Encoding of passive anticollision radio-frequency identification surface acoustic waves tags

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***Abstract*—This paper describes the encoding of anticollision radio-frequency identification tags based on surface acoustic waves. The study is based on the tag model with specific topology, which allows us to receive a response signal with time–frequency information. This research considers the collision case for several passive tags. Therefore, the proposal is to analyze the possibility of using several distinctive signs like frequency and time. We consider the model of passive surface acoustic wave tag, which contains piezoelectric substrate, interdigital transducer, and consecutive orthogonal-frequency-coded structures, which are placed in time slots. Similar topology makes possible the reliability of increasing tag identification in the collision case.**

***Keywords*—RFID, passive tag, anticollision, surface acoustic waves, OFC, SAW**

I. Introduction

Radio-frequency identification (RFID) technology, surface acoustic waves (SAW) technology, and the ultra-high frequency of SAW RFID devices with low power allow creating devices and solving issues for different applications. These systems allow remote control and detection of different objects and they can measure vehicle speed and temperature. At the base of RF instruments is an integrated principle of work, which is based on piezoelectric properties of materials that provide high operational speed, a high level of environmental friendliness, and safety in comparison with the existing systems of identification [1, 2, 3]. However, collision of the passive SAW RFID tags hinders the development of passive SAW RFID technology in industry. The collision problem for passive SAW tags leads to incorrect identification and encoding of each tag. When several tags are placed at the same time in the read field, the response signals cover each other in the time domain. This causes problems in identifying and encoding each tag. In this paper, we suggest an approach for identification of several passive SAW tags in the collision case. In general, SAW RFID tag readers define an identification code, which depends on the time delay. The time delay depends on the tag topology and the reflector's placement on it. A variety of reflector placements in slots determine the number of unique identification codes. However, in the case when the reader simultaneously interrogates several passive tags, it increases the probability of coincidence of the code groups, resulting in misidentification. This case can occur, for example, with freight cars and goods. During our research on SAW RFID tags, we combined OFC coding and time–position coding.

II. Time–Position Encoding for a Passive SAW RFID Tag Model

In general, passive SAW tags are represented as the delay line blocks with reflectors placed in time slots [4, 5, 6]. The design of such tags is shown in Fig. 1.

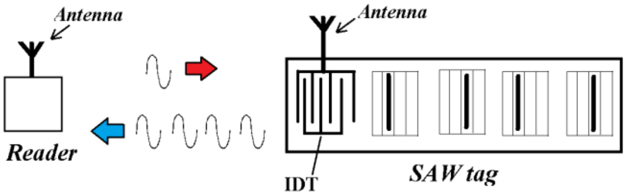

Fig. 1. Simplified model of a typical SAW RFID passive tag.

In this model, the RFID reader interrogates the passive SAW tag. In the interdigital transducer (IDT), the electromagnetic signal is transduced to an acoustic wave, which propagates along the piezoelectric substrate ($LiNbO_3$ or $LiTaO_3$). Thus, the response signal is represented by time-delayed pulses. The time delay between each pulse is determined by the SAW tag topology. The RFID reader processes the received signal and provides the possibility of getting the identification code [7, 8, 9]. It should be noted that the described coding is also called time encoding for the SAW RFID tag. It relates to distances between reflectors in the tag's topology. There are several approaches for SAW RFID tag coding:

a) The binary tag identification code is determined by the location of the reflector. In this case, the presence or absence of a response signal determines one bit of data.

b) Tags reflectors are placed in time slots. There are *N* slots for each tag total. For each tag, we have *N* reflectors and only one reflector in each slot. Specific reflector's position determines *N* possible time delay variants.

Reflector's absence or presence in each slot position determines one bit of data. The total number of possible variants of identification codes is related to passive SAW tag topology limitations and tag's size.

For this encoding method, the pulse width is approximately doubled to ensure a clear separation of adjacent positions that impulses can occupy [7, 8, 9]. In this case, each subsequent reflector decreases signal amplitude.

