Implementing a Capacitive Pressure Sensor Realized on LTCC

Cosmin Tămaş [1)], Cristina Marghescu, Ciprian Ionescu, Alexandru Vasile

1) University "Politehnica" of Bucharest, Center for Technological Electronics and Interconnection Techniques, Spl. Independentei 313, 060042-Bucharest, Romania, cosmin.tamas@cetti.ro

ABSTRACT

LTCC (Low Temperature Co-Fired Ceramic) has great potential in the field of sensors and transducers due to its thermal, electrical and mechanical properties. The paper describes work concerning a capacitive pressure sensor realized on LTCC with thick-film deposition technologies. A capacitive pressure sensor converts a change in the position of the conductive plates to an electrical signal; for this a deformable diaphragm is used [1]. In the presented case one electrode is bonded to the deformable diaphragm (an edge-clamped, circular diaphragm) and the other electrode is fixed. The signal from the sensor is processed by the AD7745 circuit. This circuit is a high resolution digital capacity-signal converter with high performances, high linearity ±0.01% and very good accuracy ±4 fF. The circuit also encompasses a voltage reference and a temperature sensor with a resolution of 0.1°C. The external connection is made through the I2C interface, using a signal control unit which processes the signal and sends the information to an LCD (liquid crystal display) and/or to a computer which, in turn, records the information for later use through the USB interface.

Keyword list: capacitive pressure sensor, low temperature co-fired ceramic, acquisition circuit

1. INTRODUCTION

We can classify sensors by using different criteria. From the point of view of the technology employed we can distinguish: sensors realized on silicone (well known and well documented technology, the sensor can be integrated on the same plate on which semiconductor components are already assembled, thus allowing the user to realize a complex sensor system which processes the data generated by the sensor and generates a digital filtered signal), sensors realized with thick film technology, etc. From the point of view of the operating principle most pressure sensors are based on a deformable diaphragm. In order to translate the mechanical displacement into an electrical signal different principles can be used: the piezoresistive principle (a Wheatstone bridge is built on the membrane), capacitive (a variable capacitor is used), electromagnetic (the deflection of the membrane induces variations of the inductance – Hall effect), piezoelectric (uses a quartz structure; the membrane induces a force F thus generating a piezoelectric effect), optic (optic fibre is used to detect movements of the membrane).

Most commercial pressure sensors are based on the piezoresistive principle [2]. The reason is the relatively high sensitivity and the fact that the output signal is proportional with the pressure on a broad pressure range. The output impedance is small, which assures protection against perturbation. A piezoresistive pressure senor realised on LTCC can be seen in fig.1. Capacitive pressure sensors have a higher intrinsic sensitivity when compared to piezoelectric sensors. On the other hand they are more sensitive to temperature but also use less power. One of the main problems of this type

1 alexandru.vasile@cetti.ro

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of sensors, next to the high output impedance and the non/linear output, is the small capacity value that has to be measured. A small value of the capacitance also means they are more susceptible to perturbations.

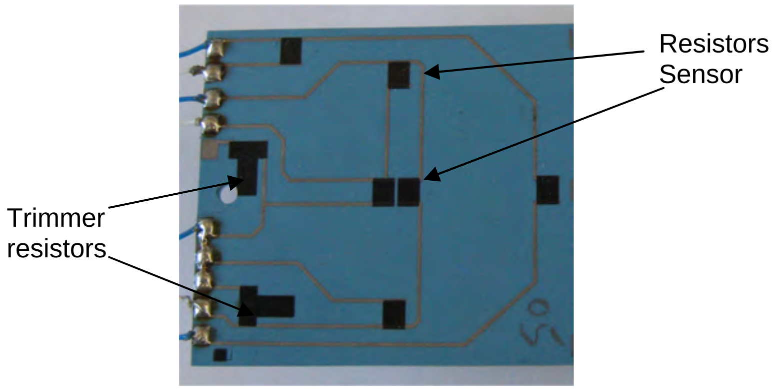

Fig. 1 A piezoresistive sensor on LTCC.

