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A MODEL FOR PREDICTING PROPAGATION-RELATED DSCS MARGIN REQUIREMENTS

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This technical report describes an analysis of the performance allocations for a satellite link, focusing specifically on a single-hop 7-8 GHz link of the Defense Satellite Communications System (DSCS). The analysis is performed for three primary reasons: (1) to re-evaluate link power margin requirements for DSCS links based on digital signalling; (2) to analyze the implications of satellite availability and error rate allocations contained in proposed MIL-STD-188-323, "System Design and Engineering Standards for Long Haul Digital Transmission System Performance;" and (3) to standardize a methodology for determination of rain-related propagation constraints. The aforementioned methodology is then used to calculate the link margin requirements of typical DSCS Binary/Quaternary Phase Shift Keying (BPSK/QPSK) links at 7-8 GHz for several different earth terminal locations.

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FOREWORD

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I. INTRODUCTION

This technical report describes an analysis of the performance allocations for a satellite link, focusing specifically on a single-hop, 7-8 GHz link of the Defense Satellite Communications System (DSCS). The analysis is performed for three primary reasons: (1) to reevaluate link power margin requirements for DSCS links based on digital signalling; (2) to analyze the implications of satellite availability and error rate allocations contained in proposed MIL-STD-188-323 [1]; and (3) to standardize a methodology for determination of rain-related propagation constraints. The methodology will then be used to calculate the link margin requirements of typical DSCS Binary/Quaternary Phase Shift Keying (BPSK/QPSK) links at 7-8 GHz for several different earth terminal locations.

II. BACKGROUND

It is well known that one of the basic parameters for determining the quality of digital information transmission is the average number of errors that are received by the user. This parameter can be expressed in many ways, the most common methods being bit-error-rate (BER) and error-free-seconds ratio (EFS). The use of EFS is becoming increasingly popular as a performance measure due to its ease of application to digital data transmission systems.

Both error parameters express the same idea; that is, the number of errors per unit of measurement. The BER expresses the average number of incorrect bits received per total bits received and is, therefore, independent of bit rate. (Hence, the confidence level of a BER measurement can vary widely based solely on the measurement time.) The EFS, on the other hand, is based on one second time periods so that two similar transmission paths with identical quantities of errors will have different EFS ratios if they have differing bit rates.

A second basic digital transmission-quality parameter is the availability of the transmission path. In general, the availability of a path is the fraction of all time that the path will perform at a given level of quality. When transmission equipment is not operating or if path propagation degrades the signal below a specified error threshold, the received signal is generally poor and the link is considered to be unavailable. Proposed MIL-STD-188-323 [1] defines the unavailability to be the fraction of time that degradations of worse than BER $= 10^{-4}$ and/or equipment outages exist for durations of one minute or longer. (This definition of unavailability was chosen to be long enough to exhaust most user system internal error control procedures and exclude most propagation outages.) As will be seen later, this new definition of availability will result in a significantly higher apparent availability number of the circuit without changing the actual circuit performance. Pictoral definitions of both the "old" and "new" availabilities are shown in Figures 1 and 2 respectively.

There are two general causes for degradation of link quality. One is equipment malfunction which is reduced by proper equipment design. The second and most significant is attenuation of the transmitted signal by precipitation in the earth-satellite path. Precipitation in the path causes absorption, scattering and depolarization of the transmitted energy and is dependent on a number of factors, including geographic location, season of the year, frequency of the carrier, and elevation angle between the earth station and satellite. For frequencies below 10 GHz (e.g., 7-8 GHz as used by DSCS and hence this report), precipitation in tne form of hail, ice, fog, heavy vapor clouds and snow are insignificant for attenuation purposes and are therefore neglected here. Only rain-related effects will be considered here. The effects of precipitation attenuation may be countered with proper transmitter power control (i.e., margin control), site diversity or by use of forward error-correcting techniques.

