Fixed and Mobile Interference Cancellation for Syrian National Earthquake Monitoring Network

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Abstract:

The performance of radio communication system can be severely degraded by the presences of Radio Interference RI signals. Indeed, this degradation may be overcome to a some good extent by using various modern coding and modulation techniques. However, the effectiveness of these techniques depends, highly on the power level of RI signals. Better still if the RI signal can be suppressed at the output of the antenna prior to entering the receiver. In this paper we propose a viable scheme for RI suppression using phase array antenna by means of adjusting the phase of the array element only (i.e. phase perturbation) so that a null or more in the overall antenna pattern in directions of RI sources are synthesized. The system is, otherwise known as Phase Only Null-Steering PHONS. The optimum phase perturbation are evaluated using constrained optimization procedure which is based on Lagrange multiplier. The performance of the proposed PHONS is evaluated using computer simulation for a number of different conditions. The proposed PHONS scheme is compared with Side Lobe Canceller using Minimum Mean Square Error MMSE criterion in term of complexity and convenience.

An earthquake monitoring network was deployed nation wide in Syria back in 1987.The network is intended to sense, register, and monitor the seismic signals, and, subsequently locate the center of the earthquake event by means of Time Of Arrival TOA. However, Being an analogue system, the network inherently, suffers from a number of drawbacks such as the constant drift of operating points. These are usually remedied by a sustained efforts of calibration and maintenance. However, The network at the radio segments, is most venerable to the RI interference. This interference enters the receivers and causing a burst false alarm and thus degrading the network performance beyond any acceptable level.

In this paper we propose the PHONS scheme as a candidate solution to solve the problem of RI interference that the network is suffering from.

1. Introduction

The man made unwanted radio signals which are emitted from either fixed or mobile sources called otherwise Radio Interference RI, can severely degrade the performance of communication or radar systems. There exists a whole class of various measures which are designed to combat such interference. These measures are basically, centered on using low-side lobe antenna, side-lobe canceller and null-steering or moving to cleaner segment of radio spectrum if possible, in addition, of course to using various channel coding schemes. However, it is for certain that for the channel coding techniques to work properly and effectively, the level of RI interference should be kept low enough not to the point in order not to saturate the receiver, which is a parameter beyond one's control. For this reason, there has been a wide spread consensus, that it would be much wiser to suppress the RI interference at the output of the antenna prior to entering the receiver, so that the signal remains within the receiver linear operating region , permitting a proper conditions for applying the coding schemes.

The majority of methods concerning null steering are based on controlling a complex weights(both amplitude and phase),an amplitude only , a phase only or element position[2],[3].Various research works[2],[3][4] indicate that null steering with a complex weights is the most efficient of all above mentioned techniques. However, the complexity involved makes it un attractive. Amplitude only null steering based system, although is less sensitive to quantization noise it dose not guarantee enough dynamic range. On the other hand, PHONS scheme seems to be the to most simplest and proved to be effective even for limited number of array elements ,but it is rather sensitive to phase quantization. The evaluation of the phase perturbation for synthesizing a nulls in directions of interference source usually develops into minimization a non linear function. There have been a numerous techniques for non linear optimization to perform null steering[5-11]. In this article we propose an efficient algorithm for calculating the required phase perturbation required to synthesize a null or more in direction of RI interference sources .The algorithm is based on the constrained optimization of non linear function using Lagrange multiplier, which is in turn can be solved using Sequential Quadratic Programming SQP using .

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2.ADAPTIVE ARRAY -A BRIEF BACKGROUND:

The concept of the Adaptive Array antenna was first introduced by Van Atta [15] and others[16].The AA antenna has advanced communication ,radar and sonar systems to new era where a very useful functions could be performed ,that otherwise could not if just by relying on conventional reflector antenna. Among these function, there are, Radio Diversity, Beam Forming ,Side-Lobe Cancellation, and Null-Steering and recently the technique of Multiple Input Multiple Output MIMO.

In general the basic structure of an AA antenna is shown in Fig.(1).

