David Arellano has been working in the Embedded Systems lab in the Electrical Engineering Department since Spring 2014 and plans on attending graduate school after receiving a bachelors degree. He also plans to stay involved with the research community after graduation. With a passion for travel, he hopes to see as much of the world as possible. Free time is spent studying theology, philosophy, and enjoying movies, music, art and nature. Family, friends, and religion have all been incredible influences in his life, and he owes all of his success to these blessings and the continuing support of loved ones.

David Arellano

Wireless Analog Passive Sensors for Small Bioelectric Signal Measurement Through Load Modulation

Faculty Sponsor
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Abstract

Fully-passive wireless body-sensors open the possibility for unobtrusive physiological signal capture and monitoring in natural settings. While capacitive analog passive wireless sensors have been developed, we present an alternative solution for signal capture based on load modulation using resistive transducers. The passive sensor is composed of a loop antenna, a tuning capacitor, and a resistive transducer suitable for the type of physiological signals to be measured. The interrogator transmits a carrier RF signal at 11.776MHz whose amplitude is modulated based on the resistive loading by the transducer. In this study, in place of a resistive transducer, an N-Channel Enhancement MOSFET is used to modulate the carrier signal with an applied small signal voltage. In previous studies, the sensor was characterized for various resistive loads of 1.2? to 82K? with an interrogator of low quality factor (Q_F). We demonstrate the effect of raising the QF of the interrogator, which increases sensitivity and allows for small signal voltage sensing at very low power levels (0dBm to +5dBm). The results demonstrate the viability of developing body-worn fully-passive sensors for small bioelectrical signal capture.

Introduction

The convenience and advantage of wireless sensing is undeniable. When monitoring multiple signals, wired sensors eventually become complex and unmanageable. However, traditional wireless sensors can themselves be ineffective due to restrictions such as battery power and size. A solution can be found in the battery-less nature of fully-passive sensors. Fully-passive sensors have already demonstrated the potential to be body-worn and unobtrusively collect physiological signals [1]-[3]. It is important at this point to distinguish the two different types of passive sensors. Passive sensors are commonly separated into two distinct categories: wireless digital passive sensors (WDPS) and wireless analog passive sensors (WAPS). WDPS contain an ASIC chip that receives power from the scanner, turns on the circuitry, and wirelessly retransmits a digital identification code or digitized signal. WDPS can collect analog signals by sampling the analog data with data acquisitions chips [4],[5]. WAPS, however, do not contain any digital ASIC chip, and can communicate via purely analog signals. WAPS have the advantages of simpler circuitry, lower cost, less complexity, extremely low power wireless transmission, and very fast response time. On the other hand, some disadvantages are higher numbers of artifacts and lower data quality and security than compared to WDPS. WAPS based on varactor and Surface Acoustic Wave (SAW) resonance have been successfully used for a multitude of remote signal capture applications [6],[7],[8],[9]. These WAPS use LC resonators, which utilize capacitive changes to modulate signals based on resonant frequency shifting [8],[9]. The SAW delay line is used for delayed backscattered signal [7].

In this paper, we demonstrate the capture of small signal voltages using a novel WAPS system based on resistive load modulation (rWAPS). Our passive sensor is a parallel RLC resonator tank circuit with damping factor (QD) set by the load resistance. By using resistive transducers to capture physiological signals, the resistive load can be changed, which alters the damping factor (QD) and, in turn, amplitude modulates the carrier RF signal. This amplitude modulation can be captured by a signal analyzer with an envelope detection scheme. For this paper, in place of a resistive transducer, we have used a MOSFET to convert voltages to a resistive variation of RSD. In doing so, we demonstrate that body-worn passive sensors could allow for remote capture of bioelectrical signals such as those utilized in Electrocardiography (ECG), Electromyography (EMG), and Electroencephalography (EEG). These proposed rWAPS still maintain the advantages of simple construction and low component count. Ultimately, this makes the body-worn sensors extremely inexpensive to fabricate and even dispose of, once monitoring sessions have ended.

Hardware Description

For prototype development, three identical sized boards have been designed using the Cadence PSPICE tool (Cadence Design System, Inc., San Jose, CA, USA). Fig. 1 shows the schematic for the interrogator device, and two different layouts for the rWAPS sensors.