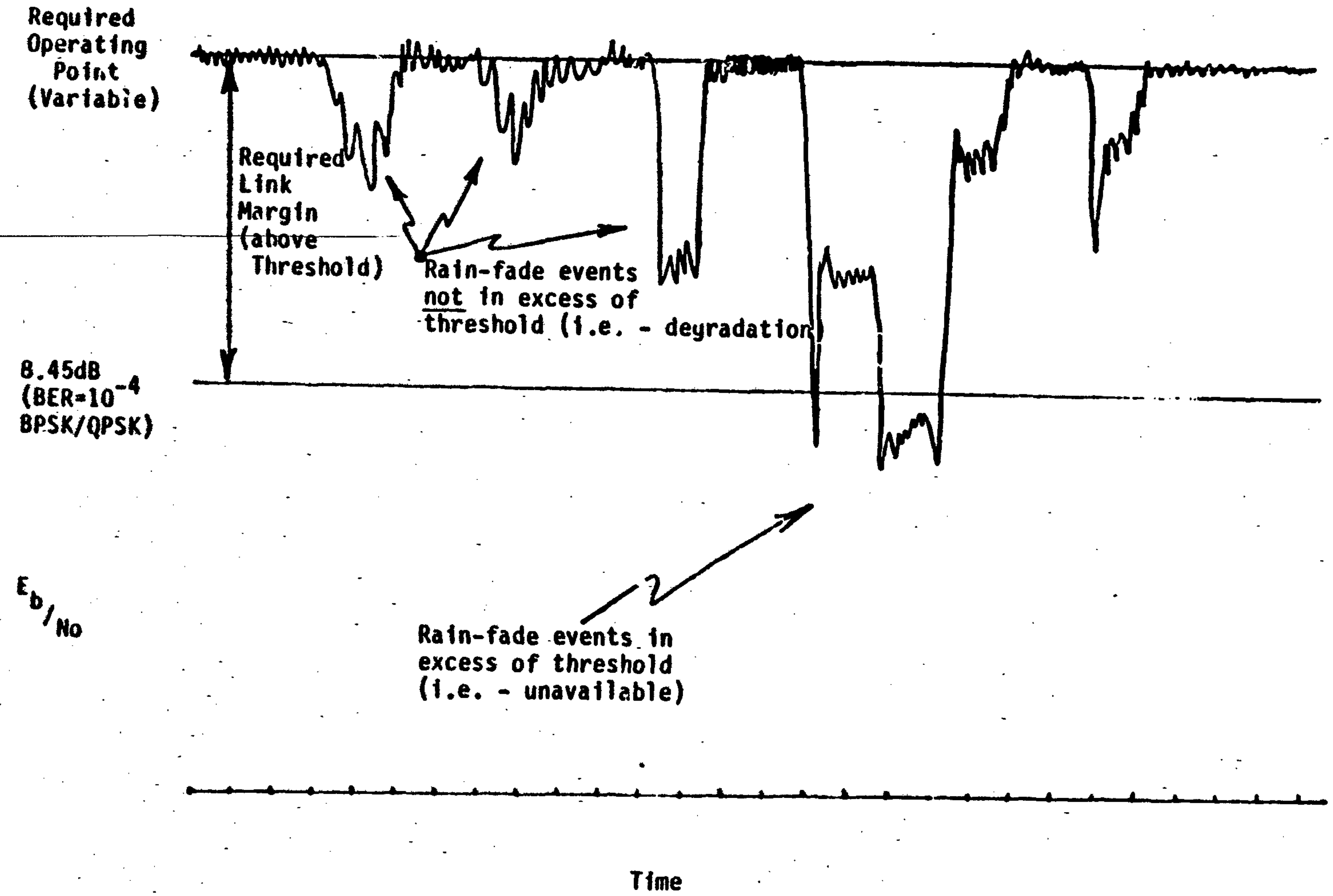

Figure 1. Pictoral Definition of Availability (cld)

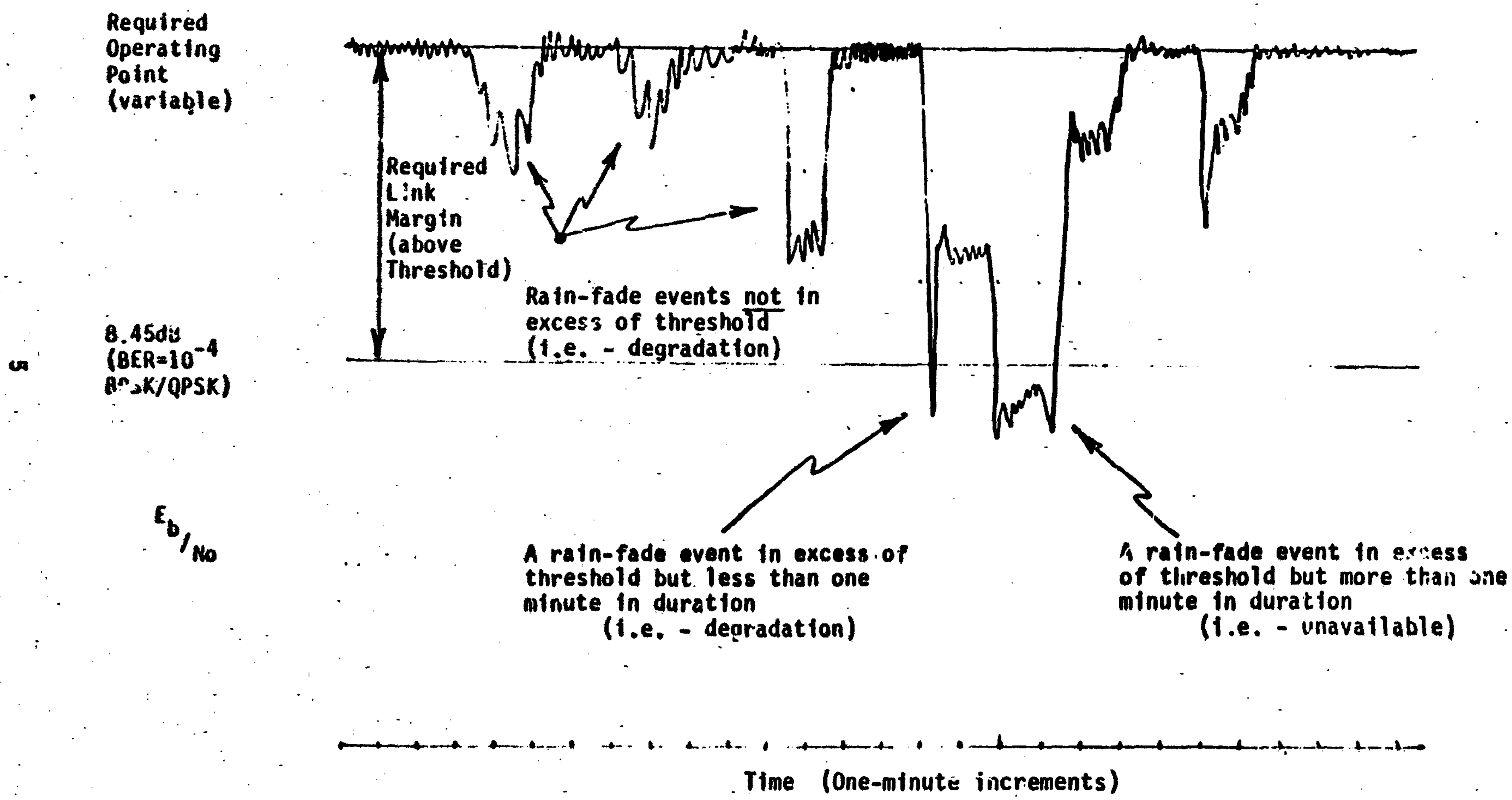

Figure 2. Pictoral Definition of Availability (new)

III. TECHNICAL DISCUSSION

1. PROBLEM DEFINITION

For many years, the nominal "static link margin" for SHF earth-satellite paths has been 6 dB. This 6 dB figure was originally calculated assuming frequency modulation (FM) analog transmission and other factors that are equally obsolete in today's digital transmission environment [2]. To arrive at a relatively accurate digital link margin, the calculation must account for digital modulation techniques, differing earth terminal sites, climates and elevation angles. Given a specific requirement for availability and error rate, each different site should be accounted for independently. Therefore, this discussion will independently calculate required margins, availabilities and error rates for eight current or future DSCS earth terminal sites.

As previously mentioned, the most serious, variable degradation to DSCS signal strength is rain-induced fading. This fading is manifested by absorption and scattering (attenuation) in the path, increase in noise temperature in the path and on the antenna, and depolarization of the transmitted field.

For the purposes of this first approximation to the attenuation problem, the aspects of noise temperature impacts of rain will not be considered.

Depolarization, although more complex, can be easily accounted for because at 7-8 GHz, it very rarely (<.005% of all time) exceeds 1 dB and then only in tropical regions. Therefore, for the purposes of this investigation, depolarization will be neglected.

