DESIGN AND PERFORMANCE ANALYSIS OF UWB CIRCULAR RING ANTENNA WITH DEFECTED GROUND STRUCTURE

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Abstract

A compact circular ring antenna with defected ground structure (DGS) has been design for Ultra-Wide Band (UWB) applications. Initially, a circular patch antenna is design by introducing a rectangular DGS structure. Further, slot has been inserted in circular patch to improve the impedance bandwidth. The proposed design covers the frequency range of 2.4-10.4GHz below -10dB. Proposed antenna has design and fabricated on FR-4 substrate having 1.5mm, 4.3 thickness and dielectric constant, respectively. The performance of the designed antenna is analyzing with optimized dimensions in terms of return loss, VSWR, radiation pattern, gain characteristics, group delay and surface current distributions. Further, performance analysis of the proposed antenna has also been compared with existing suggested antennas in literature with compact in size. The fabricated antenna shows a good result with simulations software.

Keywords:

Circular Ring, Defected Ground Structure, Fractional Bandwidth, Micro-Strip, Ultra-Wideband

1. INTRODUCTION

The demand of UWB antenna is increases day by day in the wireless communication system due to high data rate. Different techniques and applications are operated on UWB frequency spectrum, using ultra short pulses in the order of nanoseconds [1].

Several UWB antennas are designed by different shapes of patch or radiating elements like square, circular, ring, elliptical, pentagonal, hexagonal [2]-[10]. To improve the bandwidth of antenna different defected ground planes are reported by several authors [11] [12]. Further, using different shapes of DGS or slots in ground and patch can also enhance the bandwidth, gain and directivity [13]-[15]. The comparative performance of different wideband antennas is reported by several authors with impedance bandwidth and gain characteristics due to their compact structure using DGS [16]-[19].

To increase the radiated power, the directional antennas are designed by the several researchers. Due to regular or symmetrical defected ground structures and radiating elements gives the directional characteristics of antennas [20]. Directional antenna is used to radiate the power to increase the performance of the antenna. There are many directional UWB antenna has also been designed with different patch and partial ground plane. Further, wide band antennas were designed with for the frequency range of 3.1-10.6GHz using square, circular, ring and rectangular slots in patch as well as ground plane [21] [22]. Recently, UWB circular antenna is design using fuzzy approach but size of the antenna is large [23]. Further, recently Patil et al. [31] proposed the UWB antenna having size 108×108mm², but the fractional bandwidth and frequency band of the antenna are much smaller.

In this work, a compact circular ring UWB antenna with slotted ground has been presented for the applications of medical imaging and wall penetration. Design antenna achieves 2.4-10.4GHz UWB band with five resonant frequencies of 2.8, 4.5, 6.4, 8.2 and 9.4GHz, which attain 125% fractional bandwidth. The proposed antenna improves the fractional bandwidth, gain and directive radiation pattern when compared with existing reported work in literature [22]-[24], [29]-[31]. Hence, the design antenna is useful for wall imaging and radar system.

The presented works are organized as following sections. Section 2 elaborates antenna design, section 3 have comparative parametric analysis, section 4 have measured result and discussion and finally conclusion of the paper is done in section 5.

2. PROPOSED DESIGN

A circular patch antenna is designed by the arrangement of partial slotted ground structure and circular ring patch as shown in Fig.1. A circular ring antenna consist an outer and inner radius R_1 and R_2 , respectively. It has been fabricated on FR-4 substrate with dielectric constant of $\epsilon_r = 4.3$. The length and width of the antenna are $L = 50\text{mm}$ and $W = 42\text{mm}$, respectively. On the back side of the substrate a partial ground plane is kept having length and width are $L_g = 20\text{mm}$, $W = W_g = 42\text{mm}$, respectively. The width of micro-strip line is fixed on $W_f = 2\text{mm}$ to achieve well impedance matching. The length of feed line is $L = L_g + h = 20.8\text{mm}$ which is a combination of ground length and feed gap. Further, to achieve better impedance bandwidth the inner radius R_2 is inserted in circular patch. The simulation is done by software Electromagnetic (EM) simulator.

