

# Using multimeters on boats

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Multimeters measure electrical voltage, resistance, and current. For wiring and troubleshooting on boats, they can be extremely useful. Applications include: checking the continuity of wiring—locating breaks in open circuits; testing fuses and diodes; measuring battery voltage and voltage drop over wires and electrical loads; identifying “hot” and grounded wires; locating short circuits or small current leaks; and checking alternator and generator output.

A multimeter, also called a volt-ohm-milliammeter (VOM), is actually three tools in one. It is a voltmeter capable of measuring direct-current (DC) or alternating-current (AC) voltages. Its selector switch selects function and sensitivity. By repositioning the selector switch (or on some meters, by plugging the probes or wire leads into a different set of connectors), the meter becomes an ohmmeter, capable of measuring electrical resistance. Again, by flipping the switch or moving the leads, it becomes an ammeter that measures small DC currents.

## Ohm's Law

To understand the measurements made by a multimeter, it is necessary to understand Ohm's Law, stated mathematically as

$$V = IR,$$

where  $V$  = DC voltage, in volts,

$I$  = DC current, in amps  
(*amps* is short for *amperes*), and

$R$  = electrical resistance, in ohms.

(The formula for AC voltage is similar, except that the resistance  $R$ —a DC phenomenon—is replaced by a more complicated term called *impedance*.)

A resistance of 1 ohm (written  $1\Omega$ ) allows a current of 1 amp (1 A) to flow, if a voltage of one volt (1 V) is applied.



*Example:* Engineering handbooks show that a 50-foot length of No. 16 stranded copper wire has an electrical resistance of around 0.2 ohm. Ohm's Law tells us that if a current of 5 amps is flowing through the wire to, say, a VHF radio, the voltage drop over that wire is:

$$\begin{aligned} V &= IR \\ &= 5 \text{ amps} \times 0.2 \text{ ohm} \\ &= 1.0 \text{ volt.} \end{aligned}$$

So, on a 12-volt power supply, the resistance of this wire would cause a 1-volt drop, leaving only 11 volts to supply the radio. In this example, a larger wire size would be needed to provide the full voltage that the radio requires.

## Marine electronics

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### DC voltmeter

Most multimeters are designed for measuring both DC and AC voltages. This bulletin concentrates on how to measure DC voltages; procedures for making AC measurements are similar.

First, plug one of the leads into the negative terminal, properly called a *jack*, marked (-) or “COM” (for *common*). Standard electrical practice uses the black wire for the ground, which is usually the negative terminal. The other lead (usually red, to signify the “hot” side of the circuit) goes into the positive jack, marked (+). After selecting the proper DC voltage range with the selector switch, measure DC voltage by touching the (-) lead to the negative terminal or wire and the (+) lead to the positive terminal or wire.

Selecting the proper voltage range is important. It is achieved on most meters by positioning the *selector switch*, and on others, by plugging the (+) lead into different jacks. Always begin on the highest voltage range that you reasonably expect to find in whatever you are testing. If the range you start on gives a very low reading on the scale, switch to the next lower range. The most accurate reading occurs when the needle swings over most of the scale.



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A simple experiment helps to explain the voltage-measuring procedure.

Take an ordinary 1.5-volt flashlight battery; put the DC voltmeter on a high range, say, 60 volts full scale. This would mean that if the battery were putting out 60 volts, the needle would swing all the way over to full scale (figure 1). (No two brands of meter are exactly alike; figure 1 shows a typical DC voltage scale.) When you set the selector switch at 60, you read the voltage from the top row of numbers (for example, 4 means 40 volts, and so on).

When you try to read the voltage of a 1.5-volt flashlight battery on such a high range, the needle swings only a short distance (figure 2). (Note that if by mistake you should switch the leads, the needle deflects to the left—that is, in a negative direction—and the meter may be damaged. The distinction between positive and negative leads is not important when measuring AC voltage on the AC voltmeter.)

Now switch to a lower range, say 12 volts. For this range, you will read the voltage on the lower scale (figure 1), so 120 means 12 volts, 60 means 6 volts, etc. Measure the flashlight battery voltage once more. This time, the needle comes up higher—to about 15 on the scale, corresponding to 1.5 volts.

