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Non Radiative Wireless Power Transfer

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ABSTRACT

The demand for wireless products is growing due to non-usage of expensive current carrying wires. In the field of consumer electronics there is a need for wireless power transfer in applications like charging of electric vehicles and direct wireless electrical appliances. This paper outlines a recent works on magneto-inductive method of wireless power transfer. Also this review covers wireless power transfer with improved efficiency using power distribution and impedance matching method. From the analysis it is observed that proposed method based on impedance admittance converter performs well in term of efficiency.

KEYWORDS: Power Division, Wireless Power Transfer, Magnetic Resonance Coupling, Multi-Receiver and Repeaters.

INTRODUCTION

The history of wireless power transfer goes back in to the 20th century when Tesla experimented power transfer by using tuned circuit as shown in Fig 1. With this experiment, Tesla is entitled to discovery of:

1. The idea of inductive coupling between the driving and the working circuits.
2. The importance of tuning both circuits, that is, the idea of an 'oscillation transformer'.
3. The idea of a capacitance loaded open secondary circuit."

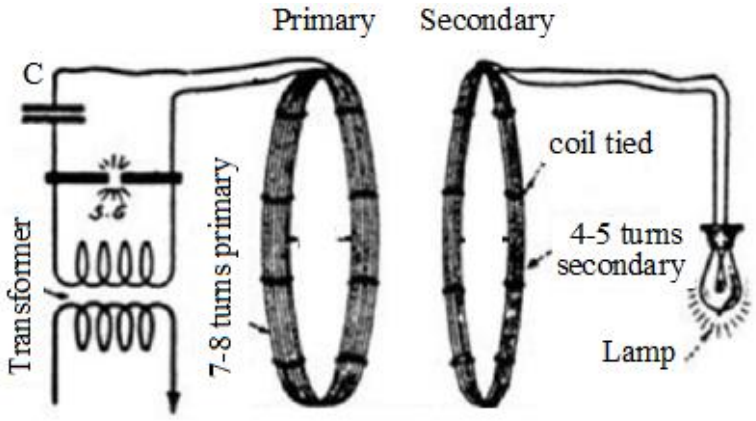

Fig. 1: Tesla's experiments on Wireless Power Transfer

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Wireless Power is usually famous by several terms, such as Inductive Power Transfer (IPT), Inductive Coupling (IC) and Resonant Power Transfer (RPT). All these terms basically describe a similar elementary method – the transmission of energy from an influence supply to associate electrical load. The basics of wireless power involve the transmission of energy from a transmitter to a receiver via associate periodical flux. Resonant power transmission could be special, however wide used methodology of inductive power transmission is restricted by similar constraints of magnetic field emissions and potency.

Many alternative ways, other than power distribution approach, are attempted to solve the efficiency problem in the area of wireless power transfer and it has been shown that efficiency can be increased in small implant [14]. But efficiency can be maintained when the distance between transmitter and receiver is increased [4]. Some work has been proposed to harvest the RF energy from TV tower and transfer the same wirelessly. Experimentally it has been proved that using RF energy mode the transmission distance can be increased sufficiently [6]. A new method has explored a new way of multi-receiver system [15,3,11] but the efficient power distribution is not properly planned. Since, there are a lot of constraints to be analyzed for efficient power transmission, the repeaters are being using along with the multi-receiver systems, so the repeaters enhance the received signal and transmits again with the required frequency so as to ensure the long distance transmission. The wireless power transfer system is being analyzed by the equivalent circuit [17,18,19,2,13] but the equations for system with a lot of antennas mentioned in [20] is highly rigorous to be analyzed at this stage, So, band-pass filter representations is being taken into consideration as mentioned in [8,5]

The equations are even suitable for taking repeaters into consideration, which actually increases the efficiency of the system. The efficiency can also be increased by taking the below mentioned methods:

(1) Adding and adjusting a 3rd coil to boost the transfer efficiency [9,10].

(2) Frequency following methodology [21,22].

(3) Resistance matching circuit [17].

