Wireless Resistive Analog Passive Temperature Sensors for Smart & Connected Community

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***Abstract*—Next generation smart and connected community (SCC) requires novel low-power technologies that will disperse in the environment to seamlessly collect data. Thus new technologies for wearables need to address this challenge to enhance mobile health (mHealth). As such, we are developing fully-passive body-worn Wireless Resistive Analog Passive (WRAP) sensors using inkjet printing (IJP) technology for various physiological signal monitoring. In this work, we present two WRAP temperature sensors to monitor core-body temperature. The paper outlines the designs, layouts, and functional test results. In one design, a manual switch is utilized to measure relative change due to the temperature sensor (NTC) in contrast to a known load. In the other design, an automated version is presented where the switching is performed with a RC-delayed transistor. The signal transition occurs after the RC-delay, where R is the resistance of the NTC. Functional evaluation shows change of transition time for different temperatures. Quantitative characterizations are currently being conducted. In combination with other WRAP sensors under development, this novel technology has promise to detect various diseases at home using smartphones that will enhance mHealth capabilities for improved SCC health.**

I. Introduction

Although rapidly emerging mobile health (mHealth) technology is already tapping into widely used smartphone infrastructure, data collection using smartphone devices is limited by a few integrated sensors (e.g., Inertial measurement unit (IMU), camera, optical sensors, temperature sensor, and GPS) [1]. Collecting core body temperature with smartphone is currently not possible. We have previously proposed Wireless Resistive Analog Passive (WRAP) sensors that can sense physical stimulation and bioelectric signals [2,3]. As temperature sensing is an absolute quantity measurement, it poses challenges such as mutual inductance variations due to change of distance or orientation of coils. We have reported WRAP temperature sensor using a dual coil approach [4]. In this work, we present two new WRAP temperature sensors that were prototyped utilizing ink-jet printing (IJP) technique.

II. Theory

WRAP sensor system consists of a scanner and a fully-passive sensor coupled with a short range wireless link. A simplified schematic of the scanner and two implementations (Type A and Type D) of WRAP temperature sensor circuits are presented in Fig. 1. The L_p and C_p constitute a transmit antenna tank circuit and impedance is matched with C_1. On the other hand, the sensor might or might not have a tank circuit, resulting a resonant or inductive coupling, respectively. For

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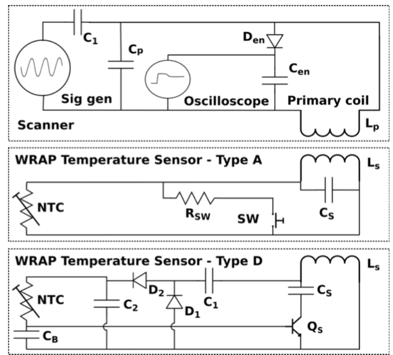

Fig. 1. A simplified schematic for WRAP scanner (top) and schematics of two types of WRAP temperature sensor circuits: Type A (middle) and Type D (bottom).

resonant coupling, a resonant capacitor C_s is connected across L_s to form a tank circuit. The transducer can be used as a damper such that the quality factor, Q, of the link changes with change of signal at the transducer (Type A). Alternatively, the transducer can be used to alter delay of a transition such that the time of transition can be correlated with the signal at the transducer (Type D).

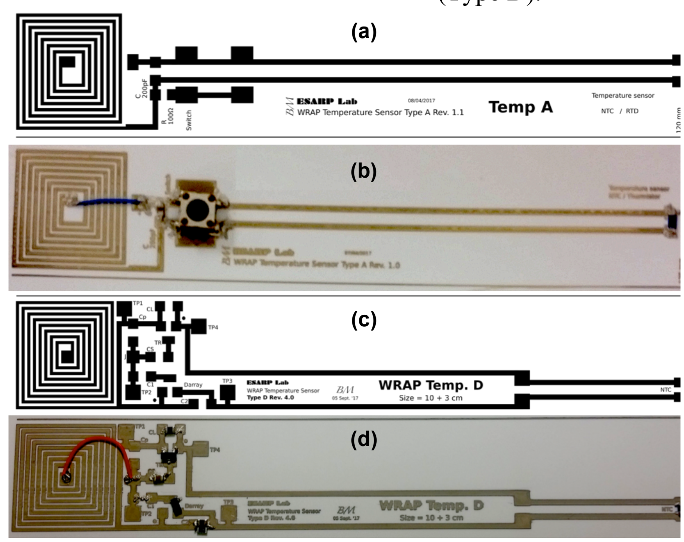

Fig. 2. (a) Layout design of WRAP temperature sensor Type A. **(b)** Photograph of a functional prototype of (a) printed on a paper. **(c)** Layout design of WRAP temperature sensor Type D. **(d)** Photograph of a functional prototype of (c) printed on a paper after population.

Negative Temperature Coefficient (NTC) transducer senses the temperature by inversely changing its resistance. Type A sensor utilizes a manual SPST-NO push switch (SW) in series with a known load (R_{SW}). Type D sensor utilizes a two-stage voltage doubler (realized with D_1, D_2, C_1, and C_2) that produces a DC voltage. A RC delay is generated with the NTC resistance and C_B that triggers a RF switching transistor, Q_S, loading the coil with C_S. The resultant amplitude modulation of carrier signal is decoded with an envelope detector (D_{en} and C_{en}).

