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A Triband Slot Antenna Loaded with Asymmetric Split Ring Resonator for Wireless Applications

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ABSTRACT: For applications involving triple bands, a small slot structure loaded with an asymmetric split ring resonator (ASRR) is suggested in this article. The slot mode, which is agitated with the help of a microstrip line feed, produces the first band. 2.24 GHz resonance frequency is the intended operating band. The second and third frequency bands are achieved by loading ASRR on the slot. The slot produces axial magnetic field required to excite the ASRR. The asymmetry introduced in the conventional SRR produces dual resonances. The ASRR gives the resonant frequencies at 2.97 GHz and 3.66 GHz. The frequency bands of the slot and ASRR can be independently tuned. The proposed geometry is verified experimentally, and it is in good agreement with the simulated one. The impedance bandwidth of all three resonant bands measured from experiment are 14.25%, 1.78%, 8.37%. The peak gains of 3.1 dBi, 2.18 dBi, and 3.29 dBi are obtained at resonant points, respectively. The designed antenna is compact and well suits for wireless application like WLAN, GPS, and LTE48/TD3600.

1. INTRODUCTION

Wireless communication field has grown extensively from the last decade and demands compact devices for transmission and reception. These devices need to be operated in two or more frequency bands, which calls for the design of dual-band, triband and multiband antennas to fit into these devices. The research community has done enormous work on the design of multiband antennas, but there exists compactness and tunability problems. In [1], multiband operation is obtained using defected ground, meandered feedline, and rectangular patch etched with a rectangular slot. Many techniques are applied to design dual-band, triband and multiband antennas using U-shaped loop and T shaped slot loading for handsets [2] and monopole with stub and strip loading [3, 4]. The miniaturized patch antenna is proposed in [5] to obtain multibands using via and U shaped multiple slots. A multiband antenna for directional wireless application is designed in [6] using resonators coupled to patch antenna. A multi-resonant modes wide-slot loaded patch antenna in [7] and a multi-cavity coupling with slot antenna in [8] are proposed for multiband applications. A miniaturized multiband antenna with arcs and L shaped strips is designed for WLAN and X band application in [9]. A resonator loaded patch antenna is designed in [10], a high performance air filled multi-mode resonant u slot antenna in [11], and a shared aperture antenna for base station application in [12] is proposed to obtain multiple bands. A design methodology is discussed to obtain multibands in printed antennas [13] and multiband monopole antenna with enhancement in bandwidth [14] for mobile handset application. In the above techniques, to obtain multiple bands much effort is needed in terms of design, feeding method, and optimization due to the sensitivity of parameters, and it is incapable to tune frequency bands independently.

To make the design and tuning capabilities to become easy process, nowadays metamaterials (MTMs) are extensively used in the antenna design and in huge demand due to their properties which are not found in natural materials [15]. These MTMs have subwavelength in nature which possess properties like backward propagation, negative permeability and permittivity, near zero refractive index, cloaking, etc. Using MTMs, a few designs obtain the dual band and triband operations. Split ring resonator (SRR) and its complementary structures are effective in the design of multiband antennas. A complementary SRR (CSRR) loaded monopole antenna in [16] is designed to achieve multibands. Meander-line resonator and split ring resonator loaded modified patch antenna in [17] will provide hexabands for various wireless applications. A slot structure with single SRR [18] and two SRRs in [19] are proposed for dual band and triband applications. A slot with single and multiple splits based SRRs in [20, 21] are designed to obtain triband operation. In the above said designs, an effort was made to obtain the independent tuning, but a pair of SRRs are employed with single and multiple splits to obtain two resonance bands. Also recently in [22], resonators with an asymmetric short stub loaded are used to obtain a reconfigurable dual band pass filter

