A Study of Perturbations in Linear and Circular Polarized Antennas in close proximity to the Human Body and a Dielectric Liquid Filled Phantom at 1.8 GHz

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***Abstract*— In the design and synthesis of wearable antennas isolation distance from the body is a critical parameter. This paper deals with the comparison of perturbations caused to the matching of simple linear and circular polarized patch antennas due to the close proximity of a human torso and rectangular box phantom filled with muscle simulating liquid at 1.8GHz. The isolated variable is return loss (S_{11}). Results show that both linear and circularly polarized antennas produce an optimal return loss closer to the surface of a typical phantom than the back of a human volunteer.**

I. Introduction

An ongoing trend in communications is the incorporation of technology both onto and into the human body [1, 2]. Most such technologies require one or more antennas. Medical imaging techniques for the early detection of problem matter in the body requires similar research [3, 4]. Also, because of the brisk take up of mobile phones and personal digital assistants (PDAs), work on the interaction of radiofrequency radiation with the body has received a great amount of interest [5, 6]. 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. Several researchers have developed tissue-mimicking (TM) phantoms for higher and lower water content human tissues at different frequencies, the earliest of which was written up in [7], in 1971 for high water contents tissue simulating phantom for frequency range of 13 to 2450MHz. More recently phantoms were fabricated by the authors of [8], [9] and [10]. These materials involve complicated fabrication methods as well as chemicals that may be difficult to obtain.

Specific absorption rate (SAR) is important in wearable antennas since it provides a measure of the interaction of fields with tissue and a high proportion of the energy produced by a wearable antenna may be absorbed by the body. Information on SAR levels associated with mobile phones and phantoms and in particular the Specific Anthropomorphic Mannequin (SAM) used for mobile phone compliance testing can be found in [11-13]. Note that fairly generic phantoms such as SAM are useful both as standards and for prototyping on-body antennas. Simply they consist of a rigid outer shell and filled with a phaseless tissue simulating liquid. Recipes for this can be found in [14] along with specifications for the standard phantom.

It turns out that humans are not an ideal medium for radio frequency propagation [15-19]. Our substance is a partially conductive medium that consists of approximately thirty different tissues 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 destruction of on-body antennas [20, 21]. Propagation on the surface of the body is more complex than the free space propagation, 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 wave) and reflections from the environment. However, the properties of wearable antennas are strongly linked to the degree of closeness (proximity) to the body.

In this paper we measure the effects of a simple tissue simulating liquid filled 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 toward the skin/shell), and planar fed (with main beam away from the skin/shell), versions of antenna are considered.

The objective of these experiments is to assess to what degree a simple SAM like phantom can be relied upon to predict a wearable antennas' optimal distance from the body during design.

II. Description of Experiment Antennas, Phantom, Volunteers and Equipment

A. Antenna Design

The antennas selected were simple microstrip patch antennas built of common 1.6mm thick FR4 board. The designs of antennas used can be found in [22] and refined using the EM simulator Microstripes. Spacers were then used (4 off), to position the antenna ground plane, first above the phantom and then above the chest and back of our volunteers. Both these antennas along with the spacer are shown in figure 1.

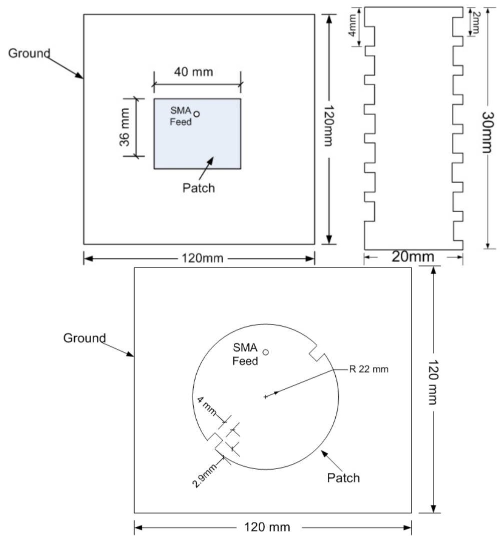


Figure 1: A line drawing of a linearly and circularly polarised patch antennas and an experimental spacer (Not to Scale).

Care was taken to ensure accurate calibration and minimise cable disturbance. A combination of metallic cap [23] and ferrite beads were used to choke off currents on the outer of the coaxial cable due to impedance mismatch at the feed. The concept of metallic cap at the end of the coaxial cable is shown in fig.5. The experiments were repeated over several days to assess repeatability. It was noted that lightly flexing the coaxial cable gave results of ± 0.5-to-1dB in S_{11}. The measurement instruments was a Anritsu Portable Network Analyser MS2026A, which operated on batteries.

