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A compact dual band MIMO PIFA for 5G applications

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Abstract. 5G applications support operations in 28, 37, 60 and 73GHz bands and is expected to support 1GHz bandwidth. In the present paper, planar inverted F antenna for 28GHz operation has been proposed for 5G applications for which a return loss of -17.46dB and a gain of 9.30dB have been observed. In addition, the design has been extended for dual band operation at 28 and 37GHz by implementing an L slot in the patch. An excellent return loss of -32.54dB and -18.57dB with a gain of 8.62dB has been observed. Moreover, a feasible bandwidth of 1.02GHz has been obtained in former design, while an enhanced bandwidth of 1.3GHz has been obtained at both bands in case of latter design. However, for better gain & data rate considerations, the previous design has been extended as a MIMO configuration with 2 antenna elements (2x1) and corresponding performance parameters have been evaluated.

1. Introduction

With an increase in customer requirements, wireless communication systems have nurtured its way of meeting them [1]. One of the major customer demands from the past few years is higher data rates. This demand from customers has made all the network operators to modify their network systems in order to sustain in the market. One of the modifications adapted by the network operators is an increment in operating frequency so that a larger number of subscribers can be faithfully served simultaneously with higher data rate as an add-on [1]. This has led to a gradual development of wireless communication systems in terms of generations, each generation coming up with a novel technology as compared to the previous ones [2]. This novelty has led to revolutionary wireless systems (4G) in comparison to previous evolutionary systems (3G). It has also led to huge data rates in the order of some tens of Mbps (50Mbps in Uplink & 100Mbps in Downlink in case of 4G). However, it has been predicted that much higher data rates in the order of Gbps will be demanded in near future. Such tremendous data rates can be achieved only when the available bandwidth is in the order of GHz which is possible only when the frequency of operation is in some tens of GHz (approx. 30GHz). Thus a new technology termed “Millimetre wave communication” has blossomed which has an expected potential to meet the needs of the future trends.

Wireless communication supporting millimetre wave communication is generally termed as 5G (Fifth generation) which is the buzz word presently heard all over the air. 5G is expected to operate at four different bands namely: 28GHz, 37GHz, 40GHz & 60GHz [3]. It can be inferred that in order to meet the requirement of operating in millimetre wave frequencies, a perfect and suitable antenna element has to be chosen. In addition the chosen antenna element needs to be miniaturized, planar, easy to fabricate & conformable with complex geometries. These requirements can be very well served by a

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Planar Inverted F Antenna (PIFA) due to its unique design, operation & planarity [4]. However, in terms of space constraint, a single element is expected to operate at multiple frequencies while not keeping expected bandwidth at stake. Such a requirement is very much feasible in case of PIFA by certain modifications in the design. In addition, for 5G applications, to achieve huge data rates, fading & propagation losses need to be carefully handled [5]. Transmission of data through a single path doesn't guarantee peak data rates at all times due to SNR degradation. Thus, MIMO technology has popped up which eliminates this anomaly by transmission of the similar data through multiple antennas and corresponding detection from the path with feasible SNR [6]. This selection procedure of path with optimal SNR is done by means of a Rake receiver.

This paper deals with three designs of PIFA compatible to operate at millimetre wave frequencies (5G). Design 1 deal with a single band PIFA operating at 28GHz, while design 2 deals with a dual band slotted PIFA operating at both 28 & 37GHz. Design III includes Multiple Input Multiple Output (MIMO) antenna configuration with 2 PIFA elements arranged side by side. The entire paper can be divided into 4 sections. Section II deals with structure & impedance matching procedure of Design I, II & III. Section III includes the simulated layouts and corresponding results. Section IV deal with the inference and discussion of results.

