World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:3, 2016

Design of Wireless Readout System for Resonant Gas Sensors

S. Mohamed Rabeek, Mi Kyoung Park, M. Annamalai Arasu

Abstract**—**This paper presents a design of a wireless read out system for tracking the frequency shift of the polymer coated piezoelectric micro electromechanical resonator due to gas absorption. The measure of this frequency shift indicates the percentage of a particular gas the sensor is exposed to. It is measured using an oscillator and an FPGA based frequency counter by employing the resonator as a frequency determining element in the oscillator.

This system consists of a Gas Sensing Wireless Readout (GSWR) and an USB Wireless Transceiver (UWT). GSWR consists of an oscillator based on a trans-impedance sustaining amplifier, an FPGA based frequency readout, a sub 1GHz wireless transceiver and a micro controller. UWT can be plugged into the computer via USB port and function as a wireless module to transfer gas sensor data from GSWR to the computer through its USB port. GUI program running on the computer periodically polls for sensor data through UWT - GSWR wireless link, the response from GSWR is logged in a file for post processing as well as displayed on screen.

Keywords**—**Gas sensor, GSWR, micro-mechanical system, UWT, volatile emissions.

I. Introduction

DETECTION and identification of volatile emissions required in wide range of applications in various industries. Traditional analytical methods such as spectroscopy chromatography are not portable, costlier and bulkier for the detection of volatile emissions. This lead to the development of arrayed sensing schemes for detection of volatile compounds and is called as electronic nose [1]. Electronic noses use multiple varying polymer coated sensors in an array to detect specific volatile component [2], [3]. Micro electro mechanical systems resonators would be an excellent candidate for the electronic noses owing to high sensitivity, scalability and ease of forming them into an array [4]. Resonant frequency of the polymer coated gas sensors shifts due to the absorption of a specific gas for which the coated polymer is sensitive to and its measure indicates the percentage of a particular gas the sensor is exposed to [4]. The resonant frequency can be determined by employing the resonant sensor as a frequency determining element in an oscillator and with the use of frequency counter.

We are developing such a polymer coated micro mechanical system resonant sensor array to detect 10 different fugitive hydrocarbons and it is in the development stage. It would greatly ease the characterization process if we have a system that can read gas sensor data from inside the gas chamber wirelessly and log the data automatically for post processing. In order to achieve this goal, we have developed the GSWR and UWT. GSWR is designed as 4" x4" stacked PCB structure with base PCB containing an FPGA, MCU, RF and the top PCB containing oscillator and comparator circuit. The entire assembly can be fit into the gas chamber while the sensor assembly is visible for proper gas sensing without any obstructions.

S. Mohamed Rabeek, Mi Kyoung Park, Annamalai Arasu M are with Integrated Circuits and Systems Laboratory, Institute of Microelectronics, A-STAR, Singapore (e-mail: sarbudeenmr@ime.a-star.edu.sg).

II. Wireless Read Out System Architecture

The wireless readout system is designed to ease and automate the gas sensing testing in the lab as resonant sensors are to be coated with different polymers and experiments to be conducted for prolonged periods of time.

For the wireless readout system, we have chosen 915 MHz RF out of 433 MHz, 915 MHz and 2.4 GHz bands considered, as it provides a better trade-off for power, size and cost [5] and further considering the future prospects of extending this system into a full blown wireless sensor network.

Fig. 1 shows the wireless readout system architecture; upper chain is the GSWR starting from polymer coated micro mechanical system resonator based oscillator which oscillates at around the resonator's resonant frequency of 6.5MHz. This is further amplified and level translated into a 3.3V square wave to be compatible with the FPGA frequency counter input. Frequency counter has a master clock of 122.88MHz and can use different gate timings such as 0.1 seconds, 1 second, 10 seconds which can be selected through MSP430 MCU firmware. In fact, the entire configuration of GSWR can be done remotely from the computer GUI program through UWT. The lower chain shows the UWT and the 10 channel GUI frequency display. Presently the system is equipped with one channel GUI system as the sensor development is in its early stages.

