Performance Evaluation of a Mobile Satellite System Modem using an ALE Method

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Abstract

This paper presents experimental performance of a newly designed demodulation concept. This concept applies an Adaptive Line Enhancer (ALE) to a carrier recovery circuit, which makes pull-in time significantly shorter in noisy and large carrier offset conditions. This new demodulation concept has actually been developed as an INMARSAT standard-C modem, and has been evaluated. On a performance evaluation, 50 symbol pull-in time is confirmed under 4dB Eb/No condition.

1 Introduction

Mobile Satellite Communications systems (MSS) have a lot of special characteristics especially in the demodulation field. First, received carrier frequency ambiguity, relative to symbol rate,f_b, becomes very large for low bit rate communications system such as MSAT or INMARSAT. Secondly, time variant channel characteristics, such as multipath fading and shadowing, cause signal amplitude and phase variations and signal dropouts. Thirdly, there are frequency change, caused by mobile acceleration or slowdown and oscilator instability. Therefore, in addition to low Eb/No operation, to maintain its carrier synchronization in the above mentioned conditions, a new carrier recovery circuit is required.

Considering INMARSAT standard-C specifications, the modem has to operate under 4dB or lower Eb/No, large carrier frequency offset (±2kHz), larger than signal baud rate (1200bps), 65Hz/sec carrier frequency change rate, and 7dB C/M deep multipath fading environment.

Generally, a Phase Locked Loop (PLL) is used as a carrier phase synchronizer. In low bit rate communications, however, pull-in and robust performance for a PLL demodulator becomes poor with low Eb/No. Therefore, a new coherent demodulation method, superior than conventional, is anticipated.

This paper presents a new coherent demodulation concept, referred to as an Adaptive Carrier Estimation DEMOdulator (ACE-DEMO)[1]. The ACE-DEMO makes pull-in time significantly shorter and has a wide pull-in range. This paper reports developed hardware performance, operating to INMARSAT standard-C specifications.

2 Carrier Recovery using ALE

2.1 ACE-DEMO Concept Figure 1 shows a proposed carrier recovery blockdiagram of ACE-DEMO[1]. The received M-PSK signal is converted to base band complex signal, $r(t)$, by a fixed frequency oscillator. Then the signal is changed to a time discrete signal, $r(i)$, by a sampler whose interval is equal to a signal baud interval (T_b). Received signal components are Additive White Gaussian Noise (AWGN) and modulation signal, whose center frequency shifts from nominal value by a carrier frequency offset value, ω. Its spectrum is shown at 1 in Fig.1. In order to extract the carrier signal, received complex signal, $r(i)$, is converted to frequency-multiplied complex signal, $x(i)$ by a multiplier. Its operation removes the modulation signal component from signal $r(i)$. Signal, $x(i)$ spectrum, as shown at 2 in Fig.1, includes a line spectrum located at the frequency of M times carrier frequency offset value, ω_0.

An ALE is a kind of adaptively tuned, high Q, narrow BPF, which enhances the line spectrum in the AWGN. Therefore, AWGN is suppressed at its output signal, $y(i)$. Its spectrum is shown at 3 in Fig.1. To recover the original carrier signal, $z(i)$, $y(i)$ is frequency-divided to $1/M$ by a frequency divider. The $z(i)$ spectrum is shown at 4 in Fig.1.

In the multiplier, received signal, $r(i)$, and complex conjugate signal of recovered carrier signal are multiplied. Finally, demodulated PSK signal, $s(i)$, is obtained.

