Progress In Electromagnetics Research C, Vol. 101, 119–132, 2020

Inset-Feed Frequency Reconfigurable Compact E-Shape Patch with DGS

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Abstract—In this paper, a new miniaturized switchable band microstrip patch antenna array using PIN-diode is presented for WLAN/WiMax applications. In the first stage DGS has been employed to miniaturize a dual band microstrip patch antenna array simultaneously resonating at 2.2 GHz and 3.8 GHz. Further in second stage RF PIN-diodes has been used to achieve the frequency reconfigurability to serve for different communication systems. The designs are verified through both simulation and measurement of fabricated prototype. The measured results were in good agreement with simulated results.

1. INTRODUCTION

In recent years, the miniaturization of antennas have become more and more important due to the increasing demand of small antennas for rapid development in wireless communications. Microstrip patch antennas (MPA) are widely used in wireless devices and offer compact size. Many techniques for reducing the size of antennas have been proposed recently, such as using Defected Microstrip Structure (DMS) and Defected Ground Structure (DGS) [1, 2]. When DGS is introduced in a microstrip antenna, the defect geometry etched in the ground plane disturbs its current distribution [3, 4]. This disturbance affects the transmission line characteristics, such as the line capacitance and inductance. In other words, introducing DGS in a microstrip antenna can result in an increase of the effective capacitance and inductance [5] which influences the input impedance and current flow of the antenna [6, 7] and thus reducing its size with respect to a given resonance frequency. Dual-band antennas are also topic of interest for wireless communications system that uses two bands of frequencies which would reduce the implementation size, cost, and complexity. Different techniques have been also reported for designing low cost, small profile, and efficient dual-band antennas, like dual-frequency operation by means of two narrow slots close to the patch radiating edges [8], dual-frequency circular microstrip antenna with an arc-shaped slot [9], slot-loaded equilateral-triangular microstrip antenna for dual-frequency operation [10], each with a combination of a slot and a parasitic wire [11]. These approaches are for fixed dual-band operation and do not allow for electronic tuning. Moreover, frequency reconfigurable antenna offers many advantages such as compact size, similar radiation pattern, and proper gain for all frequency bands compared to multiband antenna. Reconfigurable antennas represent a recent innovation in antenna design that changes from classical fixed form, fixed function antennas to modifiable structures that can be adapted to fit the requirement of a time varying system. For this reason, many antenna types have recently been developed in reconfigurable system. Different techniques and methodologies are used to design, optimize, and apply reconfigurable antennas [12]. Frequency reconfigurable antennas can change their resonant frequency to operate at specific bands along the multi-serviced radio spectrum. Advances in microwave semiconductor technologies enable the use of compact, ultra-high-quality RF and

Received 17 January 2020, Accepted 9 April 2020, Scheduled 22 April 2020

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microwave switches in novel aspects of antenna design. The switches can encompass several functions on reconfigurable antennas, for example: Selection of operating modes is achieved by switching the PIN-diode between radiators and tuning the varactor on an antenna's shorting line [13] switching between the different frequency bands through the use of RF-MEMS switches [14, 15], connect or disconnect several elements in antenna arrays by integration, and use of RF MEMS switches in microstrip patch antennas and feed structures for developing reconfigurable multiband antenna [16–19].

This paper introduces a concept of DGS based frequency reconfigurable miniaturized microstrip patch antenna array with switchable band using RF PIN diode. Initially, the proposed microstrip patch array antenna resonates at 5.2 GHz, and then DGS employed to make dual band microstrip patch antenna array resonates simultaneously at 2.2 GHz and 3.8 GHz. Further in order to achieve the frequency band selectivity PIN diodes are incorporated in the antenna. A size reduction about 65% with the frequency reconfigurability compared with the conventional one is achieved. The difference of the study from the previously reported antennas is that it incorporates miniaturization and reconfigurability in a single structure. Moreover, since the DGS is reconfigured, the broad side radiation from the patch is unaffected at the frequencies of interest.

2. MICROSTRIP PATCH ANTENNA ARRAY RESONATING AT 5.2 GHZ

The proposed 2 by 1 element array microstrip patch antenna is shown in Fig. 1. For improved impedance bandwidth two slots are introduced on each patch. In this study, an RT Duroid substrate with relative permittivity 2.2 and height 0.762 mm is used.

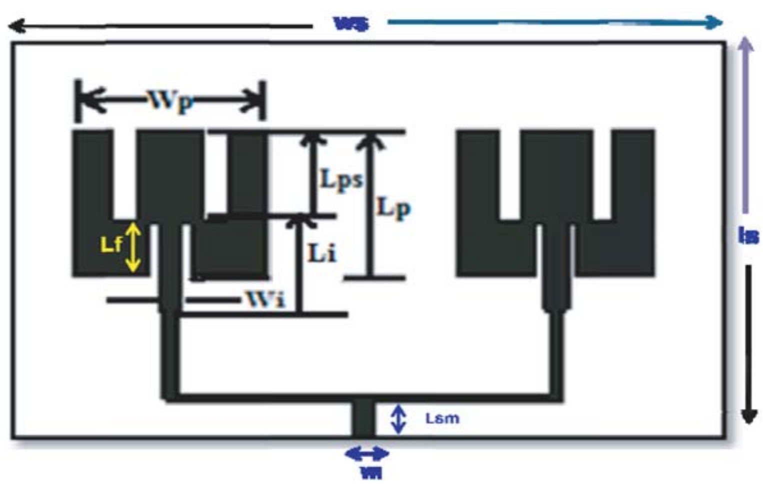


Figure 1. Front view of the E-shaped patch antenna Array.

The dimensions of antenna are optimized by using CST Microwave Studio tool. The substrate has width $ws = 82$ mm and length $ls = 67$ mm, and on the top of the substrate, a metal patch with dimension $Lf = 6.5$ mm, $Lp = 18.6$ mm, and $Wp = 22.80$ mm is connected to a 50 Ω feed line with an inset. The dimensions of inset feed are $Li = 11$ mm and $Wi = 2.3$ mm, however, the main feed line with dimension $Lam = 5.11$ mm and $Wi = 2.3$ mm. The centre to centre spacing between two antennas is λg at 5.2 GHz. A standard microstrip line 1 : 2 power divider is used to feed the two antennas, and hence the line widths are adjusted according to the power division. The simulation result of this reference antenna is shown in Fig. 2 and the radiation plot in Fig. 3.

