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DESIGN AND PERFORMANCE ANALYSIS OF A SLOT-LOADED PLANNER ANTENNA FOR FR-I NR BANDS FOR 5G APPLICATIONS

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Abstract:
This paper presents the design and performance evaluation of a slot-loaded planner antenna for FR-I NR bands n70, n7, n38, and partially n79, suitable for 5G applications. The proposed antenna is fabricated using substrate material FR4 epoxy with dielectric constant of 4.3 and thickness of 1.57mm. The antenna operates at triple band within the frequency ranges of 1.55-2.08 GHz, 2.49-2.82 GHz, and 4.49-4.8 GHz, respectively. Both simulated and measured results show a VSWR well below 2 across all bands. The antenna attains a maximum gain of 3.75 dBi at 2.75 GHz, with measured gains of 1.5 dBi for the lower band and 3 dBi for the higher band. Radiation efficiency ranges from 70% to 90%, peaking at 90%. Radiation patterns exhibit a dipole nature, with slight deviations observed at phi=90. The results confirm the antenna's efficacy in covering the designated FR-I NR bands, validating its potential for 5G communication systems.

Keywords- FR NR-I, 5G Band, Multiband, Planner antenna,

1. Introduction
Microstrip antennas, also known as patch antennas, are a type of radio antenna with a low profile, which can be mounted on a flat surface. These antennas are widely used in various applications, including mobile and satellite communications, radar systems, and biomedical devices. The microstrip antenna was first proposed by Deschamps in 1953, but it wasn't until the 1970s that practical models were developed. Microstrip antenna advantages include light weight, low cost, low profile, planar configuration, ease of conformal, suitable for arrays, etc. [1]–[3]
Further, a multi-band antenna array structure suitable for smart phones operating in LTE bands 42/43/46 has been presented using two diverse open slots on a T-shaped slot antenna [3]. Sub-6 GHz has taken the interest of researchers in designing the antenna, radio frequency circuits, and spatial filters [4]. A simple single feed design is proposed for a multi-band antenna with defected ground substrate structure [5]. A compact slot antenna with the 3 L-shaped slots and the ground plane for three operating frequency bands is proposed in [6]. In [7], the design of a four-band antenna is presented, and the structure involves a T shaped feed patch, an inverted T-shaped stub, and two E shaped stubs. Further investigations have been done in designing a partial slotted ground antenna for wideband applications [8]. In [9] author has presented a wideband patch antenna with IBW of 4.3–6.45 GHz with realised gain of 4.7 dB for wireless applications. Presented antenna comprises of compact nature. In [10] author presented a circularly polrized wideband patch radiator with frequency range from 3.4 to 9.8 GHz using substrate FR-4. FSS structure is incorporated which enhance the overall gain of antenna from 4.5 dBi to 9.5 dBi. In this study [11]author has presented bulb shaped super wideband radiator covers frequency range 2.8 to40 GHz with maximum gain of 6.1dBi. In this study [12] author introduced a CPW fed UWB antenna covering 3.2 to 16.3 GHz fabricated using FR-4 material.
In this reported antenna [13] a CPW fed circularly polrized wideband antenna with IBW of 1.9–14.3 GHz presented. Wideband operation results because of slot and circular structure is used in antenna

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structure. (Gautam et al., 2016) Further in study [14] a wideband antenna for different wireless band applications is presented and fabricated using FR-4 material covers range from 2.4–6.0 GHz.
(Ellis et al., 2023) In [15] a circular wideband antenna (1.2–2.25 GHz), reported form 1.55–2 GHz, maximum gain of 3.7 dBi with radiation efficiency of 90%. In]16] a slot-based antenna is presented with frequency range of 3.52–6.66 and 8.68–10.55GHz.
In [17] a triangular Koch fractal wideband antenna for wideband applications is presented. Theantenna has covers frequencies from 4GHz to 9.2 GHz. In [18] author introduced a rectangular and Ψ-shaped wideband antenna covers frequency from 3.8–11.4 GHz and 3.4-12.0 GHz respectively with a peak gain of 4.6dB. In [19] a tapered corners partial ground plane (PGP) stubs and T-shaped slots loaded wideband antenna covers operating range from 3.14–15.62 GHz frequency with peak gain of 5.65dB.
In this manuscript compact size multiband patch antenna has been designed and discussed which covers the under sub 6 GHZ 5G bands. Antenna simulation results are validated through measured results.
Organisation of manuscript consist of 5-sections. Section 1 deals with the introduction and literature study of 5G antenna. In section-2 reveal the antenna design stages and parametric analysis for various parameter. In section-3 deals with the result discussion on the |S11|, VSWR, gain profile and efficiency of the antenna. In section-4 deals with the conclusion part.

1.1 Basic Structure and Operating Principles

The basic structure of a microstrip antenna consists of a metallic patch on a grounded dielectric substrate. The patch can take various shapes, such as rectangular, circular, or triangular, with the rectangular shape being the most commonly used due to its simplicity in analysis and fabrication. The patch is usually fed by a microstrip line, coaxial probe, or aperture coupling. Microstrip antennas operate by resonating at specific frequencies, where the patch creates a standing wave with maximum current at the centre and maximum voltage at the edges. The radiation pattern is determined by the shape and size of the patch, as well as the properties of the substrate.

1.2 Advantages and Limitations

1.2.1 Advantages

- Low Profile and Lightweight: Microstrip antennas are thin and light, making them suitable for applications where size and weight are critical.
- Ease of Fabrication and Integration: They can be easily fabricated using printed circuit technology and integrated with other components on the same substrate.
- Versatility in Design: The shape and size of the patch can be modified to achieve different radiation patterns and polarization characteristics.

1.2.2 Limitations

- Narrow Bandwidth: One of the primary limitations is the narrow bandwidth, which restricts the frequency range over which the antenna can operate effectively.
- Low Power Handling: Due to their thin structure, microstrip antennas have limited power handling capabilities.
- Surface Wave Losses: The presence of a dielectric substrate can lead to surface wave losses, which degrade the antenna performance.

