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A Wireless Identification System Using an Efficient Antenna Based on Passive Surface Acoustic Wave(SAW) Devices

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Abstract

A UHF band wireless identification system based on passive surface acoustic wave(SAW) devices is presented in this paper. SAW ID tags were fabricated on Y-Z $LiNbO_3$ piezoelectric substrate with a good electro-mechanical coupling property. To reduce degradation of the antenna performance associated with the piezoelectric materials, an efficient design of the SAW RFID antenna is introduced. By measuring the parameters of the SAW ID tag, the performance of the antenna was tested by experimentation.

Key words : Surface Acoustic Wave(SAW), RFID Tag, Antenna Efficiency, Piezoelectric Material.

Ⅰ. Introduction

A SAW ID tag system is a wireless communication system in which the radio link between the reader and the tag is furnished by modulated back-scattered waves, as one of many passive RFID systems. As SAW devices have the ability to respond quickly, interest has grown recently in the development of SAW ID tag systems for automobile non-stop charging, road sign identification and the positioning of railway trains. It has many advantages over other identification systems, such as a longer identification distance, the absence of a material link, a lower cost, improvements in terms of rejecting interference signals and a fast response capability, etc[1]. Several papers have been published regarding a 2.4 GHz ISM band SAW ID tag system, as well as a UHF band wireless ID system on a SAW device, etc[1],[2]. However, very few papers provide antennas for SAW ID tag systems, such as a patch antenna [3], or spiral structure[4]. Considering that the readable range is mainly dependent on the antenna gain and matching[5], the design role of an antenna in a SAW ID tag system is very important. Thus, this paper focuses on the relationship between a SAW device and its antenna in terms of radiation efficiency.

Ⅱ. Implementation of the Interrogator

A block diagram of the fabricated interrogator for a SAW ID tag is depicted in Fig. 1. The interrogator consists of a transmitter and a receiver that together are single heterodyne system with an 886 MHz RF and a 70 MHz IF and for which pulse modulation is used. The signal generated from the VCO is amplified and radiated to the SAW ID tag. A switch is used for isolation and modulation. The echoes from the SAW reflectors are transmitted to the receiver of the interrogator. The signal received by the antenna is amplified and filtered in the RF-range, and then converted to IF-range.

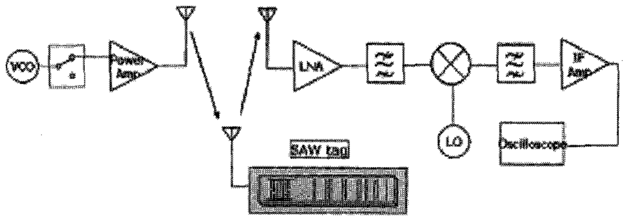

Fig. 1. The block of the interrogator for a SAW ID tag.

Given that RFID systems based on SAW devices use the same frequencies at Tx and Rx, leakage of the impulse amplified at the transmitter can lead to noise at the receiver. Thus, isolation between the transmitter and receiver is important at the interrogator. The parameters of the fabricated interrogator are shown in Table 1.

Table 1. The parameters of the interrogator system.

Transmit Power	30 dBm
System Gain	45 dB
Insertion Loss for Back-end Pulses	−40 dB
Isolation between Tx and Rx	−85 dB
System Sensitivity	−80 dB

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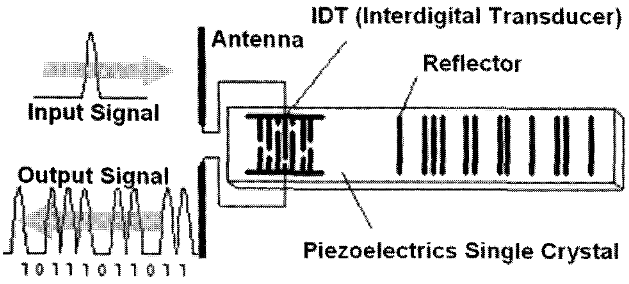

Fig. 2. SAW transponder configuration.

The readable range of a SAW RFID system can be written as following equation[6].

$$R_{\max} = \frac{\lambda}{4\pi}\sqrt[4]{\frac{P_o \times G_s^2 \times G_r^2}{k \times T_o \times B \times NF \times S/N \times D}} \quad (1)$$

where P_o denotes the Tx power, and G_s and G_r are the realized antenna gains of the interrogator and SAW transponder, respectively. D represents the insertion loss of the SAW device, B is the system bandwidth, λ is the free space wavelength of the system, and kT_0 indicates the thermal noise. As can be seen in Eq. (1), the maximum readable range of SAW RFID tags is primarily dependent on the antenna gain and the system sensitivity.