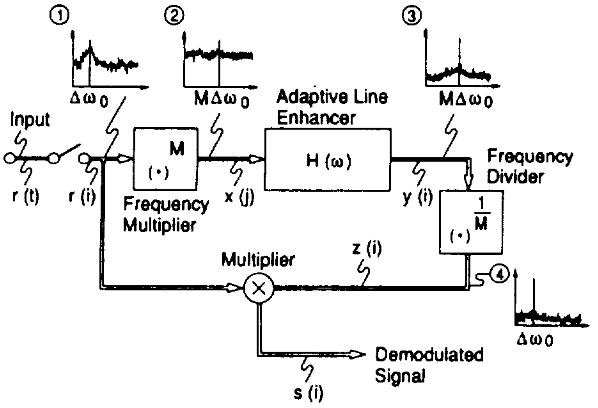

Fig. 1 ACE-DEMO Functional Blockdiagram

2.2 Adaptive Line Enhancer The ALE has developed for an adaptive noise canceler which operates as a self-tuning filter[2]. Figure 2 shows the ALE blockdiagram. the ALE consists of a delay operator, a Finite Impulse Response (FIR) filter, an adder, an adaptation constant multiplier and a coefficients controller. The delay operator, whose delay is set to T_d ($=mT_b$; 'm' is an integer number), accomplishes decorrelation between signal $x(i)$ and $y(i)$, except for the carrier signal component.

The FIR filter, a transversal filter, has L coefficients ($c_1 - c_L$) and the output signal $y(i)$ is expressed as

$$y(i) = C^T X_i, \tag{1}$$

where $C = [c_1, c_2, ...c_L]^T$; coefficient vector,
$X_i = [x(i-T_d), x(i-1-T_d), ...x(i-L-T_d)]^T$,
A^T is a transpose of vector A

Error signal, $e(i)$, derived from the difference between $x(i)$ and $y(i)$, is

$$e(i) = x(i) - y(i). \tag{2}$$

Coefficient vector C is controlled so that the mean value of $e(i)X_i$ may maintain zero. Then, the ALE becomes a narrow BPF which enhances the carrier signal, multiplied M.

There are many algorithms for controlling the coefficient. In this paper, Least Mean Square (LMS) algorithm, which minimizes a mean square error for $e(i)X_i$, is used. In this algorithm, the coefficient vector is controlled in the following manner.

$$C_i = C_{i-1} - \mu e(i) X_i^*, \tag{3}$$

where μ is the adaptation constant and C_i is $i - th$ coefficient vector.

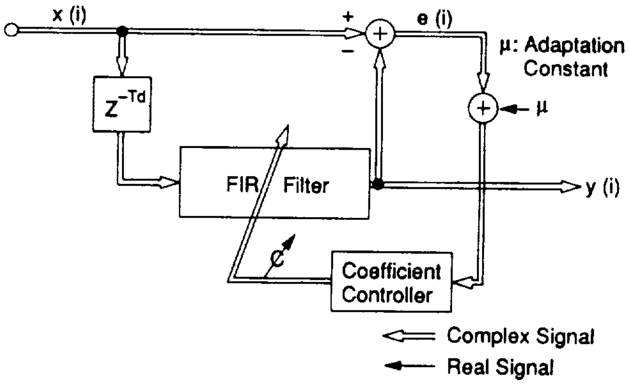

Fig. 2 ALE Blockdiagram

2.3 Pull-in Analysis In the previous analysis[1], ACE-DEMO pull-in equation is expressed as follows,

$$i_{ACE} = -0.3N_x/N_{req} log_e(0.17N_{req}/N_x). \tag{4}$$

$$L = 1.2N_x/N_{req} \tag{5}$$

$$\mu_o = 1 \tag{6}$$

where i_{ACE} is a number of symbols for pull-in,
L is a number of taps for the ALE[2],
μ_o is a normalized adaptation constant[1][2],
N_x is input noise power to the ALE
and N_{req} is required output noise power.

