

Microstrip-Line-Fed Capacitively Coupled-Patch Antenna for Wireless Application

Mandar P. Joshi^{1*}, Vitthal J. Gond², Jayant G. Joshi³

Abstract

To increase the impedance bandwidth for wireless local area network (WLAN) applications, a unique design of a microstrip-line-fed, capacitively coupled, corner-truncated microstrip-patch antenna is put forth, examined, and optimized in this research. The low profile, light weight, ease of manufacture, and compatibility with printed circuit technologies of microstrip-patch antennas are well known. Conventional-patch antennas' intrinsically small impedance bandwidth, however, is a significant disadvantage that reduces their usefulness in broadband wireless communication systems. The current work presents a methodical design strategy that combines sophisticated feeding strategies with structural alterations to overcome this limitation. An equivalent circuit model that highlights the underlying resonance characteristics is created, examined, and presented to obtain a fuller understanding of the behavior of the suggested antenna. The antenna achieves a consistent radiation performance and a significantly broad impedance bandwidth of around 6.27%, according to simulation and analysis. Additionally, the antenna has a 5.66 dBi peak gain, which makes it a viable option for dependable WLAN applications where gain, bandwidth, and compactness are crucial factors. To verify the underlying resonance behavior, an equivalent circuit model of the suggested structure is created and examined. The antenna achieves a peak gain of 5.66 dBi and a broad impedance bandwidth of roughly 6.27% with steady performance, according to simulation data. These findings are in good agreement with those of other small broadband microstrip antennas that have been documented in the literature. Therefore, by increasing bandwidth while maintaining simplicity and compactness, the suggested design provides a well-rounded solution that is ideal for WLAN systems and flexible enough to accommodate additional wireless applications that demand fast and effective operation. Because of these features, it is ideally suited for WLAN applications where compact antenna integration, fast data rates, and dependable coverage are essential. Crucially, the outcomes are in line with and sometimes better than similar broadband antenna designs documented in the literature, which frequently depend on more intricate geometries, multilayer substrates, or extra parasitic components.

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INTRODUCTION

In modern communication systems, the antennas are placed close to or integrated with radio frequency (RF) circuitry. In such systems, microstrip antennas are more feasible, since it can be directly interfaced with active and passive components of RF circuits. Large bandwidth is essential to fulfill the requirement of higher data rates. This higher data rate requirement can be accomplished by using wideband antennas in modern communication systems. However, despite many attractive features of microstrip antennas, it

suffers from a major drawback of narrow bandwidth [1]. The thickness of the substrate directly correlates with the microstrip antenna's bandwidth. Therefore, to enhance the bandwidth of microstrip antennas, thicker substrates are used. However, for some compact applications, substrate thickness matters the compactness and overall design of antenna structure. In literature, researchers have reported broadband microstrip antennas by using a thicker substrate or using a thicker substrate with a lower dielectric constant [2–9]. A Ψ -shaped microstrip antenna has been reported for broadband application using dual substrate methodology.

This research work used duroid and foam substrate to enhance the overall thickness and to lower the effective dielectric constant of the antenna [2]. The fundamental mode of resonance has been merged with higher-order orthogonal modes of the microstrip antenna to realize the broadband response. The proximity fed slotted square ring-shaped antennas are capacitively coupled to enhance the bandwidth of the microstrip antenna [3]. In Kasabegouder and Vinoy (2010) [4], a coplanar capacitive-fed microstrip antenna that is suspended above the ground plane is designed and analyzed. It is shown that the suggested method may be used to construct antennas with a good gain and an impedance bandwidth (IBW) of roughly 50% to function in a variety of microwave bands. The antenna model includes a capacitive feed strip that is fed by a coaxial probe. In Kovitz and Rahmat-Samii (2014) [5], the authors presented the direct result of the probe reactance hindering the use of thicker substrates to increase the bandwidth. Additionally, it offers a brand-new compensation method to increase the circularly polarized (CP)-patch antennas' bandwidth capacity. Our approach eliminates the influence of probe inductance by connecting a capacitive element like an annular gap or parallel plate in series with it. For a global navigation satellite system, a broadband CP microstrip antenna with a broad beamwidth and low profile is suggested.

