Three-coil wireless power transmission by increasing spacing distance and using optimal design with converter circuit

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Abstract

As the distance between transmitter and receiver increases, the frequency range used for connecting to the circuitry must also expand. The maximal power factor of a load is dependent on numerous factors, out of which the most important are the coupling coefficients between resonators, quality factors for resonators, and drive power. Enhanced wireless transmission links have been provided, based on the best results at a distance of 2.5 meters, the transmit power can be greater than 120 Watts. These demonstrate the high efficacy and efficiency of three-coil wireless power transmission (WPT). The power supply and load circuits will also be improved by WPT in additional to the coils. Simple circuitry in the WPT feeds a DC supply into an AC excitation. Two inductive coils are used in this converter circuit. Changing the two coils in the converter circuit to transmitter coils is a typical function of the WPT. It is also recommended that the receiver coil be improved. Thus, the three coils of the Wireless power technology system are formed

Keywords: *Wireless power transfer,* WiTricity,

1 Introduction

These days, magnetic resonance coupling of wireless power transfer technology is garnering a lot of attention, spanning from contactless battery charging of consumer goods to the power supply of cellular implants.

MRC-WPT (also known as) is a type of wireless power transmission that operates over short distances and at frequencies as low as a few hundred kilohertz. Long-range direct microwave radiation (at frequencies as high as GHz) is another type of wireless power transmission that operates over long distances and at frequencies as high as several GHz. Energy can be transferred wirelessly via non-radiative evanescent near fields in the strong coupling condition. At resonance, high-frequency power travels from the transmission or receiving end to the other, where it is eventually absorbed by the load, at a mid-range frequency many times greater than the physical size of either end.

When radial deviation occurs in wireless power, several approaches have been offered in the past. Expanded power delivery zones are possible in multiphase systems. Two transmitters cover a large area with high power transmission. Anti-offset capabilities can be improved by using a tight-strong connection in a cooperative working coupler. However, these solutions cannot improve transmission distance in the direction of the coil axis.

Reduced coil losses and longer transmission distances are two benefits of using superconductors. However, it is prohibitively expensive and has a limited audience at this time. Changing the power source's operating frequency or the loading effect on the transmitting and receiving coils can alter the transmission distance. Short lengths, where resonance frequencies splitting occur, boost performance. At this critical coupling threshold, the only thing limiting the maximum transmission distance is the disappearance of magnetic coupling.

Transmission range and power are maximized while efficiency is fairly maintained with three-coil wireless energy technology. Coupled mode is used to transfer power between two resonators utilizing the Time domain solution. Discussion of angular frequencies, mode couplings and quality factors gives two fundamental requirements for strong coupling. Next, the transmission efficiency and maximum load power are evaluated. Ultimately, the researchers established a 3 wireless power link that consists of 2 resonators and a device coil. At over transmission distances of 2.5 meters, the load power reached upto 120 W, according to the researchers. Between theoretical and measured values, there is a 2.5 percent discrepancy in magnitude.

Because of the development of electronic gadgets, wireless power transmission systems can be used for a wider range of purposes. Near-field power transfer using magnetic resonance coupling is becoming increasingly popular among researchers as a viable alternative to the antiquated wireless technologies of the mid-twentieth century.

The hunt for more effective and long-lasting power supply methods is, as a result, a key technology for implanted medical equipment. Now that we're in the twenty-first century, it's become clear that implanted medical equipment can safely and reliably be recharged using wireless charging. As a result, biomedical engineers are paying increasing attention to WPT technology.

The transmitter coil generates magnetic fluxes that are captured by the reception coil's induced voltage. Figure 1 shows the WPT system, which includes a DC power source, an inverter circuit, a transmittance/rectifier circuit, a load and a receiver circuit. Shifting currents can be generated by using an inverter to convert the DC power supply into an AC power supply. In the previous WPT experiments, practically all of the research focused on the design of the WPT system's coils when the system was optimized. The inverter circuit in this system is so intricate that it must be tuned in conjunction with the coil circuit.

