Design of a Signal Conditioning Circuitry for Low Powered Pellistor Gas Sensor

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Abstract— **Gas sensing- a fast growing technology owing to the importance of detecting and monitoring toxic and combustible gases has received tremendous attention in the academia and, industrial sector. Sensors are high power consumption devices and the signals can be misleading. This paper presents design of a sensor interface circuitry to reduce sensor power consumption as well as condition the sensor signal. An interface (drive) circuitry was designed, fabricated and integrated with a pellistor gas sensor. Multisim version 11.0 was used to design and simulate the interface circuitry until the desired results were obtained. Experimentation carried out by the implementation of the designed and developed virtual instrument (VI) programme in LabVIEW demonstrates that the sensor is highly sensitive to the ethanol vapour which it was exposed to and the power consumption of the heater is 42.5 mW.**

***Index Terms*—Sensors, gas, circuitry, power, simulate detecting**

I. Introduction

A sensor is a device that responds to some stimulus by generating a functionally related output [1]. Gas detection and monitoring instruments are products of safety technology which are dedicated to the detection of dangerous gas concentrations and as a result producing a signal which is translated to a visual or audio output meant to give an alert before it reaches a hazardous level for human and environment. Combustible gases such as hydrogen, methane etc. are potential treat to life and environment when they accumulate at explosive concentrations. Early technology to detect such gases involved the use of an electrically heated bare platinum filament or platinum loaded ceramic bead [1; 2]. The sensors produced using this technology has high power consumption of about 300mW at 600^{o}C [3] and slow response due to their relatively large size. These obviously made the sensors expensive, unreliable and not reproducible. The limitation of the early gas sensor were eliminated by Si micromachining technology – a technology which involves the process of fashioning microscopic mechanical parts such as beams, diaphragms, grooves, orifices, springs, gears, suspensions and a host of other complex mechanical structures out of a silicon substrate or actually on top of a silicon substrate [3].This state of the art technology allows for gas sensors with improved selectivity and response time to be manufactured through the development of sensor arrays and the integration of electronics for control and data acquisition.

Gas sensor technology is receiving tremendous attention in the industry and academia due to increasing demand of environmental monitoring and other gas detecting applications. There are a number of devices for monitoring and measuring gases in both the industrial and domestic set-up, some of which are catalytic (pellistor) gas sensor, infra-red gas sensor, semiconductor and Schottky barrier gas sensors etc [4]. Pellistor is a gas sensor that consists of two pellets with platinum coil and having one of the pellet coated with catalyst and the other poisoned to inhibit combustion of the target gas. Pellistor gas sensor stands-out because of its application in detecting combustible gases. This uses the theory of catalytic combustion which involves the combustion of gases at a temperature lower than their normal ignition temperature because of interface circuitry and microelectronic batch-fabricated compatibility. This compatibility makes mass production of pellistor gas sensor easier and consequently cheaper than the earlier ones [5].

The increase in air pollution is proportional to the rate of industrialization and overall emission levels have been rising, especially for poorer countries, at nearly 6 per cent per year [6]. Air pollutants such as oxides of carbon (CO and CO_2), oxides of nitrogen (NO and NO_2), oxides of sulphur (SO and SO_2) from various sources have remained key contaminants of the environment and therefore constitute a threat to human health and negative environmental impact. Similarly, explosive gases such as hydrogen which is the target gas for this project, methane, propane etc. are dangerous when present in air at about 4% vol. [7]. The presence of appreciable amount of these substances in air can cause harmful effects to human health, vegetation and human properties as well as the global environment [6].

