*Research Article*

# The Frequency-Independent Wideband Planar Log-Periodic Antenna For Multiband Applications

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**Abstract:** In this article, a frequency-independent wideband log–periodic (LP) multiband antenna is proposed and its measurement results in terms of different performance parameters are analyzed. This proposed antenna is designed and implemented to support transmission modes with multi resonances at 0.8, 1.8, 2.37 and 2.94 GHz. The FR-4 substrate material is used to design the suggested antenna which has a fixed dimension of 160 ×160 mm2. They can operate at GSM 800, GSM 1800, Wi-Fi and LTE bands with wider bandwidth due to its design shape and coaxial feeding technique. This symmetrical pair of novel ring-turnstile 2 arms planar log-periodic (LP) multiband antenna has a peak realized gain of 3.4, 5.8, 5.2 and 5 dBi at different resonant frequencies and is suitable for a various communication system. In terms of the S-parameter (S11), voltage standing wave ratio (VSWR), peak realised gain, surface current distribution and radiation pattern, the proposed LP multiband antenna output parameters are analysed. Besides, it has promising values of return loss (RL) less than -10 dB, VSWR less than 4 at all resonant frequency, and gain more than 3.8 dBi. The proposed antenna is a promising candidate for various communication systems because of its suitable radiation pattern properties and rising peak gain..

**Keywords:** Log Periodic planar Antenna, symmetrical pair, directional radiation pattern, directivity, bow-tie wideband antenna, gain.

## 1. Introduction

Log-periodic (LP) antennas were introduced at the end of the 1950s [1]. With the frequency logarithm, their electrical properties periodically repeat, with the lowest and highest operating frequencies being determined by the lengths of the shortest and longest resonant teeth. Because of its frequency-independent characteristic, LP antennas are commonly used in wideband communication systems [2-4]. Modern wireless communication systems have developed rapidly and the demand for wideband and high gain antennas has soared [5-8]. Among those, the log periodic antenna has always been the trending candidate since it has tremendous advantages such as being a wideband antenna with a high gain and a very simple antenna structure. Although having a list of advantages, large size has always been an issue for conventional LP antennas. The traditional LP antenna is an array of λ/2-dipole elements and the length of the longest element, which is equal to λL/2 (with λL being the free-space wavelength at the lowest operating frequency), determines its transverse distance. To make it more suitable for ever-changing modern wireless infrastructure, the LP antenna size should be concise especially in cases where space and size are an issue. We have suggested a wideband LP antenna in this paper with an operational frequency of 700 MHz to 3 GHz. This antenna is a new 2-arm log-periodic novel ring-turnstile planar multiband antenna. The planned antenna has a smaller scale and higher gain relative to standard dipoles and bowtie antennas [9] [10]. An FR4 dielectric substrate base was chosen for the desired antenna design. The dielectric constant of the substrate is 5.4 with a thickness of 1.6 mm and the attenuation coefficient $\tan\varphi$ is 0.02. The results have shown that the reflection coefficient (S11) for this antenna is less than - 10 dB whereas VSWR is less than 4. With a higher gain and stable directional radiation patterns as determined from the simulation results, the proposed multiband antenna is a suitable choice due to its multiple bandwidths and directional radiation pattern. It has a compact size and low fabrication cost compared to other candidates in this category.

## 2.The geometry of the proposed log-periodic multiband antenna

The antenna in the proposal is a log-periodic frequency-independent antenna for multiband wireless applications. It has a 2-arm novel ring-turnstile located on top of the FR-4 dielectric substrate. Just like a bow-tie antenna, it has central symmetrical saw wings. The antenna is circular and has a radius of 70 mm which locates on the square dielectric substrate. The dimensions of the square are 160×160 mm² as presented in Figure1. The proposed antenna consists of dual wings which are symmetrical to each other.

