A NEW TECHNIQUE EMPLOYING LMS ADAPTIVE ANTENNA ARRAY COMBINED WITH DS SPREAD SPECTRUM SYSTEM FOR CW INTERFERENCE

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In recent years, spread spectrum systems have been receiving much interest due their many advantages. They are used extensively in military and civilian communication sectors. Their well known properties such as low probability of intercept (LPI) and immunity to different types of interference have made the application of spread spectrum communications attractive to receivers operating in a hostile environment. To improve the performance of direct sequence spread spectrum (DS-SS) systems against narrowband and continuous wave (CW) interference, a combination of adaptive antenna array and transform domain processing (TDP) technique is proposed. The adaptive antenna excises the interference in the spatial domain in front of the DS-SS correlator receiver. For most communication systems the desired signal may arrive from any direction or at least from any direction within some sector. For this situation a least mean square (LMS) array [9,10] is the best option to track the desired signal. The difficult problem of using the LMS array in a communication system is how to obtain a suitable reference signal. As the steady state array weights depend only on the correlation between the reference signal and the received signal, it is required that the reference signal must be highly correlated with the desired signal and uncorrelated with the interference. The reference signal is generated in the proposed technique from the array output using transform domain processing (TDP) to suppress the residual unwanted signals in the array output to obtain a suitable reference signal. The combination between spatial excision and transform domain suppression of the interference gives a good improved performance for the system.

1. INTRODUCTION

As radar and communication traffic increases the suppression of interference becomes more important in all applications. The interfering signals may consist of deliberate electronic countermeasures (ECM), nonhostile RF interference (RFI), clutter scatterer returns and natural noise sources. These sources of noise cause degradation in signal to noise ratio (SNR) performance of conventional signal reception systems.

To improve the performance of the receiver system against these sources of noise, many techniques have appeared. Among these techniques there is the noise like modulation and correlation systems. A theoretical study along with experimental
verification for noise like modulation was pursued in 1950 by Basore [1], who coined the acronym noise modulation and correlation detection system, (NOMACS). These systems were used in military applications in a long-range high frequency radio teletype communication link exposed to enemy jamming. These original systems used vacuum tubes and consequently required rooms full of equipment. Spread spectrum systems really did not become practical until the advent of the transistor. With the development of integrated circuits, systems become even more manageable in package size and ease of circuit design.

The primary motivation for utilizing spread spectrum systems is the capability of the system to reject intentional or unintentional jamming. Another important advantage is its capability of low probability of intercept (LPI). This is accomplished by generating a very broad spectral bandwidth signal that is therefore hard to detect in noise. Code division multiplexing [11] is a method in which a group of carriers operate at the same nominal center frequency but are separable from the others by the low cross-correlation of the codes used. Therefore, spread spectrum code division multiplexing provides multiple access communication channels. Furthermore, having a spread spectrum modulation imposed on the data bearing carrier provides message privacy. The causal listener will be unable to decode the data. In addition, if there is a group of users with unique code for each user, one is capable of identifying the user by the particular code. Another important use of spread spectrum codes occurs in navigation and ranging, where the range errors can be made to be a small fraction of a chip, and are therefore very accurate. And finally spread spectrum signals can be used for providing multipath rejection.

The degree of protection or jamming margin of the spread spectrum communication links against hostile interference is quantified by the well known equation [2]:

\[ \text{Jamming margin (M}_j\text{)} = \frac{W}{R} - [L_{\text{sys}} + \frac{S}{\text{N}_{\text{reqd}}} ] \] ……………………..(1)

Where:
- \( W \) is the spreaded bandwidth.
- \( R \) is the data rate.
- \( L_{\text{sys}} \) is the losses in the system.
- \( S/\text{N}_{\text{reqd}} \) is the minimum SNR required for proper performance of the system.

