Tattoo Antenna Temporary Transfers Operating On-Skin (TATTOOS)

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Abstract. This paper discusses the development of RFID logo antennas based on the logos of Loughborough University and the University of Kent which can be tattooed directly onto the skin's surface. Hence, this paper uses aesthetic principles to create functional wearable technology. Simulations of possible designs for the tattoo tags have been carried out to optimize their performance. Prototypes of the tag designs were fabricated and read range measurements with the transfer tattoos on a volunteers arm were carried out to test the performance. Measured read ranges of approximately 0.5 m have been achieved with the tag only10 μm from the body.

Keywords: Aesthetic design · Body centric communication · Conducting ink · RFID

1 Introduction

RFID technology is used for tracking a variety of items. There are numerous applications where tracking of people would be beneficial which include elderly people with dementia; athletes; military; firefighters and ticketing for music or sports events. Using a tattoo tag that can be mounted directly onto the skin has many advantages over more traditional RFID tags. These include the added security and convenience to the user as the tag cannot be stolen or lost. One of the most desirable attributes of an RFID tag tattooed on the skin is an attractive shape for example a star; a smiley face or the logo of a sports team or organisation.

This paper uses the logos of Loughborough University and University of Kent in the design of the RFID tags. The antenna designs are based on the nested slot line antenna used in [1] which has a slot as the main radiating element so there is a degree of flexibility in the shape. The size of the slot was adjusted to match the antenna to the RFID chip at the desired frequency of 868 MHz. Electromagnetic simulations of the antenna designs on a human body model were used to determine the efficiency and gain of the tattoo RFID tags.

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The antenna designs were printed onto temporary transfer tattoo inkjet paper using electrically conductive paint. The antenna was on a thin layer of plastic (~ 10 μm) so it can be placed on the human body and read range measurements were carried out. The read range measurements were then compared to the simulated gain of the antennas.

2 Wearable Antennas

Wearable technology is a popular topic in multiple disciplines which include medicine, engineering, architecture and fashion [2]. In today's world the use of wireless connectivity is important which requires the development of wearable antennas. One of the difficulties with wearable antennas is attaining high levels of electromagnetic performance when in the presence of a human [3].

For the fabrication of wearable antennas a number of techniques have previously been used which have been reviewed in [4, 5]. The use of a conductive thread embroidered into clothing to create an antenna was used in [3, 6, 7]. These antennas have the advantage of flexibility and comfort for the user and do not need to be held in the hand. The efficiencies of these antennas are often reduced compared to their copper equivalents due to the embroidery process and the conductive threads used. An inkjet printed textile antenna was created in [8] which showed efficiencies of greater than 60 % with only a single layer of conducting ink. Another method for body mounted tags is to use printed circuit board substrate which regularly has a metal ground plan between the body and radiating tag. This can then be mounted on clothing or some object like a wrist band rather than directly on the skin [9, 10]. The interaction of passive metallic objects near, on and in the body has been previously examined in [11–17].

2.1 Logo Antennas

With the rapid advancement of wearable technology it is becoming commercially important that the antennas used are both functional and aesthetically pleasing so the user will be more accepting of the technology. This has led to research into logo antennas as in [18] which designed a patch antenna based on the Loughborough University shield. This work showed that the logo designs could be scaled to the required frequency and based on the geometry an optimal feed point can be chosen. With diverse designs there comes varying difficulties that have to be addressed such as concave sections, angular sections and disconnected sections.

In [19] a wearable logo textile antenna was designed based on the authors University name. It was shown that bending of the antenna affected the impedance matching but did not affect the radiation efficiency. The radiation pattern of the antenna was Omni-directional and was deformed at higher frequencies but showed good performance overall. The City University of Hong Kong's logo was designed as a patch antenna in [20]. The frequency band of the patch antenna was broadened by carefully designing slots. The wideband performance was created by effectively having two antennas with low Q so there was little reactance cancellation between them.

2.2 Transfer Tattoo Tags

In this paper the idea is to use a tag that is mounted directly on the skin, with a vanishingly thin insulating layer between the body and the tag antenna [21]. Tags such as these mean they can be used for sensing functions as they are more intimately interfaced with the skin. Additionally as these tags cannot be taken from one individual and passed onto another there is a physical security. Note, previous work demonstrates these tags last approximately 24 h without washing the skin surface and are temporary.