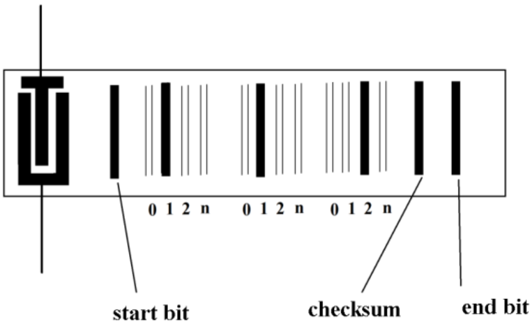

Fig. 2. Time encoding for passive SAW RFID tag.

In this case, a start pulse (reference pulse) is needed to provide timing synchronization for the received data pulses. Each impulse occupies one of the *N* possible time positions. This pulse encodes the corresponding data group of two bits. In addition, between data groups were added free of impulse gaps. Usually, the reader emits an interrogation signal in the form of a chirp signal. The response signal and the interrogation signal are shown in Fig. 3.

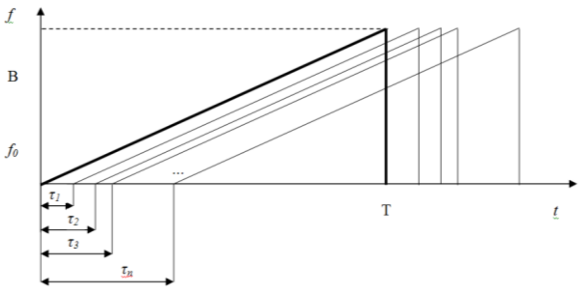

Fig. 3. Interrogation chirp signal and response signal (without loss): Bold—interrogation signal.

The time coding is used for passive tags limits capabilities of a SAW RFID system in the simultaneously tag reading case (collision). The topology that was described above is based on the time delays' measurement. It significantly reduces the number of unique identification codes for passive SAW tags. The total number of identification codes is limited by tag topology and reflectors' placement variants in time slots. In this way, only time encoding for passive SAW tags does not solve the collision problem.

A model for a passive SAW tag with time encoding is represented in Fig. 4. This model is designed in Simulink and built as a delay line [10].

This model forms the response of the passive tag. Here, the input signal goes to input 1. The delay of the response pulses is proportional to the distance propagated by the interrogation signal of the reader to the *i*th reflector, located on the passive tag. The model uses four reflectors. The delay time of each pulse reflected from the *i*th reflector is set in the "Time Delay" blocks. The received response pulses are summed in the "Sum" block and go to the output.

We suggest using frequency and phase information for SAW RFID tags' encoding. It increases the unique identification code numbers and decreases the possibility of incorrect tag identification.

III. Time–Frequency Encoding of Passive SAW RFID Tag with OFC Structures Placed in Time Slots

The radio-frequency reader interrogates tags using the signal [10]:

$$S(t) = \left[h(t - T_1') - h(t - T_2')\right] \cdot A \cdot \sum_{i=1}^{N} \sin\left(2 \cdot \pi \cdot F_i \cdot t - \varphi_i\right), \quad (1)$$

where T_1' and T_2' are the initial and finite times of the interrogation pulse, A is the pulse amplitude, F_i is the frequency of the pulse, φ_i is the phase of the pulse, and N is the number of pulses for one period of the interrogation signal.

The tag's response is formed in the IDT in the form of a pulse sequence:

$$S(t) = \sum_{i=1}^{N} \left[h(t - T_{1i}') - h(t - T_{2i}')\right] \cdot A_i \cdot \sin\left(2 \cdot \pi \cdot F_i \cdot t - \varphi_i\right), \quad (2)$$

where T_{1i}' and T_{2i}' are the initial and finite times of the response pulse.

