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SIZE MINIATURIZATION OF SLIT-BASED CIRCULAR PATCH ANTENNA WITH DEFECTED GROUND STRUCTURE

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Received 15 March 2015

ABSTRACT: *This letter proposes a novel compact circular patch antenna that is simulated, fabricated, and measured for different wireless applications. Traditional circular antenna is modified with dual T-shaped slits placed on top and bottom positions, to obtain the tri band resonant frequencies. Metallic ground plane behind the radiating patch is placed with a dual E-shaped defected ground structure (DGS) achieving size miniaturization and bandwidth (BW) enhancement at dual bands. Antenna is well performed with and without placement of DGS in terms of obtained gain. Shape, dimensions of the finite ground plane, and frequency shift property using defect on the patch are the key factors in improving the BW and reducing the size. BWs of 3.9 and 3.6% are obtained for 1.56 and 2.47 GHz bands, respectively. The optimized dimensions of DGS are selected without degrading the antenna performance. This single layer probe feed antenna is analyzed, simulated using IE3D tool and also performed experimentally. Frequency shift technique of DGS would attain compact antenna size and is also capable of providing dual bands with better impedance matching and acceptable gain.* © 2015 Wiley Periodicals, Inc. Microwave Opt Technol Lett 57:2410–2413, 2015; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.29337

Key words: *defected ground structure; circular patch; impedance bandwidth; gain; probe feed*

1. INTRODUCTION

Planar patch antenna have been researched and developed extensively in the last three decades and favorites for both military and commercial sectors. With recent advancements in field of communications, the demand of dual/tri band antennas with enhanced bandwidth (BW) was realized [1–3]. Numerous designs with different shapes of slots and slits [4] are explained in the literature which produces enhanced BWs. There has been an increasing interest in the applications of defected ground structure (DGS) in microwave and millimeter wave applications [5]. DGS is realized by etching a defected pattern in the ground plane and this etched pattern interfered with the shield current distribution in the ground plane which affects the characteristics of the antenna. This disturbance creates beneficial capacitance and inductance effect on the structure. Resonance shift property of DGS makes the frequencies to resonate at lower values and due to which the size reduction is obtained. Sharma et al. [6] discussed a technique to resonate the antenna at multibands using DGS.

Many shapes of DGS have been studied such as concentric ring, circle, elliptical, and V-slots [7]. Shape, dimension, and position of the defect determine lowering of the frequency range. Several types of slots and defects are trenched on the metallic ground plane so that the size could be reduced and impedance BW and gain can be enhanced [8]. Investigations on tri bands using circular-shaped antenna [9], C-shaped strips for wireless applications [10], dual band antenna using pin patch [11] and using ENG [12] are reported.

This article presents further investigation of dual E-shaped DGS etched on ground plane and influence the enhancement of impedance BW and improvement of radiation pattern, but also affects the actual gain. The antenna structures without and with DGS are, therefore, presented and compared. The properties such as return loss, VSWR, impedance BW, gain are simulated and discussed. The proposed antenna design is analyzed by simulation software Hyper Lynx IE3D.

2. ANTENNA THEORY AND DESIGN

A Circular patch with radius $(R) = 12$ mm on an infinite slab of 3.175-mm thick is printed on (RT/Duroid 5880) of dielectric constant $\varepsilon_r = 2.33$ was analyzed from 2 to 6 GHz in 2 MHz steps. Pictorial representation of top and bottom portion of the designed antenna is shown in Figures 1(a) and 1(b), respectively. Due to computationally efficient when compared with other regular-shaped counterparts, a circular geometry is chosen. For the design of the patch, the desired expression [13] of operating frequency with the effective radius is obtained from Eq. (1),

$$f_{nm} = \frac{\chi_{nm} c}{2\pi a_e \sqrt{\varepsilon_r}}, \text{ where } \chi_{nm} = k_{11} a \text{ and } k_{11} = \frac{2\pi\sqrt{\varepsilon_r}}{\lambda_0} \quad (1)$$

χ_{nm} is the mth zero of derivative of Bessel function, $J_n(\chi_{nm}) = 0$ and a is the radius of the circular patch.

