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Slot Loaded Compact Microstrip Patch Antenna for Dual Band Operation

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Abstract—A novel design of a compact microstrip patch antenna using meandering technique is proposed in this paper where the designed antenna seems to behave as a microstrip patch loaded with conducting strips. A rectangular microstrip patch antenna with addition of conducting strip radiates at much lower frequency than a conventional rectangular microstrip antenna, due to increase of resonant length, but it also causes the increase in total size of the antenna. In this article, the resonant frequency has been lowered significantly by loading a regular rectangular microstrip patch antenna with rectangular slot in a proper position in such a way that the whole structure looks like a strip loaded radiator. About 86.5% size reduction has been achieved experimentally with very good agreement of simulated and measured results. The equivalent circuit and approximate resonant frequency calculation have been discussed in this paper.

1. INTRODUCTION

Design of a compact microstrip patch antenna plays a very significant role in current research to follow the recent trends on realization of miniaturized wireless communication system. In recent days, microstrip patch antenna is on demand in modern communication system due to its small size, robustness and easy fabrication capabilities with RF circuit components [1, 2]. The communication devices have shown a drastic reduction over the decade with respect to their size; henceforth the focus on compactness of microstrip patch antennas in these communication devices are on the frontline of interest among various researchers.

Several techniques have been discussed in many research articles in order to design a compact microstrip patch antenna. Bhunia et al. [3] have investigated the compactness of a microstrip patch antenna with the variation of slot length on the patch and found 85% size reduction with respect to a conventional patch. They have also found 67% size reduction using some finger-like slots on the patch [4]. Chakraborty et al. [5] have designed a compact dual-band microstrip patch antenna with two unequal rectangular slots on the patch and a slot on the ground. They have reported 53.73% compactness with respect to a conventional un-slotted rectangular microstrip patch antenna in their optimized design. Das et al. [6] have proposed several designs of compact multi-frequency microstrip patch antennas incorporating different unequal slots on the patch at arbitrary locations. Miniaturization of a microstrip patch antenna using slot on ground plane without and with slotted patch has been discussed in [7, 8]. Another very popular method for designing a compact multi-frequency microstrip patch antenna is the concept of monopole antenna, using defected ground plane and modified patch [9–11]. In [9], it has been shown that with the addition of inverted L-shaped strips the antenna resonates at lower resonating frequency, and defected ground structure has given a proper impedance match. But in this design, the total size of the patch has been increased due to the addition of L-shaped strips. In [10], hybrid strips are used to generate multi-frequency, and it has been shown that the addition of an L-shaped strip

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has given an extra frequency, and about 70% size reduction has been achieved. Yang et al. [12] have proposed a new miniaturized design of patch antenna with grounded strips which are connected to the ground plane by an array of shorting pins, and thus radiating patch has been reduced by 74%. In article [13], the design of a compact patch antenna by placing inverted L- and T-shaped parasitic elements at both the radiating apertures of a microstrip patch antenna has been discussed. But in order to maintain the shape of the elements, parasitic strips are printed on additional substrates for which overall antenna thickness with respect to ground plane is much larger. Additional operating frequency is found with the loading of a pair of spur lines at the non-radiating edge, which reduces the antenna size [14]. The design of several miniaturized antennas for practical applications has been reported in some literatures [15–17]. Various approaches of designing multiband and broadband antennas have been discussed in [18–21].

In this paper, a slot loading with added spur lines rectangular planer microstrip patch antenna is proposed where 86.5% size reduction has been found with respect reference patch antenna without slot. The slots are introduced in a proper position in such a way that the antenna seems like a patch with added strips. Parametric study reveals that with incorporation of strip and spur lines, the resonant frequency goes down, which in turn offers us a compact design. In the proposed design, rectangular slots are placed symmetrically in the non-radiating edge of the antenna in such a way that the antenna behaves as an antenna with added strips, and in addition of spur lines in the same structure, the proposed antenna produces considerably frequency reduction. In this design, the total size of the antenna is not increased, but the effect of strip loading is still utilized. The effects of slots are discussed theoretically and experimentally using equivalent circuits and approximation of the resonant frequencies with the calculation of slot lengths.

2. ANTENNA CONFIGURATION AND DESIGN CONCEPT

The configuration of the reference antenna (Antenna 1) is shown in Fig. 1. The length ($L = 14\,\mathrm{mm}$) and width ($W = 18\,\mathrm{mm}$) of Antenna 1 have been calculated from conventional rectangular microstrip patch antenna design equations [22]. The substrate (Arlon AD300A) with dielectric constant $\varepsilon_r = 3$, loss tangent $\tan\delta = 0.002$ and thickness $h = 1.524\,\mathrm{mm}$ has been taken for this design. The dimensions of the ground plane have been taken as $42\,\mathrm{mm} \times 54\,\mathrm{mm}$ as if it behaves as an infinite ground plane, and the antenna has been fed by a coaxial cable at optimum location to achieve the impedance very close to the characteristic impedance of the coaxial line, i.e., $50\,\Omega$.

Figure 2 shows the configuration of Antenna 2 with the addition of a pair of strips in non-radiating edge. The configuration of Antenna 3 with two pairs of strips of unequal lengths is shown in Fig. 3, and the configuration of Antenna 4 with a pair of strips and spur lines is shown in Fig. 4. The configuration of the proposed antenna (Antenna 5) with slots and a pair of spur lines is shown in Fig. 5. In Antenna 5, the slots have been incorporated in such a way that it looks like a $14 \times 14\,\mathrm{mm}^2$ patch with strip loading.

