A LOW-PROFILE CIRCULAR DISK MICROSTRIP ANTENNA FOR DUAL ISM BAND (902MHZ AND 2.4GHZ) APPLICATION

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Abstract:

In this research work, a disk microstrip antenna has been designed with a circular radiating patch. The radiating patch and ground of the antenna are shorted with a shorting pin in order to generate another resonant band apart from the principle resonant band. Also, an optimized V-shaped slot has been introduced on the radiating patch to shift the resonant bands and improve the impedance matching. The unique feature of this antenna design is that it has dual ISM band applications. The resonant bands of the antenna are (896-932MHz) and (2.4-2.5 GHz) for ($S_{11} \leq -10$ dB) which cover (902-928MHz) and (2.4-2.48GHz) ISM application bands. The gain of the antenna is 1 dB at 2.45GHz and -28.7dB at 0.91GHz. The complete design of the antenna has been done using theoretical calculation and HFSS software. After that, it has been fabricated and different parameters have been measured using a Vector Network Analyser (VNA). It has been found that the measured results are closely similar to the simulated results.

1 Introduction

Communication technology is growing at a fast pace due to which the design of all the devices, and equipment used in it also changes in different shapes and sizes. Therefore, different shapes and sizes of the antenna are needed which can suitably fit in these devices and equipment. With the advancement of communication technology, there is also a very high demand for a single antenna that can cover more than one application band. Hence, in order to fulfill the required demand, a low-profile, different-shaped, multiband antenna is needed. A microstrip patch antenna with the modification in the conventional structure is very much suitable and fulfills the present and future demand, that's why it is attracting more research work.

After the literature survey, it has been found that a lot of research papers have been published with various shapes, sizes, and applications of microstrip patch antenna. These antennas have some merits and demerits. For example, in [1], it had been investigated that the resonant frequencies of some of the modes of a circular disk microstrip patch antenna can be tuned by using more than one shorting pin in a circular position. It had been also revealed that a dual-band antenna can be designed by using the suitable position of the shorting posts with adjustable frequency division between the same modes. A disk microstrip antenna with high-gain and side lobe suppression (SLS) was designed in [2]. This antenna had two circular disks in a stacked configuration and each disk generated a radiated field with TM_{11} and TM_{13} modes. The high gain and SLS in this antenna had been achieved through linear superposition of the radiated field generated by the two disks. Due to the presence of two circular disks that are excited by the single probe, the designed antenna is more complex and difficult to fabricate. In [3], a polarization reconfigurable circular disk antenna had been designed in which the polarization of the radiation works in either a linearly or circularly polarized mode. The linearly or circularly polarized mode had been switched by adding a reconfigurable C-shaped slot. A low-profile circular disk antenna with wideband or dual-band application and high-gain capability had

