A Simple Breath Alcohol Indicator

Electronics I for ECE Lab 6
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1 Introduction

1.1 About this Lab

We will build and test a simple hydrocarbon detector. Three teams will configure their project as a Breath Alcohol Indicator, a field device for fast, simple estimates of blood alcohol levels, whereas the other two teams will configure their project as an alarm for traces of natural gas. You are in the former group.

1.2 Background

In 2004, there were about 17,000 alcohol related traffic fatalities in the U.S., which represented about 40% of about 42,500 all traffic fatalities. This represents one alcohol-related fatality every 31 minutes. There were also 248,000 people were injured in traffic accidents where alcohol was involved – about one every 2 minutes! Perhaps more disturbingly, in 85% of all alcohol-related fatalities, the blood-alcohol concentration (BAC) of those involved in the accident was reported to be above 0.08%, the legal limit in the U.S. About 51% had a BAC over 0.16, a level at which an individual is typically severely intoxicated[1]. As high and disturbing these numbers are, there is a bit of good news in this: this numbers represent about 33% drop in alcohol related fatalities (from 26000) in 1982[2]. While the reasons for this drop is many, one could include toughened traffic laws and the now ubiquitous use of breath analyzers that can be used on the spot to test near-objectively test the individuals level of intoxication.

Breath analyzers (note that a Breathalyzer[3] is a particular brand name) are now available even for consumers who can purchase these and test their BAC at any time. These devices, like countless other consumer or medical grade biomedical equipments are designed by biomedical engineers who typically have an electrical and computer engineering background. The goal of this laboratory exercise is to give you a glimpse of this exciting and rapidly growing area of biomedical engineering, where engineering solutions are sought for real-world problems in medicine. In this lab, you will build a prototype of such a breath analyzer.

On the other hand, no concept of biological origin – including designing devices for biomedical applications – can be fully appreciated if such an exercise is divorced from the underlying physiological underpinnings. It is therefore important to at least have some understanding of the physiological affects of alcohol on humans, more specifically, on the central nervous system. This physiological effect and the associated impairment that causes ten thousands of alcohol related traffic fatalities. You are therefore asked to read about the central nervous system and the effect of alcohol on this system before coming to lab. A short review will also be provided by Dr. Polikar.

2 The Sensor

2.1 Description

The Figaro[4] TGS 2620 is a low-cost sensor for hydrocarbon vapors. Figaro mentions[5] 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[6] 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 ([6], Section 2-7 page 7).

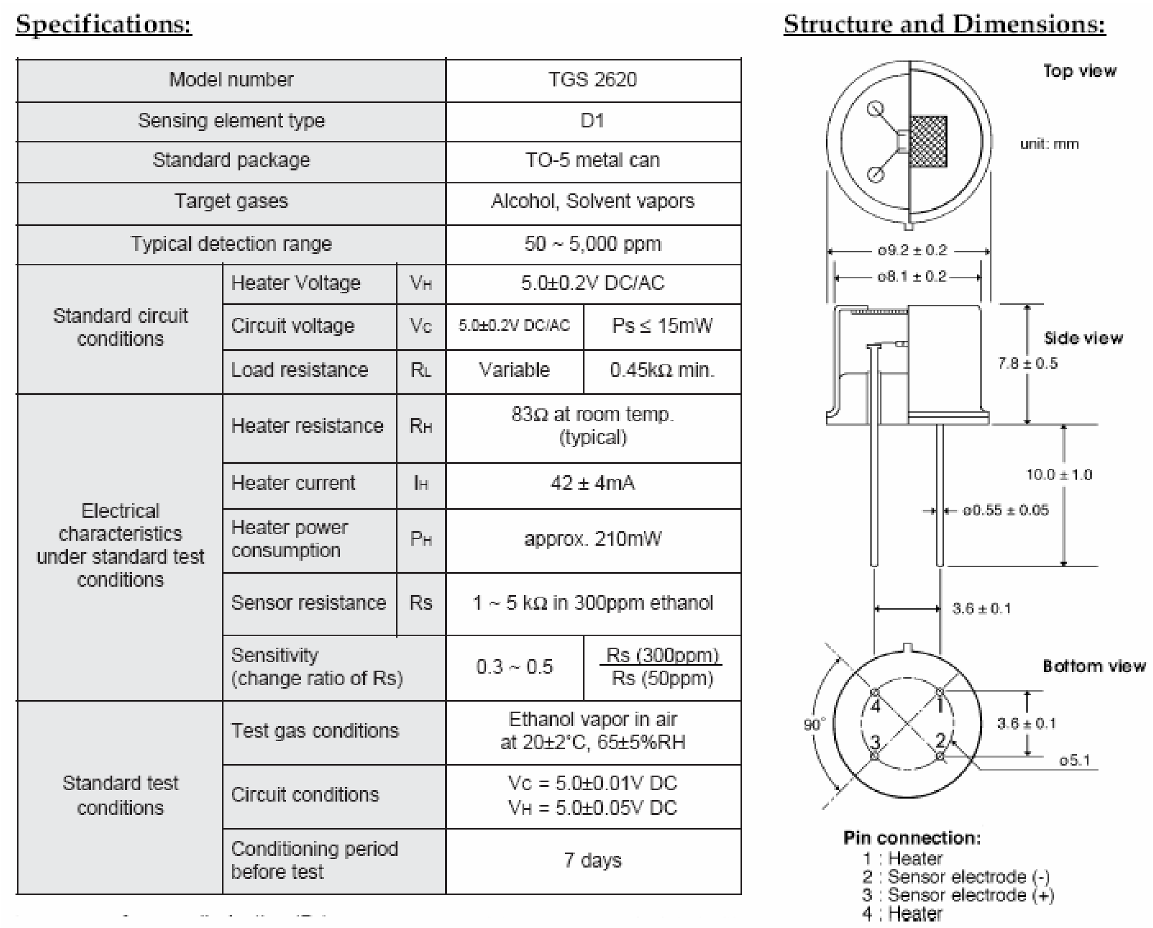
The equation for sensor resistance as a function of the gas is

