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SUMMARY

This report provides the test results and performance analysis of the multichannel error correction code decoder (MED) system for a regenerative satellite with asynchronous, frequency-division multiple access (FDMA) uplink channels. It discusses the system performance relative to various critical parameters: the coding length, data pattern, unique word value, unique word threshold, and adjacent-channel interference. Testing was performed under laboratory conditions and used a computer control interface with specifically developed control software to vary these parameters. Needed technologies—the high-speed Bose Chaudhuri-Hocquenghem (BCH) codec from Harris Corporation and the TRW multichannel demultiplexer/demodulator (MCDD)—were fully integrated into the mesh very small aperture terminal (VSAT) onboard processing architecture and were demonstrated.

INTRODUCTION

The Digital Systems Technology Branch of the NASA Lewis Research Center has an ongoing program in modulation, coding, onboard processing, and switching.[1] Recently, they completed a project to incorporate a time-shared decoder into the mesh very small aperture terminal (VSAT) onboard-processing architecture. Their primary goal was to demonstrate a time-shared decoder for a regenerative satellite using asynchronous, frequency-division multiple access (FDMA) uplink channels, thereby identifying hardware and power requirements and fault-tolerant issues that would have to be addressed in an operational system. Their secondary goal was to integrate and test, in a system environment, two NASA-sponsored, proof-of-concept hardware deliverables: the Harris Corporation high-speed Bose Chaudhuri-Hocquenghem (BCH) codec and the TRW multichannel demultiplexer/demodulator (MCDD). A beneficial byproduct of this project was the development of flexible, multichannel uplink-signal-generation equipment.

Previous reports have described the design, fabrication, and basic performance of the MCDD hardware (refs. 1 and 2). This report describes the testing and performance for a time-shared decoder. Details include the effects of the coding block length, data pattern type, unique word value, and unique word threshold. Analysis of how adjacent-channel interference affects the overall system performance also is presented.

As an introduction to the discussion of the test results, a brief review of the multichannel error correction code (ECC) decoder (MED) system and special test equipment is given first.

MULTICHANNEL ERROR CORRECTION CODING SYSTEM

The MED system is a prototype of the uplink portion of a low-rate (64-kbps) FDMA system for a mesh VSAT processing satellite. As shown in figure 1, the MED system consists of uplink-signal-generation equipment, the TRW MCDD (including radiofrequency and link-simulation equipment that were developed under a contract with TRW (ref. 3)), and the time-shared decoder. This system can produce four uncoded or coded uplink channels at a channel transmission rate of 64 kbps. The codec utilizes a BCH block code in block sizes from 224 to 480 bits, excluding a 32-bit unique word (UW) preamble that identifies the start of a block. Figure 2 shows all the hardware for the system.

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[1] For more information, visit our site on the World Wide Web (http://sulu.lerc.nasa.gov/tmp/5650/5650.html).

After a thorough evaluation of various coding formats, the UW was chosen to simplify the overall processing (ref. 1). The multichannel ECC encoder generates four channels of pseudorandom data, block encodes the data, attaches a UW to the encoded block, and passes the data to the modulator cards. The entire system is controlled by a personal computer, so one of four channels can be selected to originate from a commercial bit-error-rate (BER) test set while the other three are generated on the encoder card. The modulator card facilitates adjacent channel interference testing by digitally offsetting the center frequency of the signal.

The modulator is configured as a 64-kbps differentially encoded, offset quadrature, phase-shift-keyed modulator with 30-percent raised cosine shaping, 512 samples per symbol, and an aperture size of 12 (ref. 1). The uplink-signal-generation equipment contains two digital combiner upconverter cards—one to process the I channel data and the other to process the Q channel data. These cards also apply gain factors and add digital I and Q channels so that the final output is a composite signal that is compatible with the TRW MCDD input. The MCDD channelizes and demodulates either 2.084-Mbps or 64-kbps spectrally shaped offset quadrature, phase-shift-keyed signals.

The UW detector card identifies the beginning of data packets for each of the 32 channels and notifies the encoder block builder of the beginning of a block and of the channel in which it resides. Once the block builder card is notified by the UW detector, it builds up each block for 32 channels and notifies the multichannel ECC decoder (MED) when a full block of data is available for decoding along with the appropriate channel identification number.

The MED decodes individual data blocks in a time-shared manner, stores the decoded blocks and channel identifiers, and notifies the data switch interface of the available channels. It uses the decoder portion of the Harris BCH codec chip to decode, correct if necessary, and store the data in a dual-port random-access memory (RAM). For testing and evaluation, the computer control includes a no-code option. The data switch interface accesses the user-specified channel data from the dual-port RAM and converts it to a format that is used by a BER test set for evaluation.

SPECIAL TEST EQUIPMENT

The MED is integrated with special test equipment that simulates link degradations expected in an operational system. This equipment includes a programmable noise generator, a signal generator, and a personal computer with control software (developed at NASA Lewis) and LabVIEW (National Instruments) software that allow users to select parameters to be characterized. With this software, the parameters—data pattern, block size, digital offsets, UW threshold, adjacent channel interference, and coding or no-coding—can be changed as the test demands.

