Detecting CO in the Home

JOE Di BARTOLOMEO

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Health issues center on pollutants and toxins while safety centers on the combustion of hydrocarbon fuels. Any home with a combustion source should have two detectors, one for detecting fuel leaks (methane, propane, etc.) and the other for exhaust leaks.

Tin dioxide (SnO_2) semiconductor gas sensors are commonly used to detect both fuel and exhaust leaks. The most deadly exhaust gas, carbon monoxide (CO), is easily detected with tin dioxide sensors.

Tin dioxide sensors offer several attractive features. They are small, inexpensive, readily available, rugged, have a lifetime of five years, and are simple to use. The sensor undergoes a physical transformation when exposed to CO (i.e., its resistance changes). Rather than sensing CO, a CO detector quantifies the CO sensor response. If the CO level is too high, the detector sounds an alarm.

For many years, people were unaware of the risk of CO, and few homes were equipped with CO detectors. However, recent well-publicized cases of CO poisoning have greatly increased public awareness of the danger that CO poses.

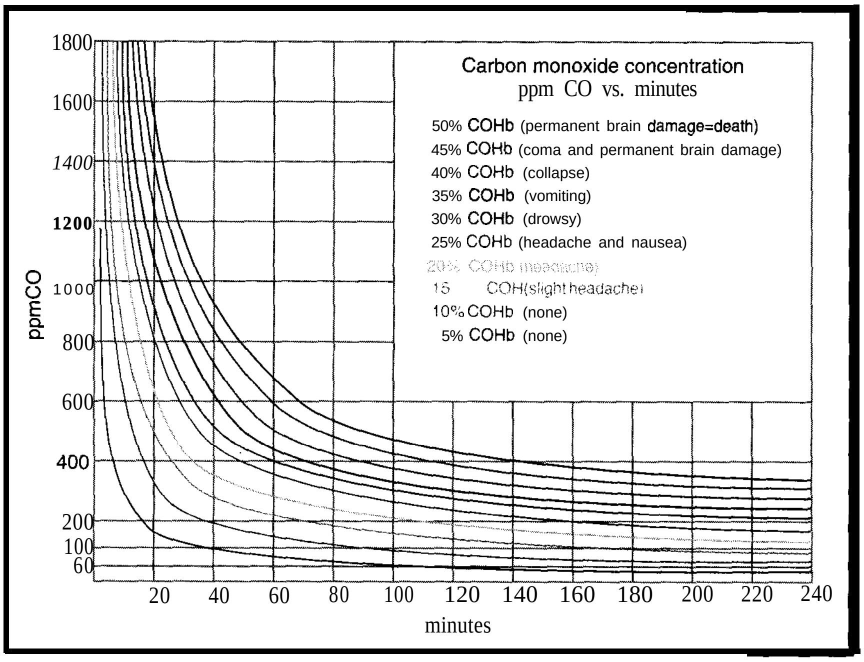

Figure 1: *Due to the nature of CO, both concentration (ppm) and exposure time (minutes) are important. CO effects on children and adults engaging in physical activity are more severe than those indicated here.*

This awareness has been accelerated by government legislation and the marketing efforts of CO detector manufacturers. In Chicago, every home must have a CO detector. This has led to a large increase in the purchase of CO detectors.

As with most consumer products, CO detector sales are price sensitive. Since no politician wants to face voters after passing legislation forcing them to purchase expensive CO detectors, there has been added political pressure to keep consumer costs down. Manufacturers now produce CO detectors in the $50 range.

Most of the consumer CO detectors use tin dioxide as the sensing element. For the average consumer, these CO detectors are fine, but for home automation and control, these sensors are too basic.

