Design of Dual Inverted Triangular 5G Microstrip patch antenna for Multiband frequencies

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Abstract
The research presented in this study involves describing and simulating a microstrip patch antenna with a dual inverted triangle and I-slot configuration. The antenna employs FR-4 epoxy as its substrate material. This antenna has the capability to resonate at the Octa frequency in the S, C, X, and Ku bands which range from 2.5 GHz to 22 GHz. Based on the analysis of the simulated data, it has been observed that the antenna exhibits resonance at various frequencies like 2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, and 21.8 Gigahertz respectively, with return losses of -26.01, -24.25, -17.82, -15.71, -34.44, -25.88 and -25 Decibel respectively. The computed impedance bandwidth of the proposed antenna has been determined to be 150 MHz, 300 MHz, 270 MHz, 160 MHz, 7410 MHz (for resonating frequencies 13.7 GHz, 15.3 GHz, and 17.4 GHz), respectively, and 1340 MHz. The achieved directivity of the antenna is 5.14dBi, 5.77dBi, 1.51dBi, 8.35dBi, 1.81 dBi, 2.24 dBi, 10.34 dBi, 6.27 dBi, and 2.46 dBi respectively. This proposed antenna maintains a VSWR that is less than 2 at all frequency bands. This Antenna is admissible for Wi-Fi, WLAN, and satellite communication trends. This antenna resonates at one of the 5G band frequencies i.e., 5GHz.
Keywords: Co-axial, 5G frequency bands (5 GHz), Return loss, directivity, VSWR, impedance BW, 5G.

1. Introduction

In In a modern communication system, there is a demand for antennas with compact size, low cost, and multiple frequency operation. A multiple-frequency band antenna comprises different applications which govern the generation of a multiband microstrip patch antenna (MPA). Multiband operation reduces the number of antennas in the system for wireless communication because MPA acquires many frequency bands in a single antenna used in a variety of wireless devices e.g., wi-fi, WLAN, Wi-max, and Bluetooth. In the literature, several techniques have been reported for achieving multiband antennas like defective ground structure, fractals, and metamaterial. The most popular technique for achieving a multiband antenna is to cut the slot of various shapes like triangular, rectangular, T, E, and U shapes inside the patch. [10,11,14,15,16].

Due to its characteristics, for example, its lighter weight, lower cost, high transmission efficiency, lower profile, and ease of fabrication, the MPA has been widely used in radar, satellite, GPS, biomedical, Wi-Max, aircraft, mobile radio, remote sensing, and handheld wireless devices. [8, 17, 18, 19]. Despite the advantages offered by the MPA, it does have certain limitations. These include lower gain, limited power handling capability, and narrow impedance bandwidth [3, 9, 10]. In the microstrip patch antenna (MPA) configuration, there exists a radiating patch and ground plane, which are surrounded by a dielectric substrate. Accordingly, antenna engineering is being studied by research scholars over the past several decades. The idea of microstrip antenna came in the 1950s by Deschamps in the USA and in France by Gutton and Baissinot. While Deschamps's report work was not published in the literature form until the 1970s. Thereafter, a microstrip

The element was authorized by Munson, and a report on fundamental rectangular and circular microstrip patches was published by Howell [8,9].

An antenna has been demonstrated to perform remarkably well when a slot array is inserted after a Chebyshev distribution. Employing a single feed point, causes it to radiate noticeably across a variety of frequency bands. [1].

For current wireless communication applications, RF front-end devices have evolved in recent years to meet increasing bandwidth needs with multiband resonance. Due to their lightweight, compact design, and ease of integration with high-end communication devices, multiband and low-profile microstrip antennas have seen an increase in demand for wireless communication. Therefore, these microstrip patch antenna's bandwidth profiles are limited and have dielectric surface currents. [2]. Due to its ability to support numerous wireless communication services, including CDMA, GSM, DCS, PCS, UMTS, and many others, multiband antennas have received a great deal of attention recently. [3]

The development of wireless technologies has accelerated recently. As technology progressed from 2G to 3G, 4G, and now 5G, there have been significant advancements in wireless communication systems. During the earlier era of 2G applications, such as the Global System for Mobile Communication (GSM), narrowband microstrip patch antennas were commonly employed for transmitting and receiving speech signals at the specified center frequency. The dimensions of an antenna are dictated by the operating frequency of the wireless system. In order to support 3G and 4G applications, LTE networks support high-frequency carrier waves, which can be used to transmit video and image files across radio frequency (RF) channels. The antenna gets smaller and smaller for various applications, that are incredibly compact and is easy to install. Low-power transceiver applications in modern wireless networks often prefer the use of compact antennas [4, 20].

