Bandwidth and Gain Improvement with SRR Based Defected Ground in Triple-Band Antenna for 5G Application

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Abstract:

A triple-band microstrip antenna based on the DGS technology is proposed with the enhancement of gain as well as improvement in bandwidth. Split Ring Resonator (SRR) is accomplished in the bottom plane which is working as a stop band in operating bandwidth. Two rectangular radiators are placed in series, where two symmetrical inverted L-shaped slots are responsible for bandwidth enhancement of the antenna. The 10 dB impedance bandwidth (IBW) of the antenna is 3.22 GHz to 3.35 GHz, 3.48 GHz to 3.58 GHz and 4.45 GHz to 4.59 GHz which can be used for 5G communication applications. The gain improvement is achieved in all operating bands and 5.2 dB maximum gain is observed at 3.23 GHz with 3.2 dB gain enhancement.

Keywords:

DGS, SRR, gain enhancement, 5G, meta-material characteristics.

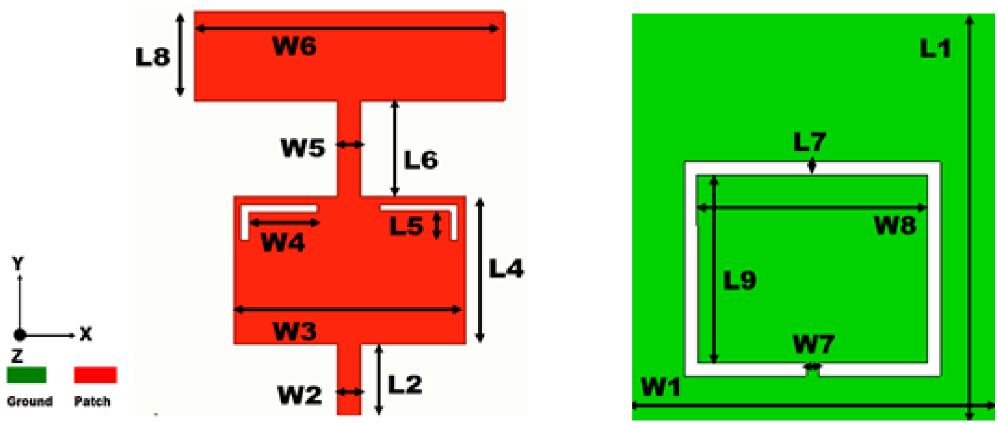
Introduction:

Due to rapid change in wireless communication, researchers are motivated to design a 5G communication antenna with significant gain. These days, considerable improvement in the designing of the antenna is observed which is used with 5G frequencies such as mobiles, tablets, laptops, etc. The multiband microstrip antenna covers different frequency band applications in place of multiple antennas, therefore it improves the functionality and compatibility of the device. Because of this, a microstrip multi-band antenna with a low profile and improved gain can be very useful for a 5G communication system. Several researches have been suggested to enhance the gain as well as bandwidth of the antenna by using defects in the ground such as CSRR and metamaterial characteristics. Defects in the ground create an alteration in surface current, resulting in different effects such as stopband, slow-wave and variation in impedance matching respectively [1]. The CSRR is accomplished in a two-element microstrip antenna as a superstrate whereas the SRR is finding the stopband characteristics which improve the 10 dB IBW in antenna [2]. In a rectangular-shaped microstrip antenna, the circular CSRR is used for the enrichment of gain and bandwidth, where CSRR is showing a slow wave factor in the ground [3]. Antenna with coaxial feed is discussed with CSRR in the ground plane, where two via are accomplished with CSRR to improve radiation efficiency, directivity as well as impedance bandwidth [4]. A semi-circular radiator with CSRR slots is proposed for multiband, where slots are used to improve the impedance matching [5]. CPW fed antenna is accomplished with CSRR in the ground plane to enhance the bandwidth [6]. Multiple CSRR in the ground plane are incorporated for gain improvement of the discussed antenna [7]. CSRR loaded rectangular-shaped antenna is used for size miniaturization where two CSRR are working as meta-resonators [8]. Inset feed microstrip antenna is proposed with the defected ground, where defects in ground miniaturize the size of the patch and improve antenna parameters [9]. CSRR based ground in achieving the metamaterial property in dipole antenna for enhancement of gain as well as bandwidth [10]. A circular FSS is unified with a horizontal strip for gain enhancement of the antenna [11]. The modified CSRR structure in the ground plane is used to obtain dual operating bands for 5G mobile applications [12]. CSRR is accomplished in the flower-shaped radiator to obtain the WLAN notch in UWB antenna [13]. Defects in ground create CP characteristics in CPW-fed antenna [14]. The SRR and DGS based FSS is designed for antenna to improve the gain of the antenna [15].