The rapid development of integrated-circuit (IC) technology during the past decades has stimulated many initiatives to fabricate catalytic gas sensors on complementary metal-oxide-semiconductor (CMOS) substrates and later to develop separate drive and signal conditioning circuits [8-10]. The integration of interface CMOS electronic (circuitry) with micro sensor is highly necessary because it allows the production of reliable, low

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cost, low power and reproducible smart gas sensor. It gives the opportunity of running the sensor at a low power and also getting signals from the sensor that may be easily analyzed. This is a major contribution to the design of efficient and low power gas sensor with accurate results. Although the integration of the gas sensing element and an interface circuitry is of tremendous advantage and importance, it is not without challenges. These challenges range from incompatible operating temperatures, non-standard CMOS material and process, constraints on the properties and geometries of ICs, poor long term thermal stability of heater material, lack of good electrical contact between electrodes and the gas sensing layers due to native oxide formation and the presence of highly reactive chemicals that can attack either the CMOS metal, silicon or even passivation layers during the pre and post--treatments for sensing material deposition [10]. Figure 1 shows a catalytic gas sensor.

Fig. 1: Catalytic Bead Sensor [4]

II. MATERIALS AND METHODS

The section presents the types of software and the electronic components used in the design of the interface circuitry. Different commercial software were used at different stages of the design, these software are Multisim, x-y extract and LabVIEW 2010 developed by National Instruments.

A. *Electronic Components*

The electronic components employed in the design and buildings of the interface circuitry are Dual operational amplifier, Instrumentation amplifier, Resistors, Capacitors, MOSFETs.

Other materials used for the experimental set-up include DAQ 6009 (191039D-01L, National Instruments), pellistor gas sensor, computer system, head space, a mini pump (NMP 095), LED display (DPM 1AS-BL, LASCAR), 30 V power stabilizer (E30/1, Farnell Instruments), connecting hose, sensor heating chamber. Detail presentation of the performance of the pellistor gas sensor integrated with the circuitry will be presented in future publication. Figure 2 shows DAQ 6009 and the pin arrangement.

B. *Design and Description of Drive Circuitry*

The design of the drive circuitry was implemented using Multisim. The circuit was chosen to be a current source circuit that uses half bridge (potential divider). The designed sensor interface (drive) circuitry is an operational amplifier (Op amp) based current source with a high precision dual op amp and a differential op amp (a special kind of instrumentation op amp). Dual op amp is used because the sensor has two Pellistors (an active and a reference element). A half bridge was used to provide the voltage on the non-inverting input (v_+) of the op amp and because of the feedback loop the voltage (V_{set}) was created and maintained on the inverting input (v_-) of the op amp. It is this voltage that drives the resistive heaters (i.e. the hot plate) which in turn set the current that creates rise in temperature and consequently increase in voltage (i.e. the signal). The drive voltage for the circuitry can be obtained from two sources viz.: using the half bridge (potential divider) and using external source such as Data acquisition (DAQ) hardware with LabVIEW software programmed to provide the required voltage (which is the case in this project). Function generator and battery can also be utilized in provision of external voltage. A temperature rise of the heaters caused by combustion of the gas culminates in an increase in resistance and consequently an increase in voltage drop across the heaters. The voltage output from the heaters are taking to the differential amplifier where the difference of the two voltages is amplified and displayed or passed through DAQ 6009 (see Figure 2) to the LabVIEW programme for processing and display on a PC. The gain for amplification is set as required using an external resistor. The gain can be from a minimum value of 5 to a maximum of 1000 for AD627 instrumentation amplifier. The final information gotten from this is observed in a display or in LabVIEW for analysis. Figure 3 shows the sensor circuitry designed using Multisim and fabricated on a PCB shown in Figure 3. Figure 4 shows the picture of the PCB.

