ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

Design and Fabrication of Slot-Loaded Microstrip Patch Antenna at 2.45 GHz

M.A.R. Ohi[1], M.S. Sadique[2], S. Hussain[3], A. Ahmed[4]

MS Student, Dept. of EEE, University of Dhaka, Bangladesh[1]

PG Student, Dept. of EEE, University of Dhaka, Bangladesh[2]

Assistant Professor, Dept. of EEE, University of Dhaka, Bangladesh[3]

Professor, Dept. of EEE, University of Dhaka, Bangladesh[4]

ABSTRACT: In recent years, microstrip patch antennas have been widely used in various communication systems such as wireless sensor networks, wireless LANs and cordless phones as well as in body area network (BAN) due to their small size, low cost, lightweight, moderate gain and single hemispherical radiation pattern. In this research work, we proposed various structures having slots on both sides of the substrate to get an efficient microstrip patch antenna having single resonant frequency at 2.45 GHz of ISM band. Firstly, various parameters of the proposed patch antennas have been calculated using commercially available simulation software CST Microwave Studio and then the characteristics of the fabricated antennas are measured using Vector Network Analyser (VNA). Emphasis has been given on the miniaturization of antenna. By comparing the simulated and measured values, it is found that both results agree very well. Among the proposed structures of microstrip patch antennas, two-slot on patch gives the best performance.

KEYWORDS: Microstrip Patch Antenna, Slot-Loaded, ISM Band, Return loss, Gain, Directivity

I.INTRODUCTION

Wireless commutation is one of the most emerging fields in telecommunication engineering which plays a vital role in our modern lives. With the rapid growth of wireless communication, low cost, lightweight, and miniaturized antennas are the desired devices for an efficient and reliable radio link [1, 2]. Microstrip patch antenna (MPA) can be the most appropriate candidate in these regard. This antenna was first proposed in early 1970s [3]. It is also known as printed antenna which is very unique and popular for several advantages like low profile, planar configuration and mechanical robustness. The application fields of MPA include mobile and satellite communication, radar, healthcare applications, GPS WLAN (Wireless Local Area Networks), etc. [4, 5, 6]. However, these of MPA is limited due to some of its conventional properties such as low gain, wide bandwidth, multiple resonance [7, 8], less efficiency and low power handling capability. To overcome these limitations, different types of patch antennas such as E-shaped slot loaded patch antenna [9] , U-shaped slot loaded patch antenna [1, 10], Sierpinski fractal based patch antenna [2], triangular shaped slot on patch antenna [7], circular shaped patch antenna [11], Hexagonal shaped patch antenna [12] and microstrip patch antenna arrays [13] have been introduced for improving the return loss, gain and bandwidth.

In this paper, we have paid attention to design a MPA having single resonance frequency with increased bandwidth by modifying the structure with slots on both sides of the substrate. Our proposed structures are designed to operate at 2.45 GHz of Industrial, Scientific and Medical radio (ISM) band in order to suppress the side lobes and reduce the size of patch antennas. The structures of patch antennas are optimized using CST software and then fabricated to measure different parameters by Vector Network Analyser (VNA) and WATS 2002 (Man &Tel Co.). The antennas are made on FR-4 substrate with thickness of 1.6 mm [14]. The magnitudes of the return losses obtained by simulation and measurement are about –33 dB and –19 dB, respectively. By comparing the resonant frequencies of simulated and measured values, it is found that both results agree very well. Among the various proposed structures, two-slot on patch gives the best performance. In Section II the design procedure of MPA is described to determine the optimized

