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# A New Microcontroller Based System for Resistance Measurements of Gas Sensing Materials

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*The present work illustrates a low cost microcontroller-based system for resistance measurements gas sensing materials. The system is based on a peripheral interface controller (PIC) 16F877A. The designed circuit consists of instrumentation amplifier with multi gain stages controlled by the PIC to amplify the voltage sensor signal. The analog to digital converter (ADC) inside the PIC measures the sensor voltage signal and sends it to the computer. The interface with the circuit, through the RS232 serial port, is managed by a program designed using LabVIEW. Two types of gas sensing materials (lab synthesized nano-particle* $NiFe_2O_4$ *powder and commercial* $SnO_2$ *powder) have been used to test the system. The sensors' resistance has been measured by the designed system during the exposure to ammonia and water vapor with different concentrations. The reproducibility of the results has been checked out. Therefore, this system can be used by manufacturers and researchers as a quality control system for gas sensing materials.*

## 1. Introduction

The industrial revolution has caused the presence of several kinds of toxic vapors, fumes and gases. The requirement to control the performing of certain reactions in factories or to investigate the toxic waste products becomes essential [1-3]. Many researchers make much effort to introduce simple low cost instruments for gas sensing measurements [4-7]. There are some environmental standards which must be investigated for public health of human, animals and plants. Air pollution with some gases may be toxic and dangerous as they are affecting the biological balance system and may cause diseases and even death. The need for gas sensors, such as electric noses, capable of providing reliable operation in harsh environment is now greater than ever [1-3,5,7,8]. Several methods can be used to detect the presence of gases in a certain volume. The most important methods are: the capacitive method (by AC measurements), the resistive method (by conductivity measurements), the gravimetric method (by quartz crystal micro-balance measurements) and the optical method (by transmission, absorption and fluorescence measurements) [8-13]. In literature, there are many efforts to establish different measuring systems based on microcontroller to detect the variation in some sensing property [5,10,14,15]. In addition, nowadays the use of computer programs such as those designed by labVIEW to serve in the interfacing between circuits and computers has become very important in research [4,10,14,16,17-19].

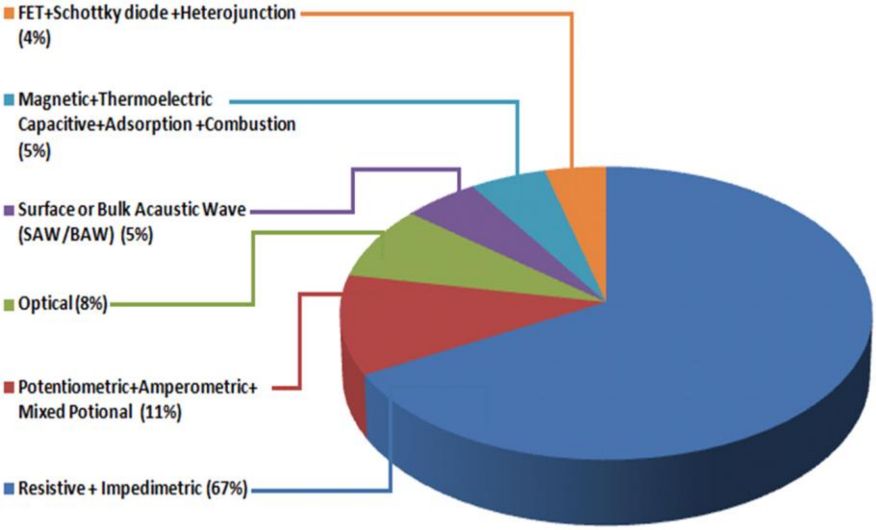


**Fig.(1):** A schematic summary diagram of various types of metal oxide-based gas sensors [20].

In the present work a microcontroller-based system along with a LabVIEW program are designed to serve in testing gas sensing materials. The resistance measurement is the most common method used in gas sensors as shown in Fig.(1) [20].

## 2. Setup Design

The system is designed to calculate the change in the resistance of a sensing material (the sensor) by measuring any small changes in the voltage drop across a resistance connected in series with it, as shown in Fig. 2-a which represents the biasing circuit (notice that it is not shown in Fig. 2-b.)