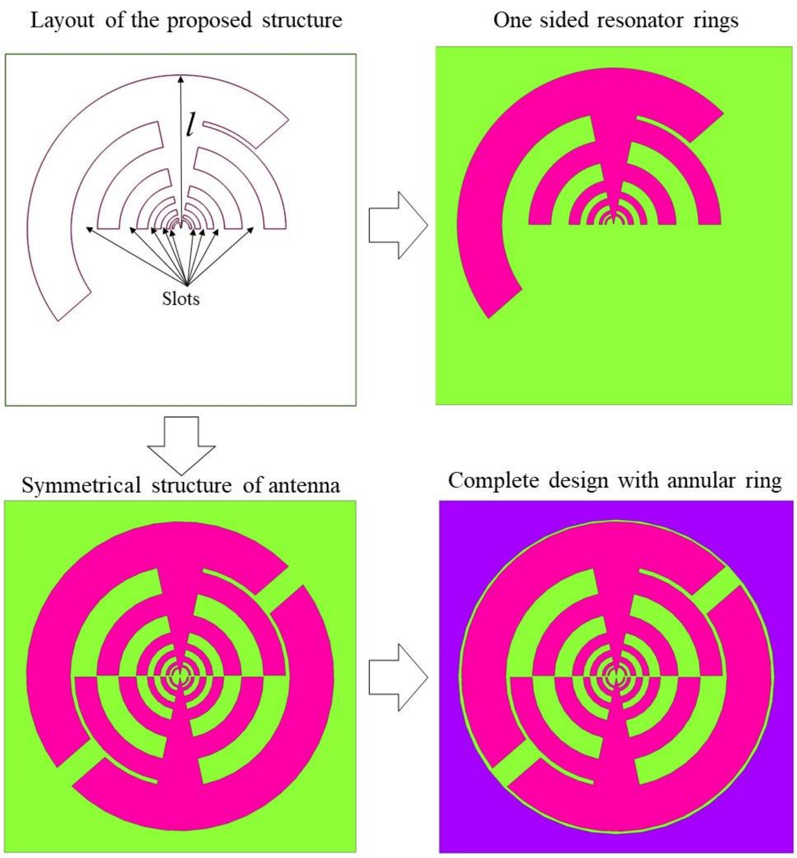



**Figure 1.** The sequential design process of the proposed antenna, a two-armed log-periodic self-complementary ring-turnstile shape with a discrete port and annular ring structure.

The wings have multiple arcs with different widths of radius and slots (but with a common centre in the feeding position) as shown in Fig. 1. The antenna patch element is arranged in such a way that the upper and lower portion complement each other along the horizontal axis as presented in Figure 2. To smoothen the external beamformer and make the antenna more directional, the symmetrical aperture is perfectly integrated with all circular rings along the vertical axis so that it maintains 50 Ω input impedance. The matching network not only reforms the nominal impedance of the aperture line to 50Ω but also works as a balun, thus modifying the external beamformer to a single $180^0$ hybrid for dual-CP use.


**Figure 2.** (a) The geometrical view with the optimized dimension of the proposed antenna, (b) prototype image of the proposed antenna.

### 3.Analysis of the antenna different performance parameters

*3.1.Scattering parameter for different frequencies*

The proposed antenna performance is simulated using CST Microwave Studio (CST). The scattering parameter is measured using the Programmable series Network Analyzer (ENA) Agilent E5062A. Return loss (S11) or scattering parameter describes the correlation between input and output ports in an electrical transmission system. It characterizes the quality of the impedance matching between the input source and the output load of the transmission line. For any proposed antenna, the value of the reflection coefficient (S11) is taken into consideration when it is less than -10 dB. The simulated and measured antenna S-parameters of the two partial steps of the proposed antenna are displayed in Fig. 3, where overall performance good agreement is achieved. It is observed from the Figure 3 of S-parameter that the propagating electromagnetic wave crosses the -10-dB line three times within the range of 700 MHz to 3 GHz. The black dash line indicates the measured return loss value which is approximately similar to the simulated value (indicate the red line). The initial resonance is found at 8 GHz and the return loss is 22 dB. The corresponding -10dB RL BW of the center frequency is 800 MHz. The antenna covers six resonant frequencies at six different bands, and these resonances occurred in the range of 700 to 3 GHz. The return loss values for all resonant frequencies are quite similar except few discrepancies. Due to the intrinsically high antenna impedance of the proposed LP antenna has return loss greater than 3dB (VSWR<4) for a 50 Ω impedance at the input port. Thus the suggested antenna design is resonant and functional in all frequency bands.

