-11)         COPTICUL)           FRUAL AT POOL, INDUL, TEST         COMMANTERT           COMMANTERT (CLU)         COMMANTERT           COMMANTERT (LIGUL)         COMMANTERT           COMMANTERT         COMMANTERT	ε > 	.1.0 - COMPUTATIONS DWLY	1000 1000
DAMMETER         CAMMETER         CAMMATER         CAMMATER         CAMAMETER         CAMAMETERS         CAMAMETERS         CAMAMETERS         CAMAMETER         CAMAMETERS         CAMAMETE	,	IMPLICIT DOUBLE PRECISION(A-H.O-Z)	800 800
COMMATTER'S TRS. NO, REPLY, BLANK CUMMATTER'S TRS. NO, REPLY, BLANK LOBICAL DDTAU, TSS. NO, REPLY, BLANK LOBICAL DDTAU, TSS. RAWE SAW RETCAL STORE SAW RETCAL DDTAU, TSS. RAWE SSS, PRERR (255), FRERR (250), FRERR (	<i></i>	PARAMETER (LJ=11)	00
UNINGLIENTLY TANE: ENVERT       0000         UNINGLIENTLY TANE: ENVERT       0000         DISLOL 41 EGOD, RESTRT       0000         DISLOL 41 EGOD, INSUB(DO), (CES5), INSUB(EGS)       0000         VIRTULA       ALDO, INSUB(TOO), (CES5), INSUB(EGS)       0000         VIRTULA       ALDO, INSUB(TOO), (CES5), INSUB(EGS)       0000         COMMON       PARENCES, INSUB(TOO), (CES5), INSUB(EGS)       0000         COMMON       PARENCES, INSUB(TOO), (CES5), INSUB(EGS)       0000         COMMON       PARENCES, INSUB(TOO), (CES5), INSUB(EGS)       0000         COMMON       PARENCE       PARANCETERS       0000         COMMON       PARANCETERS       PARANCETERS       0000         COMMON       PARENCE       PARANCETERS       00000         COMMON <td>_</td> <td>CHARACTERT YES, NO, REPLY, BLANK</td> <td>8</td>	_	CHARACTERT YES, NO, REPLY, BLANK	8
1061204.4.1 GG00, RESTRT         0004           R1M.4.8 PR106(LJ), R085(LJ), 0067(LJ)         0004           R1M.4.8 PR106(LJ), R085(LJ), 0067(LJ)         0004           R1M.4.4 PR105(LJ), R085(R100), C(625), IFSUB(625)         0004           V1RTUAL A(100), LASUB(100), C(625), IFSUB(625)         0004           V1RTUAL A(100), LASUB(100), C(625), IFSUB(625)         0044           V1RTUSY PASES PARAFERS OF PARAFERS OF PARAFERS OF PARAFERS         0044           COMMON / STZEY PASES PARAFERS OF PARAFERS         0042, JAK           COMMON / STZEY PASES PARAFERS OF PARAFERS OF PARAFERS         0042, JAK           COMMON / STZEY PASES PARAFERS OF PARAFERS         0043, JAK           COMMON / STARY / JAK         JAK         JAK	• • •	UMAKACIER*13 FNAME, GNAME Logical dotau. Test	80
DIMENSION POEQ(50). (Q.(50) REAL A (100). (1050). (0051(12) VIRTUAL 0(625). IDSUB(625). PERR(625). PSUB(625) VIRTUAL 0(625). IDSUB(625). PRER(625). PSUB(625) COMMON / TAURY DESMOL (13) %50.015. (MM COMMON / STZE/ MOLESS DEAMETERS COMMON / STZE/ DATE COMMON / STZE/ DATE	~	LOGICAL *1 6000, RESTRT	Š
Mikhard         Michol, Jasuski (JJ), ODFT(LJ)         ODFT(LJ)         ODFT(LJ)         ODFT(LJ)           Mikhard         MICON, JASUSKI (JD), (ODFT(LJ)         ODFT(LJ)         ODFT         ODFT           Mikhard         Micon         Misuski (JDO), JASUSKI (JD), (ODFT(LJ)         ODFT         ODFT           COMMON         / INPUTSKI         PASSERS         PASURETERS         ODFT         ODFT           COMMON         / SIZE/ PASSES         MARUELERS         OFF PASURETERS         ODFT         ODFT           COMMON         / SIZE/ PASSES         MARUELERS         OFF PASURETERS         ODFT         ODFT           COMMON         / SIZE/ PASSES         MARUEL         JASL         JASL         JASL         ODFT           COMMON         / SIZE/ PASSES         MARUETERS         OFF PASURETERS         ODFT         ODFT           COMMON         / RESPAR         JANN         JAUK	<i></i>	DIMENSION POPO(50), IQ. (50)	
VIRTULAL (01625), FASERS PARAMETERS OF THE R.IN       0044         COMMON VIRTULAL (01625), FASERS PARAMETERS       0074         COMMON VIRTULAL (01625), FASERS PARAMETERS       0004         COMMON VISTEX (NO       00045         COMMON VISTEX (NO       0045         COMMON VISTEX       0044         COMMON VISTEX       0044         COMMON VISTEX       0045         COMMON VISTEX       0045         COLL ERBERTOR       0045         COLL ERBERTOR       00466         COLL ER	<b>.</b>	REAL <sup>44</sup> PRLOG(LJ), JBSJR(LJ), OCPT(LJ) VIDTHM = #/100) 750000000000000000000000000000000000	000
C COMMON / INVUTSY PASSES PARAMETERS OF THE RIN COMMON / SIZEY PASSES PARAMETERS OF THE RIN COMMON / SIZEY PASSES PARAMETERS COMMON / PARSEN / JAME, TAUE, TAUE, TAUKS, TAUK3 COMMON / RSPACK / JAME, TAUE, TAUE, FALSE, TAUK3 COMMON / RSPACK / JAME, WAY, WY, WY, YY, WY, YY, WY, YY, YY, WY, YY, Y		VIRTIAL ALLUU),IASUBLIUU),C(625),ICSUB(625) VIRTIAL D(626) Inchnelegen beredlegen inchnelegen	<b>1</b> 00
C COMMON / IMPUTS/ DEBMOL (3), MCL OTS, K, MA COMMON / DEWRARY BICK, AMB, BUB, LJAM, AMB2, BAD2, AMBBAB, 0004 COMMON / DEWRARY BICK, AMB, BUB, LJAM, AMB2, BAD2, AMBBAB, 0004 COMMON / DEWRARY BICK, AMB, BUB, LJAM, AMB2, BAD2, AMBBAB, 0004 COMMON / PERPARY INHOIT TAIL, TAUZ, TAUK3 COMMON / PERPARY INHOIT TAIL, TAUZ, TAUK3 CALL DSLGO CALL DSLGO CALL BERSET(29, TRUE., FALSE., TRUE., FALSE., 15) CALL BERSET(29) CALL BERSET CALL		MON /INPUTS/ PASSES PARAMETERS OF THE RIN	
COMPACT FIRS         COMMENT         Comment First         Comment         Comment <thcomment< th="">         Comment         Comment</thcomment<>		COMMON / INPUTS/ DEBNOL (3) , NSLOTS, K, MM	
S         COMMON / DEFENSAR/ BIEK, AMB, BUB, LJAM, AMB2, BAD2, AMBBAB, TAUK3         TAU3, TAUK3, TAUK1, TAUS1, TAUK1, TAUS1, TAUK1, TAUS1, TAUK1, TAUS1, TAUK1, TAUS1, TAUK1, TAUS1, TAUK1, TAUX1, TAUK1, TAUX1, TAU		TON /SIZE/ PASSES NUMBERS OF PARAMETERS Common /Size/ md	-
S         TAU. TAU3, TAU2, TAU3, TAUK, TAUK3, TAUK3           COMMON RSPAR/ JAM(a), JAMI, MD3, IJ, RESTRI         DOMS           CALL JSLGO         RAMK / YY, 'W, 'W', 'W', 'W', 'W', 'W', 'W', '		COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB.	
COMPOUNT // KSPAUCK/W KNAUCK/W KNAUC MATA YES, MO, BLAMK //Y', WY, WY, WY, WY, WY, WY, WY, WY, WY, WY		Franks, Parker and TAUS, TAUS, TAUK, TAUK2, TAUK3	
DATA YES, ND, BLANK / YY, NY, NY, NY, NY, NY, NY, NY, NY, NY,		UNTION / FAKUEN/ KRUN, KHUI COMMON /RSPAR/ JAMI(4)_JAMI MPS 1,1 DESTRET	
CALL ERRET(29, TRUE., FALSE., TRUE., FALSE., 15) CALL ERRET(29, TRUE., FALSE., TRUE., FALSE., 15) CALL ERRET(29, TRUE., FALSE., TRUE., FALSE., 15) SLOTS=RSLOTS WORBIT=0.5D0=HW/(M=-1.00) DO 800 10-1, M0 DO 800 100-1, M0 DO 800 1000000000000000000000000000000000		DATA YES, NO, BLANK / Y, 'N', 'N', 'N'	
CALL ERRIST(29, TRUE., FALSE., TRUE., FALSE., 15) CALL ERRING SLOTS-MENCTOS WORBIT=0.500*MM/(MM-1.00) DO 800 10=1, M0 DO 800 10=1, M0 RIMEKERMOJ 3.00 DOUT=DEBMOL(10) RHOMEKERMOJ 3.00 DOUT=DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', MAT') RTE(FWME, 730) MM, DOUT M1 FE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', MAT') RTE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', MAT') RTE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', MAT') RTE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DEBMOL(10) T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(6, 776) MM, DOUT T30 FOMMAT('COJ', 11, '3', 12, 2', 'DAT') RTE(7, 'DAT') RTE(7, 'DAT', 12, 5', '', 'DAT') RTE(7, 'DAT', 12, 5', '', '', '', '', '', '', '', '', ''		CALL JSLED	5400
Constant		CALL ERRSET(29, TRUE., FALSE., TRUE., FALSE.,15) CALL ERRSET(29, TRUE., FALSE., TRUE., FALSE.,15)	
0050         00517=0.500****/(мч-1.00)         0050           00         800         10=1, NO         0051           0018         800         00+*         050           0018         800         1001         0051           0017         900         000         0053           0017         900         000         0053           0017         900         900         0053           0017         900         900         0053           0017         900         900         0053           0017         900         900         0053           730         6004         904         100           716         F00AATI (*0.0)         100         0053           730         F00AATI (*0.0)         100         0053           730         F00AATI (*0.0)         100         0053           8         5         5         10         0054           733         F000ATI (*00         100         0054		CIDTS=NGIDTS	
00 800 10-1, M0         0050           D01AUL=_THUE         0051           ENO-10.00+*(DENOL(10)/10.00)         0053           ENO-10.00+*(DENOL(10))         0051           RHOM=**EBNO/3.00         0001           100UT=DEBNOL(10)         0053           C OPEN DATA FILE         0051           730 FOMMAT(*CU3*,11,*3*,12.2*,0MT*)         0055           730 FOMMAT(*CU3*,11,*3*,12.2*,0MT*)         0055           730 FOMMAT(*CU3*,11*,3*,12.2*,0MT*)         0055           730 FOMMAT(*CU3*,11*,3*,12.2*,0MD=*,FA,4//*EB/ND=*,FA,4//*EB/ND,*,0056         0055           731 FE(5,775) NM*         0001*           733 FOMMAT(* MORKING ON *,A13)         0005           733 FOMMAT(* MORKING ON *,A13)         0004*           733 FORMAT(* MORKING ON *,A13)         0005*           733 FORMAT(* MORKING ON *,A13)         0006*		WORBIT=0.500+MM/(MH-1.00)	
BINDAL: TRUE         DOM:		D0 800 10=1, M0	0020
C OPEN DATA FILE 0052 C OPEN DATA FILE 0053.00 100UT=DEBNOL(10) C OPEN DATA FILE 0056 C MRITE(FWME,739) MM.100UT 730 FORMAT('CQJ',11, '3',12,2','DAT') MRITE(6,776) MM.DEBNOL(10) 776 FORMAT('CQJ',11, '3',12,2','DAT') MRITE(6,776) MM.DEBNOL(10) 776 FORMAT('CQJ',11, '3',12,2','DAT') MRITE(6,775) MM.DEBNOL(10) 776 FORMAT('CQJ',11, '3',12,2','DAT') MRITE(6,775) MM.2000T 5 K, 'P(e)',15K,'OOPT') 0059 0050 0050 0050 0051 0056 0057 0051 0058 00		UNIAU=_IRUE. FRM-10_00000000000000000000000000000000000	0051
C OPEN DATA FILE C OPEN DATA FILE C DEN DATA FILE C NRITE(FNAME, 730) MM, IOOUT 730 FOMMAT('COJ', 11, '3', 12', ', DAT') MRITE(6, 776) MM, DEBNOL(ID) 776 FOMMAT('COJ', 11, '3', 12', ', DAT') MRITE(6, 776) MM, DEBNOL(ID) 776 FOMMAT('COJ', 11, '3', 12', ', DAT') MRITE(5, 733) FNAME, OPTIMIME GAMMAA RESULTS'/ 0050 778 FORMAT('MORKING ON ', A13) 0063 0063 0064 733 FORMAT('MORKING ON ', A13) 0064 0066 0066		EDMU=LU_UU=*(UEDMUL(1U)/IU.DU) Rhom=K*FRMD/3 nd	0052
C OPEN DATA FILE A MRITE(FNAME, 739) MM, IOOUT 730 FORMAT('COJ', 11, '3', 12.2', 'DAT') MRITE(6,776) MM, DEBMA.(10) 736 FORMAT('COJ', 11, '3', 12.2', 'DAT') MRITE(6,776) MM, DEBMA.(10) 735 FORMAT('COJ', 11, '3', 12.2', 'DAT') MRITE(5,733) FNAME, OPTIMIM GAMMA RESUL TS'/ 0050 0063 0063 0064 733 FORMAT('MORKING ON 'A13) 0064 0066		100UT=DEBNOL ( 10)	0053
730       FORMAT('COJ',11, '3',12.2','DAT')       0055         730       FORMAT('COJ',11, '3',12.2','DAT')       0058         716       FORMAT('LCLIPPER RECEIVER, OPTIMIM GAMMA RESULTS'/       0059         725       FORMAT('LCLIPPER RECEIVER, OPTIMIM GAMMA RESULTS'/       0050         776       FORMAT('LCLIPPER RECEIVER, OPTIMIM GAMMA RESULTS'/       0053         8       SX, 'P(e)', 15X, 'Oopt')       0063         8       RITE(5,735)       FORMAT(' MORKING ON 'AL3)       0063         733       FORMAT(' MORKING ON 'AL3)       0054       0064         733       FORMAT(' MORKING ON 'AL3)       0064       0064         70FEN(UNIT-4_FILE-FNAME, STATUS-'OLD', FORM='UNFORMATITED',       0065		I DATA FILE	0055
730 FORMAT('COU', II, '?', IZ.2', DAT') MRITE(6, 776) MM.DEBMOLLOU 776 FORMAT('LCLIPPER RECEIVER, OPTIMIM GAMMA RESULTS'/ 5 'Me', IZ.5X, 'L-3', 5X, 'EB/MD=', FB.4/' EB/MJ (dB)', 0060 MRITE(5, 733) FORMAT('MORY') 0061') 0063 733 FORMAT('MORYING ON ', A13) 0064 0066 00	د	LDITTE/ENAME 730) AN TOOLT	0057
NTE(6, 776)       MM, DEBMOL(10)       0060         776       FORMAT('LCLIPPER RECEIVER, OPTIMIM GAMMAA RESULTS'/       0060         5       M=',12.51,'L-3',55,'EB/MD=',FB.4//'EB/MJ (dB)',       0062         5       S% 'P(e)',155,'Opt')       0062         6       NITE(5,733)       FLAWA       0062         733       FORMAT('MORYING ON 'A13)       0063       0064         733       FORMAT('MORYING ON 'A13)       0064       0064         70FEM(UNIT=4,FILE=FMAME,STATUS='OLD',FORM='UNFORMATTED',       0065       0065	730	HALLE(FROME_/JJ) TT 22 FULL FROMAT(FCD) TT 22 FO ATTI	0058
776 FORMAT['1.CLIPPER RECEIVER, OPTIMUM GAMMA RESULTS'/ 0051 5 (M=',12,51,'1-3',51,'EB/MD=',FB.4//'EB/MJ (dB)', 0062 5 SX,'P(e)',15X,'Qopt') 0063 MRITE(5,733) FAUMA 733 FORMAT('MORKING ON ',A13) 0064 733 FORMAT('MORKING ON ',A13) 0065 0066 0066		HRITE(6,776) MM. DEBNOL(10)	
<pre>5</pre>	176	FORMATI'ICLIPPER RECEIVER, OPTIMUM GAMMA RESULTS'/	0061
WRITE(5,733) FUANE 733 FORMAT(* MORKING ON * A13) 0064 0066 0064 00 PEN(UNIT-4,FILE+FNANE,STATUS-'OLD',FORM='UNFORMATTED', 0065		<pre>' M=',12,5X,'L=3',5X,'EB/MO=',FB.4//' EB/NJ (dB)', EY 'D[a]' IEY 'DAA'I</pre>	0062
733 FORMAT(* MORKING ON * A13) 0005 OPEN(UNIT-4,FILE+FNAME,STATUS+'OLD',FORM='UNFORMATTED', 0065	1	WRITE(5,735) FMANE	6900
CPEN(UNIT=4,FILE=FNAME,STATUS='OLD',FORM='UNFORMATTED', 0066	733	FORMAT( * MORKING ON * , AI3)	5900
	•	OPEN(UNIT=4,FILE=FNAME,STATUS='OLD',FORM='UNFORMATTED',	0006

PDP-11 CL IPL3	11 FORTRAN-77 V4.N-1 10:43:57 16-Jul-86 Page 2 1:356R.FTN;6 /F77/WR	
9035	C C MAVE AN EXISTING FILE, READ TO SEE HOM FAR ME GOT BEFORE J300 READ(4) MMJN, EBNOIN, NSLIN, TAU, TAU2, TAU3, PEOO C G HE HAVE READ A VALUE OF TAU, SO ME MON'T MEED TO RECOMPUTE JT UMTI C EITHER EB/NO, MM, OR LL CHANGES	•
0036 0037 0038 0040 0041 0042 0043 0043 0043 0043	DOTAUFALSE. JJ=0 JJ=0 JJ=0 READ(4.EMD=742) D85JR(JJ), PRLOG(JJ), QOPT(JJ) READ(4.EMD=742) D85JR(JJ), PRLOG(JJ), QOPT(JJ) READ(4.24) AC CLOSE(UNIT=4, FILE='RESUME.DAT', STATUS='UNKNOWN', READOMLY,ERR-756,FORD='UNFORMATTED') READOMLY,ERR-756,FORD='UNFORMATTED') READOMLY,ERR-756,FORD='UNFORMATTED')	
0045 0046 0047 0048	RESTRİ=JJ.EQ.JJIN 60TO 755 C MO RESUME DATA FILE, SO NE MUST BE STARTING C A POINT FROM THE BEGINNING C 756 RESTRI=.FALSE. 60TO 755	
049	C NO EXISTING FILE, THIS IS THE FIRST TIME: C CREATE FILE HEADER RECORD 750 JJ=1 C WE CAN'T READ TAU FROM A FILE, SO IF THE FIRST TIME C WE CAN'T READ TAU FROM A FILE, SO IF THE FIRST TIME C WE CAN'T READ TAU FROM A FILE, SO IF THE FIRST TIME C WE CAN'T READ TAU FROM A FILE, SO IF THE FIRST TIME C WE CAN'T READ TAU FROM A FILE, SO IF THE FIRST TIME	
050 051 053 054 055	757 FORMATIC SETTING THE THING OF GAMMAN MORE OF EB/MJ. RESTRIF.FALSE. IF(DOTAU) THEN WRITE(5,757) 757 FORMAT(* SETTING THRESHOLD*) CALL SETTAU(MM,PEOD) DOTAULE SETTAU(MM,PEOD)	
058 058 058	MRTTE(5,1991) MM, TAU MRTTE(5,1991) MM, TAU 1991 FORMAT(' M=',12,' L=3 OPT THRES = ',1PD15,8) END IF	
065 063 063 063 063 063 063 063 063 063 063	OPEN(UNIT=4, FILE=FNAME,STATUS='NEW', FORM='UNFORMATTED') URITE(4) MM,DEBMOL(10),NSLOTS,TAU,TAU2,TAU3,PEOO CLOSE(UNIT=4) 755 D0 650 13-23,MJ IF(10,660 71(13-1)-000T(13-2)+0.5D0 IF(100.600 T(13-1)-000T(13-2)+0.5D0 IF(100.60.0) IDQ=1	

.

777 777 777 777 777 777 777 777	P=00PT([JJ-1]) P=00PT([JJ-1]) P=1.D0	0115 0116 0116 0117 0118 0118 0128 0128 0128 0128 0128 0128	C NOT IN STORED LIST, COMPUTE IT CALL PSUBE(MM, PESYM, D, IDSUB, MUSED, PRERR, JPSUB, PEDO) 105-615-60 THEN 105-6615-60 THEN 105-6615-60 THEN 105-6615-60 THEN 105-6615-60 THEN 105-6615-60 THEN 105-6616 106 (105)=PESYM 106 (106)=PESYM 106 (107) 100 (105)=PESYM 100 (106) 116 (155) .001 DABS (P1-P3).LE.EPS .AND. 106 (100 PO) 116 (155) .001 DABS (P1-P3).LE.EPS .AND. 116 (155) .001 DABS (P1-P3).LE.EPS .AND. 117 (1
C IF FILE I C AND CREAT 96 770 COM	-OR EVENT PROBABILITIES DOES NOT EXIST, CALCULATE THEM TE A FILE. TTTM/E 30201	0136 0137 0138	C PREVENT ROUND-OFF FROM MAKING QOPT VS, EB/NJ MOM-MOMOTOWIC IF(13.6T.1) THEN IF(QOPT(13).LT.QOPT(13-1)) QOPT(13)=00PT(13-1) FND IF
201 201 201 201 201 201 201 201	LIELS,9936) MMT('CREATING EVENT FILE') L GENDIE(MM.IQ,NSLOTS,GOOD,A,IASUB, 	0140 0140 0142	C ELSE ELSE CTHEM IS FULL-BAND JAMMING 00PT(1J)=NSLOTS END IF 60T0 665
00 00 00 00 00 00 00 00 00 00	DSE(UNIT=3) .WOT.GOOD) GOTO 700 DTS=GANNA=PREBNO/(GANENA=R+EBNO) DT=K=RNOTS/3.DO THE PROBABILITY THE PROBABILITY TAC MOSS=1.TGS TQL (MOS).EQ.TQ) THEN ESTM=POFQ(MOS) DT 781	0143 0144 0145 0147 0147 0147 0148 0149 0149 0149 0150	C ELSE AUT LOCATED SUFFICIENTLY ACCURATELY, CUT DQ AND TRY AGA 0=0-DQ-DQ 0=1Q=1DQ-DQ 1Q=1Q-1DQ 1D(=1DQ DQ=1DQ P1=0.DO 0=1Q+1DQ 10=1Q+1DQ

