Spread Spectrum Mobile Communication Experiment Using ETS-V Satellite

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ABSTRACT

The spread spectrum technique is attractive for application to mobile satellite communications, because of its random access capability, immunity to inter-system interference and robustness to overloading. A novel direct sequence spread spectrum communication equipment is developed for land mobile satellite applications. The equipment is developed based on a matched filter technique to improve the initial acquisition performance. The data rate is 2.4kbps and the PN clock rate is 2.4552MHz. This equipment also has a function of measuring the multipath delay profile of land mobile satellite channel, making use of a correlation property of a PN code. This paper gives an outline of the equipment and the field test results with ETS-V satellite.

INTRODUCTION

The first generation of land mobile satellite communications systems will be introduced by using analog ACSSB and/or 4.8kbps digital modulation. The spread spectrum technique is also attractive for application to satellite communications, because of its random access capability, immunity to the interference with other systems and robustness to overloading of transponders. There are some articles that treat comparisons among FDMA, TDMA and SSMA systems [1][2]. However, further discussions, based on the real land mobile satellite channel, are needed.

Recently, Communications Research Laboratory has developed a novel direct sequence spread spectrum communication equipment for land mobile satellite applications, and conducted field tests with the ETS-V satellite [3] in suburban areas. The design objectives are to shorten the initial acquisition time and to keep a good performance in fading conditions. To meet these objectives, a coherent matched filter (CMF) technique [4] in which digital matched filters are employed to make code acquisition, AFC and coherent detection of data, is used in the equipment. This equipment can also operate as a multipath measurement system making use of a correlation property of a spreading PN code. This paper gives an outline of the equipment used and the test results.

PRINCIPLES OF COHERENT MATCHED FILTER TECHNIQUE

In order to extract the desired information bit stream from a matched filter (MF) output directly, an RF signal should be down-converted to baseband by using the recovered carrier signal. However, the carrier to noise power ratio at the input to the MF is generally very low. The coherent matched filter (CMF) technique makes possible the carrier recovery from the received low C/N SS signals. The CMF circuit is shown in Fig. 1. The principle of the carrier recovery circuit in Fig. 1 is based on that of a Costas loop. The special feature of this technique is that correlators are inserted into both the I and Q arm filters of the Costas loop.

The transmitted signal can be expressed as

$$S(t)=I(T_f)PN(t)\cos(\omega t+\psi(t)), \quad (1)$$

where, $I(T_f)=\pm 1$: information signal,
T_f : PN frame rate= data rate,
$PN(t)=\pm 1$: PN sequence,
ω : carrier angular frequency,
$\psi(t)$: carrier phase.

At the receiving side, S(t) is received and down-converted by using local carriers which are orthogonal each other. These local carriers are expressed as

$$S_i(t)=\cos\omega t, \quad (2)$$
$$S_q(t)=\sin\omega t. \quad (3)$$

By using eqs. (1),(2) and (3), the baseband signals in the I and Q arms are obtained as follows,

$$B_i(t)=(1/2)I(T_f)PN(t)\cos\psi(t), \quad (4)$$
$$B_q(t)=(1/2)I(T_f)PN(t)\sin\psi(t). \quad (5)$$

Then, $B_i(t)$ and $B_q(t)$ are sampled with the PN clock period and put into the correlators. When $\psi(t)$ changes gradually over a long period, as compared with the length of the PN sequence, it can be assumed that $\psi(t)$ is a constant ψ during one frame of the PN sequence. As a result, the correlator outputs are given as

$$C_i(m)=(1/2)R(m)\cos\psi , \quad (6)$$
$$C_q(m)=(1/2)R(m)\sin \psi , \quad (7)$$

where $R(m)=\sum_{k=0}^{N-1} PN(k)PN(m+k)I(m+k)$, (8)

$m=[t/T]$,
[ ] : Gauss bracket,
T : PN chip rate,
N : length of PN sequence.