2. Antenna Element Design

2.1. Single Band PIFA Element Design (Design I)

2.1.1. Structure

The antenna implemented as a part of Design I is depicted in Fig.1. The present design consists of a 5mm by 5mm patch mounted on an air substrate with a length L and width W. The patch and the ground are connected by a shorting strip placed at the top right. This position of shorting strip has been selected in order to match impedance by varying its parameters. Coaxial feeding method has been used in order to make impedance matching easier by varying the position of the feed [7]. This in addition to no feed line radiation loss has served well in obtaining efficient results to be discussed in later sections.

The antenna is compact in terms of its size as well as volume and occupies a total area of 25mm^2 (smaller than a finger nail). An air substrate with a low permittivity & slightly higher thickness (h) has been incorporated in order to increase the bandwidth [8].

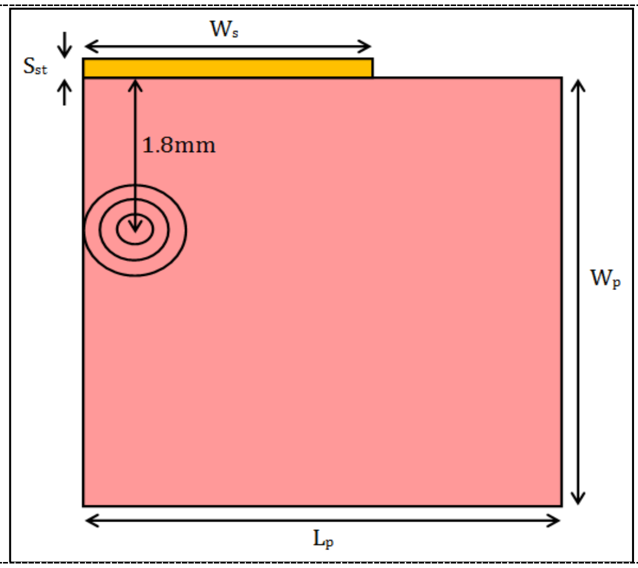

Figure 1. Structure of Single band PIFA (Design I).

Table 1. Physical dimensions of Design I.

Variable	Value (in mm)
W	15
L	15
W_p	5
L_p	5
h	0.3
S_{st}	0.1

2.1.2. Impedance Matching

The authors have tried the following possibilities to get best impedance matching:

- Position between coaxial feed and shorting strip has been increased to decrease the frequency of resonance & vice versa.
- Width of shorting plate has been increased to increase frequency of resonance and vice versa.
- Substrate height is also slightly varied in order to make the antenna resonate at desired frequency [9].

2.2. Dual Band PIFA Element Design with L slot (Design II)

2.2.1. Structure

The antenna implemented as a part of Design II is depicted in Fig.2. As a modification to previous design, an L slot has been etched out from the patch. This has been done in order split the current in such a way that it takes a longer path to flow. This has made the antenna to resonate at a second frequency.

In order to form a new band, a slot has been added in the form of loading to disturb the field distribution. Generally the excited modes in an antenna depend on the type and the position of the feed. However, the excitation of the modes can be controlled by the placement of two slots close to the radiating edges. This technique has been incorporated by the authors in order to make the excitation modes vary with respect to the slot parameters. As a result, it has been observed that the current lobe has flattened without affecting the radiation pattern [8].

In addition, the ratio of both frequencies has been varied with respect to slot positions and its lengths. A combination of two slots forming an L shape has been used in order to achieve dual frequency. The frequency ratio has been decreased by moving the slot closer to the radiating edge. However, the loading effect or frequency ratio increases with slot length [8].