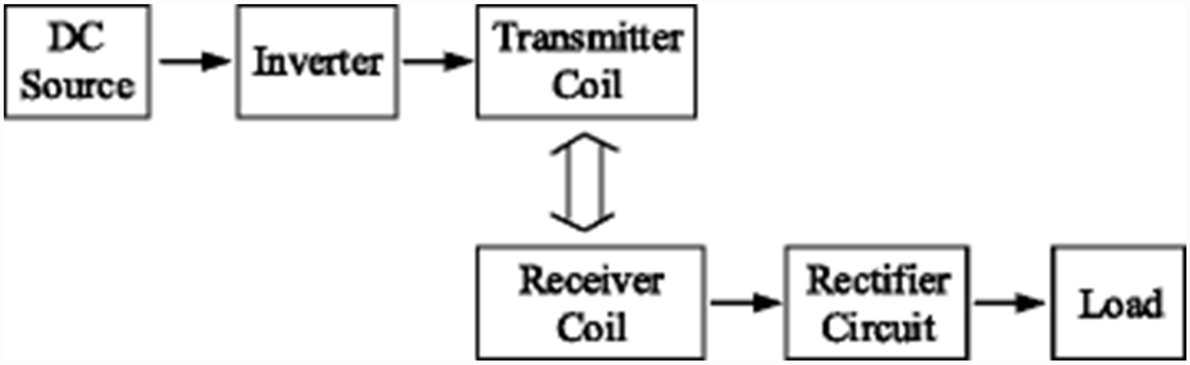


Fig: 1 Wireless power transfer system

2. Methods/experimental section

With this, the MRC-WPT system's axial transmission distance can be improved. MRC-WPT, which uses the non-radioactive near field to transmit over long distances of several kilometres at high power levels of kilowatts, is far safer and more stable than microwave transmission. Coupling coefficient between resonator and drive power can determine how much active load power can be generated. This is an electrical characteristic. If we wish to raise the load power, we need take into account the overall impact of the three elements above.

The resonator quality factor (Q = L/R) can be enhanced in two ways: (1) by raising the resistance to inductance ratio; and (2) by raising the frequency of the natural resonant frequency.

Copper tubing with a smooth single layer that is free of oxygen is an excellent material for resonators because it has high conductive qualities and can help to lessen the skin effect to a certain extent. The ratio of inductance and resistance can only be improved to a limited extent. For a higher quality factor, increasing resonance frequency is an effective method. As high as 13.56 MHz can be achieved using a quality factor of 1100~1500.

2.1 Convert circuit as feeding circuit

The WPT technology uses a convert circuit to convert the AC source that was obtained by stealing the DC source. Fig. 2 shows the feeding circuit connected in order to make simpler WPT system. There are four essential components in this circuit: a resistor R1, a DC power supply, inductors L1 and L2, and three capacitors C1, C2, and C3 with a bipolar junction transistor (BJT).

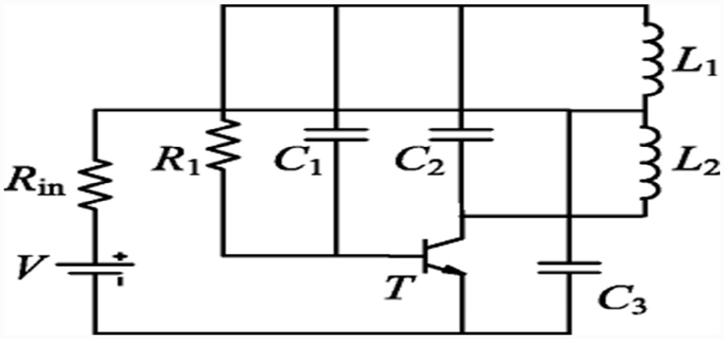


Fig: 2 **Simplified WPT system with feeder circuit**

Capacitors C2 and C3 helps to maintain stable voltage and current stability at the circuit's output, whereas, converting the circuit from DC to AC using R1 to restrict the amplitude of the BJT's input current was done by the BJT's power switch. Figures 3a and b illustrate the output voltage and current in L2 when the feeder circuit was excited by a DC voltage. The sinusoidal functions of voltage and current were evident from fig 3.

