Variations in Return Loss of Patch Antennas in the Close Proximity of Human Body and Rectangular and Cylindrical Phantoms at 1.8 GHz

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Abstract-The performance evaluation of an antenna in the presence of human body is attracting considerable interest due to the increasing use of Body Area Networks (BAN). This study investigates the variations in matching of linearly polarised and circularly polarised patch antennas due to the presence of human body and glass fibre Specific Anthropomorphic Mannequin (SAM). The return loss at 1.8GHz is measured at varying distances to study the matching behaviour. It was found that flat section phantom gave optimal return loss closer to its surface than an actual human. Also the optimal return loss for a circularly polarised antenna is at a distance that is double than that for a linearly polarised antenna. The findings of this research are particularly useful when considering the separation distance between wearable antenna and human body in both intra and inter body wireless connectivity.

Keywords-Linear and Circular Polarised Patch Antenna, Losses, Patch Antennas, Phantoms, Propagation and Specific Anthropomorphic Mannequin (SAM)

I. INTRODUCTION

An ongoing trend in communications is the incorporation of technology both onto and into the human body [i, ii]. Medical imaging techniques for the early detection of problem matter in the body can benefit from this technology[iii, iv]. With the increasing usage of cell phones and personal digital assistants (PDAs), research on the microwave interactions with the users (humans) has received a great amount of interest in recent years[v, vi]. It is now accepted that lossy biological tissue has a serious impact on the performance of an on-body antenna. However, using volunteers during the design process is not always sensible and therefore the need for body simulating phantoms that closely exhibit the properties of human tissues in the frequency ranges used for on-body networks has increased. Examples of such Tissue-mimicking (TM) phantoms can be found in [vii-x]. However, these phantoms involve complicated fabrication methods as well as chemicals that may be difficult to obtain.

Measured values for Specific absorption rate (SAR) are important in wearable antennas as it gives an insight of the interaction of fields with body tissues. The lossy nature of biological tissue makes a human body to absorb a major portion of energy which is produced by the antenna. Authors of [xi-xiii] have worked on calculations of SAR levels for mobile phones at different environments near the SAM. Note that fairly generic phantoms such as SAM are useful both as standards and for prototyping on-body antennas. They consist of a rigid outer shell, filled with a phaseless tissue simulating liquid [xiv].

It has been proved that humans are not an ideal medium for radio frequency propagation [xv-xix]. Body behaves as partially conductive medium that consists of approximately thirty different tissue types, each of which has its own different electrical properties. The dispersive and lossy nature of humans means that resonance and absorption can quickly lead to far field pattern distortion of on-body antennas [xx, xxi]. Propagation on the surface of the body is more complex than that of free space, so simple path loss rules cannot be applied to on-body propagation. On-body propagation may be considered as a combination of free space propagation, diffraction (creeping waves) and reflections from the environment. However, the properties of wearable antennas are strongly linked to the degree of closeness (proximity) to the body and to be effective a wearable antenna must be separated at some isolation distance from the human body on which it is to be analyzed. This study is therefore, concerned with the optimal separation distance between the body surface and the antenna.

In this paper, we measure the effects of a fibre glass phantom and the human body on the return loss of a linearly polarised and a circular polarised patch antenna. Both probe fed (with main beam towards the skin/shell) and planar fed (with main beam away from the skin/shell) versions of the antenna are considered.

The objective of the experiments carried out in this research is to assess the extent to which a simple SAM like phantom can be relied upon to predict an optimal distance of the wearable antenna from the body during antenna design.

II. TECHNICAL DESCRIPTION OF THE EXPERIMENTAL SETUP

A. Antenna Design

Simple patch antennas fabricated on FR4 were used in the experiments. The antenna designs [xxii]were modified using CST Microstripes. To maintain a proper distance above SAM and Human chest and back spacers were used. Fig. 1 gives a line demonstration of antennas and the positioning spacer.

