Performance Evaluation of Refinement Method for Wideband Two-Beams Formation

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Abstract—This paper presents the refinement method for two beams formation of wideband smart antenna. The refinement method for weighting coefficients is based on Fully Spatial Signal Processing by taking Inverse Discrete Fourier Transform (IDFT), and its simulation results are presented using MATLAB. The radiation pattern is created by multiplying the incoming signal with real weights and then summing them together. These real weighting coefficients are computed by IDFT method; however, the range of weight values is relatively wide. Therefore, for reducing this range, the refinement method is used. The radiation pattern concerns with five input parameters to control. These parameters are maximum weighting coefficient, wideband signal, direction of mainbeam, beamwidth, and maximum of minor lobe level. Comparison of the obtained simulation results between using refinement method and taking only IDFT shows that the refinement method works well for wideband two beams formation.

Keywords—Fully spatial signal processing, beam forming, refinement method, smart antenna, weighting coefficient, wideband.

I. INTRODUCTION

THE smart antenna systems consist of two main unit. The first main unit is antenna array and works together with the second part which is suitable signal processing unit for receiving and transmitting mode. The signal processing is the heart of systems to make them smart because it is able to steer main beam to desired direction, and deep nulls are created in the undesired direction. They can improve reliability and capacity in wireless communication systems. The smart antenna systems can be fulfilled with two additional functions: directional of arrival estimation or angle of arrival and beam steering of smart antenna [1]-[3]. Smart antenna systems can generally be classified as either switched beam or adaptive array. The switched beam smart antennas are designed to have several fixed beam patterns and decide to select the strength power signal of best fixed beam for receiving or transmitting signal. The adaptive array smart antennas allow the beam to be continually steered to some directions for providing the maximum of receiving signal or nulling of some interference [4], [5]. This is achieved by adjusting weights of each antennas used in array. Moreover, most beamforming algorithms for smart antenna systems proposed in the literature are related to the narrowband beamformer and cannot be directly extended to the wideband signal. The beamforming technique used in these narrowband systems has a bad impact of wideband signal on smart antenna systems, such as main beam squint and null shifting [6]-[8]. Thus, the

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beamforming algorithm of the current interest in the wide frequency is Fully Spatial Signal Processing. The configurations of this beamforming technique for wideband smart antenna systems consist of rectangular array antennas and set of attenuators or amplifiers. The working concept of Fully Spatial Signal Processing is that the signals are incident (or transmitted) on each antenna, then these signals are weighted by attenuator or amplifier in which the weighting values of attenuator (or amplifier) is calculated from IDFT technique. The obtained weighting coefficients are real numbers which can be realized by amplifiers or attenuators. Finally, all signals are combined into only one signal by using summing network [9], [10]. As a result, smart antenna systems can steer its main beam to any given direction, and weighting coefficients are calculated by taking IDFT to a symmetry function defining a proposed radiation pattern, so called objective function. The desired objective function is Chebyshev polynomial function because it can decrease side lobe level [11]. However, we can create several main-beams in the same time by merging multiple objective functions in order to save energy for unused area.

In literature [12], some authors have discussed about smart multi-beam concept of wideband smart antenna systems and shown the plot of Chebyshev polynomial function for two and three main beam directions. However, the range between maximum and minimum values of weighting coefficients is relatively wide and they are not integer. This is considerably impractical for hardware implementation. Therefore, this paper is to round all real-valued weights to integer number and to reduce between maximum and minimum weighting coefficient while maintaining some important radiation characteristics. The initial weighting coefficients are obtained from the original beamforming algorithm employed in fully spatial wideband beamformer. The proposed method is so called refinement algorithm. The refinement method for weighting coefficient is presented in literature [13] for only the main beam. Thus, this paper proposed to present performance of reducing the range of weighting coefficient by using the refinement algorithm.

The rest of this paper discussed about algorithm for wideband smart antenna systems, the method for producing multiple beam directions, the refinement algorithm, and its capability. The final section of this paper is the conclusion section.

