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PHASE-ONLY ADAPTIVE NULLING WITH TAGUCHI'S METHOD FOR ANTENNA ARRAY SYNTHESIS

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ABSTRACT

A new and very speedy synthesis method for linear array antennas with periodic element spacing is described. This study presents an efficient method for the pattern synthesis based on Taguchi's method. A number of representative examples are presented to demonstrate the various unique capabilities of the method. A set of phase shift weights are generated in order to steer the beam towards any desired direction and avoiding interference. For isotropic linear antenna arrays parameter. The fitness function that allows the calculations of the phase shift weights is presented. The results of Taguchi's method are validated by using rectangular patch antenna and simulated by software CST2009 (CST microwave studio). Taguchi's method is briefly described in part 2. In part 3 the formulation of the array factor for linear arrays is given and fitness function will be mentioned. The numerical results optimized by Taguchi's method are given in part 4. The last results are discuss and validated by using rectangular patch antenna and simulated by software CST2009 (CST microwave studio) in part 5. Finally, part 6 makes conclusions.

Keywords: Rectangular Patch, Radiation Pattern, Phase Shift, Array Factor, Linear Antenna Array, Synthesis Method, Antenna Arrays, Taguchi's Method

1. INTRODUCTION

Recently, wireless communication technologies have experienced fast growth. Spatial processing is considered the last frontier in the battle for improved cellular systems and smart antennas are emerging as the enabling technique. The use of adaptive antenna arrays in mobile handsets can facilitate the elimination of co-channel interference and multi-access interference among other problems. In fact, the synthesis of antenna arrays plays a very important role in communication systems. Actually another global optimization technique such as Taguchi's method (Taguchi *et al*., 2005), has been introduced to the electromagnetic and antennas communities (Weng and Choi, 2009). It was successfully used to optimize linear antenna arrays, ultra-wideband antenna, planar microwave filter design and Coplanar Waveguide (CPW) slot antenna (Lee, 2001; Ghayoula *et al*., 2009).

Taguchi's method is further demonstrated by optimization of linear antenna arrays. It`s used to regulate phase parameter to achieve a desired angular sector and avoiding interference. This study is organized as follows.

2. MATERIALS AND METHODS

2.1. Taguchi's Optimization Method

Taguchi's optimization method will be briefly described here.

Using the concept of the Orthogonal Array (OA), (Weng *et al*., 2007a). Taguchi method effectively reduces the number of tests required in an optimization process. For more details, the interested reader may consult (Weng and Choi, 2009). The steps taken in Taguchi's optimization method can be illustrated in **Fig. 1**.

2.2. Design of a Linear Antenna Array

Taguchi's method is used in the synthesis of linear antenna array (Weng *et al*., 2007b), A set of phase shift weights are generated in order to steer the beam towards any desired direction and avoiding interference (**Fig. 2**) presents the antenna array geometry.

Which has N equally spaced elements along the axis x. The element spacing is half-wavelength and the excitations of array elements are symmetric with respect to the axis z (Gie and Rahmat-Samii, 2003).

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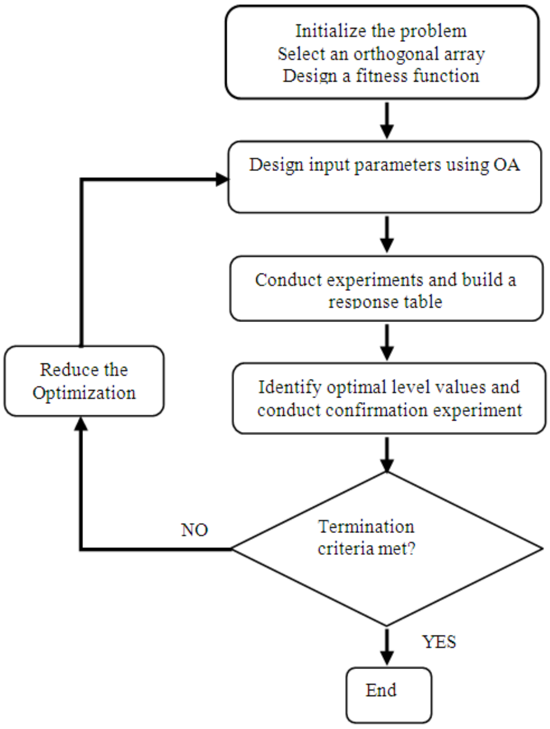


