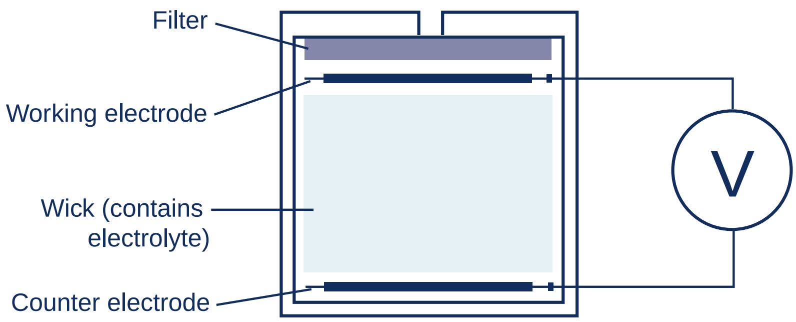
1.0 Operating Toxic Gas Cells

1.1 Two or Three Electrodes?

All Sixth Sense cells for toxic gas detection are based on electrochemical principles and can be classified as amperometric fuel cells.

The simplest form of electrochemical cell is a ‘two-electrode’ design and consists of a semi-permeable diffusion membrane, a reservoir of acid electrolyte, a sensing electrode and a counter electrode (see figure 1). The electrodes are generally a PTFE substrate coated with a catalytic mixture, usually platinum, which significantly accelerates the gas reaction. In most cases, gas diffusing into the cell reacts at the surface of the sensing electrode producing, as a by-product, a number of ions (H+) and electrons (e-). The ions travel through the acid electrolyte to the counter electrode whilst the negatively charged electrons travel to the counter electrode via the external circuit. Combining the electrons and ions at the counter electrode completes the reaction without any of the cells components being consumed. The amount of electrons produced by the reaction is directly proportional to the amount of gas present and measuring the current flowing through the external circuit is a basic gas monitor.

Figure 1 Two - Electrode Sensor



Working: $2CO + 2H_20 \longrightarrow 2CO_2 + 4H^+ + 4e^-$

Counter: $4H^+ + 4e^- + 2O_2 \longrightarrow 2H_20$

This approach harnesses the benefits of electrochemical principles - a linear, stable, repeatable output over long periods, at a reasonable cost. This has proven extremely popular in the domestic/residential carbon monoxide alarm and the commercial fire detection markets. Through automation of the manufacturing process, Sixth Sense manufacture in excess of 1 million units per year and our sensors can be supplied in volume and at a competitive price. With only two electrodes, the drive circuitry is simple and low cost, lending itself to high volume manufacture for the consumer market.

However, the two-electrode approach may not meet the requirements of all gas monitoring markets. For an electrochemical sensor to work at optimum efficiency, the potential of the electrodes needs to change in order to optimise the catalytically assisted oxidation and reduction reactions. This can be demonstrated by connecting a two-electrode device across a load resistor and applying gas. The measured potential of the sensing and counter electrodes will change in opposite directions. However, in operation it is necessary to use an operational amplifier in the circuit. In use, this will attempt to keep both electrode potentials the same and therefore the sensor cannot operate at maximum efficiency. In very high levels of gas, the potential of both electrodes will become slightly negative. This optimises the reaction at the counter electrode but limits the activity of the sensing electrode, which ultimately results in a non-linear signal. The point at which the sensor becomes non-linear is defined on the data sheets as the "maximum overload".

