ACCURACY OF DIGITAL VOLTMETERS

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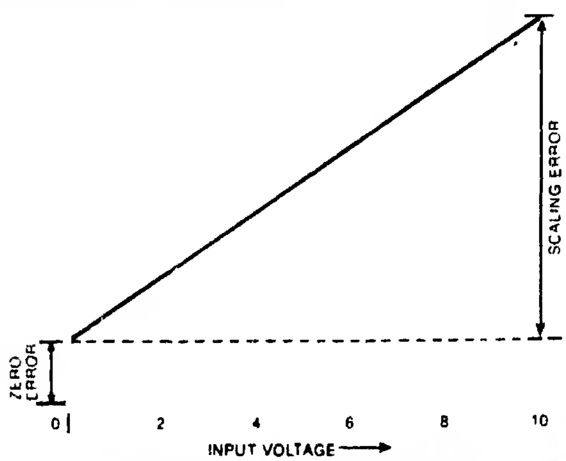
The digital voltmeters are extensively used as standard test instruments in the engineering laboratory and also as components in automated instrumentation systems. Often the exact conditions under which measurements will be performed are unknown at the time of instrument purchase. The user generally 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

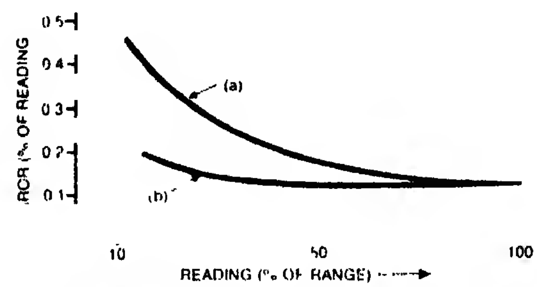


Fig. 2: **Characteristics of two DVMs having accuracy statements: (a) ± 0.05% of reading ± 0.5% of full scale, and (b) ± 0.09% of reading ± 0.01% of full scale.**

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.

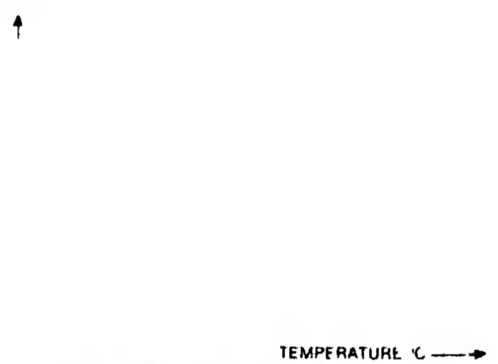


Fig. 3: Depandance of a DVM raading on tamparature over the standard 0°C to 50°C range.

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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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 nolse 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%.