and the second se

AGAIN

10:41:57         16-Jul-165         Pers 1         Control = 1:71, Multi - 1:7	Page 5 PDP-11 FORTRAN-77 V4.0-1 10:44:25 16-Jul-86 CLIPL3SGR.FTN;6 /F77/WR DM01 runowing control 2010	0001 SUBROUTINE GET(HJ,START,DBINC) C INTERACTIVE INPUT OF PARAMETERS FOR RUN 0002 IMPLICIT DOUBLE PRECISIOM(A-H,O-Z) 0003 CHARACTER-9 FIELD,BLANC) 0003 CHARACTER-9 FIELD,BLANC)	COMPANY / INVUIS/ DEBMOL(3), ASLOTS, K, MM COMMON / SIZE/ NO C DEFAULT LISTS TEMPORATILY MEEDED ARE IN SMARED STORAG C THE LARGE CONVOLUTION MARKYMA. ADDAVS	0006 COMMON /SWARE/ DSWR(3,4) 0007 DATA BLANK9/'''/ 0002 33 JULTELANK9/'''/	0009 33 FORMAT(* BITS/STMBOL (K) [2]: •,5) 0010 READ(5,3)K	0011 IF(K.Eq.0)K=2 0012 MM=2**K	0013 1 MRITE(5,2) 0014 2 FORMAT(* HOW MANY EB/MO2 [1]: 1.5)	0015 READ(5,3)NO 0016 3 FINHAT(12)	0017 IF(NC.EQ.0)MN=1 0018 D0 7 If=1.M0	0019 D0=DSmr(JN,K) 0020 4 MrITE(5,5)IN,00	vozi 5 ruchat(* EB/MO(*,12,*) {*,F9.6,*];*,\$) 0022 READ(56)FIELD 0023 FEAD(54)	0024 If (FILL) D025 If (FILL) EQ.BLANK9) THEN	256 ELSE ELSE DECODE (9.61.5751) DERMAN (7.44)	28 61 FORMAT(F9.6) 29 END IF	n 7 CONTINUE 1 NSLOTS=2400	38 WRITE(5,39) 39 FORMAT(°HOW MANY ER/NJ?[111]: '.\$)	READ(5,34,ERR=38) NJ 34 FORMAT(13)	JF(NJ.EQ.Ó) NJ=]] ]F[NJ.LT.O _ORE_NJ.ET ]]) EOTO 32	40 MRITE(5,41) A1 ECOMPTIC STADIALY VALUE FOR CALLS FOR	READ(5,42,568,40) START FUK EB/MU (DB) 150, 1: .	IF(START.EQ.0.00) START=50.00 42 FORMAT(F6.3)	IF(NJ.EQ.1) RETURN	36 FORMAT(1,50) BEANAT(2,50) BEANAL 37 EDB-351 DATHC	37 FORMATICS SUM-JUL VOIN
10:43:57       16-Jul-B6       Page 5       Pep-11         77/WR       000       000       000         Pepr       0000       000       000         Per (1J)       Per (1J)       001       001         Per (1J)       Per (1J)       000       001         Per (1J)       Per (1J)       001       001         Per (1J)       Per Per (1J)       000       001         Per (1J)       Per Per (1J)       001       001         Per (1J)       Per Per (1J)       Per Per (1J)       001         Per Per (1D)       Per Per (1J)       Per Per Per (1J)       Per	Page 5 POP-11 F CLIPL3SG	000 0000 0000	500	5000 5000 5000 5000 5000 5000 5000 500	6000 0100	0011 0012	00134 100	0015 0016	0017	6100 0050 0050 0050	0022	, 100 024 025	226	9 8 2	~	(F) (F)	ų		4	,	4	~	. A	ñ
T77/MR       10-43157       16-Jul-36       Page 5       Pub         777/MR       10-43157       16-Jul-36       Page 5       CL1         700       700       000       000       000         4907       11.2       5.5.4.7P012.5.5.4.7P012.5.       000       000         77.3.5.4.7P012.5.5.4.7P012.5.       000       000       000         7.3.5.4.7P012.5.5.4.7P012.5.       000       000       000         7.3.5.47TUS       000       000       000       000         7.3.5.47TUS       000       000       000       000         4.57TUS       000       000       000       000         4.51TUS       PRL06(13), Q0PT(13)       000       000       000         14.9       000       000       000       000       000         14.9       000       000       000       000       000       000         15.1.3       000 <t< td=""><td>Page 5 PDG CL1</td><td>888</td><td>88</td><td>888</td><td>888</td><td>100</td><td>88</td><td>88</td><td>888</td><td>888</td><td>888</td><td></td><td></td><td>22 23</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	Page 5 PDG CL1	888	88	888	888	100	88	88	888	888	888			22 23										
10:43:57 16-Jul-B6 Page 5 177/MR 10:43:57 16-Jul-B6 Page 5 108 108.38(13), PE.0007(13) 17.3.5X, 19012.5, 4X, 19012.5, 17.3.5X, 19012.5, 4X, 19015.5, 17.3.5X, 19012.5, 4X, 19015.5, 17.3.5X, 19012.5, 4X, 19015.5, 16.13, 10.498100.100 17.0.1000 17.0.1100 17.0.1100 17.0.1000 17.0.	Page 5												828	88	88	88	200	0036	803		88	0043	596	Cool of the second
a a constata de la del composición de la constata de	10:43:57 16-Jul-86 77/wR 09	09 P0PT 6) D8SJR(1J),PE,QOPT(1J)	F7.3,5X,1PD12.5,5X,1PD12.5) DLOG10(PE) 4,FILE=FANNE,STATUS="OLO",ACCESS="APPEND",	= UNE UNERTILU') BSSR([J), PRLOG([J), QOPT([J) ■4)	4, FILE=FNAME, STATUS="NEW", FORM="UNFORMATTED") M 2 DERMONTADIA DEC DEC DEC DEC DEC DEC DEC DEC	n,s,ucemut (10),NSCUIS,UBSUK,PKLUG,QUPT e4) 5) htt fremut (10)	0) TT.,DE.BMUL(10) 1,NJ 6) DE.DVII, 10, 4400, 000111, 0004011	0) UBSUK(1J),1U.**PRLUG(1J),(0PT(1J)	8) TAU /* OPTIMUM THRESHOLD FOR ABAVE IS ETA/SIGMA+*.	(°. ')														

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44:31 44:31 CCISION (CISION) CCISION (CISION) 44.31 1010 REF 655 44.44	FIAN-77 V4.0-1 JO: FTNA-77 V4.0-1 JO: SUBROUTIME PSUBE(M, SUBROUTIME PSUBE(M, COMPUTE UNCONDITIONAL ERR INTEGER LUP(4),JSUB LOGICAL*1 60,MOELS, VIRTUAL O(SS), JOSU COMPON / RSPAR/ JAN( COMPON / SSARE2/ LOM COMPON / SSARE2/ LOM SSARE2/ LOM COMPON / SSARE2/ LOM COMPON / SSARE2/ LOM SSARE2/ COMPON / SSARE2/ LOM SSARE2/ COMPON / SSARE2/ LOM SSARE2/ COMPON / SSARE2/ LOM SSARE2/ LOM COMPON / SSARE2/ LOM SSARE2/ LEVENT(M, JAM, PI FROM FILTY IS ZERO. THIS FROM FILTY IS ZERO. THIS FROM FILTY IS ZERO. THIS
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C COMPLITIONAL EXKOR PROBABILITES WHI C RECOMPUTING THEM UNNECESSARILY.

PDP-11 FORTRAN-77 V4.0-1 10:44:40 16-JU1-86 Page 10 CLIPL3SGR.FTN;6 /777/MR	0001 SUBROUTINE GENPIE(MM, MQ, MSLOTS, GODO, A, IASUB, C, ICSUB, 5 D, IDSUB, MUSED) C SUBROUTINE TO GENERATE EVENT PROBABILITIES	C IMPLICIT DOUBLE PRECISION (A-H,O-Z) 0003 LOGICAL+1 GO.602,STORE,MME,GOOD 0004 DIMENSION LUP2(4),LUP3(4) 0005 DIMENSION LUP2(4),LUP3(4) 0006 DIMENSION TUPD(4)	0007 DIMENSION LUPI(4) 0008 VIRTUAL A(100),1ASUB(100),C(625),1CSUB(625), 5 DIMENSION LUPI(4),1DSUB(625),1CSUB(625),	COUPERATER STORAGE FOR COMMONLY MEEDED CONSTANT ARRAYS C SHARED STORAGE FOR COMMONLY MEEDED CONSTANT ARRAYS 0010 C SHARED STORATE FOR (1) INUCT DEFAULT LISTS, (2) CONDITIONAL PROB GEN., C AND /31 EVENT POOD CC	0011 COMMON /SHARE LUP2,LUP2,LUP2,LUP2,LUP2,LUP2,LUP2,LUP2,	0012 DATA 1100/100/ 0013 DATA LUPA/4=1/ 0014 DATA LUPA/4=1/ C STORE= FAISE => DM41/ STORE 7ED/ ELEMENTE OF CANAGE ADDIVE	0015 CONTRACT. JUNC LENGTON DEPARTS WART. 0016 G000-TRUE. 0017 9999 IF(M0.LE.O) THEN	0018 6000=.FALSE. 0019 RETURN 0020 FWD 1F	0021 D0 80 L1=1,MM 0022 IUPD(L1)+3 0023 80 COMTINIE	C JAMMING PATTERN W/WOW-ZERO PROBABILITY ON PER-HOP BASIS 0024 NUSEA=D	C INITIALIZE VECTOR-INDEX LOOP 0025 CALL VLINIT(1,1.0W,MM) 0026 An rowTrune	0027 CALL DCCN(MM,LOW,IUPA,I,ISUB) 0028 CALL PRIHOP(I,MM,MS,075,AIM) 0029 CALL PUTIN(AIM,A,IASUB,MUSEA,IJOO,ISUB,IERR,STORE)	D030 IF(JERR.ME.O)STOP 3 C ITERATE VECTOR-INDEX LOOP 0031 CALL VLTFEF(LOW_LUP1,LINC,MM,GO) 0032 F5/CO) CATO 00	C COMPUTATION STARTS MERE. FIRST COPY A INTO D. C SINCE ARRAYS ARE A(0:1,0:1,,0:1) AND D(0:1,0:L,,0:L) C THE COPYING MUST BE DOME ON BASIS OF EQUIVALENT LIMEAR C SIRCEDITYS DATHED THAN A STENDE CONTANTANT
PDF-11 FORTRAM-77 V4.0-1 10:44:38 16-Ju1-86 Page 9 CLIPL3SGR.FTN.6 777/WR	0001 SUBROUTINE EVENT(M.JAM.PIE.D.IDSUB.NUSED) C SUBROUTINE TO LOOK UP EVENT PROBABILITY FROM STORED ARRAY C JMPLITIT DOWNE BOEFISTIMALA U 0.21	0003 LOGICAL 1 STORE NOME (A - M, L-Z) 0004 DIMENSION JANN 4), LUP (4) 0005 VIRTUAL D(625), TOSUB (625) 0006 COMMON /SWARE2/ LOW (4), LINC (4) DOC7 DATA STORE/, FALSE./	C SET UP ARRAY DESCRIPTION D(0:LL,,0:LL) WITH M DIMENSIONS 0008	C COMPUTE LINEAR EQUIVALENT SUBSCRIPT FOR JAMMING EVENT 0011 Call Locn(M.LOW,LUP,JAM,ISUB) C LOOK UP THE VALUE, 6ET 0.DO TF NOT THERE 0012 Call LOOKUP(PIE,D,IDSUB,NUSED,625,ISUB,STORE,MONE)	0013 RETURN 0014 END									

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ALIZE VECTOR	t-INDEX LOOP	1000	د	SUBROUTINE PUTIN(CIN,C,ICSUB,NUSE,MMAX,K,IER)
CONTINUE CALL LOCN()	et.t.c		225 225	IS SUBROUTINE INSERTS AN ELEMENT INTO A SPARSE AR Ich omly the hom-zero elements are kept in storag
CALL LOCN()	MA,LOM,]UPD,],[SUB2) Marit a tashe misea tingi sundi surai siya			E SWITCH STORE IS .TRUE.
CALL PUTIN	ADUT, D., 19508, WUSED, 525, 15082, 1588, 57082) ADUT, D., 1991, LINC, MM, 60)		送祖	E DOUBLE PRECISION VALUE CIN IS STORED AS C(K) W E AUXILIARY ARRAY ICSUB IS USED TO KEEP TRACK OF
2F(60)60T0	99 Towns are arenen		5 2 2 2 2 2	BSCRIPTS OF THE LORRESPONDING ENTRIES IN C.
1 866 00			c ns	VGE:
I=(NN)2017			ں د	DONBRE PRECISION CLIN
LUP3(NN)= MISEC=0	[]+]		ں ر	VIRTUAL ICSUB(NMAX), C(NMAX)
CALL VLIN	11(1,LOW,MM)		E C C	WALE FULLATURE, NUSE, NAVA, N. JERK, STUKE
CONTINUE			ວເ ບເ	IN = VALUE OF ELEMENT TO STORE = APPAY IN MHICH MON-ZEPO VALUES ARE ACTUALLY ST
CONTINUE			, 2 , 2	- MUNITY WILLIARY ARRAY FOR ACTUAL SUBSCRIPT VALUES
CALL LOCI	( M.,LOW, ]UPA, ], ISUB1)		21	JSE = NUMBER OF ELEMENTS OF C CURRENTLY OCCUPIED
D0 21 M	1, 11, 11, 10, 10, 10, 11, 13, 15, 15, 15, 15, 15, 15, 15, 15, 15, 15		- U	CRR = ERRCR RETURN CODE. O JE NO ERROR OR 1 JE THEF
[=(NN)]]]]	(MN) + I + (MN)		ئ د د	NO ROOM AVAILABLE IN C
CALL LOCI	(WM.LUPD.111,15UB3)			UNE * THUE TO STANK ZENDES EXPLICITLY, ELSE .FAL [E: IF CIN=O AND THE SUBSCRIPT K IS FOUND IN ICSUB.
	cup ( acut , 4, 1 a sub, wuse a, 1100, 1 sub1 , store , wowe) cup ( dout , 0 , 1 dsub, wused , 625 , 1 sub2 , store , wowe)		ပပ	THE ELEMENT IS DELETED BY SHIFTING DOMMARD ALL Following elements of the Array
CALL LOO	<pre>kup ( Court , C , I CSUB , MUSEC , 625 , I SUB3 , STORE , MOME) . ADNIT + DMNT</pre>		0 2 0 2 0 2 0	COANDER DOREDT H EDEWCH DATE: 11 Jawiiad
CALL PUT	IN CIN, C. ICSUB, NUSEC, 625, ISUB3, IERR, STORE)		20	
TE VECTOR.	NE.O) STOP 4 -100P FOR ARRAY D	2000		IMPLICIT DOUBLE PRECISION(A-H,O-Z) Virtual trsurtmaay) crimaay
CALL VLT	FER(11,LCN,LUP2,LINC,MM,602)	000		LOGICAL*1 STORE
IF(602) ( TF VFCTOR.	50T0 97 Linde Fire Array A	0002		IERR=0 IF(STARF) GATA S
CALL VLT	TER(1,LOW,LUP1,LINC,MM,GO)	000		JF(CIN.EQ.0.D0) 60T0 30
	010-98 Scienten abised end mevt itebation	8008	ഹ	1F (NUSE . EQ. 0) GOTO 20
NUSED=0	THE COLOR IN MENT FILMETION	0100		IF(ICSUB(I).ME.K) 60T0 10
CALL VLIN	11T(11,LON,MM)	1100		C(I)=CIN
CALL LOCI	(), 10, 10, 10, 11, 15, 18)	5100 0015	10	CONTINUE
	<pre>cup(cout_c.icsub,nusec.625,isub,store,nome)</pre>	0014		JF(WUSE.LT.MMAX) 60T0 20 1506-1
CALL PUT	(M( DIN, D, IDSUB, MUSED, 625, ISUB, IERR, STORE)	9100	:	RETURN
IF(IERR.	NE_O) STOP 5 TEP/TT (DE/1103   TWE NAM CO)		20	NUSE*NUSE+1 ) CSURENISE ) =K
IF(60) 6		6100		
RETURN		0021	30	NE LOKH DO 40 I=1, MUSE
		0023		If(ICSU8(I).EQ.K) 60T0 50
		+JM	2	

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FORTRAN-77 V4.0-1 10:44:52 16-Jul-86 Page 14 SGN.FTW;6 /F77/WR	SUBROUTINE LOOKUP(COUT,C,ICSUB,N,MAX,K,STORE,NOME)	THIS SUBROUTIME RETRIEVES AN ELEMENT OF A SPARSE ARAAY WHICH HAS BEEN STORED COMPACTLY BY STORING ONLY NOW-ZERO ELEMENTS. THE ARAAY IS DOUBLE PRECISION. USAGE: VIRTUAL ICSUG(MMAX), C(MMAX), C(MMAX) LOGICAL41 STORE, MOME DOUBLE PRECISION COUT COULL LOOKUP(COUT,C, ICSUB, M, MMAX,K, STORE, MOME) MHERE CALL LOOKUP(COUT,C, ICSUB, M, MMAX,K, STORE, MOME) COUT = WALUE OF C(K) (OUTPUT FROM SUBROUTIME) COUT = TRUE. IF ZEROES ANT TO LOOK UP STORE = TRUE. IF ZEROES ANT STORED ARAAY COME = .FALSE. IF ZEROES ANT STORED ARAAY COUTFUT QUANTITY)	10 10 10 10 10 10 10 10 10 10
PDP-1} CLIPL3	1000		0002 0003 0006 0006 0006 0006 0011 0011 0011
PDP-11 FORTRAM-77 V4.0-1 10:44:48 16-Jul-35 Page 13 CLIPL3SGR.FTN;6 /F77/WR	0025 RETURN C	C REMOVE THE ZEROED ELEMENT AND BLANP COUNT OF ENTRIES USED 0025 50 06 60 1=J,MUSE-1 0029 60 CONTINUE 0031 RETURN 0032 EMD 0032 EMD	

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DIMENSION LVEC(LMAX), LLOW(LMAX), LUP(LMAX), LINC(LMAX) (INITIALIZE ARRAY LLOM TO STARTIME VALUES OF THE MESTED LOOPS) (INITIALIZE ARRAY LUP TO STOPIME VALUES OF THE MESTED LOOPS) (INITIALIZE ARRAY LUP TO STOPIME VALUES OF THE LOOPS) CALL VLIMIT(LVEC.LLOM, LMAX) SEQUENCE AS LVEC LINC = ARRAY FOR STORAGE OF LOOP INCREMENTS, IN SAME SEQUENCE AS LVEC LMAX = NUMBER OF LOOPS MESTED LMAX = AUNBER OF LOOPS MESTED GO = LOGICAL VARIABLE, TRUE. IF JUMP BACK TO REGINNING OF STATEMENTS IN THE RAMEE OF THE LOOP SHOULD OCCUR. FALSE. OTHERWISE (1.E. OUTER-MOST LOOP TERMINATED) Page 16 DITER-MOST LOOP, LVEC(LMAX), THE INNER-MOST LOOP. LLOW = ARRAY FOR STORAGE OF LOOP STARTIMG VALUES, IN SAME SEQUENCE AS LVEC LUP = ARRAY FOR STORAGE OF LOOP FIMAL VALUES, IN SAME THE COMPANION ROUTINE VLITER HANDLES THE LOOP CONTROL AT THE CONTINUE STATEMENT IN THE ABOVE STRUCTURE LVEC = ARRAY FOR STORAGE OF LOOP INDICES. LVEC(1) IS THE DATE: 11 JANUARY 1984 THIS SUBROUTINE INITIALIZES A "VECTOR DO-LOOP" STRUCTURE DO 100 LVEC(LMAX)=LLOW(LMAX),LUP(LMAX),LINC(LMAX) DEFINED BY THE FOLLOWING PSEUDO-FORTRAW CODE: DO INO LVEC(1)-LLOW(1),LUP(1),LINC(1) DO INO LVEC(2)-LLOW(2),LUP(2),LINC(2) CALL VLITER(LVEC,LLOM,LUP,LINC,LMAX,GO) IF(60)60T0 100 16-Jul-86 . (STATEMENTS IN RANGE OF LOOPS) SUBROUTINE VLINIT(LVEC, LLOH, LMAX) DIMENSION LVEC(LMAX),LLOW(LMAX) DO 1 N=1,LMAX LVEC(N)=LLOM(N) (STATEMENTS IN RANGE OF LOOP 10:44:56 PROGRAMMER: ROBERT H. FRENCH /F77/WR LOGICAL\*1 60 CONTINUE 100 CONTINUE PDP-11 FORTRAN-77 V4.0-1 CONTINUE RETURN END WHERE CLIPL3SGR.FTN;6 USAGE 8 ົບບ ပ S J υ 1000 DIMENSION A(ILOW(I):JUP(I),...,ILOW(MDIM):JUP(MDIM)) AND ISUB(I),...,ISUB(MDIM) IS A SET OF SUBSCRIPTS FOR A, THEN THIS SUBROUTINE RETURNS IN LIMEAR THE OFFSET FROM THE ORIGIN OF A TO THE ELEMENT A(ISUB(I),...,ISUB(MDIM)), ASSUMING THE FIRST SUBSCRIPT VARIES MOST RAPIDLY. LINEAR=(LINEAR+(ISUB(J)-ILON(J)))+(IUP(J-I)-ILON(J-I)+1) MDIM = HUMBER OF DIMENSIONS THE ARRAY HAS ILOM = ARRAY OF LOWER SUBSCRIPT BOUNDS IUP = ARRAY OF UPPER SUBSCRIPT BOUNDS ISUB = ARRAY CONTAINING SUBSCRIPT FOR WHICH LOCATION IS TO BE COMPUTED Page 15 THIS SUBROUTIME COMPUTES THE COULVALENT LINEAR SUBSCRIPT FOR A MALTIDIMENSIONAL ARRAY OF NDIM DIMENSIONS DATA ILOW/IOWER limits of defined sub.cripts of array/ DATA IUP/upper limits of defined subscripts of array/ ...SET ISUB TO DESIRED SEQUENCE OF SUBSCRIPTS... CALL LOCM(NDIM,ILOW,IUP,ISUB,LINEAR) LINEAR = RETURNED VALUE OF OFFSET INTO ARRAY IN MEMORY SUBROUTINE LOCN (NOIM, ILOW, IUP, ISUB, LINEAR DIMENSION ILOW(NDIM), IUP(NDIM), ISUB(NDIM) DIMENSION ILOW(NDIM),IUP(NDIM),ISUB(NDIM) 16-Jul-86 LINEAR+LINEAR+ISUB(1)-ILON(1) 10:44:54 PROGRAMMER: ROBERT H. FRENCH IF THE ARRAY A IS DEFINED AS DATE: II JANUARY 1984 D0 10 1=1 MDIM-1 /F77/WR [+I-WION=[ L I NEAR=0 CONTINUE PDP-11 FORTRAN-77 V4.0-1 RETURN **B** USAGE : CL IPL 35GR. FTN: 6 NHERE ្ព 8

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11-40,	FORTRAN-77 V4.0-1 10:44:58 1 56r.F74:56 /F77/WR	6-Jul-86	Page 17	PDP-11 FO	RTRAN-77 Y4.0-1 10:45:00 16-Ju1-85 .FTW:6 /F77/WR	e.
1000	SUBROUTINE VLITER (LVEC, LLOW, L	UP,LINC,LMAX,60)		0001	SUBROUTIME PRIMOP(1,KM,KQ,KM,AJM)	
	C LOOP ITERATION LOGIC FOR A "VECTOR	D0-L00P*		, L, L	THIS SUBROUTINE COMPUTES THE EVENT PROBABILITY FOR ALL DOSSIBLE INMANNE DATTEGME WITH AND TED DAMARKENES WITH AND TED	. 9
	C SEE DETAILED COMMENTS IN SUBROUFINE C DADAMETED REFINITIONS	VLINIT FOR USAGE	AND		Leginger of the ANEX/FH IN PANJON FROM ALLI'L TO	¥
	C DONCO MANERO - DADEDT 4 EDEWEU			0005	IMPLICIT DOUBLE PRECISION (A-H,O-Z) Dimension 124)	
	C DATE: 11 JANUARY 1984			1000		
2000	L LOGICAL+1 60			800	DO 1 K=1,KM	
0003	DIMENSION LVEC(LMAX) "LLON(LMA	LUP(LMAX),LINC	(LMAX)	0001	KUNN=KUNN=I(K)	
	GU#, TAUE. Do Ton HDY#1 PMAY			5	I CUMITANE IF THIS IS AN IMPOSSIBILE LASE DETION WITH RESULT = 0	c
588 888 888	NSUB=LMAX+1-MDX			6000	IF (KJAM.GT.NINO(KQ.KM)) RETURN	2
000	LVECINSUB) = LVEC(NSUB) + LINC(NS	(90)		0010	KPNAX=KJAM-1	
8000	IF((LINC(NSUB).GE.O.AND.LYEC(	NSUB).LE.LUP(NSUB	)) 2011) BETIDU	0011	LPHAX=XM-X.JAM-] Iphax-pha	
0000	>	כאו אחד. שבי למחכש וח:	UDIT NETUN	0013	I TAXA TATA - I IMAX = MAXO(K PMAX _ I PMAY _ IPMAY )	
0100	100 CONTINUE			0014	PR06-1.00	
1100	GO= .FALSE.			0015	Q=KQ	
2100	RETURN			0016	DIFFMO=KN-KQ	
6100	END			/100		
				9100 9110	DU 100 LOOP = 0, IMAX F=1 AAP	
				0020	IF(LOOP.LE.KPMAX) PROD=PROD=(O-F)	
				0021	IF (LOOP.LE.JPHAX) PROD-PROD/(EN-F)	
				0022	IF (LOOP.LE.LPMAX) PROUPPROD*(DIFFMQ-F)	
				0023 0024	100 COMTINUE AIN=PROD	
				0025	RETURN	
				0026	END	

