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Design of Compact Horn Antenna Excited by Microstrip Patch in C-Band

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ABSTRACT
A high gain microstrip patch fed horn antenna operating in C-band at 6 GHz is presented. The proposed antenna uses H-shaped microstrip excited patch in FR4 and a surface mounted horn integrated on metal. The peak antenna gain is 8.6dBi and directivity is 8.9dBi. VSWR bandwidth is 24%. The proposed design is simulated with Zeland Program Manager IE3D 9.0 version software.

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Introduction

Nowadays, there are many research works going on in the design of various types of antennas as a communication system. Horn antennas are used for receiving and transmitting RF signals and they are used at UHF and even at higher frequencies. Horn is elongated structure of rectangular waveguide and is the most widely used microwave antenna. Horn antennas have a directional radiation pattern with large impedance bandwidth. They also have high antenna gain & directivity. Nowadays, they are used in microwave, space, radar, communication systems and wireless broadband applications.

Horn antenna are of various types most popular being rectangular horn antenna and Conical horn antenna. There are three types of rectangular horn antennas which include H-plane sectoral horn, E-plane sectoral horn and pyramidal horn. E-plane sectoral horn is flared in the E-plane. H-plane sectoral horn is flared in the H-plane. The most popular horn known as pyramidal horn is flared in both planes therefore its radiations characteristics are essentially a combination of the E-plane and H-plane sectoral horns. Recently, many research activities have been done on these different horn antennas. Some of them include a new dual-polarized horn antenna fed by a microstrip patch [1], Microstrip Antenna Integrated with Horn Antenna where high gain antenna configurations are obtained by integrating the suspended square microstrip antenna inside the pyramidal horn [2], high gain hybrid circular patch antenna with a surface-mounted conical horn for millimeter-wave applications [3], Accurate design method for optimum gain pyramidal horns [4], Design of Optimum Gain Pyramidal Horn with Improved Formulas Using Particle Swarm Optimization[5] and Millimeter wave antenna with mounted horn integrated on FR4 for 60GHz Gbps Communication Systems[6] is also designed.

In this paper, we present the design and radiation pattern analysis of pyramidal horn antenna at 6GHz (C-band). The proposed antenna uses H-shaped excited patch in FR4 and a surface mounted horn integrated with waveguide on ground plane. Microstrip patch antennas alone have several limitations in terms of gain, Bandwidth etc. To overcome these, Horn antenna is integrated with microstrip patch. Firstly, Microstrip patch with H-shaped slot is designed on FR4 substrate and then waveguide is designed and pyramidal horn antenna is integrated. The design has light weight & compact size structure. Simulation is performed on IE3D software and various parameters such as return loss, VSWR, Gain, Bandwidth are calculated and radiation pattern is evaluated.

Pyramidal Horn Antenna

The pyramidal horns are popular for their attractive features like light weight, low VSWR, low profile and compatibility. They have equal radiation pattern in both E-plane and H-plane along with its high gain and directivity. They can be widely used as a standard to make gain measurements of other antennas.

Consider the geometry of a pyramidal horn antenna as shown in Fig.1. To design a pyramidal horn, one usually knows the desired gain G, the wavelength, and the inner dimensions “a” and “b” of the feeding rectangular waveguide. The other parameters are then determined using a specific design method. A horn is said to be optimum when the aperture dimensions are adjusted to give maximum gain for given slant lengths in the E-plane and H-plane. According to [7], this occurs when the following relations are satisfied:

$$A=\sqrt{3\lambda L},\quad B=\sqrt{2\lambda L} \qquad (1)$$

Optimum directivities for the E-plane and H-plane sectoral horns can be obtained by selecting values of “a” and “b”.

