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A Spread-Spectrum Modem Using Constant Envelope BPSK for a Mobile Satellite Communications Terminal

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ABSTRACT

This paper describes a 5-kb/s spread-spectrum modem with a 1.275-MHz chip rate for mobile satellite communications. We used a Viterbi decoder with a coding gain of 7.8 dB at a BER of 10^{-5} to decrease the required received power. This reduces the cost of communication services. The spread spectrum technique makes the modem immune to terrestrial radio signals and keeps it from causing interference in terrestrial radio systems.

A class-C power amplifier reduces the modem's power consumption. To avoid nonlinear distortion caused by the amplifier, The envelope of the input signal is kept constant by adding quadrature channel signal to the BPSK signal. To simulate the worst case, we measured the modem's output spectrum using a limiting amplifier instead of the class-C amplifier, and found that 99% of the spectral power was confined to the specified 2.55 MHz bandwidth.

1. INTRODUCTION

Since the lower power spectral density of the spread-spectrum technique reduces interference between satellite and terrestrial communications systems, the technique has the advantage of reduced required received power. This reduces communication cost in satellite communication systems. The coding gain in forward error correction techniques such as in the Viterbi decoder also reduces received power. The service cost of a mobile satellite communication system also depends on the power consumption of the mobile terminal. Although the high efficiency of a class-C amplifier effectively reduces power consumption, the output spectrum of the usual binary phase-shift keyed (BPSK) signal is changed significantly due to nonlinear distortion. To avoid such distortion, the envelope of the input signal must be kept constant. Various constant-envelope BPSK (CE-BPSK) modulation techniques have been proposed [1-3]. When used for mobile satellite communications systems, however, these techniques have the following problems: (1) Remaining envelope variation is about 3 dB due to imperfect suppression, (2) the supplementary signal reducing the envelope variation generates a line spectrum which increases interference with terrestrial communication systems, and (3) interference between the BPSK signal and supplementary signal makes demodulation difficult.

To overcome these problems, we propose an improved CE-BPSK modulation scheme which features: (1) digital signal processing for accurate supplementary signal generation, (2) a polarity inversion switch to remove the line spectrum of the supplementary signal, and (3) a spread-spectrum technique to prevent interference between the supplementary and BPSK signals. We confirmed the improved output spectrum by computer simulation. The measured BER performance and output spectrum of the modem showed little degradation, even though a limiting amplifier with a more nonlinear characteristic was substituted for class-C amplifier.

2. CE-BPSK MODULATION

2.1 Generation of Constant Envelope Signal

Although the high-efficiency of the class-C amplifier reduces power consumption in a mobile satellite communications terminal, this amplifier's highly nonlinear output characteristic requires that the input signal have a constant envelope. We studied modulation in

which a constant-envelope BPSK signal is obtained by adding a supplementary quadrature channel signal. The conventional way of obtaining the constant-envelope signal restricts the supplementary signal to the upper half of the phase-state vector diagram[1], causing an offset in the constellation. Adding a supplementary signal generates a line spectrum which can interfere with terrestrial radio systems. The technique we propose makes positive and negative polarities of the supplementary signal equally probable, so adding the supplementary signal produces no offset or line spectrum.

The conventional circuit for generating the supplementary signal consists of analog circuits which make precise squaring and rooting difficult, requiring the following approximation to be used:

$$Q(t) = \pm(A-I(t)^2)^{1/2} \simeq A-|I(t)| \quad (1)$$

A: Constant,
I(t): BPSK signal
Q(t): Supplementary signal

The envelope of the modulated signal may deviate as much as 3 dB. Digital signal processing generates the supplementary signal our method uses, easily satisfying the following equation:

$$Q(t) = \pm(A-I(t)^2)^{1/2} \quad (2)$$

The block and phase-state vector diagrams of our constant-envelope modulator are shown in Figs. 1 and 2, and the block diagram of our circuit for generating the supplementary signal in Fig. 3. When the spread-spectrum signal is demodulated, the signal is remapped by correlation with the PN code. The supplementary signal can thus be removed in the remapping circuit by generating the supplementary signal with a small cross-correlation to the PN code at the modulator. This makes the CE-BPSK demodulator the same as the conventional BPSK demodulator, simplifying demodulation.

2.2 Polarity Switching

The conventional way of obtaining the constant-envelope signal produces an offset in the constellation and the addition of the supplementary signal generates a line spectrum. To remove the offset, we ensured that positive and negative polarities of the supplementary signal were equally probable. This required polarity switching. Switching the polarity when the supplementary signal amplitude is large varies the transient amplitude from positive to negative, or vice versa. Transient variation of the supplementary signal amplitude causes out-of-band radiation. To avoid such variation, the polarity is switched when the supplementary signal amplitude is smaller than threshold Th.