To increase half-power beamwidth (HPBW) and IBW at the same time, four parasitic branches in the shape of claws are positioned on the ground's corners [6]. A wideband multiple-microstrip dipole antenna with dual polarization has been reported [7]. The antenna is made up of a reflector, two microstrip baluns, a radiator, and a cross-shaped slot coupler. The cross-shaped slot coupler would produce four differential signals at four ends of the slot lines and function as a four-way equal-split power divider when baluns are stimulated [8]. Introduces a single-layer microstrip-fed-patch antenna that may be used for both bandwidth increase and harmonic reduction.

This is accomplished by coupling two $\lambda/4$ microstrip-line resonators close to a rectangular patch. By effectively utilizing the two resonances created by the radiating patch and non-radiating $\lambda/4$ resonators, the wideband property can be achieved. In Rathod et al. (2017) [9], an indirect microstrip-line-fed gap coupled half-hexagonal microstrip antenna (H-HMSA) in a compact design has been developed. To increase bandwidth, a method that combines a radiating half-hexagonal patch and a single shorting post with a pair of $\lambda/4$ resonators is employed.

In this research work, a corner-truncated square microstrip-patch antenna initially fed by a probe has been studied. Further, for bandwidth enhancement microstrip-line-fed, shorting pin-loaded capacitively coupled $\lambda/4$ resonator is used. The equivalent circuit model of the proposed design is analyzed and presented. The antenna provides a broad bandwidth of about 6.27% with a peak gain of 5.66 dBi.

ANTENNA GEOMETRY DESIGN

The geometry of the projected antenna structure is depicted in Figure 1(a) and (b). At the initial stage, a square-shaped patch is designed to resonate at 6 GHz. The calculated length of the square microstrip antenna using equation (1) is $L = 17$ mm. The antenna is fed using coaxial feed at $xf = 3.5$ mm. The SMA connector of 1.2 mm inner wire diameter is used to simulate this antenna. RT Duroid having $h = 1.57$ and $\epsilon_r = 2.2$ is used to design and simulate this antenna structure.

To realize circular polarization (CP), the diagonally opposite corners of a square shape have been truncated to degenerate the fundamental mode into two orthogonal modes. The realized bandwidth is

of about 6.27% (5.56–5.92 GHz). The realized axial ratio bandwidth is about 1.41% (5.62–5.70 GHz) with a peak gain of 7 dBi.

To improve the bandwidth of the antenna, a capacitively coupled microstrip-line-feed is used with a suitable gap “g”. However, it was observed that this feed changed the impedance of the proposed CP MSA. To match the input impedance of antenna, a shorting pin having radius “r” is used at the center of dipole. This divides entire dipole into an equivalent $\lambda/4$ resonator. This resonator with capacitive effect resonates at near mode resonance frequency of corner-truncated square microstrip antenna, which in turn merges with the fundamental mode, realizing a broadband response.

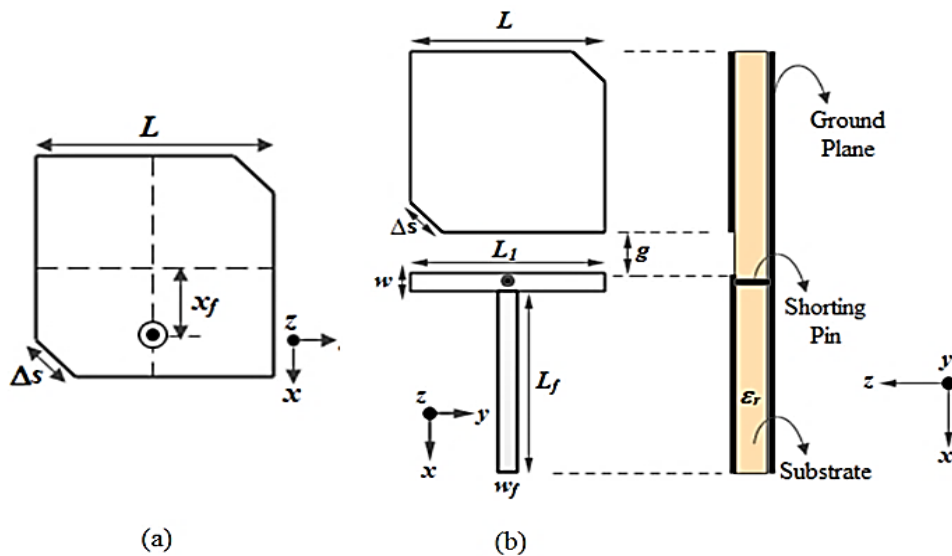


Figure 1. Geometry of antenna (a) probe-fed and (b) microstrip-line-fed.

