Small Meandered PIFA for Wireless Interrogation of Passive Sensors in a Cavity

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***Abstract*— In this paper, we present a Meandered Planar Inverted-F Antenna (MPIFA) with a small ground plane dedicated to be associated with a Surface Acoustic Wave (SAW) sensor and positioned in a cavity for temperature wireless measurements. A capacitive technique is proposed to feed the MPIFA and increase its bandwidth. The design of the antenna is presented as well as wireless interrogation results of the temperature sensor.**

I. INTRODUCTION

The rapid progress of microelectronics processes induces the shrinkage of small communicating objects and allows to think about new applications as the monitoring of the body temperature with a wireless sensor inside a patient. Consequently, the demand for low profile antennas is constantly increasing. One example is the contactless domain in the [433.05–434.79MHz] European ISM band, where radiating elements are particularly cumbersome, due to the associated wavelength. Moreover, in this frequency band, Surface Acoustic Wave (SAW) sensors are now able to react to various physical parameters like temperature, pressure, and stress without power supply battery [1], which allows a great number of wireless measurement applications, thanks to the combination of a passive sensor with a radiating element. However, the association of a SAW component and an antenna in severe environments is not an easy task.

Two of the main critical problems to solve in these kinds of applications are the close vicinity of the antenna and its size. Antennas are often placed close to metallic parts, which strongly decrease their impedances and degrade their performance For example, some particular applications require radiating elements having the capability to operate inside a metallic cavity, which is a great challenge. Moreover, at 433MHz, the miniaturization of the antenna is also a main constraint because the dimension at this frequency of a λ/4 regular monopole for example, is 17cm. During these last years, a lot of small Planar Inverted F Antennas (PIFAs) positioned over small radiating ground planes have been developed and exhibited very satisfactory radioelectric properties [2-3]. This class of antennas could be suitable for our applications.

In this paper, we present a very small PIFA (h=10mm, W=50mm, L=60mm) associated to a SAW sensor to monitor the temperature inside a metallic cylinder having a small diameter. In the first section, we describe the antenna structure. In the second part, simulated and measurement results of the antenna located in a cavity are presented and discussed. In the third section, we present the Surface Acoustic Wave (SAW) sensor and the principle of the wireless interrogator. In the last section, wireless measured temperature results of the antenna/sensor association are given. All the simulations have been carried out with the commercially available package software High Frequency Structure Simulator (HFSS) from Ansoft.

II. ANTENNA DESIGN

Fig. 1 shows a 3D view of the proposed antenna. This Meandered PIFA is made up of two metallic stacked plates on a very small ground plane. The size of the ground plane is equal to the size of the radiating plate.

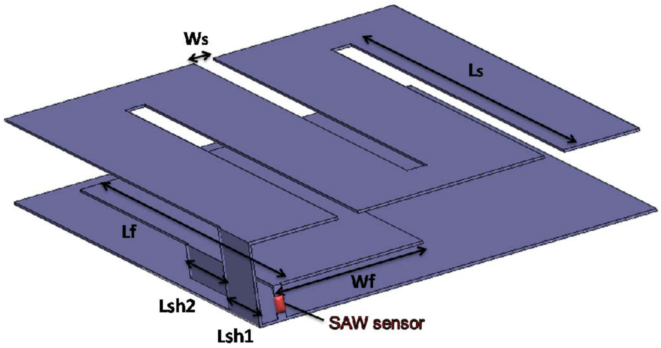

Fig. 1 3D view of the designed PIFA

The upper plate is a rectangular Meandered PIFA, directly connected to the ground plane by means of a vertical short-circuit strip. The lower plate, which consists in a small rectangular element located between the ground plane and the top PIFA, is used as a capacitive feed instead of the inductive conventional technique. This lower plate is also short-circuited to the ground plane in order to control the impedance of the structure.

