FIGARO an ISO9001 company

Application Notes for CO Detectors using TGS5xxx Series

Figaro's TGS5xxx series electrochemical CO sensors are suitable for residential CO detectors and fire detectors, and are widely used throughout the world. This document includes important technical advice for designing and manufacturing the devices using TGS5xxx sensors. Please read carefully before designing devices using these CO sensors.

IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING ITS 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 THE SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

TGS5042, TGS5342, and TGS5141 are a UL recognized components 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.*

This document is mainly designed to address residential CO detector applications. However, these design concepts can be applied to CO detectors for Recreational Vehicles (RVs) and fire alarms/detectors as well.

1. Basic Characteristics

This document covers Figaro electrochemical CO sensors TGS5042, TGS5342 and TGS5141. Expected sensor life of these models is 10 years or longer. Please refer to Table 1 for a summary of the basic differences among these sensors. Accordingly, TGS5042/5342 are most suitable for accuracy-oriented devices, while TGS5141 is best suited for size-oriented devices.

TGS5xxx series sensors are fuel cell type electrochemical sensors with two electrodes. Sensor output current changes linearly with CO concentration. To use the sensor for CO detection, sensor current should be converted to output voltage using an Op-Amp.

	TGS5042	TGS5342	TGS5141
Size	Large	Small	Compact
Expected sensor life	10 yrs+	10 yrs+	10 yrs+
Humidity dependency	no	no	yes (within±5%)
Water reservoir	yes	yes	no

Table 1 - Sensor model comparison

2. Circuit Design

2-1 *Circuit diagram*

Fig.1 shows an example circuit for CO detectors with the following conditions:

Power source: Battery
Driving voltage: 2.5V
Anti-polarization: JFET

Using this circuit, sensor output current can be converted to output voltage (Vout). In this circuit, Vout at 0ppm CO is typically set at 2.0V (Vref), and Vout will decrease as CO concentration increases. By measuring the output voltage decrease, CO concentration can be calculated.

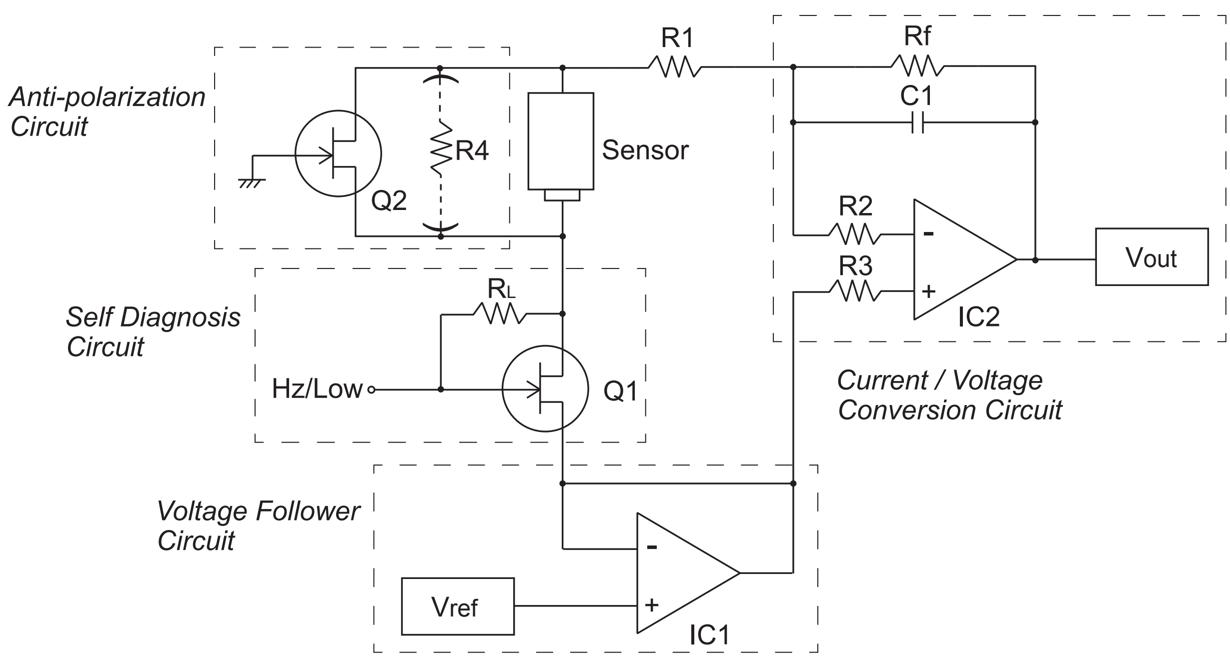

Figure 1 - Example circuit for TGS5xxx sensors

To make a circuit in which Vout increases as CO concentration increases, an inverting amplifier circuit should be added.