RESULTS AND DISCUSSION

The impedance characteristics of the projected antenna design is presented in Figure 2 with and without a shorting pin.

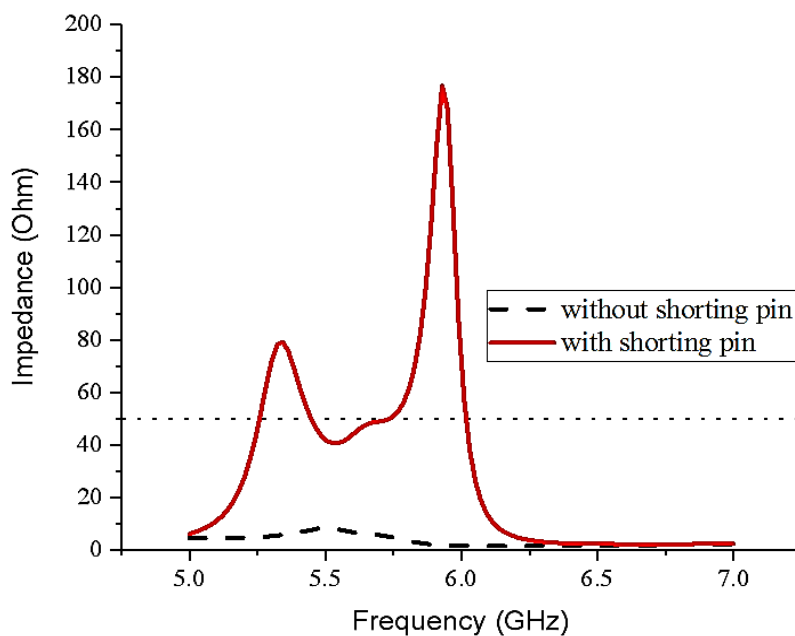


Figure 2. Impedance characteristics with and without shorting pin.

Figure 3 presents the return loss characteristics of a microstrip-patch antenna with probe fed and with capacitive coupling. Using capacitive coupling, a broadband response has been realized. The obtained IBW ($S_{11} < -10$ dB) is 11.55% (5.22–5.86 GHz) covering Wi-MAX (5.25–5.85 GHz), WLAN (5.725–5.825 GHz), and HyperLAN (5.47–5.725).

