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An Expanded-Scale Voltmeter

For accurate battery monitoring.

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Like many amateurs, I use a 12-volt deep-discharge lead-acid storage battery to power my base station radio equipment. This method has the advantage of providing emergency operation in case of a power failure without having to connect and start a generator immediately, and without having to reset computer-based equipment. It also partially isolates the battery-powered equipment from the power line, reducing the chances of damage during thunderstorms or from other line transients. Battery operation allows the use of a comparatively low-amperage 12-volt power supply or battery charger. High current demands during transmit can be supplied by the battery, which is then gradually recharged during receiving periods. The battery can be constantly recharged using a floating-type power supply, or a higher-current charger can be manually or automatically switched in and out. (An automatic charging controller was described in *73 Amateur Radio Today*, May 1992, by WBØTCZ.)

It is desirable to constantly monitor the condition of a storage battery, i.e. its terminal voltage, when it is used this way, to make sure that the battery is not overcharged or too deeply discharged. It is difficult to use a standard voltmeter with a moving pointer for this task because the useful voltage range becomes compressed into a small portion of the meter's scale, making reading the meter difficult. For example, if a 0- to 15-volt meter is used, the useful portion is from about 10 or 11 to 15 volts; the bottom two-thirds of the meter's range is not used (it would damage a lead-acid battery to discharge it below 10 volts, besides the fact that little useful power would be left). Trying to distinguish precise values in that useful upper third of the scale is difficult. One solution to this situation is to use a digital voltmeter, but even though these are dropping in price they are still fairly expensive, particularly if there is a mostly-junk-box solution available. Indeed there is—a standard analog voltmeter can be converted to an "expanded-scale" meter using the methods outlined in this article.

