Progress In Electromagnetics Research C, Vol. 108, 187–200, 2021

Miniaturized and Gain Enhancement of Tapered Patch Antenna Using Defected Ground Structure and Metamaterial Superstrate for GPS Applications

Kakani Suvarna[1, *], Nallagarla Ramamurthy[2], and Dupakuntla Vishnu Vardhan[3]

Abstract—The main intention to present this work is to miniaturize and gain enhancement of a tapered microstrip patch antenna, which resonates for Global Positioning System (GPS) of L1 band at 1.575 GHz. To accomplish this, we present a new design configuration of a Tap-Shaped Defected Ground Structure (TSDGS). It has been utilized to switch the resonant frequency from 14.5 GHz to 1.575 GHz with no adjustment of areas of the actual Tapered Microstrip Patch Antenna (TMPA). The prototype antenna is fabricated on a Roger RT Duroid substrate merely $58 \times 22\,\mathrm{mm}^2$. Conclusively, a miniaturization allowed up to 89.31%, with regard to the TMPA, is excellently accomplished. The gain of the proposed antenna is successfully enhanced with properly locating the metamaterial superstrate onto the basic patch antenna. A gain of 7 dBi improvement has been achieved. The proposed design process is done with two different solvers, ADS and HFSS.

1. INTRODUCTION

Currently, the increase of efficiency, bandwidth, and miniaturization of antennas has gotten significant need in commercial, satellite, and military wireless communication systems. Ku-band (12–18 GHz) is best known for its use in satellite broadcast communications, and it plays a good role in everyday human activities [1]. Microstrip antennas have certain restrictions like polarization problems, low gain, single operating frequency, low impedance bandwidth, and narrow bandwidth [2]. There are some techniques which have improved the performance capabilities of antenna parameters, which are fractal geometry [3], metamaterial [4–7], array configuration [8], Electromagnetic Band Gap structures (EBGs) [9], Substrate Integrated Waveguides (SIWs) [10], Defected Ground Structures (DGSs) [11, 12], different feeding techniques [13], multilayer antennas [14], Defected Microstrip Structures (DMSs) [15], Frequency Selective Surfaces (FSSs) [16], W shape slots, M-slots, and eight shape with proper location in a patch [17–19], and distinctive shapes or a combination of them are inserted as slits and notches on the surface of the patch to enhance the performance of a antenna [20]. The equivalent circuit of a DGS is composed of a tuned parallel LC resonating circuit which is series with a microstrip line. The effective inductance and capacitance values depend on the structure size and defect area. By changing the various etched off shapes with different dimensions, the required resonance frequency is obtained [21]. The different area shapes have the same role and the same characteristics of stopband, high impedance, slow wave effect, and miniaturization of size [22, 23].

DGS is one of the simple and different approaches to miniaturize a conventional patch antenna. It consists of single or multiple defects on the surface of ground plane, and it can be used for several applications. The idea of DGS has been built to improve the attributes of several microwave planar

Received 17 November 2020, Accepted 28 December 2020, Scheduled 12 January 2021
* Corresponding author: Kakani Suvarna (kakanisuvarna21@gmail.com).
[1] JNTUA, Ananthapuramu, AP, India. [2] G. Pullaiah College of Engineering, Kurnool, AP, India. [3] JNTUA, Ananthapuramu, AP, India.

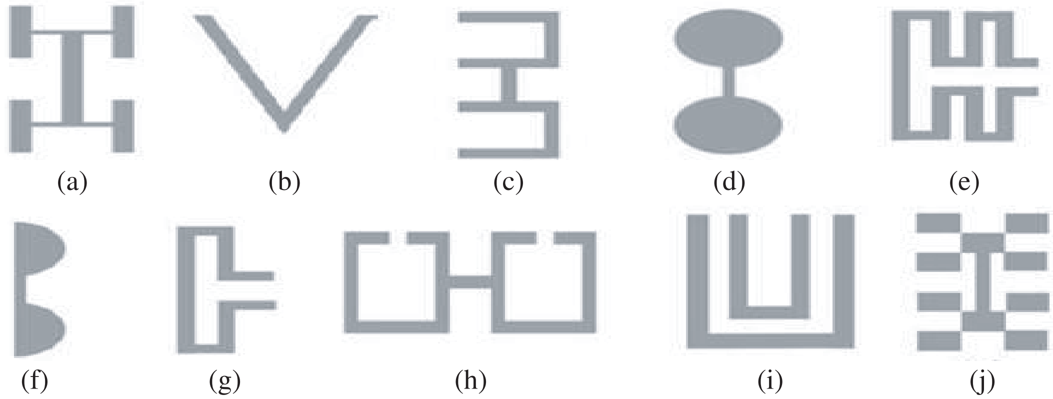


Figure 1. A few of the various shapes of DGS [36].

circuits. The various shapes of DGS geometries are shown in Fig. 1, and they include simple structures such as H-shape, V-shape, U-head dumbbell, circular head dumbbell, meander lines, half-circle, L-shape, open loop dumbbell, double equilateral U, and fractal [36]. Initially, we have done the literature survey regarding miniature concepts, which gives less than 80% of shifting frequency and 4 dBi gain of antenna in single operating bands.

So in this research article, a new Tap-Shaped Defected Ground Structure (TSDGS) which has been etched off in the ground plane is proposed. Its aim is to miniaturize the proposed TMPA, resonating at 14.5 GHz (ku-band). After the implementation of DGS method, this antenna resonates for GPS application at 1.575 GHz (L1 band). Due to this, 89.31% miniaturization is achieved. After that, a metamaterial superstrate is introduced to achieve a gain of 7 dBi or 4.85 dB.

In this article, we have planned with three sections. Firstly a tapered microstrip patch antenna design is explained, and then a tap-shaped DGS is described. Later metamaterial superstrate is introduced in Section 2. Discussion about the simulation results and analysis are summarized in Section 3, which are related to VSWR, radiation patterns, current distribution of without DGS, with only DGS, and DGS with metamaterial superstrate. Section 4 displays about the practical implementation. Finally, we provide the summary of the research work.

2. DESIGN CONFIGURATION OF ANTENNA

2.1. Tapered Microstrip Patch Antenna

This paper presents three kinds of antenna design models. Firstly, to accomplish the proposed plan, we have begun from an elementary antenna demonstrated hypothetically and the elementary tapered patch antenna length (L), width (W), quarter wave line width (w_T), characteristic impedance (Z_0), relative effective permittivity (ε_{re}), and length of the line (L_T) are calculated by using the below given formulas, and these formulas (1) to (4) are obtained from [33–35]. Fig. 2 shows the schematic geometry of the inset with quarter wavelength transformer (QWT) feed Tapered Microstrip Patch Antenna (TMPA) without DGS. This antenna resonates at 14.5 GHz in Ku-band range. After doing several optimizations, we have finally launched a novel concept of antenna which is introduced in this paper.