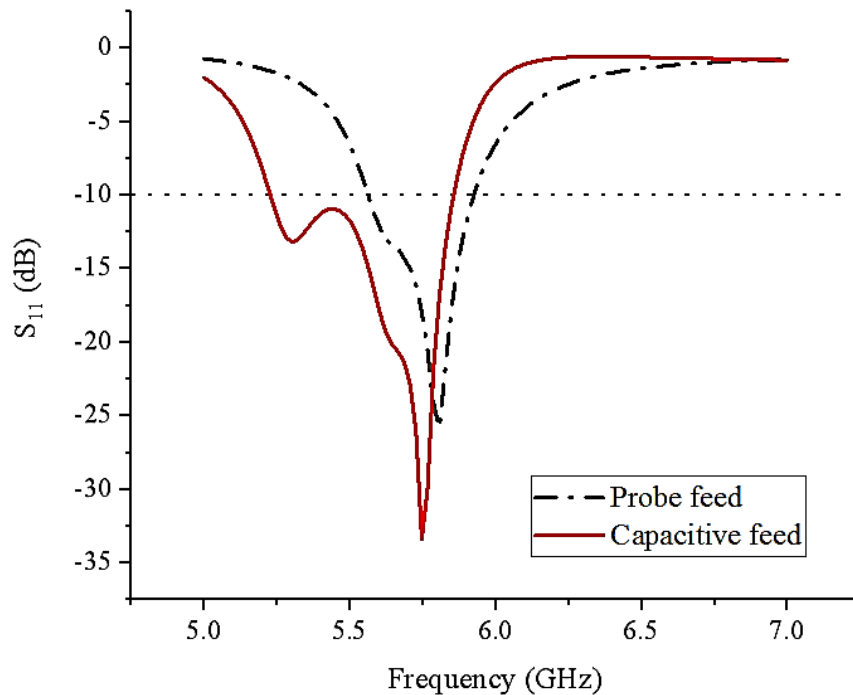


Figure 3. Return loss characteristics of probe feed and capacitive feed.

The proposed design of the antenna exhibits an axial ratio bandwidth of 1.24% (5.58–5.65 GHz) with the highest gain of 6.58 dBi. The gain characteristics are stable and flat over the entire range of axial ratio bandwidth as depicted in Figure 4.

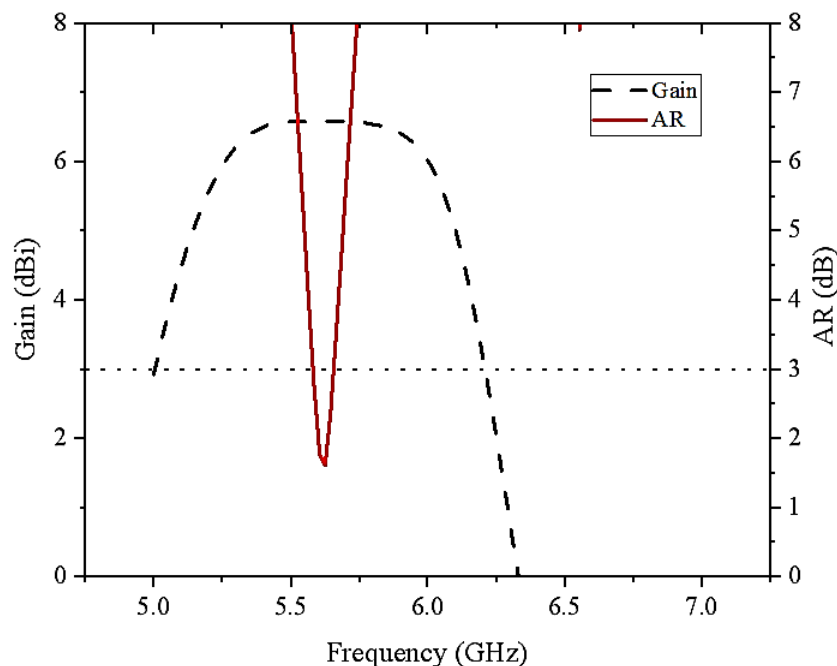


Figure 4. Gain vs axial ratio characteristics.

In both the E- and H-planes, broadside radiation characteristics are found. The antenna exhibits right-hand circular polarized (RHCP) characteristics in both planes with a gain of 6.5 dBi. Figure 5(a) and (b) represents the radiation characteristics of the proposed antenna.