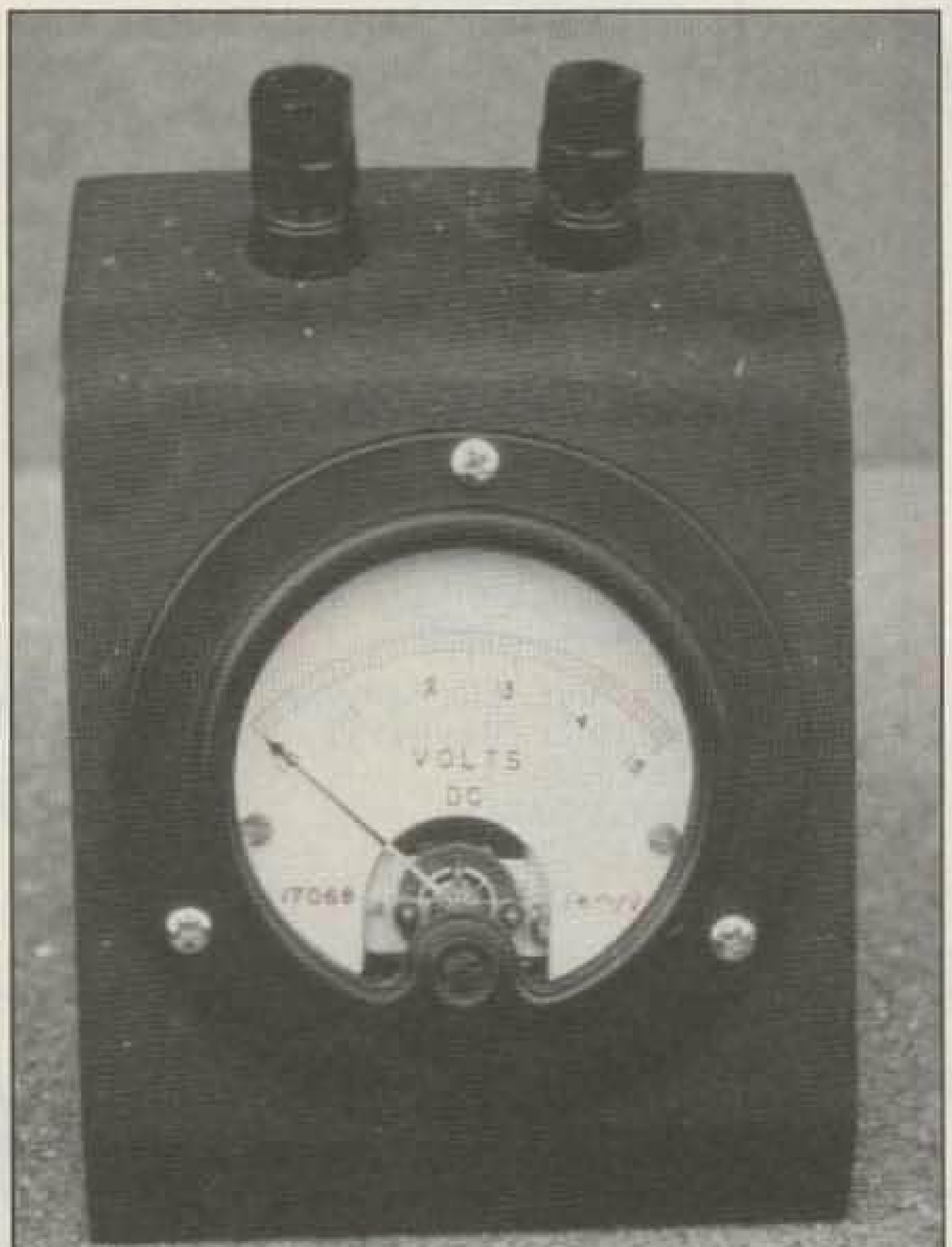

Photo A. Front view of a completed expanded-scale voltmeter, mounted in a metal case. The original 0-5 volt DC meter was modified by inking a "1" before each digit.

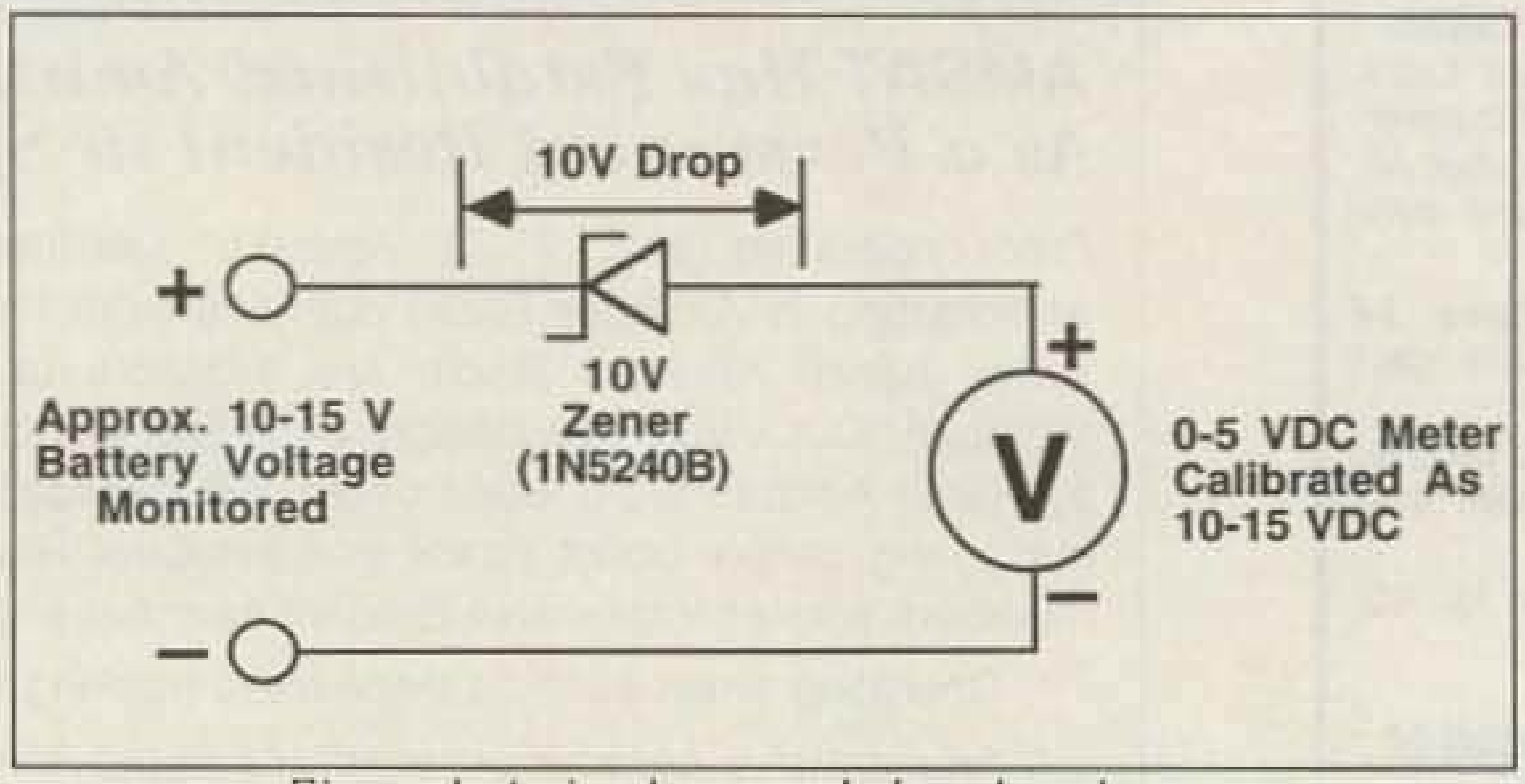

Figure 1. A simple expanded-scale voltmeter.

