4-7-4 Coded Modulation Equipment With Unequal Error Protection

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We have developed a prototype modem in preparation for the mobile satellite communication experiments using the Engineering Test Satellite VIII-type (ETS-VIII). The developed modem uses a technique called multiple block coded modulation, which provides unequal error protection among the data bits to be transmitted. This modem is suited for applications where a part of the total data bits is more sensitive to channel errors and thus needs stronger protection than the other data bits do. The principle and the structure of this prototype modem are described. Computer simulation and laboratory measuring results are presented.

Keywords
Unequal error protection, Multiple block coded modulation, Viterbi decoding, Minimum squared Euclidean distance, Bit error rate

1 Introduction

In a large number of communication applications, the transmitted data bits have different importance in terms of their sensitivity to channel errors. For example, of the 53 bytes of data contained in a single ATM cell, 5 bytes of the data correspond to the cell header, which contains an identifier of the cell, destination information, and other control information. An error occurring in the header might in some cases lead to the loss of the entire cell. Therefore, these 5 bytes are of greater significance than the remaining 48 bytes of data. In this context, unequal error protection (UEP) provides multiple levels of protection to data bits in accordance with their importance. This is realized by imposing a lower bit error rate (BER) on bits of higher significance. Within communication environments in which the SNR (Signal-to-Noise Ratio) constantly varies, as in mobile satellite communications, it can be expected that the application of UEP technology will improve the reliability of communication.

In this paper we discuss a method of providing UEP by using multiple block coded modulation (MBCM) [4]. In an additive white Gaussian noise (AWGN) environment, the minimum squared Euclidean distance (MSED) dominates BER. In MBCM the MSEDs of all data bits are first increased, and then the MSEDs of a part of data bits are further increased. In the following sections, we will first describe the basic principle of MBCM, followed by an illustration of a modem configuration developed therefrom; finally, we compare the results of laboratory measurements of modem performance to the results of computer simulation.

2 Principle

Coded modulation technology was proposed in the late 1970s; including both trellis coded modulation (TCM) [1] and block coded modulation (BCM) [2]. Later, in order to achieve a larger coding gain, multiple trellis coded modulation (MTCM) [3] and MBCM were proposed. In both MTCM and MBCM, the MSED is enlarged by assigning two or more symbols on one branch of the trellis.

Fig.1 illustrates a method of forming a coded bit matrix and the channel symbol generation of a generalized MBCM. Information bits a_i (i = 1, 2, ..., (n − 1)k+n) are read in row by row, and parity check bits c_l (l = 1, 2, ..., k+1) for each row are added in the second row and thereafter. This horizontal row of the matrix is referred to as the “bit level”; there are a total of k+2 bit levels (ℓ_1 to ℓ_{k+2}). In forming channel symbols, k symbols are generated from one vertical column. Bits corresponding to bit levels ℓ_1 and ℓ_2 are used as common bits and assigned as the first and second bits in each of these k symbols. Each one of the k symbols then takes one bit respectively from bit levels ℓ_3 to ℓ_{k+2} as the third bit. Based on this procedure, one vertical column comprises a temporal continuation of k symbols, as shown in Fig.1. When assigning these symbols to signal points in 8-PSK modulation, each bit level corresponds to the intraset distance between signal points.

$$\begin{cases} d_1^2(\ell_1) = 4\times\sin^2(\pi/8) \\ d_2^2(\ell_2) = 2.0 \\ d_3^2(\ell_3) = d_3^2(\ell_4) = \cdots = d_3^2(\ell_{k+2}) = 4.0 \end{cases} \quad (1)$$

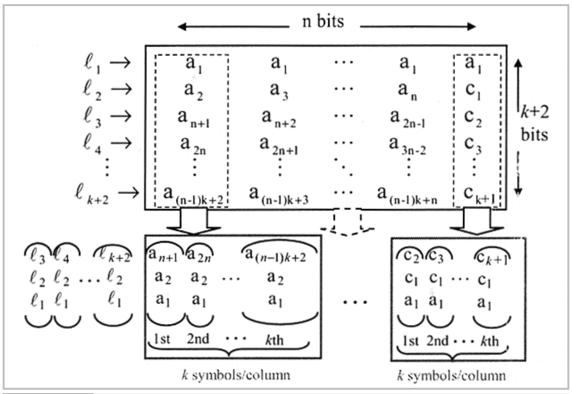

Fig.1 *Method of forming a coded bit matrix and channel symbol generation of MBCM*

