Design and Performance Analysis of Circular Microstrip Patch Antenna with Slot Modification for Dual-Band Operation

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***Abstract*—This paper demonstrates the construction of a circular microstrip patch antenna featuring a slot modification capable of operating at both 10 GHz and 20 GHz. We used electromagnetic simulation software to look at different antenna shapes, such as a simple circular patch, a single-port slot-loaded patch, and modified structures with two ports. This antenna has a better return loss, radiation efficiency, and directivity than the standard circular patch antenna. The electric field distribution and far-field radiation patterns show that the radiation properties stay the same at both frequencies. The proposed design works well for wireless communication in the microwave and high-frequency ranges.**

***Keywords:* Microstrip antenna, circular patch antenna, dual-frequency operation, slot modification, electromagnetic analysis, radiation pattern, microwave band, high-frequency wireless communication.**

I. Introduction

The microstrip patch antennas are broadly used for modern wireless communication systems due to their low profile, compactness, light weight, and ease of fabrication. Among the various shapes of microstrip patch antennas, the circular microstrip antennas are preferred for their symmetrical configuration and steady performance.

However, the conventional circular microstrip antennas are limited by their bandwidth and multiband performance. To improve the bandwidth and multiband performance, slot loading is introduced to the microstrip antennas for improve the current distribution and impedance matching.

Here a circular microstrip patch antenna with slot loading is proposed for its performance analysis at 10 GHz and 20 GHz frequencies. The performance analysis of the antenna is carried out by considering the return loss, electric field distribution, and far-field radiation patterns.

II. Antenna Design

This antenna has been designed by employing a circular microstrip patch antenna with slot modifications, aiming at enhancing the antenna's performance characteristics. The proposed antenna has been realized by employing an FR-4 substrate material, with a relative permittivity value (εr) of 4.4, a substrate thickness of 1 mm, and a total size of 25 mm x 25 mm, allowing enough space for the antenna's radiating structure, thereby maintaining a compact antenna size for modern wireless communication systems.

The radiating element is a circular copper patch printed over the top surface of the substrate, whereas the ground plane is placed over the opposite surface of the substrate. The radius of the circular patch is taken as 6.96 mm, which is optimized to attain resonance at the desired operating frequencies. The patch is excited by a microstrip line feeding technique, where the feed line is directly connected to the radiating element, i.e., the circular patch. The length of the feed line is taken as 5.54 mm, whereas the width is taken as 1mm.

In addition by improving performance of the antenna and its resonant characteristics, a rectangular slot is introduced within the circular patch. The slot has a length of 5.6 mm and a width of 1 mm.The slot also affects the distribution of the surface currents on the patch. The slot increases the effective electrical path, which improves impedance matching and introduces additional resonant modes. The values of the geometrical parameters of this antenna structure, including the substrate, patch radius, and slot size, are given in the antenna design specification table. The design is simple and compact, with good efficiency in terms of radiation characteristics.

III. DESIGN EVOLUTION

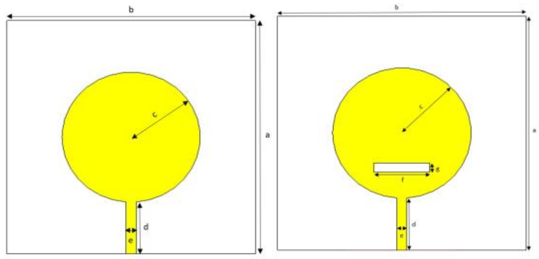
In figure 1, the proposed antenna design has been developed following three successive stages to optimize impedance matching.

In the first step, a basic circular microstrip patch antenna with a single feed line has been designed, where the circular microstrip patch antenna's radius (c) affects the fundamental resonant frequency, and the feed line's dimensions (d) and (e) affect the impedance matching.

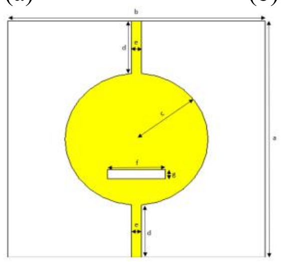
In the second step, a rectangular slot with dimensions (f) and (g) has been introduced to the circular microstrip patch antenna to optimize the surface currents to obtain additional resonant modes.

In the third step, an additional feed line has been introduced to the opposite side of the antenna, which results in a dual-fed slot-loaded microstrip patch antenna. The additional feed line improves the efficiency of the antenna at higher frequencies.

The final design has been optimized to improve the return loss compared to the previous designs.



