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Suggested Methods to Solve the Coils Misalignment for the Biomedical Implants

Abstract- *One of the major problems of the inductive coupling link in the biomedical implantable devices is the misalignment between coils. This paper produces two simple suggested methods to avoid and reduce the misalignment between two coils. The first one is to split the implanted coil into two identical coils with 450 µH of inductance where the external coil was equal to them in inductance ~ 900µH. The results show that the received powers are constant and compensated by one of the coils, which provides a stable power at the implant. The second proposed suggestion is to use two separated identical coils situated in the center angles outside the human skin. The transmitting RF power of the both coils has a same resonance frequency and received with a single small implant coil, which sums the received RF signals where the amplitudes are double. The mathematical analysis of the second suggestion is introduced.*

Keywords- *printed coils, coils misalignment, bio-implantable devices, inductive coupling links.*

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1. Introduction

Last decades, most of the bio-implantable devices such as cochlear implant, retinal implant and implanted micro system powered by using implantable batteries [1, 2]. This method has several drawbacks due to the battery-limited lifetime, size and chemical side effects [3]. The inductive coupling link is the safer method that can be used to power the implanted devices for long-term period and during light patient mode [4]. The inductive link method consists of two parts; external part fixed outside the body and internal part integrated inside the human body [5]. The power and data transmissions are done by external and internal coils inductively as shown in Figure 1. In general, the transcutaneous Bio-implantable device which use the magnetic coupling for short communication, suffer from many problems, such as short-range, loss of coupling, attenuated power and coils misalignment [6]. The major problems of the inductive coupling link is the misalignment between coils, which causes low data rate and power transmission [7]. To realize the best results, a high RF received power, and matched impedance is needed. As well, the magnetic field and the orientation angle for the coils is restrained by many factors, such as azimuth and elevation angles for the implant due to the coil movement, which was studied for several rotating possibilities for implant coil angles such as (0°, 45°,) and (90°), as demonstrated in Figure 2 [8].

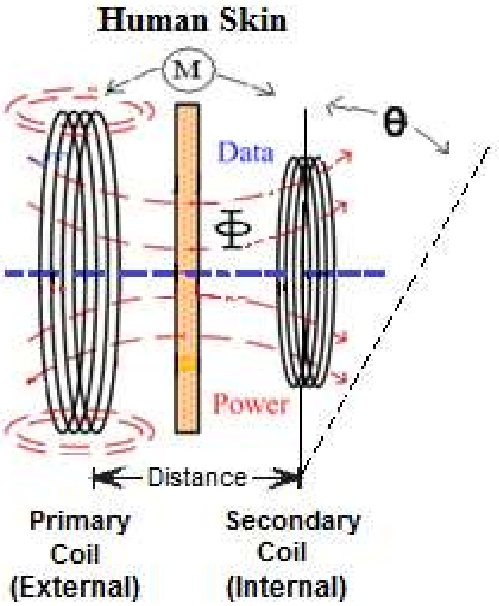

Figure 1: The alignment case of the external and implanted coil

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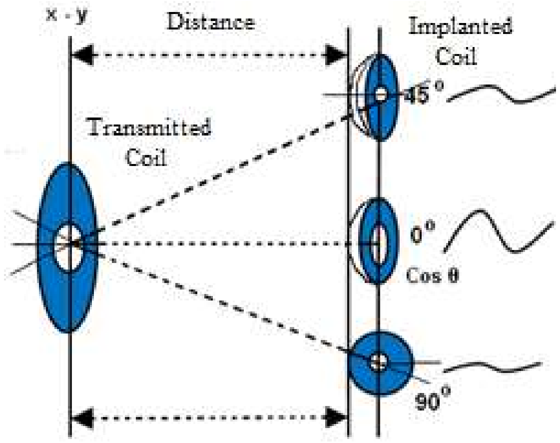

Figure 2: The misalignment analysis between two coils

Many studies investigated this problem; however, it is still needs more investigations and developments [9-14]. In this paper, simple suggestion solutions with mathematical analysis to reduce the coils misalignments effects are presented. The first suggestion is to split the implanted coils in tow identical coils in shape with the external one. The second proposed suggestion is to use two separated identical coils situated in the center angles fixed outside the human body. The transmitted power of both coils are transmitting at similar frequency, and received with a single implant coil, which sums the received RF signals where the amplitudes are double. The mathematical analysis of the second suggestion is introduced.

2. Proposed Theory for Misalignment Solution

The proposed theory for the coils misalignments is performed in two sections: firstly by divided the received coil (internal) and the transmitted coil is keep as it is. In addition, the second one is performed by split the external coil in tow coils where the implanted coil is single.

