Magnetic Field Tuning and Control for Wireless Power Transfer Using Inductive Tuning Plunger and Conical Coils

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***Abstract* – Multiple input wireless power transfer (WPT) system has drawn increased interests recently due to its enhancing ability to the efficiency of power transfer. In most cases, it uses a number of transmitters to deliver the wireless power efficiently. These transmitters can be massively used to harvest energy as much as possible and therefore reduces signal and link losses. Powering many devices using massive number of transmitters allows cross coupling occurring. In particular, signals or magnetic fields are mutually induced between transmitters. The goal of this work is to provide an efficient link for wireless power transfer and compensate for the impact of cross coupling. A tuned technique is proposed to optimize the transmit signal for a conical coil transmitter. The proposed scheme efficiently delivers the wireless power by controlling the beam of the magnetic flux. By using this new technique, we then increase the main loop gain of the wireless power signal and reduce the back gain for the receiver in such region. The results are compared to the conical coil. In addition, results illustrate that a tuned transmitter controls the magnetic flux pattern for efficient wireless power transfer.**

Keywords—wireless power transfer, coil design, magnetic field focusing

I. INTRODUCTION

Inductive coupling (IC) based transmissions are well known in wireless power transfer systems. For medical applications, wireless power transfer presents more challenge with respect to near field communication systems involving magnetic fields. The IC based power transfer is very efficient for applications within a short range due to lower transmitted power [1]. To obtain an efficient WPT yield, important features such as alignment between transceivers, sufficient delivered power, magnetic field pattern, and distance between transceivers need to be optimised [2]. Many attempts have been done to extend the inductive coupling between transceivers in particular systems with multiple transmitters [3], [4], [5], [6]. Although some of them [5] and [6] use multiple transmitters for different aspects of IC based transmission, they suggests the use of multiple transmitter coils to improve alignments. In particular, [6] suggests use of multi-dimensional wireless power transfer system with six coils in hexagonal deployed. This enables a multi directional magnetic field resulting from the transmitter. The six coils are connected together in parallel resulting in one transmitter shape. This is unlike the other researchers [3], [4], and [5] where transmitters work separately. These results do not consider the influence of multiple transmitters on each other. Using massive number of antennas at base stations (BS) in cellular networks requires a high efficiency to serve a large number of consumers in Heterogeneous networks [7], [8], [9]. Such a network is identified in fifth-generation (5G) where users need to harvest energy to reduce the uplink path loss [7], [10]. Recently, there is a complementary relation between wireless power transfer and Heterogeneous networks. As [11] and [12] show, base stations in cellular networks can be equipped with WPT system to charge users device. Wireless power transfer system has been integrated with sensor networks in [12] to understand their association. Their problem was to maximize the delivered power and minimize the number of active sources at the same time. On the other hand, due to the use of large number of transmitters, power consumption becomes another problem that need to be considered [10]. In [13], [14] researches, beam forming have been studied and used for reduce the power consumption. All the above researches have shown reasonable success in using multiple transmitters to increase the efficiency of power transfer systems. Nevertheless, the use of one tuned transmitter rather than multiple transmitters has not been considered for wireless power transfer systems. Therefore, in this paper we propose the design of the tuned transmitter coil for forming the magnetic field pattern and therefore improve efficiency. Previously, we have designed and studied a conical shaped transmitter in [15] and [16] for shaping the magnetic field pattern. Besides, we have shown how to obtain a directive magnetic flux and increase the distance of WPT. This paper extends the power transfer distance of earlier works and also demonstrates more directive magnetic flux values of the conical coil by using a second circular coil connected in parallel with the conical coil. The magnetic tuned transmitter mechanism is a newly efficient control design. This design consists of a small circular coil moving along the axis inside the conical coil, which interacts as one wireless power source. The main advantage of this magnetic field pattern control is that it increases the wireless power transfer with more stability.

The rest of this paper is summarized as follows. Section II introduces the transmitter design. Section III formulates the magnetic field pattern of all cases and presents the plotted pattern. Finally, we conclude the paper in Section IV.

