

A Novel CSRR Loaded Compact ACS Fed Monopole Antenna for Sub-6 GHz 5G Applications

Mekala Ananda Reddy, Albert Ruth Jency*,
Sharma Shabdita, and Ramasamy Pandeewari

Abstract—The design of a Complementary Split Ring Resonator (CSRR) embedded compact Asymmetric Coplanar Strip (ACS) fed monopole antenna is presented in this paper. By incorporating the ACS feed, a substantial reduction of 27% in antenna dimensions is achieved. Further miniaturization of 68.6% is obtained by embedding CSRR on the designed patch and a trapezoidal ground. The overall size of the antenna is $13.2 \times 27 \times 1.6 \text{ mm}^3$, and it is printed on an FR4-epoxy substrate. The antenna operates with a resonant frequency of 3.6 GHz and a bandwidth of 3.3 GHz (3.2–6.5 GHz). Thus it is appropriate for sub-6 GHz 5G applications. It exhibits a return loss of -28 dB and a gain of 2.8 dB at the resonant frequency. The antenna is fabricated, and the measured results match well with the simulated ones. Being a simple, cheap, and uniplanar structure, the proposed antenna can meet the requirements of a modern wireless communication system.

1. INTRODUCTION

With the rapid evolution of wireless communication technologies, there is always a growing demand for the miniaturization of various portable terminals. This brings a lot of attention from the researchers towards designing compact and low-profile antennas without compromising the gain and bandwidth. A vast number of techniques have been reported in the literature for realizing such structures. In the last decade, there is an emerging trend of using metamaterials in the planar antennas and other RF components. Metamaterials are the artificially engineered structures manifesting negative permittivity and permeability. Having these unusual properties, metamaterials not only enhance the performance of conventional antenna structures, but also lead to an extreme level of miniaturization.

Various metamaterial (MTM) inspired structures and the improvements in their performance have been studied in the literature. With slots etched on the patch and ground, MTM loaded antenna has additional resonances resulting in multiband operation and compactness [1]. A highly miniaturized version of a patch antenna is achieved by using interdigital capacitor and modified slot ring resonator on the patch and the ground, respectively [2]. MTM based fractal structure is found to produce a significant level of size reduction [3]. A considerable gain improvement and size reduction is achieved by incorporating complementary split ring resonator (CSRR) on the ground plane and radiating patch [4, 5]. A fractal patch antenna with metamaterial superstrates is proved to have a better gain than conventional antenna structures [6]. All these techniques use radiating patches backed by the ground. Sometimes these techniques fail to meet the requirement of easiness in fabrication and integration with other structures.

Recently, coplanar waveguide (CPW) feed has become increasingly popular due to its multiple advantages like uniplanar structure, wide bandwidth, etc. CPW fed MTM based patch antennas exhibit

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* Corresponding author: Albert Ruth Jency (ruthjency123@gmail.com).

The authors are with the Department of Electronics and Communication Engineering, National Institute of Technology, Tiruchirappalli 620015, India.

very good performance with reduced size [7, 8]. Efforts have been taken to prove that the antenna dimensions can be further reduced by using ACS feed which is a modified version of conventional CPW feed [9–11]. This reduction in the size of antenna finds huge applications in 5G and multiple-input multiple-output (MIMO) [12].

In this paper, a novel CSRR inspired semicircular monopole antenna fed by an ACS with trapezoidal ground plane is proposed. The characteristics of ACS fed semicircular monopole antenna is modified with the inclusion of a CSRR structure. As CSRR makes vital contribution to the change in current distribution of antenna, it plays a key role in the crucial size miniaturization attained. A remarkable improvement is observed in the return loss along with good bandwidth and gain. The antenna is printed on a Flame Retardant 4 (FR4) substrate with dielectric constant 4.4, thickness 1.6 mm, and loss tangent 0.02. The proposed antenna also satisfies the condition of an electrically small antenna. The characteristics of the fabricated antenna are validated through measurements.