The computational equations give the resonant frequencies with selective dimension of the patch. The conventional circular patch is modified with asymmetric dual T-shaped slits cut at the top and bottom positions due to which additional resonant modes exist. The relation between a and a_e is used to obtain the required value for a given h, ε_r, and f_r with actual radius "a" and is given in Eq. (2),

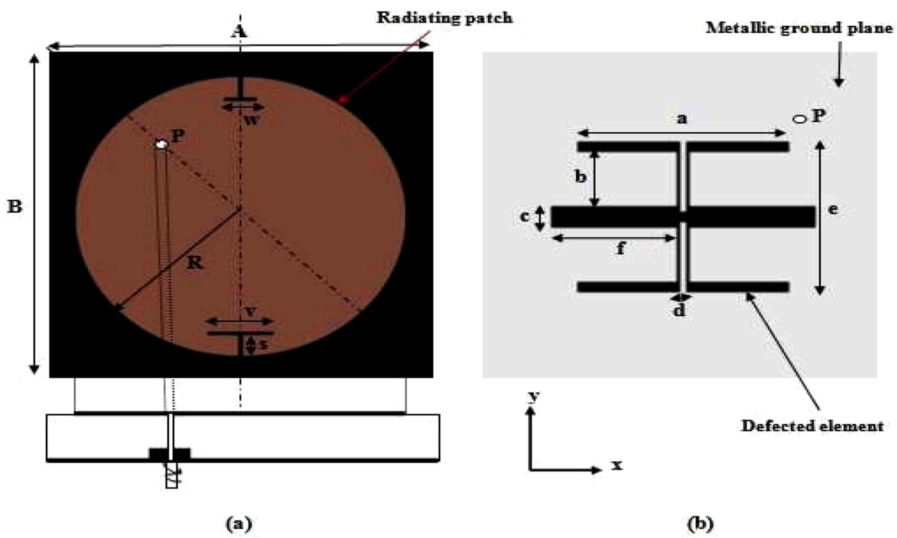

Figure 1 (a) Top view of the patch (radiating patch) and (b) bottom view of the patch (DGS). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

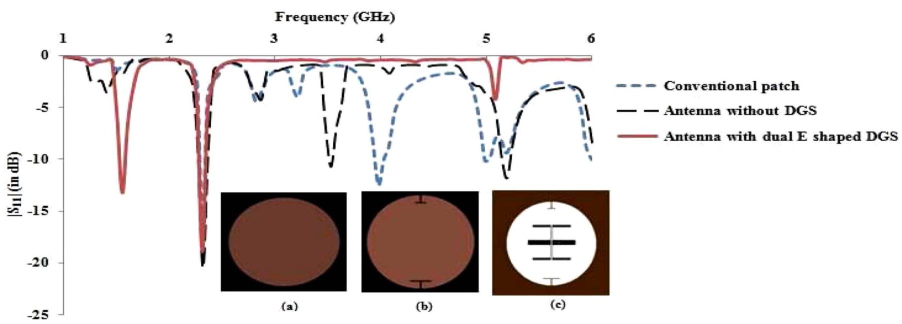

Figure 2 Return loss characteristic curve for the design structure of (a) conventional patch, (b) antenna without DGS, and (c) antenna with dual E-shaped DGS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

$$a_e = \left[1 + \frac{2h}{\pi a \varepsilon_r}\left(\ln\frac{\pi a}{2h} + 1.7726\right)\right]^{1/2} \quad (2)$$

Further, to enhance the BW dual E-shaped slot structure is chosen as defect element on the ground plane. By controlling the dimensions of the *T*-shaped slits along with the narrow slot lengths at the center of the patch, antenna resonates at tri bands with wide BW. The optimized dimensions (in mm) of *T*-slits and dual E-shaped DGS slot on the metallic ground plane is given as: $A = 32$, $B = 30$, $R = 12$, $w = s = 2$, $v = 5$, $b = 5.5$, $c = 2$, $d = 0.5$, $e = 14$, $f = 9.5$ and the coaxial probe feed position is located at point *P* with (x, y) as $(-8, 7)$ for better impedance matching.

3. SIMULATIONS AND EXPERIMENTAL RESULTS

The design evolution of antennas 1–3 are simulated using IE3D software. The basic circular patch is simulated with optimized coaxial probe fed position *P* as shown in Figure 2(a) and found to obtain dual bands. The fact that the design of such antennas is to use a method of cut and try supported by intuitive and creative ideas. This is further modified with asymmetric *T*-shaped slits as shown in Figure 2(b) by which an additional band is resonated, which is narrow in BW. Dual E-shaped slot etched on the ground plane produces tri bands with enhanced BW. The proposed final iteration, though obtain better radiation patterns and high impedance BW, provides less gain at respective resonant frequencies. The extracted 10-dB impedance BW (MHz) and gain (in dBi) for all three iterative structures are tabulated in Table 1. It is observed that the operating frequencies shifted to lower values, indicating the size reduction of the patch. The return loss characteristics for the antenna iterations designed is shown in Figure 2. VSWR value for all the iterations is maintained less than 2 for better impedance matching. The proposed antenna is fabricated and tested experimentally using Agilent E5071C vector network analyzer. Top view and bottom view of

TABLE 1 Simulated Results of the Proposed Antenna Compared with Conventional Patch

