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SAW based passive sensor with passive signal conditioning using MEMS A/D converter

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Abstract

A monolithically packaged surface acoustic wave (SAW) radio transponder and pressure sensor are developed for the application to a tire pressure monitoring system (TPMS). The device contains the wireless transponder, which converts analog signal into digital one without any auxiliary electronic circuits and transmits the converted data wirelessly. No power sources are needed for wireless transponder and pressure sensor. The touch-mode pressure sensor converts externally applied pressure into capacitance, and the SAW radio transponder radiates sensor values with pulse train to the interrogation (measurement) unit. The realization of the mechanical A/D conversion is possible since the SAW radio transponder is connected to the touch-mode capacitive pressure sensor. The SAW radio transponder and touch-mode sensor are fabricated using a surface micromachining and a bulk micromachining technologies, respectively. The performance of the integrated, passive and wireless pressure sensor meets the design specifications such as linearity, sensitivity and noise figure. Finally, experimental results for the radio transponder and the sensor without power source are presented.

Keywords: Wireless sensor; SAW radio transponder; Capacitive sensor; Touch mode; Micromachining technology

1. Introduction

SAW radio transponders have been studied by many researchers as wireless sensors [1,2]. The major application fields are RFID tag and the component of communication systems. Recently, wireless sensors have been considered as one of the emerging technologies because of a lot of application such as the environmental monitoring and the structural health monitoring systems. In Europe, the wireless sensors are developed for temperature sensors [3], torque sensors [4] and pressure sensors, which are embedded in to measure the tire pressure [5]. In general, tire pressure is not easy to measure because of the difficulty in wiring power-supply and electronic circuits. Therefore, some alternatives are considered. One is inductively coupled passive/wireless pressure sensors using MEMS technology. This technology is based on the wireless power transmission such as RF tag and SAW radio transponder. However, the pressure sensor has some limitations such as a small detecting range about 4 cm long and unstable outputs, and thus it is affected by environment conditions and temperature. The second alternative is a wireless power transmission. Wireless power transmission is studied for the application to an intra-ocular pressure sensor, which is powered wirelessly. However, the transmission range of delivered wireless power is small for practical use. Furthermore, it is difficult to deliver RF power to a distant place more than 10 m from sensor location without violating regulations on wireless communication. Therefore, SAW radio transponder might be thought to solve above limitations because it receives incident radio signals and it can reflect them into the air. The reflected signals launching on the surface of SAW radio transponder contain some information about internal status of SAW transponder such as the impedance and the loaded mass on the substrate. The varying impedance affects the reflected signal (wave) from SAW transponder, and the reader unit, which is called as the interrogator in this study, can read out this reflected signal. The varying impedance is implemented with the variable capacitance and thus the variable capacitive sensor should be developed for the external load impedance connecting to SAW radio transponder. Various types of SAW pressure sensor have been developed over 10 years. Most of the SAW pressure sensors use varying

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impedance, which has a high Q-factor to improve sensitivity. Due to the resonance circuitry like nature of the impedance loaded inter digital transducers (IDT), the applicability of a capacitive pressure sensor to the load for the splitfinger IDT depends on the Q-factor of the impedance. A low Q-factor reduces both the achievable magnitude and the phase modulation dramatically. Silicon based micromachined capacitive pressure sensors showed a very low full scale range of 1–2%. In this study, a conventional micromachining process was investigated using a borosilica glass for low cost and easy implementation, and a new design concept for measuring pressure using embedded MEMS A/D converter is proposed. The MEMS A/D converter developed is a fully passive A/D converter connecting SAW transponder and micromachined touch-mode pressure sensor. The conventional capacitive pressure sensor measures capacitance between two electrodes. Therefore, the key parameter in the micromachined capacitive pressure sensor is the gap between two electrodes. However, the gap is not an important parameter in touch-mode pressure sensor. The touch-mode pressure sensor operates at the instants of contacting two electrodes. The lower electrodes cannot move because the lower electrode is fixed the on substrate. Only the upper electrode can move. When two electrodes are touched, the touched area is increased as the external pressure is increased [6,7]. One of key parameters affecting the performance of the pressure sensor is the touching zone. This study uses the touch-mode pressure sensor and the piezoelectric characteristics of the SAW transponders for passive operation of the wireless sensor system.