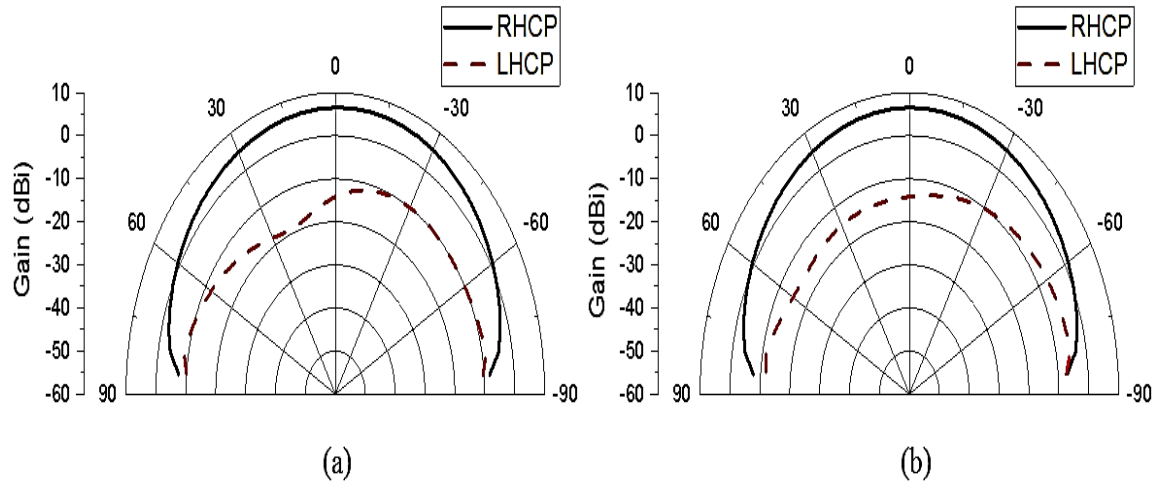


Figure 5. Radiation pattern (a) E-plane and (b) H-plane.

The radiation characteristics of RHCP have been verified by studying the surface current circulation of the proposed antenna. The observed surface current in Figure 6(a–d) is rotating in an anticlockwise direction. Therefore, the antenna exhibits RHCP radiation characteristics.

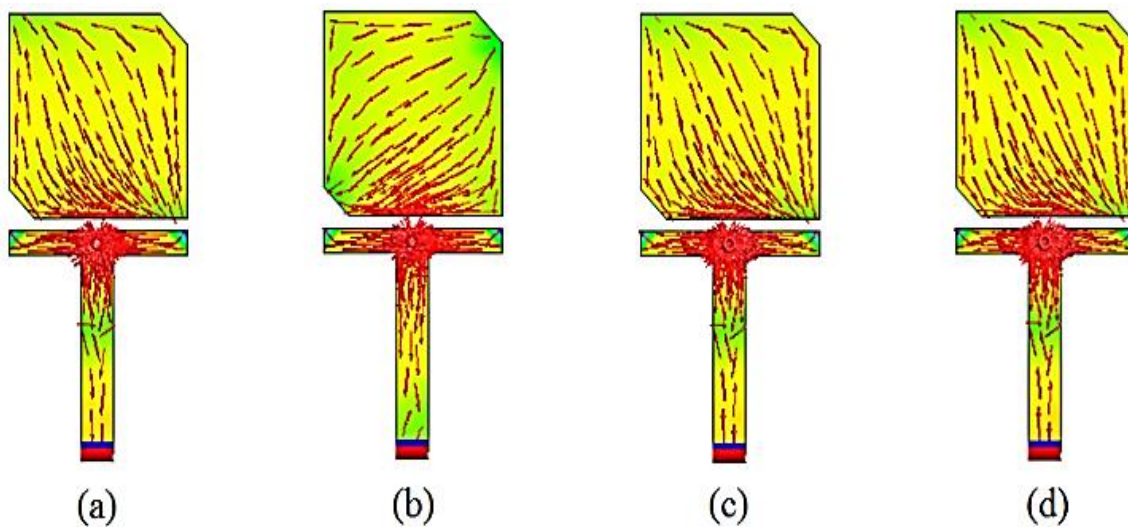


Figure 6. Surface current at (a) 0°, (b) 90°, (c) 180°, and (d) 270°.

Parametric Analysis

The effect of the gap between the corner-truncated microstrip-patch antenna and the $\lambda/4$ resonator has been investigated using parametric analysis. The parametric analysis has been carried out by varying the antenna geometry parameters such as length (L1), width w, the gap “g,” and the radius of the shorting pin. While varying the said parameters, other parameters of antenna geometry have been kept constant.

Figure 7 depicts variation of gap “g” between the corner truncated patch and the microstrip-line-fed $\lambda/4$ resonator. It is observed that, for $g = 1$ mm, optimum bandwidth of 11.55% (5.22–5.86 GHz) has been obtained.

