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Dielectric loaded Small Antenna Using Defected Ground Structure

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Abstract-A novel technique for designing small size printed antenna is proposed which is suitable for portable and multifunctional communication systems. The proposed design consists of material loading using high permittivity cylindrical rods under neath the patch and Defected Ground Structure (DGS) in the ground plane. The DGS consists of L-shaped, U-shaped and I-shaped slots. The size of the antenna has been reduced by66% as compared to a conventional antenna resonating at the same frequency. The other key feature of this antenna is impedance matched multiband response within 1-8GHzband with acceptable gain up to 4.1dB.All simulation results in this paper have been achieved from the CST Microwave Studio solver. This small size antenna can be used in portable devices for WiMAX, GPS, WLAN and Bluetooth applications.

Keywords-Small Antenna, Defected Ground Structure, WLAN, Bluetooth, Microstrip Patch Antenna.

I. Introduction

Microstrip patch antenna (MPA)is widely used in the wireless communication and portable devices due to its low profile, low cost, light weight and ease of fabrication. MPA resonates when its length becomes half of operating wavelength. However, at low radio frequency range (large wavelength)the required large size of resonating MPA becomes impractical. With the advent of new communication standards and compact wireless devices, the size of MPA needs to be reduced. Many techniques have been proposed to reduce the size of the conventional half wave MPA [i-xvi]. One simple technique is to use high dielectric constant substrate to reduce guided wavelength which results in size reduction [i]. However, this technique reduces the operational bandwidth and radiation efficiency of MPA.

Shorting wall or pins have been used in different configurations to produce small size antennas [ii-iii]. However, narrow bandwidth and reduced gain has been reported for this method. Inserting slots in the radiating patch also results into compact antenna design [iv]. This technique has drawback of high cross polarization level. Similarly resistive loading or reactive loading has been reported to reduce antenna size [v]. However this method introduces loses and thus decrease radiation efficiency. Folding the patch to transform it from single layer to multi layer has been used to produce compact antenna [vi]. However, this makes antenna structure complex and non planar.

In [vii] stepped-impedance closed ring resonator (SICRR) has been used to design electrically small antenna for WLAN and WiMAX applications. However, size is reduced at the expense of narrow bandwidth. MPAs can also be miniaturized by modifying their ground plane. Many designs that use slots in ground plane have been usedto reduce size [viii]. However backside radiation is increased in this technique.

Defected ground structure (DGS) is a new technique that has been introduced to improve MPA design for size reduction, cross polarization reduction and mutual coupling in antenna arrays. DGS having E-shaped and F-shapedslots have been used to reduce the size of antennas by 48% [ix] , while in case of I-shaped DGS size reduction is only 21% [x]. In [xi] circular ring DGS isused and size reduction of 82% is obtained but the drawback of this antenna is its reduction in gain and narrow bandwidth. In [xii] combination of multiple miniaturization techniques such as DGS ,slits on the patch and shorting pin techniques are applied together and more than 80% size reduction is obtained but at the cost of reduced efficiency. In [xiii] a dumbbell shape DGS is used for miniaturization and cavity back structure for efficiency enhancement. In cavity back structure electric walls surround the patch due to which the efficiency increases up to 10% and only 27% size reduction is obtained. Fractal geometry is another promising technique to reduce antenna size. Koch fractal patch antenna has been used to reduce antenna size up to 21 % but after few iteration gain starts to decrease [xiv]. In [xv] using novel cascaded E-type unit cell defected ground structure in conjunction with the F-shaped slot was used to reduce size by 84%. In [xvi] a novel kite-shaped slot in the radiating patch was used to obtain miniaturization by 50%.Thus narrow bandwidth and low gain is the major issue in small antenna design.

In this paper a small size MPA is proposed using dielectric loading technique in combination with DGS. Cylindrical shaped dielectric bars of high permittivity are placed underneath the radiating edges of MPA. The

DGS consists of L-shaped, F-shaped and I-shaped slots in the ground plane. Due to partial material loading the proposed design is not bulky as reported in previous works. The proposed technique significantly reduces the antenna size in addition to making it multiband. To validate the design, performance of the proposed antenna was compared with a conventional antenna and it was observed that antenna size is reduced by 66% as compared to conventional antenna operating at the same resonant frequency. Also proposed antenna exhibited acceptable impedance bandwidth, and gain within the operating band.