B. Torso Phantom with a Tissue Simulating Liquid

A rectangular phantom was made from 2mm thick glass fibre with the dimensions approximately 400mm long, 320mm wide and 210mm high shown in figure 2. These dimensions were chosen to be loosely representative of the volume of the torso of a male. Note that the use of glass fibre phantoms in microwave measurements is now accepted practice [24]. The dielectric properties of the phantom and the muscle simulating liquid are shown in table 1. A recipe for the filling substance is given in [14] . When full the phantom holds approximately 10 litres of liquid and was designed in such a way as to minimise air pockets on filling. However, slow filling and settling are advised to avoid air pockets. A picture of the torso phantom is shown in Fig. 2. When full this phantom weighs 26.8kg and is therefore portable but not unduly so.

	ε_r	$\sigma\ (S/m)$
Muscle Simulating Liquid	55.16	1.46
FR4 Board	4.5	0
PVC (Spacer Material)	4.0	10e(-6)

Table 1: Dielectric properties of muscle simulating liquid and FR4 board.

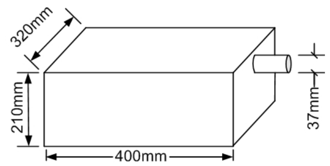


Figure 2: A line drawing of Torso Simulating Phantom (Not to Scale).

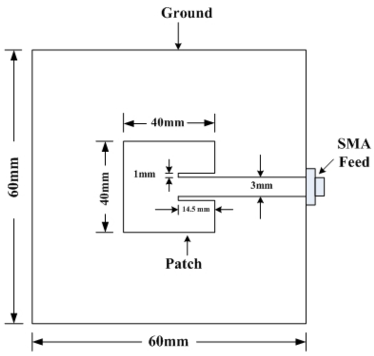


Figure 3: A line drawing of microstrip line patch antenna (Not to Scale).

C. Experimental Method

For practicality it was assumed that the range of measurements should be within 3cm of the surface of the body. This equates to several layers of clothing including an outer garment such as a coat. Previous work at Loughborough University had suggested that most garments have dielectric constants real of between 1 and 2.5 and are low loss. An exception is neoprene with a dielectric constant of 6 but this is still rare in clothing. Therefore we consider is reasonable to neglect clothing by making the assumption that the two major contributors to changes in antenna parameters when closed up to the body are the reflection at the air phantom/body interface and the loss in the tissue simulating liquid and the skin and muscle and blood of the torso.

After calibration the antenna return loss was measured at intervals of approximately 2mm over the range 2 to 30mm. An on surface measurement was not taken since the conductivity of skin at 1.8GHz (1.2 S/m), effectively shorts out the antenna and prevents conducting surfaces pooling charge in the intended way. At 2mm intervals the S_{11} was recorded for phantom and human back. The abstracted drawings of Fig. 3 show the experiment in progress. Note that the phantom is truly planar whilst the human mid top back is reasonably planar. Our volunteers were all male in their mid twenties. Since the effects we are measuring are predominantly only sensitive in the very near field we considered it reasonable to take our measurements in a laboratory. However, as a check a second setup was designed in an anechoic chamber as shown in the Fig. 4. In this setup reflections were further attenuated by properly placed sections of absorber.

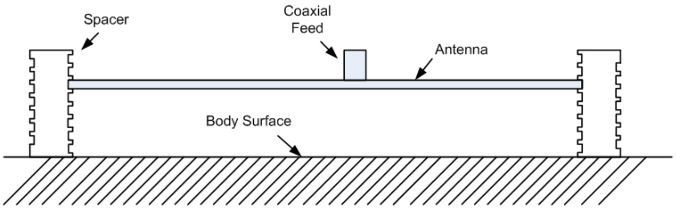


Figure 3: Placement of Antenna on the surface of Human Body.

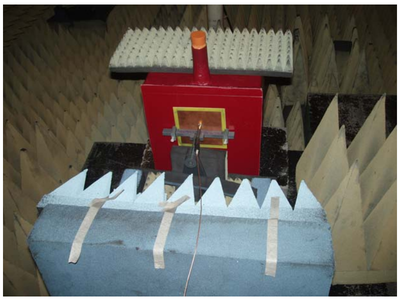


Figure 4: Placement of Antenna on the surface of Phantom.

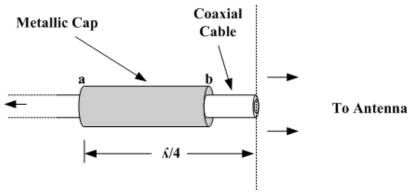


Fig. 5. Quarter wave current choke used on coaxial cable.