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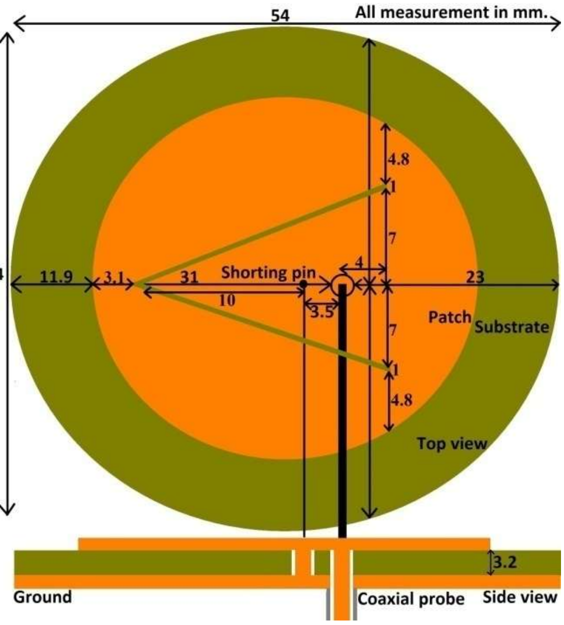
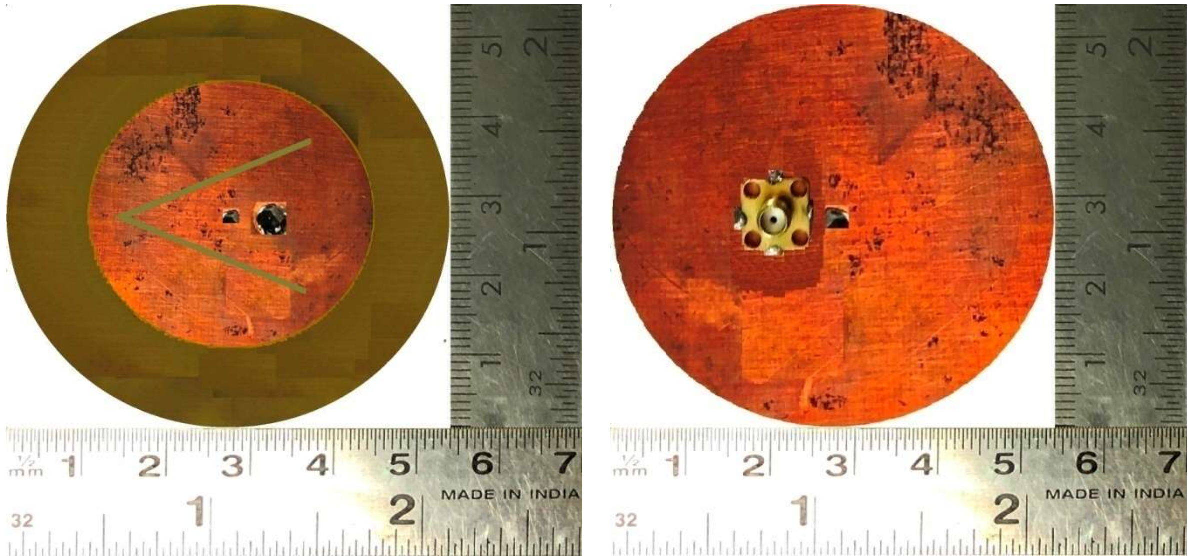
been designed in [4]. The single-layer antenna had a circle of ten nonidentical diameters shorting vias, which makes it more complex and complicated. In [5], a dual-band, high-gain, steady radiation pattern circular disk antenna operating in TM_{11} and TM_{12} modes had been designed. In this antenna design, a set of shorting pins had been loaded in circular contours beneath the circular patch to significantly raise the TM_{11} mode's resonance frequency. In the meantime, a thin slot is added to the patch's center to reduce side lobes. For use in the 5.8 GHz application band, a small, reconfigurable antenna with 360° beam steering and strong directivity had been suggested in [6]. The idea is to use the via-grounding approach around a circular patch that is shorted with an edge-grounded sector patch and encircled by arc strips. In [7], a circular disk antenna was designed with two shorting strips loaded at the non-radiating sides in order to concurrently increase the CP gain, efficiency, and polarization purity using the RSW theorem. The suggested antenna also effectively suppresses radiation in a horizontal direction, making it suitable for contemporary MIMO and array wireless applications. In [8], a circular patch antenna working in TM_{31} mode was designed with three sets of slot loadings on a single circular patch to obtain reconfigurable ±45° polarizations and high gain. Also, in [9] the simultaneous control of radiation nulls over both the E-plane and H-plane patterns had been theoretically investigated in a differential-fed three-layer stacked circular patch antenna with better gain performance.

The above examples show that, despite a large number of designs and publication of microstrip patch antennas in the literature it has still huge potential for further research and development and this motivates the present work. To satisfy the requirement of advanced communication technology for low profile, low cost, and multiband antenna, a circular disk microstrip antenna for dual ISM band (902MHz and 2.4GHz) application has been proposed here. The proposed antenna generates resonant frequency bands with optimum radiation pattern and gain which is very much suitable and compatible with devices working on ISM band applications. The design process of the antenna involves mainly four steps namely; theoretical study, design of the antenna using simulation software HFSS, optimization using simulated results, and experimental measurement of the fabricated antenna. All the above-mentioned steps are thoroughly described in the subsequent paragraphs.

2 Antenna design



(a)



(b) (c)

Figure 1. (a) Design of the proposed antenna. (b) Top view and (c) bottom view of the fabricated antenna.

The projected antenna as shown in Fig.1 (a, b, and c) has mainly three parts circular-shaped ground plane, substrate, and radiating patch. A circular thin copper sheet of 54mm diameter has been used to make the ground plane and 30.2mm diameter has been used to make the radiating patch. A circular substrate of 54mm diameter and 3.2mm height has been placed between the patch and the ground. The material that has been used for the substrate is FR4 glass epoxy whose relative permittivity (ε_r) is 4.4 and loss tangent (tanδ) is 0.02. A copper pin of 0.63mm radius and 3.2mm height has been used to short the radiating patch and ground. The position of the copper pin is 3.5mm left away from the probe on the diameter of the antenna. The radiating patch has been perturbed using a V-shaped slot with the size and position mentioned in Fig. 1(a). A 50Ω co-axial probe with an SMA connector has been connected with the antenna at a distance of 23mm from the left end point of the diameter to energize it.

