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TIME-DIVERSITY MODEM FOR TACTICAL HF TELETYPE CIRCUITS. ON-THE---ETC(U)

SEP 76 G B JOHNSON, G A CLAPP

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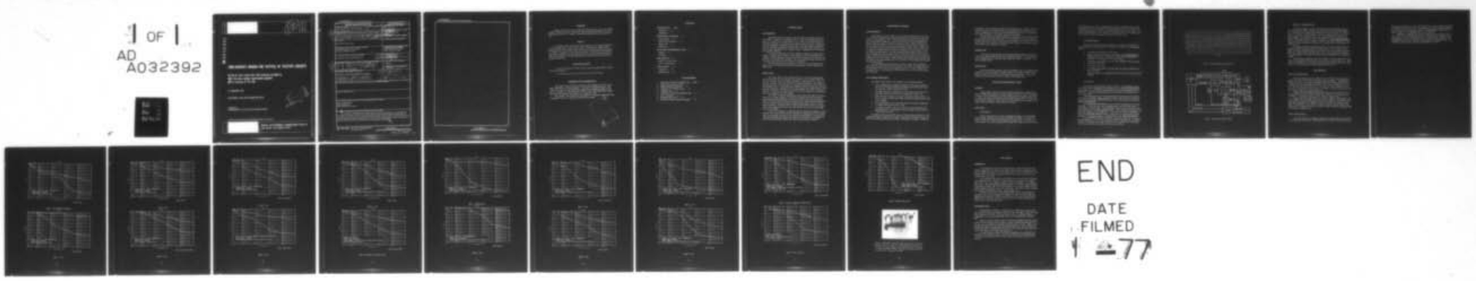

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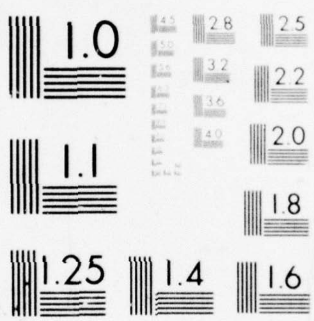

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On-the-air tests verify that time diversity provided by NELC five-tone modem significantly improves BER of tactical hf TTY link

27 September 1976

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A full-duplex FSK time-diversity modem using five tones was constructed in a unit requiring only 5.5 inches of rack space. Hf tests over a 750-km circuit showed that the time-diversity modem had error rates 100 times lower than those of a URA-17C modem for 70% of the test period. For 90% of the test time the time-diversity modem had a measured bit error rate at least 10 times better than those of the URA-17C. Greatest improvement occurred when the circuit was experiencing large fades.

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PROBLEM

Design, construct, and test an FSK time-diversity modem for use on hf TTY channels. Perform on-the-air comparisons with narrow-shift (AN/UCC-1) and wide-shift FSK (AN/URA-17C) modems to determine improvement by using time diversity.

RESULT

A full-duplex FSK time-diversity modem using five tones was constructed in a unit requiring only 5.5 inches of rack space. Hf tests over a 750-km circuit showed that the time-diversity modem had error rates 100 times lower than those of a URA-17C modem for 70% of the test period. For 90% of the test time the time-diversity modem had a measured bit error rate at least 10 times better than those of the URA-17C. Greatest improvement occurred when the circuit was experiencing large fades.

RECOMMENDATIONS

1. Upgrade USMC hf TTY circuits not fully using the assigned 3 kHz to include time-diversity modems.

2. Consider the application of time diversity to other TTY circuits

ADMINISTRATIVE INFORMATION

This report covers work done from June 1974 through June 1976 by the Radio and Modems Techniques Branch of the Radio Technology Division. The effort of the first year was independent exploratory development (NELC Z279) and the remainder was performed under XF21.222.015, WR 6-9089 (NELC N466). The report was approved for publication 27 September 1976.

The authors acknowledge the contribution of A Heaberlin, NELC/RF Communications Division, in refining the modem circuit design.

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ILLUSTRATIONS

INTRODUCTION

BACKGROUND

Experienced users of hf radio circuits are familiar with highly variable circuit quality. Variations in propagation occur on time scales ranging from fractions of a second to the 11-year sunspot cycle. Users of tactical hf circuits are especially vulnerable to fluctuating circuit quality because they must contend not only with propagation variations but also with varying path length, unfamiliarity with the immediate propagation conditions due to the short operating time in a given location, generally less than optimal antenna configurations, and substandard hf equipment alignment.

A number of techniques have been applied to improve the quality and reliability of tactical digital hf links. These include the use of oblique-incidence sounders, in-band frequency diversity, spaced antenna diversity, and coding of the data for error detection and correction. The two diversity methods are the most commonly used, since they are the easiest to implement.

The time-diversity modem described in this report was developed for the Marine Corps as an alternative method of improving the tactical hf digital data (TTY) link.

APPLICATION

The present Marine Corps tactical TTY link, to which this time-diversity modem will apply, does not approach full utilization of the available 3-kHz channel. This channel, which can support operation at 2400 bits per second (bps), is normally operated at less than 150 bps. If channel bandwidth is not required for data purposes, then it can generally be profitably used for error control. Tactical hf TTY links can use a great deal of error reduction for the reasons outlined above. Diversity combining is an effective error control method and usually the easiest to implement. Frequency diversity is available in some hf modems by combining separate data channels of the tone package.

The success of diversity combination depends upon the degree of independence of the combined channels. Two perfectly correlated channels could offer no improvement through combination, since errors would occur on them simultaneously. Frequency diversity does not always provide enough channel independence for error control because some types of fading and impulsive noise are not frequency dependent. Tactical hf TTY circuits are often limited more by impulsive noise, such as lightning and radar, and "flat fading" than by poor median signal-to-noise ratios (SNR).

In the hf environments of impulsive noise and fading the technique of time-diversity can be very effective because, although the channels may not be independent or uncorrelated, the data in each channel are uncorrelated. This report describes the time-diversity technique, the modem, and on-the-air tests conducted to measure the improvement obtained by using the time-diversity technique.

DESCRIPTION OF MODEM

TIME DIVERSITY

The technique of time diversity involves merely transmitting the same data on more than one channel with some delay between the data streams so the data streams are uncorrelated in time. When the different channels are demodulated, the converse delay is added to each data stream so they are again perfectly correlated, with the exception that the errors within the data streams are uncorrelated. The net effect in time is to delay each channel by the same period. With a number of correlated data streams containing uncorrelated errors, various schemes can be applied to combine the data streams and regenerate the data stream most likely to have been transmitted. It is easily understood that impulsive noise is capable of causing errors in all channels, but for only short periods. Each impulse will degrade each of the channels in an uncorrelated manner when the data streams are correlated at the receive modem. Delay between the channels which is greater than the period of the noise impulse will be very effective in uncorrelating the resulting errors in each channel.

The effectiveness of time diversity in impulsive noise and fast fading depends upon the delay between the data streams, the number of channels used, and the combining scheme used in the mark/space decision. Of course, SNR is also important, but it is less important in time diversity than it is in most other diversity techniques.

NELC MODEM OPERATION

The NELC modem achieves time diversity in the following manner:

1. At the modulator the incoming 75-baud TTY data stream modulates one tone by frequency shift keying (FSK) and is also fed into a digital delay line which is clocked at 75 Hz.
2. The digital delay line is tapped at the 32nd stage and the data out at that stage, delayed by 0.43 second, modulate the second tone.
3. Delay line taps at stages 64, 96, and 128 provide delays of 0.89, 1.2, and 1.7 seconds to data which FSK modulate the remaining three tones in the package.
4. After demodulation, four of the data streams are delayed sufficiently to realign all five data streams in time.
5. A continuous majority vote of the five data streams determines the final data output. A mark/space decision is made 16 times each bit, 1200 times each second.

