Application of Defected Ground Structure for Stable Gain with Ultrawide Bandwidth

Pawar Umesh Ankush, Abhijyoti Ghosh, L. Lolit Kumar Singh and Sudipta Chattopadhyay

Abstract A rectangular microstrip patch antenna integrated with ring-shaped defected ground structure has been studied for the improvement of impedance bandwidth. The use of defected ground structure (DGS) for the improvement of impedance bandwidth is a very new concept. Parametric studies have been carried out to find the optimum size of the defect. Around 46.5% impedance bandwidth (−10 dB) with 5.7 dBi peak gain is achieved with the optimum defect size. The proposed structure is very simple and easy to fabricate. The proposed structure is very much useful for the high-speed communication systems where wide impedance bandwidth along with stable radiation pattern is the primary requirement.

Keywords Microstrip patch antenna · Defected ground structure · Bandwidth · Gain · Voltage standing wave ratio

1 Introduction

In modern wireless communication systems microstrip patch antenna is the most common and popular candidate due to its simple design, low profile, thin and conformal properties. But high-speed wireless communication demands wide bandwidth with stable radiation pattern where conventional microstrip patch antenna lags as it provides narrow bandwidth (typically 2–3%) and low gain (1–3 dB) [1,

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2]. Different techniques have been adopted by the antenna researcher community to improve the bandwidth of the conventional patch antenna like use of composite substrate, feed structure modification, aperture coupled dual polarization, etc. The impedance bandwidth (−10 dB) reported in [3] is only 7% with the use of composite substrates. 24% impedance bandwidth (−10 dB) is reported with aperture coupled dual polarization structure in [4, 5]. The above structures are very complex and the fabrication process needs much efforts. Modification of the feed structures [6–10] and the shape of the patch [11–16] are also reported to improve impedance bandwidth of the conventional patch antenna. 21.5% and 20% impedance bandwidth (−10 dB) is reported by using a very complex structure with L-probe fed inverted EE-H shape slotted rectangular patch antenna [6] and suspended probe feeding [7]. Stacked patch [8] and two-layer shorted square patch [9] structure is used to obtain impedance bandwidth (−10 dB) around 16% and 11% respectively. Impedance bandwidth of 10% by the dual polarized stacked patch is reported in [10]. However, all the above structure are complex and bulky. Impedance bandwidth (−10 dB) of 30%, 27%, and 54% is reported by E shape [11], U shape [12], and ψ shape [13] patch respectively. Shorted patch has been reported in [14, 15] to attain a impedance bandwidth (−10 dB) of 22%, 11% respectively whereas 25% impedance bandwidth (−10 dB) is reported with shorted patch with defected patch surface [16].

Defected ground structure based on electronic band gap (EBG) or photonic band gap (PBG) is well-known techniques and is used to improve different radiation characteristics of the microstrip patch antenna. Z-shaped DGS is reported in [17], to achieve impedance bandwidth (−10 dB) of 12.2%. Around 6–7% impedance bandwidth (−10 dB) is reported with Dumbelled [18] and slot type [19] DGS. Compare to these, [20, 21] show 25 and 22% impedance bandwidth (−10 dB) using cross and arc-shaped DGS. However, the design of optimum cross and arc defect need much more efforts. All the above-reported article improves the impedance bandwidth by increasing the size of the defect which increases the back radiation as a results antenna performance degrades.

In the present investigation, a simple single-layer ring-shaped defected ground structure (RDGS) integrated (Fig. 1) has been studied to improve the impedance bandwidth at entire X band frequency with stable radiation pattern and gain in the entire operating bandwidth. The proposed structure improves the impedance bandwidth by decreasing the size of the defect which in turn reduces the back radiation. Around 46% impedance bandwidth with stable gain above 4 dB is obtained from the proposed structure.

