Computer Simulation of a Pyramidal Horn Antenna Using CST MWS

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Abstract- In this paper a pyramidal horn antenna will be simulated using the software CST MWS. The goal is to identify the optimal distance between feed probe and short-circuit that provides acceptable matching at $f = 1.2 f_{cut-off}$ of the TE_{10} propagation mode.

I. CONFIGURATION OF THE PYRAMIDAL HORN ANTENNA

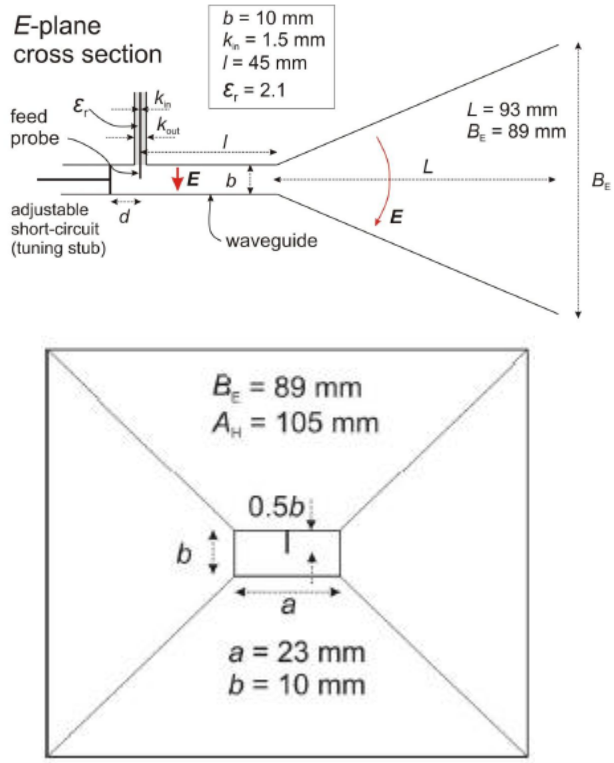

Figure 1. Horn antenna configuration.

The cut-off frequency of a TE_{mn} mode of a rectangular waveguide is defined as:

$$f_{c,mn} = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

For an air-filled waveguide the lowest cut-off frequency of the propagation modes is TE_{10} when a>b.

$$f_{c,10} = \frac{c}{2a} = 6.522\ GHz$$

Therefore the matching has to be optimized at $f = 7.826\ GHz$.

A. Simulation Setup

The procedure to analysis and to design the monopole antenna using CST is as follows:

1) Define variables and units.
2) Background material, frequency range, boundaries.
3) Configuration of the antenna with feeding port
4) Parameter sweep varying d.

B. Simulation Results

In order to identify the lowest –order resonant frequency the s11 parameter is to be represented.

- At $f_{cut-off}$, $S_{11} = -0.7dB$. The reflection coefficient decreases as the frequency increases from the cut-off, which support the theory.
- Matching at $f = 1.2 f_{cut-off}$ frequency: $S_{11} = -7.83$ dB.

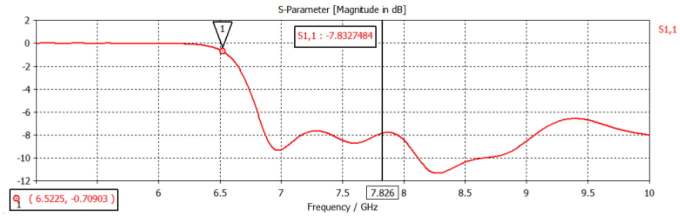

Figure 2. Reflection coefficient of the simulated horn antenna.

If the matching is considered at least -7 dB of reflection coefficient (20% reflected power), the usable impedance bandwidth is 2.37 GHz.

The 3D and 2D radiated far-field at $7.826\ GHz$ can be seen in the following figures (logarithmic scale).

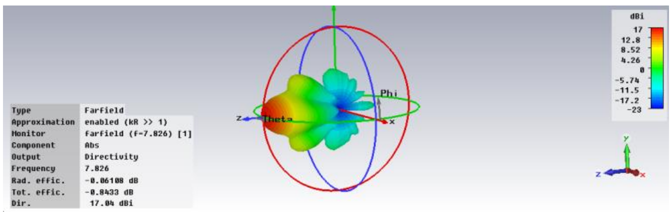

Figure 3. 3D far-field radiation pattern.