The remaining paper is organized as follows. In section II the design methodology is explained, starting with conventional design, then modified design with high permittivity material loading and finally design of DGS. In section III simulation results will be presented and discussed. These results will also be compared with conventional antenna. Section IV gives conclusions about the proposed design, its important results and its implications for future communication devices.

II. ANTENNA DESIGN

A. *Conventional Microstrip Patch Antenna*

In the first step conventional MPA was designed as a reference for our proposed model. Fig. 1 shows the top view of this reference antenna. It was modeled on FR4 substrate having dielectric constant 4.3 and thickness 5mm. Copper with 0.035mm thickness was used to model patch and ground plane on FR4 substrate. The substrate and ground plane area was kept 58 x 52mm^2.The dimension of the patch calculated through transmission line model for the resonance frequency of 2.4GHz was 32.2x27.2 mm^2. The antenna was excited using coax probe.The conventional MPA was simulated using CST MWS. The S11 plot is shown in Fig. 2.

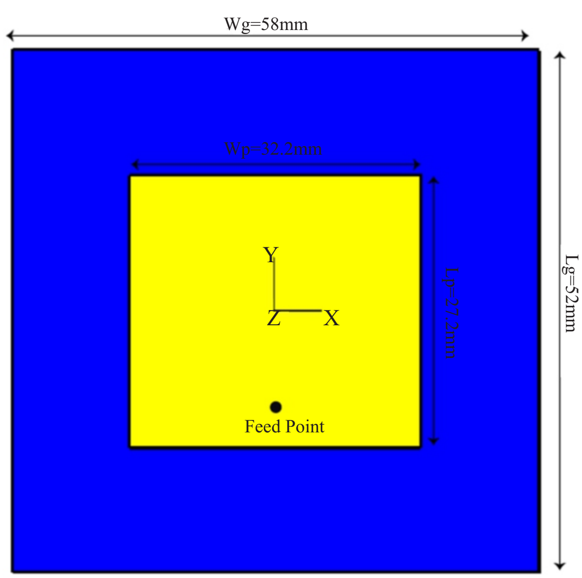


Fig. 1. Conventional MPA

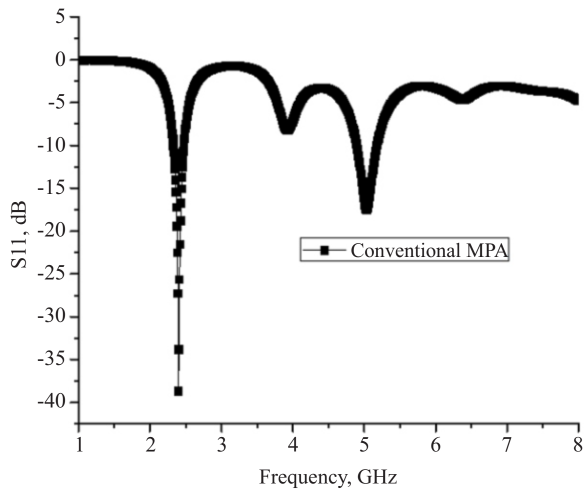


Fig. 2. S11 of conventional MPA.

B. *Modified MPA with Material Loading*

In order to reduce antenna size the conventional MPA was modified through material loading. Cylindrical shaped dielectric bars of high permittivity are placed underneath the four edges of MPA as shown in Fig. 3. The dielectric material Heraeus CT2000 having ε_r=9 and tanδ=0.003 was used.This modified antenna was simulated and S11 plot is shown in Fig. 4.