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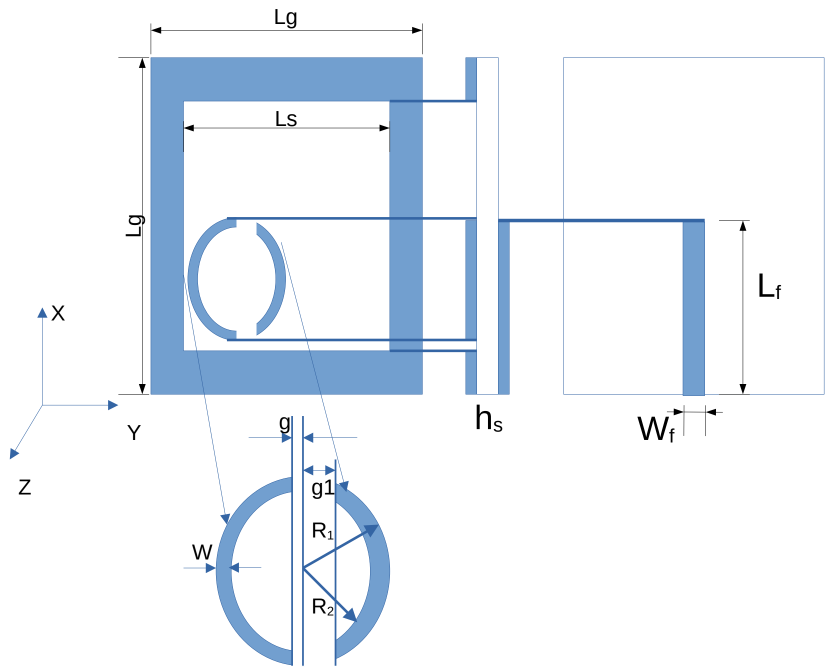

FIGURE 1. Antenna geometry.

with constant differential mode absolute bandwidth and high selectivity. But in this design the passband of two bands is controlled by the asymmetric short stub loaded resonators, and it is purely a filter application. In the proposed design, ASRR is used to obtain the radiation in two frequency bands for antenna application; a single ASRR can produce two resonance bands; and independent frequency tuning can be obtained.

In this design, a slot structure and an asymmetric split ring resonator (ASRR) are presented to obtain triple band operation. The fundamental resonance of the slot antenna produces the first band. The asymmetric split ring loaded on the slot antenna will produce second and third bands due to its plasmon resonance property. A micro-strip line is used to excite the slot structure. The power to ASRR will be coupled from the axial magnetic field produced by the slot antenna. The asymmetry introduced in the single loop SRR will produce two resonances. The ring with large portion produces the second resonance, and lesser portion of ASRR will produce the third resonance. Due to its asymmetry, a single SRR will produce two resonances. The measured impedance bandwidths of 14.25%, 1.7%, 8.37% are achieved at respective the 1st, 2nd, and 3rd frequency bands. The structure is compact with peak gains of 3.1 dBi, 2.18 dBi, and 3.29 dBi in the respective bands.

2. ANTENNA GEOMETRY AND OPERATING PRINCIPLE

The designed tri-band antenna is shown in Fig. 1 and consists of a slot antenna, ASRR, and feed structure. The slot and ASRR are etched on the top layer of an FR4 substrate ($\epsilon_r = 4.3$, $\tan\delta = 0.025$) with the thickness of $h_s = 1.6$ mm. The feed line is etched on the bottom layer of the substrate. The optimized design parameters are $L_s = 46$ mm, $L_g = 60$ mm, $W_f = 2.5$ mm, $L_f = 28$ mm, $R_1 = 11$ mm, $R_2 = 8$ mm, $W = 3$ mm (R_1-R_2), $g = 1.2$ mm, $g_1 = 0.2$ mm. Equation (1) is used to design the slot's resonance [19]. The fundamental mode TM_{01} of the slot antenna resonates. The electromagnetic coupling scheme used by the feed structure excites the slot so that the electric and magnetic fields are generated by the slot. The ASRR, which is positioned at the left side corner position of the slot, is excited by the axial magnetic field created by the slot intern. Due to asymmetry introduced in the split ring resonator (SRR), two resonances are created. The larger portion of the SRR gives the resonance at 2.97 GHz, and the smaller portion of SRR gives the resonance at 3.66 GHz. The equivalent circuit of the tri-band antenna is shown in Fig. 2(a), and the comparison between circuit simulation and EM simulation is shown in Fig. 2(b). From the figure, it is observed that the lumped element parameters in the equivalent circuit are well matched with the EM simulation. The values of lumped elements are given by: $Lsh = 0.98$ nH, $Csh = 6.18$ pF, $L_1 = 0.32$ nH, $C_1 = 8.7$ pF, $L_2 = 0.23$ nH, $C_2 = 7.66$ pF.

$$f_r = \frac{c}{2L_S}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

where c is the speed of light in free space. ϵ_r is the substrate's permittivity. f_r = resonance frequency. L_s = Length of the slot.

