THE GUIDE TO DIGITAL MULTIMETERS

EBOOK

CONTROL AUTOMATION

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The Guide to Digital Multimeters

The well-known multimeter is an incredible tool, capable of troubleshooting nearly every electrical system and fault in existence. They can be found on the desks and tool cabinets of every electrician, handyman, engineer, and technician—in all sorts of shapes, sizes, and colors. But no matter how often they are used, and what job they perform, there is always more you can accomplish with knowledge of how they work.

The Importance of a Multimeter

Electrical technicians and engineers have a wide variety of tools available. Some of these are complex, often expensive tools for measuring one specific quantity, and if used properly, they can return many times their cost with just one or two uses. However, the multimeter, which has existed since the beginning of electronics, is still the most widely used instrument in the toolbox, thanks to its versatility..

The main perception of a multimeter is the often-used name of '**voltmeter**', which is the most common quantity measured by the tool. This is usually because most meters are used to locate faults, and most faults exist in live circuits. Beyond the basic voltage, there are a variety of other functions, and even different modes within those functions, which can help any technician or engineer become more proficient at their job.

Despite the variety of uses, owning a multimeter is a bit like having a particular tool for replacing a certain kind of brake, for example. You aren't going to need it every day unless you work on brakes for a living. Same with a multimeter—don't expect to use it every day unless your job involves troubleshooting control systems or electronics. Since you wouldn't expect to spend a lot of money on that one tool that you use occasionally, make the same decision with a multimeter.

The author's collection of multimeters, which is overwhelmingly red!

Who Needs a Multimeter?

It is quite reasonable to expect that every person, at least once in their life, will find a reason to use or need a multimeter. This feat should be easy enough as long as they are willing to learn a little bit on how to use and interpret its values.

Addressing the obvious first. If you are an experienced electrical engineer or technician working on any kind of electrical system, you probably own a multimeter already. Most likely, this guide is not written for you. However, knowing how to use the meter beyond just a few functions may prove extremely useful, even with plenty of experience.

Common industries that use meters include, but aren't limited to:

- Any sort of manufacturing, distribution, and processing center
- Lumber mills
- HVAC
- Residential and commercial electrical repair
- Electronic installation

A second group that could benefit from using multimeters are homeowners. Homeowners can easily use a meter to check wall outlets for voltage. Namely, if you turn off a breaker at the main panel and want to check which outlets belong to that circuit, the meter can be a quick option. Another use is If you have a light bulb in a drawer, you can easily use a resistance meter to see if it still works properly. If it does, you can save yourself from throwing it away and spending money on a new bulb. Since most home handyman projects don't require an expensive meter, there are many options.

Another group that may benefit from having a multimeter are auto mechanics, especially as cars become more reliant on sensors and electrical control systems. In fact, they may reach the point when even the multimeter is too '**basic**' of a tool to diagnose, but for the moment, a good multimeter is essential. In this industry, it is important to select meters that can measure these auto mechanical systems a bit more easily. When it comes to vehicles, one recommendation is to have a meter that can measure direct current (**DC**) using a small fork or clamp, since cars do not use alternating current (**AC**) voltages. In a future section, clamp meters will be described in more detail.

One final potential user of multimeters are teachers. There are many who believe that teachers should also understand how to address and fix problems, and should teach those skills to students. Perhaps most importantly in a technical classroom or shop setting, these kinds of skills can save anyone hundreds or thousands of dollars over a lifetime just by having a bit of practical knowledge. One recommendation is that, if you teach and influence people, invest in tools that can teach them to work and solve problems independently—a multimeter is only a small piece of that discussion.

Where Can I Get a Multimeter?

For most general use cases, you can find hand-held meters at the same place as everything else—online. Popular onlines like **Amazon** and **eBay** often have great deals and a wide selection, but best of all, they have reviews, which can help pin-point which model would work best for both your needs and your wallet.

For slightly more reliable, purpose-built meters, hardware or home improvement stores like **Home Depot** and **Harbor Freight** carry mid-range brands that can be trusted, since the stores will only carry tools that have been verified by many technicians.

As for general-purpose, everyday tools, the number of models and brands is staggering. Fortunately, most of them work quite well for every typical task. A browse through a normal hardware store will show **Klein Tools**, **Commercial Electric**, **Cen-Tech**, **Ames**, and a host of others. As always, be sure to find trusted reviews to verify that each tool has the functions you need to complete your tasks.

If you really need the best, most reliable, and unfailing meter, there are a couple of specific options. For example, **Fluke and Amprobe** (both owned by **Fluke**) are generally the top of the line for electrical measurement tools. Keep in mind that reliability, calibration, and precision will cost you more. However, if that's going to keep you safe and alive on the job, then you need a meter that will never fail.

Another category of meters is the bench-top, plug-in style meter. These meters can sometimes have more precision and better calibration ability than hand-held varieties. A few brands that offer a history of reliability are: **Meterman**, **B&K Precision**, **Keysight**, and of course, **Fluke**. However, these ones can also cost much more but could be great for test and verification technicians who absolutely need that level of precision.

All said and done, you can expect to spend between $20 and $200 on a good meter, depending on the brand and the source. Though you certainly want to purchase the correct tool for the job; however, if you'll rarely use it, then make sure to purchase a decent meter on the low end of the price range. A more expensive brand may be more durable and withstand higher voltages, but if you don't need these benefits, don't pay extra for them.

A good multimeter will save you money, or in extreme circumstances, it could save your life. But selecting the best meter is only the first step - knowing how to fully use and understand its functions is even more important. Good tools with no knowledge of how to use them is absolutely useless. Equipped with knowledge, even having low-quality tools can still solve many problems.

Overall, a good multimeter should save you money, or in extreme circumstances, it could save your life. Despite this, selecting the best meter is only the first step— knowing how to fully use and understand its functions is even more important. Good tools with no knowledge of how to use them are absolutely useless. Equipped with knowledge, even having low-quality tools can still solve many problems.

The Many Types of Meters Available

After understanding why the meter is important in so many different applications, the next step is to recognize why there are so many specialized forms of voltmeters and multimeters—certainly if such a wide array exists, they must all be useful for some critical function.

There are a lot of ways to categorize meters since each has unique traits, for the purpose of this book, they will be split loosely into three distinct categories. These categories will include '**benchtop**', '**hand-held**', and '**special purpose**' meters.

