

Multimeter

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A **multimeter** or a **multitester**, also known as a or **VOM** (Volt-Ohm meter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. Multimeters may use analog or digital circuits—**analog multimeters** (AMM) and **digital multimeters** (often abbreviated **DMM** or **DVOM**.) Analog instruments are usually based on a microammeter whose pointer moves over a scale calibration for all the different measurements that can be made; digital instruments usually display digits, but may display a bar of a length proportional to the quantity measured.

A multimeter can be a hand-held device useful for basic fault finding and field service work or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.

Multimeters are available in a wide ranges of features and prices. Cheap multimeters can cost less than US\$10, while the top of the line multimeters can cost more than US\$5,000.



A digital multimeter

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History

The first moving-pointer current-detecting device was the galvanometer in 1820. These were used to measure resistance and voltage by using a Wheatstone bridge, and comparing the unknown quantity to a reference voltage or resistance. While useful in the lab, the devices were very slow and impractical in the field. These galvanometers were bulky and delicate.

The D'Arsonval/Weston meter movement used a fine metal spring to give proportional measurement rather than just detection, and built-in permanent field magnets made deflection independent of the 3D orientation of the meter. These features enabled dispensing with Wheatstone bridges, and made measurement quick and easy. By adding a series or shunt resistor, more than one range of voltage or current could be measured with one movement.

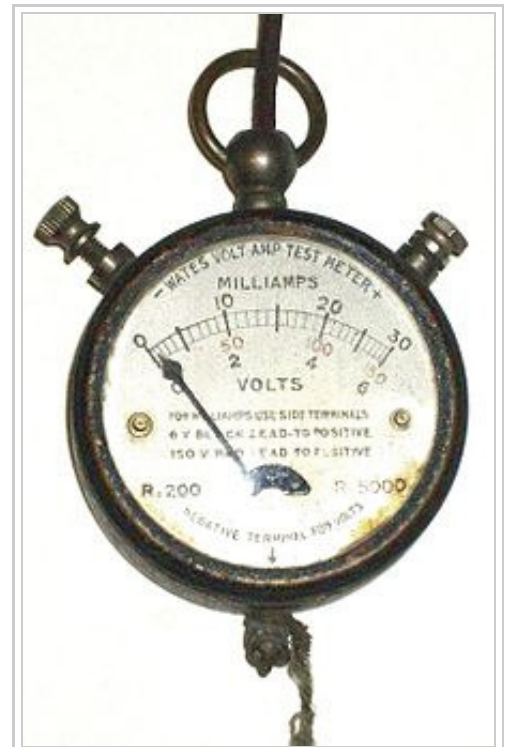
Multimeters were invented in the early 1920s as radio receivers and other vacuum tube electronic devices became more common. The invention of the first multimeter is attributed to British Post Office engineer, Donald Macadie, who became dissatisfied with having to carry many separate instruments required for the maintenance of the telecommunications circuits.^[1] Macadie invented an instrument which could measure amperes (aka amps), volts and ohms, so the multifunctional meter was then named Avometer.^[2] The meter comprised a moving coil meter, voltage and precision resistors, and switches and sockets to select the range.

Macadie took his idea to the Automatic Coil Winder and Electrical Equipment Company (ACWEEC, founded in ~1923).^[2] The first AVO was put on sale in 1923, and although it was initially a DC. Many of its features remained almost unaltered through to the last Model 8.

Pocket watch style meters were in widespread use in the 1920s, at much lower cost than Avometers. The metal case was normally connected to the negative connection, an arrangement that caused numerous electric shocks. The technical specifications of these devices were often crude, for example the one illustrated has a resistance of just 33 ohms per volt, a non-linear scale and no zero adjustment.

The usual analog multimeter when used for voltage measurements loads the circuit under test to some extent (a microammeter with full-scale current of 50 μA , the highest sensitivity commonly available, must draw at least 50 microamps from the circuit under test to deflect fully). This may load a high-impedance circuit so much as to affect the circuit, and to give a low reading.

