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DESIGN AND ANALYSIS OF LEAKY WAVE ANTENNA TO GENERATE THE BESSEL BEAM

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Abstract

Leaky wave antenna offers a thin and low profile antenna. It provides sidelobe level reduction and radiation pattern shaping. The leaky wave antenna is studied to generate the Bessel beam for a specific region. Until now, the leaky wave antenna is implemented in the higher frequency region. This paper presents the design and analysis of leaky wave antenna for the lower frequency region. The leaky wave antenna is designed and implemented at an operating frequency of 2.45GHz and 5.8GHz. Both antennas are designed by using an FR4 epoxy substrate of thickness 3.2mm. The proposed antenna represents an attractive, low cost and simple solution to generate the Bessel beam. The leaky wave antenna has various applications in the microwave region.

Keywords:

Leaky Wave Antenna, Bessel Beam, HFSS, Return Loss, VSWR, Impedance, Coaxial Feeding, VNA

1. INTRODUCTION

In the past few decades, several works have done for the generation of Bessel beams. Bessel beams are generated using aperture, holograph and resonant cavities in the optical region [1]. A new approach to Bessel beams is the superposition of two fields described by Hankel functions which is useful in the optical region [2]. Non-diffractive Bessel beam from a sub-wavelength aperture is generated by inserting a metal circular grating in front of the aperture [3]. When the incident wave is linearly polarized, the beam is axially asymmetric. The full width at half maximum of the beam is less than two wavelengths over almost ten wavelengths. The beam is decomposed in terms of a number of guided transverse electric modes of a metallic waveguide [4]. Excitation is achieved by inserting the number of coaxial loop antennas whose currents are calculated from the excitation coefficients of the guided modes. Bessel beam is generated using waveguide in the microwave frequency region, which gives narrow bandwidth. The radial waveguide consists of a capacitive sheet over a ground plane [5]. Vector approach is used which avoids approximations. Two prototypes are used for microwave and millimetre wave frequency regions.

The leaky wave antenna [6] has been widely discussed in the earlier days. The leaky wave antenna is one of the classes of the travelling wave antenna [7]. The leaky wave antenna is shown in Fig.1. Leaky wave antenna radiates waves along the length of the antenna or structure. It uses a guiding structure that supports the wave propagation. The wave is propagating along the length of the antenna or structure with wave radiating or leaking continuously along with the antenna. The periodic leaky wave antenna has a uniform structure that creates a wave which is periodically modulated [8]. Leaky wave antenna radiates wave due to discontinuities or leakage. Therefore, it is called the leaky wave antenna [10]. Until now, the leaky wave antenna is implemented at operating frequency more than 12GHz. This paper presents the implementation of the leaky wave antenna at an operating frequency of 2.45GHz and 5.8GHz.

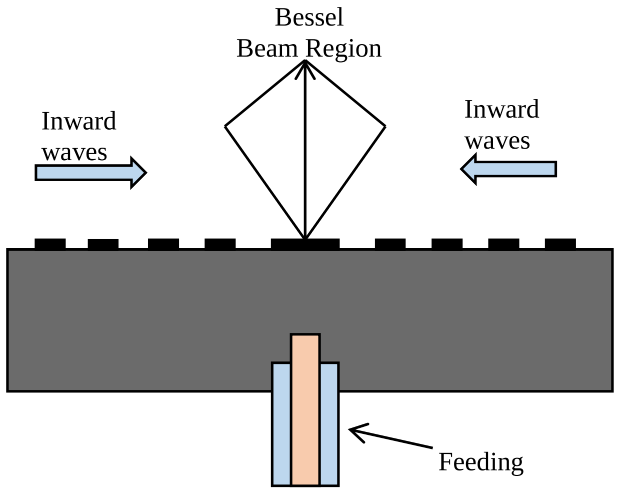

Fig.1. Leaky Wave Antenna

2. ANTENNA DESIGN

The basic parameters for the designing of leaky wave antenna which is made by using microstrip antenna are the operating frequency, material substrate and type of patch. The design methodology of the antenna is given in Fig. 2.

