DESIGN OF X BAND PYRAMIDAL HORN ANTENNA

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ABSTRACT

A horn may be considered as a flared out waveguide. In this paper, a powerful electromagnetic simulator, 3D EM solver WIPL-D software is used to design, analyse and optimize the dimensions of horn antenna which is based on MOM solution for computations. The standard horn antenna at 10 GHz for 15dB gain is modelled and the radiation pattern was observed. The horn antenna is optimized to achieve more than 20dB gain using Genetic Algorithm, radiation patterns of the optimized horn antenna are also presented. Geometry of the horn can be modelled by exploring the toolbar 'symmetry' option in WIPL-D. Design of X band Pyramidal Horn Antenna is fabricated and measured using Network Analyzer.

KEYWORDS

X Band, Pyramidal Horn, Gain, Optimization, Microwave Antennas

1. INTRODUCTION

Guglielmo Marconi demonstrated numerous advances in the field of wireless communications by radio's ability to provide continuous contact with sailing ships across the English Channel. Since then numerous experiments were carried out by different researchers to make use of electromagnetic waves to carry information. Antennas have practical uses for the transmission and reception of radio frequency signals (radio, TV, etc.). In air, those signals travel close to the speed of light in vacuum and with a very low transmission loss.

Jagadish Chunder Bose in a lecture at the London's Royal Institution recorded the first horn antenna to appear in an experiment was the pyramidal horn referred it as collecting funnel. Electromagnetic horn antennas make a transition from EM waves propagating in a guided medium, usually a waveguide, and launching it into another medium such as free-space. They occur in variety of shapes and sizes to fulfil many practical applications, such as communication systems, electromagnetic sensing, radio frequency heating, non-destructive testing and evaluation, biomedical, and as a reference source for other antenna testing. Horns are used as feeds for other antennas such as reflectors, lenses and compound antennas [1]. Due to number of impressive characteristics, rectangular aperture pyramidal horn antenna can be preferred over other types of antennas in Line of Sight Communication i.e., (i) It can be used as standard antenna for testing and calibration of other antennas in anechoic chambers, (ii) easy and straightforward design and construction with respect to quad ridge and ducal ridge pyramidal horn antennas respectively, (iii) Ability to provide radiation pattern according to requirements and Applications [2]. Whereas drawback include absence of circular polarization which is useful in satellite communication, but this advantage proves to be the main advantage in Line of Sight Communication, which require vertical polarization for communication [3].

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In this paper, the design and simulation of a small size, high gain, low VSWR, 50Ω coaxial feed, and vertically polarized rectangular waveguide pyramidal horn antenna is presented. The designed antenna has an improved VSWR performance ≤ 1.8 than the VSWR of horn as presented in [4]. Good impedance matching is achieved by selecting the proper coax feed position and length of suspended probe inside waveguide throughout the complete band. In Section 2, the significance and use of 3D EM Solver WIPL-D software is provided. In Section 3, the pyramidal horn antenna configuration and design procedure is discussed to identify its critical parameters and their effects on the antennas performance. Simulation and fabrication results of designed X-band pyramidal horn are described and discussed in Section 4.

2. WIPL-D

WIPL-D Microwave is a powerful and easy-to-use software package for fast and accurate simulation and design of microwave circuits, devices and antennas. A distinguished feature of WIPL-D Microwave is that you can create your own components specified as composite metallic and dielectric structures (3D EM components). S-parameters of the 3D EM components are computed on-the-fly during circuit simulation. 3D EM solver is a frequency domain solver based on the method of moments. It enables you to model structures of arbitrary shape using wires and plates as basic building blocks. You don't need to know the specifics of numerical modelling techniques in order to use this program efficiently. We can plot frequency response of the circuit: parameters, impedance and admittance parameters, voltages, currents, and power. Radiation pattern, near field and distribution of surface currents of an arbitrary 3D EM structure can be visualized by 2D and 3D graphs. In addition, you can overlay graphs from different projects files to present several curves on the same diagram. 3D EM components can be flexibly geometrically modelled by versatile building blocks, such as cylindrical and conical wires, quadrilateral plates which may characterize metallic or dielectric/magnetic surfaces including losses, wire to plate junctions, and protrusions, so almost any finite composite structure can be precisely modelled. Optimization of circuit parameters/behaviour affects all types of component parameters, such as: (i) lumped element values, (ii) parameters of 3D EM structures. EM modelling of composite metallic and dielectric structures includes: (i) Geometrical modelling of a real structure, (ii) Determination of the currents distributed over the geometrical model, (iii) Calculation of the quantities of interest by post-processing the computed currents. The main task for the user in EM modelling is to create an appropriate geometrical model of the structure to be analyzed and to define the excitation for the model. The rest of the analysis is carried out by the 3D EM solver with in-built EM code.

