

FIGARO

an ISO9001 company

Application Notes for CO Detectors using TGS5042

The TGS5042 is a battery-operable electrochemical CO sensor which is provided with individual sensitivity data printed on the sensor's housing, allowing users to eliminate the process of calibration using CO gas. This document offers example circuits and important technical advice for design and manufacture of detectors.



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IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET GASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.



TGS5042 is a UL recognized component in accordance with the requirements of UL2034. Please note that component recognition testing has confirmed long term stability in 15ppm of CO; other characteristics shown in this brochure have not been confirmed by UL as part of component recognition.

1. Sensor Marking

The TGS5042 comes with a sticker attached to the sensor housing (see Fig. 1) which contains individual sensor data:

One dimensional bar code

XXXX

where: xxx = x.xxx nA/ppm

This bar code indicates the sensor's sensitivity (slope) in numeric value as determined in Figaro's factory by measuring the sensor's output in 300ppm of CO. This value is also printed below the bar code--please note that three decimal places should be added to the sensitivity reading (e.g. 1827 should be read as 1.827 nA/ppm).

Sensor lot number is printed to the left of the sensitivity data in YYMMDD format.

2. Circuit Design

2-1 Basic circuit

TGS5042 is a fuel cell type electrochemical sensor with two electrodes, with sensor output current changing linearly with CO concentration. To use the sensor for CO detection, it is necessary to convert sensor current to output voltage. There are two conversion methods:

2-1a Sensor current type (see Fig. 2a)

This method directly converts sensor current into voltage according to the following equation:

$$V_{out} = I_s \times R_1$$

where: I_s = Sensor output current

2-1b Load resistor type (see Fig.2b)

This method measures generated voltage across a fixed load resistor which is connected to the sensor electrodes. In this case, sensor output is expressed by the following equation:

$$V_{out} = I_s \times R_2$$

where: I_s = Sensor output current

The load resistor type circuit does not include an op-amp. An op-amp is used to amplify voltage since sensor current is very small, in which case

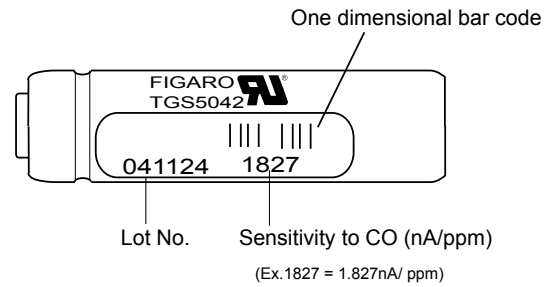


Fig. 1 - Sensor markings

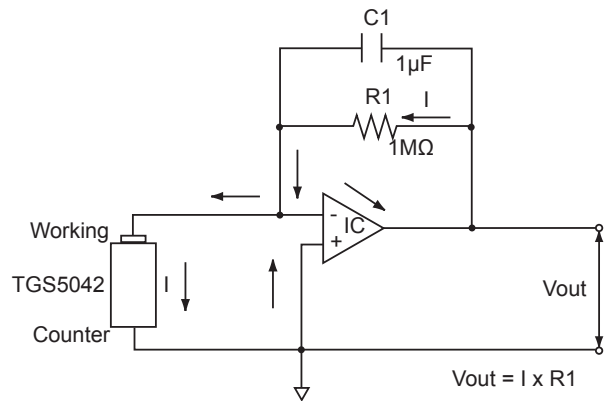


Fig. 2a - Basic circuit for amplifying sensor current

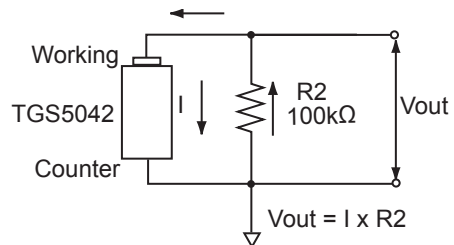


Fig. 2b - Basic circuit with fixed load resistor

the circuits of the sensor current type and load resistor type become very similar. However, large differences in characteristics can be seen

between amplifying current and using a fixed load resistor.

1) Response time to CO is slower when using a fixed load resistor (see Fig. 3). When using a fixed load resistor, the larger the value of the load resistor, the slower the response time. In addition, the expected output voltage may not be obtained if a larger than 5.6kΩ load resistor value should be selected.

2) When amplifying current, an additional load resistor or FET is required for anti-polarization of the sensor.

Note 1: Please pay attention to sensor polarity. Although the sensor's package is physically similar to that of a dry battery, the sensor's polarity is *opposite* to that of a dry battery.

Note 2: When voltage is applied to the sensor output terminal, the sensor may be damaged. Voltage applied to the sensor should be strictly limited to less than ±10mV.

2-2 Op-amp selection

When using a fixed load resistor, in most cases an op-amp is required to amplify the sensor's small output voltage.

Rail-to-Rail Op-Amps such as the following are recommended for both basic conversion circuits:

AD708, AD8698, OP07 (Analog Devices), TLC272(TI), OPA177(BB), MCP6042 (Microchip), MCP616 (Microchip), OPA2355 (TI)

For circuits employing an op-amp, Figure 4 shows the internal equivalent circuit which can be expected according to Figaro's test results. Component values are estimated as follows, including variation in sensor characteristics and temperature/humidity dependency:

- Rs: 0~1kΩ
- Rs+Rp: 10kΩ~∞
- C: 0.8mF~10mF

Off-set voltage of an op-amp (current to voltage converter) affects the base line level of sensor output. This is because a small current reaches the sensor due to the offset voltage of the op-amp, causing a voltage shift according to the

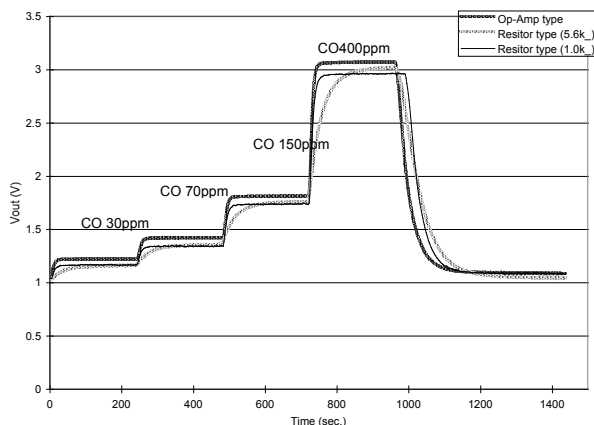


Figure 3 - Sensor response curve in various basic circuits (amplified 3.13M times)

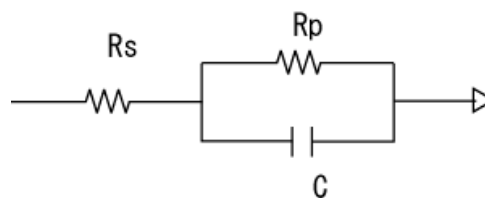


Figure 4 - Internal equivalent circuit when using an op-amp

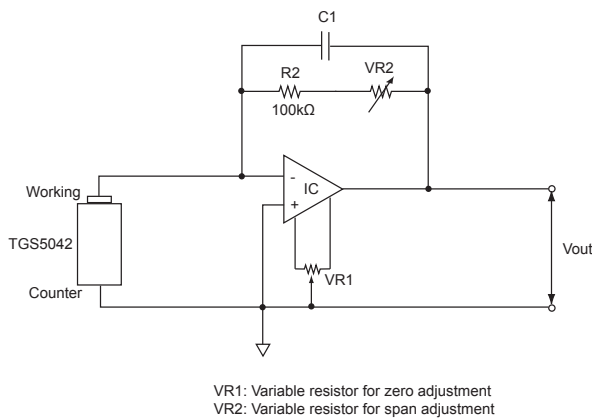


Figure 5 - Circuit example for zero adjustment

internal DC resistance of the sensor (Rs+Rp). The voltage shift drives an increase and decrease from default base line level due to the value (±) offset voltage for the op-amp. To prevent such a voltage shift, the above listed op-amps are recommended.