Fig. 1. Flow chart of taguchi method

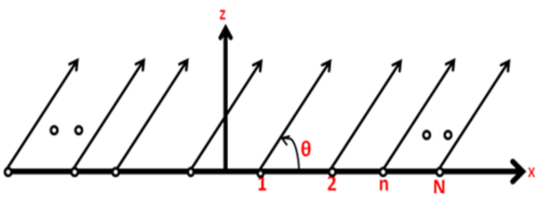


Fig. 2. Geometry of n-elements equally spaced linear array

For N-elements symmetrical array, the array factor can be written in the following equation 1:

$$AF(\theta) = \sum_{n=1}^{2N} \omega_n e^{j\varphi(n-1)(kd\cos(\theta)+\beta)} \quad (1)$$

$$\psi = kd\cos(\theta) + \beta$$

If the distance among elements is d and the reference point is the centre of the array, the new array factor is describes in equation 2:

$$AF(\theta) = \sum_{n=1}^{2N} \omega_n e^{j\varphi(n-N-0,5)\psi+\beta_n)} \quad (2)$$

Where:

2N = Number of antenna elements

ω_n = Amplitude weight at element n

β_n = Phase shift weight at element n

ψ = $\frac{2\pi}{\lambda} d\sin(\theta) = kd\sin(\theta)$

θ = Angle of interfering or desired signal

In this study, only the phase shift weights are considered, so the amplitude weights are constant. And if the phase shifts are odd symmetry, the array factor can be written in the below equation 3 and 4:

$$AF(\theta) = 2\sum_{n=1}^{N} \cos[(n-0.5)kd\sin(\theta) + \beta_n] \quad (3)$$

And in its normalized form:

$$AF_n(\theta) = \frac{1}{N}\sum_{n=1}^{N} \cos[(n-0.5)\psi + \beta_n] \quad (4)$$

This equation represents a mathematical description of the antenna radiation pattern and can be used by optimization algorithms (Zuniga *et al*., 2010). The Taguchi algorithm is able to search for optimal phase shift weights using a fitness function based on this array factor.

3. RESULTS

The following example was used to demonstrate the performance of the Taguchi algorithm. We will regulate the phase parameter to achieve a desired user and avoiding interference. To resolve the problem of direct beam forming, an array of 8 Isotropic elements is defined, so N = 4 which is the dimension of the problem. (**Fig. 3**) shows an illustration of the desired and interfering angles. The geometry of the linear array is defined as follows: The distance d of any two adjacent elements is set to $\lambda/2$.

Where λ is the wavelength. k equals to $(2\pi)/\lambda$ and represents the wave number; amplitude $\alpha(n) = 1$ and β_n, is the excitation phase that will be optimized in this interval [-180°,180°].

The algorithm stops after 100 iterations there are two conditions to be met, the fitness consists of two functions: F (θ_1) which will attempt to maximize the value of the array factor for the direction of user1 (desired angle).

While a second function, F (θ_2) must minimize the array factor for the direction of user2 (interfering angles). The following fitness function is deduced in equations 5-9:

$$fitness = F_1 - F_2 \quad (5)$$

Where:

$$F_1 = |AF(\theta_1)|^2 \quad (6)$$

$$= \left|\frac{1}{N}\right| \sum_{n=1}^{N} \cos[(d-0.5)k\sin(\theta_1)+\beta_n]^2 \qquad (7)$$

$$F_2 = \left|AF(\theta_2)\right|^2 \qquad (8)$$

$$= \left|\frac{1}{N}\right| \sum_{n=1}^{N} \cos[(d-0.5)k\sin(\theta_2)+\beta_n]^2 \qquad (9)$$

where, θ_1 and θ_2 correspond to the angles of user1 and user2 respectively.

4. DISCUSSION

Table 1 and 2 show the simulation results of the proposed approach when it is used with prescribed steering and null interference.

