BY
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ALL ABOUT METERS

Of all the tools and equipment on a hobbyist's workbench, perhaps the most useful and versatile is the multimeter. They are relatively inexpensive and simple to use, and yet they can provide essential readings of voltage, current, and resistance—measurements imperative to building even the most sophisticated circuits.

Because of their necessity, meters are readily available in a staggering variety of shapes, sizes, and features from an array of foreign and domestic (U.S.) manufacturers.

This article will explain the important concepts behind the operation of both analog and digital meters. It will also present the major design considerations for each family of meter (volt, amp, and ohm), so you can build them to suit your own particular needs.

Analog-Meter Concepts. Until the last decade, the vast majority of all available test instruments contained analog meter movements to display readings. The overall design of this analog movement has changed very little since 1881 when a French physicist by the name of Jacques Arsene d'Arsonval developed the mechanism. In his honor, the devices are collectively known as d'Arsonval movements.

The d'Arsonval movement is truly a marvel of engineering in its simplicity and great versatility. They are ideally suited for use in ammeters, voltmeters, ohmmeters, and bridge circuits. Analog movements based on d'Arsonval's design have been employed extensively in more exotic test instruments such as decibel, power, and frequency meters (just to name a few).

d'Arsonval Operation. The functioning of the d'Arsonval movement is remarkably straightforward. In its simplest form, a coil of fine wire is wrapped about a cylindrical iron core to form an electromagnet (Fig. 1). The electromagnet is then mounted on very-low-friction bearings between the poles of a permanent magnet. A tension spring, stops, and a pointing nee-

With a little knowledge you can build your own meter circuits. We provide you with what you need to know to design ammeters, voltmeters, and ohmmeters.

dle are added to complete the unit.

When a current is applied to the meter, some portion of it is made to flow through the electromagnet. The current flow generates a field in the electromagnet that opposes the field of the permanent magnet. The conflicting fields create a torque that causes the electromagnet to rotate on its bearings and tense the spring. Since the torque and the current are proportional, the greater the current, the greater the torque on the movement, and the more the needle deflects. As the current drops, the tensed spring will tend to move the needle back to its rest position. Thus the position of needle can be used to indicate the amount of current flowing in the meter.

The rest or zero position on d'Arsonval movements can usually be adjusted by turning a small set screw located on the front of their enclosure. Typically, meters are "zeroed" with all current disconnected. Never use a zero-calibration screw as an offset or trim adjustment. d'Arsonval movements are very delicate devices and can be damaged by careless calibration.

d'Arsonval movements are rated in terms of their full-scale current requirement (I_{FS}) and their internal resistance (R_{INT}). For example, a typical meter movement might have specifications of 1 mA and 43 ohms. Those parameters will become very important when we discuss analog meter design. Let's take a close look at the operation and design of the most common analog meter applications—measuring current, voltage, and resistance.

DC Ammeter Design. Ammeters measure the amount of current flowing through them. So in order for a meter to measure the current flowing through a branch in a circuit it must be inserted in that branch.

The simplest ammeter is the meter movement itself as shown in Fig. 2 (R_a and R_b are just two components in the circuit). Manufacturers already produce a variety of meters designed and calibrated to function over a broad range. As you can see from the meter's specifications, it will deflect to its full scale at 1 mA and will add 43 ohms to the series circuit. As long as the circuit carries 1 mA or less, the meter will read properly without the need for support components. If current should rise above 1 mA, the needle will be forced (or "pegged") against the clockwise stop. Severe or repeated surges can easily wrench the electromagnet off its delicate bearings, damage the internal springs, or burn out the coil. Be sure to use caution when applying current to meter movements. It is often a good idea to place a fast-acting fuse in line with the meter leads to protect it from excessive current.

Notice that d'Arsonval movements are polarized—current can only be applied to the meter in one direction to ensure clockwise rotation. A reversal of current will "peg" the needle against its counterclockwise stop possibly damaging the movement as mentioned before.

But what if you want to measure more current than the movement alone can handle? Easy, simply add a "shunt resistor" (R_{SHUNT}) across the movement as shown in Fig. 3. The input current (I_{INPUT}) that is applied to the meter circuit will split into meter current and shunt-resistor current (I_{SHUNT}). Just how much current will flow through the resistor will depend upon its value and the value of the meter resistance (R_{INT}).

The shunt resistor serves two very important functions: it channels some current away from the movement to extend its useful range, and it reduces the overall resistance of the unit. Reducing the resistance minimizes the load the meter places on the circuit.

