A Simple Hydrocarbon Vapor Detector and Alarm

Electronics I for ECE Lab 6
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James K Beard, Ph.D.
Assistant Professor
Rowan University
beard@rowan.edu

Adapted from a concept by
Dr. Robi Polikar
polikar@rowan.edu

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1 Introduction

We will build and test a simple hydrocarbon detector. Three teams will configure their project as a breathalyzer, a field device for fast, simple estimates of blood alcohol levels. Two teams will configure their project as an alarm for traces of natural gas, and three teams will configure their project as a breathalyzer.

2 The Sensor

2.1 Description

The Figaro[1] TGS 2620 is a low-cost sensor for hydrocarbon vapors. Figaro mentions[2] alcohol sensors, organic vapor detectors and alarms, and solvent detectors for factories, dry cleaners, and semiconductor industries.

This sensor is a thick film metal oxide semiconductor[3] such as tin oxide, SnO_2, with a heating element. When the metal oxide is heated in air, donor electrons in the crystal surfaces transfer to adsorbed oxygen, generating a coating of negatively charged oxygen ions. Capacitive charge-balancing effects generate a positively charged space charge layer in the semiconductor, which pinches off the conductive layer and reduces current flow. When a gas is present that can react with the layer of oxygen ions, this decreases the number of oxygen ions which in turn reduces the space charge and increases current flow. The sensor must be warmed up and allowed to stabilize to achieve the desired accuracy, but if this is done, very reliable results are possible for long periods of usage. Warm-up time for the TGS 2620 is given as two minutes, once initial on-time exceeds a stabilization time of about an hour; initial stabilization for first-time use is given in Figaro documentation as two days ([3], Section 2-7 page 7).

The equation for sensor resistance as a function of the gas is

$$R_S = A \cdot \left[C\right]^{-\alpha} \tag{2.1}$$

where

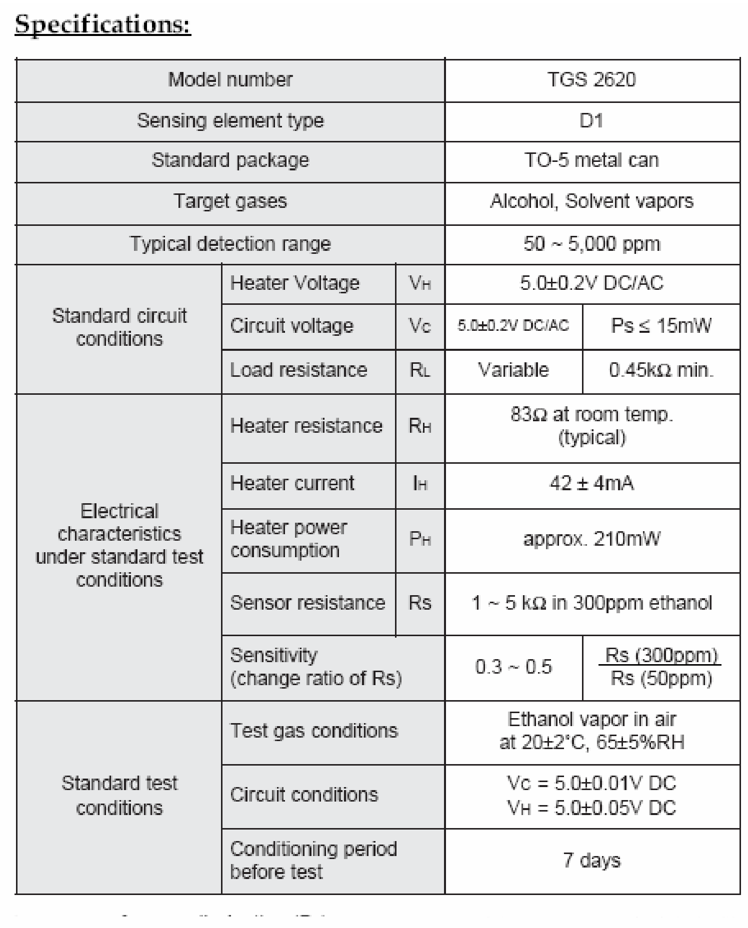
$R_S =$ Resistance of the sensor

$A =$ Constant for this particular sensor

$\left[C\right] =$ Gas concentration

$\alpha =$ Slope of the R_S curve on a log-log plot.