It is observed that the reference antenna resonates at 5.2 GHz with very good impedance matching. The bandwidth is however not appreciable. The other band at around 9.5 GHz is due to the E-shaped patch. This is also observed in the results for single E-shaped patch. The simulated radiation pattern shows a gain of 10 dBi in both E and H planes. To achieve miniaturization, a defected ground structure is used as described in the next section.

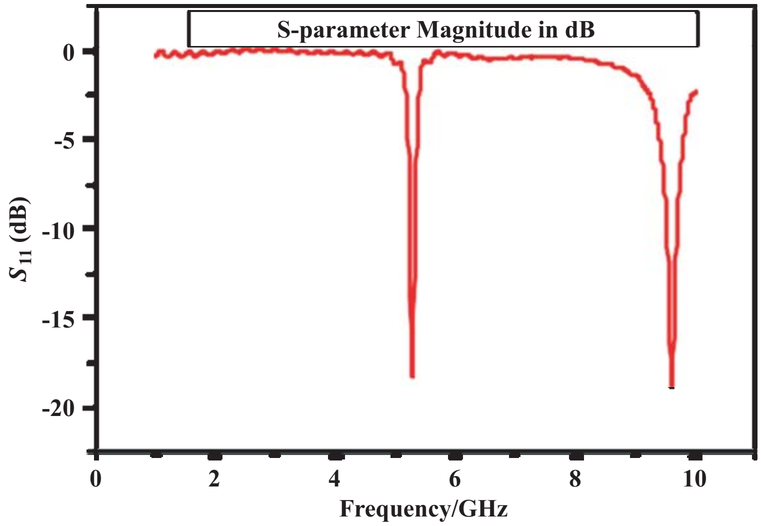
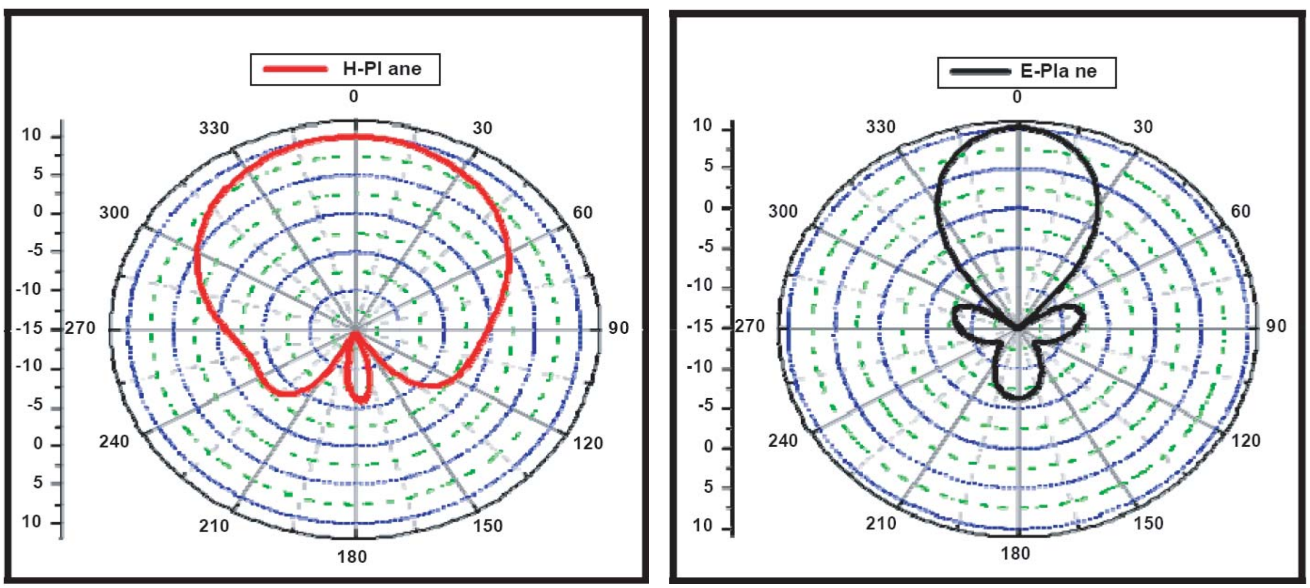


Figure 2. Simulated S_{11} of the patch antenna (Wp = 22.80 mm, Lp = 18.6, Wi = 2.3 mm, Lps = 12 mm) array resonating at 5.2 GHz.



(a) (b)

Figure 3. Radiation Pattern of the antenna array shown in Fig. 1. (a) H-plane. (b) E-plane.

3. DEFECTED GROUND STRUCTURE (DGS)

The DGS equivalent circuit consists of a parallel tuned circuit in series with the transmission line to which it is coupled as shown in Fig. 4. The different shapes of DGS structure have the same role and same characteristics of slow wave effect and high impedance, band rejection, miniaturization of size with the same equivalent circuit [20]. However, to improve the circuit performance of antenna the shape of DGS can be further changed or modified. In this work, we have employed DGS for antenna miniaturization. When DGS is introduced in a microstrip antenna, the defect geometry etched in the ground plane disturbs its current distribution. This disturbance changes the characteristics of the patch radiator by including some parameters (slot resistance, slot capacitance, and slot inductance) to the

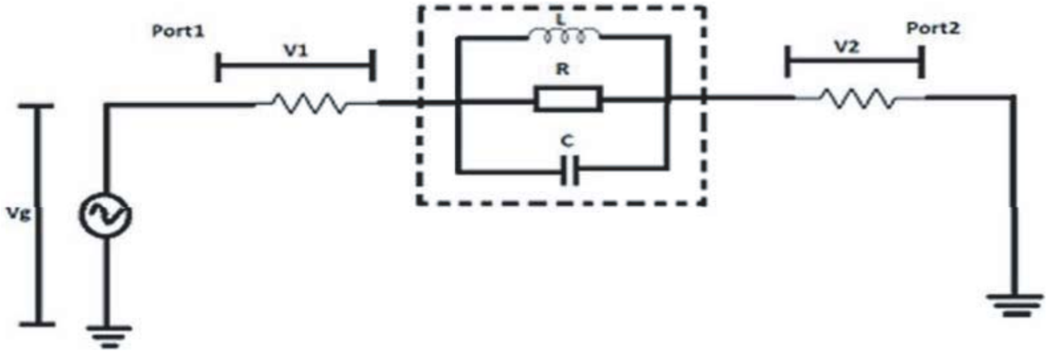


Figure 4. Equivalent Circuit of DGS [21].