The inner and outer radius of the proposed antenna are calculated based on equations [28].

$$R_1 = \frac{58 \times 10^9}{f_r \sqrt{\epsilon_{\text{reff}}}} \quad (1)$$

$$R_2 = 0.30 R_1 \quad (2)$$

where, R_1 and R_2 are outer and inner radius, respectively, f_r is resonant frequency of antenna, and $\epsilon_{\text{reff}} = \sqrt{\frac{\epsilon_r + 1}{2}}$ effective dielectric constant of substrate. The lowest resonant frequency of the proposed design is 2.8GHz. The detailed design parameters of circular ring antenna are given in Table.1.

Fig.1. Geometry of (a) circular disc antenna (b) proposed circular ring antenna; (c) side view of structure

Table.1. Design Parameters of the Antenna

Parameters	Description	Dimensions (mm)
L	Length of Antenna	50
W	Width of Antenna	42
h_s	Height of Dielectric Substrate	1.5
L_g	Length of Ground	20
W_g	Width of Ground	42
W_f	Width of MS Feed line	2
L_f	Length of MS Feed line	20.8

R_1	Outer Radius of Patch	10
R_2	Inner Radius of Patch	3
h	Height of Feed Gap between Ground and Feed line	0.8

3. COMPARATIVE PARAMETRIC ANALYSIS

3.1 RETURN LOSS (S_{11} dB) VARIATION

The parametric analysis has been carried out by varying radius of circular patch (R_1 , R_2), feed width (W_f) and separation between ground plane and circular patch and width of ground of two different designs as shown in Fig.1. The comparative return loss variation of circular disc and ring antennas are shown in Fig.2. A circular disc antenna bandwidth can be enhanced by inserting a slot in radiating patch. As seen in Fig.2, the bandwidth of a disc antenna is obtaining 2.6 - 10.3GHz below -10dB. The return loss variations are calculated -15.4dB, -31.2dB, -13.2dB, -18.7dB, -17.2dB at 2.8GHz, 4.7GHz, 6.5GHz, 8GHz, 9.6GHz resonant frequency, respectively. Further to improve the bandwidth of antenna, a circular slot of radius R_2 is 3mm has been introduced in radiating patch. By inserting a slot, lower cut off frequency 2.6GHz is slightly shifted to 2.4GHz and higher cut off frequency 10.3GHz is shifted to 10.4GHz and frequency band of 2.4-10.4GHz has been obtained at 2.8GHz, 4.5GHz, 6.4GHz, 8.2GHz and 9.4GHz resonance frequencies. The fractional bandwidth of proposed design achieves 125%, whereas fractional bandwidth of the reference antenna is 119%. Therefore, proposed antenna is suitable for radar, medical imaging, wall imaging and ground penetrating.

Fig.2. Simulated return loss (S_{11} dB) plots of circular disc and circular ring UWB antenna

3.1.1 Return loss variation with outer radius (R_1) and inner radius (R_2):

The comparative return loss variation for circular disc and circular ring antenna has been shown in Fig.3. It can be observed that the impedance matching has been poor at $R_1 = 10$ mm for circular disc between 3-4GHz frequency also the higher cut off frequency is shifted towards lower side. Whereas the impedance

bandwidth has been improving at the same dimensions of the outer radius for circular ring antenna. Therefore, impedance bandwidth achieves 125% in the band of 2.4-10.4GHz. Also impedance matching has been improving in entire specified UWB band by inserting a ring slot in the patch. Hence, the optimized dimensions have been chosen for outer and inner radius $R_1 = 10\text{mm}$ and $R_2 = 3\text{mm}$, respectively as can be seen in Fig.3 and Fig.4.

