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A MULTI INTERFERENCE CANCELLER USING LMF AND LMS ADAPTIVE ANTENNA ARRAY

SOLEIT* E. A., ALLAM* A. M., EL-BARBARY* K. A., HENEIDI** M. Z.

ABSTRACT : Multi interference cancellation using adaptive antenna arrays is the objective of this paper. A comparison between the performance of the least mean square error (LMS) and the least mean fourth error (LMF) is presented. The performances of both algorithms are compared through computer simulations. The effects of the number of interference sources, and the change of the direction of arrival and the frequency of interference sources on the performance of the adaptive interference canceller is evaluated. It is found that the performance of the LMF is better than the LMS when the number of jammers is high.

KEY WORD

Adaptive Antenna Array

* Egyptian Armed Forces.
** Syrian Armed Forces.

1. INTRODUCTION

Adaptive interference cancellation has recently great attention to cancel the interference signals without a priori knowledge of the interference high order statistics[1,3,14]. The interference cancellation principle aims to generate a good estimate of the interference jamming source, and subtract its estimate from the receiver's observation. A lot of work has been done in this area depending on the beam forming techniques[1,10]. However those techniques depend on the stationary properties of the jamming and the interference signals[1,2]. Adaptive techniques are introduced in this work to cancel the jamming and the interference sources that are generated from the non-stationary environments, where the angles of arrival and the frequencies of the interference sources change[3].
Hence, the LMS adaptation algorithm that is based on the mean square error criterion suffers from slow adaptation speed during the tracking mode of the non-stationary targets. Hence, the least mean fourth (LMF) adaptation algorithm is introduced to provide a high convergence time during both the transient and the tracking modes[15].
In this paper a comparison between the performance of LMS and LMF adaptation algorithms is presented. It is found that the LMF algorithm exhibits a better adaptation speed and improvement factor than the LMS one.
This paper includes five sections. Section two is concerned with the LMS and LMF adaptive interference canceller. Section three presents the adaptation algorithms. Section five presents the simulation results. Conclusion of the whole paper is given in section five.

2. Adaptive Interference Canceller

Fig.1 depicts an adaptive interference canceller, which contains N reference array elements. The signal from the i^{th} element is splitted with a quadrature hybrid into an inphase signal $x_{JI}(t)$ and a quadrature signal $x_{JQ}(t)$. Each signal is weighted by a corresponding weight w_i or h_i respectively. The weighted signals are then summed to produce the array output signal $y_{ref}(t)$[9,14].
An error signal e(t) is obtained by subtracting the array output $y_{ref}(t)$ from another signal called the primary signal $x_{pr}(t)$ that is obtained from the primary omni-directional antenna. The array output is given by:

$$y_{ref}(k) = \sum_{j=1}^{N} (w_{jI} x_{jI}(k) + w_{jQ} x_{jQ}(k)) \tag{1}$$

where I, Q are the inphase and quadrature components respectively, N is the number of reference elements. The error signal is defined as[2,6,13]:

$$\begin{aligned} \varepsilon(k) &= x_{pr}(k) - \sum_{j=1}^{N} (w_{jI} x_{jI}(k) + w_{jQ} x_{jQ}(k)) \\ \varepsilon(k) &= x_{pr}(k) - W_I^T X_I - W_Q^T X_Q \end{aligned} \tag{2}$$

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$$\begin{aligned}\varepsilon(k)&=x_{pr}(k)-\sum_{j=1}^{N}(w_{jI}x_{jI}(k)+w_{jQ}x_{jQ}(k))\\ \varepsilon(k)&=x_{pr}(k)-W_I^TX_I-W_Q^TX_Q\end{aligned} \quad (2)$$

where W_I, W_Q, X_I , and X_Q are the inphase and quadrature weight and reference input vectors respectively[2].