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{\mathit{eff}}}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L \tag{1}$$

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{8h}{w_T}+\frac{w_T}{4h}\right) \tag{3}$$

$$L_T = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{re}}} \tag{4}$$

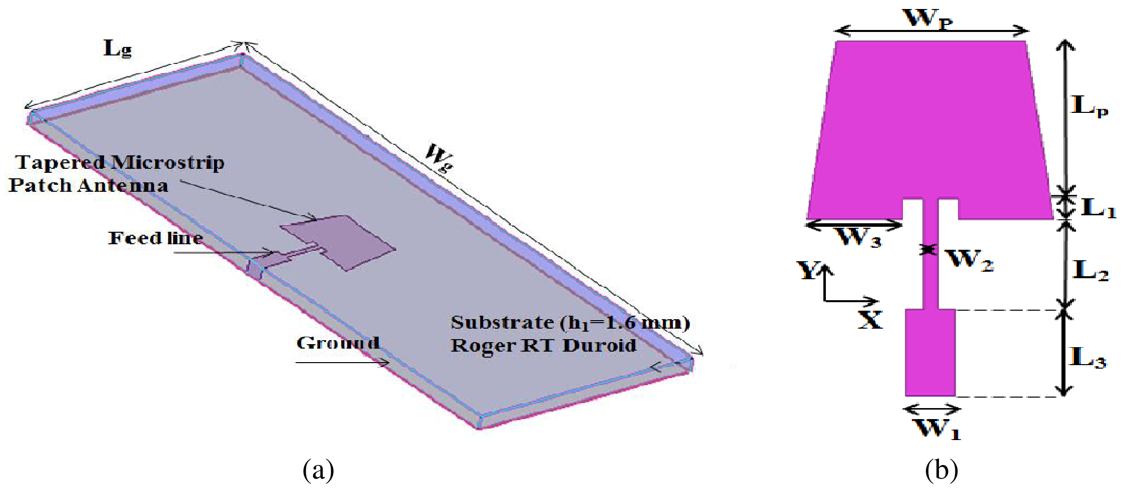


Figure 2. Proposed antenna geometry — (a) Perspective view (Ant#1); (b) Top view of conventional planar antenna (Ant#1).

The proposed planar antenna is printed on a Roger RT Duroid substrate with a loss tangent of 0.0009 ($\tan\delta$), relative permittivity of 2.2, whole area of $58 \times 22 \times 1.6\,\mathrm{mm}^3$, and it is analyzed by using two different solvers, ADS layout and HFSS. Table 1 gives the optimized dimensions of antenna parameters.

Table 1. The optimized dimensions of the tapered microstrip patch antenna.

Antenna parameter	Dimensions [mm]
L_P	5.26
L_1	0.7
L_2	3
L_3	2.9
W_P	6.5
W_1	1.7
W_2	0.5
W_3	3.3

2.2. Defected Ground Structures (DGS)

Secondly, the etched off aperiodic and periodic structures as defects in the metallic ground plane of microwave planar devices are known as DGS. This will bring major attraction to the microwave researchers. By utilizing these periodic structures, higher degree of miniaturization with greater slow wave rate is obtained. The repetition of single or multiple defects with a limited distance is known as periodic shaped structures. At the point, when DGS has been located on the metallic ground plane of the planar transmission line, the resonant frequency can be shifted from one position to another position due to the variation in the dimensions of the novel TSDGS which resonates for GPS at 1.575 GHz as shown in Fig. 3. The optimized DGS dimensions are shown in Table 2.

2.3. Metamaterial Unit Cell on Superstrate Layer

According to the work of Smith et al., the negative permittivity is obtained from the S-parameters [31]. In this article, the Nicolson-Ross-Weir (NRW) technique [32] has been implemented to attain the negative permittivity (ε) and negative permeability (μ) of metamaterial unit cell. These characteristics

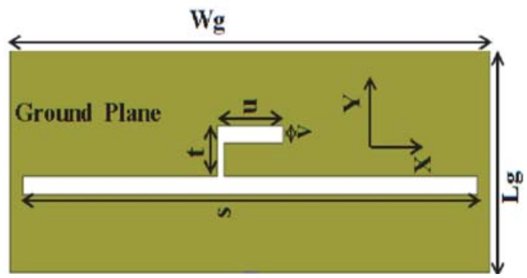


Figure 3. Bottom view of patch antenna with only DGS (Ant#2).

Table 2. The optimized defected ground structure (DGS) dimensions.

Antenna parameter	Dimensions [mm]
s	4.85
t	55
u	8
v	1.6
L_g	22
W_g	58

are retrieved and computed by HFSS. Equations (5) to (9) are used to determine all parameters, where K_0 is a wave number, and d is the thickness of the substrate.

$$v_1 = s_{21} + s_{11} \tag{5}$$

$$v_2 = s_{21} - s_{11} \tag{6}$$

$$s_{11} = re(s_{11}) + j(im\,(s_{11})) \tag{7}$$

$$s_{21} = re(s_{21}) + j(im\,(s_{21})) \tag{8}$$

$$\mu = \frac{2}{jk_{0d}} * \frac{1-v_2}{1+v_2} \quad \text{and} \quad \varepsilon = \frac{2}{jk_{0d}} * \frac{1-v_1}{1+v_1} \tag{9}$$

Table 3. Dimensions of metamaterial unit cell.

Antenna parameter	Dimensions [mm]
A_{out}	9.15
A_{in}	8.35
w_t	0.4
s	0.4
Gap	0.8
w_{strip}	0.4
l_{strip}	10.5
a	2.8
b	0.925
c	1.85
d	34.3

Thirdly, a metamaterial unit cell is designed on a superstrate of TMPA which resonates for a similar frequency to DGS. It is placed above the TMPA with an air gap of 51 mm, and it has been used for gain enhancement. The superstrate consists of four metamaterial unit cells on an FR-4 substrate ($\varepsilon = 4.4$) with 1.6 mm thickness and 4 metallic strip lines on the other side of the same substrate. The whole dimensions of the metamaterial superstrate layer are $58 \times 22\,\text{mm}^2$, and it is located at a distance "d" of 34.3 mm apart from each other. Finally, superstrate layer is designed, analyzed, and simulated for double negative properties of permittivity and permeability. It is optimized for the desired frequency band and has been specially used to increase the gain of TMPA to 7 dBi. The proposed unit cell is analyzed by using the high frequency structural simulator (HFSS). The optimized dimensions of the metamaterial unit cell are listed in Table 3, and the metamaterial unit cell geometry is as shown in Fig. 4. The top view of the superstrate has four metamaterial unit cells, and it is introduced onto the conventional patch antenna with an air gap between them as shown in Fig. 5.

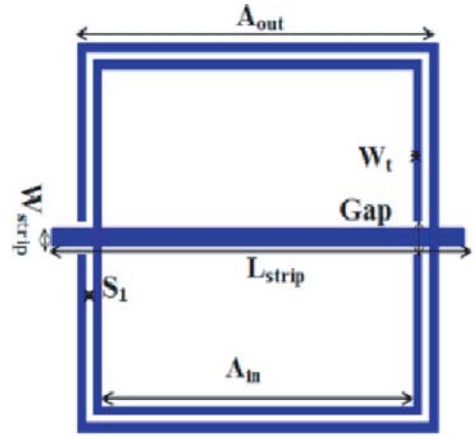


Figure 4. Geometry of metamaterial unit cell.