The NELC modem accepts TTY data at 75 baud using a 20-mA loop. The modulator generates a five-tone audio signal, containing the undelayed data stream and the four identical delayed data streams, and presents this signal at 0 dBm for transmission. The demodulator section of the modem accepts a 0-dBm tone package from a radio receiver and generates five data streams for realignment and diversity combination to provide the received digital data stream on a 20-mA loop to a crypto or teletype. The NELC modem is fully duplex.

The five-tone audio signal is generated by frequency shift keying (±42.5 Hz) of the standard TTY center frequencies of 765, 1105, 1445, 2125, and 2805 Hz. Standard Navy UCC-1 filters are used in the demodulator. Five LEDs on the front panel provide visual indication of the performance of each of the five data streams with respect to the majority vote stream.

MODEM COST

The prototype modems each contain approximately $1500 in parts and in addition cost approximately $2000 each to assemble at NELC. The five TTY filters, comprising the most expensive items within the modem, are available in the Federal Supply System.

MODEM SIZE

The four prototype modems built for the Marine Corps were designed with enough space inside the cabinet to permit addition of a second complete modem circuit, so the 5-1/4-by-19-by-13-inch chassis is much larger than it needs to be. Production models would be 0.25 the volume of these prototypes.

ON-THE-AIR PERFORMANCE TESTS

PURPOSE

Theory suggests that five-tone time diversity will provide a significant bit error rate (BER) improvement over single channel on the air. Hence, the purpose of this test was to establish the on-the-air performance of the NELC modem and to measure the relative performance of this modem and the URA-17C under identical on-the-air conditions. The URA-17C is nearly identical in modulation to the modem used in the Marine Corps tactical TTY circuit.

TEST PLAN

HF CIRCUIT

The hf circuit used in the test was established between the NAVCOMMSTA Stockton transmitter site at Dixon, California, and NELC, San Diego, California, a distance of 750 km (approximately 466 statute miles). The path is entirely overland. The audio signal was fed by phone line from San Diego to Dixon and transmitted at hf via an omni-directional antenna at 50-1000 watts. Usually minimum power was used, except for the unmanned nighttime test periods. The hf signal was received at NELC by an R-1051D receiver and a 10- or 32-foot whip antenna (approximately 3 or 9.6 metres). Frequencies of 4.0 and 9.9 MHz were used. Figure 1 shows the frequency schedule of the test series.

TEST PROCEDURE

The test procedure, which was automated, was designed to measure bit errors alternately by using the NELC modem and the URA-17C in the following manner:

1. A modem was switched into the circuit.
2. Three seconds after the switch, all counters in the COUNTER/CONTROLLER were reset. This permitted the ICC-220 TRANSMISSION TEST SET to synchronize on the received data.
3. A bit-error total printout was made after 10 000 bits had been transmitted (133.3 seconds).
4. All counters were reset.
5. A bit-error total printout was made after the second 10 000 bits had been transmitted.
6. Alternate modem was switched into the circuit and the test sequence was repeated.

TEST SETUP

The receiver site test setup is shown in figure 2. The transmitted tones (1575-2425 Hz) for the URA-17C are generated by the HP-5100 SYNTHESIZER as controlled by the TEST SET digital sequence and the SYNTHESIZER CONTROLLER. This tone generation scheme was checked out for accuracy prior to the on-the-air tests.

The test set sequence (511-bit pseudorandom) is the same for both modems, but is fed to the NELC modem through the built-in 20-mA loop and fed to the URA-17C tone generator (HP-5100) through a 0-5 V signal acting on the SYNTHESIZER CONTROLLER.

The COUNTER/CONTROLLER counts both bits transmitted and received bit errors. It also drives the relay to simultaneously switch transmit audio, receive audio, and receive data. The PRINTER receives its print command and bit-error data from the COUNTER/CONTROLLER. Bits transmitted are counted from the 75-Hz signal out of the TEST SET. An inhibit level from the PRINTER is fed to the COUNTER/CONTROLLER to ensure that no counting occurs during printing. The printing sequence is outlined above under TEST PROCEDURE.

The transmitter at Dixon, an FRT-84, accepts the signal from the phone line and transmits it at hf. The transmitter output is monitored on a spectrum analyzer at San Diego and partially controlled by the signal level fed to the phone line. Power levels are also monitored and controlled at Dixon.

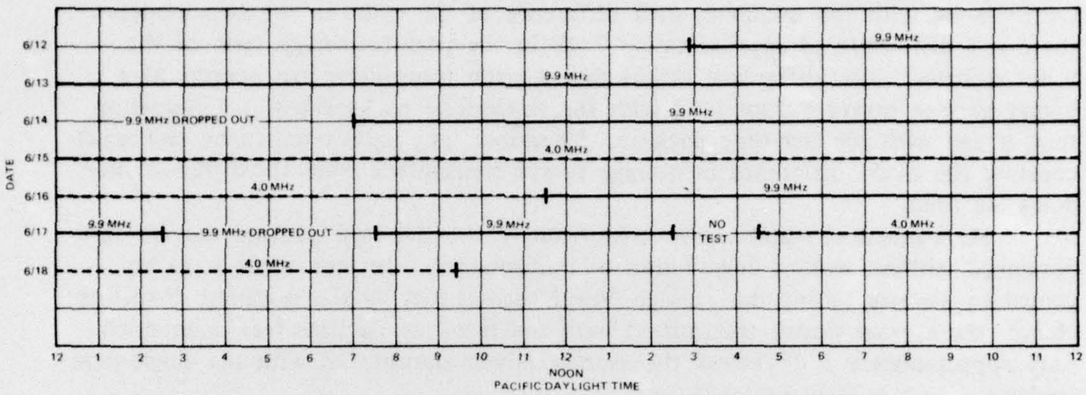


Figure 1. Frequency schedule for on-the-air tests.

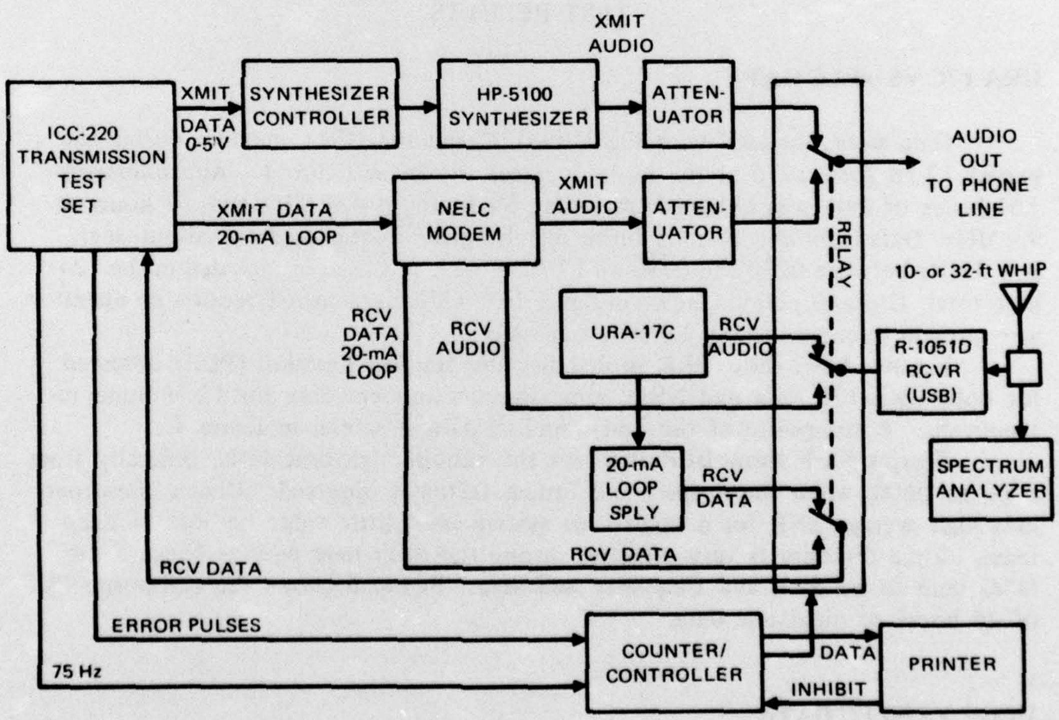


Figure 2. Receive site test setup at NELC.