Fig. 2: DAQ 6009 hardware and the pin arrangement

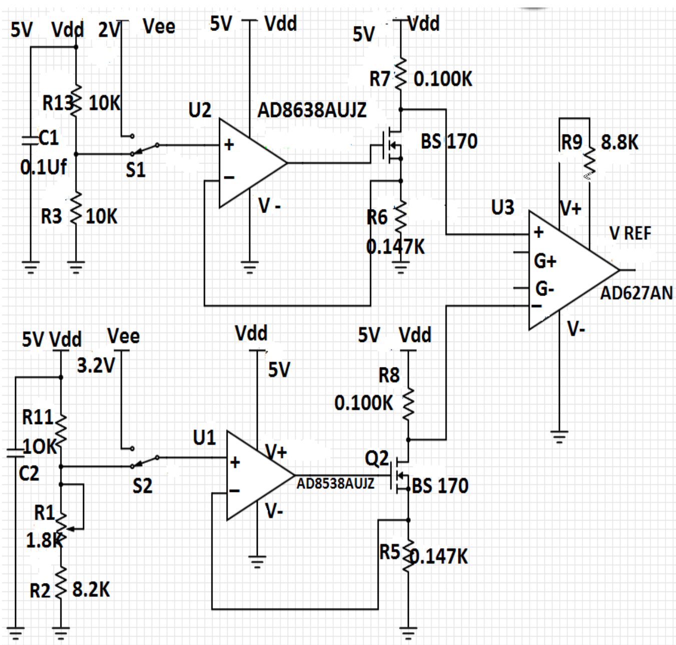

Fig. 3: Designed Sensor Drive Circuitry

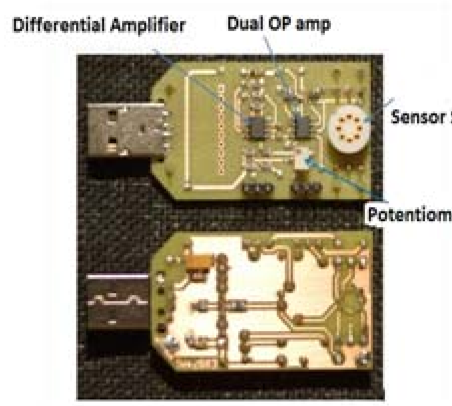

Fig. 4: Final PCB for the sensor interface circuitry (display not present)

C. Circuit Operation

The operation of this circuit depends on the feedback loop. The goal of the circuit is

to use low input power to drive a circuit which is responsible for powering a gas sensor in order to be able to burn hydrogen gas at a temperature far less than its normal ignition temperature with the use of a catalyst. This is achieved in the following way: The supply voltage is 5 volts and by means of a voltage divider which consist of two equal (10 kΩ) fixed resistors R_{13}, and R_3 half of this supply voltage is input to the non-inverting terminal of the dual op amp. In the configuration of the circuit, op amp has very huge impeadance in giga and tera ohms which implies that no reasonable current passes through the op amp and will continue to change its output until the value of the inverting (V_+) and the non-inverting (V_-) are equal (i.e. 2.50V). This sets the voltage (V_{set}) that drives the active and the passive heaters(R_5 and R_6.) and set the current in the hot plates. The current raises the temperature of the heaters which consequently increases the resistance of these elements, but due to the fact that the active heater is coated with catalyst and supports combustion of the target gas which in this case is hydrogen gas and it burns below its normal ignition temperature, its temperature will rise more as a result of the temperature of combustion and that of the reference element will be limited due to the fact that it is poisoned to inhibit combustion of the target gas. The difference in voltage owing to the temperature difference which is the signal generated is fed into the differential amplifier which amplifies the difference with a gain of 34.28.

D. Experimental Procedure

After setting up the experiment as shown in Figure 5, the sensor was set at 500°C and was allow running for 48 hours in order to burn off the solvent. It was allowed a settlement time of 48 hours after which it was tested for response with ethanol. The sensor was first tested with ambient air using a control valve and the response was noted and recorded. This was repeated with varying heater voltage. A mini pump was used to bubble ethanol gas from a headspace containing liquid ethanol and passed to the sensor through the tiny plastic hose and the gas chamber. Ethanol was used as a test gas for the sensor and because of time and Health & Safety constraints.

