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SLOT LOADED CAPACITIVE FED SUSPENDED RMSA WITH MEANDERED GROUND PLANE

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Abstract

In this paper, variations in the Capacitive fed suspended RMSA configurations have been proposed. Initially, the reference antenna consists of a rectangular patch of the size of (35.5 × 45.6) mm^2 and a small rectangular feed patch of the size of (1.4 × 4) mm^2 residing on the same substrate suspended above the ground plane. The coaxial probe is used to feed the small patch, which in turn excites the radiator patch electromagnetically, yielding a large impedance bandwidth (BW) of 39%, with good gain and broadside radiation pattern. By, meandering the ground plane of reference antenna with three rectangular slots, the prototype antenna is fabricated and measurement has been carried out to validate the result for a compact broadband response. Later, by loading a pair of rectangular slots in the radiating patch of the reference antenna in addition to the rectangular slots in the ground plane, the prototype antenna is fabricated and measurement has been carried out to validate the result for compact dual-band response.

Keywords: Coupled capacitive feed, Dual-band, electromagnetically, meandering slots, Rectangular microstrip antenna (RMSA), Reference antenna (RA), Slot loaded.

1. Introduction

Microstrip Antennas (MSA's) are popular as it is used in most of the wireless communication systems offering various advantages. However, the limitation of its narrow bandwidth (BW) restricts its application in many of the wideband communication systems. Though, there are many approaches [1] to improve the bandwidth, one of the ways is to increase the thickness between the patch and the ground plane.

Probe feed or coaxial feed is popular and widely used in MSA as it can feed the patch at any arbitrary position without much difficulty. However, as the height of the substrate increases the inductance associated with the probe length may lead to unavoidable impedance mismatch. This impedance mismatch can be compensated by embedding slots in the microstrip patch, changing the shape of the probe or by using a novel feed technique such as capacitive or proximity fed patch [2, 3]. Kasbegoudar et al. [2] proposed a capacitive fed MSA, in which, provides a wide bandwidth of 50% for C band at 5.9 GHz with RT Duroid substrate (RO3003) having $\mathcal{E}_r$ = 3.0 and thickness of 1.56 mm. In addition, the antenna can be made to resonate at any frequency in L, S, C or X-band by optimizing the design parameters.

Increase in the bandwidth of MSA due to increasing in the height of the substrate or decrease in $\mathcal{E}_r$ of the substrate both result in the reduction of the resonant frequency of MSA, which in turn reduces the antenna size. Wong [4] and Kuo and Wong [5] reported the meandering technique (embedding slots) in the antenna's ground plane proved to be an efficient method of reducing the size and enhancing the bandwidth of MSA. Variations in slots in radiating patch and ground plane were analysed for compact and broadband operations [6-8]. Dual frequency MSA's operating at two separate bands for transmitting and receiving is preferred in all wireless applications [9-11]. Resonant slot lengths cut at appropriate locations in the patch generate modes, which add up to the patch modes resulting in multi-band MSA [12, 13].

The basic configuration of the proposed antenna is discussed with its design details in Sections 2 and 3 provides simulation and experimental validation of the prototype.

2. Antenna Geometry

To begin with, reference antenna (capacitive fed RMSA) is designed and optimized to resonate at 2 GHz using FR4 substrate. Later, the ground plane of the RA is meandered using rectangular slots. Further, along with the meandered ground plane, dual rectangular slots are etched in the radiating patch of RA. The geometry of the reference antenna and the proposed antennas are discussed in detail below.

2.1. Design of capacitive fed RMSA

The basic geometry of Reference Antenna (RA), consisting of a rectangular radiating patch of size (L, W) = (35.5, 45.6) mm, is designed to resonate at f_r = 2 GHz for the fundamental TM_{10} mode [1]. The substrate is positioned on top of the ground plane at a height filled with air as a substrate. Adjacent to the radiating patch, there is a small rectangular feed patch placed in the same plane. Instead of a direct feed to the MSA, an electromagnetically coupled capacitive feed is used for improvement in the bandwidth with broadside radiation characteristics. This feeding mechanism provides compensation for increased feed inductance.

