Wireless Powering System for Implantable Bio-Mems Sensor

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Abstract – **The aim of this proposal is to design a wireless powering system for an Implantable Bio-MEMS Sensor which is used to power up the implanted sensor inside the human body. It is highly desirable due to obviation of batteries or piercing wirings. The implanted sensor is powered up it senses the measureable parameters in the human body and the sensed signals are transmitted to the receiver section that is kept outside the human body. RF powering relies on an inductively coupled electromagnetic link to wirelessly transmit RF power from an external unit to an implanted system. This technique has been widely used for biomedical implants. The system consideration including the inductive coupling and the circuit building blocks of power management are given.**

Keywords: **Inductive Coupling , RF Powering**

I. INTRODUCTION

Implantable biomedical devices have, particularly in recent years, had much attention with regard to their application for a variety of uses involving both stimulation and monitoring. In direct contrast to wearable monitoring healthcare systems [1], one of the key issues for implanted devices is the satisfactory provision of power on an ongoing basis. For short-term experimentation it is quite possible for sufficient power to be provided trans-cutaneously, a good example of this being the 3-month implantation testing of the Utah Array [2]. For long-term implantation however the Power needed can vary considerably [3, 4].

Implants have in fact been used for a variety of applications, including an alternative sensory input and neural control of prostheses as well as a new means of communication [5]. Trans-cutaneous power delivery for any long term will however always carry with it the chance of infection for the recipient as well as the possibility of mechanical leveraging. Clearly an onboard/on chip power pick up device that avoids trans-cutaneous power supply is an attractive alternative which will most likely result in more widespread use of the technology [6]. Some devices, which require several milliamps of stimulating current, such as those used in the deep brain stimulating electrodes for the treatment of Parkinson's disease, need full battery implantation [7]. This technique then suffers from the requirement of periodic battery replacement. On the other hand, it is possible to consider energy harvesting within the body. This approach is however still in its infancy and its practical usefulness is yet to be fully realized [8].

Wireless power delivery offers the advantages that it reduces the risks (particularly because of infection) associated with either battery replacement surgery or a trans-cutaneous supply. Inductive coupling can be employed for such power transfer, but the efficiency of transfer is a (very sensitive) function of coil dimensions and the distance between them. Resultant efficiencies for biomedical implants are, as a result, generally very low [9], particularly so in a practical, working environment. The most attractive scheme is arguably therefore coupling between magnetically resonant objects [10].

Although the idea of wireless power has been explored extensively in the literature with several competing power delivery techniques being considered, the most directly relevant are those in which power is not directed, but rather it is absorbed. This feature allows magnetic currents to exist in a passive mode, that is, the energy does not persist in the environment continuously but rather is tapped into on demand. As a consequence of this, less energy is consumed to drive the circuits.

In this paper a method for the transmission of power by magnetic resonance in order to power biomedical implants is discussed. What is made apparent here is the small size and relatively few components required in the method described as compared to the relatively large and efficient amount of power transmitted.

The transmission frequency selected for the system is few hundred kHz. Consideration was given as that the particular transmission frequency used should not have any deleterious effect on human tissue. Clearly this is vitally important if power is to be supplied, such as implants, by the method described in this paper. What is important here is the concept of 'safe' zones, that is, signal frequencies for which previous studies have shown that, over a reasonable time period, normal-effects have been witnessed. According to Soma *et al.* [11] a frequency range of 100 kHz to 4 MHz, at the power levels considered here, has been shown to be suitable for this aim. This study is therefore performed within this frequency range. Nevertheless, in the scheme of magnetic resonance for power transmission, it has already been determined that the transmission does not interact with off resonant objects [12]. Using an on-board miniature solid-state high-power amplifier, we demonstrate here a prototype capable of delivering reliable operating characteristics suitable for practical implants requiring a steady power supply of anything from 4.5 to 6V dc.

