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Compact Metamaterial Antenna with High Directivity for Bio-Medical Systems

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Abstract

In this paper, high directive antenna using metamaterial property is presented for wireless medical systems. The antenna is constructed by semi-circular patch and hexagonal closed ring resonator (HCRR). For medical applications such as wireless patient movement monitoring, telemetry and telemedicine, communication devices working at ISM band frequency is needed. Here, the requirement is completed with improved directivity such as 16 dBi. And also impedance matching also achieved with low reflection loss −20 dB. This antenna works for multiple frequency bands (Industrial, Scientific and Medical-ISM 2.45 GHz, WLAN 5.3 GHz and GSM 1.9 GHz) with improved directivity.

Keywords

Double Negative Metamaterial, Back Propagation, Hexagonal Closed Ring Resonators

1. Introduction

Recent years metamaterial, a new design methodology contributes mainly in medical applications such as diagnosis of cancer cells, cancer treatment, patient monitoring, brain signal analysis, communication devices within body and body temperature, blood pressure monitoring etc., In this related works, the reduced size of the antenna is aimed. Metamaterial concepts are mainly focused for size reduction and improving the conventional patch antenna characteristics [1]-[5]. Here, the antenna consists of hexagonal shape metamaterial resonators at ground plane to reduce the back wave propagation which harms patient body tissues.

The proposed antenna is also called as double negative metamaterial antenna because of negative permittivity as well as negative permeability values present in the antenna. Since the ground plane comprises of hexagonal metamaterials, it may be considered as defective ground structure antenna. Multiband PIFA antenna was designed by Chang *et al.* [6] which was mainly used for mobile applications (900 MHz and 1900 MHz). Jie *et al.* [7] developed a monopole antenna for GSM applications such as 850 MHz, 900 MHz and Directive Communications Systems 1710 - 1880 MHz. In [8], Chen *et al.* designed T-shape microstrip antenna with modified design methodology which works for multiband frequencies. A crescent-shaped wireless antenna was proposed and it covers 1.7 GHz to 3.1 GHz frequency band. In [9], Sung *et al.* developed L-shaped antenna with modified structure operates at 3.51 GHz frequency band. But the antenna was not fitted to mount on mobile devices. Here, a high directive antenna is proposed with defective ground structure. A hexagonal shape resonator is imported at ground side of antenna in order to reduce the back propagation towards human body.

2. Antenna Design Methodology

2.1. Antenna Specifications

The proposed metamaterial antenna structure is presented in **Figure 1**. At 1.6 mm thick FR-4 substrate, the HCRR unit cell array is simulated and fabricated. The proposed antenna is also printed on a 1.6 mm thick FR-4 substrate of dimensions 35.4 × 27.6 × 1.6 mm^3. The antenna is developed with a semi-circular copper conductor at the topside and the HCRR array in the ground plane. The antenna design specifications are listed in **Table 1**.