Being such a well established technology silicone is the technology preferred for many pressure sensors. Other technologies, such as LTCC and thick film, are used for specific applications. Compared with sensors realized using semiconductor materials, ceramic sensors are bigger, more robust and have a smaller sensitivity but can be employed over a bigger temperature range. Most ceramic sensors realized using thick film technology employ as sensing element a diaphragm. When pressure is applied a deflection appears. This is converted in an electric signal through the changes that appear in components realized in thick film.

LTCC allows the user to develop multilayer circuits using single tapes, on which conductive, resistive or dielectric pastes are applied. In an LTCC process almost all pastes that are applied are printed on the greensheet using thick film techniques. This technology also allows the integration of passive components (resistors, capacitors, inductors) in the substrate. In a typical LTCC package the substrate is the fired LTCC tape and all active/passive components are integrated/screen-printed on this structure. LTCC is similar with HTCC (High Temperature Co-fired Ceramic) but has the advantage that it allows the use of low resistivity conductors (silver, gold, copper, alloys with palladium and platinum) – the firing temperature for LTCC being below 1000°C (usually around 850°C). Other advantages include: cost efficiency for high volumes, high packaging density, reliability (each layer can be inspected before firing for errors and can be replaced if needed), and high print resolution of conductors.

In order to detect a change in pressure the capacitive pressure sensor relies on the measurement of a displacement. The movement of the diaphragm-bonded electrode with respect to the fixed electrode allows for a changing capacitor value to be obtained between the electrodes (in figure 2 the LTCC-based capacitive pressure sensor can be seen) .

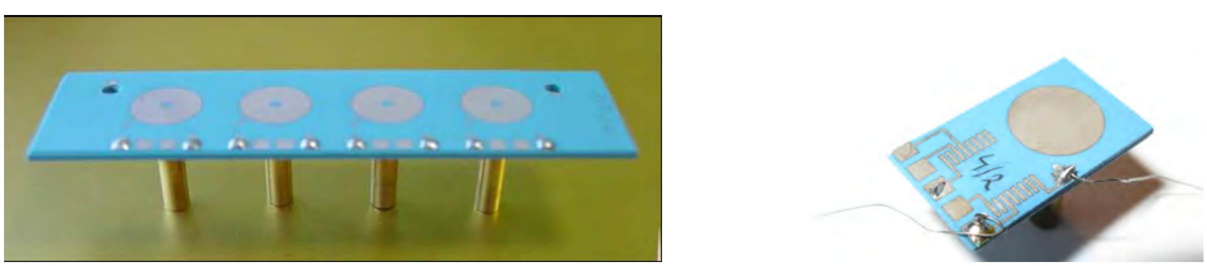

Fig. 2: The capacitive pressure sensor.

A piezoresistive and a capacitive pressure sensor have been developed using LTCC. Both piezoresistive sensors and capacitive sensors rely on the elastic deformation of a membrane for the measuring of the pressure. As with classic ceramic sensors, the sensing elements, in the case of the piezoresistive sensor - the resistors are located in maximum deflection regions

– near the central part and near the limits of the circular diaphragm. Two resistors are stretched and two compressed. The layout is realized so that the resistors can be connected to a Wheatstone bridge through external connections. The main difference is that while the piezoresistive type measures the stress in the membrane the capacitive type measures the deflection. The membrane is usually circular. When compared with piezoresistive sensors, capacitive ones have higher sensitivity, lower power consumption and less sensitive to drift. Despite this only a small portion of the market for pressure sensors is represented by this type of sensor. One of the disadvantages of capacitive pressure sensors, for some applications, is that they tend to be bigger: the value of the capacitance is directly linked to the dimensions, and a smaller capacitance is more susceptible to noise. Another problem is that they require the conditioning circuit to be as close as possible in order to avoid parasitic capacitances.