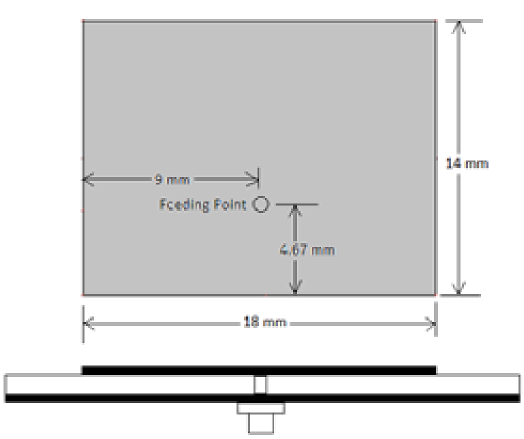


Figure 1. Configuration of Antenna 1.

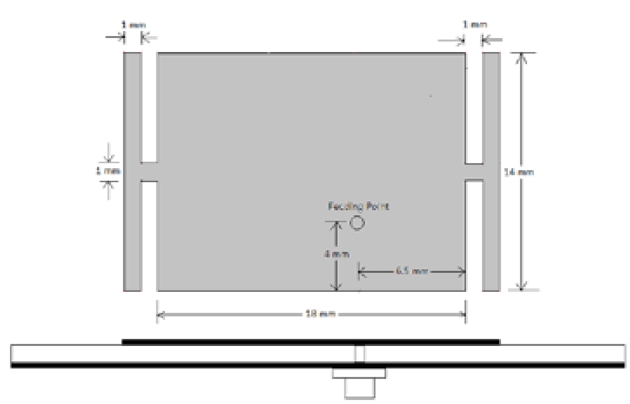


Figure 2. Configuration of Antenna 2.

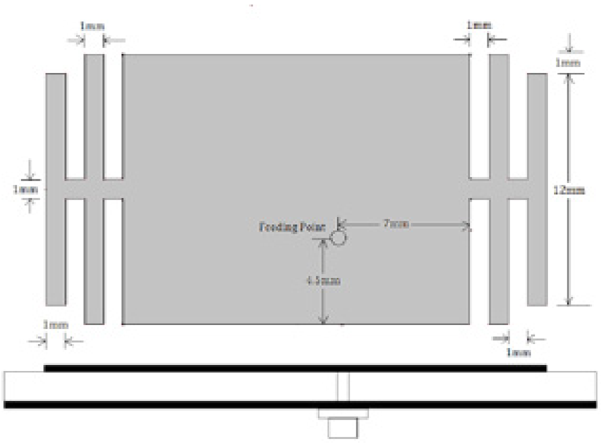


Figure 3. Configuration of Antenna 3.

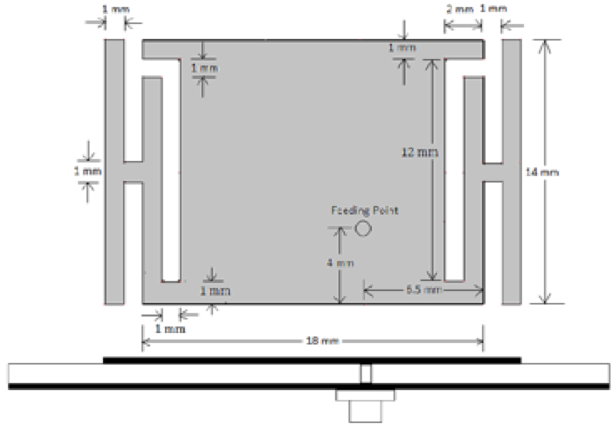


Figure 4. Configuration of Antenna 4.

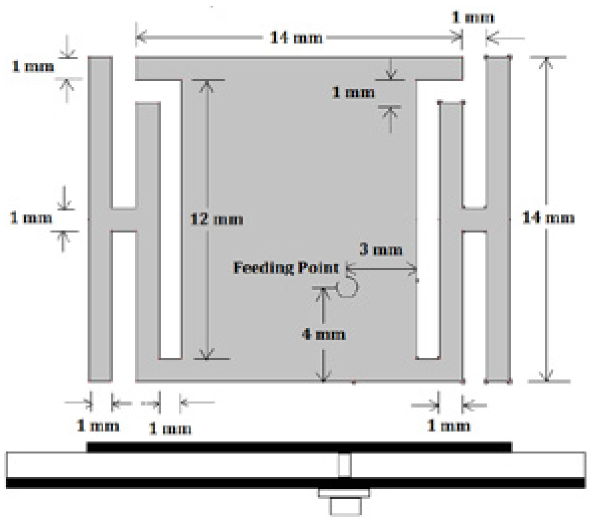


Figure 5. Configuration of Antenna 5.

3. EQUIVALENT CIRCUIT

The equivalent circuits of all antennas have been approximated and shown in Figs. 6(a)–6(e). A conventional microstrip patch antenna (Antenna 1) can be modelled as a simple RLC resonant circuit shown in Fig. 6(a). The values of R, L and C can be determined by conventional formulae given in [23].