The more accurate analysis of horn antenna is based on the solution of integral equation by the MOM or FDTD [5-6]. An electromagnetic simulator which uses method of moment's technique for computations, WIPL-D pro was used for analysis and design of horn antenna at 10GHz. In WIPL-D, the electromagnetic modelling is of two parts, Geometrical modelling and Modelling of currents. In Geometrical modelling, any arbitrary metallic structure can be considered as composed of appropriately interconnected plates and wires. In modelling of Currents, The current along wires and over plates are approximated by polynomial expansions, whose basis functions automatically satisfy the continuity equations at the element junctions and free ends. Determination of unknown current expansion coefficients is based on the solution of EFIE for current distribution [7-8]. By applying Galerkin method, the EFIE is transformed into a matrix system which is solved by using L U Decomposition method [9].

3. DESIGN OF PYRAMIDAL HORN

3.1. Rectangular Waveguide

A waveguide is a hollow conducting tube which is used to transfer electromagnetic power efficiently from one point in space to another. Among guiding structures are typical coaxial cable, the two-wire and microstrip transmission lines, hollow conducting waveguides (rectangular & cylindrical), and optical fibres. The choice of structure is dedicated by: (i) the desired operating frequency band, (ii) the amount of power to be transferred, and (iii) the amount of transmission losses that can be tolerated. Among waveguide types rectangular waveguides are used to transfer large amounts of microwave power at frequencies greater than 3GHz. For example at 5GHz, the transmitted power might be 1 MW and the attenuation only 4dB/100m [10]. The dimensions of the desired X-band rectangular waveguide, which satisfy the conditions i.e., $b \leq a$ and $L = 0.75\lambda_g$ where a = broad wall dimension of waveguide, b = narrow wall dimension of waveguide, L = length of waveguide and λ_g = guided wavelength.

3.2. Pyramidal Horn Antenna

The pyramidal horn antenna is excited by a waveguide which is fed by a coaxial cable and it is assumed that antenna is made up of PEC; the plates of finite thickness are modelled as infinitesimally thin plates resulting in surface currents that represent the sum of interior and exterior antenna currents. Initially the geometry of a horn antenna with dimensions of aperture broad wall la = 2.66", aperture narrow wall lb =1.95", length of the horn l3 =5.46", similarly dimensions of waveguide broad wall a=0.9", waveguide narrow wall b=0.4", waveguide length l=1.57" is modelled as shown in Figure 1. Pyramidal flared section of horn antenna is the most significant part in the antenna design, which varies the impedance of waveguide from 50Ω at the feeding point to 377Ω at the aperture of the antenna [11].

One can use the symmetry feature in both electric and magnetic planes, so only half or quarter of given antenna can be modelled. The gain obtained is15.50dB, near field is observed and analysis characteristics for different models of antenna like with and without symmetry were tabulated.

The second part of the paper is to optimize the dimensions of the aperture and length of horn to get the gain of 20dB. There are seven different optimization methods are available with WIPL D pro optimizer [12]. Out of those, the most robust global optimization algorithm known to date, Genetic Algorithm was selected. It optimizes the project file by simulating the Darwinian evolution principle. i.e., survival of the fittest if the starting optimization parameter values are in the vicinity of optimal solution, this algorithm is useful to find the best solution with very low probability of being trapped in other local optima. The constraints introduced on horn geometry by specifying lower and upper limits for the optimization parameters la the range is given from

2.5"to 5", lb from 2" to 5" and l3 from 5" to 11". Number of bits per variable=16, algorithm type is binary, cross over probability =0.8, mutation probability=0.2, total no of generations=50, number of iterations=79. After 189sec, optimizer displayed the difference between found solution and the criterion is 0.0. Optimized dimensions are la=4.87", lb=3.62", l3=10.06" as shown in Figure 2. Radiation pattern for the optimized horn antenna was observed. The gain obtained is 20 dB. The near field is also obtained.