Keeping these literatures in mind, a single CSRR slot in the ground is created to increase the gain and 10 dB IBW of proposed antenna. The CSRR structure exhibit stopband characteristics, modifying the lumped network and controlling the grating lobs. With the proposed design the microstrip antenna owes three operating bands from 3.22 GHz to 3.35 GHz, 3.48 GHz to 3.58 GHz and 4.45 GHz to 4.59 GHz with gain enhancement in all bands, which can be useful for 5G Sub-6 GHz applications.

Antenna design and evolution step:

The CSRR based microstrip antenna is illustrated in Fig. 1(a), the FR4 material (εr =4.4) with 1.6 mm thickness is used. The optimized geometry of antenna are L1 = 65 mm, W1 = 60 mm, L2 = 10 mm, W2 = 3 mm, L3 = 33 mm, W3 = 30 mm, L4 = 20 mm, W4 = 6 mm, L5 = 4 mm, W5 = 3 mm, L6 = 13 mm, W6 = 40 mm, L7 = 2 mm, W7 = 2 mm, L8 = 12 mm and W8 = 33 mm. The designing of the antenna is finalized in three progressive steps as shown in Fig. 1 (b). The s-parameter is illustrated in Fig. 1 (c).

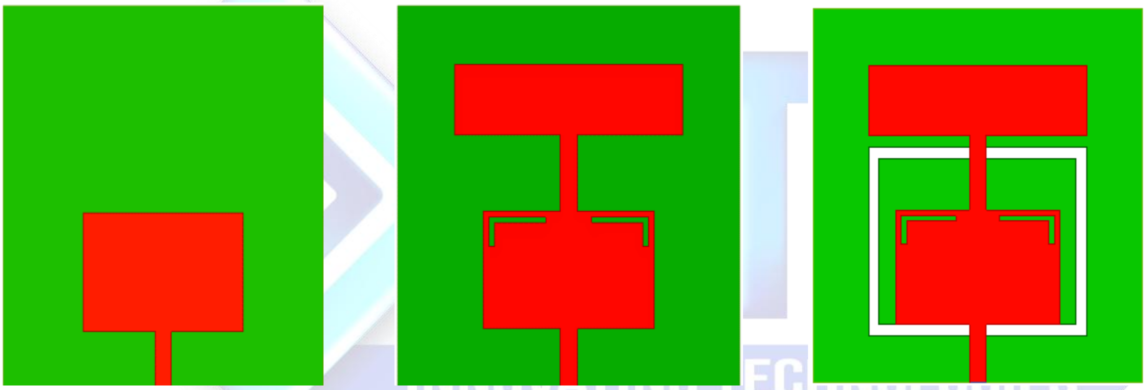


(a) (b)

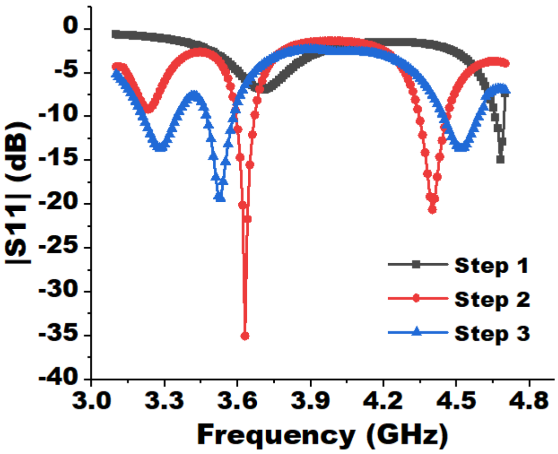
Fig. 1 Proposed antenna geometry **(a)** Radiator **(b)** Ground plane