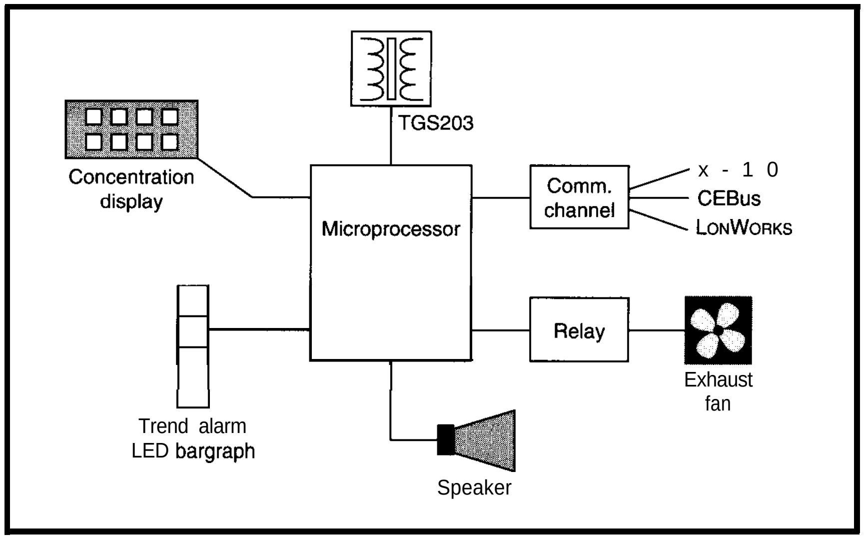

Figure 2: *A CO detector is ideal for use in home automation and control.*

WHAT IS CO?

Carbon monoxide is an odorless, colorless gas that is extremely toxic. It is the leading cause of death by poison in North America. From 1979 to 1988, over 50,000 people died of carbon monoxide poisoning in North America, of these deaths approximately half were accidental. It's commonly referred to as the silent killer and is difficult to diagnose since the symptoms are similar to those of the common cold or flu.

Carbon monoxide is a byproduct of the incomplete combustion of hydrocarbons. During combustion, the separation of the hydrocarbon fuel releases energy. The separated carbon and hydrogen atoms bond with the oxygen in the air to form water vapor (H_2O) and carbon dioxide (CO,). If combustion is complete, no CO is produced.

Incomplete combustion occurs when there is an excess or deficiency of the combustion components. Normally, incomplete combustion is due to the air-to-fuel ratio being too low (i.e., there's not enough combustion air). In this case, the dislodged carbons cannot find enough oxygen atoms and carbon monoxide forms.

a) CO Conc. (ppm)	(Min.)
b) CO Conc.	
±5	
+3/–5	480

The UL specifications for CO detectors include both a response time (a) and a false-alarm resistance (b) criterion. Both are based on concentration versus exposure time.

In the average home, several combustion sources powered by hydrocarbon fuels can potentially generate CO. The most common sources are furnaces, stoves (heating and cooking), space heaters, clothes dryers, and fireplaces. Properly installed and maintained, these appliances pose no threat.

When CO is inhaled, it inhibits the delivery of oxygen throughout the body, and the victim is asphyxiated. CO combines with hemoglobin (the oxygen carriers in red blood cells) to form carboxyhemoglobin (COHb). CO is particularly dangerous because hemoglobin's affinity to CO is much greater than its affinity to oxygen.

When the COHb level is about 15%, the victim experiences slight headaches and dizziness. At 25%, the victim has severe headaches and nausea. Between 30% and 40%. the victim vomits and may collapse. Exposure beyond 40% COHb causes permanent brain damage, coma, and eventually death (see Figure 1).

THE TECHNOLOGY

There are several commercial manufacturers of CO detectors. Most adhere to the Underwriters Laboratories standard UL 2034, which states, "A carbon monoxide detector shall operate at or below the plotted limits for the 10% COHb curve."

As you can see in Figure 1, the time required to reach 10% COHb depends on the concentration of CO. Clearly, if one is exposed to 1000 ppm, a 10% COHb level is reached more quickly than if the individual is only exposed to 100 ppm.