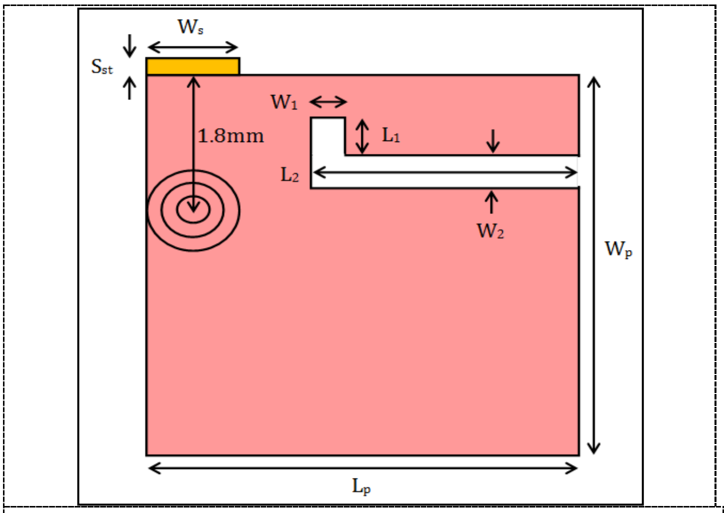

Figure 2. Structure of Dual band slotted PIFA (Design II).

Table 2. Physical dimensions of Design II in addition to Design I.

Variable	Value (in mm)
W_1	0.3
L_1	0.5
W_2	3.3
L_2	3.3

2.2.2. Impedance Matching
The antenna matching has been made for both the frequency bands by varying the following parameters:
- Width & length of shorter section of L slot.
- Width & length of longer section of L slot.
- Position of L slot.
- Distance between L slot and edge of patch.

2.3. Dual Band MIMO PIFA Design (Design III)

2.3.1. Structure
The antenna implemented as a part of Design III is depicted in Fig.3. As a modification to previous design, a second antenna element has been added for enhancement of gain and better data propagation. In order to eliminate the interference of adjacent antenna elements, a minimum spacing of λ/2 (5.36mm) has been maintained. Moreover, this spacing between elements needs to be compromised with the overall size of structure and isolation between individual antenna elements. The current design has two elements and hence data takes two different and independent paths.

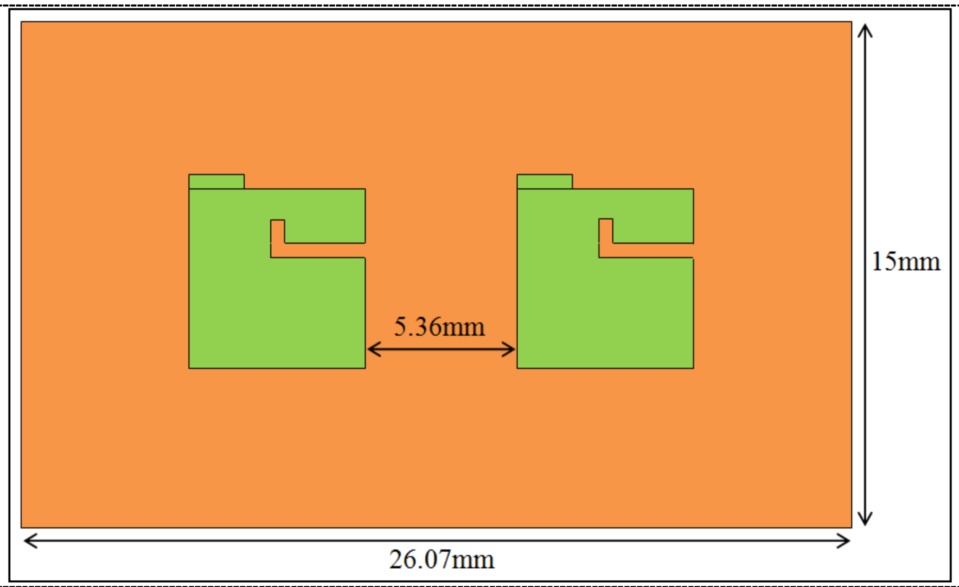

Figure 3. Structure of Dual band MIMO PIFA (Design III).

