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A Temperature Modulation Circuit for Metal Oxide Semiconductor Gas Sensor

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Abstract

The procedure of temperature modulation of the metal oxide semiconductor gas sensor has been widely used for extracting characteristic response of a gas. This paper presents a Pulse Width Modulation (PWM) based temperature modulation circuit for semiconductor metal oxide gas sensor. A PIC microcontroller is programmed to generate different modulating 8 bit digital signal which is converted to analog signal using Digital to Analog Converter (DAC). The analog signal is then used to control a PWM based driver circuit which drives the heater of the metal oxide gas sensor. The kinetic response of a gas and metal oxide gas sensor materials are temperature dependent. The experimental results show that as the heating voltage of the gas sensor changes in different way, the sensor surface temperature also changes and the characteristic response of a particular gas sensor also varies in different way in presence of a gas. Hence the proposed system proves to be one of the efficient procedures to find out the best heating voltage waveform for a gas sensor to discriminate a particular gas easily. This way the selectivity of the gas sensor can also be improved.

Keywords: Gas Sensor, Metal Oxide Semiconductor, Temperature Modulation

1. Introduction

With the industrial revolution, the effect of toxic and explosive gases on human life becomes a matter of concern for people. These led to the development of number of sensing technology for detection of different gases present in the environment. Metal Oxide Semiconductor (MOS) gas sensor recently gained wide popularity due to its low cost and repeatability. These sensors combine a gas sensing element with a heating element because sensitivity and selectivity of gas sensing materials are temperature dependent. Metal Oxide Semiconductor (MOS) sensors operate at around 300°C to 550°C of its sensing surface.

MOS gas sensors are generally operated at constant temperature. This operating temperature is usually maintained at a constant set point by applying a DC voltage across a resistive heater built into the device. Sarry F[1], MOS gas sensors were operated in constant temperature mode to discriminate gases in air conditioned system. The performance of the gas sensor can be improved by controlling the temperature of the semiconductor surface, since the reaction rates for different volatile compounds are a function of surface temperature[2–4]. Recent works demonstrated that modulating the operating temperature of a MOS gas sensor can achieve a high degree of selectivity[2,5,6].Temperature modulation of the semiconductor gas sensor using periodic heating voltage has been reported to have several advantages[7,8]. Firstly a cyclic temperature variation can give a unique response for each gas as rate of reaction of the different analytic gases are different at different temperature. Secondly low temperature may lead to the accumulation of incompletely oxidized contami-

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nant, which may get removed during cyclic oscillating voltage. Third, thermal cycling can lead to improvements in sensitivity because for each gas there is a heater voltage for which it shows maximum conductance-temperature characteristics[2].

Temperature modulation of MOS gas sensors virtually raises the number of sensors to several thousands from limited number of physical sensors[9]. The gas sensor heater has relatively large power consumption and needs specialized circuit to deliver the power to the heater. A transistor emitter follower circuit controlled by a base voltage can be used to drive the gas sensor heater. However there will be power loss in the emitter follower transistor configuration. Pulse Width Modulation (PWM) is considered as a technique for applying power to a load in a very efficient manner without dissipating much heat. A microcontroller can be used to control the duty cycle of a PWM output that drives the average power to the heater[10]. Casanova R[11], a mixed mode temperature control circuit for gas sensors has been described. The system is basically emitter follower based driver with on board microcontroller for controlling. In our research the main aim is to vary the temperature of gas sensor array according to pre programmed waveforms. The requirement of our system is to design a circuit for temperature modulation without dissipating much extra power. The design of our temperature modulation circuit is based on pulse width modulation which saturates the driving transistor fully as against emitter follower configuration which does not fully turn on the driving transistor. This leads to increase driving transistor resistance in emitter follower configuration which results in additional power loss in the circuit.

