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Feed-forward and Feedback Timing Recovery Algorithms for MSK

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Abstract - This research paper addresses feed-forward and feedback timing recovery algorithms for MSK. Both the algorithms do not require previous or simultaneous acquisition of carrier phase. Timing error estimation is done over AWGN channel. Performance analysis is made based on the simulation results.

I. INTRODUCTION

MSK modulation is kind of continuous phase modulation which has attractive properties such as continuous phase at bit transitions, constant envelope. MSK also makes use of the available bandwidth efficiently which is one of the main reasons why MSK has attained considerable attention in the modern wireless communication.

Timing recovery is the first synchronization operation processed by the digital receiver and so is a vital part of any synchronous receiver [1].To demodulate the signal correctly in the receiver, knowledge of carrier phase, symbol timing, and frequency offset are required [2].One of the global synchronization approaches such as maximum-likelihood approach is not very practical due to its computational complexity. There are other data-aided algorithms which are proposed to extract the timing information in [3].The timing information in [3] is extracted by the argument difference between every symbol. This algorithm however works well at high SNR cases but degrades dramatically at low SNRs.

In this paper feed-forward and feedback methods for timing recovery has been presented. Feed-forward structure can quickly capture the information, suitable for emergency communication but feedback structure can more accurately restore the signal [4]. The feed-forward method proposed is computationally less complex and shows a better performance at lower SNRs when compared to the algorithm proposed in [3]. The feedback method presented in this paper is a simple structure which is suited for digital implementation. Both feed-forward and feedback algorithms proposed in this paper do not require previous or simultaneous acquisition of carrier phase. From the simulation results it is seen that feedback method shows better performance than feed-forward method over AWGN channel.

The paper is organized as follows. In Section II the feed-forward timing synchronization is presented. In Section III feedback timing synchronization technique is presented. In
section IV simulation results are presented .In Section V conclusions are drawn.

II. FEED-FORWARD METHOD FOR TIMING RECOVERY

The feed-forward algorithm presented in this section is a data-aided algorithm based on two statistical variables. The signal model for MSK system is shown in Fig 1.

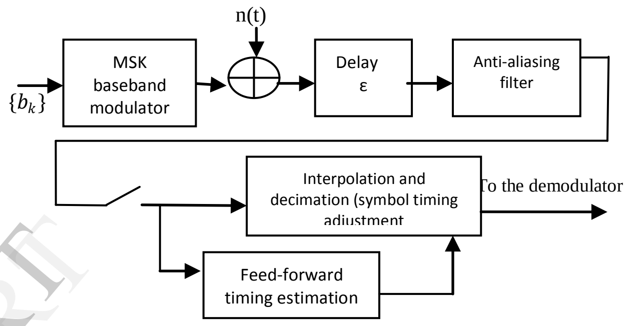

Fig 1. Signal Model for MSK System

The received signal is oversampled at the time $\left(k+\frac{i}{N}\right)T$ is written as,

$$z_{k,i} = e^{j\left(\phi\left(KT+\frac{iT}{N}-\varepsilon T\right)+2\pi f_{\Delta}\left(k+\frac{i}{N}\right)T+\psi\right)} + n_{k,i} \qquad (1)$$

where ε (-0.5,0.5) is the fraction of symbol duration by which received signal is time shifted w.r.t the original signal. f_{Δ} is the frequency offset between transmitter and receiver, ψ is the initial offset and ϕ is the information bearing phase.

Timing Error Estimation

To estimate the timing error, the m-lag fourth order non-linear transformation is chosen:

$$R_m(i) = \{E\left(z_{k,i}\, z^*_{k-1,i}\right)\left(z_{k-m,i}\, z^*_{k-m-1,i}\right)\} \qquad (2)$$

Due to the limited length of pilot symbols, the fourth order expectation $R_m(i)$ is obtained by averaging the samples,

$$\hat{R}_m(i) = \frac{1}{L-m-1}\sum_{k=m+2}^{L}\left(z_{k,i}\, z^*_{k-1,i}\right)\left(z_{k-m,i} z^*_{k-m-1,i}\right) \qquad (3)$$

The estimated timing error is obtained by ,

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$$\hat{\varepsilon} = \frac{1}{2\pi} arg \left[\sum_{index=0}^{N-1} -sgn_{index} FR(index) \right] \qquad (4)$$

where,

$$sgn_{index} = \begin{cases} 1 & index = 1 \\ -1 & index = N-1 \\ 0 & otherwise \end{cases}$$

$FR_m(n)$ is the discrete fourier transformation of $\hat{R}_m(i)$.

