

Open-Ended Waveguide Radiation Characteristics – Full-Wave Simulation versus Analytical Solutions

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Introduction

Flush mounted aperture antennas are widely used and are often approximated by an aperture in an infinite conducting surface. The equivalent circuit parameters for the canonical problem of a rectangular waveguide radiating into a half-space (i.e., an infinite conducting flange) is equivalent to that for the parallel plate guide but using the guide wavelength. In 1951 Marcuvitz obtained an approximate solution by the variational method assuming a constant aperture field [1]. Since then this canonical problem has received much attention with solutions obtained by various rigorous, approximate and numerical methods. Here we select some of the published results for comparison to numerical results obtained by the Method of Moments (MoM) using FEKO (www.feko.info) and the Finite Element Method (FEM) using Ansoft’s HFSS (www.ansoft.com). The analytic results are based on the correlation matrix (CM) [2], transverse operator (TO) [3] and an integral equation method (KP) [4]. Although rigorous, these methods can be complicated and assume an infinite, zero-thickness conducting flange. To address realistic and possibly conformal antenna installations a numerical model is typically more accurate and more useful for antenna design. To this end FEKO is used to simulate a rectangular waveguide in a finite size flat plate for a single incident TE₁₀ mode. HFSS is used to simulate the waveguide with an infinite conducting flange. The results are used to estimate how large a waveguide flange is required to approximate the HFSS and previously published results for an infinite flange.

FEKO and HFSS Models

The model is shown in Figure 1 for waveguide width, a , and height, b , centered in a square flange having edge length, L , where the flange with $L = 2.86a$ is shown. The geometry is constructed for the case $a/b = 2.25$ with results normalized to the guide width. Symmetry is used to reduce the computational requirements with magnetic symmetry along the guide height and electric symmetry along the guide width. Selected results are summarized when $a = 0.7\lambda_0$, where λ_0 is the free space wavelength then the guide wavelength for this case is

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{2a}\right)^2}} = 1.43\lambda_0 \quad (1)$$

Waveguide modes are launched using the rectangular waveguide port in FEKO which does not allow excitation of evanescent modes. Any propagating modes can be excited with this source model but here only fundamental mode excitation is considered. The far end of the waveguide is terminated in an absorbing waveguide port to simulate an infinite guide.

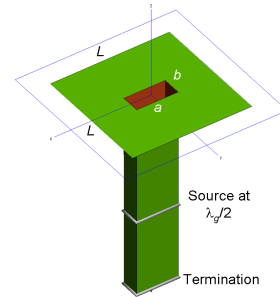


Figure 1. Flanged waveguide model

The excitation port is placed at $\lambda_g/2$ from the open end at all frequencies so that the reflection coefficient calculated by FEKO corresponds to the aperture reflection coefficient without additional post-processing. The simulations provide the TE₁₀ mode complex reflection coefficient, Γ , and field solution for various square flanges. The aperture admittance is then calculated according to:

$$Y = Y_0 \frac{1 - \Gamma}{1 + \Gamma} = G + jB \quad (2)$$

If a wire probe and voltage source were used to excite the guide, then the reflection coefficient would be for the probe input impedance (typically 50 Ω) rather than the reflected TE₁₀ mode. The conductance (G) and susceptance (B) of the aperture admittance are shown in Figure 2 for the case $a/b = 2.25$. The results indicate that as the flange size increases the variations with frequency become small with $L = 5.71a$ being sufficient to approximate an infinite flange. The aperture susceptance is more sensitive to the flange size and so would be less accurate when using an infinite flange to approximate an actual antenna configuration. Figure 3 compares the $L = 11.43a$ case and an open waveguide without a flange ($L = 0$) from FEKO with the HFSS infinite flange ($L = \infty$) result. These results can be compared to figure 2 in [2].

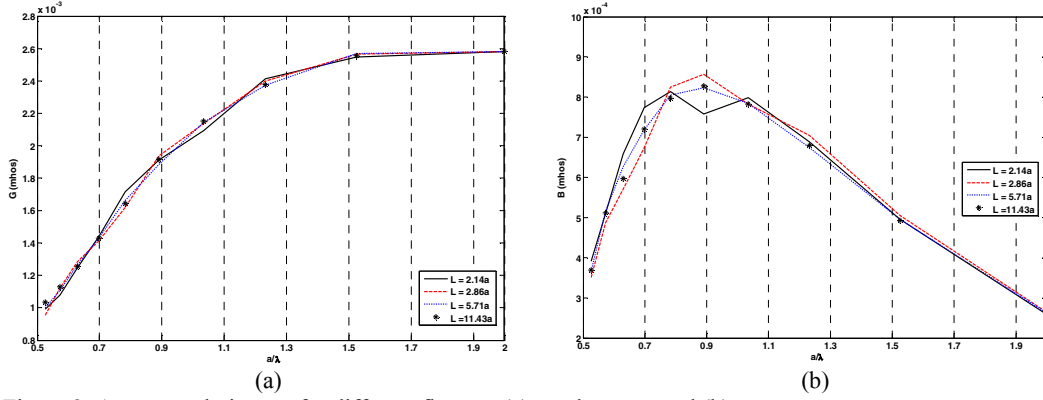


Figure 2. Aperture admittance for different flanges: (a) conductance and (b) susceptance.