You can use the following formula to calculate the proper value for just about any shunt resistor:

$$R_{SHUNT} = R_{INT}I_{FS} / (R_{INPUT}I_{FS})$$

The amount of current flowing in the shunt itself can be determined with the following relationship:

$$I_{SHUNT} = I_{INPUT} - I_{FS}$$

The first step is to determine the amount of current that must flow through R_{SHUNT}. If you want to build a meter to read 0–1 amp (full scale), but you have a meter on hand that carries only 1 mA (full scale), then I_{SHUNT} will be:

$$1 - .001 = 0.999 \text{ amps}$$

Using this value, we find the value of R_{SHUNT} to be:

$$43 \times .001/0.999 = .043 \text{ ohms}$$

If a .043-ohm shunt resistor is used, the movement will reach full scale when 1 amp flows through the meter. It is always a good idea to keep the overall resistance of the assembly as low as possible to minimize the loading effects of the meter on the circuit under test.

Another consideration is the power dissipated by the shunt resistor, which can be expressed as:

$$P_{shunt} = I_{SHUNT}{}^2R_{SHUNT}$$

For our previous example, the .043-ohm shunt resistor will dissipate:

$$0.999^2 \times .043 = .043 \text{ W}$$

So a ⅛-watt resistor would do just fine. Now this is a very small value, but suppose our meter was to measure up to 100 amps. Then I_{SHUNT} would almost be 100 amps:

$$100 - .001 = 99.99 \text{ amps}$$

R_{SHUNT} would be:

$$43 \times .001/99.99 = .00043 \text{ ohms}$$

Power would then be:

$$(100)^2 \times .00043 = 4.3 \text{ watts!}$$

That would require at least a 5-watt resistor, which would be much larger and run much hotter than our previous ⅛-watt resistor. Always consider the power dissipation.

A multi-range ammeter can be created by simply making several appropriate shunt resistors available to the meter via a rotary switch. You can calculate the value of a shunt resistor for each range just as we did in the single-range example. Keep in mind that you do not have to stick to powers of 10 when you choose maximum currents. Feel free to pick any current range(s) that suits your particular needs.

If you do decide to build a multi-

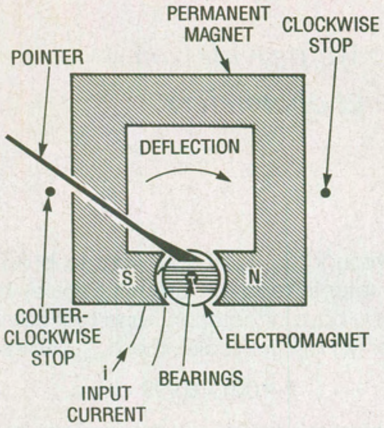


Fig. 1. This is a simple d'Arsonval movement. The deflection of the needle is proportional to the input current (i).

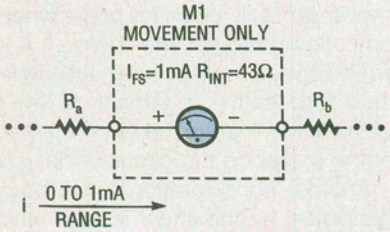


Fig. 2. A simple meter movement must be inserted in a series to a circuit to measure current flow.

range ammeter be sure that the switch you use is make-before-break, or that at least one meter lead is disconnected, any time you change ranges. That will prevent any surges of current through the movement in the brief instant that the switch may be moving between positions.

Don't worry if the values of resistance you calculate seem exotic; precision resistors down to 0.1 ohm are available. Also remember that resistors can be combined in series and parallel networks to obtain even lower values.

The 1-mA, 43-ohm meter movement used in our previous examples is just one of the many units that are currently on the market. Commercial DC-ammeter movements are available in ranges from 0–25 μA all the way up to 0–15 amps. Their resistance can be as high as 3700 ohms, or as low as .003 ohm (depending on the scale).

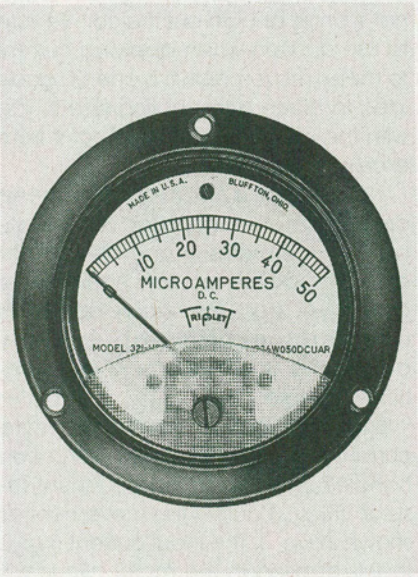
DC Voltmeters. Voltmeters measure the potential difference between any two points in a network. For a voltmeter to function properly, it must be placed in parallel with the load creating the voltage drop.

It is easy to use a standard d'Arsonval movement in voltmeter applications. This is done by re-arranging its circuit configuration. Since our meter is now measuring voltage, we must consider what voltage will cause a full scale deflection. For the meter used in our previous examples, according to ohm's Law it would take:

$$.001 \times 43 = .043 \text{ volt}$$

to cause full deflection. That means that if we were to use the movement alone, an input of 43 mV would deflect the meter fully. That value is commonly referred to as the meter's "voltage sensitivity" or VS.