C ADAPTIVE DUAINATURE ALGORITHM XL - LONER LIMIT OF INTESRAL (IN) Y - UALUE OF INTEGRAL (IN) Y - VALUE OF INTEGRAL (IN) C QR - MAME OF A OUADRATUNE RULE SUBROUTIME (IN) C ALL ORTL, JUL, F, Y) F - NAME OF FUNCTION TO BE INTEGRATED (IN) C OLL ERROR TOLERAMCE FOR FINAL ANSWER (IN) C OLL ERROR AN OF SIZE N, MUST NOT BE FIRD MORK ARRAY OF SIZE N, MUST NOT BE FARAN S MORK (IN) N - SIZE OF MORK AND STACK; MAX. NO. OF BISECTIONS (IN) N - SIZE OF MORK AND STACK; MAX. NO. OF BISECTIONS (IN) N - SIZE OF MORK AND STACK; MAX. NO. OF BISECTIONS (IN) C O - NOE RROR AN OF SIZE N, OLT FROM MORK AND C O - NOE RROR AN OF SIZE N, MUST NOT BE ATTAINING REQUIRED TO ZERO, EITHER ASS'ING FOR TOO TIGHT A TOLERANCE OR ROUND-OFF PREVENTS R. H. FRENCH, 14 AUGUST 1984 SUBROUTINE ADQUAD(XL,XU,Y,QR,F,TOL,HORK,STACK,HEAP,N,KODE) Page 20 10:45:05 16-Jul-86 IMPLICIT DOUBLE PRECISION(A-H,0-Z) EXTERNAL F DIMENSION WORK(N), STACK(N), HEAP(N) 2 CALL (R(A,XM,F,P1) CALL (R(XM,B,F,P2) CALL (R(XM,B,F,P2) IF(DABS(T-P1-P2).LE.EPS) 60T0 IT WORK(1)=XU CALL QR(XL,XU,F,T) HEAP(1)=T IF(NPTS.GT.N) THEN KODE=1 /F77/WR (M=(A+B)\*0.500 HEAP(NPTS)=P2 STACK(1)=5PS B=MORK(NPTS) HORK [ NPTS)=XH I+ST9N=ST9N PDP-11 FORTRAN-77 V4.0-1 **RETURN** NPTS=1 EPS=TOL KODE=0 Y=0.00 END JF A=XL CLIPL3SGR.FTN;6 C SPLIT 10 ပပပ ပပပ 0019 0021 0022 0023 0023 0023 0023 0023 0027 0026 8 Page 19 16-Jul-86

EPS=EPS/2.00

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C DEFAUT LISTS FOR INTERACTIVE PARAMETER INPUTS C ARE SHARED MITH LARGE MORKING STORAGE ARRAYS SINCE THEY MAY BE DESTROYED ONCE THE INPUT PARAMETERS ARE SET UP DATA DSMR /13.3524700, 12.3133DG, 10.94443DO, S 10.606572DD, 9.62840D, 8.152443DO, S 9.09401DO, 8.1590DD, 8.15245DO, S 8.07835DO, 7.1996DO, 6.069646DO/ C FREQUENTLY NEEDED COMSTANT ARRAYS AND SCALAKS END C WEIGHTS AND ABSCISSAS FOR 10-POINT GAUSSIAN QUADRATURE C BLOCK DATA C INITIALIZE SHARED CONSTANTS IMPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /SHARE/ DSNR(3,4) COMMON /SHARE2/ LON(4),LINC(4) COMMON /WTS/ X(5),W(5) DATA X/ 0.14887433938163100, 0.43339539412924700, 0.67940956829902400, 0.86506336668898500, 0.9390652851717200 / DATA W/ 0.295524214145500, 0.2190863651598200, 0.14945134916058100 / 0.14945134430268800 / 10:45:03 /F77/WR PDP-11 FORTRAN-77 V4.0-1 CLIPL3SGP. FTN:6 **6**10 8000 9000 100 80

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Page 22	ACK "HEAP "N.KOC											ADV AND CTACY	ANK AND JAKE	TTANE (TW)	(NI) SNOT				FOR T00	VENTS																											
16-Ju1-86	QR, F, TOL, WORK, ST		[N]	(N)		SUBROUTINE (IN)	INCE		TEGRALED (JN)	ANSMER (IN)	E MILT LAT BE	TA, MUSI NUI BE	A MUNI LINUICIU	11 I I I I I I I I I I I I I I I I I I	MA. NO. UP BISEC			IALL	<b>10, EITHER ASKING</b>	OR ROUND-OFF PRE	1 ACCURACY		A U 0 7)	(7-0 <sup>4</sup> U-V	UCAD/W)													010 20									
10:45:08 77/uR	ADQUA2(XL,XU,Y,	URE ALGORITHM	IT OF INTEGRAL (	IT OF INTEGRAL (	INTEGRAL (OUT)	QUADRATURE RULE	TH CALLING SEQUE	LL QR(XL,XU,F,Y)	UNCTION TO BE IN	EXANCE FOR FINAL	T UT 314E M (JM) BY ADDAY OF 51%F	KK AKKAT UF 312E V ADDAV CTTC V	A MKMY, SIZE N,	T AJ THUR ( 14)	ukk anu siauk; n	ICALOR (OU!)	EKKUK	RK ARRAYS TOO SM	S DIVIDED TO ZER	BHT A TOLEPANCE	TAINING REQUIRED	AUGUST 1984	NIGLE DOCTICITION	MARE LVERIDIAN	SOPPIN STARTAN			. XII.F.T)					۲ ۲	5)	.500	(M.F.PI)	.B.F.PZ)	9 (SA3.11.(24-14		A) THEN				=XN	-P2	ş	
77 V4.0-1 /Fi	SUBROUTINE	IVE QUADRATI	- LOWER LIN	- UPPER LIM	- VALUE OF	A TO BHAN -			- NAME UP FI	- EKKUK 10LI	- NURA ANKA	- SECUNU NU	- INUMU ALIA		- SIZE OF W	- EKKUK INU.			2 EP	Ĩ	AT	FRENCH, 14	INDI ICIT OV	EVTEDNAL E	DIMENSION I	Y=0.00	NORK(1)=XU	CALL OR XL	HEAP(1)=T	A=XL	I=ST dhi	EPS=TOL	STACK(1)=EI	B=NORK (NPT	XM=(A+B)*0	CALL OR (A,)		1-1)(1)485(1-1	LI WDTC_WDTC+	TELEVEDTS CT		RETURN	END IF	<b>WORK (NPTS)</b>	HEAP (NPTS).	T≖P] roc-roc/o :	
EURTRAN-7 SGR.FTN;6	Ĺ	C ADAPTI	א ט	2	רי רו	ج	<b>ن</b> ر	י ט ני	י קי הי					: ، د			، ر	ပ	ں	ပ	: ں	С. В. Н.	<b>د</b>											10				r cn 11	1 2411								
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Page 21																																															
16-Ju)-86																																															
. FORTRAN-77 V4.0-1 10:45:05 SGR.FTN;6 /F77/WR	IF(EPS.EQ.O.DO) THEN	RETURN	END IF	STACK (NPTS)=EPS		L PINISMEU A PIECE	ZU TAPELALATEN	EPS=SIAUR(WFIS) T-MERD(MDTC)	I = TIEAT ( NT LO) NDTC = NDTC _ 1		TE(NDTS EQ O) DETNOM																																				
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145:08     16-Jul-86     Page 23     PDP-11 FORTRAM-77 V4.0-1     10:45:12     16-Jul-86       16     CLIPL3SGR.FTN,6     //777/MR     //777/MR       16     SUBROUTINE 06:10(A,6,F,AMSWER)       16     C     SUBROUTINE 06:10(A,6,F,AMSWER)       17     C     RF.:     ABRANOWITZ & STEEUN, EO. 25.4.30 AND TABLE 25       17     R. H. FREMCH, 28 FEBRUARY 1966     POD03       18     C     R. H. FREMCH, 28 FEBRUARY 1966       19     C     R. H. FREMCH, 28 FEBRUARY 1966       10     C	TRAM-77         W.O-1         10:45:08         16-Jul-66           FTN,6         /F77/MR         10:45:08         16-Jul-66           IF(FPS_EQ.0.00)         THEN         0001         SUBROUTINE 06.10(A,6,F,ANSHEN)           IF(FPS_EQ.0.00)         THEN         0001         SUBROUTINE 06.10(A,6,F,ANSHEN)           IF(FPS_EQ.0.00)         THEN         0001         SUBROUTINE 06.10(A,6,F,ANSHEN)           RETURN         KUDF2         0001         SUBROUTINE 06.10(A,6,F,ANSHEN)           RETURN         KET         ABRAUOUTINE 06.10(A,6,F,ANSHEN)           VALUEND         CEF         ABRAUOUTINE 06.10(A,6,F,ANSHEN)           FINISHED A PIECE         0001         SUBROUTINE 06.10(A,6,F,ANSHEN)           VALOLAC         FINISHED A PIECE         ABRAUOUTINE 05.10(A,4,0,0.2)           VALOUALAC         FINISHED A PIECE         ABRAUOUTINE 05.10(A,4,0,0.2)           VALOUALAC         FINISHED A PIECE         ABRAUOUTINE 05.12(A,4,0.2)	Page 24		ł	4.													
Diff. 1600 23 245:08 16-Jul-86 Pare 23 P0P-11 F000 C C C R C	FTN:6 M1 10:45:08 16-Jul-86 Pare 23 PDP-11 FORT FTN:6 /F77/MR DIFERENCE FOR CLIPL3SBA.F PDP-11 FORT FF(EPS.ED.0.00) THEN FORT FF(EPS.ED.0.00) THEN FORT RETURN RETURN FERVERS FRACK(MPTS) = EPS RETURN RETURN RETURN RETURN RETURN PTS-MPTS-1 PTF(MPTS) = EPS RETURN PTS-MPTS-1 PTF(MPTS) = EPS RETURN PTS-MPTS-1 PT	RAN-77 V4.0-1 10:45:12 16-Jul-86 TN;6 /F77/WR	SUBROUTINE DGIO(A, B, F, ANSWER)	O-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVI	EF.: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.	. H. FRENCH, 28 FEBRUARY 1986	IMPLICIT DOUBLE PRECISION (A-H,O-Z)	COMMON /WTS/ X(5),W(5)	ANSUER=0.00	BMAUZ=(B+A)/2.00 P2402=(B+A)/2.00	07AU2=(87A//2.00) 00 10 1=1 5	C=X(I)*BMA02	Y1=BPA02+C	Y2=BPA02-C	ANSWER=ANSWER+W(I)*(F(Y1)+F(Y2))	CONTINUE	ANSWER=ANSWER+BMAO2	RETURN END
145:08 16-Jul-86 Pare 23 HEN CC 145:08 16-Jul-86 Pare 23 Pare 23 Pare 23 Pare 23 Pare 24 Pare	FTN:6 /FT)/MR 16-Jul-86 Page 23 PI FTN:6 /FT)/MR 10:45:08 16-Jul-86 Page 23 PI FTN:6 /FT)/MR 16:45:08 16-Jul-86 Page 23 PI FTURN END FT FTURN END FTURN END FTURN END FTURN END FTURN END FTURN	DP-11 FORTRA LIPL3SGR.FTN	100			د د د	د 00	603	004	202 202		008	600	010	011	012 10	013	014 015
16-Jul-86 HEN URN	FTNAM-77 VA.0-1 10:45:08 16-Jul-86 FTN:6 /F77/MR IF(EPS.E0.0.00) THEN KODE=2 KODE=	Page 23																
16- 16- URN	TRAM-77 V4.0-1 10:45:08 16- .FTN:6 /F77/MR 10:45:08 16- IF(EPS.Eq.0.D0) THEN RODE=2	յս1-86																
	TRAN-77 V4.0-1 FTN:6 /F77/MR IF(EPS.EQ.0.D0) T KODE=2 REDUR RETURN END IF STACK(NPTS)=EPS 6010 10 V=Y+PL+P2 0 V=Y+PL+P2 T=HEAP(NPTS) MPTS=NPTS-1 AB IF(NPTS.EQ.0) RE1 G010 10 END FOR COLO FOR COLO F	0:45:08 16-									IURN							

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C ALL QR(L,XU,F,Y) C F - WARE CALLING SEQUENCE CALL QR(XL,XU,F,Y) C TOL - ERROR TOLERANCE FOR FIAL ANSWER (IN) C TOL - ERROR TOLERANCE FOR FIAL ANSWER (IN) C HORK - WOPY ARRAY OF SIZE N (IN) C STACK - SECOND WORK ARRAY OF SIZE N, MUST NOT BE SAME ARRAY AS WORK (IN) C HEAP - THIRD WORK ARRAY SIZE N, DISTINCT FROM WORK AND STACK HEAP - THIRD WORK ARRAY SIZE N, DISTINCT FROM WORK AND STACK C H - SIZE OF WORK AND STACK, MAX. NO. OF BISECTIONS (IN) C KODE - ERROR INDICATOR (OUT) C 0 -- WOER ARRAY SIZE N, DISTINCT FROM WORK AND C KODE - ERROR INDICATOR (OUT) C 0 -- WOER ARRAY SIZE N, DISTINCT FROM WORK AND C 1 -- WORK AND STACK, MAX. NO. OF BISECTIONS (IN) C 0 -- WOER ARRAY SIZE N, DISTINCT FROM WORK AND C 1 -- WORK AND STACK, MAX. NO. OF BISECTIONS (IN) C 0 -- WOER AND STACK, MAX. NO. OF BISECTIONS (IN) C 0 -- WOER AND STACK, MAX. NO. OF BISECTIONS (IN) C 0 -- WOER AND STACK ANALL C 1 -- WORK AND STACK ON DIALL C 2 -- EFS DIVIDED TO ZERO, EITHER ASKING FOR TOO TIGHT A TOLERANCE OR ROUND-OFF PREVENTS C ATTAINING REQUIRED ACCURACY SUBROUTINE ADQUA3(XL,XU,Y,QR,F,TOL,MORK,STACK,HEAP,M,KODE) Page 25 XM=(A+B)\*0.5D0 CALL QR(A,XM,F,Pl) CALL QR(XM,B,F,P2) C \*\*\* MAKE IT A RELATIVE TEST FOR THIS INTEGRAL \*\*\* C \*\*\* MAKE IT A RELATIVE TEST FOR THIS INTEGRAL \*\*\* IF(DABS(T-P1-P2).LE.DABS(T\*EPS)) GOTO 20 C SPLIT IT ADAPT'VE QUADRATURE ALGORITHM XL - LONER LIMIT OF INTEGRAL (IN) XU - UPPER LIMIT OF INTEGRAL (IN) Y - VALUE OF INTEGRAL (OUT) GR - MANE OF A QUADRATURE RULE SUBROUTINE (IN) 16-Jul-86 IMPLICIT DOUBLE PRECISION(A-H,O-2) EXTERNAL F DIMENSION WORK(N),STACK(N),HEAP(N) KODE=D 10:45:14 Y=0.D0 WORK(1)=XU CALL QR(XL,XU,F,T) HEAP(1)=T IF(NPTS.GT.N) THEN KODE=1 /F77/MR HEAP(MPTS)=P2 T=P1 EPS=EPS/2.D0 MORK (NP TS) = XM STACK(1)=EPS B=MORK (NPTS) NPTS=NPTS+1 RETURN PDP-11 FORTRAN-77 V4.0-1 CLIPL3SGR.FTN;6 EPS=TOL NPTS=1 EKO IF A=XL C SPLIT ្ឋ ပပ 0018 **100** J-14

 PDP-11
 FORTRAM-77
 V4.0-1
 10:45:14
 16-Jul-86

 CLIPL3SGR.FTN;6
 /F77/MR
 10:45:14
 16-Jul-86

 0028
 IF(EPS.EQ.0.DO)
 THEN
 00:35
 00:30

 0029
 RETURN
 NGDE=2
 00:31
 END
 16

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 RETURN
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 RETURN
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 END IF
 END IF
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 END IF
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PDP-11 CLIPL3S	FORTRAN-77 V4.O-1 10:45:21 16-Jul-R6 Page 29 GR.FTN;6 /F77/WR	P0P-1 CLIPL
1000	SUBROUTINE MINSER(F.FMIN.XMIN.STEP.GUESS.BLIM.ULIM.TOL)	1000
	C SEARCH FOR MINIMUM OF F(X) OVER THE INTERVAL BLIM <= X <= ULIM	1200
	C TROUBLE MAY OCCUR IF F(X) HAS MULTIPLE LOCAL MINIMA WITHIN THE C SEARCH INTERVAL OR IF THE FUNCTION IS VERY STEEP AND STEP IS C TOO BIG.	0023 0024 0024
	C F = MAME OF FUNCTION TO BE MINIMIZED C FMIN = MINIMUM VALUE OF F(X) OVER INTERVAL C VMIN = VALUE OF F(X) OVER INTERVAL	0056 0026
	C STEP = INITIAL STEP STATE FOR SEARCH C STEP = INITIAL STEP STATE FOR SEARCH C GUESS = INITIAL GUESS AT XMIN, BLIM <= GUESS <= ULIM C BLIM = LOWER LIMIT OF SEARCH INTERVAL	6200 8200
	C ULIM = UPPER LINIT OF SEARCH INTERVAL C TOL = TOLERANCE ON XMIN, SEARCH STOPS WHEN DX < TOL	0030 0031 0035
	C NOTE: F MUST BE A DOUBLE PRECISION FUNCTION OF ONE DOUBLE PRECISION C Argument. Any parameters can be passed from the Caller Via C A common block.	0033
	C C PROSRAMMER: ROBERT H. FRENCH DATE: 17 MARCH 1986	0034 0035 0035
ງ-1	L IMPLICIT DOUBLE PRECISION(A-H,0-Z) X-GUESS	0037
ີ້ອີອີ 16	SLMAX=DABS(X-BLIM) SLMAX=DABS(ULIM-X)	0038
900	DX=DMINI(STEP,SLMAX,SUMAX)	6600
		0040
500	FIRENE GOING IN THE RIGHT DIRECTION?	
0010	IF(F1.LE.F0) GOTO 100 C MO. SWITCH DIRECTION	0041
1100	04 - DX 51 - 5( Y - X)	0043
0013	IF(F1.LE.F0) 60T0 100	
	L ELSE ME MUSI BE GLOSE IV A MIN. AI A-GUESS, SU CUI C STEP SIZE AND TRY AGAIN	
0014	DX=DX/10.DO IF(DABS(DX).GE.TEST) GOTO 10	
0016	C CLOSE ENOUGH AT GUESS 12 Xmin+x	
0017 0018	EMIN=FO RETURN	
	C C NOM GOING RIGHT DIRECTION. C KEEP GOING UNTIL PAST MINIMUM BY OME STEP.	
6100	100 X2=X+DX+DX	
0020	C HAVE WE REACHED END POINT? IF(X2.GT.ULIM .OR. X2.LT.BLIM) GOTO 110	

. . . . . . . . . . . . . . . . . . .

2-11 11-11	FORTRAN-77 V4.0-1 10:45:21 16-Jul-86 Page 3 GR.FTW,6 /F77/MR C 411 //	8
-	U ALL UN DIE F2=F(X2) C PAST MINE (X2)	
~	IF(F2.6E.F1) GOTO 200 CMO. STEP AGAIN	
	F0+F1 F1+F2	
	C MIN MAY BE AT AN ENDPOINT. CUT STEP SIZE AND TRY AGAIN	
	110 IF (DABS(DX).LE.TEST) GOTO 120	
	X=X+DX FO=F1	
_	115 0X-0X/10.00	
	60T0 100	
	C MIN MUST BE AT THE ENDPOINT (OR MITHIN MINIMUM DX THEREOF) 120 If(x2,1f brim) Gato 122	
	C MIN AT X=ULIM	
	I21 FM3M=F(XM1W)	
	RETURN C'MIN AT BLIM	
	122 XMIN=BLIM GOTO 121	
	C HAVE PASSED MIN. IS IT LOCATED CLOSELY EMOUGH YET?	
	C NO, CUT STEP SIZE AND TRY AGAIN	
	6070 115 C nowei	
	C SINCE FD >= F1 & F2>= F1 AND ABS(DX) <min. call="" dx,="" f1="" mi<br="" the="">300 FMIN=F1</min.>	Е
	XMIN=X+DX Return	
	END	

7 V4.0-1 SUBROUTI A MESK/FH A JAMMIN JSUB - LLL - PROB - P	GR.FTN:6 GR.FTN:6 SUBROUTI C RANDON MFSN/FH C GIVEN A JUMMIN C C COMMON / S C COMMON / C COMMON / C COMMON / C COMMON / C COMMON / C C FF ANTING C C C C C C C C C C C C C C C C C C C	10:45:25 16-Jul-86 Page 31 /F77/WR	NE PSEL(JSUB,MM,PROB) IN PARTIAL BAND MOISE JAMMING, Convent Little (Iddee Deceived	G CVENT, WITH LLIFTEN MELLIFEN M	DOUBLE PRECISION(A-H.0-2) M JSUB(HM), MORK(30), STACK(30), HEAF(30) DG10, PGRAND NCHNN(0:3)	UPPLATIV NUTARY ABB. BAB, LJAN, AAB2, BAB2, AABBAB, "Dempar/ Bigs, Tau2, Tau3, Tauk, Tauk2, Tauk3 "Parden/ Rhom, Rhot "Parden/ Jamsc "Scjam/ Jamsc	,µM 18+JSUB(I) E WHICH MILL REMAIN IF THIS IS THE MCTHING-JAMMED CASE 00+DSQRT(0.5D0+RHOM),DSQRT(2.D0+TAU))	20 5. JANNED, SET UP JANNING-RELATED QUANTITIES 1.00.(RHOT 16K-1.DO 16K/1.DO	AAB*AAB DO/BK1 BAB+BAB B=AAB*BAB TaU/B15K TAU/215K	2.DO+DSQRT(0.5DO+RHOT),DSQRT(2.DO+TAUK)) OF NONSIGNAL CHANNELS WITH Lm HOPS JAMMED	-0,3  -0 E =2,00 UB(1)
	FORTRAN-7 GR.FTW.6 C GRVENC C GRVENC C GRVENC C GRVENC C C SET U C C C SET U C C C U	7 V4.0-1 /F77	SUBROUTINE P	JSUB - JAM JSUB - JAM HIL - ALM HIL - ALM PROB - ALP	IMPLICIT DO DIMENSION J: EXTERNAL DG INTEGER NCH	COMMON / DEM COMMON / DEM COMMON / PARI COMMON / QUE: COMMON / SCU	DO 6 1=1,MM DO 6 1=1,MM KSUB=KSUB+J, KORTINUE P VALUES MHL Q0=Q(2,DO=D) D1=1,D0	TAUK=0.DO YTHING IS JA IF{KSUB.NE. BIGK=RHON BK1=BIGK- BAB=BIGK-	AB2:=A46* BAB=1.00/ BAB2=BAB* PABBAB=AA TAUK=TAU/ TAUK2=TAU/ TAUK2=TAU/	Q1=Q(2.00 END IF	DO 10 1=0,3 MCHAN(T)=0 CONTINUE DO 11 1=2,4 KSUB=JSUB(1

16-Ju1-86		ITY IN SECTIONS	, PGRAND, 1. D-8, WORK,	DE)	
0-1 10:45:25 /F77/WR	PART ÓF THE DENSITY Ties(Jsub,MM,Ptie)	INUOUS PART OF THE DEMS	-0.00 15ECT=1,3 5ECT=1)*TAU ECT*TAU ADQUAD(XL,XU,CHUMK,DE10	STACK,HEAP,30,KO) TEST2(KODE,10) =PCONT+CHUNK NUE	SETHER 1. DO-PCONT-PTIE 4
FORTRAN-77 V4.( GR.FTN;6	C DO THE TIE O	C DO THE CONT.	PCONT PCONT XL=(15 XU=151 CALL /	CALL . PCONTI	C PUT THEM TOC C PROB=1 RETURI
DP-11	560		041 042 042 043	045 046 047	048 049 050

