Design and Parametric Analysis of Pyramidal Horn Antenna with High Efficiency

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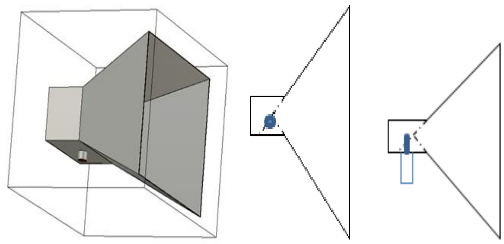
Abstract **- An efficient pyramidal horn antenna has been designed and fabricated to cover CDMA and GSM bands (820 MHz to 960 MHz). The effect of probe length, probe radius and its location from the short wall of the waveguide on the impedance matching, resonance frequency and bandwidth of the horn antenna have been studied using CST Microwave studio. Simulation result shows maximum efficiency of 80% at 850 MHz and it varies between 72% and 80%. As the frequency increases from 700 MHz to 1130 MHz, the gain monotonically increases from 8.4 dBi to 12.6 dBi with main lobe remains in broadside direction. The antenna has also been simulated using IE3D and the results have been compared with those obtained using CST. The pyramidal horn antenna has been fabricated and the measured results are in good agreement with the simulated results.**

Index Terms **- CDMA, GSM, high efficiency, parametric analysis, pyramidal horn.**

I. INTRODUCTION

Microwave horn antennas are generally used as a feeding element for large reflector and lens antennas in communication systems. It is used as a standard gain antenna for calibration purposes of other antennas and high gain element in phased array system. It has a very important characteristic that its radiation pattern in any plane (either E or H-plane or both) can be adjusted by changing the aperture dimensions or length of the horn [1] with negligible variations in the other parameters of the horn. It also has advantage of low cost, ease of excitation and fabrication. It provides a wide impedance bandwidth, narrow beamwidth with high directivity depending upon the parameters of the horn. By proper selection of the feeding element, a wideband horn antenna can be obtained [2].

The 3-D geometry along with E and H-plane views of a pyramidal horn antenna is shown in Fig.1.



(a) (b) (c)

Fig.1. (a) 3-D geometry (b) H-plane (c) E-plane of a pyramidal horn antenna.

The directivity of a pyramidal horn antenna is given by [3]

$$D = 4\pi\varepsilon_{app}\frac{AB}{\lambda^2} \quad (1)$$

where A,B are the horn aperture dimensions and ε_{app} denotes the aperture efficiency.

In the literature, details are available related to the design of an optimum gain pyramidal horn antenna [4-8] but parametric analysis related to the feed parameters are not readily available. In this paper, the design and parametric analysis of a pyramidal horn antenna with coaxial probe feed is discussed, followed by simulated and fabricated results. Also, a parametric analysis has been done by varying the horn length and aperture dimensions of the horn antenna. The horn length has been optimized to obtain maximum efficiency for a given aperture.

II. PYRAMIDAL HORN ANTENNA DESIGN

A. Design Specifications

Initially, a simple pyramidal horn antenna has been designed based on approximate formulae given in [4]. To excite the horn, a coaxial to waveguide adaptor with a cylindrical probe as a feeding element has been designed. A coaxial to waveguide adaptor with probe as a feed element acts like an impedance transformer that transforms the impedance from 50 ohm to the waveguide impedance (more than the free space impedance). After the initial design, various parameters: length of the horn, dimensions and position of the probe feed element, waveguide dimensions, etc. have been optimized by the parametric analysis.

B. Simulation Results

Fig.2 shows $S_{11} \leq$ -10dB from 700 MHz to 1130 MHz with 47% bandwidth including the CDMA and GSM Bands. The realized gain in Fig.3 shows that gain increases monotonically from 8.5dBi at 700 MHz to 12.6dBi at 1130 MHz. The radiation pattern at 700, 850, 1000 and 1100 MHz in E and H-planes is shown in Fig.4. It is observed from the figure that radiation pattern is stable over the entire range of impedance bandwidth and radiation is in broadside direction over the required range. The HPBW in E-plane is higher than that in H-plane because current distribution is cosine in H-plane unlike uniform in the E-plane.

