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Wideband Probe-Fed Rectangular Patch with Defected Ground Structure for Cross Polarization Suppression

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Abstract—In this paper, a new method of improving cross-polarization (XP) performance on a wideband microstrip antenna is proposed, by adopting a defected ground structure (DGS). This F-slot shaped defected ground structure (F-DGS) exhibits considerable improvement in terms of XP properties, broad boresight angular suppression, and impedance bandwidth ($S_{11} < -10\,\text{dB}$). Lower than $-26\,\text{dB}$ XP level is achieved over 206° angular range, while the impedance bandwidth is broadened to 15.5%. Both wideband rectangular patches with and without F-DGS have been fabricated and experimented.

1. INTRODUCTION

Applications of defected ground structure (DGS) in enhancing the performance of microstrip patches have been established for decades. Single or multiple defects are usually created on the ground plane (GP) to provide slow wave effect in the frequency below band-gap and fast-wave effect above band-gap frequency [1]. In [2], a pair of dot-shaped DGSs was applied to circular patch reducing cross-polarized (XP) radiations for the first time. Subsequently, several DGS geometries have been explored for circular patches [3–5]. Then, DGS was even found suitable for different patch shapes such as ellipse, rectangle, square, and triangle [6–13]. It is apparent in [10] that when a linearly shaped full wavelength DGS was introduced, rectangular patch realized a suppression of XP fields well below $-30\,\text{dB}$, better than folded rectangular DGS.

Microstrip patch antennas are very widely used in communication systems nowadays. Due to the characteristic of narrow impedance bandwidth, most designs before were focused on XP characteristics at resonant frequency. With the developing requirements of wideband antennas, the XP radiation in whole broad operating band is a major concern. A circular DGS was presented in [14] to reduce XP for wideband rectangular patch. But it is important to note that the patch was fed by microstrip line, possessing the nature of lower XP values than coaxial probe.

Considering the probe-fed rectangular patch, most earlier designs were symmetric about E- and H-planes. However, some recent investigations presented a different point of view, indicating that high XP levels over H-plane was due to the asymmetry of the composite fields. For this reason, a new way of changing the DGS geometries in tune with the asymmetric modal fields was provided [8, 10]. Different asymmetrically shaped DGSs were discussed in [15]. Among four proposed designs, the folded-out L-slot shaped DGS had optimum effect with folded end located near the probe. More than 28 dB isolation between co-pol and cross-pol was obtained over 190° angular range. Nevertheless, this configuration is not appropriate for wideband operating.

To alleviate above limitation, we have explored a DGS applied to a wideband probe-fed rectangular patch for the first time, called F-slot shaped defected ground structure (F-DGS). It is demonstrated that the impedance bandwidth of a patch with F-DGS is improved to 15.5%. Furthermore, F-DGS

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shape is asymmetric to achieve best suppression, and the antenna obtains lower than −26 dB XP level over 206° angular range throughout the whole operating band.

The paper is organized as follows. Section 2 describes working principles and geometry design. Section 3 discusses the comparison of measured results with simulated ones. Finally, conclusions are drawn in Section 4.

2. WORKING PRINCIPLES AND GEOMETRY DESIGN

The study is done near 11 GHz, and an RT5880 substrate with $\varepsilon_r = 2.2$ and $h = 1.575$ mm is used. Fig. 1 shows the configuration of a wideband probe-fed rectangular patch with F-DGS, which contains a pair of F-slot shape defects. Each defect consists of a rectangular defect paralleled with E-plane and two different short lines. The bigger short line is closer to the probe while the smaller one is farther and composes the folded section. Optimized parameters are furnished in Table 1.