Vacuum Tube Voltmeters or valve voltmeters (VTVM, VVM) were used for voltage measurements in electronic



1920s Pocket Multimeter



Avometer Model 8

circuits where high impedance was necessary. The VTVM had a fixed input impedance of typically 1 megohm or more, usually through use of a cathode follower input circuit, and thus did not significantly load the circuit being tested. Before the introduction of digital electronic high-impedance analog transistor and field effect transistor (FETs) voltmeters were used. Modern digital meters and some modern analog meters use electronic input circuitry to achieve high-input impedance—their voltage ranges are functionally equivalent to VTVMs.

Additional scales such as decibels, and functions such as capacitance, transistor gain, frequency, duty cycle, display hold, and buzzers which sound when the measured resistance is small have been included on many multimeters. While multimeters may be supplemented by more specialized equipment in a technician's toolkit, some modern multimeters include even more additional functions for specialized applications (e.g., temperature with a thermocouple probe, inductance, connectivity to a computer, speaking measured value, etc.).

Quantities measured

Contemporary multimeters can measure many quantities. The common ones are:

- Voltage, alternating and direct, in volts.
- Current, alternating and direct, in amperes.
The frequency range for which AC measurements are accurate must be specified.
- Resistance in ohms.

Additionally, some multimeters measure:

- Capacitance in farads.
- Conductance in siemens.
- Decibels.
- Duty cycle as a percentage.
- Frequency in hertz.
- Inductance in henrys.
- Temperature in degrees Celsius or Fahrenheit, with an appropriate temperature test probe, often a thermocouple.

Digital multimeters may also include circuits for:

- Continuity; beeps when a circuit conducts.
- Diodes (measuring forward drop of diode junctions, i.e., diodes and transistor junctions) and transistors (measuring current gain and other parameters).
- Battery checking for simple 1.5 volt and 9 volt batteries. This is a current loaded voltage scale. Battery checking (ignoring internal resistance, which increases as the battery is depleted), is less accurate when using a DC voltage scale.

Various sensors can be attached to multimeters to take measurements such as:

- Light level
- Acidity/Alkalinity(pH)
- Wind speed
- Relative humidity

Resolution

Resolution versus Accuracy

Resolution and accuracy in a multimeter are not equal. The resolution of a multimeter is the smallest part of the scale which can be shown. The resolution is scale dependent and in high end digital multimeters it can be configured, with higher resolution measurements taking longer to complete. For example, a multimeter that has a 1 mV resolution on a 10V scale can show changes in measurements in 1 mV increments. Absolute accuracy is the error of the measurement compared to a perfect measurement. Relative accuracy is the error of the measurement compared to the device used to calibrate the multimeter. Most multimeter datasheets provide relative accuracy. To compute the absolute accuracy from the relative accuracy of a multimeter add the absolute accuracy of the device used to calibrate the multimeter to the relative accuracy of the multimeter.^[3]

Digital

The resolution of a multimeter is often specified in "digits" of resolution. For example, the term $5\frac{1}{2}$ digits refers to the number of digits displayed on the display of a multimeter.

By convention, a half digit can display either a zero or a one, while a three-quarters digit can display a numeral higher than a one but not nine. Commonly, a three-quarters digit refers to a maximum value of 3 or 5. The fractional digit is always the most significant digit in the displayed value. A $5\frac{1}{2}$ digit multimeter would have five full digits that display values from 0 to 9 and one half digit that could only display 0 or 1.^[4] Such a meter could show positive or negative values from 0 to 199,999. A $3\frac{3}{4}$ digit meter can display a quantity from 0 to 3,999 or 5,999, depending on the manufacturer.

While a digital display can easily be extended in precision, the extra digits are of no value if not accompanied by care in the design and calibration of the analog portions of the multimeter. Meaningful high-resolution measurements require a good understanding of the instrument specifications, good control of the measurement conditions, and traceability of the calibration of the instrument.

Specifying "display counts" is another way to specify the resolution. Display counts give the largest number, or the largest number plus one (so the count number looks nicer) the multimeter's display can show, ignoring a decimal separator. For example, a $5\frac{1}{2}$ digit multimeter can also be specified as a 199999 display count or 200000 display count multimeter. Often the display count is just called the count in multimeter specifications.

