Analysis of Slotted Waveguide Antennas on Large Platforms Using an Equivalent Model

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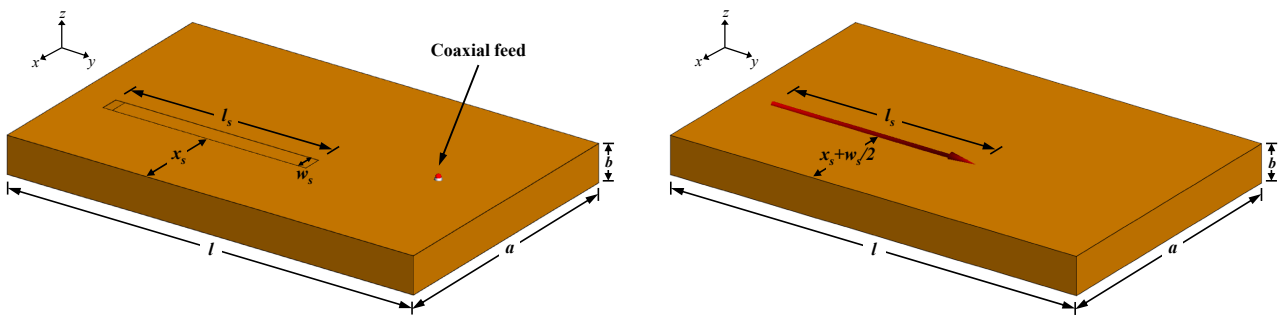
Abstract

This paper proposes to analyze SWAs on large platforms using an equivalent model of the SWAs. Based on Huygens' principle, magnetic currents, derived from the tangential electric field measured along the slot, are placed on the slot. The SWA is then equivalent to a conducting cavity with magnetic current source which can be modeled using the integral equation. The proposed method avoids the modeling of the complex structures in the waveguide. It also allows the analysis of SWAs without knowing the detailed design inside the waveguide, which is important when only limited information is provided by SWA vendors. Simulation results are presented to illustrate the effectiveness of the proposed method.

1. Introduction

Slotted waveguide antennas (SWAs) are widely used in airborne applications [1]. Various methods have been proposed for the analysis of SWAs [2-6]. Most existing methods analyze the SWAs without considering the effect of the platform where SWAs are mounted. However, the radiation characteristics of SWAs may be significantly changed by the platform. Hence, it is necessary to analyze SWAs together with the platform. In practice, there are two challenges in the analysis of SWAs on large platforms. First, vendors of SWAs may not provide detailed information of geometry and structure inside the waveguide, which prevents direct analysis of SWAs. Second, even with the detailed information of geometry and structure, the structure may be so complex that the direct analysis of the SWA is time and resource consuming.

In order to overcome the two challenges, this paper proposes to analyze SWAs on large platforms using an equivalent model of SWAs. In the equivalent model, the slot is covered by perfect electric conductor. From Huygens' principle, equivalent magnetic current exits on the slot. The original problem is then reduced to a rectangular conducting cavity with magnetic current excitation, which can be easily analyzed using the integral equation method like the method of moments (MoM). The advantages of the proposed method lie in the following two aspects. First, the proposed method eliminates the requirement of the detailed design information of SWAs. Second, it avoids the modeling of the complex structures inside the waveguide. The proposed method is detailed in Section 2 and simulation results are presented in Section 3. Finally, conclusions are drawn in Section 4.



(a) SWA **(b) Equivalent model**

Figure 1. Illustration of (a) the SWA and (b) its equivalent model. In (b), the slot is covered by perfect electric conductor and the arrow represents the equivalent magnetic current existing on the slot.

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2. The Proposed Method

Figure 1(a) shows the geometry of the SWA. In Figure 1(a), it is assumed that a coaxial feed is used to excite the waveguide. On the broad wall of the rectangular waveguide, a slot is created for radiation. The waveguide may be filled by dielectric to reduce the physical size and improve the performance. However, the detailed design information is usually not provided by the vendor. Furthermore, due to the complexity of the design inside the waveguide, direct analysis of the SWA is challenging, especially when the SWA is mounted on a platform.