II. CONICAL COIL DESIGN

A. Description of the Design

In this work, we utilize one conical transmitter equipped with circular coil to form the tuned conical transmitter and one circular coil receiver (see Fig. 1). Each coil of the transmitter with inductance L is considered as one resonant circuit, which includes also one capacitor with capacitance C and an internal resistor of resistance R. The secondary coil of the transmitter is presented to determine the values and shapes of electromagnetic field patterns each time it is tuned.

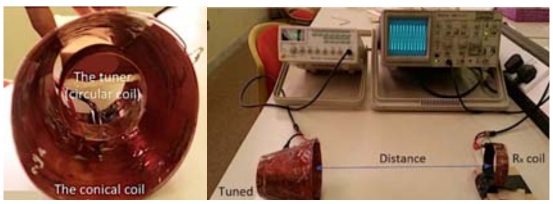
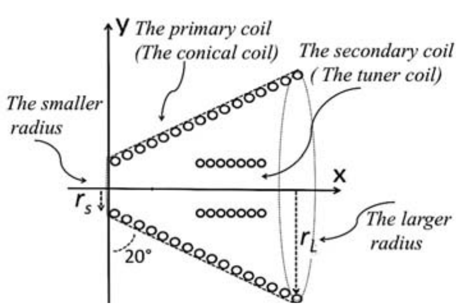
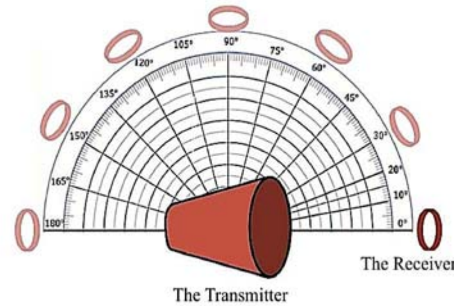


Fig. 1. Pictorial view of conical coils

The model of the conical inductor has inclination angle of 20°. Experiments and the results returned by polar plots were compared with the magnetic field patterns from different cases. By the design, we aim to form the radiation pattern of the conical coil as function of its tuned coil, and therefore extend the range of the inductive power transfer wirelessly. Figure 1, shows the pictorial view of the tuned conical coil structure. In Figure 2(a) the geometrical and physical parameters of the design with the tuned coil are introduced. The conical scheme is wound in a concentrated manner. The number of 79 turns, inclination angles of 20° and their radius (large radius equals to 5cm and small radius equals to 3cm) determines the shape of the conical. The circular coil plunger, which acts as a tuner has 8 turns and radius, equals to 2.5cm. It moves inside the conical transmitter. Table I lists the calculated inductance for the introduced coils. Note that the radius of the circular coil is smaller than the smallest radius of the conical by 5mm. In this way, the circular plunger can move along the central line inside the cone freely. The receiver has 16 turns and its radius equals to 2.5cm. Transceivers are designed to resonate at a frequency of about 1.5MHz. All the coils were wound manually. Therefore small errors are predictable.