Fig. 3 shows the electric field and surface current of the proposed design at 2.24 GHz, 2.97 GHz, and 3.66 GHz. It gives magnitude of the field, and current is the greatest at the corresponding resonant frequencies. The reflection coefficients with and without ASRR are shown in Fig. 4(a). It is obvious that the slot without ASRR has a single resonance and that it pro-

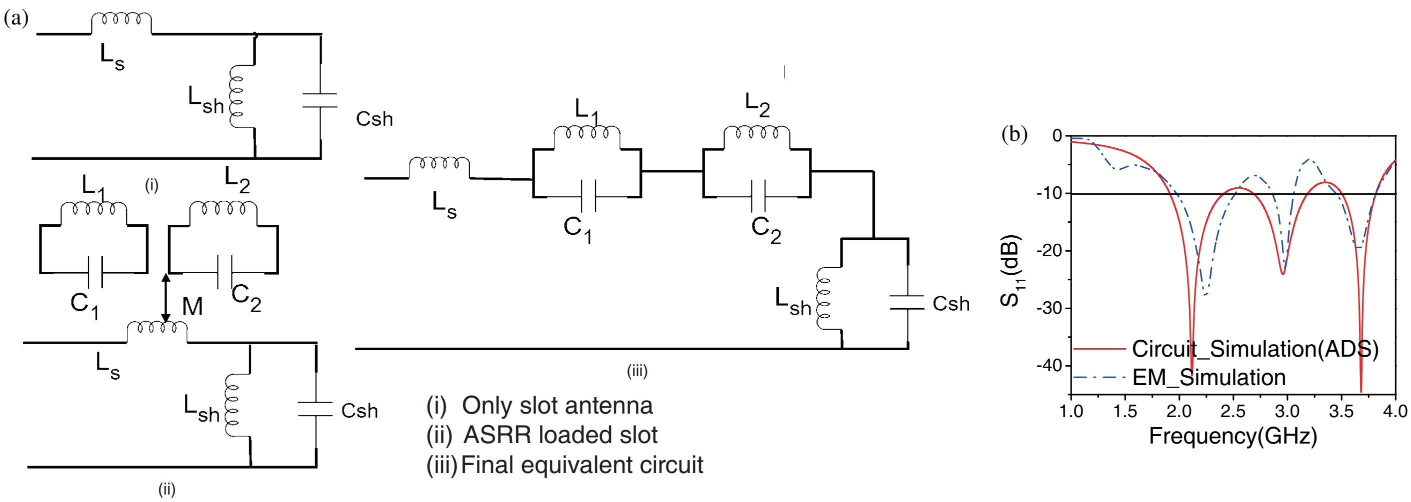

FIGURE 2. (a) Equivalent circuit of the proposed design. (b) Comparison between Circuit Simulation and EM simulation.