3. Adaptation Algorithm

The adaptation algorithm is used to update the weights toward their optimum values, which minimizes a certain performance index. In this paper the least mean square and the least mean fourth of the error signal are used. The mean squared error is defined as[2,9]:

$$\xi = E[\varepsilon^2(k)] \tag{3}$$

Substituting Eq. (2) in Eq. (3) yields:

$$\begin{aligned}\xi &= E[(x_{pr}(k) - (W_I^T X_I + W_Q^T X_Q))^2] \\ &= E[((x_{pr}(k))^2] - 2E[x_{pr}(k)X_I]^T W_I \\ &- 2E[x_{pr}(k)X_Q]^T W_Q + W_Q^T E[X_Q X_Q^T]W_Q + W_I^T E[X_I X_I^T]W_I\end{aligned} \tag{4}$$

It is clear that the MSE, ξ is a quadratic function of the weight coefficient vectors W_I , W_Q . Hence, there is an optimal solution W_{opt} that can be obtained itteratively using the well known LMS adaptation algorithm [2,9,16]as:

$$W_I(k+1) = W_I(k) + 2\mu\,\varepsilon(k)\,.\,X_{ref\,I}(k) \tag{5}$$

$$W_Q(k+1) = W_Q(k) + 2\mu\,\varepsilon(k)\,.\,X_{ref\,Q}(k) \tag{6}$$

Where μ is the step size of the adaptation, which must be in the interval

$$0<\mu \leq 1/\lambda_{max} \tag{7}$$

where λ_{max} is the maximum eigenvalue of the autocorrelation matrix ϕ_r of the observation vector X_{ref} [2,3].

On the other hand, the mean fourth of the error signal can be expressed as[2,14]:

$$\begin{aligned}\eta &= E[(x_{pr}(k) - (W_I^T X_I + W_Q^T X_Q))^4] \\ &= E[\varepsilon^4(k)]\end{aligned} \tag{8}$$

The steepest descent adaptation algorithm for the LMF is given by:

$$W = W - \mu\nabla_W \tag{9}$$

The gradient vector can be estimated for the mean fourth error (MFE) surface criterion as:

$$\nabla_W = \frac{\partial\eta}{\partial W} = -4\varepsilon^3(k)X_r(k) \tag{10}$$

substituting Eq.(10) into Eq.(9), yields the LMF adaptation algorithm as [13,15]:

$$W_I(k+1) = W_I(k) + 4\mu(\varepsilon^3(k))\ X_{ref\,I}(k) \tag{11}$$

$$W_Q(k+1) = W_Q(k) + 4\mu(\varepsilon^3(k)).\ X_{ref\,Q}(k) \tag{12}$$

4. Simulation Results

The performance of the LMS, and the LMF algorithms is evaluated through computer simulations. The performance measure is evaluated in the transient and the steady states. The transient response is measured by the learning behavior of the mean squared error (MSE), ξ and the mean fourth error (MFE), η versus iteration time. The steady state is measured by the polar diagrams of the antenna array gain, and the improvement factor (IMF) in the output signal to interference plus noise ratio after convergence. The performance is measured when the input signal to noise ratio SNR=3dB, input interference to noise ratio INR=22dB, the number of reference elements N =10 elements, and the step size $\mu=3*10^{-5}$, the direction of arrival of the desired signal $\theta_0=3^0$, the initial weights w, h are zeros, so the array initial gain is a circle. The carrier frequency of the desired signal f_c equals 900 MHz, and the sampling frequency $f_s=8\ f_c$. Then the sampling time t_s equals the reciprocal of f_s. The antenna array is performed in two cases, 1) varying the angle of arrival, 2) varying the frequency of the interference sources. Moreover multi interference sources are considered.

4.1 The Changing of the Interference Frequency

In this case single and multiple interference sources are considered. The carrier frequency of the interference source is varying in steps.

4.1.1 Single interference source

The interference frequency changes each 2500 samples according to:

$$f_{c1}=f_c\,(1+0.05(k-1)) \qquad (13)$$

where k is the time index, The learning curve and the directivity pattern of the LMS, and the LMF are shown in Fig 2a,b, and Fig. 3a,b respectively. It is apparent from the illustrated figures that the LMF algorithm possesses a higher convergence rate than the LMS one. The directivity patterns of both algorithms in the steady state are nearly, similar.