Finally, try the lowest range that can still measure 1.5 volts on the meter. This might be 3 volts full scale. The scale in figure 1 corresponding to this range is the middle one, where 30 means 3 volts and 15 means 1.5 volts.

**Remember:** If you don't know approximately what the voltage is before you make the measurement, start with a very high range and work *down* to more sensitive settings. Stop with the range where the needle movement covers most of the meter scale. If you should try to measure a 12-volt battery on the 3-volt range, the needle would swing up against a pin to the right, and you might very well ruin the meter.

#### Two final notes about voltmeters:

1. All multimeters have a *zero-adjustment knob* that applies only to the ohmmeter function for measuring resistances. It has no application in voltage measurement. There is also a *zero-adjusting screw* for setting the needle to rest at 0 volts when no voltage is applied. You will only need to adjust this on rare occasions—perhaps when you buy the meter or after it has been bumped around a lot.
2. Be careful to read DC voltage on the DC-voltage scale. The AC-voltage scale is slightly different.

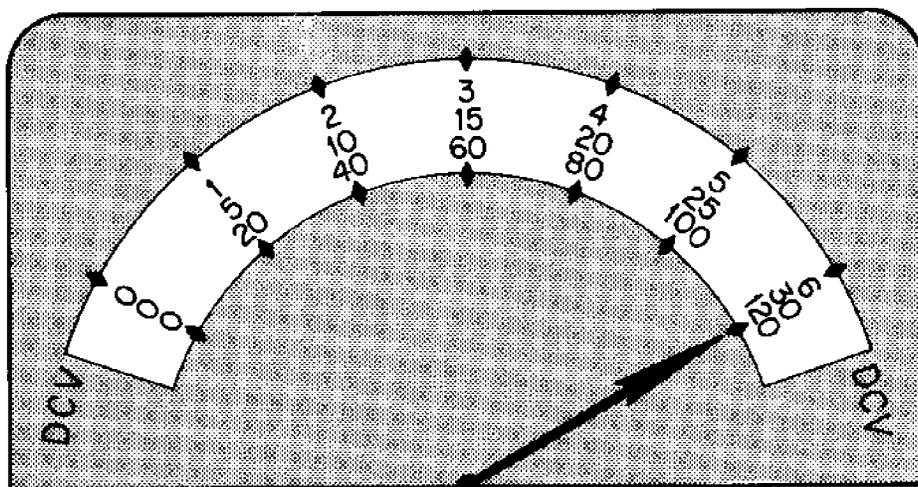


Figure 1.—The multimeter working as a voltmeter, measuring a 60-volt battery.

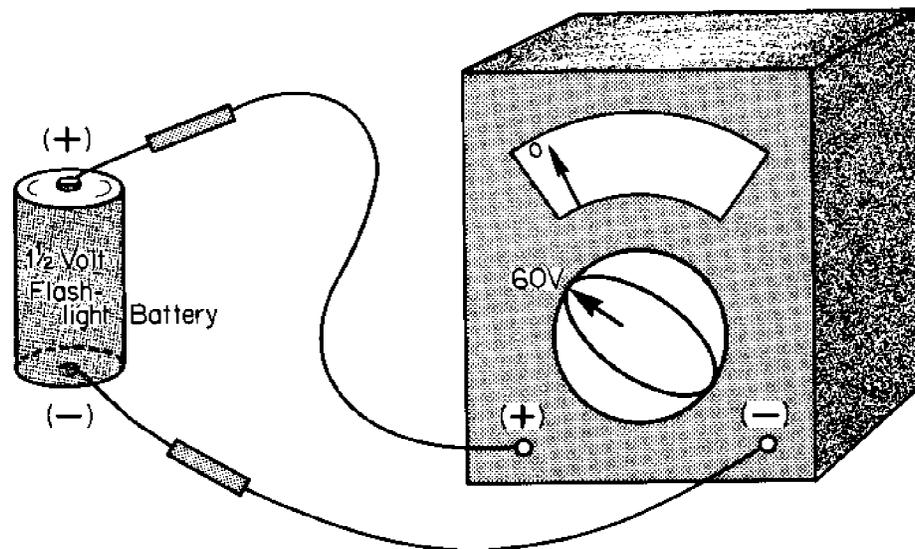


Figure 2.—This is the same DC voltmeter range as in figure 1, but now the meter is measuring a 1.5-volt flashlight battery.

