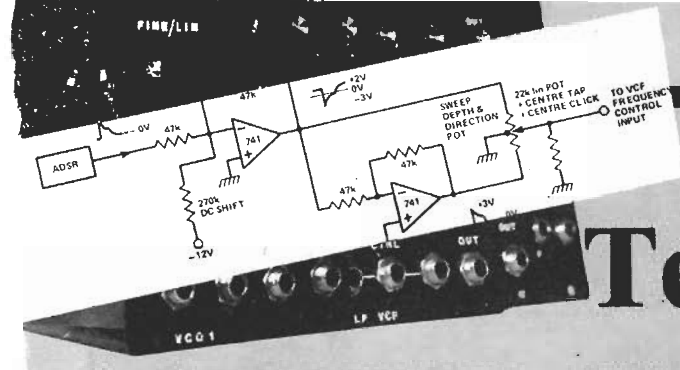

Instrumentation Techniques Part 1

Nowadays, measurement usually means digital measurement. Tim Orr looks at instrumentation techniques with details of how to use DVM chips to get all the basic ranges of a multimeter, and more!

THE FOLLOWING sections should give you enough information to go ahead and design your own digital multimeter, customised to give exactly the ranges and features you find most useful. We also look at techniques for measuring temperature and dealing with very small signals.

Dedicated DVMs

Intersil make a pair of DVM chips (Fig. 1, Fig. 2) that make life very easy if you want to measure and display a voltage. These chips are the ICL7106 and the 7107 and they seem to have become an industry standard. The first device is an LCD version and the whole lot consumes a mere 1 mA when running; it can run from a single 9V battery. The second device uses an LED display. The display may consume up to 100 mA, making battery operation a problem. Several companies make modules that contain both the DVM chip and a display. All you need to do is power it up and send it a voltage. It is, in fact, an 'instant' DVM module — no talent required.

The Intersil chips have a differential input with an input current of only 10 pA maximum, 1 pA typical. The devices have an auto zero facility so that they automatically cancel out any offset voltages at the input. The input sensitivity is 200 mV, but by connecting various amplifers, attenuators, RMS and dB converters and filters to the DVM chip a wide range of signal measurements can be performed.

Measuring Voltage . . .

Figure 3 shows the standard 1 megohm input impedance decade attenuator that is used in most digital multimeters. The very high input impedance of the 7106/7 produces negligible loading of the attenuator network. Figure 4 shows a standard four decade DC voltmeter circuit. If voltages below 200 mV are to be investigated then a preamplifier with low offset and drift characteristics is needed. The resistors used in the attentuator are standard E96 values and can be obtained with a 0.5% tolerance.

. . . Current . . .

Figure 5 is a current meter circuit; the current is made to pass through shunt resistors. This sets up a DC voltage (no more than 200 mV) which is measured by the DVM chip. The input is protected by a diode bridge that pops the fuse when the input voltage exceeds 1V8 (three diode voltages) and the current exceeds 3 A. If you could pass unlimited current through the resistor network then you would probably end up with a fire!

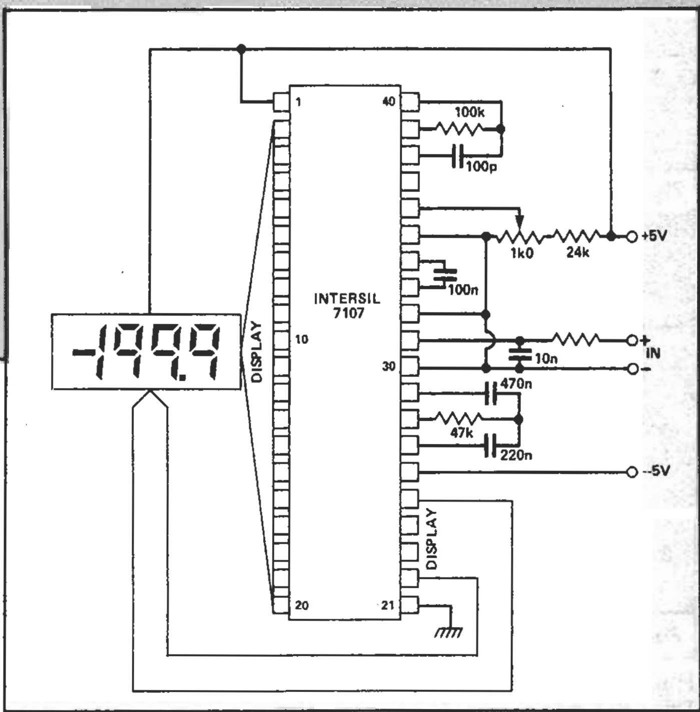

Fig. 2 The Intersil ICL7107 with LED display.