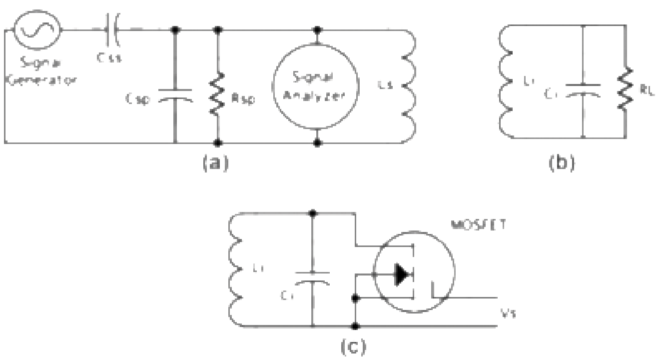

Fig. 1 (a) Schematic of WAPS Interrogator (b) Schematic of transducer based sensor (c) Schematic of MOSFET based sensor

Fig. 1(b) shows the board, which implements a resistive transducer for signal sensing. Fig. 1(c) demonstrates a sensor board that was designed for a MOSFET in place of a transducer. The antenna design was inspired by similar designs from [10]. The interrogator board has two SMA connectors, one for the carrier input V1, which delivers carrier signals at 11.776MHz, and the other one for the signal analyzer. The capacitor C_{SS} is used to match the antenna to 50 Ω. The second capacitor C_{SP} is used to adjust the resonant frequency of the circuit, with the loop antenna (L_S) designed as a planar inductor. The terminal resistor (R_{SP}) is used to raise the Q_F of the interrogator for maximum sensitivity. The passive sensor has a matching coil L_I and a capacitor C_I to tune the antenna for a matching resonant frequency. In Fig. 1(b) a resistive load R_L is shown that represents a resistive transducer. In Fig. 1(c) the MOSFET is used to convert input voltage (V_S) to a correlated resistive variation of R_{SD}. Another SMA connector is used on this board to deliver a noise reduced signal from the signal generator to the MOSFET via coaxial cable.

Printed Circuit Boards (PCBs) were designed using Cadence Allegro SPB 16.6 (Cadence Design Systems Inc., San Jose, CA, USA). The sensor and interrogator boards are identical in size, measuring 6.89cm x 4.19cm. Fig. 2 shows the PCB layout of the three boards. Fig. 2 (Left) demonstrates the PCBs for both the interrogator device and resistive transducer based sensor. These boards share identical circuitry, but are populated differently, based on Fig. 1(a) and Fig. 1(b). Fig. 2 (Right) is the new PCB fabricated for the purpose of voltage sensing using a MOSFET.

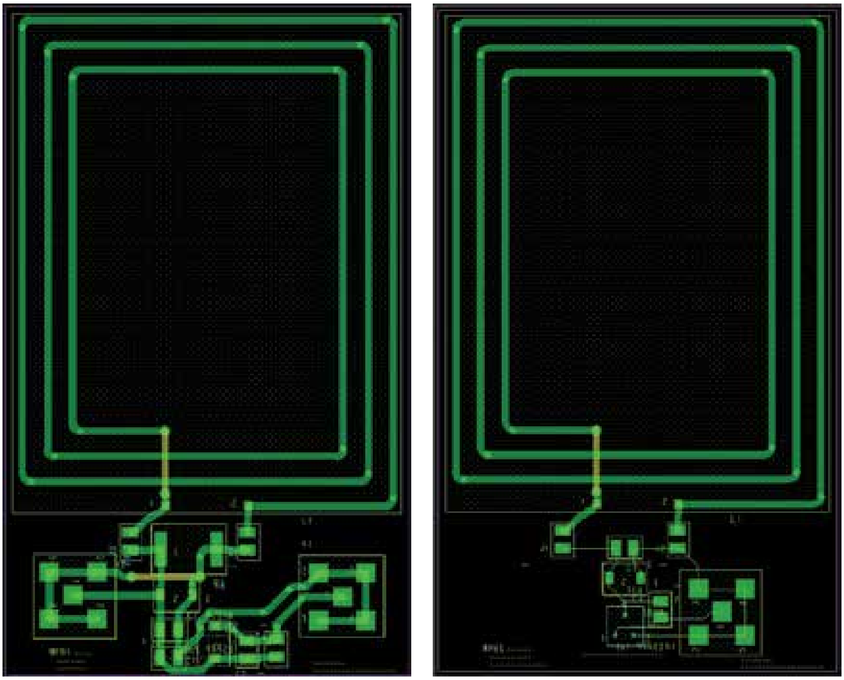

Fig. 2 (Left) PCB layout of interrogator and transducer sensor
(Right) PCB layout of MOSFET based sensor

The PCBs were fabricated by Advanced Circuit (Aurora, CO, USA).

The test fixture in Fig. 3 keeps the boards in parallel at a fixed co-axial position.