4.1.2 Multiple interference sources

We assume that the frequency of the first interference source changes as in Eq. (13), and the frequency of the other sources changes in the form:

$$f_{cj}=f_c\,(1\pm0.01\,j\,f_c) \qquad , j=1,2,3,..nj-1 \qquad (14)$$

where nj is the number of jammers.
The learning curves of the LMS, and the LMF algorithms for five interference sources are shown in Fig. 6a,b respectively, where it is clear that the convergence rate and the improvement factor are better for the LMF algorithm.
We can see that the convergence rate of the LMF algorithm is better than that of the LMS algorithm, while the improvement factor after convergence of both algorithms are similar.
The learning curve and the directivity pattern of the LMS, and the LMF algorithms for three interference sources are shown in Fig. 4a, b and Fig.5a, b

We can conclude that both the LMS and the LMF algorithms are not affected significantly by the change of the frequency of the first interference source.

4.2 The Changing of the Angle of Arrival (AOA) of the Interference Sources

The simulations are presented for single and multiple interference sources. The angle of arrival of each interference source changes each 2500 sample, and the frequencies of the interference sources are as in Eq.(14).

4.2.1 Single Interference Source

The performance measure is described by the learning curve for both the LMS and the LMF algorithms, which are shown in Fig.7a,b respectively. It is evident that both algorithms are affected by the change of the AOA of the interference source. It is concluded that the convergence rate for the LMF algorithm is better than that of the LMS one.

4.2.2 Multiple interference sources

The performance of the LMS and the LMF algorithms is evaluated for two cases. The first case four interference sources are considered. The tracking performance is measured via the learning curves, which are shown in Fig. 8a,b for the LMS, and the LMF algorithms.

It is clear that the LMF algorithm provides a smaller convergence time than that of the LMS one.

The second cases, for five interference sources, the performance measures are expressed by the learning curves in the transient mode, and the directivity patterns are traced in the steady state after convergence of the weight coefficient vector, which are shown in Fig 9a, b for the LMS algorithm and 10a,b for the LMF algorithm. It is clear that the LMF algorithm's convergence rate is faster and it isn't affected by the change of the angle of arrival of the interference sources as the LMS algorithm.

5. Conclusion

Evaluation of the performance of both the LMS and the LMF algorithms using adaptive antenna array is performed for both the transient and the steady state phases of the interference cancellation.

The steady state performance of the adaptive antenna array using LMF and the LMS algorithms is less sensitive to changing the frequency of the interference sources, because the adaptive antenna array matches with the frequency change.

Moreover, the convergence rate of the LMF algorithm is better than that of the LMS algorithm for cases of frequency and AOA variations.

Furthermore, the improvement factor in the signal to interference plus noise ratio of the LMF algorithm is better than the LMS algorithm for multi interference sources.

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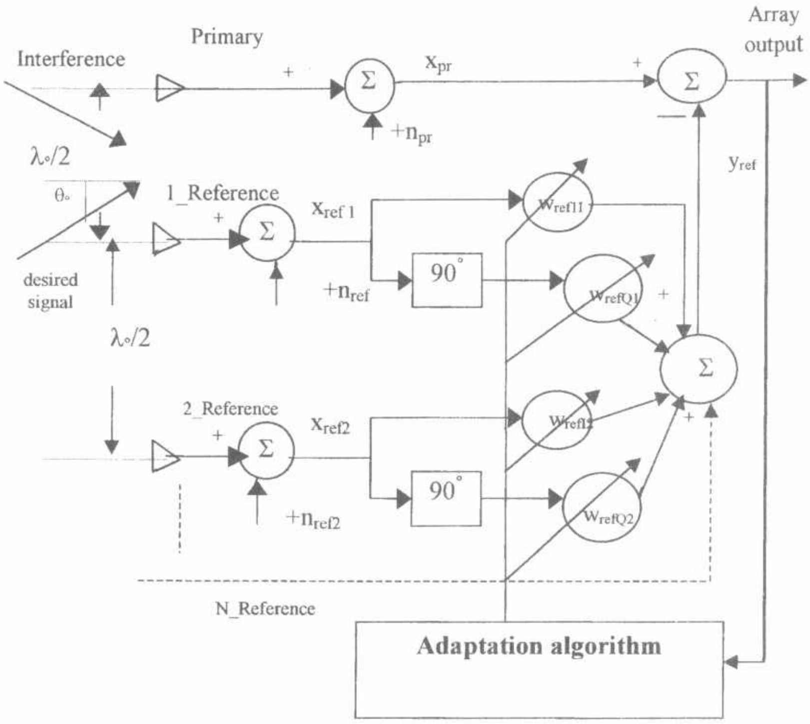

Fig. 1 Adaptive interference canceler using adaptive antenna array.

