HOMEMADE AMMETERS AND VOLTMETERS

P/N 82701

By Jim Weir (EAA 86698)
Vice-President, Engineering
Radio Systems Technology
10985 Grass Valley Ave.
Grass Valley, CA 95945

REPRINTED SPORT AVIATION
OCTOBER 1980

WHEN THE TIME comes to install the electrical system in an aircraft, it is customary (although not required by the FAR) to instrument the system with a meter that tells us whether our battery is charging or discharging electrical current. Since the electrical current from a battery is measured in amperes, the instrument that measures this parameter is called an ampere-meter, or more commonly, an **ammeter**.

With the advent of such sophisticated devices as alternators, transistorized voltage regulators, solar cell chargers and the like, it has become necessary to not only measure whether the battery is charging or discharging, but to measure the actual battery voltage itself. Measuring the voltage helps avoid such common occurrences as overcharge, undercharge, regulator failure and improper charge circuit adjustment. Your author remembers vividly one specific instance of spending $200 to fix two Mark-12 radios and replace the battery on an aircraft whose voltage regulator had jiggled loose and put 14.8 volts on the poor old battery bus!

This article will zero in on how to convert relatively inexpensive "surplus-store" panel meters to measure any current or voltage you choose. Of course, those of you who have been following my series of articles know that I am tighter than a gnat's mouth stretched over a rain barrel, so that you can expect these meters to be built at the lowest possible cost.

Let's do the ammeter design first, because it is the harder of the two meters. What we need to scrounge from the surplus store is a **zero-center** milli-ammeter. No, a milli-ammeter is **not** an ammeter with a thousand legs, but rather a meter that measures very small currents on the order of several one-thousandths of an ampere. Within some rather wide limits, say ±1 to ±100 milliamperes full scale range, it matters little as to the actual meter sensitivity. Use whatever SurplusSam has on the shelf. If, for example, you find a meter that swings from center to full scale with 5 milliamperes (5 mA), you have what is called a 5-0-5 mA meter, and that will work just fine.

For our illustration purposes, we will use a meter that has a sensitivity of 25-0-25 mA. Note that, for example, the meter face may be marked −30 0 −30 amperes, but the basic meter movement is still 25-0-25 mA. You may find meters marked in amperes, volts, gigaseconds, roentgens, watts or gallons, but they will usually all have a basic meter sensitivity in milliamperes. It is your job to get old SurplusSam to measure the sensitivity before you buy the meter, or get one of the elecktronikers in the Chapter to measure it for you. You will also have to make your own meter face so that the needle reads the parameter you wish to measure. In the case of the ammeter, you have to letter a face for the full scale value in amperes.

The second measurement you will have to make is the **internal resistance** of your meter. Again, get SurplusSam to do it for you or get someone in the Chapter

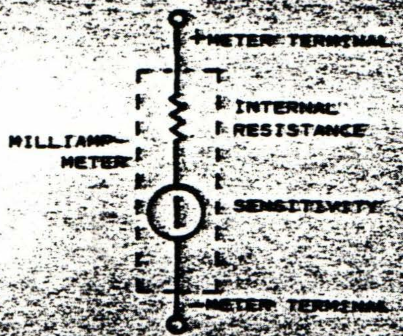

FIGURE 1. THE TWO MOST IMPORTANT THINGS TO KNOW ABOUT YOUR METER ARE THE INTERNAL RESISTANCE IN OHMS AND THE SENSITIVITY IN MILLIAMPERES.

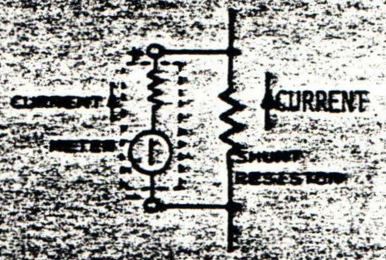

FIGURE 2. MOST OF THE CURRENT IS CONDUCTED THROUGH THE HEAVY (LOW-OHMS) SHUNT, AND ONLY A TINY BIT THROUGH THE METER. NOTE THAT IF THE SHUNT WERE TO OPEN UP, THE METER WOULD BE INSTANTLY DESTROYED.

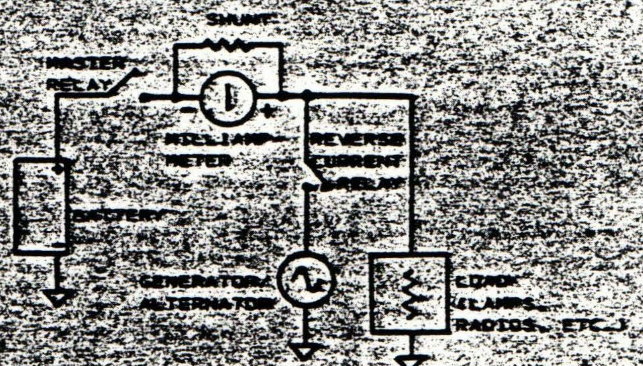

FIGURE 3. USING A SHUNT AND A MILLI-AMMETER TO MEASURE BATTERY CHARGE AND DISCHARGE.