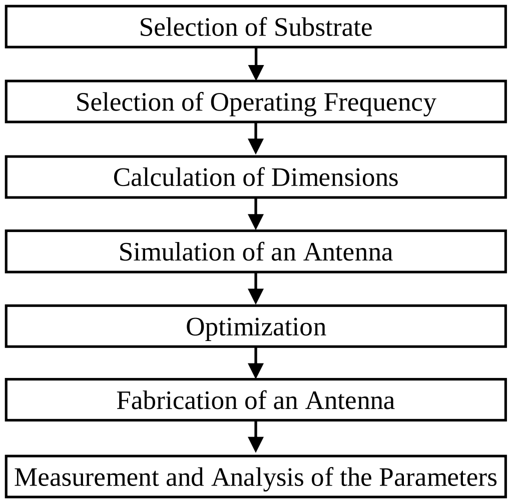

Fig.2. Design Methodology

The leaky wave antenna is fabricated on an FR4 epoxy substrate with a thickness of 3.2mm. It has dielectric constant ε_r of 4.4 and loss tangent of 0.017. The substrate is selected based on the cost of a substrate and its availability in the market. FR4 is cheap, easily available in market and good enough for general purpose applications. Coaxial feeding is used for the leaky wave antenna. The inner conductor of the coaxial connector extends through the substrate and is soldered to the radiating patch. The outer conductor is connected to the ground plane. It provides advantages such as ease of fabrication, easy to match and low spurious radiation [14]. The dimensions of the coaxial feed used for designing the above antennas are such as radius of coaxial pin (PEC) = 0.7mm, radius of probe = 0.7mm and height of probe = 5mm.

The radiator patch is made by circular patch and rings around it. The leaky wave antenna is designed for the operating frequency of 2.45GHz and 5.8GHz. Two slots are inserted on a circular patch to improve the gain of the leaky wave antenna which operates at 5.8GHz. The circular patch of leaky wave antenna is designed by using the following formulae:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{0.5}} \tag{1}$$

$$F = \frac{8.791\times 10^{9}}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

where, h is the height of the substrate, f_r is the resonating frequency and ε_r is the relative permittivity, respectively. Values for the different parameters of the leaky wave antenna for the central frequency of 2.45GHz and 5.8GHz are shown in Table.1. The radius of a patch is calculated using the above formulae. The radius of a patch of leaky wave antenna having an operating frequency of 2.45GHz is 16.4mm. The radius of a patch of leaky wave antenna having an operating frequency of 5.8GHz is 13.15mm.

$$W \frac{C}{2 f_0}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \tag{4}$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \tag{5}$$

$$L = \frac{C}{2\sqrt{\varepsilon_{eff}}}\left(\frac{1}{f_0}\right)-2\Delta L \tag{6}$$

$$L_g = 12h + L \tag{7}$$

$$W_g = 12h + W \tag{8}$$

From the above formulae, the length and width of the leaky wave antenna is calculated. The dimensions of the leaky wave antenna with an operating frequency of 2.45GHz is 100mm×110mm. The dimensions of the leaky wave antenna with an operating frequency of 5.8GHz is 70mm×60mm.

Table.1. Values for the Different Parameters of Leaky Wave Antenna

Parameters	**Operating Frequency: 2.45GHz**	**Operating Frequency: 5.8GHz**
Radius of a patch (mm)	16.4	13.15
Width of rings (mm)	1	1
Length of a substrate (mm)	100	70
Width of a substrate (mm)	110	60

3. RESULTS

Ansoft HFSS 13.0 is used to simulate the leaky wave antenna. HFSS is a full wave FEM based solver for electromagnetic structures. It utilizes a 3D full-wave Finite Element Method (FEM) to compute the electrical behaviour of high frequency and high-speed components. Fig.3 and Fig.4 shows the front view and the back view of a simulated antenna having an operating frequency of 2.45GHz. The circular patch is surrounded by the rings.