III. RESULTS

The first set of experiments was done using probe fed antennas with main beam facing toward the phantom shell and human body. This arrangement provided for the maximal amplitude of reflected wave and surface current. This would not be typical in wearable antennas but may be so in medical imaging. Chart 1 and chart 2 show the return loss versus distance from the surface of the volunteers body and dielectric filled phantom for linearly and circularly polarised antennas at 1.8GHz. It can be seen that in the presence of the phantom the match is generally better closer to the phantom when compared to the body. The rates of change of the responses are roughly the same. However, the effects due to the body occur right shifted in that they happen to the same degree at a greater distance. Note that in general circularly polarised antennas exhibit lower Q than linear antennas and therefore the difference in rate of change of return loss is as expected.

To test the behaviour of an antenna with its main beam directed away from the surface a microstrip line patch antenna [22] was used to gather the results for return loss presented in Chart 3. Since only the reduced back lobe of the antenna now interacts with the surface of the body or the phantom the rate of change of mismatch is now reduced and therefore the knee of the response is not as clear. However, the conclusions gained from the first set of experiments are still true although.

Chart 1: Comparison of S_{11}(dB) Measurements for Dielectric Liquid filled Phantom and Back of a Human Body for Linearly Polarised Antenna at 1.8GHz

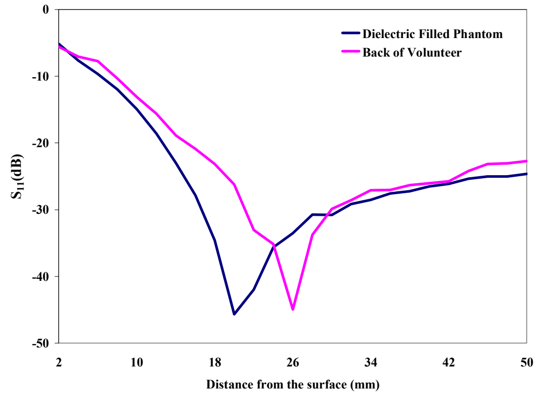


Chart 2: Comparison of S_{11}(dB) Measurements for Dielectric Liquid filled Phantom and Back of a Human Body for Circularly Polarised Antenna at 1.8GHz

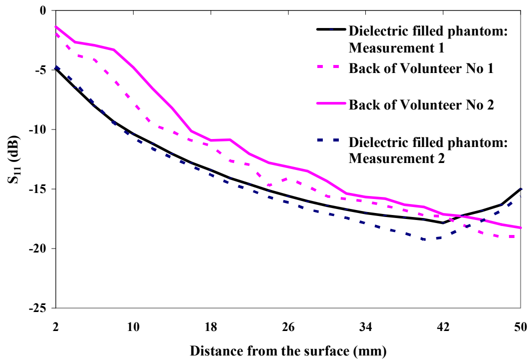
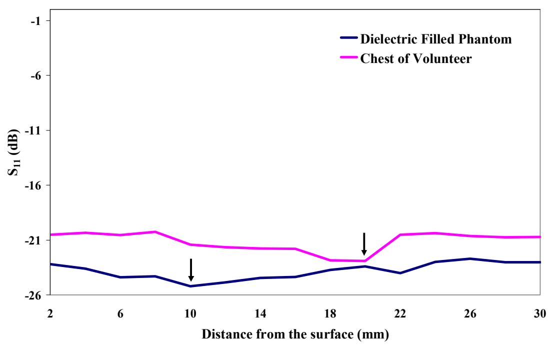


Chart 3: Comparison of S_{11}(dB) Measurements for Dielectric Liquid filled Phantom and Back of a Human Body for Microstrip line Linear Polarised Antenna at 1.8GHz



IV. Conclusions

Since the volunteers, the phantom used and the antennas considered are all specific the authors are reluctant to draw detailed specific conclusions from the experiments herein. More work would need to be completed at a wider range of frequencies; the effects of curvature of the phantom and the choice of tissue simulating liquid require closer analysis. The body and the phantom also detune the patch to a lower operating frequency of resonance (the body more than the phantom) and they both produce a broad-banding effect on the resonant curve. No correction has been made for this. It is also likely that since the phantom and body are finite and phantom is rectangular some effects due to polarisation and edges will be apparent between types of wearable antennas. However we can reasonably draw the following general conclusions:-

The phantom changes the match of the antenna in a similar way to a human torso. Isolation distance should be increased when considering insulating layers of clothing for on body antennas if using a phantom of this type for tuning. Similarly considering the linear and circular polarization of the antenna, results suggest that the best match for circularly polarized antennas comes nearly at double the distance as of linearly polarised antenna.

V. References

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