DGS Based Coaxially Fed Microstrip Slotted Rectangular Patch Antenna with Improved Gain and Bandwidth

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Abstract. Most often, the conventional microstrip rectangular patch antennas have a limited gain and bandwidth performance. In this paper, an enhancement in the gain and bandwidth parameters are achieved by slotted radiating patch and using a defected ground structure respectively. The proposed antenna design with design frequency of 3.5 GHz has been evolved isometrically in different design stages (design iterations). The work initially considers an existing single band Microstrip rectangular patch antenna design of low gain and another work of single band antenna with a slotted patch geometry offering an improved gain but limited in its bandwidth. The change in the widths of the ground, substrate and the patch along with the addition of addition of slots into this design results into a completely different geometry featuring multiband operation with an improved gain and the use of defected ground structure in the final stage counters the limited bandwidth operability. All the involved iteration designs have been simulated over HFSS-15 for the performance parameters of the reflection coefficient, bandwidth, radiation pattern and gain. The designs of the last two stages have been fabricated and validated. The measured results have been found to be in close approximation to the simulated ones.

Keywords: Defected ground structures, coaxially fed, slotted patch geometry, multiband operation.

1. Introduction

The microstrip patch antennas have completely revolutionized the antenna industry because of their small size, light weight, low profile, compatibility with most MMIC designs and conformability to non-planar structures [1]. The use of these microstrip patch antennas for communication, medical, military and several other purposes is tremendously increasing.

Several literature works can be found in the design of basic rectangular microstrip patch antenna using coaxial feed [2, 3]. Kaushal and Shanmuganantham in [4] proposed a basic rectangular microstrip patch antenna in which performance review of a four-stage design of a slotted microstrip rectangular patch antenna for a multiband operation was studied which offered a single band low gain of 3.83 dBi. Also, the antenna proposed by. Karade [5], offered a peak gain of 1.423 dBi at 2.44 GHz. In both the cases and in most others based on similar lines, the proposed basic patch structures have been found to resonate at a single frequency with low gain and limited bandwidth. Research has proven that the use of techniques like an introduction of slots into the geometry of patch and defected ground structures can shoot the values of gain and mitigate the limitations of low gain and narrow bandwidth [6, 7]. The microstrip slotted rectangular patch antenna proposed in [8] offered significantly high gains and bandwidths at each of its three resonant frequencies. The miniaturized microstrip patch antenna that was proposed in [8] offered a reflection coefficient of -16.3 dB with a peak gain of 6.6 dBi at 11.77 GHz, reflection coefficient of -43.2 dB and a peak gain of 29.2 dBi at 20.03 GHz and a reflection coefficient of -12.1 dB with a peak gain of 21 dBi at 30.39 GHz. Also, the offered bandwidths included 3.74 GHz, 6.65 GHz and 580 MHz respectively.

In another slotted rectangular microstrip patch antenna that Kaushal and Shanmuganantham proposed, a dual-band resonance was reported [9]. A reflection coefficient of -13.2 dB, 10.54 GHz bandwidth and a peak gain of 14.7dBi was reported at 30.87 GHz while a reflection coefficient of -12.5 dB, 1.87 GHz bandwidth and a peak gain of 14.5 dBi was obtained at 36.25 GHz. Still, another microstrip rectangular slotted patch proposed in [10] for S, Ku, and K band applications offered respective reflection coefficients of -12.8 dB, -21 dB and -10.6 dB and maximum gains of 6.2 dBi, 17.1 dBi and 16.2 dBi at3.12 GHz, 15.18 GHz and 24.04 GHz respectively. The truncated rectangular microstrip patch antenna design using a dumbbell shaped defected ground structure in [11] offered a bandwidth of 523.3 MHz against that of 265.78MHz obtained from the use of truncated rectangular microstrip antenna. Other multiband techniques used multiple elements, fractals, and genetic based antennas [12-16].

Considering the single band operability, low gain and narrow bandwidth limitations of the simple rectangular microstrip patch antenna design in [17], the use of slotted patch geometry for improved gain performance with added multiband feature was considered. The microstrip slotted rectangular patch antenna proposed [17] offered a single band peak gain of 4.5 dBi and a bandwidth of 50 MHz. The work seemed to be far deficient in terms of number of bands, gain and the obtained bandwidth. Using this work as a reference, modifying this design by changing the width of the ground, substrate and patch and an addition of slots in a definite pattern resulted into a completely different geometry with an added band that offers comparatively higher gain. The use of defected ground structure results into an enhanced bandwidth.

