A Newly Proposed Multi-band Rectangular Patch Antenna Using Defected Ground Structures

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Abstract— A new microstrip patch antenna that resonates on more than one frequencies and yields sufficiently high bandwidth is presented. Several variations of the proposed design are simulated using practically used dielectric materials. Detailed input return loss plots, VSWR plots, and radiation pattern plots are presented. A comparative study of all simulated results is presented. The design that yields the best performance is chosen for further optimization using deliberately-created defects in the ground plane, called Defected Ground Structures (DGS). It is observed that improvement in bandwidth is achievable through using the DGS.

1. INTRODUCTION

Microstrip antennas are a very popular kind of antennas because of their unique advantages like compact size, conformability, cheaper cost when produced in large numbers, etc. [1–9]. In the initial period of evolution of these antennas, the ground plane on one side of the substrate was left unperturbed. However, of late, deliberately-created defects in the ground plane, called Defected Ground Structures or DGSs, have started attracting attention too. The introduction of DGS allows extra degrees of freedom in optimizing the performance. If suitably used, the DGS can

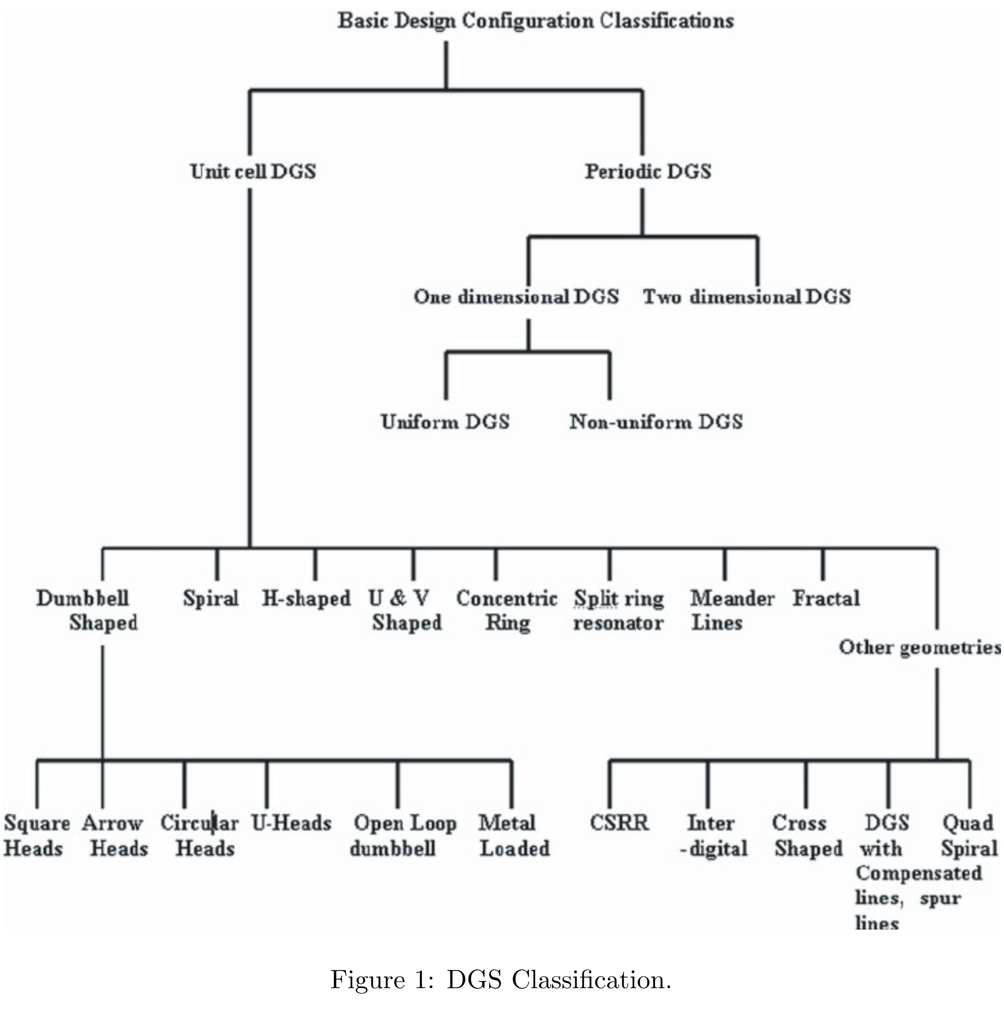

Figure 1: DGS Classification.

lead to substantially-improved antenna designs [10–17]. A diagram classifying the various DGSs analyzed so far is depicted in Figure 1 (taken from [9]). The large amount of DGS geometries that are possible are depicted in Figure 2 (taken from [9]). The typically-employed design procedure for DGS-based designs is described in Figure 3.

