2B4-4

Scan Reflection Coefficient of Open-Ended Waveguide Array

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1. Introduction

Mutual Coupling is responsible for all the unique characteristics of large phased array antennas. The prediction of mutual coupling is essential procedure in a viewpoint of scan performance, for example, scan blindness, range, etc. A scanning array not only has different element impedance, but each of them varies with scan angle. These element input impedances are scan impedances which can be expressed as the scan reflection coefficient. The concept of scan reflection coefficient has been utilized to understand the characteristics of phased array antennas [1].

As an element of X-band phased array, open-ended waveguide is generally used. It is possible to calculate the scan reflection coefficient of an infinite waveguide array having rectangular or triangular grid [1,2]. For a finite 1-D array, Pozar [3] described the scan reflection coefficient in terms of the scattering parameters.

In this paper, an 8×8 open-ended rectangular waveguide with triangular grid, which has ±45˚ E-plane scan range and ±20˚ H-plane scan range in X-band, is considered in order to investigate the scan reflection coefficient characteristics. Firstly, the scan reflection coefficient, or the scan return loss, of this subarray is simulated using CST's MWS simulator and compared with that of an infinite open-ended rectangular waveguide array simulated with Ansoft's HFSS. Secondly, the MWS-simulated scan reflection coefficient is compared with the measured one. The measured scan reflection coefficient is calculated from the measured scattering parameters. In this calculation of the measured scan reflection coefficient from the measured scattering parameters Pozar's 1-D description [3] of the scan reflection coefficient in terms of the scattering parameters is expanded to 2-D description in order to be applied to our 8×8 planar subarray.

2. Finite Array Structure

Fig. 1 shows a finite rectangular waveguide array with a triangular grid. The triangular grid array is utilized because it uses about 15% fewer elements than a rectangular grid array of identical aperture area [1]. The element spacing is determined not to have grating lobes within the desired maximum scan angle($\theta_{\max}$). E-plane element spacing d_x in Fig. 1 is determined by $d_x \le \lambda_u /(1+\sin\theta_{\max})$ where λ_u is the wavelength at the upper frequency of the desired bandwidth. E-plane element spacing is determined 0.59 λ_u for the E-plane scan range of ±45˚, and the resultant E-plane scan range is ±63˚@f_l, ±53˚@f_o, and ±45˚@f_u where f_l, f_o, and f_u means the lower, center, and upper frequency, respectively. On the other hand, H-plane element spacing d_y in Fig. 1 is determined not by the formula but by a grating lobe diagram [2] because the subarray has a triangular grid structure. For the realization of this subarray in X-band the width of WR-90 standard waveguide is reduced to about 0.6 λ_u in order to make H-plane element spacing of 0.37 λ_u possible for the H-plane scan range of ±20˚. The resultant H-plane scan range is ±35˚@f_l, ±29˚@f_o, and ±24˚@f_u.

ISBN: 978-4-88552-223-9 C3055©IEICE

3. Relation of Scan Reflection Coefficient and Scattering Parameters

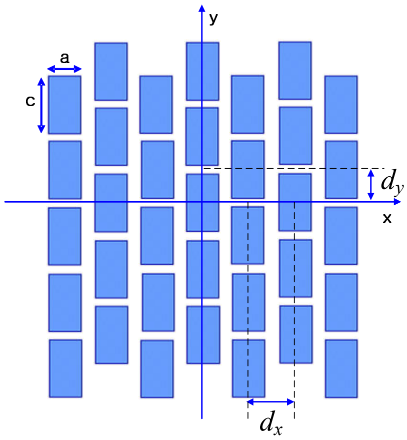


Figure 1: A finite array with triangular grid.

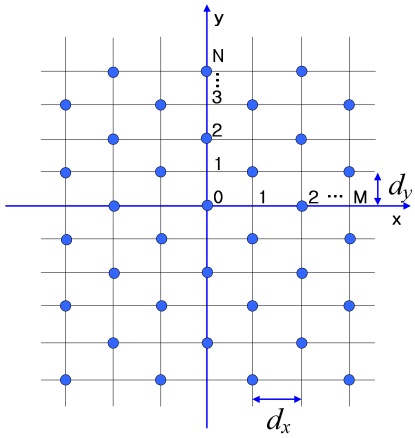


Figure 2: Geometry of 2-D element array.

Eq. (1) shows the relationship between the scan reflection coefficient and the scattering parameters for the case of 1-D linear array [3].

$$\Gamma_{m_0}(\theta) = e^{jkm_0 d \sin\theta} \sum_{(m)} S_{m_0 m} e^{-jkmd \sin\theta} \tag{1}$$

where $\Gamma_{m_0}(\theta)$ is the scan reflection coefficient at the m_0 th element, d is the element spacing, and $S_{m_0 m}$ is the scattering parameter.

