Design and Analysis of UWB Microstrip Patch Antenna Loaded With Modified SRR and DGS for WBAN Applications

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Research Article

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Abstract

Wireless Body Area Network (WBAN) is the booming field incorporating the recent wireless sensor networks and miniaturized wearable devices. There are growing appeals for WBANs in medical and non-medical applications due to its flexibility and portability. This paper proposes an Ultra Wide Band (UWB)Microstrip patch antenna loaded with modified Split Ring Resonator (SRR) and Defective Ground Structure (DGS) for WBAN applications. The proposed antenna has a modified SRR structure and DGS at the ground and a patch scratched over the surface of the Arlon substrate with 1.6mm thickness. The structure is partially grounded and also loaded with meta-material to reduce the back-body radiations. The performance metrics of the proposed antenna are analysed and compared with different antenna configurations. The proposed UWB Microstrip patch antenna operating at 5.2GHz yielded a return loss of -21.12dB, VSWR of 1.19, higher efficiency and less Specific Absorption Rate (SAR) making it the best choice for biomedical applications.

I. Introduction

Wireless Body Area Network (WBAN) is the field which has gradually broadened due to the growing tradition of wireless sensor networks and miniaturization of electrical devices. It allows portability, flexibility and mobility. There are growing appeals for WBAN in medical and wearable applications, for instance remote patient monitoring, biofeedback, smart watches, bags and garments etc., [1–3].WBAN are also accountable for sampling, one-to-one care, and dealing with numerous kinds of vibrant cyphers, such as heart rate, temperature, blood pressure, electrocardiogram (ECG) signals, etc., and non-medical applications [4, 5].

The WBAN permits wireless communication from or to the body via wearable and conformal antennas. The necessities of wearable antennas for recent applications are low cost, light weight and should be almost maintenance-free. Therefore, wearable antennas take an essential part in wireless on-body centric communications and draw momentous interest in research. The wearable antenna's role is in close proximity to the human body and therefore the loading effect due to the lossy nature of body tissues coupled with their high conductivity and dielectric constants demands the design of a high radiation efficiency antenna. Body-Centric Wireless Communication Systems (BWCS) is classified as on-body, off-body and in-body/implanted communications. In a WBAN, numerous body sensors are implanted on or in the human body to intellect the biological signals of patients. After sensing the physiological signals, the sensor nodes send the sensed data to the Processing Unit. Among these, implantable antennas face more challenges due to the poor and complicated in-body working situation. [6–10]

The Ultra Wide Band (UWB) technology based wireless Communication systems and devices with the frequency allocation of 3.1–10.6 GHz by Federal Communications Commission (FCC) support low cost, low power, and high data rate (110–200 Mbps) applications over short ranges (4–10 m).The UWB antennas must be electrically small and economical without compromising on their performance. The low transmitted power in UWB systems restricts the applications for short range or to moderate data rate.

A conformist patch antenna loaded with a full ground plane is characteristically narrowband. Thus to achieve an ultra-wide bandwidth, several bandwidth enhancement techniques using multiple resonators and slots are depicted in the literature [11–13].

Wearable devices such as glucose sensors, pulse oximeter sensors, electrocardiogram (ECG) sensors monitor the bio-signals and identify diseases in the premature phases for immediate medical actions. These sensors also provide alerts for irregular signs in patients suffering from long-lasting diseases. They gather restrained bio-signals, share the data with other devices, and send it to data analysing devices such as smart-phones and smart-watches [14–16].Amidst of various types of antenna, the microstrip patch antenna is widely used in wireless applications due to its low profile, low cost, low fabrication complexity, light weight and simple in architecture.[17, 18].

Ii. Background

Microstrip antennas offer Uni-directional radiation pattern which is most required in the field of Bio-medical applications in order to suppress the Electro Magnetic radiation from exploring into the human body. Besides the good characteristics, the microstrip antennas suffer from a very narrow bandwidth which is a function of the dielectric constant of substrate and substrate thickness. This necessitates to concentrate more on the substrate selection during the process of antenna design. [19].A dual band textile antenna based on the conventional square-patch based Artificial Magnetic Conductor (AMC) is inspected in terms of Specific Absorption Rate (SAR). With the insertion of AMC structure in the antenna, the SAR is reduced suggestively, but the size of the antenna is comparatively larger (120 mm x120 mm) [20, 21].

A compact monopole antenna with Kapton polyimide as substrate with a dielectric constant of 3.5 and a loss tangent of 0.002 integrated with a slotted AMC ground plane is designed for telemedicine applications with the operating frequency of 2.45GHz. The calculated SAR values were very low with a reduction of 64% when compared to the same antenna structure without AMC. Nevertheless, there is performance degradation in terms of return loss and shift in resonant frequency [22].