2.3.2. Performance Analysis
In order to evaluate a MIMO configuration, Envelope Correlation Coefficient (ECC) [10] plays a major role which gives a measure to describe how much the communication channels are isolated with each other.

$$ECC, \rho = \frac{|S_{11}{}^{*}S_{12} + S_{21}{}^{*}S_{22}|^2}{|(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} = 0.2894\ (28GHz)\ \&\ 0.0011\ (37GHz) \quad (1)$$

It has been observed that both the ECCs of the proposed MIMO antenna are below 0.3 over the complete 5G frequency band, which is much lower than criterion of low ECC (ECC < 0.5) [11]. In addition to ECC, diversity gain plays a major role in evaluating MIMO configuration. Diversity gain is effective at mitigating multipath situations because different antennas offer several copies of same signal. The antenna diversity gain is given by:

$$G_{div} = 10\sqrt{1-|\rho|^2} \quad (2)$$

It has been observed that for ρ = 0.2894 (28GHz), G_{div} = 9.572 & for ρ = 0.00113 (37GHz), G_{div} = 9.999. For two uncorrelated antennas and an accepted bit-rate error of 1%, the theoretical diversity gain is 10 dB [12]. Thus the practical diversity gains evaluated are almost comparable to the theoretical values.

3. Simulation & Results

The above two designs have been implemented in Ansoft HFSS. The coaxial port excitation has been implemented by means of vias and has been excited using a wave port.

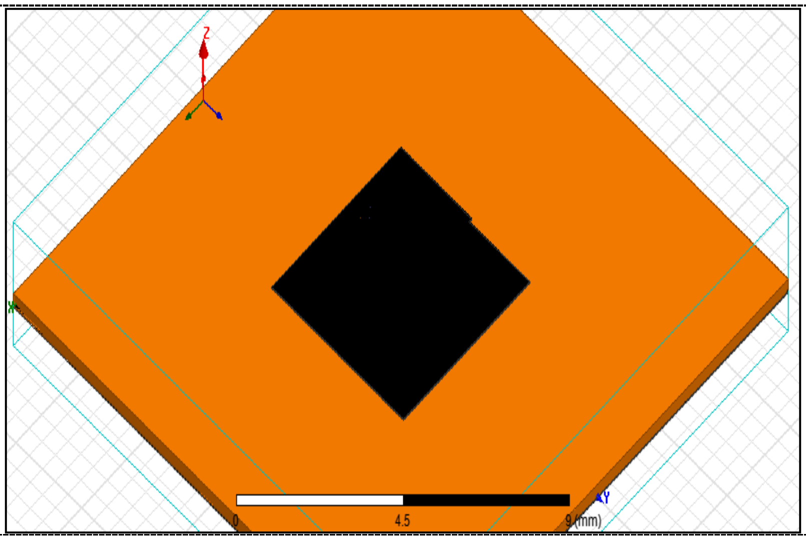

Figure 4. Simulated structure of Design I.