The equivalent circuit of Antenna 2 is shown in Fig. 6(b). The strip loading affects the electric field discontinuities mostly over magnetic field discontinuities, which can be modelled by inserting an

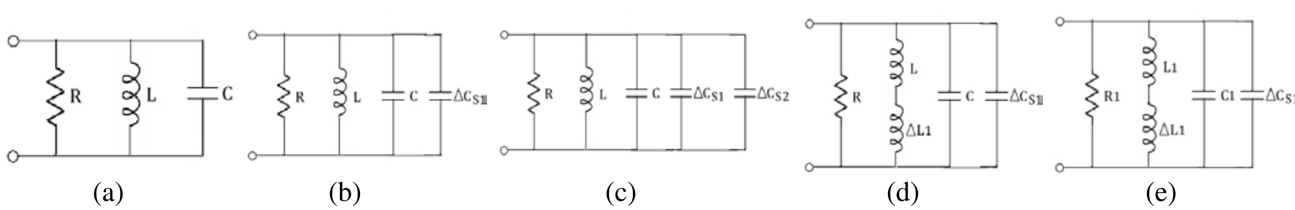


Figure 6. Equivalent circuit of (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4 and (e) Antenna 5.

additional capacitance ΔC_{S1} in parallel with the equivalent circuit of Antenna 1. Similarly due to the addition of another strip in Antenna 3, another additional capacitance ΔC_{S2} is considered in the equivalent circuit shown in Fig. 6(c). The configuration of Antenna 4 is the modification of Antenna 2 by inserting a pair of spur lines. Due to the insertion of spur lines at the edge part of the patch, the current has to flow around the spur lines, thus increasing the length of the current path which can be

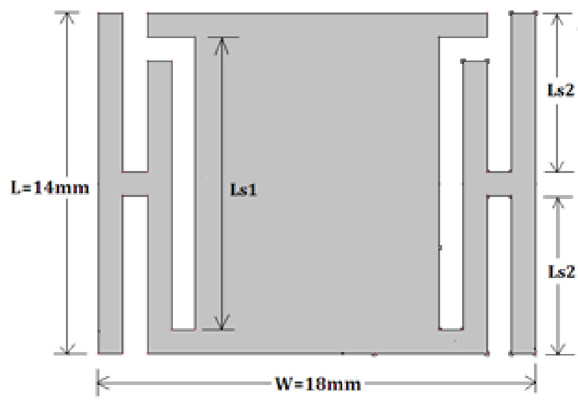


Figure 7. Proposed Antenna 5 with variable slot and spur line length.

Table 1. Effect of resonant frequency, return loss and gain with the variation of $\boldsymbol{L_{s1}}$ where $\boldsymbol{L_{s2}} = 6.5\,\text{mm}$ (Fig. 7).

L_{s1} in mm	Resonant Frequency (GHz)	Return Loss (dB)	Gain (dBi)
12	**2.25**	**17**	**1**
	6.74	**17**	**6**
11	2.45	10	11
	6.74	14	5.5
10	2.62	15	0.2
	6.74	14	5.8
9	2.83	11	2
	6.74	14	6
8	3.04	10	3.5
	6.74	13	5.7

Table 2. Effect of resonant frequency, return loss and gain with the variation of $\boldsymbol{L_{s2}}$ where $\boldsymbol{L_{s1}} = 12\,\text{mm}$ (Fig. 7).

L_{s2} in mm	Resonant Frequency (GHz)	Return Loss (dB)	Gain (dBi)
6.5	**2.25**	**17**	**1**
	6.74	**17**	**6**
6	2.3	4	−1
	6.78	15	5.5
5.5	2.32	18	0.5
	6.86	18	5.8
5	2.35	30	1.5
	6.94	23	5
4.5	2.38	7	−0.3
	6.98	25	6

modelled as an additional series inductance ΔL_1 [24] in the equivalent circuit shown in Fig. 6(d). The equivalent circuit of proposed Antenna 5 structure is shown in Fig. 6(e). Antenna 5 can be considered as a patch with $14 \times 14\,\text{mm}^2$ dimension loaded with strips and spur lines. According to this consideration, the equivalent circuit of Antenna 5 is the same as the equivalent circuit of Antenna 4 where R_1, L_1 and C_1 are taken for $14 \times 14\,\text{mm}^2$ patch and ΔL_1 and ΔC_{S1} taken for spur line and strip loading, respectively.

4. PARAMETRIC STUDY

Some parametric studies have been carried out to achieve optimum dimensions of the slots on proposed Antenna 5. With the variation of L_{S1} and L_{S2} shown in Fig. 7, the simulated resonant frequencies, return losses and gains for Antenna 5 are given in Table 1 and Table 2 and illustrated in Figs. 8–13.

It has been observed from Table 1 and Figs. 8–10 that much lower resonant frequency with good return loss has been found for $L_{s1} = 12\,\text{mm}$, and acceptable gains have also been achieved. So taking $L_{s1} = 12\,\text{mm}$, it has also been seen from Table 2 and Figs. 11–13 that much lower frequency with acceptable return loss and gain has been found for $L_{s2} = 6.5\,\text{mm}$. Thus $L_{s1} = 12\,\text{mm}$ and

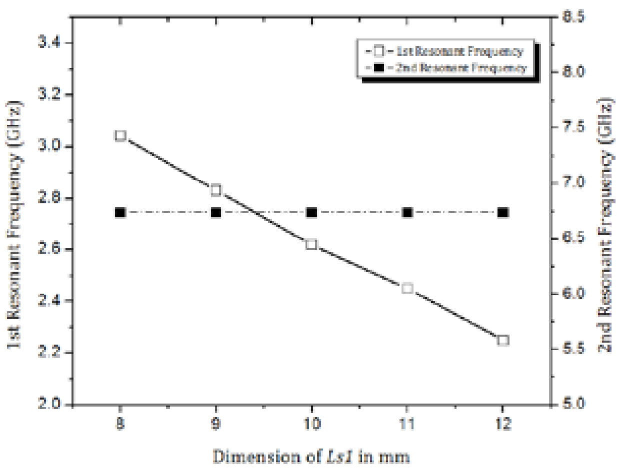


Figure 8. 1st and 2nd resonant frequencies with variation of L_{s1}.

