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ADAPTIVE ARRAY SYSTEM FOR JAMMING SOURCES CANCELLATION IN TWO DIMENSIONAL PLANES

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Abstract: The aim of this paper is to enhance the desired signal reception while suppressing the reception of inference signals to get maximum signal to interference plus noise ratio (SINR) at the output. Airborne interference sources need to be canceling in two planes azimuth and elevation to ensure an active cancellation for these sources. It is found that a circular array adaptive antenna system has a good capability to track any source in two planes simultaneously so that it has been chosen .The function of proposed model is to put the main lobe in the direction of desired signal while creating nulls in the direction of interference sources .In this paper we proposed a circular adaptive antenna array system configuration in conjunction with minimum mean square error (MMSE) algorithm to suppress or cancel the effect of deliberated interference sources in the elevation and azimuth planes .The effect of interference signal parameters on the designed system performance is analyzed and investigated such as the output signal plus interference to noise ratio (SINR) and interference to noise ratio (INR).The results show that the proposed system exhibit a good cancellation performance in the azimuth and elevation plane in the direction of interferences sources while keeping track a maximum reception in the direction of desired signal.

Keywords: *adaptive array , adaptive beam-forming processing , smart antenna , uniform circular antenna array , minimum mean square error algorithm, signal to interference plus noise ratio , interference to noise ratio.*

الهوائيات الطورية المتكيفة لالغاء مصادرالتشويش في مستويين

الخلاصة: يهدف هذا البحث الى تحسين استلام الاشارات المرغوب بها وتخميد اشارات التداخل للحصول على اعلى نسبة اشارة الضوضاء والتداخل((SINR . ان مصادر الضوضاء المحمولة جواً تحتاج الى الحذف بمستويين الافقي والعمودي للتاكد من فعالية الالغاء لهذه المصادر . وجدنا إنه الهوائيات الطورية الدائرية تمتلك إمكانية جيدة في متابعة اي مصدر ضوضاء في مستويين في آن واحد ولذلك تم اختياره في هذا البحث. إن مهمة النموذج المقترح هي في وضع الفص الرئيسي للهوائي الدائري بإتجاة الاشارة المرغوب بها بينما توليد اصفار في نموذج الأشعاع الهوائي بإتجاة مصادر التداخلات. في هذا البحث تم اقتراح منظومة هوائيات دائرية تعمل بخوارزمية معدل مربع اقل نسبة خطأ (MMSE) لغرض تخميد او الغاء تأثيرات التداخلات المقصودة في المستويين العمودي والافقي . تأثيرات معاملات اشارة التشويش على تصميم وكفاءة المنظومة المقترحة تم تحليلها والتحري عنها كدراسة معامل الأشارة المفيدة الى التداخلات والضوضاء في خارج المنظومة (SINR) وكذلك دراسة نسبة التداخلات الى الضوضاء في خارج المنظومة (INR) . بينت نتائج البحث إن المنظومة المقترحة اعطت نسبة الغاء جيدة لمصادر التداخل في المستويين الافقي والعمودي بينما حافظت على توفير اعظم استلام بإتجاة الأشارة المفيدة.

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1. Introduction

Adaptive array processing plays an important role in diverse application areas, such as radar, sonar systems and wireless communication. Adaptive arrays are capable for spatial filtering, which makes possible to receive a desired signal from a particular direction while simultaneously blocking the interference signals from other directions [1]. Adaptive beam forming processor uses a complex signal processing beam forming algorithms in order to steer the main lobe of array towards a desired direction while suppressing or eliminating the interference sources. If a complex weight were used and adaptively updated in real time, according to receiving environment this process is called adaptive beam-forming. In this process a high directivity beam is steered in the direction of desired signal while nulls are created in the direction of interfering sources, this process leads to an improvement in the output signal to interference plus noise ratio (SINR). A summary of beam forming techniques is presented in [2]. An overview of signal processing techniques used for adaptive antenna array system is described in [3].
A “smart antenna” is generally referred to any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Smart antennas are generally encompassing both switched beam array system, and adaptive phase array system. Switched beam system has several available fixed beam patterns. While in an adaptive phased array system, the beam pattern changes as the desired user and the interference angle move by using electronic manipulation instead mechanical manipulation; this manipulation involves changes in both the amplitude and phase excitation of the antenna elements [4].

