ACCURACY OF DIGITAL VOLTMETERS

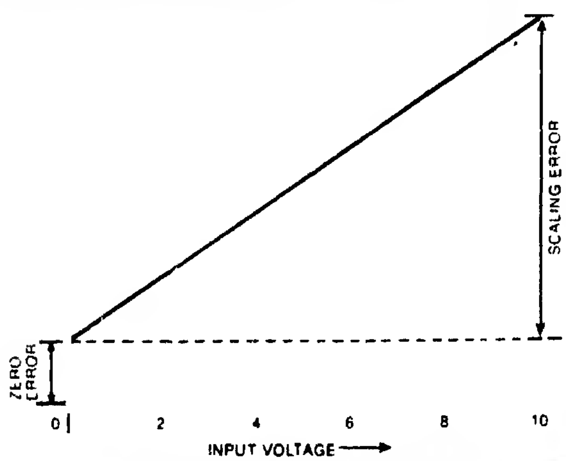
K. Kalidas

The digital voltmeters are extensively used as standard test instruments in the engineering laboratory and also as components in automated instrumentation systems Often the exact conditions under which measurements will be performed are unknown at the time of instrument purchase. The user generally prefers an instrument whose performance is relatively independent of environment and has a good degree of accuracy over the range of applications. But the user must know two factors; the accuracy of the instrument he needs, (a highly accurate instrument can mean an unnecessary expense when it is only intended for use in a system of lower accuracy) and what the manufacturer means by accuracy of the instrument for his range of applications.

Here an attempt is being made to describe how precisely the accuracy of a digital voltmeter (DVM) can be specified by the manufacturers, and evaluate the sensitivity, resolution and various other sources of errors that can affect the measurements. A discussion on the selection of an instrument for a given measuring application is also presented

Accuracy specification of a DVM

The accuracy statement of a DVM defines the limit of error within which a digital voltmeter will indicate the values of the parameter being measured. It is normally assumed that the error is specified with respect to a standard volt.



Gig. 1: **The error of a reading over a single range of readings of a DVM.**

The accuracy specifications are usually expressed in two parts: **a percentage** of reading error and a percentage of full scale error. **This is** because some sources of error are fixed and are **independent** of the input signal, while other sources vary with **the magnitude** of the input signal. The fixed errors **expressed as a percentage** of full scale error are generally related to **the internal noise** level, amplifier zero drifts and **offset voltages arising in switches** used in the DVM. The errors proportional to signal amplitude, expressed as a percentage of reading, are associated with the inaccuracies in amplifier gain, divider networks and the internal reference voltage. The effects of these two types of errors on the actual accuracy of a reading are significantly different

A typical accuracy statement for a 4½-digit (maximum reading 19999) DVM may be ± 0.05% of reading + 0.02% of

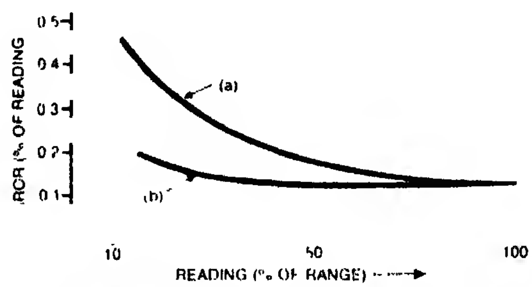


Fig. 2: **Characteristics of two DVMs having accuracy statements: (a) ± 0.05% of reading ± 0.5% of full scale, and (b) ± 0.09% of reading ± 0.01% of full scale.**

range. The ± 0.02% of range in the above statement is thus equivalent to ± 4 in the last digit. At the top end of the range, the maximum error will be 0.05% of 19999±4 = 14 or 0.07%. At the lower end of the range, just before it is switched to a more sensitive range, the maximum error is 0.05% at 2000 + 4 = 5 or 0.25%.

