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Secondary-side de-tuning to enable wide-range Inductive Power Transfer for a wrist worn sensor

S Burrow and L Clare

Department of Aerospace Engineering, University of Bristol, UK

stephen.burrow@bristol.ac.uk

Abstract. Powering body worn electronics via inductive power transfer is made more challenging by the poorly constrained relative position of the coils and the consequential wide range of magnetic coupling between them. Somewhat counter intuitively for systems that must operate with coupling factors varying over an order of magnitude it is the design of the receiver side circuits during periods of high coupling that can be most problematic. In this paper a novel low-cost, low power receiver circuit is presented that can automatically compensate for higher coupling by altering the secondary tuning.

1. Introduction

Secondary active tuning is a concept that has been previously proposed for some IPT applications at high power levels in the context of output voltage regulation or compensation for parameter variations, for example in [1]. Parameter variations in an IPT system can be large and hence conventional regulation strategies may be insufficient. Emerging applications are pushing this parameter variation even further, requiring IPT to operate over a wide range of coupling and with poorly constrained coils.

Figure 1. An Illustrative mock-up of the IPT system for powering wrist worn sensors

The application considered here is an IPT system designed to power a wrist worn sensor, and where the TX coil is embedded within furniture, e.g. the arm of a chair. Components of this system can be seen in figure 1. The system has a design goal to operate over a 300mm hemisphere, which results in coupling factors ranging over an extreme range.

2. System behaviour

The components of the IPT system are shown in figure 2, comprising a 145 mm diameter flexible TX coil wound on fabric, shown with TX side driver circuitry; A rectangular 25 mm x 45 mm RX coil housed in wrist mountable plastic package, shown with power conditioning electronics.

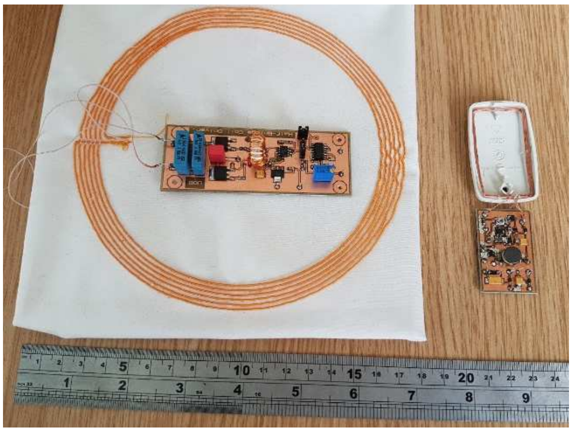

Figure 2. The IPT system showing TX and RX coils, and associated electronics.

The measured coupling factor between TX and RX coils is illustrated in figure 3. It can be seen how the coupling varies over a significant range: 0.06-0.001. Because the coupling ranges over low values (even the highest coupling level is low by conventional IPT system standards) a 'series/parallel' doubly tuned arrangement is used, i.e. the primary tuning capacitor is in series with the coil, whilst the secondary tuning capacitor is in parallel with the coil. This allows sufficient induced voltage in the secondary at the lowest coupling levels to commutate rectifier diodes and start-up the receiver side circuitry, however this results in voltages in excess of 50V appearing across the tuned circuit during peak coupling and the circulating currents in the RX side coil would produce conduction losses several times the useful power output, potentially creating a danger of burns for the wearer.

