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A Post Processing Procedure for Surface Acoustic Wave RFID Using COMSOL

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Abstract— In recent years, much attention has been paid to SAW RFID research and its applications. Many methods have been proposed for coding the SAW RFID tags [1]-[4]. Among this, best provided methods for coding these devices is time position and phase encoding. The data capacity of the tags is significantly enhanced by extracting additional phase information from the tag responses [5].However post processing of the tag in simulation and extraction of the phase from Interrogated signals of the tag is complicate and time consuming. In this work, we have proposed a simple post processing method using COMSOL Multiphysics to find the exact phase of the Interrogated signals of the tag.

Index Terms— Surface acoustic wave, SAW RFID tag, Piezoelectric, IDT.

I. INTRODUCTION

In recent years, much attention has been paid to SAW RFID research and applications [1]-[4]. SAW RFID has many unique advantages over the competing technologies, for example, it functions over wider temperature range up to 350oC, it is essentially passive and chipless. These tags are simply fabricated using single-metal-layer photolithographic technology which is a standard tool today in IC fabrication. Therefore, SAW RFID can be used to provide good solutions to the problem of identification in harsh environments where IC-based RFID (semiconductor-based RFID) have been failed to fulfil the needs of high-tech industry.

SAWs are ultrasonic waves propagating along the surface of solids. The intensity of the SAW is confined more or less within 1 λ thickness of the substrate. The operation of SAW devices is based on piezoelectricity, a coupling between a material's electrical and mechanical properties. In certain dielectric crystals, the application of mechanical stress produces an electric polarization. Conversely, such a crystal undergoes a mechanical distortion when an electric field is applied. This property is used in SAW devices and in many other applications to produce a mechanical output from an electrical input or vice versa.

The principle of operation of a SAW tag is shown schematically in Figure 1. Substrate in SAW tags is usually made of a material with strong piezoelectricity, such as $LiNbO_3$ and Quarts. In start of operation, reader emits an Interrogated Signal towards the tag. This signal is received by the tag antenna and is converted to Surface acoustic wave by the IDT. The generated SAW pulse then propagates along the surface of the substrate. The SAW pulse is partially reflected and partially transmitted by each of the code reflectors, placed at precisely determined positions on the substrate. The reflected SAW pulse returning to the IDT carries a code based on the positions of the reflectors and is then reconverted into an electrical form and retransmitted by the tag antenna. The response signal is detected and decoded by the reader.

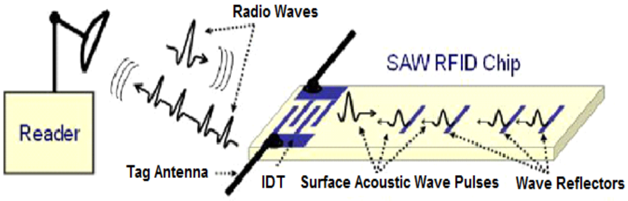

Fig. 1: Operation of a SAW tag system [7]

Recently, several methods have been proposed for coding the SAW RFID tags. Best provided method for coding these devices is time position and phase encoding because for this case, the data capacity of the tag is significantly enhanced by extracting additional phase information from the tag responses [5]. However post processing of the tag and extraction of the phase from Interrogated signals of the tag is complicate and time consuming. In recent studies very complicated post processing in FEMSAW and MATLAB [5]-[6] was carried out to do this task. In this work, first in section 2, we review the mostly used coding method on RFID tags. Then in section 3, propose a simple post processing method using COMSOL Multiphysics to obtain the exact phase of the Interrogated signals of the tag. To save computation time, a 2-D model is proposed.

II. REFLECTOR CODING ON SAW RFID TAGS

In the following section we review the used coding method that commonly used in RFID tags.

A. Time Position Encoding

In time position encoding, a time window is reserved for each code reflector. As shown in Figure 2, this time window is divided into five slots, one of the first 4 of which is occupied by a reflector. In other words, each reflector has 4 possible positions, corresponding to 2 bits of data [5].