Table 1. Excitations for different steering lobes and null interference

	Synthesized excitations (phases)	
	Main lobe at -40°Null at 30°	Main lobe at -50°Null at 20°
	β_n	β_n
N	69.0502°	69.0538°
1	162.6982°	179.0013°
2	-54.3478°	-7.7110°
3	44.9444°	129.8318°
4	69.0502°	69.0538°

Table 2. The different parameter of rectangular patch antenna

L	W	h	tgδ	εr
36 mm	36mm	4 mm	2.10^{-2}	2.5

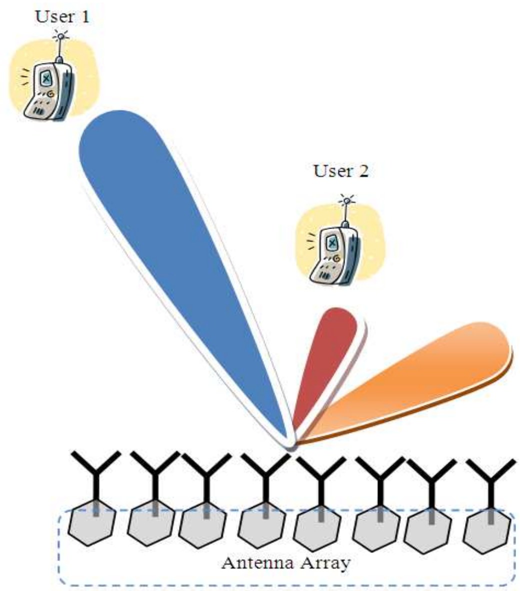


Fig. 3. Radiation pattern for desired and interfering angles

As the (**Fig. 4-5**) indicate, we can observe the performance of our algorithm. Figure show that the main lobe is directed to the appropriate sector and avoiding interference.

4.1. Validation of Results Obtained by Taguchi's Method

To validate the results obtained by our numerical tool for optimization (Taguchi's Method) we will refer to rectangular patch antenna. An eight-element linear rectangular patch (band 2.45 GHz, substrate plexy Glass with 4 mm height), uniformly (λ/2) spaced has been realised (**Fig. 6**) and tested for 2 cases of steered beams with null control.

The proposed design has been tested with good results. A 8-elements collinear half-wavelength patch array (**Fig. 7**) with centers separated is now used for synthesis purposes considering excitations with variable phases.

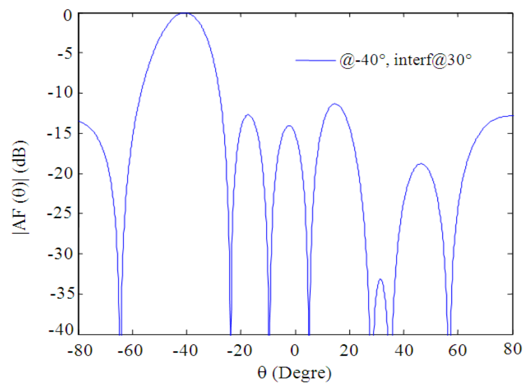


Fig. 4. Radiation pattern for desired and interfering angles -40, 30°C

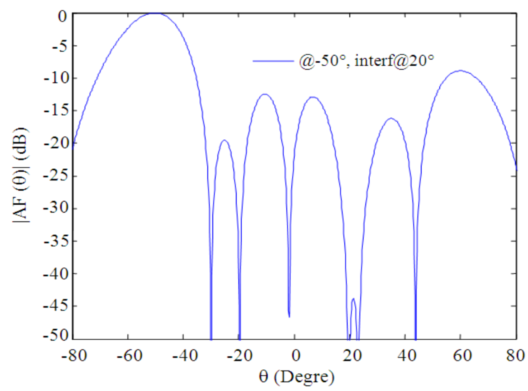


Fig. 5. Radiation pattern for desired and interfering angles -50°, 20°

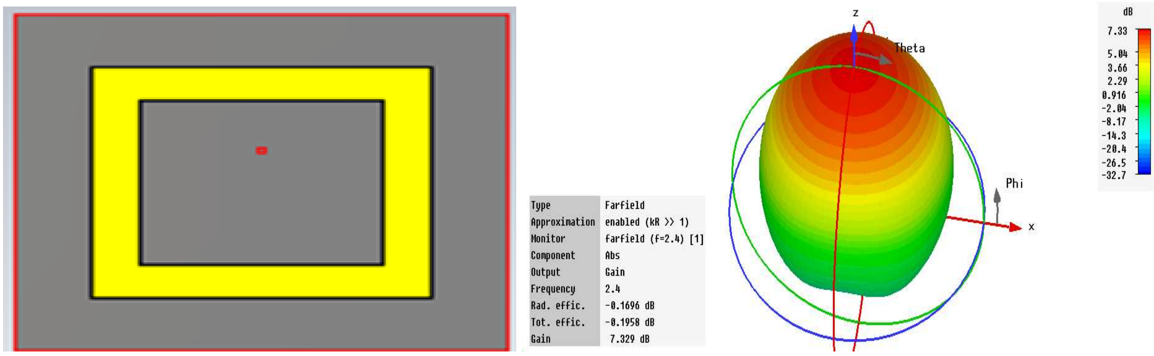


Fig. 6. The geometry of the antenna in microstrip technology (rectangular patch)