From this equation it can be observed that if \( W \) is restricted due to technology or allocation constraints, then the jamming margin decreases as the data rate increases. Thus for high data rates the advantages of spread spectrum techniques are limited. To improve the performance of the DS spread spectrum systems there were different signal processing techniques. These include the area of interference rejection by the use of adaptive notch filters (transform domain processing) as well as the area of adaptive spatial filtering (adaptive antenna arrays) [3].

In the first area, lieu F.M. and Giordano A. A. [4] presented digital whitening techniques for improving spread spectrum communication performance in the presence of narrowband jamming in Feb. 1978. Ketchum, J.W. and Proakis, J.G. proposed many adaptive algorithms for estimating and suppressing narrowband interference in DS spread spectrum systems [5] in May 1982. The researches were continued in this area till 1989 when Milstein, Das and Gavageiz presented adaptive narrow-band interference rejection in a DS spread spectrum intercept, receiver using transform domain processing techniques [6]. In these techniques, a tapped delay line is used as a
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The received signal is a composite of a direct sequence binary phase shift keying (DS BPSK) signal, narrowband interference, and additive thermal noise. Since the bandwidth of the interference is relatively narrow compared to the intercepted DS spread spectrum signal, inspecting the transform of the composite signal enables the processor to decide on the presence and center frequency of the interference. Utilizing this information two techniques are implemented for rejecting the detected interference: (1) the narrowband interference is adaptively excised by multiplying the transform of the received signal with an appropriate function containing nulls at the desired locations and (2) the interference is attenuated to the desired level (such as noise level) by employing the saturation property of an amplifier. The resulting waveform is then inverse transformed. Finally the output of the inverse transformer is used as the input to the detection device. Fig. (1.1) shows the block diagram of adaptive transform domain processing receiver.

In the other area, adaptive spatial filtering, adaptive antenna arrays have been studied extensively for narrow-band communication applications. An adaptive antenna is an antenna that controls its own pattern by means of feedback control while the antenna operates. These antennas change their patterns automatically in response to the signal environment. They do so in a way that optimizes the signal to interference plus noise ratio (SINR) in the array output [7].

An adaptive array is a system consisting of any array of sensor elements and a real time adaptive signal processor that automatically adjusts the array beam sensitivity pattern so that a measure of the quality of the array performance is improved. The adaptive array functional diagram of Fig. (1-2) shows the principle system elements that an adaptive array must possess if it is to achieve successfully the twin objectives of enhancing desired signal reception and rejecting undesired interference signal. The principle adaptive array system elements consists of the sensor array, the pattern forming network, and the adaptive pattern control unit or adaptive processor that adjusts the variable weights in the pattern forming network. The array itself consists of N-sensors designed to receive signals in the propagation medium of interest.

The output of each of the N-elements is directed to the pattern forming network where the output of each sensor element is first multiplied by a complex weight (having both amplitude and phase) and then summed with all other weighted sensor element outputs to form the overall adaptive array output signal. The weight values within the pattern forming network then determine the overall array beam sensitivity pattern. This is the ability to shape the overall array pattern that in turn determines how well the specified system requirements can be met for a given signal environment.
R. Kohno and others [8] proposed a combination of an adaptive array antenna and a canceller of the interference for direct sequence spread spectrum multiple access system. This system suppresses interfering spread spectrum signals, i.e. cochannel interference, with arrival angles different from that of a desired user by using a null steering array antenna and eliminate by means of a canceller the residual interference and cochannel interference having an arrival angle the same as that of the desired spread spectrum signal.