Converting a Standard Analog Meter

An established way of making an expanded-scale voltmeter is to place a zener diode in series with a voltmeter of smaller range. For example, see Figure 1: A 1N5240B 10-volt zener is placed in series with a 5-volt full-scale voltmeter. The meter will not respond at all until the input voltage reaches at least 10 volts and the zener starts conducting, so the left-hand end of the meter's scale represents 10 volts or below. Any input voltage above 10 produces a proportional increase in meter reading; full scale deflection occurs with 15 volts input, which produces 5 volts across the voltmeter. This is a particularly easy conversion to make: The meter can be opened up and the scale easily modified by placing a "1" before each digit of the 0-to-5 scale, thus relabeling the scale 10 to 15 volts, with no other meter modifications needed.

Though apparently easy to accomplish, this method is disappointingly inaccurate. The weak point is the drop across the zener; it won't be a constant 10 volts, or probably 10 volts at any time. Since most voltmeters are high-resistance by design, the zener current will be much lower than its "test current," which is the point where its voltage drop should be equal to 10. In this example, for the 1k ohm/V meter used, the meter's internal resistance will be its full-scale rating of 5V times 1k ohm per volt, or 5k ohm; or, 1 mA full-scale current. The maximum zener current will be this 1 mA, far below the 1N5240B's test current of 20 mA, and of course the current varies by a large factor over the meter's range. Therefore, the zener voltage will probably be below 10, and will vary some. In addition to these problems, the zener has a tolerance, or stated initial accuracy: The 1N5240B is rated as 5%, or plus or minus 0.5V, from 10V. Most other 10V zener part numbers have even worse accuracy, perhaps 10 or 20 percent.

Testing

To determine how well, or how poorly, the simple expanded-scale meter worked, I selected three new 1N5240B zeners at random and breadboarded the circuit and checked the zener drop and meter readings with a good-quality digital multimeter (the 5-volt meter was first checked and found to be quite accurate). Over the meter's range, the actual zener voltages varied only by 10 mV on the best zener, by 40 mV on another, but by 120 mV on the worst. However, all zener drops were well below 10 volts, with an average of 9.46 volts at mid-scale. This would produce an average error of over half a volt. The worst zener's drop was 9.34 volts, for a mid-scale error of 0.66 volts. There's no easy way to reduce the error because a zener isn't adjustable. The scale could be painstakingly recalibrated using the DMM, but that's no fun, nor would it be attractive.

To improve accuracy and provide for easy, precise adjustment, I developed the circuit shown in Figure 2. Two inexpensive three-terminal IC voltage regulators are used, provid-