2. System Design

The system scheme for temperature control of MOS gas sensor heater is shown in Figure 1. At the heart of the system there is PIC microcontroller 18F448 from Microchip Corporation. The PIC microcontroller computes and generated different signal waveforms. The waveforms are encoded by 8 bit digital signal which is available at the output port of the microcontroller. PIC microcontroller 18F443 is programmed to generate 10 different modulating waveform like DC, rectangular, sinusoidal, saw-tooth, sigmoid (+ve half), exponential, triangular, decreasing saw-tooth, decreasing sigmoid (+ve half) and decreasing exponential waveform having amplitude of 5 volts. The time period of a cycle of the waveforms is 50 seconds. The 8-bit digital signal is then converted to analog signal in the range of 0 to 5 volts by DAC 506 manufactured by Maxim semiconductors. The microcontroller can control the output of the DAC from 0 to 5 volts. The analog voltage of the DAC then controls the duty cycle (from 0 to 100 %) of the PWM driver circuit. The PWM signal then drives the MOS gas sensor array whose temperature is dependent on the duty cycle.

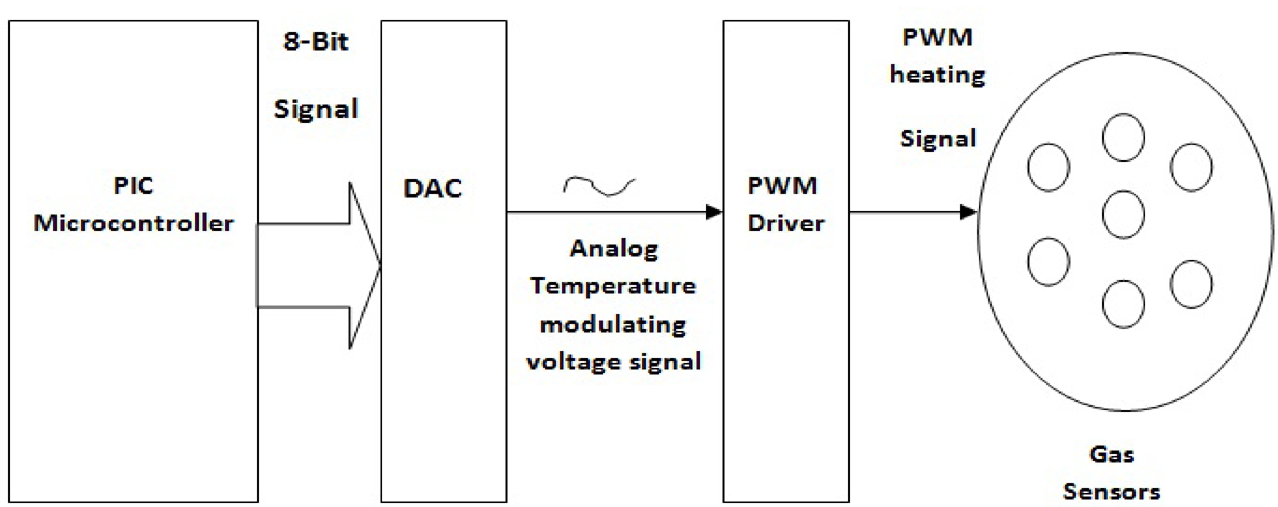

Figure 1. Scheme of MOS gas sensor heater temperature modulation.

3. PWM Heater Driver Circuit

The detail circuit diagram of the PWM heater driver circuit is shown in Figure 2. The circuit basically consists of a 555 timer based saw-tooth waveform generator circuit. The timer ic is operated in astable mode. The transistor Q1 in the circuit charges the timing capacitor C1 using constant current. This produces a saw-tooth waveform at point P1 as shown in Figure 3(A). The frequency of the saw-tooth waveform determines the frequency of the subsequent PWM signal.

In order to reduce the harmonic effects of the PWM signal on sensor response, the saw-tooth frequency is kept low at 10 Hz. The saw-tooth waveform at point P1 has a dc offset and rises to 2/3rd Vcc. The dc offset of the saw-tooth waveform is removed and maximum amplitude is limited at 5 volt by an op-amp (U3:A) operated as a differential amplifier. The resulting output voltage at point P2 is shown in Figure 3(B). This signal subsequently goes to inverting terminal of another op-amp operated as a comparator. The other input to the comparator is connected to the DAC waveform signal generated by the microcontroller.

