AD-A059 836 ARIZONA UNIV TUCSON ENGINEERING EXPERIMENT STATION F/G 9/3
EXTRAPOLATION OF BIT ERROR RATE MEASUREMENTS: EXPERIMENTAL RESU--ETC(U)
SEP 78 L C SCHOOLEY, G R DAVIS DAEA18-74-A-0271

UNCLASSIFIED NL

1 OF 1

AD
A059836

END
DATE
FILMED
12-78
DDC

LEVEL II

Sixth Bimonthly Technical Report

Contract No. DAEA18-74-A0271/005

EXTRAPOLATION OF BIT ERROR RATE MEASUREMENTS: EXPERIMENTAL RESULTS (PRELIMINARY REPORT)

Prepared for

U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

Prepared by

L. C. Schooley
G. R. Davis

15 SEPTEMBER 1978

(9) Bimonthly Technical Report. no. 6,

(6) EXTRAPOLATION OF BIT ERROR RATE MEASUREMENTS: EXPERIMENTAL RESULTS (PRELIMINARY REPORT).

Sixth Bimonthly Report

Contract No. (15) DAEA18-74-A-0271/005

Prepared for

U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

Prepared by

(10) L. C. Schooley, Ph.D., P.E.
Associate Professor

and

G. R. Davis, M.S.
Research Associate

Approved by

L. C. Schooley
Department of Electrical Engineering
University of Arizona
Tucson, Arizona 85721

(12) 41p.

(11) 15 September 1978

78 10 02 023

033 868

LB

TABLE OF CONTENTS

1.0 INTRODUCTION

This is the sixth bimonthly report to be prepared for the Material Test Division, Instrumentation and Methodology Branch, of the U. S. Army Electronic Proving Ground, Fort Huachuca, Arizona, under Contract DAEA18-74-A-0271/0005. The purpose of the contract is to undertake a program of applied research which will provide comprehensive standards and test methodologies to include recommended instrumentation, data collection, data reduction, and analysis criteria for digital communications systems. The primary objective is to identify meaningful, measurable parameters, recommend instrumentation required to obtain these measurements, and to provide analysis methodologies and performance criteria.

The last report [1] provided some suggested configurations for system tests of those Tri-Tac assemblages that contain, as components, items from the family of digital group multiplexers. A progress report was also presented on the experimental work that had just been initiated in an attempt to verify the hypothesis that variations in the internal equipment anomalies which contribute to errors in detection of digital signals cause a lateral displacement of the theoretically shaped curve of bit error rate (BER) versus signal to noise ratio [2].

The experimental work has been essentially completed with some minor exceptions. However, there has been insufficient time to complete the analysis of the data or to describe the details of the experiments in a final form. This will, therefore, be a preliminary report meant only to outline the work that was accomplished and to provide some initial comments on the significance of the results.

2.0 INVESTIGATION OF THE VALIDITY OF EXTRAPOLATION IN THE ESTIMATION OF VERY LOW BIT ERROR RATES

2.1 Introduction

Investigations of test methods and performance criteria for digital communications systems have shown that long term bit error rate, by itself, provides an incomplete picture of the characteristics of a real channel [3]. An adequate description of real channel operation requires statistics, such as error burst distributions, which are obtained from analysis of the error patterns. It has been shown, however, in the evaluation of modulators/demodulators exclusive of the transmission media, that relative performance in the presence of Gaussian noise is a sufficient criterion [4]. Curves of long term bit error rate versus signal to Gaussian noise ratio or received signal level are, therefore, useful results of bench testing (back-to-back mode) of digital modulation hardware.

At low to moderate data rates, considerable test time can be expended in obtaining reasonably accurate data points for the plotting of such error curves. For example, at 32 Kbps it would require approximately one hour to count sufficient errors to obtain a single data point at an error rate in the neighborhood of 10^{-7} with some degree of confidence in the result. When it is necessary to reconstruct complete error curves under a variety of conditions, the test time required can quickly become excessive. For this reason methods other than straight counting of errors have been sought for estimating very low bit error rates.

The technique of extrapolation has shown considerable promise as an accurate and relatively fast method for obtaining curves of long term bit error rate versus signal to noise ratio. The procedure is to obtain a single point of the curve at a high error rate (possibly 10^{-4}) with a high degree of confidence, and then to fit a theoretical error curve (error function or exponential based upon the modulation scheme) through this point. This has led to the hypothesis that small variations in equipment anomalies result in a lateral shift of the error curve, but that the curve retains its theoretical shape.

2.2 Objective

The objective is to verify the above-stated hypothesis, both mathematically and experimentally, for a variety of modulation schemes. Expressions will be derived for the effect upon error rate in each type system of small variations of carrier synchronization (phase jitter), symbol synchronization (baud timing jitter), intersymbol interference, and receiver nonlinearities. Experimental verification will be attempted where feasible. This report contains a preliminary description of the experimental verification of the effects of baud timing and carrier phase jitter, and nonlinearities.

3.0 EXPERIMENTAL EFFORTS

3.1 General

The experimental work for the most part was conducted at the Digital Transmission Evaluation Program (DTEP) test facility at Fort Huachuca during June and July 1978, with some additional work at Bell Aerospace in Tucson during the first part of August. The cooperation and assistance provided by the personnel at these facilities was truly outstanding and greatly appreciated. Without this valuable assistance the task would have been considerably more difficult and prolonged; indeed, impossible to accomplish within the time frame.

The primary objective, as mentioned earlier, was to experimentally verify the hypothesis that small variations in the internal anomalies which contribute to errors in digital demodulators cause a lateral displacement of the characteristic curve of bit error rate versus received signal to noise ratio, while the curve retains its theoretical shape at the higher levels of signal to noise ratio.

Toward this objective, in each of the experiments described below, the equipment was first tested as it was found at the test facility to establish a base or reference curve of BER versus signal to noise ratio (in some cases, received signal level (RSL)). Attempts were then made to induce increased jitter in the demodulators or to simulate the effects of increased jitter by offsetting the timing of the receiver. Data were then taken to determine the effect of these perturbations on the equipment performance, as related to the reference curve. In one case non-linearities were introduced to determine their effect on the BER curve.

3.2 VICOM T1-4000 Tests

3.2.1 Equipment Description. The VICOM T1-4000 is primarily a digital time division multiplexer which converts from 2 to 8 nonsynchronous T1 channels into a single 12.5526 Mbps data stream for transmission over a coaxial cable or radio facility. The T1 inputs (Bell System Standard) are 1.544 Mbps signals in a return to zero (RZ) alternate bipolar format (also termed AMI, alternate mark inversion). The high level output can either be a serial binary no return to zero (NRZ) or a three level partial response signal. It is in the three level partial response mode that the multiplexer acts as a modulator/demodulator converting this external signal from/to the internal NRZ format.

Since the T1-4000 is essentially a multiplexer it must be operated with a nominal input signal level which is too high for the inherent front end noise to effect the error rate. Therefore, external noise had to be added to the signal to establish the error curves. A random noise generator with a reasonably flat spectrum over the required bandwidth (approximately 8 MHZ) that would produce the necessary noise power was not available. To obtain the desired result, a microwave radio set (the AN/FRC-162) was utilized as a transmission facility. The input signal to the radio receiver could then be attenuated to a low enough level for the receiver front end noise to produce the necessary range of signal to noise ratios.

The AN/FRC-162, manufactured by Collins Radio, is a frequency modulated line-of-sight microwave radio which operates in the 8 GHZ band. The radio was modified to accept the 12.5526 Mbps three-level partial response output of the T1-4000. The AGC features of the radio provide a constant level output signal to the T1-4000, regardless of the signal level at the input to the receiver. The effect of the FM detection on the probability distribution of the noise will be discussed in later reports. The test results support the basic assumption that the effects of the noise are the same as those predicted from a Gaussian distribution.

The HP-3780A Error Measuring Set is a pattern generator/error detector in one instrument for measurement of loop errors with data rates from 1 Kbps to 50 Mbps. Error count is indicated on a front panel LED display. Alternatively BER is calculated and displayed every 10^6, 10^8 or 10^{10} bits, as desired. An indication is given if the error count is less than 100 errors in any period. Signal output is either AMI or NRZ.

3.2.2 **Test Configuration.** The equipment configuration for the test is shown in Figure 1. The HP-3780A Error Measuring Set was used to generate a pseudo-random T1 signal which was connected to a single channel of T1-4000. The T1-4000 three level partial response signal was then connected to the FRC-162 transmitter. The transmitter radio frequency output was connected to the receiver via waveguide which contained two calibrated attenuators for adjustment of the signal level. After demodulation in the FM receiver the three level partial response signal was fed back through the T1-4000 to the 3780A for detection of errors.

3.2.3. **Procedure.** The AGC voltage of the radio receiver was calibrated to establish the received signal level (details in later report). Bit error rate measurements were made for received signal levels in the range of from -65 to -80 dbm which correspond approximately to signal to noise ratios of 29.5 to 14.5 db respectively. A bit error rate curve vs.

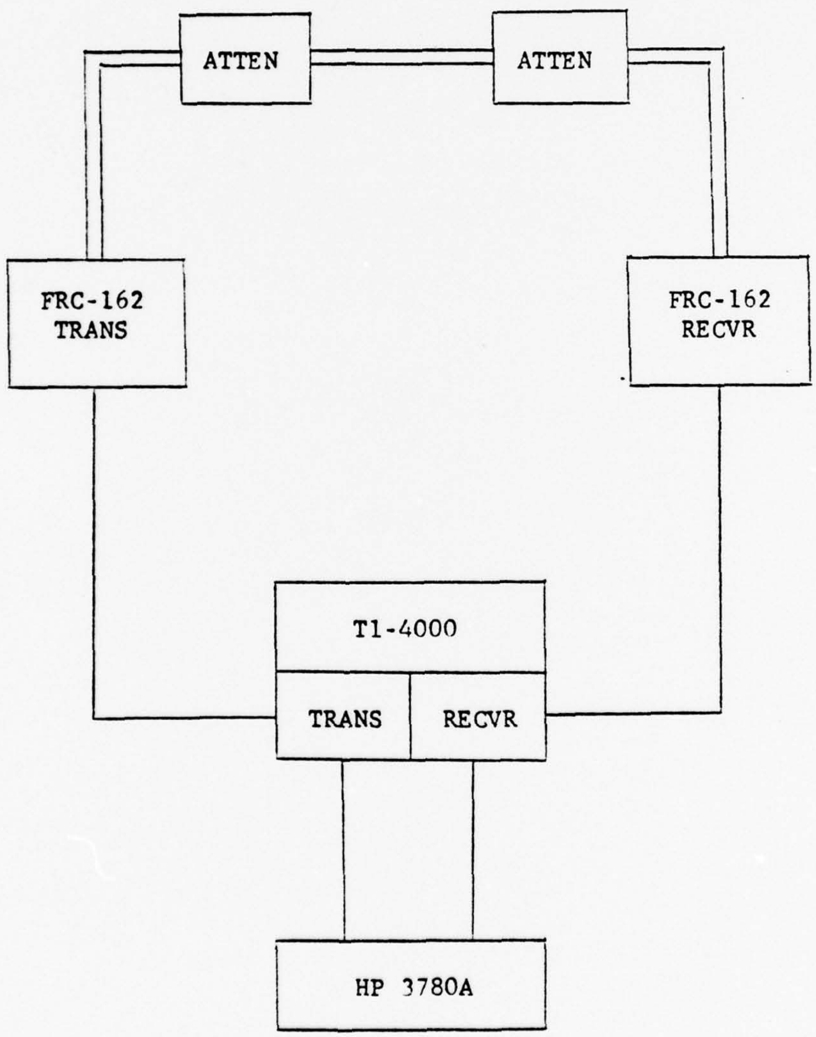


Figure 1. Equipment Configuration: Vicom T1-4000 Tests.

received signal level was plotted and compared with a theoretical curve (error function). Readings were taken in several different T1 channels to verify that the errors were randomly distributed and, therefore, producing the same error rates in each channel.

