How to use digital voltmeter modules
Part 1

The popular DPM-05 digital voltmeter module with 3½-digit liquid crystal display is a very convenient 'workhorse' for a myriad of applications. This two-part feature tells you how to put it to use. The ETI-161 Digital Panel Meter is very similar and can be used in many of the circuits given.

Ray Marston

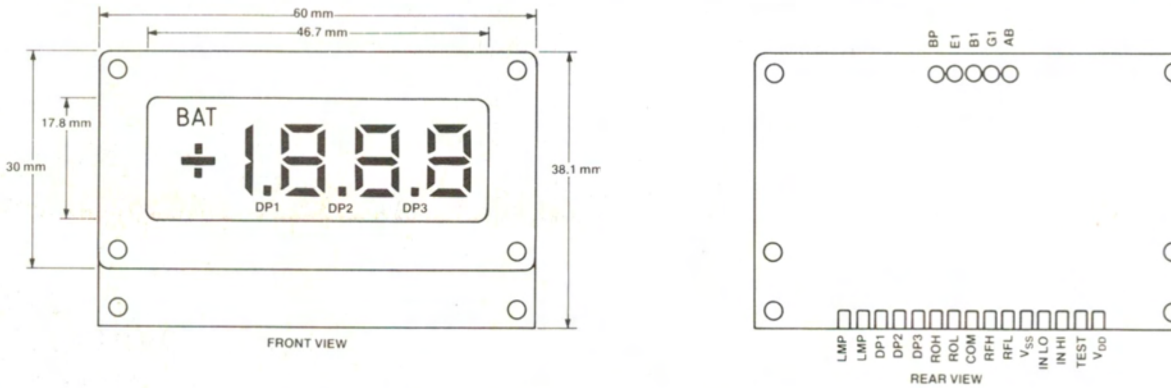


Figure 1. Physical details (left) and terminal notations (right) of the DPM-05 module.

MODERN DIGITAL VOLTMETER (DVM) modules can be used to replace moving coil meters in virtually all important 'analogue' measuring applications. Most of these modules combine an Intersil ICL7026, 7126 or 7136 analogue-to-digital (A-D) converter chip and a 3½-digit liquid crystal display plus a band-gap voltage reference and a few other components, into a compact module that consumes less than 1 mA from a 9 V supply and costs little more than a good quality moving coil meter.

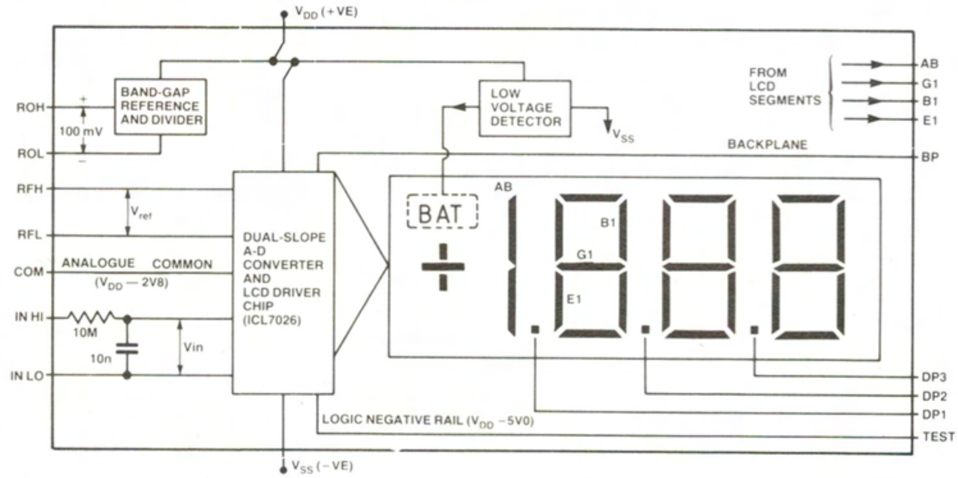
Usually, these modules have a basic full-scale measurement sensitivity of ±199.9 mV, with 100 uV (2000-count) resolution and a typical calibrated accuracy of 0.1% ±1 digit, but can be used to read any desired current or voltage range by connecting suitable shunts or potential dividers to the input terminals. When connected to suitable external circuitry, the modules can be made to indicate ac voltage or current, resistance, capacitance, frequency, temperature, or any other parameter than can be converted into a linear analogue voltage or resistance. I'll show you how later in this two-part feature.

Several companies manufacture 3½-digit LCD DVM modules. Generally, these modules differ only in details of their internal circuitry and displays and in the number and notations of their user-available terminals. The DPM-05 module manufactured by Printed Circuits International Ltd, imported and distributed here by Jaycar, is probably

CHARACTERISTIC	DATA (at 25°C)
Display	3½ digit LCD
Full scale sensitivity	±199.9 mV
Power supply voltage	9 Vdc nominal (range 7 to 10 V)
Supply current	1 mA typ, 2 mA max
Initial calibration accuracy	better than ±0.15% of reading ±1 count
Zero-input reading	±000.0 typ.
Display resolution	1 count = 100 μV
Input leakage current (at V_{in} = 0)	1 pA typ, 10 pA max
Operating temperature	0°C to +50°C
Clock frequency	40 kHz typ
Sample rate	2.5 readings/s
'Low battery' indication voltage	7.2 V typical

Table 1. Main parameters and features of the DPM-05 module.

