Technical Information on Usage of TGS Sensors for Toxic and Explosive Gas Leak Detectors

Figaro TGS sensors are a type of thick film metal oxide semiconductor which offer low cost, long life, and good sensitivity to target gases while utilizing a simple electrical circuit. These sensors are especially suited to application in gas leak detectors for toxic and explosive gases.

Sensor Characteristics

Circuit

Detector Design

Manufacturing Detectors

Production Facilities

Manufacturing Process

1. Operation Principle

The sensing material in TGS gas sensors is metal oxide, most typically SnO_2. When a metal oxide crystal such as SnO_2 is heated at a certain high temperature in air, oxygen is adsorbed on the crystal surface with a negative charge. Then donor electrons in the crystal surface are transferred to the adsorbed oxygen, resulting in leaving positive charges in a space charge layer. Thus, surface potential is formed to serve as a potential barrier against electron flow (Figure 1).

Inside the sensor, electric current flows through the conjunction parts (grain boundary) of SnO_2 micro crystals. At grain boundaries, adsorbed oxygen forms a potential barrier which prevents carriers from moving freely. The electrical resistance of the sensor is attributed to this potential barrier. In the presence of a deoxidizing gas, the surface density of the negatively charged oxygen decreases, so the barrier height in the grain boundary is reduced (Figures 2 and 3). The reduced barrier height decreases sensor resistance.

The relationship between sensor resistance and the concentration of deoxidizing gas can be expressed by the following equation over a certain range of gas concentration:

$$R = A[C]^{-\alpha}$$

where: R = electrical resistance of the sensor

A, α = constant

$[C]$ = gas concentration

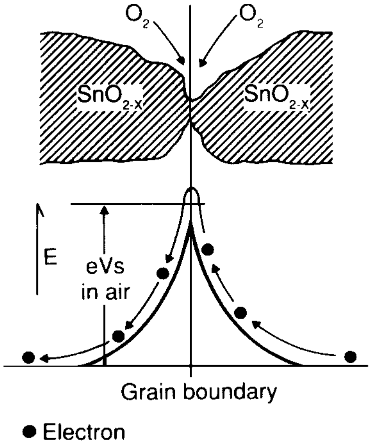


Fig. 1 - Model of inter-grain potential barrier (in the absence of gases)

$$1/2O_2 + (SnO_{2-x})^* \rightarrow O^-ad(SnO_{2-x})$$
$$CO + O^-ad(SnO_{2-x}) \rightarrow CO_2 + (SnO_{2-x})^*$$

Fig. 2 - Scheme of the reaction between CO and adsorbed oxygen on SnO_2

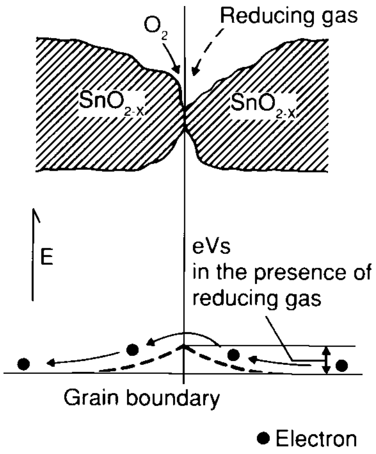


Fig. 3 - Model of inter-grain potential barrier (in the presence of gases)

2. Sensor Characteristics

2-1 *Dependency on partial pressure of oxygen*

Figure 4 illustrates the relationship between oxygen pressure in the atmosphere (PO_2) and the resistance of a typical TGS sensor in clean air. Note that reduced oxygen pressure will decrease the sensor's resistance.

2-2 *Sensitivity to gas*

According to the formula in *Section 1*, the relationship of sensor resistance to gas concentration is linear on a logarithmic scale within a practical range of gas concentration (from several ppm to several thousand ppm). Figure 5 shows a typical example of the relationship between sensor resistance and gas concentration. The sensor will show sensitivity to a variety of deoxidizing gases, with relative sensitivity to certain gases optimized by the formulation of sensing materials and operating temperature. Since actual sensor resistance values vary from sensor to sensor, typical sensitivity characteristics are expressed as a ratio of sensor resistance in various concentrations of gases (Rs) over resistance in a certain concentration of a target gas (Ro).

2-3 *Sensor response*

Figure 6 demonstrates typical behavior when the sensor is exposed to and then removed from a deoxidizing gas. Sensor resistance will drop very quickly when exposed to gas, and when removed from gas its resistance will recover to its original value after a short time. The speed of response and reversibility will vary according to the model of sensor and the gas involved.