2-2 *Setting reference voltage (Vref)*
Since the Op-Amp used for converting sensor current to output voltage may have an offset voltage that is less than 0V, it is possible for Vout to be less than 0V if Vref would be set at 0V. Therefore, it is necessary to set Vref at a value higher than the absolute value of the offset voltage. In this example circuit, the reference voltage is set at 2V.

Although higher reference voltage increases signal resolution for CO detection, when using a battery to power the circuit, Vref should be less than the cut-off voltage of the battery (i.e. the lower-limit voltage at which battery discharge is considered complete). This should be considered as the upper limit of Vref.

Vref is also used as a switch voltage (VGS) of the JFET for anti-polarization (*see Sec 2-5*) and self diagnosis (*see Sec 2-10*). In this example circuit, Vref should be set ≥1.5V since this value is necessary for cut-off voltage VGS(OFF) between the Gate and Source of the JFET.

2-3 *Voltage follower circuit*
To prevent the possibility of Vref being influenced by other parts of the overall circuit, Voltage follower plays a role to keep Vref stable as well as to convert impedance of reference voltage.

2-4 *Anti-polarization circuit*
When stored in an open circuit condition (i.e. no connection between the working electrode and counter electrode), an electrical charge will accumulate on the electrodes. This effect is referred to as polarization. Since sensors are shipped and stored in an open circuit condition, an anti-polarization circuit as shown in Fig. 1 (using a JFET) is recommended to allow the electrodes to discharge so that sensor output will stabilize.

Instead of using the anti-polarization circuit shown in Fig.1, a fixed resistor (R4) can be used for anti-polarization. While a fixed resistor is more cost effective, it takes a longer time to discharge the sensor. Since stabilization time depends on the level of polarization, it is recommended to check stabilization time in the user's actual circuit under actual ambient conditions. Please note that the smaller the resistor value, the larger the offset voltage. The larger the resistor value, the longer the time to stabilize output.

2-5 *Current/Voltage conversion circuit*
Sensor current output is converted into voltage as shown in Fig.1. Vout is expressed by the following formula:

$$Vout = Vref - Is \times Rf + Voffset$$

Is: sensor current
Rf: feedback resistor
Voffset: offset voltage of Op-Amp

2-6 *Amplification factor (gain)*
Since the sensor's output current is very small, in order to achieve sufficient resolution for converting to output voltage, the current should be amplified by an Op-Amp.

The required amplification gain is determined by selecting Vcc, JFET, and a microprocessor in terms of sensor output range, target gas concentration, and required accuracy. The formula for determining gain is as follows:

$$Gain = (Vref - Vmax)/(Imax \times T \times Cmax)$$

where:
Vref = voltage at 0ppm
Vmax = voltage at Cmax
Imax = max. sensitivity to CO (nA/ppm)
T = Temp dependency coefficient [I(50°C)/I(20°C)]
Cmax = upper limit of CO detection range (ppm)

Please refer to Appendix 2 for temperature dependency coefficients for each sensor model.

The following is an example of how to decide amplification gain. In the following circuit conditions, it is calculated to set 520k or higher gain:

Vcc: 2.5V
Microprocessor: 10 bit
Minimum required number of bits: 4 bits
Detection range: 0~1,000ppm CO
Full scale: 1,000ppm CO
Sensor output at 0ppm CO: +2V
Sensor output at 1,000ppm CO (Vmax): 0V
Max. sensor current of TGS5141 (Imax): 3.2nA/ppm
Temperature dependency of TGS5141:
I(50°C)/I(20°C) = 1.225 (*refer to Sec 6-3*)

Gain = (2.0V – 0V) / (3.2nA x 1.2 x 1,000ppm) = 520k

In case the minimum required is 4 bits, resolution will be 3.9ppm.

$$\text{Resolution} = \text{Cmax} / 2^{M} \times \text{Bmin}$$

where:
Cmax = maximum target CO concentration
M = Number of bits in microprocessor
Bmin = Minimum number of bits required

$$1000\text{ppm} / 2^{10} \times 4 = 3.9\text{ppm}$$

With 520k or higher amplification gain, enough signal resolution can be obtained to pass EN50291 (i.e. to distinguish between 36ppm and 50ppm).