As internet technology developed, the spectrum designated for mobile phone bands became overcrowded. The growing demand for wireless services has driven the advancement of small and multiband communication antennas in today's wireless communication networks. The wireless communication system heavily relies on the antenna, emphasizing its critical role in the overall functionality and performance of the system since it increases cellular system capacity, broadens the coverage area, and streamlines the network. The design of patch antennas is significantly influenced by the dielectric constant of the substrate, underscoring its vital importance in the antenna's overall configuration and performance [5, 6]. A dual Inverted triangular patch with an I-slotted multiband microstrip patch antenna is shown in the present research. The antenna has been implemented on a glass epoxy substrate having a permittivity of 4.4. With an optimal return loss of less than -10 dB, this antenna performs between 2.5 and 22 Gigahertz respectively, and has eight resonant frequencies including 2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, and 21.8 Gigahertz respectively. The proposed antenna's resonant frequencies comprised the S, C, X, KU, and K bands, which are commonly utilized in modern wireless communications techniques like GSM, CDMA, Bluetooth, WLAN, and WiMax.

2. Design Antenna

Fig. 1 depicts the top & isometric views of the multiband antenna. The proposed design includes a dual Inverted triangular patch loaded with an I-shape slot to enable octa-band operation with enhanced antenna performance parameters. A multiband microstrip patch antenna (MPA) is created using an FR-4 epoxy substrate, having a substrate thickness of 1.6 mm and a relative permittivity of 4.4. The proposed antenna was created and tested using HFSS. The implemented antenna works at a frequency of 2.7 GHz. The following equation has been utilized for calculating more parameters for the MPA, including patch length & width, ground length, and antenna width.

$W_p = c / (2f_r\sqrt{((\varepsilon_r+1) / 2)})$ {1}

Here c is the light's speed = 3×10^8 meter/sec, The operational frequency is f_r = 2.7 GHz, and Relative permittivity (εr) equals 4.4 putting this value in equation {1}, we get the value of the Width of the patch Wp= 33.56 mm.

$\varepsilon_{eff} = (\varepsilon_r+1) / 2 + (\varepsilon r -1) / (2 [1+12h / W_p] 0.5)$ {2}

Here The substrate's thickness is h which is 1.6 mm putting the value of ε_r, Wp, and h in equation {2}, we calculate the value of effective dielectric constant ε_{eff}.

$L_{eff}=c/(2fr\sqrt{\varepsilon ff})$ {3}

Here putting the value of c, fr, and εff, we get the value of effective length Leff.

$\Delta l=0.412h [(\varepsilon_{eff} + 0.3) / (\varepsilon_{eff} - 0.258)] \times [(W_p/h + 0.264) / (W_p / h + 0.8)]$ {4}

Here putting the value of ε_{eff}, W_p, h, we get the value of the extension length.

$L_p=L_{eff} - 2\Delta l$ {5}

We obtain the patch's length Lp, to be 25.91 mm by putting the values of L_{eff} and Δl into equation 5.

With the use of the two equations below, one can determine the width & length of the ground surface.

