Bulletin of Electrical Engineering and Informatics
Vol. 8, No. 2, June 2019, pp. 586~595
ISSN: 2302-9285, DOI: 10.11591/eei.v8i2.1495

Microstrip patch antenna with defected ground structure for biomedical application

Md. Shazzadul Islam, Muhammad I. Ibrahimy, S. M. A. Motakabber, A. K. M. Zakir Hossain, S. M. Kayser Azam
Department of Electrical and Computer Engineering, International Islamic University Malaysia, Malaysia

Article Info

Article history:

Received Jan 10, 2019
Revised Feb 28, 2019
Accepted Mar 15, 2019

Keywords:

Antenna array
Biomedical application
Defected ground structure
Inset fed
ISM band
Patch antenna

ABSTRACT

Proper narrowband antenna design for wearable devices in the biomedical application is a significant field of research interest. In this work, defected ground structure-based microstrip patch antenna has been proposed that can work for narrowband applications. The proposed antenna works exactly for a single channel of ISM band. The resonant frequency of the antenna is 2.45 GHz with a return loss of around -30 dB. The -10dB impedance bandwidth of the antenna is 20 MHz (2.442-2.462 GHz), which is the bandwidth of channel 9 in ISM band. The antenna has achieved a high gain of 7.04 dBi with an increase of 17.63% antenna efficiency in terms of realized gain by using defected ground structure. Three linear vector arrays of arrangement 1×2, 1×4 and 1×8 have been designed to validate the proposed antenna performances as an array. The proposed antenna is light weighted, low cost, easy to fabricate and with better performances that makes it suitable for biomedical WLAN applications.

Corresponding Author:

Muhammad I. Ibrahimy,
Department of Electrical and Computer Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100, Kuala Lumpur, Malaysia.
Email: ibrahimy@iium.edu.my

1. INTRODUCTION

Wearable devices are becoming popular rapidly because of its flexibility and necessity of using in different disciplines like healthcare, industrial, environmental monitoring and so on. Especially in healthcare, the growth of wearable devices is increasing for better medical services. In most of the cases, the wearable devices are needed to be worked wirelessly to ensure its operational flexibility. Different wireless communication technologies i.e., Wi-Fi, ZigBee, WLAN, Bluetooth/WPAN, WSN, Body Area Network (BAN) etc are the common topologies for these devices to be worked wirelessly. An antenna is the most important component for wireless communication technology that makes these wearable devices able to transmit and receive the signal wirelessly. To meet the certain requirements for wearable devices, proper design of an antenna is still a great challenge for the design engineers. The basic requirements of antennas are lightweight, small and with low manufacturing cost, which should be taken into account while designing antennas for these particular wearable devices. In so many different kinds of antennas, microstrip patch antenna fills all these requirements in a very good way. Because of its significant performances, designers and engineers are always preferring patch antenna for different wearable devices that communicate wirelessly [1].

Patch antennas are more popular because it is simple to design and can be modified easily to match expecting resonant frequency, impedance, polarization and radiation pattern. Hence, when the antenna works near to human body, in most of the cases it can lose its performances as the human body behaves as a dielectric lossy material. Because of the discontinuity of different dielectric properties of different human tissue, the antenna performances can be degraded in terms of directivity gain and efficiency. Different initiatives have been utilized like slots on the patch, different dielectric materials, feeding technics and defected ground structures (DGS) to improve the antenna performance. In [2], the authors have shown how the antenna feeding position and feeding technique can effect on the antenna performance. A rectangular microstrip patch antenna has been designed that resonates at 2.45 GHz. To design the antenna, the authos have used 1.6mm thick FR4 substrate and they utilized inset feeding technique. Several authors have also used FR4 substrate to design their antenna with different methods such as, different slots on the radiating patch or ground plane and sometimes both have been utilized in many works [3-7]. In [3], the authors have designed split ring resonator on the ground plane to improve and have been achieved a bandwidth of 100 MHz. With the DGS technique, 5.93 dBi directivity gain has been archived. In [4], an inset-fed antenna with DGS has been proposed to enhance antenna performance. The antenna has a minimum return loss with a wide bandwidth. However, the directivity of the antenna is 3.049 dBi only. In [5], an wide bandwidth of 117 MHz has been achieved with a U shape DGS while the antenna gain is 2.80 dBi. In [6], authors have proposed rectangular shape patch antenna with a new approach of a switched beam on the top plane and slots on the ground plane. Circular shaped dumbbell DGS has been proposed in [7]. With the particular approach, the authors have been able to miniaturize the antenna size of around 74.5%. An inset-fed patch antenna with slots on the top plane has been introduced in [8]. By using different substrate authors have been able to achieve high gain and a minimum return loss of their proposed antenna. To design the antenna, an RT Duroid with 1.6mm thickness has been used. An antenna with DGS on 1.52 mm thick Taconic RF-5 has been proposed in [9]. The antenna resonates at 2.45 GHz with a wide bandwidth of 380 MHz. A pentagon-shaped microstrip patch antenna with DGS has been proposed in [10]. In this paper, a comparatively thin FR4 substrate with a thickness of 0.8 mm has been used. With the design, authors have been able to achieve a minimum return loss of -31 dB with a good directivity gain of 5.28 dBi. However, the antenna has a poor total efficiency of -17 dB. In [11, 12], authors have been proposed square-shaped ring resonator loaded patch antenna with L and U-shaped DGS. The proposed antenna has achieved a wide bandwidth of 70 MHz with a directive gain of 1.5 dBi.

