

SMALL ANTENNA BASED ON A MEMS MAGNETIC FIELD SENSOR THAT USES A PIEZOELECTRIC POLYMER AS TRANSLATION MECHANISM

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Abstract — This paper shows the proof of concept for an on-chip antenna using a MEMS structure and an electroactive polymer as detection mechanism. On-chip antennas tend to be very inefficient, which becomes worst when designing electrically small antennas. One solution may be the use of different approaches to receive the electromagnetic fields. The detection using magnetic MEMS sensors is a possible approach. The MEMS sensing structure requires a translation mechanism, where polymeric materials with outstanding electroactive properties, like Poly(vinylidene fluoride) (PVDF), may be a solution.

It is shown that the use of β -PVDF layers makes possible the on-chip reception of low-frequency electromagnetic waves, which may contribute for more efficient wireless (bio)microdevices.

Keywords : Antenna, MEMS, magnetic sensor.

I - Introduction

It is expected a high degree of miniaturization and efficiency for wireless microsystems applied to health monitoring [1]. The integration of efficient small antennas on those microdevices for biomedical applications will be a challenge [2]. The techniques used to build micro-antennas based on standard antenna miniaturization must be replaced by the development of new solutions to work with high efficiency, at relatively low frequencies (within the range kHz - MHz) [3], leading to innovative solutions in the medical field. A proposal to overcome such problems is the antenna integration with the remaining microdevice (fig. 1).

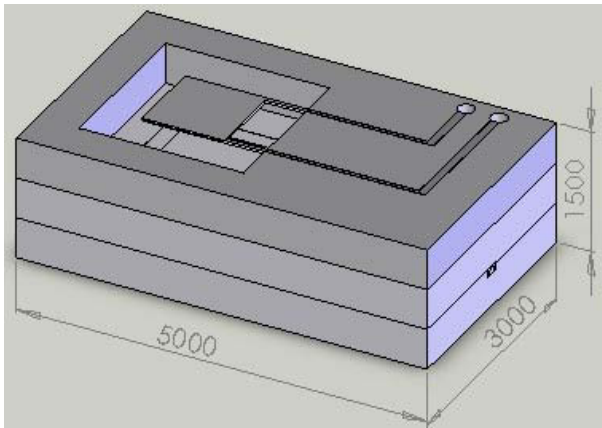


Figure 1: Global artistic view of the wireless biomedical microdevice (All dimensions are in μm) [3].

This solution uses wafer level packaging to bond several wafers, where the antenna is placed on the top wafer. This paper will be dealing with a solution to the antenna.

After the work on design, modeling and simulation of the on-chip MEMS antenna [4], it was necessary to fabricate the proposed antenna, measure it, and see how it compares with the developed model.

In this paper, we describe the fabrication of the proposed antenna, which uses the PVDF as a translation mechanism from the mechanical domain to the electric domain. Before obtaining an on-chip antenna, a scaled up model and prototype were obtained to be used for proof of concept. The paper presents the results obtained from the model, the antenna prototype, and the signal obtained with this antenna approach.

II - Operating principle of the antenna

This antenna operation is based on the Lorentz force that relates the force felt on a current carrying wire, in the presence of a magnetic field. That relation can be written as:

$$\vec{F}_L = (\vec{B} \times \vec{I})L \quad (1)$$

where L is the length of interaction, B is the magnetic field and I is the current [3]. In this work, a cantilever was used as a structure to detect the magnetic field component of an electromagnetic wave.

When the magnetic field acts on the cantilever, which is free to move, it may easily start oscillating when the incoming signal has the same frequency then the cantilever resonant frequency. To extract the information present in the carrier, the oscillation is converted to an electric voltage using the PVDF, an electroactive polymer. Using the PVDF on top of the cantilever, it produces a voltage in response to a deviation, leading to a simple electronic readout and a low operating power.

This type of antenna may become very smaller, since the structure oscillations depend on the dimensions and material properties. This means that higher frequencies require smaller mechanical structures, leading to smaller antennas, as desired.