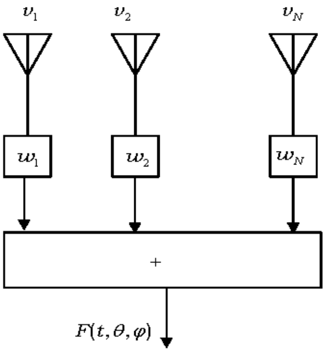


Fig.(1):The basic structure of AA antenna

It consists of a number N of receiving elements, placed at equal distance chosen to be $d = \frac{\lambda}{2}$ to prevent grating lobes. The receiving elements can be an acoustic sensors or omni directional antennas in case of a radio system (the case beforehand).As the wave plan makes an arrival angel with the bore sight of the antenna, then the out put of array elements ν_n will suffers a phase shift $\psi_n = n\frac{\pi}{\lambda}\sin(\theta) = u$,providing a spacing between array elements equals to the half of wavelength i.e. $d = \frac{\lambda}{2}$ so that grating lobes do not occur [17].The out put of each elements is then given by:

$$\nu_n = u(t)e^{j(w_0 t+\psi_n)} = u(t)e^{j(w_0 t+n\frac{\pi}{\lambda}\sin\theta)} \quad (1)$$

Where : $u(t), w_0$ are the complex modulating envelope and carrier frequency respectively.

Using matrix notion we may represent the out puts of array elements by the vector v where : $\mathrm{v}^T = [\nu_1 \nu_2 \nu_3 \ldots\ldots \nu_N]$ .And in same fashion the array weights vector is $\mathrm{w}^T = [w_1\, w_2\, w_3 \ldots\ldots w_N]$

In general, these weights are complex quantity such as:

$$w_n = A_n e^{j\varphi_n} \,.$$

The out put of the array is therefore given by :

$$y(\varphi_n, \theta, t) = \mathrm{w}^T\mathrm{v} = \sum_{n=0}^{N-1} w_n \nu_n \quad (2)$$

With adaptive array antenna there are two kingdoms. The first is centered on the time statistical characteristics of the signal and it leads to various RI cancellation schemes such as the one based on Minimum Mean Squared Error MMSE. The second is the centered on the spatial characteristic of the signal and leads to beam forming and null-steering. In the coming paragraph we well present a very brief introduction of these techniques.

2.1 Beam Forming:

Both of beam forming and null-steering concepts belong to the second kingdom in that we drop the time statistical characteristics of the signal i.e. putting $t = 0$ and hence:

$$\nu_n = e^{j\psi_n} \quad (3)$$

In this case the output of the array is called Array Factor, and in fact it is the square-root of directional array gain. Assuming omni directional elements i.e. $A_n = 1$,and no artificial phase shift i.e. $\varphi_n = 0$ the array facto is ,hence expressed as:

$$F(\varphi_n, \theta) = y(\varphi_n, \theta) = \mathrm{w}^T\mathrm{v} = \sum_{n=0}^{N-1} w_n \nu_n = \sum_{n=0}^{N-1} e^{j\psi_n} \quad (4)$$

When a gradient phase shift such as $\varphi_n = n\varphi_0$ is inserted in the bath of each array elements then the main beam of the array can be steered to angel α away from the bore sight as:

$$F_s(\varphi_n, \theta) = \sum_{n=0}^{N-1} e^{j(\varphi_n+\psi_n)} = \sum_{n=0}^{N-1} e^{j(\psi_n+n\varphi_0)} = F_s(\varphi_n, \theta + n\varphi_0)$$
(5)

Electronic(phase) beam steering array antenna are utilizesed extensively in modern radar and communication systems.

