Technical Information

Digital Multimeters

Digital multimeters convert analog signals to digital information. In general, DMMs have a minimum of five typical functions. They are DC voltage, AC voltage, DC current, AC current, and resistance. While specifications vary, most DMMs can be described with block diagrams similar to **Figure 1**.

Analog to Digital Conversion

The A/D converts the analog input signal to a digital output and is primarily responsible for key instrument characteristics of reading speed, linearity, resolution, normal mode rejection, and precision. The digital output is shown or obtained in several ways. One way is visually, via the front panel with a display of digits and other information. Another way is electronically, with results sent via a port (GPIB, RS-232, USB, or Ethernet) to a computer for further processing.

Resolution

Resolution is defined as the smallest detectable change on any range referenced to full scale. For example, if an instrument displays a maximum of 19,999 on any range, and the smallest detectable change in the input signal is ±1 least significant digit (LSD), then the resolution is 1/19999 or 0.005%.

Resolution is commonly expressed as a whole number plus a fraction, e.g., 5½ digits. The whole number represents the number of digits that can display the numbers from 0 to 9. The fraction indicates that the most significant digit has one or more non-zero states, that is, it can display 0, 1, or 2.

Sensitivity

Sensitivity is similar to resolution in that it deals with the smallest change of the input signal the instrument can detect. However, sensitivity is not referenced to full scale, so it is expressed in absolute terms and applies to the lowest range on any function. The sensitivity of a 7½-digit DMM is 10nV if its lowest measurement range is 200mV.

Accuracy

Accuracy is specified as a two-term specification: ±(% of reading + % of range) or as (ppm of reading + ppm of range). The closer to zero on the range that the percent of range term of the specification is, the greater the weight it has in the accuracy calculation. The closer to full scale on the range the percent of reading term of the specification is, the greater the weight it has in the accuracy calculation. The best accuracy is obtained near full scale.
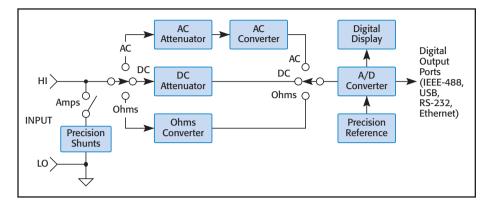

Figure 1: DMM Block Diagram

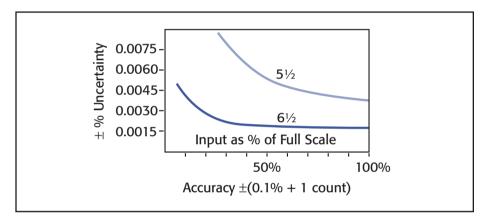**Figure 2: Expected Reading Uncertainty: 5½- vs. 6½-Digit DMMs**

Accuracy is also generally stated under several conditions, including ±1°C, ±5°C operating temperature, and 24-hour, 90-day, and one-year calibration intervals. The expected accuracy can be improved by controlling temperature variations in the environment and by electing more frequent calibration intervals. **Figure 2** illustrates the effect on accuracy at various levels of input signal within the measurement range. Accuracy for both meters is specified at ±(0.1% + 1 count).

Loading and Input Impedance

Loading is the disturbance to the circuit being measured caused by the finite input impedance of the DMM. Input impedance is the equivalent resistance and capacitance of the input terminals of the DMM.

Loading error (**Figure 3**) is the difference between the voltage measured by the meter (V_M) and the voltage of an ideal source (V_S).

Voltage burden error (**Figure 4**) is the difference between the expected current through the load (R_L) and the measured current (I_M) caused by the finite voltage drop of the measuring instrument.

Two-Wire vs. Four-Wire Ohms

Two-terminal DMMs source test current through the measuring test leads, terminating at the HI-LO inputs of the DMM. This two-wire ohms system works fine for most resistance measurement applications. However, the I-R drop in the test leads (R_L) can cause inaccuracies that become apparent in lower resistance measurements (**Figure 5**).