The SAW sensor is both connected to this lower plate and the ground plane using a thin strip. The parameters allowing to optimize the antenna are the width and the length of the slot of the PIFA (W_s, L_s), the width and the length of the capacitive feed (W_f, L_f), the length of the short-circuit L_{sh1}, and the length and the location of the shorting strip L_{sh2}.

III. RESULTS AND DISCUSSIONS

Various tuning parameters have been identified in order to reduce the overall antenna size because the antenna is intended to be integrated in a 100mm height and 90mm diameter cavity.

One method which can reduce the initial PIFA size is the meandering of the top plate [4]. The antenna dimensions can be drastically reduced by this way. The width of the short circuit L_{sh1} has also a very important role on the frequency location of the antenna resonance. When the width of the short-circuit decreases, the inductance behavior of the antenna increases and the resonant frequency becomes lower because the path of the currents flowing on the radiating plate becomes slightly longer.

However, when these techniques are implemented, a good matching is difficult to maintain in all the band of interest. Indeed, with an inductive conventional feed, the bandwidth is too small for this application. The relative bandwidth at -6dB is around 0.015% (Fig. 2). A capacitive feed can overcome this effect [5]. A lower metallic plate with optimized dimensions to provide such a capacitive effect is suitable. After optimization of the dimensions to reach a good SAW sensor/antenna impedance matching, thanks to this capacitive feed, the obtained bandwidth is around 0.15% which is still not enough. A second short circuit L_{sh2} was then added between the capacitive plate and the ground plane to optimize the input impedance and to increase the relative bandwidth to 0.35% (Fig. 2).

It should be noticed that the measured SAW sensor impedance is (45-j13)Ω around its resonance frequency. The size of the ground plate of the antenna has not been optimized in the same way because the antenna system was intended to be positioned in the back of the metallic cavity.

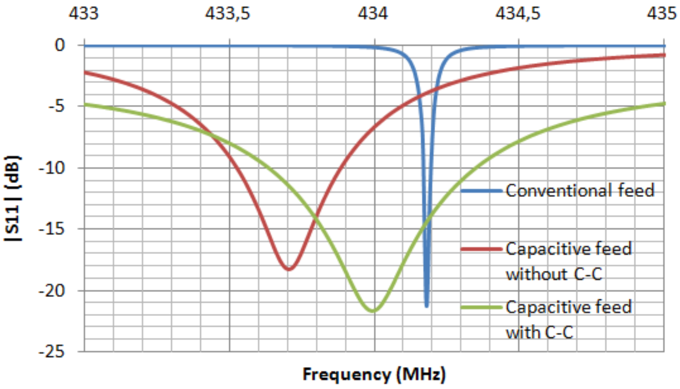

Fig. 2 Effect of the three different types of feed on the bandwidth

The overall size of the optimized MPIFA is 60mm x 50mm x 10mm (λ/11 x λ/13 x λ/69). A prototype was fabricated and measured in the cavity (100mm height, 90mm diameter) using a 50Ω SMA connection instead of the insertion of the sensor (Fig. 3).

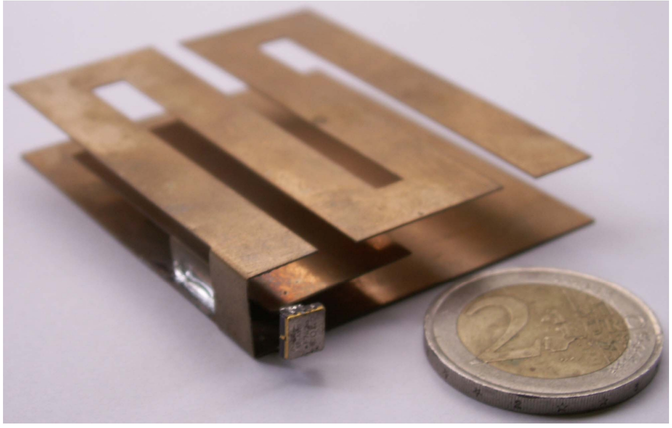

Fig. 3 Picture of the prototype

The simulated and measured reflection coefficients are presented in Fig. 4. The difference between simulated and measured S_{11} is attributed to the SMA connector placed too close to the radiating element and the influence of the feeding cable positioned along the cavity wall.

