High efficiency dielectric resonator antenna using complementary ring resonator for bandwidth enhancement

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ABSTRACT

A complementary ring resonator (CRR) technique is used to improve the bandwidth of the dielectric resonator antenna (DRA) while maintaining other parameters such as the efficiency and the gain. Parametric experiments were conducted in order to demonstrate the suggested antenna's working guideline. The bandwidth of the proposed Antenna is boosted by 769 percent as compared to the antenna without the CRR technique. The proposed antenna has high efficiency of 94 percent and a tiny dimension of around 30×30×12 mm. The suggested antenna has a frequency range from 2.61 to 3.65 GHz, which is suitable for S-band applications. Computer simulation technology (CST) was used to implement the design and obtain the results.

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1. INTRODUCTION

Permanently, researchers are developing highly efficient antennas to reduce dissipated power. One of the highly efficient antennas is the dielectric resonator antennas (DRA) due to the less metal required in the antenna structure. The DRA has numerous benefits, including less metallic loss, high gain, and various far-field patterns that correlate to different modes [1]. This feeding mechanism can produce a variety of patterns, such as omnidirectional and directed radiation patterns [2]. These properties of DRA are high-efficiency antennas due to having surface wave or loss conductor loss. The feeding mechanism in DRA are uncomplicated, like probes, apertures, and microstrip lines. S-band is a spectrum of frequency ranging from 2 to 4 GHz. Which has many applications such as wireless fidelity (Wi-Fi), industrial, scientific and medical band (ISM band), long-term evolution (LTE), and fifth generation (5G) applications. [3], [4].

Many techniques, as an example, partial ground plane [5], and the ground plane's window slot [6], are employed to increase DRA's impedance bandwidth. Other factors including as directivity, gain, and efficiency are affected by several bandwidth impedance techniques. Hence, it needs to design a DRA that does not have a significant influence on directivity, gain, or efficiency. Moreover, many techniques were applied to improve the impedance bandwidth with patch antennas such as believed half-cut structure [7], p-i-n diode switching [8], Sierpinski carpet fractal monopole antenna (SCFMA) [9] and also by using double stub matching with proximity coupled feed [10]. Some researchers use two techniques such as a complementary split-ring resonator (CSRR) with defected patch structure (DPS) [11]. Moreover, by using Substrate Removal may easily enhance the bandwidth and efficiency [12]. Lately, numerous metamaterial (MMT) periodic configurations have been proposed utilising their filtering behaviour to improve the antenna performances. These MMT structures are as follows: 1) electromagnetic bandgap (EBG) [13]-[15], 2) frequency selective surfaces (FSS) [16], [17], and 3) split-ring resonator (SRR) [18], [19].

In this research work, the dielectric waveguide model (DWM) was employed to build a rectangular DRA in the experiment, and a direct microstrip feed line was used to feed the antenna. According to the results, the antenna's -10-impedance bandwidth is extremely small. Wherefore, the impedance bandwidth was increased from 120 MHz to 1.043 GHz by using complementary ring resonator (CRR) technique which is a ring slot on the ground plane. The -10-impedance bandwidth is 1.043 GHz range from 2.616 to 3.658 GHz. Many applications are operating in this frequency band. 5G is one of these applications that have a range from 3.3 to 3.6 GHz [20]. Table 1 shows the parameter of the antenna compared with other related work, which shows the proposed antenna is smaller in size than others and the CRR technique enhances the bandwidth to 769%.

Table 1. Comparagen between this research work with the other related

Ref	(F_L-F_H) GHz	BW (%)	Enhance BW (%)	Size mm	Shape	Radiation Efficiency (%)	Technique
[21]	2.49 to 2.69	8	120	50×50×13	Rectangular	90	CHR
[22]	2.61-3.65	21	203	35×35×26	Rectangular	-	Parasitic Patch
[23]	2.83-5.36	62	47.4	100×11	Cylindrical	-	Circular Disk and Annular Ring
This Work	2.61-3.65	33	769	30×30×12	Rectangular	94	CRR