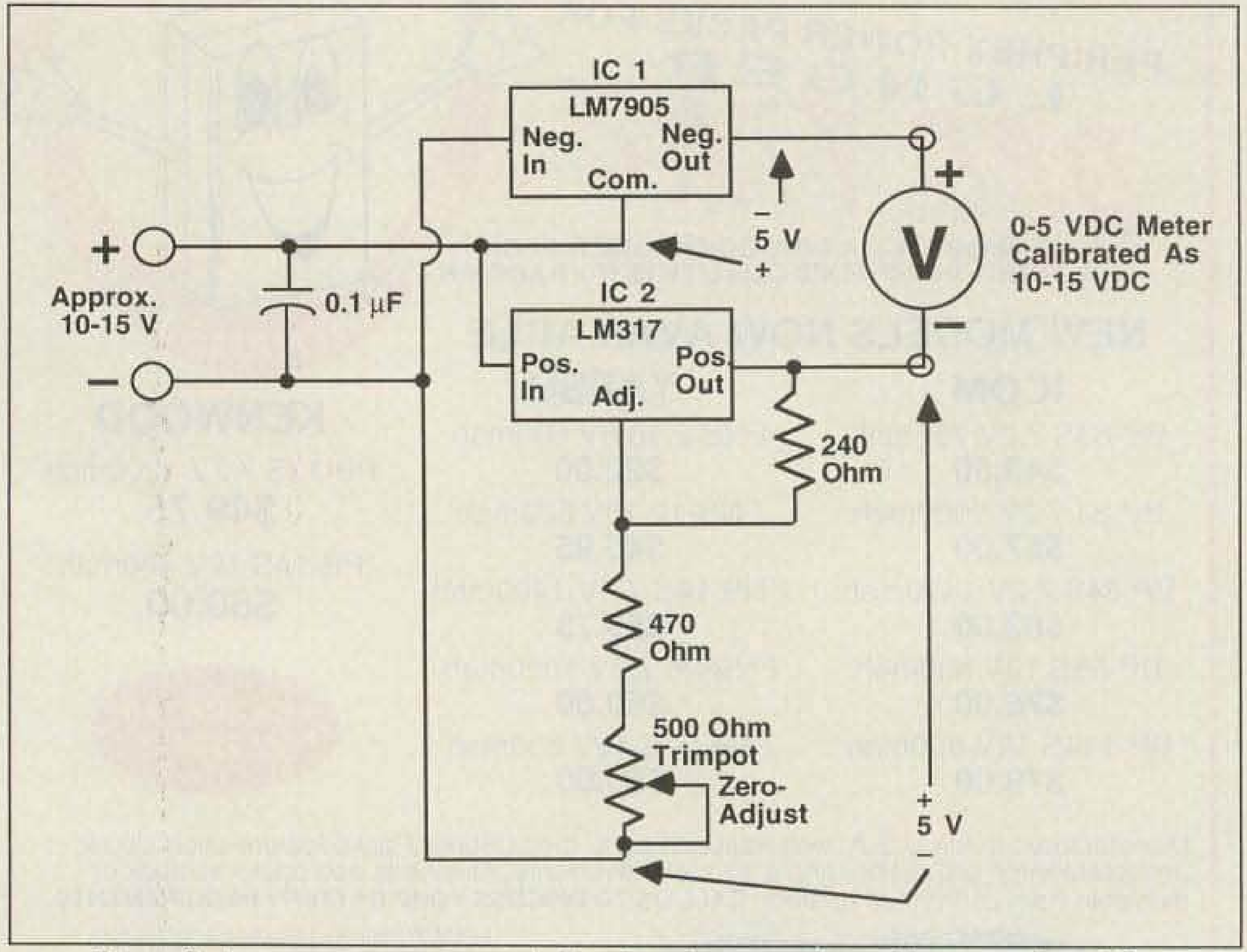

Figure 2. A more accurate expanded-scale voltmeter using voltage regulator ICs.

ing accurate scale expansion and a trimpot for calibration. The "trick" in this circuit is the unusual way IC1 is used: This is a negative-supply regulator, used in an inverted fashion. Its output voltage is negative 5 volts with respect to its common reference, which is connected to the positive input voltage, while its negative input is connected to the negative side of the input voltage. The upshot of this is that IC1's output with respect to circuit common (the negative input voltage) is always 5 volts below the positive input. In other words, as the input varies from +10 to +15VDC, IC1's output varies from +5 to +10 VDC with respect to circuit common. IC2 provides a constant +5 VDC with respect to circuit common; the voltmeter is connected between the regulator outputs, so it "sees" 0 to 5 volts as the input varies from 10 to 15 volts. Therefore, the expanded-scale meter results.

It is tempting to consider eliminating IC2 and changing IC1 to a 7910, producing a 10-volt drop directly. The problem is that IC1, like many regulators, requires a minimum of 1.7V more input than output, so then the meter wouldn't be accurate below 11.7 volts input. IC2 provides an inexpensive reference at +5V to solve the problem, with the additional 5-volt offset of IC1 adding up to the 10V drop needed. Since both ICs are operating as 5-volt regulators, the accuracy is fine to well below 10 volts input.

IC2 is shown as an adjustable regulator, rather than fixed, to allow precise trimming at the zero, or 10-volt, end of the meter scale. The data book says that a minimum load current for a LM317 of 3.5 mA typically is required to maintain accuracy; the meter will usually draw less than this. However, I experienced no problems. A load resistor could be added if needed.

IC1 could be changed to an LM337 negative-voltage variable regulator, if desired, to provide a full-scale trim as well; or the meter's dropping resistance could be varied to accomplish calibration at full-scale. Using a partly-variable meter dropping resistance to provide full-scale trim is discussed in the section on selecting meters. In the example pictured, the 5-volt meter's accuracy was so good that full-scale trimming was unnecessary. Measured error was less than one minor division (0.1V) anywhere in the meter's range.

Since the meter current is low, the regulator ICs can be either the low-current types or the more common TO-220 package types; no heat sinks are needed. Since any of several regulator packages might be chosen, a pictorial wiring diagram has not been shown. Point-to-point wiring on a perf-board is very practical; just make sure you have the proper pin configuration for your regulator packages, and follow the wiring shown in Figure 2. Photo B shows a completed meter, mounted in a cabinet, with the circuit of Figure 2 mounted on a perf-board attached to the meter terminals. This unit was built using one low-power (TO-92) package and one TO-220 package (what I had in the parts drawer). The zero-adjust pot is visible on the lower left.