#### The ohmmeter

You can change the multimeter into an ohmmeter by just turning the selector switch or by plugging the leads into a different set of jacks. The ohmmeter measures how much electrical resistance (in ohms) exists between any two points. The commonest application is to check for zero resistance (signifying a complete circuit, or continuity) or infinite resistance (no connection or an open circuit).

The accuracy of very-low-resistance readings is not usually very good. For example, few multimeters can directly measure the 0.2-ohm wire resistance of the earlier (Ohm's Law) example. (If an ammeter in the line gives you the current reading, you can measure the voltage drop with the multimeter, then, using Ohm's Law, divide the voltage by the current to calculate line resistance.)

The steps for measuring resistance are:

1. Use the meter as a voltmeter to make sure there is no voltage between the two points of interest. Even a weak voltage, such as between two through-hull fittings, will lead to a faulty resistance reading. (This frequently occurs when checking out the bonding of a boat. Two unbonded metal objects will often be at different voltage levels because of a static charge, a current leak, or dissimilar metal properties. This will disrupt the ohmmeter reading and may even make it less than zero.) **Warning:** Using an ohmmeter on a hot wire can ruin the meter.
2. Put the *selector switch* on the lowest, most sensitive ohmmeter scale. This may be marked "R × 1", meaning that you can read the resistance, R, directly off the meter without multiplying by anything but 1.

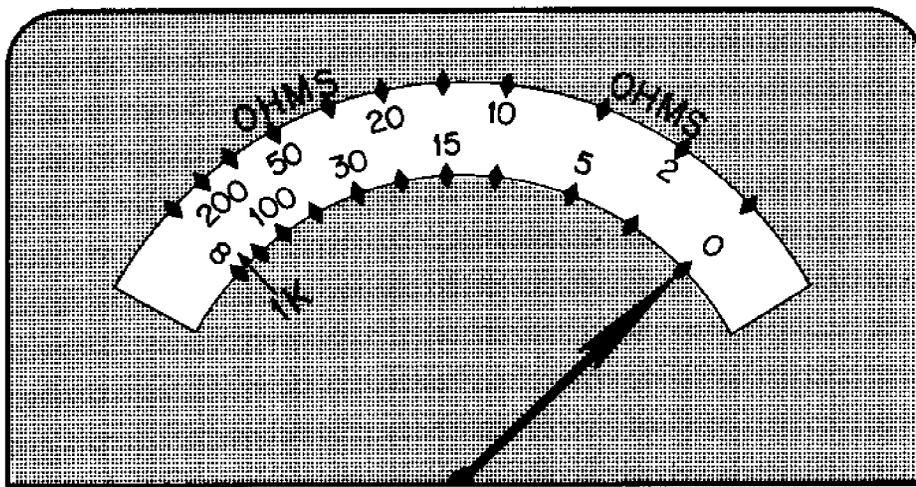


Figure 3.—The multimeter is now switched into its ohmmeter function.