Analog

Resolution of analog multimeters is limited by the width of the scale pointer, vibration of the pointer, the accuracy of printing of scales, zero calibration, number of ranges, and errors due to non-horizontal use of the mechanical display. Accuracy of readings obtained is also often compromised by miscounting division markings, errors in mental arithmetic, parallax observation errors, and less than perfect eyesight. Mirrored scales and larger meter movements are used to improve resolution; two and a half to three digits equivalent resolution is usual (and is usually adequate for the limited precision needed for most measurements).



Display face of an analog multimeter

Resistance measurements, in particular, are of low precision due to the typical resistance measurement circuit which compresses the scale heavily at the higher resistance values. Inexpensive analog meters may have only a single resistance scale, seriously restricting the range of precise measurements. Typically an analog meter will have a panel adjustment to set the zero-ohms calibration of the meter, to compensate for the varying voltage of the meter battery.

Accuracy

Digital multimeters generally take measurements with accuracy superior to their analog counterparts. Standard analog multimeters measure with typically three percent accuracy,^[5] though instruments of higher accuracy are made. Standard portable digital multimeters are specified to have an accuracy of typically 0.5% on the DC voltage ranges. Mainstream bench-top multimeters are available with specified accuracy of better than $\pm 0.01\%$. Laboratory grade instruments can have accuracies of a few parts per million.^[6]

Accuracy figures need to be interpreted with care. The accuracy of an analog instrument usually refers to full-scale deflection; a measurement of 30V on the 100V scale of a 3% meter is subject to an error of 3V, 10% of the reading. Digital meters usually specify accuracy as a percentage of reading plus a percentage of full-scale value, sometimes expressed in counts rather than percentage terms.

Quoted accuracy is specified as being that of the lower millivolt (mV) DC range, and is known as the "basic DC volts accuracy" figure. Higher DC voltage ranges, current, resistance, AC and other ranges will usually have a lower accuracy than the basic DC volts figure. AC measurements only meet specified accuracy within a specified range of frequencies.

Manufacturers can provide calibration services so that new meters may be purchased with a certificate of calibration indicating the meter has been adjusted to standards traceable to, for example, the US National Institute of Standards and Technology (NIST), or other national standards laboratory.

Test equipment tends to drift out of calibration over time, and the specified accuracy cannot be relied upon indefinitely. For more expensive equipment, manufacturers and third parties provide calibration services so that older equipment may be recalibrated and recertified. The cost of such services is disproportionate for inexpensive equipment; however extreme accuracy is not required for most routine testing. Multimeters used for critical measurements may be part of a metrology program to assure calibration.

Some instrument assume sine waveform for measurements but for distorted wave forms a true RMS converter (TrueRMS) may be needed for correct RMS calculation.

Sensitivity and input impedance

When used for measuring voltage, the input impedance of the multimeter must be very high compared to the impedance of the circuit being measured; otherwise circuit operation may be changed, and the reading will also be inaccurate.

Meters with electronic amplifiers (all digital multimeters and some analog meters) have a fixed input impedance that is high enough not to disturb most circuits. This is often either one or ten megohms; the standardization of the input resistance allows the use of external high-resistance probes which form a voltage divider with the input resistance to extend voltage range up to tens of thousands of volts. High-end multimeters generally provide an input impedance >10 Gigaohms for ranges less than or equal to 10V. Some high-end multimeters provide >10 Gigaohms of

impedance to ranges greater than 10V.^[7]

Most analog multimeters of the moving-pointer type are unbuffered, and draw current from the circuit under test to deflect the meter pointer. The impedance of the meter varies depending on the basic sensitivity of the meter movement and the range which is selected. For example, a meter with a typical 20,000 ohms/volt sensitivity will have an input resistance of two million ohms on the 100 volt range ($100\text{ V} * 20,000\text{ ohms/volt} = 2,000,000\text{ ohms}$). On every range, at full scale voltage of the range, the full current required to deflect the meter movement is taken from the circuit under test. Lower sensitivity meter movements are acceptable for testing in circuits where source impedances are low compared to the meter impedance, for example, power circuits; these meters are more rugged mechanically. Some measurements in signal circuits require higher sensitivity movements so as not to load the circuit under test with the meter impedance.^[8]

Sometimes sensitivity is confused with resolution of a meter, which is defined as the lowest voltage, current or resistance change that can change the observed reading^[citation needed].