FIGURE 4. THE RST 'NEW SURPLUS' VOLTMETER AND AMMETER WITH MILLIAMP-METER MOVEMENTS.

with a good low-power ohmmeter to make the measurement. This is a rather delicate measurement, and it is possible to frap the meter quite easily if you are ham-handed with the ohmmeter. In our case for the sample meter, I measured the internal resistance as 3.9 OHMS. Call this value "M". M=3.9 for our sample illustration problem.

Now we need to calculate the value for the ammeter shunt and we are all done. The **shunt** is simply a piece of very heavy wire that conducts most of the current flow around the sensitive milliammeter, leaving a very small amount of the total current flow to go through the milliammeter. For example, if we put a 0.39 OHM resistor across the milliammeter, about 90 percent of the current would pass through this shunt, and only about 10 percent of the total current flow would pass through the milliammeter. If we make the shunt 0.039 OHMS, 99 percent of the current would pass through the shunt and only 1 percent through the meter and so on. We can make the milliammeter have any full-scale value we wish, simply by choosing the correct value for the shunt resistance. In fact, if we divide the desired full-scale reading for the ammeter by the full-scale sensitivity of the milliammeter, we come up with a meter factor called "N". Remembering that the resistance of the meter is called "M", the shunt value is calculated very simply as S=M/N (shunt resistor is equal to the meter resistance divided by the meter factor).

In our example, N=30 AMPS/25 milliamps = 30/.025 = 1200. Since M=3.9 OHMS, the value of the shunt resistor necessary to convert our 25-0-25 milliammeter to a 30-0-30 ampere ammeter we will need to shunt the milliammeter with a shunt of: S=M/N = 3.9/1200 = .0033 OHMS. Easy, no?

Well, not quite. How do we make a .0033 OHM resistor? Will the gentleman who said "very carefully" please sit down. Let's think about it just a bit. What has a very low, but yet finite, resistance? How about a piece of heavy wire? **Wire** has resistance and the fatter the wire the lower the resistance. Since the battery is connected to the generator/load bus with wire, if we choose this length of wire carefully, we can make the wire connection perform double-duty as the ammeter shunt. There is absolutely no use in making a separate shunt if you have the capability of using a piece of wire that has to be there anyway as the shunt. Use the wire table to figure out the wire size and length that you need for your shunt. For example, since I need a 0.0033 OHM shunt, and if I have a 3 foot run between my battery master switch relay and the generator/load bus terminal, the table shows that 3.3 feet of AWG 10 wire will give the correct shunt value. Since the table also shows that AWG 10 is good for 30 AMPS, the problem is complete. The meter leads connecting to both ends of the AWG 10 may be any convenient wire size. The extra 0.3 foot of wire may be coiled or cabled to keep it out of the way. Of course, if you want to make a shunt, you can do it by simply coiling up the correct length and size wire in a minibox.

Now, how about the voltmeter, and let's do two types. First, let's do a voltmeter that goes from 0 to 16 volts, and then we'll do one that suppresses the lower end of the scale and goes from 10 to 15 volts.

For the 0 to 16 volt meter, let's say that we found a surplus meter that goes from 0 to 25 mA full scale with an internal resistance of 20 OHMS. The first order of business is to carefully remove the meter face and hand-letter a new scale that goes 0 to 16 volts. Then, since we know that we want the meter to read full-scale with 16 volts applied, a little bit of OHM's law and math shows us that R=E/I, and so the meter multiplier resistor should be 16 volts/25 mA = 16/.025 = 640 OHMS. Another way of verbalizing OHM's law in this case is to say that the approximate meter multiplier resistor is equal to the desired full-scale reading in volts divided by the meter's full-scale sensitivity in amperes. The actual resistor itself should be 640 OHMS less the meter internal resistance, so the actual meter multiplier resistor will be 620 OHMS.

