Multi-Frequency T-Slot Loaded Elliptical Patch Antenna for Wireless Applications

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Abstract – In this paper, a multi frequency microstrip antenna (MSA) for wireless applications is designed. The proposed MSA comprised of elliptical patch antenna with T-slot. This antenna is fed by coaxial probe. The design parameters are major and minor axis of elliptical patch, length and width of T-slot and feeding point of probe. The proposed antenna can provide optimized multi frequency by varying the above design parameters. FR-4 substrate with dielectric constant 4.4 is chosen. The multi frequencies are 1.57 GHz, 1.96 GHz and 3.4 GHz, which covers the applications such as GPS and 4G LTE. The simulation of the antenna is performed using the ANSOFT HFSS and it is analyzed for S_{11} (dB) and radiation pattern. The prototype antenna is fabricated for optimized dimensions and tested using vector network analyzer. Simulation and experimental results are compared with each other.

Index Terms — Coaxial feed, elliptical patch antenna, multi-frequency, T-slot.

I. INTRODUCTION

The microstrip antenna (MSA) is one of the most preferred antenna structures for wireless applications and handheld devices. They are small in size, light weight and low volume. Generally, the multi-frequency MSA are divided into two categories: i) multi-resonator antennas and reactively loaded antenna. In the first category, the multi-frequency operation is achieved by means of multiple radiating elements, each supporting strong currents and radiation at its resonance. It includes the multilayer stacked-patch antennas using circular, annular, rectangular and triangular patches [1], [2]. A multi-resonator antenna in coplanar structures can also be fabricated by using aperture-coupled parallel microstrip dipoles [3]. As these antenna structures usually involve multiple substrate layers, they are of high cost. Large size is another drawback of the multi-resonator antenna, which makes it difficult for the antenna to be installed in hand-held terminals. The second category is reactively load MSA, to obtain multi frequency operation of the antenna such as multi-slotted patch, rectangular patch with two T-slots, truncated circular patch with double U-slot, square spiral patch antenna and pi-shaped slot on rectangular patch [4-9]. These structures involve complex calculation, design, higher frequency ratio and lower bandwidth as compared to proposed antenna. Therefore, the proposed antenna consists of a simple T-slot which is loaded on the elliptical patch antenna and it is fed by coaxial probe. The dimensions of the proposed antenna are optimized using HFSS in such a way that it provides multi-frequency. The paper is organized as, proposed antenna design is discussed in Section 2, followed by simulation and experimental results in Section 3, and Section 4 concludes the paper.

II. ANTENNA DESIGN

The proposed antenna is shown in Fig. 1 (top view) and Fig. 2 (side view). The elliptical patch of semi major axis ‘a’ and semi minor axis ‘b’ is printed on the FR-4 substrate (ε_r=4.4). A T-slot of length ‘l’ and width ‘w’ is slotted in the elliptical patch.

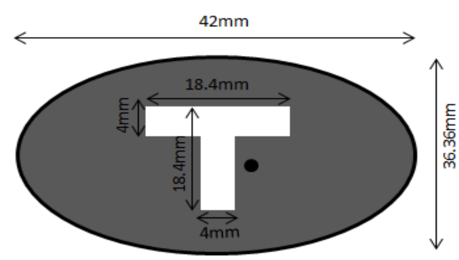

Fig. 1. Top view of proposed antenna.

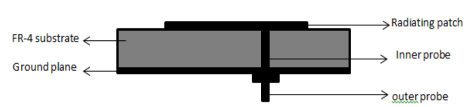

Fig. 2. Side view of proposed antenna.

The resonant frequency of elliptical patch is given as [10]:

$$fr = \frac{c\sqrt{q}}{\pi a e\sqrt{\varepsilon_r}}, \quad (1)$$

where c is velocity of light, (3*10^8 m/s), e is eccentricity of elliptical patch as:

$$e = \sqrt{1-(b|a)^2}, \quad (2)$$

where 'a' is the semi major axis of the elliptical patch, 'b' is semi minor axis of the elliptical patch, ε_r is dielectric constant of the substrate, q is the approximated Mathieu function of the given mode and eccentricity is calculated from [11]. The order of few modes of elliptical patch antenna is TM_{11} and TM_{21} and is based on the q value function. In this paper, TM_{11} mode is chosen. Then the q value for TM_{11} mode is given.

