AFAL-TR-74-308

THE USE OF CODED COMMUNICATIONS TO OVERCOME IONOSPHERIC SCINTILLATION FADING

SYSTEM AVIONICS DIVISION (AA)
INFORMATION TRANSMISSION BRANCH (AAI)

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This technical report has been reviewed and is approved for publication.

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In an effort to improve UHF satellite communications during the times it is affected by ionospheric scintillation fading, a simulation program was undertaken to investigate coding and interleaving. By making use of the times when the UHF signal is unfaded, it appears that forward error correcting coding can improve message readability. Interleaving of data bits is necessary to convert the long bursts of errors into a somewhat random error pattern which can be corrected by the coding. One-half rate binary feedback coding, one-half rate

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Abstract continued:

Viterbi coding and one-third rate Viterbi coding was tried. Various interleaving dimensions were also investigated. A UHF SATCOM channel with fading was simulated using actual scintillation fade data previously collected. The various types of coding/interleaving were played through the channel and the performance of each of these combinations was compared with the uncoded message. The results showed that an improvement in message readability can be achieved with coding/interleaving.

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FOREWORD

This report was prepared by Messrs. Allen Johnson and John H. Garrett, System Avionics Division. Information Transmission Branch (AFAL/AAI), Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was accomplished under Project No. 1227, "Advanced Microwave Communications", Task No. 122722 "Communication Test and Evaluation", Work Unit 12272214 "Scintillation Fade Protection", between December 1973 and August 1974.

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SECTION I
INTRODUCTION

Increased emphasis is being placed on the use of communication satellites for improving the reliability and increasing the range of mobile communications. Mobile communication systems utilizing satellites are subject to the problems of multipath fading and ionospheric scintillation.

Multipath fading also occurs during standard ground-to-air line-of-sight communications. Directive antennas, frequency diversity, space diversity, and frequency spreading will usually alleviate the effect of this problem. However, ionospheric scintillation fading is not experienced during conventional ground-to-air communication. This type of fading is caused by irregularities in the ionosphere at altitudes ranging from three hundred to six hundred kilometers.

The effect of ionospheric scintillation on the received signal from a UHF communication satellite operating at approximately 300 MHz is shown in Figure 1. The signal can experience fading of up to 25 dB with fade duration ranging from one to ten seconds. The methods used to alleviate the effects of multipath fading such as antenna directivity, frequency diversity, space diversity, and frequency spreading do not necessarily reduce the effect of fading caused by ionospheric scintillation.

Ionospheric scintillation is caused when irregularities in the F layer of the ionosphere increase in intensity and cause bending of the electromagnetic waves passing from the satellite to the earth through these irregularities. An artist's concept of an ionospheric model is shown in Figure 2 (Reference 1). A defraction grading effect, or a series of peaks or nulls, occurs on the ground. The ionospheric structure moves horizontally at a rate ranging from 50 to 200 meters per second causing the fading effect to move over the earth's surface.

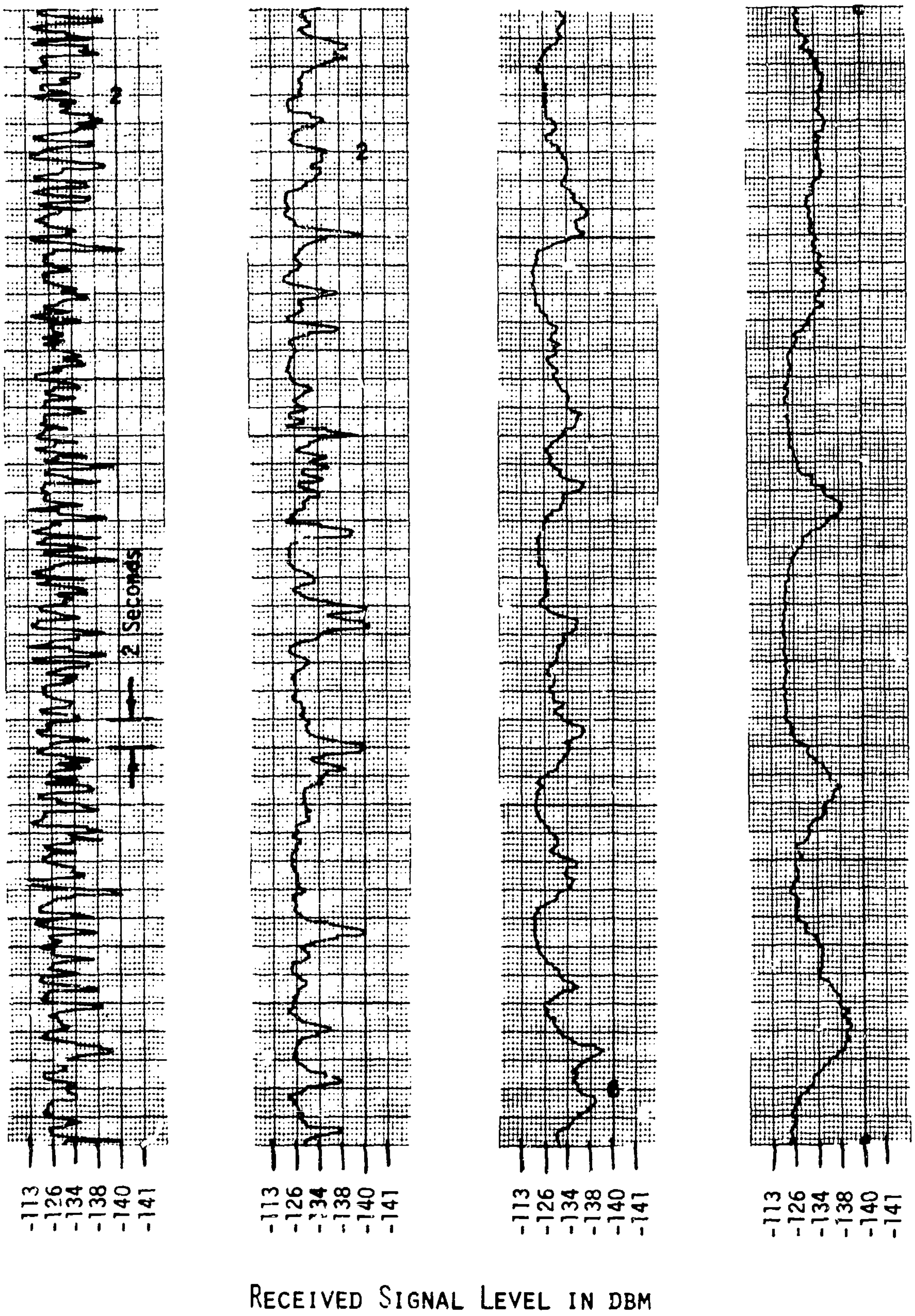


Figure 1. UHF Received Signal With Scintillation Fading

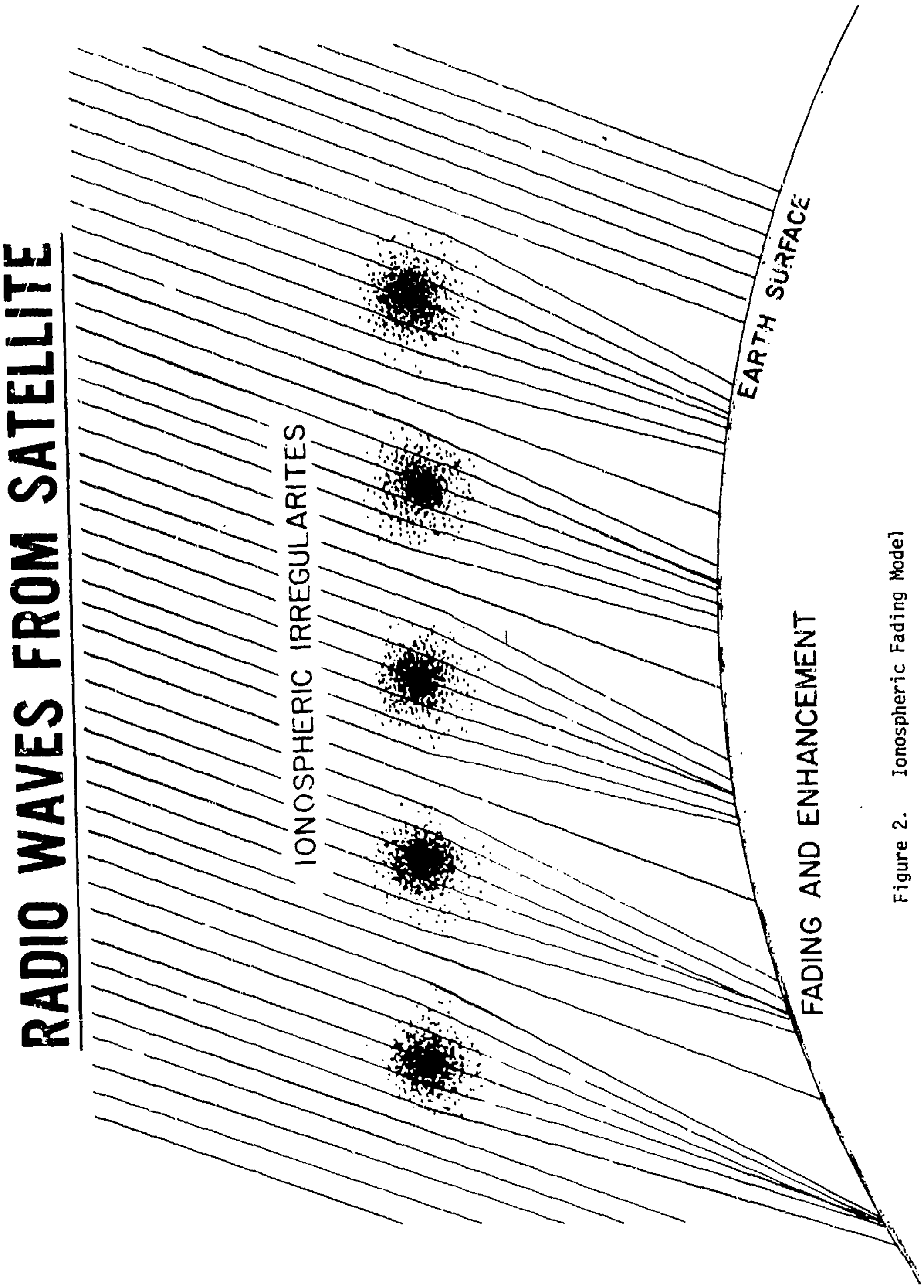


Figure 2. Ionospheric Fading Model

Ionospheric scintillation fading occurs primarily in the equatorial region of the earth, Figure 3. The effect is most pronounced within 20° of the magnetic equator. Similar fading occurs in the polar regions within 20° to 30° of the magnetic pole. The mid-latitudes of the earth are seldom effected by this phenomena.

The depth of the fading caused by ionospheric scintillation is frequency dependent, decreasing with an increase in frequency. The effect of this phenomena causes serious communication problems in the HF, VHF, and UHF bands ranging from a few megahertz (MHz) to approximately 1000 MHz. Above 1000 MHz the fading depth decreases to only a few dB and can be handled with the link margin normally designed into mobile communications links.

Ionospheric scintillation is predominantly a nighttime effect, normally occurring a few hours after local sunset and dissipating prior to sunrise. The extent of the effect of this phenomena is dependent upon the time of year, usually peaking during the spring and fall equinox periods. It tends to be at a minimum during the summer and winter. It is also affected by the sunspot activity, magnetic storms, and a host of other minor factors.

Even though ionospheric scintillation fading is a function of frequency, geographical location, and time of occurrence, there are many mobile communication systems which are required to operate in the vulnerable geographic regions and time zones. Therefore, various schemes are being explored to alleviate the effects of ionospheric scintillation.

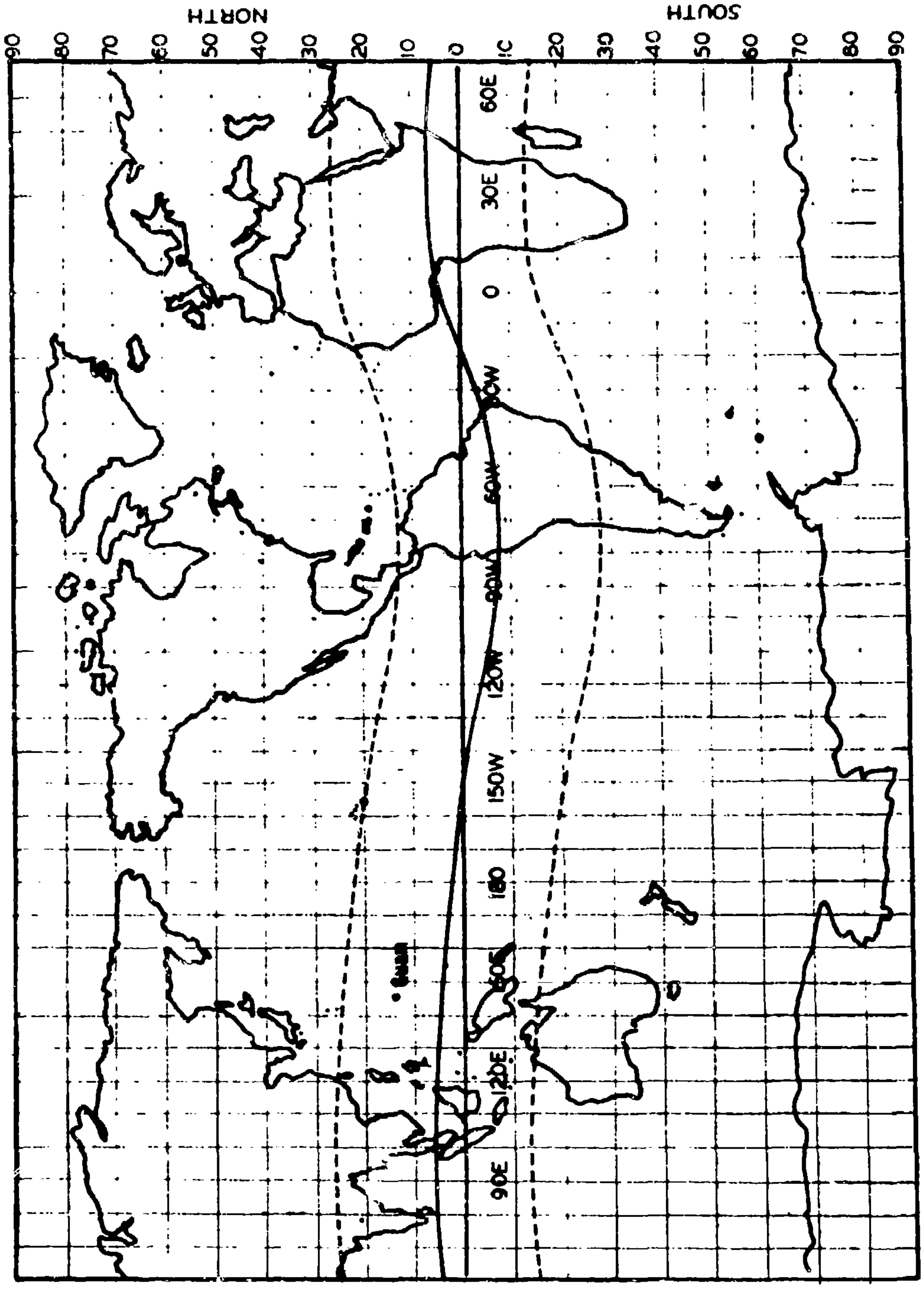


Figure 3. Map Of Equatorial Scintillation Problem Area

SECTION II
POSSIBLE SOLUTIONS

There are a number of schemes which could be used to reduce the effect of ionospheric scintillation. The most obvious solution is to increase the transmitting frequency to a point where it is negligibly affected by this phenomena. However, operation of mobile terminals (especially aircraft) becomes extremely expensive and in most cases very complex when the frequency exceeds the 1000 MHz band. Directive antennas normally used at the microwave frequencies with their inherent requirement for steering make terminals complex, large, and expensive.

The use of frequency diversity (transmitting two or more frequencies which are far enough apart so they do not fade coherently) does not offer a significant performance improvement. The ionospheric scintillation phenomena normally affects frequencies uniformly over a two to one bandwidth. At the low UHF frequencies approximately 300 MHz of frequency separation would be required to provide any improvement. Such frequency separation would be awkward to achieve because of the significant differences in equipment implementation at the different frequencies.

The use of space diversity or antenna diversity to alleviate the effects of ionospheric scintillation would require antenna separations of 500 to 1000 meters. This is impractical for use on an airborne platform.

One scheme which does appear to offer some potential for improvement is to more fully utilize the time period when the signal is not in a faded condition. Through the use of coding or message repeating it should be possible to reduce the effects of ionospheric scintillation.

The fades caused by ionospheric scintillation are normally short in duration, generally lasting from a fraction of a second to a few seconds. An unfaded period of approximately two to four times the duration of the fade normally follows the fade. Therefore, it should be possible to provide enough redundancy in the message either through coding or message repeating to get the message through. The fact that the structure of the fading varies considerably makes it a nontrivial problem to choose an optimum code or message repeating format. In an attempt to identify an optimum scheme, a UHF satellite channel disturbed by ionospheric scintillation, was simulated in a laboratory computer and various types of coding, interleaving, and message formatting were tried through the channel.

The types of coding selected for use in the simulation included a one-half rate binary feedback code, a one-half rate convolutional code with Viterbi decoding, and a one-third rate convolutional code with Viterbi decoding (References 2 and 3). The characteristics of these codes are given in Table 1. A block-type interleaver was used in the simulation with various interleaving dimensions, Table 2. A simple message repeating scheme was also tried in which the message was broken into segments and each segment repeated several times.