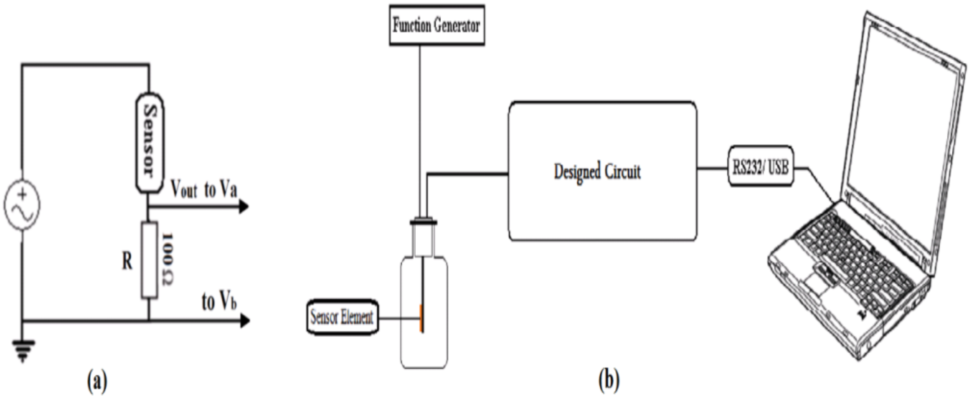


**Fig. (2):** (a) The sensor biasing circuit. (b): The block diagram of the measuring system.

A block diagram of the measuring system is shown in Fig. (2-b) the sensor element is placed inside a well sealed glass bottle. Two types of sensing materials ($NiFe_2O_4$and $SnO_2$) have been used in the present work to test the performance of the system. The sensor element consists of a relatively thick film of the sensing material cast coated on two interdigitated electrodes [1,21,22]. One of the electrodes is connected to the biasing voltage taken from function generator and the other to the series resistor (shown in Fig. 2-a). This resistor is connected to the designed circuit which will amplify the output voltage signal and convert it to a digital form to be delivered to the computer via an RS232/USB converter.

The block diagram of the designed circuit is shown in Fig. (3). It consists of a high input impedance differential instrumentation amplifier [23-25] taking one of its inputs from $V_{out}$ shown in Fig. (2-a) and the other to the ground. The details of the amplifier circuit are shown in Fig.(4). The gain values are (10, 100, 1000 and 10000) followed by an amplifier with gain values of (1, 2.5 and 5) to increase the available gain options. A manual DC offset circuit is introduced to remove any DC offset component that may be found in the final gain. This part of the circuit is used only if the biasing voltage is DC, and it has to be manually changed with every gain choice, for this reason using an AC biasing voltage will be preferred because it is much more time and effort saving where just by using a DC blocking capacitor in series with the gain resistor - the need of changing the offset level manually every time the gain changes, is avoided.

