

## Rejection of PSK Interference in DS-SS/PSK System Using Adaptive Transversal Filter with Conditional Response Recalculation

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**Abstract:** PSK interference rejection using complex adaptive filter with conditional response recalculation in DS-SS/PSK system is considered in this paper. New adaptive filter decreases error probability for several orders of magnitude when compared to the standard adaptive transversal filter.

**Keywords:** PSK interference rejection, Adaptive filter.

### 1 Introduction

Spread spectrum, by its very nature, is an interference-tolerant modulation. However, there are situations where the processing gain is insufficient and adaptive filters must be employed [1, 2]. The influence of non-linear correlation receiver on the rejection of non-Gaussian and impulse interferences is analysed in paper [3]. Rejection of PSK interference in DS-SS system using modified complex adaptive filter is considered in [4-8]. Performance of DS-SS system that uses adaptive transversal filter with conditional response recalculation (CRR-ATF) is considered in this paper. The use of CRR-ATF significantly decreases the error probability in case of interference power dominance.

### 2 System model

Block diagram of the DS-SS receiver is shown in Fig. 1. There is additive Gaussian noise ( $n(t)$ ) and PSK interference ( $j_{PSK}(t)$ ) besides the DS-SS/PSK signal at the input of receiver. The input signal is

$$s_{in}(t) = s(t) + j_{PSK}(t) + n(t), \quad (1)$$

$$s(t) = m_1(t, Q)e_1(t, \Delta)\cos(\omega_c t), \quad (2)$$

where  $m_1(t, Q)$  is bipolar rectangular data bits having period  $T$ ;  $e_1(t, \Delta)$  is binary pseudo random pulses having duration  $\Delta$  seconds;  $\omega_c$  is the carrier frequency of the DS-SS signal. Ratio  $Q=T/\Delta$  is the processing gain of the system.

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$$j_{PSK}(t) = Ap_1(t, T_h) \cos(\omega_I t + \theta), \quad (3)$$

where  $p_1(t, T_h)$  is pseudo random variable which determines the sequence of the interference bits;  $\omega_I$  is the carrier frequency of the interference,  $A$  is amplitude of the interference and  $T_h$  is duration of each PSK interference bit.

Input signal is multiplied by a carrier, filtered and sampled. It can be expressed, at the input of the adaptive filter, as

$$x(k) = s_0(k) + J_{PSK}(k) + N_0(k), \quad (4)$$

where

$$J_{PSK}(k) = A \cdot p_1(k, T_h) \cdot e^{-j(\Delta\omega_1 \Delta k + \theta)}, \quad (5)$$

$$\Delta\omega = \omega_1 - \omega_c, \quad t = k\Delta \quad \text{and} \quad A = 10^{\frac{J/S}{20}}. \quad (6)$$

Desired signal is

$$s_0(k) = m_1(k, Q) e_1(k, \Delta). \quad (7)$$

Noise is referred to as  $N_0(k)$ :

$$N_0(k) = \frac{\sigma}{\sqrt{2}} N'_a(k) + j \frac{\sigma}{\sqrt{2}} N'_b(k), \quad (8)$$

where  $N'_a(k)$  and  $N'_b(k)$  are Gaussian random variables which variances are equal to 1.

The adaptive filter model is shown in Fig. 2. Two filters are considered in this paper (ATF or CRR-ATF).

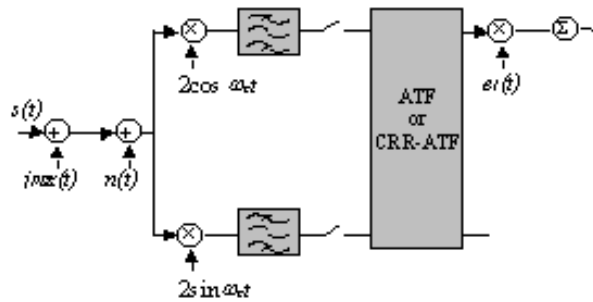


Fig. 1 - System model.

In case of PSK interference, absolute values of adaptive filter complex weights decrease from the reference signal to the filter end. Therefore classical adaptive filter limits

the influence of partial errors that are contained in this distant filter branches. This effect is more emphasized if the PSK interference has wider bandwidth.