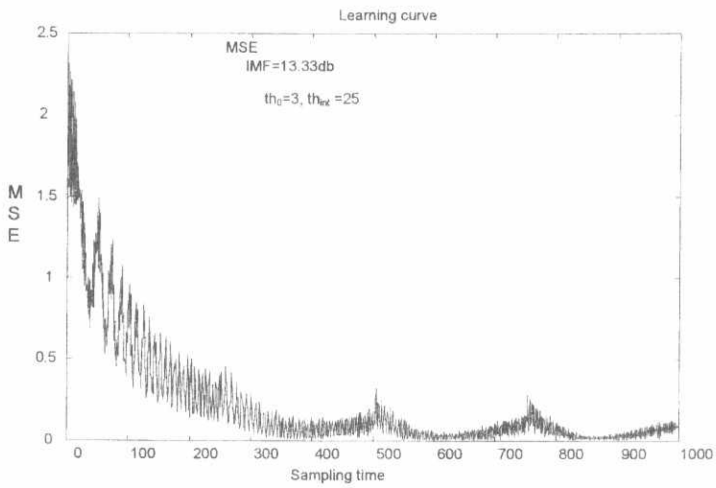

Fig 2a The learning curve of the MSE for a single interference

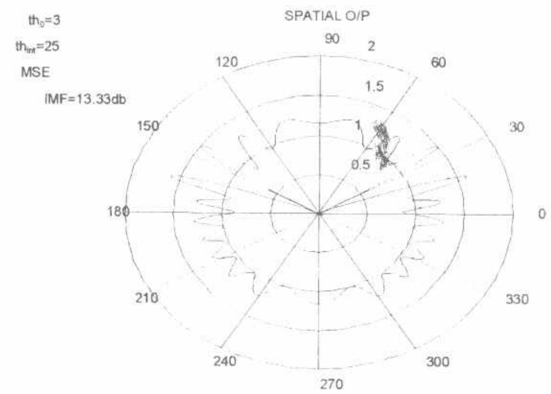

Fig 2 b MSE directivity pattern, for single interference

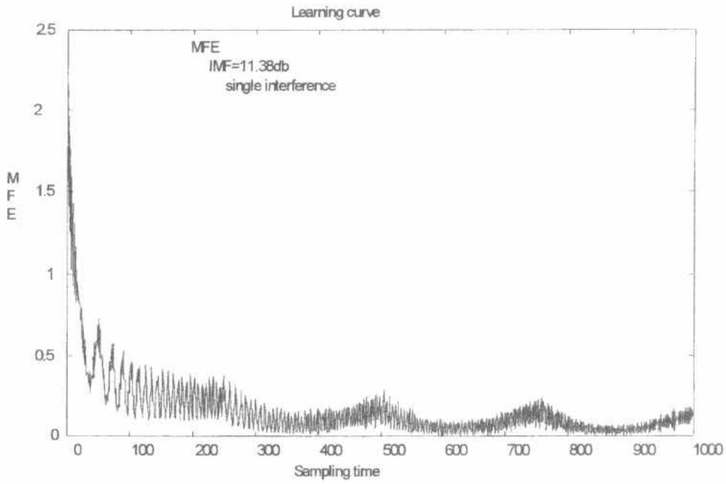

Fig 3 a The learning curve of the MFE for a single interference

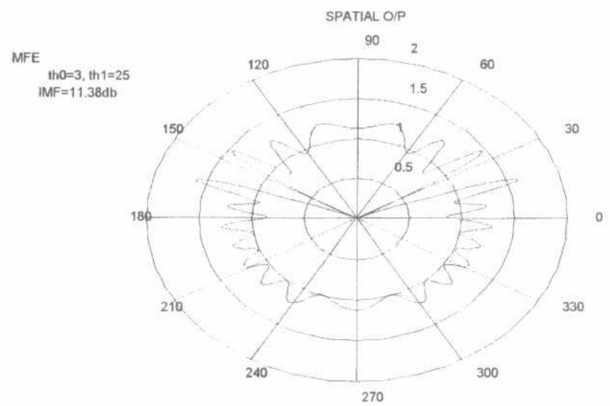

Fig 3 b MFE directivity pattern, single interference