A wearable antenna operating at 700 MHz is proposed with a Polycarbonate as substrate with AMC in the form of 2*2 array at the base. It exhibits a return loss of about – 25 dB and gain of 3.7 dBi but the efficiency is only 50 % and the size is too large (60 mm* 60 mm) [23].A Folded dipole antenna with AMC as a ground plane is portrayed that enables the gain of the antenna and also prevents the human body from unsought exposure to EM radiation. It also reduces the impedance mismatching due to the nearness of human body tissues[24].

The performance metrics of a square shaped SRR antenna is compared with a square shaped Closed ring Resonator (CRR) Microstrip antenna. The squared SRR antenna yielded a gain of 8.9dB, efficiency of 97.75% and SAR of 0.163W/Kg. It portrays that the SRR antenna outperforms the CRR antenna [25]. A miniaturized UWB slot antenna with frequency tunable and reconfigurable structure based on S-shaped split ring resonators (S-SRRs) shorted with PIN diode for band reject and band pass filter is designed [26, 27].

A split ring resonator (SRR) is one of the metamaterial elements that has negative permeability and negative permittivity. The electrical dimensions of a metamaterial unit cell is much smaller than the wavelength of the operating wave and thereby makes it a perfect applicant for microwave component miniaturization. Antenna Size reduction is the foremost requisite in wireless applications, satellite and military communications. The problem associated with reducing the size of patch is antenna performance degradation in terms of efficiency, bandwidth, gain and a swing in resonant frequency. Henceforth, the current research emphasizes on attaining a compromise between the size of antenna and performance so as to meet the necessities of wireless applications.

This paper proposes the design of a circular shape double Ring patch antenna. A square shape double Split Ring Resonator (SRR) and Defective Ground Structure (DGS) are loaded on the ground, making the fabrication simple and operating at a frequency of 5.2 GHz. The patch antenna proposed in this design is small in size for Arlon is used as the substrate material that has a relative permittivity of 10.2.The main objective of this antenna design is to enhance the gain and directivity which in turn enhances the radiation efficiency of the antenna, minimizes the size and SAR thereby making it appropriate for wearable applications.

The paper is ordered as follows; Third section represents the design and structure of Antenna. Fourth section presents the simulated output and analysis. Finally, the conclusion is presented in the fifth section.

Iii. Design And Structure Of Antenna

There are three popular models for the analysis of the antenna. They are i) transmission line model, ii) cavity model and iii) full wave model. The Transmission line model is used in our work because of its simplicity in design. In this method, the radiating edge of the patch located at the end opposite to the feed is modelled as a pair of transmission lines and is excited at 180 degree out of phase. It neglects the variations along the radiating edges and the effect of feed.

There are four types of feeding techniques such as microstrip line feed, coaxial feed, aperture coupled feed and proximity coupled feed . Microstrip line feed is the most simplest among the feeding techniques and this type of feed is easy to fabricate. Microstrip line feed is connected directly to the radiating patch. This is done by drawing a strip line and connecting it to the patch. An inset cut is made to avoid the usage of impedance matching networks.

Arlon is used as the substrate material because of its features such as high dielectric constant that helps in reducing the size of the circuit, low insertion loss, inexpensive, light in weight and offers robustness. Therefore this material is well suited for components using low impedance lines. The Proposed UWB antenna geometry (top view, bottom view,3D view) consisting of two hollow rings joined using four strips connected to a T-shaped feed with a modified SRR shaped ground plane is shown in Fig 1a,b and c respectively. The size of the substrate is 21.46*24.6*1.6.

In the structure shown in Fig.1.a, a microstrip line feed is connected to the edge of the radiating patch. There occurs impedance mismatching that is overcome by using stubs. Stubs are widely used for reducing impedance mismatch. It is positioned at a distance in such a way that the real part of admittance must be unity. The length of the stub is 6mm and the width of the stub is 4mm. A closed ring resonator is used on the patch which acts as radiator. To enhance the performance of the proposed antenna, various inductance slots are integrated in to the patch. The radius of the patch is r_1= 9mm and r_2=4mm and the width of the inductance slot is 2mm. Furthermore, air holes are drilled on the antenna to avoid the spurious radiations and the close proximity of the antenna to the human body achieves circular polarization.