Please note for circuits employing an op-amp, when a fixed load resistor is used for anti-polarization, only an op-amp with small leak current (such as AD708 , OPA2355) can be used.

When an op-amp with large leak current is used, offset voltage may fall outside of the adjustable range by leak current. (see 2-5 *Anti-polarization Circuit*).

To obtain high accuracy in an analog circuit, an op-amp with a zero adjustment function, such as LF356 (National), is recommended. In Figure 5, a typical zero-span adjustable circuit using LF356 is shown.

2-3 *Baseline design of sensor output*

Since sensor output may have a negative value due to the offset voltage of the op-amp, the baseline of sensor output should be set $>1V$. If an anti-polarization circuit (using JFET), and a self diagnosis circuit (see *Items 2-6 and 2-12*) are added, the base line of sensor output should be set $>2V$.

2-4 *Microprocessor*

Incorporating a microprocessor into a circuit offers several advantages. The complex calculation of alarm concentration based on COHb and temperature compensation can be carried out by the microprocessor, simplifying circuit design. By recording sensor sensitivity data from the sensor's bar code label in the microprocessor and by using the microprocessor to compensate for offset voltage, the calibration process for detector production can be greatly simplified. In addition, useful values such as a maximum CO concentration and a sensor output timing chart can be recorded in the microprocessor as additional functions.

From the viewpoint of signal resolution, the recommended specification of a microprocessor is 10 bit or higher.

2-5 *Anti-polarization Circuit*

When the sensor is stored without connection between the working electrode (W) and counter electrode (C), polarization will occur between the electrodes. When a polarized sensor is connected to an operating circuit, it takes about one hour to stabilize sensor output (refer to 3-5 *Influence of Storage in TGS5042 Technical Information*).

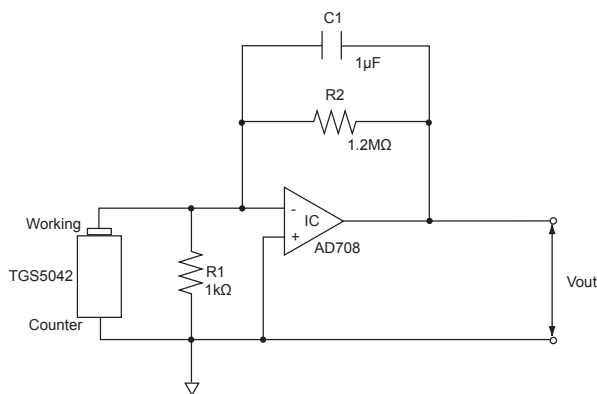


Figure 6 - Anti-polarization circuit using a fixed resistor

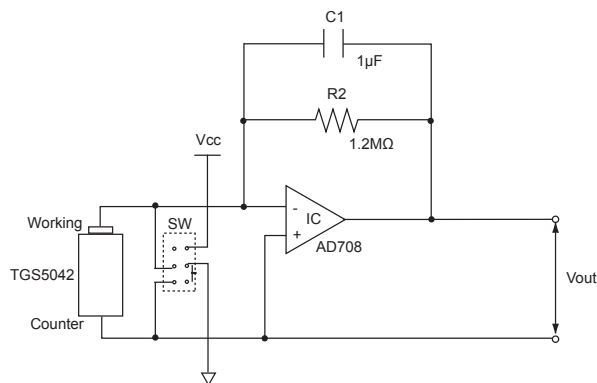


Figure 7 - Anti-polarization circuit using an external switch

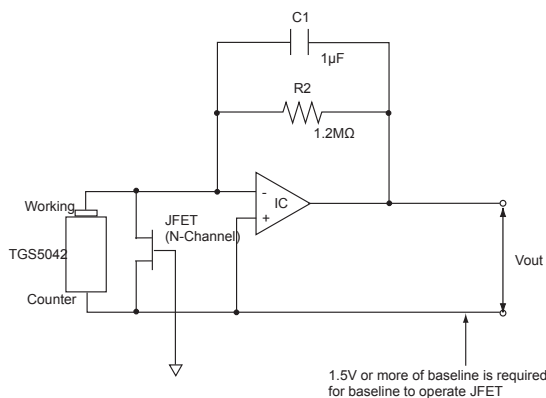


Figure 8 - Anti-polarization circuit using an N-channel JFET

To avoid polarization during storage, it is necessary to keep a short-circuit (or $<1k\Omega$ resistance) between the electrodes. In this manner, measures such as a timed warm-up period for stabilizing the sensor are not required in circuit design.

In a load resistor type circuit, it is not necessary to add additional parts for anti-polarization since the circuit already contains a load resistor between the sensor electrodes.

A sensor current type circuit can use three methods for anti-polarization:

1) *JFET (Figs. 8 and 9) - Figaro's recommendation*
 This method is normally used in CO alarms without an external switch. In this case a JFET (Field Effect Transistor) is recommended. Junction type transistors are not recommended due to their large leak current. MOSFETs cannot be used.

2) *Fixed resistor (Fig. 6)*
 As a simple method, a fixed load resistor can be used. In this case, it is necessary to use an op-amp with very low leak current (such as AD708 or OPA2355). Op-amps with large leak current may cause offset voltage to fall outside of the adjustable range.

To avoid polarization on the sensor during power-off, Figaro recommends that both of electrodes of the sensor be shorted by using a JFET (see Item 2-5.1 above). Alternatively, adding a fixed resistor (10~100k Ω) between both electrodes will have a similar effect for anti-polarization. However, since this effect will be smaller than in case of using a JFET, the recovery time after powering on may be longer. Furthermore, resistors between both sensor electrodes may cause a large shift from the base amplified signal.

3) *External switch (Fig. 7)*
 This method is normally used for CO analyzers where there is an external switch to control power on/off. By using an external switch, the connection between the W and C electrodes can be controlled, whether open or short ($<1k\Omega$) circuit.

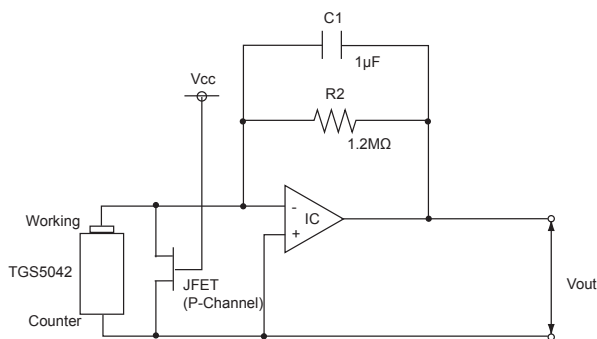


Figure 9 - Anti-polarization circuit using a P-channel JFET

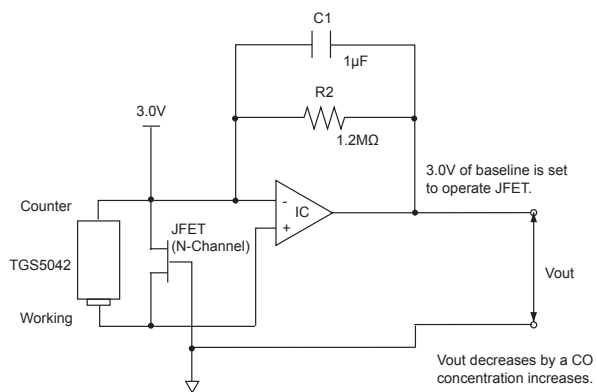


Figure 10 - Circuit for extending effective voltage range using N-channel JFET

It is necessary to choose a P-channel or N-channel FET, depending on the required effective output range, gain, and the variation range of V_{cc} . Figures 8 and 9 show the basic circuit for each type.