SPECIAL CONSIDERATION

This test attempts to compare the performance of two different modems, one with single-tone FSK modulation and the other with five-tone FSK modulation. Along with the frequency-shift difference of the tones in the two modems, there is a difference of approximately 7 dB in the peak-to-average ratio of the tone packages. This difference means that a given transmitter can operate at a higher average power output level with the single-tone package without distortion than it can with the five-tone package. Therefore, any valid comparison test must consider the likely difference in average power transmitted when the different modems are used.

As a practical matter, some distortion of the five-tone package can be experienced without serious degradation of performance. In fact, more is to be gained by slightly raising the average power than is lost by the resultant distortion. Hence, the average power transmitted with the five-tone package was maintained only approximately 5 dB below the average power transmitted with the single-tone package.

No distortion occurred to either tone package in this test because the transmitter used is capable of 10 kW and the actual outputs were 50-1000 watts. However, the 5-dB difference was carefully maintained and monitored both at the signal source to the phone lines and on the spectrum analyzer at hf.

TEST RESULTS

URA-17C VS NELC DATA

Data were obtained with the URA-17C and the NELC modem during the period 12-18 June 1976 at the hf frequencies shown in figure 1. Approximately 124 hours of data was obtained, including 54 hours at 4.0 MHz and 70 hours at 9.9 MHz. Data from long periods during which a given frequency dropped out, such as 9.9 MHz between 0230 and 0730 on 17 June, were not used or included in the 124-hour total. Dropout periods shown in figure 1 (9.9 MHz) occurred because no operators were present to change to the 4.0-MHz frequency.

Figures 3A-G show BER probability distribution function (PDF) observed for both URA-17C data and NELC time-diversity modem data for 12-18 June, respectively. A composite of the 124 hours of data is shown in figure 4.

Figures 5A-F show BER PDF for the various nighttime tests, generally from 2100 to 0600, when the deepest and fastest fading is observed. During these periods high average SNR for a single-tone system is of little value because of deep fades. Time diversity is very effective during the deep fade periods because the fades tend to be short and frequency selective. Figure 6 shows the composite PDF of 46 hours of nighttime data.

UCC-1 VS NELC DATA

Time and equipment availability permitted a short comparison test between the time-diversity modem and a single-channel UCC-1 modem. The same test setup was used for the UCC-1 test as for the URA-17C test. The synthesizer generated the 1955 (±42.5) Hz UCC-1 tone. Approximately 45 hours of data was obtained in the UCC-1 vs NELC time-diversity test. A composite PDF of these data is shown in figure 7. One nighttime PDF is shown in figure 8.

Although the nighttime data shown in figure 8 may be extreme, they are valid. Some of the error-producing activity was observed by an operator and a photograph of the UCC-1 fading which was occurring is shown in figure 9. The average SNR for the UCC-1 was 20-30 dB, but errors were observed as the fast, deep fades occurred which caused an average BER of near 10^{-2}.

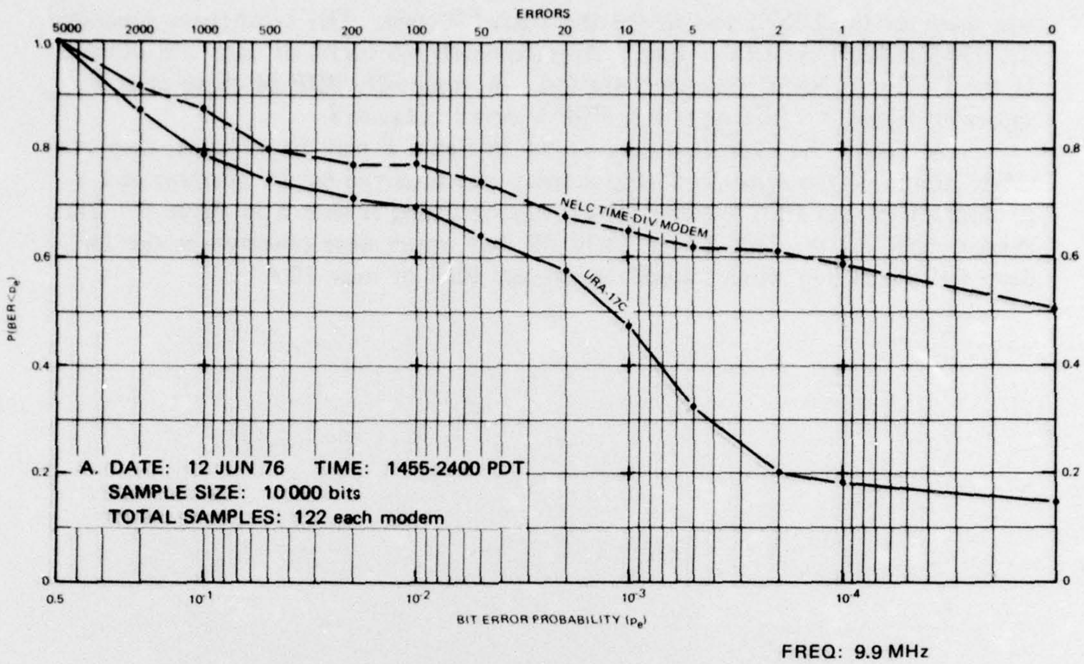


Figure 3. BER probability distribution.