The specifications of the TGS 2620, taken from [2], are shown below as Figure 1.



Specifications:

Model number			TGS 2620	
Sensing element type			D1	
Standard package			TO-5 metal can	
Target gases			Alcohol, Solvent vapors	
Typical detection range			50 ~ 5,000 ppm	
Standard circuit conditions	Heater Voltage	V_H	5.0±0.2V DC/AC	
	Circuit voltage	V_C	5.0±0.2V DC/AC	Ps ≤ 15mW
	Load resistance	R_L	Variable	0.45kΩ min.
Electrical characteristics under standard test conditions	Heater resistance	R_H	83Ω at room temp. (typical)	
	Heater current	I_H	42 ± 4mA	
	Heater power consumption	P_H	approx. 210mW	
	Sensor resistance	Rs	1 ~ 5 kΩ in 300ppm ethanol	
	Sensitivity (change ratio of Rs)		0.3 ~ 0.5	Rs (300ppm) / Rs (50ppm)
Standard test conditions	Test gas conditions		Ethanol vapor in air at 20±2°C, 65±5%RH	
	Circuit conditions		Vc = 5.0±0.01V DC VH = 5.0±0.05V DC	
	Conditioning period before test		7 days	

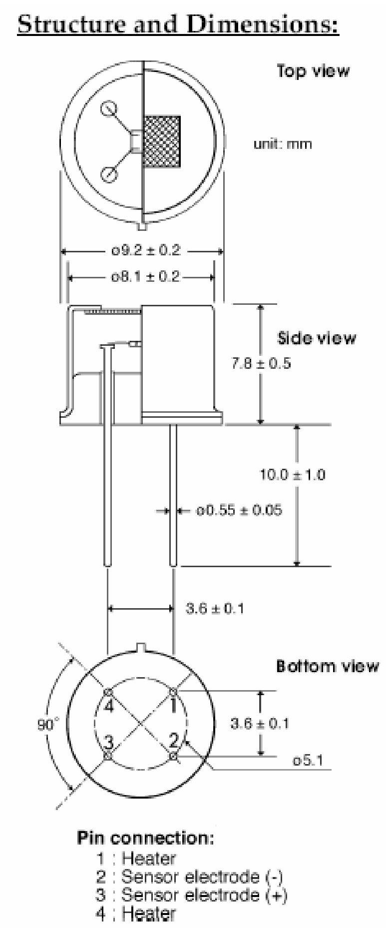


Figure 1. TGS 2620 Specifications and pin out from [2].

2.2 Capabilities

The TGS 2520 is capable of sensing any gas that can be catalyzed to react with oxygen ions at a moderate temperature, including carbon monoxide, although it is optimized to sense hydrocarbon vapors. Since the sensor characteristics are functions of oxygen availability, relative humidity, and ambient temperature, highest accuracy is obtained using standard air conditions and temperature compensation. For our use, errors on the order of 10% are acceptable so this degree of control and compensation are not needed.

2.3 Base Circuit

This type of sensor is intended to be used as a voltage divider, with the sensor resistance at the voltage source. This provides an output which increases with gas concentration in a circuit of minimum complexity. The other resistor also serves as a power limiting resistor, ensuring that the power in the sensor itself never exceeds it maximum rating of 15 milliwatts. The equation for the minimum value of a load resistance R_L to limit power to a sensor resistance R_S is

$$R_L \geq \frac{V_C^2}{4 \cdot P_{MAX}} . \tag{2.2}$$

For a supply voltage V_C of 5 Volts and a maximum load power of 15 milliwatts, the minimum load resistance is

(2.3) $$R_L \geq 41.67\,\Omega \text{ (5 Volts, 15 milliwatts)}.$$

The base circuit is shown below in Figure 2.