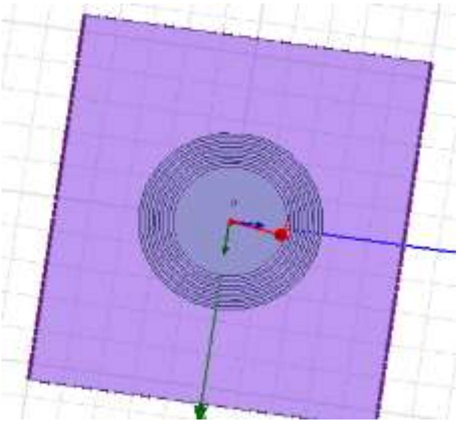

Fig.3. Front View of Simulated Antenna having an Operating Frequency of 2.45GHz

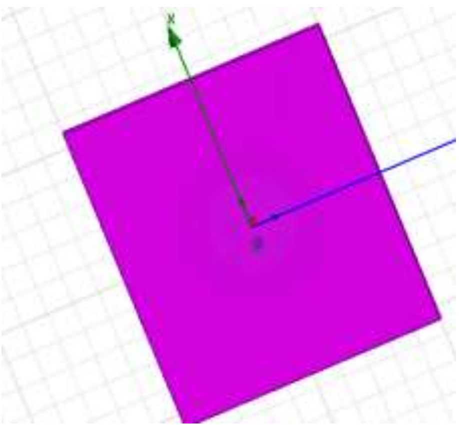

Fig.4. Back View of Simulated Antenna having an Operating Frequency of 2.45GHz

The return loss of simulated antenna having an operating frequency of 2.45GHz is shown in Fig.5. The return loss should be below -10dB. The obtained return loss is -16.5335 as per expectation. The obtained bandwidth is 139MHz as shown below.

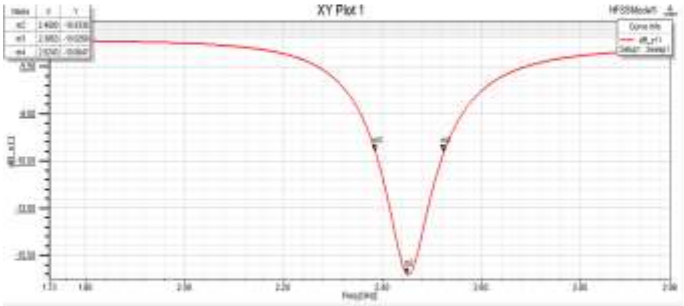

Fig.5. Return Loss of Simulated Antenna having an Operating Frequency of 2.45GHz

Ideally VSWR should be 1. The VSWR of a simulated antenna having an operating frequency of 2.45GHz is 1.6186 as shown in Fig.6. The obtained VSWR is accurate and below 2.

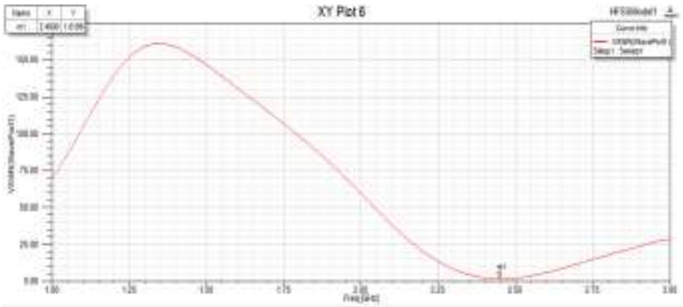

Fig.6. VSWR of Simulated Antenna having an Operating Frequency of 2.45GHz

The impedance should be 50Ω. The obtained impedance of the simulated antenna is 48.9129Ω as mentioned in Fig.7.

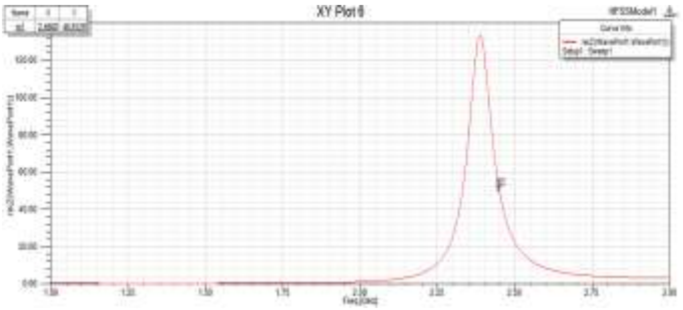

Fig.7. Impedance of Simulated Antenna having an Operating Frequency of 2.45GHz

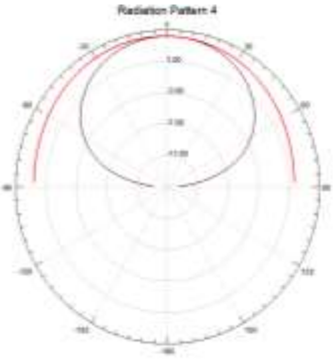

Fig.8. Radiation Pattern of Circular Patch Antenna having Operating Frequency 2.45GHz