1.3 Applications

Microstrip antennas are used in a wide range of applications, including:

- Mobile Communications: Their compact size makes them ideal for use in mobile phones and other

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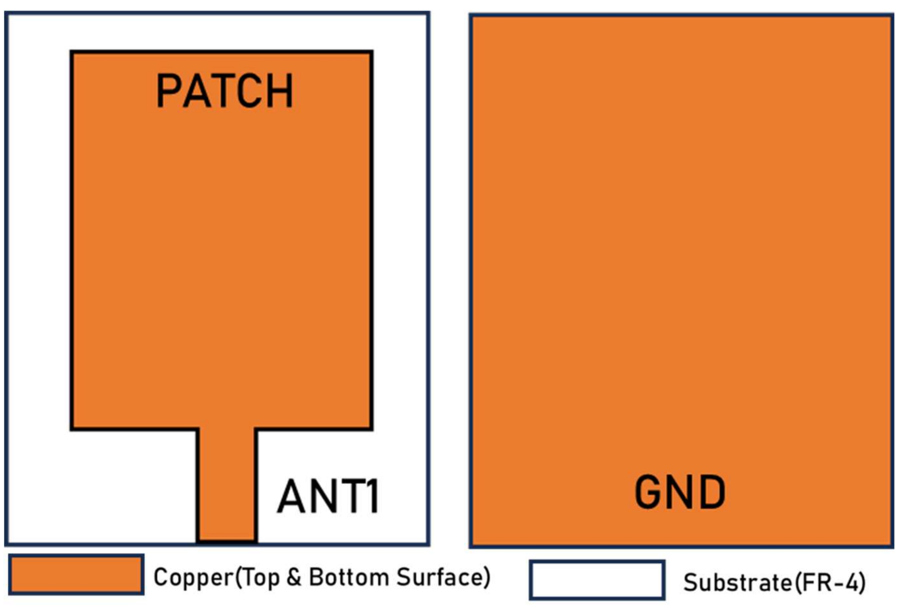
portable communication devices.

- Satellite Communications: They are used in satellite transponders and ground station equipment due to their lightweight and planar con- figuration.
- Radar Systems: Microstrip antennas are employed in various radar systems, including airborne and marine radar.
- Biomedical Devices: They are used in wearable and implantable devices for biomedical monitoring and telemetry.

2. Design Steps of proposed antenna:

Proposed prototype of antenna is fabricated using substrate material FR-4 epoxy with dielectric constant of 4.3 and thickness of 1.57mm. Figure (1) depicts the evolutionary design steps of proposed antenna. Proposed antenna has four design steps from rectangular antenna design to final slot loaded, inset feed with partial ground structure for final optimum results for desired bands. From Figure 1(a) ANT1 consists of full ground plane which radiates at 3GHz and 5GHz but having very low impedance bandwidth and |S11| depth. In further step partial ground is used which converts the proposed design into dual band which radiates at 1.9GHz and 3.4GHz with |S11| about -15dB and frequency ranges from 1.4GHz to 2.3Hz and 2.7GHz to 3.4GHz respectively as shown in Figure 1(b). In third iteration as shown in Figure 1(c) inset feed with partial ground is used which provides the impedance matching at 1.25GHz with |S11| more than -20dB but impedance bandwidth is limited also other band is not optimum. In final steps in Figure 1(d), vertical and horizontal slots are cut on the patch along with inset feed and partial ground provides the desired results. The antenna radiates at triple band with centre frequency 1.75GHz, 2.3GHz and 4.6GHz respectively.



(a) Design-I

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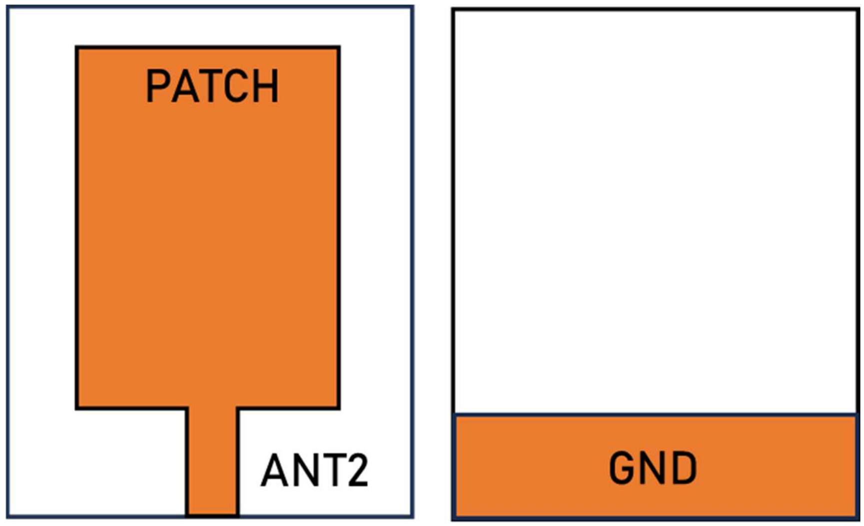
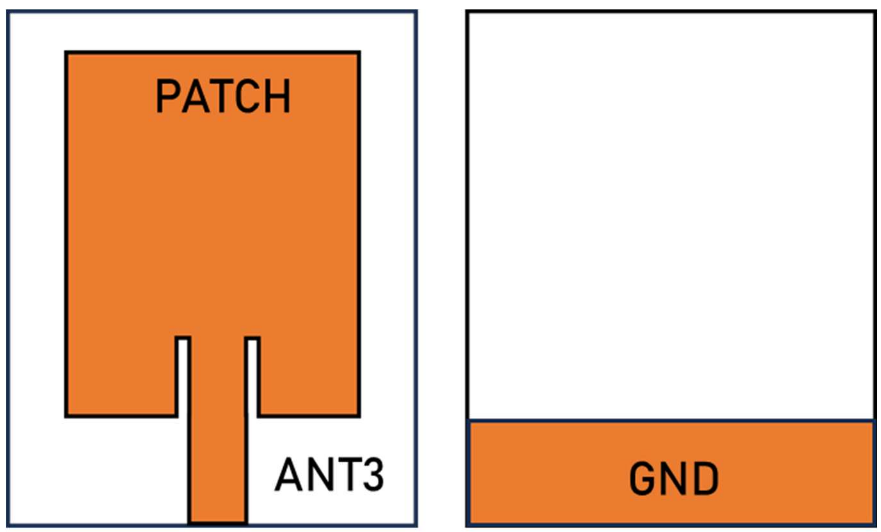