The programmable noise generator is adjusted by LabVIEW auto-testing procedures to obtain the BER measurement, which is eventually plotted against the ratio of input energy per information bit to the noise, E_b/N_o.

TESTING AND RESULTS

Because the linear block codes can provide a wide range of code rates, it is necessary to normalize E_b/N_o to analyze the BER performance of the system. Given the TRW MCDD's fixed transmit bit rate R_T of 64 kbps, the information bit rate R_I is defined as follows:

$$R_I = R_T R_C$$

where R_C is the code rate of the system.

This normalization facilitates the graphical analysis of various code rates to represent E_b/N_o versus BER performance. Because the traffic occurs in bursts, the percentage of seconds in error was plotted as a function of E_b/N_o for various tests to increase our understanding of the relationships for coded and uncoded transmissions.

Effects of Data Pattern

A test of measuring BER performance with different pseudorandom bit sequences showed that the decoder is sensitive to the type of data that are being sent through the link. In order to understand the hidden relationships between how data were being packaged and what the uncoded and coded BER were, it was necessary to vary the block size. As shown in figure 3, for the pseudorandom bit sequence $2^{15}-1$, if any block is corrupted with errors, the decoder discards all blocks that make up the full $2^{15}-1$ data pattern. On the other hand, if the pseudorandom bit sequence 2^7-1 is used, the data corruption may be limited to only one or two blocks. The UW and its value parameters are held constant.

Figures 4(a) and (b) indicate the performance curves when coding of various block sizes is applied to 2^7-1 and $2^{15}-1$ data patterns, and they show a theoretical BER measurement curve for comparison. For a 224-bit block, there is an improvement of up to 0.5-dB with the 2^7-1 pattern in comparison to the $2^{15}-1$ pattern. On the other hand, for a 464-bit block, the $2^{15}-1$ pattern yielded a 0.5-dB improvement over 2^7-1. This is more evident in figures 5(a) and (b), where the percentage of seconds in error are plotted as a function of E_b/N_o. The primary reason for the improvement is that with a bigger block size the $2^{15}-1$ pattern needs fewer blocks to complete the full pattern, and therefore, the likelihood of losing several blocks if some data are corrupt decreases. Similarly, if the block size is small and the data pattern used is 2^7-1, the likelihood of losing multiple blocks if just one block is corrupted increases. The same holds true for uncoded transmissions.

Effects of Block Size

The effects of using various block sizes for coded and uncoded transmissions were analyzed for the 2^7-1 length pattern. So that the relationship between the block size and coding gain could be studied, parameters such as the UW threshold and the UW value were held constant. Only a single channel was active so that any degradation caused by adjacent channel interference would be eliminated. As shown in figure 6(a), as the block size was increased for the coding option, the code rate increased and the percentage of seconds in error decreased. This happened because the number of times that the data pattern could fit into a block increased as the block size was increased. Figure 6(b) indicates that for the no-coding option, as block size was increased, the coding gain was insignificant for low signal-to-noise ratios but was as much as 0.5 dB for high signal-to-noise ratios.

Effects of Unique Word Value

Because we utilize a block code, a UW is required to identify the beginning of the block, even though our data are transmitted continuously. The UW is not forward error correction encoded. Detection of the UW indicates a known position in the data frame. With this system, frame acquisition can be essentially immediate. However, the UW must be relatively long, in comparison to the data frame, to keep the probability of false detection low—thus, adding overhead bits and processing time to the system.

It is assumed that UW values that have high autocorrelation and low cross-correlation—such as Barker, Williard, Neuman-Hofman, and Maury-Styles sequences—can give the best throughput. Unfortunately, in some cases the known Barker and Williard sequences are too short to provide the best code word in random binary data (ref. 4).

Consequently, Neuman-Hofman and Maury-Styles sequences were used to test the effects of the UW value. The source data and block size were held constant to a 2^7-1 length pattern and 448 bits, respectively. A good synchronization code word is one with a small absolute value for its "correlation side lobes." A correlation sidelobe, C_k, is the value of the correlation of a code word with a time-shifted version of itself (ref. 4). Two different 24-bit synchronization words from the Neuman-Hofman sequences were selected for testing; one with an absolute value of $|C_k| = 4$ and the other with $|C_k| = 9$ (refs. 5 and 6). Since the UW required for the MED system is 32-bit, the first byte of the synchronization word was appended to the 24-bit synchronization word for simplicity. As shown in figure 7, the coding gain was approximately 1.0 dB for the UW with $|C_k| = 4$ when compared with uncoded transmission. On the other hand, the coding gain was approximately 0.5 dB when the UW with $|C_k| = 9$ was used.

The criterion for the Maury-Styles synchronization word selection was similar to the normal desirable correlation property of any synchronization sequence except that random data were assumed for both the front and back sequences in which the synchronization word was embedded. Two Maury-Styles sequences were used: one 30-bit sequence and another 29-bit sequence, with probabilities of false detection of 2.07×10^{-7} and 4.09×10^{-7}, respectively (ref. 7). As depicted in figure 8, the decoder performance was better at higher signal-to-noise ratios for coded transmissions.

Effects of Unique Word Threshold

For testing the effects of UW threshold values on the system for coded and uncoded transmissions, two different UW values from the UW value test were used, and the source data pattern length and block size were held constant at 2^7-1 and 448, respectively.