original parameters of the antenna (i.e., resistance, capacitance, and inductance). In other words, any defect etched in the ground plane under the patch changes the effective capacitance and inductance by adding slot resistance, capacitance, and inductance. Thus, introducing DGS in a microstrip antenna can result in an increase of the effective capacitance and inductance which influences the input impedance and current flow of the antenna [6] and thus reducing its size with respect to a given resonance frequency.

4. DUAL MODE MINIATURIZED RESONATOR WITH DGS

In order to shift the resonance frequency of the conventional microstrip antenna array (Fig. 2), a new DGS geometry is etched on the metallic ground plane of the antenna shown in Fig. 5 and Fig. 6. Initially the microstrip patch antenna array is designed to be resonant at the WLAN band, i.e., 5.2 GHz. Further DGS is integrated on the metallic ground plane of the antenna. The detailed DGS geometry with the specified dimensions is as shown in Fig. 7, and Fig. 8 shows the antenna performance with DGS. It is observed that the resonance frequency has been significantly influenced by the DGS, and the microstrip array antenna is simultaneously resonant at the 2.2 GHz, i.e., WLAN band, and 3.8 GHz, i.e., WiMax band.

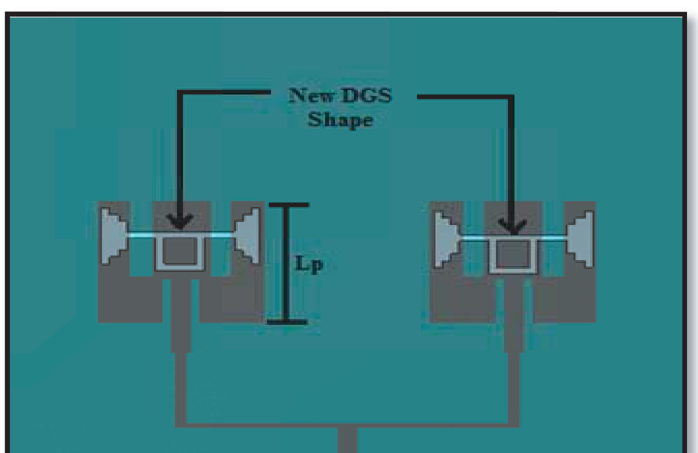


Figure 5. Microstrip 2 by 1 Element array antenna with DGS.

DGS adds L and C effect and is resonant in nature. With integration of DGS in the ground of the Patch antenna, due to slow wave effect, the resonance frequency of the antenna is reduced. To get desired the resonance frequency, after integration of the DGS, the size of the radiating element can be reduced, which makes the antenna compact. Thus, DGS plays a major role in achieving a compact

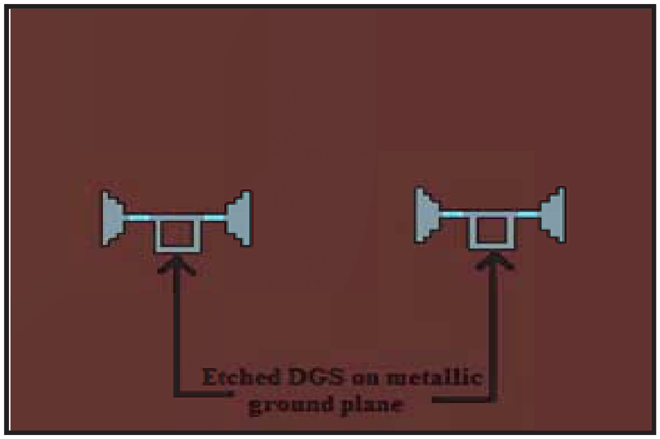


Figure 6. "Back-view" of Microstrip 2×1 antenna array with DGS element.

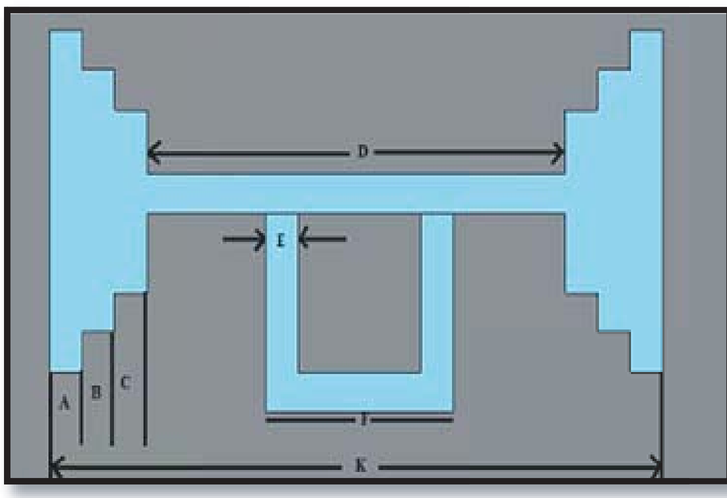


Figure 7. DGS geometry ($K = 20\,\text{mm}$, $D = 14\,\text{mm}$, $A = B = C = E = 1\,\text{mm}$, $F = 8\,\text{mm}$).

radiator. By parametric sweep of the DGS dimensions, one can get desired resonance frequency of the antenna as well as compact size of the antenna. In our case however, we intend to have the final antenna to resonate at a lower frequency, and therefore, no change in the dimensions of the patch is incorporated.

Although the physical size of the antenna array is same due to integrated DGS, antenna now works simultaneously at two lower frequencies. Table 1 shows the comparison between sizes of an antenna which resonates at 2.2 and 3.8 GHz with and without DGS. Thus with the integrated defective ground structure, an appreciable maximum size reduction about 82% along with dual frequency band operation of microstrip patch antenna array has been achieved.