(b) Design-II



(c) Design-III

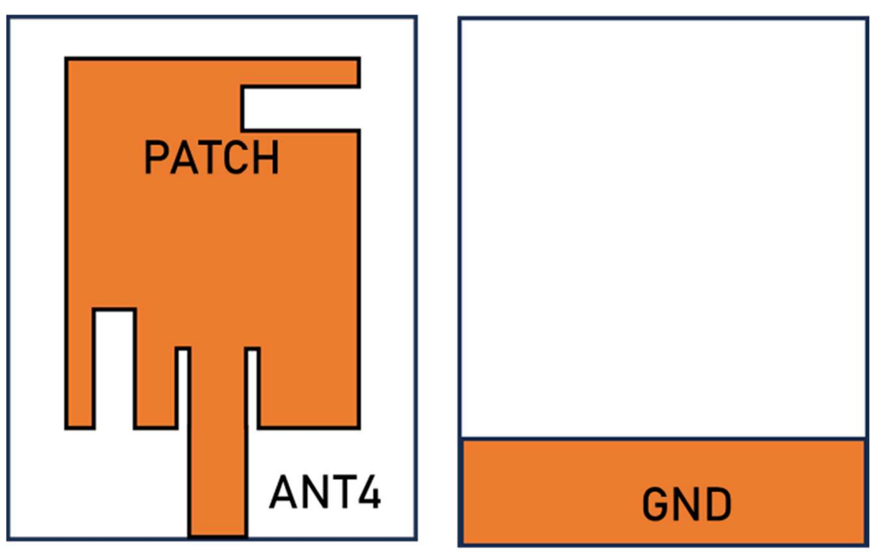


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Figure 1. Evolutionary design steps of proposed antenna

Table 1. FR-I NR Frequency band of proposed antenna with frequency range

Achieved band	FR-I NR P.B.	Uplink Frequency (GHz)	Downlink Frequency (GHz)	BW (MHz)	Duplexin
Ist band	n70	1.695-1.71	1.995-2.02	90	FDD
2nd Band	n7	2.5-2.67	2.62-2.69	70	FDD
	n38	2.57-2.62	2.57-2.62	50	TDD
3rd Band	n79	4.4-4.8	4.4-4.8	400	TDD

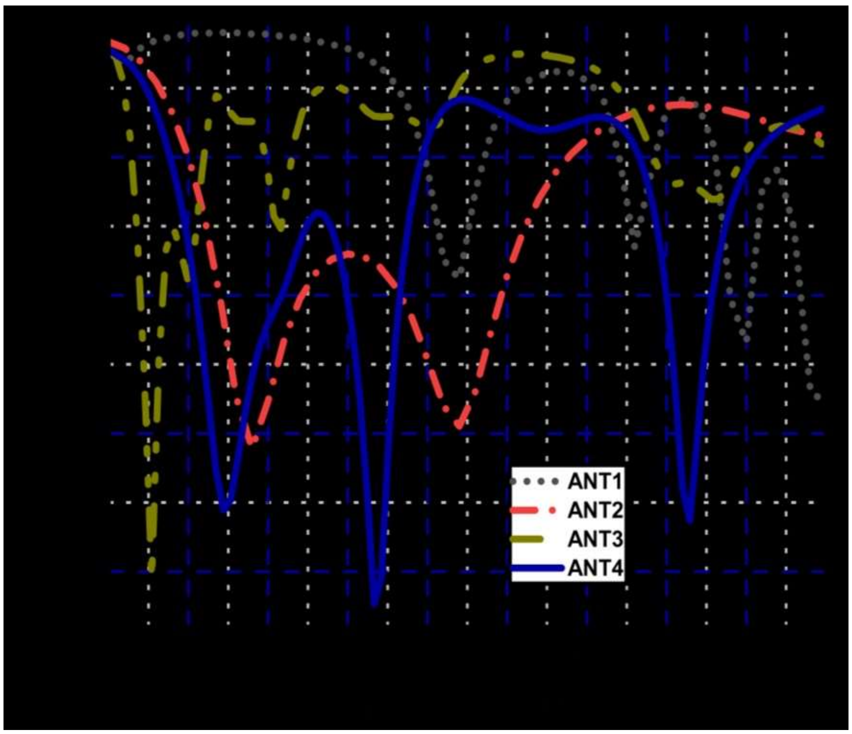

Figure 2. |S11| of different design steps of proposed antenna for desired frequency range

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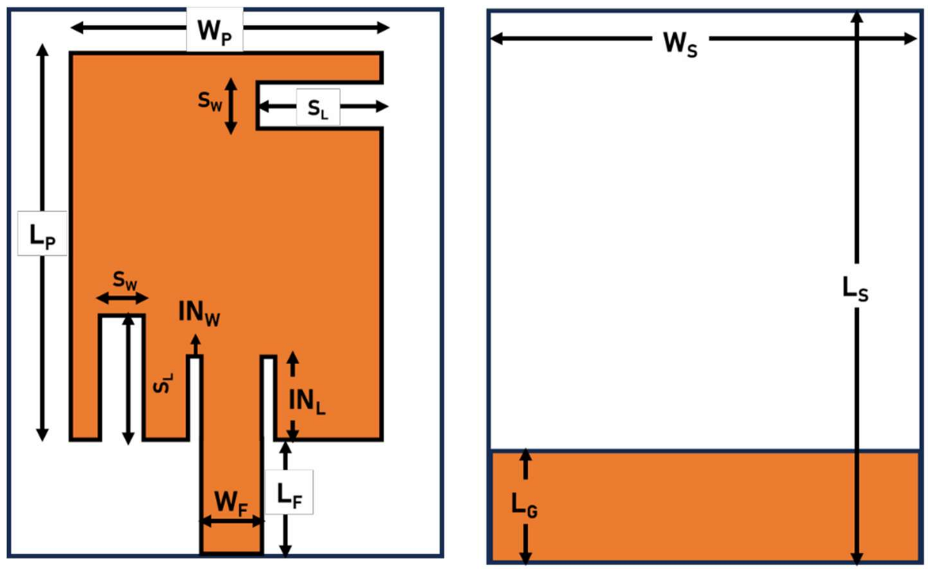