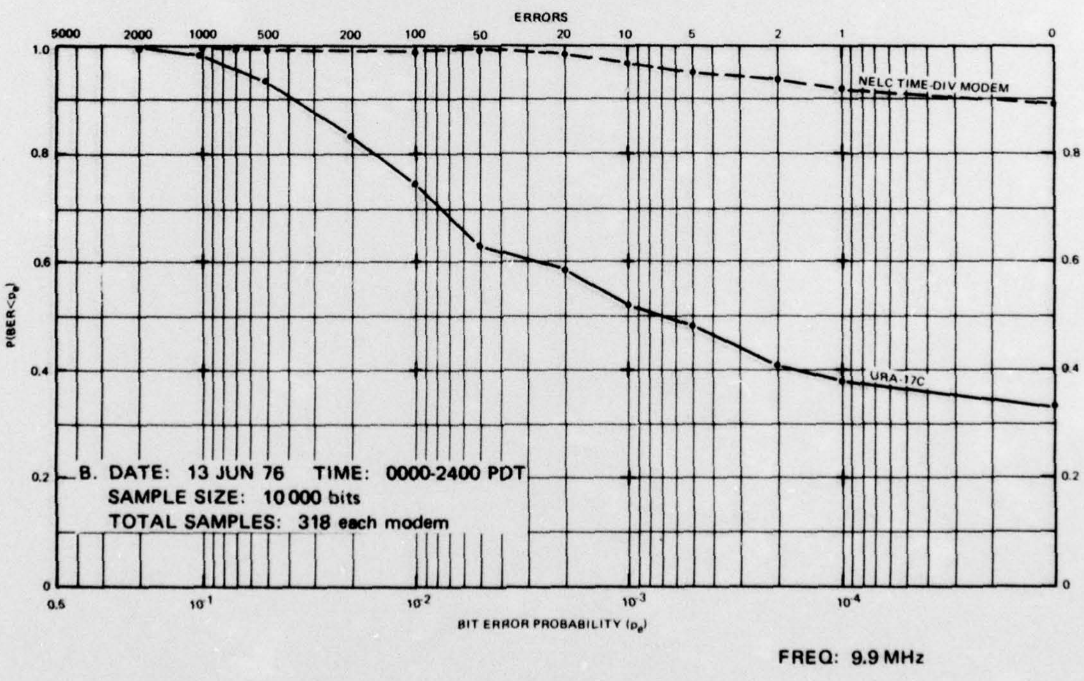
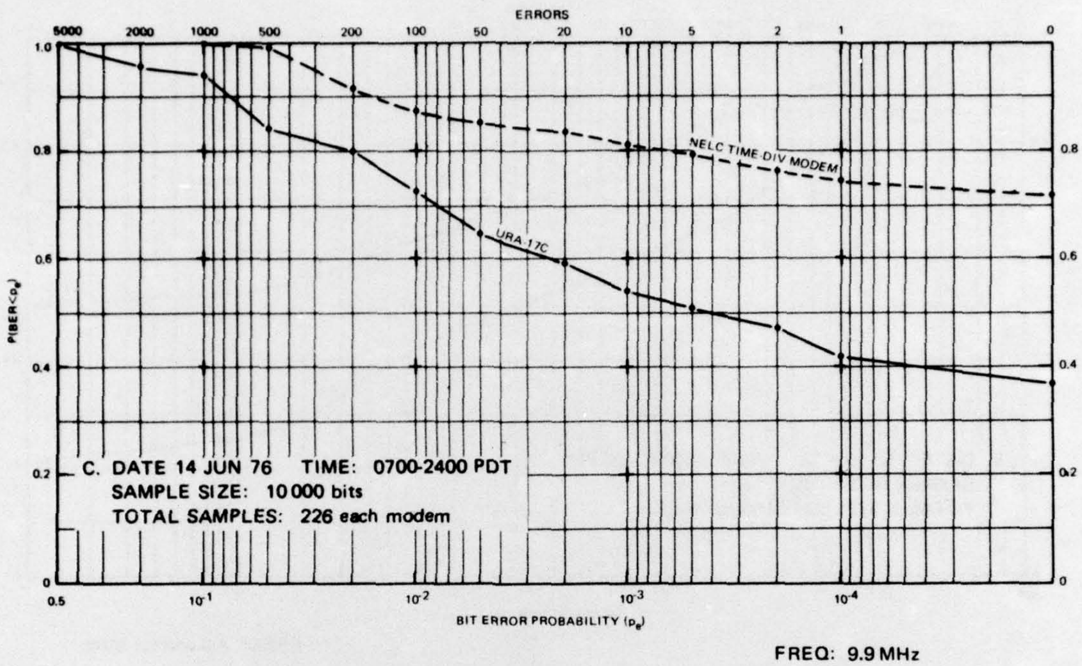


Figure 3. Cont.



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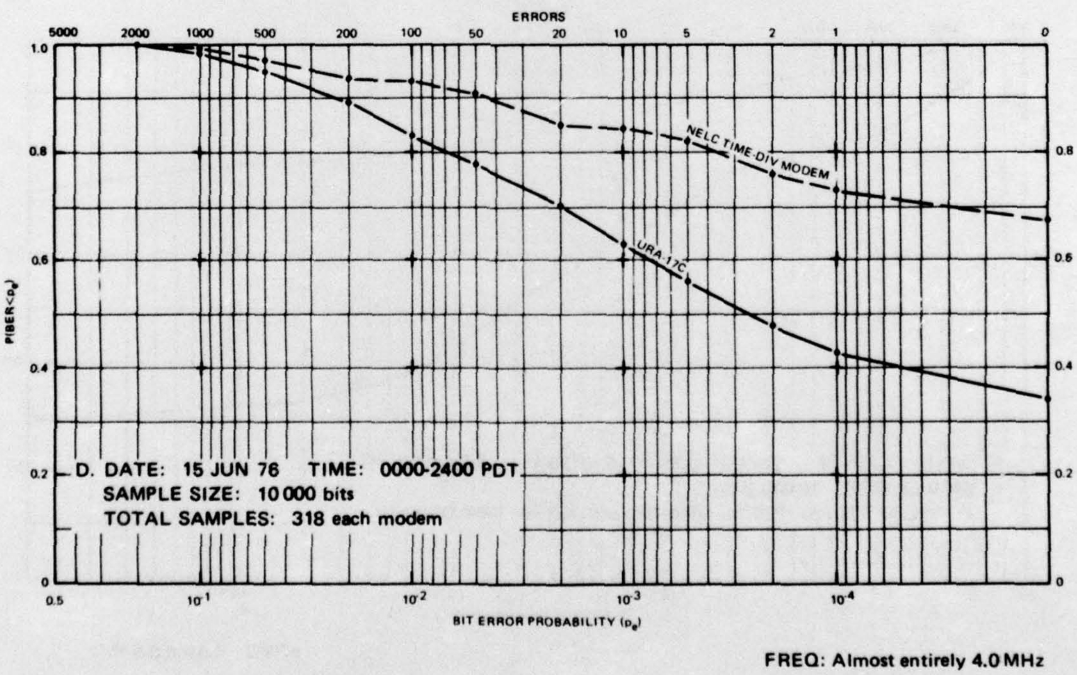

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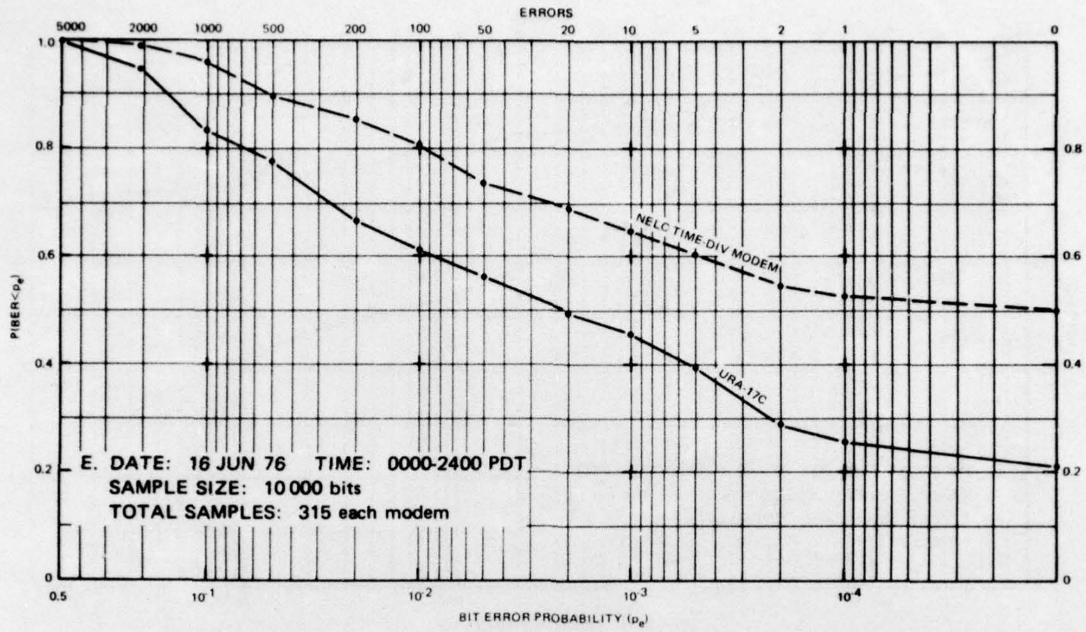