A possible process for creating the tags uses inkjet printing to deposit a layer of conducting ink on a transfer paper which is used for creating transfer tattoos. Once the tag design is printed onto the transfer surface of the tattoo paper, the ink is sintered to render the printed shape conducting. The sintering process usually involves heat but other techniques at lower temperatures such as plasma, chemical or photonic treatments can be used which save energy and reduce damage to transfer material. It is then required to mount an RFID transponder chip to the antenna structure which can be done using a conducting epoxy resin. The next step is to apply a thin adhesive polymer layer over the conducting surface which is used to attach the transfer to the skin. Once the transfer is applied water is used to remove the paper backing from the transfer.

The end result is a conductive RFID tag in between two polymer layers. This means that the ink is not in direct contact with the skin and fixes the fragile antenna structure. During the sintering stage there is optimization required between obtaining a high enough conductivity value in the ink without burning the paper or making the ink too frail. If the conductivity is not high enough the ink surface will degrade and break the circuit, whereas if the ink is too frail it will have an increased chance of failure while mounted on the flexible skin surface [22]. The use of this technique will result in the fabrication of logo tattoo antennas being a cheap and convenient process [23].

3 Antenna Design

The antenna designs were based on nested slot line antennas [24] which radiate at the RFID UHF band through surface currents being produced on a conductive patch. The schematic of the nested slot line can be seen in Fig. 1 and shows the parameters; l for slot length, w for slot width, L for antenna length, W for antenna width, t the distance the slot is from the edge, and G the gap width at the input for the antenna. The RFID chip is connected between the two coplanar lines at the gap G. The chip has a negative reactance so an inductance is required from the antenna to cancel it out for maximum power transmission. An inductance is produced by an electric field being induced inside the slot and a current loop caused to flow around the outside of it. The effective aperture size of the antenna is large enough to provide improved efficiency through the current being free to spread out over the patch, and the width of the slot being small compared to wavelength [25].

The antenna designs are based on the logos of Loughborough University and the University of Kent. For the University of Kent logo an image of the logo was subtracted from a patch antenna and the K of the logo was used as the slot for the antenna, see Fig. 2a. For the antenna based on the logo for Loughborough University an image

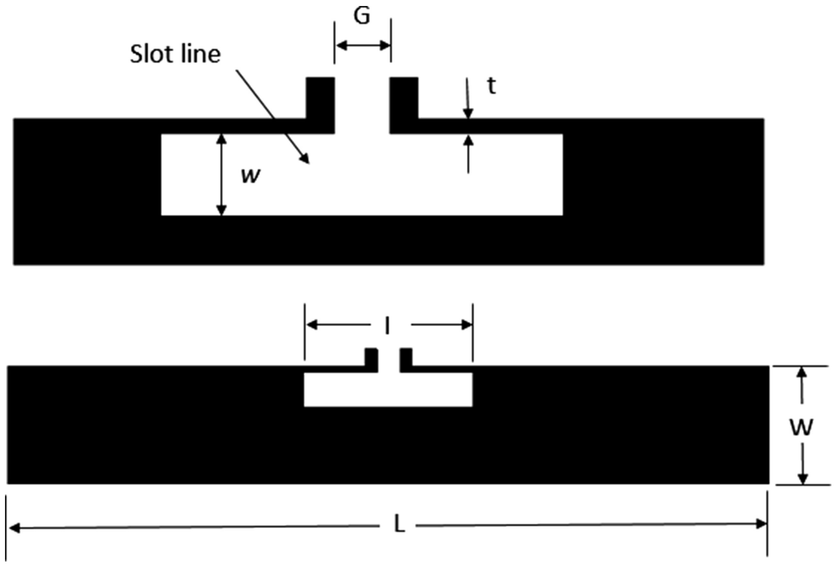

Fig. 1. Nested slot line antenna schematic

of the Loughborough University shield was converted to a CAD file so that it could be designed with a slot on the side of it, see Fig. 2b. Please note permission was requested to use the university logos for this paper and the institutions retain all copyright and trademark rights.