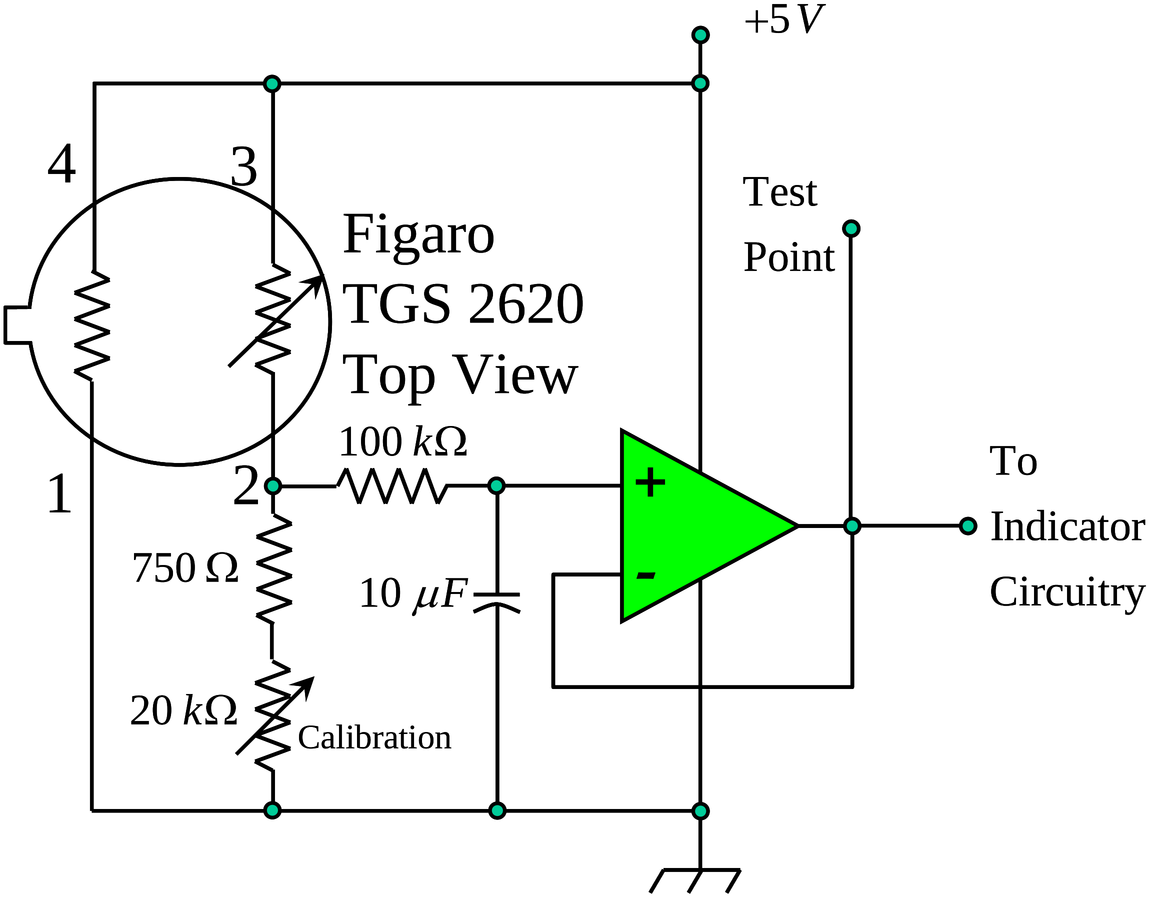


Figure 2. Base sensor circuit for detection of hydrocarbon vapors. Note pin out of sensor is for top view.

Note that we have a minimum load resistance of 750 Ohms, which meets our requirements for limiting sensor power and protecting sensor accuracy. The RC circuit of 100 kOhms and 10 microfarads provides a startup delay that prevents a false high voltage output when power is initially applied to the circuit as well as the more obvious function of filtering noise and limiting rate of change of the output. Note that an output follower is provided in the base circuit, and the operational amplifier is explicitly driven from 5 Volts and ground. The LM324 is designed to operate in this configuration, and its common mode range is ground to 3.5 Volts. The follower provides a voltage source for use as a test point for calibration and other uses that insulates the circuit output from the resistance of 100 kOhms from the RC circuit.