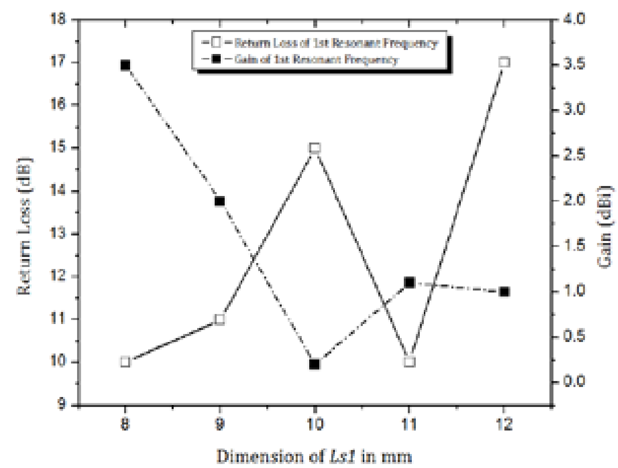


Figure 9. Return loss and gain with variation of L_{s1} for 1st resonant frequency.

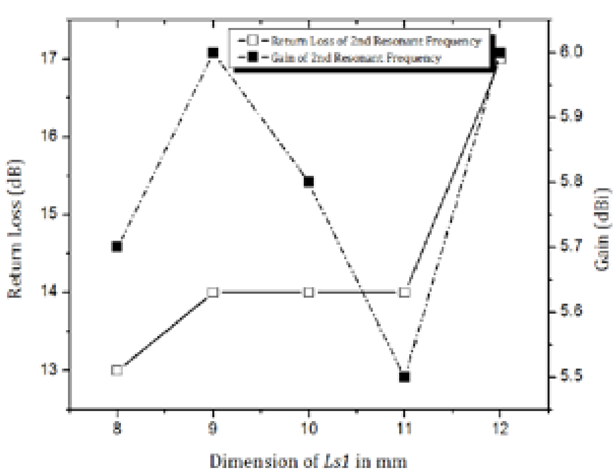


Figure 10. Return loss and gain with variation of L_{s1} for 2nd resonant frequency.

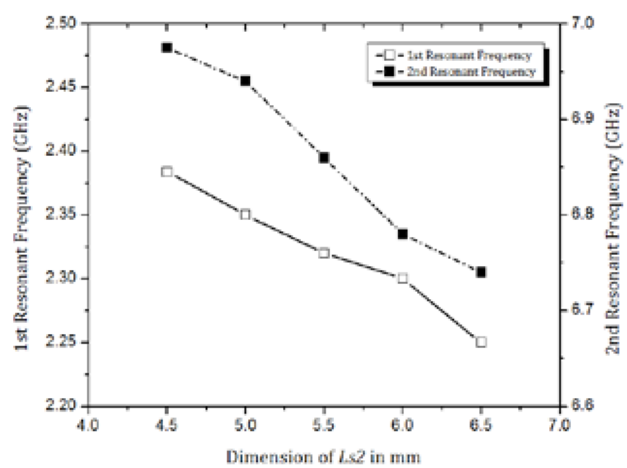


Figure 11. 1st and 2nd resonant frequencies with variation of L_{s2}.

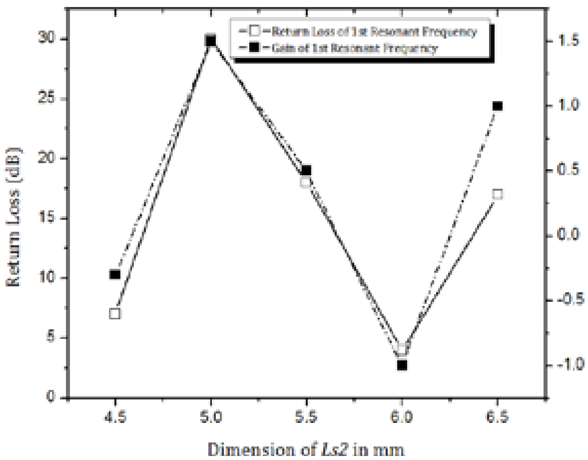


Figure 12. Return loss and gain with variation of L_{s2} for 1st resonant frequency.