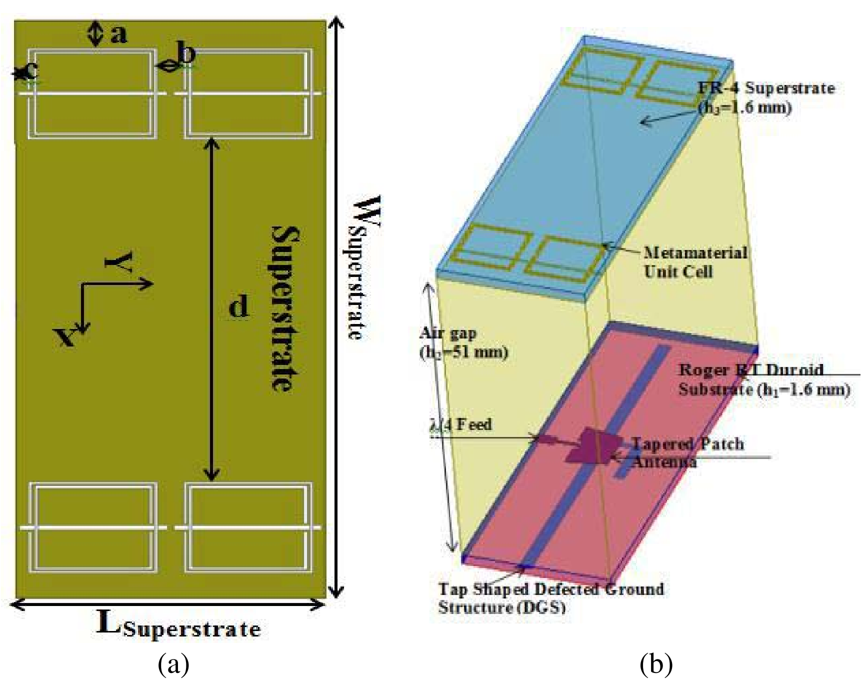


Figure 5. (a) Top view of superstrate (Ant#3); (b) Final construction of single band patch antenna incorporated with metamaterial unit cell.

3. RESULTS, ANALYSIS AND DISCUSSIONS

The proposed Tapered Microstrip Patch Antenna (TMPA) is simulated with two distinct Electromagnetic (EM) simulation softwares: ADS and HFSS. In these results, we discuss the return loss, current distribution, radiation patterns, parametric analysis of long slot, VSWR, and the characteristics of the unit cell such as relative permittivity and relative permeability.

3.1. Return Loss

The measured and simulated return losses of proposed antenna are acquired from a basic conventional patch antenna by using ADS and HFSS, which are shown in Fig. 6. It brings good input impedance matching at 14.5 GHz with a small acceptable shift in ADS as compared with HFSS solver. The reflection coefficient of tap-shaped DGS gives good matching at 1.575 GHz with return losses of −26.51 and −33.11, respectively, is obtained. Its bandwidth is equal to 230 MHz (1.48 GHz to 1.69 GHz).

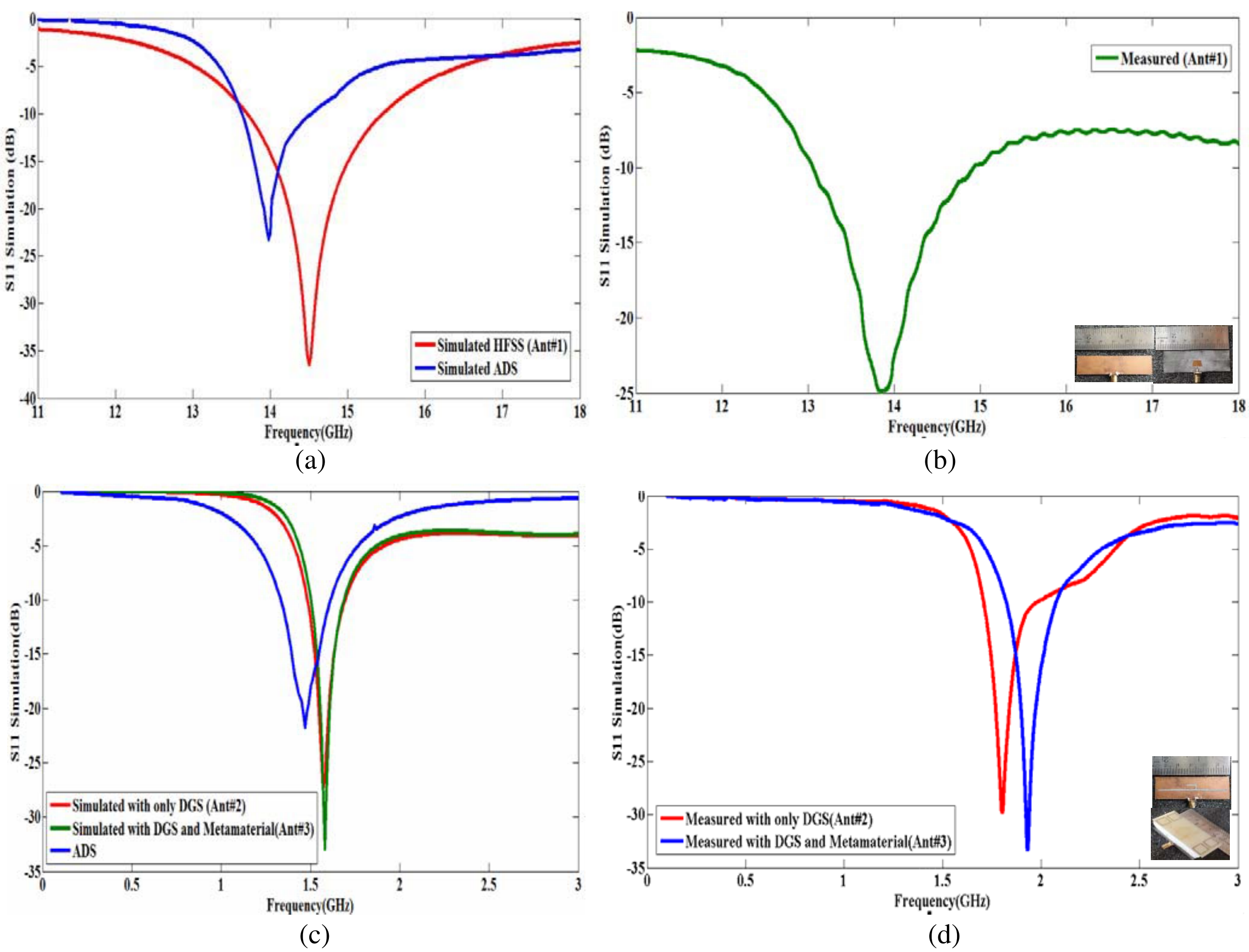


Figure 6. Return loss simulated and measured — (a) & (b) TMPA at 14.5 GHz without DGS (Ant#1); (c) & (d) with only DGS; with DGS and metamaterial at 1.575 GHz (Ant#2 & 3).

3.2. Parametric Analysis of Long Slot (s) in mm

We can see that the effect of TSDGS which permits to switch its location of the resonant frequency from 14.5 GHz to 1.575 GHz. The proposed TSDGS is designed and analyzed for the effect of different lengths of a long slot 'S' in mm. The impact of DGS, as the length of the space expanding, gives the effect of moving the principal resonances (Right to Left) to bring down frequencies. A tap-shaped long slot length 's' is 45 mm (solid line curves) which has the first resonance at 1.85 GHz, whereas the subsequent resonance is nearly at 1.8 GHz for 's' = 46 mm. Further, with an increment of this parameter, i.e., 54 mm and 55 mm, we can notice the existence of resonant frequencies at 1.6 GHz and 1.575 GHz with return losses of −25.3 dB and −26.51 dB, respectively. The parametric study of the tap-shaped DGS antenna has been done by using HFSS. The return loss of the tap-shaped long slot with different lengths 's' is presented in Fig. 7.