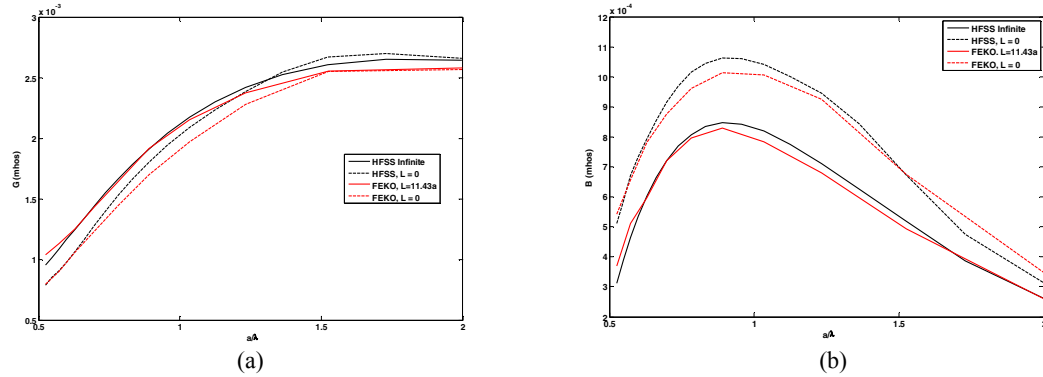


Figure 3. Aperture admittance for an infinite and no flange from HFSS compared to $L = 11.43a$ and no flange from FEKO: (a) conductance and (b) susceptance.

For comparison to other published results for which the waveguide width (height) is defined as $2a'$ ($2b'$), the scale is adjusted to be in terms of a' rather than $a = 2a'$. The normalized conductance is shown in Figure 4 as a function of ka' when $a/b = 2.25$. The HFSS infinite flange results are included compared to FEKO with $L = 0$ (no flange) and the case $L = 11.43a$. The results are in good agreement with the KP method which compares well to measured data [4, 5] although these simulation results are limited to frequencies above cutoff. The reflection coefficient magnitude and phase are shown in Figure 5 for comparison to figures 5 and 6 of [4] where the tabulated results from [2-4]

are included. The reflection coefficient magnitude using the TO method is larger than that obtained by other methods since the imaginary part is more than 11% larger than the result using CM [4].

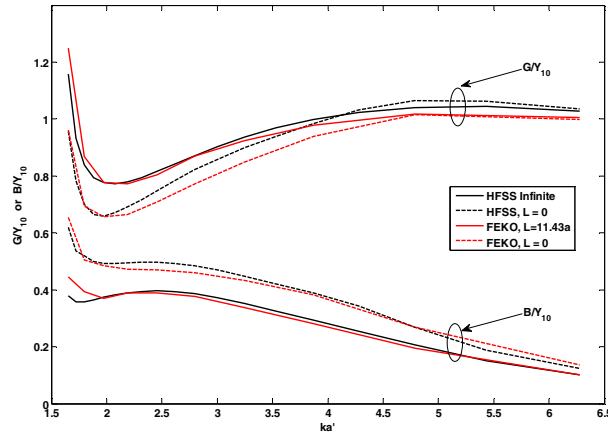


Figure 4. Normalized admittance for an infinite flange and no flange from HFSS compared to $L = 11.43a$ and no flange from FEKO.

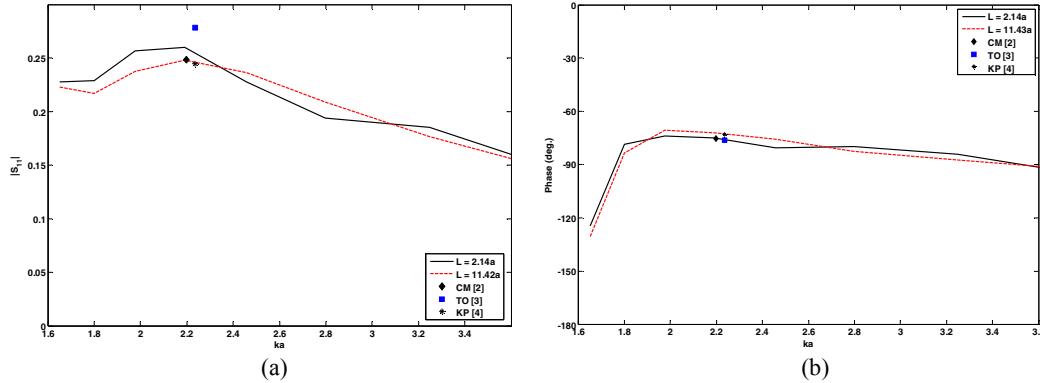


Figure 5. Reflection coefficient as a function of ka' when $a/b = 2.25$ with $L = 2.14a$ and $L = 11.43a$ compared to published results: (a) magnitude and (b) phase