III. GSWR Architecture

As the gas chamber size is limited the entire GSWR assembly to be fit within a volume of 4" x 4"x 2". It should be powered from single 5 V DC supply and hence the required voltage regulators are provided on board. Signal integrity of high speed signals are verified and sufficient supply decoupling is provided as this system is running at 122.8MHz.

Fig. 2 shows the GSWR architecture. As this system to be developed into a commercial system later, the architecture is chosen such that it is viable commercially and all the critical components chosen to be easily available and lower in cost while having minimal power consumption. It also provides migration path to an integrated readout circuit. Entire GSWR is implemented in a stacked PCB assembly and fits in the volume requirement mentioned above. GSWR's MCU centric architecture with low cost RF transceiver and on board antenna can yield lower system cost when realized finally.

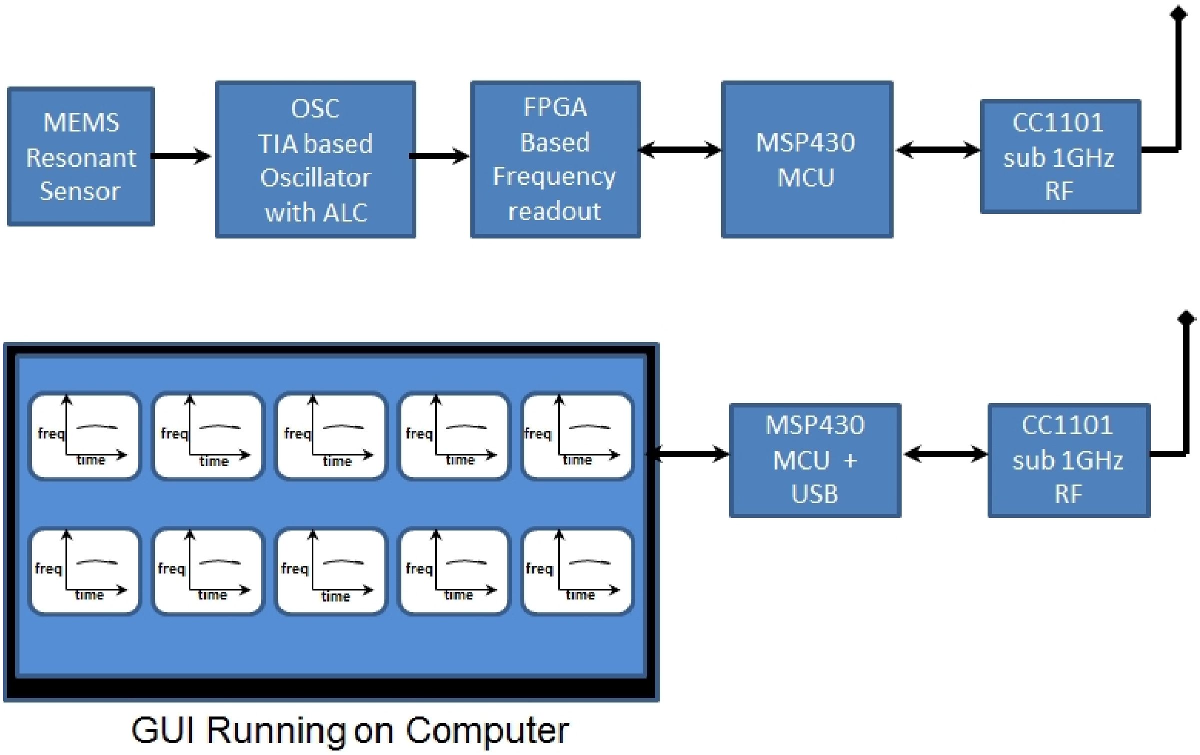

Fig. 1 Wireless readout system architecture

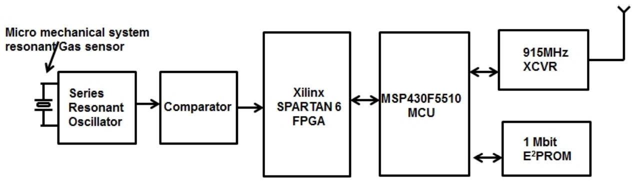

Fig. 2 GSWR Architecture

A. Series Resonant Oscillator with Comparator

Fig. 3 shows the schematics of the oscillator. A trans-impedance amplifier architecture which guarantees optimum motional current detection and provides actuation voltage which is in phase with the detected current is chosen [6]. Over all tuneable gain range is modified to 13.2K to accommodate our micro mechanical system resonator. It is based on the four stage trans-impedance amplifier. Wide band ultralow noise operational amplifier OPA656 provides current to voltage conversion of 2K2. This followed by two stage high speed low noise amplifiers of AD8045 which provide tuneable gain up 6. Last stage is based on AD8131 which provide differential output voltages $V^0$and V^{180} to drive resonator and an on chip compensation capacitor on the resonator. V^0 output is further processed in an LT1711 comparator to generate 3.3V square wave compatible with the FPGA readout. Total oscillator with comparator circuit consumes 85mA.