Figure 3(a). Physical dimensions of proposed antenna

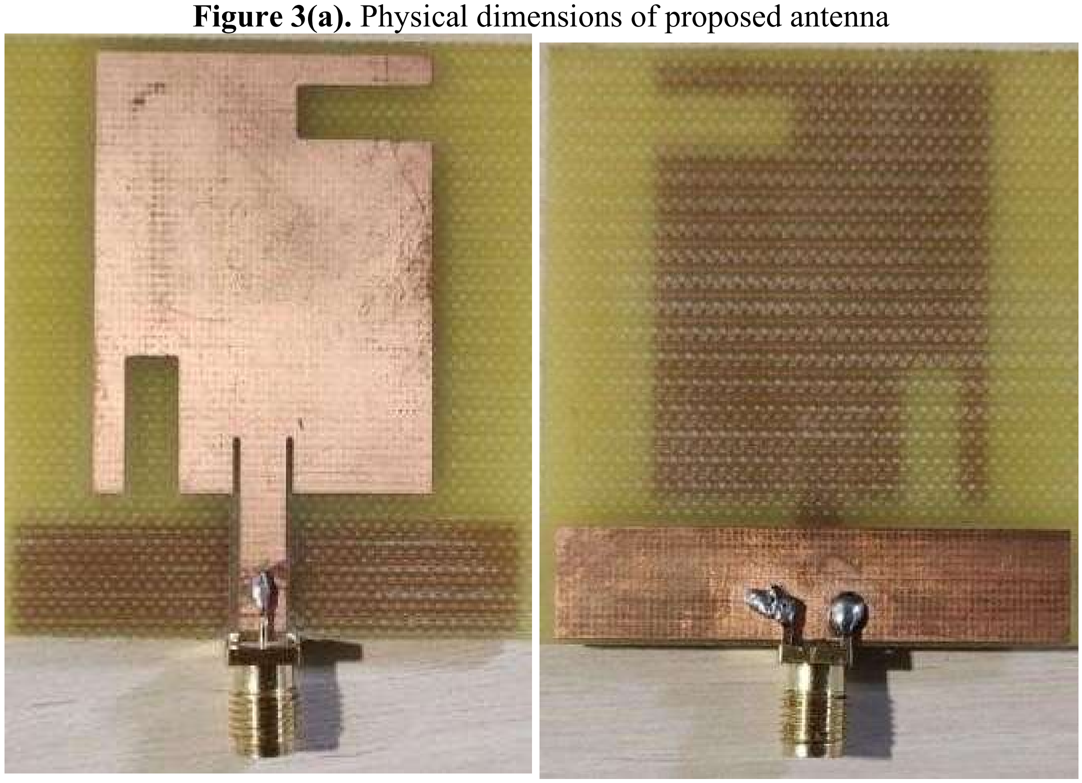

Figure 3(b). fabricated proto type of proposed antenna

Table II. Parameter values of physical dimensions

Parameters	**WP**	**LP**	**WS**	**LS**	**LG**
Value (mm)	30	39.5	55	45	10

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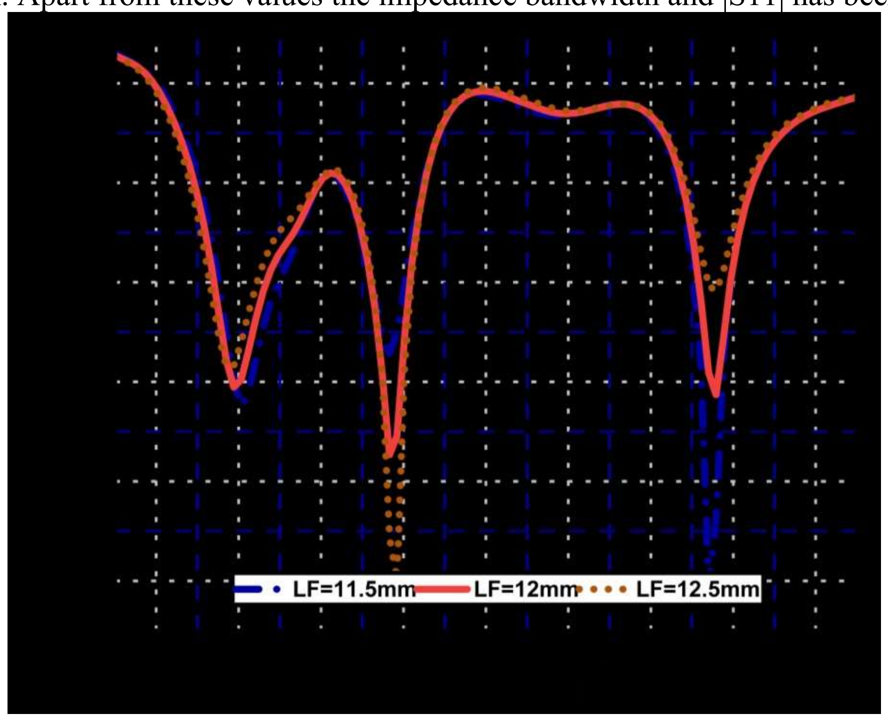
Parameters	**INL**	**INW**	**WF**	**LF**	**SL & SW**
Value (mm)	6	0.6	4	12	12 & 4.5

2.2 Parametric Study of proposed antenna

To achieve the desired working range for the proposed antenna different parametric analysis has been carried out. After designed the basic rectangular patch antenna using the transmission line equations. Different iteration has been performed for the parameter feed width, feed length, partial ground, slot length, slot width, patch width and patch length. Then the final optimized designed is presented in this study which radiate for FR-I NR band at three distinct bands.

2.2.1 Parametric analysis for Feed length and width:

Figure 4(a) and (b) shows that parametric analysis for feed length and width is carried out. It can be observed form the Figure 4(a) the optimum length of the feed is achieved at 12mm whereas the optimum feed width is achieved at 4mm. the parametric analysis has been carried for feed length from 11.5 to 12.5mm whereas for feed width from 3.5 to 4.5 mm. The optimum length and width are achieved at 12mm and 4mm. Apart from these values the impedance bandwidth and |S11| has been deteriorated.