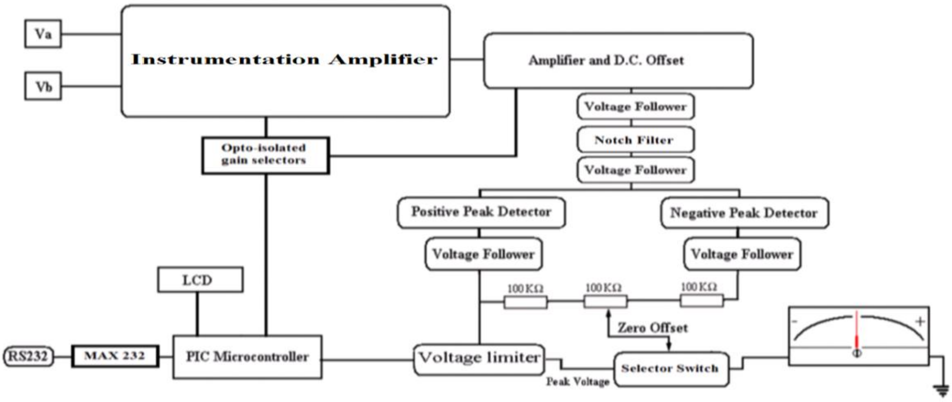


**Fig. (3):** The block diagram of the designed circuit.

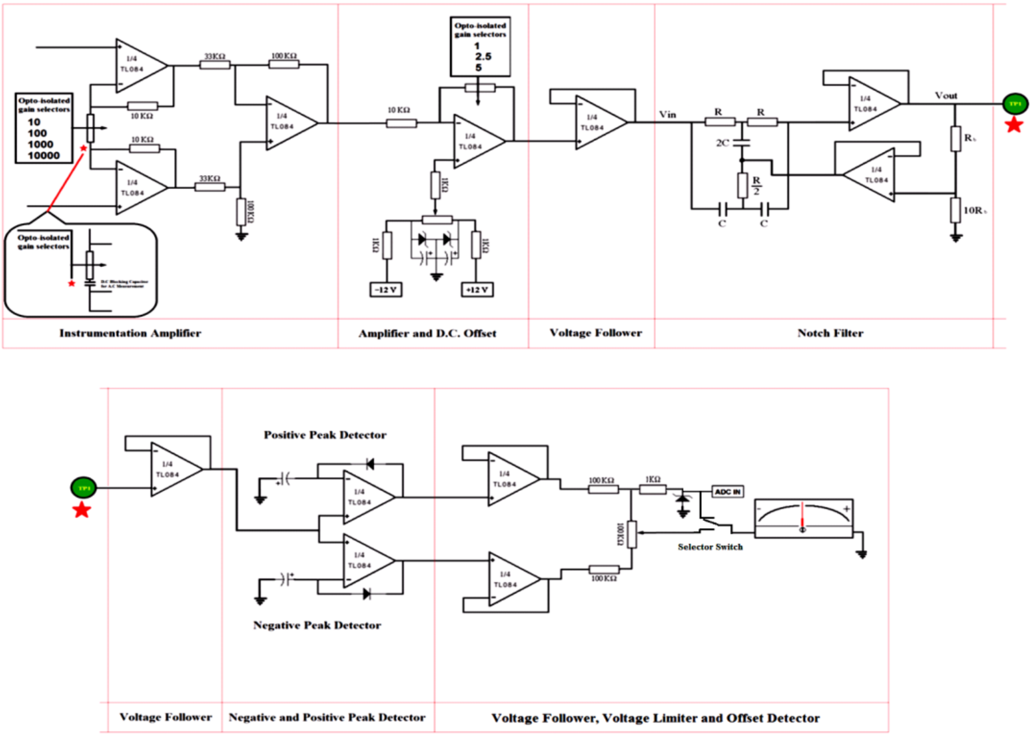


**Fig.(4):** Details of the amplifier circuit.

A voltage follower is used to match the impedance from high to low. This procedure avoid any probable change in the amplified signal that may occur due to the next stage. In the case of using AC biasing voltage, the amplified signal is filtered through a notch filter. The buffered signal is fed to both negative and positive peak detector. Then, the output signals are mixed using a resistor network for checking the zero level adjustment as shown in both Fig. (3 & 4).

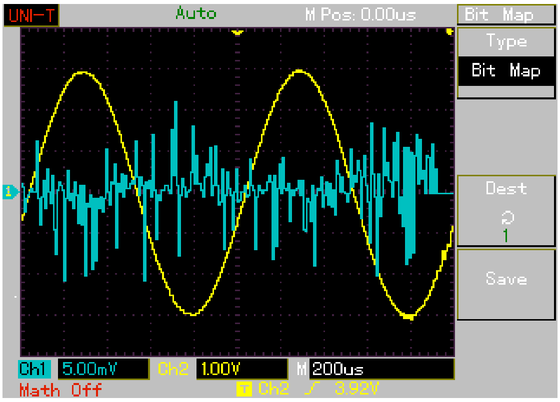


**Fig.(5):** The input voltage ($V_a$) and the output signal after amplification and noise cancellation by the designed amplifier.

From Fig.( 5), it is clear that the voltage $V_a$ can't be measured without using the amplifier circuit to provide a high gain and low noise. The signal from the positive peak detector is introduced to a (10-bit) analogue to digital converter (ADC) in the PIC microcontroller which then transmits the collected data to the PC through RS232. The PIC microcontroller also controls the gain of the amplifier through seven opto-isolated gain selectors. The system as a whole is controlled by two software programs. The first has been embedded in the PIC microcontroller and written by mikroBasic language. The second software program is a labVIEW program used to auto control the gain, measure the time and finally to plot the relation between the voltage signals and both time and gas concentration.

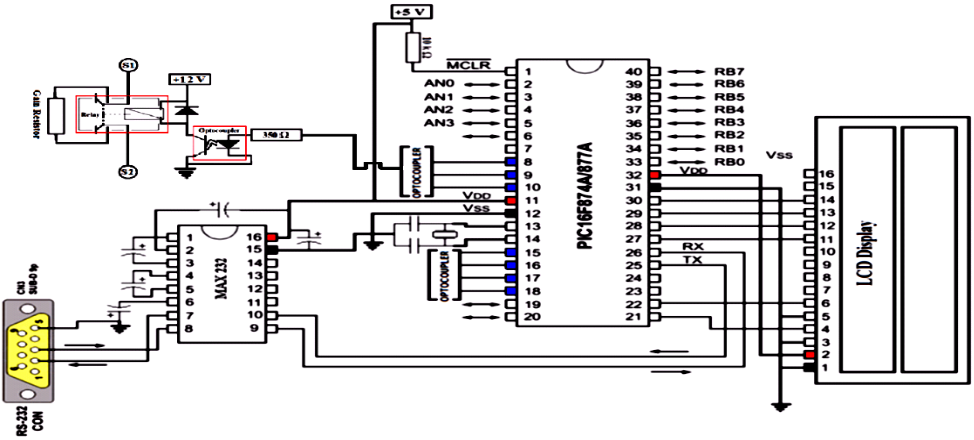


**Fig.(6):** The PIC microcontroller interface with Max232, an LCD and only one of the opto-isolated gain selector (at the upper left of the figure).