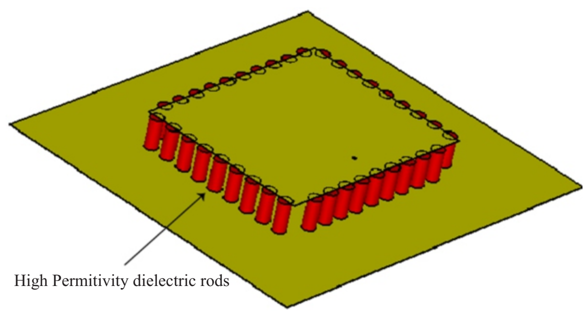


Fig. 3. MPA with material loading

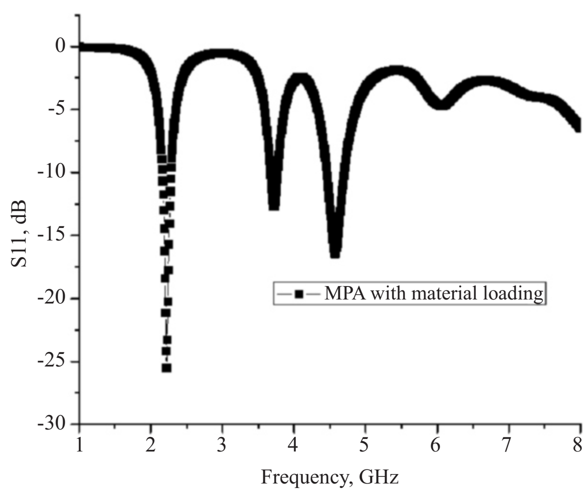


Fig. 4. S11 of Modified MPA with material loading

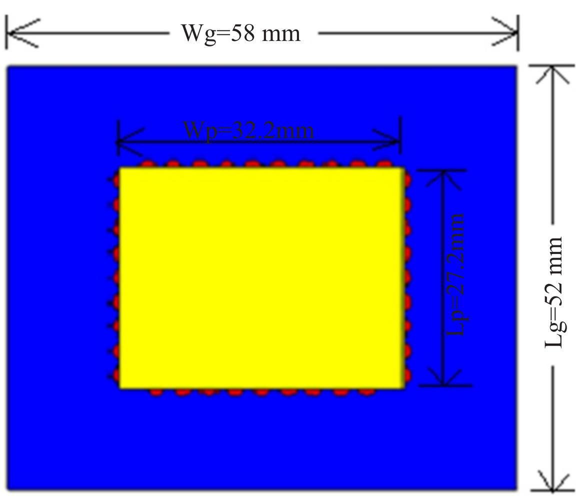
C. Modified MPA with Material Loading and DGS

In order to further reduce antenna size DGS was introduced in addition to material loading. DGS consists of L-shaped, F-shaped and I-shaped slots as shown in Fig. 5. The slots dimensions were optimized by parametric simulation in CST. The DGS was used to improve impedance matching in different bands in addition to size reduction.

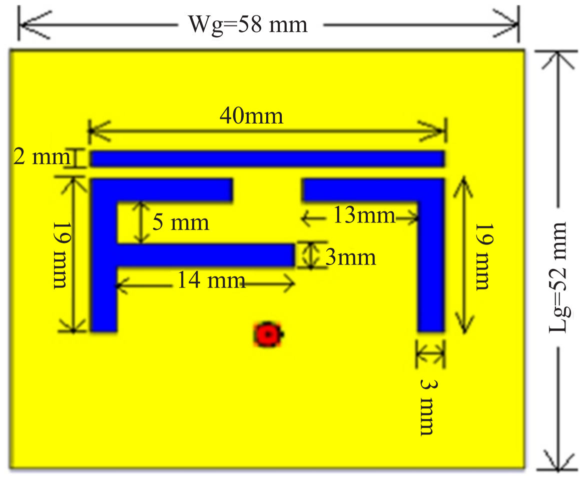
II. RESULTS AND DISCUSSION

The reference conventional MPA was simulated in CST to analyze its radiation characteristics. The S11 plot is shown in Fig. 2. It shows that the antenna is resonating at fundamental frequency 2.4GHz with a return loss of -38.7dB. The antenna has impedance bandwidth of 146.5MHz. The antenna is also resonating at higher order frequencies of 3.6GHz and 5GHz. However, impedance matching is not acceptable with S11=-7dB at 3.6GHz.

The conventional MPA with material loading was also simulated in CST to analyze its radiation performance. The S11 plot is shown in Fig.4. It shows that the resonant frequency has shifted down from 2.4GHz to 2.2GHz amounting to 23% of size reduction at the same resonant frequency. The return loss is -25dB at 2.2GHz,-13dB at 3.7GHz and -17dB at 4.6GHz. The impedance bandwidth for S11< -10dB is 120MHz at 2.2GHz, 102MHz at 3.7GHz and 241MHz at 4.6GHz.



