Passive Wireless Sensor Resilient to Environmental Interference Using Dual-Resonant MEMS Architecture

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***Abstract*— In this paper we present a wearable passive wireless sensor equipped with a dual-MEMS architecture and designed to be immune to measurement error caused by environmental interference. The sensor is lightweight and robust and is energized via a pulse modulated sinusoidal signal transmitted by an external antenna. By incorporating two low loss piezoelectric MEMS devices composed of similar substrate materials we were able to negate the effects of environmental interference on the sensor. Our design was tested with temperature variation and results illustrate almost complete negation of the effect of temperature variation.**

Keywords—MEMS; BioMEMS; Resonator; Sensor; Wearable; Wireless; Piezoelectric; Respiration

I. INTRODUCTION

Monitoring of biomedical signatures of the human body, especially the four vital signs: temperature, respiration rate, heart rate, and blood pressure, is a requirement in almost all interactions with medical professionals and is a flagship feature of wearable consumer electronics.

Despite the benefits, the deployment of biomedical sensors to all relevant settings is limited often not by their accuracy, but by patient compliance. Cumbersome measurement sensing setups attached to patients with tubes and wires reduces mobility and decreases the chances of patient compliance [1].

To tackle this challenge, we previously developed a respiration and temperature sensor composed of a Micro-Electro-Mechanical (MEMS) resonator connected to a commercial flexible RFID antenna operating in the ISM band (@902MHz) [2]. We illustrated that our sensor was capable of wirelessly measuring human respiration profile by proxy of vapor condensation and also difference in temperature of exhaled and inhaled air. Difference in temperature translates to a change in elasticity of the MEMS microstructure which in turn results in a shift in the resonance frequency. Whilst feasible in static environments, changes in environmental settings results in a shift in frequency and measurement error.

Here we present a sensor designed to overcome the limitations of passive wireless measurement in time varying environments by incorporating a pair of MEMS resonators with similar temperature-frequency characteristics. Our measurements show significant improvement in measurement accuracy compared to a similar sensor without dual-MEMS architecture.

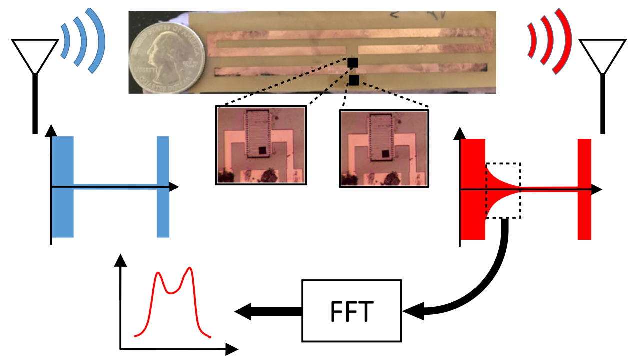

Fig. 1 (color online) Measurement setup of passive wireless sensor. The sensor is excited by a pulse modulated sinusoidal signal (blue) via an external antenna. Response (red) is received via secondary antenna, and following time gating and FFT analysis the two resonance frequencies are extracted as two peaks in the FFT spectra.

II. SENSOR COMPOSITION AND MEASUREMENT

The sensor is made up of two MEMS resonators connected in parallel and wirebonded to flexible dipole antenna. Here we utilize two Thin Piezoelectric on Substrate (TPoS) operating at close frequencies and near the ISM band (902-928 MHz). Close operational frequency of the resonators assists in design of a dipole antenna with acceptable efficiency at both frequencies. However, if the resonators operate at too close a frequency we risk misidentification during measurement.

TPoS MEMS resonators were chosen based on their low insertion loss and superior quality factor [4]. Devices used here are composed of a piezoelectric layer sandwiched between two metal layers stacked on top of a nanocrystalline diamond substrate. AlN with a thickness of 650nm formed the piezoelectric layer and the nanocrystalline substrate had a thickness of 2µm. Details of the operation of the MEMS device, including the fabrication process can be found in [5]. The resonators used here were measured to operate at 888.5MHz and 887.6MHz with an insertion loss of 6dB and 9dB, respectively.

As shown in Fig. 1 our sensor is energized wirelessly by a pulsed sinusoidal signal transmitted from an external antenna. The sensor's response waveform is recovered by a second external antenna during the off period of the excitation signal. Using time gating the two resonance frequencies of the sensor are extracted from the response using Fast Fourier Transform (FFT) analysis. Hann window was utilized to facilitate detection because of the proximity of the two frequencies. An example of the measured FFT spectrum is shown in Fig.2.