Structure	Resonant Freq. (GHz)	Impedance Bandwidth (MHz)	% BW	Gain (dBi)
Conventional	2.315	50	2.16	3.5
	4	60	1.5	5.1
Antenna without DGS	2.28	60	1.85	4.49
	3.51	60	1.70	−1.37
	5.18	60	1.16	8.25
Antenna with dual E-shaped DGS	1.56	42	2.35	4.6
	2.3	62	2.69	3.99

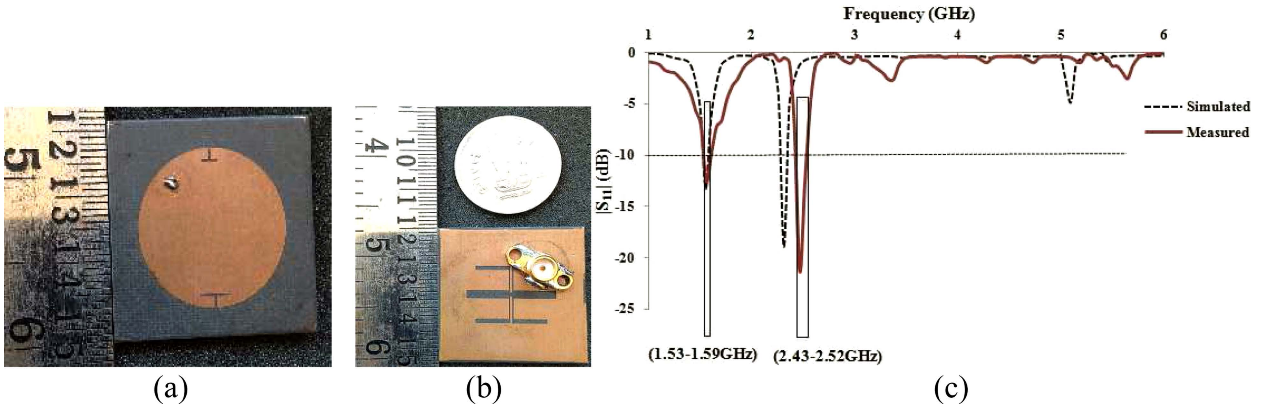

Figure 3 Fabricated antenna (a) top view, (b) bottom view, and (c) measured and simulated return loss curve. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

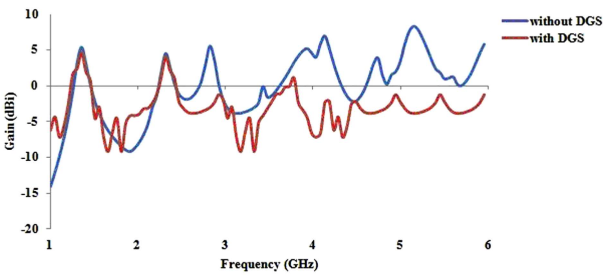

Figure 4 Gain versus frequency for antenna with and without DGS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

demonstrated antenna is shown in Figures 3(a) and [3](b), respectively. The measured and simulated return loss curve for the antenna is presented in Figure 3(c). The impedance BW values at dual resonant modes produce 60 MHz and 90 MHz, respectively.

The frequencies for antenna without DGS resonate at 2.28, 3.51, and 5.18 GHz, respectively, and the measured antenna with dual E-shaped DGS resonates at 1.56 and 2.475 GHz. The return loss curve confesses that the resonant frequencies for the proposed antenna are shifted to lower values with better impedance BW. The gain versus frequency response for the antenna with and without DGS is denoted in Figure 4 and outperforms the consistent maintenance of values at low frequencies with resonant shift method. Measured and simulated copolarized and

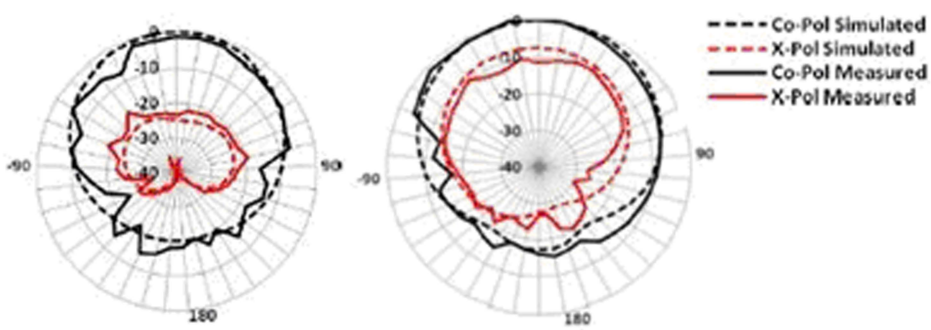

Figure 5 Simulated and measured co and cross polarized radiation patterns in *E*-plane (*YZ*) (a) 1.56 GHz and (b) 2.475 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