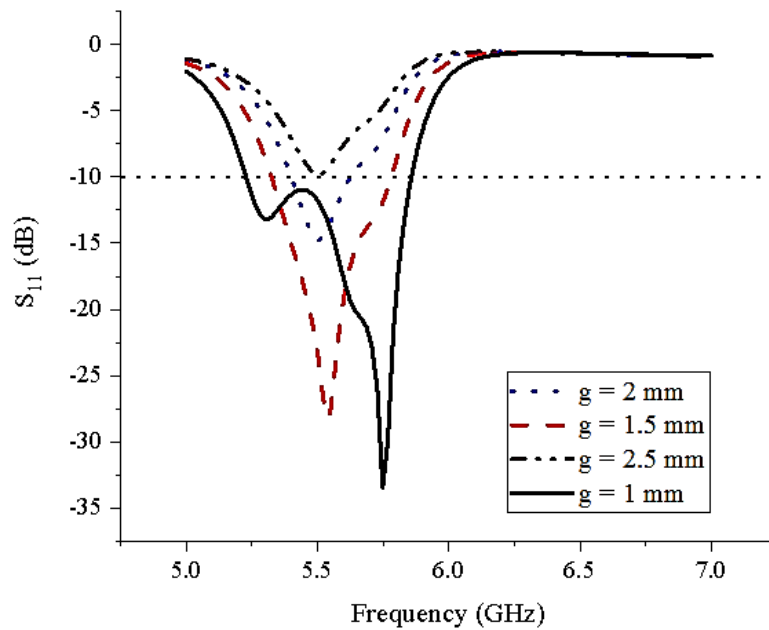


Figure 7. Result of variation of gap “g”.

The parametric analysis for the variation of $\lambda/4$ resonator length has been studied. The length L_1 is calculated for a frequency of nearly 5.2 GHz. However, it is observed that optimum bandwidth and impedance matching of the antenna has been realized for length $L_1 = 17$ mm as presented in Figure 7. The effect of variation of $\lambda/4$ resonator width is also studied and presented in Figure 8. It is important to study the effect of width of resonator as it directly affects the gap between resonator and patch.

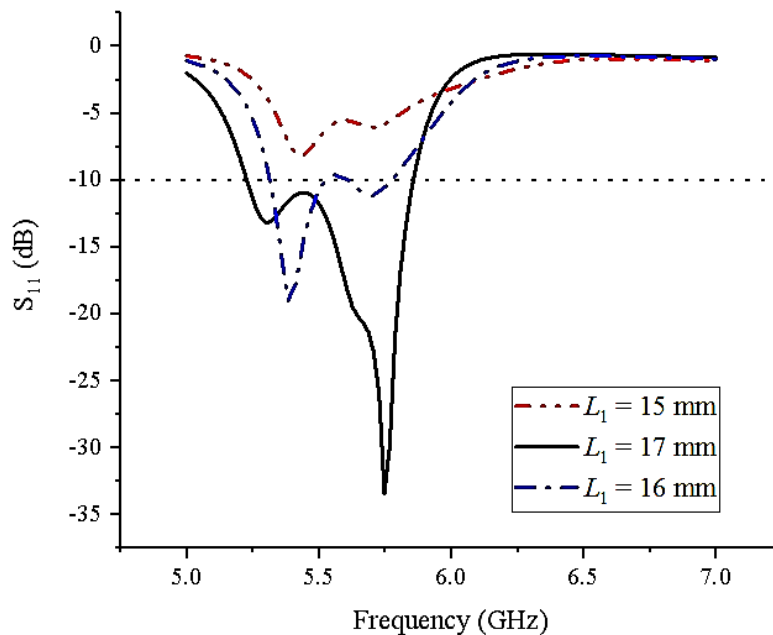


Figure 8. Result of variation of length L_1 .

It is observed that variation of the width w of the resonator changes the gap between the resonator and the patch. For $w = 2.5$ mm, the gap is very minimum, and antenna realized a very narrow IBW. However, for a maximum gap of $w = 1.5$ mm, the resonance frequency shifts to the lower side of the frequency. Therefore, an optimum value of $w = 2$ mm, maximum IBW has been realized as shown in Figure 9.