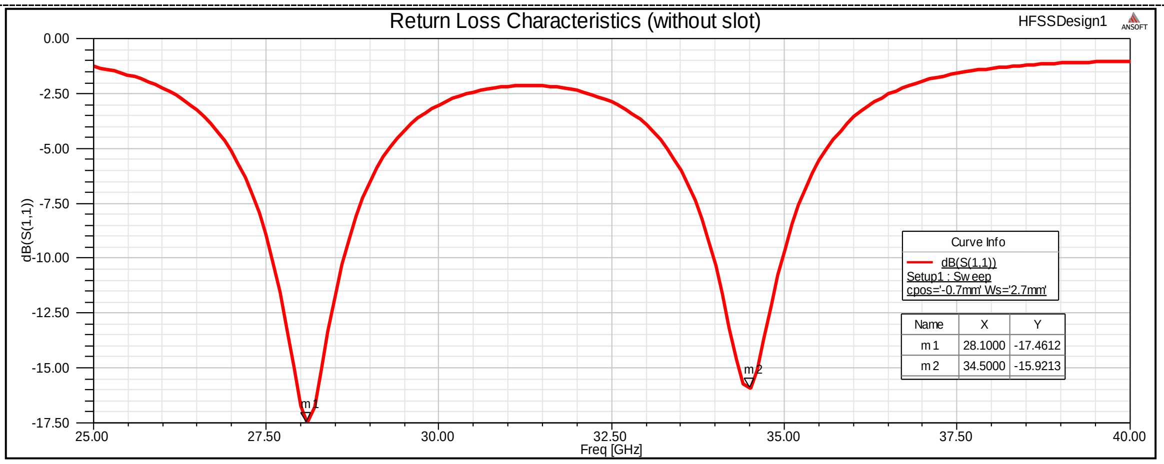

Figure 5. Return loss characteristics of Design I.

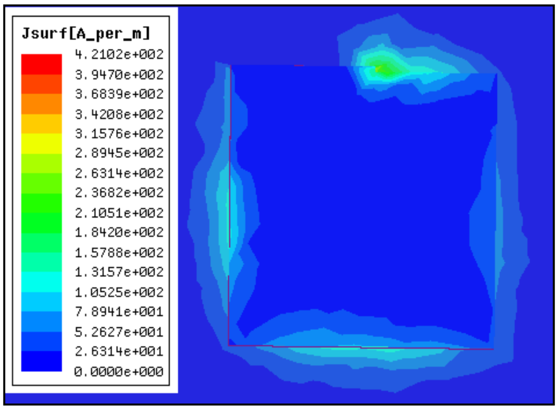

Figure 6. Surface current distribution of Design I.

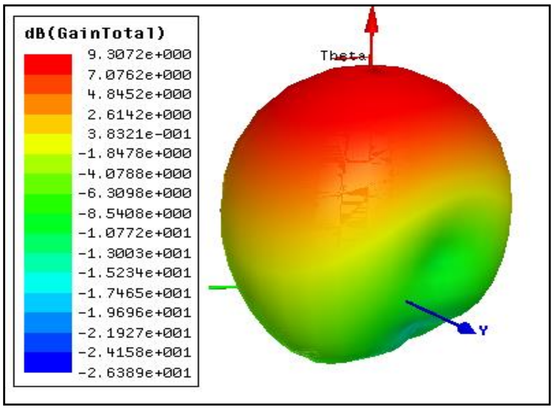

Figure 7. Gain characteristics of Design I.

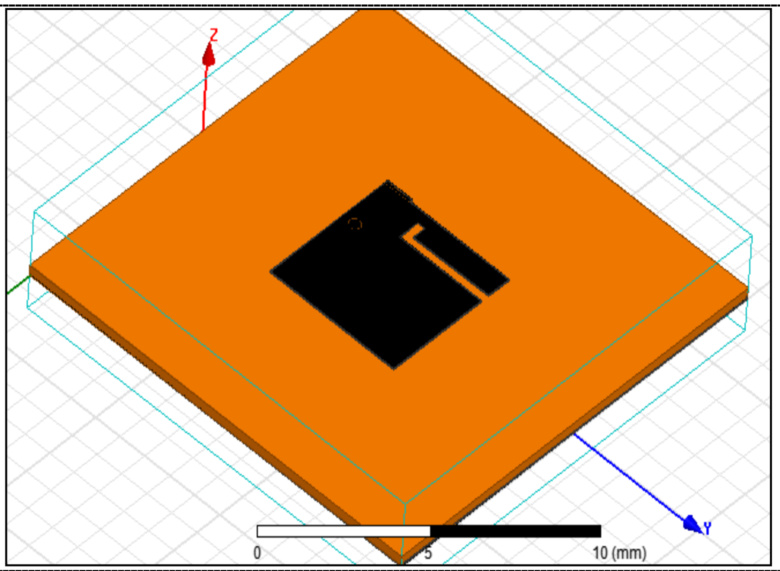

Figure 8. Simulated structure of Design II.