The most easily understood explanation of the classical development for determination of radio-frequency wave attenuation due to rain is presented by Ippolito [3] and assumes that the intensity of the wave degrades exponentially as it propagates through the volume of rain. The rain drops are generally considered to be spherical and the contributions of each drop are additive and independent of the other drops. The specific attenuation (the often seen $A = aR^b$ relation, where A is the specific attenuation in dB per unit distance, R is the rainrate in units of depth per unit time, and a and b are functions of frequency and rain temperature) is then found from these assumptions. The drops in actual rain are not all uniform in size and three drop-size distributions are commonly used: Laws and Parsons [4], Marshall and Palmer [5], and Joss, et al [6]. The a and b constants used in the $A = aR^b$ relation are dependent on which drop-size distribution is assumed. This relation is used in virtually all of the present rain attenuation models.

Perhaps the most widely used rain models are those developed by R. K. Crane. Crane's two-component model [7] accounts for attenuation due to both convective rain cells (such as a thunderstorm) and widespread light rain regions (referred to as debris), and is most useful for diversity considerations. Crane's Global Model [8] is best used for the statistical estimation of the attenuation distribution for a particular path and assumes a Law and Parsons [4] drop-size distribution.

In a project for the Naval Electronic Systems Command, Feldman, et al [9], have extended Crane's Global Model. The extension is based upon weather observations and statistical determinations at a number of selected sites and frequencies of Navy interest. The model retains Crane's "rain-rate regions" although correction factors are calculated to account for statistical variations within each region. Another extension of the Crane global model made by the Feldman model is the division of annual rain statistics into seasonal values. The model developed by Crane and extended by Feldman, et al, is the model used for this investigation.

One DSCS earth terminal site in each of Crane's rain-rate regions was selected for analysis in this investigation.

2. METHODOLOGY

In the following analysis, the goal is to compute required link margin for selected DSCS sites given the new availability and error-free second allocation contained in the draft standard. To accomplish this, the problem is worked somewhat in reverse. That is, using a mathematical model which translates the new definition of availability (with the one-minute time criteria) to the old availability (independent of time), a link margin to meet a required 10^{-4} BER is determined. The fine-grain structure of rain-induced fades below the 10^{-4} BER threshold is then analyzed to determine on a statistical basis, those fades of duration less than one minute which contribute to error-free second performance vice those of greater than one minute duration which contribute to unavailability. Summing fade contributions to error-free second performance with error-free second contributions when no rain is occurring then yields the overall error-free second performance for the link. This process is then iterated until a link margin is determined which yields an error-free second availability performance consistent with the allocations in proposed MIL-STD-188-323.

Specific steps in the analysis are as follows:

a. When considering weather-related phenomena, it is relatively simple to understand that certain periods of the year produce degradations that are, on the average, better or worse than other periods. As stated previously, the Feldman, et al, report divides the annual rainfall statistics into four three-month "seasons". For a worst-case analysis, such as this investigation, the worst three-month "season" is determined for use throughout the calculation.

b. As stated in section II, two definitions of availability exist and a method of mathematically transitioning from one to the other is developed.

c. Having identified the worst season and "new" availability (with the one-minute time criteria), one must first convert the "new" availability to the "old" availability. Then is is possible to determine the required link margin needed to achieve this required availability (based upon the "new" or "old" availability).

d. It is known that fade durations span the range of one or two seconds to many minutes. Because of the "new" availability definition, the depth of fades with durations under one minute and those of greater than one minute are required for a thorough analysis. Using the models of Feldman, et al, these depths can be calculated and the corresponding error rates determined.

e. Having found the error rates for the various fractions of time —i.e., rain fades less than threshold, rain fades more than threshold with durations of less than one minute, and rain fades more than threshold with durations of greater than one minute—the next logical step is to add the fractions in a manner as to determine the overall error rate.

f. The analysis will then be concluded by taking a given margin and calculating the resultant availability and error rate.

3. CALCULATIONS

The objective of this section is to demonstrate a step-by-step calculation of the availability and error-free-second ratio of any phase shift keying (PSK) link given the location of the earth terminal, elevation angle to the satellite and the bit rate of the data (proposed MIL-STD-188-323 uses a 64 kb/s pulse code modulation (PCM) voice channel and therefore, so does this analysis).

For this example, the Fort Detrick, MD, earth terminal is considered, using a 10.2° elevation angle to the Atlantic DSCS satellite.

a. The worst 3-month period (season) must first be found. This is accomplished by calculating the expected attenuation using the Feldman model:

$$A(P) = L(\theta)\alpha(f,Rp)\gamma(D)[kRp(P)]^{\beta(f,Rp)-\delta(D)} \qquad (1)$$

where $A(P)$ is the attenuation at a given exceedance probability (P); $L(\theta)$ is the path length through the rain (a function of elevation angle, (θ)); $\alpha(f,Rp)$ and $\beta(f,Rp)$ are empirical constants from Table I (functions of frequency and rain-rate); $\gamma(D)$ and $\delta(D)$ are empirical functions of D (the surface projection of the appropriate portion of the propagation path) and are corrections to the spatial correlation function for rain-rate; k is a correction factor for statistical differences within a rain-rate region; and