The simulated radiation pattern is omnidirectional but not presented in this paper.

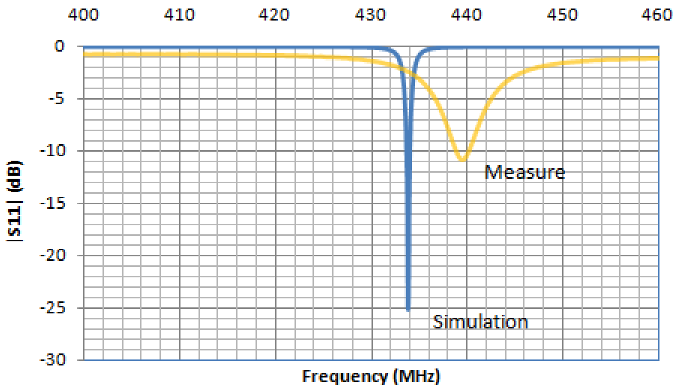

Fig. 4 Simulated and measured magnitude of the reflection coefficients |S11| in dB of the antenna presents in Fig. 3

IV. SAW SENSOR AND WIRELESS INTERROGATION

A SAW sensor is composed of an InterDigital Transducer (IDT) and reflectors placed onto a piezoelectric substrate. Such a device uses the piezoelectric effect to convert an incoming electromagnetic wave into a mechanical wave. Temperature variations 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 allowing the determination of different physical quantities: resonator sensors and delay line sensors [6]. SAW resonator technology is used in this work.

Such a resonator can be modeled by a Butterworth Van-Dyke (BVD) equivalent circuit. In this model, the circuit is composed of two resonant parallel RLC networks (Fig. 5) in order to limit the influence of the environment on the result of the measurement.

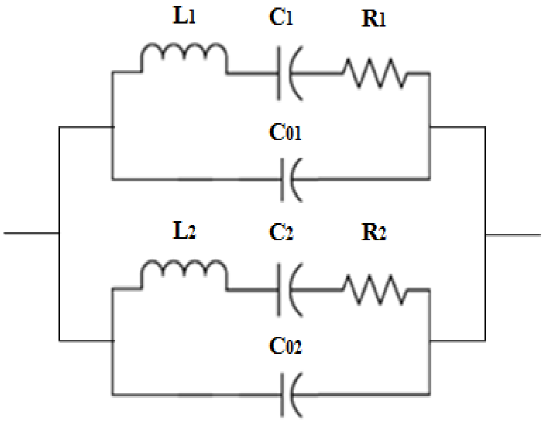

Fig. 5 BVD circuit model of the SAW sensor

A measurement with one resonator exhibits a high radio channel influence on the frequency of the SAW because a variation of antenna impedance, induced by a modification of the environment, makes a shift on the resonance frequency. In order to minimize this influence, two resonators are therefore needed to achieve a differential frequency measurement [7]. The response of the sensor (two resonances frequencies) can be observed in Fig. 6.

When the physical quantity to measure changes, the first resonance associated to the frequency f_{saw1} shifts whereas the second resonance, associated to the frequency f_{saw2} stays tuned and is used as a reference. The absolute temperature is computed using this difference between the two frequencies. Each resonator has a very high quality factor (Q~10000) in order to obtain a good temperature resolution (0.1°C).