III. FEEDBACK METHOD FOR TIMING RECOVERY

In this section a data-aided simple feedback structure is presented. The block diagram of the structure is shown in figure 2.

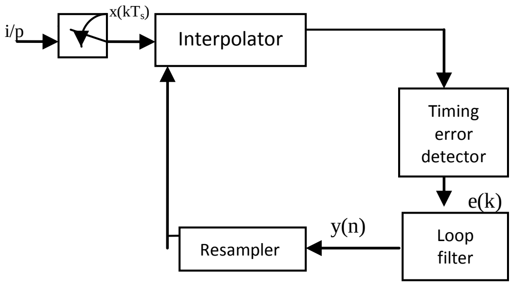

Fig (1):Feedback structure

The MSK signal model is

$$x(t) = e^{j(2\pi f_0 t+\theta)} \sqrt{\frac{2E_s}{T}} e^{j\psi(t-\tau,\alpha)} \qquad (1)$$

We assume that the sampling time is $t_m = kT + nT_s + \tau_k$ where T is the symbol period, T_s is the sampling period and $T_s = \frac{T}{N}$, $k = int\left(\frac{m}{N}\right)$, $n = m \bmod N$ and τ_k is the timing error. We take the samples one step before and after the generic symbol interval, $kT + \tau_k$ which gives,

$$e(k) = (-1)^{D+1}\Re\{x^2(KT - T_s + \tau_{k-1})x^{*2}[(k-D)T - T_s + \tau_{k-D-1})\} - (-1)^{D+1}\Re\{x^2(KT + T_s + \tau_k)x^{*2}[(k-D)T + T_s + \tau_{k-D})\} \qquad (2)$$

D is the design parameter taking integer and positive values. D=1 is good choice for MSK. The error signal from the timing error detector is sent to the loop filter. The error signal generated by the error detector is the noisy estimate of phase error. The loop filter processes e(k) in order to generate useful error by suppressing the effect of noise as much as possible. Loop filter design is done by taking the ideal filter points, the discrete time domain loop filter of the recursive equation:

y(n) = y(n-1) + c2*[e(n)-e(n-1)]+c1*e(n) (3)

where $c1 = \frac{2\omega_n\xi}{K}$, $c2 = \frac{\omega_n^2}{K}$, ω_n denotes loop bandwidth, ξ denotes damping and K is the loop gain. Now we resample the resulting signal at time instants $t = kT_i$ where T_i is synchronized with the signal symbols. Now the correct set of signal samples is identified by the base point index m_k and correct set of filter samples is identified by the fractional interval μ_k[5].Here we interpolate the resulting signal from the resampler by the scheme pointed by M.Moeneclaey where the use of NCO is eliminated. Two successive interpolations are performed for time instants

$$kT_i = (m_k + \mu_k)T_s \qquad (4)$$

$$(k+1)T_i = (m_{k+1} + \mu_{k+1})T_s \qquad (5)$$

Subtracting these two expressions and rearranging slightly gives recursion

$$m_{k+1} = m_k + \frac{T_i}{T_s} + \mu_k - \mu_{k+1} \qquad (6)$$

m_{k+1} is an integer, Then since $0 \le \mu_{k+1} \le 1$,

$$m_{k+1} + \mu_{k+1} = m_k + \frac{T_i}{T_s} + \mu_k < m_{k+2} \qquad (7)$$

Hence the increment in the sample count from one interpolation to the next is

$$m_{k+1} - m_k = int\left[\frac{T_i}{T_s} + \mu_k\right] \qquad (8)$$

To compute the fractional interval μ_k, recognize that the fractional part of the increment is zero i.e.,

$$f_p[m_{k+1} - m_k] = 0 = f_p\left[\frac{T_i}{T_s} + \mu_k - \mu_{k+1}\right] \qquad (9)$$