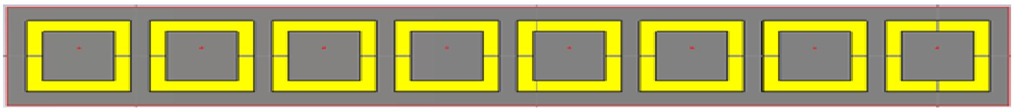


Fig. 7. Eight elements antennas array

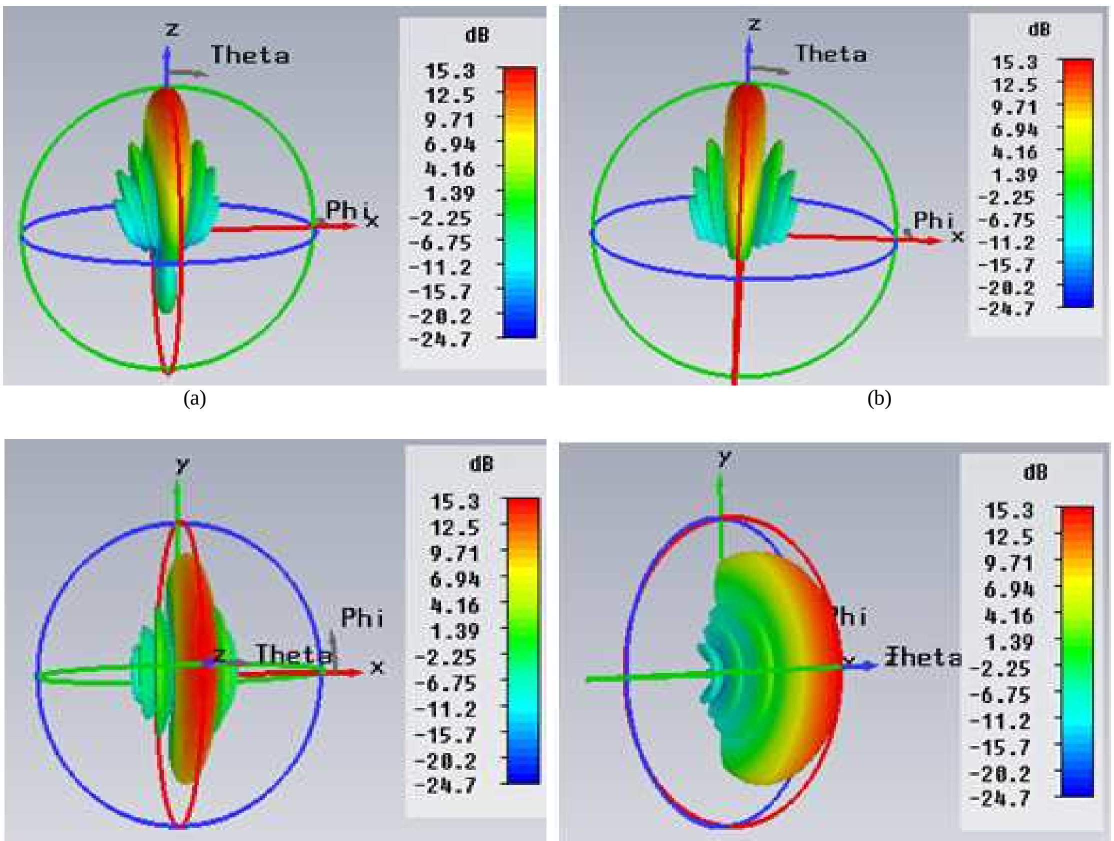
