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Experimental analysis of rectangular and circular slot PIFA for 5G communication applications

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Abstract: This paper presents experimental analysis of Planar Inverted F Antenna (PIFA) with two different slot shapes i.e. rectangular Split ring resonator (SRR) and circular SRR for 5G band applications. The proposed rectangular SRR PIFA covers GPS L1 (1575.42 MHz), GSM 900 (890-950 MHz), GSM 1800 (1710-1880 MHz) and 5G communication and circular SRR PIFA can cover GSM 1800, GSM 1900 and 5G communication applications. The area of both antennas is 12×6 mm^2 built on ground plane of area 18.4×12 mm^2. The FR4 substrate of thickness 1.5 mm is used as dielectric medium between patch and ground plane. The results for return loss, VSWR and radiation pattern are presented. The achieved S11 values and VSWR values are acceptable.

Keywords: multiband, PIFA, SRR, 5G

I. INTRODUCTION

With technology spreading roots everywhere, it is now certain that in few years we will be using 5G technology. 5G (fifth-generation) means increased data rates, prolonged battery life, additional number of connected devices as well as reduced end to end latency. 5G will aid in the development of new technologies such as Internet of Things (IoT), Device to device (D2D) communication, etc. It is assumed that by year 2020, approximately 31 billion devices will be connected to internet. With the arrival of 5G, one has to upgrade our gadgets. Also, we desire to have our portable devices to be more sleek and compact. In any communication device, apart from processing circuitry, antenna plays an essential role. Thus antennas also need to be advanced to meet the 5G requirements at various frequency bands from 6 GHz to 38 GHz to accommodate data rates in the ranges from 10 to 50 Gbps [1].

Recent years has seen lot of work in the field of antenna designing for 3G and 4G communication applications. Special microstrip antennas are being designed to accommodate 5G technologies. From the wide range of antennas, Planar Inverted F Antenna (PIFA) plays a crucial role. It appeared first in literature in year 1987. It is a compact antenna with a short pin or post at one corner and a feed pin or point located along its length as shown in **Figure 1**. These are often used in portable devices[2].

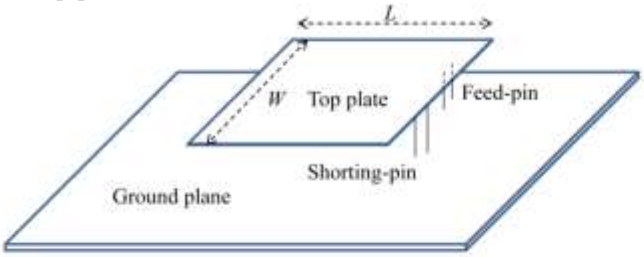

Figure 1. Basic structure of PIFA antenna [3]

The general equation for obtaining resonant length of PIFA is given in equation (1) as follows:

$$L+W-W_s=\lambda/4 \quad (1)$$

Here, L and W is the length and width of the top radiating element, W_s is the width of shorting plate, λ is wavelength, respectively. PIFA antenna is preferred mainly due to the fact that it is a $\lambda/4$ antenna.

II. RELATED WORK

Ref. No.	Work done
Ref. (Ahmad W. and Khan W. T., 2017) [4]	Presented for the first time, the design of a dual band PIFA antenna for 5G applications on a low-cost substrate with widest bandwidth and smallest form factor in both high frequency bands (28 GHz and 38 GHz)
Ref. (Ishfaq M. K., et al, 2017) [5]	Offered a novel multiband split-ring resonator based PIFA for 5G applications covering frequency bands such as 6GHz (5–7GHz), 10GHz (9–10.8GHz), and 15GHz (14-15GHz) suitable for 5G communications.
Ref. (Morshed K.M. et al, 2016) [6]	Demonstrated a compact slotted PIFA with a superstrate that covers 28 GHz millimeter wave frequency bands.
Ref. (Hashem Y. A. M. K. et al, 2016) [7]	Displayed a 6-element dual-band multiple-input multiple-output PIFA covered 28/38 GHz for the future millimeter-wave 5G cellular communication systems.
Ref. (Haraz O. M. et al, 2015) [8]	Presented a three-element, single-band PIFA system that operates at 28 GHz band for the future millimeter-wave 5G wireless communication applications.

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III. Proposed Antenna Model

In this section, the antenna structure for two proposed designs is mentioned. The first proposed design consists of a rectangular split ring resonator (SRR) in the top patch element as shown in **Figure 2**. The second proposed design has a circular SRR as shown in **Figure 3. Figure 4** represents the side view of both designs.