2-7 *Operational amplifier (Op-Amp)*
A rail to rail Op-Amp is recommended for usage. Depending on the balance among power consumption, accuracy, and electric noise, a suitable Op-Amp for devices should be selected. The following Op-Amps are recommended by Figaro: MCP6042, MCP617 (Microchip), TSV914 (STMicroelectronics).

2-8 *Electrical noise prevention*
Since sensor current is very small and amplification gain is large, the sensor is easily influenced by external electrical noise. As a result, it is necessary to implement measures to minimize electrical noise in the circuit pattern, power supply, etc.

There are three options as a countermeasure for electrical noise:
1) Use an electric noise filter
2) Use a voltage follower circuit
3) Use an RC circuit for power input, output, and amplification of the Op-Amp.

Specifically, by increasing the values of C1 and/or R1 in Fig.1, influence by electric noise can be reduced. However, response speed will become slower as C1/R1 increases, so it is necessary to decide the C1 or R1 value considering the balance between electric noise levels and response speed.

If incoming noise is too large to be prevented by the above measures, additional countermeasures can be taken:
* Use a microwave absorber sheet
* Protect metallic shielding over the electronic circuit

2-9 *Technique for passing 5000ppm CO exposure test*
Most electrochemical CO sensors have long recovery time after exposure to high CO gas concentration. As a result, detectors using them cannot pass the 5000ppm CO exposure test of EN50291 (5.3.6) without some countermeasure. When amplified sensor output exceeds the Vcc of the Op-Amp after exposure to 5,000ppm CO, sensor output in air will show a lower voltage than Vref for a while (this phenomenon is referred to as ‘undershoot’). As a result, sensitivity to CO temporarily is decreased, resulting in non-conformity to EN50291.

As a countermeasure to undershoot, two methods can be suggested:
1. Amplify by two steps
The first amplification gain is set so that sensor output does not exceed the Vcc of the Op-Amp. The second amplification gain is set to have enough signal resolution.
2. Switch amplification gain depending on sensor output (*see Fig. 2*)

2-10 *Self diagnosis circuit*
Self diagnosis is a safety measure required by the UL2034 standard to detect a sensor malfunction. Figaro’s self diagnosis circuit checks for malfunction of 5xxx-series sensors by using the capacitance of the sensor. By activating JFET Q1 (*see Fig. 1*), the sensor is disconnected from the amplification circuit, and at the same time, an electric charge is applied to the sensor

by an external power supply. By measuring the discharged pattern, sensor malfunction can be judged.

Sensitivity to CO can be lost due to wire breakage, short circuit, or if the sensor's water reservoir (if applicable) were to dry up. These type of malfunctions can be detected via self diagnosis. 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--this technique is intended to detect catastrophic failure of CO sensing.

Precaution for designing a circuit

Depending on the component values in the circuit, negative feedback control of the op-amp during self diagnosis may not work properly, resulting in the difference of Vref between operating conditions and self diagnosis. The Vref change may cause sensor performance damage due to direct application of voltage to the sensor. To avoid the difference of Vref in between operating conditions and self diagnosis, it is necessary to set Vref, Vc and Rf so that their values meet the following equation:

$$Vref/RL < (Vcc(VOH) - Vref)/Rf$$

The basic steps of self-diagnosis are:

1) *Temporarily cut the sensor off from the circuit and apply a current*

Activate a transistor (Q1) and apply a minute current to the sensor for a certain period (e.g. 1µA for 5 sec.). Please decide current value and the current flow period so as not to exceed 10µC of accumulated electric charge:

(electric charge = current x current flow period)

2) *Reconnect the sensor to the circuit*

At the completion of the current flow period, deactivate Q1 and reconnect the sensor to the circuit. Then current applied to the sensor will be discharged.

