The Electronics Workshop

MEASURING WITH METERS

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A meter (a.k.a. VOM, volt-ohm-meter, multimeter) is the most useful tool one can have for troubleshooting electrical problems on a layout. It can tell you if there's a short or an open in the wiring, if a track gap has opened up, if a locomotive's motor is defective or if a component is defective. It can tell you if you have a voltage drop in your wiring, it can tell you how much current a locomotive is drawing and it can tell you how much voltage a power supply is putting out. It can tell you a lot of things about the electrical parts of your layout, but it doesn't say, "Hey, that light bulb's defective!" You have to be able to interpret what it's telling you. Hopefully, I can help you with that.

There are two kinds of meters, analog and digital. An analog meter has a pointer, which moves across a scale on the meter face much like the speedometer in a car. A digital meter has a display of numbers like the display of a digital clock or watch. ***(Photo #1)***

Photo 1: This is a photo of both meters together. The digital meter has a 3½-digit display; that is it can display three digits plus the number 1 on the left. It has four sockets for the probes: the second socket from the left is for the black probe which stays there; the leftmost socket is for measuring voltage and resistance; the next one is for measuring current up to 200 mA and the one on the far right is for measuring current up to 10 amps.

This analog meter happens to have its probe sockets on the top end of the case. They are identified along the top of the meter face. The second from the left is the common for the black probe, which stays in that socket. The one on the far left is for measuring resistance and current up to 250 mA; the third one is for measuring voltage and the one on the far right is for measuring current up to 10 amps.

Both types of meters have the same basic functions and make the same types of measurements. They all measure A.C. volts, D.C. volts, A.C. current, D.C. current and ohms (resistance). Since both types of meters operate basically the same way, I'll talk about how to use them first before getting into specifics about each kind later.

So, what are the advantages of one over the other? The digital meter has a more accurate readout. It doesn't require you to interpret the reading. The analog meter is good for watching changes. You can see the increase in track voltage as a momentum throttle does its thing and you can see the pointer swing back and forth as a locomotive goes over dirty track or over an open rail joiner or causes a momentary short. The disadvantage of a digital meter is if the voltage or current is varying slightly, the digits are constantly changing which can be distracting. Also, as the range increases, the number of decimal places becomes fewer. ***(Photo #6)*** The disadvantages of an analog meter are that it requires interpretation of the reading, the scales are not as highly accurate as a digital readout, depending on the user's interpretation, and it will require a little mental arithmetic to get the value. The cost of both kinds of meters is similar.

Your meter will have a display, either a faceplate with a lot of numbers on it and a pointer, or a window for the digits. It will have a knob for selecting the function and the ranges within each function, although there are auto ranging digital meters, which are more expensive. There will be two probes, one red and one black, with three, sometimes four sockets to plug them into. The black probe goes into one of the sockets, usually marked COM and it may be colored black. It stays in that socket. The red probe has two sockets to plug into. One will be marked volts/ohms or may be colored red. The other socket is marked current and to take current measurements the red probe is moved to that socket. It is used only to take current measurements. It may have a fourth socket to measure currents to 10 amperes.

The dial around the knob is marked off in sections for A.C. volts, D.C. volts, A.C. current, D.C. current and resistance measurements. Within each section are ranges of measurements, expressed as the maximum for that range. There is one other selection on the knob for digital meters, and that is the off position. Always turn a digital meter off when you're finished using it or the battery will run down. An analog meter doesn't need an off position, but never leave it in the resistance section or diode test position when you put it away. If the probes were to come together or both touch metal, it would draw current from its battery, running it down. ***(Photos #2 & #3)***

When selecting a range to measure something, be sure to select a maximum that is above the expected voltage or current. If you don't know, start with the highest range and work down from there. It doesn't hurt to measure a voltage on a setting that is way higher than needed; you just won't get as accurate a reading. Measuring a voltage on too low a scale can damage an analog meter's pointer as it slams into the end stop. A digital meter will usually just display an overload indication and not be damaged. Most meters have very small current ranges and either meter could be damaged by measuring too high a current. There are fuses in the current circuit, which should blow to protect the meter. Never have the probes connected to a live circuit when you turn a meter on or when you are selecting the type of measurement to make. You could, for instance, turn the knob through a resistance section to get to a voltage section, and the voltage on the probes can damage the meter. It is safe to turn the selector from a high value range to a lower one with the probes connected so long as you don't turn it too far and go lower than the voltage you're measuring.

Measuring D.C. voltage

The symbol used to identify the D.C. voltage section on the dial is a horizontal solid line over a horizontal dashed line. Turn the knob to select the appropriate range, or if you don't know what the voltage is, select the highest range. On a digital meter, the ranges will be marked as 2, 20, and 200. The actual maximum measurable value is a tiny bit less. For instance, the highest value that can be measured on the 20-volt range is 19.99 volts. The 20-volt range will probably be the most useful one for us. ***(Photo #4)***

Place the red probe on the positive point to be measured and the black probe on the negative point. Be very careful to get them the right way around for an analog meter. If they're backwards, the pointer will slam into the left end stop and may be damaged. If you get the probes of a digital meter backwards, it will still give the correct reading, but with a minus sign in front of it.