FREQ: 4.0 and 9.9 MHz

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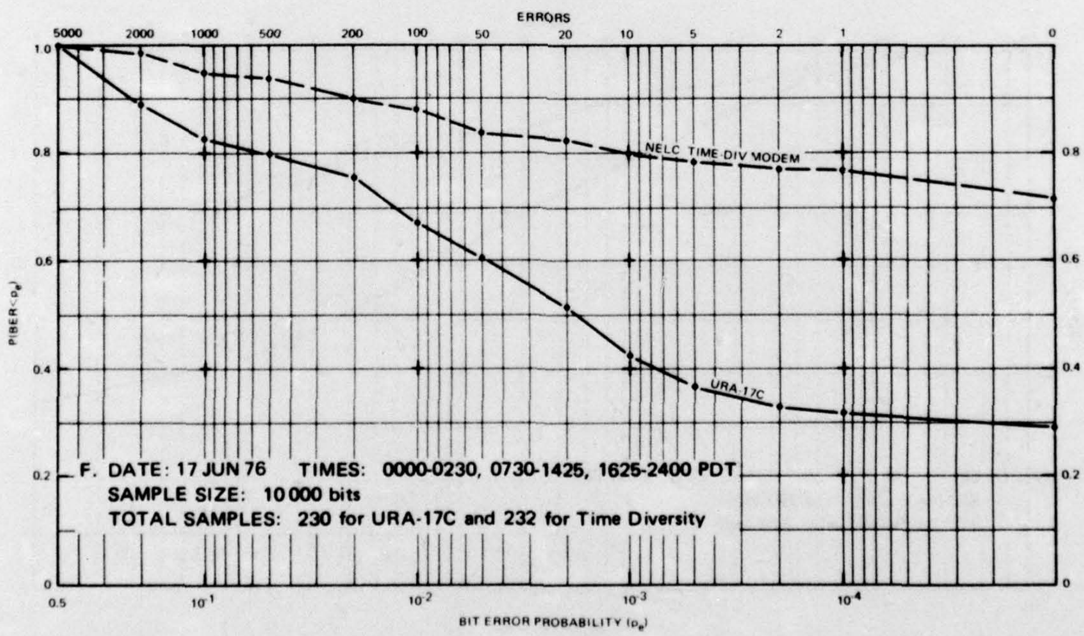

FREQ: 4.0and 9.9 MHz

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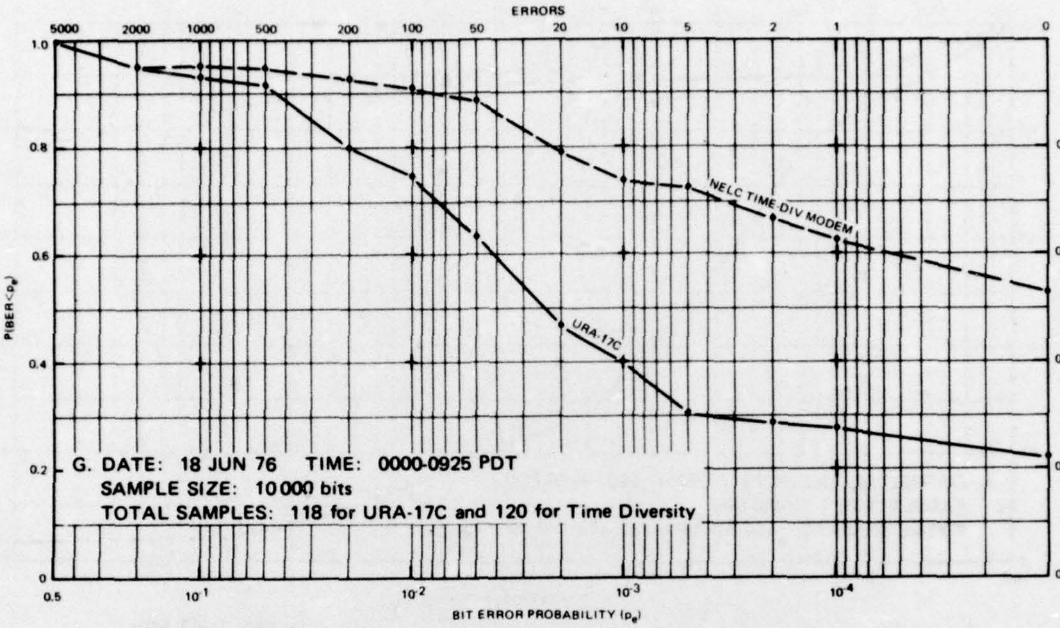
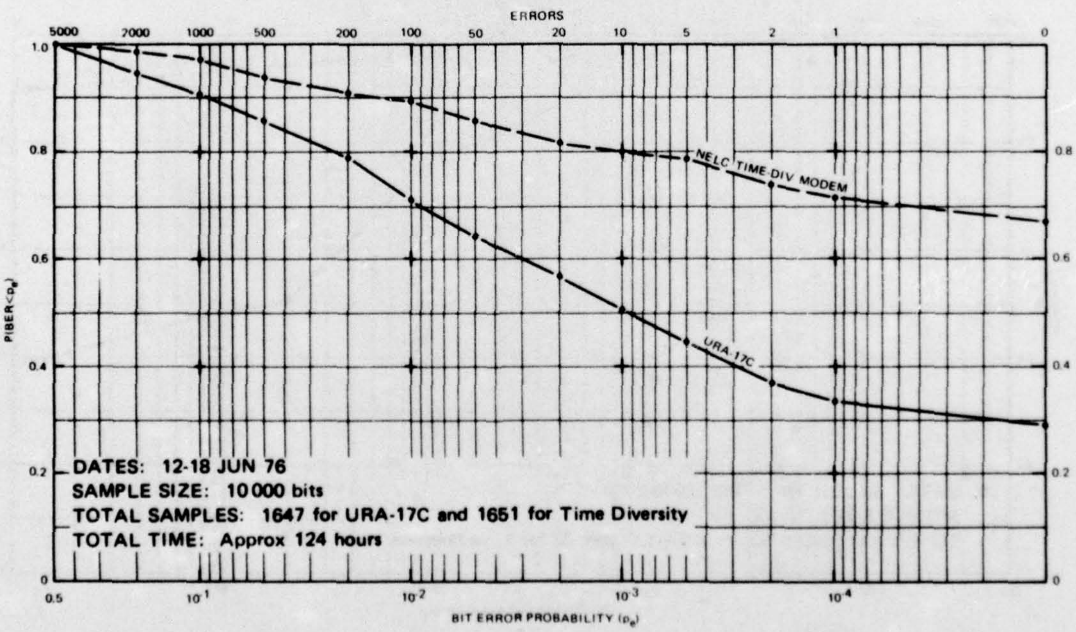


FREQ: 4.0 MHz

Figure 3. Cont.



FREQ: 4.0 and 9.9 MHz

Figure 4. Composite of 124 hours of data.