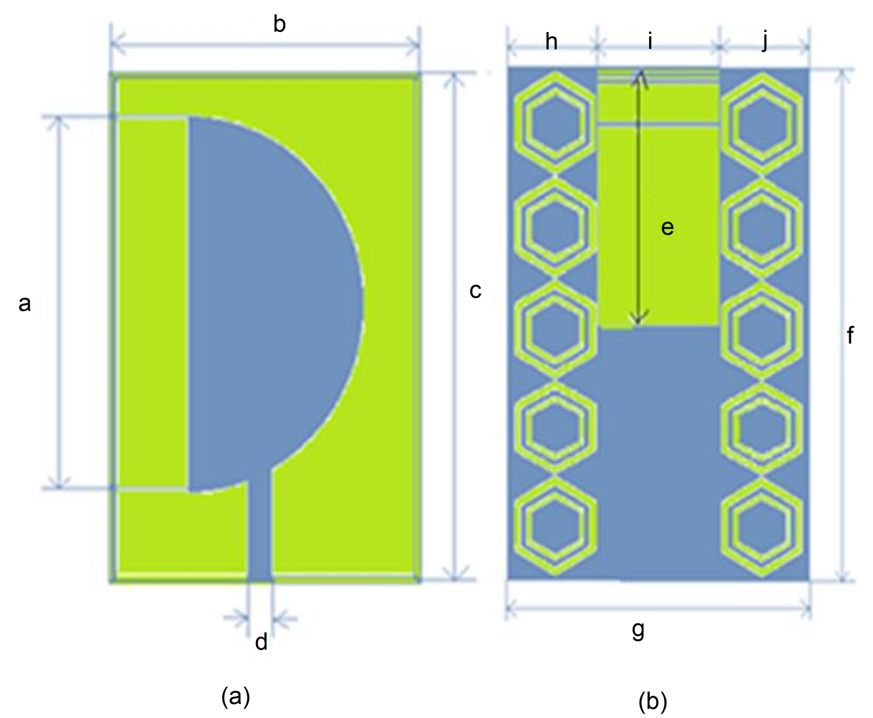


Figure 1. Proposed antenna (a) top view (b) bottom view.

Table 1. Antenna dimensions.

Parameters	Dimensions in mm	Parameters	Dimensions in mm
Diameter of the semicircle, a	27.6	Feed width of the antenna, d	1.25
Width of the antenna, b, g	27.6	Length of the gap, e	17.7
Length of the antenna, c, f	35.4	Width of the gap, i	11.6

2.2. Hexagonal Closed Ring Resonators (HCRR)

Hexagonal closed ring resonator (HCRR) is obtained by alternatively placing the metal parts and apertures. HCRR can be excited by incident electric field. HCRR is designed to exhibit negative permittivity and permeability at resonant frequency. HCRR can be placed in either radiating side or non-radiating side of antenna. HCRR loaded ground used for size miniaturization, performance enhancement and also to design beam steerable antenna. HCRR was placed on the non-radiating side to design beam steerable antenna and to control the radiation pattern. Refractive index of the loading part affects the beam direction.

$$\theta = kd = \frac{2\pi}{\lambda_0} nd \quad (1)$$

k—Equivalent wave number, λ_0—wavelength of free space, *d*—unit length in the propagation direction, *n*—refractive index.

From Equation (1), it is clear that larger *n* results in large phase shift, thus larger beam steering angle. HCRR loading part can be used as a phase shifter to achieve beam steering. HCRR provides phase shift to the electro-magnetic fields of the antenna. The cost of the phase shifter that employ solid state devices, micro electromechanical systems structures, ferrite materials, or photo conducting switches is too high to be applied in practice. HCRR loaded ground plane provides low cost solution to design beam steerable antenna.

Metamaterial HCRR are characterised by unit cell test. This is performed by positioning the array structure between two positive and negative ports on x-axis and a transverse electromagnetic (TEM) wave is sent along this waveguide port. At y and z axes, the perfect electric conductor (PEC) boundary and perfect magnetic conductor (PMC) boundary were assigned as shown in Figure 2. Using CST Microwave Studio software, unit cell is simulated in the frequency ranges of 1 - 6 GHz for investigations of metamaterial defective ground structure.

3. Results and Discussion

The optimised patch shape, patch position and array size of HCRR are determined as shown in Figures 3-8. The proposed semi-circular patch antenna is simulated for 1 - 10 GHz frequency range.

As in [10], the scattering parameters are retrieved and by MATLAB code the permittivity, permeability and refractive index values are computed. All the results are obtained

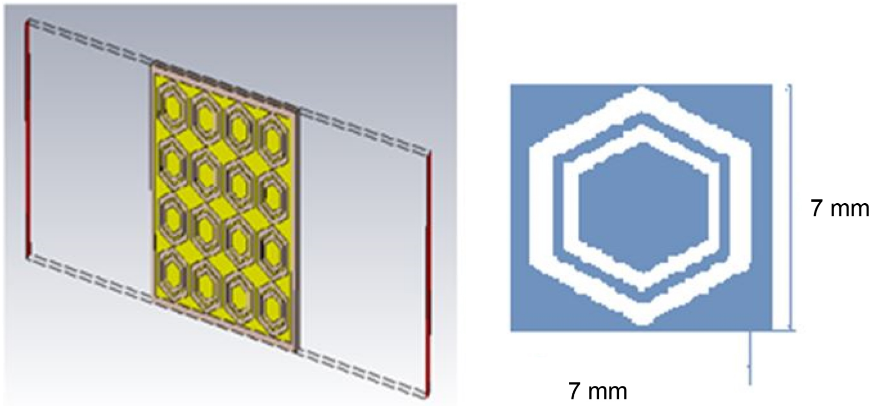
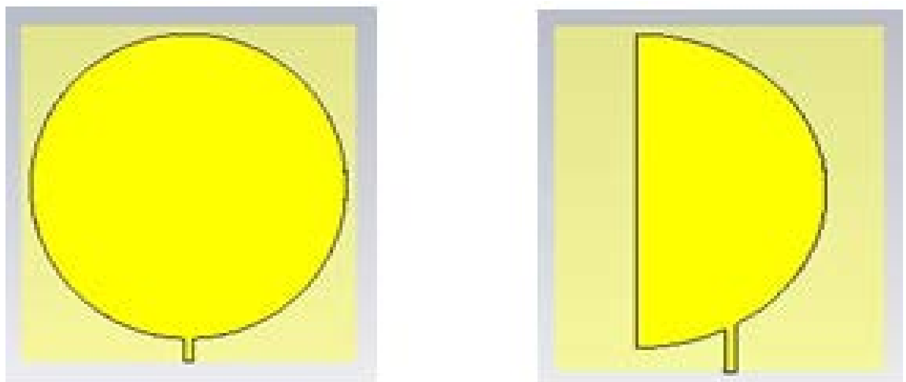