In step 1, a rectangular radiator with the full ground is used with a 50 Ω impedance feed width. The rectangular radiator dimensions are 30 mm x 20 mm, where it is combined with microstrip feed of length 11 mm and width 3 mm. The antenna exhibits narrow impedance bandwidth (10 dB) due to the poor matching, with a centre frequency 4.7 GHz. In step 2, the second rectangular radiator is combined in series with two symmetrical L-shaped slots, which increases the electric length as well as inductive element, improving the matching (impedance) of the antenna. The 10 dB IBW varies from 3.6 GHz to 3.66 GHz and 4.35 GHz to 4.45 GHz. In the final step, for improving the realized gain and operating bandwidth, SRR is introduced in the ground plane. SRR in the ground plane exhibit stopband characteristics which modify the lumped element and control the grating lobes. The 10 dB IBW in the final step is obtained from 3.22 GHz to 3.35 GHz, 3.48 GHz to 3.58 GHz and 4.45 GHz to 4.59 GHz which can be applied for 5G communication.

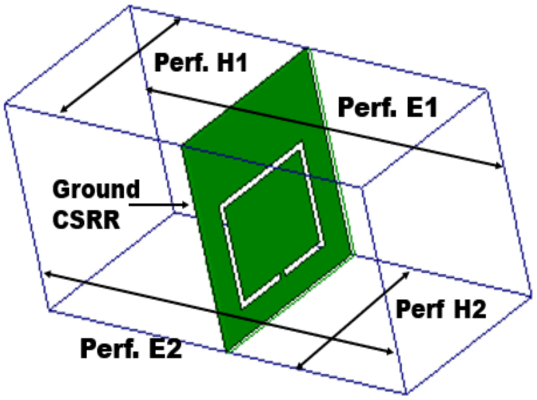
The s-parameter of the ground unit cell is analysed with waveguide structure, where PEC and PMC is used in x and y plane and wave port is used in z plane (top and bottom side) and it is shown in Fig. 1 (c). The extracted value of |S11| and |S21| reveals that the unit cell work as a stop band, since |S21| achieved 10 dB bandwidth from 3.1 GHz to 4.7 GHz. The value of the stopband is higher in the operating band, which influences the surface current, therefore enhancement in operating bandwidth is achieved. The stopband behaviour of the ground plane also controls the grating lobes, which causes significant gain improvement.



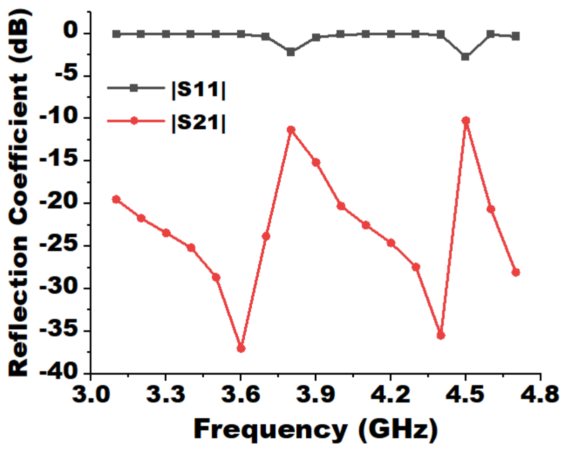
(a)



(b)



(c)



