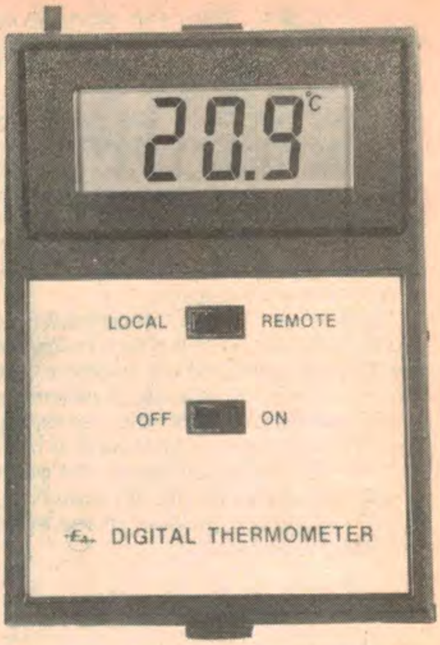
Simple circuit uses an LCD module

Digital Thermometer



Here is a handy portable digital thermometer which can measure temperatures from below freezing to around the boiling point of water with a resolution of 0.1°C. The liquid crystal display has digits which are 15mm high for easy legibility. Most of the circuitry is incorporated in a new 3½ digit LCD voltmeter module which is the basis of the unit.

by JEFF SKEEN and LEO SIMPSON

Accurate temperature measurement can be one of the hardest things to achieve outside of the laboratory. Many hobbies such as keeping tropical fish, photography and electronics all require a close watch to be kept on the temperature. With conventional mercury thermometers found in the home, resolution is rarely better than 1°C and often the absolute accuracy of the thermometer is suspect. Trying to read a thin column of mercury can be very difficult, particularly in a darkroom, and the scale often rubs off thermometers that are in constant use.

From the foregoing, we feel that this new thermometer is sure to be a popular project. It can be built with two temperature sensors: one internal for "local" or ambient temperature measurements and one "remote" for temperature measurement in tanks and so on.

Our new Digital Thermometer uses a DPM-200 LCD panel meter which has been imported by Jaycar Pty Ltd and which will be used in a number of future projects. The DPM-200 module will retail for $39.50. Also available will be a neat matching case which really adds the finishing touch to this project. The case will retail for $5.50.

Full technical details of the DPM-200 module are featured within this article.

CIRCUIT DESCRIPTION

Since a major part of the circuitry is provided by the DPM-200 module, the circuit diagram of the Digital Thermometer looks very simple, as indeed it is. The DPM-200 module should be regarded as an accurate voltmeter which can read up to ±199.9mV but which is connected to read temperature in degrees Celsius. To this end, the "°C" annunciator is enabled by connecting pin 18 on the module to pin 34. One of the decimal points is also enabled in this way: pin 28.

The temperature sensors employ LM334 current generator integrated circuits which produce an output current which increases linearly in proportion to the Absolute temperature which is measured in degrees Kelvin, °K.

The amount of variation of current, with temperature, may be set by an external resistor connected between the "R" and "-V" outputs of the LM334. With the appropriate value of resistance connected, the output current may be adjusted over the range 1μA to 10mA per °K. In this design the 100Ω multi-turn potentiometers in series with the 150Ω resistors are used to set the LM334 output current to 1μA/°K.

The output of the LM334 flows through a 1kΩ resistor and into the "Com" input pin 4, of the display module. The Com input is maintained at approximately 2.8 volts below the positive supply rail and all voltages measured by the display module are measured with respect to this. The current flowing through the 1kΩ resistor generates a voltage that increases at the rate of 1mV per °K. This voltage is measured by the "In Hi" input of the display module which has very high input impedance and so does not load the 1kΩ resistor to any appreciable extent.

A problem does arise however, because at normal temperatures the voltage developed across the 1kΩ resistor is greater than the full-scale voltage reading of the display module. Also, we wish to measure °C not °K and so we require the display module to read zero when the input voltage is actually 273.2mV. Both these problems can be solved by providing an offset or nulling voltage of 273.2mV that will "null out" or cancel the effect of 273.2mV being present at the input when the temperature is 0°C.