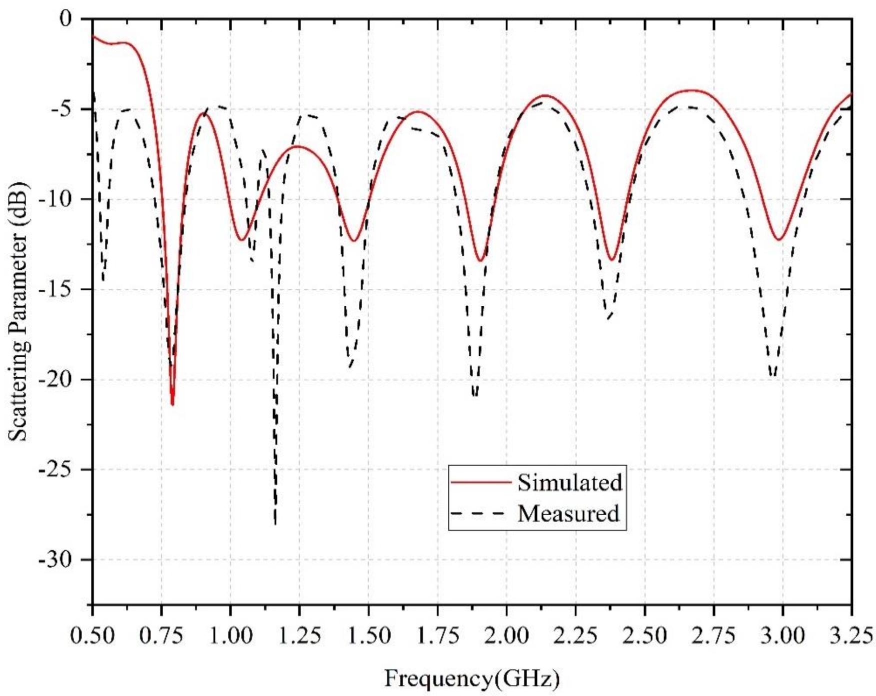



**Figure 3.** Comparison between simulated and measured scattering parameter (S11) of the proposed antenna.

*3.2.Maximum realized gain VS frequency curve and standing wave ratio (VSWR)*

The amount of power transmitted in the direction of an isotropic source is defined by the antenna gain. The simulated and measured maximum realized gain is in good agreement with the resonance frequency of the proposed antenna as depicted in Figure 4. A lower value of realized gain is found to be 3.7 dBi at 0.8 GHz which is the lowest value than other resonance frequencies. With an increase in frequency, peak realized gain has also increased and the maximum realized gain is found to be 5.8 dBi.

