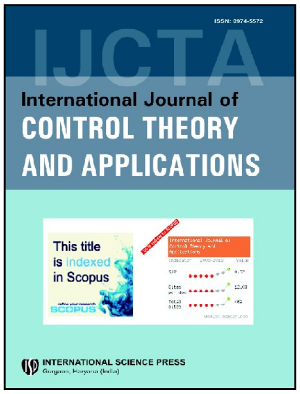

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A Novel Compact Printed Wideband On-Body Monopole Antenna for the Diagnosis of Heart Failure Detection

Avinash Kumar[1] and Ritesh Kumar Badhai[2]

[1,2]Department of Electronics and Communication Engineering, Birla Institute of Technology, Mesra, Patna Campus, Patna, India
E-mails: [1]avinashkumar1030@gmail.com and [2]riteshkbadhai@bitmesra.ac.in

Abstract: *Objectives:* The objective of the paper is the design of the novel compact Antenna for the Diagnosis of Heart Failure Detection. *Methods/Analysis:* This on-body proposed monopole antenna is matched to the human body so that most of the energy will be radiated inside the human body and obtains stronger reflections for image processing. The antenna is simulated on human torso body phantom, used with the compact microwave transceiver, and the proper data acquisition with a suitable processing algorithms to build a system that will use for the early detection of heart failure. *Findings:* A novel compact printed wide-band on-body monopole antenna with omnidirectional radiation is proposed in this paper for medical diagnosis. By using a simple rectangular ring-shaped radiator and the meandered-shaped microstrip structure which lies in the middle of the ring-shaped radiator are combined in one system and microstrip transmission line feed is used for excitation. After the optimization of the antenna parameters, the antenna is characterized by optimized dimension is $0.033\lambda_0 \times 0.025\lambda_0 \times 0.0014\lambda_0$ (where λ_0 is the wavelength of lowest simulated operating frequency in air), wide operating bandwidth of 86.5 % i.e., from 0.27GHz to 2 GHz, with peak gain of 0.752dBi, 0.65dBi, 0.88dBi and 3.32dBi at frequencies 500MHz, 800MHz, 1.15GHz and 1.8GHz respectively and the better simulated efficiencies. The proposed antenna is also simulated on human torso body phantom. The detection is realized by continuous and regular monitoring of the fluids accumulation in the lungs (pulmonary edema) that is associated with heart failure. *Novelty /Improvement:* This paper presents an innovative wideband on-body printed monopole antenna proposed for Body Area Network (BAN) that working with better efficiencies, gain, and good return losses for the early detection of accumulation of fluid inside the lungs which is the main reason for heart failure.

Keywords: Wideband antenna, On-body, Monopole, Heart failure detection, SAR (Specific Absorption Rate).

1. INTRODUCTION

The common process of the microwave diagnostic through imaging is mainly the computation of the difference in the electrical properties as between the permittivity of diseased and healthy tissues to track the possible differences or variations and have potential to locate the abnormal tissue[1]. To track small tissue irregularities, a system with high resolution is required, which generally uses high-frequency bands. But, the attenuation of the signal is high at the higher frequency band in most of the tissues because of their short wavelength[2].

This microwave-based imaging and detection techniques have the ability to be reliable, low cost and diagnostic tools are mobile for the different medical diagnostic program. Unlike in the magnetic resonance imaging (MRI) and the computed tomography (CT) scan which is the microwave-based common and classical detection techniques, a long-term monitoring system used for patients to track the various diseases, such as breast cancer, head stroke, and congestive heart failure[3-4]. Due to further development in the biomedical field, the main reason behind these diseases is the accumulation of fluid (mainly water content) inside the lungs; and is recognized as pulmonary edema, which causes a consequence differences in the electrical mainly dielectric properties of the tissues in the lungs part and these differences are compute by using microwave-based imaging techniques. In this technique, the differences are continuously monitoring only in the amplitude and/or phase of the received microwave signal after reflection or transmitted throughout the human body[5]. Based on dissimilarities of the refracted received signals and comparing them to the received signal with the healthy body, and then differences indicate the presence and the content of fluid in the lungs part can be detected.

The main well-known phenomenon is that microwave energy was absorbed more in the tissue where water accumulation is high, as in the case of lungs part (pulmonary edema), than in low water content tissues, as in the healthy lungs. Hence, both parameters as reflection and also the transmission measurements of the lungs are the main point to compute, because both parameters are highly unstable to changes in water content of lung part[6].

Also, low propagation losses inside the conductive human tissue, give low far-field gain as well as transmitted power was also limited due to factor safety, which confines the communication range. In order to maintain the mobility and enlarge the communication distance, the implantable devices are combined with wearable devices, in which case an on-body repeater is needed.

