Sensor Actuator System for use in a wireless installation bus with an application example

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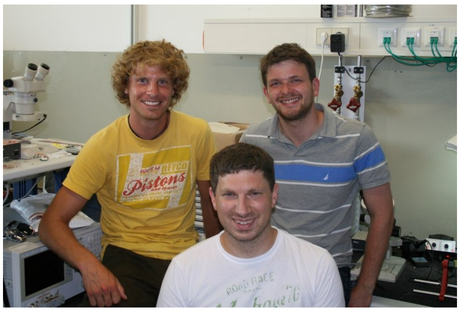
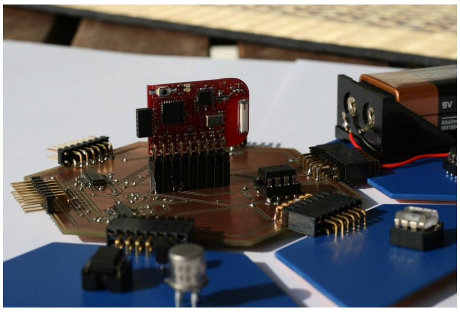
TI Parts used in project:

Quantity	TI Part Number	TI Website
2	TPS7201	http://focus.ti.com/docs/prod/folders/print/tps7201.html
1	TLC251	http://focus.ti.com/docs/prod/folders/print/tlc251.html
1	OPT101	http://focus.ti.com/docs/prod/folders/print/opt101.html
1	ez430-RF2500	http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500.html
1	SN74LVC3G04	http://focus.ti.com/docs/prod/folders/print/sn74lvc3g04.html
2	SN74HC11	http://focus.ti.com/docs/prod/folders/print/sn74hc11.html
4	TS12A44514	http://focus.ti.com/docs/prod/folders/print/ts12a44514.html





This report describes the development of a modular sensor system. Exemplary we built up a gas and a brightness sensor module as well as a main module with a MSP430 microcontroller and a power supply unit. The MSP430 microcontroller on the main module gathers the data from the sensors and sends it to an access point to store and process it. Experimental results show the ability of the whole system to monitor the light intensity, the temperature and the methane concentration in a room. This is the first step towards an intelligent building regulating.

Introduction

With this project we want to demonstrate a modular system with the ability to monitor different parameters of its environment in order to ensure comfortable living conditions. The system consists of a main board, which can be equipped with special modules. Each module has its own function such as measuring the gas concentration or actuating an external active component. The main board gathers data from the extension modules and is able to control actuators using active modules. Due to the wireless communication of the main board, it is also possible to combine two or more of those systems.

By combining several of those systems a whole building can be monitored and controlled. On the one hand this leads to an increased standard of living and on the other hand this could reduce the energy consumption for heating or electrical light. With a known temperature, the heating could be switched off and the ventilation in the bathroom can also be perfectly regulated if the air humidity is known. You can think of many other possibilities to apply micro systems in order to build an intelligent house that only wait to be realized.

In the following we want to demonstrate how to implement some components for such a system with the aid of TI parts.

Motivation For Project

We are all students of micro systems engineering in the 10th semester. During our studies we learned much about the theory of sensor and actuator principles and our knowledge was also supplemented by some practical work. Transforming our know how into real working devices is what we wanted to do. There were lots of ideas how to build up useful systems for the application in the real world. In this context the TI Analog Design Contest was the perfect opportunity for us. With its large range of products on offer TI gives us the possibility to transform ideas into a system, to assemble and to test it. The results should show that we are able run through a whole process of development.

Theoretical Background

One of the most important features of this system is the possibility to monitor environmental conditions with easy to use wireless sensor arrays that communicate with one central access point. To ensure low energy consumption, error free communication and an easy to use system, the eZ430-RF2500 development tool and the SimpliciTI protocol are used. The eZ430-RF2500 wireless development tool consists of two eZ430-RF2500T target boards with MSP430 microcontrollers, a battery pack and a USB-powered emulator for programming and debugging. A detailed description can be found at the TI website [1]. With the SimpliciTI protocol, we are able to build a wireless network of sensors and actuators with low power consumption. The range of this network can be extended due to the possibility of using repeaters . A full description of the SimpliciTI protocol can be found on [2].

To demonstrate the possibilities of such a system, we built two different sensor boards: a brightness sensor and a methane gas sensor. The brightness sensor uses the OPT101, a silicon photodiode with a transimpedance amplifier on chip. The datasheet can be found on [3].