The piezoelectric polymers are materials with the ability to transform mechanical energy into electrical energy and vice versa. They may be developed from a few nanometers to hundreds of micrometers, making them interesting for many applications in microsystems, as sensors and as actuators. One application is for radio-frequency microdevices, mainly for switching and/or

tuning applications. However, the integration of electroactive polymers in the processing steps of microdevices is still hard to achieve.

a) Piezoelectric material (PVDF)

The proposed mechanism of detection is based on a piezoelectric material such as PVDF. In the last decades it has been increasing interest on electroactive polymeric materials technological applications, especially in the electronics engineering domain. Among polymers, Poly(vinylidene fluoride) (PVDF) and (vinylidene flouride) (VDF) copolymers has remarkable properties leading to electro-optics, electro-mechanical and bio-medical applications. In particular its piezo and pyroelectric properties provide possibilities for many technological applications. The semicrystalline nature of PVDF, combined with the occurrence of at least four crystalline phases (α , β , δ and γ) implies a challenging physical microstructure. The most frequently described and important phase is the β one due to its high piezo and pyro-electric properties, when compared to the other crystalline phases and even compared to other polymeric materials [5].

b) Electroactive transduction mechanism

The piezoelectric response is responsible for the sensor and actuator behavior of the polymer. In this sense, larger piezoelectric coefficients will allow larger deformations for a given voltage.

In the thickness mode, piezoelectric actuators increases or decreases its thickness according to the inverse piezoelectric relation:

$$\epsilon_3 = d_{33}E_3, \quad (2)$$

where ϵ_3 is the strain of the actuator, d_{33} is the piezoelectric coefficient and E_3 is the applied electric field. In eq. (2) the index 3 of the symbols mean that only the piezoelectric 3 axis is considered. This axis corresponds to the thickness direction of the polymer. For a given application, other piezoelectric coefficients could be more suitable.

The piezoelectric response is determined both by thickness changes and by the variation of the dipole moment of the film at constant thickness [6, 7]. It is proposed that 2/3 of the total piezoelectric response correspond to dimensional variations of the film, whereas the remaining 1/3 is due to the different contributions related to variations of the dipolar moments [7].

Theoretical calculations lead to a value of $|d_{33}| \sim 25.19 \text{ pC.N}^{-1}$ [8], close to the obtained experimentally for corona poled β -phase PVDF ($|d_{33}| \cong 28 \text{ pC.N}^{-1}$) [9]. The piezoelectric coefficients strongly depends on the processing conditions of the material [10]

III – Modeling

Based on a previous work [4], a scaled model was

built to predict the behavior of a larger structure. It was necessary to understand if the fields and forces associated to such a scaled model would be in a range that could be easily generated and measured. Fig. 2 shows the options simulated with the model, to understand what would be the best positioning for the MEMS antenna.

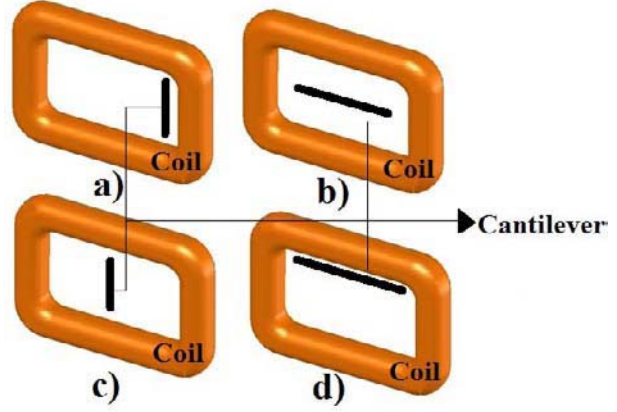


Figure 2: a) Cantilever aligned with the transverse axis parallel to the coil and its smaller segments. b) Cantilever aligned with the longitudinal axis of the coil is parallel to its major segments. c) Cantilever aligned with the transverse axis of the reel. d) Cantilever very close to a larger segment.

The figure shows both the cantilever and the magnetic field generator. A static analysis was used for simulations, and a voltage of 5 V was considered for coil excitation. To obtain the desired magnetic field, the cantilever was placed 2 mm apart from the coil. Table 1 shows a summary for the simulation results.

Table 1: Results for force and displacement, considering different cantilever positions.

Position	$\vec{B}_{total,min}$	$\vec{B}_{total,max}$	$\vec{F}_{mag,max}$	Displacement
a	200 μT	119 mT	1.27 μN	1,6 mm
b	781 μT	139 mT	3.27 μN	5 mm
c	618 μT	335 mT	3.22 μN	4 mm
d	201 μT	119 mT	1.27 μN	1,6 mm

Results from table indicate position b) as the place for larger force and displacement. The maximum force obtained is precisely when the cantilever is aligned with the longitudinal axis of the coil, leading to a larger displacement. This is the place to use for measurements.