As a note, there are many professionals with far more experience, having devoted their careers to obtaining special skills which could warrant different opinions on multimeter needs. If you need to learn more about such an application, seek out a professional in the field and learn from that experience.

Terms and Definitions

Before discussing the variety of available meters, there are a couple of basic terms that will appear:

Accuracy - how close a measurement is to the actual value. If the voltage of a battery is 9 volts, and the meter reads 9 volts, this is an accurate reading. If the voltage is actually 9.12 volts, and the reading simply says 9 volts, it's still accurate, but it doesn't seem to have very many details of precision.

Calibration - the process of measuring accuracy against a traceable standard ensuring the most accurate measurements possible.

Precision - how many decimals are displayed to show that actual value. In the real world, the is no such thing as 9 volts. It's probably like 8.9875, or maybe 9.017, or likely very close to 9, but not exactly. A precise meter will show more and more digits ; however, precision does NOT mean accuracy. It may show a lot of digits, but there is a chance they might be wrong. The best meter would have many decimals of precision AND calibrated accuracy. There is no way to increase the precision of a meter, only buying a meter with more display digits.

Benchtop Multimeters

This category is the least familiar to most people concerned with residential or personal use, but has the longest history. These meters are usually found with a footprint that would take up about 1 sq ft on the top of a workbench, with a height of 2 to 3 inches. They include a display consisting of 7-segment light-emitting diodes (**LEDs**) (or newer color displays) with an array of buttons on the front.

These meters are desired for high-precision testing and design labs due to their extra decimals of precision above handheld meters. They are also designed to hold their accuracy for a longer time and allow periodic calibration to ensure that they are giving the technician an exact value.

A few drawbacks are that they can be expensive (hundreds to thousands of dollars) and a bit bulky for everyday use when mobility is key. However, for a permanent bench setup, they are highly sought after for military, avionics, semiconductor, and communication system electrical design and testing.

For hobbyists or test bench setups in an electrical service shop, a benchtop power supply and multimeter combination may be a great way to test components and prototype circuits.

Handheld Multimeters

This category is the stereotypical voltmeter candidate.Type the term into a search bar and the handheld variety will be instantly displayed. When you need to test an everyday component, like checking the voltage of a battery, this is the ultimate handy tool.

The variation is usually just in the size and functions of the unit. They will almost always have a round dial in the center to select the function, a liquid crystal (**LCD**) digit display above the dial, and plugs for test leads right below the dial. More robust meters with a wider array of functions tend to be a bit larger, while some can fit easily in a pocket, great for low-risk, low-investment quick testing.

A digital multimeter, although this one does not automatically range through relative scales of each function, in other words, it's non-autoranging.

When you examine the test lead connection ports, there will be a couple of choices. It will either have two ports: one red and one black, or it will have four ports: three reds and one black.

The 4-port meter is built for testing small currents in a circuit, usually in small PCB or breadboard circuits. This function could be useful for many home-built circuits, but must be used with caution, because a little bit of misuse can damage the current meter (**ammeter**).

The meter with only 2 ports cannot measure current in this way. However, this configuration can often be found in clamp-on multimeters or the smallest meters with only voltage and resistance sensing abilities. The clamp meters can measure current, just not through the test leads.

Some individual companies or regulations may dictate what protection levels are necessary for meters, and that may lead to only the expensive ones allowed in these settings. However, for general everyday use, you shouldn't need to shy away from the cheaper options. There is such a wide array of products available, they can cost less than 10 dollars or a couple hundred dollars or more for a high-quality, specialized product.

The 'pocket-size' kind of meter. Maybe not the most durable or functional, but it works well and looks pretty neat, too...

Specialty Multimeters

The amount of features and functions of every multimeter can be exhaustive, especially considering the ones for custom purposes. Here is a breakdown of more generally available or used meters.

The clamp or fork style current meter is common for industrial use where large currents and voltages are in use. The current driving those large motors would be far too large to ever test through a typical meter, and it would be extremely dangerous to be exposed to such a high energy output test point. These special meters can measure current by simply being placed around a safe, insulated conductor. Typically they just measure AC current, but some of them also measure small DC amperes as well, making them useful for control circuit troubleshooting.

Most clamp and fork meters also have the function select dial and test lead ports that can measure most of the other typical functions.

Some multimeters have unique semiconductor measuring properties as well, but these are rare since most of the time semiconductor parts are soldered on a PCB making them harder to test with meters. Usually used for transistors, they can measure polarity, gain, and leakage current. Usually, they'll have a small set of 3 or 4 little holes labeled with letters E, B, and C in some order. These work well for bipolar transistors, and you wouldn't use this function very often, but sure handy when you do need it.

Another handy test tool, a small circuit tester, may loosely be called a '**multimeter**' except it doesn't measure live circuits, so it can't measure voltage and current. This small circuit tester is made for measuring a vast assortment of devices and components and gives you information that most standard meters won't have like the series resistance of capacitors or the inductance of an inductor, the pin layout of a transistor.

One final type are Insulation multimeters, which are related to **mega-ohmmeters** (often called **meggers**) that deliver large voltages that can test extremely high resistances. These can be useful for troubleshooting line-to-ground insulation in motors or the insulation between conductors in a wire bundle. Insulation multimeters can read circuits in the normal range, just like a typical multimeter, but can also be safely placed into an output range delivering up to 1000 volts or more, simply from the AA or 9 V batteries. One thing to note is to never, ever use these functions to test the resistance of circuits with small components because that voltage output would almost certainly destroy them, even with a small output current.

Test Leads and Accessories

Nobody would ever buy a really expensive car without a steering wheel installed. You'd never buy a nice new house and overlook the fact that it doesn't include doorknobs. Likewise, it's a terrible idea to invest in a quality multimeter and forget to consider the test leads—after all, it's the only way the meter will connect to the outside world.

A vast assortment of test leads and attachments.

When it comes to test leads, there is a surprising variety. Most meters will include the standard default set with a single set of each red and black cable, with a pointed silver tip. These work sufficiently for most tasks, hence being the default choice, but it won't work in all situations. Like with multimeter types, there are many different options depending on the use case and situation.