3 Antenna design procedure with parametric study

For the design of the projected antenna, first, a circular-shaped radiating patch along with a circular ground plane and substrate has been selected, so that a low-profile disk antenna can be designed. After the selection of the radiating patch, a theoretical calculation has been done with various radius lengths and mathematical equations 1 and 2 [10-13] to find the resonant frequency of the antenna around the ISM (2.4 GHz) application band.

$$a_e = a\left\{1+\frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2} \tag{1}$$

$$f_r = \frac{8.791\times 10^{10}}{a_e\sqrt{\varepsilon_r}} \tag{2}$$

where,
a=Radius of patch
a_e=Effective radius of patch
h=Height of the substrate
f_r=Resonant frequency

After various theoretical calculations, the radius length of 15.1mm of the radiating patch provided a primary resonant frequency of 2.63GHz close to the needed result. Having a theoretical resonant frequency of 2.63GHz for a 15.1mm radius length, a circular disk microstrip antenna has been designed using simulator software HFSS with the same radius length as mentioned above. After that, at the arbitrary probe position, the designed antenna is simulated and analyzed. The analysis showed unwanted results because of a mismatch of probe impedance and antenna impedance due to inappropriate probe position. Therefore, before making any modification in the conventional structure, the probe position has been optimized by shifting the position of the probe 1 mm. on the diameter of the circular patch from the left end to the right end and subsequent analysis of the results. Following the analysis of the results, it has been found that the impedance of the antenna and probe impedance is well matched at the probe position 4mm right from the center on the diameter of the circular patch. In this way, the optimum probe position has been found and at that probe position, the resonant frequency is 2.6GHz almost the same as the theoretical resonant frequency with a resonant frequency range (2.56-2.63GHz). The initial design of the antenna with reflection coefficient (S_{11}) and input impedance (Z_{11}) graph has been displayed in Fig.2 (a, b, and c).