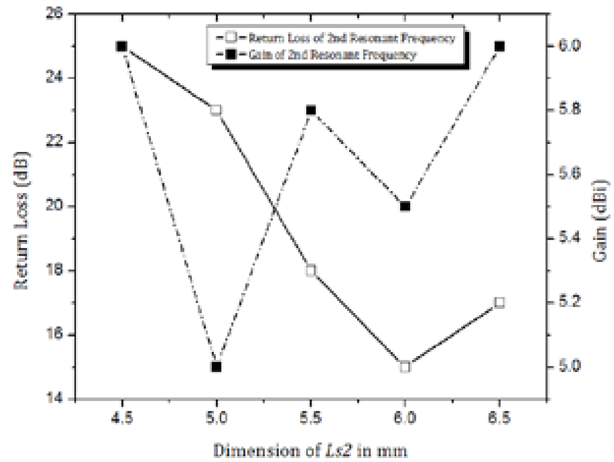
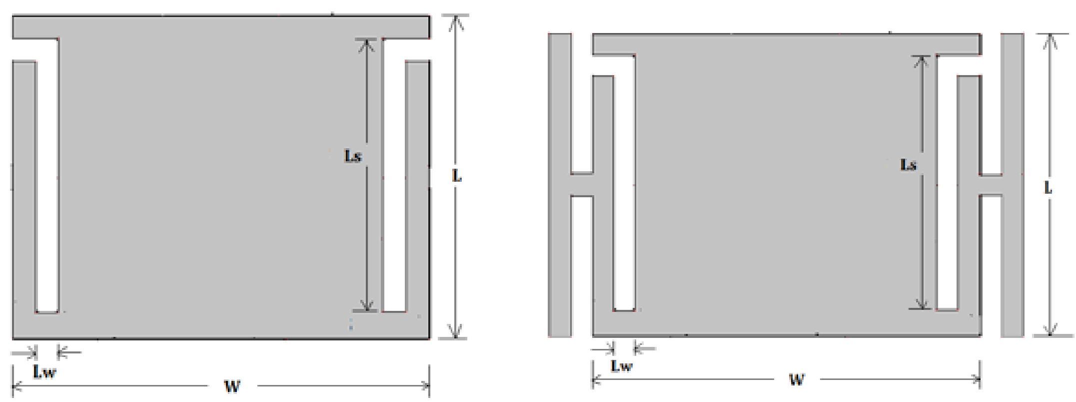


Figure 13. Return loss and gain with variation of L_{s2} for 2nd resonant frequency.



(a) (b)

Figure 14. Antenna dimensions (a) without strip loading and (b) with strip loading for parametric study.

$L_{s2} = 6.5\,\text{mm}$ have been taken as optimum values in Antenna 5 design which radiates 2.25 GHz and 6.74 GHz frequencies with return loss 17 dB for both, and gains have been found 1 dBi and 6 dBi, respectively.

After parametric study, it has been investigated that the first resonant frequency goes much lower with the increase of spur line slot length. The effect of the variation of spur line slot length with and without strip loading has been examined for the patch with dimensions $18 \times 14\,\text{mm}^2$ and $14 \times 14\,\text{mm}^2$. The proposed antenna structure shows $W = 18\,\text{mm}$ and $L = 14\,\text{mm}$ with only slot loading that looks like a patch of $W = 14\,\text{mm}$ and $L = 14\,\text{mm}$ with slot and strip loading. The antenna dimensions for parametric study are shown in Figs. 14(a)–14(b). The slot length vs first resonant frequency graph is shown in Fig. 15.

Figure 14(a) shows the antenna with spur lines only, and Fig. 14(b) shows the antenna with spur lines and strip loading. From the graph, shown in Fig. 15, it has been observed that the resonant frequency decreases with the increase of slot length L_s taking $L_w = 1\,\text{mm}$. The resonant frequency has been lowered considerably for the antenna with spur line and strip loading, compared to the same antenna with spur line only. But it has been observed from the graph shown in Fig. 15 that the resonant frequency of antenna having dimension $14 \times 14\,\text{mm}^2$ with spur line and strip loading is almost the same as the resonant frequency of antenna having dimension $18 \times 14\,\text{mm}^2$ with spur line and strip loading for

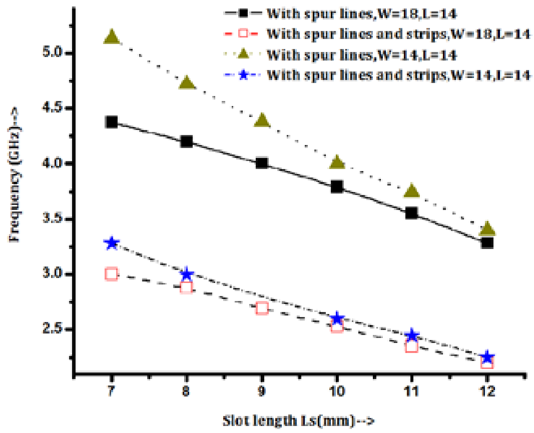


Figure 15. Slot length vs. frequency graph.

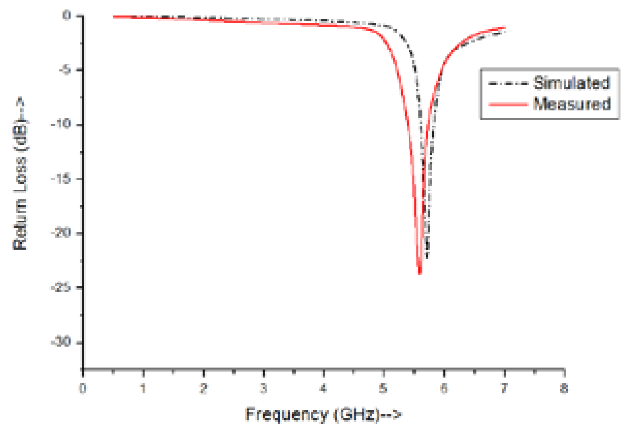


Figure 16. Frequency vs. return loss graph for Antenna 1.

