Tunable Open ended Planar Spiral Coil for Wireless Power Transmission

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***Abstract*—A novel wireless power transmission (WPT) system with adaptive frequency tuning and a novel primary coil is presented. The primary transmitting coil is an open-ended single conductor spiral coil, where the traditional inductive resonator would include a secondary ground conductor. In addition, an Open-ended Spiral Coil (OSC) tuning technique has been applied to adjust the resonance frequency of the transmitting resonator to enhance the efficiency of the WPT system. The tuning method is found to improve the output DC voltage 60 percent after tuning the resonance frequency in nominal distance from 2cm up to 20cm with an excitation voltage of 20V at 13.54 MHz.**

I. Introduction

Interest in Wireless Power Transmission (WPT) has been increasing in recent years because of its convienience and potential to eliminate the complexity and cost involved in direct cabling. WPT systems can be divided to two major categories: long and short range power transmission. In long range transmission, receivers are located in the vicinity of the transmitting coil. In short range transmission inductive coupling, capacitive coupling, and resonant inductive coupling are prominent methods [1][2]. For resonant inductive coupling a transmitter (Tx) and receiver (Rx) coil are resonant at the excitation frequency. The resonant based WPT structure demonstrates relatively high efficiency compared to other methods. However, this method is susceptibile to distance or angle variation between the coils. Therefore, tuneability is desirable for efficiency to be maintained [3].

Conventional inductive WPT uses coils with a return path ground wire, which imposes wiring complexity and cost in Tx side. Using a new method similar to the dipole antenna theory, a λ/2 long open-ended wire that acts as a non-radiating-resonator is fed with a single signal line. The resonator structure is similar to the use of an end-fire helix resonator in WPT [5], [6]. Since there is no "actual ground" in the system conventional methods of variable tuning and matching the transmitter coil do not work and must be modified.

In this paper we propose a WPT system utilizing an open ended spiral transmission coil with tuning operating at 13.54 MHz. it will be shown that, the tunability increases the DC output voltage better than 60% in short and approximately 50% in long distances across a load resistance of 10 kΩ.

II. Theory of Operation and Simulation

OSC transmitter can be described as a half -wavelength resonator which is partially shortened by a parallel capacitor used for tuning. Standing waves are generated on the resonator because current is reflected at the open end, where it is constrained to be zero.

The length of the resonator is related to the operational frequency according to

$$\frac{\lambda}{2} = \frac{c}{f_r \times 2 \times \sqrt{\varepsilon_{eff}}} \quad (1)$$

where ε_{eff}, is the effective permittivity, c and f_r are the speed of light and the resonance frequency, respectively. Fig. 1 shows the schematic for the transmitter measurement and the lumped element model for the WPT system with a single wire open ended adjustable inductor.

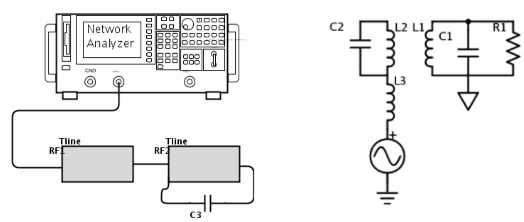


Fig. 1. Schematics setup for WPT system and its circuit model

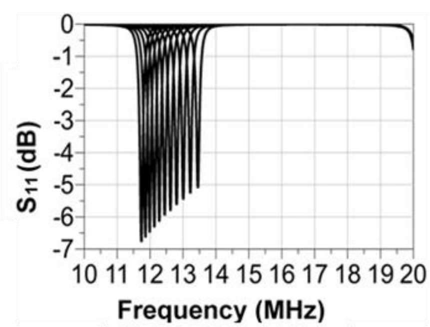


Fig. 1. ADS simulation for the tunable open ended planar spiral coil

L_2 and L_3 in represented the inductance of the primary coil, which has a physical length of 13m with respect to fabrication errors. Electromagnetic (EM) Method of Moments simulation is done using Advanced Design System (ADS) and results for the open-ended tunable inductor is shown in Fig.2. Tuning has done with a capacitor in parallel with certain length of the transmitter inductor and the other open side of the inductor which used as a virtual ground since there isn't any actual ground in the system.