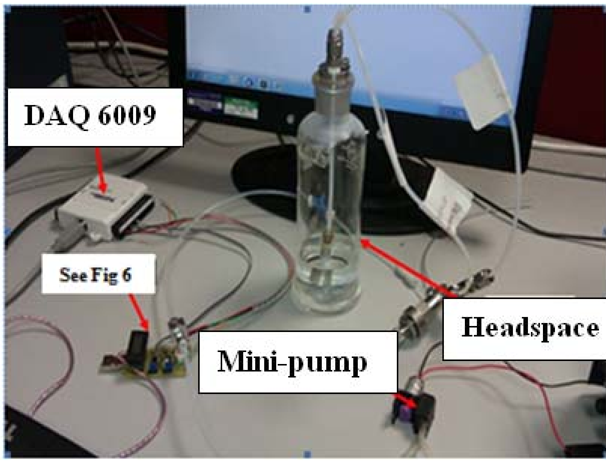

Fig. 5: Experimental set-up for testing response to ethanol vapour

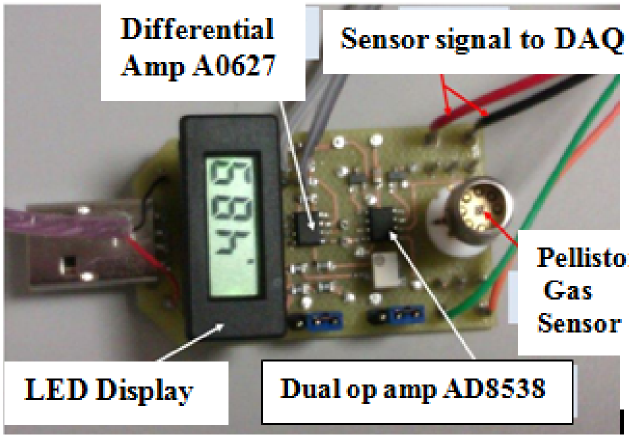

Fig. 6: Pellistor sensor mounted on interface circuitry

III. RESULTS AND DISCUSSION

The results of the device voltage and current requirement over a temperature range and the power consumption of the device are presented in Figures 7, 8, and 9.

The results of the experiment with ethanol vapour are also presented. The response of the sensor to ethanol at 600°C corresponding to heater voltage of 2.5 V is presented in Figure 11. Sensor characteristics such as selectivity, stability, recovery time will be investigated and the result presented in the next conference. From Figure 7, it is clear that the temperature of the device increases with increase voltage. This implies a proportionality relationship and for the device to be raised to an operating temperature of 600°C, a voltage of not less than 2.5 V is applied.

Because of constraints from materials point of view, the temperature of the sensing element cannot be increased endlessly without a limit as can be seen in the Figure 7.

Figure 8 shows the current requirement of the device; a current of 17.5 mA is required at the sensor operating temperature 600°C although the sensor circuit simulation gave a 17.0 mA. The current requirement can be seen to increase with temperature.

The relationship is not linear because the temperature of the heater at any time depends also on the heat transfer conditions the heater is exposed to. Although there will always be temperature rise with increase in current flow.
Figure 9 shows the power requirement of the sensor. This is an important aspect of the sensor design and development because reduced power consumption in an important aim in the recent SOI-CMOS sensor design. This gives sensors of this kind an edge over the past ones with high power consumption of about 1W.

The power consumption which has a direct relationship with current and voltage can be seen to increase with increase temperature. This is expected as the earlier graph present both current and voltage as being proportional to rise in temperature. The power consumption of the heater is 42.5 mW at a temperature 600°C. This is quite a good power consumption rate and can be power with a potable dc supply. Figure 10 shows the result of the resistance-temperature relationship which was discussed in chapter three. Increase in temperature is the basic misbrands on which the operating principle of pellistor gas sensor is based.