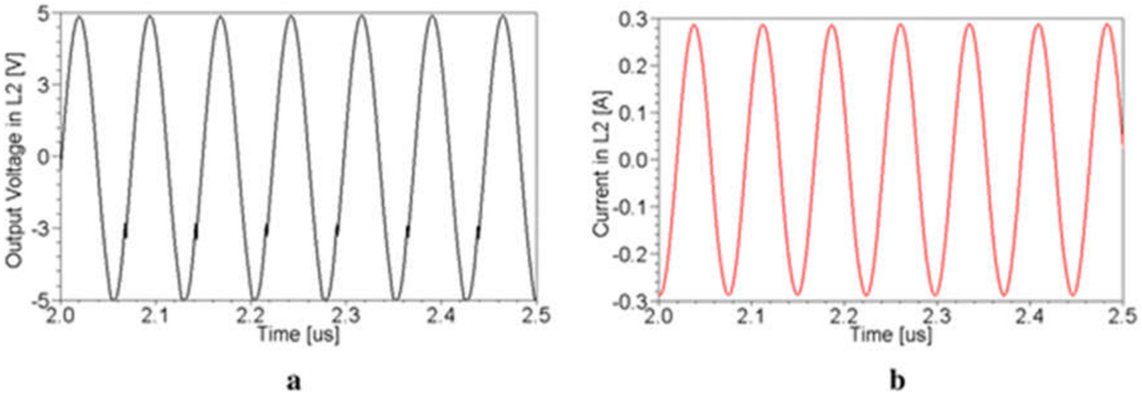


Fig. 3:-**The sine wave representing the output voltage and current of inductance *L*2**

There are three components that affect the feeding circuit's operating frequency: L1, C2, and L2. The frequency can be calculated by.

$$\mathrm{fo} = \frac{1}{2h\sqrt{(l1+l2)c2}} \qquad \text{---------} \ (1)$$

The test procedure begins with an examination of the converting circuit. The circuit's technical parameters are given in the table 1.

This circuit's frequency is 13.56 MHz when the values of capacitance and inductance are replaced. Figure 3 shows the current and voltage in L2. There is a noticeable change in the output voltage in L2 from the DC source, with a 5-V amplitude. In the WPT system, the shifting EM field generated by the current in L2 is a critical component.

Table 1. Converter circuit specifications

System Parameters	**System Parameter values**
V	5 V
$L1$	0.1 μH
$L2$	0.2 μH
$R1$	5.1 kΩ
$C3$	220 nF
$C1$	1 nF
$C2$	459 pF

3 Uniqueness of MRC-WPT using coupled mode theory

Fig. 2 depicts a basic layout of the magnetic resonance wireless power transfer system, which includes 3 sections which performs the operations like coupling, transforming, and transmitting. Inductive coupling is used to convert low voltage/high current to high voltage/low current on resonator a2, a1 for use in devices such as power supplies. EM resonant coupling between resonators leads at comparatively less transmitting loss and high impedance, when the system is tuned into a resonant state. Its resistance, capacitance, and voltage are referred to as (ra1,2), (ca1,2), (Ia1,2), and (Va1,2) correspondingly. Device coil-to-non-resonant source coupling is not considered here.