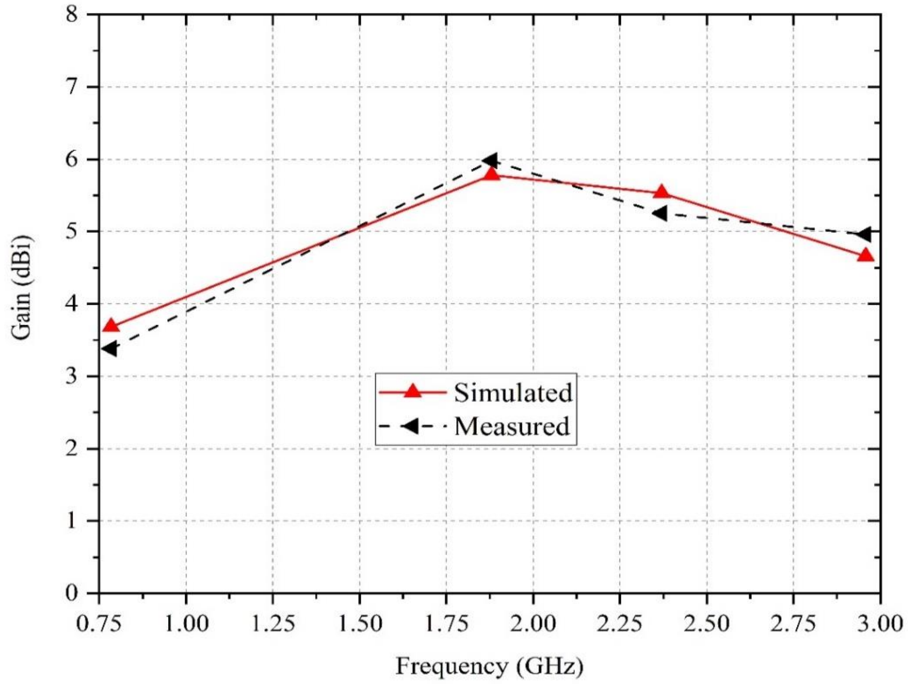



**Figure 4.** The comparison between simulated and measured peak realized gain of the antenna.

The gain at 2.378 GHz and 2.98 GHz are 5.55 dBi and 4.7 dBi respectively, which is a steady decrease of gain over frequency. The simulated standing wave ratio (VSWR) is shown in Figure 5. VSWR is less than 4 for the operational frequency ranging from 700 MHz to 3 GHz. The multiple peaks in VSWR are caused by the slots of the proposed antenna. The optimized width and gap of the symmetrical rings are chosen after a parametric sweep to obtain a high value of VSWR.