Pull-in symbol, i_{ACE}, is evaluated quantitatively and compared with that of conventional PLL-DEMO. Figure 3 shows a pull-in characteristics comparison between ACE-DEMO and PLL-DEMO[1]. In the comparison, each phase jitter is equally set to 0.16[rad], at 0dB Eb/No condition. In the figure, the PLL rapidly increases the pull-in symbol by 2nd power of carrier frequency offset, ω. Even if there is no carrier frequency offset, non-linear characteristics for the PLL phase detector makes acquisition longer, and it is observed that the PLL pull-in symbol is about three times longer than that of the ACE-DEMO. ACE-DEMO has constant pull-in symbol. Its pull-in frequency range, F_{pir}, is,

$$F_{pir} = \pm f_b/2M \qquad (7)$$

where f_b is signal baud rate.

Therefore, the ACE-DEMO realizes both wide pull-in range and short pull-in time simultaneously.

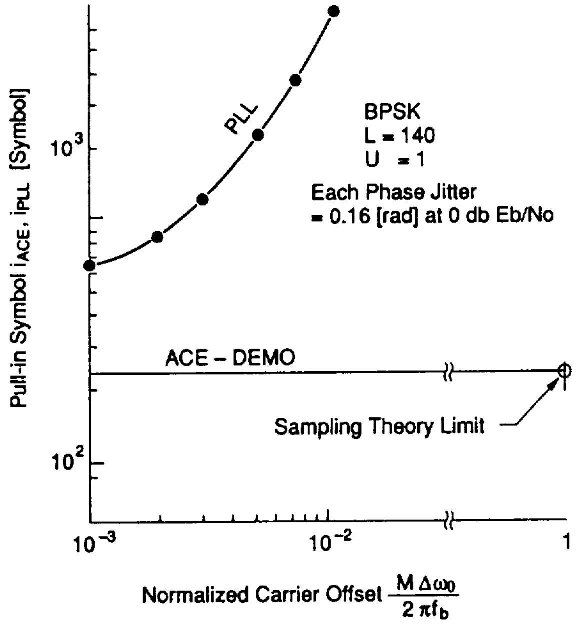

Fig. 3 Pull-in Range Comparison Between PLL and ACE - DEMO

3 Hardware Design

A demodulator using the ALE method has been developed for the INMARSAT standard-C (STD-C) coast earth station system. Table 1 and Figure 4 show STD-C specifications and blockdiagram, respectively. By substituting f_b=1200Hz and M=2 into Eq.(7), ±300Hz pull-in range for ACE-DEMO is derived. Since the carrier frequency offset value ±2kHz as shown in Tablel exceeds this pull-in range limit, a rough carrier frequency offset estimation is necessary. This estimation is carried out by the upper block of Fig 4, which includes a *filterbank* to improve the S/N ratio, a *frequency-multiplier* to remove the modulation component, a *FFT*, and a *max power detector* in which the carrier frequency offset can be detected as a single peak. The clock timming is estimated by the middle block, include a *LPF*(low pass filter) to extract the clock signal component and a *correlator* to calculate the clock phase error[3].

Input signal is first frequency-shifted by the estimated carrier frequency offset. This frequency-shifted signal is filtered by a *I&D* (Integrate and Dump) *filter* according to the estimated clock timming and fed into the *ACE-DEMO*.

Table 1 STD-C specification

moduration ; unfiltered BPSK
symbol rate ; 1200baud or 600baud
carrier frequency uncertainty ; ±2kHz
carrier frequency change rate ; 65Hz/sec
signal to noise ratio ; Eb/No = 4.7dB
multipath Rician fading ;
C/M =7dB pitch = 0.7Hz
packet structure (signaling channel)
unique word ; 64symbol
data length ; 252symbol