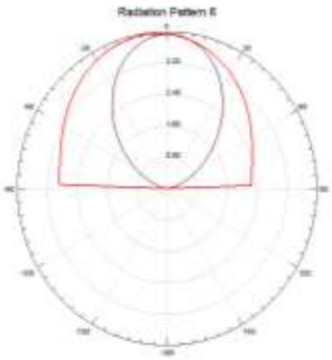

Fig.9. Radiation Pattern of Leaky Wave Antenna having Operating Frequency 2.45GHz

The radiation pattern of the circular patch antenna and leaky wave antenna having an operating frequency 2.45GHz is shown in Fig.8 and Fig.9 respectively. Compared to the circular patch antenna, leaky wave antenna provides more concentrated radiation pattern.

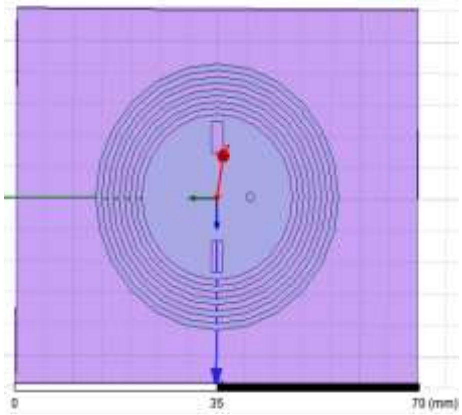

Fig.10. Front View of Simulated Antenna having an Operating Frequency of 5.8GHz

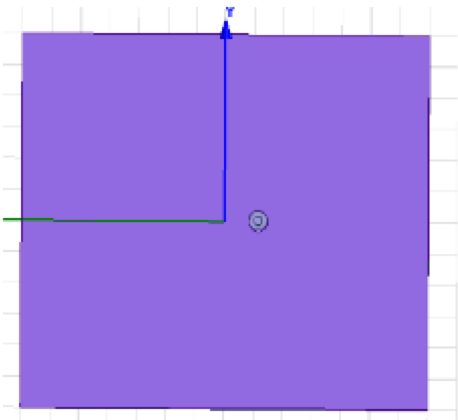

Fig.11. Back View of Simulated Antenna having an Operating Frequency of 5.8GHz

The front view and the back view of a simulated antenna having an operating frequency of 5.8GHz are shown in Fig.10 and Fig.11. Two slots are inserted on a circular patch.

The return loss of simulated antenna having an operating frequency of 5.8GHz is -32.9353 as shown in Fig.12. The obtained bandwidth of simulated antenna having an operating frequency of 5.8GHz is 460MHz.