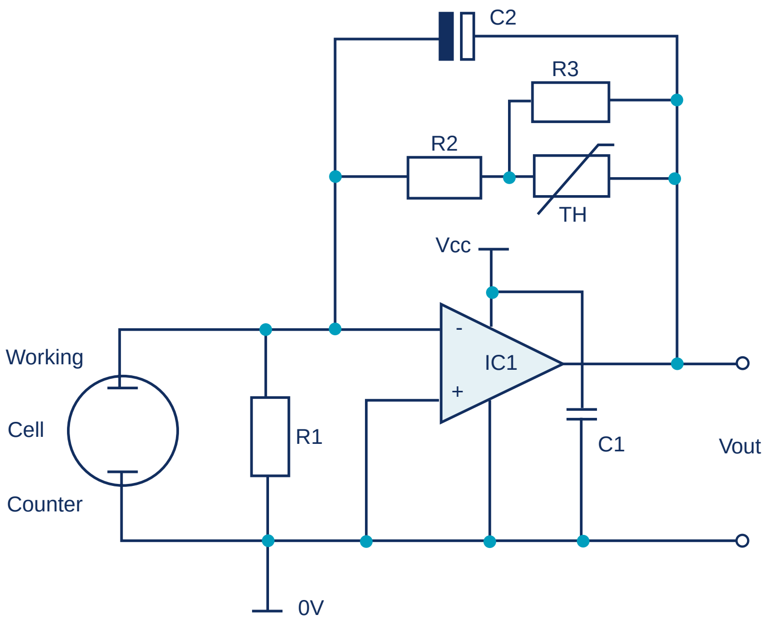
All electronic components have an operating tolerance and therefore do not work perfectly all of the time. As such, whilst an OpAmp is designed to maintain a zero potential difference between its inputs, in extreme situations there can be a minor difference. Since the two electrode potentials of a sensor try to move in opposite directions during operation, it is possible for the sensor to polarise very slightly (+/- 3-4mV). This can occur after long periods in high gas concentrations and when the gas is removed the sensor will be slightly unstable until such time as the sensor has de-polarised. Depending on the degree of polarisation, this recovery period can be a number of hours.

The combined result is that the two-electrode sensors are normally restricted to use where low levels of gas are being monitored and/or where the finished product is alarm only and operates in a "latched mode". For other applications, mainly in the industrial sector, a three-electrode sensor is recommended. In this case a third (reference) electrode is added. This is held in an environment in which it will not see gas and therefore plays no part in the reduction/oxidation reactions in the sensor. As such the reference electrode will maintain constant potential. In operation, the measurement is taken between the sensing and the reference electrodes, allowing the potential of the counter electrode to change as necessary without affecting that of the working electrode. Therefore, the performance of a three-electrode sensor is more efficient and generally they will have a higher output than that of a two-electrode device and can be used to monitor a wider range of gas concentrations.

1.2 Operating Circuits for Two-Electrode Sensors

For most applications using two-electrode sensors, neither the absolute resolution nor the response time is overly critical. It is therefore possible to use lower cost components in the drive circuitry.
The basic circuit is a current to voltage converter with a permanent load resistor across the two sensor electrodes to prevent polarisation during an un-powered period. An example of this is shown in figure 2.
For gases that are oxidised at the working electrode the output from the circuit will be **positive** and for gases that are reduced, the output will be **negative**.

Figure 2 Two - Electrode Circuit



Recommended values:		
R1	=	10k
R2	=	120k
R3	=	100k
TH	=	Thermometrics DKF503
C1	=	100nF
C2	=	22uF
IC1	=	TLC27L2

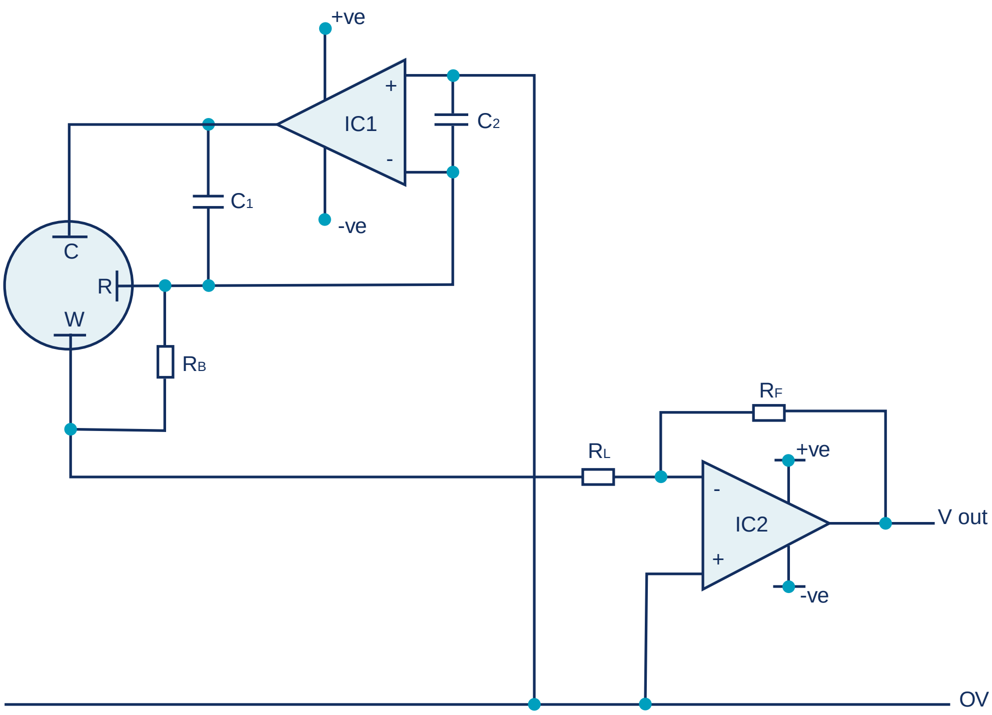
This circuit uses a low-cost OpAmp with an input offset voltage of 10mV and therefore a high value for R1 is required to ensure an acceptable zero offset from the OpAmp output. Whilst this does not affect the response time of the circuit, it will exhibit a longer stabilisation period.