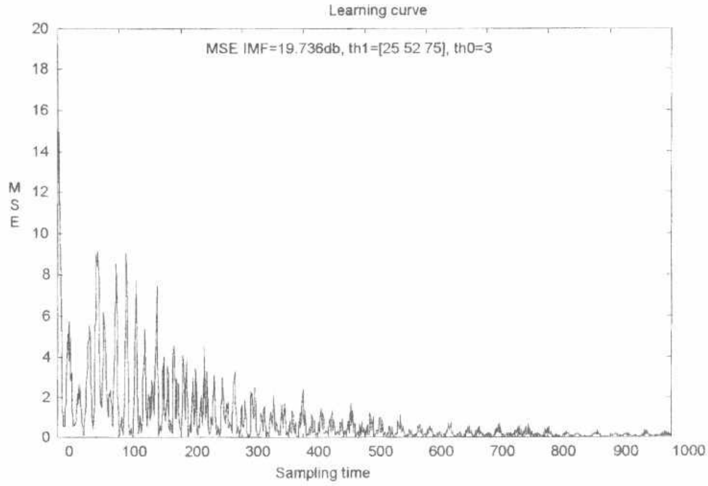

Fig 4 a the learning curve of the MSE for three interferences

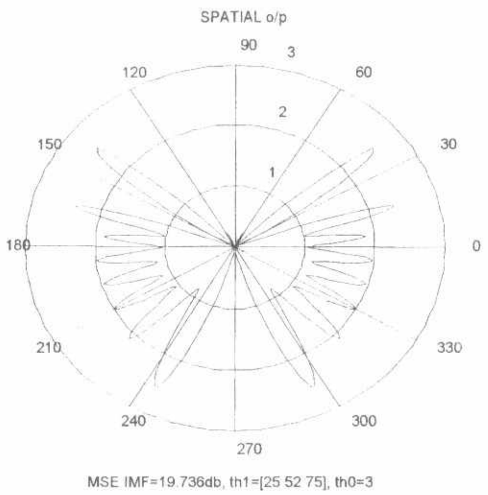

Fig 4 b MSE directivity pattern, three interferences

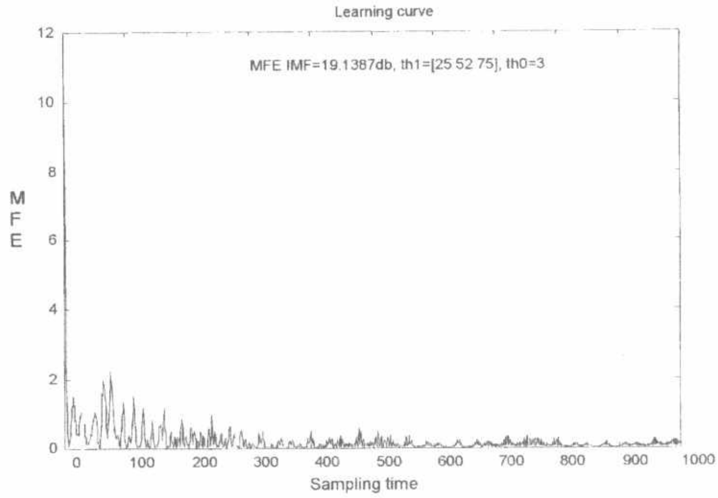

Fig. 5a The learning curve for the MFE for three sources

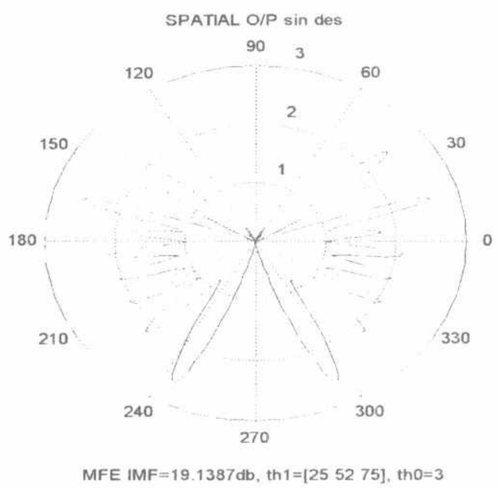