Figure 2. Block diagram 'user view' of the DPM-05 module.



the best known and most widely available model, and is very typical of the genre, so we'll refer to this specific device throughout the rest of this article. Figure 1 shows the physical details and terminal notations of the DPM-05 and Table 1 lists its main parameters and features.

The ETI-161 Digital Panel Meter module is very similar. This was published in the August 1982 issue and kits are widely available. The accompanying panel shows the circuit and a rear view of the pc board with equivalent connections to those of the DPM-05 annotated. Note that the ETI-161 does not include the band-gap reference. Lab Notes in the November 1980 issue gives circuit details of a band-gap reference that could be adapted to the circuits in this feature, if necessary.

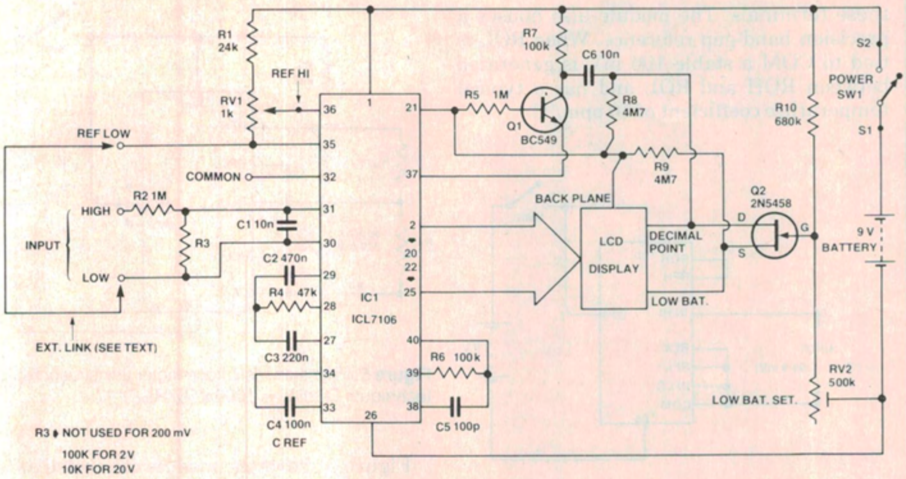
DPM-05 basics

Figure 2 shows the block diagram 'user view' of the DPM-05, which is normally powered from a 9 V battery connected between the V_{DD} and V_{SS} terminals. The heart of this particular unit is an ICL7026 chip which is a complete dual-slope analogue-to-digital converter and LCD driver. In essence, this chip automatically compares the relative values (ratios) of V_{ref} and V_{in} and produces an LCD display of 1000 x V_{in}/V_{ref}, updating the display about 2½ times per second.

Thus, if V_{ref} is 100 mV and decimal point DP3 is activated, the display reads 10.0 with an input of 10.0 mV, or 199.9 with an input of 199.9 mV. The module automatically displays the polarity of the input signal, gives automatic zero adjustment, and gives over-range indication by blanking the three least significant digits of the display. The three decimal points of the LCD are externally available at the DP1 to DP3 terminals, and can be turned on by pulling the appropriate terminal to V_{DD}. The module also houses a 'low battery' detector, which turns on an 'annunciator' in the display when the battery voltage falls below 7.2 volts.

It is important to note that the DVM module actually displays the relative *ratios* of the input and reference voltages. To give maximum versatility, each of the voltages is applied to the module via a *pair* of terminals (RFH and RFL for the reference, IN HI and IN LO for the input), and the integrator chip responds to the differential values of these inputs. In use, these terminals must be tied (either directly or indirectly) to within 500 mV of the COM terminal. When correctly used, the terminals have typical input impedances of about 5000 megohms, and pass typical leakage currents of only a few picoamps. The IN HI terminal incorporates an integrating ripple-reduction filter.

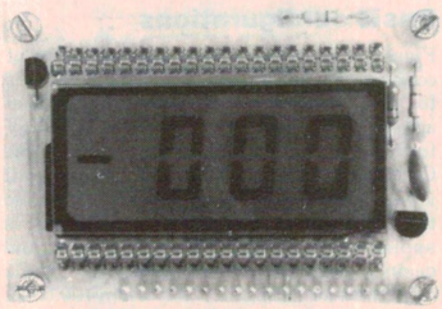
The module has two built-in reference-voltage sources. The voltage between the COM and V_{DD} terminals is zener-regulated at 2V8 and has a typical temperature co-efficient of 80 ppm/°C, so any reference voltage below this value can be obtained by wiring a simple potential divider between▶



ETI-161 Panel Meter. Circuit of the ETI-161 panel meter project which can be used in almost all the applications circuits given in this two-part series. Many circuits require direct access to 'REF HI' (RFH), in which case delete R1 and RV1.

