



Deposited via The University of Leeds.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/id/eprint/124317/>

Version: Accepted Version

---

**Proceedings Paper:**

Tribe, J, Oyeka, D, Batchelor, J et al. (2015) Tattoo Antenna Temporary Transfers Operating On-Skin (TATTOOS). In: Design, User Experience, and Usability: Users and Interactions. Evolving Computability. Lecture Notes in Computer Science. DUXU 2015: 4th International Conference of Design, User Experience, and Usability, 02-07 Aug 2015, Los Angeles, CA, USA. Springer, pp. 685-695. ISBN: 978-3-319-20897-8. ISSN: 0302-9743. EISSN: 1611-3349.

[https://doi.org/10.1007/978-3-319-20898-5\\_65](https://doi.org/10.1007/978-3-319-20898-5_65)

---

© 2015, Springer International Publishing Switzerland. This is a post-peer-review, pre-copyedit version of a chapter published in Design, User Experience, and Usability: Users and Interactions (Lecture Notes in Computer Science). The final authenticated version is available online at: [https://doi.org/10.1007/978-3-319-20898-5\\_65](https://doi.org/10.1007/978-3-319-20898-5_65). Uploaded in accordance with the publisher's self-archiving policy.

**Reuse**

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

**Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.

# Tattoo Antenna Temporary Transfers Operating On-Skin (TATTOOS)

James Tribe<sup>1</sup>, Dumtoochukwu Oyeka<sup>2</sup>, John Batchelor<sup>2</sup>, Navjot Kaur<sup>1</sup>, Diana Segura-Velandia<sup>1</sup>, Andrew West<sup>1</sup>, Robert Kay<sup>1</sup>, Katia Vega<sup>3</sup>, and Will Whittow<sup>1</sup>

<sup>1</sup>Loughborough University, Loughborough, UK  
{j . t r i b e , w . g . w h i t t o w } @ b o r o . a c . u k

<sup>2</sup>University of Kent, Canterbury, UK

<sup>3</sup>Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil

**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 antenna 10  $\mu\text{m}$  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.

The antenna designs were printed onto temporary transfer tattoo inkjet paper using electrically conductive paint. The antenna was on a thin layer of plastic ( $\sim 10 \mu\text{m}$ ) 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

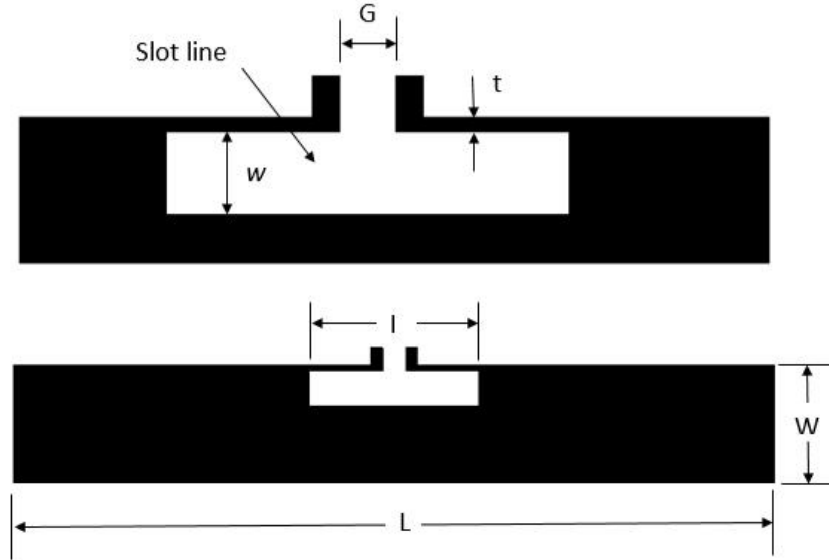
In this paper the idea is to use a tag that is mounted directly on the skin, with a vanishingly thin insulating layer between the body and the tag antenna [21]. Tags such as these mean they can be used for sensing functions as they are more intimately interfaced with the skin. Additionally as these tags cannot be taken from one individual and passed onto another there is a physical security. Note, previous work demonstrates these tags last approximately 24 hours 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