Photo 2: This is a close-up of the selection dial on the digital meter. It has five function ranges plus a diode/continuity test, a logic test where it can be used to test digital logic circuits and an off position. You will see that most of the range selections are multiples of 2 – i.e. 2, 20, 200. The actual maximum measurement is just less than 2 or 20 etc. For instance, on the 20-volt range, the maximum measurement is 19.99 volts. The highest D.C. and A.C. voltage ranges have different maximums.

To measure track voltage, simply select the 20-volt range and place one probe on each rail. To see if you're experiencing a voltage drop to the rails, first measure the voltage right at the output of the throttle, then measure the rails where you think you're experiencing voltage loss and compare the two readings. To check if a frog is getting power, place one probe on the stock rail that isn't connected to the frog and the other probe on the frog. You should see full track voltage. If an auxiliary power supply seems to have a lower output voltage than it should, measure the voltage right at its terminals, then disconnect the wires and measure again. If the voltage in the first measurement is significantly lower than the second, you most likely have too much load on the power supply and should divide the load between two power supplies. Note that unregulated power supplies will put out higher than their stated voltage with no load connected.

Measuring A.C. voltage

It's the same procedure as measuring D.C. voltage with the exception that it doesn't matter which probe goes to which side of the circuit. The A.C. voltage section will be marked with a wavy line. Select the appropriate range within the section and take your measurement. You can use a multimeter on its A.C. setting to measure DCC track voltage. However, since it is not a pure sine wave, but a mixture of D.C. and pulses, you won't get an accurate reading. It will be good enough to tell if you have lost voltage to a section of rail or if you have a significant voltage drop.

Photo 3: This is a close-up of the analog meter's dial and face. Unlike the digital meter, the ranges don't follow a pattern of multiples of 2. If you compare the ranges to the maximum numbers on each of the meter's scales, you will see how they match up. The scales require some interpretation as you read them. For instance, if you are using the 10 V.D.C. range, you will read the black scale marked 0, 2, 4, 6, 8, 10. If you are using the 100 V.D.C. range, you will use the same scale, but now you multiply the reading by 10 so that they now become 0, 20, 40, 60, 80, 100. The D.C.V. scale that goes from 0 to 50 is used for both the 5-volt and the 50-volt ranges. There are separate scales for 10 V.A.C. and A.C. amps.

There is only one resistance scale, the one at the top. To use it, you note what value the pointer is at and multiply it by the selected range. For instance, if the pointer is at 20 and you are using the X1K range, the value is 20,000 ohms; if you are using the X100 range, then the value is 20 hundred or 2,000 ohms; on the X10 range it would be 200 ohms.

I previously mentioned that you should try to have the pointer in the middle of the range when measuring resistance. As you can see, the numbers are compressed at both ends, but spread out in the middle making it easier to get an accurate reading in the middle.

Photo 4: This shows both meters measuring the voltage of a fresh 9-volt battery. The digital meter shows 9.60 volts. The analog meter is using the 0, 2, 4, 6, 8, 10 scale. The odd number values are designated by a thicker mark between the even numbers. The smallest divisions represent two volts. You can see that the pointer is right on the 9.6-volt mark. It's just a matter of counting the marks: number 8, big mark 9, little marks 2, 4, 6 giving you 9.6 volts.

Photo 5: This shows the two meters measuring the same 10,000 ohm resistor. The digital meter shows 10.70 or 10,700 ohms. The analog meter's pointer is almost on the 10 mark using the X1K range.

Measuring resistance

The resistance section will be identified by the symbol for ohms, the Greek letter omega (Ω). With a digital meter, you will want to select a range that provides you with the most decimal points for accuracy. If you select a range that is too low, the display will either flash or blank out. Turn the knob to a higher range. With an analog meter, you will want a range that puts the pointer somewhere near the middle of the scale. Important warning: make very sure there is no voltage at all in the circuit you are measuring. Any amount of voltage entering the meter during a resistance measurement can damage the meter. Disconnect both sides of any power source or throttle from the circuit you are measuring. ***(Photo #5)***

With an analog meter, you first have to zero the meter to compensate for decreasing battery voltage as the battery ages. Select the range you want then hold the tips of the probes against each other. Turn the zero adjust knob or thumbwheel until the pointer is exactly at the last mark on the resistance scale. You may have to repeat this procedure if you select a different range to measure. The same warning about not having any voltage in the circuit also applies here.

Measuring components

If you are measuring a component to see if it's defective, disconnect one side of the component from the circuit it is in. If left in the circuit, other components around it could change the reading you get. You can measure the value of a resistor that hasn't been installed yet (maybe the color code is hard to read) by holding the ends of the probes against each lead with your fingers. The resistance of your skin from one hand to the other is way too high at the low voltage that the meter uses to influence the reading. You can check a diode to see if it's defective by setting the range to a high one and measuring the diode's resistance. Note whether the reading is open circuit or low. Reverse the probes. The reading will now be the opposite of what it was before for a good diode. An open or low reading in both directions indicates a defective diode.