TABLE 1

CODE CHARACTERISTICS

I. BINARY FEEDBACK CODE 1/2 rate k = 10 L = 11 G1 = 3462	where: R = constraint length L = look ahead parameter G = co-generator
II. CONVOLUTIONAL ENCODING/VITERBI DECODING 1/2 rate k = 7 G1 = 133 G2 = 171	
III. CONVOLUTIONAL ENCODING/VITERBI DECODING 1/3 rate k = 7 G1 = 133 G2 = 145 G3 = 175	

TABLE 2

INTERLEAVER CHARACTERISTICS

I. WITH BINARY FEEDBACK ENCODER: BLOCK INTERLEAVERS 1) 22 x 49 bit interleaver 2) 22 x 237 bit interleaver
II. WITH 1/2 RATE VITERBI DECODER: BLOCK INTERLEAVERS 1) 22 x 50 bit interleaver (32 bit memory) 2) 33 x 33 bit interleaver (32 bit memory) 3) 64 x 82 bit interleaver (32 bit memory) 4) 32 x 163 bit interleaver (17 bit memory) 5) 32 x 164 bit interleaver (32 bit memory)
III. WITH 1/3 RATE VITERBI DECODER: BLOCK INTERLEAVERS 1) 22 x 75 bit interleaver (32 bit memory) 2) 44 x 37 bit interleaver (22 bit memory) 3) 96 x 66 bit interleaver (32 bit memory) 4) 64 x 98 bit interleaver (32 bit memory)

SECTION III
SIMULATION

The simulation was done on the Air Force Avionics Laboratory's PDP-11/20 computer. The flow diagram for the simulation is [illegible]ted in Figure 4 (Reference 4). A straight line approximation [illegible] modulator detection performance curve was used in the simulation, Figure 5. From this curve a one dB change in signal level would result in a factor of 10 change in bit error rate (BER) performance over the typical operating range. The normalized ratio of energy per bit divided by noise per cycle is designated E_b/N_0. The approximation assumes that at an extremely high signal level no errors occurred, while at extremely low signal levels a 50% BER was chosen.

To improve the authenticity of the simulation the ionospheric scintillation fade data used in the simulation were actual fade data recorded during a September 1971 Air Force Avionics Laboratory (AFAL) Ionospheric Scintillation Flight Test (Reference 1). During that flight test, magnetic tape recordings were made of the received downlink signal strength from a UHF satellite. For the simulation these analog signal levels were digitized and systematically sampled.

For this simulation the transmission rate was 75 bits per second (bps) for both the encoded and uncoded teletype message. Therefore, for a one-half rate code the actual information transmission rate would drop to 37 1/2 bps, and for a one-third rate code the actual information rate would drop to 25 bps. Since interleaving was also used, there was a time delay between the original message being typed at the transmitter and the received message at the receive-teletypewriter due to the storage which is inherent in an interleaver and the effect of the coding.

The sequence of the simulation was as follows: First, the 13 millisecond data bit was fed into the computer memory; second, the signal level of the digitized received signal curve was sampled. Then a comparison was made between the signal level and the demodulator

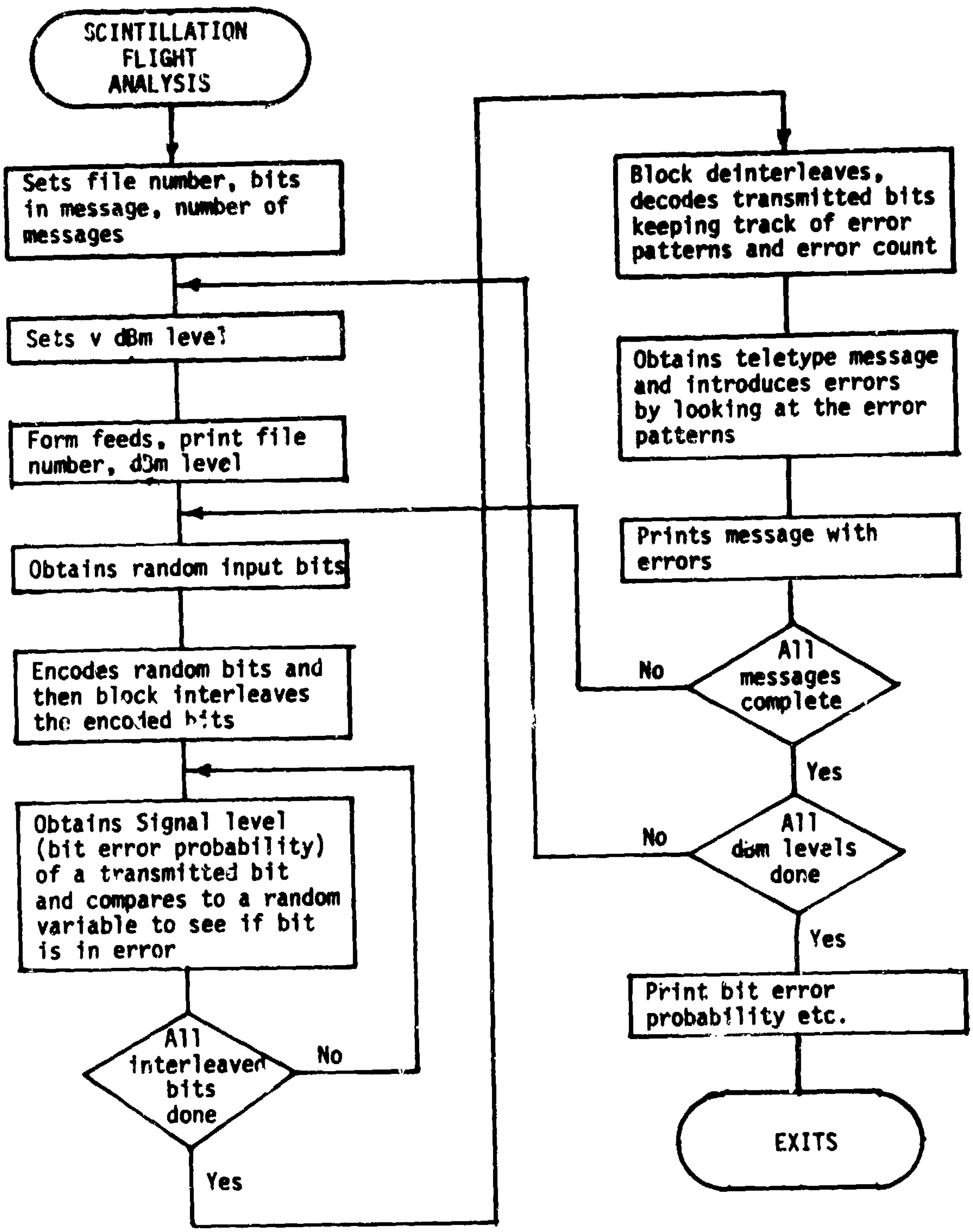


Figure 4. Simulation Flow Diagram

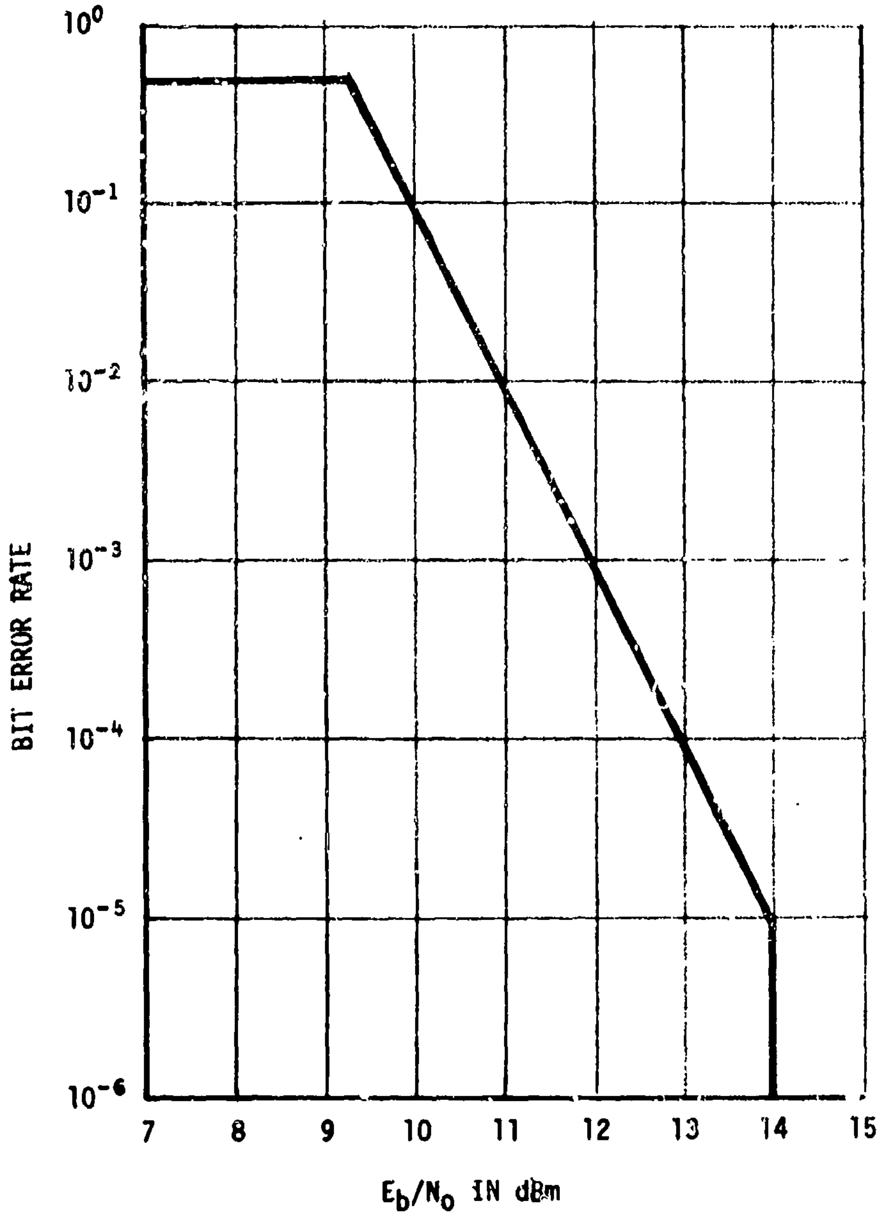


Figure 5. Idealized Modem Performance Curve

performance curve to determine the probability of error for that bit of data. The determination as to whether a bit was to be in error was dependent upon the BER and a random number generator. The random number generator produced a uniform random variable over the range 0-1. Whenever the random variable was less than or equal to the probability of error, the output bit was in error. The process would then resume by selecting the next data bit and processing it. The next phase of the process was decoding (error correction) according to the decoding scheme selected during that particular computer run. The output of the decoder was teletype data. Seven bits constituted a teletype character. If any one of the seven sequential bits was in error, the teletype character "X" was printed. If none of the seven teletype bits were in error, the correct message bit was printed. The duration of the entire message was approximately five minutes.

Eight different five-minute segments of ionospheric scintillation fade data were used in the simulation to determine the performance of each of the coding/interleaving schemes under various types of fading, Figures 6 through 13. The limitations of the simulation included the fact that a linear demodulator curve was used and that perfect bit timing was assumed, allowing data to be processed at the optimum time. Also, the framing of the teletype character was perfect, so that an error would not cause the teletype framing to get out of sync.

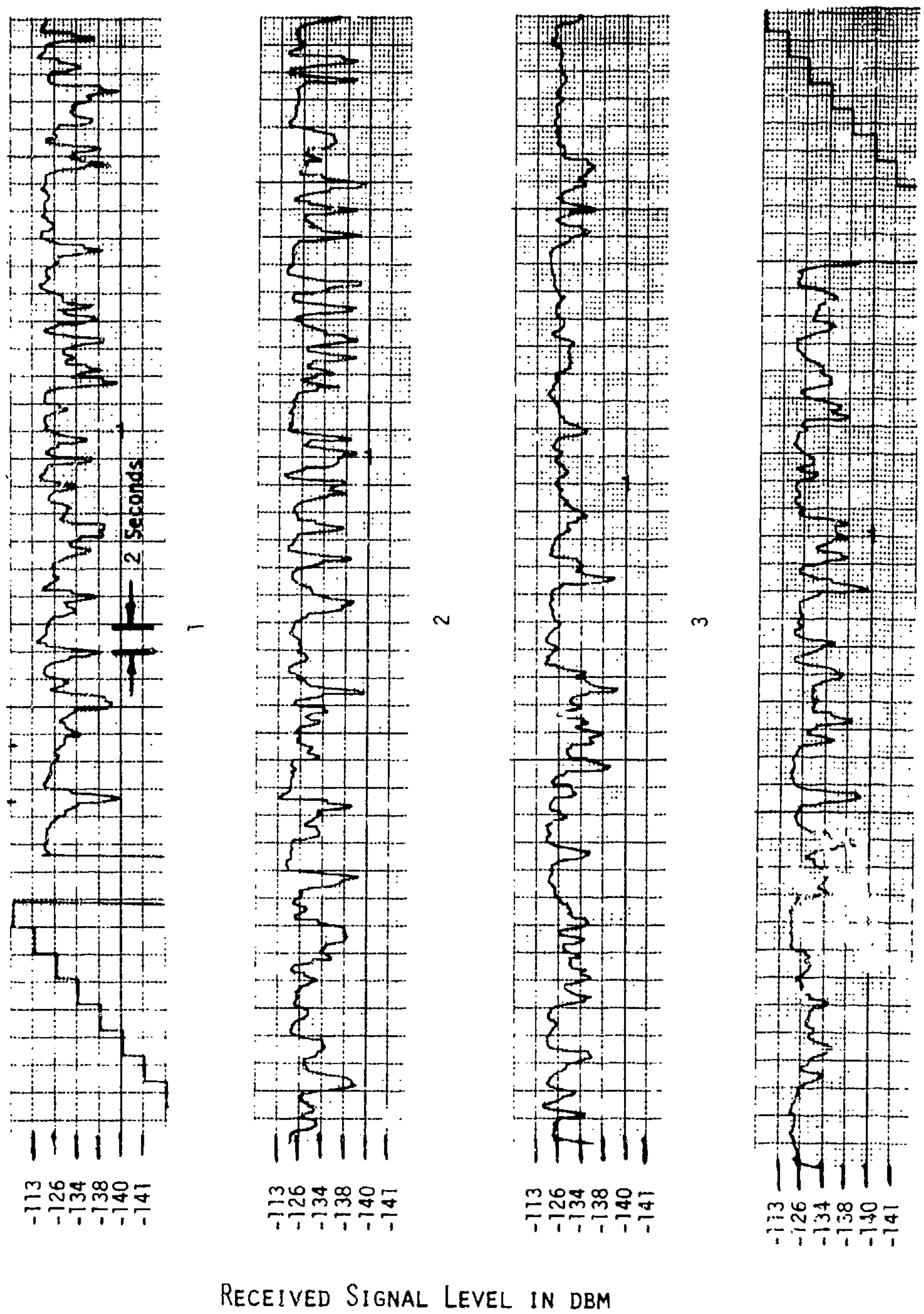
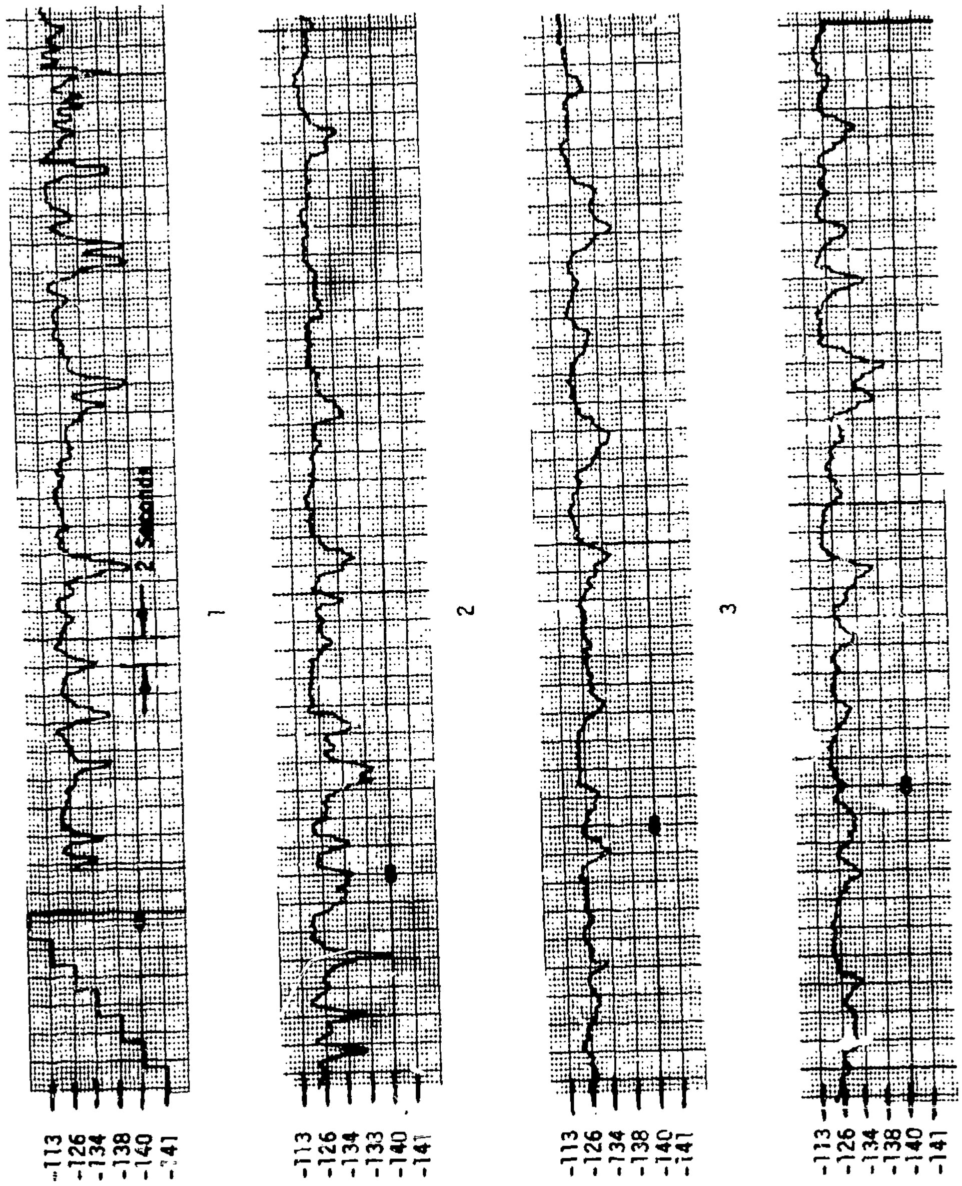