Unfortunately, a voltmeter that only reads up to 43 mV is not very useful in most practical situations, but it is possible to extend the range of the meter by



This is the front view of a typical d'Arsonval-type meter movement. Note the zero-adjust screw.

adding a current-limiting resistor in series with the movement. This limiting resistor serves two very important purposes. First, it dissipates enough energy to let the meter read within its rated range. Second, it adds resistance to the meter network, minimizing the loading of the circuit under test.

Effectively, the limiting resistor is chosen so that the current flowing through the movement is equal to I_{FS} when the maximum desired input voltage is applied. Remember that d'Arsonval movements are polarized; be sure to apply voltage with the proper polarity.

You can use the following formula to calculate the value of the limiting resistor:

$$R_{LIMIT} = (V_{MAX} - I_{FS} \times R_{INT})/I_{FS} \quad \text{(eq. 1)}$$

Let's say we want to use our 1-mA, 43-ohm meter movement in a voltmeter design that will measure up to 20 volts. We know:

$$V_{MAX} = 20 \text{ volts}$$
$$VS = I_{FS} \times R_{INT} = .043 \text{ volt}$$
$$I_{FS} = .001 \text{ amp}$$

Using equation 1, we can determine the value of R_{LIMIT}:

$$(20 - .043)/.001 = 19957 \text{ ohms}$$

A 20,000-ohm resistor will work satisfactorily. Give it a try.

One word of caution: To achieve the best performance from the meter at lower voltage ranges, keep the limiting resistor as close as possible to the calculated value. That is because the meter circuit will be more sensitive down at lower ranges since the voltage across the meter will be closer to the voltage dropped across the limiting resistor. If R_{LIMIT} has poor tolerance, the reading will be less accurate. Higher ranges are less sensitive since the meter's voltage versus the applied voltage is so much smaller, so you can afford to be more lenient with the limiting resistor's tolerance.

Unlike the shunt resistors in our ammeter circuits, limiting resistors are almost always low-power (1/8 or 1/4-watt) devices. That is the general rule since only a small amount of current will ever

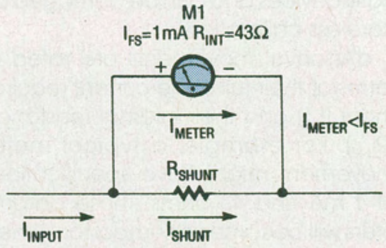


Fig. 3. An expanded-range ammeter is really a simple ammeter movement in parallel with a "shunt" resistor.

flow through them. For our voltmeter example, the power dissipated by the limiting resistor would be:

$$.001^2 \times 19957 = .01996 \text{ watt}$$

That's well within the range of a 1/8-watt resistor.

Multi-range voltmeters are equally easy to put together. Work out the appropriate resistor values by using equation 1 for each scale that will be needed. Use a simple rotary switch to select the desired resistor, and thus the scale. For 1-, 5-, and 10-volt ranges the limits can be calculated as follows:

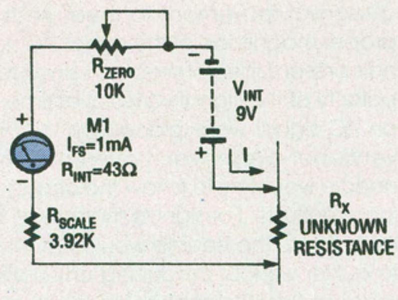


Fig. 4. A meter's internal voltage source is used to drive an ohmmeter circuit.

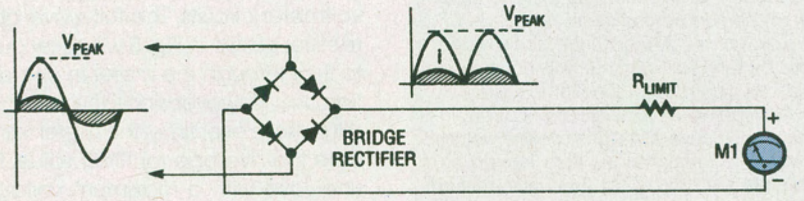


Fig. 5. A simple diode bridge can turn a DC voltmeter into an AC voltmeter. However, the voltage drop across the diodes must be taken into account when determining the value of the limiting resistor.

$$R1 = (1 - .043)/.001 = 957 \text{ ohms},$$
$$R2 = (5 - .043)/.001 = 4957 \text{ ohms},$$
$$R3 = (10 - .043)/.001 = 9957 \text{ ohms}$$

There is no limit to the number of ranges that you could add.

Ohms/Volt Ratings. Many voltmeters carry an ohms-per-volt rating. That rating can be used to determine both the meter's internal resistance and the current sensitivity (I_{FS}).