3) *Self diagnosis determination is carried out*

By measuring the output voltage level after reconnecting the sensor to the circuit, self

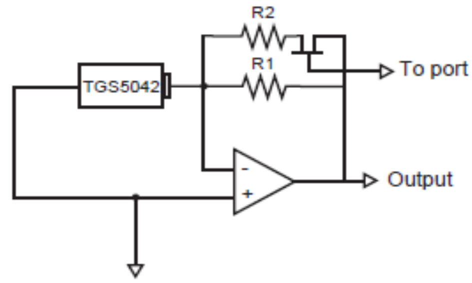

Figure 2 - Circuit for changing gain using a FET

diagnosis determination can be carried out. By observing the output level, the circuit can distinguish between normal sensors and abnormal sensors as follows:

<u>Normal sensors</u>:

Vout drops lower than 1.5V and recovers to its initial level (Vref) after discharging the charged current.

<u>Short and open sensors</u>:

Vout shows similar level to initial level (Vref) since current is not charged in Step 1 of the self-diagnosis procedure.

To then distinguish between short and open sensors, it is recommended to measure Vout at Step 1 of the self diagnosis procedure.

short sensors: Vout = Vcc
open sensors: Vout ≈ Vref

<u>Sensors with water reservoir dried up (5042/5342)</u>:

In low ambient humidity:

Vout ≈ Vref

In other ambient humidities:

Vout drops and recovers to Vref

(*Vout drop is smaller than for normal sensors*)

Please note that the above voltage level is based on the circuit shown in Fig.1.

Since output level depends on the customer's circuit design, please decide the judgment level according to the circuit. A sample sensor with a dried up water reservoir is available upon request for users to conduct such a test.

Sensor output recovers to its initial level about one minute after sensor judgment in Step 3 of

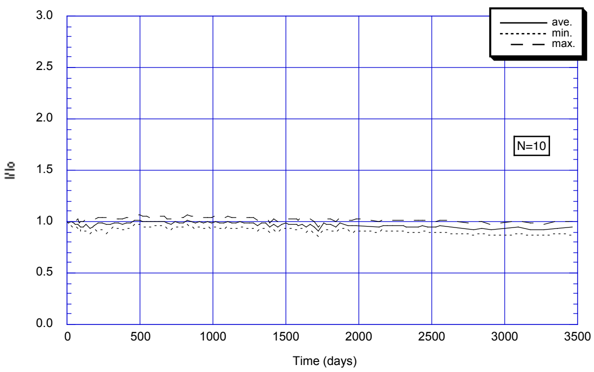

Figure 3 - Typical long term stability of TGS5042

the self diagnosis procedure. Please note that the larger/longer current is applied to the sensor, the longer it takes to complete self diagnosis.

***Note*:**
Please restart normal operation mode when sensor output recovers to its initial level (Vref) 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. 1 is 180 seconds or more. To shorten the interval, minimize the current applied to the sensor (less current/shorter duration). However, the smaller the current, the more difficult it will become to distinguish between normal sensors and abnormal sensors. Users should conduct a verification test using their actual circuit.

3. Compensation of Long Term Drift

Fig. 3 shows typical long term stability data. Electrochemical CO sensors tend to show decreased sensitivity over time. For better accuracy, long term drift can be compensated. Please consult Figaro for further details.

4. PCB and Housing Design

4-1 *Position dependency of the sensor*

TGS5141 has no position dependency since the sensor does not have any liquid inside. On the other hand, TGS5042 and 5342 have a water reservoir. While these sensors have no position dependency in normal usage such as in residential CO detectors, 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 in case the water in the reservoir freezes quickly.

4-2 *Thermistor location*

A thermistor should be located as near to the sensor as possible in order to accurately measure ambient temperature around the sensor.

4-3 *Housing design for quick response*

For applications where quick response is required, such as simple CO analyzers, the gas inlet of the sensor should be located at the detector slit/opening. A small compartment with slits in at least two sides to promote airflow is also recommended. Refer to Fig. 4 for an example of suggested housing design.