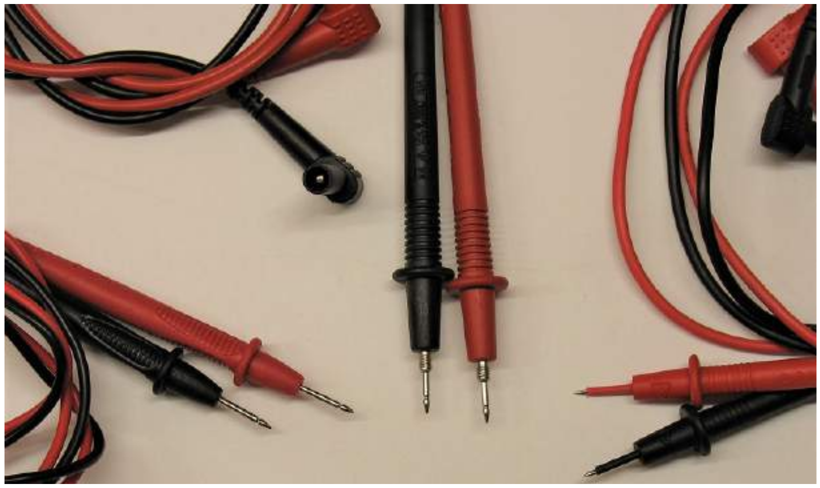
With that in mind, the most common to cover are:

- Standard set
- Alligator clips
- Mini grabbers
- Jaw adapters
- Extensions

The Standard Set

Basic multimeter leads must always include a set of 2x cables, one is red the other is black. They usually have about 3/4 inch of exposed metal at the end, terminating with a pointed tip. About 1/4 inch away from the end is a small shoulder used for anchoring the test lead inside some devices such as industrial terminal blocks, or attaching some extra fitting which grabs the metal, giving it a point to connect without sliding off the end.

A few variations of this basic cable style exist, and one that is often found useful includes a very short threaded shoulder just as the metal tip begins. Many end attachments such as alligator clips and grabbers may use this thread to provide a great secure attachment. Although not always vital, it does provide some security in making measurements.



A close-up of several 'standard' meter leads. They include the default standard, the one with a small threaded section, and the insulated fine-point tips from left to right.

Another common option is close to the normal lead, but only a very fine point is exposed at the very end. When making measurements of very small points that are located close to each other, touching the two leads can cause a short circuit and instant irreparable failure. The tightly insulated leads help keep the circuit safer for those tiny measurements.

Alligator Clips

Named from its resemblance to the mouth of an alligator, these clips are designed to securely connect to test points on circuit boards or exposed wire ends. With one lead securely clamped, it leaves one hand free to ensure that safety can be taken and the instruments and controls may be adjusted as necessary.

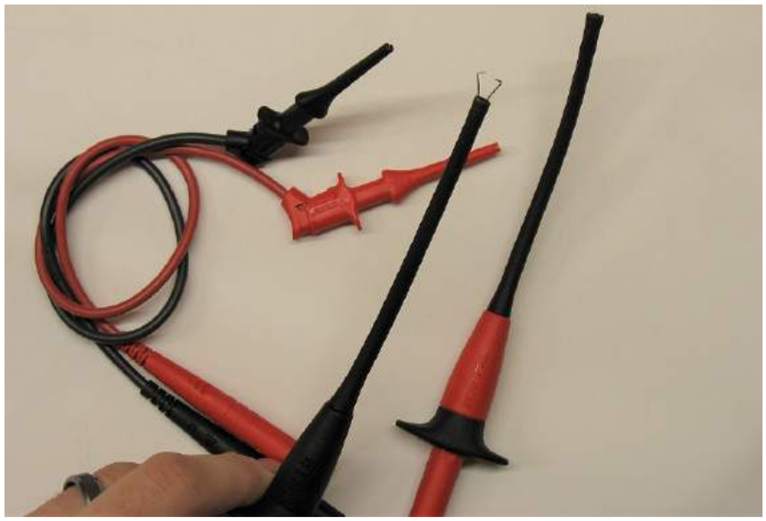
Most of the time these will simply slide or thread onto the end of a normal test lead. Other times, it may be an external cable that clamps to both the test lead and to the circuit board. This method has a few drawbacks, namely how the cable has the tendency to come off the end of the test lead. This issue could be harmless in my cases, but if the situation was expensive or potentially hazardous, you may not want to take that kind of risk.

A few alligator clip ends. Note that the exposed metal one usually has an insulated jacket over the top, but it's been removed to show what it looks like inside.

A final option is sometimes the alligator clips are permanently located at the end of the test lead cables. In other words, it's devoted to being alligator clips only. If you find that you need the clips a majority of the time, maybe these cables are a good investment.

Mini Grabbers

These attachments are similar to the alligator clips, but the end is a small, spring-loaded hook. This can be useful for measuring values on a circuit board where the only access point is the wire end of a through-hole resistor or diode, barely exposed on the board. They are limited to very small diameter wires, so they are best used in situations that are too close-quarters, or too small for the alligator clips.

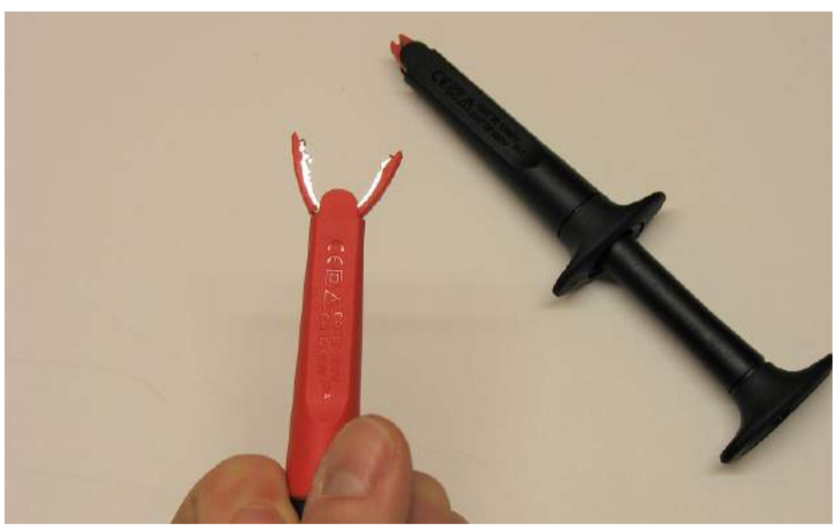


Mini grabbers, one integrated into the leads and the other is an attachment for the end of an extension cable.