4. RESULTS

4.1. Simulated Results

All evaluations are presented here are performed on Intel Core2duo@1.80Ghz. Figures 2,5 shows the 3D pattern, Figures 3,6 shows near field pattern, Figures 7-11 represent different phi cut and theta cut polar and rectangular plots. The gain observed is 15dB and 20dB respectively. Figure 12 shows the comparison of patterns for half and no symmetry for modelling the horn antenna. Table .1 consolidates analysis characteristics for different models.

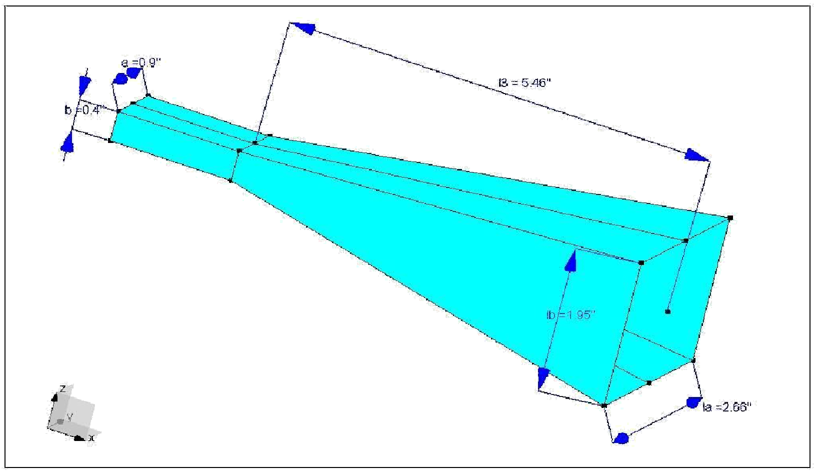

Figure 1. Geometry of 15dB simulated horn antenna at 10GHz

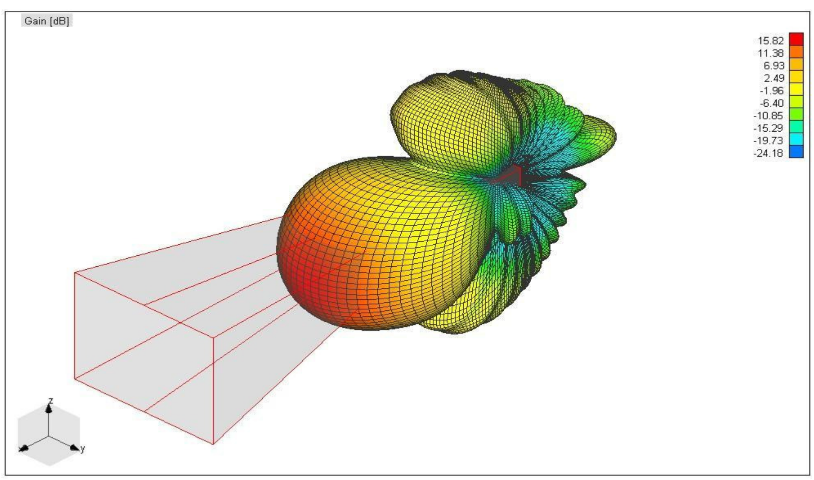

Figure 2. Far field pattern for 15dB.