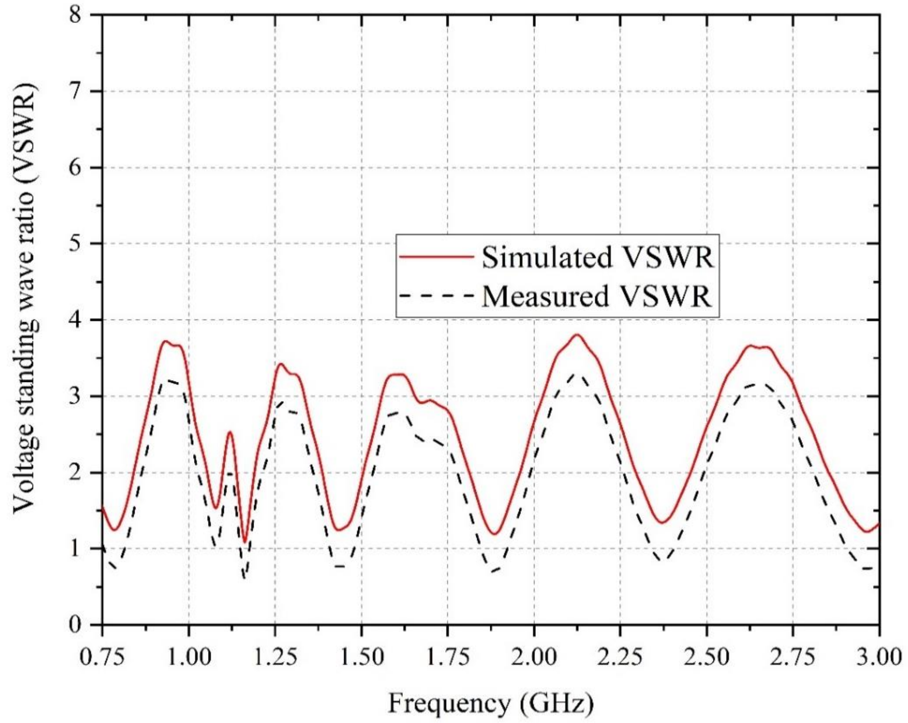



**Figure 5.** The comparison between simulated and measured VSWR of the antenna.

*3.3.Current distribution for different frequency bands*

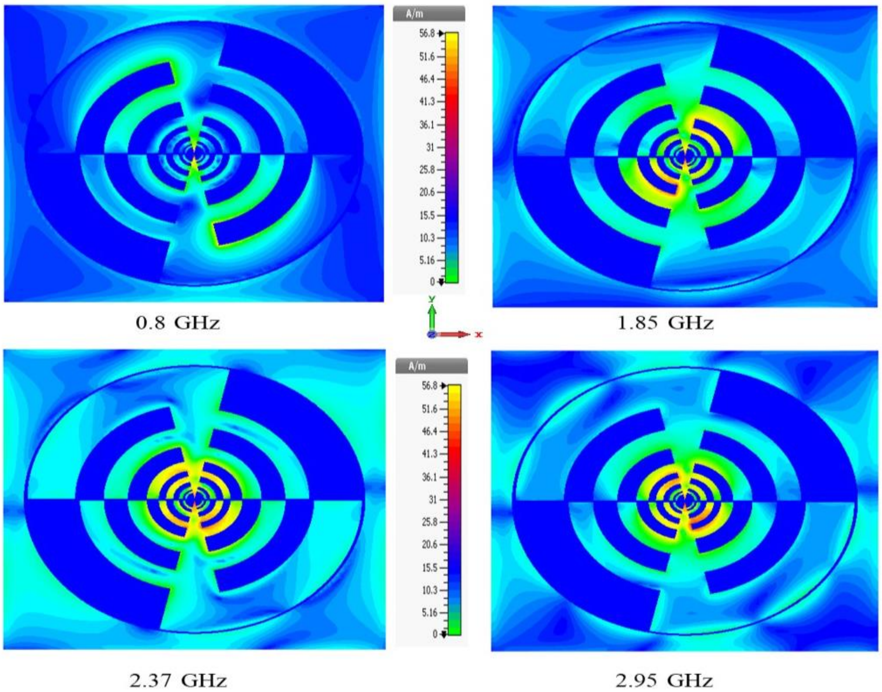



**Figure 6**. Current distribution at different frequency bands.

The simulated surface current distributions at different resonance frequencies 0.8 GHz, 1.8 GHz, 2.378 GHz, and 2.98 GHz of the proposed antenna are shown in Figure 6. At 0.8 GHz and 1.8 GHz, the surface current distribution of the symmetrical pairs of novel ring-turnstile 2 arms is relatively stronger than other resonance frequencies. The domain mode in these frequencies is more excited and contributed by the 2 arms. The density of surface current distribution at 2.378 GHz and 2.98 GHz frequencies are stronger around the microstrip feed line.

*3.4.Directivity radiation pattern in polar form for different frequency bands*

The directivity or radiation pattern is one of the prime performance parameters to evaluate an antenna. It clarifies the direction of any type of antenna at which the electromagnetic signals are radiated in a specific direction. Fig.7 shows the directivity radiation pattern of the antenna at different resonant bands. It can be seen that the cross-pol stays within the parameter of the co-pol which indicates proper antenna characteristics. These polar plots are shown from the relevant radiation patterns from $\varphi = 0$ to $\varphi = 90$ The antenna directivity can reach 3.66 dBi, 5.82 dBi, 5.58 dBi and 4.72 dBi for the frequency bands of 0.78 GHz, 1.85 GHz, 2.37 GHz and 2.95 GHz respectively. These radiation patterns are distributed between both the elevated plane (XY-plane) and the horizontal plane (YZ-plane). For XY-plane, $\varphi$ is kept zero to measure the directivity phi $D[\varphi]$ (co-pol) and the directivity theta $D[\theta]$ (cross-pol). The simulated and measured directivity radiation patterns for both planes (XY & YZ) are in excellent agreement. Besides, the radiation pattern is directional for all resonant bands as well. All these characteristics assure wide application of the antenna in cases that need stable radiation patterns and high gain.