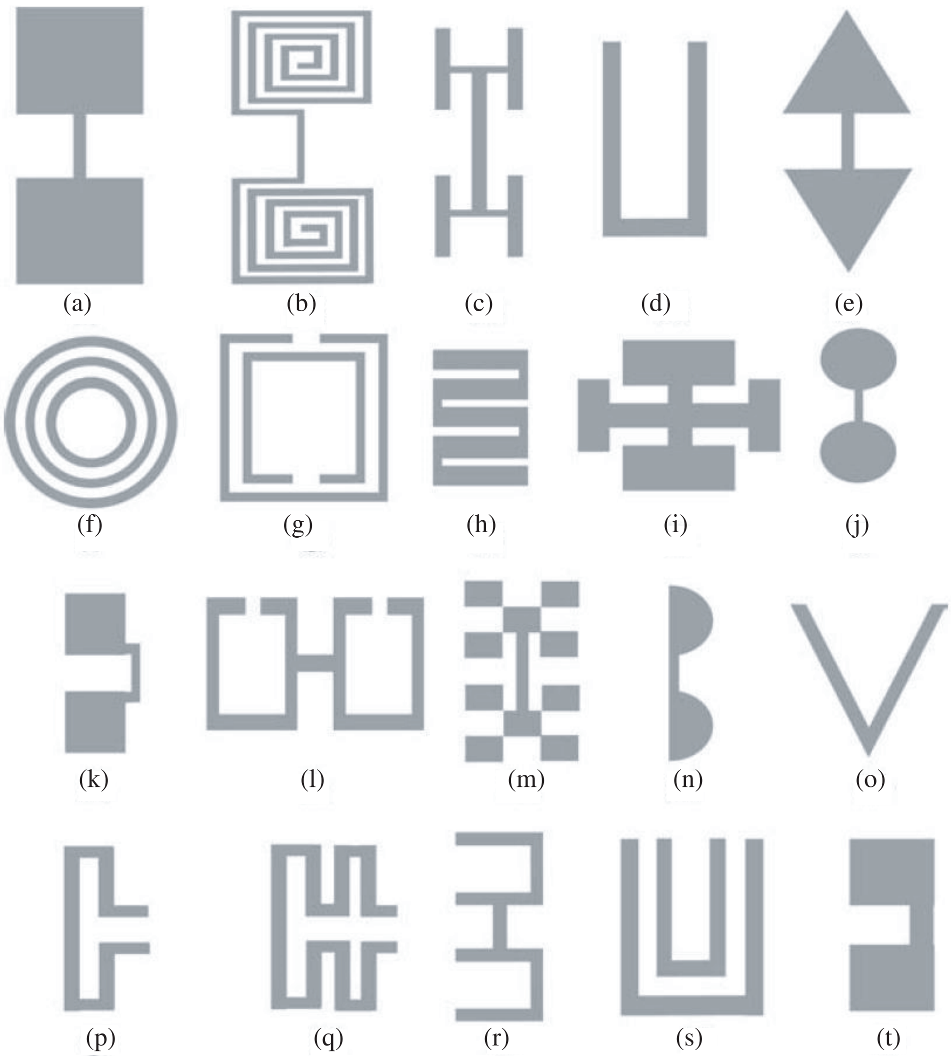

Figure 2: Various DGS geometries: (a) dumbbell-shaped, (b) spiral-shaped, (c) H-shaped, (d) U-shaped, (e) arrow head dumbbell, (f) concentric ring shaped, (g) split-ring resonators, (h) interdigital, (i) cross-shaped, (j) circular head dumbbell, (k) square head connected with U slots, (l) open loop dumbbell, (m) fractal, (n) half-circle, (o) V-shaped, (p) L-shaped, (q) meander lines, (r) U-head dumbbell, (s) double equilateral U, (t) square slots connected with narrow slot at edge.