(a) parameters



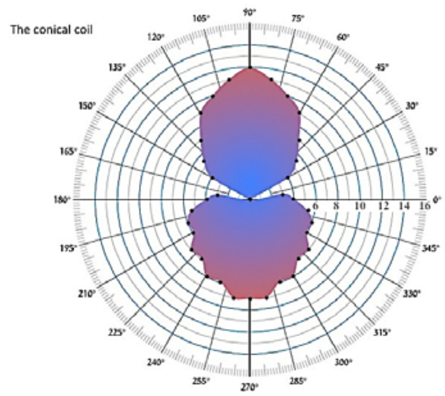
(b) location of the receiver

Fig. 2. Geometry and physical parameters of tuned conical coil

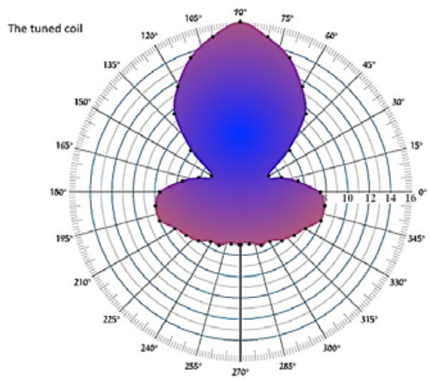
III. SIMULATION AND MEASUREMENTS

We have implemented six cases in this paper. The practical results were compared with simulations. The relationship between the position of the receiver and radiation pattern of the transmitters are introduced. To verify the design results, six experiments were conducted. In all six cases, the input voltage is set to 20volts at the transmitter. A circular coil resonating at the same frequency receives the obtained magnetic flux. The receiver is moved along a semicircular arc above the tuned conical coil as shown in Figures 2(b). Then the radiation pattern is recorded at the same radius. To normalize the results the distance at which the received voltage is 1V is recorded. Figure 4 shows the basic structure of the tuned conical coil transmitter. The larger radius is rL and the smaller radius is rS. The small radius is set at 3cm and the larger radius is set at 5cm. It should be noted that the small and larger radius are flexible [15] and depends on its application use. The induced flux pattern between the receiving coil and the tuned conical coil is recorded along the dome. The measured results of the non-tuned conical coil (conical transmitter without the tuner connection) is shown in Figure 3(a). From Figures 3(b) to 3(f), the magnetic field from the tuned conical coil is better improved. The back lobe of the conical coil have been modified and reduced.

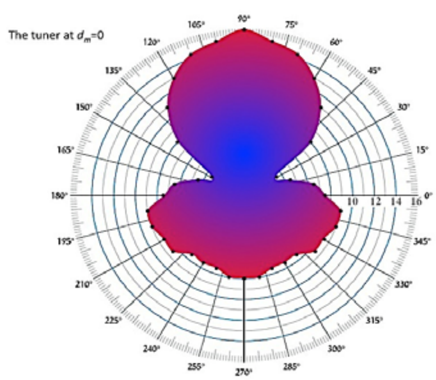
This achievement is very important to biomedical implantable devices such as retinal implants due to its ability to increase the main beam of the power delivered to the receiver. It also covers the area where for example an unpredictable capsule can move. In this manner, the tuner conical transmitter must be carefully designed so that it can satisfy the desired requirements. Among that, the delivered power is sufficient and stable, irrespective of the applications used.