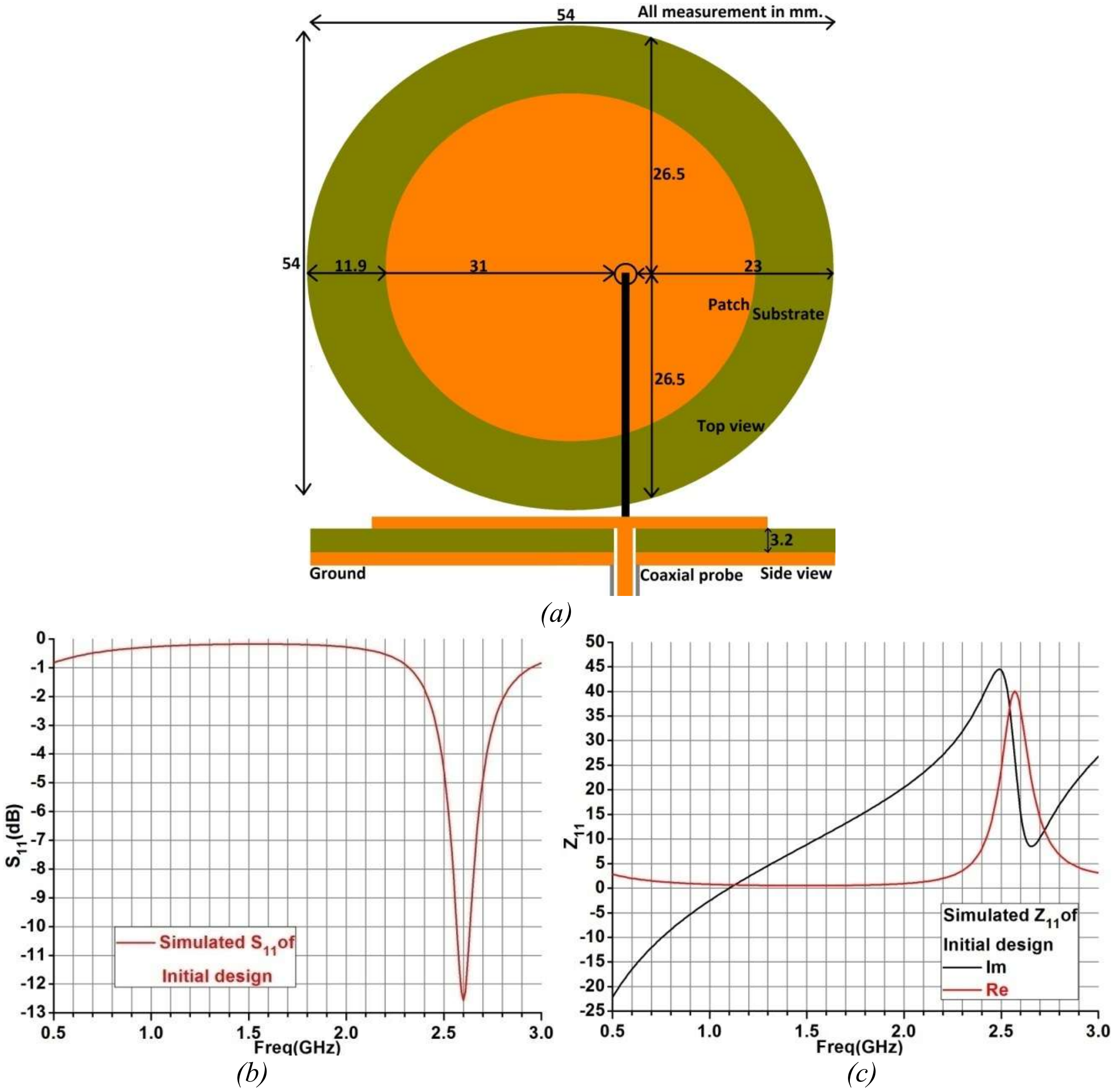


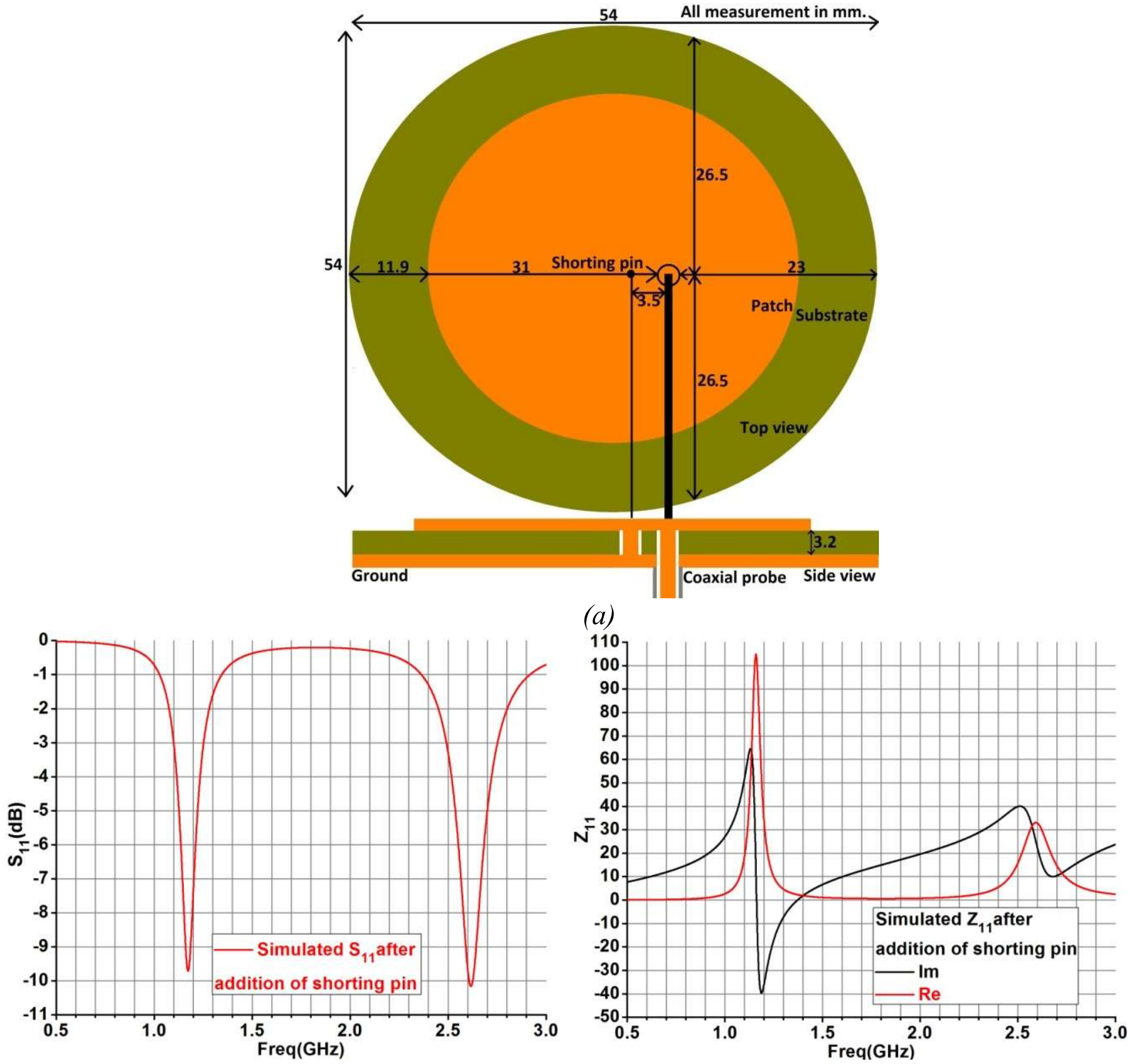
Figure 2. (a) Initial design of the proposed antenna with optimum probe position. (b) S_{11} and (c) Z_{11} of the antenna at the above-mentioned probe position.