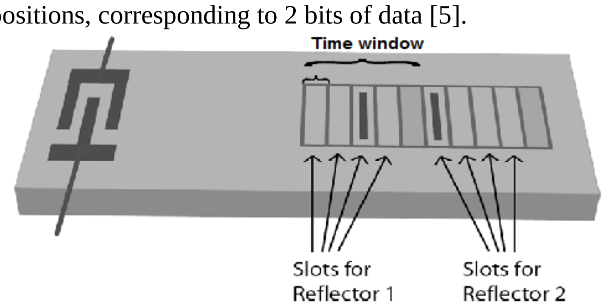

Fig. 2: Principle of time position encoding [5].

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B. Time Position and Phase Encoding

A significant enhancement of data capacity can be achieved by combining time position encoding with phase encoding and uses both the time delay and phase information of reflected pulses. This scheme consists of placing the reflectors more precisely within their slots. We introduce phases of 0◦ , −90◦ , −180◦ , and −270◦ by shifting the reflector positions by multiples of λ /8, as depicted in Fig. 3. When the combined time position and phase encoding is used, each reflector has 4 possible time positions and 4 possible phases. This sums up to 16 different states and corresponds to 4 bits of data[5].

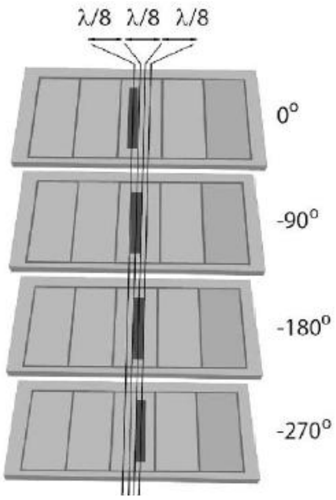

Fig. 3: Principle of phase encoding. Proportions are not correct [5].

III. POST PROCESSING OF THE SAW RFID TAGS

In pervious section we showed that reflectors on the tag can be used as a coder and reflected signal from these coders contain the information of code reflectors. So in our simulation, we need to decode the response of the tag and extract phase of Interrogated signal of the tag. In recent studies very complicated post processing in FEMSAW and MATLAB has been proposed to carry out this task. In this work, we propose a simple post processing method using COMSOL Multiphysics to obtain the exact phase of the Interrogated signals of the tag.

The procedure for phase calculation of the signal is as given below. If the input signal applied to input IDT is $S_i = A_i \cos(\omega t + \varphi_i)\, \text{rect}(t/\tau)$, then the output signal are $S_f = A_f \cos(\omega t + \varphi_f)\, \text{rect}(t/\tau)$, where $\text{rect}(x) = 1$, when $0 < x < 1$ and $\text{rect}(x) = 0$ Otherwise; τ is the width of the defined rectangular pulse; ω is the input IDT's harmonic frequency; A_i and φ_i are the amplitude and initial phase of the input signal, respectively; and A_f and φ_f are the amplitude and initial phase of the final output signal, respectively. By multiplying $\sin\omega t$ and $\cos\omega t$ with S_f, respectively, we have

$$S_I = A_f \cos(\omega t + \varphi_f) \sin \omega t.rect(t/\tau)$$
$$= \frac{1}{2} A_f (\sin(2\omega t + \varphi_f) - \sin \varphi_f).rect(t/\tau), \quad (1)$$
$$S_Q = A_f \cos(\omega t + \varphi_f) \cos \omega t.rect(t/\tau)$$
$$= \frac{1}{2} A_f (\cos(2\omega t + \varphi_f) + \cos \varphi_f).rect(t/\tau), \quad (2)$$

Then S_I and S_Q pass through low pass filters, so the signals with frequency 2ω are filtered out, and the output becomes:

$$I = -\frac{1}{2} A_f \sin \varphi_f .rect(t/\tau), \quad (3)$$
$$I = -\frac{1}{2} A_f \sin \varphi_f .rect(t/\tau), \quad (4)$$

Thus, phase can be calculated as

$$\varphi_f = -\tan^{-1} \frac{I}{Q}. \quad (5)$$

We intend to perform this procedure on the reflected signal from tag. First, we use a sample tag with just one reflector to show the applicability of the method is practical. We then perform this procedure on a tag with 5 reflectors.