(a) Parametric analysis of feed length

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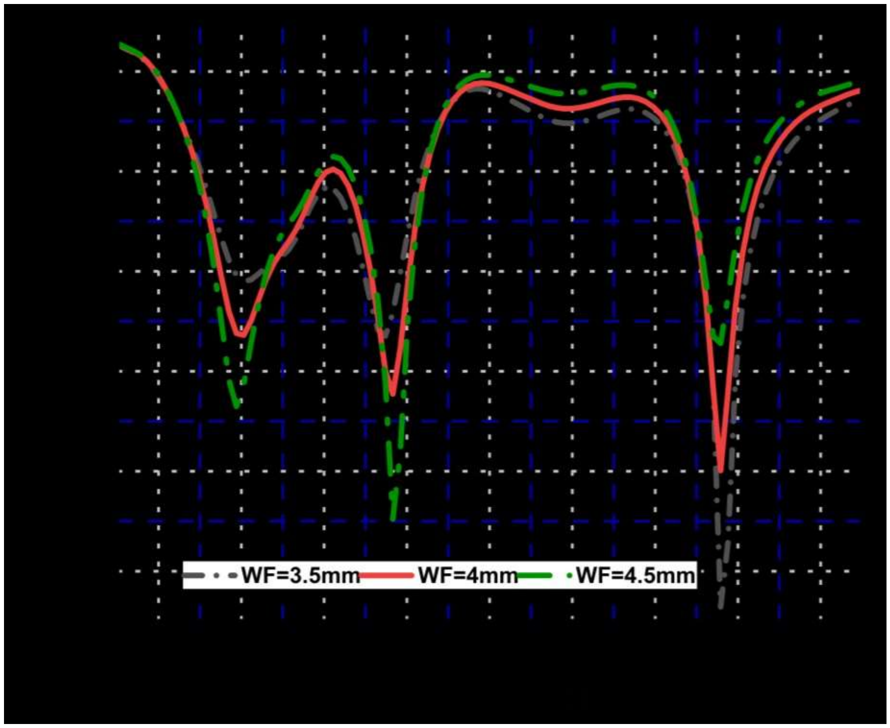

(b) Parametric analysis of feed width

Figure 4 (a) Parametric analysis of feed length **(b)** Parametric analysis of feed width

2.2.2 Parametric analysis for partial ground

It can be observed form the Figure 4(c) that desired partial ground length has been achieved at 10mm. while for other values the |S11| and IBW is less. The parametric analysis is carried out for partial ground ranging form 9.5 mm to 11.5mm. it can be seen that LG for less than 10mm only one desired band is achieved cantered at 1.6GHz. while values greater than 10mm only any of two band is achieved third band is deteriorated.

2.2.3 Parametric analysis for patch width and length

Figure 5(a) and (b) shows that parametric analysis for patch width and length is carried out. It can be observed form the Figure 5(a) the optimum width of the patch is achieved at 30mm whereas the optimum

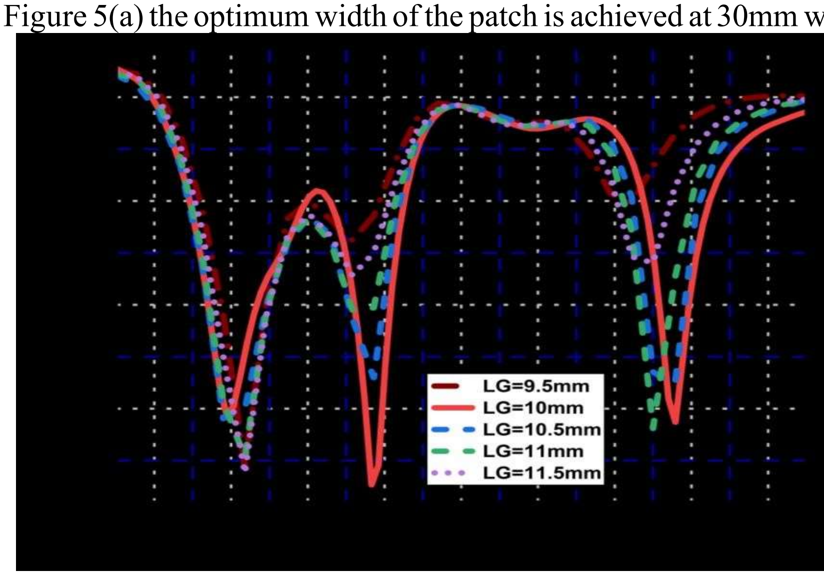

Figure 4(c) Parametric analysis of Partial Ground

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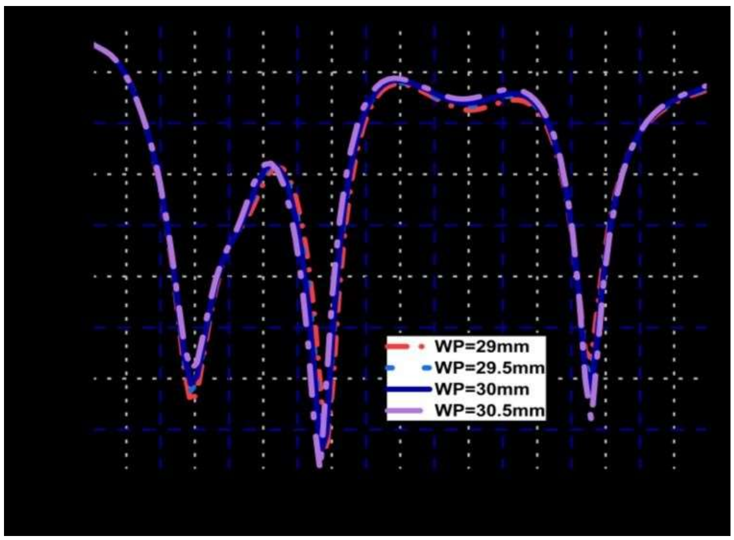
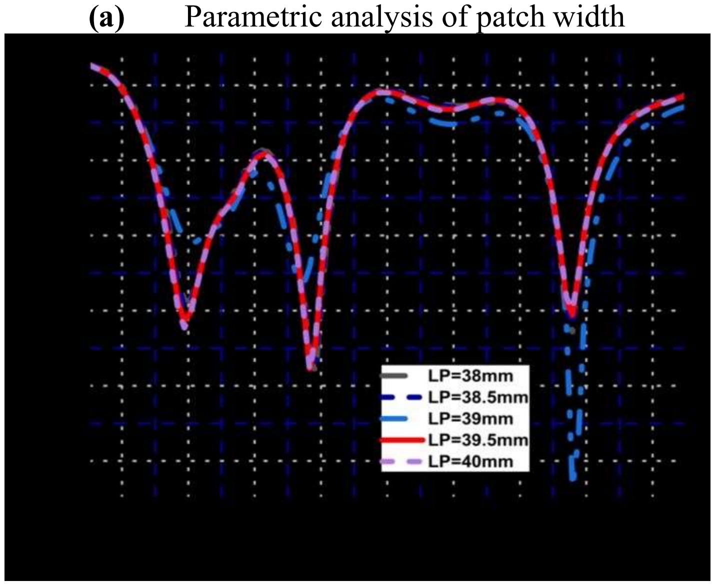
patch length is achieved at 39.5mm. The parametric analysis has been carried for patch length from 38 to 40mm whereas for feed width from 29 to 30.5 mm. The optimum length and width are achieved at 30 and 39.5mm. Apart from these values the impedance bandwidth and |S11| has been deteriorated.