Fig. 2 shows the geometry of a finite element planar array for the 2-D scan reflection coefficient calculation. Herein, we propose Eq. (2). Eq. (1) can be expanded to Eq. (2) in order to be applied to 2-D planar array case. Eq. (2) describes the relationship between the scan reflection coefficient and the scattering parameters for the case of 2-D planar array.

$$\Gamma_{m_0 n_0}(\theta,\phi) = e^{jk(m_0 d_x \sin\theta\cos\phi + n_0 d_y \sin\theta\sin\phi)} \sum_{(m)}\sum_{(n)} S_{mn}^{m_0 n_0} e^{-jk(md_x \sin\theta\cos\phi + nd_y \sin\theta\sin\phi)} \tag{2}$$

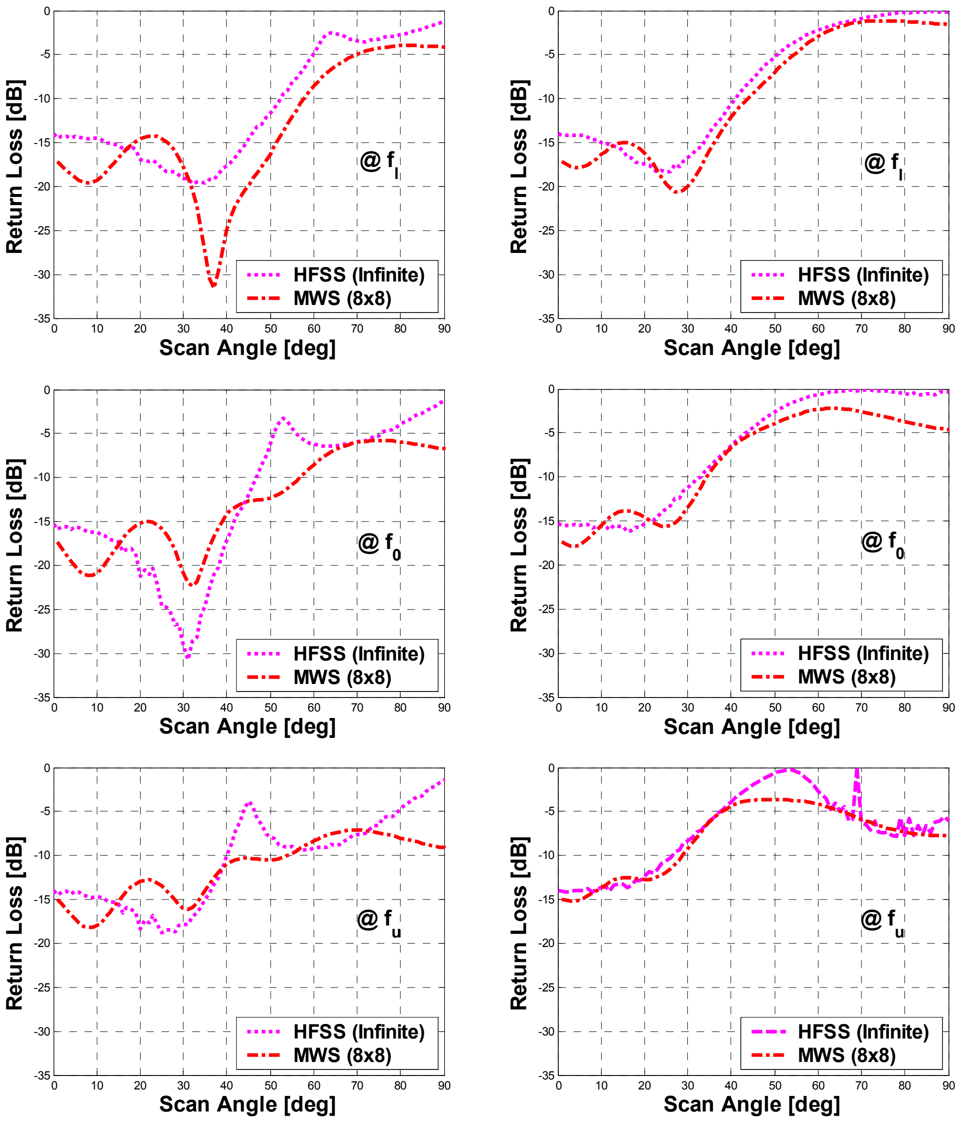
where $\Gamma_{m_0 n_0}(\theta,\phi)$ is the scan reflection coefficient at the element (m_0, n_0), $S_{mn}^{m_0 n_0}$ is the scattering parameter between input element (m, n) and output element (m_0, n_0) and is equal to $S_{m_0 n_0}^{mn}$. $\Gamma_{m_0 n_0}(\theta,\phi)$ depends on the scan angle θ and ϕ unless $S_{mn}^{m_0 n_0} = 0$ for $m_0 \neq m$ and $n_0 \neq n$. If $\theta = 0$ (boresight) regardless of ϕ, Eq. (2) becomes

$$\Gamma_{m_0 n_0} = \sum_{(m)}\sum_{(n)} S_{mn}^{m_0 n_0} \tag{3}$$

Once we have the simulated or measured data of scattering parameters or coupling coefficients in a planar array , we can calculate the scan reflection coefficient at every element regardless of the element type (waveguide, dipole, etc.) using Eq. (2).