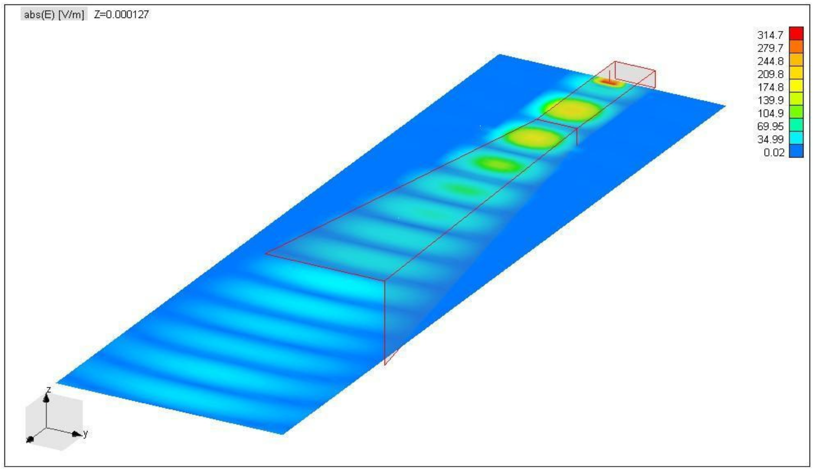

Figure 3. Near field pattern for 15dB

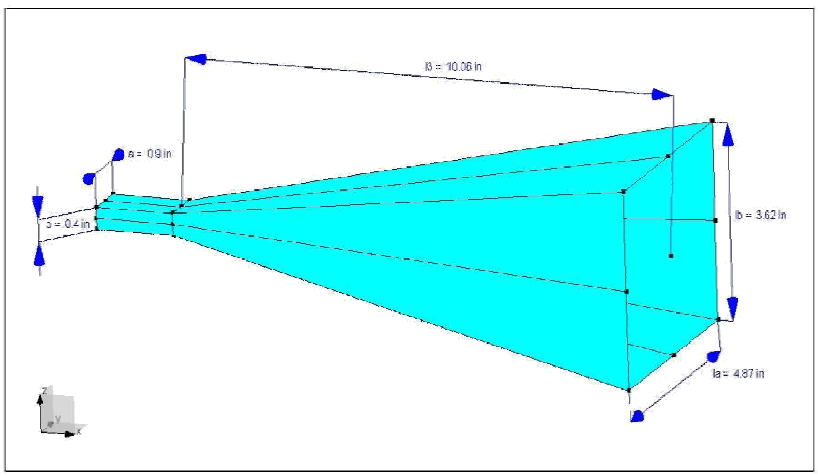

Figure 4. Geometry of 20dB optimized horn antenna at 10GHz

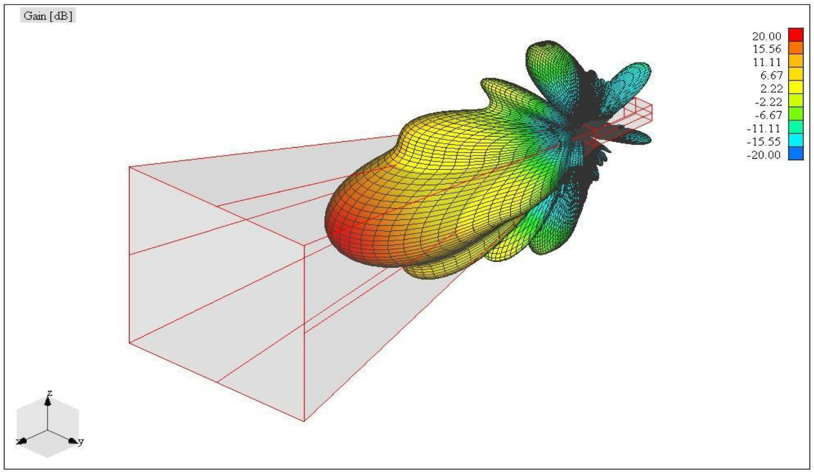

Figure 5. Radiation pattern of optimized antenna for 20dB.

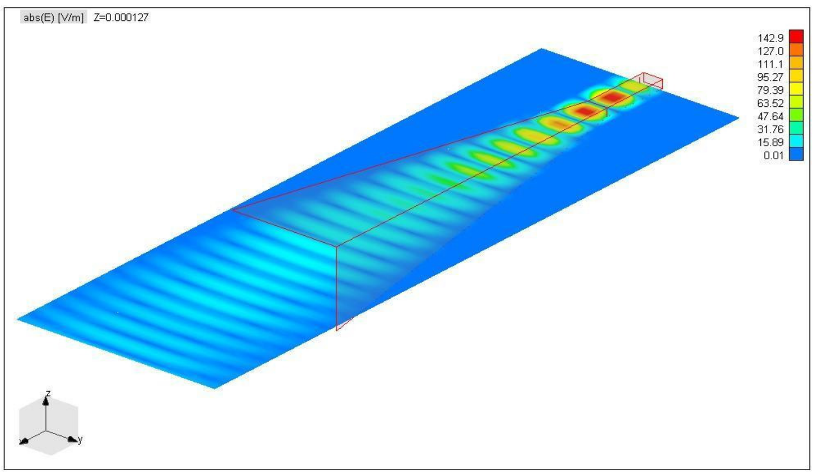

Figure 6. Near field pattern for 20dB.