(a) (b)



(c)

Figure 1: (a) Geometry of the antenna with one port and no slot, (b) Geometry of the projected antenna with one port and one slot, (c) Geometry of antenna with one slot and two ports

Table 1: Antenna Specifications

Antenna Design Specifications	Value (mm)
Substrate length (a)	25
Substrate width (b)	25
Main circular patch radius (c)	6.96
Feed length (d)	5.54
Feed width (e)	1
slot length (f)	5.6
slot width (g)	1

IV. RESULT AND DISCUSSION

The performance of this circular microstrip patch antenna with slot modification is simulated using electromagnetic simulation techniques. The performance of the antenna is investigated in terms of return loss, surface current distribution, and radiation patterns. The simulated results have shown the improvement in the performance of the antenna after the introduction of the slot and the additional feed configuration.

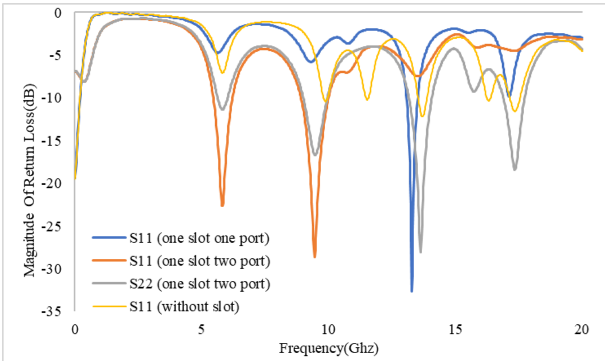


Figure 2: Combined S11 and S22 of all the three antennas

Figure 2 indicates the combined S11 and S22 parameters of the three different antenna configurations, which include the basic circular patch antenna without a slot, the circular patch antenna with a rectangular slot, and the slot-loaded circular patch antenna with two ports. The return loss curve shows the performance of the antenna at various stages of design.

For the first configuration, which is the simple circular patch antenna, it is clear that the antenna has only a single resonance feature with average impedance matching. From the return loss curve, it is clear that the return loss values are consistently close to -10dB.

In the second configuration, when the rectangular slot is inserted inside the circular patch antenna, it is clear that the return loss has been improved when compared with the basic configuration of the antenna. The insertion of the rectangular slot has interrupted the current, thus increasing the length of the antenna. This results in the generation of more resonance modes, thus a deeper return loss value.

In the final configuration, where two ports are introduced in a slot-loaded circular patch antenna, further improvement is

seen in the impedance matching characteristics of the antenna. The S11 and S22 curves in figure 2 shows stronger resonances as the return loss is seen to be less than -20 dB for the operating frequency range.
The presence of multiple resonances is an indication of a dual-frequency operation of the antenna and its suitability for microwave communication.

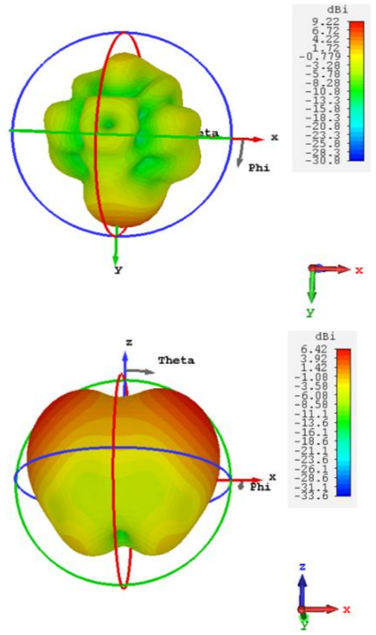


Figure 3: 3D radiation pattern of the antenna with no slot

Figure 3 indicates a circular patch antenna without a slot, its radiation pattern follows a typical broadside radiation pattern, in which maximum radiation is experienced along a direction perpendicular to the plane. The radiation pattern is almost symmetric due to the circular shape of the patch.

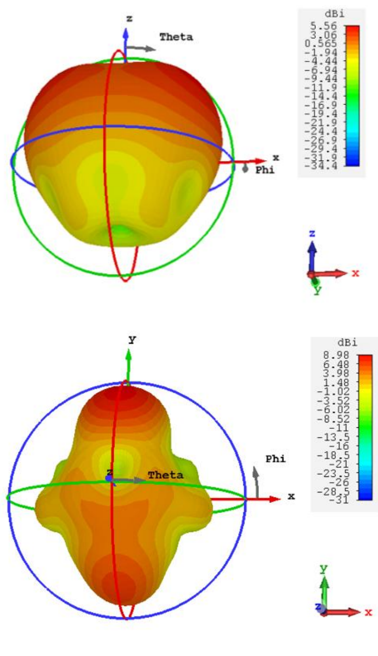


Figure 4: 3D radiation pattern of the antenna with slot.

In figure 4, once the slot is placed within the circular patch, the radiation pattern is seen to be stable while minor changes in the radiation intensity are noted. This is because the slot changes the current distribution on the patch without affecting the radiation pattern, thereby indicating a stable radiation characteristics.