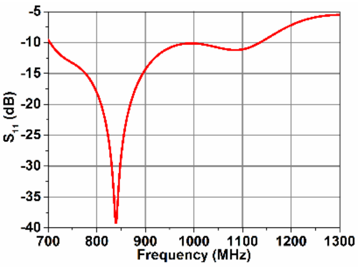


Fig.2. S_{11} magnitude plot of pyramidal horn antenna.

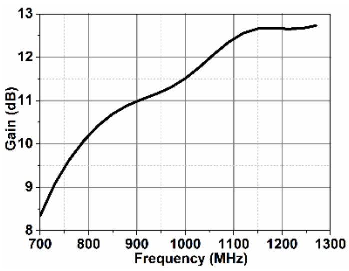
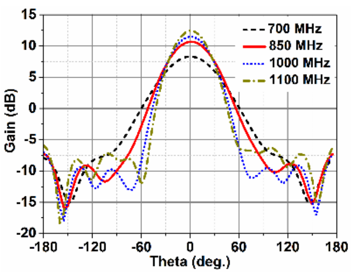
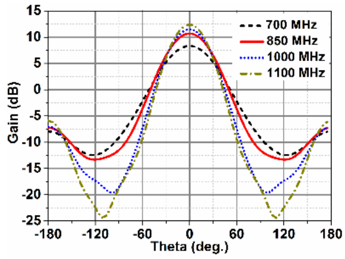


Fig.3. Gain plot of designed pyramidal horn antenna.



(a)



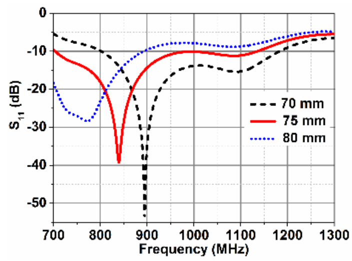
(b)

Fig.4. Radiation pattern in (a) E & (b) H-planes of pyramidal horn antenna.

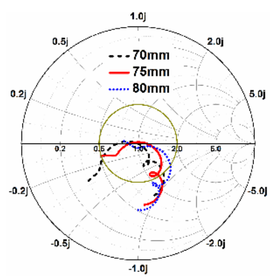
III. PARAMETRIC STUDY

A. Effect of variation of feed element length

As the probe length increases, the resonance frequency decreases. In addition, the capacitive effect increases as the length of the monopole antenna increases. Since the gap between the feeding element and waveguide wall reduces which increases the capacitive reactance [9], which can be seen from the input impedance plot given in Fig.5(b).



(a)

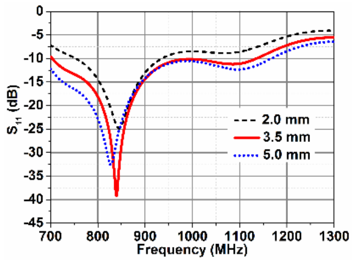


(b)

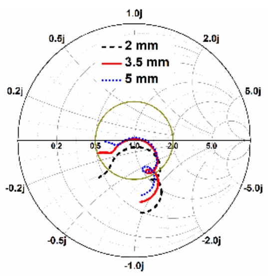
Fig.5. Effect of feed probe length on (a) $|S_{11}|$ and (b) input impedance of pyramidal horn antenna.

B. Effect of variation of feed element radius

As the probe radius increases, the resonance frequency decreases slightly because of increase in fringing fields [9], which increases the effective length. The bandwidth increases with increase in the thickness of the feeding element from 2 mm to 5 mm as shown in Fig. 6(a). This is due to the fact that the length to diameter ratio decreases with increase in the diameter of the feeding element and the impedance variations reduces as shown in Fig.6(b).



(a)



(b)

Fig.6. Effect of feed probe radius on (a) $|S_{11}|$ and (b) input impedance of pyramidal horn antenna.

C. Effect of variation of feed element position

As the position of the feed element from the short circuited waveguide wall changes, the reflected signal from the short wall of the waveguide interferes constructively or destructively (depends on the distance). By properly adjusting the position of the feed element, input impedance matching can be improved over the required frequency range as shown in Fig.7.