For a voltmeter with a given ohms/volt rating, the I_{FS} can be determined simply by taking the reciprocal of the rating:

$$I_{FS} = 1/(\text{ohms-per-volt rating})$$

If you use a voltmeter marked at 20,000 ohms/volt, the full-scale current of the movement would be:

$$1/20{,}000 = 50\ \mu A$$

Conversely, if you wish to determine a voltmeter's ohms-per-volt rating, just rearrange the formula to take the reciprocal of I_{FS}:

$$\text{ohms-per-volt rating} = 1/I_{FS}$$

For our 1 mA meter, its rating would be:

$$1/.001 = 1000 \text{ ohms/volt}$$

Try to keep the ohms-per-volt rating as high as possible to reduce loading on the circuit under test.

The internal resistance for each voltmeter scale can be easily calculated knowing the full-scale current of the movement and the maximum voltage rating of the particular scale:

$$R_{INPUT} = V_{MAX}/I_{FS}$$

For our example voltmeter, its input resistance would be:

$$20/.001 = 20{,}000 \text{ ohms}$$

Just remember that the input resistance for a particular scale is the same regardless of the actual amount of voltage applied.

As you know from our discussion on ammeters, there are a number of types and ranges of meter movements available to suit a wide variety of applications. It is important to note also that there are many movements on the market already configured and marked as voltmeters. They can be handy if you can not find the resistor values to suit your needs, but it will limit you to a single scale.

Ohmmeters. Ohmmeters measure the resistance across two points in a circuit. In order to do that, an ohmmeter must be placed across the component(s) to be measured—just like a voltmeter.

However, unlike a voltmeter or ammeter, resistance must be measured with the circuit power off. That is because ohmmeters supply their own current for ease of use; any additional voltage from the circuit under test may cause enough extra current to damage the meter. Even if damage does not occur, any reading would be worthless since the meter is calibrated to work from its internal voltage only.

We can use d'Arsonval movements to build our own ohmmeter as shown in Fig. 4. That type of ohmmeter is known as a "series ohmmeter" because of the series circuit it forms with the resistor. The design is also referred to as a "mid-range," or "general-purpose" ohmmeter. Although it is capable of measuring from 0 ohm to infinity, the non-linear response of the meter only allows accurate readings up to about ⅓ of the meter's scale (depending upon the chosen scale). Accurate measurements below 1 ohm would require the use of additional circuitry to compensate for errors caused by such factors as lead length and contact resistance. Measurements over 10 megohms would require higher excitation voltages to generate meaningful current in a circuit.

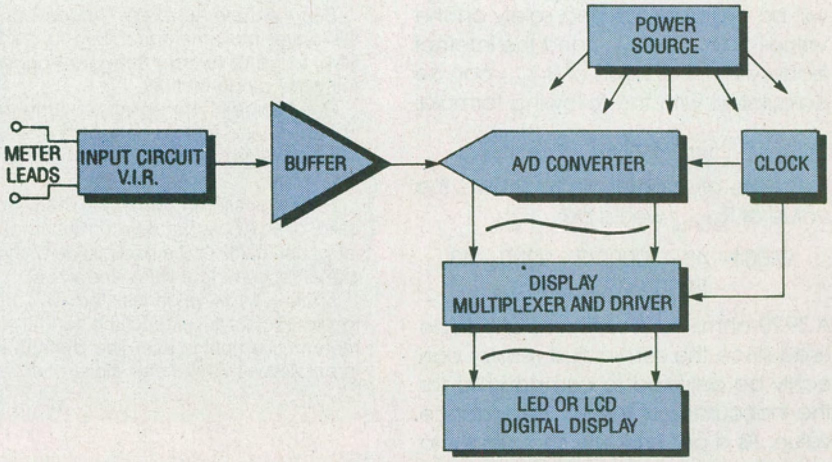
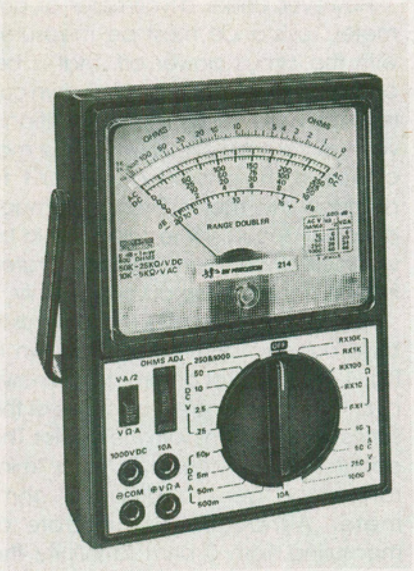


Fig. 6. This is a block diagram of a basic digital meter. The input circuit is programmed by the switches which are not shown here.

For our ohmmeter of Fig. 4, the choice of zero resistor (R_{ZERO}) is almost arbitrary. It can be as large or small as you like. Its purpose is to compensate for any variations in voltage or component values within the meter. A larger value of R_{ZERO} will give you a larger range of compensation, but will tend to drift more due to temperature and humidity. A smaller value will offer a smaller range of compensation, but it will be more sensitive. For our purposes, a



Here is an overall view of a typical analog VOM. It can perform the three basic measurements.