For applications where this is not acceptable or where a higher resolution is required, such as fire detection, a number of changes can be made to improve the overall performance. Firstly it is possible to use a different OpAmp with a lower input offset voltage such as an OP90 with a typical offset voltage of 150uV. The value of R1 can then be lowered significantly and the final value can be set depending on the precise requirements for the maximum zero offset that can be accommodated. In practise R1 could be removed altogether and replaced with a J-FET (eg. J177). This allows optimum performance but ensures that the electrodes are shorted when the circuit is un-powered. To further improve the stabilisation of the circuit, it is possible to include a 10-20 Ohm resistor between R1 and the negative input of the OpAmp. This slightly increases the response time, but the affect is negligible and the circuit output will be more stable.

1.3 Operating Circuits for Three-Electrode Sensors

Most applications using three-electrode sensors require higher resolution, faster response time and rapid stabilisation. For these reasons we recommend a dual-OpAmp circuit that combines performance and flexibility. A suitable circuit is shown in figure 3. For a specific type of sensor, the circuit can be optimised for use with a full range of gas types. One example of this is the MICRO range and an optimised variation of the standard circuit is shown in figure 4.

Figure 3 Standard Three - Electrode Circuit



- V_{OUT} = Gas Conc x Cell Output x R_F
  - If R_F is 100k, cell output is 50nA/ppm and gas concentration is 100ppm then
  $V_{OUT} = 100 \times (50 \times 10^{-9}) \times (100 \times 10^{3}) = 0.5V$

- Output is positive for oxidising sensors (CO & H_2S) and negative for reducing sensors (CL_2).
  If it is necessary for all outputs to be positive, please contact Sixth Sense for advice

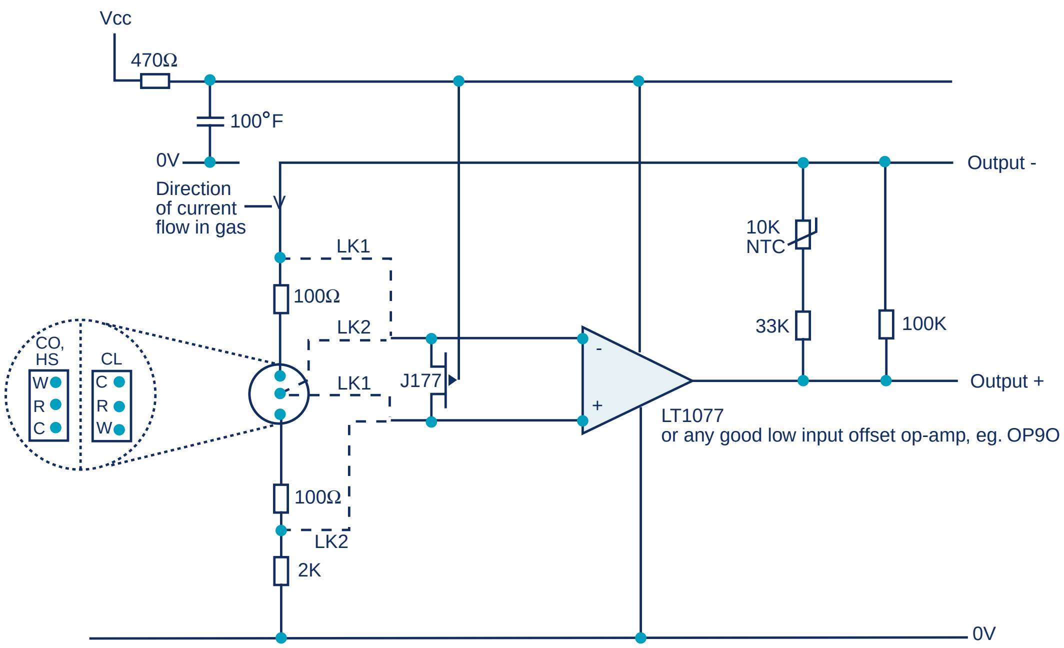
- R_L is the cell load resistor (typically 5-50Ω). A small value of R_L will increase noise, but give a faster speed of response; and vice versa. Sensor data sheets provide recommended values for each sensor