Written above works, presents their design on thick dielectric materials and most of the authors have been tried to achieve wide bandwidth. But for narrowband WLAN applications, an extra component like bandpass filter should be used to avoid signal interference and to specify channel [13, 14]. To overcome the limitation of using extra component, an initiative has been taken to design an antenna with specific channel bandwidth. In this work, a thin Taconic TLX-8 dielectric material has been used to design the antenna. The thickness of the substrate is 0.5 mm, dielectric constant 2.55 and loss tangent 0.0019. The antenna is with a low fabrication cost, lightweight and comparatively small. The proposed antenna is able to work for a single channel, and it has successfully covered the 20 MHz channel width standards of IEEE 802.11 g/n (OFDM). In ISM band, there are 14 different non-overlapping channels for WLAN applications. The proposed antenna has covered exactly the channel 9 bandwidth, that is 20 MHz (2.442-2.462) and 2.452 GHz. certer frequency.

In section 2, the paper discusses the methodology for antenna design and formulas for parameters calculation. With several figures and comparison table of having and not having DGS, the paper describes the results and discussions in section 3. Also, a benchmarking table has given to benchmark this work with some recent works in section 3. In subsection 3.1, it shows three vector array performances of the proposed antenna. The paper ends with a conclusion in section 4.

2. ANTENNA DESIGN

To design an antenna, the middle frequency of ISM band has been chosen as the resonant frequency of the antenna at 2.45 GHz. It has been tried to keep return loss as minimum as possible nearly at the resonant frequency. The proposed antenna is a microstrip patch antenna based on inset-fed technique. The design method and calculation formulas of parameters have been taken from [15, 16] and then optimized the parameters with the CST MWS. The substrate dielectric constant ε_r is not an open choice variable and it depends on which dielectric material has to be used to design the antenna. To design the proposed antenna, a thin and lightweight Taconic TLX-8 substrate with the dielectric constant of 2.55 has been used. The thickness of the substrate is 0.5 mm and loss tangent is 0.0019. Instead of other parameters and properties, the dielectric constant and substrate thickness has been set as constant values

As a design procedure, the radiating patch length (L_p) and patch width (W_p) have been calculated by the specified resonant frequency (f_r) for the antenna with dielectric constant (ε_r) and height (h) of the substrate by using following formulas:

Calculation of Patch width (Wp)

$$W_p = \frac{c}{2\, f_r \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

Calculation of Patch length (Lp) -

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-\frac{1}{2}} \tag{2}$$

$$L_{eff} = \frac{c}{2\, f_r \sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = 0.412h\, \frac{(\varepsilon_{eff} + 0.3)\left(\frac{Wp}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{Wp}{h} + 0.8\right)} \tag{4}$$

$$L_p = L_{eff} - 2\Delta L \tag{5}$$

Where f_r is resonant frequency, W_p is patch width, L_p is the patch length, h is thickness, ε_r is the dielectric constant of the substrate and c is the speed of light: 3×10^8.

To get better efficiency of the antenna performance, it is very important to determine where should be the feed point for perfect impedance matching between the radiating patch and feed line. For inset-fed patch antennas, the calculation of inset length (y_o) and inset width (x_o) is very crucial. As if, the input impedance of the inset-fed microstrip patch antenna depends on the inset length (y_o) and to some extent on inset width (x_o). The resonant frequency shifted with the variation of inset width and the return loss of the antenna changes in the variation of inset length. Inset width (x_o) has to be equal or more than half of the microstrip feed line width, (W_f). For our proposed design, inset width (x_o) has been taken as same as microstrip feed line width (W_f) and feedline length (L_f) is the optimized value. Feed line width and inset length have been calculated with the following formulas:

$$W_f = \frac{7.48 \times h}{e^{\left(Zo\frac{\sqrt{\varepsilon_r + 1.41}}{87}\right)}} - 1.25 \times t \tag{6}$$

$$y_o = \frac{Lp}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_o}{R_{in}}}\right) \tag{7}$$