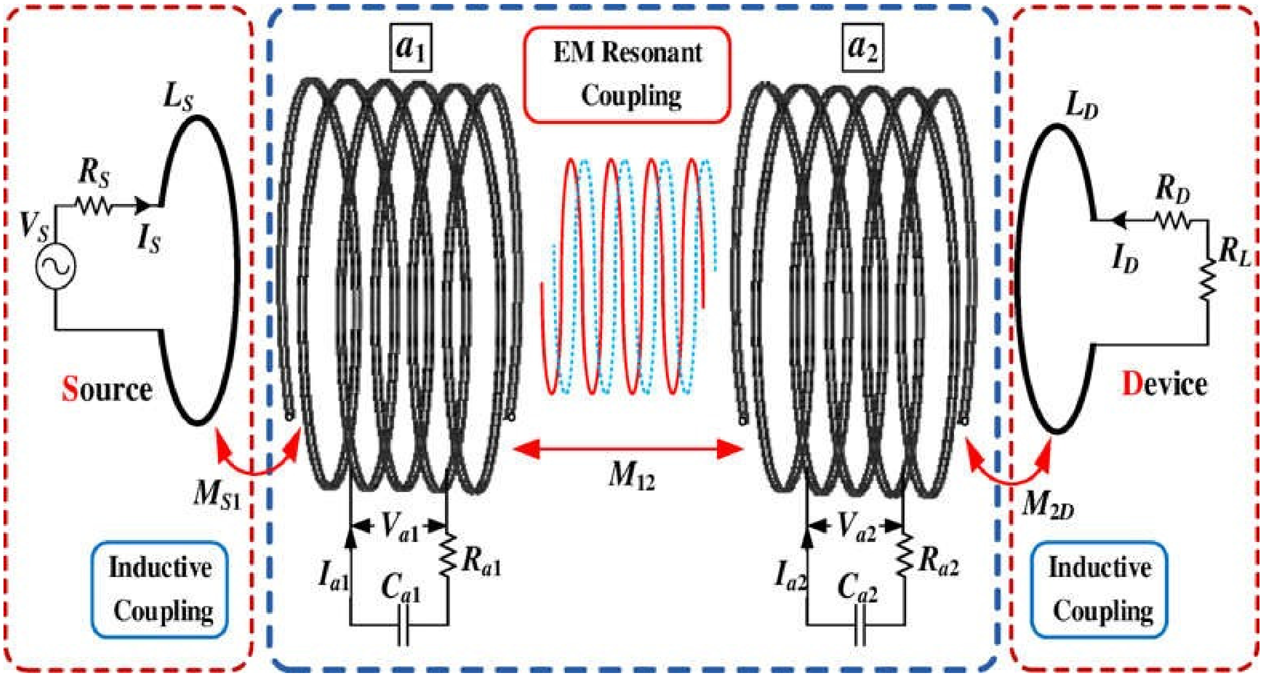
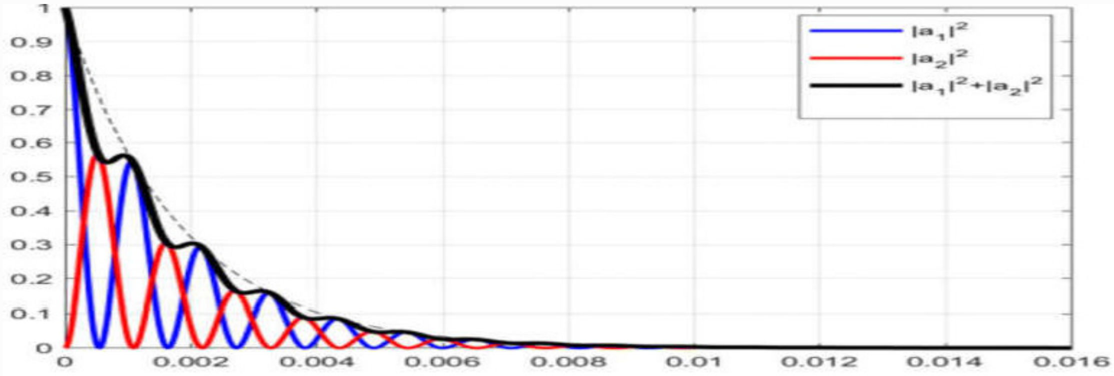