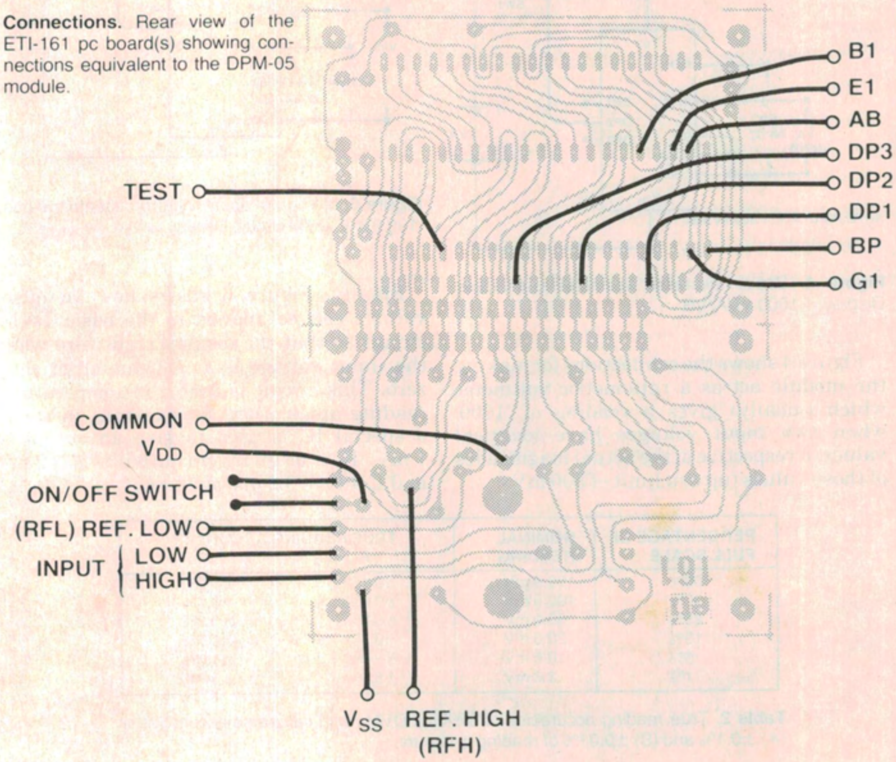
SPECIFICATIONS

Full scale readout	depends on setup. Full scale sensitivity is 199.9 mV
Resolution	100 uV
Accuracy	< 1 digit when correctly calibrated
Display	3½-digit LCD
Input Impedance	> 10^{12} ohms
Input bias current	approx. 2 pA
Polarity indication	automatic
Conversion method	dual slope
Reference	internally generated ±100 ppm
Power supply	9 V @ approx. 1 mA



ETI-161. View of the Panel Meter project published in the August 1982 issue.

Connections. Rear view of the ETI-161 pc board(s) showing connections equivalent to the DPM-05 module.



these terminals. The module also houses a precision band-gap reference. When ROL is tied to COM a stable 100 mV is generated between ROH and ROL and has a typical temperature coefficient of 50 ppm/°C.

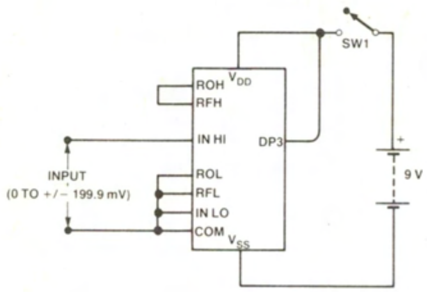


Figure 3. Standard '199.9 mV full-scale' connection of the DVM module.

Basic configurations

Figures 3 to 6 show four different ways of connecting the terminals of a DVM module to give different types of measurement action. Figure 3 shows the standard '199.9 mV full scale' DVM configuration. Here, the COM, IN LO, RFL and ROL terminals are all joined together, ROH is shorted to RFH so that the 100 mV band-gap reference is applied across the reference terminals, and decimal point DP3 is tied to V_{DD} so that the unit gives a reading of '100.0' when 100.0 mV is applied between IN HI and IN LO.

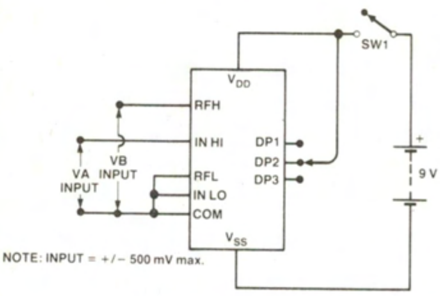


Figure 4. Basic ratiometric voltmeter connection. Display = 1000 x VA/VB.