In this work a combination of a LMS adaptive array and DS spread spectrum system is proposed. Transform domain signal processing (TDP) is used to generate the reference signal. The Fourier transform of the array output signal is obtained. An envelope detector is used to locate the position and the width of the narrowband interference. A soft limiting is used to limit the signal to the noise level in the frequency band where the interfering signal presents. The inverse Fourier transform is taken to the limiter output to give the reference signal that is required to the feedback control loop.
2. PROPOSED METHOD

In the proposed system an 4-element LMS adaptive array is employed. Each element is assumed to have omni-direction pattern. The desired signal is in phase on each element (corresponding to a signal arriving from broadside), and the interference has a propagation phase shift \( \psi_i = n \sin \theta_i \) (corresponding to an arrival angle \( \theta_i \) off broadside for half-wavelength element spacing). The input signals in the elements of the array are calculated by multiplying the input signals in the first element by the corresponding vectors \( U_d \) and \( U_i \) as follows:

\[
X(n) = x_d(n)U_d + x_i(n)U_i + x(n) ..............................................................(2)
\]

Where: \( x_d(n) \) and \( x_i(n) \) are the desired signal and interferer samples in the first element, \( U_d \) and \( U_i \) are the desired signal and interferer vectors respectively and are given by:

\[
U_d = [1 \quad \theta^{j\psi_d} \quad \theta^{j2\psi_d} \quad \theta^{j3\psi_d}]
\]

\[
= [1 \quad 1 \quad 1 \quad 1]^T ..............................................................(3)
\]
\[ U_i = [1 \quad \theta^{j\psi_i} \quad \theta^{j2\psi_i} \quad \theta^{j3\psi_i}]^T \] …………………..(4)

The output signal of each element is multiplied by a complex weight and summed with the weighted outputs from the other elements to give the array output.

\[ S(n) = \sum_{i=1}^{4} W_i(n) x_i(n) \] ………………………………………..(5)

In initial guess for the weight vector is taken to be:

\[ W(0) = [1 \quad 0 \quad 0 \quad 0]^T \] ………………………………………..(6)

The weights are updated according to the discrete LMS algorithm:

\[ W(n+1) = W(n) + 2\mu e(n) X^*(n) \] ………………………………………..(7)

The error signal \( e(n) \) is the difference between the actual array output signal and the reference signal.

\[ e(n) = r(n) - S(n) \] ………………………………………..(8)

The reference signal \( r(n) \) is generated from the array output by transform domain processing (TDP). The discrete Fourier transform (DFT) of the output signal of the array is calculated using FFT algorithm. The envelope of the transformer output is detected and compared with the threshold level to decide on the presence of the CW or narrowband interferer and determine its center frequency and bandwidth. Soft limiter is used to attenuate the interference components to a desired level in the transform domain. The output of the inverse FFT is the reference signal \( r(n) \), it depends upon the output signal of the adaptive array \( s(n) \), the adaptation process is continued till the optimum weights are reached (corresponding to constant minimum mean square error).

The steps of adaptation “\( \mu \)” is chosen to satisfy the stability and convergence condition given by:

\[ \frac{1}{P_{in}} > \mu > 0 \] ………………………………………..(9)

Where: \( P_{in} \) is the total power of the input signal.

In the following sections, the results are discussed for different scenarios of desired signal and undesired signals.
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reference signal generation

array output $S(t)$

To DS correlator

Fig. (2.1) Block diagram of the proposed
3. EXPERIMENTAL RESULTS:

The array output composite signal consists of the direct sequence biphase shift keying desired signal $s_d(t)$, CW or narrowband interfering signal $s_j(t)$ and additive white Gaussian thermal noise signal $s_n(t)$.

$$s(t) = s_d(t) + s_j(t) + s_n(t)$$

Generation of additive white Gaussian noise (AWGN) in the following figure.

3.1 Results for Single Tone CW Interferer:

In this section results of computer simulation of the proposed system are depicted. The presence of a single tone CW interferer is considered. The desired input signal to the array is DS-SS signal arriving from the broadside direction and producing in phase signals on all the elements of the array. The RF carrier frequency is assumed to be 70 MHz, the desired signal-to-noise ration (SNR) at the array input is assumed to be: 0, 10, 20 dB. The arrival angle of the interferer is varied from: 0 to 19.5° to 45°. The frequency deviation of the interferer with respect to the carrier frequency is changed to be 0, 0.5, and 2 MHz. we will present the effect of the different parameters of the considered scenarios on the proposed system performance.