Ⅲ. Antenna Design for a Saw Transponder

The configuration of a SAW transponder is depicted in Fig. 2[7]. It consists of an antenna, an IDT(interdigital transducer), and a number of reflectors. The antenna connected to the IDT facilitates the transfer of an electromagnetic wave into a surface acoustic wave, and vice versa. Thus, it should have good impedance matching to the IDT and good efficiency.

In a SAW transponder, the antenna efficiency can be determined by the location of the SAW device. As piezoelectric materials have a high level of loss and high permittivity (85 in the z-axis, and 29.5 in the xy-plane), the dense electric flux density in the lossy piezoelectric material $LiNbO_3$ can decrease the radiated power of the antenna when the SAW device is close to the antenna. In addition, a piezoelectric coupling loss and a dielectric loss can decrease the antenna efficiency. When a SAW device is near a place where the current density of the antenna is high, a rapid decrease in efficiency and reduction in the radiated power of the transponder can occur. To reduce these losses, it is desirable that SAW devices are not close to the antenna.

A simulation for antenna efficiency based on the location of the SAW device on a meandered dipole antenna in disregard of a wire bonding is depicted in Figs. 3 and 4, and the results of the simulation are shown in Table 2. The antenna efficiency of the antenna is dependent on the location of the piezoelectric material and the distance from the piezoelectric material to where the current density in the antenna is high. Fig. 3 means the severe mismatching loss and Fig. 4 shows the loss due to the piezoelectric material. Fig. 5 shows the loss versus the distance from the interrogator according to the antenna efficiency in the fabricated remote wireless identification system based on passive SAW device. The loss also includes a piezoelectric loss, a path loss as well as an antenna gain. As is shown in this figure, greater than 10 dB of received power is dependent on the differences in the antenna efficiency. This causes a decrease of more than tens of centimeters in the readable range, considering the sensitivity of the receiver. Thus, consideration of these effects of SAW devices during the design process is required.

SAW devices also can affect the impedance and the operating frequency of the antenna. A SAW transponder

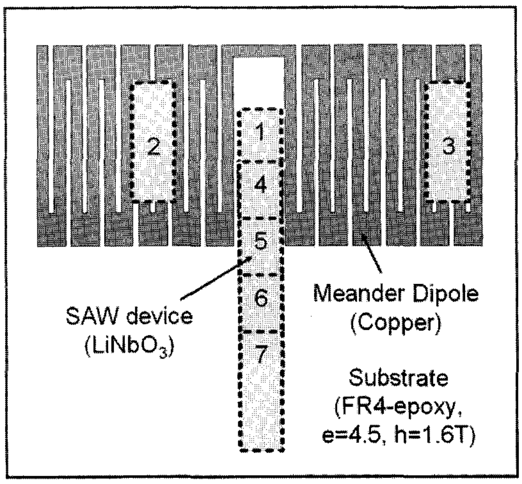

Fig. 3. Location of the SAW device on meander dipole.

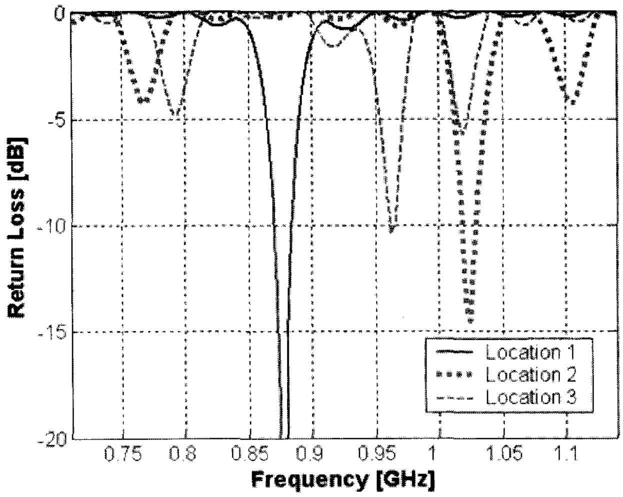

Fig. 4. Simulated return loss for various locations of the SAW device.