Table I. Monthly and Seasonal Precipitation Data

Location	Parameter	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
N. Atlantic	Precipitation (mm)		300			250			175			200	
40N 75W	Precipitation Freq	.21	.26	.25	.23	.20	.18	.14	.12	.11	.15	.18	.20
N. Atlantic	Precipitation (mm)		200			100			100			200	
65N 0	Precipitation Freq	.36	.40	.38	.35	.30	.20	.20	.20	.30	.30	.31	.33
Mediterranean	Precipitation (mm)		150			50			20			75	
35N 20E	Precipitation Freq	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.09	.09
Persian Gulf	Precipitation (mm)		25			20			25			25	
15N 60E	Precipitation Freq	.10	.10	.10	.10	.10	.10	.08	.08	.09	.10	.10	.10
Indian Ocean	Precipitation (mm)		450			400			400			525	
0 75E	Precipitation Freq	.10	.10	.11	.10	.09	.12	.12	.12	.12	.11	.09	.08
W. Australia	Precipitation (mm)		75			60			50			20	
20S 115E	Precipitation Freq	.10	.08	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
East Indies	Precipitation (mm)		600			500			200			150	
5S 120E	Precipitation Freq	.10	.12	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
Philippines	Precipitation (mm)		200			300			400			200	
15N 120E	Precipitation Freq	.11	.08	.09	.08	.08	.08	.09	.11	.11	.10	.11	.09
Sea of Japan	Precipitation (mm)		100			300			200			180	
40N 135E	Precipitation Freq	.40	.44	.35	.20	.19	.20	.21	.19	.17	.17	.20	.23
Bering Sea	Precipitation (mm)		100			75			100			100	
60N 175W	Precipitation Freq	.38	.25	.33	.31	.31	.30	.25	.31	.31	.30	.35	.35
N.E. Pacific	Precipitation (mm)		400			200			150			400	
45N 125W	Precipitation Freq	.17	.20	.17	.15	.13	.12	.10	.10	.04	.10	.17	.17
Hawaii	Precipitation (mm)		125			80			75			100	
20N 155W	Precipitation Freq	.09	.08	.10	.08	.10	.10	.10	.10	.10	.10	.10	.09
Panama	Precipitation (mm)		200			400			600			600	
10N 80W	Precipitation Freq	.10	.10	.10	.10	.10	.10	.17	.20	.20	.18	.15	.10

Note: From Feldman, et. al [9]

$R_p(P)$ is the one-minute surface-point rain-rate for a given exceedance probability. For the purposes of establishing worst season in this example, P is chosen to be 1.0% which is equal to the DSCS design goal of 99% availability (actually, the value of P is unimportant as long as changing the resultant $R_p(P)$ does not cause a change of α and β). These various factors are calculated as follows:

$$L(\theta) = \overline{FH}/\sin\theta; \text{ where } \overline{FH} \text{ is the mean seasonal freezing height from (Feldman pp 54-57)} \tag{2}$$

$$D = D^* \text{ for } D^* \leq 22.5 \text{ where } D^* = \overline{FH}/\tan\theta \tag{3}$$

$$D = 22.5 \text{ for } D^* > 22.5 \tag{4}$$

$$k = R_{m,d}/R_{c,d} \tag{5}$$

where $R_{m,d}$ is the measured, daily precipitation (the total seasonal precipitation (mm) from Table I divided by 90 days per season) and $R_{c,d}$ is the regional characteristic daily rainfall (mm/da) from Table II.

$$\gamma(D) = 1 + (D/4.5) - 0.23\,(D/4.5)^2 + 0.0215\,(D/4.5)^3 \tag{6}$$

$$\delta(D) = (D/21.5) - 0.98\,(D/21.5)^2 + 0.446\,(D/21.5)^3 \tag{7}$$

α, β, and $R_p(P)$ are chosen from Tables III and IV.

In this example, the constants and solutions to equation (1) are:

	Dec-Feb	Mar-May	Jun-Aug	Sept-Nov
rain-region	D	D	D	D
$\overline{FH}$ (km)	2.5	3.5	4.4	4.2
k	1.33	1.11	.8	.9
α	.00549	.00549	.00549	.00549
β	1.185	1.185	1.185	1.185
Rp	3.1mm/hr	3.1mm/hr	3.1mm/hr	3.1mm/hr
A(dB)	.63	.75	.76	.78

Table II. REGIONAL CHARACTERISTIC VALUES OF PRECIPITATION FREQUENCY AND AVERAGE DAILY PRECIPITATION

	Characteristic Values	
Region	Precipitation Frequency	Average Precipitation (mm/day)
A'	0.10	0.5
B'	0.25	1.0
C	0.30	2.5
D	0.15	2.25
E	0.10	4.25
F	0.08	0.75
G	0.20	3.25
H	0.20	6.5

Note: From Feldman, et al [9]

Table III. TABULATION OF α, β FOR USE IN R_p^{β}

Temperature = $0^{o}C$

Frequency (GHz)	α (LP_L)	α (LP_H)	β (LP_L)	β (LP_H)
1.0	6.41×10^{-5}	5.26×10^{-5}	0.891	0.947
7.5	5.49×10^{-3}	4.28×10^{-3}	1.1850	1.2585
8.2	6.95×10^{-3}	5.84×10^{-3}	1.1870	1.2396
21	7.05×10^{-2}	8.21×10^{-2}	1.1141	1.0728

Temperature - $20^{o}C$

Frequency (GHz)	α (LP_L)	α (LP_H)	β (LP_L)	β (LP_H)
1.0	3.84×10^{-5}	3.17×10^{-5}	0.889	0.945
7.5	3.52×10^{-3}	2.77×10^{-3}	1.2941	1.3644
8.2	4.72×10^{-3}	4.29×10^{-3}	1.2998	1.3322
21	7.68×10^{-2}	9.66×10^{-2}	1.1016	1.0367

Note: From Feldman, et al [9]; interpolated where necessary. LP refers to the Laws and Parsons drop-size distributions. The subscripts L and H refer to low and high rain rates; the transition is at about 40 mm/hr.

TABLE IV. Cumulative Precipitation-Rate Distributions (See Figure 3)

P, Percent of Year	Value of Precipitation Rate (mm/hr) that is Exceeded P Percent of the Time							
	A[1]	B[1]	C	D	E	F	G	H
0.001	7.5	15.0	80	102	168	56	129	251
0.002	7.1	13.7	62	86	144	51	109	220
0.005	6.4	11.2	40	64	117	33	83	178
0.01	5.6	9.1	28	48	96	22.5	67	147
0.02	4.6	7.1	19	35	77	15.0	51	115
0.05	3.4	4.8	11	22	52	8.5	33	77
0.1	2.5	3.4	7.3	15	35	5.3	22	51
0.2	1.75	2.4	4.8	9.8	20.5	3.3	14	30
0.5	1.05	1.5	2.7	5.2	8.7	1.7	7	13.5
1.0	.68	1.0	1.75	3.1	4.1	1.0	4.0	6.6
2.0	.40	.64	1.10	1.8	1.8	0.56	2.2	3.0
5.0	.145	.31	0.56	0.7	0.49	0.21	0.78	0.88
10.0	.05	.16	.33	0.24	0.10	0.0	0.30	0.31
20.0	0.0	.07	.16	0.0	0.0	0.0	0.10	0.10

Note: From Feldman, et al [9]

Examination of the above results indicate that the period of September through November is the worst.