Wireless Power Transfer using the magnetically coupled resonators method has been widely used for medical specialty and client physical science applications. However, a typical analysis of wireless power transfer has centered on customary operation conditions and isn't applicable for sensible applications.

In a multiple-receiver wireless power transfer system with repeaters, most of the energy is being transmitted with minimal losses in the transmission. The system has a specification that the receiver is being checked and only the required quantity of power is being transmitted, so energy can be conserved in the long run.

This paper is organized as follows. The methodology for resistance matching and manageable power division is proposed in section 2. The equations derived are being analyzed for two numbers of receivers and repeaters. Section 3. proposed another approach namely impedance matching method for WPT. To validate the proposed method, the simulations were being performed and presented in section 4 followed by conclusion in section 5.

Wpt Using Two-Receivers Two-Repeaters:

A two receiver wireless power transfer system is shown in Fig. 2. Both the receivers, Rx1 and Rx2, are coupled with one transmitter, Tx, through transmitting and receiving antennas. The coupling in between the Rx1 and Tx is $\mathbb{C}_{12}$, whereas the coupling in between the Rx2 and Tx is $\mathbb{C}_{13}$,. It is assumed that there is no cross coupling between two receivers. Both the couplings are expressed in terms of impedance-admittance converter [7].

$$\mathbb{C}_{12} = \frac{I_{12}}{\omega_0\sqrt{L_1 L_2}} \qquad \mathbb{C}_{13} = \frac{I_{13}}{\omega_0\sqrt{L_1 3}} \tag{1}$$

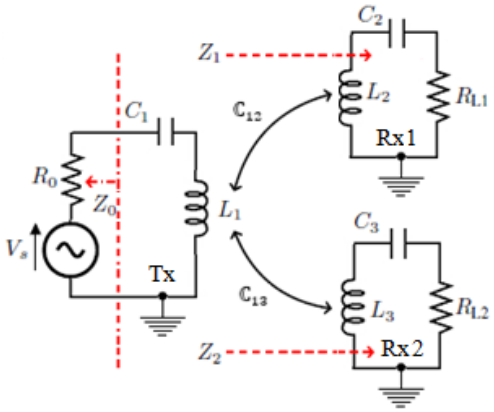

Fig. 2: A two receiver system

where I_{12} and I_{13} are characteristic impedance of the impedance-admittance converter (IAC). An IAC converter converts the impedance into admittance as shown in Fig. 3, where the impedance Z_{in} is inversely proportional to the load impedance Z_L [12].

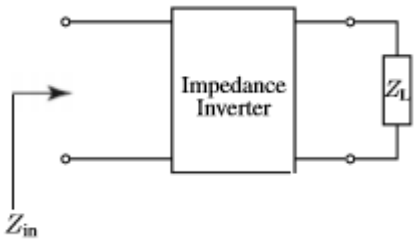

Fig. 3: Impedance-admittance converter

In other words, a normalized input impedance is equals the normalized load admittance.

$$Z_{in} = \frac{I^2}{Z_L} \tag{2}$$

In this work, the IAC is used as a coupling between two antennas. Apart from the couplings shown in equation (1), there exists many external couplings which divide the resistance of resonator's terminal by the reactance of the resonator [7,8].

$$\mathbb{C}_{01} = \frac{R_0}{\omega_0 L_1} \qquad \mathbb{C}_{23,1} = \frac{R_{L_1}}{\omega_0 L_2} \qquad \mathbb{C}_{23,2} = \frac{R_{L_{12}}}{\omega_0 L_3} \tag{3}$$

If all the antennas as well as the power sources are operating at akin resonant frequencies then the impedances of all the antennas can be omitted and the impedances indicated in the Fig. 1 can be expressed using equations (1), (2) and (3) as

$$Z_0 = R_0 = \mathbb{C}_{01}\omega_0 L_1$$
$$Z_1 = \frac{{I_{12}}^2}{R_{L_1}} = \frac{{\mathbb{C}_{12}}^2}{\mathbb{C}_{23,1}}\omega_0 L_1$$
$$Z_2 = \frac{{I_{13}}^2}{R_{L_2}} = \frac{{\mathbb{C}_{13}}^2}{\mathbb{C}_{23,2}}\omega_0 L_1 \tag{4}$$

where Z_1 and Z_2 are the impedances from transmitter to the Rx1 and Rx2 respectively. For analysis purpose, Fig. 1 is represented in Fig. 4 which comprises mutual inductance terms also.