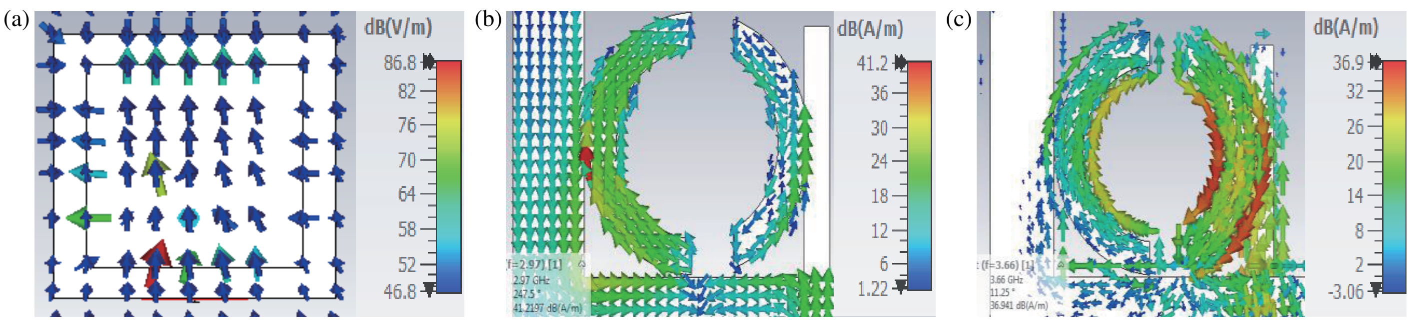

FIGURE 3. (a) Electric field distribution of slot antenna at 2.44 GHz. (b) Surface current distribution of ASRR @2.97 GHz. (c) Surface current distribution of ASRR @3.66 GHz.

duces a triple-band response when being loaded with ASRR. The sensitivity of design parameters are found using parametric variations. The slot length (L_s), ASRR radius (R_1), ASRR width, and the split gap of ASRR (g and g_1) are considered for parametric analysis as shown in Fig. 4. In Fig. 4(b), the reflection coefficient ($S_{11} < -10$ dB) variations are observed in all three resonances. As slot dimension Ls varies, the resonance will change. Smaller dimension leads to the increase in the frequency, and larger dimensions leads to the decrease in the frequency. The ASRR radius is more sensitive towards reflection coefficient, and as the radius increases, the frequency decreases and vice-versa. For ASRR, as the split gap increases, resonance will shift to a higher frequency due to decrease in the length. Similarly, the ASRR strip width also affects the resonance; as the width increases, resonance shifts to lower frequency and leads to poor matching; if strip width decreases, the matching improves, and resonance shifts to higher frequency. This study concludes that the reflection coefficient values of all three bands are affected by the respective variations in the dimensions. Also, as the slot dimensions are varied, the ASRR resonance will not change, and if the ASRR dimensions are varied, the slot resonance remains unchanged. This shows that the two frequency bands of slot and ASRR can be independently tuned.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The constructed tri-band antenna for experimental verification is shown in Fig. 5 along with its front and back views. Fig. 6(a) compares the simulation and measurement findings for the reflection coefficient. The measured impedance bandwidths are 14.25% (2.02 GHz–2.33 GHz), 1.78% (2.89 GHz–3.04 GHz), and 8.37% (3.46 GHz–3.8 GHz), while the simulated impedance bandwidths are 24.66% (1.96 GHz–2.5 GHz), 6.7% (2.89 GHz–3.04 GHz), and 10.75%. Fig. 6(b) displays the simulated and measured gain plots, and Fig. 6(c) displays the simulated radiation efficiency. The results of the experiments and simulations accord fairly well. At frequencies of 2.24 GHz, 2.97 GHz, and 3.66 GHz, respectively, the observed peak gains are 3.1 dBi, 2.18 dBi, and 3.29 dBi, while the simulated radiation efficiencies are 91.5%, 75.54%, and 76.6%. Fig. 7 displays the measured and simulated radiation patterns. All resonance bands in the figure radiate effectively in the broadside direction. Some of the patterns are tilted due to asymmetry in the structure of SRR. In all radiation patterns at corresponding resonant frequency bands, there is more than -15 dB cross polarization values with respect co-polarization. Table 1 compares the suggested design with earlier works. The size of designed antenna in comparison with other designs is less except a few designs. The design is simple with not much sensitivity concerning opti-