b. Because the "Feldman" availability is defined as the percent of time that attenuation does not exceed the defined threshold (regardless of duration) and proposed MIL-STD-188-323 defines availability (hereafter called "MIL-STD" availability) as the percent of time that the attenuation does not exceed a defined threshold for durations of greater than one minute, a method for transitioning from one definition to the other must be found. Since the MIL-STD availability is a subset of the Feldman availability (i.e., includes only fades greater than one minute), a simple method is available to accomplish this. Feldman unavailability includes a certain percentage of less than threshold fades with durations of greater than one minute and the remainder less than one minute. To find the percentage of these fades greater than one minute, another constant, k', must be used. k' relates the precipitation frequency at the point of interest to the frequency for the entire rain-rate region. Simply find the point-season precipitation frequency (the seasonal precipitation frequency at a specified geographical location) from Table I and divide it by the characteristic frequency (the annual precipitation frequency for the rain-rate region) from Table II (for this example, k' = 1.20). Then find the corrected exceedance probability (P) by multiplying the Feldman availability by k'. Use this corrected value on the abscissa of Figure 3 to find the rain-rate (mm/hr). This rain-rate must also be corrected by multiplying by k/k' (k value from step a. above). The percent probability of durations exceeding one minute may then be found from Figure 4. Having found this percentage value, it is multiplied by the Feldman unavailability to determine the MIL-STD unavailability. In this instance, the required unavailability is to be .40%. (.40% was chosen so that the path availability was relatively close to the 99.665% specified in the draft standard and so that it was equal to the actual operational availability of the average DSCS earth terminal). From this, "trial and error" iterations must be performed by varying the Feldman unavailability until the specified MIL-STD availability is found. After several iterations, the Feldman unavailability is found to be .49% with 81% of this time having fade durations greater than one minute.

c. Using Feldman's model, the minimum margin required to meet the availability specified can now be calculated using equations 1-7 and P = .49%. For the example, the minimum required margin is found to be 1.13 dB.

d. If the margin is exceeded for durations less than one minute, the resultant condition is attributed to signal degradation (error performance) rather than outage (unavailability). Therefore, the next step must be to calculate the average depth of these shorter fades. It has been calculated that for .49% of all time, fades in excess of the margin occur and that 81% of this time are for durations greater than one minute; therefore, for the remaining 19% or .09% of all time (.49% x 19%), fades of less than one minute are experienced.

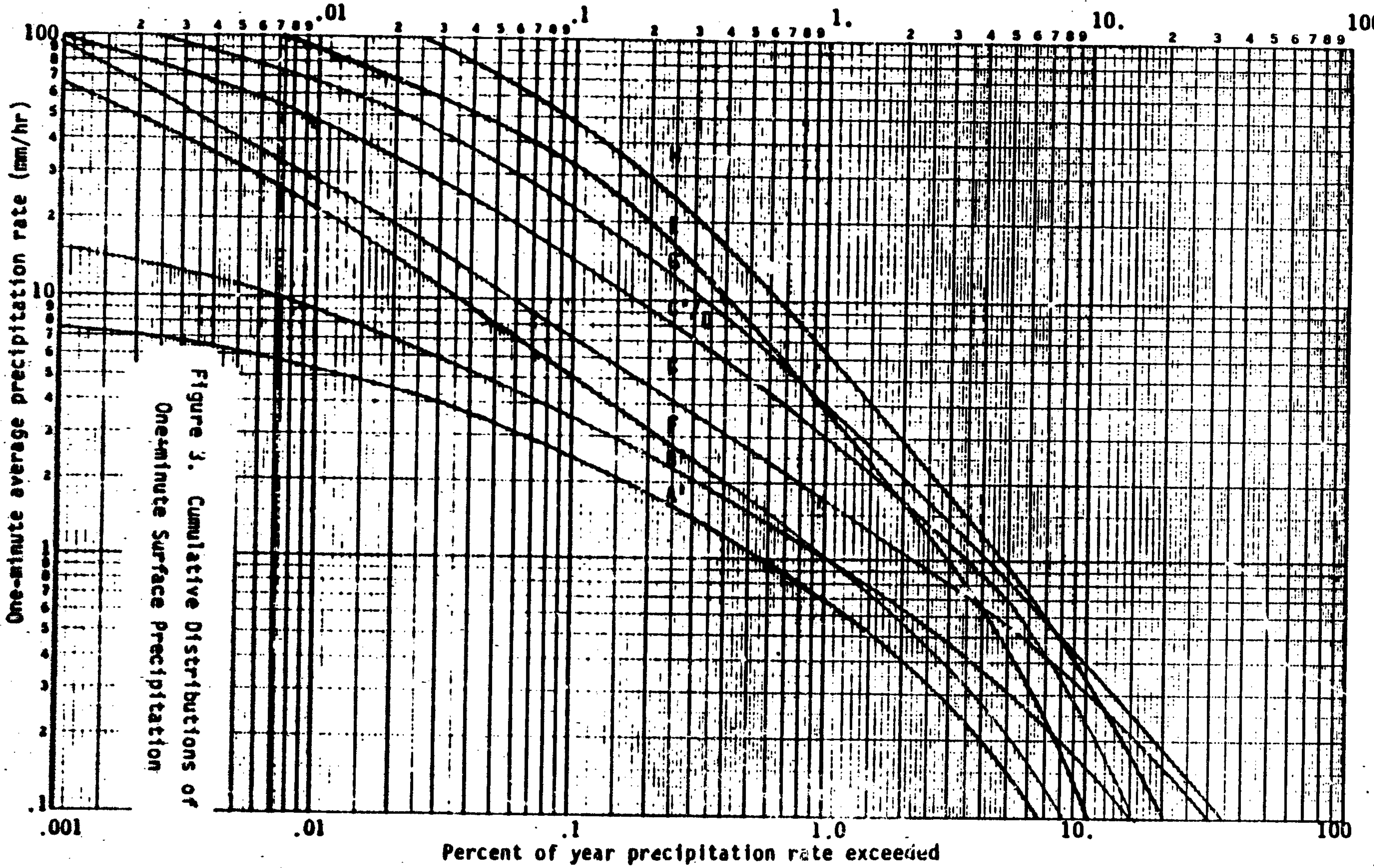

Figure 3. Cumulative Distributions of One-minute Surface Precipitation

From Feldman et al [9]