The baud timing of the T1-4000 receiver is controlled by a phase lock loop (PLL) circuit in the receiver input unit. Baud timing jitter was induced by varying the bias voltage of the voltage controlled oscillator in the PLL. Considerable detail on the PLL and detection circuit will be provided in subsequent reports. Data were taken for several different settings of this PLL voltage to demonstrate the effect of baud timing jitter on the bit error rate curves.

To determine the effect of receiver nonlinearities upon the bit error rate, the frequency response of the discriminator in the FM receiver was purposely distorted. Bit error rate curves were then made with several observable aberrations of the discriminator response curve.

3.2.4 Results. The bit error rate curves described above were plotted for three different T1-4000 systems (except for the discriminator variations). The results were similar in all cases. The initial curves were found to adhere very closely to the theoretical shape (see Figure 2). The theoretical curves in all figures are correct in shape, but are laterally shifted for convenient comparison.

The variations of the PLL voltage produced the anticipated lateral shifts in the error curves while maintaining the theoretical shape except in the extreme variations (see Figures 3 and 4). The deviation from the theoretical shape in the case of extreme variations was not unanticipated and will be discussed in detail in subsequent reports. No method was

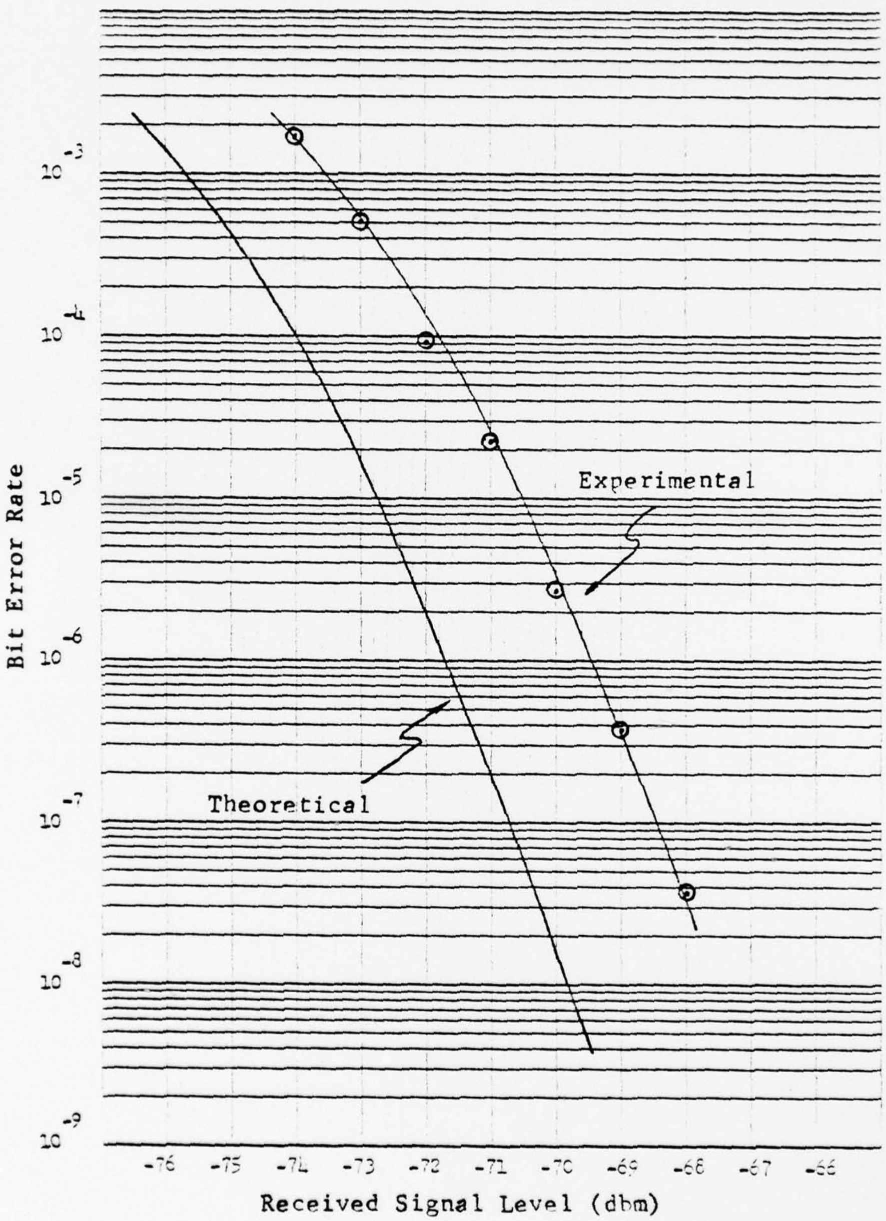


Figure 2. BER vs RSL, Experimental and Theoretical. Vicom T1-4000, model 11H0009.

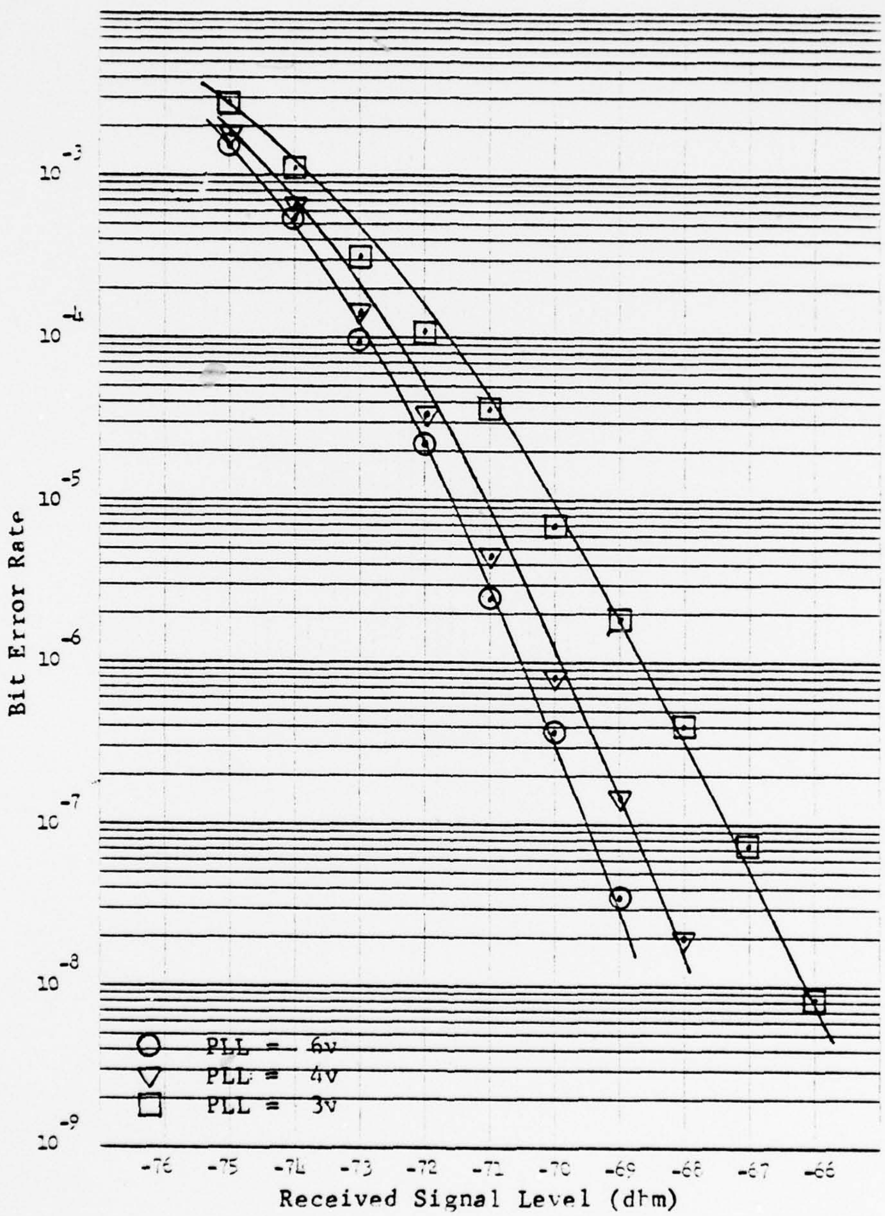


Figure 3. BER vs RSL with PLL variations
Vicom T1-4000, model 11H0009.