For the e values between 0 and 0.4:

$$q_{11} = 0.847e^2 - 0.0013e^3 + 0.0379e^4, \quad (3)$$

For the e value between 0.4 and 1.0:

$$q_{11} = - 0.0064e + 0.8838e^2 - 0.0696e^3 + 0.082e^4, \quad (4)$$

Here, the eccentricity of 0.5 is chosen and the canter frequency is taken as 2 GHz. By substituting the canter frequency and eccentricity values in the above equations, the dimensions of the elliptical patch can be calculated. The T-slot length and width can be determined by parametric study.

For TM_{11} mode, the theoretical value of resonant frequency for elliptical patch of semi major axis 21 mm is found to be 2 GHz. This is the theoretical resonant frequency value for elliptical patch without T-slot. The multi frequency resonance can be obtained by properly designing the length and width of the T-slot and also the feed point of the probe. This plays a major role in optimizing the frequency.

III. SIMULATION AND EXPERIMENTAL RESULTS

The simulation of the above designed antenna was performed using ANSOFT HFSS software. The FR-4 substrate size of 10 0mm*100 mm*1.6 mm is chosen as a dielectric material. Coaxial probe is used for exciting the patch. Return loss (dB) is defined as that the difference in dB between power sent towards antenna under test (AUT) and power reflected [12]. The requirement for reflection co-efficient of wireless devices specifies 10 dB return loss bandwidth.

The parametric study of the antenna is performed using Ansoft HFSS. Table 2 shows the S_{11} (dB) values for different lengths of T slot, keeping the width constant. As the length of the T-slot is increased, the resonant frequency is decreased. The length and width of the T-slot is chosen as 17.8 mm and 4 mm to obtain the optimized desired multi-frequency. A prototype is fabricated for the dimensions given in Table 1. The photograph of the antenna is shown in Fig. 3. The fabricated antenna is tested using vector network analyzer. Figure 4 shows the comparison of both simulated and measured S_{11} (dB) vs. frequency (GHz).

Table 3 shows the comparison of simulated and measured output.

Table 1: Design specifications

Design Parameters	Values
Semi major axis 'a'	21 mm
Semi minor axis 'b'	18.18 mm
Eccentricity 'e'	0.5
Substrate thickness h	1.6 mm
Dielectric constant 'ε_r'	4.4
Length of the T-slot 'l'	18.4 mm
Width of the T-slot 'w'	4 mm
Feed point	(6,3)

Table 2: Parametric study (w = 4 mm)

Length (mm)	Resonant Frequencies (GHz)	Corresponding S_{11} (dB)
17.8	1.57	-31.06
	1.96	-19.83
	3.43	-21.76
17	1.58	-18.73
	1.94	-24.6
	3.25	-15.73
16.5	1.63	-16.61
	1.99	-21.06
	3,41	-15.34
16	1.67	-14.26
	1.99	-20.79
	3.4	-12.28

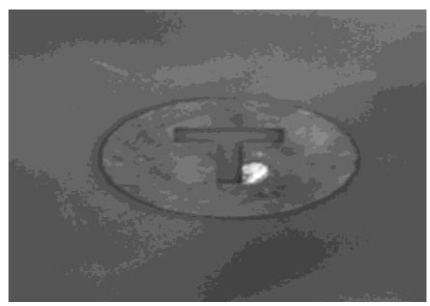

Fig. 3. Photograph of fabricated antenna.

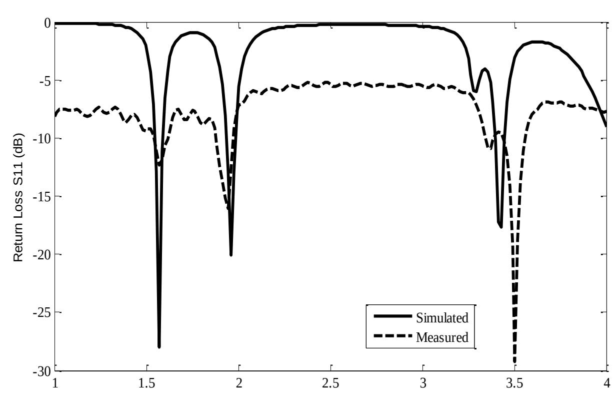

Fig. 4. S_{11} (dB) vs. frequency (GHz).