2.2 The Phase-Only Null Steering -The proposed method

-Problem Formulation:

The array gain called the array factor $F(\theta, \varphi_n)$ is given by :

$$F(\theta, \varphi_n) = \mathrm{w}^T\mathrm{v} = \sum_{n=0}^{N\ -1} e^{j(u+\varphi_n)} \quad (6)$$

where : $u_n = \frac{n\pi}{\lambda}\sin\theta$

The array power gain in direction θ is $:\left|F(\theta,\varphi_n)\right|^2 = \left|\mathrm{w}^T\mathrm{v}\right|^2 = \left|\sum_{n=0}^{N\ 1} e^{j(u+\varphi_n)}\right| = \mathrm{w}^T\mathrm{vw}$ (7)

We seek a phase vector $\varphi^T = [\varphi_0\ \varphi_2\ \varphi_3 \ldots \varphi_{N-1}]$ so that the array power gain in the main direction $\left|F(\theta_0,\varphi_n)\right|^2$ is maximized ,while the power gain in the directions of interference $\left|F(\theta_i,\varphi_n)\right|^2$ is minimized. The maximization $\left|F(\theta_0,\varphi_n)\right|^2$ of is equivalent to minimization $-\left|F(\theta_0,\varphi_n)\right|^2$. This task can be achieved with the help of the well known Non-Linear Programming NLP such that:

3-

4-

$$\text{Minimize } -\left|F(\theta_0,\varphi_n)\right|^2$$

Subject to constraint $\left|F(\theta_j,\varphi_n)\right|^2 = L_j \quad j = 1,\ldots\ldots mm$

and constraint $\left|F(\theta_i,\varphi_n)\right|^2 \le L_i \quad i = mm+1,\ldots\ldots m$

$$-2\pi \le \varphi \le 2\pi$$

where L_i and L_i is the specified level antenna side lobes and of null attenuation in interference direction respectively.

The problem of NLP can be carried out with the help of Lagrange function such as:

$$L(\varphi_n\ \ ,\lambda) = \ \left|F(\theta,\varphi_n)\right|^2 + \sum_{k=1}^{m} \lambda_k \left(\left|F(\theta,\varphi_n)\right|^2 \quad L_k\right) \qquad (8)$$

or

$$L(\varphi_n\ \ ,\lambda) = \ \mathrm{w}^T\mathrm{vw} + \sum_{k=1}^{m} \lambda_k \left(\mathrm{w}^T\mathrm{vw} \quad L_k\right) \qquad (9)$$

where: $\varphi \in R^N$, L_k is the constraint, and $\lambda = [\lambda_1\ \lambda_2\ \lambda_3\ \lambda_m]^T \in R^m$,is the vector of the

$$L(\varphi_n\ \ ,\lambda) = \ \mathrm{w}^T\mathrm{vw} + \sum_{k=1}^{m} \lambda_k \left(\mathrm{w}^T\mathrm{vw} \quad L_k\right). \quad (10)$$

The SQP starts form an initial iteration φ_n , Which is an initial approximate solution ,and an approximation of Hessian matrix such as $A \approx H = \nabla^2_{\varphi} L(\varphi_n\ \ ,\lambda) = \partial^2 / \partial\varphi_i \partial\varphi_j (L(\varphi_n\ \ ,\lambda))$

The SQP can be solved by using Newton unconstrained optimization, where the objective $-\left|F(\theta_0,\varphi_n)\right|^2$ function is replace by quadratic approximation $-\nabla(\left|F(\theta_0,\varphi_n)\right|^2)^T d + \frac{1}{2} d^T A d$,hence, it becomes a matter of solving the quadratic programming problem:

$$\text{minimize } -\nabla(\left|F(\theta_0,\varphi_n)\right|^2)^T d + \frac{1}{2} d^T A d \ (10)$$

subject to :

$$\nabla(\left|F(\theta_j,\varphi_n)\right|^2)^T d + \left|F(\theta_j,\varphi_n)\right|^2 = L_j \quad j = 1,\ldots\ldots,mm$$

and:

$$\nabla(\left|F(\theta_i,\varphi_n)\right|^2)^T d + \left|F(\theta_i,\varphi_n)\right|^2 \le L_i \quad i = mm+1,\ldots\ldots m$$

The above programming can be carried out recursively in the following steps:

Start with $k = 1$,and randomly generated vector $\varphi^T = [\varphi_0\ \varphi_2\ \varphi_3 \ldots \varphi_{N-1}]$ and an initial solution $d_1^T = [d_0\ d_1\ d_2 \ldots d_{N-1}]$

1- solve the QSP given in Eq.(10)and get d_k and λ_{k+1}

2- calculate the step length α_k in $\varphi_{k+1} = \varphi_k + \alpha_k d_k$ evaluate A_{k+1} from A_k using quasi-Newton formula.