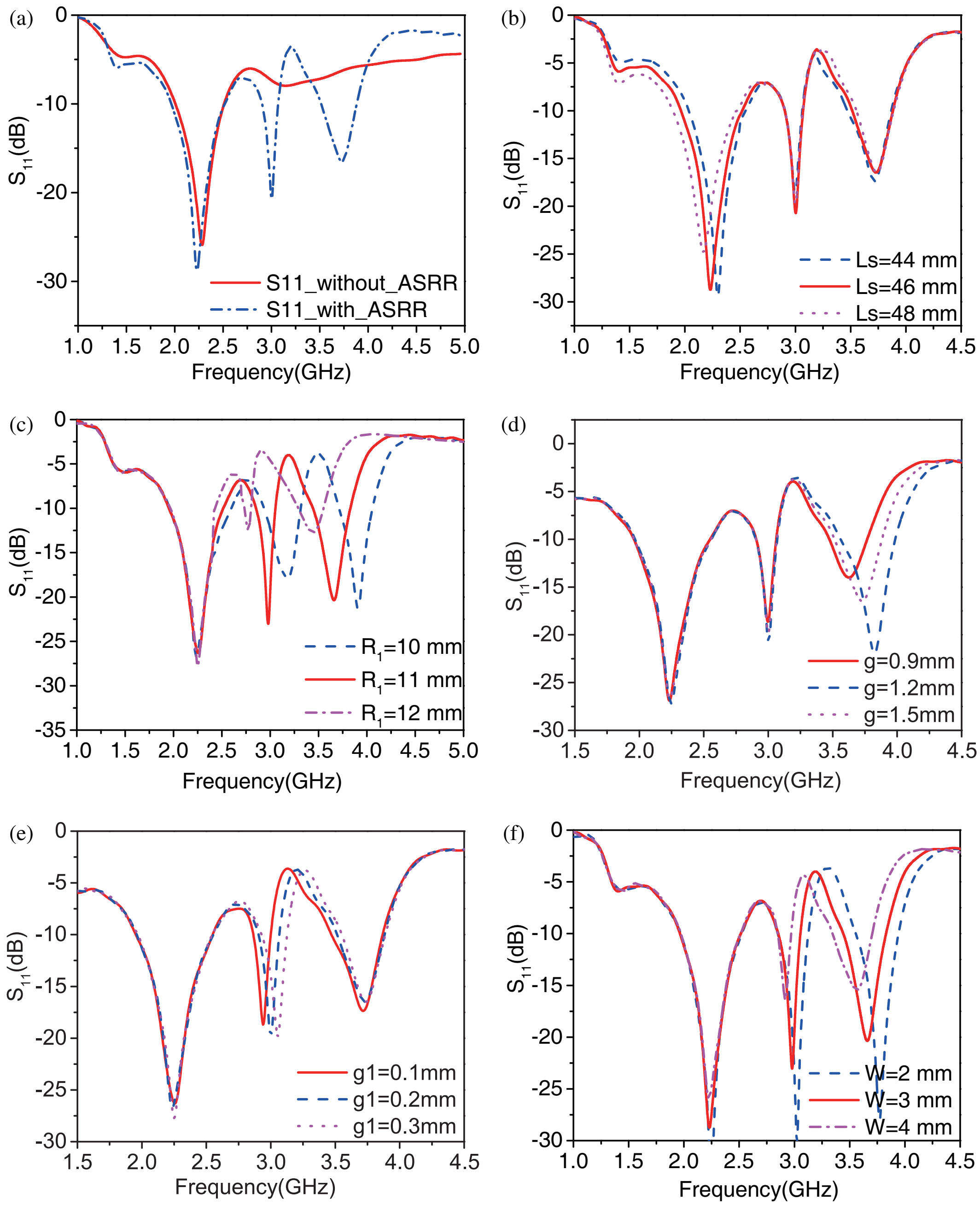

FIGURE 4. Simulated $S11$ of proposed design, (a) with and without ASRR, (b) due to variation of Ls, (c) due to variation of radius, (d) due to variation of g, (e) due to variation of $g1$, (f) due to variation of w.

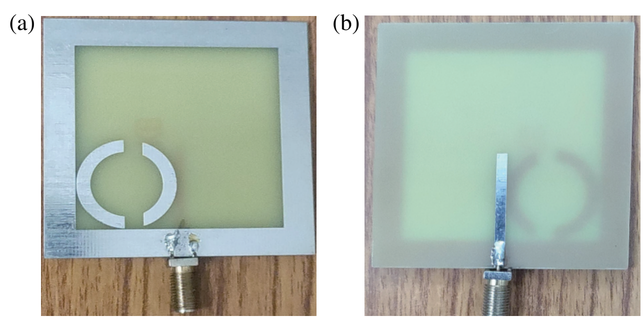

FIGURE 5. Fabricated prototype of the deigned triband antenna. (a) Front view. (b) Back view.