Increase in temperature of the heater as a result of voltage applied and heat of combustion of the target gas gives rise to an increase in the resistance of the heater. At the 600°C operating temperature limit, the resistance of the heater is about 140 Ω.

Figure 12 shows the response of the sensor to air blown from empty 500ml distilled water bottle. The result shows a cooling of the sensor as the response dropped from an average of 0.95 V to an average of 0.7 V. The varying drops as can be seen is a function of the volume of the air blown.

Figure 13 shows the response of sensor to ethanol at a voltage setting of 2 V. The response is quite rapid and higher with 2.5 V that with 2.0 V.

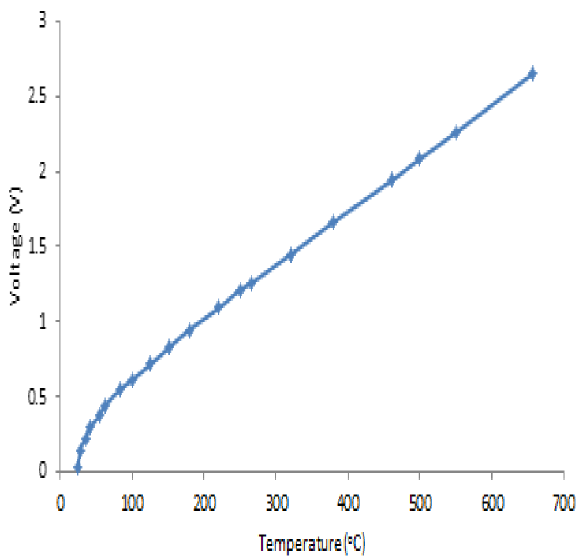

Fig. 7: Voltage requirement of the device

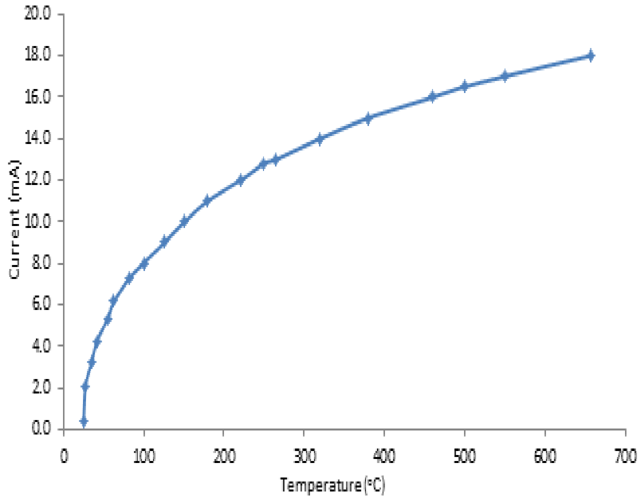

Fig. 8: Current requirement of the device

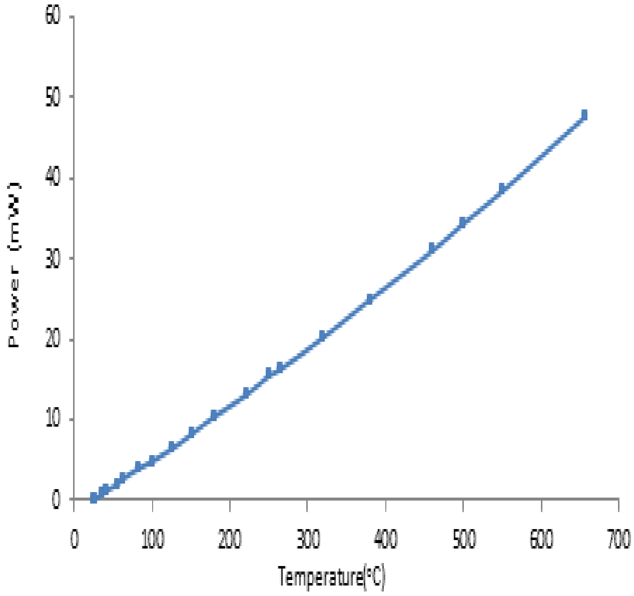

Fig. 9: Device power consumption

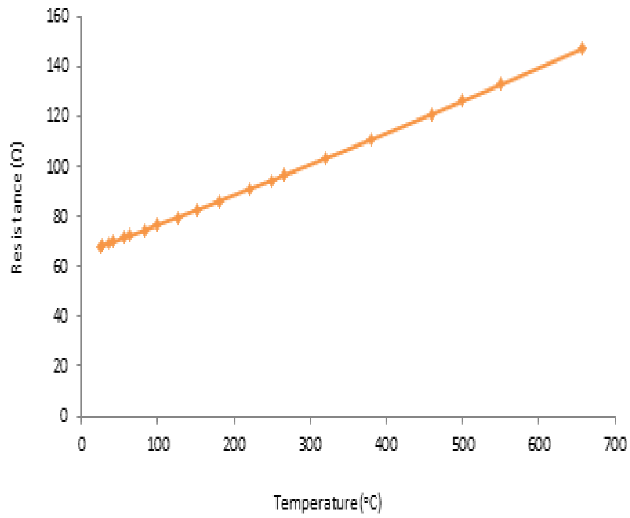

Fig. 10: Variation of heater resistance with temperature

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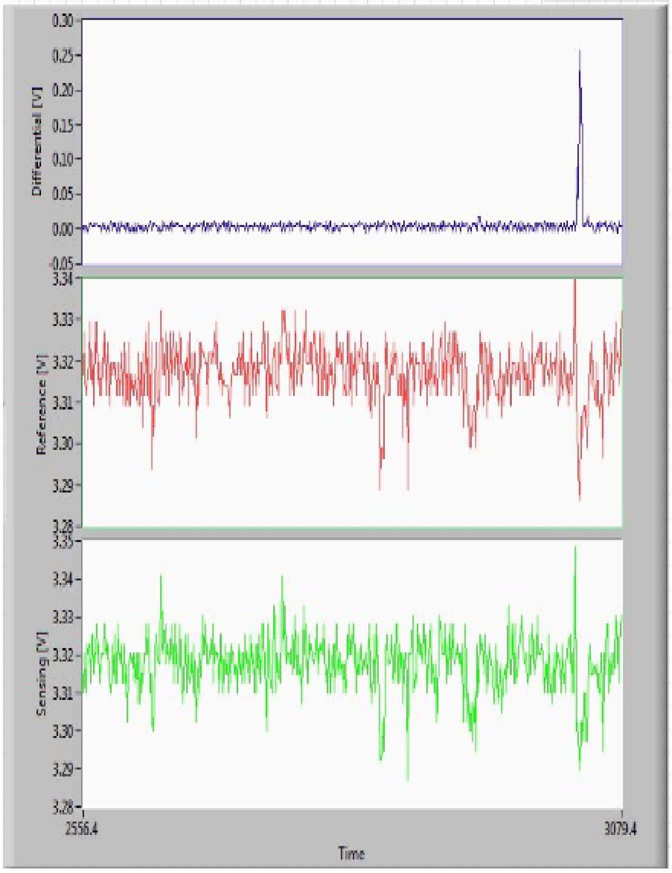