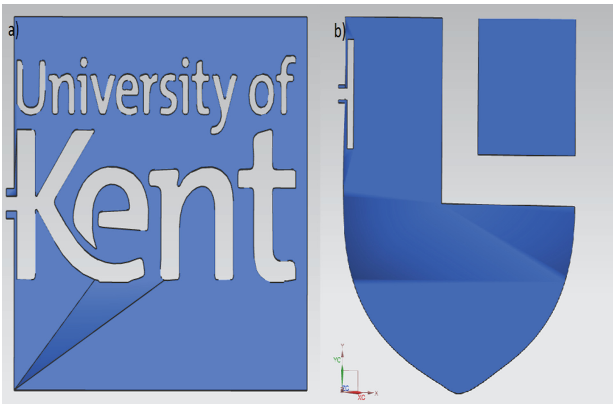

Fig. 2. Tattoo antenna designs: a) University of Kent logo, and b) Loughborough University shield.

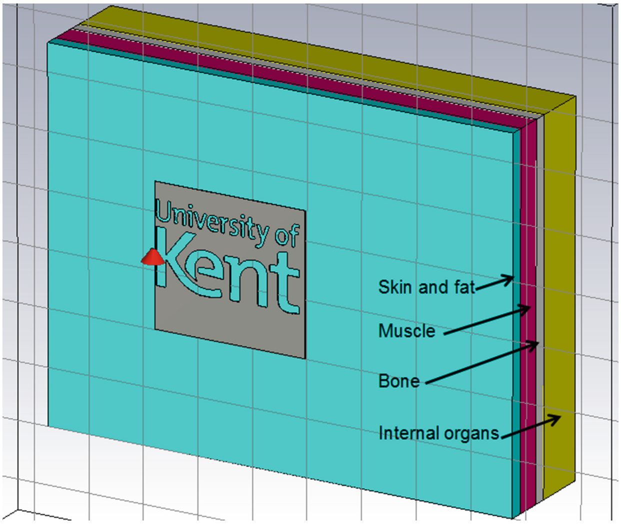

Fig. 3. RFID tag on human body model

4 Antenna Simulations

The tags were simulated using CST on a multilayer model of human tissue being used to represent the human body, see Fig. 3. The parameters used in the simulation for the model of the human body can be seen in Table 1 [26]. To represent the RFID chip an impedance of 23.3-j145 Ω for the port at the input to the antenna. The metal used for the antennas was copper at a thickness of 200 µm. The parameters of each tag were adjusted to get the tag to resonate at the required frequency of 868 MHz while optimizing the gain and efficiency. Both of the antennas had a gap width of 2 mm for the chip and had the slot 0.5 mm from the edge. The University of Kent antenna had a length of 50 mm, a width of 60 mm, a slot length of 20 mm and a slot width of 3 mm. The Loughborough University antenna had a length of 63 mm, a width 53 mm, a slot length of 24.5 mm and a slot width of 2 mm. The simulated s11 values for the University of Kent logo and the Loughborough University logo can be seen in Figs. 4 and 5 respectively. The gain values for the University of Kent logo antenna and the Loughborough University shield were -17.1 dBi and -19.9 dBi respectively. Note, these values are less than conventional antennas as there is only a 10 µm separation between the tag and the skin.

Table 1. Human model: electrical parameters at 900 MHz [26]

Layer	ε_r	σ (S/m)	Layer thickness (mm)
Skin and fat	14.5	0.25	5
Muscle	55	0.94	10
Bone	12.6	3.85	5
Internal organs	52	0.91	20