3.1.2 Return loss variation with micro-strip feed width (W_f):

The effect of feed width on return loss are shown in Fig.5 for circular disc and circular ring antenna. It can be observed that by increasing the value of feed width the lower as well as higher cut off frequency is almost constant for both designs but the impedance bandwidth is increases for the circular ring antenna. The impedance matching has also been improved in the entire UWB band. Therefore, the optimized dimension of the feed width is taken as $W_f = 2\text{mm}$.

3.1.3 Return loss variation with ground plane width (W):

It is observed that lower the higher cut off frequency of the both designs are almost same when width of ground is varying from 40mm to 44mm. Further, the lower impedance matching has been obtained (see Fig.6) between 3-4GHz. Whereas in case of circular ring design the lower cut off frequency slightly shifted to lower side at the same dimensions and impedance matching has been improve in the frequency band 3-4GHz. Therefore the optimized dimension of the ground is select at $W=42\text{mm}$.

Fig.3. Effect of outer radius (R_1) of both of circular disc and circular ring antenna

Fig.4. Simulated outcomes by varying inner radius (R_2) of circular ring antenna

3.1.4 Return Loss variation with ground length (L_g):

Return loss variation for circular disc and circular ring antennas has been shown in Fig.7. It has been seen observe that when length of the rectangular ground is varying from 19mm to 21mm lower cut off frequency shifted toward the lower side and higher resonant frequencies are shifted toward the higher side, Therefore, the impedance matching is not good at $L_g = 19\text{mm}$ and 21mm for both the antennas. Further, better impedance matching has been achieved at $L_g = 20\text{mm}$ for circular ring antenna.

Fig.5. Simulation return loss of micro-strip line W_f for circular disc and circular ring antenna

Fig.6. Effect of width of antenna W on return loss of the circular disc and circular ring antenna

Fig.7. Effect of ground length L_g on return loss of the circular disc and circular ring antenna

The parametric performance analysis of the proposed design has been given in Table.2 in terms of fractional bandwidth, return loss, resonance frequencies.

Table.2. Parametric performance analysis with variations of R_1 , R_2 , W_f , W and L_g

Circular Ring Antenna	Parameters Variation (mm)	Resonance Frequencies (GHz)	Return Loss (dB)	Frequency Band (GHz)	Impedance BW (%)
Outer Radius of Patch	$R_1 = 10$	2.8/4.5/6.4/8.2/9.4	-34.7/-18.7/-15.9/-15.7/-17	2.4-10.4	125
	$R_1 = 10.5$	2.9/4.1/6.4/9.6	-30/-20.7/-13.8/-21.8	2.4-7	97
	$R_1 = 11$	2.9/6.4/9.5	-19.7/-10.4/-28.3	2.4-4.8	66
	$R_2 = 1$	2.8/4.5/6.5/8.2/9.4	-34.7/-19.6/16.6/-15.6/-16.3	2.4-10.4	125

Inner Radius of Patch	$R_2 = 3$	2.8/4.5/6.4/8.2/9.4	-34.7/-18.7/-15.9/-15.7/-17	2.4-10.4	125
	$R_2 = 5$	2.8/4.4/6.5/8.2/9.4	-35.4/-17.0/-17.7/-15.8/-15.4	2.4-10.2	123
	$R_2 = 7$	2.6/4.4/6.3/9.5	-31.7/-12.5/-26.5/-16.1	7.3-10.3	34
Feed Width of Micro-strip Line	$W_f = 1.5$	3/4.3/6.6/9.7	-25.3/-25.1/-17/-17.4	2.4-11.2	129
	$W_f = 2$	2.8/4.5/6.4/8.2/9.4	-34.7/-18.7/-15.9/-15.7/-17	2.4-10.4	125
	$W_f = 2.5$	2.7/4.5/6.5/9.6	-29.3/-15.9/-14.1/-19	2.3-7.1	102
Width of the Antenna	$W = 40$	2.8/4.5/6.5/9.6	-44.1/-22/-16.3/-17.3	2.4-10.7	126
	$W = 42$	2.8/4.5/6.4/8.2/9.4	-34.7/-18.7/-15.9/-15.7/-17	2.4-10.4	125
	$W = 44$	2.8/4.4/6.4/8.9/9.2	-30.6/-16.5/-15.7/-18.4/-16.9	2.4-10.2	123
Ground Length	$L_g = 19$	2.6/6.1/8.0	-22.3/-20.6/-31.5	3.7-7.1	62
	$L_g = 20$	2.8/4.5/6.4/8.2/9.4	-34.7/-18.7/-15.9/-15.7/-17	2.4-10.4	125
	$L_g = 21$	3.2/6.7/9.8	-23.7/-10/-22.5	2.5-4.8	63