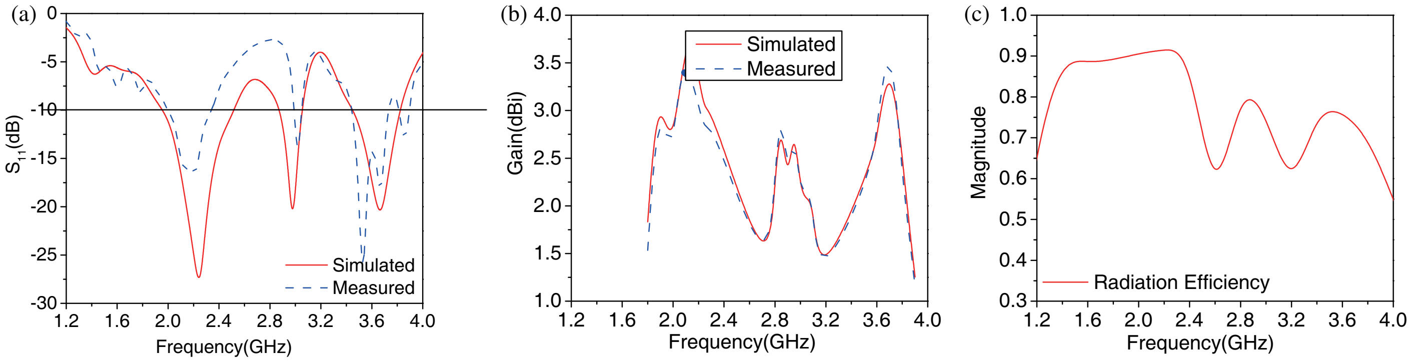

FIGURE 6. Simulated and measured. (a) S_{11} (dB). (b) Gain. (c) Simulated radiation efficiency.