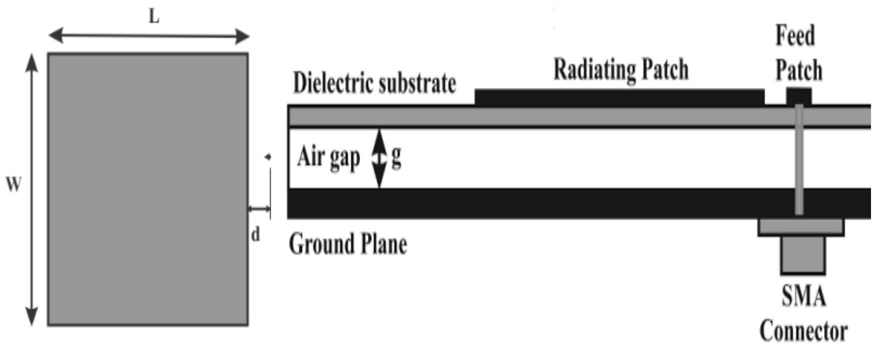
The basic principle underlying the operation of the reference antenna is capacitive coupling between the driven patch and the radiating patch. The gap introduces a capacitance into the feed so that it can cancel out the inductance added by the probe feed. Figure 1 shows the geometry of the prototype wherein a larger patch works as the radiator and the smaller one acts as a feed patch using, which radiator is excited by capacitive means. Coaxial probe feed is positioned, at the centre of the feed patch to excite it. A finite ground plane with size 75 × 75 mm^2 is used in the design. The radiating patch and feed patch used for the RA are both rectangular in shape.

The design parameters of the RA are listed in Table 1. By optimizing, the dimensions of the feed patch (*t* and *s*), distance (*d*) between the feed patch and the radiator patch and air gap distance (*g*) between the substrate and the ground plane, Impedance bandwidth of RA can be significantly increased to 39%. The air gap distance [2] given by Eq. (1)

$$g \cong 0.16\lambda c - h\sqrt{\varepsilon_r} \quad (1)$$

where λ_c is the wavelength corresponding to the centre frequency of the operational band, *h* is the height of the substrate and ε_r is a dielectric constant of the substrate.

This is because, by adding air between the radiating patch and the ground plane the effective dielectric constant below the patch reduces, thus increasing the bandwidth and efficiency of the antenna [14]. Optimizing the air gap distance '*g*' is a very important design parameter, as it is responsible for merging the two close resonance frequencies into a single operational band below -10 dB return loss. A slight shift in the resonant frequency is also observed. This is due to the fact that as air gap increases, the effective dielectric constant changes leading to a change in effective width and length of the patch. The distance (*d*) between the radiating patch and the feed patch have a very small effect on the bandwidth although it affects the impedance matching. The impedance bandwidth of the antenna slightly decreases with an increase in the feed patch width (*t*), provided other parameters are kept constant, but the bandwidth loss can be recovered to its actual value by decreasing the length of feed patch [15]. Considering an improvised bandwidth, impedance matching and broadside radiation characteristics, the various parameters such as *s*, *t*, *d* and *g* are optimized for the RA and are shown in Table 1 [12].



(a) Top view. **(b) Side view.**

Fig. 1. Reference antenna.

Table 1. Typical dimensions of RA at 2 GHz.

Parameter	Dimension
Length of radiating patch (*L*)	35.5 mm
Width of radiating patch (*W*)	45.6 mm
Feed patch length (*s*)	4 mm
Feed patch width (*t*)	1.4 mm
Distance between feed patch and radiating patch (*d*)	1 mm
Air gap between the substrates (*g*)	15 mm
Dielectric constant ($\mathcal{E}_r$)	4.4
Substrate thickness (*h*)	1.6 mm

2.2. Design of capacitive fed RMSA with meandered ground plane

Three rectangular slots of the same length (~λ_0/4) and width (~λ_0/100) operating at a frequency of 2 GHz are cut in the ground plane of the RA. The slots are aligned side by side with equal spacing of *L*/4 from each other as shown in Fig. 2. The width of the slot is 1 mm. The length of the slot is (L_i +L_o), where L_i is the slot length inside the projected image of radiator patch in ground plane and L_o is the length of slot outside the projected image of radiator patch in the ground plane [4, 5]. A coaxial probe is used to excite the feed patch at the centre, which in turn excites the radiating patch. This forms the proposed Antenna-I.

