Build an Accurate Battery Voltmeter

by
Alex Mason

The battery article in last month's Home Power gave information and graphs that determine a battery's state of charge using voltage measurement. Many readers wrote in and asked for details about accurate voltage measurement for their systems. So here is a homebrew project-- a simple to make, accurate voltmeter that can be left on line all the time.

Voltage vs. State of Charge

The state of charge (SOC) of a lead acid battery can be determined by measuring its voltage. Details and graphs about the relationship between SOC and voltage are in Home Power #1. If you don't have a copy of HP#1 to refer to, then please write Home Power (POB 130, Hornbrook, CA 96044) and we'll send you a copy of Home Power #1, postpaid, for $2.

Analog vs. Digital Metering

Without any doubt digital metering is more accurate and easier to read than analog metering. Digital metering reads out in numbers (either LCD or LED like your digital watch), while analog meters use the old standard electromechanical meter movement (like the fuel gauge in your car).

If you wish to go to the expense of a digital multimeter (DMM), then I recommend the Fluke Model 77 which costs about $145. It is very accurate (0.3%) and well worth the money because it is so versatile. We use one for all sorts of metering jobs. The problem with using DMMs for battery measurement is that they use small internal batteries to power the meter. This is OK for most uses, but in an AE system we need to have a readout on our battery's voltage ALL the time, 24 hours a day. This means that the expensive DMM is tied to a single purpose, and constant operation wears out the DMM's internal, expensive, batteries very quickly. What is necessary is an accurate battery voltmeter that can be left on line all the time, and is powered by the large batteries in the AE system, not by small internal batteries.

Expanded Scale Analog Battery Voltmeter

This metering circuit was developed by Electron Connection Limited for its customers. While Electron Connection encourages you to build this circuit for your own use, we do reserve all commercial rights to this design. The idea is to use an analog dc ammeter in a circuit that will accurately measure the batteries voltage. This circuit produces an expanded scale voltmeter. Most analog voltmeters start reading a 0 volts. This is really a waste for battery systems as a lead acid battery will have about 10 to 11 volts even when just about empty. So the portion of the meter's scale between 0 and 10 volts is not used. Wasting this portion of the meter's scale decreases the resolution and thereby the accuracy of the meter. This circuit allows the meter to start reading at 11 volts and to display full scale at 16 volts (a very fully charged battery while still under charge). This is called an expanded scale, and makes the meter much more accurate to use.

All the components for this metering project are available at most Radio Shack stores, or from just about any electronics supply house. Cost of the parts should be between $20. and $40., depending on your hardware sources. Construction time is about 1 hour for an experienced assembler. This circuit is powered by the battery under measurement, and never requires the use of small batteries to power the meter.