Table 3: Simulated and measured S_{11} (dB)

Parameters	Simulation Output	Measured Output
Frequency (GHz)	1.57 1.96 3.4	1.58, 1.946 3.5
S_{11} (dB)	-31.06, -19.83 and -21.76 respectively	-11.26, -16.36 and -19.09 respectively

Figure 5 shows the radiation pattern at 1.57 GHz. It is simulated using HFSS for φ=0° E plane (XZ plane) and φ=90° (YZ plane). The coordinate system is XYZ and the antenna is placed in XY plane. It has very low gain of -4.53 dB and HPBW of 84 degrees. Figure 6 shows the radiation pattern at 1.96 GHz has a very low gain of -0.3357 dB and HPBW of 84 degrees. Figure 7 shows radiation pattern at 3.43 GHz, which has butterfly pattern. FR4 is lossy substrate. The loss tangent of the substrate is high, which affects the performance of the antenna. It may be the reason for low gain. Moreover, size of the patch is very small. The gain of the antenna is directly proportional to cross sectional area of the patch. The T shaped slot is etched from this patch, which also reduces the area of the patch; hence, further reduces the gain. In [13], a truncated elliptical patch is discussed, which also has a low value of gain.

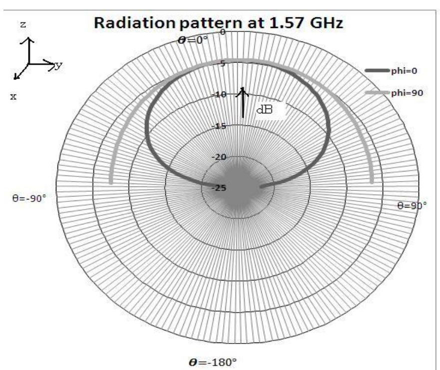

Fig. 5. Radiation pattern at 1.57 GHz.

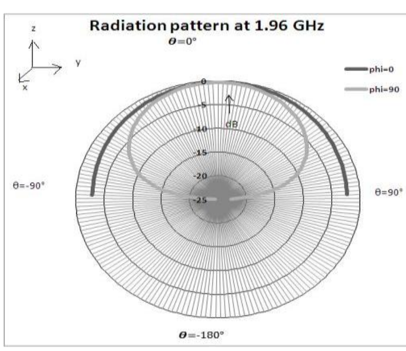

Fig. 6. Radiation pattern at 1.96 GHz.

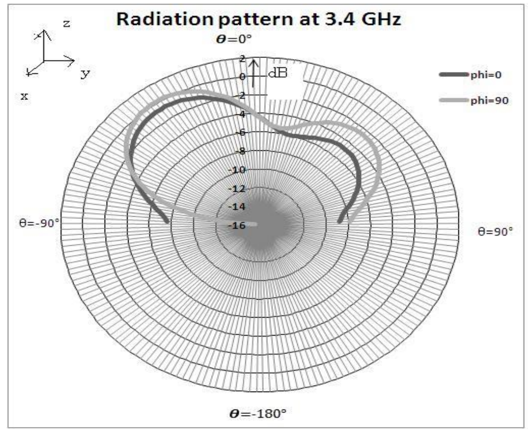

Fig. 7. Radiation pattern at 3.4 GHz.

The proposed antenna may be compared with some of antennas given in references. It is described below. In [4], multi-slotted antenna of size 39.6 mm*47.9 mm is patched on the FR-4 substrate. The antenna is very large size and of very complicated structure than proposed antenna. The square patch of size 30 mm*30 mm with T-slot and defective ground structure is discussed in [5]. The antenna resonates at multi-frequency. The structure is simple but it does not provide better return loss than proposed antenna. In [6], the truncated circular patch of radius 40 mm is patched on the FR-4 substrate with double U slot. Air gap is introduced between the substrate and ground plane. Use of air gap may increases the size of the antenna. This air gap is avoided in the proposed antenna. In [7], the antenna of rectangular patch with size 23.4 mm*18.2 mm is patched on the substrate and two T-slots are made on this patch. The antenna is fed by microstrip feed. But this antenna uses two T-slots to produce multi frequency. In [8], the square spiral patch antenna with size 33.7 mm*33.7 mm is patched on the FR-4 substrate. The antenna is of very large size and complicated design as compared to proposed antenna.

