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New Symbol Timing Algorithm for Multi-level Modulation Scheme

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ABSTRACT

In this paper, a simple algorithm for detection of timing error of a synchronous, band-limited, multi-level data stream is proposed. The proposed algorithm can be applied to multi-level PAM, M-ary PSK, or M-ary QAM. The proposed agorithm for M-ary PSK requires only two samples per symbol for its operation, and it is based on the concept of transition logic table and transition level table. In order to prove the steady-state operation of the proposed algorithm, its performance is evaluated and compared to BECM by Monte Carlo simulation method under Gaussian noise and fading noise channel environments. The comparison results confirm that the performance of proposed algorithm is superior to that of BECM in jitter characteristics.

Ⅰ. Introduction

Symbol timing has traditionally been performed using analog means. There has, however, been great interest recently[1]-[9] in designing circuits for symbol synchronization from signal samples, that are suitable for use in all digital receivers which can be implemented in VLSI. There are two methods for symbol synchronization; the first in which sampling is performed at the baud rate[1]-[2], and the second in which sampling is at a higher rate[3].

Baud-rate sampling which is a one sample per symbol decision directed algorithm is proposed by Mueller & Muller[2]. This algorithm has the advantage of reducing circuit complexity but for maximum advantage the signal samples which are used to derive symbol synchronization must also be utilized for other receiver functions such as equalization and threshold detection. But the decision directed algorithm is attractive due to the single symbol-centered sample, particularly for high-speed applications, but the defect of decision-directed algorithm is failing at low signal-to-noise ratios.

Typical NDA (Nondecision Directed Algorithm) which is proposed by Gardner[3] use two samples per symbol, taken from the interpolating matched filter output at and halfway between the estimated decision instant; therefore the computational complexity of the interpolating matched filter is twice as large as for the M&M Algorithm. Gardner Algorithm may be written as

$$\varepsilon_n = (I_{2n} - I_{2n-2}) \cdot I_{2n-1} + (Q_{2n} - Q_{2n-2}) \cdot Q_{2n-1} \qquad (1)$$

where ε_n is PD(Phase Detector) output, I and Q indicate the inphase or quadrature component of the symbol sample, respectively, and the subscript $2n-1$ indicates the samples lying midway between the symbol-centered samples of the $(n-1)$th and nth symbols. Also this algorithms completely fails for very small rolloffs because of its quadratic nature.

Despite of the above disadvantages, because of the

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advantages of being applied to band limited modulation techniques, Gardner Algorithms have been widely used. But, Gardner Algorithm can be applied to only two-level signal such as BPSK/QPSK modulation signal. It is very important to develope new symbol timing algorithms for multi level signal.

In this paper, a new MLT(Multi Level Transition) algorithm which can be applied to Multi level PAM, M-ary PSK, or M-ary QAM is proposed. The proposed MLT algorithm requires only two samples for its operation, and it is based on the concept of transition logic table and transition level table. In order to prove the steady-state operation of MLT algorithms, Monte Carlo simulation method under Gaussian and fading noise channel environments is adopted to compare the performance of MLT and BECM. BECM also requires only two samples for its operation, and is widely applied to various modulation schemes. In this paper, fading noise channel using Jake's model is modeled[11]. The comparison result exhibits that the overall performance of MLT is better than BECM, especially in jitter characterstics.

Ⅱ. Algorithm Description

Fig. 1 shows a block diagram of digital modem structure requiring two sample per symbol. This paper considers only the upper two blocks of Fig. 1, which represents the symbol synchronization part.

Typically, Gardner algorithm can only be applied to 2-level signal such as BPSK and QPSK modulation techniques. By modifying Gardner Algorithm, a new symbol timing algorithm is proposed for multi-level signal as shown in Eq. (2).

$$\varepsilon_n = \left(I_{2n-1} - \frac{I_{2n}+I_{2n-2}}{2}\right)\times\left(\frac{I_{2n}-I_{2n-2}}{2}\right) + \left(Q_{2n-1} - \frac{Q_{2n}+Q_{2n-2}}{2}\right)\times\left(\frac{Q_{2n}-Q_{2n-2}}{2}\right) \qquad (2)$$

In Fig. 2, it is shown that the sampling instant leads to ideal sampling instant. In the case of 2-level, transition level become 0;on the other hand, in the case of Multi-level, transition level must be estimated using the adjacent samples lying midway between the symbol-