Figure 6. UHF Received Signal With Scintillation Fading - File 1



RECEIVED SIGNAL LEVEL IN DBM

Figure 7. UHF Received Signal With Scintillation Fading - File 2

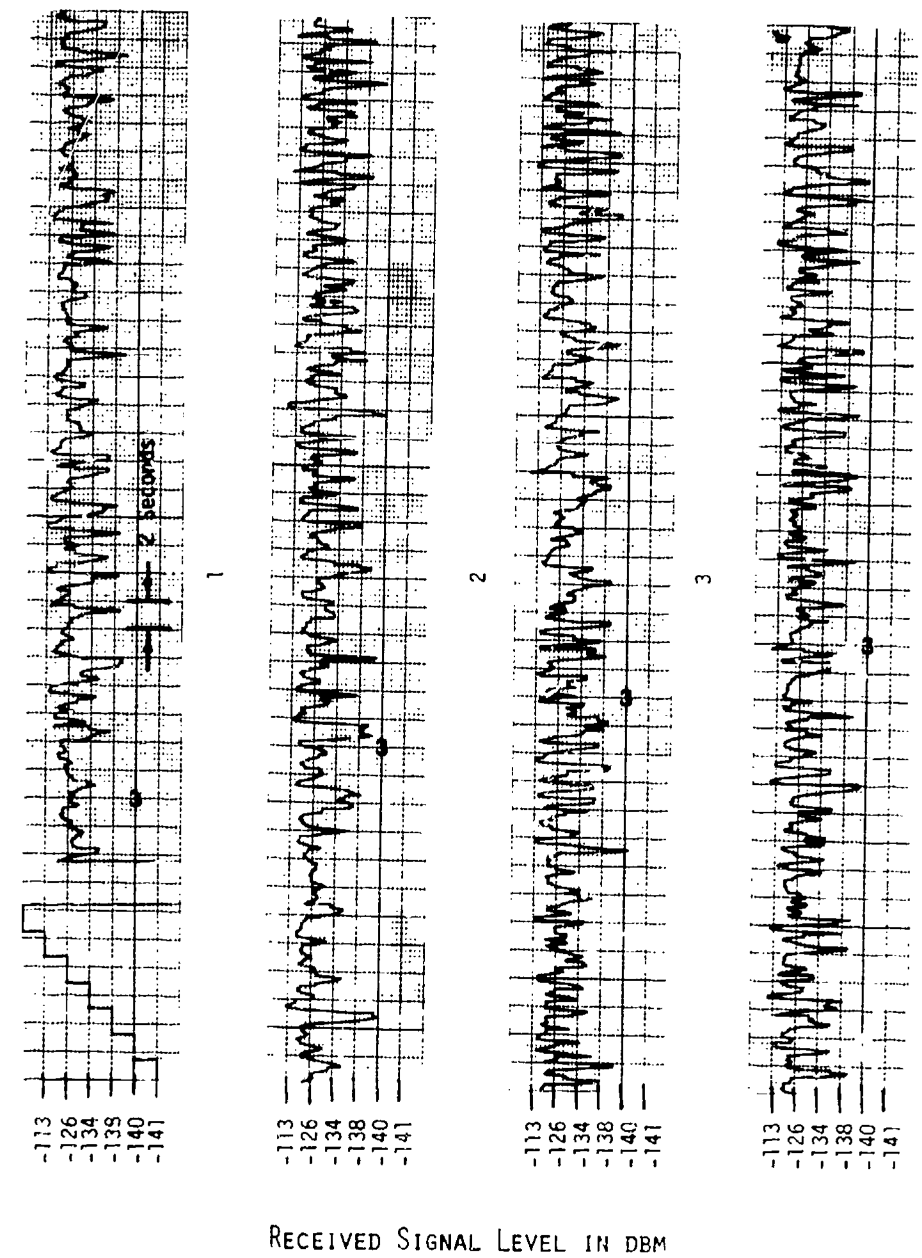


Figure 8. UHF Received Signal With Scintillation Fading - File 3

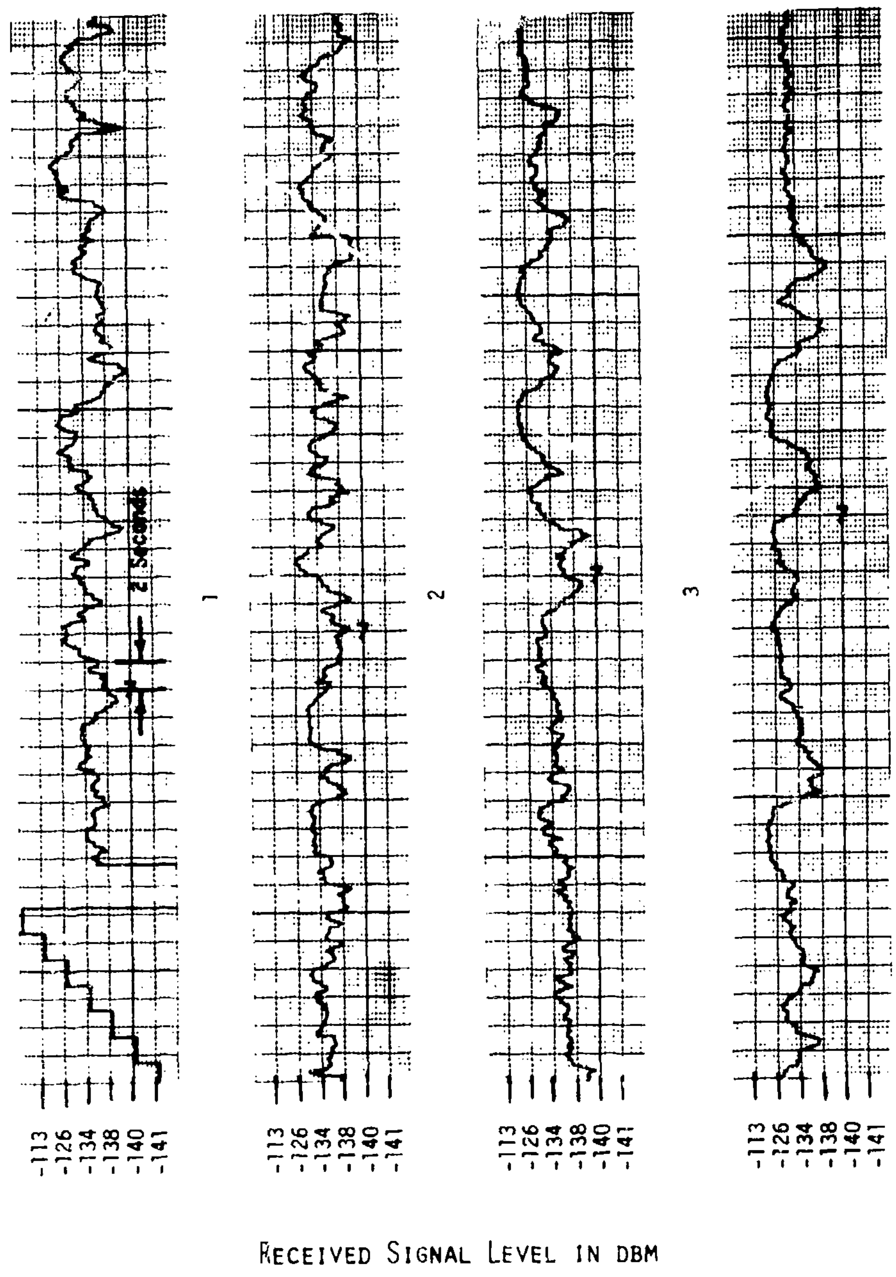


Figure 9. UHF Received Signal With Scintillation Fading - File 4

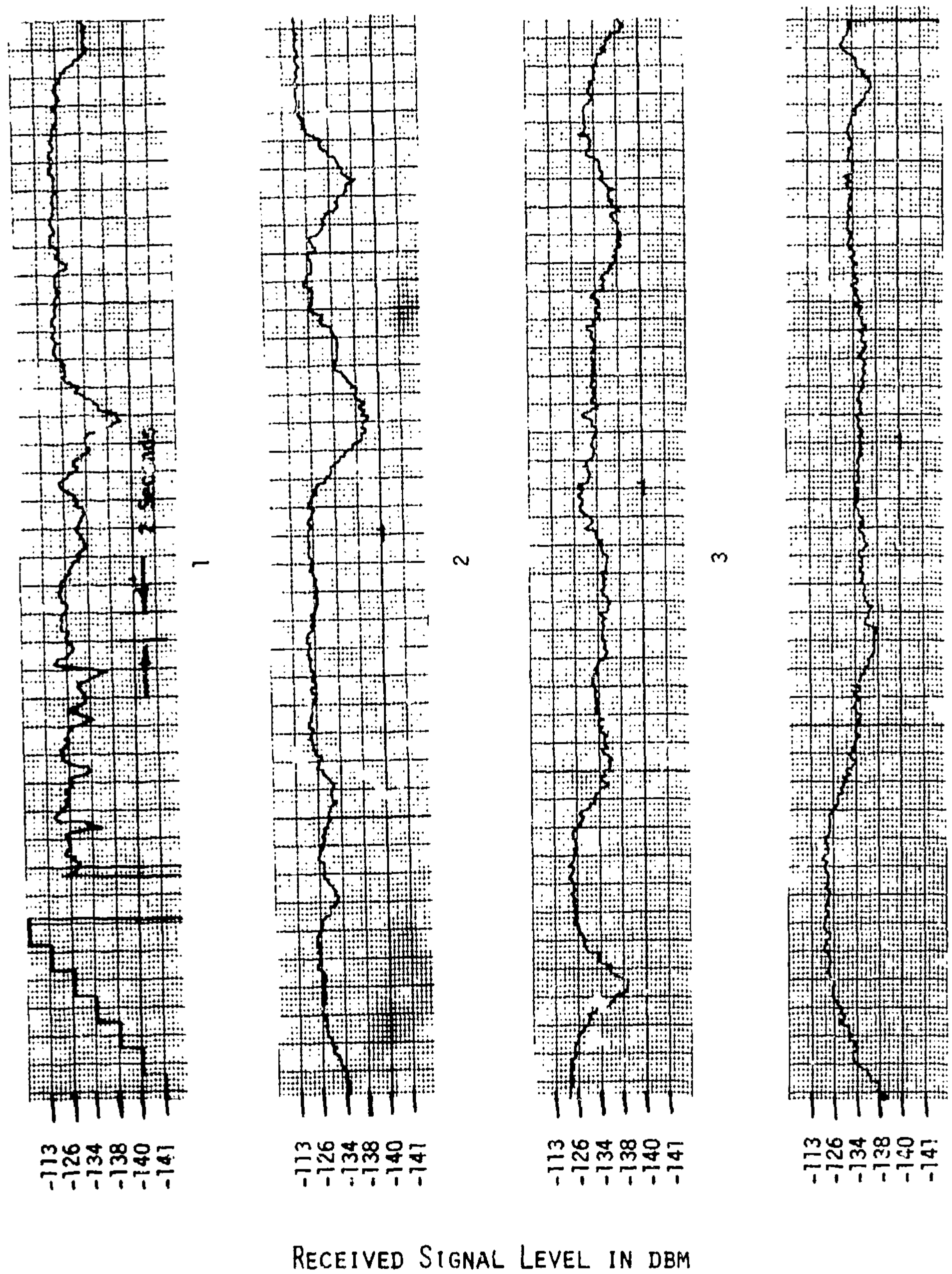


Figure 10. UHF Received Signal With Scintillation Fading - File 5

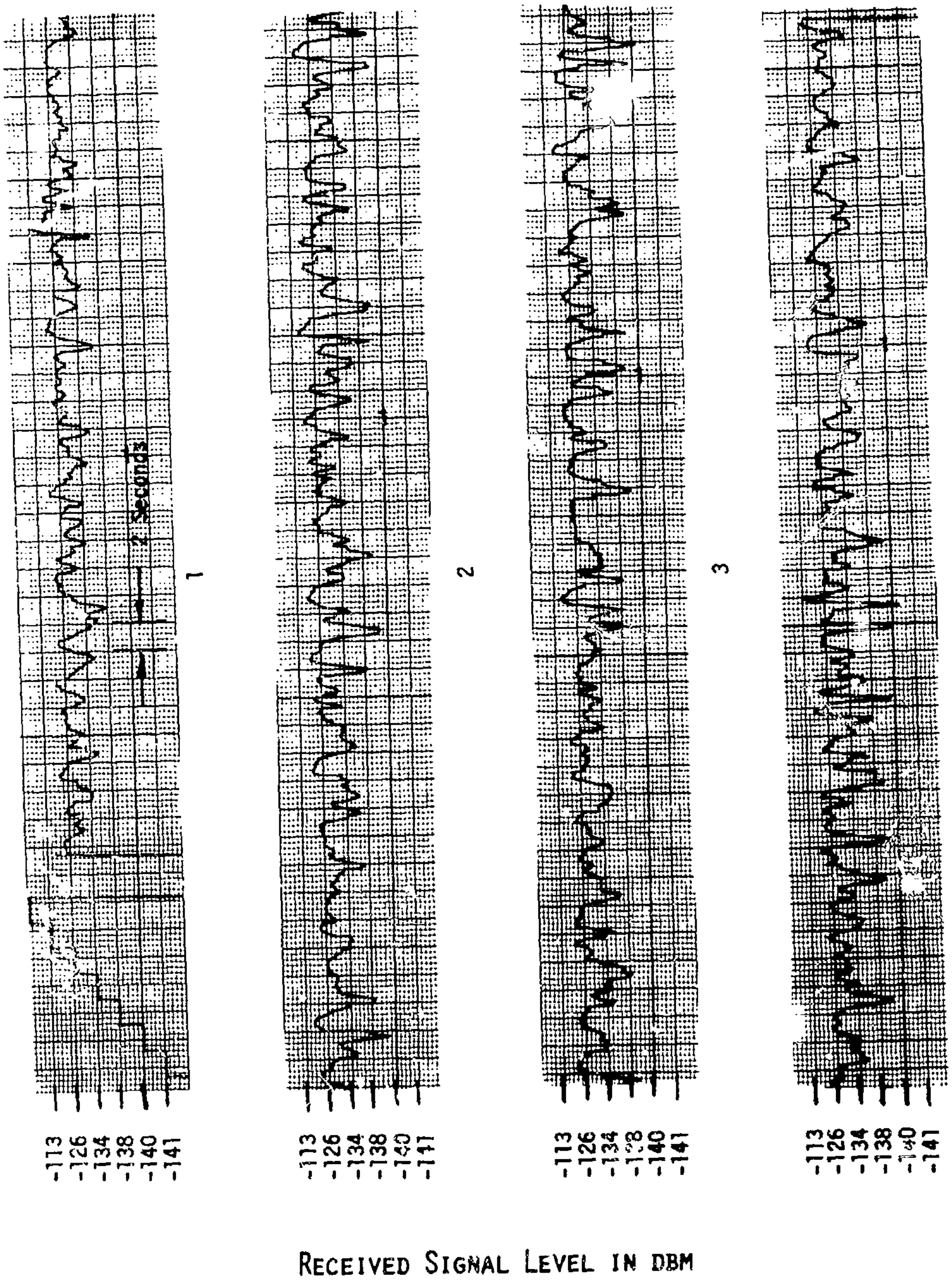
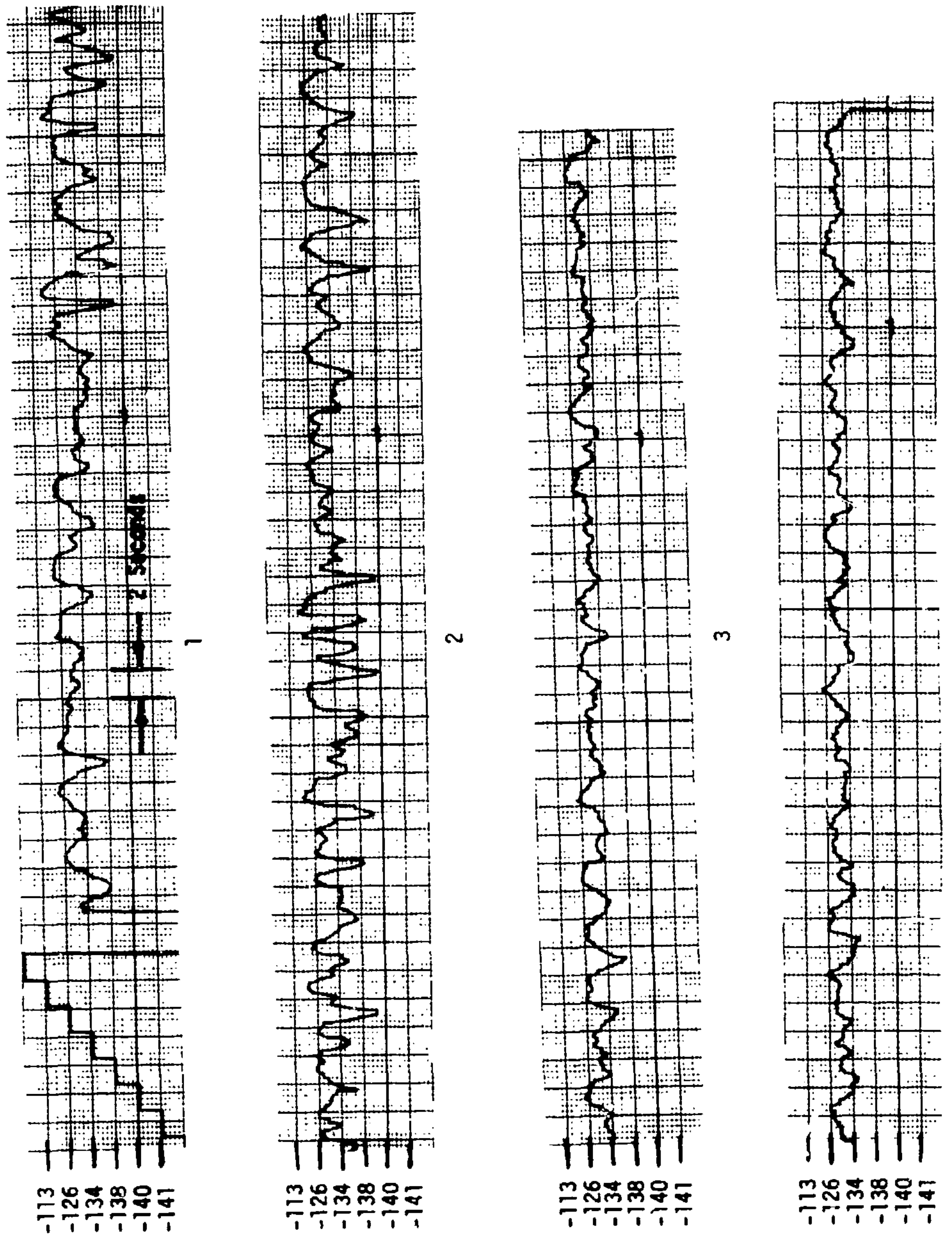