5. Packaging Design

The sensor may be susceptible to poisoning by out-gas from packing materials. For example, certain printing inks and insufficiently cured plastics may emit vapors that could adversely

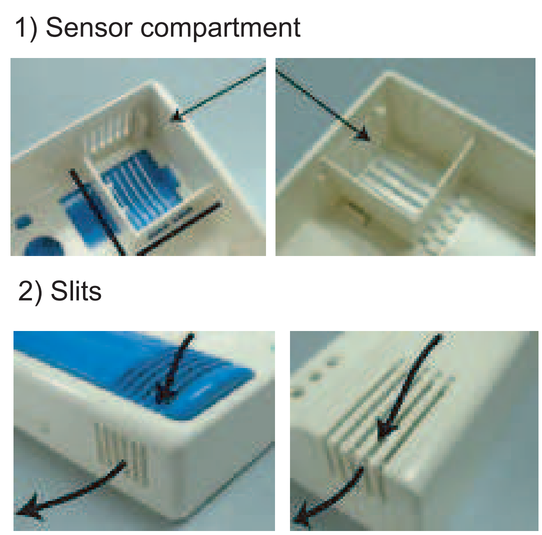

Figure 4 - Sensor compartment design

affect sensitivity. Be sure that all printing inks and plastics (especially styrene) are completely cured prior to usage. In addition, since dew condensation may take place inside the TGS5042/5342 sensors, inhibiting its ability to sense CO, it is recommended that any bag in which the detector is placed should NOT be sealed. Ideally, packages should be designed so that ambient air can diffuse into the detectors. As an additional precaution, a charcoal bag may be placed inside packaging materials to protect from the effects of out-gassing from packaging materials.

A storage test should be conducted with final packaging by the detector maker to determine if the sensor is damaged/influenced by packaging.

6. Calibration

6-1 *Calibration Using CO Gas*

1) After powering the circuit, wait 5 minutes to stabilize sensor output in clean air

2) Perform the zero adjustment process by measuring sensor output in clean air (V0) (*see Note 1 below*)

3) Inject C1ppm of CO gas

where: C1 = target concentration of CO

4) After stabilizing sensor output (e.g. 3~4 min), measure sensor output (V1)

5) Calculate sensor sensitivity α from V0 and V1 values:

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

Using this method, accuracy of ±5% can be obtained for display readings. Please note that temperature should be in the range of 20˚C±2˚C during the calibration process since the sensor has dependency on temperature.

<u>Note 1</u>: 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 a CO concentration less than 10ppm after subtracting detector output without sensor.

6-2 *Calibration using sensor barcode data*

Using individual data printed on sensor, which is measured at Figaro's factory before shipping, can considerably simplify the calibration process. Though the expected accuracy is less than that for calibrating with CO gas, this method can achieve significant reduction in handling costs while achieving acceptable accuracy. Subject to adjustment due to variation in environmental conditions, on average, calibration using barcode data would yield accuracy of approx. ±15%.

6-2-1 *Sensor Marking*

The barcode shown on the sensor body (*see Appendix 1*) contains the following individual sensor data:

One dimensional bar code:
xxxx
Two-dimensional barcode:
xxxxYYMMDDnnnnnnnnnnnnnnnnn

where:
xxxx = sensor's sensitivity (slope) numeric value (e.g. 1827=1.827nA/ppm)
YYMMDD = sensor's sensitivity measuring date in year/month/date format (*see Appendix 1*)

6-2-2 *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 printed on the sensor body.

2) Using a barcode reader (*see Appendix 1*), read the barcode and input directly to the microprocessor.

6-2-3 *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 this value into an EEPROM or microprocessor. This value should be read from the finished detector (i.e. after installation of sensor, op-amp, etc.).

To obtain higher accuracy, keep ambient temperature in a range of 20±10°C and be sure that the ambient air is completely free of CO.

6-3 *Temperature compensation*
It is necessary to continuously write the thermistor output into the microprocessor. Inside the microprocessor, temperature compensation is carried out by using the compensation coefficient table shown in *Appendix 2*. Temperature compensated CO sensitivity (αt) is calculated by the following equation:

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

where: CF = compensation coefficient at certain temperature

6-4 *Calculation of CO concentration*
CO concentration (C) can be calculated by using sensor output (Vout), offset voltage (V0), temperature compensated CO sensitivity (t), and gain (A) in the following formula:

$$C = (Vout-Vo)/A/\alpha t \quad [\textit{Equation 1}]$$

Depending on the op-amp, offset voltage has a large temperature dependency as shown in Fig. 5. To compensate temperature dependency, it is recommended to make a table of offset voltage at different temperatures Vo(T) in the microprocessor, and Vo in Equation 1 should be replaced by Vo(T) in Equation (1'):

$$C = (Vout-Vo(T))/A/\alpha t \quad [\textit{Equation 1'}]$$

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. 6 shows a basic flow chart of signal processing.