I. Implantable Pair Receiver Coil

Generally, for reducing the misalignment between coils and improving the receive power, the first suggested solution is to split the implant coils into two identical coils, as shown in Figure 3, as this that will harvest the most magnetic flux intensity. Each of the split implanted coil with 450 µH of inductance where the external coil was equal to them in inductance ~ 900µH. The prospective design in Figure 3 was analyzed and created into a lumped equivalent circuit module as shown in Figure 4, where the magnetic coupling coefficient and the mutual coupling shared the transmitted magnetic flux from the coil transmitter. The reader and dual implant coils with their lumped elements are given in Table 1.We analyzed these relations of magnetic coupling coefficients in mathematical form. By analysis of the coupling coefficient between three coils, the coupling relation between L_T and L_{imp1}, L_{imp2} can be expressed as explain below. The coupling relation between L_T and L_{imp1}, L_{imp2} can be expressed as given below.

$$\frac{M_1}{L_T} = \frac{N_{imp1}}{N_T} K_1 \tag{1}$$

$$\frac{M_2}{L_T} = \frac{N_{imp2}}{N_T} K_2 \tag{2}$$

Where N_T presents the number of turns for the transmitted coil. The mutual coupling relation of the split implanted coils L_{imp1} and $Limp2$ can be given in (3) and (4)

$$\frac{M_3}{L_{imp1}} = \frac{N_{imp1}}{N_T} K_1 \tag{3}$$

$$\frac{M_4}{L_{imp2}} = \frac{N_{imp2}}{N_T} K_2 \tag{4}$$

From the above equations, we can substitute and get the mutual inductance between coils as

$$M_1^2 = K_1^2 L_T L_{imp1} \tag{5}$$

Then

$$M_1 = K_1 \sqrt{L_T L_{imp1}} \tag{6}$$

$$M_2^2 = K_2^2 L_T L_{imp2} \tag{7}$$

Then

$$M_2 = K_2 \sqrt{L_T L_{imp2}} \tag{8}$$

The quality factor for the external and both internal coils can be calculate by (9) respectively.

$$Q_T = \frac{\omega L_T}{R_T} \;,\; Q_{imp} = \frac{\omega L_{imp}}{R_{imp}} \tag{9}$$

Based on Mesh Coupling Analysis Circuit the implant load power can be given in the equation below:

$$P_{imp.} = \left(I_{imp}\right)^2 * R_L \tag{10}$$

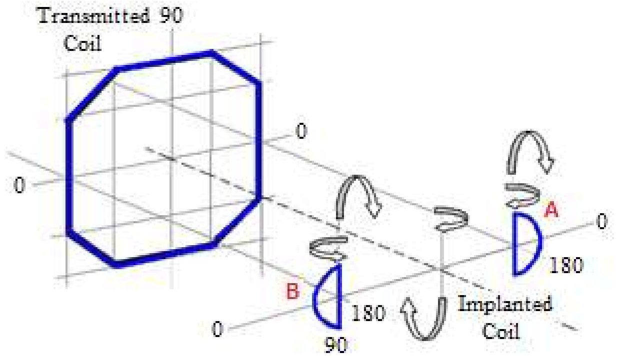

Figure 3: The first solution for splitting the implant coils in to two parts

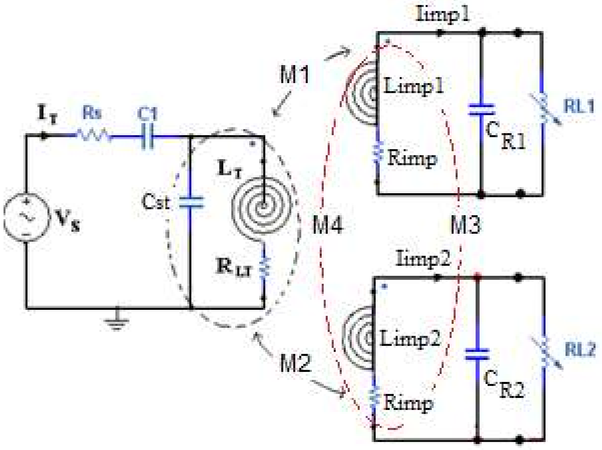

Figure 4: Lumped equivalent circuit with dual for inductive coupling module

Table 1: The lumped elements value of the equivalent circuit

L_T μH	$L_{imp(1,2)}$ μH	N_T	R_{LT} Ω	R_{imp1} Ω	R_{imp2} Ω	C_{ST} nf	C_{R1} nf	C_{R2} nf	K	R_L Ω
900	450	6	1	0.5	0.5	3.3	1.8	1.8	0.03	150

