A Chebyshev Tapered TEM Horn Antenna

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Abstract — An exponential TEM horn antenna with Chebyshev impedance taper is designed and constructed. The results show improved directivity of the antenna and a wider range of frequencies with a VSWR less than two, over the entire band.

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1. INTRODUCTION

TEM horn antennas have been used as wideband antennas for various applications. Typical applications for these antennas include EMC experiments, Ground Penetrating Radar (GPR) and feeds for reflectors [1, 2]. These antennas have the advantages of wideband, no dispersion, unidirectional and easy construction. However it has the disadvantage of a large size. Several methods have been introduced to improve the performance of the antenna and reduce its size. Some researchers have tried to reduce the size of the antenna by resistive loading, but this reduces the antenna efficiency. One other solution is to modify the shapes of the plates.

In this paper we have used a Chebyshev impedance taper for the antenna resulting in a better VSWR and improved gain.

2. TEM HORN PRELIMINARIES

The basic TEM horn antenna consists of two linear or exponential tapered metal plates [3]. The spacing between the plates can be linear or exponential. Linear tapered antennas can be built easily in contrast to an exponential taper; however exponential taper has the advantage of smooth impedance variations. The antenna acts as a transformer to match the transmission line and the free space. The antenna can be assumed as a multistage impedance transformer. To increase the frequency band of VSWR < 2, the number of steps should be increased such that the impedance varies continuously and smoothly. An alternative is using tapered transmission line.

Among the various impedance tapers, Chebyshev has the preferred optimum characteristics. This taper has equal-amplitude minor lobes and is an optimum design in the sense that it gives the smallest minor-lobe amplitude for a fixed taper length and vice versa [4]. In this model a Chebyshev impedance taper is used to match the characteristic impedance at the feed point to the impedance of free space at the antenna aperture. The impedance at each point of the antenna can be calculated by [4]:

\[
\ln \tilde{Z} = \left( \frac{p}{2\pi} + \frac{1}{2} - \frac{p}{2\pi \cosh \pi u_0} \right) \ln \tilde{Z}_L + \ln \tilde{Z}_L + \frac{1}{\pi \cosh \pi u_0} \sum_{n=1}^{\infty} \cos \pi \sqrt{n^2 - u_0^2 - \cos n\pi} \sin np
\]

Where, \( \tilde{Z} \) is the normalized impedance at each point, \( \tilde{Z}_L \) is the normalized load impedance which in this case is the intrinsic impedance of free space (377 \( \Omega \)), \( Z_0 \) is the characteristic impedance (100 \( \Omega \)) of the feed line, \( \pi u_0 = \beta_0 L \), \( \pi u = \beta L \), \( p = 2\pi \frac{x - L/2}{L} \) where \(-\pi < p < \pi \) and \( L \) is the taper length. If we assume the TEM horn as a parallel waveguide, we obtain the equation for \( w(z) \) as:

\[
w(x) = \eta d(x)/Z(x)
\]

Where, \( d(x) \) is separation of the plates, \( w(x) \) is the width of the plates and \( \eta \) is the intrinsic impedance of the free space. Let \( d(x) \) be an exponential of the form

\[
d(x) = \alpha e^{\beta x}
\]

Where \( \alpha \) and \( \beta \) are constants to be identified. Design parameters can be calculated by equations (1), (2), and (3).
3. MODELING AND SIMULATION OF THE ANTENNA

A TEM horn antenna is simulated using FEKO which is based on method of moments. Chebyshev impedance taper is used to match the characteristic impedance at the feed point to the impedance of the free space at the antenna aperture. The separation of the plates is exponential as shown in Figure 1. The area around the feed is locally distorted such that a gap source can be placed between the two planar elements.

![Figure 1: Tapered TEM horn antenna.](image)

The dimensions of the structure are shown in Table 1. The antenna length is 60 cm and the aperture of the antenna is 50 cm × 50 cm.

<table>
<thead>
<tr>
<th>X [cm]</th>
<th>Z[Ω]</th>
<th>d [cm]</th>
<th>W [cm]</th>
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<tr>
<td>−10</td>
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<td>1</td>
<td>3.7</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>1</td>
<td>3.7</td>
</tr>
<tr>
<td>5</td>
<td>103.05</td>
<td>1.36</td>
<td>4.9</td>
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<tr>
<td>10</td>
<td>110.05</td>
<td>2.06</td>
<td>6.84</td>
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<tr>
<td>15</td>
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<td>3.1</td>
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</tr>
<tr>
<td>50</td>
<td>377</td>
<td>50</td>
<td>50</td>
</tr>
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</table>

With the same dimensions we have simulated an exponential impedance taper antenna. Figure 2 shows the simulated VSWR over the entire frequency band of 400–5000 MHz for the Chebyshev

![Figure 2: VSWR of the Chebyshev impedance taper antenna vs. frequency.](image)
Figure 3: VSWR of the exponential impedance taper antenna vs. frequency.

antenna and Figure 3 shows the VSWR for the exponential antenna. The comparison of these two figures show that the Chebyshev taper has better matching over a wider range of frequencies.

4. EXPERIMENTATION AND MEASUREMENT

An experimental antenna is constructed using the results of the simulation, as shown in Figure 4. The material for the conducting plates is copper with 1-mm thickness, and for simplicity a ground plane and the image theory is used. For supporting and fixing the plate, a Styrofoam with $\varepsilon_r = 1.05$ is used. The antenna length is 60 cm with the center frequency of 2.7 GHz and with dimensions of the aperture as 50 cm×50 cm. The antenna is fed through a coaxial cable connected directly to the antenna plate. The parallel plate section of the feeding point has the dimensions of 1 cm×1.89 cm with 12 cm in length.

Figure 4: The experimental antenna.

Figure 5: Measured VSWR of the antenna.

The VSWR of the antenna is measured by a 8410A network analyzer and the measured VSWR of the TEM horn over the frequency band of 447.4 MHz to 5 GHz is observed to be less than 2.0.

5. CONCLUSION

An exponential TEM horn antenna with Chebyshev impedance taper is simulated and constructed. The results show, better matching at the feed point and over wide range of frequencies. In this design, impedance changes smoothly from the feed line to the antenna aperture. In comparison with exponential impedance taper, it has wider frequency band with improved VSWR less than 2.

REFERENCES

