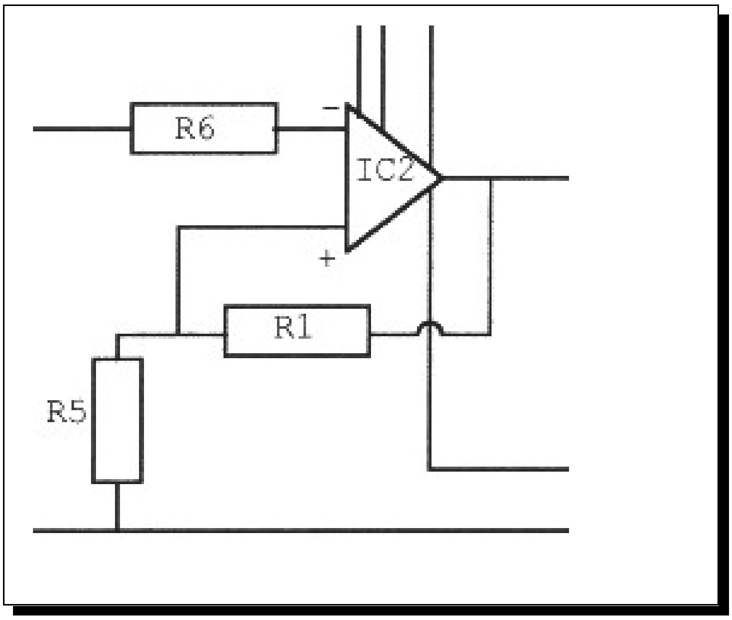
Circuit Design Considerations

Calculating the gain of the circuit

The fuel cell has an operational range of 7mV to 13mv in air according to the specifications of the manufacturer. Beyond these limits the performance of the fuel cell cannot be guaranteed, therefore it was necessary to design a circuit which would not allow a cell which is outside of these limits to calibrate to 21% in air.

As the panel meter display is configured to operate as a voltmeter it is necessary to have 21mV applied across it to give a reading of 21% in air. Since the minimum operational voltage of the fuel cell is 7mV then the amplifier must have a gain of 3 to obtain a reading of 21% when 7mV is applied to it. [fig.1]



[fig.1]

R1 = 22K
R5 = 11K

Using Gain = $\frac{R5+R1}{R5}$ Gain = $\frac{11+22}{11} = 3$

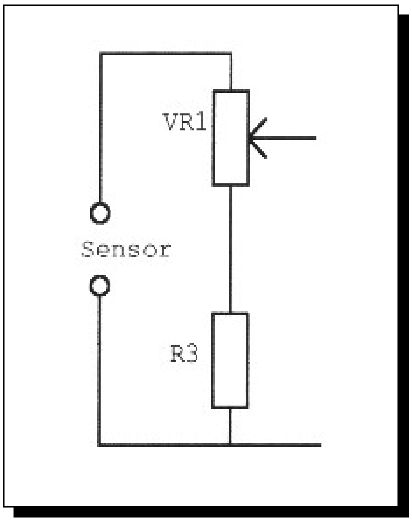
An input voltage of 7mV delivers a voltage of 21mV to the panel meter, any lower than 7mV will not deliver 21% and hence a fuel cell which falls beneath the lower specified limit will not calibrate to 21% in air, ensuring a low output cell can not be used on the instrument.

Calibrating the sensor input tolerances

If the gain of the amplifier is fixed at 3 then an input of 13mV, which is the maximum input we would want the circuit to allow to calibrate, would give a reading of 39%. It is therefore necessary to introduce a potential divider to the input to drop an input voltage of 13mV down to 7mV to allow the op-amp to multiply it by 3 and hence display 21% on the panel meter.

The initial circuit used in development used a 10K potentiometer and a 10K fixed resistor as a potential divider, which could drop 13mV down to 6.5mV to provide a working prototype [fig.2]. It can be seen however that this is not ideal as it would allow input voltages as high as 14mV to be dropped to 7mV and hence calibrate to 21% which is beyond the specification of the fuel cell.

$$\text{Vsensor} = 7 \times \frac{10+10}{10} = 14\text{mV}$$



[fig.2]

R3 = 10K
VR1 = 10K linear

If we calibrate this potential divider by altering R3 we can allow 13mV to be the maximum sensor voltage that can deliver 7mV. To find the ideal ratio:

$$\frac{13}{7} = 1.86$$

By replacing R3 with an 8K2 resistor we find:

$$7 \times \frac{10 + 8.2}{10} = 12.74\text{mV}$$

This allows a small safety margin ensuring that a 13mV input or above will not calibrate.