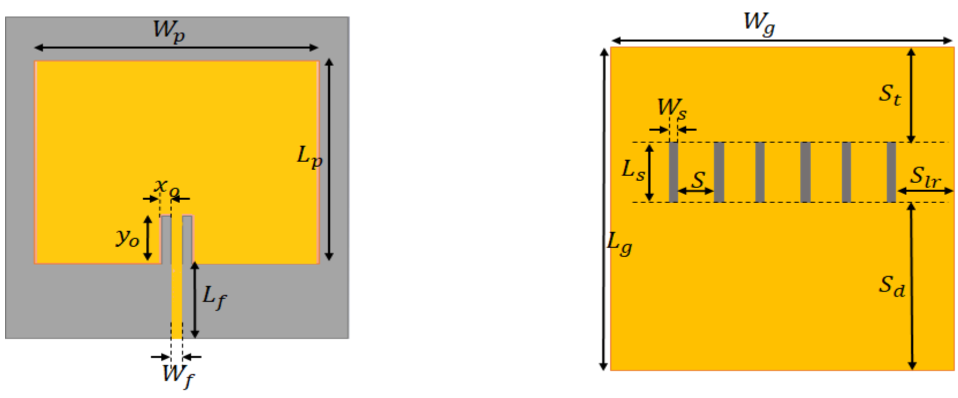
Where W_f is microstrip feed width, y_o is inset length, Z_o is input Impedance and R_{in} is input Resistance. Ground plane width (W_g) and ground plane length (L_g) have calculated with the following formulas [16]:

$$W_g = 6h + W_p \tag{8}$$

$$L_g = 6h + L_p \tag{9}$$

After getting the dimensions of the radiating patch, feed line and ground plane, the structure has modelled and simulated using CST MWS. The antenna geometry has shown in Figure 1. Some parameters have been optimized in CST for getting desired results and the final optimized values are given in Table 1. After design the antenna, it has been noticed that the antenna has not achieved good efficiency. So, to achieve the maximum efficiency of the antenna, the DGS technique has been utilized. Several numbers of parallel slots have been placed vertically and horizontally on the ground plane behind the rectangular patch to achieve the desired efficiency. Generally, DGS is used to make the antenna size compact and to increase efficiency. Several parametric studies have been done in terms of slots length, width, placement and the numbers of slots. A good amount of surface current can be accumulated on the patch only by placing 6 vertically rectangular shape slots on the ground plane behind the middle of the radiating patch. The optimized dimensions of the slots are given in Table 1.

The proposed antenna is not fed with coaxial probe feed technique. So, it will be difficult to design rectangular or circular shape multiple element array because of the difficulty in feeding. That's why, three different linear vector arrays (MIMO - Multiple Input and Multiple Output) of 1x2, 1x4 and 1x8 have been designed in CST Studio and has shown in Figure 2.

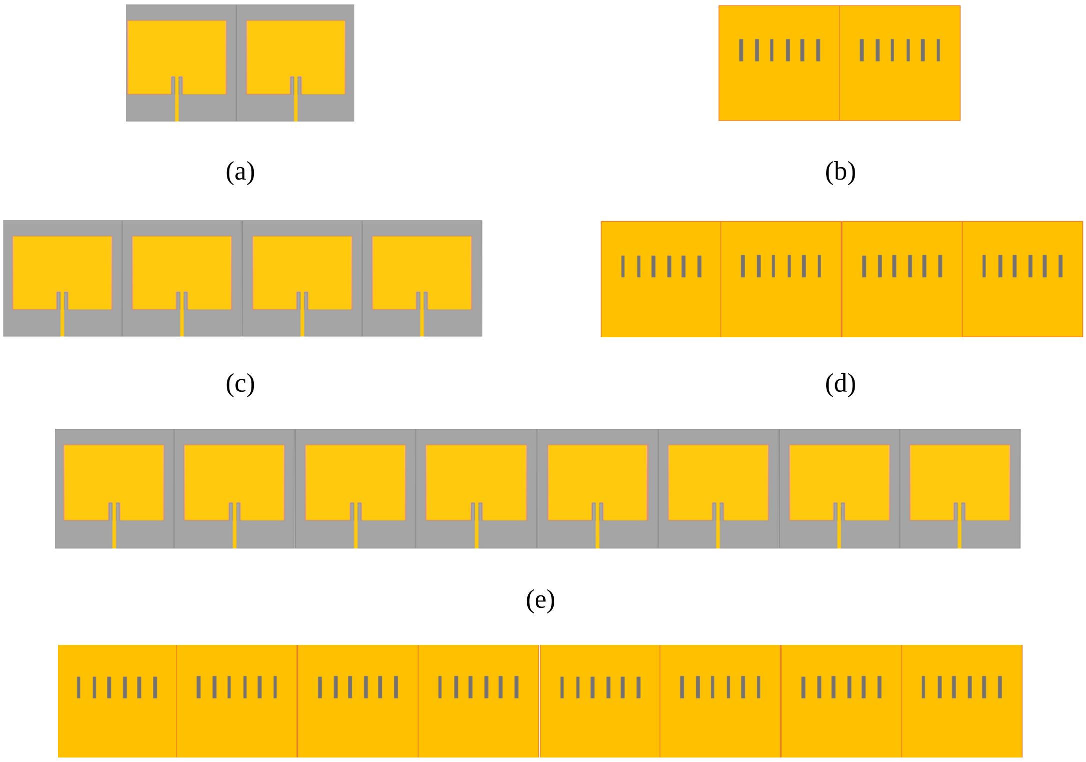


(a) (b)