Like the alligators, they can be found as external cables or as dedicated test leads. There are even sets of end adapters with the grabbers at the end of a flexible 6-inch long tool for the end of an extension lead.

Jaw Adapters

These jaws often look a lot like an alligator clip, but they are opened much like a syringe by squeezing the handle. They are usually much more precise than the alligator ends and are made for precision work.



The syringe-style action of a jaw adapter for the end of an extension cable.

In most of my industrial and PCB testing, I haven't used the jaws very much. When a hands-free, but very secure connection must be made, I wouldn't always trust the standard alligators - but the jaw adapters will be a very trustworthy connection.

Extensions

The extension cables open up all kinds of other possibilities. Both ends of these cables could fit into the meter base plug. So the other end is free to connect any of a variety of attachments. You could even mix and match depending on what the specific case called for.

An extension cable with similar connectors on both ends. Either end can connect to the meter, or to the attachments.

One example is where someone used normal '**banana**' cables as an extension to a meter; however, a cautionary note, these cables are not insulated like meter extension leads. The banana style does work, but care must be used, and they should probably not be used for precision work as the resistance characteristics are not designed for measurements. When multimeter leads are designed, they intentionally add very, very little resistance. Other wires may add just enough resistance to destroy the accuracy of the readings.

A selection of several of the tips that can be added to the end of extension cables to increase capabilities when making very specific measurements.

The tips for the end of these extensions can be of all sorts including, but certainly not limited, to the ones mentioned above.

Above all else, be sure to have the right tool for the right job. If you are going to invest in the tools and learn how to use them properly, then you must also have the proper equipment for interfacing those tools with the real world. Considering that entire sets of leads and accessories can be commonly found for around 20 dollars or less, it can be an easy investment to ensure easy, reliable measurements.

DC Voltage Measurement

Reading a constant voltage from most digital multimeters is extremely simple - turn the dial to the DC voltage icon and place the test leads at two exposed circuit contact points, and a number appears. But this simple reading is only scratching the surface of a function that is designed to be much more capable than a single reading.

On some meters, especially the older style of analog multimeter, most of the readings must be selected to be read at the proper range. If you want to measure a specific voltage, you must select the appropriate value range. These are called '**manually ranging**' meters in contrast to the common auto-ranging type.

Manual Range Selection

To use these types of meters, you must first determine what voltage you expect to measure, or at least close. If you have an industrial control system in front of you, 24 volts is the likely measurement. A small computer board might be more likely at 3.3–5 volts.

Whatever that target voltage happens to be, you'll need to select the range with a value just above that number. Sometimes, the ranges might include 1, 10, 100, and 1000 volts, or perhaps 2, 20, 200, and 2000 volts. In this scenario of testing a 24-volt system, you must choose the 100– or 200–volt range, respectively, since the 10– or 20–volt range is too small.

A manual ranging meter showing selections of 200 mV through 600 V as well as ranges for current and resistance.

If that range selection is too small in value, the meter will read '**OL**' which means '**over limit**'. Some people might say '**over load**', which is an accurate description but implies a dangerous situation. However, in this situation, this was not true and it was not dangerous—simply above the limit.

On an analog meter; however, the needle will instantly move to the far side of the display. This is the equivalent of showing '**OL**' on the screen.

If the range selection is unnecessarily large, for example, if you expect to read a 5-volt signal but you place the meter onto the 1000 volt range, it might show simply 5. Basically, you don't have any way to know if that value is actually 4.6, or maybe 5.3 volts. Too large of a range will result in a very imprecise reading, since more of the display digits are devoted to displaying large numbers. On an analog display, if the full range is 1000 volts, a measurement of 5 volts would hardly even move the needle, and it's hard to make a good judgment call when the needle has barely moved.

Using the Range Button

Most useful meters will either have the manual range selection on the dial, or it will have a button labeled '**range**', but usually not both.

This button can be beneficial for finding short circuits and troubleshooting parallel control components, although the function is often completely overlooked.

In a set of multiple parallel normally open buttons, one might become broken, shorted, or the spring inside may have failed, causing a constant connection. This can be a difficult situation to troubleshoot because the voltage will always read 0, no matter which button failed. You'd have to remove them one by one and test each time to find the one that raises the voltage back to 24.

Instead, you can select the lowest range, or press the '**range**' button on the meter, until the lowest range is selected. On some meters, there may be a '**mV**' function which can work as well.

When you measure the voltage drop across the circuit of parallel buttons, you should see just a few millivolts. The auto range would always show 0 volts unless you manually make this range change. Those few millivolts are due to the tiny resistance of the switch contacts. Small, but not quite 0.

As you press the parallel buttons one at a time, the equivalent resistance (and therefore voltage) will reduce to half because now both the failed switch and the working one are closed. The small reading of millivolts should get even smaller.

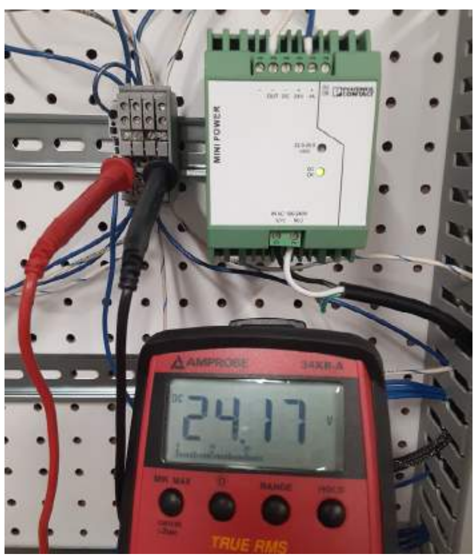
Once you finally test the failed component, the reading shouldn't change—it was already closed, you don't change it by pressing the button.

Now you have found the failed parallel switch without having to remove a wire.

A short circuit is similar—you can locate the difference between the few millivolt drop of a functioning wire versus the virtually 0-volt drop of a short circuit.

Using the Min/Max Button

Most of the time, there is an ability to record a minimum or maximum voltage which is one step better than the simple instantaneous reading that shows '**right now**' only.



A multimeter can display instantaneous voltage values, or minimum/maximum to locate surge or dropout events.

This detection can measure the amount of voltage drop from power supplies when a large capacitive device turns on, or the flyback surge from an inductive load that has been turned off.