$$R_S = A \cdot [C]^{-\alpha} \tag{1.1}$$

where

$R_S =$ Resistance of the sensor
$A =$ Constant for this particular sensor
$[C] =$ Gas concentration
$\alpha =$ Slope of the R_S curve on a log-log plot.

The specifications of the TGS 2620, taken from [5], 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 [5].

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

$$R_L \geq \frac{V_C^2}{4 \cdot P_{MAX}}. \tag{1.2}$$

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

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

The base circuit is shown below in Figure 2.

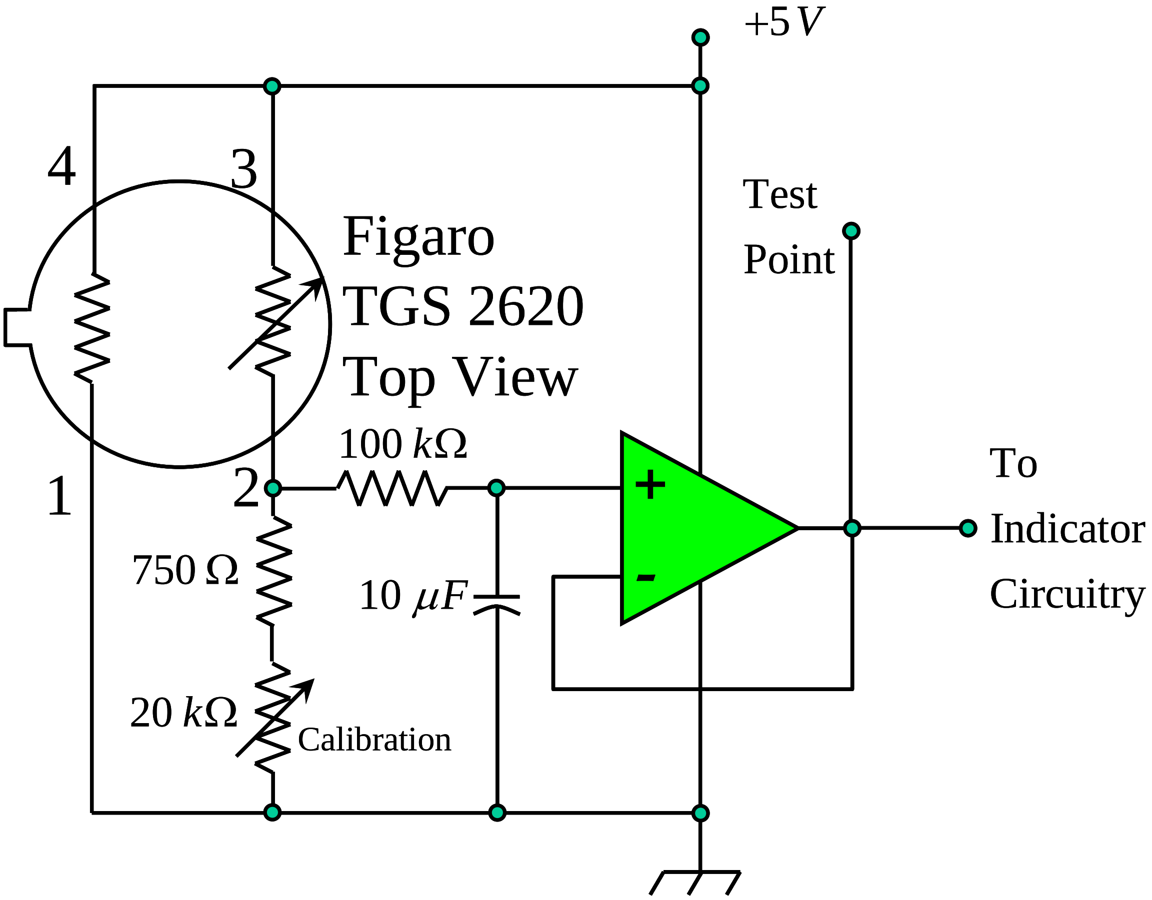


