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Design and analysis of multiband circular microstrip patch antenna for wireless communication

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ABSTRACT

The study proposes a novel Approach of Circular Microstrip Patch Antenna for Multi-Band. The Proposed Antenna Dimension is $(40\times30\times1.6)\text{mm}^3$ on the FR-4, Which has ε_r equals(4.3) and Loss tangent (0.002). Both Patches and Grounds are Copper Material With Thickness (0.035 mm) Five Bands are Achieved, At Resonance Frequencies (9.658 GHz), (11.68 GHz), (16.054 GHz), (21.28 GHz), and (29.704 GHz) Respectively. This Antenna Operates In Wireless Applications for Operation in The X-Band, Ku-Band, Ka-Band, K-Band, and 5G. Also it is Works for Radar, Satellite Communications, Wireless Network Computer, Medical Communication Devices, and Local Multi Point TV, to Detect Vehicles Speeding, Especially in Europe Vehicles Speeding, Especially in Europe. The Proposed Antenna is Effectively Manufactured and Checked Using a Vector Network Analyzer (VNA) and is Simulation Using CST-MW Software version 2019.

Keywords: Circular Microstrip, 5G, X-band, Gain, VNA.

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1. Introduction

An expanding number of users are interested in multiband antennas, in part because they can reduce the number of antennas that must be employed [1]. In [2], the authors have developed a number of ways for obtaining wideband and multiband properties. A microstrip patch's gain and directivity can be improved using an antenna array [3]. It is crucial that antennas be designed in modern mobile communication devices, as they are an integral aspect of these systems. However, an antenna can be regarded as a device that converts electromagnetic waves inside an antenna to radiating waves in a medium such as air in transmitting mode and vice versa kha[4-6]. The microstrip antenna is one type of antenna that is designed to operate in a specified frequency range because it is reliant on frequency. An antenna's basic structure is made up of three layers: conducting patches, dielectric substrates and conducting grounds [7-9]. Printed microstrip patch antennas, such as FR4 and Roger. As a result of its compact, low profile configuration and ease of integration with microwave circuits [10, 11]. It is therefore suitable for wireless communication systems, cellular phones, radar systems, and satellite communication systems [12-15].

2. The proposed antenna

The Microstrip Antenna consists of three layers: conducting patches on the one side and dielectric substrates with a ground plane on the other. Although square, rectangular, circular, and elliptical are the most often used geometries for microstrip patch antennas, any continuous design is feasible.

2.1. The proposed microstrip antenna

The basic geometry of the designed circular patch microstrip antenna with radius a=10 mm is shown in Figure (1)

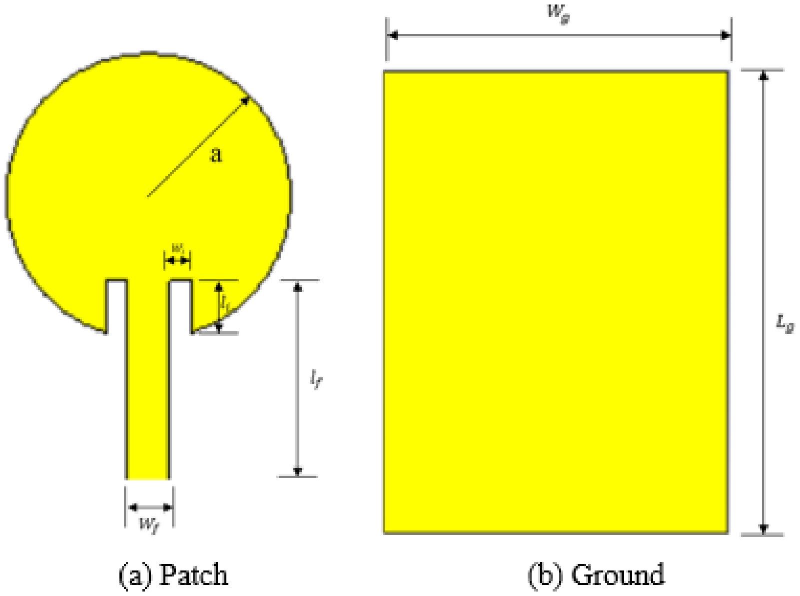


Figure 1. The Initial values of the designed patch antenna, (a) patch layer (b) ground layer