Figure (6) also shows the analogue input node AN0 into which the amplified voltage signal is introduced. AN1 is connected to an LM35 temperature sensor (not shown in figure) to measure the temperature of the sensing element.

AN2, AN3 and the port B (0-7) may be used in future development of the circuit considering the DC bias and/or function-generator control.

Max232 IC is used to adapt the signal levels between the PIC and the serial port RS232. The LCD is used to display the data sent from the computer to the PIC and vice versa. Also, it displays the temperature of the sensing element.

## 3. System Testing

The designed system has been used to measure the dynamic resistance change of some gas sensing materials as a function of time at different concentrations of the detected gases of course, the change in the dynamic resistance is manifested by a change in the voltage signal sent to the amplifier.

### 3.1. Sample Holder

As shown in Fig.(7) the sample holder consists of two connectors for the two interdigitated electrodes, heater to vary the temperature of the sensing materials and LM35 temperature sensor to measure the heater temperature to be monitored and displayed on the LCD.

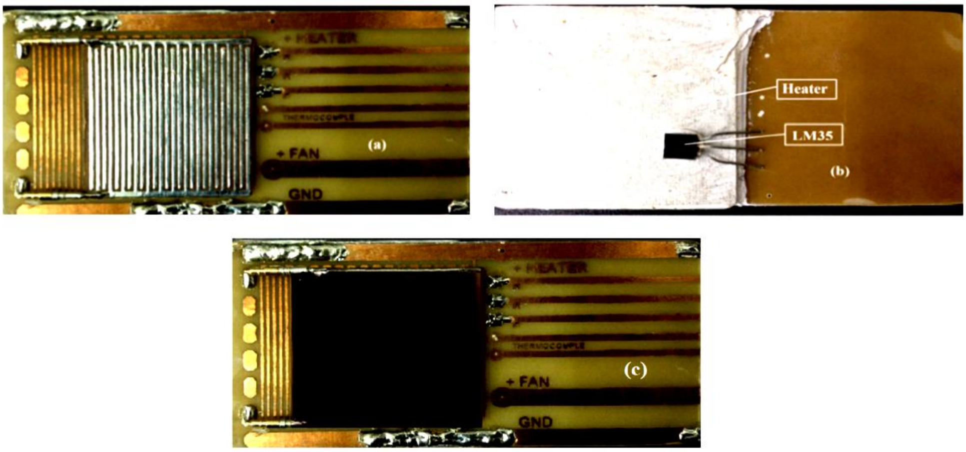


**Fig.(7):** Sample holder (a: front view, b: back view and c: one of the tested sensing materials ($NiFe_2O_4$) cast coated on the interdigitated electrodes)

### 3.2. The Electrodes

The interdigitated electrodes have been made with the traditional printed circuit board PCB methods then coated with a layer of tin to prevent the interaction of the copper electrodes with the sensing gases e.g. ammonia. Fig.(8). shows 13 pairs of the interdigitated electrodes and their dimensions. The interspacing between electrode’s fingers (about 448 um) has been measured by (Motic Images Plus 2.0 ML) software program associated with National DC3-420T Digital Microscope.

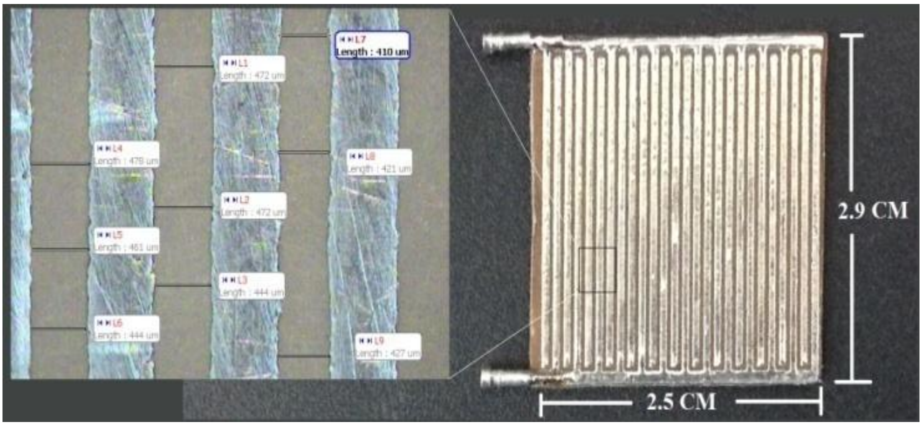


**Fig. (8):** The interdigitated electrodes coated with tin**.**

## 3.3. Sensing Materials

Two sensing materials have been used in the practical test with different concentrations of ammonia and water vapor. As mentioned above, the first sensing material is a lab synthesized nano-particle $NiFe_2O_4$ powder and the second is commercial $SnO_2$ powder.