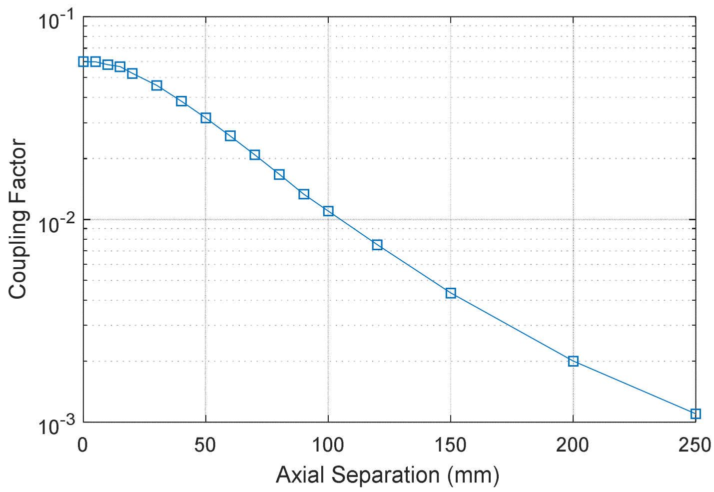

Figure 3. Coupling factor against axial coil separation.

3. Secondary detuning circuit

The proposed method of detuning the secondary circuit is based a passive circuit switching-in additional tuning capacitance in response to excessive voltage across the tuned circuit, figure 4. This is implemented via the circuit shown in figure 5.

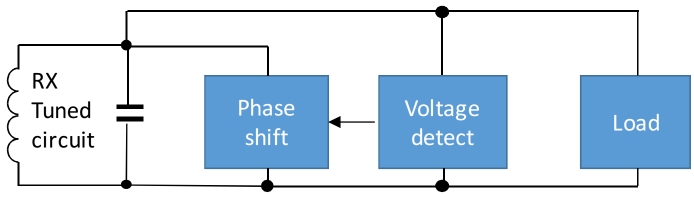

Figure 4. Block diagram of the detuning concept.

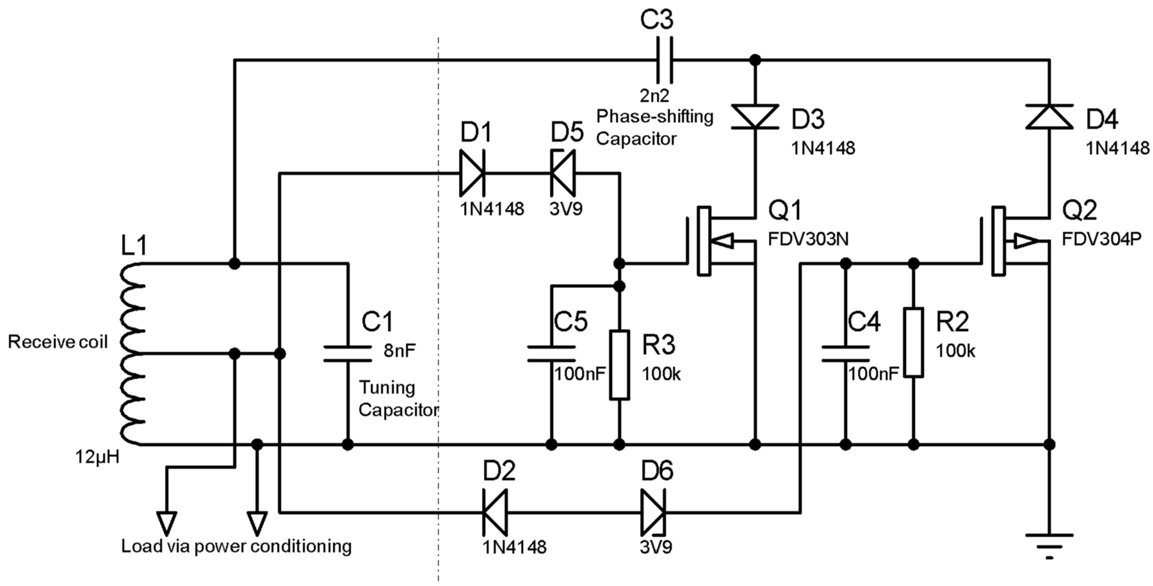

Figure 5. Secondary tuned circuit and detuning circuit diagram.

