Analysis of a Waveguide Slot Antenna with Baffles Including Periodicity in the Transverse Direction

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1. Introduction

Single-layer slotted waveguide arrays [1] have been proposed not only for radio link systems but also for plasma excitation [2]. When a single layer slotted waveguide array is used for plasma excitation, conducting baffles parallel to the waveguide axis are placed in the exterior region as shown in Fig.1. A Spectrum of Two-Dimensional Solutions (S2DS) is used to effectively analyze an infinitely-long structure uniform along the waveguide axis [3][4]. In the present paper, the mutual slot coupling in the external region including the baffles is evaluated by using the S2DS approach which is based on the assumption that the excitation is uniform in the direction transverse to the waveguide axis. To calculate the reactions by Galerkin's Method of Moments (MoM) with the S2DS method, the spatial-domain magnetic currents and dyadic Green's functions are Fourier transformed into the spectral domain by using Parseval's theorem [5]. In the region exterior to the baffles, the periodicity in the transverse direction reduces the inverse Fourier integral to a discrete sum. The inverse Fourier integral with respect to the waveguide axis is evaluated numerically. In order to confirm the accuracy of the MoM/S2DS technique, the frequency characteristics of the transmission and reflection coefficients are compared to results obtained by Ansoft HFSS (ver.8). The agreement is good except near fictitious resonances due to the mode expansion in the dyadic Green's function in the baffle region.

2. S2DS Formulation

Fig.1 shows the analysis model for a waveguide slot array antenna with baffles which is periodic in the transverse direction. The field equivalence theorem is used to divide the model into a number of canonical regions as shown in Fig.2. The external reaction Y_o in the equivalent model is written as a sum of contributions from the two magnetic currents $\mathbf{M}_s$, the slot current, and $\mathbf{M}_a$, the apeture current:

$$Y_o = Y_{os} + Y_{oa} = \iint_{S_s} ds_o \mathbf{M}_s^* \cdot \iint_{S_s} ds_s \overline{\mathbf{G}}_I \cdot \mathbf{M}_s + \iint_{S_s} ds_o \mathbf{M}_s^* \cdot \iint_{S_a} ds_s \overline{\mathbf{G}}_I \cdot \mathbf{M}_a , \qquad (1)$$

where $\overline{\mathbf{G}}_I$ is the magnetic field dyadic Green's function due to a unit magnetic current in a rectangular waveguide (region *I*). The first term Y_{os} on the right-hand side of Eq.(1) is calculated in the spatial domain through the use of the virtual cavity method [6]. Because it is difficult to integrate the secondary current

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$\mathbf{M}_a$, which spreads infinitely along the y direction in the spatial domain, Y_{oa} is calculated in the spectral domain by the S2DS method. From Parseval's theorem, Y_{oa} is expressed in the frequency domain as

$$Y_{oa} = \frac{1}{2\pi}\int_{-\infty}^{+\infty} dk_y \int_{S_s} dx_o \tilde{\mathbf{M}}_s^*\left(k_y\right)\cdot \int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \tilde{\mathbf{M}}_a\left(k_y\right), \tag{2}$$

where ~ above a quantity indicates its Fourier transform. The reaction Y_{oa} is evaluated by numerical integration with respect to k_y. The unknown k_y spectrum of the current $\tilde{\mathbf{M}}_a\left(k_y\right)$ is now expressed as a function of the spectrum of the given source $\tilde{\mathbf{M}}_s\left(k_y\right)$ by imposing the 2-D continuity condition of magnetic field on the interface:

$$-\int_{S_s} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \tilde{\mathbf{M}}_s\left(k_y\right) + \int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \tilde{\mathbf{M}}_a\left(k_y\right) = -\int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_{II}\left(k_y\right)\cdot \tilde{\mathbf{M}}_a\left(k_y\right), \tag{3}$$