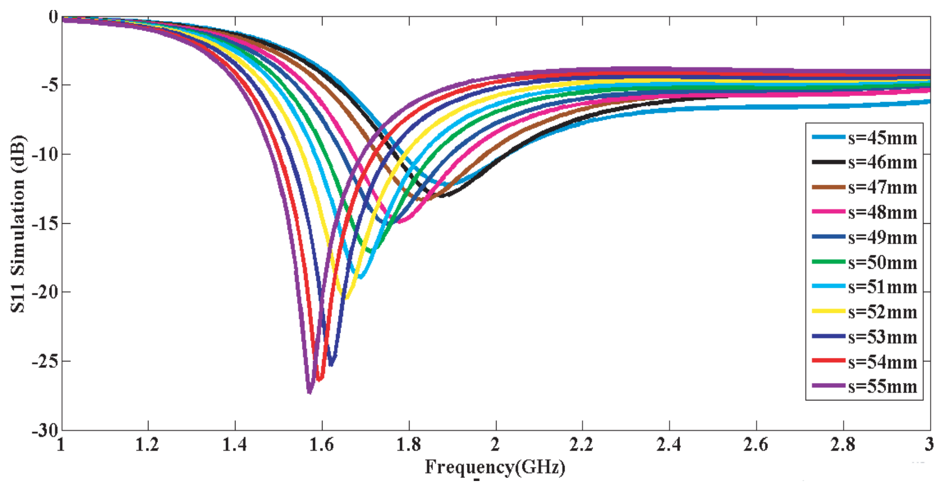
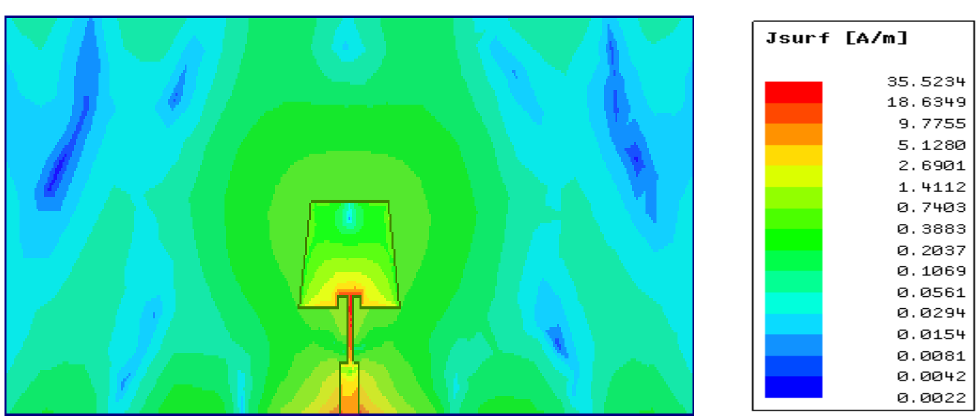


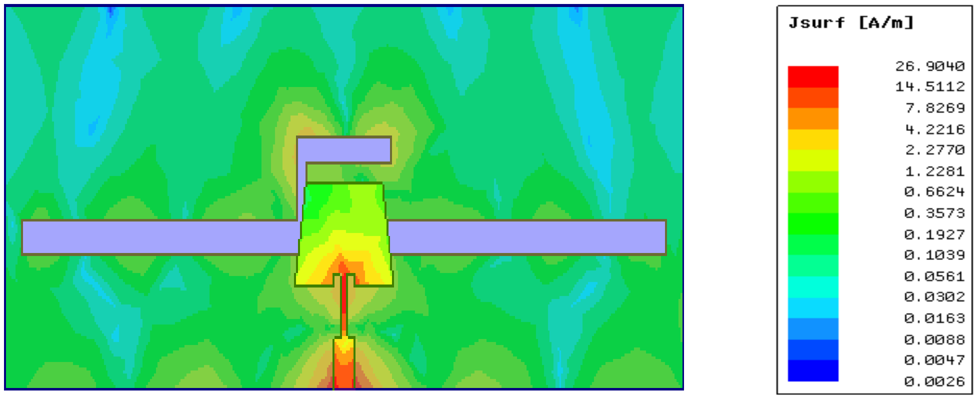
Figure 7. Parametric analysis of tap shaped-long slot with various lengths 's' in mm (Ant#2).

3.3. Current Distribution

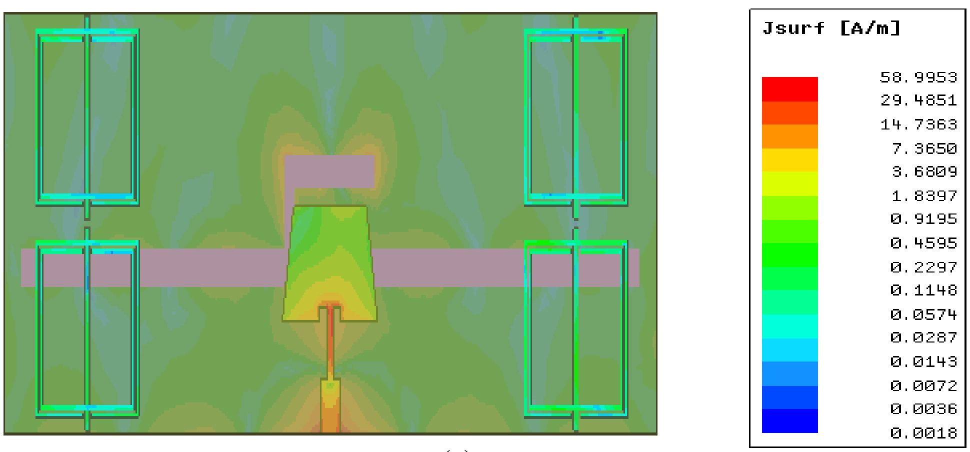
The distributions of different surface currents are acquired from the simulation of HFSS for TMPA without DGS, with only DGS, with DGS and metamaterial superstrate at 14.5 GHz and 1.575 GHz, respectively, and three dimensional gain plots are observed in Fig. 8. The ground plane defects disturb the distribution of current. This current focuses around the TSDGS and metamaterial, and as a result, excitation is controlled. Due to this, the electromagnetic waves propagate through the substrate and will change the resonance at particular peak value.