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-77 V1.A-1 10:45:36 16-Jul-86 Page 36 6 /F77/WR	DOUBLE PRECISION FUNCTION P21(Y) SIGNAL CHANNEL P.D.F. WITH CHANGE OF VARIABLE Y-AX	IMPLICIT DOUBLE PRECISION (A-H,O-Z) DIMENSION MORKI(30), STACKI(30), HEAP1(30) Logical*1 Regi, Reg3 External dgx, F30a1, F30a2, F30b1, F30b2, F31A, F31b1, F31b2, F31b3, F31c2,	F32A, F32B1, F32B2, F32B3, F32C2, F33A1, F33A2, F33B1, F33B2 COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, F01, 102 COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABAB4, TAUE TAUE TAUE TAUE TAUE	COMMON /PARDEN/ RHON, RHCT COMMON /QUES/ 00, Q1 COMMON /XCOM/ XCOM COMMON /OUTER/ XXX, XXXX	IF(LJAM.GE.I) THEN XXXK=Y/BIGK YE-XXX	TIK+TF-IAU2//BIGK YTX2={Y-TAU2}/BIGK END IF REG1=Y.GE.O.DO .AND. Y.LT.TAU	REG2=Y.GE.TAU .AND. Y.LT.TAUZ REG3=Y.GE.TAU2 .AND. Y.LT.TAU3 Tings ying of distance	ITACE HUPS FEN STABUL 60T0 (3100, 3200, 3300, 3400), LJAN+1	NO HOPS JANNED	IF(REG1) THEN B&RG1=DSQRT(12.D0+RHDN+Y) 101-2 Call DXBT(3100)	PZ]={Y/(3.00*RHOM))*DEXP(BARG1-Y-3.D0*RHOM)*B1 ELSE IF(REG2) THEN BARG1=DSQRT(8.00*RHOM*(Y-TAU))	101±1 CALL DXBT(3101) PART=1.500*00*DS0RT(2.00*(Y-TAU)/RHOM)	*DEXP(BARG1_Y+TAU-2.DO*RHOM)*B1 XCOM=Y+3.DO*RHOM CALL ADQUA2(Y-TAU,ANSWER,DGX,F3OA1,1.D-9,WORK1,STACK1,	HEALL TEST2(KOD,3100) PART=PART+ANSWER/2.00
P-11 FORTRAN	000	2222	86 38	88923	2 E <b>2</b> E 2	91.895)	00 85	3000 3000	ىدىر	3100	5885	828		ور تح م
<b>೪</b> ರ	8 8	8888	88	8888	38888	8888	88	8		8888	888	388	000	600 600
Page 33		aab2, bab2, aabbab, , tauk2, tauk3				Page 34			KODE, 101, 102	· FROM CALL NUMBER ', IS)	Page 35			.12," FROM CALL NUMBER ',15)
16-Jul-86	PGRAND(BETA) A-H,O-Z)	BAB, LJAM, TAU3, TAUK,		-		16-Jul-86	açı f	A-H, 0-Z)	az, BI, BZ,	00E = ',12,'	16-Ju1-86		JA2/ADOUA3	04 CODE = ',
NN-77 V4.0-1 10:45:30 N:5 /F77/WR	DOUBLE PRECISION FUNCTION I IMPLICIT DOUBLE PRECISION(A INTEGER NCHAN(0:3) COMMON /SCJAN/ JANSC	COMMON / DEANCHI/ NUMAN COMMON / DEANPAR/ RIGK, AAB, TAU, TAUZ, COMMON / PARDEN/ RHOM, RHOT COMMON / QUES/ Q0, Q1 BEON-1 PO	D0 10.3 D0 11-0.3 IF(MCMM(I).NE.O) THEN LJAM-I X-GL(BETA)	PROD-PROD-DXI(X,NCHAM(I)) END IF CONTINUE LJAM-JANSC V-D7156TAN	PERAND=Y*PROD PERAND=Y*PROD RETURN END	AN-77 V4.0-1 10:45:33 V:6 /F77/WR	SUBROUTINE TEST(ID) STIPM CODE EDAM RESSED ENHO	IMPLICIT DOUBLE PRECISION(A	LUMMUM /LUCALS/ BANGI, BANG IF(KODE.EQ.O) RETURN MRITE(5.1) KODE. ID	I FORMAT(* BESSEL FUNCTION CC 570P 'FATAL ERROR' END	AN-77 V4.0-1 10:45:35 V:6 /F77/WR	SUBROUTINE TEST2(KODE,1D)	SF RETURN CODE FROM ADQUAD/ADQU IF(KODE.EQ.O) RETURN MPTTF(5,1) KODE TO	I FORMAT(' ADAPTIVE INTEGRAT( STOP 'FATAL ERROR' END
PDP-11 FORTR CLIPL35GR.FTI	600 600 600 600 600 60 60 60 60 60 60 60	698 688 888 688	0010 0011 0013 0013 0013	0015 0015 0016 0016 0016 0017 0017 0017 0017 0017	0019 0020 0021	L POP-11 FORTR 1- CLIPL3SEP.FTI	ر <mark>1000</mark>	د د 0003	0005 0005	0006 0007 0008	PDP-11 FORTR CLIPL3SGR.FTI	1000	0003 0003 0003	0004 0005 0006

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7 V4.O-1 10:45:36 16-Jul-96 Page 39 /F77/WR	PART=PART+2.DO+01*ANSWER/BJGK XCOM=Y+2.DO+RH0T+RHON CALL ADQUA2(TAU,Y,ANSWER,DGX,F32B3,1.D-9,WOKK1,STACK1, HEAP1,30,KOC) CALL TEST2(KOD,3304) P211=PART+ANNER(BJGK*BIGK) ELSE IF(REG3) THEN BARG1=DSQRT(4.DO+RHON+(Y-TAU2))	101=0 CALL DXBT(3305) PART=03*01=0EXP(BARG1=Y+TAU2-RHOM)+B2 BARG1=05GRT(4.D0=RHOT+YTK2) 101=1 101=1 CALL DXBT(3306) PART=PART +2.E0=01*00=EXP(BARG1=YTK2-RHOT)*B1/BIGK CALL DXBT(3306) PART=PART CALL ADDUAZ(Y-TAU,TAU,ANSWER,DGX,F33B1,1.D-9,WORK1,STACK1,	CALL TEST2(K0D, 3305) PART=PART+00*ANSMER/(BIGK+BIGK) XCON=YTK+RHOM-RHOI XCON=YTK+RHOM-RHOI XCON=YTK+RHOM-RHOI XCON=YTK+RHOM-RHOI CALL ADQUAZ(Y-TAU, TAU2, ANSWER, DGX, F32C2, 1. D-9, WORK1, STACK1, HEAP1, 30, KOD PART=PART+2. DOP-RHOI - 3306) PART=PART+2. DOP-RHOI - ANSWER/BIGK XCOM=Y+2. DOP-RHOI - RHON	CALL AUQUAZIY - IAU, TAUZ, AMSMER, UGX, F 3283, 1. 0-9, WORKI, STACKI, HEAP1, 30, KOO) Call TEST2(KOG, 3307) P71=PART+AMSMER/(BIGK*BIGK) ELSE P21=0.DO END IF 60T0 9000 THREE HOPS JAMMED	IF(REGI) THEN BARG1=DSGRT(12.D0*RH0T*YK) 101=2 CALL DXBT(3400) PZ1=(Y/(3.D0*RHON))*DEXP(BARG1-YK-3.D0*RHOT)*B1/BIGK ELSE IF(REG2) THEN BARG1=DSGRT(8.D0*RHOT*YTK) 101=1 CALL DXBT(3401) PART=1.5D0*01*BSGRT(2.D0*(Y-TAU)/RHOM) *AFEXP(BARG1-YK-2.D0*(Y-TAU)/RHOM)	XCON+YK+3.DO+RHOT XCON+YK+3.DO+RHOT CALL ADQUA2(Y+TAU,TAU,ANSWER,DGX,F33A1,1.D-9,MORK1,STACK1, HEAP1,30,KOD)
FORTRAN-7 SGR.FTN;6	**	~ ·	~ ~	<b></b> 	ي 200 م	~ ~
PDP-11 CLIPL3:	0121 0122 0123 0124 0125 0126 0127	0128 01120 01130 01130 01131 01132 01132 01132	1000 J-20	0145 0145 0147 0147 0148 0148 0149 0150	0151 0155 0155 0156 0156 0156 0156 0156	0161 0162

Page 40	"HORKI, STACKI,	/BIGK L.D-9,MMKK1,STACK1,	L.D-9,WORK1,STACK1,	
16-Ju1-86	BIGK+BIGK   , DGX,F33A2,1.D-9, )) (; 3) hre1	161 - YTK2 - RHOT) + B1/ MSMER , DGX , F 33B1 , 1	//(BJ&K*BJ&K) MSMER,DGX,F33B2,J )) ,3)	
10:45:36 /F77/WR	EST2(K00, 3400) 4RT+0. 500*AMSMER/ DQUA2(TAU, Y, AMSMER HEAP1, 30, K00 EST2(K00, 3401) RT+AMSMER/DX1(B1GH REG3) THE DOMANTA DOMANTANY	(BT (3402) D0+01+01+0EXP (BM TK+2. D0+RH0T Dqua2 (Y-TAU, TAU2, A HEAP1, 30, KOO SST2(KOD, 3402)	wr 1-3.00-RH0T	
77 V4.0-1	CALL T PART=P PART=P CALL A CALL T PZ1=PA RARG1= RARG1=	TO1-0 CALL D PART=3 CALL A CALL T	CALL A COMENT CALL A CALL T PZ1=PA ELSE PZ1=0.1 END IF	CONTINUE Return End
L FORTRAN- 35GR.FTN;5	~	~	~	0006
PDP-1	0163 0164 0165 0166 0167 0169	0170 0173 0173 0173 0173	0179 0179 0179 0180 0181 0182 0183 0183	0184 0185 0186

14.0-1 10:46:02 16-Ju1-86 Par /F77/MR	.Е. IF(REG3) ТНЕМ M2T=Y-TAU2 M.=1.DO-DEXP(TAU-TAUK-Y)+(AAB+f1.DO+Y)-AABBAB-AAB+Y L=1.DO-DEXP(TAU-TAU2-YK) - BAB2+DEXP(TAU2-TAU2-YK) E. IF(Y.GE.TAU3) ТНЕМ	L = 1.00 E L = 0.00 0 1F	Two hops Janmed Regi) Them A=1.do-bardeyp(-y)-Aardedexp(-yk) A=1.do-bardeyk)	E IF(REG2) ТНЕМ L=1.DO-DEXP(TAUK-YK) *(DEXP(-Y)*(BAB2-BAB#YTK)	+UEXF(=TK)=(MB2-BMBF(=TAUX_)) +2.D0+AABAB+DEXP(TAU-TAUX_Y) 16 IF(REG3) THEN 14=1.D0-DEXP(TAUX-TAU-YK)+(BAB+YTK2 14AB+1.D0+VV)-AABABAP		O 9000 Three hops Jaaned	Y.GE.O.DO .AND. Y.IT.TAU) THEN [1=1.DO-DEXP(-YK)*(1.DD+YK+O.5DO+YK*YK) E. IF(Y.GE.TAU .AND. Y.LT.TAU2) THEN 1=1.DO-DEXP(-YK)*(1.DD+TALK+O.5DO+TAUK*TANK) 	<pre>iE IF(Y.GE.TAU2 .AND. Y.LIT.IDATIK-TIK-TIK-TIK- ii=1.00-DEXP(-YK)*(1.00+2.00+TAUK +0.500*TRW*TAUK-(2.00+TAUK)*YTK2+0.500*YTK2*YTK2)</pre>	1 = 1.00 =
RTRAN-77 V .FTN;6			3300 IF(		••••••••••••••••••••••••••••••••••••••		601	3400	, , ,	
DP-11 FO LIPL3SGR	033 034 035 036	033 041 041	88 970	044 045	046 047	048 049 051 051	500	054 055 056 057	058 059 059	9 061 062 065 9 06 9 06
		. *								
Page 41	CTION	2, BAB2, AABBAB JK2, TAUK3				EXP(-Y)		121)-UEAP(-1)		*DEXP(-Y)  +YMT))+
16-Ju)-86 Page 41	(Y) TRIBUTION FUNCTION	-H.D-Z) AB, LJAM, AAB2, BAB2, AABBAB AU3, TAUK, TAUK2, TAUK3 U	25		), LJAM+1	±DEXP(-Y) U#TAU MT-YMT+YMT)+DEXP(-Y)	Orthouse the second s	U.SUUTTREITREIJ-UEAR(-1)		J+(1.00+AAB+Y)*DEXP(-Y) 
10:46:02 16-Jul-86 Page 41	N FUNCTION GL(Y) UMULATIVE DISTRIBUTION FUNCTION VARIABLE Y=AX	PRECISION (A-H,D-Z) REG2, REG3 BIGK, AAB, RAB, LJAM, AAB2, BAB2, AABBAB TAU, TAU2, TAU3, TAUK, TAUK2, TAUK3 .AND. Y.LT.TAU	.AND. Y.LT.TAJZ .AND. Y.LT.TAJ3 HEN IGK	SYMBOL	0, 3300, 3400), LJAM+1 Jammed	+++0.5DO++++)+DEXP(-Y) HEN +TAU+0.5DO+TAU+TAU +(1.DO+TAU)+*MT+*MT)+DEXP(-Y)	HEN +TAU+TAU+0.5D0*1AU*TAU	DU-LIAUTTHELT-U.SUUTTHELTTHELTTHELTTHELTTHELTTHE	- JANNED	DEXP(-YK)+BAB+(1.DO+AA9+Y)+DEXP(-Y) HEN -YMT)+{DFXP{-YK}+{AA8+{AA8+YMT})+
V4.0-1 10:46:02 16-Jul-86 Page 41 /F77/WR	OUBLE PRECISION FUNCTION GL(Y) GNAL CHANNEL CUMULATIVE DISTRIBUTION FUNCTION 1TH CHANGE OF VARIABLE Y=AX	MPLICIT DOUBLE PRECISION (A-H,D-Z) OGICAL®1 REG1, REG2, REG3 OMMON /DENPAR/ BIGK, AAB, RAB, LJAM, AAB2, BAB2, AABBAB OMMON /DENPAR/ BIGK, AAB, RAB, LJAM, AAB2, BAB2, AABBAB EG1=Y.GE.O.DO .AND. Y.LT.TAU3, TAUK, TAUK2, TAUK3 EG1=Y.GE.O.DO .AND. Y.LT.TAU3	EG2=Y.GE.TAU .AND.Y.LT.TAJ2 EG3=Y.GE.TAU2 .AND.Y.LT.TAU3 F(LJAM.GT.O) THEN YK=Y/BIGK YYK=(Y-TAU)/BIGK	THEE HOPS PER SYMBOL	0T0 (3100, 3200, 3300, 3400), LJAM+1 NO HOPS JAMMED	<pre>F(REG1) THEM EL=1.D0-(1.D0+Y+0.5D0+Y+Y)+DEXP(-Y) ELSE IF(REG2) THEM YMT=Y-TAU GL=1.D0-(1.D0+TAU+0.5D0+TAU+TAU GL=1.D0-(1.D0+TAU)+YMT=YMT=YMT=YMT+YMT+YDEXP(-Y)</pre>	ELSE IF(REG3) THEN YM2T=Y-TAU2 GL=1.D0-(1.D0+TAU+TAU+0.5D0*1AU*TAU		SOTO 900G ONE HOP JAMMED	JF(REG1) THEN GL=1.DO-AAB2*DEXP(~YK)+BAB*(1.OO+AAB+Y)*DEXP(~Y) ELSE IF(REG2) THEN YMT=TAU GL=1 DO-DFXP(_YMT)*(DFXP(-YK)*(AAB*(AAB+YMT))+
FORTRAN-77 V4.0-1 10:46:02 16-Jul-86 Page 41 SGR.FTN;6 /F77/WR	DOUBLE PRECISION FUNCTION GL(Y) C NON-SIGNAL CHANNEL CUMULATIVE DISTRIBUTION FUNCTION C WITH CHANGE OF VARIABLE Y=AX C	IMPLICIT DOUBLE PRECISION (A-H.O-Z) LOGICAL*1 REG1, REG2, REG3 COMMON /DENPAR/ BIGK, AAB, RAB, LJAM, AAB2, BAB2, AABBAB 5 TAU, TAU2, TAU3, TAUK, TAUK2, TAUK3 REG1=Y.GE.O.DO .AND. Y.LT.TAU	REG2=Y.GE.TAU .AND. Y.LT.TAU2 REG3=Y.GE.TAU2 .AND. Y.LT.TAU3 IF(LJAM.GT.O) THEN YK=Y/BIGK YTK=(Y-TAU)/BIGK YTX=/Y-IAU3)/PIGK	END IF C THREE HOPS PER SYMBOL	С 3000 6010 (3100, 3200, 3300, 3400), LJAM+1 С NO HOPS JAMMED	C3100 IF(REG1) THEM GL=1.D0-(1.D0+Y+0.5D0+Y+Y)+DEXP(-Y) ELSE IF(REG2) THEN YMT=Y-TAU GL=1.D0-(1.D0+TAU+0.5D0+TAU+TAU 4 +(1.D0+TAU)+0MT-YMT+DEXP(-Y)	ELSE IF(REG3) THEN YM2T=Y-TAU2 GL=1.DO-(1.DO-TAU+TAU+O.5DOPTAUPTAU	5 -(2.004-JAU)77M2/40.50077M2/17018/1701 ELSE 1F(Y.GE.TAU3) THEN ELSE ELSE ELSE GL=0.DO	GOTO 9006 C ONE HOP JANNED	L 3200 IF(REGI) THEN GL=1.DO-AB2*OEXP(-YK)+BAB*(1.00+AA9+Y)*DEXP(-Y) ELSE IF(REG2) THEN WT=Y-TAU CI II DY-DEXP(-YWT)*(DEXP(-YK)*(AAA+YMT))+

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5/2) 5/2)

PDP-11 FORTRAM-77 V4.0-1 10:46:15 16-Ju1-86 Page 46 CLIPL3GR.FTN;6 /F77/WR	DOOL DOUBLE PRECISION FUNCTION F30A2(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM+0, C SECOND INTEGRAL	DOO2         IMPLICIT DOUBLE PRECISION(A-H,0-Z)           D003         EXTERNAL DETEN, F30ABA           D004         EXTERNAL DETEN, F30ABA           D005         EXTERNAL DETEN, F30ABA           D005         COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102           D005         COMMON /INNORK/ MORK(30), STACK(30), HEAP(30)           D006         COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB,           D007         COMMON /PERDEN/ RHON, RHOT           D008         COMMON /PARDEN/ RHON, RHOT           D009         COMMON /QUES/ Q0, Q1           D009         COMMON /AVCM	DDIO COMMON /OUTER/ XXX, XXXX DDII COMMON /INNER/ NAMK MAAK DDI2 MAMH-U DDI2 CALL ADQUA3(U-TAU,TAU,AMSMER,DGTEN,F30ABA,1.D-10,	S         WORK, STACK, HEAP, 30, KOD           D014         CALL TEST2(K.00, 3112)           D015         BARG1=DSQRT(4, DO*RHOM*(XXX-U))           D016         101=0           D015         D015	0018 F30A2=DEXP[BARG1=XCOM]+B1+ANSNER 0019 RETURN 0020 END	PDP-11 FORTRAM-77 V4.0-1 10:46:17 16-Ju1-86 Page 47 CLIPL3SGR.FTN;6 /F77/MR 3001 DOUBLE PRECISION FUNCTION F30ABA(U)	C C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=0, C SECOND INTEGRAL'S INNER INTEGRAL; ALSO L=3, LJAM=1, SECOMD C REGION, THIRD INTEGRAL, INNER INTEGRAL.	2002 MPLICIT DOUBLE PRECISION(A-H,O-2) 2003 COMMON /LOCALS/ BARG1, BARG2, 81, 82, KODE, IO1, IO2 2004 COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB,	0005 COMMON / PARDEN/ RHON, RHOT 0006 COMMON / QUES/ 00, Q1 0007 COMMON / XCOM/ XCOM	0008 COMMON /DUTER/XXX,XXX 0009 COMMON /INNER/MMN, MAMX 0010 BARG1=DSQRT(4.00*RNOM=U) 0011 CALL DBESI(BARG1,0,B1,KODE)	0012 CALL TEST(13110) 0013 BARG2=DSQRT(4.D0*RHOM*(MMM-U)) 0014 CALL DBESI(BARG2,0,B2,KODE) 0015 CALL TEST(13111) 0016 F30ABA=B1*B2 0017 RETURM 0017 FMD
11 FORTRAN-77 V4.0–1 10:46:11 16–Jul-86 Page 43 JL35GR.FTN;6 /F77/MR	SUBROUTINE BPROD(EDENT) C C compute two bessel functions, arguments and results in common	C IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, TO1, TO2 CALL DXBT(IDEMT) CALL DXBESI(BARG2,TO2,B2,KODE) CALL TEST(IDEMT+1) RETURN E END	-11 FORTRAN-77 V4.O-1 10:46:12 16-Jul-86 Page 44 PL35GR.FTN;6 /F77/WR	11 DOUBLE PRECISION FUNCTION F30AI(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=0, C FIRST INTEGRAL	<ul> <li>IMPLICIT DOUBLE PRECISION (A-H, 0-2)</li> <li>COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, T01, T02</li> <li>COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB,</li> <li>COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, RAB2, AABBAB,</li> <li>COMMON /DENPAR/ BIGK, AAB, TAU3, TAUK, TAUK2, TAUK3</li> </ul>	Decomposition of the second of	0 BARG2=DSQRT(4.DO+RHOM+(XXX-U)) 1 101=1 2 102=0 3 Call BPROD(3110) 3 c-ncort3 Prom(2100)	5 F30A1<5.00-07100 5 F30A1<5*((DEXP(BARG1+BARG2-XCON)+B1)+B2) 6 RETURN 7 END	-11 FORTRAN-77 V4.0-1 10:46:14 16-Jul-86 PL356R.FTN;6 /F77/wR	L SUBROUTINE DXBT(ID) C Call DXBESI AND TEST RETURN CODE	C IMPLICIT DOUBLE PRECISION(A-H,D-Z) COMMON /LOCALS/ BARG2, B1, B2, KODE, IO1, IO2 CALL DXBESI(BARG1,IO1,B1,KODE) CALL TEST(ID) CALL TEST(ID) E PAD P E D

PDP-11 FORTRAN-77 V4.0-1 10:46:23 16-Jul-86 Page 50 CLIPL3SGR.FTN;6 /F77/MR 0001 DOUBLE PRECISION FUNCTION F31A(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=1, C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=1,	C IMPLICIT DOUBLE PRECISION(A-H, D-Z) 0002 COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB, 0003 COMMON /DENPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB, 0005 COMMON /PARDEN/ RHOT 0005 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0006 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0005 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0006 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0005 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0007 COMMON /LOCALS/ BARG1, BARG2, BI, B2, KODE, 101, 102 0008 BARG1=BSQRT(4, DO*RHOT*(XXX, XXX 0009 BARG1=BSQRT(4, DO*RHOT*(XXX, U/BIGK)) 0010 101-0 0011 102-0 0011 102-0 0013 COLL BPRDD(3210) 0014 F31A=DEXP(BARG1+BARG2-XCON)*B1*B2*DSORT(2.DO*J/RHON) RETURN 0016 END	PDP-11 FONTRAN-77 V4.0-1       10:46:25       16-Jul-86       Page 51         CLIPP.35GR.FTN;6       /F77/MR       0018LE       PRCTION FUNCTION F3181(U)         C001       DOUBLE PRECISION FUNCTION F3181(U)       0008LE       PRESION, FIRST INTEGRAL         C       INTEGRAND FUNCTION F3181(U)       13.40%       L3M#1.         C       INTEGRAND FUNCTION F3181(U)       13.40%       L3M#1.         C       C       INPLICIT DOUBLE PRECISION(A-H, 0-2)       ABS2, AABBAB.         D002       IMPLICIT DOUBLE PRECISION(A-H, 0-2)       ABS2, AABBAB.       ABS2, AABBAB.         D003       COMMON /DEENPAR/ BIGK, ABB, BAB, LJAM, ABS2, BABC3, AABBAB.       TAU; TAU2; TAU3, TAUX, TAU3, TAUX, TAUX, TAUX, TAUX, TAUX, TAUX, TAUX, TAU3, TAUX, TAUX, TAUX, TAUX, TAUX, TAU3, TAUX, TAUX, TAUX, TAUX, TAUX, TAU3, TAUX, TAU3, TAUX, TAUX
10:46:20 16-Jul-RK Paop 48 7/WR :ISION FUNCTION F30B1(U) N FOR SIGMAL CHANNEL DENSITY, L=3, LJAM=0, :ST INTEGRAL	BLE PRECISION(A-H, 0-Z) (LS/ BARG1, BARG2, B1, B2, KODE, 101, 102 (AR/ BIGK, AAG, BARG, LOAM, AAB2, BAB2, AAGBAB, TAU, TAU2, TAU3, TAUK, TAUK2, TAUK3 EN/ RHOM, RHOT (Y OD 01 (Y COM (R/ (XY' XXXK 4.D0+RHOM+(U-TAU)) 4.D0+AHOM+(U-TAU)) 4.D0+AHOM+(U-TAU)) 4.D0+AHOM+(U-TAU)) 120) 120) 120)	10:46:21 16-Ju1-86 Page 49 77/MR CISION FUNCTION F30B2(U) ON FOR SIGMAL CHANNEL DENSITY, L=3, LJAM=0, ECOMD INTEGRAL OUBLE PRECISION(A-H, 0-Z) GUELE
SGR.FTN77 V4.O-1 SGR.FTN.56 /F7 DOUBLE PREC C INTEGRAND FUNCTIO C THIRD REGION, FIR	C IMPLICIT DOL COMMON /LOCA COMMON /LOCA COMMON /CUES COMMON /CUES COMON /CUES COMON /CUES COMMON /CUES COMMON /CUES COMMON /CUES C	FORTRAN-77 V4.0-1 SGR.FTN;6 / FF C INTEGRAND FUNCTI C INTEGRAND FUNCTI C SECOND REGION, S C IMPLICIT D EXTERNAL 0 COMMON /IN COMMON /IN COMUN /IN COM