The gas sensor from Figaro used in this project is based upon the change in resistivity of an metal oxide (MOX) which depends on the influence of oxidizing and deoxidizing gases. The resistivity is sensitive to hydrogen, ethanol, iso-buthane, carbon monoxide, methane and humidity. Bad smelling flavors and sulphur compounds normally appear in a very small concentration so that it is very hard to detect them. The air quality has to be measured via the methane concentration, which is the biggest part of human exhalation. Consequently the sensor is suitable for detecting the two possible sources for the need of increased ventilation in a bathroom: bad smell and high humidity.

For the measurement it is important that the temperature of the metal oxide is kept constant at about 400 °C. Therefore the temperature has to be measured and a heater has to be controlled accordingly. On this chip both functions are combined in a heating element made of platinum: the current through the element heats the chip while the resistivity of the element is proportional to the temperature. The implementation of a control circuit to keep the temperature constant is explained in the next section. Figure 1 shows a schematic drawing of a MOX gas sensor.

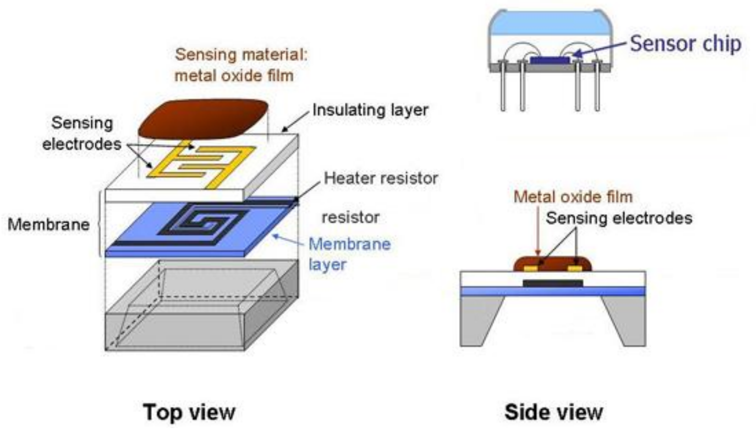


Figure 1: Schematic drawing of a MOX gas sensor [4].

Implementation

The design is based on a modular system containing a mainboard with a MSP430F2274 microcontroller, a board for power supply and several sensor and actuator extension boards. All the boards can be connected to the central mainboard via an easy „plug and play“ system.

Figure 2 shows a possible arrangement with the battery board, a brightness sensor, a gas sensor and three free sensor board slots.