2. ANTENNA IMPLEMENTATION

2.1. Antenna design

The suggested antenna is the rectangular shape dielectric resonator, which may be constructed using the DWM. The size of the rectangular dielectric resonator can be estimated using the TE_{111} mode of equations of the DWM [24]-[26]:

$$f_\circ = \frac{C_\circ}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x{}^2 + k_y{}^2 + k_z{}^2} \tag{1}$$

$$k_x = \frac{\pi}{L} \tag{2}$$

$$k_z = \frac{\pi}{2H} \tag{3}$$

$$k_y \tan\left(\frac{k_y W}{2}\right) = \sqrt{(\varepsilon_r - 1)k_\circ{}^2 + k_y{}^2} \tag{4}$$

$$k_\circ = \frac{2\pi f_\circ}{C_\circ} \tag{5}$$

Where,
$f_\circ$: Resonant frequency
C: denotes the speed of light in free space.
K: denotes the wavenumber in free space.
K_X, K_Y, and K_Z: denotes the wavenumbers within the DR in X, Y and Z directions.
W and L: denotes the length and the width of the rectangle dielectric resonator.
H: denotes the width of the rectangle dielectric resonator.

The DRA's dimensions are swept using computer simulation technology (CST) microwave studio to achieve improved results. Table 2 provides the finished antenna's entire dimensions, along with a description and millimetre values. Figure 1 shows the structure of the Antenna. Its contents of flame retardant (FR-4) substrate with double side copper material. The dielectric constant of the FR-4 substrate is 4.3. Behind the FR-4 substrate is the ground plane and above it is the microstrip feed line with DR.

Table 2. Dimension of the antenna

Description of the Dimension	Acronyms	Value (mm)
The DR Width	Wd	15
The DR Length	Ld	15
The DR Hight	Hd	10
The Ground Width	Wg	30
The Ground Length	Lg	30
The Ground Thickness	Hg	0.035
The Substrate Hight	Hs	1.6
The Width of the Feed Line	Wf	3.137
The Length of the Feed Line	Lf	12.5

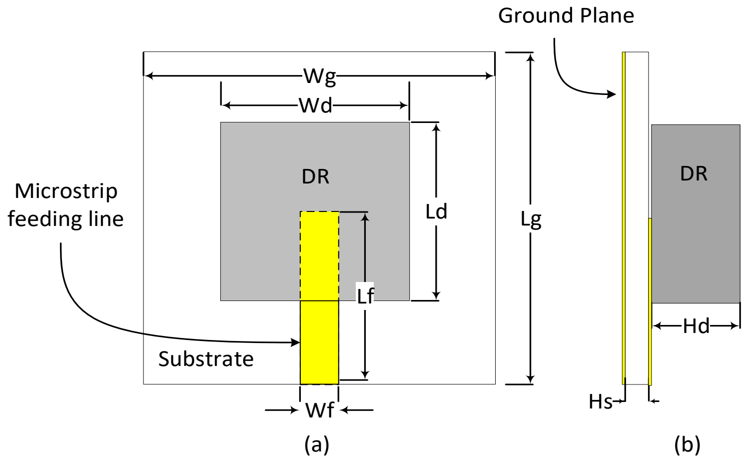

Figure 1. The front and side view geometry of the antenna

2.2. Design the CRR

To enhance the bandwidth by using the CRR technique. Figure 2 shows the geometry of the CRR in the ground plane. The ring shape slot is in the middle of the antenna. The width of the ring (Wr) and, the outer radius of the ring (R).

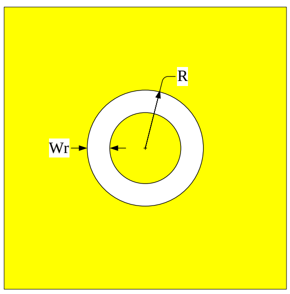

Figure 2. The antenna ground plane and the CRR structure

Parameter sweep, which is built into the CST microwave studio, is used to carefully examine each parameter. The parameter study on CRR has two parameters the width of the ring (Wr) and the outer radius of the ring (R). While fixing the width of the ring (Wr) to 2 mm and changing the outer radius of the ring (R) (see Figure 3) the optimum value of the outer radius is 8 mm. The -10-impedance bandwidth is 768 MHz from 2.644 to 3.413 GHz. The best value of the outer radius (R) while fixing the width of the ring (Wr) at 3 mm and adjusting the outer radius of the ring (R) (see Figure 4) is 8 mm. From 2.629 to 3.500 GHz, the -10-impedance bandwidth is 871 MHz. While fixed the width of the ring (Wr) to 4 mm and changing the outer radius of the ring (R) (see Figure 5) the optimum value of the outer radius is 8 mm. The -10-impedance bandwidth is 961 MHz from 2.619 to 3.581 GHz.