where $\tilde{\bar{\mathbf{G}}}_{II}\left(k_y\right)$ is the 2-D dyadic Green's function in the outer region. The integral equation in Eq.(3) is solved by Galerkin's method of moments. The k_y spectrum $\tilde{\mathbf{M}}_a\left(k_y\right)$ of the magnetic current on the aperture between the baffles is expanded by the basis functions $\tilde{\mathbf{m}}_{aq}\left(k_y\right)$ as $\tilde{\mathbf{M}}_a\left(k_y\right) = \sum_q \tilde{f}_q\left(k_y\right)\tilde{\mathbf{m}}_{aq}$. By substituting this expansion and choosing $\tilde{\mathbf{m}}_{aq}$ as the weighting function, one reduces Eq.(3) to a set of linear equations with respect to the unknown coefficients $\tilde{f}_q\left(k_y\right)$:

$$\begin{aligned} &-\int_{S_a} dx_o \tilde{\mathbf{m}}_{ap}\left(k_y\right)\cdot \int_{S_s} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \tilde{\mathbf{m}}_s\left(k_y\right) + \int_{S_a} dx_o \tilde{\mathbf{m}}_{ap}\left(k_y\right)\cdot \int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \sum_q \tilde{f}_q\left(k_y\right)\tilde{\mathbf{m}}_{aq}\left(k_y\right) \\ &\qquad = -\int_{S_a} dx_o \tilde{\mathbf{m}}_{ap}\left(k_y\right)\cdot \int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_{II}\left(k_y\right)\cdot \sum_q \tilde{f}_q\left(k_y\right)\tilde{\mathbf{m}}_{aq}\left(k_y\right). \end{aligned} \tag{4}$$

Due to the periodicity in the transverse direction, the integral with respect to x may be converted to a discrete sum

$$\begin{aligned} &-\int_{S_a} dx_o \tilde{\mathbf{m}}_{ap}\left(k_y\right)\cdot \int_{S_s} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \tilde{\mathbf{m}}_s\left(k_y\right) + \int_{S_a} dx_o \tilde{\mathbf{m}}_{ap}\left(k_y\right)\cdot \int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot \sum_q \tilde{f}_q\left(k_y\right)\tilde{\mathbf{m}}_{aq}\left(k_y\right) \\ &\qquad = -\frac{1}{p_x}\sum_{t=-\infty}^{t=\infty} \tilde{\mathbf{m}}_{ap}\left(\frac{2t\pi}{p_x}, k_y\right)\cdot \tilde{\bar{\mathbf{G}}}_{II}\left(\frac{2t\pi}{p_x}, k_y\right)\cdot \sum_q \tilde{f}_q\left(k_y\right)\tilde{\mathbf{m}}_{aq}\left(\frac{2t\pi}{p_x}, k_y\right). \end{aligned} \tag{5}$$

$\tilde{f}_q\left(k_y\right)$ is obtained by solving Eq.(5) for the spectrum of the given magnetic current $\tilde{\mathbf{M}}_a\left(k_y\right)$. Finally Y_{oa} is given in the following form:

$$Y_{oa} = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\left(\sum_q \tilde{f}_q\left(k_y\right)\int_{S_s} dx_o \tilde{\mathbf{m}}_s^*\left(k_y\right)\cdot\int_{S_a} dx_s \tilde{\bar{\mathbf{G}}}_I\left(k_y\right)\cdot\tilde{\mathbf{m}}_{aq}\left(k_y\right)\right)dk_y \,. \tag{6}$$

The slot magnetic current $\mathbf{M}_s$ is obtained by the external (Eq.(6)) and internal reactions. From the slot current $\mathbf{M}_s$, the transmission and reflection coefficients are easily calculated.

3. Results

The transmission and reflection coefficients (S_{11} and S_{21}) for a single slot and baffles of varying heights are shown in Figs. 3 and 4, respectively. Both the S2DS solution and a reference HFSS solution are plotted. The results of the two different analyses coincide well with each other in amplitude and phase over a wide frequency range. The HFSS solution exhibits a slight ripple not seen in the S2DS solution. In Fig.4, one notices failures in the S2DS solution which occur at frequencies associated with the modal cutoff frequencies (resonances) of the waveguide of region *I*. The rectangular waveguide of region *I* results from the particular choice of equivalent models. To remove the fictitious resonances, both an electric current and magnetic current may be used on the lower aperture surface which allows one to replace the rectangular waveguide equivalent model for region *I* with a parallel-plate waveguide equivalent model. For a sufficiently small baffle width, the fictitious resonances will not occur. Finally, it is noted that the S2DS computation speed is approximately ten times faster than that of HFSS.