2.2. The necessary design equations

For circular microstrip patch antennas, the radius (a) can be determined by the resonance frequency((f_r) by [16].

$$a = \frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon_r F[\ln(\frac{F\pi}{2h})+1.7726]}}} \quad (1)$$

$$F : \frac{8.791 \times 10^9}{f\sqrt{\varepsilon_r}} \quad (2)$$

where
h refers to the substrate thickness
ε_r stands for relative dielectric constant of the substrate
f is operating frequency

The ground plane is in the bottom. the ground plane and obtained [17].

$$L_g=6h+a \quad (3)$$

$$W_g=6h+a \quad (4)$$

Where:
$L_{g\ and}\ W_g$ are the length and width of ground planes, respectively.

The feeder length (L_f) and feeder width (W_f) can be expressed by [18].

$$L_f=\frac{\lambda_g}{4} \quad (3)$$

$$W_f=\frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (4)$$

$$\lambda_g=\frac{\lambda}{\sqrt{\varepsilon_{reff}}} \quad (5)$$

$$\lambda=\frac{c}{f} \tag{6}$$

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{W}\right]^{-0.5} \tag{7}$$

L_f is the length of feed line
W_f is the width of feed line
λ_g is guided wavelength
λ and c: are free space wavelength and the speed of Light= 3×10^8 m/sec respectively.
f: is the resonance frequency
ε_{reff} is substrate effective relative dielectric constant

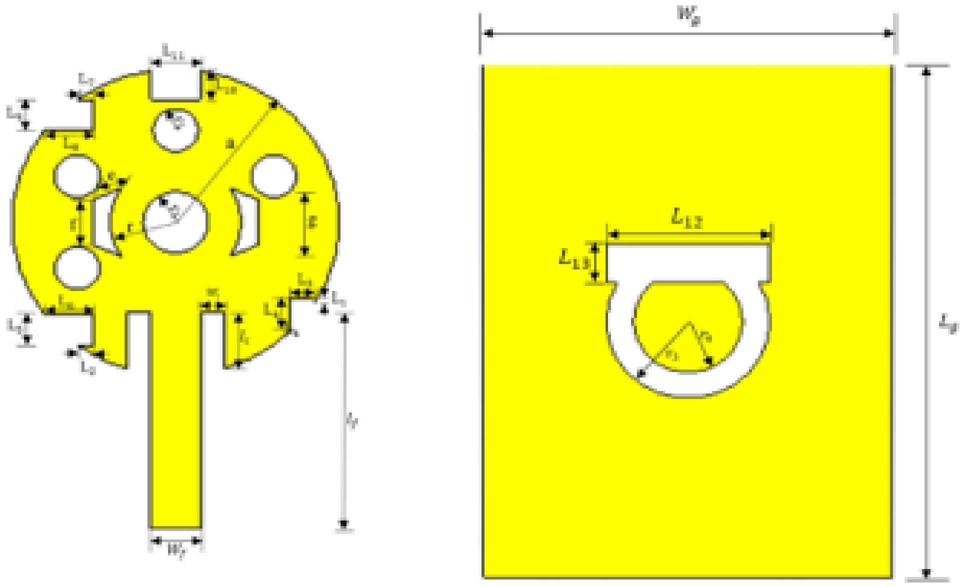
Table 1 the parameter initial values:

Table 1. The Calculated values of the initial parameters

Antenna Parameters	Values(mm)
W_g	19.6
L_g	19.6
W_s	19.6
L_s	19.6
t	0.035
L_f	14
W_f	3
L_i	4
W_i	1.5
A	10
H	1.6

The parametric study were done and it was observed that the values of W_g=30 mm, L_g=40 mm, W_s =30 mm, and L_s =40 mm are the optimum values, and five bands were obtained.

