



Design and Analysis of Triple Band Microstrip Patch for 5G Application

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Abstract— This paper presents a novel triple-band microstrip patch antenna designed to operate at 2.45 GHz, 8 GHz, and 14 GHz, catering to various wireless applications such as WiMAX, WLAN, C-band downlink, and Ku-band radar, while also addressing the future demands of 5G and 6G technologies. The proposed antenna features a circular patch with rectangular arms and a Defected Ground Structure (DGS), implemented on an FR4-5880 substrate. The compact design exhibits high efficiency and bidirectional radiation patterns, making it a suitable candidate for emerging wireless communication technologies.

Keywords— Triple-band antenna, microstrip patch antenna, Defected Ground Structure (DGS), 5G and 6G technologies, wireless communication.

I. INTRODUCTION

The swift advancement of wireless communication tech demands more effective, smaller, and multi-frequency antennas to handle the increasing need for faster data, wider bandwidth, and easy integration into today's gadgets. Technologies like IEEE 802.16e WiMAX, IEEE 802.11a WLAN, C-band downlink, and Ku-band radar need antennas that can work on several frequency ranges without losing performance. The arrival of 5G and the future rollout of 6G highlight the necessity for adaptable antennas that can function across a broad spectrum of frequencies, from the sub-6 GHz bands used in early 5G to the millimeter-wave frequencies anticipated for 6G.

Microstrip patch antennas are well-regarded for their thin design, simple manufacturing, and compatibility with printed circuit boards (PCBs). These antennas are often preferred for wireless devices due to their simplicity, light weight, and capability to support multiple frequency bands. Therefore, this paper presents a new triple-band microstrip patch antenna designed to operate at 2.45 GHz, 8 GHz, and 14 GHz. This design addresses key applications like WiMAX, WLAN, C-band downlink, and Ku-band radar, while also catering to the future demands of 5G and 6G technologies.

Microstrip patch antennas, a relatively recent development in antenna engineering, typically feature a single-layer structure comprising a radiating patch, a ground plane, a substrate, and a feeding mechanism. These antennas

are often integrated with printed strip-line feed networks and active devices. Classified as single-element resonant antennas, their characteristics, such as radiation pattern and input impedance, are fixed once the operating frequency is determined. The radiating patch, typically a thin metallic strip (or array) significantly smaller than the free-space wavelength (λ_0), is situated on one side of a thin, non-conducting substrate, with a metallic ground plane on the opposite side. Commonly fabricated from conductive materials like copper or gold, the patch can be designed in various shapes. The radiating patch and feed lines are usually created through photo etching on the dielectric substrate, which has a thickness ranging from 0.01 to 0.05 of the free-space wavelength (λ_0). The primary function of the substrate is to provide mechanical support and maintain the necessary spacing between the patch and the ground plane. Furthermore, substrates with high dielectric constants are often employed to load the patch, thereby enabling a reduction in its overall size.

A. THEORETICAL ANALYSIS

The described circular patch microstrip antenna, featuring rectangular arms and a Defected Ground Structure (DGS), is specifically engineered to operate at 2.45, 8, and 14 GHz. This antenna design is implemented on a commercially available FR4-5880 substrate characterized by a thickness (h) of 1.6 mm, a dielectric constant of 4.4, and a loss tangent of 0.02. The antenna's radiating element consists of two circular patches supported by four rectangular arms situated on the top layer, while the DGS is etched on the bottom layer. This configuration enables the achievement of multiple resonance frequencies. Excitation is provided through a transmission line feed. Recognizing the crucial role of mathematical modelling in engineering design, the authors aim to share their antenna design methodology, employing both mathematical formulations and computational tools to tackle the associated design complexities. Mathematical modelling, defined as the process of representing real-world scenarios with mathematical equations, is employed to gain deeper insights into the problem and to discover novel characteristics of the antenna. The methodology for designing the presented triple-band microstrip patch antenna centres on the utilization of two circular radiating elements