3. SIMULATION

We used computer simulation to evaluate the performance of our proposed technique. To raise the transmitter power efficiency , we must reduce the power of the supplementary signal. If the rolloff factor decreases, the maximum amplitude of the BPSK signal increases. In our CE-BPSK modulator, the quadrature signal supplements the difference between the maximum amplitude and minimum amplitude of the BPSK signal. Thus, if the rolloff factor decreases, the supplementary signal power increases. The 100% rolloff filter we used for spectrum shaping raised the transmitter's power efficiency, as shown in simulation (Fig. 4). The transmitted power increases 1.7 dB when the 100% rolloff filter is used. Since a class-C amplifier reduces power consumption at least 3 dB, CE-BPSK modulation reduces power consumption by at least 1.3 dB. Using computer simulation we calculated the power spectrum of the CE-BPSK signal after the limiting amplifier (Fig. 5). 99% of the spectral power was confined to the specified 2.55 MHz bandwidth using CE-BPSK modulation. 91% of the spectral power was confined to the same bandwidth using BPSK modulation. Out-of-band radiation performance is improved markedly by adding the supplementary signal to the BPSK signal through a nonlinear amplifier.

In our spread-spectrum modulator, one cycle of the PN code sequence is not inverted when the information is "one," and one cycle of the sequence is inverted when the information is "zero." The PN code sequence modulated by the information is transmitted. At the demodulator, when the cross correlation between the received signal and the PN code is positive, "one" is received and, when it is negative, "zero" is received. Interference signal having no cross correlation to the PN code are removed[4]. However, An interference signals similar to the PN code cannot be removed. In the CE-BPSK demodulator, the received supplementary signal becomes the BPSK interference signal. To estimate degradation due to the interference signal, we calculated the cross correlation between supplementary signal and the PN code (Fig. 6). Because the cross correlation is negligible, we

assume that the degradation in BER performance due to interference is negligible.

4. MODEM

Table 1 lists the system parameters of the CE-BPSK spread-spectrum modem, which operates at a 1.275-MHz chip rate and a 70-MHz IF frequency. The information rate is 4.8 kb/s without forward error correction and 2.4 kb/s with it. Adding unique words increases the data rate of the modem to 5 kb/s. We used direct sequence modulation to spread the spectrum. Because the PN code length is 255, the process gain is 24 dB. The lower spectral power density of the spread-spectrum technique reduces interference with terrestrial radio systems, and the spread-spectrum demodulator reduces interference from terrestrial radio systems[4].

4.1 Modulator

The modulator (Fig. 7) encodes the forward error correction code, inserts unique words into the transmitted data stream, and performs spread spectrum and CE-BPSK modulation. We used digital signal processing to generate the supplementary signal and to shape the BPSK signal spectrum. The CE-BPSK signal has a small envelope variation.

4.2 Demodulator

The demodulator (Fig. 8) remaps the spread spectrum signal, removes the supplementary signal, demodulates the BPSK signal, and decodes the forward error correction code. The BPSK signal can be demodulated after analog-to-digital conversion by digital signal processing. A Costas loop was implemented in software using a digital signal processor.

4.3 Forward Error Correction

The high-coding gain of the Viterbi decoder enables forward error correction convolutional encoding to be used. We selected a code rate of 1/2. The Viterbi decoder uses an 8-level soft decision and a 7-bit constraint length. Its path memory circuit uses path tracing, so the single LSI decoder is compact[5].

5. RESULTS OF EXPERIMENT

5.1 Output Spectrum

To verify the performance of CE-BPSK modulation, we fed the CE-BPSK signal through a limiting nonlinear amplifier instead of a class-C amplifier, (Figs. 9 and 10). Signal spectra at the modulator output are shown Figs. 11 and 12 for comparison. When BPSK modulation was used with the limiting amplifier, the sidelobe signal power increased. When CE-BPSK modulation was used with the limiting amplifier, the percentage of the bandwidth signal power (2.55 MHz) was 99% of the total signal power, the same as the value obtained with the linear amplifier. These results show that out-of-band radiation is markedly improved by adding the supplementary signal to the BPSK-modulated signal when a nonlinear amplifier is used.

