Non-contact Hand Interaction with Smart Phones Using the Wireless Power Transfer Features

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***Abstract* — The interaction between human and smart phones is mainly based on press buttons and touch screens. As wireless charging based on wireless power transfer (WPT) coils is standardized and becoming a competitive feature for smart phones in recent years, it is also possible to control smart phones without contact by interacting with their wireless charging coils. In this paper, a non-contact method to interact with smart phones based on their wireless charging coils is proposed and investigated. A Colpitts oscillator is built and tested using a standard WPT coil as part of the resonant tank elements. Experiment results show that the resonant frequency of the coil is heavily influenced by hand movement, which could be further interpreted as the interaction between human and smart phones. By analyzing the resonant frequency changes of multiple coils embedded into a phone, it is possible to determine which hand movement is performed by a user.**

***Index Terms* — non-contact smart phone interaction, wireless charging, Colpitts oscillator, spectrogram.**

I. Introduction

Smart phones have been enjoying a boom in the 21st century. The interaction between human and smart phones gradually changed from button pressing to screen touching in the past decade. Lately, as a trend of wireless applications, wireless charging is growing up as a competitive feature for smart phones. Since the applications of smart phones have largely extended from traditional communication to various areas such as healthcare, gaming, and utility control, it will be very beneficial if smart phone users can interact their phones without physically touching the phone.

The basic idea of wireless charging is that power is wirelessly transferred based on the electromagnetic coupling between planar coils. Two kinds of devices are used – the base station and mobile device, which provides and consumes inductive power, respectively. The base station is a power transmitter that consists of a transmitting coil, and the mobile device contains a power receiver hosting a receiving coil.

In terms of the interaction between human body and the coil, instead of using the coil in the smart phone as a power receiver, the coil also can be used to send alternating magnetic field to interact with human hand. The hand movement in front of the wireless charging coil changes the coil's conductivity distribution, which creates an effective coil impedance that is also called reflected impedance [1].

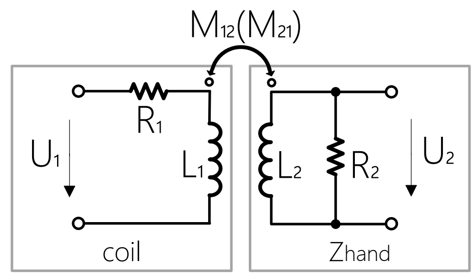


Fig. 1. Circuit model of inductive non-contact interaction.

Furthermore, the impedance change will result in a drift in the resonant frequency, which can be measured using a simple Colpitts oscillator structure and a frequency counter. Thus the WPT coil can recognize different hand movements with little extra hardware expense, which makes it possible for us to interact with smart phone without any contact.

The physical principle of the impedance change of WPT coil is discussed in Section II. The circuit design and analysis are also shown in this section. In Section III, experiments are carried out and results are analyzed. A conclusion and discussion on future works are presented in Section IV.

II. Physical Principles and Circuit Design

Hand movement in front of the coil interrupts the electromagnetic near-field introduced by the coil, which results in the impedance change of the coil. This enables us for non-contact interaction with the coil by impedance measurements, which can be modeled with a transformer model, as shown in Fig. 1.

The non-contact interaction can be described with traditional transformer equations. The coil is modeled as inductor L_1 with resistor R_1 in series considering the resistance of the coil itself, while human hand is modeled as L_2 and R_2 in parallel. Coil and hand are electromagnetically coupled via the mutual inductance $M_{12} = M_{21}$. This interrelationship can be described by two equations in frequency domain

$$U_1 = R_1 I_1 + j\omega L_1 I_1 - j\omega M_{12} I_2 \quad (1)$$

$$U_2 = j\omega L_2 I_2 - j\omega M_{12} I_1 \quad (2)$$

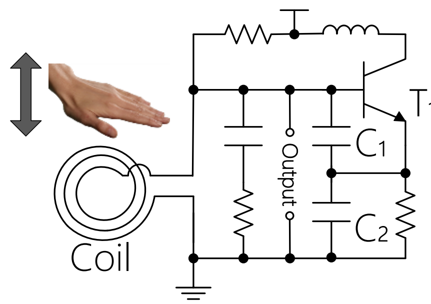


Fig. 2. Oscillator circuit with inductive coil.