Now let us suppose the DAC output voltage is around 1 volt. This would produce a low voltage at the output of the comparator for the duration of the saw-tooth waveform having voltage greater than 1 volt. Figure 3(C) depicts the resulting waveform at the comparator output (P4) which is applied to the input of transistor Q2. The transistor Q2 is configured as an inverter and the resulting waveform at the output of the transistor at point P5 is depicted in Figure 3(D). The signal finally drives the power mosfet Q3 which drives the sensor heater. The mosfet Q3 is a p-channel mosfet and therefore it will be on at low going duration of the waveform at P5. Figure 3(E) depicts the final voltage waveform appearing across the sensor heater (P6). The input voltage (at drain) of the power mosfet is set at 5.35 volt regulated by a switching

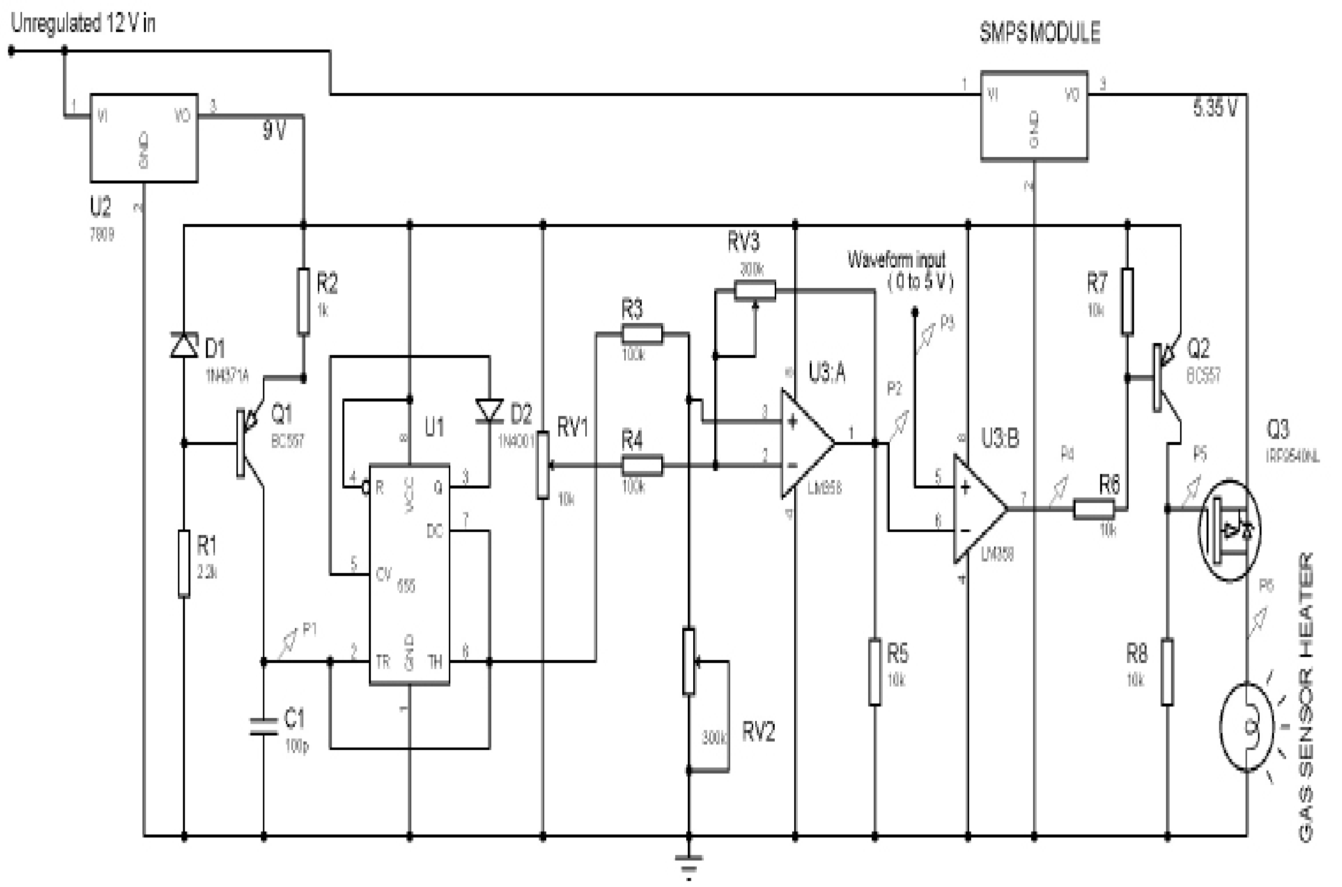

Figure 2. Detailed circuit diagram of the PWM heater driver.