Figure 1. Proposed antenna geometry, (a) top view, (b) ground view [16]

Table 1. Physical dimensions of the proposed antenna

Parameters	W_p	L_p	W_f	L_f	x_o	y_o	W_g	L_g	W_s	L_s	S	S_{lr}	S_t	S_d
Dimensions (mm)	46	38	1.41	15	1.41	10	55	60	2	10	6	9.5	21	29



(a) (b) (c) (d) (e) (f)

Figure 2. The linear antenna array, (a) front view of the 1x2 array, (b) back view of 1x2 array, (c) front view of the 1x4 array, (d) back view of 1x4 array, (e) front view of the 1x8 array, (f) back view of 1x8 array

3. RESULTS AND DISCUSSION

The simulation of the proposed antenna and antenna array have been done in CST MWS and the simulated result of the return loss (S_{11}) of the proposed single antenna with and without DGS has shown in Figure 3 and in Figure 4 the VSWR response of the antenna.

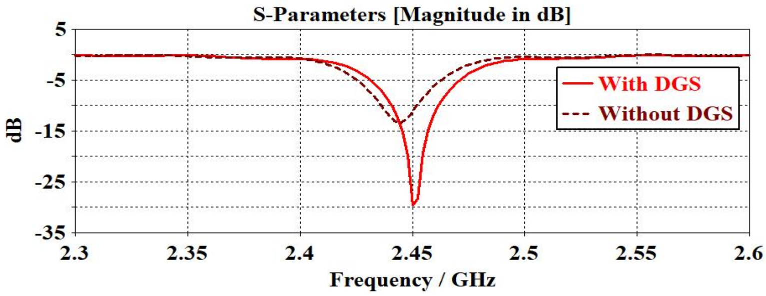


Figure 3. S-parameter of the antenna with and without DGS at the resonant frequency [16]

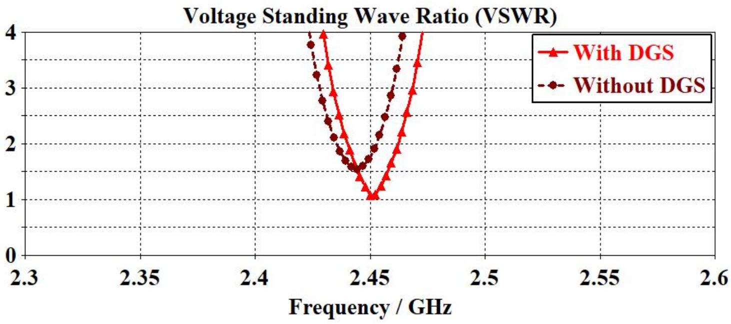
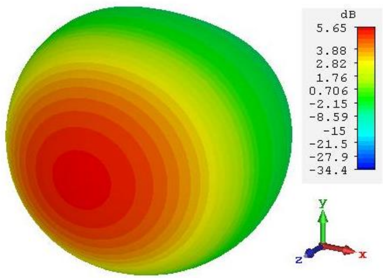
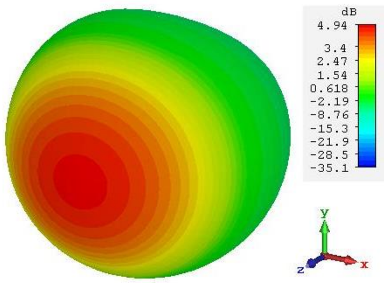


Figure 4. VSWR of the proposed antenna [16]

The 3D plot of the far-field radiation pattern of the antenna in dB value with DGS and without DGS has shown in Figure 5.



(a)



(b)

Figure 5. The 3D radiation pattern, (a) with DGS, (b) without DGS

As shown in Figure 3, the simulated result of the return loss (S_{11}) of the antenna is as low as around -30 dB with DGS and it has a sharp resonance exactly at 2.45 GHz. The -10dB bandwidth of the antenna with DGS is 20 MHz which is from 2.442 GHz to 2.462 GHz. On the other hand, it can also be seen from Figure 3 that the value of S_{11} without DGS is around 13.5 dB. Moreover, the antenna without DGS resonates at 2.44 GHz with a less bandwidth of 16 MHz only. The return loss (S_{11}) of the antenna has decreased around 16 dB with DGS. Figure 4 contains the VSWR response of the antenna with and without DGS. It is seen that with the use of the DGS, the VSWR value is improved from 1.53 to 1.06. With DGS, the antenna patch size has become smaller with 177 mm^2 decreasing in the area. From Figure 5, it can be seen that with DGS, the antenna achieve higher total efficiency (-1.39 dB) compare to the design without DGS (-2.147 dB) which leads to an increased (17.63%) realize gain of 5.65 dB with DGS. The increase in the realized gain of the antenna has been calculated with (10).

$$\% \, increasing = \frac{G_w - G_{wo}}{G_{wo}} \times 100 \quad (10)$$

Where, G_w is the gain of the antenna with DGS and G_{wo} is the realized gain of the antenna without DGS in the linear value of 5.647 dB and 4.937 dB respectively. The maximum realized gain over frequency for the whole bandwidth has shown in Figure 6. It can also be seen from Figure 6 that with having DGS the gain flatness of the antenna for whole bandwidth is more stable than without having DGS.