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<ul> <li>ORTRAN-77 V4. O-1 10:46:27 16-Jul-86</li> <li>R. FTY, F. V. O.1 10:46:27 16-Jul-86</li> <li>R. FTY, F. V. O.1 10:46:27 16-Jul-86</li> <li>DOUBLE PRECISION FUNCTION F3182(U)</li> <li>C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, C SECOND REGION, SECOND INTEGRAL</li> <li>THUL, TAUS, /li></ul>	Page 52 PGP-11 FORTRAM-77 V4.O-1 10:46:31 16-Jul-R6 Page 54 CLIPL3SGR.FTW;6 /F77/WR	COOL DOUBLE PRECISION FUNCTION F31C2(U)	L=3, LJAM=1, Č INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=1, C THIKD REGION, SECOND INTEGRAL	DE. 101, 102 B2, BAB2, AABBAB, 0004 0000	0005 COMION / PARDEN/ RHOT 7005 COMION / PARDEN/ RHOT 7005 COMION / QUES/ 00, 01 0007 COMION / XCOM/ XCOM	0008 COMMON /OUTER/ XXX, XXXK 0009 UK-U/BIGK 0000 BADCI ACADAMTA/4VVV HV/	$\begin{array}{c} 0.010 \\ 0.011 \\ 0.012 \\$	0014 CALL BPROD(3130) 0015 F31C2=DEXP(BARG1+BARG2-XCOM-U+UK)+B1+B2 0016 RETURN 0017 END	Page 53 PDP-11 FORTRAN-77 V4.0-1 10:46:33 16-Ju1-86 Page 55 CLIPL35GR.FTN:56 /F77/WR	0001 DOUBLE PRECISION FUNCTION F33A1(U)	L=3, LJAM=1, Č INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=3, C	C         IMPLICIT DOUBLE PRECISION(A-H, D-2)           0002         COMMON / LICIT DOUBLE PRECISION(A-H, D-2)           0013         0003           0014         S           0015         COMMON / LICIT DOUBLE PRECISION(A-H, D-2)           0013         DI 102           0014         S           0015         COMMON / DEHPAR/ BIGK, AMB, BAB, LJM, ADK, BAB2, AABBAB.           0005         COMMON / PARDEN/ RHOM, RHOT           AUK2, TAUK3         D000           AUK2, TAUK3           0005         COMMON / DEHPAR/ BIGK, AMB, BAB2, AABBAB.           0005         COMMON / DEHPAR/ RHOM, RHOT           AUK2, TAUK3         D000           AUK2, TAUK3         COMMON / DUTER/ XXX, XXXK           0005         COMMON / OUTER/ XXX, XXXK           00010         BARG2=DSORT(4.000-RHOT-UK)           0011         BARG2=DSORT(4.000-RHOT-UK)           0012         DO12           0013         DO12           0013         DO12           0013         DO12           0013         DO12           0013         DO12           0014         CALL DOMON / OUTER/ XXX, XXK, UK)           0012         DO12           0013         DO12
	ORTRAN-77 V4.O-1 10:46:27 16-Jul-86 SR.FTN:6 /677/WR	DOUBLE PRECISION FUNCTION F3182(U)	C INTEGRAND FUNCTION FOR SIGNAL CHANKEL DENSITY,	COMMON /LOCALS/ BARGI, RARG2, B1, B2, K0 COMMON /LOCALS/ BARGI, RARG2, B1, B2, K0 COMMON /DEMPAR/ BIGK, ARB, BAB, LJAM, AA	COMMON /PARDEN/ RHON, RHOT COMMON /QUES/ 90, Q1 COMMON /XCOM/ XCOM	COMMON /BUTER/XXX,XXX BARGISORT(4.DOMRHON+U) NV-L/DTCV	BARG2=DS(RT(4.00=RHOT=(XXXK-TAUK-UK)) 101=0 102=0	LUCEV CALL BPROD(3222) F3182=DEXP(BARG1+BARG2-XCON-U+UK)*B1*B2 RETURN END	-0RTRAN-77 V4.0-1 10:46:29 16-Jul-86 38.FTH:6 /F77/WR	DOUBLE PRECISION FUNCTION F31B3(U)	C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY,	C IMPLICIT DOUBLE PRECISION(A-H, 0-Z) EXTERNAL DETEN, F30ABA COMMON /LUCALS/ BAREL, BARG2, B1, B2, KO COMMON /LUCALS/ BAREL, BARG2, B1, B2, KO COMMON /LUCALS/ BAREL, BARG2, B1, B2, KO COMMON /DARDEN/ RHOM, RHOT TAU, TAU2, TAU3, TAU3, TAU4, TA COMMON /PARDEN/ RHOM, RHOT COMMON /DARDEN/ RHOM, RHOT COMMON /COM, XCOM COMMON /JUCK, NHOM, RHOT COMMON /INVER/ XXX, XXXK COMMON /INVER/ XXX, XXXK COMMON /INVER/ MAN, MANK MAN-U MAN-U MAN-U MAN-U MAN-U MAN-U MAN-U MONK, STACK, HEAP, 30, KOD) CALL TEST2(KOD, 3222) UK=U/BIGK BARG1-DSGRT(4.D0-RHOT+(XXXK-UK)) 101=0 CALL DXBT(3222) CALL DXBT(322) CALL DXBT(3222) CALL DXBT(3222) CALL DXBT(3

PDP-11 FORTRAN-77 V4.0-1 10:46:39 16-Ju1-86 Page 58 CLIPL3SGR.FTN;6 /F77/WR	0001         DOUBLE PRECISION FUNCTION F33B1(U)           C         INTEGRAND FUNCTION FOR SIGMAL CHANNEL DENSITY, L=3, LJAM=3, THIRD REGION, FIRST INTEGRAL           0002         INPLICIT DOUBLE PRECISION(A-H, D-2)           0003         COMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0003         COMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0004         SCOMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0005         COMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0006         COMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0006         COMMON /LOCALS/ BARG1, BANG2, B1, B2, KODE, 101, 102           0007         COMMON /LOCALS/ BARG1, BANG2, B1, B3, LJAM, AB3, LJAM, AB3, LJAM, AB3, BABA3, TAU, TAUZ, TAUZ, TAUZ, TAUX, TAUZ, TAUZ, TAUX, TA	PDP-11 FDRTRAM-77 V4.0-1 10:46:41 16-Jul-36 Page 59 Cliplascr.FTN;6 /F77/wr	0001         DOUBLE PRECISION FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=3, C INTEGOAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=3, C SECOND REGION, SECOND INTEGRAL           0002         FINELICIT DOUBLE PRECISION(A-H, 0-2) EVIERNAL DETEN, F33ABA         BN05, UI           0003         COMMON /LOGIEL PRECISION(A-H, 0-2) EVIERNAL DETEN, F33ABA         BN05, UI           0003         COMMON /LOGIEL PRECISION(A-H, 0-2) EVIERNAL DETEN, F33ABA         BN05, UI           0003         COMMON /LOGIEL PRECISION(A-H, 0-2) EVIERNAL DETEN, F33ABA         BN05, TAUX,
PDP-11 FORTRAN-77 Y4.0-1 10:46:35 16-Jul-86 Page 56 CLIPL3SGR.FTN;6 /F77/WR	0001DGUBLE PRECISION FUNCTION F33A2(U)CINTEGRAND FUNCTION FOR SIGNAL CHARNEL DENSITY, L=3, LJAM=3,CSECOND INTEGRAL0003INTEGRAL0004CORPON FUNCTIONE PRECISION(A-H, 0-2)0005EXTERNAL DGTEN, F33ABA0006CORPON /LOCALS/ BARG2, B1, B2, KODE, IO1, IO20005CORPON /LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO20006CORPON /LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO20007CORPON /LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO20008CORPON /LORK/ HORK (30), STACK(30), STACK(30)0009CORPON /LORK/ MAR, ABB, BAB, LJAM, AB2, BAB2, AABRAB,0007CORPON /PARDEN/ RHOM, RHOI0008CORPON /LORES/ 00, Q100010CORPON /LORES/ 00, Q10011COPHON /LORES/ XXX, XXX0012COPHON /LINER/ XXX, XXX0013CALL ADQUAJU-TAU, ANSWER, DGTEN, F33ABA, 1. D-10,0014CALL TEST2(KOD, 312)0015CALL TEST2(KOD, 312)0016BARG10-DS(R1(4, DOPRHOM*(XXXK-UK)))0017CALL DOVER/ORDEL/TONNENTER0018CALL DOVER/ORDEL/TONNENTER0019CALL DOVER/ORDEL/TONNENTER0019CALL DOVER/ORDEL/TONNENTER0010CALL DOVER/ORDE/TONNENTER0011CALL DOVER/ORDE/TONNENTER0012CALL DOVER/ORDE/TONNENTER0013CALL DOVER/ORDE/TONNENTER0014CALL DOVER/ORDE/TONNENTER0015CALL DOVER/ORDE/TONNENTER0016CALL DOVER/ORDE/TONNENTER0017CALL DOVER/ORDE/TONNENTER<	- 0020 RETURN 5 0021 END	PDP-11         FORTRAM-77         V4.0-1         10:46:38         16-Jul-86         Page 57           CL1PL3SGR.FTN;6         /F77/MR         /F77/MR         /F77/MR         Page 57           0001         DOUBLE PRECISION FUNCTION F33ADA(U)         ENTERAND FUNCTION F03.51GNAL CHANNEL BENSITY, L=3, LJAM=2, SECOND         Control INTEGRAL; ALSO L=3, LJAM=2, SECOND           0002         CECTOND INTEGRAL; INTER INTEGRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONDON           0003         CONNON /INTEGRAL; INTERRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONDON           0003         CONNON /INTEGRAL; INTERRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONNON           0003         CONNON /INTEGRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONDON           0003         CONNON /INTEGRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONDON           0003         CONNON /INTEGRAL; MAR, INTEGRAL; ALSO L=3, LJAM=2, SECOND         CONDON         CONDON           0003         CONNON /INTEGRAL; MAR, NUL, TAU3, TAU3, TAU3, TAUS, WIK3         CONDON           0003         CONNON /OUTER/Y KXX, XXX, XXX         CONNON /INTEGRAL MAR, MAR         CONNON /INTEGRAL MAR, MAR           0004         CONNON /INTEGRAL MAR, MAR         CONNON /INTER/ MAR, MAR         CONNON /INTER/ MAR<

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PDP-11 FORTRAN-77 V4.0-1 10:46:48 16-Ju1-86 Page 62 CLIPL3SGR.FTN;6 /F77/WR	0001 DOUBLE PRECISION FUNCTION F32B2(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=2, C SECOND REGION, SECOND INTEGRAL	G002         IPPLICIT DOUBLE PRECISION(A-H, 0-2)           0003         COMMON /LOCALS/ BARGI, BARGZ, BI, B2, KODE, IOI, IO2           0004         COMMON /LOCALS/ BARGI, BARGZ, BI, B2, KODE, IOI, IO2           0005         COMMON /DENPAR/ BIGK, AMB, BAB, LJAM, AAB2, BAB2, AABBAB,           0005         COMMON /DENPAR/ BIGK, AMB, BAB, LJAM, AAB2, BAB2, AABBAB,           0005         COMMON /DENPAR/ RHOM, RHOT           0006         COMMON /PADDEN/ RHOM, RHOT           0007         COMMON /OUTER/ XXX, XXXX           0009         UK=U/BIGK           0010         BARGI=DSQRT(4.DO*RHOT*UK)           0011         D1-0           0012         BARGI=DSQRT(4.DO*RHOT*UK)           0013         D1-0           0014         CALL BPRON(3322)           0015         F322B-EDSQRT(4.DO*RHOT*UK)           0016         BARGI=DSQRT(4.DO*RHOT*UK)           0012         DARGI=DSQRT(4.DO*RHOT*UK)           0013         D2-0           0014         CALL           0015         F322B-EDSQRT(4.DO*RHOT*UK)           0016         BARGI=DSQRT(4.DO*RHOT*UK)           0017         D140           0018         CALL           0019         CALL           0016         FAUCI      <	PDP-11 FORTRAN-77 V4.0-1 10:46:50 16-Jul-86 Page 63 CLIPL3SGR.FTN;6 /F77/WR DDD1 DD146: DD6F1510W ENWETIOW 53222010	C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=2, C SECOND REGION, THIRD INTEGRAL	0002         ]>РР. I.CIT DOUBLE PRECISION(А-H, O-Z)           0003         EXTERNAL DGTEN, F33AA           0004         EXTERNAL DGTEN, F33AA           0005         EXTERNAL DGTEN, F33AA           0006         COMMON / LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO2           0006         COMMON / LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO2           0006         COMMON / LOCALS/ BARG1, BARG2, B1, B2, KODE, IO1, IO2           0006         COMMON / LOCALS/ BARG1, BARG2, BAB2, BAB2, AABBAB, TAUK, TAUK2, TAUK3           0007         COMMON / PARDEN/ RHOM, RHOT           0008         COMMON / PARDEN/ RHOM, RHOT           0009         COMMON / PUES/ON, Q1           0000         COMMON / PUES/ON, Q1           0001         COMMON / VIER/ XXX, XXX           0010         COMMON / INTER/ MM, MMC	0012 WATELY DIGA 0013 WATELK 0014 S. CALL ADQUA3(U-TAU, TAU, ANSWER, DGTEN, F33ABA, I.D-10, 0015 CALL TEST2(KOD, 3322) 0016 BARG1=DSQRT(4.DD*RHOM*(XXX-U)) 0017 D100 0017 D100 0019 F32B3=DEXP(BARG1-XCON-UK+U)*B1*ANSWER 0019 RETURN 0020 RETURN 0021 END
PDP-11 FORTRAN-77 V4.0-1 10:46:44 16-Jul-86 Page 60 CLIPL3SGR.FTN:6 /F77/WR	0001 DOUBLE PRECISION FUNCTION F32A(U) C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=2, C FIRST REGION	0002         1MPLICIT DOUBLE PRECISION(A-H, 0-Z)           0003         COMMON /LCCALS/ BAREL, BAREZ, BL, BZ, KODE, TOL, TOZ           0004         S           0005         COMMON /LCCALS/ BAREL, BAREZ, BIL, BAR, LJAN, AUZ, BRBZ, ANBBAB,           0005         TAU, TAUZ, TAU3, TAUX, TAUK, TAUK2, TAUB, AUZ, BAB, LJAN, AUZ, BAB, LJAN, AUZ, BAB, LJAN, AUZ, BAB, LJAN, AUZ, BAB, COMMON /PARDEN/ RHOT           0006         COMMON /PARDEN/ RHOT           0007         COMMON /PARDEN/ RHOT           0007         COMMON /PARDEN/ RHOT           0007         COMMON /VOUTRY/ XXX, XXXK           0007         COMMON /XCOM           00010         BARGI=DSQRT(4.00-RHOT*UK)           0011         BARGI=DSQRT(2.00-RHOT*UK)           0112         DOIL2           0113         DOIL2           0114         COI-RHOT*UK)           0112         DOIL2           0114         CALL BPROO(3310)           0115         CALL BPROO(3310)           0114         CALL BARG2-XCOM)+B1+B2+DSQRT(2.DO-U/RHON)           0115         CALL BPROO(3310)           0115         CALL BPROO(3310)           0116         CALL BPROO(3310)           0115         CALL BPROO(3310)	C > POP-11 FORTRAM-77 V4.0-1 10:46:46 16-Jul-86 Page 61 O CLIPL3SGR.FTN;6 /F77/MR OOD1 MONBLE PRECISION FINITION F3281/11	C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=2, C SECOND REGION, FIRST INTEGRAL	D002         IMPLICIT DOUBLE PRECISION(A-H, 0-2)           0003         COMMON /LOCALS/ BARGI, BARG2, BI, B2, KODE, 101, 102           0004         COMMON /LOCALS/ BARGI, BARG2, BJ, B2, KODE, 101, 102           0004         COMMON /LOCALS/ BARGI, BARG2, BJ, B2, KODE, 101, 102           0005         COMMON /DENPAR/ BIGK, AAB, BAR, LJAM, AAB2, BAB2, AABBAB,           0005         COMMON /PARDEN/ RHOT           0006         COMMON /PARDEN/ RHOT           0005         COMMON /PARDEN/ RHOT           0006         COMMON /VES/ 00, 01           0007         COMMON /VCDM/ XXX, XXXK           0008         UX=U/BIGK           0010         BARG1=DSQRT(4.00-RHOT*UK)           0011         BARG2=DSQRT(4.00-RHOM*(XXA-U))	0012 102-0 0013 102-0 0015 CALL BPR00(3320) 0015 F32B1=DEXP(BARG1+BARG2-XCOM-UK+U)+B1+B2+S 0015 F32B1=DEXP(BARG1+BARG2-XCOM-UK+U)+B1+B2+S 0017 RETURN 0018 END

Page 65	THAT (7)MU(7)_	2, BAB2, AABBAB, BK2, TAUK3		(1)								
16-Ju1-86	TIE) DECISION GIVEN ' TIED (A-H,0-2) 1 mc(7) 1 HP'	BAB, LJAM, AAB: TAU3, TAUK, TA		(q1,JSUB(1)) ))+DXI(CUE1,JSUB							-	.INC, #4-1, GO)
- 10:46:54 F77/MR	E TIES(JSUB, MM, P ILITY OF CORRECT TED CHANNELS ARE DOUBLE PRECISION	PZLM(2:8) 60 ENPAR/ BIGK, AAB TAU, TAUS	UEST QO, Q1 IGNAL CHANNELS (-TAU)		OOP PARAMETERS		THE TIE EVENTS	kit(nu,llow,m4-1) 1,m4-1 500+nu(1)	)/(1.DO+NUSUM)	().EQ.1) THEN 20D+P2LM(M)	100+(1.00-P2LM(M) **00^115	TER (NU, LLON, LUP, I TO 30 E*PIL
RTRAN-77 V4.0-1 .FTN;6 /1	SUBROUTINI COMPUTE PROBAB SEVERAL SATURA IMPLICIT	CONNON /P	COMPANY // // // // // // // // ////////////	CULLEULENER PILEDXI(Q DO IO I=2 P2LM(I)=0 10 CONTINUE	SET UP VECTOR L	D0 20 I=1 LLOM(1)=0 LINC(1)=1 LUP(1)=1 LUP(1)=1 20 CONTINUE PTIE=0.D00	START LOOP ON T	CALL VLIN 30 NUSUM=0 00 40 1=1 NUSUM=NUS	40 CONTINUE FRAC=1.DO PROD=1.DO	IF (NU(M-) PROD=PR	END=PR00=PR PR00=PR END IF END IF PR0=PR0=PR0=PR0=PR0=PR0=PR0=PR0=PR0=PR0=	CALL VL TI CALL VL TI 1F(GO) GG PTIE=PTIE RETURN FND
PDP-11 FO	000 000 000 000	0004 0005	C 0008 0008 0010 0008 0010 0008 0001 00000 0001 00000 00000 00000 00000 00000 00000 0000	0011 0013 0014 0015 0017		0016 0013 0013 0019 0020 0020 0021		0023 0023 0024 0025	0026 0027 0028	0030 0030 0030	2000 2003 2000 2003 2000 2000	0039 0039 0040
FORTRAN-77 V4.0-1 10:46:52 16-Ju1-86 Page 64 56R.FTN;6 /F77/MR	DOUBLE PRECISION FUNCTION F32C2(U) C C INTEGRAND FUNCTION FOR SIGNAL CHANNEL DENSITY, L=3, LJAM=2, C THIRD REGION, SECOND INTEGRAL	C IMPLICIT DOUBLE PRECISION(A-H.Q-Z) COMMON /LOCALS/ BARG1, BARG2, B1, B2, KODE, 101, 102 COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB, 5 COMMON /DEMPAR/ BIGK, AND, TAU2, TAU3, TAUK, TAUK2, TAUX3	COMMON / PLAUEN/ NHOW, NHUI COMMON / QUES/ QO, QI COMMON / NUTER/ XXX, XXXK UK=U/BIGX BARGI=DSQRT(4,DOMRHOM*(XXX-U))	101=0 BARG2=DSQRT(4.D0+RHOT*(UK-TAUK)) 102=0 CALL BPROD(3330) F32C2=DEXP(BARG1+BARG2-XCOM-UK+U)*B1*B2	RE TURN END							
PDP-11 F CLIPL356	1000	0002 0003 0004	0005 0007 0008 0009 0009 0010	0011 0012 0013 0014 0015	0016 0017	J-27						

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.11 FORTRAN-77 V4.0-1 10:47:01 16-Jul-86 Page 67 PL356R.FTN;6 /F77/WR	L SUBROUTINE SETTAU(MM,PEOO) C SEARCH FOR OPTIMUM THRESHOLD IN ABSENCE OF JANNING	C IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL PUNJAH COMMON /DEMPAR/ BIGK, AAB, BAB, LJAM, AAB2, BAB2, AABBAB, 5 COMMON /PARDEN/ RHON, RHOT, TAU3, TAUK, TAUK2, TAUK3 5 COMMON /PARDEN/ RHOT, RHOT	5 COMMON /QUES/ QO, Q1	Č GUESS BASED ON PRÉVIOUS RESULTS C	8 GUESS=8.00 9 STEP=1.00 1. Erro M-4 (=3 THE POTIMIN THORSAND IS 8.15	CALL MINISER PUNJAM, PEHIN, TAUOPT, STEP, GUESS, 0. DO,	I TAUETAUOPT 2 TAU2=TAU+TAU	3 TAU3=TAU2+TAU 4 PEO0=PEMIN 5 END 6 END
PDP- CL IF	1000		88		88	001(	88	
10:46:59 16-Jul-86 Page 66	RECISION FUNCTION PUNJAM(ETA) NJAMMED P(E) FOR OPT. THRESHOLD SEARCH	EN JAMMING EVENT IS (0,0,,0), THE VARIABLES GK, AAB, BAB, TAUK, TAUK2, AND TAUK3 ARE NOT ED IN THE COMPUTATIONS, AND HENCE DO NOT NEED BE SET UP BEFORE CALLING PSEL FROM THIS FUNCTION	DOUBLE PRECISION(A-H.O-Z) N NGJAM(4) THEFTS/ NEAMU (3) NSI DTS K MM	DENDAR/ BIGK, ANB, BAB, LJAM, AB2, BAB2, AABBAB, DENDAR/ BIGK, ANB, BAB, LJAM, AB2, BAB2, AABBAB,	W/0,0,0,0,0/	+ETA 2+ETA	L ( HO.JAM, HM, P)	
TN:57 V4.0-1	DOUBLE 1 FUNCTION FOR (	MOTE: M B U	DIMENSI	COMMON	DATA NO. LJAM-O TAN-ETA	TAU2=TAU TAU3=TAU	CALL PSI	re turn End
PDP-11 FOR CLIPL3SGR.J	1000		0003 0003	5000	0006 0007 0007	0000	0011 0012	5 8 J-28

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#### APPENDIX K

### COMPUTER PROGRAM FOR SELF-NORMALIZING RECEIVER WITH M=2, L=2

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the self-normalizing receiver when M=2 and L=2, with jamming fraction  $\gamma$  as a parameter.