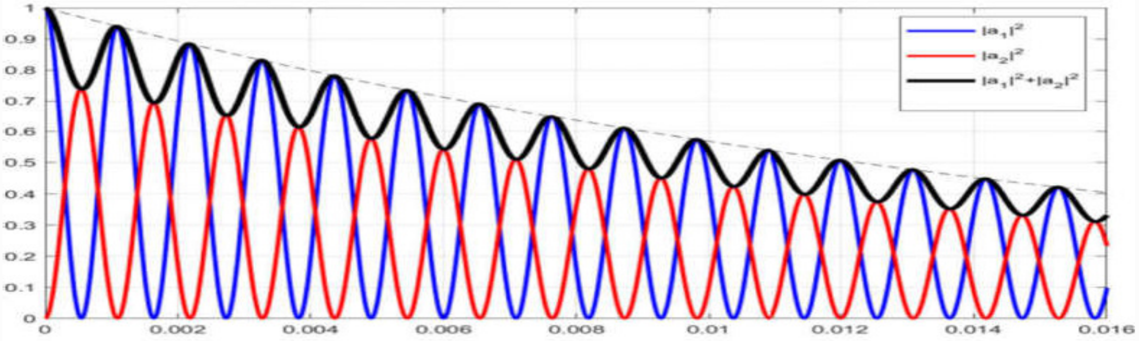
Fig. 4. An illustration of the coupled theory of the field-circuit

MRC-WPT system with a direct field circuit concept. An illustration of the coupled theory of the field-circuit is depicted in Figure 4. Inductive coupling connects the device and source coils to the resonant coils, while EM resonant coupling allows the resonant coils to transmit power. The energy coupling rate is denoted by the two mode coupling; the loss rate is denoted by the two quality factors. An energy transfer bridge between the device and the source must be formed by resonators with a high quality factor.

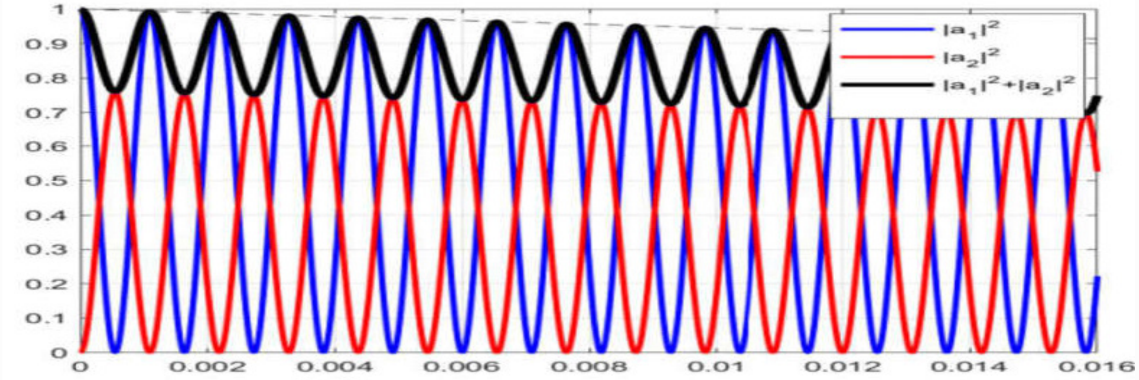
Fig.5 depicts the normalized energy exchange relationship between resonators, in which the energies of resonators 1, 2, and the overall system are represented by $|a_1|^2$, $|a_2|^2$ and $|a_1 + a_2|^2$. The overall energy decays exponentially if the quality factor (q) is present. Joule loss and radiation loss, both of which can be described as the absorption and radiation of Q values, are two of the most common causes of attenuation in linear systems. Even though there is almost 100 % energy exchange as demonstrated in Fig.5a with $\omega 2 = \omega 1$ and differently in coupling, it cannot keep sustaining and attenuating after numerous cycles. A few times their length separates the two resonators in a typical setup. Hence, the term "loose coupling mode" is used. This is the primary cause of the decrease in overall efficiency and transmission power seen in Fig. 3b when angular frequencies diverge substantially, which is referred to as the "weak coupling mode." Fig.5c shows that when both conditions are met, the system operates in what is referred to as a "tight coupling" or "strong mode" mode, in which the theoretical proportion of energy exchange approaches 100 %.