2. Device design

To use the SAW device as a wireless transponder, some characteristics of SAW device such as intrinsic and given parameter in frequency domain should be analyzed using analytical methods. Among various methods, P-matrix is the most significant and well-known formalism to calculate SAW device's characteristics such as the efficiency of propagation, the phase and amplitude of reflected wave in frequency domain. The P-matrix is calculated from the s-parameter, which is measured by the specially designed equipment like network analyzer. The distribution of group velocity of the elastic wave traveling on the piezoelectric substrate, a direction of acoustic axis and a direction of vibration should be completely analyzed for the optimal design of SAW radio transponder and for using piezoelectric materials such as $LiNbO_3$, quartz and $LiTaO_3$. The velocity of surface acoustic wave can be calculated with the use of elastic coefficient, piezoelectric constant, dielectric constant and density of the piezoelectric substrate such as $LiNbO_3$ and $LiTaO_3$ of which lattice structure composed in single crystal. Thus, a shape of inter digital transducers (IDT) finger can be designed on the basis of the characteristics of piezoelectric substrate, which is mentioned previously. In this study, the dimension and shape of the SAW IDT and reflector are designed as depicted in Fig. 1.

In Fig. 1, the substrate of SAW transponder assumed to be YZ-$LiNbO_3$ and the propagation velocity, v, is equal to 3488 m/s. If an operating frequency band is industrial science and medical (ISM) band of 315 MHz, a width of one IDT (a), spacing between fingers (b) and an acoustic wavelength can be described as following equations:

$$\lambda = \frac{v_p}{f} = 11.07\ \mu\text{m} \tag{1}$$

$$a = b = \frac{\lambda}{4} = 2.768\ \mu\text{m} \tag{2}$$

From the above equations and Fig. 1, a length of wireless transponder (d) and a length of finger (h) are 0.55 mm and 1.66 mm, respectively. A length of finger is designed as 100–200 times long as one acoustic wavelength to compress the effect of bulk acoustic wave (BAW) which is generated simultaneously with SAW from IDTs on SAW substrate [1].

The P-matrix is an essential idea to predict the efficiency of reflected wave, generated at the reflector IDT on SAW transponder and to evaluate the electro-mechanical coupling. An electro-mechanically coupled equivalent model of an IDT on piezoelectric substrate and the P-matrix are shown below [8] (Fig. 2(a)).

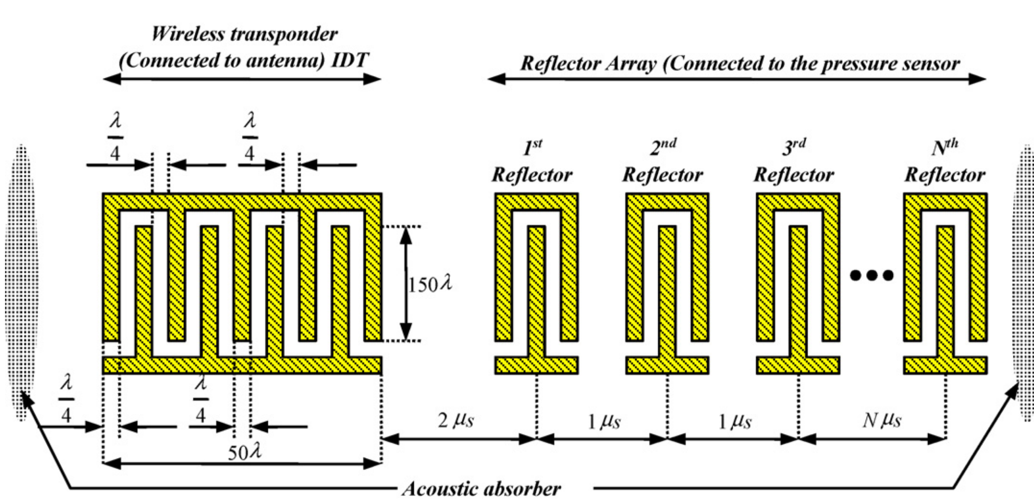

Fig. 1. The schematic illustration of SAW IDT for passive/wireless sensor system.