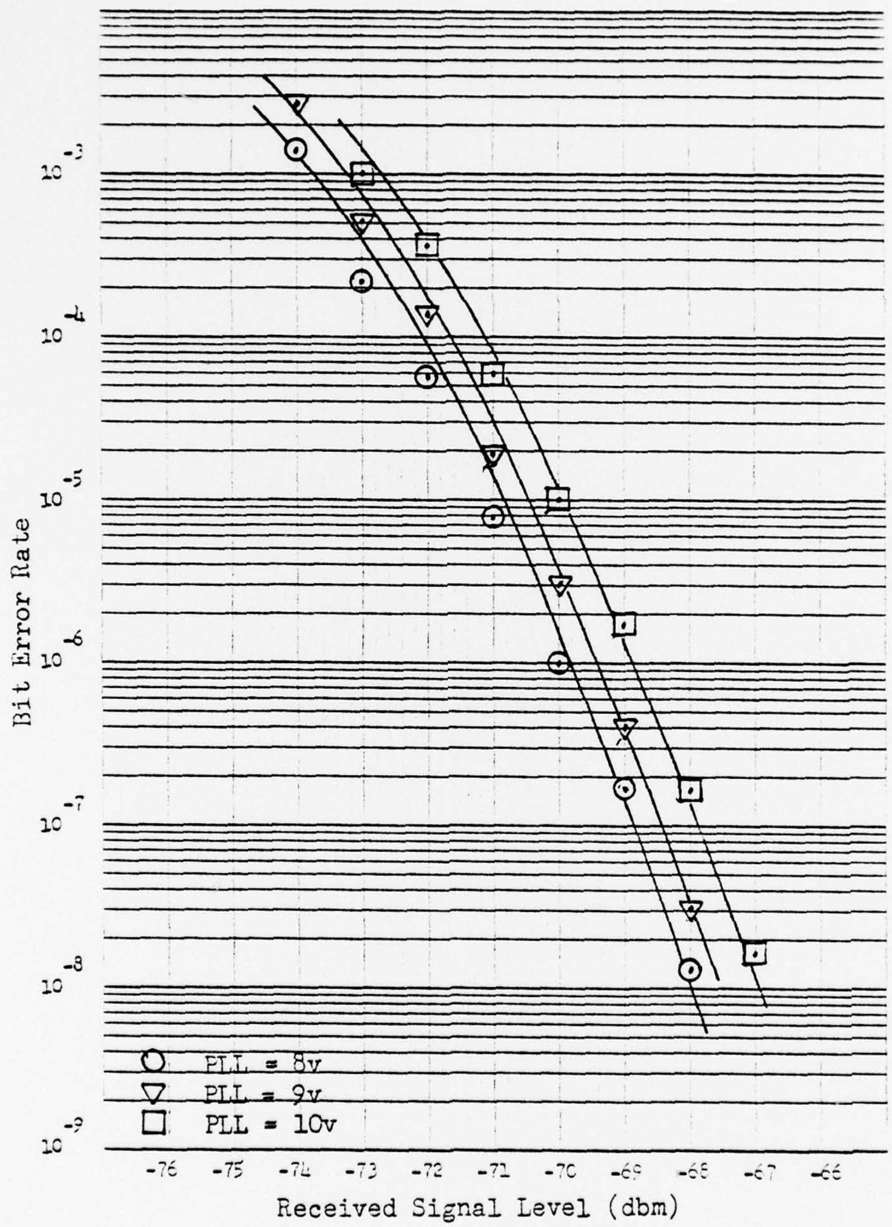


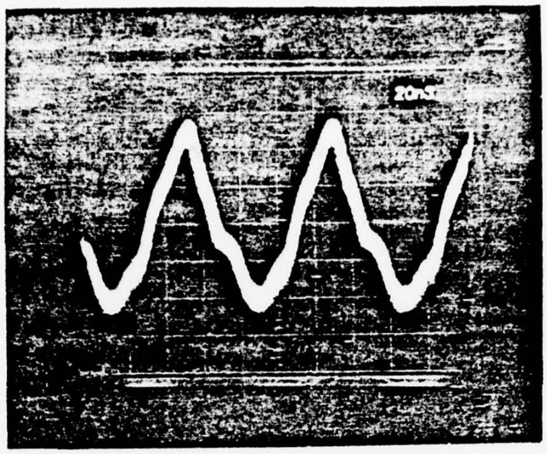
Figure 4. BER vs RSL with PLL variations (2)
Vicom T1-4000, model 11H0009.

available for quantitatively measuring the amount of phase jitter induced by the variations of the PLL voltages (jitter meter under development); however, the oscilloscope pictures shown in Figures 5 and 6 illustrate the qualitative effect. In these pictures, the transmitter timing was used for sweep synchronization while viewing the receive timing signal output of the PLL for different bias voltage settings.

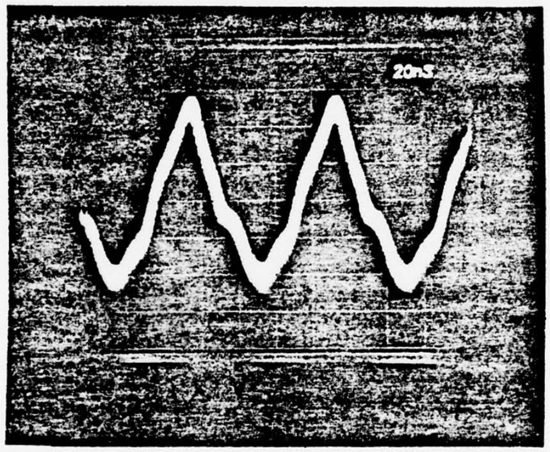
Figure 7 shows the results achieved by variation of the discriminator linearity. Figure 8 contains oscilloscope pictures of a frequency sweep of the discriminator output. A sweep signal generator was used with frequency varying ±25 MHZ about the 70 MHZ IF (Center) frequency. The scope was calibrated in 5 MHZ per horizontal unit, so that the 50 MHZ sweep covers the entire scope face with 70 MHZ at the center. Operation of the FRC-162 with the nominal 45 MHZ bandwidth discriminator is a normal practice, even though the signal bandwidth is approximately 8 MHZ. This accounts for the seeming disparity between apparent linearity and the error rates, since the only meaningful portion of the curve is ±4 MHZ from the 70 MHZ center frequency. This suggests some interesting and possibly quite significant impacts upon receiver alignment techniques that will also be discussed in more detail in subsequent reports.

3.3 Lenkurt 261A

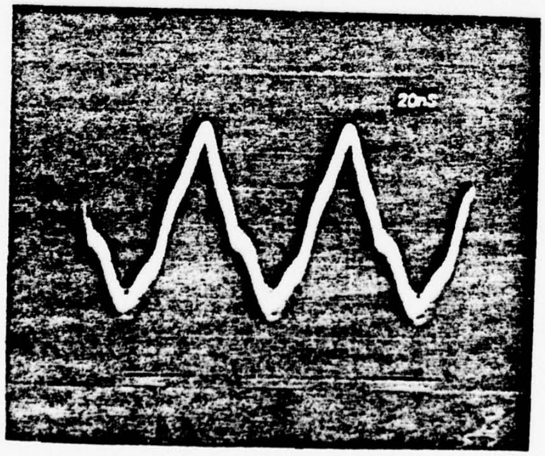
3.3.1 Equipment Description. The Lenkurt 261A is a digital data transmission set designed to operate at 2400 bps over a conditioned voice frequency channel. It is designed to accept 2400 bps data from business machines, computers, and other digital terminal equipment provided with EIA



PLL = 3v

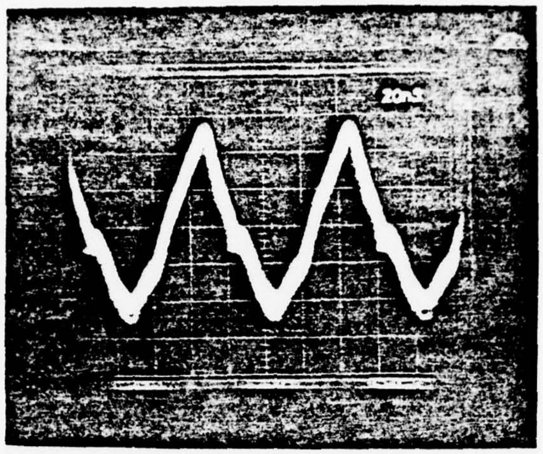


PLL = 4v

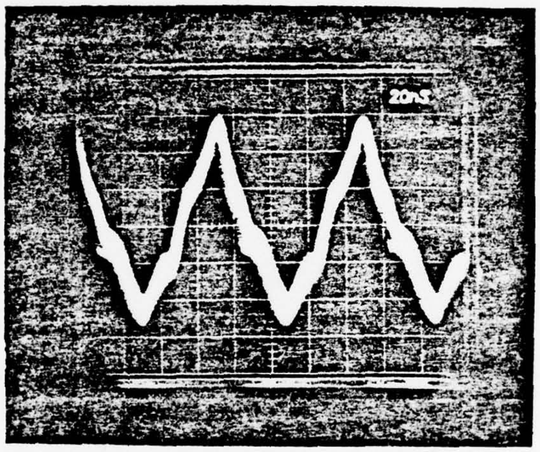


PLL = 6v

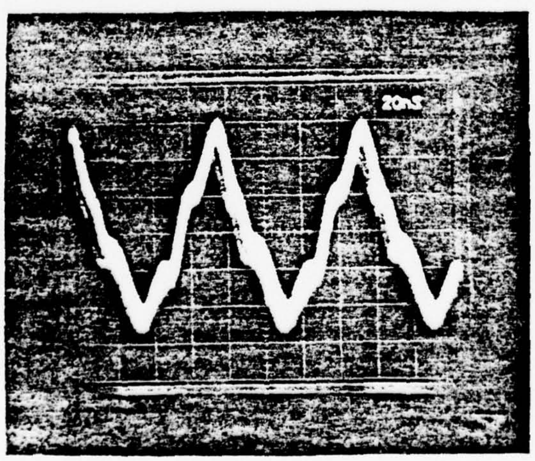
Figure 5. PLL output jitter. Bias voltage 3,4,5 volts.
Vicom T1-4000, model 11H0009.



PLL = 8v



PLL = 9v



PLL = 10v

Figure 6. PLL output jitter. Bias voltage 8,9,10 volts, Vicom T1-4000, model 11H0009.