Table 2. Efficiency for various locations of the SAW device.

Location Number	#1	#2	#3	#4	#5	#6	#7
Efficiency (%)	56	33	41	77	86	89	95

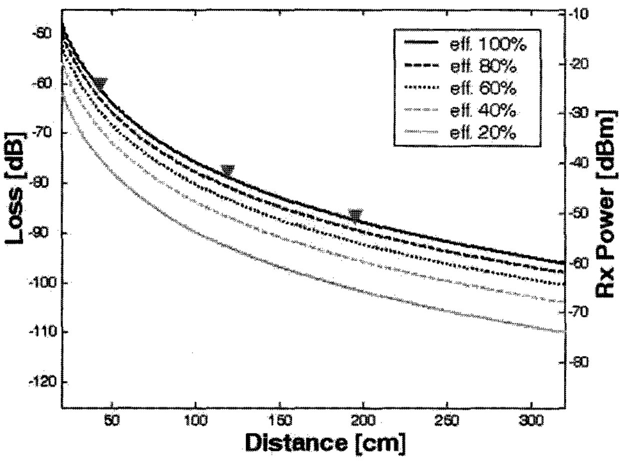

Fig. 5. Loss versus the distance from the interrogator according to antenna efficiency.

does not provide a large space for the matching network. Accordingly, considering these characteristics, a matching structure that has a freedom of design with a good compatibility to two-wire transmission lines in addition to compactness, such as what is found in a T-matching structure[8] or an inductive coupling structure[9] is effective and required for a SAW transponder.

Ⅳ. Experiments and Measurements

Fig. 6 shows the proposed antenna structure designed considering the efficiency and matching of a SAW device. A small-sized dipole antenna with curled arms is designed to provide distance from the SAW device. Due to this space, the antenna can overcome the loss from the piezoelectric material. In Fig. 6, the SAW device lies apart from the antenna wire in order to minimize degradation of the radiation efficiency. With the T-matching structure, the dipole antenna input impedance is matched to 50 ohm, which is the IDT impedance of the fabricated SAW device. The IDT electrode is wire-bonded to the antenna port. A rigid substrate was used for the antenna fabrication in order to secure the SAW device.

The proposed antenna is fed by a balanced port, and the input impedance of such an antenna is conventionally measured by using a balun that forces opposite and equal currents in each part of the radiator. However, even if an impedance calibration is performed, there are subtle effects such as stray capacitance, thus the exact impedance will not be as expected. In other words, the accuracy of the impedance relies on how ideal the balun is. Thus, researches on measurements without the balun, using for example as S-parameter method that requires neither a balun device nor a large ground plane, as well as an image method that uses an infinite ground plane and an image theory have been reported[11],[12]. In the case of the proposed structure, an image method was used for the measurement of the input impedance, and this is shown in Fig. 7.

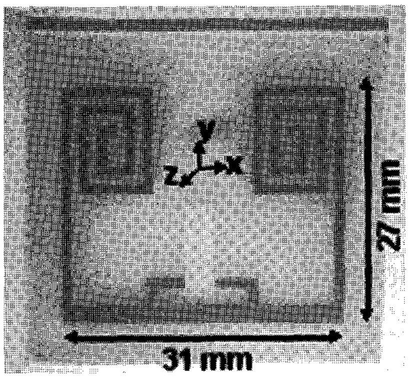

Fig. 6. The fabricated SAW transponder.

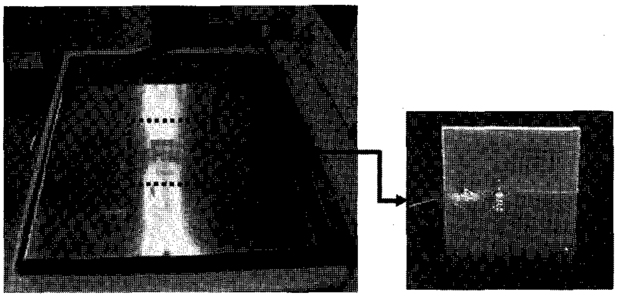

Fig. 7. The measurement setup that analyzes the input impedance of the proposed antenna using the image method.