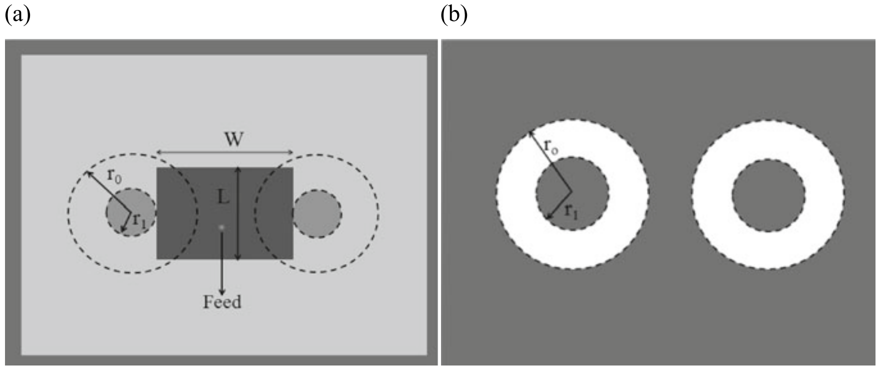

Fig. 1 Schematic representation of the proposed ring defected ground structure integrated rectangular microstrip patch antenna **a** top view, **b** bottom view

2 Theory, Parametric Studies and Proposed Structure

2.1 Theory, Parametric Studies

In conventional microstrip patch antenna patch (conductor) and ground plane (conductor) are placed in the either side of the dielectric substrate where electric walls (PEC) are formed by top (patch) and bottom (ground plane) conductors while four open boundaries are considered as the magnetic walls (PMC). Placing a defect in the ground plane modifies the electric fields between patch and the ground plane which finally alters the input and radiation characteristics of patch antenna. Now when the defect is introduced in the ground plane losses in the cavity model of the antenna increases which in turn increases the bandwidth of the antenna. Optimum performance of the patch in terms of impedance bandwidth depends on the geometry of the defect so the defect needs to be chosen very carefully.

Therefore, to increase the bandwidth of the patch antenna a pair of ring-shaped defect is placed on the ground plane near the non-radiating edges of the patch. The outer radius of the ring is kept fixed at 6 mm (i.e., $r_o = 6$ mm) while the inner radius (r_i) of the ring is varying to change the overall defect structure.

The impedance bandwidth, quality factor, and loss of an antenna are related as

$$\text{Bandwidth (BW)} = 1/Q_T \tag{i}$$

$$1/Q_T = 1/Q_r + 1/Q_d + 1/Q_c \tag{ii}$$

$$Q_T \cong 1/\text{Loss} \tag{iii}$$

where, Q_T, Q_r, Q_d, Q_c are total quality factor, quality factor due to radiation, quality factor due to dielectric and quality factor due to conductor respectively.

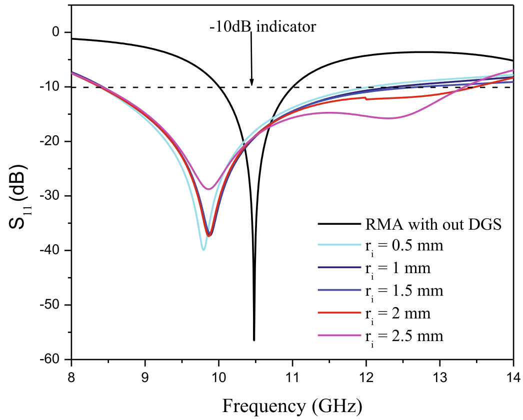

Fig. 2 Reflection coefficient profile for conventional and proposed antenna for different values of inner radius (r_i) keeping outer radius fixed ($r_o = 6$ mm)