Figure 2. Base sensor circuit for detection of hydrocarbon vapors. Note pin out of sensor is for top view.

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 (1.1) 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

$$\beta = \left[\frac{300}{50}\right]^{-\alpha} \tag{1.4}$$

as given in the data sheet. The inverse of (1.4) is

$$\alpha = \frac{-\ln(\beta)}{\ln\left(\frac{300}{50}\right)} = \frac{-\ln(\beta)}{1.792}. \tag{1.5}$$

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 (1.1) 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 [8] for our laboratory.

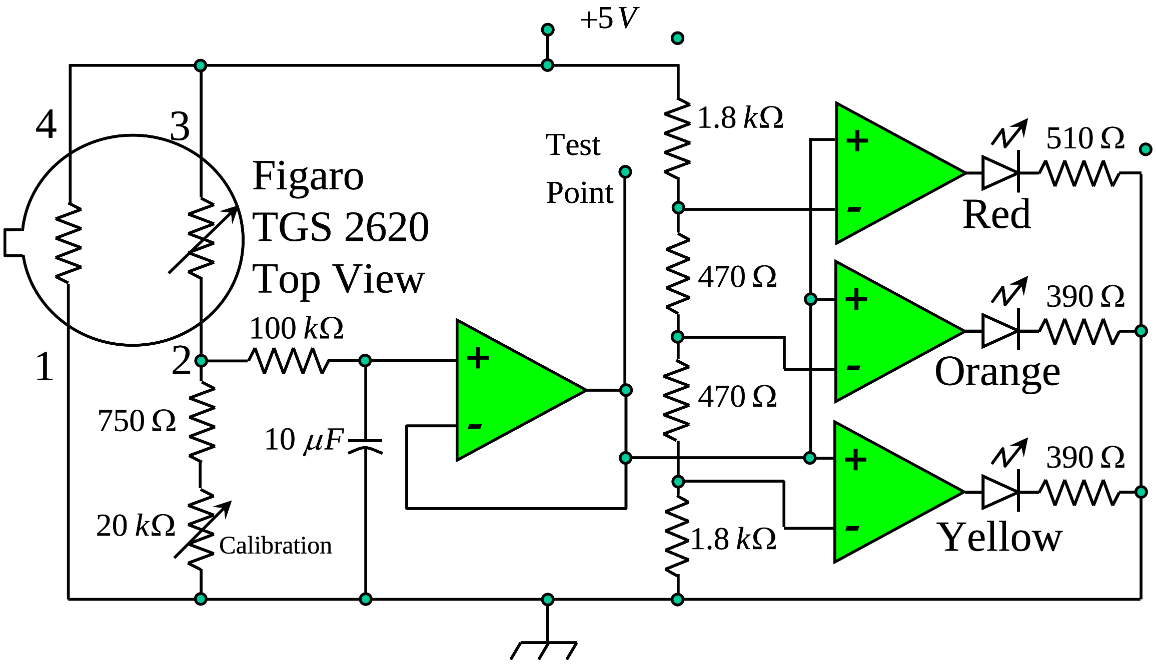


Figure 3. Circuit for our laboratory. Note that pin out of sensor is for top view.