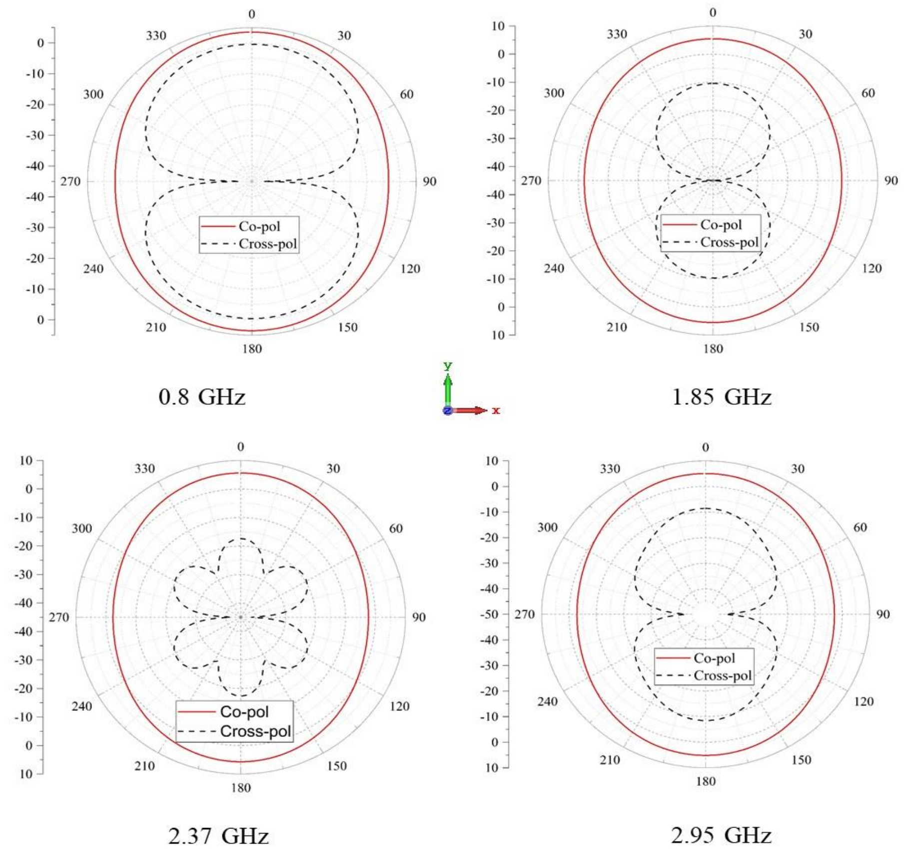
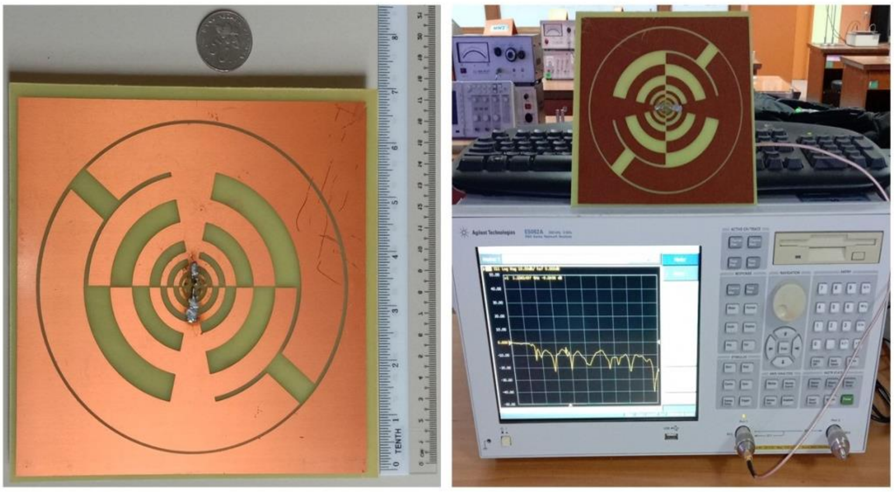