**Fig. 1.** Nested slot line antenna schematic

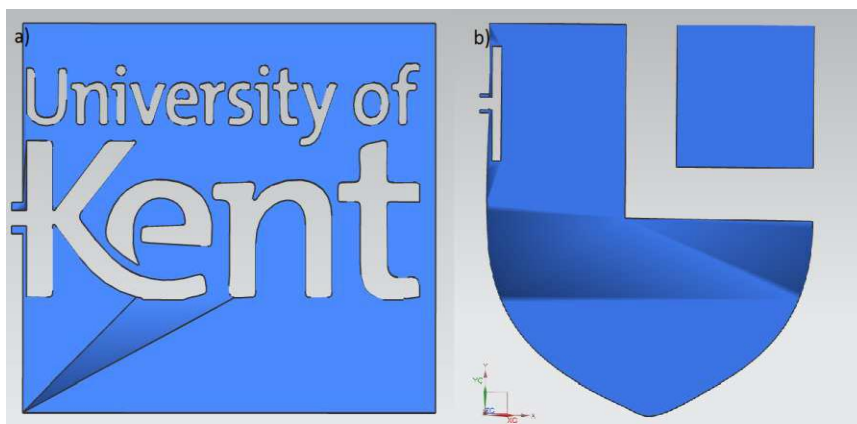
effective aperture size of the antenna is large enough to provide improved efficiency through the current being free to spread out over the patch, and the width of the slot being small compared to wavelength [25].

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 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 Institution retains all copyright and trademark rights.

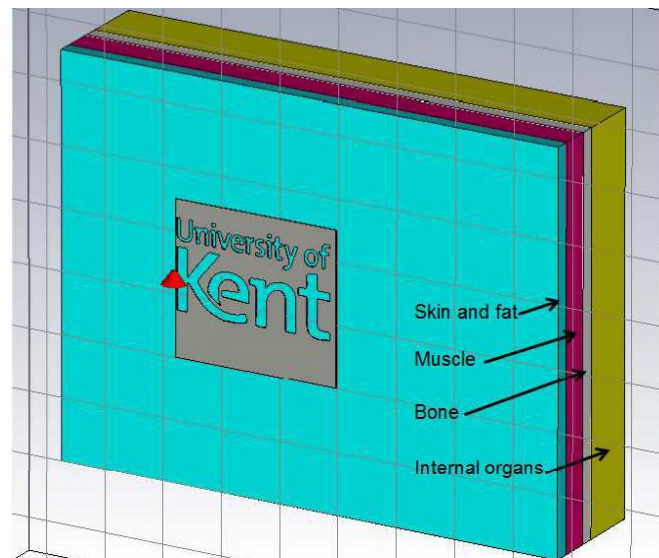
#### 4 Antenna Simulations

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  $23.3-j145 \Omega$  for the port at the input to the antenna. The metal used for the antennas was copper at a thickness of  $200 \mu\text{m}$ . 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 3mm.

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  $s_{11}$  values for the University of Kent logo and the Loughborough University logo can be seen in **Fig. 4** and **Fig. 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. The radiation efficiency for the University of Kent logo was 1.01% and for the Loughborough University shield was 0.51%. Note, these values are less than conventional antennas as there is only a 10  $\mu\text{m}$  separation between the tag and the skin.



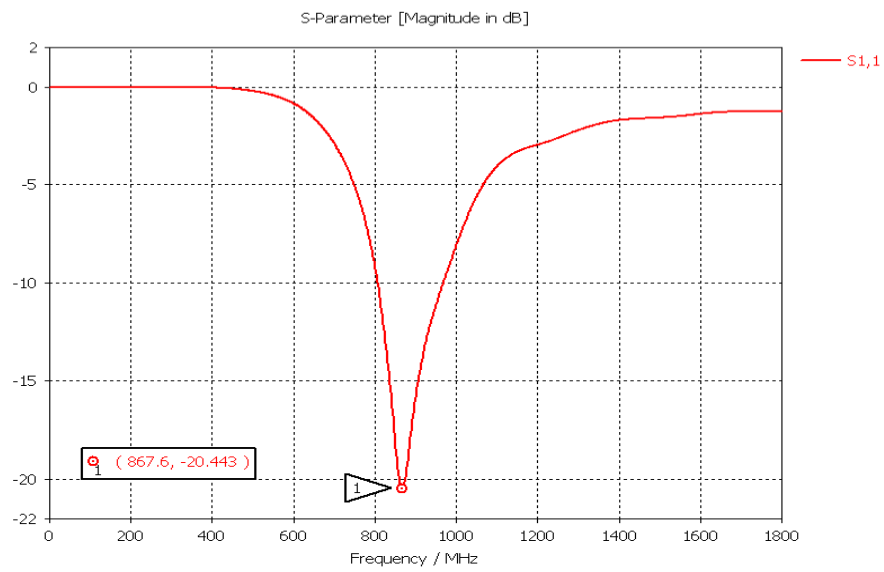
**Fig. 2.** Tattoo antenna designs: a) University of Kent logo, and b) Loughborough University shield