IV – Antenna Fabrication

The cantilever was obtained by coating a piezoelectric film in both sides using an evaporated aluminum layer, which form the electrodes. The polymeric material is based on the polyvinylidene fluoride (PVDF) polymer in its electroactive (β) phase. It can be processed in the form of a film by extrusion, injection or from the solution, usually in the non electroactive α

phase. In order to obtain the electroactive β phase, the α phase films must be submitted to mechanical stretching at temperatures below 100°C and with a reason of stretching (ratio between the final and the initial lengths of the sample) from 4 to 7 [11]. After getting the electroactive β phase, the material must be activated by poling. This is done by subjecting the film to an electric field with amplitude larger than 60 MV/m along the thickness direction.

For the present work, high performance films were used [5]. Unoriented films exclusively in the β phase were obtained from the crystallization of PVDF from solution with N,N-Dimethyl Formamide or Dimethyl Acetamide at temperatures below 70 °C. The electromechanical properties of the film were improved by a treatment that consists on pressing, stretching and poling at high temperature. A final step of stretching at a temperature around 80°C results in oriented films, which further increases the material performance. Final film thickness ranged from ~20 to 60 μm .

After that, in order to metalize the PVDF sample, a thin layer of aluminum (Al) (500 nm) was deposited onto both sides of the sample by thermal evaporation. The current was applied in the range of 100-150A at pressures between 10^{-5} to 10^{-6} mbar. The Al layer thickness was obtained by the crystal thickness sensor in gold and thickness controller SyCon STM-100.

Finally, several “U” shapes with different sizes were formed in order to obtain the desired structure. Fig. 3 shows one prototype used for measurements.

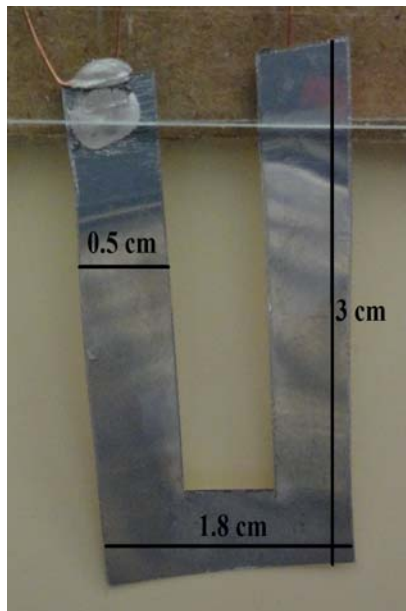


Figure 3: Antenna prototype.

Due to the small thickness of Al layer, the electrical wiring to readout electronics was made using conductive silver ink glue.

V – Measurements setup

With the antenna structure completed, the readout electronics was connected to the antenna output.

Figure 4 shows the block diagram used. A notch filter tuned to 50 Hz was required since the resonant frequency for the developed structures was in this frequency neighborhood.

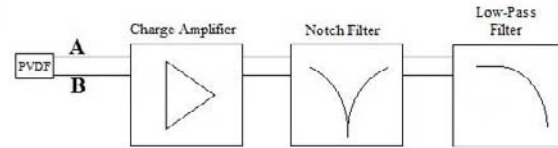


Figure 4: Block diagram to obtain the signal generated by PVDF foil.

It was also required a setup to generate the magnetic field that the MEMS antenna will read. Despite we are trying to develop a device to receive electromagnetic waves, at this point it was enough to generate only the magnetic field that will represent the magnetic component of an electromagnetic wave. Figure 5 shows the setup two main blocks: RF signal source and fabricated receiving antenna.

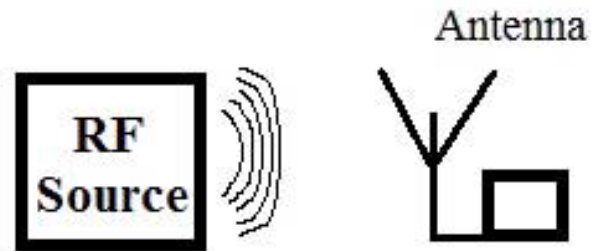


Figure 5: Setup used for measurements.

The RF signal source was obtained from a rectangle coil-shaped, measuring 40x57x8.5 mm³. To produce the required magnetic field, the coil has of 200 turns of copper, with 200 micrometers in diameter.