The proposed antenna is modified by etching slots in the patches and ground planes to improve the performance of the antenna with the help of the current distributions. Therefore, Figure 2 is the response of the antenna after improvement.



a) Patch layer (b) Ground layer

Figure 2. The Geometry of the Improved Proposed Antenna, (a) Patch Layer, (b) Ground Layer

Figure 3 is the reflection coefficient (S_{11}) of the final modified antenna. It was noted that the gain in the operating regions is between (0 -10)dB as shown in Figure 4.

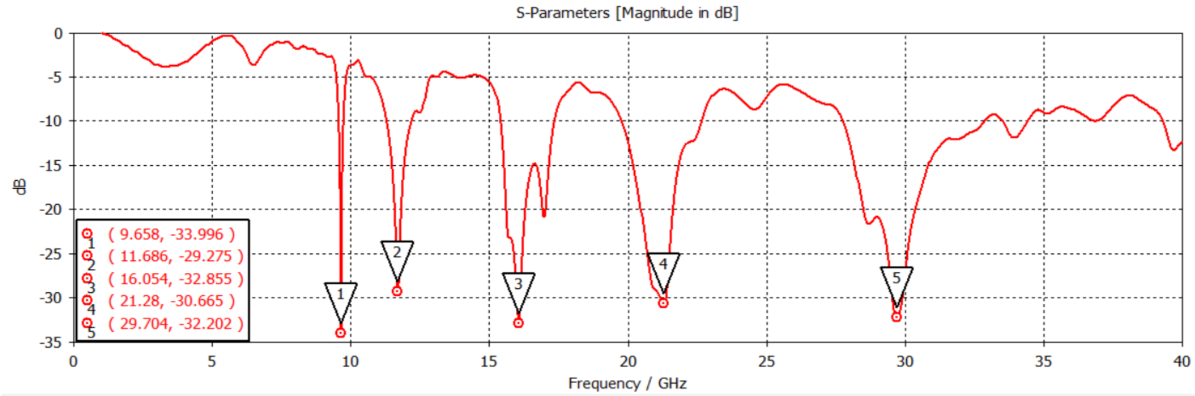


Figure 3. The reflection coefficient (S_{11}) versus frequency

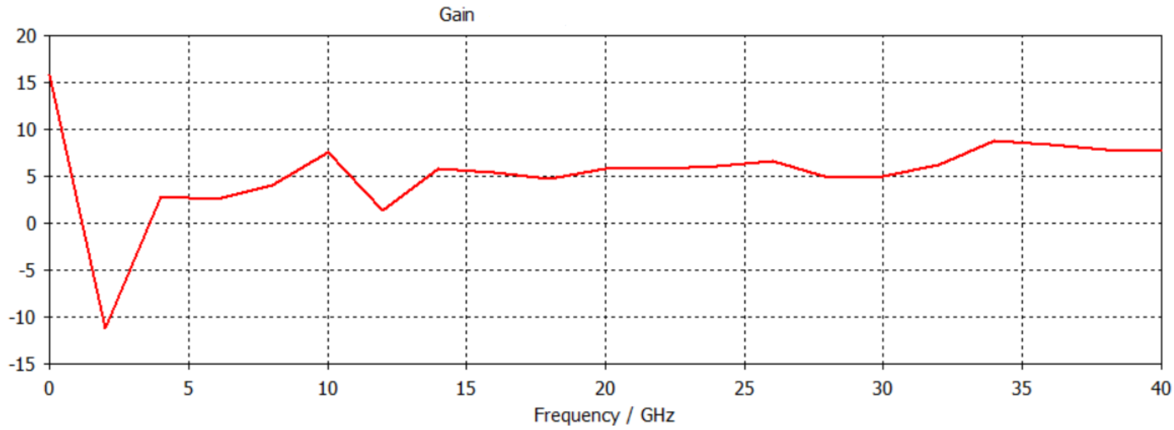


Figure 4. The gain curve vs frequency

For final values of the parameter as listed in Table 2 we have five bands and the gain in the selected frequency as seen in Figure (3-4), operation at

