Construction of wireless sensor for harsh environment operation

G.Tarapata 1,3, J.Weremczuk1, R.Jachowicz1, X.C.Shan2, C.W.P.Sh2

1Institute of Electronic Systems, Warsaw University of Technology, Warsaw, Poland
2Singapore Institute of Manufacturing Technology (SIMTech), Singapore
3National University of Singapore, Singapore

Abstract

The paper presents empirical results of wireless and battery less smart sensor system made with three different techniques. The system has been both designed and fabricated to meet harsh environment requirements for sensor operation. In this work FR4 laminate (PCB), Low Temperature Co-fired Ceramics (LTCC) and Polyethylene Terephthalate foil (PET) were used as a sensor electronic board. According to the substrates three different techniques and materials were used to fabricate conductive traces. The paper reports comparison of electrical parameters obtained during tests for each type of board.

Keywords: smart sensors, wireless communication, measurement systems

1. Introduction

Sensors designed for operation in harsh environment (e.g. chemical or high humidity / high temperature) required special protection of their structure. Typically, wire electric contacts are the weakest points of whole sensor construction. To increase reliability of the sensor, wire connections could not be allowed. However the sensor has to be supplied somehow with energy and has to transmit the measurement signal. Many different wireless sensors constructions with RF data transmission are supplied with power by battery. This solution has a lot of drawbacks (short life time, requirement of battery charging or replacement, bigger dimensions, etc.).

In our design the sensor is passive (has no battery). However required supply energy is transmitted to the sensor wirelessly using special coils embedded in the sensor structure and in the reader [1,2,3]. Those coils are also used for digital data transmission (similar to RFID systems). The sensor structure has no wire connections; therefore it is easy to encapsulate or to exchange it. The smart sensor can operate with some distance to the reader (e.g. sensor can measure some chemical parameters in liquid environment and send data to transceiver which is located nearby in nonaggressive environment), see Fig.1.

In some reported in the literature [4, 5] applications the similar idea was used for smart sensor network realization. However, there were used wireless sensors equipped with some battery and also wireless sensors powered with RF filed with additional thermal power harvesting module. In contrary to these works, our system is powered only through electromagnetic coupling.
2. Sensor fabrication techniques and construction

Sufficient energy transmission between two modules can be achieved using coils of high Q factor. To compare different techniques and board materials the same patterns (coil and traces to connect electronic components) for temperature sensor were printed. The wireless sensor structure has been designed and fabricated under cooperation of Warsaw University of Technology (WUT) and Singapore Institute of Manufacturing Technology (SIMTech).

Designed circuit board for the sensor was fabricated on double layer substrate [3]. On the back side the planar rectangular coils was realized and on the top layer conductive traces were fabricated and electronics components were assembled. To minimize circuit board size SMD components were used.

2.1. PCB Structure

For that sensor structure a glass epoxy laminate (FR4) with double side 35μm cooper metallization was used. Conventional techniques such as photolithography and wet etching were used for trace formation on the PCB substrate. The electronics components were soldered to the substrate.

2.2. LTCC Structure

Another sensor was fabricated on multilayer Low Temperature Co-fired Ceramic. The antenna and conductive traces was fabricated with Heraeus TC8101 gold paste and for this a screen printing technology was used. To assembly the components the Loctite 3880 conductive adhesive glue was applied. Soldering method was inadequate for the maintenance because the gold paste has been dissolved by soldering alloy.

2.3. PET Structure

The Polyethylene Terephthalate foil with 0.2mm thickness was used for third version of the sensor. All conductive traces pattern was made by double layer Asahi L-411AW silver paste and screen printing technology was used. Because of low melting temperature of the PET substrate only low temperature conductive adhesive glue (like Loctite 3880) could be used for the components mounting.

The techniques and materials which were used for traces formation have significant impact on their electrical and mechanical properties. These techniques have also influence on time of structures fabrications and on their costs. LTCC substrate has very good temperature and mechanical parameters, but it requires specialized facilities. PET and screen printing technology are relatively chip and convenient for mass production, but this solution have some drawback. Conductive pastes have rather low conductivity; therefore quality factor of the antenna would be unfortunately rather low. Three designs of different substrate fabrication are shown below: PCB (Fig.2a), LTCC (Fig.2b) and PET (Fig.2c).
Smart sensor unit (presented in Fig. 2) was based on the MSP430F2012 low power microcontroller (from Texas Instruments). There are also: RF front-end electronics (modulator/demodulator and rectifier); a power supply with voltage regulator; and a data acquisition unit. The measurement block is universal, therefore the interface can operate with any type of sensor. To test the interface operation, the sensor part has been facilitated with a temperature sensor.

3. Tests

3.1. Coils tests

The network vector analyzer (Rohde & Schwarz ZVA50) was used to measure impedance characteristic of the coils. The measurement was taken for pure antenna coil and next coil was tuned to the 13.56MHz RFID frequency by parallel capacitor. Achieved self-resonance frequency for each substrate (without additional capacitor) was higher than 13.56MHz (some of 110MHz for all kind of substrates). Bigger differences were observed for coils Q-factor. Sample characteristic of self-resonance (impedance and phase change) are reported in Fig. 3.

![Coils tests](image)

**Table 1.** The comparison of fabricated sensor coils resistances and quality factor at frequency 13.56MHz for different substrates.

| Substrate | Trace material | Coil resistance [Ω] | R/Ω [mΩ] | Q  |
|-----------|----------------|---------------------|----------|----|
| PCB       | Copper         | 1.8                 | 1.45     | 39.79 |
| LTCC      | Gold paste     | 8                   | 6.46     | 6.14 |
| PET       | Silver paste   | 20                  | 16.14    | 3.37 |
3.2. Power and data transmission tests

Figure 4 shows the induced voltage on the sensor antenna output as a function of the distance from the reader for each substrate. It is well seen that induced voltage strongly depends on material resistivity (Q-factor).

![Graph showing induced voltage vs distance]

Fig. 4. Output voltage at sensor coil in function of distance from reader coil. Big dot indicates the maximal distance for reliable digital data transmission between sensor and reader.

The highest voltage was induced on sensor fabricated with Cu coil (PCB). The worse results were observed for LTCC and PET substrates. Achieved transmission distance is marked with solid dots (Fig. 4). The electronic components, which have been used in wireless sensor, required only 1.8V of power supply. The operation distance limit results from the sensitive threshold of the reader unit. It was also observed that for optimally designed and tuned antenna coil, very important were antenna dimensions [3] because for backscatter modulation the operation distance is proportional to the antenna size.

4. Conclusion

LTCC and PET substrates have many advantages (high temperature of operation, flexibility, etc.) however we found that series resistance of coils (some of 10-20 Ω), higher than coils fabricated on PCB (some of 2 Ω), shorten maximal wireless sensor operation distance to 1.5 cm (in comparison to 3 cm for PCB). Our further work will focus on increasing of metal layer thickness on LTCC and PET substrates. In near future ink-jet print technology will also be tested.

References

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