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

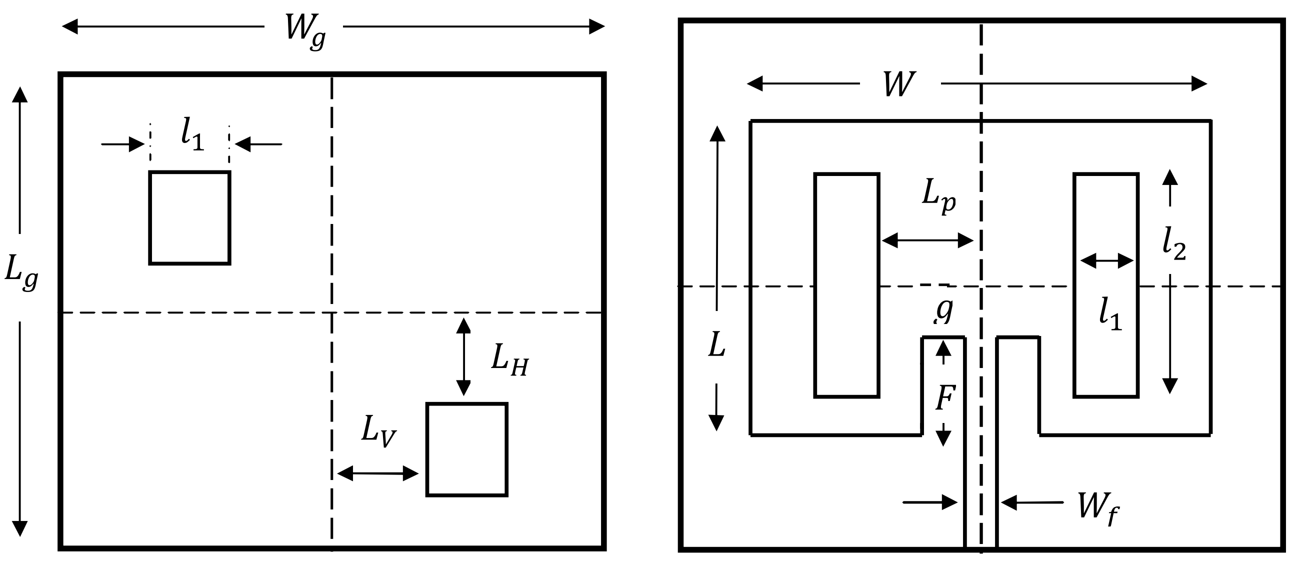
Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

dimensions. The simulated and measured results of the proposed antennas are presented in Section III and IV, respectively. A comparative analysis of all data is given in Section V. Section VI concludes the research work findings.

II.DESIGN OF SLOT-LOADED MICROSTRIP PATCH ANTENNA

The return loss characteristic of a conventional MPA has several resonant peaks. To get a MPA having only one resonant frequency the structure is customized with slots on both sides of the substrate. First both sides of the substrate are divided into four quadrants by two dashed central vertical and horizontal lines. The patch is placed symmetrically at the middle of the substrate. We have studied four types of antennas; (a) conventional MPA without slot, (b) MPA with two diagonal slots on the ground plane, (c) MPA having two parallel slots on the patch, and (d) MPA consisting of slots on both sides. In Fig.1, schematic diagrams of slots introduced on patch and ground plane are shown.



(a) (b)

Fig.1 Proposed structure of slot-loaded microstrip patch antenna, (a) back view, and (b) front view.

For designing a rectangular MPA [4,5], some parameters such as - resonant frequency (f_r), substrate thickness $(h_s)$and relative dielectric constant (ε_r) are to be known, and some parameters such as patch length (L), patch width (W), ground plane length (L_g), substrate or ground plane width (W_g) and effective dielectric constant $(\varepsilon_{reff})$are to be calculated by using the known parameters. We have calculated these parameters by using the following equations.

The width of the metallic patch, W is calculated from the expression below:

$$W = \frac{C_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

where C_o is the free space light velocity. Generally $W_g \cong 2 \times W$and $L_g \cong 2 \times L$. Let us define a new parameter named patch profile (PP) as

$$PP \equiv W / h_s \qquad (2)$$

For $PP > 1$, the expression of the effective dielectric constant, ε_{reff} of the microstrip antenna is

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \left[\frac{\varepsilon_r-1}{2}\right]\left(1+\frac{12}{PP}\right)^{-1/2} \tag{3}$$