The 1MΩ, multi-turn potentiometer provides the necessary offset voltage adjustment. It is connected between "Ref BG" which is a very stable voltage source of 1.2 volts, and "Com". The wiper arm of the potentiometer is then connected to the "In Lo" input of the display module and the necessary offset voltage of 273.2 mV is generated between the "In Lo" input and "com", the "In Lo" input being the more positive of the two.

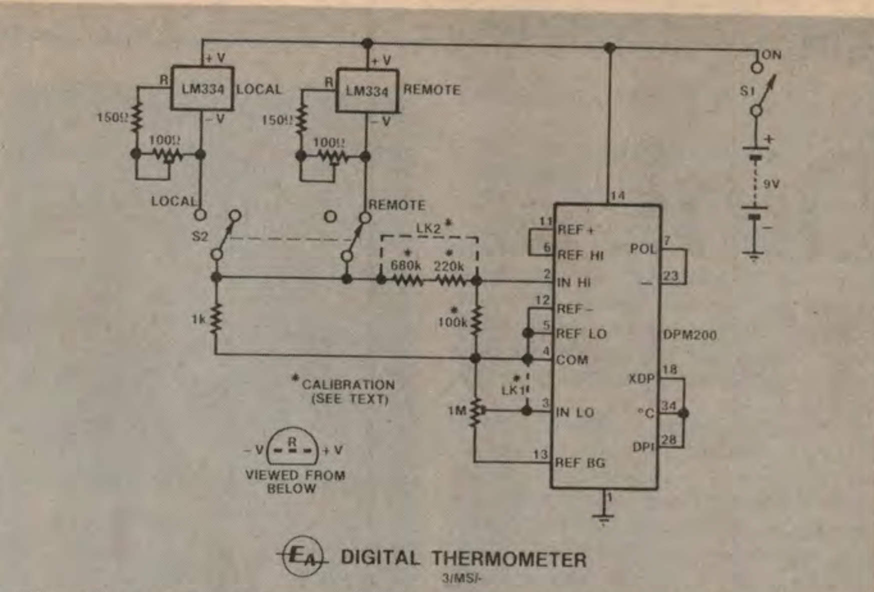
Essentially, that is all there is to the circuit apart from the three resistors which are marked with asterisks. These are only used for calibration during construction of the thermometer and are not present in the circuit of the completed project. The only other connection to the module which interests us in this circuit is the link from pin 7 to 23. This enables the – annunciator, which tells us when the temperature is below 0°C.

The additional resistors and the link, which are used in the calibration procedure, connect the module together to form a digital voltmeter with a full scale reading of 2V. The voltage across the 1kΩ resistor, and hence the current supplied by the LM334 at zero °C, is adjusted by the 100Ω potentiometers while the module is in this mode.

While our circuit specifies LM334 temperature sensors, these are only guaranteed by National Semiconductor for temperatures between 0°C and +70°C. To guarantee reliable operation over more extreme temperature ranges you will have to use the LM234 which is guaranteed over the range from −25°C to +100°C or the LM134 which is guaranteed over the range from −55°C to +125°C. However the two latter devices are more expensive and not readily available.

However, for most applications it appears as though the LM334 will give satisfactory performance even if used at temperatures outside its normal temperature range. More specifically, we feel confident that the LM334 will operate reliably at temperatures below freezing and up to 100°C provided the bare sensor is not immersed in water.

Current drain of the circuit is normally about 0.5mA which means that a type 216 9V battery should have a long life. The circuit will work at voltages from 15V down to 5V but battery voltages lower than 7V will light up the low battery warning on the display.



The components marked with asterisks are used for calibration during construction.