II. External Pair Transmitter Coil

There are several technical keys and suggestions had been produced to solve the problem of the coils misalignments between the coils. In this research, a simple method with mathematical analysis to reduce the misalignments problem between the coupled coils is also produced. The method is done by using two divided identical spiral circular external (transmitted) pancake coils situated in center angles fixed outside the human body. The external spiral circular coils are transmitting the RF signal at the similar Industrial Scientific Medical (ISM) band frequency 135 KH$_Z$ and have the same shape, same inductance and same geometric parameters. Each separated external coils (T$_{X1}$ and TX2) powered with different sources such as V$_{S1}$ and V$_{S2}$ respectively. The transmitted RF signal received by a small size of single implanted coil (received coil) R$_X$ tuned to the same resonant frequency 135 KH$_Z$ as shown in Figure 5. The implanted coil R$_X$ harvest and sum the received RF signal. Henceforth, the output amplitudes of the RF signal at the received coil will be double and this increased the system efficiency.

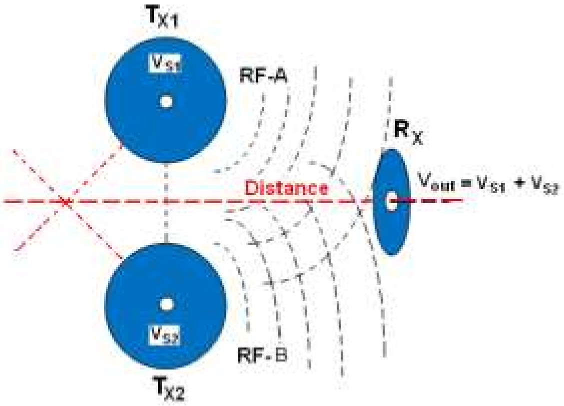

Figure 5: The second proposed idea of using two identical sources

The first coil T$_{X1}$ poweredby the source V_{S1} is expressed in (11). Where the second coil T$_{X2}$ powered by the source V_{S2} is expressed in (12) respectively.

$$V_{S1}(t) = A_1 \cos(\omega t + \Phi_1) \qquad (11)$$

$$V_{S2}(t) = A_2 \cos(\omega t + \Phi_2) \qquad (12)$$

The implanted (received) coil was added the received magnetic fields of the two external coils together, which produce AC voltage. The implanted coil harvest and sums the two received magnetic fields; the output voltages V_{out} can be expressed mathematically as given in (13) and (14) respectively.

$$V_{out\,\Sigma} = V_{S1}(t) + V_{S2}(t) \qquad (13)$$

$$V_{out\Sigma} = [A_1 \cos(\omega t + \Phi_1) + A_2 \cos(\omega t + \Phi_2)] \qquad (14)$$

Because of

$$\cos u + \cos v = 2\, coc \left(\frac{u+v}{2}\right) cos \left(\frac{u-v}{2}\right) \qquad (15)$$

Then

$$V_{out\,\Sigma} = A_1 + A_2\left[\cos\left(\frac{(\omega t+\emptyset_1)+(\omega t+\emptyset_2)}{2}\right)\cos\left(\frac{(\omega t+\emptyset_1)-(\omega t+\emptyset_2)}{2}\right)\right] \quad (16)$$

In case, where both sources are equals in phase, hence Eq. (16) can be written as given in (17).

$$V_{out\,\Sigma} = \frac{2(A_1+A_2)}{2}\left[\cos(\omega t+\Phi_1)+(\omega t+\Phi_2)\cos(\omega t+\Phi_1)-\cos(\omega t+\Phi_2)\right] \quad (17)$$

If the phases of both signals are equals ($\Phi_1 = \Phi_2$), hence, the output summation of the internal coil is given in equations as:

$$V_{out\Sigma} = A_1 + A_2[\cos(\omega t+\Phi_1)\, X \cos(\omega t+\Phi_2)] \quad (18)$$

Because of the implanted coil have a lumped element such as parasitic capacitor C_P and parasitic resistance R_P as shown in Figure 6. Therefore, the lumped element acts as a band pass filter (BPF) to remove the second harmonics of the received RF signal. The output RF signal will be creating a double voltage at the implant coil as expressed in (19).

