A Lossless Current Monitor

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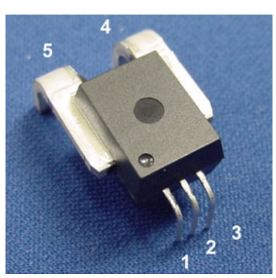
Measuring high currents at low voltages has always been a problem. The classic way to measure current is to measure the voltage drop across a series resistor – easy in the vacuum-tube era when we had lots of voltage and low current, but transistor circuits won't tolerate much voltage drop without affecting circuit operation. An ammeter just combines the resistor and voltmeter – I've used one for years, but it doesn't have very good accuracy or resolution. The choice of resistor is a problem: while a large resistance produces too much voltage drop, a very small resistor produces a small voltage drop, so getting good resolution is difficult. To get decent resolution, we must accept some loss.

Another problem is that it is difficult to measure a small voltage difference between two large voltages; for example, if we are measuring a 50 millivolt drop from a 12 volt battery, we might be trying to accurately measure the difference between 12.8 volts and 12.75 volts. Some commercial "power analyzers" avoid this problem by putting the resistor in the negative lead. This works fine if there is no other path for current, but care is required. Suppose we wanted to measure the current drawn by a mobile transceiver; if we simply inserted the power analyzer in the power wires, the voltage drop in the negative wire would cause some of the current to flow through the coax braid and back to the car frame. The stray current would not show up in the measurement, so the reading would be too low. This is not a defect, just a caution for the user (who should have read the instruction manual).

However, there is another way to measure current. Current passing through a conductor creates a magnetic field around the conductor. If we can measure the magnetic field, we can calculate the current – AC current meters use the magnetic field by making the conductor part of a transformer. Transformers don't work on DC, but semiconductors called Hall-effect devices respond to magnetic fields.

Recently, I came across some current sensors using Hall-effect devices made by Allegro Semiconductor (www.allegromicro.com). The smallest, the ACS750SCA-050 is rated at 50 Amps (newer version is ACS756). Since you can buy them with no minimum quantity, I got hold of a couple. They look like plastic power transistors with two humongous extra leads coming out the sides. Current passes directly from one large lead to the other, so there is essentially no voltage drop. The chip measures the magnetic field created and amplifies it to a calibrated output voltage. The only power needed is 5 volts at a few milliamps. The three small leads are for power, ground, and the output voltage.



To make this device useful, we need a convenient readout. One approach would involve an analog-to-digital converter and a computer, but I prefer cheap and simple. I looked through the spare parts bin and found a couple of small LCD digital panel meters. These are readily available for under $10, but most of them cannot measure the circuit powering them – they must be powered from a floating 9V battery. However, there are a couple that do not have this limitation and can be powered from the circuit being measured so a separate battery is not needed (I used model 14505ME from www.mjpa.com. The model 16177ME looks like a good replacement.).

The output from the Allegro current sensor is 50 millivolts per amp, starting from approximately 2.5 volts with zero current. The maximum output at 50 amps is 5 volts with current in the forward direction and 0 volts in the reverse direction. For direct reading, we must amplify the output to 100 millivolts per amp, shift the decimal point to read amps directly, and offset the resting voltage to zero. These functions are readily accomplished with inexpensive op amps. My first attempt wasn't really satisfactory, so I consulted an expert, Byron, N1EKV, and came up with the circuit shown in the schematic, Figure 1.