The 32-bit UW was made up of the 29-bit Maury-Styles sequence from the UW value test, appended with three zeros. As the UW threshold was increased from 29 to 31, the likelihood that there was a correct beginning on the block increased. However, as shown in figure 9, the BER performance degraded because it was more likely for a block to be missed because the UW value was not received correctly. When the UW threshold value was relaxed and set to 28, the system performance degraded to an unacceptable BER. This can happen because the encoder may encode part of the data block as a perfect replica of the UW, which allows the system to identify a false beginning of the block.

When another 32-bit-sequence UW value was used, probabilities for both missed blocks and falsely identified blocks were less then 10^{-3}. This 32-bit word was obtained by block encoding the pair of 16-bit UW's through a (31,16,7) code-generator polynomial (ref. 7). Interestingly enough, as the threshold for this UW sequence was increased from 24 to 31, the likelihood that the beginning of the block would be correctly identified increased. As the UW threshold was relaxed below 23, the BER of the system tended to degrade. Therefore, the system is sensitive to the UW value and to the size of the UW threshold.

Effects of Adjacent Channel Interference

Various adjacent channel frequency offsets were applied to evaluate the effects of adjacent channel interference on coded and uncoded transmissions. The source data pattern, block size, UW threshold, and UW value were held constant. Figure 10 shows the low-frequency offset for 5-, 10-, and 15-percent digital interference. The low, high, and low-high offsets were varied to test adjacent channel effects. Figure 11 depicts the effects for the high-frequency offset for 5-, 10-, and 15-percent interference as they were applied for coded data. For higher signal-to-noise ratios, as the percentage of interference was increased, the performance of the system degraded significantly. For low and low-high frequency offsets, the performance of the system degraded moderately in all cases for coded and uncoded transmissions.

CONCLUSIONS

This system can be improved vastly for better performance and fewer errors. One potential improvement to the MED hardware would be to implement a time-shared decoder that can decode 32 simultaneous asynchronous FDMA channels with a custom application-specific integrated circuit, a couple of dual-port RAM's, and a codec chip residing in a multichip module. Because the block size of 448 bits performed the best, it could be employed as the optimum block size for this system. For coded transmissions, the Neuman-Hofman sequence with $|C_k| = 4$ performed better than the Maury-Styles sequence.

Because errors occur in bursts, the BCH codec often deals with multiple errors in a block, and sometimes it is unable to correct all of these errors. If an interleaver is implemented after the encoder, distributing the errors among the various blocks, the codec will deal with fewer errors per block during error detection and correction. Of course, a de-interleaver must be designed to keep track of the order in which the data block was received and interleaved. Other coding schemes may also be investigated for better performance.

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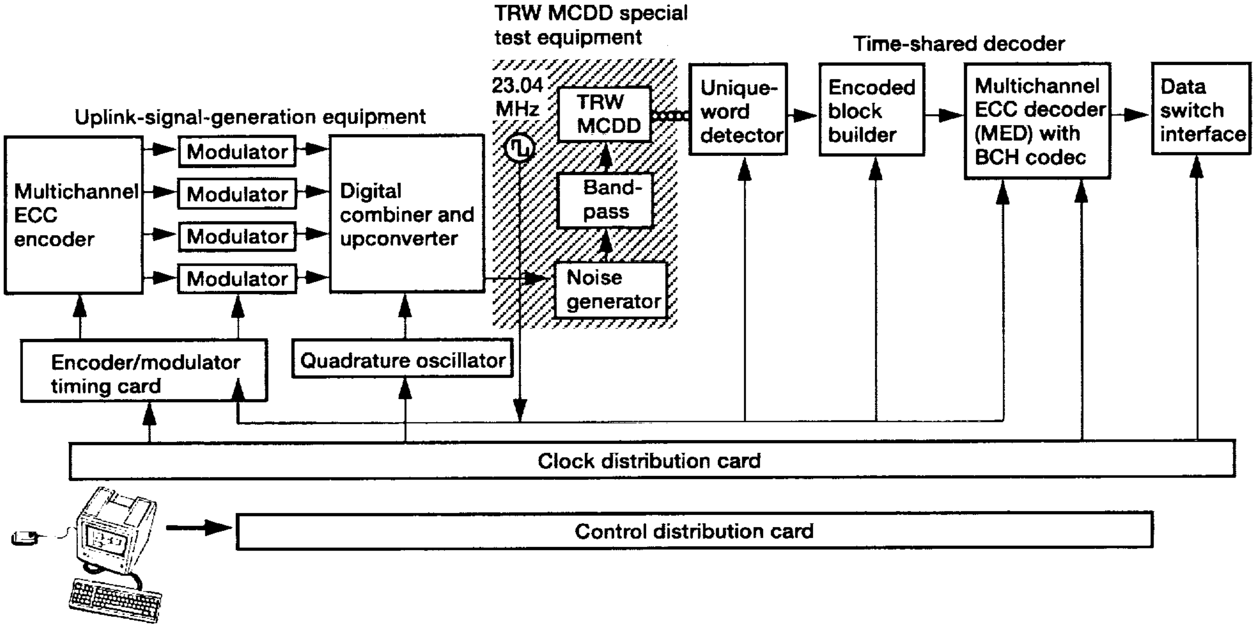

Figure 1.—MED system: uplink-signal-generation equipment and time-shared decoder.