The length of metallic patch L is determined using Eq.(3)

$$L = L_e - 2.\Delta L \tag{4}$$

where effective length L_e is defined as

$$L_e = \frac{C_o}{2f_r}\left(\varepsilon_{reff}\right)^{-1/2} \tag{5}$$

The calculation of the length extension is obtained from the underneath expression:

$$\Delta L = 0.412h_s\frac{(\varepsilon_{reff}+0.3)[PP+0.264]}{(\varepsilon_{reff}-0.258)[PP+0.8]} \tag{6}$$

The goal of this research work is to design a MPA for the resonant frequency of 2.45 GHz (i.e. wavelength $\lambda = 122.4$ mm). First, we have placed two square slots whose dimension is represented by $l_1$on the ground plane. The slot-dimension l_1 is assumed to be related with the resonant wavelength λ and expressed by the following equation

$$l_1 = \lambda/2^k \tag{7}$$

where $k$is an integer and λ is in millimeter. We have varied $k = 2$ to 7 to achieve our goal. But from the analysis it is found that $k = 6$ gives the satisfactory return loss characteristics. The square slots are placed diagonally at distances of L_V and L_H from the central dashed vertical and horizontal lines, respectively on the ground plane as shown in Fig.1(a). The distances L_V and L_H are assumed to be related with l_1 in the following equations:

$$L_V = R_V.l_1 \tag{8}$$

$$L_H = R_H.l_1 \tag{9}$$

where R_V and R_H may vary from 1 to 14, and 1 to 10, respectively to keep the slots inside the substrate area. However, from the analysis we have taken $R_V = R_H = 5.45$.

Then we have placed two rectangular parallel slots on the patch side. Each slot is kept $L_p$distance away from the central vertical line. We have expressed L_p in terms of l_1 by the following equation:

$$L_p = R_p.l_1 \tag{10}$$

where R_p varies from 1 to 9 to keep the slot within the patch boundary. From the results of simulation we have taken $R_p = R_V$. Slots are placed symmetrically on both sides of the horizontal dashed line as shown in Fig.1 (b). The width of each slot is taken same as the width of the square slot on the ground plane (i.e.l_1), and the length l_2 of the slot is expressed as

$$l_2 = R_L \times l_1 \tag{11}$$

where R_L may vary from 1 to 14 to keep the slots inside the patch. But from the analysis we have taken $R_L = 6$. We have calculated the characteristics of MPAs with front and back slots separately as well as in combined condition.

Equations (1-5) are the empirical ones to calculate the dimensions of MPA. The results obtained using these equations are used in Eq. (6) to (10) for simulation to get the desired characteristics of MPA. We have optimized the dimensions for each of the four types of antennas. All the optimized dimensions for the four types of MPA are given in Table – 1.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

Table-1 Dimensions of MPAs obtained from calculation/simulation.

Antenna Parameters	Patch Antenna Dimension without slot (mm)	Patch Antenna Dimension with slot (mm)		
		Two-diagonal slots on the ground plane	Two parallel slots on the patch	Slots on ground plane and also on patch
Substrate Width, W_g	76	60.8	60.8	60.8
Substrate length, L_g	58	45.44	45.44	45.44
Patch Width, W	38	38	38	38
Patch length, L	29	28.4	28.4	28.4
Feed line width, W_f	3.137	3.137	3.137	3.137
Feed line length, F	8.85	8.85	8.85	8.85
Notch, g	1	0.79	0.79	0.79
Slot width, l_1		1.913125	1.913125	1.913125
Slot length, l_2		1.913125	11.47875	11.47875

III. RESULTS OBTAINED FROM SIMULATION

For the simulation we have used CST Microwave Studio software. Focus has been given on the miniaturization as well as the suppression of side lobe resonance. Slots are introduced to increase the bandwidth of MPA having single resonance frequency. For simulation of MPA we used FR-4 substrate whose dielectric constant is 4.3 and thickness of the substrate is 1.6 mm and have a loss tangent of 0.02 [14]. Fig. 2 and Fig. 3 shows the obtained return loss characteristics and radiation patterns of the simulated antennas, respectively.