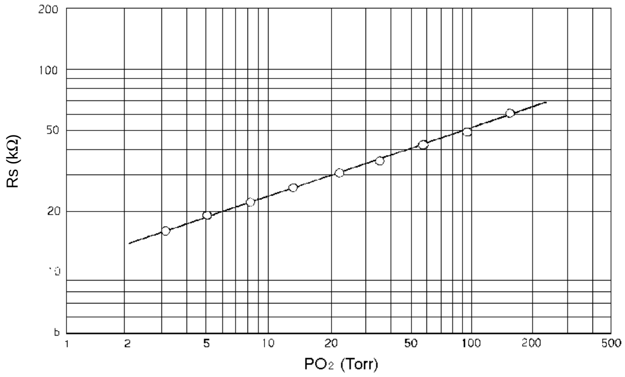


Fig. 4 - Typical dependency on PO_2

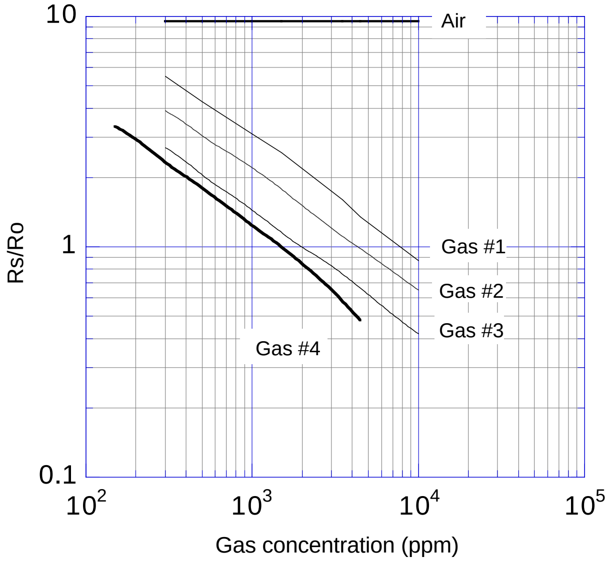


Fig. 5 - Typical sensitivity characteristics

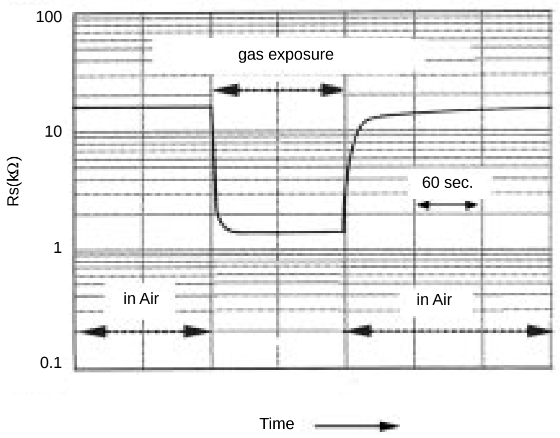


Fig. 6 - Typical sensor response

2-4 *Initial action*

As shown in Figure 7, all sensors exhibit a transient behavior referred to as "Initial Action" when stored unenergized and later energized in air. The Rs drops sharply for the first few seconds after energizing, regardless of the presence of gases, and then reaches a stable level according to the ambient atmosphere. The length of initial action depends on the atmospheric conditions during storage and length of storage and varies by sensor model. This behavior should be considered when designing a circuit since it may cause activation of an alarm during the first few moments of powering (*refer to Section 4-6*).

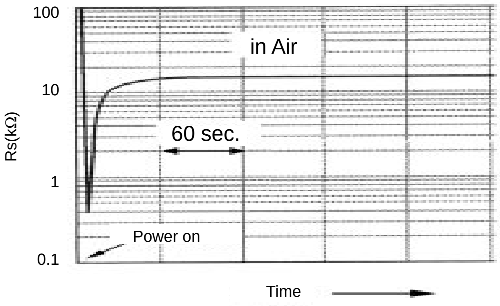


Fig. 7 - Typical initial action

2-5 *Dependency on temperature and humidity*

Since the detection principle of TGS sensors is based on chemical adsorption and desorption of gases on the sensor's surface, ambient temperature and humidity will affect sensitivity characteristics by changing the rate of chemical reaction. Figure 8 shows a typical example of these dependencies. A compensation circuit for temperature dependency should be considered when using TGS sensors (*refer to Section 4-3*).