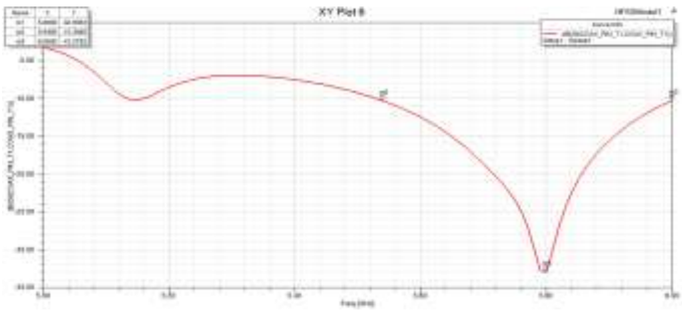

Fig.12. Return Loss of Simulated Antenna having an Operating Frequency of 5.8GHz

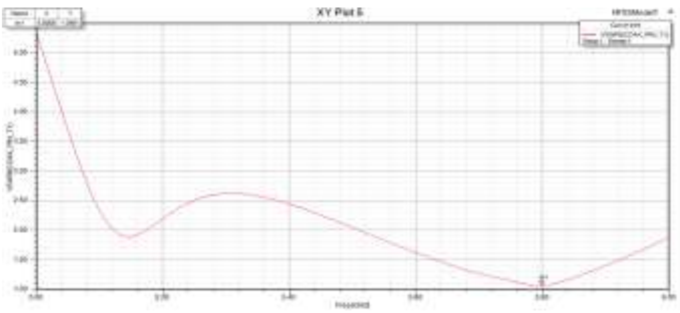

Fig.13. VSWR of Simulated Antenna having an Operating Frequency of 5.8GHz

The obtained VSWR of a simulated antenna having an operating frequency of 5.8GHz is 1.0461 as expected. The impedance of a simulated antenna having an operating frequency of 5.8GHz is 52.2482Ω as mentioned in Fig.14.

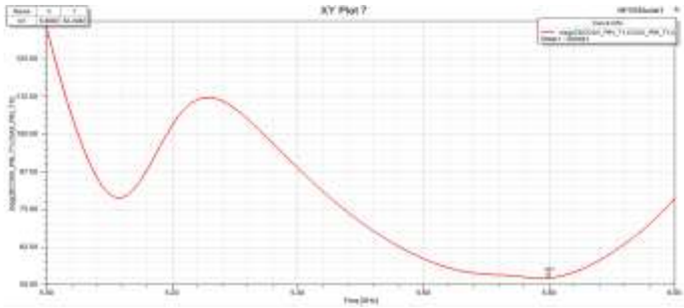

Fig.14. Impedance of Simulated Antenna having an Operating Frequency of 5.8GHz

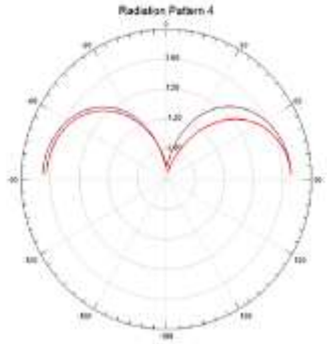

Fig.15. Radiation Pattern of Circular Patch Antenna having Operating Frequency 5.8GHz

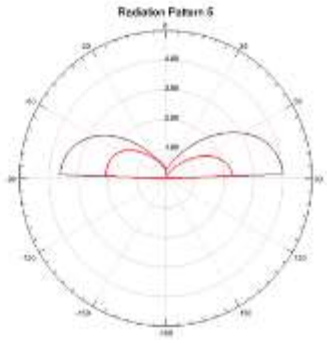

Fig.16. Radiation Pattern of Leaky Wave Antenna having Operating Frequency 5.8GHz

The Fig.15 and Fig.16 demonstrate the radiation pattern of the circular patch antenna and leaky wave antenna having an operating frequency 5.8GHz. The leaky wave antennas are working as per the specifications and the results of the simulations are as per expectations. Therefore, the proposed antennas can be fabricated.

The antennas can be fabricated manually by the process of etching. The process of etching uses a strong acid such as HCl, H_2SO_4 or chemicals such as ferric chloride (FeCl) for removing the wafer from the surface of the substrate. Another process of hardware manufacturing is microfabrication which uses the photolithographic technique. The leaky wave antenna is fabricated using FR4 epoxy substrate having dielectric constant ε_r of 4.4 and a thickness of 3.2mm. The fabricated antenna is tested on Vector Network Analyzer (VNA). The Fabricated antennas were tested for Return Loss, VSWR and Impedance on Vector Network Analyzer (VNA) as shown in Fig.17.