$L_s = 12\,\text{mm}$. So the antenna having dimension $14 \times 14\,\text{mm}^2$ with spur line and strip loading has been taken as more compact size than the antenna having dimension $18 \times 14\,\text{mm}^2$ with spur line and strip loading. Thus the slots have been introduced in proposed Antenna 5 having dimension $18 \times 14\,\text{mm}^2$ such a way that it looks like an antenna having dimension $14 \times 14\,\text{mm}^2$ with spur line and strip loading. Antenna 5 with the proposed design has radiated almost the same first resonant frequency which has been radiated from antenna having dimension $18 \times 14\,\text{mm}^2$ with spur line and strip loading where effective patch size is $22 \times 14\,\text{mm}^2$.

5. RESULTS AND DISCUSSION

The return losses of all antennas have been studied using method of moment based software (IE3D), and the return losses of fabricated Antenna 1 and Antenna 5 have been measured using vector network analyzer. The simulated results of all antennas are shown in Table 3. The measured results of Antenna 1 and Antenna 5 are shown in Table 4.

The simulated and measured frequencies vs return loss graph for reference Antenna 1 is shown in Fig. 16. The simulated frequency vs return loss graphs for Antenna 2, Antenna 3 and Antenna 4 are shown in Fig. 17. Fig. 18 shows the simulated and measured frequencies vs return loss graph for

Table 3. Simulated results.

Antenna	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz), %
Antenna 1	5.6	24	200, 3.57%
Antenna 2	3.5	20	30, 0.8%
	5.6	24	120, 2.14%
	6.3	14	130, 2.06%
Antenna 3	2.8	15.7	30, 0.7%
	5.67	19	270, 4.8%
	6.8	19.4	40, 0.6%
Antenna 4	2.2	14	20, 0.8%
	5.7	20	260, 4.56%
	6.7	14	30, 0.44%
Antenna 5	2.25	17	40, 1.75%
	6.74	17	90, 1.26%

Table 4. Measured results of Antenna 1 and Antenna 3.

Antenna	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz), %	Frequency Ratio
Antenna 1	5.6	24	200, 3.57%	-
Antenna 5	2.2	20	70, 3.18%	$\frac{f_2}{f_1} = 2.9$
	6.4	17	90, 1.4%	

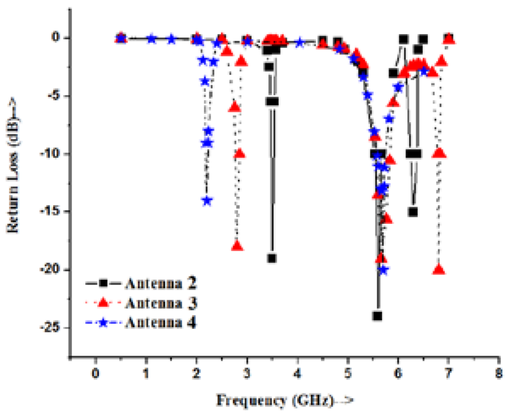


Figure 17. Frequency vs. return loss graph for Antenna 2, Antenna 3 and Antenna 4.

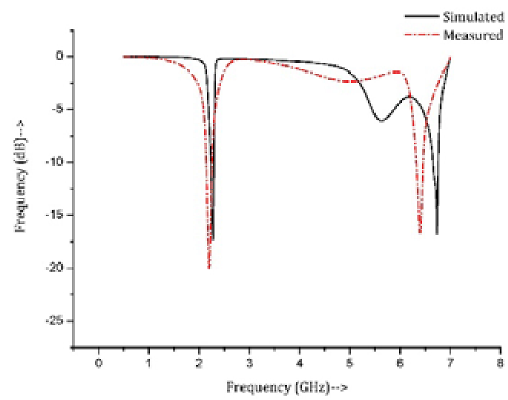
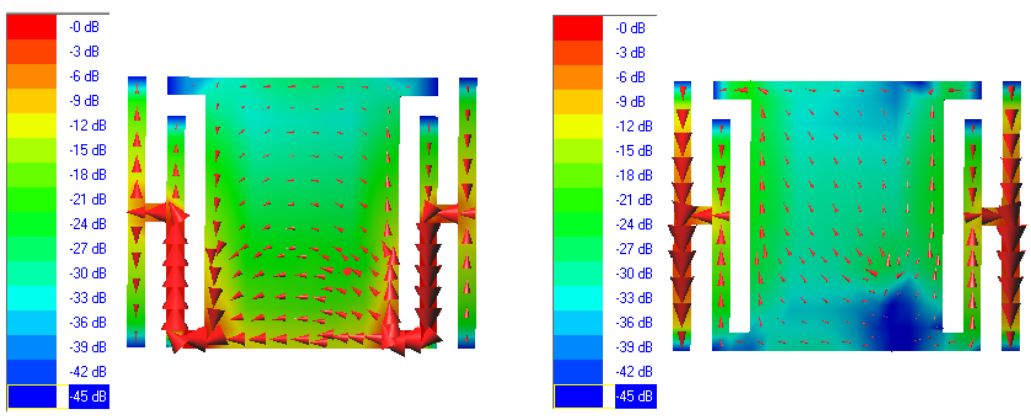


Figure 18. Frequency vs. return loss graph for Antenna 5.