However, there is a limitation with using the min/max function. The meter reads and stores voltage for a certain time period, with a certain time delay between readings. If the surge is too fast, you may miss it entirely. If it happens outside the reading time period, it also may miss the reading. If you expect a surge or drop to be happening on a very regular basis, you may need to turn to an oscilloscope. There are special industrial scopemeters which are handheld devices that show visuals of changing voltages.

This reading can be extremely useful when control devices appear to power off every now and then and you want to examine the cause. By placing the meter on the input voltage line and letting it record, you could find the culprit. If the minimum voltage drops by just a few volts, it might be enough to turn off the controller, but the suspect is probably a large device powering on. If the voltage drops to near zero, then a short has likely occurred and the power supply has turned off momentarily to protect itself.

The symptom is the same in either case (controller briefly losing power) but the extra information can help make a better informed decision to locate the cause.

Another common use of this function is locating breaker overcurrent faults. In these situations, a clamp meter can measure the current and record the highest value at the exact moment the breaker tripped. Even if the breaker doesn't trip, but you notice the current still increased momentarily to just below the breaker trip point, a better troubleshooting analysis can be made.

The goal of the multimeter is not to fix the problems, but to give you enough information to make the right decision.

The face value of the DC voltage on a multimeter is a fairly straightforward reading. The extra knowledge of pairing that reading with the manual range selection and the min/max functions could bring more information and accuracy to the reading of voltage and ultimately, the solution to electrical faults.

Frequency and Duty Cycle

For DC and AC measurements, a cyclic frequency, listed on the dial as **Hz**, can identify sine and square wave frequencies. These are useful in verifying proper 50/60 Hz for residential voltages, or higher frequencies for sound and signal testing in natural, analog waveforms. A DC frequency is most often used for square waves, such as the carrier frequency of a pulse-width modulated (**PWM**) signal.

In addition to simple frequency, those PWM signals being modulated, exhibit a percentage of their time HIGH vs LOW. This can directly correlate to the speed of a motor, or the brightness of a light—both being common applications of PWM signals. This multimeter function is often used for verifying operation of such PWM controls as the speed of a motor is adjusted up and down.

AC Voltage Measurement

To measure DC voltage with a multimeter, simply place the COM lead at the reference point and the V lead at the point to be measured. The reading should show the continuous, unchanging voltage at that point. This can be perfect for circuits powered by batteries and AC to DC power supplies.

In every aspect of industrial and residential electrical systems, there is another type of voltage measurement which is every bit as important—AC voltage. Simply measuring the voltage isn't that difficult, really not much different from DC, but understanding the implications that AC has on a circuit—that can be extremely important.

Since AC stands for alternating current, this means that the energy is supplied by applying a voltage in both directions, reversing the application many times per second. In the US, this is 60 times per second, in the UK and other parts of the world, it is 50 times per second, which appears to simply be based on historical standardization in certain parts of the world, not because of any traceable scientific reason.

The frequency of alternation means that it will reach a maximum voltage 60 times every second (although briefly) then fall to a minimum voltage the same number of times (again briefly). The voltage will spend an exactly equal amount of time positive as it does negative, which can be important to understand for voltage measurement.

Root Mean Square (RMS)

All in all, it can be essential that there are two different ways to read voltage. This is because, on the DC measurement scale, you can only see the voltage as a snapshot of that exact moment. If there is any variance, it will be displayed at least as fast as the LCD screen can refresh. Trying to use this same scale to measure an alternating voltage would be too fast to see. The voltage will change by hundreds of volts 60 times per second. The instantaneous voltage would be changing too quickly for the screen to keep up, and too fast to read even if it was capable of reading that fast.

True RMS meters will always have an AC voltage measurement, indicated by the sine-wave line above the V.

In these alternating cases, the meter is less interested in the instant value, but instead the value over a long period of time, or how much power you can actually get out of the applied voltage. This could be referred to as '**how much DC voltage you would need to apply to get the same power output**'. There are mathematical formulas that relate the minimum and maximums to the equivalent DC output.

There are a couple of strategies used in obtaining these values. Since mathematical formulas may seem like an easy solution, they are not always used because real-world situations aren't always free of errors and anomalies.

Instead, there are a few other methods:

1. Use an actual DC conversion circuit to turn the AC voltage into DC and measure the output of a load resistor. Sometimes this is a small heater and the temperature is measured. This works for all kinds of unusual alternating waves.
2. Convert AC to DC to get an average, then scaling that value to the proper root mean square (**RMS**) value. Simple averages can be tricky because the average of an alternating wave is zero volts. Despite seeming simple and easy, it only works for perfect waves, which isn't always a thing in the real world.
3. Measure and log the voltages for a while, then calculate the RMS which has some complicated background, but boils down to individual calculations for each wave.

Out of these three options, the first option and the last option can often lead to the best results when the wave isn't nice and '**perfect**'. This is called '**True RMS**' and can be seen printed on most higher-quality meters.

Other Effects from AC

The effect of alternating voltages on capacitors and inductors must also be considered. Specifically, the response of capacitors and inductors to the alternating voltage is a function of the frequency of the applied alternating voltage. Therefore, it's often important to consider the applied frequency of the AC voltage, not just the voltage itself.

In pure DC circuits, capacitors have no current passing through them—they provide an infinite resistance to a DC voltage. However, capacitors do pass current when an AC voltage is applied. The current through a capacitor increases with increasing frequency. This current through a capacitor can drastically change the operating properties of a circuit if the current is flowing when it should not be. In the case of a capacitive circuit, the AC current will be higher than DC current. If both are present, the capacitor can even be used to remove the DC signal (called a '**coupling capacitor**').

On the other hand, inductors provide no resistance to DC voltages but provide extra resistance when an alternating voltage is applied. When the voltage alternates, the resistance increases because the inductor resists the change in current, not the current itself. In these inductive circuits, AC current will be less than DC current.

In many cases, there will be both a DC and an AC part of the voltage, which alternates, not perfectly, to the same positive and negative levels. Some meters are able to measure this; however, it can be tricky with just a multimeter alone, thus, an oscilloscope could be more useful.

The act of measuring AC voltage is quite simple, almost identical to DC measurements. Simply place the two multimeter leads at the appropriate points in the circuit and measure the voltage difference. Keep in mind that it's important to know the difference between instant values from DC and the equivalent RMS values from AC, to know which is appropriate to choose depending on the case.