Figure 4 shows the connections for making the module act as a ratiometric voltmeter which (ideally) gives a reading of '1000' when two input voltages have identical values, irrespective of the actual magnitudes of those values (up to a limit of 500 mV).

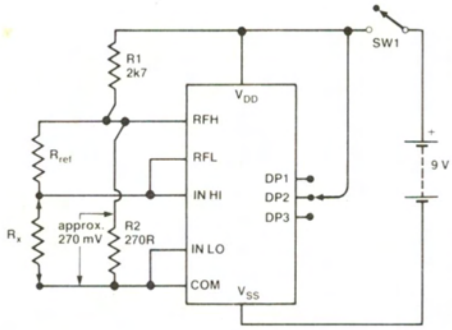


Figure 5. Precision resistance meter using ratiometric technique. Display = 1000 x R_x/R_{ref}.

Figure 5 shows the module connected as a precision ohmmeter. Here, potential divider R1-R2 generates roughly 270 mV between the R1-R2 junction and the COM terminals, and this voltage is used to energise potential divider R_{ref}-R_x. Identical currents flow through these two resistors, and the generated voltage of R_{ref} is applied across the RFH and RFL reference terminals, and the generated voltage of R_x is applied across the IN HI and IN LO input terminals. The display reading thus equals 1000 x R_x/R_{ref}. If R_x has a decade value (1k0, 10k etc), the display gives a direct readout of the R_x value, the reading being independent of the actual value of energising voltage developed across R2.

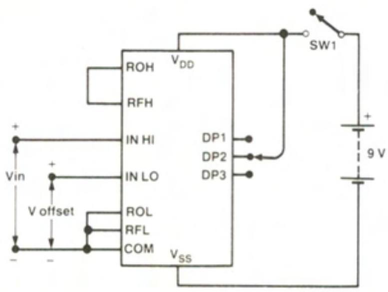


Figure 6. Method of applying zero-offset to the basic '199.9 mV' DVM circuit. Display = $V_{in} - V_{offset}$.

Finally, Figure 6 shows how an offset voltage can be applied to the basic 'DVM' circuit so that the display reads zero when the input voltage is at a value other than zero. This circuit is useful in temperature-reading applications for example, in which a special IC is used to give an output of 1 mV/°K, thus giving an output of 273.2 mV at 0°C and 373.2 mV at 100°C.

PERCENTAGE OF FULL SCALE	NOMINAL READING	TRUE READING ACCURACY A	B
100%	199.9 mV	±0.15%	±0.05%
50%	100.0 mV	±0.2%	±0.1%
25%	50.0 mV	±0.2%	±0.2%
10%	20.0 mV	±0.5%	±0.5%
5%	10.0 mV	±1.0%	±1.0%
1%	2.0 mV	±5.0%	±5.0%

Table 2. True reading accuracies of 3½-digit DVMs with calibrated accuracies of (A) ±0.1% and (B) ±0.01% of reading ±1 count.

By feeding the output of the IC between the COM and IN HI terminals and applying a 273.2 mV offset voltage between COM and IN LO, the module (which reads the *differential* value of the input) can be made to give a direct reading of temperature in degrees Centigrade.

Some finer points

If you intend to use a DPM-05 or similar module in a project, there are some fine 'usage' points that you will need to know. Let's deal with these points under various sub-headings.

Calibration accuracy. As supplied, a DVM module is pre-calibrated to read 199.9 mV full scale, with a typical accuracy of ±0.1% of reading ±1 count, at 25°C, this calibration being valid *only* when the module is used in the precise configuration shown in Figure 3. It should be noted that the best attainable accuracy of a 3½-digit (2000-count) meter is ±1 digit, and this corresponds to an actual reading accuracy of 0.05% at full scale, to 0.5% at 10% of full scale, and to 5% at 1% of full scale. Table 2 shows the reading accuracies of two meters, having different calibration accuracies, at various percentages of full scale.

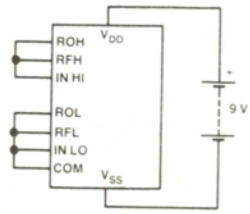


Figure 7. Ratiometric-accuracy test circuit. Ideally, the meter should read '1000'. Typically, the reading may be '998' (= 0.2% low).

Ratiometric accuracy. The DVM is a ratiometric reading unit. If connected as shown in Figure 7, with identical voltages applied to the RFH and IN HI terminals, it should ideally read '1000' ±1 count.

In practice, modules typically give a reading that is about 0.2% below this figure. This discrepancy is caused by the potential divider action of the internal 10M filter resistor and the input impedance on the internal IN HI line.

When the meter is supplied for use in the 'voltmeter' mode, it is calibrated to allow for ratiometric errors.