$L_g = 6h + L_p = 35.51mm$ {6}

$W_g = 6h + W_p = 43.16mm$ {7}

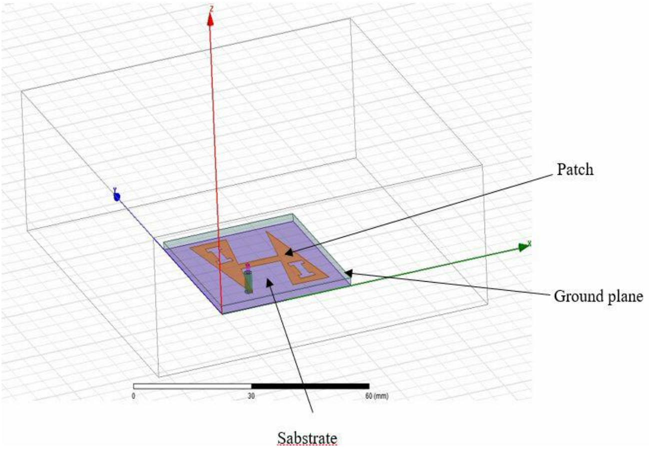


Fig. 1(a)

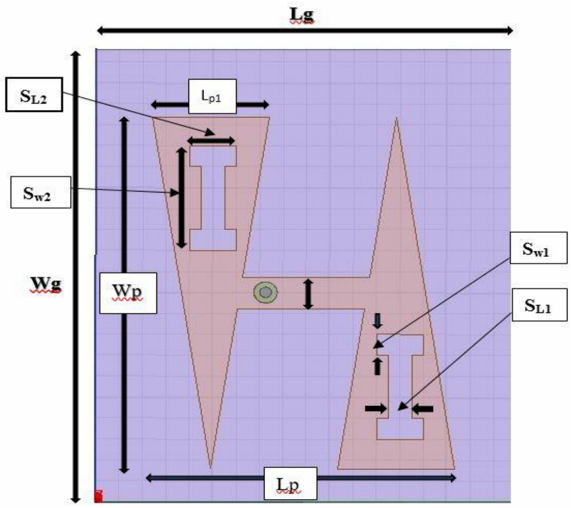


Fig. 1(b)

Fig. 1 Developed Multiband Antenna (a) isometric sight (b) Top sight.

In this multiband microstrip patch Antenna, we have used a co-axial probe feeding for designing the antenna. In This type of feeding technique, the main benefits are that the co-axial feeding can be placed entire patch of the microstrip antenna. Here we analyze different feed positions of the patch. And finally, we placed a feed where we get excellent impedance matching for the multiband frequency band.

3. Result and discussion

This study focuses on implementing a microstrip patch antenna with a Dual Inverted Triangle with an I-slot design on a FR 4 epoxy substrate. The aim of the research is to achieve multiple frequency bands using this antenna configuration. The HFSS software was utilized for conducting this research. Figure 2 illustrates the return loss in decibels (dB) at various resonance frequencies: 2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, and 21.8 Gigahertz respectively. The corresponding return loss values were recorded as -26.0, -24.25, -17.82, -15.71, -34.44, -25.88, -25.26, and -20.41 Decibels respectively. The antenna also exhibited impedance bandwidths of 150 MHz, 300 MHz, 270 MHz, 160 MHz, and 7410 MHz (the resonance frequencies of 13.7, 15.3, and 17.4 GHz respectively), as well as 1340 MHz at respective frequencies.

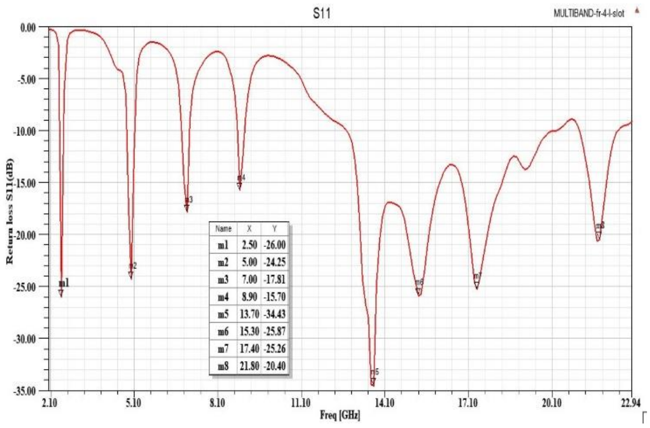


Fig. 2 S11 parameters

Table. I Dimension of the Microstrip multiband antenna.