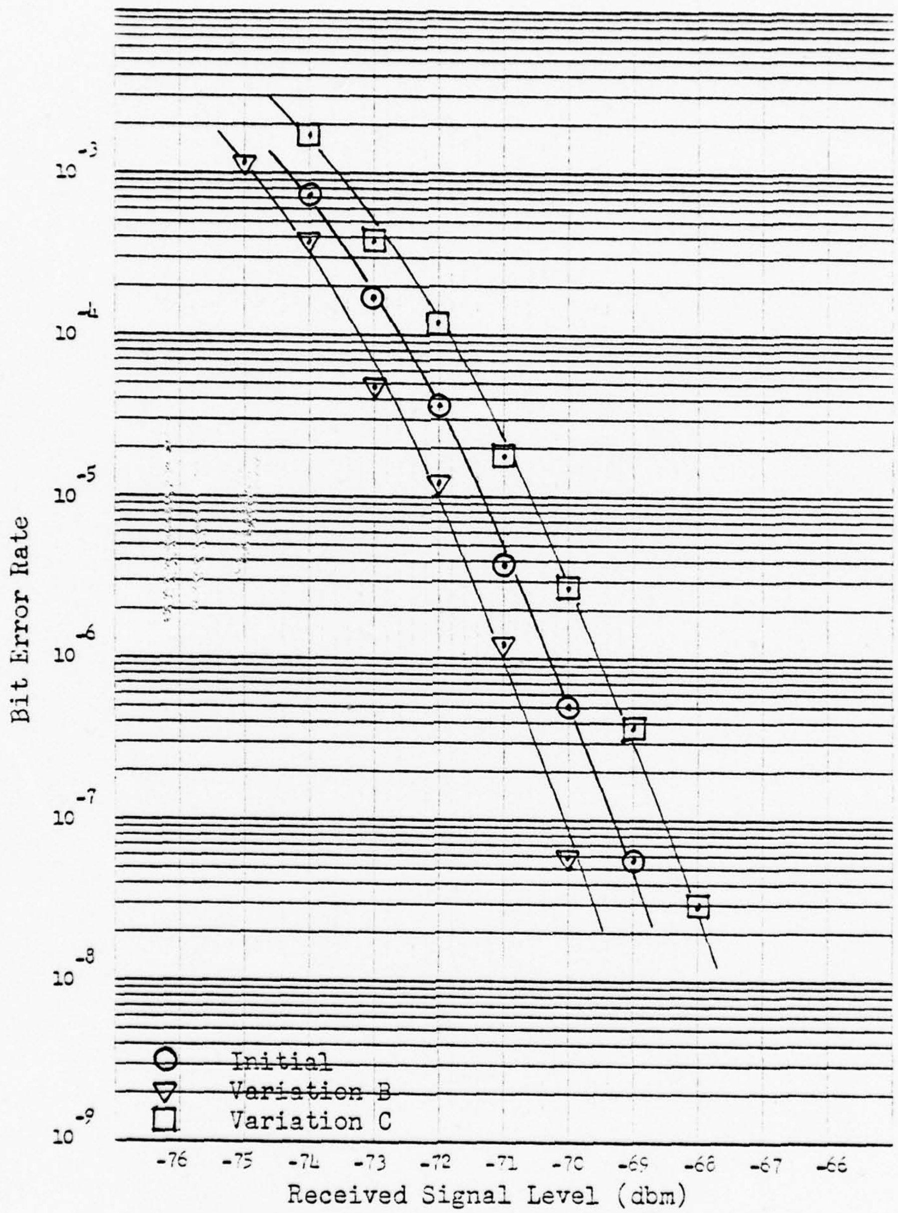
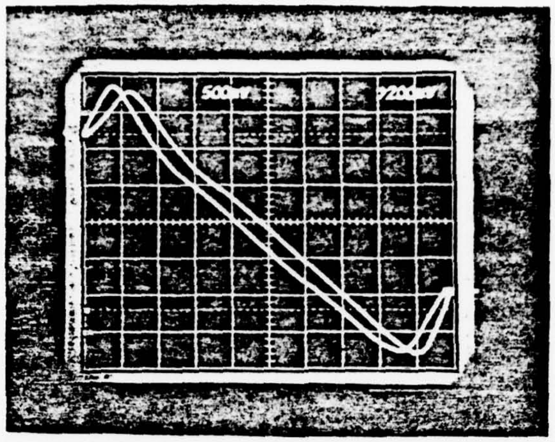
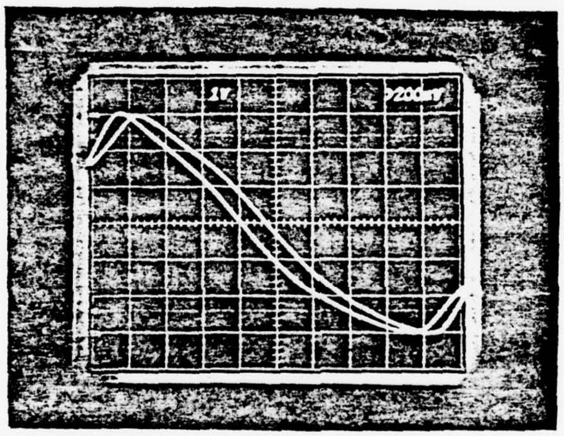


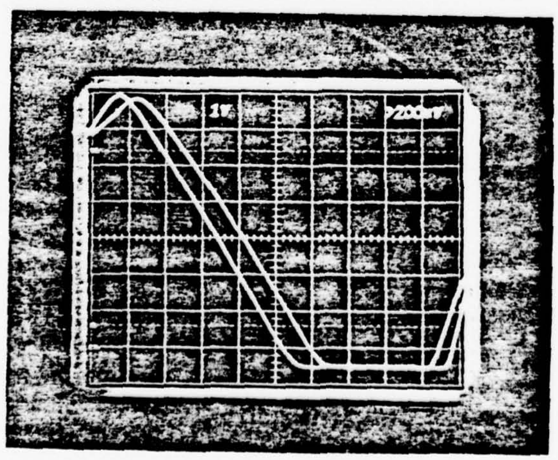
Figure 7. BER vs RSL with discriminator variations. Vicom T1-4000, model 11H0009.



Initial



Variation B



Variation C

Figure 8. Discriminator linearity variations.
Vicom T1-4000., model 11H0009.

Standard RS-232C interfaces. The line side output is a combination of a synchronous duobinary encoding technique with frequency shift keying (FSK) modulation.

The Lenkurt 26C Data Set is end-to-end compatible with the 261A and is essentially the same in electrical characteristics; however, it has been physically configured for rack mounting.

The General Radio Company Type 1390-B Random Noise Generator is capable of providing high level, essentially Gaussian distributed, noise which has a relatively flat frequency content over a bandwidth of 20KHz (500KHz and 5MHz bandwidths may be selected). The set uses a gas-discharge tube as its noise source. The noise output is amplified, filtered and equalized to attain the relatively flat spectrum over the desired bandwidth.

The HP 1645A Data Error Analyzer generates a pseudo-random bit stream to loop through the equipment under test, and return for analysis. Errors are counted and displayed on the front panel. The equipment can be operated with an external timer and recorder. This was the only error measuring set that was available which had an RS-232 interface capability.

3.3.2 Test Configuration. A block diagram of the test configuration is shown in Figure 9. The pseudo-random data generated by the HP 1645A was transmitted to the modulator section of the data set over the RS-232 connection. Since the modem line side was a balanced 600 ohm nominal output impedance and the noise generator (and the power measuring device) were both unbalanced, audio transformers were used to add the signal and noise. A detailed discussion of the effects of the mismatch, metering, and loading will be provided in the final report; however, the consequence is that, at

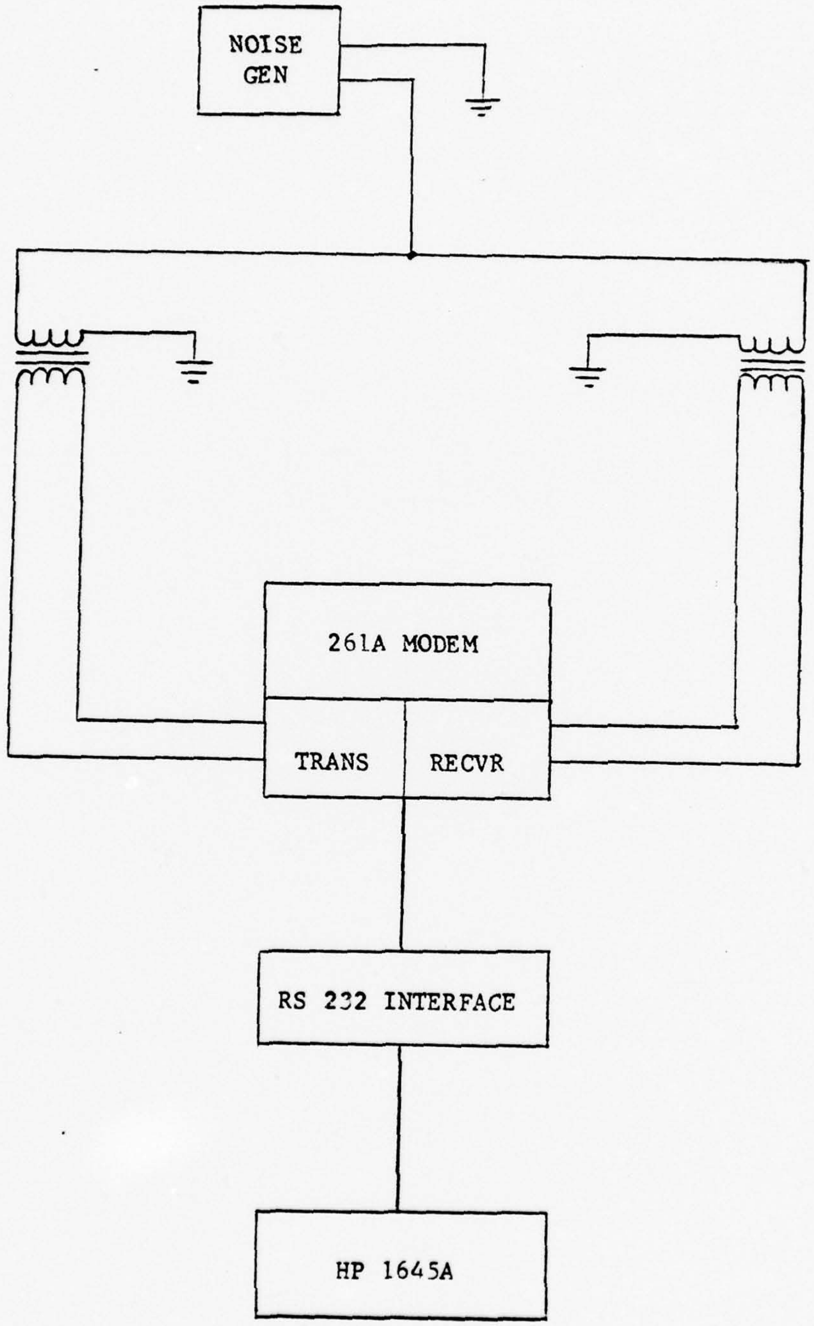


Figure 9. Equipment Configuration: Lenkurt 261A Tests.

voice frequencies, the effects are negligible for the purposes of demonstrating the desired phenomena. The demodulator output was then looped back to the HP 1645A for comparison with the generated signal and the detection of errors. In the normal mode of operation, the modem provided the timing for the data generator. This situation was altered during one of the test modes and will be described in the next paragraph.

3.3.3 Procedure. Bit error rate versus signal to noise ratio curves were plotted for three 261A modems and one 26C operating in the most common mode. Normally both the transmit and the receive timing of the modem are derived from a 1.92 MHz internal oscillator. The transmit timing signal is provided via the RS 232 interface to the data terminal being serviced (in this case the HP 1645A). The receive timing is aligned with the received data by means of a variable ratio divider driven by data transitions (not a phase locked loop, but the same effect--details provided in subsequent reports).