- Amplifiers are precision low input offset types, eg. OP90 or similar

- C_1 and C_2 help to reduce sensor signal noise and EMC susceptibility.
  Typical values are C_1 4.7nF and C_2 47pF

- R_B stops the sensor polarising when the circuit is powered off (typically 1-10k). This can be replaced with a J-FET (eg. J177).
- Some sensors require temperature compensation circuitry (eg. CO). A simple compensation network can be incorporated into this circuit by replacing R_F.
- Some sensors, eg. CO_2, require a small bias voltage across their electrodes. For information on this type of circuit, please contact Sixth Sense

Figure 4 Micro Circuit



- LK1 used for positive output sensors (CO & H_2S)
- LK2 used for negative output sensors (CL_2)

1.4 Environmental Conditions

Most electrochemical sensors exhibit a small change in output due to changes in environmental conditions. In most applications, these are unnoticeable and can be ignored, but where greater measurement resolution is required, simple compensation can be incorporated into the drive circuit. Typical effects are:

- **Pressure** - most Sixth Sense products are 'partial-pressure' sensors and therefore the diffusion rate of the target gas will change in line with ambient pressure. Therefore there can be a perceived change in sensor output. This is typically less than $\pm$1% signal per 100mBar change

- **Temperature** - all electrochemical sensors rely on catalytic reactions and as such the output of the sensors are affected by changes in temperature, accelerating or impeding the reaction. Fortunately this effect is extremely repeatable and can be compensated easily using either a standard thermistor in the drive circuit or by using look-up tables pre-programmed into a suitable E^2PROM. All product data sheets contain details about the degree of temperature compensation required and further details can be obtained from Sixth Sense. Some sensors, eg. CO, also display a small change in the baseline signal and details are given on the relevant data sheets.

- **Humidity** - most electrochemical sensors contain a small amount of acid based electrolyte which, by its nature, is hygroscopic. Therefore, water vapour will be either absorbed or released from/to the surrounding atmosphere depending on the relative humidity. Sixth Sense products have been optimised to work unaffected for long periods in the range 15-90% RH. Long periods in excess of 90% R.H or below 15% R.H. can affect the performance of electrochemical sensors. If this is a possibility, please contact Sixth Sense for further information. At all times it is imperative that 'non-condensing' conditions are maintained to prevent water droplets forming on the sensor itself.

- **Oxygen** - most electrochemical sensors require small amounts of oxygen at the counter electrode in order to complete the catalytic reaction. They should not, therefore, be used in applications where no oxygen will be present in the surrounding atmosphere. For short periods, ie. less than 10 minutes, they can operate without oxygen since there will be sufficient absorbed in the electrolyte. This allows calibration with dry gases.

1.5 Effect of Interfering Gases

Due to the highly active nature of the catalysts that are used in electrochemical sensors, they can oxidise or reduce gases other than the target gas. In these cases, the sensor exhibits a cross-sensitivity which can, on occasion, be used to extend the measurement capability of the sensor. For example, chlorine sensors exhibit a significant cross-sensitivity to chlorine dioxide (ClO_2), Bromine (Br_2) and Ozone (O_3) and can therefore be used as a suitable sensor for detecting these gases when none of the others are present.

Where at all possible and appropriate, the effect of interfering gases is reduced by careful catalyst selection, the use of on-board filters or by applying a bias voltage between the working and reference electrodes. Details of all cross-sensitivities are included on individual data sheets.