Contrary to the purposes of other implementations [11, 12] of specific interest here, is to question whether a scheme could be accomplished using small coils of a few turns driven by a simple amplification circuit. The goal of this exercise is therefore to establish a driving circuit with a minimum amount of components, thereby reducing device complexity and emitted heat.

As a physical demonstration of the operating characteristics of the method described, we have set a requirement to maintain a sufficiently high-powered signal to reliably power a lamp. The reasoning being that if the technique can function well in terms of such external requirements, it will certainly perform adequately in the case of an implant specification. In this regard, it has not been our goal to deliver power at the sort of distances reported on in [12] where efficiencies of 40% are perhaps the upper target. Rather, here we attempt to compare directly with transmission over relatively short distances (a few cm), as reported on in [10] with a high efficiency of transmission (over 90%) being our target.

An overriding aim is to overcome power supply issues, eminently apparent in the study of biomedical implants, by realizing a wireless scheme which is sufficiently powerful such that an implant can reliably receive its power remotely. Hence, the direction of power transmission as well as the size of technology involved has been important in our studies. Firstly, in the section that follows, we give a theoretical underpinning of the scheme. Following this we provide some experimental power transmission results. It is worth stressing that these have been obtained from an actual prototype transmission network rather than a computer simulation.

II. WIRELESS POWER BY MAGNETIC RESONANCE

A. Inductive Power Transfer

The concept of wireless power transfer, first described by Poynting and experimentally verified by Tesla, has been illustrated in the literature as a viable method to transport electrical current between distant points [10].The extension of this method herein maintains a significant amount of useful power transmitted at intensities of less than 15V in which, across a volume of air, the magnetic waves are exchanged between two or more coupled resonators.

Consider a circuit consisting of a single loop of insulated wire wound in such a way as to create a circular loop of a few turns. This loop, connected in parallel to a capacitor, becomes one-half of a resonant circuit. The length of the wire loop in transmitter is then replicated to construct a similar loop placed on an independent circuit board positioned a distance away and which is connected in parallel with a capacitor of the same reactive value and a load. In its entirety this becomes the second-half of a resonant circuit. Each half of the resonant circuit is placed a distance from the other. The transmitter is connected to a power source such that the LC circuit is excited. Owing to the symmetry between each half of the circuit, magnetic waves flow from transmitter → receiver at resonance frequency f_0 with an efficiency η. When energized, this circuit engages an electrical field in the loop in transmitter, creating a magnetic field which is coupled to the loop in rerceiver. By placing the load in parallel to the loop in receirver, magnetic energy is converted into electrical current. The arrangement is illustrated in Fig. 1.

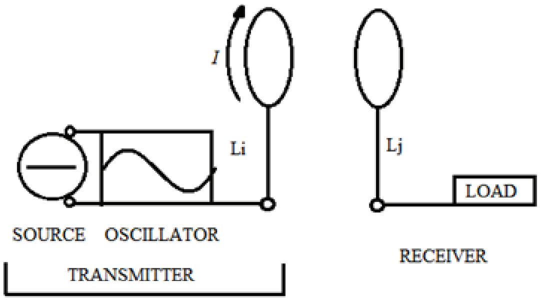

Fig. 1 Model for inductive wireless power

B. Efficiency of the scheme

The efficiency η of the experimental model is calculated to be

$$\mathrm{m} = \frac{k_{ij}^2 Q_i Q_j}{1 + k_{ij}^2 Q_i Q_j} \tag{1}$$

Where K_{ij} is the coupling coefficient, Q_i, Q_j are the quality Factor of the coils L_i and L_j driven at resonance frequency η_0. Since the efficiency of the given coil geometry is of interest, the coupling coefficient K_{ij} mutual inductance M_{ij} between distant coils L_i and L_j, and the quality factors of all the coils must be determined.

Meanwhile, the coupling coefficient between magnetically Coupled coils in general is defined as

$$k_{ij} = \frac{M_{ij}}{\sqrt{L_i L_j}} \tag{2}$$

where M_{ij} is the mutual inductance, L_i and L_j the self inductances of the coils.