CONSTRUCTION

All the circuit components apart from the temperature sensors are mounted on a small printed circuit board measuring 69 x 71mm and coded 82th2. This board has been designed to fit into the plastic case that comes with the DPM-200 display module and its use is recommended because of the small clearance between the display module and other components once the case is assembled. The thermometer is calibrated as it is built so the construction details should be followed closely.

The resistors specified for this project are all 1% metal film types. This is not so much for accuracy but for the high thermal stability of this type of resistor.

Begin construction by mounting all components, except for the 1MΩ potentiometer and link Lk2 on the printed circuit board. Take care not to forget link Lk1 which replaces the 1MΩ potentiometer for the moment.

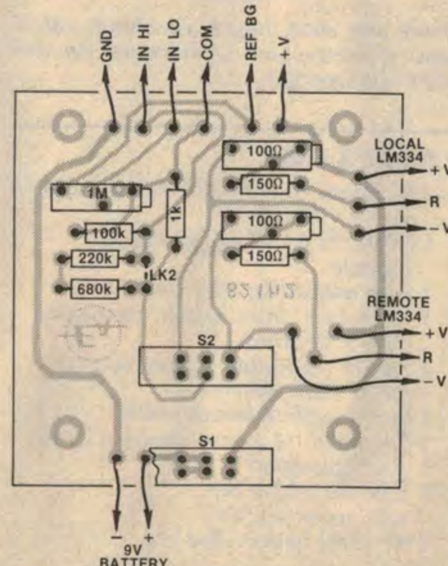
The holes for the switch tags may need to be enlarged slightly, depending upon the type of switches supplied. The switches are inserted so that the top of the switch body is not more than 10mm above the PC board. More than this and the two halves of the plastic case may not fit together. Some switches may have side supports that are too long and these should be trimmed to 10mm in length.

Solder the switches into place, then mark out holes for the switch actuators in the top of the plastic case. To obtain the correct positions, take measurements off the front panel artwork printed in the magazine. The front panel fits into the recess in the top of the plastic case and measurements on the plastic case should be made from the edges of the recess.

When the hole positions have been marked out, use a drill with a diameter smaller than the width of the switch hole to drill out most of the plastic in the hole. A small triangular, square, or flat file can then be used to take the hole out to its proper size and to square up the corners.

Before the two halves of the plastic case will fit together two small locating stubs will have to be removed from the bottom half of the case. These are the two stubs next to the top snap clip. They can be snipped off quite easily with a pair of side cutters and the rough edges finished off with a small file.

The PC board can now be screwed into place, the two halves of the case clipped together, and a check made to see that the switch actuators can move freely in their holes in the case. If they don't, pull the case halves apart, remove the offending plastic from the sides of the hole with a flat file and then square up the hole again.



Note that the high value fixed resistors are removed after calibration.

Trim the Scotchcal front panel to size with a sharp pair of scissors. Holes can be made in the front panel for the switch actuators by pushing the point of a "Stanley knife" blade through the aluminium and making a line of small holes along the inside of the black borders. By running the knife blade along the line of holes, they can be joined together to form the cut-out required for the switch actuators. A ruler placed along the border side of the hole will prevent the front panel being scratched and also provide a straight edge along which to run the knife blade.

The backing paper can now be removed from the Scotchcal and the front panel stuck into place. Assemble the case halves again and check that the switch actuators will still move freely. If not, use a flat file to open up the holes in the Scotchcal front panel until the switches move freely.

The display should now be inserted into the top half of the case and checked to see that it mounts flush with the case. If it does not, then very carefully bend over Q1 and the associated resistors near it on the DPM-200 module as these will probably be touching the circuit board. Take extreme care when bending the resistors because the leads can easily be broken off. An alternative to bending over the components is to shave a small amount of plastic off the mounting posts for the PC board.

The display and the PC board can now be wired together using an 8cm length of ribbon cable, and then the point-to-point wiring on the display module completed. It is easiest if the display module is not mounted in the case at this stage. Solder the wires from the battery clip onto the PC board, taking care that the polarity is the right way around and then screw the PC board back into the lower case half.