Reference accuracy. The built-in '100 mV' reference (between ROH and ROL) of the module is factory-calibrated so that the meter reads '100.0 mV' with 100.0 mV input applied. The precise value of the reference voltage depends on the ratiometric accuracy of the meter. Thus, if the ratiometric accuracy is 0.2% low (reading 998), the reference is also set 0.2% low (at 998 mV) to give the correct 'voltmeter' accuracy.

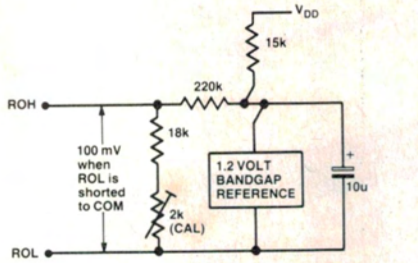


Figure 8. Typical bandgap reference circuit has an output impedance of about 20k.

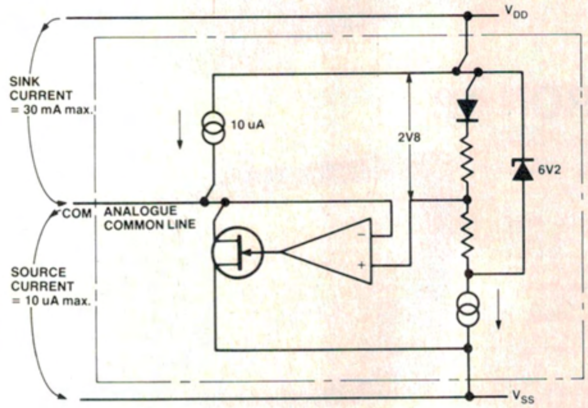


Figure 9. Analogue COMmon line biasing circuit within the A-to-D converter chip.

The reference output is accurate only when ROL is tied directly to COM (which is normally 2V8 below V_{DD}) and when ROH is loaded by an impedance greater than 50 megohms or so. Figure 8 shows the typical circuit of a band-gap reference. The output impedance of the circuit is about 20k so an external loading of 2M would introduce an error of 1%, and a loading of 20M an error of 0.1%. The high input impedance of the RFH terminal causes negligible loading.

Input connections. The A-D converter chip houses analogue and digital circuitry. All analogue action is internally referenced to the COM (common) line of the chip. Normally, the INPUT and REFERENCE inputs should be tied (directly or indirectly) to within 500 mV of the COM line, and under these conditions the terminals have very high input impedances and draw leakage currents of only a few picoamps. If the terminals are biased at voltages significantly different from COM, the input leakage currents may rise to several hundred picoamps, invalidating the auto-zero action of the chip. The chip may be damaged if the terminals rise above V_{DD} — 0.5 V or below V_{SS} + 1 V.

'COM' terminal. The COM terminal of the module is connected to the circuit of Figure 9 within the A-D chip, and this circuit enables the COM terminal to be used as either a precision voltage reference, as a current sink for external circuitry, or as an externally-biased analogue-reference point.

When used as a voltage reference, only very low external sink currents (below 100 uA) must be allowed to flow between V_{DD} and COM. Under this condition the basic calibration of the module is valid, and the COM terminal is held about 2V8 below V_{DD}, with a temperature coefficient typically less than 80 ppm/°C.

When used as a current sink, external currents of up to 30 mA can be allowed to flow between V_{DD} and the COM terminal (which has an impedance of about 15 ohms in this mode). In this mode, however, the basic calibration of the module may be invalid, and the RFH and RFL terminals may have to be driven from an external reference.

The COM terminal can source currents up to a maximum value of only 10 uA. Consequently, the common line of the A-D chip can be tied to a value that is more than 2V8 below V_{DD} by simply connecting the COM terminal to an external bias voltage of the required value. In this mode, the basic calibration of the module is invalid, and the RFH and RFL terminals must be driven from an external reference; the INPUT and REFERENCE terminals must be tied within 500 mV of COM (see Figure 12). Note that COM should not be allowed to fall to a value more than 4V7 below V_{DD}.

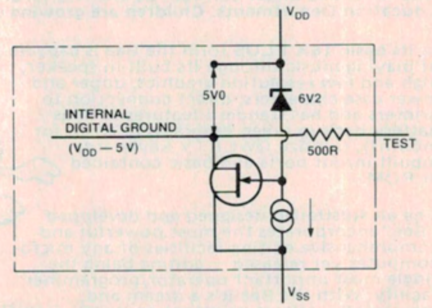


Figure 10. Internal digital ground biasing circuit of the A-to-D converter chip.

TEST & BP. The negative or ground rail of the digital circuitry of the A-D chip is internally biased at about 5 V below V_{DD} by the circuit of Figure 10 and is coupled to the TEST terminal via a 500 ohm resistor. This terminal can be used as the negative rail of external digital circuitry that is powered from V_{DD}, provided that the TEST currents do not exceed 1 mA.

If TEST is shorted directly to V_{DD} the LCD should read '−1888'; under this condition 10 mA flows into the TEST terminal and a steady dc voltage is applied to the LCD; this voltage may burn the display if sustained for several minutes.

