Design of a Simulated Tri-Bandwidth circular patch with slot for X and C bands applications

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ABSTRAC: Scientists continue to improve the performance and efficiency of microstrip antenna designs as technology evolves, aiming to improve their adaptability to different environments and constraints. These antennas play an important role in modern communication technologies and in signal path systems demonstrate development, computer modeling and testing of microstrip line and coaxial cable with G-shaped slots in the strip. The antenna was designed and simulated using CST simulation software. Antenna performance was analyzed, considering several factors such as return loss, gain, directness, bandwidth, 3D radiation patterns and more. Simulated results showed that the proposed antennas exhibit a wide frequency range, with the microstrip line feed antenna and coaxial cable obtaining a value of 61% and 65%, respectively. These two antennas exhibited remarkable gain which are 7.784 dBm and 7.787 dBm, respectively. The microstrip line achieved a maximum feed efficiency of 93.12%, while the coaxial cable achieved a maximum feed efficiency of 97.65%. The findings suggest that providing the antenna with coaxial cable as opposed to fine tape line improves its performance. Antennas with coaxial cable have wider bandwidth, higher gain, and better efficiency compared to microstrip line antennas.

Keywords: Feeding techniques, Microstrip line ,Coaxial cable ,G-shaped slot ,CST simulation software

1. Introduction

Wireless communication systems are one of the most advanced works in the area of communication telecom. An antenna is a component of electrically conductive material or a connected system of conductive material, specially designed to enable the transmission or reception of electromagnetic waves. Several types of antennas are available, such as microstrip antennas, which combine a thin conductive material with a thin dielectric material on the back.. The modern microstrip antenna plays an essential part in the field of wireless communications. The utilization of microstrip patch antennas has been prevalent in today's world owing to its exceptional adaptability within a wide variety of applications. The antennas are intentionally designed and fabricated in different shapes and dimensions, enabling them to efficiently function over a range of frequency bands. The technology exhibits versatility across various domains, encompassing long-range radio transmissions, radar systems, space communications, broadband terrestrial communications, amateur radio communications, and other contemporary uses [1].

The design of these antennas necessitates the incorporation of frequency range modification capabilities, thereby enabling customization of the antenna's operational frequency to align with specific requirements. Antennas possess a straightforward and uncomplicated design and construction, hence resulting in a relatively economical expense [2][3].

Previous investigation in this particular field has demonstrated that the Microstrip patch antenna (MPSA) and its related substrate characteristics have a significant influence in describing the performance and application suitability of the antenna, contingent upon the specific application context [4][5]. The transmitter has the capability to employ Multiple Signal Processing Algorithms (MSPA) utilizing a single frequency band and a significantly broad range of frequencies. This implies that the antenna is employed for the purpose of transmitting signals or data at a singular, predetermined frequency. This implies that the gadget might potentially be engineered to emit signals at a designated frequency, hence serving the purpose of mitigating any potential interference with concurrent signals present in the surrounding environment. Conversely, a broad bandwidth signals the antenna's ability to transmit data across a diverse spectrum of frequencies. This implies that it possesses the capability to facilitate the transmission of substantial volumes of data over diverse frequency ranges, a crucial attribute in contexts that necessitate extensive data transfers, such as high-speed communication networks. By virtue of including both qualities, the use of MSPA in the transmitter facilitates the transmission of substantial volumes of data across diverse frequencies as well as a singular frequency, rendering it well-suited for applications encompassing high-speed radio communications and radar systems.