In literature survey, a lot of different antennas have been proposed that are used as a various way in medical diagnosis system. For the detection of breast cancer, a simple monopoles narrowband antenna with coaxial cable was proposed[7], which was then placed in a matching liquid filled the tank to emulate the breast tissues, used in an active microwave imaging system. A planar microstrip-fork-fed slot-antenna which was printed on a high permittivity substrate[8]. Another microstrip patch antenna has been used for the detection of breast cancer that works in the range 4–9.5 GHz[9]. TEM-based horn antennas were used for near-field microwave imaging which was based on aperture raster scanning have been used[10].

This paper presents a compact printed wideband on-body monopole antenna that is used for the medical diagnosis such as heart failure detection. A miniaturization technique is used which is based as the extension of the electrical length of the proposed antenna is responsible for the lowest operating frequency which is done by using a folded meander-shaped patch lies between the middle of the main rectangular ring-shaped radiator is introduced in one antenna. The proposed antenna having compact dimension as 36mm × 28mm × 1.6mm, that allow working at a wide frequency bandwidth of 1.73GHz (270MHz-2.0GHz). In order to the penetration of the electromagnetic energy into the lung (pulmonary edema), a human torso phantom is used having the electrical properties of human tissues (skin, fat, muscle, lungs) in the torso area. A simple compact structure of monopole antenna is adopted here that work from 0.27GHz to 2GHz.

The design and simulation work was performed using the Ansys High-Frequency Structure Simulator (HFSS), which works on the principle of Finite Element Method (FEM).

2. ANTENNA DESIGN AND ANALYSIS

2.1. Antenna Configuration:

Figure 1 shows the dimensional configuration of the proposed on-body wideband monopole antenna, where the darker part is a patch on the top of the substrate and the lighter part indicates the ground. The proposed antenna having compact dimension as 36.5 mm × 28 mm × 1.6 mm. The top radiation body is a rectangular ring-shaped antenna with a meander-shaped patch which lies between the rectangular ring. The overall patch structure is excited by the transmission line feed. The ground plane of the antenna is placed at the bottom of the substrate with two sets of stubs additionally attached, one in "L" shape and the other in "I" shape. The antenna is fabricated on the substrate of FR4 ($\varepsilon_r = 4.4$, $\tan \delta = 0.02$) with a thickness of 1.6 mm and wideband matching is achieved by parametric tuning. The detailed associated dimensions are listed in Table 1.