The total error of a reading over a single range of readings of a DVM is as shown in Fig. 1

Considering two DVMs having accuracy statements as: (a) ± 0.05% of reading ± 0.05% of full scale and (b) ± 0.09% of reading + 0.01% of full scale, it is evident from Fig. 2 that the two accuracy statements permit the same error at full scale, but a DVM with accuracy statement (b) Is better than the other as it is two times more accurate when measuring signals at one-tenth of the full scale

Sensitivity and Resolution

A DVM which can just detect 10 mV is said to have a sensitivity of 10 mV. However if it can just distinguish between two levels 10 mV apart, for instance 19.98 and 19.99 volts, then it is said to have a resolution of 10 mV.

It is also important to note that a statement that the resolution is 10 mV does not imply that the instrument is as accurate as this. In particular, the input attenuator and range control can affect accuracy, resolution and sensitivity.

Effects of environment

The accuracy specification defined by the manufacturers generally expresses the performance of DVM under optimum conditions and within a definite period of time or check out. It is the built-in accuracy which takes into account the resolution, short-term stability of the internal reference, and precision of the resistors used as range dividers. In addition to this built-in accuracy, the accuracy of the DVM is also affected by the environmental factors such as temperature, humidity, superimposed noise, ground loops and high source resistance.

Time and temperature effects

Digital voltmeters of similar specifications will show different accuracies when they are operated over extended periods of time and range of temperatures. Every DVM requires periodic recalibration: the frequency of recalibration is determined by the accuracy required.

The manufacturer usually provides a statement defining an instrument's temperature coefficient. Like accuracy statement, the temperature coefficient statement is also given in two parts. A typical temperature coefficient statement might be ± 0.0002% of reading ± 0.0001% of range per degree centigrade The error corresponding to this statement along with the accuracy statement (± 0.004% of reading ± 0.001% of range) at 25 ± 5°C a DVM is shown in Fig. 3 for a temperature range from 0°C to ± 50°C, which is generally accepted as the standard temperature range for specifying the operation of DVMs.

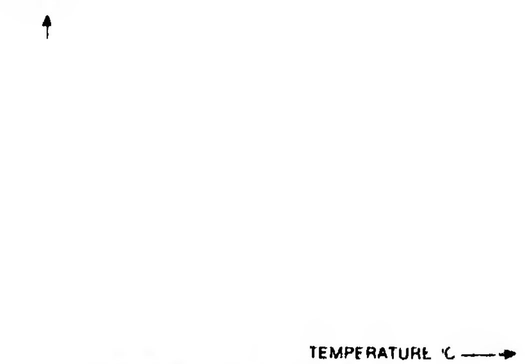


Fig. 3: Dependance of a DVM reading on temparature over the standard 0°C to 50°C range.

Effect of load errors

The load error also affects the measurement of a DVM. In order to make the full use of the accuracy of digital equipment, it is to be realised that a ratio of 1: 1000 between the source impedance and the input impedance of the voltmeter will double the error of an 0.1% instrument. Hence an input resistance of at least 10 megohm is a must for a digital voltmeter

Effect of offset current errors

The offset current in the amplifiers is an important source of error when measurements are made in high-ohmic circuits. One nano-ampere offset current produces an error of 10 in the last digit of an instrument with 10 μV resolution, when it is passed through an impedance of 100 megohms. The offset current is temperature dependent, and hence compensation must be provided to reduce this current to a low minimum value.

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At present he is working as a research officer (Telecom) in the Instrumentation division of Central Water & Power Research Station, Pune, since 1976. Here he is engaged in the design & development of instruments for measuring the hydrological parameters. He is interested mainly in microwave solidstate devices and digital electronics.

He received the best project work award from the director of technical education, Tamil Nadu in 1972.

Effects of series mode errors

The series-mode signal is the AC signal present in a DC measurement output. This AC signal can be eliminated in DVM by using the integrating analogue to digital coverters. The extent to which the AC signal (series-mode signal) is rejected by an instrument is expressed in terms of the series-mode rejection ratio (SMRR), which is generally somewhere in the range between 100: 1 (40 dB) and 1000: 1 (60 dB) with respect to a specified frequency.