augmented with rectangular arms, all situated on an FR4 substrate. This configuration is specifically tailored to achieve resonant frequencies at 2.45, 8, and 14 GHz. The antenna's architecture incorporates a defected ground structure (DGS) on its underside, and excitation is provided through a transmission line (T.L.) feed. To optimize the dimensions of the circular patches and rectangular arms, thereby improving impedance matching and maximizing bandwidth, comprehensive parametric studies were performed using the Advance Design System (ADS) software. The resulting compact antenna design, with dimensions of 46x38x1.6 mm³, exhibits high efficiency and bidirectional radiation patterns, positioning it as a viable candidate for emerging wireless communication technologies such as 5G and 6G. This design process commences with the selection of the substrate material, the desired resonant frequency, and the substrate's thickness. Following this specification, the length, width, and diameter of the radiating patch are determined through established mathematical relationships.

A. Frequency of operation

The specified frequencies of 2.45 GHz, 8 GHz, and 14 GHz represent the operational bands for this triple-band microstrip patch antenna, indicating the points at which it achieves optimal resonance and performance. This particular frequency selection strategically caters to a diverse range of wireless applications, including the IEEE 802.16e WiMAX standard, IEEE 802.11a WLAN technology, C-band downlink communication systems, and Ku-band radar applications. The antenna's operating frequency is a fundamental parameter that dictates its applicability across different wireless communication technologies and its effectiveness in signal transmission and reception within the designated frequency range.

B. Equations:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{L}\right)^{-0.5} \quad [2]$$

Step 1: Calculation of diameter of each circular path (D):

The diameter of circular patch is given as eq [5]:

$$D = 2 * T \left[1 + \frac{2h}{\pi T \epsilon_r} \left(\ln \left(\frac{\pi T}{2h}\right) + 1.7726\right)\right]^{-0.5}$$

Where,

T = Thickness of the conductor

h = Height of the dielectric substrate

ε_r = Relative permittivity (dielectric constant)

Step 2 : Calculation of effective dielectric constant (ε_{eff}) eq [6] :

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{L}\right)^{-0.5}$$

Where,

L = Length of antenna

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h = Height of the dielectric substrate

ε_r = Relative permittivity (dielectric constant)

Step 3 : Calculation of Lengths (L_{1,2,3,4,5,6}) of rectangular arm: The lengths of rectangular arms are given by eq [4]:

$$L_{1,2,3,4,5} = \frac{c}{2F_r} \sqrt{\frac{2}{\epsilon_r + 1}}$$

Where,

C = 3 * 10⁸ m/sec (speed of light)

F_r = Resonant frequency

ε_r = Relative permittivity (dielectric constant)

Step 4 : Calculation of Widths (W_{1,2,3,4,5,6}) of rectangular arm: The width of rectangular arms is given by eq [8] :

$$W_{1,2,3,4,5} = \frac{1}{2F_r \sqrt{\epsilon_{eff}} \sqrt{\epsilon_0 \mu_0}} - 2\Delta W$$

Step 5: Calculation of the length extension (ΔL): The length extension is eq [8]:

$$\Delta W = 0.412h * \left\{ \left(\frac{\epsilon_{eff} + 0.3}{\epsilon_{eff} - 0.258} \right) * \left(\frac{L}{h} + 0.264 \right) \right\}$$

These days, microstrip patch antennas are widely used in wireless devices due to their small size, light weight, and ease of construction. For printed circuit boards (PCBs), which are found in practically all contemporary electrical devices, they are the ideal size. The concept is fairly simple: a thin layer of metal called the patch is applied to a material called the substrate, and underneath that is another layer of metal called the ground plane. Depending on the frequency at which the antenna is intended to operate, the patch's shape may vary. It could be oval, round, or rectangular. These antennas are perfect for small devices like wearable electronics, cell phones, and satellites because of their small size. The fact that they typically only cover a small range of frequencies is their only drawback. The concept is fairly simple: a thin layer of metal called the patch is applied to a material called the substrate, and underneath that is another layer of metal called the ground plane. Engineers have cleverly gotten around that by employing unique materials to boost performance, making tiny holes in the patch, or stacking numerous layers to increase the antenna's range.