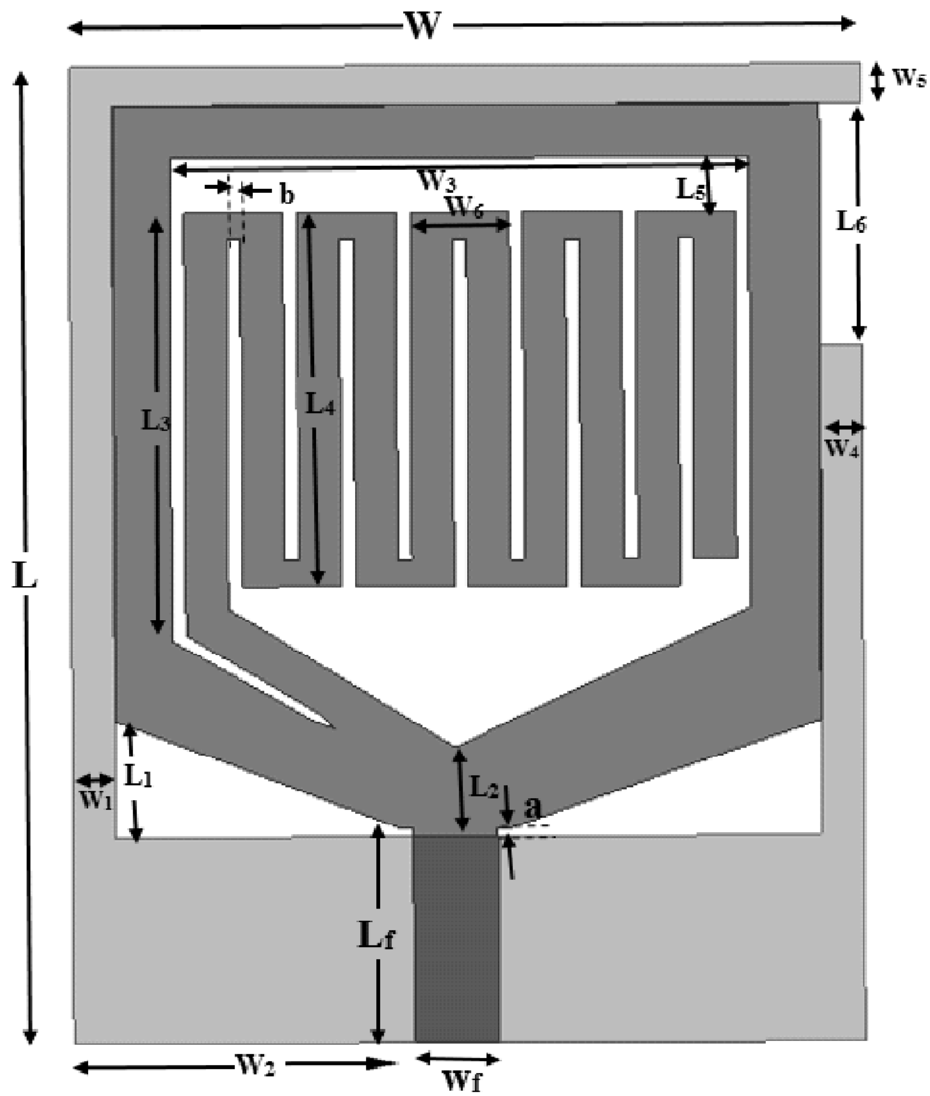


Figure 1: Dimensional configuration of the proposed on-body antenna

Table 1
Detailes Dimension of the Proposed Antenna (Unit: Millimeters)

L = 36.5	W = 28	$W_f = 3$	$L_f = 8$
$L_1 = 4.3$	$L_2 = 3$	$L_3 = 16$	$L_4 = 14$
$L_5 = 2$	$L_6 = 8$	$W_1 = 1.5$	$W_2 = 12$
$W_3 = 20.5$	$W_4 = 1.5$	$W_5 = 1.5$	$W_6 = 3.5$
a = 0.3	b = 0.5		

As shown in Figure. 2, its radiation body is placed at 5mm gap directly attached to the human torso body-equivalent phantom to minimize the contact losses[11]. The human phantom body model that is present in HFSS EM simulator, has a 2 mm of geometric accuracy and also contains skin, muscles, bones and full cardiovascular organs, almost 300 parts that are used in our consideration in design. Because the electrical properties of tissues as relative permittivity and conductivity are frequency dependent, taken from[12].