The radiation from the antenna is along both the positive and negative Z axis. The metamaterial is used at the bottom of the substrate to reduce the back radiations. It also provides protection to the underlying tissues wherein the human body does not observe RF energy which is considered to be carcinogenic. The metamaterial exhibits extraordinary properties such as negative permittivity, permeability and refractive index. Metamaterial is composed of a metallic wire array and split ring resonator. Split ring resonator is a simple LC circuit. When the magnetic field is perpendicular to the split ring resonator, a current will be induced. Due to the splits in the circuit, current flow leads to building up of charges in the gap and the energy will be stored in capacitance. For frequencies below the resonant frequency, split ring resonator keeps up with the magnetic field, providing a positive response. As the frequency increases, SRR cannot keep up with the H field, thereby negative response is produced. To overcome these issues, a modified split ring resonator with Defective ground structure is included at the base. The defective ground structure also avoids spurious radiations and enhances the performance of the antenna. The size of the base region is l_1=18mm, w_1=1mm, l_2=1.5mm, w_2=15mm, l_3=16mm, w_3=1.5mm, l_4=1mm, w_4=17mm.The simulation is done using High Frequency Structure Simulator (HFSS) software.

Iv. Results And Discussion

The proposed UWB Microstrip Patch Antenna Loaded with modified SRR and DGS is designed, simulated using HFSS and the performance of the antenna is recorded. The front and back view of the fabricated antenna is shown in figure 2 a and b respectively.

The various performance metrics include return loss, Voltage Standing Wave Ratio (VSWR), gain, directivity and SAR are measured. These parameters are also compared for different configurations of the antenna.The different configurations are

- SRR Antenna without holes and DGS structure(Antenna -1)
- Modified SRR Antenna without holes and DGS (Antenna- 2)
- Modified SRR Antenna with holes and DGS structure(Proposed Antenna -3).

Return loss: The proposed antenna 3 yielded a return loss of below -20dB in the frequency range of 4.57 to 5.49 GHz as shown in figure 3a. A return loss of below -20dB very clearly indicates that there is just 1% of reflection and about 99% of power is delivered to the antenna.

The return loss of the antenna for various configurations is presented in Fig 3.b. At 5.2GHz resonant frequency, the antenna 1(Red colour) and antenna 2(Green colour) yielded the return loss of -14.3dB, -19.6dB respectively. For the same resonant frequency, it is clearly evident from the fig 3.b. that the proposed antenna 3(Blue colour) resulted in a return loss of -21.12dB which is well appreciated.

VSWR: It determines the impedance matching between antenna and transmitter. When the value of VSWR is small, it leads to better impedance matching between antenna and transmitter and hence more power is delivered to the antenna. Figure 4.a. clearly portrays that the proposed antenna 3 yields a VSWR of 1.19 at the resonant frequency of 5.2GHz which is very much desirable as it should be less than 2 for 90% of power to be delivered to the antenna.

The output graph of fig 4.b shows that at a resonant frequency of 5.2GHz, the antenna1 and 2 yielded a VSWR of 1.47 and 1.23 respectively. For the same resonant frequency, the proposed antenna 3 yielded a VSWR of 1.19 which is most appreciated.

Specific Absorption Rate (SAR): The SAR value specified by Federal Communication Commission for antennas are 1.6 W/Kg for 1g of tissue according to the US standard and 2.0 W/Kg according Europe standard. When an electric device is placed close to the head and body more radiation will be absorbed.The lesser the value of SAR, lesser will be absorption of microwave energy by the human body. These radiations are known to cause cancer. The greater the exposure to the radiation , greater would be the damage to the tissues.

Figure .5 shows a SAR value of 0.001 W/Kg for the proposed antenna. This demonstrates that there is no back radiation. The metamaterial at the bottom of the substrate provides isolation thereby preventing the underlying region to be exposed to any microwave radiation.

Antenna Gain: The gain of the transmitting antenna depends upon how it converts the power supplied at the input into radio waves in a particular direction. The radiation pattern of the proposed antenna is shown in figure 6. Figure 7 shows a higher gain of 6.6dB in the UWB band of 3.1-10.6 GHz and this leads to higher efficiency.

Antenna Directivity: It refers to the concentration of radiation of an antenna in a particular direction and is expressed in dB. Higher the directivity, the beam will be more focused by the antenna. The directivity was found to be 6.62 dB as shown in Fig.8 that resulted in an efficiency of 99.9% .

Table1: Comparison of Antenna Performance Metrics with different antenna structures

Antenna Parameter	Antenna With SRR structure		Antenna With modified SRR structure	
	Without holes and DGS	With holes and DGS	Without holes and DGS	With holes and DGS
Return Loss(dB)	-14.3	-17.4	-19.6	**-21.12**
VSWR	1.47	1.35	1.23	**1.19**
Gain(dB)	-0.781	-0.69	-0.515	**6.626**
Directivity(dB)	-1.043	-0.845	-0.663	**6.628**
Efficiency	74.88%	81.65%	77.67%	**99.9%**
SAR(W/Kg)	2.13	1.55	1.32	**0.001**

Table 1 shows the comparison of antenna performance metrics with different antenna structures.It is evident from the table that the proposed UWB antenna operating at 5.2GHz yielded an efficiency of 99%, greater gain and directivity, minimum SAR and smaller in size for on-body applications.