Eq. (8) is the cross-correlation between the received PN sequence and the reference PN sequence. Since both PN sequences are the same, R(m)is the autocorrelation function of the PN sequence. The amplitude of the autocorrelation peak R(m), equals N at $m=nN$ ($n=0, 1, 2, \ldots$) and $R(m)=1/N$ at $m\neq nN$. In the same manner as for the Costas loop, an error signal is generated at $m=nN$ by multiplying C_i and C_q in eqs. (6) and (7) resulting in

$$C(nN)=-(1/8)I^2(nN)R^2(0)\sin(2\psi), \quad (9)$$

where $R(0)=R(nN)$ is the autocorrelation peak.

Since $I^2(nN)$ and $R^2(0)$ are positive and constant, eq. (9) is a function of ψ only. This phase error signal is generated once per PN frame, and controls the VCO which generates the local carrier. Consequently, the carrier recovery and coherent detection of the data can be accomplished.

OUTLINE OF SS EQUIPMENT

The SS equipment was developed based on the CMF technique, using 8bit digital correlators. Major specifications and a block diagram of the equipment are shown in Table 1 and Fig.2.

An antenna system is composed of two micro-strip patches excited in a higher mode and two patches used separately for transmitting and receiving. Each antenna has an ominidirectional beam. A linear amplifier is used for transmitting to avoid any broadening effect of the filtered BPSK spectrum. A Linear Predictive Coding (LPC) vocoder of 2.4kbps is installed as voice codec. The voice data is spread with a PN sequence of length 1023 and then modulates the carrier signal by BPSK. The spectrum is band limited to 3MHz, which corresponds to the bandwidth of the ETS-V transponder. A Unique Word (UW) of 31bits PN sequence is used instead of data when the initial acquisition is performed.

In the receiver, AFC,synchronization with the spreading PN code and coherent demodulation of the data can be achieved with the CMF technique. The received signal is down-converted into I and Q channels and digitized to 8bits at a rate of twice the chip rate. The digitized signals are then processed by digital correlators of length of 2046, twice the code length. The matched pulse appears every 2046 cycles of the clock at the correlator outputs and the data clock of 2.4kHz is recovered by detecting peaks of the matched pulse train. The product of matched pulses in both I and Q ch. has the information on phase error of the local carrier as mentioned in the previous section. The coherent detection is achieved using this error signal as in a Costas loop receiver.

The initial acquisition and AFC are accomplished as follows. There are two stages of frequency search modes during the initial acquisition, the coarse search mode and the fine search mode. In the corse search mode, the frequency slot where the correlation peak is maximum is determined by sweeping the local carrier in 1kHz steps from -10kHz to +10kHz. The correlation peak is detected by finding the maximum after recursive integration over 32 PN frames. After finding the frequency slot, the fine search mode is started at that slot. In the fine search mode, the local carrier is swept by 30Hz steps within a ±510Hz bandwidth. The sweep is stopped when the carrier recovery loop is locked to the received carrier and the UW is successfully detected. After initial acquisition has been accomplished, frequency tracking is performed by the carrier recovery loop. When the frequency drift accumulates, the local carrier frequency is shifted.

This equipment can be used as a multipath measuring receiver as well as a communication terminal. When the base station transmits the spreading PN signal without any information data, the correlator outputs of the matched filter are time correlation functions between the received PN signal which contains multipath components and the reference PN signal. As the autocorrelation function of the PN signal exhibits a peak at zero time shift and at multiple of PN length N, and is nearly zero everywhere else, this correlator output corresponds to the multipath delay profile, i.e. impulse response of the channel. Fig.3 shows the multipath measuring adapter. Recursive integrators are used to improve the S/N of the outputs.