2. ANTENNA DESIGN AND GEOMETRY

The steps involved in the design of the proposed antenna are elaborated in Figure 1, and the simulated return loss at each level of evolution is shown in Figure 2(a). The design starts with a conventional circular monopole antenna of radius 7.7 mm fed by CPW. The resonant frequency of this antenna is 4.4 GHz covering the frequency band of 3.6 to 8.4 GHz with a return loss of -26 dB. In the second step, ACS feed is introduced by removing a half portion of the conventional structure. This cuts off the circular monopole into semicircular one and greatly reduces the volume of the antenna. As one of the ground planes is removed, the surface current is concentrated more on the feed line and the radiating monopole. The structure has a resonant frequency of 4.2 GHz and an operating band of 3.8–7.05 GHz achieving 27% size reduction. Next, the semicircular antenna is loaded with a CSRR structure. This again alters the current distribution on the antenna, and the electrical length traveled by the surface current increases. As a result, there exists another down-shift of the resonant frequency to 3 GHz, and the return loss S_{11} is improved to a value of -47 dB. This results in further miniaturization of 61%. Finally, the rectangular ground of ACS feed is modified into a trapezoidal ground. The new structure resonates at 2.8 GHz with a bandwidth of 4.7 GHz over the frequency range of 2.35 to 7.05 GHz, retaining the return loss of -47 dB. The overall miniaturization of the final design attained is 68.6%. Thus the proposed antenna offers commendable size reduction and good return loss. The geometry of CSRR embedded semicircular monopole antenna fed by ACS with trapezoidal ground is shown in Figure 2(b).

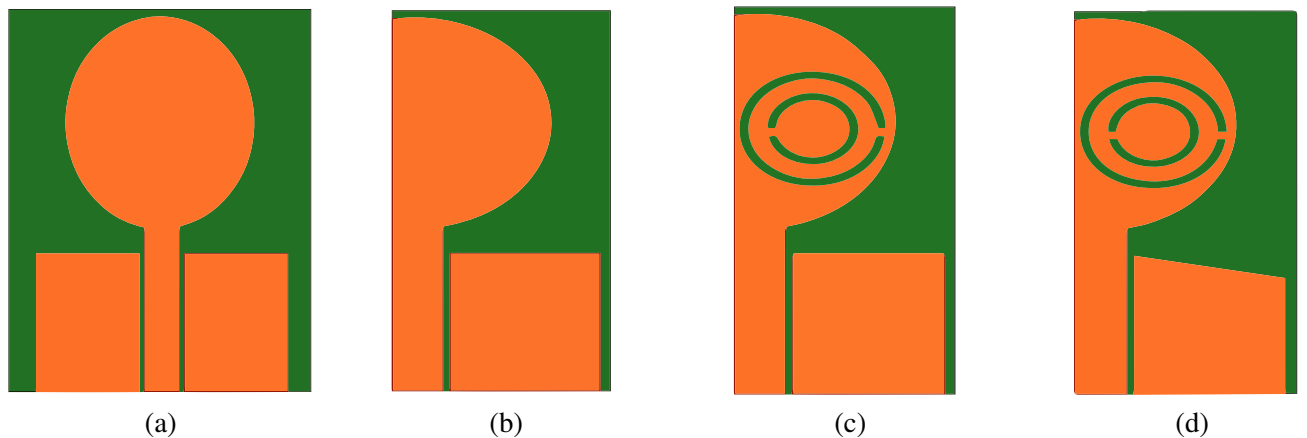


Figure 1. Steps in constructing the proposed antenna.

3. PARAMETRIC ANALYSIS

In any conventional antenna, CSRR introduces an LC resonating structure as depicted in the equivalent model shown in Figure 3(e). The L_{CSRR} and C_{CSRR} values of this structure are decided by the metallic