2.2.4 Parametric analysis for slot length and width

Figure 6(a) and (b) shows that parametric analysis for slot length and width is carried out. It can be observed form the Figure 6(a) the optimum width of the slot is achieved at 4.5mm whereas the optimum slot length is achieved at 12mm. The parametric analysis has been carried for slot length and width from 11.5 to 13mm and 4 to 5mm respectively. Apart from these values the impedance bandwidth and |S11| has been deteriorated.



(a) Parametric analysis of patch width



(b) Parametric analysis of Patch Length

Figure 5 (a) Parametric analysis of patch width (b) Parametric analysis of Patch Length

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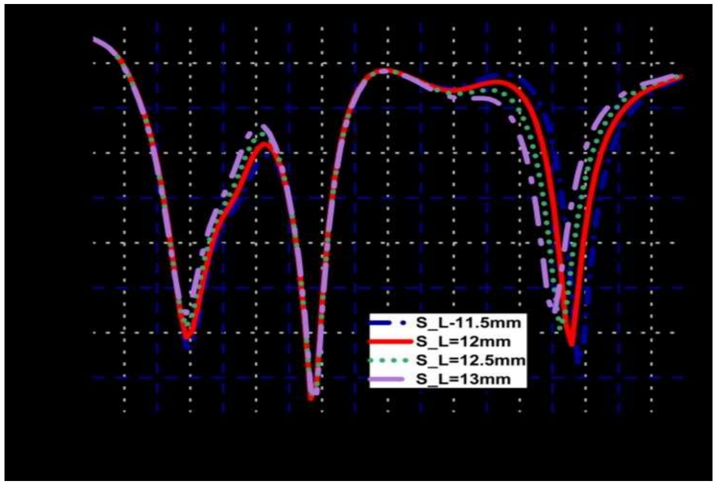

(a) Parametric analysis of slot length

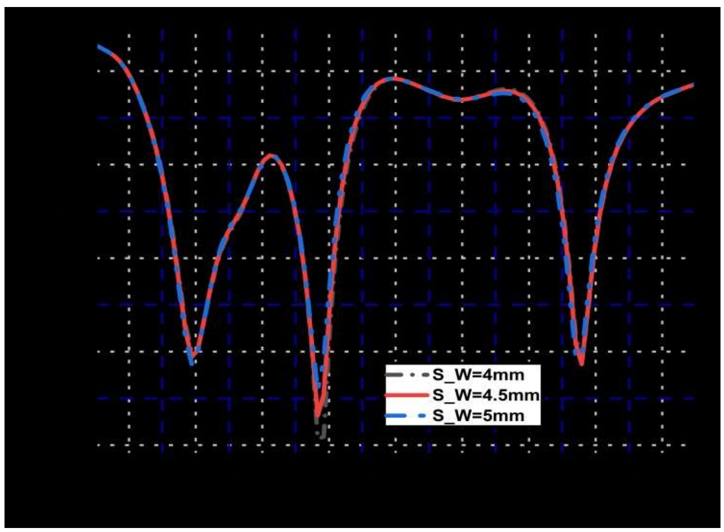

Figure 6(b) Parametric analysis of slot width

Figure 6(a) Parametric analysis of slot length **(b)** Parametric analysis of slot width

3. Results and discussions

3.1 Simulated and measured |S11| and VSWR

It is observed from the Figure 7(a) that proposed antenna is radiated at three distinct FR-I NR band n70, n7, n38 and n79. The frequency range for the proposed antenna are 1.55GHz to 2.08GHz, 2.49GHz to 2.82GHz and 4.49 GHz to 4.8GHz. The corresponding |S11| (measured) are -19dB, -21dB and -22dB in desired band of operation. The Measured |S11| has shown the close agreement with simulated results with slight shift of resonant frequency for higher band. Figure 7(b) depict the simulated and measured VSWR results. VSWR for both simulated and measured results are well below 2 for all three working bands.

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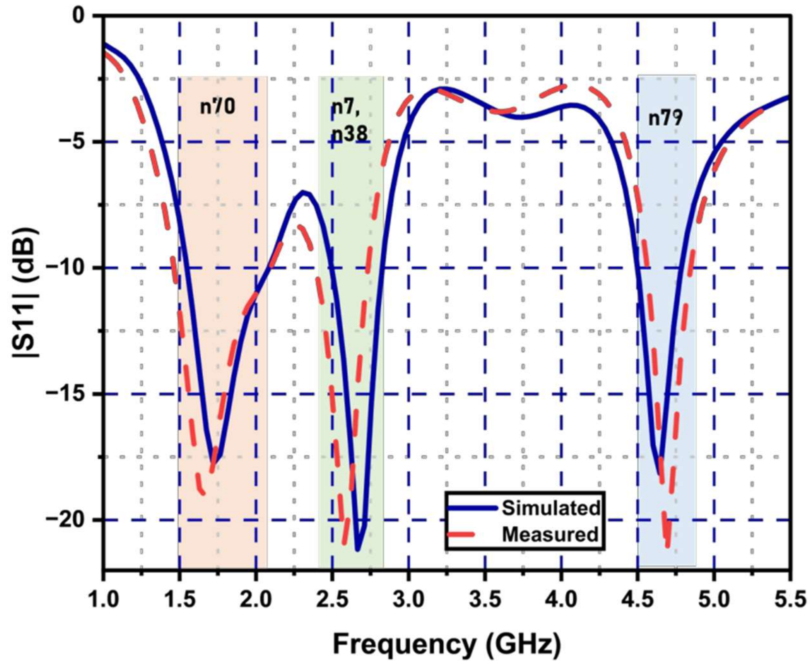
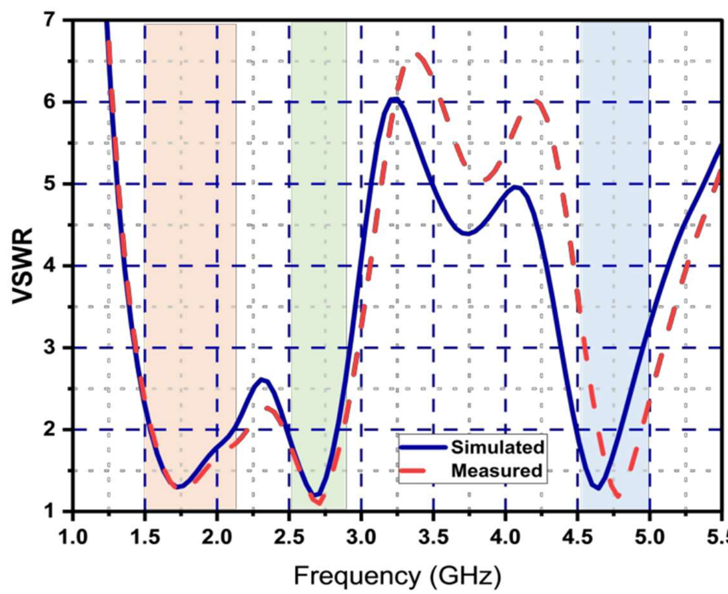


