# Frequency-Tunable Sensing-Antenna for Wireless Sensor Applications

R. Khelladi, M. Djeddou and F. Ghanem

**Abstract**—In this paper, a novel design of sensor-antenna is proposed. The approach consists on integration a capacitive sensor in a very narrowband triangular antenna that can send raw information through the antenna's resonant frequency. As a result, we obtain a corresponding table between the resonant frequency of the sensor-antenna and the measured physical parameter. The simulated results of the designed sensor-antenna will be presented and discussed. The simulation results are promising and show that the use of the proposed sensor-antenna can be a good alternative for low energy consumption and low cost wireless sensor node.

**Index Terms**—microstrip antenna, narrowband antenna, sensor-antenna.

## 1 Introduction

Low-cost and high-performance sensors are increasingly required for advanced systems, especially in applications that require very small and cheap devices [1]. Next to the demands on costs and performance, it is also needed to reduce the sensor energy consumption in order to prolong the sensor node lifespan. In this context, several research works in wireless sensor network (WSN) have recently been reported in the literature to solve the energy consumption problem and therefore the cost [?], [2]–[6]. The effective solution for the latter problem makes the subject of the paper. It concerns the study and design of a prototype integrating an antenna and sensor in the same device called sensor-antenna. In this paper, we propose a new generation of a purely Radio Frequency (RF) sensor-antenna other than conventional sensor node used in WSN. Indeed, in contrast to the architecture of the conventional sensor nodes, the configuration in the proposed design avoids using any processing blocks, as employed in the conventional sensor node; i.e., no processor component that consumes power is used, and no need to use any digital data module to wirelessly transmit the information about the measured physical parameter. The proposed design consists on integrating a capacitive sensor in a narrowband antenna, which can send raw information (RF pulses) through its operating frequency which depends on the value of the physical parameter to measure (a change of each physical parameter is presented by a shift of the resonant frequency of the antenna). As a result, a corresponding table between the resonant frequency of the sensor-antenna and the measured physical parameter is obtained. The sensor-antenna is designed by two stages; the first stage consists of very narrowband antenna design. At the second stage we insert a capacitive sensor on the designed narrowband antenna with parameters adjustment.

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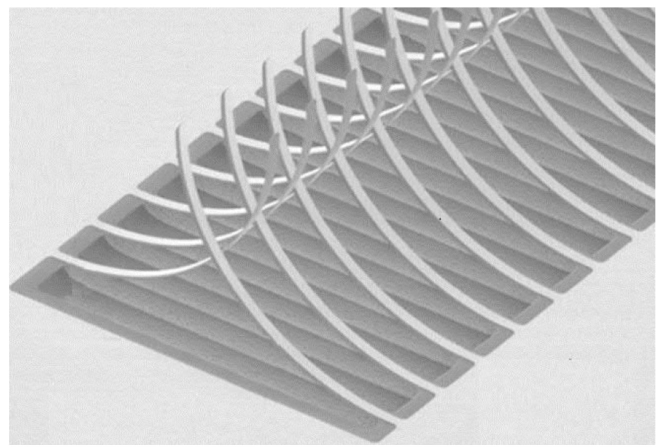

Fig. 1. Concept of capacitive temperature sensor proposed in [8] .

## 2 Capacitive Sensor

Capacitive sensors are devices that exploit the sensitivity of one or more of their composing elements to the physical parameter to measure. The variation of this parameter would induce either a mechanical or a dielectric change in the sensitive element properties, which produces a change in the device equivalent capacitive value [7].

An example of such sensor is the temperature sensor presented in [8] given in figure (1). In this case, a variation in the temperature would stimulate a mechanical bending of the moving arms, thus, a variation of the device equivalent capacity [7].

## 3 Sensor-antenna design and study

### 3.1 Narrowband triangular-antenna configuration

In this section, a highly narrowband triangular antenna operating at nearly $2.4GHz$ is designed. The layout of the microstrip antenna is shown in figure (2). It consists of a simple triangular patch, computed by using the transmission line model [3]. The patch is designed on a Teflon substrate with dielectric constant of $\epsilon = 2.57$ and $tan\,\delta = 0.0018$. The thickness of the substrate is $h = 0.8mm$. As shown in figure (2), the patch has the following parameters shown in table 1. The units of all parameters are given in millimeter (mm). The design and parameter optimisation of our antenna is done using transient solver in CST Microwave Studio.

$$I_d = \frac{V_{ind}}{R} \tag{1}$$

The antenna provides at $10dB$ return loss, a bandwidth of $11.42MHz$ with a fractional bandwidth of $Bw(\%) = 0.48\%$. The realized gain of the antenna is $5.54dB$.