(a)



(b)

Fig. 5. MPA with material loading and DGS (a) front view (b) back view

The effect of material loading using high permittivity cylindrical rods is to increase the effective permittivity of the substrate. This decreases the resonant length which results in size reduction of antenna. One of the important feature of this modified antenna is multiband response with satisfactory impedance bandwidth and gain as shown in Table I. The modified MPA has

TABLE I
RESULTS OF MODIFIED MPA WITH MATERIAL LOADING

fr (Ghz)	f1=2.2	f2=3.7	f3=4.6
Return loss(dB)	-25.5	-12.7	-16.4
BW(MHZ)	120	102	241
Gain(dB)	5.57	5.1	1.3
VSWR	1.11	1.6	1.3

Finally the proposed antenna consisting of material loading and DGS was designed and simulated in CST. The S11 plot is shown in Fig. 6. The result shows that the resonance frequency has further shifted down from 2.2GHz to 1.5GHz amounting to size reduction of 66%.

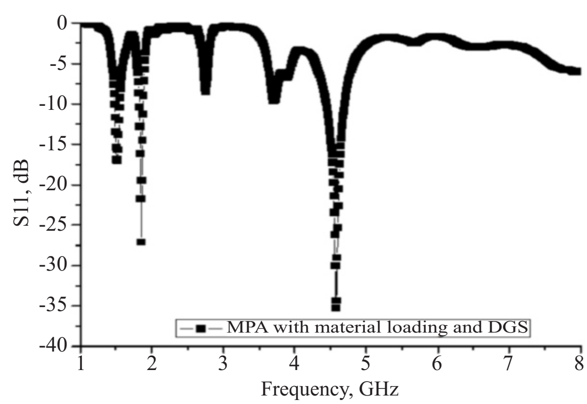


Fig. 6. S11 of MPA with material loading and DGS

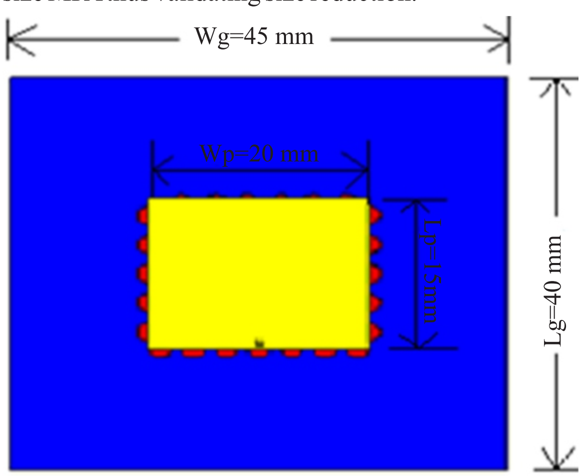
DGS disturbs the current distribution on the ground plane as well as patch due to which antennasize is further reduced. DGS was optimized in CST to improve the impedance matching in the multi bands. The antenna has S11< -10dB impedance bandwidth of 65.5MHz at 1.5GHz, 59MHz at 1.8GHz and 251MHz at 4.6GHz. Table II summarizes the radiation properties of proposed antenna.

TABLE II
RESULTS OF MODIFIED MPA WITH MATERIAL LOADING AND DGS

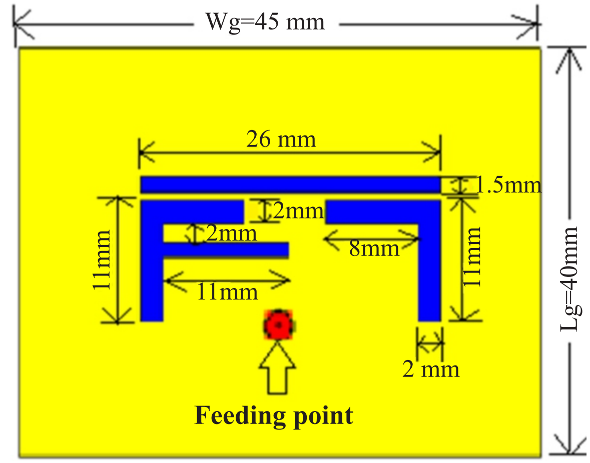
fr (Ghz)	f1=1.5	f2=1.8	f3=4.6
S11 (dB)	-17.0	-25.6	-36.9
BW(MHZ)	65.5	59	251
Gain(dB)	3.5	1.6	4.49
VSWR	1.3	1.11	1.02