Now mark out the position of holes in the case for the local and remote temperature sensors. Ensure that there is enough room for wires from the sensors to run through the holes without fouling the PC board. On the prototype we located a hole for the local sensor directly under the snap clip on the lower case half. The hole for the remote sensor cable was located in the corner of the same panel.

If both temperature sensors are to be employed then the local one may now be glued into the hole made for it in the case. Leave about half of the sensor body extending from the case so that there will be a good air circulation around the sensor. Once wires are soldered to the sensor, place small pieces of spaghetti tubing over the bare leads to prevent them shorting one another.

An external probe assembly should now be constructed. We used an empty pen tube as a case and glued the sensor body in one end with epoxy adhesive. Again leave at least half of the sensor body extended from the tube so that there will be good thermal contact between the sensor and the environment. Also make sure that the adhesive seals the sensor leads completely because if any moisture finds its way between the sensor leads the temperature reading will be incorrect.

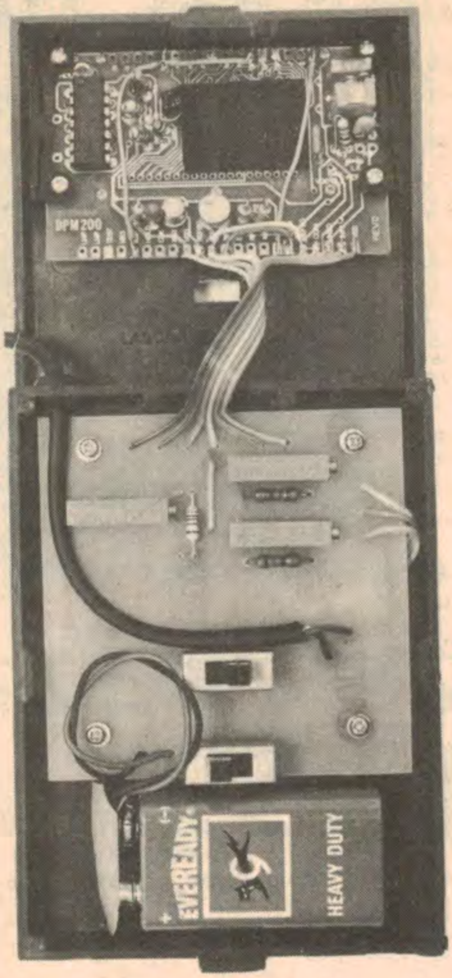
The cable from the remote sensor to the PC board is critical. For best results this cable should have conductors that are as thick as possible so that lead resistance will not upset the readings. Twin core shielded cable may be used if the distance is one metre or less, however the shield must be connected to the −V output of the sensor. A greater separation between the remote probe and the PC board (up to 100 metres), may be achieved by removing the 100Ω potentiometer and the 150Ω resister associated with the remote probe and locating them in the probe body, near the sensor.

If it is envisaged that the probe may be used in either extremely hot or corrosive environments, eg a car engine bay, then it would probably be best to construct a probe using a small bore aluminium or stainless steel tube as a case.

If only a local sensor is to be employed then this should be prepared for calibration by installing it into a temporary, waterproof probe. The reason for specifying that the probe be waterproof is that during calibration the sensor is placed into a mixture of ice and water. This is assuming an accurate thermometer is not available. If one is available, then the sensors may be calibrated without recourse to an ice-water mixture and a waterproof probe is not necessary.

CALIBRATION

With the probe built, all that is left to do is to double check the circuit for errors. If none are found turn the thermometer on, switch the sensor switch to the "local" position, and adjust the 100Ω potentiometer associated with the local sensor until a reading of around 30.0 appears on the display. Place half a dozen ice cubes in a glass, just cover with water, and insert the probe. Leave for



Note the short length of ribbon cable and point-to-point connections on the DPM-200 module.