Constraints	**Size**
Patch conducting's length Lp	25.91 mm
Patch conducting's width Wp	33.56 mm
Ground surface length Lg	35.51 mm
Ground surface width, Wg	43.16 mm
Substrate height h	1.6 mm
Operating frequency fr	2.7 GHz
Relative dielectric constant εr	4.4
One Triangle base length Lp1	10 mm
Width of transmission line b/w triangle Wt	3 mm
I Slot length SL2	4 mm
I slot length SL1	2 mm
I slot width Sw1	2 mm
I slot width Sw2	10 mm

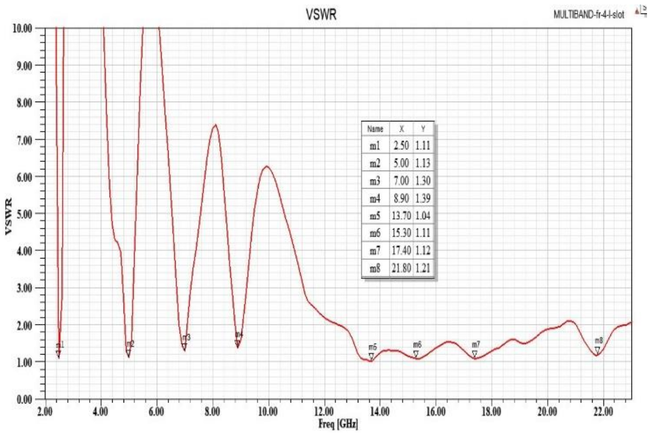


Fig. 3 VSWR vs Freq (GHz)

The performance of the simulated VSWR is shown in Figure 3. 2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, and 21.8 Gigahertz respectively resonance frequencies' VSWR values were measured as 1.11, 1.13, 1.30, 1.39, 1.04, 1.11, 1.12, and 1.21, respectively. As depicted in Figure 3, the VSWR remains below 2 for all active bands, consistent with previous findings.

The directivity results shown in Figure 4 clearly demonstrate that the simulated antenna achieves enhanced directivity at the resonant frequencies of 2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, and 21.8 Gigahertz respectively, with corresponding values of 5.14 dBi, 5.77 dBi, 1.51 dBi, -0.17 dBi, 10.32 dBi, 6.27 dBi, and 2.46 dBi, respectively. The gain at various frequencies is displayed in Figure 5.

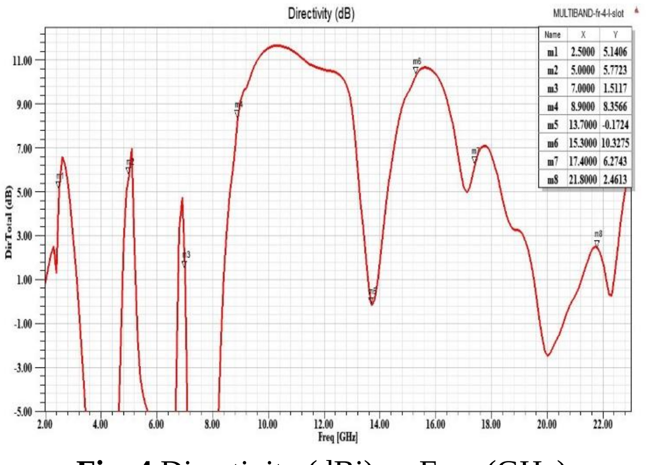


Fig. 4 Directivity (dBi) vs Freq (GHz)