### 3.2 Proposed sensor-antenna Design

In order to design a sensor-antenna, a rectangular shaped slot with dimension $(W_{slot} \times L_{slot})$ is introduced in the antenna configuration proposed on subsection 3.1. Also, an RF capacitor (C), used as capacitive sensor for temperature measurement, is inserted on the slot, as depicted in figure (4).

The parameters of the designed sensor-antenna are as follows:

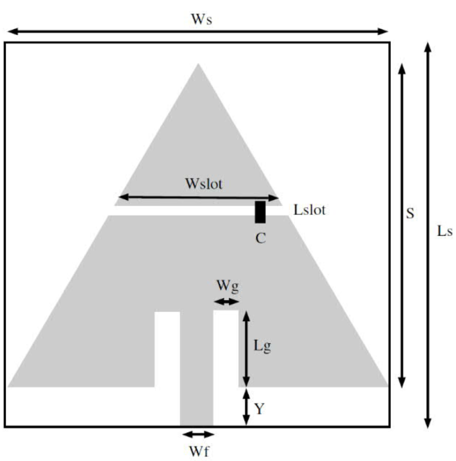


Fig. 2. Layout of the designed microstrip triangular-antenna based on transmission-line model

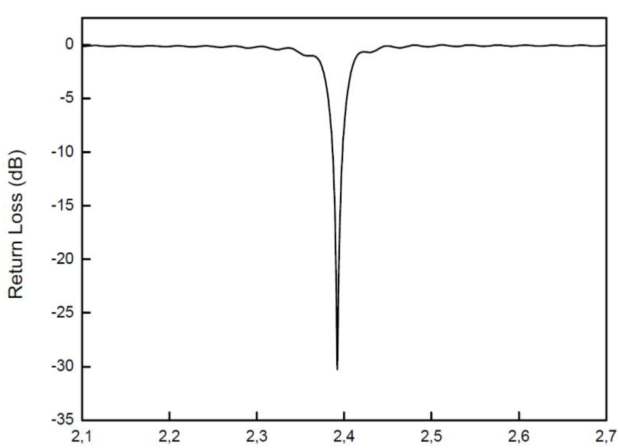


Fig. 3. Layout of the designed microstrip triangular-antenna based on transmission-line model

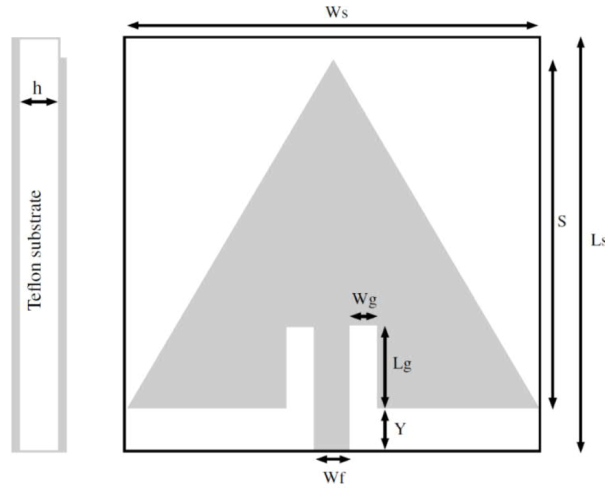


Fig. 4. Schematic of the triangular sensor-antenna.

TABLE 1
Parameters of the proposed triangular sensor-antenna..

| $\omega_s$ | $\omega_s$ | $\omega_s$ | $\omega_{slot}$ | $Y$ | $L_s$ | $L_f$ | $L_g$ | $\omega_{gslot}$ | $S$ |
|---|---|---|---|---|---|---|---|---|---|
| 57 | 2 | 2.4 | 25 | 2 | 51 | 8 | 9 | 1.5 | 43 |

### 3.3 Simulation results

The figure (5) shows the behavior of the proposed sensor-antenna when the capacitor C changes. From figure 5, we can see that the operating band of the antenna can be tuned over a wide range of the frequency according to the capacitance value. Also, the tuning is accurately achieved, thanks to the narrowband characteristic. The bandwidth is approximately less than $1\%$ at each operating frequency.