II. SMART ANTENNA SYSTEMS

A. Fully Spatial Signal Processing

The configuration for wideband beamformer of smart

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antenna systems consists of rectangular array of $N_1 \times N_2$ antenna elements where d_1 and d_2 are array inter-element spacing in two orthogonal directions and along with amplifiers or attenuators and summing network [14] as shown in Fig. 1.
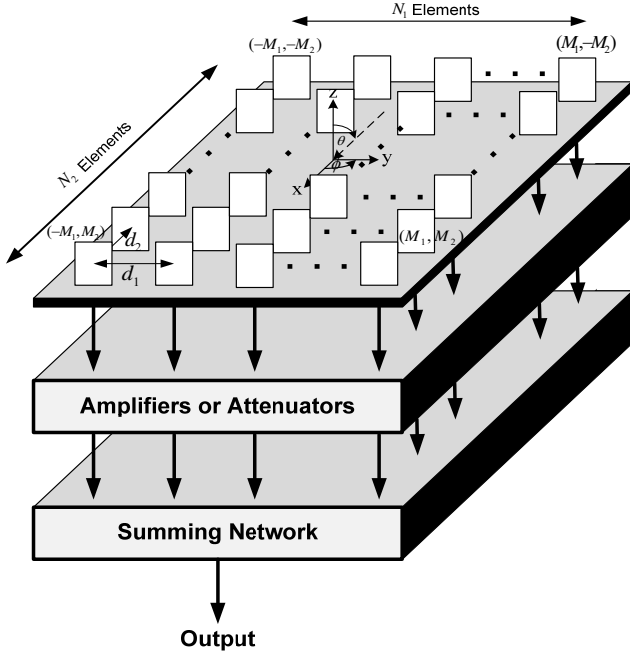

Fig. 1 Configuration of wideband beamformer

The direction of incident signal is determined by azimuth angle (ϕ) and the elevator angle (θ), when $\theta = 90°$, the phase of the signal at element (m_1, m_2) obtained with reference to the array center is given by

$$\psi(m_1, m_2) = (2\pi f / c)(d_1 m_1 \sin\phi + d_2 m_2 \cos\phi) \quad (1)$$

where f is the frequency variable, c is the speed of light, and ψ is the steering vector. Therefore, the array frequency-angle response can be written as

$$H(f, \phi) = G(f, \phi) \cdot \sum_{m_1=-M_1}^{M_1} \sum_{m_2=-M_2}^{M_2} w_{m_1, m_2} e^{j\psi} \quad (2)$$

and $H(f, \phi)$ is so called objective function.

B. Beamformer Using IDFT

Beamformer using IDFT is discussed to develop fully spatial signal processing based on rectangular array, where it is assumed that the origin point (0,0) is located at center of the antenna array. Then, assuming that two auxiliary functions are introduced as

$$u_1 = (fd_1 / c)\sin\phi \quad (3)$$

$$u_2 = (fd_2 / c)\cos\phi \quad (4)$$

These two functions are related by

$$(u_1 / u_2) = (d_1 / d_2)\tan\phi \quad (5)$$

The array frequency-angle response or objective function in (2) becomes

$$H(u_1, u_2) = \sum_{u_1=-0.5}^{0.5} \sum_{u_2=-0.5}^{0.5} G(u_1, u_2) w_{m_1, m_2} e^{j2\pi(u_1 m_1 + u_2 m_2)} \quad (6)$$

In order to determine the weighting coefficients w_{m_1, m_2} in (6), a modified IDFT and two auxiliary functions are applied to H as shown in (7):

$$w_{m_1, m_2} = \left(\frac{1}{N_{u_1} N_{u_2}}\right) \times \left(\sum_{u_1=-0.5}^{0.5} \sum_{u_2=-0.5}^{0.5} \left(\frac{H(u_1, u_2)}{G(u_1, u_2)}\right) \cdot e^{-j2\pi u_1 m_1} e^{-j2\pi u_2 m_2}\right) \quad (7)$$