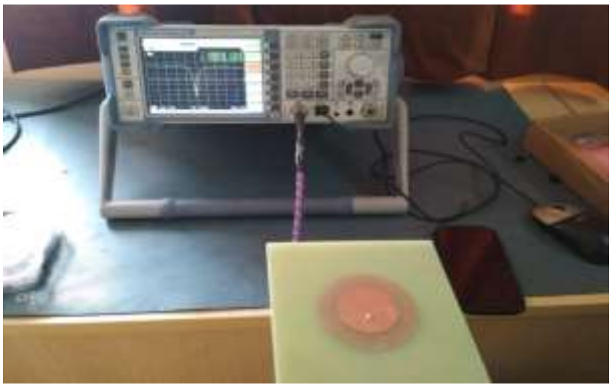

Fig.17. Testing of Antenna on Vector Network Analyzer (VNA)

The front view and the back view of the fabricated antenna having an operating frequency of 2.45GHz are shown in Fig.18 and Fig.19.

Fig.18. Front View of Fabricated Antenna having an Operating Frequency of 2.45GHz

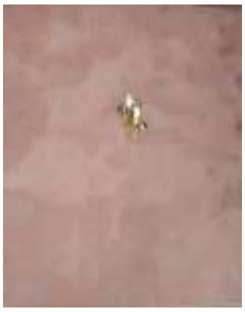

Fig.19. Back View of Fabricated Antenna having an Operating Frequency of 2.45GHz

Return loss should be below -10dB as per expectation. The return loss of fabricated antenna having an operating frequency of 2.45GHz is shown in Fig.20. The obtained return loss of fabricated antenna is -12.315dB. VSWR is 1.065 as shown in Fig.21.

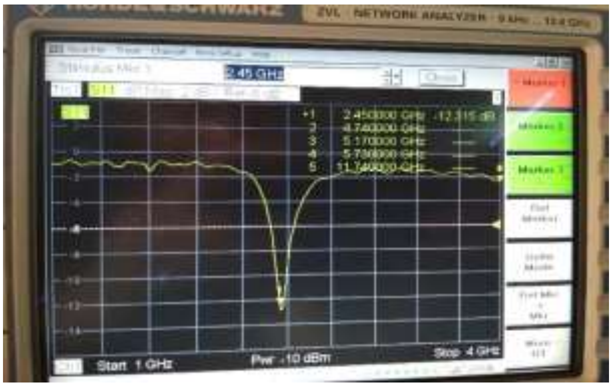

Fig.20. Return Loss of Fabricated Antenna having an Operating Frequency of 2.45GHz

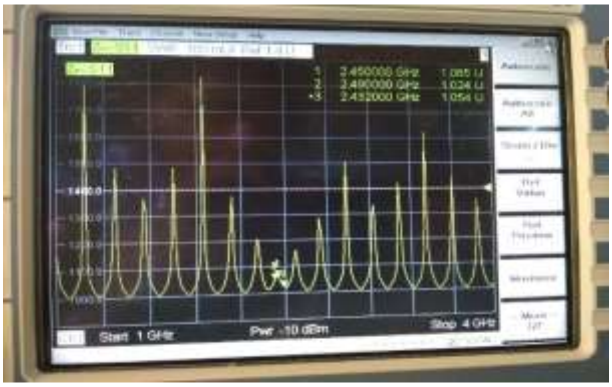

Fig.21. VSWR of Fabricated Antenna having an Operating Frequency of 2.45GHz

The obtained impedance of the fabricated antenna having an operating frequency of 2.45GHz is 48.462Ω.

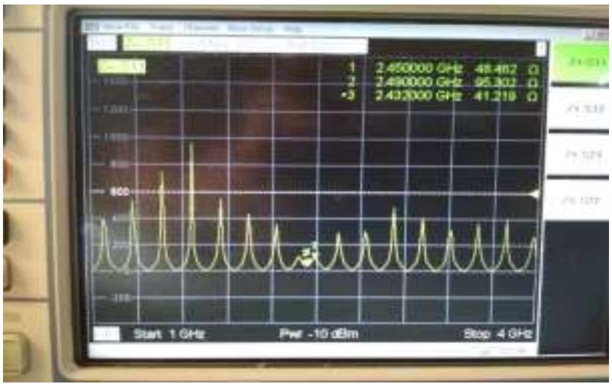

Fig.22. Impedance of the fabricated Antenna having an Operating Frequency of 2.45GHz

The front view and the back view of the fabricated antenna with two slots on a circular patch having an operating frequency of 5.8GHz are shown in Fig.23 and Fig.24.