The section I gives a brief overview of the rectangular microstrip patch antennas, the research transition from conventional rectangular structures to slotted geometries. The geometry and the specifications of the proposed design iterations are discussed in section II. Section III includes the discussion of the comparison of major results including the reflection coefficient, bandwidth, radiation pattern and gain for the two design iterations including the modified slotted rectangular patch antenna structure and the modified slotted rectangular patch antenna structure with a defected ground.

2. Proposed antenna design

The proposed antenna design is evolved isometrically in different design stages (design iterations). Initially, a reference antenna (Figure 1) is chosen followed by modifications in the radiating patch (in stage 2 as shown in Figure 2) and then the subsequent modification of ground in the final stage shown in Figure 3.The basic rectangular microstrip patch antenna design in [4] was found to offer limited characteristics. This rectangular patch is design using the following design equations [1]:

Width of rectangular patch

$$W_p = \frac{c}{2f_r}\left(\sqrt{\frac{2}{\varepsilon_r+1}}\right) \quad (1)$$

Effective relative permittivity of substrate

$$\epsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2} \quad (2)$$

Extension in length of a patch on each side due to the fringing effect

$$\Delta l = 0.412h\left[\left(\frac{\varepsilon_{reff}+0.03}{\varepsilon_{reff}-0.258}\right)\left(\frac{W+0.264}{W+0.8h}\right)\right] \quad (3)$$

Length of the patch

$$L_1 = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta l \quad (4)$$

where, f_r denotes the fundamental frequency of operation, ε_r denotes relative permittivity of substrate and h denotes the substrate height.

The length and the width of the ground plane are calculated using the following formulae:

Length of ground: $Lg=L=L_1+6h$ (5)

Width of ground: $Wg=W=W_1+6h$ (6)

Considering the fact that the slotted patch antennas offer multiple bands with comparatively higher gain and bandwidth, the slotted patch antenna in [17] (Figure 1) seems to be far deficient in terms of the offered gain and bandwidth. The proposed work uses this antenna geometry in [17] as reference design. The antenna design parameters used in [17] are given in Table 1. A change in the width of the ground, substrate and the patch along with an addition of slots in the definite pattern would result into the geometry shown in Figure 2 (fabricated antenna in Figure 3). The slotted radiating patch results into the shooting of gain to higher values. The geometry uses a 68 mm x 90.5 mm FR4 epoxy substrate that is 1.6 mm thick and has a relative permittivity of 4.4 and a dielectric loss tangent of 0.02. The feeding technique used is coaxial feed because of the ease of fabrication and the flexibility in the choice of location of the feed to provide an input impedance of 50 Ω at the design frequency of 3.5 GHz. In both the geometries, the region of the substrate is shaded in purple and that of the patch is shaded in yellow. The flipside views indicate the ground region that has been shaded in pink color.

Table 1: Antenna design parameters (mm) of Ref. [17]

Parameters	Dimensions (mm)
L	64
W	62.5
R	20
r	14

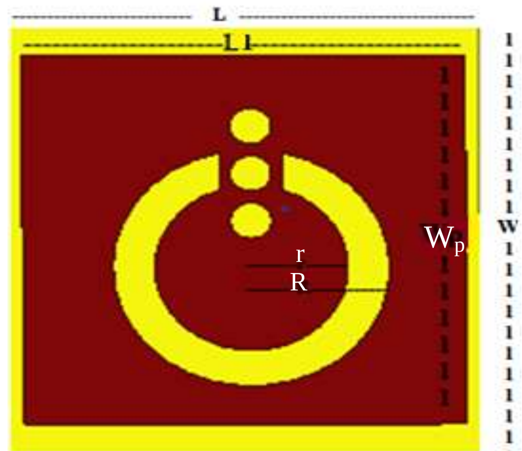
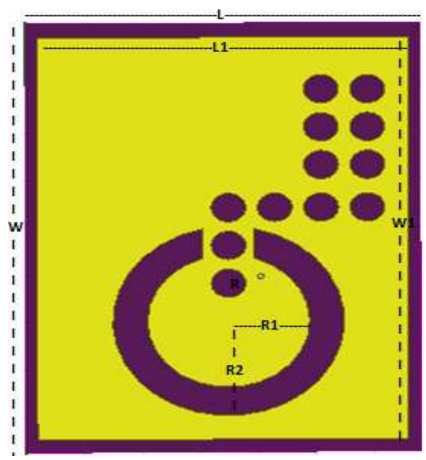