5. RECONFIGURABLE ANTENNAS USING PIN DIODE SWITCHES

Reconfigurable antennas extend the functional possibilities of regular antennas by changing their configuration. In order to achieve reconfigurability electrically actuated switch, i.e., PIN diodes are used. Initially ideal switch models are used to imitate PIN diode switches for proof of concept, i.e., the opened (OFF) and closed (ON) states of the switches are simulated in the absence or presence of a metal pad with the area $\text{WSW} \times \text{LSW} = 0.2 \times 0.4\,\text{mm}^2$, respectively as shown in the Fig. 9. This is

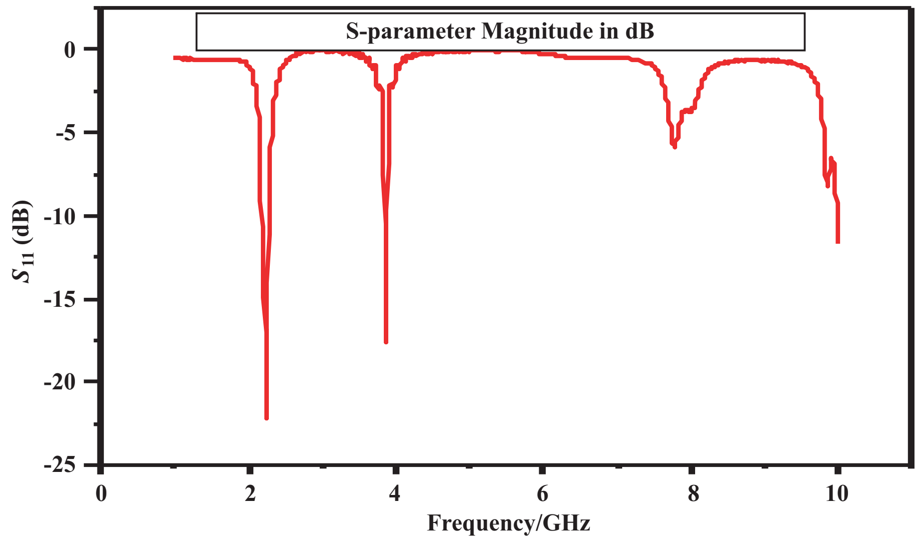


Figure 8. Simulated S_{11} of the dual patch antenna with DGS resonating at 2.2 GHz and 3.8 GHz.

Table 1. Size comparison of antenna.

Resonating Frequencies	Resonatingpatch size without DGS	Resonating patch size without DGS	Size Reduction
5.2 GHz	424 mm^2	424 mm^2	-
3.8 GHz	819.15 mm^2	424 mm^2	50%
2.2 GHz	2459.99 mm^2	424 mm^2	82%

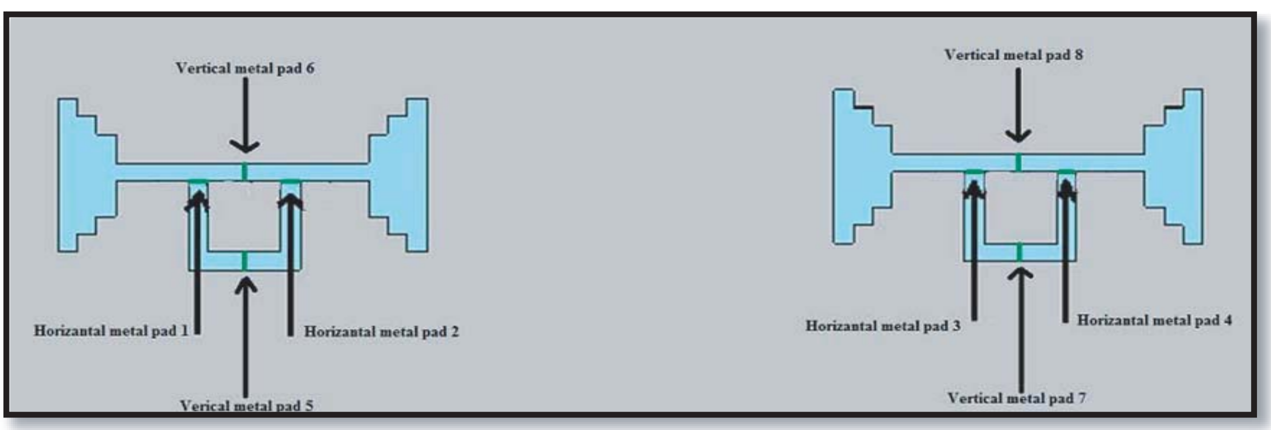


Figure 9. "Back-view" of Microstrip 2 by 1 element array with metal pad.

approximately the same area of the real PIN diode switch. Further the metal pads are replaced by PIN diode NADP402-1230P which is forward biased with 0.7 V and 10 mA. It exhibits an ohmic resistance of 3 Ω and intrinsic capacitance of 0.1 pF for forward bias. For DC biasing the PIN diode without leakage of RF signal to the DC bias line, the RF choke inductor was attached. Fig. 10 shows complete circuit required to replace each ideal short by PIN diodes with additional biasing circuits, and Fig. 11 shows back view of a microstrip 2 by 1 element array to replace each ideal short by PIN diodes with biasing circuits.

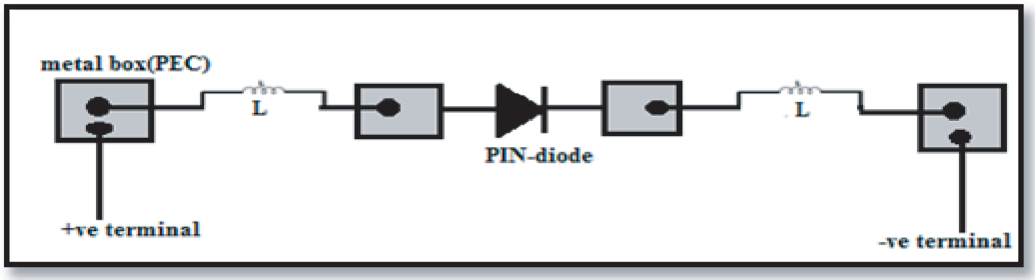


Figure 10. Biasing circuit to replace each ideal short by PIN diode.