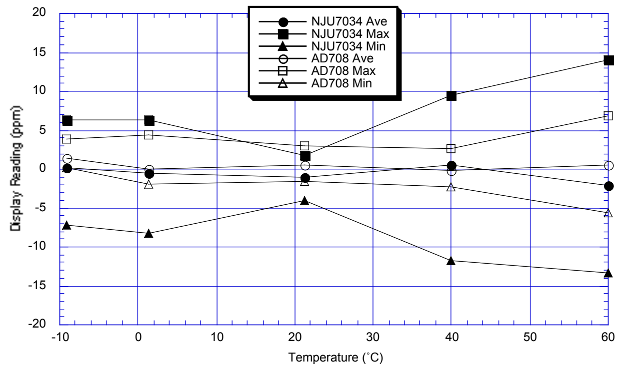

Figure 5 - Temperature dependency of offset voltage for op-amps

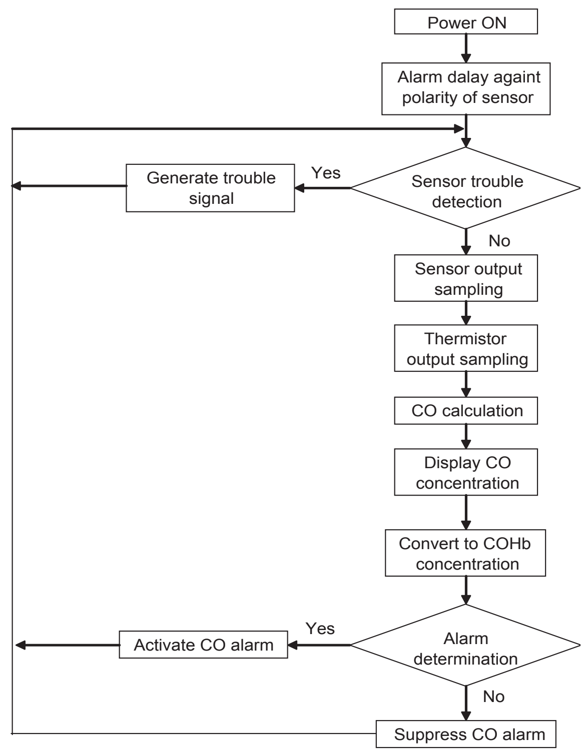

Figure 6 - Signal processing flowchart

7. Manufacturing Process (Fig. 7)

7-1 *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. Dew condensation should be avoided. Sensors should be stored for a maximum period of 6 months. Sensors with a water reservoir (TGS5042/5342) should NOT be stored in a moisture-proof bag (such as an aluminum coated bag) to prevent dew condensation.

7-2 *PCB assembly*
Flux should be sufficiently dried before sensors are assembled onto a PCB to avoid any contamination of the sensor by flux vapors.

7-3 *Sensor assembly*
The sensor is shipped from Figaro in an open circuit condition, causing sensor polarization. As a result, the sensor requires a period during which it is shorted in order to remove the effects

No.	Soldering Material				Flux	
	Company	Model	Composition	Melting Temp	Company	Model
1	Solder Coat Co. Ltd.	LLS 219	Sn/3.0Ag/0.5Cu	Soldus line: 217˚C Liquidus line: 219˚C	Koki Company Limited	JS-E-11
2	Nihon Genma Mfg. Co., Ltd.	NO303T H B20	Sn/3.0Ag	Soldus line: 221˚C Liquidus line: 223˚C	Tamura Corporation	EC-19S-8
3	Koki Company Limited	S3X	Sn/3.0Ag/0.5Cu	Soldus line: 217˚C Liquidus line: 219˚C	Koki Company Limited	JS-E-15X

Table 2 - Wave soldering materials

of polarization (*please refer to Sec. 2-4 for more detail*).

All models can be directly soldered onto a PCB. Recommended conditions for manual soldering:

Temperature of soldering copper head: 360°C
Period: < 5 sec.

Figaro has confirmed that wave soldering can be done without adverse effect by using the materials shown in Table 2. When different materials will be used, a test should be conducted before production starts to see if there would be any influence on sensor characteristics.