PDP-11 SELFL2	FORTRAN	-77 V4.0-1 09:50:01 17-Ju1-86 Page 1 3 /F77/TR:BLOCKS/MR	POP-11 FORTRAN SELFL2M2.FTN;1	-77 Y4.0-1 09:50:01 17-Ju1-86 Page 2 3 /F77/TR:BLOCKS/MR
1000	Ĺ	PROGRAM SELF22	0034	JJ=1
	C SELF	NORMALIZING RECEIVER, M=2, L=2	C KEEP	ON GOING
	C PROG	rsis: L.E. Miller Ram: R.H. French	0035 620 0036	D0 700 IJ=JJ,MJ MRITE(5,821) IJ
2000	L)	INPLICIT DOUBLE PRECISION (A-H,0-Z)	0037 821 0038	FORMAT(* IJ = *,13) DBEBNJ=DBJO+{[J-1]*DJ
		PAKAMETER(IM=2, L=2, MSLOTS=2400) CHARACTER-13 FNAME	0039 0040	DEBNJ(1J)=DBEBNJ EBNJ=10.00#*(D8EBNJ/10.D0)
808		REAL DEBNJ(126), PELOG(126) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK	0041 0042	RH0J=E8NJ/2.00 RH0J]=G <b>ayna</b> arh0j
000	**	COMMON /PARMS/ NO, NJ, MG, DEBNOU (5), GAMLST(10), Debnji (126), dj. drja	6000 8400	RHOT=RHOJ) *RHOM/(RHOJ] +RHOM) RTCL=BHOM/PHOT
8000 000	•	CALL ERRSET(29, TRUE., FALSE,, TRUE., FALSE, 15) CALL GET	0045	Call PSUBE(10, PE) Defined 11 = 2016
0100		00 900 [0=1,00 FRMA.=[0 F0A=//ERAMUL/ 70) /10 PO)	0047	PECLORI UNIT=4.FILE=4.FILE=4.STATUS=*OLO*, ACCESS=*APPEND*,
0012		RHOWE EBOO/2.DO Inditi = REBMO/2.DO	6 8900 8900	RRITE(4) DEBNJ(1J), PELOG(1J)
0014			0050 700	CONTINUE CONTINUE
0016		GANNA=GANLST(IG) IQ=GANNA=NSL0TS+0.5D0	0051 \$	OPEN(UNIT=4,FILE=FMAME,STATUS='MEW',ACCESS='SEOUENTIAL', FORM='UNFORMATTED'}
(100 K-1	Ľ	[G0UT=1000.00+GAMMA+0.500	0052	NRITE(4) M. L. DEBNOL(IÓ), GANNA, NSLOTS, NJ, DEBNJ, PELOG CLASEVINITTAN
2	5 P806	tess file	0054	WRITE(6,710) M, L, DEBMOL(10), GAMMA, MSLOTS,
0018 0019	ہم د	WRITE(FWANE,1) 100UT,160UT FORMAT(*522,12.2,14.4,'.DAT')	0055 710 5	FORMAT('ISELF-MORMALZIME RECEIVER FOR M+'II'' AND L=',II/ 5X,'EB/HO = ',EB.5', dB',5X,'EB'MMA'',1P10,3.5X,'MSLOTS=',I4
0020 0021	2	WRITE(5,2) FMAME FORMAT(* MORKIMG ON FILE *,AI3)	0056 800	' EB/NJ (dB)',8X,'P(E)'/ <nj>(4X,OPF4.1,8X,1PD10.3/)) CONTINUE</nj>
0022	<b>بر</b> ر	OPEN(UNIT=4,FILE=FNAME,STATU5**OLD',ERR=810, FORM="UNFORMATTED',ACCESS="SEQUENTIAL")	0057 900 0058	CONTINUE STOP "PLEASE PURGE S22*,DAT"
	C HAVE	A PROGRESS FILE, READ IT	6500	END
0023 0024	• د	READ(4) EBNOIN, GNMMIN, DBJOIN, DJIN If(EBNOIN.NE.DEBNOL(10) .OR. GAMMIN.NE.GAMMA .OR. DBJOIN AF OD NO DO DIN AT NO .TTO .TTO .CON.		
0025 0026	<b>,</b> [a	usualin.me.usua .uk. uulm.me.uu) sior 'File Cukkupi' Jje0 11-11-1		
0027	120	READ(4, END=802) DEBNJ(JJ), PELOG(JJ) GOTO ROI		
6200	802	CLOSE (UNIT=4) 6070 820		
	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	ILE, MUST CREATE IT		
1600	810	OPEN(UNIT=4,FILE=FNAME,STATUS='NEW',FORM='UNFORMATTED', ACFECC-'SECMEMITAL')		
0032 0033	•	WRITE(4) DEBMOL(10), GAMMA, DBJO, DJ CLOSE(UNIT=4)		

SELFL2	2.FTN;13	/F77/TR:BLOCKS/MR		8
1900		SUBROUTIME GET Artige dim papameted tublife	666	847 8
		ALITYE KUM PANAMETEK INTUIS	88	2
000 0000		IMPLICIT DOUBLE PRECISION(A-H,O-Z) DIMENSIGN DGAM(IO), DOLST(5)	88	252
1000		CHARACTER+8 REPLY, BLANKS	8	222
5000	~	LUTTUR / PARTS/ NU, NJ, NG, UEBNOL(2), GATL31(10), DEBNJE (126), DJ, DBJO	88	35
0000	•	DATA DGAM/1.D-3, 2.D-3, 5.D-3, 1 D-3 2 D-3 5.D-3		055
	• ••	1.0-1, 2.0-1, 5.0-1, 1.00/	8	62
0007	*	DATA DOLST/ 13.3524700, 12.313300, 10.9444300, 14.85 16.02713500/	(25300, 00) 00	860
9000	•	DATA BLANKS/' '''''''''''''''''''''''''''''''''''	00	80
6000	~ (	WRITE(5,2)		
0100	2	FUCHMAI(' HUM MANY EB/TU! [II ') Rean(s 3 FRR=1) mn		
0012	m	FORMAT(11)		
0013		IF(NO.EQ.O) NO=1		
0014		JF(MO.LT.O .OK. MO.GT.5) GOIO I DD & TMm1 MO		
0016	4	WRITE(5,5) IN, DOLST(IN)		
0017	ĥ	FURMAT(3X,'EB/NO(',I1,') [',F8.5,' dB]: ',5) dean/e e edd-a) dedv v		
8100 c	9	KEAU(3,0,EKK=4) KEFLI FORMAT(A8)		
0020		IF (REPLY.EQ.BLANKS) THEN		
0021		DEBNOL(IM)=DOLST(IM) Fist		
0023		READ(REPLY,7,ERR=4) DEBNOL(IN)		
0024	~	FORMAT(F8.5)		
0026	æ	CONTINUE		
0027	<b>و</b> 5	WRITE(5,10) Forwart': Hrv Many Cammar [10] : \$)		
0029	3	PEAD(5,11,ERR=9) NG		
0030	11	FORMAT(12) TECHE ER AL ME-10.		
0032		IF(MG.LT.0 .0R. MG.GT.10) GOTO 9		
EE00	;	DO 15 IN=1,NG		
0035	1 1 1 1	Frount(3x, Gamma(', 12,') [', F5.3,']: ', \$)		
0036	;	RLAD(5,14,ERR=12) GAMLST(IN)		
0038 0038	<b>*</b> 1	IF(GANLST(IN).EQ.0.DO) GANLST(IN)=DGAM(IN)		
0039	;	IF (GANLST(IN).LE.0.D0 .OR. GANLST(IN).GT.1.D0) 60T0	12	
	89	LUNIINUE WRITE(5,17)		
0042	17	FORMAT(' HOW MANY EB/NJ? [126] ',\$) Deanls te ede=is) mj		
888	18	FEARING, LA EAN-IV NO		
0045	i	IF(MJ.EQ.0) NJ=126		

1 09:50:10 17-Ju1-86 /F77/TR:8L0CKS/WR DP-11 FGRTRAN-77 V4.0-1 ELFL2M2.FTN;13 / <u>ട</u>്

Page 4

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FF(MJ.LT.0.0R. NJ.GT.126) 6070 16
MAITE(5.20)
FORMAT(' STARTIMG VALUE FOR EB/NJ f0 dB]: ',\$)
FEAD(5.21,ERR=19) DBJO
FEOMAT('5.2)
FEOMAT('5.2)
DJ=0.00
DJ=0.00
FF(MJ.GT.J) THEN
WRITE(5.23)
FORMAT(' INCREMENT FOR EB/NJ f0.4 dB]: ',\$)
FEOMAT(' INCREMENT FOR EB/NJ f0.4 dB]: ',\$)
FEOMAT('5.23)
FORMAT('5.23)
F 22 21 24

COMPUTE FORMALTY No.1.         Desc 15 (CLARC/FNL3)         The TL (FML2)         Operation (CLARC/FNL3)         Desc 15 (CLARC/FNL3) <thdesc (clarc="" 15="" fnl3)<="" th=""> <thdesc (clarc<="" 15="" th=""><th>, HORK , STACK , HEAP ,</th><th>, MORK , STACK , HEAP , ALL '</th><th>Page 7</th><th></th><th>P 246 6</th><th>Page 9</th></thdesc></thdesc>	, HORK , STACK , HEAP ,	, MORK , STACK , HEAP , ALL '	Page 7		P 246 6	Page 9
1.1. Generating and the second sec	FTN;13 /F77/TR:BLOCKS/WR CALL ADQUAD(0.D0,1.D0,PART,D616,F108,1.D-9, 5 IF(KODE.NE.O) STOP 'ADQUAD ERROR SIXTH CALL	PART=PI1*P11*PART PB=PB+PART CALL ADQUAD(0.00,1.00,PART,DG16,F10C,1.0-9, 20,K00E) IF(KODE.ME.O) 5100 *ADQUAD ERROR SEVENTH CA PART=2.00*PI1*P12*PART PART=0.500*DEXP(_RHOT)*(1.00+RHOT/3.DN) PART=0.500*DEXP(_RHOT)*(1.00+RHOT)*(1.00+RHOT/3.DN) PART=0.500*DEXP(_RHOT)*(1.00+RHOT)*(1.00+RHOT/3.DN) PART=0.500*DEXP(_RHOT)*(1.00+RHOT	PE-PB RETURN END KTRAN-77 V4.0-1 09:50:23 17-Ju)-86 .FTN;13 /F77/TR:BLOCKS/WR	DOUBLE FRECISION FUNCTION PIO1(Z) IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK D=1.DD+(BIGK-1.DO)*Z X=BIGK*RHOM*Z/D PIO1=BIGK*DEXP(X-RHOM)*(1.DO+X)/(D*D) RETURN RETURN	<pre>%FTRAN-77 V4.0-1 09:50:25 17-Ju1-86 .FTN:13 /F77/TR:BLOCKS/MR DOUBLE PRECISION FUNCTION P110(2) IMPLICIT DOUBLE PRECISION(A-H,0-2) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK D=BIGK-(BIGK-1.00)*2 X=RHOT*2/D P110-BIGK*DEXP(X-RHOT)*(1.00+X)/(P*D) RETURN RETURN FMD</pre>	FTN:13 FTN:13 FTN:13 FTN:13 FTN:13 FTN:13 FTN:13 FTN:14 FOUBLE PRECISION FUNCTION F01A(V) IMPLICIT DOUBLE PRECISION(A-H.O-Z) COMMON /ROSE/ RHON, RHOM-V)*PIOI(V) F01A=(1.00-V)*0EXP(-RHOM+V)*PIOI(V)
-1.1         00:50:17         17-Jul-56         Рас 5           CONCTINE RIOKS MARET         50:50:17         17-Jul-56         Рас 5           SUBROUTIME FSUBELITY         SUBROUTIME PSUBELITY         50:80:0110         Part 10:00016         Part 10:00017         Part 10:00017	SELFL2M2. 0042 0043	0044 0045 0045 0047 0048 0048 0050 0051 0051	0053 0054 0055 0055 PDP-11 FC	0002 0003 0004 0006 0006 0006 0006 0006 0006	P0P-11 FC SELFL2M2. 0001 0003 0004 0005 0005 0005 0007	0000 0001 0001 0002 0003 0004
-11         F09:50:17         17-Jul-56         P           -11         SUBROUTIME PSUBE(10, FE)         (5:0):1.1-Jul-56         P           SUBROUTIME PSUBE(10, FE)         SUBROUTIME PSUBE(10, FE)         (5:0):1.1-Jul-56         P           SUBROUTIME PSUBE(10, FE)         SUBROUTIME PSUBE(10, FE)         (5:0):1.1-Jul-56         P           SUBROUTIME PSUBE(10, FE)         SUBROUTIME PSUBE(10, FE)         (5:0):1.1-Jul-56         P           SUBROUTIME PSUBE(10, FOLD, FOLD)         FOLD, FOLD         (5:0):1.1-Jul-56         P           SUBROUTIME FSUBE(10, FOLD, FOLD)         FOLD, FOLD         (5:0):1.1-Jul-56         P           SUBROUTIME FSUBROW, PORDABILITIES         COMPARETER (SLOT5-20):5100:5100:5000         P         P           SUBROUTIME PROBABILITY         FOLD, FOLD, FOLD, FOLD, FOLD, FOLD, FOLD         P         P           SUBROUTIME PROBABILITIES         COMPARETER (SLOT5-20)/SLOTFR         P         P         P           SUBROUTIME PROBABILITIES         P		, F10C		itack, heap , itack, heap ,	FACK, HEAP ,	itack "Heap " Itack "Heap "
<pre></pre>	· · · · · · · · · · · · · · · · · · ·	А-Н,О-2) (0) (20), НЕАР(20) (20), НЕАР(20) (20), НЕАР(20) (20), F108, F108 (20), F108	1.07РЯ (НОМ)=(].D0-RHON/3.D0)	(, 16416, FULA, J. J Y. MUNK, ) ERROR FIRST CALL' E. 16616, FO18, 1. 11-9, MORK, S ERROR SECOND CALL'	r,beig,fida,i.d-9,wokk,5 ) Error Third Call' (FF-RSUM) )1*RDIFF+RSUM)	F, DG16, F01C, I. J9, MORK, S DERROR FOURTH CALL' L'D516, F01D, 1, D-9, MORK, S DERROR FIFTH CALL'
	F77/TR:BLOCKS/MR /F77/TR:BLOCKS/MR BROUTIME PSUBE(1Q,PE) ERROR PROBABILITY	PLICIT DOUBLE PRECISION NAMETER (SLOTS=2400.DO) NAMETER (SLOTS=2399.DO) NAMETER (SLOTS=2399.DO) NAMETER (SLOTP=575600. MENSION WORK(20), STACK TERNAL DG16, F01A, F01B, MMON /ROSE/ RHON, RHOT, SCHEMTAL SUGAL DOMARTI	LCENENT	WL ADQUAULU.UU, MUL, WAKI 20, KODE) 20, KODE) 20, KODE) 2000 1000 1100 1000 20, KODE ME 20, KODE 20, KODE ME 20, K	LL DOUAD(0.D0,1.D0,PAR) 20,KODE) 20,KODE) 20,KODE) 20,KODE,NE.0) STOP 'ANDUAD 27-2.00*P10*P13*PART 39-P8+PART 39-P8+PART 3115-FHNM-RHOT 3115-	
	LL TURING THE IS			83# 5383# 5 ~ ~		5 #225 #2

Page 11 Page 14 Page 13 Page 12 Page 10 DOUBLE PRECISION FUNCTION FOID(V) IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /ROSE/ RHON, RHOT, GANMA, BIGK FOID=(1,DO-V)\*DEXP(-RHOT\*V)\*PIO1(V) RETURN END D=V+BICK\*OMV FOI8=PIO1(V)+BICK+DEXP(-V+RHOM/D)+OMV/D RETURN DOUBLE PRECISION FUNCTION FOLC(V) IMPLLCIT DOUBLE PRECISION(A-H,0-Z) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK FOLC=PIOI(V)\*PIIOI(V) DOUBLE PRECISION FUNCTION FIDA(V) INPLICIT DOUBLE PRECISION(A-H.O-Z) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK FIDA=(1.DO-V)+DEXP(-RHOM+V)+P11D(V) RETURN 17-Jul-86 17-Jul-86 DOUBLE PRECISION FUNCTION PIIOI(V) IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /ROSE/ RHON, RHOT, GANHA, BIGK 17-Jul-86 DOUBLE PRECISION FUNCTION FOIB(V) IMPLICIT DOUBLE PRECISION(A-H,O-Z) COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK 17-Jul-86 17~Jul-86 D=B16x+V+OMV P1101=OMV+DEXP(-B16x+RHOT+V/D)/D RETURM 09:50:34 /F77/TR:BLOCKS/MR C 09:50:32 C:09:50:29 P3:50:31 09:50:31 /F77/TR:BLOCKS/MR 09:50:27 /F77/TR:BLOCKS/WR V-00. I=VM0 U-00.1=VM0 PDP-11 FORTRAN-77 V4.0-1 SELFLZM2.FTN;13 PDP-11 FORTRAN-77 V4.0-1 PDP-11 FORTRAN-77 V4.G-1 SELFL2M2.FTN;13 PDP-11 FORTRAN-77 V4.0-1 POP-11 FORTRAN-77 V4.0-1 RETURN B ENG S S SELFLEM2.FTN; 13 SELFL2M2.FTN;13 SELFLZM2 FTN;13 **6**00 **100 6**00 000

17-Jul-86 Page	n F108(V) M(A-H,O-Z) , Gamm, B1gk	17-Jul-86 Page	r FIOC(V) ((A−H,0−Z) <b>Ganna</b> , Bi <b>c</b> x V)≏Pil0(V)
PDP-11 FORTRAM-77 V4.0-1 09:50:35 SELFL2M2.FTN:13 /F77/TR:BLOCKS/W	0001 DOUBLE PRECISION FUNCTION 0002 IMFLICIT DOUBLE PRECISION 0003 COMMON /ROSE/ RHON, RHOT, 0004 F108-P110(V)+P1101(V) 0005 END	PDP-11 FORTRAN-77 V4.0-1 09:50:37 SELFL2M2.FTN,13 /F77/TR:BLOCKS/WR	0001 DOUBLE PRECISION FUNCTION 0002 IMPLICIT DOUBLE PRECISION 0003 COMMON /ROSE/ RHON, RNOT, 0004 FIOC=(1.00-V)≠DEXP(-RHOT* 0005 RETURN 0006 END

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C ADAPTIYE QUADRATURE ALGORITHM C XL - LOWER LINIT OF INTEGRAL (IN) XU - UPPER LINIT OF INTEGRAL (IN) Y - VALUE OF INTEGRAL (OUT) C R - NAWE OF A OUMDANTARE RULE SUBROUTINE (IN) C R - NAWE OF A OUMDANTARE RULE SUBROUTINE (IN) C R - NAWE OF A OUMDANTARE RULE SUBROUTINE (IN) C R - NAWE OF A OUMDANTARE RULE SUBROUTINE (IN) C R - NAWE OF FUNCTION TO BE INTEGRATED (IN) C C - ERROR TOLERANCE FOR FINAL ANSAGER (IN) C NORK - HORK ARRAY OF SIZE M, MUST WIT BE C MORK - HORK ARRAY OF SIZE M, MUST WIT BE C MORK ARRAY OF SIZE M, DISTINCT FROM MORK AND STACK SAME ARRAY S MORK (IN) C N - SIZE OF WORK AND STACK; MAX. NO. OF BISECTIONS (IN) C NODE - ERROR INDICATOR (OUT) SUBROUTINE ADOUAD(XL,XU,Y,QR,F,TOL,MORK,STACK,HEAP,N,KODE) Page 17 I -- WORK ARRAYS TOO SWALL 2 -- EPS DIVICED TO ZERO, EITHER ASKING FOR TOO TIGHT A TOLERANCE OR ROUND-OFF PREVENTS ATTAINING REQUIRED ACCURACY R. H. FRENCH, 14 AUGUST 1984 17-Jul-86 IMPLICIT DOUBLE PRECISION(A-H,O-Z) EXTERNAL F DIMENSION MCKK(N),STACK(N),HEAP(N) KODE=0 Y=0.DG MCK(1)=XU CALL QR(XL,XU,F,T) HEAP(1)=T XM=(A+B)\*0.5500 Call (R(A,XM,F,P1) Call (R(XM,B,F,P2) Call (R(XM,B,F,P2) IF(DABS(T-P1-P2).LE.EPS) 60T0 20 IT 1 09:50:38 /F77/TR:BLOCKS/MR IF(NPTS.GT.N) THEN KODE+1 Return A=XL NPTS=1 EPS=TOL STACK(1)=EPS B=WORK(NPTS) HEAP(NPTS)=P2 T=P1 END IF WORK (NPTS) = XM I+STQN=STQN PDP-11 FORTRAN-77 V4.0-1 SELFL2M2.FTN;13 C SPLIT 30 K-6 0019 0020 0021 0023 0025 0025 0026 0026 1000

EPS=EPS/2.00

L 09:50:38 /F77/TR:BLOCKS/WR TW:13 IF(EPS.EQ.0.00) THEN RETURN END IF STACK(NPTS)=EPS GOTO 10 C FINISHED A PIECE 20 Y=Y+P1+P2 EPS=STACK(NPTS) T=HEAP(NPTS) T=HEAP(NPTS) IF(NPTS.EQ.O) RETURN GOTO 10 Emd NPTS=NPTS-1 A=B PDP-11 FORTRAN-77 V4.0-1 SELFL2M2.FTN;13 0028 0031 0033 0033 0033 0034 0035 0036 0039 0040 0040

Page 18

17-Ju1-86

Page 19 C WEIGHTS AND ABSCISSAS FOR 16-POINT GAUSSIAN QUADRATURE REF .: ABRAMONITZ & STEGUN, Fn. 25.4.30 AND TABLE 25.4 C 16-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL 17-Jul-86 DATA X/ 0.09501250983763744018500, 0.28160355077925691323000, 0.4580167765722738634200, 0.6178762440264374844700, 0.555404408355003033895500, 0.755404408355003033895500, 0.75540408355003033895500, 0.98940093499164933259607800, 0.18945061045506849628500, 0.18945061045506849628500, 0.18959598816576333818900, 0.12452931156543387502303 IMPLICIT DOUBLE PRECISION (A-H,0-Z) DIMENSION X(8), W(8) ANSWER=ANSWER+H(1)\*(F(Y1)+F(Y2)) SUBROUTINE DG16(A,B,F,ANSWER) 1 09:50:41 /F77/TR:BLOCKS/WR R. H. FRENCH, 28 FEBRUARY 1986 ANSWER=ANSWER=BMA02 Return Eni) ANSNER=0.D0 BHAO2=(8-A)/2.D0 BPAO2=(8+A)/2.D0 D0 10 1=1,8 C=X(1)=BNAO2 C=X(1)=BNAO2 Y1=BPA02+C Y2=BPA02-C PDP-11 FORTRAN-77 V4.0-1 SELFL2M2.FTN;13 / CONTINUE 2 0006 0007 0009 0010 0012 0012 0013 0014 0015 0016 0017 0017 0003 0003 0005 **1**000 1000 K-7

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#### APPENDIX L

### COMPUTER PROGRAM FOR SELF-NORMALIZING RECEIVER WITH M=2, L=3

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the self-normalizing receiver when M=2 and L=3. The program searches numerically for the worst-case jamming fraction.