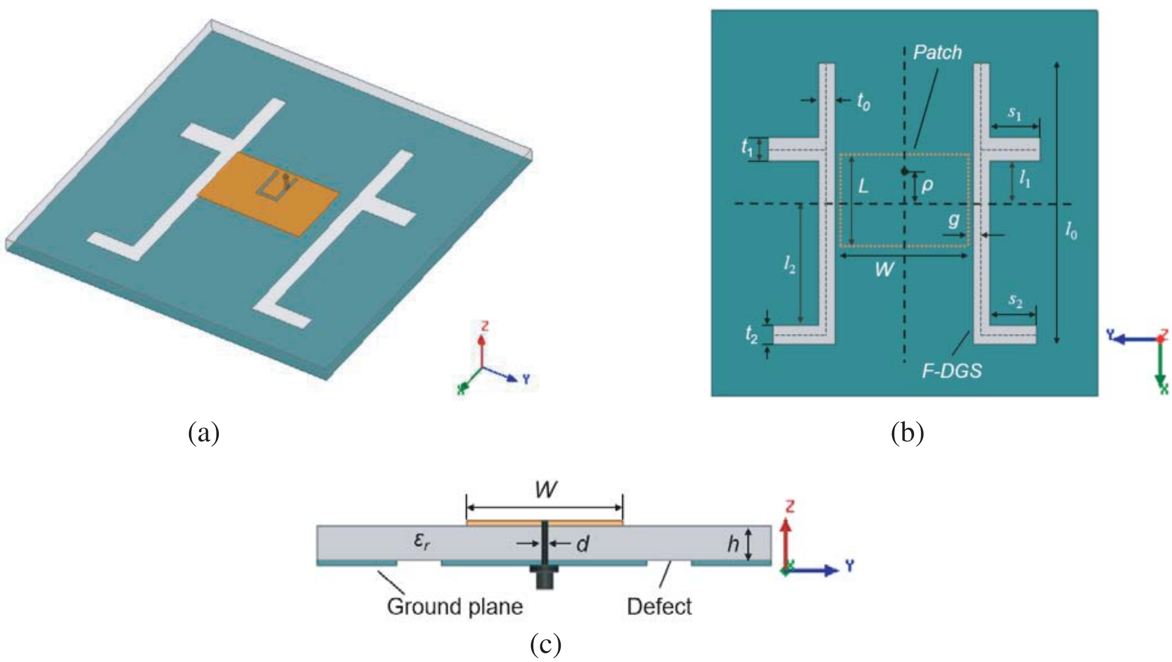


Figure 1. Probe-fed wideband rectangular patch with F-DGS, (a) 3-D model of the configuration, (b) view from ground plane side, (c) cross-sectional view.

Table 1. Optimized parameters of the probe-fed wideband rectangular patch with F-DGS.

Parameters	L	W	ρ	g	l_0	l_1
Value (mm)	8.6	13.76	3.48	−0.4	30.6	4.7
Parameters	l_2	t_0	t_1	t_2	s_1	s_2
Value (mm)	13.8	1.5	2.5	1.5	5.5	5

As illustrated in Fig. 2, the radiation from a rectangular patch is equivalent to that from two parallel slots adjacent to the patch [16]. According to this, the perimeter fields of the probe-fed rectangular patch are depicted in Fig. 3. It can be seen from Fig. 3(a) that the vertical arrows indicate the co-polarized fringing field of the dominant mode (TM_{10}), generated by the slot between radiating edges and the ground plane. The horizontal arrows in the first higher mode (TM_{02}) indicate the cross-polarized fringing field, generated by the slot between non-radiating edges and the ground plane, as

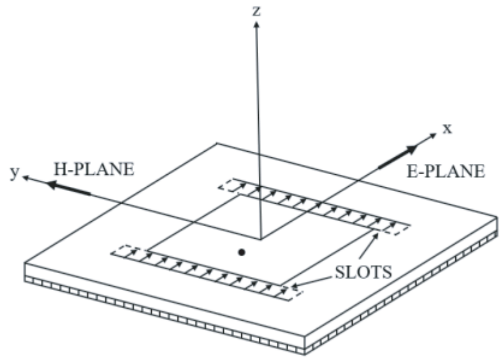


Figure 2. Slot model configuration of a microstrip patch.