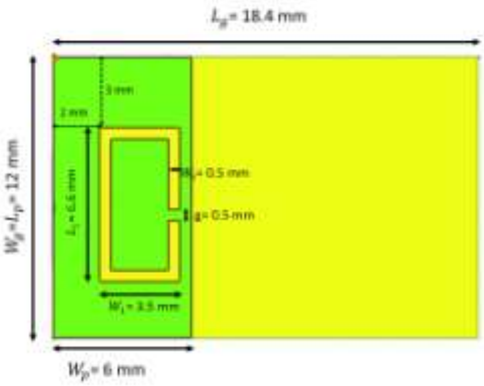

Figure 2. Top view of Proposed design 1

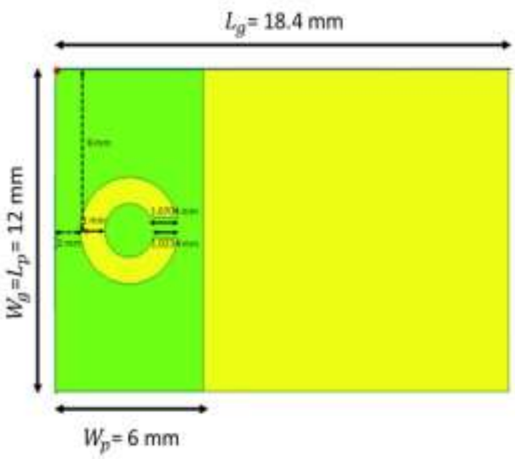

Figure 3. Top view of Proposed design 2

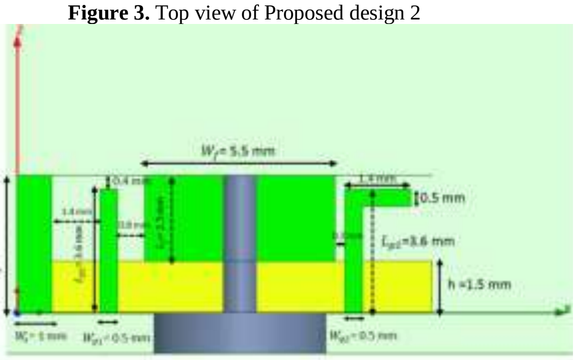

Figure 4. Side view of proposed design

The antenna structure of first design comprises of a radiating plate called patch on which a rectangular SRR is built, a shorting plate, a ground plane, a FR4 substrate of permittivity 4.4 and height h, two shorted parasitic elements and a coaxial feed with feeding plate. The second proposed design consists of a circular SRR and all the same elements as the first design. The dimensions of radiating plate, ground plane/ substrate, shorting plate, parasitic 1, parasitic 2 and feed plate are $W_p \times L_p$, $W_g \times L_g$, $W_s \times L_s$, $W_{p1} \times L_{p1}$, $W_{p2} \times L_{p2}$, $W_f \times L_f$ respectively. The detailed measurements of proposed antennas are given in **Table 1.**

Table 1. Detailed measurements of proposed PIFA antenna

Parameter	Value (mm)	Parameter	Value (mm)
L_g	18.4	W_{p1}	0.5
W_g	12	L_{p2}	3.6
L_p	12	W_{p2}	0.5
W_p	6	L_f	2.5
L_s	4	W_f	5.5
W_s	1	h	1.5
L_{p1}	3.6	g	0.5

IV. Problem Statement

The design problem tackled is to design a PIFA antenna in an EM Simulator for 5G communication applications such as satellite communication and mobile communications. Antenna performance is compared for rectangular as well as circular slots in the antenna. Two types of slots are cut in the patch of PIFA antenna and analysed.

V. Observation and Analysis

It is observed with the aid of simulator that circular slot PIFA should be preferred over rectangular slot PIFA due to better bandwidth and improved return loss parameter.