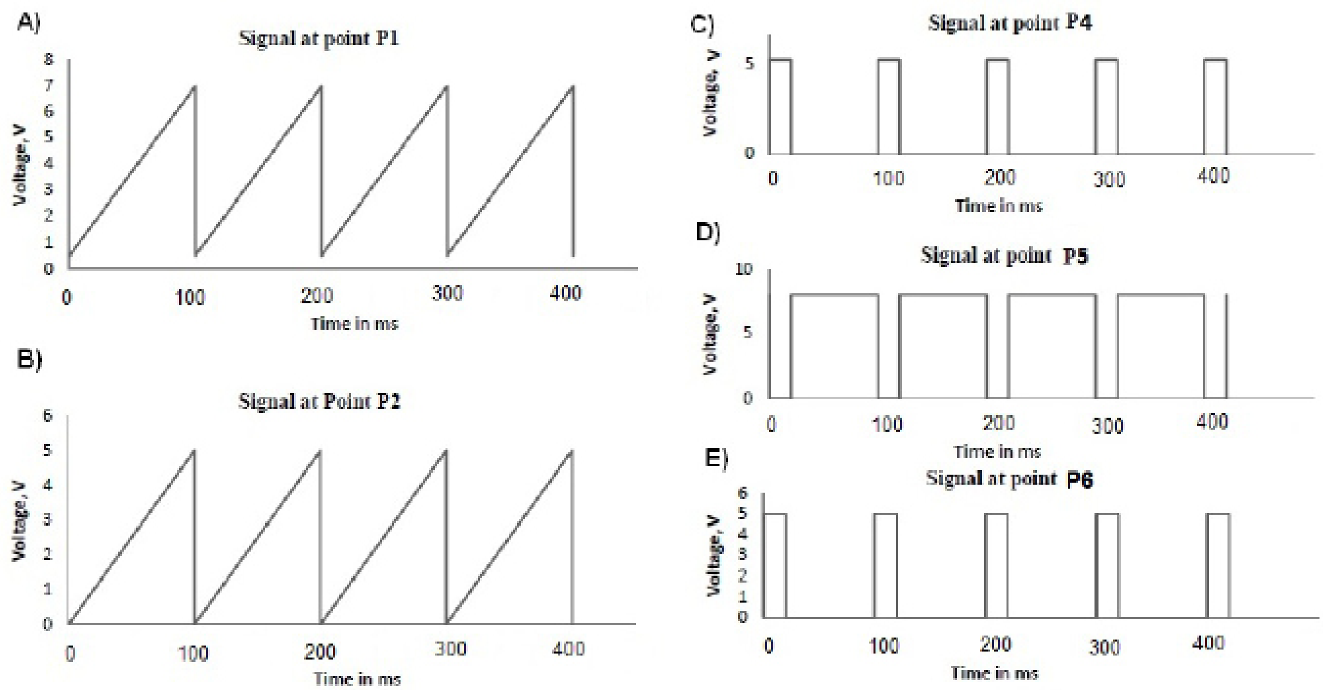

Figure 3. Different waveform patterns at different points of the PWM heater driver circuit.

regulator power module. The maximum peak voltage across the MOS sensor heater is required to be within 5 volt for safety of Figaro MOS gas sensors and Hanwei MOS gas sensors which are used in our system. A margin of 0.35 volt (depending on full load current) higher voltage is applied to the input of the power mosfet in order to compensate the voltage drop across the mosfet.

4. Result

This section presents various results of the temperature modulating circuit. Figure 4 shows the various waveforms measured using Digital Storage Oscilloscope (DSO) shown in Figure 4(A) at different points of the PWM driver circuit. In Figure 4(B) the upper trace shown the saw-tooth waveform generated by the timer ic at point P1. The lower trace in Figure 4(B) is the saw-tooth waveform obtained at point P2 after the differential amplifier stage. It is seen that the waveform ranges from 0 to 5 Volts. In Figure 4(C) the upper trace shows the PWM waveform produced at point P4 along with the trace of the saw-tooth waveform at point P2 when a small voltage is applied at point P3. In Figure 4(D) the lower trace shows the inverted waveform at point P5 after the transistor inverter stage. The final PWM waveform applied across the MOS gas sensors is shown by the upper trace in Figure 4(D) whose maximum magnitude is 5 volt.