Fig.1. Antenna Geometry of Ref [17]



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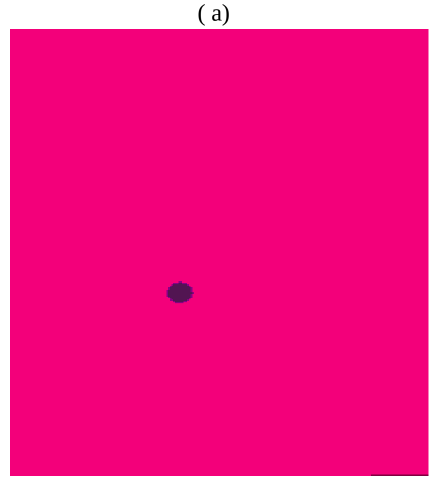


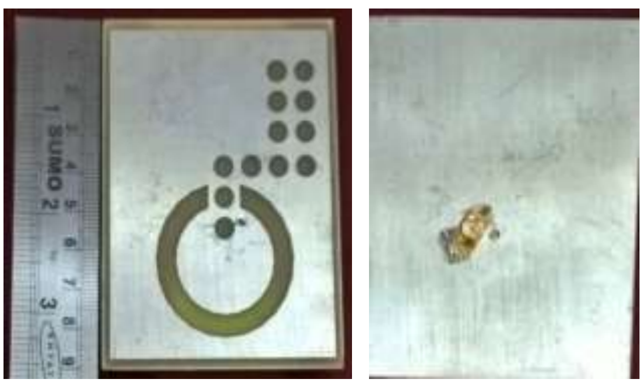
(b)

Fig.2. Geometry of the first stage iteration: a) Top view b) Flipside view of the ground upon rotation towards the right.

Figure 3 shows the fabricated structure of the simulated design of the first iteration. The requirement of further improvement in the bandwidth results into the modification of the design of iteration 1 with the design having a modified ground structure as indicated in Figure 4. This defected ground structure would lower the quality factor of the antenna and improve its bandwidth. The fabricated prototype for the design in the final stage is shown in the Figure 5. The geometrical parameters of the designs used in both the iterations are listed in Table 2.

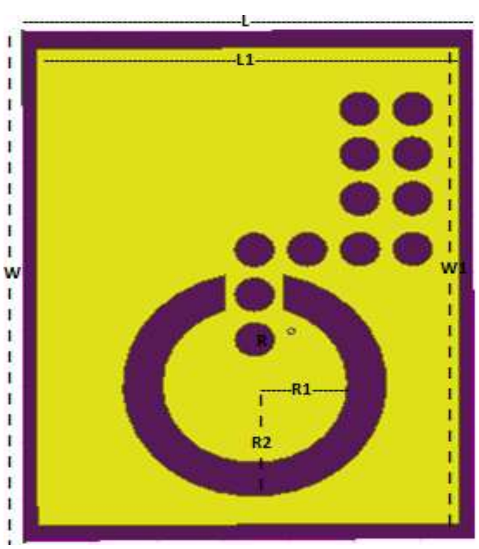
Table 2: Geometrical parameters of the antenna used in both iteration

Parameters	Value (mm)	Parameters	Value (mm)
L	68	L3	50
W	90.5	W3	15
L1	64	W4	35
W1	85	R	3
L2	40	R1	14
W2	14	R2	20



(a) (b)

Fig.3. Fabricated prototype of the first stage iteration: a) Top view b) Flipside view of the ground upon rotation towards the right.



(a)