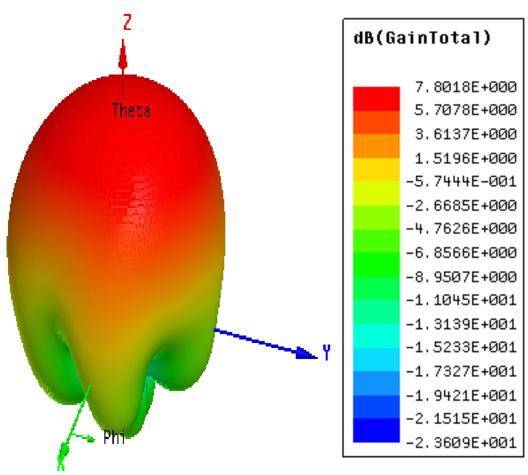
(a)


Jsurf [A/m]
26.9040
14.5112
7.8269
4.2216
2.2770
1.2281
0.6624
0.3573
0.1927
0.1039
0.0561
0.0302
0.0163
0.0088
0.0047
0.0026

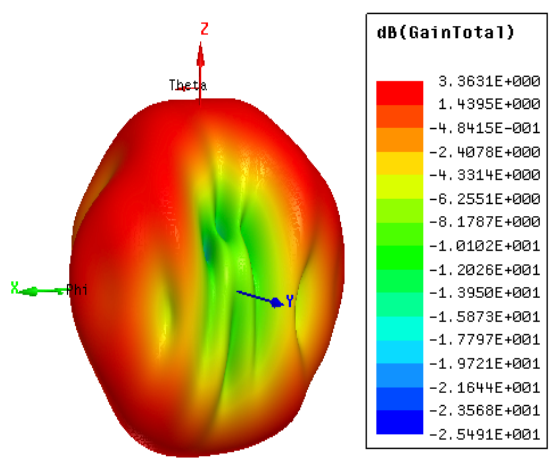
(b)


Jsurf [A/m]
58.9953
29.4851
14.7363
7.3650
3.6809
1.8397
0.9195
0.4595
0.2297
0.1148
0.0574
0.0287
0.0143
0.0072
0.0036
0.0018

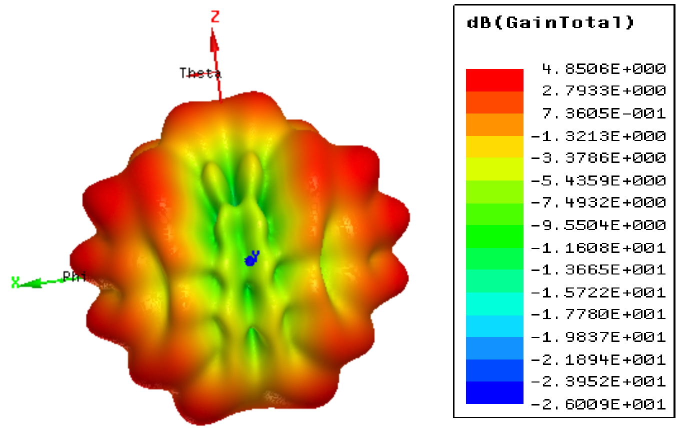
(c)


Z
Theta
Y
Phi
X
dB(GainTotal)
7.8018E+000
5.7078E+000
3.6137E+000
1.5196E+000
-5.7444E-001
-2.6685E+000
-4.7626E+000
-6.8566E+000
-8.9507E+000
-1.1045E+001
-1.3139E+001
-1.5233E+001
-1.7327E+001
-1.9421E+001
-2.1515E+001
-2.3609E+001

(d)


Z
Theta
X
Phi
Y
dB(GainTotal)
3.3631E+000
1.4395E+000
-4.8415E-001
-2.4078E+000
-4.3314E+000
-6.2551E+000
-8.1787E+000
-1.0102E+001
-1.2026E+001
-1.3950E+001
-1.5873E+001
-1.7797E+001
-1.9721E+001
-2.1644E+001
-2.3568E+001
-2.5491E+001

(e)



(f)

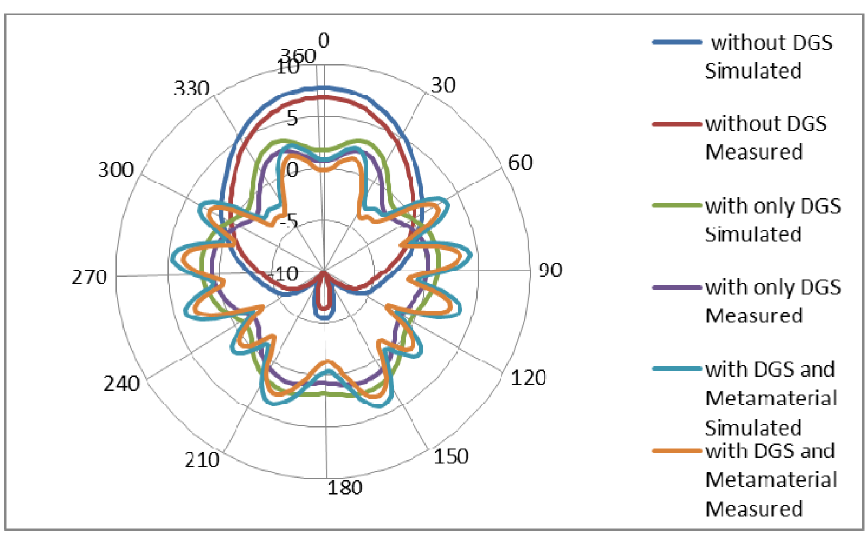
Figure 8. The distribution of surface current and three dimensional gain plot — (a) & (d) at 14.5 GHz without DGS (Ant#1); (b) & (e) at 1.575 GHz with only DGS (Ant#2); (c) & (f) at 1.575 GHz with DGS and superstrate metamaterial (Ant#3).

3.4. Radiation Pattern

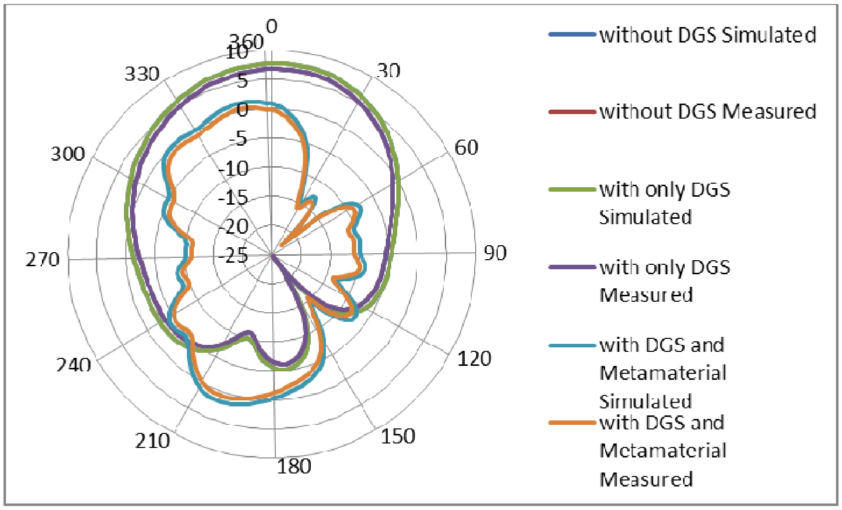
The radiation patterns of H-plane ($\phi = 90$) and E-plane ($\phi = 0$) of the proposed antenna without DGS, with only DGS, and with DGS and metamaterial are presented in Fig. 9. The conventional antenna radiates on both sides of ground plane due to the aperture efficiency performance. As a result, it produces a higher back lobe radiation level which explains the gain reduction about 3.36 dB. The increase of lateral and longitudinal radiations will describe this gain reduction due to the propagation of surface waves. Especially, these radiations adversely affect the main lobe power, and therefore a reduction of the gain is produced.