Anooz *et al*. designed rectangular MSPA's with G-Shape slot for Microwave Applications to operate at covers tri-bands of 7.51, 8.01, and 10.68 GHz, with a bandwidth of about 15.47% and an efficiency of 97.35% [6]. Khidre *et al*. designed dual-band microstrip antenna operating in the 2-4.5 GHz frequency range. The frequency range can be adjusted from 1.45 to 1.93 GHz. The observed increase in gain within the frequency range (2.22 to 2.26 GHz) is measured at 7 dBi, exhibiting an efficiency of 89%. Conversely, within the frequency range (3.24 to 4.35 GHz), the gain ranges from 4 to 6.8 dBi, accompanied by varying efficiencies ranging from 38% to 90% [7]. Rana *et al*. designed a 2×2 antenna array using a cylindrical dielectric resonator at an operating frequency of 9.04 GHz to achieve high gain. A model has been manufactured with the dielectric material FR-4 of the substrate, and experimental measurements have been carried out. The array exhibit a bandwidth of 2.9% and a gain of 14.8 dBi at the resonance frequency [8]. P.S. Bakariya *et al.* designed a multi-band microstrip antenna to operate at multiple frequencies between 2300 and 5825 MHz. The antenna had dielectric substrate with thick 0.8 mm to achieve exceptional performance within a wide range of frequency. The antenna provides steady gain over operating bands and outstanding radiation characteristics for "LTE2300 (2300–2400 MHz), Bluetooth (2400–2485 MHz), WiMAX (3.3–3.7 GHz), and WLAN (5.15–5.35 GHz, 5.725–5.825 GHz)" [9]. R. S. Reddy et al. Design a compact twin T-slot antenna on each side of a coaxially and circularly fed rectangular microstrip patch with a faulty floor structure for wireless packages. The antenna produces triple operating frequencies to cover both the WLAN 2.45/5.28 GHz and WiMAX 3.5 GHz bands with dimensions of 40 x 28 x 3.A hundred seventy five mm [10]. Z. H. Zarghani *et al*. designed an antenna array using a central and dual-band configuration, wherein each individual element of the array is composed of a square ring and an outer layer. The fixed-location feed consists of a solitary horn antenna. The antenna exhibits exceptional characteristics, boasting a peak gain of 23.4 dBi at a frequency of 8.2 GHz. Furthermore, it demonstrates a bandwidth of 33% for a gain of 3 dBi and a gain of 17% for a gain of 1 dBi. When operating at a frequency of 13.2 GHz, the system attains a peak gain of 25.7 dB, accompanied by a bandwidth of 30% for a 3 dB decrease and 14% for a 1 dB decrease [11]. S Liu *et al*. designed a U-shape patch antenna with four bands and a polarized line that has been specifically engineered for use in WiMAX and WLAN. bandwidths of 2.1%, 3.3%, 7.1%, and 5.0% were attained at center frequencies of 3.35 GHz, 3.70 GHz, 5.20 GHz, and 5.80 GHz, respectively. The first design of this antenna consisted of four non-traditional U-shaped replicas positioned on the patch [12]. Sekhar M. Et al. Designed a 3 band round ring patch antenna using a small rectangular microstrip of feeding simulated on substrate of 2 mm thickness. It is suitable for X, Ku, and K-band programs due to its compact structure. The go back losses acquired are -35. Eighty dB, -forty two.39 dB, and -44.98 dB at 8.96 GHz, 14. Forty-four GHz and 18.97 GHz, respectively [13].

In this work, a new design of a circular patch with a G-shaped slot on the patch is presented. The circular patch has a radius of 8.02 mm for each type of technique feed and has triple resonant frequencies of X-band and C-band. This antenna isdesigned with FR-4 material with a dielectric constant of 4.3 substrates, and thickness of 1.6 mm, while copper as patch and ground materials. The design uses two types of feeding techniques and has triple resonant frequencies in the X-band and C-band.

1. Method and Proposed Antenna Design

A circular MSPA was demonstrated using computer simulation software CST to design and analyze antennas. The proposed antenna was designed for a wide range of frequencies within the X-band and C-band. Figure 1(a, b) shows the two types of a circular patch antenna with G-shape slot. its parameters and physical dimensions are given in Table1. There are two types used for feed which are microstrip line and coaxial cable for antenna design. The dimensions of antenna for both microstrip and coaxial are 45 x 45 x 1.6 mm^3, with radius of circular 8.02 mm used for the simulation. The design aims to achieve a triple frequency band by studying the effect of the slot on the gain beam, return loss, VSWR and antenna efficiency. The calculation of the radius of a circle can be achieved by utilizing the following formulas [14]:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{0.5}} \qquad (1)$$