Fig. 4 shows the sine wave V^0 output of the oscillator circuit and has amplitude of 1.8V Pk. pk.

As per [4] to achieve the target limit of detection for ethanol of 1 ppm the phase noise requirement is derived to be -80dBc/Hz with an offset frequency of 1 KHz. The phase noise of the oscillator is measured using a signal source analyser and is shown in Fig. 5, which is -100dBc/Hz for an offset frequency of 1 KHz. This is better than the -80dBc/Hz and can achieve 1 ppm limit of detection. Close to carrier phase noise follows $1/f^3$ in frequencies between 1Hz to 100Hz.

B. FPGA Frequency Counter

Xilinx SPARTAN XC6SLX9 FPGA is used in the GSWR mainly due to its programmability and flexibility in implementation of the various functions. A multiplexed 10 channel frequency counter is implemented for measuring the frequency of the comparator output. Multiplexed 10 channel frequency counter will be useful when the multichannel gas sensor is ready to be tested.

The frequency counter runs at 122.88MHz and the FPGA core is implemented using Verilog and is completely synchronous design with 122.88MHz as the master clock and other required clocks are implemented as clock enables. The signal coming from the comparator is routed to the FPGA. FPGA first samples the input signal and transfers it into its clock domain and then starts measuring the frequency. The gating signals required by the frequency counter such as 10 Hz, 1 Hz and 0.1 Hz is generated by using chain of divide by N counters. There is an SPI slave controller built into the

FPGA so that MCU can talk to the FPGA for configuration as well as reading the frequency counter data. On board emulated JTAG controller based on FT2232D is implemented to ease programming of the FPGA from the PC. Fig. 6 shows the GSWR node and the open cavity QFP52 package houses the resonant sensor.

