ABSTRACT: The TEM horn with elliptic E-plane profile has been shown to give extremely wide bandwidth performance as far as VSWR and gain is concerned. In this article, the variation in radiation pattern versus frequency is explored, and it is shown that, dependant on choice, E-plane or H-plane radiation patterns that are virtually independent of frequency can be obtained.© 2009 Wiley Periodicals, Inc. Microwave Opt Technol Lett 51: 607–612, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24109

1. INTRODUCTION

The so-called TEM horn has proven to be extremely popular for the realization of very wide bandwidth performance, where gain and input VSWR are concerned. Various approaches to realizing the desired wide bandwidths are employed, making use variably of impedance and dimensional tapers [1–6]. In all cases, the emphasis is on obtaining wideband performance, mostly for impedance. The analytical description of the TEM horn is extremely limited, with the exception of [7], where the characteristic impedance of the radial lines that constitute the TEM horns on a point-by-point basis is derived. Thus, to date approaches to design are limited to the realization of the best impedance match, making use of the information of [7], in combination with the various tapers. Little or no effort is made to present information as to the effect of dimensions on parameters such as gain or radiation pattern as a function of frequency.

Recently, the application of an elliptic function to describe the plate separation was introduced [4–6], and it was shown that extremely wideband performance could be achieved. However, the radiation pattern properties were not considered per se. It was shown in [6] that very good agreement could be achieved between measured values on a physically constructed horn, and numerical analysis by means of the commercial software FEKO® [8] for a number of variables.

In this article, the validity of the numerical analysis employed in the calculation of horn properties is re-established by extensive comparison of additional measured and calculated

FREQUENCY-INDEPENDENT PERFORMANCE OF ELLIPTIC PROFILE TEM HORNS

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values of radiation pattern for the horn described in [6]. Once it is confirmed that the numerical model properly approximates the physical structure, the numerical analysis is used to evaluate the properties of a series of horns, designed by the procedure described in [6], through a systematic variation of dimensions. From this information, the structure of TEM horns that displays virtually frequency-independent radiation patterns in some planes is identified.

2. HORN ANALYSIS: CALIBRATION

To establish the validity of the numerical analysis, radiation patterns for both $E$- and $H$-planes were measured on the pro-

![Figure 3](https://www.interscience.wiley.com) Comparison of measured and calculated $E$-plane radiation patterns over the band 0.5–18 GHz for the extreme bandwidth horn. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
totype, as well as calculated at 0.5, 1, 2, 4, 8, 12, 15, and 18 GHz. Previously, the horn was analyzed only at 0.5, 4, and 12 GHz [6].

The horn described in [6] is electrically very large, with overall dimensions of horn length of 480 mm, a width of 366 mm, and a height of 732 mm, as shown in Figure 1. At 18 GHz, this corresponds to a structure of $29 \times 22 \times 44$ wavelengths. When folded flat, the two horn plates each measures $655 \times 367$ mm, as shown in Figure 2 ($40 \times 22$ wavelengths). In the numerical model, the horn plates were divided into triangles of

Figure 4  Comparison of measured and calculated $H$-plane radiation patterns over the band 0.5–18 GHz for the extreme bandwidth horn. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
maximum size λ/8 on any side at the highest frequency of analysis. Figures 3(a)–3(h) show the E-plane radiation patterns comparing measured and calculated values, whereas the corresponding patterns are given for the H-plane in Figures 4(a)–4(h).

The correspondence between the measured and calculated values is excellent for both polarizations and across the entire frequency range, at least for the main beams and down to a level of −10 dB. At frequencies above about 15 GHz, some of the minor sidelobes lie outside of this level.

Because of this extent of agreement, the numerical analysis can now be used with confidence to predict the properties of a series of horns of varying dimensions that constitute a parametric study of the elliptic profile TEM horn.