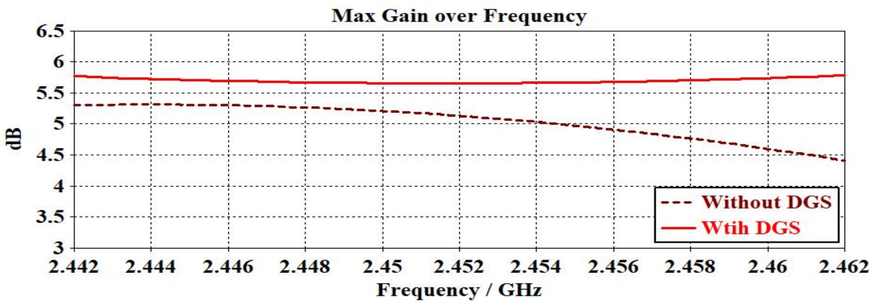
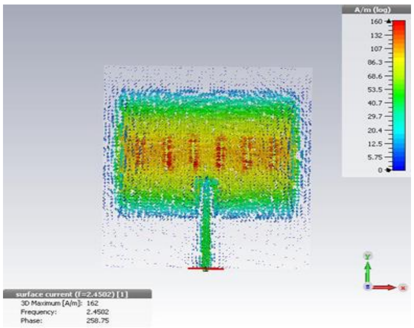
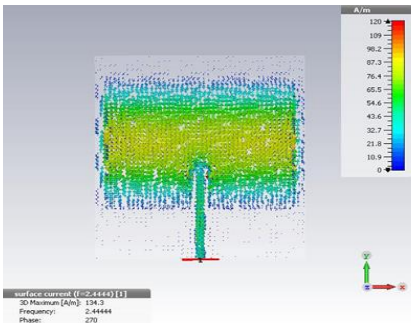


Figure 6. Realized gain over frequency for the whole bandwidth

The current density at the resonant frequency shows a greater amount of accumulated current on the radiating patch. The accumulated current density is above 160 A/m of the design with DGS that is almost 30 A/m more compared to the design without DGS as shown in Figure 7. A summary table of above-mentioned discussions about the antenna improvements with DGS has been given in Table 2.



(a)



(b)

Figure 7. The surface current of the antenna at the resonant frequency, (a) with DGS, (b) without DGS [16]

Table 2. Comparison table improvement of the antenna with and without DGS

Name	With DGS	Without DGS
Antenna dimenssions (W/L), mm.	46/38	50/38.5
Return loss (S_{11}), dB	- 29.73	-13.46
Bandwidth, MHz	21	15.9
VSWR	1.0675	1.5303
Surface current, A/m	162	132.3
Total efficiency, dB	-1.390	-2.147
Gain, dB	5.65	4.94

The polar radiation pattern of the proposed antenna has given in Figure 8. The directivity gain of the antenna is 7.04 dBi with a boresight main lobe direction at 0^0 deg. and 3db angular width is around 92^0.

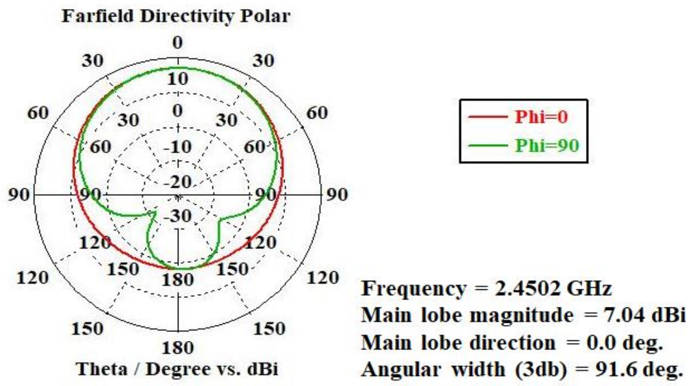


Figure 8. Radiation pattern (polar) of the antenna with boresight main lobe direction

The proposed antenna has been benchmarked with some existing works and has given in Table 3. The antenna has achieved the maximum efficiency than other works in terms of directivity gain and return loss. It can be seen from the table that the antenna has a narrow bandwidth of 20 MHz which is the focus of the research.