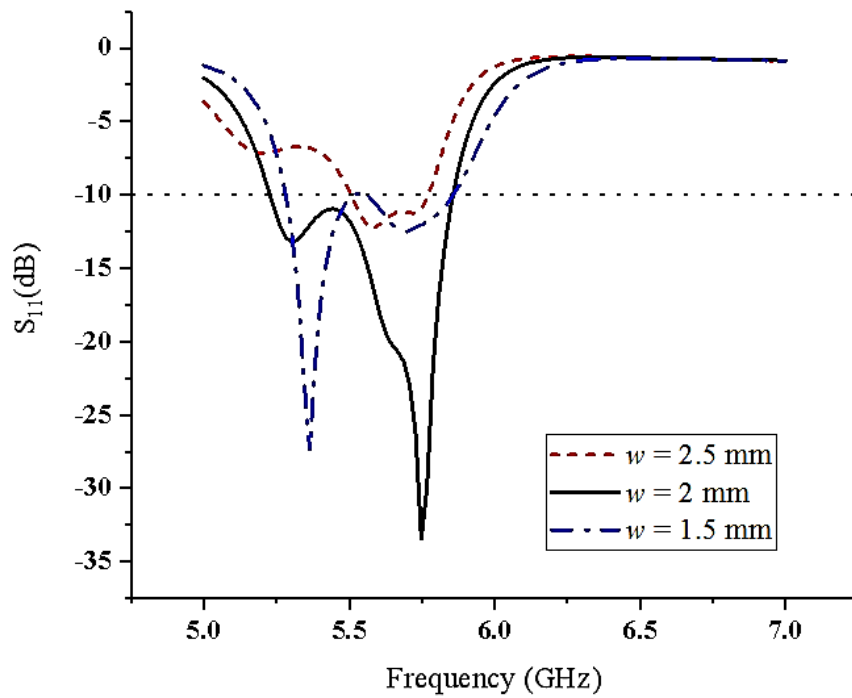


Figure 9. Result of variation of width w .

The shorting pin, used for impedance matching having radius “ r ” is also varied to study its effect. It is observed that, for $r = 0.4$ mm, the narrow bandwidth has been realized. For $r = 0.6$ mm, antenna exhibits dual band response. Maximum IBW has been realized as $r = 0.5$ mm as presented in Figure 10.

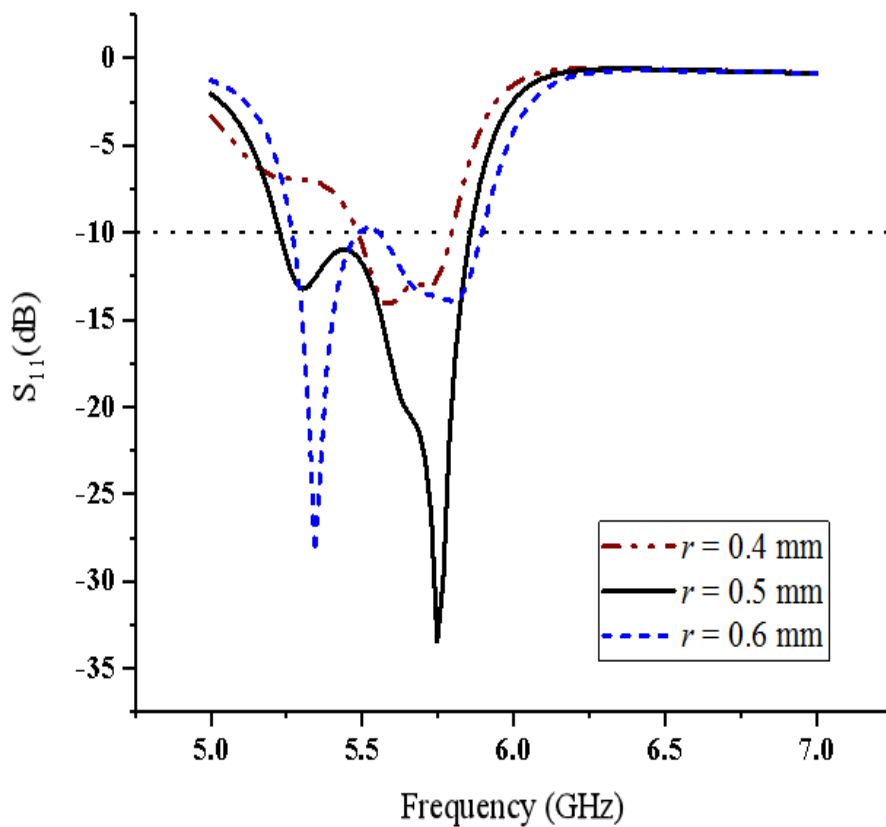


Figure 10. Result of variation of “ r ”.