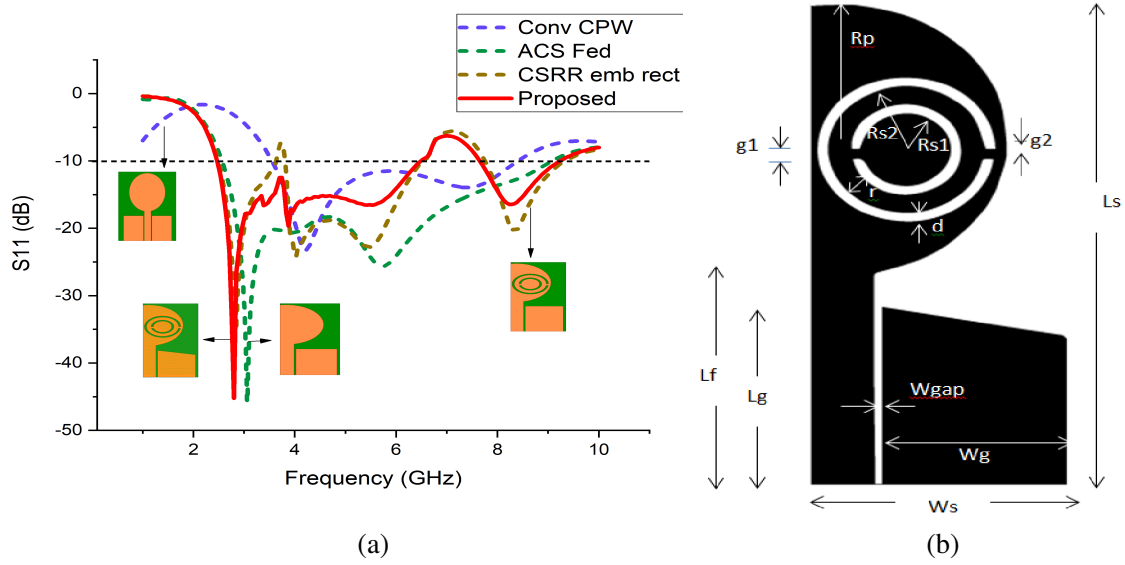


Figure 2. (a) S_{11} in each stage of construction. (b) Proposed antenna geometry.

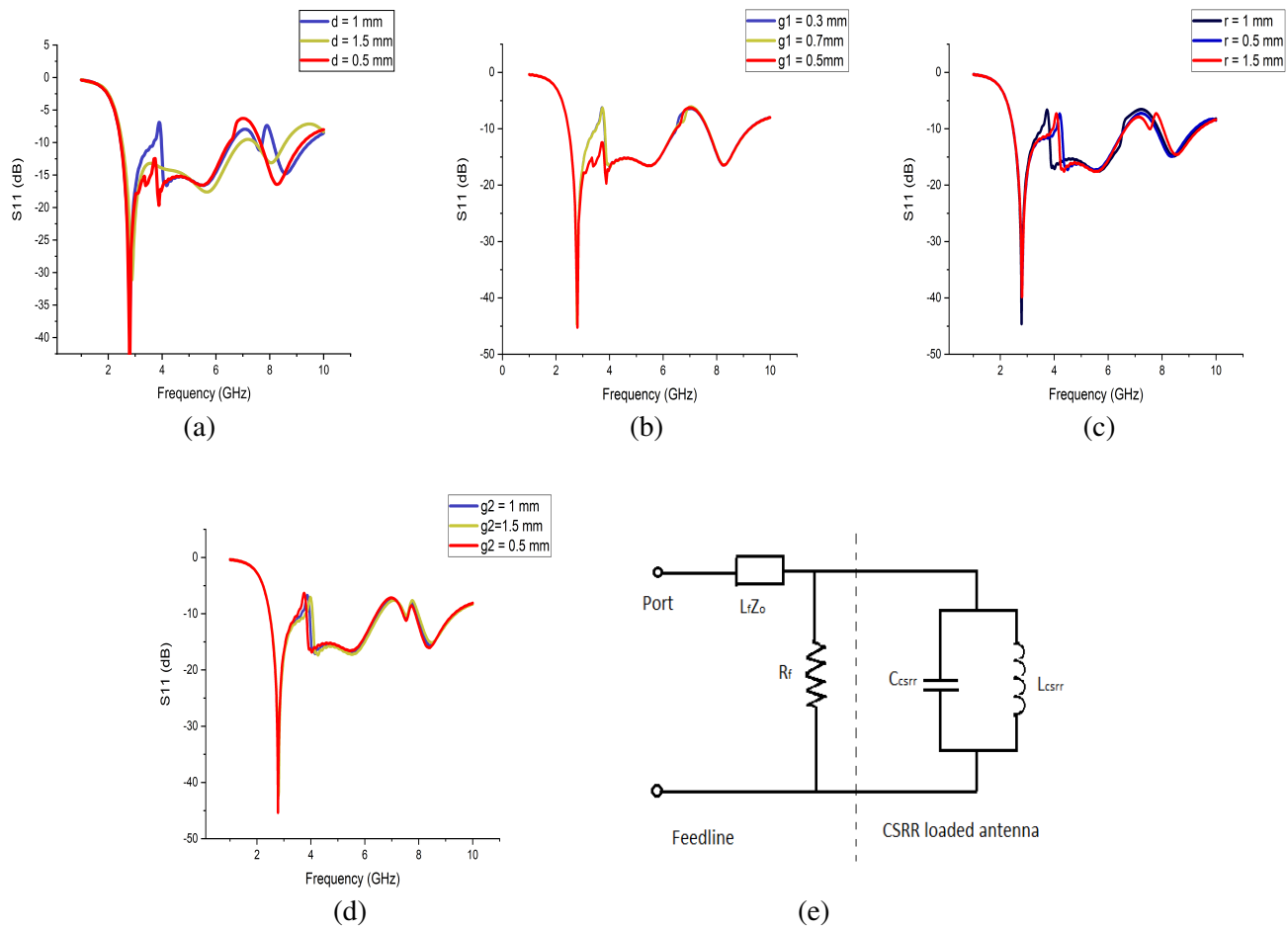


Figure 3. (a)–(d) Parametric study. (e) Equivalent model of the proposed antenna.