- Nano-particle $NiFe_2O_4$ powder has been synthesized by the self-combustion method [26-28]. This material has been chosen to be tested as one of the gas sensing promising materials according to literature [27-31].
- The other gas sensing material is commercial $SnO_2$ chosen also according to literature [21, 22, 32, 33].

Both sensing materials have been ground in an agate mortar then mixed with some drops of distilled water to form a paste which has been cast coated on the interdigitated electrodes.

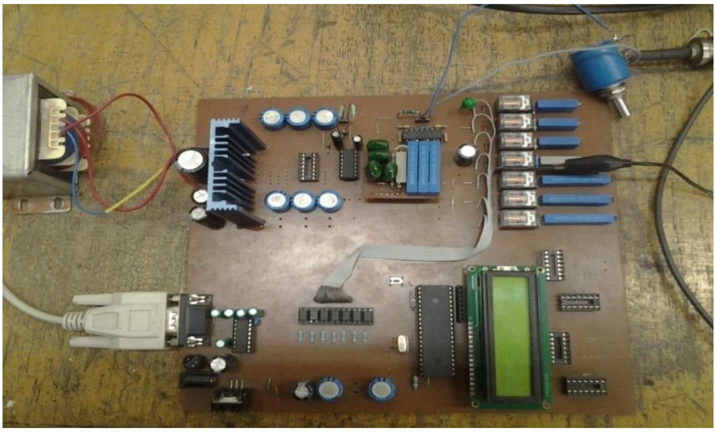
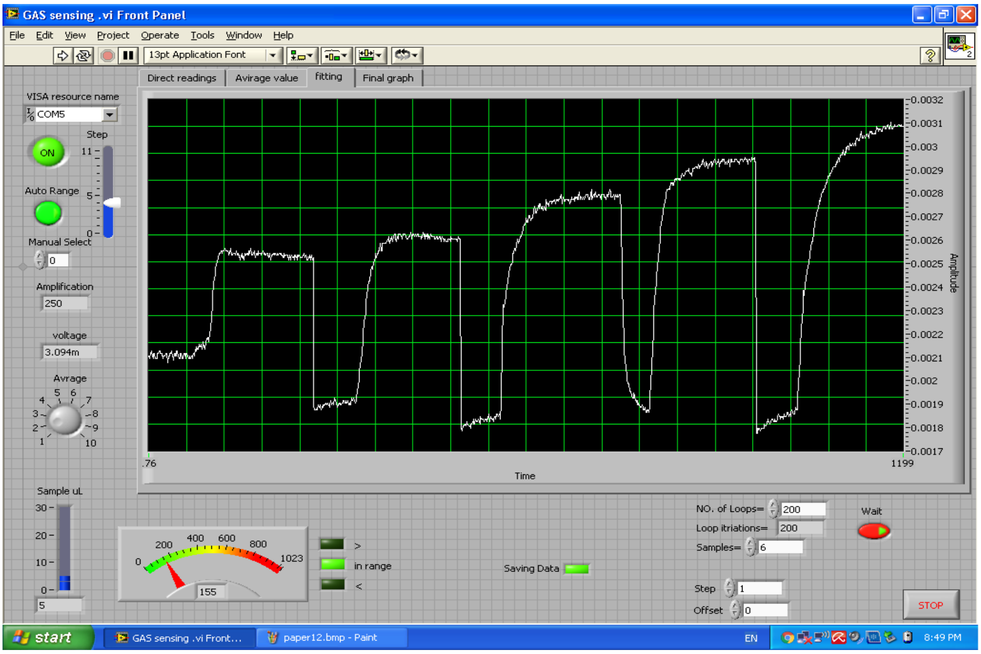


**Fig. (9):** A photograph of the designed circuit**.**

## 3.4. Software Program

The operation program has been written by lab VIEW. This program makes an interface between the PIC microcontroller and the computer through RS232 serial port. The selection of the serial com port is available on the front panel. The gain can be adjusted manually or automatically by the program. In the automatic mode, if the ADC value is greater than a predetermined maximum value, the program will decrease the gain of the amplifier by one step then record the ADC value. If the digital signal becomes within the predetermined range, no further variation in the gain will occur, otherwise the gain will decrease step by step until the signal becomes within that range and vice versa.