Effects of common-mode errors

Common-mode voltages are those voltages which appear in both sides of a signal line to a common reference point, generally the common point of earth. The common-mode rejection (CMR) is usually specified separately for DC and AC voltages.

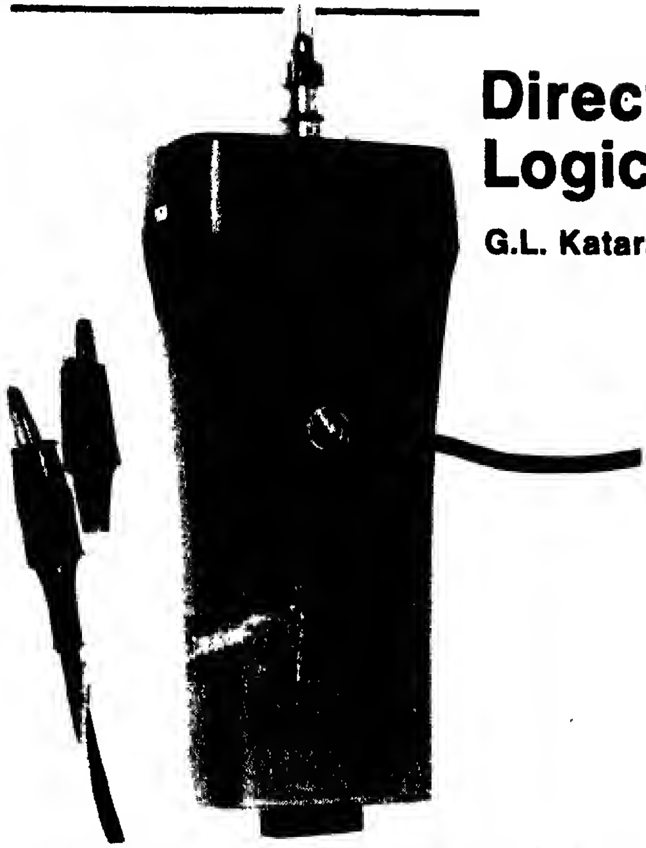
The CMR for DC depends mainly on the insulation between the low voltage lead and the voltmeter ground. For good common-mode rejection for AC signals, the stray capacitance between the low voltage leads and the ground should be as low as possible.

Effect of thermal noise

Another source of error which is encountered mainly at the lower end of the range is due to thermal noise. The thermal noise of the input resistance gives rise to an error voltage in the AC ranges at open input. It can be calculated from:

$$V = \sqrt{R^2 - S^2}$$

where V is the voltage applied to the input, R is the reading displayed and S is the error voltage of the instrument at the same source impedance as the circuit to be measured. With the source impedances up to 10 kilohms, most AC ranges will not give more than 1% of range end value error voltage. At a reading of 10% of range this means that the error due tc noise is of the order of 0.5%.



Direct Reading Logic Probe

Make Yourself EFY Tested

G.L. Kataria

The advent of the digital electronics era in the field of electronics has made a tremendous impact. Most electronic instruments now do not have the conventional moving coil panel meters which have been replaced by the digital readouts, thus eliminating the possibility of taking wrong observations on the meter. Gradually more and more items are being converted into the digital form, and it is quite likely that the coming generations would use a lot of digital systems.

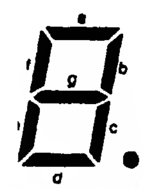
The changing concepts have brought a corresponding change in the servicing techniques also. A number of new test instruments have been developed for fault diagnosis and servicing of digital equipments. One such versatile test equipment, which I have found to be very handy and useful, is the logic probe. A logic probe is used to check the logic states in digital circuits. It can help a lot in diagnosing faulty digital circuits in which the logic states are probed and tallied with the correct or actual conditions that should have been present if the circuit was functioning properly.

