Design and optimisation of compact RF energy harvesting device for smart applications

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An optimised design of a radio frequency energy harvesting antenna is presented. The antenna is based on a compact ferrite rod which, together with the electronics, can directly replace batteries in suitable applications. The antenna is optimised such that the energy available for the applications is maximised, while considering constraints such as the device geometry and the Q-factor. That the antenna can power a wireless sensor node is shown from the ambient medium wave transmissions.

Introduction: Harvesting energy from radio waves is not new and the crystal radio receiver is a well-known example [1]. More recently, research has targeted TV transmissions [2], but this requires a cumbersome antenna and the penetration of these signals into buildings is low. Besides this, there are several related devices reported in the literature that harvest energy from radio waves (see, for example, [3]). Such devices enable autonomous operation of low-power electronic devices such as those found in smart buildings, environmental sensors and smart meters.

A generic energy harvester consists of a transducer and a signal conditioner, which are connected to the user device. For a radio frequency (RF) energy harvester, the transducer is an antenna, where the harvested energy depends on the design of the antenna and the related electronics (RF–DC converter). Design factors include: physical size and geometry, electrical efficiency, output voltage and proximity to the transmitter. Although antenna design has been well researched for the purpose of communication, the design for RF energy harvesting applications is a growing area. The challenge is to design a compact antenna that satisfies the power output requirements and fits within certain physical dimensions and budget requirements. Our research focuses on ambient medium wave (MW) transmissions due to their high transmit power (>2 kW), number of transmitters (there are 69 in the UK) and favourable signal propagation when compared with higher-frequency transmissions. This Letter presents the design optimisation of a compact ferrite rod antenna for powering smart applications as well as results from a concept demonstrator. This has been enabled by the modelling and the simulation work presented in [4, 5].

Principle of operation: This design considers a compact ferrite rod antenna, chosen because it provides a compact solution at low frequencies such as the MW transmissions that we target for operating our antenna, chosen because it provides a compact solution at low frequencies. This design considers a compact ferrite rod antenna for powering smart applications as well as results from a concept demonstrator. This has been enabled by the modelling and the simulation work presented in [4, 5].

RF energy harvesting devices like those described above suffer from the problem of maximum power extraction. The optimisation algorithm is executed in MATLAB and uses multiple start points to find a global maximum. The optimal antenna configuration obtained for the given constraint has a core length of 0.58 m, a core diameter of 0.043 m and 71 turns of the wire.

Performance analysis: Consider a rod antenna that is constructed by using the above specification and using a ferrite rod with a relative permeability of 300 (which equates to an effective permeability of 118); and a silk covered 0.07 mm diameter litz wire wound around an insulator tube that is placed around the rod.
With reference to Fig. 1, our simulation shows that the resulting induced alternating voltage at the open circuit terminals of the windings reduces from 57.7 V to 900 mV as the antenna is moved to 10 km from the transmitter. The Figure also shows the maximum available power as a function of the distance from the transmitter. Each point represents an optimal antenna configuration for the corresponding distance. The amount of power available to power the device reduces from 5 W at 1 km to 0.98 mW at 10 km, and is constrained by the self-resonance frequency of the antenna which prevents larger antenna geometries from easily being used.

**Validation:** We have constructed an experimental device (shown in Fig. 2) with 59 turns of litz wire wound around a core of 100 mm, diameter 30 mm and \( \mu_r = 400 \). The coil has a length of 50 mm and a diameter of 36 mm. The measurements show that the device can deliver 0.24 mW to a 1 k\( \Omega \) load when operating indoors and approximately 22.5 km from the 150 kW transmitter. A similar device has been used to successfully power a digital device by using energy harvested from a broadcast transmitter operating at 900 kHz.

**Conclusions:** We have presented an optimised design of a compact RF energy harvesting antenna for extracting energy from ambient MW transmissions. The design maximises the received power while satisfying the application requirements including load voltage, \( Q \)-factor, ferrite core material, physical dimensions and type of wire. We have shown that more than 0.24 mW can be delivered to a 1 k\( \Omega \) load at a distance of up to 20 km from a 150 kW transmitter and have demonstrated that our device is able to power a sensor node.

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One or more of the Figures in this Letter are available in colour online.
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**References**