The advantage of a P-channel FET is a wider effective voltage range. However P-channel FETs have higher cost, weakness against applied voltage fluctuation, and they require higher operating voltage than 5V (making them unsuitable for applications which need $<5V$). Recommended P-channel FETs are J177, J270 (Fair Child), and 2SJ103 (Toshiba).

N-channel JFETs are widely available in many models, have lower cost, and are more stable to voltage fluctuation of power supply. Their disadvantage is their narrower effective voltage range. However, one option to extend their effective voltage range is to shift baseline to V_{cc} as shown in Fig.10. In the example circuit, output

voltage decreases with a CO concentration increase. The recommended N-channel JFETs are J201, PN4117 (Fair Child), and 2SK117 (Toshiba).

2-6 Amplification Circuit (see Figs. 11 and 12)

In a load resistor type circuit, voltage can be amplified by using either an inverted or non-inverted amplifier. Depending on the method, the gain is slightly different. Please note that direction of W and C electrodes are opposite between non-inverting and inverting amplifier circuit.

Non-inverting amplification has lower leak current from the sensor to the op-amp since the working electrode is connected to the positive (+) terminal of the op-amp. To prevent leak current, setting a voltage follower between sensor output and the op-amp is recommended (refer to Sec. 2-8 Leak Current Prevention Circuit).

2-7 Amplification Factor (gain)

It is necessary to decide gain by selecting Vcc, JFET and the op-amp in terms of sensor output range, target gas concentration range, and required accuracy.

For example, a gain of at least 2.5 million is calculated to be necessary for the following example CO detector:

- 5V Vcc
- 10 bit microprocessor
- Accuracy: ±20% of reading
- Detection range: 0 ~ 750ppm

To extend the detection range, it is necessary to increase Vcc or to use a microprocessor with higher resolution. For conformity to EN50291, Figaro recommends at least a 10bit A/D converter with 1.2M to 1.4M times as a gain value.

To meet EN50291 requirements, a CO alarm must be able to distinguish the output signal (voltage) between 30ppm and 50ppm of CO. For obtaining an appropriate gain value which can meet with this requirement, the full scale of CO concentration and baseline of output signal in a CO alarm should be decided before starting

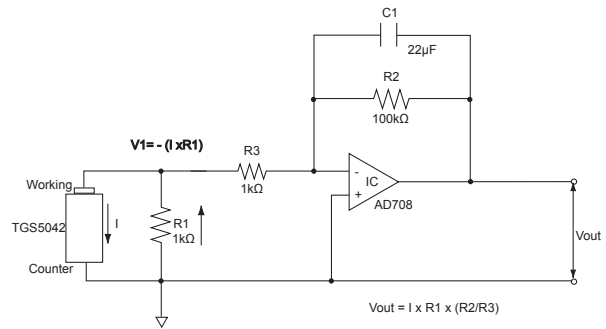


Figure 11 - Inverting amplifier circuit

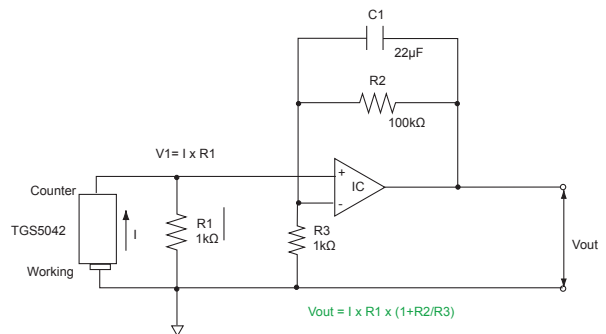


Figure 12 - Non-inverting amplifier circuit

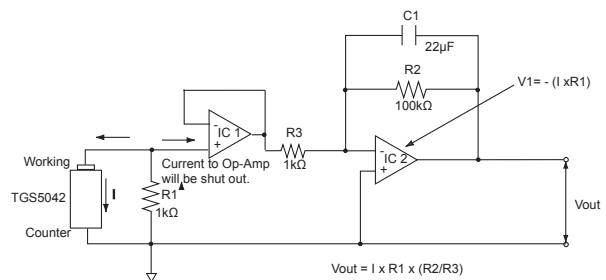


Figure 13 - Leak current measure using a voltage follower

circuit design. For example, if a circuit voltage (Vcc) would be 5V, the appropriate gain value is obtained as follows:

- full scale of CO conc.: 1000ppm
- baseline of sensor output (in 0ppm CO): +1V
- max CO sensitivity of TGS5042: 2.4nA/ppm
- temp dependency of TGS5042: I(60°C)/I(20°C)=1.2

Gain: 1.38×10^6 -times = $[5V-1V] / [2.4 \times 1.2 \times 10^{-9}(V/ppm) \times 1000(ppm)]$

In the above conditions, since a 10bit A/D converter can distinguish the difference in sensor

output between 30ppm and 50ppm CO, Figaro recommends using at least a 10bit A/D converter and 1.2M to 1.4M-times as a gain value in the circuit.

2-8 Leak Current Prevention Circuit (Fig. 13)

In a fixed load resistor circuit, a non-inverting amplifier circuit is recommended for simplicity. For further countermeasures, adding a voltage follower between sensor output and the op-amp is recommended.

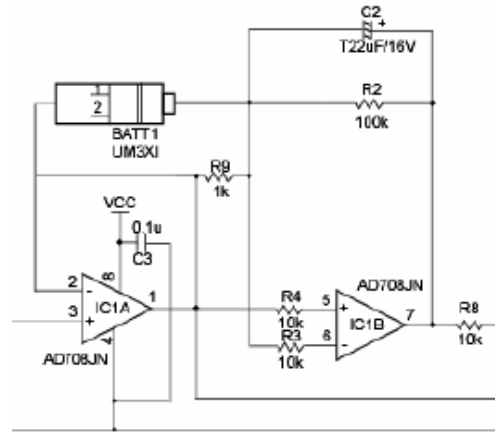


Figure 14 - Electrical noise prevention circuit

2-9 Electrical Noise Prevention

Since sensor impedance is 10Ω or less, the sensor itself will not be a source of electric noise. However, the sensor is easily influenced by external electric noise since sensor output is very small in both basic circuits. Therefore, it is necessary to incorporate measures into the circuit pattern and power supply to eliminate electrical noise.

Three options to prevent electrical noise:

- 1) Use an electrical noise filter
- 2) Use a voltage follower (see Sec. 2-8 Leak Current Prevention)
- 3) Build up an RC network with a resistor and capacitor in place of the feedback resistor of the op-amp. The recommended time constant (T) of RC circuit for power input is 2~2.5 seconds since the value in the basic recommended circuit is 2.2 seconds.

To prevent external electrical noise, setting a noise filter inside the detector, making a noise prevention circuit pattern, and averaging the output signal are recommended.

In addition to reduce electrical noise due to radio waves, adding fixed resistors (R3 and R4 as shown in Figure 14) on the input terminal of the op-amp is also effective. Please not that the capacitor between the output and input terminals (C2 on Figure 14) should not be added when a CMOS type op-amp is used.