The antennas were optimized with our previously described iterative method for optimal printed spiral coil (PSC) [5]. The WRAP sensor layouts were fabricated with inkjet printing (IJP) technique (DMP-2831, Fujifilm Dimatix Inc., NH) [6]. The layouts (single layer) and photographs of printed and populated sensors are shown in Fig. 2. Silver nanoparticle ink (Metalon JS-B40, Nanosilver Ink, Novacentrix, TX) was used for the conductive traces printed on paper substrates (Glossy photo-paper, 10.4 mil). The components were connected to the pads of the traces using silver epoxy (8331S, MG Chemicals, Surrey, B.C., Canada) and cured for 24 hour in forced air.

III. EXPERIMENTAL SETUP

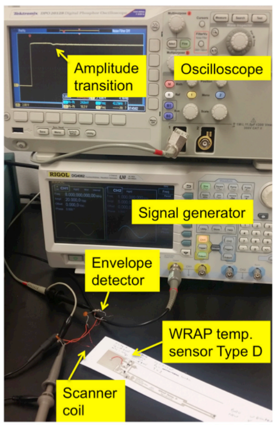

Fig. 3. Setup for functional verification of the sensor.

Fig. 3 depicts experimental setup for the sensor placed on the scanner coil (under the sensor). A 10-turn magnetic coil acts as the scanner coil. A signal generator (DG-4062, Rigol Tech., Beijing, China) produces bursts of 0.5 s carrier signals (8 MHz, 20 V_{pp}). The output of the envelope detector is fed to an oscilloscope (DPO-2012B, Tektronix, Beaverton, OR) that triggers at the rising edge of the envelope detector output. The collected data was saved in CSV format, and processed with Matlab (Mathworks, Natick, MA).

IV. RESULTS

Table I shows some key features of these two types of sensors. The number of pads dictates the number of silver epoxy bonding, which is a labor-intensive fabrication task.

Table I: Component count (in terms of terminals, T) and pads

Type	Description	Component count	Number of pads
A	Manual	Two-T: 2, Four-T: 1	8
D	Automated	Two-T: 8, Three-T: 1	19

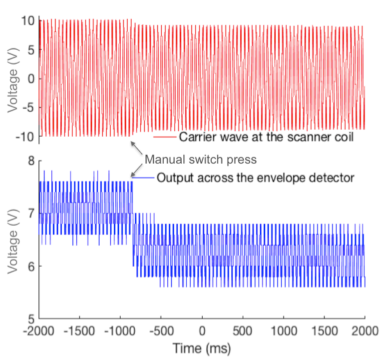

Fig. 4. Response of a WRAP temperature sensor of Type A.

For Type A sensors, when the switch is pressed, a known impedance is applied across the coil that is used to determine mutual coupling (Fig. 4). When the switch is released, the NTC loads the coil that correlates with temperature. A simple lookup table (LUT) can be utilized to determine the temperature value.

For Type D sensors, when a carrier signal is applied, the base voltage of the transistor, Q_S, starts to rise at a rate set by RC, where NTC is used as the R. When the voltage at the base is larger than the transistor base threshold voltage (i.e. 0.6 V), the transistor turns on, causing a loading of the carrier signal, resulting a signal transition at the envelope detector.

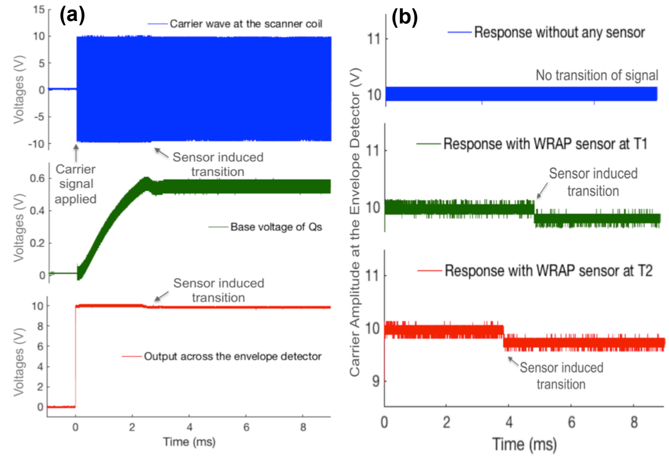

Fig. 5. Functional test response of WRAP temperature sensor Type D. **(a)** Carrier waveform, Base voltage of Qs, and output across the envelope detector. **(b)** A signal transition is observed with sensors where the time of transition is dependent on the temperature.

A set of representative signals for WRAP temperature sensor Type D is shown in Fig. 5. Signals with sensors at two temperatures (T1 and T2) in contrast to signal without a sensor demonstrates the transition time dependence on temperature. A comprehensive characterization and calibration of the relation between the temperature and transition time are presently being conducted.

V. CONCLUSION

This work shows that absolute signals, such as temperature, can be measured with WRAP sensor system using RC-delayed transition where time of signal transition can be correlated with the signal magnitude. Even though Type A sensors are easier to fabricate, Type D sensors are suitable for practical applications due to automated triggering and will be further investigated. These IJP prototyped low-cost body-worn disposable WRAP sensors will be deployed for monitoring community health under our current SCC project pilot study.

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