The number of measurements for each concentration must be determined (200 for example) before operation. Also, the number of different concentrations that will be tested in one run must be determined too and inserted to the labVIEW program whose front panel is shown in Fig.(10). At the beginning of the run, the output voltage at zero concentration (air) is measured from which the sensor resistance is measured. After the predetermined 200 measurements the program will wait until the user cleans the test chamber and inserts another concentration of the test gas. The program saves the collected data of the predetermined number of concentrations in one file. It can be seen in the front panel shown in Fig. (10) the measurements of one run for five different concentrations with 200 seconds for each measurement. The virtual instrument block diagram of the gas sensing program is shown in Fig. (11).



VISA resource name COM5

Manual Select 0

Amplification 250

voltage 3.094m

Sample uL 5

155

NO. of Loops= 200

Loop itriations= 200

Samples= 6

Step 1

Offset 0

**Fig.(10):** The front panel of the gas sensing designed program.

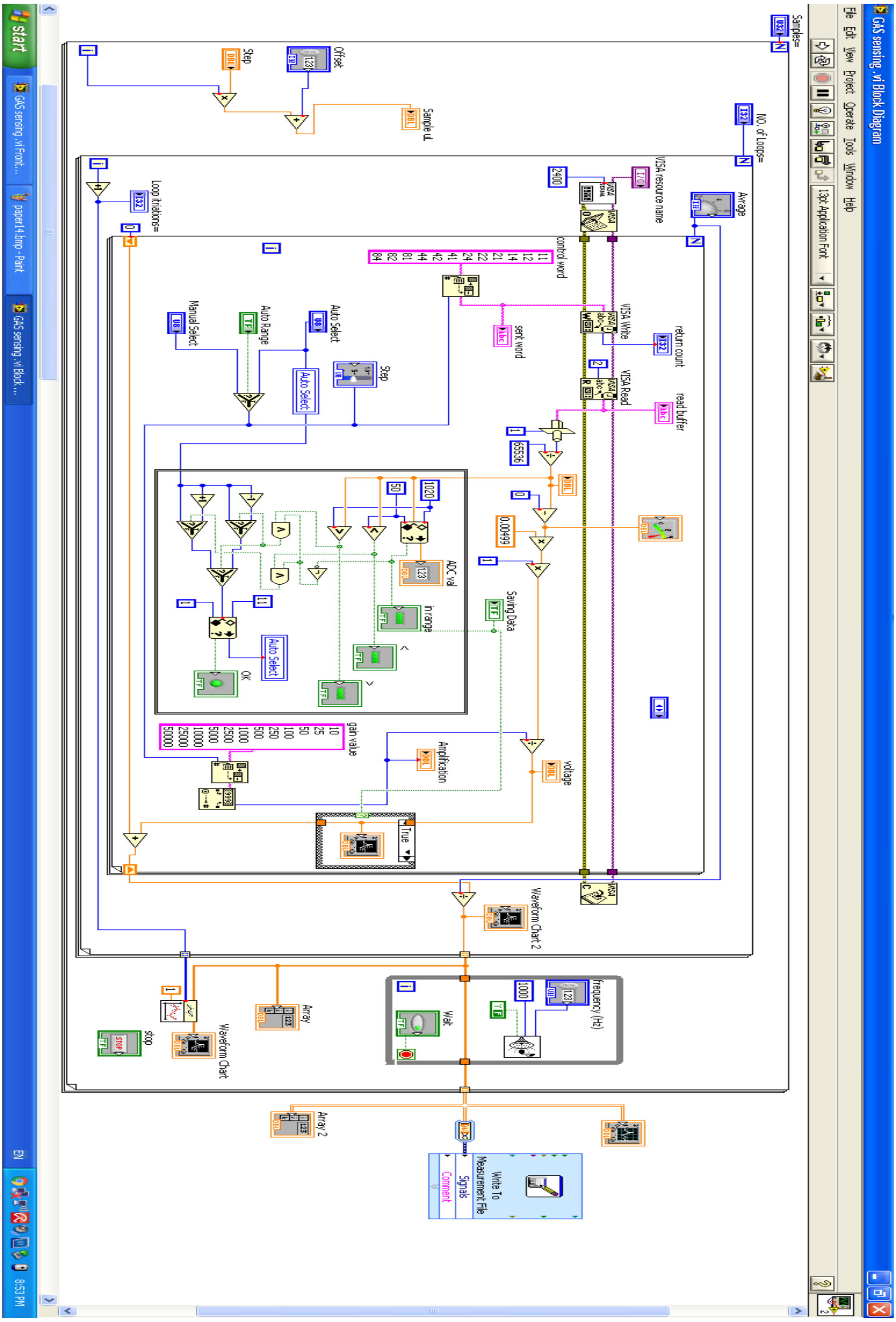


**Fig. (11):** The virtual instrument block diagram of the gas sensing program.

## 4. Results and Discussion

As mentioned before the above illustrated test has been performed for a $NiFe_2O_4$ sensing element coated on the interdigitated electrodes with different concentrations of ammonia. The output voltages have been measured as a function of time and the sensor resistance has been calculated from the relation:

$$R_S = \frac{V_T - V_{out}}{V_{out}} \times R \quad ,$$

Where R is the resistance connected in series with the sensor and across which the output voltage is taken, $V_T$ is the input voltage of 5 V peak and $V_{out}$ is the measured voltage.