Adaptive phased array antenna system can be formed with different geometries. In general, these geometries can be classified based on the number of dimensions and can be extend to: linear (one-dimensional) , planar (two-dimensional) and conformal (three-dimensional).

This paper is divided into the following sections: in section 2 and 3 introduce the problem formulation and system consideration. Section 4 and 5 presented a mathematical modal and system performance parameters, section 6and 7 is for analysis, simulation and result discussion, finally section 8 concludes the paper.

2. Problem formulation

Cancel all airborne jamming sources against land or ship-born radars in azimuth and elevation planes simultaneously needs a configuration of phased array system which can provide full prior information about the spatial coordination of the airborne interferences sources. This information is then explored to design an adaptive system which can be used with a suitable algorithm to optimize the system SINR performance. A required driving weight vector in the path of received signals is needed in order to get this achievement by readjust the beam forming processor by changing the overall pattern shape in a way to put nulls in the directions of these interference sources in 2-D planes $(\theta, \emptyset)$ while keeping a main beam in the desired direction.

3. System consideration

3.1. Designing consideration background

Uniform linear array can only manipulate a direction in one-plane with spatial span range from (0-π) While the uniform circular array antenna (UCAA) can manipulate the direction of arriving signals in two planes $(\theta, \emptyset)$ .So UCAA have received significant attentions in the design of angle of arrival estimation systems [5]. Various kinds of works had been carried out to modify the radiation pattern of basic circular arrays system by optimizing its geometry to improve side lobe levels [6] [7] [8], improve adaptive beam-forming performance [9] [10] [11], and finally to reduce mutual effect between antenna elements [12][13][14] .etc.

3.2. Proposed modal system constriction

Comparing with linear array, the size of circular array can be fixed while the number of elements can be increased. For a circle with the fixed radius, the number of antennas which are arranged on its conference is flexible. [15] In our work, UCAA is used with N array elements distributed uniformly distributed on circumference of circle with inter element spacing between elements (d) with a radius R which is equal to

$$R = \frac{d}{2\sin\left(\frac{\pi}{N}\right)} \qquad (1)$$

This geometry offers azimuth angular coverage $(\emptyset)$ in the range from (0^{o} -2π) while angular elevation (θ) is covered in a range from (0^{o} - $\frac{\pi}{2}$) .

Fig.1 shows the geometry of uniform circular antenna array with N number of isotropic array antenna elements uniformly distributed on circumference of circle in x-y plane.

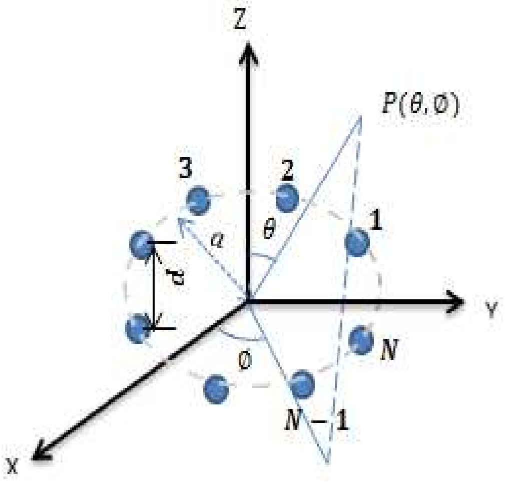


Figure 1. Uniform circular array antenna geometry

The array factor of uniform circular array antenna of N equally spaced elements is given by [12]:-

$$AF(\theta,\emptyset) = \sum_{n=1}^{N} I_n e^{i(KRsin(\theta)\cos(\emptyset-\emptyset_n))} \qquad (2)$$

Where (I_n) is the exaction current of the nth element, the phase constant K is equal to:-

$$K = 2\pi/\lambda \qquad (3)$$

and$\emptyset_n$ is the azimuth angular position of the nth element and its equal to

$$\phi_n = \frac{2\pi(\mathrm{n}-1)}{N} \qquad (4)$$

4 .The mathematical model [16],[17],[18]

Array antenna system consisting of N antenna elements as shown in Fig. 2. The received signals from each element is multiplied by a complex weight and summed to form the array output.