In order to validate size reduction obtained using the proposed technique another MPA was designed to resonate back at 2.4GHz as shown in Fig.7. The size of antenna was found to be 20x15 mm^2. The S11 plot for this antenna is shown in Fig.8. It shows that the small size MPA which is 66% smaller than conventional antenna is resonating at the same fundamental frequency of 2.4GHz as conventional antenna. Another characteristic feature of proposed design is its matched multiband response. The multiband resonating frequencies are 2.4GHz, 3.33GHz, 4.28GHz, 6GHz, and 7.58GHz. The impedance bandwidth for S11< -10dB is 160MHz at 2.4GHz, 100MHz at 3.3GHz,120MHz at 4.3GHz, 320MHz at 6GHz and 430MHz at 7.6GHz.The radiation performance of this antenna is summarized in Table III.

Fig. 9 shows the S11 comparison of conventional MPA with large size and the proposed small size MPA with material loading and DGS. It is clear from S11 plot that the proposed MPA is operating on the same fundamental resonant frequency of 2.4GHz as the large size MPA thus validating size reduction.



(a)



(b)

Fig. 7. Small size MPA resonating at 2.4GHz (a) front view (b) back view

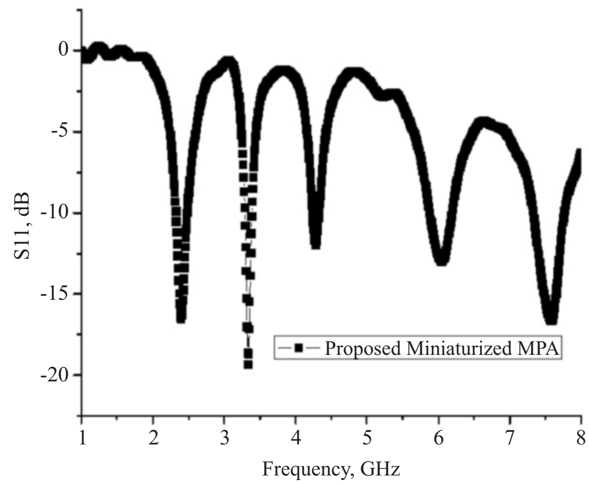


Fig. 8. S11 of proposed MPA resonating at fundamental resonant frequency of 2.4GHz

TABLE III
RESULTS OF SMALL SIZE PROPOSED ANTENNA

fr (Ghz)	f1=2.4	f2=3.3	f3=4.3	f4=6	f5=7.6
S11 (dB)	-16.5	-19.3	-12	-13	-16.6
BW(MHZ)	160	100	120	320	430
Gain(dB)	4.1	4	3.5	4.7	4
VSWR	1.3	1.2	1.5	1.5	1.3

Thus, Conventional MPA resonating at fundamental frequency of 2.4GHz would have a foot print of 32.2×27.2=875.84mm^2, while our proposed MAP design has a footprint of 20×15 =300mm^2, which means size reduction of 66%.

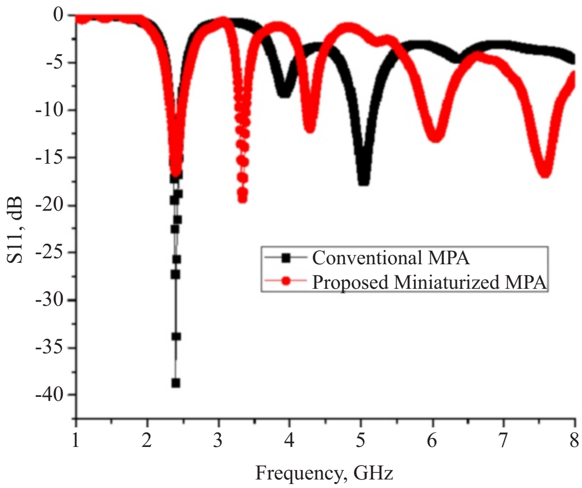


Fig. 9. S11 comparison of proposed small size MPA with conventional MPA.