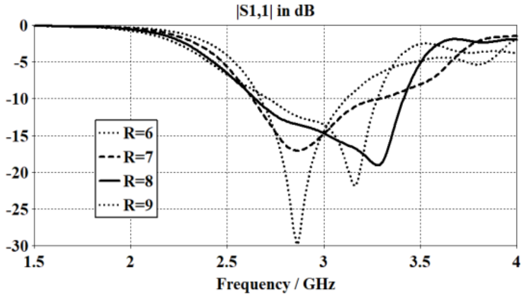

Figure 3. Return loss of the antennas with varied values of the outer radius of the ring (R). While fixed the width of the CRR (Wr=2)

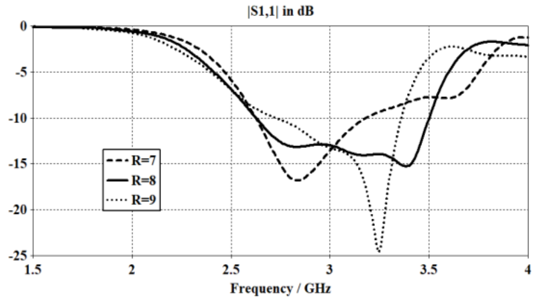

Figure 4. Return loss of the antennas with varied values the outer radius of the ring (R). While fixed the width of the CRR (Wr=3)

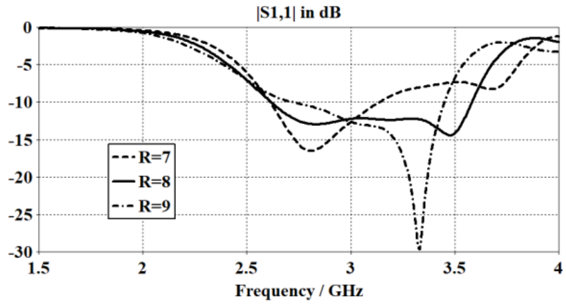

Figure 5. Return loss of the antennas with varied values the outer radius of the ring (R). While fixed the width of CRR (Wr=4)

While fixing the width of the ring (Wr) to 5 mm and changing the outer radius of the ring (R) (see Figure 6) the optimum value of the outer radius is 8 mm. The -10-impedance bandwidth is 1.041 GHz from 2.616 to 3.658 GHz. While fixing the width of the ring (Wr) to 6 mm and changing the outer radius of the ring (R) (see Figure 7) the optimum value of the outer radius is 8 mm. The -10-impedance bandwidth is 1.041 GHz from 2.616 to 3.658 GHz. The parameter study denotes that the increasing of Wr leads to increases the bandwidth with degreasing the efficiency, as the results tableted in Table 3 below.

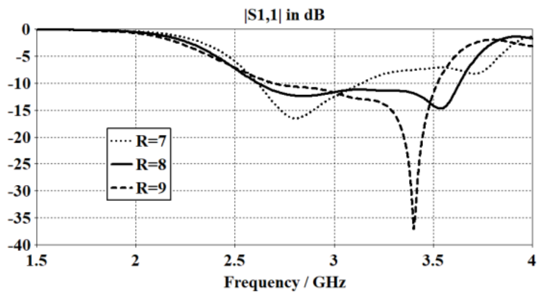

Figure 6. Return loss of the antennas with varied values of the outer radius of the ring (R). While fixing the width of the CRR (Wr=5)

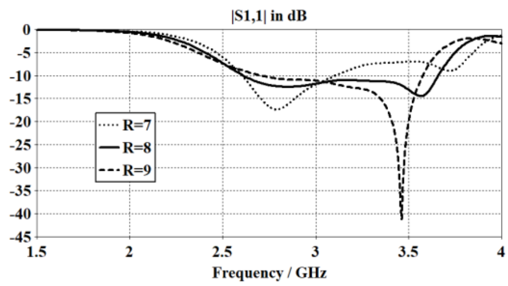

Figure 7. Return loss of the antennas with varied values of the ring's outer radius (R). While fixed the width of the ring (Wr=6)

Table 3. The effects of changing the value of Wr on the bandwidth and radiation efficiency

Wr Value	Bandwith MHz	Rad. Efficiency at 3 GHz
2	781.8	97%
3	869	96%
4	959	96%
5	1015	94%
6	1041	94%

3. RESULTS AND DISCUSSIONS

At 3.0 GHz, the antenna's reflection coefficient is -10.60 dB, and the impedance bandwidth at -10 dB is 121 MHz, with a frequency range of 2.969 to 3.09 GHz. The primary goal of this research project is to increase the antenna's bandwidth. Therefore, the CRR was applied to the ground plane to increase the impedance bandwidth. At 3.0 GHz, the antenna's reflection coefficient is -11.80 dB, and the -10 dB impedance bandwidth is 1.045 GHz, a frequency range of 2.61 to 3.65 GHz. The reflection coefficient for both antennas is shown in Figure 8. Figure 9 illustrates a three-dimensional picture of the antenna's radiation pattern at 3 GHz using CRR. Figure 10 illustrates the maximum gain for both antennas as a function of frequency.