(a) Simulated and measured |S11|



Simulated and Measured VSWR

Figure 7(a) Simulated and measured |S11| (b) Simulated and Measured VSWR

3.2 Gain and Radiation Efficiency

From the Figure 8(a) simulated and measured gain has been depicted. Maximum gain is achieved 2.75Ghz 3.75dBi whereas for lower band measured gain is slightly reduced due to losses and other environmental factor while doing the measurement. For mid band gain almost same and for higher band slightly more than simulated one. Peak gain for lower band is achieved around 1.5dBi (measured) for higher band it is around 3dBi (measured). The radiation efficiency varies from 70 to 90% with peak radiation efficiency is achieved 90%.

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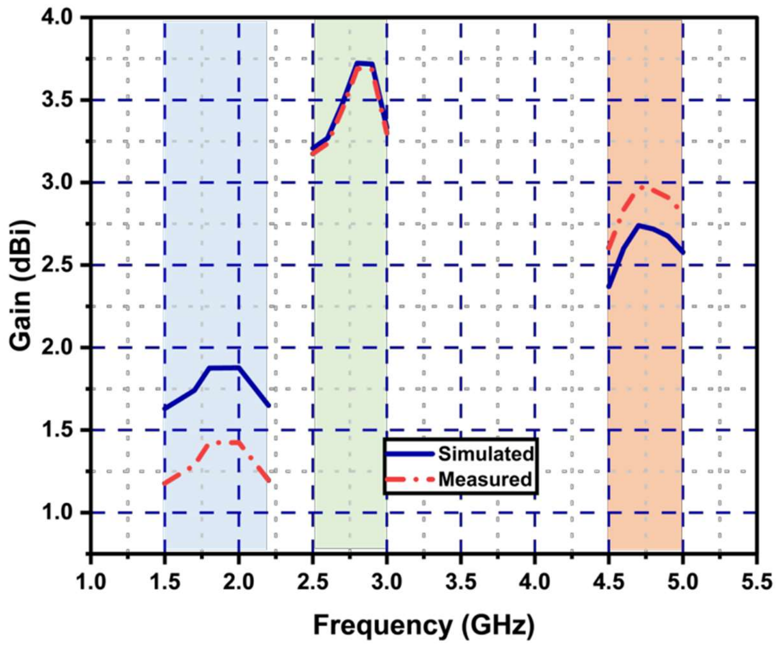
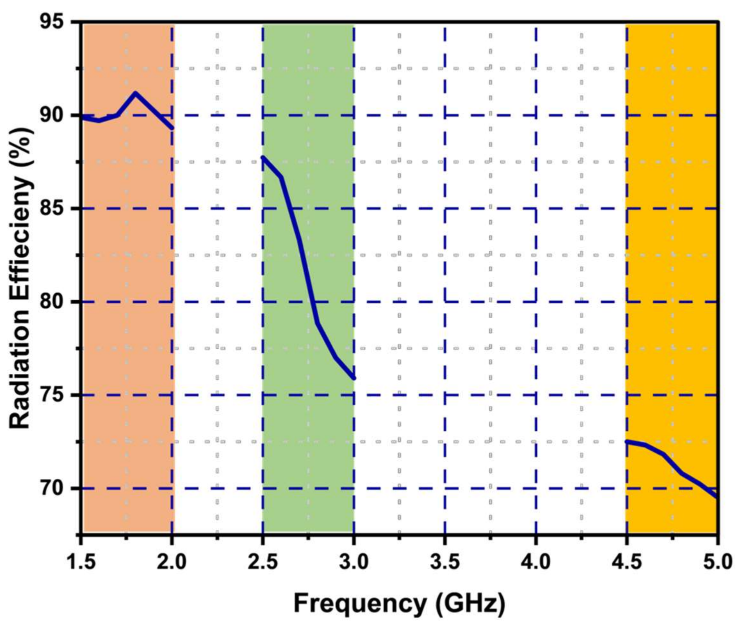


(a) Simulated and measured gain vs frequency plot



(b) Simulated radiation efficiency

Figure 8(a) Simulated and measured gain vs frequency plot (b) Simulated radiation efficiency

3.3 Radiation Pattern and surface current

Figure 9 shows the 2D radiation pattern at 1.76Ghz and 2.67Ghz respectively. It can be observed form the radiation pattern graph antenna shows dipole pattern. Also, at phi=90 plot is slightly inclined whereas phi=0 shows the perfect circle. Figure 10 depicted the surface current distribution of proposed antenna. It can be seen that strong current density is at feed and around the slot is occurred. Also, due to partial ground strong current density at ground plane beneath the feed line is observed.

