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Defected Ground Magneto-Electric Dipole with Trivial Back Radiation

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Abstract—A magneto-electric dipole antenna with high front to back ratio (FBR) for femtocell base station is proposed. By using circular defects in the ground plane, the back radiation of the antenna is reduced. The prototype antenna achieves high FBR without affecting the bandwidth and gain. At $S_{11} = -10\,\text{dB}$, the simulated and measured impedance bandwidths of the proposed antenna are 58.06% (1.54–2.8 GHz) and 60.9% (1.55–2.91 GHz), respectively. The measured FBR value ranges from 21 to 29 dB. Stable unidirectional radiation pattern at both planes and average gain of 7 dBi are also obtained.

1. INTRODUCTION

Unidirectional broadband antenna such as magneto-electric dipole (MED) antenna has become popular among researchers due to its excellent radiation characteristics such as broad beamwidth and stable directional pattern [1–8]. However, most of the MED antennas were designed either to improve bandwidth [9–15] or to reduce the size [16–19]. In [9], an E-type dipole with stairway feed was discussed with impedance bandwidth of 60.3% (1.84–3.43 GHz). A MED with trapezoidal patches and modified ground structure was proposed in [10]. The antenna had a bandwidth of 91% (3.05–8.2 GHz). Using bowtie dipole and folded vertical patch, the wideband MED with a measured bandwidth of 95.2% (1.65–4.65 GHz) was reported in [11]. A MED antenna designed with bowtie electric dipole and center fed loop was studied in [12]. The antenna had a bandwidth of 110% (3.08–10.6 GHz). Further, a few dual-band MEDs were also proposed using two-layer geometry [13, 14] and simpler geometry [15].

The size of the MED, particularly, the height of the antenna can be reduced using different ground geometries [16–19]. Ge and Luk [16] presented a low profile MED antenna with cavity reflector and coaxial feed to achieve a small size of $112 \times 112 \times 20\,\text{mm}^3$. Similarly, Li and Luk [17] demonstrated a low profile antenna with reduced size of $95 \times 120 \times 10.79\,\text{mm}^3$ using U-shaped reflector and modified feed. In [18], the overall dimension of the MED is reduced to $68 \times 56 \times 20\,\text{mm}^3$ by employing minimum ground structure. With H shaped tapered ground, the size of the MED [19] was reduced to $36 \times 36 \times 1.5\,\text{mm}^3$. To the best of the authors' knowledge, none of the MED antenna is designed to suppress the back lobe while retaining the other properties like bandwidth and/or gain of the antenna.

Generally, the surface waves generated on the finite ground plane tend to diffract after reaching the edge or discontinuity. This diffracted energy interferes with desired radiation and leads to undesired back lobes. In the literature, various techniques like high impedance surface ground [20] or soft surface ground [21] are proposed to suppress the back radiation. Therefore, in this paper, we have shown the back lobe of the MED can be easily brought down by simply etching circular slots in the ground.

In this paper, we present a simple technique to improve the front to back ratio (FBR) of the MED. The fabricated antenna is composed of main electric and magnetic dipoles shorted to defected ground. With high FBR and stable radiation characteristics it will fulfill the deployment requirement of small cells.

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2. ANTENNA CONFIGURATION AND ANALYSIS

The configuration of the proposed MED is shown in Fig. 1. It is composed of two horizontal semicircular patches with slit and two vertical rectangular patches shorted to the defected ground. The electric dipole (semicircular patches) and magnetic dipole (shorted rectangular patches) of the proposed complementary antenna contribute to symmetrical unidirectional pattern at both the planes. The radius of semicircular patch is r, while the width of the rectangular patch is $2r$. The two horizontal patches are separated by a gap distance G. The slit on the horizontal patches are employed to improve the return loss characteristics. The horizontal patches and the ground ($GL \times GW$) are isolated by H distance which is approximately equal to a quarter of wavelength at 2.2 GHz. The hook shaped structure with segments a, b and c is used to feed the dipoles. The length $(a+b+c)$ and width (d) of the segments is selected to have optimal impedance matching of 50 ohms. Two circular apertures of radius se are etched on the ground to improve the FBR. Here, the back radiation is reduced by suppressing the surface wave diffraction from the edges of the ground plane.