2-10 Temperature Compensation Circuit

Temperature compensation can be done in one of two ways:

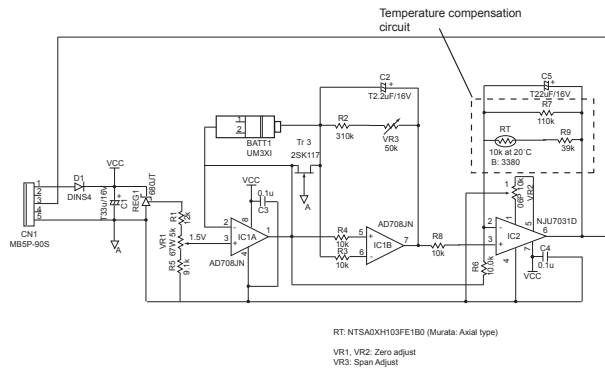


Figure 15 - Temperature compensation circuit

- 1) Input the thermistor's signal into the microprocessor and compensate it with the temperature compensation table which is also stored inside microprocessor (refer to Item 3-Calibration for details of the compensation process, and refer to Appendix 1 for temperature compensation factors).

- 2) Make an analog circuit with a negative temperature coefficient (NTC) thermistor and resistors in place of the feedback resistor of IC2 (see Fig.15)

2-11 Self Diagnosis Circuit (patented by Figaro)

Sensitivity to CO would be lost in case several failure modes were to occur, such as wire breakage, short circuit, or in case the sensor's water reservoir were to dry up. By using Figaro's patented self diagnosis circuit,

malfunctions involving loss of CO sensitivity can be detected.

Please note that this method cannot detect CO sensitivity loss caused by lack of gas diffusion when dust or water droplets cover the pin holes for gas diffusion. In addition, slight loss of CO sensitivity cannot be detected by self-diagnosis.

Depending on the user's circuit design, factors for self diagnosis such as current value, self diagnosis period, measurement timing, and voltage range for judgement may vary. Therefore, it is recommended that experimentation with the user's circuit be conducted for fine tuning these factors in self diagnosis.

Figs. 16, 17, and 18 show examples of the circuit, timing chart, and process chart.

The basic steps of self-diagnosis are:

1) *Temporarily cut the sensor off from the circuit*
 Activate a transistor (TR2) to temporarily isolate

the sensor from the circuit so that self test may be conducted without activating an alarm.

2) *Apply a minute current to the sensor*
 Activate a transistor (TR1) and apply about 1 μ A (absolute maximum rating: 5 μ A), which simulates exposure to about 1000ppm CO. This current should be applied for 2~5 seconds. If the sensor is normal, sensor current will be output and then quickly recover to its base level.

3) *Reconnect the sensor to the circuit*
 1~2 seconds after self diagnosis current is terminated (TR3 is reset), activate TR2 and reconnect the sensor to the circuit. Then current applied to the sensor will be discharged.

4) *Self diagnosis determination is carried out*
 Approx. 5 seconds after the sensor is reconnected to the circuit, if the sensor output falls within the range of 2.3 ~ 3.8V (normal output expected in 1000ppm of CO), which corresponds to 0.4 to 2 μ A of sensor current, the sensor can be judged to have normal CO sensitivity. If the sensor

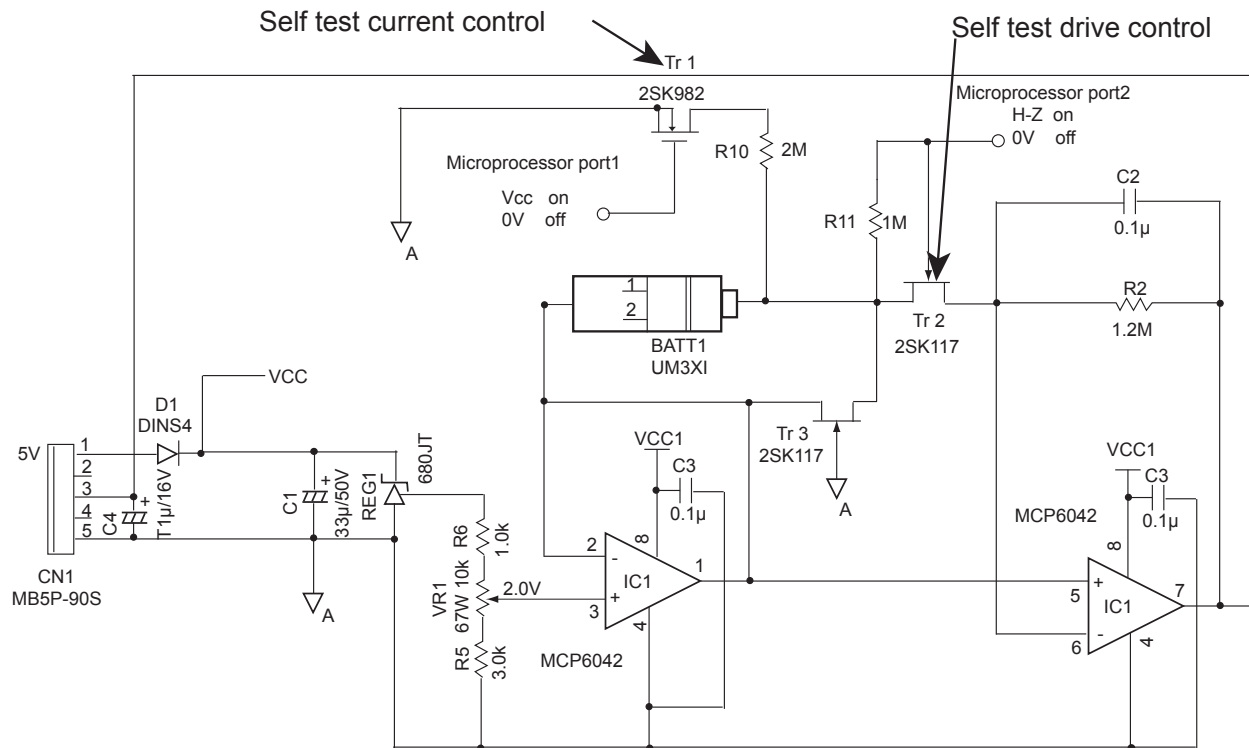


Figure 16 - Self diagnosis circuit

output is $\geq 3.8V$, the sensor is judged to be short circuited. If the sensor output is $< 2.3V$, the sensor is judged to be open circuited. Please refer to Fig. 19 (see following page) for the V_{out} pattern corresponding to each of these cases.

Note: The above V_{out} range is valid only for the circuit shown in Fig.16. When gain of amplification and/or measuring timing is different, the V_{out} range would be changed.

Sensor output recovers to its initial level about 1 minute after the sensor judgement in the step 4 above. The total self diagnosis time for Steps 1-4 is 1~2 minutes. Please note that the larger or longer current is applied to the sensor, the longer it takes to complete self diagnosis. The self diagnosis process should be carried out periodically to ensure that the sensor has sufficient CO sensitivity to afford protection.

Note:

Please restart normal operation mode when sensor output recovers to its initial level after the self diagnosis operation. The interval between self diagnosis operations should be set considering the recovery period for the sensor. If current is applied to the sensor before it can recover to its initial level, the sensor may be damaged due to overcharging.

The recommended self diagnosis interval for the circuit in Fig.16 is 180 seconds or more. To shorten the interval, it is recommended to minimize the current applied to the sensor (less current/shorter duration). However, the smaller the current, the more difficult to distinguish between normal sensors and abnormal sensors. Users should conduct a verification test using their actual circuit.