A. RETURN LOSS

The return loss (RL) of conventional MPA (without slot) is shown in Fig.2(a) which has two resonant frequencies at 2.415 GHz and 3.725 GHz . The magnitudes of RL at these two frequencies are found to be –33.76 dB and –37.28 dB, respectively. In order to suppress the sidelobes, we have designed another three types of slot-loaded antennas. Fig. 2(b) represents the RL for first type of slot-loaded MPA having two diagonal slots on the ground plane. In this figure, two resonant frequencies are found at 2.45 GHz and 3.74 GHz with magnitudes of –29.27 dB and –36.75 dB, respectively. Note that by adding slots at the back side, the first resonance frequency is same as our desired one i.e. 2.45 GHz, but the second resonance frequency with large magnitude is an unwanted peak. To reduce the unwanted resonant peak at 3.74 GHz, we have designed a second type of slot-loaded MPA with two parallel-slots on the patch. Fig. 2(c) shows the returm loss curve of only front slot loaded antenna. By observing this figure, a great improvement of RL characteristics has been achieved by the insertion of two slots on the patch. Here the main resonant frequency is at 2.45 GHz with magnitude of –37.58 dB and the magnitudes of other resonances are about $-(10 \pm 2)$ dB which can be considered to be negligible ones. To get an even better characteristics, we have designed third type of slot-loaded MPA which is the the combination of the previous two types of antennas. Fig. 2(d) shows the RL of both back and front slot loaded antenna, where there is only one resonant peak at 2.45 GHz and other sidelobes are suppressed quite a lot.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

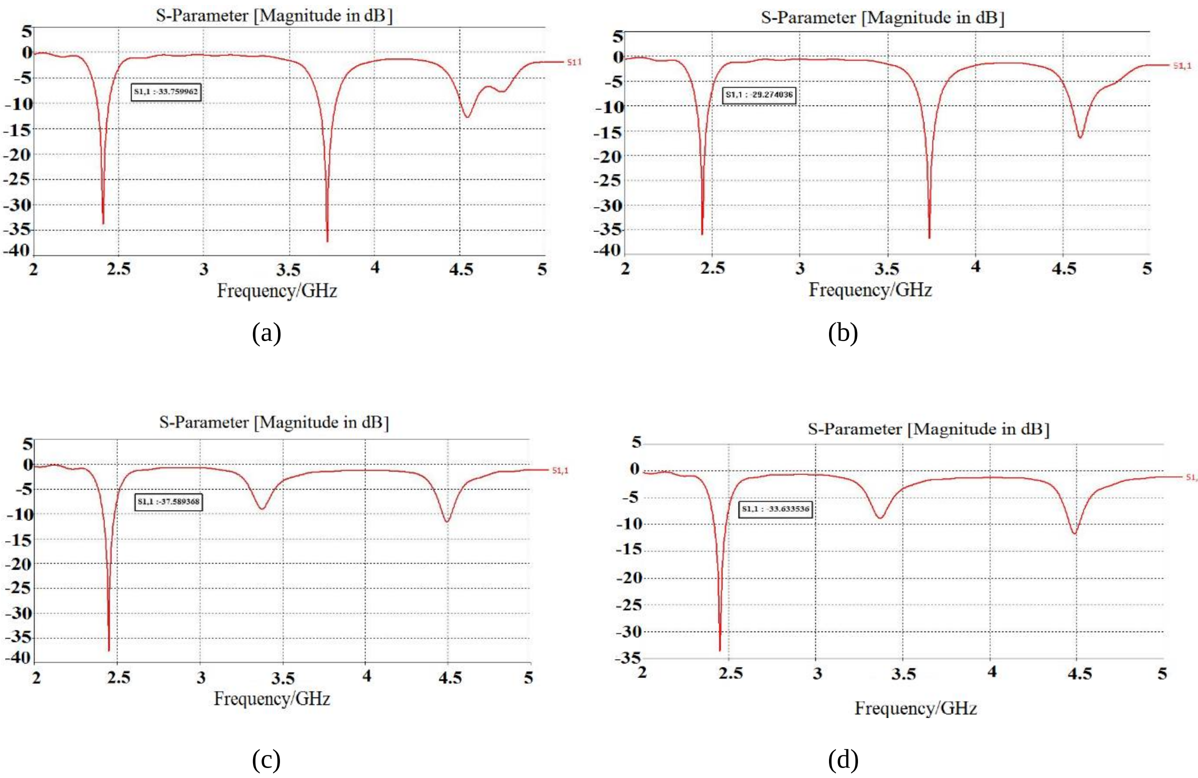
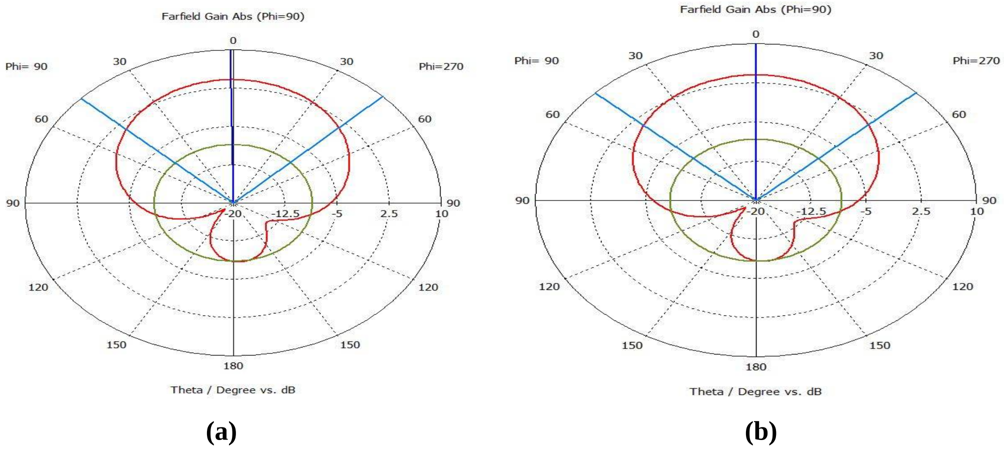