The table below shows the following results:

The maximum voltage at the op-amp which, when the potentiometer is turned up to it's maximum value is the same as the input voltage.

The minimum voltage that will be present at the input to the op-amp for the given input voltage, this is found by dividing the input voltage by 1.82 which will be the case when the potentiometer is turned down to it's minimum value.

The minimum and maximum percentage readings that will be seen on the display, this is found by multiplying the inputs to the op-amp by its gain of 3.

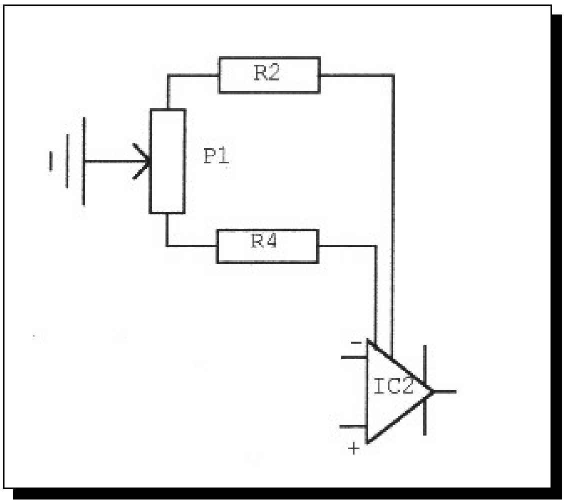
Vin (Max Voltage at op-amp)	Min Voltage at op-amp	Min % Displayed	Max % Displayed
7.0mV	3.85mV	11.5%	**21%**
12.74mV	7.0mV	**21%**	39%

It can be seen from this table that the minimum input voltage from the cell that can be calibrated to 21% is 7mV, and the maximum that will calibrate is 12.74mV, we have therefore calibrated the input tolerances.

In practice this means that any cell that has drifted beyond the manufacturer's specification will not calibrate to 21% in air. The instruction manual reflects explicitly that any cell that does not calibrate in air must not be used.

Op-amp zero off-set adjustment

The op-amp IC2 has a null off-set between pins 1 and 5. The circuit incorporates a 1K trim pot in-between two 4K7 resistors to allow the adjustment of the output of the op-amp to zero when no input voltage is present. This is a feature that allows recalibration of the instrument back to a zero baseline should tolerances within the circuit drift causing the zero value to alter. [fig.3]



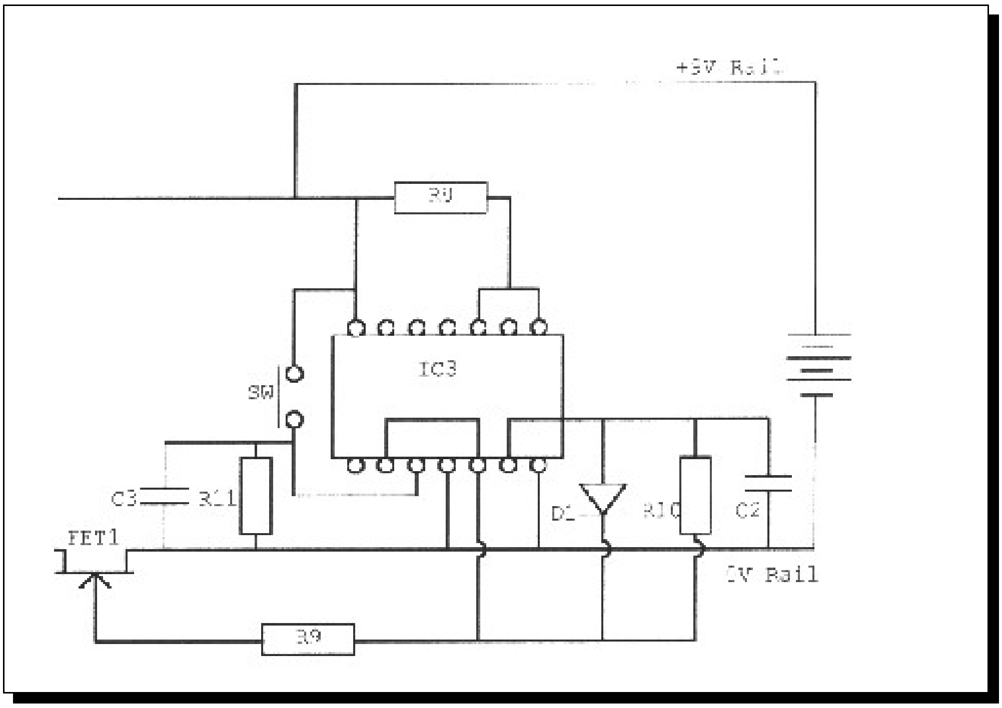
[fig.3]

Auto switch off timer

Aside from the display, which is a DPM400 panel meter configured as a voltmeter, the rest of the circuit is concerned with the automatic switch off function. [fig.4]

The auto-off feature was thought necessary due to the way in which the analyser is used. It may be many weeks or months between periods of using this instrument and it may often be subject to rough handling where it is carried in a kit bag with other items of equipment, allowing the possibility of it accidentally being switched on and left on for long periods.