Figure 2. Unit cell diagram.



(a) (b)

Figure 3. Patch antenna shape (a) full circle (b) semi-circle.

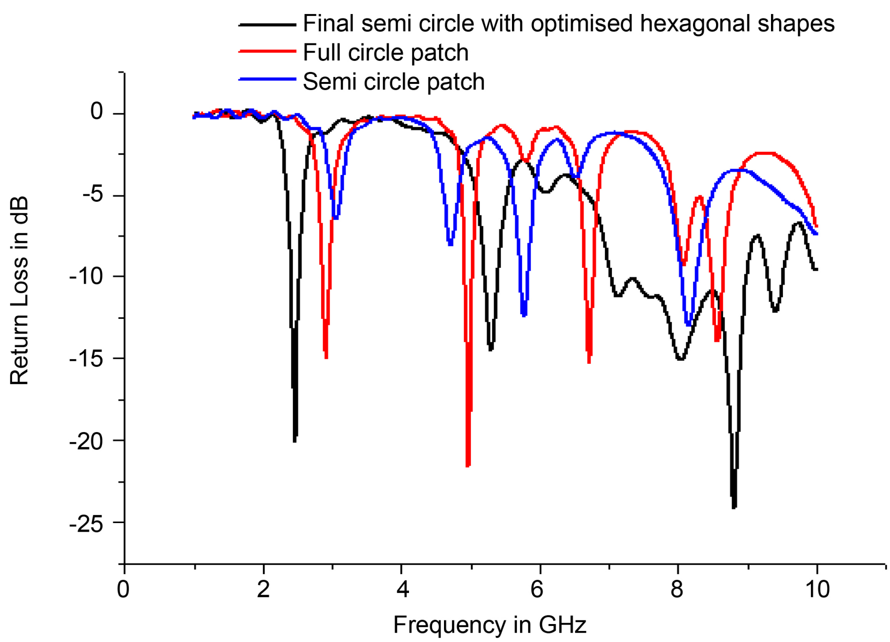


Figure 4. Comparison study of shape of patch antenna.

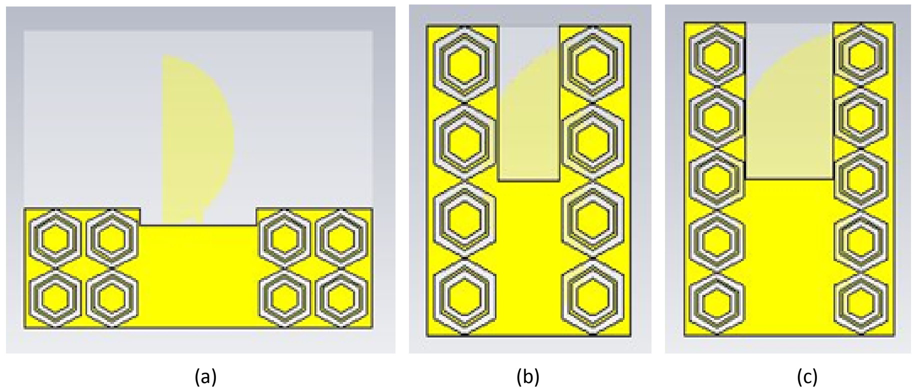


Figure 5. Different hexagonal array (a) 2 × 4 (b) 4 × 2 (c) 2 × 5.