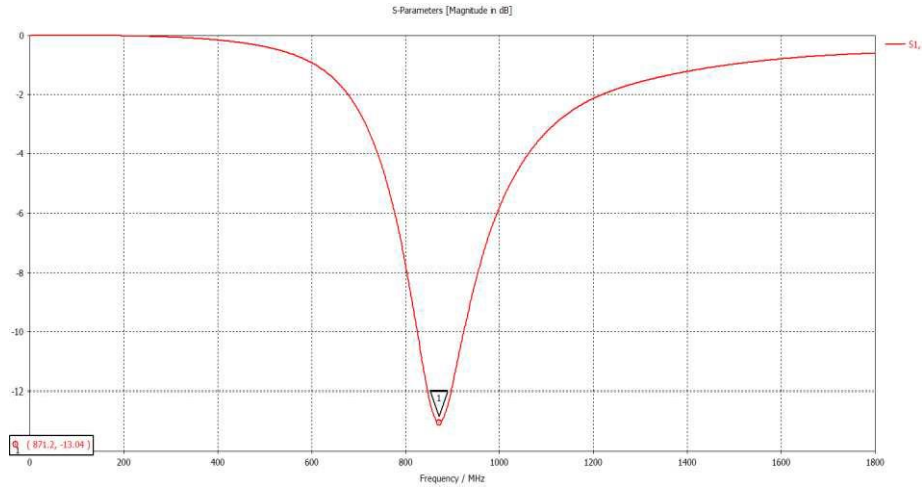
**Fig. 3.** RFID tag on human body model

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

Layer	$\epsilon_r$	$\sigma$ (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



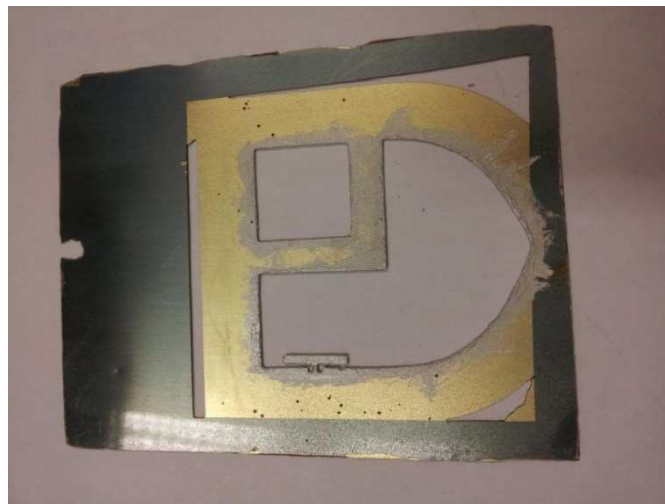
**Fig. 4.** Simulated s11 for University of Kent tag



**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 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. 6.** Loughborough University shield antenna stencil



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

Read range measurements were 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. 8. Read range measurement of Kent logo tag