The above initial design of the projected antenna does not fulfill the desired requirement. Therefore, it has been modified to find the desired results by using the techniques and processes mentioned below.

3.1 Effect of shorting of radiating patch with the ground using copper pin

As the conventional disk antenna has a single resonant band, therefore, it needs to be modified so that it can be used for more than one application band. For this purpose, the radiating patch and ground of the antenna are shorted with a copper shorting pin that generates another resonant band (central resonant frequency 1.175GHz) apart from the principle resonant band (central resonant frequency 2.6GHz). The shorting of the patch with the ground causes the inclusion of parallel inductance with the patch [14-16]. Therefore, it forms a parallel Inductive and capacitive (LC) resonance with stray patch capacitances leading to an additional resonant band which makes it an antenna with dual application band.

The position of the shorting pin has been optimized by shifting it 1 mm. on the diameter of the circular patch from the left end to the right end and subsequent analysis of the simulated results. Following the analysis of the results, it has been found that the optimum shorting pin position is 0.5mm right from the center on the diameter of the circular patch. Fig.3 (a, b, and c) shows the antenna design with optimized pin position and graph of S_{11} and Z_{11} of the antenna.



(a)

(b) *(c)*

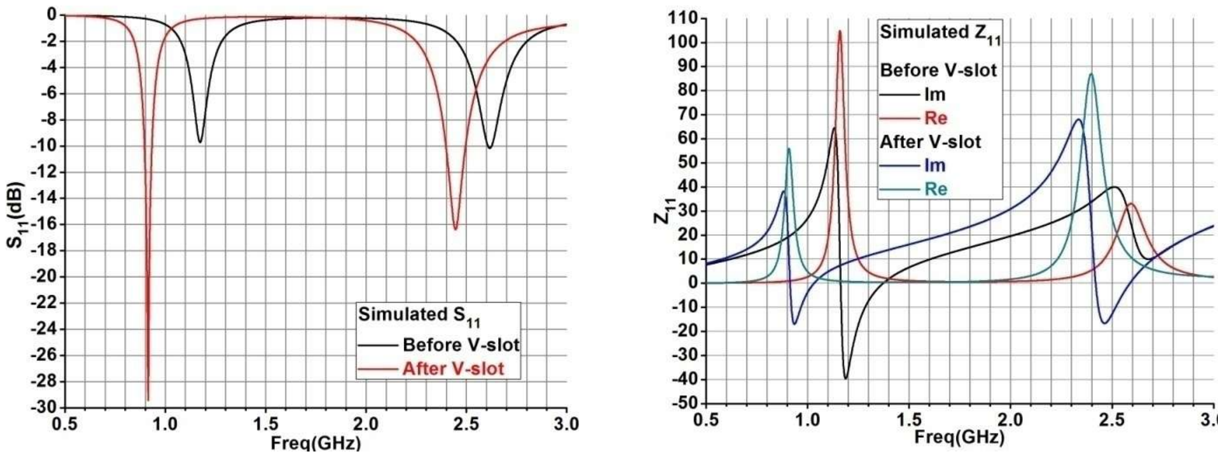
Figure 3. (a) Design of the antenna with the addition of the optimized shorting pin. (b) S_{11}, and (c) Z_{11} of the antenna.

From Fig.3 (b and c), poor reflection coefficient (S_{11}) can be absorbed because of improper impedance matching of the antenna, and also, both the resonant band needs smaller shifting to cover the desired application band. Therefore, further modification has been done to the above antenna structure.