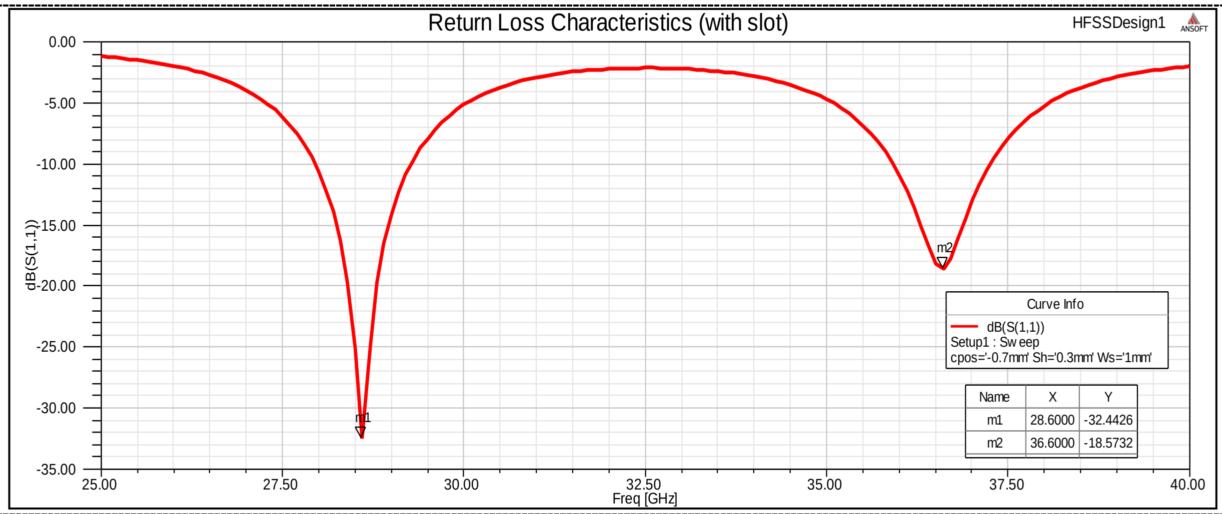

Figure 9. Return loss characteristics of Design II.

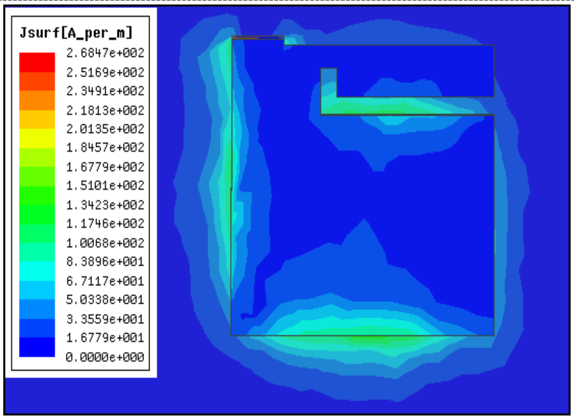

Figure 10. Surface current distribution of Design II.

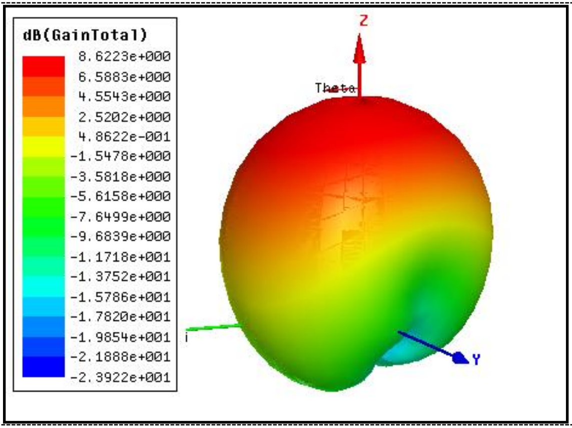

Figure 11. Gain characteristics of Design II.