(black) and dielectric parts (white), respectively. Parametric analysis has been made on all important parameters of the structure, shown in Figures 3(a)–3(d). The width of CSRR slot d has a considerable effect on the functioning of the antenna. It is because this value controls the capacitance of the structure and hence the frequency and bandwidth of operation. Next, the slit widths g_1 & g_2 and the distance between the inner and outer slots r are subjected to parametric analysis. These parameters indicate the metallic parts, and hence the inductance of the structure is altered by these values. The effect of all these parameters are studied through a number of simulations, and the finalized optimal values are listed in Table 1.

Table 1. Optimized parameters.

Parameter	value (mm)	Parameter	value (mm)	Parameter	value (mm)	Parameter	value (mm)
W_s	13.2	R_p	7.7	L_s	27	W_{gap}	0.4
d	0.5	R_{s1}	5	W_g	8.8	R_{s2}	2.5
L_g	9.2	g_1, g_2	0.5	L_f	11.6	r	1.5

4. RESULTS AND DISCUSSION

The trapezoidal grounded ACS feed improves the overall performance of CSRR embedded monopole antenna. All the simulation works and parametric studies are performed using CST Microwave Studio. The antenna is fabricated, and the results are measured using Anritsu MS46122B Vector Network Analyzer. Figure 4(a) shows the plot that compares the simulated and measured return losses. The measured bandwidth of the antenna is 3.3 GHz covering the band of 3.2 GHz–6.5 GHz. The measured resonant frequency is 3.6 GHz with S_{11} of -28 dB. The slight variation in the measured results may be due to the practically unavoidable losses such as cable loss and equipment tolerances.

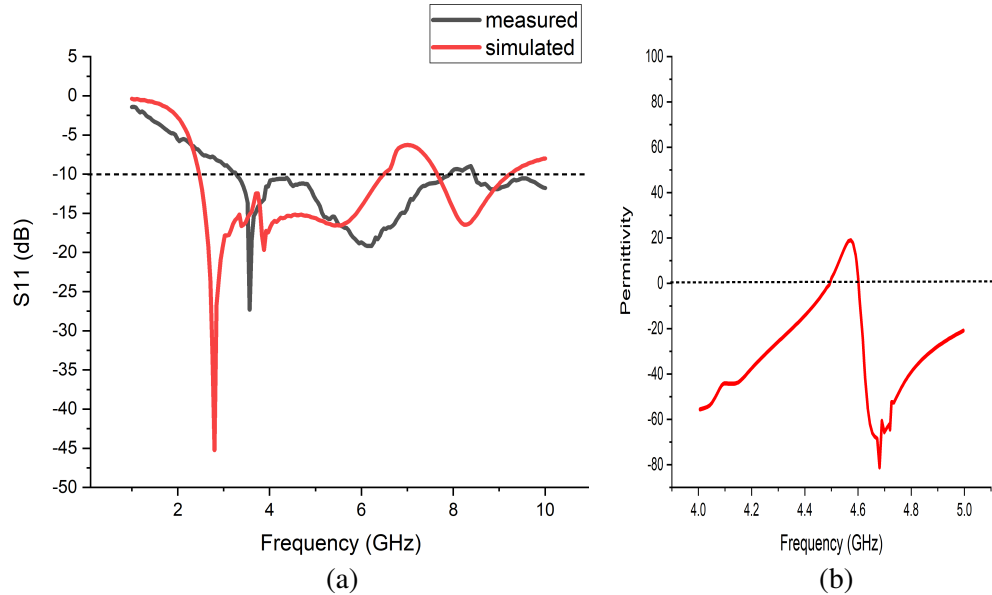


Figure 4. (a) Simulated and measured return loss. (b) Extracted permittivity.

CSRR is a complementary version of Split Ring Resonator (SRR), offering negative permittivity. The metamaterial characterization of the proposed design is studied by extracting the permittivity of the structure. Figure 4(b) shows that the permittivity goes negative around 4.6 GHz. Photographs of



Figure 5. (a) Fabricated antenna. (b) Measurement setup.