A meter will usually have a special position for testing diodes and checking for continuity. It is indicated by the diode symbol. When using this position to test a diode, do the same thing as previously described. It will show an open circuit in one direction and a low reading (around 500) in the other direction. It may or may not beep at the low reading. When checking for continuity or shorts, place the probes on either side of the suspect location. If they are connected, the meter will beep and show zero resistance.

To check if an incandescent lamp is defective, set the meter to a low ohms range and hold one probe on the centre contact of its base and the other on the threaded part or against the two wire leads if the bulb has wire leads. A good bulb will show some resistance, a defective bulb will show an open circuit.

Measuring current

Measuring current is a bit more complicated. There are two important things that need to be done. First, the red probe needs to be moved to the current measuring socket. Measuring current with the red probe in its normal socket could damage the meter. Second, the circuit to be measured has to be interrupted and the meter placed in series between the source and the load. Select the highest range in the section if you're not sure how much current the load is drawing. Turn off the power to the source. Disconnect one wire from the source's output. Attach one probe to the source's output terminal. If the source is D.C. and you disconnected the positive output, attach the red probe to the terminal; if you disconnected the negative output; attach the black probe to the terminal. Attach the other probe to the end of the wire, which you removed. It is best to use jumper wires with alligator clips to attach the probes rather than trying to hold them on. Turn on the power to

Photo 6: #1

Photo 6: #2

Photo 6: #3

Photo 6: #4

Photo 6: #5

the source. If necessary, turn the knob on the meter to a lower setting. Be very careful not to turn it so low that the current is higher than the setting. This could damage the meter or at the least, blow the internal fuse. Turn off the source's power before removing the meter and reattaching the wire.

Most inexpensive meters have an upper limit of 250 mA (¼ ampere). This rather limits its use for us, as it's insufficient to measure the current of some locomotives or a large lighting setup for instance. More expensive meters will be able to measure currents up to 10 amperes with a fourth socket just for the 10 A. measurement. The 250 mA scale is good for measuring the amount of current drawn by a single lamp or LED.

Batteries

Both types of meters have an internal battery. A digital meter will likely have a 9-volt battery to both run the electronics and provide current for the resistance measurements. Analog meters need a battery only for the resistance measurements and will most likely use two AA or AAA cells. Digital meters have a low battery indicator to tell you when to replace the battery. The battery in an analog meter will need replacing when you can no longer zero the meter for resistance measurements.

Photo 6 (Left): These five photos show the effect of the changes in precision with a digital meter depending on what range is used.
#1 shows one decimal point for the 200 mV (millivolt) range. The maximum value would be 199.9 mV. One decimal place is quite sufficient for millivolt values.
#2 shows three decimal points for the 2-volt range. The maximum value would be 1.999 volts.
#3 shows two decimal points for the 20-volt range. The maximum value would be 19.99 volts. This would be the most frequently used range for us.
#4 shows one decimal point for the 200-volt range. The maximum value would be 199.9 volts. When measuring voltages that high, one decimal place is sufficient.
#5 shows no decimal points for the 1,000-volt range. The maximum value would be 1,000 volts. For general and hobbyist use, the accuracy of fractions of a volt isn't really needed at those high voltages and we would likely have no need for the 1,000-volt range.

There are many more advanced measurements that can be made with a multimeter and tests on more complicated components like transistors and capacitors, but I don't have room to get into them here. I'll come back to them in a future article.

Buying a meter

A meter suitable for model railroad use won't cost much. You should be able to get one for under $20. If you want one with more bells and whistles or high accuracy, you'll pay more. The meter you choose should have these minimum specifications: D.C. voltage ranges from 100 mV to 200 volts; A.C. voltage ranges from 1 volt to 200 volts; resistance ranges from 10 ohms to 10 megohms; current ranges from 100 mA to 10 amps.

One consideration in analog meters is its sensitivity, expressed in ohms per volt. That indicates how much resistance is introduced into the circuit when measuring voltage. A meter with sensitivity of 1,000 ohms per volt, for instance, would insert 10,000 ohms into the circuit on the 10-volt range. This may be low enough to draw current from the circuit and give a false reading. A meter with sensitivity of 1 megohm per volt would insert a resistance of 10,000,000 ohms into the circuit, which is negligible. Digital meters all have a very high sensitivity so it isn't a concern. Digital meters have their accuracy expressed as a percentage.

Before you use an analog meter for the first time, you will likely need to zero the pointer. At the bottom of the window there will be what looks like the head of a screw. If the pointer isn't right on the first mark on the scale, very carefully turn this screw a tiny bit until the pointer is right on the first mark. You may have to repeat this procedure some time in the future if the meter is jostled around a lot over time.

Photographs

I've included a number of photographs of my meters to illustrate the points I've discussed. The digital meter is a 14 year old Wavetex 15XL, a moderately priced professional meter. The analog meter is a Pro-Point that I bought at a hardware store on sale for $20 (regular price $30), which proves that a good quality meter can be bought at little cost. It has features that one would expect to find on a more expensive meter like a 10-amp scale, a large meter face and a mirrored scale.