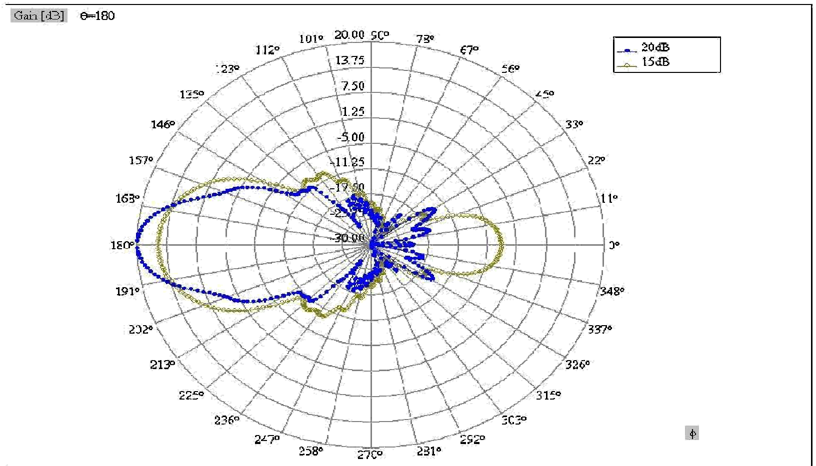

Figure 7. Overlay of theta cut polar plot

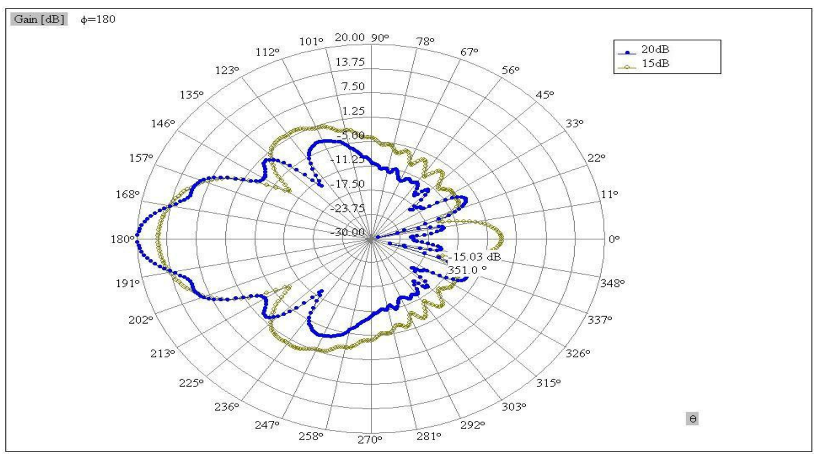

Figure 8. Overlay of phi cut polar plot

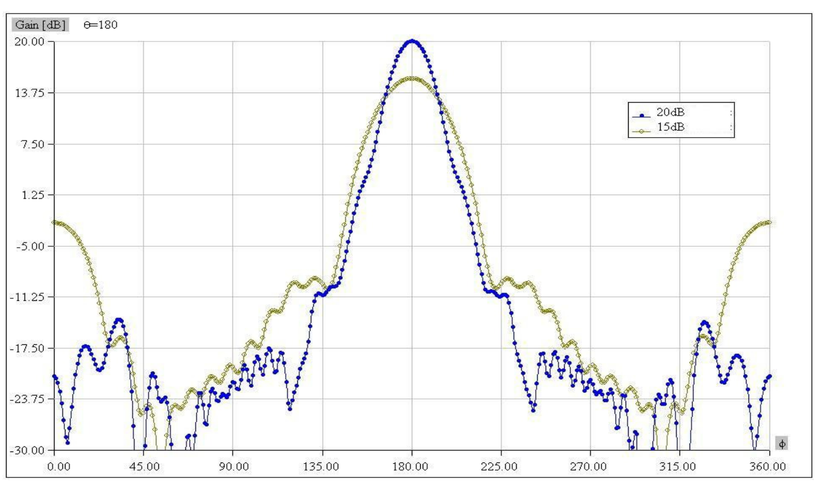

Figure 9. Overlay of theta cut rectangular plot

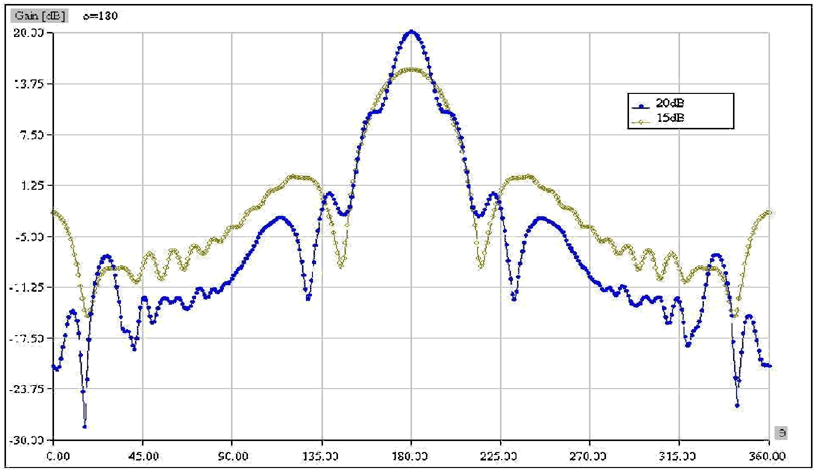

Figure 10. Overlay of phi cut rectangular plot

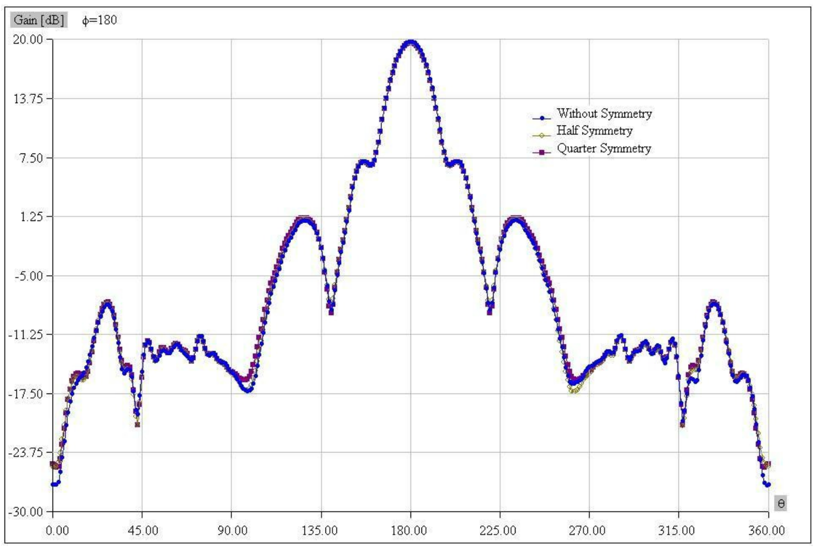

Figure 12. Comparison of different symmetries using WIPL-D

Table 1.comparision of different symmetric characteristics.

Horn Antenna Gain	Type of Symmetry Used	Size of EFIE matrix	CPU TIME (sec)	Memory Required (MB)
20 dB	Without Symmetry	2835	158	61.3
	Half Symmetry	1394	126	14.82
	Quarter Symmetry	717	121	3.92
15 dB	Without Symmetry	1059	90	8.55
	Half Symmetry	518	88	2.04
	Quarter Symmetry	273	85	0.57

4.2. Experimental Results

The optimized pyramidal horn antenna is fabricated using brass material and inside walls are coated with silver with waveguide dimensions a=0.9", b=0.4", and l=1.57", aperture dimensions la=4.87", lb=3.62", and l3=10.06", and waveguide co-axial adapter is used as per specifications square flange is 41.5mmx41.5mm as shown in Figure 13-15.