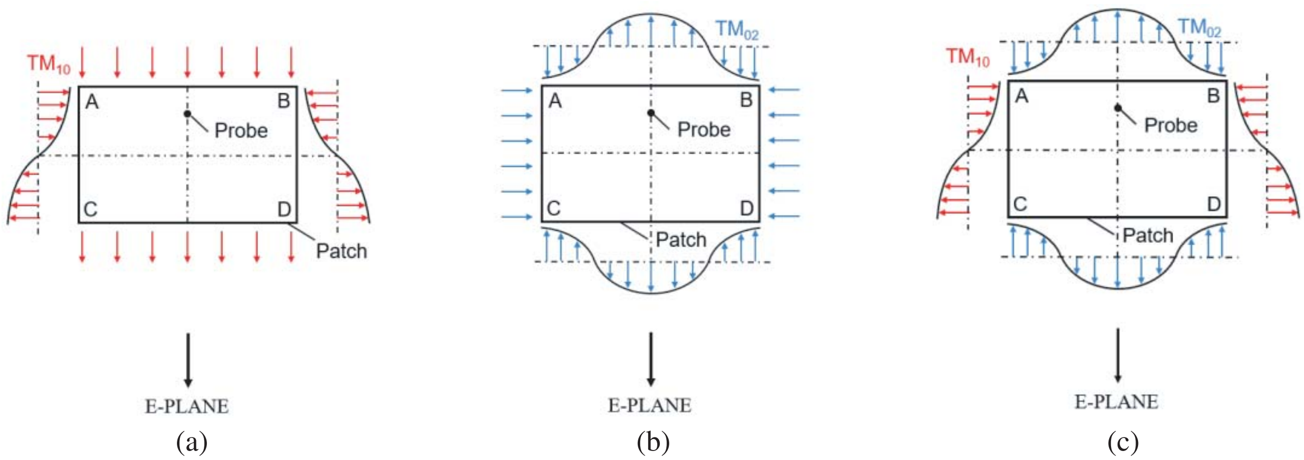


Figure 3. Perimeter fields of a rectangular patch, (a) TM_{10} mode, (b) TM_{02} mode, (c) resultant composite fields. The heavy dot indicates the feed probe location.

portrayed in Fig. 3(b) [17]. The arrows are more densely distributed around the patch corners due to the concentration of electric fields there. In this case, addressing the fringing field between non-radiating edges and ground plane is a practical idea to suppress XP radiations. By creating defects adjacent to the non-radiating edges on the ground plane, DGS is supposed to influence the radiating slots of TM_{02} mode, resulting in lower XP values.

The composite fields under a probe-fed rectangular patch can be seen from Fig. 3(c). TM_{10} and TM_{02} modes combine in phase near corners A and B, thus the composite fields get stronger there. At the same time, the fields get weaker at other two corners C and D because TM_{10} and TM_{02} modes combine in the opposite phase. In addition, the electric field of TM_{02} mode is also concentrated at A and B due to the offset of probe feed. All the factors above result in the asymmetry of composite fields beneath a rectangular patch. Moreover, a U-slot patch is used to broaden the bandwidth of the proposed configuration, causing radiating fields further complicated [18]. Therefore, asymmetric geometry of a DGS has been conceived in this paper.

The structure of F-DGS is discussed here. Referring to the parameters depicted in Fig. 1(b), the length of the rectangular defect l_0 is set at 30 mm, close to free space wavelength λ_0 [12]. The width t_1 is kept at 1.5 mm [5], and g is optimized to realize optimum reduction in XP fields. To expand the impedance bandwidth, two pairs of short lines are incorporated to introduce extra resonant frequencies. These two pairs of short lines are different in size. The bigger pair is closer to the probe due to a stronger influence of TM_{02} mode there. And the smaller one is at the other side and farther. Though the smaller pair seems to hardly affect the fringing field along non-radiating edges, it is conducive to better XP suppression at high frequencies and wider bandwidth in fact. In addition, short lines are

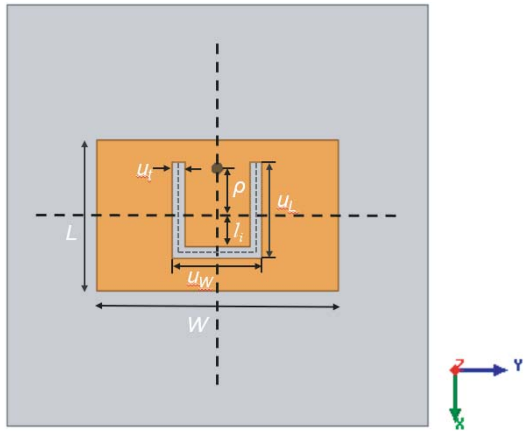


Figure 4. Probe-fed wideband rectangular patch without F-DGS.