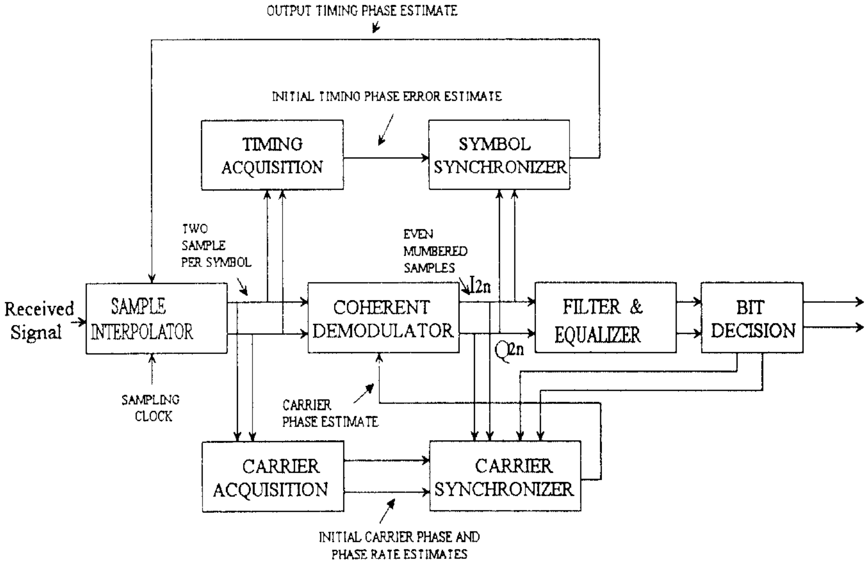


Fig. 1 The Structure of Overall Digital Modem

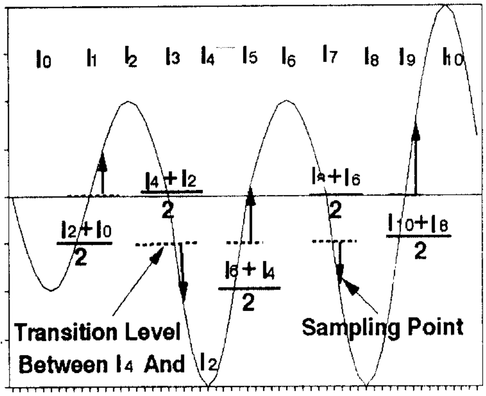


Fig. 2 The Conceptual Diagram of I-Channel Transition Level

centered samples of the (n − 1)th and n-th symbols.

From the Eq. (2) and Fig. 1, define I_{Mn}, Q_{Mn} as follows:

$$I_{Mn}=(I_{2n}+I_{2n-2})/2 \qquad (3)$$
$$Q_{Mn}=(Q_{2n}+Q_{2n-2})/2$$

where I_{Mn}, Q_{Mn} represent Transition Estimation Level for I and Q Channel, respectively.

Similarly, define I_{Tn}, Q_{Tn} as follows:.

$$I_{Tn}=(I_{2n}-I_{2n-2})/2 \qquad (4)$$
$$Q_{Tn}=(Q_{2n}-Q_{2n-2})/2$$

where I_{Tn}, Q_{Tn} represent Transition Level Detection for I and Q Channel, respectively. Then, Eq. (2) can be written as

$$\varepsilon_n=(I_{2n-1}-I_{Mn})\times I_{Tn}+(Q_{2n-1}-Q_{Mn})\times Q_{Tn} \qquad (5)$$

The algorithm given by Eq, (5) is directly applied to M-ary QAM.

In order to apply Eq. (5) to M-ary PSK, the n-th and (n − 1)th I,Q channel symbols can be replaced by $(2K+1)/M$ and $(2L+1)/M$, respectively. In such case, Eq. (4) can be expressed as follows:

$$I_{Tn}=\cos\frac{2K+1}{M}\pi-\cos\frac{2L+1}{M}\pi \qquad (6)$$

$$Q_{Tn}=\sin\frac{2K+1}{M}\pi-\sin\frac{2L+1}{M}\pi \qquad (7)$$

where, M = 2, 4, 8, ⋯, and K, L = 0, 1, 2, ⋯, (M − 1). Transition logic of I, Q channel, I_{Tn}, Q_{Tn} are determined by Table 1. The n-th and (n − 1)th detected phase symbol are θ_{2n}, θ_{2n-2}, respectively.