4. Conclusion

A waveguide slot array antenna comprised of a single slot and baffles that is periodic in the transverse direction is analyzed with a MoM/S2DS method. Accuracy of results is compared against an HFSS reference solution. Future work is the inclusion of multiple slots in the baffle region.

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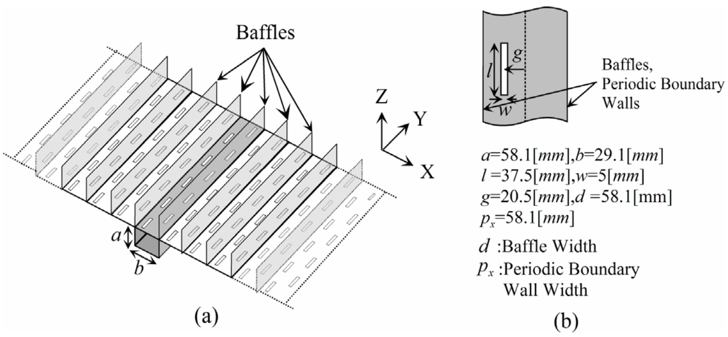

Fig1. Analysis model of a waveguide slot array antenna with baffles which is periodic in the transverse direction

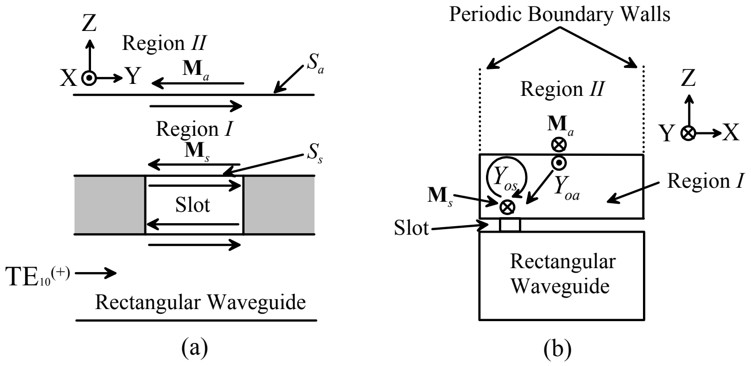

Fig.2 Canonical regions and equivalent currents

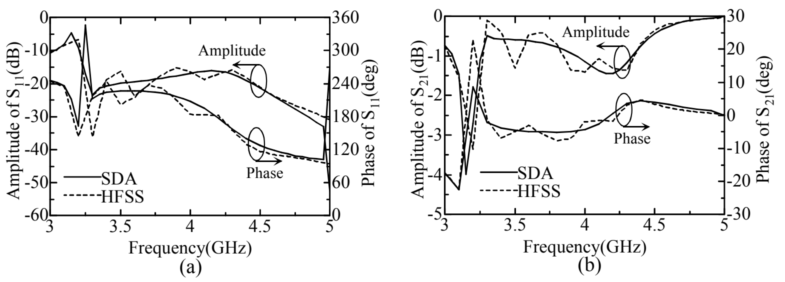

Fig.3 Frequency characteristics of (a) the reflection coefficient S_{11} and (b) the transmission coefficient S_{21} when the baffle height d is 0.4λ.

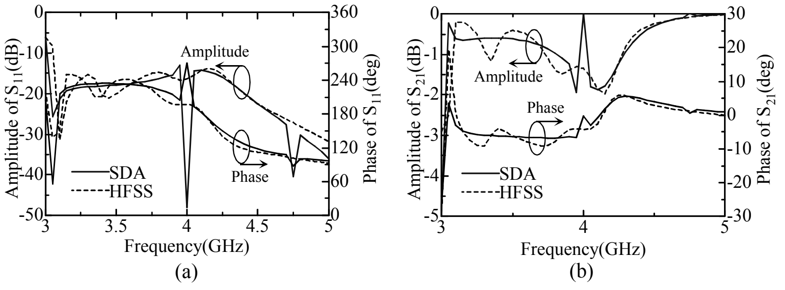

Fig.4 Frequency characteristics of (a) the reflection coefficient S_{11} and (b) the transmission coefficient S_{21} when the baffle height d is 0.5λ.