Fig 2. Simulation RL of proposed antennas; (a) Without slot, (b) Only back-slot loaded, (c) Only front-slot loaded, (d) Both back- and front-slot loaded.

B. FAR-FIELD GAIN PATTERN

Antenna gain is defined as antenna directivity times a factor representing the radiation efficiency. Radiation efficiency is always lower than 100%. So the antenna gain is always lower than antenna directivity. This efficiency quantifies the losses in the antenna and is defined as the ratio of radiated power (P_r) to input power(P_i). The directivity of an antenna is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. Fig. 3 shows the simulation results of the radiation patterns of our four types of antennas.



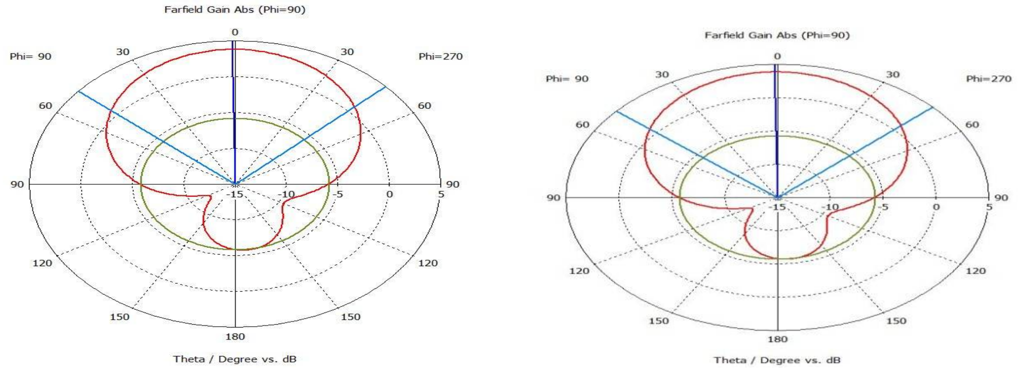
ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017