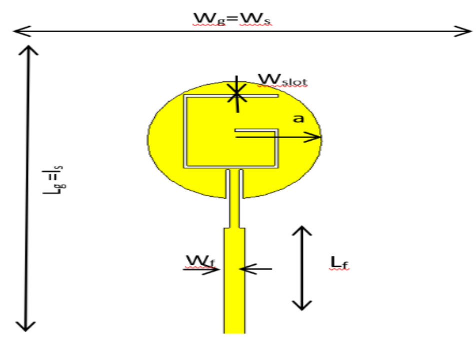
$$F = \frac{8.791 * 10^9}{f\sqrt{\varepsilon_r}} \qquad (2)$$

Where a denote the radius of the circular patch, F is a force between charges, f is the operating frequency, ε_r is a dielectric constant of the substrate and h thickness of substrate [15].

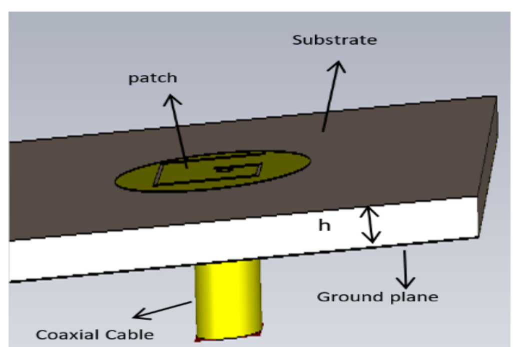
The substrate and ground plane defined according to the typical dimensions i.e. length (Ls, Lg) and width (Ws, Wg). It is calculated using the following formulas [14]:

$$Ls = 2x \text{ Diameter of the patch } = 2 \times (2a) \qquad (3)$$

$$Ws = 2x \text{ Diameter of the patch } = 2 \times (2a) \qquad (4)$$



(a)



(b)

Figure.1 Proposed antenna structure for (a) microstrip feed line and (b) Coaxial feed.

Table 1. Specified Parameters for both proposed antenna**.**

Antenna	Type of feeding	L_s mm	W_s mm	L_g mm	W_g mm	Radius of circular (a) mm	W_f mm	L_f mm	W_{slot} mm
Circular patch	Microstrip line	45	45	45	45	8.02	1.9	2.44	0.3
Circular patch	coaxial	45	45	45	45	8.02	-----	------	0.3

2. Results and Discussion

S-parameter and VSWR

The return loss (S_{11}) values express the overall effectiveness or efficiency of the antenna in transmitting or receiving signals. The return loss (S_{11}) curves are simulated for the triple band antenna. Figure 2 (a, b) shows S_{11} for two types of feeding with a G-slot. The operator frequencies of the antenna for microstrip line feeding were 5.376, 6.44, and 10.6178 GHz, and it showed return loss (S_{11}) of -18.53, -17.38, and -19.17 dB, respectively. While the operator frequencies of antenna for coaxial fed were 6.174 ,8.75, and 12.166 GHz, and showed return loss of -19.05, -34.59 and -18.51 dB, respectively. The three operational bands, for each two-feeding technique, have bandwidths with 10dB down impedance for microstrip line and coaxial fed was determined to be 1.4% ,1.9%, 2.0%, 2.48%, 3.5%, and 3.37%, respectively. Such that the bandwidth was

calculated according to the following formula [15].

$$\mathrm{BandWidth(BW)} = \frac{(\mathrm{f_H} - \mathrm{f_L})}{\mathrm{f_o}} 100\% \qquad (5)$$

where f_o is effective frequencies (center frequency), f_H is the higher frequency, and f_L is the lower frequency.