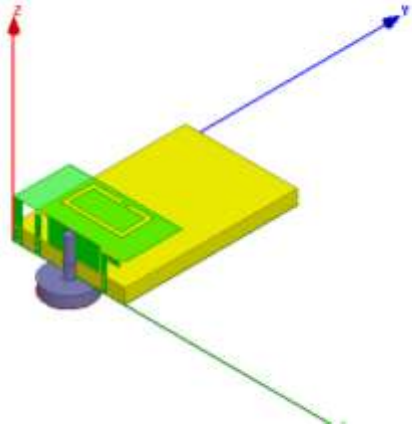

Figure 5. PIFA with a rectangular slot (3D view)

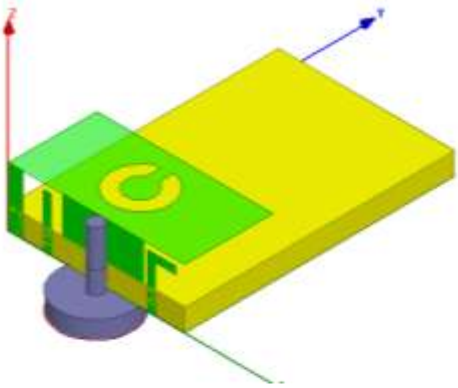

Figure 6. PIFA with a circular slot (3D view)

VI. Simulation and Experimentation

Return Loss or S11 Parameter

Return Loss or S11 Parameter specifies how much power is reflected back to the input of an antenna when the input power is applied to it [9]. The return loss is usually measured in decibels. **Figure 7.** shows return loss for rectangular slot PIFA. The graph shows five resonant frequencies i.e. 0.9010 GHz, 1.7010 GHz, 5.3010 GHz, 8.3010 GHz and 12.2010 GHz with S11 value of -18.9338 dB, -16.3111 dB, -21.2844 dB, -13.4675 dB and -12.9566 dB respectively. The impedance bandwidth of antenna at -10dB S11 value is 0.1635 GHz, 0.4478 GHz, 1.9 GHz, 0.9 GHz and 1.5 GHz with % Bandwidth of 18.43 %, 26.28 %, 35.50 %, 10.65 % and 12.34 % respectively. The antenna covers wireless applications such as GPS L1, GSM 900, GSM 1800 and 5G communication bands i.e. 6 GHz, 8 GHz and 12 GHz.

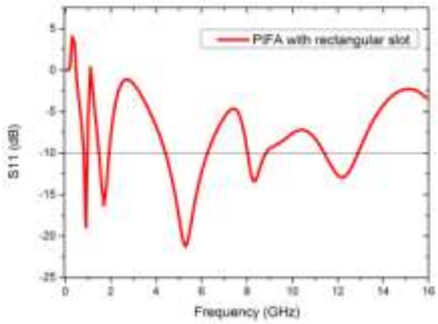

Figure 7. S11 parameter for rectangular slot PIFA

Figure 8. shows return loss for circular slot PIFA. The graph shows four working resonant frequencies i.e. 1.1010 GHz, 1.8010 GHz, 5.6010 GHz and 11.8010 GHz with S11 value of -15.8725 dB, -15.3376 dB, -20.9547 dB and -16.1956 dB respectively. The impedance bandwidth of antenna at -10dB S11 value is 0.2565 GHz, 0.4317 GHz, 2.5262 GHz and 1.5171 GHz with % Bandwidth of 24.92 %, 23.62 %, 43.59 % and 12.81 % respectively. The antenna covers wireless applications such as GSM 1800, GSM 1900 and 5G communication bands i.e. 6 GHz and 12 GHz. **Figure 9.** shows the comparison of rectangular SRR vs. circular SRR PIFA in terms of return loss values.

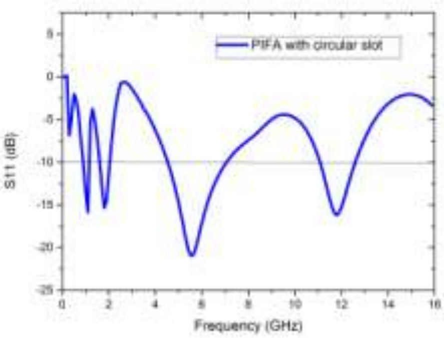

Figure 8. S11 parameter for circular slot PIFA

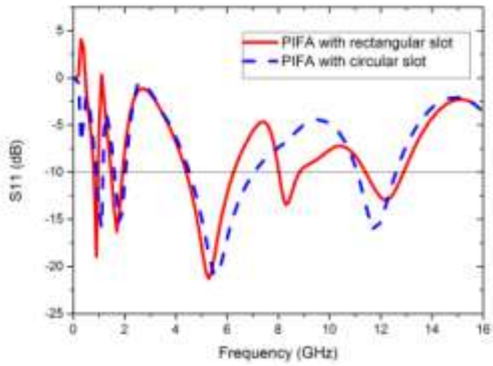

Figure 9. S11 parameter for rectangular as well as circular slot PIFA

VSWR (Voltage Standing Wave Ratio)

Figure 10. shows VSWR graph for rectangular SRR PIFA. The observed VSWR values are 1.2549, 1.3610, 1.1888, 1.5385 and 1.5806 at the corresponding S11 values. The obtained VSWR values are satisfactory i.e. less than 2.