V. Conclusion

This paper presents a UWB Microstrip patch antenna loaded with modified SRR and DGS structure for Wireless Body Area Network applications.The performance of the proposed antenna-3 is analyzed and is compared with various antenna configurations.The comparison of performance metrics elucidates that the designed antenna outperforms all other configurations and yields higher Gain,VSWR of 1.19, an efficiency of 99%, SAR of 0.001W/Kg. These results clearly communicate that the proposed antenna is the best choice for wearable/wireless body area network applications.

Declarations

Conflict of interest

A miniaturized DUWB slot antenna with frequency tunable and reconfigurable structure based on S-shaped split ring resonators (S-SRRs) shorted with PIN diode for band reject and band pass filter is designed with in future.

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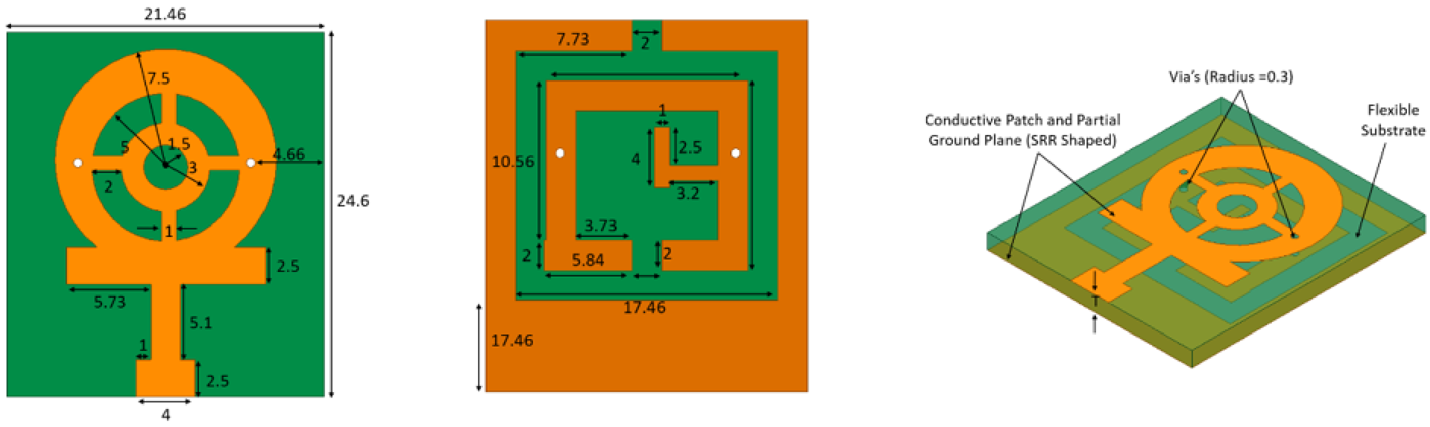
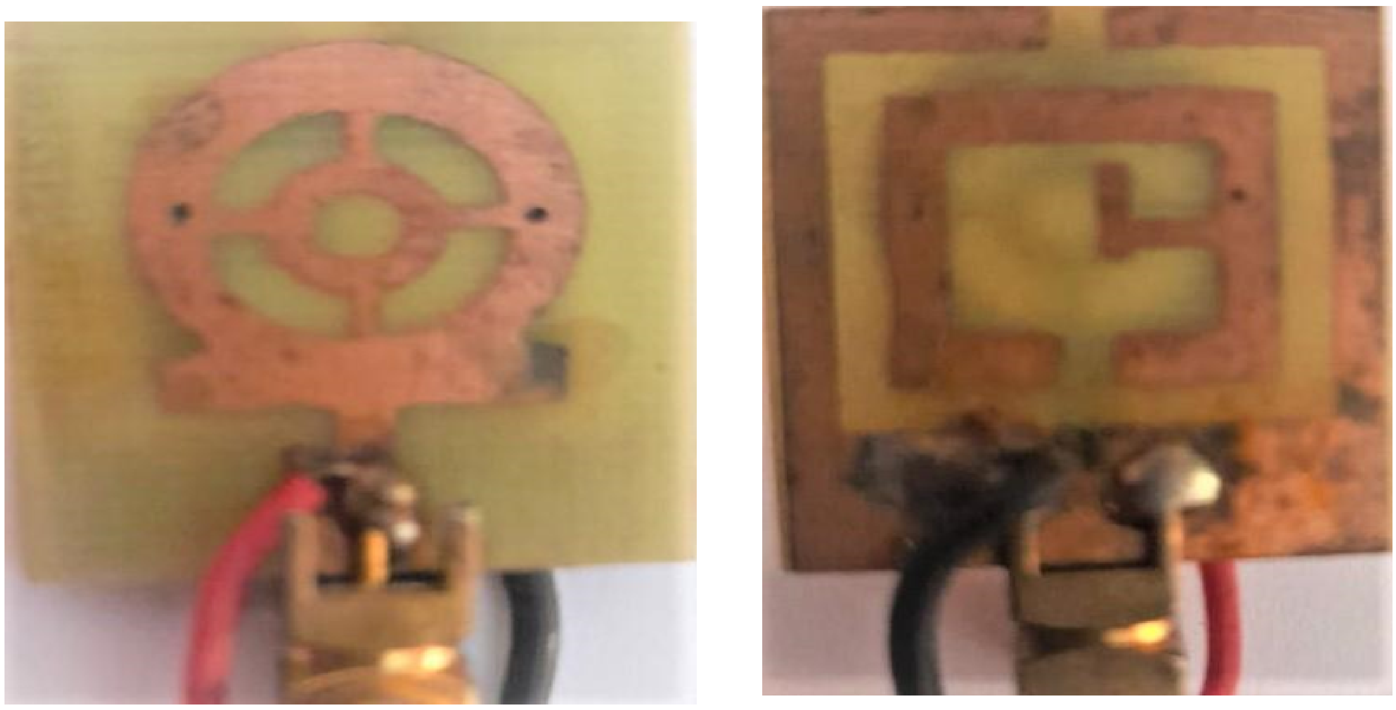
Figures