5.2 BER Performance

The BER versus carrier-to-noise-density ratio (C/N_0) was measured with IF back-to-back connection for both the linear and limiting amplifiers (Fig. 13). The BERs shown are with and without forward error correction and supplementary signal. When the linear amplifier was used, the difference in BER performance between CE-BPSK and conventional BPSK was 1.8 dB, almost the same as the contribution of the supplementary signal (1.7 dB). Thus, interference between the BPSK and supplementary signals is negligible. The coding gain with forward error correction was 7.8 dB at a BER of 10^{-5}, almost the same as the 8-dB theoretical value. When the limiting amplifier was used, the modem has almost the same BER performance as that using the linear amplifier.

6. CONCLUSION

We developed a spread-spectrum modem using CE-BPSK modulation for mobile satellite communications. The constant envelope signal enables a class-C amplifier to be used to ensure decreased power consumption and increased transmission power. The spread-spectrum modem reduces interference with terrestrial radio systems. We verified the effectiveness of our technique for spread spectrum communication by measuring the modem's output spectrum and BER performance. Our results show this modem to be promising for use in mobile satellite communications.

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Premodulation Filtering," Microwave Journal, Vol. 21 January 1978.
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3) **E. Dickerson** *et al.*, "Generation of Constant Envelope Signals," IEEE Trans., COM-30, no. 12, December 1982.
4) **R.C. Dixon**, "Spread Spectrum Systems", New York, John Wiley, 1976.
5) **A. Yamashita** *et al.*, "A New Path Memory for Viterbi Decoders," Globecom'87, Tokyo, Japan, 1987, pp. 2076-2079.

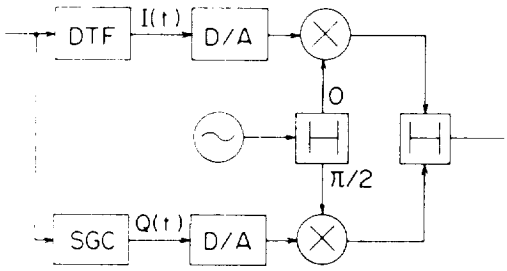


Fig. 1 Modified constant-envelope modulator

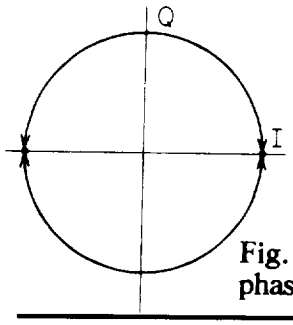


Fig. 2 Modified CE modulator phase-state vector diagram

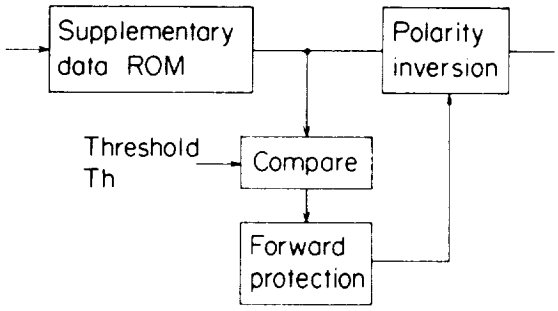


Fig. 3 Supplementary signal generation circuit

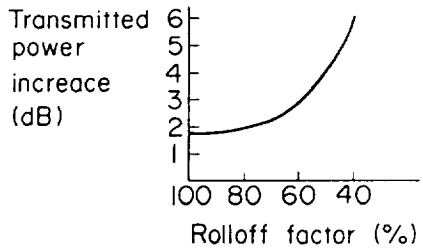


Fig. 4 Relation between increased transmitted power and rolloff factor

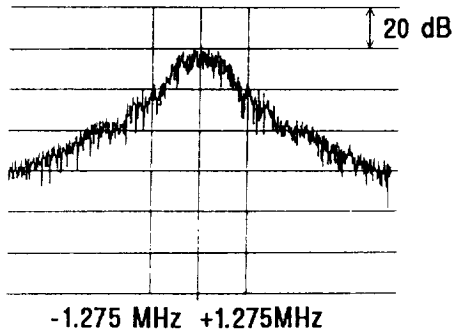


Fig. 5 CE-BPSK signal spectrum (simulated)

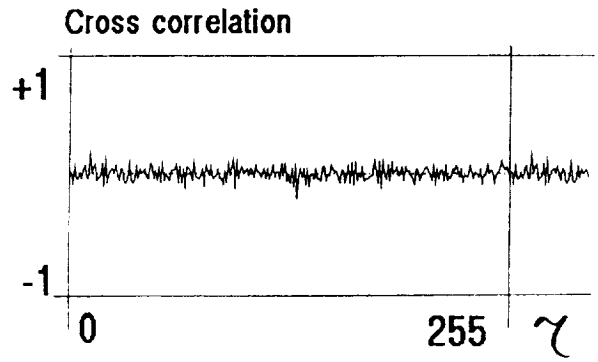
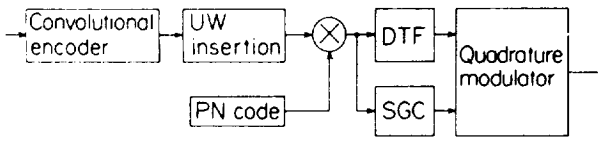