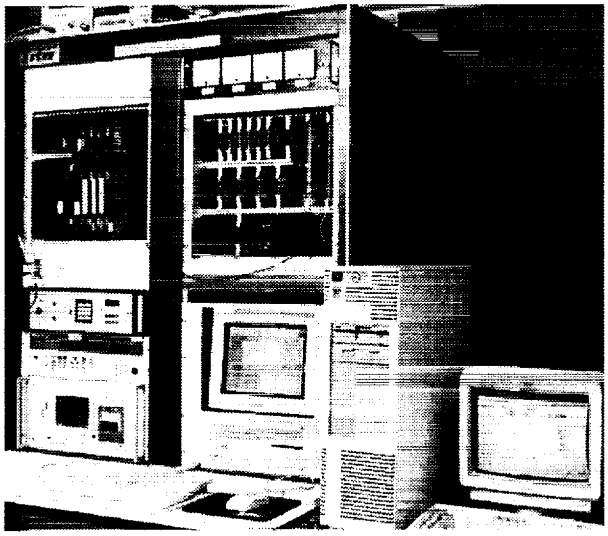

Figure 2.—Uplink-signal-generation equipment, TRW multichannel demultiplexer/demodulator (MCDD), time-shared decoder, and special test equipment.

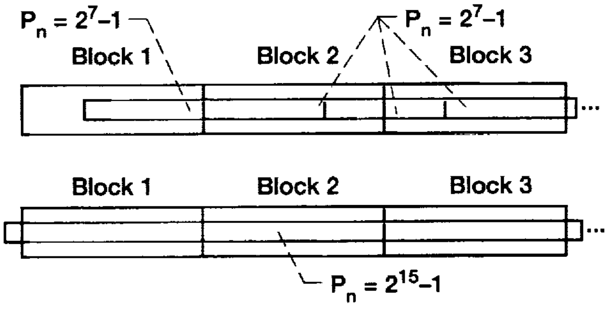

Figure 3.—Data message allocations within a coded block for both 2^7-1 and $2^{15}-1$ pseudorandom bit sequences, P_n.