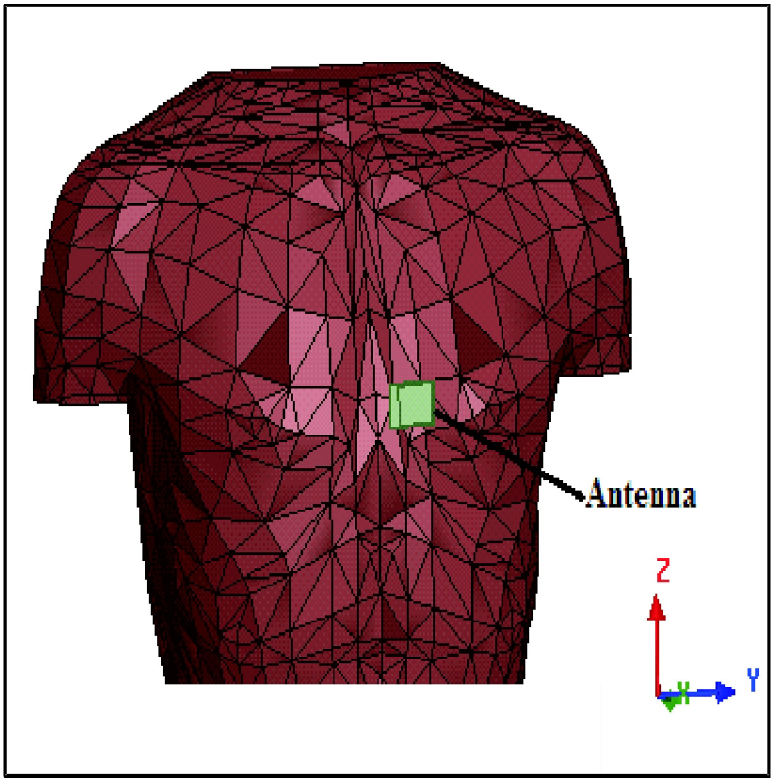


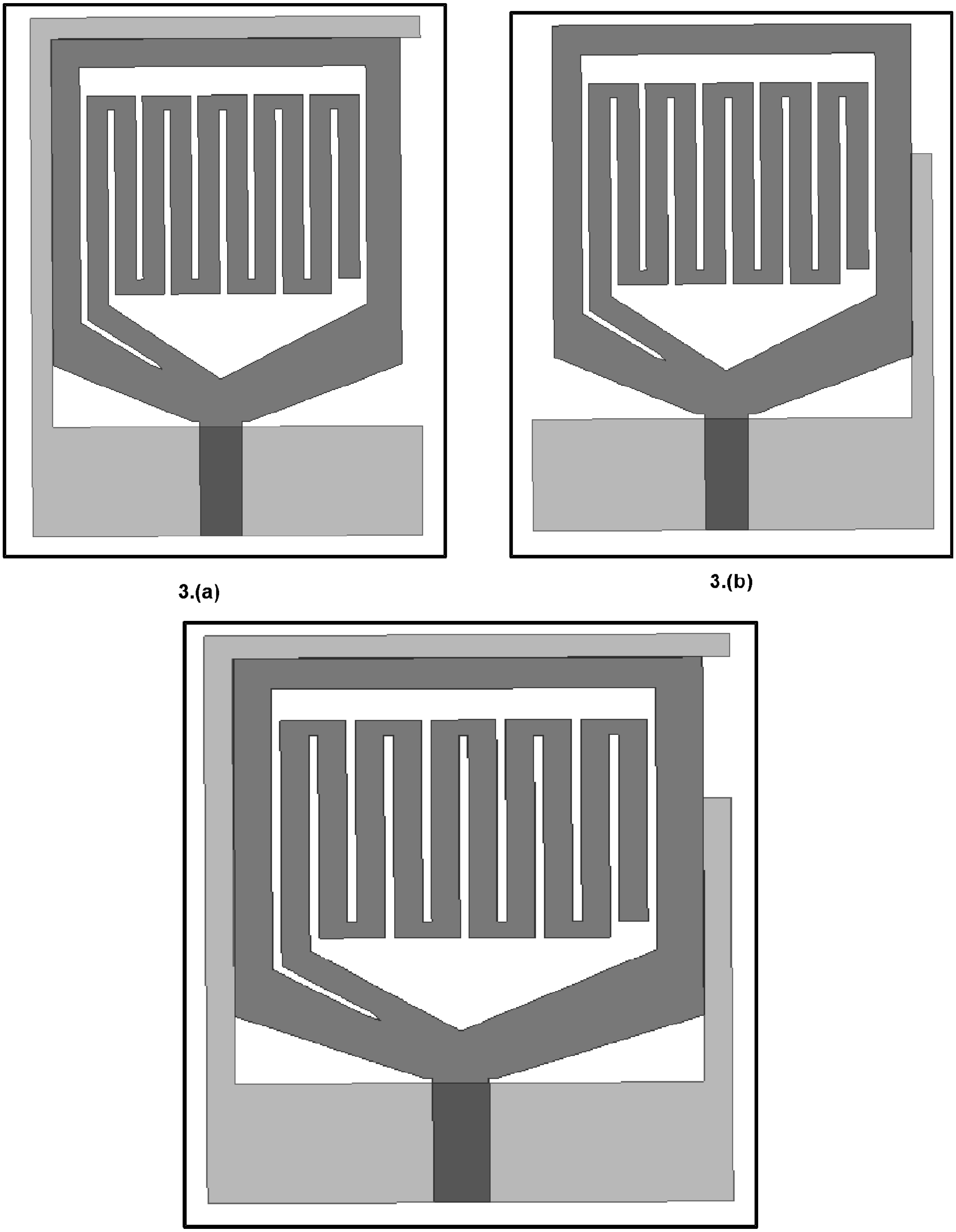
Figure 2: Antenna attached to the skin surface of the torso-equivalent phantom

2.2. Working Principle

The Due to the fact that for a structure with the ground pin such as a planar Inverted-F antenna (PIFA), low-frequency signals will be shorted for BCC applications[13], therefore a non-shorted compact monopole antenna with limited ground plane without stubs is proposed as the initial design of the on-body antenna.

As depicted in Figure 3 above, its radiation body and ground plane are placed side-by-side, which is also advantageous for the analysis, where the radiation body of the antenna can act as the TX electrode and strong electric fields can be radiated out of the antenna. The meander-shaped structure with the rectangular ring-shaped radiator is responsible for the lower frequency with wide bandwidth. Additionally, two stubs one of "L" shaped and the other one "I" shaped is etched to the ground plane to improve impedance matching and make a contribution in size reduction also. Its simulated return loss is shown below in Figure. 4 labeled as "Case 1".

To make the antenna resonant at the desired frequency band, two attempts are discussed as shown in Figure. 3(b) and 3(c). Compared to the initial design, an I-shaped stub is connected to the ground for case 1, while an adding to other L-shaped stub is adopted to get proposed antenna. From Figure. 4, it is seen that the adding of the stubs that extend the current path and improves the matching of characteristics impedance so that a wide range of bandwidth is achieved.



3.(a) 3.(b)

3 (c)

Figure 3: The three structures of on-body antenna: (a) Case 1, (b) Case 2, (c) Proposed antenna