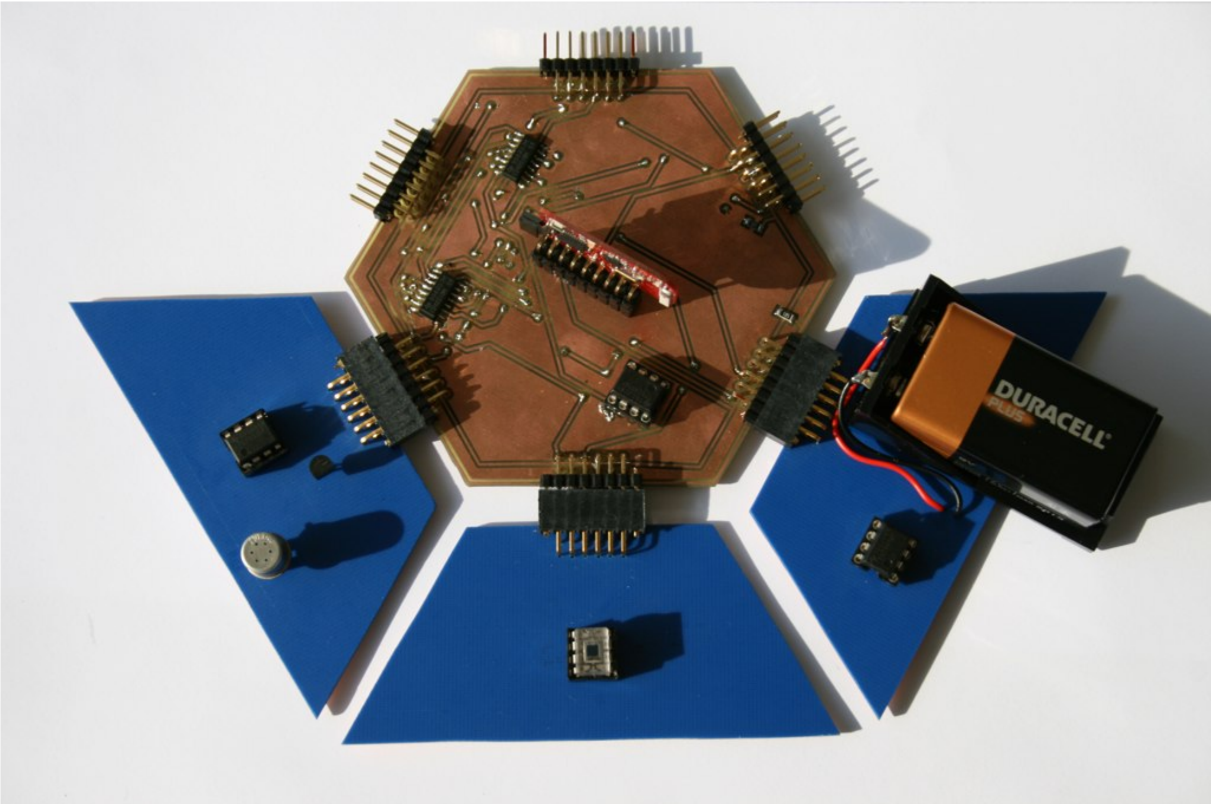


Figure 2: The whole system containing the mainboard, two sensor modules (gas and brightness sensor) and a supply unit.

The core of the system is the eZ430-RF2500 development board: The MSP430 microcontroller receives and processes the data from the different plugged in sensor boards. These processed data will be sent wireless to a central access point - the second eZ430-RF2500 board that is connected to a PC. The access point is able to receive the information from different sensor arrays in order to react on unintended states with signals for actuators. For example in case of high humidity or smell nuisance, the window could be opened or a fan could be turned on.

To ensure the power supply, two voltage regulators (TPS7301QP) are used. The first one is placed on the power supply board to regulate the battery voltage to a value of 9 V. The second chip on the mainboard is responsible for the for the microcontroller's supply voltage of 3.3 V. Due to the battery supply, the system has to save power which makes it useful to disconnect the sensor boards from the supply voltage between two measurements. For this reason we decided to use two analog switch ICs (TS12A44514) for enabling the power supply for every single board. Two other switches are used for enabling the board's data lines.

All the switches are controlled via the pins P3.0, P3.1 and P3.2 of the microcontroller. The data lines are connected to the Pin P2.3 whose input can be used as a digital input or as an analog digital converter, depending on the connected board. The identification of the extension boards is realized with a three bit binary code, using tree pins of the connection plug. The three identification lines of every board are connected to the Pins P2.0, P2.1 and P2.2 of the microcontroller and via a high resistance to ground, so that normally the signal is logical „0“. For generating a logical „1“ the corresponding line is connected via a resistance to the supply voltage on the extension board. Due to the fact that the supply voltage of every board is only enabled if it is used, the different identification lines don't affect each other. Figure 3 shows the schematical design of the mainboard.