2.5 Additional Considerations for a Field Breath Alcohol Indicator

2.5.1 Alternative multi-week project: microcontroller circuit

The Breath Alcohol Indicator 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 0.08% BAC and is less accurate at higher and lower BAC levels. A microcontroller would enable enhanced performance over a wider range of BAC.

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.

2.5.2 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 [5].

Temperature compensation can be added through incorporation of a thermistor in the voltage divider, as discussed in [6]. 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 Breath Alcohol Indicator is used.

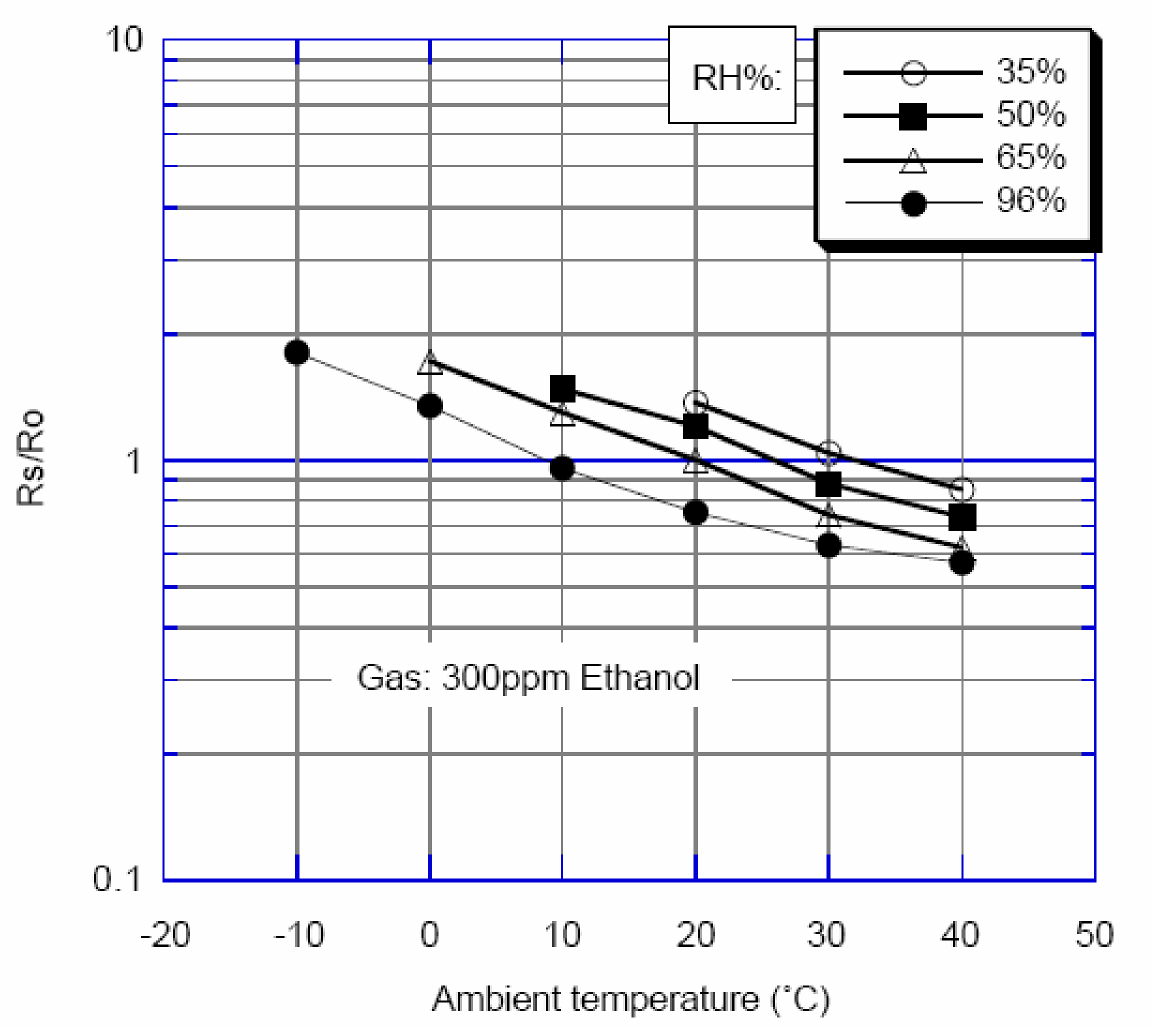
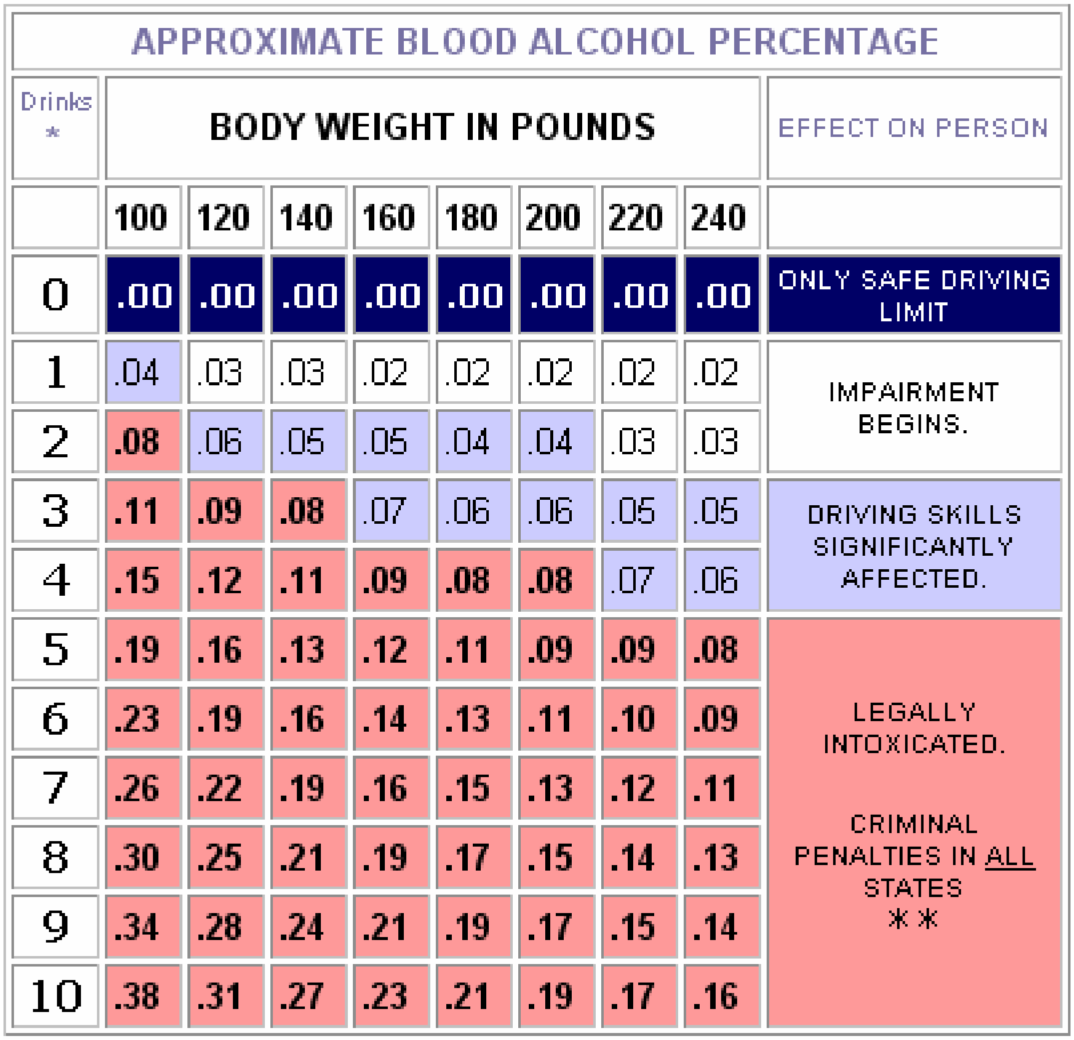