Fig. 5b MFE directivity pattern, for three interference sources

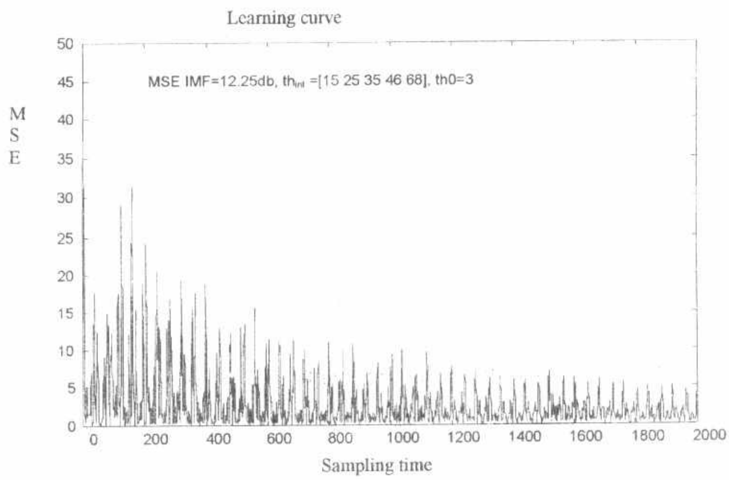

Fig. 6a The learning curve of the MSE for five interference sources

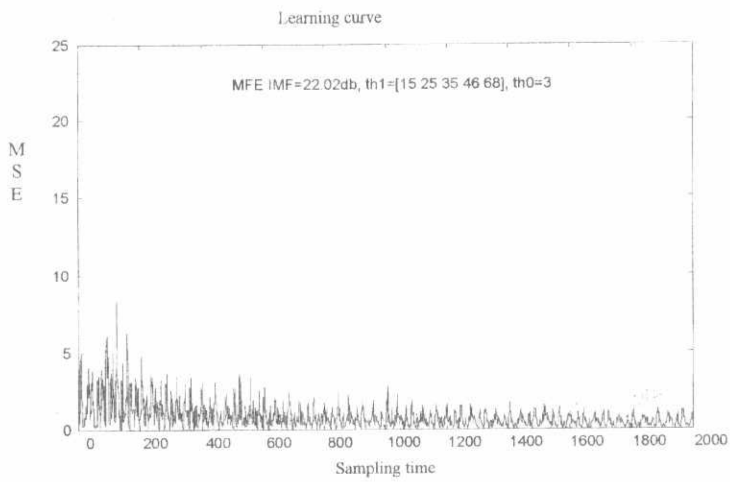

Fig. 6b The learning curve of the MFE for five interference sources

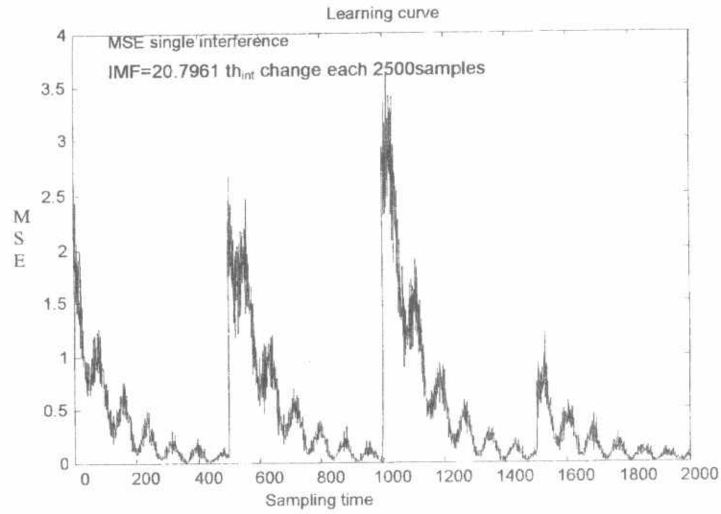

Fig. 7a Learning curve of the MSE for a single interference source.