Gain of the antenna can be related to its physical area by given formula:

$$G_0=\frac{4\pi AB}{2\lambda^2} \qquad (2)$$

The directivity is one of the parameters that is often used as a figure of merit to describe the performance of an antenna [7]. To find the directivity, the maximum radiation is formed. The directivity of the pyramidal horn can be written as:

$$D_p=(\pi\lambda^2/32ab)\ .\ D_E D_H \qquad (3)$$

where D_E and D_H are directivities of the E-plane and H-plane sectoral horn [7]

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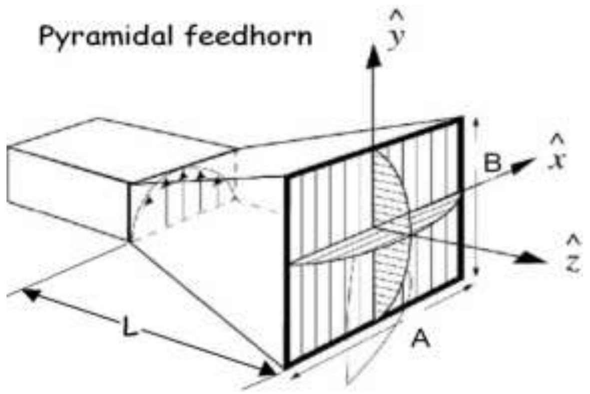

Fig. 1. Pyramidal horn antenna

Design of pyramidal horn antenna

The design was performed to accomplish wide bandwidth with high gain & high efficiency levels. The antenna was designed using IE3D simulation software [8]. Proposed design shows a horn antenna mounted on FR4 substrate where the waveguide part of the horn is integrated on FR4 substrate.

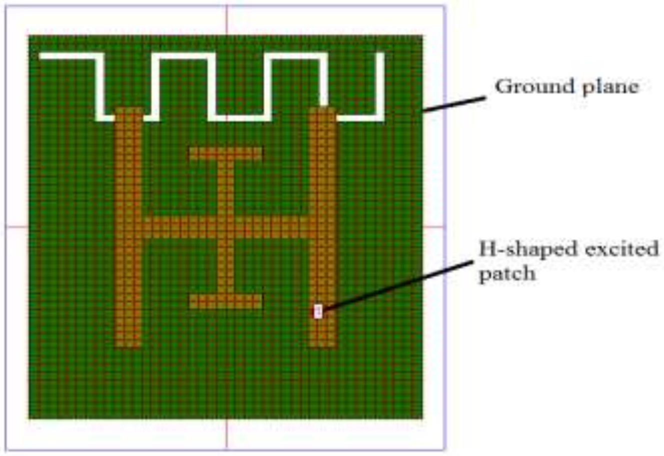

Fig. 2 H-shaped excited patch and ground plane.

First, a rectangular microstip patch is designed on substrate with following parameters: Operating frequency= 6GHz, dielectric constant $\varepsilon_r = 4.3$, height of the dielectric substrate h = 1.5 mm, $\tan \partial = 0.019$. H-shaped slot is created on patch and mender-slot is created on ground plane for gain and bandwidth enhancement as shown in Fig. 2 and coax probe feed is given on patch as shown in Fig.3. Pyramidal horn antenna is fed by rectangular H-shaped excited microstrip patch.

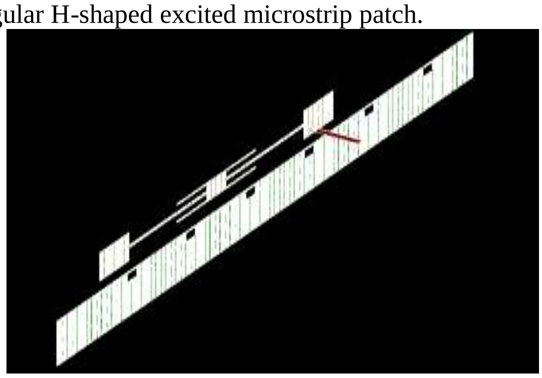

Fig.3. 3D view of H-shaped excited microstrip patch and ground plane connected by coaxial feed.