PARTS LIST

- *1 PC board coded 82th2 and measuring 69 x 71mm*
- *1 DPM-200 liquid crystal display module*
- *1 case measuring 80 x 110mm*
- *1 Scotchcal front panel measuring 71.5 x 59.5mm*
- *2 LM334 adjustable current sources*
- *2 DPDT slide switches*
- *1 8cm length of ribbon cable*
- *1 1m length of 2-core shielded cable*
- *1 small grommet*
- *1 tube for probe body*
- *4 self tapper screws*
- *1 9V (216) battery and clip*

RESISTORS (¼W, 1% tolerance)
1 x 680kΩ, 1 x 220kΩ, 1 x 100kΩ,
1 x 1kΩ, 2 x 150Ω,
1 x 1MΩ multi-turn trimpot
2 x 100Ω multi-turn trimpot

NOTE: Components specified are those used in our prototype. Components with higher ratings may generally be used providing they are physically compatible.

about 10 minutes after which the display reading should drop to around 27.5.

Adjust the 100Ω potentiometer until a reading of 27.3 appears on the display. The temperature sensor has now been adjusted to give an output of 1μA per °K. For people adjusting the sensor with the aid of a thermometer, turn the 100Ω potentiometer until the display reads 27.3 + thermometer reading/10. For a room at 23°C this is a display reading of 27.3 + 23/10 = 29.6. Now remove the link marked LK1 on the circuit and insert the 1MΩ potentiometer in its place. Solder LK2 onto the PC board, and then insert the probe back into the water-ice mixture.

Again leave the probe in the ice-water mixture for about 10 minutes, then adjust the 1MΩ potentiometer until the display reads 00.0. The correct offset voltage has now been reached and the thermometer is calibrated. To calibrate the other sensor, place the probe just calibrated next to it, wait for about 10 minutes to allow the temperatures to equalise, then take a note of the probe temperature. Switch to the sensor to be

> We estimate that the cost of parts for this project is approximately
>
> **$60**
>
> including two temperature sensors.

calibrated and adjust the 100Ω potentiometer associated with this sensor until the display reads the same as the probe just calibrated.

The second sensor has now been calibrated and no adjustment should be made to the offset voltage. People calibrating the probe with the aid of a thermometer should adjust the 1MΩ potentiometer until the display reads the same as the thermometer temperature.

CONCLUSION

The thermometer as built is an accurate device but allowance should be made for the way in which the temperature is measured. To obtain the most accurate readings the whole sensor should be in good thermal contact with the object being measured and time allowed for the two temperatures to equalise. If you are measuring say heatsink or transistor temperatures then a smear of heat conducting grease on the end of the probe will provide much better thermal contact.

A changeover between °C and °F can be made quite easily by switching in a 1.8kΩ resistor in place of the 1kΩ resistor and an offset voltage of 460mV in place of the present 273mV. The °C annunciator should be turned off when displaying temperatures in Fahrenheit.