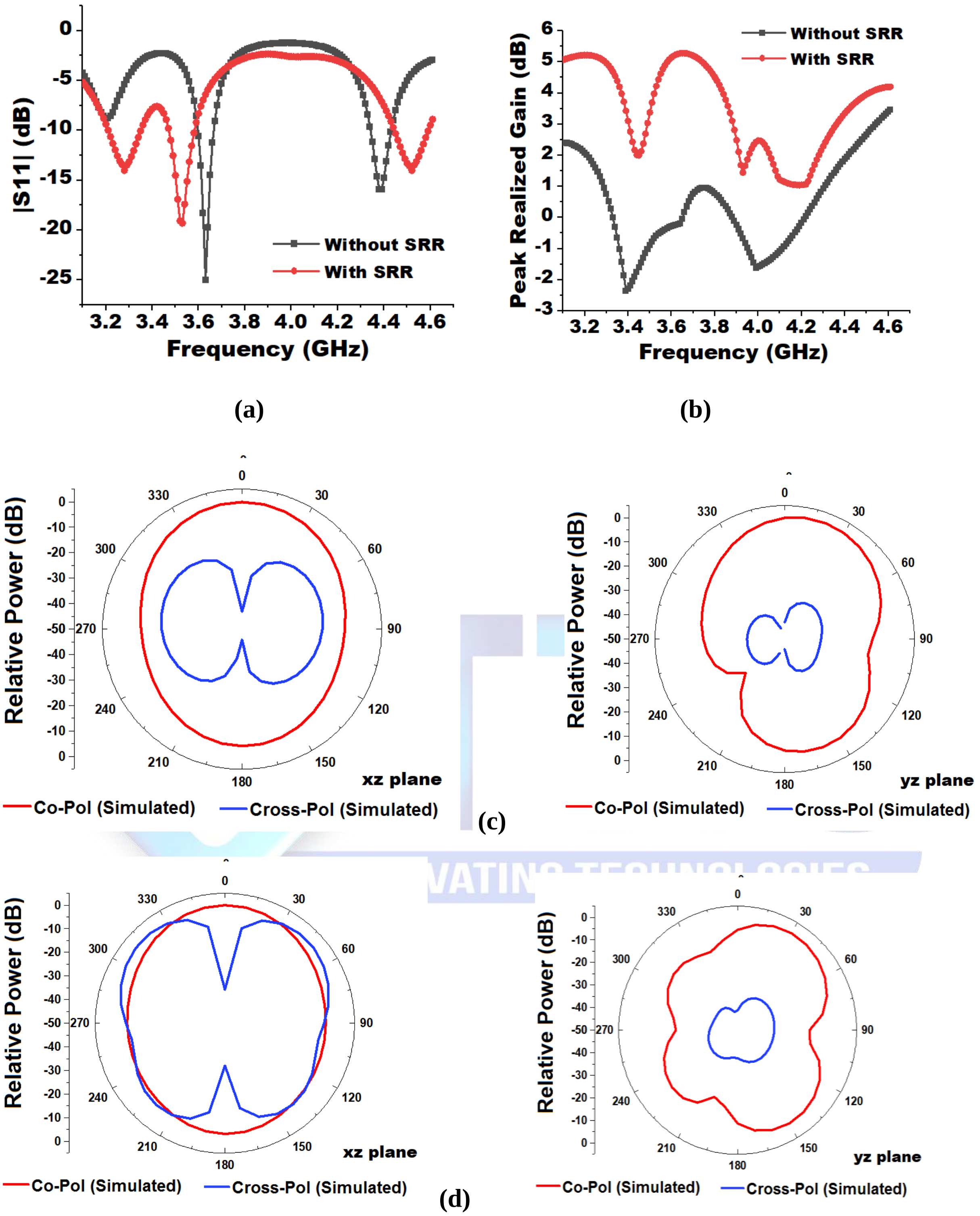
(d)

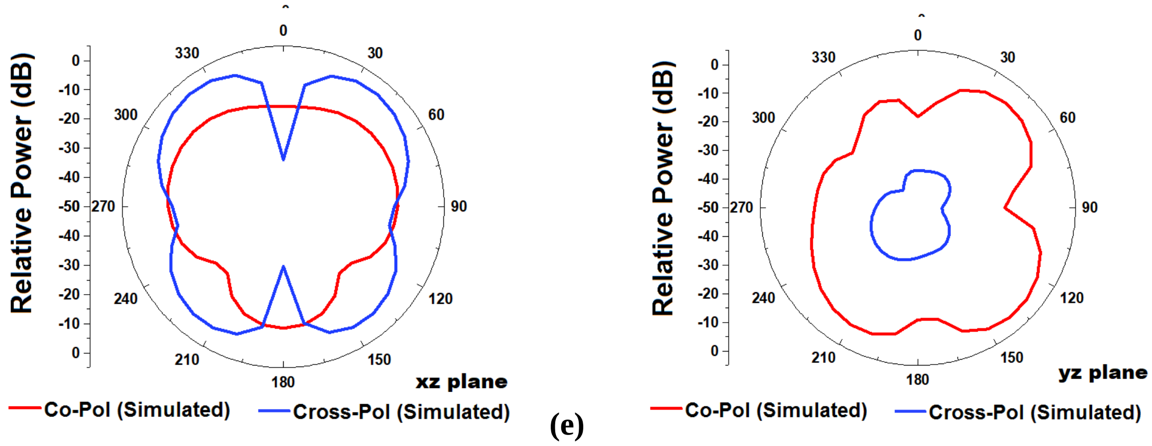
Fig. 2 (a) Antenna evolution steps**, (b)** The simulated |S11| of antenna steps and **(c)** wave port arrangement to extract Reflection coefficient of CSRR **(d)** Reflection coefficient of CSRR