(a) (b)

Figure 19. Current distribution of Antenna 5 at (a) 2.28 GHz and (b) 6.74 GHz.

proposed Antenna 5.

From the measured result, it has been found that the reference Antenna 1 resonates at 5.6 GHz with 24 dB return loss, and simulated result shows that Antenna 2 resonates at 3.5 GHz, 5.3 GHz and 6.3 GHz. The simulated first resonant frequency has been found much lower, i.e., 2.8 GHz for Antenna 3. With the addition of a pair of spur lines in Antenna 4, the simulated first resonant frequency has been lowered considerably, i.e., 2.2 GHz. According to measured results, the fabricated proposed Antenna 5 with slot and spur lines resonates at 2.2 GHz with 20 dB return loss and 6.4 GHz with 17 dB return loss which reduces the antenna size by 86.5% with respect to the reference antenna. The 10 dB bandwidth at 2.2 GHz and 6.4 GHz of Antenna 5 has been found 70 MHz (3.18%) and 90 MHz (1.4%), respectively. To investigate the dual-band operational mechanism of Antenna 5, the simulated antenna current distributions are shown in Figs. 19(a)–19(b).

It can be observed from the current distribution that majority of electric currents are concentrated around the spur lines and slots. It implies that in Antenna 5 structure the non-radiating edges which look like strips loading for cutting four slots have a significant effect on the antenna performance of lowering the frequency. The resonant frequencies can be calculated from the current path length as shown in Fig. 20.

The electrical lengths have been calculated from current distribution at simulated 2.25 GHz and 6.74 GHz for Antenna 5.

L_{C1} and L_{C2} are the average lengths for current paths of the first resonant frequency of 2.25 GHz (TM_{10} mode) and second resonant frequency of 6.74 GHz (TM_{01} mode). L_{C1} and L_{C2} are calculated from Fig. 20 as follows:

$$L_{C1} = W + (L_1 + L_1) \times 2 = 46\,\text{mm} \quad \text{and} \quad L_{C2} = L = 14\,\text{mm}.$$

The first and second resonant frequencies have been calculated from the following equations:

$$f_1 = \frac{c}{2L_{C1}}\sqrt{\frac{2}{1+\varepsilon_r}} \quad \text{and} \quad f_2 = \frac{c}{2\sqrt{\varepsilon_{reff}} \cdot L_{C2}}.$$

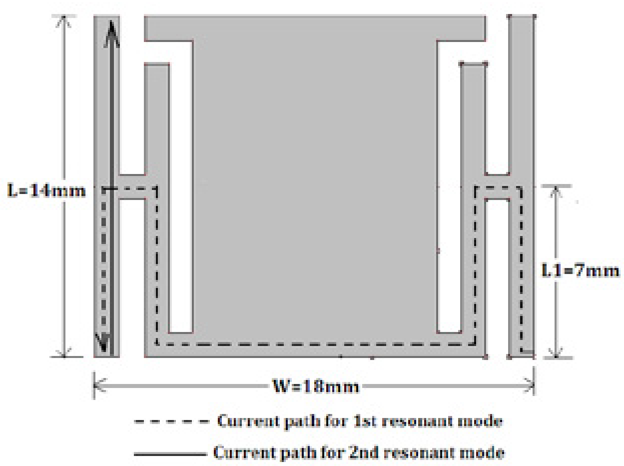


Figure 20. Slot length dimensions of Antenna 5.

Figure 21. Fabricated Antenna 5 structure.

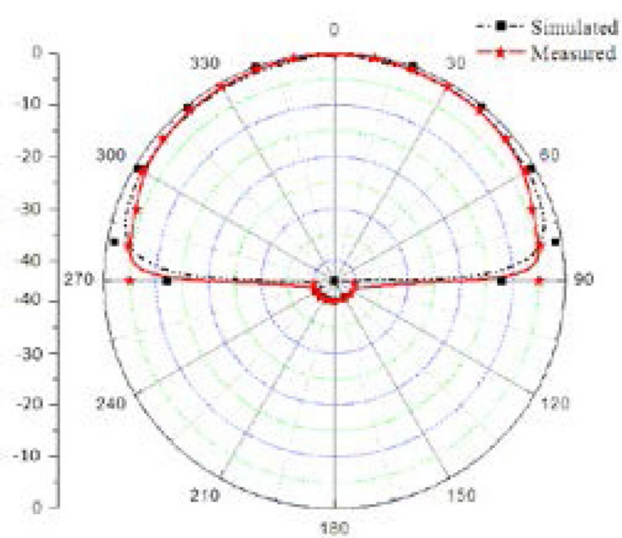


Figure 22. Radiation pattern of Antenna 1 at 5.6 GHz.

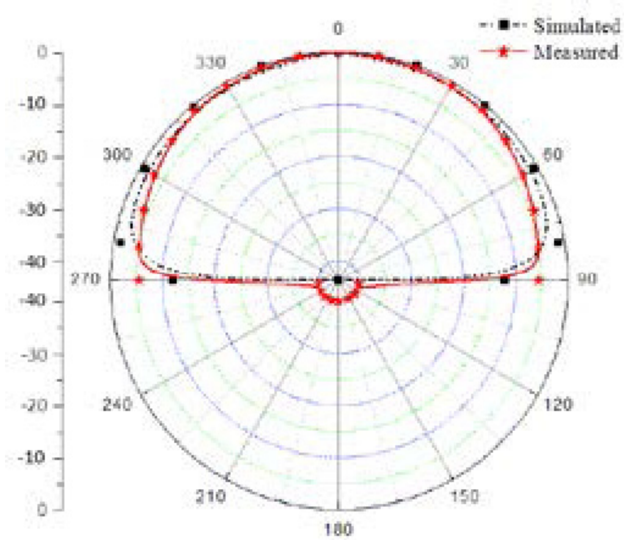


Figure 23. Radiation pattern of Antenna 5 at 2.2 GHz.