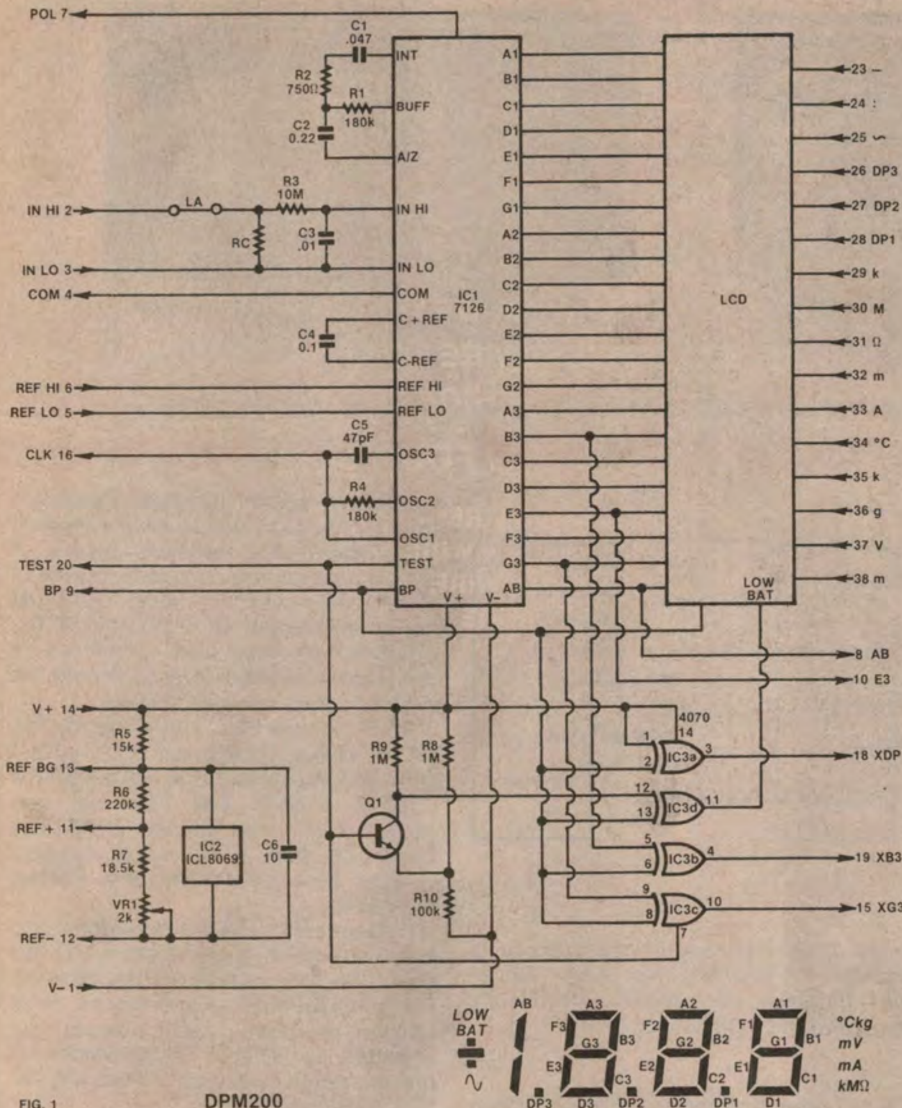
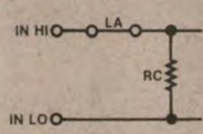


FIG. 1 DPM200



REQUIRED FULL SCALE	LA	RC
2V	9M	1M
20V	9.9M	100k
200V	9.99M	10k
2kV	9.999M	1k
200uA	LINK	1k
2mA	LINK	100Ω
20mA	LINK	10Ω
200mA	LINK	1Ω

FIG. 2

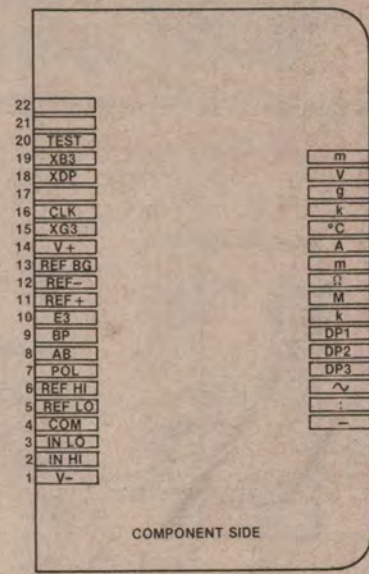


FIG. 3

The circuit of the DPM200 module is split into three parts: A-D converter (IC1), voltage reference (IC2) and exclusive-OR gates (IC3).

The DPM-200 is a new panel meter module imported by Jaycar Pty Ltd. On board the module are all the components necessary to provide the basis of a wide range of accurate instruments. We will be publishing a number of projects using this module for the display and so we present here some application notes on the module to allow you to become familiar with how it operates.

Physically the DPM-200 module is a double sided printed circuit board assembly with an integral 3½-digit liquid crystal display mounted on one side. The LCD has a black bezel surround measuring 72 x 36mm while the gold-plated PC board measures 68 x 45mm.