Figure 2 illustrates the effect of aperture loading on the behavior of the s-parameters of the MED. The antenna with defected (circular) ground does not affect the bandwidth significantly compared with the antenna without defects (regular) in the ground. However, it is noted that the small variation in the bandwidth is observed for the defected ground antenna due to left shift of the lower resonance. The simulated S_{11} of the MED before and after the introduction of ground defect is 52.58% (1.64–2.81 GHz) and 58.04% (1.54–2.8 GHz), respectively. Similarly, the FBR and gain are also studied for the antenna

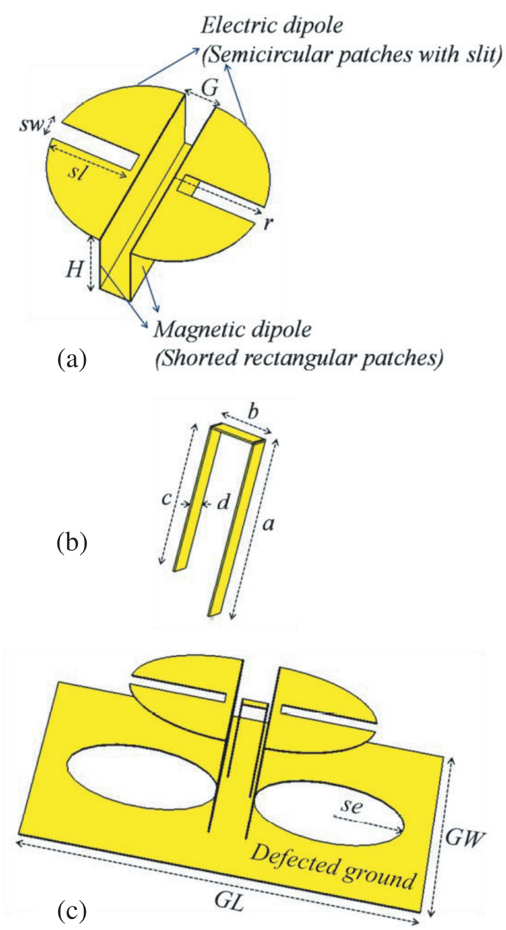

Figure 1. Antenna Configuration. (a) Electric and magnetic dipoles, (b) hook shaped feed structure, (c) proposed antenna (MED with defected ground).

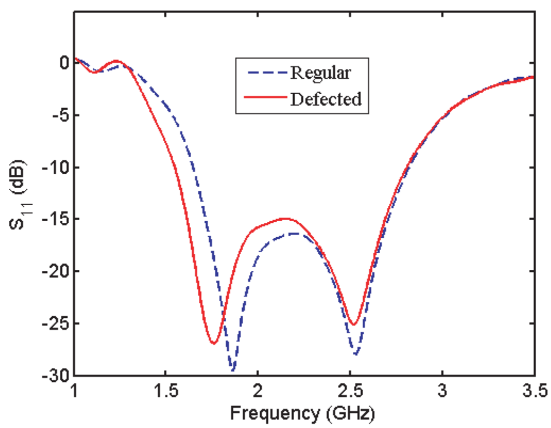

Figure 2. Simulated S_{11} of the MED with and without defect (regular) in the ground.

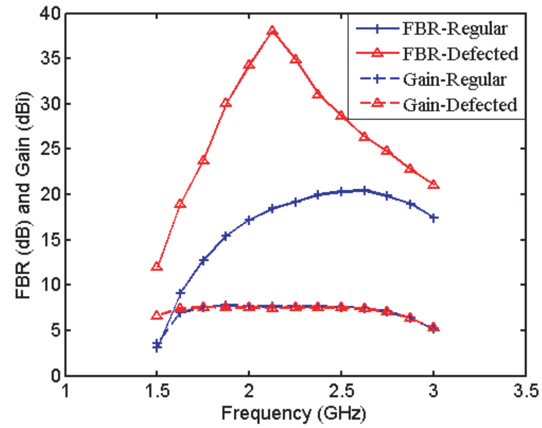

Figure 3. FBR and gain of the MED with and without defect (regular) in the ground.

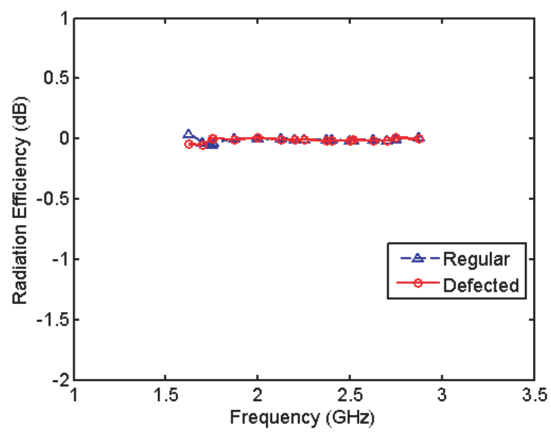

Figure 4. Radiation efficiency of the MED with and without defect (regular) in the ground.