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PDP-11 FORTRAM-77 V4.0-1 10:01:40 17-Jul-86 Page 2 SELFL3M28.FTN;16 /F77/MR	C MO FILE, MUST CREATE IT C MO FILE, MUST CREATE IT C B10 OPEN(UNIT=4,FILE=FNAME,STATUS='WEW',FONDH='UNFORMATTED', C B10 OPEN(UNIT=4,FILE=FNAME,STATUS='WEW',FONDH='UNFORMATTED', ARLITE(4) DEBNOL(10), DBJO, DJ 0038 CLOSE(UNIT=4) 0039 JJ=1	CKEEP 2M 601M6 EXCOLOLIAN: SAVED FF ARRAY C INVALIDATE SAVED FF ARRAY C INVALIDATE SAVED FF ARRAY CONTINE	0071         BIGK-RHOM/RHOT           0072         BIGK1=BIGK-1.D0           0073         A07=1.D0-RH0T-RHOT-RHOT-6.D0           0074         A17=0.550-RH0T-RHOT-8.H0T/6.D0           0075         A17=0.550-RH0T-8.H0T/6.D0           0075         A27=.RH0T+(1.DH-0.500-RH0T)           0076         A27=.RH0T+6.L00           0077         B0_6RH0M+8.
PDP-11 FCRTRAN-77 V4.O-1 10:01:40 17-Jul-86 Page 1 SELFL3M28.FTW;16 /F77/WR	0001 PROGRAM SELF23 C SELF MORMALIZING RECEIVER, M=2, L=3 C ANALYSIS: L.E. MILLER C PROGRAM: R.H. FRENCH C PROGRAM: R.H. FRENCH C METMOD: SELF-CONVOLUTION OF THE MARGINAL DENSITY	0002         IMPLICIT DOUBLE FRECISION (A-H, Q-2)           0003         PARAMETER (LOTFR=575/600. DO)           0005         UGLICL TEST           0005         UGLICL TEST           0005         UGLICL TEST           0006         REAL DEBMU(126), PELOG(126), QOPT(126)           0007         VIRTUAL FEBMU(126), PELOG(126), QOPT(126)           0010         VIRTUAL FEBMU(126), PIL, PI2           0011         SCOMMON /PIES/ PIO, PIL, PI2           0012         COMMON /PIES/ PIO, PIL, PI2           0013         COMMON /PIES/ PIO, PIL, PI2           0014         COMMON /PIES/ PIO, PIL, PI2           0015         COMMON /PIES/ PIO, PIL, PI2           0016         COMMON /PIES/ PIO, PIL, PI2           0011         COMMON /PIES/ PIO, PIL, PI2           0012         COMMON /PIES/ PIO, PIL, PI2           0013         COMMON /PIES/ PIO, PIL, PI2           0014         COMMON /PIES/ PIO, PIL, PI2           0015         COMMON /PIES/ PIO, PIL, PI2           0016         COMMON /PIES/ PIO, PIL, PIZ           0011         COMMON /PIES/ PIO, PIL, PIZ           0012         COMMON /PIC, PIO           0013         CULL EFT           0014         COMMON / PIC, PIC           0015	0028 READ(4) EBMOIN, DBJOIN, DJIN 0029 IF(EBMOIN.NE.DE8MOL(10).0R. 1030 JJ=0 0031 801 JJ=JJ+1 0032 READ-802) DEBNJ(JJ), PELOG(JJ), QOPT(JJ) 0034 802 CLOSE(UNIT=4) 0035 GDT0 801 0035 GDT0 820

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PDP-11 FORTRAM-77 V4.0-1 10:01:40 17-Jul-86 SELFL3M28.FTN,16 /F77/WR	Page 3 POP-11 FOR SELFL3H28.1	TRAN-77 V4.0-1 / 10:01:40 17-Jul-86 Page 4 FTN;16 /F77/WR
0079 CO=RHOT+RHUT+(RHOM-RHOT)+2.DO=RHOM+RHOT 0080 C1=RHOM+(RHOM-RHOT)*(RHOT=RHOT-RHOM+RHUT-R 0081 CALL PSUBE(PE,PEOL0_1Q)	0120 0121 0122	CLOSE(UNIT=4) 700 CONTINUE 0PEN(UNIT=4, FILE=FNAME, STATUS='NEW', ACCESS='SEQUENTIAL', 6PEN='LINE ROMATTED')
0082 P3-PE 0083 IF(P3.GT.P2 .AND. IQ.LT.NSLOTS) THEN C KEEP ON GOING, WE ARE NOT PAST THE MAXIMUM	0123 0124 0125	MRITE(4) M. L. DEBMOL(IO), NSLOTS, NJ, DEBNJ, PELOG, QOPT CLOSE(UNIT=4) MRITE(6,710) M, L, DEBMOL(IO), MSLOTS,
0085 P_1==2 0085 P2=P3 0086 P_10=MI(10+100, MSL0T5)	0126	<pre>\$ (000000000000000000000000000000000000</pre>
0087 (FULL) (FUL		<pre>5</pre>
0089 ELSE 0090 PHAX=DMAXI(P1,P2,P3) 0090 FPGAAA ONIAN=PMAX	0127 0128	800 CONTINUE 900 CONTINUE
0022 TEST=(DABS(P1-P2).LE.EPS .AND. DABS(P1-P 0092 t DABS(P2-P3).LE.EPS)	P3).LE.EPS .AND. 0129 0130	STOP 'PLEASE PURGE S23*.DAT' End
0093 IF(TEST .0R. ID0.E0.1 C. 0R. ((.NOT.TEST) .AND. 10.E0.NS	SLOTS)) THEN	
C WE ARE DONE WHEN ALL 3 ARE CLOSE TOGETHE C DR WHEN WE REACHED FULL-BAND JUMMING AND	ER OR WHEN DQ=1 D P(E) IS STILL	
C INCREASING		
0094 PUP = PHAX 0095 IF (P2.6T.P3) THEN	, 11 s	
	0-1HE 3	
$\frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{10000} \frac{1}{10000} \frac{1}{10000} \frac{1}{100000} \frac{1}{10000000000000000000000000000000000$		
C PREVENT KUUNU-UPP FRUM MAKIMA QUPT V3. ED/NU MAY MOOR IF(1J.GT.1) THEN		
0009 IF(Q0PT(IJ).LT.Q0PT(IJ-1)) Q0PT(I.	J)=00PT(IJ-1)	
0101 ELSE		
C THE OPTIMUM IS FULL-BAND JAMMING		
0104 60T0 665 G105 F1 SE		
C NOT LOCATED SUFFICIENTLY ACCURATELY,	CUT DO AND TRY AGAIN	-
0106 (a=()-00-00 0107 10-100-100		
0108 IDq=10q/2		
0111 P1=0.00		
		· · · ·
0114 6010 709 0115 END IF		
011 000 CEUCUIU)	SS= • APPEND • •	
G119 WRITE(4) DEBNJ(1J), PELOG(1J), QOPT(1J)		

17-Jul-86

10:02:02

IMPLICIT DOUBLE PRECISION(A-H,0-Z) DIMENSION DOLST(5) CHARACTER-8 REPLY, BLANKS COMMON /PALONS/ NO, NJ, DEBNOL(5), COMMON /PALONS/ NO, NJ, DEBNOL(5), DATA DOLST/ 13.35247D0, 12.3133D0, 10.94443D0, 14.89253D0, 16.027135D0/ Page 5 FORWAT(" STARTING VALUE FOR EB/NJ [50 dB]: ',\$) READ(5,21,ERR=19) D8JG FORMAT(F5.2) WRITE(5.5) IN. DOLST(IN) FORMAT(3x.'E8/MO(',11,') [',F8.5,' dB]: ',\$) READ(5,6,ERR-4) REPLY IF(NJ.GT.1) THEN WRITE(5,23) FORMAT(' INCREMENT FOR EB/NJ [-1 dB]: ',5 READ(5,24,ERR=22) DJ FORMAT(F5.0) 17-Jul-86 IF(MJ.EQ.0) MJ=51 IF(MJ.LT.0 .00. MJ.GT.126) 60T0 16 MRITE(5,20) WATTE(5,17) FORMAT(' HOW NANY EB/NJ7 [51] '**.**\$) Read(5,18,E2R=16) N.) WRITE(5,2) FORMAT(\* HOW MANY E8/NO? [1] \*,5) READ(5,3,ERR=1) NO FORMAT(11) READ(REPLY,7,ERR=4) DEBMOL(IN) FORMAT(F8.5) IF(M0.EQ.0) M0=1 IF(M0.LT.0 .0R. M0.ET.5) 60T0 1 IF(DBJ0.EQ.0.00) DBJ0=50.00 DJ=0.00 C INTERACTIVE RUN PARAMETER IMPUTS IF(DJ.EQ.0.00) DJ=-1.00 10:01:57 FORMAT(A8) IF(REPLY.EQ.BLAUKS) THEN DEBNOL(IN)=DOLST(IN) \_/F77/WR SUBROUTINE GET DATA BLANKS/ 00 8 IN+1, NO FORMAT(I3) CONTINUE PDP-11 FORTRAM-77 V4.0-1 SELFL3M28.FTN:16 END IF Return End 18 <u>n</u> ខ្ល ص 1168 1 5 600 L-4 9000 8

CALL ADQUAI(0.00,1.500,PE,DGIOA,PDF,1.0-3,1.0-1, WORK,STACK,HEAP,20,KODE) IF(KODE.ME.0) STOP 'ADQUAI ERROR' PEOLD(1Q)=PE END IF RETURN END C VIE HAVE A SAVED VALUE FROM A LARGER STEP SIZE C IMPLICIT DOUBLE PRECISION(A-H,O-Z) VIRTUAL PEOLO(2400) DIMENSION MORK(20), STACK(20), HEAP(20) EXTERNAL DEIOA, PDF IF(PEOLD(10),ME.-1,D0) THEN C C COMPUTE ELEMENTAL EVENT PROBABILITIES C SUBROUTINE PSUBE(PE, PEOLD, IQ) C C COMPUTE ERROR PROBABILITY C FT/WR PE=PEOLD( 10) ELSE PDP-11 FORTRAN-77 V4.0-1 SELFL3M28.FTN:16 ں 0008 1000 **8**00

Page 8			
7-Jul-86			
  2:03 1.		· · ·	· · · · · · · · · · · · · · · · · · ·
 /uR	EPS 175) 1) Return		
 14.0-1 /F77.	ACK (MPTS)= A PIECE A PIECE 54P1+P2 54STACK (MP 55STACK (MP 55STAC		
TTRAN-77 1 FTN:16			
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Page 7	ið stack ( in)	60T0 20	
	DE) IN) BE MORK AN SECTIONS	.E. ABSTOL)	
`-Ju)-B6	HEAP, N, KGF HEAP, N, KGF HEOUTINE ( HATED (IN) HER (IN) HUST NOT TINCT FRO NO. OF BI	AP(N) AP(N) DABS(T).L	
:03 17	XU,Y,QR,F X,STACK,F MM MM RAL (IN) RAL (IN) RULE SUB RULE SUB RULE SUB FILAL SUB FILAL SUB FILAL SUB FILAL SUB FILAL SUB FILAL SUB FILA FILA FILA FILA FILA FILA FILA FILA	1510M(A-H NCK(N),HE NCK(N),4E STOL)	<b>P-16)</b>
10:02: MR	DQUAL(XL, NOR OF INTEG OF INTE	BLE PRECI RK(N),STA U,F,T) U,F,T) 0 (F,P1) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,P2) (F,T)	I) THEN A S/2.D0,5.
1.0-1 /F77/	COUTINE AL NUMBRATURE LEE LIMIT FER LIMIT FER LIMIT FER LIMIT LE OF A CM LITE CALL CALL CALL CALL CALL CALL CALL CALL	LICIT DOU ERNAL F ENSLON WO 200 0.00 0.00 0.00 0.00 0.00 0.00 0.00	S=#015+1 NPTS-6T.# 006=1 006=1 = TE 1 ETURN 1 (NPTS)=P 1 = DMAX3(EP
RAN-77 V4 TN;16	Subs Subs XL - LON XL - LON XL - LON XL - LON AR - NAN CR - NAN CR - NOR CR -		
P-11 FORTI FL3M28.F1	<ul> <li>&lt; 3 ≤ 3 ≤ 3 ≤ 2 ≤ 2 ≤ 3 ≤ 3 ≤ 3 ≤ 3 ≤ 3 ≤</li></ul>	555588688991175145585 , 5 , 5 , 5 , 5 , 5 , 5 , 5 , 5 , 5 ,	2020 2222 2222 2222 2222 222 222 222 22
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17-Jul-86

10:02:06

IF(MPTS.EQ.0) RETURN GOTO 10 END /F7//IR STACK(NPTS)=EPS 60T0 10 C FINISHED A PIECE EPS=STACK(NPTS) T=HEAP(NPTS) I-ST9N=ST9N Y=Y+P1+P2 PDP-11 FORTRAN-77 V4.0-1 8-4 SELFL3M2B.FTN:16 2 0800 0029

CALL 0R(A,XM,F,P1) CALL 0R(AM,B,F,P2) TEST=OMAX1(EPS\*DABS(T),ABSTOL) IF(DABS(T-P1-P2).LE.TEST .OR. DABS(T).LE.ABSTOL) 60T0 20 C WORK - WORK ARRAY OF SIZE N (IN) C STACK- SECOND WORK ARRAY OF SIZE N, MUST NOT BE C HEAP- THIRD WORK ARRAY, SIZE N, DISTINCT FROM WORK AND STACK C HEAP- THIRD WORK ARRAY, SIZE N, DISTINCT FROM WORK AND STACK C N - SIZE OF WORK AND STACK; MAX. NO. OF BISECTIONS (IN) C KODE - ERROR INDICATOR (OUT) Page 9 C ADAPTIVE QUADRATURE ALGORITHM XL - LOWER LIMIT OF INTEGAAL (IN) XU - UPPER LIMIT OF INTEGAAL (IN) C Y - VALUE OF INTEGAAL (OUT) C R - NAME OF AUADRATURE RULE SUBROUTINE (IN) C NITH CALLING SEQUENCE NITH CALLING SEQUENCE CALL OP(XL, XU, F, Y) C F - NAME OF FUNCTION TO BE INTEGRATED (IN) C OL - ERROR TOLERANCE FOR FINAL ANSWER (IN) C ABSTOL-ABSOLUTE ERROR TOLERANCE (IN) SUBROUTINE ADQUA2(XL,XU,Y,QR,F,TOL,ABSTOL, NORK,STACK,HEAP,N,KODE) 17-Jul-86 IMPLICIT DOUBLE PRECISION(A-H,O-2) EXTERNAL F DIMENSION WORK(M),STACK(N),HEAP(N) KODE=0 Y=0.00 C 0 -- NO ERROR C 1 -- NORK ARRAYS TOO SWALL C R. H. FREMCH, 14 AUGUST 1984 EPS=OMAX1(EPS/2.00,5.0-16) 10:02:06 NPTS=NPTS+1 IF(NPTS.ET.N) THEN KODE=1 CALL QR(XL,XU,F,T) HEAP(1)=T \_/F77/MR 0H=(A+B)+0.500 NORK (NFTS)=XM HEAP (NPTS)=P2 STACK(1)=EPS B=WORK(NPTS) HORK(1)=XU PCP-11 FORTRAN-77 V4.0-1 SELFL3M28.FTN;16 RETURN EP S= TOL I=SLON END IF 1-21 X= C SPLIT -2 0012 0013 0015 0016 0017 0019 0019 0019 0021 0023 0023 0025 0025 0025 0027 0027 1000 0200

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JI-86 Page I				1. BK Dave 13		(2	ssian quadrature										
FORTRAN-77 V4.0-1 10:02:10 17-Ju 128.FTN;16 /F77/WR	STACK(NPTS)=EPS 6010 10 C ETWITCUED A DIFCE	C FINISHEW A FICLE 20 Y=Y+P1+P2 TEPESETACK(NPTS) TEMEAPTC) WDTCAMPTC)	A=B IF(MPTS.EQ.O) RETURN	END FODTDAM -72 VA A_1 10-02-13 12.44	128.FTN:16 /F77/WR	BLOCK DATA IMPLICIT DOUBLE PRECISIOM(A-H,O-2 COMMON /GQWTS/ X(5),M(5)	C C WEIGHTS AND ABSCISSAS FOR 10-POINT GAUS C	DATA X/ 0.148874338991631D0. \$ 0.433395394129247D0. \$ 0.679409568299024D0.	<pre>\$ 0.86506336668898500, \$ 0.97390652851717200 / DATA W/ 0.29552422471475300,</pre>	<b>5</b> 0.26926671930999600, <b>5</b> 0.21908636251598200, <b>5</b> 0.14945134915058100,	\$ 0.06667134430868800 / END						
FUP-11 SELFL30	0029 0030	0031 0033 0033 0033	0035 0036 0037 0037	0038 0038	SELFLOW	000 0003 0003		000	0005		9000						
rage 11					RK AND STACK	(NI) SNOI								ISTOL) 60T0 20			
Ŕ	R, F, TOL, ABSTOL, X, HEAP, N, KODE)	(NI) (NI)	RE SUBROUTINE (IN) NENCE Y)	INTEGRATED (IN) DAL ANSWER (IN) E (IN) W	ZE N. MUST NOT BE N. DISTINCT FROM NO	MAX. NO. OF BISECT	SMALL	M(A-H,0-Z)	N),HEAP(N)				BCT/M )	r .OR. DABS(T).LE.AB			
-ln(-/I	7.0		- 50 -		Z Z	Êğ	<b>38</b> <b>1</b> 00	C1510	TACK				-	TEST			
V4.0-1 IO:02:10 I/-Ju!- /F77/WR	UBROUTINE ADQUA3(XL,XU,Y,Q MORK,STAC	E QUADRATURE ALGORITHM LOMER LIMIT OF INTEGRAL UPPER LIMIT OF INTEGRAL VANIE OF INTEGRAL	MANE OF A QUADRATURE R WITH CALLING SE CALL OR XL, XL, U, F	NAME OF FUNCTION TO B ERROR TOLERANCE FOR F ABSOLUTE ERROR TOLERA	THIRE WORK ARRAY OF THIRE WORK ARRAY OF	SAME ARRAY AS NORK Size of Nork and St Error indicator (ou	0 NO ERROR 1 NORK ARRAYS Rench, 14 August 1	implicit double pre Externál f	NIMENSION MORK(N),S (DDE=0 /=0.D0	NORK(1)=XU Call QR(XL,XU,F,T) EEAP(1)=T	1=XL 10TS=1 :PS=TOL	5TACK(1)=EPS 3=MORK(NPTS) 0==(A+R)=(_5D0	ALL QR(A,XM,F,P1) ALL QR(XM,B,F,P2) ALL QR(XM,B,F,P2)	ESI = UMAXI (EFS=UMBS) [F(DABS(T-P]-P2).LE. [T	PTS=NPTS+] [f(nPTS.GT.N) THEN kone=1	RETURN END IF	AORK (NPTS) = XM HEAP (NPTS) = P2

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POP-11 FORTRAN-77 V4.0-1 10:02:18 17-Jul-86 Page 16 SELFL3M2B.FTN;16 /F77/WR	0001 SUBROUTIME DGIOC(A,B,F,ANSMER) C 10-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL C REF.: ABRAMOMITZ & STEGUM, EO. 25.4.30 AND TABLE 25.4 C R. H. FRENCH, 30 MAY 1966 C R. H. FRENCH, 30 MAY 1966 IMPOINT (A-H, 0-7)	0002 COMPANY (GQNTS/ X(5), 4(15) 0003 COMPANY (GQNTS/ X(5), 4(15) 0006 BPA02=(B-A)/2.00 0005 BPA02=(B-A)/2.00 0007 D0 10 1=1,5 0009 Y1=BPA02=C 0010 1=1,5 0010 T2=BPA02=C 0010 1=1,5 0010 20 10 1=1,5 0011 ANSWER-ANSWER-HU(1)*(F(Y1)+F(Y2)) 0012 10 CONTINUE 0013 ANSWER-ANSWER-BNAAD2 0013 RETURN 0014 END 0015 END	PDP-11         FORTRAM-77         V4.0-1         10:02:20         17-Jul-86         Page 17           SELFL3M28.F7W;16         /F77/MR         /F77/MR         Page 17         Page 17           SELFL3M28.F7W;16         /F77/MR         /F77/MR         Page 17         Page 17           0001         DOUBLE PRECISION FUNCTION PDF(Z)         POF(Z)         Page 17         Page 17           0002         DNPLICIT DOUBLE PRECISION (A-H, 0-Z)         PARAMETER (CUSP=1.00)         PARAMETER (CUSP=1.00)         PARAMETER (CUSP=1.00)           0003         EXTERML DELOB, CONVO2         DONVO2         DONVO2         DONVO2           0004         EXTERML DELOB, CONVO2         DONVO2         DONVO2         DONVO2           0005         DIMENSION WORK(20), STACK(20), MEAP(20)         MEAP(20)         DONVO2           0007         ZEE=Z         DONVO2         DONVO2         DONVO2           0000         VI=MAXIGO DO12-1.00)         YI-1.00)         DO12-1.00)         DO12-1.00)	0000         XU-ENTIAI(2.00.2)           0010         FF(XL.GE.CUSP.OR. XU.LE.CUSP) THEN           0011         STALL ADQUAZ(XL,XU,PDF.DE108,COWV02,1.D-4,1.E-10, IF(XL.GE.CUSP.OR. STACK, HEAP. 20, KODE)           0012         TFF(XOE.ME.O) STOP 'ADQUAZ ERROR'           0013         CALL ADQUAZ(XL,USP,PX,D6108,COMV02,1.D-4,1.E-10, IF(KODE.ME.O) STOP 'ADQUAZ ERROR'           0013         CALL ADQUAZ(XL,USP,PX,D6108,COMV02,1.D-4,1.D-10, IF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0015         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           016         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0015         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0016         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0017         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0018         TF(KODE.ME.O) STOP 'ADQUAZ-1 ERROR'           0019         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0017         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0018         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0019         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           00102         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0011         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0012         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'           0013         TF(KODE.ME.O) STOP 'ADQUAZ-2 ERROR'
PDP-11 FORTRAW-77 V4.O-1 10:02:14 17-Ju1-86 Page 14 SELFL3M28.FTW.16 /F77/MR	COOI SUBROUTINE DGIOA(A,B,F,ANSWER) C 10-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL C REF.: ABRAMONITZ & STEGUN, EQ. 25.4.30 AND TABLE 25.4 C R. H. FRENCH, 30 MAY 1986	0002 IMPLICIT DOUBLE PRECISION (A-H,U-L) 0003 COMMON (20MTS/ X(5), M(5) 0005 BPAQ2-(6-A)/2.DO 0005 BPAQ2-(6-A)/2.DO 0006 BPAQ2-(6-A)/2.DO 0000 II I=1,5 0008 C-X(1)*BPAQ2 0010 II-1,5 0010 ANSMER-M(1)*(F(Y1)+F(Y2)) 0011 ANSMER-MSMER+W(1)*(F(Y1)+F(Y2)) 0013 ANSMER-ANSMER+W(1)*(F(Y1)+F(Y2)) 0014 EFURN 0014 EFURN 0015 EMD	<ul> <li>PDP-11 FORTRAM-77 V4.0-1 10:02:16 17-Jul-86 Page 15 SELFL3M28.FTW;16 /F77/MR</li> <li>SELFL3M28.FTW;16 /F77/MR</li> <li>ODOI SUBROUTIME D6108(A,B,F,ANSMER)</li> <li>ODOI SUBROUTIME D6108(A,B,F,ANSMER)</li> <li>C 10-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL</li> <li>C 10-POINT GAUSSIAN INTEGRATION OVER ARBITRARY INTERVAL</li> <li>C REF.: ABRAMONITZ &amp; STEGUN, EQ. 25.4.30 AND TABLE 25.4</li> <li>C R. H. FREMCH, 30 MAY 1986</li> </ul>	0002       IMPLICIT DOUBLE PRECISION (A-H, D-Z)         0003       COMMON /GQNTS/ X(5), M(5)         0005       BM02=(B-A)/2, DO         0007       DO 10 [1,5         0008       DPA02=(B-A)/2, DO         0007       DO 10 [1,5         0010       DO 11 [1,5         0011       NISHER-0.00         0012       DO 10 [1,5         0013       Y2-BFA02-C         0014       ANSKER-ANGIER-BM02         0015       CONTINUE         0014       END         0015       RETURN