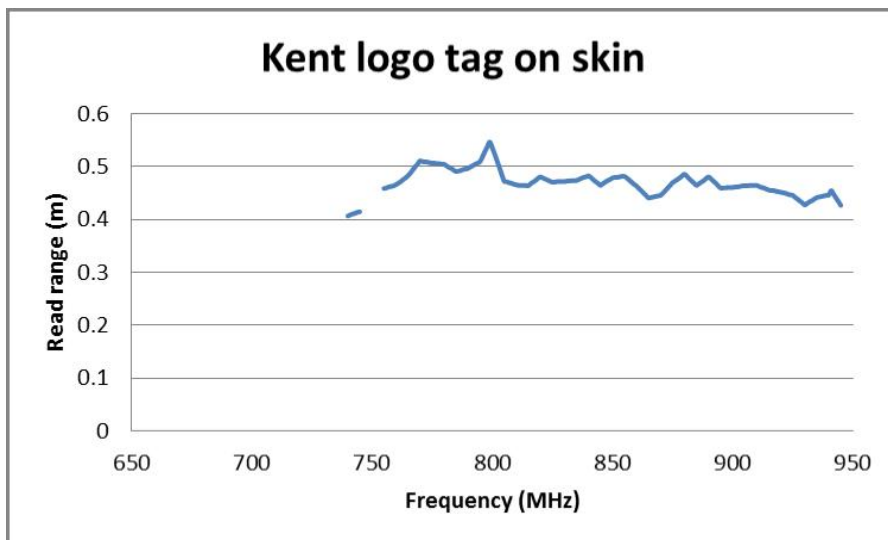


Fig. 9. University of Kent logo tag on skin read range measured results

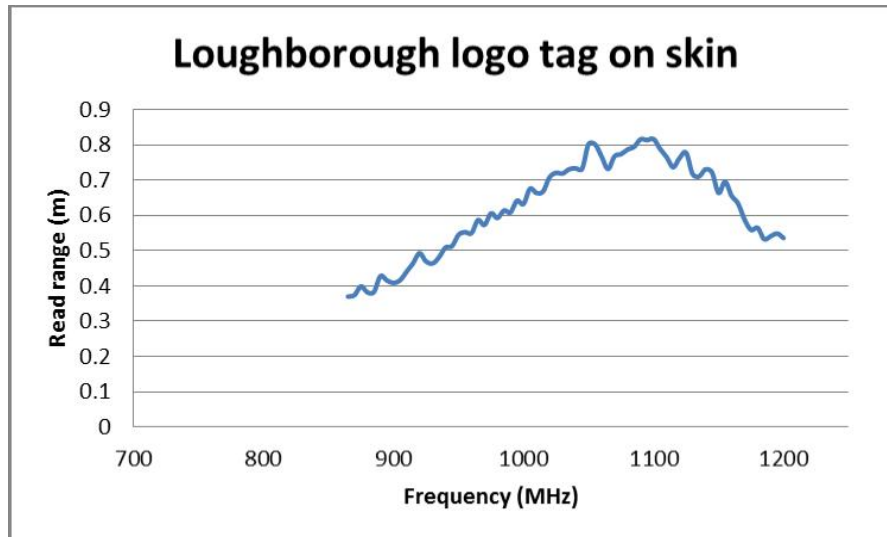


Fig. 10. Loughborough University logo tag on skin read range measured results

## 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  $\mu\text{m}$  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.

## References

1. Ziai, M., Batchelor, J.: Temporary on-skin passive UHF RFID transfer tag. *IEEE Trans. Antennas Propag.* 59, 3565–3571 (2011).
2. Cranny-Francis, a., Hawkins, C.: Wearable technology. *Vis. Commun.* 7, 267–270 (2008).
3. Chauraya, A., Zhang, S., Whittow, W., Acti, T., Seager, R., Dias, T., Vardaxoglou, Y.C.: Addressing the challenges of fabricating microwave antennas using conductive threads. *Proc. 6th Eur. Conf. Antennas Propagation, EuCAP 2012.* 1365–1367 (2012).
4. Gupta, B., Sankaralingam, S., Dhar, S.: Development of wearable and implantable antennas in the last decade: A review. *2010 10th Mediterr. Microw. Symp. MMS 2010.* 251–267 (2010).