The back-plane (BP) drive signal to the display switches fully between TEST and V_{DD} at the clock frequency divided by 800. With a 40 kHz clock, BP has a frequency of 50 Hz (giving a period of 20 mS). Note that the calibration accuracy of the module is independent of the clock frequency, which is thus not designed to be particularly stable.

Auxiliary terminals. The DPM-05 has a number of auxiliary terminals that are used only in special applications. The two LMP terminals give access to a backlight bulb fitted to the LCD in some special modules.

The AB terminal connects to the '1000' digit of the LCD, and the E1, B1 and G1 terminals connect to the E, B and G segments respectively of the '100s' digit of the LCD. These terminals can be decoded with the BP signal to detect the over-range (O/R) and under-range (U/R) states of the module and thence activate auto-ranging circuitry, etc. Figure 11 shows the external decoder circuit that must be used; the two ICs are powered from the V_{DD} and TEST terminals.

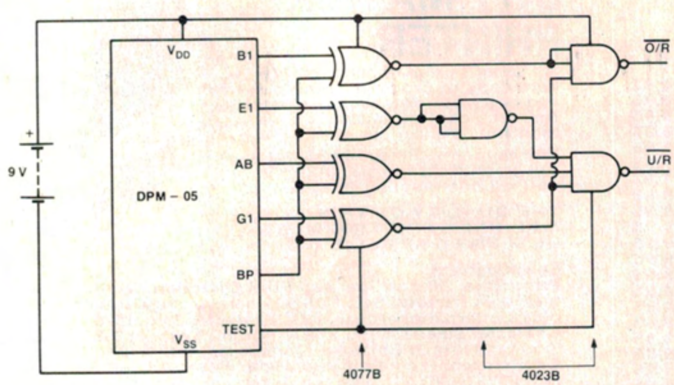


Figure 11. Circuit for developing under-range and over-range signals from the DPM-05.

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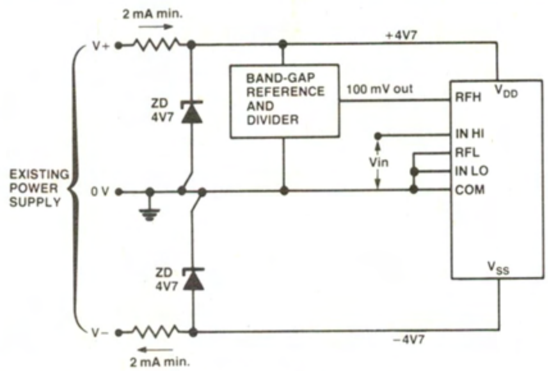
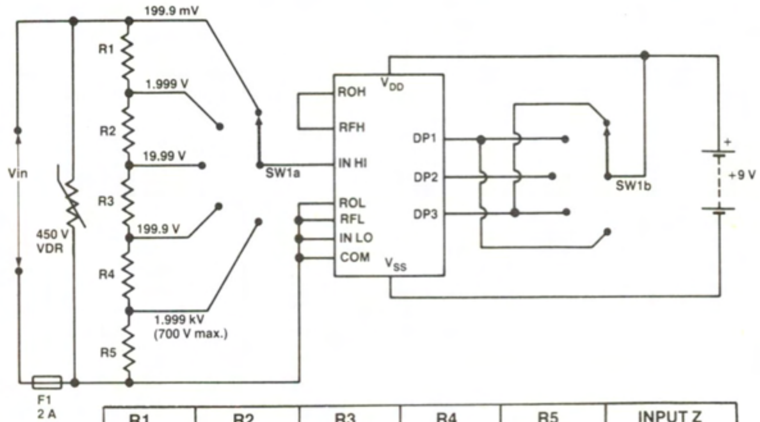


Figure 12. Method of building the module into existing equipment that is powered from split supply rails.



R1	R2	R3	R4	R5	INPUT Z
9M 10M	900k 1M	90k 100k	9k 10k	1k 1110R	10M 11.11M

Figure 15. Five-range dc voltmeter.

Power supplies

The most popular application of the DVM module is as a self-contained multimeter which is used as a general purpose test instrument. In this type of application the module is simply powered from a 9 V battery connected between V_{DD} and V_{SS}.

The module can, however, be built into existing equipment and used in dedicated measuring/indicating applications.

If the equipment is powered from a single-ended supply, the module must be powered from its own 'floating' supply, derived from either a battery or from a separate winding of a mains transformer.

In the case of a battery-powered instrument, the supply to the meter can be switched by a spare pair of contacts on the main switch.

If the equipment is powered from split supplies, the module can be powered from the existing power rails by using the connections shown in Figure 12, in which COM is tied to the common rail, V_{SS} is fed from −4V7, V_{DD} from +4V7, and the REFERENCE and INPUT terminals are referenced to the COM terminal. The RFH terminal must be driven from an external reference, as shown.