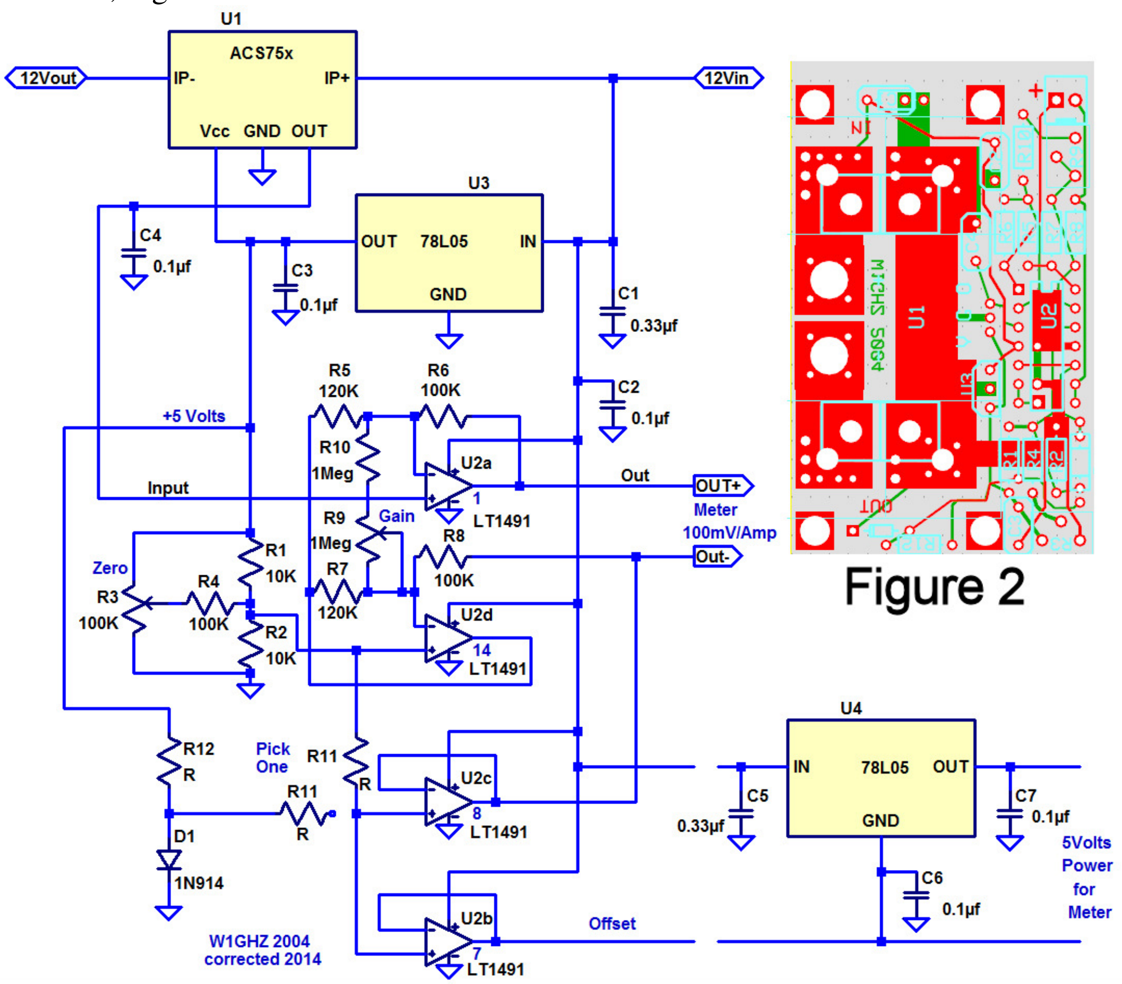


Figure 2

Figure 1 - Lossless Current Monitor

Two of Byron's special circuits are included. The first, consisting of R1, R2, R3, and R4, provides an adjustable offset voltage to zero the meter; R4 limits the adjustment range to a small variation around the nominal value, 2.5 volts. The second is a variable gain differential amplifier using U2a and U2d and the associated resistors, to amplify the sensor output with reference to the offset voltage. The other two op amp sections buffer the offset voltage: U2c for the negative terminal of the meter, and U2b to raise the meter power to the offset voltage. The latter is necessary because the digital power meter has limited common mode range (the difference between the negative side of the meter power and the voltage being measured). The power for the meter is regulated at 5 volts above the offset voltage by U4, while power for the Allegro current sensor, U1, is regulated at 5 volts above ground by U2. (R12 and D1 are not used, they were for an alternative offset scheme).