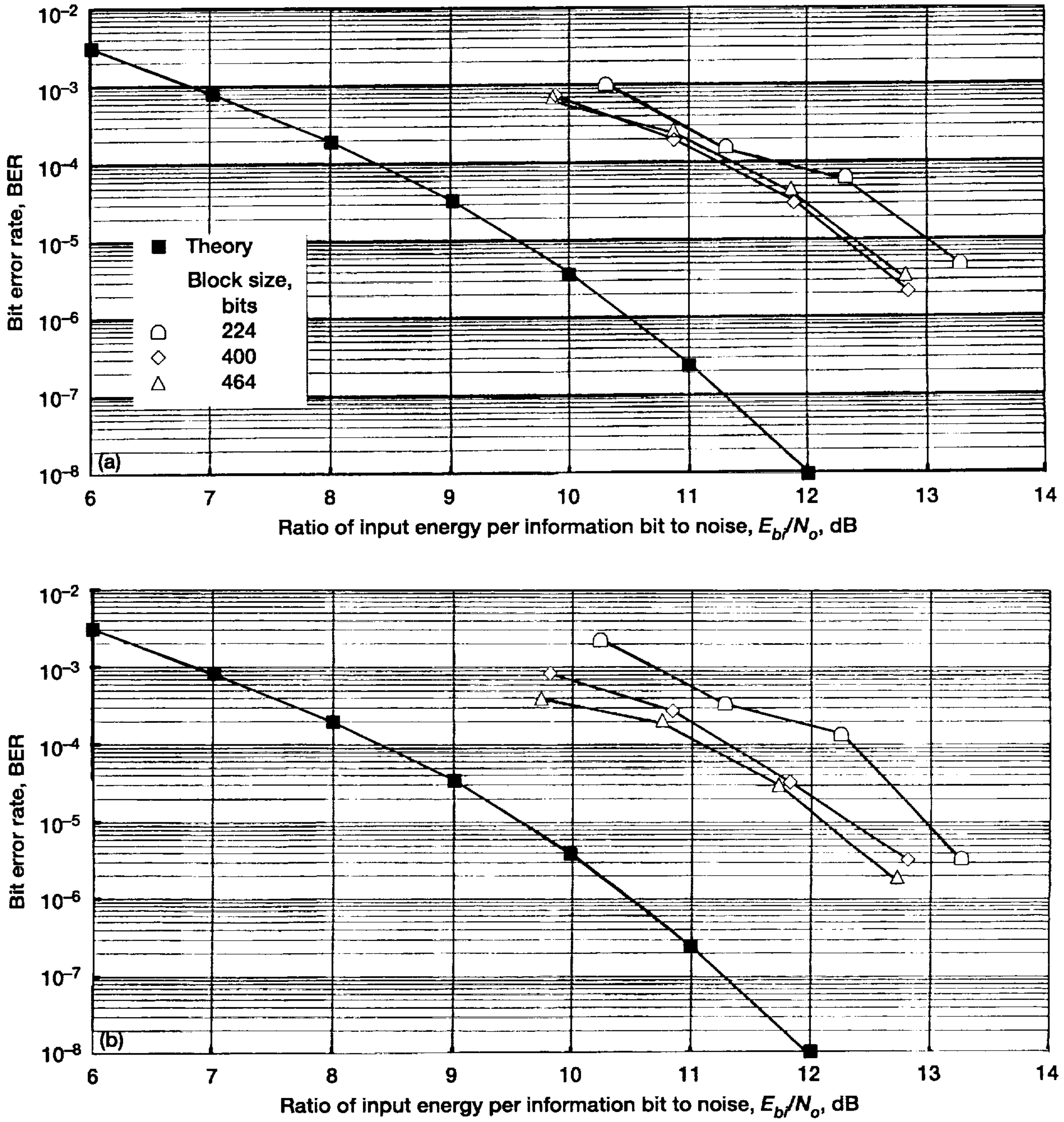

Figure 4.—BER performance with coding applied for various blocks. (a) 2^7–1 pseudorandom bit sequence. (b) 2^{15}–1 pseudorandom bit sequence.

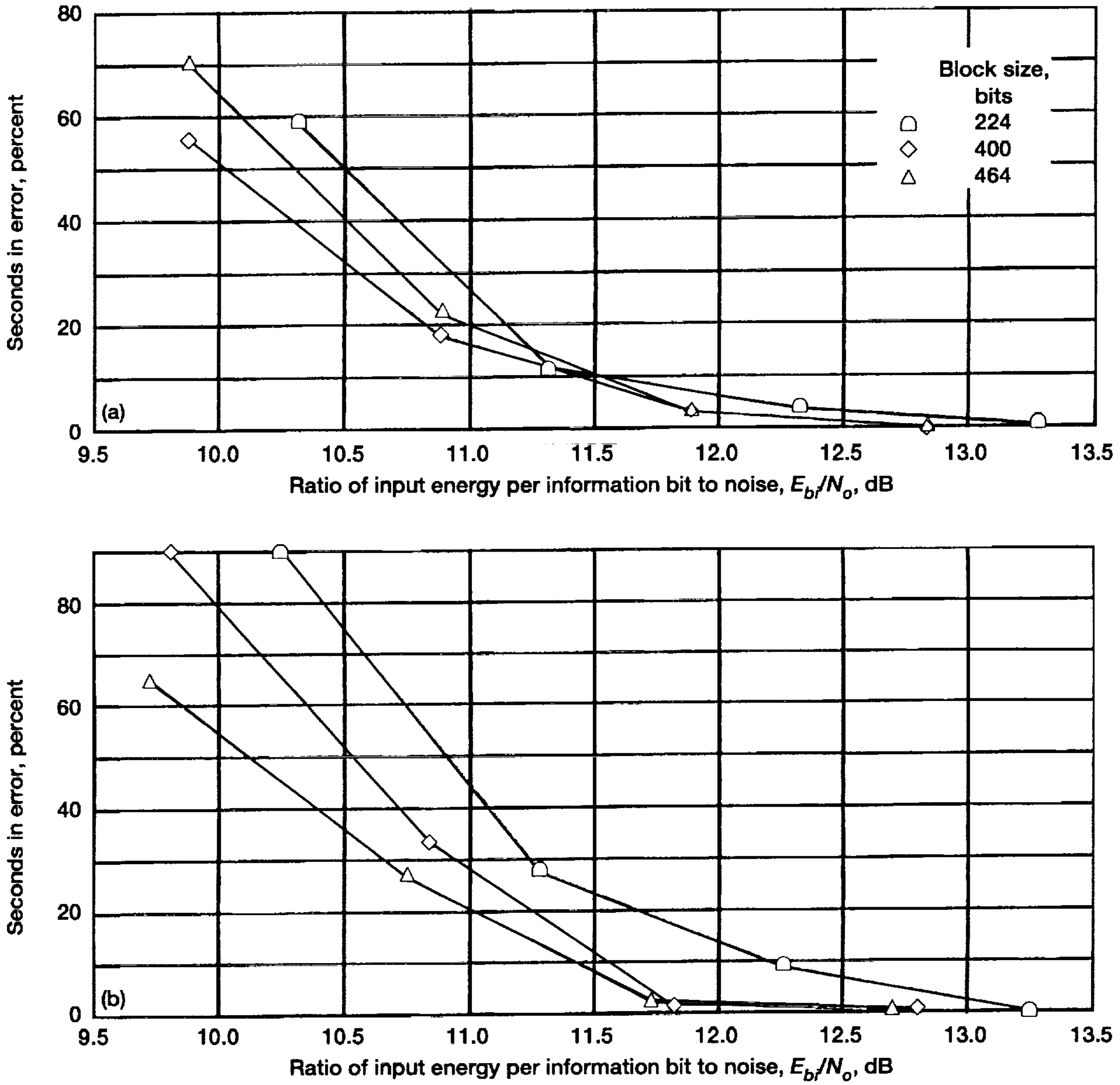

Figure 5.—Percentage seconds in error with coding applied for data pattern effects. (a) 2^7–1 pseudorandom bit sequence. (b) 2^{15}–1 pseudorandom bit sequence.