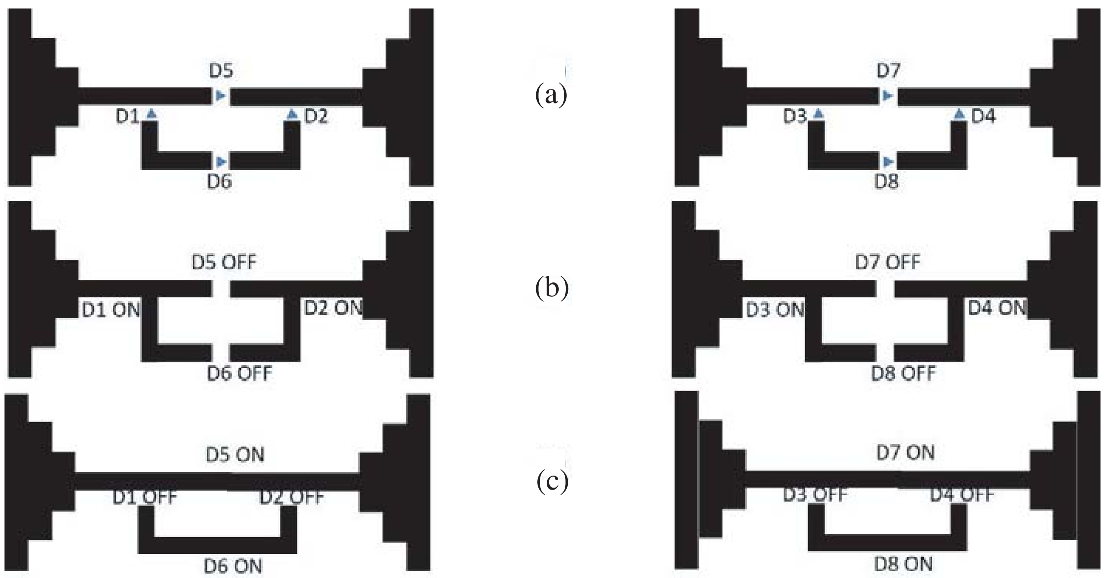


Figure 11. Back-view of microstrip array to replace each ideal short by PIN diodes with biasing circuits. (a) General placements of the diodes: D1–D4 are horizontal diodes and D5–D8 are vertical diodes. (b) Case II of switching to obtain 2.2 GHz and (c) Case III of switching to obtain 3.8 GHz.

The proposed reconfigurable antenna is designed to generate single frequency band that enables frequency reconfigurability using switched PIN diodes with defected ground structure. As observed from Fig. 8, the size reduction of the integrated defective ground structure along with dual frequency band operation of microstrip patch antenna array has been achieved. Further in order to generate preferred single frequency band, the PIN diodes are placed in such a manner that they can make or break the continuity between a complete DGS etched on the metallic ground plane.

Total eight diodes are inserted into the etched DGS. Four diodes (Diode 1 to Diode 4) are called horizontal diodes, and remaining four diodes (Diode 5 to Diode 8) are called vertical diodes as seen in Fig. 11. The four switching states are described in Table 2. When the four horizontal placed diodes are in ON state (Case II) and therefore act as a closed switch, continuity within a complete DGS structure breaks. However, since four vertical diodes are OFF, they do not affect the complete DGS structure. This ON-OFF condition of diode changes current distribution, and the antenna resonates only at single frequency at 2.2 GHz, i.e., WLAN band as shown in Fig. 12. On the other hand, when the four horizontal placed diodes are OFF and act as open switch, and four vertical placed diodes are ON and act as a closed switch (Case III), the current takes a longer path, and hence the antenna resonates only at another single frequency at 3.8 GHz, i.e., WiMax band as shown in Fig. 13. When all diodes correspond to OFF state (Case I) and act as open switches, there is no effect on the continuity of the etched DGS structure, and hence antenna resonates at 2.2 and 3.8 GHz simultaneously. Conversely when all the diodes correspond to ON state (Case IV), the antenna resonates at 4 GHz. Table 2 shows

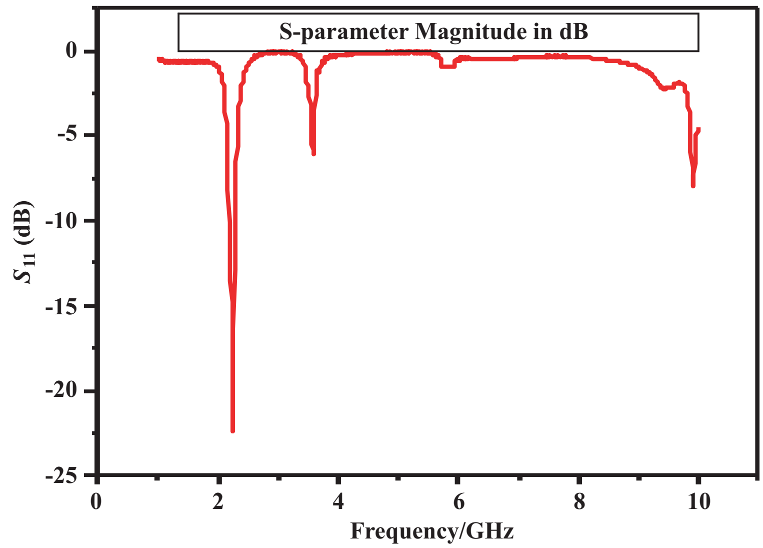


Figure 12. Simulated result of antenna resonant at 2.2 GHz.