(a) (b) (c)

Figure 1

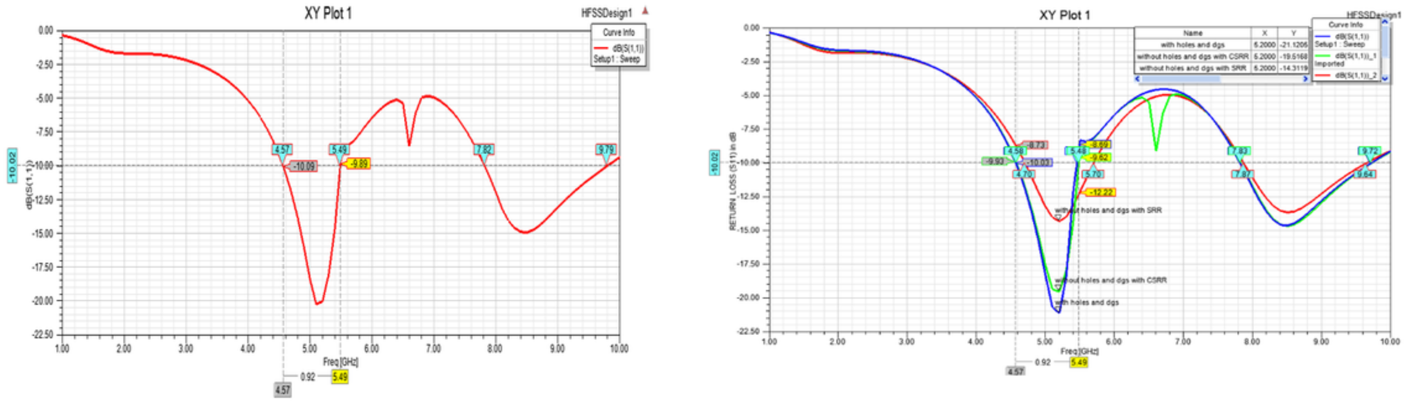
Antenna geometry (a) Top View (b) Bottom View (c) 3D View



(a) (b)