Also, the output voltage has been recorded at different concentrations. $V_{out}$ is plotted in Fig. (12-a) as a function of time. $R_s$ is plotted as a function of gas concentrations in Fig. (12-b).
Then the sensitivity of the sensor has been calculated according to

$$S\,\% = \frac{R_A - R_g}{R_A} \times 100$$

Where, $R_A$ is the sensor's resistance measured in the air and $R_g$ is the sensor's resistance measured in the presence of the tested gas [28- 30].

The gas sensing mechanism of oxide semiconductors to reducing gases can be understood as follows: When a semiconductor sensor is exposed to a gas, the change in resistance is mainly due to the reaction between the reducing gas and the oxygen species adsorbed on the surface of the semiconductor. The adsorption of gas, which depends on both the type of test gas and the sensor material, might affect the response characteristic [29].

It is also known that the n-type materials respond to reducing gases by a decrease in the electrical resistance and to oxidizing gases by an increase in resistance, in the presence of the test gases. On the same lines the reverse is observed in p-type semiconducting oxides which respond to reducing gases by an increase in the electrical resistance and to oxidizing gases by a decrease in resistance. Therefore the behavior of the resistance of the investigated samples shown in the figures is quite expected and in agreement with literature.

A plot of the concentration (in logarithmic scale) vs. the sensitivity is drawn in Fig. (12-c). Here, it is worth mentioning that if the sensitivity of the sensing material exhibits a linear relation with the gas concentration this would be an indication for a good sensing material.

For the present investigated Ni ferrite sensor, it has been found that the relation between the sensitivity and the concentration of the gas is almost linear indicating a good sensing material to ammonia in agreement with literature [27-31].

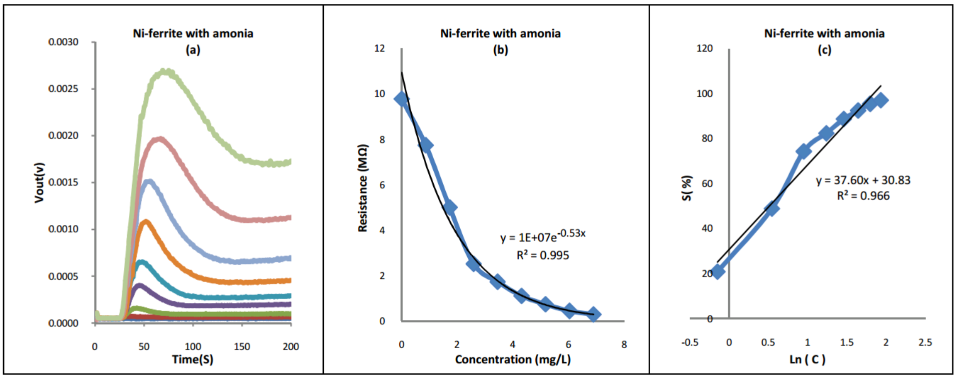


**Fig.(12):** The response of the $NiFe_2O_4$ thick film for different concentrations of ammonia. [(a) output voltage vs. time. (b) Resistance vs. different gas concentrations. (c) Sensitivity vs. concentrations in logarithmic scale.]

Testing the same film with water vapor has been performed at different concentrations and the relation between ln (C) and S is plotted in Fig.(13-c) indicating a good sensitivity to water vapor.

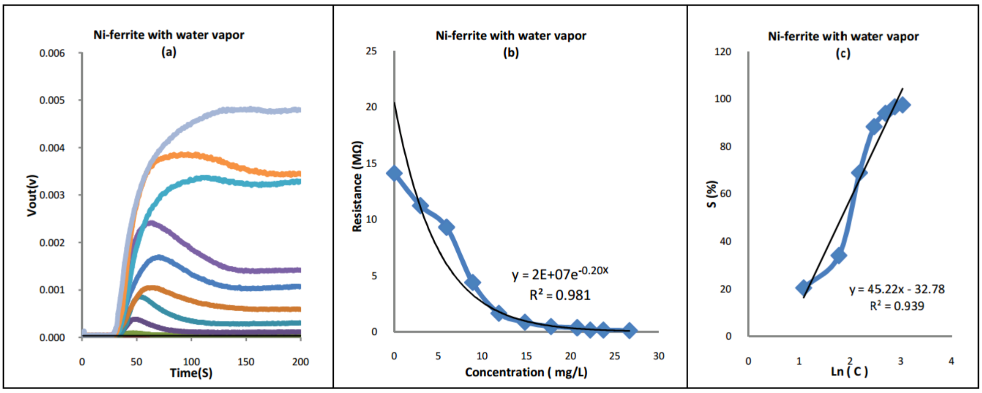


**Fig.(13):** The response of the $NiFe_2O_4$ thick film at different concentrations of water vapor. [(a) output voltage vs. time. (b) Resistance vs. different gas concentrations. (c) Sensitivity vs. concentrations in logarithmic scale.]