Figure 4. Sensor variation in temperature and humidity from [5].

3 The Breath Alcohol Indicator

3.1 Blood Alcohol Content

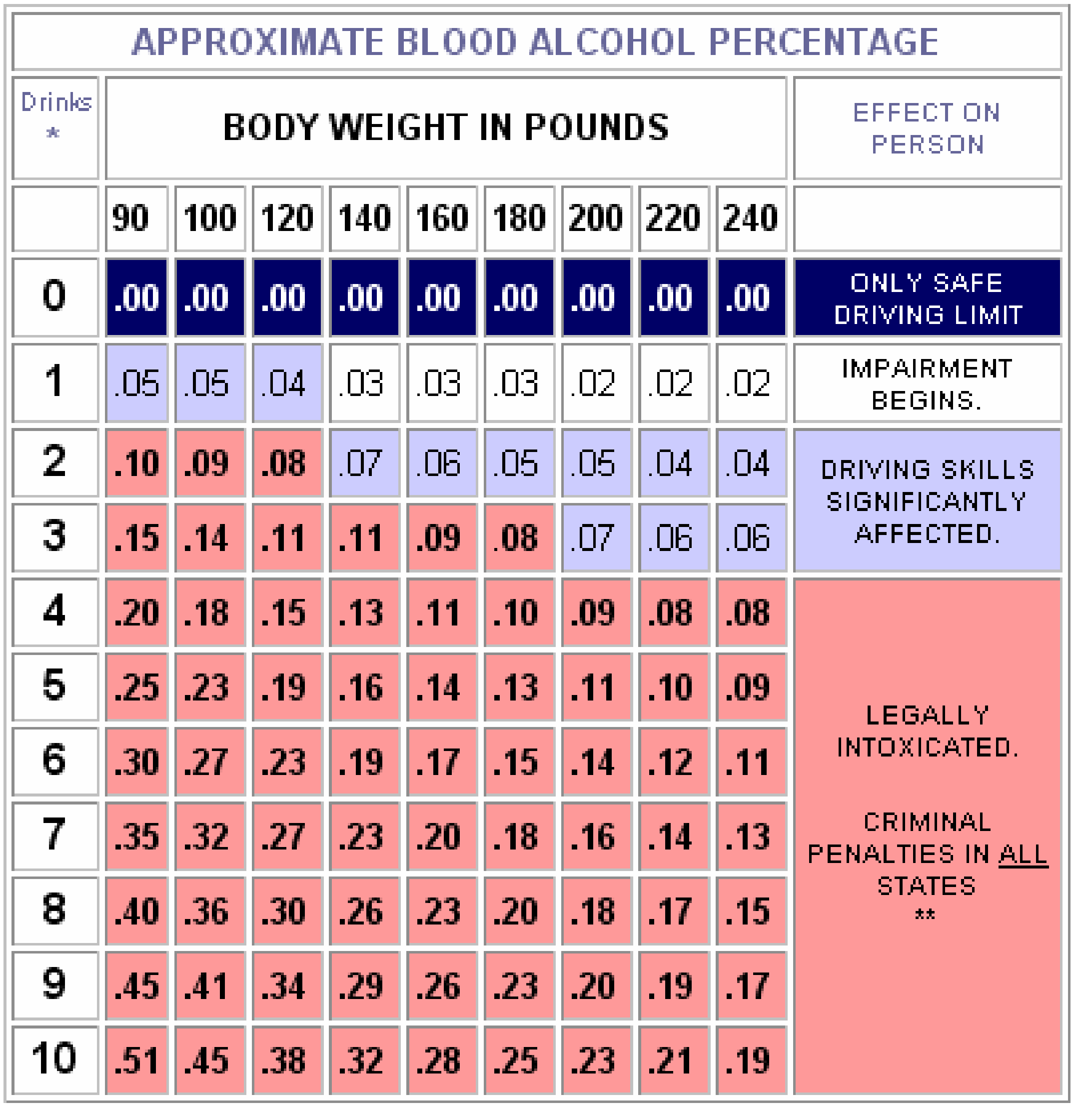
An estimate of BAC can be made from the charts[7] shown below as Figure 5 and Figure 6. As a notional sensor, the Breath Alcohol Indicator as we are building it today can provide a quick check about whether you are in the red zone, or near the red zone, in the event that you need to drive. As a safety accessory, this may be the convincing data that a taxicab or other alternative to driving is appropriate. Detailed examination of [7], published as a web page by a campus police organization, and says repeatedly in the most direct possible terms that driving with any alcohol in your system is ill advised.