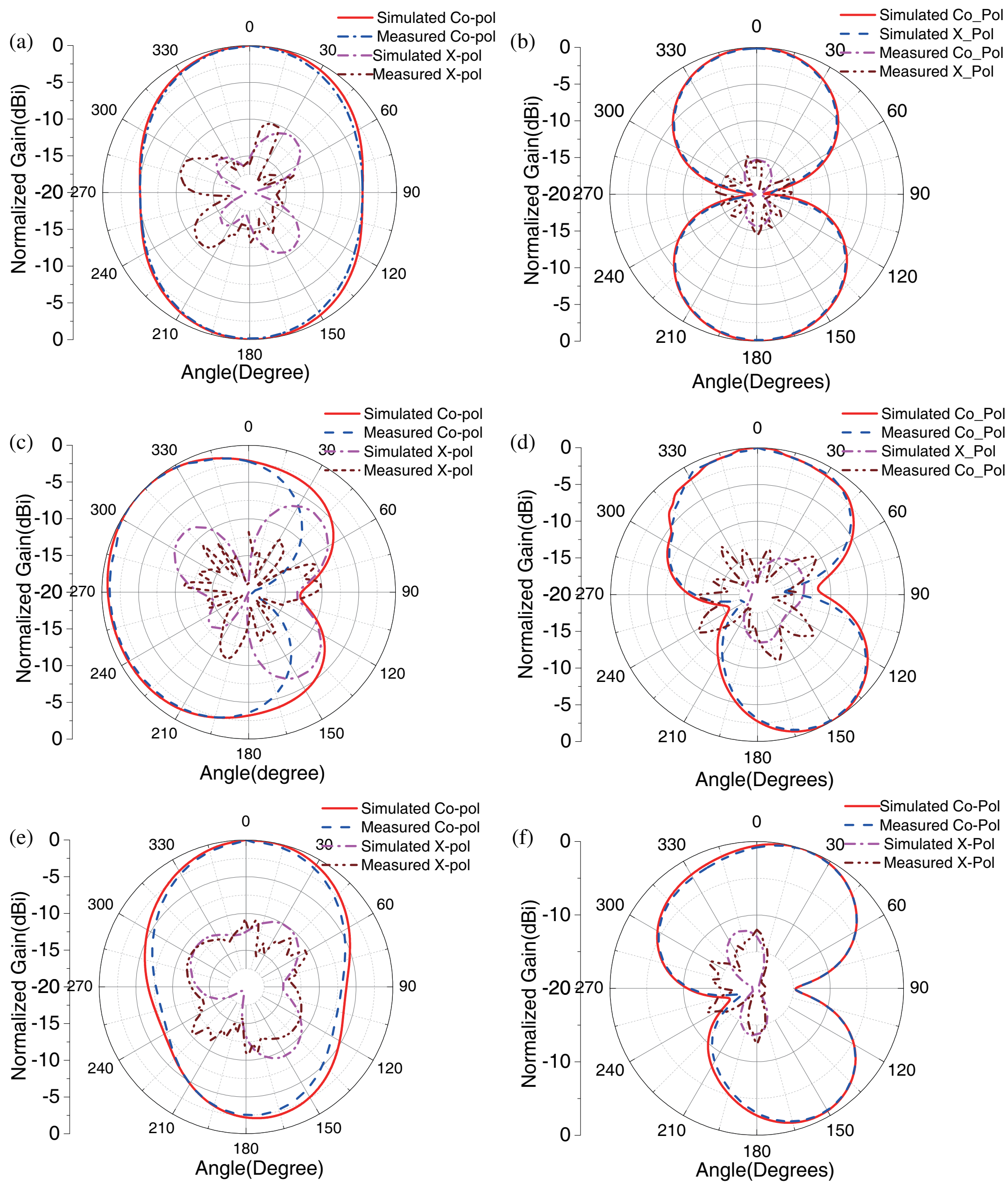

FIGURE 7. Simulated and measured radiation pattern of proposed design at 2.24 GHz. (a) XZ plane. (b) YZ plane, at 2.97 GHz. (c) XZ plane. (d) YZ plane, at 3.66 GHz. (e) XZ plane. (f) YZ plane.

TABLE 1. Comparison between the Proposed Tri-band antenna and other recent works.

Ref.	Size	Resonant Bands	Impedance Bandwidth (%)	Peak Gain (dBi)	Proposed Method	Independent Tuning of all bands
[10]	$0.025\lambda_0^2$	2.4,3.5,4.6,5.8	2.9,3.1,1.5,2.7	3.1,4.4,3.5,3.5	slot antenna with resonators	No
[11]	$0.041\lambda_0^2$	0.86, 2.5, 2.6	6.1,17,16	3,8.9,8.1	Air filled antenna with slots	No
[14]	$0.12\lambda_0^2$	1.86, 3.4	44,24	2.4,3.2	Monopole structure	No
[16]	$0.118\lambda_0^2$	4.27, 5.5, 7.20	2.1,17.6,3.19	1.9,0.9,0.9	Stub loaded monopole antenna	No
[18]	$0.075\lambda_0^2$	1.65,1.93,2.2	4.24, 3.11, 12.73	1.08,1.82,2.93	Ring slot and SRR	No
[19]	$0.51\lambda_0^2$	3.1, 4.7	13.15, 13.62	5.9, 6.2	Slot with two SRRs	Yes
[20]	$0.27\lambda_0^2$	2.6, 4.2, 4.6	21.92, 2.85, 2.13	4.4, 3.9, 3.8	Slot with two SRRs	Yes
[21]	$0.68\lambda_0^2$	4.15, 4.77, 5.1	64.54 (Covers all bands)	2.88, 1.96, 2.96	Slot with Two SRRs	Yes
[Prop.]	$0.19\lambda_0^2$	2.24, 2.97, 3.66	14.25, 1.78, 8.37	3.1, 2.18, 3.29	Slot with single SRR	Yes

where λ_0 is free space wavelength

mization and tuning capabilities. Also, a few designs have independent tuning characteristics, but multiple elements of SRRs are needed which in turn made design little complex. The proposed construction offers good performance in terms of gain, bandwidth, and tuning capabilities with straightforward design and small.

4. CONCLUSION

A slot antenna and an asymmetric split ring resonator for triple band operation are proposed successfully and verified experimentally. The three bands resonate at 2.24 GHz, 2.97 GHz, and 3.66 GHz with bandwidths of 290 MHz, 150 MHz, and 340 MHz. The slot produces lower resonance, and higher resonances are produced due to asymmetry introduced in the split ring resonator. The resonance bands can be tuned independently. The proposed design is compact, in low profile, and well suited in the wireless applications like WLAN, GPS, and LTE48/TD3600. Also it can be used for S band Radar applications where small frequency ratio is essential.

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