2-12 Proposed circuit using $V_{cc}=3V$

In case that the V_{cc} is +3V, the maximum gain value can obtain 0.7M-times under conditions which is described in previous section.

$$\text{Gain: } 0.69 \times 10^6 \text{ -times} = \frac{[3V-1V]}{[2.4 \times 1.2 \times 10^{-9}(V/ppm) \times 1000(ppm)]}$$

This small gain value may not meet EN50291 requirements due to the small signal resolution

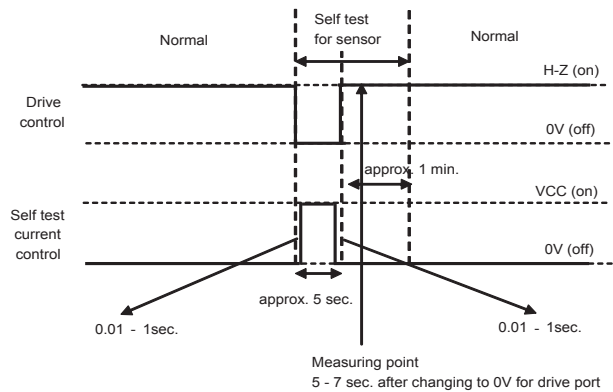


Figure 17 - Self diagnosis timing chart

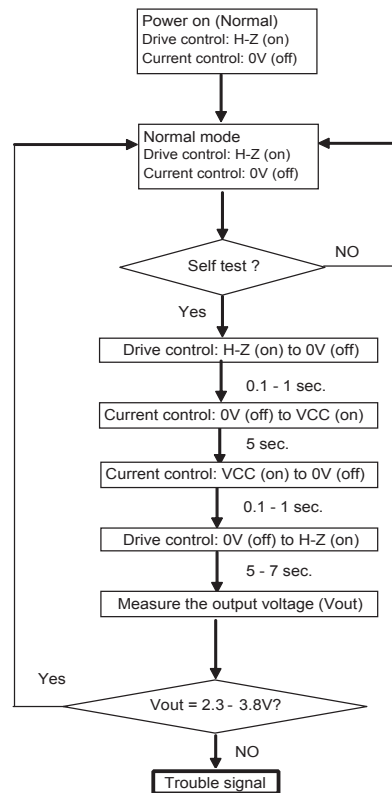


Figure 18 - Self diagnosis flow chart

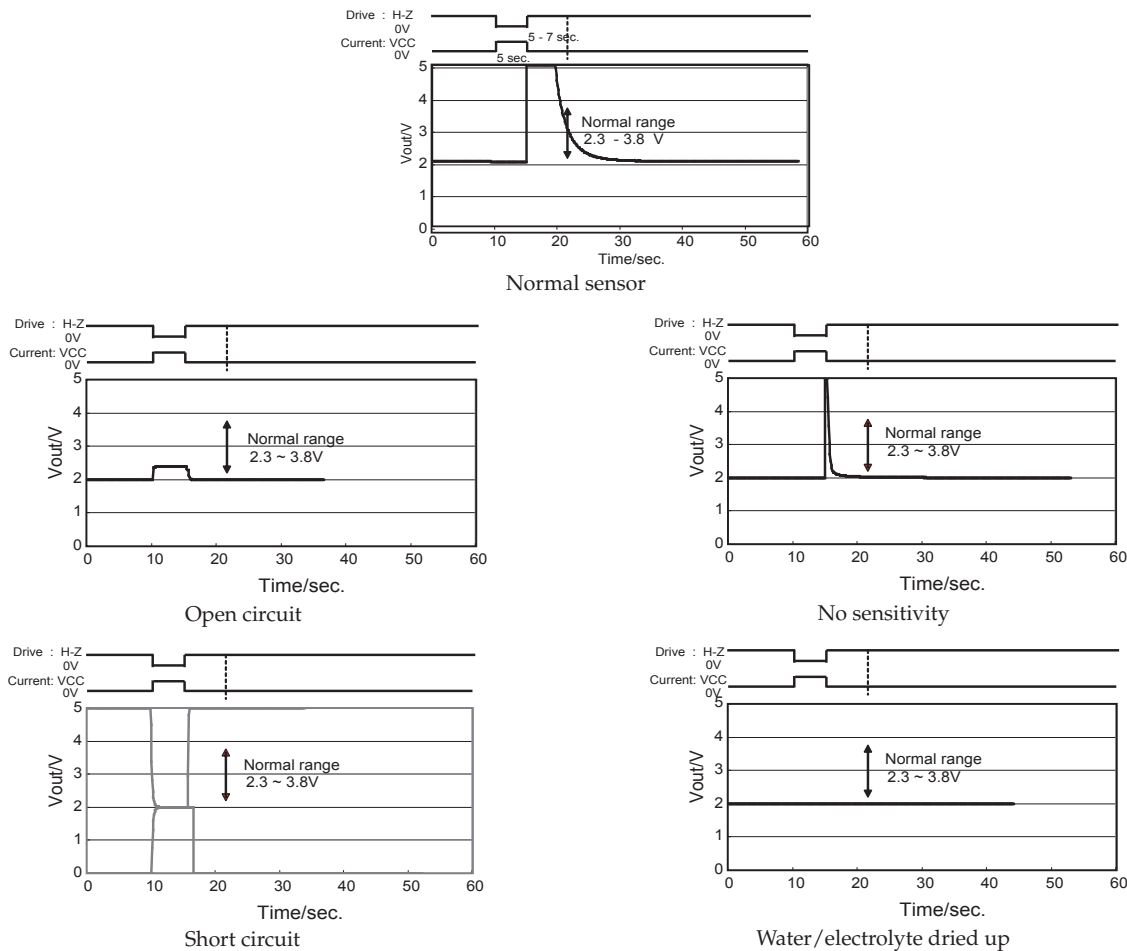


Figure 19 - Self diagnosis Vout response patterns

between 30ppm and 50ppm CO. As a solution, Figaro suggests the following three types of circuits:

1) *Gain switching circuit (Fig. 20)*

The gain value of a second amplifier (IC2) is switched by the micro controller according to the output signal of the micro controller. By setting a large gain value while the sensor is in low CO concentration range, adequate detection resolution is achieved even if Vcc is 3.0V.

2) *Opposite-baseline circuit (Fig. 10)*

In this circuit, the sensor is set up in the opposite direction (i.e. the working electrode is connected to the positive input terminal of the op-amp rather than the negative). Since the voltage between the source and gate of the JFET is fixed at 3.0V only during power-on, the JFET can make a short circuit for anti-polarization except

during the powering-on period. As a result, the acceptable detection range of sensor output falls between 0 and 3V.

3) *Change-baseline circuit (Fig. 21a)*

In the circuit shown in Figure x, the baseline and gain values can be changed according to application of voltage in V1 and V2. As shown in Figure 21b, when Vcc of 3.0V and 0V are applied to V1 and V2 respectively during a short time, the baseline of sensor output changes to lower voltage. Gain value is also increased before applying V1 and V2. Thus, by controlling both V1 and V2, a detector can achieve high detection resolution when the detector is exposed to a low concentration of CO.

2-13 *Proposed circuit for 5000ppm CO exposure test*

Most electrochemical CO sensors show very long recovery time after high CO gas exposure.