Mounted between the display and the PC board is an integrated circuit chip which is terminated directly to the board. In the accompanying photographs, the area occupied by the chip is marked by a piece of black insulation tape. Also accommodated on the board is a 4070 quad two-input exclusive-OR gate, a transistor, an additional IC which is described below, a preset pot which should not be touched or adjusted and a few resistors and capacitors.

The DPM-200 module is essentially a high input impedance voltmeter with a full scale reading of 199.9mV. Various annunciators are available (such as °C, kg, mV, decimal points etc) and these may be connected as desired.

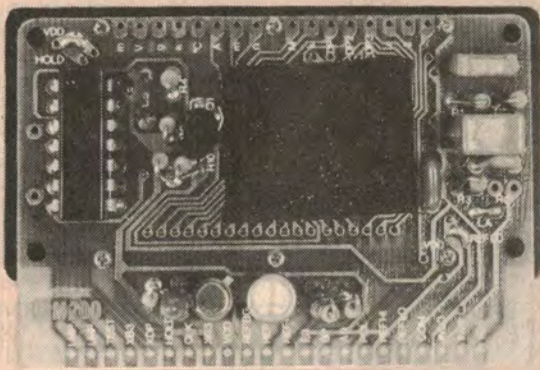
The heart of the digital panel meter is the Intersil 7126 dual slope integration analog to digital converter chip. This chip also drives the liquid crystal display direct and yet draws only 50μA.

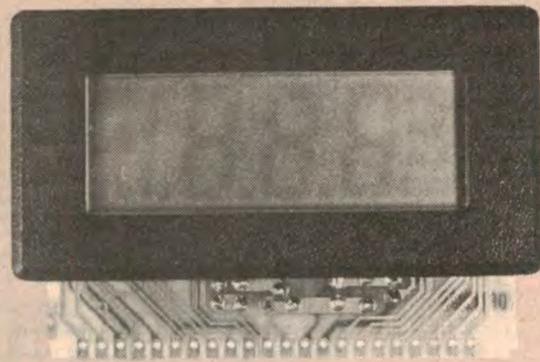
Components R1, R2 and C1 on Fig. 1 determine the integrator time constant while C2 reduces the susceptibility to noise of the auto-zero circuitry and determines the speed of recovery from overload. The display is guaranteed to read zero for an analog input of zero volts. An input filter is formed by R3 and C3 and assists with overload protection of the 7126 chip. The input voltage may exceed the supply voltage provided the input current does not exceed 100μA. The input impedance is greater than 100MΩ.

The frequency of the internal oscillator appearing at the clock output is determined by C5 and R4 and is set at 48kHz in the modules supplied. The backplane signal necessary to drive the LCD is set at a frequency of 60Hz while the display is updated three times per second.

As supplied, the module is calibrated by means of VR1 for a full scale reading of 200mV with link LA in circuit and resistor RC omitted. Fig. 2 shows how the input sensitivity may be altered and how the module may be converted for current measurements.

The 7126 chip has an internal voltage reference that maintains circuit common at approximately 2.8V below the positive supply. The temperature coefficient of the internal reference is typically 80ppm/°C. A potential divider could be placed across the internal reference and used to derive the voltage required for the converter





These two views show the actual size of the DPM-200 module. Note the REF trimpot which must not be fiddled with.

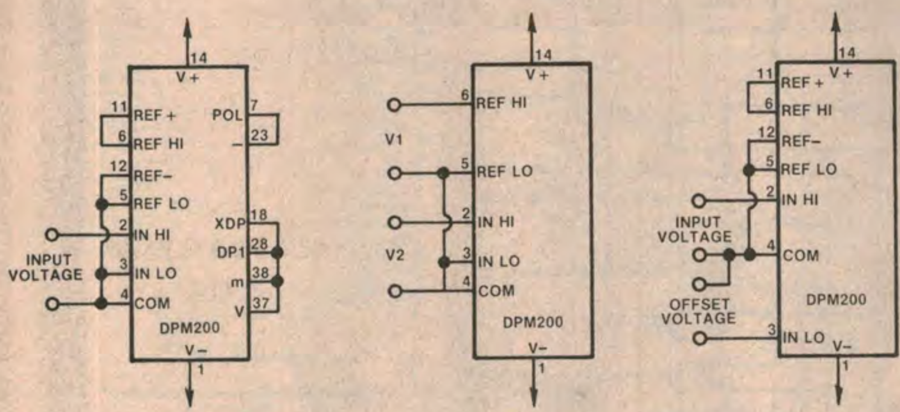


FIG. 4 (a) (b) (c)

