Performance characterization of inductive coupling system

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Abstract: The use of biomedical implants has been on the rise over the recent past years and this use is expected to increase exponentially over the coming years. Such devices are becoming the most feasible interface to monitor the betrothed parameters. Biomedical implants usually require a low input voltage which is provided making use of inductive coupling. Inductive coupling not only solves the powering issue but also helps to collect the data through non-invasive means. Power transfer efficiency of an inductive link system depends upon factors like mutual coupling, separation between the coils and most importantly the shape of the input voltage. The power transferred or signal received as a result of coil separation under optimum size conditions are reported in contemporary works. This paper comes is testing the effect of different shaped input voltages on the performance of inductive coupling system in terms of power transfer efficiency. Circuits have been tested for three different types of input waveforms of sine, square and ramp. Comparison of plots shows that the shape of input plays a major role on the entire performance of inductive coupling system.

1. Introduction

Inductive coupling based power transfer has several advantages over other methods. It is immune to environmental factors such as dust, water, or chemicals. Inductive coupling transfers electrical power between two isolated coils placed in closed vicinity to each other. The contiguity and the nearness of coils play a vital role in the generation of low power electrical field that inter-connects them and hence allows the transfer of electricity between the two systems. Powering the implanted devices and collecting data sensed from such devices is being studied recently. Different techniques have been proposed for these purposes. Energy harvesting from different sources from the external environment such as thermal, light and piezoelectric is used which is not suitable in the case of biomedical implanted devices like using solar energy harvesting faces problems regarding the limitation of working environment[1-3]. So, transmitting energy wirelessly to the implant devices using implanted and external antenna is considered to be a suitable solution to all these issues [4].

Inductive coupling has several advantages over the others for powering and telemetry purposes, such as the implanted devices can be operated continuously because external source keeps providing the power and its independent environmental factors such as temperature, light etc. A telemetry chip using inductive coupling supplies power to and transmits data from an implantable sensor. Such sensors offer several advantages to study and monitor the human body. The telemetry system used two coils to transmit both power and data. The distance between coils is up to 25 mm [5]. Inductive power transfer for transferring the power wirelessly is being used in different applications. For example, Inductive coupled charger used for charging of mobile phones or other handled devices. Biomedical

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application for this technique is to power up and collect data from implanted devices such as cochlear
and retinal implants and inductive coupling is used to fulfil this. [7].
These previous papers studied the performance of the telemetry system using a sinusoidal power
supply only; this work will focus on studying the performance by simulating different input wave
forms as a voltage source including sinusoidal, square and triangular inputs. Moreover, this work will
study the effect of the capacitance at the load side on the power transfer efficiency.

2. Analysis of the telemetry System
A two coils inductive coupling circuit is shown in Fig. 1 and in order to find out the power transfer
efficiency, the values of I1 and I2 need to be evaluated. There are two methods to do so i.e. Applying
KVL and VNA, or by reflecting the source or load loop impedance. Both ways have been illustrated
below.

Fig. 1: Two loop inductive coil system

Applying KVL on the source loop

\[ V_s = (Z_s + R_1 + j\omega L_1)I_1 - j\omega MI_2 \]  (1)

For the load loop

\[ 0 = -j\omega MI_1 + (R_2 + j\omega L_2 + Z_s) I_2 \]  (2)

We assume that

\[ (Z_s + R_1 + j\omega L_1) = Z_{11} \]  (3)
\[ (R_2 + j\omega L_2 + Z_s) = Z_{22} \]  (4)

Putting these in Eq. 1 and Eq. 2 we get

\[ V_s = Z_{11}I_1 - j\omega MI_2 \]  (5)
\[ 0 = -j\omega MI_1 + Z_{22} I_2 \]  (6)

\[ I_1 = \begin{bmatrix} V_s \\ 0 \end{bmatrix} = \begin{bmatrix} -j\omega M \\ Z_{22} \end{bmatrix}^{-1} \begin{bmatrix} V_s Z_{22} \\ Z_{11}Z_{22} + \omega^2 M^2 \end{bmatrix} \]  (7)
The power efficiency is given by:
\[
P_{\text{eff}} = \frac{P_{\text{receive}}}{P_{\text{sent}}} \times 100
\]

Substitute equation 9 in 13 we get:
\[
P_{\text{eff}} = \frac{|I_2|^2R_1}{|I_s|^2V_s} \times 100
\]

Substitute the value of $I_1$ in equation 7 we get the following:
\[
P_{\text{eff}} = \frac{w^2M^2 R_1}{|Z_{22}| |Z_{11}Z_{22} + w^2N^2|} \times 100
\]
Figure 2: Inductive coupling system

For the circuit shown in fig. 2 assume that R1, R2, L1, L2, M, and Vs have the values 5, 15, 1\,\text{mH}, 4\,\text{mH}, 1\,\text{mH} and 200\,\text{volts} respectively. The terms \( Z_{11} \) and \( Z_{22} \) as a function of \( w \) are given by:

\[
Z_{11} = 10 + 0.001\,w + j
\]

\[
Z_{22} = 30 + 0.004\,w + j
\]

The values of the power sent from the source loop, the power received by the load and the power efficiency is calculated according to the equations for the circuit shown in figure, these value plotted and shown in fig.3 (a) and 4 (a). The simulation results for these parameters are shown in fig.3 (b) and 4 (b).

![Power sent and received](image1)

Figure 3 (a): Analytical plots for power sent and received as a function of frequency, both x and y axis in logarithmic scales.

![Power sent and received](image2)

Figure 3 (b): Simulation plots for power sent and Power received as a function of frequency, Red line is the power received while the green line is power sent, both x and y axis in logarithmic scales.
2.1 Different input wave forms

We used three different shapes of voltage sources in simulation of the inductive coupling system using Pspice. The wave forms shown in Fig. 5 are of the same amplitude and the corresponding plots for power transfer efficiency are shown in Fig 6. Power received at the load side has been shown in Fig 7 when all three different supplies are used.

Figure 5: Different voltage sources.
3. Discussion and comparison

Comparison between simulation results and the analytical plots for power sent, power received and power transfer efficiency in Fig. 3 and Fig. 4 shows that both exactly match. The power transfer efficiency in fig 4 have a maximum value at 1.6 kHz frequency, which can be referred to as the resonant frequency for this circuit. So the telemetry system needs to be tuned to this frequency for maximum power transfer in this case.

According to the simulation results shown in fig 6, the shape of the voltage source has no effect on the value of the power transfer efficiency. And this is because the PSPICE simulation deals with the three shapes as an AC source during the AC analysis. However, the results for the transient analysis in fig. 7 shows clear differences in terms of power received for the different shapes. The highest power is received in the case of square wave voltage source.

4. Conclusions

The telemetry system based on coupled coils structure is studied using three shapes of voltage sources. The currents, impedances and the power equations are derived for both circuits. The efficiency of these circuits is studied as a function of frequency, using analytical and simulation plots which are both exactly matched. The simulation results show that there is no effect of the source shape on the power efficiency in the AC analysis while it shows differences in the power received in the transient
simulation, the highest power could be received to the load is in the case of using a square wave power supply.

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