3.5. VSWR

VSWR is pertinent to the coefficient of reflection, and it is explained as the ratio of higher voltage value to the lower voltage value of a standing wave which has been stored in the dielectric. One of the specific parameters of tapered microstrip patch (TMPA) antenna is VSWR (voltage standing wave ratio). The limit of VSWR of TMPA is not exactly or equivalent to 2. This scale is fulfilled by all



(a)



(b)

Figure 9. Radiation patterns of measurement and simulation for without DGS, with only DGS, and metamaterial superstrate with DGS — (a) (E-plane) and (b) (H-plane).

resonant frequencies. The worthy estimation of VSWR must be in the range from 1 to 2. Fig. 10 shows simulated and measured plots of VSWR of the proposed model with values of 1.03, 1.09, and 1.04 for the corresponding resonant frequencies of 14.5 GHz and 1.575 GHz, respectively.

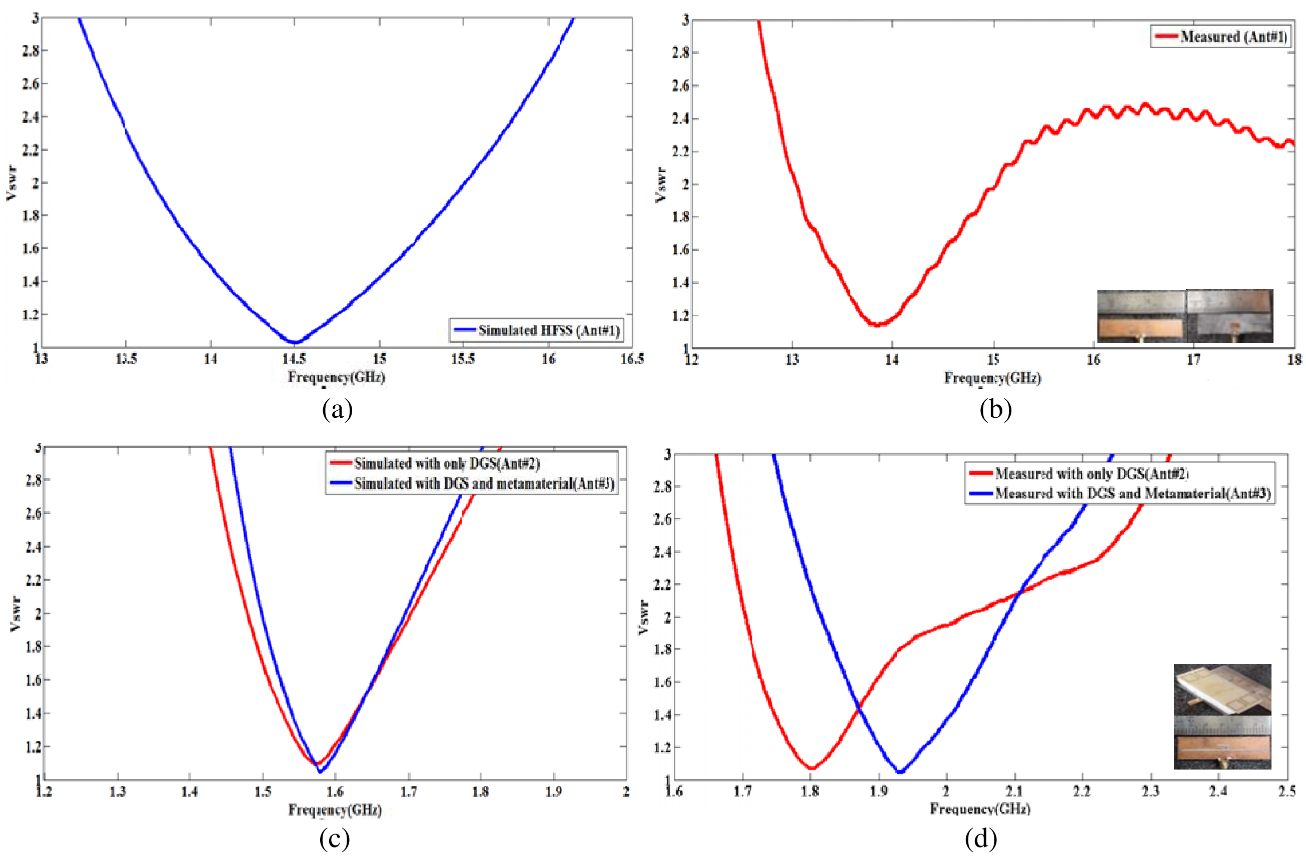


Figure 10. VSWR plot for the proposed model — (a), (b) at 14.5 GHz; (c), (d) at 1.575 GHz.

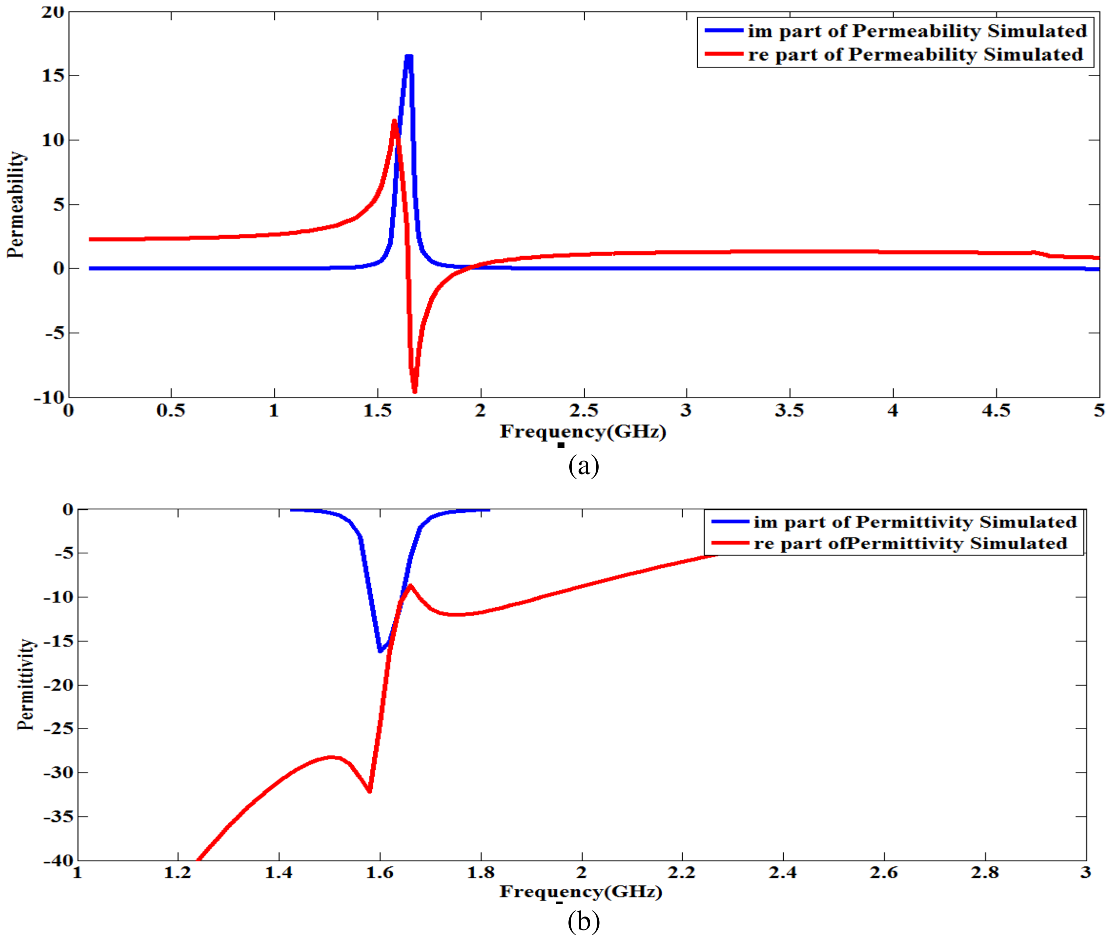


Figure 11. The real and imaginary values of (a) permittivity and (b) permeability.