Table 3. Comparison table of the antenna to benchmark with existing work

Ref.	f_r	S_{11}	Bandwidth, MHz	Gain, dBi
[4]	2.4	- 26.01	78	3.049
[5]	2.45	- 21.19	117	2.80
[6]	2.45	- 18	40	3.9
[11]	2.45	- 26.9	140	3.56
[12]	2.47	- 22.35	70	1.5
This work	2.45	- 29.73	20	7.04

3.1. Antenna array performance analysis

Usually, it is possible to increase antenna gain by designing an antenna array. Three linear MIMO arrays of 1x2, 1x4 and 1x8 have been designed and simulated in the same environment in CST simulator. The antenna parameters are as same as described before in section 2. The reason behind choosing MIMO array is, it is one of several forms of smart antenna technologies. By using MIMO arrays, there has a freedom of using antenna performances either individually or combinedly. The s-parameter of the 1×2, 1×4 and 1×8 linear arrays have shown in Figure 9. As discussed before that the reason behind designing antenna arrays is to increase antenna gain. In all three different linear arrays, the antenna realized gain has increased significantly and the gain flatness of the antenna arrays over the bandwidth is stable. The maximum realized gain of the antenna arrays over frequency for the entire bandwidth has given in Figure 10. The polar radiation pattern and 3D directivity pattern of the antenna arrays have given in Figure 11. The combined antenna performances have considered for all the simulated results of the antenna arrays that are given.

From Figure 9, it can be clearly seen that the return loss of antenna arrays is as low as around -25 dB and there were no changes in the bandwidth. The mutual coupling effects between two nearby antennas are good enough and the (S_{21}) value is around -17.5 dB for the 1×2 array. Moreover, for 1×4 and 1×8 linear arrays the mutual coupling effect is as same as the 1×2 array, which is -17.5 dB as shown in Figure 9. Figure 10 comprises the maximum realized gain over frequency. The realized gain over frequency for 1×2, 1×4 and 1×8 linear arrays are around 8dB, 11dB and 13dB respectively, which shows a steady increase gain for antenna arrays. It can be seen from Figure 11 that the main lobe direction is still in the boresight direction and the directivity gain is improved significantly. For 1×2 array the directivity gain is 9.17 dBi, for 1×4 array the directivity gain is 11.7 dBi and for 1x8 array the directivity gain is 14.5 dBi. The results have clearly shown that the proposed inset-fed microstrip patch antenna with DGS can work as an array with better performances.

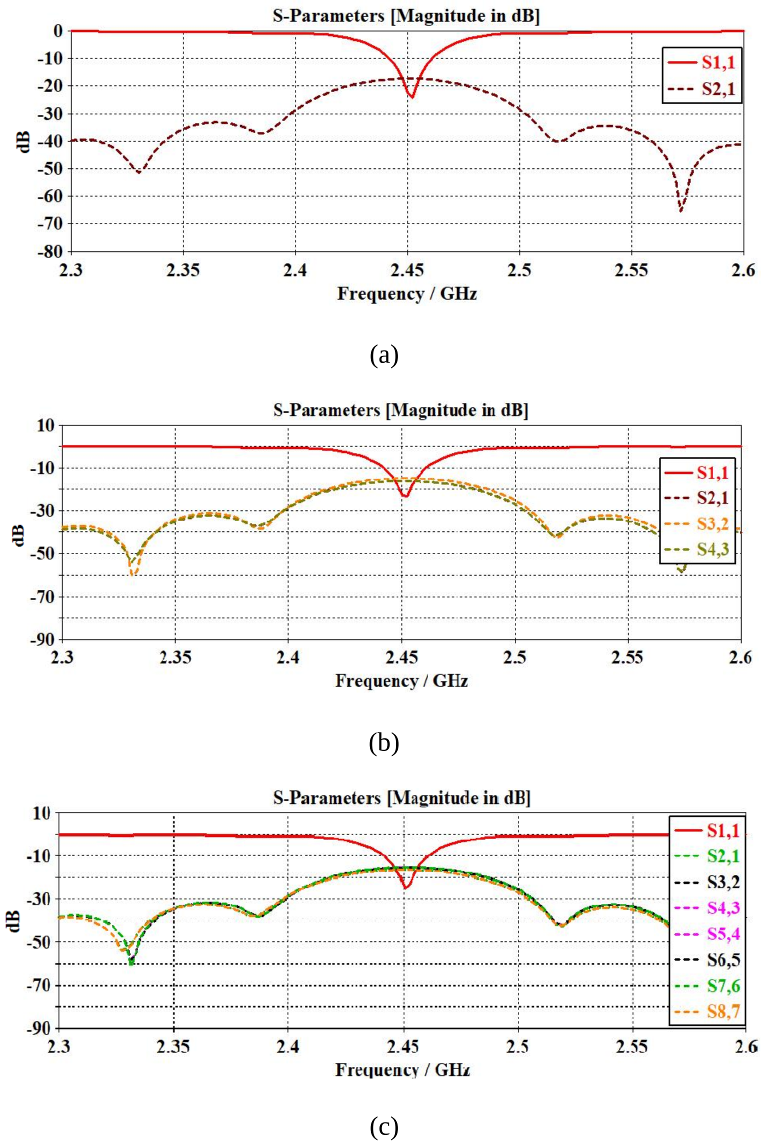


Figure 9. S-parameter of the linear array, (a) 1x2 array, (b) 1x4 array, (c) 1x8 array