The data sheet information shown in Figure 1 shows that both the base coefficient A and the sensitivity coefficient α in (2.1) vary between sensors, particularly the base coefficient. Thus each sensor must be calibrated before use, and the 20 kOhm variable resistor that makes up most of the resistance of R_L provides a way to do this. The value of R_L should be determined to make the output voltage half of V_C at the most critical value in the sensor application, because the output voltage of the voltage divider is most sensitive to the gas concentration $\left[C\right]$ when this is done. This provides the best circuit sensitivity and accuracy at this value of $\left[C\right]$. The value of α varies significantly as shown by the related value

(2.4)
$$\beta = \left[\frac{300}{50}\right]^{-\alpha}$$

as given in the data sheet. The inverse of (2.4) is

(2.5)
$$\alpha = \frac{-\ln\left(\beta\right)}{\ln\left(\frac{300}{50}\right)} = \frac{-\ln\left(\beta\right)}{1.792}.$$

The range of values of α is 0.39 to 0.67, a ratio of about 7:4. For notional use, this variation is acceptable if the sensor is calibrated at the most critical value of $\left[C\right]$ for the application, and use of the sensor is limited to a range of $\left[C\right]$ centered on this value. We will use a notional value of 0.53 for α in this laboratory. Note that (2.1) breaks down for zero $\left[C\right]$ so that sensor resistance in air is not useful in calibration. This defines the calibration requirements for our sensors:

- A notional value of 0.53 for α,
- Ignore sensor resistance in clear air, and
- Calibrate the sensor for an output of 2.5 Volts for the critical gas concentration for the intended use.

2.4 The complete circuit

The circuit shown in Figure 3 below incorporates the basic sensor circuit of Figure 2 and provides a center threshold at which calibration is done, and thresholds symmetrically arrange about that point. The voltages at the op-amps used as comparators are 1.98 Volts, 2.5 Volts, and 3.01 Volts, neglecting variations in the resistance values, which have a tolerance of 5%. This is a translation of the circuit found in [3] for our laboratory.

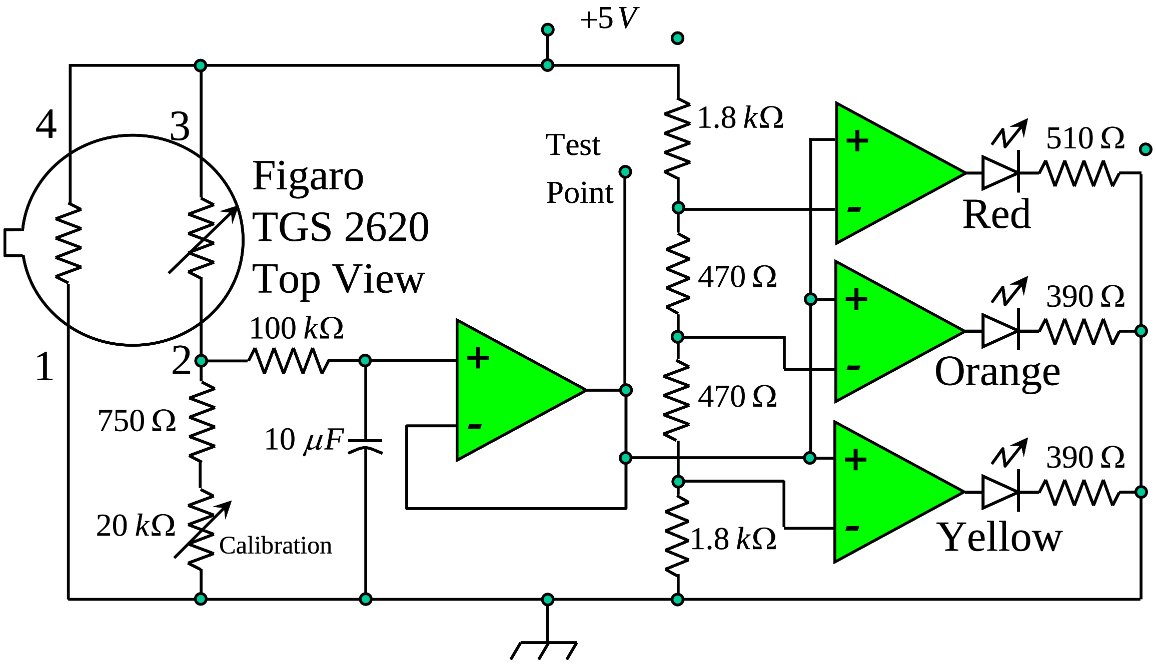


Figure 3. Circuit for our laboratory. Note that pin out of sensor is for top view.