Further to this the inductance of a circular loop is

$$\begin{aligned} L_i &\cong \mu_o \mu_r n_i^2 r_i \left(ln \frac{8 r_i}{R_i} - 2 + Y \right) \\ L_j &\cong \mu_o \mu_r n_j^2 r_j \left(ln \frac{8 r_j}{R_j} - 2 + Y \right) \end{aligned} \tag{3}$$

where r_i, r_j is the loop radius and R_i, R_j is the wire radius, n_i, n_j is the number of turns and Y is the flow constant of the skin-effect of the emitted radiation.

To determine the mutual inductance M_{ij} apparent in this case, Stokes' theorem yields the value.

$$M_{ij} = \frac{\iint_{S_j} B \cdot n \, dS}{I_{L_i}} \tag{4}$$

where S_j is the area of the receiver coil, B is the magnetic field, Ili is the current passing through the transmitter secondary coil and n is the vector normal across free space. The loaded qualities, Q_i, Q_j as a property of the capacitance C_i, C_j, resistance R_i, R_j, and inductance L_i, L_j of the circuits containing the transmitter and receiver coils, respectively, are defined as

$$Q_i = \frac{1}{R_i}\sqrt{\frac{L_i}{C_i}} \qquad Q_j = R_j\sqrt{\frac{L_j}{C_j}} \tag{5}$$

The quality factor of the receiver Q_j is shown for the parallel case. For comparative purposes, the quality of the transmitter is also derived from the resonance frequency at the oscillator as

$$Q_i = \frac{\omega_o L_i}{R_i} \tag{6}$$

The quality factor, with reference to (5), is based on those properties – inductance, capacitance and resistance – which allow it to manifest a state of resonance between each half of the circuit. By inspection of the equation – and when compared to (6) – the amount of energy available to each receiver is due to the energy consumed in the work being performed given the system's ability to send a limit of quantity of energy given the arrangement within the oscillator. Therefore a system with multiple receivers will have an 'additive' quality in that the transmission will support more than one receiver equally subject to its orientation and position.

The physical specification of the inductive link coil is given in the Table I.

Table I Inductive Link Coil Physical Specification

Coil	Coil radius (mm)	Wire radius (mm)	Wire length (mm)	No. of turns
L_i	25	0.4	1570	10
L_j	25	0.4	1570	10

III. Experimental Results

Each receiver was operationally tested in one of two modes:

1. AC mode: receiver contains a capacitor and a lamp.
2. DC mode: receiver contains a capacitor, a full-wave Rectifier Bridge and a DC motor.

The receiver circuits in each mode were constructed differently, although each used a coil loop wound with the same physical characteristics as the transmitter coil. Each had a capacitor of the same value placed in parallel.

For one of the AC modes, a bias resistor was added in parallel to increase the Q value. For all DC modes, converting the radio-frequency signal to direct current was straightforward using diodes as a bridge rectifier results in Minimum voltage drop.

In this paper a lamp is fixed in the secondary side i.e. the receiver end. The source in the transmitter side used is regulated power supply giving an input of around 7 to 8V dc.

The input is given to the oscillating circuit which produces an oscillation of frequency about 140KHz. This oscillating frequency is passed to the transistor circuit to amplify and the switching operation of transistor produces a variation in current flow in the transmitter coil.

This variation of current flow in the coil produces an EMF in the coil. This induced EMF is then coupled to the receiver side coil by the property of mutual induction.