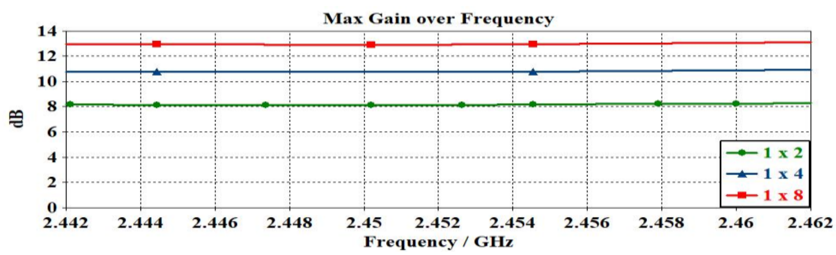


Figure 10. Maximum realized gain over the frequency of the antenna arrays

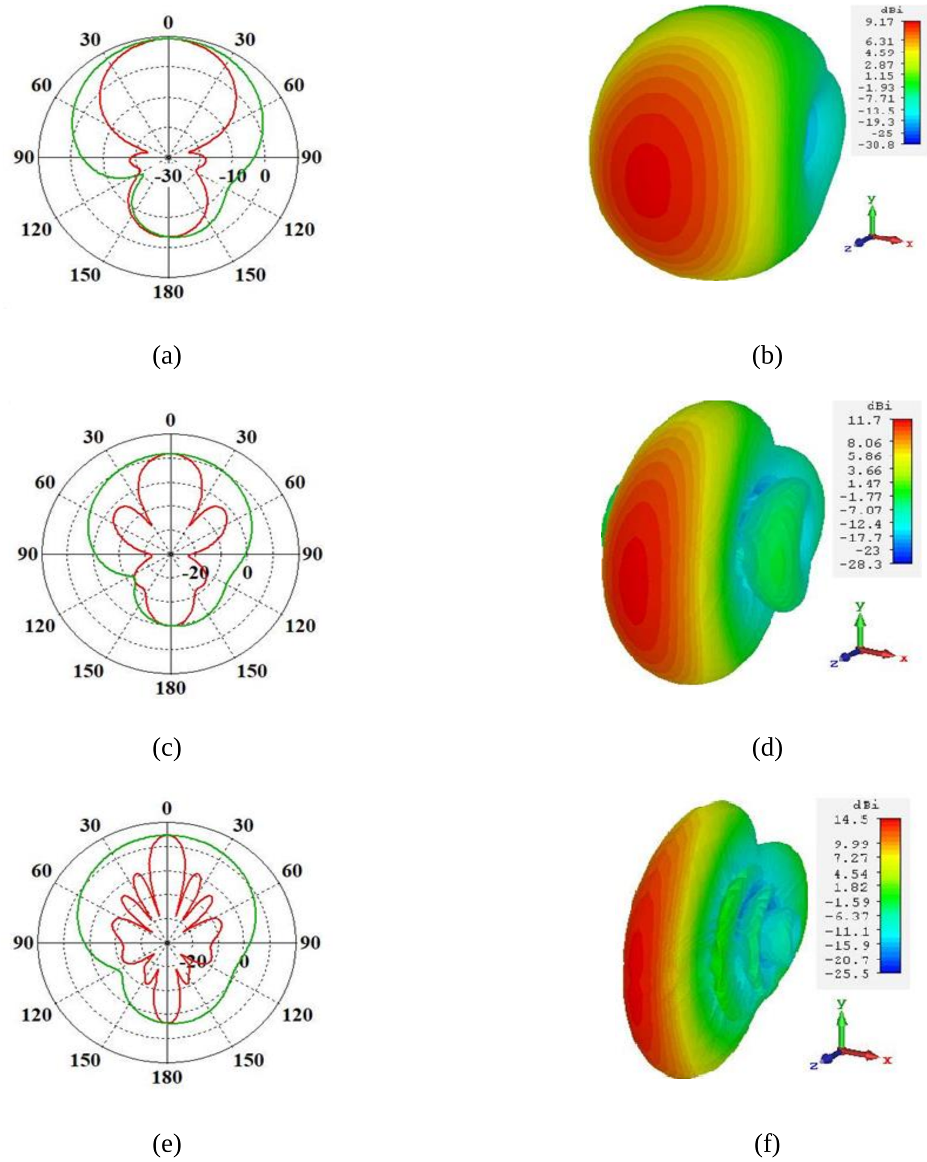


Figure 11. Far-field radiation pattern of the antenna array, (a) polar pattern of 1×2 array, (b) 3D directivity pattern of 1×2array, (c) polar pattern of 1×4 array and (d) 3D directivity pattern of 1×4 array, (e) polar pattern of 1×8 array, (f) 3D directivity pattern of 1×8 array