Waveguide is designed on ground plane, so its dimensions are same as that of ground plane which are equal to a=24.357mm and b=20.5128mm. Waveguide length is 3mm from source to open end of waveguide. Horn antenna is designed by selecting horn length L=50mm for 6GHz frequency range. Pyramidal standard gain horns are designed using equation (1). Therefore, horn antenna dimensions are calculated as A=86.6mm and B=70.7mm. The basic geometry of horn antenna is shown in fig.4. and 3D view of design is shown in Fig.5. showing all the dimensions.

Ground plane consists of mender-shaped slot for impedance matching for maximum power transfer in forward direction.

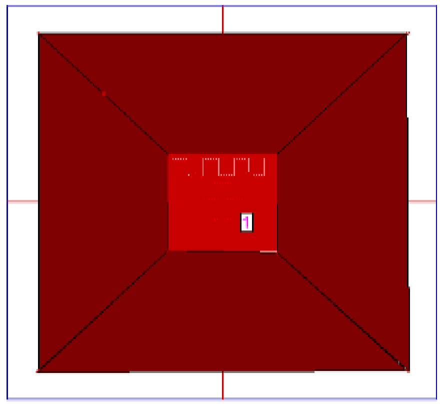

Fig.4. Geometry of proposed horn antenna with excited patch and waveguide integrated horn

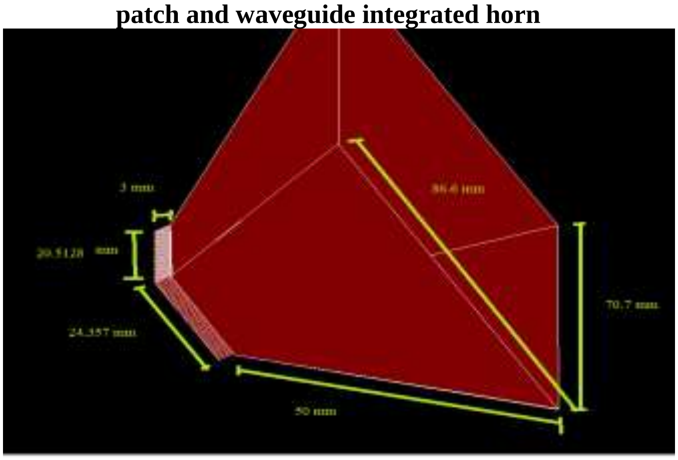

Fig. 5. 3D view of horn antenna showing all the dimensions of waveguide and horn

Simulation Results

The proposed horn antenna configuration is simulated on IE3D software with operating frequency f_o = 6 GHz. Return loss and radiation pattern is evaluated. The simulated return losses versus frequency for the design is shown in Fig.6. The return loss is less than -10dB for frequencies ranging from 3.6GHz to 4.6GHz which is -18.13dB at 3.9GHz. VSWR versus frequency curve is shown in Fig.7. VSWR is less than 2 for frequencies ranging from 3.6GHz to 4.6GHz. VSWR Bandwidth is 24% approximately. Smith Chart is shown in Fig.8. Gain is another important parameter, which is related to directivity. The gain of a horn is usually very close to its directivity because the radiation efficiency is very good (low losses). High directivity leads to high gain. Gain versus frequency curve is shown in Fig.9. Gain is 7.19dBi for 3.9GHz. Also peak gain is 8.6dBi and Directivity is 8.9dBi at frequency 4.6GHz. Gain is also verified by formula used in (2). Directivity versus frequency curve is shown in Fig.10. Directivity is 7.59dBi for 3.9 GHz. Axial ratio as shown in Fig.11. is less than 3dB for overall frequency range which shows linear polarization. Efficiency of Horn antenna given in terms of radiation efficiency and antenna efficiency is shown in Fig.12. Radiation efficiency is above 95% and antenna efficiency is above 90% for frequencies 3.6GHz to 4.6 GHz. 3D radiation pattern at frequency 4.6GHz is shown in Fig.13.