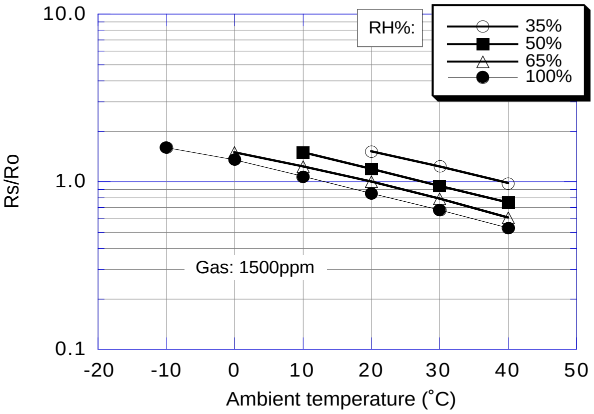


Fig. 8 - Typical temperature and humidity dependency

2-6 *Long term stability*

Figure 9 shows typical data of long term stability for TGS series sensors. Generally, TGS sensors show stable characteristics over time, making them suitable for maintenance-free operation.

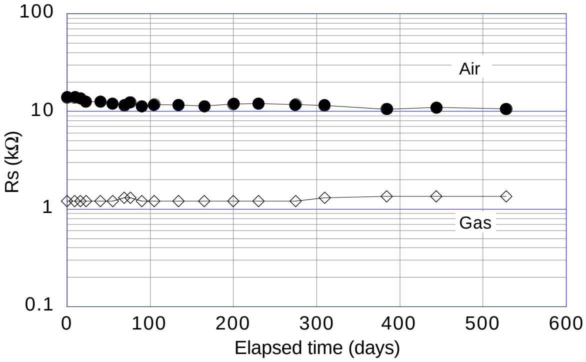


Fig. 9 - Typical long term stability

2-7 *Heater voltage dependency*

TGS sensors are designed to show optimum senitivity characteristics under a certain constant heater voltage. Figure 10 shows a typical example of how gas sensitivity varies depending on heater voltage. Since the sensor has a heater voltage dependency, a constant regulated heater voltage must be supplied to the sensor according to specifications

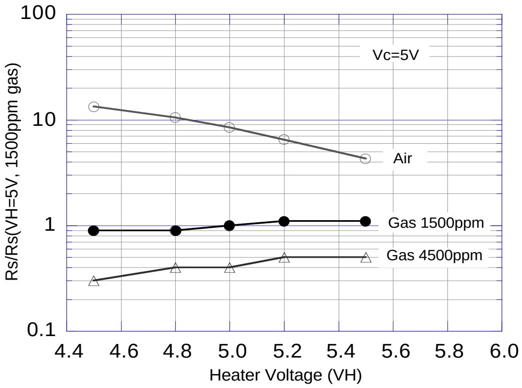


Fig. 10 - Typical heater voltage dependency

3 Cautions on Usage of Figaro Gas Sensors

3-1 *Situations which must be avoided*

1) Exposure to silicone vapors
If silicone vapors adsorb onto the sensor's surface, the sensing material will be coated, irreversibly inhibiting sensitivity. Avoid exposure where silicone adhesives, hair grooming materials, or silicone rubber/putty may be present.

2) Highly corrosive environment
High density exposure to corrosive materials such as H_2S, SO_x, Cl_2, HCl, etc. for extended periods may cause corrosion or breakage of the lead wires or heater material.

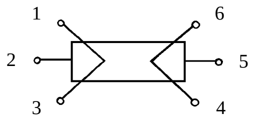
3) Contamination by alkaline metals
Sensor drift may occur when the sensor is contaminated by alkaline metals, especially salt water spray. This may also happen if the sensor is exposed to inorganic elements.

4) Contact with water
Sensor drift may occur due to soaking or splashing the sensor with water.

5) Freezing
If water freezes on the sensing surface, the sensing material would crack, altering characteristics.

6) Application of excessive voltage
If higher than specified voltage is applied to the sensor or the heater, lead wires may be damaged or sensor characteristics may drift, even if no physical damage or breakage occurs.

7) Application of voltage on lead wires
On six-pin type sensors, if a voltage is applied on the lead wires between pins 1 and 3 and/or pins 4 and 6, this would cause breakage of the lead wires.



3-2 *Situations to be avoided whenever possible*

1) Water condensation
Light condensation under conditions of indoor usage should not pose a problem for sensor performance. However, if water condenses on the sensor's surface and remains for an extended period, sensor characteristics may drift.

2) Usage in high density of gas
Sensor performance may be affected if exposed to a high density of gas for a long period of time, regardless of the powering condition.