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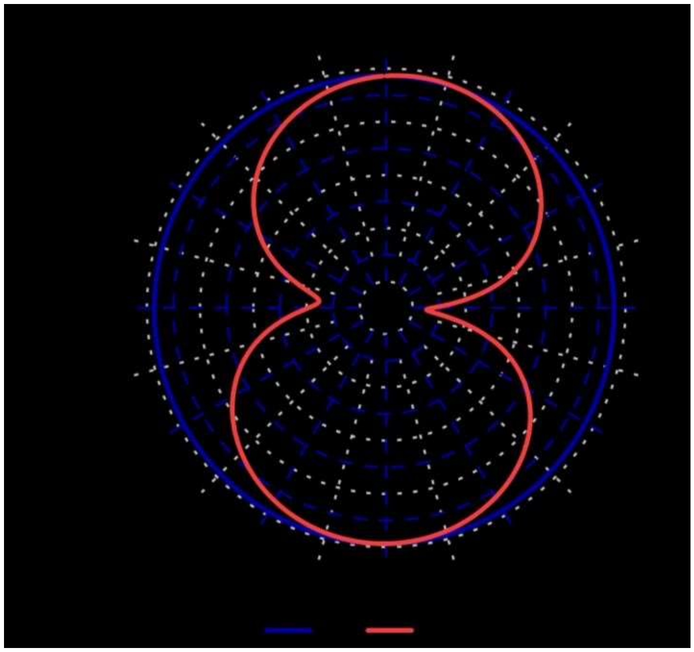
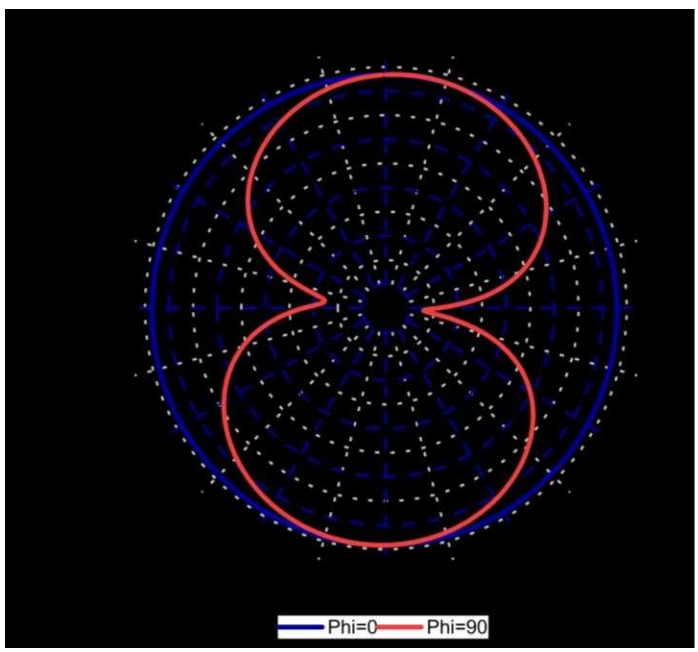


(a) Radiation pattern at 1.76GHz



(b) Radiation pattern at 2.67GHz

Figure 9(a) Radiation pattern at 1.76GHz (b) Radiation pattern at 2.67GHz

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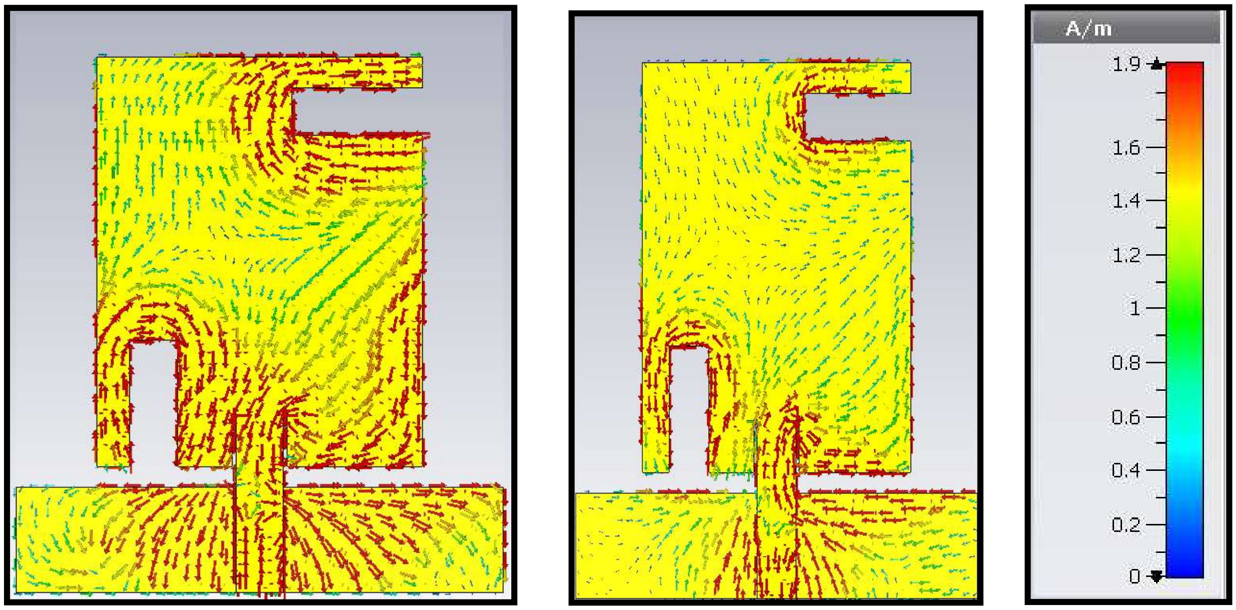

Figure 10(a) Surface current distribution at1.76GHz (b) Surface current distribution at 2.67GHz

Current Trends and Future Directions

The development of microstrip antennas continues to evolve with advancements in materials and fabrication techniques. Recent trends include the use of metamaterials to enhance performance characteristics, such as bandwidth and efficiency. Additionally, research is focused on developing reconfigurable antennas that can adapt to changing frequency and polarization requirements. The integration of microstrip antennas with flexible and wearable electronics is another promising area of research.

4. Conclusions

The research presents the development and evaluation of a slot-loaded planner antenna optimized for operation within FR-I NR bands n70, n7, n38, and partially n79, suitable for 5G applications. The antenna presented triple the bands ranging from 1.55 GHz to 2.08 GHz, 2.49 GHz to 2.82 GHz, and 4.49 GHz to 4.8 GHz, with corresponding measured |S11| values of -19 dB, -21 dB, and -22 dB, respectively. Measurements and simulated results have close agreement with a slight change of shift in resonant frequency at higher bands. The Voltage Standing Wave Ratio (VSWR) for both simulated and measured results remain below 2 across all operating bands, confirming efficient impedance matching. The antenna achieves a maximum gain of 3.75 dBi at 2.75 GHz. The radiation efficiency varies between 70% and 90%, with a peak efficiency of 90% is achieved.

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