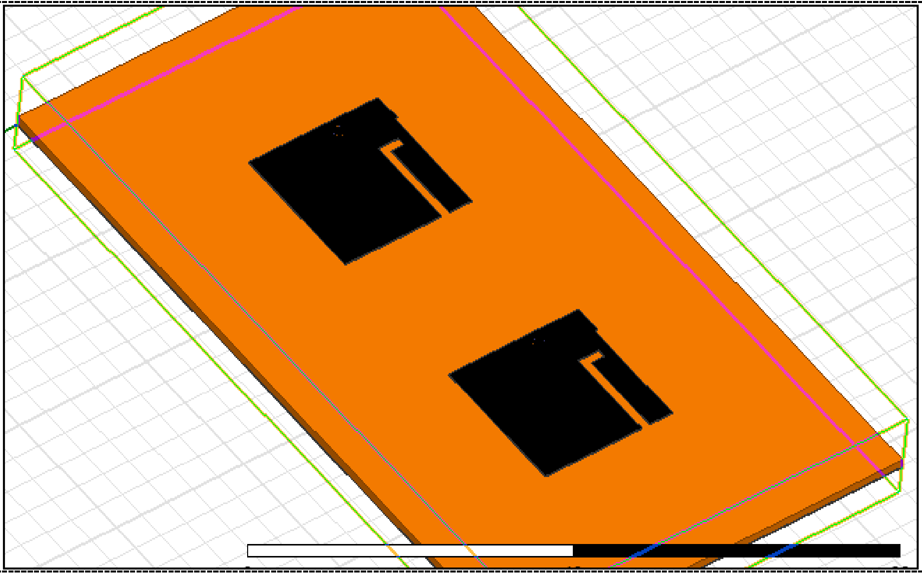

Figure 12. Simulated structure of Design III.

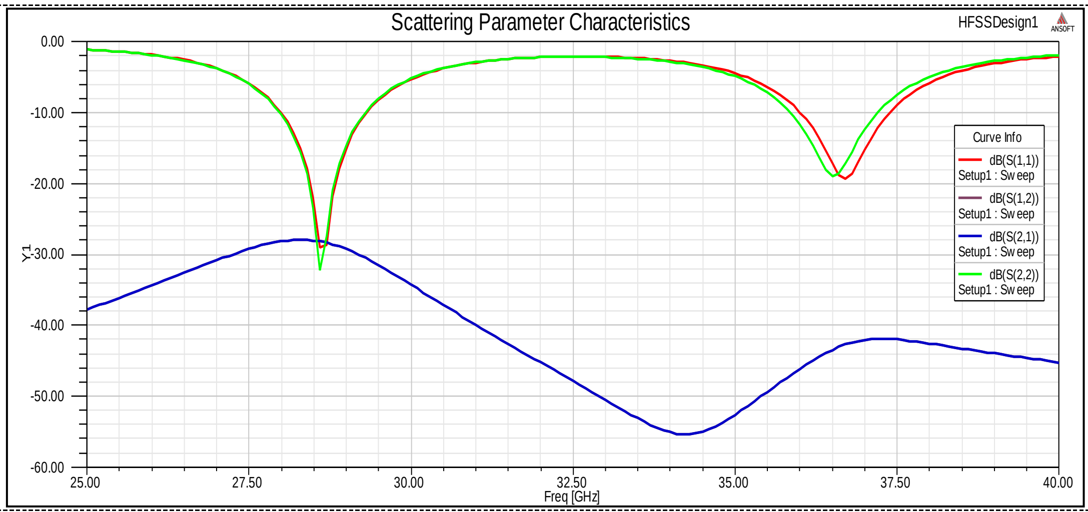

Figure 13. Return & isolation loss characteristics of Design III.