In (2) U_2 is zero considering that hand has high resistance. Solving (2) for I_2 and inserting the result into (1) gives the input impedance of the first mesh, which is the reflected impedance of the inductive coil $Z_{ind,r}$ due to electromagnetic coupling with hand

$$Z_{ind,r} = R_1 + j\omega L_1 + \frac{\omega^2 M_{12}^2}{j\omega L_2} \quad (3)$$

Separating equation (3) into the real and imaginary parts will give us information on the effective resistance and reactance of the reflected coil impedance, which will directly affect the resonant frequency of the inductive coil.

The oscillator circuit whose frequency is determined by the coil impedance Z_{ind} is shown in Fig. 2. Hand is moving back and forth in front of the inductive coil to demonstrate the non-contact interaction. The resonant frequency is measured at the base of the transistor T_1.

The frequency of the oscillator f_{osc} is given by

$$f_{osc} = \frac{1}{2\pi}\sqrt{\frac{1}{L_{ind,0}C_{osc}} - (\frac{R_{ind}}{2L_{ind,0}})^2} \quad (4)$$

where $L_{ind,0}$ is the inductance and $R_{ind,0}$ is the resistance of the empty coil. The frequencies of the coil f_{osc} with and without any object in front of the coil acting as a damping resistance can be calculated with (4) by $R_{ind} = R_{ind,0}$ and $R_{ind} = R_{ind,0} + \Delta R_{ind}$, respectively. As discussed, changes in conductivity distribution in front of the inductive coil due to hand movement will affect the impedance of the coil and will eventually change the resonant frequency of the circuit.

III. Experiments for Non-contact Interaction

Fig. 3 shows the prototype oscillator circuit with the wireless charging coil disassembled from an off-the shelf smart phone, Samsung Galaxy S4. It should be noted that the oscillator circuit can be easily integrated into a CMOS chip and fully integrated into the phone or directly on the WPT coil board.

Fig. 3. The off-the-shelf wireless power transfer coil for non-contact interaction with the phone, the coil and the customer designed driving circuit.