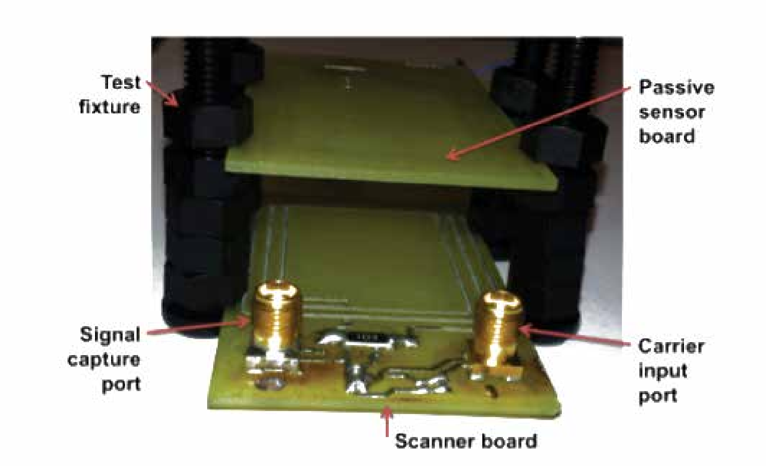

Fig. 3 Sensor Test Setup

Method

A Rigol DG4062 (Rigol Technologies Inc., Beijing, China) signal generator is used to capture the sensor characteristics in the Frequency Spectrum with the new high Q interrogator. A 0dBm signal is chirped from 9MHz to 14MHz.

For signal modulation, a 10Hz signal is applied between the MOSFET gate and source by the same signal generator producing the carrier frequency. The lower limit of the signal generator is only 2mV so a 20dB attenuator was used to achieve smaller voltages. The carrier frequency is set to 11.776MHz at +5dBm. This frequency and power level were chosen based on the data collected from the high QF interrogator characteristics. The MOSFET used is an Enhancement mode N-Channel MOSFET from Diodes Incorporated.

The output is connected to a DSO-X 2024A (Agilent Technologies Inc., Santa Clara, CA, USA) Oscilloscope. The oscilloscope is AC coupled with Peak Detect as the acquisition mode, and ASCII X-Y as the output option. Data from the oscilloscope is saved as a .cvs file, and then analyzed and plotted in Matlab.

The scanner and the passive sensor maintained a separation distance of 22mm position for all measurement by using the testing fixture (Fig. 3).

Results

Fig. 4 shows the sensor characteristics in the frequency spectrum using the high QF interrogator and the sensor board depicted in Fig. 1(b).

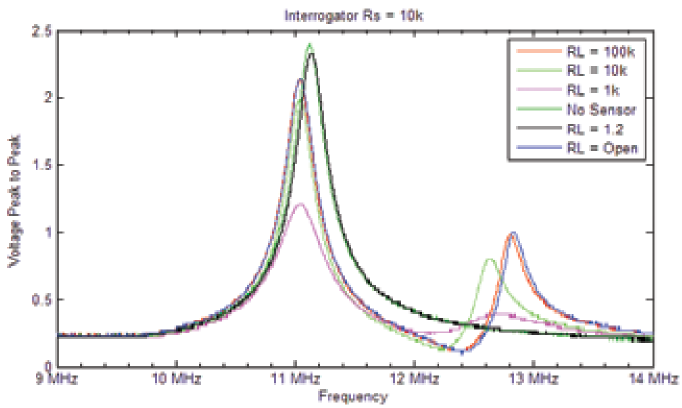

Fig. 4 Interrogator Frequency Characteristics RSP = 10k

It is important to note the modulation potential seen near 12.5MHz. The amplitudes at this frequency between resistive loads 100kΩ and 1.2Ω demonstrate a response sensitivity analogous to a 9.8x magnitude difference. This is a considerable improvement from previous experiments, which demonstrated response sensitivities of 3x or less [11]. This increase in sensitivity is vital for detection of the small signals being sensed by the MOSFET.

Fig. 5 and Fig. 6 show the positive envelopes of the reflected signals corresponding to 1mV and 400μV input signals to the MOSFET (Vs) respectively. When a voltage is applied to the MOSFET between the gate and the source, the reflected signal is modulated accordingly due to the resistive response of the MOSFET. Fig. 5 and Fig. 6 show the modulated envelope of the 11.776MHz carrier signal captured by the interrogator. A 1mV sine wave modulation is clearly visible in Fig. 5. Additionally, the 400uV sine wave seen in Fig. 6 was found to be the lowest discernable signal achievable with our current set up.