3-set $k = k+1$ .Terminate when solution is found, or go to step 2.

2.3 The MMSE Radio Interference Cancellation Scheme:

The basic architecture of Minimum Mean Squared Error known other wise as Coherent Side Lobe is shown in Fig.(2).This scheme is based on the assumption that the array elements called auxiliary elements contain RI signal only, where as the main channel $m(t)$ contains useful signal $s(t)$ and RI signal $I(t)$ .The auxiliary elements vector is weighted and summed to form an estimate of RI signal such as:

$$x(t) = \mathrm{w}^T\mathrm{v} = \sum_{n=0}^{N-1} w_n v_n \qquad (12)$$

and subtracted from main channel to form the out pout of the system:

$$y(t) = m(t) - \mathrm{w}^T\mathrm{v} = m(t) - \sum_{n=0}^{N-1} w_n v_n \ (13)$$

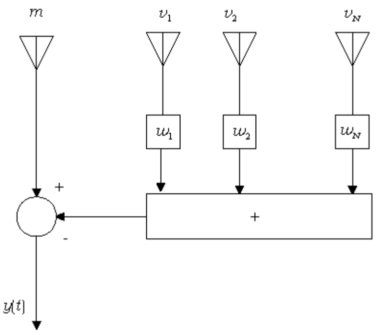


Fig.(2):The basic structure of MMSE RI cancellation

Based on the initial above assumption ,the minimization of the mean square "error" $\overline{y^2(t)}$ (i.e. the pout power) will ensure the cancellation of RI signal.
Perusing this criterion []yields a set of weights given by:

$$\mathrm{w} = R_{mm}^{-1} \rho_{mv} \qquad (13)$$

Where :

$$R_{mm}^{-1} = E\{\mathrm{w}^T \mathrm{m}(t) m^T(t) \mathrm{w}\} \qquad (14)$$

and : ρ_{mv} is the cross correlation between main and auxiliary signals.
is the autocorrelation matrix of signal in the main channel .The MMSE scheme provides an effective and robust cancellation of RI interference, But its costly in terms of computation burden ,where the inverse of correlation matrix R_{mm}^{-1} has to be estimated in real time.

3. Simulation results

The performance of null-steering scheme based on SQP minimization has been evaluated by means of simulation. The simulation starts with an array antenna of $N = 16$ of omni directional elements with Dolph-Chebshyve typering window ensuring $-20dB$ side lobe level as shown in Fig.(3).

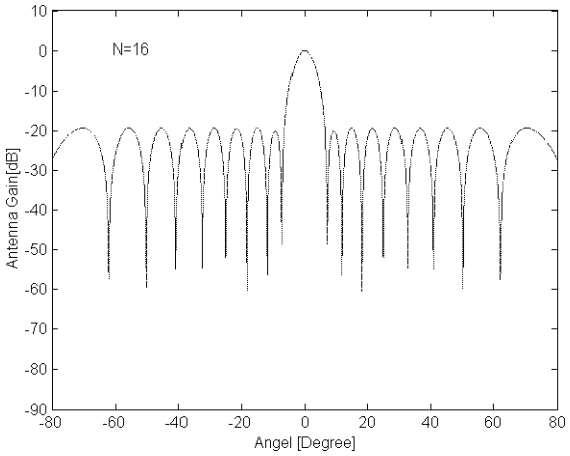
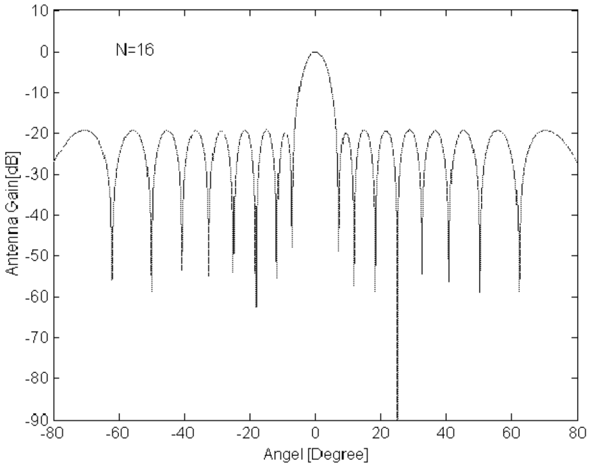