III. MEASURED RESULTS AND DISCUSSION

The transmitting open-ended coil was implemented on Rogers 5880 (a thickness of 0.79 mm and permittivity of 2.2+/- 0.02). A traditional coil made resonant with a parallel capacitor is used for receive with a 10 KΩ load. Both TX and RX resonators are tuned to 13.54 MHz using variable parallel capacitor in Tx side and series one in the Rx side or varying distances between 2.5 cm and 20 cm. Fig. 3. shows the experiment setup for the reported WPT system.

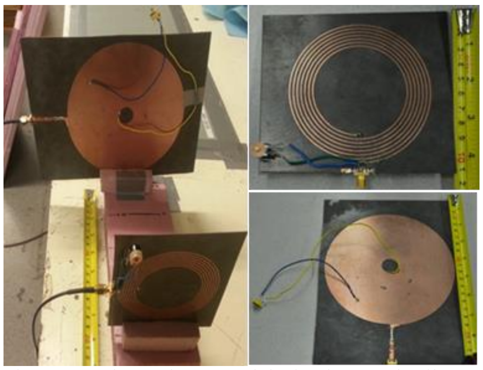


Fig. 3. Experimental setup and the implemented coil's structures

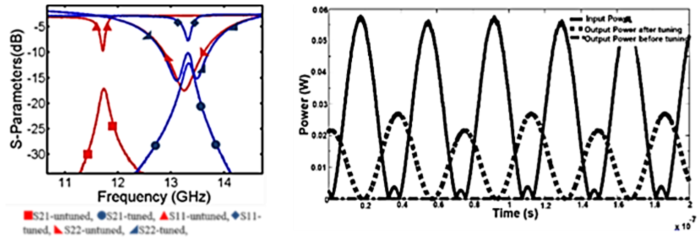
Table 1
Specifications of the coils

Parameter	Tx	Rx
d_0(mm)	153.30	91.40
d_i(mm)	20	40
n(turns)	48	9

In a conventional structures a matching circuit would be used to tune the resonance frequency and the impedance to the power source or any other optimum load to have a high efficiency. In the OSC structure, standing nodes along the coil can be used as virtual grounds. Using this technique tuning for the planar coil is possible. Fig. 4.(a) shows S-parameter measurements for the tunable primary open ended planar spiral coil for different values of the tuning capacitor. As result reveals there is 5 dB improvement of S_{21} after tuning method applied to the transmitter coil and make both transmitter and receiver to resonance at the same frequency while the distance varies. The RF to DC conversion was performed by a Tripler circuit performing at 13.54 MHz with low-threshold bias voltages Schottky diodes (SDM40E20LS-7-F). Output DC voltage measured at different distances from 2.5 cm to 20cm and presented in Fig.5. According to these results, an improvement of 60 percent was observed after tuning the primary single-wire coil in short distances (<5cm) and about 50 percent for larger distances of the secondary coil. Efficiency without rectification were found with 7cm spacing between Tx and Rx coils. The time average of the input power (measured from the current and voltage at transmitter coil input) was divided by the output power calculated from the measured voltage delivered to a 50 Ω load. Measurement were done with the use of a Tektronix DPO 710604C oscilloscope, Ct-2 current probe, P6248 differential voltage probe and a RIGOL DG4102 signal generator. With transmitter tuning, the efficiency can be varied from 2%, as a worst case, to as high as 48%. Fig.4. (b). Since efficiency is highly load dependent future work will include receiver matching for optimum load to improve performance.

I. CONCLUSION

This work presents a unique tuning technique for open ended planar spiral coil structures and demonstrates its enhancement to the efficiency of a WPT system. The reported WPT system operates at 13.5 MHz with source voltage amplitude of 20 V_{p-p}.



(a) (b)

Fig. 4. (a) S-parameter measurements for two different values of the tuning capacitors ,(b) Measurement results of instantaneous power.

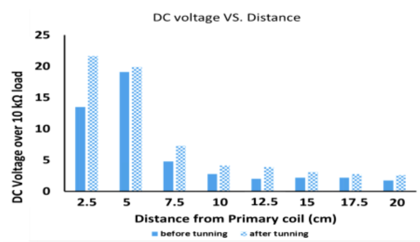


Fig. 5. Output voltage comparison between tuned and not-tuned primary resonator with a load resistance of 10kΩ as coil seperation is varied.

II. REFERENCES

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