The final dimensions of DGS slots have been obtained after extensive parametric study on different dimensions. Figure 10 shows one particular parametric analysis executed by varying the length of I-shaped slot.

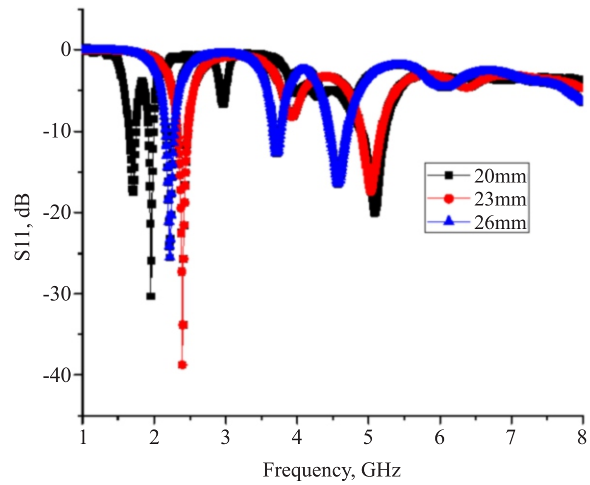


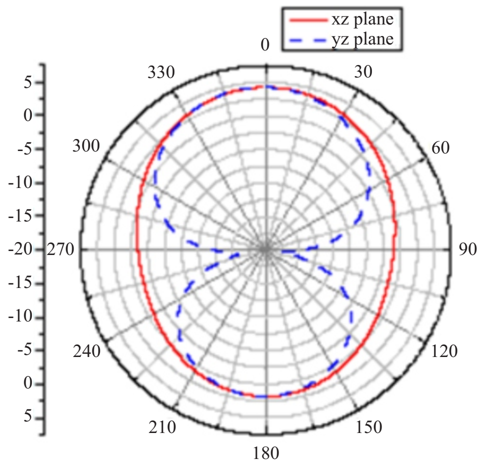
Fig. 10. S11 for different lengths of I-shaped slot

Table IV compare the proposed antenna characteristics with the state of the art in the literature. As can be seen our proposed antenna is better not only in terms of reducing size but also showing multiband response with acceptable radiation performance within all operating bands.

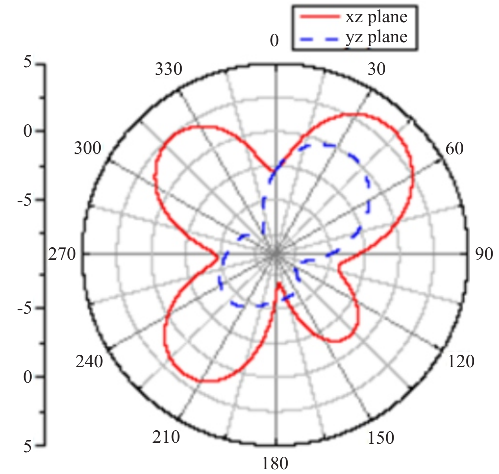
The proposed antenna was also simulated for its radiation pattern behavior. Fig.10 shows the radiation pattern in the XZ and YZ planes at different resonating frequencies. The proposed antenna has peak gain of 4.1dB at 2.4GHz, 4.0dB at 3.3GHz, 3.5dB at 4.3GHz, 4.7dB at 6GHz and 4dB at 7.6GHz. The XZ plane patterns is almost symmetrical while YZ planes pattern show asymmetrical behavior. The direction of maximum radiation varies slightly at different resonating frequencies.

