Magnetic inductive power transfer for wireless sensor networks

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***Abstract*—This paper discusses the use of magnetic inductive techniques to recharge wireless sensor nodes. An overview of the existing literature on magnetic inductive coupling between coils is given. The coupling coefficient of a non-resonant solenoidal coil link is determined, and it is shown that non-resonant coupling is not a viable option. A hybrid type coil is presented, and it is shown that the hybrid coil's coupling coefficient for similar parameters is higher than that of a solenoidal coil.**

I. Introduction

Wireless sensor networks (WSNs) are limited by power supply. Unless externally powered, a sensor is dependent on its batteries' lifetime. While increased battery capacity does increase the sensor's lifetime, it also increases cost and size. Various energy scavenging techniques to recharge sensor batteries have been investigated, ranging from converting seismic vibrations [1] or thermal gradients [2] to energy, to converting ambient radio signals to energy [3]. While these techniques have great potential, it has not yet been shown that they are capable of producing enough power to supply a wireless sensor node.

Magnetic inductive techniques have distinct advantages over energy scavenging techniques: charging is independent of environmental concerns such as cloudy days, seismic stable times and days when the ambient radio signals are weak because of weather conditions. Another advantage of using magnetic inductive techniques rather than energy scavenging techniques is that the coils used to transmit and receive power are inexpensive when compared to collectors such as solar panels.

Current research in magnetic inductive power transfer is focused on short range power transfer, where the diameter of the transmitting coil is larger than the distance of power transfer. Obviously this will not be acceptable for the case of a WSN where the distance between the transmitter and the receiver is in the meter range. Despite the advantages of using magnetic inductive techniques it is not yet clear whether it is indeed possible to design an inductive link that is both efficient enough and small enough to be used in a WSN.

Faxes to the attention of Mrs. Ferreira

This paper investigates the current literature available on magnetic inductive power transfer as well as a possible hybrid coil type to make the magnetic inductive link more efficient.

II. Overview of existing literature

The coupling coefficient between two magnetically coupled coils is given by [4]:

$$k = \frac{M_{12}}{\sqrt{L_1 L_2}} \tag{1}$$

where M_{12} is the mutual inductance and L is the self-inductances of the coils. Thus, in order to determine the coupling coefficient between two coils, it is necessary to determine the self-inductance of each coil, as well as the mutual inductance between the coils. When coupled mode theory is considered, it is also necessary to determine the natural frequency of the coils, as the coupling frequency also influences the coupling rate. According to [5], the coupling rate between the coils is:

$$\kappa = \frac{\omega \cdot M_{12}}{\sqrt{L_1 L_2}} \tag{2}$$

In order to determine the natural frequency of a coil, the stray capacitance of the coil (caused by the stray capacitances between the turns of the coil) must be determined. The natural frequency of the coil is then given by [6]

$$\omega = \frac{1}{2\pi\sqrt{LC_{stray}}} \tag{3}$$

There are two coil types which are commonly used for wireless power transfer: solenoid type coils and planar coils.

III. Feasibility of using magnetic inductance for WSNs

To determine whether magnetic inductive power transfer is a feasible option for WSNs, a system of two solenoidal coils is investigated. The coil diameter was chosen as 3.2cm, which is the same as the width of a MICAz[1] wireless sensor node.

[1]http://www.xbow.com

The number of turns was chosen as 6, which gives a height of 1.4cm when using a wire diameter of 1mm and a pitch of 1.6mm, which is as high as a MICAz sensor node without a battery pack. A solenoidal coil with a diameter of 3.2cm has a theoretical inductance of 1.49μH, a capacitance of 535fF and a centre frequency of 177MHz. The simulated results have a centre frequency of 171 MHz, which is close enough to the mathematical results to confirm the accuracy of the inductance and capacitance. At a distance of 1m, the coupling coefficient between the two coils is 6×10^{-6} which is obviously too small for practical use.

If the system acts in a strongly coupled region, however, the coupling rate can be increased [5] as in (2). Although non-resonant induction is very inefficient for midrange applications, as demonstrated above, it must still be shown whether resonant induction is efficient enough for use in WSNs.

IV. Hybrid coil design

In this section a hybrid coil type is proposed: a hybrid configuration of planar coils and a solenoidal coil. A number of planar coils are stacked in parallel with each other to form a structure resembling a solenoidal coil. An example of a hybrid coil is shown in Figure 1. In this example, the inner turns of only the top layer is shown, and the coil was cut in half on the y-axis to keep the figure clear and concise.

The advantage of this coil type is an increased coupling coefficient (1), because of the parallel configuration.

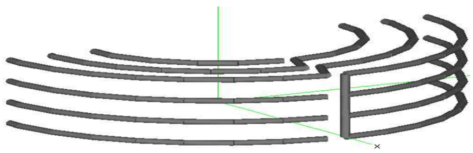

Fig. 1. A hybrid coil

A. Mathematical verification

In order to verify the increased coupling coefficient of the hybrid coil, single layer solenoidal coils and hybrid coils with similar parameters were considered. Both types had 6 turns, loop radii of 16mm, wire radii of 0.5mm and equal separation distances.

The solenoidal coil's inductance was determined to be 1μH, and its coupling coefficient is 6×10^{-6}. The hybrid coil's inductance is 9.4nH, and its coupling coefficient is 148×10^{-6}, which is 24 times better than for the similar sized solenoidal coil.

V. Work in progress

To determine the feasibility of using magnetic inductive techniques to recharge WSN nodes, much work still needs to be done. Issues that need to be addressed include:

- The ”strongly coupled region” must be investigated.
- The theoretical results for the hybrid coil must be verified.
- The quality factor of the hybrid coil must be determined.

VI. Conclusion

Magnetic induction outside the strongly coupled region is not a feasible option to recharge wireless sensor nodes. With coupling coefficients ranging in the $x \times 10^{-6}$ range for a separation of 1m, it is simply too inefficient to be feasible. Magnetic induction in the strongly coupled region must still be investigated before a conclusion can be made as to the ultimate feasibility of magnetic induction as a power transfer means.

The theoretical results for a hybrid type coil are promising. It is still necessary, however, to verify the results experimentally.

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