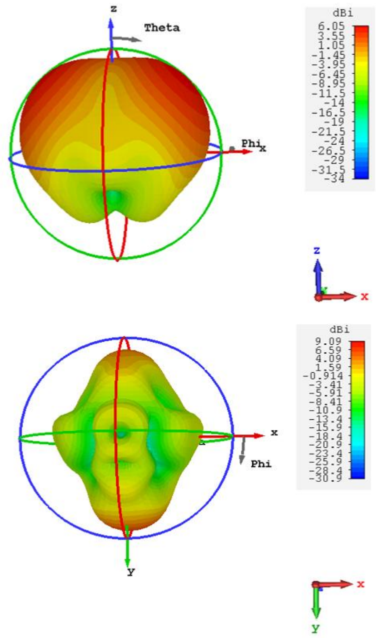


Figure 5: 3D radiation pattern of the antenna with slot and two ports.

In figure 5, the last slot-loaded dual-port structure, the 3D radiation pattern demonstrates improved radiation strength and directivity over the previous structures. The radiation is still broadside, and the symmetry of the structure, being a circular patch, helps maintain the radiation in the desired direction.
This demonstrates that the proposed antenna structure has improved radiation performance while still being capable of dual-band operation.

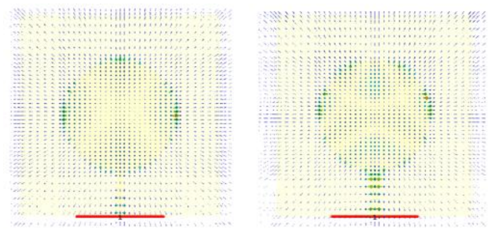


Figure 6: Surface current distribution of the antenna with no slot.

Figure 6 indicates a basic circular patch antenna, the current is mainly concentrated along the edges of the circular patch and the feed line. The current is distributed in a symmetrical pattern along the edges of the patch, and this gives the fundamental resonant mode of this patch antenna.

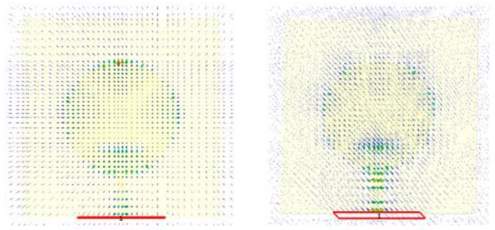


Figure 7: Surface current distribution of the antenna with one slot.

However, as the rectangular slot is introduced in figure 7, the structure, the distribution of the surface currents has changed considerably. The presence of stronger currents near the edges of the slot reveals that the slot has interrupted the normal flow of the currents and has made the currents take a longer path around the slot boundaries. This has increased the length of the antenna and has produced more resonant modes.

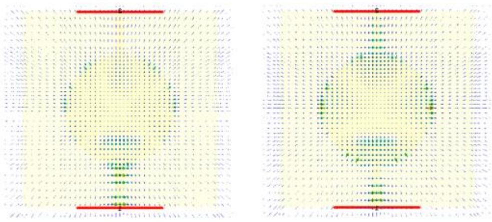


Figure 8: Surface current distribution of the antenna with one slot and two ports.

In figure 8, the dual-port slot-loaded configuration, the current distribution becomes more uniform and intense around the feed lines and the slot region. The additional feed line enables a more efficient distribution of current across the radiating patch, thereby increasing the efficiency of the antenna and its performance at higher frequency levels.

V. CONCLUSION

The design of a circular microstrip patch antenna with slot modification for dual-band operation has been discussed. The performance analysis of the antenna has been discussed. The antenna has been designed using FR-4 material. The size of the antenna is compact, i.e., 25 mm x 25 mm. The antenna is suitable for various microwave communications. The antenna has been designed with a circular microstrip patch of radius 6.96 mm. The microstrip feed is used to feed the antenna. The rectangular slot is used to improve the electrical length of the patch.

The proposed antenna design has been created through three stages: a traditional circular patch antenna, a slot-loaded circular patch antenna, and a dual port slot-loaded antenna. Simulation results have proven the importance of the introduction of the slot in the antenna, which improves impedance matching and creates additional resonance modes. The proposed final configuration with two ports has improved the performance of the antenna, reaching deeper levels of return loss.

The analysis of the surface current distribution has proven the importance of the slot in changing the current path, thus creating additional resonance modes. The 3D radiation pattern has proven the stability of the broadside radiation pattern with improved directivity. In general, the proposed antenna has a simple, compact, and efficient configuration with improved performance in terms of return loss and radiation characteristics, thus suitable for microwave and high-frequency wireless applications.