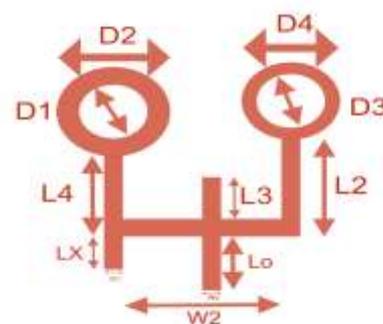


Figure 1 Patch design

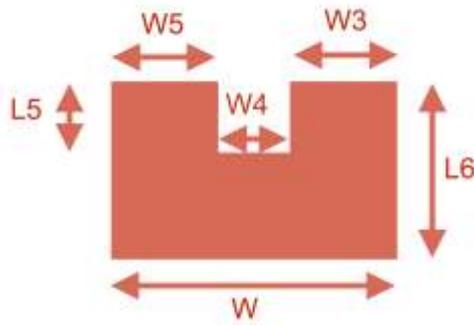


Figure 2 Ground design

dBi and 87% efficiency, A triple-band mm-wave patch antenna with resonating frequencies at 2.4, 5.5, and 28 GHz, having dimensions of $45 \times 40 \times 0.508 \text{ mm}^3$ and gain values of 1.95, 3.76, and 7.35 dBi, respectively, introduced a radiating MPA for conventional sub-6 GHz/5G applications, utilizing an Arlon-AD 300C substrate with a $52.92 \times 55.56 \times 1.2 \text{ mm}^3$ size and achieving a gain of 7.15 dBi at 5.65 GHz. A C-shaped ring antenna integrated with an artificial magnetic conductor (AMC) and Styrofoam layer, with a total size of $54 \times 54 \times 3.9 \text{ mm}^3$ and operating at 2.4 GHz with a 6.21 dB gain and 81% efficiency, As mentioned in, a planar monopole antenna with a partial ground plane, sized at $38 \times 50.5 \times 1 \text{ mm}^3$, achieved operation in the ISM band (2.075–2.625 GHz) with a peak gain of 7.76 dBi and

Parameters of Antenna						
SR. No.	Circular Patch Variables		Rectangular Arms Variables		Ground Plane	
	Variables	Optimized Dimensions	Variables	Optimized Dimensions	Variables	Optimized Dimensions
1	D1	9	W_0	2.5	W_3	18
2	D2	15	W_1	2.5	W_4	10
3	D3	9	W_1	23.4	W_5	18
4	D4	13	L_0	9	L_0	10
5	L5	10	L_1	3	L_0	25
6	L6	11	L_2	13.4	Total Length (L)	46
7			L_3	8		
8			L_4	12.1	Total Width (W)	38
9			L_x	7		

D. MEASUREMENTS

This paper reviews various established microstrip antenna designs, including those tailored for specific applications, ultrawideband (UWB) operation, reconfigurability, and dual, triple, and multiband functionalities. The incorporation of techniques such as Defected Ground Structures (DGS) and metamaterials to enhance bandwidth is also highlighted. For instance, a microstrip antenna utilizing DGS, with dimensions of $59.5 \times 47 \times 1.6 \text{ mm}^3$, achieved triple-band resonance at 1.57, 2.45, and 3.53 GHz. presented a compact UWB inverted triangular antenna featuring dual-notch bands, offering three operational frequency ranges within the UWB spectrum: 3–4.17, 5.33–6.5, and 8.9–12 GHz. Similarly, a compact printed UWB antenna with tri-notched characteristics at 3.5, 5.5, and 8.1 GHz, occupying a volume of $30.2 \times 25 \times 0.762 \text{ mm}^3$. A $32 \times 30 \times 1.6 \text{ mm}^3$ quadruple-band notched UWB antenna, covering notched bands at 3.1–3.6, 4.9–6.1, 7.5–8.4, and 10.2–11 GHz, detailed a UWB MIMO antenna comprising a chip antenna, an isolator stub, and a PCB with a partial ground plane. The chip antenna patch, sized at $10 \times 10 \times 0.8 \text{ mm}^3$ and embedded on FR4, along with a $30 \times 30 \text{ mm}^2$ PCB, operated at 2.45 and 9 GHz with a peak gain of 4.5 dBi. A reconfigurable pattern monopole antenna with two pin diodes, having overall dimensions of $32 \times 59 \times 0.8 \text{ mm}^3$, exhibiting an operating frequency band of 3.36 to 3.6 GHz, realized gain of 2.13 to 4.93 dBi, and efficiency of 62% to 82%. proposed a $34 \times 34 \times 1.6 \text{ mm}^3$ patch antenna for UWB-MIMO applications with notched triple-band characteristics, covering 3.3–3.9, 5–6, and 7.4–8.5 GHz with varying radiation efficiencies. A sub-6 GHz 5G four-element triple-band MIMO antenna for wireless applications, designed on an FR-4 substrate with dimensions of $16 \times 16 \times 1.6 \text{ mm}^3$, operating at 3.72–3.82, 4.65–4.76, and 6.16–6.46 GHz with an average gain of 2.5 dBi. A four-port UWB-MIMO antenna on an FR4 substrate, with an overall size of $30 \times 30 \times 1.6 \text{ mm}^3$, achieving operation from 3.1 to 12 GHz with a maximum gain of 6.2