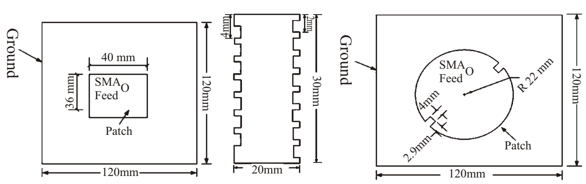

Fig. 1. An unscaled line diagram of patch antennas and experimental spacer

A particular care was given for the accurate calibration and minimized cable disturbance. A combination of metallic cap [xxiii] and ferrite beads were used for the purpose of chocking any surface currents on the coax because of the mismatch in impedance at the feeding point. This concept of metallic cap at the end of the coaxial cable is shown in Fig. 2.

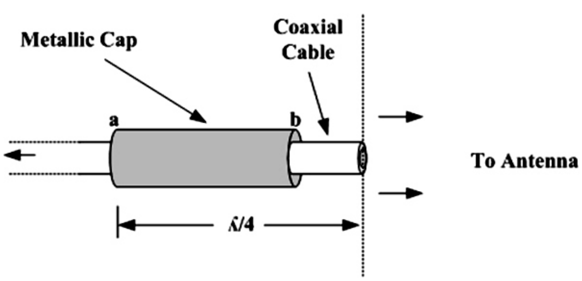

Fig. 2. Quarter wave current choke used for surface currents at the cable

The repeatability of the experiments was ensured by performing them repeatedly for few days. It was also observed that a variation of ± 0.5-to-1dB in S_{11}(dB) was monitored due to any flexing in the coaxial cable during the experiments. A Portable Network Analyzer operated on batteries was used in all measurements. To test the behaviour of an antenna with its main beam directed away from the surface of the human body and the SAM, a microstrip line, linear polarised [xxii] and circular polarised [xxiv] patch antennas were used as shown in Fig. 3.

B. The Phantom Muscle Simulating Dielectric Liquid

The phantoms were manufactured from 2mm thick glass fibre and are shown in Fig. 4. The dimensions of these phantoms were so selected to closely match with the size of human body. Note that in microwave measurements use of glass fibre as a phantom material is a validated practice [xxv-xxvii].

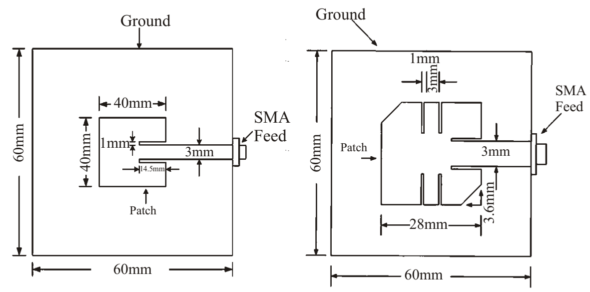

Fig. 3. A line diagram of a microstrip line patch antennas

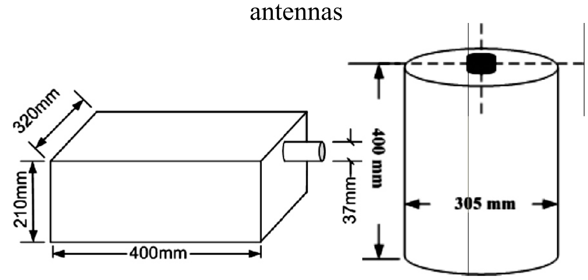

Fig. 4. An unscaled line diagram of Phantoms

The electrical properties of the SAM and the dielectric fluid used to simulate human muscle are given in Table I. A comprehensive procedure for making the muscle simulating liquid can be found in [xiv]. The volume of the phantom could accommodate approximately 10 liters of liquid and special care was taken to avoid air pockets while filling the phantoms. This was achieved by slow filling and settling of the liquid.

TABLE I
ELECTRICAL PROPERTIES OF MATERIAL USED IN EXPERIMENTS

	ε_r	$\sigma(S/m)$
Muscle Simulating Dielectric Liquid (MSL)	55.15	1.47
FR4 chip	4.5	0
Glass Fibre	4.5	6e(-3)
PVC Spacer	4.0	10.01e (-6)

C. Measurement Procedure

The measurements were performed for the separation distance of 3cm from the surface of the body which is nearly equivalent to the several layers of usual clothing (T-Shirt) and may be an outer garment such as a coat. Previously research work at Loughborough University [xxviii, xxix] had mentioned that dielectric constants for most of the garments varies from 1 to 2.5 and are low loss, so the clothing effect can be neglected. Therefore, The two main reasons associated with the variation in the return loss of the wearable antennas are as follows:

The reflection from the surface of the human body or SAM and

Losses in the skin and muscle of the human body and the dielectric liquid used in the phantoms

Standard calibration technique was adopted for the calibration to normalize the cable losses. The S_{11}(dB) measurements were taken for a range of 2 to 30mm with 2mm steps in every interval. The antenna was not allowed to touch the human skin while measuring the return loss to avoid the shortening of the antenna with the human skin because of the finite conductivity of skin at the intended operational frequency of 1.8GHz. Fig. 5 shows the experimental setup.

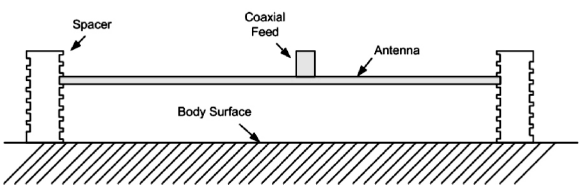

Fig. 5. Antenna positioning with respect to the surface of a Human Body and Phantoms

It can be seen that the phantom is fully planar and the human mid top back is approximately considered to be planar. All volunteers were male and were in their mid-twenties. Since the effects measured are only sensitive in the very near field, so the measurements were taken in a laboratory. For authentication, another experimental setup inside in an anechoic chamber was designed to further reduce the reflections by using RF absorbers. This is setup is shown in Fig. 6.

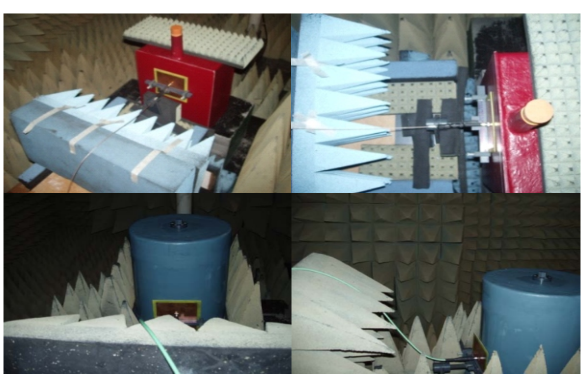

Fig. 6. Antenna positioning on the Phantoms inside the Anechoic Chamber

D. Antennas, Human Torso and Phantoms Models

The simulated linear and circular polarised patch antennas at 1.8GHz are shown in Fig. 7 (a) and 7 (b) respectively. The dimensions of their patches are given in Table II. The ground plane in each case was 120x120x1.6 mm^3.

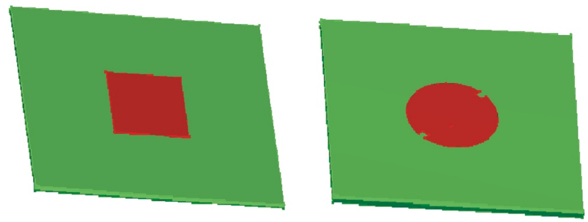

Fig. 7. (a) Linear polarised rectangular patch antenna, (b) Circular polarised circular patch antenna

TABLE II
DIMENSIONS OF THE PATCHES AND GROUND PLANES OF RECTANGULAR AND CIRCULAR PATCH ANTENNAS AT 1.8GHZ

Antenna type	Ground Plane (mm^3)	Patch Dimensions
Rectangular Patch	120x120x1.6	Length=36mm Width=40mm
Circular Patch	120x120x1.6	Radius=22mm

Simple three layer human body model was created in CST Microstripes. These kind of layered models are common in practice [xxx-xxxii]. The simulated model contained layers of muscle, dry skin and wet skin. The dimensions of the cylindrical model approximated the human torso, 290mm from stomach to back, 418mm from shoulder to shoulder and 450mm for vertical height from shoulder to waist. Similarly, 2mm thick fibre glass models of rectangular and cylindrical phantoms were also created and their dimensions were carefully chosen so as to match the human body model dimensions as given above. These models with an antenna on the top are shown in Fig. 8. The parametric study was carried out by changing the distance between antenna and human body models.