Fig.23. Front View of Fabricated Antenna having an Operating Frequency of 5.8GHz

Fig.24. Back View of Fabricated Antenna having an Operating Frequency of 5.8GHz

The obtained return loss of fabricated antenna which operates at a frequency of 5.8GHz is -22.105dB as mentioned in Fig.25.

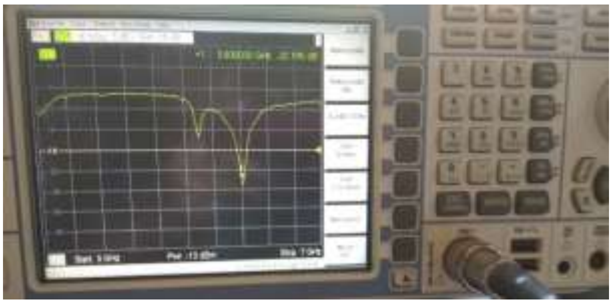

Fig.25. Return Loss of Fabricated Antenna having an Operating Frequency of 5.8GHz

The VSWR of the fabricated antenna having an operating frequency of 5.8GHz is shown in Fig.26. The obtained VSWR of fabricated antenna which operates at a frequency of 5.8GHz is 1.548.

Fig.26. VSWR of Fabricated Antenna having an Operating Frequency of 5.8GHz

The obtained impedance of fabricated antenna having an operating frequency of 5.8GHz is 54.667Ω as shown below.

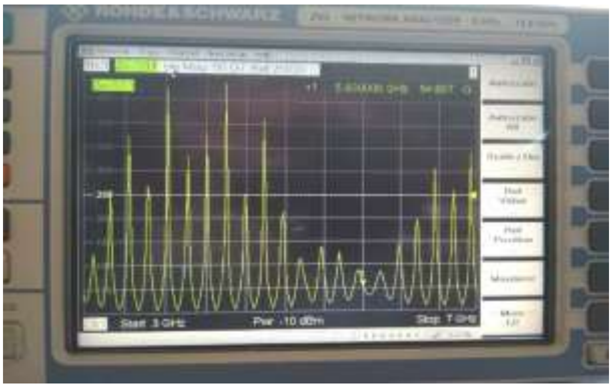

Fig.27. Impedance of the Fabricated Antenna having an Operating Frequency of 5.8GHz

Table.2. Simulated and Fabricated Results of Leaky Wave Antenna

Parameters	Operating Frequency: 2.45GHz		Operating Frequency: 5.8GHz	
	Simulated	**Fabricated**	**Simulated**	**Fabricated**
Return Loss (dB)	-16.5335	-12.315	-32.9363	-22.105
VSWR	1.6186	1.065	1.0461	1.548
Impedance (Ω)	48.9129	48.462	52.2482	54.667

The Table.2 shows the simulated and fabricated results of leaky wave antenna having an operating frequency of 2.45GHz and 5.8GHz. There is a difference between the simulated and fabricated results due to fabrication errors and the noise present in the environment. The obtained results are found to be accurate. Therefore, the leaky wave antenna is working as per the specifications. The obtained results are improved as compared to the microstrip patch antenna.

4. CONCLUSION

This paper presents detailed information on the leaky wave antenna. The leaky wave antenna is an attractive, thin, low cost and simple solution to generate the Bessel beam. The return loss of the simulated and fabricated antenna is below -10dB. The VSWR of the simulated and fabricated antenna is found to be between 1 and 2 which is essential for the antenna to work efficiently in the resonating frequency. The bandwidth of the leaky wave antenna is improved as compared to a microstrip patch antenna. The obtained impedance of the leaky wave antenna having an operating frequency of 2.45GHz and 5.8GHz is nearly 50Ω. The simulated and fabricated results are obtained at 2.45GHz and 5.8GHz frequency for the proposed design with deviation due to fabrication errors and the noise present in the environment. The obtained results are found to be satisfactory as all of them are working as per the specifications.

The leaky wave antenna is designed and implemented in the lower frequency region. Therefore, it can have various applications in the lower frequency region. Future work can be done to explore the far-field response of the leaky wave antenna.

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