If we take a look at the squares of partial errors absolute value we can conclude that it is convenient to use just some of the partial errors at a time, in order to minimize filter response. Therefore we made a modification of ATF. The modified filter is based on the classical ATF which response is modified using a certain condition. The modified response is calculated using weights, which are normalized over modulo in order to avoid partial errors rejection from certain filter branches. Now, a set of partial errors, which will influence the response, is determined. They are determined on the basis of the following condition: square of partial error modules has to be less than the average value of the sum of all partial errors modules.

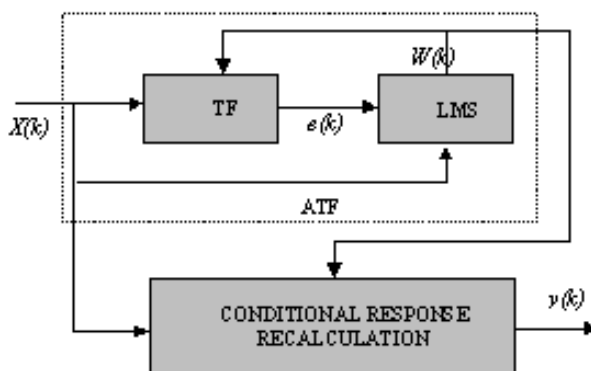


Fig. 2 - CRR-ATF model.

Conditional response recalculation is defined by:

$$C_i(k) = \left| X_0(k) - \frac{W_i(k)}{|W_i(k)|} X_i(k) \right|^2, \text{ for } -M < i < M, i \neq 0, \quad (9)$$

$$C(k) = \frac{1}{2M} \sum_{\substack{i=-M \\ i \neq 0}}^M C_i(k), \quad (10)$$

$$y_i(k) = \begin{cases} X_0(k) - \frac{W_i(k)}{|W_i(k)|} X_i(k) & , C_i \leq C \\ 0 & , C_i > C \end{cases}, \text{ for } -M < i < M, i \neq 0, \quad (11)$$

$$n_i(k) = \begin{cases} 1 & , C_i \leq C \\ 0 & , C_i > C \end{cases}, \text{ for } -M < i < M, i \neq 0 \quad (12)$$

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$$n(k) = \sum_{\substack{i=-M \\ i \neq 0}}^M n_i(k) \quad (13)$$

and

$$y(k) = \frac{1}{n(k)} \sum_{\substack{i=-M \\ i \neq 0}}^M y_i(k), \quad (14)$$

where  $W_i(k)$  are ATF complex weights, and  $y(k)$  is the CRR-ATF output. The ATF and CRR-ATF use the same standard LMS algorithm

### 3 System Performances

Since we consider the transmission of the PSK signal, bit error probability will be defined for the in-phase signal and the quadrature signal is not considered.

The error probability is

$$Pe = \frac{1}{n_{aa}} \sum_{l=1}^{n_{aa}} \frac{1}{M} \sum_{n=1}^M Pe^{(l)}(nQ), \quad (15)$$

where  $n_{aa}$  represents the number of ensemble members, and

$$Pe^{(l)}(nQ) = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{SNR^{(l)}(nQ)}{2}} \right). \quad (16)$$

where  $n = 1, \dots, M$  and  $M$  is the number of bits in the considered member of the ensemble. Index  $l$  represents the ordinal number of ensemble member with respect to the whole statistical ensemble. Ordinal number of bit which error probability is being computed is referred to as  $n$ .

Value  $SNR^{(l)}(nQ)$  represents signal to noise ratio of  $n$ -th bit of the PSK signal in the  $l$ -th member of ensemble:

$$SNR^{(l)}(nQ) = SNR^{(l)} \cdot Q \quad (17)$$

and

$$SNR^{(l)}(nQ) = \frac{\left[ \frac{1}{QM} \sum_{k=1}^{QM} DS^{(l)}(k) \right]^2}{\left[ \frac{1}{Q} \sum_{k=nQ}^{(n+1)Q} (DS^{(l)}(k))^2 - \left[ \frac{1}{QM} \sum_{k=1}^{QM} DS^{(l)}(k) \right]^2 \right]} \quad (18)$$