Unfortunately, the divisions on the 0-16 volt meter are so small that it is difficult to tell immediately the difference between, say, 13.6 and 14.2 volts. What we really need to do is expand the scale so that we only read that part of the scale that is of interest. I mean, when the battery bus voltage drops below 10 volts, what difference does it make if it drops to 7 or 8 volts? What we are really concerned with are battery voltages between 10 and 15 volts. Fortunately, the addition of one cheap part and the recalculation of one resistor will give us this "expanded scale" type of voltmeter. This cheap part is called a "zener diode", and zener diodes come in voltage ratings from about 3 to over 100 volts. If we choose a 10 volt zener, our voltmeter will have a "zero", or starting point of 10 volts. 12 volt zeners would cause the meter scale to start at 12 volts, 8 volt zeners start the scale at 8 volts and so on. Since we want to go from 10 to 15 volts on our voltmeter, a 10 volt zener will be just right. To calculate the meter multiplier resistor, first subtract the starting point (zero or zener) voltage from the desired full-scale voltage. In our case this number is (15-10)=5 volts. Then divide this voltage by the full scale meter sensitivity, and you have the total meter multiplier resistor value. Again, for our example, the meter multiplier resistor is 5/.025=200 OHMS. Subtracting the meter internal resistance of 20 OHMS leaves 180 OHMS for the actual multiplier resistor. There you have it — a nickel resistor, a dime zener and a surplus meter gives you a relatively sophisticated suppressed zero voltmeter.

Of course, I realize that not every homebuilder has immediate access to surplus meters. I also realize that the artwork required to reface a meter can get very tricky, especially for the smaller, sealed meters. So for those of you who want a pair of silkscreened scale meters, one voltmeter and one ammeter, plus the zener diode and multiplier resistor for the suppressed zero voltmeter, I have arranged for Radio Systems Technology, 10985 Grass Valley Ave., Grass Valley, CA 95945, (916) 272-2203, to supply these parts as a kit to EAA members for $16. Just ask for the "Voltmeter-Ammeter Kit" and you will get (strangely enough) one ammeter screened −30 0 +30 with a full scale sensitivity of 25-0-25 mA and an internal resistance of 3.9 OHMS, and one voltmeter screened 10-15 volts with a 0-25 mA sensitivity and an internal resistance of 20 OHMS — just like the example I used in this article! Plus, one 10 volt zener diode and one 180 OHM resistor. You will need to supply any mounting brackets and hardware, plus the ammeter shunt as described in this article.

I hope that I have been able to shed some light on the subject of electrical instrumentation, and that you will be able to use those old klunker meters that you had in the junk box for something other than paperweights.

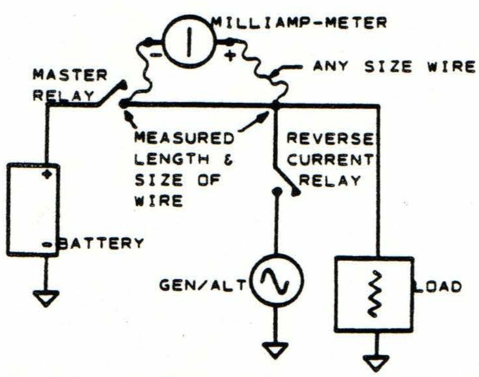

FIGURE 5. USING THE AIRCRAFT WIRING TO ACT AS A LOW-OHMS SHUNT INSTEAD OF A SPECIALLY WOUND SEPARATE SHUNT.

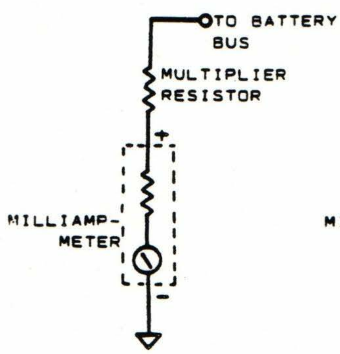

FIGURE 6. A VERY BASIC VOLTMETER MADE FROM A MILLIAMMETER AND A RESISTOR

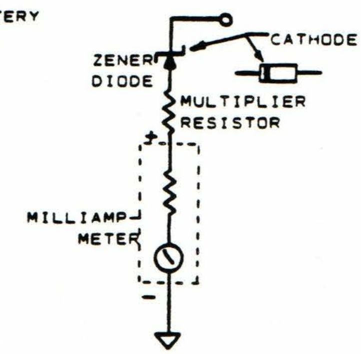

FIGURE 7. A SUPPRESSED-ZERO VOLTMETER MADE WITH THE ADDITION OF A ZENER DIODE.

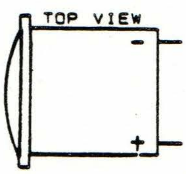

FIGURE 8. THIS IS THE TERMINAL ARRANGEMENT ON THE RST METERS. IF YOU USE SURPLUS METERS, BE SURE TO PROPERLY IDENTIFY THE + AND − LEADS.

AWG SIZE	OHMS PER FOOT	MAX CURRENT (AMPS)
6	.00039	60
8	.00063	45
10	.00099	30
12	.00159	23
14	.00253	17
16	.00402	13

FIGURE 9. A WIRE TABLE SHOWING RESISTANCE PER FOOT AND MAXIMUM CURRENT HANDLING CAPACITY (FROM FAA PUBLICATION AC-43-13-1A FOR BUNDLED WIRES).