The Voltage Standing Wave Ratio (VSWR) is quantifying the extent of impedance matching in a transmission line. Figure 3 (a, b) exhibits VSWR < 2 at operator frequencies as shown in table **2.**

Table 2 shows that when the values are close to the ideal. It indicates that both antennas demonstrate good impedance matching at all resonance frequencies. Additionally, VSWR is related to the reflection coefficient, which quantifies the power reflected by the antenna. The relationship between VSWR and the reflection coefficient (Γ) can be described as follows [15]:

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \quad (6)$$

Thus, S_{11} is return loss expressed in terms of the reflection coefficient (Γ) using following equation [15]:

$$RETRUN\ LOSS\ (RL) = -20\ Log_{10}\ |\Gamma| \quad (7)$$

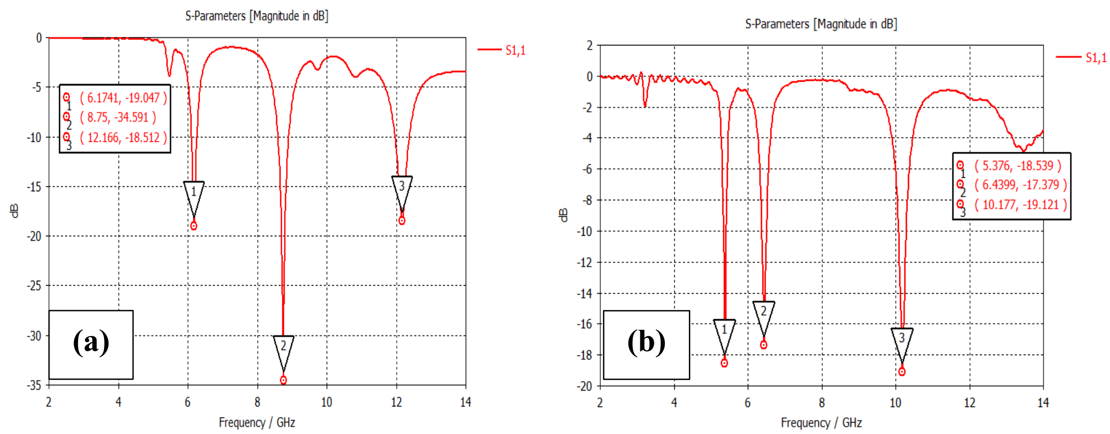


Figure: 2 S-parameters curve for the triple-band antenna for (a) Microstrip feed line, (b) Coaxial cable feed.