DC Current Measurement

Voltage measurements are the most common function in a multimeter for good reason. In general, voltage is the potential for energy to be consumed in a circuit. Yet having potential does not mean that the energy is being used properly, or used at all. Another electrical property, current, is only present when electricity is in motion. Understanding current can give insights that voltage alone cannot often show.

As an example of where the current might be a helpful property, imagine testing a failed 24 V relay coil in a circuit. If the relay has gone bad, there is a good chance the coil is open or '**infinite**' resistance. A voltmeter alone would show 24 volts across the coil, but that voltage would exist as well, even if the coil was in '**perfect**' working order. A quick current measurement would show zero amps in the failed relay, but instead the proper current in a working device, possibly 100 to 200 milliamps or more.

There are often alternatives to measuring current, many of them intentionally designed for this application. Despite its uses most technicians will stay away from the current measurement and try to obtain that information with other methods since the procedure for measuring current can be tricky, and if done improperly could damage the multimeter.

How to Test for Current

Before beginning, one important note is that this section is not addressing clamp or fork-style current meters. Though these models have an important function within industrial settings by removing many of the safety problems; for now, we will examine only the standard in line current measuring method—the AC measurement section will describe these styles later.

The test leads must be connected a bit differently for current measurements than for voltage measurements. The COM point continues to be the common connection for all measurements. The third (and often fourth) point will be reserved and marked with mA and A respectively, indicating the milliamp and amp current test connections. The mA port will be limited to only a few tenths of an amp. The A port will allow up to roughly 10 amps, but be sure to verify the safe ratings for your own meter.

Many meters will sound an alarm if the function dial is set to the amps check, while a test lead is not in the correct port or the other way around. The connections and functions must match. If this beeping tone sounds, check to make sure the leads and the function set are correct.

To measure the current, the circuit must be disconnected so that the meter actually becomes a part of the circuit. Current is the rate of electrical flow, so it's like measuring liquid or gas flow with a turbine flow gauge—it must be directly in the path of the flow. This is very different from voltage, which must only touch two exposed metal parts in the circuit to obtain a relative voltage between them.

With the circuit broken open, the red positive lead of the meter is placed on the exposed connection closer to the +V side of the circuit, and the black COM lead closer to the common ground. If an AC measurement is being obtained, the polarity does not matter, but for sake of understanding, the black line wire is considered the source and the white neutral is considered the common return.

A measurement with a positive sign will indicate current flowing properly from + to – through the meter. If the number is negative, the current is flowing in reverse or perhaps the meter was connected improperly, or there is a problem in the circuit construction causing current to flow in reverse through that particular point.

Cautions in Current Measurement

Since the meter must withstand the entire flow of the circuit, the meter must be protected from dangerous current levels. A set of fuses protects the delicate internal circuitry.

Fuses can usually be accessed near the battery compartment. Two current test ranges will make use of two fuses - be sure to use the correct range!

Usually, the mA port is protected for around 400 mA and the A port can withstand up to about 10 A (although the exact values are usually printed on each meter). If that current is exceeded, the fuse will fail and become open.

This situation can be dangerous because the current will no longer flow in the meter, giving the technician a false sense of safety where there appears to be no current, but in reality, the circuit is only waiting for that meter to be removed and current will instantly flow once again. Since there usually isn't an indication on the LCD screen showing a failed fuse, there is no way to really know when this event happens.

Another safety concern arises from how the user must now break open the circuit and make a new failure point. The user is right in the path of the flow and must exercise extreme caution to not let the other meter lead touch anything other than the appropriate points. It's not just a matter of bad measurements, it could even cause extreme disasters. This is why it's avoided when possible.

If you must measure current with an in-line meter, always use the higher capacity amps plug first. If it shows a value below the mA limit, then that plug should be safe to use as well. Test the meter in a known working circuit (one option is an LED and resistor on a 9-volt battery). This will ensure that the fuses are intact. You can then remove power to make the connections using terminal blocks or other connection terminals—basically, try not to just cut wires. After that, re-apply power, make the test, then remove power to repair the circuit.

Overall, it can be more time-consuming to measure current and safety must be observed; however it can lead to information that voltage tests are incapable of providing without a lot of extra work.

AC Current Measurement

Using a multimeter to measure current is often discouraged due to the difficulty of disconnecting a part in the circuit then placing the meter in-line properly so that damage does not occur, since it can be easy to blow a fuse if the meter is placed even slightly improperly. Despite the challenges, it can be a valuable function on the meter; however, it is worth emphasizing the greater risk than for measuring voltage or resistance.

All in all, AC current is an important quantity to learn in the case of industrial settings. When large devices like motors are used, it is essential to learn current consumption during startup and during operation. In a normal meter, there would be many of the same risks, but in this case, the currents would be likely in the 10’s or 100’s of amps. Even when they are being used properly, the meters would fail.

In most of these industrial handheld meters, one end of the meter is devoted to a spring-loaded clamp, or sometimes a stationary fork, which can be placed around a wire to measure current without placing the user or the meter in the path of the current flow.

Clamp Meters

The innovative concept used to indirectly measure AC current comes from one of the oldest concepts in electronics—magnetic induction on coils from alternating current.

In a clamp meter, a ferrous coil is contained inside the loop that is opened to allow the wire placement inside and then closed to complete the coil, similar to a transformer. A secondary coil inside the body of the meter can determine the input current by reading the generated voltage over a small fixed load resistor.

A standard clamp meter with spring-loaded jaws for measuring large AC currents.

This method is much faster and safer than normal in-line meters. The meter is not in the path of electricity, and therefore is not subjected to current which would destroy the fuse. None of the live circuit current actually travels through the meter at all. Since the circuit does not need to be broken open to place the meter and then repaired after measurement, the reading is much faster.

Clamp Meter Limitations

Although they can be an excellent choice for industrial settings, there are a couple of limitations to clamp meters that should be observed.

First, they are usually only meant for measuring AC current in the same manner that transformers will only respond to AC inputs. In some DC clamp meters, a Hall effect sensor is placed at the very tip of the meter and can measure DC current as well—even very small amounts of current. This can be a very handy tool to have in your toolbox, just do not assume that all AC clamp meters measure DC in the same manner.