We developed a custom lightweight flexible strip dipole antenna with a matching loop to facilitate the operation of the sensor. Details of the design of the antenna can be found in [3]. The S-parameters of the resonators were recorded prior to wirebonding and the antenna was designed to match the resonators to maximize power delivered to the resonators. The antenna was fabricated on a flexible Pyralux sheet with a copper and polymide thickness of 35µm and 25µm, respectively.

By incorporating two resonators with similar temperature-frequency profiles and tracking the difference in resonance frequencies we can cancel the overlaying effect of environmental interference change whilst maintaining sensitivity to other changes. As an example of environmental interference measurement results shown in Fig. 2 illustrate cancellation of frequency shift resulting from temperature rise from a heating event using the dual-MEMS architecture.

III. DISCUSSION

Almost all physical phenomena used in sensing applications have a temperature dependency. With a footprint of only 2mm our dual-MEMS architecture was able to completely eliminate the effect of temperature on the measurement without any circuits or complex compensation algorithms. Because of the wide adoption of MEMS devices in sensing applications, we believe that dual-MEMS architecture can have a significant impact on wireless sensors. The measured response of the application of this sensor as for a single cycle is shown in Fig.3.

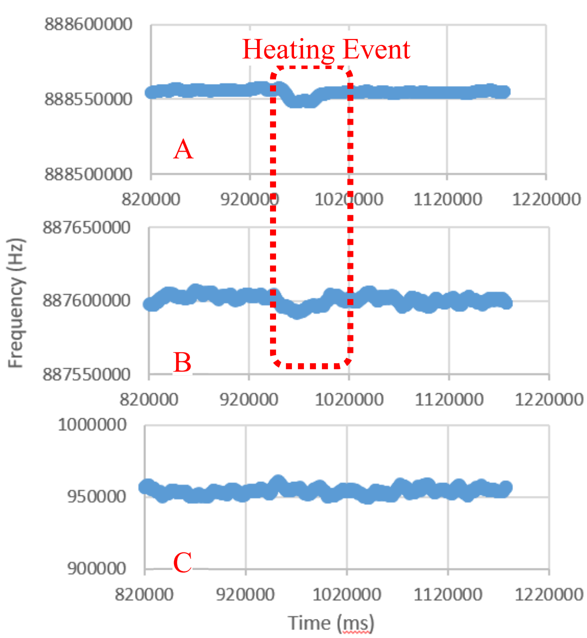

Fig. 2 (color online) Resonance frequency of 888.55MHz (A) and 887.6MHz (B) resonators extracted from sensor's response and their differential (C). Heating event starting at 952 s and lasting 3 seconds can be detected in (A) and (B) but cannot be observed in the differential (C).

IV. CONCLUSIONS

A novel method for canceling the effect of environmental interference on passive wireless sensors is presented. Here we incorporate a dual-MEMS architecture in our sensor by connecting two piezoelectric MEMS resonators, operating at close frequencies, in parallel. Low insertion loss offered by thin-film piezoelectric on silicon MEMS resonators combined with a custom dipole antenna designed to transfer maximum power were found to be critical to the operation of the sensor. The sensor is energized via an external antenna and FFT analysis is used to extract the two resonance frequencies from its response. We showed that while temperature variation shifts the measured resonance frequency of a single-MEMS sensor the difference between the resonance frequencies of a dual-MEMS sensor remains largely unaffected. Our results show an almost complete removal of the effects of temperature change.

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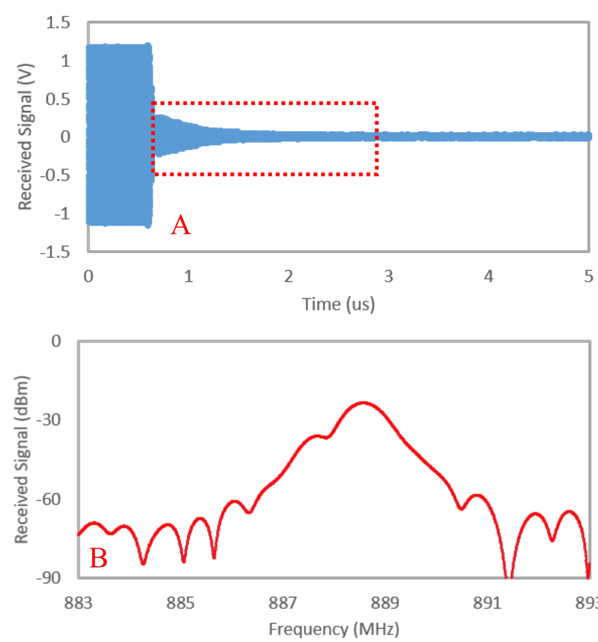

Fig. 3 (A) Measured time response of the sensor with gating window highlighted. (B) Same response after FFT analysis is shown. The two peaks of the FFT spectra (visible here) are tracked as the two resonance frequencies.