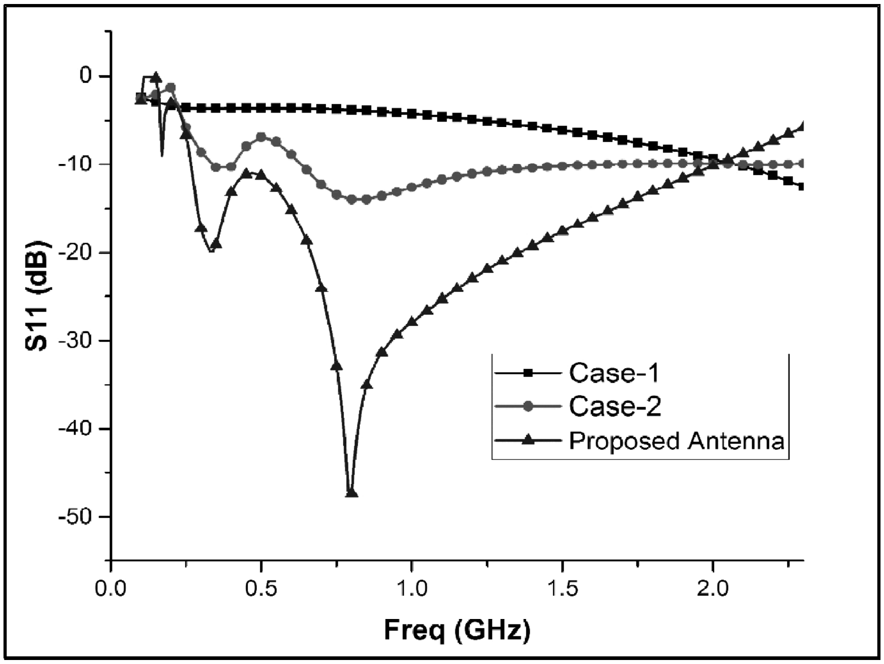


Figure 4: Comparison of the S11 (dB) of the case 1, case 2 and proposed antenna

From Figure 5, it is noted that with the tuning of the gap between the both stub i.e., distance between the horizontal arm of L- stub and I-shape stub as L6, different current paths formed at the ground plane, and difference type of return loss appears at the different resonant frequency with a different wideband gap. The optimized result was obtained at L6=4 mm, at which is the proposed antenna.

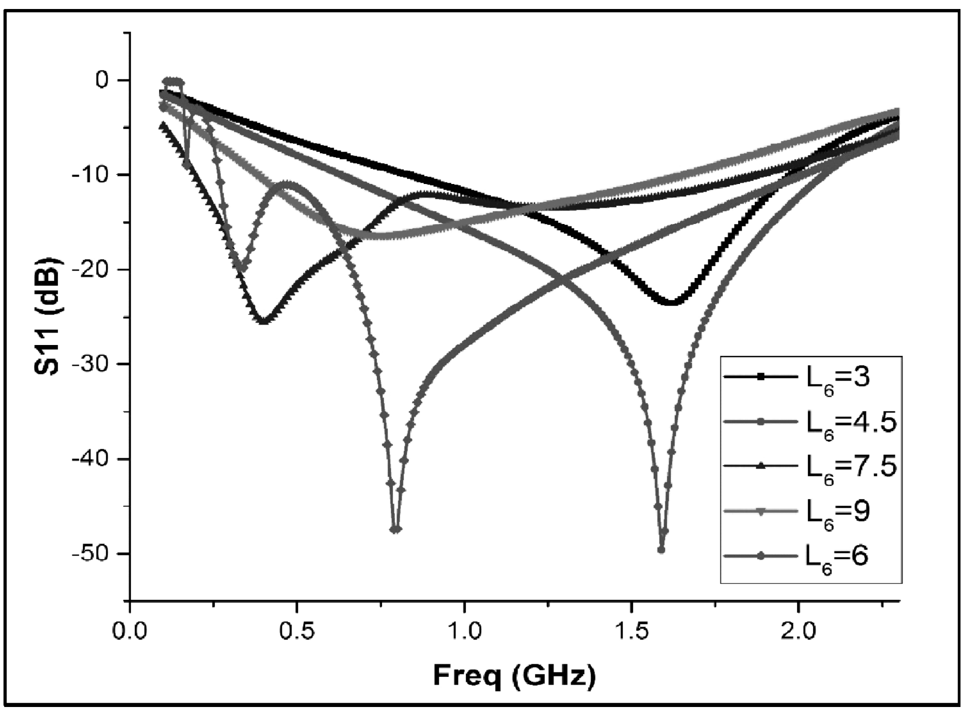


Figure 5: Comparison of the S11 varying with the differences between of stubs i.e., L6.

The total electric field on the radiation pattern at frequencies as 500 MHz, 800 MHz, 1.15 GHz and 1.8GHz are shown below in Figure 6 that show their direction and intensities.

3. RESULT AND DISCUSSION

For working in the On- body real-time heart failure detection, the antenna is placed on human torso-phantom with a 5mm gap from the body. The Simulated return loss of the designed antenna with the phantom having