This article presents details of one such probe which besides being low-cost is very compact and yet easy to assemble. An important feature of this probe is that it actually displays the logic conditions—a logic zero being indicated by the display of an actual numeral '0' and a logic one state being displayed as an actual numeral '1'. Above all, the presence of a pulse or of a pulse train is displayed by the alphabet 'P'. This probe thus differs from some other commercially available probes in which the presence of a logic zero or logic one is indicated by the glow of LED (light emitting diode) lamps.

The digital probe being discussed has been designed primarily for use in digital circuits based on the most popular TTL logic (transistor transistor logic). The TTL ICs are most widely used and have become a very big trend setter in the field of digital electronics.

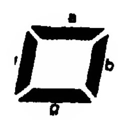
In TTL logic the worst case logic zero condition is any voltage between 0V and 0.8V, and the worst case logic one condition is any voltage from 2V to 5V. Voltages greater than 0.8V and less than 2V do not define any logic condition and hence in TTL circuits such voltages can be termed as 'incorrect logic.' The logic probe detects and displays the true logic zero and logic one conditions. For incorrect logic conditions or open circuit conditions the display is simply blanked off, i.e. neither '0' nor '1' is displayed.

For the indications of the logic conditions a 7-segment common cathode LED display has been used in this probe. A



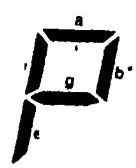
D P =DECIMAL POINT

(a) Segments configuration



(b) Indication of logic '0' condition

(c) Indication of logic '1' condition



(d) Indication of pulse condition.

(e) Indication of incorrect logic condition or open circuit condition (All segments are off) (The decimal point has been used as a 'power on' indicator)

Fig. 1: Segments configuration and the resultant indications obtained.

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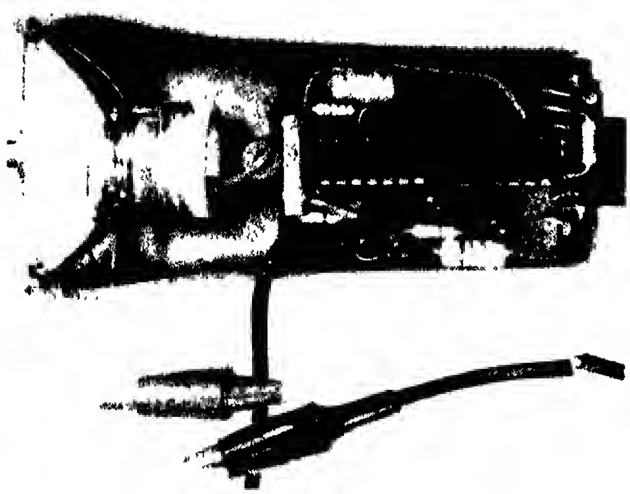
common anode LED display may instead be used with some modifications. The segments configuration and the indications obtained are as shown in Fig. 1. The segments 'a', 'b', 'g' and 'f' glow for the indication of the actual '0' (zero) and segment 'e' glows for the indication of the actual '1' (one). The combined segments 'a', 'b', 'g' and 'f' along with segment 'e' glow to give the indication of a single pulse or a pulse chain. The incorrect logic or open circuit condition (the probe tip not connected anywhere) is indicated if all the segments remain off. The decimal point has been used as a 'power on' indicator.

Fig. 2 shows the complete circuit of the direct reading logic probe. Diode D1 and gates 1, 2 and 3 form the circuit that detects logic zero condition. Diode D1 ensures that for voltages between 0V and 0.8V the logic zero detecting circuit becomes active while for voltages above 0.8V it remains inactive. Diodes D2 and D3, transistor T1 and gate 4 form the circuit that detects logic one condition. D1, D2 and T1 ensure that for all voltages between 2V and 5V the logic one circuit becomes active while for voltages below +2V it remains inactive. Thus, for voltages greater than 0.8V and less than 2V both the detecting circuits remain inactive.