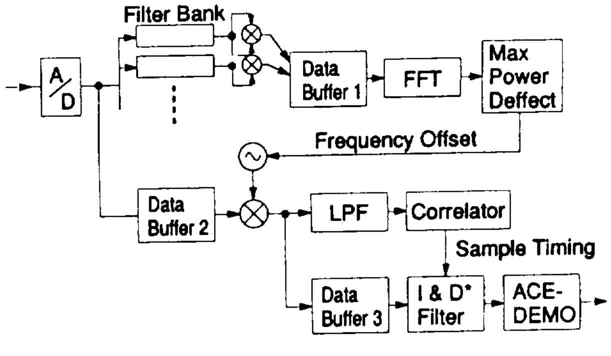

Fig. 4 STD-C Hardware Functional Blockdiagram

Since no preample sequence are used for the signaling channel of STD-C, a switch-back preambleless demoduration technique [4] is adopted. The data is once stored to a data buffer and fed into the ACE-DEMO from the end of the data in reverse order(the backward processing). When the carrier is recovered and the unique word is detected, the data is fed into the ACE-DEMO from the beginning of the data again(the forward processing). The backward proseccing is for carrier frequency acquisition, therefore the acquisition must be achieved within 252 symbols, the packet data length. The data is demodulated in the forward processing.

Figure 5 shows the developed hardware board. It is composed of single chip DSP(TMS320C26), instruction ROM, data RAM, and I/O ports. Number of ALE taps is 128.

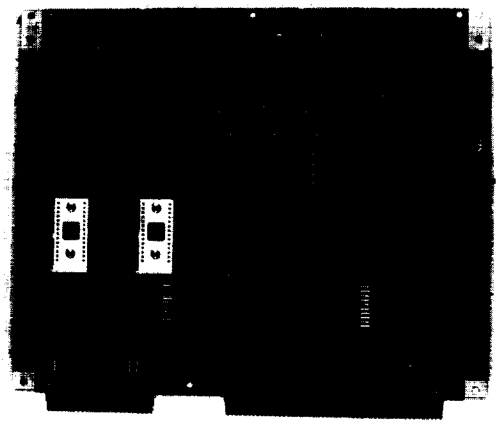

Fig.5 Developed Hardware Board

4 Measured Performance

4.1 BER performance Figure 6 shows the measured BER performance of the developed hardware. In this measurement, Rician fading factor is set to 15,10,7dB C/M (Carrier to Multipath power ratio) and 0.7Hz fading pitch. As shown in this figure, it is obvious that the developed demodulator tracks the carrier changes due to Rician fading with low Eb/No condition.

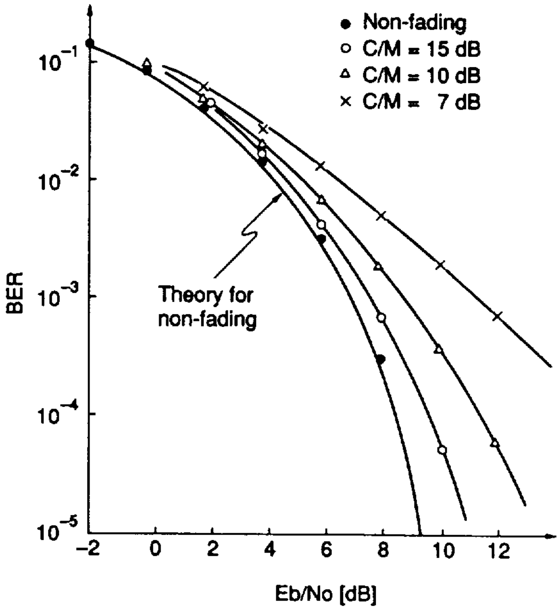

Fig. 6 BER Performance

4.2 ACE-DEMO Pull-in Performance Figures 7 and 8 show the measured pull-in performance for the signaling channel. In these measurements, in order to evaluate the performance of the ACE-DEMO itself, the rough carrier frequency offset estimation is not used and the clock timming is extracted by the transmission clock.