REFERENCES

[1] Q.-S. Wu, X. Zhang, L. Zhu, J. Wang, G. Zhang, and C.-B. Guo, “A single-layer dual-band dual-sense circularly polarized patch antenna array with small frequency ratio,” IEEE Trans. Antennas Propag., vol. 70, no. 4,pp. 2668–2675, Apr. 2022.

[2] C.-M. Su and K.-L.Wong, “A dual-band GPS microstrip antenna,” Microw. Opt. Techn. Lett., vol. 33, no. 4, pp. 238–240, May. 2002.

[3] H. Yang, Y. Fan, and X. Liu, “A compact dual-band stacked patch antenna with dual circular polarizations for BeiDou navigation satellite systems,” IEEE Antennas Wireless Propag. Lett., vol. 18, no. 7, pp. 1472–1476, Jul. 2019.

[4] C. Deng, Y. Li, Z. Zhang, G. Pan, and Z. Feng, “Dual-band circularly polarized rotated patch antenna with a parasitic circular patch loading,” IEEE Antennas Wireless Propag. Lett., vol. 12, pp. 492–495, 2013.

[5] J.-D. Zhang, W. Wu, and D.-G. Fang, “Dual-band and dual-circularly polarized shared-aperture array antennas with single-layer substrate,” IEEE Trans. Antennas Propag., vol. 64, no. 1, pp. 109–116, Jan. 2016.

[6] K.-F. Tong and T.-P. Wong, “Circularly polarized u-slot antenna,” IEEE Trans. Antennas Propag., vol. 55, no. 8, pp. 2382–2385, Aug. 2007.

[7] J. Ghalibafan, A. Attari, and F. Hojjat-Kashani, “A new dual-band microstrip antenna with U-shaped slot,” Prog. Electromagn. Res. C, vol. 12, pp. 215–223, 2010.

[8] T. Huynh and K.-F. Lee, “Single-layer single-patch wideband microstripantenna,” Electron. Lett., vol. 31, no. 16, pp. 1310–1312, Aug. 1995.

[9] K.-P. Yang and K.-L. Wong, “Dual-band circularly-polarized square microstrip antenna,” IEEE Trans. Antennas Propag., vol. 49, no. 3, pp. 377–382, Mar. 2001.

[10] Z.-X. Liang, D.-C. Yang, X.-C. Wei, and E.-P. Li, “Dual-band dual circularly polarized microstrip antenna with two eccentric rings and an arcshaped conducting strip,” IEEE Antennas Wireless Propag. Lett., vol. 15, pp. 834–837, 2016.

[11] K. Chen, J. Yuan, and X. Y. Luo, “Compact dual-band dual circularly polarised annular-ring patch antenna for BeiDou navigation satellite system application,” Microw., Antennas Propag., vol. 11, no. 8, pp. 1079–1085, Jul. 2017.

[12] Y. Li, B. N. Tian, J. G. Xue, and G. D. Ge, “Compact dual-band circularly polarized antenna design for navigation terminals,” IEEE Antennas Wireless Propag. Lett., vol. 15, pp. 802–805, 2016.

[13] Y. F. Lin, C. H. Lee, S. C. Pan, and H. M. Chen, “Proximity-fed circularly polarized slotted patch antenna for RFID handheld reader,” IEEE Trans. Antennas Propag., vol. 61, no. 10, pp. 5283–5286, Oct. 2013.

[14] P. C. Sharma and K. C. Gupta, “Analysis and optimized design of single feed circularly polarized microstrip antenna,” IEEE Trans. Antennas Propag., vol. 31, no. 6, pp. 949–955, Nov. 1983.

[15] X. L. Bao and M. J. Ammann, “Dual-frequency dual-sense circularly polarized slot antenna fed by microstrip line,” IEEE Trans. Antennas Propag., vol. 56, no. 3, pp. 645–649, Mar. 2008.

[16] Nasimuddin, Z. N. Chen, and X. M. Qing, “Dual-band circularly polarized S-shaped slotted patch antenna with a small frequency-ratio,” IEEE Trans. Antennas Propag., vol. 58, no. 6, pp. 2112–2115, Jun. 2010.

[17] S. L. Steven Yang, A. A. Kishk, and K. F. Lee, “Wideband circularly polarized antenna with L-shaped slot,” IEEE Trans. Antennas Propag., vol. 56, no. 6, pp. 1780–1783, Jun. 2008.

[18] J. S. Row, “Dual-frequency circularly polarised annular-ring microstrip antenna,” Electron. Lett., vol. 40, no. 3, pp. 153–154, 2004.

[19] Y. J. Sung and Y. S. Kim, “Circular polarised microstrip patch antennas for broadband and dual-band operation,” Electron. Lett., vol. 40, no. 9, pp. 520–522, 2004.