An infinite combination of concentration and exposure time leads to 10% COHb. UL deals with this by ensuring that a CO detector responds in less than 90 minutes when exposed to 100 ppm of CO, in less than 35 minutes with 200 ppm, and in less than 15 minutes with 400 ppm since these exposure rates all cause a person's COHb level to be 10% (see Table 1). However, the detector should not respond when exposed to 100 ppm for 5 minutes or 15 ppm for 480 minutes. A CO detector built to the UL standard is sufficient for the average home.

Any CO detector intended for home automation and control should pass the UL standard, but needs additional features such as:

- display of the CO concentration
- an output that is compatible with CEBus, X-10, and LonWorks
- a form-C relay for control of a venting fan
- a trend alarm

Figure 2 offers a basic setup for a CO detector in a home automation and control system.

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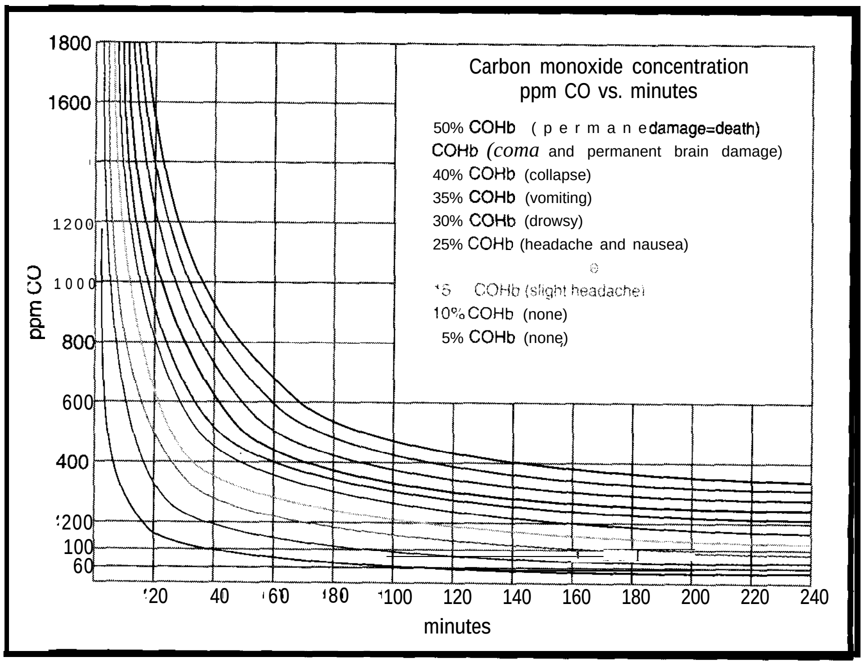


Figure 1: *Due to the nature of CO, both concentration (ppm) and exposure time (minutes) are important. CO effects on children and adults engaging in physical activity are more severe than those indicated here.*

of the tin dioxide sensor is highly nonlinear. The common approach is to normalize the sensor's response.

To do this, an arbitrary concentration is'chosen, usually 100–1000 ppm at 20°C and 60% RH. The resistance of the sensor at this concentration is designated as R_o. Using the resistance at 1000 ppm (R, is supplied by the manufacturer), you can determine the concentration by measuring the resistance of the sensor and scaling it to R_o.

Notably, even though the 8 13 responds better to CO than methane, it is rarely used as a CO detector since its operating temperature is about 400°C. As Figure 3 shows, the selectivity to CO increases as its temperature decreases. The curves illustrate how unselective these sensors can be and that care must be taken to select the proper sensor.