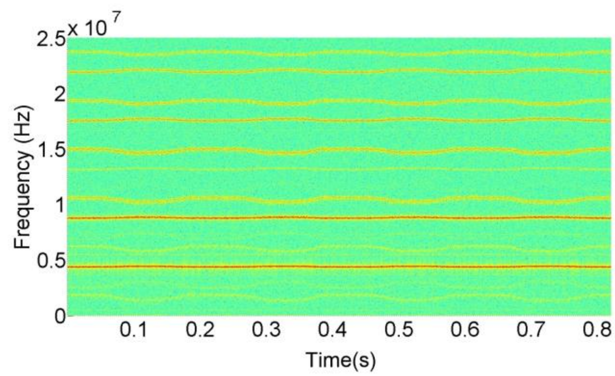


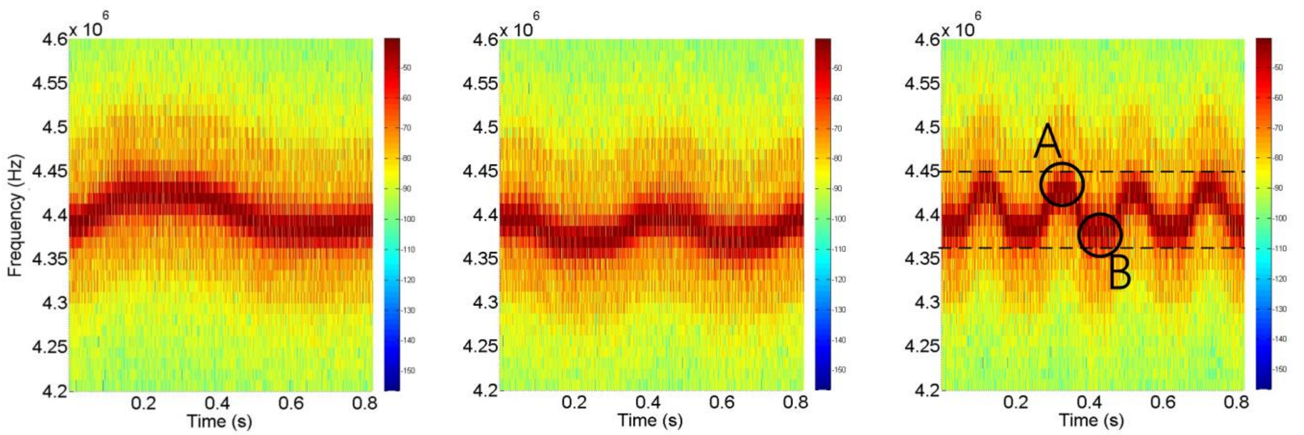
Fig. 4. Short-time FFT of resonant waveform when hand movement is performed in front of the inductive coil.

Experiments were performed by setting the oscillator circuit upright on a table, with an oscilloscope connected to the oscillator output to measure the real-time circuit response while a hand was waving in front of the wireless charging coil. As discussed in Section II, the impedance change will directly affect the resonant frequency of the circuit.

Considering that the interaction between human and smart phone should have a rapid response, hand movements are performed in a short time interval. In this experiments, an oscilloscope was used to record waveform for 0.8 second. Several different hand movements were performed to demonstrate that the inductive coil has different responses to different hand movements.

In the experiment, the subject person waved his hands once, twice and three times in front of the coil without touching it. The whole waveform was recorded during this 0.8 second using the oscilloscope with a sampling rate of 50 MHz. Then short-time FFT was applied to analyze the data recorded.

Fig. 4 shows the short-time FFT results of monitoring



(a) (b) (c)

Fig. 5. Zoom-in view around fundamental resonant frequency of the coil. (a), (b) and (c) show how resonant frequency changes when different hand movement (waved one, twice and three times, respectively) is performed in front of the coil in 0.8 second.

hand movements. From the result we can see that the fundamental frequency is around 5 MHz, which is the resonant frequency of the oscillator built based on the wireless charging coil. There are higher order harmonics of the fundamental tone, from which we can easily observe that there are variations of the oscillation frequency due to hand movement in front of the coil. However, when we take a zoom-in view of the fundamental frequency, the resonant frequency drift can also be easily observed. Fig. 5 shows the change of the fundamental frequency due to hand movements.

The zoom-in view of the fundamental frequency variation clearly demonstrated the effect that hand movement on the coil's resonant frequency. Taking Fig. 5 (c) as example, "A" has a resonant frequency of about 4.45 MHz while "B" is around 4.35 MHz, which means "A" is where the hand was closest to the coil and "B" is where the hand is the farthest from the coil. The resonant frequency of the inductive coil keeps changing as hand moves towards and away from the coil. These changes in resonant frequency can be further processed to interact with smart phones, which makes hand movement interaction with smart phones possible.

IV. Discussion and Future Work

Wireless power transfer coil of smart phones is used as a wireless sensor to demonstrate the feasibility of non-contact hand interaction between human and smart phones based on standard smart phone WPT coils. A Colpitts oscillator is built using the inductive coil as part of the resonant tank to send electromagnetic field to interact with human hand. Hand movement without touching anything will affect the impedance of the coil, which will result in variation of the oscillator resonant frequency. Experiments have been performed to measure the variation of the oscillation frequency, which turned out to be easy to detect, hence making noncontact interaction between human and smart phones possible.

A standard smart phone WPT coil is measured 2.8cm × 3.2cm, which is much smaller than a smart phone. It is thus possible to embed a 2 × 2 coil array inside a smart phone. With this arrangement, the smart phone can detect relative distance of the hand, more gesture patterns, and the direction of hand movements in a plane parallel with the phone. This will be continued future works of this study.

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