Flexible On-Body Coils for Inductive Power Transfer to IoT Garments and Wearables

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***Abstract*—Inductive power transfer is a promising technology for ambient charging and powering of wearable devices without the need for direct user intervention. Existing systems typically use circular or rectangular coils built using inflexible wire and fixed into a rigid shape. This paper explores the design of receiver coils for wearable inductive power transfer. Our study demonstrates receive coil designs that visually embody patterns or logos do not significantly reduce receive voltage compared to a traditional wire loop of the same number of turns, giving designers flexibility over the appearance of wearable power transfer coils.**

I. Introduction

Inductive power transfer is gaining in popularity as an enabling technology for powering wearables, and many other pervasive designs [1]. Inductive power transfer decouples the device from its charging source and can replace the need for direct user intervention during charging. Inductive power transfer works by establishing a time varying magnetic field around a transmit coil and taking energy from this magnetic field using a receive coil [2]. Both coils must be sufficiently close and aligned during charging.

Inductive power transfer to wearables is gaining interest as a key enabler [3]. Challenges for wide adoption include seamless integration of transmit coils into a user's everyday environment, electromagnetic safety levels, and the comfortable and desirable design of the receive coil when worn by the user.

Receive coils for inductive power transfer will typically be constructed from copper wire or braid and fixed into a simple geometric shape, such as a circle or rectangle. This simple geometric nature of receive coils make wearing an on-body receive coil easily identifiable and potentially unattractive thus limiting the uptake of inductive power transfer to wearables. Fixing the coil into a rigid shape helps to maintain a constant inductance; however such a coil can, depending on placement, interfere with natural movement and cause the wearer discomfort, especially for smart garments. Embedding the receive coil into a garment or wearable device can cause excess bulk in some on-body locations and remove the visual cues that the user has to understand how or where to align with the transmit coil to maximise power transfer.

This paper explores how to give designers for inductively powered Internet of Things enabled garments or wearables, the freedom to create flexible, visually appealing and efficient on-body coils through practically demonstrating receive voltage performance similar to rigid wire coils. We use thin copper and multiple turns are realised with a plastic membrane.

II. Prior art

Antennae constructed from copper tape have been previously demonstrated [4], alongside printed RFID tags in the shape of logos [5]. Flexible coils for inductive power transfer in textiles has been demonstrated using plastic coated wire weaved into a garment [6]. Achieving multiple turns using this method requires loops of increasing radius, which may be unsuitable for confined on-body spaces such as the wrist. Furthermore this method requires a textile based backing, whilst the flexible copper tape coils proposed in this paper can be used with a variety of substrates.

Here we present the unique contribution of multiple coil designs for power transfer, shaped into logos or emblems. The flexibility to choose any coil shape or design allows the potential for attractive logos. De-embedding of coils is enabled by removing the size and position constraints posed by hidden or embedded coils. Lots of clothing contain logos or emblems and companies go to great lengths to brand their clothing. People wear logos or emblems on clothing as this enhances their emotional attachment to the garment, as described in Section 5.2 of [7]. Knight *et al.* [8] comfort assessment of wearable computers includes an emotional attachment to the item, where the user is worried about how they look when wearing the technology. Convincing people to wear an on-body receive coil for IoT garments or wearables requires integration into our everyday life. By creating coils as logos or emblems the emotional attachment of on-body inductive power transfer will be increased over a traditional coil, in a similar aesthetic bases as the aestheticode has to original QR code [9].

III. Coil fabrication

The copper tape coils were cut out using a craft cutter [10]. Plastic film is used to insulate each layer. A circular copper tape flexible loop of radius 15 mm was constructed and compared to a circular 24 standard wire gauge loop of radius 15 mm. Three additional logo-based coils were also fabricated; a bird, a cat and a fire emblem. Each coil fabricated in this paper consisted of 5 turns. The voltage generated across the coils could be increased by adding more turns. All 5 coils can be seen in Fig. 1.