The reflection coefficient of the fabricated antenna for SAW ID tag can be calculated by the following equations (Eq. 2)[13].

$$Z_{image} = \frac{1+\Gamma_{image}}{1-\Gamma_{image}} \times Z_O$$

$$Z_{proposed} = 2 \times Z_{image}$$

$$\Gamma_{proposed} = \frac{Z_{proposed} - Z_O}{Z_{proposed} + Z_O} \qquad (2)$$

The measured return loss is shown in Fig. 8. The radiation is omni-directional in the y-z plane with a radiation efficiency of approximately 93 % with 0.85 dBi of the simulated realized gain. An identification experiment using the proposed antenna was performed, with the results displayed in Table 3 and marked by triangles in Fig. 5. Received powers were recorded through a spectrum ana-

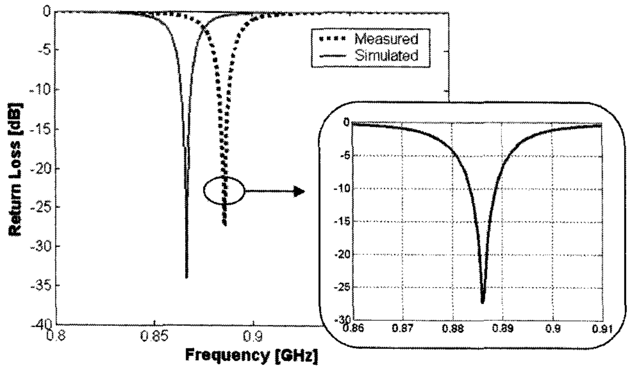

Fig. 8. Measured return loss of the antenna using the image method.

Table 3. Experimental Rx Power.

Tx Power [dBm]	Distance [cm]	Measured Rx Power [dBm]	Calculated Rx Power [dBm]
36	35	−28	−26.24
36	120	−44	−46.94
36	190	−55	−57.62

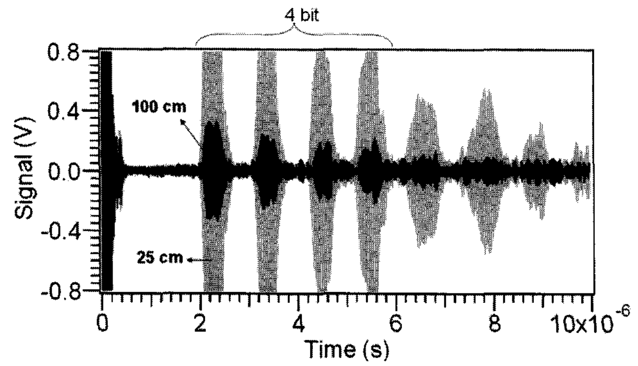

Fig. 9. Pulse response of a four-bit SAW transponder apart at distances of 25 cm and 100 cm.

lyzer connected with an Rx antenna. The measured Rx powers were similar to the calculated ones.

Fig. 9 shows the time domain pulse response of a four-bit SAW transponder at distances of 25 cm and 100 cm. Shown is a drop-off in the strength of the received signal as the transponder is farther away. The signals following the four-bit signal are echo pulses that result from the finger-paired reflectors. They can be eliminated by a wave absorber at the transponder edge.

V. Conclusion

In this paper, a UHF band wireless identification system based on passive surface acoustic wave devices is presented. SAW ID tags were fabricated on a Y-Z $LiNbO_3$ piezoelectric substrate with a good electro-mechanical coupling property. To reduce the degradation of the antenna performance associated with the piezoelectric materials, an efficient design of the antenna for SAW ID tags was introduced. The design minimizes the decrease of the radiation efficiency from the SAW device, as shown by the experiments performed. From an identification measurement of a SAW ID tag, the antenna performance was tested via experimentation. The proposed antenna is based on these considerations. This antenna is viable for use as an antenna for a SAW transponder.

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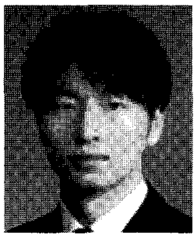

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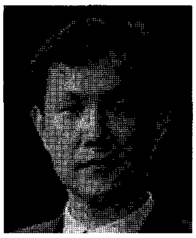

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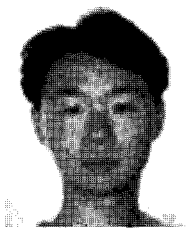

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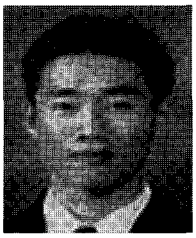

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