The Characteristics of Wide-Band/Wide-Scan E-plane Notch Phased Array Antenna

Jun-Yeon Kim*, Joon-Ho So*, Moon-Que Lee and Chang-Yul Cheon****

Abstract - A wide-band E-plane notch phased array antenna having bandwidths of 3:1 and a scan volume of ± 45° is designed considering the active element pattern (AEP) with analysis of the full structure of E-plane notch phased array antenna. Using the numerical E-plane waveguide simulator as an infinite linear array in the broadside angle, the active reflection coefficient (ARC) of the unit element is optimized in the design frequency range. To evaluate the convergence of the AEP, the simulation of full array as changing the number array is investigated, and the minimum numbers of array that have characteristics similar to the AEP of an infinite array are determined.

Keywords: Notch phased array antenna, Active Element Pattern, Active Reflection Coefficient

1. Introduction

The end-fire tapered slot antenna, often called a notch or Vivaldi antenna, has been used as a wide-band radiator or wide-band/wide-scan phased array antenna [1, 2]. In recent years, the numerical computations for a unit cell of array are intensively conducted using the periodic boundary conditions through the summation of Floquet modes [3, 4], or through the numerical waveguide simulators [5]. In these works, the active scattering parameters that include mutual coupling effects among the array were optimized for realizing wide-band and wide-scanning phased array antenna, and the AEP was obtained using the approximated equation assuming there were no grating lobes in its pattern [6]. The approximated array analysis method has the advantage of rapid computation time, but results are inaccurate [7]. The accurate calculation of the AEP is crucial to estimating the effective radiation power of the transmitter or the receiving antenna gain for the wide-bandwidth and wide-scanning phased array system [2].

In this paper, in order to design a wide-band/wide-scan phased array antenna, the ARC of the E-plane linear notch array is optimized using the numerical E-plane waveguide simulator for the unit element with the simple circuit model in [3]. Furthermore, the ARC for the scan angles is calculated through analysis of the complete finite E-plane phased array antenna structure. To predict the variation of the AEP, the convergence of the AEP of the finite array with the numbers of array is studied. Through the investigation of the AEP as a function of scan angle, the variation of gain for all scan angles can be predicted.

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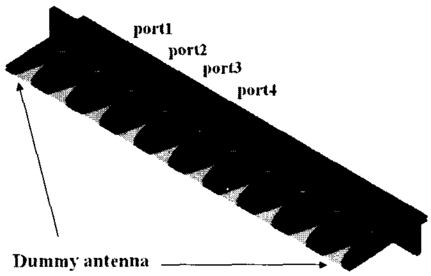


Fig. 1 An E-plane notch phased array antenna with 8 elements and 2 dummy antennas.

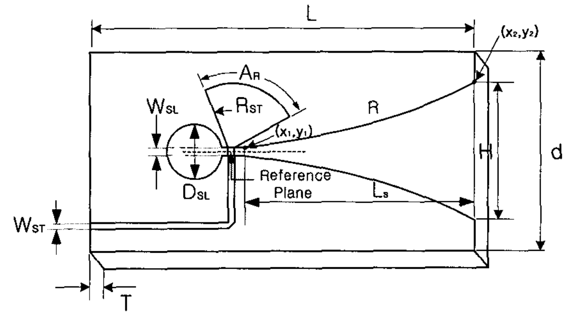


Fig. 2 Unit Element of notch array and its parameters

2. Design of Unit Element Using Numerical Waveguide Simulator

The structure and design parameters of E-plane phased array and the unit element are shown in Fig. 1 and Fig. 2. The performance of the notch antenna is determined from variation of design parameters such as opening rate (R), length of Tapered slotline (L_S), length of stripline stub (R_{ST}), radial stub angle (A_R), diameter of slotline stub (D_{SL}), width of stripline and slotline (W_{ST}, W_{SL}), length of antenna (L), height of aperture (H) and antenna (d). To obtain proper wide-band performance, the shape of stripline stub and slotline stub are usually radial or circular. The design of large phased array antenna usually takes the infinite array approach in which each radiator is treated as if it is in an infinite array environment. In order to design an E-plane phased array antenna, we used the numerical E-plane waveguide simulator in Fig. 3, which included the effects of mutual coupling among elements in an infinite linear array environment. Image theory of electric field and magnetic field is applied to the boundary condition of the antenna.