Figure 11. UHF Received Signal With Scintillation Fading - File 6



RECEIVED SIGNAL LEVEL IN DBM

Figure 12. UHF Received Signal With Scintillation Fading - File 7

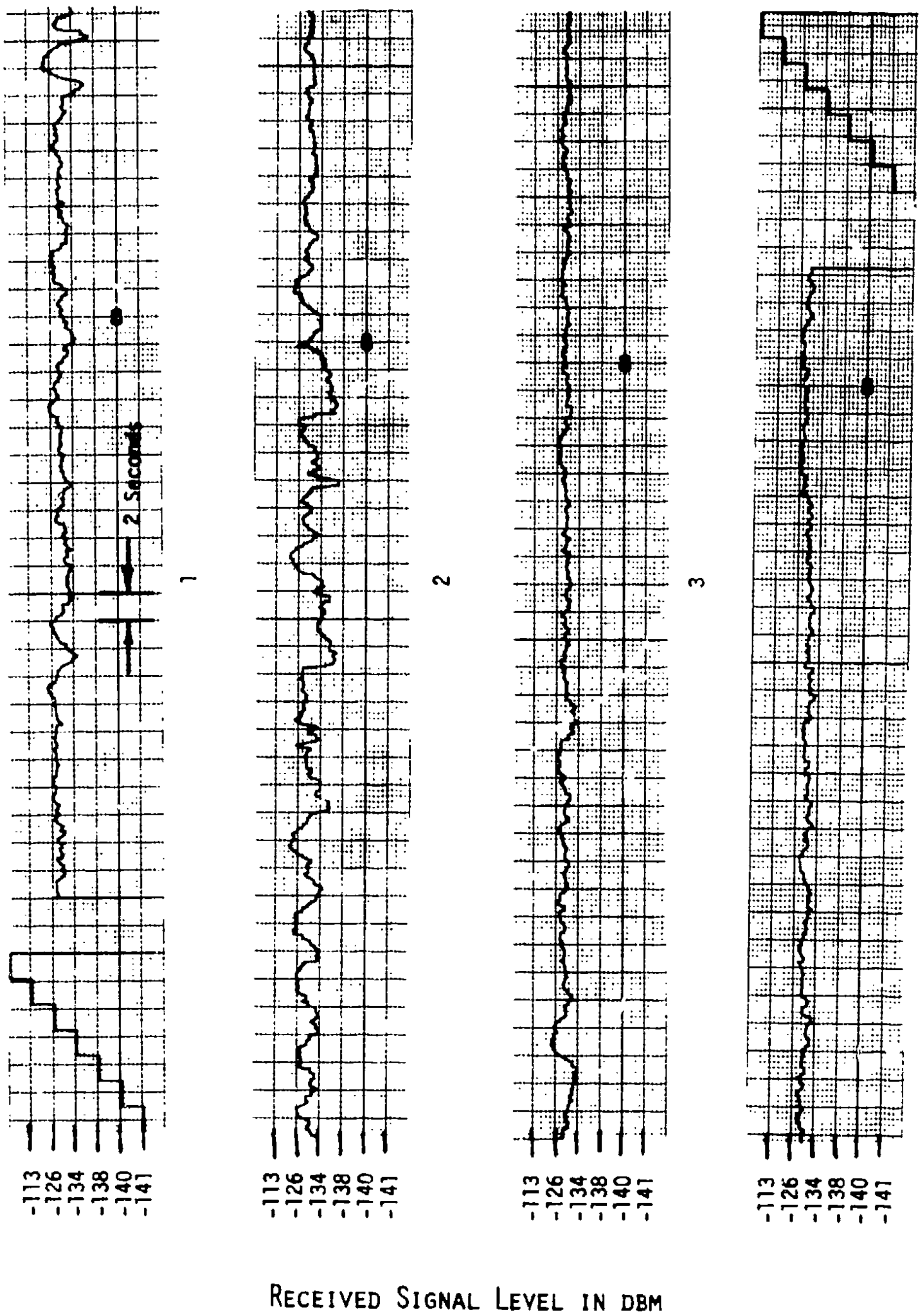


Figure 13. UHF Received Signal With Scintillation Fading - File 8

SECTION IV
RESULTS

The BER performance for each of the various combinations of coding, interleaving, and repeating techniques was calculated for each of the eight ionospheric scintillation fading data samples and is shown in Figures 14 through 21. A "signal level index" was used so that different absolute received signal levels could be assigned to the recorded analog data. For the simulation the 10^{-3} BER point of the demodulator performance curve was set to various absolute received signal levels (-130, -132, -134, -136 and -138 dBm). In practice the differing signal levels could be obtained by increasing the satellite downlink power or increasing the receiving terminal antenna gain. For each level the complete simulation was run and a BER was determined. The BER was determined by dividing the total errors in a message by the number of bits in the message. Then the next received signal level was selected and the simulation was rerun.

Note that the BER performance plots of the coded data had a very sharp threshold. Also, at the lower received signal levels the coded/interleaved signal performed worse than the uncoded signal. Both of these results were expected since many of the coding schemes cannot correct the errors when the BER drops below 5×10^{-2} (5%). However, when the BER approached 10^{-2} (1%), the coding/interleaving scheme showed considerable improvement over the uncoded signal.

The fade duration characteristics of each of the eight data segments are contained in Table 3. This data shows how often a given fade duration occurred during the five minute data segment. For example, a one second fade was the most common and fades longer than 2.5 seconds seldom occurred. The number of error-free lines completed for each of the eight data segments is shown in Figures 22 through 29. For example, Figure 24 shows that the coding with a received signal level of -134 dBm provides approximately fifteen error-free lines of message while the uncoded signal provides no error free lines. However, due to