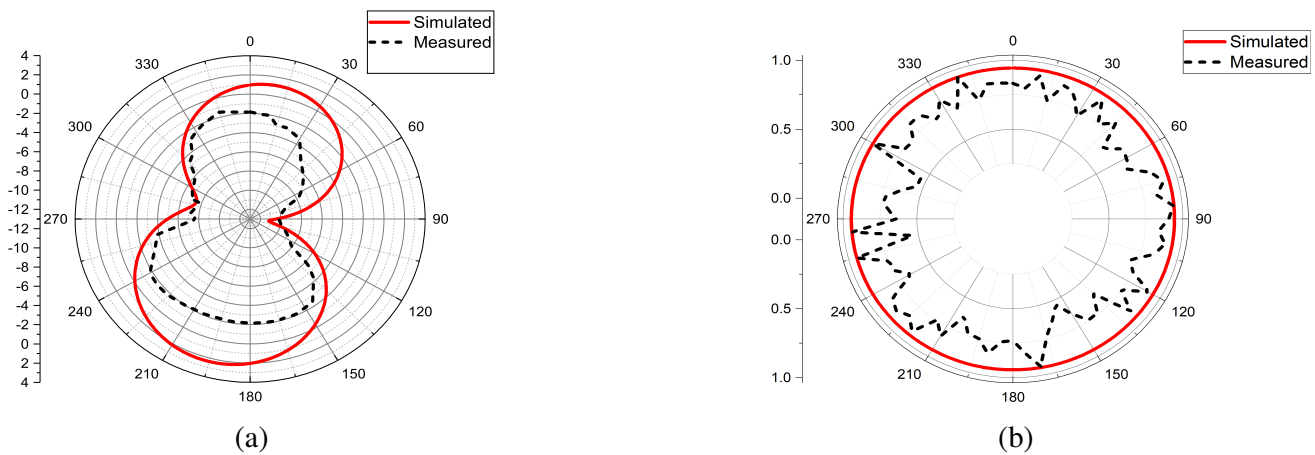


Figure 6. (a) *E* plane pattern (b) *H* plane pattern of the proposed antenna at 3.6 GHz.

Table 2. Comparison of the proposed antenna with existing antennas.

Ref	Feed Used	Operating Band (GHz)	Overall Size (mm ³)	Gain (dB)	Substrate
[13]	CPW	3.42–3.85, 4.82–6.85	20 × 27 × 1.6	1.83, 2.3	FR4
[14]	Microstrip	3.12–5.529	20 × 30 × 1.5	1.87, 2.69	FR4
[15]	Microstrip	0.75–0.79, 1.41–1.45, 2.1–2.14, 3.44–3.51, 3.8–3.87, 5.17–5.2, 5.97–6.38	30 × 30 × 1.6	1.1, 1.3, 1.1, 1.6, 1.7, 1.8 and 2.2	FR4
Proposed work	ACS	3.2–6.5	13.2 × 27 × 1.6	2.8	FR4

the fabricated antenna and measurement setup are shown in Figure 5. The simulated and measured radiation patterns in the *E* and *H* planes are shown in Figure 6. It can be observed that like any monopole antenna, the *E* plane pattern is bidirectional, and the *H* plane pattern is omnidirectional. Table 2 compares the proposed antenna with other antennas intended for the same application.

The proposed structure also satisfies the condition of electrically small antenna with its dimensions $0.123\lambda \times 0.252\lambda$. The electrical size of the antenna ka is verified to be 0.891 where k represents the wave vector for the operating frequency 2.8 GHz and a , the free space radius enclosing the antenna structure. It means that the CSRR loaded antenna proposed in this paper can radiate effectively with good reactive and resistive matching.

5. CONCLUSION

In this work, a compact CSRR loaded trapezoidal grounded ACS fed monopole antenna is presented. The CSRR structure alters the path of the surface current and enables the antenna to resonate at a low frequency with wide bandwidth. A miniaturization of 68.6% is realized, and the proposed antenna is extremely compact. The structure is optimized through parametric simulations. The antenna works with a resonant frequency of 3.6 GHz with reflection coefficient of -28 dB. The -10 dB bandwidth of the antenna is 3.3 GHz ranging from 3.2 GHz to 6.5 GHz. The antenna is fabricated, and the results are verified. With good impedance matching, bandwidth, and gain, this electrically small antenna is found to be a better choice for sub-6 GHz 5G applications.

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