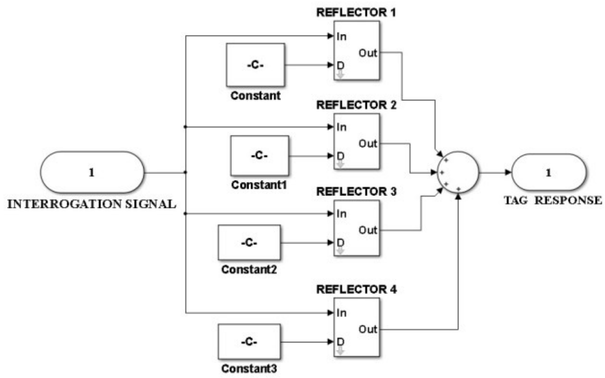

Fig. 4. SAW RFID model as a time delay in the Simulink.

This research takes a simple model with four slots and one reference reflective structure. This model uses time slots T_1–T_{12}, as shown in Fig. 5.

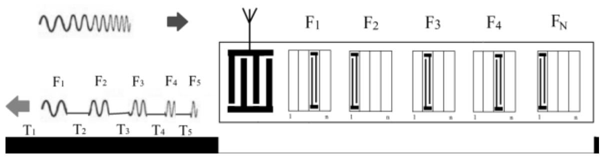

Fig. 5. Passive tag with reflective structures in the slots.

In this model, the position of the reflective structure in the time slot is matched with a certain frequency; it determines the binary code. The first slot has durations from T_1 to T_3, second from T_4 to T_6, third from T_7 to T_9, fourth from T_{10} to T_{12}. Time slots $T_{i1} = T_4 - T_2$, $T_{i2} = T_7 - T_6$, and $T_{i3} = T_{10} - T_9$, are set between slots containing reflective structures [11].

The availability of time–frequency attributes allows the creation of a time–frequency matrix for tag *A*, which is shown in Fig. 6.

	T_2-T_1	T_3-T_2	T_4-T_3	T_5-T_4	T_6-T_5	T_7-T_6	T_8-T_7	T_9-T_8	$T_{10}-T_9$	$T_{11}-T_{10}$	$T_{12}-T_{11}$
F_1	0	1	0	0	0	0	0	0	0	0	0
F_2	0	0	0	0	1	0	0	0	0	0	0
F_3	0	0	0	0	0	0	0	0	0	0	0
F_4	0	0	0	0	0	0	0	0	0	0	0

Fig. 6. Time–frequency matrix for tag *A*.

Thus, using information about time and frequency of the first tag, the RFID reader forms the binary code A_2 = 01001000000. Zeros fill spacing between slots. Placement of the reflective structure in a certain position denotes either "0" or "1." The reflected signal from tag *A* in the time domain is shown in Fig. 7.

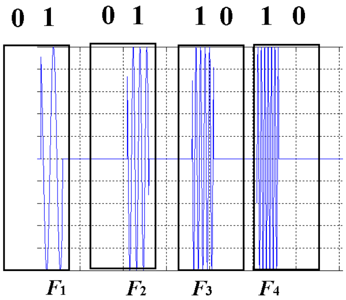

Fig. 7. Response signal of the passive SAW tag *A*.

Here, T_d is the pulse length, T_{slot} is the time slot boundary, T_s is the shift time of the reflective structure. Using time intervals and frequencies of pulses at the collision situation moment allows building the time–frequency matrix. Then, shifting both matrices in the time domain with a given step allows them to be separated.

	T_2-T_1	T_3-T_2	T_4-T_3	T_5-T_4	T_6-T_5	T_7-T_6	T_8-T_7	T_9-T_8	$T_{10}-T_9$	$T_{11}-T_{10}$	$T_{12}-T_{11}$	$T_{12}-T_{13}$
F_1	0	1	1	0	0	0	0	0	0	0	0	0
F_2	0	0	0	0	1	1	0	0	0	0	0	0
F_3	0	0	0	0	0	0	0	0	1	0	0	0
F_4	0	0	0	0	0	0	0	0	0	0	1	1

Fig. 8. Time–frequency matrix of tags *A* and *B*.

Similarly, we obtained the code of tag B_2 = 01001001001. Forming two time–frequency arrays *A* and *B* allows us to create a model of the tags' collision.