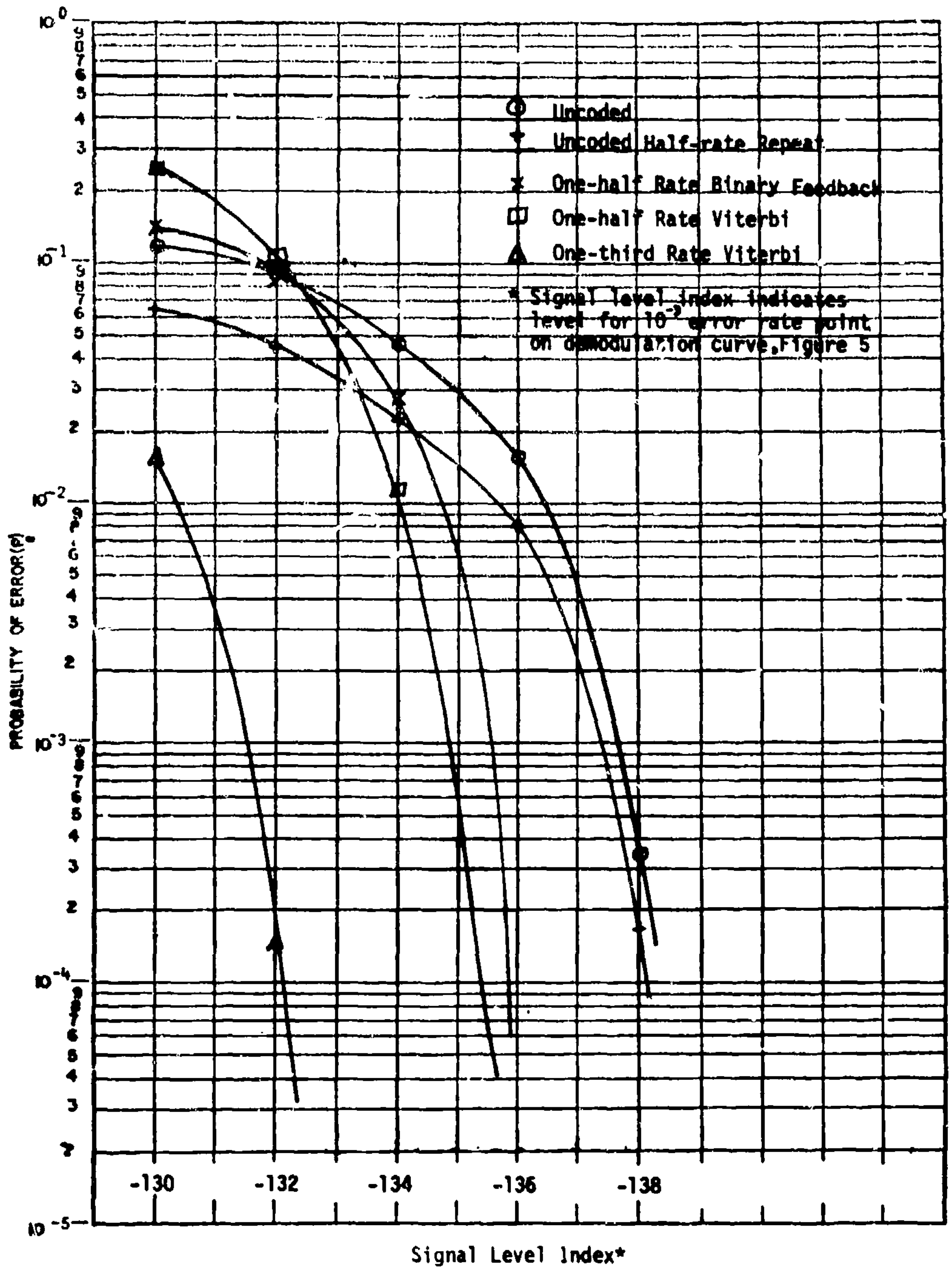


Figure 14. Bit Error Rate Performance - File 1

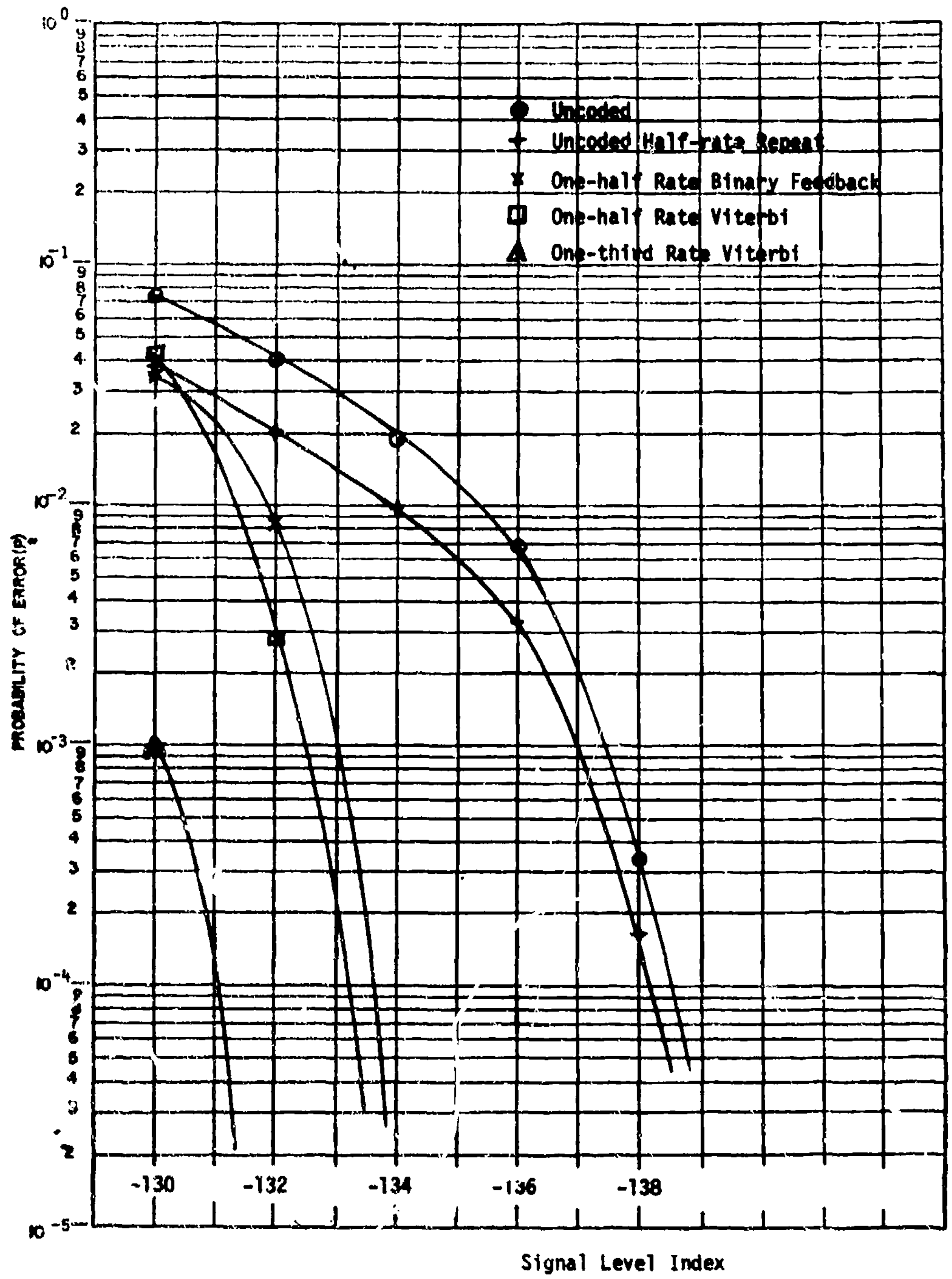


Figure 15. Bit Error Rate Performance - File 2

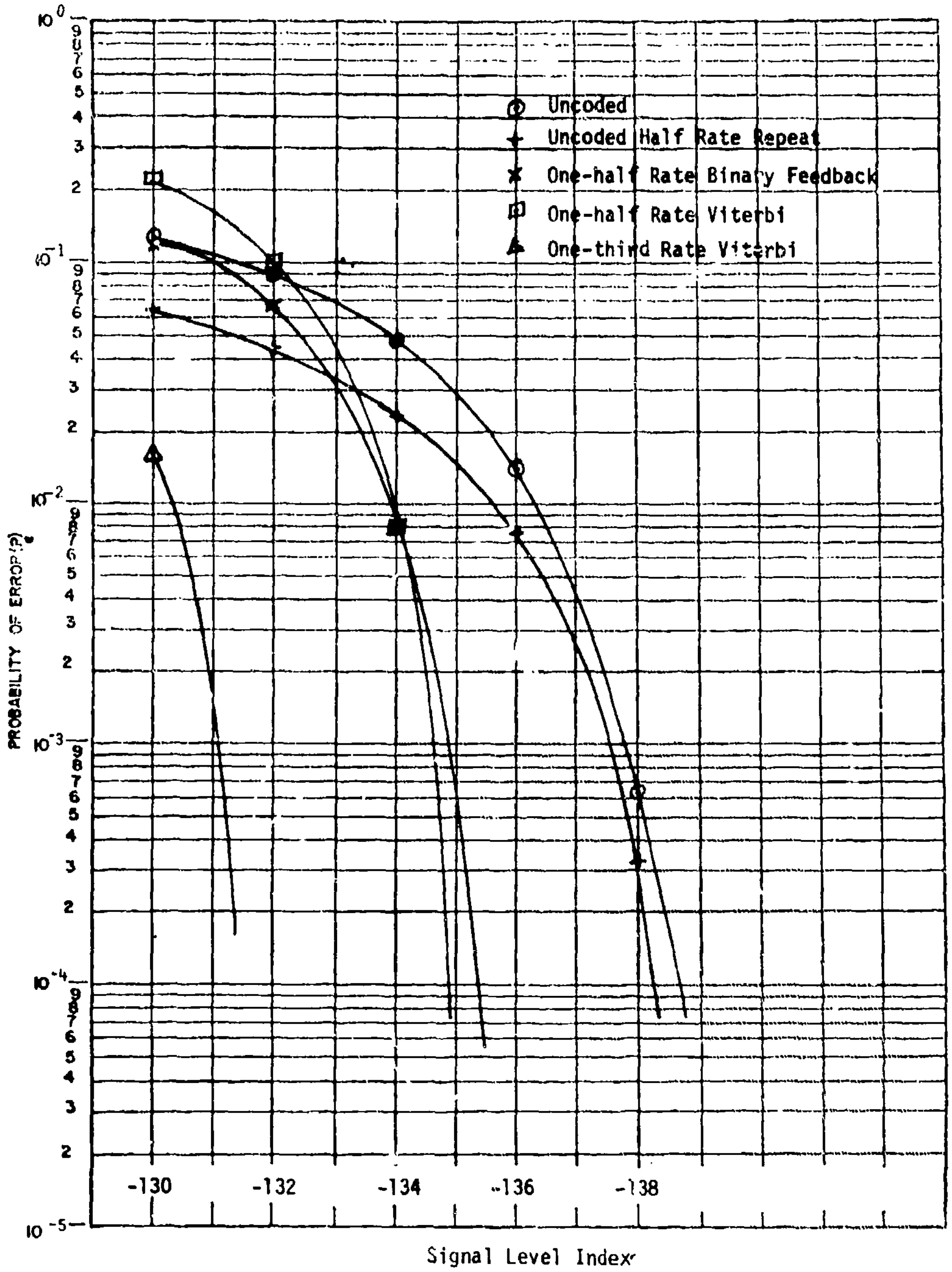


Figure 16. Bit Error Rate Performance - File 3

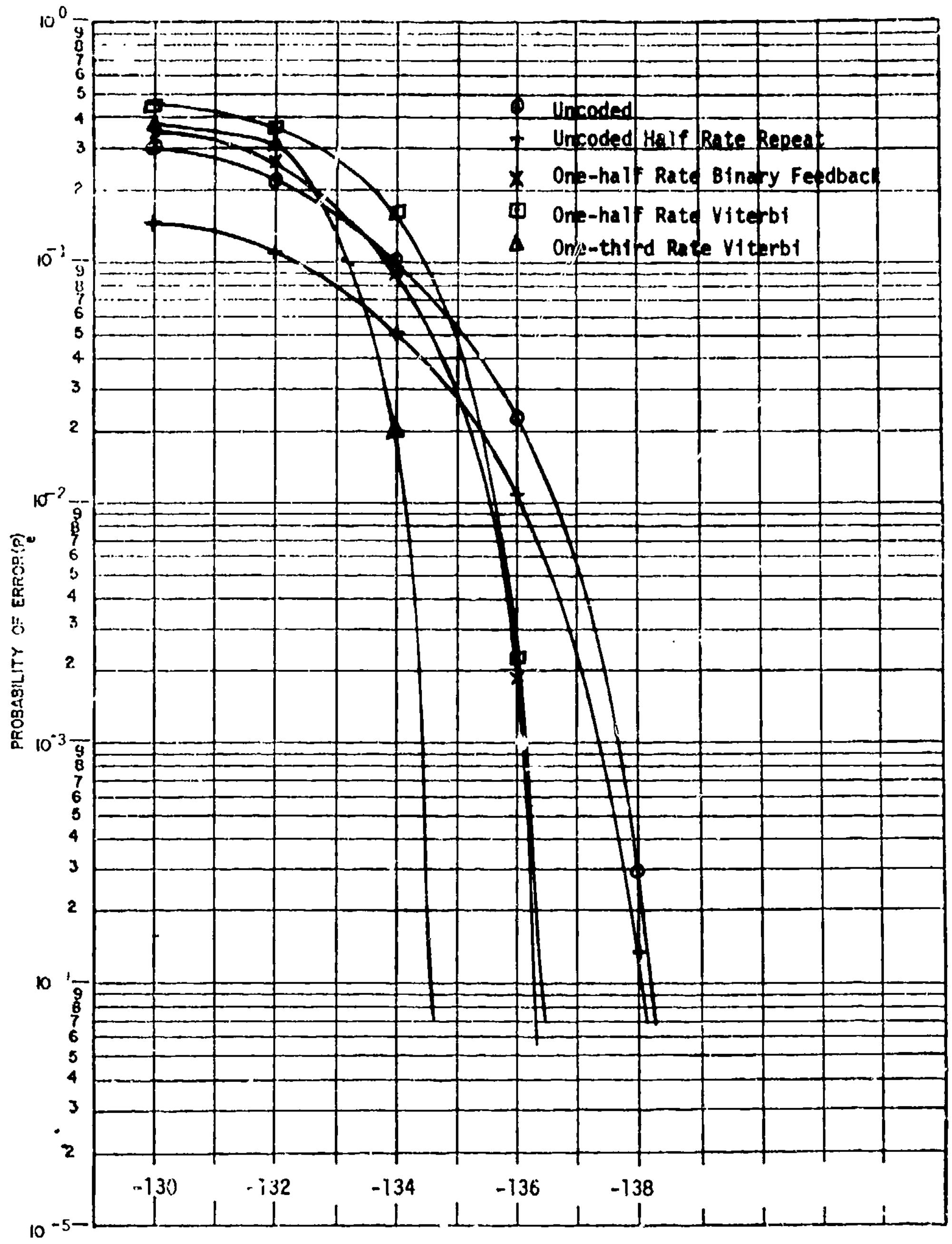


Figure 17. Bit Error Rate Performance - File 4

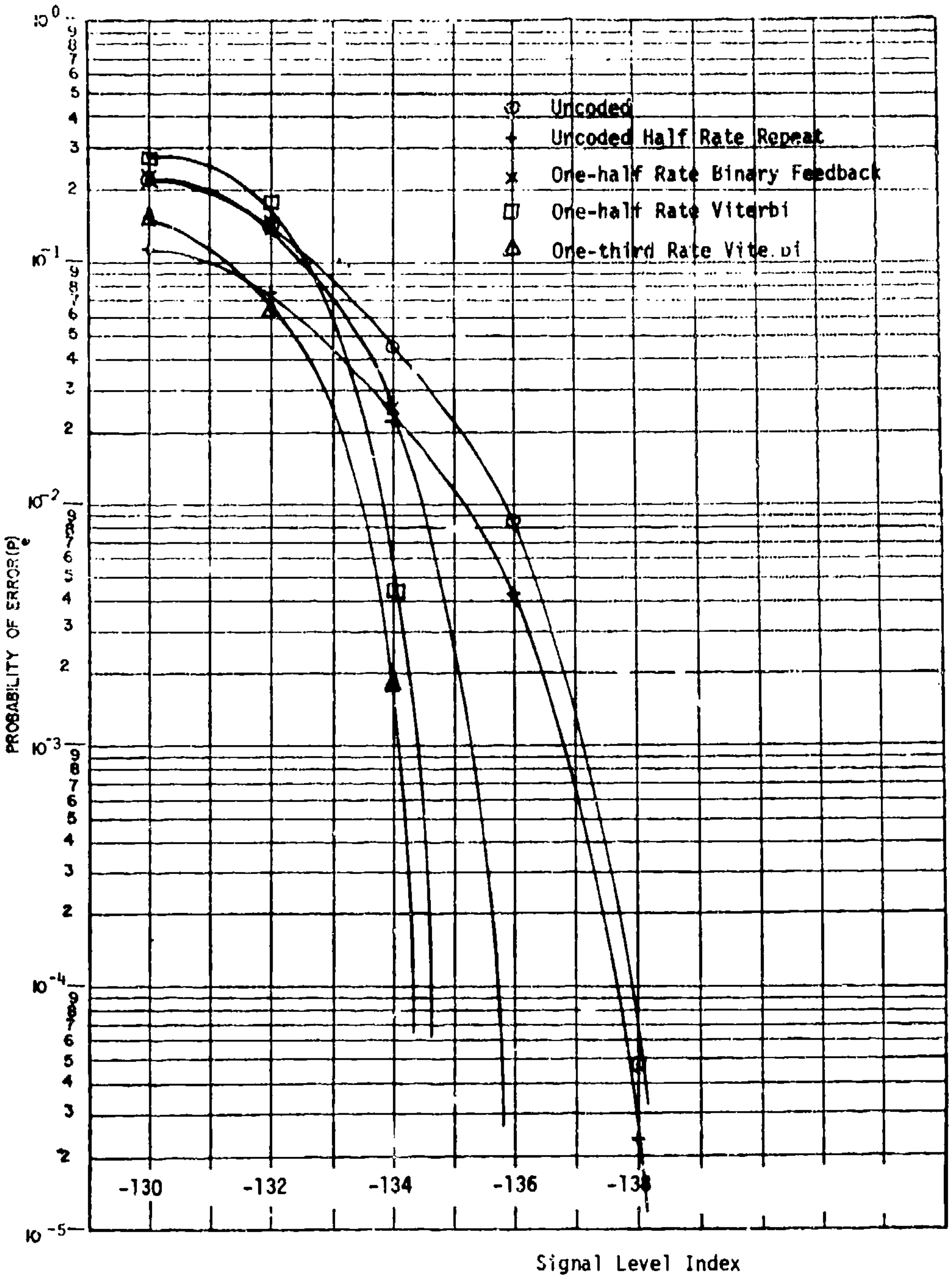


Figure 18. Bit Error Rate Performance - File 5

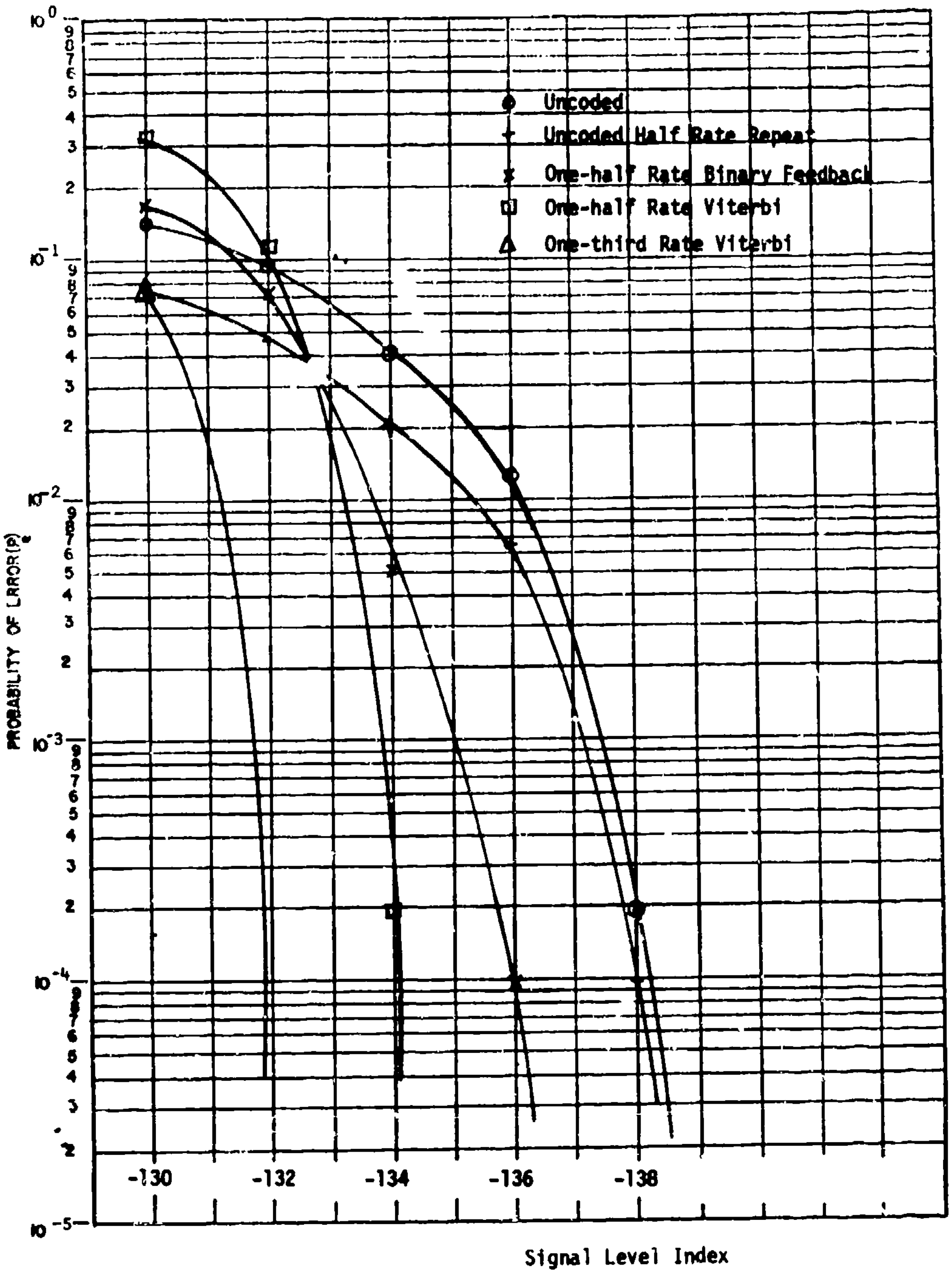


Figure 19. Bit Error Rate Performance - File 6

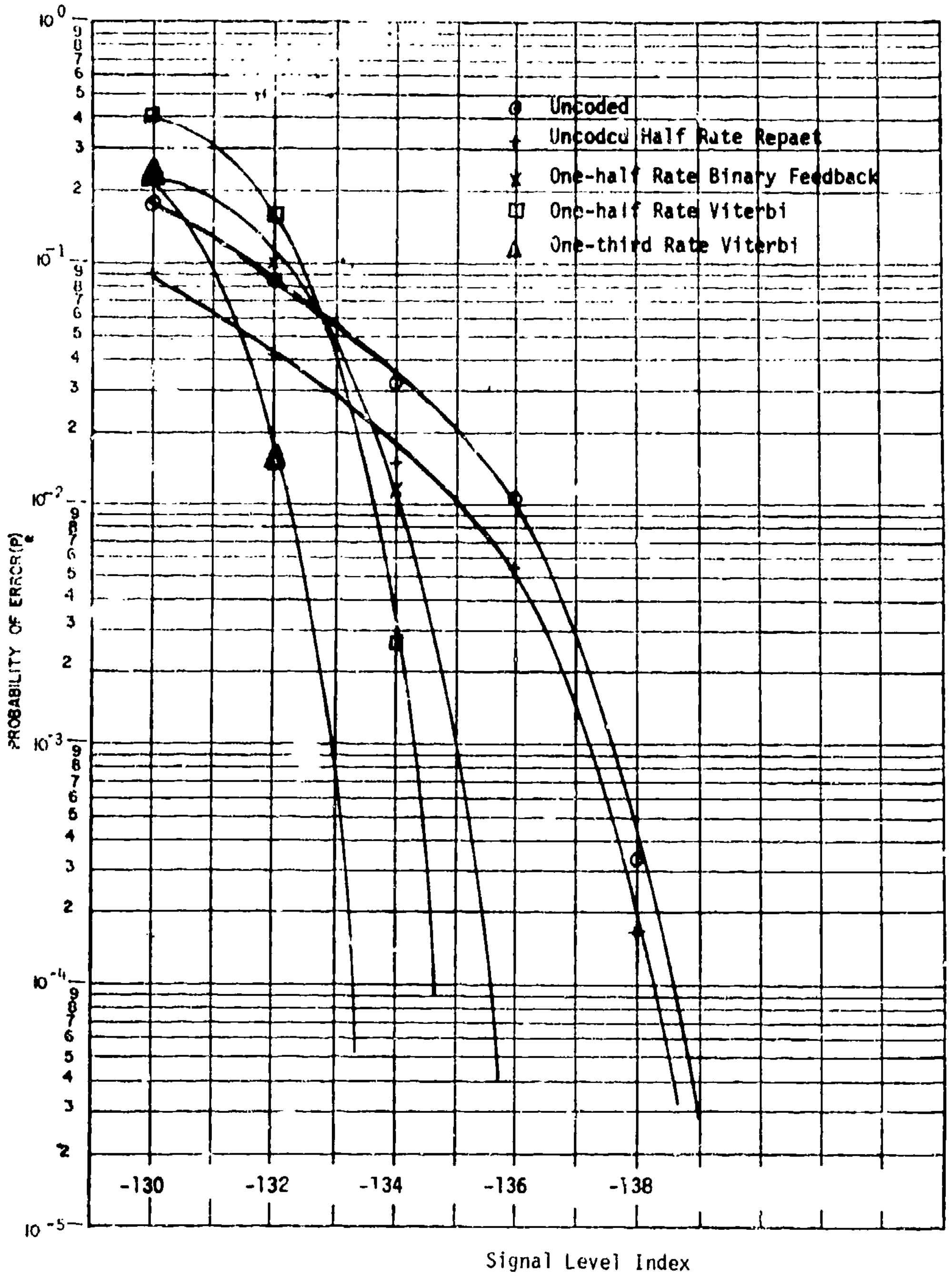


Figure 20. Bit Error Rate Performance - File 7

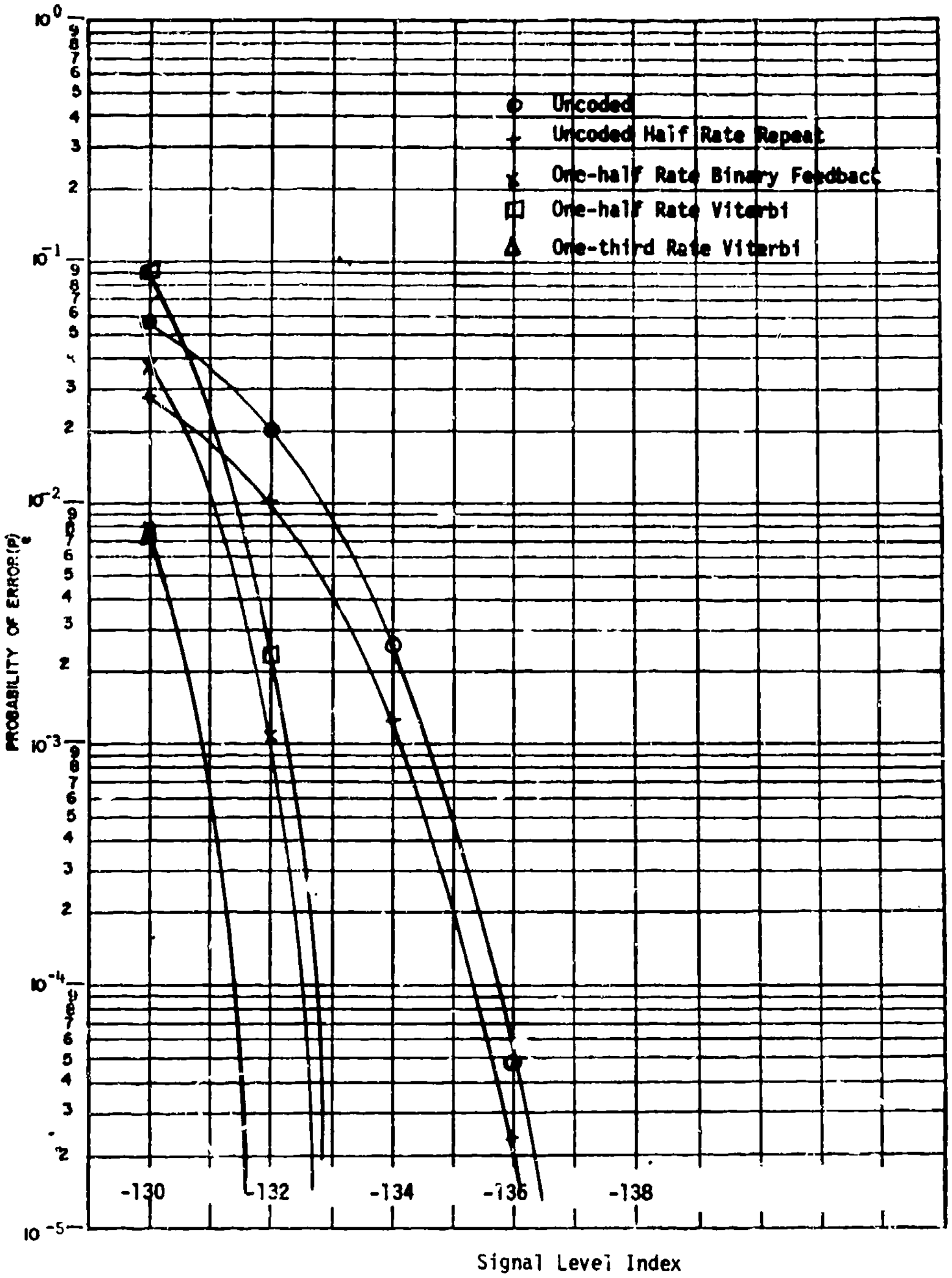


Figure 21. Bit Error Rate Performance - File 8

TABLE 3

FADE DURATION CHARACTERISTICS

Number of occurrences in simulation run

DATA FROM FIGURE NUMBER	DURATION - SECONDS*												TOTAL FADES
	.1	.25	.5	.75	1.0	2.5	5	7.5	10	25	50	75	
6		0	8	13	24	32	4	0	1	0			(82)
7		0	3	7	13	24	1	0					(48)
8	0	48	48	24	19	10	0						(149)
9		0	2	5	11	19	4	4	1	0			(46)
10			0	1	2	7	1	2	2	3	1	1	(20)
11	0	5	10	13	28	2	0						(58)
12	0	2	13	5	12	14	1	0					(47)
13		0	1	2	4	2	0						(9)
TOTAL FADES	0	55	85	70	113	112	11	6	4	3	1	1	(459)

*Duration of time signal remained 6 dB below median signal level.