On the other hand, when calculating the Hamming distance for each bit level illustrated in Fig.1, because the bits corresponding to levels ℓ_1 and ℓ_2 are used as common bits for the k symbols, the Hamming distance for these two levels respectively thus becomes k-times the Hamming distance of the block code of each level. Therefore, the Hamming distance of each level becomes $\delta_1(\ell_1) = k\times n$, $\delta_2(\ell_2) = k\times 2$, and $\delta_3(\ell_{other})$=2. The MSED of each bit level can be calculated using the above results.

$$\begin{cases} d_E^2(\ell_1) = d_1^2(\ell_1)\times\delta_1(\ell_1) = 4\mathrm{k}\times\mathrm{n}\times\sin^2(\pi/8) \\ d_E^2(\ell_2) = d_2^2(\ell_2)\times\delta_2(\ell_2) = 4\mathrm{k} \\ d_E^2(\ell_3) = d_E^2(\ell_4) = \cdots = d_E^2(\ell_{k+2}) = d_3^2(\ell_3)\times\delta_3(\ell_3) = 8.0 \end{cases} \quad (2)$$

The above formulas show that the MSEDs of levels ℓ_1 and ℓ_2 are linearly proportional to the value of k. Therefore, the MSEDs of levels ℓ_1 and ℓ_2 can be enlarged by making k larger. Since the MSEDs of other levels are fixed at a value of 8.0, they are not affected by the value of k. In order to set the MSED of a level ℓ_1 comparable to or more than the MSED of a level ℓ_2, it is necessary to set the value of the code length n shown in Fig.1 to 7 or more. Table 1 tabulates values of the MSEDs of bit levels ℓ_1 and ℓ_2 for n = 7 and k = 2, 4, and 6. A trade-off occurs as k becomes larger: the transmission rate R_T (the number of information bits per channel symbol) decreases. Transmission rate R_T is also given in Table 1. This rate is calculated by the following formula.

$$R_T = \frac{n-1}{n} + \frac{1}{k} \quad \text{(bits/symbol)} \quad (3)$$

Although the details are omitted here, Viterbi decoding for MBCM of Fig.1 can be performed using an 8-state trellis diagram. However, the branch variable of the trellis changes with the value of k[4].

Table 1 *Relationship between MSEDs of levels ℓ_1 and ℓ_2, transmission rate R_T and k*

	MSED(ℓ_1)	MSED(ℓ_2)	R_T(bits/sym.)
k=2	8.2	8.0	1.36
k=4	16.4	16.0	1.11
k=6	24.6	24.0	1.02

3 Modem configuration

The developed modem consists of three units: a baseband unit, an IF modulation unit, and an IF demodulation unit. The IF modulation unit is used to quadrature-modulate the baseband signal into a 140-MHz IF signal, while the IF demodulation unit plays the opposite role, demodulating the 140-MHz IF signal. The baseband unit, acting as the core of the modem, is explained in more detail below.

Fig.2 shows the configuration of the baseband unit. The input information bits are first separated into three levels according to their significance, with the bits of these respective levels brought into correspondence with the three levels of MBCM: ℓ_1, ℓ_2, and ℓ_{other}. RS (204, 188) coding and a 1/2-rate convolutional coding are respectively applied to these three bit sequences. Next, an MBCM coding operation is performed, and data is mapped to 8-phase PSK signal points using three output bits. To facilitate synchronous operation on the modulation side, the symbol sequence of the 8-phase PSK is subjected to frame formatting, D/A converted (after passing through a roll-off filter), and sent to the IF modulation unit. On the other hand, on the demodulation side, the signal from the IF demodulation unit is A/D converted; subsequently the carrier and clock are recovered after passing through a roll-off filter. Frame synchronization is then established, and Viterbi decoding is performed for MBCM. Finally, Viterbi decoding for convolutional code and decoding for RS (204, 188) are conducted; the demodulated bits of the three levels are thus output. Both of the transceiver low-pass filters are raised cosine filters. A roll-off factor of 0.3 is equally root-distributed between the transmitter and receiver. A Costas loop is also adopted to extract the carrier. Processing of the RS (204, 188) code and the convolutional code can be switched on or off.