A shift of matrices *A* and *B* relative to each other with the pitch T_{slot} creates the *A* and *B* tag codes. The resulting matrix *C* that was shifted by one step is shown in Fig. 8.

The code bits that trapped the separation intervals $T_{i1} = T_4 - T_3$, $T_{i2} = T_7 - T_6$, $T_{i3} = T_{10} - T_9$, $T_{i4} = T_{12} - T_{13}$, determine the place of the reflective structure of tag *B*. The presence of a reference pulse makes it possible to separate tags in the given frequency range from F_1 to F_2.

Specific passive SAW tag topology allows us to get time–frequency information for coding, which is represented in Equation 2. It provides the possibility to build a time–frequency matrix in the reader. The reader processes the response signals and executes the anticollision algorithm.

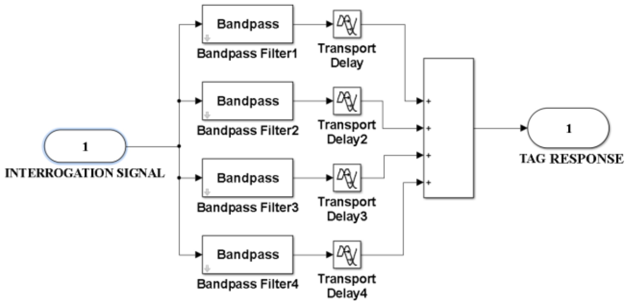

Fig. 9. A simplified model of the passive SAW RFID tag with time–frequency information.

We consider the collision case between two passive tags *A* and *B*, with the same number of reflecting structures and different identification codes.

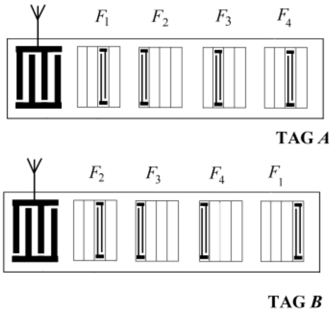

Fig. 10. Collision case for two SAW tags.

As is shown in Fig. 10, the first and third structures of tags *A* and *B* are placed in the same time slot places. In this way, these structures have different central frequencies. For the first tag, we have F_1, F_2, F_3, F_4 and for the second tag F_2, F_3, F_4, F_1. The reader receives reflected signals from the passive tags, which contain information about frequencies and time delays. As a result, the reader creates a matrix, which is shown in Fig. 11.

The reader uses this information and makes a shift of columns in the time domain. This shift is equal to the $T_{12} - T_1$ interval. Thus, information about frequency and time delays allows highlighting the identification code of each tag in the collision case. For tag *A*, the code is 01 10 10 10. For tag *B*, the code is 01 01 10 01.

IV. RESULTS

As is shown in Fig. 11, the signal received from the SAW passive tag with four reflectors comes to the RFID reader. The signal comes to the inputs of four parallel-connected band-pass filters. If one of the response pulses has its frequency matched with the frequency range of the bandwidth, it comes to the frequency counter and then to the delay detection unit. Each delay detection unit determines the delay between pulses and compares it with the given delays matrix in the reader's memory. The presence or absence of a signal in the specific interim means that the reader writes this information in the matrix in Boolean data format.

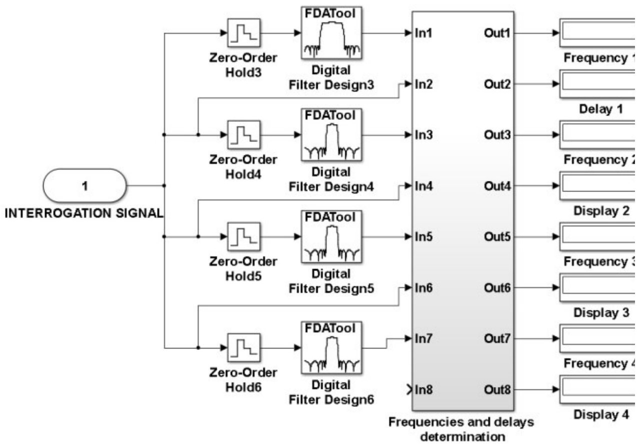

Fig. 11. Model of the SAW RFID system in Simulink.