Fig. 4(a) shows module connections for measuring a floating voltage source of 200mV maximum. Polarity and mV annunciators are enabled. 4(b) shows the arrangement for measuring ratio of two voltages. 4(c) shows the method of connecting an offset voltage if a zero display is required when the input is not zero.

reference input. The displayed reading is 1000Vin/Vref with Vref normally equal to 100mV.

However, in the DPM-200, a bandgap reference integrated circuit (IC2), is used to provide reference voltages. This integrated circuit acts like an extremely stable 1.2V zener diode and a voltage divider between REF BG and REF- is used to produce the 100mV Vref that is required for the converter reference. The module comes with Vref already adjusted to 100mV and VR1 therefore should not be varied.

The bandgap reference will maintain regulation with supply voltages down to 5V. A low battery detection circuit, Q1, is included in the module to provide an advance warning of battery failure directly on the display.

R8 and R10 form a voltage divider across the supply that acts to turn Q1 off when the supply voltage falls below a threshold level set by R10. When Q1 turns off the collector goes to a high level and exclusive-OR gate IC3d then acts as an inverter. A signal which is in anti-phase with the backplane input is thus generated and used to provide a drive signal for the LOW BAT warning. R10 may be changed if a different warning threshhold is required, some typical values being 220kΩ for a warning at 7.2V and 100kΩ for a warning at 6.4V.

An exclusive-OR gate IC3a provides an inverted backplane signal that can be used to drive any combination of the annunciators on the module. These annunciators are normally "floating" and under operation in an electrically noisy environment, may appear when not required. Annunciators may be suppressed by direct connection to the backplane if not required, or connected to the backplane by a 1MΩ resistor if required at certain times. The 1MΩ resistor prevents spurious signals from turning on the annunciator yet allows normal operation of the annunciator when connected to XDP.

The exclusive-OR gates IC3b and IC3c provide outputs that may be used to enable annunciators if the module is used in auto-ranging applications.

Pin connections for the DPM-200 module are shown in Fig. 3. The analog inputs can accept differential voltages from 0.5V below the positive supply to 1.0V above the negative supply. A typical common-mode rejection ratio of 86dB exists over this range. The COM pin is maintained at 2.8V below the positive supply and provides a convenient method of establishing the correct common-mode voltage.

An N-channel FET, internal to the ICL 7126, allows COM to sink up to 100μA while still remaining at 2.8V below the positive supply. The FET will only source 1μA however, so COM may easily be tied to a more negative voltage thus over-riding the internal reference.

Reference inputs are differential and may be generated anywhere within the power supply voltage of the module. For module applications where auto-ranging is used, four outputs are provided to enable annunciators or provide range switching. These are AB, E3, XG3 and XB3.

The POL output is a square wave that changes phase when the analog input changes polarity. With the analog input positive, the POL output is in phase with the backplane signal. When the analog input goes negative the POL output changes to being in anti-phase with the backplane signal.

The clock output (CLK) can be used for systems timing or as an input, in which case the internal oscillator may be over-ridden and the sample rate changed.

The module is supplied with REF+ adjusted to +100mV with respect to REF-. REF BG is + 1.2V with respect to REF-.

When the TEST pin is connected to the positive supply all the LCD segments should turn on and the display should read -1888 if none of the annunciators is connected. TEST should not be connected to the positive supply for long periods because a DC potential is applied to the segments and this may cause damage. TEST may also be used as a negative supply with a maximum load of 1mA.