Table 1. MPSK Transition Logic Table

θ_{2n}	θ_{2n-2}	I_{Mn}	Q_{Mn}
$\frac{2K+1}{M}\pi$	$\frac{2L-1}{M}\pi$	$\left[\cos\frac{2K+1}{M}\pi -\cos\frac{2L-1}{M}\pi\right]$	$\left[\sin\frac{2K+1}{M}\pi -\sin\frac{2L-1}{M}\pi\right]$

Also, Eq. (6) and (7) can be expressed as follows:

$$I_{Mn}=\left\{\cos\frac{2K+1}{M}\pi+\cos\frac{2L+1}{M}\pi\right\}/2 \qquad (8)$$

$$Q_{Mn}=\left\{\sin\frac{2K+1}{M}\pi+\sin\frac{2L+1}{M}\pi\right\}/2 \qquad (9)$$

Transition level of I, Q channel, I_{Mn}, Q_{Mn} are determined by Table 2.

Table 2. MPSK Transition Level Table

θ_{2n}	θ_{2n-2}	I_{Tn}	Q_{Tn}
$\frac{2K+1}{M}\pi$	$\frac{2L-1}{M}\pi$	$\left[\cos\frac{2K+1}{M}\pi +\cos\frac{2L-1}{M}\pi\right]$	$\left[\sin\frac{2K+1}{M}\pi +\sin\frac{2L-1}{M}\pi\right]$

Base on the result of Eq.(6) to (9), Eq.(2) can be modified by Eq.(10), which is applied to M-ary PSK modulation scheme. Fig. 3 shows the block diagram of the proposed algorithm for M-ary PSK.

$$\varepsilon_n=\left[I_{2n-1}-\left(\cos\frac{2K+1}{M}\pi+\cos\frac{2L+1}{M}\right)/2\right]$$

$$\times\left(\cos\frac{2K+1}{M}\pi-\cos\frac{2L+1}{M}\right)/2 \qquad (10)$$

$$+\left[Q_{2n-1}-\left(\sin\frac{2K+1}{M}\pi+\sin\frac{2L+1}{M}\right)/2\right]$$

$$\times\left(\sin\frac{2K+1}{M}\pi-\sin\frac{2L+1}{M}\right)/2$$

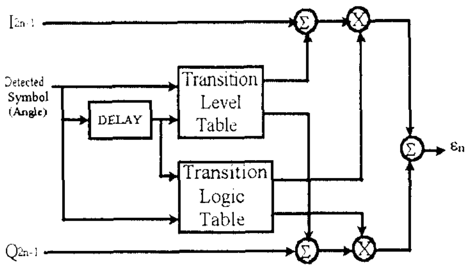


Fig. 3 The Proposed Algorithms for M-ary PSK Signal

Ⅲ. Simulation Results

For simplicity, the performance of only STR part is considered. The following list summarizes the conditions for simulation.

- ▶ rolloff factor of rasied cosine filter, $\alpha=0.5$
- ▶ the number of sample per symbol is set at 16.
- ▶ AWGN as well as Jake's fading channel are used.
- ▶ 8PSK and 16QAM modulation scheme are used.
- ▶ 2nd order loop filter is used where damping factor is set to 1.0. and Loop Filter BW(B_LT_S) is set to 0.005.
- ▶ Monte-Carlo simulation method is adopted.
- ▶ symbol rate is set to 100Kbps.
- ▶ In fading channel, Doppler frequency is set to 30Hz and two values of fading index (Dm) 0.01 and 0.1 are used.

It is important to realize that as Dm gets smaller, the degree of fading gets more severe. When Dm becomes less than 0.1, Rayleigh fading distibution is assumed and is shown in [11].