III. MULTI-BEAM FORMATION

This section presents the concept to produce multiple beams for fully spatial beamformer. The Chebyshev polynomial function is chosen for objective function because it can reduce side lobe level and this function is also stable over a designated wide frequency band [15]. Therefore, the Chebyshev polynomial function can be expressed as

$$H(u_1, u_2) = \begin{cases} X & , desired\ frequency\ band \\ \dfrac{1}{\sqrt{10}} & , otherwise \end{cases} \quad (8)$$

where

$$X \begin{cases} (-1)^N \cosh(N \cdot \operatorname{arccos} h|x|) & , x < -1 \\ \cos(N \cdot \operatorname{arccos} x) & , |x| \leq 1 \\ \cosh(N \cdot \operatorname{arccos} hx) & , x \leq 1 \end{cases}$$

and

$$x = x_0 \cos(u / 2)$$

$$x_0 = \cosh \frac{\operatorname{arccos} SLL_{dB}}{N - 1}$$

$$u = \left(\frac{2\pi}{\lambda}\right) d \sin\phi$$

$$x = x_0 \cos\left(\left(\left(\frac{2\pi}{\lambda}\right) d \sin\phi\right) / 2\right)$$

or

$$x = x_0 \cos((\pi \sin[a \tan(u_1 / u_2 - \phi_0)]) / 2)$$

where SLL_{dB} is the desired side lobe level in decibel.

The procedure to produce multi-beam formation is implemented as follows. The new objective function is produced by merging multiple objective functions as written in (9)

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$$H(u_1,u_2) = H_{d_1}(u_1,u_2) + H_{d_2}(u_1,u_2) + \\ H_{d_3}(u_1,u_2) + ... + H_{d_n}(u_1,u_2) \tag{9}$$

and $H_{d_1}(u_1,u_2), H_{d_2}(u_1,u_2), H_{d_3}(u_1,u_2),..., H_{d_n}(u_1,u_2)$ is standard for objective functions in which the main beams are directed to $d_1, d_2, d_3,..., d_n$, respectively.

The objective function can be plotted from (9) as shown in Figs. 2 and 3 when two and three directions of main beam are required [12].

IV. REFINEMENT ALGORITHM

This section presents the refinement method for reducing the range of weighting coefficient for two beams formation. Therefore, the set of weighting coefficient values is obtained by taking IDFT of the values of $H(u_1,u_2)/G(u_1,u_2)$ in the u_1, u_2 plane in (7) which is defined as

$$W_0 = \{w_{o,1}, w_{o,2}, w_{o,3},..., w_{o,N}\} = \{w_{o,i}\} \tag{10}$$

where $i = 1, 2, 3,..., N$ and N is number of antenna array. The set from IDFT method is rounded to integer valued weights as shown in

$$W_r = Int\{w_{o,1}, w_{0,2}, w_{o,3},..., w_{o,N}\} \\ = Int\{w_{o,i}\} = \{w_{r,i}\} \tag{11}$$

or

$$W_r = \{w_{r,1}, w_{r,2}, w_{r,3}..., w_{r,N}\} \tag{12}$$

Then, the required characteristics of radiation pattern should be used in the following parameters:

1) Main beam has two directions ϕ_o^1 and ϕ_o^2, respectively.
2) First null beam width of two main beams are Θ_o^1 and Θ_o^2, respectively.
3) The maximum of minor lobe level is δ_{max}.
4) The maximum of weighting coefficient is w_{max}.

The procedure to reduce the range of weighting coefficients consists of the following five steps:

Step 1. Determine the maximum of weighting coefficient in (11) or (12) that is

$$w_{max}^{(k)} = \max_{i=1}^{N} \{w_{r,i}\} \tag{13}$$

where $k = 1, 2, 3,...$ is the order of iteration.

Step 2. Decrease the maximum of weighting coefficient by weighting step size (Δw), which is an integer and $\Delta w > 0$.

$$w_{max,j}^{(k)} = \left\| w_{max}^{(k)} - \Delta w \right\| \tag{14}$$

where $j = 1, 2, 3,....$ and then, replace $w_{max,j}^{(k)}$ with $w_{max}^{(k)}$ in the set of W_r. That is

$$w_{max,j}^{(k)} \Rightarrow w_{max}^{(k)} \tag{15}$$

Step 3. Multiply W_r by steering vector ψ, therefore the array output is

$$y_j^{(k)} = \sum_{i=1}^{N} w_{r,i} e^{\psi} \tag{16}$$

Step 4. Now, the radiation pattern is obtained from (16), and then, checking for some significant characteristics of radiation pattern such as direction of two main beams, beamwidth of two main beams and maximum of minor lobe level can be determined according to the following conditions:

1) The maximum of weighting coefficient in (14) is less than that of (10)

$$w_{max,j}^{(k)} \leq w_{o,max} \tag{17}$$

2) The first and second directions have no deviation greater than $\Delta\phi$

$$\phi_o^1 - \Delta\phi \leq \phi_{r_1}^{(k)} \leq \phi_o^1 + \Delta\phi \tag{18}$$

$$\phi_o^2 - \Delta\phi \leq \phi_{r_2}^{(k)} \leq \phi_o^2 + \Delta\phi \tag{19}$$

3) The both of first and second beamwidths have no deviation greater than $\Delta\Theta$

$$\Theta_{r_1}^{(k)} \leq \Theta_o^1 + \Delta\Theta \tag{20}$$

$$\Theta_{r_2}^{(k)} \leq \Theta_o^2 + \Delta\Theta \tag{21}$$

4) The maximum of the minor lobe level is deviation not higher than $\Delta\delta$

$$\delta_r^{(k)} \leq \delta_{max} + \Delta\delta \tag{22}$$

where w_{max} is the desired maximum of weight coefficient, $\Delta\phi$ is deviation of main beam angle, $\Delta\Theta$ is deviation of the first null beam width, $\Delta\delta$ is deviation of maximum minor lobe level.

Step 5. Repeat the steps 1 to 4 until the maximum of weighting coefficient is zero under these conditions, and then the set of new solution is obtained for the refinement method.

V. REFINEMENT METHOD CAPABILITIES

In this section, the refining performance of the proposed concept is tested through computer simulation by using

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MATLAB in terms of radiation pattern. We present the objective function which is Chebyshev polynomial function and compare between only taking IDFT and refinement method for two main beams formation operating frequency from 1.9 to 2.5 GHz. We divided into the following three cases.

Case I: Initial conditions are produced, and two main beams are directed to $-50°$ and $60°$, respectively, and an 8×8 array of omnidirectional antennas is used. For smart antenna systems, the weighting coefficients are calculated by taking IDFT directly to the objective function presented in section II and III, and the radiation pattern result is shown in Fig. 2. The maximum weight of this condition is 16.5 dB as shown in literature [12], and then, we used the refinement method for this set of weighting coefficient. The parameters given for the refinement method are $\Delta\phi = 5°, \Delta\Theta = 5°$ and $\Delta\delta = 5\,dB$. The decreasing step size of weighting coefficient is 1 dB. As a result, after performing the refinement method, its dynamic range of weights can be reduced from 16.5 dB to 11 Db, and the radiation pattern is illustrated in Fig. 3.
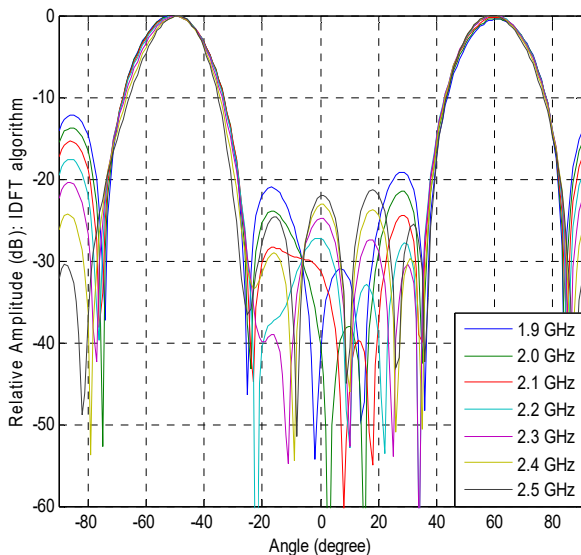

Fig. 3 Radiation pattern using the proposed refinement method when two main beams are pointed to $-50°$ and $60°$, respectively