(c) **(d)**

Fig 3. Radiation pattern of gain (a) without slot, (b) only back slot loaded, (c) only front slot loaded, (d) both sides slot loaded

The gain for the conventional MPA is 4.18 dB which operates at 2.45 GHz of frequency and side lobe level is -12.6 dB. For the second type of antenna the gain is 3.99 dB whereas the operating frequency remains the same as for the previous one and side lobe level is reduced to -12.3 dB. For the third and fourth type of antenna gain is 3.8 dB and 3.85 dB, respectively and side lobe level is -9.6 dB for both type of antennas. Table-II list out the proposed antenna parameters obtained from simulation. For our proposed antennas, the bandwidths are enhanced, the VSWRs are also reduced to unity, and the reference impedance is very close to 50 Ω.

Table II. Proposed antenna parameters obtained from simulation.

Design Name	**Resonant frequency (GHz)**	**Magnitude of resonant peak (dB)**	**Gain**	**Directivity**	**Bandwidth (MHz)**	**VSWR**	**Ref. Impedance (Ω)**
A. Conventional	a) 2.41 b) 2.45 c) 3.72 d) 4.54	a) –33.76 b) –9.48 c) –37.28 d) –12.78	MLM = 7.05 dBi AW =92.8 deg	MLM =4.14 dB AW(3db)= 92.8 deg	63	2.009	49.19
B. Two diagonal back slot loaded	a) 2.45 b) 3.74 c) 4.6	a) –29.27 b) –36.75 c) –16.55	MLM = 7.04 dBi AW=93.2 deg	MLM =3.99 dB AW =93.2 deg	70.4	1.07	49.16
C. Two parallel front slot loaded	a) 2.45 b) 3.38 c) 4.5	a) –37.58 b) –8.99 c) –11.54	MLM = 6.46 dBi	MLM= 3.8 dB AW =96.6	70	1.02	49.52

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

			AW =96.6 deg	deg			
D. Both front and back slot loaded	a) 2.45 b) 3.375 c) 4.485	a) –33.69 b) –8.85 c) –11.75	MLM = 6.46 dBi AW =96.6 deg	MLM= 3.85 dB AW =96.6 deg	70	1.04	49.52

MLM: Main Lobe Magnitude, AW: Angular Width

IV. MEASURED RESULTS OF FABRICATED ANTENNAS

For the fabrication of MPA, we have used FR-4 substrate whose dielectric constant is 4.3 and thickness of the substrate is 1.6 mm [14]. The copper clad board is first masked according to our patch and ground plane size. Feric chloride solution is made for wet chemical etching of MPA substrate. After etching and cleaning, SMA port is attached by fixing an aluminium mount. Different parameters of these fabricated antennas were measured using Vector Network Analyzer (Rohde & Schwarz–ZVH8).

Two types of Rectangular MPA are fabricated: i) one has two parallel-slot on patch, and ii) the other has slots on both sides of the substrate. Fig. 1 shows the diagrams of these antennas and the corresponding dimensions are given in Table-1. For the fabrication we have considered one digit after the decimal (see Table-1). The final size of our MPA is 60.8 mm by 45.4 mm. The return loss characteristics (S_{11}) of the fabricated antennas are measured with a VNA and Fig. 4 and 5 shows the obtained return loss characteristics of the fabricated antennas. The resonant frequency of the front parallel-slot MPA is found precisely at 2.45 GHz with the magnitude of -19.11dB. However, the resonant frequency of the second one is deviated to 2.55 GHz with the magnitude of -19.61dB. It is clear that the resonant frequencies of the fabricated antennas are found very close to the desired value, but the magnitudes are found less than the simulated results.