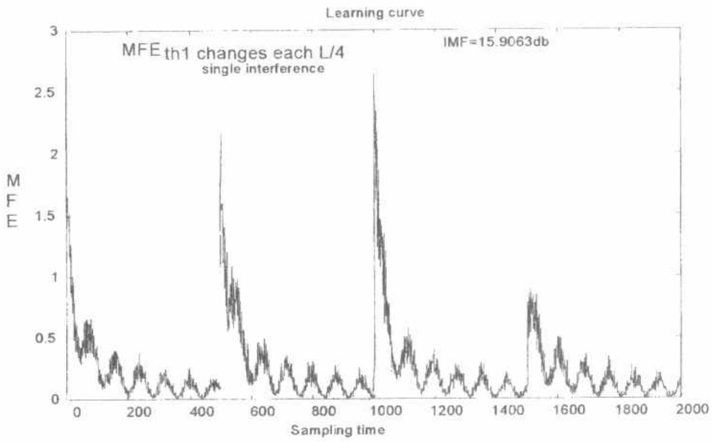

Fig. 7b Learning curve of the MFE for a single interference source.

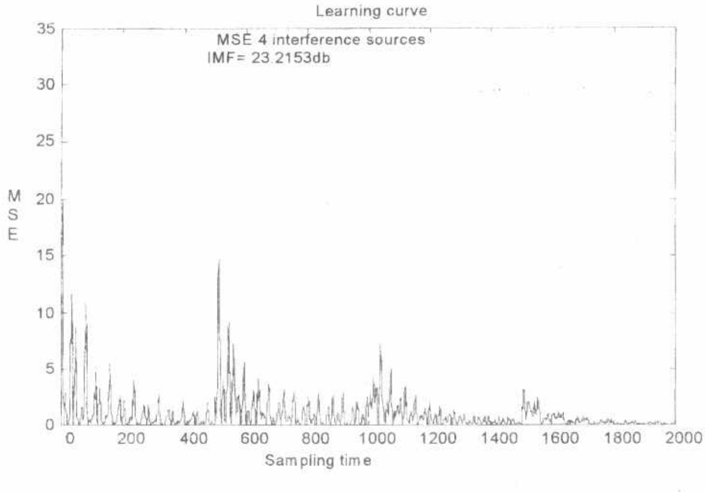

Fig. 8a Learning curve of the LMS for four interference sources.

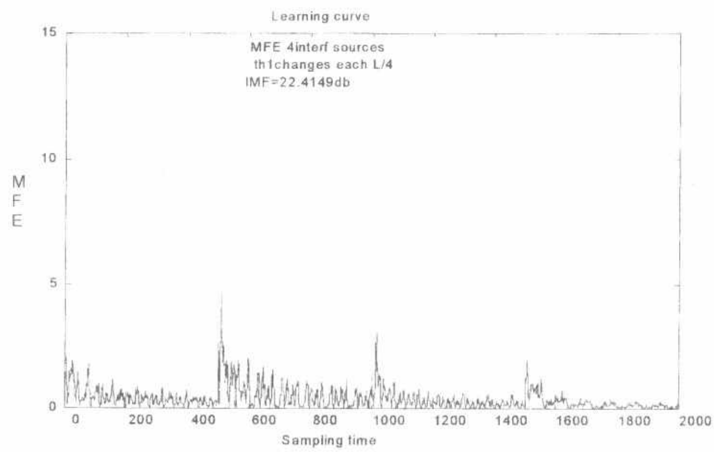

Fig. 8b Learning curve of the LMF for four interference sources.