- The return loss (S_{11}=-33.996dB) for first band (9.5663-9.7437)GHz at resonance frequency(f_r=9.658GHz) gain equals to 6.968 dB, which is appropriate for X-band applications such as radar applications used for cloud development studies because they can detect microscopic water particles and also light perception such as snow, and satellite communication utilized for military requirements for land, airborne.
- The return loss (S_{11}=-29.275dB) for second band (11.289-12.195)GHz at resonance frequency(f_r=11.686GHz) gain equals to 2.3468 dB, which is suitable to works with X-band and Ku-band application such as fixed satellite services and some or radar applications for military .
- the return loss (S_{11}=32.855dB) for third band (15.386-17.352)GHz at resonance frequency(f_r=16.054GHz) gain equals to 5.3692 dB, It is compatible with Ku-band applications, particularly downlinks in direct transmission satellites for satellite televisions and other specialized applications such as NASA's Tracking Data Relay Satellite, and radar, particularly police traffic speed detectors.
- The return loss (S_{11}=-30.665dB) for forth band (19.783-22.669)GHz at resonance frequency(f_r=21.28GHz) gain equals to 5.8201dB, which is suitable to works with K-band because of K-band is in between Ku-band and Ka-band and thus manipulated in short range applications.
- The return loss (S_{11}=-32.202dB) for fifth band (27.771-32.866)GHz at resonance frequency(f_r=29.704GHz) gain equals to 4.989 dB, which is appropriate for usage with Ku-band communications mostly manipulated by satellite communications, the uplink frequency for satellite communications radar, 5G, and experimental communications, such as NASA's Kepler probe. The group delay of the antenna varies from (-1 to +3) nsec that indicate minimum distortion and lay in the normal range (-3 to +3) nsec that means it’s able to transmit the electrical pulse with minimum distortion as seen in Figure 5.

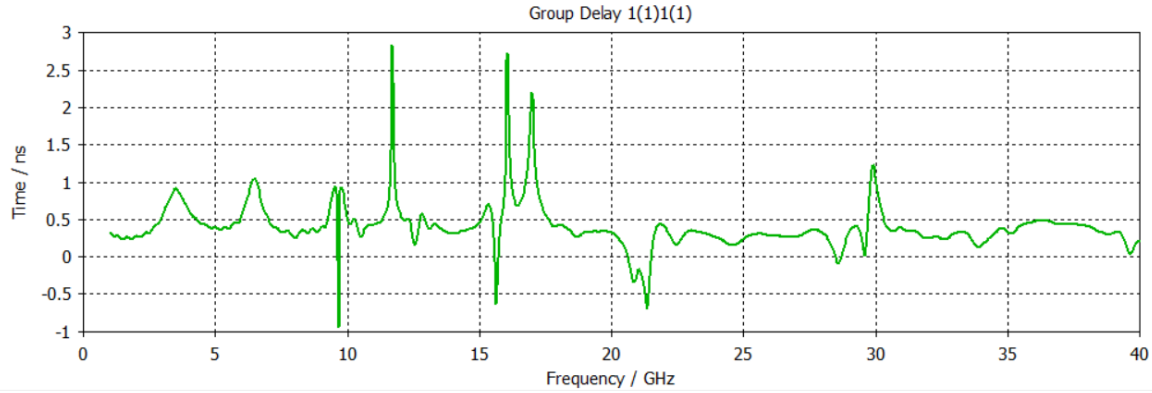
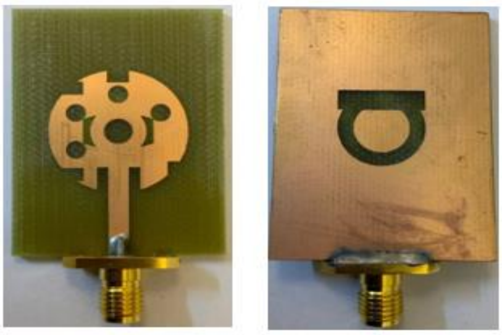