In order to determine the effects of baud timing jitter, efforts were made to offset the actual timing of the received data and the internal receive timing prior to alignment with the received data. To accomplish this, the HP 1645A was timed with a separate variable oscillator and the modem was strapped to obtain its transmit timing from the HP 1645A acting as the data terminal.

3.3.4 Results. Figure 10 shows the bit error rate versus signal to noise ratio curves obtained for a single 261A data set. The curves for the other two 261A's were almost identical and could not be distinguished if plotted on the same coordinates. The curve for the 26C is shown in Figure 11.

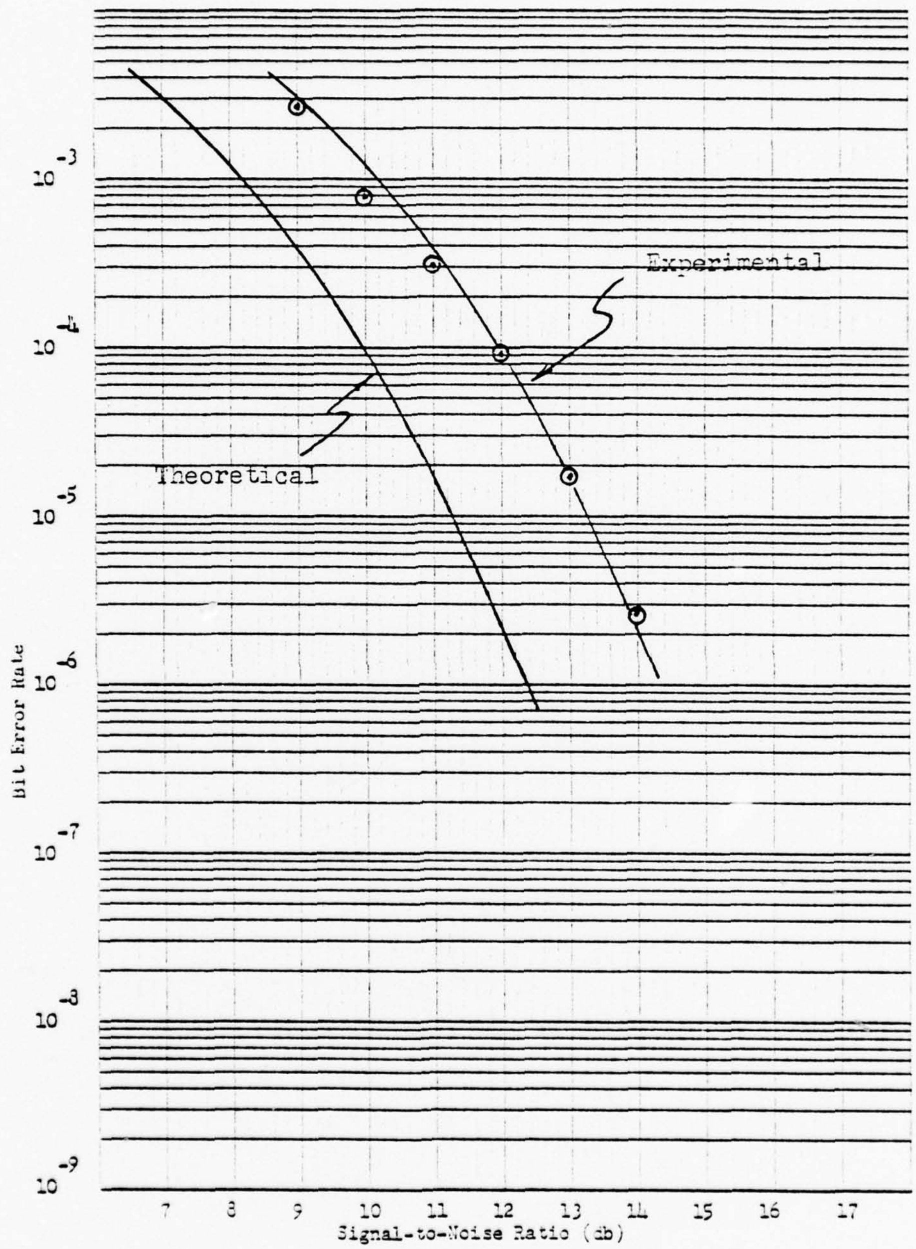


Figure 10. BER vs S/N, Lenkurt 261A, #1.

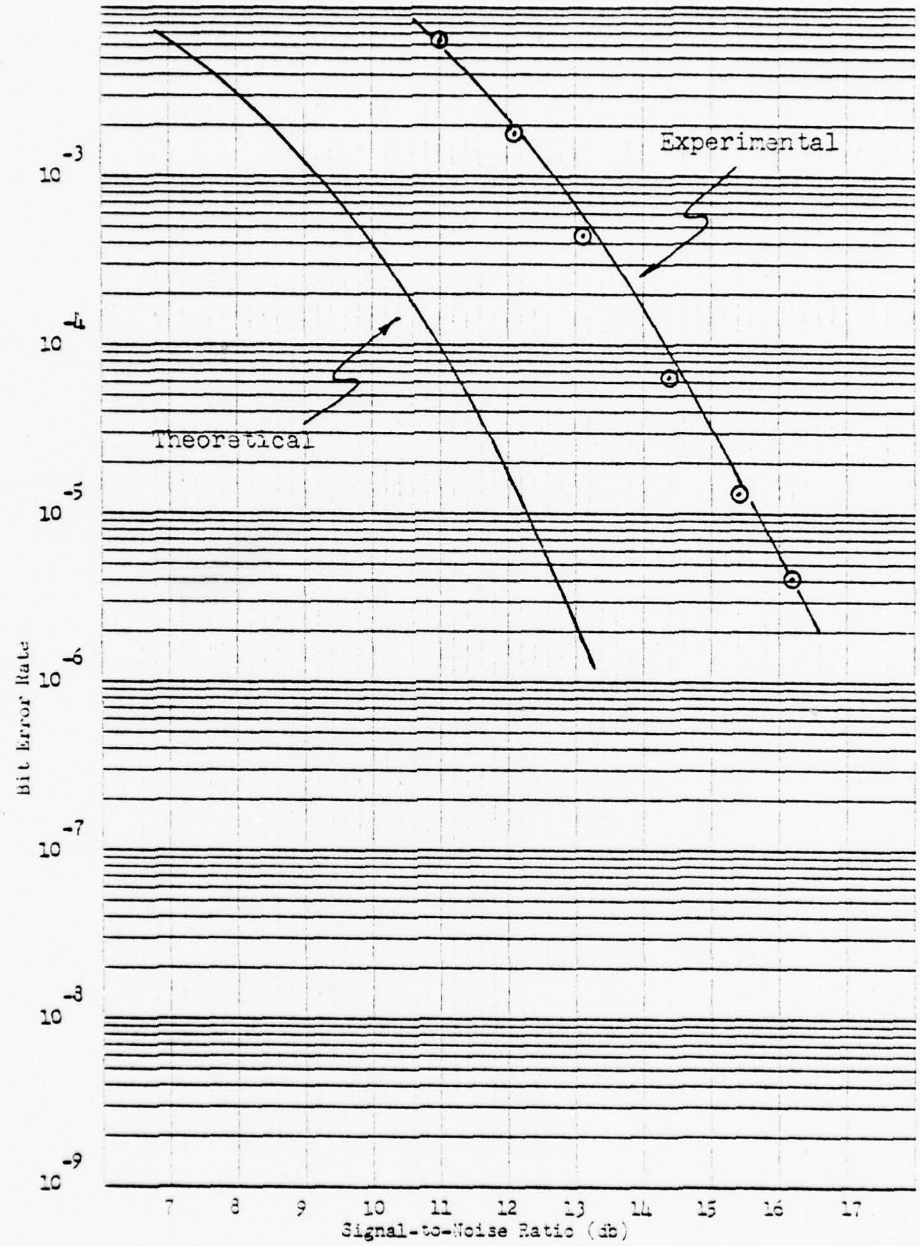


Figure 11. BER vs S/N, Lenkurt 26C.

It is interesting to note that the 26C, which is much more elaborately packaged and probably considerably more expensive, was approximately 2db more susceptible to noise than the 261A. In both cases, the curves are very similar in shape to the theoretical.

Both the internal oscillator of the 261A and the square wave generator used for external transmit timing appeared very stable when checked with a frequency counter and when displayed on an oscilloscope. Unfortunately, when the timing was offset by as much as 2 Hz, the 1645A lost synchronization even though the modem appeared to operate satisfactorily. When the external timing was set for precisely 2400 Hz the error analyzer maintained synchronization and an error curve was plotted. The result is shown in Figure 12. Even though, as mentioned above, both oscillators appeared quite stable and the timing was not deliberately offset, timing the transmit and receive sections from separate sources resulted in a shift in the error curve of approximately one db. The curve using internal timing for both transmit and receive was repeated in this same time frame to insure that the shift was not caused by external (test setup or other environmental) factors.

3.4 MW-518

3.4.1 Equipment Description. The MW-518 tested here is an engineering model of a modification to the commercial MW-518 FDM-FM radio set manufactured by Collins Radio. This is essentially the same radio equipment as the AN/FRC-162 modified for quadrature phase shift keying operation (QPSK). The radio set accepts a 12.5526 Mbps MECL logic signal and