Fig. 2 Radiation pattern using the IDFT method when two main beams are pointed to $-50°$ and $60°$, respectively

Case II: The first main beam is pointed to $-30°$, and the second is $20°$ for array antennas which have the same size as in the first case. The radiation pattern is demonstrated in Fig. 4 for using IDFT method. From the simulation results, the maximum of weighting coefficient is 43 Db, and then, we take the set of weight to refine, and significant parameters are $\Delta\phi = 3°, \Delta\Theta = 3°, \Delta\delta = 3dB$. The decreasing step size of weighting coefficient is 1 dB. The result showed that this method can reduce the maximum of weighting coefficient from 43 dB to 16 dB. The radiation pattern using refinement method for two main beams is shown in Fig. 5.
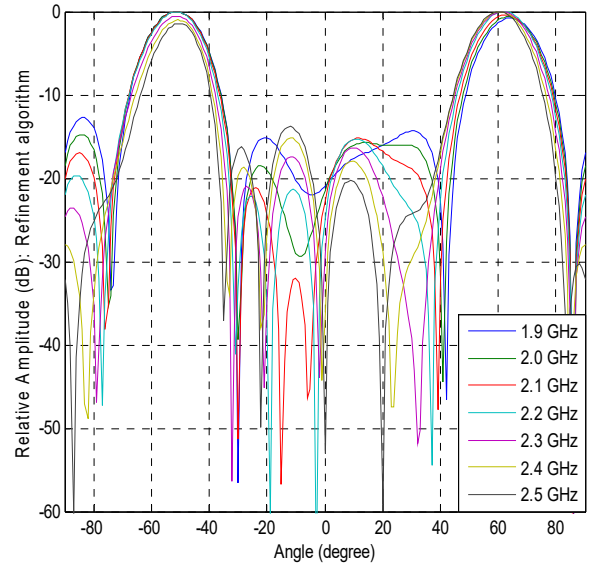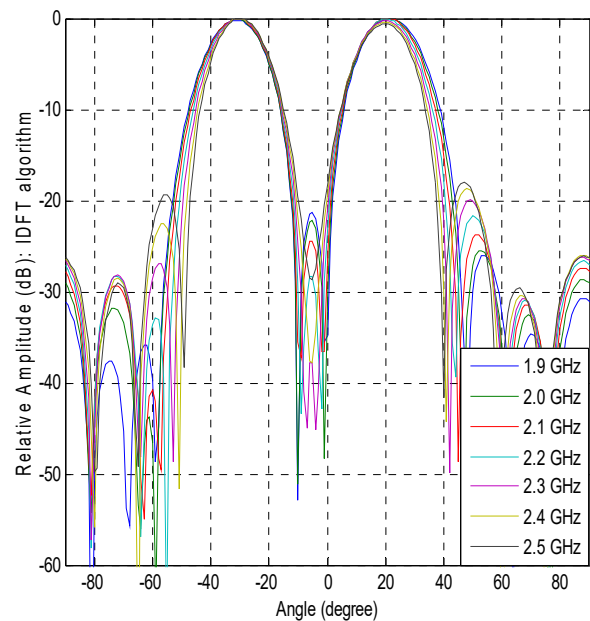

Fig. 4 Radiation pattern using the IDFT method when two main beams are pointed to $-30°$ and $20°$, respectively

From the second case, if we change all parameters which are $\Delta\phi = 5°$, $\Delta\Theta = 5°$, $\Delta\delta = 5dB$, the refinement method can reduce to 12 dB, and radiation pattern is demonstrated in Fig. 6.

Case III: This case is present when two main beams are directed to -65 and $65°$, respectively. The result of radiation pattern is shown in Fig. 7 and the maximum of weighting coefficient is 34 dB when we used the IDFT method.