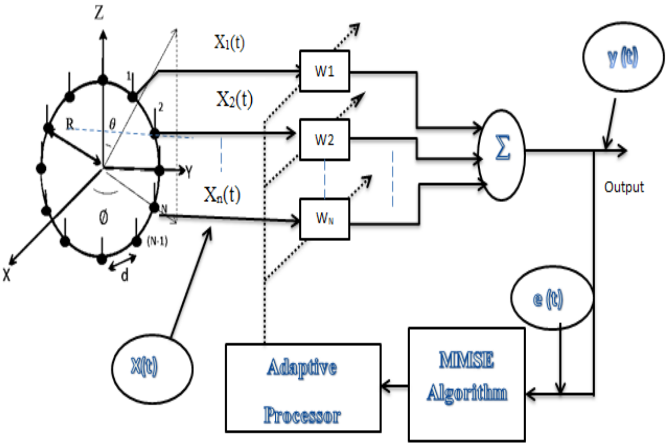


Figure 2. Uniform circular adaptive system

The received signal by any element can be expressed in scalar form as:-

$$x(t)=x_d(t)+x_i(t)+x_n(t) \qquad (5)$$

Eq.(5) In vector form can be written as: -

$$x(t)= x_d(t) + x_i(t) +x_n(t) \qquad (6)$$

Where: $x_d(t)$, $x_i(t)$ and $x_n(t)$ are desired , interference and thermal noise vectors of dimensions (1xN) ,respectively. If the desired signal is incident from angle $(\theta_{d,}\emptyset_d)$, then the received desired signal can be expressed in scalar form as :-

$$x_d(t) = A_d e^{i(w_0 t+\Psi_d)} \quad (7)$$

Eq.(7)In vector form can be written as :-

$$x_d(t)=A_d\, e^{i(w_0 t+\Psi_d)}\, u_d \quad (8)$$

where A_d is the signal amplitude, w_o is the center angular frequency, Ψ_d is the carrier phase angle and it is random variable uniformly distributed on (0^o- 2π) and $u_d$is a desired signal array vector containing the inter-element phase shift .For circular array geometry, the antenna elements are disturbed along a circle of radius R and the relative phase at the nth element with respect to the center of the array is: -

$$\psi_d=\frac{2\pi}{\lambda} R \sin \theta_d \cos(\phi_d - \phi_n) \qquad (9)$$

where ϕ_n *given by* (4)then u_d is given by :-

$$u_d=[e^{-i\psi_d 1}, e^{-i\psi_d 2}, \dots, e^{-i\psi_d N}]^T \qquad (10)$$

Where T denoted, transpose. If the interference is incident from angles $(\theta_i, \emptyset_i)$, the interference signal can be expressed in scalar form as: -

$$x_i(t) = A_i e^{i(w_0 t+\Psi_i)} \qquad (11)$$

Eq. (11) in vector form can be written as:-

$$x_i(t) = A_i e^{i(w_0 t+\Psi_i)} u_i \qquad (12)$$

Where A_i is the interference amplitude, Ψ_i is the carrier phase angle and it is random variable uniformly distributed on (0^o-2π) and independent of Ψ_d,and $\mathbf{u}_i$ is an interference signal array vector containing the inter-element phase shift. ψ_i is given by:

$$\psi_i=\frac{2\pi}{\lambda} R \sum_{l=1}^{M} \sin\theta_i \cos(\emptyset_i - \emptyset_n) \qquad (13)$$

where M is the interference sources number so that the and u_i given by :-

$$ui = [e^{-i\psi_i 1}, e^{-\psi_i 2}, \dots, e^{-i\psi_i N}]^T. \qquad (14)$$

The thermal noise voltage of the nth array element is zero mean and variance σ^2. The array thermal noise voltages are assumed to be mutually uncorrelated and uncorrelated with ψ_i, ψ_d, $\mathbf{x}_d$and $\mathbf{x}_i$. The noise vector express in vector form as :

$$\boldsymbol{x}_n(t) = [n_1(t), n_2(t), \dots, n_N(t)]^T \qquad (15)$$

The adaptive array output signal is:

$$y(t) = \sum_{i=1}^{N} w_n{}^* x_i(t) \qquad (16)$$

Where (*) is a complex conjugate notation. Eq. (16) can be written in a vector form as:

$$y(t) = w^H x(t) \qquad (17)$$

Where H is the a transpose conjugate, and

$$w = [w_1, w_2, \dots, w_n]^T \qquad (18)$$

The covariance matrix of received signal vector of array antenna is defined as

$$Cov[xx] = E[x^* x^T] = R_{xx} \qquad (19)$$

Where “E” denotes the expected value of random variable. Since $\mathbf{x}_d(t)$, $\mathbf{x}_i(t)$ and $\mathbf{x}_n(t)$ are assumed to be mutually uncorrelated the overall covariance matrix of received signal can be written as :-

$$\boldsymbol{R}_{xx} = \boldsymbol{R}_{dd} + \boldsymbol{R}_{ii} + \boldsymbol{R}_{nn} \qquad (20)$$

Where , $\boldsymbol{R}_{dd}, \boldsymbol{R}_{ii},$ and $\boldsymbol{R}_{nn}$ are (N x N) a desired signal ,interference and thermal noise autocorrelation matrices respectively .To search for an optimum value for weight vector (**w**) which can be applied in the channels of array system to maximize the desired signal reception and minimize or suppress the effects of interference sources , The minimum mean square error (MMSE) adaptive algorithm where be used with LMS adaptive processor and the Weiner-Hopf solution for optimum weight is found to be [18]

$$\mathbf{w}(t) = \boldsymbol{R}_{xx}{}^{-1} \boldsymbol{r}_{xd} \qquad (21)$$

Where $\boldsymbol{r}_{xd}$ is a cross correlation vector between reference signal and the received signal and equal to

$$\boldsymbol{r}_{xd} = E\ [\boldsymbol{x}(\boldsymbol{t})^*. d(t)] \qquad (22)$$

Where d(t) is the replica of desired signal.

5. System performance parameters [19]

In order to evaluate the performance of proposed modal the following measuring tools are used.

5.1 The output signal to interferences plus noise ratio (SINR) of the system

This parameter give a clear figure about the ability of the system to improve the desired signal level with respect to suppress interference signals level. The array output voltage due to desired, interference and thermal noise signals are $y_d(t)$,$y_i(t)$ and $y_n(t)$ respectively ,and they can be expressed as

$$y_d(t) = \mathbf{w}^H \mathbf{x}_d(t) \qquad (23)$$

$$y_i(t) = \mathbf{w}^H \mathbf{x}_i(t) \qquad (24)$$

$$y_n(t) = w^H x_n(t) \qquad (25)$$

SINR of the adaptive array system is defined as the ratio of the desired signal power to the interference plus thermal noise powers at the output of system and can be written as:

$$SINR = \frac{Pd}{Pi+Pn} \qquad (26)$$

$$Pd(t)= E\{ |y_d(t)|^2 \}=| w^H x_d(t)\, x_d(t)^H w| =w^H R_{dd}\, w \qquad (27)$$

$$Pi(t)= E \{| y_i(t)|^2 \} = | w^H x_i(t) x_i(t)^H w| = w^H R_{ii}\, w \qquad (28)$$

$$Pn = E\{ |y_n(t)|^2\}=| w^T x_n(t) x_n(t)^H w| =w^H R_{nn} w \qquad (29)$$

Therefor the output SINR is given by:

$$SINR = \frac{W^H R_{dd} W}{W^H R_{ii} W + W^H R_{nn} W} \qquad (30)$$

5.2. The interference to noise ratio (INR) at the output

This parameter gives a figure about the level of interference signals in the output of the system with respect to thermal noise level which can be considered a measuring tool for qualifying the adaptive processer goodness when dealing with interference sources in different scenarios.

INR of the adaptive array system is defined as the ratio of interference signal power to thermal noise power at the output of system and can be written as

$$INR = \frac{Pi}{Pn} (31)$$

$$INR = \frac{W^H R_{ii} W}{W^H R_{nn} W} (32)$$

6. Simulation & Results

In this section, the performance of the uniform distrusted circular antenna array is tested. The test is based on the study of the adapted radiation pattern and the output SINR of the system. The proposed model is programmed by MATLAB 8.3. The following assumptions are considered:

1- The mutual coupling effects between antennas elements are neglected because the inter element spacing is taken to be (d > 0.5 λ).