3) Storage for extended periods
When stored without powering for a long period, the sensor may show a reversible drift in resistance according to the environment in which it was stored. The sensor should be stored in a sealed bag containing clean air; do <u>not</u> use silica gel. *Note that as unpowered storage becomes longer, a longer preheating period is required to stabilize the sensor before usage.*

4) Long term exposure in adverse environment
Regardless of powering condition, if the sensor is exposed in extreme conditions such as very high humidity, extreme temperatures, or high contamination levels for a long period of time, sensor performance will be adversely affected.

5) Vibration
Excessive vibration may cause the sensor or lead wires to resonate and break. Usage of compressed air drivers on assembly lines may generate such vibration, so please check this matter.

6) Shock
Breakage of lead wires may occur if the sensor is subjected to a strong shock.

7) Soldering flux
Sensors should be soldered manually. Wave soldering or automatic soldering mechanisms may generate large amounts of flux vapors which may cause a drift in sensor performance which is similar to the effect of silicone vapors (*refer to Sec. 6-2.3/4).*

4. Circuit Design

4-1 *Load resistor (RL)*

Signal output is obtained through the RL which also acts as a sensor protector by regulating sensor power consumption (Ps) below the rated value for the sensor. Proper selection of the RL for an individual sensor enables the sensor to provide uniform characteristics so that users can apply the sensor under the best characteristics.

Figure 11 shows typical sensitivity characteristics of a sensor. Figure 12 shows gas concentration vs. output voltage (VRL) when the sensor is used in a circuit (such as that shown in Figure 14) along with various RL values (5kΩ, 2.5kΩ, 1kΩ).

Figure 13 shows the relationship between Rs/RL and VRL/Vc. At the point where Rs/RL equals 1.0, the slope of VRL/Vc reaches its maximum. At this point, the optimal resolution of signal at alarm concentration can be obtained. As a result, it is recommended to use an RL whose Rs/RL value is equal to 1.0 at the concentration to be detected. A variable resistor (RL) is recommended for optimal results.

4-2 *Signal processing*

The conventional method to process signal output is to use a comparator as shown in Figure 14. When the VRL exceeds a preset value (Vref), the comparator signal activates external equipment such as a buzzer or LED lamp.

Usage of a microprocessor is becoming more popular for signal processing. Microprocessors are commonly used and inexpensive, and they can perform the same function as a comparator in addition to other useful functions such as temperature dependency compensation, auto-calibration, etc.

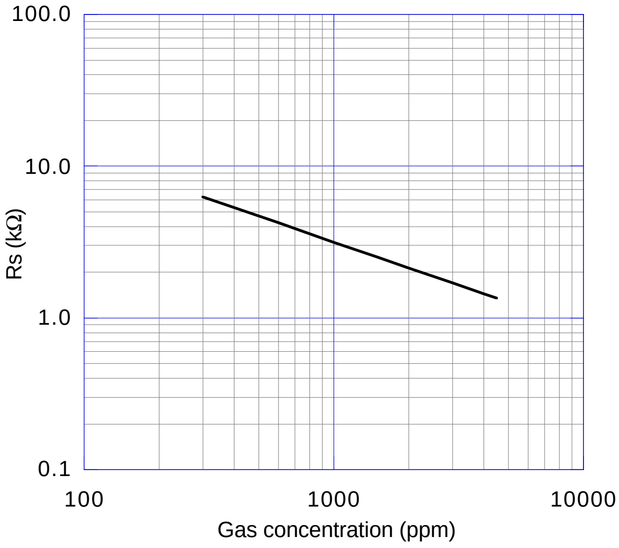


Fig. 11 - Sensitivity characteristics (Rs)

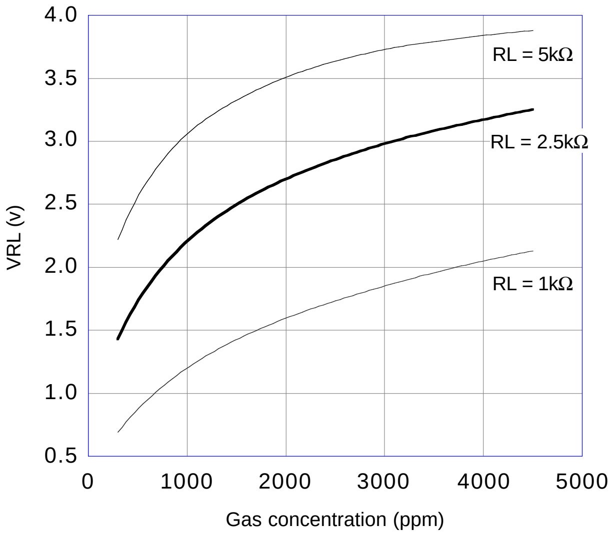


Fig. 12 - Sensitivity characteristics (VRL)