3. PARAMETRIC EVALUATION OF HORN PROPERTIES: CALCULATION

The parametric evaluation of the elliptic profile horn was performed on a series of four horns, all with the same length of 480 mm, but with heights of 240, 480, 732, and 960 mm, respectively, as shown in Figure 5; the nominal horn dimensions in mm are given in Table 1. Note that although the horn length is fixed, both height and width change simultaneously, in order that the impedance determined by the Hecken taper described in [6] is realized. Longer or shorter lengths of horn will give the same performance for the same aspect ratio as the principle of frequency scaling can be applied. The horn 732–480 serves as reference.

E- and H-plane patterns were calculated for frequencies at 1 GHz intervals between 1 and 18 GHz, and the radiation patterns from 3 to 18 GHz plotted on the same axes as shown in Figure 6 for both the E- and H-planes (this constitutes a total of 16 radiation patterns on each polar pattern).

The calculated gain and VSWR performance for the four horns is shown in Figures 7 and 8, respectively.

4. EVALUATION

The radiation properties of elliptic profile horns are discussed in [5], where it is shown that the lowest operating frequency of the horn corresponds to a total horn length of one-half wavelength (measured along the surface of the horn). This is termed the first dipole mode, and more dipole modes occur as the frequency is increased, until the horn radiates sufficient energy in the aperture direction so that the structure functions as a horn rather than a dipole.

For all of the horns analyzed, the radiation patterns showed that at frequencies below 3 GHz, the dipole effect was still very strong, as evidenced by periodic variations in gain and impedance. Also, the radiation patterns strongly exhibit dipole characteristics, as can be seen in Figures 3(a) and 3(b) and 4(a) and 4(b). Consequently, radiation patterns below 3 GHz were not included in the polar patterns of Figure 6.

As the horn height is increased, the various horns retain nominally the same main lobe width in the E-plane at about 20°. The small horn (240–480) has the smallest spread of E-plane radiation pattern with frequency, being almost frequency-independent over the entire 3–18 GHz band [Fig. 6(a)]. As the horn aspect ratio increases, the E-plane spread increases.

In the H-plane, however, the small horn has a radiation pattern that varies substantially with frequency. As the aspect ratio is increased, the H-plane radiation pattern spread decreases, until the smallest spread is observed for an aspect ratio of ~1 [Fig. 6(b)]. Beyond that, the spread in H-plane radiation pattern increases again with increasing aspect ratio. At the same time, there is a substantial increase in beamwidth. The increase in beamwidth is accompanied by a decrease in gain. For all cases, the gain remains fairly flat with frequency.

All the horns display nominally the same VSWR performance, except at the lower frequencies, where the larger horns obviously have a lower dipole mode. This is to be expected as all the horns were designed with the same Hecken impedance taper. The VSWR remains below 2 from 1 GHz upward, and for all the horns rises above 2 at around 12 GHz, remaining below 3–18 GHz. This is not perturbing, as impedance analysis showed that the reactive part of the input impedance increases uniformly with frequency, whereas the real part is constantly too high. It would therefore be easy to correct the high-frequency performance, and will cause little degradation at low frequencies.

5. CONCLUSIONS

This parametric analysis of the elliptical profile TEM horn design has shown that such horns can be designed to give a predetermined performance. The overall length of the horn is determined by the lowest operating frequency, whereas the type of H-plane radiation

<table>
<thead>
<tr>
<th>Horn Designation</th>
<th>Length (l) (mm)</th>
<th>Height (h) (mm)</th>
<th>Width (w) (mm)</th>
<th>h/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>240–480</td>
<td>480</td>
<td>240</td>
<td>120</td>
<td>0.50</td>
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<tr>
<td>480–480</td>
<td>480</td>
<td>480</td>
<td>240</td>
<td>1.00</td>
</tr>
<tr>
<td>732–480</td>
<td>480</td>
<td>732</td>
<td>366</td>
<td>1.525</td>
</tr>
<tr>
<td>960–480</td>
<td>480</td>
<td>960</td>
<td>480</td>
<td>2.00</td>
</tr>
</tbody>
</table>
A horn aspect ratio of approximately unity gives $E$- and $H$-plane radiation patterns that are not only approximately equal in size but also to a very large extent frequency-independent.

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REFERENCES


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