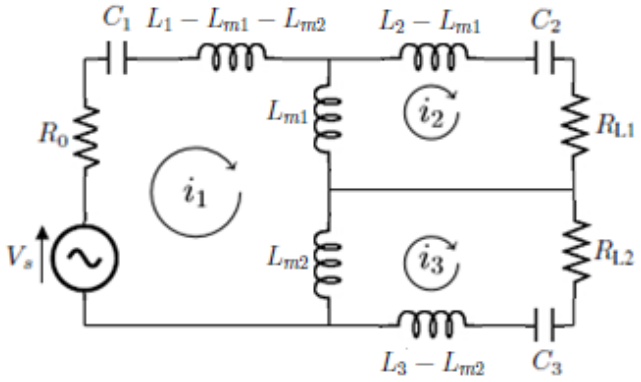

Fig. 4: Equivalent circuit of two receiver system

From Fig. 3, KVL equations can be written as:

$$V_s = i_1 R_0 - i_2 j\omega_0 L_{m1} - i_3 j\omega_0 L_{m2}$$
$$0 = i_2 R_{L_1} - i_1 j\omega_0 L_{m1}$$
$$0 = i_3 R_{L_2} - i_1 j\omega_0 L_{m1} \tag{5}$$

Solving above current equations and substituting mutual inductance and the load impedance from equation (1) and equation (3), the following equation can be obtained:

$$\frac{V_s}{i_1} = \mathbb{C}_{01}\omega_0 L_1 + \frac{{\mathbb{C}_{12}}^2}{\mathbb{C}_{23,1}}\omega_0 L_1 + \frac{{\mathbb{C}_{13}}^2}{\mathbb{C}_{23,2}}\omega_0 L_1 \tag{6}$$

First, second and third terms of equation (6) representsZ_0, Z_1 and Z_2 respectively. According to the equation (6) the Fig. 1 can be further redrawn in Fig. 5 as:

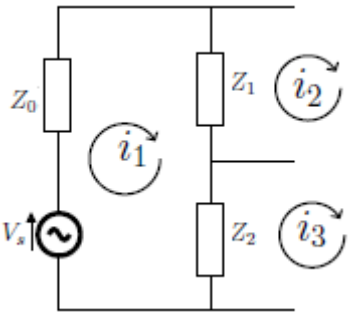

Fig. 5: Simplified two receiver systems.

By applying maximum power transfer theorem on Fig. 4 impedance matching is attained provided the following conditions to be satisfied.

$$Z_0 = Z_1 + Z_2$$

$$\mathbb{C}_{01} = \frac{\mathbb{C}_{12}{}^2}{\mathbb{C}_{23,1}} + \frac{\mathbb{C}_{13}{}^2}{\mathbb{C}_{23,2}} \tag{7}$$

As the same current is flowing through Z_1 and Z_2, power division ratio is given as:

$$Z_1 : Z_2$$

$$\frac{\mathbb{C}_{12}{}^2}{\mathbb{C}_{23,1}} : \frac{\mathbb{C}_{13}{}^2}{\mathbb{C}_{23,2}} \tag{8}$$

Now if the IAC is implanted between receiver and load, new external couplings can be defined as [19]:

$$\mathbb{C}_{23,1} = \frac{I_{23,1}{}^2/R_{L_1}}{\omega_0 L_2} \tag{9a}$$

$$\mathbb{C}_{23,2} = \frac{I_{23,2}{}^2/R_{L_2}}{\omega_0 L_3} \tag{9b}$$

Where $I_{23,1}$and $I_{23,2}$are the characteristic impedances of the inverters to be employed in Rx1 and Rx2 respectively.