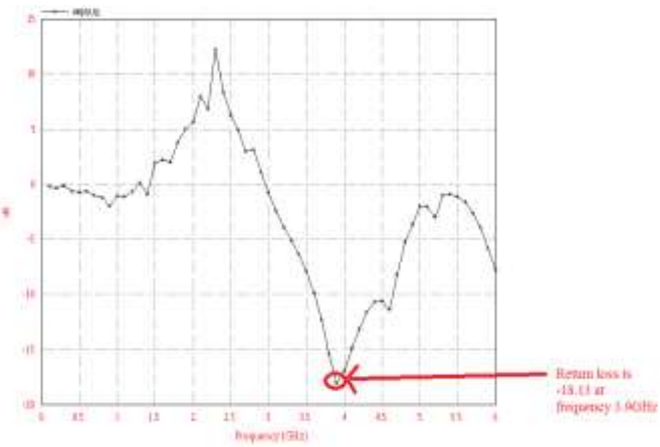

Fig. 6. Return loss versus frequency curve. Return Loss is minimum at -18.13dB at 3.9GHz.

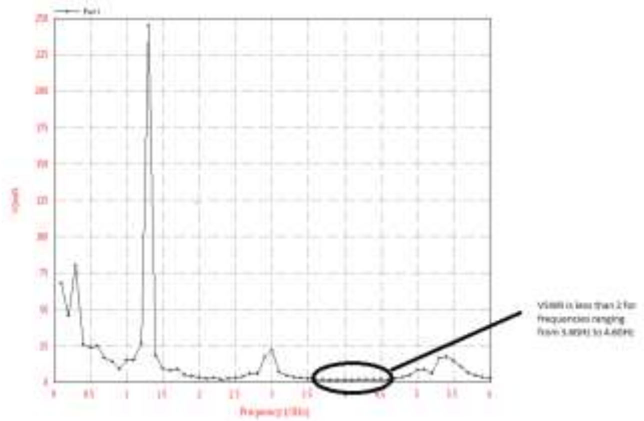

Fig. 7. VSWR versus frequency curve

VSWR is less than 2 in frequency range 3.6GHz to 4.6GHz and minimum 1.2 at 3.9GHz.

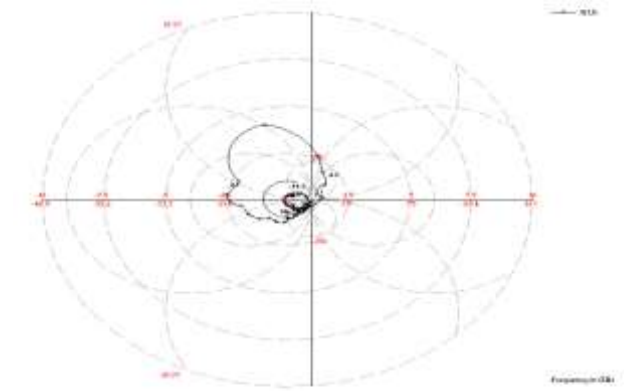

Fig.8. Smith Chart

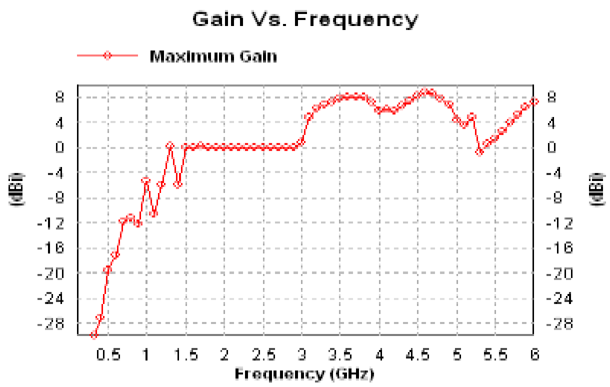

Fig.9. Gain versus frequency curve. Gain is above 8dBi mostly in frequency range 3.6GHz to 4.6GHz range. Peak gain is 8.6dBi.