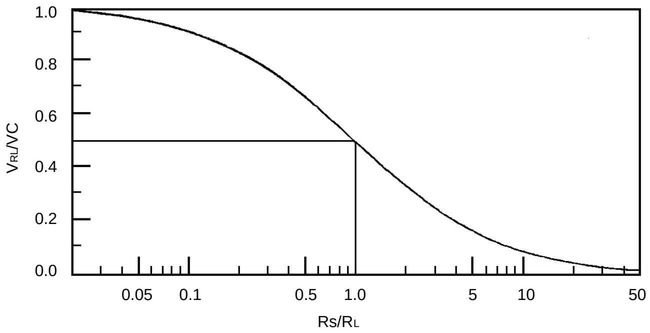


Fig. 13 - Relationship between Rs/RL and VRL/Vc

4-3 *Temperature compensation circuit*

Figure 15 shows a typical sensitivity curve for a target gas under several ambient conditions. Without a compensation circuit, the alarm point could vary from 600ppm to 3400ppm when calibrated at 1500ppm of target gas in conditions of 20˚C/65%RH.

Assuming a constant average RH of 65%, the Vref in Figure 14 can be changed by using a thermistor in order to compensate for this dependency to a certain degree. For example, Vref may be changed from 2.5v to 3.1v (under 40˚C and 65%RH) or to 1.9v (under -10˚C). The results of using a compensation circuit are illustrated in Figure 16 and Table 1.

Measuring Condition		Gas Concentration (ppm)	
Temp. (°C)	Humidity (%RH)	with Comp. Circuit	w/o Comp. Circuit
-10	65	1400	3400
0	65	1450	3100
10	65	1475	2500
20	65	1500	1500
30	65	1505	1000
40	65	1520	600

Table 1 - Effect of compensation circuit

To select a thermistor and additional resistors, the following method is suggested:

1) Identify the range of ambient temperature and humidity expected in the application. Extremes of -10˚C and 40˚C/40%~65%RH could be considered, with an average value of 20˚C and 65%RH.

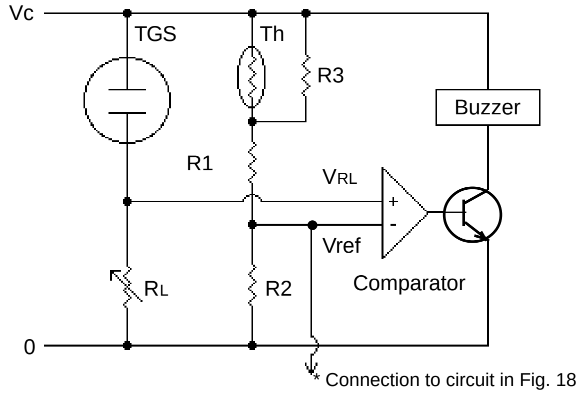
2) Obtain sensitivity characteristic curves to the target gas at the above range of ambient conditions.

3) Decide the thermistor and the additional resistor to approximate the average curve.

Recommended values for a compensation circuit such as that shown in Figure 13 are shown below:

Th : Rs(25˚C) = 8kΩ	B = 4200
R1 = 0.8kΩ	R2 = 5.8kΩ
R3 = 10kΩ	

Note: *Compensation of humidity dependency under a constant temperature cannot be achieved using this method.*