The front view, Photo A, shows the slightly modified scale to the original 5-volt meter (the hand-inked "1's" were added before the original numbers), as discussed earlier. Though not shown in the picture, an inline fuse (1/2 amp was used) is in the circuit wiring between the battery and the meter. Always provide a fuse in any circuit attached to a storage battery; if anything shorts and you don't have one, that battery's high current capability will get you in serious trouble very quickly! The meter can be left on continuously; its current consumption is about 7 mA using a 1 mA meter movement.

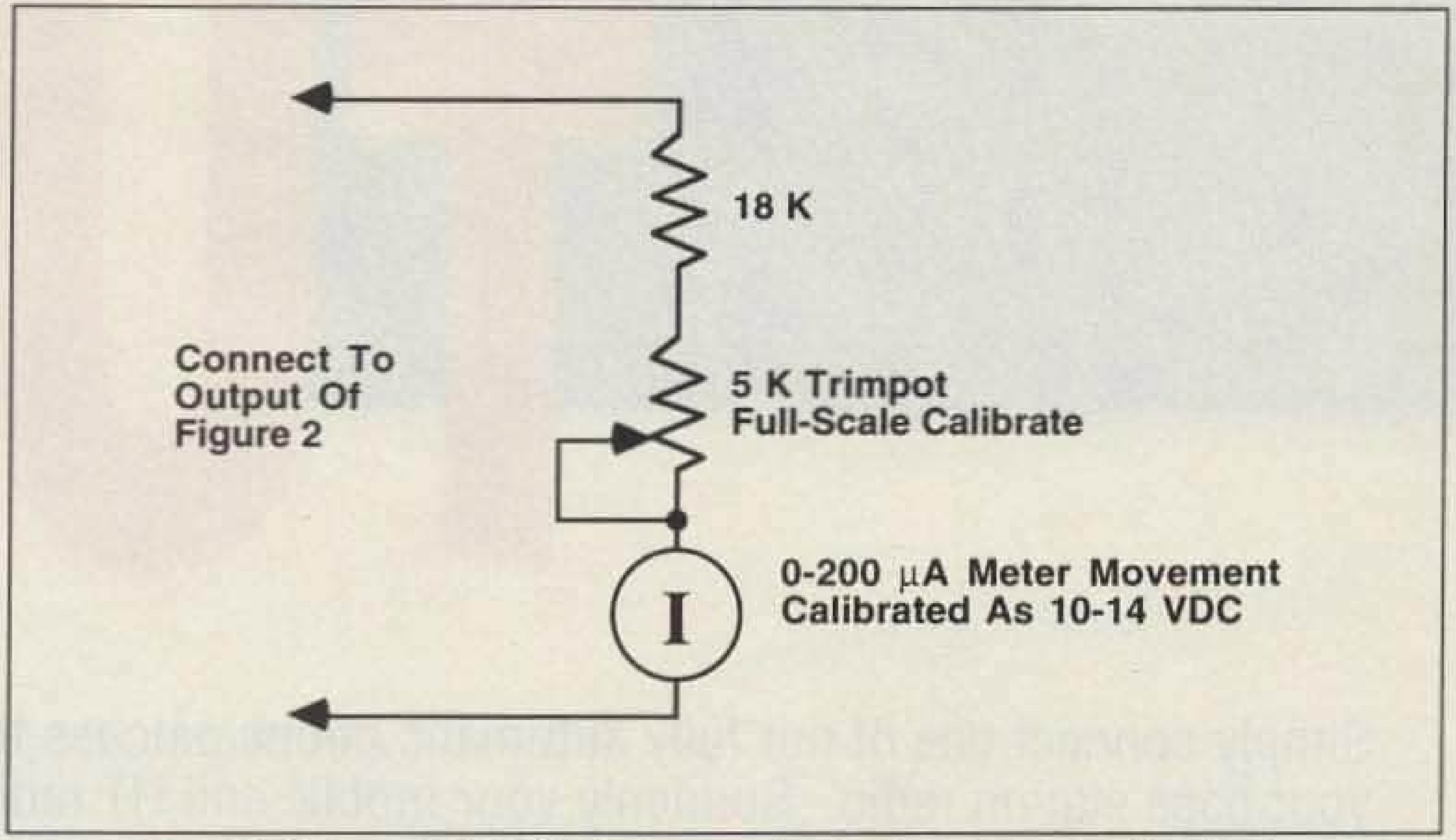

Figure 3. Using a basic 200 microamp meter movement as a 4-volt voltmeter.

Photo C shows another unit that was built with an ammeter included for monitoring either charging current or load current, as desired. Again, note that a fuse is installed.