(a) loose coupling mode



(b) weak coupling mode



(c) strong and tight coupling mode

Fig 5. **Normalized energy exchange relationship between resonators**

4. Ideal Initial analysis

First, the feeding circuit as depicted in Fig. 2 is examined to determine how the wireless power transmission works. A BJT is kept in the amplifier area while various parameters in the feeding circuit are examined. An evaluation of capacitors C1 and C3 is conducted. Figure 6a shows the L2 current as a function of C1, whereas Figure 6b shows the L2 current as a function of C3.

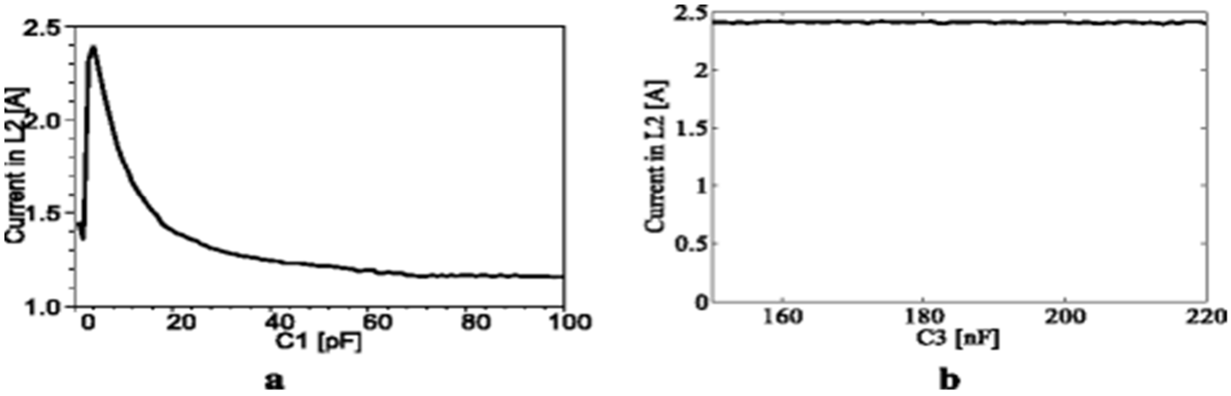


Fig. 6:-**Output current in *L*2 varied with *C*1 and *C*3**

L2's output current is seen in Fig. 6a to peak at roughly four pico farads (pF) with C1. Figure 6b shows that the output current in L2 is unaffected by the magnitude of the feeding circuit's capacitor (C3). We already know that the voltage gain of a BJT circuit is quite large.

As illustrated in Fig. 6, the parameter resistor (R1) in the feeding circuit has an effect on the output current in the inductor (L2). When resistor R1 is set to roughly 3 kOhm, the output current of inductor L2 reaches its maximum value.

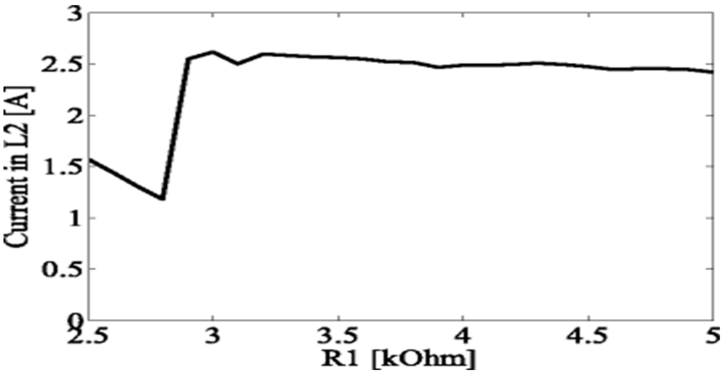


Fig. 6:- **Output current in inductor (*L*2) varied with resistance (*R*1)**

5. Optimization method

The model is analysed using a differential evolution algorithm (DE). It's quick to set up, simple to use, and lightning-fast in terms of computing. This algorithm uses two equations to generate possible solutions:

$vi=xr1+F(xr2-xr3)$, ----------------- *(1)*
$uj,i=\{ vj,i$if $r4\leq cr$ *or* $j=k$ ---------------*(2)*

$\{xj,i$, otherwise $j=1,2,3\ldots\ldots D$ ----*(3)*

where, *xr1*,xr2, and *xr3* denotes the solutions; v_i indicates the mutant vector; and u_i represents a candidate solution. Equations (4) and (3) are respectively, the mutation operation and crossover operation in DE.