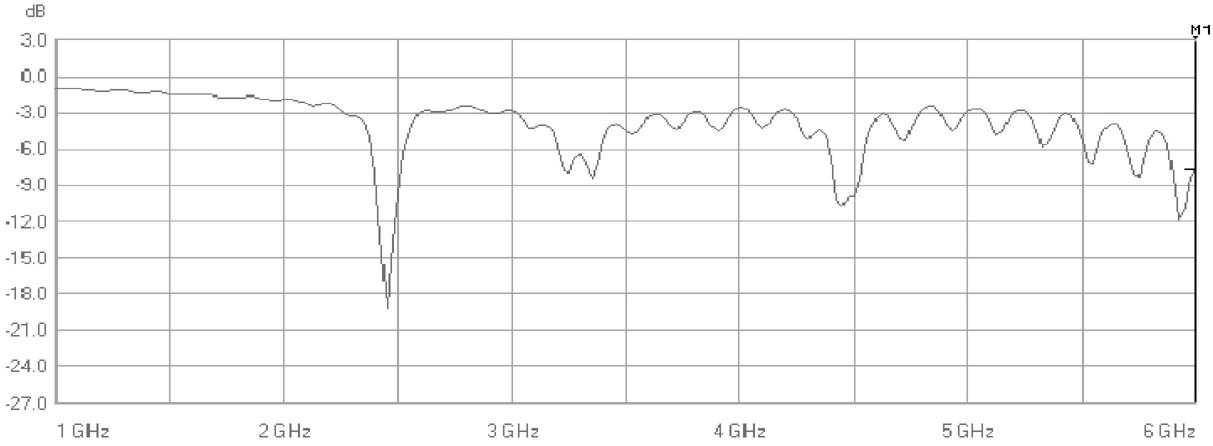


Fig. 4. Return loss S_{11} parameter for only front slot loaded Fabricated Antenna

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

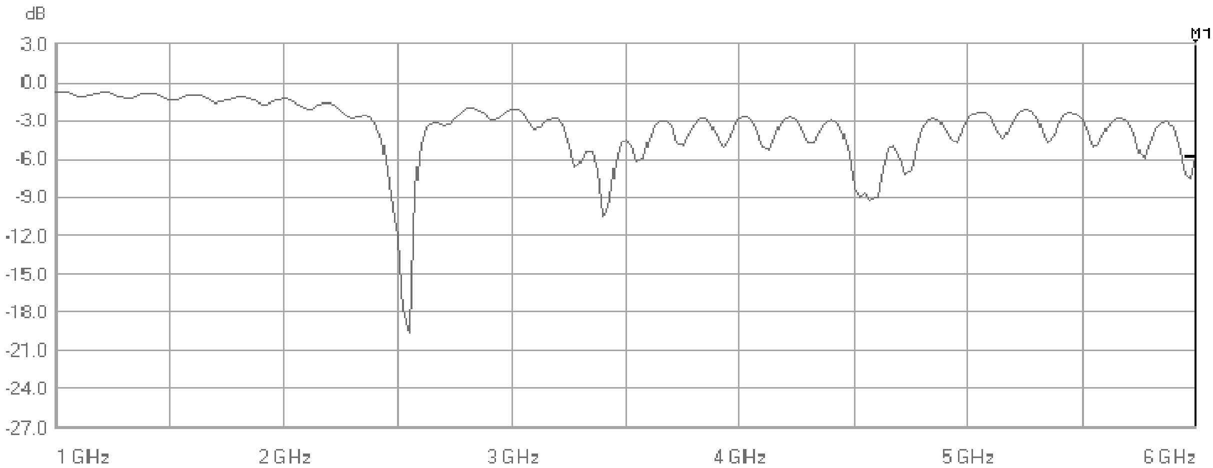


Fig.5. Return loss S_{11} parameter for both side slot loaded Fabricated Antenna

Table III. Measured results of proposed fabricated antennas.

