Dual Coil for Remote Probing of Signals using Resistive Wireless Analog Passive Sensors (rWAPS)

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***Abstract*—Resistive wireless analog passive sensors (rWAPS) uses resistive transducers for wirelessly capturing remote signals. This fully passive technology is low-cost, fast, miniature, maintenance free, and disposable. However, obtaining absolute measurements with this sensors are challenging as the amplitude modulation of impedance loading is a function of both the signal magnitude and the mutual coupling of the sensor and interrogator coils. This paper presents a novel dual coil design to resolve this challenge. In this design, the rWAPS sensor composes of two coils tuned at different probing frequency such that they do not offer coupling. The reference coil provides information of the mutual coupling coefficient, while the other sensor coil measures the signal of interest. Thus, the absolute value of the measured signal can be determined by considering the mutual coupling coefficient using a calibration curve or a look-up table. The concept has been verified with a test setup where the reference coil is tuned at 6.5 MHz and the sensing coil is tuned at 13.5 MHz. The data of reference coil showed correlation on the separation distance while unperturbed with the signal magnitude, which is sensed by the sensing coil of the rWAPS system.**

I. Introduction

Fully-passive wirelessly powered sensor networks present significant opportunity as they are maintenance free, miniature, low-cost and disposable [1,2]. Most of these technologies are based on digital passive sensor circuits that require Application Specific Integrated Circuit (ASIC) chips on the sensors, such as RFID [1-3]. The chip receives the wireless power, turns on the circuitry and wirelessly retransmits the ID or sensed signal after digitization to the interrogator. The implication being the requirement of ASIC chip at each sensor node that increases cost per sensor, the latency of response (typically 0.5 s) as it powers up to the quiescent state for operation of the analog circuit, and consequent higher power requirement. An alternate approach is to transmit data in analog form, for example modulating the carrier frequency using capacitive (varactor) variation that correspond the biosignals [4]. In contrast, we proposed a new class that uses resistive transducers to remotely capture biosignals [5,6]. Various types of biosignal capture with these sensors have been demonstrated, however, these signals were differentially encoded in nature, i.e. the information relies on changes of signal magnitude rather than absolute values of the signals. For instance, heart rate can be determined by detecting subsequent peaks using pressure transducer positioned on a peripheral artery using rWAPS [5]. The challenge in capturing absolute values from rWAPS is that the amplitude of the modulated signal is dependent on both the signal magnitude and the mutual coupling of the interrogator and the sensor coils. This paper presents a novel dual coil approach where one coil serves as a reference measurement to compute the mutual coupling, while the other coil measures the signal whose absolute value can be computed.

II. Theory and Setup

The proposed schematic is shown in Fig. 1. The signals at the sensors correlate to the transducer resistance (R_S) changes, and modulate the envelope of the carrier signal (f_c) according to the following impedance loading theory.

$$Z_{Tx} = X_{Rx} + j\omega L_i \,\|\, \frac{1}{j\omega(C_{i\_s}+C_{i\_p})} \,\|\, R_{i\_p} \qquad (1)$$

$$\text{where } X_{Rx} = \frac{(\omega M)^2}{Z_{Rx}} \text{ and } Z_{Rx} = j\omega L_s \,\|\, \frac{1}{j\omega C_s} \,\|\, R_s . \qquad (2)$$

To determine the absolute value of the signal, in addition to correlation of the signal with R_s, values of all parameters of (1) and (2) must be known. As the modulation index is change after deployment as the distance between the coils changes, absolute value of the signal cannot be determined using only the sensor coil. In the dual coil approach, an internal coil serves as a reference (R_r is known), and a lookup table or a calibration curve can be used to determine M.

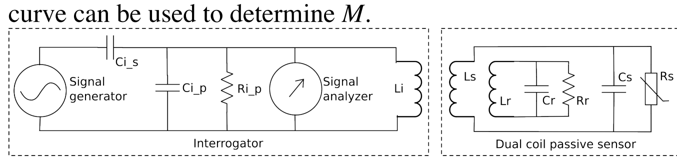

Fig. 1. Schematics of the proposed dual coil rWAPS. The first subscripts *i* for interrogator, *s* for sensor, and *r* for reference circuit, and the second subscripts *s* for series and *p* for parallel components.

Note that the two coils at the sensor do not need to be electrically connected, and the f_c of the reference coil must be spectrally apart from that of sensor coil to avoid coupling. For test the concept, we have prepared prototypes with f_c of sensor at 13.5 MHz while fc of reference coil was set at 6.5 MHz.

The experimental setup is shown in Fig. 2, where the bottom PCB serves as the interrogator coil, and the top PCB contains a reference coil and a sensing coil. The transmitter signal generator power was set to 0 dBm. The data was collected with a sweep of 1 to 20 MHz (normalized at 10 MHz). The output of the primary coil was connected to a DSO-X 2024A (Agilent Technologies Inc., Santa Clara, CA) Oscilloscope with AC coupling setting. The data were captured for three co-axial coil gaps of 5 mm, 10 mm and 15 mm.