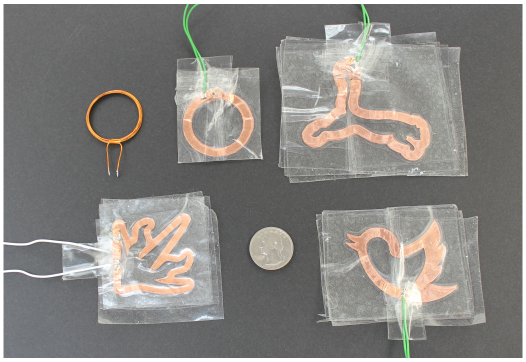

Fig. 1. Fabricated coils.

Coil	Measured inductance (μH)	Measured resistance (Ω)	Measured Q at 100 kHz	Inductance change with de-formation
Wire loop	1.824	0.0405	28.20	-
Flexible loop	1.740	0.1384	7.904	9.1%
Bird	1.685	0.1386	7.632	3.6%
Cat	2.340	0.2250	6.530	4.0%
Fire emblem	2.356	0.1670	8.862	2.3%

TABLE I

INDUCTANCE, Q VALUES AND PERCENTAGE INDUCTANCE CHANGE WHEN COIL IS DEFORMED FOR THE FABRICATED COILS.

IV. METHODOLOGY

The coil inductance and Q factor at 100 kHz for each of the coils was measured. These parameters are key to assessing a coil's performance in the inductive power transfer system. Table I demonstrates the similarity between the inductance of the coils. The measured inductance of the wire loop and flexible copper loop are within 5%. The significant differences between the Q factors are caused by higher AC resistance of the copper tape compared to the wire. The Q of the coils could be improved by using thicker tape or a larger width; we used 35μm thick by 5mm wide copper. Table I also shows the maximum observed change in inductance when the coil is deformed from planar to a 90° deformation. This acted to slightly reduce the inductance and small curvatures exhibit significantly less variation in inductance.

The copper tape coil Q factors at 100 kHz are still within usable parameters. To test this we performed a comparative test of inductive power transfer between all 5 coils. A class E transmitter topology [11] tuned to 100 kHz with a circular planar transmit coil constructed from 28 SWG wire with a 15mm radius, 19 turns, 19.06μH inductance and a Q of 35.74 at 100 kHz. Each of the flexible receive coils were tuned to 100 kHz using a tuning capacitor and the peak open circuit voltage across the coils was measured using an oscilloscope. The coils under test were moved in 5mm increments vertically away from the transmit coil and were kept co-axial. The results of the tests are shown in Fig 2.

Fig 2 shows the similar performance between the wire loop, bird and flexible loop coils. The cat coil has receive

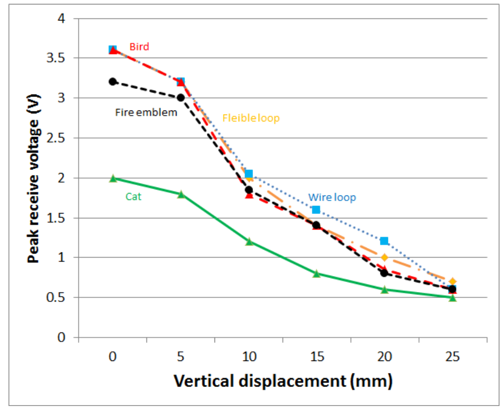

Fig. 2. Peak receive voltage with vertical displacement and co-axial coils.

voltages in proportion to the overlapping area of the transmit coil (280 mm^2 compared to the total area of 706.9 mm^2). This result is consistent with Faradays law of induction and practically demonstrates the designer has the freedom to use on-body flexible coils for inductive power transfer fabricated from copper tape, without significant performance reduction.

V. CONCLUSION

This work has practically demonstrated designers of on-body inductive power transfer have the freedom to create flexible, emblem or logo based receive coils without a performance reduction. The work enables more aesthetically pleasing coils to be developed and widens the appeal of on-body inductive power transfer. Future work consists of human factors research assessing the desirability of bespoke and customisable designs.

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