The loudspeaker model in this study and the one used in the TEAM workshop problem 22 have many similarities, although the loudspeaker model in this research takes a much longer simulation time than earlier models because of its many constraints. As a result, the methods listed below can be used to address our issue.

First, we use the DE technique multiple times to attack the issue at hand. We employ random initialization for the first trial and integrate the best solution discovered in prior trials into the starting population in subsequent trials. Thus, DE is in a strong position for the next round of competition.

Second, solution revisiting occurs after an algorithm has reached global or local optimality. Everything can be stored in a binary space-partitioning structure by using this method. For us, saving simulation time outweighs any additional memory use that may be required by using this method.

We believe that with the help of these two methods, we can come up with a viable solution.6 Three-coil wireless

The wireless power transfer can be viewed as a three-coil system, as depicted in Fig. 7, as we mentioned in the feeding circuit. Combining the L1 and L2 coils into a single transmitter coil yields L3, this serves as a reception coil. The mutual inductance between the two coils is referred to as M.

Coil strength is inversely proportional to its current, according to electromagnetic theory, which can be expressed as (4).

$H(x,r)=I.r^2/2\sqrt{}(r^2+x^2)^2$------------ (4)

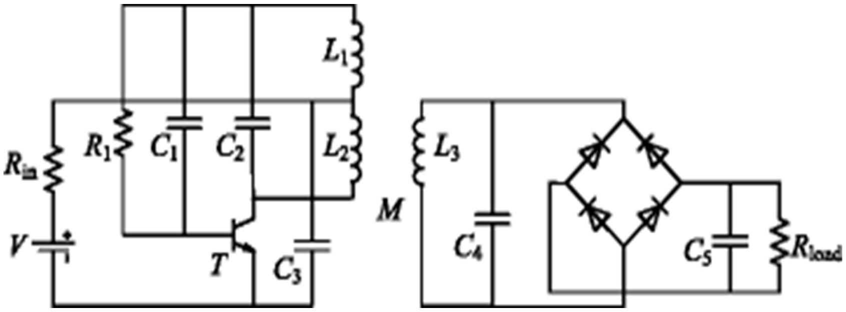


Fig. 7 wireless power transfer system with the feeding circuit and the load circuit

Where *r* indicates the radius of the circular coil. From the above equation, it can be seen that *H* can be maximized when $r=2–\sqrt{}x$r=2x. Therefore, the outer diameter of the transmitter coil can be chosen from *DT_out*=22–√*d*DT_out=22d where *d* represents the power transfer distance.

The size of the receiver coil must be decided before the rest of the design can proceed. The WPT system is thought to be intended for use in implanted medical devices in this study. The receiver coil should have the smallest possible diameter. The chosen frequency is 13.56 MHz. The WPT system depicted in Fig. 7 has been optimized as an integrated system based on the aforesaid analysis.

During optimization the optimization objective function is the power transfer efficiency which is expressed as:

$\eta=P_{load}/P_{source}=I^2_{receiver}R_{load}/U_{source}I_{transmitter}$------------------------(5)

subject to $D\,T_{out}=2\sqrt{2}d$..(6)

where P_{load} and P_{source} denotes the power in the load and the source respectively, $I_{recevier}$ and $I_{transmitter}$ indicates the currents in the receiver coil and the transmitter coil, respectively. The diameter of the transmitter coil and the power transmission distance are the constraints.

6. Conclusion

Implantable medical devices stand to benefit greatly from wireless power transfer technologies. The optimization design for the WPT system incorporates not only the coil system but also the influence of the power supply, unlike the earlier experiments in this study. The WPT system uses a simple feeding circuit to transform a DC source into an AC source in order to simplify it. Firstly, the feeding circuit's properties are examined and their link to each other is established in this work. The WPT system can then be optimized and designed using the optimization process. The perfect findings suggest that this strategy is capable of obtaining the WPT system's optimal performance.

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