The PWM heating signal is applied across the gas sensors and measurements is taken using a sample gas. A pc based data acquisition system as reported in[12] was used to acquire the sensors signal as well as the temperature modulating analog signal. A labview based data acquisition program was developed to display the results. Figure 5 shows a snapshot of the graphical user interface during a data acquisition process. In the figure a waveform chart wherein the response voltage of the gas sensors as well as the temperature modulating analog signal is shown. The temperature modulating analog signal is the signal with larger amplitude. In the figure we see the various temperature modulating waveforms produced by the microcontroller. Each wave pattern is generated for two cycles with time period of 50 seconds. The waveforms with smaller amplitudes are the response signals produced by various gas sensor to a sample chemical (*acetonitrile*) in response to the varying temperature modulating waveform.

A Matlab plot of response voltage waveform of two sensors TGS830 (Sensor 1) and MQ4 (Sensor 2) for acetonitrile vapours is shown in Figure 6. It is observed that the sensors responds with a characteristic response waveform during a cycle of heating waveform. The characteristic

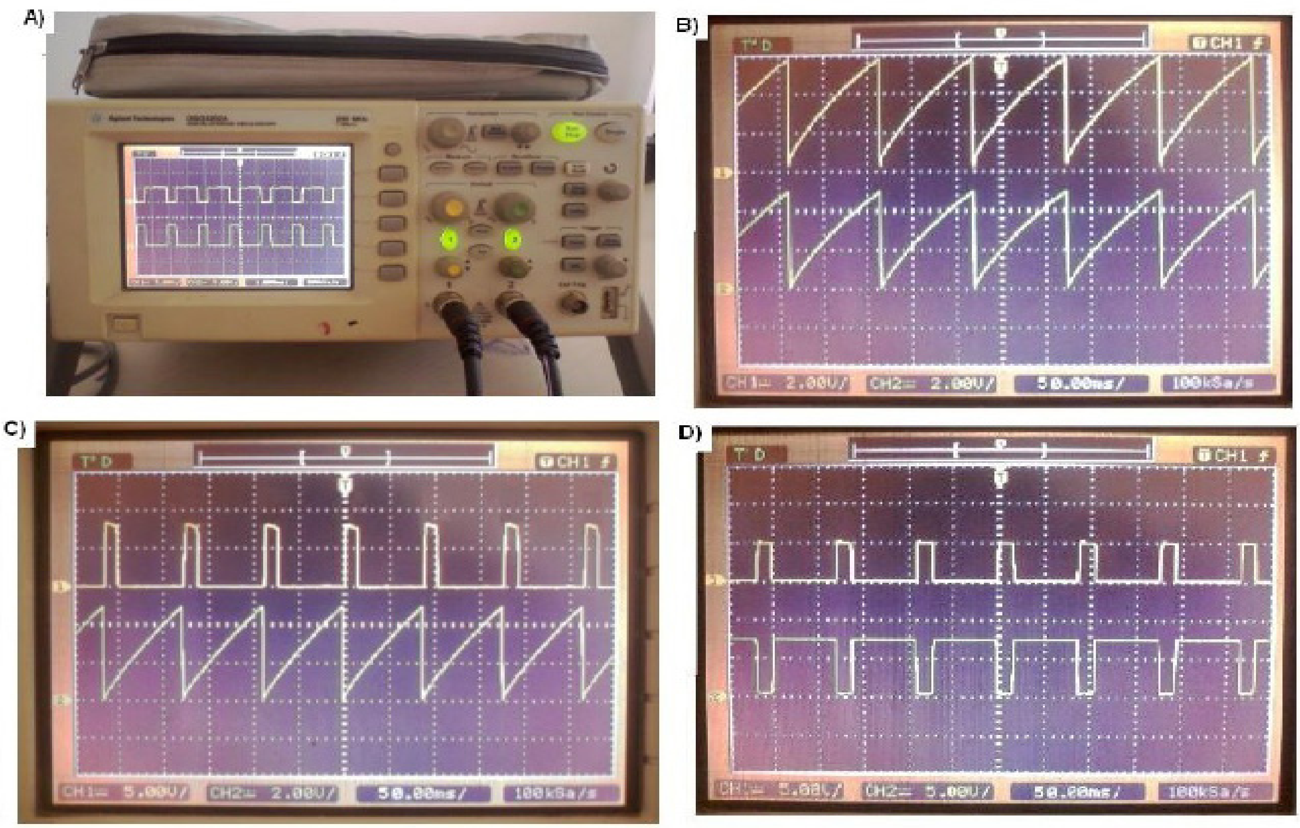

Figure 4. Oscilloscope measured waveforms at various points P1, P2, P4, P5 and P6 of the heater driver circuit.

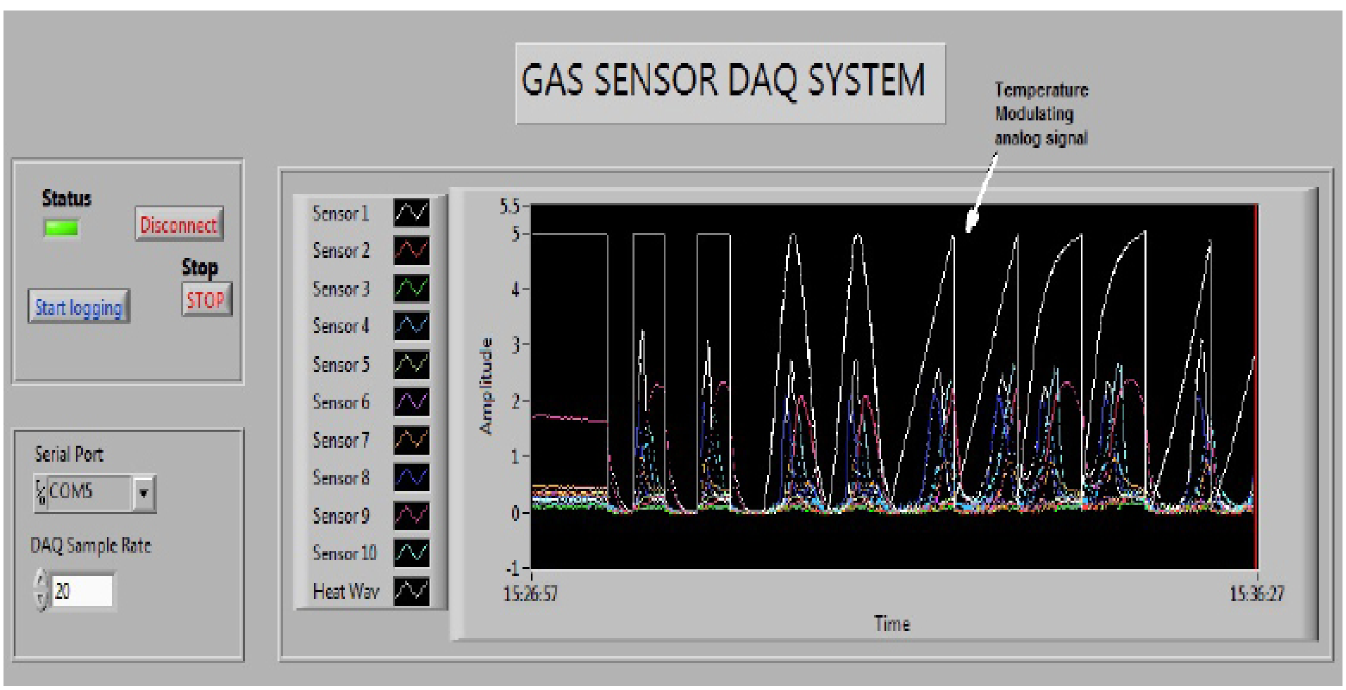

Figure 5. The real time response of gas sensor in presence of a sample gas along with the different modulating wave patterns generated by the microcontroller.