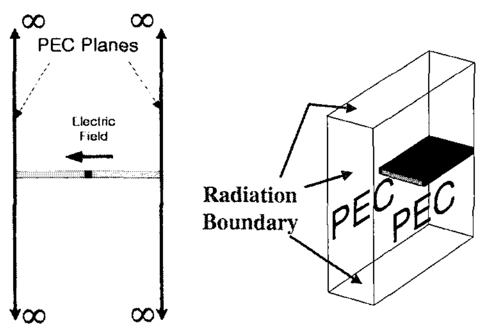


Fig. 3 Numerical E-plane waveguide simulator

The objective of the design is that the ARC is below -10dB in the 3:1 frequency band at all scan angles. To satisfy this aim, we have changed the parameters and simulated notch antenna in the waveguide simulator. Table 1 shows optimum parameters determined from numerous simulations.

In this work, the simulation of the notch antenna is performed using a commercial time-domain solver. We compared the impedances of a single antenna and that of the waveguide simulator using equivalent circuit modeling. The equivalent circuit model of the notch antenna is explained in [3]. The resistance and reactance of a single antenna and the waveguide simulator are shown in Fig. 4 and Fig. 5. From these results, it was found that the E-plane phased array antenna has greater wide-band performance than a single antenna over the frequency band. In Fig. 5, the reactance variation of the stub is opposite that of the waveguide simulator over the frequency band, which results in improved overall performance. The reflection coefficients of single element and waveguide simulator are shown in Fig. 6. And in order to confirm the result of the waveguide simulator, the ARC of 8-element array at the 4th port, where the beam scan angle is zero degrees, is calculated using equation (1) in the next section. In the case of a single antenna, the size of aperture is so small in low frequency that it provides poor performance. But in the case of array, the ARC is improved by mutual coupling from adjacent elements. The results of 8-element array show good agreement with that of the waveguide simulator.

Table 1 Optimum parameters of the notch antenna

Substrate		R	0.05	A_R	40°
Thickness	Dielectric constant	L_S	29.85mm	H	16mm
		R_{ST}	8mm	L	50mm
3.2mm	2.2	W_{ST}	0.8mm	W_{SL}	1.1mm
		d	26.49mm	D_{SL}	7.2mm