2- The inter element spacing is equal to 0.75 λ to prevent the grating lobes.

3-The number of isotropic array element sensors are ten.

6.1. Scenario (1)

In this scenario the ability of the system to suppress one interference source is tested. The desired direction elevation angle θ_d=90^{o} and the azimuth angle $\emptyset_d$ =40^{o} with input power ratio (SNR) =0 dB .The interference source elevation angle θ_i =50^{o} and azimuth angle $\emptyset_i$ =70^{o} with input power ratio (INR) =20 dB . Fig.3show that, the quiescent case exhibit maximum gain in the desired direction with the absence of interference source. When there is an interference source from elevation angle $\theta_i = 50^o$ the adaptive process determined anew adapted weight vector in the path of received signal which cause a beam-forming circuit to put deep null in the direction of the interference source while keeping a maximum pattern gain in the direction of desired signal . The weight vector in this case is changed from quiescent case w_q (only the desired and thermal noise present) which is equal to

$$w_q = [\overset{w1}{(0.909)}, \overset{w2}{(0.0909)}, \overset{w3}{(0.0909)}, \overset{w4}{(0.0909)}, \overset{w5}{(0.0909)},$$

$$\overset{w6}{(0.0909)}, \overset{w7}{(0.0909)}, \overset{w8}{(0.0909)}, \overset{w9}{(0.0909)}, \overset{w10}{(0.0909)}]^T$$

To anew adapted weight (desired ,thermal noise and interference signals present) :

$$w_{adt} = [\overset{w1}{(0.1177 + 0i)}, \overset{w2}{(0.0745 - 0.0067i)}, \overset{w3}{(0.0928 + 0.022i)},$$
$$\overset{w4}{(0.745 + 0.0067i)}, \overset{w5}{(0.745 + 0.0067i)}, \overset{w6}{(0.1177 + 0i)},$$
$$\overset{w7}{(0.0928 - 0.22i)}, \overset{w8}{(0.0928 - 0.22i)}, \overset{w9}{(0.0928 - 0.22i)}, \overset{w10}{(0.0745 + 0067i)}]^T$$

The adapted weight vector elements is just a complex weight emerged in the path of received signals.

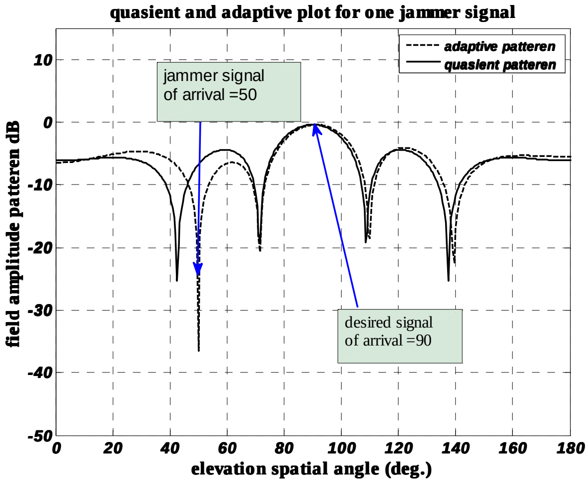


Figure 3, Quiescent and adaptive pattern plot for elevation plane

Fig.4 shows that the interference source for azimuth angle$\emptyset_i = 70$ is suppressed by the system. It can be conclude that by a proper choice weight vector, the system can suppress the interference source simultaneously in two planes. $(\theta, \emptyset)$.

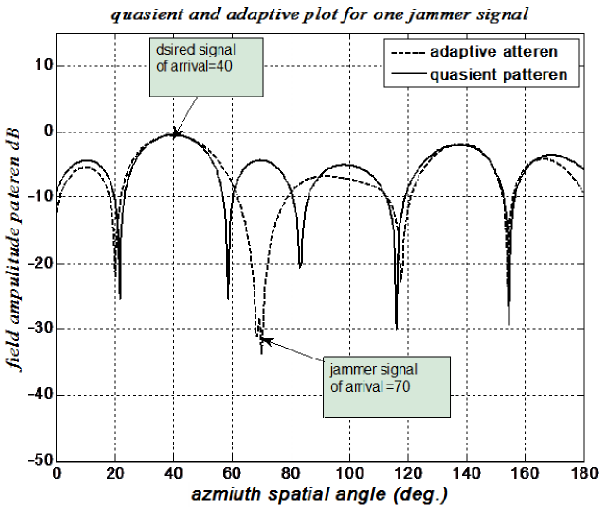


Figure 4, Quiescent and adaptive pattern plot for azimuth plane

6.2.Scenario (2)