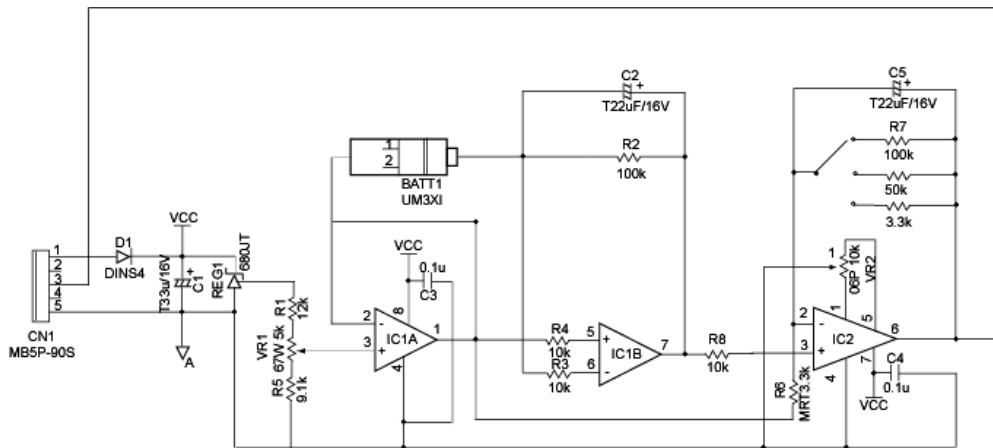


Figure 20 - Gain switching circuit

As a result, detectors cannot meet the 5000ppm CO exposure test of EN50291 (5.3.6) without some countermeasure. TGS5042 displays faster recovery time than other types of electrochemical sensors, so it may be possible to pass the test. However, if the amplified signal of the sensor exceeds Vcc (max output level of op-amp) in 5000ppm CO due to large gain, the sensor output in air after exposure of 5000ppm CO would drop below the baseline for a while (undershoot), temporarily causing reduced sensitivity to CO which may lead to failure to meet ES50291.

As countermeasure to the phenomenon of undershoot, the overflow current of the sensor should be canceled during the period when the amplified sensor signal exceeds Vcc. For example, by installing four diodes in the amplifier circuit (see Figure 22), the overflow

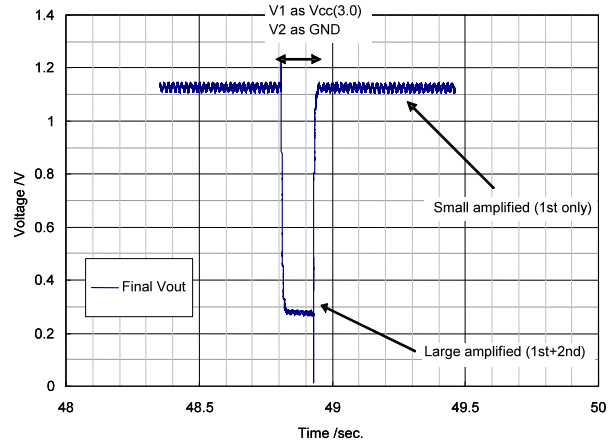


Figure 21b -Change of baseline sensor output using Vcc-3.0V on V1 and Vcc-0V on V2

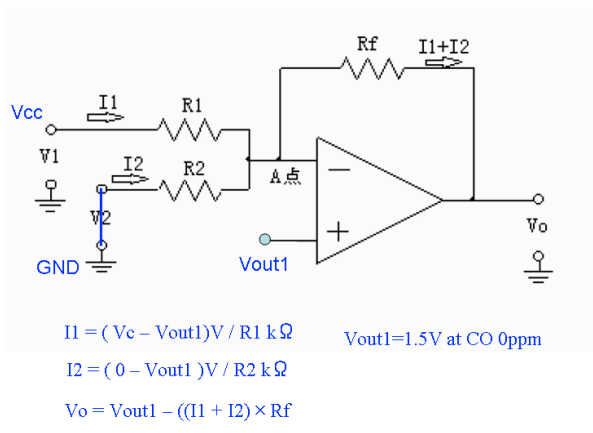


Figure 21a - Change baseline circuit

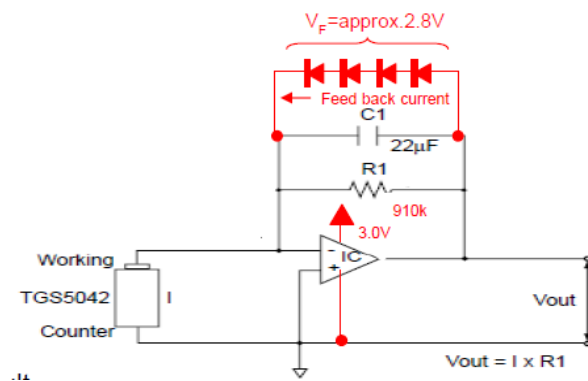


Figure 22 - Basic circuit condition using a diode

current goes back to the sensor through the diodes during the period when the amplified signal exceeds 2.8V.

Alternatively, switching the gain of the amplified output signal is also effective. Figure 23 shows a sample circuit diagram which can change the gain by using a FET.

A similar function can also be done by “Change-baseline circuit” as described in *Item 2-12.3* above. In both of these cases, Figaro recommends a gain value of 100,000 to 200,000-times when the amplified output signal is higher than V_{cc} .

3. PCB and Housing Design

3-1 Position Dependency of the Sensor

TGS5042 has no position dependency in normal usage such as in residential CO detectors. However, for applications where ambient temperature can change drastically and suddenly to less than -20°C , it is recommended that the sensor should be placed in a vertical position with the working electrode upward. If the sensor is positioned horizontally or vertically with the working electrode down, the sensor may be structurally damaged by large volume expansion if water in the reservoir freezes.

3-2 Thermistor Location

It is recommended that a thermistor is located as near to the sensor as possible in order to accurately measure ambient temperature around the sensor.

3-3 Housing Design for Quick Response

For applications where quick response is required, such as for simple CO analyzers, it is recommended that the gas inlet of the sensor be located at the detector slits or opening. It is also recommended to make a small compartment with slits in at least two sides (*see Fig.24*).

3-4 Sensor Lead Configuration

There are two lead configurations for TGS5042. The best version will depend on the user's application.

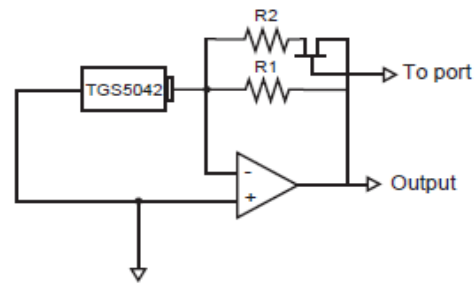


Figure 23 - Circuit for changing gain using a FET

1) Sensor compartment



2) Slits



Figure 24 - Sensor compartment design

TGS5042-A00: Sensor with SUS lead pins

The hard pins enables the sensor to be mounted directly to the PCB, simplifying the assembly process.

TGS5042-B00: Sensor with flexible nickel ribbon

The flexible nickel ribbon allows for a variety of methods for connection to the PCB. This type is also suitable for insertion into a socket. The flexible nickel ribbon may be broken by strong mechanical shock, drop, or vibration, so it is recommended that the sensor body be affixed onto the PCB by using two-sided tape or wire, for example.

4. Sensor Calibration

4-1 Calibration Using CO Gas

- 1) After powering the circuit, wait 5 minutes to stabilize sensor output in clean air (*see Note 1*)
- 2) Measure sensor output in clean air (V0) (*See Note 2*)
- 3) Inject C1ppm of CO gas
- 4) After stabilizing sensor output (e.g. 3 to 4 min), measure sensor output (V1)
- 5) Calculate sensor sensitivity α from V0 and V1 values:

$$\alpha = (V1-V0) / C1$$

Using this method, accuracy of $\pm 5\%$ can be obtained for display readings. Please note that temperature should be in the range of $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$ during the calibration process since the sensor has dependency on temperature.

Note 1: In principle, due to the nature of electrochemical cells, pre-heating before calibration is not required. However, in actual manufacturing, it is recommended to wait 5~10 min. before calibration to stabilize sensor output in the circuit.

Note 2: If CO gas is present during the zero adjustment process, a correct zero adjustment cannot be carried out. A detector should be checked in advance to verify that it generates

output corresponding to CO a concentration less than 10ppm after subtracting detector output without sensor.

4-2 Calibration Using Individual Sensor Data

Using individual data printed on sensor, which is measured at Figaro factory before shipping, can considerably simplify the calibration process. Though the expected accuracy of $\pm 15\%$ accuracy in this method is less than that for using CO gas, this method can achieve significant reduction in handling costs while achieving acceptable accuracy.