The modem has three basic symbol rates: 150 ksps, 600 ksps, and 1,200 ksps. A switch is used to select one of these rates. In addition, in order to perform comparison with other modulation systems, the baseband unit is also inplemented with BPSK, QPSK, 8-PSK, and BCM. For MBCM, parameter k can take values of 2, 4, and 6. Selection from among these systems can be performed using panel selection switches. Table 2 tabulates the information bit rates when the three basic symbol rates are used by each of these schemes. Note that in Table 2, processing of the RS (204, 188) code and the convolutional code was activated (switched on). If convolutional code

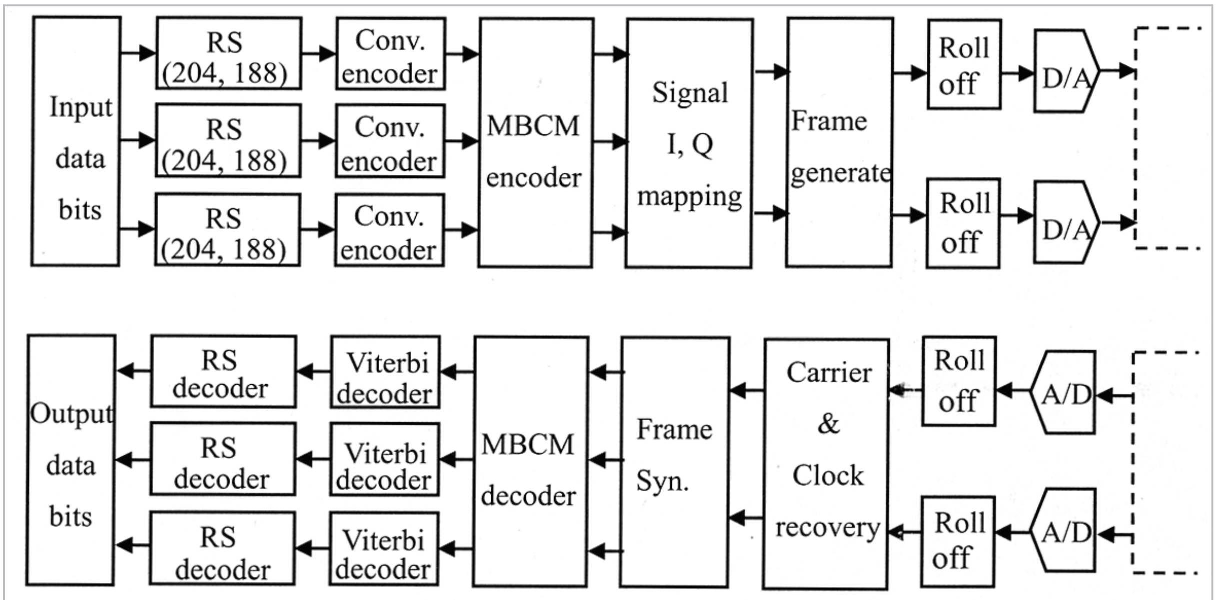

Fig.2 *Block diagram of configuration of baseband unit*

Table 2 *Transmitted information bit rates of various schems for three basic symbol rates (with forward error-correcting code)*

	Transmitted information bit rates (bps)								
	symbol rates = 150 ksps			symbol rates = 600 ksps			symbol rates = 1200 ksps		
	ℓ_1	ℓ_2	ℓ_{other}	ℓ_1	ℓ_2	ℓ_{other}	ℓ_1	ℓ_2	ℓ_{other}
BPSK			65800			263200			526400
QPSK		65800	65800		263200	263200		526400	526400
8-PSK	65800	65800	65800	263200	263200	263200	526400	526400	526400
BCM	9400	56400	65800	37600	225600	263200	75200	451200	526400
MBCM(k=2)	4700	28200	56400	18800	112800	225600	37600	225600	451200
MBCM(k=4)	2350	14100	56400	9400	56400	225600	18800	112800	451200
MBCM(k=6)	1566	9400	56400	6266	37600	225600	12533	75200	451200

processing is switched off, all of the information bit rates shown in Table 2 will be doubled. Fig.3 is a diagram of the connections among the baseband unit, the IF modulation unit, and the IF demodulation unit. The figure also shows the interface characteristics of each connection. This modem will be connected to an MPEG-4 codec via a router; a corresponding interface is installed in the baseband unit.