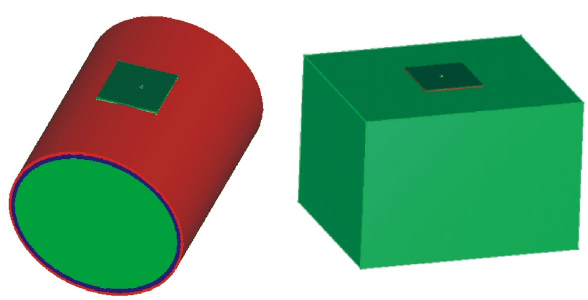

Fig. 8. Simulated (a) human body and (b) rectangular phantom models in CST Microstripes with patch antenna on their top at 1.8GHz

III. RESULTS

A. Experimental Results

To get the maximal amplitude of the reflected waves and surface currents, probe fed linear and circular polarised antennas were used, with their main beam directed towards the surface of the rectangular phantom and human body. This may not be typical in wearable antennas but may be such in medical imaging. The measured S_{11}(dB) at varying distances from the surface of the human body and muscle simulating liquid (MSL) filled phantom at operational frequency of 1.8GHz for linear and circular polarised patch antennas is shown in Fig. 9 and Fig. 10 respectively. It can be observed that for rectangular phantom, the best match occurs at a distance of 15mm from the phantom and for the human body it occurs at a distance of 26mm from the surface. When compared, the variations in the match resemble each other; but for human body it occurs right shifted, approximately 10mm.

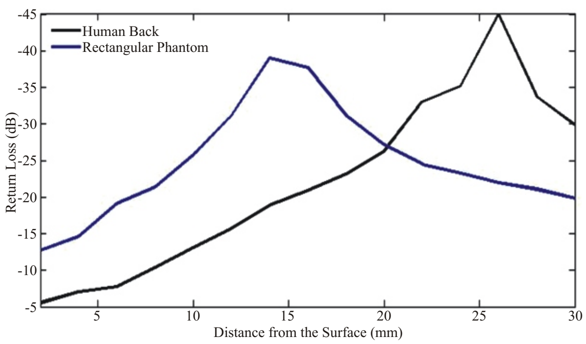

Fig. 9. Recorded S_{11}(dB) Variations for Rectangular SAM and Back of a Human Body. Antenna Type: Linear Polarised Operational Frequency: 1.8GHz

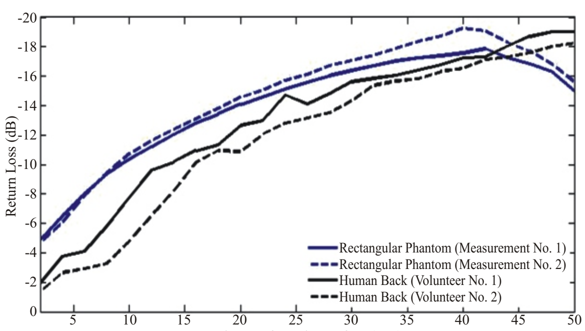

Fig. 10. Recorded S_{11}(dB) Variations for Rectangular SAM and Back of a Human Body. Antenna Type: Circular Polarised Operational Frequency: 1.8GHz

In the 2nd set of experiments, both rectangular and cylindrical phantoms were used in comparison to the human body, for linear and circular polarised antennas at 1.8GHz inside in an anechoic chamber. The measured S_{11}(dB) at varying distances from the surface of the human body and muscle simulating liquid (MSL) filled rectangular and cylindrical phantoms at operational frequency of 1.8GHz for linear and circular polarised patch antennas is shown in Fig. 11and Fig. 12 respectively. It can be observed that when compared with rectangular phantom, both human body and cylindrical phantom resonates the antennas exactly at the same distance, and right shifted by 6-10mm.