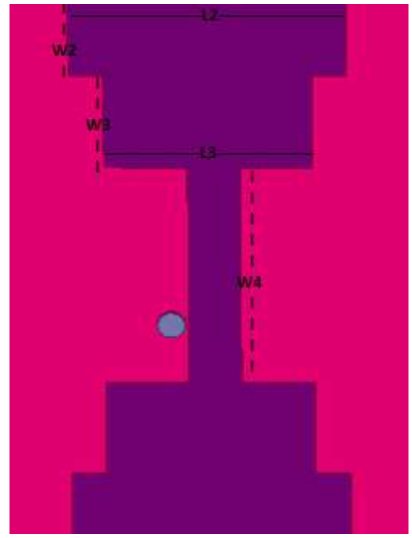


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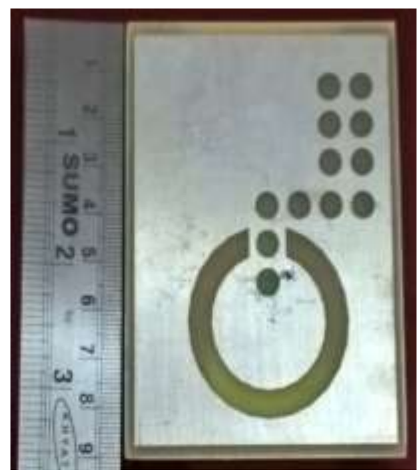
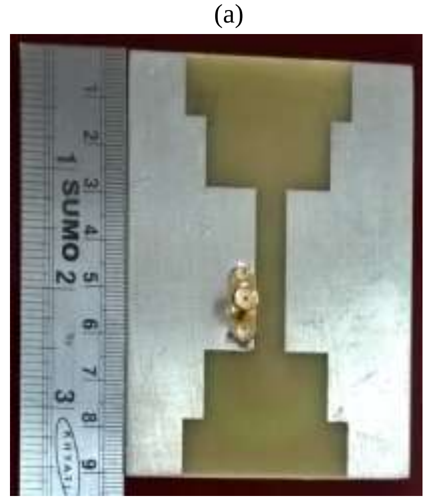
Fig.4. Geometry of the final stage iteration (a) Top view (b) Flipside view of the defected ground upon rotation towards the right.



(a)



(b)

Fig.5. Fabricated geometry of the final stage Iteration: (a) Top view b) Flipside view of the defected ground upon rotation towards the right.

3. Results and discussion

Figure 6 shows the comparative reflection coefficient [17] plot of the two design iterations and their fabricated counterparts. The graph considers the simulated set of values which are plotted against the set of values received upon measurement. The fabricated prototypes are validated for the reflection coefficient plot using Rhode and Schwarz ZVA 40 VNA [18] operating in a range of 10 MHz to 40 GHz. The reflection coefficient and the bandwidth values corresponding to different resonant frequencies for the two design iterations and their fabricated counterparts are listed in Table 3. It is observed that the modifications into the geometry of antenna in [17] (considered as a reference design) resulted into the appearance of an additional band. A considerable improvement in the bandwidth is noticed for design in the second iteration that uses a defected ground. The fabricated prototypes of the two design iterations are tested in the anechoic chamber for their radiation patterns. The Figure 7 and 8 show the measured and simulated results of the fabricated prototypes of the two design iterations. The curves in the patterns are obtained in the upper half of the plane as the ground plane is assumed to be infinite. The cross polarized radiation is well below -20 dB for all resonant frequencies in all the design stages. The numerical values of the gain obtained at different center frequencies of the respective corresponding design iterations and their fabricated counterparts are listed in Table 3. The antenna geometry in [17] taken as a base reference for this proposed work had limitations of low gain. The modifications to this reference antenna resulted in a geometry of first iteration design that produced dual-band operation with significantly higher gains. Further, use of a defected ground structure resulted into exorbitantly higher gains.