Following the same procedures and calculations, a cast coated $SnO_2$ sensing material has been tested for ammonia and water vapor at different concentrations. The response to ammonia is displayed in Fig. (14 a, b, & c) whereas the response to water vapor is displayed in Fig. 15 (a, b, and c).

It can be seen that the relations in Fig.(14-c & 15-c) are almost linear indicating that the $SnO_2$ sensing element is a good sensor of ammonia and water vapor in agreement with literature [22,32,33].

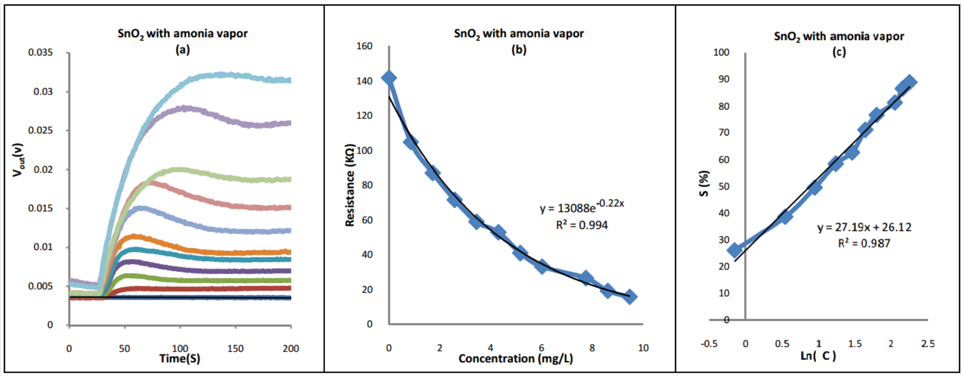


**Fig.(14):** The response of the $SnO_2$ thick film at different concentrations of ammonia. [(a) output voltage vs. time. (b) Resistance vs. different gas concentrations. (c) Sensitivity vs. concentrations in logarithmic scale.]

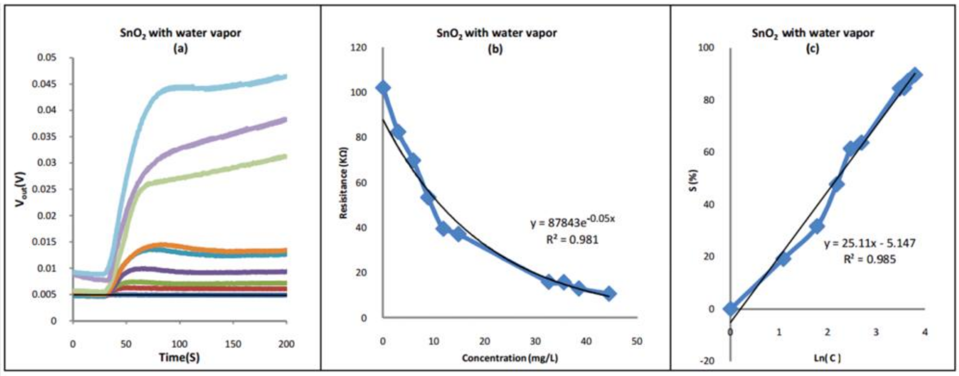


**Fig.(15):** The response of the $SnO_2$ thick film at different concentrations of water vapor. [(a) output voltage vs. time. (b) Resistance vs. different gas concentrations. (c) Sensitivity vs. concentrations in logarithmic scale.]

## 5. Conclusions

The designed system has been tested by using two gas sensing materials and it has proved that it is able to detect any small changes in the sensing property due to any minute quantities of the detected gas. For the above investigated materials the relation between the concentration and sensitivity has displayed fair linearity indicating a good expected quality of those sensors in agreement with literature.

The circuit shows a good performance as a real time dynamic measuring system for quality control of gas sensing materials prepared for laboratory or industrial applications. The low cost of the designed circuit (about 20$) offers an aid to researchers to perform their tasks easily. Moreover, the idea of using RS232 to interface the designed instrument with labVIEW may be very useful for researchers and device users because it is a widely spread interface in scientific instruments.

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