There is parameter  $DS^{(l)}$  in (18) which is determined as follows

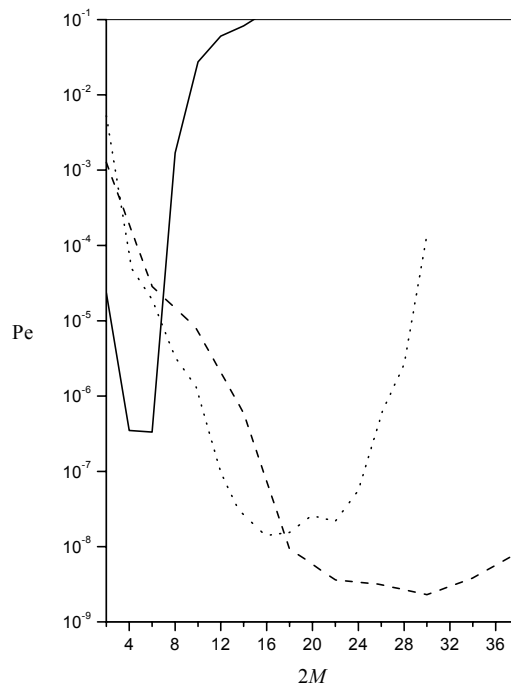
$$DS^{(l)}(k) = \text{Re}\{y^{(l)}(k)\} \cdot \text{sgn}\left[\text{Re}\{s_0^{(l)}(k)\}\right], \quad (19)$$

where  $y(k)$  is adaptive filter output signal at the moments  $k\Delta$ .

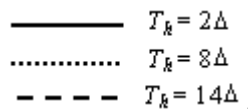
#### 4 Numerical Results

System performances are analysed by a quasi-simulation technique. The error probability at the output of receiver is calculated based on formula having signal to noise ratio (SNR) as a parameter and it is obtained by simulation and computed before the decision is made.

Fig. 3 shows the error probability as a function of filter length, for different interference bit rates.



**Fig. 3** - Error probability as a function of CRR-ATF length,

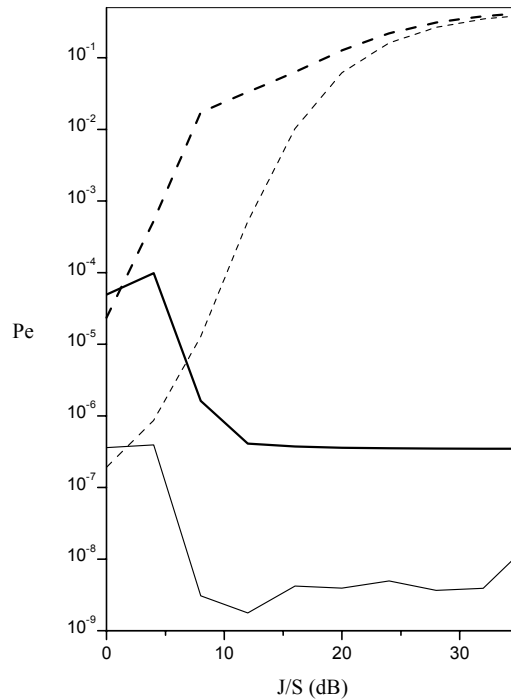


The result stands for PSK interference, signal to noise ratio is  $\text{SNR} = 0$  dB and  $\omega_1\Delta = 20^\circ$ . It can be noted that high bit rate interference is rejected more efficiently

with a short filter, while in case of narrowband interference it is desirable to have filters with greater length.

Error probability as a function of the interference power at the input of the receiver is shown in Fig. 4. The result stands for PSK interference, signal to noise ratio is  $SNR = 0$  dB and  $\omega_1\Delta = 20^\circ$ .

On the basis of Fig. 4 one can conclude that performances of CRR-ATF are significantly better than ATF, both for  $T_h = 2\Delta$  and  $T_h = 14\Delta$ . It is very important to notice that the error probability for CRR-ATF does not increase when interference power increases, and the system based on ATF can not operate for higher interference power (for example  $J/S=30$ dB,  $Pe \approx 0.5$ ).



**Fig. 4** - Error probability as a function of the interference power,

- ATF,  $T_k = 14\Delta, 2M = 4$
- ATF,  $T_k = 2\Delta, 2M = 4$
- CRR-ATF,  $T_k = 14\Delta, 2M = 40$
- CRR-ATF,  $T_k = 2\Delta, 2M = 4$ .

One can also note the improvement of ATF performances because the interference has narrower spectrum.

## 5 Conclusion

Interference rejection using complex adaptive filter with conditional response recalculation in DS-SS/PSK system is considered in this paper. This paper also considers the influence of filter length on the system performance. It was shown that wideband interference is best rejected with short filter, and longer filters are the most appropriate for narrowband interferences. CRR-ATF has much better performances than ATF, especially in case of high interference power. Performances of CRR-ATF are also better in case of wideband interference.

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