2. LTCC-BASED CAPACITIVE PRESSURE SENSOR

Among the ceramic technologies LTCC is a multilayered technology (it relies on the use of green tapes that are stacked one on top of the other and fired together) that allows the development of 3D structures.

Some material properties of LTCC are presented in table 1[4].

Tab. 1 LTCC material properties

Characteristics	Value
Density (ρ)	3.1 [g/cm^3]
Thermal Expansion Coefficient	5.8x10^{-6}[1/K]
Thermal conductivity (k)	3.3 [W/mK]
Elastic Modulus (E)	110 [GPa]
Temperature Coefficient of elastic modulus	-240x10^{-6} [1/K]
Poisson ratio (ν)	0.17

The basic structure of a capacitive pressure sensor developed in this technology is that of two electrodes, one of them bonded to the diaphragm (fig. 3).

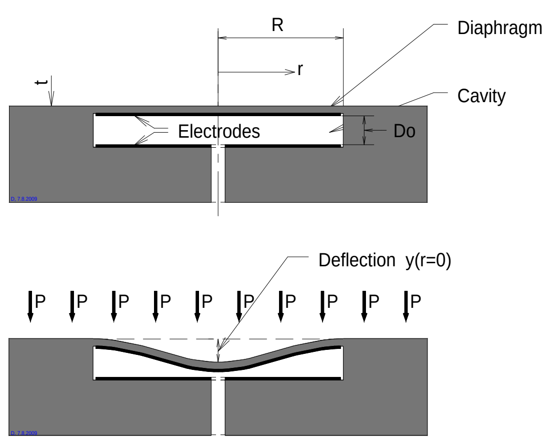

Fig. 3: Capacitive pressure sensor – basic functioning principle.

The value of the capacitance is determined by the distance between electrodes, the surface of the electrodes and the dielectric used:

$$C_0 = \varepsilon \frac{A}{d} \quad (1)$$

When pressure is applied an elastic deflection ensues. The deflection can be computed with (2), form the deformable plates theory:

$$y(r) = \frac{3P(1-\upsilon^2)(R_d^2 - r^2)^2}{16Et^3} = y_0(R_d^2 - r^2)^2 \quad (2)$$

If we neglect the fringing field the value of the capacitance can be computed using (3):

$$C(P) = \varepsilon_0 \varepsilon_r \int_0^{2\pi} d\theta \int_0^{R_d} \frac{rdr}{D_0 - y(r)} \quad (3)$$

The following lettering has been used: *y(r)* represents the deflection at *r* (measured from the centre) when the pressure *P* is applied, *E* – the elastic modulus, *v* - the Poisson ratio, *t* – the thickness of the diaphragm and R_D – the radius of the diaphragm. *C(P)* is the value of the capacitance when the pressure *P* is applied. It is possible to solve (3) analytically by substituting *y(r)* from (2). In order to further simplify the dimensionless parameter $\beta = y_0/D_0$ is introduced and the variable is changed from *r* in *x*:

$$x = \sqrt{\beta}\left(R_d^2 - r^2\right) \quad (4)$$

It follows:

$$C(P) = \frac{\pi \varepsilon_0}{\sqrt{\beta} D_0} \int_{\sqrt{\beta} R_d^2}^{0} \frac{dx}{x^2 - 1} \quad (5)$$

Respectively,

$$C(P) = \frac{\pi \cdot \varepsilon_0}{2 D_0 \sqrt{\beta(p)}} \ln \left| \frac{\sqrt{\beta(p)} R_d^2 + 1}{\sqrt{\beta(p)} R_d^2 - 1} \right| \quad (6)$$

These equations are valid when pressure is applied on the upper side.

We can conclude that the output parameter is influenced by the permittivity - ε_r, the radius of the electrodes - R_e, the distance between the electrodes (without deflection) - D_0 and by the deflection *y(r)*.