For general-purpose digital multimeters, the lowest voltage range is typically several hundred millivolts AC or DC, but the lowest current range may be several hundred milliamperes, although instruments with greater current sensitivity are available. Measurement of low resistance requires lead resistance (measured by touching the test probes together) to be subtracted for best accuracy.

The upper end of multimeter measurement ranges varies considerably; measurements over perhaps 600 volts, 10 amperes, or 100 megohms may require a specialized test instrument.

Burden voltage

Any ammeter, including a multimeter in a current range, has a certain resistance. Most multimeters inherently measure voltage, and pass a current to be measured through a shunt resistance, measuring the voltage developed across it. The voltage drop is known as the burden voltage, specified in volts per ampere. The value can change depending on the range the meter selects, since different ranges usually use different shunt resistors.^{[9][10]}

The burden voltage can be significant in very low-voltage circuit areas. To check for its effect on accuracy and on external circuit operation the meter can be switched to different ranges; the current reading should be the same and circuit operation should not be affected if burden voltage is not a problem. If this voltage is significant it can be reduced (also reducing the inherent accuracy and precision of the measurement) by using a higher current range.

Alternating current sensing

Since the basic indicator system in either an analog or digital meter responds to DC only, a multimeter includes an AC to DC conversion circuit for making alternating current measurements. Basic meters utilize a rectifier circuit to measure the average or peak absolute value of the voltage, but are calibrated to show the calculated root mean square (RMS) value for a sinusoidal waveform; this will give correct readings for alternating current as used in power distribution. User guides for some such meters give correction factors for some simple non-sinusoidal waveforms, to allow the correct root mean square (RMS) equivalent value to be calculated. More expensive multimeters include an AC to DC converter that measures the true RMS value of the waveform within certain limits; the user manual for the meter may indicate the limits of the crest factor and frequency for which the meter calibration is valid. RMS sensing is necessary for measurements on non-sinusoidal periodic waveforms, such as found in audio signals and variable-frequency drives.

Digital multimeters (DMM or DVOM)

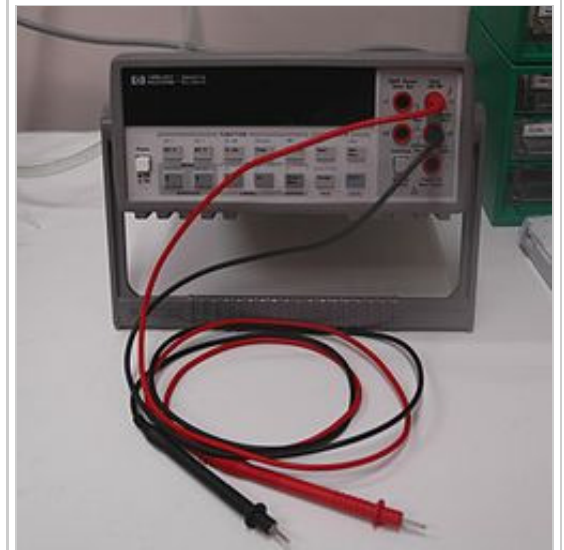
Modern multimeters are often digital due to their accuracy, durability and extra features. In a digital multimeter the signal under test is converted to a voltage and an amplifier with electronically controlled gain preconditions the signal. A digital multimeter displays the quantity measured as a number, which eliminates parallax errors.