Secondly, these meters are typically not great at measuring small AC currents. Often, the precision is only down to 0.1 amps, so attempting to measure less than that, such as a modern LED light circuit, could result in a display reading of zero amps. However, in an example case of motors and contactors, such precision is not required. This lack of precision also means that you cannot be entirely sure of the accuracy of the measurement since it only displays intervals of 0.1 amps at a time.

Additionally, it should be noted that you can purchase '**leakage clamp meters**' that are specifically designed for measuring very small currents, though this isn't the normal type of industrial clamp meter.

Another limitation of measurement is the requirement to have a single isolated conductor for measuring. Since the measurement relies on a single alternating path, if both the L and N lines are in the clamp together, the current directions will cancel each other and the result will be zero amps. This result applies to 3-phase current measurements as well.
The conductors must be separated enough to allow the clamp to be placed around just one wire at a time.

Maximizing the Clamp Meter's Potential

There are some ways that you can overcome some of the obstacles presented by clamp meter measurements and maximizing its potential.

Starting off, if you have a meter that does not contain a clamp meter function, it doesn't always mean you need to purchase a new meter. There are a wide variety of adapters, or technically '**transducers**', that convert the AC current measure by a clamp into a millivolt output. This adapter can be connected to a normal multimeter and the millivolts are read as amps. Often they measure both AC and DC currents and can cost much less than a new meter.

To combat the lack of precision with small current readings, there is a simple trick that can be performed. Just like winding a transformer, increasing the number of loops of wire will increase the induced voltage. If you have a little bit of slack in the AC wire, loop it through the clamp jaw a few times. The reading on the display of the meter should multiply with each loop.

When a suitable precision is reached, simply divide the reading by the number of times the wire passes through the jaws in order to determine the actual current.

Looping the wire through the jaws will multiply the current reading, giving a much better reading. In this image, be sure to divide the resulting current by /3 because the wire passes through the jaws 3x times.

For devices that need to be plugged into an outlet, the cord could restrict your ability to separate the conductors. Unless you want to carefully strip insulation from the cable jacket and reveal the three wires, this can make things difficult. However, there are current line splitters which often look like a plastic '**figure 8**' and are placed between the receptacle and the cable plug to allow measurement of current using a clamp meter.

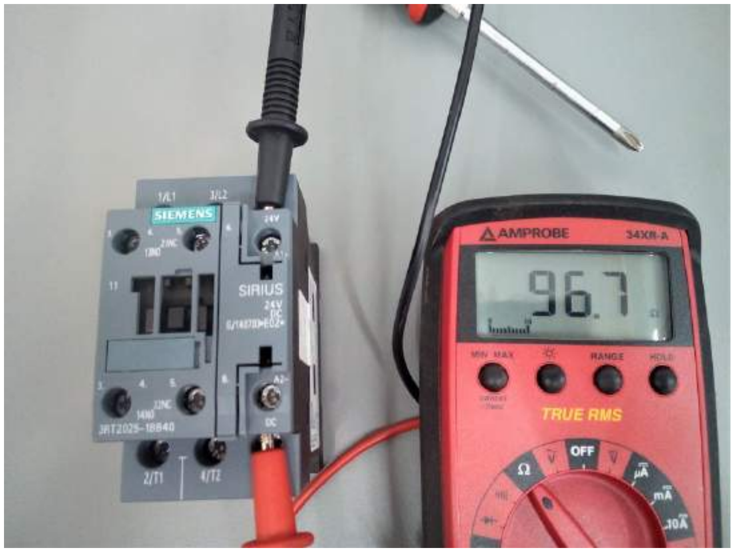
Overall, clamp-on current meters can be a safe, quick troubleshooting tool, especially for industrial technicians. They can be beneficial when measuring large AC currents.

Unfortunately, for voltage and current measurements—both DC and AC—you need to be connected to an active power supply. What if you need to identify problems when the circuit is removed or if the power supply is failed? Voltage and current will not help you.

Resistance and Continuity

In most situations, a measurement of voltage or current is most useful to track down a failure in a control circuit. Voltage requires only that power is applied; the load does not need to be active. Current does require the circuit to have electricity actively flowing, though clamp-type meters allow this to be a simple measurement. However, if the power must be removed from the circuit, then neither of these two measurements can properly show any information and an alternative must be used.

One solution is through resistance measurements. Resistance values show how much electricity could pass through a device if voltage were to be applied. A resistance, measured in ohms, is the relationship between voltage and current. High resistance leads to low current, while low resistance leads to high current.



A resistance test of a contactor shows a coil resistance of around 97 Ohms. According to the part datasheet, the value should be 98 Ohms, this one works well.

A resistance value of zero, or nearly zero, is considered a '**short**' circuit and can cause a fuse or breaker to trip with excessive current. At the other extreme, a very high resistance value, which the meter shows as OL, is an '**open**' circuit and the current will be nearly nothing.

Benefits of Resistance Measurements

When used properly, the resistance value can actually tell more than voltage or current alone can show. In a control circuit, voltage always tends to be lost either at the load device or at the first point at which the circuit is '**open**'. This may be an open switch or a broken wire, among other reasons, but from any of these sources, the voltage drop will be the full source voltage and it does not give us any indication of how much electricity is flowing.

In fact, an open switch with full voltage will lead to zero current flow, while a load device with full voltage drop will have some non-zero current flow, even though the measurement is the same.

Resistance allows a technician to verify two separate facts about the circuit. First, if voltage were to be applied, current will flow. If some amount of resistance exists in the circuit, then we can say with certainty that some current will be flowing when the circuit is properly connected and powered.

The second fact learned from resistance is the value of how much current will be flowing when power is applied. This is a fact that voltage measurements cannot determine, so in some cases, resistance may be more important than voltage alone. If a relay coil has partially failed, it may still drop all of the source voltage just like before, though the current draw may be different. Resistance could prove that the relay will conduct some current, and it may show exactly how much current will flow.

According to Ohm's law, for a control circuit with a single load, simply divide the source voltage (24 V, or 120 V, etc.) by the measured resistance. This will be the resulting current.

Since power must be removed to make resistance tests, it's important to understand the function of the meter to make proper tests that show correct information.

Cautions Against External Voltage

The first important thing to understand is that the meter develops its own voltage (from the battery) to send electricity through the test device. The test device drops some voltage and the meter internally drops the remainder with a series voltage divider. Using the ratio of internal fixed resistance and measured voltage versus the battery voltage, the test device resistance can easily be calculated and displayed.