Finding and Choosing a Meter

Finding a suitable meter shouldn't be hard or expensive. If the junk box doesn't yield a good candidate, a hamfest flea market surely will. Again, the easiest approach is to use a 0- to 5-volt DC voltmeter, as has been discussed. If you can't find one one of those, often you can modify another meter. For example, what if you have a 0-150 VDC meter (see Photo D). Useless, right? Nope; carefully take it apart and look for the series dropping resistor. Short it out and it is back to the basic milliamp or microamp meter movement. Then replace it with a new dropping resistor of proper size for 5-volt sensitivity (outside the meter, probably,

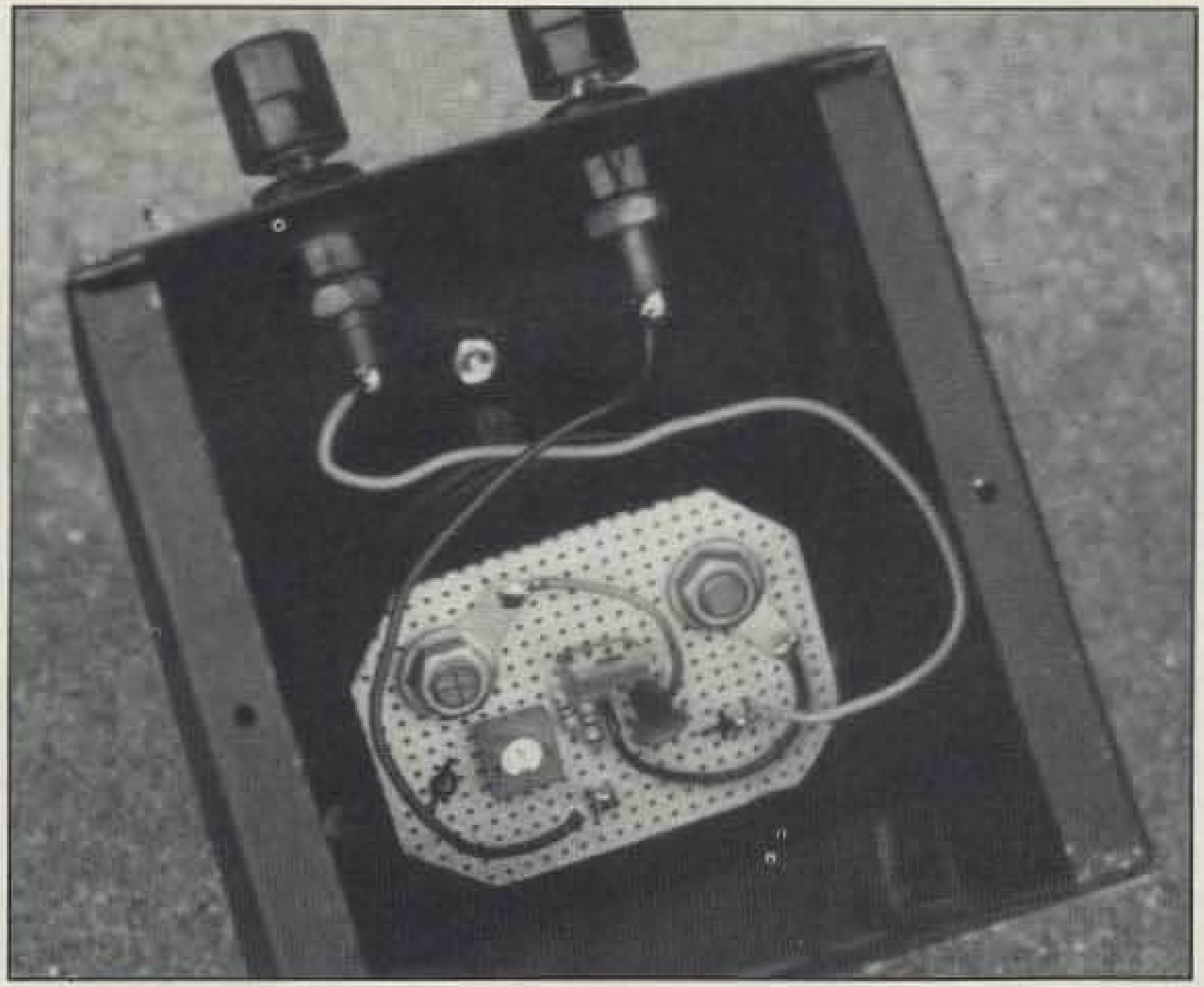

Photo B. Rear view of a completed expanded-scale voltmeter. The circuit of Figure 2 is mounted on a perf-board which is attached to the meter terminals.