TABLE 2 Performance Comparison of Different Circular-Shaped Antenna Types with Proposed Antenna

Year/ Reference	Antenna Description	Volume (mm^3)	Freq. (GHz)	10-dB RLBW (%)	Gain (dBi)
2013 [9]	Tri band circular antenna	60 × 60 × 0.8	2.4	11.1	3.2 dBc
			3.5	11	4.3 dBc
			5.2	5.3	5.2 dBc
2009 [10]	Tri band antenna	44 × 20 × 0.76	2.55	13	1.2
			3.4	13	
			5.2	10	
2008 [11]	Dual band pin patch	32 × 32 × 0.4	2.5	22	1
			5.7	34	
2014 [12]	Dual band using ENG	60mm with	2.56	–	1.83
		2 mm thickness	4.26		2.2
[Proposed work]	Slit-based circular patch with	**32 × 30 × 3.175**	**1.56**	**3.9**	**4.4**
	dual E-shaped DGS		**2.47**	**3.6**	**3.8**

cross-polarized radiation patterns observed in *E*-plane (*YZ*-plane) for both dual band frequencies are shown in Figures 5(a) and [5](b). Table 2 illustrates the detailed comparative results of different circular-shaped antenna configurations with the proposed work. The parameters obtained denote that compact size and acceptable gain are obtained with the proposed antenna.

From the observations, it shows that proposed antenna satisfies the operation of frequency lowering with the introduction of DGS on to the metallic ground plane. It is clearly shown that a gain of 4.6 dB and good radiation pattern are observed at 1.56 GHz lower frequency band. Size reduction of 68% is obtained with the proposed dual band antenna with the frequency shift property.

4. CONCLUSION

In this letter, a slit-based circular patch antenna with dual E-shaped DGS has been designed and presented to obtain dual bands and enhanced impedance BW. From the iterations transformed from classic circular patch to modified proposed antenna, it is shown that additional resonant modes obtained. By means of DGS, dual impedance bands which can meet the requirements for GPS L1 band and ISM band standards have been achieved. Moreover, patch antenna has advantage of giving better radiation patterns and high impedance at both dual bands. Size reduction is also obtained from the frequency shift property with the usage of defect. Appreciable gain is obtained besides the changes made on the ground plane.

ACKNOWLEDGMENT

The authors would like to acknowledge Prof. NVSN. Sarma, Professor in Department ECE, NIT Warangal for his immense support during the fabrication and measurements of the developed antenna system.

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A CPW-FED TRIPLE BAND OCSRR EMBEDDED MONOPOLE ANTENNA WITH MODIFIED GROUND FOR WLAN AND WIMAX APPLICATIONS

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Received 16 March 2015

ABSTRACT: *A coplanar waveguide fed triple band antenna is proposed for wireless local area network (WLAN) and worldwide interoperability for microwave access (WIMAX) applications. The proposed antenna consists of rectangle monopole with modified ground plane and open complementary split ring resonator (OCSRR) loading. The overall size of the antenna is 30 × 40 × 0.8 mm^3, which provides Omnidirectional pattern in all three bands. The prototype of antenna is designed, fabricated, and measured. The measured −10 dB impedance bandwidths are 300 MHz (2.40–2.70 GHz), 680 MHz (3.32–4.00 GHz), and 1040 MHz (4.76–5.8 GHz) with resonance frequency at 2.6 GHz,3.4GHz, and 5GHz, respectively, which is suitable for WLAN/WiMAX applications. Parametric study on OCSRR is discussed to validate the results. Simulated and measured results of the antenna are presented and discussed.*
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Key words: *metamaterials; multiband antenna; monopole antenna; open complementary split ring resonator; wireless local area network; worldwide interoperability for microwave access*

1. INTRODUCTION

Due to the tremendous growth of wireless communication applications, there is an enormous demand for antenna with multiband operation. In particular, wireless local area networks (WLANs) and Worldwide Interoperability for Microwave Access (WiMAX) technology have been extensively used in commercial, industrial, and medical applications. The allocated spectrum for these WLAN systems is 2.4–2.483, 5.15–5.35, and 5.725–5.85 GHz centered at 2.4, 5.2, and 5.8 GHz, respectively. And for WIMAX is 2.5–2.69, 3.3–3.8, and 5.25–5.85 GHz centered at 2.5 GHz, 3.5 GHz, and 5.8 GHz, respectively. Various design strategy have been proposed for the design of multiband antenna. Planar version of monopole antenna and slot antenna are the two most widely studied for multiband antenna. Planar monopole antennas have received great attention than slot antenna due to their promising features like low profile, wide bandwidth, and good radiation characteristics.

Dual band was generated by surrounding the monopole by ground plane on both top and bottom with microstrip line to connect both ground planes [1]. The radiating element in the