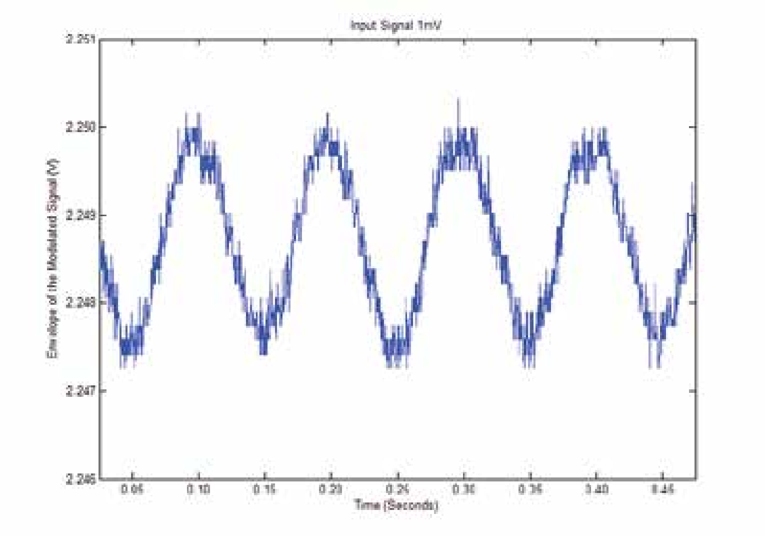

Fig. 5 VS = 1mV

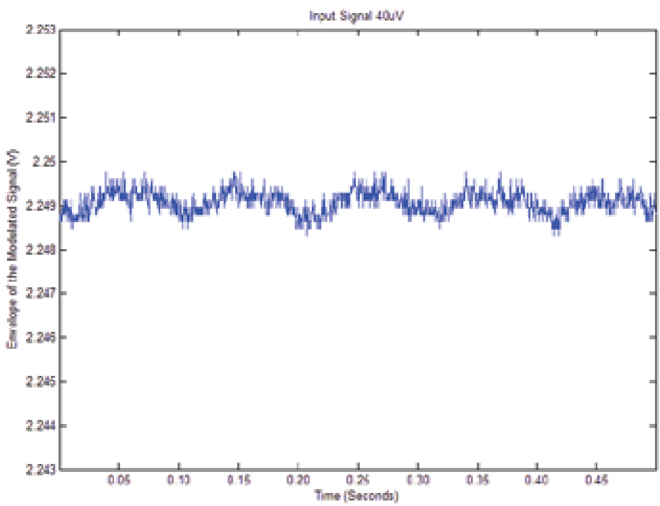

Fig. 6 VS = 400uV

Fig. 7 shows the voltage response of the rWAPS sensor, seen in Fig. 1c, with an enhancement type N-MOS. The region near the origin is amplified in the inset for comparison with the second order polynomial curve found in the drain current response of a typical N-MOS transistor. Fig. 7 illustrates the response expected from our set up in this experiment. As the figure demonstrates, we are operating in a region comparable to the ohmic region described by typical MOSFET characteristic curves, and are using the MOSFET as a voltage controlled resistor.

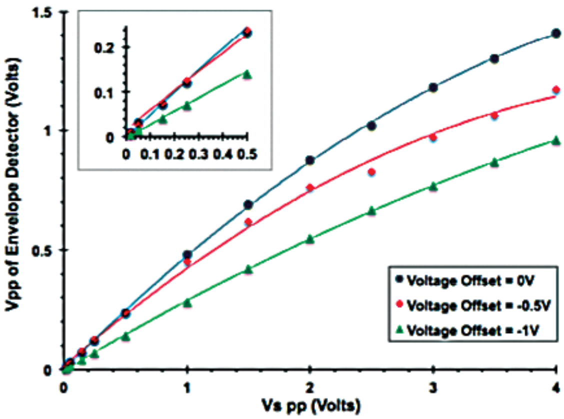

Fig. 7 Voltage response of WAPS Fig. 1c with an enhancement MOSFET along with second order polynomial trend lines

Conclusions

In this paper, we have investigated a novel method for wireless small signal voltage sensing using purely passive components. By using a MOSFET without DC bias on our passive sensor to convert voltages into a respective resistance, we have demonstrated the ability to modulate an 11.766MHz carrier signal visible at the interrogator. Through experimentation we have shown that our wireless analog passive sensors have the ability to capture voltages as small as 400μV. Such sensitivity could allow for the rWAPS sensor to capture bioelectrical signals such as ECG and EMG that exist in the milli- and sub-millivolt range. Future research will attempt to improve coil design, and a wider variety of MOSFETs must be examined in order to fine tune transistor characteristics beneficial for our purpose of voltage controlled resistance.

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