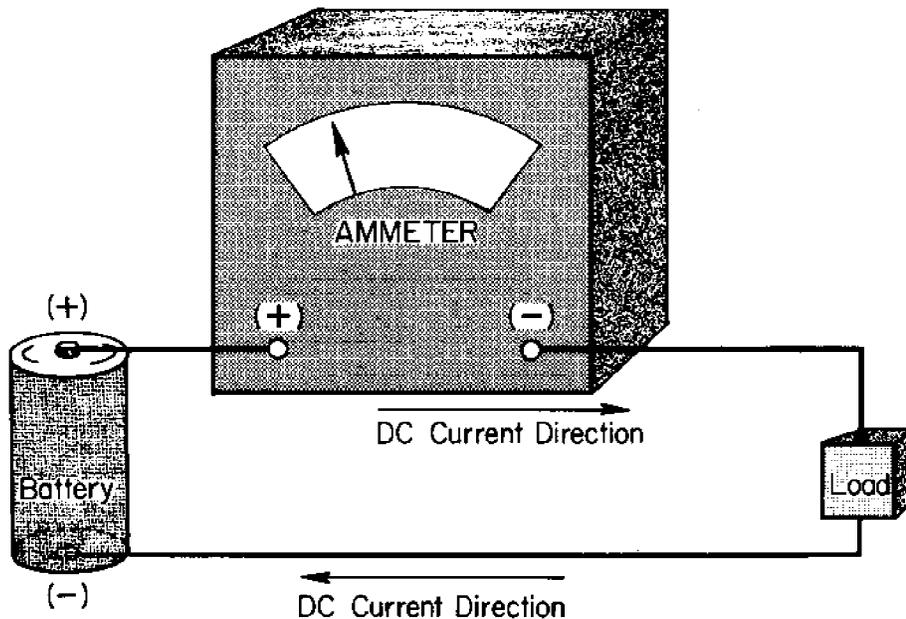


Figure 4.—Here the multimeter is working as an ammeter.

3. Touch the probes together. Since they make an excellent electrical connection, the resistance should read zero (figure 3). If it does not, adjust the *zero adjust knob* until it does. When you separate the two leads, you break the electrical connection, and the ohmmeter reading should be  $\infty$  (a symbol meaning infinity). When there is no electrical connection between the ohmmeter leads, the resistance is effectively infinite.
4. Once the ohmmeter is zeroed, you can begin measuring resistances. Since resistances should be measured only on wires in which no current is flowing, it does not matter which lead on the ohmmeter goes on which end. A corroded or damaged connector can produce a resistance in a circuit where you would normally find  $0 \Omega$ . This can be true also when rust or grease

is coating the metal object touched by the ohmmeter probe. Note that on the ohmmeter scale, "K" means *thousand*; a reading of 1 K means one thousand ohms. When a resistance reading is very large—close to  $\infty$  on the scale—you should switch to the next higher range setting to get a more accurate reading. With the selector switch on the "R  $\times$  100" setting, for example, a reading of 5 means  $5 \times 100$ , or 500. It is important to remember that each time you change the resistance range, you must zero the ohmmeter, as in step 3, above.

## DC ammeter

Unlike the voltmeter, which measures voltage from outside the electrical circuit, an ammeter is used *in* the circuit. To measure current in a wire, you must break the wire and attach the leads so that the current flows through the meter (figure 4—which uses the conventional definition that current flows from positive to negative). The ammeter should be used in the circuit so that its (+) lead, or probe, connects ultimately to the (+) battery terminal, and the (-) lead to the negative battery terminal. In this configuration, a positive current will be measured on the ammeter. If you installed the ammeter in the opposite way, the needle would swing toward the left, off the scale of the meter.

The ammeter function of most multimeters is too sensitive, by itself, to be useful for common electrical circuits on boats. This is because the current drawn by a depth meter or radio, for example, is generally on the order of several amps, while current measured by most multimeters is on the order of only milliamps. (*Milli-* means *thousandth*; 1 milliamp is  $1/1000$  of an amp.) But meters having a maximum range of several hundred milliamps are good for measuring leakage currents, provided you are careful to avoid excessively high amperage, which will burn out the meter.

As with the other functions of the multimeter, the ammeter has several ranges. The highest, which may be 300 mA (300 milliamps =  $300/1000$  amp = 0.300 amp), should be tried first. (Be careful: a larger current will probably burn out the meter.) As before, a scale reading of 30 means 300 mA, 20 means 200 mA, and so on (figure 5).

The most accurate reading occurs when the needle swings over most of the scale. If the needle does not deflect very much—indicating a current much smaller than 300 mA—try a lower range setting. Note that a range labeled, for example, "60  $\mu$ A" means 60 *microamps*, or 60 one-millionths (0.000060) of an amp.

### Buying your multimeter

Multimeters are available at most electronics shops. Prices range from around \$15 up, with a typical price being \$25. Battery power is needed to use the meter for the ohmmeter function only; the voltmeter and ammeter can be used without it. You need to replace batteries when you can no longer zero the ohmmeter with the probes touched together.