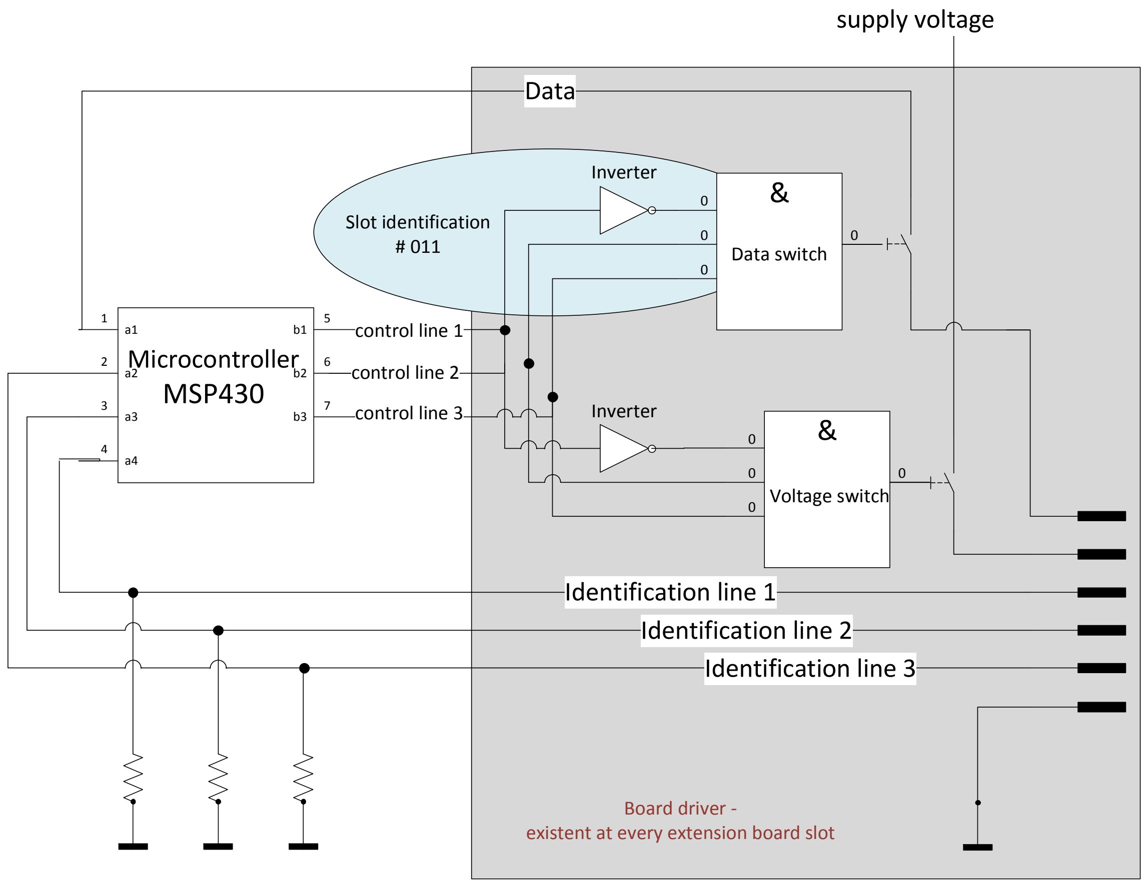


Figure 3: Schematical design of the mainboard. The inverters and switches in the grey box are built in for every extension slot seperately.

The information needed for the signal processing of each board is stored in the MSP430. As an application example we built two different sensor boards: A brightness sensor and a gas sensor (sensitive to methane). The first board is equipped with the OPT101 from TI, a photodiode with integrated impedance amplifier. To achieve a lower sensitivity for detecting the bright daylight, the DC gain of the amplifier is decreased to about $^1/_2$ of the original one. Therefore a 470 kΩ resistor is connected in parallel with a 33 pF capacitance as amplifier feedback between the Pins 2 and 5 of the OPT101.

The gas sensor board uses a Figaro TGS2600 sensor. Since the sensor signal depends on the temperature (see last section), the heater current has to be regulated so that the sensor element works at a constant temperature. Therefore the temperature depending resistance of the heater is build into a Wheatstone bridge, which provides an proportional output voltage (see figure 4). This voltage is load into a PI-Regulator, consisting of the TLC251CP operational amplifier from TI and a feedback-resistor and -capacitor for controlling the DC amplification and the time constant. The regulated output voltage drives a BS170 nMOS transistor, which is connected in series with the Wheatstone bridge so that it controls the current trough the heater. To ensure a minimum current in the circuit, a resistor is placed in parallel with the transistor. This configuration provides a stable sensor temperature.

To convert the change of resistance of the MOX sensor element into an analyzable voltage, a half bridge (voltage divider) consisting of two resistors is used.