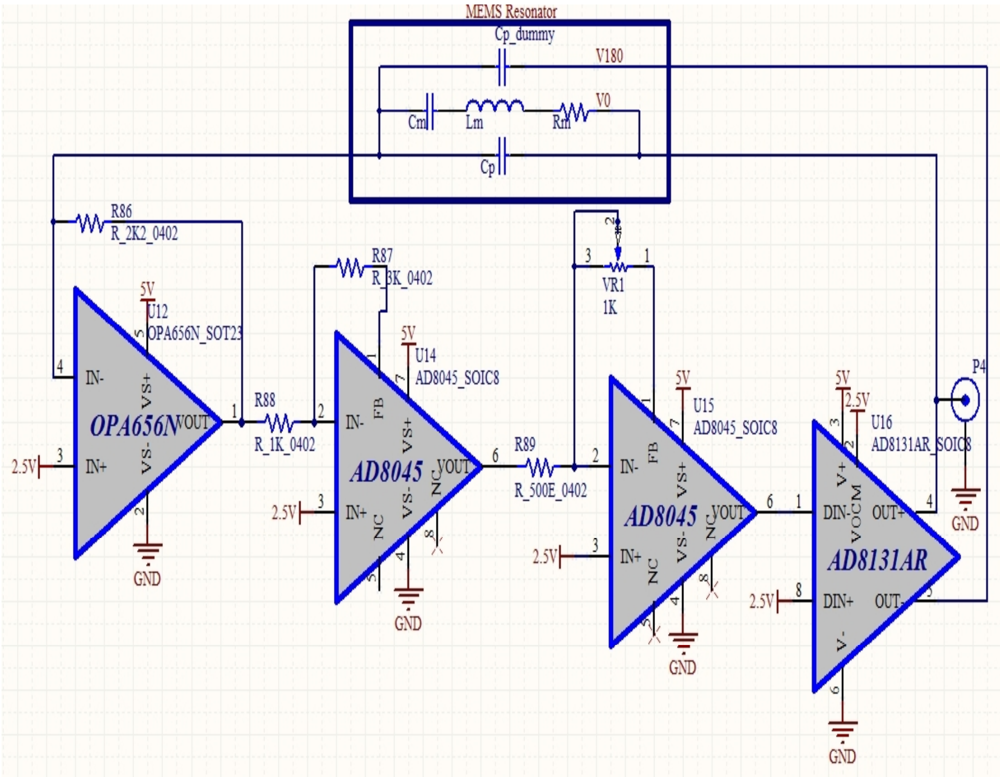

Fig. 3 Series resonant oscillator

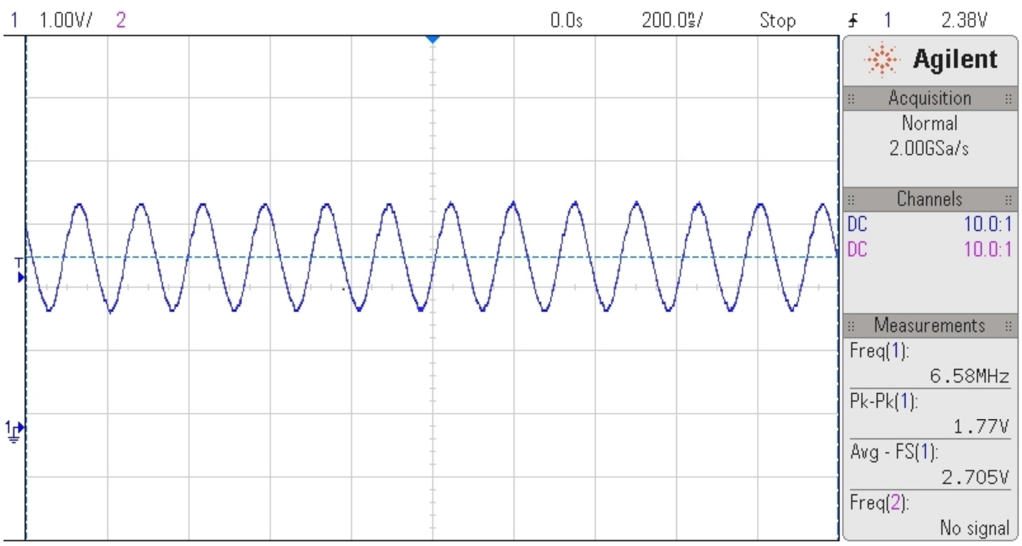

Fig. 4 Closed loop oscillator output

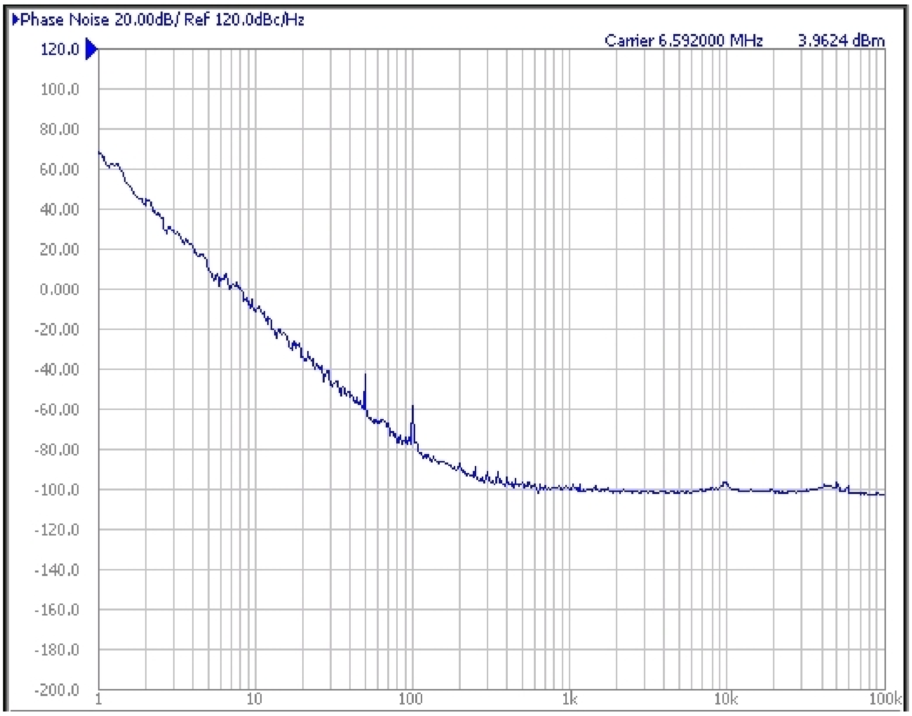

Fig. 5 Phase noise measurement

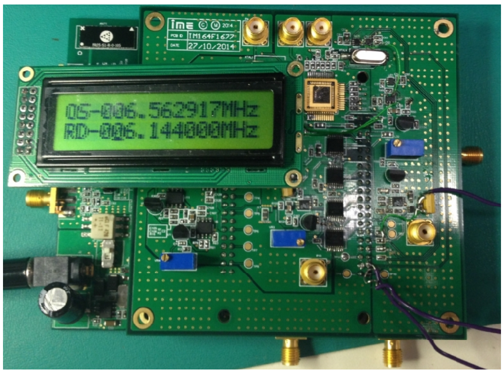

Fig. 6 GSWR node

C. GSWR Processor

MCU in the GSWR performs RF transmissions and gas sensor measurements and other housekeeping functions. An MCU with sufficient on chip Flash memory, scratch RAM and amble processing power, MSP430F5510 from Texas Instruments [7] is chosen. This has up to 25 MHz clock speed and ultralow 2.1µA standby power and 32 Kbytes code storage Flash memory and 6 KB scratch pad SRAM. MCU uses SPI port to talk to RF transceiver as well as to the FPGA.

Considering the future low power operation requirements, the firmware operates the MCU at 1MHz in active mode and switches it to 32 KHz in sleep mode. Low power methodology such as RF to sleep when not in use and peripherals disabled when not in use is followed. MCU firmware is written in C and compiled for the MSP430F5510 processor. On power up the firmware initializes interrupts, general purpose IO, SPI port, real time clock (RTC) and watch dog timer and then waits for the FPGA to boot up by polling FPGA's SPI status register. Upon successful status register reading, it initializes the frequency counter and oscillator select sequence. It configures the RF transceiver to be able to connect to the UWT then puts it to sleep. All the unused pins of MCU are configured as input to conserve idle mode power consumption. Thereafter, firmware waits for the sensor poll command from GUI software through UWT. Whenever a frequency poll command received from UWT an RF received interrupt is generated. MCU serves that interrupt by first enabling the oscillator for a given sensor channel and then measuring frequency of oscillation. Later it sends the measured frequency value and time stamp to UWT through the 915 MHz RF link. UWT in turn sends the received data to the GUI through the USB port of the computer. Status indication LEDs are provided and USB port of this MCU can be used for debugging purposes.