The receiving antenna module was formed by the PVDF antenna connected to the readout electronics. The fabricated and tested PVDF antenna has the dimensions shown in Fig. 3. The cantilever thickness is the result of 110 μm PVDF and 500 nm of Al in both faces. Large dimensions were selected to allow cantilever vibration at low frequencies, so it can be observed with naked eyes.

It is injected in the coil an AC signal, a sinusoid (frequency adjustable) with maximum amplitude of 5V. The frequency of this signal was varied during the experiment until we find the resonant frequency of the cantilever at around 12 Hz. At this frequency the displacement of maximum amplitude of the cantilever was 4 cm.

To move the cantilever, two techniques could be used to have a reacting force to the magnetic field generated by the coil. The first used consists on passing a DC current through the cantilever, and the second uses a permanent magnet placed on the cantilever surface. With the first technique, the cantilever displacements obtained were in the order of μm , since the current

allowed was very small, due to the thin layer of aluminum. With the second technique, the displacements obtained were in the order of mm. Since it is easier to read, the second technique was chosen for testing for proof of concept.

Figure 6 shows the final setup used for measurements.

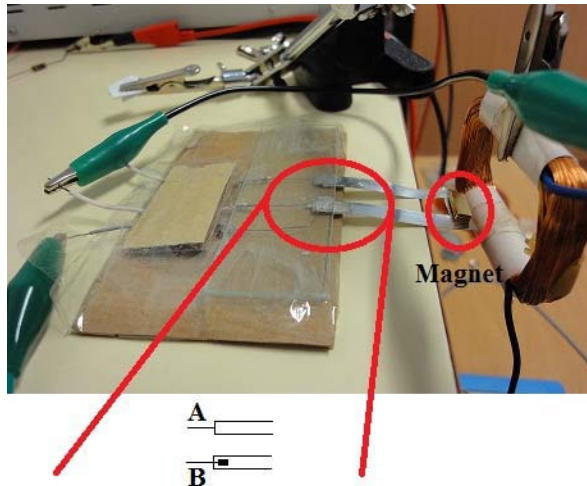


Figure 6: *Experimental setup.*

In the previous figure, magnet position and output leads from the antenna are highlighted.

V – Results and Discussion

Figure 7 shows the measured results, when a sinusoid with 12 Hz was applied to the source coil.

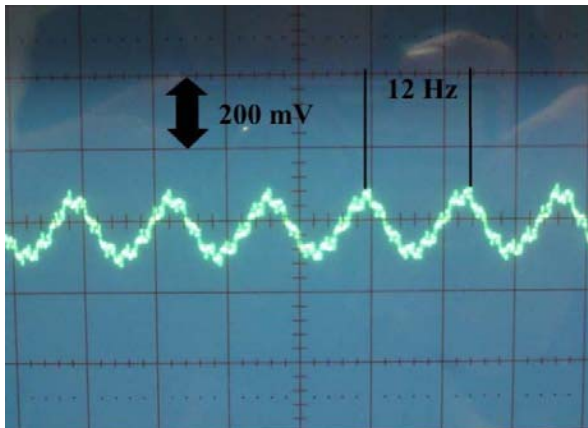


Figure 7: *Signal obtained from the vibrating cantilever, after amplification and filtering.*

The antenna signal that was generated by the deformation of the piezoelectric material was easily amplified up to 200 mV peak to peak. The frequency of this signal is 12 Hz, the structure resonating frequency. That signal was only present when the coil was turned on and for frequencies where the structure was oscillating. That allows to safely concluding this is a viable solution for receiving magnetic fields.

The present results were obtained with the cantilever very close to the source coil, and the received signal

drops very fast when the receiving cantilever moves away from the coil. However, it is not a problem of the receiving antenna. The problem is that the magnetic field also drops because it is not a radiated field. It is expected that for a radiated field, this solution will also work, and will operate in the antenna far field.

It was also possible to verify that the experimental results for displacement agreed with the results obtained from simulations. The values were in the same range of magnitude. Some differences appear to be from the many variables that are difficult to control for the mechanical setup.

VI – Conclusions

This paper presents a new solution for a small receiving antenna, with increased efficiency. It was possible to demonstrate the operation of a low-frequency telemetric link. It was possible to test the MEMS antenna deformation translation to a voltage.

Next step will be to use the obtained models to design a new antenna for fabrication using the standard microfabrication technologies.

Acknowledgments

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