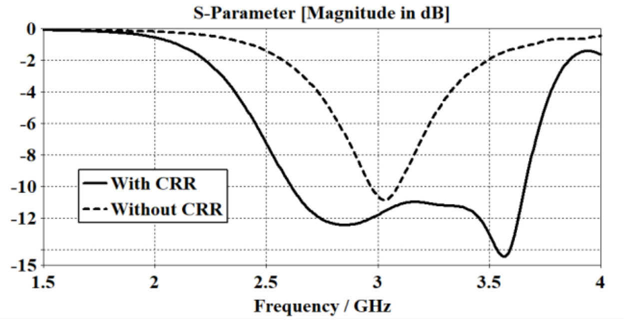

Figure 8. Return loss of both antennas without and with CRR

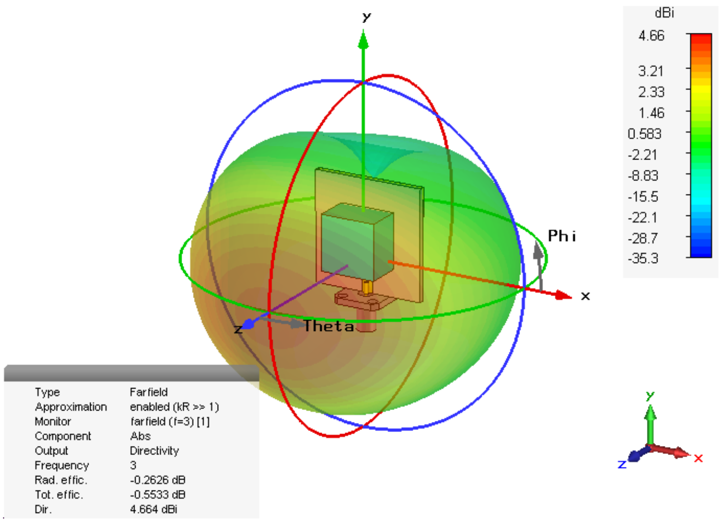

Figure 9. The radiation pattern in three-dimensional view for the antenna with CRR at 3 GHz

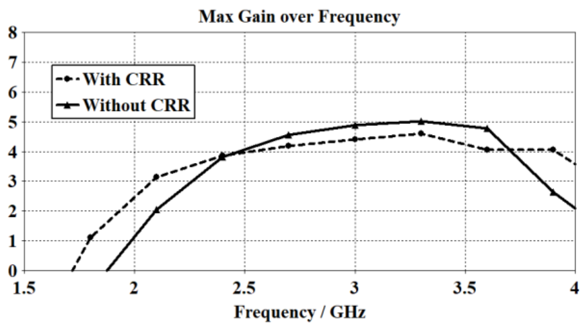

Figure 10. The gain for the without and with CRR antennas

Table 4 compares the antennas with and without CRR for the following metrics at 3 GHz such as the antenna bandwidth, gain, directivity, and radiation efficiency. This CRR technique, unlike other techniques in the literature, the CRR technique has minimal impact on directivity and gain.

Table 4. The parameters result of the antennas without and with CRR

Parameter	Antenna without CRR	Antenna with CRR
Impedance bandwidth	121 MHz	1.043 GHz
Directivity at 3 GHz	5.09 dBi	4.66 dBi
Gain at 3 GHz	5.88 dB	4.40 dB
Rad. Efficiency at 3 GHz	95%	94%

4. CONCLUSION

The impedance bandwidth for dielectric resonator antennas was enhanced using a CRR technique. The CRR is scratched into the ground plane and works with the feeding mechanism which is microstrip feedline to increase impedance bandwidth while maintaining other antenna parameters. As a consequence, this method may easily achieve a wide bandwidth with slightly effects on other antenna parameters for examples efficiency, directivity and gain. The suggested antenna's bandwidth is increased by 769 percent compared to the antenna without the complementary ring resonator technique. Additional research is required to fabricate the antenna in the future.

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