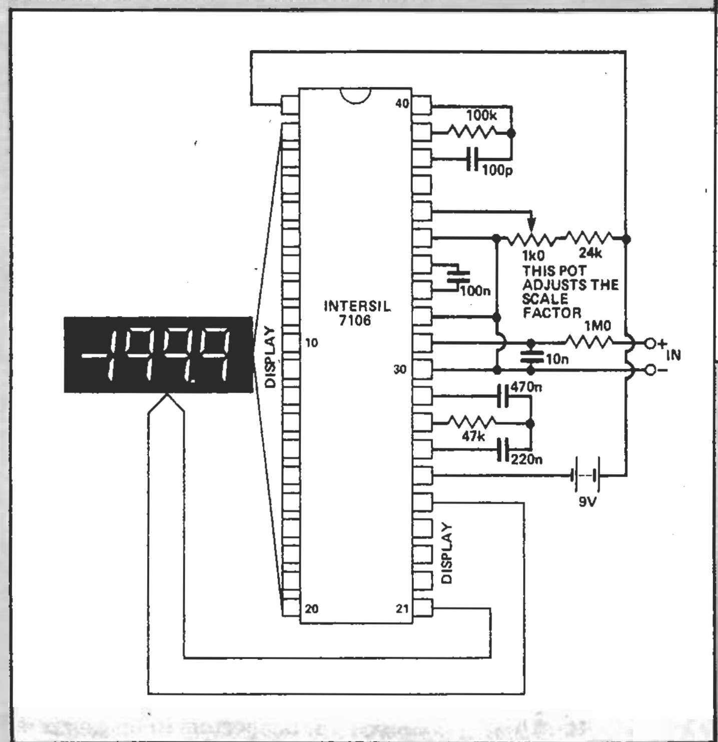

Fig. 1 The Intersil ICL7106 with liquid crystal display.

. . . And Ohms

Figure 6 is an ohmmeter circuit. The 741 op-amp generates a precision and stable −1V2 DC reference voltage which causes a fixed current to flow into the virtual ground input of the LF355; the current will be 10 mA using the 120 ohm resistor,

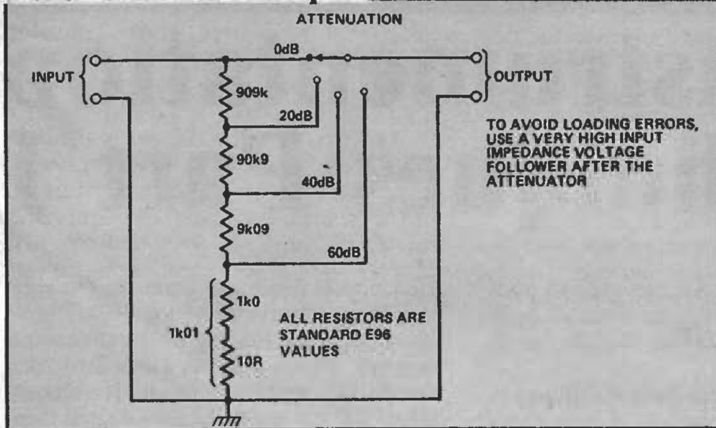

Fig. 3 A 20 dB step attenuator.

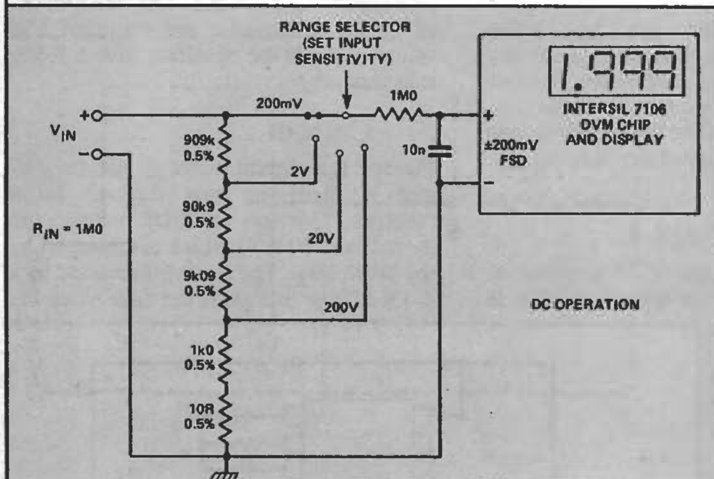

Fig. 4 A decade 3½ digit digital voltmeter.