4. CONCLUSIONS

A rectangular shaped inset fed patch antenna has been proposed with DGS for biomedical applications. The antenna has been designed and simulated with CST MWS at the center frequency of ISM band at 2.45 GHz. By placing 6 rectangular shaped vertically parallel slots on the ground plane, a great amount of current density has been accumulated on the radiating patch. With the DGS, an increase of 17.63% efficiency has been achieved in terms of the realized gain. With the optimized parameters of the antenna, the return loss has been achieved as minimum as around -30 dB. The VSWR of the antenna is 1.06, accumulated current density is above 160 A/m and the total efficiency of the antenna is -1.39 dB. The directivity gain of the antenna is 7.04 dBi with a boresight radiation pattern at 0^0. The proposed antenna exactly works for a single 20MHz channel width of ISM band that is channel 9. To validate the proposed antenna performance, three different 1×2, 1× 4 and 1× 8 arrays (MIMO) have been designed and the array performances have discussed. The future attempts of the proposed antenna will be, to validate the simulated results with fabrication and to convert the design on the flexible substrate.

ACKNOWLEDGEMENTS

This research has been supported by the Research Management Centre, International Islamic University Malaysia under the project of RIGS17-006-0581.

REFERENCES

[1] C. A. Balanis, Antenna theory: analysis and design. John Wiley & Sons, 2005.
[2] S. Shrestha, *et al.*, “A New Fractal-Based Miniaturized Dual-Band Patch Antenna for RF Energy Harvesting,” *International Journal of Antennas and Propagation*, vol. 2014, pp. 1–9, 2014.
[3] R. Pandeeswari and S. Raghavan, “Microstrip antenna with complementary split ring resonator loaded ground plane for gain enhancement,” *Microwave and Optical Technology Letters*, vol. 57, no. 2, pp. 292–296, 2014.
[4] P. A. Nawle and R. G. Zope, “Rectangular microstrip patch antenna for 2.4 GHz communication using defected ground structure,” *IJAFRC*, vol. 2, iss. 1, pp. 1–11, 2015.
[5] D. S. Marotkar and P. Zade, "Bandwidth enhancement of microstrip patch antenna using defected ground structure," *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, Chennai, 2016, pp. 1712-1716.
[6] A. R. Chandran, *et al.*, “Microstrip patch based switched beam antenna at 2.45 GHz for wireless sensor network applications,” *Journal of Electromagnetic Waves and Applications*, vol. 31, no. 13, pp. 1333–1341, Jul. 2017.
[7] A. Ghaloua, *et al.*, “A Miniature Microstrip Antenna Array using Circular Shaped Dumbbell for ISM Band Applications.” *International Journal of Electrical and Computer Engineering (IJECE)*, 2017; 8(5): 3793-3800.
[8] I. Ali and R. Y. Chang, “Design of Dual-Band Microstrip Patch Antenna with Defected Ground Plane for Modern Wireless Applications,” *2015 In Vehicular Technology Conference (VTC Fall)*, 2015, pp. 1-5.
[9] T. V. Hoang, T. T. Le, Q. Y. Li and H. C. Park, "Quad-Band Circularly Polarized Antenna for 2.4/5.3/5.8-GHz WLAN and 3.5-GHz WiMAX Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1032-1035, Dec. 2016.
[10] R. Raihan, M. S. A. Bhuiyan, R. R. Hasan, T. Chowdhury and R. Farhin, "A wearable microstrip patch antenna for detecting brain cancer," *2017 IEEE 2nd International Conference on Signal and Image Processing (ICSIP)*, Singapore, 2017, pp. 432-436.
[11] S. Manna, *et al.*, “Microstrip Patch Antenna with Fractal Structure Using Superstrate Operating in ISM Band,” *Advances in Communication, Devices and Networking*, pp. 321–328, 2018.
[12] R. H. Patel, *et al.*, “An Electrically Small Antenna Using Defected Ground Structure for Rfid, Gps And Ieee 802.11 A/b/g/s Applications,” *Progress in Electromagnetics Research*, vol. 75, pp. 75–81, 2018.
[13] S. M. K. Azam, *et al.*, “Microstrip Coupled Line Bandpass Filter With Radial Stubs for Narrow-Band Applications,” *Int. J. GEOMATE*, vol. 13, no. 40, Dec. 2017.
[14] S. M. K. Azam, *et al.*, “A Compact Bandpass Filter Using Microstrip Hairpin Resonator for WLAN Applications.” *2018 IEEE 7th International Conference on Computer and Communication Engineering (ICCCE)*, 2018, pp. 313-316.
[15] D. Pozar, "Input impedance and mutual coupling of rectangular microstrip antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 30, no. 6, pp. 1191-1196, November 1982.
[16] M. S. Islam, *et al.*, “A Rectangular Inset-Fed Patch Antenna with Defected Ground Structure for ISM Band.” *2018 IEEE 7th International Conference on Computer and Communication Engineering (ICCCE)*, 2018, pp. 104-108.