EXPERIMENTAL RESULTS

Loop-Back Test

Figs.4(a)(b)(c) show the loop-back test results of initial acquisition time performance at transmitting frequency offsets of -8kHz, 0 and +8kHz, respectively. The initial acquisition time is defined as the time interval between when the SS signal transmission is started and when the UW is detected at the receiver. In these figures, the bars indicate the minima and the maxima and the dots indicate the average over 30 trials. The mean acquisition times are 900ms at f=-8kHz, 800ms at f=0 and 700ms at f=+8kHz, respectively, when C/No is greater than 44dBHz. These values correspond to the theoretical prediction of frequency sweep time. Therefore it can be seen that code acquisition and carrier recovery are accomplished in a very short time compared to frequency sweep. The lowest C/No where the initial acquisition succeeded is 36dBHz, the synchronization is lost within a few seconds at levels below 38dBHz, however.

Fig.5 shows the bit error performance for loop-back tests in a Gaussian noise environment. The solid curve indicates the theoretical BPSK performance with differential encoding and coherent detection. The experimental result shows good agreement with the theoretical curve: the degradation is only 0.7dB. The degradation due to the limited quantizer levels in the matched filter was considered in a computer simulation. From our simulation, a four bit quantizer is sufficient for the case of a white Gaussian noise channel. The dotted line indicates the experimental results with only a 1bit quantized correlator, which was developed previously [4]. The great advantage of using multi-bit quantized correlators can be seen.

Field Tests

The field test was performed with the ETS-V satellite (150° E). Table 2 shows an example of the link budget. The base earth station transmitted both the SS signal and a CW carrier for simultaneously measuring C/No. The equipment installed in a measuring van received both signals. The elevation angle to the ETS-V is around 47 degrees. In order to evaluate basic performance, there was no interfering signal other than the desired SS and CW signals. The frequency separation between the SS and CW signals was 4.5MHz. During the experiment the main obstacles that caused fading or shadowing were roadside trees and utility poles. Data such as signal level, data error pattern, state of synchronization and running conditions were recorded in a data recorder.

Fig. 6 shows the cumulative time distribution of the received signal level. The dotted line indicates the theoretical Rician statistics with K, the ratio of direct component power to diffused component power, equals 12dB, and agrees well with the measured level above 10% of time. The received signal level below 10% of time does not exhibit Rician statistics and corresponds to shadowing by obstacles. Fig. 7 shows the relation between BER and C/No, averaged over 20 seconds. The solid line indicates the theoretical curve for BPSK in a Rician fading channel with K=12dB, which matches the measured cumulative distribution of the received signal level in Fig. 6. There are some points with higher BER of around 0.1 at low C/No condition. This is due to erroneous data being output during the sync loss condition caused by shadowing by obstacles. The BER performance agrees well with that of BPSK with Rician fading statistics, and the spreading of the spectrum to 3MHz has not affected the BER performance in this experiment.

CONCLUSION

The outline of the spread spectrum communication equipment developed was briefly discussed. The fundamental performances such as initial acquisition time and bit error rate were shown to be acceptable. The field test experiments were conducted in a suburban area with the ETS-V satellite. The BER performance in the field tests corresponded to that of non-SS BPSK on a Rician fading channel. However, further data collection must be needed in urban, suburban and rural areas to evaluate the effects of fading and multipath. The results of the multipath measurement using this equipment will be reported near future.

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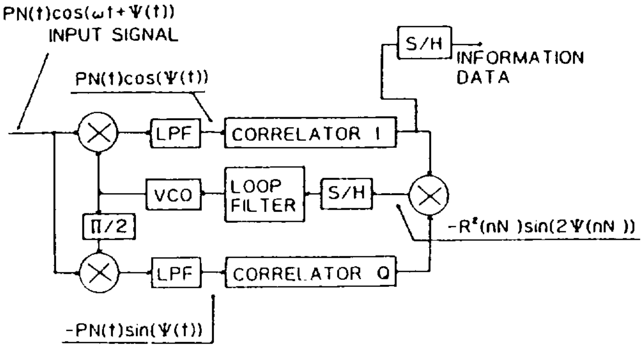