4-2-1 Input sensitivity data into microprocessor

Sensor data from the label can be read into the microprocessor in one of two ways:

- 1) Manually input the user readable value on the label, located beneath the one dimensional bar code (this value is nA/ppm and contains three decimal places).
- 2) Using a barcode reader which can read Code-128, read the one dimensional barcode and input directly to the microprocessor (this value is nA/ppm and contains three decimal places).

4-2-2 Compensation of offset voltage (zero adjustment)

To compensate for offset voltage which is created by the sensor and operational amplifier, measure the offset voltage (V0) in clean air (0ppm of CO) and write into an EEPROM or a microprocessor. This value should be read from the finished detector (after installation of sensor, op-amp, etc.).

To obtain higher accuracy, keep ambient temperature in a range of $20 \pm 10^{\circ}\text{C}$ and be sure that the ambient air is completely free of CO.

4-3 Temperature Compensation

There are two methods for temperature compensation:

- 1) *Using a microprocessor*
In case of using a microprocessor, it is necessary

to read the thermistor output and write it into the microprocessor. Inside the microprocessor, temperature compensation is carried out by using the compensation coefficient table shown in Appendix 1. Temperature compensated CO sensitivity (αt) is calculated by the following equation:

$$\alpha t = \alpha / CF$$

where: CF = compensation coefficient at certain temperature

2) Without using a microprocessor

In case of not using a microprocessor, this process can be eliminated.

4-4 Calculation of CO Concentration

CO concentration can be calculated by using sensor output (V_{out}), offset voltage (V_0), temperature compensated CO sensitivity (t), and gain (A) in the following formula:

$$C = (V_{out} - V_0) / A / \alpha t \quad \text{Equation 1}$$

Depending on the op-amp, offset voltage has a large temperature dependency as shown in Fig.25. To compensate the temperature dependency, it is recommended to make a table of offset voltage at different temperatures $V_0(T)$ in the microprocessor, and V_0 in Equation 1 should be replaced to $V_0(T)$ in Equation 1'.

$$C = (V_{out} - V_0) / A / \alpha t \quad \text{Equation 1'}$$

Actual gain (A) should be measured instead of calculated or specified at a theoretical value since such value may not be obtained in actual measurement.

Fig.26 shows basic flow chart of signal processing.

5. Manufacturing Process

5-1 Handling and storage of sensors

Prior to usage, sensors should be stored in Figaro's original sealed bag under conditions of 5~30°C, 30~80%RH, and avoiding dew condensation for a maximum period of 6 months. Do NOT use a moisture proof bag (such as an aluminum coated bag) for prevention of dew condensation. When the sensor is shipped from Figaro, the sensor is in an open circuit

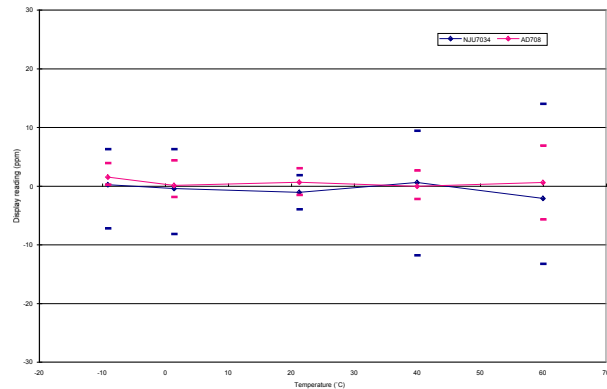


Figure 25 - Temperature dependency of offset voltage for op-amps

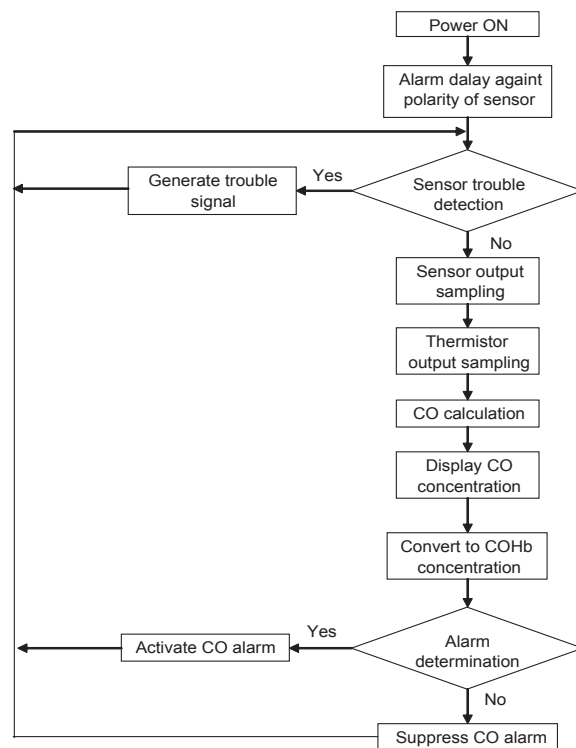


Figure 26 - Signal processing flowchart

condition, resulting in sensor polarization. The sensor will require a warm up period of about one hour to stabilize output.

5-2 PCB assembly

Flux should be sufficiently dried before sensors are assembled onto the PCB to avoid any contamination of the sensor by flux vapors.

No.	Soldering Material				Flux	
	Company	Model	Composition	Melting Temp	Company	Model
1	Solder Coat Co. Ltd.	H63E	Sn/37Pb	183°C	Tamura Kaken Corp	ULF-20 (Cl free)
2		H63E	Sn/37Pb	183°C	Asahi Chemical Research Laboratory Co., Ltd.	AGF-780R
3		H63A	Sn/37Pb	183°C	Asahi Chemical Research Laboratory Co., Ltd.	AGF-550BK
4		LLS219A-B18 (Pb free)	Sn/3.0Ag/0.5CuNi/Ge	Soldus line: 271°C Liquidus line: 221°C	Tamura Kaken Corp	EC-19S-8

Table 1 - Wave soldering materials

5-3 Sensor assembly

The sensor electrodes of model -B00 are short-circuited by the Nickel ribbon when the sensors are shipped. Before mounting the sensors on a PCB, the Nickel ribbon of model -B00 should be cut. Model -A00 is shipped in an open-circuited condition, so the sensor output should be stabilized by shorting the sensor (*refer to FAQ for advice on short-circuiting*). Both models -A00 and -B00 can be directly soldered onto a PCB.

In case the -B00 model is inserted into a socket, it is recommended to cut Ni ribbon as short as possible from the welded part. Do NOT peel away the Nickel ribbon with strong force at the working electrode side. The mechanical force may damage the sensor electrode.

The metal ribbon of the -B00 model is for electrical connection and therefore should not be used to affix the sensor to a PCB. For securing the sensor to a PCB and to prevent disconnection of the Ni leads, the sensor should be attached to a PCB using wire, two-sided tape, etc.

Recommended conditions for manual soldering:

- Temperature of soldering copper head: 380°C
- Period: < 10 sec.

Figaro has confirmed that wave soldering can be done by using the materials shown in Table 1. When different materials will be used, a test should be conducted before production starts to see if there would be any influence to sensor characteristics.

5-4 Final assembly

Avoid any shock or vibration which may be caused by air driven tools. This may cause breakage of the sensor's lead wires or other physical damage to the sensor.

5-5 Gas test

Test all finished products in the target gas under normal operating conditions. Keep the atmospheric conditions in the chamber stable, utilizing a user-defined standard test condition which is based on applicable performance standards and on anticipated usage for detectors. Remove any traces of smoke, adhesives, gases, or solvents from the chamber.