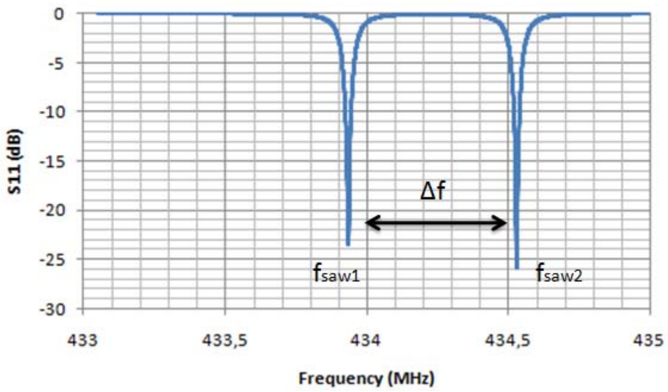

Fig. 6 Simulated magnitude of the reflection coefficients |S11| in dB of the SAW sensor

The association of an antenna with an IDT is a device which 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 made up of an external interrogation unit and the antenna/SAW sensor to be interrogated (Fig. 7).

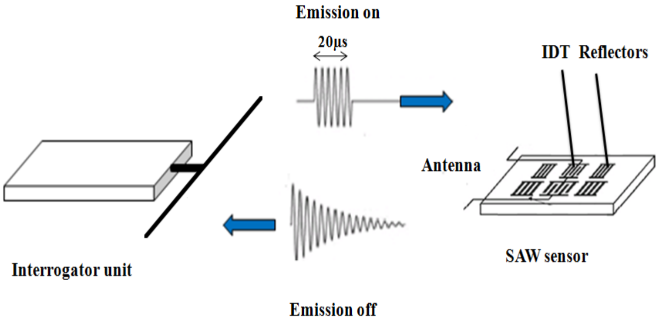

Fig. 7 Principle of the wireless interrogation

First, the interrogator generates an f_0 carrier frequency modulated by a short rectangular RF pulse during a T=20µs time interval. This procedure is repeated for different frequencies in the ISM band. When the interrogator frequency is equal to the resonance frequency 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 then 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. A resonant frequency is determined when the received 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 (Tx) and receive (Rx) mode.

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

A temperature SAW sensor was soldered on the feeding part of the small plate and a wireless interrogation of the system was performed when the whole system antenna/sensor is positioned in a metallic cavity. The cavity with the SAW sensor device was placed inside a heat oven. The interrogator unit is positioned outside, close to a heat oven. Figure 8 shows the measured evolution of the temperature encountered inside the cavity and specially modified on purpose. A classical wire temperature sensor is used to make a reference measurement.

A very good correlation between the interrogation results and the locally measured temperatures is obtained.

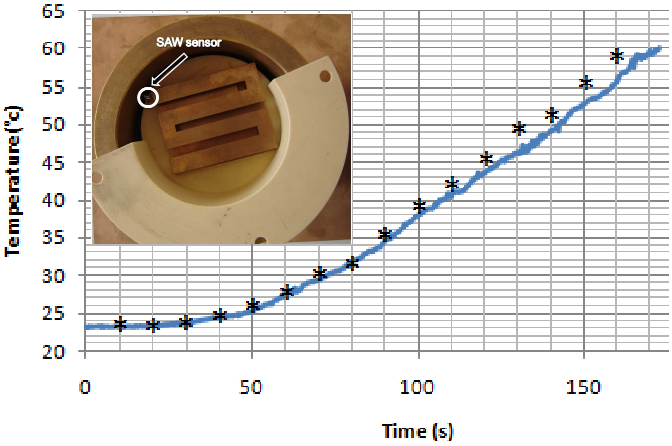

Fig. 8 Wireless measured temperature (-) results and locally measured temperature (*)

V. CONCLUSION

This paper focused on the design of a small meandered PIFA positioned over a small ground plane. This low profile antenna matched to a SAW sensor is dedicated to wireless temperature measurements when the system is positioned in a metallic circular cavity. We have shown that it was possible to strongly shrink a traditional λ/4 antenna's dimensions and to obtain a good matching with a SAW sensor when the whole system is placed in the cavity. This association can be useful for wireless temperature measurement in hard environments.

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