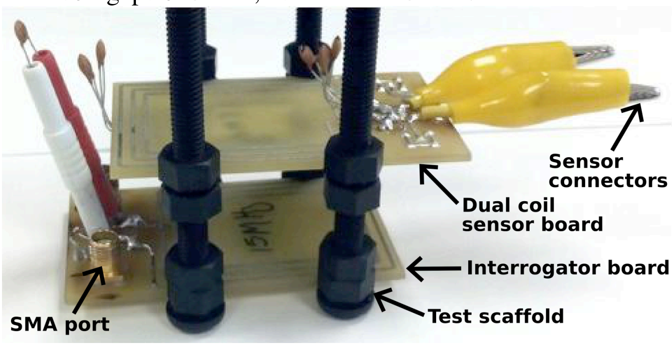

Fig. 2. The experimental setup of the rWAPS with the scaffold.

III. Experimental Results

The test results (Fig. 3) show that the spectral scan depicting two sets of peaks (split), one at 6.5 MHz and the other at 13.5 MHz. The R_s of the sensing coil (13.5 MHz) was varied from 220 Ω to 82 kΩ, and open circuit (inf.) load.

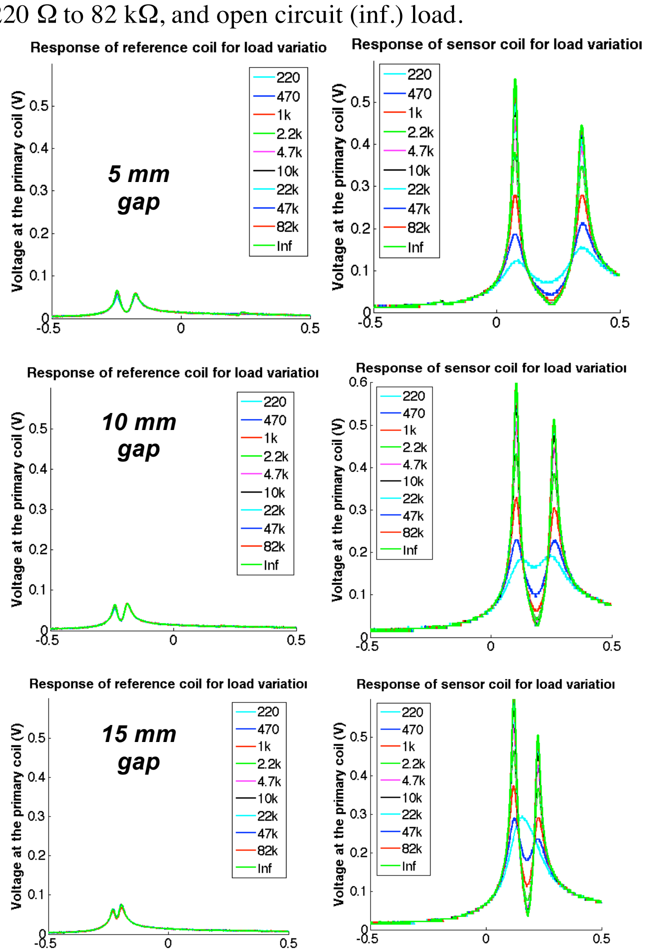

Fig. 3. Responses for reference coils and sensing coils for change of load resistance in the sensing coil at three co-axial gaps between the interrogator and the sensor plotted against normalized frequency.

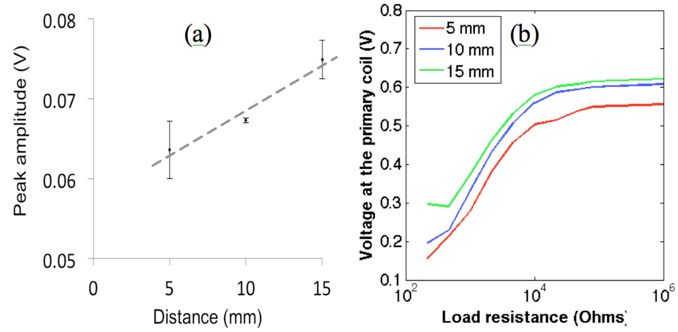

Fig. 4. (a) Peak amplitude of reference coil response linearly varies for different distances. (b) Peak amplitude of sensing coil varies with load as well as distances.

Peak values of reference coil response for 5 mm, 10 mm, and 15 mm are 0.0658 V, 0.0681 V, and 0.0761 V, respectively, with a maximum variation of 9.4 mV, 9 mV, and 8 mV, respectively. Fig. 4(a) depicts how peak amplitude at 6.5 MHz changes at different distances between the interrogator and independent of load variation. Fig. 4(b) shows the peak responses due to variation of load resistances at sensing coil for three different distances.

IV. Conclusions

The challenge of obtaining absolute measurement with rWAPS has been resolved by utilizing a novel dual coil sensor design, where the inner coil acts as a reference coil to determine the modulation index that incorporates variables like mutual inductance factors and distance between coils, and the outer coil acts as sensing coil using a priori lookup tables based on the reference coil data.

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