Table 4. Comparison of different published literatures and proposed antenna.

Ref., year	**Technique**	**Substrate material**	**Antenna size (mm^3)**	**Switching Resonant Frequency *GHz***	**Miniaturized Percentage**	**Gain (dBi)**	**Gain (dB)**	**Application**
[24] 2014	DGS	FR4	$13 \times 12 \times 1.58$	5.7 *to* 3	47.36	2.14	0.01	WiMAX
[25] 2017	DGS	FR4	$34 \times 34 \times 1.6$	5.8 *to* 2.5	56.89	1.75	0.4	ISM
[26] 2017	DGS	FR4	$27.9 \times 35.75 \times 1.6$	5.8 *to* 2.45	57.77	4.835	2.087	ISM
[27] 2017	DGS	FR4	$34 \times 34 \times 1.6$	5.8 *to* 2.45	57.77	No-Data	No-Data	ISM
[28] 2017	DGS	FR4	$11.5 \times 10.5 \times 1$	7.4 *to* 5.4	27.02	No-Data	1.6	ISM
[29] 2017	DGS	FR4	$27 \times 30 \times 1.6$	10 *to* 3.5	65.0	4.41	2.26	WiMAX
[30] 2019	DGS	FR4	$34 \times 34 \times 1.6$	13 *to* 2.4	81.53	3.83	1.68	WLAN
Proposed system	DGS and metamaterial	Rogers RT/ Duroid 5880 FR4	$58 \times 22 \times 1.6$	14.5 *to* 1.575	89.13	7	4.85	GPS

3.6. Relative Permittivity and Relative Permeability of the Metamaterial Unit Cell

Figure 11 shows negative characteristics of permittivity and permeability for metamaterial unit cell at 1.575 GHz. We can determine the effective permeability and permittivity of a metamaterial-slab from HFSS simulations by using Floquet port analysis concept. The results are obtained for negative permittivity and permeability of superstrate in the desired frequency band at 180 degree orientation.

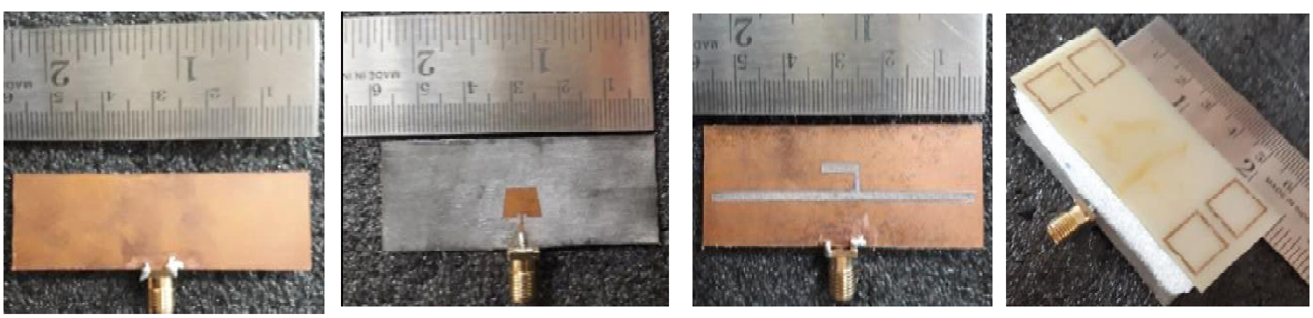
Finally, we can see the summary of other published literatures in comparison with proposed antenna for various parameters in Table 4 and comparison of simulated and measured results of proposed antennas in Table 5.

Table 5. Comparison of simulation and measured results of proposed antennas.

Type of Antenna		**Bandwidth (GHz)**	**Return loss (dB)**	**VSWR**	**Resonant frequency (GHz)**
TMPA Without DGS	Simulated	1.75	−36.46	1.03	14.5
	Measured	2	−25	1.09	13.95
TMPA with only Tap shaped DGS	Simulated	0.23	−26.51	1.09	1.575
	Measured	0.25	−29	1.06	1.75
TMPA with Tap shaped DGS and Metamaterial	Simulated	0.19	−33.11	1.04	1.575
	Measured	0.20	−33.5	1.03	1.9

4. PRACTICAL IMPLEMENTATION

The fabrication of all models after the analysis of the simulation results for the proposed tapered patch antenna without DGS, with only DGS, and with DGS and metamaterial superstrate is shown in Fig. 12, and the prototype antenna has a size of $58 \times 22 \times 1.6\,\mathrm{mm}^3$. The proposed antenna is fabricated by utilizing an MITS prototyping machine and experimented with using the Vector MS2037C Network Analyzer (VNA).



(a) (b) (c) (d)

Figure 12. Fabricated prototype of antenna — (a) bottom view of conventional planar antenna (Ant#1); (b) top view patch antenna (Ant#1); (c) back view of miniaturized antenna with only DGS (Ant#2) and (d) top view of metamaterial superstrate with DGS (Ant#3).

5. CONCLUSION

In this paper, we have developed a creative methodology of miniaturized tapered microstrip patch antenna by using DGS technique. At first, the basic proposed convention antenna was tried at 14.5 GHz. The goal of this work was to shift the resonance frequency from 14.5 GHz to 1.575 GHz. When a tap-shaped DGS is employed in the ground plane of the tapered patch antenna, the surface current flow is wandered, and consequently the electrical length of antenna is expanded. So by expanding the electrical length of the antenna, the resonance frequency is moved. After this achievement, a miniature tapered microstrip patch antenna has been developed, examined, and validated for Global Positioning System in satellite navigation system (GPS) application. The proposed antenna gain is successfully enhanced through the incorporation of the metamaterial superstrate onto the tapered patch antenna. A gain of 7 dBi has been improved, and miniaturization is up to 89.31%, with respect to the conventional tapered microstrip patch antenna, and is effectively carried out.