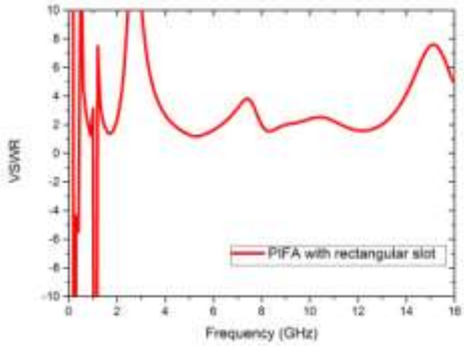

Figure 10. VSWR for rectangular slot PIFA

Figure 11. shows VSWR for circular SRR PIFA. The perceived VSWR values are 1.7982, 1.4127, 1.1968 and 1.3668 at the corresponding S11 values. The obtained VSWR values are satisfactory i.e. less than 2.

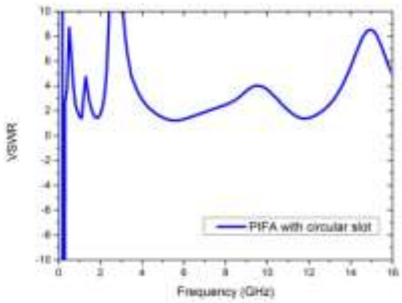

Figure 11. VSWR for circular slot PIFA

Figure 12. shows VSWR of circular slot PIFA vs. rectangular slot PIFA.

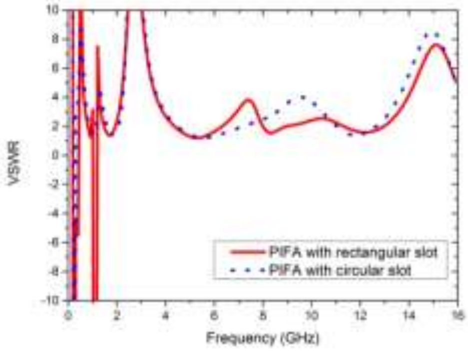

Figure 12. VSWR for rectangular and circular slot PIFA

Radiation Pattern

Radiation pattern of an antenna is important parameter which tells about its radiation properties in three dimensional space using coordinates theta (θ) and phi (ϕ).Usually, the radiation pattern in E-plane (xz-plane: ϕ=0°) and H-plane (yz-plane: ϕ=90°) is measured. **Figure 13.** and **Figure 14.** shows radiation pattern of rectangular slot PIFA at frequency 0.9010 GHz and 1.7010 GHz respectively. The observed radiation pattern is nearly omnidirectional in both graphs.