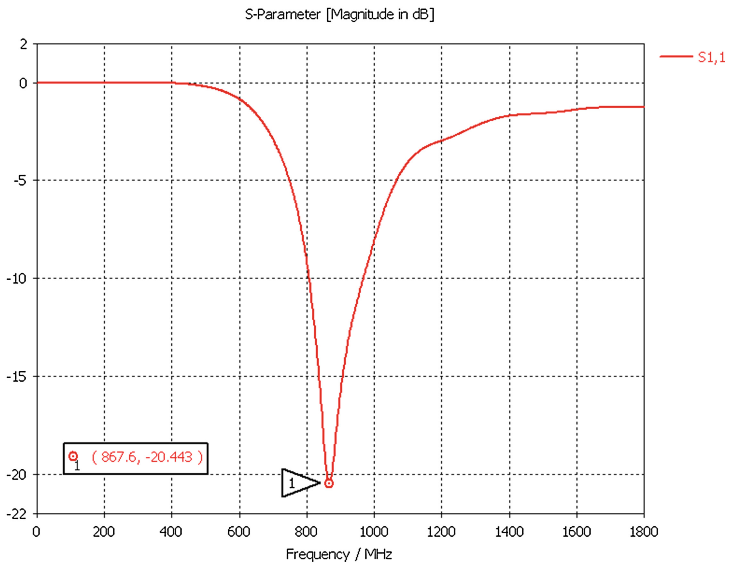

Fig. 4. Simulated s11 for University of Kent tag

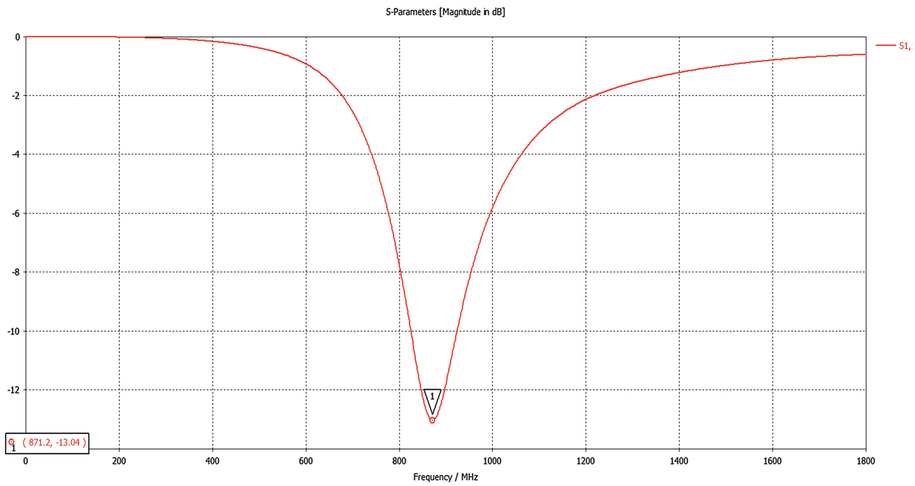

Fig. 5. Simulated s11 for Loughborough University tag

5 Fabrication and Read Range Measurements

The tags were fabricated by first etching the antenna structure pattern as a negative in a thin metal stencil; an example can be seen in Fig. 6 which was used for the Loughborough University logo antenna. An electrically conductive silver paint was then

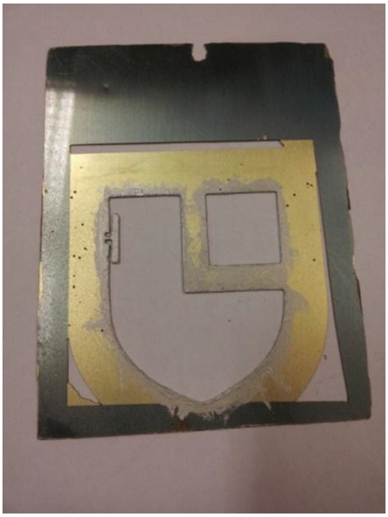

Fig. 6. Loughborough University shield antenna stencil

Fig. 7. Loughborough University shield transfer tattoo tag on the arm of a volunteer

deposited on temporary transfer tattoo inkjet paper using the stencils as a profile to form the metalized layer. The RFID IC is then attached to the input ports of the tattoo tag antennas. The transfer tattoo tags can then be placed on a volunteer's arm. There is a thin layer of plastic between the skin of the volunteer and the antenna Fig. 7.

Fig. 8. Read range measurement of Kent logo tag

Read range measurements where then carried out using the Tagformance lite measurement device in Fig. 8. The read range measurements for the University of Kent logo tag can be seen in Fig. 9 which shows that the read range at the EU UHF RFID band (868 MHz) was 44 cm and at the US UHF RFID band (924 MHz) was 47 cm. The Loughborough University logo tag had a read range of 37 cm in the EU band and 49 cm in the US band which can be seen in Fig. 10. The Kent logo having a larger read range at the EU band is consistent with the simulations as it had a higher gain and radiation efficiency at that frequency.