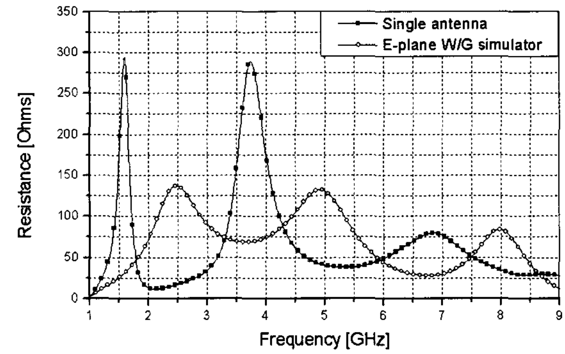


Fig. 4 Resistance of single antenna and waveguide simulator

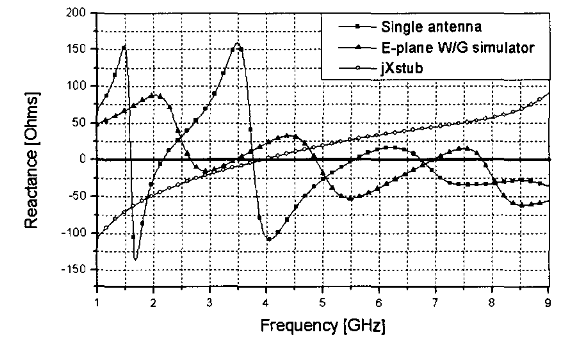


Fig. 5 Reactance of single antenna and waveguide simulator

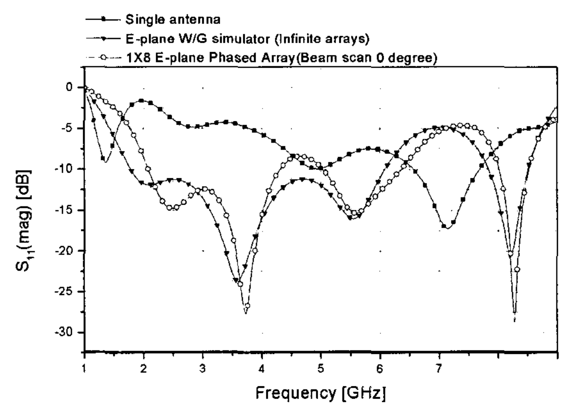


Fig. 6 Comparison of reflection coefficients

3. Analysis of ARC and AEP of the E-plane Notch Phased Array

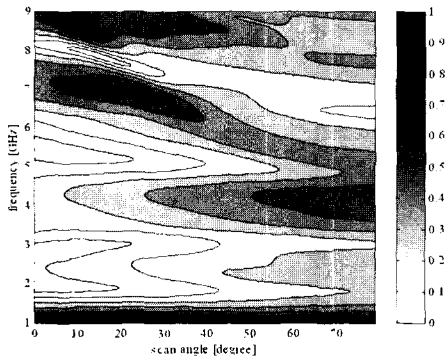
3.1 Active Reflection Coefficient

In order to scan the main beam to a specific direction, every radiator should be excited with uniform amplitude and its phase delay properly controlled for beam steering. The ARC is defined at each element in an array antenna and it is different from the reflection coefficient of a single antenna since it includes the mutual coupling coefficients. When a phased array antenna steers its main beam, at some specific angle there could be total reflection due to mutual coupling between surrounding radiating elements. In order to design a phased array antenna having good performance, it should avoid total reflection in the scan volume. Generally in the wide-band system, the ARC below -10dB is required as a design objective. For scanning the beam to the angle θ, the ARC at the m-th element is calculated by Eq (1). S_{mn} is a coupling coefficient at the m-th element when the n-th element is excited [6].

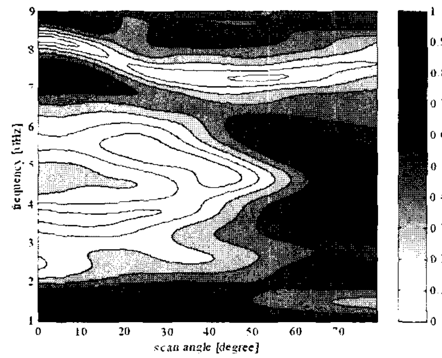
$$\Gamma_m(\theta) \equiv e^{jkmd\sin\theta} \sum_{n=1}^{N} S_{mn} e^{-jknd\sin\theta} \quad (1)$$

Where, d is the spacing between elements.

To evaluate the ARC as a function of scan angle, the mutual coupling coefficients for the full structure of the array antenna in Fig. 1 should be calculated. The ARC in all scan angles is calculated using equation (1) with the coupling coefficients acquired from the simulation. To improve edge effect, we placed the dummy antenna on the side of the edge element. The ARC with variation of scan angle at edge element (1st port) and at center element (4th port) is shown in Fig. 7. The ARC of the edge element showed poorer performance than that of the center element by edge effect. Its performance improves inside of the array. Fig. 7 shows the results indicating that the performance of the E-plane phased array antenna arrives at our goal.



(a) The ARC in edge element



(b) The ARC in center element

Fig. 7 The ARC of an E-plane phased array antenna

3.2 Active Element Pattern

The accurate calculation of the AEP is very important to estimating the effective radiation power of the transmitter or the receiving antenna gain for the wide-band and wide-scanning phased array system [2]. The AEP can be approximately calculated using a simple equation with the ARC, but gave inaccurate results in the low frequency range [7]. In this work, therefore, to achieve a precise result, the AEP is calculated from the analysis of the full structure of the finite array antenna, where the center element is excited and the others are terminated in 50Ω. In order to determine the minimum size of array having the same AEP of an infinite array, we simulated the full array and investigated the AEP as the numbers of array changed. The AEP of above a 5-element array is converged in Fig. 8. Thus, in the case of the E-plane notch antenna, we can predict the AEP of infinite array, solving it with only 5-elements. These results of the converged AEP provide a reliable guideline for the design of the linear or planar phased array. Through the investigation of the AEP as a function of scan angle, the variation of gain for all scan angles can be predicted. In order to evaluate the result, the beam steering pattern and the AEP of a 1× 8 E-plane array are shown in Fig. 9, where the array elements have the weighting values of the phase delays for the 6GHz beam scan angles. The result shows that the variation of normalized gain is below -3dB and the variation of the beam steering pattern and the AEP are in good agreements.