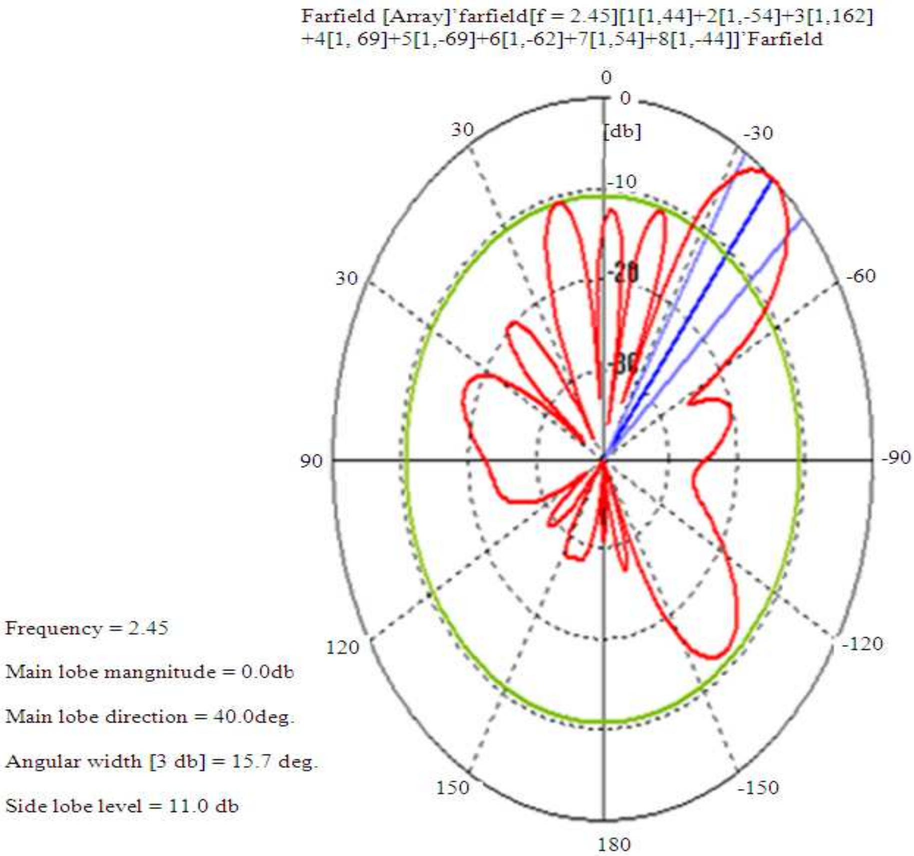
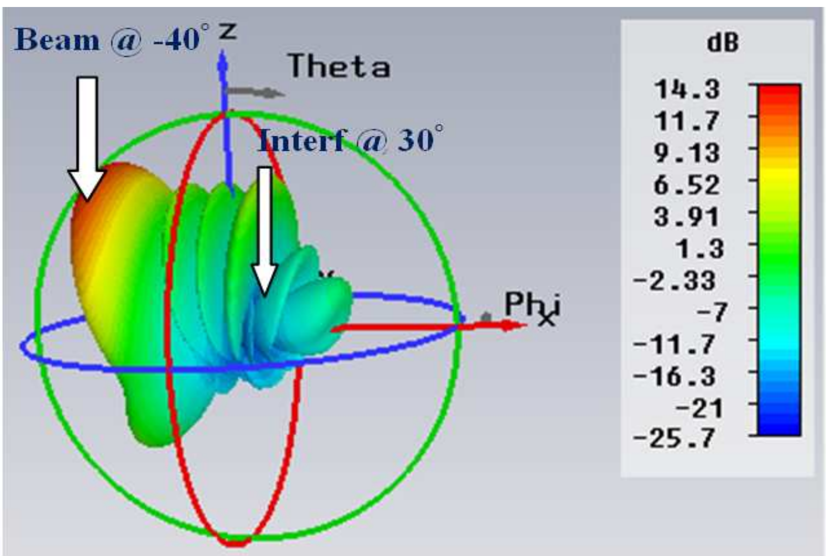