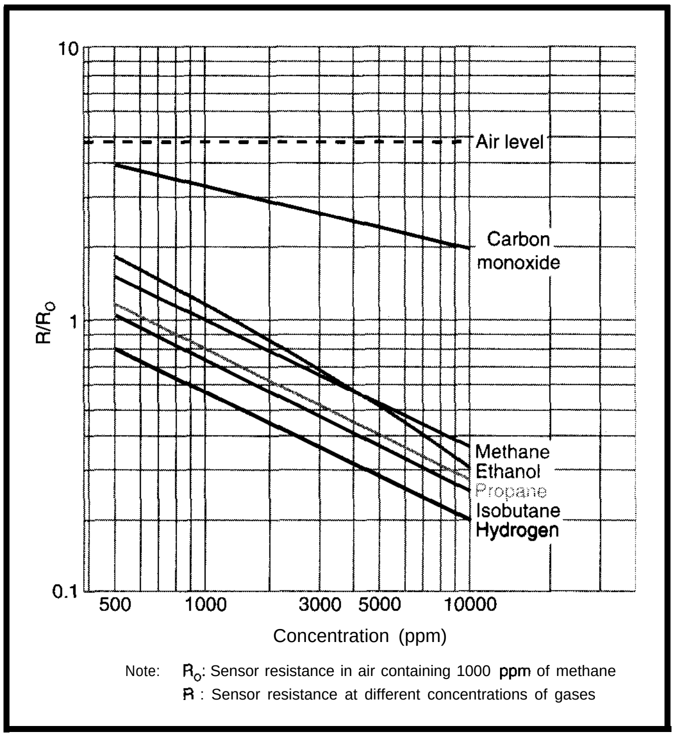


Figure 4: *The ratio of resistance to concentration is unique to each detector These statistics hold true for the Figaro 813. Note the concentration is plotted on a log scale.*

FIGARO TGS203

The TGS203 manufactured by Figaro Engineering is commonly used for detecting CO. The sensing element is an n-type SnO_2 semiconductor, which has a resistance change when exposed to CO. The resistance decreases as the CO concentration increases.

As with all semiconductor sensors, the operating temperature determines sensitivity. The TGS203 is unique in that its operating temperature is below 100°C—a sharp contrast to other semiconductor gas sensors that operate in the 400°C range. At this low temperature, the TGS203 response to CO is slowed. However, there's a significant gain in selectivity from interference gases.

By running the sensor below 100°C, water vapor and airborne contaminants deposit on the surface of the sensor and cause interference. To eliminate interference, the TGS203 operates in a two-temperature cycle. The sensor runs at the high temperature for 60 s to boil off the water vapor and contaminants and then it is run at the low temperature for 90 s to stabilize it. Once the sensor stabilizes, a CO reading is taken.

As Figure 5 shows, the TGS203 is a four-pin device. The sensor has two heating elements and the sensing element is represented by a rectangular box in the center. In actual fact, the sensor is woven into the heater elements. Electrically, the sensor's terminals are between pins 1 and 3 or between pins 2 and 4. The user selects which pair of pins to use.

Suggested operating temperatures for the TGS203 are 300°C for the high temperature and 80°C for the low temperature. The sensor's temperature is controlled by the current passed through the heaters (the greater the current, the higher the sensor temperature).

To achieve the suggested operating temperatures, the high current should be 369 mA and the low current 133 mA. Figure 6 and Table 2 present a basic circuit used to measure CO using a TGS203. Q1, Q2, and Q3 are MOSFET switches and CC 1 and CC2 are constant-current sources.

The measurement cycle begins by running the heater at the high temperature to clean the surface. This is done by closing Q1 and Q2 switches and opening switch Q3. The cleaning cycle lasts 60 s. Next, the sensor is run for 90 s at the low temperature to stabilize it. This is done by closing switches Q1 and Q3 and opening Q2. In the final step, the sensor's resistance is measured. This is done by opening all three MOSFET switches and measuring the voltage V,. The sensor resistance can easily be found from:

$$R_s = \frac{V_C - V_L}{V_L} \times R_I$$

Knowing R_s and R_o, the CO concentration can be determined. Figure 7 shows the sensitivity characteristics of the TGS203. Note when V_L is read, no heater current is applied, which causes the sensor temperature to begin dropping. To keep water vapor and other contaminants from depositing on the sensor surface, this read time should be as short as possible.