3.2 Loading of a V-shaped slot on the radiating patch

From the literature, it has been found that the slotting of the radiating patch causes shifting of the frequency band towards the lower side of the frequency range due to elongation of the surface current path

[17-21]. It also causes the inclusion of capacitive reactance with the patch due to which impedance matching and return loss of the antenna is improved [22]. Based on the above idea, a V-shaped slot has been introduced on the radiating patch and observed the corresponding simulated results. The simulated results have shown an improvement in impedance matching and shift of the frequency band which can be observed in Fig.4 (a, and b). After that, the size and position of the V-slot have been optimized by varying the size and position and observing the corresponding simulated results. The modified antenna with the optimum size and position of the V-slot has been depicted in Fig.1 (a). Further modification in the dimension of the V-slot shows unwanted results. Fig.4 (a, and b) shows simulated S_{11} and Z_{11} of the antenna before and after the addition of an optimized V-shaped slot on the radiating patch.



(a) *(b)*

Figure 4. (a) S_{11} and (b) Z_{11} of the antenna with the addition and without the addition of the V-shaped slot.

Following the above process, the final design of the antenna has been made and a prototype of it has been fabricated as displayed in Fig.1 (b & c). The different parameters of the fabricated antenna have been measured using a Vector Network Analyzer benchtop (Model No.E5071B) and an anechoic chamber.

4 Result

The simulated and measured results for different parameters of the designed antenna have been summarized in Table 1.

Table 1.

Parameters	**Simulated**	**Measured**
1st Resonant band ($S_{11} \le -10$ dB)	(0.896-0.933 GHz) 37MHz, 4.05%	(0.899-0.935 GHz) 36MHz, 4.02%
2nd Resonant band ($S_{11} \le -10$ dB)	(2.400-2.495 GHz) 95MHz, 3.88%	(2.405-2.499 GHz) 94MHz, 3.85%
Efficiency (%)	27 at 0.91GHz and 82 at 2.45GHz	22 at 0.91GHz and 78 at 2.45GHz
Gain (dB)	-28.7dB at 0.91GHz and 1 dB at 2.45GHz	-25.1dB at 0.91GHz and 0.95 dB at 2.45GHz
Application	1. (902MHz) ISM band 2. (2.4GHz) ISM band	

Graphs of different parameters of the antenna with measured results have been shown in Fig. (5, 6, 7, 8, 9, and 10).

It can be absorbed from Table 1 and Fig.7 & 8 that the gain and radiation efficiency of the resonant band (0.896-0.933 GHz) of the proposed antenna is poor. The main causes of the poor gain and radiation efficiency are dielectric losses and conductor losses. A high dielectric constant or loss tangent substrate like FR4 converting more of the input power into heat rather than radiated energy reduces radiation efficiency and gain. Apart from that, the metal conductors in the microstrip antenna lead to resistive heating, decreasing the amount of power available for radiation, thus impacting both gain and radiation efficiency. The gain and radiation efficiency can be improved by using low dielectric constant and low loss tangent substrate materials like Teflon (PTFE) or Rogers laminates and low-loss metals.

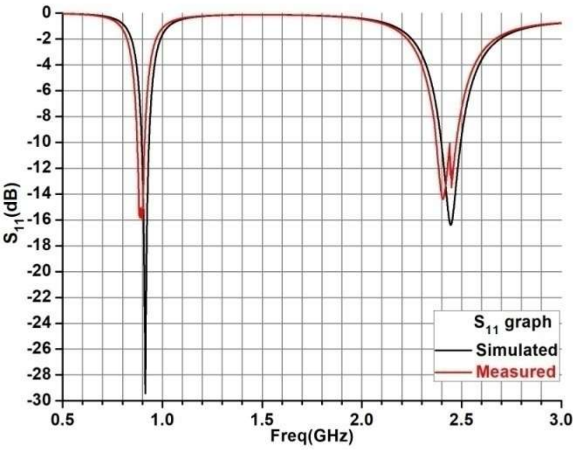


Figure 5. Measured and simulated S_{11}.

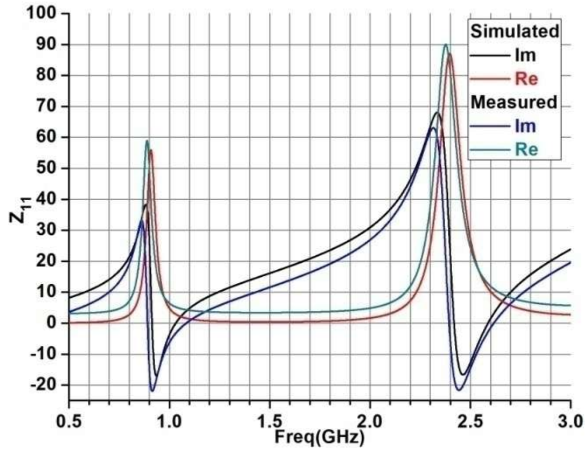


Figure 6. Measured and simulated input impedance.