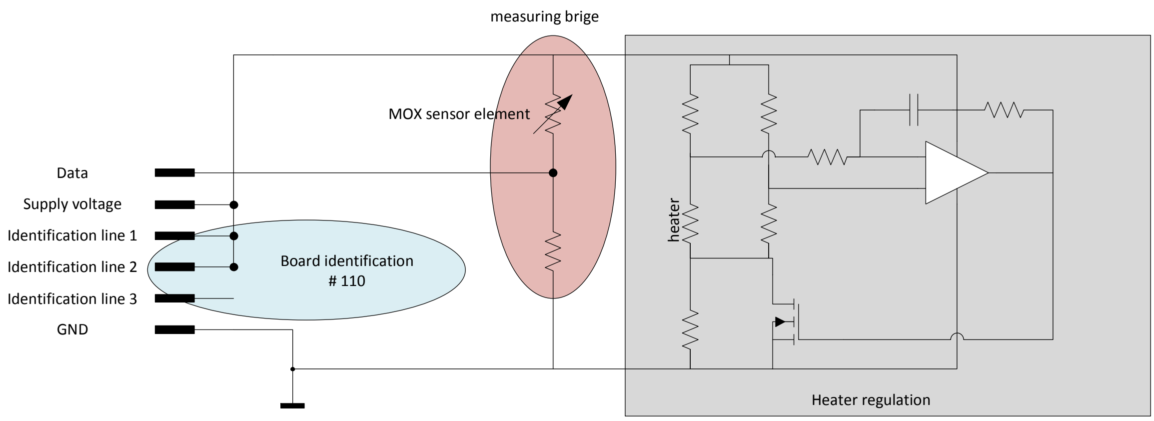


Figure 4: Schematical design of the gas sensor extension board.

Experimental Results

Gas sensor

Figure 5 shows a diagram of the measured gas concentration over time. The testing conditions were maintained by butane gas of a lighter in a good ventilated room at 25 °C. A very short gas pulse at a distance of about 20 cm was given to the sensor at $time = 175\,\mathrm{s}$ which leads to a tiny peak visible in the diagram. The two bigger peaks are the results of gas pulses with a duration of about 1 s. The maximum value of the sensor is reached by putting the lighter directly in front of the gas sensor. The time needed for relaxation of the signal is several minutes due to the fact that the surface of the sensor is completely covered by the test gas and the desorption process of the molecules needs high temperature and time.

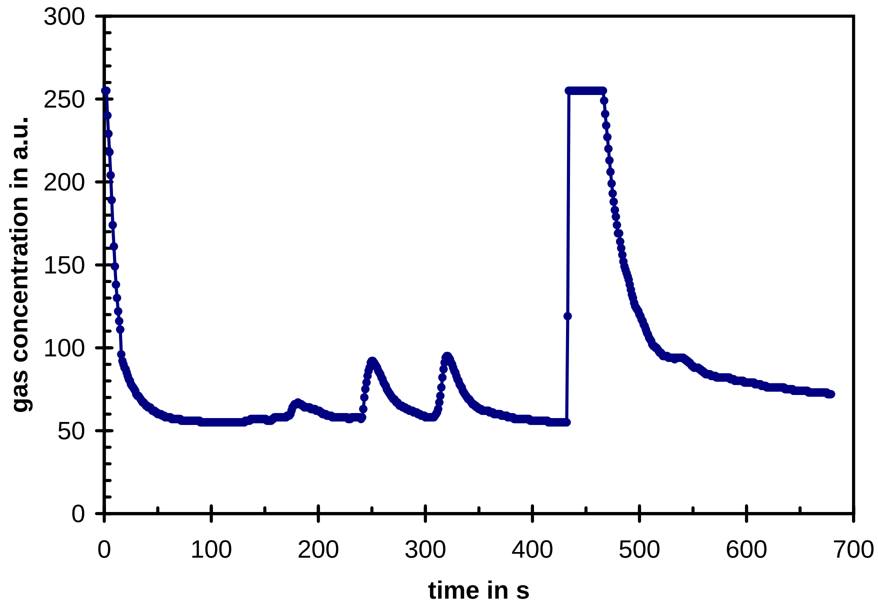


Figure 5: Measured signal of the gas sensor.

Brightness sensor

The brightness sensor was tested at a desk in the middle of a room under different illumination conditions. Figure 6 shows the data sent to the access point during this test. At the beginning the sun is shining into the room through a window. Under this condition the sensor signal is at its maximum value of 255. The minimal value between the 20th and the 30th second is reached by putting a finger on the sensor (simulating a complete darkness). Between the 40th and the 70th second the roller blind is getting closed. This causes a drop of the sensor level to about 50 which corresponds to a sparsely illumination. If the ceiling lighting is switched on (between the 75th and 95th second) the sensor level goes up to about 90 and falls back afterwards. Opening the roller blind by tilting the fins at $time = 110\,\mathrm{s}$ brings the sensor level back to its maximum.