Fig.(3): A initial 16 elements array radiation pattern with Dolph-Chebchyve window

A single null is synthesized at $\theta = 25\deg$ as illustrated in Fig.(4).It was a sheer coincidence that this null coincided with a minima of side lobe in the original Dolph-Chebshyve array pattern, and this minima augmented the depth of the null .



Fig(4): A single null synthesized at $\theta = 25^0$

Anther null was synthesize deliberately at $\theta = 30\deg$ where side lobe maxima occurs and the result in null still exhibits an excellent depth of $-70dB$ as shown in Fig.(5).

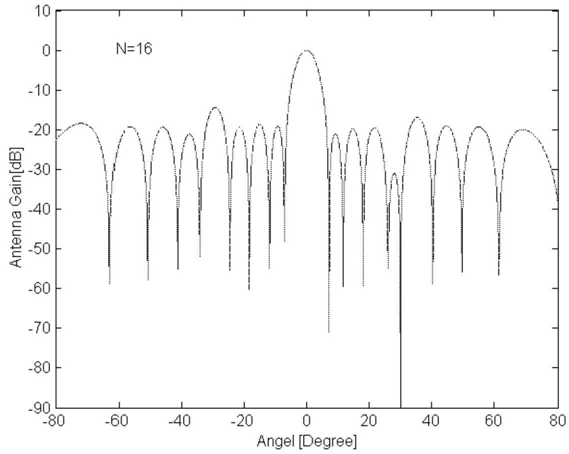


Fig.(5):Anther null synthesized at $\theta = 30^0$

With the array size is still the same $N = 16$, a broad null was synthesized by letting $L_i = 0.001$ for $\theta = 25 - 28\deg$ .The performance for this broad null is shown in Fig.(6),we still obtain an excellent null depth, but at the expense of small but satisfactory side lobe perturbation.

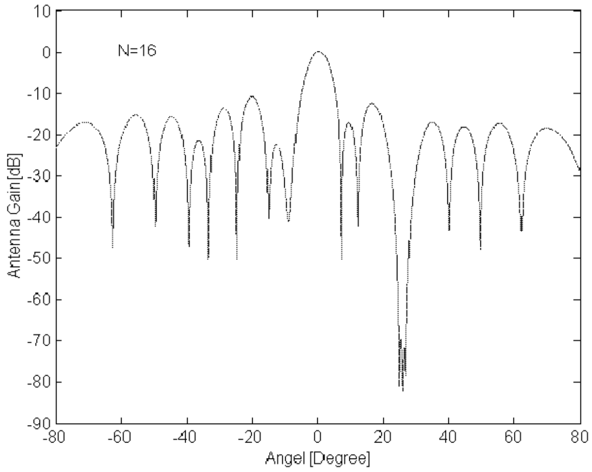
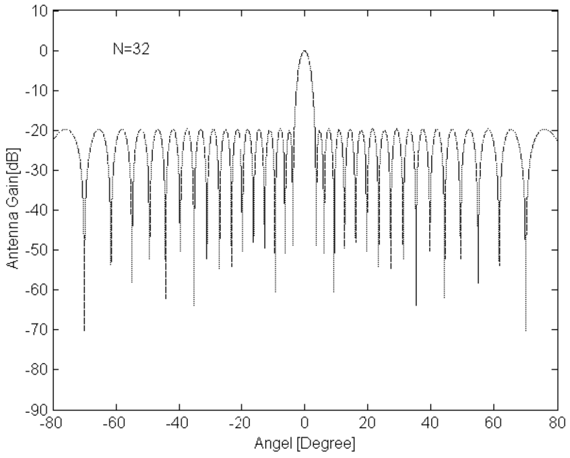
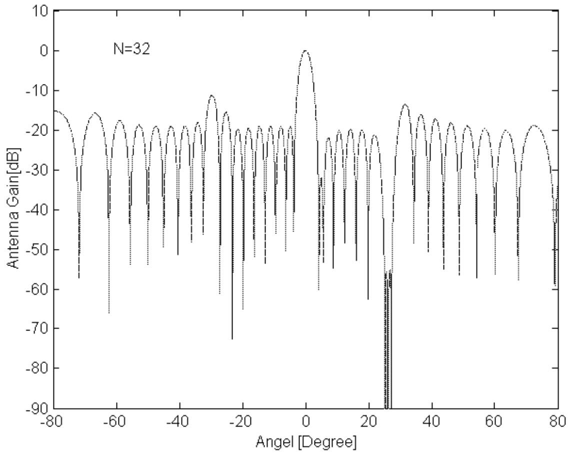