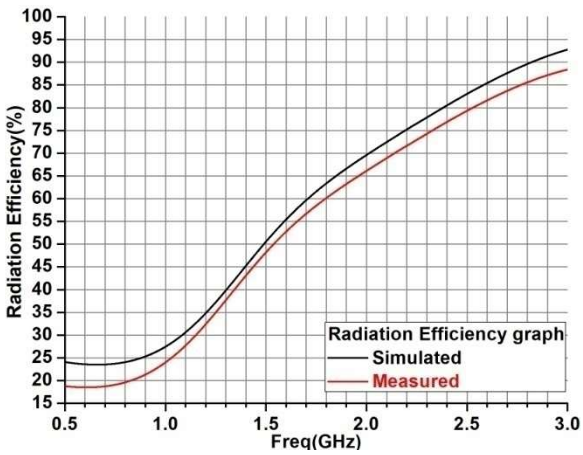


Figure 7. Measured and simulated radiation efficiency.

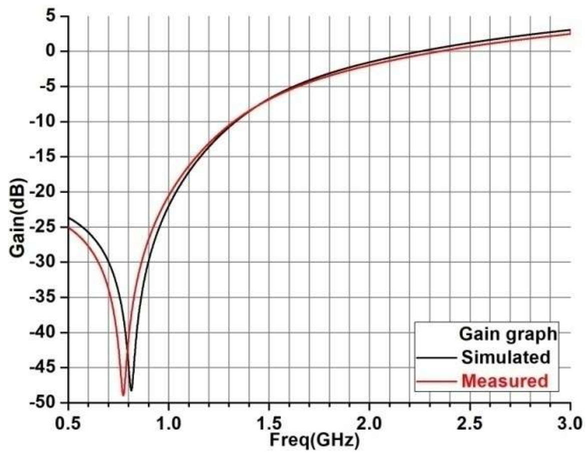
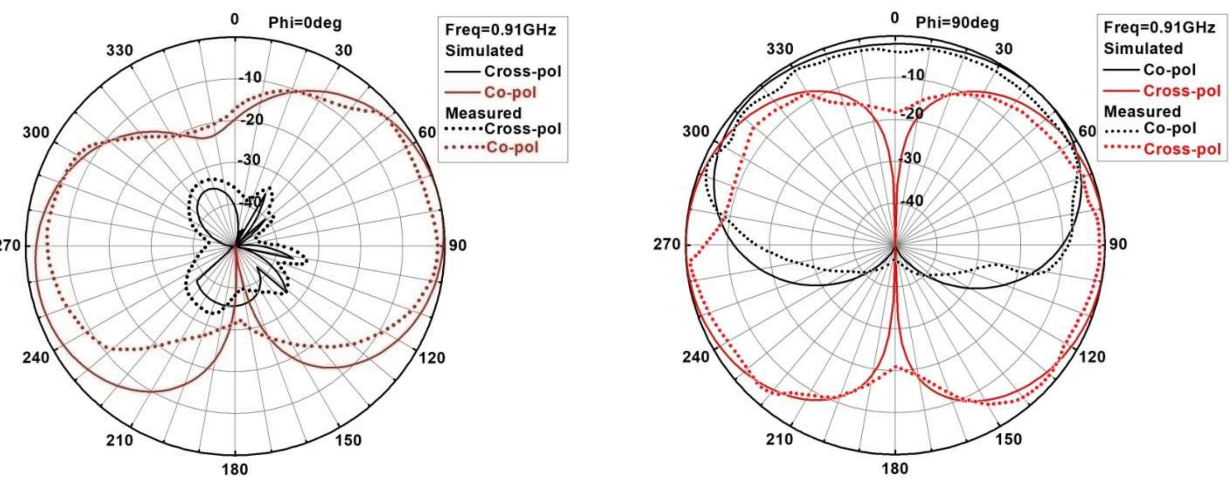
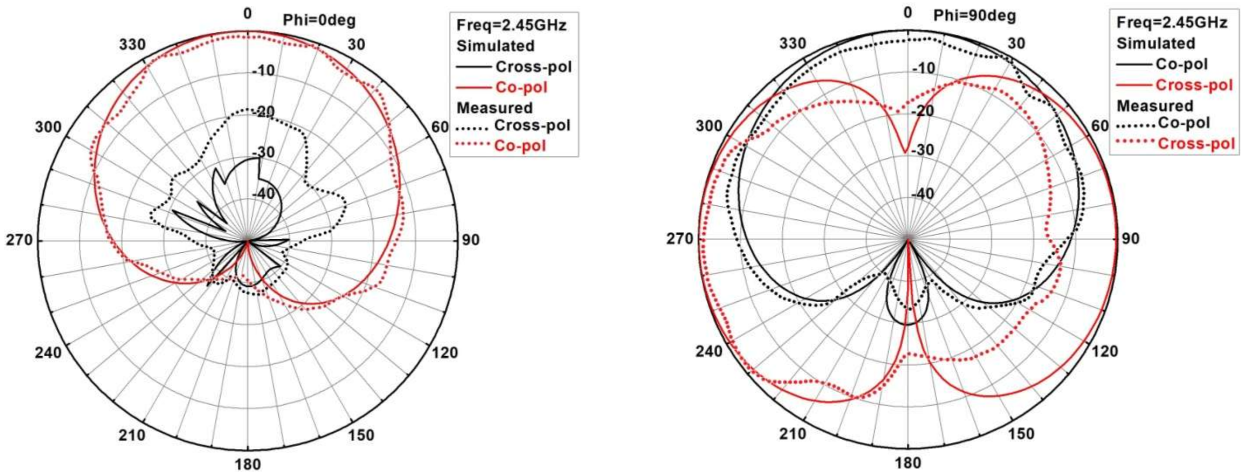