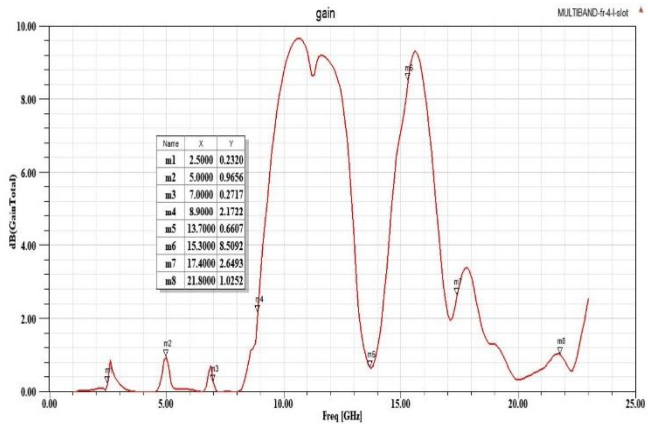
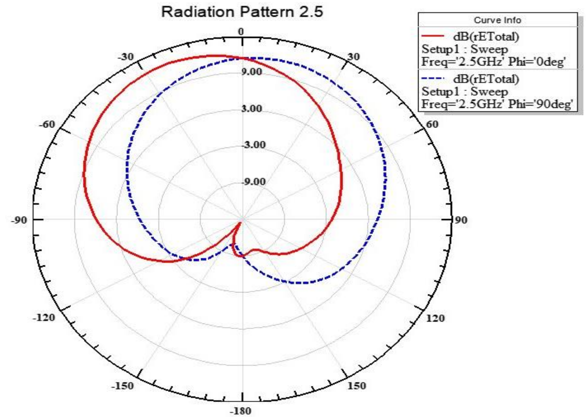
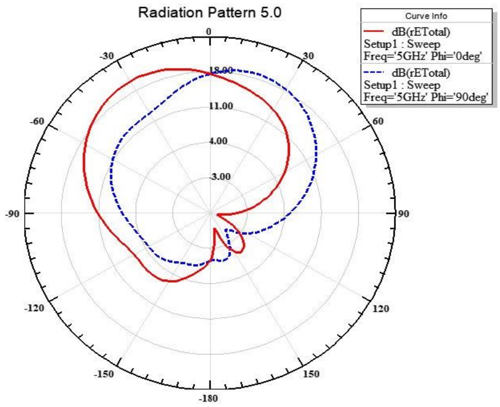


Fig. 5 Gain vs Frequency

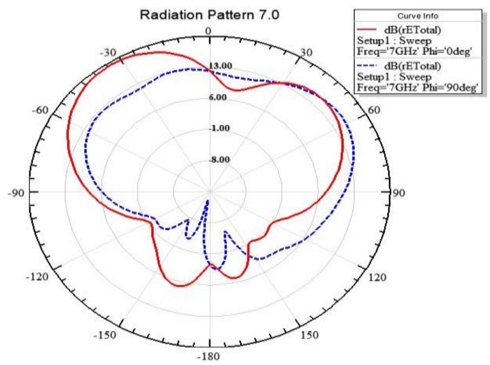
Figures 6(a) to 6(h) illustrate the two-dimensional radiation properties of the antenna in both the E-plane and H-plane. The antenna design exhibits omnidirectional radiation patterns, indicating that the emitted radiation is evenly distributed in all directions across the operating frequency bands. The radiation patterns remain stable and consistent, indicating the antenna's ability to maintain a reliable and consistent signal transmission throughout its operating bands.



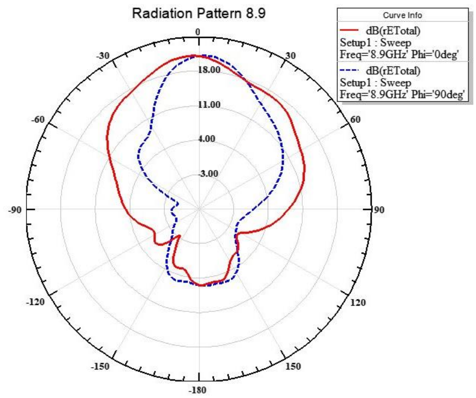
(i)



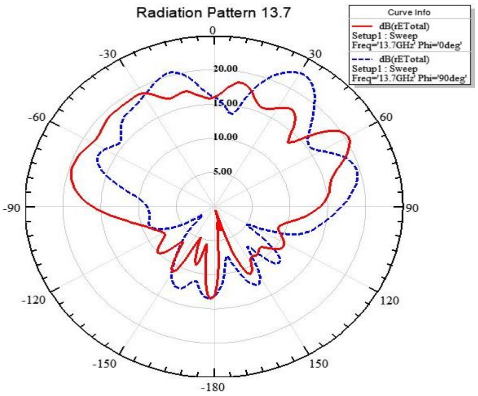
(ii)