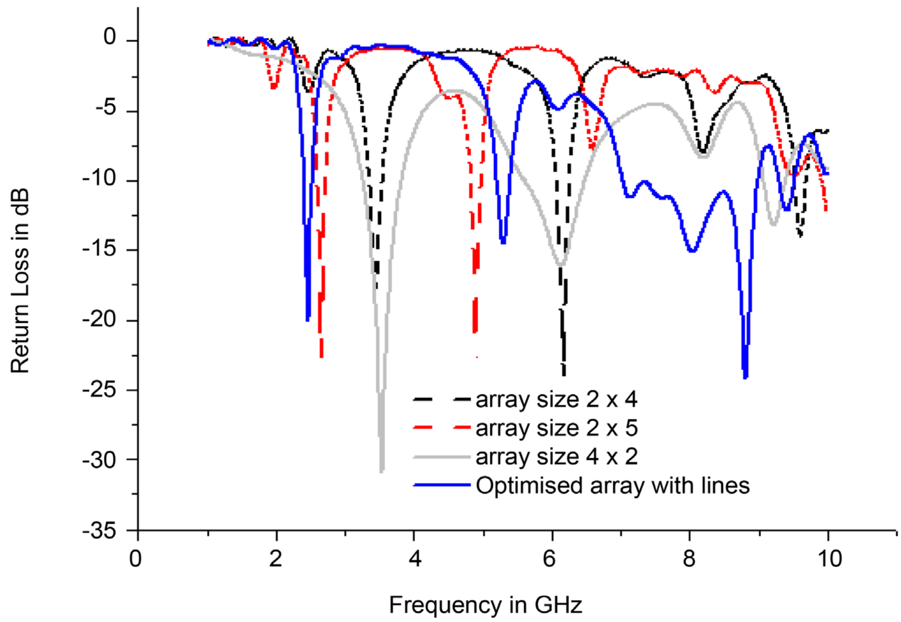


Figure 6. Comparison study of array size of hexagonal shape.

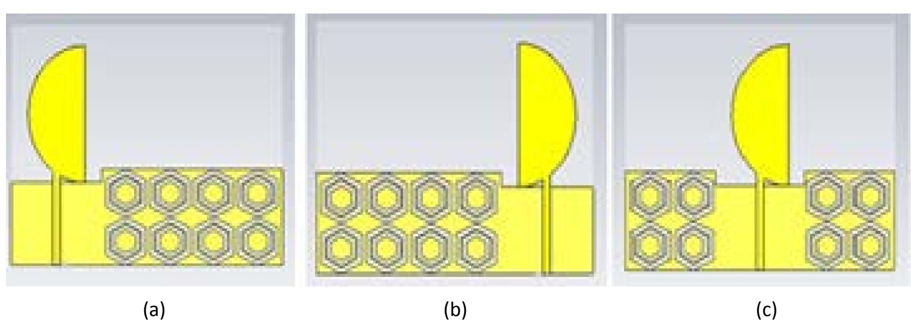


Figure 7. Different position of patch (a) left side (b) right side (c) middle.

with negative sign. It also observed from Figure 9 that, there are two resonance points at lower end frequency of 1.963 GHz and higher end frequency of 5.03 GHz where the DNG characteristics of the metamaterial have been found. Therefore, the hexagonal