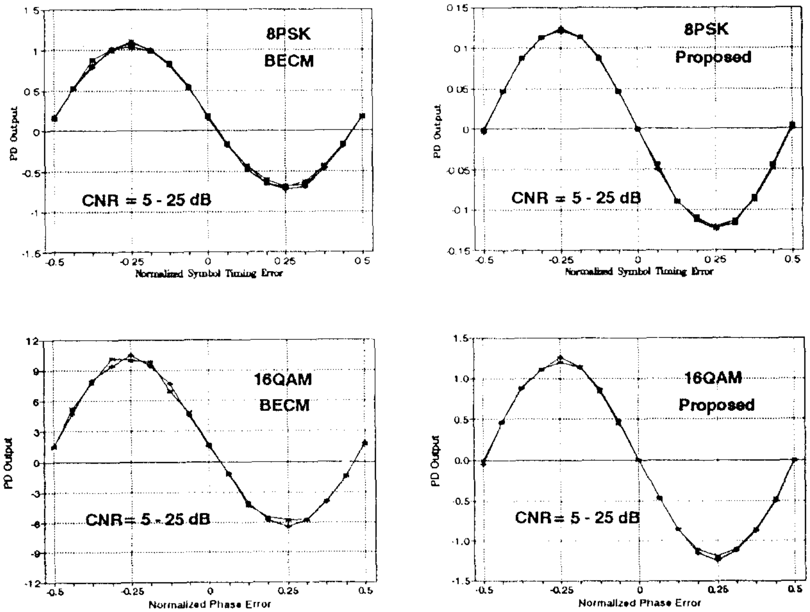
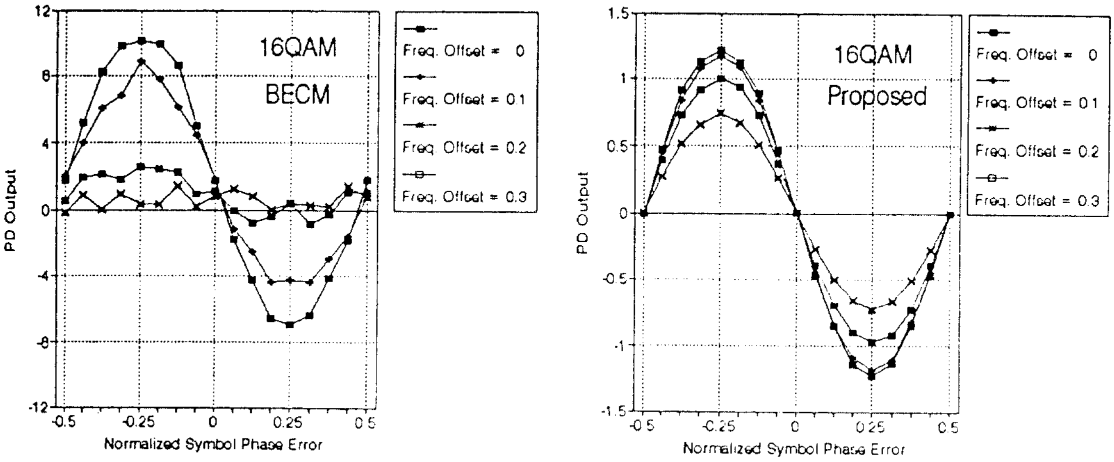


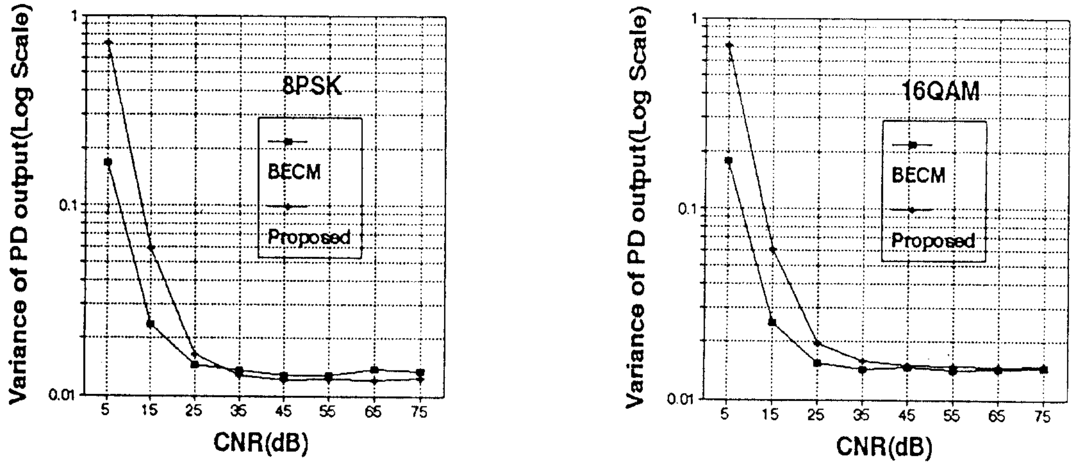
Fig. 4 The mean of PD Output Characteristics (S-curve)