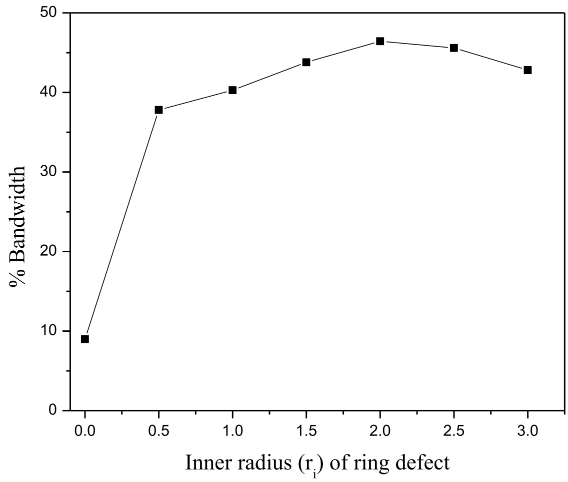

Fig. 3 Variation of impedance bandwidth (−10 dB) as a function of radius of the inner circle (r_i) keeping outer radius of the ring fixed ($r_o = 6$ mm)

Introduction of the ring defect ($r_o = 6$ mm and $r_i = 0.5$ mm) suddenly increases the loss due to the radiation from the corner of the radiating edges of the patch which results sudden improvement of impedance bandwidth characteristics of the proposed antenna compare to the conventional patch antenna. The impedance bandwidth of the conventional patch antenna is only 9% whereas the same with ring defect ($r_o =$ 6 mm and $r_i = 0.5$ mm) becomes almost 38% which is clear from Figs. 2 and 3. Introduction of the defect increases the effective permittivity of the antenna due to which resonant frequency of the proposed antenna shifts towards the lower side of the spectrum [22, 23].

The concentration of the magnetic field near the non-radiating edges of the patch is more. As the value of inner radius (r_i) of the ring increases the amount of conduction region due to the presence of the copper increases. The increment of the conduction region increases the losses due to the conduction which in turn decreases the value

Table 1 Details parameters of the proposed ring DGS integrated rectangular microstrip patch antenna on 70 mm × 70 mm ground plane

L (mm)	W (mm)	h (mm)	r_o (mm)	r_i (mm)	ε_r
8	12	1.575	6	2	2.33

of Q_c and finally the value of Q. As the substrate (dielectric) is kept unmodified so the loss due to dielectric remains same in both the cases. With $r_i = 2$ mm the inner radius of the ring reaches just below the non-radiating edge of the patch where most of the magnetic fields from that area terminates in the copper ground plane and results maximum conduction loss. The maximum conduction loss will produce minimum quality factor which results maximum impedance bandwidth (47%). The further increment of the inner radius decreases the bandwidth which is evident from Fig. 3. So the optimum size of the ring defect is $r_o = 6$ mm and $r_i = 2$ mm.

2.2 *Proposed Structure*

Initially, a rectangular patch antenna with ground plane 70 mm × 70 mm, patch size 8 mm × 12 mm with PTFE material as substrate (thinness (h) = 1.575) has been considered. A ring-type defected with inner circle radius "r_i" and outer circle radius "r_0" has been placed at the ground plane just below the non-radiating edges of the patch (Fig. 1). The different parameters of the proposed structure are presented in Table 1.

3 Results and Discussions

The results [24] obtained from the proposed ring DGS integrated rectangular microstrip patch antenna is discussed in this section. The reflection coefficient profile of conventional RMA and proposed RDGS-integrated RMA with optimum values of r_o and r_i is presented in Fig. 4. The conventional RMA resonates at 10.48 GHz and the proposed antenna resonates at 9.86 GHz. The improvement of the impedance bandwidth is clearly visible from Fig. 4. The impedance bandwidth (−10 dB) almost covers the full X band (8–12 GHz) of frequency.

Therefore,

$$\frac{2(f_H - f_L)}{(f_H + f_L)} = 0.5 > 0.2 \tag{iv}$$

and [25], the present proposed structure can be considered as Ultrawide Band (UWB) patch antenna.