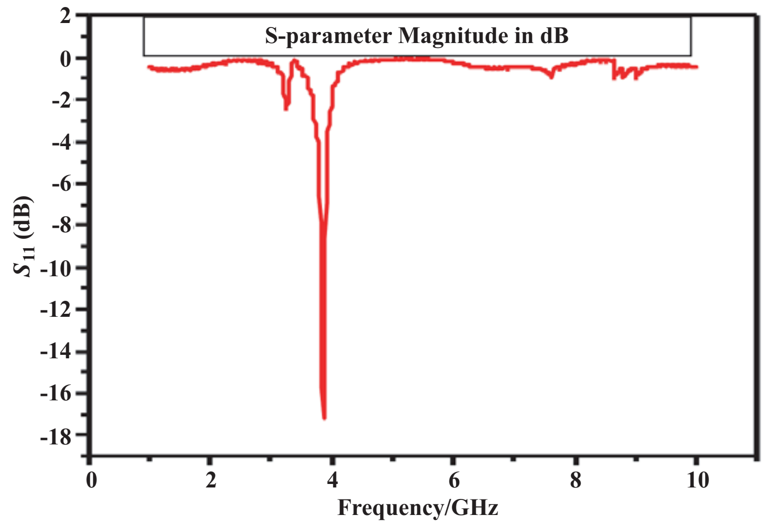


Figure 13. Simulated result of antenna resonant at 3.8 GHz.

all four modes of operation.

Table 2 shows all four cases for different modes of operation (MODE1–MODE4) with the performance of antenna array in terms of gain, bandwidth, and efficiency as shown below. In CASE 1 all the diodes are in OFF condition, and hence influence in resonance frequency is due to a complete etched DGS structure. However due to the ON-OFF condition of diode current distribution in DGS structure is disturbed which affects the resonance frequency as shown in CASE2–CASE3. Back lobe radiation due to DGS structure affects the gain and efficiency of antenna array.

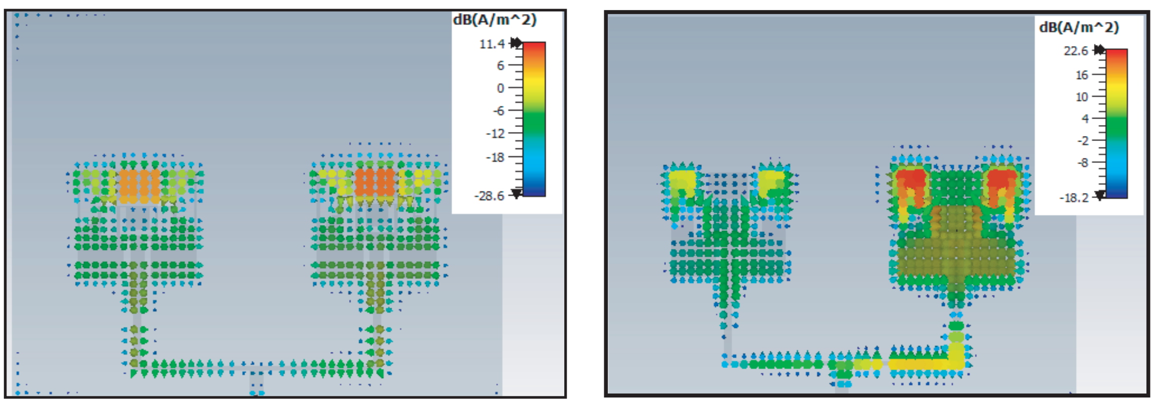
The surface current distribution pattern for CASE 2 and CASE 3 are shown in Fig. 14 below.

6. FABRICATION AND MEASUREMENT

A prototype of designed microstrip patch antenna array without DGS as a reference antenna is fabricated. The antenna array with DGS and switchable PIN diodes is also fabricated as proposed antenna. We have used an RT-Duroid substrate with relative dielectric constant 2.2 and thickness

Table 2. Different modes of operation with ON/OFF state of PIN diode.

Modes of Operation	Horizontal Diodes Switching State				Vertical Diodes Switching State				Antenna resonates at Frequencies GHz		Gain dBi	BW	Efficiency
	D1	D2	D3	D4	D5	D6	D7	D8					
CASE1	**All Diodes OFF**												
MODE 1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	2.2	3.8	5.7	130 MHz /110 MHz	87%
CASE2	**Horizontal Diodes ON, Vertical Diodes OFF**												
MODE 2	ON	ON	ON	ON	OFF	OFF	OFF	OFF	2.2	-	4.8	130 MHz	82%
CASE3	**Horizontal Diodes OFF, Vertical Diodes ON**												
MODE 3	OFF	OFF	OFF	OFF	ON	ON	ON	ON	-	3.8	3.9	110 MHz	81%
CASE4	**All Diodes ON**												
MODE4	ON	ON	ON	ON	ON	ON	ON	ON	4	-	6.28	120 MHz	82%



(CASE 2) **(CASE 3)**

Figure 14. Surface current distribution at the resonance frequencies of interest.

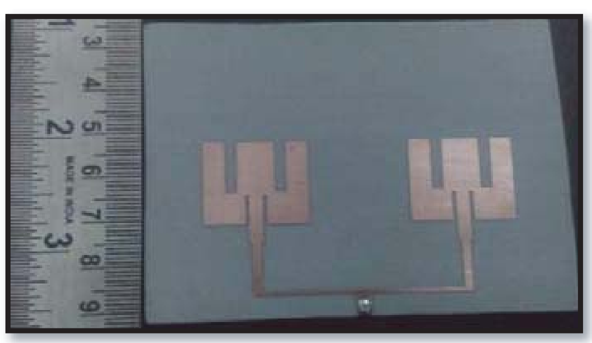
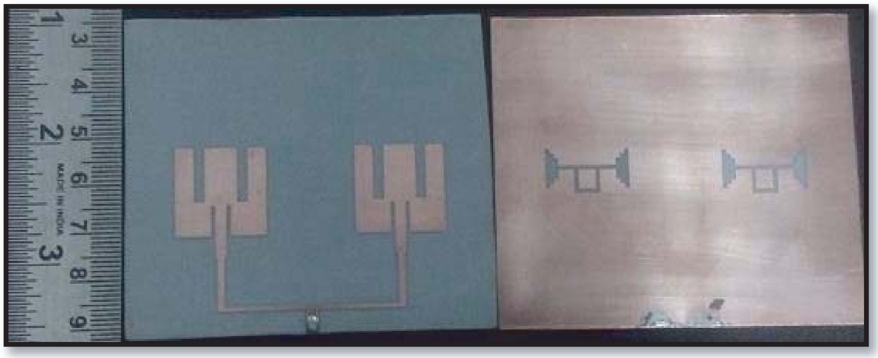


Figure 15. Prototype of the fabricated 2×1 element microstrip patch antenna array without DGS.