Wpt Using Impedance Matching:

Although wireless power transfer via resonance coupling is in a position to transmit power efficiently as compared to inductive technique, but the gap for transmission continues is restricted to a couple of meters. This restriction is extended by using more number of repeater antennas but at the cost of complicated system which leads to a difficult solution to the derived equation pertaining to more number of repeaters. Band-pass filter style is easy and seems to be straight forward; however it is not simple in real time implementation. This paper presented a power division technique in combination with impedance matching technique with repeaters. The technique combines the benefits of each existing equivalent circuit and band-pass filter circuits. The resultant circuit is shown in Fig. 5. Where the impedance matching is performed by modifying resistivity Z_4. Hence,

$$Z_4 = Z_3 \tag{10}$$

In order to satisfy (10), the required I_{34} is to be calculated. Using (2) and Fig. 6:

$$Z_1 = R_0$$

$$Z_2 = \frac{I_{12}{}^2}{Z_1}$$

$$Z_3 = \frac{I_{23}{}^2}{Z_2} \tag{11}$$

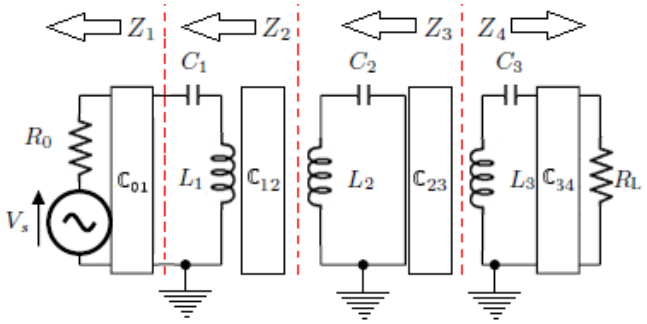

Fig. 6: Wireless Power Transfer with three repeaters.

The system is in resonance and thus the impedance of the antenna is neglected. From equations (1), (3) and (10) the required $\mathbb{C}_{34}$ is derived:

$$\mathbb{C}_{34} = \mathbb{C}_{01} \times \frac{\mathbb{C}_{23}{}^2}{\mathbb{C}_{12}{}^2} \tag{12}$$

An IAC can be inserted in the box indicated by $\mathbb{C}_{34}$ in Fig. 5 to satisfy equation (12). All the equations derived are confined to two receivers and two repeater system. Based on same analogy the all obtained equations can be extended for multi-receivers and multi-repeater system. If n number of receivers and $m-2$ number of repeaters are anticipated then external coupling can be expressed as

$$\mathbb{C}_{01} = \frac{R_0}{\omega_0 L_1} = \sum_{j=1}^{n} \mathbb{C}_{01,j} \tag{13}$$

From equation (8), power received by individual receiver is:

$$p_j|_{j=1\ to\ n} = \frac{\mathbb{C}_{01,j}}{\mathbb{C}_{01}} \times 100\% \tag{14}$$

and the external coupling for individual receiver is:

$$\mathbb{C}_{m,m+1,j} = \frac{\left(\mathbb{C}_{m,m+1,j}\right)^2 / R_{Lj}}{\omega_0 L_{mj}} \tag{15}$$

Simulation Result:

This section presents the simulation results to validate the proposed method: power distribution and impedance matching approach for WPT. For simplifying the solution cross coupling in between the receivers and repeaters and internal resistances of the antennas are considered to be zero. Basic components used in circuit are inductors, capacitors and resistors. The elementary values these components are listed in Table I.

Table I: Simulation Parameters

Components	Value
$L_1 = L_{21} = L_{31} = L_{22}$	$10\mu H$
$C_1 = C_{21} = C_{31} = C_{22}$	$13.9\ pF$
$R_0 = R_{L_1} = R_{L_2}$	50Ω
$\mathbb{C}_{12,1} = \mathbb{C}_{23,1}$	0.05
f	$13.56MHz$
$\mathbb{C}_{12,2}$	0.1

Initially the ratio of power received by load R_L, p_1/p_2 is set to 1. By using the above components values the equation (13) and equation (15) yield the numerical results which are listed in Table II.