Fig.(6): A broad null synthesized at $\theta = 25 - 27^0$

Through the this simulation , it was found that these side lobe perturbation can be considerably improved by increasing the array size. The array size was doubled i.e. putting $N = 32$ with the use of the same $-20dB$ Dolph-Chebshyve typering window as shown in Fig.(7).The same broad null extending over the same angle range $\theta = 30 - 32\deg$ was synthesized with a very good result as shown in Fig.(8).with this result we still get a very good null depth for less side lobe perturbation.



Fig(7): A initial 32 elements array radiation pattern with Dolph-Chebchyve window



Fig(8): A single broad null synthesized at $\theta = 25 - 27^0$

Fig.(9) depicts the result of synthesizing two nulls. The first null location is at $\theta = -40\deg$ and the second null location is at $\theta = 25\deg$ .Again the depth of these two nulls are more than satisfactory.

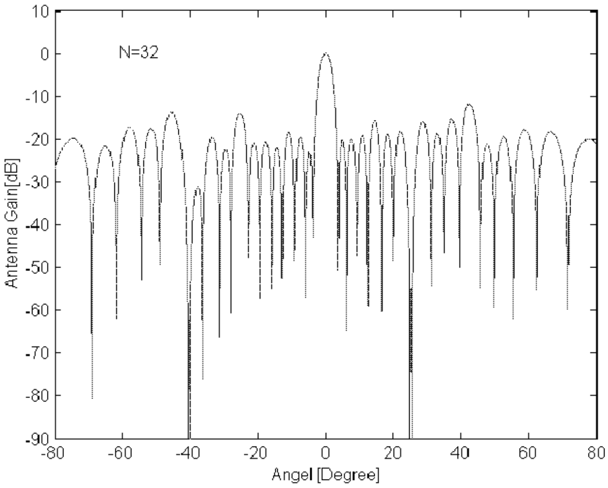


Fig.(9): two nulls synthesized at $\theta = -40^0$ **and** $\theta = 25^0$

We have carried the simulation one step ahead and test for the minimum array size with which we can still synthesize a null. It was found using simulation , that the minimum number of array element for satisfactorily performance is $N = 7$ as Fig.(10a,10b) depicts where a null in synthesized at $\theta = 40\deg$.It was found that reducing the array size below $N = 7$ would dilute the array gain in main direction.

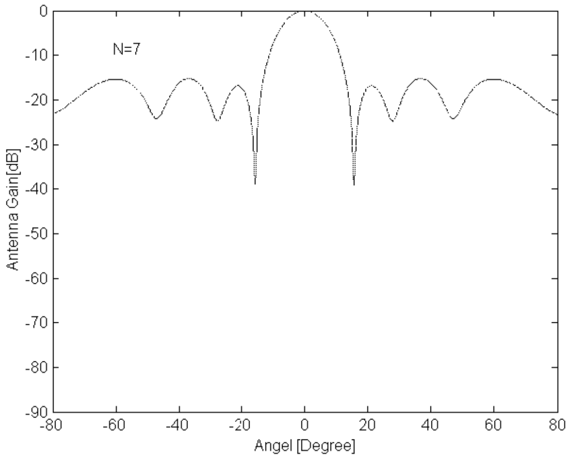


Fig.(10,a): A initial 7 elements array radiation pattern with Dolph-Chebchyve window