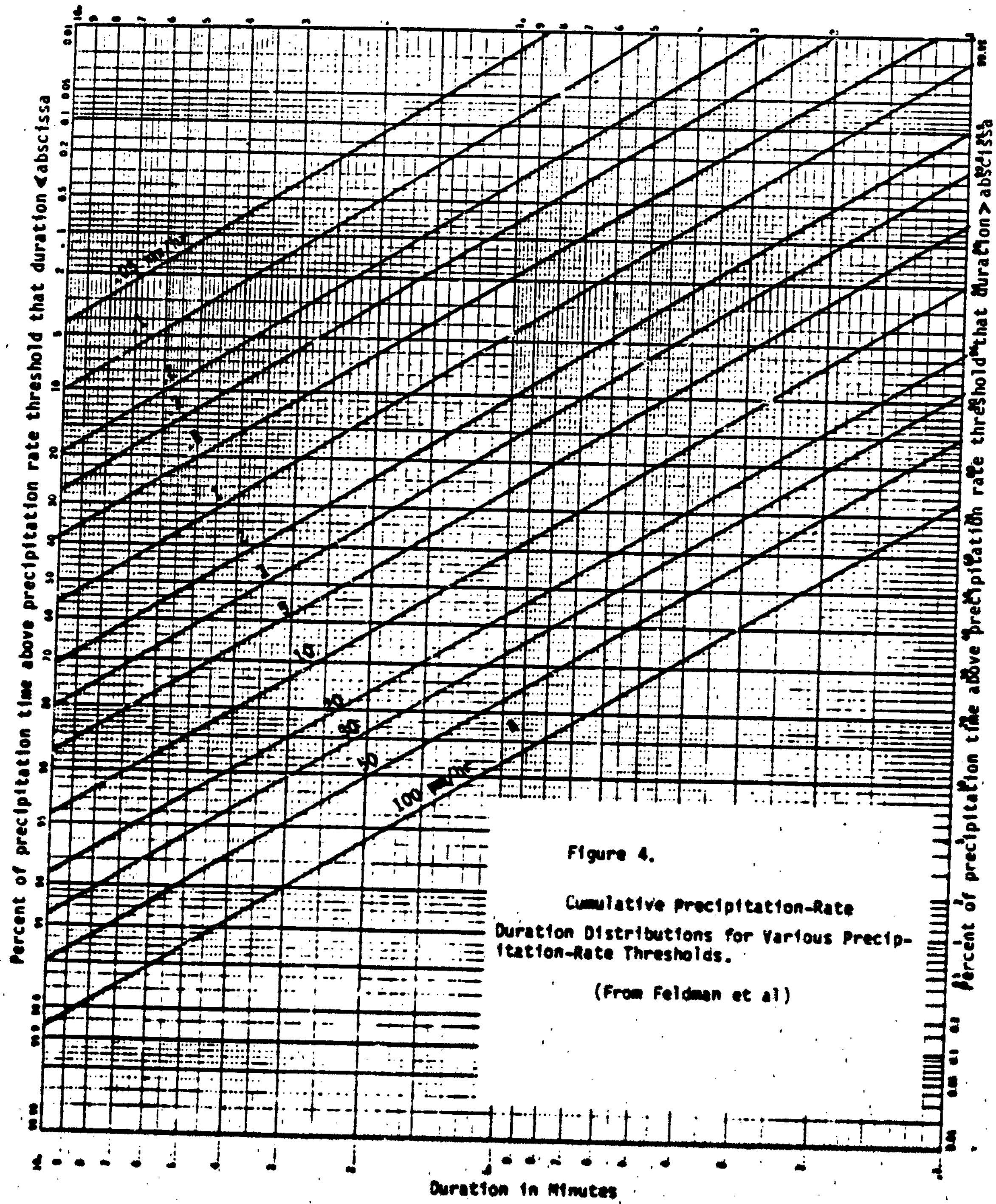

Figure 4.

Cumulative Precipitation-Rate Duration Distributions for Various Precipitation-Rate Thresholds.

(From Feldman et al)

The corrected rain-rate is found from Figure 3 (applying k and k' as in Step b) and again equations 1-7 are used to calculate the average (<1 minute duration) fade depth of 1.85 dB.

e. Having found the average fade depth for degradations of duration less than one minute, the corresponding BER may be calculated.

$$BER = Q\left[2 \text{ antilog} \left(\frac{8.45 + \text{required margin} - \text{avg fade depth}}{10}\right)\right]^{1/2} \qquad (8)$$

where Q is the complementary error function (often referred to as "erfc"). For the Fort Detrick example, the BER is calculated to be 9.7×10^{-6}.

Then using CCITT's relation [10] to determine the percent error free seconds:

$$EFS\% = 100\ e^{-BE} = 53.7\% \qquad (9)$$

(where B is the bit rate in bits per second and E is the bit error rate in errors per bit). Therefore, it can be seen that 46.3% (100-53.7) of all observed seconds are in error due to rain attenuation in excess of the threshold (required margin) with durations less than one minute. This assumes a random error condition (worst case). For the same BER of 9.7×10^{-6} under burst error conditions the resulting percentage of errored seconds would be much lower [10, 11].

Recounting, it has been determined that:

(1) For .4% of all observed time, outages exist due to fades exceeding one minute which contribute to unavailability

(2) For .04% (46.3% x .09%) of all observed time, errorred seconds are incurred due to excess rain with durations less than one minute.

(3) From (a) and (b) above, it can be seen that 99.56% of all time, errors that occur are due to "clear air," rain less than threshold, and equipment errors.

f. From Figure 3, using the k and k' corrections as before, it can be seen that for the .49% of all time that rain exceeds the threshold, the average rain-rate is 3.45 mm/hr. Therefore, assuming a 2192 hour season (365.33 da per yr / 4 seasons per yr x 24 hr per day), at least 37.0 mm of rain is accounted for. From Table I, an average of 200 mm of rain will fall during the season; therefore, 163 mm of rain falls during the remaining 99.51% of the season.

