Adjustable Passive RFID Skin Mounted Sticker

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***Abstract*— Passive Radio Frequency Identification (RFID) can be limited by such aspects as size that make overcoming the capacitive loading introduced by human tissue difficult when intending to produce an efficient antenna with a high read range. It is still possible to design a small and thin RFID tag with a read range above half a meter. Here we present such a design with a diameter of less than 3 cm. By utilizing a breathable polyurethane polymer with two thicknesses, it is possible to use a single tag design for human tissue (dielectric constants ranging from a 22 to 40) with only a slight loss in antenna read range. It is more cost effective to just adjust the polyurethane thickness for a single design than to tune the antenna design itself. Volunteers one and two had read ranges above one meter while volunteer three (with permittivity of 40) caused the largest shift in antenna resonance from 865 MHz (EU band) and required an increase in polyurethane thickness from 1.1 mm to 1.5 mm. However, both designs still produced read ranges above 0.5 meters which could be further tuned with future adjustments to increase read range. This led to a passive RFID design that can be worn by most people with a simple thickness adjustment if needed.**

Keywords— UHF, RFID, Wearable, Antenna, Design

I. INTRODUCTION

The use of passive RFID (battery free) antenna designs in such diverse fields as security, warehousing, pharmaceutical, medicine and *etc.* are primarily due to ease of 'install' compared to tethered systems (less obstruction and wiring components). A passive RFID tag functions by receiving a command (a continuous wave) from a reading antenna and then sending back the received data via a backscattered modulation. Passive RFID sensor designs can utilize sensors that function based on thickness shear mode, magnetic acoustic resonance, resonant inductor-capacitor-resistor (LCR) transducers and *etc.* [1]. Also, by understanding the basic idea that a target's appearance (mostly physical and geometrical) can impact the overall antenna impedance matching to the chosen IC chip, most of these designs can be manufactured in a way to become self-sensing systems [2]. A 'self-sensing' approach is appealing as it removes the need for additional sensors or electronic components producing a more cost-effective tag design [2].

Utilizing an etched LRC circuit RFID tag can further reduce the cost (no need for extra components as all components included in the antenna structure) while showing great potential for wearable applications due to the ability to overcome human tissue capacitive loading [3,4]. The present paper only exhibits the matching methods for developing a wearable dipole antenna that could be utilized in a future design as a self-sensing sensor due to the clear sensitivity to any dielectric change upon the attached target as this sensor design was based on our 865 MHz tuned version of [5]. The design from [5] was chosen as it was able to produce read ranges above 4 meters even with mounting on liquids with permittivities ranging from 2 to 80 (encompassing most human tissues).

II. METHODS

An arm phantom was modelled with CST Microwave Studio ® software [6] and a SPEAG® Dak-3.5 probe system [7] provided dielectric properties of volunteer forearms for any necessary body models. This led to a simplified body phantom design that consisted of a single block of tissue (60 x 60 x 50 mm) with permittivities ranging from 22 to 40 and conductivity ranging from 0.2 to 0.7 S/m at 865 MHz (Table 1). This accounted for bone, muscle, fat and skin [3, 8] in a single block (based on dielectric probe readings) to predict the detuning effect with variable human tissue while reducing simulation meshing with this simplified body phantom design. An RFID wearable should be co-designed with the body in mind; the near body effects, mainly capacitive loading, must be accounted for within the calculations for the transponder chip and tag impedance matching as this will cause a large frequency shift and gain drop leading to reduced read ranges and antenna attenuation [3]. This can be accomplished as described in [5] by 'shunting' the system to produce better impedance matching between the IC and the antenna. However, as [5] had already accounted for the need of a shunt when working within the dielectric range of human tissue, this paper only determines what layer of polyurethane is needed to allow for this design to function when mounted on the human body while providing a respectable read range.

Antenna read range determines RFID system performance quality and minimum 'wake-up' power needed to activate an RFID IC. The maximum read range is determined by:

$$r_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{QG_{rd}G_{tg}P_{rd}}{P_{th}}} \tag{1}$$

where G_{rd} is the reader antenna gain; G_{tg} is the gain of the tag; q is impedance mismatch factor between the tag and IC; λ is the reader transmitted frequency; P_{rd} is the reader transmitted power; and P_{tg} is the received power by the tag [9]. Only changes to G_{tg} or Q can be made as all other system aspects are pre-set and cannot be adjusted due to the antenna reader limitations and RFID frequency band regulations within countries [8].