The proposed antenna is an elliptical shape of semi major axis 21 mm and semi minor axis 18.18 mm with T-slot on the elliptical patch. The antenna is fed by coaxial feed. There is no air gap. FR-4 substrate of thickness 2 mm with dielectric constant 4.4 is chosen. The antenna structure is simple and provides better return loss.

IV. CONCLUSION

From the analysis, it is concluded that the proposed antenna resonates at three different frequencies. The frequencies are 1.57 GHz, 1.96 GHz and 3.4 GHz, which has S_{11} (dB) of -31.06, -19.83 and -21.76 respectively. The frequencies can cover applications such as GPS and LTE. Simulation and measurement results are presented for validation of the design and slight deviation is observed, which is below the tolerable limit of 5%. It is due to substrate, connector losses and fabrication tolerances.

REFERENCES

[1] J. S. Dahele, K. F. Lee, and D. P. Wong, "Dual-frequency stacked annular- ring microstrip antenna," *IEEE Trans. Antennas Propagat*., vol. AP-35, no. 11, pp. 1281-1285, 1987.

[2] J. Wang, R. Fralich, C. Wu, and J. Litva, "Multifunctional aperture-coupled stacked antenna," *Electron. Lett*., vol. 26, no. 25, pp. 2067-2068, 1990.

[3] F. Croq and D. M. Pozar, "Multifrequency operation of microstrip antennas using aperture coupled parallel resonators," *IEEE Trans. Antennas Propagat.*, vol. 40, no. 11, pp. 1367-1374, 1992.

[4] S. Natarajamani, S. K. Behera, and R. K. Mishra, "Design of multi slotted and multfrequency patch antenna," *Applied Electromagnetic Conference*, Kolkata, 2009.

[5] S. De, P. Samaddar, S. Sarkar, S. Biswas, et al., "Compact high gain multi-frequency microstrip antenna," *International Journal of Soft Computing and Engineering*, vol. 2, no. 6, 2013.

[6] S. Murugan, E. Sathish Kumar, and V. Rajamani, "Design and analysis of double U slot loaded dual frequency microstrip antenna," *Progress In Electromagnetics Research C*, vol. 45, pp. 101-112, 2013.

[7] D. Ramya Keertana, M. V. S. D. N. N. Murthy, B. Yeswanth, et al., "A novel multi frequency rectangular microstrip antenna with dual T shaped slots for UWB applications," *IOSR Journal of Electronics and Communication Engineering*, vol. 9, no. 1, 2014.

[8] A. Ghosal, A. Majumdar, S. Kumar Das, A. Das, "Wideband and multi-frequency square spiral microstrip patch antenna," *International Journal of Innovative Research in Computer and Communication Engineering*, vol. 3, no. 2, 2015.

[9] S. Das, P. P. Sarkar, and S. K. Chowdhury, "Modified π-shaped slot loaded multi-frequency microstrip antenna," *Progress In Electromagnetics Research B*, vol. 64, pp. 103-117, 2015.

[10] J. A. Ansari, K. Kumari, A. Singh, and A. Mishra, "Ultra-wideband co-planer microstrip patch antenna for wireless applications," *Wireless Pers. Commun*., vol. 69, pp. 1365-1378, 2013.

[11] I. J. Bahl and P. Bhartia, *Broadband Microstrip Patch Antennas*. Dedham: Artech House, 1980.

[12] T. S. Bird, "Definition and the misuse of return loss," *IEEE Antenna Propagation Magazine*, vol. 51, no. 2, pp. 166-167, 2009.

[13] P. Sekra, S. Shekhawat, et al., "Design of circularly polarised truncated elliptical patch antenna with improved performance," *Indian Journal of Radio & Space Physics*, vol. 40, pp. 227-233, 2011.