Table II: Obtained Numerical Results

Parameters	Value
$\mathbb{C}_{01}$	0.06
$\mathbb{C}_{01,1} = \mathbb{C}_{01,2} = \mathbb{C}_{34,1}$	0.03
$\mathbb{C}_{23,2}$	0.3413
$I_{34,1}$	35 Ω
$I_{23,2}$	120 Ω

Figure 7 and Fig. 8 show the transmission power efficiency curve with respect to frequency with and without impedance matching respectively. In Fig. 7, reflection ratio η_{11} is around 35% before impedance matching which is made zero with impedance matching, as shown in Fig. 8. Figure 8 also depicted that, due to impedance matching transmission efficiencies η_{21} and η_{31} are nearly equal, i.e., power received by both the receiver is equal. It is noted that, in both the cases, simulation is performed with equal power distribution.

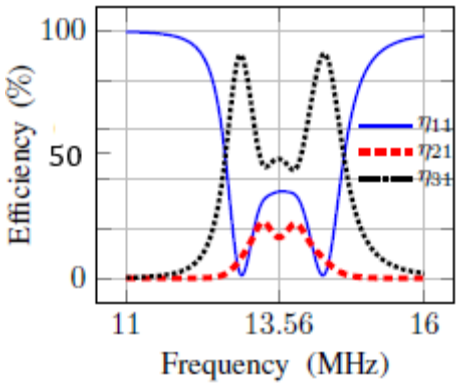

Fig. 7: Efficiency of equal power distribution method with impedance mismatching.

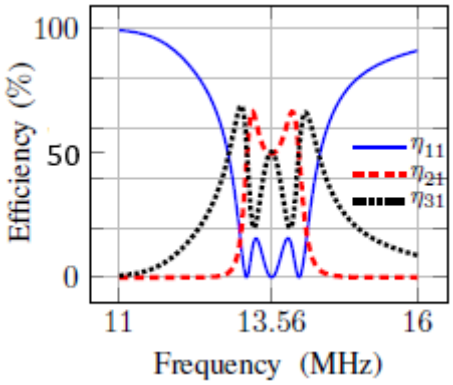

Fig. 8: Efficiency of equal power distribution method with impedance matching.

Figure 9 show the efficiency curves by employing power distribution in the ratio of 7.5:3.5 and characteristics impedance of invertor are $I_{23,1} = 42\ \Omega$ and $I_{23,2} = 156\ \Omega$ respectively. This result is similar to Fig. 8 with regard to reflection ratio. In this result also reflection ratio is made zero but transmission efficiencies η_{21} and η_{31} are 75% and 35% respectively.

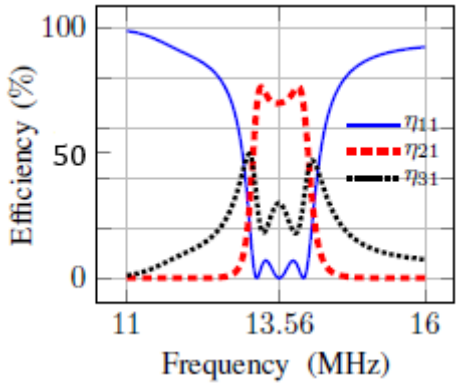

Fig. 9: Efficiency of 7:3 power distribution methods with impedance matching.

Conclusion:

A critical review on non radiative wireless power transfer using power distribution and impedance matching technique using impedance-admittance converter is presented in this paper. Initially a two receiver system was taken into consideration for simulation to analyze the efficiency issue on three different parameters. Further this technique is expanded analytically, for multi-receiver multi-transmitter system. Internal and external couplings are derived and an impedance-admittance converter is inserted in between receiver and load resistor. Through results, it is shown that the power distributive method with perfect impedance matching using IAC improved power efficiency and reduced reflection ratio to almost nil. The distance between transmitter and receiver is required to increase which may be taken as a future work.

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