7-4 *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.

7-5 *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 Technical Info for TGS5042, TGS5342, and TGS5141*). If exposed to a mixture of CO and N_2, the sensor reacts to CO by consuming oxygen molecules inside the 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.*

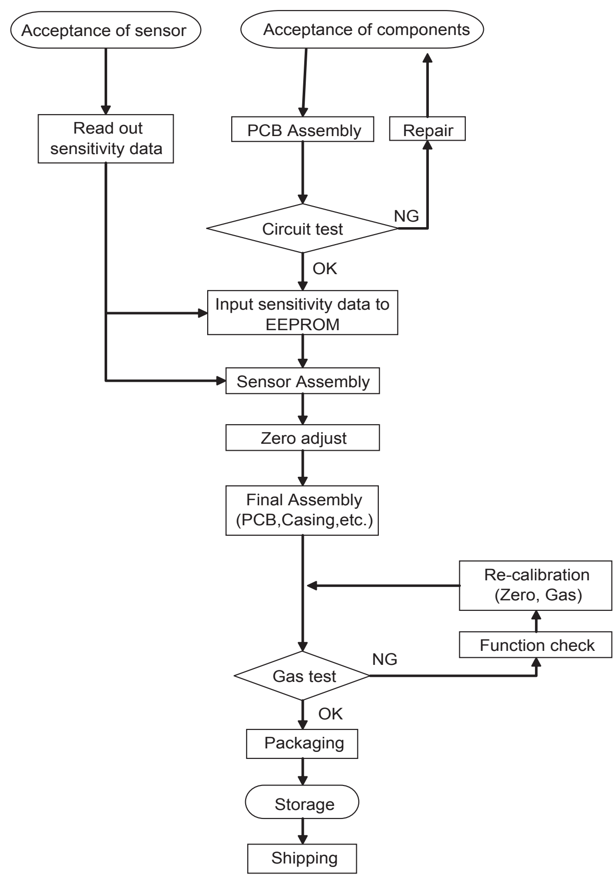

Figure 7 - Manufacturing flow chart

7-6 *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, avoid storage in extremely low humidity--sensor life may be shortened. Please refer to *Sec. 6-Cautions* in *Technical Info for TGS5042, TGS5342, and TGS5141* for additional information.

7-7 Packaging
Never expose the sensor to a vacuum. Sudden exposure to a vacuum may temporarily damage the sensor. Be sure to follow the precautions detailed in *Sec. 5--Packaging Design*.

8. 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 to confirm their long-term characteristics and maintain a record of such tests.

9. Frequently Asked Questions
Q: *What approvals do Figaro CO sensors have?*
A: All TGS5xxx series sensors have received UL2034 component recognition.

Q: *Is it true that long term stability 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, Figaro CO sensors exhibit good accuracy. With an optimized sensor structure and electrodes, the sensors maintain very stable electrode potentials. As a result, the sensor shows excellent long term stability.

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 Fig.1 on page 2 of *TGS5042/5342/5141 Technical Information*.

Q: *How long does it take to stabilize sensor output after storage when the sensor electrodes are open circuited?*
A: The stabilization period depends on the degree of polarization. For example, if sensors are exposed to 100ppm CO for 10 min. while in open circuit condition, when using a JFET for anti-polarization, it takes about 5 min. of short circuit condition to discharge the sensor short.

In case of using a fixed resistor for anti-polarization, depending on the resistor's value, the stabilization period will vary. It is recommended to monitor sensor output within the actual circuit for stabilization, since the time required depends on stabilization period for both the CO sensor as well as the circuit itself.

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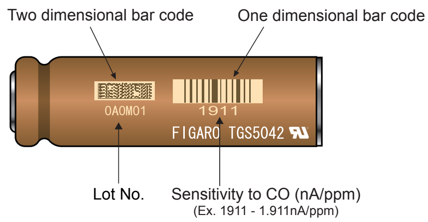
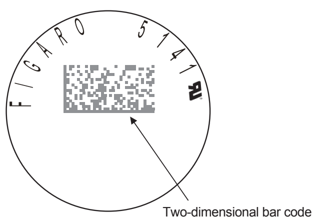
Appendix 1 - Sensor Marking