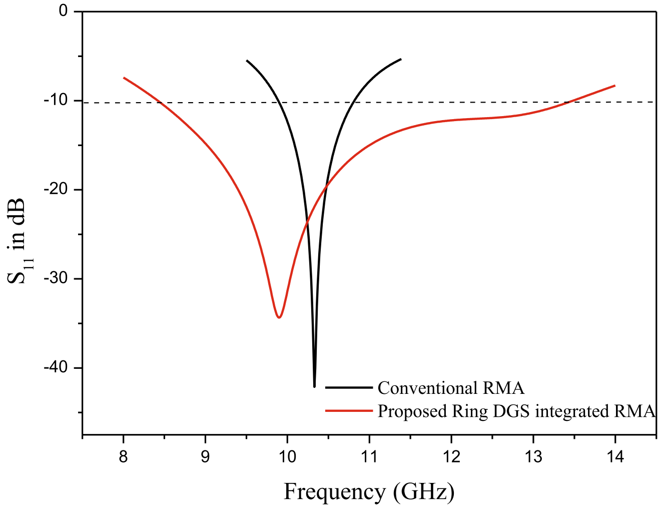

Fig. 4 Comparison of reflection coefficient profile of the convention RMA and proposed ring DGS integrated RMA

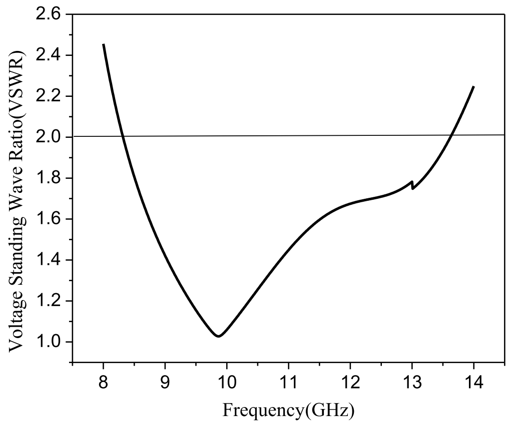

Fig. 5 VSWR profile for proposed antenna for $r_i = 2$ mm and $r_o = 6$ mm

The VSWR profile of the proposed antenna is shown in Fig. 5. The VSWR is reported to be below 2 which further confirm the wide bandwidth of the proposed antenna.

The gain of the proposed structure is 5.7 dBi which is quite good compared to the gain of the conventional patch antenna (2–3 dBi). Figure 6 shows the variation of the gain of the proposed structure over its whole impedance bandwidth. Gain maintains almost stable pattern within the operating bandwidth of the proposed structure except at the higher end of the spectrum. This may be due to more loss at higher frequency side.

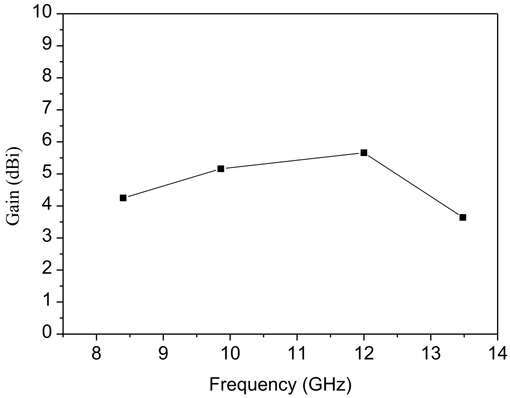

Fig. 6 Variation of gain as a function of frequency for the proposed structure with $r_i = 2$ mm and $r_o = 6$ mm

Figure 7 shows the complete radiation characteristics of the proposed RDGS in the entire operating band. It is clear from the figure that the E-plane and H-plane co polarization pattern is quite stable in the whole operating spectrum from 8.38 to 13.49 GHz.

4 Conclusion

A simple single element ring DGS integrated rectangular microstrip patch antenna is propose to achieve wide bandwidth with a stable gain in entire operating bandwidth. Wide bandwidth is always desirable from microstrip planer structure. Wide bandwidth through defected ground structure is a very new concept. Around 47% impedance bandwidth (−10 dB) is obtained from the proposed structure. In the proposed structure the bandwidth is increased by decreasing the size of the defect. The proposed structure covers the whole X band frequency. The proposed structure is simple and can be utilized for the applications where wide bandwidth is the primary requirement.