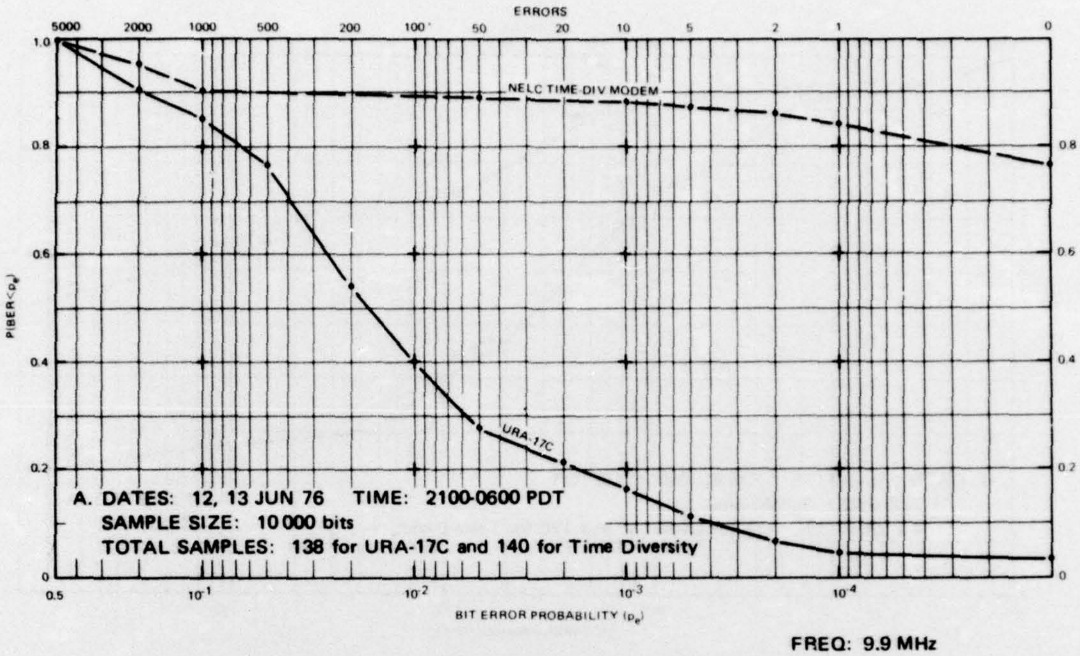
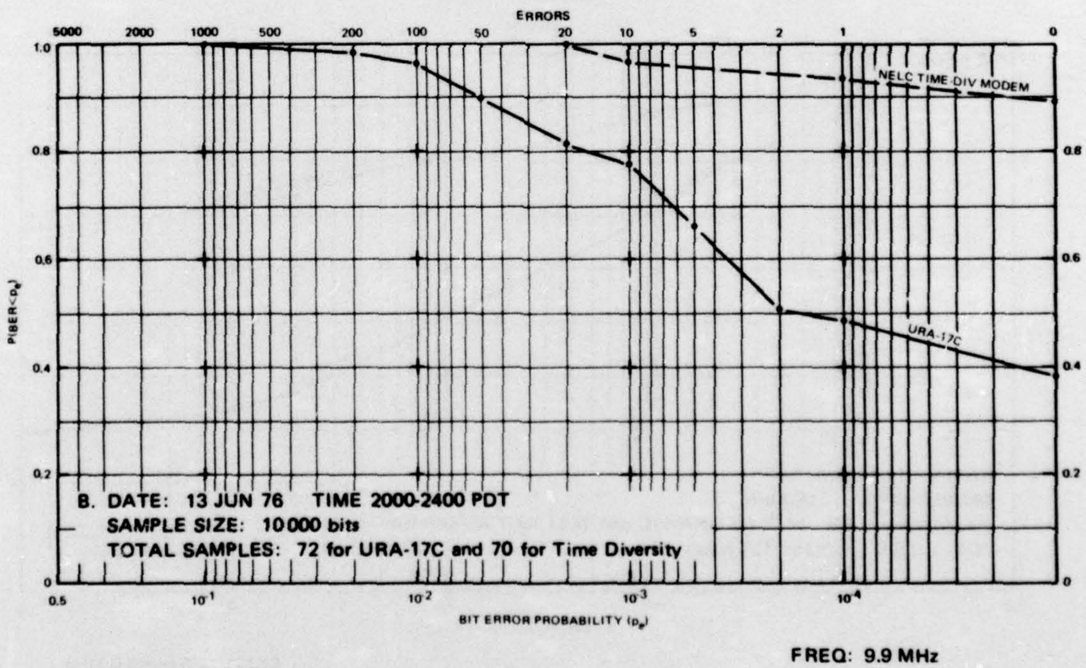


Figure 5. Nighttime data.



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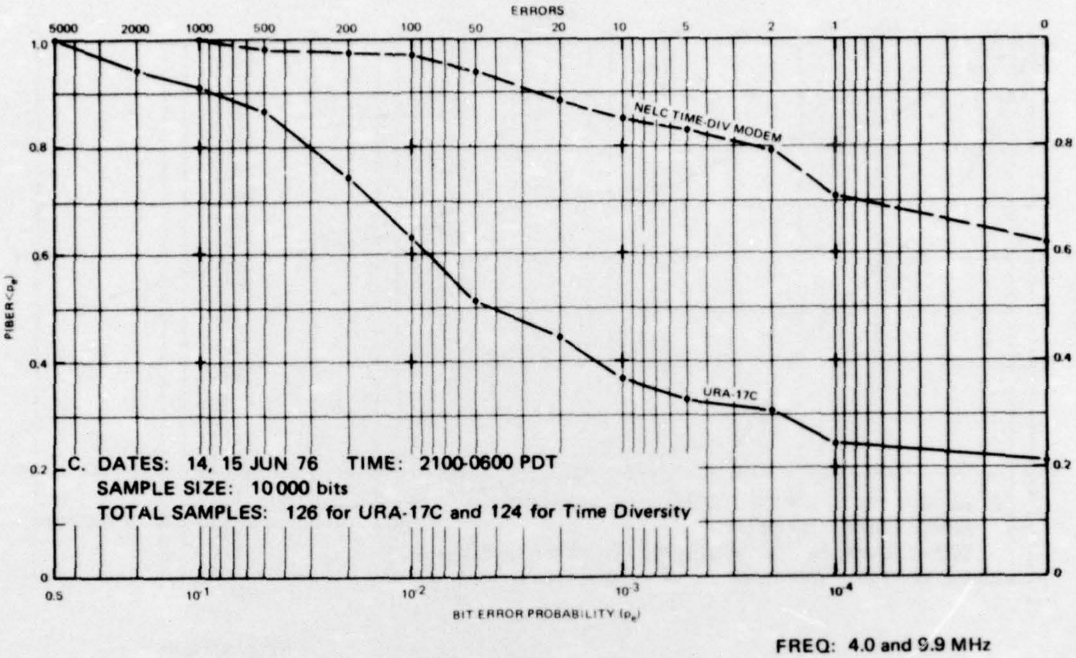

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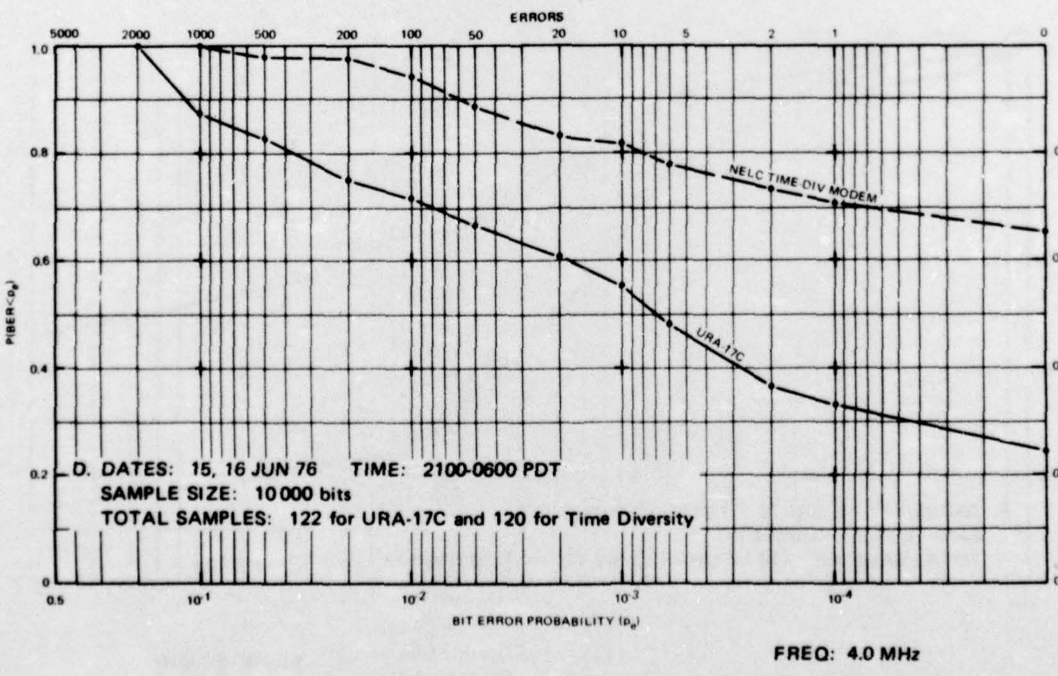