10,000-ohm rheostat will be used.

The meter scale is set with a fixed-value scale resistor, R_{SCALE}. The meter will be calibrated based solely on the values of R_{SCALE}, R_{ZERO}, and the internal battery V_{INT}. The value of R_{SCALE} can be calculated with the following formula:

$$R_{SCALE} = V_{INT}/I_{FS} - R_{INT} - R_{ZERO}/2$$

For the ohmmeter circuit shown, the value of R_{SCALE} would be:

$$9/.001 - 43 - 10000/2 = 9000 - 43 - 5000 = 3957 \text{ ohms}$$

A 3920-ohm, 1% ¼-watt resistor can be used since the zero-adjust resistor can easily be adjusted to compensate for the inaccuracy of the scale-resistance value. As a general rule, though, try to keep your scale resistor close to the calculated value. Remember that the greater the difference between your calculated scale resistance and your actual scale resistance, the more you must adjust the zero-adjust resistor to compensate for that error. That means you will automatically lose a portion of your adjustment range just to compensate for a poorly selected resistor.

An ohmmeter must be recalibrated each time the scale is changed, or after periods of disuse. In order to calibrate our ohmmeter, first set the zero adjustment to the approximate center of its range, then short the test leads together. That establishes a current flow through the meter-test circuit itself, which will cause the meter to deflect. If R_{ZERO} is in the center of its range and R_{SCALE} is very close to its calculated value, the meter should deflect fully counterclockwise to indicate zero resistance. If the needle swings too far clockwise, or not far enough, simply adjust R_{ZERO} until the needle rests on the fully clockwise marking. That will now represent zero ohms. Separate your test leads and the needle should fall to the fully counterclockwise marking. That represents infinite resistance (or an open circuit). Your ohmmeter is now calibrated for your chosen scale.

When you place an unknown resistance between the test leads, it will complete the meter circuit and cause the meter to deflect. The amount of the deflection will depend on the value of the unknown resistance.

Meter Glossary

Accuracy—A percentage of error which states how closely a meter reads the actual value of an input signal. The smaller the percentage is, the more accurate the meter. Many commercial meters can measure to 0.5% accuracy.

d'Arsonval Movement—an electromechanical indicator using an electromagnet that is free to rotate within the magnetic field of a permanent magnet. The coil will rotate in direct proportion to the amount of current flowing through it.

High ohms—A resistance scale using a slightly higher voltage that will allow semiconductor junctions to be forward-biased when placed across the meter leads.

Low ohms—A resistance scale using a low battery voltage that will not forward-bias semiconductor junctions.

Multimeter—A versatile meter capable of measuring several ranges of either voltage, current, or resistance. Also known as a "Multitester" or "VOM (volt-ohm-milliammeter)."

Ohms/volt—A voltmeter rating that indicates the effective impedance (or current sensitivity) of the voltmeter scale. The rating is typically used to describe analog meters.

Rectifier-type AC meter—A conventional DC meter movement modified to read the RMS value of voltage through a bridge or full-wave diode rectifier.

Resolution—The smallest amount of change that a meter is capable of detecting. The rating is most often applied to digital meters.

RMS (Root Mean Square)—The effective value of an AC signal. It is commonly calculated as 70.7% of the peak value of the AC signal (assuming a pure sine wave).

Shunt—A low-value resistor used in ammeter circuits to extend the range of the meter movement in use. The shunt is used in parallel with the meter movement. ■

AC Modifications. The meters we have discussed this far have been strictly DC instruments—current must move steadily in one direction in order for the d'Arsonval movement to measure the proper magnitude of the signal. AC signals present special problems since the polarity of the signal varies over time. If an AC signal were placed on a conventional d'Arsonval movement, the needle would try to follow the changes in magnitude. For signals more than 15 Hz or 20 Hz, the needle would just tend to quiver without producing any useful reading. For AC signals to be measured accurately, they must first be converted to a corresponding DC level.

A simple bridge rectifier circuit can be used for AC to DC conversion for our voltmeter circuits. The full-wave bridge rectifier shown in Fig. 5 will allow current to flow through the meter in one direction only. However, since the voltage will still pulsate over time, the meter will indicate the average (or RMS) value. For a sinewave with a maximum voltage of V_{PEAK}, that is:

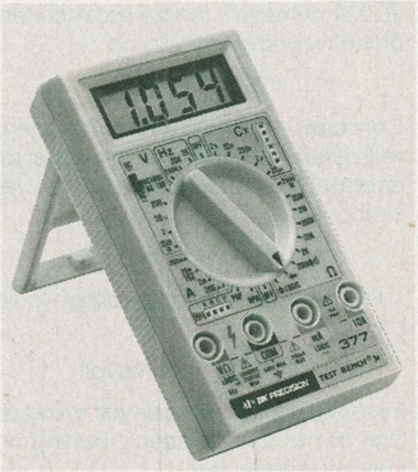
$$0.707 \times V_{PEAK}$$

and the value for the limiting resistor must be found from:

$$R_{LIMIT} = (V_{PEAK} - I_{FS} \times R_{INT} - 1.2)/I_{FS}$$

Already assembled AC-voltmeter movements that can measure up to 300 volts are commercially available.