After shifting of columns, we get two identification codes. Thus, we can separate the tags from each other using time–frequency information.

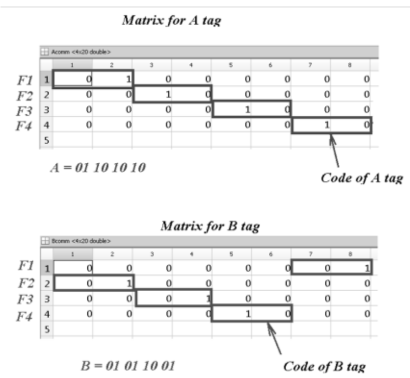

Fig. 12. Matrix for tags *A* and *B* in the collision case.

This anticollision identification approach can also be applied for temperature measurement in the switchgears and other high-voltage devices. SAW RFID based on devices allows us to carry out monitoring of temperature. Temperature alters correlation properties of the tag response. As a rule, response signal modulation allows us to get a temperature value from each tag. As an example, we consider the innovative technology of wireless passive temperature sensors, which have already been used for a real-time online monitoring system. Passive wireless temperature sensors are installed in the contact point of the distribution equipment to measure the contact temperature. An antenna is installed in the line of sight from the sensors to provide wireless communication with the temperature sensor. The temperature reader is placed in the compartment of the automatic devices. If the sensor temperature exceeds the specified threshold level, the reader indicates the event on the LED panel and sends a message to the automation system by the commutation relays. The reader transmits the temperature data to the industrial computer by an RS-485 interface. The industrial computer is connected to a local network. In this case, the operator can view and analyze the temperature data by web access.

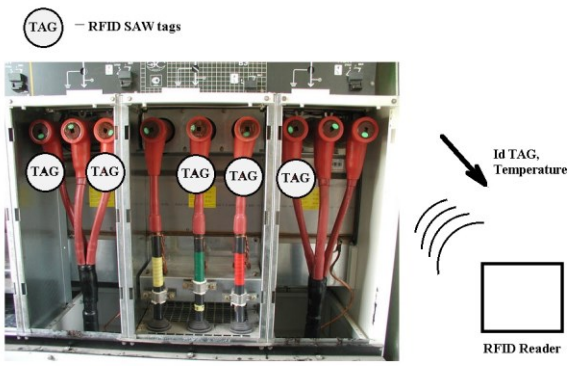

Fig. 13. Example of application in a multisensor system for the control of electrical equipment's temperature.

In general, such systems use only one sensor for wireless monitoring. Our solution expands the possibilities for RFID wireless temperature monitoring systems based on the passive SAW sensors [12]. SAW RFID tags with time–frequency information provide the possibility of increasing number of passive temperature sensors for one switchgear. In this case, we could potentially use at least seven tags.

Thus, the temperature measurement example explains real-world measurement results. In addition, it illustrates the basic idea of how to realize our solution in practice.

V. CONCLUSION

In this paper, we propose a model that allows solving the collision problem using the frequency–time separation of passive SAW tags. Specific reflective OFC structures, which are placed in time slots on the surface of the piezoelectric substrate, make it possible to get a unique identification code, which contains time–frequency information. Reflectivity structure positioning and its placement in the time slots determine the total number of codes and decrease the possibility of incorrect identification.

Our approach is based on a combined coding method including orthogonal-frequency coding and encoding of the pulse time position. The combined coding method allows us to increase the number of tags that are interrogated simultaneously.

Anti-collision algorithm potentiality increases the number of identification tags and any passive wireless smart sensors. The number of variants for placing reflective structures in time slots, the number of slots, as well as the technological capabilities of producing SAW devices and the dimensions of the piezoelectric material substrate determine the number of identified tags.

Our research covers the application of the SAW RFID tag in temperature measurement in the electrical industry. As is shown above, we increased the number of possible sensors.

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