(a) BECM

(b) Proposed

Fig. 5 PD Output versus Normalized Frequency Offset



(a) 8PSK

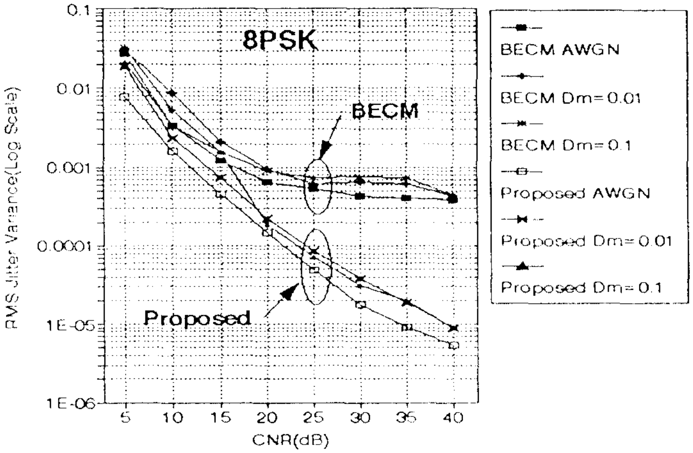
(b) 16QAM

Fig. 6 The Variance of PD output versus CNR at the point of zero timing phase error

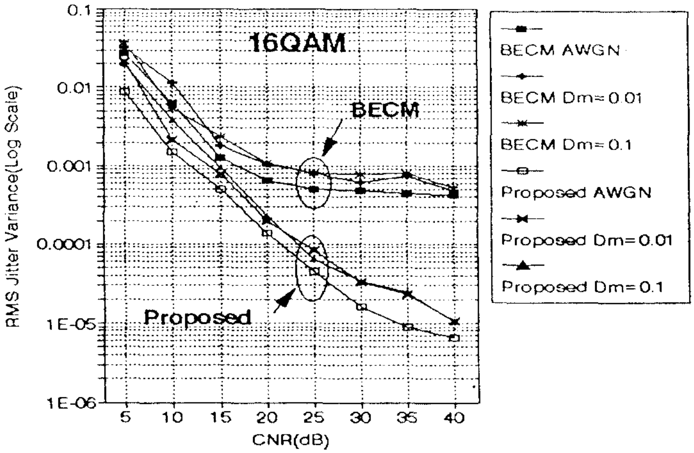
Fig. 4. shows S-curve about 8PSK and 16QAM. There is little variation in PD output according to the various CNR in the case of both BECM and MLT. From the S-curve, it is clearly shown that at the point of zero timing phase error, MLT has no biased PD output, whereas BECM does so.

Fig. 5. shows PD output characteristics in terms of normalized frequency offset. In MLT, it is confirmed that the performance degradation in PD output in response to frequency offset is negligible compared to that of BECM. In Fig. 6, we can see the variance of PD output according to the CNR at the point of zero timing phase offset. From Fig 6, it is shown that the variance of PD output for BECM is better than that of MLT for low CNR. However, there is no difference between two algorithms for high CNR.

In Fig. 7, jitter characteristics, which is very important performance index of digital timing tracking loop, are shown under the AWGN and various fading channel environments. The performance of MLT algorithm is superior to that of BECM in the 8PSK as well as 16QAM. Especially, the influence of fading is not so significant in the jitter characteristic.



(a) 8PSK



(b) 16QAM

Fig. 7 Jitter Performance Characteristics

Ⅳ. Conclusions

In this paper, a new algorithm which can be applied to multi-level PAM, M-ary PSK, and M-ary QAM is proposed. In order to prove the steady-state operation of proposed algorithm, we compare its performance to that of BECM in terms of S-curve and RMS Jitter under AWGN and fading channel environments. The comparison result assures that the performance of proposed algorithm is superior to BECM, especially in the aspect of jitter characteristics. In addition, it is shown that the proposed algorithm gives an acceptable outcome in fading channel. Therefore, the proposed algorithm in this paper is expected to operate well in practical digital symbol synchronization for digital communication systems.

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