In the present work, a new design using rectangular patch antenna along with four T-structures (for making the design compact) is proposed and analyzed. A dumb-bell type of DGS is used to further improve the performance.

2. DESIGN PROCEDURE

The design procedure followed was, more or less, in conformance with Figure 3. A low-loss dielectric substrate Rogers RT/duroid 5880 (from Rogers Corporation) was selected. This substrate's dielectric constant is $\epsilon_r = 2.2$ (nominal value) and its loss tangent is $\tan\delta = 0.0009$ (nominal value). The substrate thickness was selected to be $h = 3.2$ mm. The dimensions of the ground plane were calculated to be 55 mm by 45 mm.

As the starting point, the dimensions of the patch were calculated using well-known equations available in literature and, for easy reference, reproduced below.

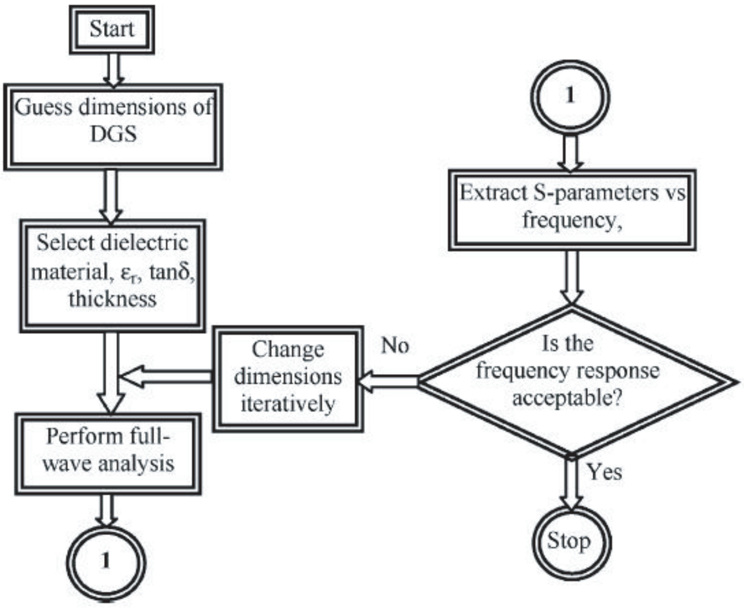

Figure 3: The design and analysis method for DGS-based antennas.

Width of the patch is given by

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}} \tag{1}$$

where the notations are in SI unit and f_r is the desired resonant frequency. Taking fringing field into consideration, the effective dielectric constant ϵ_{eff} is given by

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{2}$$

The increment in length due to fringing field is calculated using

$$\Delta L = \frac{h}{\sqrt{\epsilon_{eff}}} \tag{3}$$

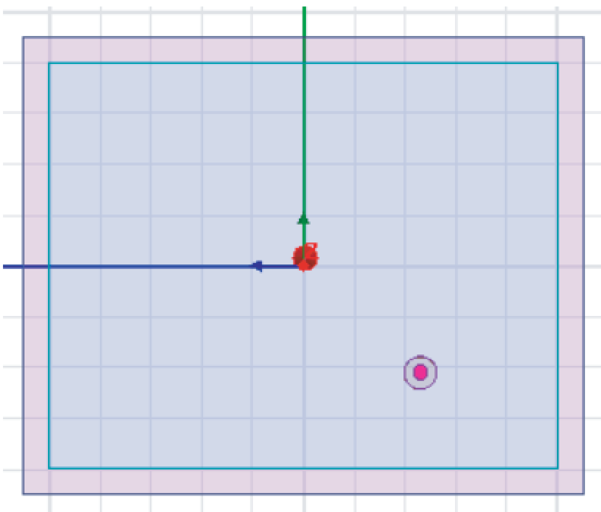

Figure 4: Basic rectangular MSA.