TESTING

To test your CO detector, you need a test setup. A proper test setup requires a test chamber capable of temperature and humidity control. The sample air flowing into the chamber must be controlled by flow controllers. Tanks of clean air and CO are required.

Of course, this is a very expensive proposition. Instead, a simple test setup can be made using a plastic container and its lid, a rubber stopper, syringe, and some silicone. Get an ordinary plastic container and sealing lid (e.g., Rubbermaid). Drill two small holes in the lid. Pass wires through one hole and place a stopper in the other. Seal around the holes with silicone to maintain an air seal. (The stopper needs to be made of self-healing rubber.)

Now, by inserting the syringe through the rubber stopper, inject a known amount of CO into the container. If you have a 100-l container, 1 cc of pure CO gives a concentration of 100 ppm. Using this method, virtu-

Figure 5: *The TGS203 CO sensor includes a sensing element, rectangular box, and a heater element.*

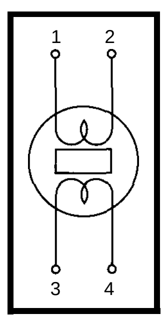


Table 2: *The TGS203 CO sensor requires two different temperatures (and hence, two current levels) for its various modes* **of** *operation.*

Operation	Time	Heater Current	Sensor Temp.
Clean	60 s	369 mA	300°C
Stabilizing	90 s	133 mA	80°C
Read	>1 s	0 mA	>80°C

Trend alarms are very useful. If 100 ppm for 90 minutes is toxic, what about 90 ppm for 120 minutes or 50 ppm for 240 minutes? Any time there is an elevated CO level, say more than 40 ppm, a trend alarm actuates. Although elevated CO levels are not lethal, they indicate a problem.

THE CO SENSOR

For more than 30 years, it's been known that the surface conductance of semiconductor oxides is influenced by the composition of gasses in ambient air. When the oxide surface is contacted by a gas it is sensitive to, its conductance changes. In effect, the semiconductor oxides are gas-sensitive resistors. This behavior is exploited to produce gas sensors from many different semiconductor oxides, tin dioxide being the most common.

The response of a tin dioxide semiconductor sensor is completely dependent on the reaction at the sensor-to-air interface at the sensor's surface. The dominate reaction at the surface of the semiconductor oxide sensors involves the change in concentration of surface oxygen species.

When an n-type semiconductor, such as tin dioxide, is exposed to an ambient that contains oxygen (e.g., air), the oxygen traps electrons. At the surface, a charge builds up and resistance changes.

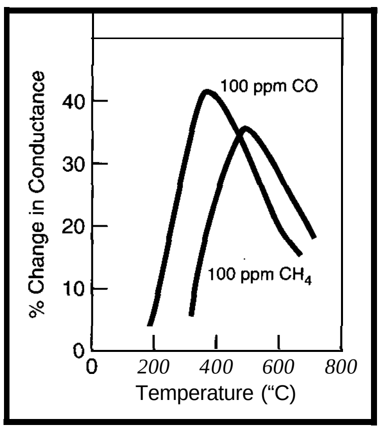


Figure 8: **CO sensor** *operating temperature can have a large effect on sensor response. Note that at lower operating temperatures, the sensor's response to CO improves.*

The charge continues to build until saturation is reached and resistance stabilizes. The surface is now extremely sensitive to any change in oxygen concentration. When the sensor comes in contact with a reducing gas, such as CO, the concentration of surface oxygen decreases, which in turn decreases the sensor's resistance. The surface reaction for CO is:

$$2C0 + 0, \rightarrow 2CO_2 + e^-$$

Any gas accepting or donating an electron causes a change in the concentration of oxygen at the sensor surface. This means any reducing or oxidizing gas causes the sensor to respond. In fact, tin dioxide sensors are capable of sensing many gases.