The detuning circuits operates as follows: The RX coil, L1, and tuning capacitor C1 form a parallel resonant circuit, tuned to operating frequency of the IPT system (in this case 500kHz). The load is connected across a tap winding on the primary coil; using a tapped winding gives a useful additional degree of freedom when designing the system. Detuning is achieved by the addition of C3 in parallel with the RX tuned-circuit, by means of a bi-directional electronic switch, comprising Q1, Q2, D3, D4. D1 and D2 rectify positive and negative half-cycles, smoothed by C5 R3 and C4 R2, to supply gate voltage to Q1 (N-channel) and Q2 (P-channel) respectively. The gate voltage is proportional to the load voltage and when the gate threshold is reached, Q1 and Q2 start to conduct, Q1 during positive half-cycles and Q2 during negative half-cycles, effectively applying C3 across the tuned circuit.

A key feature of this system is that it is passive, and diverting practically no additional power from the load, whereas previously reported de-tuning schemes which have active circuitry and are typically aimed at higher power applications [1].

Figure 6 shows experimental results for the load power output measured on the AC side of the RX circuit, showing the effect of the de-tuning circuit as the coil separation decreases. The suppression of load power can clearly be seen and represents an AC voltage reduction across the load from 26 Vrms to 15 Vrms. The phase shift given in figure 5 represents the phase of the voltage across the secondary resonant circuit relative to the TX coil current.

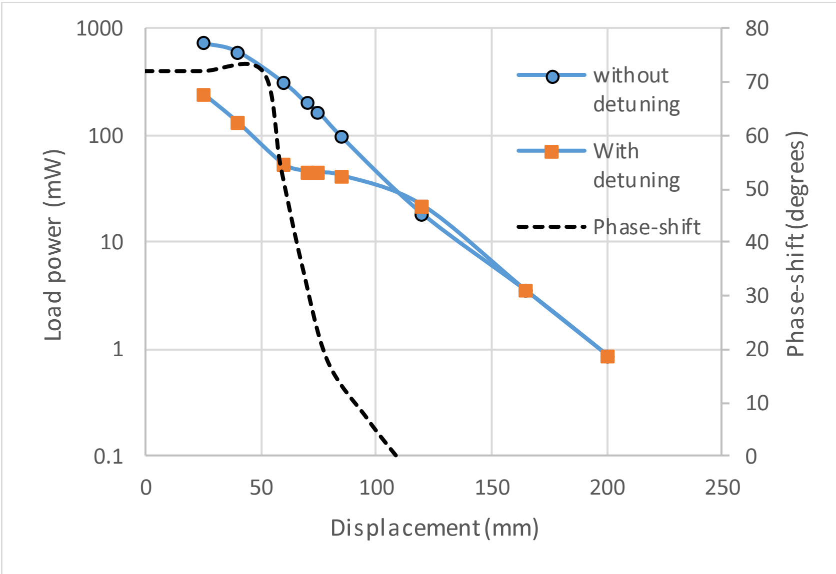

Figure 6. Load power (into optimum AC load resistance) with and without detuning and phase shift caused by switching in capacitor.

4. Conclusion

A low complexity, low cost approach to compensate for excessive induced voltage/power in IPT systems operating over large ranges of couplings has been described. The detuning circuit as shown reduces the voltage across the parallel RX resonant circuit by approximately 40%, and the power in the load by approximately 65%. The power loss dissipated as heat in the RX coil is also reduced accordingly. Alternative Zener diodes and detuning capacitor values can adjust the behavior as required.

The RX-side power rejection strategy described in this paper can be contrasted to the TX side power regulation strategies using a communication link to feedback secondary parameters to the TX driver. It is likely that the RX side power rejection is advantageous for low cost systems and where multiple RX coils might operate with a single TX coil.

References

[1] Tian, Jianlong & Hu, Aiguo & Nguang, Sing. (2017). Secondary Side Output Voltage Stabilization of an IPT System by Tuning/Detuning through a Serial Tuned DC Voltage-controlled Variable Capacitor. Journal of Power Electronics. 17. 570-578. 10.6113/JPE.2017.17.2.570.