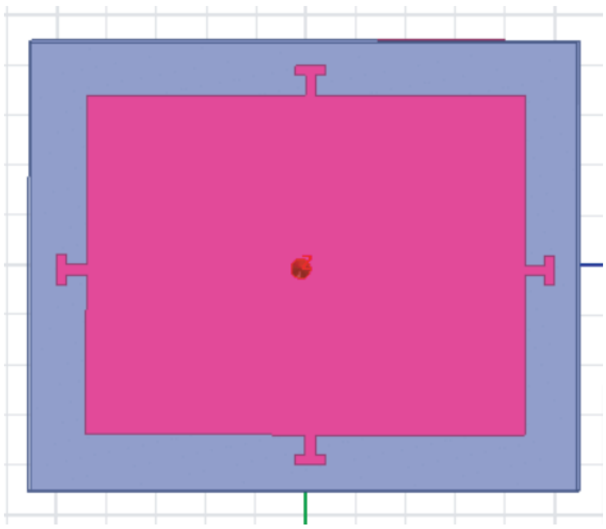

Figure 5: Modified compact antenna with T-structures.

Length of patch is given by

$$L = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} - 2(\Delta L) \tag{4}$$

The use of Equations (1) to (4) yielded $W = 50\,\text{mm}$ and $L = 40\,\text{mm}$ for $f_r = 2.4\,\text{GHz}$. These values were used to start the analysis using an available EM simulator.

During simulations, four T-structures were introduced to make the design compact as shown in Figure 5. In addition, a dumb-bell shaped DGS was introduced as shown in Figure 6.

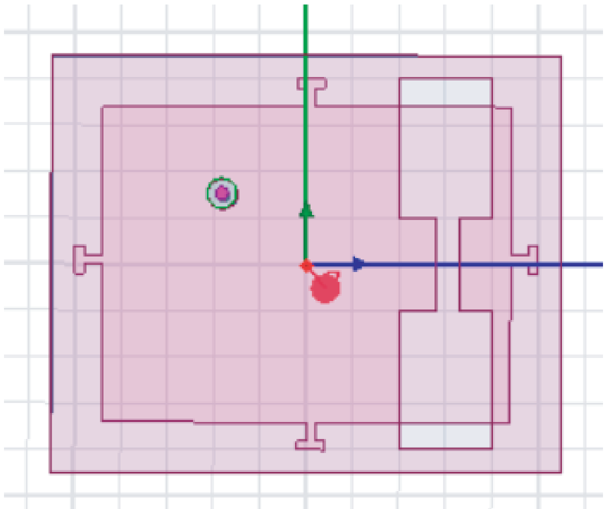

Figure 6: Dumb-bell type DGS introduced to design shown in Figure 5.

3. RESULTS AND DISCUSSION

All the demonstrated models were designed and simulated utilizing a 3D EM simulator. The results are shown in Figures 7 to 11. Figure 7 demonstrates **"Return Loss"** behavior of these designs. Impedance bandwidth is ascertained for frequency range for which return loss is less than 10 dB. **VSWR** behaviour of these models is shown in Figure 8. It can be seen that applying T-structure enhances VSWR curve significantly and a little improvement is contributed by DGS. **Radiation pattern** of these models is shown in Figures 9–11. As can be observed from these figures that radiation intensity and F/B ratio improve significantly for models shown in Figures 10 and 11 compared to Figure 9.

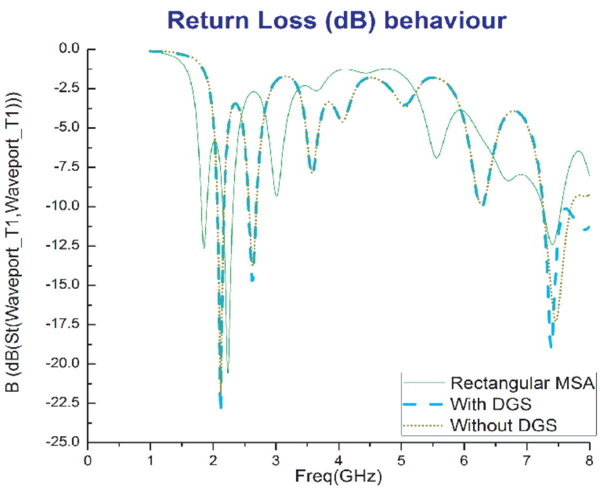

Figure 7: Return loss behavior.