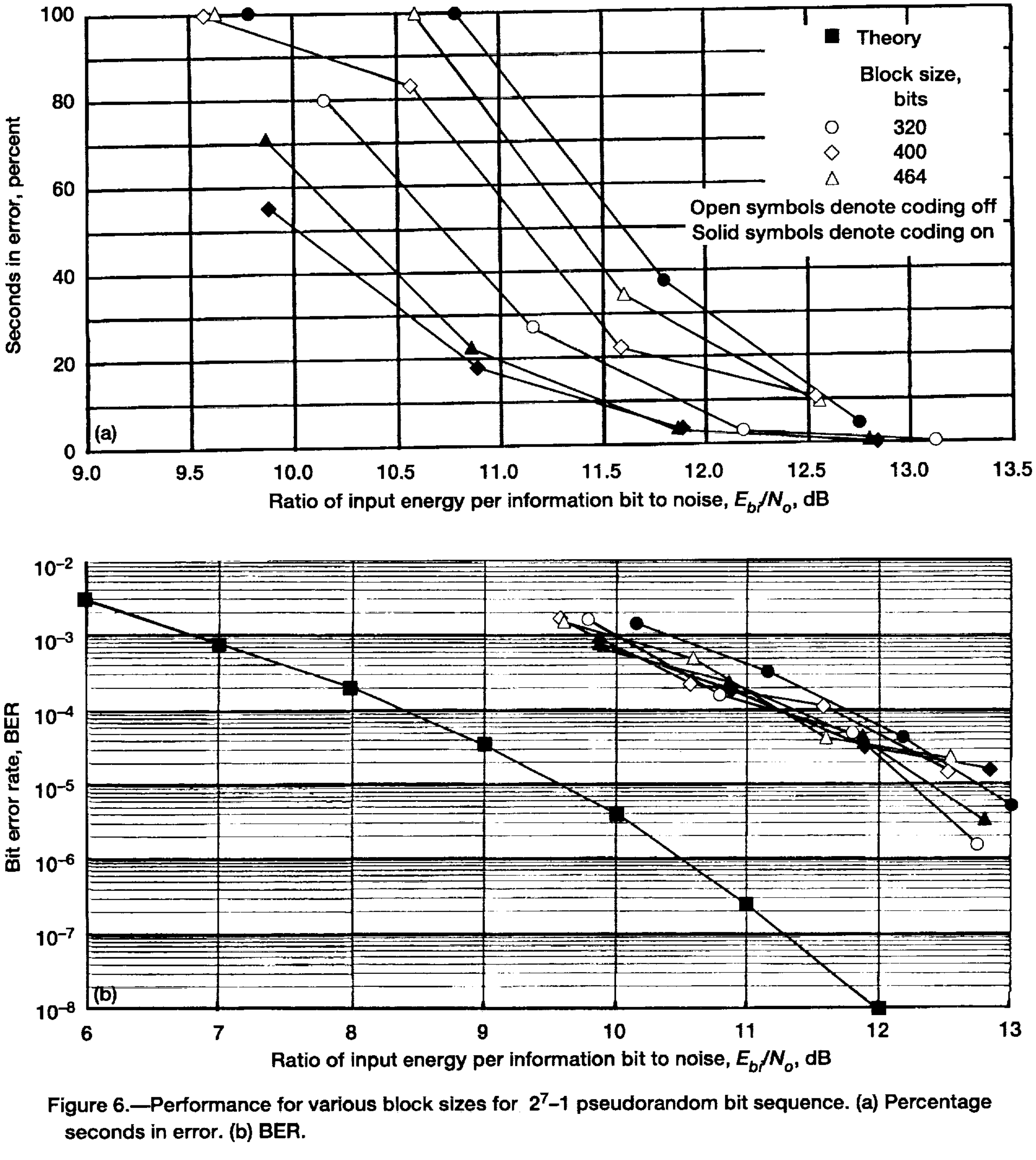

Figure 6.—Performance for various block sizes for 2^7–1 pseudorandom bit sequence. (a) Percentage seconds in error. (b) BER.