We decided it was necessary to have an auto off for safety reasons, if a diver does not check the battery before setting of on a dive trip they may find themselves doing their final preparations for a dive and discovering they have a flat battery, this presents the possibility of the diver continuing regardless or having to miss their set dive plan.



[fig.4]

R10 = 6M8
C2 = 33uF

IC3 is a CD4013BP dual flip-flop, [fig.5] it has been configured to act as a toggle switch by connecting the data input of flip-flop 1 (pin 5) to the buffered output (pin 2).

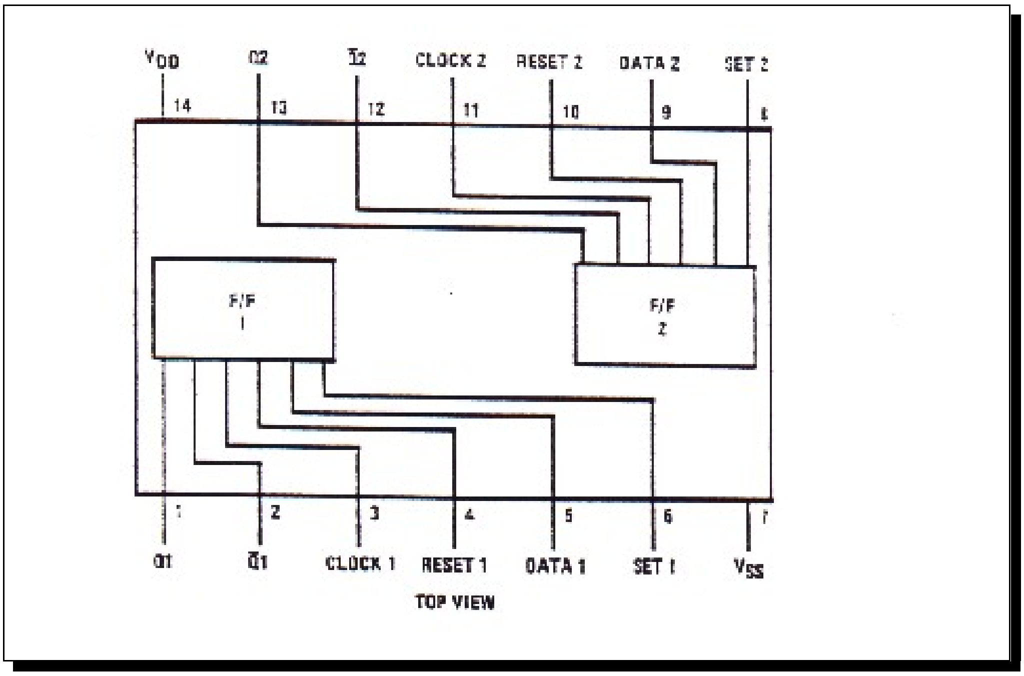
The capacitor C3 serves to de-bounce the switch. By pressing the switch the clock1 input (pin 3) is set to a logic 1 state, which toggles the flip-flop setting the buffered output (pin 2) and the data (pin 5) to a logic 1 state. This logic 1 state is applied to the base pin of the transistor, switching on the circuit.

Whilst the unit is on current flows through R10 and C2, as C2 charges the voltage between R10 and C2 rises. This voltage is present at the set1 (pin 6) of the flip-flop and as current flow through C2 slows this voltage reaches a high enough value to trigger the flip-flop.

This toggles the output to zero, which then switches off the transistor, shutting down the circuit, C2 discharges through the diode resetting the timer.

The auto switch-off time is determined by the values of R10 and C2, these have been set to give a switch off time of approximately 3 to 4 minutes.

The auto switch-off can be disabled by replacing C2 with a link wire. Models will be produced with no auto-off function for use in dive shops or other places where regular or



constant monitoring is required.

[fig.5 CD4013BP dual flip-flop]

Pin 14 is connected to the 9V rail and pin 7 to the zero volt rail. The reset and set pins of flip-flop 2 are both set to a logic one state to disable it.

Power is provided by PP3 / MN1604 type 9v alkaline battery, rated at 550mA hours.
The on current is approximately 2mA and the off current is under 2uA. This extremely low quiescent current means the battery is not being drained by the auto-off function.