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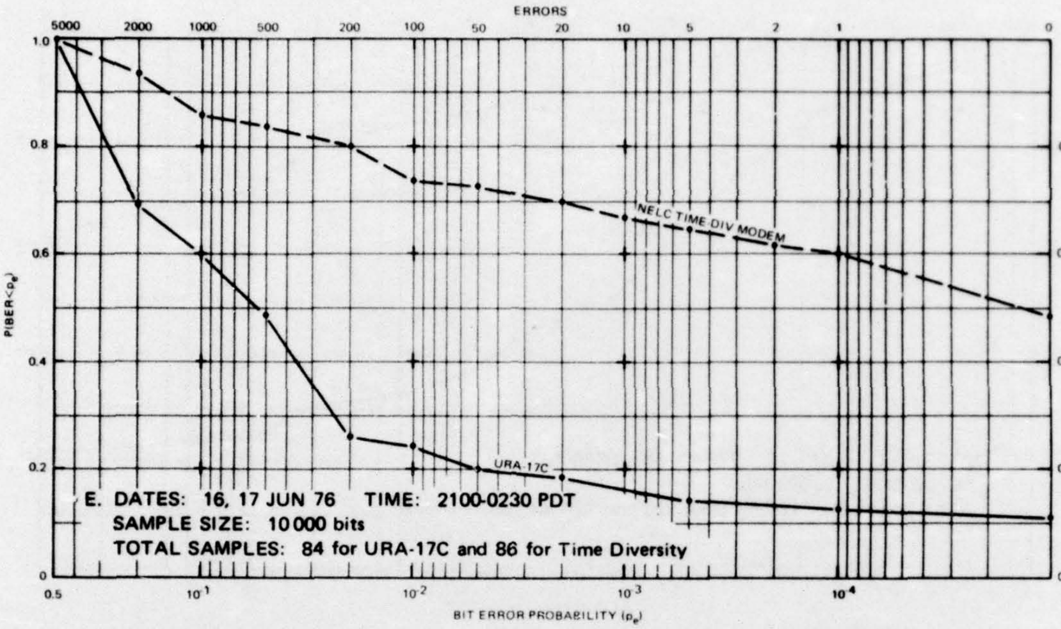

FREQ: 9.9 MHz

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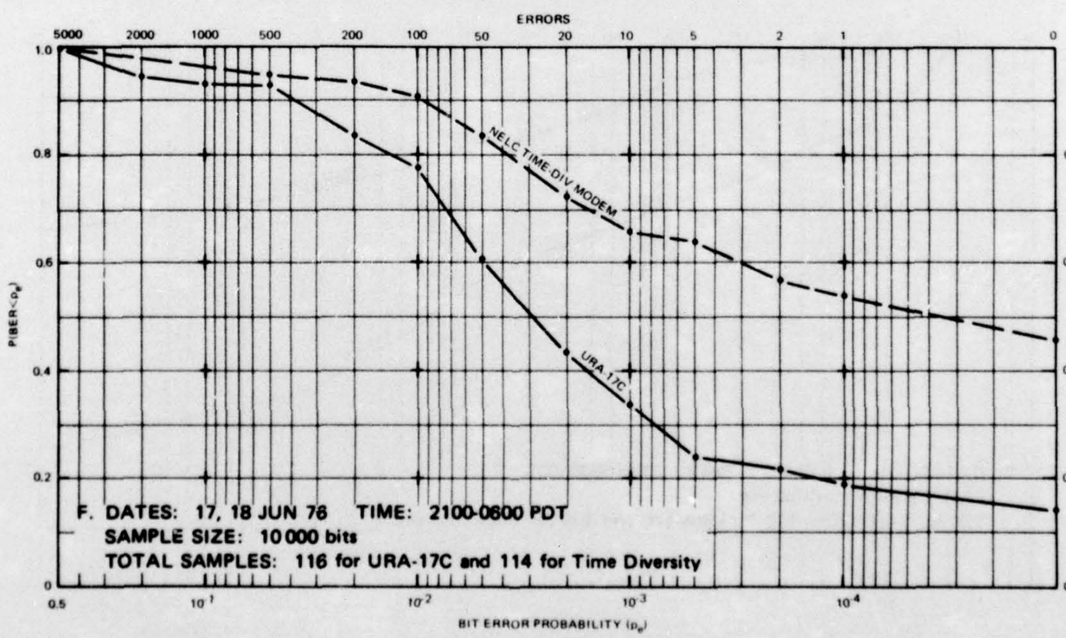

FREQ: 4.0 MHz

Figure 5. Cont.

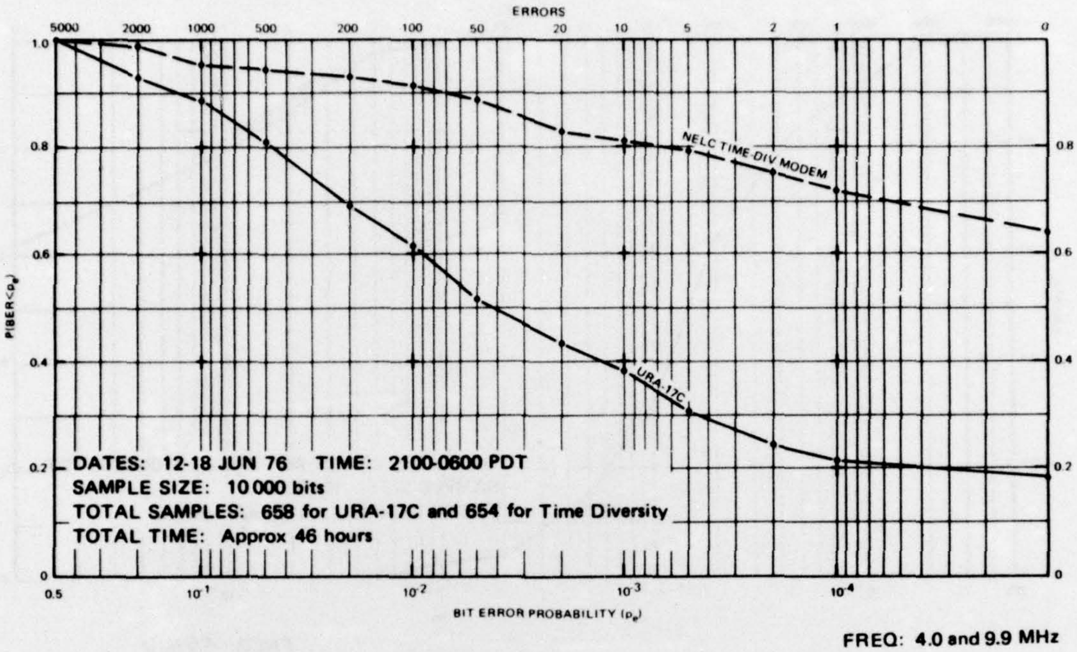

Figure 6. Composite of 46 hours of nighttime data.