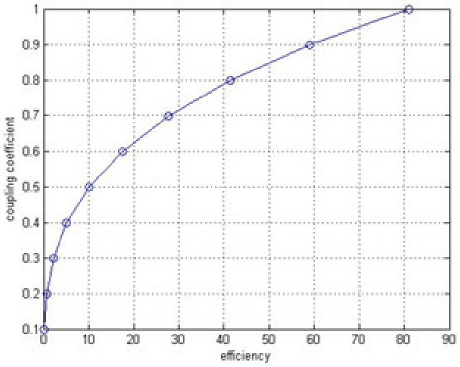

Fig. 2 variation of efficiency with coupling coefficient

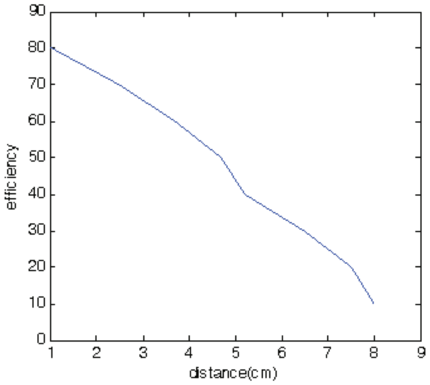

Fig. 3 variation of efficiency with transmission distance

The maximum power is transfer at a distance of 2cm to 4cm and the maximum distance the power can be coupled is about 15cm. When using AC mode and rotating at an angle θ, as illustrated in Fig. 2, the signal performance of a receiver r was observed when θ was between 40˚ and 90˚ offset from t. In this range, the luminescence falls off and remains steady at θ = 90˚.

The variation of the efficiency with the coupling factor is given in Fig 2 from the equation (1). The efficiency is more for coupling factor value equal to 1. In Fig 3 the variation of efficiency with transmission distances variation. When both the transmitter and receiver kept near they produce the high efficiency.

IV. System Performance

It is possible to affect the Q-factor of the coil by subtracting the series resistance from the transmission circuit, while adding parallel resistance to the receiver circuit. This is achievable particularly when using high-wattage resistors at low quantities of resistance.

For example, by adding a 500Ω resistor in parallel with the load raises the Q-factor of the circuit thereby causing the lamp to give off a brighter luminescence. In doing so it also improves the efficiency of the circuit.

By increasing the length of the wire after the rectifier circuit, the useful range of the DC signal was extended to 12 cm. At higher voltages, that is, those at 9V and greater, the heat given off was found to be minimal in the circuits tested. What heat existed was found to be concentrated around the capacitor in parallel with the loop and was linearly related to the input current. The maximum power was transmitted in this experiment by driving the amplifier circuit at 12 V. At this level, significant heating of the transmitter's capacitor was found. Changing the input voltage altered the output voltage, that is, there was no apparent storage of magnetic energy in the magnetic field.

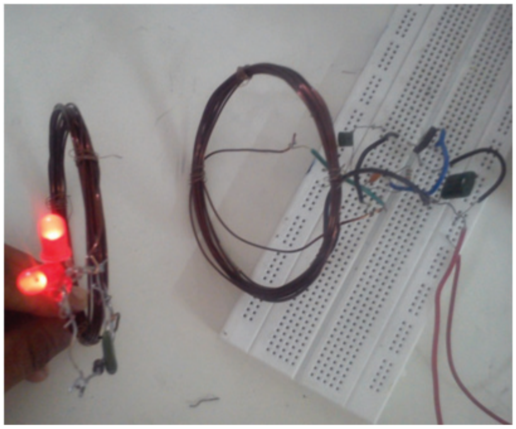

Fig. 4 Experimental Setup for wireless inductive power

V. Conclusion

In this paper, the method and means of effective wireless power for the purpose of powering biomedical implants has been described. The focus of this paper is on the description and experimental testing of power delivery for such an application area.

However, the method of power delivery is general and can be applied to other applications which require wireless power transfer on scales both large and small. The experimental results show that significant improvements in terms of power transfer efficiency are achieved by directly connecting the LC circuit to an amplifier circuit instead of excitation being achieved from an external sinusoidal source. Our measured results were found to be in very good.

The next step clearly will need to involve tests involving actual biological tissue. Although, by analyzing the results from previous comparable studies [10], it is not anticipated that there will be any issues of significance, nevertheless such a study is a necessity before the actual practical application of the procedure can go ahead in situ.

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