Small Meandered PIFA Associated with SAW Passive Sensor for Monitoring Inner Temperature of a Car Exhaust Header

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ABSTRACT: Wireless sensors based on passive Surface Acoustic Wave (SAW) technology serve to accurately determine physical quantities in harsh environments. In this paper, we present a meandered Planar Inverted-F Antenna (PIFA) with a small ground plane designed to be associated with a SAW sensor to monitor the inner temperature of a car exhaust header. The SAW sensor, the design of the antenna, the association of both elements and some wireless interrogation results are presented.

INTRODUCTION

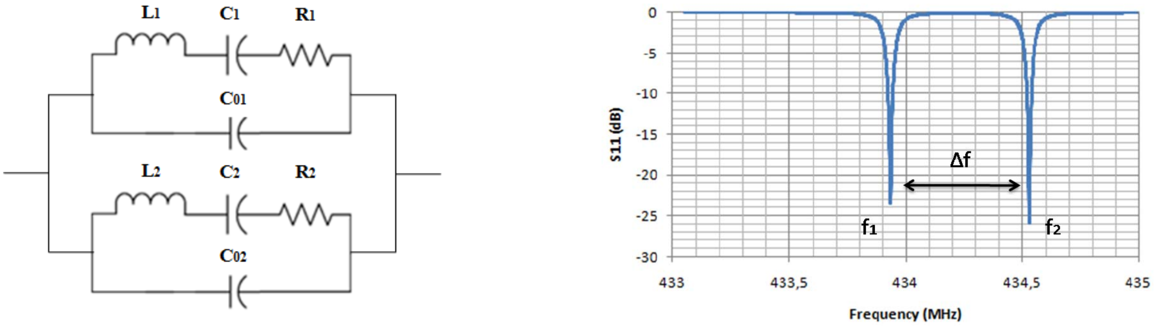
The rapid progress of microelectronics induces the shrinkage of small communicating objects. Consequently, the demand for low-profile and miniature antennas is constantly increasing. One example is the contactless domain in one of the European ISM band [433.05MHz–434.79MHz]. Surface Acoustic Wave (SAW) sensors are able to measure various physical parameters like temperature, pressure, and stress without power supply battery [1-2]. One SAW sensor application consists in temperature measurement of engines in order to monitor over-heating. However, the vicinity of several metallic parts and the small available space for the antenna/sensor structure are difficulties to overcome. Indeed, metallic environment generally degrades an antenna performance. Moreover, at 433MHz, the miniaturization of the antenna toward a reasonable size is also a big challenge (the dimension of a $\lambda/4$ monopole being 17cm). During these last years, a lot of small Planar Inverted F Antennas (PIFAs) with very satisfactory radioelectric properties have been developed [3-4]. This class of antennas could be suitable for our application.

In this paper, we present a small PIFA matched to a 50Ω SAW sensor for monitoring the inner temperature of a car exhaust header. The paper is divided into three main sections. First, we introduced the SAW sensor and the wireless interrogator. In the second part, we describe the design of the antenna. In the last section, simulated and measured results of the antenna/sensor association are presented and discussed. All simulations are carried out with Ansoft High Frequency Structure Simulator (HFSS) software.

SAW SENSOR AND WIRELESS INTERROGATION

A SAW sensor is composed of an InterDigital Transducer (IDT) and reflectors placed onto a piezoelectric substrate. Such a devices use the piezoelectric effect to convert an incoming electromagnetic wave into a mechanical wave. Changes in temperature modify the elastic constant of the substrate which induces a modification of the velocity of the mechanical wave propagation. There are two different types of SAW sensors that allow the determination of different physical quantities: resonator sensors and delay line sensors [5]. SAW resonator technology is used in this work.

A resonator can be modeled by a Butterworth Van-dyke equivalent circuit. In this model, the circuit is composed of two resonant parallel RLC network (fig.1a) in order to limit the influence of the environment on the resonant frequency of the SAW sensor. In fact, two resonators are needed to achieve a differential frequency measurement. The two resonances can be observed in figure 1b. When the physical quantity to measure is varied, the first frequency f_1 shifts whereas the second frequency f_2 stays tuned and is used as a reference. The absolute temperature is computed with the difference between these two frequencies. Each resonator has a very high quality factor (Q~10000) in order to obtain a good temperature resolution (0.1°C).



(a) (b)

Fig.1 (a) Circuit model of the SAW sensor. (b) $|S_{11}|$ frequency behavior.

The association of an antenna with an IDT can be wirelessly interrogated. This passive technology has a great advantage compared to active sensors, especially when they are not easily accessible to change the battery. The entire system is composed of an external interrogation unit and the antenna/SAW sensor to be interrogated.