PRACTICAL APPLICATIONS

DC volt & current meters

The DVM module is supplied ready-calibrated to give a full scale reading of ±199.9 mV dc. The module can be made to give alternative full scale dc voltage readings by connecting the input voltage to the module via a decade potential divider, as shown in Figure 13, or can be made to act as a dc current meter by wiring a suitable shunt resistor across the input terminals, as shown in Figure 14.

Note in both diagrams that the appropriate decimal point of the display must be tied high on each range, as indicated.

The module can be used as a five-range dc voltmeter by using the connections shown in Figure 15; the table shows alternative potential-divider component values to give input impedances of 10M or 11.11M.

Precision '9'-decade (9M, 900k, etc) resistors are used in most multimeters and are available from several component suppliers. Note that in multi-range applications the circuit should be provided with some form of overload protection, and in the diagram this is given by fuse F1 and by a voltage-dependent resistor (VDR) or 'transient suppressor' across the divider. Also note that on the '1.999 kV' range the maximum input is actually limited to 700 volts by the VDR.

The module can be used as a five-range dc current meter by using the connections shown in Figure 16. Note here that the generated voltages of the shunts are directly monitored by the DVM module, and that variations in the switch resistance of SW1a have no effect on the accuracy of measurement; a separate input terminal is used for the '2 Amp' measurement. The circuit is protected against positive and negative overloads by diodes D1-D2 and fuse F1.

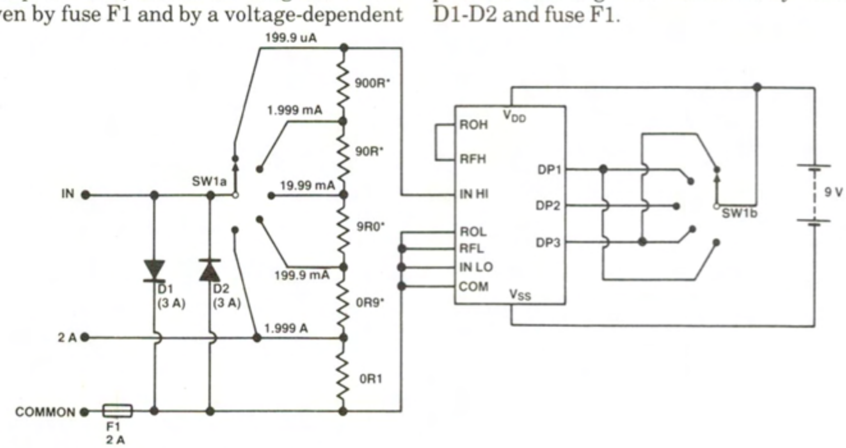


Figure 16. Five-range dc current meter.

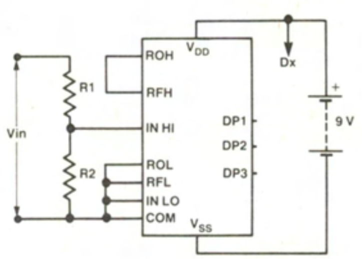


Figure 13. The DVM module can read alternative dc voltage ranges by connecting the input via a potential divider.

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R1	R2	V FULL SCALE	DECIMAL POINT HIGH
0	10M	199.9 mV	DP3
9M	1M	1.999 V	DP1
9M9	100k	19.99 V	DP2
10M	10k	199.9 V	DP3
10M	1k	1.999 kV	DP1

R1	I FULL SCALE	DECIMAL POINT HIGH
10k	19.99 µA	DP2
1k	199.9 µA	DP3
100R	1.999 mA	DP1
10R	19.99 mA	DP2
1R	199.9 mA	DP3
0R1	1.999 A	DP1
0.01R	19.99 A	DP2

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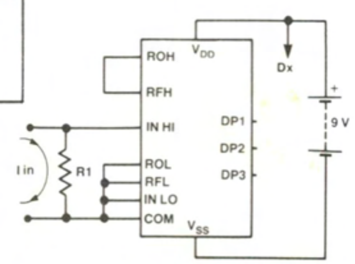

Figure 14. The DVM module can be made to read dc current by connecting a shunt resistor across its input.

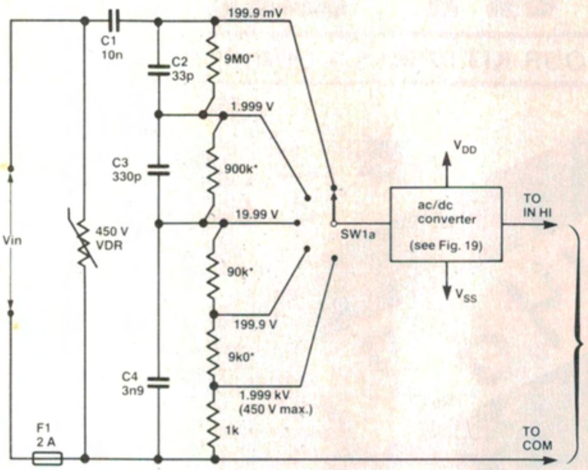

Figure 17. Modification of the Figure 15 circuit, to act as a five-range ac voltmeter.