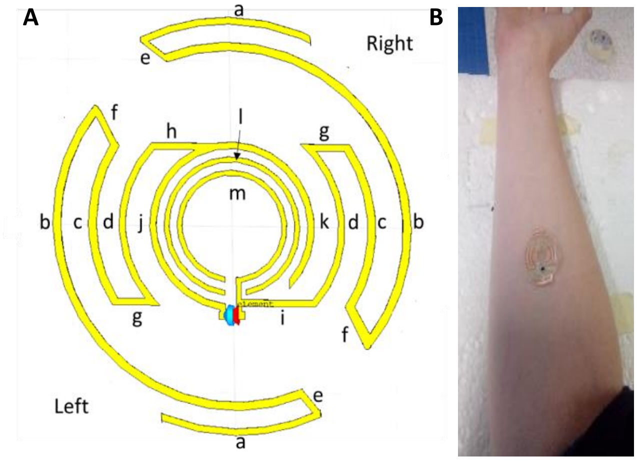
TABLE I. DIELECTRIC PROPERTIED OF VOLUNTEER FOREARMS INCOMPARISON TO BMI

Volunteer	SPEAG Dak Probe Dielectric Properties (865 MHz) [a]		
	Permittivity (294.25 K)	*Conductivity (S/m)*	*BMI*
One	22	0.27	20.6
Two	30	0.42	27.2
Three	41	0.67	24.6

[a] No variability was seen within three replicates for each volunteer

The copper etched dipole antenna was matched to a Higgs-3 Gen 2 RFID integrated circuit (IC) with an impedance of 31-j216 Ω [10] by utilising a matching resonating loop shunt for frequency resonance within the EU ultra-high frequency (UHF) range (865 MHz) (as described in [5]). UHF was chosen as it is known to provide relative high gain for standard matched antennas allowing for increased read ranges in comparison to other frequency bands as well as higher data-rates than HF [3].

The final design was around 30 mm in diameter with a highly meandered half-wave dipole and matching loop system (Fig. 1) [5]. The sides had total lengths of 88.6 mm and 80.6 mm, with a total dipole length slightly above (adjusted for meandering) the 160 mm needed for half-wave dipole at 865 MHz.



	a	b	c	d	e	f	g	h	i	j	k	l	m
Length (mm)	15	33	12	12.5	3.3	3.7	3.5	5	6	13	13.5	23	20

Figure 1. A) Dimensions (mm) of an on-skin antenna sticker design with the Higgs-3 IC; B) Copper etched tag on mylar with a polyurethane layer and skin.

Three volunteers were chosen for testing as they represented an appearance of normal to muscular body types and a wide dielectric range (ε_r of 22, 30 and 40) (Table 1). In order to reduce the need for tag tuning for each volunteer, two polyurethane thicknesses were chosen to provide a minimum of 0.5 m read range (for all volunteers) at 865 MHz within both simulation and measurement. This decision was based on the effect of tag decoupling from skin with increased polyurethane thickness (simulated as lossy silicone within CST) [11]. A balance between read range and tag thickness (*i.e.* how cumbersome the design was) had to be struck; it was decided that sacrificing read range to produce the thinnest possible design was preferable for a wearable tag.

All measurements were conducted in triplicates using the Voyantic Tagformance Pro RFID antenna measurement system [12]. The antenna reader was set to frequency sweeps (between 800MHz to 1000MHz) with 5 MHz intervals and power (from 0dBm to 30dBm) sweeps with 0.1 dBm intervals. The system was calibrated for a 30 cm distance between the reader and tag which was maintained between all readings. All readings were repeated in triplicates to determine testing repeatability.

III. RESULTS

It was expected that with increasing permittivity of body tissues (as seen between the volunteers), there would be a downward shift seen in resonant frequency (*i.e.* increase in permittivity leads to decrease in resonant frequency) if no adjustments were made to reduce the capacitive loading effect of the body [4]. Increasing the polyurethane thickness is a simple solution for reducing the tag and skin coupling effect (Fig. 2) in order to bring the read range above (or near) 0.5 meters (or a measured transmitted power below 22 dBm). This was done by increasing polyurethane thickness between the skin to 1.1 mm for volunteers one and two, and 1.5 mm for volunteer three (Fig. 3).