D. Low Power 915MHz Radio

GSWR and UWT wireless link is in 915 MHz band and the RF chain is implemented using sub 1 GHz radio transceiver chip from Texas Instruments [8]. This transceiver has a sensitivity of -104dBm in 38.4 K baud GFSK and has a programmable transmit power, but programmed by default to 0dBm. Transmit current is about 17.2mA in 0dBm transmit power and consumes 15.6mA in receive mode. Sleep current of 200nA helps much in power sensitive applications. Simple stop and wait protocol is implemented for the GUI ←→ UWT ←→ GSWR communication link. But the entire design is provisioned such that a full wireless sensor network protocol such as Texas Instrument's SimpliciTI can be run on both GSWR and UWT.

E. Power Supply

There are two switching regulators on board GSWR one is ADP2303 3A, 700 KHz switching regulator to convert the 5V to 3.3V to supply all the devices on board GSWR including IO ports of FPGA. Another one is LTC3419 600mA, 2.25 MHz switching regulator which steps down 3.3V to 1.2V to supply the core of the FPGA.

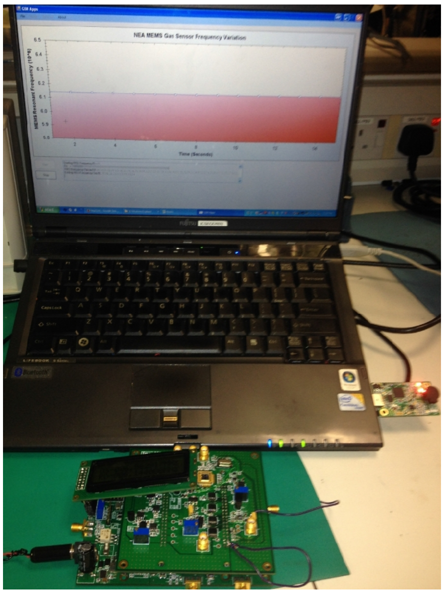

Fig. 7 Wireless readout system in operation

IV. UWT Architecture

Fig. 8 shows the architecture of the USB wireless transceiver. UWT is designed based on MSP430F5510 processor and the CC1101 RF transceiver.

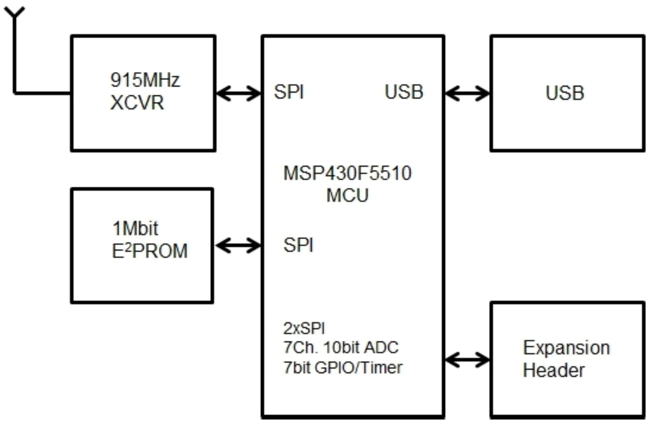

Fig. 8 UWT Architecture

UWT is similar to that of the RF module of the GSWR. It is size is 2“x 1.25“and can be readily plugged into the USB port of the computer. GUI software running in the computer sends poll sensor commands every 1/30/60/300 seconds. UWT then routes the poll command to GSWR through 915 MHz RF link. Response back from GSWR is processed and sent to the GUI through UWT USB port. The data received by the GUI is plotted in a graph as Time Vs Frequency as shown in Fig. 7. Frequency data received is also stored in a file in comma separated value format, to ease further post processing. Fig. 9 shows the picture of the UWT.