Equivalent Circuit

Figure 11 depicts the equivalent circuit of the proposed antenna structure. The equivalent circuit analysis of proposed antenna has been carried out to understand the radiation phenomenon. Here, the microstrip line is used to feed $\lambda/4$ resonator. This resonator is parasitically or capacitively coupled with corner-truncated CP microstrip antenna. In the presented antenna geometry, the microstrip line can be represented by two series inductors and shunt capacitors [1]. The shorting pin can be represented by a shunt inductor [8–10]. Due to the shorting pin, the resonator is divided into two monopoles, which are represented by inductance L_1 and capacitance C_1 . This feed geometry is capacitively coupled with corner truncated patch. Therefore, there exists a gap capacitance called c_g and two edge capacitances, namely c_{g1} and c_{g2} . Further, the corner truncated patch can be represented by using parallel R_2 , L_2 , and C_2 circuit.

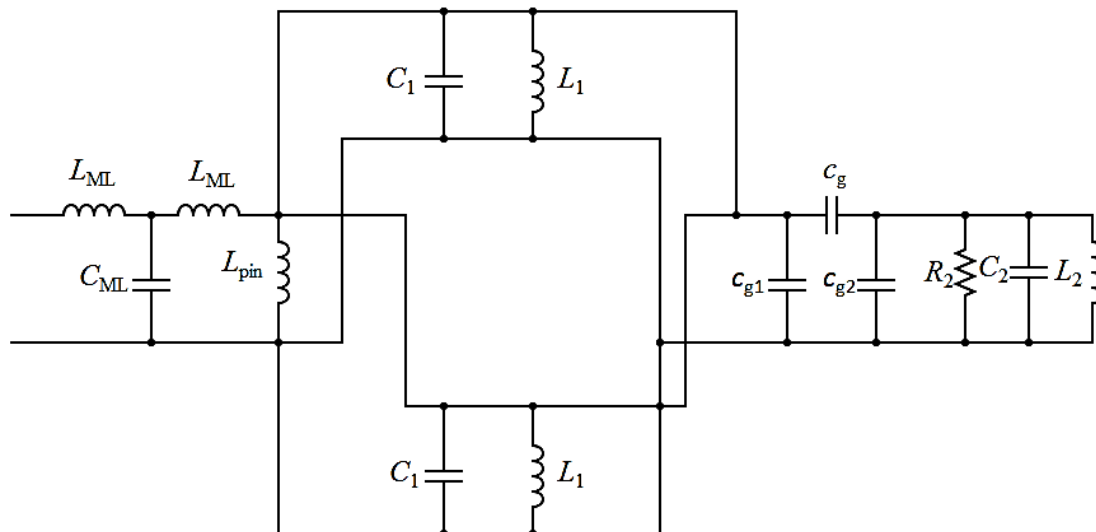


Figure 11. Equivalent circuit model.

Arbw–Axial Ratio Bandwidth

The obtained simulated results are parallel with previously reported simulation results and are presented in Table 1.

Table 1. Comparison with previous results.

| Ref | Imp. BW % | Gain (dBi) | ϵ_r | h (mm) | ARBW % |
|----------|-----------|------------|--------------|----------|--------|
| [7] | 48 | 8.9 | 4.4 | 25 | – |
| [9] | 8 | 6 | 2.5 | 1.6 | – |
| [8] | 8.4 | 7.6 | 2.33 | 1.57 | – |
| Proposed | 11.55 | 6.6 | 2.2 | 1.57 | 1.24 |

CONCLUSION

In the proposed research work, a corner-truncated microstrip antenna is fed using quarter-wavelength microstrip line using capacitive coupling. The antenna offers an improved IBW of 11.55% with 1.24% of axial ratio bandwidth. The observed radiation characteristics are in the broadside direction with a maximum gain of 6.6 dBi. The shorting pin technique has been implemented to realize the dipole for gap coupling, which helps to improve the bandwidth of the antenna. The proposed design of the antenna is appropriate for various wireless applications.

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