From Huygens' principle, one can derive the equivalent model shown in Figure 1(b), where the slot is covered by perfect electric conductor. The arrow represents the magnetic current M_y. M_y can be obtained by two ways. First, from the tangential field sampling E_x, M_y can be calculated as

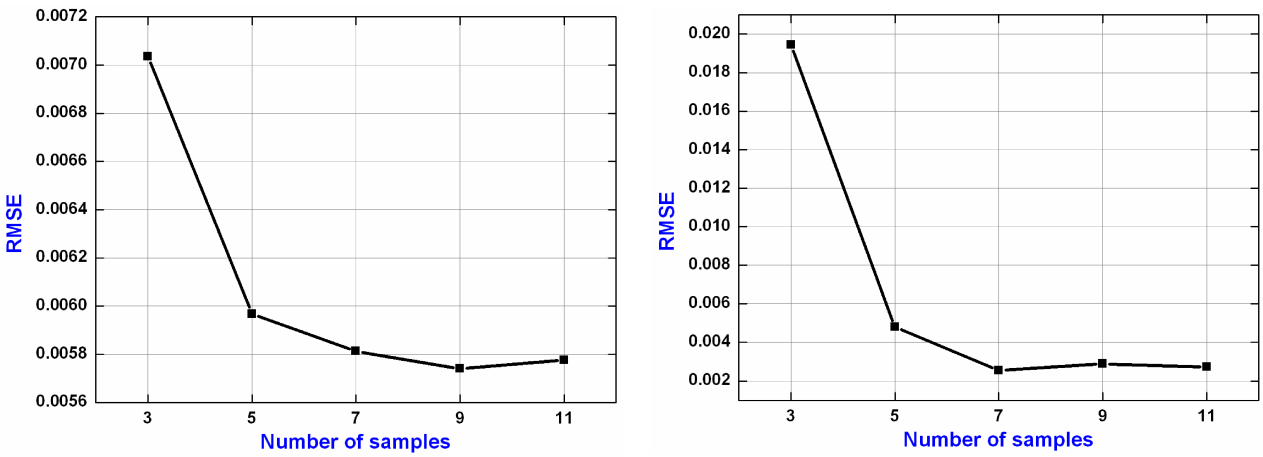
$$M_y = -E_x \tag{1}$$

where E_x is the x-component of the electric field along the slot shown in Figure 1(a) and it may be obtained by measurement. In [7], this approach has been used for the prediction of radiation from shielded printed circuit boards. Alternatively, if the measurement of E_x is difficult, M_y may be reconstructed from the radiation pattern data which can be provided by the vendor. This can be achieved using a global optimization method like the differential evolution algorithm [8]. In this work, it is assumed that E_x is available and M_y is readily computed from (1).

The equivalent model shown in Figure 1(b) consists of a rectangular conducting cavity and a set of magnetic current sources. We further assume that the platform where the SWA is mounted is made of perfect electric conductor. The equivalent model together with the platform is then modeled by the following hybrid integral equation [9]

$$\begin{aligned} -\alpha(\vec{r})\frac{j}{\omega\mu}\left[\hat{t}(\vec{r})\cdot\vec{E}^i(\vec{r})\right]+\frac{j}{k}\left[1-\alpha(\vec{r})\right]\hat{n}(\vec{r})\times\vec{H}^i(\vec{r}) &= \alpha(\vec{r})\hat{t}(\vec{r})\cdot\iint_S\left[1+\frac{1}{k^2}\nabla\nabla\cdot\right]\vec{J}(\vec{r}')G(\vec{r},\vec{r}')d\vec{r}'+ \\ \frac{j}{k}\left[1-\alpha(\vec{r})\right]\frac{\vec{J}(\vec{r})}{2}-\frac{j}{k}\left[1-\alpha(\vec{r})\right]\hat{n}(\vec{r})\times\iint_S\vec{J}(\vec{r}')\times\nabla' G(\vec{r},\vec{r}')d\vec{r}' & \end{aligned} \tag{2}$$