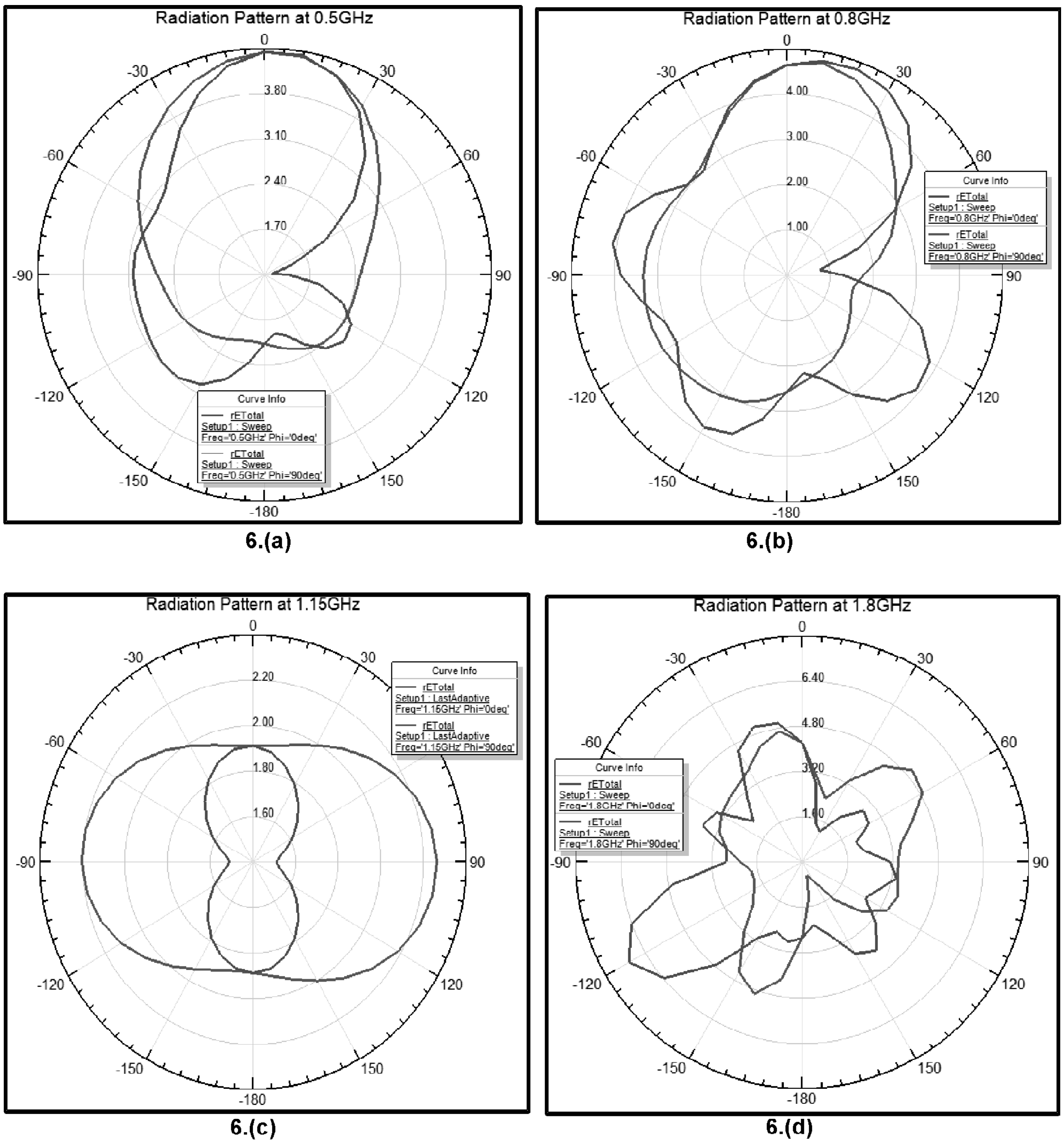


Figure 6: Radiation pattern of total electric field at (a) 500MHz, (b) 800MHz, (c) 1.15GHz and (d) 1.8GHz

bandwidth efficiency of 83.45% (0.48GHz-2.9GHz) is shown in Figure 7, compared with the proposed antenna without phantom and good agreement is achieved, can be clearly observed from the figure 7.