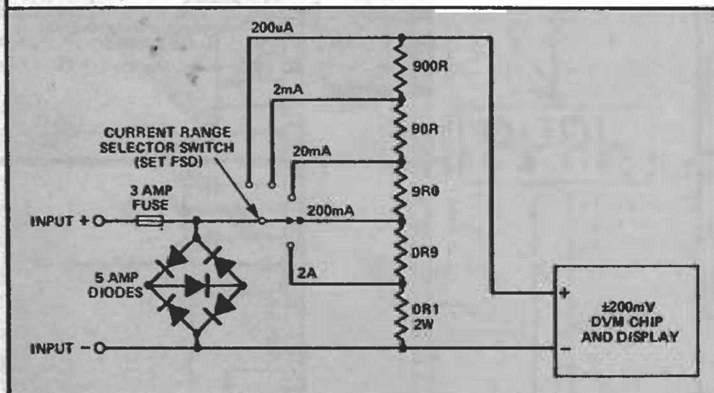

Fig. 5 A five decade DC current meter.

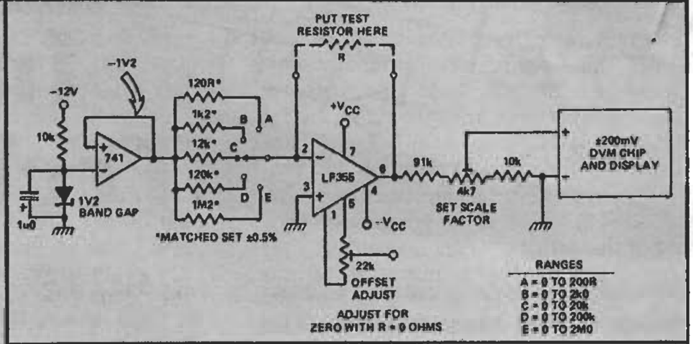

Fig. 6 A five decade ohmmeter.

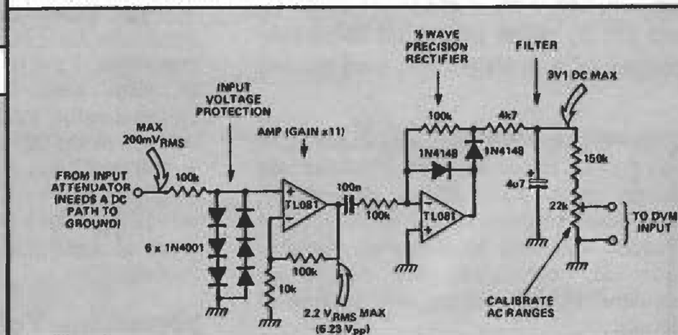

Fig. 7 An AC voltage and current converter. This is only accurate for sine waves.

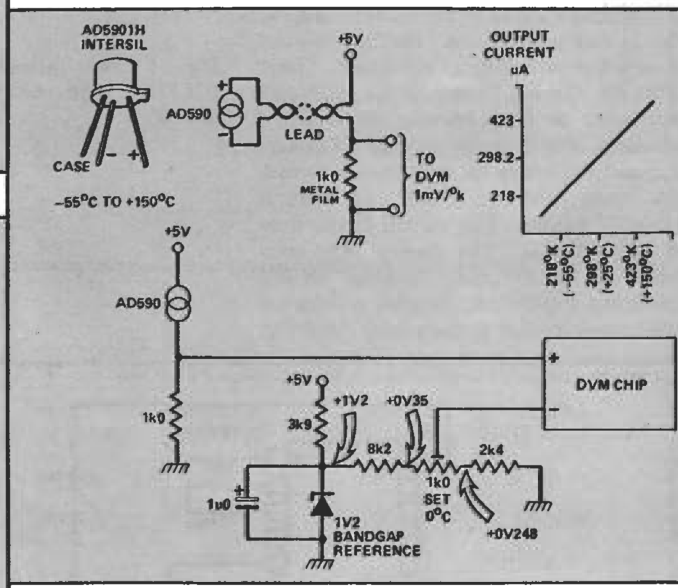

Fig. 8 Reading degrees Kelvin (top) and Centrigrade (bottom).

1 mA using the 1k2 resistor and so on. This fixed current also flows through the test resistor which is the feedback route for the LF355 and in doing so sets up a voltage that in linearly proportional to the value of the test resistor. At 'full-scale-deflection' the output of the LF355 is 2 V which is attenuated to 200 mV; this voltage is then fed to the DVM chip. The LF355 is a JFET op-amp which has a small input current and offset voltage and low temperature drift characteristics. Even so it is better to run the output at 2 V and then attenuate it to 200 mV, because this also attenuates any residual offsets and other errors. The bandgap diode is a national LM113.

Figure 7 shows a simple AC converter circuit. It can be used to measure VRMS and IRMS for a sine wave input. The circuit is a high impedance buffer/amplifier with a half-wave precision rectifier and smoothing circuit.