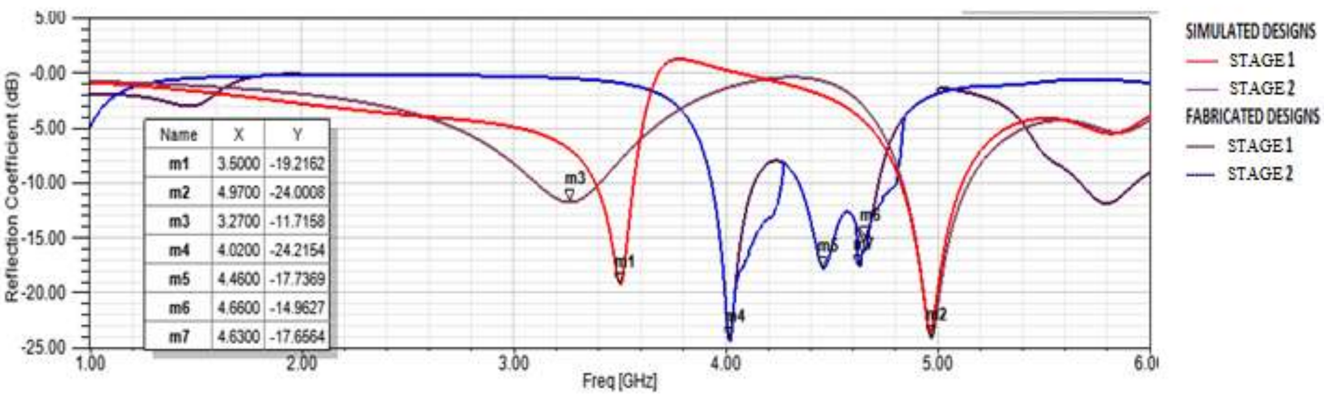


Fig.6.Comparative reflection coefficient plot of the two design iterations and their fabricated prototypes

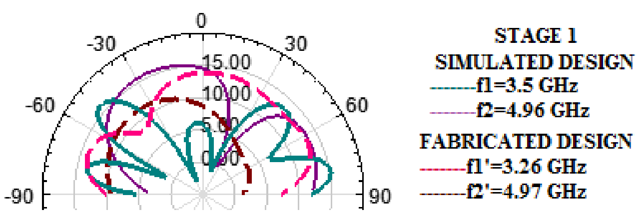


Fig.7. Comparative radiation pattern plot of the stage 1 simulated design and its fabricated prototype.

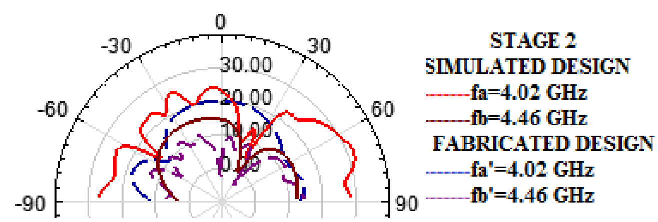


Fig.8. Comparative radiation pattern plot of the stage 2 simulated design and its fabricated prototype.

Table 3: Comparison of reference, simulated, and fabricated designs

Parameters	Reference Antenna [10]	Simulated Iteration 1 Design	Fabricated Iteration 1 Design	Simulated Iteration 2 Design	Fabricated Iteration 2 Design
Dimensions of patch (mm)	64 x 62.5	64 x 85	64 x 85	64 x 85	64 x 85
Number of Bands	Single (1)	Dual (2)	Dual (2)	Dual (2)	Dual (2)
Resonant Frequency (GHz)	2.83	f_1=3.5 f_2=4.96	f_1'=3.26 f_2'=4.97	f_a=4.02 f_b=4.46	f_a'=4.02 f_b=4.46
Reflection Coefficient (dB)	-12.7	-19.2 (f_1) -23.5 (f_2)	-11.7 (f_1') -24 (f_2')	-24.2 (f_a) -17.7 (f_b)	-17.7 (f_a') -17.7 (f_b')
Bandwidth (%)	0.0176	0.037 (f_1) 0.056 (f_2)	0.086(f_1') 0.060(f_2')	0.082 (f_a) 0.10 (f_b)	0.074 (f_a') 0.807(f_b')
Peak Gain (dBi)	4.5	17.1 (f_1) 14.1(f_2)	14.7 (f_1') 9.7 (f_2')	16 (f_a) 30.4 (f_b)	13.2 (f_a') 28 (f_b')

Table 3 compares the reference antenna [17] and the two design iterations (simulated and fabricated). An improvement in the gain is clearly indicated at every stage, the use of defected ground structure in the final stage results into an enhanced pattern and bandwidth respectively. The measured results are found to be in close agreement with the simulated ones.

4. Conclusion

The technique of increasing the number of slots in the geometry of the patch and that of using a defected ground structure is considered to mitigate the limitations of low gain and narrow bandwidth in a reference antenna that has been considered as an improvement over the basic rectangular patch antenna. The two design iterations that follow on considering the base design make use of a 68 mm x 90.5 mm x 1.6 mm FR4 epoxy substrate and coaxial feeding technique. The designs were simulated over HFSS-15 and itwas observed that the modifications into the geometry of the reference antennaresult into the appearance of an additional band. A considerable improvement in the bandwidth was noticed for design in the second iteration that uses a defected ground structure. The structures have furtherbeen fabricated and validated using Rhode & Schwarz ZVA 40 VNA of 10 MHz to 60 GHz operation range and anechoic chamber. The measured results clearly hold a close agreement with the simulated ones.