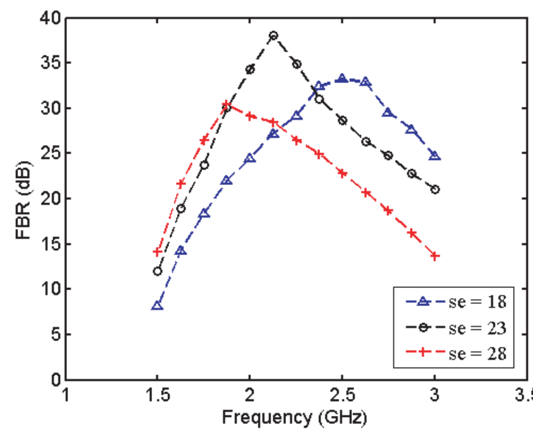

Figure 5. Parametric variation of defect radius (se in mm) on FBR.

with defect and without defect as presented in Fig. 3. Further, this modified structure accounts for non trivial FBR improvement of approximately 45% over the frequency band (1.7–2.7 GHz). In this range, the FBR value varies from 22 to 38 dB for defected ground antenna and from 11.3 to 20.4 dB for regular ground antenna. Moreover, the introduction of defects on the ground has minimal impact on the gain and does not deteriorate the gain. Fig. 4 shows the effect of aperture loading has less impact on the radiation efficiency.

Also, through the parametric study the optimum value of the aperture radius is chosen. Fig. 5 and Fig. 6 show the FBR and gain response of the MED for various values of slot radius *se*. The final optimized parameters value (in mm) of the proposed antenna is as follows: $GL = 120$, $GW = 120$, $r = 32$, $sl = 29$, $sw = 7$, $G = 11$, $H = 30$, $a = 29$, $b = 8$, $c = 24$, $d = 4$, $e = 1$, $se = 23$.

The effect of defects on the radiation characteristics of the antenna is understood by studying the current distribution as shown in Fig. 7. It is observed that the current distribution on the horizontal and vertical patches is the same for both the antennas, whereas the current distribution on the ground planes varies between them. The introduction of defects makes the current to take longer path along the circular boundary and also absence of conductor (defects) on ground leads to negligible current flow thereby reducing the back radiation of the antenna. From Fig. 7(b), it is seen that the current along $\pm x$-axis is reduced due to suppression of the edge diffraction on the ground plane. The simulated radiation pattern depicted in Fig. 8 shows that the defected ground antenna has reduced back radiation compared to regular ground antenna.

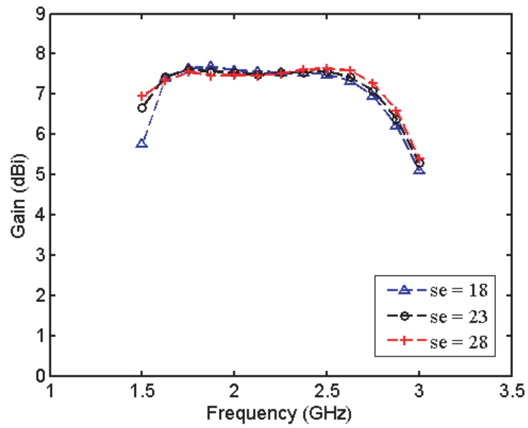

Figure 6. Parametric variation of defect radius (*se* in mm) on gain.

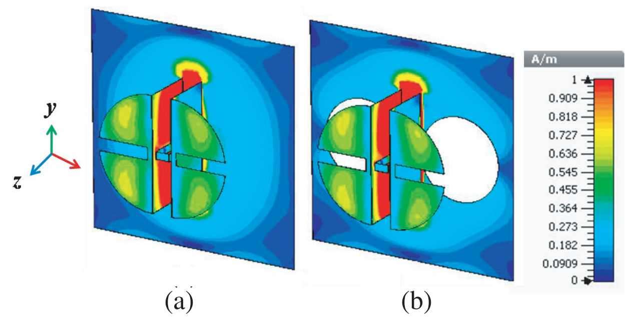

Figure 7. Current distribution of the antenna at 2.4 GHz. (a) With regular ground, (b) with defected ground.