80.12% efficiency. An antenna array module for simultaneous operation at 3.5 GHz (sub-6 GHz) and 26 GHz mm-wave frequencies, fabricated on a commercial FR-4 substrate with a total size of $154 \times 66 \times 0.6 \text{ mm}^3$ and achieving -10 dB input impedance matching in both bands for 5G smartphones,

This study focuses on the design of a microstrip patch antenna for triple-band operation at 2.5, 6, and 14 GHz. The antenna features double circular ring patches etched on its top side and a partial-rectangular DGS on the bottom. The entire structure is fabricated on an FR4 (5880) substrate with dimensions of $46 \times 38 \times 1.6 \text{ mm}^3$ and is fed using a planar T.L. feeder. The design was simulated using CST MWS, and a prototype was developed. The resulting antenna demonstrated triple-band operation with gain values up to 6 dB, radiation efficiency exceeding 85%, and bidirectional radiation characteristics.

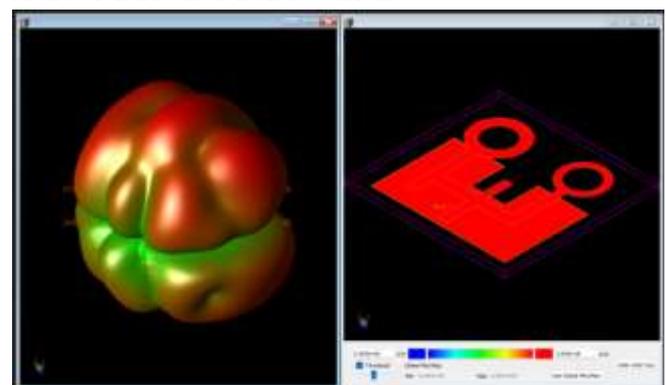


Figure 3. 3D Radiation Pattern

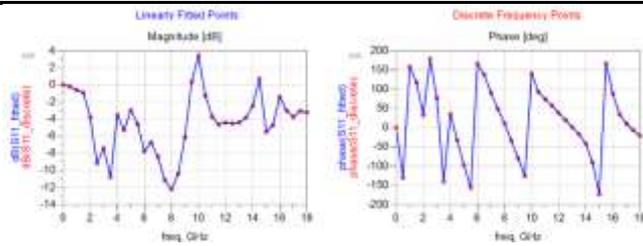


Figure 4 Simulated Result



Figure 7 Fabricated Antenna Back Side

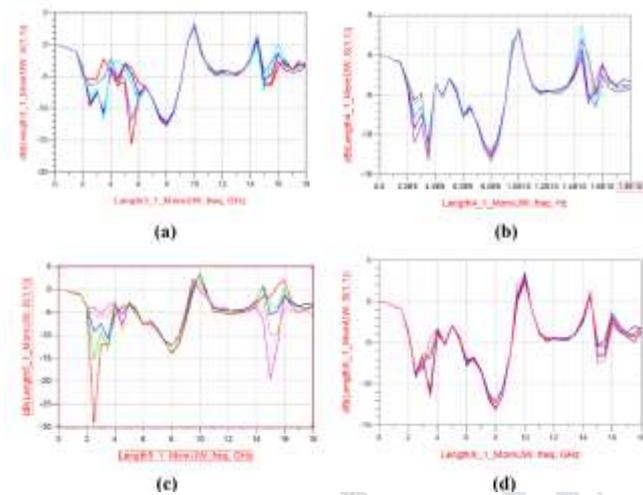


Figure 5 Simulated S11 iterations of circular patch antenna with the different Arm widths (a) L3, (b) L4, (c) L5 and (d) Lx