References

[1] P. Bhartia, R. Garg, A. Ittipiboon, and I. J. Bahl, *Microstrip Antenna Design Handbook*, Artech House, 2000.

[2] Nayna, A. K. M. Baki, and F. Ahmed, Comparative study of rectangular and circular microstrip patch antennas in X Band, *International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT)*, Bangladesh, 2014.

[3] S. Das, P. P. Sarkar, and S.K. Chowdhury, Analysis of slits loaded compact printed antenna for multi-frequency operation, *International Journal of Advances in Microwave Technology*, vol. 2, no. 1, pp. 80-84, 2017.

[4] Deepanshu, T. Shanmuganantham, Performance review of four stage design of a three way slotted microstrip rectangular patch antenna for multiband operation, *IEEE International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)*, Kerala, 2017.

[5] Karade and P.L. Zade, A miniaturized rectangular patch antenna using ssrr for WLAN applications, *IEEE International Conference on Communications and Signal Processing (ICCSP)*, Melmaruvathur, India, 2015.

[6] M. T. Islam, M. Cho, M. Samsuzzaman, and S. Kibria, *Compact antenna for small satellite applications*, *IEEE Antennas and Propagation Magazine*, vol. 57, no. 2, pp-30-36, April 2015.

[7] R. Kiruthika and T. Shanmuganantam, Design and measurement of novel dual band microstrip patch antenna for radar applications, *International Journal of Advances in Microwave Technology*, vol. 2, No 3, pp. 126-130, August 2017.

[8] Deepanshu and T. Shanmuganantham, Design of multi utility high frequency dual band slotted android logo patch antenna using coaxial feed, *International Conference on Antenna Test and Measurement Society (ATMS)*, Hyderabad, India, 2017.

[9] Deepanshu and T. Shanmuganantham, High frequency slotted robot patch antenna for multiple space applications, *International Conference on Antenna Test and Measurement Society (ATMS)*, Hyderabad, India, 2017.

[10] D. Kaushal and T. Shanmuganantham, Microstrip slotted caterpillar patch antenna for S, Ku and K-band applications, *Journal of Materials Today:* Elsevier, 2016.

[11] N. A. Khan and B. A. Singh, Microstrip antenna design with defected ground structure, *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, vol. 9, no. 2, PP. 46-50, 2016.

[12] C. Puente, J. Anguera, C. Borja, and J. Soler, Fractal-Shaped antennas and their application to GSM 900/1800, *The Journal of the Institution of British Telecommunications Engineers*, vol.2, Part 3, July-Sept. 2001.

[13] Anguera, C. Puente, and C. Borja, A procedure to design wideband electromagnetically-coupled stacked microstrip antennas based on a simple network model, *IEEE Antennas and Propagation Society International Symposium*, vol. II, pp.944-947, Orlando, USA, July 1999.

[14] J. M. J. W. Jayasinghe, J. Anguera, and D.N. Uduwawala, A simple design of multiband microstrip patch antennas robust to fabrication tolerances for GSM, UMTS, LTE, and Bluetooth applications by using genetic algorithm optimization, *Progress in Electromagnetic Research M*, vol. 27, pp. 255-269, 2012.

[15] J. Anguera, C. Puente, and C. Borja, Dual frequency broadband microstrip antenna with a reactive loading and stacked elements, *Progress in Electromagnetics Research Letters*, vol.10, pp. 1-10, 2009.

[16] J. Anguera, G. Font, C. Puente, C. Borja, and J. Soler, Multifrequency microstrip patch antenna using multiple stacked elements, *IEEE Microwave and Wireless Component Letters*, vol.13, no.3, 2003.

[17] D. Kaushal, T. Shanmuganantham, Mono band microstrip slotted power button antenna for aviation communication, *Indian Journal of Innovations and Development*, vol 5, no.11, pp.1-6, 2016.

[18] A. Katyal and A. Basu, Compact and broadband stacked microstrip patch antenna for target scanning applications, *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 381-384, 2017.

Biography of the authors

Deepanshu Kaushal received his B.Tech. degree in Electronics and Communication from Punjab Technical University in 2014. He is currently a second year M. Tech (E.C.E.) student of Pondicherry University and is doing his project on 'Microstrip Slotted Patch Antennas for Multiband Operation' under the guidance of Dr. T. Shanmuganantham. His area of interest includes antennas, fractals, metamaterials and terahertz antenna technology. He has 24 conference papers and 11 journals till date.

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