3. RESULTS

A photograph of the prototype MED is presented in Fig. 9. It is made up of aluminium and copper sheet of thickness 1 mm. The outer conductor of 50 ohms standard connector is soldered to the ground of the antenna, while the inner conductor to the hook shaped feed. The S_{11} measurement is carried out using vector network analyzer (VNA) from Rhodes & Schwarz ZVH8. The radiation pattern and gain measurement are also done using VNA as per the procedure presented in [26, 27]. Fig. 10 shows S_{11} validation of the prototype antenna. At $S_{11} = -10$ dB, the experimental impedance bandwidth is 60.9% (1.55–2.91 GHz), which is in close agreement with simulated bandwidth of 58.04% (1.54–2.8 GHz). However, a small discrepancy between them is seen due to cable loss and fabrication margin. Fig. 11 shows the normalized radiation pattern of the prototype MED in both principal planes at different frequencies. The experimental FBR value varies from 21 to 29 dB. Also, the antenna achieves half power beamwidth of more than 65 degrees in both the planes, while the experimental gain value ranges from 6.6 to 7.3 dBi in the frequency range 1.7–2.7 GHz as depicted in Fig. 12. The proposed antenna with this moderate gain, can be suitable candidate for outdoor femtocell base station applications. Moreover, the measured values of FBR and gain of the proposed MED agree closely with the simulated values. Table 1 summarizes the functional characteristics of the proposed MED antenna.

It is shown that the loading of defects on the ground is one of the promising techniques to reduce the back radiation of the MED without affecting the other functional characteristics of the antenna. The defected MED offers 45% improvement when compared with regular MED and also better FBR values than the other antennas reported in the literature. Table 2 shows comparison of functional characteristics of proposed MED with other antennas. The proposed antenna show better FBR values can be achieved

Table 1. Functional characteristics of proposed MED.

Frequency (GHz)	HPBW (degree)		FBR (dB)	Gain (dBi)	Percentage Impedance Bandwidth at $S_{11} = -15$ dB
	$\varphi = 0$	$\varphi = 90$			
1.7	Sim: 71.4 Meas: 65	Sim: 84.6 Meas: 74	Sim: 22 Meas: 21	Sim: 7.5 Meas: 7.3	Sim: 58.06% (1.54–2.8 GHz) Meas: 60.9% (1.55–2.91 GHz)
2.4	Sim: 77.4 Meas: 68	Sim: 84.6 Meas: 77	Sim: 30.5 Meas: 29	Sim: 7.6 Meas: 7	
2.7	Sim: 79.3 Meas: 71	Sim: 84.4 Meas: 77	Sim: 25.3 Meas: 26	Sim: 7.4 Meas: 6.6	