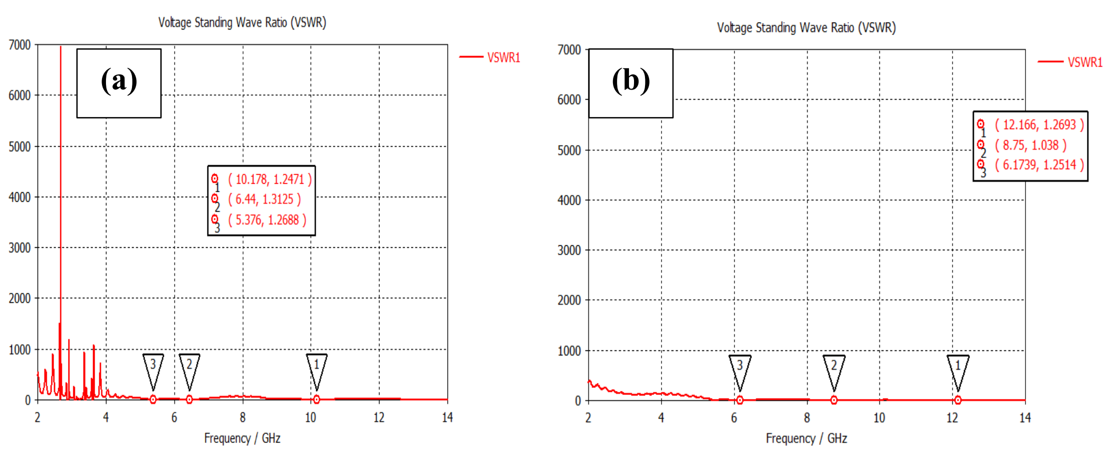


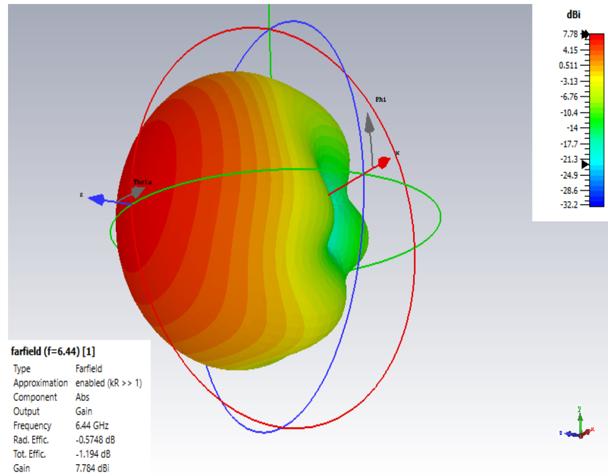
Figure.3: VSWR for the triple-band of the proposed antenna (a) Microstrip feed line, (b) Coaxial cable feed.

Table 2. VSWR values at triple –band of both the proposed antennas

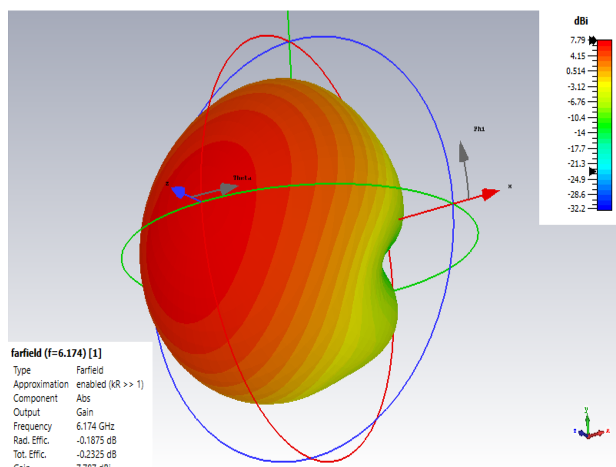
Type of feeding	Frequency (GHz)	Value of VSWR
Microstrip line	5.376	1.26
	6.44	1.31
	10.6178	1.24
Coaxial	6.174	1.25
	8.75	1.037
	12.166	1.269

Gain and Radiation Pattern:

The radiation from the edges of the patch generates a far-field radiation pattern. This radiation pattern illustrates that the antenna emits more power in one specific direction compared to other directions. Consequently, the antenna exhibits a particular directivity, often quantified in dB. The antenna's gain signifies its efficiency and directional capabilities. For the antenna to operate effectively, the gain value should exceed 3dB. The proposed antenna demonstrates a gain of approximately is 7.784 dB, and 7.787 dB. Additionally, the antenna for stipe line and coaxial feeding exhibits a directivity of 8.359 dBi, and 7.974 dBi, respectively. The radiation efficiency values of the tow proposed antenna structure are found to be 93.12 %, and 97.6% respectively. Figures 4 and 5 depict the gain and directivity characteristics of the proposed antenna.



(a)



(b)

Figure .4: 3D-Radiation pattern of both the proposed antenna (a) Microstrip feed line, and (b) Coaxial cable feed

Table 3 provides a comprehensive and comparative analysis of the proposed circular antenna with a G-slot. It shows the comparison of the effects of both microstrip line and coaxial feeding methods. The results indicate that the circular patch antenna with coaxial feeding offers several advantages, including a wider bandwidth, lower VSWR, and enhanced return loss when compared to the circular antenna using microstrip line feeding. Furthermore, the circular antenna with coaxial cable feeding exhibits superior gain and directivity.

Distribution of Surface Current

The current density distribution on the surface of the strip antenna is utilized to comprehend and examine the manner in which the current is spread over the antenna and how this impacts its performance. The objective is to enhance the antenna design and ascertain methods to optimize its performance. By analyzing the distribution of current density, we can identify the places that exhibit the highest performance. This allows us to concentrate our design efforts on these areas in order to enhance the overall performance of the antenna, as illustrated in Figure 6.