Fig. 11: Sensor response to ethanol at 2.5 V

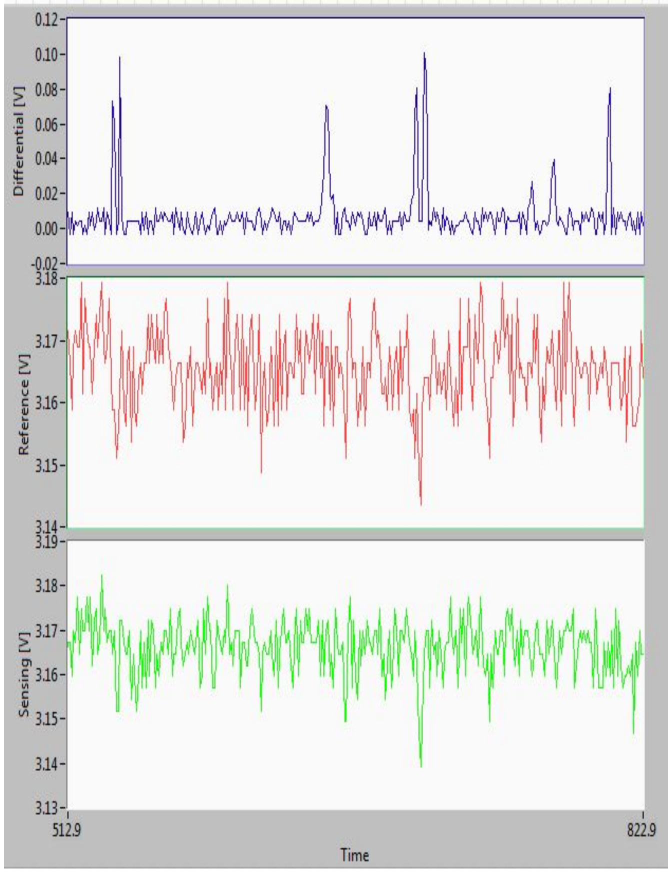

Fig. 13: Sensor response to ethanol at 2 V

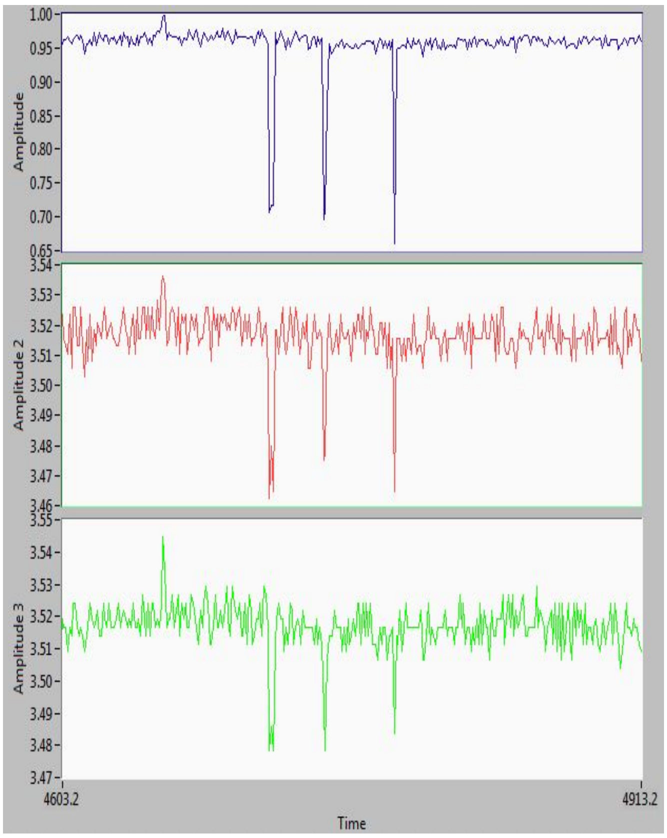

Fig. 12: Sensor response to air at 1.5 V

IV. CONCLUSION

This paper presents the design of a pellistor gas sensor signal conditioning circuitry. It is aimed at developing a circuit with low powered gas sensor signal conditioning circuits. The results of some performance parameters and relationship are presented. More detailed performance with different combustible gases will be presented in the next conference.

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1. Date of modification : May 27, 2014
2. Included the name of the university where the research was carried out and the names of the supervisors. The sentence after citing of reference 4 of the introduction was re-casted. NO2, SO2 and CO2 were changed to NO_2, SO_2 and CO_2.