Results and Discussion:

The proposed multiband antenna is designed on HFSS-13 EM software. The 10 dB |S11| varies from 3.1 GHz to 4.7 GHz as depicted in Fig 3 (a). The |S11| in dB of the multiband antenna without CSRR in-ground varies from 3.6 GHz to 3.66 GHz and 4.35 GHz to 4.43 GHz. The improvement in impedance matching is achieved on operating bands from 3.22 GHz to 3.35 GHz, 3.48 GHz to 3.58 GHz and 4.45 GHz to 4.59 GHz by introducing SRR in the ground plane. The overall bandwidth enhancement of 164 % occurs in the proposed design of a multiband antenna. The realized gain of the antenna is also enhanced due to the stop band characteristics of SRR. SRR improves the overall gain of the antenna in all reported operating bands and the maximum realized gain achieved is 5.2 dB at 3.23 GHz with 3.2 dB gain enhancement as illustrated in Fig. 3 (b). At 3.28 GHz centre frequency, realized gain is 5.07 dB with SRR, while 1.14 dB without CSRR, similarly at 3.53 GHz centre frequency realized gain is 4.22 dB with CSRR, while -0.56 dB without CSRR and at 4.53 GHz centre frequency realized gain is 4.06 dB with CSRR, while 2.9 dB without CSRR. Therefore 3.93 dB, 4.82 dB and 1.16 dB gain enhancement are achieved in the proposed multiband antenna at centre frequencies. The normalized radiation pattern in xz and yz direction is illustrated from Fig. 3(c-e) at 3.28 GHz, 3.53 GHz, and 4.6 GHz centre frequencies. Radiation patterns are omnidirectional and stable, where high cross-polarization is found which can be applicable for portable devices [16, 17].

The comparative analysis is studied in table 1 where the bandwidth enhancement of the proposed antenna is 164 %, which is higher than another compared antenna. The three operating bands are achieved with a single CSRR in the ground plane. The significant gain enhancement is reported in all operating bands and 3.2 dB gain enhancement is observed at 3.2 GHz frequency. It reveals that the proposed multiband antenna accomplished with CSRR enhances the gain as well as improves the impedance bandwidth.


|S11| (dB)
Frequency (GHz)
Without SRR
With SRR
(a)
Peak Realized Gain (dB)
Frequency (GHz)
Without SRR
With SRR
(b)
Relative Power (dB)
xz plane
Co-Pol (Simulated)
Cross-Pol (Simulated)
Relative Power (dB)
yz plane
Co-Pol (Simulated)
Cross-Pol (Simulated)
(c)
Relative Power (dB)
xz plane
Co-Pol (Simulated)
Cross-Pol (Simulated)
(d)
Relative Power (dB)
yz plane
Co-Pol (Simulated)
Cross-Pol (Simulated)



(e)

Fig. 3 (a) |S11| of the proposed antenna (b) Gain of the multiband antenna with and without SRR (c), (d) and (e) Radiation at frequency 3.28 GHz, 3.53 GHz and 4.6 GHz respectively.

Table 1. Comparative study of proposed work with another recent literature

References	**No. of operating bands**	**The technology used in Ground**	**Operating bands (GHz)**	**Bandwidth Enhancement in %**	**Gain Improvement (dB)**
Proposed work	Triple	SRR	3.22-3.35, 3.48-3.58, 4.45-4.59	164	3.2
2	Single	CSRR	5.3-6.1	60	3.7
3	Single	CSRR	2.01-3.34	67	3
8	Single	CSRR	2.3-2.4	5.92	1.57
9	Single	DGS	2.41-4.24	--	1.67
10	Single	CSRR	3.2-4.4	2.2	3.7

Conclusion:

The proposed multiband antenna is designed with two series rectangular radiators and a defective ground structure. The series rectangular radiator increases the electric length and improves the impedance matching. The SRR in the ground-based stopband characteristics enhances the bandwidth and improves the overall gain, where SRR perturbs the surface current and control the grating lobes. This antenna covers three operating bands which may be applicable for 5G Sub-6 GHz communications.

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