Figure 5. The group delay values versus frequency

Table 2. The optimum values of the parameters of the designed antenna

Antenna Parameters	Values(mm)	Antenna Parameters	Values(mm)
W_g	30	L_1	0.27
L_g	40	L_2	1
W_s	30	L_3	1.5
L_s	40	L_4	2
T	0.035	L_5	2
L_f	14	L_6	3
W_f	3	L_7	1
L_i	4	L_8	3
W_i	1.5	L_9	2
A	10	L_{10}	2
H	1.6	L_{11}	3
R	4	L_{12}	12
r_1	2	L_{13}	3
r_2	1.4	e	1.8
r_3	6	f	3
r_4	4	g	4.39

The designed antenna was fabricated and tested practically by using vector network analyzer (VNA) up to 20GHz as shown in Figure 6.



a) Patch layer (b) Ground layer

Figure 6. The Geometry of the Fabricated Proposed Antenna, (a) Patch Layer (b) Ground Layer

Figure 7 compares the Simulation results and the practical result. It is noted that there is a reasonable acceptance between practical and simulated results.

Figure 7. The shows the reflection coefficient (S_{11}) versus frequency of simulation and fabrication results

Table 3 shows the comparison of our research work with previous work.

Table 3. The optimum describe the comparison between our proposed antenna and many published paper

Antenna References	Dimensions(mm)	Patch Shape(radius(mm))	Resonance Frequency (GHz)	Band (GHz)	S_{11}	Gain(dB)
[19]	35×20×1.6	Circular (10)	19.14	17.986-24.814	-24.3	5.46
			30.02	29.017-31.973	-18.6	5.41
			34.91	33.684-41.068	-28.8	6.6
[20]	40× 40 ×1.6	Circular(15.6)	2.42	------	-35.62	3.05
			5.33	------	-28.89	2.94
[21]	50×40×1.6	Circular(12)	3.48	2.2995-2.84	------	2.5
			5.52	3.36-5.9273	------	4
[22]	36×36×1.6	Circular(9)	8.77	8.31-9.1	-52	------
			10.6	10.41-10.71	-21.66	------
[23]	120×120×1.6	Circular(25)	1.02	0.998-1.36	-14.9	-8.64
			1.66	1.645-1.676	-13.1	-6.96
			2.55	2.528-2.631	-19.6	-5.42
			3.7	3.673-3.736	-26.8	-3.9
			4.93	4.885-4.984	-44.1	7.24
The Proposed Antenna	40×30×1.6	Circular(10)	9.658	9.5663-9.7437	-33.996	6.968
			11.686	11.289-12.195	-29.275	2.3468
			16.054	15.386-17.352	-32.855	5.3692
			21.28	19.783-22.669	-30.665	5.8201
			29.704	27.771-32.866	-32.202	4.929

We notice that the proposed antenna offer five bands, in addition with reduced size and gain enhancement as compared with other authors, Many slots are made in the patch and the ground planes to enhance the gain, reflection coefficient and group delay and the final variation of gain, reflection coefficient with frequency.

3. Conclusions

A multiband circular antenna is proposed for multiband application. The addition of different slots in the patch layer and ground layer enhance the bandwidth and gain respectively, The size $(40\times30\times1.6)mm^3$. The Proposed Antenna is Effectively Manufactured and Checked Using a Vector Network Analyzer (VNA). It is noticed the practical results is in reasonable acceptance with the simulation results. The significant variation between the simulated and practical findings is related to errors of the fabrication caused by the patch's borders having difficult to manufacture., and the Variation of ε_r with frequency.

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Declaration of competing interest
The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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