<table>
<tr><th>Sensor</th><th>Marking</th></tr>
<tr><td>
</td><td>1. One dimensional bar code (see Note 1)
2. Two dimensional bar code (see Note 2)
3. User readable format
* 6-digit Lot Number is printed below the two dimensional bar code (YYMMDD) (see Note 3)
* Sensitivity per ppm (nA) is printed below the one dimensional bar code
(e.g. 1827=1.827nA/ppm)</td></tr>
<tr><td>
</td><td>1. One dimensional bar code (see Note 1)
2. User-readable format
* 10-digit Lot Number is printed above the bar code (YYMMDDAAAA) (see Note 3)
* Sensitivity per ppm (nA) is printed below the one dimensional bar code
(e.g. 1827=1.827nA/ppm)</td></tr>
<tr><td>
</td><td>1. Two-dimensional bar code (see Note 2)</td></tr>
</table>

<u>**Note 1**</u>: The one dimensional bar code indicates the sensor's sensitivity (slope) in numeric value as determined by measuring the sensor's output in 300ppm of CO:

xxxx = x.xxx nA/ppm

<u>**Note 2**</u>: The two-dimensional bar code indicates:

xxxxYYMMDDnnnnnnnnnnnnnnnnnn

where:
xxxx = sensor's sensitivity (slope) in numeric value by measuring sensor output in CO 300ppm
(e.g. 1827=1.827nA/ppm)
YYMMDD = sensitivity measuring date in year-month-day format
(e.g. 150401 = April 1, 2015)
nnnnnnnnnnnnnnnnnn = 18-digit manufacturer's serial number

<u>**Note 3**</u>: User readable Lot Number indicates:

YYMMDDAAAA

where:
YYMMDD = sensor's sensitivity measuring date in year-month-day format. Refer to Table 3 below for month coding.
(e.g. 150D01=April 1st, 2015)
AAAA = 4-digit manufacturer's serial number

Example barcode readers:
TGS5042/5342: KEYENCE: SR-D100H
TGS5141:
KEYENCE: SR-G100, SR-1000,
SIEMENS: MV320, MV325, MV440
DATALOGIC: PowerScan 9500 DPM
Smart phone application:
i-nigma (iPhone)
Barcode Scanner (Android)

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Code	0A	0B	0C	0D	0E	0F	0G	0H	0J	0K	0L	0M

Table 3 - Month coding conversion table

Appendix 2 - Temperature Compensation Coefficients

Temp (˚C)	CF (I/Io)		Temp (˚C)	CF (I/Io)	
	TGS5042/5342	TGS5141		TGS5042/5342	TGS5141
-10	0.752	0.6745	30	1.060	1.0750
-9	0.761	0.6854	31	1.066	1.0825
-8	0.771	0.6963	32	1.071	1.0900
-7	0.780	0.7072	33	1.076	1.0975
-6	0.789	0.7181	34	1.080	1.1050
-5	0.799	0.7290	35	1.085	1.1125
-4	0.808	0.7399	36	1.089	1.1200
-3	0.817	0.7508	37	1.094	1.1275
-2	0.826	0.7617	38	1.098	1.1350
-1	0.835	0.7726	39	1.101	1.1425
0	0.844	0.7835	40	1.105	1.1500
1	0.852	0.7944	41	1.109	1.1575
2	0.861	0.8053	42	1.112	1.1650
3	0.870	0.8162	43	1.115	1.1725
4	0.878	0.8271	44	1.118	1.1800
5	0.887	0.8380	45	1.121	1.1875
6	0.895	0.8489	46	1.124	1.1950
7	0.903	0.8598	47	1.126	1.2025
8	0.911	0.8707	48	1.128	1.2100
9	0.919	0.8816	49	1.130	1.2175
10	0.927	0.8925	50	1.132	1.2250
11	0.935	0.9034			
12	0.943	0.9143			
13	0.950	0.9252			
14	0.958	0.9361			
15	0.965	0.9470			
16	0.972	0.9579			
17	0.980	0.9688			
18	0.987	0.9797			
19	0.994	0.9906			
20	1.000	1.0000			
21	1.007	1.0075			
22	1.013	1.0150			
23	1.020	1.0225			
24	1.026	1.0300			
25	1.032	1.0375			
26	1.038	1.0450			
27	1.044	1.0525			
28	1.050	1.0600			
29	1.055	1.0675			