$$V_{out\Sigma} = A^2\cos(\omega t+\Phi) \quad (19)$$

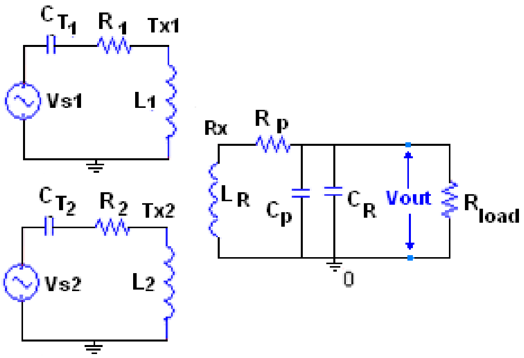

Figure 6: Block diagram of the proposed link with parasitic elements

3. Results and Discussions

This study introduces suggested solutions with mathematical analysis to reduce the misalignment effects between the inductive coupling link based on spiral circular coils. The first method is performed by split the implanted coil in two identical coils having the same shape and dimensions. Both coils A and B were identical with 450μH of inductance, where the reader coil was equal to them in inductance ~ 900μH. This structure is able to harvest the most of the magnetic flux intensity as well as the transmitted data and power with high efficiency. To test and validate the implantable coils performance with varied distances is simulated as shown in Figure 7. The MATLAB model has been mathematically validated by simulation and verification of the inductive coupling design and calculation for the optimum power transfer over wireless coupling link. From the simulation results, it can be seen that the best delivered power to the implanted coil is accurate when the implantable coil align and closer to the external coil.Figure. 8 shows the relationship between the implantable dual received power and orientation receive angle. The results obviously indicate that the wireless received powers are constant and compensated by one of the coils, which provides a stable power at the implant. Whereas, the disadvantage of this structure is that the relatively large size of the implantable coil, which limited some of the required applications. The second solution is explained mathematically and performed by dividing the external coil into two coils of spiral circular coils. Both divided coils are having the same shape, same dimensions, and same operating frequency. In this way, the implanted (received) coils able to sum all the received RF signal without losses. Hence, the amplitudes will be double, and this will increase the implanted devices efficiency. The advantage of the proposed design is that, the implanted (received) coil harvests most of the transmitting magnetic fields, influenced by both external sources V_{S1} and V_{S2}. While the disadvantage of the design is that the orientation angles of both external coils are critical to fix to the required angles hence, it need to readjust their angles commensurate with the body movement.

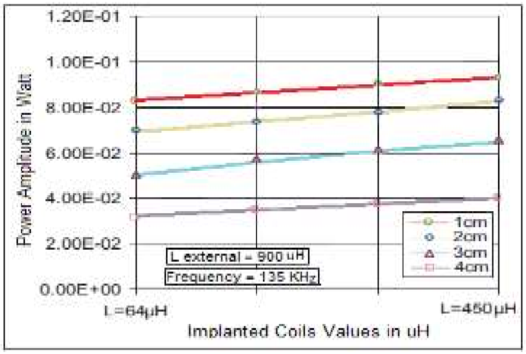

Figure 7: Optimum received power at differences distance between the coils

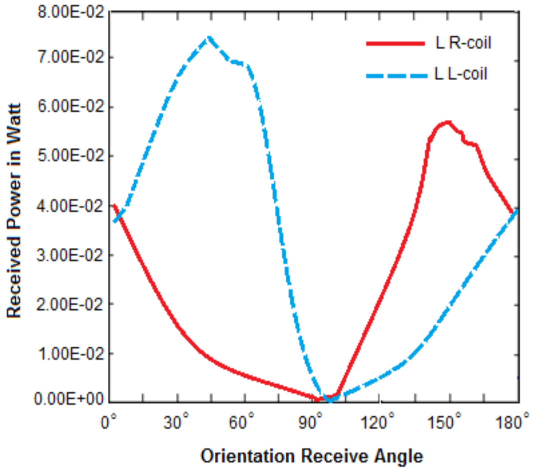

Figure 8: The relationship between the implantable dual received power and orientation receive angle

4. Conclusions

In the inductive coupling links for biomedical applications, the misalignment between two coils is the main problem faces the designers. In this paper, two solutions were suggested to solve the misalignemnt problems based on splitting the implanted coil into two identical coils to harvest most of the received energy as proved mathematically. The results indicate that the received powers are constant and compensated by one of the coils, which provides a stable power at the implant. The second solution is to divide the transmitted coil (external) into two identical coils, then, the implanted coil can sum most of the transmitted energy as proved mathematically and the output amplitudes will be double and this increased the efficiency. The proposed structures may be useful for the bio-implanted devices such as the implantable cardiac pacemaker.

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Author(s) biography

Dr. Saad Mutashar was born in Baghdad, Iraq in January 1961. He received his B.Sc and M.Sc degrees in 1984 and 1986 respectively from University of Belgrade, Serbia. In 2014, his PhD degree from National University of Malaysia (UKM). Since 2005 a Lecturer at the University of Technology, Iraq. The field of interest, Microelectronics, Designing implantable micro-system stimulator, bio-medical implantable devices and inductive coupling links for bio-medical applications. He is an IEEE member.