3.1.1 Effect of interferer’s arrival angle:

The performance of the proposed system under the effect of arrival angle of the interferer is tested through the following scenarios with the following common parameters and SNR = 0 dB:

<table>
<thead>
<tr>
<th>Desired signal: RF carrier frequency $f_0$</th>
<th>= 70 MHz.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreading PN code length</td>
<td>= 127 chips.</td>
</tr>
</tbody>
</table>
Spreading PN code clock rate = 2.5 Mbit/sec.
Data rate = 0.5 Mbit/sec.
SNR = 10 dB.
Arrival angle = 0. (arrives from the broadside direction)

Single tone CW interferer: INR = 20dB.
Angle of arrival = 19.5°.
(measured from the broadside).
Random phase shift = \(\frac{\pi}{4}\).

Thermal noise: Additive white Gaussian with zero mean and \(\sigma^2 = 1\).

Array parameters:
Number of elements \(N = 4\).
Omnidirectional pattern for each element.
Half wavelength element spacing \((d = \frac{\lambda}{2})\).

Scenario (1): Arrival angle of the interferer \(\theta_I = \theta_d = 0°\).
Scenario (2): Arrival angle of the interferer \(\theta_I = 19.5°\).
Scenario (3): Arrival angle of the interferer \(\theta_I = 45°\).

The results of these scenarios are shown in Fig. (1) when both of the desired signal and interferer arrive from the same direction (broadside), the MSE that is reached is nearly (-35 dB) after nearly (600) iterations, while for the case of \(\theta_I = 19.5°\) the minimum MSE reached at the steady state is (-120 dB) after (600) iterations. As the angle of arrival of the interferer is 45°, the steady state is reached faster after nearly (500) iterations. It can be seen that as the interferer becomes close to the desired signal the performance degrades. The worst case is when the interferer tone arrives from the same direction as the desired signal. The null formed in this case will affect the overall performance of the system. The degradation in the performance occurs simply because the desired signal falls in the null formed in the array pattern in direction of the interferer. The array is better able to null the interferer if the angular separation from the desired signal is large.

3.1.2 Effect of INR:

The performance of the proposed system was tested under different interference to noise ratios. The test was carried out assuming 5-scenarios with the same common parameters as in subsection (1) except the following special parameters:

Scenario (1): there is no interfering signal. i.e. thermal noise only, SNR = 0 dB.
Scenario (2): INR = 0 dB, SNR = 0 dB.  Scenario (3): INR = 10 dB, SNR = 0 dB.
Scenario (4): INR = 20 dB, SNR = 0 dB.  Scenario (5): INR = 30 dB, SNR = 0 dB.

The results of these scenarios are shown in Fig (2) when there is no interfering signal the steady state is reached after nearly (600) iterations. The minimum MSE that is reached is (-130 db). For INR=0 db the steady state is reached after nearly (1200) iterations. The MSE that is reached in this case equals (-115 dB). It is noticed that as the INR increases the performance is improved and the system reaches the steady state faster because the time constant is proportional to the inverse of the input power to the array. In the region where the interferer power is small compared with the desired signal and thermal noise, it has little effect on the array feedback and the convergence
is slow. When the interference power increases enough, however, the interference begins to dominate the error signal and the array feedback corrects against it. As the interference power increases further the feedback loop gain in the array increases. This increasing feedback loop gain causes the output interference to drop when the input interference is increased. Finally for large enough input interference power (approximately 30 dB above the desired signal), the MSE begins to increase again.