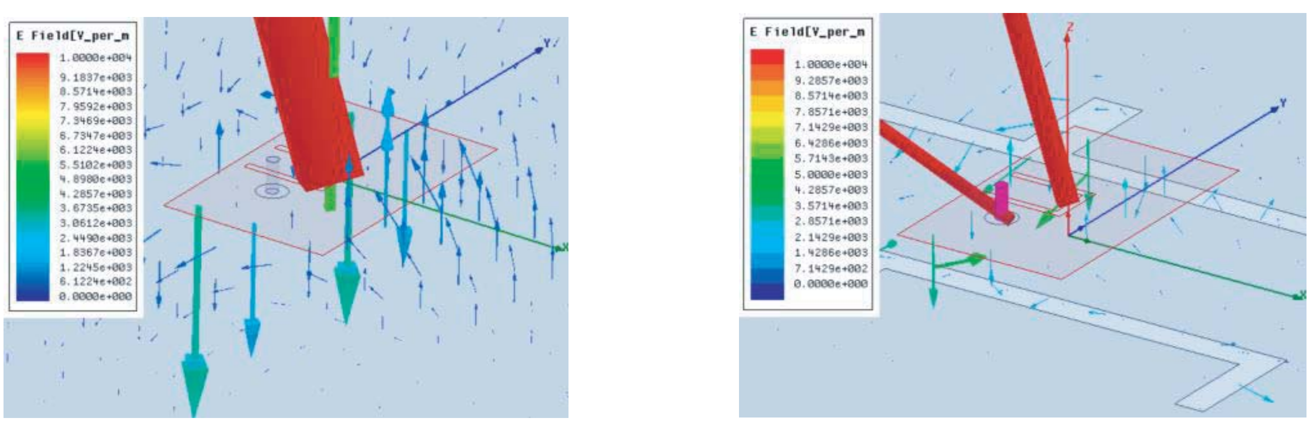
Table 2. Optimized parameters of the probe-fed wideband rectangular patch without F-DGS.

Parameters	L	W	ρ	U_L	U_W	U_t	l_i
Value (mm)	8.6	13.76	3.48	4.2	2.8	0.4	0.1

supposed to extend outside to avoid infringing the primary radiating mode. In this way, the length and location of short lines are adjustable according to different operating frequencies.

For comparative study, identical wideband rectangular patch without F-DGS has been used, as shown in Fig. 4. This conventional configuration adopts the same RT5880 substrate with $\varepsilon_r = 2.2$ and $h = 1.575$ mm. Parameters are furnished in Table 2.

The simulated E-field distributions obtained using High Frequency Structure Simulator for antennas with and without F-DGS are shown in Fig. 5. The field in a patch with F-DGS (Fig. 5(b)) is much more uniformly distributed than a conventional patch (Fig. 5(a)). As known, the electric vectors near non-radiating edges are responsible for XP fields. In Fig. 5(b), the vertical components (along z-axis) are replaced by horizontal ones (along y-axis) in some extent. The cancelation of horizontal components happens in the far field due to their opposite directions, and this, in turn, validates suppression of XP. Although not shown, similar observation is noted for antennas at other frequencies.



(a) (b)

Figure 5. Simulated electric fields in the substrate of a wideband rectangular patch, (a) with conventional ground plane, (b) with F-DGS.