Figure 13. Fabricated Pyramidal Horn Antenna

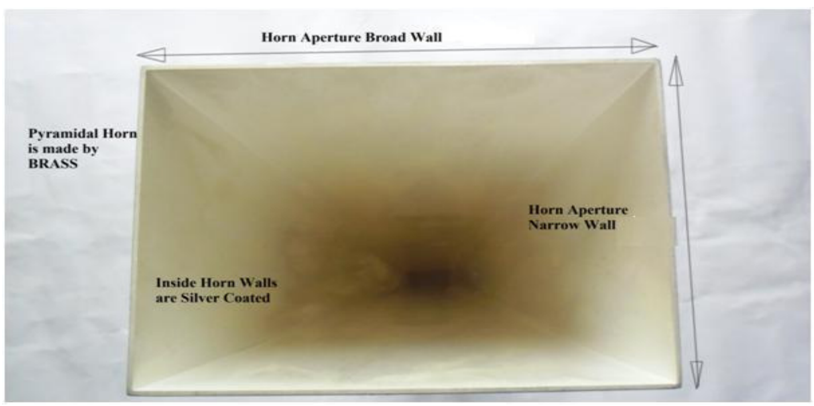

Figure 14. Designed Aperture of Pyramidal Horn dimensions

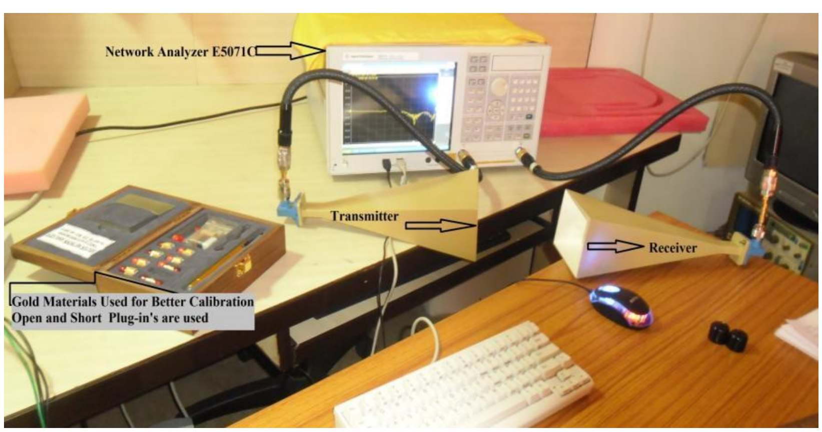

Figure 15. Network Analyzer E5071C Experimental Setup

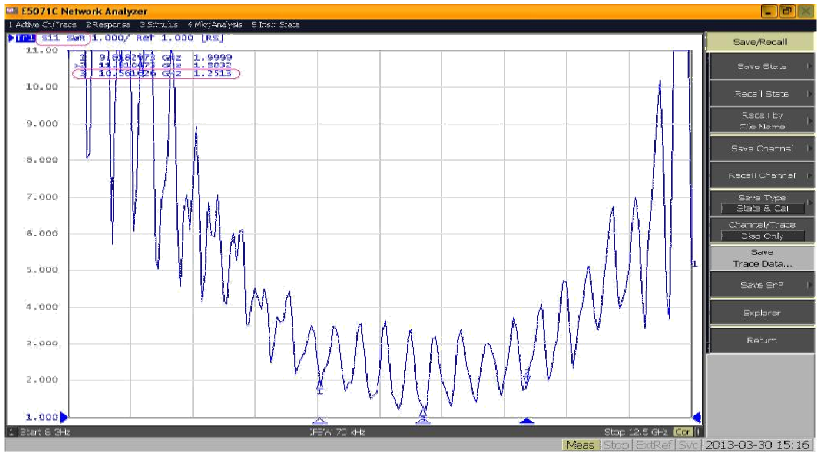

Figure 16. At 10GHz frequency obtained VSWR is 1.2

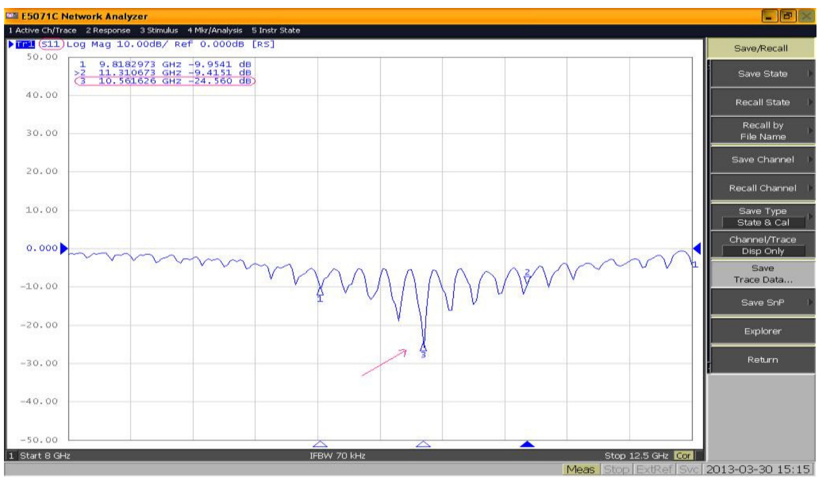

Figure 17. Return Loss Obtained Resonant Frequency at 10.5GHz

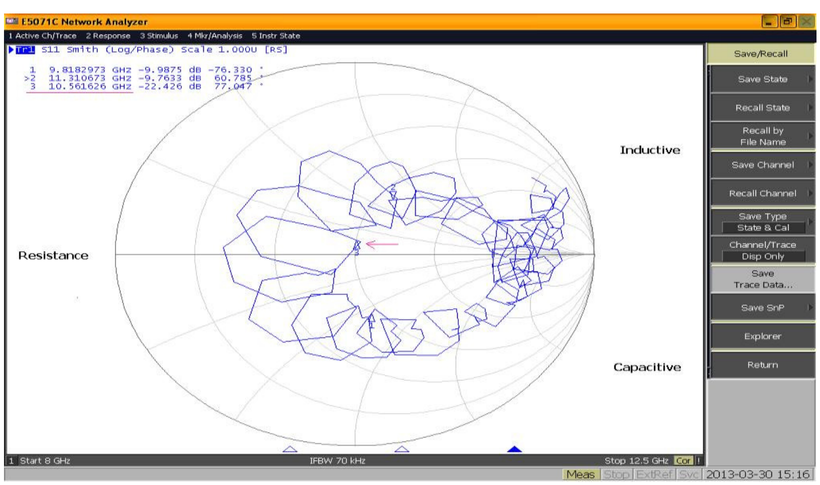

Figure 18. Smith Chart Obtained Resonant Frequency at 10.5GHz as r+jx Ω

4.2.1. Practical Gain Calibration

The distance between transmitter and receiver d=4”. This distance partially satisfies the condition measurement in far-field is $d \geq \frac{2D^2}{\lambda_0}$ where D=maximum dimension of horn aperture, wavelength λ_0 = 1.12” for dip frequency f=10.5GHz. The gain of pyramidal horn antenna is given as $G = \frac{4\pi d}{\lambda_0}\sqrt{\frac{P_r}{P_t}}$ [13-14] here received power of horn P_r =41.2dB and transmitted power of horn P_t =35dB. The obtained practical gain, G=19.54dB in line of sight with $\theta=\phi=0°$.

4.3. Rectangular Waveguide Standards

Standard Notation for Rectangular Waveguide is WR and for Circular Waveguide is WC as per IEEE standard notations as shown below Table 2.

Table 2. Rectangular Waveguide Standards.

Frequency Band	Waveguide Standard	Frequency Limits (GHz)	Inside Dimensions (inches)
C band	WR-137	5.85 to 8.20	1.372 x 0.622
X band	WR-90	8.2 to 12.4	0.900 x 0.400
Ku band	WR-62	12.4 to 18.0	0.622 x 0.311