APPROXIMATE BLOOD ALCOHOL PERCENTAGE

Drinks *	BODY WEIGHT IN POUNDS								EFFECT ON PERSON
	100	120	140	160	180	200	220	240	
0	.00	.00	.00	.00	.00	.00	.00	.00	ONLY SAFE DRIVING LIMIT
1	.04	.03	.03	.02	.02	.02	.02	.02	IMPAIRMENT BEGINS.
2	.08	.06	.05	.05	.04	.04	.03	.03	
3	.11	.09	.08	.07	.06	.06	.05	.05	DRIVING SKILLS SIGNIFICANTLY AFFECTED.
4	.15	.12	.11	.09	.08	.08	.07	.06	
5	.19	.16	.13	.12	.11	.09	.09	.08	LEGALLY INTOXICATED. CRIMINAL PENALTIES IN ALL STATES **
6	.23	.19	.16	.14	.13	.11	.10	.09	
7	.26	.22	.19	.16	.15	.13	.12	.11	
8	.30	.25	.21	.19	.17	.15	.14	.13	
9	.34	.28	.24	.21	.19	.17	.15	.14	
10	.38	.31	.27	.23	.21	.19	.17	.16	

Figure 5. Blood acohol content for males vs. number of drinks (see text). Subtract 0.01% for each 40 minutes since drinking began.



APPROXIMATE BLOOD ALCOHOL PERCENTAGE

Drinks *	BODY WEIGHT IN POUNDS									EFFECT ON PERSON
	90	100	120	140	160	180	200	220	240	
0	.00	.00	.00	.00	.00	.00	.00	.00	.00	ONLY SAFE DRIVING LIMIT
1	.05	.05	.04	.03	.03	.03	.02	.02	.02	IMPAIRMENT BEGINS.
2	.10	.09	.08	.07	.06	.05	.05	.04	.04	DRIVING SKILLS SIGNIFICANTLY AFFECTED.
3	.15	.14	.11	.11	.09	.08	.07	.06	.06	
4	.20	.18	.15	.13	.11	.10	.09	.08	.08	LEGALLY INTOXICATED. CRIMINAL PENALTIES IN ALL STATES **
5	.25	.23	.19	.16	.14	.13	.11	.10	.09	
6	.30	.27	.23	.19	.17	.15	.14	.12	.11	
7	.35	.32	.27	.23	.20	.18	.16	.14	.13	
8	.40	.36	.30	.26	.23	.20	.18	.17	.15	
9	.45	.41	.34	.29	.26	.23	.20	.19	.17	
10	.51	.45	.38	.32	.28	.25	.23	.21	.19	

Figure 6. Blood alcohol vs. number of drinks (see text) for females. Subtract 0.01% for each 40 minutes since drinking began.

3.2 Calibration and detection

Calibration of the Breath Alcohol Indicator circuit of Figure 1 is done by stabilizing the sensor by waiting at least two minutes after power is applied, then exposing the sensor to air containing the critical amount of alcohol vapor, then adjusting the 20 kOhm calibration potentiometer so that the orange LED just flickers. This should be done within two or three seconds to best replicate actual usage of the sensor. Response of the circuit, from Figaro data for Breath Alcohol Indicator use of the TGS 2620[8] is shown as Figure 7 below.

The relationship between BAC and alcohol vapor concentration in breath is given in [8]. We repeat that information as Table 1 below. Note that 300 ppm, the alcohol vapor concentration used most often as a calibration limit in Figaro documentation corresponds to about 0.115% BAC, but a more modern critical value of 200 ppm, corresponding to a

BAC of 0.077% is more appropriate for a Breath Alcohol Indicator. Note that BAC in percent is obtained by alcohol vapor content in breath by dividing by 2600. We provide a sensor response to BAC with this calibration below.

Table 1. Alcohol vapor concentration in breath as a function of BAC.

In Breath		**In Blood**		
mg/liter	ppm	mg/100 ml	mg/cc	%
0.05	26	10	0.1	0.01
0.10	52	20	0.2	0.02
0.20	104	40	0.4	0.04
0.25	130	50	0.5	0.05
0.30	156	60	0.6	0.06
0.40	208	80	0.8	**0.08**
0.50	260	100	1.0	0.10
0.60	312	120	1.2	0.12
0.70	364	140	1.4	0.14
0.80	416	160	1.6	0.16
0.90	468	180	1.8	0.18
1.00	520	200	2.0	0.20

For a Breath Alcohol Indicator calibrated this way, the output can be computed using (1.1). Table 1 and (1.1) provide the curve given in Figure 7. Note that the amber LED comes on at BAC 0.0358%, the orange LED comes on at 0.08%, and the red LED comes on at 0.165%. The amber and red LEDs come on at about half and twice the 0.08% calibration point.