PDP-11 FORTRAM-77 V4.0-1 10:02:22 17-Ju1-86 Page 19 SELFL3M2B.FTN;16 /F77/WR	0038 IF(KODE.NE.O) STOP 'ADQUA3-4' 0039 P2-P2+P11*P11*PART 0040 CALL ADQUA3(YL,YU,PART,DGIOC,F1010,1,D-6,1.D-11, 5 MORK, STACK, HEAP, 20, KODE)	0041 IF(KODE.NE.O) STOP 'ADQUA3-6' 0042 P2=P2+PI1*P11*PART 0043 END IF	0044 IF(PII.NE.0.00 AND. P12.NE.0.00) THEN 0045 CALL ADQUA3(YL,YU,PART,DG10C,F0111,1.0-6,1.D-11, 5 STACK HEAD 20 KADF)	0046 IF (KODE.NE.O) 570P ADQUA3-5' 0047 P2=P2+2.D0+P11+P12+PART 0048 CALL ADQUA3(YL.YU.PART_DG10C.F1011.1.D-6.1.D-11.	\$ 16(K, 00E, 0049 570C, 16AP, 20, KODE) 0049 15(KODE, NE, 0) 570P • 400UA3-7 0050 P2=P2+2.00+P11+P12+PART	0051 EMD IF 0052 CONV02=P2+P1(ZEF W) 0053 RETURN 0054 EMD	PDP-11 FORTRAN-77 V4.0-1 10:02:30 17-Ju1-36 Page 20 Set et anst FTM-16 /F77/MR	0001 DOUBLE PRECISION FUNCTION P1(2) 0001 DOUBLE PRECISION FUNCTION P1(2)	0003 COMON /ROSE/ RHON, RHOT, GAUPLA, BIGK, BIGKI 0004 COMMON /PIES/ PIO, PII, PI2 0005 RNZ=RHOM+Z	0007 PI=PIO*DEXP(RNZ-RHOW)*(1.DO+RNZ) 0008 BKIZ=BIGK1*Z 0008 BKIZ=BIGK1*Z	0010 A=BIGK+NZ/D 0011 P=BIGK+DEXP(A-RHON)+((1.D0+A)/D)/D 0012 D=BIGK-BK1Z	0014 01=01=01=01+BIGK*DEXP(A_RHOT)*((1.00+A)/D)/D) 0014 P1=P1+P12*DEXP(RTZ-RHOT)*(1.00+RTZ) 0016 RETURN 0017 END	PDP-11 FORTRAM-77 V4.0-1 10:02:32 17-Ju1-86 Page 21 SELFL3M28.FTW.16 /F77/WR	0001 DOUBLE PRECISION FUNCTION F0001(Z) 0002 IMPLICIT DOUBLE PRECISION (A-H,0-Z) 0003 COMMON /PASSW/ DUBEVU 0004 F0001=P00(Z)+P01(DUBEYU-Z) RETURN 0005 END
PDP-11 FORTRAN-77 V4.0-1 10:02:22 17-Jul-86 Page 18 SELFL3M28.FTN;i6 /F77/MR	0001 DOUBLE PRECISION FUNCTION CONVO2(W) 0002 INPUIDIT DOUBLE PRECISION(A-H,0-Z) 0003 EXTERNAL DGIOC, FODOL, FODOL, FOILO, FOILI, FI010, 5 EIOIL	0004 DIMENSION MOLL 0005 COMMON /PASSM/ DUBEYU 0005 COMMON /PASSM/ DUBEYU	0007 COMMON / ROSE/ RHOT, GAMMA, BIGK, BIGKI 0008 COMMON / RONCON/ AON, AIN, AZN, A3N, A0T, AIT, AZT, A3T,	OD09         D0000         D00000         D00000 <td>0012 RTT=RH0T+W 0013 RT2=RH0T+W 0013 RT2=RH0T+RH0T 0014 RSUM=RH0T+RH0N</td> <td>0015 TRNT=2.D0+RHOM+RHOT 0016 IF(M.LT.1.D0) THEN 0017 P2=P10+P10+DEXP(RZN-2.D0+RHOM)*W*(1.D0+RZN+RZN+6.D0) 4P12+P12+DEXP(RZT-2.D0+RHOT)*W*(1.D0+RZT+RZT+RZT/6.D0)</td> <td><pre>\$ +2.00*PIO*PI2*(DEXP(RZN-RSUM)*(RHON*R12*W-TRNT) \$ +DEXP(RZT-RSUM)*(RHOT*RHDT*R12*W+TRNT))/ \$ 5 * 50*</pre></td> <td>0019 ELSE 201=4-1.DO 0020 201244-2.DO 0022 201244-2.DO</td> <td>+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2</td> <td><pre>&gt; +2.U0*P10*P12*(UEXP(RHOM=ZM2)*(E0+E1*ZM1) 0022 END IF 0022 END IF</pre></td> <td>0024 TL=UNEXI(0.100,4) 0024 YU=DMINI(1.D0,4) 0025 IF(PIO.NE.0.D0.AND.PI1.ME.0.D0) THEN 0026 CALL ADQUAS(YL,YU,PART,DEIDC,FOOD1,1.D-6,1.D-11,</td> <td>3         MORE, STACK, HEAP, 20, KUDE)           0027         IF(KODE.ME.O) STOP 'ADQUA3-1'           0028         P2=P2+2.DD0+P10+PART           0029         CALL ADQUA3(YL,YU,PART)           0029         STALL ADQUA3(YL,YU,PART)           0020         STACK, HEAP, 20, KODE)           0020         STACK, HEAP, 20, KODE)</td> <td>0031 P2=P2+2.D0*PIO*PI1*PART 0032 EMD IF 0033 IF(PIL.ME.0.00) THEN</td> <td>0034 CALL AUQUAS(YL,YU,PAKI,J6JUC,F0JUL,1.0-6,1.0-11, 0035 IF(KODE.NE.O) STACK, HEAP, 20, KODE) 0036 P2=P2+2.DO+P11*PART 0037 CALL ADQUAS(YL,YU,PART,D61OC,F0110,1.0-6,1.0-11, 0037 S CALL ADQUAS(YL,YU,PART,D61OC,F0110,1.0-6,1.0-11,</td>	0012 RTT=RH0T+W 0013 RT2=RH0T+W 0013 RT2=RH0T+RH0T 0014 RSUM=RH0T+RH0N	0015 TRNT=2.D0+RHOM+RHOT 0016 IF(M.LT.1.D0) THEN 0017 P2=P10+P10+DEXP(RZN-2.D0+RHOM)*W*(1.D0+RZN+RZN+6.D0) 4P12+P12+DEXP(RZT-2.D0+RHOT)*W*(1.D0+RZT+RZT+RZT/6.D0)	<pre>\$ +2.00*PIO*PI2*(DEXP(RZN-RSUM)*(RHON*R12*W-TRNT) \$ +DEXP(RZT-RSUM)*(RHOT*RHDT*R12*W+TRNT))/ \$ 5 * 50*</pre>	0019 ELSE 201=4-1.DO 0020 201244-2.DO 0022 201244-2.DO	+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2+PI2	<pre>&gt; +2.U0*P10*P12*(UEXP(RHOM=ZM2)*(E0+E1*ZM1) 0022 END IF 0022 END IF</pre>	0024 TL=UNEXI(0.100,4) 0024 YU=DMINI(1.D0,4) 0025 IF(PIO.NE.0.D0.AND.PI1.ME.0.D0) THEN 0026 CALL ADQUAS(YL,YU,PART,DEIDC,FOOD1,1.D-6,1.D-11,	3         MORE, STACK, HEAP, 20, KUDE)           0027         IF(KODE.ME.O) STOP 'ADQUA3-1'           0028         P2=P2+2.DD0+P10+PART           0029         CALL ADQUA3(YL,YU,PART)           0029         STALL ADQUA3(YL,YU,PART)           0020         STACK, HEAP, 20, KODE)           0020         STACK, HEAP, 20, KODE)	0031 P2=P2+2.D0*PIO*PI1*PART 0032 EMD IF 0033 IF(PIL.ME.0.00) THEN	0034 CALL AUQUAS(YL,YU,PAKI,J6JUC,F0JUL,1.0-6,1.0-11, 0035 IF(KODE.NE.O) STACK, HEAP, 20, KODE) 0036 P2=P2+2.DO+P11*PART 0037 CALL ADQUAS(YL,YU,PART,D61OC,F0110,1.0-6,1.0-11, 0037 S CALL ADQUAS(YL,YU,PART,D61OC,F0110,1.0-6,1.0-11,

Page 27		Page 28		Page 29			Page 30		
P-11 FORTRAN-77 V4.0-1 10:02:41 17-Ju1-86 LFL3M28.FTN:16 /F77/WR	01 DOUBLE PRECISION FUNCTION FI011(2) 02 INPLICIT DOUBLE PRECISION (A-H.O-Z) 03 COMMON /PASSA/ DUBEVU 04 FI011=P10(2)*P11(DUBEVU-Z) 05 EVD 05 EVD	P-11 FORTKAN-77 V4.0-1 10:02:42 17-141-66	01 000BLE PRECISION FRWTION POG(Z) 02 IMPLICIT DOUBLE PRECISION(A-H,O-Z) 03 C29900H /ROSE/ RHOM, RHUT, CAMMA, BIGK, BIGKL 04 P.C2900H /ROSE/ RHOM-2 RHOM, RHUT, CAMMA, BIGK, 05 RETURN 06 END 06 END	P-11 FURTRAN-77 V4.0-1 10:02:44 17-Ju1-86 LFL3M28.FTN;16 <i>j=77/N</i> R	01 00UBLE PRECISION FUNCTION POI(2) 02 1MPLICIT DOUBLE PRECISION (A-H.O-2) 03 COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK, BIGK 04 RNZ-RHON+2 05 BK12-BIGK1+7 05 D=1.00+BK12 06 D=1.00+BK12 07 A=BIGK+RY2/0 08 POILARICK+NE70(A, BHOM)+6/(1, DNAA)/01/0	10 END	P-11 FORTRAN-77 V4.0-1 10:02:45 17-Jul-86 LeL3M2B.FTN;16 /F77/WR 01 DOUBLE PRECISION FUNCTION P10(2) 02 IMPLICIT DOUBLE PRECISION(A-H,0-2) 03 COMMON /ROSE/ RHON, RHOT, GAMMA, BIGK, BIGK	05 BK12=B16K1+Z 05 D=B16K1+Z 05 0-2017(0)	00 PI-BIGK+DEXP(A-RHOT)+((1.D0+A)/D)/D 09 RETURN 10 END
Page 22 PD	88888	Page 23 FC	85888	Page 24 PG	8888888	Page 25 00	58 888 58 888	Page 25 00	3888
. FORTRAN-77 V4.0-1 10:02:34 17-Ju1-86 M28.FTN;16 /F77/WR	DOUBLE PRECISION FUNCTION FOOJO(Z) IMPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /PASSW/ DUBEYU FOOJO-POO(Z)*PIO(DUBEYU-Z) RETURN END	FCMTRAN-77 V4.0-1 10:02:35 17-Jul-86 M28.FTW;16 /F77/WR	DOUBLE PRECISION FUNCTION FOID1(2) IMPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /PASSW/ DUBFYU FOID1=P01(2)=P01(DUBEYU-Z) RETURN END	L FORTRAN-77 V4.0-1 10:02:37 17-Jul-86 3428.FTN;16 /F77/WR	DOUBLE PRECISION FUNCTION FOIIO(2) IMPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /PASSW/ DUBEYU FOIIO=POI(2)*PIO(DUBEYU-Z) RETURN END	FORTRAM-77 V4.0-1 10:02:36 17-Jul-86 3428.FTN;16 /F77/MR	DOUBLE PRECISION FUNCTION FOILI(2) INPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /PASSA/ DUBEYU FOILI=POI(2)*PII(OUBEYU-Z) RETURN END	FORTRAM-77 V4.0-1 10:02:40 17-Jul-86 M2B.FTN;16 /F77/WR	DOUBLE PRECISION FUNCTION FIDIO(2) IMPLICIT DOUBLE PRECISION (A-H,O-Z) COMMON /PASSA/ DUBEYU FIDIO=PID(2)*PIO(DUBEYU-Z) RETURN END
POP-1: SELFL:	0003 0003 0003 0003 0003 0003 0003 000	POP-1	0001 0001 0005 0005 0005	POP-1	50000000000000000000000000000000000000	POP-1 SELFL	0001 0002 0004 0004 0005	PDP-1 SELFL	0001 0002 0004 0005 0005 0005

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	L-11	P11(Z) A-H.O- GAMMA, D+RHOT						
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<u>87</u>	10:02	RECI PRECI HON, R -RHOT)						
64	77/MR	CISIO OUBLE SE/ RI HOT*Z						
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APPENDIX M

## COMPUTER PROGRAM FOR PRACTICAL ADAPTIVE GAIN CONTROL RECEIVER

The following pages contain the source code listing for the FORTRAN-77 program used for numerical computations of the performance of the practical adaptive gain control receiver for FH/RMFSK.

PDP-11 PACJAG	FORTRAN- C.FTN;7	77 V4.0-1 10:38:25 17-Jul-86 Page 1 /F77/TR:BLOCKS/WR	PDP-11 FOR PACJAGC.FTI	RAN-77 V4.0-1	10:38:25 17-3u1-86 /F77/TR:8L0CKS/WR	Page 2
1000	ſ	PROGRAM PRAC22	0034 L	1-00		
	C PRACI	ICAL ACJ/ASC RECEIVER, M=2, L=2		EEP ON GOING		
	C ANAL!	SIS: L.E. MILLER Ams. R.H. FREMCH	0036 0036	20 D0 700 I	J=JJ,NJ B21) IJ	
	0	14 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 -	0037	21 FORMAT(	[1] = ',13)	
2000		IMPLICIT DUUBLE PRECISIUM (A-H,U)-2) Parameter(m=2, 1=2, NSL0T5*2400)	0039	DEBNJ(1J)	540+(1/11)*DJ )*OBFBK:]	
1000		CHURACTER+13 FNUME	0040	EBNJ=10.	DO**(DBEBNJ/10.D0)	
500 500 500		REAL DEBNJ(126), PELOG(126) Commony /Rocs/ Rhom. Rhot Camma. Rick	0041	RHOJ=EBN RHOJ]=EBN	J/L MMA+RHAJ	
0001		COMMON /PARMS/ NO, NJ, MG, DEBNOL(5), GAMLST(10),	0043	RHOT=RHO.	J1+RHON/(RH0J1+RHON)	
auuu	~	DEBNJL(126), DJ, DBJO Cali Eddeft/20 Trife Faise Tzife Faise 15)	0044	CHA=X918	M/RHOT BELTO DE)	
888		CALL GET	0046	PELOG(1J	)=DLOG10(PE)	
000		D0 900 IO=1,MO FEMALIO POALETENNI (10) 110 MO	0047	INU)NEN(UNI	T=4.FILE=FNAME_STATUS=*OLD*,ACC	CESS='APPEND',
1100		EDRUMILU.UUT"(UEDRUL(IU)/IU.UU) RHOWSERMO/L	0048	A FUN	TE "UNF (ROM LED") DE RNJ(13) _ PELOC(13)	
0013		10001=DEBNOL ( 10)	600	CLOSE ( UN	IT=4)	
0014 100		D0 800 IG=1, NG	0050	00 CONTINUE		
4100 		GATTERATION STORE STO	1600		1=4,F1LE=FNAME_STATUS='NEW',ACC M=*11NFDRMATTFD*1	CESS=' SEQUENTIAL'
4100 M-		IGOUT=1000.D0+6AHMA+0.5D0	0052	MRITE(4)	M. L. DEBNOL(IO), GAMMA, NSLOT	TS, NJ,
2	C DDDCI		MAR 2		DEBNJ, PELOG TT_A\	
			0054	WRITE(6.	710) M. L. DEBNOL(10). GANNA. 1	MSLOTS,
0018	-	WRITE(FRAME,1) 1000/T,1600/T FDDMAT/*R22* 12 2 14 4 * /haT*)	0055	\$ 10 FORMAT(*)	(DEBNJ(1J),10.00++PELOG(1) IPRACYICAL ACJ_AGC RFFFIVER FOR	J),IJ=1,NJ) 8 Mar / 77
00200	4	URITE(5,2) FINAME		S - AND L=	.,11/5X,'EB/NO = '.F8.5,' d8'.5	5X. GAMMA= '
0021	2	FORMAT(* WORKING ON FILE * A13) Adentihity=a file=emane statis="(n)" ed0=a10		S IPDIO.3,	5X,'KSLOTS=','I4/' EB/NJ (dB)',8 NDEA 1 BY 10010 2/11	8X, P(E)'/
7700	~	FORME UNFORMATTED', ACCESS='SEQUENTIAL')	0056	00 CONTINUE	(//c*n1041*vo*1*+140	
	C HAVE	A PROCRESS FILE, READ IT	0057 0058	OC CONTINUE STOP PLI	EASE PURGE 822+ DAT"	
	د، ا		0059	END		
0023		READ(4) EBNOIN, GAPPHIN, DBJOIN, DJIN Iffendin.me dernni/ID) .dr. Gapphin.ne gappaa .dr.				
	~	DBJOIN.ME.DBJO . OR. DJIN.ME.DJ) STOP 'FILE CORRUPT'				
0025	LUB BUI	JJ=0 JJ=1/41				
0027	100	READ(4, END=802) DEBNJ(JJ), PELOG(JJ)				
0028	ţ	60T0 801				
0000	ž	cLUDE(UMI)=4) 60T0 820				
	1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	ILE, MUST CREATE IT				
0031	ر 10	OPERCINTIE4. FILE=FNAME_STATUS=*NEW'_FORM=*UNFORMATTED'_				
0032	~	ACCESS='SEQUENTIAL') MRITE(4) DEBMOL(10), GANMA, DBJO, DJ				
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PDP-11 I	FORTRAN- FTN;7	.77 V4.0-1 10:38:34 17-Ju1-86 Page 3 /F77/TR:BLOCKS/WR	POP-11 FORTRAN-77 V4.0-1 10:38:34 17-Ju1-86 PACJAGC.FTN;7 /F77/TR:BLOCKS/MR	<u>a</u>
1000	C C INTER	SUBROUTIME GET Aactive Rum Parameter Imputs	0046 IF(NJ,LT.0 .0R. NJ.GT.126) GOTO 16 0047 19 NRITE(5,20) 0048 20 FORMAT(' STARTING VALUE FOR EB/NJ [0 dB]: •,5)	
0003 0003	υ	IMPLICIT DOUBLE PRECISION(A-H,O-Z) Dimension dgam(10), dousi(5)	0049 READ(5,21,ERR=19) DBJO 0050 21 FORMAT(F5.2) 0051 DJ=0.D0	
000		CHARACTER+8 REPLY, BLANKS COMMON /PARMS/ NO, M3, NG, DEBNOL(5), GAMLST(10),	0052 IF(NJ.GT.1) THEN 0053 22 MRITE(5,23)	
9000	••••	DATA DGAM/1.D-3, 2.D-3, 5.D-3, 0BJO	0054 23 FORMAT('INCREMENT FOR EB/NJ [0.4 dB1: ',5) 0055 read(5,24,ERR=22) dJ	
	~~	1.D-2, 2.D-2, 5.D-2, 1.D-1, 2.D-1, 5.D-1, 1.DO/	0056 24 FORMAT(F5.0) 0057 24 IF(DJ.EQ.0.00) DJ=0.400	
000	~	DATA DOLST/ 13.35247D0, 12.3133D0, 10.94443D0, 14.89253D0, 16.027135D0/	0058 EWD IF 0059 RETURN	
8000 8000	' <del>-</del>	DATA BLANKS/' '/ WRITE(5,2)	0060 EMD	
00100	2	FORMAT(' HOW MANY EB/NO? [1] '.\$) Read(5,3,Err=1) no	PDP-11 FORTRAN-77 V4.0-1 10:38:42 17-Jul-86 P	Ъ.
0013 0013	m	FORMAT(II) If(n0.Eq.0) n0=1		
0014		IF(NO.LT.0 .0R. NO.GT.5) 6070 1 Do B 1W-1 MO	0001 SUBROUTINE PSUBE(IQ,PE) r	
9100 N	4.	NUTE(5,5) IN, DOLST(IN) RATIE(5,5) IN, DOLST(IN) Fromatics from to in (1 to c c i ad), i t)	Č COMPUTE ERROR PROBABILITY	
à 88 1-3	n	FURTAN (34, EB/MULT,11,1) (1,50.5, 00): ,4) READ(5,6,ERR=4) REPLY	0002 IMPLICIT DOUBLE PRECISION(A-H,0-Z)	
0200 0020	¢	FORMAT(AB) IF(REPLY.EQ.BLANKS) THEN	0003 PARAMETER (SLUTS=2400.00) 0004 PARAMETER (SLUTS]=2399.00)	
0021 0022		DEBMOL(IN)=DOLST(IN) ELSE	0005 PARAMETER (SLOTPR=5757600.00) 0006 DIMENSION WORK(20), STACK(20), HEAP(20)	
0023	٢	READ(REPLY,7,ERR=4) DEBMOL(1W) FORMATIFR.5)	0007 EXTERNAL DGAU20, POF 0008 common /rose/ Rhon, Rhot, Gamma, Bick	
0025	. c	ENDIF	0009 COMMON /PIES/ PIO, PII, PIZ	
0027	00	UNITE(5,10)	C COMPUTE ELEMENTAL EVENT PROBABILITIES	
0028 0029	10	FORMAT(" HOW MANY GUTTA? [JU! "\$) Read(5.11.err=9) ng	0010 C Q=10	
0030	11	FORMAT(i2) is/ac fo 0) actio	0011 P10=(SL0TS-Q)*(SL0TS1-Q)/SL0TPR 0012 P11=0+(SL0TS_0)/SL0TPR	
0032		IF (M6.LT.0. OR. M6.6T.10) GOTO 9	0013 P12=0+(0-1.00)/SLOTPR 0013 P12=0+(0-1.00)/SLOTPR 0014 P12=0+(0-1.00)/SLOTPR	
0034 0034	12	UU IS INTE(5,13) IN,DGAM(IN)	0.14 CALL AUGUAT(U.00,1.00,1.00,100,000)	•
0035 0036	13	FORMAT(3X,'GAMMA(',I2,') [',F5.3,']: ',\$) READ(5,14,ERR=I2) GAMLST(IN)	0015 IF(KODE.NE.O) STOP 'ADQUAL ERROR' 0016 G1+G(1.D0)	
0037 0038	14	FORMATIF8.6) IF(GANLST(IN).EQ.0.DC) GAMLST(IN)=DGAM(IN)	0017 PE=2.D0+PE+61*61 0018 RETURN	
0039 0040	ň	IF(GANLST(IN).LE.0.DO .OR. GAMLST(IN).GT.1.DO) GOTO 12 CONTINUE	0019 END	
0041	16	WRITE(5,17) Fermati' How Many Fr/M1? [126] '.\$)		
6900		READ(5,18, ERR=16) NJ		
0045	10	15(NJ.EQ.0) NJ=126		

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age 7		age B	ර ප රිද
TRAN-77 V4.0-1 10:36:44 17-Ju1-86 P. 4:7 /F77/TR:BLOCKS/WR	FINISHED A PIECE FY+P1+P2 EPS=STACK(NPTS) T=HEAP(NPTS) MPTS=NPTS-1 A=B IF(NPTS.EQ.O) RETURN GUTO 10 END	TRAM-77 V4.0-1 10:38:47 17-Ju1-86 P. N;7 /F77/TP:BLOCKS/WR 17-Ju1-86 P. DOUBLE PRECISION FUNCTION PDF(2) IMPLICIT DOUBLE PRECISION (A-H,0-Z) PDF=F(2)*6(2) RETURN END	RAM-77 V4.0-1       10:38:48       17-Jul-86       P.         N:7       /F77/TR:BLOCKS/WR       10:38:48       17-Jul-86       P.         DOUBLE PRECISION FUNCTION F(X)       PRECISION FUNCTION F(X)       P.       P.         IMPLICIT DOUBLE PRECISION A.       PII. PI2       P.       P.         COMMON /PIES/ PIO, PII. PI2       P.       P.       P.         COMMON /PIES/ PROVE       RNX.X1)*(1.00-RHON/X1)/(X1*X1)       P.       P.         PARTI-DEXP(-RNX/X1)*(1.00-RHON/X1)/(X1*X1)       P.       P.       P.         PART2-BIGK*DEXP(-RNX/D)*(1.00-RHON/D)/(D*D)       P.       P.       P.         PART3-BIGK*DEXP(-RNX/D)*(1.00-RHON/D)/(Y1)/(Y1*X1)       P.       P.       P.         PART3-BIGK*DEXP(-RNX/D)*(1.00-RHON/D)/(Y1)/(Y1*X1)       P.       P.       P.         PART3-BIGK*DEXP(-RNX/D)*(1.00-RHON/D)/(Y1)/(Y1*Y1)       P.       P.       P.         PART3-BIGK*DEXP(-RNX/D)*(1.00-RHON/D)       P.       P.       P.
PDP-11 FOR PACJAGC.FT	0033 0033 0034 0035 0035 0035 0037 0037 0037 0037 0037	PDP-11 FOR PACJAGC.FT 0001 0002 0003 0004 0005	PDP-11 FOR PACJA6C.FT 0002 0005 0005 0013 0013 0013 0015 0015 0015
-11 FORTRAN-77 V4.0-1 10:38:44 17-Jul-86 Page ő Jagc.FTN:77 / / / / / / / / / / / / / / / / / /	SUBROUTINE ADQUAI(XL,XU,Y,OR,F,TOL,ABSTOL, SUBROUTINE ADQUAI(XL,XU,Y,OR,F,TOL,ABSTOL, C ADAPTIVE QUADRATURE ALEORITHM C XL - LOWER LIMIT OF INTEGRAL (IN) C XU - UPPER LIMIT OF INTEGRAL (IN) C Y - VALUE OF ANDRATURE RULE SUBROUTINE (IN) C QR - MANE OF A QUADRATURE RULE SUBROUTINE (IN) C C ALL OR(XL,VE,Y)	C F - WAME CF FUNCTION TO BE INTEGRATED (IN) C TOL - ERROR TOLERANCE FOR FINAL ANSMER (IN) C ABS:0L-ABSOLUTE ERROR TOLERANCE (IN) C MORK - MORK ARRAY OF SIZE N (IN) C MORK - MORK ARRAY OF SIZE N (IN) C HEAP- THIRD MORK ARRAY OF SIZE N, DISTINCT FROM MORK AND STACK (IN) C HEAP- THIRD MORK ARRAY SIZE N, DISTINCT FROM MORK AND STACK (IN) C HEAP- THIRD MORK AND STACK, MAX. MO. OF BISECTIONS (IN) C NOE - ERROR INDICATOR (OUT) C 0 MO ERROR C 1 MORK ARRAYS TOO SMALL	C K. H. FRENCH, 14 AUGUST 1964 EXTERNAL F DIMENSION MORK(N),STACK(N),HEAP(N) DIMENSION MORK(N),STACK(N),HEAP(N) DIMENSION MORK(N),STACK(N),HEAP(N) COLL QR(1)=T COLL QR(1)=T A=XL
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<b>S</b> SS	-86	16K 12*PART2)			
<b>XX</b>	17-Jul	t 6(X) 12 12 • GANENA, 8 • J/XK1 1)/XK1 1/XK +PART3)+P			
X	10:38:51 t:BLOCKS/W	M FUNCTIO PRECISION 10, PI1, 1 HON, RHOT, 1 M/XI)/XI VI/XI)/XI C C-RHON/XK K+RHOT/XK PI1+(PART			
955 675	0-1 /F77/TR	E PRECISIC CIT DOUBLE M /PIES/ F M /ROSE/ F			
	RAN-77 V4.	DOUBI 1001 1001 1001 1001 1000 1000 1000 10			
	PDP-11 FORT PACJAGC.FTN	0001 0005 0006 0006 0006 0006 0007 0001 0011 0011	M-5		
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