In this scenario we test the ability of the system to deal with more than one interference source simultaneously (three interference sources) coming from different directions in elevation and azimuth domains, with the following assumptions: The desired signal angle of arrival is$\theta_{d=}90^o$,$\emptyset_d = 40^o$with input (SNR) =(0 dB , 0dB , 0dB) , three interferences sources arriving from elevation angles $\theta_i = (0^0, 50^o, 71.5^o)$,with azimuth angles $\emptyset_i = (21.5\,^o, 70^o, 90^o)$ with input INR's (20 dB, 20 dB , 20dB) respectively . Fig.5 shows that a deep nulls have been formed in the directions of interference sources while the main beam has been kept in the direction of desired angle, comparing the adapted pattern with quiescent pattern, one can deduce that the system is capable to deal with more than one interference source by putting a complex weight vector in the path of received signals, in such a way to reshape the quiescent pattern to put nulls in the direction of interference sources. The adapted weight vector which has been calculated for this scenario is

$$w_{adt} = [\ \overset{w1}{(0.0856 - 0i)}, \overset{w2}{(0.0964 - 0.335i)}, \overset{w3}{(0.0842 + 0.05i)},$$

$$\overset{w4}{(0.0842 + 0.05i)}, \overset{w5}{(0.0964 + 0.335i)},$$

$$\overset{w6}{(0.0.0856 - 0i)}, \overset{w7}{(0.0964 + 0.0335i)},$$

$$\overset{w8}{(0.0842 - 0.05i)}, \overset{w9}{(0.08420 - 0.05i)}, \overset{w10}{(0.0964 + 0.0335i)}]^T$$

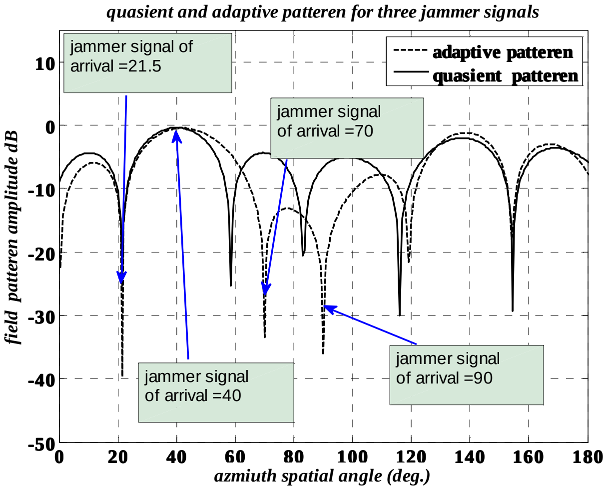


Figure 5, Quiescent and adaptive pattern plot for elevation plane

Fig.6 shows that the system is also completely suppressed the same interference sources arriving from different in the azimuth angles.