This gives an average rain rate of .075 mm/hr. Again using equations (1)-(7), the average attenuation experienced is .058 dB, and from equation (8) the BER is 7.6×10^{-8} (still assuming a 1.13 dB static margin). This yields an EFS fraction of .99512 (99.512% EFS) or an errorred-second fraction of .00488 (0.488% ES).

g. To find the overall error rate for any 30 day period, three error sources are considered:

(1) Excess rain (duration < 1 min) errors = 1,033 ($.0004 \times .996 \times 30 \times 24 \times 60^2$)

(2) "Clear" air errors = 12,580 ($.00488 \times .9951 \times 30 \times 24 \times 60^2$)

(3) Equipment errors (BER $\leq 10^{-9}$) = 166

total = 13,779 errors

The overall EFS% is then $100(1 - [13{,}779/(.996 \times 30 \times 24 \times 60^2)]) = 99.47\%$.

h. Because the proposed MIL-STD specifies an EFS criteria of 99.9%, a margin greater than the calculated "required margin" must be used and, the actual path availability must be determined. Experience has shown that at least a 3 dB margin must be allowed for; and then using Figure 3, k, k' and equations (1)-(7), it is relatively simple to determine through trial and error that for 3 dB, a 21 mm/hr rain rate must occur. Using the procedure of paragraph b, the "Feldman" unavailability is found to be .028% and the "MIL-STD" unavailability is .011%, or conversely the resulting "MIL-STD" availability is 99.939%.

Table V displays the results of this sample calculation along with the results calculated (following the same procedures) for seven other DSCS earth stations in differing rain-rate regions. Figure 5 shows the relationships between margin and EFS% and "MIL-STD" unavailability for the Fort Detrick example. The points on the plot were calculated using the same procedures from step b above and varying the margin.

Table V. SINGLE PATH STATISTICS

Location (Sat)	Elevation Angle ( )	Worst 3-Month Season	Rain-Rate Region*	Minimum Required Margin (dB)**	Average*** Excess Rain Atten (dB)	Average*** Non-Excess Attn (dB)	Overall Availability (w/3dB margin)	Overall EFS %	BER**** (64 kbps)
Ft. Detrick, MD (At)	10.2	Sep-Nov	D	1.13	1.85	.058	99.970	99.466	8.4×10^{-8}
Howard AFB, Panama (EP)	26.3	Jun-Aug Sep-Nov	H	1.21	2.33	.025	93.950	99.247	1.2×10^{-7}
Wahiawa, HI (WP)	50.5	Sep-Nov	F	.20	.96	2×10^{-6}	99.999	99.585	6.5×10^{-8}
Croughton, GB (At)	29.7	Jun-Aug	C	.09	.31	2×10^{-3}	99.995	99.588	6.4×10^{-8}
Iceland (At)	17.3	Sep-Nov	A'	.115	.39	3×10^{-3}	99.999	99.587	6.4×10^{-8}
Elmendorf AFB, AK (EP)	19.6	Jun-Aug	B'	.13	.45	4×10^{-3}	99.999	99.586	6.4×10^{-8}
Clark AFB, PI (WP)	20.2	Jun-Aug	G	.59	1.05	.012	99.995	99.447	8.4×10^{-8}
MacDill AFB, FL (At)	15.6	Dec-Feb	E	1.21	2.78	.07	99.926	99.488	8.0×10^{-8}

*From Feldman, et al

**Calculated for 99.6% availability

***Assumes 3 dB margin used

****Assumes a random error distribution (worst case)

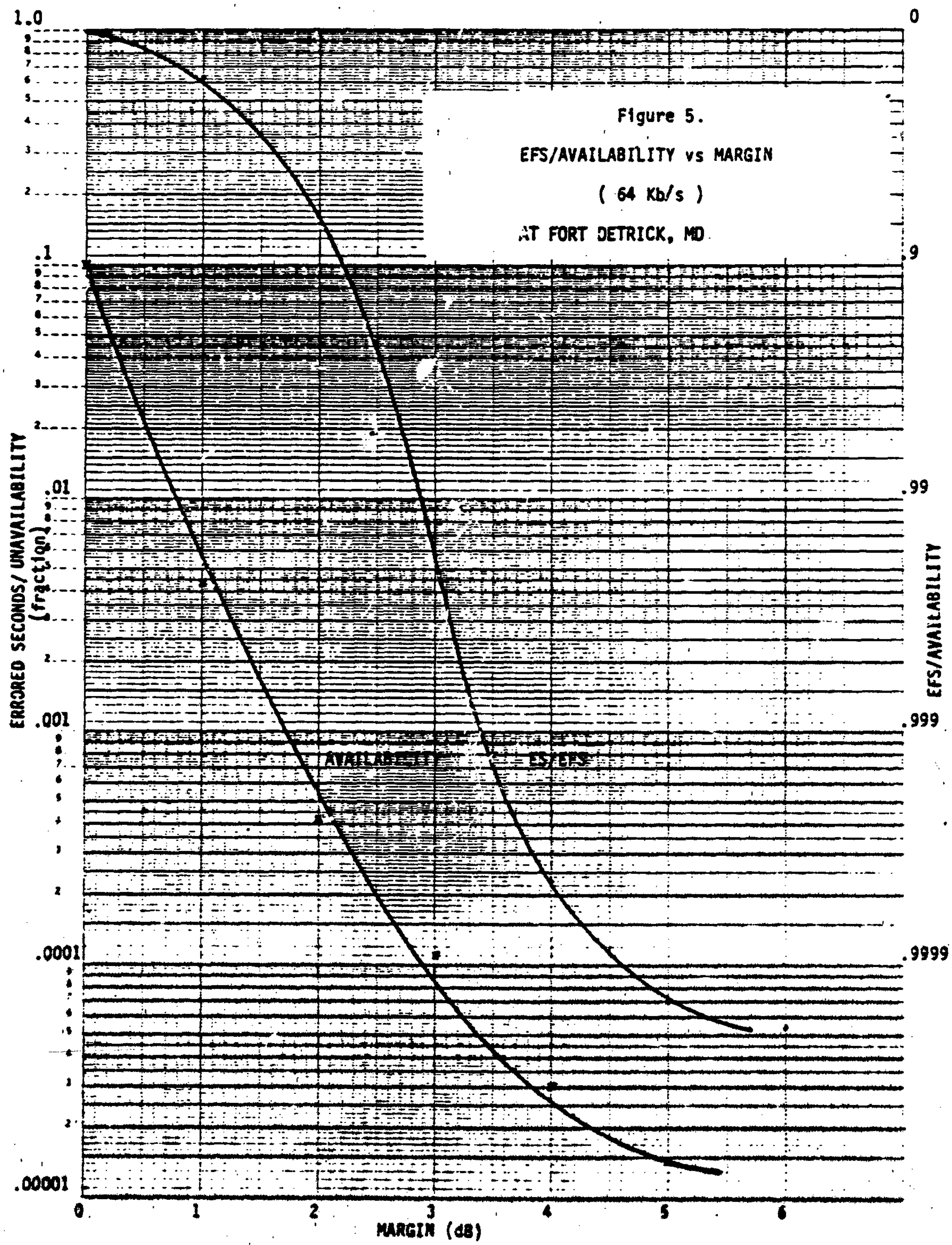

Figure 5.
EFS/AVAILABILITY vs MARGIN
(64 Kb/s)
AT FORT DETRICK, MD
1.0
.1
.01
.001
.0001
.00001
0
.9
.99
.999
.9999
ERRORED SECONDS/ UNAVAILABILITY (fraction)
EFS/AVAILABILITY
AVAILABILITY
ES/EFS
0
1
2
3
4
5
6
MARGIN (dB)