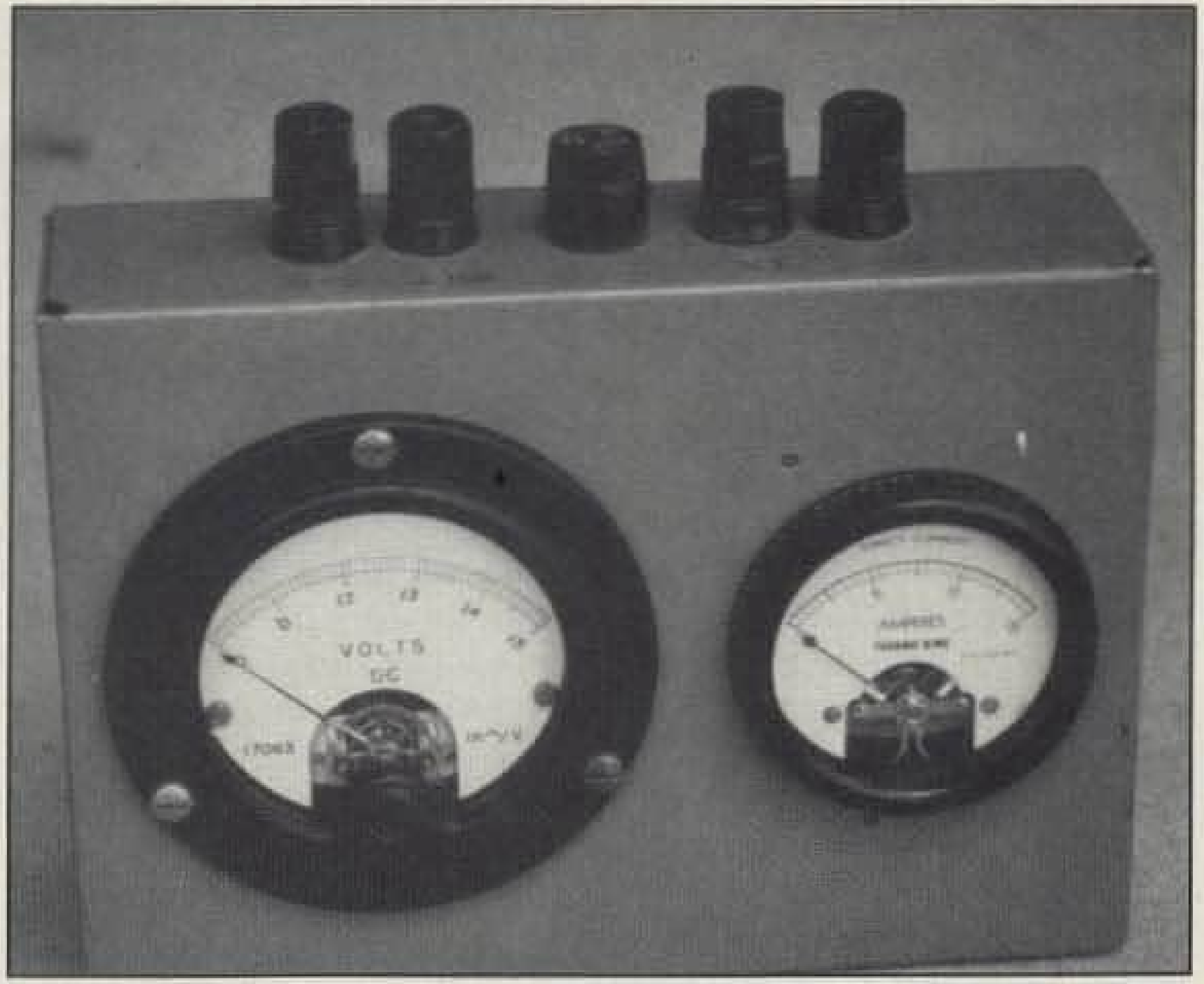

Photo C. Another example of an expanded-scale voltmeter. This unit includes a series ammeter to monitor charging current.

where it can be conveniently mounted on the perf-board). Often, either the meter's current sensitivity or its ohms-per-volt rating is stated in a lower corner of the meter scale; if not, calculate meter full-scale current sensitivity from full-scale voltage rating divided by series resistance. In a few cases the original resistor may be mounted outside the meter, on a board on its terminals; in some cases the resistor might be inside the meter but made harder to identify and access.

Keep in mind that the meter's scale will have to be renumbered; ideally, look for a meter with five major scale segments so that the 1-volt divisions will fall in place. Watch out for sealed meters that can't be opened, for non-linear-scale meters, or for AC meters. These are much harder, if not impossible, to modify. Look for meters that have scale divisions that would ideally divide each volt-spread into tenths.