2.5 Alternative multi-week project: microcontroller circuit

A microcontroller circuit would differ from the circuit of Figure 3. The simplest “new” circuit would take the output of the voltage divider base circuit of Figure 2 and simply digitize it and make that signal available for processing. Processing steps could include

- Implementation of the two minute wait for sensor warm-up and stabilization,
- Calibration using a pushbutton when a calibration control vapor is present,
- Direct measurement of R_S through a current source and an analog to digital converter across the sensing element,
- Computation of gas concentration $[C]$ from R_S by computation of a logarithm,
- Appropriate alerts or indications for the gas concentration $[C]$, and
- Output of displays such as numerical gas concentration on an LCD or other directly read output.

Use of a current source to drive the sensor resistance, making the output voltage proportional to R_S, will provide greatest sensitivity at lowest gas concentrations without compromising accuracy at higher gas concentrations and could simplify the problem of providing accurate gas concentrations over a wider range. The microcontroller will switch the current source to keep the output voltage within a given range such as 0.3 Volts to 3 Volts and maintain good accuracy over the entire range over which the sensor is capable of providing an output.

2.6 Additional Considerations for a Field Breathalyzer

2.6.1 Alternative multi-week project: microcontroller circuit

The breathalyzer circuit built for this laboratory is similar to those used in the field for many years and is quite well suited for the purpose. However, this circuit is calibrated at a critical point that corresponds to the onset of detection and is less accurate at higher vapor levels. A microcontroller would enable enhanced performance over a wider range of vapor levels.

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2.6.2 Temperature and humidity compensation

The variation in the sensor output as functions of temperature and humidity is shown below in Figure 4, which is taken from [2].

Temperature compensation can be added through incorporation of a thermistor in the voltage divider, as discussed in [3]. In a microcontroller solution, a temperature sensor such as the National LM35 series can provide a separate analog input for temperature compensation. A humidity sensor such as the Humirel HS 1100 requires additional circuitry and significant complication, since this and most other low cost humidity sensors are capacitive, and measurement of humidity is essentially translated into a capacitance measurement problem, but this is an added opportunity if a microcontroller based vapor detector is used.