The behavior of the sensor-antenna is more illustrated in figure (6) that presents the resonant frequency of the antenna as a function of the capacitance C.

This proposed sensor-antenna using tunable-frequency propriety could be adopted for wireless sensor use, when the capacitance is corresponding to some physical quantity such as temperature, gas pressure, etc. Indeed, the variation of the temperature environment changes the sensor C value, and this will shift the narrowband resonant frequency of the antenna. The latter will be associated with the accurate measured physical parameter, without using any signal processing that consumes much power.

Moreover, this processor free configuration can be powered by using a simple circuit of energy harvesting from the Electromagnetic $(EM)$ field surrounding the environment and therefore, the energy consumption is considerably reduced and the sensor lifespan could be utilized for a longer period.

In order to justify that those narrowband resonances are radiating, the simulated radiation efficiency as a function of the frequency is presented in figure 7.

From figure (7), the radiation efficiency of the antenna rises from $57\%$ up to $74\%$ according to the change of the sensor capacitance C from $5.6pF$ to $1.9pF$, respectively.

In order to examine the effect of the sensors C on the radiation properties, the simulated radiation patterns are presented at different frequencies.

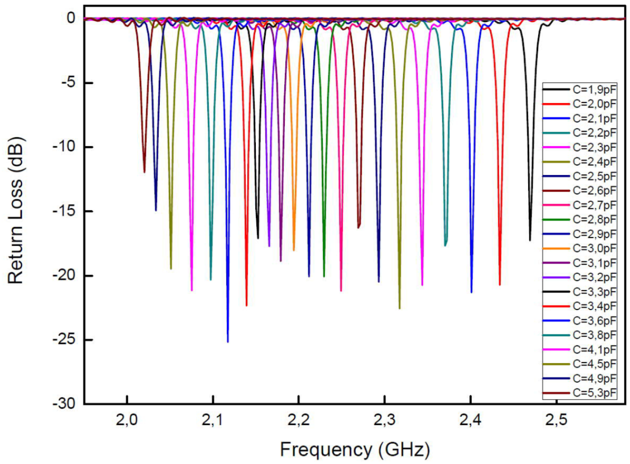


Fig. 5. Simulated return loss $(S_{11})$ for different value of capacitor C.

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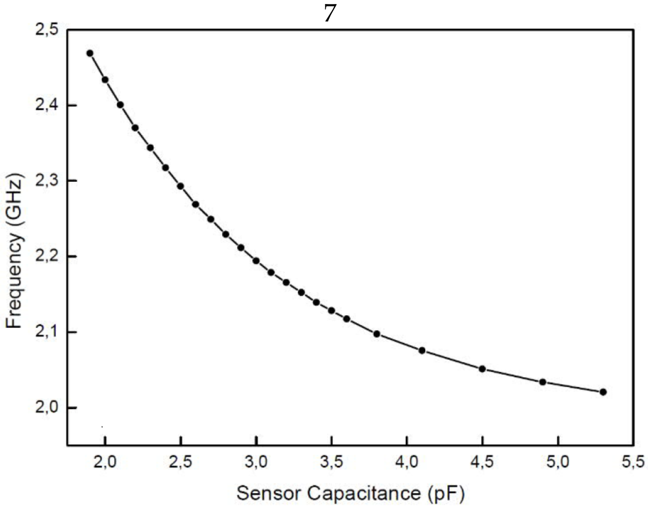


Fig. 6. Capacitor C effect on the resonant frequency.