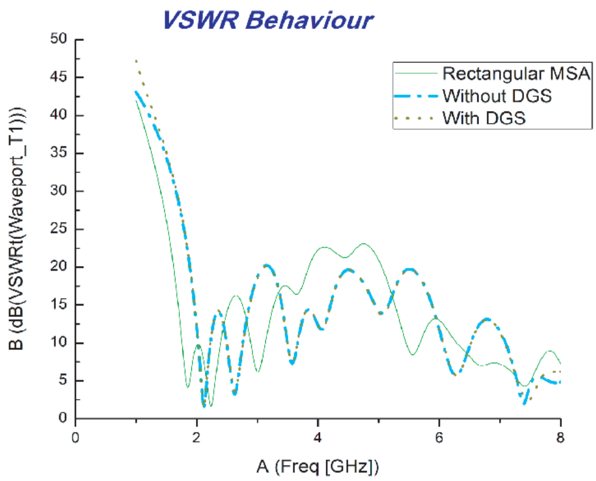

Figure 8: VSWR behavior.

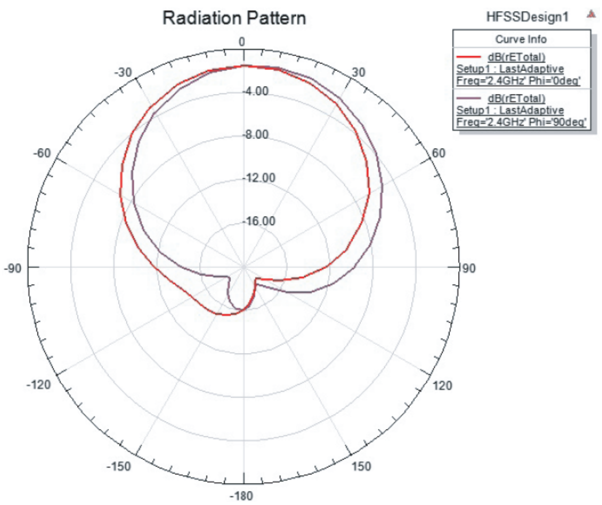

Figure 9: Radiation pattern of basic rectangular MSA shown in Figure 4.

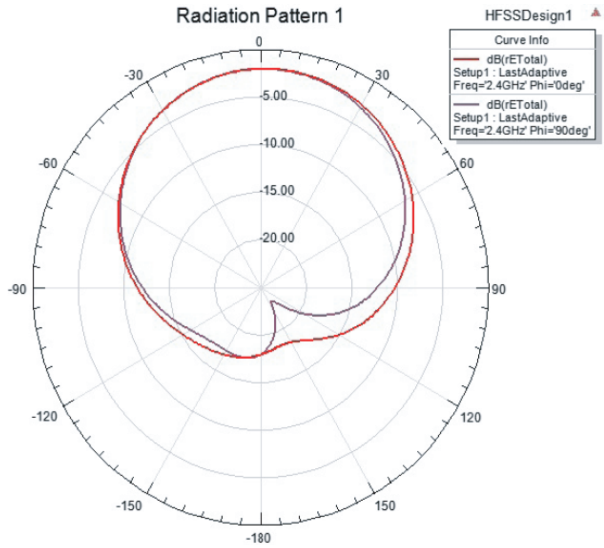

Figure 10: Radiation pattern of modified compact antenna with T-structures shown in Figure 5.

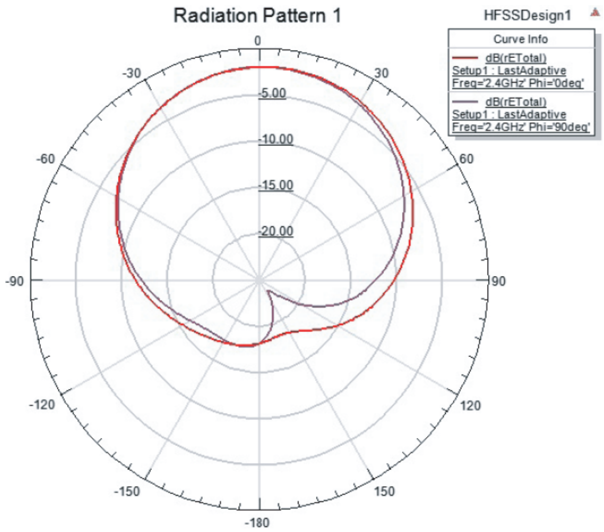

Figure 11: Radiation pattern of dumb-bell type DGS introduced to design shown in Figure 6.

Table 1: Comparative Study of all designs.