Modern digital multimeters may have an embedded computer, which provides a wealth of convenience features. Measurement enhancements available include:

- **Auto-ranging**, which selects the correct range for the quantity under test so that the most significant digits are shown. For example, a four-digit multimeter would automatically select an appropriate range to display 1.234 instead of 0.012, or overloading. Auto-ranging meters usually include a facility to 'freeze' the meter to a particular range, because a measurement that causes frequent range changes is distracting to the user. Other factors being equal, an auto-ranging meter will have more circuitry than an equivalent, non-auto-ranging meter, and so will be more costly, but will be more convenient to use. An other reason to 'freeze' the range is that this somewhat avoids 'hunting' which is a situation where the meter continuously switches between two neighbouring ranges as when the instrument is in the low range, the value is too large but too small in the larger range, although this may seem counter-intuitive, for non-ohmic systems/devices this is possible.
- **Auto-polarity** for direct-current readings, shows if the applied voltage is positive (agrees with meter lead labels) or negative (opposite polarity to meter leads).
- **Sample and hold**, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- Current-limited tests for voltage drop across semiconductor junctions. While not a replacement for a transistor tester, this facilitates testing diodes and a variety of transistor types.^{[11][12]}
- A **graphic representation** of the quantity under test, as a bar graph. This makes go/no-go testing easy, and also allows spotting of fast-moving trends.
- A low-bandwidth **oscilloscope**.^[13]
- Automotive circuit testers, including tests for automotive timing and dwell signals.^[14]
- Simple data acquisition features to record maximum and minimum readings over a given period, or to take a number of samples at fixed intervals.^[15]
- Integration with tweezers for surface-mount technology.^[16]
- A combined LCR meter for small-size SMD and through-hole components.^[17]

Modern meters may be interfaced with a personal computer by IrDA links, RS-232 connections, USB, or an instrument bus such as IEEE-488. The interface allows the computer to record measurements as they are made. Some DMMs can store measurements and upload them to a computer.^[18]

The first digital multimeter was manufactured in 1955 by Non Linear Systems.^{[19][20]}



A bench-top multimeter from Hewlett-Packard.

Analog multimeters

A multimeter may be implemented with a galvanometer meter movement, or less often with a bargraph or simulated pointer such as an LCD or vacuum fluorescent display. Analog multimeters are common; a quality analog instrument will cost about the same as a DMM. Analog multimeters have the precision and reading accuracy limitations described above, and so are not built to provide the same accuracy as digital instruments.

Analog meters are able to display a changing reading in real time, whereas digital meters present such data in a manner that's either hard to follow or more often incomprehensible. Also an intelligible digital display can follow changes far more slowly than an analogue movement, so often fails to show what's going on clearly. Some digital multimeters include a fast-responding bargraph display for this purpose, though the resolution of these is usually low.

Analog meters are also useful in situations where it's necessary to pay attention to something other than the meter, and the swing of the pointer can be seen without looking at it. This can happen when accessing awkward locations, or when working on cramped live circuitry.

Analog displays are also used to very roughly read currents well above the maximum rated current of the meter. For this, the probes are just touched to the circuit momentarily, and how fast the pointer speeds towards fsd is noted. This is often done when testing state of charge of dry batteries.

Analogue meter movements are inherently much more fragile physically and electrically than digital meters. Many analogue meters have been instantly broken by connecting to the wrong point in a circuit, or while on the wrong range, or by dropping onto the floor.

The ARRL handbook also says that analog multimeters, with no electronic circuitry, are less susceptible to radio frequency interference.^[21]

The meter movement in a moving pointer analog multimeter is practically always a moving-coil galvanometer of the d'Arsonval type, using either jeweled pivots or taut bands to support the moving coil. In a basic analog multimeter the current to deflect the coil and pointer is drawn from the circuit being measured; it is usually an advantage to minimize the current drawn from the circuit. The sensitivity of an analog multimeter is given in units of ohms per volt. For example, a very low cost multimeter with a sensitivity of 1000 ohms per volt would draw 1 milliampere from a circuit at full scale deflection.^[22] More expensive, (and mechanically more delicate) multimeters typically have sensitivities of 20,000 ohms per volt and sometimes higher, with a 50,000 ohms per volt meter (drawing 20 microamperes at full scale) being about the upper limit for a portable, general purpose, non-amplified analog multimeter.