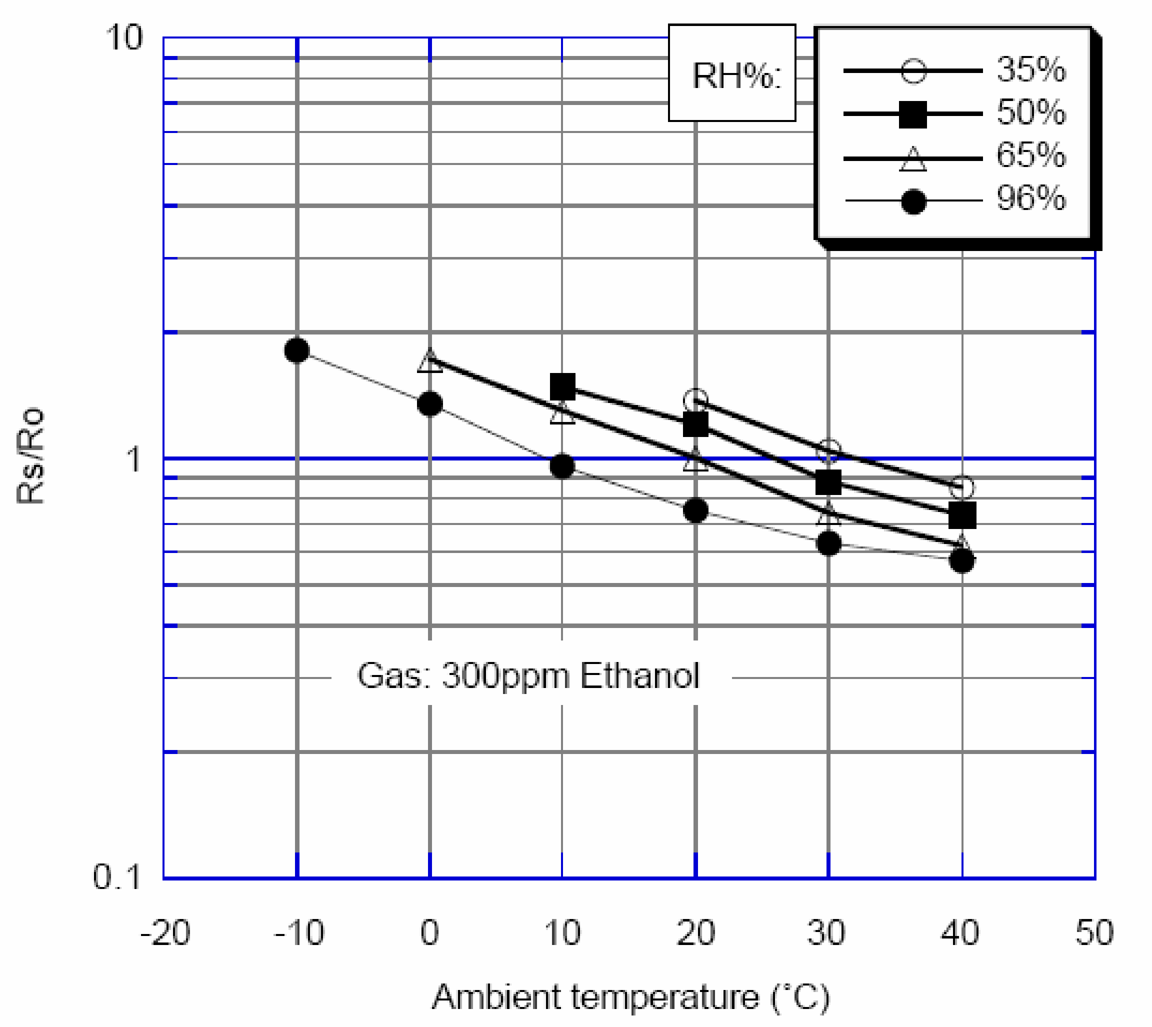

Figure 4. Sensor variation in temperature and humidity from [2].

3 The Hazardous Vapor Alarm

3.1 Detectable trace amounts

The sensitivity of the TGS 2620 to various gases is given in [2] as a set of curves that we reproduce here as Figure 5.