However, if the leads are placed on a live circuit, the internal measured resistance may be more than the battery source voltage. This 'impossible' scenario is shown on the display as a negative value.

If you see a negative value shown on the screen, remove the leads immediately. Hopefully it has not damaged the meter, but a high voltage can be dangerous. If the meter is manually ranging, the lowest resistance scales will be the most likely range to be damaged by an external voltage.

To give absolute peace of mind that you can prevent this external voltage problem, simply remove one of the wires leading to the device. This will ensure that the device cannot be a part of the active circuit. If possible, simply (and cautiously) remove the device from the circuit completely and drain any stored energy by touching the leads briefly, that way there's no chance of external voltage input.

To guarantee proper readings, try to remove at least one connection of the resistor, isolating the component from the rest of the circuit.

Testing Solid State Devices

The other caution that deserves emphasis with all modern electronics is the attempt to test solid-state devices. In purely resistive circuits, the phrase '**linear**' means a constant resistance for all voltages—raise the voltage and the current will also increase at the same rate. However, for solid-state devices like diodes and transistors, the amount of applied voltage may change the resistance.

Common sense can be very misleading here because the device under test may show a legitimate resistance value when removed from the circuit, leading the technician to believe the device is working properly. However, when returned to the circuit and the circuit voltage is different, this may drastically alter the resistance. In these cases, it's important to use voltage tests when the circuit is live for solid-state testing. Often, a small value resistor is placed in series with a solid-state device. From there, you can measure the voltage of the resistor, along with its known resistance, and the current can be calculated.

Using the Continuity Function

There are many cases in which the exact value of resistance is not useful information–only the efficiency of the test. In the case of testing wires for breaks and switches for open conditions, the resistance will either be infinite or virtually zero. The continuity function will register an audible '**beep**' if the resistance is low.

Typically, continuity thresholds are on the order of 10–100 ohms, so be sure to use caution when using this test function. If you are attempting to locate a short circuit, but the resistance back through a second parallel path is less than 100 ohms, it is possible that the continuity '**beep**' will sound, even though you did not locate the short, only the parallel path. This error would lead to incorrect analysis. Only use the continuity function if all other possible circuit paths are of sufficiently high resistance. Continuity is a useful function, as long as you are aware of its possible limitations.

To test the continuity threshold of your own multimeter, connect the **+V** and **COM** leads to the middle and outside terminals of a potentiometer. Next, turn the function to continuity and turn the dial until the beep turns on and off with small motions in either direction. Finally, turn back to the standard resistance function to read this exact continuity threshold.

Extra Measurement Capabilities

Voltage, current, and resistance form the basis of Ohm's Law, and from these three measurements, most troubleshooting is a snap. However, when variations in a circuit can happen quickly, or when the components themselves do not behave in a predictable, linear pattern, a few other measurement options must be exercised.

Capacitance

The first additional measurement option is capacitance. To understand capacitance, it's important to understand what a capacitor is first.

A capacitor is a storage device for electrical energy, sharing some similar properties to a battery, but with different internal chemistry. These devices store and discharge energy more rapidly than a typical battery, so they are useful in situations when voltage is rapidly climbing and falling.

Measuring capacitance. Note the connection of the meter leads and the symbol indicated, matching the negative (-) symbol on the capacitor.

Capacitors have many functions, and subsequently have a variety of different construction styles—electrolytic, ceramic, tantalum, and many others. Many multimeters are able to measure the capacity of these capacitors, expressed in units of microfarads (**µF**).

Capacitor measurements must be done out-of-circuit, like the resistors. Parallel components may alter the capacitance value, and any externally applied voltage will destroy the accuracy of the readings.

Some capacitors (especially **electrolytic**) are polarized, with one lead indicated as a negative (**–**) or positive (**+**). The multimeter leads must match this polarity. Ceramic, and many other constructions, are non-polar which means that they can be tested without regard to direction. However, large electrolytic types may be outside of the measurement range of the meter. Consult the manual if you intend to measure such large devices.

This capacitor is beyond the capability of the meter. Probably not by much, as the capacitor is listed at 3900 µF, but the meter can measure up to 4000 µF. The tolerance of the capacitor must have brought it slightly outside of the measurement range.

Keep in mind that capacitors have a slightly larger tolerance than most other devices, with many of them considering +/- 20% to still be an acceptable value. This can greatly increase or decrease the actual capacitance value of the device even though it is still fully functional.

Diodes

Another measurement option is through testing diodes. Though testing diodes is not an extremely common practice for control systems, it can be useful for circuit analysis. In such a circuit space, rectifier diodes in power supplies are a simple arrangement of 4x diodes in a series-parallel combination. Bipolar transistors can also be tested to verify the operation of the base-emitter voltage.

In a control system environment, diodes are placed in parallel with inductive devices like solenoids or contactor coils. Without these diodes, large voltage spikes can damage or destroy control system equipment. Often these diodes are mounted into the body of the coil device, or they may be attached inside the same terminal blocks as the two wires supplying the load device.

Diodes are tested with polarity observed, and voltages between 0.4 and 0.7 volts are expected depending on the current limit of the diode.

Some meters can also verify the proper operation of LEDs. However, even the smallest red and green LEDs will require a voltage of around 2 volts to illuminate and pass current. Many multimeter diode tests do not deliver much more than 1 volt, and it is likely that the LED will not exhibit any voltage drop or illumination when tested as a diode. Be sure to use an alternative test method for LEDs, and do not assume that it is failed.

Temperature

Many multimeters have the symbols for **Fahrenheit** and **Celcius** temperature measurements. These are designed to be used with a K-type thermocouple adapter with red and black connectors to be inserted in place of the normal leads.

Assortment of K-type probes and adapters for measuring temperature.

Thermocouples generate a small voltage under different temperatures, so it is placed with the lead arrangement identical to a voltage test. Selecting °F or °C will convert the small voltage measured by the meter into the equivalent temperature reading on the display.

Conclusion

Some meters provide even further measurements for bipolar transistor gain values, as well as sometimes for induction, load testing of small batteries, and high-powered diode functions for testing LEDs.

Equipped with the proper tool, and the knowledge of how to use the tool, you are prepared to safely approach nearly any electrical fault, gather the right data, and make the best assumptions possible. If you can save even a small amount of time and replace the proper parts, your contribution to the solution of an electrical failure is of immeasurable value.

Now go build something awesome.