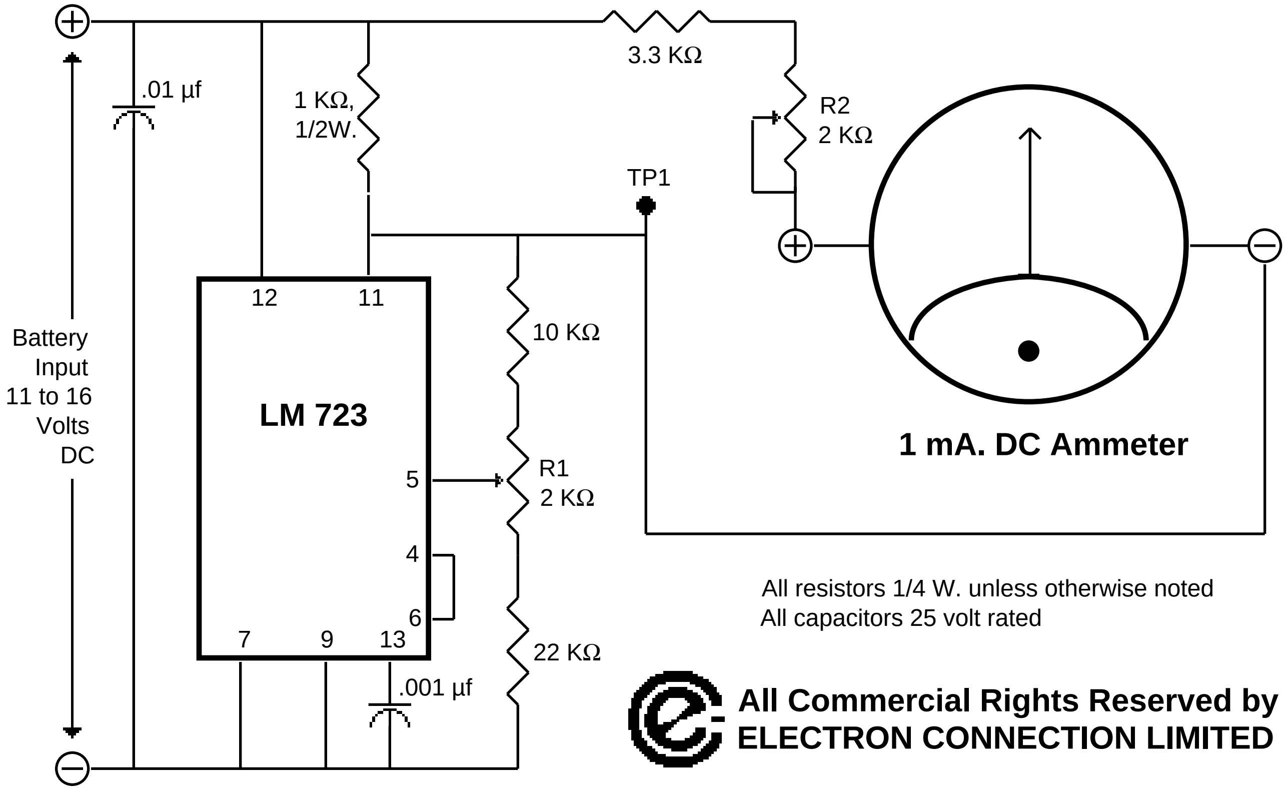
We don't have space here to give an electronics primer for those not familiar with electronic construction. What we do offer is the schematic for the circuit on the next page. If you can't figure out how to build this meter from the schematic, then please seek out an electronics person who can aid you. For those wishing the meter already constructed and calibrated, please send $75. to Electron Connection Ltd., POB 442, Medford, OR 97501, and allow six weeks for delivery because we hand build each and every one to order.

Electronic Nitty-Gritty

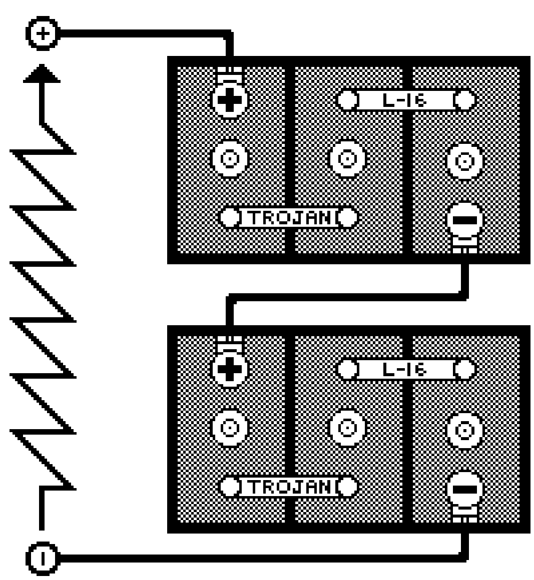
This circuit uses a 1 mA. DC Ammeter as an expanded scale voltmeter. The meter has its ground elevated to 11 volts by the use of an LM 723 voltage regulator in shunt mode. This makes the meter very accurate as there are no series semiconductors in the measurement circuit. Full scale reading and the 11 volt ground level are both adjustable by using the potentiometers in the circuit. R1 is the adjustment for the shunt regulator. Adjust R1 until Test Point 1 (TP1) is at 11 Volts. Then adjust R2 until the meter reads the battery's voltage at the time. Use an accurate DMM to calibrate this circuit.

Average power consumption of this meter is about 5 milliWatts. When on line 24 hours a day, power consumption is less than 0.1 Watt-hours per day. This meter is super-efficient and can be left on line all the time with a minimum of power consumption.

11 to 16 VDC Expanded Scale Battery Voltmeter



All resistors 1/4 W. unless otherwise noted
All capacitors 25 volt rated



Expanded Scale Voltmeters

Jeff Damm

Building accurate and inexpensive battery state of charge instrumentation is easily done with very few parts. If you're willing to do some scrounging, the final meter can be built very cheaply and easily.