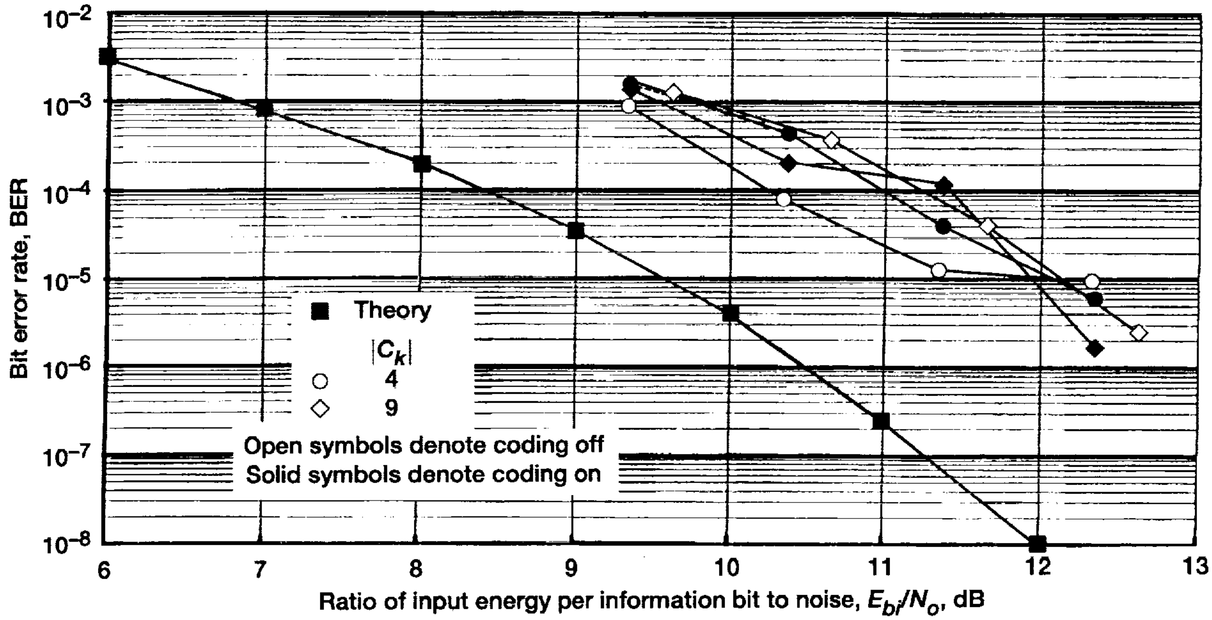

Figure 7.—BER performance for Neuman-Hofman unique words with correlation sidelobes, $|C_k|$, of 4 and 9.

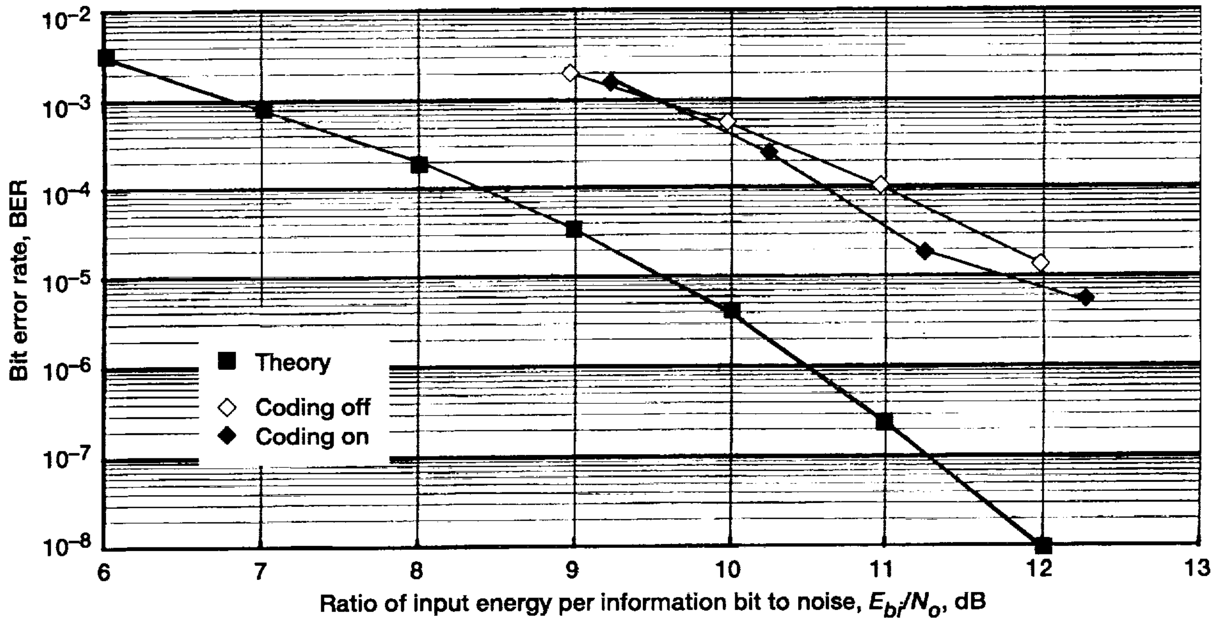

Figure 8.—BER performance for Maury-Styles unique word.