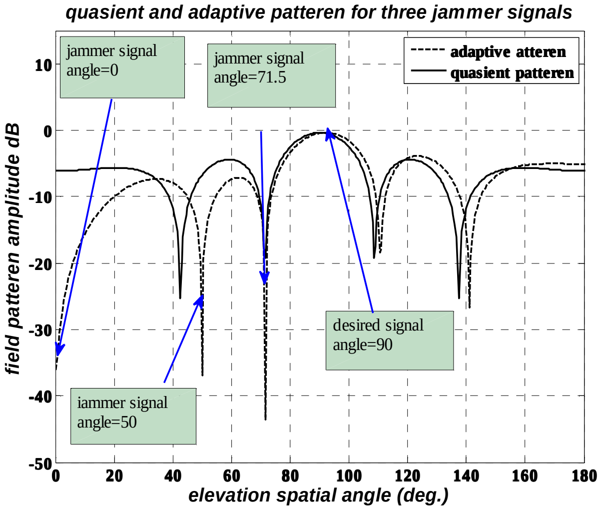


Figure 6, Quiescent and adaptive pattern plot for azimuth plane

6.3. Scenario (3)

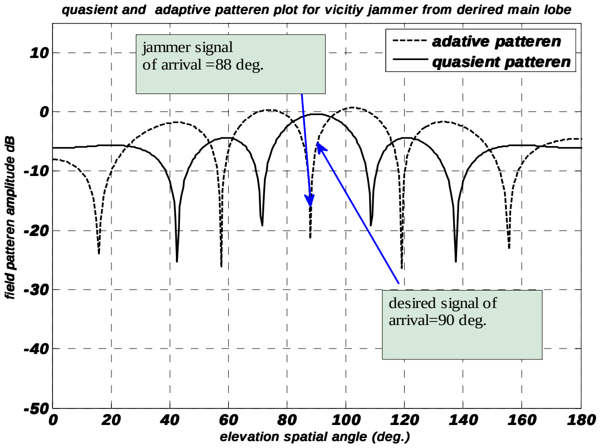
In this scenario the behavior of the system to deal with interference source arriving in the vicinity of main lobe of the array is tested, with the following assumptions: desired signal arriving angles are $\theta_{d=}90^o, \emptyset_d = 40^o$ with input SNR =0 dB, interference source arriving angles are $\theta_i = 88^o$ and $\emptyset_i = 38\ ^o$ with input INR= 20 dB . Fig. 7 shows that when the interference source arriving from direction situated in main beam region near to desired signal direction. The system create a null in front of interference source direction while trying to keep a reasonable pattern gain in the desired direction but not a maximum gain, due to the existence of interference source in the main beam region . The adapted weight vector which performs this process is:

$$w_{adt} = [\ \overset{w1}{(0.0134 + 0i)}, \overset{w2}{(0.022 + 0.1116i)}, \overset{w3}{(0.0358 + 0.1795i)},$$

$$\overset{w4}{(0.0358+0.1795i)},\overset{w5}{(0.022+0.1116i)},\overset{w6}{(0.0.134-0i)},$$

$$\overset{w7}{(0.022-0.1116i)},\overset{w8}{(0.0358-0.1795i)},$$

$$\overset{w9}{(0.0358-0.1795i},\overset{w10}{(0.022-0.1116i)}]^{T}$$

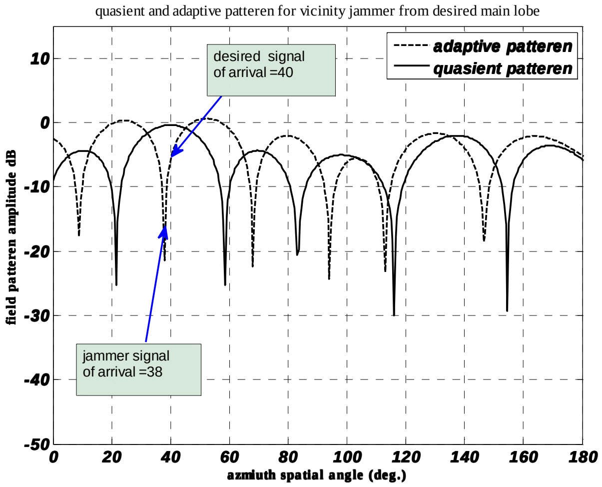

quasient and adaptive patteren plot for vicitiy jammer from derired main lobe

jammer signal of arrival =88 deg.

desired signal of arrival=90 deg.

Figure 7, quiescent and adaptive pattern plot in elevation plane

Fig.8 shows that for azimuth domain the system also creates null in the direction of interference source while keeping a less gain pattern in desired direction due to the same reasons mentioned in Fig.7.


quasient and adaptive patteren for vicinity jammer from desired main lobe

desired signal of arrival =40

jammer signal of arrival =38

Figure 8, quiescent and adaptive pattern plot in azimuth plane

6.4. Scenario (4)

In this scenario the output SINR of the system is tested for the case when angle of arrival of interference source scan a spatial span from (0^{o}) to (π), with the following assumptions: the desired signal directions are $\theta_{d=}90^{o}$,$\emptyset_{d} = 40^{o}$, with input SINR = 0 dB, with input INR= 20 dB .Fig.9 shows that the system exhibit a constant output

SINR for all elevations angles of arrival scanned by interference source except the case when interference angle coincide with desired direction ,the output SINR drops from 10 dB to -20 dB because the system is forced to put null in the direction of interference source to offer-20 dB attention in this direction while for other angles the system is succeeded for canceling the effect of interference source and keeping constant output SINR .