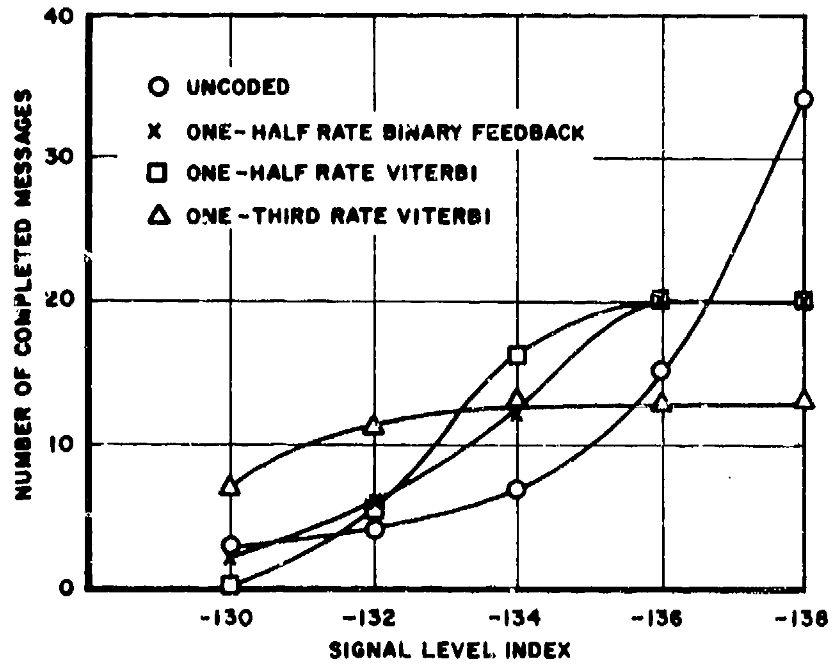


Figure 22. Messages Completed - File 1

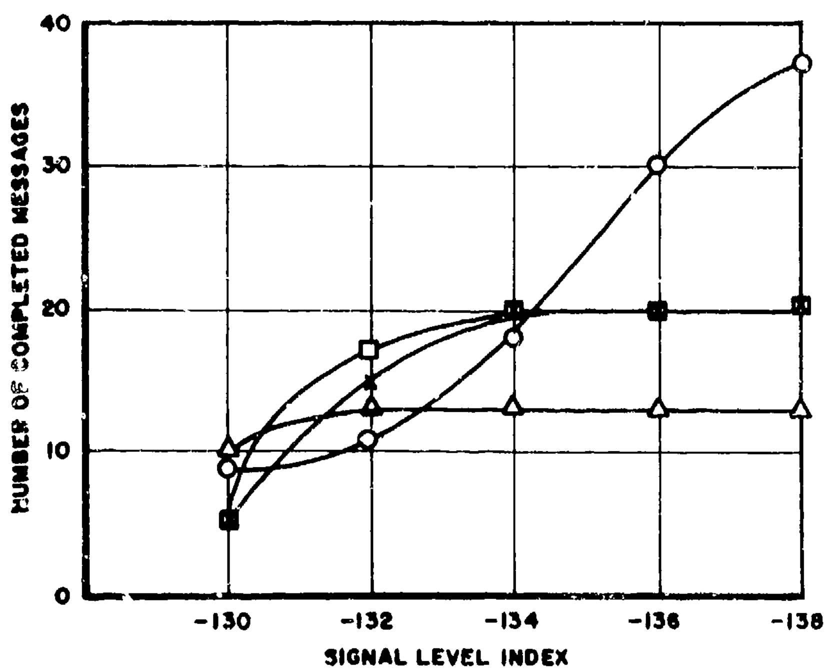


Figure 23. Messages Completed - File 2

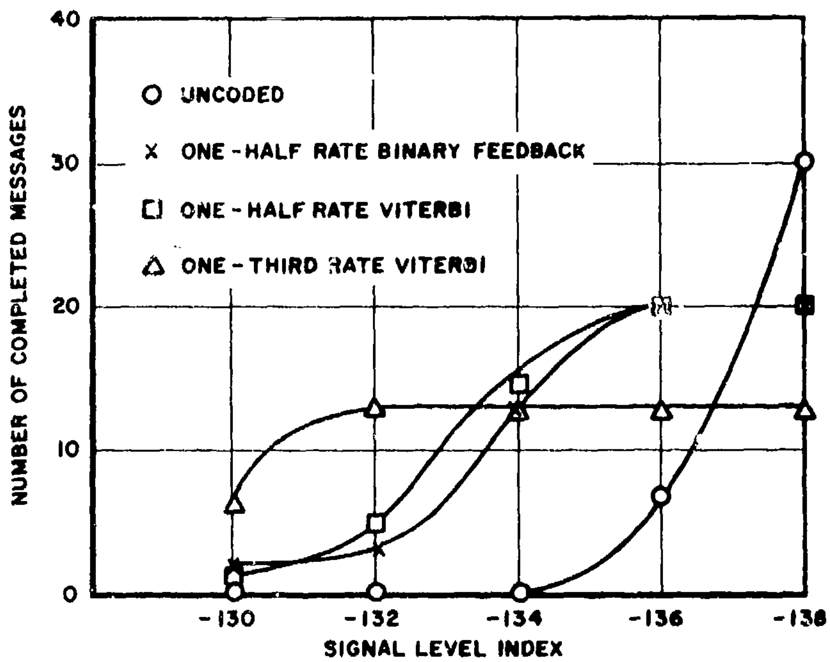


Figure 24. Messages Completed - File 3

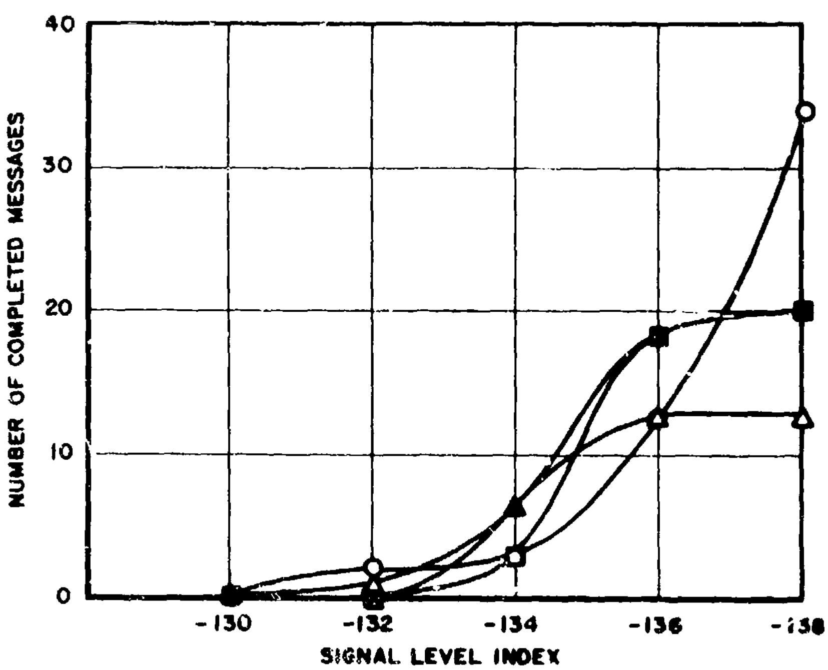


Figure 25. Messages Completed - File 4

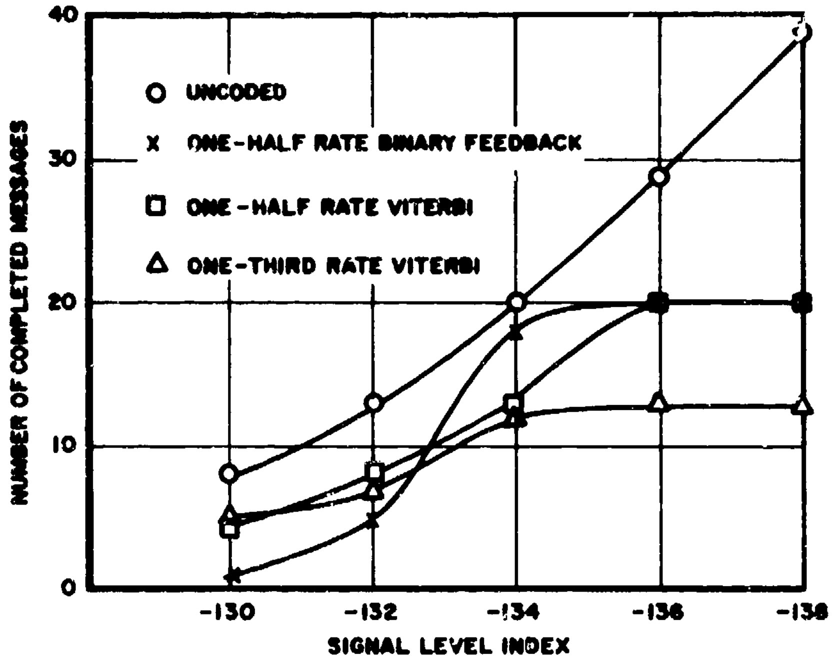


Figure 26. Messages Completed - File 5

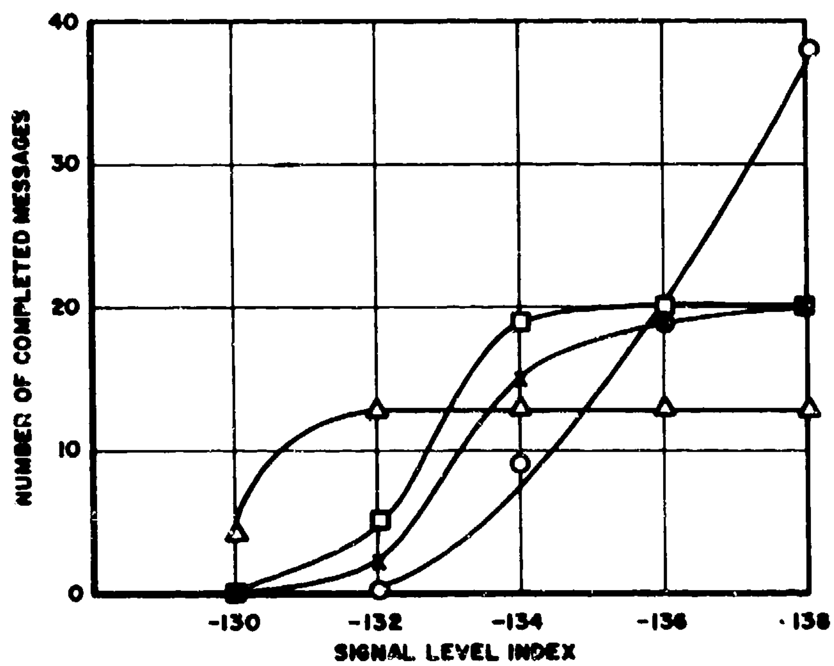


Figure 27. Messages Completed - File 6

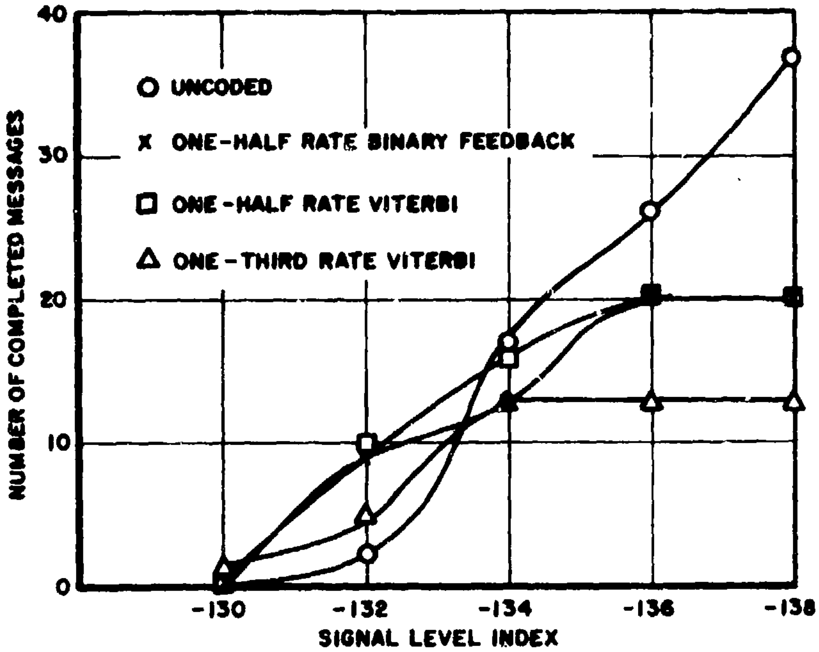


Figure 28. Messages Completed - File 7

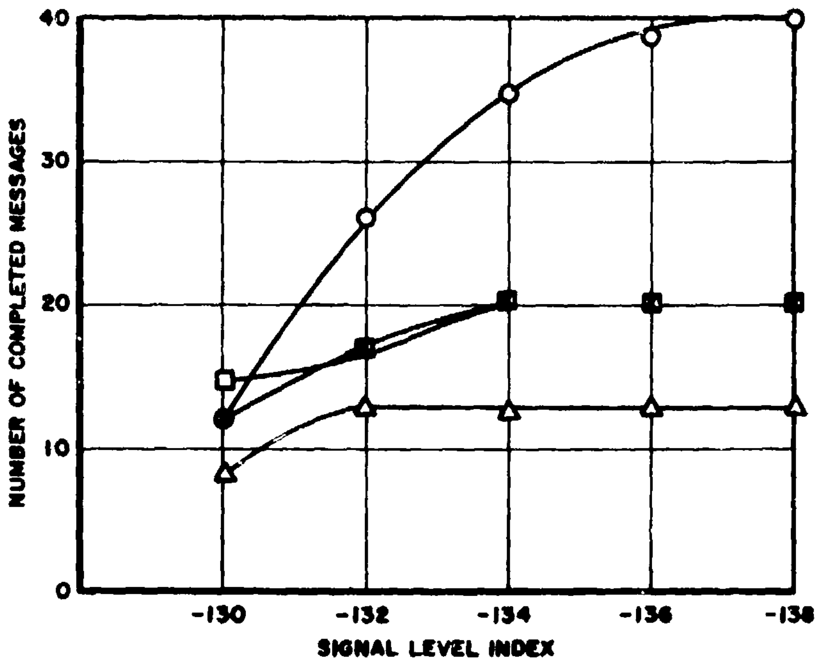


Figure 29. Messages Completed - File 8

the change in the characteristics of the fading, Figure 25 shows that the uncoded message gets through almost as many correct lines or messages as some of the coded messages.

The text used during the simulation is shown in Figure 30. Figure 31 shows the received text with a poor received signal, uncoded. There are errors in every line except the first line of the uncoded message. With one-half rate encoding, the errors have been substantially reduced, Figure 32. With one-third rate encoding the message is error free, Figure 33. The rapid fading type of scintillation shown in Figure 8 produced these results.

Using the less severe type of scintillation shown in Figure 13, the uncoded message is relatively good with errors in only 13 of the 40 lines, Figure 34. The one-half rate coding is only slightly better with errors in 3 of the 20 lines, Figure 35. The one-third rate coding provides an error-free message, Figure 36.

Using the long, deep fades shown in Figure 9, the fading is so severe that the uncoded message is useless, Figure 37. However, the fading structure is such that coding/interleaving offer little improvement. Both the one-half rate coding, Figure 38, and the one-third rate coding, Figure 39, still provide a useless message.

One of the variables in the simulation was the interleaving dimension. The effect of binary feedback coding without interleaving on the error rate is shown in Figure 40. It also compares two interleaving dimensions. Similar information for the one-half rate Viterbi coding is shown in Figure 41, while Figure 42 shows the one-third rate Viterbi coding.