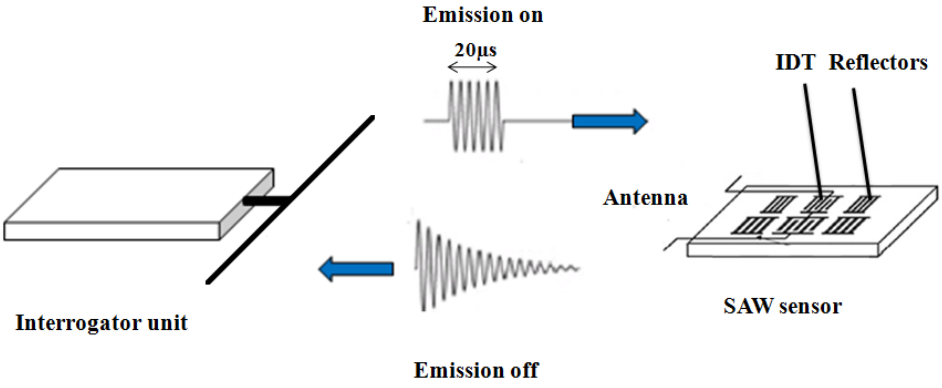


Fig. 2 Principle of the wireless interrogation.

First, the interrogator generates a short rectangular RF pulse during a time interval T=20µs with an f_0 carrier frequency. This procedure is repeated for different frequencies in the ISM band. When the interrogator frequency f_0 is equal to the resonance of the resonator f_{saw}, a maximum of energy is stored in the SAW. Then, when the interrogator stops the transmission, it switches to the receive mode and is able to measure the receive energy from the discharge of the resonator into the antenna. For each frequency, the interrogator measures the received signal and its associated frequency. One resonant frequency is determined when the receive signal power is maximal. It is possible to deduct the received power of the Friis formula. The received power P_r depends on the interrogator output power P_e, the interrogator antenna gain G_i and the sensor antenna gain G_{saw}, the distance r between the interrogator and the sensor, the matching and the loss α between the antenna and the sensor, the quality factor of the SAW sensor which modified the time required to discharge the sensor τ, the interval time of the transmission T and the commutation time T_{com} between the transmit (T_x) and receive (R_x) mode [Equation (1)].

$$P_r = P_e \cdot \frac{G_i^2 \cdot G_{saw}^2 \cdot \lambda^4}{(4 \cdot \pi \cdot r)^4} \cdot \alpha \cdot \left(1 - e^{-\frac{T}{\tau}}\right) \cdot \left(e^{-\frac{t_{com}}{\tau}}\right) \quad (1)$$

ANTENNA DESIGN

The proposed radiator is a folded antenna which is made up of the association of one metallic plate with a very small ground plane ($\lambda/9$ x $\lambda/9$) (Fig.3). The upper element is a rectangular meandered PIFA, directly connected to the lower plate by means of a vertical shorting strip. This lower plain element acts as a small ground plane. The SAW sensor is both connected to the upper plate and the ground plane using a small strip. The parameters allowing the optimization of the antenna performance are the slot width and length (W_s, L_s) of the PIFA, the length of the short-circuit L_{sh1} and the relative location of the feeding strip L_f to the short-circuit.

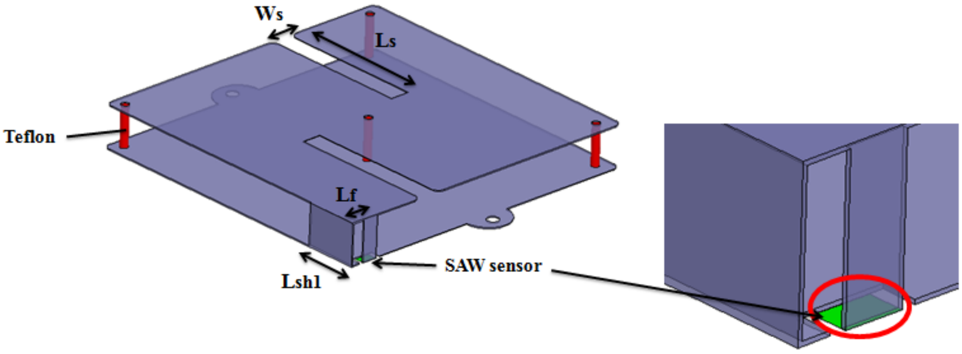


Fig. 3 3D view of the PIFA and zoom of the SAW connection.

RESULTS

Various tuning parameters have been identified in order to reduce the overall antenna size while keeping good radioelectrics properties. One method to reduce the PIFA size consists in meandering the top plate [6]. The antenna dimensions can be drastically reduced in this way. The width of the short circuit L_{sh1} has also a very important role on the value of the resonance frequency. When the width of the short-circuit decreases, the positive imaginary part of the input impedance of the antenna increases and the resonant frequency lowers because the path of the currents flowing on the radiating plate becomes slightly longer. When all these techniques are implemented, a good matching is achieved when tuning the position of the feeding strip (L_f). The overall size of the optimized structure is 80mm x 80mm x 10mm ($\lambda/9$ x $\lambda/19$ x $\lambda/70$). To validate the antenna performance, a prototype was fabricated and measured using a 50Ω SMA connector (Fig.4). The SMA connector is not illustrated on this picture.