Fig. 6 Cross correlation between supplementary signal and PN code

Table 1 Modem parameters

Modulation:	Spread-spectrum with CE-BPSK
Initial synchronization:	Digital matched filter
Tracking:	Delay locked loop
IF frequency:	70 MHz
Data rate:	4.8 kb/s without FEC
	2.4 kb/s with FEC
Modem bit rate:	5 kb/s
Chip rate:	1.275 Mb/s
Process gain:	24 dB
Forward error correction:	R = 1/2, K = 7 soft-decision Viterbi decoder
Carrier-to-noise density ratio:	40 dB·Hz to 60 dB·Hz

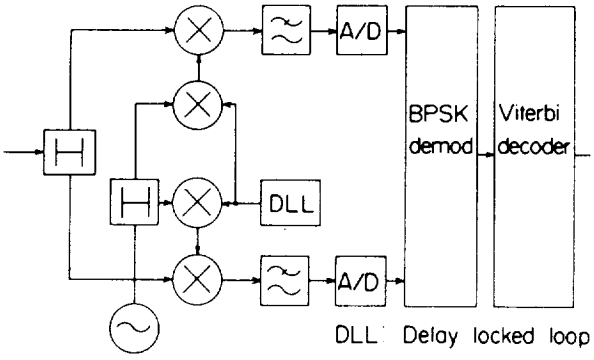


UW: Unique words
DTF: Digital transversal filter
SGC: Supplementary signal generation circuit

Fig. 7 Modulator

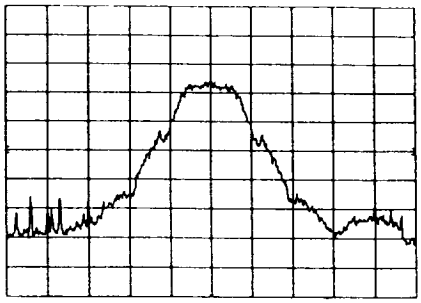
10 dB/div
1 MHz/div
Resolution
BW: 30 kHz

Fig. 11 BPSK signal spectrum at modulator output



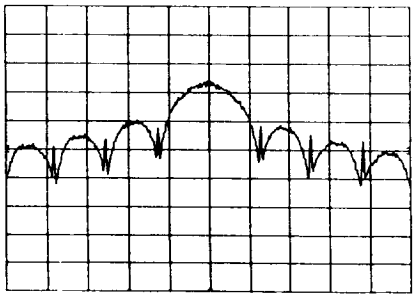
DLL: Delay locked loop

Fig. 8 Demodulator



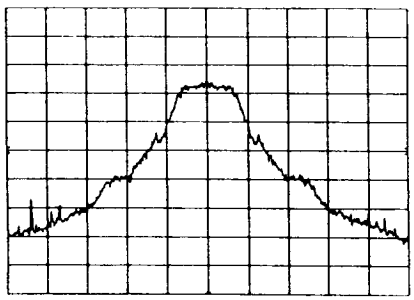
10 dB/div
1 MHz/div
Resolution
BW: 30 kHz

Fig. 12 CE-BPSK signal spectrum at modulator output



10 dB/div
1 MHz/div
Resolution
BW: 30 kHz

Fig. 9 BPSK signal spectrum with limiting amplifier



10 dB/div
1 MHz/div
Resolution
BW: 30 kHz

Fig. 10 CE-BPSK signal spectrum with limiting amplifier

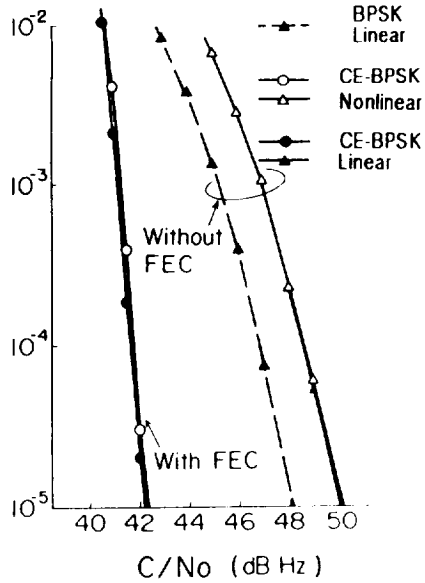


Fig. 13 BER performance