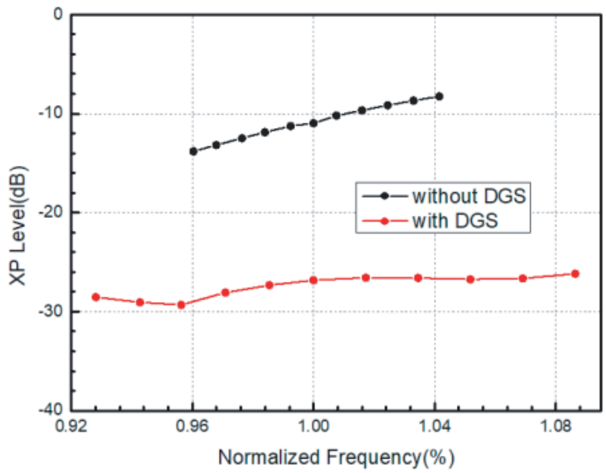


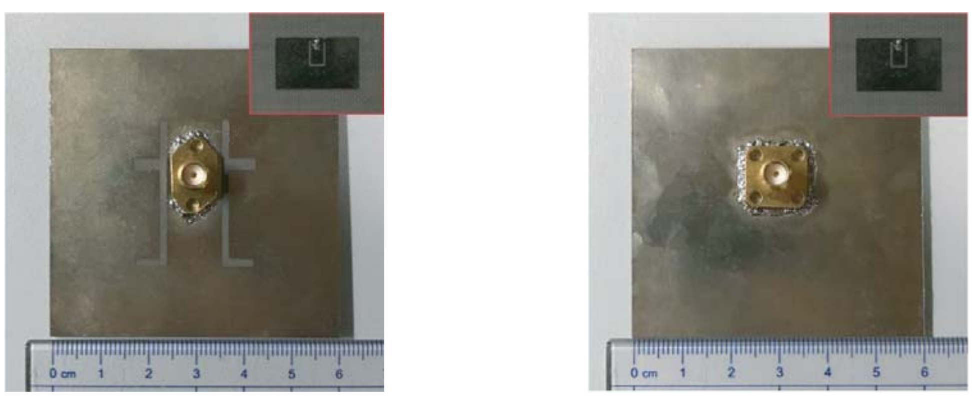
Figure 6. Variation of XP levels in H-plane with normalized frequency for two configurations.

Therefore, F-DGS is remarkably effective.

The variation of XP level with normalized frequency for two configurations is documented in Fig. 6. Since XP gain usually increases with frequency, the XP value of a conventional wideband rectangular patch increases from −13.81 to −8.26 dB. For a patch with F-DGS, striking change is observed, varying from −29.32 to −26.18 dB. Besides considerable reduction in XP radiations, extension in bandwidth and decrease in fluctuations of XP level are also apparent.

3. COMPARISON OF MEASURED AND SIMULATED RESULTS

Wideband rectangular patches with and without F-DGS have been fabricated. Photographs of the antennas from the ground plane side are shown in Figs. 7(a) and (b). The patches are presented in the inset.



(a) (b)

Figure 7. Photographs of two prototypes, (a) with conventional ground plane, (b) with F-DGS. GP size: 60 mm × 60 mm. View of the radiating side of the antenna is shown in the inset.

Experimental results are obtained using an N5244A network analyzer and an anechoic chamber. The input reflection coefficients are depicted in Fig. 8. Simulated results are also incorporated showing close mutual agreement. Notice that in measured results, impedance bandwidth of both antennas is expanded slightly compared with simulated results. The conventional wideband patch increases from