Figure 2

Fabricated proposed antenna (a) front view (b)Back view

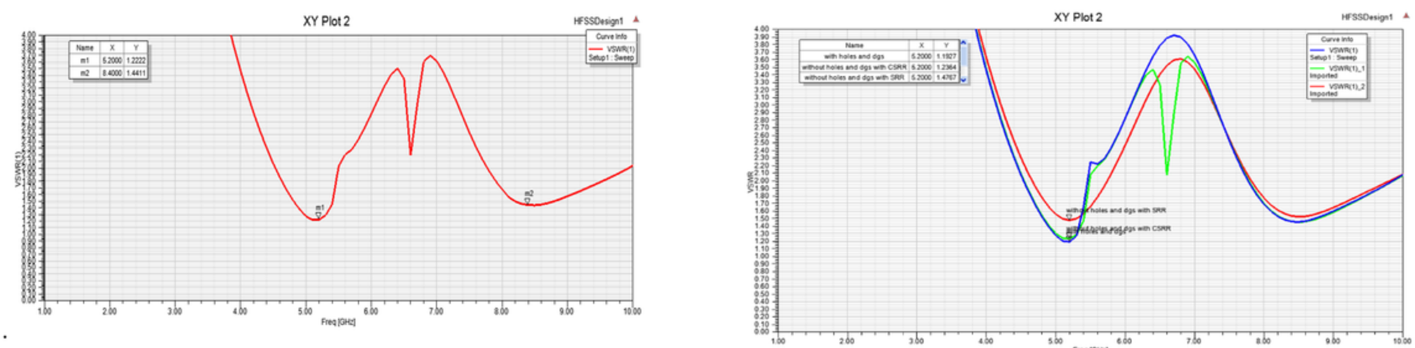


a

b

Figure 3

a. Return loss(S11) in dB b. Comparison of Return loss(S11) in dB for different antenna structure



a

b

Figure 4

a. VSWR of the proposed antenna 3 b. Comparison of VSWR for different antenna structures