Fig. (1): The MSE for single tone CW interferer with different arrival angles when SNR=0 dB, Δf=0.5 MHz and arrival angle of the desired signal equals zero (coming from the broadside)

The desired signal output power is affected by the input interference power because the interference power influences the patterns. When the interferences is much stronger than the desired signal the array nulls the interference regardless of what happens to the desired signal. If the interference happens to be too close to the desired signal the interference null is close to the desired signal, and there is a reduction in the desired signal power at the array output because of this null.
3.1.3 Effect of SNR:

To test the proposed system with different SNR, the previous five scenarios, with SNR = 0 dB, were repeated with SNR = 10 and 20 dB. The results for SNR = 10 dB are shown in Fig 3. It is noticed that there is an improvement in the performance for the case of INR = 30 dB because the difference between the interference power and the desired signal power is 20 dB. The effect of the interference null on the desired signal is reduced. When the INR = 0 dB there is a degradation in performance because the interference becomes very small compared with the desired signal power and so it has little effect on the array feedback.
3.1.4 Effect of the Number of Elements in the Array:

The number of elements in the adaptive array (N) is changed to be 7-elements instead of 4 elements. The following scenarios are considered to compare the results with those of 4-element cases:

Scenario (1): \(\text{SNR} = 20 \text{ dB}, \quad \text{INR} = 0 \text{ dB}\).  
Scenario (2): \(\text{SNR} = 20 \text{ dB}, \quad \text{INR} = 10 \text{ dB}\).

The results of these two scenarios, with single tone CW interferer that has an arrival angle equals 19.4° measured from broadside and frequency deviation 0.5° MHz are plotted in Fig.(4) with the results for the same parameters except \(N = 4\) from the previous scenarios. It can be noticed that the performance is improved especially for high INR. For \(\text{INR} = 10 \text{ dB}\) a minimum MSE of (-135 dB) is reached at the steady state after (600) iterations when \(N = 7\), while for \(N = 4\) the MSE at the steady state is (-125 dB) and it is reached after (1100) iterations. The performance is improved because
as the number of elements increases the number of degrees of freedom increases and the output SINR increases. All the results of this section are summarized in table (1).

Table (1) results for single tone CW interfere

<table>
<thead>
<tr>
<th>No.</th>
<th>Desired signal $\theta_d = 0$ $f_d = 70$ MHz, SNR dB</th>
<th>Interferer $\theta_i$ F MHz INR dB</th>
<th>No. of Iterations</th>
<th>MSE dB</th>
<th>Number of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>19.5 70 20</td>
<td>600</td>
<td>-120</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>19.5 70.5 20</td>
<td>600</td>
<td>-120</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>19.5 72 20</td>
<td>600</td>
<td>-120</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0 70.5 20</td>
<td>600</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>19.5 70.5 30</td>
<td>910</td>
<td>-15</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>45 70.5 20</td>
<td>500</td>
<td>-120</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0 70.5 10</td>
<td>600</td>
<td>-45</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>- - -</td>
<td>600</td>
<td>-130</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>19.5 70.5 0</td>
<td>1200</td>
<td>-115</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>19.5 70.5 10</td>
<td>600</td>
<td>-130</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>19.5 70.5 30</td>
<td>1000</td>
<td>-120</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>19.5 70.5 20</td>
<td>1100</td>
<td>-125</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>19.5 70.5 0</td>
<td>1100</td>
<td>-25</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>19.5 70.5 10</td>
<td>1100</td>
<td>-100</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>19.5 70.5 0</td>
<td>1100</td>
<td>-38</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>19.5 70.5 10</td>
<td>1100</td>
<td>-125</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>20</td>
<td>195 705 0</td>
<td>1100</td>
<td>-45</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>195 705 10</td>
<td>600</td>
<td>-135</td>
<td></td>
</tr>
</tbody>
</table>
Fig. (4) Comparison between MSE for \( N = 4 \) and 7 elements when SNR = 20 dB for INR = 0 and 10 dB respectively arriving from direction making 19.5\(^\circ\) with broadside and \( \Delta f = 0.5 \) MHz

### 3.2 Results for double tone CW interferes:

Here we present the results of computer simulation test of the proposed system when two CW interferers are considerer to incident on the array from two different directions. The test were carried out by many scenarios with the following common parameters:

- **Desired signal:** biphase DS-SS signal.
  - RF carrier frequency
  - Spreading code sequence length = 127 bit.
  - Spreading code sequence chip rate = 2.5 Mb/s
  - Data rate (R) = 0.5 Mb/s
  - Angle of arrival = 0\(^\circ\). (coming from broadside)

- **Two CW interferes:**
  - Parameter | first | second
  - Frequency | 70.5 MHz. | 71 MHz.
  - Angle of arrival | 19.5\(^\circ\) | 30\(^\circ\).
  - Phase shift | \( \pi/4 \) | \( \pi/4 \).
• Thermal noise: AWGN with zero mean and variance $\sigma^2 = 1$.
• Array: Number of elements $N = 4$. (Omnidirectional pattern for each element)
  Half wavelength element spacing $d = \lambda/2$.

3.2.1 Effect of INR:

The effect of the INR on the performance of the proposed system when two CW interferers are considered as depicted by the following scenarios:

- Scenario (1): $\text{SNR} = 10 \text{ dB}, \quad \text{INR}_1 = 0 \text{ dB}, \quad \text{INR}_2 = 0 \text{ dB}$.
- Scenario (2): $\text{SNR} = 10 \text{ dB}, \quad \text{INR}_1 = 10 \text{ dB}, \quad \text{INR}_2 = 0 \text{ dB}$.
- Scenario (3): $\text{SNR} = 10 \text{ dB}, \quad \text{INR}_1 = 20 \text{ dB}, \quad \text{INR}_2 = 0 \text{ dB}$.
- Scenario (4): $\text{SNR} = 10 \text{ dB}, \quad \text{INR}_1 = 30 \text{ dB}, \quad \text{INR}_2 = 0 \text{ dB}$.

The results of these scenarios are plotted in Fig (5). As the array has four elements, it has three degree of freedom. It uses on of them to make a pattern maximum in the direction of the desired signal. It consumes the other two degrees of freedom to make a null in the direction of each of the two interferers. As the INR of the first interferer increases the depth of the null formed by the array in its direction increases and the performances is improved. The mean square error that is reached for $\text{INR} = 30$ and 0 dB is nearly (-45 dB) while in case of $\text{INR} = 20$ and 0 dB is nearly (-35 dB). When the level of the first interferer is 10 dB (the same level as the desired signal), the minimum MSE is nearly (-20 dB) which is smaller than that of the previous two cases. This is because the interferer is so weak that it has a little effect on the weights of the array. The null depth that is formed in the direction of the first interferer is less than that in cases of stronger interferer.

3.2.2 Effect of number of elements in the array:

We consider here an adaptive array with 7 omnidirectional elements and half wavelength element spacing. We assume different signal scenarios to compare the performance of the system with that of the case of 4-element array. The results are plotted in Fig.(6) for the scenario of $\text{SNR} = 20 \text{ dB}$ and $\text{INR}_1=\text{INR}_2=30 \text{ dB}$ when $N=4$ elements and 7-elements respectively. We can note that the performance is better when $N = 7$ than for $N = 4$. In the first case ($N=7$) the steady state is reached after (520) iterations instead of (1120) iterations in case of $N = 4$. The MSE that has been reached equals (-38 dB) for $N = 7$ while for $N = 4$ it equals (-20 dB) this result agrees with that was obtained in case of single CW interferer. All the results of this section are summarized in Table (2).
Fig. (5) The MSE for the case of two CW interferers with different INR when SNR = 10 dB, the frequencies of the two interferers are 70.5 MHz and 71 MHz and their arrival angles are 19.5°, 30 degrees respectively.