* Connection to circuit in Fig. 18

Fig. 14 - Conventional circuit for temperature compensation

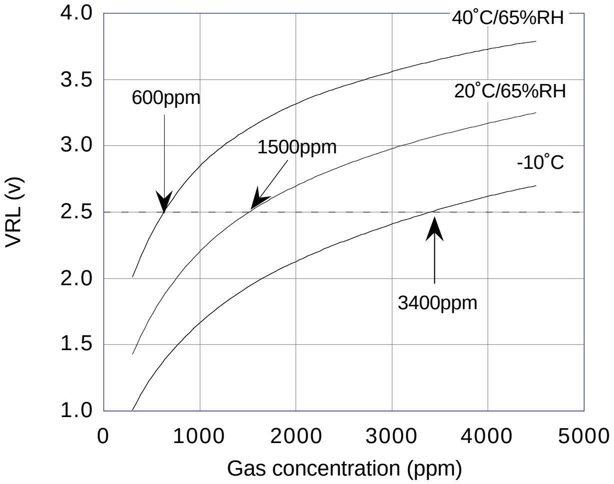


Fig. 15 - Alarm point under several ambient conditions

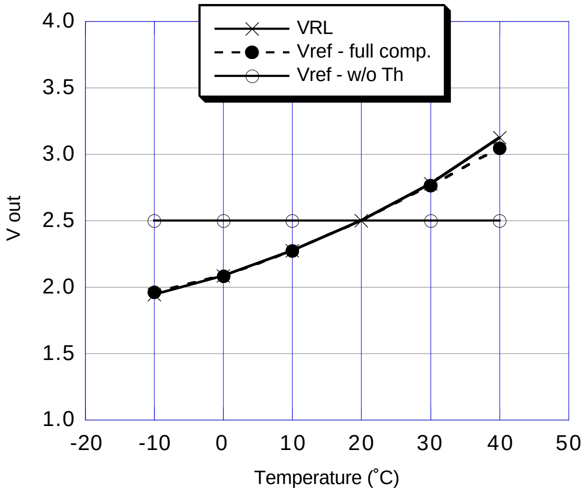


Fig. 16 - Effect of compensation circuit

4-4 *Inrush current of heater of TGS2000 series*

The heater material of the sensor has its own temperature dependency. Figure 17 shows both the inrush current and steady state of heater current under various ambient temperatures for the TGS2000 series. This chart illustrates that inrush current is approximately 50% higher than the steady state current. Since heater resistance shows a lower value at low temperatures, this would cause a larger than expected current at room temperature. As a result, when a device using the sensor is first powered on, an abnormally high current may be generated during the first few moments of energizing. Therefore protection from inrush current should be considered for incorporation into circuit design.

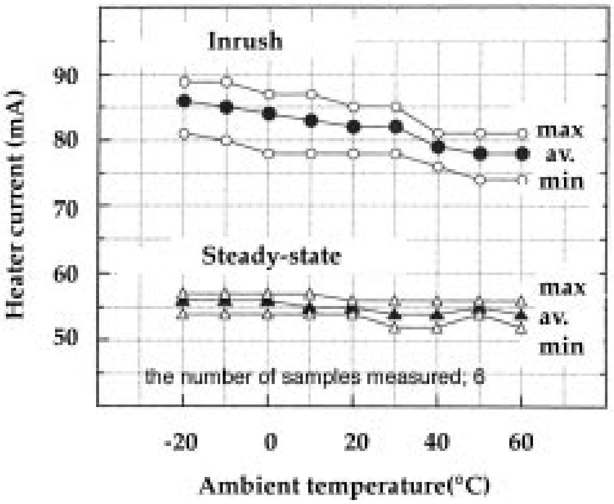


Fig. 17 - Ambient temperature dependency of heater current for TGS2000 series sensors

4-5 *Sensor breakage detection circuit*

Breakage of the sensor's heater can be detected by a resistor connected to the heater in series. The voltage across the connected resistor can be used for this purpose.

4-6 *Preventing initial action from activating an alarm*

As described in *Section 2-4*, Rs drops sharply for the first few seconds after energizing to a value lower than Vref, regardless of the presence of gases, and then moves towards a stable level according to the ambient atmosphere (*initial action*). Since this behavior during the warm-up process would be likely to activate an alarm during the first few moments of energizing, to prevent initial action from activating an alarm, a circuit such as that shown in Figure 18 should be used. This circuit should be located between the comparator and the RL.

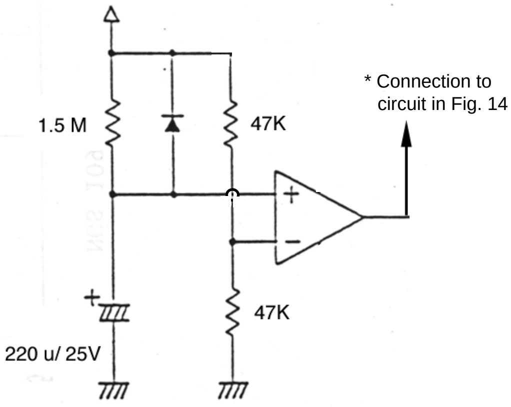


Fig. 18 - Prevention of alarm activation due to initial action

4-7 *Buzzer delay circuit*

To prevent false alarm caused by transient interference gases such as alcohol in cooking vapors, a delay circuit similar to that shown in Figure 18 can be used. This circuit should be placed between the comparator and the buzzer.