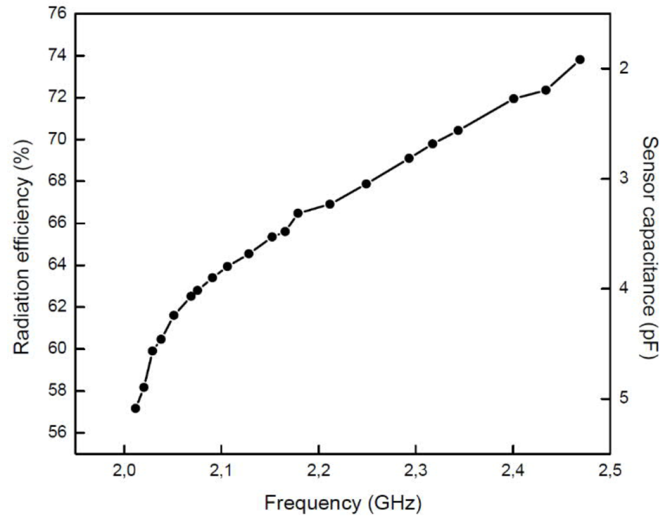


Fig. 7. Simulated radiation efficiency of the designed antenna.

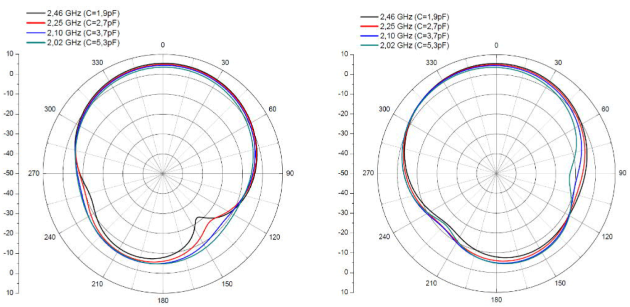


Fig. 8. Sensor C effect on the simulated radiation patterns.

The figure (8) shows the E-plane and H-plane simulated radiation patterns of the proposed antenna for four resonant frequencies. From figure (8), a slightly deviation on the radiation patterns can be observed according to the frequency variation. It can be concluded that the change of the capacitor value of the sensor does not considerably affect the radiation properties of the antenna.

## 4 Conclusion

In this paper, a sensor-antenna using a frequency tunability is presented. The main idea revealed in this work consists on integrating a capacitive sensor modeled by a variable capacitor on a very narrowband antenna, in order to get very accurate physical parameter measurement. The simulated results were satisfying and corroborate the feasibility of the idea. The proposed sensor-antenna is a good candidate for low energy consumption wireless sensor applications

## References

[1] Anton Bakker and Johan H Huijsing. Micropower cmos temperature sensor with digital output. *IEEE Journal of Solid-State Circuits*, 31(7):933–937, 1996.

[2] Mokhtar Aboelaze and Fadi Aloul. Current and future trends in sensor networks: a survey. In *Second IFIP International Conference on Wireless and Optical Communications Networks, 2005. WOCN 2005.*, pages 551–555. IEEE, 2005.

[3] Dimitrios Zorbas, Patrice Raveneau, and Yacine Ghamri-Doudane. Assessing the cost of rf-power harvesting nodes in wireless sensor networks. In *2016 IEEE Global Communications Conference (GLOBECOM)*, pages 1–6. IEEE, 2016.

[4] ASM Zahid Kausar, Ahmed Wasif Reza, Mashad Uddin Saleh, and Harikrishnan Ramiah. Energizing wireless sensor networks by energy harvesting systems: Scopes, challenges and approaches. *Renewable and Sustainable Energy Reviews*, 38:973–989, 2014.

[5] Xiao Lu, Ping Wang, Dusit Niyato, Dong In Kim, and Zhu Han. Wireless networks with rf energy harvesting: A contemporary survey. *IEEE Communications Surveys & Tutorials*, 17(2):757–789, 2014.

[6] Margarita Puentes, Andreas Penirschke, Martin Schussler, and Rolf Jakoby. Microwave mass flow meter for industrial applications based on a lefthanded transmission line resonator. In *2009 German Microwave Conference*, pages 1–4. IEEE, 2009.

[7] Rafik Khelladi, Farid Ghanem, Mustapha Djeddou, and Mourad Nedil. Dual-band sensor–antenna design for low energy consumption/cost wireless sensor nodes. *IET Microwaves, Antennas & Propagation*, 13(1):48–54, 2018.

[8] Sean Scott and Dimitrios Peroulis. A capacitively-loaded mems slot element for wireless temperature sensing of up to 300 c. In *2009 IEEE MTT-S International Microwave Symposium Digest*, pages 1161–1164. IEEE, 2009.