where $\vec{J}$ is the current density, S denotes the surface of the conducting cavity and the platform, and $\vec{r}$ and $\vec{r}'$ are observation and source points locating on S. In (2), G is the free space Green's function, k is the wavenumber, and $\alpha(\vec{r})$ is the combination factor. If $\vec{r}$ belong to an open surface, $\alpha(\vec{r})$ is set to one. Otherwise, it is choose to be between zero and one to improve the convergence of iterative solvers [9]. $\vec{E}^i$ and $\vec{H}^i$ are the electric and magnetic fields illuminating the cavity and the platform and these fields are computed from M_y. From equation (2), $\vec{J}$ is solved using the method of moments and the radiated fields are then calculated from $\vec{J}$ and M_y.

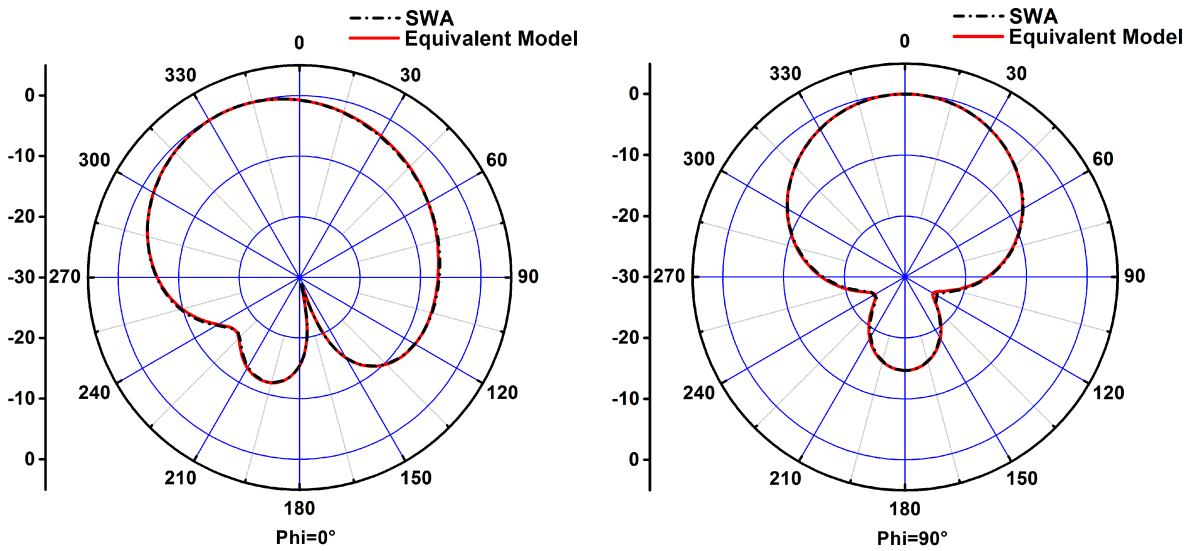


(a) *E*-plane **(b) *H*-plane**

Figure 2. Root mean square error (RMSE) of radiation patterns in *E*- and *H*-planes.