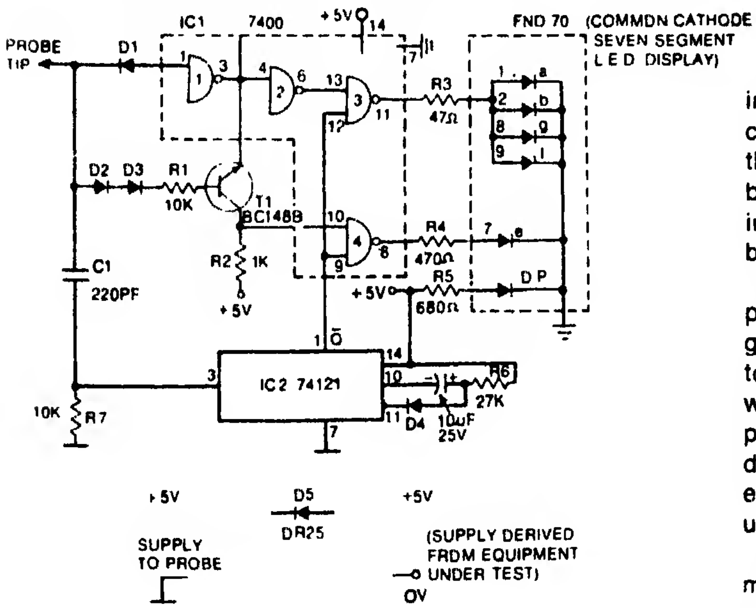


Fig. 2: Complete circuit diagram of the direct reading logic probe.

The components C1, R7, IC2, C2, R6 and D4 constitute the pulse detecting circuit. Once IC2 becomes active, it causes gates 3 and 4 to drive the segments 'a', 'b', 'g', 'f' and 'e' so as to display the letter 'P' for about half a second—the period for which the monostable IC gives output, once a pulse is applied at its input terminal (pin 3). The monostable IC2 can detect pulse width down to about 50 nano-seconds. Thus, even a single pulse of such a small duration can be detected using this logic probe.

The NAND gates 3 and 4 have been used a bit in an unusual manner—here they are sourcing a large current (about 3 mA per segment of LED display) which has been restricted by the resistors R3 and R4. Diode D5 has been used to save the logic probe from getting damaged in case the supply terminals are connected to the wrong polarities. Supply voltage for the probe is obtained directly from the equipment under test.

The wiring and layout of the components is not very critical. The prototype was housed in a small plastic torch case, making it very handy and easy to use. □

PARTS LIST

- IC1—7400 integrated circuit (Quad two input NAND gate)
- IC2—74121 integrated circuit (monostable)
- (pin 7 is the ground terminal and pin 14 is for + 5V, for both the ICs)
- D1-D4—Any silicon diode like 1N914 or 1N4148
- D5—Germanium diode DR25
- Display used—FND 70
- R1, R7—10 kilohm resistor
- R2—1 kilohm resistor
- R3—47 ohm resistor
- R4—470 ohm resistor
- R5—680 ohm resistor
- R6—27 kilohm resistor
- C1—220 pF ceramic capacitor
- C2—10 µF, 25V electrolytic capacitor
- Misc: A small needle-like probe tip, enclosure such as a miniature battery case, a small piece of laminate sheet for mounting the components, shielded single-core flexible wire, two small crocodile chips for connecting to power supply

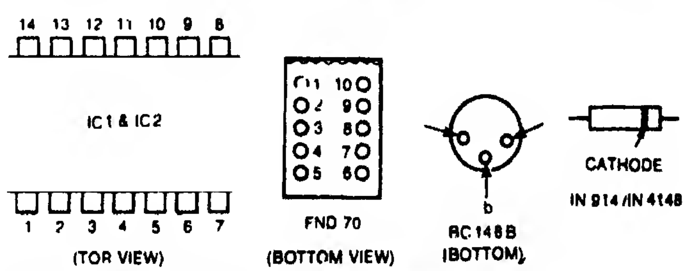


Fig. 3: Pins configuration of devices used.