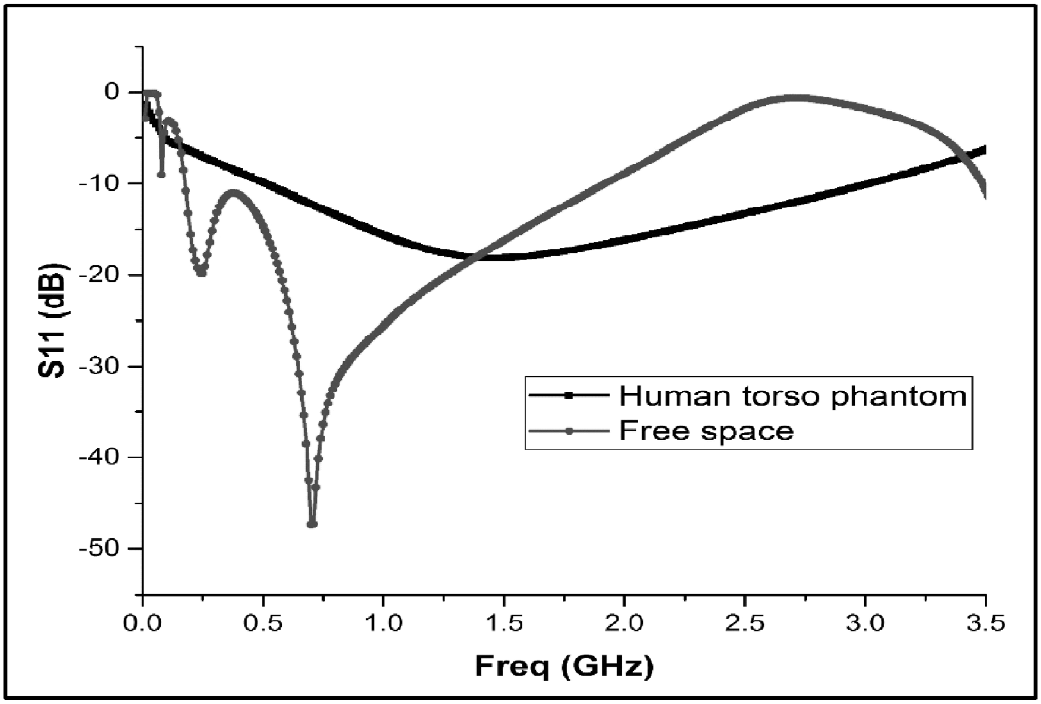
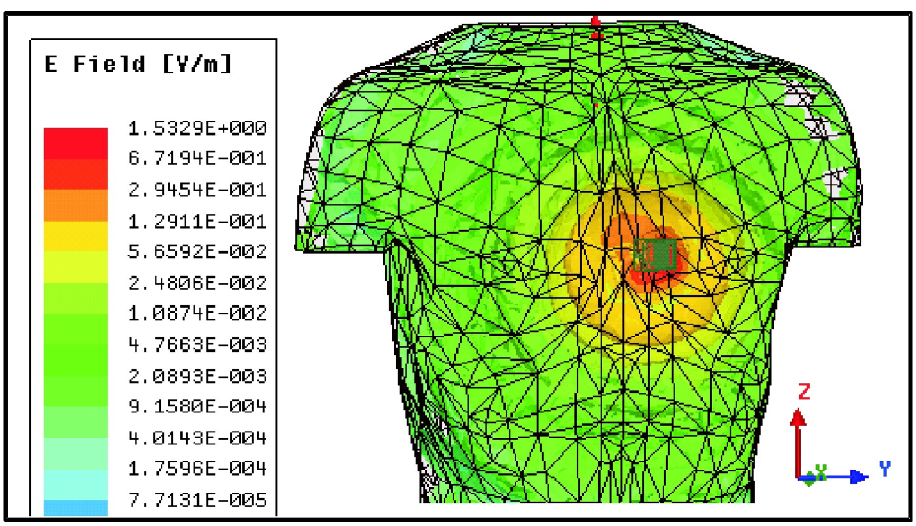


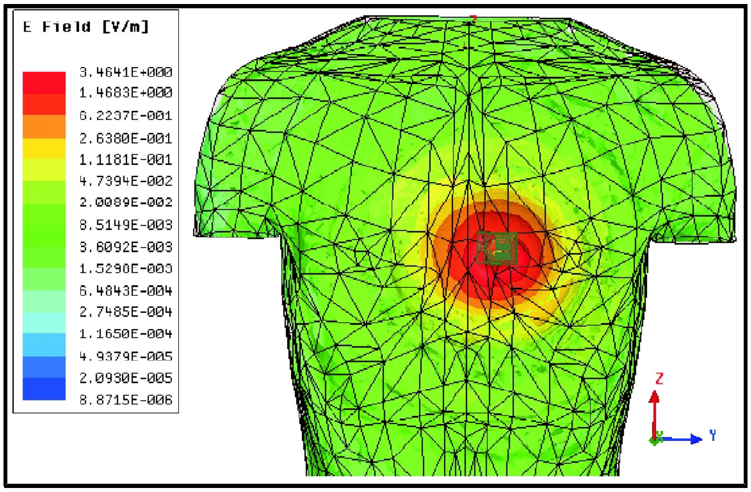
Figure 7: Comparison of the Return loss (S11) between free space and human phantom body

3.1. Electric Field Distribution

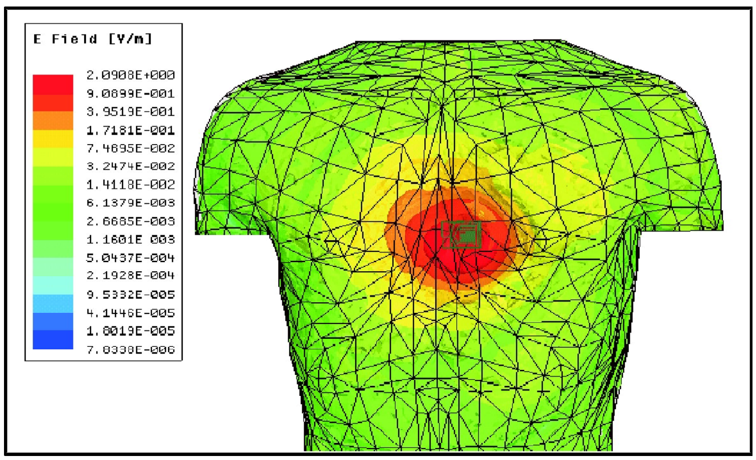
The effect of the distribution of electric field of the proposed on-body antenna on a human torso body phantom model is evaluated. The Electric field produced due to the electromagnetic heating effect on human body depends on the frequency of operation, tissue dielectric properties and their configuration of source[12]. The Electric field distribution inside the torso body phantom is shown in Figure 8, indicates that lower operating frequencies provide more penetration than the higher frequencies, as same as our requirement.