Table I shows three types for simulation to validate the performance of the proposed refinement method for fully spatial beam-former. Some parameters, e.g. maximum of

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weighting coefficients (w_{max}), deviation of main-beam angle $(\Delta\phi)$, first null beamwidth $(\Delta\Theta)$ and maximum of minor lobe level $(\Delta\delta)$ are different in each type. For type I, all parameters are assumed for ideal case with no error. Running the simulation shows that maximum of weighting coefficient can be reduced from 43 dB to 25 Db, and its radiation pattern is shown in Fig. 8. This means that this case is successful for the proposed refinement method. After that, we refine the obtained weights from IDFT and varied parameters as shown in Table I. However, for type II and III, can reduce the maximum of weighting coefficient slightly from 43 dB to 20 dB and 19 dB, can be reduced, respectively, and radiation patterns are shown in Figs. 9 and 10. The radiation patterns of Figs. 9 and 10 showed that the minor lobe level is increased for only between two main beams.
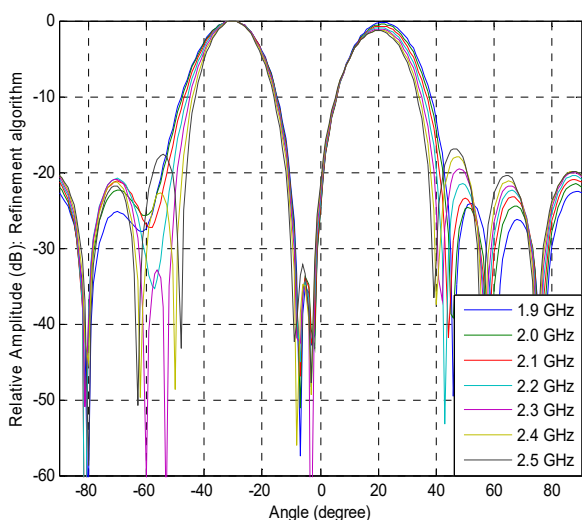

Fig. 5 Radiation pattern using the proposed refinement method when two main beams are pointed to $-30°$ and $20°$, respectively
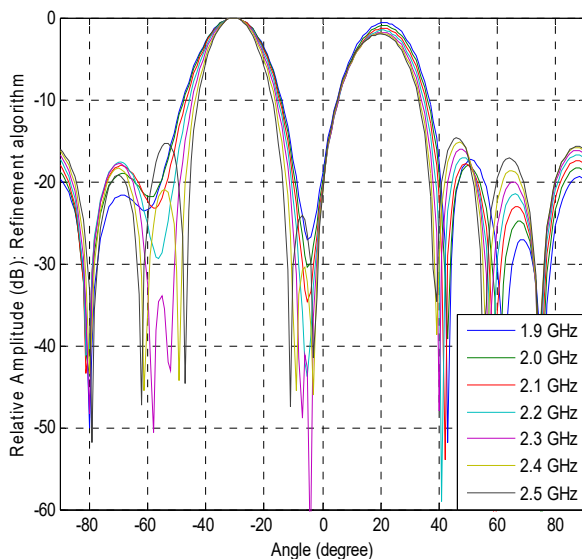

Fig. 6 Radiation pattern using the proposed refinement method when $\Delta\phi = 5°$, $\Delta\Theta = 5°$, $\Delta\delta = 5\,dB$
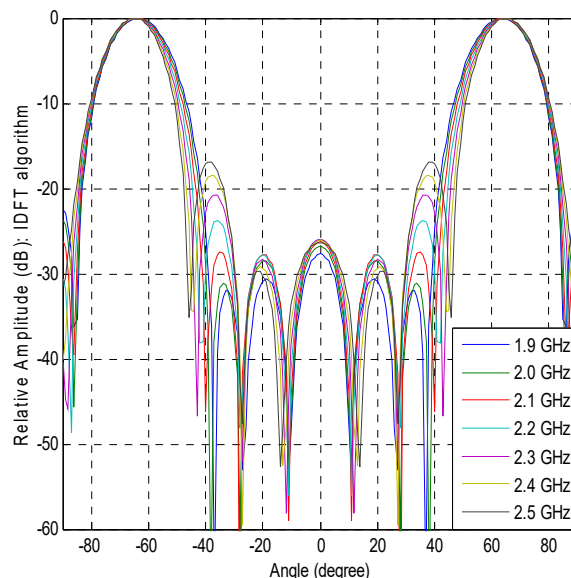

Fig. 7 Radiation pattern using the IDFT method when two main beams are pointed to $-30°$ and $20°$, respectively