Do NOT use Nitrogen balanced CO gas. Oxygen molecules are required for the reaction of the sensor with CO (*refer to Sec. 2-Operation Principle of TGS5042 Technical Info*).

During exposure to a mixture of CO and N₂, the sensor reacts to CO by consuming oxygen molecules inside sensor. After consuming all the oxygen molecules inside sensor, the sensor will not react to CO.

Dry/bottled CO gas can be used since the sensor's humidity dependency is very small.

NOTE: Without testing after final assembly, detectors have no guarantee of accuracy or reliability.

5-6 Storage of Finished Products

Detectors should be stored in a clean air

environment at room temperature. Storage in dirty or contaminated environments should be avoided. Also, void storage in extremely low humidity--sensor life may be shortened. Please refer to *Sec. 6-Notes in TGS5042 Technical Info* for additional information.

5-7 Packaging

When a plastic clam shell is used for packaging of a CO detector, a small charcoal filter should be placed inside to avoid potential influence by organic vapors generated from the package.

Never expose the sensor to a vacuum. Sudden exposure to a vacuum may temporarily damage the sensor.

6. Quality Control

1) A sample of finished products from each production lot should be tested to confirm alarm concentration. Check whether these samples are acceptable for shipment and maintain a record of these tests.

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

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

7. Expected Performance

Considering sensor variation as well as the tolerances of electric components such as the op-amp and thermistor, display accuracy of $\pm 20\%$ can be expected when individual bar code data of TGS5042 is used for calibration. This level of accuracy may not be obtained if low quality components are used. For higher accuracy, gas calibration for each sensor is recommended.

8. Frequently Asked Questions

Q: *What approvals does TGS5042 have?*

A: The sensor has received UL2034 component recognition.

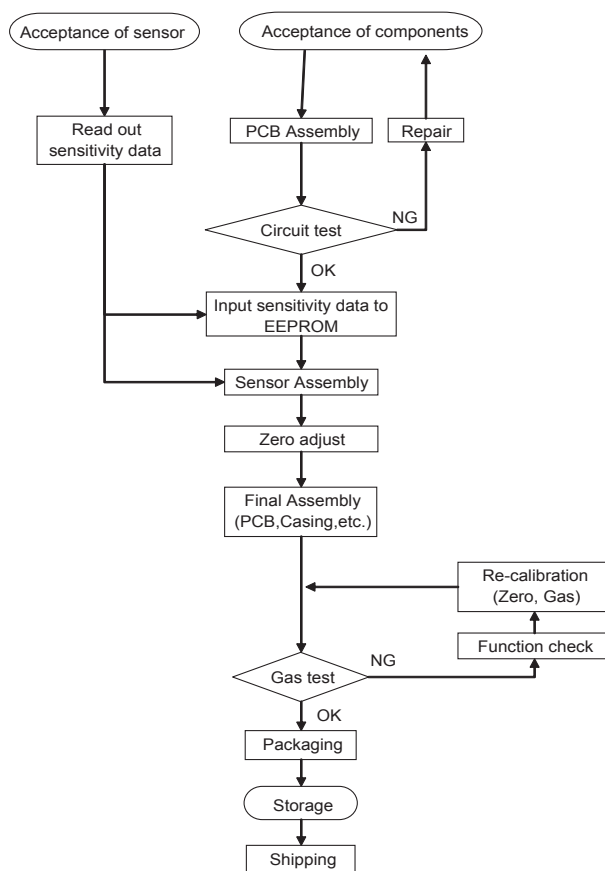


Figure 27 - Manufacturing flow chart

Q: *How long is the expected life of TGS5042?*

A: Unlike some electrochemical sensors which are short-lived, the expected sensor life is more than 10 years under normal operating condition.

Q: *Is it true that the accuracy of two-electrode electrochemical CO sensors is less than that of three-electrode type sensors?*

A: While this may be true for sensors whose electrode potentials are unstable, the TGS5042 exhibits good accuracy. With an optimized sensor structure and electrodes, TGS5042 maintains very stable electrode potentials. As a result, the sensor shows excellent long term stability, drifting by only 2% over 2000 days.

Q: *Where does CO gas enter into the sensor?*

A: There are three pin holes in the working electrode which act as a gas inlet. Refer to Figure 1 on page 2 of the *TGS5042 Technical Information*.

Q: *Does the sensor comply to RoHS restrictions?*

A: Yes.

Q: *How long does it take to stabilize sensor output after storage when the sensor electrodes are open-circuited?*

A: According to Figaro's test results, short-circuiting the sensor for one hour should be sufficient to stabilize sensor output after as much as 6 months storage in fresh air. Nevertheless, the period to reset the sensor's polarization depends on the type(s) of gases existing in ambient air, ambient conditions, storage period, and the customer's circuit. For achieving the best results, Figaro recommends that users conduct tests at their production facility to determine the optimal stabilization period for sensor output in air.

Q: *Are any special precautions needed to use TGS5042 for a simple CO analyzer?*

A: To obtain quick response, the gas inlet of sensor of the sensor should be located nearest to the detector slits or opening. For this application, TGS5042-B00 is recommended. Please cut the Nickel ribbon as short as possible and connect an insulated copper wire by soldering. In addition, it is recommended to make small compartment with slits at least in two sides around the sensor. Refer to Sec. 3-3 Housing Design for Quick Response.

Q: *How can electric noise be prevented?*

A: Since sensor impedance is 10Ω or less, the sensor itself will not be a source of electric noise. However,

the sensor is easily influenced by external electric noise since sensor output current is very small. Power-supply noise should be minimized, an anti-electrical noise circuit pattern should be made, and a CR circuit should be used to prevent influence of electrical noise.

If incoming noise is too large to be prevented by the above measures, these additional steps should be taken:

- coat the detector case with a copper board
- use anti-EMI material
- place metal mesh around the electric circuit

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Appendix 1 - Temperature Compensation Coefficients

Temp (°C)	CF (l/l ₀)	Temp (°C)	CF (l/l ₀)	Temp (°C)	CF (l/l ₀)
-40	0.453	0	0.844	40	1.105
-39	0.463	1	0.852	41	1.109
-38	0.473	2	0.861	42	1.112
-37	0.483	3	0.870	43	1.115
-36	0.493	4	0.878	44	1.118
-35	0.503	5	0.887	45	1.121
-34	0.513	6	0.895	46	1.124
-33	0.523	7	0.903	47	1.126
-32	0.534	8	0.911	48	1.128
-31	0.544	9	0.919	49	1.130
-30	0.554	10	0.927	50	1.132
-29	0.564	11	0.935	51	1.134
-28	0.574	12	0.943	52	1.135
-27	0.584	13	0.950	53	1.136
-26	0.594	14	0.958	54	1.137
-25	0.605	15	0.965	55	1.138
-24	0.615	16	0.972	56	1.139
-23	0.625	17	0.980	57	1.139
-22	0.635	18	0.987	58	1.139
-21	0.645	19	0.994	59	1.139
-20	0.655	20	1.000	60	1.139
-19	0.664	21	1.007	61	1.139
-18	0.674	22	1.013	62	1.139
-17	0.684	23	1.020	63	1.139
-16	0.694	24	1.026	64	1.139
-15	0.704	25	1.032	65	1.139
-14	0.714	26	1.038	66	1.139
-13	0.723	27	1.044	67	1.139
-12	0.733	28	1.050	68	1.139
-11	0.742	29	1.055	69	1.139
-10	0.752	30	1.060	70	1.139
-9	0.761	31	1.066		
-8	0.771	32	1.071		
-7	0.780	33	1.076		
-6	0.789	34	1.080		
-5	0.799	35	1.085		
-4	0.808	36	1.089		
-3	0.817	37	1.094		
-2	0.826	38	1.098		
-1	0.835	39	1.101		