To avoid the loading of the measured circuit by the current drawn by the meter movement, some analog multimeters use an amplifier inserted between the measured circuit and the meter movement. While this increased the expense and complexity of the meter, by use of vacuum tubes or field effect transistors the input resistance can be made very high and independent of the current required to operate the meter movement coil. Such amplified multimeters are called VTVMs (vacuum tube voltmeters),^[23] TVMs (transistor volt meters), FET-VOMs, and similar names.



Inexpensive analog multimeter with a galvanometer needle display

Probes

Main article: Test probe

A multimeter can utilize a variety of test probes to connect to the circuit or device under test. Crocodile clips, retractable hook clips, and pointed probes are the three most common attachments. Tweezer probes are used for closely-spaced test points, as in surface-mount devices. The connectors are attached to flexible, thickly-insulated leads that are terminated with connectors appropriate for the meter. Probes are connected to portable meters typically by shrouded or recessed banana jacks, while benchtop meters may use banana jacks or BNC connectors. 2mm plugs and binding posts have also been used at times, but are less common today.

Clamp meters clamp around a conductor carrying a current to measure without the need to connect the meter in series with the circuit, or make metallic contact at all. For all except the most specialized and expensive types they are suitable to measure only large (from several amps up) and alternating currents.

Safety

All but the most inexpensive multimeters include a fuse, or two fuses, which will sometimes prevent damage to the multimeter from a current overload on the highest current range. A common error when operating a multimeter is to set the meter to measure resistance or current and then connect it directly to a low-impedance voltage source. Unfused meters are often quickly destroyed by such errors, fused meters often survive. Fuses used in meters will carry the maximum measuring current of the instrument, but are intended to clear if operator error exposes the meter to a low-impedance fault. Meters with unsafe fusing are not uncommon, this situation has led to the creation of the IEC61010 categories.

Digital meters are rated into categories based on their intended application, as set forth by IEC 61010 -1 ^[24] and echoed by country and regional standards groups such as the CEN EN61010 standard.^[25] There are four categories:

- **Category I:** used where equipment is not directly connected to the mains.
- **Category II:** used on single phase mains final sub-circuits.
- **Category III:** used on permanently installed loads such as distribution panels, motors, and 3 phase appliance outlets.
- **Category IV:** used on locations where fault current levels can be very high, such as supply service entrances, main panels, supply meters and primary over-voltage protection equipment.

Each category also specifies maximum transient voltages for selected measuring ranges in the meter.^{[26][27]} Category-rated meters also feature protections from over-current faults.^[28]

On meters that allow interfacing with computers, optical isolation may protect attached equipment against high voltage in the measured circuit.

DMM alternatives

A general-purpose DMM is generally considered adequate for measurements at signal levels greater than one millivolt or one milliampere, or below about 100 megohms—levels far from the theoretical limits of sensitivity. Other instruments—essentially similar, but with higher sensitivity—are used for accurate measurements of very small or

very large quantities. These include nanovoltmeters, electrometers (for very low currents, and voltages with very high source resistance, such as one teraohm) and picoammeters. These measurements are limited by available technology, and ultimately by inherent thermal noise.

Battery

Hand-held meters use batteries for continuity and resistance readings. This allows the meter to test a device that is not connected to a power source, by supplying its own low voltage for the test. A 1.5 volt AA battery is typical; more sophisticated meters with added capabilities instead or also use a 9 volt battery for some types of readings, or even higher-voltage batteries for very high resistance testing. Meters intended for testing in hazardous locations or for use on blasting circuits may require use of a manufacturer-specified battery to maintain their safety rating. A battery is also required to power the electronics of a digital multimeter or FET-VOM.

See also

- Ammeter
- Avometer
- Electronic test equipment
- Meter (electronics)
- Ohmmeter
- Voltmeter

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External links

- Multimeter Tutorial (<http://www.robotplatform.com/tools/multimeter/multimeter.html>) - Lots of useful information on Digital multimeter usage.

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Categories: Electronic test equipment | Electronics work tools | Measuring instruments

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