A dedicated state of charge meter for lead acid and nicad batteries can be built very easily with four basic components: a zener diode, a resistor, a potentiometer, and a current meter. The current meter can be either a micro-ammeter or milli-ammeter. Figure 1 shows a basic schematic for a generic system that is easily designed for battery banks ranging from 6 VDC to 120 VDC. A design procedure using only Ohms law will allow the builder to customize the state of charge meter for his/her system needs.

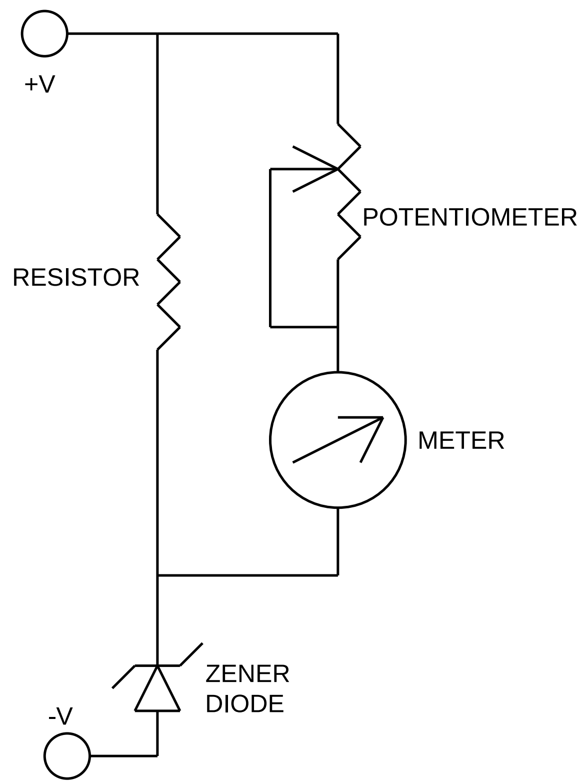


Figure 1 shows the general schematic for the generic state of charge meter. The zener diode is chosen to be a few volts below the minimum voltage of interest, i.e. less than the battery voltage at a minimum SAFE discharge condition. A 12 VDC system would need a zener voltage between 9 VDC and 11 VDC The resistor is chosen to limit current into the zener to about 5 mA. The potentiometer is chosen to provide a current that will give maximum meter reading for the condition of full charge voltage minus the zener voltage. The zener voltage is independent of battery voltage (for the case of the battery never going completely dead!). Now lets design a state of charge meter for a 12 Volt battery.

Start with a 10.0 VDC zener (1N961B). In order to flow 5 mA of current through the zener, we use Ohm's law to determine the proper resistor value. The voltage we need to use is the voltage DIFFERENCE between the battery voltage and zener voltage, which is 12 VDC-10 VDC =2.0 VDC. From Ohms law we have:
R=E/I=2VDC/.005A=400 Ohms
Since 400 Ohms is not a standard 5% resistor value, we would want to compromise with 390 Ohms or 430 Ohms. We have now established a standing current in the zener diode. A few milliAmps to about 10 milliAmps will be quite sufficient to "turn the zener on", which implies that we could use resistor values between 220 Ohms and 1000 Ohms and still have a well behaved reference voltage.

Jeff Damm on New Year's Eve 1985, working 75m SSB on a homemade 10 Watt Ham Radio from a snow cave at 6,500' on Mt. Hood in Northern Oregon.

The voltage across the zener diode is essentially constant with respect to the current passing through the zener. If the battery voltage moves around, which it will (that's why we are doing this in the first place), the zener voltage will remain fixed at 10 VDC. the design concept is to use a meter to measure the difference between the fixed zener voltage and the batteries positive terminal. In our case, the voltmeter is formed by the potentiometer and the milliAmp meter shown in Figure 1.

In our present design example, we need to measure a battery voltage range between 10 VDC and 15 VDC, assuming that there is no load on the batteries and full charge is nearly 15 VDC. Our potentiometer/milliammeter will then need to cover a range of 0 VDC to 5 VDC, since we are referencing against the zener voltage. Let us assume that we have a 1 mA. full scale meter movement. Using Ohms law, we can calculate the necessary pot resistance as:
R=E/I=5V/1mA=5k Ohms
A 10k pot would do the job nicely. A better choice would be a 4700 Ohm resistor and a 1000 Ohm pot in order to offer a mechanical "fine tune" on the calibration of the entire circuit. Lets do another arbitrary design for a 24 VDC system.