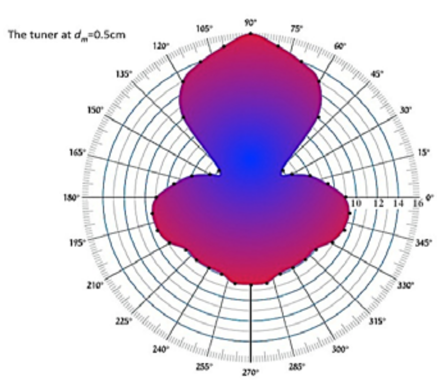
(a) conical coil



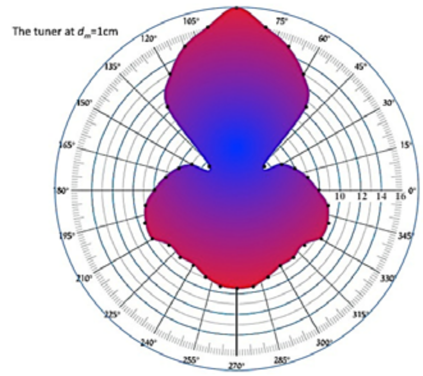
(b) tuner coil inside at the edge



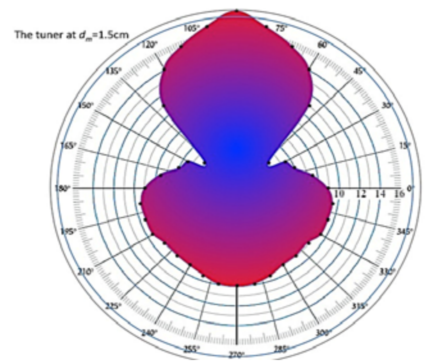
(c) tuner coil at dm=0cm



(d) tuner coil at dm=0.5cm



(e) tuner coil at dm=1cm



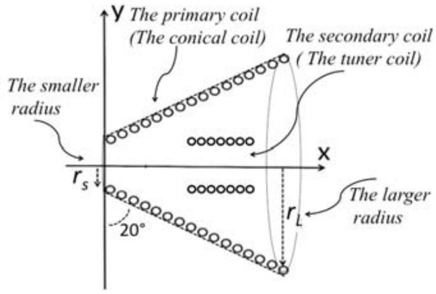
(f) tuner coil at dm=1.5cm

Fig. 3. Magnetic field patterns of Tuned conical coil

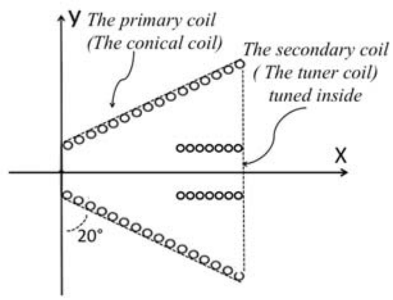
From Figures 3(a) to (f), the tuned conical coil however offers better-focused flux distribution as the tuner set on the edge of the larger radius. At the same case, the main and back lobes are controllably better. The beam width of the main lobe and back lobe in the case where the distance dm=0 has more power and wider than the main lobe of the other cases. No voltage drops are recorded at the transmitter sides for all cases.

Overall, the tuned conical coil transmitter provides better controllable flux when compared with conical coil. Fig. 4(a) to 4(d) shows the tuned cases of the tuner coil surrounded by the conical coil.

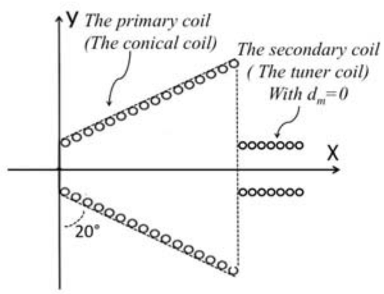
The large number of turns of conical coil yields non-uniform magnetic field along with the x-axis. We summarize the effect of the tuner movements in 5 steps of distance, the edge, dm=0 , dm=0.5cm, dm=1cm and dm=1.5cm from the conical.



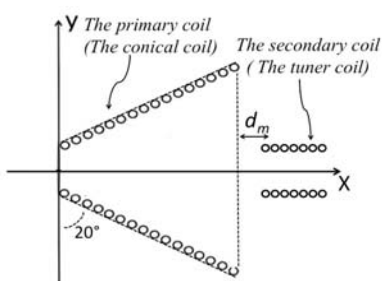
(a) the tuner coil inside



(b) the tuner coil at inner edge



(c) the tuner coil at outer edge



(d) the tuner coil at dm

Fig. 4. Tuner movements along the x-axis of the Conical coil

The ideal position value of the tuner coil is shown in Figure 3(c) for dm=0. It provides the comparison for different dm distance of the tuner coil movements. We observe that the better case is the highest at the edge since it has the lowest back beam. The best performance efficiency of wireless power transfer is with increasing the dm distance. In addition, the performance of the side beam at dm=0.5cm is close to that at dm=1cm and dm=1.5cm.

IV. CONCLUSIONS

In this paper we have proposed and implemented an innovative wireless power transfer system in which a movable plunger is used to shape and control the created magnetic field. Introduction of the plunger not only increases the transmission distance but also the beamwidth of the magnetic field. We have also shown that the use of a moving magnetic plunger reduces the back-firing of transmitters to within reasonable extends. This effect is essential when wireless power need to be focused at a receiver and ensures optimum power is received. In medical application back lobes are essentially not suitable. This design could be optimized for such applications.

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