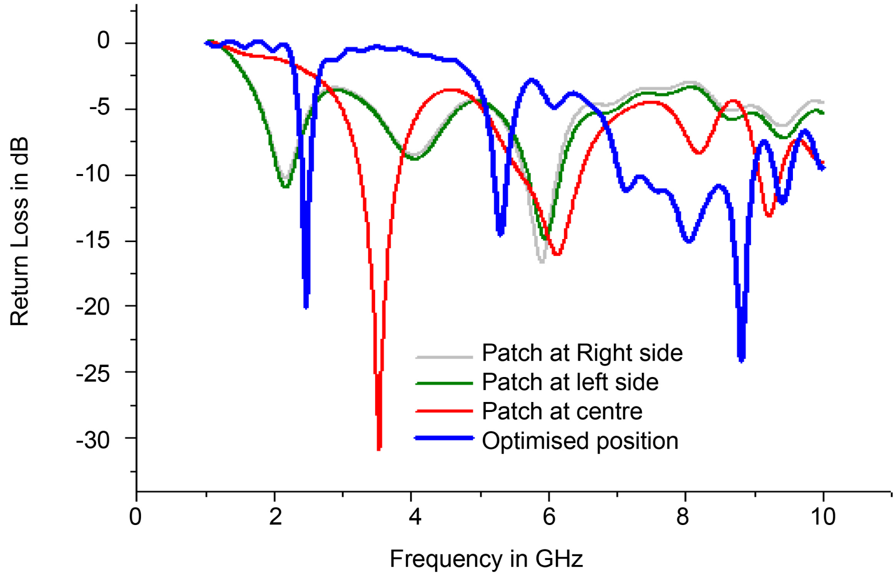


Figure 8. Effect of position of patch.

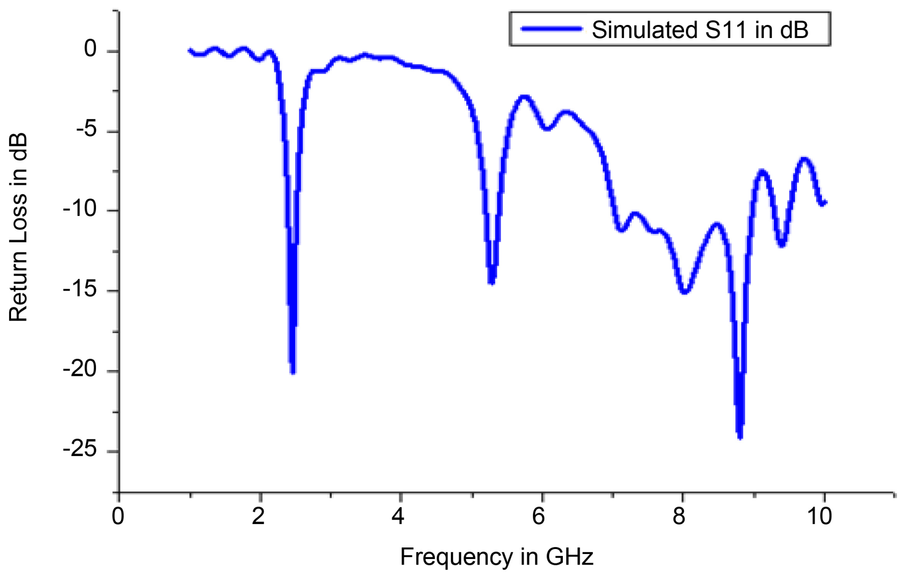


Figure 9. Simulated return loss in dB.

resonator achieves double-negative medium of about 1 GHz at the lower band and about 0.01 GHz at the upper band. The unit cells are arranged in periodic manner so that LC resonator formed.

The testing set up is shown in Figure 10. The device shown is Portable Network analyser. As shown in Figure 11 and Figure 12, the proposed antenna results bandwidths of 30 MHz (1.8 - 2.1 GHz), 70 MHz (2 GHz - 2.7 MHz) and 1.8 GHz (4.2 - 6 GHz), enabling it to operate in GSM band frequencies (1800, 1900, 2100), ISM band frequency (2.45 GHz), and WLAN (5.47 - 5.9 GHz). But a small variation is noted between the measured and simulated reflection coefficients due to soldering effects of the

Figure 10. Testing set-up.