Unfortunately, the solution is not so simple for AC ammeters. Introducing the voltage drops produced by the rectifier diodes can have very adverse effects on the circuit under test. Luckily, commercial AC-ammeter movements are available off-the-shelf that can measure up to 300 amps. Commercial VOM's (volt-ohm-milliammeters) are readily available from many different vendors. Prices for analog meters can range anywhere from $20 to $200.



This DMM can measure frequency, H_{fe}, and capacitance as well as resistance, amperage, and voltage.

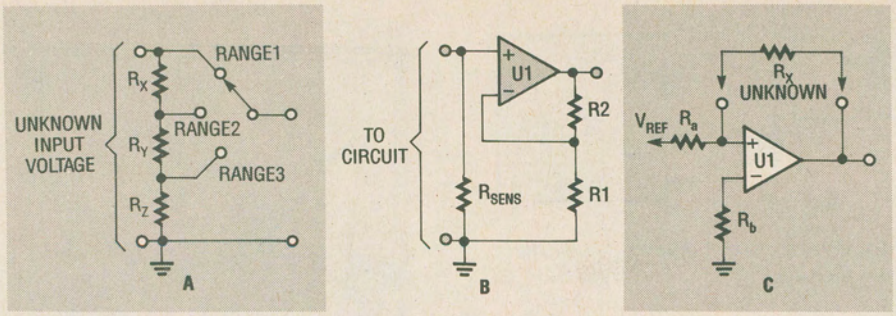


Fig. 7. These various input circuits can allow for a digital-meter circuit to detect voltage (A), current (B), and resistance (C).

Digital-Meter Concepts. Unlike the analog meters we have discussed, digital meters make extensive use of VLSI (Very Large Scale Integration) devices to accomplish the functions required to drive a multi-segment display. Although modern semiconductor technology has made single IC chips that perform many digital-meter functions possible, all DMM's (digital multimeters) contain the sections shown in Fig. 6.

The input-circuit section is informed by the switches and controls on the unit about the type of input that will be applied to it (*i.e.* voltage, current, or resistance). Figure 7 demonstrates just a few of the possible input circuits.

After some conditioning, the signal passes from there to the the A/D converter via a buffer. The buffer circuit provides some measure of isolation and further signal conditioning.

The A/D converter is the very heart of a DMM. It is responsible for converting the analog signal delivered from the outside world into an equivalent digital word that will be interpreted by the display driver. The operations of the A/D converter are regulated by a local clock signal that can be up to several kilohertz. Another local clock signal controls the operation of the display.

The display-driver section consists of code-converting circuitry and a display multiplexer. The code-converting circuit accepts raw digital information generated by the A/D converter, and generates the corresponding BCD (binary-coded decimal) numbers that will appear in the display. The multiplexer is synchronized to the code converter so that the appropriate display element is activated when the BCD code is generated. Multiplexing the display in this way is usually done at a very high rate so the display appears "flicker-free."

Lastly, there's the power source. Unlike the analog meters that we have covered, DMM's require some source of power to operate. Hand-held DMM's use a battery (often a typical 9-volt battery). More sophisticated benchtop DMM's usually have a built-in power supply.

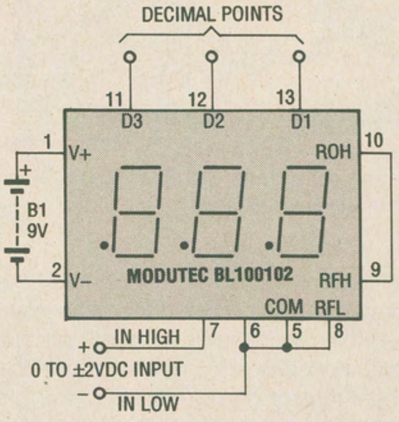


Fig. 8. A pre-packaged digital panel meter can be employed directly as a digital voltmeter.

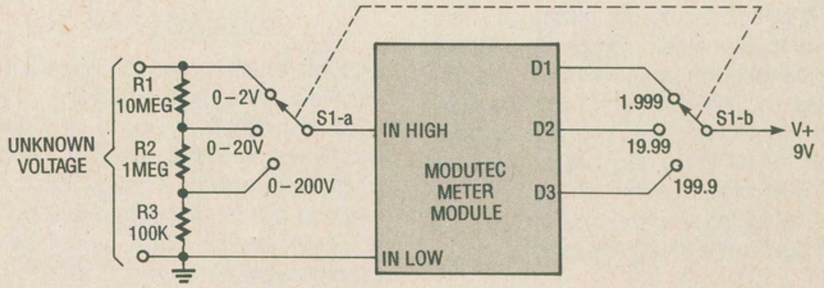


Fig. 9. A simple voltage divider can greatly extend the range of your digital voltmeter. Note the switch selects the proper decimal point for a reading.