IV. FINDINGS AND CONCLUSIONS

1. As a result of this analysis, several significant findings and conclusions have been reached.

a. The most significant finding is that the "nominal" 6 dB margin used in the DSCS system design appears to be excessive. One must only look at Figure 5 and note that a minimum margin of 3.55 dB is required to meet the specifications of proposed MIL-STD-188-323 [1]. An additional amount (perhaps .5 dB) should be added to compensate for other climatological path anomalies such as depolarization. Therefore, a 4 dB margin would be sufficient at Fort Detrick to counteract any propagation conditions which could cause performance lower than the specified standard. This, of course, assumes that the path anomalies are not abnormal, e.g. no nuclear scintillation. It is, therefore, recommended that SHF static margins be reevaluated for each site independently and verified, by physical error measurements, to provide proper margins and increase channel capacity of the links. Additionally, the phenomena of increase in noise temperature, both of the atmosphere and the antenna, should be calculated and measured to determine its magnitude.

b. Within the satellite community, there is a general lack of understanding of the error-free-second (EFS) parameter. Figure 6 displays a plot of BER versus EFS that may be used for convenient conversion at 64 kb/s. Using equation (8), EFS ratios for other bit rates are simple to calculate. Since the equation assumes a random distribution of independent errors, it therefore, ignores "burst errors" which must be a concern in satellite communications. It does, however, approximate the wose case errored second condition. The error-free-seconds models, as used in the articles of Huckett and Thow [11] and Rollins [12], are based on a sum of Poisson distributions and, therefore, account for some clusters of errors.

c. While the rain attenuation models currently available are very good, the Feldman model and the results presented in Table V make it apparent that individual site characteristics must be measured to assure accurate values particularly at EHF frequencies. This requires a minimum of 7 to 10 years of rain data collection and, therefore, makes using these rain models desirable, if not necessary.

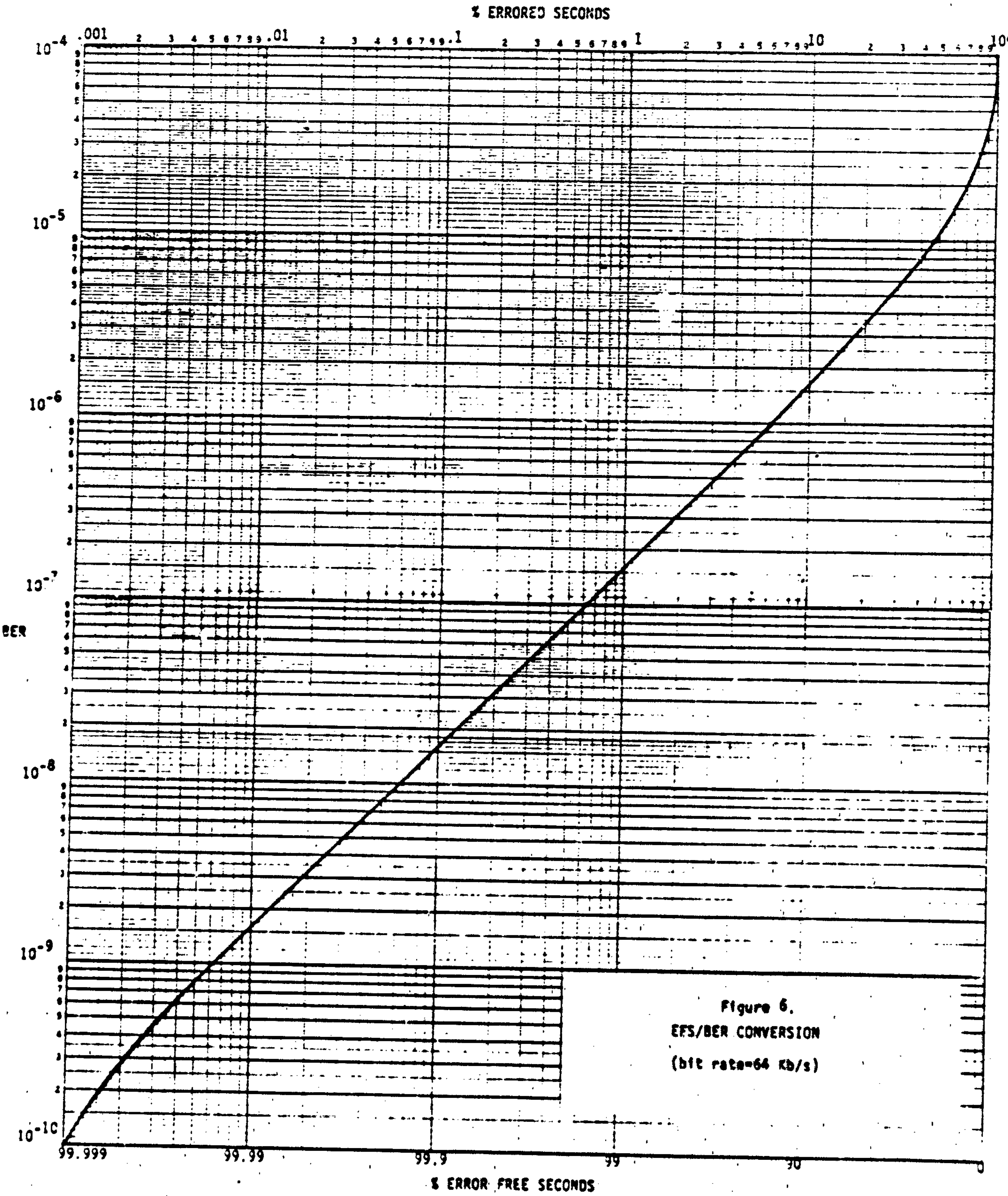

Figure 6.
EFS/BER CONVERSION
(bit rate=64 Kb/s)

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