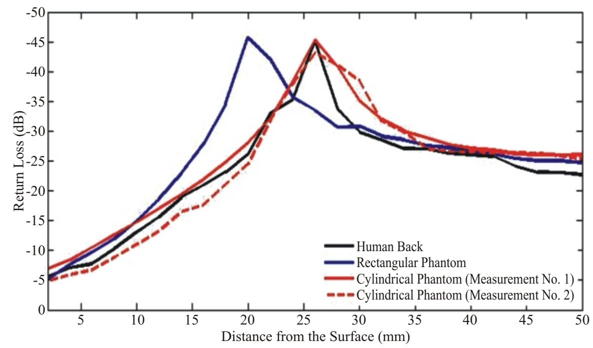

Fig. 11. Recorded S_{11}(dB) Variations for Rectangular and Cylindrical SAM and Back of a Human Body. Antenna: Linear Polarised Operational Frequency: 1.8GHz

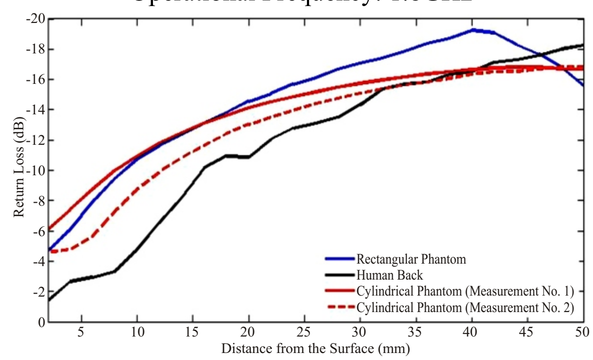

Fig. 12. Recorded S_{11}(dB) Variations for Rectangular and Cylindrical SAM and Back of a Human Body. Antenna: Circular Polarised Operational Frequency: 1.8GHz

In 3rd set of experiments, microstrip line patch antennas shown in Fig. 3, were used with their main beam directed away from the surface of the human body and phantom. The radiations in this case are mainly blocked by the ground plane, and only reduced back lobe interacts with the human body. Therefore, there is no considerable change in return loss versus distance from the surface, as shown in Fig. 13 and Fig. 14. The knee of the response in Fig. 13 and Fig. 14 (demonstrated with the help of arrows) reflects that both for linear and circular polarised antennas, null in the match occurs 10mm before for rectangular phantom as compared to that of the human body and cylindrical phantom. It shows that the conclusions drawn from the 1st and 2nd set of experiments are correct.

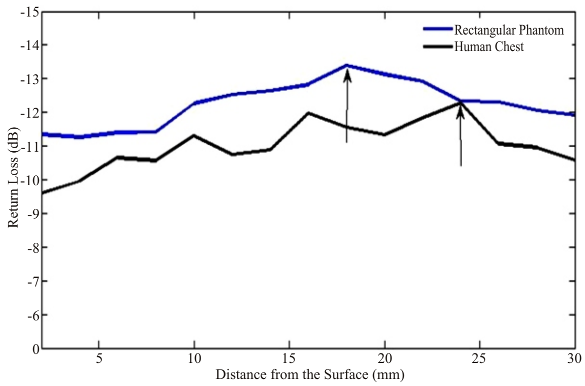

Fig. 13. Comparison of S_{11}(dB) Measurements for a Dielectric Liquid filled Rectangular Phantom and Chest of a Human Body for a Microstrip Line Linear Polarised Antenna at 1.8GHz

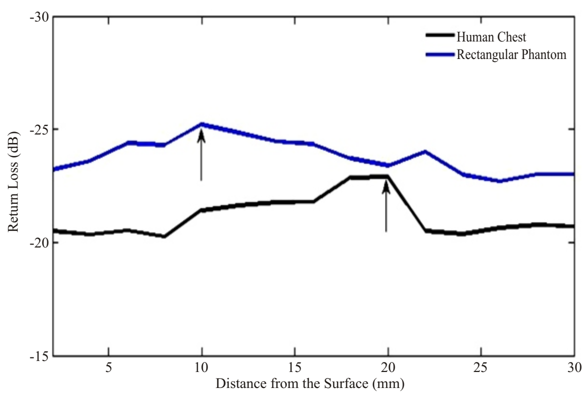

Fig. 14. Comparison of S_{11}(dB) Measurements for a Dielectric Liquid filled Rectangular Phantom and Chest of a Human Body for a Microstrip Line Circular Polarised Antenna at 1.8GHz

B. Simulation Results

As discussed earlier, to strengthen our experimental results and conclusions, CST Microstripes was used to simulate antennas, 2mm glass fibre rectangular and cylindrical phantoms and human body models.