Antenna Type	Resonant frequency (GHz)	Magnitude of resonant peak (dB)	SWR	Bandwidth (MHz)
Two parallel-slot on patch	a) 2.45 b) 3.34 c) 4.48	a) –19.11 b) –8.32 c) –10.63	1.26	90
Slots on both sides	a) 2.55 b) 3.4 c) 4.57	a) –19.61 b) –10.44 c) –9.42	1.23	100

V. CONCLUSION

In this paper, we have designed and fabricated MPA which will have only one resonant frequency by introducing slots on both sides of the substrate. The size of antenna is reduced to a minimum level of 60.8 X 45.4 mm^2. With the use of slots, the bandwidth as well as the magnitude of RL is increased. The resonant frequencies found by simulation and fabrications are very close to the desired value of 2.45 GHz. The measured values of RL-magnitudes are found to be –19 dB which is less than the simulated results. For our proposed antennas, the VSWRs are reduced to unity, and the reference impedance is very close to 50 Ω. Thus it is found that single resonant frequency microstrip patch antenna can be made by using slots on both sides of the substrate. Such MPA is intended to design for the application in body-area-network research of our laboratory.

VI. ACKNOWLEDGEMENT

This research work was conducted in Microwave and Optical Fibre Communication Laboratory in our department funded by Higher Education Quality Enhancement Project (HEQEP). We are thankful to Hasanur Rahman Chowdhury and Md. Sahil Hassan, graduate student of our laboratory for their assistance in preparing the devices. The authors also would like to thank technical persons of the Central Science Workshop, University of Dhaka for their support.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

REFERENCES

.

[1] K. N. Lal, A. K. Singh, "Modified design of microstrip patch antenna for WiMAX communication system", *Students' Technology Symposium (TechSym), 2014 IEEE*, pp. 386-389, 2014.

[2] Sika Shrestha et al., "Design of 2.45 GHz Sierpinski fractal based miniaturized microstrip patch antenna",*18th Asia-Pacific Conference on Communications (APCC) 2012 IEEE,* pp. 36-41, 2012.

[3] Sanjay R. Bhongale, Pramod N. Vasambekar, "Square shaped microstrip patch antenna at 2.45GHz", *International Journal of Science and Research (IJSR),*Vol. 4, Issue no. 10, pp. 1651-1653, 2015.

[4] C. A. Balanis, "Antenna Theory, Analysis and design", Third Edition John Wiley & Sons, Inc., 2005.

[5] David M. Pozar, "Microwave Engineering", Third Edition, John Wiley & Sons, Inc., 2005.

[6] Raj Kumar, "Gps microstrip rectangular patch antenna at 2.45 GHz mounted over angular towers", *International Research Journal of Engineering and Technology*, vol. 02, pp. 255-261, 2015.

[7] K. Mondal et al., "Effect of feeding locations on bandwidth, gain and resonance frequency of the patch antenna", *2015 International Conference on Microwave and Photonics (ICMAP)*, 2015.

[8] Prakash Kumar Mishra et al., "Multiband Microstrip Antenna for 4G Mobile Application", *2015 Fifth International Conference on Communication Systems and Network Technologies,* IEEE, pp. 60-63, 2015.

[9] V.K. Singh et al., "Dual wideband stacked patch antenna for Wimax and WLAN applications", *Computational Intelligence and Communication Networks(CICN), 2011 International Conference,* pp. 315-318, Oct 2011.

[10] V.K. Singh et al., "E-Shaped microstrip antenna on Rogers substrate for WLAN applications,"*Computational Intelligence and Communication Networks(CICN), 2011 International Conference,* pp. 342-345, Oct 2011.

[11] J. T. Aberle et al., "Scattering and radiation properties of varactor tuned microstrip antennas", *IEEE Antennas Propagat.Soc. Int. Symp. Digest*, vol. 4, pp. 2229–2232, 1992.

[12] Ahmed Al-Shaheen, "New patch antenna for ISMm band at 2.45 GHz", *ARPN Journal of Engineeringand Applied Sciences,*Vol. 7, No. 1, January 2012.

[13] Giang Bach Hoang et al., "Research, design and fabrication of 2.45 GHz microstrip patch antenna arrays for close-range wireless power transmission systems", *International Conference on Advanced Technologies for Communications (ATC)*, IEEE, pp.259-263, 2016.

[14] Sayeed Z. Sajal et al., "A Microstrip patch antenna manufactured with flexible Graphene-Based conducting material", *IEEE, AP-S 2015*, pp. 2415-2416, 2015.

.