Frequency (GHz)	**Without DGS**		**With DGS**	
	S_{11} **(dB)**	**Bandwidth (MHz)**	S_{11} **(dB)**	**Bandwidth (MHz)**
2.12	−23.4	160	−21.99	180
2.63	−14.54	210	−13.76	230
7.46	−17.45	270	−17.31	310

4. CONCLUSION

Compact MSA operating at three different frequencies viz. 2.12 GHz, 2.63 GHz and 7.46 GHz, which covers Wi-Fi band (2.4 GHz–2.483 GHz) is reported. The design provides sufficiently large bandwidth at all three frequencies. It is observed that introducing a dumb-bell type defected ground structure helps in improving the performance of the antenna in terms of return loss and bandwidth. The design can be further optimized by introducing other types of defected ground structures and by using different substrate materials.

REFERENCES

1. Garg, R., P. Bhartia, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House Inc., Norwood, MA, 2001.
2. Balanis, C. A., *Antenna Theory: Analysis and Design*, 3rd Edition, John Wiley & Sons, New Jersey, 2005.
3. Pozar, D. M. and D. H. Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*, Wiley-IEEE Press, 1995, ISBN:978-0-7803-1078-0.
4. 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 Transactions on Antennas and Propagation*, Vol. 51, No. 3, 457–468, 2003.
5. Fries, M. K. and R. Vahldieck, "Small microstrip patch antenna using slow-wave structure," *Antennas and Propagation Society International Symposium*, Vol. 1–4, 770–773, July 2000.
6. Shackelford, A. K., K.-F. Lee, and K. M. Luk, "Design of small-size wide-bandwidth microstrip-patch antennas," *IEEE Antennas and Propagation Magazine*, Vol. 45, 75–83, 2003.
7. Luk, K. M., C. L. Mak, Y. L. Chow, and K. F. Lee, "Broadband microstrip patch antenna," *Electronics Letters*, Vol. 34, No. 15, 1442–1443, 1998.
8. Chakraborty, S., S. K. Moitra, S. Tewary, A. Kumari, and M. Chakraborty, "Design and analysis of dual band, DGS integrated compact microstrip antenna," *Advances in Optical Science and Engineering, Springer Proceedings in Physics*, Vol. 166, 161–169, June 2015.
9. Guha, D. and Y. M. M. Antar, *Microstrip and Printed Antennas: New Trends, Techniques and Applications*, Wiley Online Library, February 2011, ISBN 13: 978-1-119-97298-3.
10. Liu, H., Z. Li, and X. Sun, "Compact defected ground structure in microstrip technology," *Electron Letters*, Vol. 41, 132–134, 2005.
11. Kumar, S. and R. Tomar, "A dual-band compact printed monopole antenna using multiple rectangle-shaped defected ground structures and cross shaped feed lines," *Microwave and Optical Technology Letters*, Vol. 57, No. 8, 1810–1813, August 2015.
12. Liu, J. X., W. Y. Yin, and S. L. He, "A new defected ground structure and its application for miniaturized switchable antenna," *Progress In Electromagnetics Research*, Vol. 107, 115–128, 2010.
13. Wang, L. T. and J. S. Sun, "The compact broadband microstip antenna with defective ground plane," *IEEE International Conference on Antennas and Propagation*, Vol. 2, 622–624, April 2003.
14. Khandelwal, M. K., B. K. Kanaujia, S. Dwari, S. Kumar, and A. K. Gautam, "Analysis and design of wide band Microstrip-line-fed antenna with defected ground structure for Ku band applications," *International Journal of Electronics and Communications*, Vol. 68, No. 10, 951–957, October 2014.
15. Kumar, M. and V. Nath, "Analysis of low mutual coupling compact multi-band microstrip patch antenna and its array using defected ground structure," *Engineering Science and Technology, an International Journal*, Vol. 194, No. 2, 866–874, June 2016.
16. Chakraborty, S., S. Pal, and M. Chakraborty, "High performance DGS based compact microstrip patch antenna," *Proceedings of 1st International Science & Technology Congress 2014*, 405–409, Elsevier Publications 2014, 2014.
17. Garg, R., I. Bahl, and M. Bozzi, *Defected Ground Structure (DGS): Microstrip Lines and Slotted Lines*, Artech House, 305–341, 2013.