Fig. 1. Principle of CMF loop

Table 1. Major specification of SS equipment

Antenna	Higher Mode Microstrip Patch, 6dBi
RF Frequency	1648.5MHz(Tx) / 1546.5MHz(Rx)
HPA	20W Linear
CODEC	LPC Vocoder
Data Rate	2.4kbps
PN Code	M-sequence, Length 1023
PN Chip Rate	2.4552MHz
Modulation	BPSK, Differential Encoding
Demodulation	CMF, Coherent Detection
Matched Filter	8bits Digital Correlator, 2046stages
AFC Range	±10kHz

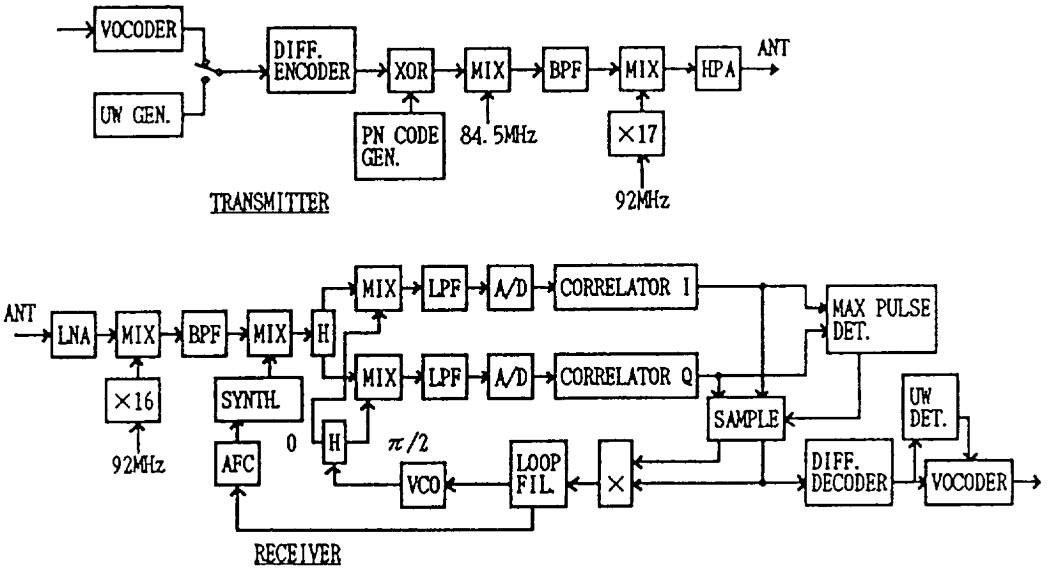


Fig. 2. Block diagram of SS equipment