E. FABRICATION & SIMULATION

1) Design and Simulation:

Define Specifications: The process begins with defining the antenna's requirements, such as operating frequency, bandwidth, gain, radiation pattern, polarization, and impedance matching.

Choose Antenna Type: Based on the specifications, an appropriate antenna type (e.g., dipole, patch, horn, array) is selected.

Design and Modeling: Using electromagnetic simulation software (e.g., HFSS, CST Microwave Studio, FEKO), the antenna geometry is designed and optimized to meet the desired performance characteristics. This involves determining the dimensions, shape, and material properties.

Performance Analysis: The simulated antenna performance (e.g., S-parameters, radiation patterns, gain) is analyzed to ensure it meets the design goals. Iterations and adjustments to the design are often necessary.

2) Material Selection:

Conductor: Highly conductive materials like copper, aluminum, or gold are typically chosen for the radiating elements and ground plane to minimize losses.

Substrate (if applicable): For printed antennas (e.g., patch antennas), a dielectric substrate with specific permittivity and loss tangent is selected. Common substrate materials include FR-4, Rogers materials, and ceramics.

Connectors and Cables: Appropriate connectors (e.g., SMA, N-type) and coaxial cables with suitable impedance are chosen for signal input/output.

Supporting Structures: Materials for mechanical support, such as plastics, metals, or composites, are selected based on environmental conditions and structural requirements.

3) Antenna Testing :

Testing of the antennas is done by using R&S@ZVL Vector Network Analyzer in RF and Microwave lab. The R&S@ZVLVNA is a powerful and portable network analyzer in the compact class. It is the instrument to combine the functions of a network analyzer, spectrum analyzer and power meter in a single box.



Figure 8 R&S@ZVL Vector Network Analyzer



Figure 6 Fabricated Antenna Front Side

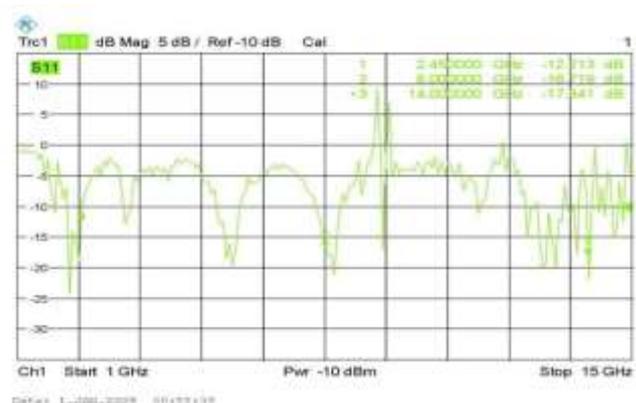


Figure 9 Result of Antenna Testing on VNA

CONCLUSION

These days, microstrip patch antennas are widely used in wireless devices due to their small size, light weight, and ease of construction. In this research, an UWB microstrip patch antenna operating in triple-band, covering 2.45, 8 and 14 GHz resonance frequencies was designed. These frequencies have implications for modern wireless technologies, especially 5G/6G applications. The design steps of the proposed antenna are discussed in detail. It is based on reducing the overall antenna size by using circular-radiator patches besides DGS, all printed on the same substrate. The strong couplings between both driven and parasitic patches offer triple-band operation with three different frequency resonances. Moreover, this configuration experimentally achieves proper impedance matching, gain, and efficiency values. The radiation characteristic enhancements of the proposed antenna in the overall operating frequency ranges are thus fulfilled. The results show that the efficiency and gain values of the planned antenna reach up to 85% and almost 6 dBi with good bi-directional radiation characteristics.

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