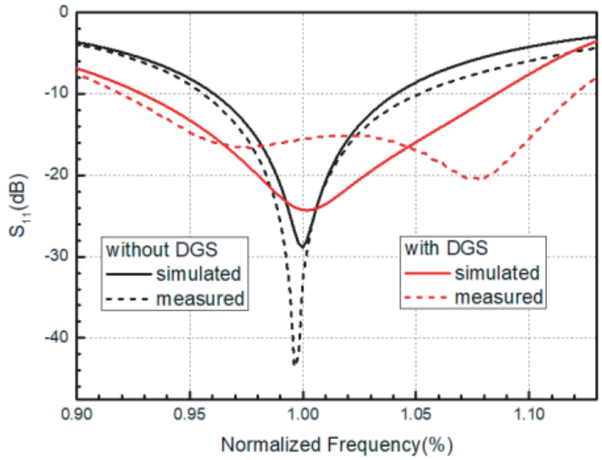
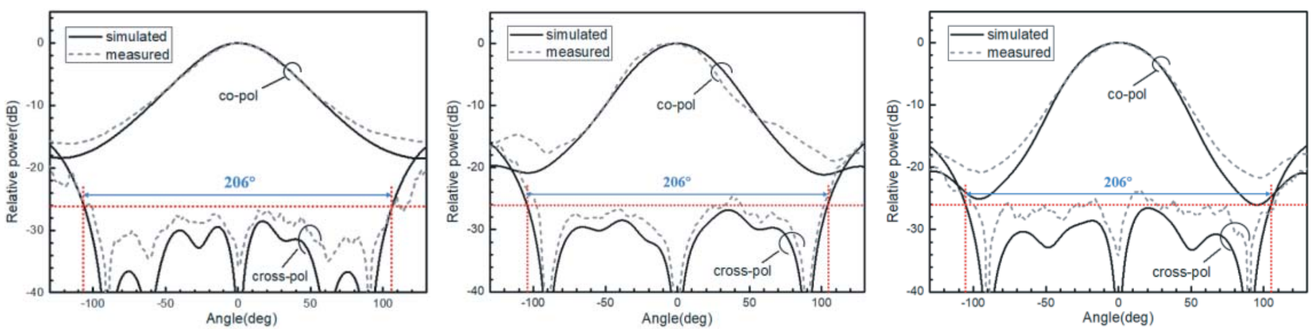
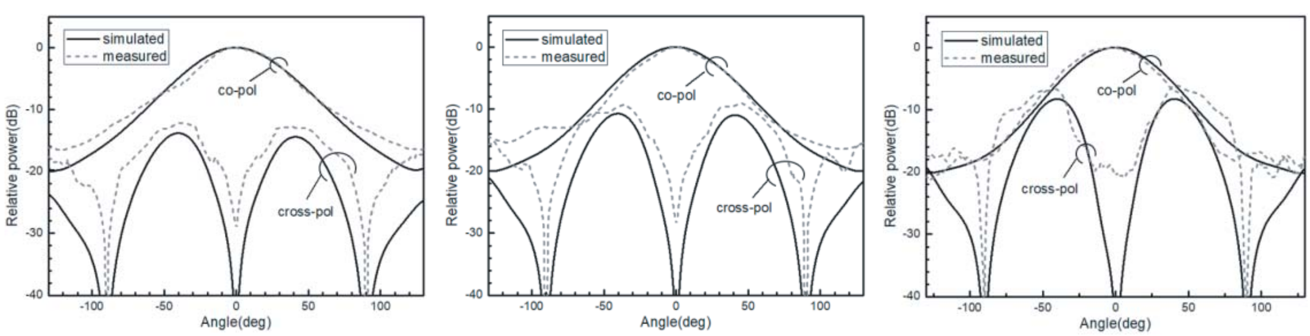


Figure 8. Measured and simulated S_{11} versus frequency with and without DGS.



(a) (b) (c)

Figure 9. H-plane radiation patterns of a wideband rectangular patch with F-DGS, (a) $f = 10.2$ GHz, (b) $f = 11$ GHz, (c) $f = 11.8$ GHz.



(a) (b) (c)

Figure 10. H-plane radiation patterns of a wideband rectangular patch with conventional ground plane, (a) $f = 10.2$ GHz, (b) $f = 10.6$ GHz, (c) $f = 11$ GHz.

8.1% to 9.5%. As for the patch with F-DGS, the bandwidth changes from 15.5% to 19.6%. It is caused by the presence of the SMA probe, influencing the radiating fields of F-DGS. In this case, F-DGS is very attractive in wideband applications.

Measured radiation patterns obtained at different frequencies for antennas with and without F-DGS are shown in Figs. 9 and 10, respectively. Simulated data are also incorporated. The presence of F-DGS shows little influence on the gain. As known, the gain usually increases with frequency. Considering different impedance bandwidths of two antennas, normalized quantities are displayed here for better comparison. The XP radiation in H-plane of the patch with F-DGS is reduced by 16–18 dB. This also helps in achieving a wide angular span of 206° over which XP radiation shows more than 26 dB isolation relative to the peak gain. E-plane patterns are not included as they do not exhibit significant change due to F-DGS. Our conjecture of introducing the DGS pattern to weaken the orthogonal fringing fields is thus verified. In a realized prototype, some deviations from ideal design result in some asymmetry, and their common sources are manually fitted probe and sometimes fabrication tools.

4. CONCLUSION

This investigation provides a complete description of XP fields radiating principles. By weakening the first higher order mode, F-DGS is very effective to improve XP performance due to the asymmetric geometry. Wideband rectangular patches with and without F-DGS are fabricated and experimented. The results indicate that the proposed design is really attractive in wideband and wide angular range applications.