4. Conclusion

A wide-band E-plane notch phased array antenna having bandwidths of 3:1 and a scan volume of ± 45° has been designed considering the characteristics of active element pattern. The ARC of the unit element using the E-plane waveguide simulator has shown to be in good agreement with the analyzed results of the full structure of the finite array. The converged results of the AEP and the minimum numbers of array that have characteristics similar to the infinite array AEP were presented. The finite array analysis of the AEP permits the prediction of the gain variation with the beam scan angle, and can be applied to the characterization of the planar notch phased array.

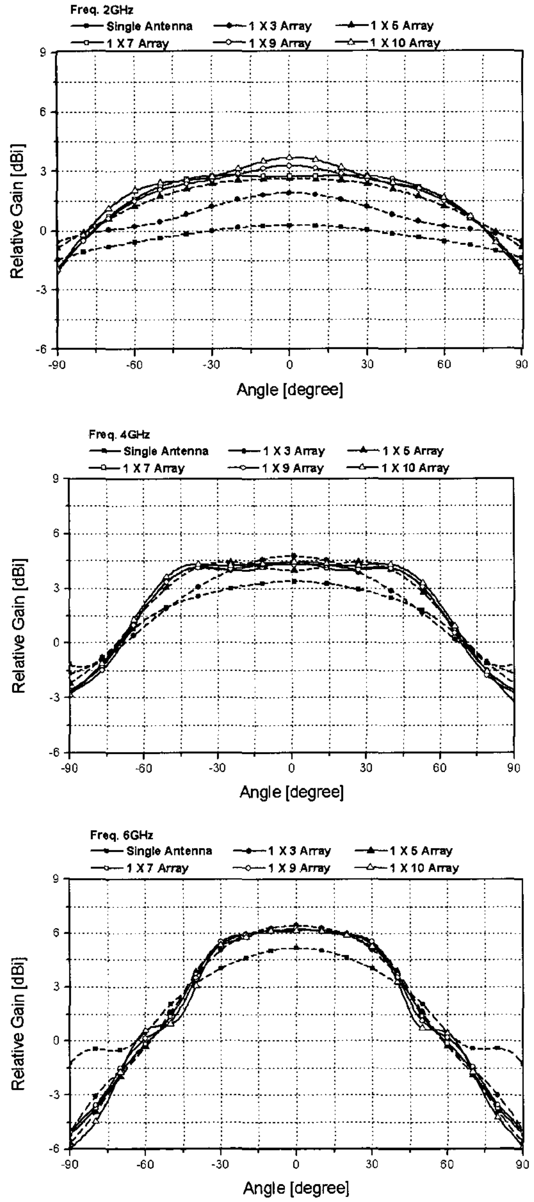


Fig. 8 The convergence of AEP with the numbers of the finite notch array.

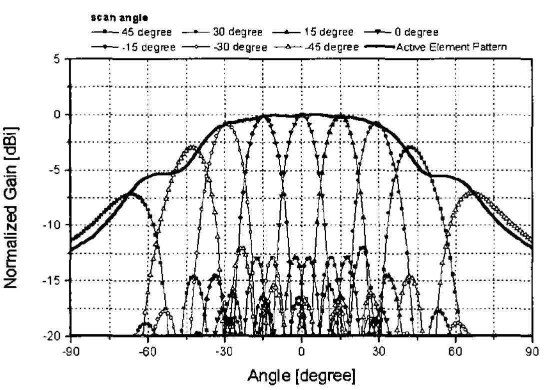


Fig. 9 Comparison between the converged AEP and the beam steering patterns with the 8-elements and 2-dummy elements.

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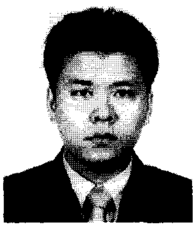

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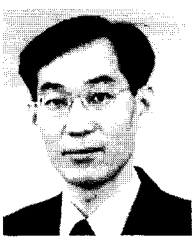

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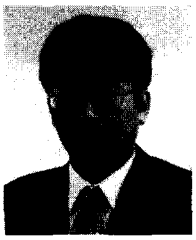

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