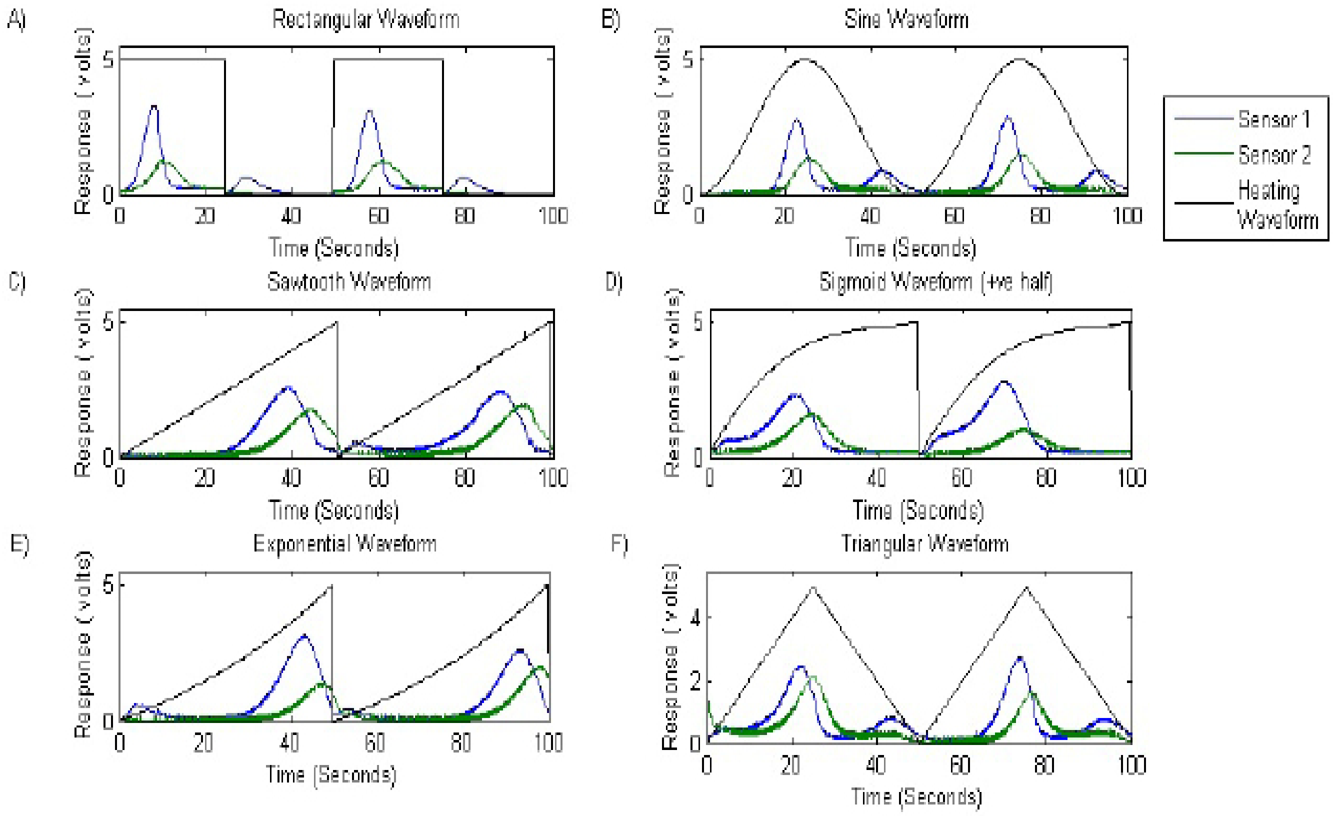

Figure 6. Plot of response voltage sensor 1 and sensor 2 to acetonitrile vapours for various heating waveform.

response waveform is dependent on the gas as well as on the shape of the heating waveform. The characteristic response waveform is a signature of a particular gas. Features from the characteristic response waveform are extracted for pattern classification.

5. Conclusion

The conductivity of MOS gas sensor is a function of surface temperature. The selectivity of MOS gas sensor can be improved by varying the sensor surface temperature. A suitable circuit for varying the surface temperature of MOS gas sensor is desirable to study temperature modulation effects of gas sensor. We have developed a pulse width modulation based temperature modulation circuit for varying the temperature of MOS gas sensors. Result shows that the circuit is able to vary the temperature of MOS gas sensors using various modulation waveforms. These modulation waveforms resulted in various signature response waveforms from the sensors which can be used to discriminate various gases. In subsequent investigation the best modulating waveform for discrimination of gas will be studied.

6. References

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