Fig. (6) The MSE for the case of two CW interferers with equal INR = 30 dB and SNR = 20 dB for N = 4 and 7 elements respectively.
3.3 Results for three CW interferers:

In this section we present the results when three CW interferers are considered. The desired signal is a biphase DS-SS signal with the same parameters as in section (3.1.1) the interfering signals are considered to be three CW interferers with the following parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>First Tone</th>
<th>Second Tone</th>
<th>Third Tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>70.5 MHz</td>
<td>71 MHz</td>
<td>72 MHz</td>
</tr>
<tr>
<td>Angle of Arrival</td>
<td>19.5°</td>
<td>30°</td>
<td>45°</td>
</tr>
</tbody>
</table>

The thermal noise is assumed additive white Gaussian noise with zero mean and variance $\sigma^2$.

The adaptive LMS array has 4-elements with half wavelength spacing between elements. Each element has omnidirectional pattern. The behavior of the proposed system is tested with the following scenarios.

3.3.1 The three CW interferes have equal INR = 0 dB:

Scenario (1): SNR = 0dB.
Scenario (2): SNR = 10dB.
Scenario (3): SNR = 20dB.

The learning curves for these scenarios are plotted in Fig (7). It is noticed that as SNR increases the performance becomes better, when SNR = 20 dB, the system reaches the steady state after nearly (1120) iterations and the oscillation is damped. In this case the interfering signals are small compared with the desired signal so its effect on the weights is small while the effect of the desired signal is strong.
3.3.2 The three CW interferers have equal INR = 10 dB

Scenario (4): SNR = 0dB.
Scenario (5): SNR = 10dB.
Scenario (6): SNR = 20dB.

The results of these scenarios are plotted in Fig. (8). We can note that as SNR increases the performance becomes better also. When the SNR = 20 dB (higher than INR) the MSE that is reached at the steady state is (-42 dB) which is less than that reached in scenario (3) by nearly (10 dB). All the results of this section are summarized in Table (3).
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Fig. (8) The MSE for the case of three CW interferers with equal INR of 10 dB each for different SNR when the arrival angles of the interferers are 19.5, 30 and 45 degrees and their frequencies are 70.5 MHz, 71 MHz and 72 MHz respectively.

Table (3) Results for three CW interferers:

<table>
<thead>
<tr>
<th>No.</th>
<th>Desired Signal ( f = 70 \text{ MHz} )</th>
<th>1st ( \theta = 0 )</th>
<th>2nd ( \theta = 19.5 )</th>
<th>3rd ( \theta = 45 )</th>
<th>No. of Iter.</th>
<th>MSE dB</th>
<th>Number of elements</th>
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</tr>
<tr>
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</tr>
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4. CONCLUSIONS AND FUTURE WORK:

We have presented a new technique employing LMS adaptive antenna array combined with DS spread spectrum system for protection of CW interference. The reference signal is generated from the array output signal by using transform domain processing (TDP) technique. The proposed system has been examined by computer simulation. The learning curve, that show measurements of the interference suppression of the array and its dependence on various factors, are plotted. We have seen that the array provides a significant degree of protection to the system besides its inherent immunity to CW interference. The performance depends on the interference level at the input of the array. For low interference power, when the interference power is small compared with desired signal and thermal noise, it has little effect on the array feedback. When the interference power increases enough, however, the interference begins to dominate the error signal and the array feedback corrects against it. As the interference power increases further, the feedback loop gain in the array increases and the output interference drops. For large enough input interference power (approximately 30dB above the desired signal), the output interference begins to increase again and the steady state MSE increases.

We have seen that the system performs better when there is an adequate spatial separation between the desired signal and interfering signals. The closer the interference is to the desired signal, the more interference power will be present at the array output. Because the interference will be higher up on the main beam of the pattern. The interference null is close to the desired signal and there is a reduction in the desired signal power at the array output because of this null.

The error signal is made up of three components:

1. The desired signal minus the reference signal.
2. The thermal noise and
3. The interference.

To minimize the overall mean square error, the array feedback makes a compromise between these three components. In the general the weights that yield minimum error signal do not match the array output desired signal to the reference signal exactly. Rather, they compromise between thermal noise, interference and desired signal contributions to the error signal. The final weight setting compromises between decreasing the noise and increasing the desired signal.