A basic milliamp or microamp meter movement can also be used; a series resistor doesn't have to be removed in this case. Use a movement of not more than a few milliamps, though, or it will be a power-waster, and the dropping resistor may have to be high-power, too. For example, suppose you have a 200-microamp meter with only four scale segments. It could be modified to a 4-volt full-scale voltmeter with a series resistance of 20k ohm (series resistance is approximately the full-scale meter voltage desired divided by full-scale current sensitivity). Using the circuit shown in Figure 2, an expanded-scale display of 10 to 14 volts would result. If an 11- to 15-volt range is preferred, IC1 could be changed to a 7906, or IC2 readjusted for a 6-volt drop. The original scale divisions would be fine for the 4-volt range, and the original numbers and microamp label could be covered with white paint or gummed labels and the meter face then relabeled. Full-scale trim can be provided by making about 10 to 20 percent of the total dropping resistance variable with a trimpot; Figure 3 shows a possible meter circuit. If a high-voltage voltmeter is being modified to 4 or 5 volts full-scale, these same considerations apply, once the basic full-scale current sensitivity is found.


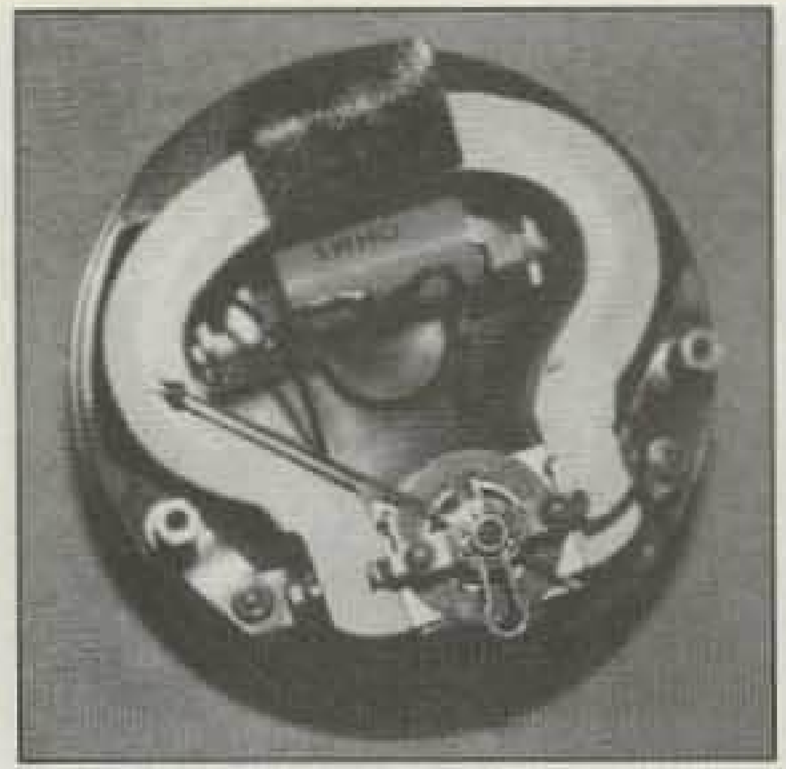

Photo D. Left: This high-voltage DC voltmeter can be modified for low-voltage expanded-scale use. Right: Internal view of the high-voltage meter. The dropping resistor is the large cylinder located in the middle of the horsehoe magnet. This resistor can be replaced with the proper value for low voltage use (see text).

The Voltmeter in Use

Once the expanded-scale voltmeter is built, what should be observed? For manual recharging when the battery is low, the expanded-scale voltmeter shows precisely when to begin recharging. With either an automatic charging system like WBØTCZ's, or with a float-charger, the expanded-scale voltmeter allows constant monitoring to assure that all is well. The terminal voltage of a fully-charged lead-acid storage battery in a constant state, being float-charged with a recharge current barely more than load current to allow for slight trickle charge, should be in the range of 13 to 13.8 volts, depending on temperature, battery design, age, etc. A battery hydrometer can be used to determine full charge, then the voltage checked and the float-charger set; my unit worked out at 13.3V. Under high-current recharge from a partly discharged state, terminal voltage can safely be higher, perhaps 14 to 14.4 volts or so for a few minutes to a few hours. During a deep discharge, the battery terminal voltage quickly drops to about 12.6 and then gradually decreases from there; recharging should begin, or operation ceased, if the terminal voltage drops below 10.5 to 11 volts. Readings outside these ranges indicate a problem that must be investigated.

When using a storage-battery setup, remember to take sensible precautions for ventilation and protection against acid spills, and use fuses and other precautions against short circuits. The water level should be periodically checked and adjusted as needed; float-charging causes a gradual loss of water, and if the lead plates become exposed to air the battery's lifetime will be shortened. The deep-discharge marine-type batteries are far more suitable for this service than are automobile batteries, and are worth the higher cost. Use of the expanded-scale meter, as discussed in this article, will help to maximize the lifetime of this expensive investment. 73