For a 24 VDC state of charge meter, we could use a 22 VDC zener (1N969B). The current setting resistor value is
R=E/I=(24V-22V)/2mA =1000 Ohms
Remember that there is nothing sacred about how much current we stand in the zener as long as we have at least a few mA. The 1N969B is rated at 400 mW of power dissipation. Power is V times A so we can calculate what the maximum zener current could be before we run into overheating and reliability problems from flowing too much current through the zener. Since P=VA, we know that A=P/V, and hence the maximum current that we can safely put into the 22 VDC zener is:
A=P/V=400mW/22VDC=18.18 mA.
A safe bet would be to use something between 1 mA and 15 mA of current in the zener. Let's assume that we have access to some cheap 200 microAmp meters (200 µA full scale). Our batteries will come out to a little less than 30 VDC when fully charged. This means that we need to measure a charge-discharge range of a little less than 8 volts (full charge battery voltage minus discharge voltage). Our potentiometer needs to make our 200 µA meter behave like an 8 VDC meter. Ohms law tells us that we will have:
R=E/I=8VDC/20µA=40k Ohms
A pot value of 50k Ohms would work here. A better alternative for fine tuning would be to use a 39k resistor in series with a 5k pot. The ultra-nerd (and expensive!) method would call for a 50k 10 turn pot for gross adjust and a 1k pot for fine tuning.

Alternative choices for zeners

1N5241B- 11.0 VDC	1N5251B- 22 VDC
1N5240B- 10.0 VDC	1N969B- 22 VDC
1N961B- 10.0 VDC	1N1359A- 22 VDC
1N962B- 11.5 VDC	1N5232B- 5.6 VDC

Low voltage zeners can also be wired in series to generate other reference voltages. A pair of 5.6VDC zeners in series would yield an effective zener voltage of 11.2 volts.

I am assuming that calibration will be be done with an accurate DVM (digital voltmeter). Using the DVM in voltage mode across the meter/pot nodes while adjusting the pot to "set" the meter is all that is necessary. My personal choice would be to calibrate the entire meter assembly with a variable power supply in place of the actual battery to be monitored. HP2 has a very similar article by Alex Mason based on a 723 voltage regulator IC.

The latter design examples will have custom meter scales. A custom scale will provide the best resolution. However, a user friendly scale that matches the mechanical meter scale would give up resolution for the convenience of an already calibrated scale. Our 24 V example would then require a 10 VDC range, hence a pot value of R=E/I=10VDC/200µA=50k. If you go through a few examples, it can be readily seen that the pot will allow alot of options for scale choice. Don't forget that you can also remove the cover of most meters and pencil in your own scale marks on a custom version.

Meters can be expensive if purchased new. Cheap (low to medium quality) meters can run $8 to $15 new, depending on the supplier. If one is on a budget, or a true scavenger like myself, there are nice alternatives. Remember that dead stereo receiver that you never got fixed? If it has one or more meters in it's front panel, they are almost always 100µA to 300µA movements. They are asking to be gutted. Even if the receiver still works. Also, the small round meters found on the little cassette tape player/recorders are usually 1mA movements. Soil moisture meters are often a few hundred microamp meters. Another excellent choice to look for meters is at Amateur Radio fairs, also known as Hamfests. Used meters can be obtained at Hamfests for usually 50 cents to $1.50 in good working order, on an "as is" basis.

Many of the volume/tone/bass controls on FM receivers and cassette recorders are suitable sources for the potentiometer used in this project. Unknown value pots can be verified with the Ohm-meter function of a DVM. If the pot value that you salvage is too large in value, an external resistor may be paralleled with the pot to reduce its equivalent value.

Mail order is another option for new meters and components. Two good sources are:

DC Electronics	Mouser Electronics
P.O. Box 3203	11433 Woodside Ave.
Scottsdale, Az 85271	Santee, Ca. 92071
1-800-423-0070	619-449-2222

Both DC and Mouser will accept Visa or MasterCard. Mouser and DC Electronics carry a good assortment of zener voltages, resistors and potentiometers.

Construction time for this SOC meter should only take a few hours at most, depending on prior electronics skill level and cosmetic details the builder wants. I can be reached during the evenings at 503-645-0213 (Portland). The cheapest way to talk shop is via Amateur radio. I can be found via 3860 kHz on the 75 meter ham band most evenings. I am also planning to be a regular participant in the Sunday afternoon 40 meter Home Power Net, 13:30 PDT on 7230 kHz. Jeff Damm,18205 N.W. Bronson Rd. Apt O1, Portland, Oregon 97229