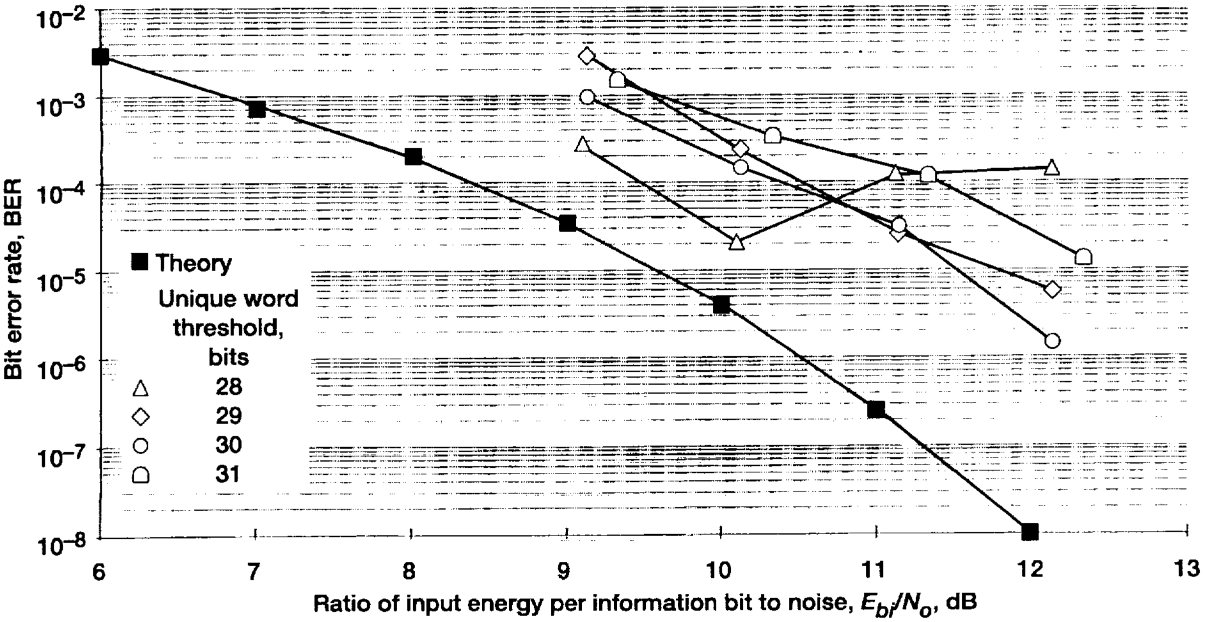

Figure 9.—BER performance for Maury-Styles unique word for various unique word thresholds.

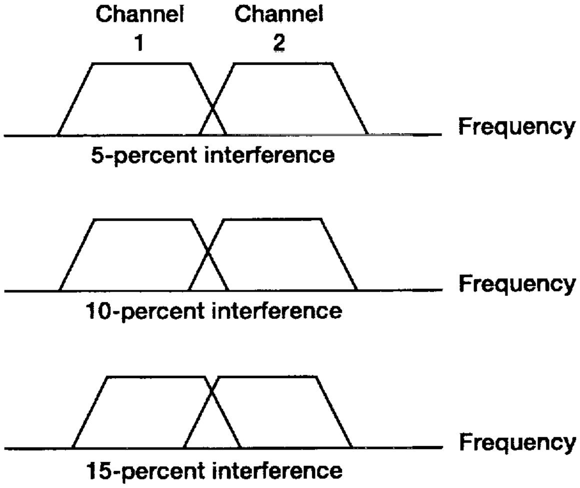

Figure 10.—Effects of adjacent channel interference for low-frequency offset.

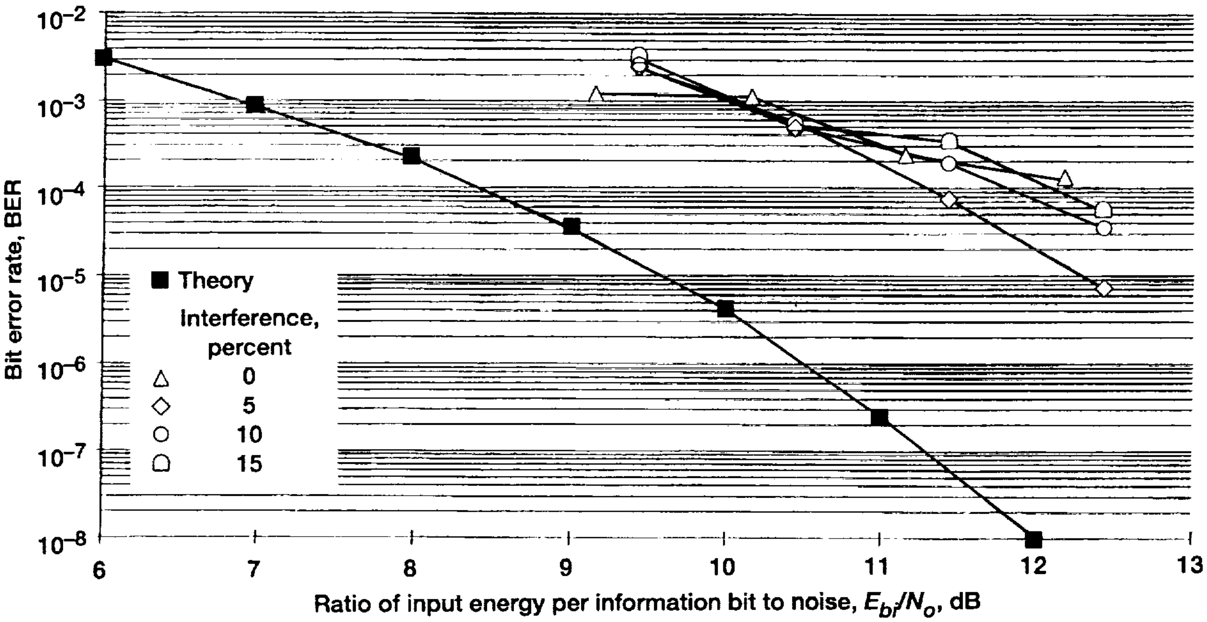

Figure 11.—BER performance for adjacent channel interference for various offsets.

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