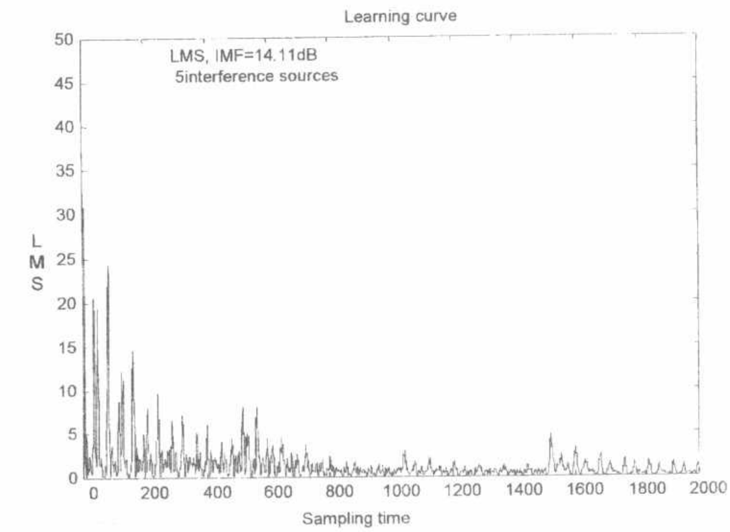

Fig. 9a Learning curve of the LMS for five interference sources.

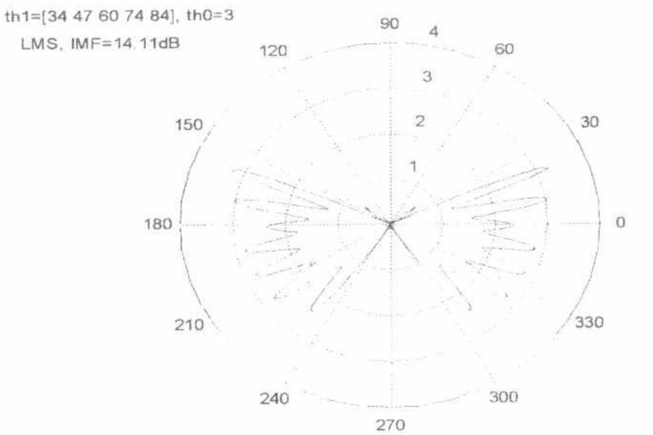

Fig. 9b Directivity pattern of the LMS for five interference sources.

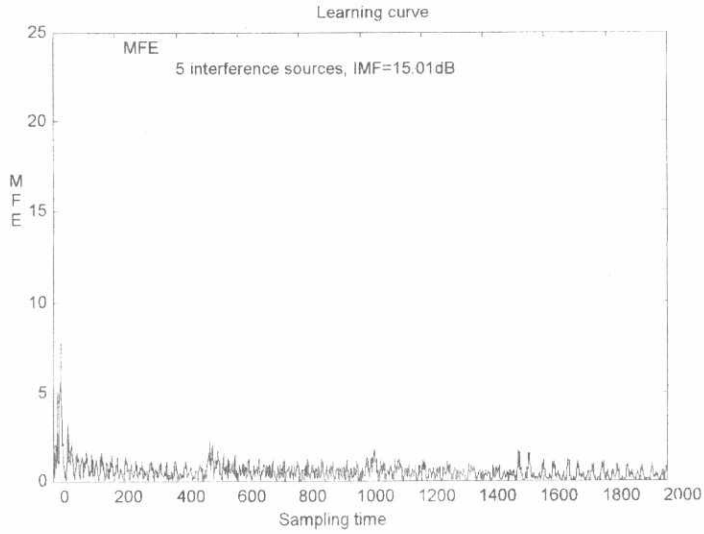

Fig. 10a The learning curve of the LMF for five interference sources.

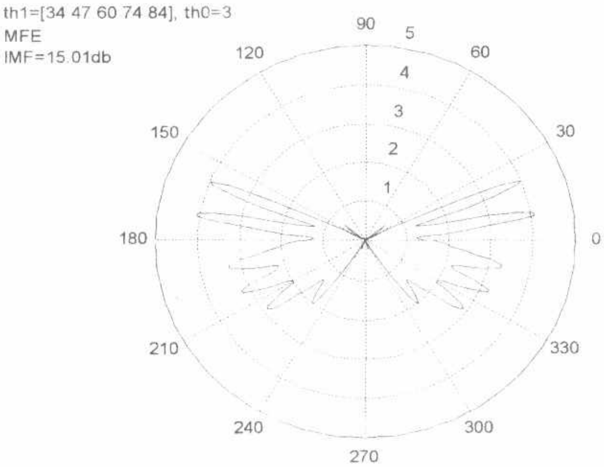

Fig. 10b Directivity pattern of the LMF for five interference sources.