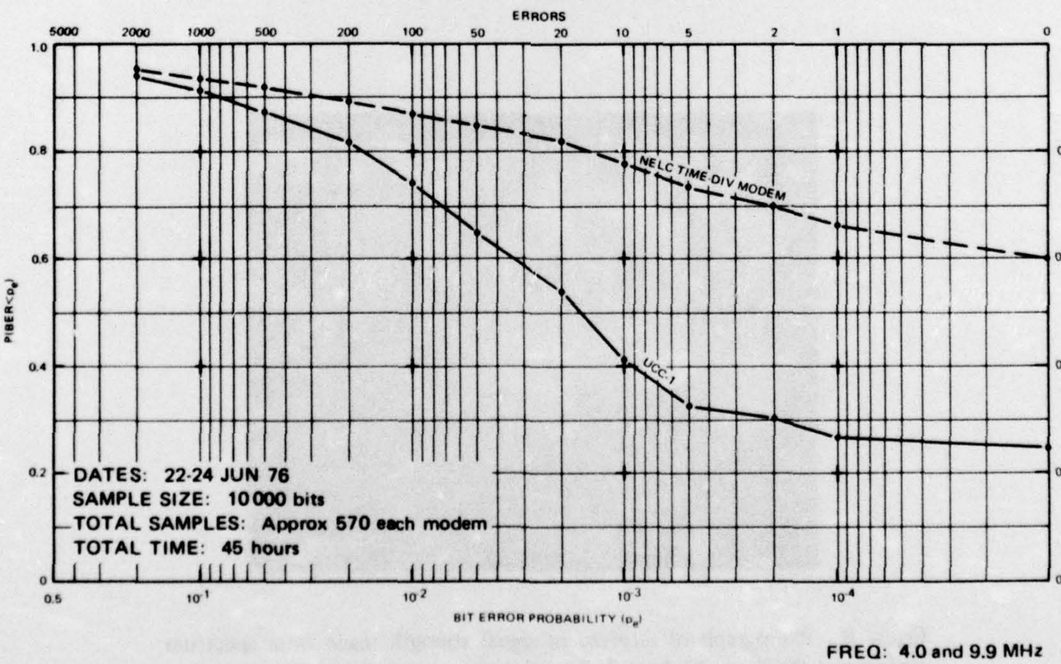

Figure 7. UCC-1 composite.

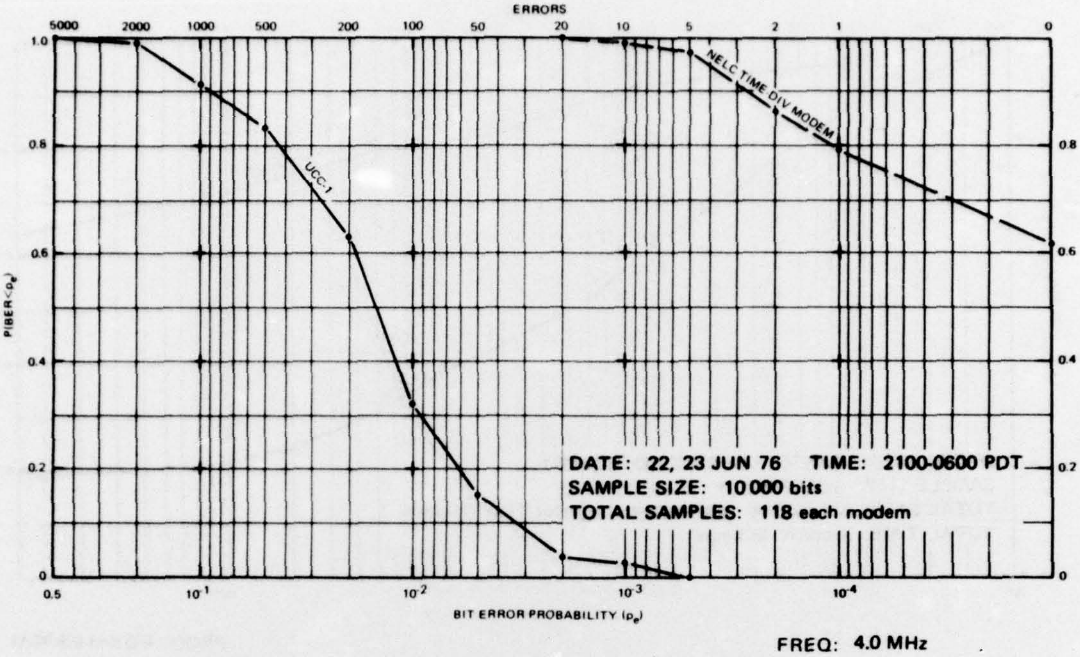

Figure 8. Nighttime data, UCC-1.

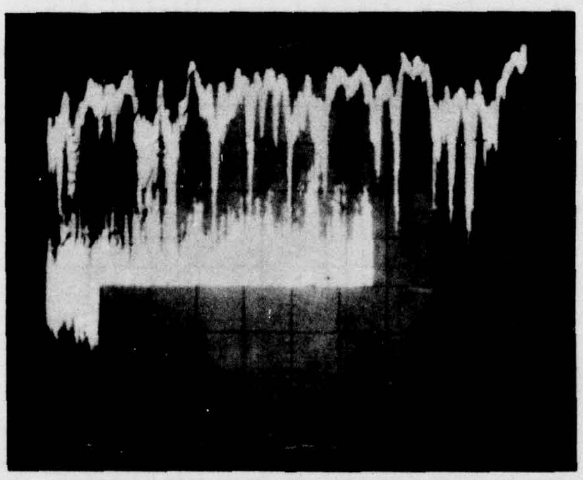

Figure 9. Photograph of received hf signal strength made from spectrum analyzer at 0015 on 23 June 1976. Spectrum analyzer is tuned to receive signal and is not sweeping. Signal strength is in dBm. Time scale is 10 s/div. Bandwidth is 300 Hz. Top trace shows signal and bottom trace shows noise. Frequency is 4.0 MHz.

CONCLUSIONS

COMPOSITES

The composite probability distribution function (PDF) indicates that time diversity, specifically as provided by the NELC five-tone modem, significantly improves the BER performance of a 100-word-per-minute TTY circuit when the NELC modem replaces the standard single-tone modem over paths in which fading and impulsive noise are present.

The composite PDF provides much information on the relative performance of the modems tested. However, a common point of comparison is the percentage of time that a given modem provides acceptable performance, say a BER of 10^{-3} or less. By that standard, according to figure 4, the NELC modem provided acceptable performance 80% of the time during the test while the URA-17C provided acceptable performance only 51% of the time. The NELC modem extended the acceptable performance period by approximately 58%.

Another interpretation of the composite PDF is BER improvement as a function of time. The composite PDF indicates that 90% of the test time the time-diversity modem had a BER at least 10 times better than that of URA-17C. Eighty percent of the test time it was at least 20 times better, and 70% of the time it was at least 100 times better.

NIGHTTIME DATA

The nighttime conditions in which fast deep fades occur are more like the conditions expected for longer hf paths both day and night. Hence, the nighttime composite for URA-17C and time diversity (fig 6) is probably closer to a long-distance hf path performance PDF than is the around-the-clock composite (fig 4).

Figure 6 indicates that the URA-17C provided acceptable performance 38% of the test time while the NELC modem provided acceptable performance 81% of the test time, an increase in acceptable performance time of 113%. Figure 6 also indicates that 90% of the time the time-diversity BER was at least 18 times better than the URA-17C BER, 80% of the time it was at least 50 times better, and 70% of the time it was at least 300 times better.

A time-diversity modem of the NELC configuration was expected to be superior to the single-tone modem. The results observed in this test verify that expectation and demonstrate that the NELC modem performs as expected on hf channels.