5. Rais, N.H.M., Soh, P.J., Malek, F., Ahmad, S., Hashim, N.B.M., Hall, P.S.: A review of wearable antenna. *Loughborough Antennas Propag. Conf. LAPC 2009 - Conf. Proc.* 225–228 (2009).
6. Seager, R., Zhang, S., Chauraya, A., Whittow, W., Vardaxoglou, Y., Acti, T., Dias, T.: Effect of the fabrication parameters on the performance of embroidered antennas. *IET Microwaves, Antennas Propag.* 7, 1174–1181 (2013).
7. Acti, T., Zhang, S., Chauraya, A., Whittow, W., Seager, R., Dias, T., Vardaxoglou, Y.: High performance flexible fabric electronics for megahertz frequency communications. *LAPC 2011 - 2011 Loughborough Antennas Propag. Conf.* (2011).
8. Chauraya, A., Whittow, W.G., Vardaxoglou, J.C., Li, Y., Torah, R., Yang, K., Beeby, S., Tudor, J.: Inkjet printed dipole antennas on textiles for wearable communications. *IET Microwaves, Antennas Propag.* 7, 760–767 (2013).
9. Moradi, E., Koski, K., Ukkonen, L., Rahmat-Samii, Y., Björminen, T., Sydänheimo, L.: Embroidered RFID Tags in Body-Centric Communication. *2013 International Workshop on Antenna Technology (iWAT)*. pp. 367–370 (2013).
10. Manzari, S., Occhiuzzi, C., Marrocco, G.: Feasibility of Body-Centric Systems Using Passive Textile RFID Tags. *IEEE Antennas Propag. Mag.* 54, 49–62 (2012).
11. Panagamuwa, C.J., Whittow, W., Edwards, R., Vardaxoglou, J.C., McEvoy, P.: A study of the validation of RF energy specific absorption rates for simulations of anatomically correct head FDTD simulations and truncated DASY4 standard equipment measurements. *European Conference on Antennas and Propagation*. pp. 1–5 (2006).
12. Panagamuwa, C.J., Whittow, W.G., Edwards, R.M., Vardaxoglou, J.C.: Experimental verification of a modified Specific Anthropomorphic Mannequin (SAM) head used for SAR measurements. *2007 Loughborough Antennas Propag. Conf. LAPC 2007 Conf. Proc.* 261–264 (2007).
13. Stergiou, K., Panagamuwa, C., Whittow, W., Edwards, R.: Effects of metallic semi-rimmed spectacles on SAR in the head from a 900MHz frontal dipole source. *Loughborough Antennas Propag. Conf. LAPC 2009 - Conf. Proc.* 721–724 (2009).
14. Whittow, W.G., Panagamuwa, C.J., Edwards, R.M., Vardaxoglou, J.C.: On the effects of straight metallic jewellery on the specific absorption rates resulting from face-illuminating radio communication devices at popular cellular frequencies. *Phys. Med. Biol.* 53, 1167–1182 (2008).
15. Whittow, W., Panagamuwa, C.J., Edwards, R., Vardaxoglou, J.C.: Specific absorption rates in the human head due to circular metallic earrings at 1800MHz. *2007 Loughborough Antennas Propag. Conf. LAPC 2007 Conf. Proc.* 277–280 (2007).
16. Whittow, W.G., Edwards, R.M., Panagamuwa, C.J., Vardaxoglou, J.C.: Effect of tongue jewellery and orthodontist metallic braces on the sar due to mobile phones in different anatomical human head models including children. *2008 Loughborough Antennas Propag. Conf. LAPC.* 293–296 (2008).
17. Panagamuwa, C.J., Whittow, W.G., Edwards, R.M., Vardaxoglou, J.C.: A Study of the Effects of Metallic Pins on SAR using a Specific Anthropomorphic Mannequin (SAM) Head Phantom. *European Conference on Antennas and Propagation*. pp. 1–6 (2007).
18. Whittow, W.: Antenna Emblems Reshaped as Icons and Aesthetic Logos (Aerial). *Microw. Opt. Technol. Lett.* 55, 1711–1714 (2013).
19. Mahmud, M.S., Dey, S.: Design, performance and implementation of UWB wearable logo textile antenna. *2012 15 Int. Symp. Antenna Technol. Appl. Electromagn.* 1–4 (2012).
20. Chow, Y., Fung, C.: The city university logo patch antenna. *Asia Pacific Microwave Conference*. pp. 4–7 (1997).

21. Ziai, M., Batchelor, J.: RFID TAGs as transfer tattoos. 2011 Loughborough Antennas and Propagation Conference (LAPC). pp. 1–4 (2011).
22. Sanchez-Romaguera, V., Ziai, M. a., Oyeka, D., Barbosa, S., Wheeler, J.S.R., Batchelor, J.C., Parker, E. a., Yeates, S.G.: Towards inkjet-printed low cost passive UHF RFID skin mounted tattoo paper tags based on silver nanoparticle inks. *J. Mater. Chem. C*. 1, 6395 (2013).
23. Batchelor, J., Parker, E.: Inkjet printing of frequency selective surfaces. *Electron. Lett.* 45, 1–2 (2009).
24. Marrocco, G.: RFID Antennas for the UHF Remote Monitoring of Human Subjects. *IEEE Trans. Antennas Propag.* 55, 1862–1870 (2007).
25. Kraus, J., Marhefka, R.: *Antennas*. McGraw-Hill, New York (1988).
26. Gabriel, C., Gabriel, S., Corthout, E.: The dielectric properties of biological tissues: I. Literature survey. *Phys. Med. Biol.* 41, 2231–49 (1996).