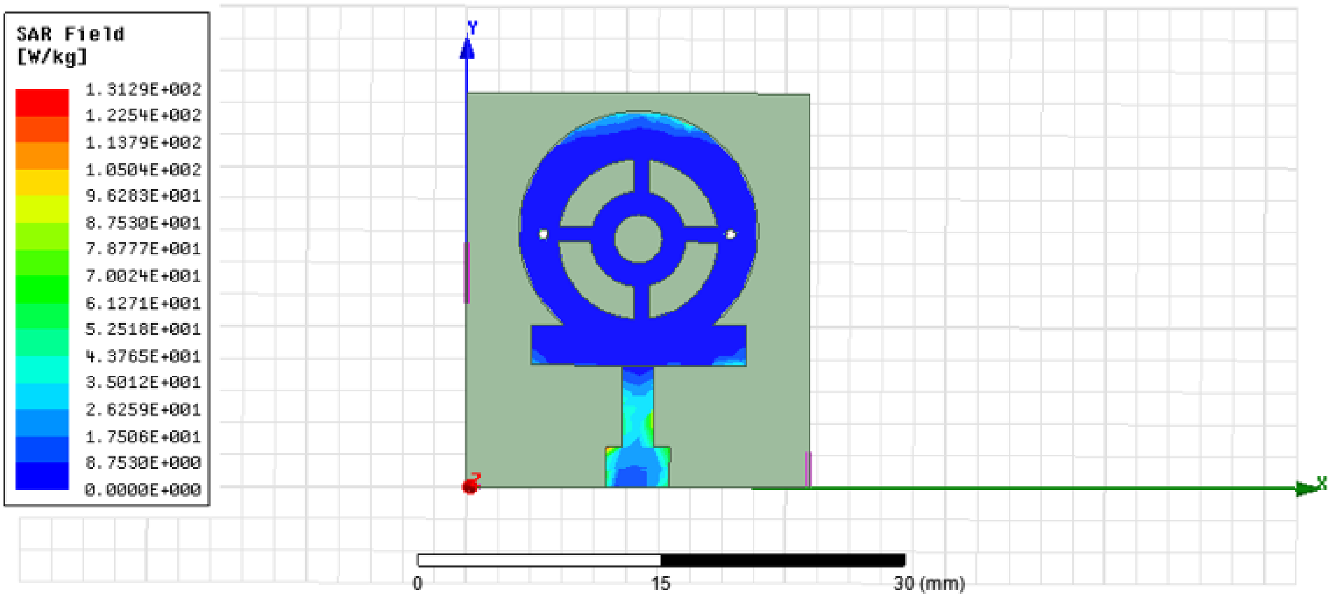


Figure 5

Specific Absorption rate

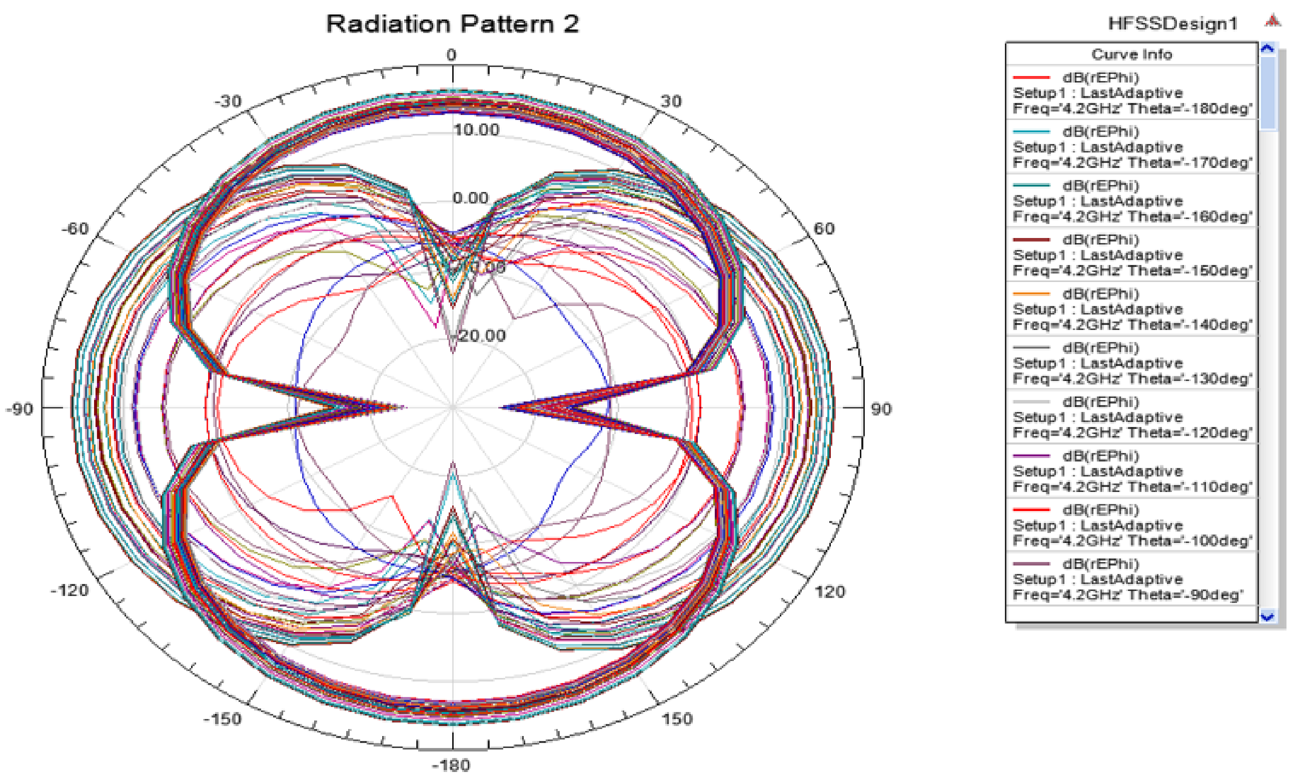


Figure 6

Antenna Radiation Pattern