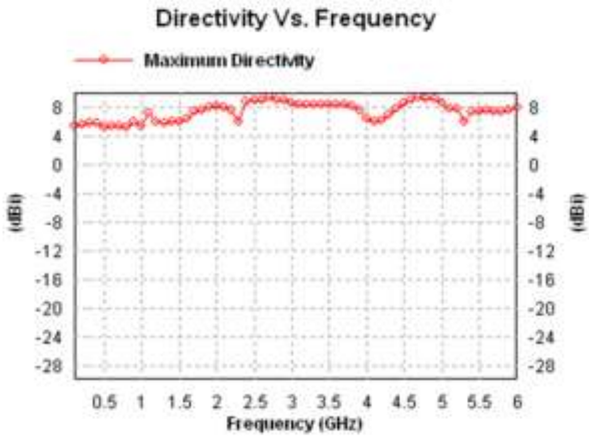

Fig.10. Directivity versus frequency curve. Directivity is maximum 8.9dBi at 4.6GHz.

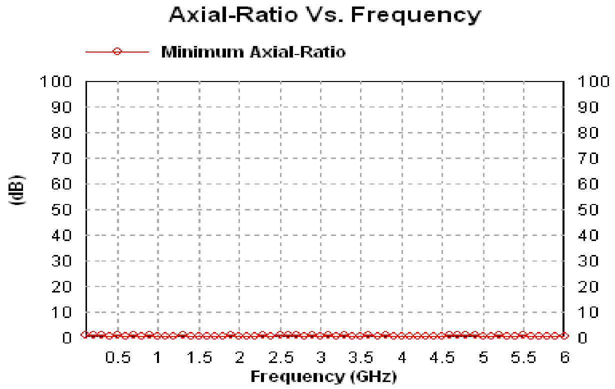

Fig.11. Axial Ratio versus frequency curve. Axial ratio is 0dB which shows linear polarization.

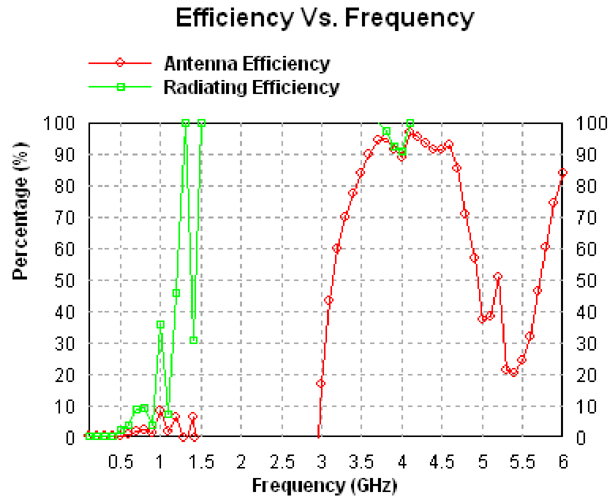

Fig.12. Efficiency versus frequency curve. Efficiency is above 90% indicating low losses.

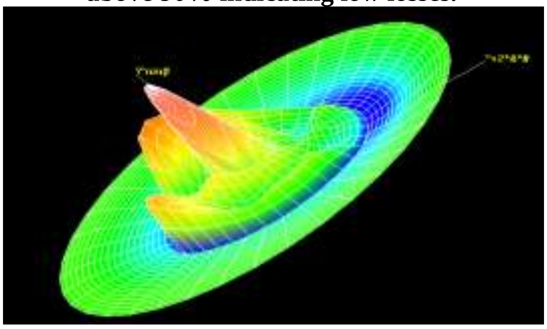

Fig.13. 3D radiation pattern at 4.6GHz showing gain of 8.6dBi

Conclusion

The horn antenna at 6GHz operating frequency (C-band) is designed successfully and simulated. All the parameters of antenna have been carefully studied to achieve superior performance. The antenna covers frequency range from 3.6GHz to 4.6GHz with good return loss characteristics. The radiation pattern of antenna resulted in peak gain of 8.6dBi and directivity of 8.9dBi at frequency 4.6GHz. Efficiency of antenna is very good which covers Radiation efficiency above 95% and antenna efficiency above 90%. The antenna weight and size are small as compared to classical horn antennas. The proposed antenna can be used in space programs, satellite communication and Wimax applications etc.

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