A. Simulation of Sample Tag

The sample tag has one reflector and one IDT is placed on LiNbO3 substrate. One period of IDT or reflector consists of 2 electrodes whose wavelength, λ is 4 µm. Pitch of electrodes, p, is 2 µm, and thickness of electrodes h is 0.2 µm. A layer of air with a thickness of 0.5µm has been assumed to exist on top of the substrate. The boundary conditions of substrate are explained below. Free boundary condition is given to the top surface of the substrate and The Bottom surface is assumed fixed in its position. Piezoelectric Devices (pzd) module was employed in this simulation. For having the best accuracy, the model was meshed with pre-defined "Extremely fine" parameter on the surface of substrate and "Normal" parameter in the other places. In this simulation, we use time dependent analysis.

The response signal of this tag is multiplied with $\sin\omega t$ and $\cos\omega t$, respectively using COMSOL equations, then we use Electrical Circuit (cir) module to simulate low pass filter performance. In this module all the components are electrical components. We use a resistor and a capacitor which is attached together in series to show performance of a low pass filter. One of the signals is shown in frequency domain in figure 4, before and after filtering. We see that the component of signal with frequency of 2ω is filtered out.

After filtering, phase can be calculated as shown in figure 5. In this figure, time response and phase response of the tag are shown simultaneously. As seen the phase of reflector is 1.25 rad (143°).

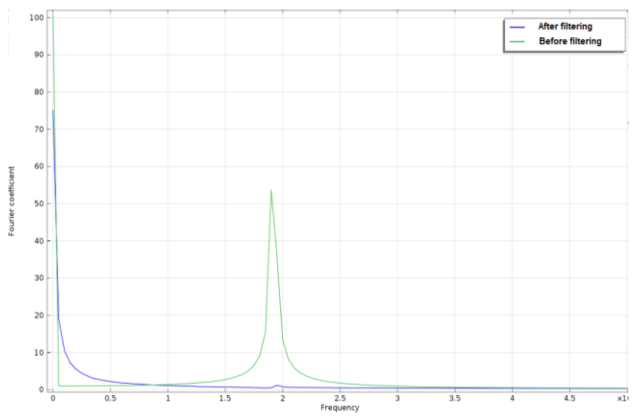

Fig 4: Signal in frequency domain before and after filtering

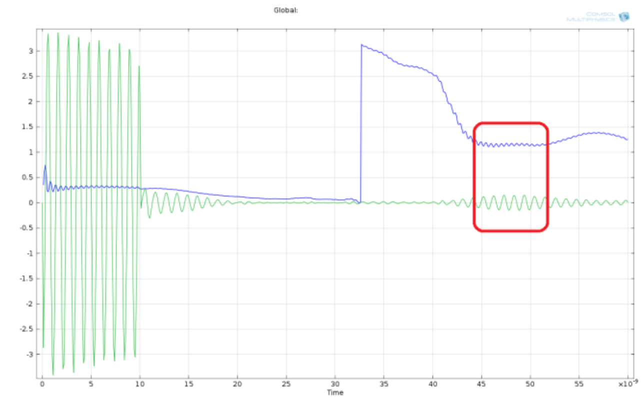

Fig 5: time response and phase response of the sample tag

When the reflector is shifted in space, a change in the phase is observed. For example, if we displace the reflector in λ/8 (1μm), we will observe that the phase is 0.42 rad (48°)(Fig 6). As expected, the phase difference is 90°.