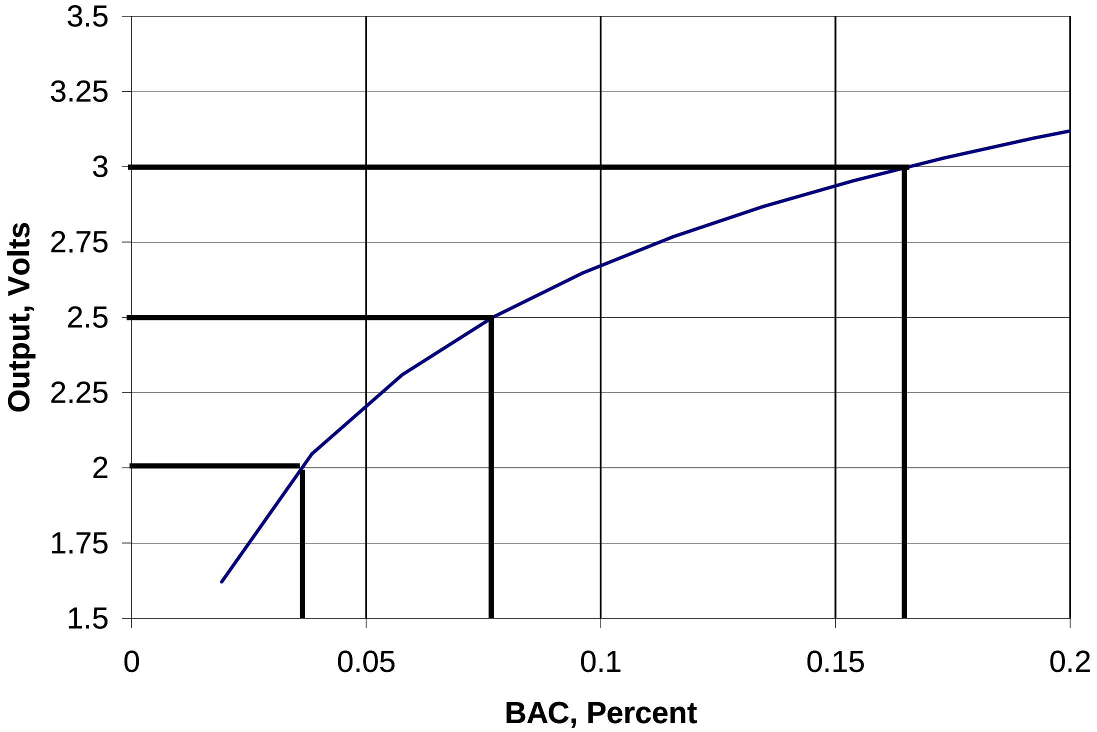


Figure 7. BAC versus Breath Alcohol Indicator sensor circuit output voltage.

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. When that period is up, notify the instructor that your experiment is ready for calibration. The instructor will have ready a test apparatus made up of a solution containing a small amount of Listerine Antiseptic™ mouthwash in four ounces of bottled water, kept in a half-pint water bottle. The test apparatus is this test solution and a soda straw.

The calibration process requires that bubbles blown through the solution through a soda straw. The sensor is placed near the mouth of the water bottle to expose it to vapors from the test solution. This provides only a few seconds before the alcohol vapor concentration begins to decline. During this period, adjust the calibration potentiometer so that the amber LED is just beginning to light.

4.4 Testing the Breath Alcohol Indicator

The first test is to simply move the sensor near the mouth of the top of the mouthwash bottle and observe the warning lights. This establishes the capability of the breath alcohol indicator to detect alcohol vapor.

A second test is to have a team member sniff the mouthwash, breath normally for a few seconds, wait one minute, and then gently exhale through the mouth over the sensor. Any indication by the breath alcohol indicator demonstrates how quickly alcohol can enter the bloodstream through vapors carried in the air.

Other tests will be discussed in the laboratory.

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 Breath Alcohol Indicator 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 curve of Figure 7.

References

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[1] http://www.alcoholalert.com/drunk-driving-statistics.html
[2] http://pubs.niaaa.nih.gov/publications/arh27-1/63-78.htm
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[4] Figaro Sensors, web site http://www.figarosensor.com/ .
[5] Figaro Product Information from TGS 2620 data sheet dated October 2000.
[6] *Technical Information on Usage of TGS Sensors for Toxic and Explosive Gas Leak Detectors*, Figaro Engineering, Inc. document dated November 2004.
[7] University of Okalahoma Police Department, published on web page http://www.ou.edu/oupd/bac.htm
[8] *Application Notes for Breath Alcohol Testers using TGS2620*, Figaro Engineering, Inc., Ver. 1.0 Revision 11, March 2003.