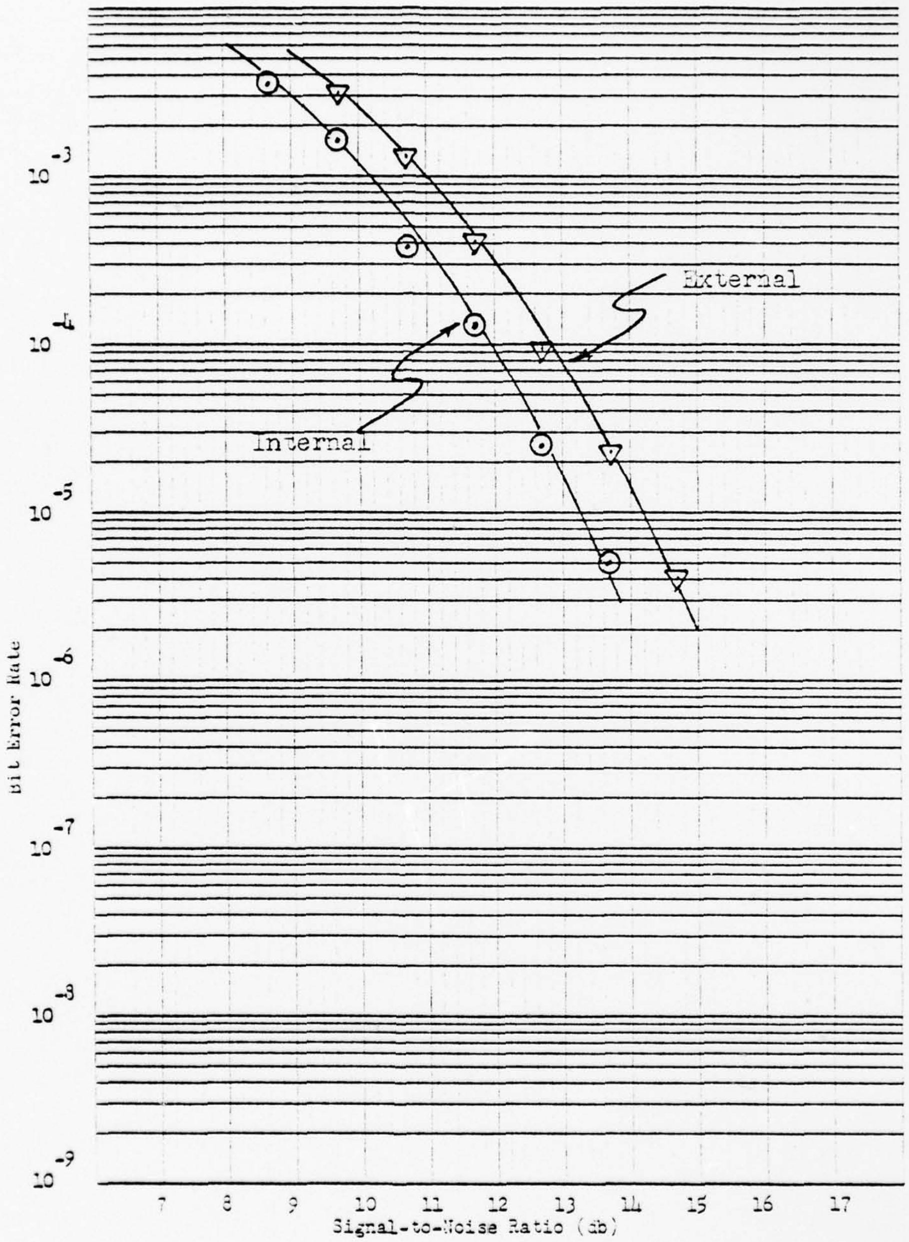


Figure 12. Ber vs S/N, Internal and External Timing:
Lenkurt 261A, #1.

performs the QPSK modulation and detection internally at the IF level. Although the data is differentially encoded prior to modulation, the detection scheme is coherent (nondifferential).

The HP 3760A Data Generator and HP 3761A Error Detector are used in combination for the generation of a pseudo-random data stream and for the detection of errors. The data generator can be triggered either internally or externally up to 15 Mbps. The output can be either NRZ or RZ, with the level variable from 0.1 to 3.2 volts (50 ohm output impedance). The 3761A is specifically designed to receive the data stream of the 3760A and to count errors after comparison with an internal closed loop reference sequence synchronized by a sync pulse generated every sequence by the 3760A. Errors may be counted over a gating period or BER can be calculated and displayed upon the receipt of 100 or more errors.

3.4.2 Test Configuration. The test configuration is shown in Figure 13. The interface box was a locally fabricated device to convert the TTL logic of the 3760/3761 to the MECL logic of the MW-518. The interface box also provided clock to both the data set and the modulator section of the MW-518. Data was transmitted at 19.804 Mbps. As in previous tests, the AGC voltage of the receiver was calibrated to determine the receive signal level. Attempts were made to record BER at signal levels from -70 to -80 dbm corresponding to an approximate signal to noise ratio of 24 to 14 db, respectively.

3.4.3 Procedure. As before, the first step was to obtain a BER versus received signal level curve as a base for comparison prior to attempting any alterations of the internal timing, or other parameters. However, the

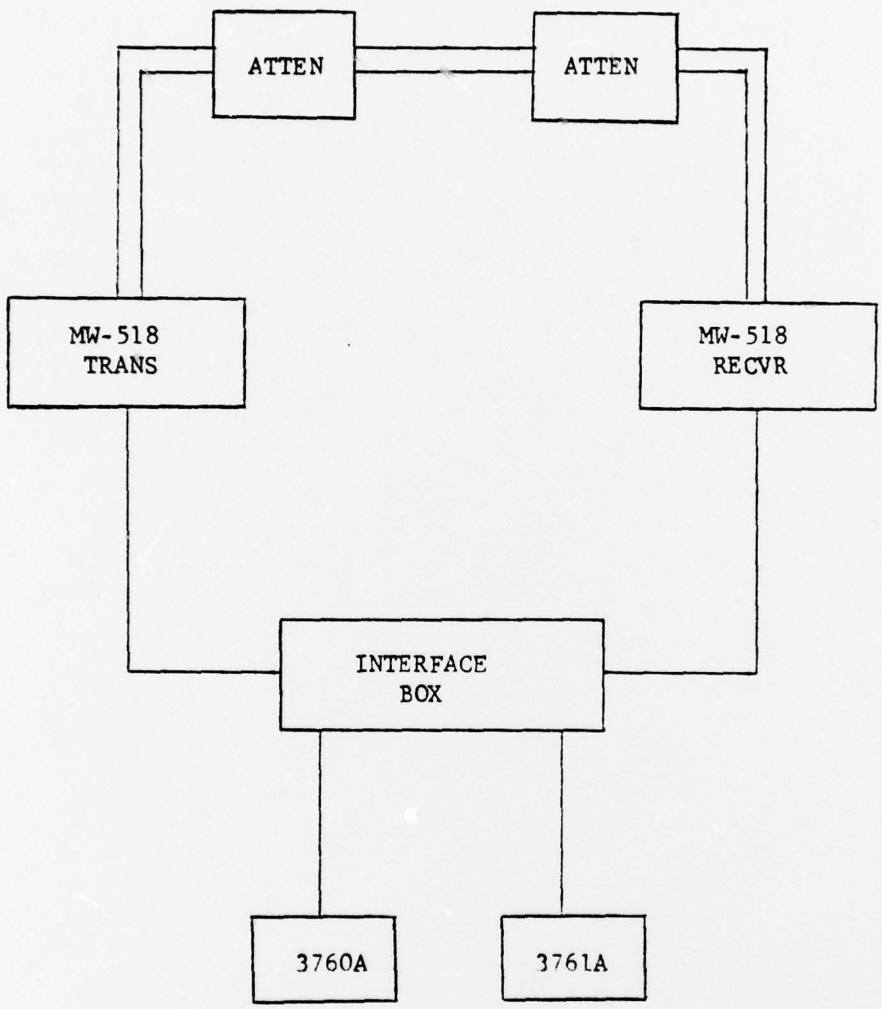


Figure 13. Equipment Configuration: MW-518 Tests.

considerable difficulties encountered in attempts to obtain consistent (repeatable) BER data precluded any attempts to directly demonstrate the effects of jitter, or other anomalies. Three separate problems were encountered that contributed to the overall difficulties.

The first problem arose from the fact that carrier recovery in the receiver occurs at four times the 70 MHZ IF frequency, where the coherent detection of the QPSK signal is accomplished. This causes a 4-phase ambiguity. The resolution of the ambiguity results in different error rates at the same signal level depending upon which phase was acquired upon synchronization. This problem will be discussed in more detail in subsequent reports.

The second problem was the extreme sensitivity of the MW-518. The receiver repeatedly lost synchronization without apparent cause, even at relatively high signal levels (76-77 dbm). At no time was lock maintained at a signal level of -80 dbm, or less, for a sufficient period to obtain a BER reading. At each loss, the signal levels had to be increased to approximately -70 to -72 dbm to regain synchronization. Unfortunately, upon each resynchronization the system had the opportunity to lock on different phases of the carrier.

The final problem which compounded the situation was the apparent sensitivity of the system to heat. The AGC versus RSL curves were found to vary by as much as 1 db between the morning and afternoon (and from day to day). This was attributed to temperature variations, since the test site air conditioning was not working properly during the period of the tests and ambient temperatures varied by at least 10 degrees. The demodulator module of the receiver was noted to operate at a very high temperature. Although this did not necessarily affect the AGC voltage, it probably contributed to the instability of the system.

It appeared that there would be no possible way to discriminate between variations in BER intentionally induced and those due to the above-described phase and heat problems. For this reason, no attempts were made to induce jitter, or other anomalies, into the operation of the system.

3.4.4 Results. After many attempts, two separate curves of BER versus signal to noise ratio were obtained during a single short time period (approximately one hour), while the ambient temperature was essentially constant. The data points of each curve were obtained without loss of synchronization, but the system was resynchronized between the two groups of data. The differences in the curves were, therefore, attributed to the system having locked onto different phases in the carrier recovery. Discussion of the method used to attempt to identify the different phases will be included in future reports. Figure 14 shows the two curves that were obtained. The phases were arbitrarily numbered one and two. The curves do adhere reasonably to the theoretical shape and were consistent with the results of previous tests

3.5 RDS-80

3.5.1 Equipment Description. The RDS-80 is a QPSK radio system manufactured by Raytheon. The multiplexer accepts up to 25 T1 (1.544 Mbps) lines and delivers a 40.15 Mbps data stream to the quadrature phase modulator.