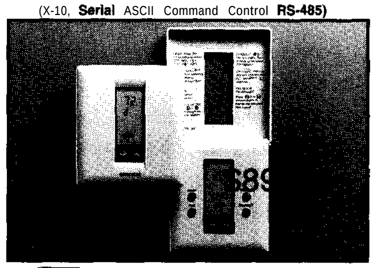
This sensitivity can lead to a lack of selectivity. Fortunately, sensors can be "tuned" to a particular gas. Although several methods enhance selectivity, the only one in the user's control is sensor operating temperature.

The semiconductor sensor's response to any particular gas is greatly dependent on its operating temperature. Figure 3 shows the typical behavior of an SnO_2 sensor. When operated at 500°C, the sensor is more sensitive to CH, than to CO. However, at 375°C, it is more sensitive to CO than CH,.

Normally, sensors operate between 300°C and 600°C. For CO, the sensor actually operates below 100°C, where the semiconductor oxides respond well to CO but not to other gases. To further reduce interference, the sensors are fitted with an activated carbon filter.

The sensors are usually four-pin devices with two pins for the sensor and two for the heater. A constant voltage or current is applied to the heater, which maintains the sensor at a constant temperature.

The response of the sensor is measured through its resistance change. Figure 4 shows the response curve of the Figaro 8 13 tin dioxide methane gas sensor. As you can see, the response



ally any concentration can be obtained in the container. Although this method is not exact, it is sufficient for most applications.

With tin dioxide sensors, there are a few points to keep in mind. First, as briefly mentioned, temperature and humidity affect them. If the sensors have been on the shelf for a period of time, they must be burned in before use.

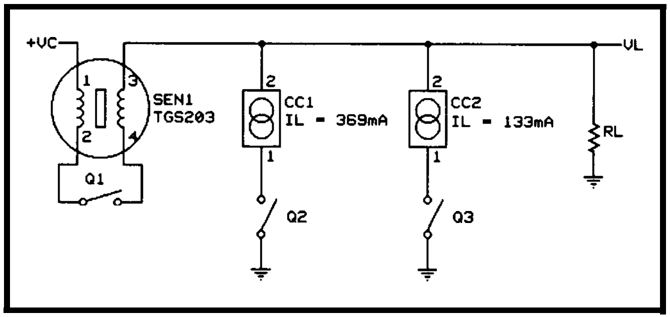


Figure 6: *Cleaning and stabilizing times can be varied to suit the application. However, the reading time should be kept as short as possible.*

The cost of tin dioxide sensors is quite reasonable (approximately $12 for one). Their lifetime is about five years. Figaro makes using the TGS-203 very simple in that they sell a hybrid chip, the FIC 540 1, that controls the TGS203. Figaro's application package is quite good and helps you get the sensors up and running quickly.

FURTHER APPLICATIONS

Tin dioxide semiconductor gas sensors are versatile. They can be used to detect many gasses. In addition to detecting methane (natural gas), they can detect ozone (generated by home air cleaners), CFC (from air conditioners and refrigerators), hydrocarbons (from paints and varnishes), and even smoke. In industrial situations, tin dioxide sensor can detect sulfurs and ammonia. And, in case you or one of your guests drank too much, they can even detect breath alcohol.

Nearly every municipality has outdoor air-quality standards. Monitoring stations throughout a municipality gather data for local pollution indexes. No such effort is made for home air, even though we spend 75% of our time indoors (90% in northern climes).

With growing public awareness of the danger of CO and other airborne compounds, legislation will be enacted. As the home automation industry is discovering in the communications debate between X-10, LonWorks, or CEBus, a standard is required for the industry to grow. This is also true for indoor air detection. A standard is needed so manufacturers can start producing detectors for the home automation market.

In fact, if a standards committee for detection of airborne toxins in the home has not been started, I'll start a committee. Do I have any volunteers?