TABLE I
PARAMETERS GIVEN IN SIMULATION FOR REFINEMENT ALGORITHM

Parameters	Type of refinement		
	I	II	III
$\Delta\phi$ (degrees)	0	3	5
$\Delta\Theta$ (degrees)	0	3	5
$\Delta\delta$ (dB)	0	3	5
Maximum of weighting coefficient (dB)	25	20	19

Fig. 8 Radiation pattern using the proposed refinement method for type I

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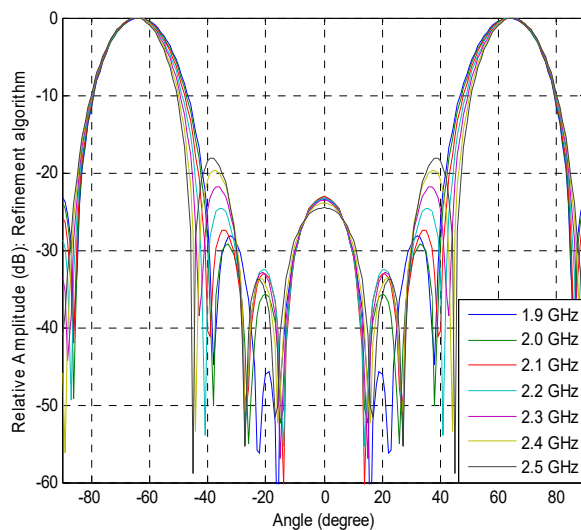International Journal of Electrical and Computer Engineering
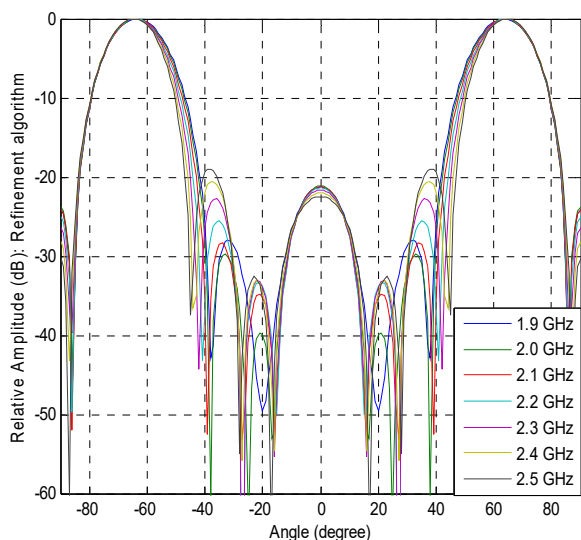Vol:11, No:1, 2017

Fig. 9 Radiation pattern using the proposed refinement method for type II
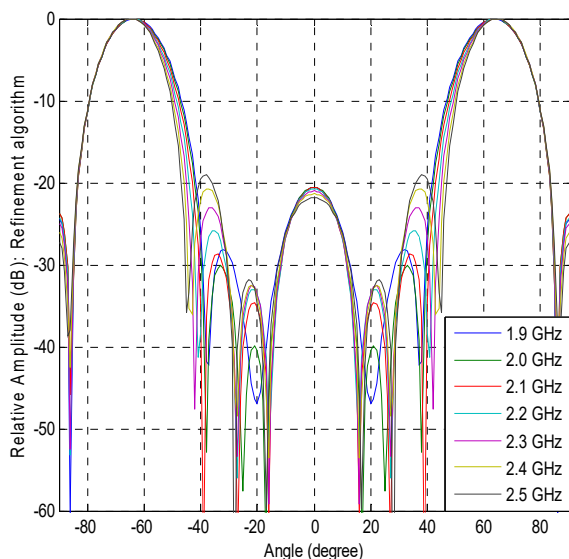

Fig. 10 Radiation pattern using the proposed refinement method for type III

VI. CONCLUSION

The refinement method for two beams formation of wideband smart antenna has certainly reduced the range of weighting coefficient under controlling some characteristics of radiation pattern such as mainbeam, beamwidth, and maximum minor lobe level. The results demonstrated a performance to confirm the proposed concept.

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