4. Simulated and Measured Results

HFSS is utilized to simulate the scan reflection coefficient of an infinite open-ended waveguide array, while MWS is used for the 8×8 subarray. Using the scattering parameter (or coupling coefficient) data obtained by MWS simulation, we calculated the scan reflection coefficient using Eq. (2).



(a) E-plane (b) H-plane

Figure 3: HFSS- and MWS-simulated scan return losses.

Fig. 3 shows that the MWS-simulated scan return loss and HFSS-simulated one at the center element of the array. Note that in Fig. 3 the scan return loss instead of the scan reflection coefficient is ploted for convenience. The maximum return loss is observed near the maximum scan angle in the HFSS simulation. This maximum return loss occurs due to scan blindness and the corresponding angle is the blind angle. Two results are relatively in good agreement within the maximum scan angle range of $\pm 45^\circ$ in the E-plane and $\pm 20^\circ$ in the H-plane. If the element number of the subarray becomes larger and larger, the scan return loss characteristic gets closer to that of an infinite array.

Fig. 4 shows the fabricated 8×8 subarray and the scattering parameter (or coupling coefficient) measurement setup. All the elements are terminated with the matched loads except for the excited and measured element ports. A waveguide end-launcher adapter is used for each input and output port. Fig. 5 shows the simulated and measured scan return losses at the center element of the fabricated 8×8 subarray at the center frequency f_0. Two results are reasonably in good agreement by improving the fabricated waveguide end-launcher adapters utilized in the scattering coefficient measurement, whose matching characteristic is not good enough, better agreement may be obtained.

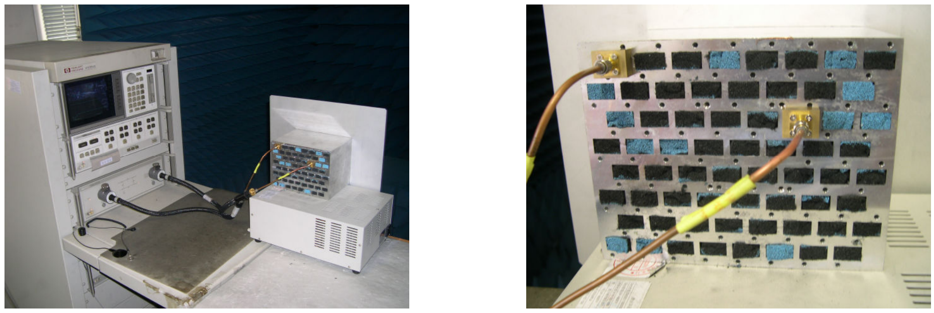
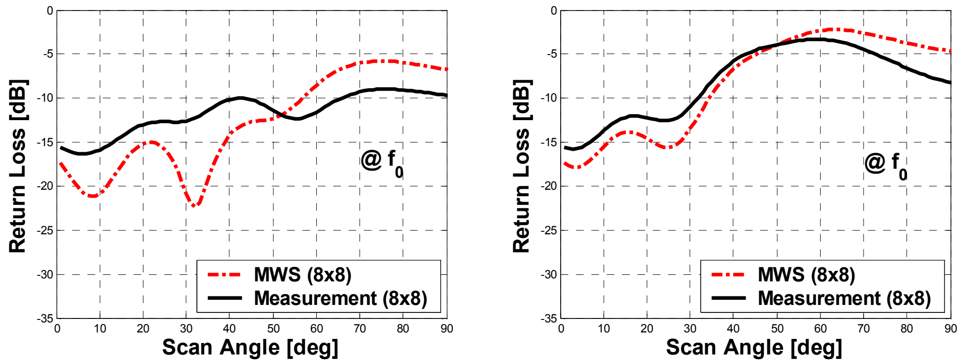


Figure 4: Fabricated 8×8 subarray and its S-parameter measurement setup.



(a) E-plane (b) H-plane

Figure 5: Simulated and measured scan return losses.

5. Conclusions

An 8×8 open-ended rectangular waveguide array with triangular grid in X-band is considered in order to investigate the scan reflection coefficient characteristics. The scan reflection coefficient, or the scan return loss, of this subarray is simulated using CST's MWS simulator and compared with that of an infinite open-ended rectangular waveguide array simulated with Ansoft's HFSS. The measured scan reflection coefficients are calculated from the measured scattering parameters and they are also compared with the simulated ones. We confirmed that scan reflection coefficient simulation results for the finite array are useful in the design of large phased array antennas because the essential scanning characteristics of the large array can be predicted by a finite subarray if the subarray has reasonable number of radiating elements.

Acknowledgments

This research was supported by the Agency for Defense Development, Korea, through the Radiowave Detection Research Center at KAIST(Korea Advanced Institute of Science & Technology).

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