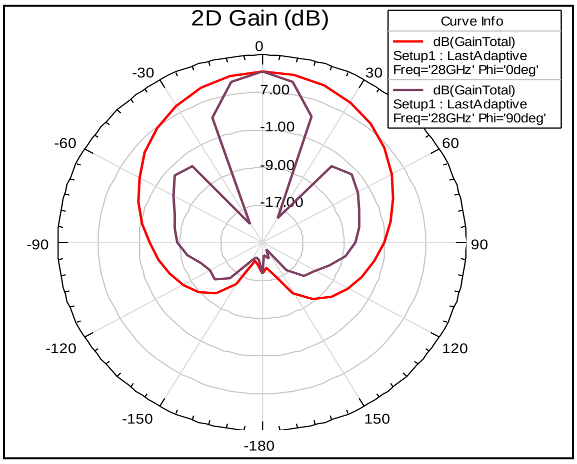

Figure 14. 2D Gain characteristics of Design III.

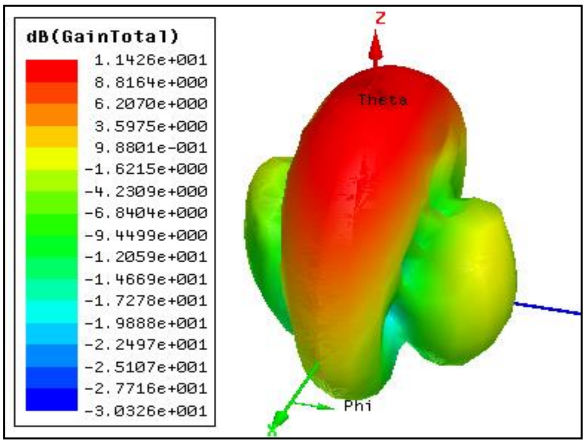

Figure 15. 3D Gain characteristics of Design III.

4. Inference & Discussion

It can be observed from the results of Design I that a return loss of -17.46dB has been obtained with a gain of 9.30dB. Perfect impedance matching has been obtained which is reflected in the amount of return loss.

In case of Design II, the L slot has been placed in the location of maximum current flow in order to reduce the flow of current which can be observed from Fig.5. It can be also observed that by varying the width and length of slot, near exact dual band frequencies of 28 & 37GHz have been achieved. In addition, excellent return loss characteristics have been obtained at both the frequencies while maintaining a gain of 8.62dB.

In case of Design III, as expected, an improved gain of 11.42dB has been observed with minimal reduction in radiation efficiency (η). In addition, enhancement in bandwidth has also been observed as compared to previous design. An excellent isolation of -30dB and -42dB has been observed at 28GHz & 37GHz respectively.

Table 3. Comparison of proposed designs.

Parameter	Design I		Design II		Design III	
	Band 1	Band 2	Band 1	Band 2	Band 1	Band 2
f_r (GHz)	28.10	34.50	28.6	36.6	28.6	36.7
RL (dB)	-17.46	-15.92	-32.44	-18.57	-29.03	-19.42
B.W. (GHz)	1.02	0.98	1.32	1.33	1.33	1.45
% B.W.	3.64	2.64	4.71	3.59	4.75	3.91
G (dB)	9.30		8.62		11.42	
η	0.98945		0.91423		0.8949	

5. Conclusion

A compact single band PIFA & dual band slotted PIFA have been designed to operate at millimetre wave frequencies & finds apt application in 5G technology. Design I & II with single & dual operating frequency respectively are observed to have a wide bandwidth of 1.3GHz for all operating frequencies which is a vital requirement for 5G applications. In addition, a typical gain of 9.30 & 8.62dB in the two designs which is very much optimal for utilization of current antenna design in 5G mobile handsets. The user or the customer can choose either of the designs as per his requirement whether he wants the antenna to operate in single or dual band. The MIMO design simulated by authors has showed faithful results in terms of its performance parameters as evaluated in previous sections. However, the current design can be extended to 4 elements for further enhancement in performance.

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