Measuring Temperature

Intersil makes a device called the AD5901H which converts temperature into current; the device generates an output current of 1uA per degree Kelvin. Absolute zero in degrees Kelvin is −273.2 °C and so 0 °C = 273.2 °K. If this temperature-dependent current is dumped into a 1k0 resistor than the voltage across the resistor will increase by 1 mV per degree K (or C) — see Fig. 8. The operating range of the device is −55 °C to +150 °C which will generate a voltage change of 205 mV across the 1k0 resistor. This can easily be displayed on the ±200 mV range of the DVM chip. The sensor plus the DVM and display make a very simple and compact battery operated digital thermometer.

Amplifying Small Signals

Often you need to amplify very small DC voltages. The ouput from strain gauges or thermocouples is very small, often below 1 mV. This would hardly cause any movement in a 200 mV DVM chip. However, an amplifier that will operate in the sub-millivolt area is quite difficult to make with any accuracy. For example, a 741 op-amp might have an input offset of 2mV (Table 2). This error is actually bigger than the voltage we are measuring!

There are four main sources of error. I_B, the input bias current, has to flow through R1 and R2 and in doing so upsets the gain equation. Note that I_{B-} is not exactly the same value as I_{B+}! V_{OS} is the input offset voltage which represents a DC input imbalance. This also upsets the gain equation. Furthermore, V_{OS} has a temperature coefficient V_{OSTC} which is the maximum change in V_{OS} per degree C. So the amplifier will drift with temperature. V_N is the input noise voltage, which is multiplied by the fixed gain on the amplifier. If the noise is similar in amplitude to the input voltage then you are going to get noisy readings. Finally, the input offset voltage drifts with time — it ages! Very few manufacturers provide information regarding this parameter.

The selection chart (Table 2) shows a range of instrumentation and ordinary op-amp error parameters. The way to overcome these errors is to use a suitable op-amp rather than to use a low performance part and to try and cancel out all the drifts and offsets. The details given in the chart only show some of the many parameters that manufacturers specify. Devices are often graded into several performance categories, so if you want to design high quality amplifiers then refer to the manufacturers' detailed data.

TABLE 1

DEVICE	E IN uV RMS (AVERAGE OF SEVERAL SAMPLES)	NOISE LEVEL RELATIVE TO NE5534 IN dBs
NE5534 (SIGNETICS)	0.59	0
RC4136 (RAYTHEON)	0.87	+3.4
RC4739 (RAYTHEON)	1.00	+4.6
RC4558 (RAYTHEON)	1.05	+5.0
TL081 (TEXAS)	1.61	+8.7
741 (VARIOUS MANUFACTURERS)	1.72	+9.3

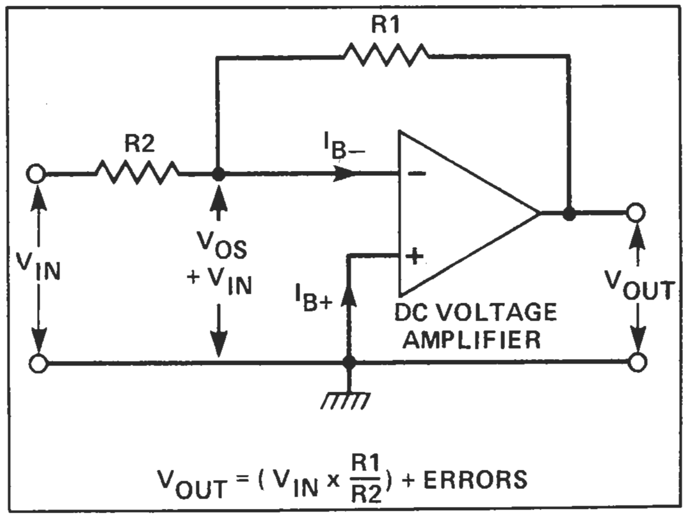

Fig. 9 Choosing a precision op-amp. Table 1 (left) gives some typical noise results, Table 2 (below) shows typical values for the errors shown in the above diagram.

TABLE 2

DEVICE MANUFACTURER	LM363 NAT. SEMI	ICL7650 INTERSIL	LF355 NAT. SEMI	TL081 TEXAS	741 —	725 —	OP-27A/E PMI
I_B	2 nA	10 pA	30 pA	5 pA	80 nA	42 nA	10 nA
V_{OS}(uV)	30	1	2000	5000	2000	500	10
V_{OSTC} (uV/°C)	2	0.05	5	20	2	0.6	0.2
NOISE (V_n) (nV/√Hz)	12	2 uV_{pp}	20	20	14	9	3
LONG TERM DRIFT	—	100 nV/month	—	—	—	—	200 nV/month
COMMENTS	A_V = 100	Chopper stabilised op-amp	JFET op-amp	JFET op-amp	Bipolar op-amp	Instrumentation op-amp	Ultra-low noise precision op-amp

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