In general, the results of the simulation showed an improvement of 2 to 4 dB in the performance of a one-half rate coded signal with interleaving compared with the uncoded signal and a 5 to 7 dB improvement in the one-third rate coded signal with interleaving compared with the uncoded signal. The message repeating technique showed less than a one

FILE # 8

UNCODED AT -130 DBM

WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION FADING, OR A HOST OF OTHER PROPAGATION ANOMALIES.
THERE ARE SOLUTIONS WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY), JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEP- TION OF IONOSPHERIC SCINTILLATION FADING. THIS PROBLEM IS A RELATIVELY NEW ONE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE PROBLEM IS CAUSED BY AN INHOMOGENEOUS IONOSPHERE AT APPROXIMATELY 300 TO 600 KILOMETERS. MINOR IRREGULARITIES IN THE IONOSPHERE ARE AMPLIFIED BY AN INTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDING PATTERNS OF NULLS AND PEAKS ON THE GROUND, FIGURE 1.
EXTENSIVE TESTS WERE RUN IN 1971 TO INVESTIGATE THE CHARACTERISTICS AND MODEL THE EFFECT. EXAMPLES OF SIGNAL LEVEL DATA TRANSMITTED FROM A SATELLITE AND RECEIVED IN AN AIRCRAFT ARE SHOWN IN FIGURES 2, 3 AND 4. THE FADES OCCUR FOR A DURATION OF .1 SECOND TO 10 SECONDS WITH A PERIOD OF 1/2 SECOND TO 60 SECONDS. THE SIGNAL LEVEL IS FADED 6 DB BELOW THE AVERAGE FOR ONLY 5 TO 10% OF THE TIME. HOWEVER, THE SIGNAL REMAINS FADED LONG ENOUGH AND FADES OFTEN ENOUGH TO MAKE NORMAL UNCODED TELETYPE TRANSMISSION TOTALLY UNREADABLE FOR PERIODS OF 5 TO 30 MINUTES.
THE OBJECT OF THIS SIMULATION IS TO USE CODING AND INTERLEAVING TO OVERCOME THE EFFECT OF FADING. THE TYPICAL UHF SATELLITE TELETYPE COMMUNICATION SYSTEM OPERATES WITH FROM 6 TO 10 DB OF MARGIN. WITH A GOOD SIGNAL THE LINK RUNS AT A .001% ERROR RATE. AN ACCEPTABLE ERROR RATE IS 0.1%. WITH SCINTILLATION FADING THE ERROR RATE TYPICALLY REDUCES TO .10%.
ACTUAL RECEIVED SIGNAL LEVELS WERE RECORDED ON TAPE DURING OUR 1971 SCINTILLATION FLIGHT TESTING. THESE ANALOG TAPES HAVE BEEN DIGITIZED WITH A SAMPLE RATE OF OVER 1000 SAMPLES PER SECOND.
THE SIMULATION WILL EFFECTIVELY COMPARE THE ERROR RATE SEEN BY UNCODED, CODED, AND CODED/INTERLEAVED SYSTEMS AS THEY ARE PLAYED THROUGH THE TAPED SCINTILLATION FADING SIGNAL LEVELS.
THE SIMULATION PROCEDURE WOULD BE TO READ THE SIGNAL LEVEL VALUES FROM THE DIGITIZED TAPE. ASSUME THAT THE AVERAGE UNFADED SIGNAL LEVEL IS AN E3/NO = 18 DB. SAMPLE THE SIGNAL LEVEL AT THE DATA RATE (75 BPS) AND KEEP A TIME HISTORY OF THE PROBABILITY OF ERRORS FOR A SHORT SEGMENT OF THE FADING TAPE (5 MINUTES). DETERMINE THE ERROR RATE WITHOUT CODING. REPEAT THAT PROCEDURE WITH EACH COMBINATION OF CODING/INTERLEAVING AND MEASURE THE ERROR RATE. IN THIS WAY THE BEST CODING/INTERLEAVING COMBINATION CAN BE DETERMINED FOR SEVERAL DIFFERENT

Figure 30. Example of Data Message - No Errors

```
FILE # 3

UNCODED      AT -134 DBM


WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED
INXXHE SYSTEM BY LOW SIGNAL, JAMMING, MULTIXXTH FADINXXXXXXXTILLATION
FADING, OR A HOST XXXXTHER PROPAGATION ANOMALIXXX            XX
YXXXE ARE SOLUTIONSXXHIXX PROTECT AGAINST MULTIPATXXXADING (XXXERSITY),
JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THEXXXXEP-
TION OFXIONOSPHERIC SCINTILLATION FADING. THIS PROBLEM IS X RELATIVELXX
NXXXONE, IXXXTIFIED ONLY WITHXXXXXXXXXXST THREE OR FOUR YEARS. THE
PROBLEM IS CAUSED BY AN INHOXXGXNEOUS IONOSPHERE AT APPROXIMATELXXX00  X
XY AN INTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR
XXREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDIXG
PATTXXXXXOFXXXXXXXXND PEAKS ON THE GROUND, FIGURE 1.      XXXXXXXXXXXX
EXTENSIVE TESTXXWERE RUN IN 1971 TO INVESTXXXTE THE CHARACXERISTICS AND
MODEL THE EFFECT. EXAMPLES OF SXXXXXXLEVEL DATA TRANSMITTED FROM A XXX
SATEXXITE AND RECEIVED IN ANXAIRCRAFT ARE SHOWN XX FIGURES 2,X3 AND 4.
XXXXXADES OCCURXFOR A DURATION OF .1 SECOXXXTO 1XXXECONDS WITH A PXXIOD
OFXXX2 SECOND TO 60 SECONDX. THE SIGNAL LEVEL IS FADED 6 DB BELOW THE
AVERAGE FOR ONLY 5 TO 10% OF XXX TIME. HOWEVEXXXXHE SIGNAL REMAINS
FADED LONG ENOUGH AND FAXXXXOFTEN ENOUGH TXXXAKE NORMAL UNXXXED TELEXYPE
TRANSMISXXON TOTALLXXXXREADAXLE FOR PERIODS OF 5 TO 30 MINUTES.
THE OBJECT OF THIS SIXULATION IS TO USE CODING AND INTERLEAVING TO     X
COMXUXICATION SYSTXXXXXERATES WITH FXXM 6 TO 10 DXXXF XXXXXX. WITH  XX
A GOOD SIGNAL THE LINK RUNS XXXA X001% EXXXR RATE. AXXXXCEPTABLE
ERROR RXXXXIS 0.1%.XXWITH SCINTILLATION FADING THE ERROR RATE TYPICALLYX
ACTUAL RECEIVED SIGNAL LEVELSXWERE RECXXXXX ON TAPE XURING OUR 1971
SCINTILLATION XXXGHT TESTING. THESE ANALOG TXXXS HAVE BEENXXXXXXIZXXX X
                                                                      X
CODED, AND CODXD/INTERLEAVED SYSTEMX AS THEY ARXXXXXXXX THROUGH THE
TAPED SCINTILLXXXXX FADING XXXNAL LEXXXX.
THE SIMULATION PROCEDURE WOULD BE TO READ THE SXGNAL LEVEL VALXXXXX
XROM THE DIGITIZED TAPE. ASSUME THAT THEXXXXRAGE UNFADED SIGNAL
LXXXXXIS AN XXXNO = 18 DB. SAMPLE THE SIGNAL LEVELXXX THE DATA         X
FOR A SHORT SEGMENT OF THE FXXXXG TAPE (5 MXXXXES). DETERMINE THEXXX
ERROR RATE WITXXXX CODING. REPEAT THATXXROCEDURE WITH EACH COMBINATIONX
CODING/INTERLEAVIXXXCOMBINATION CAN BE DETERMINED FOXXEVERALXXXFFERENT
```

Figure 31. Example of Data Message - Uncoded

FILE # 3

BINARY FEEDBACK - BLOCK INTERLEAVER(22*237) AT -134 DBM

WHEN COMMUNICATING THROUGXXA UHF SATELLITE, ERRORS CAN BE INTRODUCED
IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION
FADING, OR A HOST OF OTHER PROPAGATION ANOMALIES.
THERE ARE SOLUTIONS WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY),
JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEP-
TION OF IONOSPHERIC SCXXTILXXXXON FADING. THIS PROBLEM IS A RELATIVELY
NEW ONE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE
PROBLEM IS CAUSED BY AN INHOMOGENEOUS IONOSPHERE AT APPROXIMATELY 300
TO 600 KILOMETERS. MINOR IRREGULARITIES IN THE IONOSPHERE ARE AMPLIFIED
BY AN INTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR
IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORREXPONDIXX XXX X
PATTERNS OF NULLS AND PEAKS ON XHE GROUND, FIGURE 1.
EXTENSIVE TESTS WERE RUN IN 19XXXTO INVESTIGATE THE CHARACTERISTICS AND
MODEL THE EFFECT. EXAMPLES OF SIGNAL LEVEL DATA TRANSMITTEXXXROM A
SATELLITEXAXD RECEIVED IN AN AIRCRAFT ARE SHOWN IN FIGURES 2, 3 AND 4. X
XX 1/2 SECOND TO 60 SECONDS. THE SIGNAL LEVEL IS FADED 6 DB BELOW THE
AXXXXGE FOR OXXY 5 TO 10% OF THE TIME. HOWEVER, THE SIGNAL REMAINS
FADED LONG ENOUGH AND FADES OFTEN ENOUGH TO MAKE NORMAL UNCODEDXXXXXXXX
TRANSXXXXXXXXXCTALLYXXXREADABLE FOR PERIODS OF 5 TO 30 MINUTES.

Figure 32. Example of Data Message - Binary Feedback Coder

FILE # 3

CODED - VITERBI WITH BLOCK INTERLEAVER AT -134 DBM

WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION FADING, OR A HOST OF OTHER PROPAGATION ANOMALIES.
THERE ARE SOLUTIONS WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY), JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEPTION OF IONOSPHERIC SCINTILLATION FADING. THIS PROBLEM IS A RELATIVELY NEW ONE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE PROBLEM IS CAUSED BY AN INHOMOGENEOUS IONOSPHERE AT APPROXIMATELY 300 TO 600 KILOMETERS. MINOR IRREGULARITIES IN THE IONOSPHERE ARE AMPLIFIED BY AN INTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDING PATTERNS OF NULLS AND PEAKS ON THE GROUND, FIGURE 1.
EXTENSIVE TESTS WERE RUN IN 1971 TO INVESTIGATE THE CHARACTERISTICS AND

Figure 33. Example of Data Message - Viterbi Decoder

FILE #

UNCODED AT -132 DBM

WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED
IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION
FADING, OR A HOST OF OTHER PROPAXXTXXXXANOMALIES.
THERE ARE SOLUTIONS WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY),
JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEP-
TION OF IONOSPHERIC SCINTILLATION FADING. THIS PROBLEXXIS A RELATIVELY
NEW ONE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE
PROBLEM IS CAUSED BY AN INHOMOGENEOUS IONOSPHERE AT APPROXIMATELY 300
TO 600 KILOMETERX.XXXXXXXXXXREGULARITIES IN THE IONOSPHEREXXXXXXXXXIFIED
BYXAX XNTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR
IRREGULARITIES FORM A DEFRAXTION GRADING EFFECT WITH CORRESPONDING
PXTTERNS OF NULLS AND PEAKS ON THE GROUND, FIGURE 1XXX
EXTENSIVE TESTS WERE RUN IN 1971 TOXXXXXXXXXXTX THE XHXRACTERISTICS ANDX
XXXXXXXXXXXXXXXXXXIVED IN AN AXXCRXXXXXXXEXSHXXXXXXXXIGUXXXXX, XXAND 4.
THE FADES OCCUR FOR A DURATION OF .1 SECOND TO 10 SECONDS WXXXXXXXXRIODX
XXXXAGE XOX ONLY 5 TO 10% OFXTXE TIMEX HOWEVER, THE SIGNAL REMAINS
FADED LONG ENOUGH AND FADES OFTEN ENOUGH TO MAKE NORMAL UNCODED TELETYPE
TRANSMISSION TOTALLY UNREADABLE FOR PERIODS OF 5 TO 30 MINUTES.
THE OBJECT OF THIS SIMULATION IS TO USE CODING AND INTERLEAVING TO
OVERCOME THE EFFECT OF FXDING. THE TYPICAL UHF SATELLITE TELETYPE
COMMUNICATION SYSTEM OPERATES WITH FROM 6 TO 10 DB OF MARGIN. WITH
A GOOD SIGNAL THE LINK RUNS AT A .001% ERROR RATE. AN ACCEPTABLE
ERROR RATE IS 0.1%. WITH SCINTILLATION FADING THE ERROR RATE TYPICXXLY
REDUCES TO .10%.
ACTUAL RECEIVED SIGNAL LEVELS WERE RECORDED ON TAPE DURING OUR 1971
SCINTILLATION FLIGHT TESTING. THESE ANALOG TAPES HAVE BEEN DIGITIZED
WITH A SAMPLE RATE OF OVER 1000 SAMPLES PER SECOND.
THE SIMULATION WILL EFFECTIVELY COMPARE THE ERROR RATE SEEN BY UNCODED,
CODED, AND CODED/INTERLEAVED SYSTEMS AS THEY ARE PLAYED THROUGH THE
TAPED SCINTILLATION FADING SIGNAL LEVELS.
THE SIMULATION PROCEDURE WOULD BE TO READ THE SIGNAL LEVEL VALUES
FROM THE DIGITIZED TAPE. ASSUME THAT THE AVERAGE UNFADED SIGNAL
LEVEL IS AN EB/NO = 10 DB. SAMPLE THE SIGNAL LEVEL AT THE DATA
RATE (75 BPS) AND KEEP A TIME HISTORY OF THE PROBABILITY OF ERRORS
FOR A SHORT SEGMENT OF THE FADING TAPE (5 MINUTES). DETERMINE THE
ERROR RATE WITHOUT CODING. REPEAT THAT PROCEDURE WITH EACH COMBINATION
OF CODING/INTERLEAVING AND MEASURE THE ERROR RATE. IN THIS WAY THE BEST
CODING/INTERLEAVING COMBINATION CAN BE DETERMINED FOR SEVERAL DIFFERENT

Figure 34. Example of Data Message - Uncoded

FILE # 8

BINARY FEEDBACK - BLOCK INTERLEAVER(22*237) AT -132 DBM

WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED
IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION
FADING, OR A HOST OF OTHER PROPAGATION ANOMALIES.
THERE ARE SOLUTIOND WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY),
JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEP-
TION OF IONOSPHERIC SCINTILLATION FADING. THIS PROBLEM IS A RELATIVELY
NEW OXE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE
[illegible]IED
BY AN INTERACTION OF THE IONO AND THE MAGNETIC FIELD. THESE MAJOR
IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDING
PATTERNS OF NULLS AND PEAKS ON THE GROUND, FIGURE 1.
EXTENSIVE TESTS WERE RUN IN 1971 TO INVERTIGATE THE CHARACTERISTICS AND
MODEL THE EFFECT. EXAMPLES OF SIGNAL LEVEL DATA TRANSMITTED FROM A
SATELLITE AND RECEIVED IN AN AIRCRAFT ARE SHOWN IN FIGURES 2, 3 AND 4.
THE FADES OCCUR FOR A DURATION OF .1 SECOND TO 10 SECONDS WITH A PERIOD
OF 1/2 SECOND TO 60 SECONDS. THE SIGNAL LEVEL IS FADED 6 DB BELOW THE
AVERAGE FOR ONLY 5 TO 10% OF THE TIME. HOWEVER, THE SIGNAL REMAINS
FADED LONG ENOUGH AND FADES [illegible]EN ENOUGH TO MAKE NORMAL UNCODED TELETYPE
TRANSMISSION TOTALLY UNREADABLE FOR PERIODS OF 5 TO 30 MINUTES.

Figure 35. Example of Data Message - Binary Feedback Coder

FILE # 8

VITERBI - RATE 1/3 - BLOCK INTERLEAVER(96*66) AT -132 DBM

WHEN COMMUNICATING THROUGH A UHF SATELLITE, ERRORS CAN BE INTRODUCED
IN THE SYSTEM BY LOW SIGNAL, JAMMING, MULTIPATH FADING, SCINTILLATION
FADING, OR A HOST OF OTHER PROPAGATION ANOMALIES.
THERE ARE SOLUTIONS WHICH PROTECT AGAINST MULTIPATH FADING (DIVERSITY),
JAMMING (SPECTRUM SPREADING), AND MOST OTHER ANOMALIES WITH THE EXCEP-
TION OF IONOSPHERIC SCINTILLATION FADING. THIS PROBLEM IS A RELATIVELY
NEW ONE, IDENTIFIED ONLY WITHIN THE PAST THREE OR FOUR YEARS. THE
PROBLEM IS CAUSED BY AN INHOMOGENEOUS IONOSPHERE AT APPROXIMATELY 300
TO 600 KILOMETERS. MINOR IRREGULARITIES IN THE IONOSPHERE ARE AMPLIFIED
BY AN INTERACTION OF THE IONS AND THE MAGNETIC FIELD. THESE MAJOR
IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDING
PATTERNS OF NULLS AND PEAKS ON THE GROUND, FIGURE 1.