REFERENCES

1. Malisuwan, S., J. Sivaraks, N. Madan, and N. Suriyakrai, "Design of microstrip patch antenna for Ku-band satellite communication applications," *International Journal of Computer and Communication Engineering*, Vol. 3, No. 6, November 2014.
2. Patel, N., J. Singh, and M. Tiwari, "Rectangular microstrip patch antenna for wireless communications at 6.5 GHz," *International Journal of Scientific & Engineering Research*, Vol. 5, No. 3, March 2014, ISSN 2229-5518.
3. Khanna, G. and N. Sharma, "Fractal antenna geometries: A review," *International Journal of Computer Applications (0975–8887)*, Vol. 153, No. 7, November 2016.
4. Borazjani, O., M. Naser-Moghadasi, J. Rashed-Mohassel, and R. A. Sadeghzadeh, "Design and fabrication of a new high gain multilayer negative refractive index metamaterial antenna for X-band applications," *International Journal of RF and Microwaves Computer Aided Engineering*, Wiley, April 26, 2020.
5. Soba, J., Chairunnisa, and A. Munir, "Dual-band patch antenna incorporated with SRR for GPS and WLAN application," IEEE, 2017.
6. Raja Lakshmi, P. and N. Gunavathi, "Gain enhancement of cross shaped patch antenna for IEEE 802.11ax Wi-Fi applications," *Progress In Electromagnetics Research Letters*, Vol. 80, 91–99, 2018.
7. Devi, K. A., C. H. Ng, C. F. Kwong, C. K. Chakrabarty, and N. Md. Din, "Investigations on characteristics of metamaterial based patch antenna for RF energy harvesting at GSM 900," *Electrical and Electronic Engineering*, Vol. 5, No. 1A, 7–13, 2015.
8. Asadullah, G. M., M. R. Islam, M. S. Islam, and M. M. H. Mahfuz, "A circular equivalent planar array configuration for 5.8 GHz radar application," *AIP Conference Proceedings*, March 2020.
9. Kovacs, P. and T. urbanec, "Electromagnetic band gap structures: Practical tips and advice for antenna engineers," *Radio Engineering*, Vol. 21, No. 1, April 2012.
10. Kumar, A. and S. Raghavan, "A review: Substrate integrated waveguide antennas and arrays," *Journal of Telecommunication, Electronic and Computer Engineering*, Vol. 8, No. 5 May–August 2016, ISSN: 2180-1843, e-ISSN: 2289-8131.
11. Khandelwal, M. K., B. K. Kanaujia, and S. Kumar, "Defected ground structure: Fundamentals, analysis, and applications in modern wireless trends," *Hindawi International Journal of Antennas and Propagation*, Vol. 2017, 2017.
12. Kumar, A. and K. V. Machavaram, "Microstrip filter with defected ground structure: A close perspective," *International Journal of Microwave and Wireless Technologies*, Vol. 5, No. 5, 589–602, 2013.
13. Sibi Chakravarthy, S., N. Sarveshwaran, S. Sriharini, and M. Shanmugapriya, "Comparative study on different feeding techniques of rectangular patch antenna," IEEE, 2016.
14. You, C., M. M. Tentzeris, and W. Hwang, "Multilayer effects on microstrip antennas for their integration with mechanical structures," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 4, April 2007.
15. Jose Alfredo, H., F. Iturbide, I. Garcia-Ruiz, V. Molina-Lopez, and R. Acevo-Herrera, "A Defected Microstrip Structure (DMS) behavior for reducing rectangular patch antenna size," *Microwave and Optical Technology Letters*, Vol. 43, No. 6, December 20, 2004.
16. Anwar, R. S., L. Mao, and H. Ning, "Frequency selective surfaces: A review," *Applied Sciences*, 2018.

17. Joshi, N. K. and P. A. Upadhye, "Microstrip patch antenna with W-shape slot using dual dielectric substrates," *2nd International Conference on Communication Engineering and Technology*, 2019.
18. Karamchandani, S. H., S. Shubham, H. D. Mustafa, S. N. Merchant, and U. B. Desai, "Dual band M-shaped UWB patch antenna for wireless body area networks," IEEE, 2011.
19. Meena, M. L. and M. Kumar, "Eight shape microstrip patch antenna with crescent slot for wide band applications," *Conference Paper*, September 2013.
20. Mishra, R. G., R. Mishra, P. Kuchhal, and N. Prasanthi Kumari, "Performance enhancement of rectangular microstrip antenna by inserting notches and slits," January 2018.
21. Parkt, J.-S., J.-H. Kimt, J.-H. Leet, S.-H. Kimt, and S.-H. Myungtt, "A novel equivalent circuit and modeling method for defected ground structure and its application tooptimization of a DGS low pass filter," *2002 IEEE MTT-S Digest*, 2002.
22. Kapoor, S. and D. Parkash, "Miniaturized triple band microstrip patch antenna with defected ground structure for wireless communication applications," *International Journal of Computer Applications (0975–8887)*, Vol. 57, No. 7, November 2012.
23. Kapoor, S. and D. Parkash, "Microstrip patch antenna with SKEW-F shaped DGS for dual band operation," *Progress In Electromagnetics Research M*, Vol. 19, 147–160, 2011.
24. Elftouh, H., N. A. Touhami, and M. Aghoutane, "Miniaturized microstrip patch antenna with defected ground structure," *Progress In Electromagnetics Research C*, Vol. 55, 25–33, 2014.
25. Er-Rebyiy, R., J. Zbitou, M. Latrach, A. Tajmouati, A. Errkik, and L. El Abdellaoui, "New miniature planar microstrip antenna using DGS for ISM applications," *TELKOMNIKA*, Vol.15, No. 3, 1149–1154, September 2017.
26. Ghaloua, A., J. Zbitou, L. El Abdellaoui, and M. Latrach, "A miniature circular patch antenna using defected ground structure for ISM band applications," *ICCWCS'17*, Larache, Morocco, November 14–16, 2017.
27. Er-Rebyiy, R., J. Zbitou, M. Latrach, A. Tajmouati, A. Errkik, and L. El Abdellaoui, "A novel design of a miniature low cost planar antenna for ISM band applications," *ICCWCS'17*, Larache, Morocco, November 14–16, 2017.
28. Mouhssine, A., Z. Doulfakar, R. Dakir, A. Erkkik, and M. Latrach, "A new compact and miniaturized CPW antenna with DGS and paper substrate for ISM band application," *ICCWCS'17*, Larache, Morocco, November 14–16, 2017.
29. Er-Rebyiy, R., J. Zbitou, A. Tajmouati, M. Latrach, A. Errkik, and L. El Abdellaoui, "A new design of a miniature microstrip patch antenna using defected ground structure DGS," IEEE, 2017.
30. Suvarna, K., N. Ramamurthy, and D. V. Vardhan, "A miniature rectangular patch antenna using defected ground structure for WLAN applications," *Progress In Electromagnetics Research C*, Vol. 95, 131–140, 2019.
31. Smith, D. R., S. Schultz, P. Markos, and C. M. Soukoulis, "Determination of negative permittivity and permeability of metamaterials from reflection and transmission coefficients," *Phys. Rev. B*, 2002.
32. Chen, H. J., J. Zhang, Y. Bai, Y. Luo, L. X. Ran, Q. Jiang, et al., "Experimental retrieval of the effective parameters of metamaterial based on a waveguide method," *Optics Express*, Vol. 14, No. 26, 2006.
33. Huang, Y. and K. Boyle, *Antennas from Theory to Practice*, A John Wiley and Sons, Ltd., Publication, 2008.
34. Bahl, I. J. and P. Bhartia, *Microstrip Antennas Dedham*, Artech House, 1980.
35. Balanis, C. A., *Antenna Theory: Analysis and Design*, 3rd Edition, Wiley, 2005.
36. Guha, D. and Y. M. M. Antar, *Microstrip and Printed Antennas New Trends, Techniques and Applications*, John Wiley Sons Ltd, 2011.