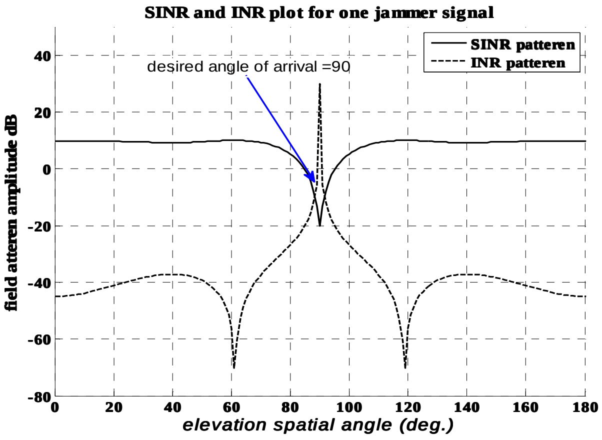


Figure 9, SINR and INR plot in elevation plane

Fig.10 show the output SINR for azimuth case. It can be seen that the system offered a fixed output SINR of about 10 dB when the interference angle of arrivals is from direction rather than the desired direction. While the output SINR drops from 10 dB to -20 dB when the interference direction is on a right angle with desired direction.

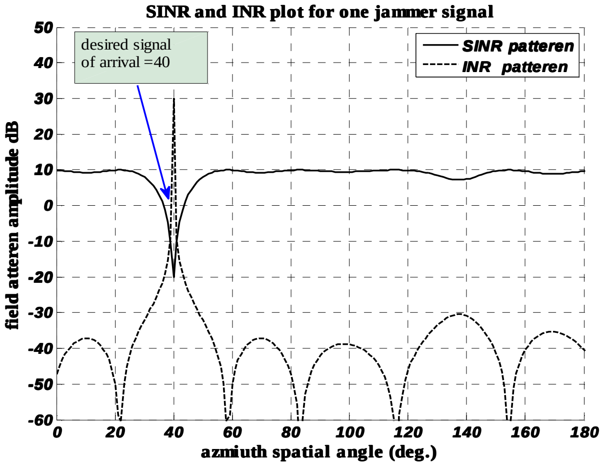


Figure 10, SINR and INR pattern plot in azimuth plane

7. Conclusions

The proposed adaptive array system with circular array antenna configuration with maximum signal to noise ratio algorithm is able to track the desired signal in both directions (azimuth and elevation) and exhibit a maximum pattern gain in the desired direction with the existence of more than one of interference sources arriving from different directions in azimuth and elevation planes rather than the direction of desired signal. The mount of nulling created in the front of the interference sources is proportional to the level of received interference signals. When the main beam of the array is subjected to interference sources, the system is still able to suppress the effect of this source while keeping reasonable gain pattern in the desired direction, meanwhile the inference source is not at the right angle of desired signal. The system is also exhibit a constant output SINR for all arriving angle of interference source except the case when the interference arriving from angles overlaps with desired angles in both planes azimuth and elevation causes the system exhibit poor performance.

Abbreviations

N	number of array sensors
d	inter element spacing between elements
R	radius of circle
$\emptyset$	azimuth angular coverage in the range from (0^o -2π)
θ	elevation angular coverage in a range from (0^o - $\frac{\pi}{2}$)
I_n	is the exaction current of the n^{th} element
K	phase constant
$\emptyset_n$	azimuth angular position of the n^{th} element
$x_d(t)$	desired signal vector of dimension (1xN)
$x_i(t)$	interference signal vector of dimension (1xN)
$x_n(t)$	thermal noise vector of dimension (1xN)
w_o	center angular frequency
$E[\,]$	expected value of random variable
w	weight vector
R_{xx}	overall covariance matrix of received signal
r_{xd}	cross correlation vector between reference signal and the received
w_q	quiescent weight vector
w_{adt}	adaptive weight vector

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