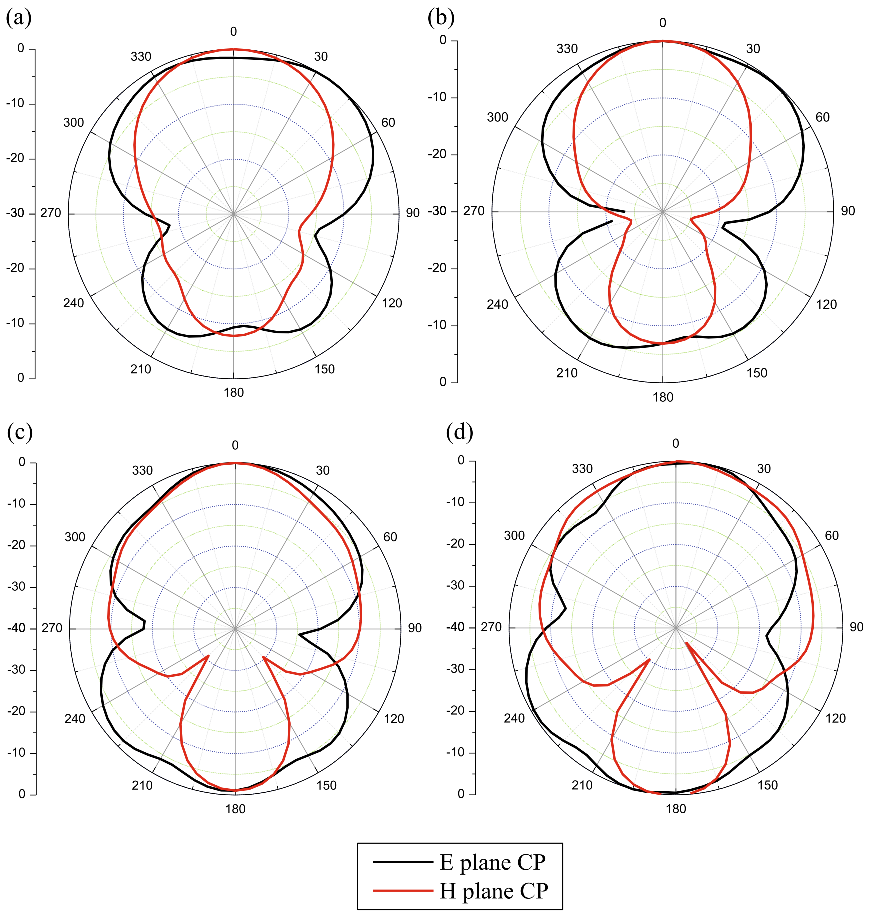

Fig. 7 Radiation pattern for E-plane and H-plane with proposed RDGS-integrated RMA at different frequencies **a** 8.38 GHz, **b** 9.86 GHz, **c** 12.75 GHz, **d** 13.49 GHz

References

1. Garg R, Bhartia P, Bahl I, Ittipiboon A (2001) Microstrip antenna design handbook. Artech House, Norwood
2. Guha D, Antar YMM (eds) (2011) Microstrip and printed antennas—new trends. Techniques and Applications. John Wiley, U.K
3. Chattopadhyay S, Siddiqui JY, Guha D (2009) Rectangular microstrip patch on a composite dielectric substrate for highgain wide-beam radiation patterns. IEEE Trans Antennas Propag 57:3324–3327
4. Gao S, Li LW, Leong MS, Yeo TS (2003) A broad-band dual-polarized microstrip patch antenna with aperture coupling. IEEE Trans Antenna Propag 51:898–900
5. Lai CH, Han TY, Chen TR (2008) Broadband aperture coupled microstrip antennas with low cross polarization and back radiation. Prog Electromag Res Lett 5:187–197