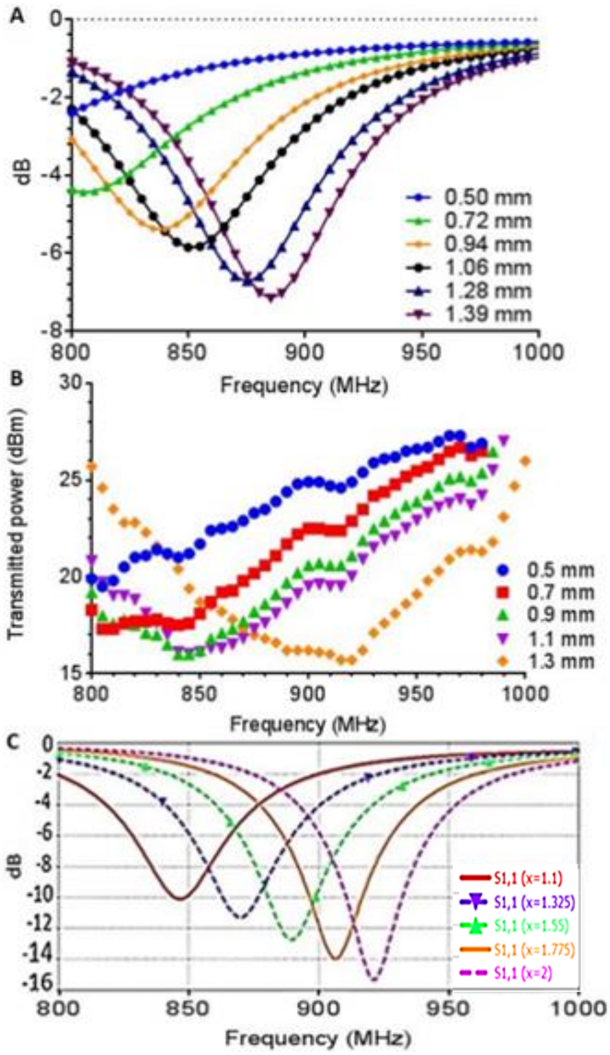


Figure 2. Effect of polyurethane thickness (volunteer one) on sticker resonant frequency for A) CST simulated and B) measured resonant frequencies. C) CST simulated permittivity of volunteer three showed a need for a polymer thickness between 1.3 and 1.6 mm to a achieve a frequency resonance at 865 MHz.Value ‘x’ represents the polyurethane thickness in milimeters for simulated design.

The 1.1 mm polyurethane thickness provided the best measured frequency resonance at 865 MHz (Fig. 2A and 2B) as predicted with simulation for volunteer one. Simulation showed that the ideal thickness was between 1.06 and 1.28 mm to achieve a resonance at 865 MHz. It can be seen that as the tag is further decoupled from the skin, the transmitted power needed to activate the IC is reduced (Fig. 2B).

The simulation estimated a directivity magnitude of 1.89 dBi and 166° main lobe direction (Fig. 3) suggesting a unidirectional appearance with a slight offset and a 1.43 meter simulated read range with a total efficiency of near -7 dBi. It is expected to see power dissipation within human tissues which can led to reduced antenna total efficiency; anything above -20dB total efficiency should be considered a usable design for body mounted RFID wearables. However, it should be noted that the total efficiency seen within all designs did not fall below -14dB.

The measured read range at 865 MHz for volunteer one was 1.49 meters suggesting that the simulated tag sensitivity of -17 dBm slightly underestimated the actual tag sensitivity when body mounted (Fig. 4). Overall, there was a good correlation between the simulated resonant frequencies and measured resonant frequencies for each volunteer (Fig. 4). At 865 MHz, the read range for each permittivity was 1.49, 1.23m and 0.63m (εr = 22, 30 and 40, respectively) (Fig. 4 B). Volunteer one with the lowest permittivity and BMI, had the highest read range with volunteer three having the lowest read range.

[4] showed that an increase in perceived muscle content, increased dielectric properties (such as permittivity and conductivity) causing increased antenna attenuation and reduced read ranges for RFID systems; an increased conductivity reduced antenna IC matching and efficiency while permittivity effected the resonant frequency rather than efficiency [4]. This is understandable as pure muscle has a dielectric constant near 60 [11] causing volunteer three to exhibit the largest frequency shift (without polyurethane thickness adjustment) due to tag as expected.