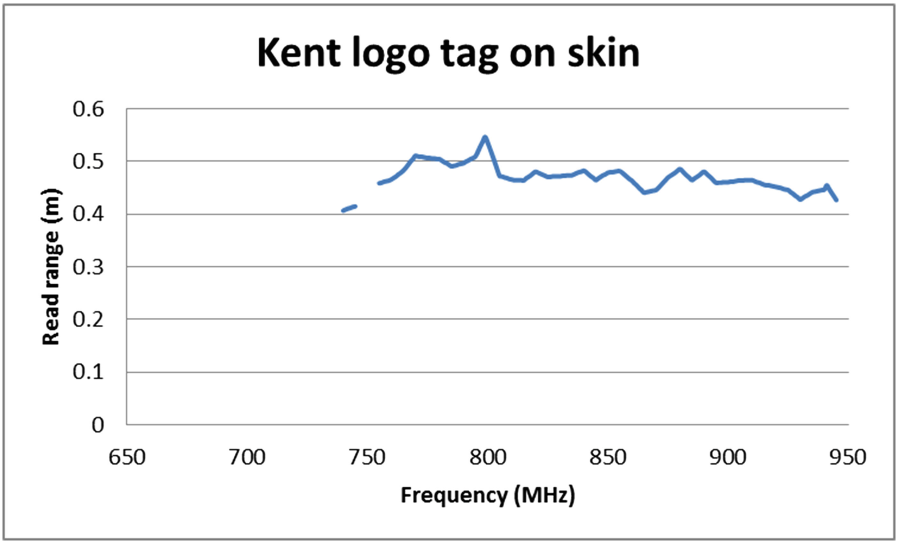

Fig. 9. University of Kent logo tag on skin read range measured results

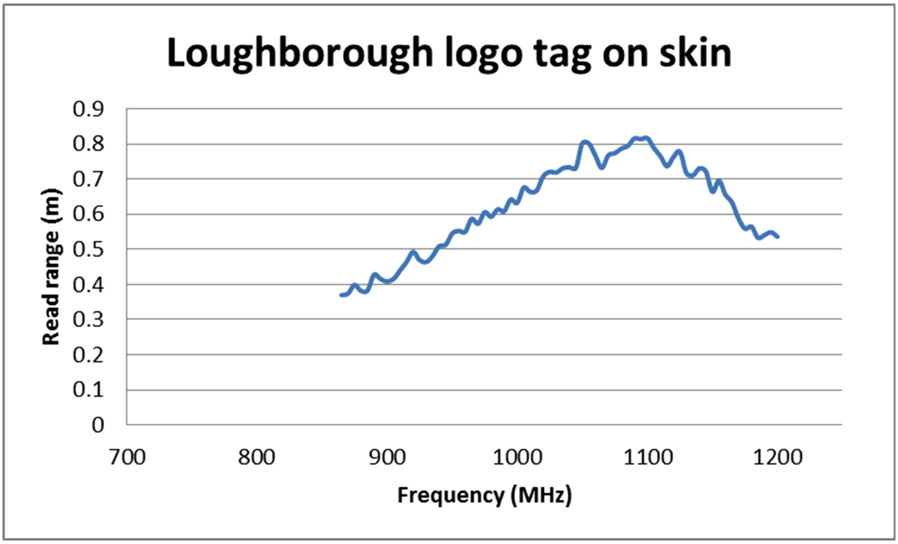

Fig. 10. Loughborough University logo tag on skin read range measured results

6 Conclusions

This paper has shown that RFID tags using aesthetic shapes can be tattooed directly onto the skin's surface. The logos of Loughborough University and the University of Kent have been used as the designs of antennas by using a slot as the main radiating element. Results showed that when mounted on a forearm, the Loughborough University and University of Kent's logo tags achieved read ranges of 37 cm and 44 cm respectively. These read ranges are impressive considering the antennas are aesthetic shapes and are mounted directly on the skin with only a 10 μm thick adhesive layer. The use of aesthetic shapes opens up a number of applications for the use of tattoo tags as the user experience will be enhanced. The use of inkjet printing with a conductive ink to fabricate the antennas could make this a cheap and convenient process.

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