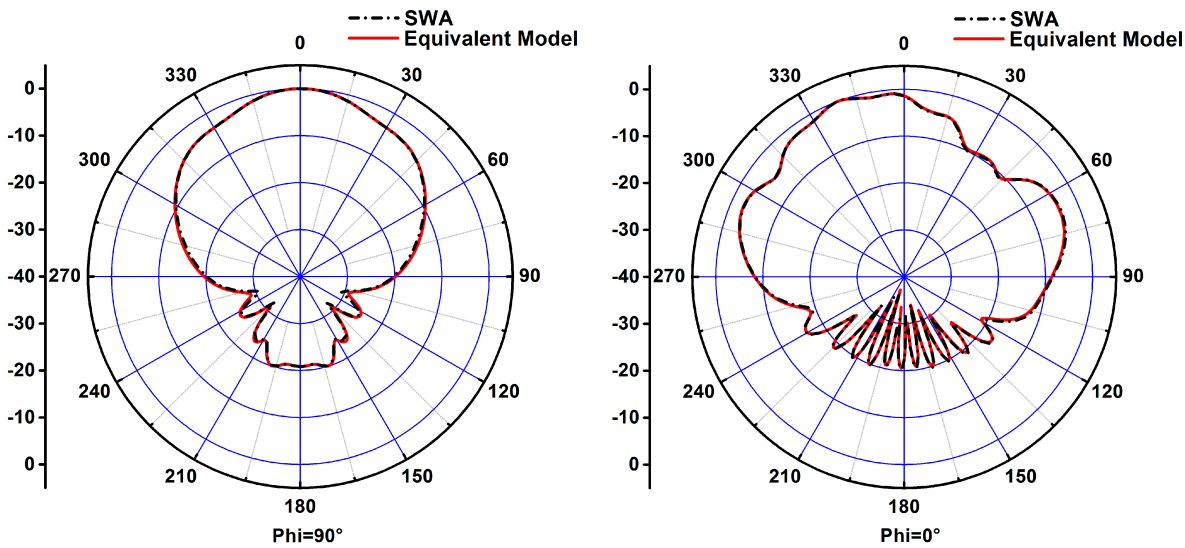
3. Simulation Results

Geometry of the SWA under consideration is the same as the one shown in Figure 1(a), except that the excitation is assumed to be a waveguide port placed at the front end. Values of the geometry parameters are: a=23.47 mm, b=3.12 mm, l=24.01 mm, w_s=1.63 mm, and x_s=7.82 mm. The frequency of operation is 8.933GHz. In the equivalent model, the accuracy is affected by the number of E_x samples along the slot. Figure 2 illustrates the root means square error (RMSE) of the radiation patterns against the number of samples. When computing the RMSE, the reference results are those obtained using the original model. From Figure 2, it is observed that the RMSE is a few thousandths when the number of samples is larger than five. Since the slot length is half of the guide wavelength, the sampling rate should be at least ten points per guide wavelength. Figure 3 presents the simulation results obtained using five samples of E_x. The agreement between SWA and the equivalent model is excellent.



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

Figure 3. Radiation patterns of SWA and its equivalent model in *E*- and *H*-planes.



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

Figure 4. Radiation patterns of installed SWA and its equivalent model in *E*- and *H*-planes.

The equivalent model is then placed above a rectangular conducting plate. The plate is concentric with the cavity, and the distance between them is b. The dimensions of the plate are 6λ and 5λ in x- and y-directions, respectively, where λ is the wavelength in free space. Figure 4 presents the radiation pattern computed by different

models. It is observed that results from the equivalent model agree very well with those by direct analysis of SWA. From Figures 3 and 4, it is seen that the radiation pattern of SWA is significantly changed by the conducting plate. Note that the equivalent model requires no detailed design information of the SWA (e.g. feed, dielectric filling, etc.). Therefore, the proposed method is very useful when detailed design information is unavailable.

4. Concluding Remarks

The analysis of SWAs on large platform has been realized using an equivalent model of SWA. The equivalent model is based on the Huygens' principle and it is highly accurate. More importantly, the equivalent model eliminates the requirement of detailed design information of the SWA. Because such information is often unavailable to those who install SWAs on a platform, the proposed method is very useful when optimizing the placement of SWA on a platform. In the present work, the magnetic current source is obtained from tangential fields. Work is undergoing to reconstruct the magnetic current from the radiation pattern provided by the vendor.

5. References

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