REFERENCES

1. Guha, D. and Y. M. M. Antar, *Microstrip and Printed Antennas New Trends, Techniques and Applications*, Wiley Int. Sc., U.K., 2010.
2. Guha, D., M. Biswas, and Y. M. M. Antar, "Microstrip patch antenna with defected ground structure for cross polarization suppression," *IEEE Antennas Wireless Propag. Lett.*, Vol. 4, No. 1, 455–458, Dec. 2005.
3. Guha, D., C. Kumar, and S. Pal, "Improved cross-polarization characteristics of circular microstrip antenna employing arc-shaped defected ground structure (DGS)," *IEEE Antennas Wireless Propag. Lett.*, Vol. 8, 1367–1369, Dec. 2009.
4. Esa, M., U. Jamaluddin, and M. S. Awang, "Antenna with DGS for improved performance," *Proc. IEEE Asia-Pac. Conf. Appl. Electromagn. (APACE)*, 1–4, 2010.
5. Kumar, C. and D. Guha, "Nature of cross-polarized radiations from probe fed circular microstrip antennas and their suppression using different geometries of defected ground structure (DGS)," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 1, 92–101, Jan. 2012.
6. Zulkifli, F. Y., S. T. Lomorti, and E. T. Rahardjo, "Improved design of triangular patch linear array microstrip antenna using isosceles-triangular defected ground structure," *Proc. of Asia-Pacific Microwave Conf.*, Bangkok, Dec. 11–14, 2007.
7. Kumar, C. and D. Guha, "Modulation of substrate fields: Key to realize universal DGS configuration for suppressing cross-polarized radiations from a microstrip patch having any geometry," *IEEE Antennas and Propagation Society Int. Symp. Digest*, Chicago, IL, USA, Jul. 8–13, 2012.
8. Kumar, C. and D. Guha, "Defected ground structure (DGS)-integrated rectangular microstrip patch for improved polarization purity with wide impedance bandwidth," *IET Microw. Antennas Propag.*, Vol. 8, No. 8, 589–596, Jun. 2014.
9. Ghosh, A., D. Ghosh, S. Chattopadhyay, and L. Singh, "Rectangular microstrip antenna on slot type defected ground for reduced cross polarized radiation," *IEEE Antennas Wireless Propag. Lett.*, Vol. 14, 321–324, Feb. 2015.
10. Kumar, C. and D. Guha, "Reduction in cross-polarized radiation of microstrip patches using geometry independent resonant-type defected ground structure (DGS)," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 6, 2767–2772, Jun. 2015.
11. Kumar, C., M. I. Pasha, and D. Guha, "Microstrip patch with nonproximal symmetric defected ground structure (DGS) for improved cross polarization properties over principal radiation planes," *IEEE Antennas Wireless Propag. Lett.*, Vol. 14, 1412–1414, 2015.

12. Pasha, M. I., C. Kumar, and D. Guha, "Rectangular microstrip patch with symmetrically shaped defected ground structure for improved cross-polarization characteristics," *IEEE Applied Electromagnetics Conference (AEMC)*, Guwahati, India, Dec. 18–21, 2015.
13. Tanha, M. A. and P. V. Brennan, "Wideband T-squared patch antenna with reduced cross-polarization," *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, 700–703, Turin, Italy, Sep. 2015.
14. Khandelwal, M. K., B. K. Kanaujia, S. Dwari, and S. Kumar, "Design and analysis of microstrip DGS patch antenna with enhanced bandwidth for Ku band applications," *International Conference on Microwave and Photonics (ICMAP)*, Dhanbad, India, Dec. 13–15, 2013.
15. Kumar, C. and D. Guha, "Asymmetric geometry of defected ground structure for rectangular microstrip: A new approach to reduce its cross-polarized fields," *IEEE Trans. Antennas Propag.*, Vol. 64, No. 6, 2503–2506, Jun. 2016.
16. Derneryd, A. G., "Linearly polarized microstrip antennas," *IEEE Trans. Antennas Propag.*, Vol. 24, No. 6, 846–850, Nov. 1976.
17. Huang, J., "The finite ground effect on the microstrip antenna radiation panem," *IEEE Trans. Antennas Propag.*, Vol. 31, 649–653, 1983.
18. Weigand, S., G. H. Huff, K. H. Pan, and J. T. Bernhard, "Analysis and design of broad-band single-layer rectangular U-slot microstrip patch antennas," *IEEE Trans. Antennas Propag.*, Vol. 51, No. 3, 457–468, Mar. 2003.