Summary

As an example of how the input impedance changes with increasing flange size the reflection coefficient is shown in Figure 6 compared to the CM result for the case $a = 0.7\lambda$. The TO and KP results correspond to the case when $a = 0.711\lambda$. In this plot the flange edge length is expressed in wavelengths and the discrepancy from theory is about 6% [2]. The reflection coefficient for selected FEKO results and the HFSS infinite flange are compared to other methods in Table 1. It is important to point out these tabulated comparisons and those in [3, 4] may not be at exactly the same frequencies. Obviously the input impedance is not very dependent on edge reflections when the flange is sufficiently large. However the radiation pattern is highly sensitive to the presence of the flange and this is where a numerical simulation can be used to optimize an antenna installation to obtain the desired performance.

Calculated radiation patterns are compared in Figure 7 for the E-plane and H-plane patterns. The open waveguide without a flange result ($L = 0$) is included compared to the finite size square flange length in wavelengths. Increasing the flange size reduces the backlobes and increases the front to back ratio. This part of the pattern is highly

dependent on the actual antenna installation and an infinite flange approximation can not be used to investigate such effects. Notice that the E-plane pattern has a null on boresight while the H-plane pattern has a peak

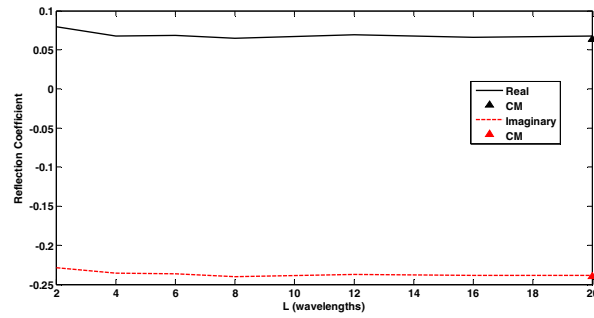


Figure 6. Reflection coefficient as a function of the square flange edge length when $a/b = 2.25$ compared to that obtained using the CM [2]

Table 1. Comparison of simulation results when $a = 0.7\lambda$ to numerical results from theory.

Source	S_{11}
FEKO, $L = 5.71a$	$0.0763 - j0.2358$
FEKO, $L = 28.6a$	$0.0672 - j0.2384$
HFSS, $L = \infty$	$0.0720 - j0.2345$
CM, $a = 0.7\lambda$ [2]	$0.0632 - j0.2403$
TO, $a = 0.711\lambda$ [3]	$0.0655 - j0.2709$
KP, $a = 0.711\lambda$ [4]	$0.0713 - 0.2344$

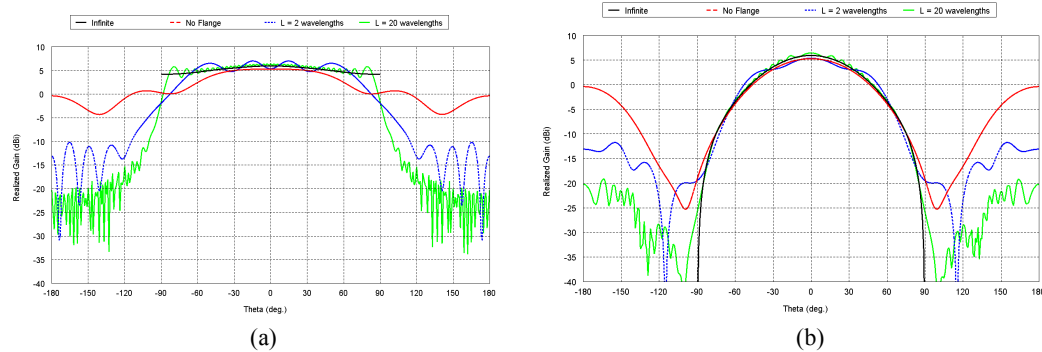


Fig. 7. Gain pattern as a function of the square flange edge length, L , with $a/b = 2.25$ and $a = 0.7\lambda$ for the (a) E-plane and (b) H-plane.

References

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