4 Laboratory measurement results

Laboratory measurements were conducted to investigate the performance of the modem. Fig.4 shows a block diagram of the measurement system employed. Two modems were used (as a transmitter and a receiver, respectively), and the output of the transmitter was connected to a variable attenuator (ATT) to allow for adjustment of the SNR. Next, noise-generator output was combined with the post-

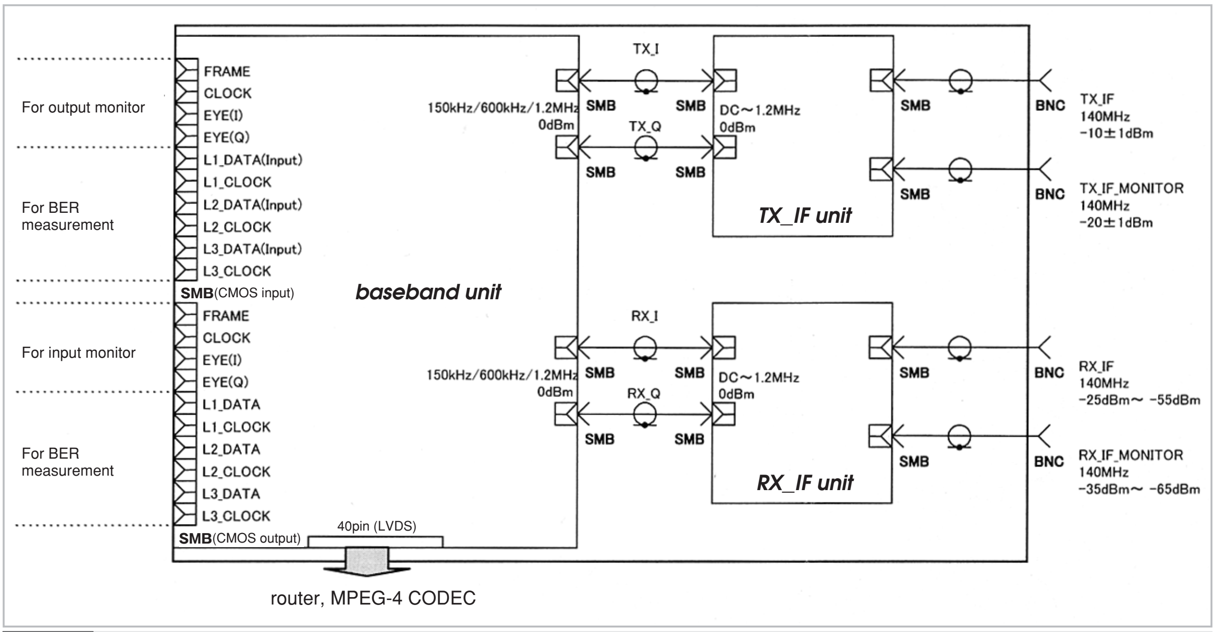

Fig.3 *Connection and interface characteristics between units*

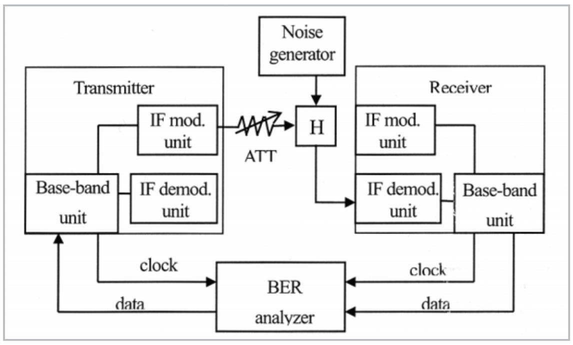

Fig.4 Block diagram of measurement system

ATT signal through hybrid synthesis, with the resultant signal input to the receiver. A BER analyzer was used to measure BER; the analyzer transmitted and received data in synchronization with the modem clock. Sample measurement results are shown below, together with the results of computer simulation for comparison. It should be noted that the forward error-correcting code was off for all of the results shown here.