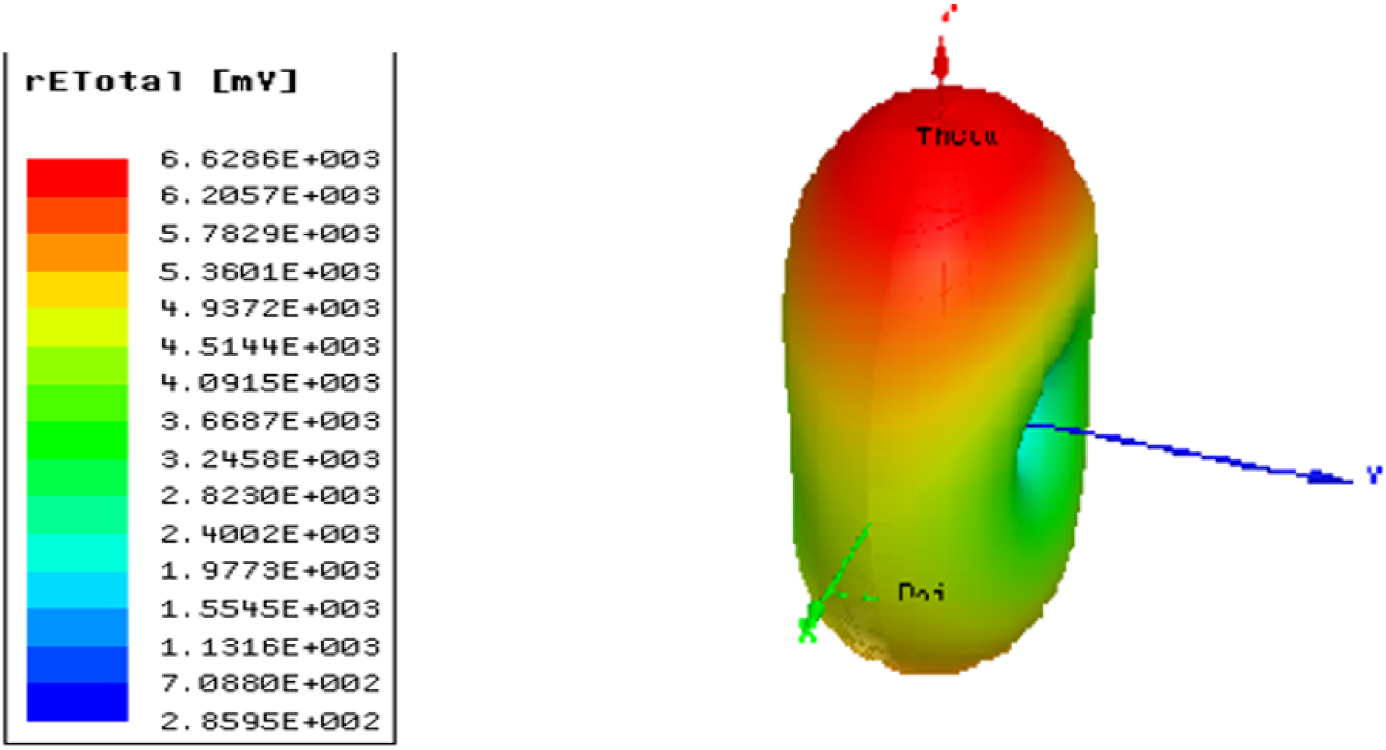


Figure 7

Antenna Gain

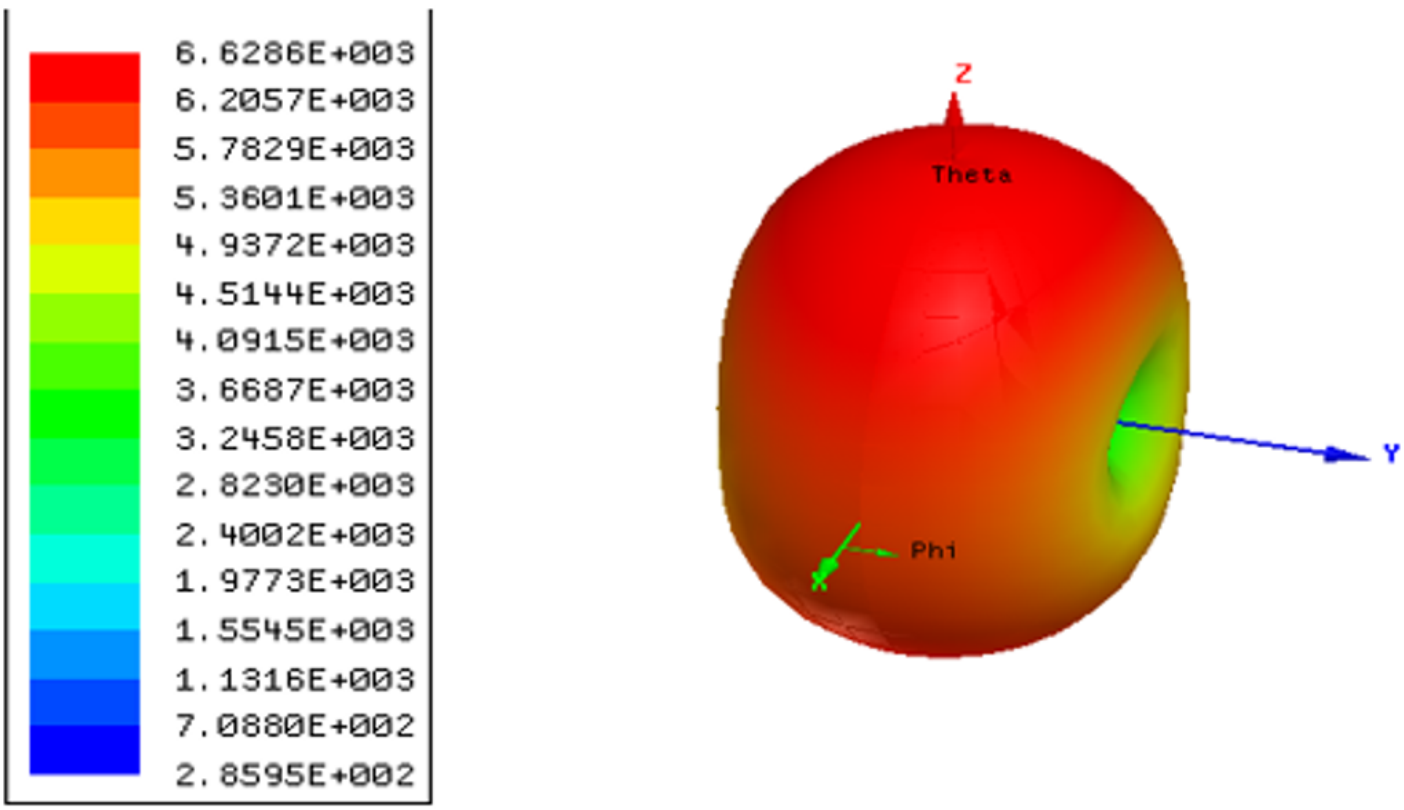


Figure 8

Antenna Directivity