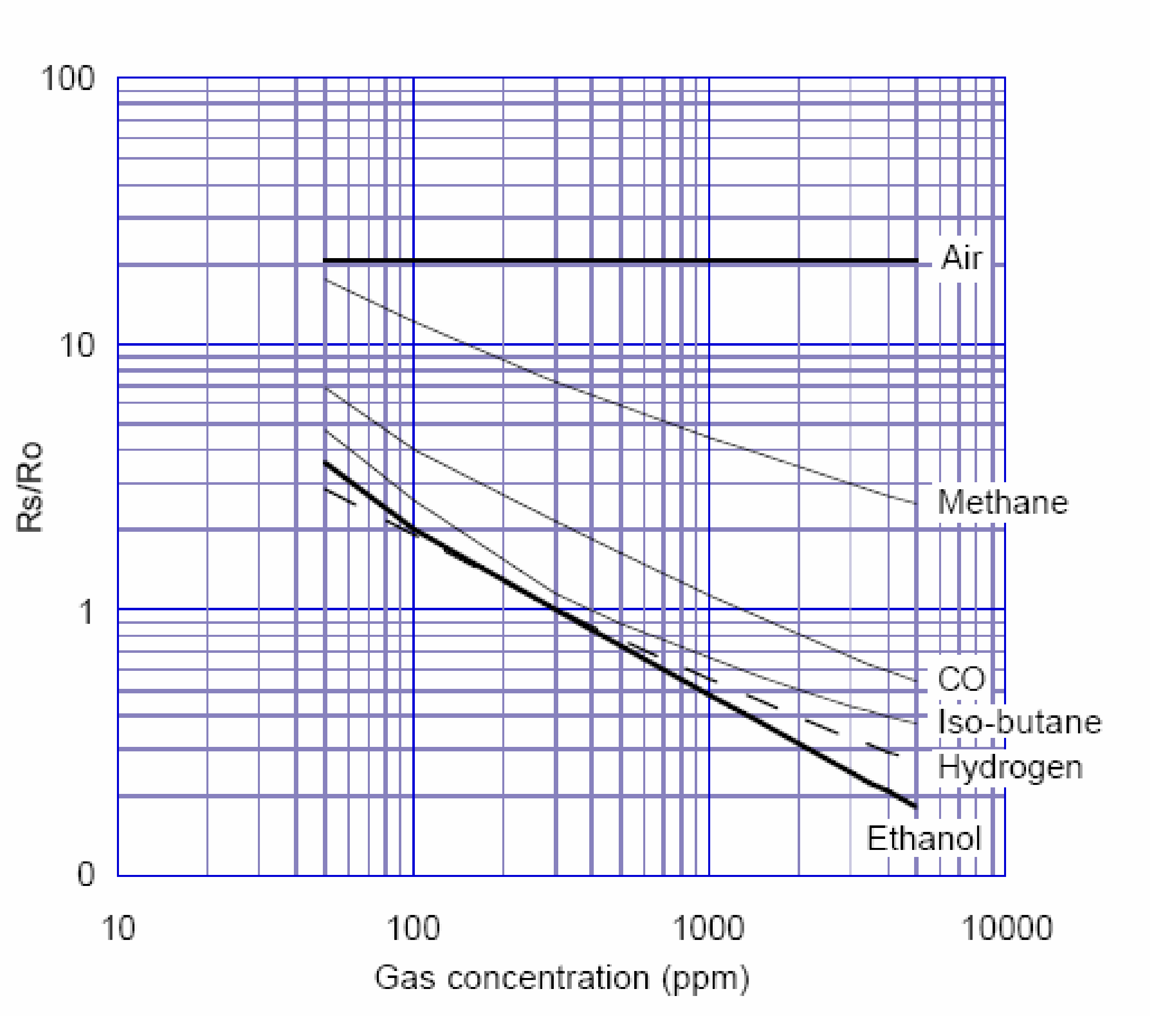

Figure 5. Sensitivity of the TGS 2620 to various gases from [2].

3.2 Calibration and detection

Examination of Figure 5 shows that (2.1) breaks down below gas concentrations of 50 ppm, and that the sensor begins working at gas concentrations where (2.1) predicts values of R_S lower than the value that the sensor exhibits in clear air. Thus the calibration with the highest sensitivity for any given sensor is to adjust the calibration resistance so that the yellow LED is just below flickering in clear air. Then, when the detector "sees" any of the gases to which it is sensitive, the first LED will light. From Figure 5, the sensor will "see" on the order of 50 ppm of methane (natural gas), and 10 ppm or less of carbon monoxide, butane, or other organic solvents.

Quantitative measurement of vapor levels is possible with this instrument. The circuit must be calibrated by the use of a controlled reference sample. This is beyond the scope of this laboratory.

Note the output of the circuit, if the sensitivity of the sensor is 50 ppm for the vapor detected. Using the relationships characterizing the behavior of the sensor from [3], we have the circuit behavior at the test point shown in.