5. Detector Design

(See Figure 19 for sample flowchart)

5-1 *Circuit*

1) When a thermistor is used to compensate for temperature dependency, note that the thermistor will compensate for temperature variations which may occur around the sensor. Therefore, place the sensor and thermistor in an area where they will not be affected by heat generated by the circuits.

2) Be sure to adhere to the specified sensor heater operating conditions such as voltage, current, heating cycle, and detection timing.

3) When designing circuit configuration (pattern width, distance between circuit paths, and layout), take into consideration the large current which flows through the sensor.

4) The value of the load resistor should be set close to the sensor's resistance value at the alarm setting. When a variable resistor is used, consider its adjustable range.

5) The circuit function should include a fail-safe mode for detection of lead wire or heater breakage and sensor element deterioration.

5-2 *Detector casing*

1) The case should have a partition around the sensor and a sufficient number of wide slits at the opening so that gases can diffuse rapidly.

2) Design the case so that heat dissipation is maximized from the case.

5-3 *Prototype evaluation test*

Prototype evaluation test should be conducted to see whether or not mass production may be started.

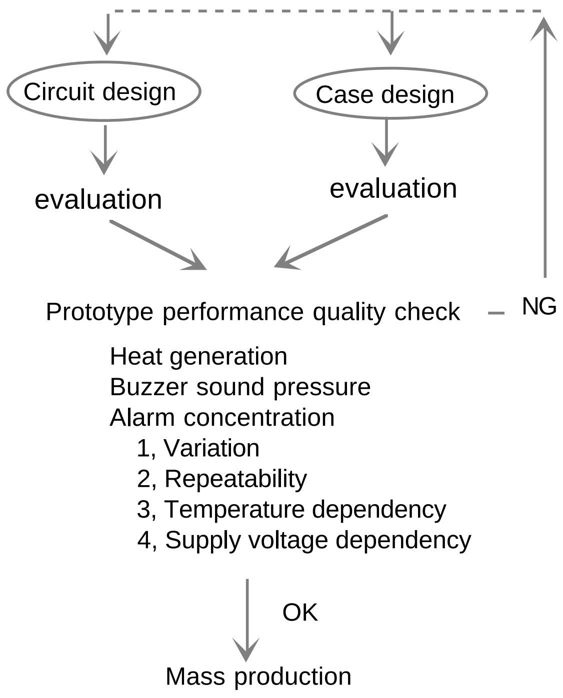


Fig. 19 - Flowchart for design of detectors

6. Manufacturing of Detectors

6-1 *Production facilities*

1) Preheating facility for sensors and detectors
The rated voltage at the rated cycle should be applied constantly regardless of fluctuation in supply voltage. The preheating process should be carried out with sensors/detectors fixed upright, the same as their mounting position on a wall.

2) Gas chamber
Avoid using insulation or sealing materials which may give off fumes after curing, such as silicone sealants and solvent-based adhesives. The air and gas mixture should be provided at a measured and

controlled temperature and humidity. The capacity should be large enough—one liter or more per one sensor. Gas should be supplied to detectors using a static gas mixture, thus avoiding direct gas flow onto the sensor which would cause a false high reading. The gassing process should be carried out with detectors fixed upright, the same as their mounting position on a wall.

3) Factory environment
The environment should be clean and free from organic vapors such as alcohol. Special attention should be paid to the environment around the preheating facility for sensors / detectors—keep these areas free from influencing gases, especially silicone vapors. If volatile cleaners such as trichloroethylene, freons, or floor sealants are to be used, all products should be removed from the area to be treated and not returned until the area has been thoroughly ventilated.

6-2 *Manufacturing process*

(*sample flowchart of mfg. process shown in Fig. 20*)

1) Handling and storage of sensors
Sensors should be stored in a sealed bag containing normal clean air.

2) Sensor preheating
The minimum period for sensor preheating is 2 days, but for best results, 7 days or longer preheating is *strongly* advised. Be sure to adhere to standard circuit conditions and maintain clean atmospheric conditions when preheating.

3) PCB assembly
Flux residue must be carefully wiped off after soldering.

4) Sensor assembly
Manual soldering is strongly advised. Solders composed of Sn63:Pb37 or Sn60:Pb40 with non-chloric resin flux (MIL: RMA Grade; for example, Almit KR-19) are recommended for usage.

