

AAN 111

MODELLING AMPEROMETRIC
ELECTROCHEMICAL GAS SENSORS

When designing circuits, electronic engineers frequently ask for an equivalent model of a sensor. This equivalent model allows simulation of the potentiostatic circuit, which is required to both measure and control an amperometric electrochemical gas sensor.

Application Note AAN 105 explains how to design a potentiostatic circuit, and Application Note AAN 104 explains how an amperometric electrochemical gas sensor operates.

This Application Note shows how you can simulate a gas sensor, using just capacitors and resistors. Of course, electrochemical sensors are more complex, so the limitations of this model are also explained.

The Model

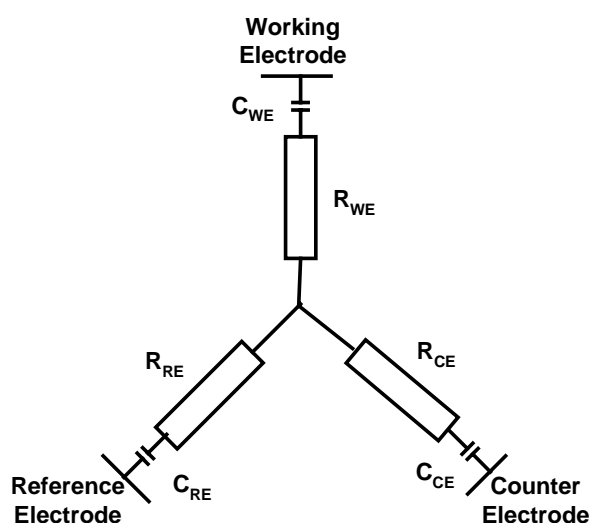
Alphasense amperometric electrochemical gas sensors use three electrodes:

- **Working electrode** reacts with the target gas
- **Counter electrode** generates a current that balances the working electrode current
- **Reference electrode** sets the operating potential of the working electrode for best performance.

All three electrodes are connected internally through the electrolyte, so a common central node is an essential part of the model. The electrolyte can be modelled simply as a resistor.

Each electrode can be modelled simply as a large capacitor- this is explained below. The electrodes also have a small resistive component, but this is included as part of the electrolyte resistance.

We can now construct our equivalent model:



The following table shows the values of the elements described earlier for A and D series CO and H₂S sensors.

		CO-AF	H2S - A1	CO-DF	H2S-D1
Working	R _{WE} (Ω)	1	1	1	1
	C _{WE} (mF)	150	250	60	100
Reference	R _{RE} (Ω)	1	1	1	1
	C _{RE} (mF)	50	50	10	10
Counter	R _{CE} (Ω)	1	1	1	1
	C _{CE} (mF)	100	100	20	20

Electrochemical Considerations

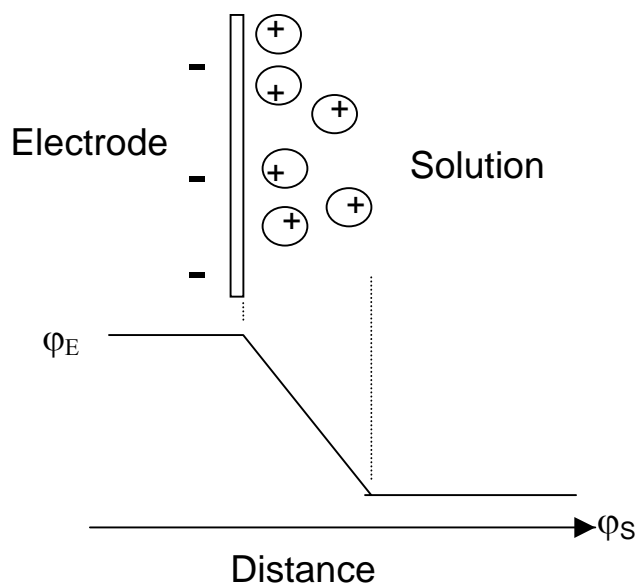
The elements described in the first section of this application note can be derived from a basic knowledge of electrochemical interfaces.

R

The resistor elements describe the ohmic resistance associated with the electrodes. For best sensor operation, these values are minimised; this is achieved with the use of high ionic strength electrolyte and optimisation of the electrode geometry.

C

Consider an electrode immersed in an electrolyte in which the electrode is biased negative to the potential of zero charge (pzc), such that the electrode has an excess of electrons at the surface. An excess of positively charged ions resides on the solution side of the interface, in order to maintain electroneutrality. This situation is described schematically below,



where ϕ_E and ϕ_S are the potentials of the electrode and solution respectively. Most of the potential drop occurs in the region close to the electrode where a net accumulation of positively charged species has occurred.

This situation can be described electrically as a capacitor.

Limitations of the model

The model presented here is an abridged version of a more complicated, lumped element equivalent circuit. Indeed it is beyond the scope of this note to include all of the details of the system such as transmission lines, resistance to charge transfer. Therefore, for the purposes of simulating toxic sensors a few points should be considered:

- Capacitance is frequency dependent and, in particular, low frequency measurements are dominated by the capacitance associated with the porous nature of the electrode, as explained above. At high frequencies, capacitance is dominated by solution resistance, but potentiostatic circuits are low frequency circuits. See Application Note AAN 103.
- Capacitance is a complex function of the bias potential. Therefore, any instantaneous shift in bias potential will result in charging/discharging of the electrode, resulting in an unstable reading for several minutes.
- If sensors are used in low humidities, loss of electrolyte will increase the internal resistance from about 1 ohm to 10 ohms. This will change the RC of the sensor, which may affect noise immunity and possibly circuit stability.