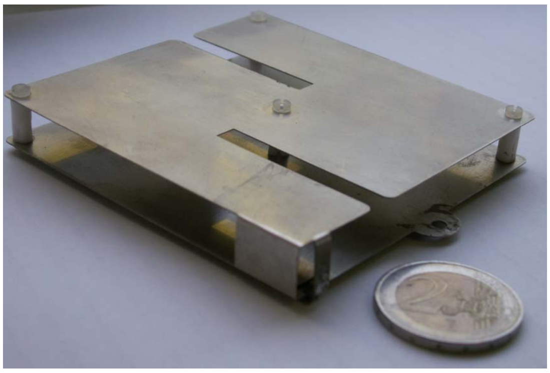
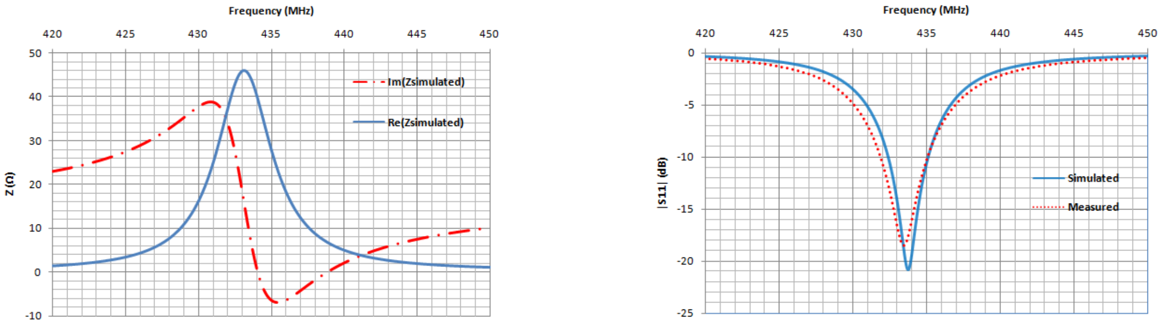


Fig.4 Picture of the prototype.

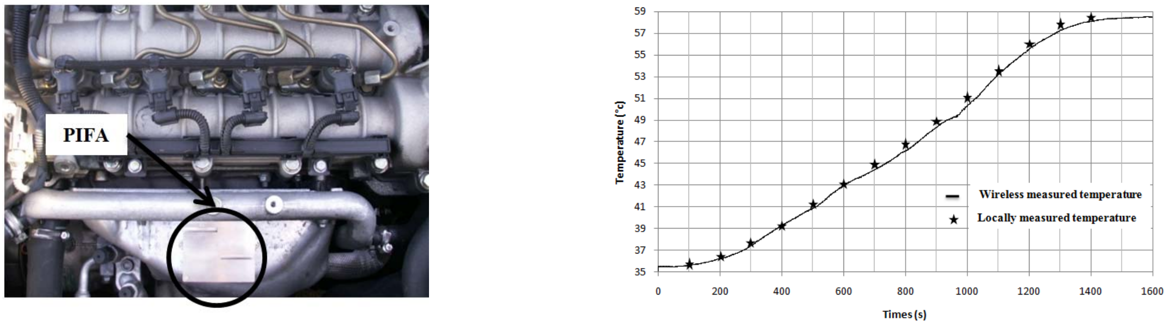
It should be noticed that the measured input impedance of the SAW sensor is (45-j10) Ω at each resonant frequency. At 434MHz, the real part of the input impedance of the antenna is close to the SAW impedance (42Ω) (fig.5a). The simulated and measured reflection coefficient of the fabricated antenna is presented in Figure 5b. Measurements agree well with the simulated results performed with HFSS.



(a) **(b)**

Fig.5 (a) Simulated input impedance vs freq. (b) Simulated and measured reflection coefficient $|S_{11}|$ in dB.

Then, a wireless interrogation of this system was performed in a car exhaust header. The sensor is fixed on the car exhaust header (Fig.6a). The interrogator unit is positioned under the car at a 1m height and the engine hood remains closed during the measurement. The initial temperature is 35°C, at 30s the engine is turned on. The temperature increases to 58°C. A very good correlation between the retrieved results and the locally measured temperature with a wire is obtained. Figure 6b shows the evolution of the temperature encountered in the car exhaust header.



(a) **(b)**

Fig.6 (a) PIFA on the car exhaust header. (b) Wireless measured temperature compared to locally temperature.

CONCLUSION

This paper presented the design of a small meandered PIFA realized on a small ground plane dedicated to be associated with a passive SAW temperature sensor and integrated in a harsh metallic environment like a car engine. The results show that it is possible to achieve a good antenna/sensor association and that the whole system is able to achieve accurate temperature measurements in the car exhaust header.

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