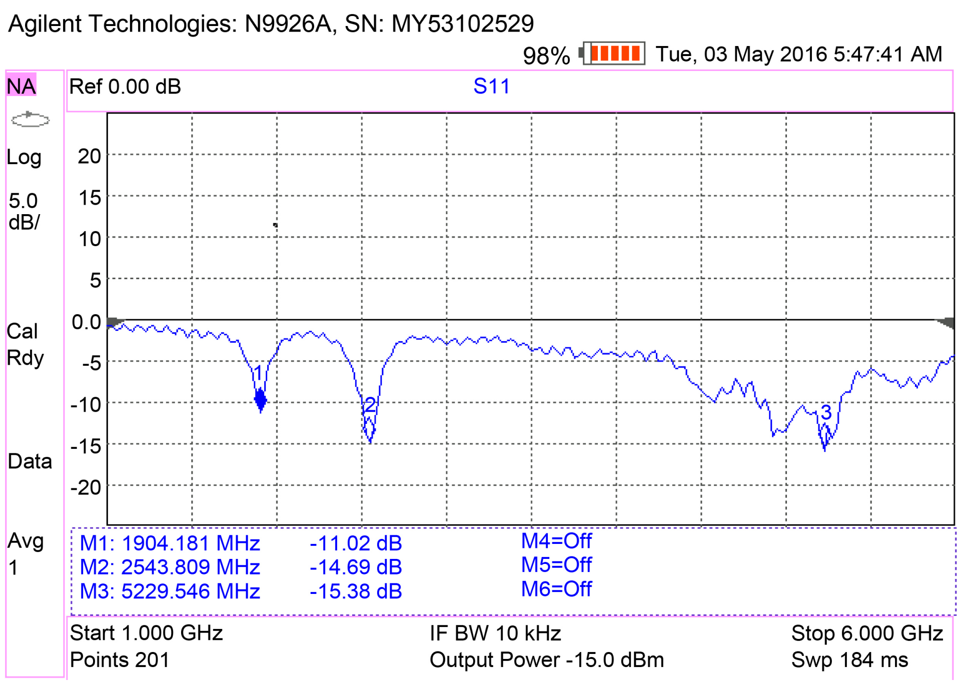


Figure 11. Measured reflection co-efficient.

SMA connector.

The proposed antenna result as shown in Figure 13 shows better antenna directivity performances. The measured radiation patterns at 2.4 GHz are demonstrated for both Phi = 0˚ (Figure 14) and Phi = 90˚ (Figure 15) are included and it is cleared that the

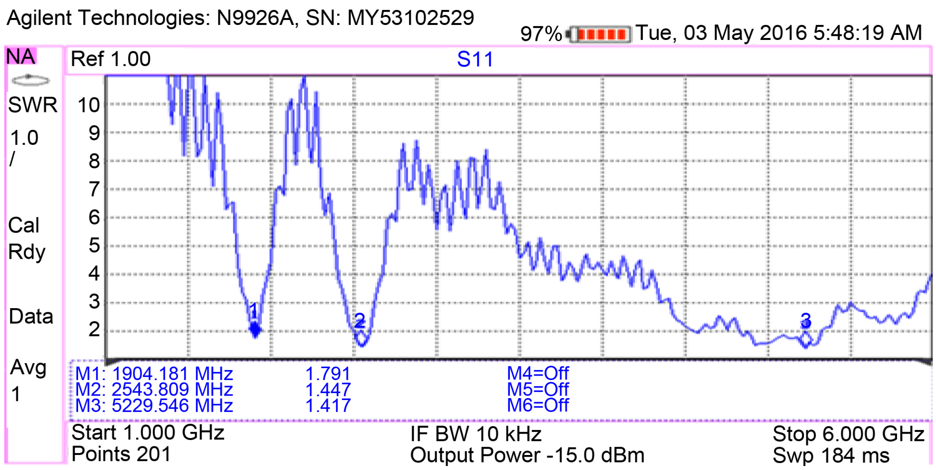


Figure 12. Measured VSWR of proposed antenna.

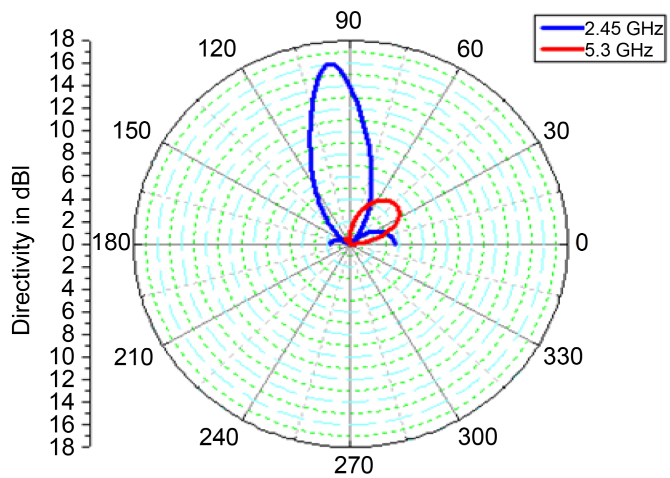


Figure 13. Directivity of proposed antenna.