**Figure 7**. Directivity radiation pattern in polar form for different resonant frequencies.

### 4.Measurement Result

Figure 8 (a) depicts the prototype image of the proposed LP antenna. To validate the simulated results, the LP antenna prototype is fabricated and measured. A controlled experimental environment in the applied EM laboratory is used to measure the antenna performance parameters The E5062A ENA Series network analyzer (Figure 8 (b)) with a frequency range of (300 kHz – 3GHz) is used to examine the antenna parameters such as scattering parameter (S11), peak realized gain VS frequency, VSWR, surface current distribution, and far-field radiation pattern of the proposed antenna. In the above performance comparisons, it is proved that simulations and measurements are in good agreement. Although overall measurement results are in good agreement with the simulated results, there are some minor discrepancies due to several errors in prototype fabrication in the PCB lab. Figure 3 shows the comparison between simulated and experimental results of the reflection coefficient |S11| of the LP antenna. As mentioned, the prototype antenna shows excellent performance with RL $\leq$ –10 dB from 0.7 GHz to 3 GHz. Besides, the measured peak realized gain within the operating frequency band varies from 3.2 to 5.8 dBi, as shown in Figure 4. The measured VSWR (Figure 5) of the prototype antenna varies from 0.5 to 3.3 within the operating frequency ranges (0.7 GHz to 3 GHz).



(a) (b)

**Figure 8.** The measurement setup in the lab environment, (a) prototype image of the proposed antenna, (b) measured RL result.

The measured directivity radiation patterns in x-z and y-z planes for different phase angles (phi) within 0.7 and 3 GHz frequency bands are plotted in Figure 7. The beam shapes (phi =0) at 0.8 GHz, 1.8 GHz and 2.9 GHz are placed symmetrically along the y-axis which intersects the beam (phi=90). But the far-field directivity at 2.37 GHz is different from other operating frequency bands which are positioned isotopically along the x-axis with major and minor lobs respectively.

## 5.Conclusion

In this paper, we have shown the design of an LP antenna for multiband operations using an FR-4 substrate. With a return loss coefficient S11< -10 dB, we can conclude that the measurement results have been satisfactory. Moreover, the gain and directivity of the antenna are impressive for all resonant bands. Both simulation and measured results show that the antenna is directional and has stable radiation patterns within these bands. Considering the above performances, it can be deduced that the proposed antenna with a compact size is an excellent candidate for long-distance broadband UWB technology like GPR systems and different types of MIMO applications such as aircraft technology, electronic warfare, and many other military applications.

## References

1. R. H. Du. Hamel, D. E. Isbell, “Broadband Logarithmically Periodic Antenna Structures”, IRE Int. Conv. Rec., vol. 5, pp. 119–128, March 1957
2. F. Dubrovka, S. Martynyuk, “Design and development of ultra-wideband antennas for various applications”, in Proc. Int. Conf. on Mathematical Methods in Electromagnetics, 2006, pp. 95–98
3. S.-Y. Chen, P.-H. Wang, P. Hsu, “Uniplanar log-periodic slot antenna fed by a CPW for UWB applications”, IEEE Antennas Propag. Lett., vol. 5, pp. 256–259, 2006
4. Mruk, J.R., Kefauver, W.N., Filipovic, D.S., “Band Rejection Methods for Planar Log-Periodic Antennas”, Antennas and Propagation, IEEE Transactions on, vol.58, no.7, pp.2288-2294, July 2010
5. Kim, S.-W., Noh, S.-K., Yu, H.-G., Choi, D.-Y., “Design and analysis of a quasi-Yagi antenna for an indoor location tracking system”, Sensors 2018, 18, 4246
6. Yoon, S.J., Choi, J., “A low-profile broadband array antenna for home repeater applications”, J. Electromagn. Eng. Sci. 2018, 18, 261–266
7. Bang, J., Lee, J., Choi, J., “Design of a wideband antipodal vivaldi antenna with an asymmetric parasitic patch”, J. Electromagn. Eng. Sci. 2018, 18, 29–34
8. Kwon, T.-S., Lee, J.-G., Lee, J.-H., “The gain estimation of a Fabry-Perot Cavity (FPC) antenna with a finite dimension”, J. Electromagn. Eng. Sci. 2017, 17, 241–243
9. C. Balanis, Antenna Theory, Analysis and Design. New York: Wiley, 2005
10. Y. T awk, K. Y. Kabalan, A. El-Hajj, C. G. Christodoulou, J. Costantine, “A Simple Multiband Printed Bowtie Antenna”, IEEE Antennas And Wireless Propagation Letters, vol. 7, pp. 557–560, 2008

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