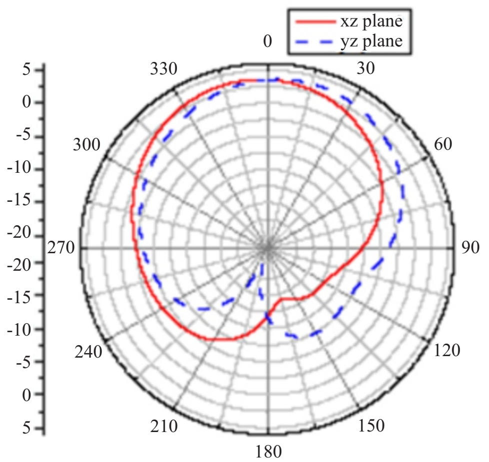
TABLE IV
COMPARISON OF PROPOSED MODEL TO EXISTING STATE OF THE ART MINIATURIZATION TECHNIQUES

Reference	Technique	Bands	Size (mm^3)	BW (Ghz)	Size reduction	Substrate
[i]	high permittivity	Single band	180×175×47	0.86 - 0.952	50%	Air
[iii]	Shorting pin	Dual band	78×78×60	0.422 -0 .550	75%	Foam
[iv]	Slots on patch	Dual band	37.7×28.4×1.6	1.640 - 1684 2.10 - 2.18	23%	FR4
[vi]	Folded patch	Single band	305×305×7	3.57- 6.18	50%	Air
[viii]	Slots in ground	Single band	38×38×1.6	2.982 -3.125	83%	FR4
[x]	I-shaped DGS	Single band	36×36×0.7	2.415-2.484	21%	Rogers RO3003
[xi]	Circular ring DGS	Single band	36×36×0.7	2.415-2.484	82%	Rogers RO3003
[xiv]	Fractal geometry	Single band	48×48×1	2.415-2.484	21%	FR4
This work	High permittivity rods DGs	Multi band	20×15×5	2.3 - 2.5 3.3 - 3.4 4.25 - 4.35 5.87 – 6.19 7.32 – 7.76	66%	FR4



(a)





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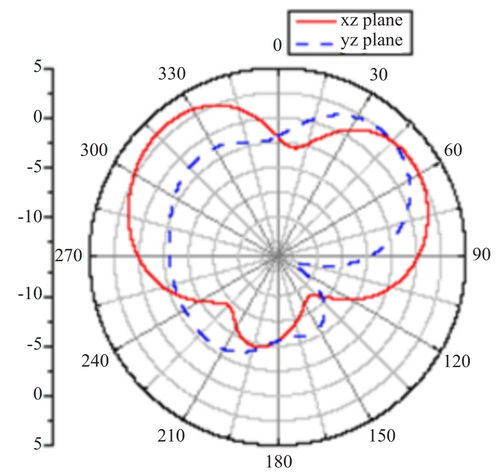
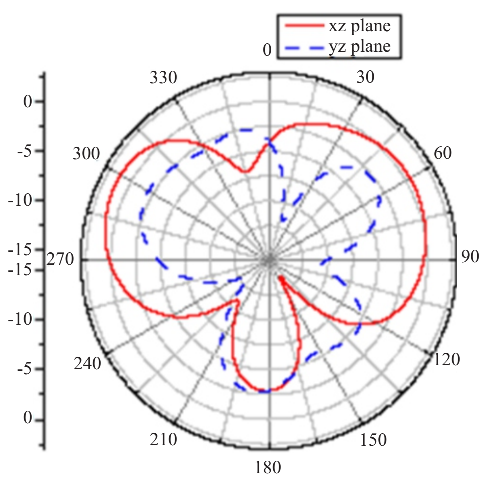


(d)



(e)

Fig.11. Radiation pattern of proposed small size MPA in XZ and YZ planes at (a) 2.4GHz (b) 3.33GHz (c) 4.30 GHz (d) 6.0 GHz (e) 7.6 GHz

IV. CONCLUSION

A small size MPA has been proposed using novel material loading and DGS technique. For material loading cylindrical shaped dielectric material with high permittivity is used underneath the patch. DGS consists of L-shaped, F-shaped and I-shaped slots optimized to reduce antenna size and impedance matching. The proposed antenna size is reduced by 66% as compared to conventional MPA operating at the same frequency. The proposed technique also make this miniaturized antenna multiband within 1 to 8GHz band. The proposed antenna has peak gain of 4.1dB at 2.4GHz, 4.0dB at 3.3GHz, 3.5dB at 4.3GHz, 4.7dB at 6GHz and 4dB at 7.6GHz.The proposed antenna is simple in structure, compact in size and exhibits good impedance matching, acceptable gain and stable radiation pattern across the operating bands. The radiation performance of this antenna makes it suitable for WLAN, Bluetooth, GPS and WiMAX applications.

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