0.762 mm. Fig. 15 shows the size of microstrip patch antenna array without DGS. Figs. 16(a) and (b) show size of the top and back views respectively of dual band microstrip patch antenna array with DGS. Figs. 17(a) and (b) show size of the top and back views respectively of the reconfigurable microstrip



(a) (b)

Figure 16. Prototype of the fabricated (a) 2 × 1 element miniaturized dual band microstrip patch antenna array with DGS. (b) Back view with etched DGS.

(a) (b)

Figure 17. Prototype of the fabricated. (a) 2 × 1 element frequency reconfigurable miniaturized microstrip patch antenna array. (b) Back view with switchable band using PIN diode.

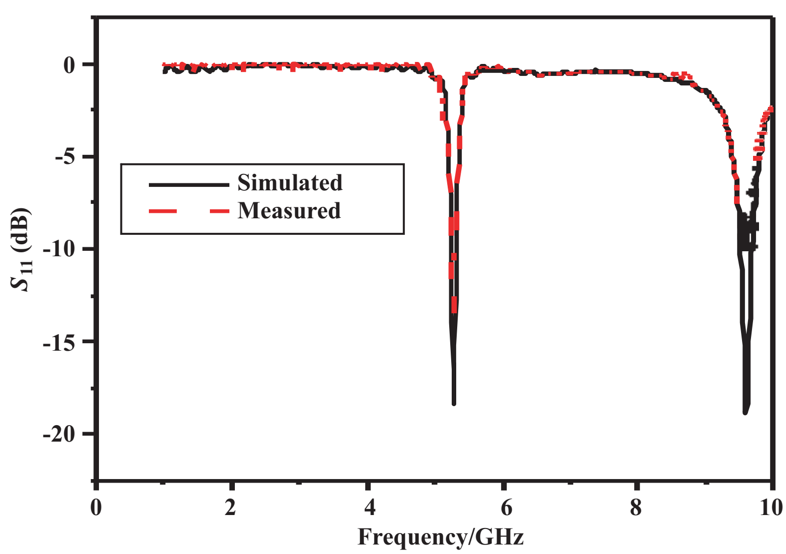


Figure 18. Comparison of simulated and measured results of the 2 × 1 array without DGS.

patch antenna array with PIN diode.

S_{11} parameter is measured and compared to the simulated result. Fig. 18 shows the comparison between measured and simulated results of microstrip patch antenna array without DGS resonating at 5.2 GHz with the gain of 10.01 dBi. Comparison between measured and simulated results of microstrip patch antenna array with DGS resonating simultaneously at 2.2 GHz with the gain 4.8 dBi and at 3.8 GHz with the gain 3.9 dBi for WLAN and WiMax application respectively is as shown in Fig. 19.

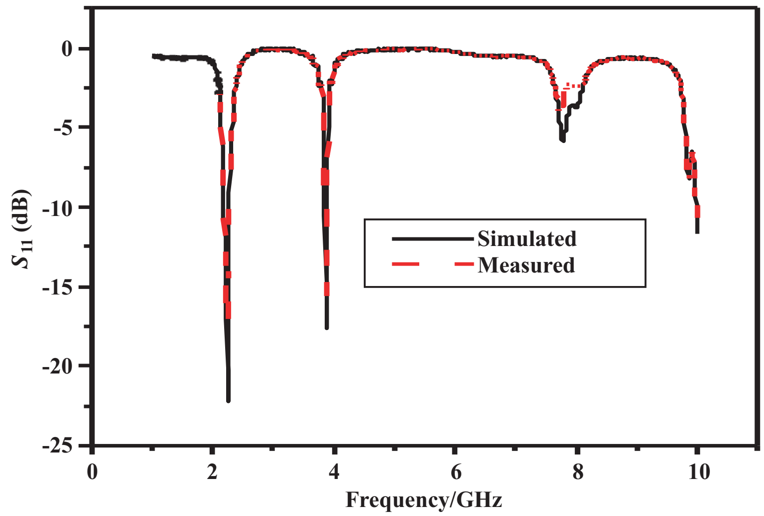


Figure 19. Comparison of simulated and measured results of 2×1 array with DGS.

Figures 20 and 21 show the comparison between measured and simulated results of reconfigurable microstrip patch antenna array using switchable PIN diodes for different switching modes resonating at 2.2 and 3.8 GHz. As the high back lobe is caused by DGS in ground plane the measured gain in operation band is reduced. Fig. 22 and Fig. 23 show the measured radiation pattern in E plane and H plane for 3.8 and 2.2 GHz, respectively.

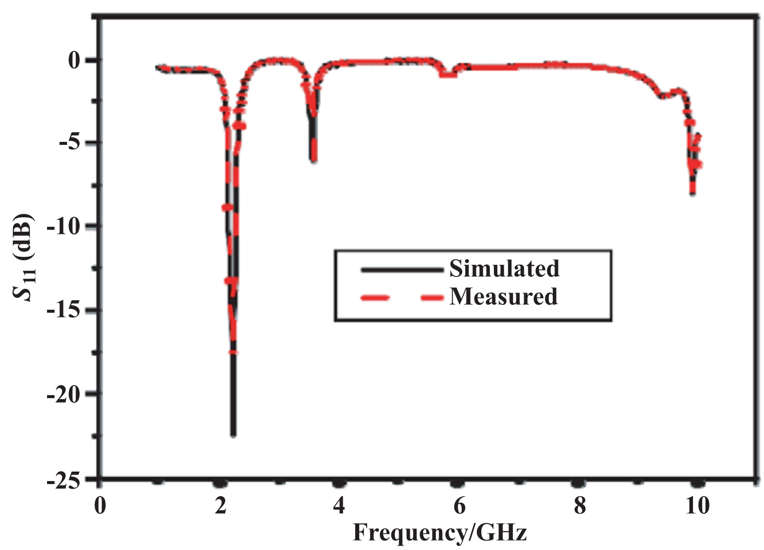


Figure 20. Comparison of simulated and measured results of reconfigurable 2×1 array with resonance at 2.2 GHz.