In general, the better the quality of the meter, the lower the DC voltage it can read. A good meter can more accurately measure DC voltages in the range of 1 volt. Another characteristic frequently noted on meters is "10,000 ohms per volt" or "20,000 ohms per volt" (sometimes printed as "20 K $\Omega$ /V"). The "20,000 ohms" refers to the internal resistance of the meter. The greater this internal resistance, the less the meter disturbs a circuit when you take a voltage reading, and thus the more accurate the reading.

### Summary

#### DC voltmeter

*Examples of applications:* checking batteries, measuring voltage drops, identifying hot and grounded wires, checking charger output.

#### To use:

1. Plug leads into (- or "COM") and (+) jacks.
2. Turn selector switch to highest DC-voltage range.
3. Touch negative (-) probe to negative wire or terminal, positive (+) probe to positive wire or terminal.
4. Continue to try smaller DC-voltage ranges until needle deflects over most of the meter scale (the most accurate condition).

#### Note:

- a. The procedure for measuring AC voltage is similar. Be careful to read AC voltage on the right scale; it is different from the DC-voltage scale.
- b. The needle should rest at "zero volts" when not in use. If it does not, turn the adjusting screw.

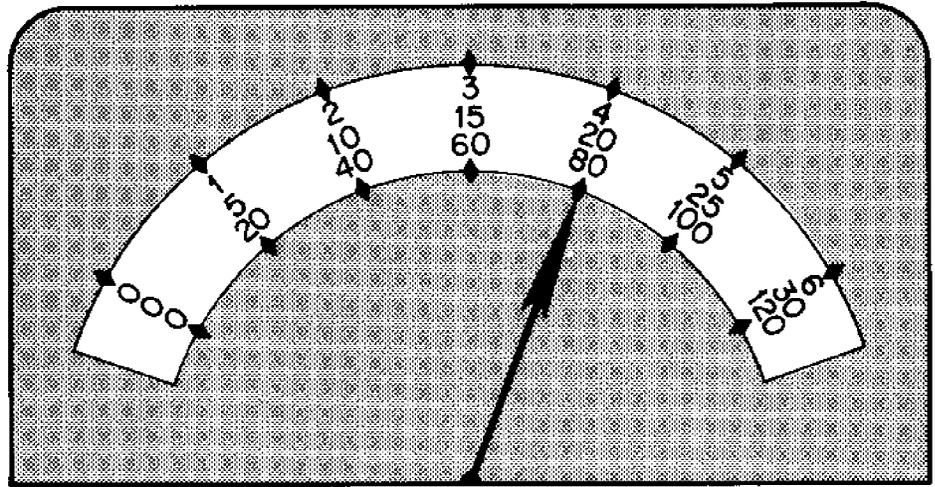


Figure 5.—The ammeter shows 200 mA on the milliamp scale.

### Ohmmeter

*Examples of applications:* check for continuity, quality of the boat's bonding system, damaged diodes and fuses.

#### To use:

1. Use the voltmeter to insure that no voltage exists between measuring points.
2. Turn the selector switch to the lowest ohmmeter scale.
3. Touch the probes together and zero the needle with the zero-adjust knob (not with the needle-adjusting screw).
4. Measure resistance, making sure that the probe makes good electrical contact.
5. Use a higher range if the needle is indicating near  $\infty$  on the scale.

#### Note:

- a. The ohmmeter function is the only one requiring batteries in the meter.
- b. The meter must be zeroed (step 3) each time you change the range.

### DC ammeter

*Example of application:* low-level leakage current.

#### To use:

1. Turn the selector switch to the maximum DC-amp range.
2. Connect the meter into the circuit so that the (+) lead or probe connects ultimately to the (+) battery terminal and the (-) lead or probe, to the negative battery terminal.
3. If the needle deflection is small, turn the selector switch to the next lower DC-amp scale.

*Note:* Most multimeters have a maximum current capacity that is much too low for common DC circuits. Be careful to use the meter only when current will not exceed the limits of the ammeter.



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