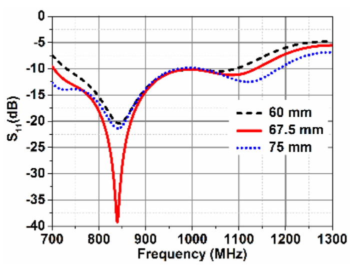


Fig.7. Effect of feed location on input impedance of pyramidal horn antenna.

D. Effect of variation of horn length

It has been shown in [10] that the gain of the horn antenna depends on the aperture of horn and the axial length of the horn antenna. So, the selection of horn length is as important as horn aperture dimensions. It can be shown that same gain can be obtained by two horns having different apertures by varying the horn length. A smaller horn length with larger aperture gives the same gain as given by the longer horn length with smaller aperture. In our design, we have selected the horn length larger than that obtained by the approximate formulae [4]. If the length of the horn is small in terms of λ, then approximation involved in calculation of aperture phase error significantly affects the performance of the antenna. Hence, exact aperture phase error formulae have to be used instead of the approximate formulae. Also, the aperture dimension increases (in terms of λ) with increase in frequency. This results in corresponding increase in the maximum aperture phase error, affecting the gain and other characteristics of the antenna. Therefore, to achieve the reasonable performance over the entire range of bandwidth, the length of the horn should be maintained according to the highest usable frequency instead of the centre frequency.

The efficiency vs horn length plot is shown in Fig.8. For smaller horn length, efficiency is poor and as the length increases, the efficiency increases as explained in [10]. But there is a little variation in the efficiency with the horn length after certain value.

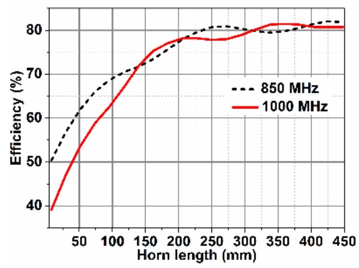


Fig.8. Variation of efficiency with horn length of pyramidal horn antenna for two different frequencies.

E. Effect of variation of horn aperture with constant aspect ratio

The effect of the variation of the horn aperture with constant aspect ratio and a fixed horn length on the directivity of the antenna is observed. It can be seen from the directivity plot (Fig.9) that the rate of improvement in the directivity decreases with increase in the aperture dimension beyond a certain limit especially at the higher frequencies. As the frequency increases, phase error increases which decreases the efficiency of the horn antenna.

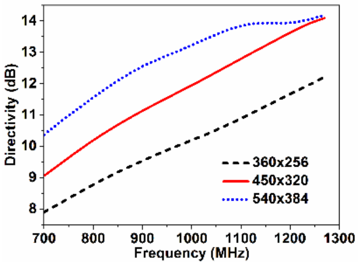


Fig.9. Directivity vs frequency with constant aspect ratio.

IV. SIMULATED AND MEASURED RESULTS

The designed pyramidal horn has been fabricated as shown in Fig.10. The measured results have been compared with corresponding simulated results in Fig.11. It is observed from the results that measured impedance bandwidth is 52% which is comparable to simulated impedance bandwidth of 47% and 49.5% using CST and IE3D respectively.

Fig.10. Photograph of fabricated pyramidal horn antenna.

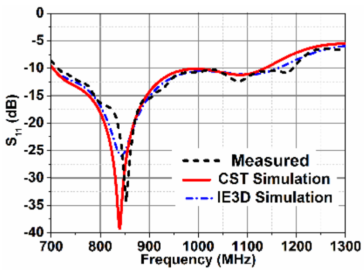


Fig.11. Simulated and measured S_{11} of pyramidal horn antenna.

V. CONCLUSION

An efficient pyramidal horn antenna has been designed, simulated and fabricated. The effect of various probe feed parameters on the characteristics of the antenna has been studied. The radiation pattern characteristics shows the stability over the entire bandwidth of 47%. The designed antenna has a high efficiency (72% to 80%) and gain varies from 8.4 dBi to 12.6 dBi as frequency increases from 700 MHz to 1130 MHz.

ACKNOWLEDGMENT

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