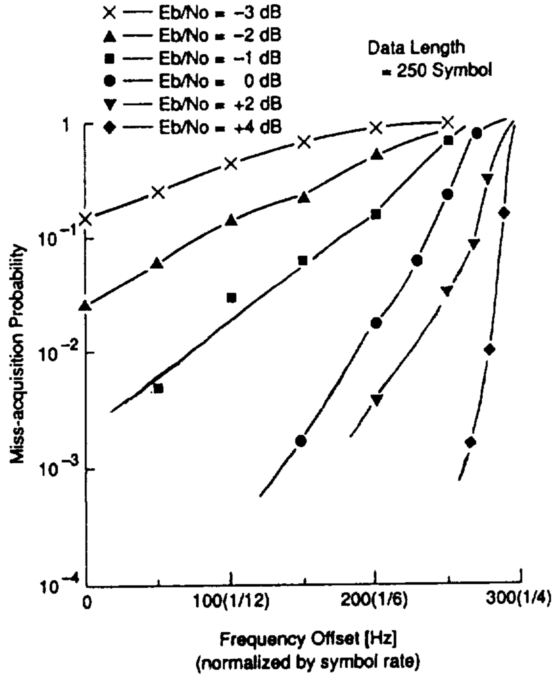

Fig. 7 Pull-in Performance (1)

The packet structure is the same as a STD-C signaling channel.The pull-in is decided when the unique word is detected.

Figure 7 shows the relationship between miss-acquisition probability and carrier frequency offset. In principle, the ACE-DEMO pull-in characteristic has no relation with the carrier offset up to ±300 Hz as mentioned before, but in this mesurement, it degrades as carrier frequency offset becomes large. It is due to fact that the phase jump occurs at the frequency divider of ACE-DEMO by the noise and that there are the power loss at the I&D filter caused by frequency offset. 270Hz ACE-DEMO pull-in range is obtained at 10^{-3} miss-acquisition probability under 4 dB condition, so that it has a much wider pull-in frequency range than the conventional PLL. For STD-C signaling channel application, the accuracy of rough carrier frequency offset estimation is allowed to this level.

Figure 8 shows the relationship between miss-acquisition probability and data length. The acquisition is achieved within 150 symbols for 0dB Eb/No and within 50 symbols for 4dB Eb/No. It is a much shorter pull-in time than the conventional method. It satisfies to STD-C signaling channel specifications

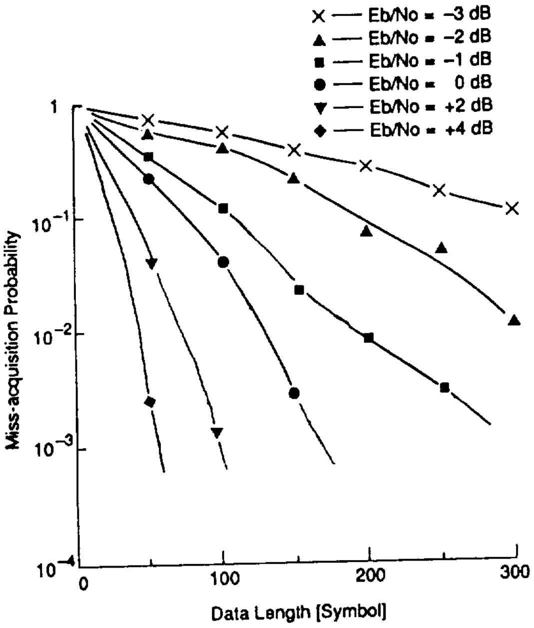

Fig. 8 Pull-in Performance (2)

5 Conclusion

This paper presents a new coherent demodulation concept, ACE-DEMO, based on ALE. The proposed demodulator has many merits. they include;

(1) wide pull-in frequency range,
(2) short pull-in time,
(3) pull-in time independent of carrier frequency,
(4) short pull-in time for reacquisition from outage.

Hardware using this concept has been actually developed for the INMARSAT standard-C coast earth station system, using a 320C26 (T.I.) DSP. In measurement evaluation, excellent BER performance is derived in the severe environment called for by STD-C specifications, which include Rician fading of 7dB C/M, and 4dB Eb/No. The ±270 pull-in frequency range and 50 symbol pull-in time of ALE method is confirmed, so that this demodulator presents attractive advantages especially when apply to a low bit rate communication systems such as STD-C signaling channel.

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