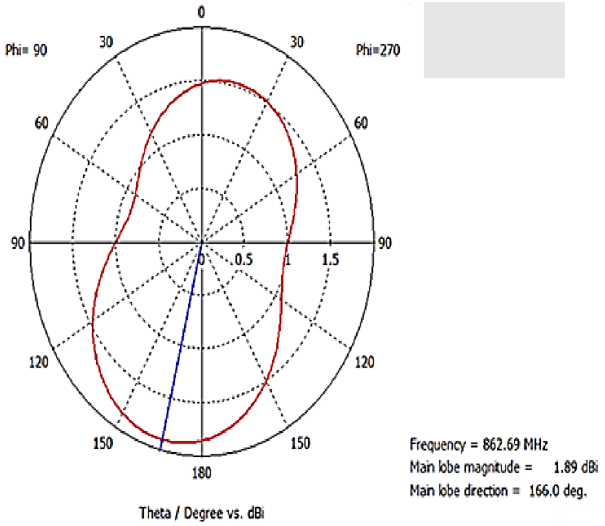


Figure 3. The simulated polar plot for antenna directivity cut at phi 90° when mounted on body of volunteer one with a unidirectional appearance at a main lobe directivity of 166°.

The presented data correlates with [4] as there was a noticeable decrease in read range between volunteer one and two, and then three as the dielectric constant increased. This suggests a parallel relationship must exist between an increase in dielectric properties for human tissue and an increase in the polyurethane thickness decoupling tag from skin. Basically, as tissue dielectric properties increase, so should the polyurethane thickness or another compensation must exist to reduce the antenna detuning by the increased tissue capacitive loading. Decoupling an RFID tag from skin should be a priority if attempting to achieve a higher read range with increased system capacitance.

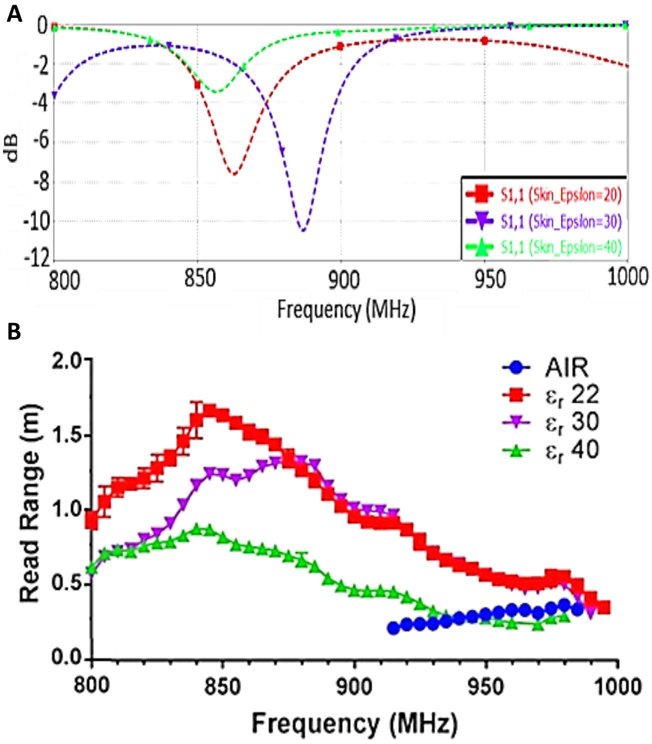


Figure 4. A) Simulated S_{11} (tag input reflection coefficient) mounted on body model. Simulation accounted for both permittivity and conductivity of each volunteer. B) Measured read range for tag mounted on volunteers. Polyurethane thickness of 1.1mm (ε_r = 22 and 30) or 1.5mm (ε_r = 40) in both A and B. Measured data represents three replicates each.

I. CONCLUSION

The wearable skin-mounted design was made to utilize the dielectric properties of human tissues to reduce size without losing function as high dielectric properties will cause a leftward shift in resonant frequency. This design was able to produce read ranges above 0.5 meters for all volunteers (ranging permittivities from 22 to 40) even with a small, thin and simple design. There was a decrease in read range for the higher permittivity volunteer (it did remain above 0.5 m), however any permittivity below 30 produced a read range above 1.2 meters. Also, once the tissue dielectric properties read above 30 permittivity, there was a need to increase the polyurethane layer to help decouple the tag from the skin. This design needs to be further improved as a read range above 1 meter would be preferable even at the higher dielectric constants. Still this current published design can be utilized for low cost, minimal signal outage and unobtrusive application for human mounted needs.

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