Table 3: Performance comparison between both of the proposed antennas.

Type of feed	Return Loss(dB)	Bandwidth%	VSWR	Γ Reflection coefficient	Gain (dBi)	Directivity (dBi)
Microstrip line	-18.53	1.4	1.26	0.11	7.370	8.316
	-17.38	1.9	1.31	0.13	7.784	8.359
	-19.17	2	1.24	0.10	6.878	7.851
Coaxial	-19.05	2.48	1.25	0.111	7.787	7.974
	-34.59	3.5	1.037	0.018	7.128	7.309
	-18.51	3.37	1.269	0.11	7.097	7.269

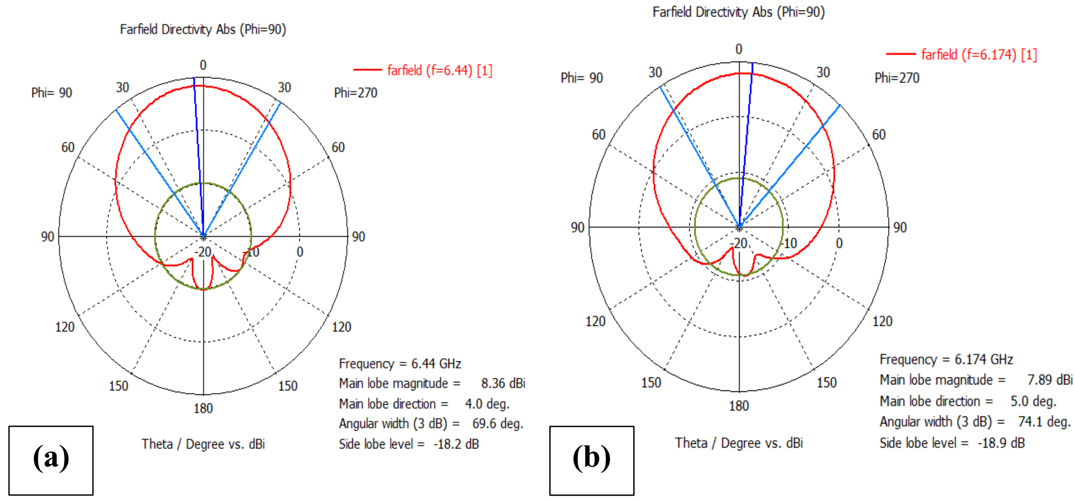


Figure.5: 2D-Directivity of both proposed antenna's Microstrip feed line, and (b) Coaxial cable feed.