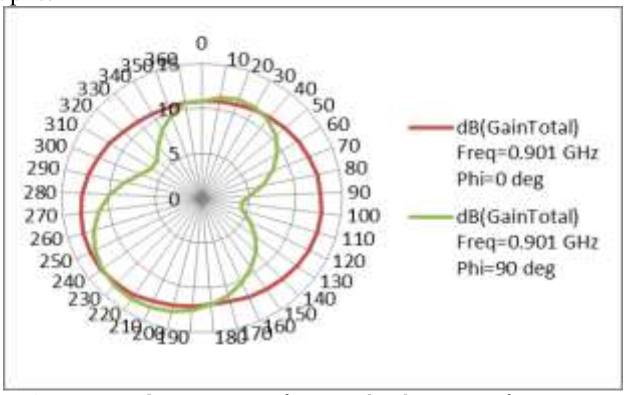

Figure 13. Radiation pattern of rectangular slot PIFA at frequency = 0.9010GHz

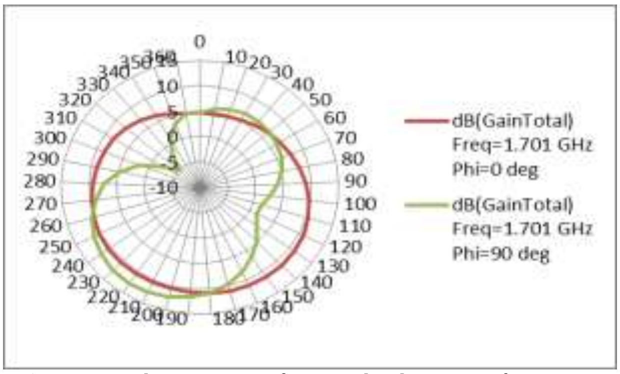

Figure 14. Radiation pattern of rectangular slot PIFA at frequency = 1.7010GHz

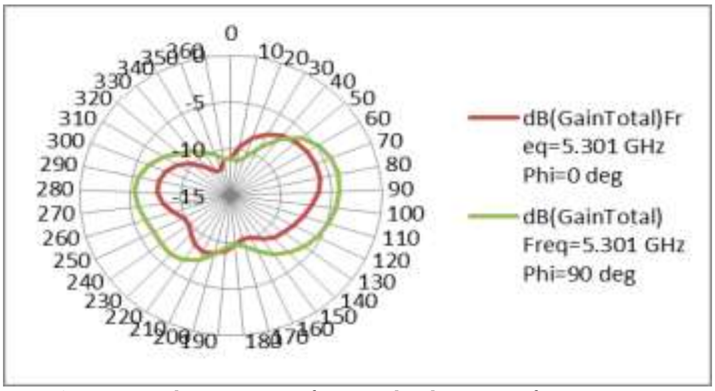

Figure 15. Radiation pattern of rectangular slot PIFA at frequency = 5.3010GHz

Figure 15. shows radiation pattern of rectangular slot PIFA at frequency 5.3010GHz. The obtained pattern is butterfly pattern.

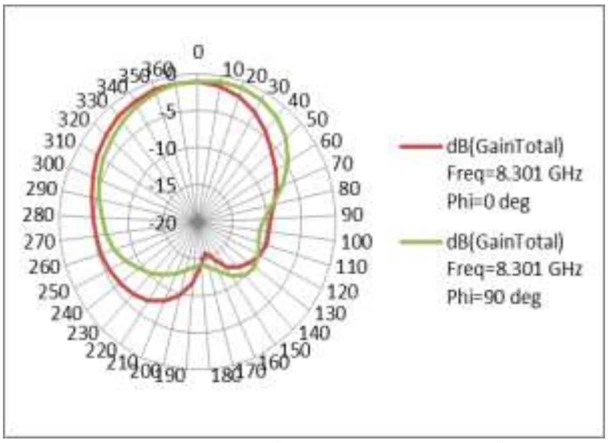

Figure 16. Radiation pattern of rectangular slot PIFA at frequency = 8.3010GHz

Figure 16. and **Figure 17.** shows radiation pattern of rectangular slot PIFA at frequency of 8.3010GHz and 12.2010GHz respectively. The obtained radiation pattern is unidirectional pattern like of half-wavelength antenna in both measurements.

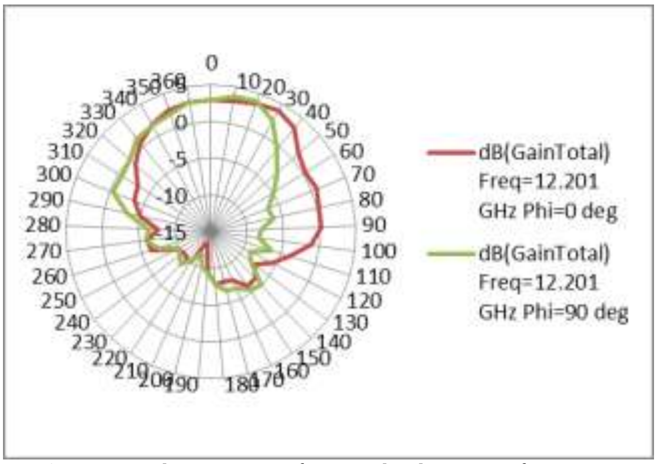

Figure 17. Radiation pattern of rectangular slot PIFA at frequency = 12.2010GHz

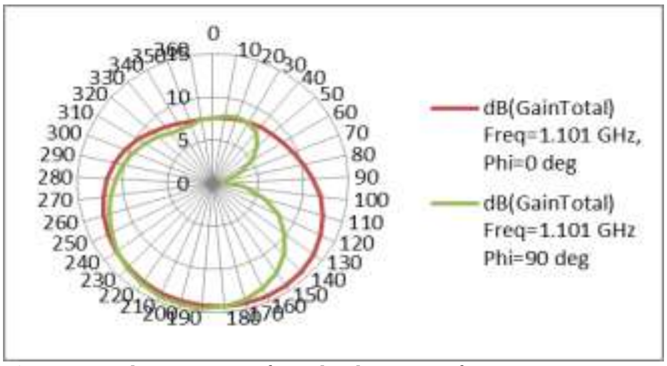

Figure 18. Radiation pattern of circular slot PIFA at frequency = 1.1010GHz

Figure 18. and **Figure 19.** show the radiation pattern of circular slot PIFA at frequency 1.1010GHz and 1.8010GHz. The obtained pattern is nearly omni-directional in both the graphs.