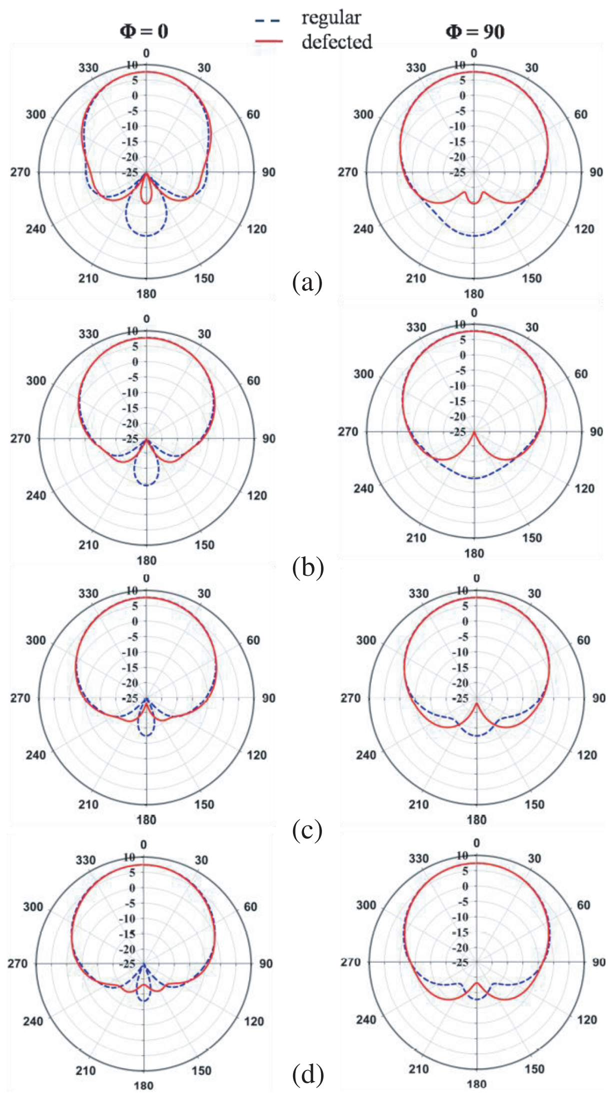

Figure 8. Figure 8. Simulated radiation pattern of the proposed MED compared with regular ground MED in $\varphi = 0$ and $\varphi = 90$ planes. (a) 1.7 GHz, (b) 2 GHz, (c) 2.4 GHz, (d) 2.7 GHz.

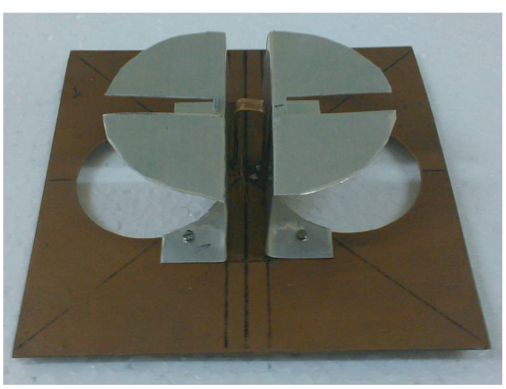

Figure 9. Photograph of the prototype MED.

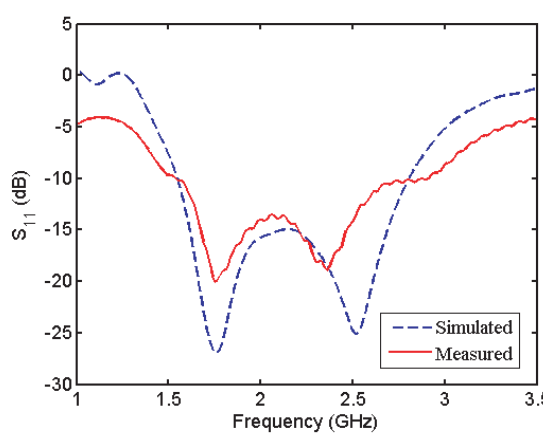

Figure 10. S_{11} validation of the prototype MED.

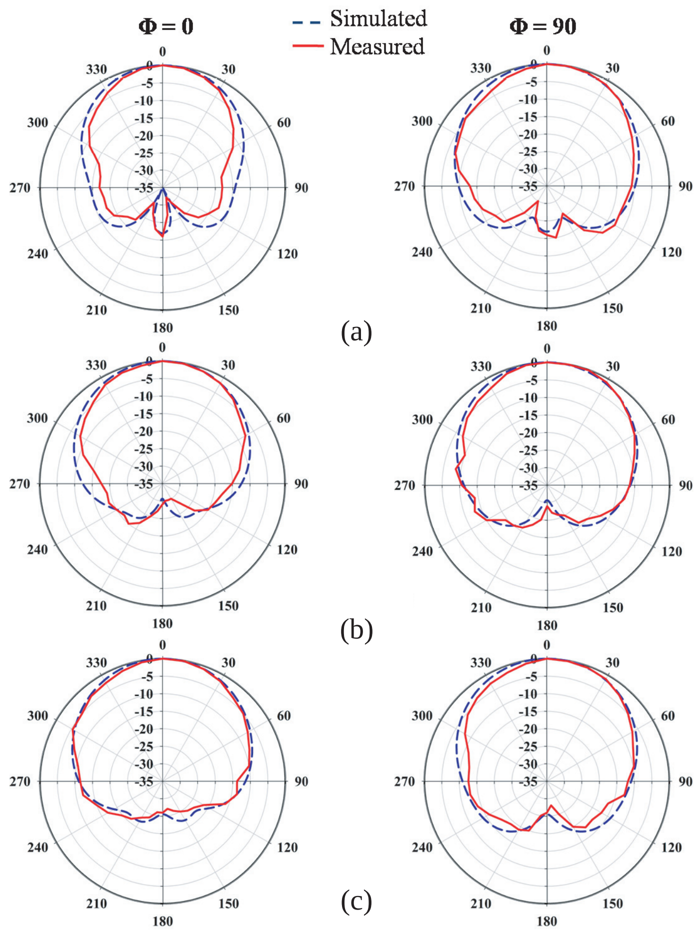

Figure 11. Radiation pattern validation of the prototype MED. (a) 1.7 GHz, (b) 2.4 GHz, (c) 2.7 GHz.