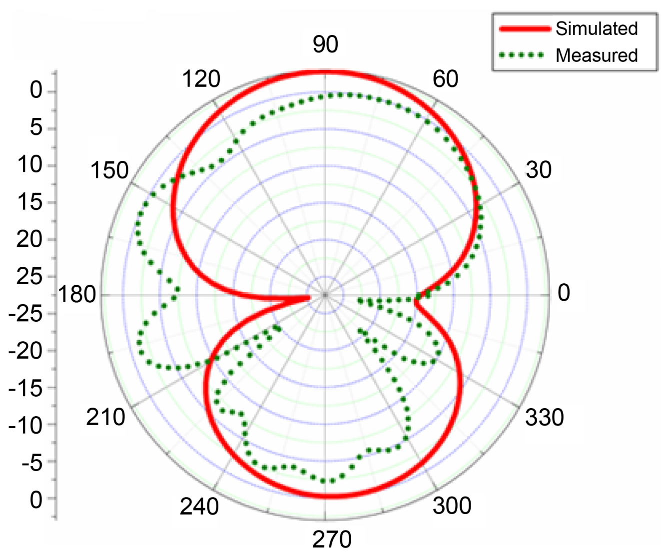


Figure 14. Measured E-field pattern at 2.45 GHz.

radiation pattern is nearly omnidirectional for *H* field pattern.

In Table 2, it shows that, the proposed antenna with the compact size of 35.4 × 27.6 × 1.6 mm³ has an antenna size at least 83% less than [8], 69% less than [9], and 88% less than the reference antenna [10] dimension.

4. Conclusion

The size of the proposed antenna is reduced from reference antenna. The propagation characteristic of directivity is enhanced at the level of 16 dBi. The return loss is also very low (<−20 dB) at 1.9 GHz, 2.45 GHz and 5.3 GHz. Hence, the antenna is suitable for wireless applications GSM, ISM and WLAN. The radiation pattern is measured for 2.45 GHz. In future, reduction of specific absorption rate of the antenna is targeted. This high directive antenna is useful for the measurement of contactless breathing and electroencephalography signals.

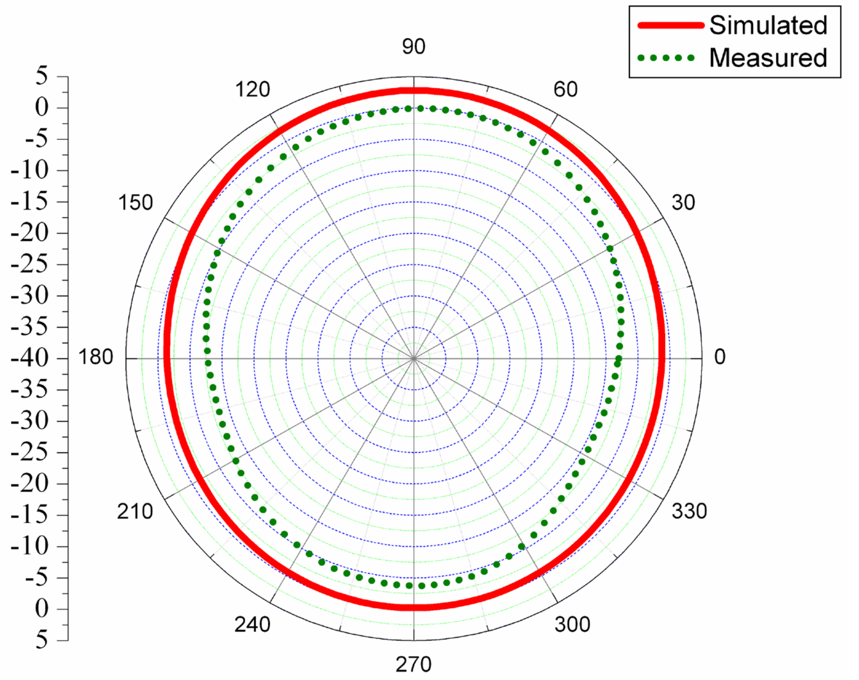


Figure 15. Measured H-field pattern at 2.45 GHz.

Table 2. Comparison of reference antennas and proposed antenna.

Antenna	Dimensions in mm	Directivity in dBi
[1]	37 × 47	Not available
[7]	15 × 26	6
[8]	65 × 40	7
[9]	57 × 37.5	6.4
[10]	60 × 60	5.6
Proposed antenna	35.4 × 27.6	16

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