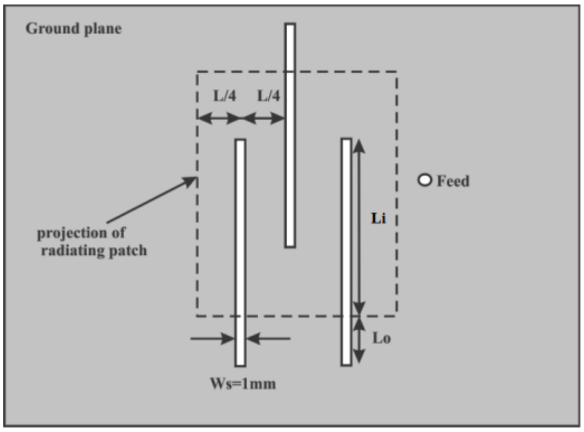


Fig. 2. Top view (ground plane).

2.3. Design of slot loaded capacitive fed RMSA with meandered ground plane

Dual rectangular slots of same length and width are loaded at the non-radiating edges of the radiating patch of the RA with the meandered ground plane. The slots lie very close and run along the radiating edges of the radiating patch as shown in Fig. 3. The length of the slot L_s = 44.6 mm (~λ_0/2) and width W_s = 1 mm (~λ_0/100) operating at 2 GHz. This forms the proposed Antenna-II.

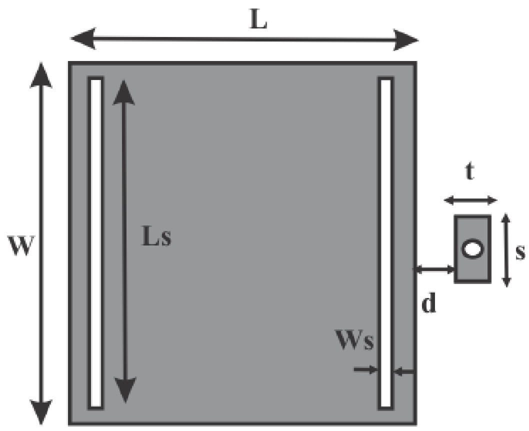


Fig. 3. Top view (patch).

3. Experimental Results and Discussion

The characteristics of the RA and the proposed Antennas I and II are investigated by using MOM based powerful 3D, broadband, full wave electromagnetic solver HyperLynx Full-Wave Solver [16]. The proposed antennas are fabricated using FR4 substrate (with dielectric constant 4.4, loss tangent 0.02, thickness 1.6 mm). The simulation results are validated using Rohde and Schwarz ZVH-8 vector network analyser.

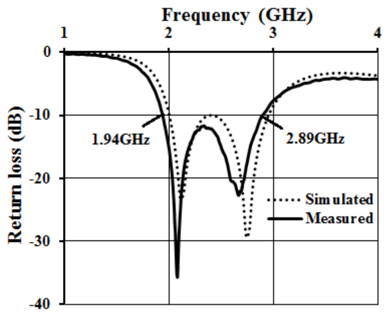
3.1. Experimental results of capacitive fed RMSA

The reference antenna with the proposed geometry is shown in Fig. 1 with dimensions listed in Table 1 [12]. The pin of the SMA connector is extended by using copper wire to excite the feed patch through the air gap.

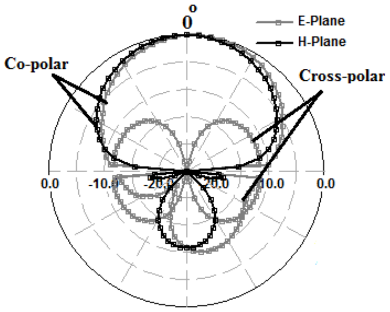
Figure 4(a) shows the $|S_{11}|$ characteristics of the reference antenna. For RA, fundamental resonant mode TM_{10} is excited at 2.42 GHz with 10 dB return loss. The measured return loss (S_{11}) is much below -10 dB (VSWR < 2) corresponding to a frequency range of (1.94-2.89) GHz providing an impedance bandwidth of 950 MHz (39%). The simulated and measured results are in close agreement with each other.

The co and cross-polarized E-plane and H-plane radiation patterns of the prototype at selected frequencies within the operational band are shown in Figs. 4(b) to (d) for frequencies at 2 GHz, 2.5 GHz and 2.89 GHz respectively. H-plane radiation patterns are broadside and symmetrical at all frequencies, however, there is small asymmetry in E-plane radiation patterns especially at high frequencies due to asymmetrical feed arrangement.