Digital Meter Design. Many of the vital elements needed to build a digital meter are already available in the form of commercial panel meters. These compact and versatile assemblies are inexpensive and easy to use.

In our first voltmeter-design example, we will use the Modutec Series BL100 digital panel meter (available through various nationwide distributors such as Newark Electronics, Chicago, IL) as a 0 to ± 2-volt voltmeter (see Fig. 8). Since the DPM itself has a range of 0 to ± 2 volts DC, signals falling in that range can be connected directly to the meter without the aid of any voltage-dividing components. The meter can be operated conveniently from a single 9-volt battery. In this particular model, a low-battery indicator informs you when the battery power drops below 7.2 volts.

The BL100102 is referred to as a 3-½-digit meter. That means that the display consists of 3 full seven-segment digit displays and an indicator for a leading "1" called a "half" digit. Therefore, the meter can display numbers anywhere from a −1999 to +1999. If you use a 4-½-digit meter, then there will be 4 complete seven-segment numbers plus a leading 1, and so on.

The schematic of our digital voltmeter in Fig. 8 is very straightforward. Power is applied to the V+ and V− terminals (pins 1 and 2). The signal to be measured is connected to the IN HI and IN LOW pins. Notice that there are also a few other simple connections to be made. The IN LOW pin must be connected to the COM (common) pin as well as the RFL (reference low) pins of the module. That establishes the common reference point between our meter and any circuit under test. Also note that the ROH pin is connected to the RFH pin. That simply allows a 1:1 scale so the meter will interpret and scale the signal properly. No other pins need to be connected.

If you want to extend the range of the voltmeter, you can add a voltage-divider network such as the one in Fig. 9. With the selector in the 0–2-volt range, a 0 to ± 2-volt signal would be connected directly to the input. In the 0–20-volt range, the 10-megohm resistor forms a 9:1 voltage divider with the 1-megohm and 100,000-ohm resistors. If 20 volts were applied to the network, almost 18 volts would be dropped across the 10-

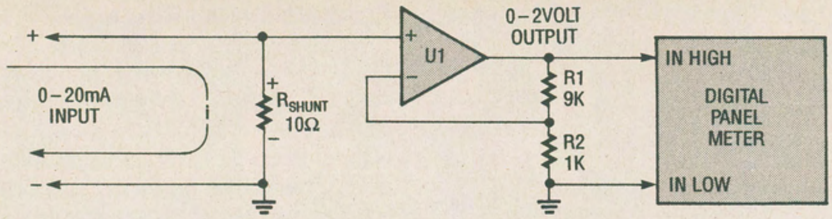


Fig. 10. An operational amplifier can be added to convert current into voltage for the digital panel meter. The shunt resistor determines the range.

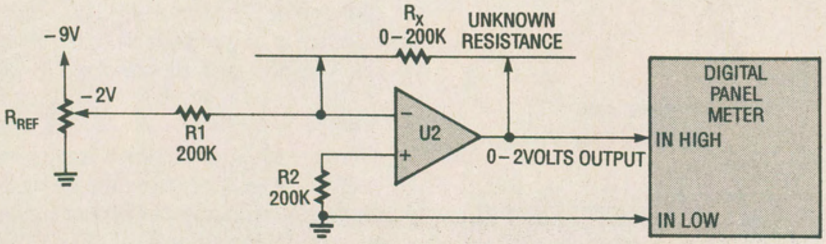


Fig. 11. An operational amplifier can be used to form a resistance sensor for a digital panel meter. The reference voltage sets the range of the meter reading.

megohm resistor, leaving about 2 volts at the input. In the 0–200-volt position, a voltage divider is formed between the 10-megohm and 1-megohm resistors, and the 100,000-ohm resistor resulting in a ratio of about 100:1. A 200-volt input will yield about 2 volts at the input to the module. You can alter the values of the divider resistors to achieve other voltage-division ratios.

A ganged selector switch can be used to select the appropriate decimal place for each scale as shown. The desired decimal point can be lit simply by connecting it to V+. In the 0–2V position, the left-most decimal point will be lit. The middle point will light in the 0–20V range, and the one on the right will light in the 0–200V position.