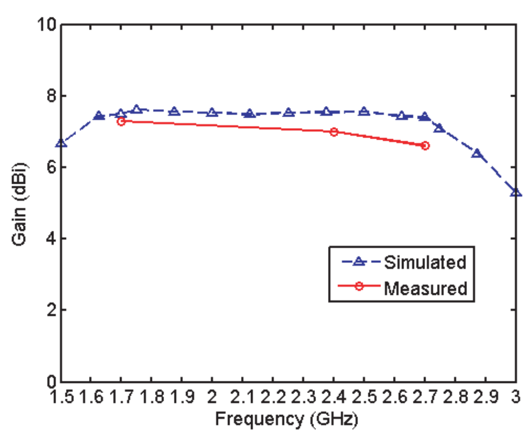

Figure 12. Gain validation of the prototype MED.

by using two circular defects in the ground. We had earlier employed a similar ground defect technique to improve the FBR of the planar dipole antenna [28]. However, this antenna employs single circular defect on the reflector plane and the operation of the antenna is different from the proposed MED. Therefore, using ground defect can be a simple solution to improve the FBR of unidirectional antennas.

Table 2. Comparison of functional characteristics of proposed MED with other antennas.

Antennas	Impedance bandwidth	Gain (dBi)	Half power beam width (Both planes) degree	Front to back ratio (dB)	Size (L × W × H) mm^3
Ref. [10]	91.6% (3.05–8.2 GHz) for SWR < 2	9.3 (average)	48.7 to 56.6, 30 to 69	19.5 to 24	$2.49\lambda_c\times 2.31\lambda_c\times 0.56\lambda_c$
Ref. [11]	95.2% (1.65–4.65 GHz) for SWR < 2	7.9 ± 0.9	Broad beamwidth	10	$1.26\lambda_c\times 1.26\lambda_c\times 0.24\lambda_c$
Ref. [16]	54.8% (1.86–3.3 GHz) for SWR < 1.5	8.6 ± 0.8	Broad beamwidth	14	$0.96\lambda_c\times 0.96\lambda_c\times 0.17\lambda_c$
Ref. [17]	51.5% (1.96–3.32 GHz) for SWR < 1.5	5.8 to 8	Broad beamwidth	18.3 to 20	$0.84\lambda_c\times 1.06\lambda_c\times 0.09\lambda_c$
Ref. [22]	46.3% (1.98–3.17 GHz) for SWR < 2	7.9 (average)	62 to 79, 66 to 73	19.5 to 20.1	$0.86\lambda_c\times 0.86\lambda_c\times 0.15\lambda_c$
Ref. [23]	58.6% (1.58–2.89 GHz) for SWR < 1.5	8 to 9.4	Broad beamwidth	17	$1.34\lambda_c\times 0.78\lambda_c\times 0.25\lambda_c$
Ref. [24]	45.6% (1.86–2.96 GHz) for SWR < 1.5	8.1 ± 0.8	60	11 to 25	$1.04\lambda_c\times 1.04\lambda_c\times 0.17\lambda_c$
Ref. [25]	17.1% (2.68–2.8 GHz) for SWR < 2	6.5 ± 0.5	Broad beamwidth	20	$1\lambda_c\times 1\lambda_c\times 0.84\lambda_c$
Proposed antenna (This work)	60.9% (1.55–2.91 GHz) at $S_{11} = -10$ dB	6.6 to 7.3	65 to 71, 74 to 77	21 to 29	$0.89\lambda_c\times 0.89\lambda_c\times 0.22\lambda_c$

4. CONCLUSION

In this correspondence, a magneto-electric dipole with defected ground is designed and verified experimentally. It is shown that by using simple techniques such as defects on the ground, the back radiation of the MED can be reduced significantly. The proposed antenna achieves higher FBR than the antenna without ground defects. The measured FBR and gain values range from 21 to 29 dB and 6.6 to 7.3 dBi, respectively. The impedance bandwidth measured at −10 dB return loss of the defected ground antenna is 60.9% (1.55–2.91 GHz). With wide beamwidth and high FBR, it can be employed for LTE femtocell base stations.

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