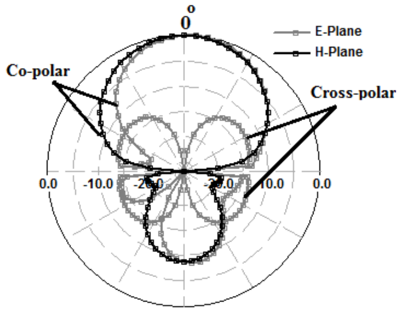
As the total substrate thickness increases, the probe length increases, thus, the feed patch acts as a top-loaded monopole antenna, which radiates and is responsible for the high cross-polar levels. The gain versus frequency plot as shown in Fig. 4(e) shows a peak gain of 7.07 dBi at 2.5 GHz with gain reducing at higher frequencies due to an increase in cross-polar levels. The fabricated configuration is tested on R and S vector network analyser as shown in Figs. 5(a) and (b).



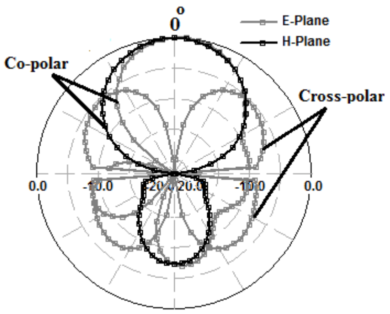
(a) $|S_{11}|$ characteristics of reference antenna.



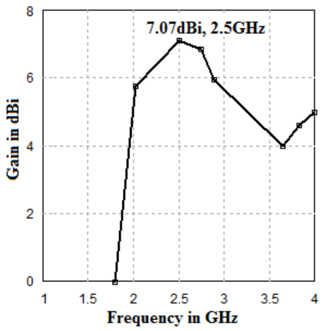
(b) E-plane and H-plane radiation pattern at 2 GHz.



(c) E-plane and H-plane radiation pattern at 2.5 GHz.

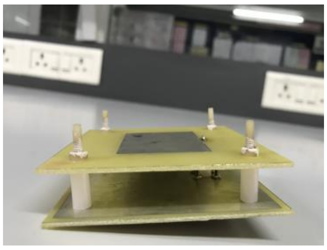


(d) E-plane and H-plane radiation pattern at 2.89 GHz.

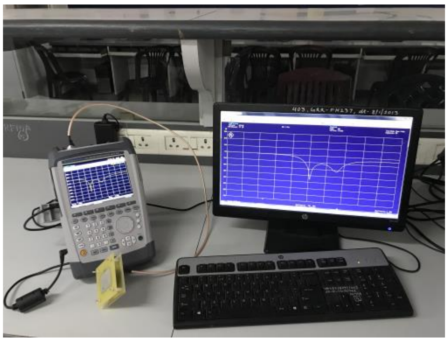


(e) Variation of gain vs. frequency characteristics.

Fig. 4. Experimental results of capacitive fed RMSA.



(a) Antenna prototype.



(b) Testing on vector network analyser.

Fig. 5. Fabricated configuration.

3.2. Experimental results of capacitive fed RMSA with meandered ground plane

For the proposed Antenna-I as discussed in Fig. 2, the slot length L_o for the prototype is fixed to be at 10 mm [4, 5]. A parametric study is carried out by varying the slot length L_i from 0 to 35 mm, keeping L_o fixed at 10 mm and their width's W_s constant at 1 mm. The effect of varying the slot length L_i on parameters such as resonant frequency and impedance bandwidth of the proposed antenna is studied. As the slot length, L_i increases from 0 mm to 35 mm (~λ_0/4), lowering in the resonant frequency and increase in the impedance bandwidth is observed. The resonant frequency decreases due to the path length of the surface current around the slots. The meandering technique (embedding slots) in the ground plane of antenna effectively reduces the quality factor of the proposed antenna and accounts for enhanced bandwidth.

In case of slot length (L_i = 35 mm and L_o = 10 mm), the resonant frequency is lowered to 1.8 GHz, i.e., the resonant frequency is approximately 0.76 times that of RA giving a size reduction of about 23%. To further validate the results, the simulated and measured S_{11} characteristics are shown in Fig. 6. The measured return loss is much below -10 dB (VSWR < 2) corresponding to a range of frequencies (1.49-2.28) GHz, providing an impedance bandwidth of 41.9% at the optimized slot length. The simulated and measured results are in reasonable agreement with each other.

Front to back ratio and the backward radiation increases due to the embedded slots in the ground plane resulting in bi-directional radiation patterns in both E and H planes. The fabricated configuration is tested on R and S vector network analyser as shown in Figs. 7(a) and (b).