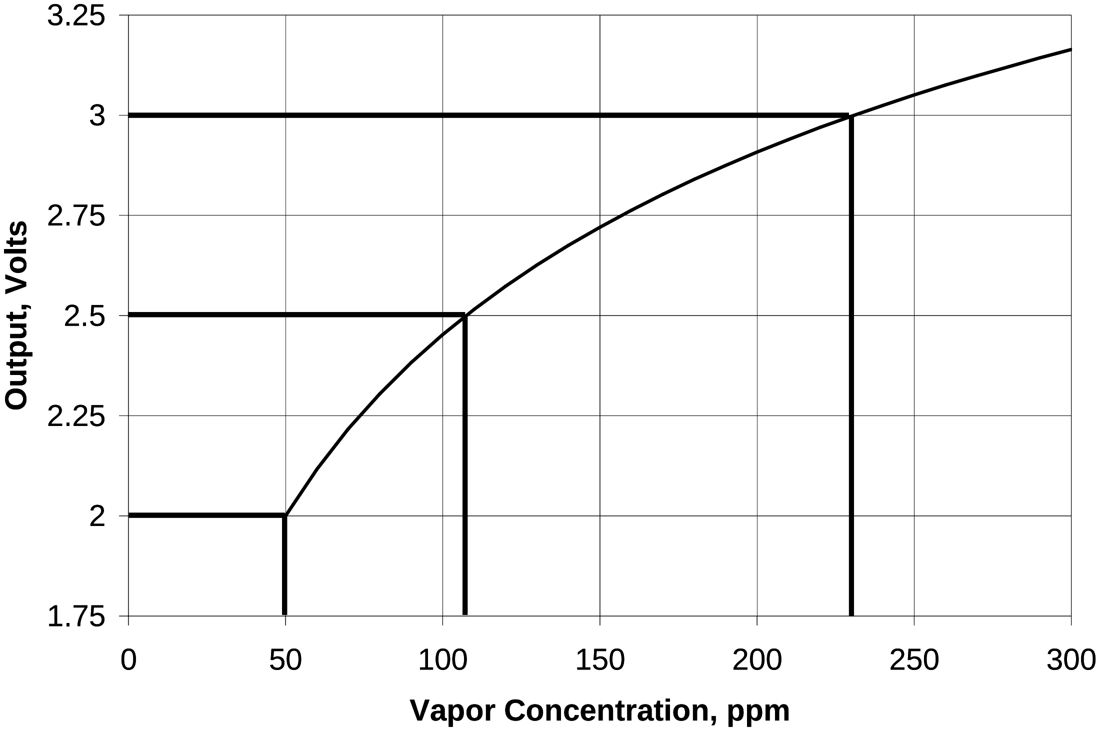

Figure 6. Output voltage versus gas concentration.

Note that if the sensor detects 50 ppm and the calibration turns on the amber LED at that level, the orange LED comes on at about 110 ppm and the red LED comes on at about 230 ppm. Each successive LED turns on about twice the concentration of the previous LED.

4 Constructing the Circuit

4.1 Mounting the Sensor

In building the circuit, mount the sensor in a transistor socket. The leads on this sensor are Kevlar and are difficult to solder. Use a cable of about three feet or 1 meter length to allow manipulation of the sensor without moving the breadboard.

4.2 Building the Circuit

Build up the rest of the circuit on a wireless breadboard. Begin by building the base sensor circuit shown in Figure 2, and make sure that the signal is present and that the calibration potentiometer can provide a voltage at two Volts or higher when the potentiometer is set at its highest resistance. Then, use Figure 3 as a guide to build the rest of the circuit. Use the laboratory power supply on the 5 Volt setting.

We may not be able to provide three colors of LEDs. If they are all red, for example, keep track of which ones are the first, second and third LED. Below, the first LED is referred to as the yellow LED, the second as the amber LED, and the third as the red LED.

4.3 Calibration

When powering up the circuit for the first, time, make sure that the calibration potentiometer is set to provide the highest resistance, $20\ k\Omega$. Let the circuit settle for at least ten minutes. At least one LED should be lit (the yellow one).

Allow the circuit to operate in clear air for ten minutes. This is required to stabilize the sensor after a period of storage. When turning it on for the first time in a few hours, only a two minute stabilization period is required.

The hydrocarbon sensor is calibrated by making sure that the sensor is in clear air, and then turning down the resistance in the calibration potentiometer until the yellow LED just goes out. If the clear air resistance of the sensor is too high for this to occur, replace the $20\ k\Omega$ calibration potentiometer with a $100\ k\Omega$ potentiometer and try again. A high clear air resistance probably means a more sensitive TGS 2620.

5 The Report

Prepare a report due in one week. The guidelines for the report are on the course web site at

http://rowan.jkbeard.com/Electronics_I_ECE_Materials/Report_Guidelines.htm.

The calibration and testing of your Detector and Alarm shall be treated as a separate experiment that follows the building and testing of the electrical circuit.

In your report, describe the circuit of Figure 2 and the functions of each element of the circuit. Describe how you determined whether it worked properly. Then, describe the additional elements of the full circuit of Figure 3. Describe the operation of the three op-amps that perform as comparators and LED drivers.

Describe the calibration process and measure the value of the sum of the calibration resistance and the 750 Ohm limiting resistor, and how this value provides you with a calibration that matches the onset of one of the LEDs lighting.

6 References

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[1] Figaro Sensors, web site http://www.figarosensor.com/

[2] Figaro Product Information from TGS 2620 data sheet dated October 2000.

[3] *Technical Information on Usage of TGS Sensors for Toxic and Explosive Gas Leak Detectors*, Figaro Engineering, Inc. document dated November 2004.