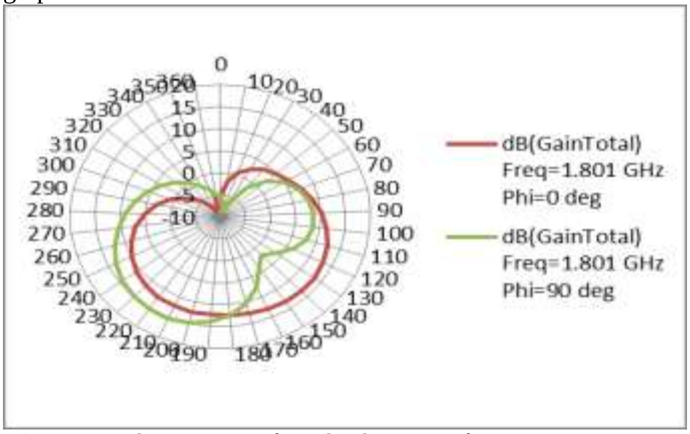

Figure 19. Radiation pattern of circular slot PIFA at frequency = 1.8010GHz

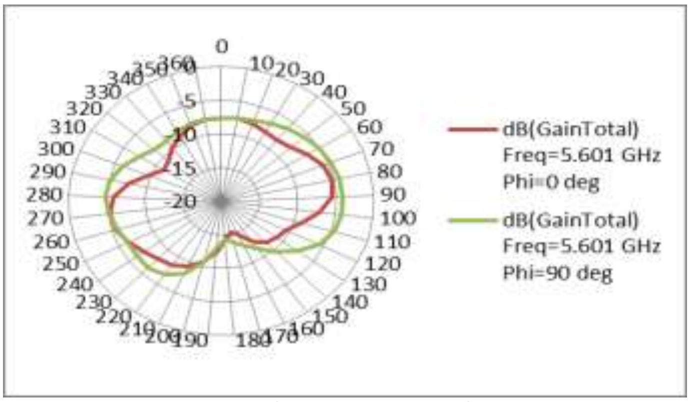

Figure 20. Radiation pattern of circular slot PIFA at frequency = 5.6010GHz

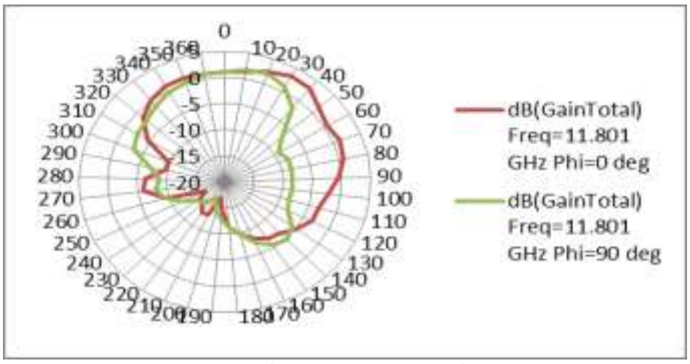

Figure 21. Radiation pattern of circular slot PIFA at frequency = 11.8010GHz

Figure 20. and **Figure 21.** show the radiation pattern of circular slot PIFA at frequency 5.6010GHz and 11.8010 GHz. The pattern is unidirectional like of a half-wavelength antenna i.e. microstrip patch antenna.

VII. Conclusion

In this paper, experimental analysis of rectangular and circular slot PIFA for 5G communication applications is presented. The two models of PIFA in terms of different shaped slots i.e. rectangular slot and circular slot are proposed. Circular slot PIFA shows better results in terms of bandwidth and improved return loss at higher frequency band. The resultant bandwidth of rectangular slot PIFA antenna can cover GPS L1 (1575.42 MHz), GSM 900 (890-950 MHz), GSM 1800 (1710-1880 MHz) and 5G communication and circular slot PIFA can cover GSM 1800, GSM 1900 and 5G wireless communication applications. In future perspective, this research work could be implemented as PIFA with meta-materials used in the substrate or ground plane structure.

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