Conclusions

- The modular system is ready to use. Different modules can be connected and are identified automatically. Transmission and processing of gathered data is possible.
- The gas sensor with its temperature control circuit works well. It is possible to measure an increased concentration of butane. From this it follows that it is also possible to detect methane gas.
- The brightness sensor allows the measurement of the light intensity. Different illumination conditions can be distinguished.

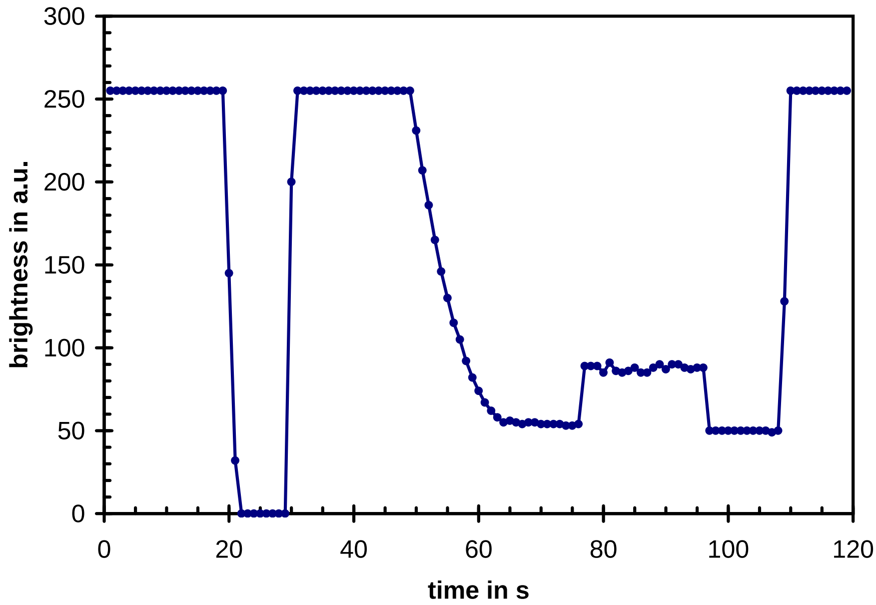


Figure 6: Measured signal of the brightness sensor.

- The power consumption of the overall system is 430 mW. Especially the gas sensor consumes approximately 400 mW. This means that the system can run maximum two hours if it is supplied by a 9 V block battery.

Summary

In this project we successfully built up a modular system consisting of a mainboard, two sensor modules and a supply unit (see figure 2). One sensor module is equipped with a gas sensor and a control circuit which keeps the temperature of the sensor chip constant. The other module contains a photodiode with integrated impedance amplifier (OPT101). The supply unit consists of a 9 V block battery and a voltage regulator (TPS7301QP). To keep the system flexible the mainboard has a special design which allows every other module to be connected in every free slot. The core of the system is the board with the eZ430-RF2500 development tool with the MSP430. This microcontroller is responsible for the transmission of gathered data to the access point.

Our experimental results show that the data generated by the sensor modules and transmitted by the mainboard are reasonable. Therefor it is convincing that the system works well and that it can be extended with various modules like other sensors or driving stages for actuators.

Future Plans

The aim of this system is to monitor and react on different surrounding conditions, so it has to run permanently. Because the energy supply is given by a battery, this is only possible if the system needs very little power. The MOX gas sensor needs the greatest part (ca. 400 mW). The overall energy consumption of this module can already be reduced by switching off the supply voltage between two measurements. Nevertheless a gas sensor sensitive to methane with a lower power consumption must be found. In any case the power management has to be improved.

In order to show the real capability of such a system, more modules must be build and the system has to be tested under real conditions. Therefore the development of different actuator modules with driver stages is necessary. For example, actuators that can open a window or regulate a fan are needed for adjusting the air quality. With additional modules the performance could be observed in a field test over a longer time period. This would reveal if the system is really able to ensure comfortable living conditions and to safe energy for heating rooms or not.

Acknowledgment

First of all we want to thank TI for the great opportunity to take part on the Analog Design Contest. We also thank TI for the parts given to us and the Fritz Hüttinger chair of microelectronics, the chair of gas sensors and the chair of biomedical microtechnology for the support.

References

[1] http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500.html

[2] http://focus.ti.com/docs/toolsw/folders/print/simpliciti.html

[3] http://focus.ti.com/lit/ds/symlink/opt101.pdf

[4] http://nano.tkk.fi/en/research_groups/electron_physics/research/gas_sensors02.jpg