Fig.5 shows BER corresponding to bit levels ℓ_1, ℓ_2, and ℓ_{other} in the case of MBCM with k = 6. For comparison, the BER performance with BPSK modulation is also shown. The BPSK modulation transmission rate is 1 bit/symbol, whereas the transmission rate in the case of MBCM with k = 6 can be calculated by formula (3), yielding approximately 1.06 bits/symbol. Measurement was conducted for the three basic symbol rates: 150 ksps,

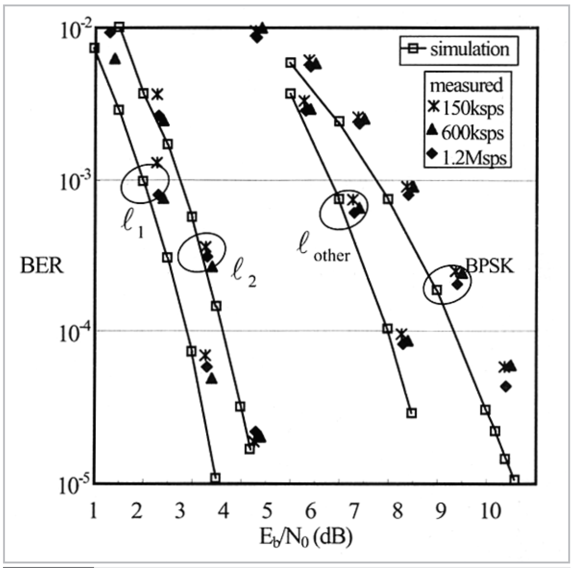

Fig.5 BER of each level with MBCM (k = 6)

600 ksps, and 1,200 ksps; nearly the same BER was obtained for each. Compared with the results of computer simulation, deterioration in measured data is about 0.5 dB or less. MBCM provides lower BERs for all levels because MBCM features larger MSED values than available in BPSK modulation. Moreover, at levels ℓ_1 and ℓ_2, BER was drastically reduced relative to ℓ_{other}.

Next, illustrating the effect of the value of k, BERs of level ℓ_2 when k = 2, 4, and 6 are shown in Fig.6. As these measurement results show, BER lowers as the value of k rises. Similarly, the three basic symbol rates show equivalent BER performance and exhibit excellent agreement with the results of computer simulation.

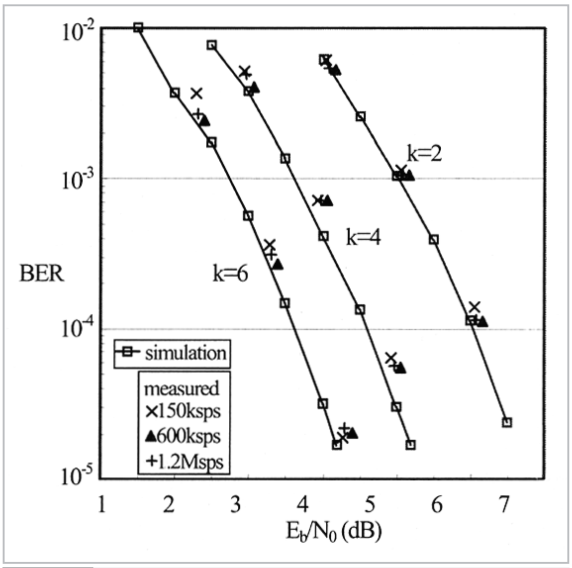

Fig.6 Influence of value of k on BER for level ℓ_2

5 Concluding remarks

This paper describes the terminal modem developed for the mobile satellite communication experiments using the ETS-VIII. This modem features unequal error protection (UEP) based on MBCM technology, with the characteristics of UEP confirmed in laboratory measurements. We are now trying to apply the features of UEP within the modem to MPEG-4 image transmission, and will carry out further related experiments using the ETS-VIII.

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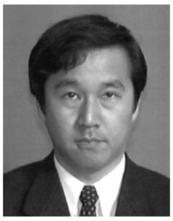

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