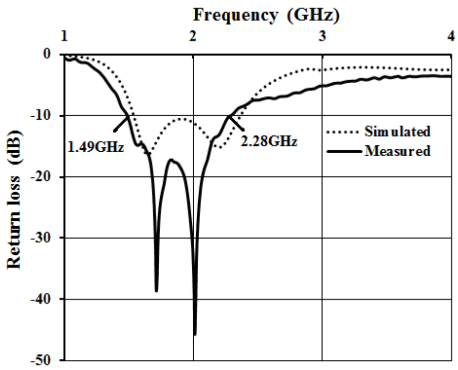
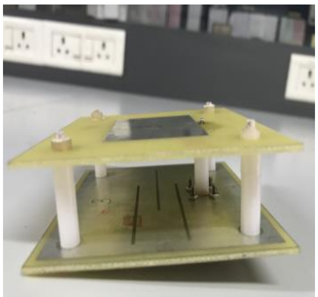
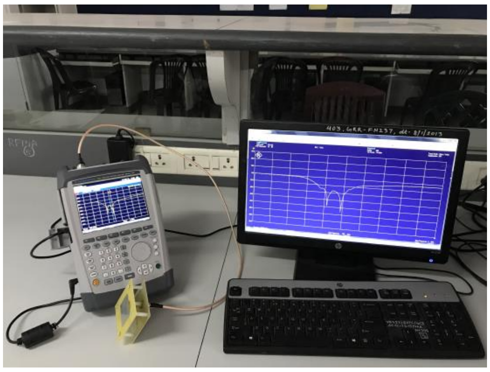


Fig. 6. |S_{11}| characteristics for proposed Antenna I when L_i = 35 mm.





(a) Antenna prototype. **(b) Testing on vector network analyser.**

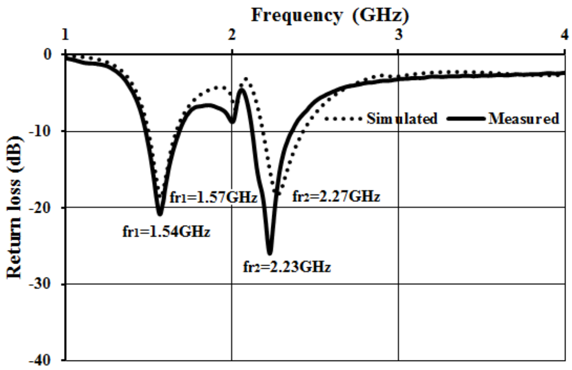
Fig. 7. Fabricated configuration.

3.3. Experimental results of slot loaded capacitive fed RMSA with meandered ground plane.

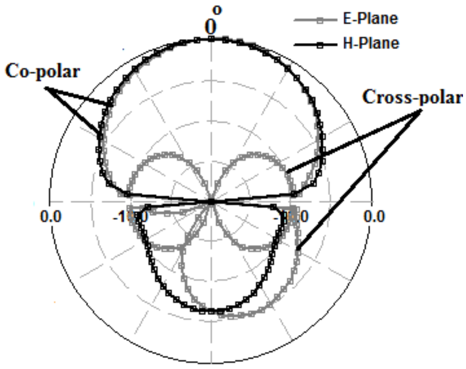
For the proposed Antenna-II as discussed in Fig. 3, dual rectangular slots are loaded in the radiating patch having length L_s = 44.6 mm and width W_s = 1 mm [8]. A parametric study is carried out by varying the slot length L_i (length inside the projected image of radiator patch) from 0 to 35 mm keeping L_s at 44.6 mm and width W_s at 1 mm. The effect of varying the slot length L_i on parameters such as resonant frequency and impedance bandwidth of the proposed antenna is studied.

As the slot length, L_i increases from 0 mm to 35 mm, lowering in both the resonant frequencies is observed. In case of slot length (L_i = 35 mm and L_o = 10 mm), the first resonant frequency (f_{r1}) is reduced to 1.56 GHz, which is about 0.64 times that of RA, giving a size reduction of 35% and second resonance (f_{r2}) is reduced to 2.2 GHz, which is about 0.92 times that of RA, giving a size reduction of 8%. The proposed antenna does not provide any higher-order resonant frequency if the slot length is further increased. At this optimal slot length, there is a significant reduction in size and bandwidth of the proposed antenna with frequency ratio (f_{r2}/f_{r1}) of 1.42 resulting in a compact dual-band characteristic. Results clearly indicate that f_{r1} has a bandwidth of 12.65% and f_{r2} has a bandwidth of 10.29%.