3.2 VSWR

The mismatch power between antenna and feed line has been defined by VSWR of any antenna. The comparative simulated VSWR plot of circular disc and circular ring antenna has been shown in Fig.8. The value of VSWR of circular ring antenna is lower than reference antenna which is 1.5. Therefore, the proposed antenna gives the better impedance matching between micro-strip feed line and radiator.

Fig.8. Simulated VSWR variation for circular disc and circular ring antenna

3.3 GAIN

The simulated gain variation of proposed antenna and circular disc antenna has been shown in the Fig.9. It can be seen that; the proposed antenna gives slightly higher gain than circular disc antenna. Hence simulated maximum peak gain is 6.5dBi for

circular ring antenna whereas maximum peak gain is 6.4dBi for circular disc antenna at the same frequencies (9.4GHz). Therefore, both antennas give the identical gain in frequency band of 3-9.5GHz.

3.4 GROUP DELAY

The comparative simulated group delay for circular disc and circular ring antenna are shown in Fig.10. The maximum group delay variation for circular disc is 3ns whereas the group delay variation circular ring antenna is up to 1ns. Therefore, the group delay variation of proposed UWB antenna show a linear phase when compare to a circular disc antenna.

3.5 SURFACE CURRENT DISTRIBUTIONS

The simulated surface current distribution of the proposed antenna and circular disc antennas are shown in Fig.11 at 2.8GHz and 6.5GHz resonant frequencies, respectively. It is observed that the current is mainly concentrates on the edges of circular patch, MS feed line and ground plane which increases the path length of the current due to their symmetrical defected structures. Hence the resonant frequencies of circular disc antenna are decreases when compared with circular disc antenna due to increase the path length of current.

Fig.9. Simulated gain of circular disc and circular ring antenna

Fig.10. Simulated group delay of circular disc and circular ring antenna

Fig.11. Simulated surface current distribution (a), (c) for circular disc antenna and (b), (d) for circular ring antenna at different resonant frequencies, respectively

4. MEASURED RESULTS AND DISCUSSIONS

Performance of the proposed antenna has been affected mainly due to inner and outer radius, feed width and separation between ground and patch. The detailed comprehensive study has been discussed in section 3. Therefore, proposed circular ring antenna has been fabricated with optimized dimensions as given in Table.1 and measurement has been carried out on Vector Network Analyzer (VNA) as shown in Fig.12. It can be seen in Fig.13

measured and simulated results are approximately same. The minor variations in measurements is due to soldering of SMA connector and atmospheric conditions: a) $f = 2.8\text{GHz}$, b) $f = 2.8\text{GHz}$, c) $f = 6.5\text{GHz}$ and d) $f = 6.5\text{GHz}$.