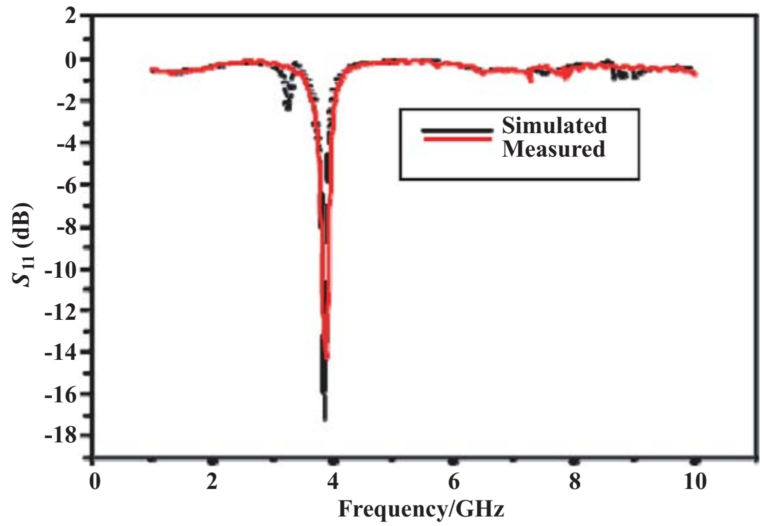


Figure 21. Comparison of simulated and measured results of reconfigurable 2×1 array with resonance at 3.8 GHz.

Table 3. Comparison of proposed work with reported work.

REF. NO.	ANTENNA SIZE	FREQUENCY BAND	EFFICIENCY	GAIN
6	$(47.2 \times 24.4)\,\text{mm}^2$	3.15 GHz 4.47 GHz	Not mentioned	2.35 dBi 4.35 dBi
7	$22\,\text{mm} \times 36\,\text{mm} \times 1.6\,\text{mm}$	2.4/5.2/5.8-GHz WLAN	95.93% at 5.7 GHz.	maximum gain of 6.4 dBi at 5.64 GHz with a maximum gain variation of 1.6 dBi.
10	$75\,\text{mm} \times 75\,\text{mm}$	1.7 to 1.8 GHz 2.3 to 2.7 GHz	Not mentioned	Not mentioned
13	$30 \times 70\,\text{mm}^2$	1.85–1.99 GHz 1.92–2.18 GHz 3.4–3.6 GHz 5.15–5.825 GHz	63–93%	2.84, 2.81, 1.25, and 1.49 dBi at USPCS, WCDMA, m-WiMAX, and WLAN, respectively.
Proposed work	$424\,\text{mm}^2$ patch size Overall size: $(82 \times 67)\,\text{mm}^2$	Dual band (2.2 and 3.8 GHz) Individually resonate at 2.2 GHz and 3.8 GHz using diode	82–87 %	3.9 to 5.7 dBi

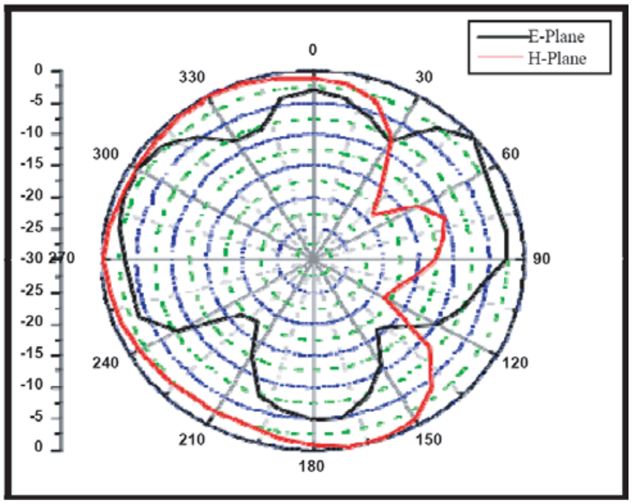


Figure 22. Measured radiation patterns in E plane and H plane at 3.8 GHz.

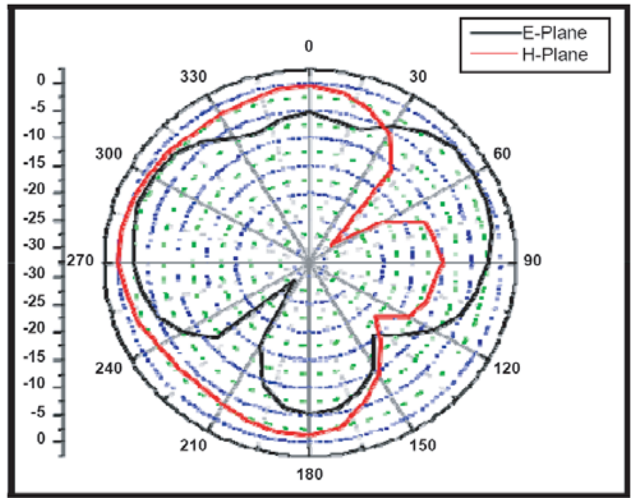


Figure 23. Measured radiation patterns in E plane and H plane at 2.2 GHz.

Table 3 below shows comparison of the proposed antenna design with some reported work in terms of antenna size, frequency bands, gain, and efficiency.

7. CONCLUSION

In this work combination of microstrip patch antenna array with new defective ground structure which results in appreciable size reduction of about 65% along with dual frequency band operation as well as PIN diodes for reconfigurable design is presented. In the first stage miniaturization procedure initiated with etched new shape DGS gives size reduction with a dual frequency band operation. In the second stage reconfigurable design with PIN-diode covering the WLAN and WiMax bands has been demonstrated with analysis and measurement. The proposed antenna is able to select the separate frequency band and achieves the maximum size reduction keeping the physical volume of the antenna constant without degrading the performance much. Overall, the simulated and measured results show good agreement, and hence the proposed antenna is suitable for wireless communication application.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance and support of The Science and Engineering Research Board (SERB), Department of Science and Technology, Govt. of India for supporting this work (Grant File No. EMR/2016/007229/EEC).

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