Figure 36. Example of Data Message - Viterbi Coder

FILE # 4

UNCODED AT -132 DBM

```
                                                                    X
XXXXXXX OR A HOST OF OTHER PROPAGATIXX ANOMXXXXXXXXXXXXX  XX  XX    X
                                                                    X
NEW ONE, IXXNXIFIXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX YEARS,  THE
PROBLEM IS CAUSED BY AN INXXXXXXXXXXXXONXXXXERE AT APPROXIMATELY 300 XX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXFXXXXXWITH XXXXXXXXXXXNG
PATTERNS OF NULLS AND PEAKSXXXXXXXXXXXXXXXXXXXXUXE XXXXXXXXXXXXXXXXXXX
                                                                    X
XXXXXXXXXXXXX RECEIVED XXXXXXXXXXXXXXXXXXXXXXXXXXN FIGUREXXXXXXXXXX 4, X
XXXXXXXXXXXXXXXXXXXXXXXXXXDXXXXXXXXXXXXXXXXXXXXXHFXXATELLXXXXTELETYPE X  X
XXXXXXXXXXNALXTHE LINK RUNS AT A .001% ERROR RATE,  AN ACCEPTABLE
EXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXY
REDUCES TO .10%,          XXXXXXXX
ACTUAL RECEIVED SIGNAL LEVELSXWXXXXXXXXXRDEX XXXXXXXXXXRING OUR 1971    X
XXXXXXMULATION WILL EFFECTIVELY COMPARE THE ERROR RATE SEEN BY UNCODED,
                                                                    X
XXXXXXXXXXXXXLATXXXXXAXXXG SIGNAL LEVELS,                           X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXSUME THAXXXXEXXXXRXXEXUNFADED SIGNAL
LEVEL IS AN EB/NO = 18 DB,  SAMPLE THE SIGNAL LEVEL AT THE DATA     X
XXXXXXXXXXXXXXXXXXXXXXXXXE FADING TAPE (5 MINUTES),  DETERMINE THE
ERROR RATE WITHOUT CODINGXXXXXPXXXXXXXXXXXXXXXXXXXXXXXXXXCH COMBINATION
OFXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXEXROR RAXX,  IN XHIS WAY XHE BEST
CODING/INTERLEAVING COMBINATION CAN BE DETERMINED FOR SEVERAL DIFFERENT
```

Figure 37. Example of Data Message - Uncoded

FILE # 4

3INARY FEEDBACK = BLOCK INTERLEAVER(22*237) AT -132 DBM

```
                                                                                      X
XXERNXXXXXXXXXXXXXXXXXXXXEHXXXXXXXXXXXXXXXXXXXXXXXXXXRXXXXXXXXBIMXXXXXXXXXXXXXXXXXX
OF 1XX 8XXXXD XXX60 SECONDX,  THXXXXXXXX LEVEL IXXXADED 6 DX BELOW THE
                                                                                      X
XXXXXXIXXXON TOXXXXXXUNREADABLE FOR PERIXXXXOF 5 TXXXX MIXUXEXX
```

Figure 38. Example of Data Message - Binary Feedback Coder

```
FILE # 4

VITERBI - RATE :'3 - BLOCK INTE'LEAVER(96*66) AT -132 DBM

                                                                          X
[illegible] OF [illegible]RLIFIED
IRREGULARITIES FORM A DEFRACTION GRADING EFFECT WITH CORRESPONDING
PATTE^NS OF NULLS AN^ PEAKS ON THE GROUND, FIGURE 1.                  X
```

Figure 39. Example of Data Message - Viterbi Coder

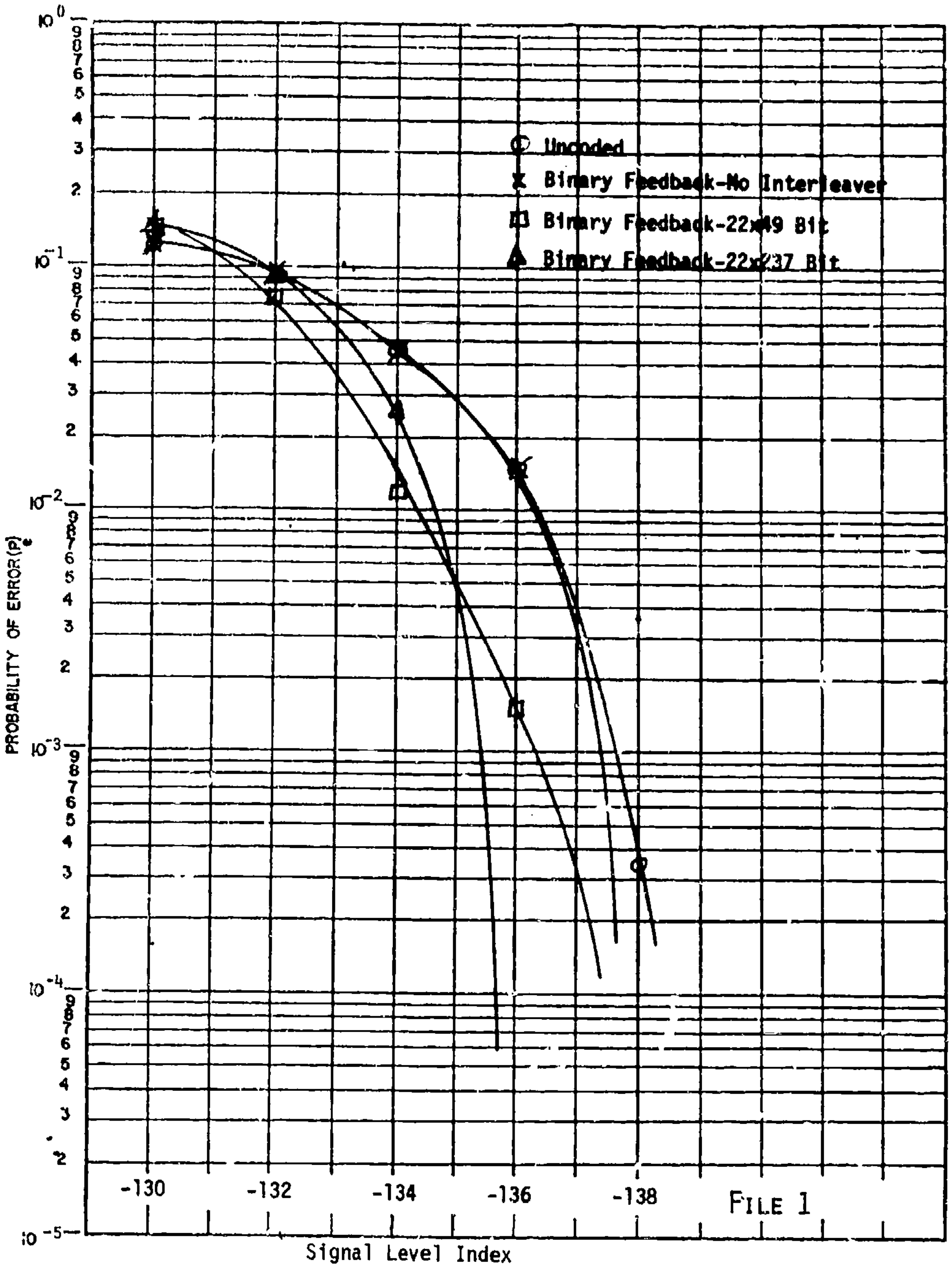


Figure 40. Effect of Interleaver Size on Binary Feedback

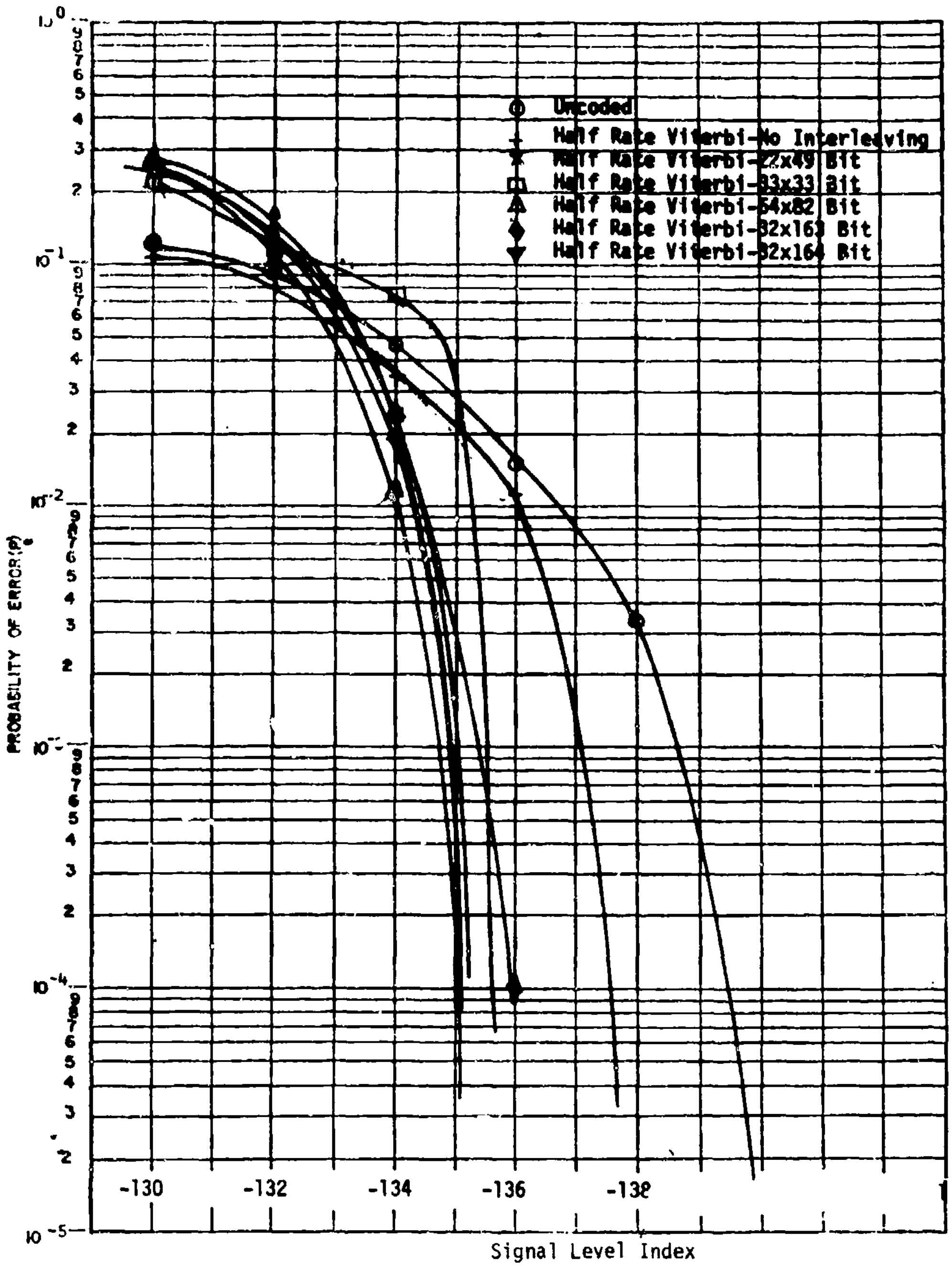


Figure 41. Effect of Interleaver Size on Half Rate Viterbi Coder

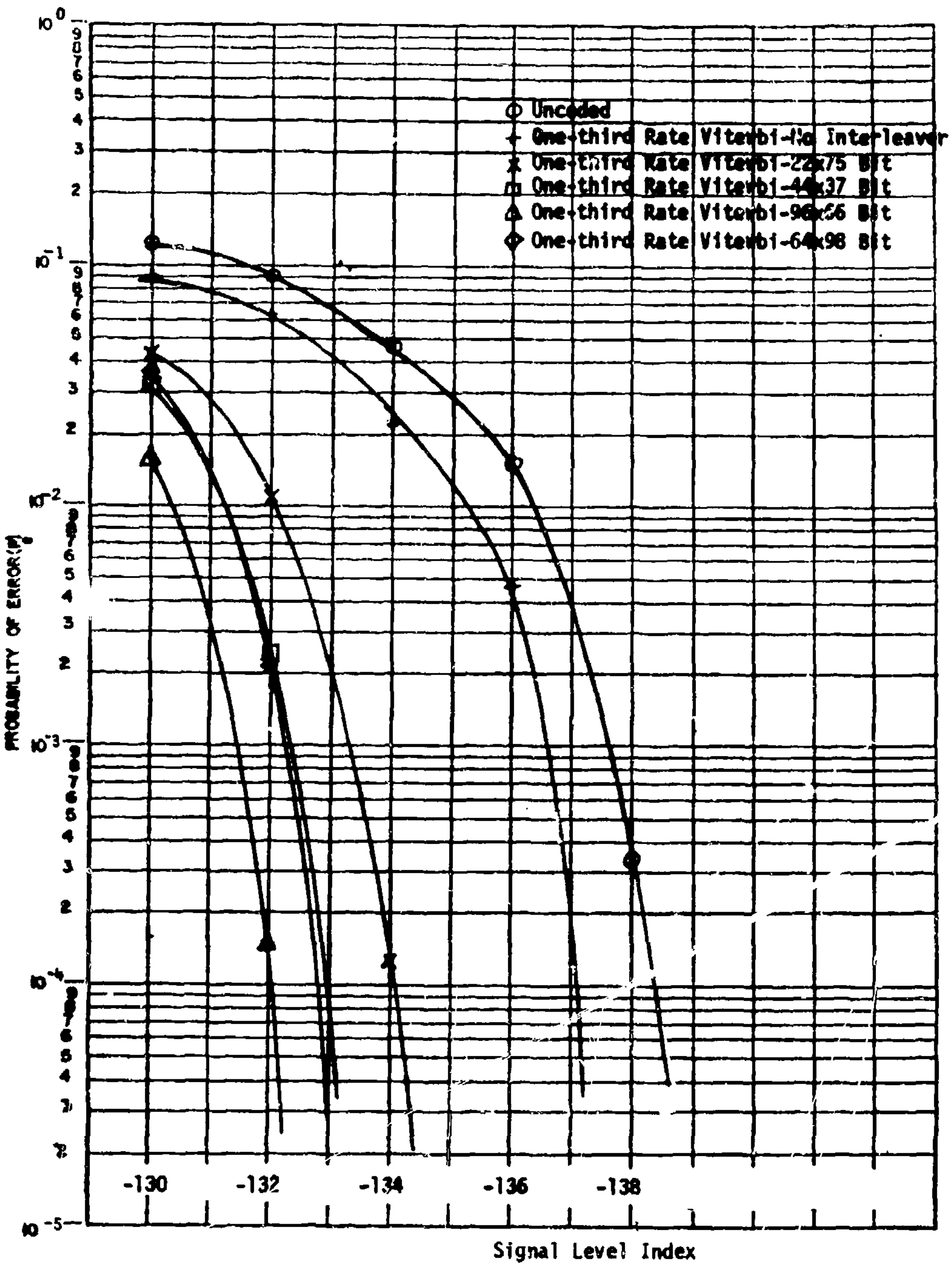


Figure 42. Effect of Interleaver Size on One-Third Rate Viterbi Coder

dB improvement for the one-half rate repeating. The improvement was determined by selecting an acceptable BER, such as 10^{-3}, and reading the difference in the required received signal for each type of coding.

However, the one-half rate code requires twice as much time to send the same amount of information as a message without coding and the one-third rate code requires triple the time to send the same amount of information as the uncoded message. To be comparable the uncoded message should be sent at one-half the data rate that a one-half rate coded message is sent, or one third the rate that a one-third rate coded message is sent. Assuming linearity, there would be a 3 dB improvement in the performance of the uncoded message compared with the one-half rate and a 5 dB improvement in the uncoded message with the one-third rate simply due to the data rate factor.

Therefore, the true BER improvement of the coding was small. However, the readability of the message may improve more than the BER improvement indicates. The coded message often provides long error-free portions of message with occasional burst errors. The uncoded message or repeated message often is unreadable with errors occurring throughout the message.

SECTION V
CONCLUSIONS

The simulation of ionospheric scintillation improvement using various types of coding has shown that for certain types of fading structure coding/interleaving can provide a reduction in BER performance and a significant improvement in the message readability of the simulated system when compared with an uncoded message. However, there were fading structures where a simple message repeating technique could be nearly as effective as a sophisticated coding/interleaving. In some cases the fading could be so severe that even with coding no useful information could be received.

During the simulation the effect of various interleavers was determined. The results showed that as the interleaving block size is increased, a large improvement in BER can be achieved. However, once an acceptable interleaving dimension is achieved, there is little gain in increasing the dimension any more. This is a logical conclusion since once the interleaver has spanned the distance between two fades, no further improvement is likely. To increase the interleaving distance further would mean spanning part of the second fade.

Since the coding and interleaving cuts down on the data throughput, it may be desirable to use some type of adaptive system which operates uncoded when the effect of ionospheric scintillation is small and switches to a coding/interleaving scheme after fading has reached an unacceptable level. The measure of effectiveness requires a duplex link or half duplex link where the receiving terminal can respond and indicate its message quality. For example, an aircraft communicating with a ground terminal could send the message in the clear. If the reply from the ground terminal to the aircraft is received with errors, the aircraft would assume that its message going to the ground terminal also had an unacceptable number of errors and would switch to a coded mode; the data would be re-sent.

An effort which remains to be accomplished is a determination of the complexity of implementing an uncoded modem, a modem with repeating techniques, and a modem with the various types of coding/interleaving simulated. As a first approximation, Table 4 contains a gross estimate of the number of integrated circuits required to achieve a simple 75 bps modem under these various conditions. To determine what type of coding/interleaving to build into a modem the user would have to determine the required BER performance of the system as well as the relative cost of a more or less sophisticated coding technique.

Such a trade-off study should be made before a modem design is implemented and a cost effective coding/interleaving could be chosen for that particular application.

TABLE 4
RELATIVE COMPLEXITY OF MODEM/CODER/INTERLEAVER

	INTEGRATED CIRCUIT COUNT*		
	Modem Only	Encoder/Decoder + Interleaver	Total
Modem (no encoding)	100	0	100
Modem (automatic message repeating)	110	0	110
Modem (with 1/2 rate binary feedback encoding block interleaving)	100	45	145
Modem (with 1/2 rate convolutional encoding, Viterbi decoding-block interleaving)	100	85	185
Modem (with 1/3 rate convolutional encoding, Viterbi decoding-block interleaving)	100	105	205

*The relative complexity/cost/size of the modem and encoder/interleaver can be measured by how many integrated circuits are required to implement it.

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4. J. H. Garrett, Scintillation Fading Protection Simulation Program, AFAL-AAI-TM-74-27, Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio, August 1974.

☆U.S.Government Printing Office: 1975 — 657-023/706