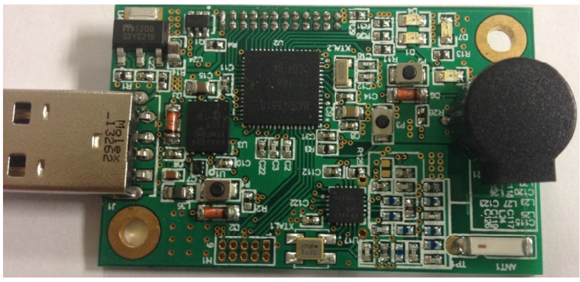

Fig. 9 USB wireless transceiver

UWT is designed such that it is bus powered from the USB port of the computer. Later the UWT’s firmware can be updated with protocols like SimpliciTI from Texas Instruments to form a wireless gas sensor node. Sensor portion can be easily implemented through the expansion header provided on board UWT as this connector brings out MCU’s multiplexed 7 channel 10 bit ADC, SPI ports and the timer ports. UWT can also be powered through the expansion connector.

V. Conclusion

In this paper, the design of the wireless read out system for the micro mechanical system based resonant gas sensor have been presented and an MCU and FPGA centric architecture which eases experimentation and provides flexibility is presented. Small form factor USB wireless transceiver also designed and integrated into the wireless readout system. End to end sensor measurement and frequency read out is demonstrated. With this system various combinations of micromechanical system sensors with varying polymers can be tested and characterized to ease the development of arrayed multi-channel fugitive hydro carbon sensor.

Next phase would be to integrate the multi-channel oscillator and FPGA readout into a single chip and use along with the arrayed resonant micromechanical system gas sensor to detect up to 10 different hydrocarbons while minimizing the size and power consumption.

Acknowledgment

This work was supported by the Agency for Science and Technology Research (A*STAR) Singapore, Science and Research Engineering Council (SERC) under grant number 1224104045.

References

[1] F. Röck, N. Barsan, U. Weimar, Electronic Nose: Current Status and Future Trends, Chemical Reviews 108 (2008) 705–725.

[2] E.J. Severin, B.J. Doleman, N.S. Lewis, An Investigation of the Concentration Dependence and Response to Analyte Mixtures of Carbon Black/Insulating Organic Polymer Composite Vapor Detectors, Analytical Chemistry 72 (2000) 658–668.

[3] N.S. Lewis, Comparisons between Mammalian and Artificial Olfaction Based on Arrays of Carbon Black–Polymer Composite Vapor Detectors, Accounts of Chemical Research 37 (2004) 663–672.

[4] Pettine, J., M. Patrascu, D. M. Karabacak, M. Vandecasteele, V. Petrescu, S. H. Brongersma, M. Crego-Calama, and C. Van Hoof. "Volatile Detection System Using Piezoelectric Micromechanical Resonators Interfaced by an Oscillator Readout." *Sensors and Actuators A: Physical* 189 (2013): 496-503.

[5] S. Mohamed Rabeek, M. Kumarasamy Raja, Steve Schiefen, Michael K. Dempsey, Ruey Feng Peh, and Minkyu Je, "Wireless Tag and Reader Module Design for Automated Hand Hygiene Documentation and Reminder System in Hospitals," International Journal of Information and Electronics Engineering vol. 3, no. 1, pp. 16-19, 2013.

[6] Patrascu, M., J. Pettine, D. M. Karabacak, M. Vandecasteele, S. H. Brongersma, and M. Crego-Calama. "Oscillator-Based Volatile Detection System Using Doubly-Clamped Micromechanical Resonators." *Procedia Engineering* 25 (2011): 1533-1536.

[7] "Low Power Mixed Signal Controller MSP430F550x Data Sheet," Texas Instruments Inc. SLAS645B-JULY2009-REVISED JULY2010.

[8] "Low-Power Sub-1 GHz RF Transceiver CC1101 Data Sheet," Texas instruments Inc. SWRS061F-January 2010.