3. DATA ACQUISITION SYSTEM

The signal from the capacitive sensor is processed by the data acquisition system through the AD7745 circuit. The block diagram of the data acquisition system can be observed in figure 4 and that of the AD7745 circuit in figure 5. This circuit consists mainly of a high resolution capacitance-digital signal converter (basically a sigma/delta analogue/digital converter with a 24 bit resolution and 21 effective bits) with a high performance, high linearity ±0.01% and good accuracy (it can measure up to femto Farads). The circuit also includes a voltage reference and a temperature sensor with a 0.1°C resolution. The circuits communicates through the I2C interface with a signal control unit (built around the PIC 16F73 circuit) where the data is processed and sent to a LCD display and/or to a PC unit where the data can be recorded for further analysis.

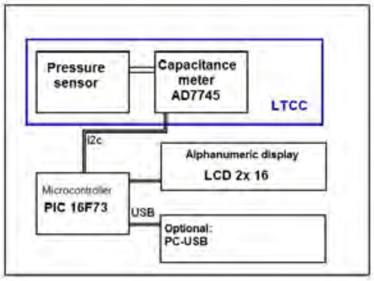

Fig. 4: Data acquisition system.

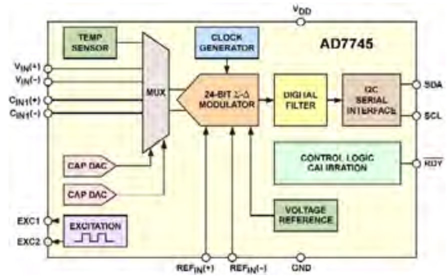

Fig. 5: Block diagram AD7745 [7].

The data acquisition system has been realised using a Microchip PIC16F73 microcontroller. This includes a control unit of the I2C data bus (needed for communicating with the AD7745 circuit), an ADC on 10 bits, an internal calibrated oscillator, EEPROM memory etc.

The program uses a calibration routine for the sensor. The data regardless if it is data generated by the capacitive pressure sensor or by the temperature sensor is being constantly read. The hexadecimal value is converted into a base 10 signal and then several corrective measures are applied. Finally the value is displayed on the LCD. For the long term monitoring the system is connected to a PC unit using FTDI circuit (serial-USB converter) [3].

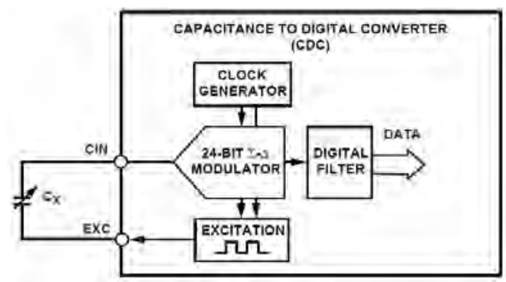

Fig. 6: Capacitance measurement - basic principle.

4. MEASUREMENT RESULTS

The measurements have generated the following results:

Tab. 2 Values of the capacitance obtained using the system presented.

Temperature(^{o}C)	Pressure (mbar)								
	0	50	100	200	300	400	500	600	700
70	4.642	4.638	4.634	4.626	4.619	4.611	4.604	4.596	4.589
50	4.644	4.640	4.636	4.629	4.621	4.614	4.606	4.599	4.591
25	4.650	4.646	4.642	4.635	4.627	4.620	4.612	4.605	4.597
0	4.657	4.653	4.650	4.643	4.635	4.627	4.620	4.613	4.605
-25	4.664	4.660	4.657	4.649	4.642	4.634	4.626	4.619	4.611

The results have been in concordance with those obtained using commercial measuring circuits.

5. CONCLUSIONS

Although piezoresistive pressure sensors are the most common commercial solution, capacitive pressure sensors are better suited for specific applications. In order to assess the best application for the capacitive pressure sensor developed a data processing and recording system had to be developed. Using this system the sensor can be studied in different conditions.

We have developed a conditioning circuit for the capacitive pressure sensor. The results obtained prove the viability of the solution chosen. We aim to further refine this solution for practical applications of this sensor.

Acknowledgments

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