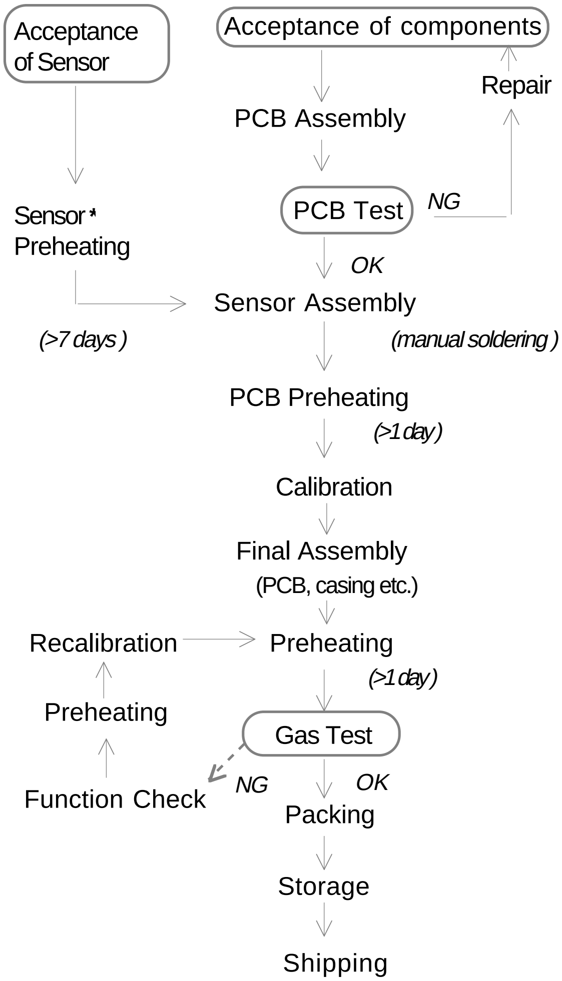


Figure 20 - Flowchart for mfg. detectors

5) PCB Preheating
The minimum period for PCB preheating is 2 hours, but for best results 1 day or longer is *strongly* recommended. Be sure to adhere to standard circuit conditions and maintain clean atmospheric conditions when preheating.

6) Calibration (*refer to circuit in Figure 14*)
Be certain to calibrate all products using the appropriate target gas concentration(s). Keep the atmospheric conditions in the chamber stable for temperature and humidity. Remove any traces of smoke, adhesives, gases, or solvents from the chamber.

Ex1) When calibrating a detector using a variable load resistor, place the detector in the gas chamber. Prepare the alarm concentration of gas in the test chamber. Adjust the V_{RL} in gas so as to correspond to the Vref.

Ex2) When calibrating a detector using a temporary load resistor (R_L*), place the detector in the test chamber. Prepare the alarm concentration of gas in the chamber. Measure the voltage across the R_L* to obtain Rs at the alarm concentration. Replace the R_L* located inside the detector with an R_L that is equal to the Rs measured above.

Note: Be sure that the alarm concentration of gas is humidified to ambient levels. If not, calibration results will be very different from what would be expected under normal usage.

7) Final assembly
Avoid any shock or vibration which may be caused by air driven tools.

8) Preheating of final assembly
The minimum period for preheating final assemblies would be 2 hours, but for best results it is *strongly* recommended that 1 day or more preheating be done. Be sure to adhere to standard circuit conditions and maintain clean atmospheric conditions for preheating.

9) Gas test
Test all finished products against the target gas. Keep the atmospheric conditions in the chamber stable—20˚C±2˚C and 65%±5%RH are strongly advised. Remove any traces of smoke, adhesives, gases, or solvents from the chamber.

10) Recalibration after failing gas test
If no problems are noted after circuit function test, recalibration should be conducted. Preheating time should be twice as long as the unenergized period after the gas test for purposes of stabilizing the detector sufficiently. Recalibration should not be repeated more than four times.

11) Storage of finished products
Detectors should be stored in a clan air environment. Avoid storage in dirty or contaminated environments. Cautions listed in *Section 6-1.3* also apply.

7. Quality Control

1) Sample a certain number of finished products from each production lot to confirm alarm concentration. Check whether these samples are acceptable for shipment and maintain a record of these tests.

2) Sample a certain number of finished products periodically to confirm the alarm concentration under extreme conditions (e.g. -10˚C or 40˚C and 85%RH) and maintain a record of these tests.

3) Sample a certain number of completed products periodically to confirm their long-term characteristics and maintain a record of such test.

Important Reminder

Without calibration and testing after final assembly, detectors have no guarantee of accuracy or reliability.