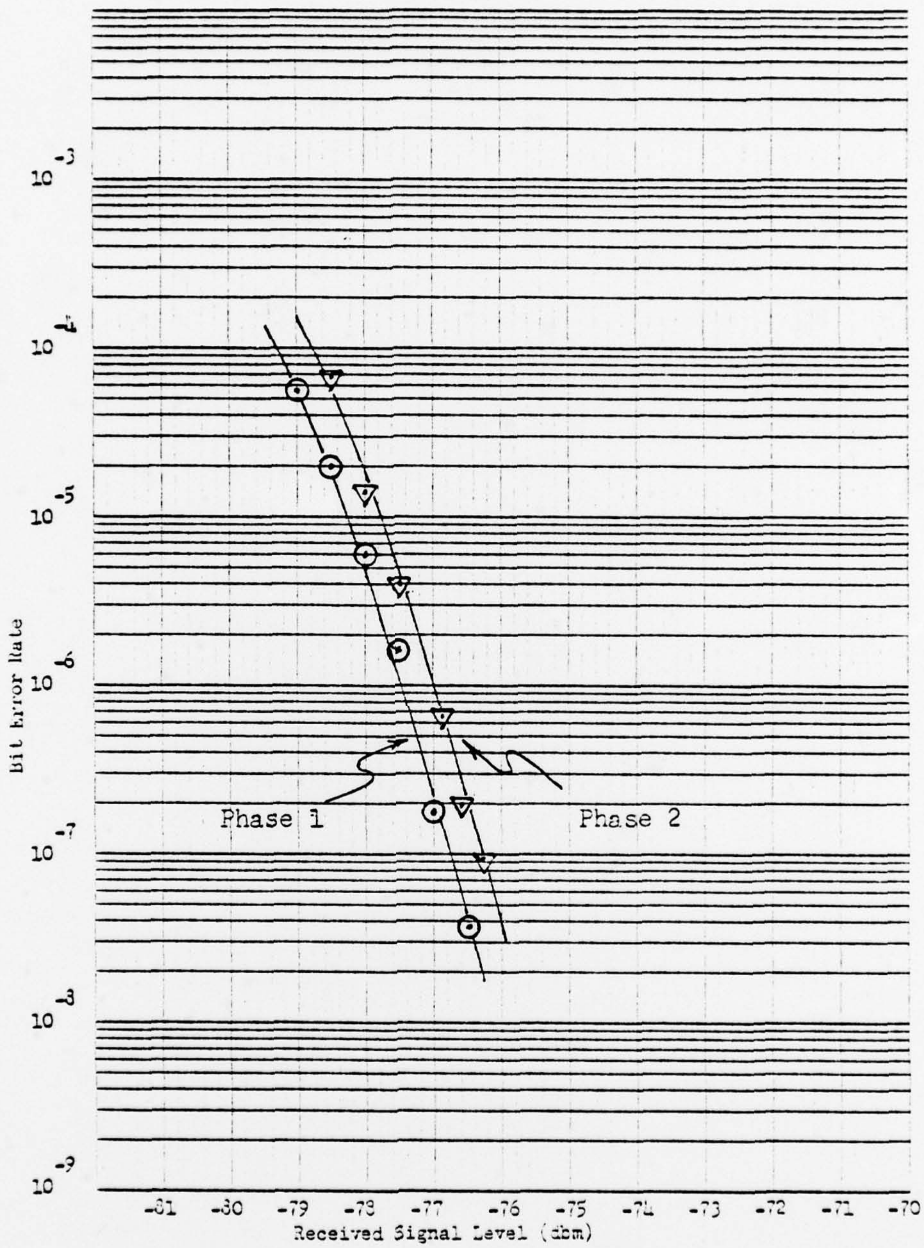


Figure 14. BER vs RSL, MW-518.

Modulation is accomplished at the IF (70 MHZ) level and the signal is then up converted to the 11 GHZ band. Demodulation is coherent from a recovered carrier.

The HP 3780A error measuring set was described in Paragraph 3.2.2.

3.5.2 Test Configuration. The equipment configuration for the test is shown in Figure 15. The RDS-80 transmitter timing was utilized to key the 3780A at 40.18 Mbps. This signal was then fed directly to the radio modulator section of the RDS-80 by passing the multiplexer. The attenuators in the waveguide were calibrated so that the received signal level could be read directly. The 40.15 Mbps NRZ signal was returned directly from the demodulator to the 3780A, again by-passing the multiplexer so that errors were detected at the high data rate.

3.5.3 Procedure. An initial curve of BER versus received signal level was plotted to serve as a basis for future comparisons. Data points were taken for signal levels in the range of -71 to -81 dbm which corresponded approximately to a signal to noise ratio of 19 to 9 db, respectively. The relationship of signal to noise ratios to received signal levels will be discussed in some detail in future reports.

Baud timing jitter was simulated by adjusting the phase of the 20 MHZ timing which is generated in the data regeneration module of the receiver. This was accomplished by adjustment of a trimming capacitor in the output of the phase locked loop. Again, this will be a subject for considerable discussion in future reports. The orientation of the trimming capacitor was used to identify the several states for which BER curves were plotted.

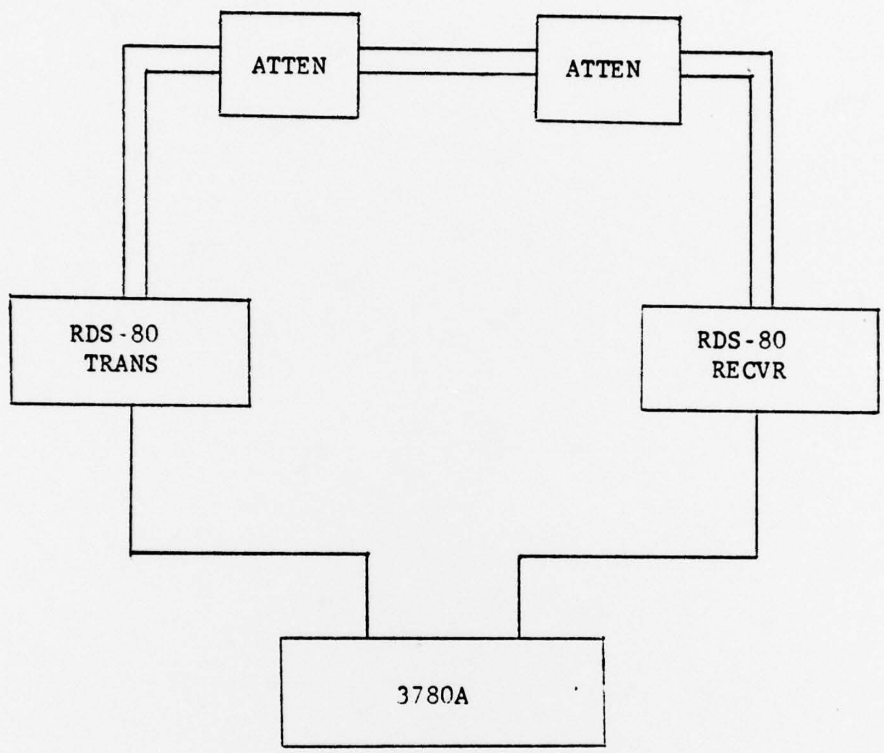


Figure 15. Equipment Configuration: RDS-80 Tests.

Carrier phase jitter was simulated by offsetting the phase of the recovered carrier used for the QPSK demodulation. This was accomplished by varying an inductor in the output of the carrier recovery circuit. The amount of adjustment to this coil was used to identify the states for which BER curves were plotted. This effect will also be discussed in considerable detail in future reports.

3.5.4 Results. Figure 16 shows that the initial curve compared quite favorably with the anticipated theoretical error function shape. The lateral shifts of the curves caused by the phase offset of the baud timing are illustrated by the example curves of Figure 17. The similar results obtained by offsetting the phase of the recovered carrier are shown by the curves of Figure 18. Unfortunately, it was not possible to measure quantitatively the amount of phase offset that was induced in each case. Considerable analysis is still required to determine the relationship between the effects of offset and jitter. This will be a subject for future work.

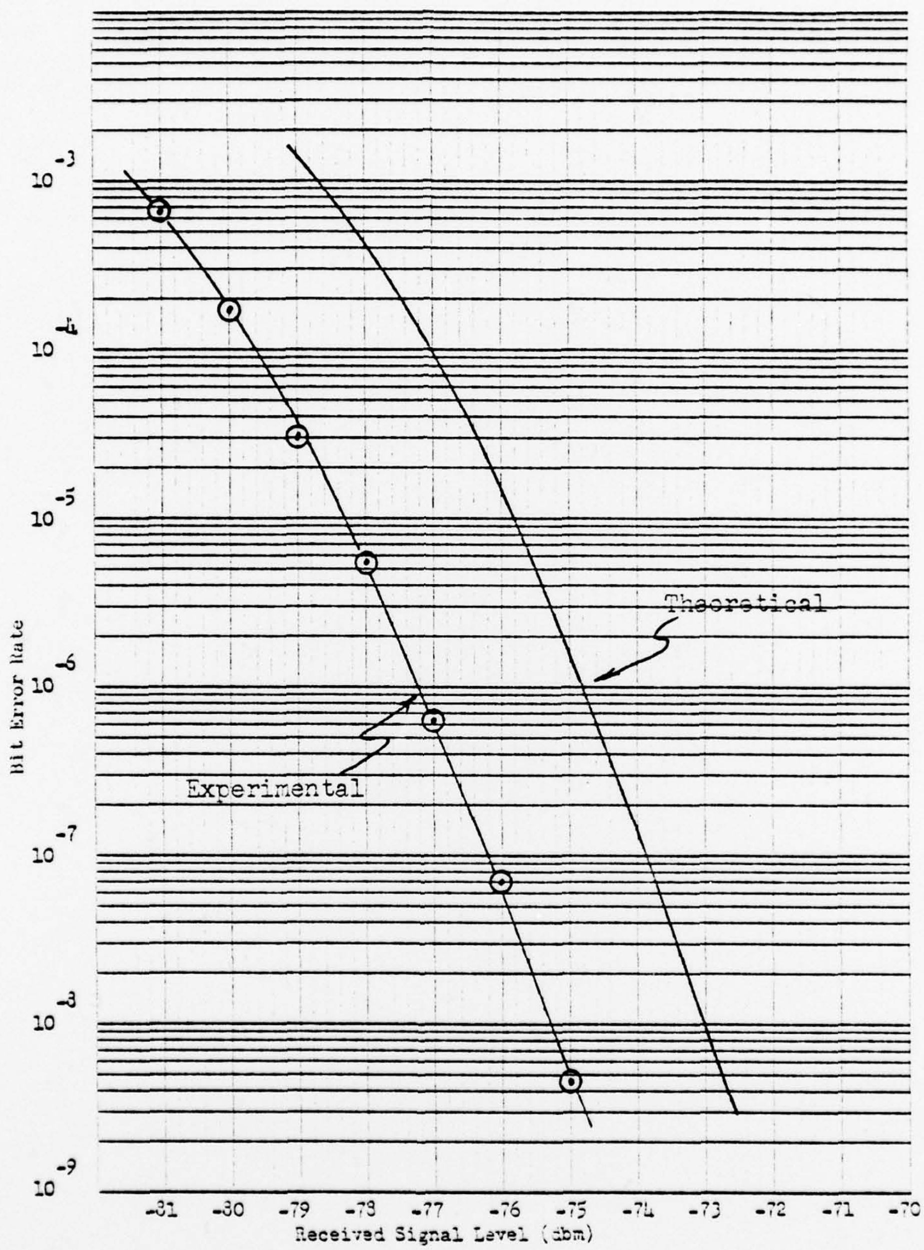


Figure 16. BER vs RSL, RDS-80.