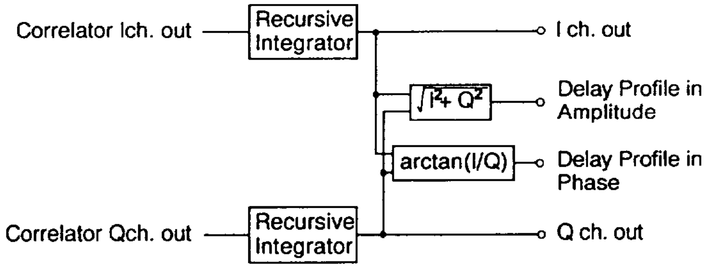
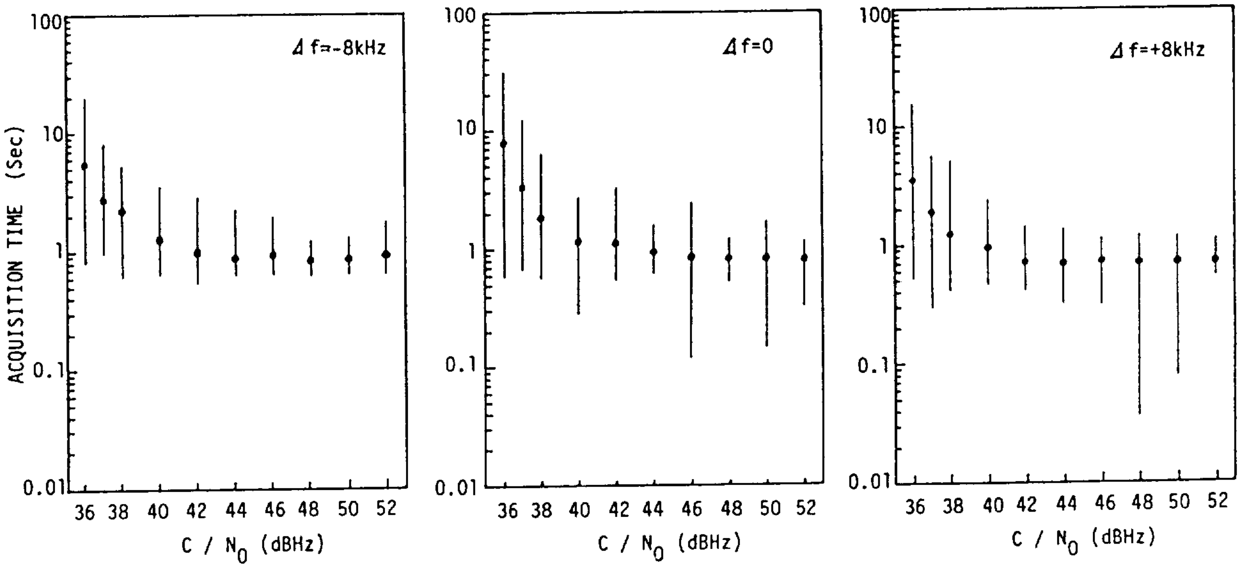
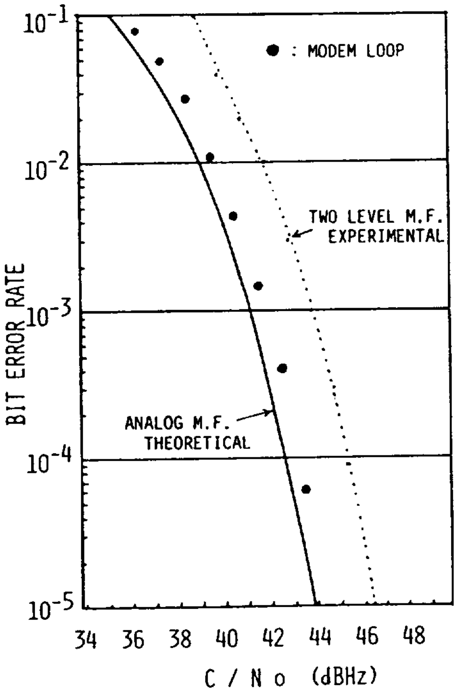


Fig. 3. Block diagram of multipath measurement adapter



(a) Frequency offset -8kHz (b) Frequency offset 0 (c) Frequency offset +8kHz

Fig. 4. Initial acquisition time performance in a loop-back test



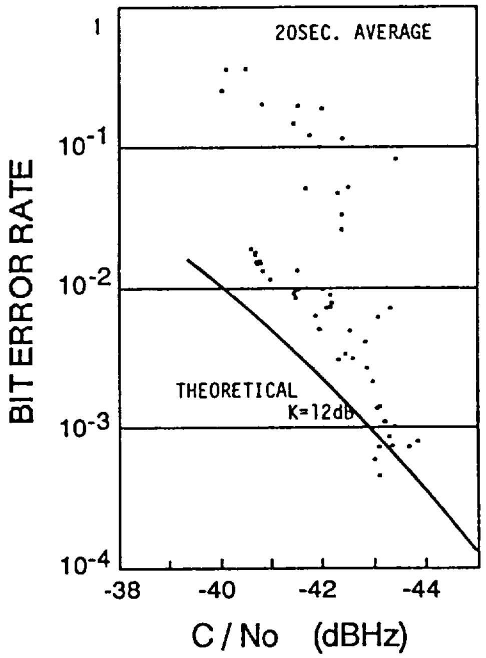


Fig. 5. Bit error rate performance in a loop-back test

Fig. 7. Bit error rate performance in the field test

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