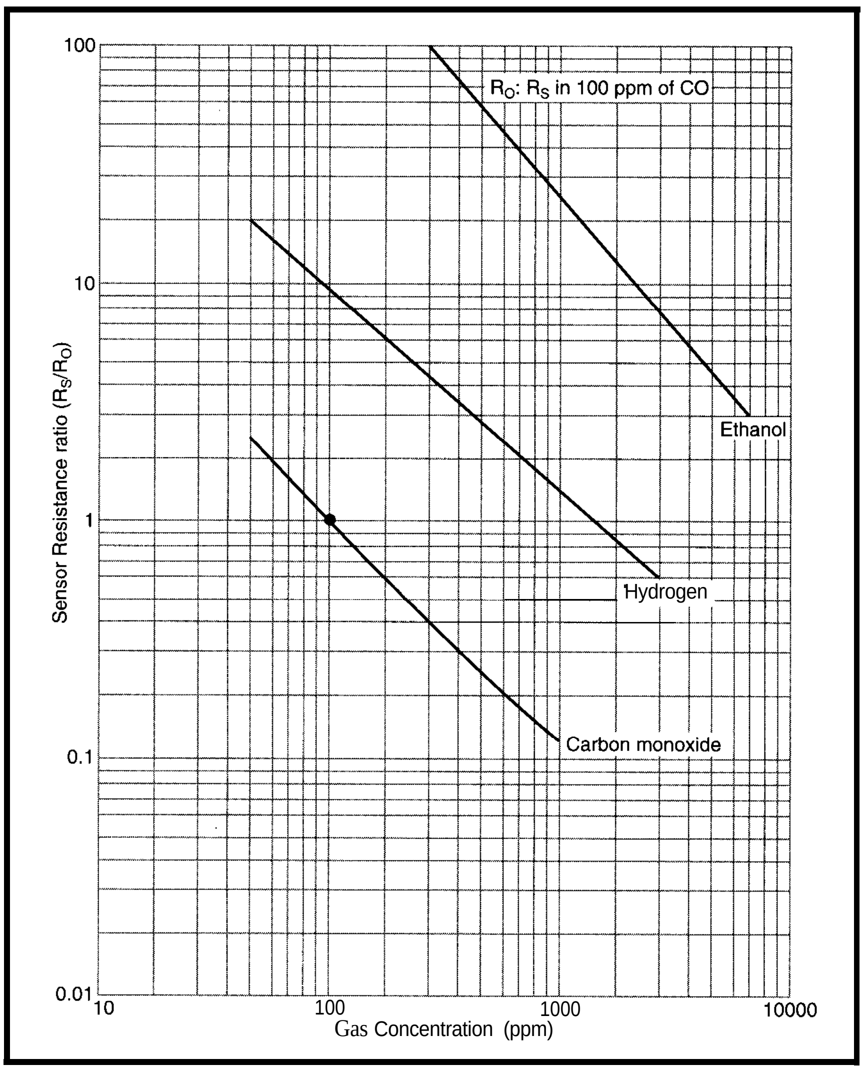


Figure 7: *The TGS203 exhibits different sensitivity characteristics for various gasses. Note that R_o is taken at 100 ppm.*

Joe Di Bartolomeo, P.Eng., is the chief engineer at Unisearch Associates, the world leaders in Tunable Diode Laser Spectroscopy (TDLS) for ambient air monitoring. He has worked extensively with low-noise analog electronics, embedded microcontrollers, artificial intelligence, and tin dioxide sensors. He may be reached at (905) 669-3547, ext. 234.

CONTACT

Figaro Engineering, Inc.
P.O. Box 357
1000 Skokie Blvd., Ste. 575
Wilmette, IL, 60091
(708) 256-3546
Fax: (708) 256-3884

I R S

413 Very Useful
414 Moderately Useful
415 Not Useful