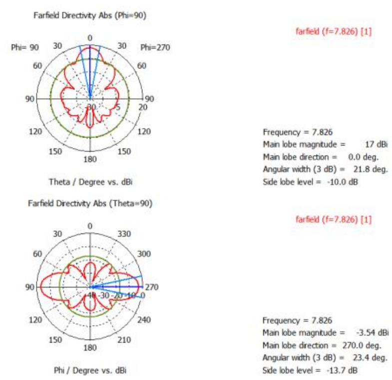

Figure 4.E-plane (above) H-plane (below) far-field radiation pattern.

E-plane:

- 3-dB beamwidth: 21.8º

- Side lobe level: -10 dB
- Main lobe magnitude: 17 dBi

H-plane:

- 3-dB beamwidth: 23.4º
- Side lobe level: -13.7 dB
- Main lobe magnitude: -3.54 dBi

C. Simulation Results

By sweeping the parameter d, distance between the probe and short-circuit in the waveguide (d), the matching level can be tuned. The following figure shows the variations caused.

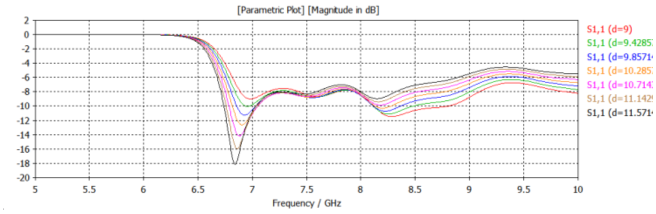

Figure 5. Variation of matching level.

When increasing d, the matching at the lower usable frequencies, close to cut-off, increases. On the other hand, at $f = 1.2f_{cut-off}$ and higher frequencies the reflection coefficient increases. Hence, the result of increasing d, is the decrease of the usable impedance bandwidth.

II. COMPARISON WITH ANALITICAL RESULTS

Directivity of the pyramidal horn can be calculated as:

$$D = \frac{4\pi}{\lambda^2} A_e \tag{2}$$

Where A_e, is the effective aperture:

$$A_e = A_p \cdot \varepsilon_{ap} \tag{3}$$

The aperture efficiency can be defined as follows:

$$\varepsilon_{ap} = e_t \varepsilon_t \varepsilon_s \varepsilon_a \tag{4}$$

In order to obtain the aperture efficiency it is needed to calculate the following parameters:

$$R_1 = R_H \frac{A_H}{A_H - a} \tag{5}$$

$$R_2 = R_E \frac{B_E}{B_E - b} \tag{6}$$

$$t = \frac{{A_H}^2}{8\lambda R_1} \tag{7}$$

$$s = \frac{{B_E}^2}{8\lambda R_2} \tag{8}$$

In this case, $R_H = R_E = L$. Computing (5),(6),(7) and (8), and substituting all values into (4), (3) and (2) the directivity can be obtained.

$$R_1 = 119.085\ mm \quad R_2 = 104.77$$

$$t = 0.3 \quad s = 0.2467$$

$$\varepsilon_{ap} = 0.56$$

Analytical value of directivity:

$$D = 16.53\ dB$$

Regarding to the half-power beamwidth in both E- and H-plane:

$$\Delta\theta_{3dB}^{E} = 56\frac{\lambda}{B_E} = 24.1º \tag{9}$$

$$\Delta\theta_{3dB}^{H} = 78\frac{\lambda}{A_H} = 28.45º \tag{10}$$

The side-lobe levels are defined by the distribution of the field of the TE propagation mode:

$$SLL_E = -10\ dB$$

$$SLL_H = -13.27\ dB$$

III. CONCLUSIONS

Comparing theoretical results with simulated results it can be appreciated that the directivity is quite similar. Side-lobe levels of the simulated results are quite similar to theory. However there is a difference between the calculated and simulated half-power beamwidth. This is due to the fact that theoretical values are calculated by optimal values of phase error.

Based on the transmission line theory the characteristic impedance of the feed port can be calculated as:

$$Z = \eta \frac{ln(b/a)}{2\pi} \tag{11}$$

Where:

$b \equiv$ Outer conductor radius.
$a \equiv$ Inner conductor radius.
$\eta \equiv$ Wave impedance.

$$\eta = \frac{120\pi}{\sqrt{\varepsilon_r}} \tag{12}$$

Since the relative permittivity of the Teflon is 2.1, then:

$$Z = \frac{120\pi}{\sqrt{2.1}} \frac{\ln(2.5/0.75)}{2\pi} = 49.85\ \Omega \approx 50\ \Omega$$