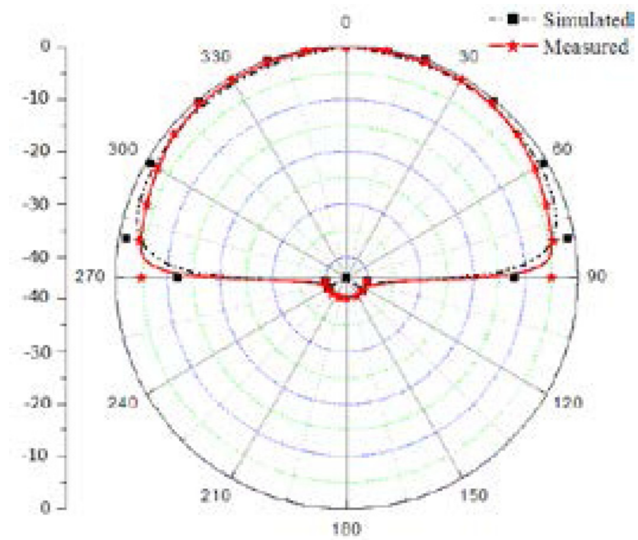


Figure 24. Radiation pattern of Antenna 5 at 6.4 GHz.

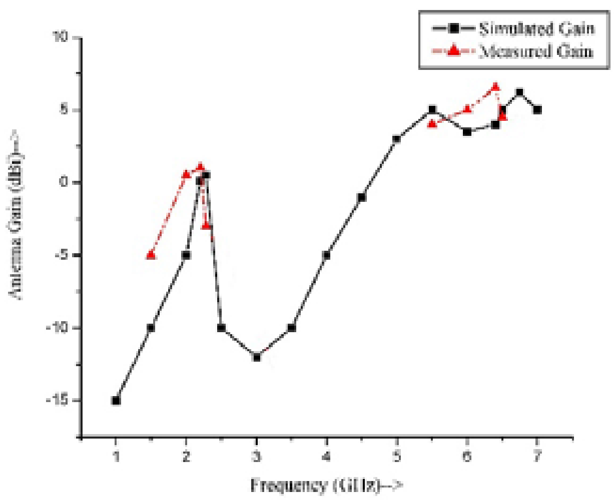


Figure 25. Frequency vs absolute gain of Antenna 5.

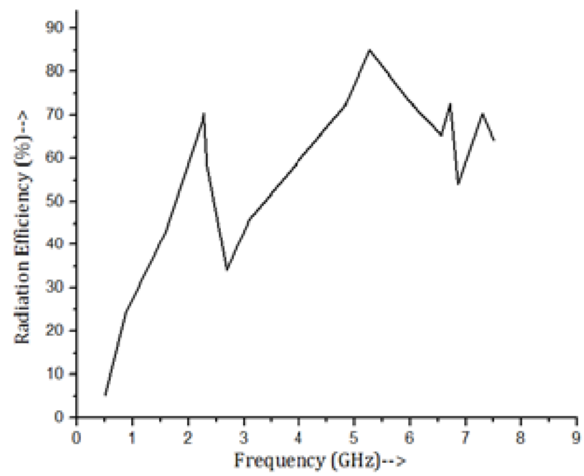


Figure 26. Frequency vs radiation efficiency of Antenna 5.

where, $\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2\sqrt{(1+10\frac{h}{W})}}$.

The calculated first and second resonant frequencies are $f_1 = 2.3$ GHz and $f_2 = 6.48$ GHz which are almost the same as simulated and measured results.

The fabricated Antenna 5 is shown in Fig. 21. The measured radiation patterns of Antenna 1 and proposed Antenna 5 are shown in Figs. 22–24. The 3 dB beamwidth has been found as 160° and 155° at 2.2 GHz and 6.4 GHz, respectively. The measured gains of Antenna 5 have been found as 1.1 dBi at 2.2 GHz and 6.5 dBi at 6.4 GHz, shown in Fig. 25. The radiation efficiencies at 2.25 GHz and 6.74 GHz of Antenna 5 have been calculated and found as 68.6% and 72.6%, respectively which is shown in Fig. 26.

6. CONCLUSION

A dual-mode dual-band compact microstrip patch antenna with slotted patch which looks like an antenna with strip and spur line loading has been presented in this paper. Due to the strip loading, the resonant frequency has been lowered, and the resonant frequency can be reduced further by using added spur lines. But as with the addition of strips, the overall patch size is increased, and the slots are introduced on the patch such a way that it seems to behave as a patch, loaded with strips. The effects of strips loading has been utilized in the proposed antenna by introducing slots only. From the simulated and measured results, it has been found that the proposed antenna shows the dual-mode (TM_{10} and TM_{01}), dual-band (S and C) operation, and the size of the antenna has been reduced by about 86.5% with respect to the reference antenna.

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