From which we get,

$$\mu_{k+1} = \left[\mu_k + \frac{T_i}{T_s}\right] mod - 1 \qquad (10)$$

IV. Simulation Results

Feed-forward and feedback methods are simulated using Matlab. We take the oversampling factor as 8 with the length of pilot symbols L as 16.Symbol period is taken as 10^{-7}.Here the algorithm accuracy is measured in terms of variance and variance of the estimated timing error is given by,

$$var(\hat{\varepsilon}) = E\{\hat{\varepsilon}^2\}$$

$$\approx \left[\frac{1}{2\pi}\right]^2 \frac{E\{(Im\ X)^2\}}{E\{(Re\ X)^2\}}$$

where

$$X = \sum_{i=0}^{N-1} \frac{1}{L-m-1} \sum_{k=m+2}^{L} (z_{k,i} z_{k-1,i}^*)(z_{k-m,i} z_{k-m-1,i}^*) e^{-j4\pi f_\Delta T} \left(e^{\frac{-j2\pi(N-1)i}{N}} - e^{-\frac{j2\pi i}{N}}\right)$$

Figure(1) shows the timing estimation of feed-forward scheme at different SNRs.

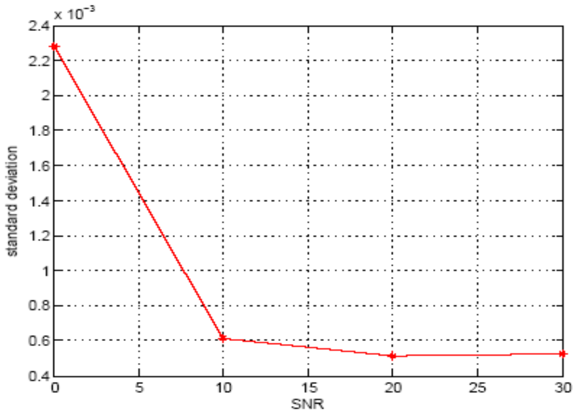

Fig (1). Standard Deviation of estimated timing error vs SNR

In the feedback method the sampling frequency f_s is taken as 64MHz with loop bandwidth is taken as 0.05. Figure(2) shows the timing error estimation of feedback loop over AWGN channel.

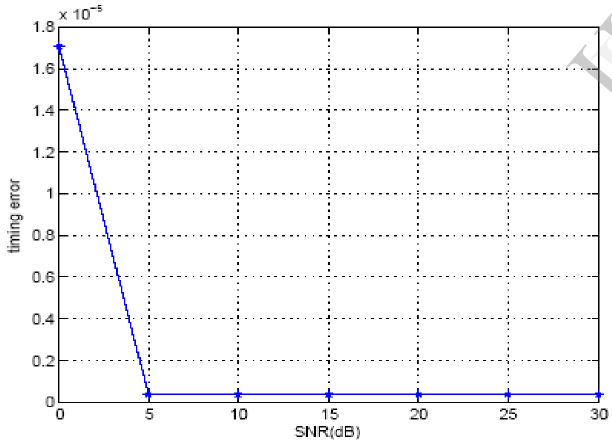

Fig (2). Estimated timing error vs SNR

From the simulation results we can infer that feedback method can more accurately restore the information in the presence of AWGN channel when compared to feed-forward method. After a certain period it is possible to make the error almost zero in feedback method so that accuracy of getting back the original signal is more when compared to feed-forward. Thus feedback method shows a better performance when compared to feed-forward scheme.

V. CONCLUSION

In this paper novel feed-forward and feedback methods for timing error estimation for MSK are proposed. Timing error for both the methods at different SNRs have been plotted and analyzed. From the simulation results it is seen that feedback method shows a better performance than feed-forward scheme and feedback technique can more accurately restore the information when compared to feed-forward scheme.

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