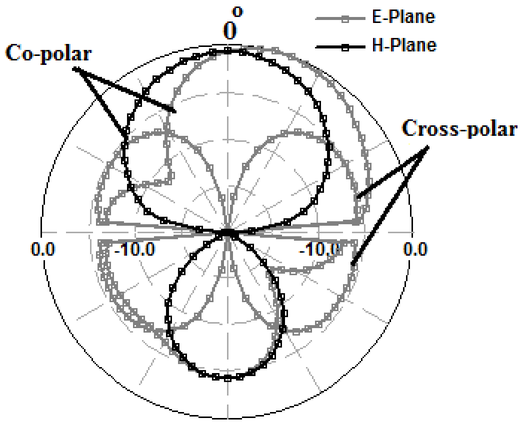
To further validate the results, $|S_{11}|$ characteristics are shown in Fig. 6. The simulated and measured results are in close agreement with each other. The co and cross-polar E-plane and H-plane radiation patterns of the proposed antenna at an optimum slot length of L_i = 35 mm for f_{r1} = 1.57 GHz as shown in Fig. 8(a) presents broadside radiation similar to the reference antenna (RA). At the second resonant frequency f_{r2} = 2.27 GHz in Fig. 8(b), the E-plane radiation pattern is tilted by 30º from broadside direction due to high cross-polar levels. Front to back ratio is higher due to the defective ground plane. Cross-polar levels are high as 6 dB compared to the co polar level. However, H-plane radiation patterns are broadside and symmetrical at both frequencies. The fabricated configuration is tested on R and S vector network analyser as shown in Figs. 9(a) and (b).



(a) $|S_{11}|$ characteristics for proposed Antenna-II when L_i = 35 mm.

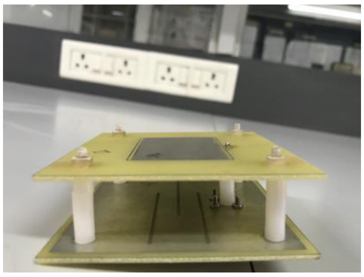


(b) E-plane and H-plane radiation patterns at 1.57 GHz.

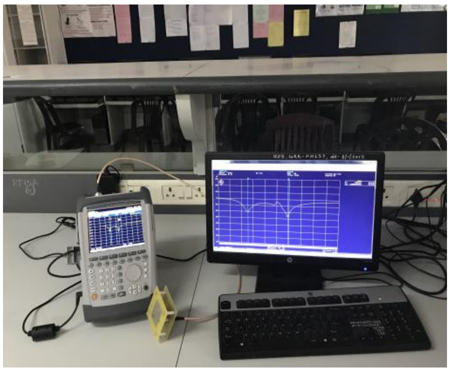


(c) E-plane and H-plane radiation patterns at 2.27 GHz.

Fig. 8. Experimental results of slot loaded capacitive fed RMSA with meandered ground plane.



(a) Antenna prototype.



(b) Testing on vector network analyser.

Fig. 9. Fabricated configuration.

4. Conclusion

Capacitive fed suspended MSA configurations with low-cost FR4 substrate works well for increasing the impedance bandwidth of MSA to 39% as compared to the reference, which provides 50% impedance bandwidth with a much expensive RT Duroid substrate. By integrating slots inside the ground plane of MSA, impedance bandwidth was further increased to 41.9% and a size reduction of 24% has been achieved in the proposed Antenna Configuration-I, resulting in a Compact Broadband antenna design.

Later, loading a pair of parallel slots in the radiating patch, dual-frequency band with fractional bandwidths of 12.65% and 10.29% with a size reduction of 35% and 8% at the first and the second resonant frequency respectively has been achieved in proposed Antenna Configuration -II, resulting in a Compact Dual-band antenna design.

Nomenclatures

d	Distance between feed patch and radiating patch
f	Frequency
g	Air gap between the substrates
h	Substrate thickness
L	Length of the radiating patch
S_{11}	Return loss
s	Feed patch length
t	Feed patch width
W	Width of radiating patch

Greek Symbols

ε_r	Dielectric constant
λ	Wavelength

Abbreviations

BW	Bandwidth
MSA	Microstrip Antenna
RA	Reference Antenna
RMSA	Rectangular Microstrip Antenna
TM	Transverse Magnetic
VSWR	Voltage Standing Wave Ratio

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