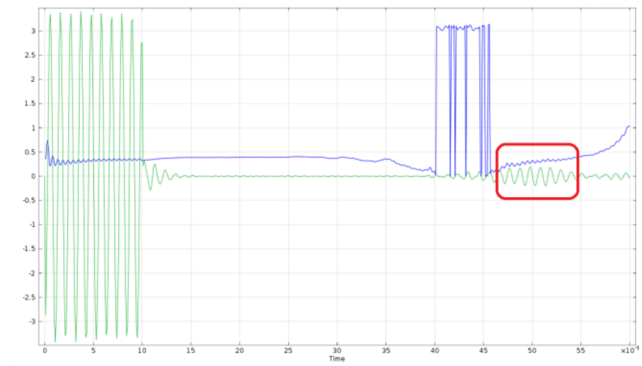

Fig 6: time response and phase response of the sample tag after displacing the reflector

B. Simulation of Tag with 5 Reflectors

In this section, we simulate a tag with 5 reflectors. The structure of the device is shown in Figure 7. The distance from IDT to first reflector is 20 λ. The distance between reflectors is 10 λ. The input signal is $A\cos(\omega t+\varphi)\mathrm{rect}(t-\tau)$, where A equals 0.5 V; φ is a random initial phase; ω is 856 MHz and τ is 10 ns. In this simulation, we use time dependent analysis. IDT structure and boundary conditions of substrate are as section 3.2. Device simulation results are shown in Figure 8. In this figure, the first peak is reflected signal from first reflector and the following 4 are the output voltage amplitudes which are reflected from following 4 reflectors. The result, for proposed procedure for calculating the phase, is shown in figure 9. As seen in this figure, the phase of the signal in each reflector is easily filtered out.

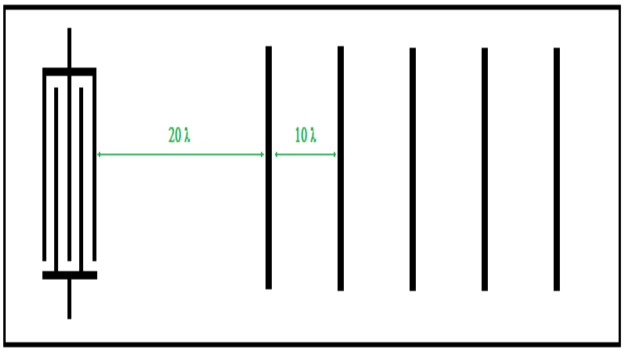

Fig. 7. Structure of the Tag with multi reflectors

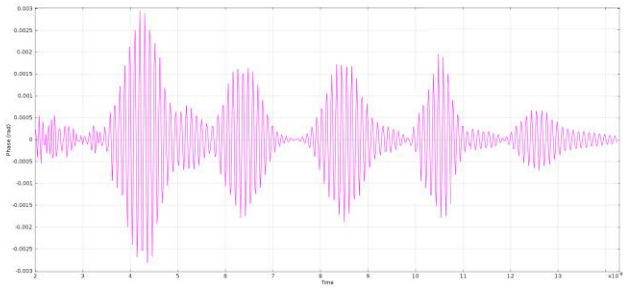

Fig. 8. Tag response in time domain

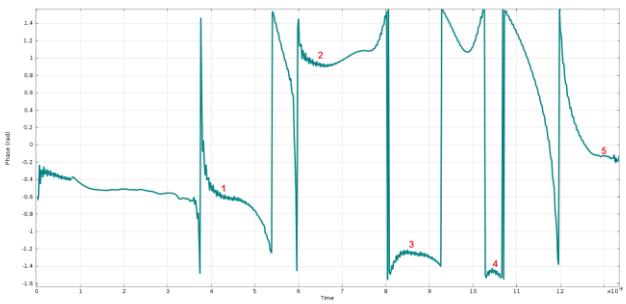

Fig. 9. Phase of Interrogated signal

IV. CONCLUSION

In recent works, many methods have been proposed for coding the SAW RFID tags. One of the best provided methods for coding these devices is time position and phase encoding, because the data capacity of the tag is significantly enhanced by extracting additional phase information from the tag responses. However post processing of the tag and extraction of the phase from Interrogated signals of the tag is complicate and time consuming.. In this work, we proposed a post processing method using COMSOL Multiphysics to obtain the exact phase of the Interrogated signals of the tag and used a sample tag with 1 reflector to show that this method is practical, and then performed this procedure on a tag with 5 reflectors. We observed that the proposed method is very simple in comparison with the recent methods. Also this procedure saved the computation time.

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