Fig. 15 shows the variation in return loss of the linear polarised antenna at different distances from the surfaces of glass fibre rectangular phantom and human body models. Similarly, Fig. 16 shows variations in return loss of circular polarised antenna when its distance is varied from the surfaces of glass fibre rectangular and cylindrical phantom and human body model. It can be observed clearly in and Fig. 16 that when considered against human body and cylindrical phantom, there is always a right shift in the resonance of linear and circular polarised antennas.

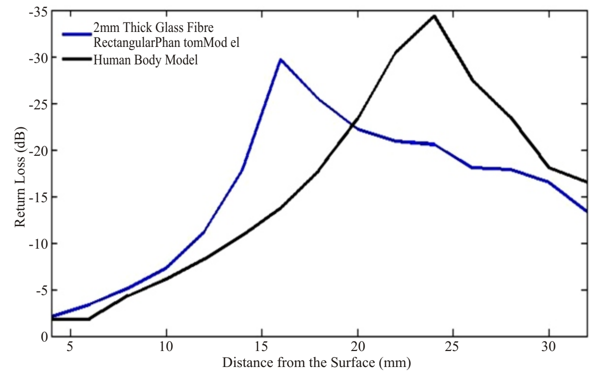

Fig. 15. Comparison of S_{11}(dB) Measurements for a 2mm Glass Fibre Rectangular Phantom and a Human Body Model for Linear Polarised Antenna at 1.8GHz

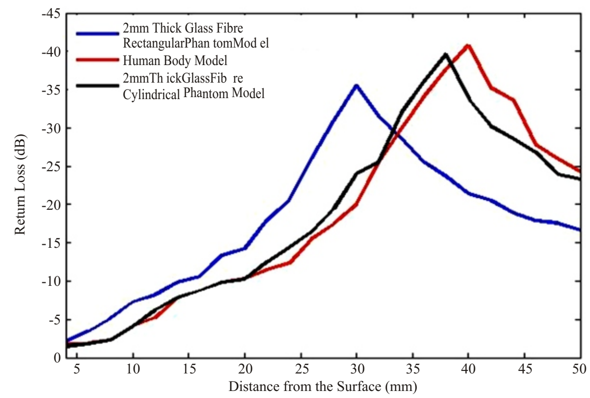

Fig. 16. Comparison of S_{11}(dB) Measurements for a 2mm Glass Fibre Rectangular and Cylindrical Phantom and a Human Body Model for Circular Polarised Antenna at 1.8GHz

IV. CONCLUSIONS

This paper investigates the mismatch variations of the patch antennas placed close to the biological tissue and fiberglass made rectangular and cylindrical phantoms. Just according to the expectations both human body as well as the phantoms changes the resonance to a low frequency.

A number of experiments were performed to draw thorough conclusions. In every set of experiments, it was found that the resonance of a patch antenna, whether linear polarised or circular polarised, occur approximately 10mm before for rectangular phantom as compared to that of the human body and cylindrical phantom. The only reason to the cause seems to be the edges of the rectangular phantom. So the recommended option in shapes of the phantom is the cylindrical one in antenna measurements inside or outside the anechoic chamber. Furthermore, the results suggest that *null* of the match for circular polarised antenna occurs at approximately double the distance as compared to the linear polarised antenna, both for the rectangular and the cylindrical phantom. The outcomes of the experiments were also verified when main beam of the antenna was directed away from the body surface. In this set of experiments as shown in Fig. 13 and Fig. 14, the variations in mismatch were not noticeable when the distance from the surface was varied; yet a closer view of the mismatch patterns shows that *null* of the resonance curve in case of rectangular phantom occurs at approximately 10mm before that of the human body model for linear and circular polarised antennas. Also the best match for circular polarised antenna occurs at nearly double the distance of the linear polarised antenna. At the end, the simulation results as shown in Fig. 15 and Fig. 16, also confirmed the afore-mentioned conclusions.

Based on the experimental results obtained in this research, it is recommended that the separation distance must be increased while using rectangular phantoms in wearable antenna measurements.

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