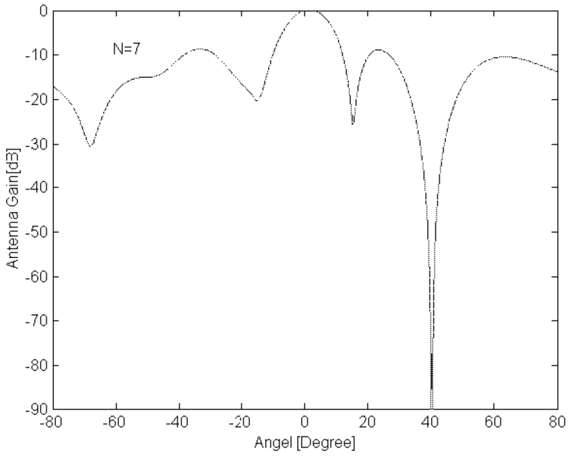


Fig.(10,b): A single null synthesized at $\theta = 40^0$

4. The proposed interference cancellation for the national Syrian earthquake monitoring network

The national Syrian earthquake monitoring network comprises of a number of field stations scattered nationwide and covering the major local seismic faults .Each field station is composed of seismic sensors (geophones) and a radio transmitter. The seismic vibration is picked up by the seismic sensors and transmitted via radio link to either gathering and monitoring center or to anther field station which acts as a sensing point and radio relay in the same time.

In both radio transmitter and receiver a Yagi-Udda type of antenna is used. As it is the case with any radio system ,the link suffers for the ever existing man-made RI. The RI can be either of fixed or mobile location. It enters the receiver from the side lobes of the antenna, causing a burst of false alarms and, thus, degrading the performance of the network.

At the Institute of Applied Science and Technology HISAT, Damascus-Syria the author has been leading a technical team who undertook the task of improving the performance of this network.

The work represented in this article serves as a theoretical basis for such undertaking. And by the end of the day one has to make the choice between either PHONS or MMES Side-Lobe canceller.
It seems to be that there is no clear cut solution in particular when we make the comparison between the two techniques.

The MMSE interference cancellation techniques has several pros. It is fully adaptive in sense it does not require a prior knowledge of direction of RI sources ,instead the null is adaptively adjusted in these RI source directions. And as such it is perfectly suitable for both mobile and fixed RI sources. The cons are first, an extensive signal processing tasks has to be executed in real time which include the inverse of the autocorrelation matrix. It requires a perfectly matched (complete super heterodyne receivers),and hence it can not be added to the already existing communication network using it's present receivers on Ad-hoc basis. And finally no receiver saturation is allowed hence it works on mild RI level RI .The PHONS cancellation scheme on the other has the following cons. It is much simpler and can be implemented at the output of the array elements using either analogue or digital phase shifters , and no signal processing is required. Second, as such it require single receiver and hence can be added to the existing network on Add-hoc basis. Third, since the RI cancellation takes place before the receiver ,there will be no receiver saturation for any level RI interference expected .The cons of the PHONS can be as follows. It is sensitive to phase quantization ,and it does require the knowledge of the direction of RI source *A priory* .

5. Conclusion

The proposed method of SQP optimization proved to be very effective in evaluating the phase perturbation needed to synthesized a null or more in the array radiation pattern in direction of RI sources by means of PHONS scheme . The performance of PHONS in term of RI cancellation effectiveness can be equivalent to that of MMSE based RI cancellation techniques. It's simplicity and the fact that it can be added to existing communication systems makes attractive and viable solution for remedying the fixed prescribed location RI interference that the national seismic monitoring network is suffering from. For mobile RI locations ,the solution may be found by incorporating the MMSE based RI cancellation technique.

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