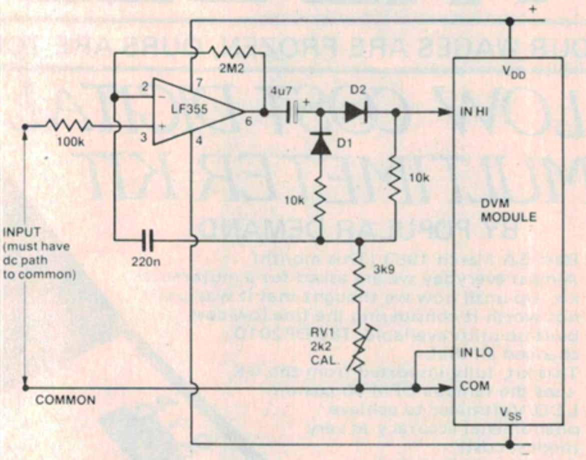

Figure 19. Precision ac/dc converter.

AC volt & current meters

Figure 17 shows how the Figure 15 circuit can be modified to act as a five-range ac voltmeter that has a frequency response flat within 1 dB to about 120 kHz.

Input signals are fed to the attenuator via dc-blocking capacitor C1, and the attenuator is frequency compensated by C2 to C4. The attenuator output is fed to the input of the module via a precision ac/dc converter, which gives a dc voltage output equal to the RMS value of a sinewave input.

Figure 18 shows how the Figure 16 circuit can be similarly modified to act as a five-range ac current meter. In this case it is not feasible to prevent dc currents feeding into the shunts: instead, dc-blocking is done at the output of the shunts via C1-R1, and the resulting ac signals are fed to the input of the DVM module via a precision ac/dc converter.

Note that the input protection network of this circuit differs from that of Figure 16 in that pairs of diodes are wired in series.

Figure 19 shows the circuit of the precision ac/dc converter for use with the above two circuits. The gain of the converter can be set to precisely 2.2 via RV1, to give a dc output voltage that is equal to the RMS value of a sinewave input.

The converter is powered from the supply rails of the module, and is designed around an LF355 op-amp, which can operate quite happily from the 2V8 between V_{DD} and COM.

Resistance meters

The easiest way to use a DVM module as a resistance (ohm) meter is to use it in the ratiometric configuration shown in Figure 5. This technique has two major advantages. First, it is very stable and inherently self-calibrating, the meter reading being equal to R_x x (RV/R_{ref}), where RV is the ratiometric value of the meter when used in the Figure 7 test cicuit. RV is typically only 0.2% low, so measurement accuracy is determined primarily by R_{ref}. The second advantage is that very low test voltages are generated across R_x, the maximum voltage being ⅔ of the energising voltage (typically 100 to 300 mV) at full scale. Figure 20 shows how the module can be connected as a practical five-range ohmmeter. ●

Next month

In the concluding part next month will be a 25-range DMM, temperature, capacitance and frequency meters plus practical construction advice.

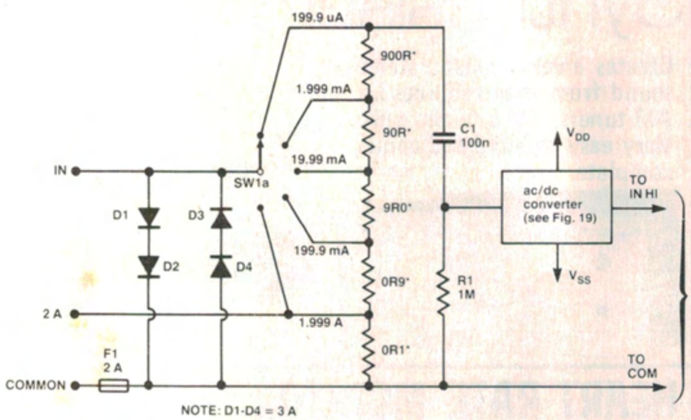

Figure 18. Modification of the Figure 16 circuit, to act as a five-range ac current meter.

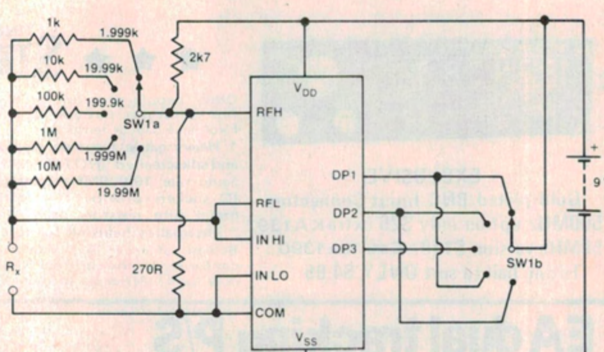

Figure 20. Five-range ohmmeter.