Figure 8. Measured and simulated gain.



(a) (b)

Figure 9. (a) Normalized radiation pattern in X-Z plane and (b) Y-Z plane at 0.91GHz frequency.



(a) *(b)*

Figure 10. (a) Normalized radiation pattern in X-Z plane and (b) Y-Z plane at 2.45GHz frequency.

From the above graphs shown in Fig. 5, 6, 7, 8, 9, and 10, it can be examined that the measured and simulated results closely match with a little shift in the measured results due to erroneous soldering of the connector with the ground and the patch of the antenna, impure substrate material and inadequate measuring environment which is not considered during the simulation.

The radiation pattern shows the radiation characteristics of the antenna as a function of space coordinates. The radiation performance of the linearly polarized antenna is often described in two planes (Phi=0^0 and 90^0). Fig. 9 and 10 show the simulated and measured co-pol and x-pol in the two-dimensional plane at 0.91GHz and 2.45GHz frequencies with Phi=0^0 and 90^0 and theta (Ө) between 0^0 to 360^0. It can be seen from Fig. 9 and 10 that the proposed antenna has a broadside radiation pattern.

Table 2 shows a comparison of the designed disk antenna performance with existing disk antennas in the literature and it also shows the merit of the proposed antenna.

Table 2.

Ref. no.	**Disk antenna diameter (mm)**	**Resonant band ($S_{11} \leq -10$ dB)**	**Impedance Bandwidth ($S_{11} \leq -10$dB)**	**Gain**	**Application**
[23]	60	1.59GHz and 2.19GHz (Resonant freq.)	17MHz,--- and 19MHz,---	---	Dual-band
[24]	75	(5.7-6.3GHz)	600MHz, 12.8%	5.7dBi	Mobile wireless communications
[25]	42	(3.995-4.025GHz) and (4.94-6.06GHz)	30MHz, 0.75% and 1.12GHz, 20%	5.1and (5.8–8) dBi	Wireless communication
[26]	30	10.02 GHz (Resonant freq.)	---	9.85dBi	Broadside gain applications
[5]	50	(3.654-3.712 GHz) and (5.844-5.976 GHz)	58MHz,1.57% and 132MHz,2.23%	10.2 and 10 dBi	3.6 and 5.9 GHz WLAN
This work	54	(0.896-0.933 GHz) and (2.400-2.495 GHz)	37MHz, 4.05% and 95MHz, 3.88%	-28.7dB at 0.91GHz and 1 dB at 2.45GHz	(902MHz)ISM band and (2.4GHz) ISM band

5 Conclusion

A low-profile circular disk microstrip antenna for dual ISM band (902MHz and 2.4GHz) application has been proposed in this research work. The designed antenna in the proposed work covers a couple of application bands with satisfactory performance. A detailed introduction with an adequate literature review has been presented prior to the design process of the antenna. Next, a complete design process has been described including a theoretical calculation using mathematical equations with proper reason and justification at every step of the process. After that, the different parameters of the antenna have been given in tabular form with both measured and simulated results. The merit of the antenna is that it is a simple, low-profile circular disk antenna with dual ISM band applications. There is no major complex technique used in the design which adds unnecessary complexity. Hence, the proposed antenna is very much suitable as per the requirement of the advanced communication technology for low profile, low cost, and usable for more than one application band.

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