Fig. 8. (a, b, c, d). 8- Elements array pattern with (patch array antenna@2.45 GHz)

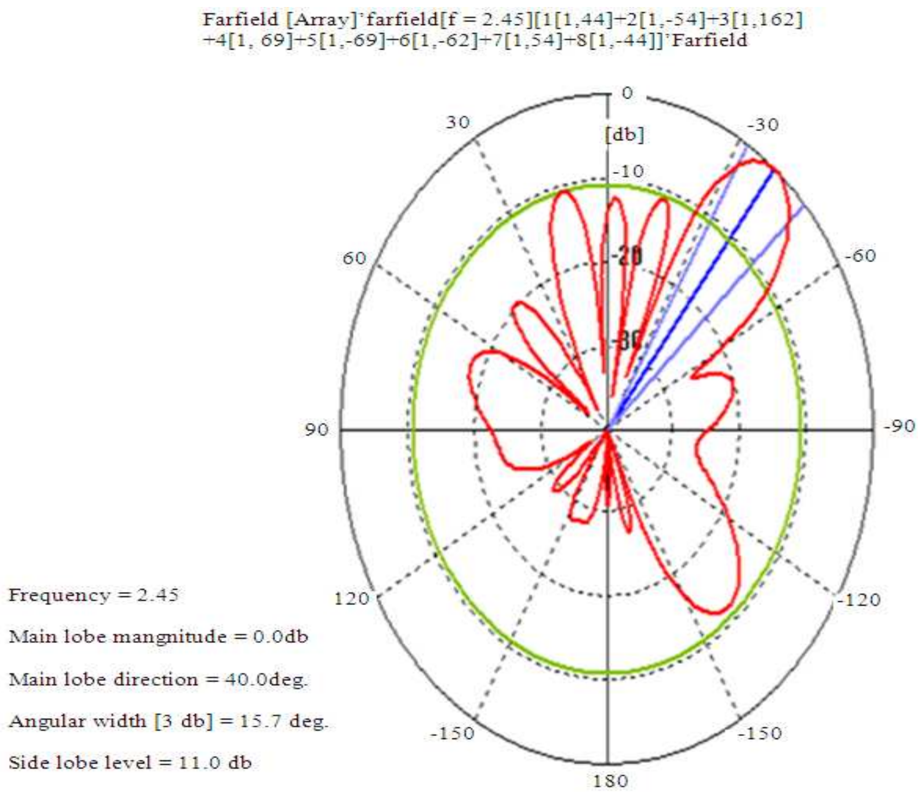


(a)

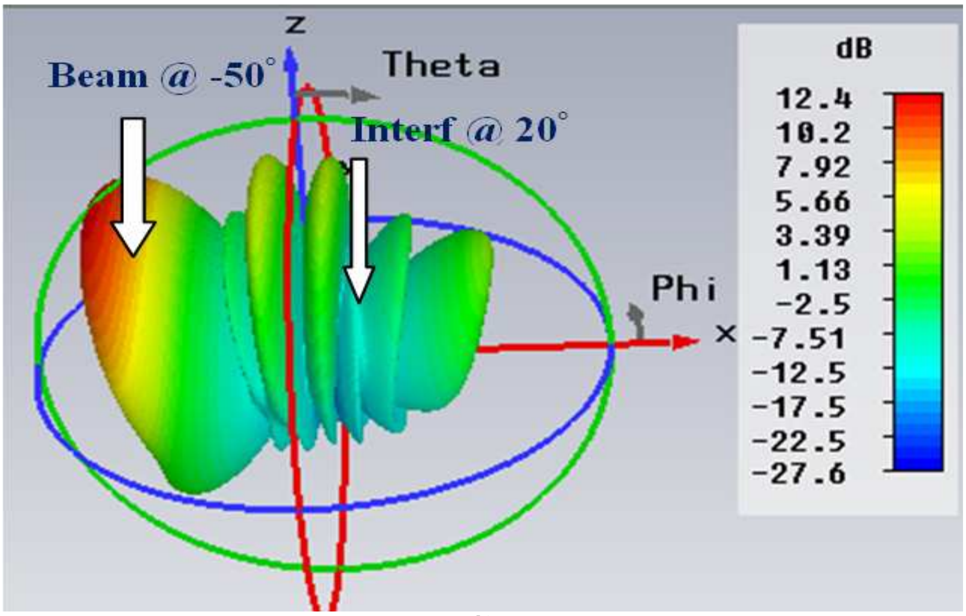


(b)

Fig. 9a, b. Radiation pattern for desired and interfering angles -40°, 30°



(b)



(b)

Fig. 10. (a, b) Radiation pattern for desired and interfering angles -50°, 20°

We have used the software CST2009 (CST microwave studio) in the simulation of radiation pattern of 8 elements linear array (rectangular patch).

Figure 8 presents the Radiation pattern simulated at different angle of view, with a frequency of 2.45 GHz and uniform excitations (amplitude and phase).

Figure 9a, b and 10a, b show radiation pattern of 8 elements linear array (patch) with excitation phases optimized by Taguchi's method (sector beam pattern and null steering).

5. CONCLUSION

In this study, a global optimization technique based on Taguchi's method is used (in the synthesis of linear antenna array) to obtain a set of phase shift weights. These weights were optimized in order to maximize the power of the main lobe at a desired direction while keeping nulls towards interferers. The results of Taguchi's method are validated by using array antenna (rectangular patch).At present; the possibility for optimizing both phase and amplitude is being investigated.

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