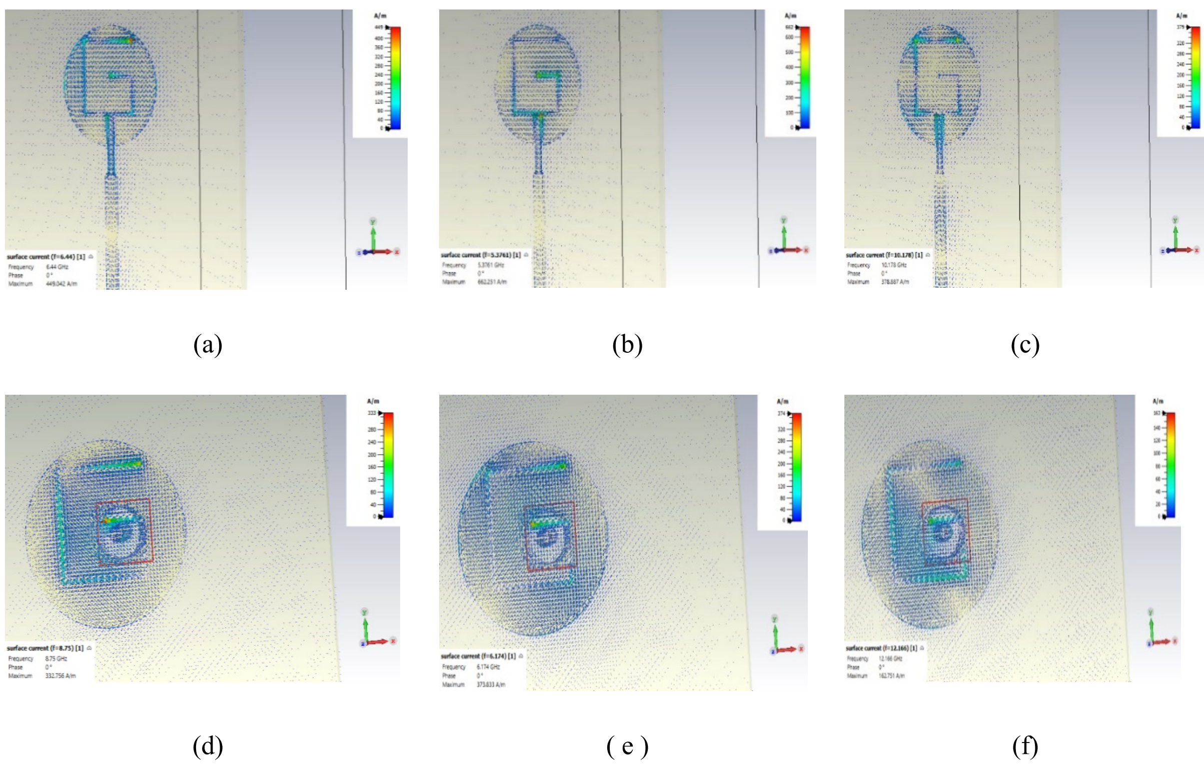


Figure.6: surface current patterns over triple-resonance frequencies for both proposed antenna's

(a) 5.376 GHz, (b) 6.44 GHz, (c) 10.178 GHz, (d) 6.174 GHz, (e) 8.75 GHz, (f) 12.166 GHz.

Table 4 includes comparison between other published works and the suggested antenna. It is noteworthy that the novel antenna proposed here delivers superior results in terms of bandwidth and compactness as a single-element antenna when compared to the findings in other relevant literature.

Table 4: Comparison between the proposed antenna and others work.

Ref.	Shape of patch	Thickness of substrate mm	Shape of slot	Type of feeding	Operator frequency (GHz)	S_{11} parameter (dB)	Band width	Gain (dB)	Efficiency %
[6]	Rectangular	1.6	G	Coaxial cable	7.51 8.01 10.68	-37.6 -19.5 -54.1	15.47%	6.62	97.35 %
[16]	Rectangular	1.6	H	Coaxial cable	2.42	------	19%	-------	-------
[17]	Rectangular	1.5	E	Coaxial cable	1.9 2.4	------	30.3%	-------	-------
[18]	Rectangular	---	C	Coaxial cable	1.25 2	-16.25 -23.75	12.05% 19.82%	5.509	89 %
Our study	circular	1.6	G	microstrip line	5.3761 6.44 10.178	-18.53 -17.38 -19.17	1.4% 1.9% 2%	7.784	93.12%
				Coaxial cable	6.174 8.75 12.166	-19.05 -34.59 -18.51	2.48% 3.5% 3.37%	7.787	97.6%

4. Conclusion

The present study introduces a circular three-wire antenna with a G-shaped slot, which results in a bandwidth spread in the frequency range of about 61.7% and 65.3% for coaxial feed, respectively. This proposed antenna is compact and suitable for both X-band and C-band applications. The antenna maintains constant gain, bandwidth, and polarization characteristics with acceptable levels of cross-polarization. We can also note that the effect of a slot, this causes an important phenomenon in the electromagnetic field distribution around the antenna known as These slots work as channels or distributes the final electromagnetic measurement of the antenna. The effect of this process depends on the precise configuration of the antenna and where it is installed, according to the simulation results. These observations suggest that such antennas could be developed in the future.

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