6. Islam MT, Shakib MN, Misran N (2009) Design analysis of high gain wideband L-probe fed microstrip patch antenna. Prog Electromag Res 95:397–407
7. Chen ZN, Chia MYW (2003) Broad-band suspended probe-fed plate antenna with low cross-polarization level. IEEE Trans Antennas Propag 51:345–346
8. Loffler D, Wiesbeck W (1999) Low-cost X-polarised broadband PCS antenna with low cross-polarisation. Electron Lett 35:1689–1691
9. Baligar JS, Revankar UK, Acharya KV (2001) Broadband two-layer shorted patch antenna with low cross-polarisation. Electron Lett 37:547–548
10. Granholm J, Woelders K (2001) Dual polarization stacked microstrip patch antenna array with very low cross-polarization. IEEE Trans Antennas Propag 49:1393–1402
11. Yang F, Zhang X, Ye X, Samii, YR (2001) Wide-band E-shaped patch antennas for wireless communications. IEEE Trans Antenna Propag 49:1094–1100
12. Tong KF, Luk KM, Lee KF, Lee RQ (2000) A broad-band U-slot rectangular patch antenna on a microwave substrate. IEEE Trans Antennas Propag 48:1148–1152
13. Sharma SK, Shafai L (2009) Performance of a novel Ψ-shape microstrip patch antenna with wide bandwidth. IEEE Antenna Wirel Prop Lett 8:468–471
14. Ghosh A, Chakraborty S, Ghosh SK, Singh LLK, Chattopadhyay S, Basu B (2017) Slot loaded microstrip antenna: a possible solution for wide banding and attaining low cross polarization. In: International conference on intelligent computing communication & devices, advances in intelligent computing & system, Springer
15. Poddar R, Chakraborty S, Chattopadhyay S (2016) Improved cross polarization and broad impedance bandwidth from simple single element shorted rectangular microstrip patch: theory and experiment. Frequenz 70:1–9
16. Ghosh A, Chattopadhyay S, Singh LLK, Basu B (2017) Wide bandwidth microstrip antenna with defected patch surface for low cross polarization applications. Int J RF Microw Comput Aided Eng 27:1–10
17. Kandwal A, Sharma R, Khah Sunil K (2013) Bandwidth enhancement using Z-shaped defected ground structure for a microstrip antenna. Microw Opt Technol Lett 55:2251–2254
18. Ghosh A, Chakraborty S, Chattopadhyay S, Nandi A, Basu B (2016) Rectangular microstrip antenna with dumbbell shaped defected ground structure for improved cross polarised radiation in wideelevation angle and its theoretical analysis. IET Microw Antennas Propag 10:68–78
19. Ghosh A, Ghosh D, Chattopadhyay S, Singh LLK (2015) Rectangular Microstrip antenna on slot type defected ground for reduced cross polarized radiation. IEEE Antennas Wirel Propag Lett 14:324–328
20. Ghosh A, Chattopadhyay S, Chakraborty S, Basu B (2017) Cross type defected ground structure integrated microstrip antenna: a novel perspective for broad banding and augmenting polarization purity. J Electromag Waves Appl 31:461–476
21. Chakraborty S, Chattopadhyay S (2017) Arc cornered microstrip antenna with defected ground structure for broadbanding and improved cross polarization suppression over whole skew planes. Int J Microw Wirel Technol 9:437–446
22. Oraizi H et al (2008) Miniaturization of Wilkinson power dividers by using DGS. Prog Electromagn Res Lett 4:113–120
23. Boutezdar et al (2011) An improvement of DGS lowpass/bandpass filters using H slot resonators and coupling matrix method. J Microw Opt Electromagn Appl 10:295–307
24. HFSS, High frequency structure simulator, Ver. 14, Ansoft Corp. USA
25. Wiesbeck W, Adamiuk G, Sturm C (2009) Basic properties and design principles of UWB antennas. Proc IEEE 97:372–385