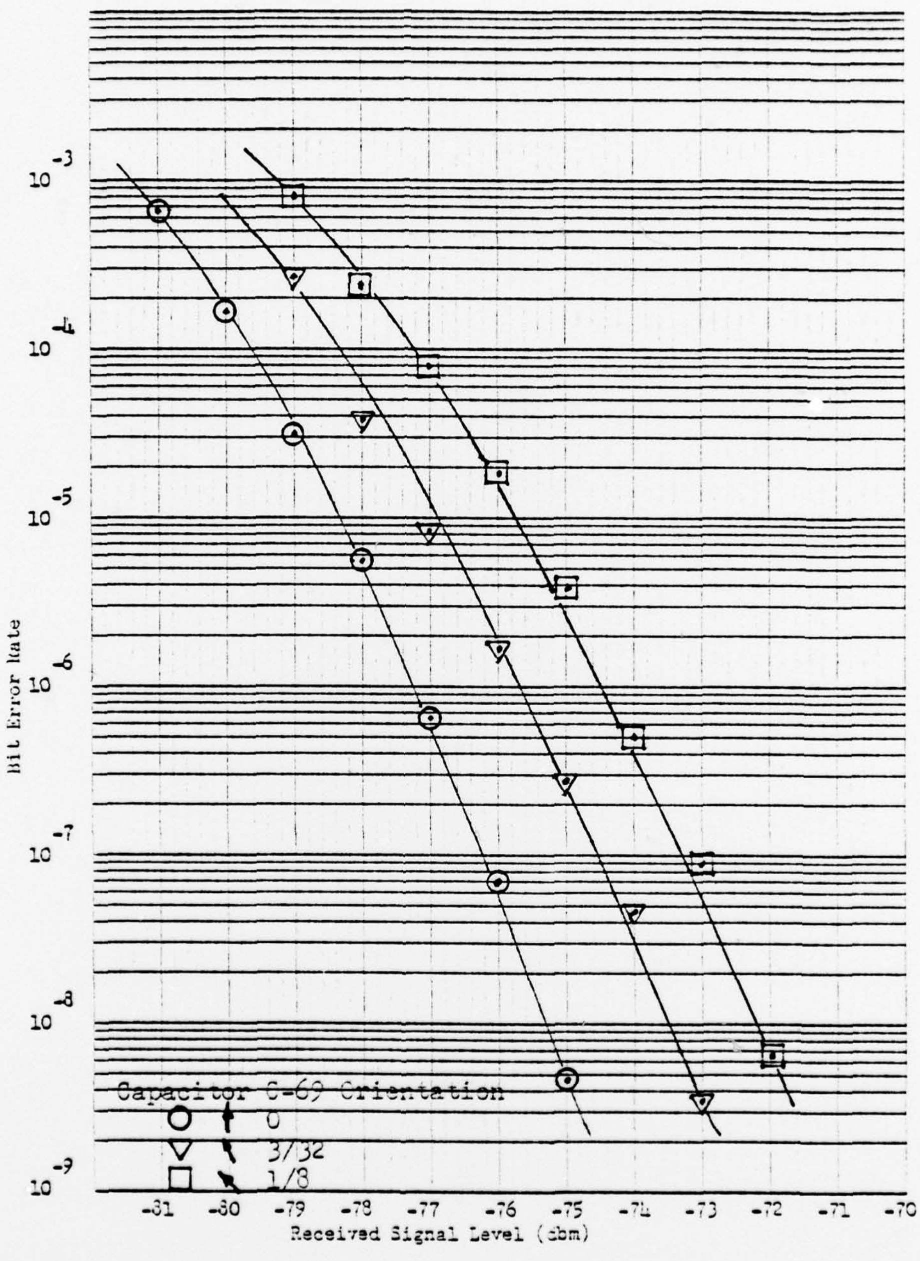


Figure 17. BER vs RSL, with baud timing offset. RDS-80.

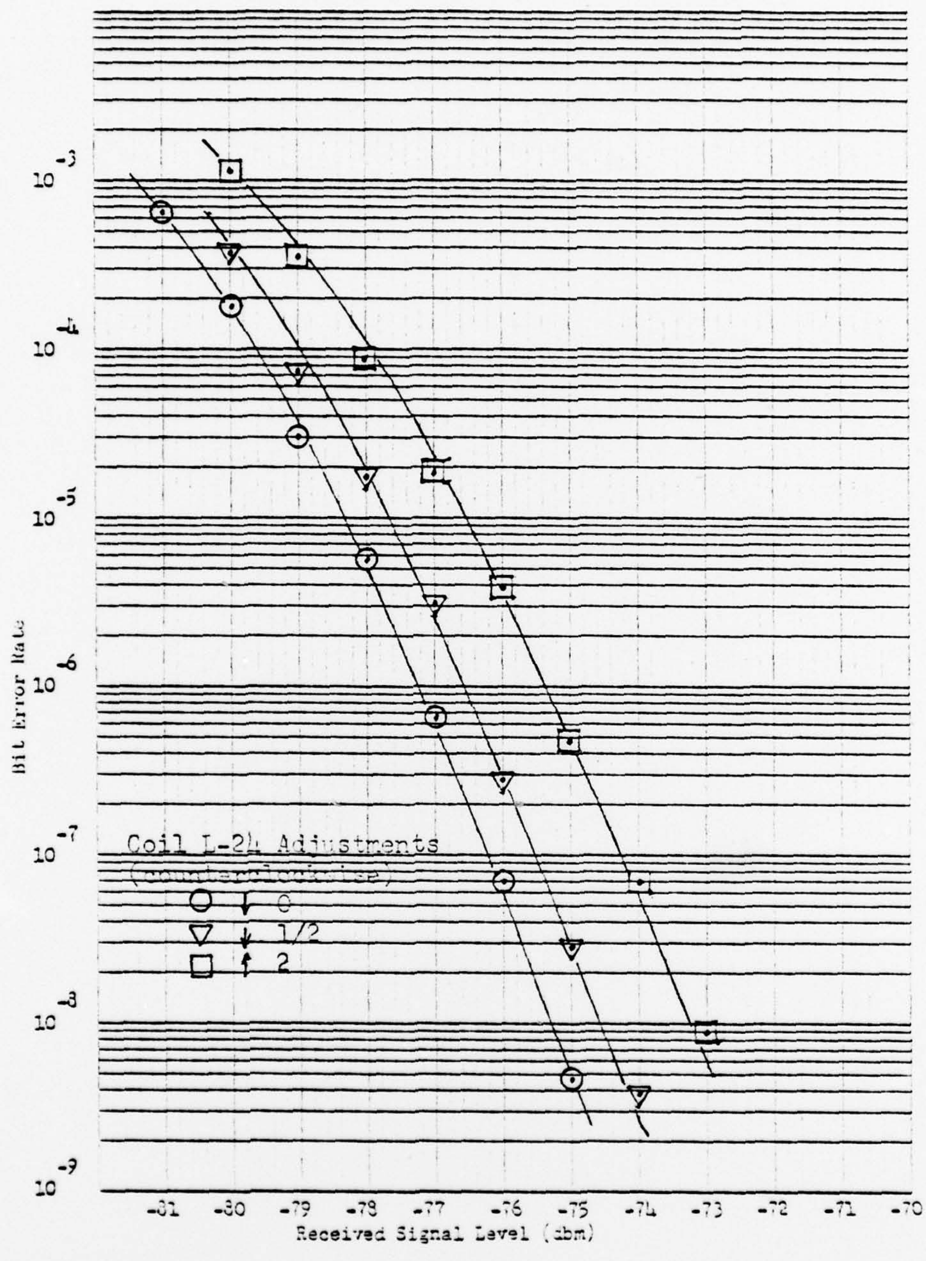


Figure 18. BER vs RSL, with carrier phase offset. RDS-80.

4.0 SUMMARY AND CONCLUSIONS

The experimental work described ~~above~~ here, was conducted in an attempt to verify the hypothesis that small variations in the internal anomalies which contribute to errors in digital demodulators cause a lateral displacement of the characteristic curve of bit error rate versus received signal to noise ratio, while the curve retains its theoretical shape at the higher levels of signal to noise ratio. Experiments were conducted on available digital communications systems which encompassed three different methods of modulation. Where feasible, perturbations of error causes were introduced into the systems to determine their effect upon the BER curves.

Baud timing jitter effects were investigated for a three level partial response modulation system, a frequency shift keyed modulation system, and a quadrature phase shift keyed modulation system. The effects of carrier phase jitter were examined in two quadrature phase shift keyed systems of different design. Receiver nonlinearities were investigated in the three level partial response system.

Due to limited resources (primarily time and availability of equipment) it was not possible to study all types of digital modulation systems. Also, due to individual design details, it was not feasible to introduce each type of perturbation into each system studied. Nevertheless, the experiments performed appear to be sufficiently representative to form an adequate experimental base for the completion of the task.

As has been noted in this preliminary report, considerable analysis of the data remains to be accomplished and will be required prior to a statement of quantitative results. However, even a cursory examination of the curves indicates that the curves do match the theoretical shape so long as the variations of the induced impairments remain small. Considerable analysis remains to determine the precise 'goodness of fit' of these curves based on the variances of the data.

It is also obvious that changes in the amounts of baud timing jitter, carrier phase jitter, and receiver nonlinearities do cause lateral shifts of the error curves as hypothesized. Again, however, several questions remain. For example, what is the emperically derived expression for the amount of lateral shift, and how does it compare with theoretical results? Also, how much shift can occur without distortion of the curves? These and other similar questions will be investigated in subsequent reports.

Another easily observable result is that, even when the curves do distort from the theoretical shape they never cross. This observation, as well as experience gained during the experiments, yields a conclusion which has potentially greater benefit than the saving of test time. <u>BER measurements of this kind can be extremely useful in new techniques for equipment alignment</u>.

To illustrate a possible technique, it is evident from the experimental data that present tuning procedures do not produce the ideal setting of the PLL voltage in the Vicom T1-4000, nor the best response from the FRC-162 receiver discriminator. BER measurements can be made as a final check after the normal procedures have been completed. The signal to noise ratio (RSL) can be set to a level to produce a fairly high BER (10^{-5} to

10^{-4}) and each parameter can be tuned independently to produce the minimum BER, monitored on an error measurement set such as the HP 3780A. Ultimate fine tuning can be accomplished in this manner.

Although our study is far from complete, the results to date are certainly promising. We anticipate that the final conclusion will have significant impact upon new improved methodologies for testing of digital communications systems and the operational alignment of receivers and demodulators.

REFERENCES

1. Schooley, L. C. and G. R. Davis, "Investigations of Methodologies for Testing Digital Communications Systems," Technical Report, Engineering Experiment Station, University of Arizona, Tucson, Arizona, July 1978.

2. Schooley, L. C. and G. R. Davis, "Instrumentation and Methodologies for Testing and Evaluation of Digital Communications Systems and Equipment," Technical Report, Engineering Experiment Station, University of Arizona, Tucson, Arizona, May 1977.

3. Schooley, L. C. and G. R. Davis, "Introduction to Testing and Evaluation of Digital Communications Systems and Equipment," Technical Report, Engineering Experiment Station, University of Arizona, Tucson, Arizona, April 1977.

4. Lucky, R. W., J. Salz, and E. J. Weldon, Jr., Principles of Data Communications, McGraw-Hill, 1968.