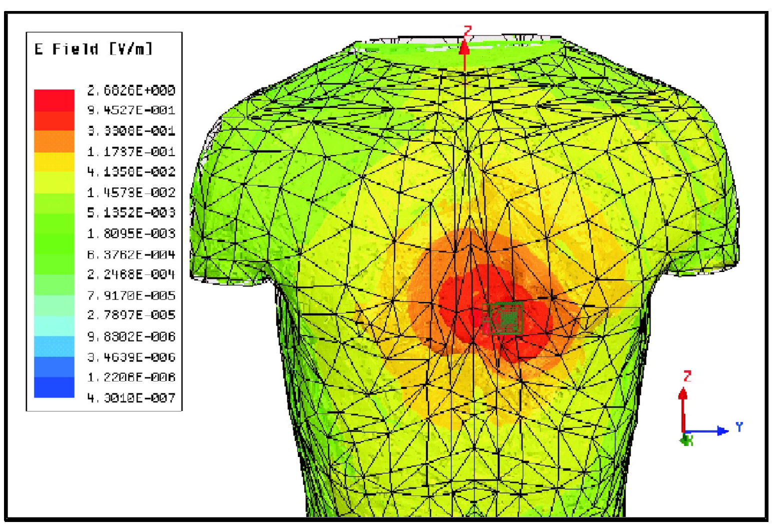
(a)



(b)



(c)



(d)

Figure 8: Electric field distribution on torso human phantom at (a) 500MHz (b) 800 MHz (c) 1.15GHz and (d) 1.8GHz)

3.2. The Gain of Antenna:

There are another two important standards which are elaborate the antenna performance working in the vicinity of the human body, one is its gain and the other is its SAR value. The gain of proposed on body antenna at different frequencies is given in Table 2.

Table 2
Simulated Values of the Antenna Parameters

Frequencies (GHz)	*Peak Gain (dBi)*	*Radiation Efficiency (%)*	*Front-to-Back (F/B) ratio (dB)*
0.5GHz	0.752	84.2	4.11
0.8GHz	0.65	62.8	1.94
1.15GHz	0.88	54.6	8.25
1.8GHz	3.32	91.7	5.85

3.3. Specific Absorption Rate (SAR) Evaluation:

Assuming that the designed on-body antenna is attached on the regular human torso phantom as a rectangular box with a 5mm gap as depicted in Figure. 2. The human tissues like skin, fat, muscle, lungs in the torso area and each of these layers are the lossy medium as equivalent transmission lines[13]. The content of water plays an important role regarding penetration of electromagnetic wave inside the body. The frequency-dependent properties of the tissues in the torso are taken from[14], shown in Table 3. Note that the thicknesses of the human tissues are assumed to be taken for a standard average person.

Table 3
Torso Tissues Parameters

Tissue	*Dielectric Constant*	*Thickness (mm)*	*Conductivity (S/m)*
Skin	51	2	2
Fat	6	20	0.2
Muscle	55	18	1
Lungs	53	140	0.7

Due to the safety concern of human body, the specific absorption rate (SAR) is evaluated at the operating frequencies i.e., at 500MHz, 800MHz, 1.15GHz, and 1.8GHz as given in Table.4 which is lower than the limit define by IEEE. Since the IEEE C95.1-1999 standard[15] restricted that the SAR value averaged over 1 gram of any tissue should be less than 1.6 W/Kg, which is more critical than C95.1-2005 [16].

Table 4
Simulated Value of Sar at 1-gram Tissue

Operating Frequencies	*500MHz*	*800MHz*	*1.15GHz*	*1.8GHz*
SAR (W/Kg)	0.468	0.013	0.025	0.044

4. CONCLUSION

A wideband on-body antenna has been proposed for heart failure detection system based on microwave-imaging. The compact size antenna has been designed using meandered type of folded structure, while achieving with its wide operating bandwidth 86.5% (270MHz – 2.0GHz). This paper presents an innovative wide-band on-body printed monopole antenna proposed for Body Area Network (BAN) that working for the early detection of accumulation of fluid inside the lungs which is the main reason for heart failure. The working principle of the proposed on-body antenna is discussed. In spite of very small volume, good radiation patterns, as well as better gain, are achieved over the entire operation wideband during simulation.

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