It was found also that the performance of the system does not depend on the interference frequency. We expected this result since the array excises the interference by forming a null pattern in the direction of the interference in the spatial domain.

The proposed system operates to null the interference during the prelock up phase before code timing has been established. When the adaptive array operates with more interfering signals incident on it than it has degrees of freedom, the array does not form a null on each interferer. In this situation the array attempts to minimize the overall mean square error.

REFERENCES


تقنية جديدة مستخدمة أقل متوسط مربع خطا لمصفوفة هوائيات متكيفة متحدة مع المتتابعة المستمرة لنظام الطيف المنتشرالتداعي المستمر

نظراً للزيادة المطردة في كثافة الموجات الكهرومغناطيسية لأغراض الرادار والاتصالات ظهرت الأمزكى الكبرى لتصميم نظام لمقاومة التداخل والشوهرة التي تتعرض لها نظم الاستقبال للأغراض المختلفة.

ويتناول هذا البحث زيادة زيادة إمكانات نظام الطيف المنتشر (spread spectrum) في التغلب على التداخل والشوهرة والتي تعتبر من أهم مميزات هذه النظم حيث جعلتها تحتل مكاناً في مقدمة نظام التعديل في الاستخدامات العسكرية المختلفة وكذا الاتصال بالأشعة الصناعية.

وتتميز هذه النظم بالإضافة إلى فاعليتها الشديدة ضد التداخل والشوهرة، بنطاق ترددي واسع جداً بالمثابرة بالنطاق الترددي للمعلومات المرسلة، وهذا يقلل من كثافة القدرة المشعة مما يحرم أي متصنث من الحصول على المعلومات المرسلة.
والجديد في هذا البحث هو تقديم نظام جديد لزيادة قدره هذه النظم على مقاومة التداخل والشوشرة وخاصة التداخل الناجح عن الموجة المستمرة ذات التردد الواحد أو النطاق التردد الصغير، حيث اقترح استخدام هوائي من نوع (Adaptive Antenna Array) المصفوفة المتزامنة (LMS) يعمل بخوارزم أقل متوسط لمربع الخطأ. والإشارة المرجعية (reference signal) وخرج النظام ، وقد استخدم نظام المعالجة في الوسيط التردد الصغير مع الاستفادة من خاصية السعة الثابتة لإشارة المتابعة المباشرة (Transform Domain Processing) من نظام الطيف المنتشر لتوليد الإشارة المرجعية. وتم اختبار النظام المقترح بفترات وجود إشارة تداخل من مصدر واحد أو من مصادر من ثلاثة مصادر ومن اتجاهات مختلفة، وكان التحسن في متوسط مربع الخطأ يتراوح بين (50-150 ديسبيل) للحالة الأولى، (30-40 ديسبيل) للحالة الثانية، (25-35 ديسبيل) للحالة الثالثة، معتدماً على قدرة إشارة التداخل وقريبها أو بعيداً من الإشارة المطلوبة، ولاحظ أنه بزيادة عدد العناصر في مصفوفة الهوائي يزيد من التحسن في أداء النظام، واتضح التأثير الإيجابي لمستوى الإشارة المطلوبة، فزيادة قدرة الإشارة المطلوبة بالنسبة للضوضاء (SNR) تزيد من قدرة النظام على مواجهة إشارات داخل ذات قدرات عالية (INR) ويتميز النظام المقترح عن النظم السابقة بأنه بدأ العمل في توليد الإشارة المرجعية بمجرد إدارته للعمل أو عند تغيير الإشارات في الوسط الذي يعمل فيه، قبل الوصول للتزامن الكامل في المستقبل بين طور شفرة المتابعة المستقبلية والمتتابعة المولدة، بل لأنه زيادة على ذلك يعمل على سرعة إتمام عملية التزامن الكامل في المستقبل وتسهيل الزمن المطلوب لإتمام هذا التزامن.