Ka band	WR-28	26.5 to 40.0	0.280 x 0.140

In this paper, Rectangular Waveguide WR-90 specifications are used with a=0.9” and b=0.4”.

5. CONCLUSIONS

From table 1, it is implied that if symmetry is used, the memory required, number of unknowns, or the size of EFIE matrix are drastically reduced. The time for evaluation is also considerably reduced. No difference in the radiation patterns was observed for half and quarter symmetries.

Observed standard horn dimensions for 15 dB and after optimization gives 20 db with reduced reflections. The gain obtained with the optimized dimensions of horn exactly met with specified criterion using genetic algorithm. WIPL D pro is a useful tool for better 3D and 2D analysis and design of different antenna structures within less time. By Using WIPL D simulation results, we have fabricated our pyramidal horn antenna of 20dB and measured using Open field Antenna Test (OAT). WIPL D pro is a useful tool for better 3D and 2D analysis and design of different antenna structures within less time. By Using WIPL D simulation results, we have fabricated our pyramidal horn antenna of 20dB and measured using Open field Antenna Test (OAT) using Network Analyzer E5071C equipment. And we have obtained very good results with the fabricated model. The obtained Gain is 19.54dB (approx. 20dB), Resonant Frequency is 10.5GHz (approx. 10GHz), VSWR is 1.2 and Normalized Impedance 50+j5Ω (at 10.5GHz horn antenna acts as pure reactance particularly which is inductive) as shown in Figures 16-18.

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