1.6 Stabilisation

All three-electrode sensors from Sixth Sense are delivered fitted with a shorting link across the electrodes. This ensures that they arrive ready to use and do not require further stabilisation when they are fitted into a product. This link must not be removed until just prior to use and the drive circuitry must ensure that the working and reference electrodes are shorted during un-powered periods. Failure to do this will mean that the sensor may require a period of some hours to stabilise.

Since most customers purchase the two-electrode sensors in very large volumes, they are not normally fitted with shorting links. Instead, they should be shorted and left to stabilise at least two hours prior to use. Please contact Sixth Sense should you wish sensors to be delivered with shorting links pre-fitted.

Some sensors require a small bias voltage, eg. CO_2, and to ensure that they are ready to use on delivery, they are fitted with a small PCB that maintains the correct bias voltage across the electrodes. This should be removed prior to use and returned to Sixth Sense for credit against further purchases.

1.7 Physical Protection

Whilst the sensors are manufactured to withstand normal environmental conditions, they should be protected from dirt, dust and water ingress. This can be achieved cost-effectively by installing a semi-permeable membrane barrier between the sensor and the external atmosphere (eg, PTFE or Gore-Tex™). If this is not used, it is possible that the sensor may become blocked, preventing gas from diffusing in.

1.8 Intrinsic Safety

Information is given on individual data sheets, stating the maximum current during normal operation, the maximum open circuit voltage and the maximum short circuit current, all of which must be considered when designing products that must be intrinsically safe. Theoretically it is possible for an electrochemical sensor to produce up to 1.25V during an open circuit, but since most of the reactions are irreversible the full potential is never reached. In summary all electrochemical sensors from Sixth Sense meet the following:

'At no time, regardless of the fault status, will the Sixth Sense range of sensors produce a voltage greater than 1.3V and a current greater than 1.0A'

1.9 Calibration

All gas detection products should be tested and calibrated using the target gas prior to use. Once in use, Sixth Sense products are designed for extended use without re-calibration but they should be verified, and calibrated, if necessary, at least every six months. Some applications are regulated by legislation that dictates the minimum calibration intervals and these should be observed at all times. Where calibration is not possible, a suitable cell supervision circuit should be used, details of which are given in Application Note 3. Since most electrochemical sensors are linear, then only a single-point calibration is required. The concentration of gas used should represent the actual concentrations to be experienced in the field, typically the upper alarm limit of the gas detector. Where it is not possible to prescribe this, a concentration towards the upper limit of the sensor range should be used. To avoid pressurising the sensor and so affecting it's performance, flow rates in excess of 1litre/minute should be avoided. It is, however, important to ensure that the sensor is exposed to sufficient gas to obtain a stable reading. Table 1 gives examples of suitable calibration concentrations and minimum flow rates required for effective calibration. The data shown is based on a minimum exposure time of five minutes. For gases not shown, please contact Sixth Sense for assistance.

Table 1

Gas	Concentration (ppm)	Minimum Flow Rate (ml/min)
Carbon Monoxide	200	150
Hydrogen Sulphide	20	250
Chlorine	10	1000

1.10 Testing

All toxic gas sensors from Sixth Sense are individually tested with their target gas prior to delivery. Using a unique computerised testing system, over a dozen parameters are recorded during the test cycle and recorded against the corresponding serial and batch numbers. For further details about the test procedure or to arrange for test results to be sent with your sensors, please contact Sixth Sense.

1.11 Identification & Packaging

All toxic gas sensors from Sixth Sense are individually labelled and identified by part number, gas type, serial number and the batch/date code. If required, further information can be added upon request, such as sensor output or your company name. For specific labelling requirements, please contact Sixth Sense for advice.

Our gas sensors are packaged in hermetically sealed containers to protect them from the stresses of transportation and environmental conditions. We recommend that they are stored in their original packaging to maximise their operating life. For shipments over 100 units, sensors are packed in trays of 100 and up to 10 trays will be sealed in a metallised plastic outer bag which is subsequently sealed in a ruggedised cardboard box for shipment. Both the outer bag and box will be marked as detailed above.

For more specific details on packaging or to arrange an alternative method, please contact Sixth Sense.