Fig.12. Fabricated circular ring antenna and measurement setup
(a) Front view; (b) Back view; (c) Proposed antenna measurement setup

It has been observed that 120% fractional bandwidth is achieved by measurements in the frequency band of 2.6-10.4GHz below -10dB. Further, the simulated radiation pattern of circular disc and circular ring antenna are shown in Fig.14 at different resonant frequencies the calculated half power beam width (HPBW) or 3dB angular width of circular disc is 81, 62.6, 50.9 at 2.8GHz, 6.5GHz and 8GHz resonant frequencies, respectively. Further the angular width of proposed antenna is 93.5, 49.6 and 34.2 at same resonant frequencies. Therefore, the radiation pattern of the circular disc antenna shows a bidirectional pattern whereas the proposed antenna gives a directional radiation pattern. Hence the design antenna is suitable for radar system.

Fig.13. Measured and simulated return loss (S_{11}) plot of the fabricated antenna

Fig.14. Simulated radiation pattern (a), (b), (c) for circular disc, (d), (e), (f) for circular ring antenna

Further the performance analysis of circular disc and circular ring antennas are given in Table.3 in terms of bandwidth, gain, impedance bandwidth, half power beam width and applications. Furthermore, the comparative analysis of the proposed antenna and earlier reported antennas in literature have also been given in Table.4.

Table.3. Calculated and simulated parameters of circular disc and circular ring antenna

Antenna Parameter	Circular Disc (Reference Antenna)	Circular Ring Antenna
Resonance Frequency (GHz)	2.8	2.8
	4.7	4.5
	6.5	6.4
	8	8.2
	9.6	9.4
-10dB Bandwidth (GHz)	2.6-10.3	2.4-10.4
Gain (dBi)	6.4	6.5
Impedance Bandwidth (%)	119	125
HPBW (°)	81/66/62/50/105	93/123/49/32/32
Applications	Military, Precision Location and Tracking	Medical Imaging and Ground Penetrating Radar

Table.4. Comparative performance analysis of proposed antenna and previously reported antennas in literature.

Reference	Antenna Size (mm ²)	Frequency band (GHz)	Fractional Bandwidth (%)	Gain (dBi)
[21] 2010	$0.7\lambda_0 \times \lambda_0$ (31.2×44.2)	3.6-10.1	94	NA
[22] 2012	$0.6\lambda_0 \times 0.7\lambda_0$ (30×32)	3.1-10.6	109	5
[23] 2013	$1.6\lambda_0 \times 1.6\lambda_0$ (50×50)	8-12	40	6.4
[24] 2014	$0.5\lambda_0 \times \lambda_0$ (30×30)	4-7.2	57	3
[25] 2015	$0.8\lambda_0 \times 0.8\lambda_0$ (32×32)	6.4-9.5	39	8.2
[26] 2016	$1.3\lambda_0 \times 1.3\lambda_0$ (50×50)	4.1-11.5	95	8.4
[27] 2016	$0.5\lambda_0 \times 0.5\lambda_0$ (30×30)	2.8-8.9	104	6.3
[29]2016	$1.1\lambda_0 \times 1.2\lambda_0$ (55×56)	1.58-11.54	151	5.5
[30]2017	$0.6\lambda_0 \times 0.5\lambda_0$ (30×26.4)	2.87-10.4	113	NA
[31]2017	$1.6\lambda_0 \times 1.6\lambda_0$ (108×108)	3.1-6	63	9.7
Proposed Antenna	$0.9\lambda_0 \times \lambda_0$ (42×50)	2.4-10.4	125	6.5

5. CONCLUSIONS

In this paper, a circular ring UWB antenna having partial ground plane has been presented and compared with circular disc antenna. To achieves better impedance matching the optimized dimensions of the proposed antenna have been carried out, fabricated and tested. The design antenna archives 125% fractional bandwidth in the UWB band of 2.4-10.4GHz. The circular ring antenna operates into five resonant modes of 2.8, 4.5, 6.4, 8.2 and 9.5GHz in the specified UWB band. The design antenna gives good agreement between measured and simulated results. Further, the antenna size, bandwidth, gain characteristics and fractional bandwidth of the proposed antenna have also been compared with earlier reported antennas in literature.

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