Four-wire ohms or Kelvin measurements bypass the voltage drop across R_L by bringing two high impedance voltage sense leads out to the unknown R_X. There is very little current in the sense circuit because of the high input impedance, so there's effectively no I-R drop in the leads, and the voltage seen by the sense

Loading Error $= -\dfrac{R_S}{R_S + Z_M}$ and $Z_M = \dfrac{R_M X_M}{R_M + X_M}$
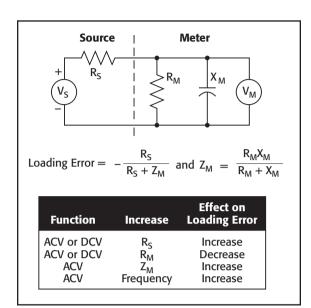
Function	Increase	Effect on Loading Error
ACV or DCV	R_S	Increase
ACV or DCV	R_M	Decrease
ACV	Z_M	Increase
ACV	Frequency	Increase

Figure 3: Loading Error

1. $I_S = \dfrac{V_S}{R_L}$ for $V_M = 0$ **2.** $I_M = \dfrac{V_S - V_M}{R_L}$

Voltage Burden Error $= \dfrac{I_M - I_S}{I_S} = -\dfrac{V_M}{V_S}$

$V_M \propto \dfrac{I_M}{I_{FS}} V_B$ where V_B is the maximum burden voltage and I_{FS} is the full scale current.

Figure 4: Voltage Burden Error

terminals is the same as the voltage developed across R_X.

Speed and Settling Time

Every meter has a settling time associated with its input circuit. The reading rates or measurement speeds of instruments are independent of the settling times. For high resolution meters, it may be necessary to allow time for input settling to achieve full rated accuracy.

Several parameters affect measurement speed, including integration rate (NPLC), filter setting, ranging, AutoZero, trigger delays, and display settings. For maximum measurement speed, set these parameters:

    Integration rate = 0.01
    Filter = disabled
    Range = fixed (no auto range)
    AutoZero = disabled
    Trigger Delay = 0.0
    Display = disabled

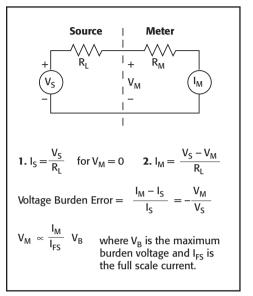Note that maximum speed settings do not produce the greatest accuracy.

Normal and Common Mode Rejection

Normal mode interference is the interference mixed in with the incoming signal. Most normal mode interference is at line frequency and its harmonics. *NMRR* (Normal Mode Rejection Ratio) is specified in dB at line frequencies of 50Hz and 60Hz. Normal mode interference is detected as a peak noise or deviation in a DC signal.

$$NMRR = 20 \log \frac{(peak\ measurement\ deviation)}{(peak\ normal\ mode\ interference)}$$

CMRR (Common Mode Rejection Ratio) specifies the ability of a meter to reject signals common to both input HI and LO. This term is generally measured with a 1kΩ imbalance in one of the leads. A larger imbalance will cause CMRR to be worse. CMRR is specified at DC, 50Hz, or 60Hz, and (like NMRR) is expressed in dB. CMRR applies to both DC and AC measurements and appears as an offset error to the desired signal.

Overload Protection

This is a measure of electrical ruggedness and should be sufficient to protect the meter from commonly encountered line voltages. Typically, the ranges most susceptible to high voltage are the lowest voltage range (e.g., 100mV) and the
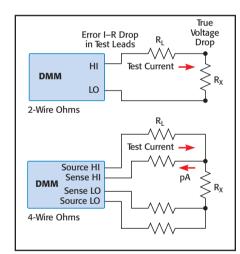

Figure 5: 2-Wire vs. 4-Wire Ohms

ohms ranges. Similar to overload protection is the maximum common mode voltage at which the meter can be used. This is the maximum voltage from earth ground that the input LO or COMMON terminal can withstand safely. The input terminal should always be at the lowest impedance.