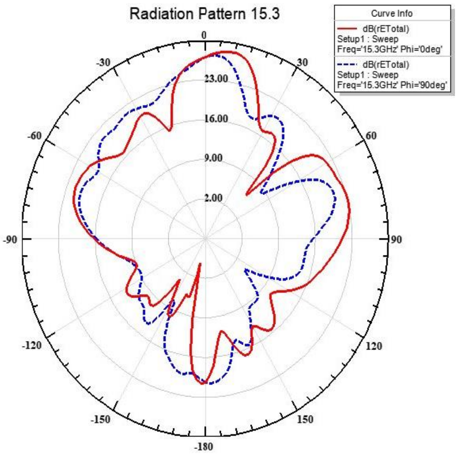
(iii)



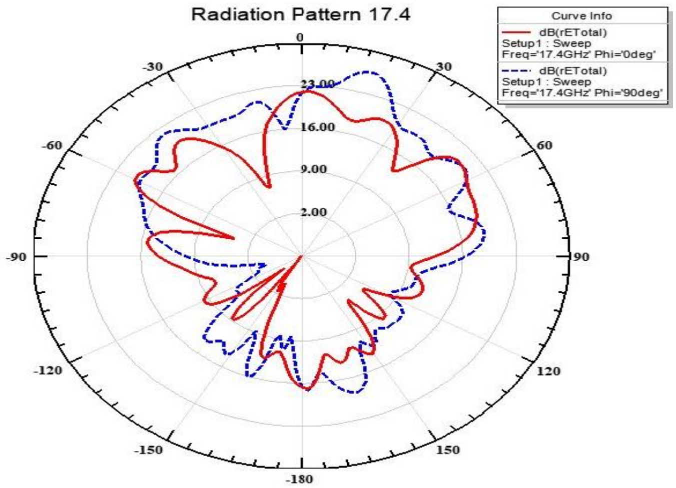
(iv)



(v)



(vi)



(vii)

Fig. 6 E and H planes' respective radiation patterns at (i) 2.5 Gigahertz, (ii) 5 Gigahertz, (iii) 7 Gigahertz, (iv) 8.9 Gigahertz, (v) 13.7 Gigahertz, (vi) 15.3 Gigahertz, and (vi) 17.4 Gigahertz

Table II illustrates comparisons between simulate antenna and existing antenna works previously in use.

References	Antenna Dimensions	Substrate materials	Operating Frequencies (GHz)	Bandwidth Achieved (MHz)	Return Loss (dB)
Pathak, R et. al. (2021)	47.55 × 51.88 × 0.24 mm^3	Roggers R03003, h = 0.25mm	3.48, 6.24, 7.5,	150, 310, 330	-27.77, -28.8, -33.98

Mahendran, K. et. al. (2020)	30 × 50 × 1.6 mm^3	FR4 h = 1.6mm	3.5, 4.1, 5.6, 9.7	NA	-12.01, -11.7, -19.54, -14.16
Chinnagurusamy, B. et. al. (2021)	40 × 35 × 1.6 mm^3	FR4 h = 1.6mm	5.16, 6.6, 7.21, 8.32, 9.96	350 200 380 600 1100	-16, -12.5, -15, -24, -15
Proposed antenna	**35.51 × 43.16 × 1.6 mm^3**	**FR4 h = 1.6mm**	**2.5, 5, 7, 8.9, 13.7, 15.3, 17.4, 21.8**	**150, 300, 270, 160, 7410 1340**	**-26, -24.25, -17.81, -15.70, -34.43, -25.87, -25.26, -20.40**

4. CONCLUSION

Based on the analysis of the simulated results mentioned earlier, it can be concluded that the Dual Inverted Triangle with I-slot microstrip patch antenna exhibits excellent performance in terms of return loss, VSWR, and directivity. Moreover, the antenna operates within a frequency range of 2.5 GHz to 20 GHz, providing wideband coverage. These frequency bands are found in S, C, X, Ku, and K bands which have many applications in modern communication like wireless communication such as 5G communication, GSM, CDMA, Bluetooth, WLAN, WiMax, satellites communication, and weather radar.

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