Ammeter. Remember that our meter module can only read DC voltage. In order for the meter to read current, the current signal must be converted into a related voltage signal. The circuit addition in Fig. 10 uses an operational amplifier configured as a non-inverting amplifier. The meter leads can be inserted into the circuit just like an analog ammeter. Current will flow through the shunt resistor and generate a voltage drop. The potential is amplified by the factor of:

$$R1/R2 + 1$$

The multiplication factor would then be:

$$9000/1000 + 1 = 10$$

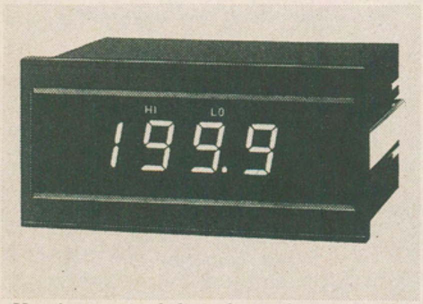
and the resulting output voltage will be supplied to the digital module.

For the circuit of Fig. 10, a 10-ohm resistor will sense the current in the 0 to 20 mA range. In that range, R_{SHUNT} will develop a potential from 0 to 0.2 volts. At 20 mA, the 0.2-volt DC signal will be amplified by 10 to yield 2 volts to the module. In this case, 20 mA will cause a full-scale response. The middle decimal point may be used in this range (19.99 mA). As a general rule, try to keep the sense resistor as small as possible to reduce the load on the circuit under test.

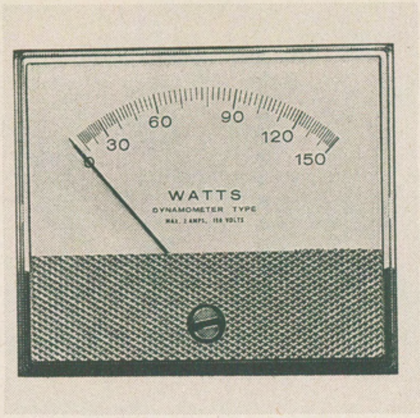
For a 0 to 200 mA range, try a 1-ohm sense resistor in place of the 10-ohm resistor. At 200 mA, the potential across R_{SHUNT} will be:

$$0.2 \times 1 = 0.2 \text{ volts}$$

That will be amplified by 10 to provide 2 volts to the digital panel meter. At 200 mA, the DPM will be at full scale for a display of 199.9 mA, so you must use the right decimal point. Try some different scales, but be careful of excessive power dissipation in the shunt resistor.



Here's a typical digital panel meter with an LED display. It requires front-end circuitry and switches to be really useful.



This specialized analog meter is based on a d'Arsonval movement modified to measure watts.

Digital Ohmmeter. Of course, the digital module can not measure resistance directly. Like current, resistance must be converted into an equivalent value of voltage in order to be displayed.

The circuit of Fig. 11 can be used to sense an unknown value of resistance by using an operational amplifier configured as an inverting amplifier. The input and output of the op-amp will have opposite polarity. The amplification factor is:

$$-R_x/R1$$

With infinite resistance (no connection), the output would be:

$$-(\infty/R1) \times -2$$

which means the reading is a positive over-range or 199.9 ohms. If R_X is 0 ohms the output would be:

$$-(0/R1) \times -2 = 0$$

The zero for the meter can be adjusted by altering the the reference voltage via potentiometer R_{REF}. This particular circuit has a useful range from 0 to 200,000 ohms before reaching the top of the DPM's scale. When R_X = 200,000 ohms, the output will be:

$$-(-2) \times 200{,}000/200{,}000 = 2 \text{ volts}$$

which produces a display of 199.9k ohms. Use the right decimal place (D3) for this scale.

To change the scale, change R1 and R2 (they must be equal). For a 0–20,000-ohm scale, replace R1 and R2 with 20,000-ohm resistors and turn on the middle decimal point (D2). Any unknown resistance greater than 20,000 ohms will cause an over-range reading. For the very best circuit performance, try to keep the values of R1 and R2 as close together as possible.

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METER FUNDAMENTALS

(Continued from page 34)

The great disadvantage of this circuit is the need for a negative reference voltage. But it is very important; it will ensure that the operational amplifier will produce a positive output across its range. A simple solution is to add a second 9-volt battery in the reverse direction to provide the required negative voltage.

Finally, there are a myriad of digital panel meters on the market. Feel free to experiment with various types of meters. Be sure to carefully consider their input ranges and alter your op-amp circuits accordingly. Many commercial DMM's are on the market. In many instances, their prices are comparable with analog meters.

Conclusion. Voltmeters, ammeters and ohmmeters are by no means the only types of meters available. A diverse array of other meters make use of the analog and digital techniques that we have discussed here. For example, wattmeters commonly measure power to a component by measuring voltage as well as current. Frequency meters indicate the rate of a signal's repetition. Meters can be found that specialize in measuring physical parameters such as temperature, pressure, capacitance, inductance, and transistor gain. There are many more.

In spite of this diversity however, VOM's and DMM's continue to be the fundamental electronic test instruments. Versatile, inexpensive, and easy to use, they can be found on just about any hobbyist's workbench.

The material covered here represents the basic technology and applications used to measure voltage, current, and resistance in both analog and digital forms. Go ahead and build some of the circuits here. You may be surprised at just how easy (and useful) they can be. ■