The circuit fits on a small printed circuit board from ExpressPCB (www.expresspcb.com) shown in the photo of the interior, Figure 3. The PC board layout is shown in Figure 2, and is available on my web page, www.w1ghz.org. I built two versions of the current monitor, shown in Figure 4 and 5. The one on the left is limited to 20 amps since I set the meter range jumper to 2 volts full-scale for better resolution, and shifted the decimal point in the meter. The one on the right, with the larger 75-amp PowerPole connectors that I prefer for batteries, is limited to 50 amps by the current sensor (higher current sensors are available). The meter is measuring 5 volts to display 50 amps.

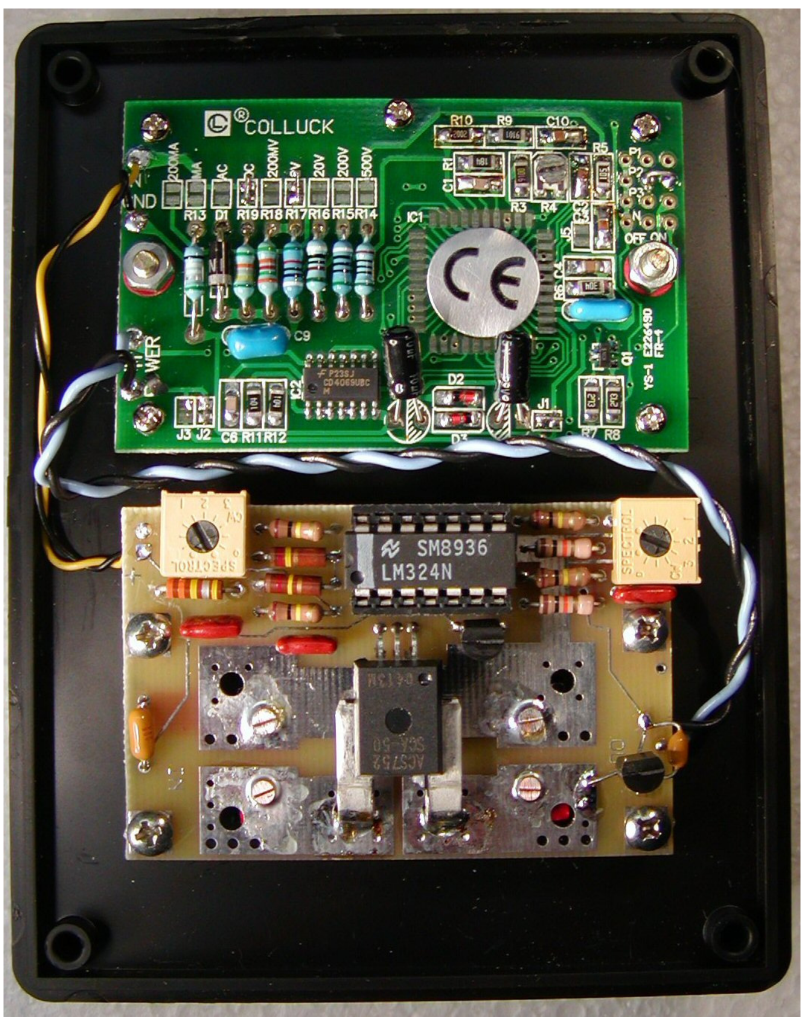


Figure 3

Calibration is pretty straightforward: connect the input side to 12 volts and adjust R3 until the meter reads 0.00 amps. Then connect a load to the battery and adjust R9 to read the correct current; I used a good digital multimeter, rated at 0.7% accuracy, for comparison. There is a slight interaction between the two adjustments, so go back and forth a couple of times.

Operation should be obvious: put the current monitor in the power lead of whatever you wish to measure – the PowerPole connectors make this easy. Since the meter reads in either direction, you can't go wrong; if the monitor is placed at the battery, you can monitor charging and discharging current. Since the current measurement is isolated, you don't have to worry about overcurrent, unlike a digital multimeter (Mine uses special $11 fuses! Guess how I know.), and voltage drop is minimal – I measured 6 millivolts at 10 amps, less than the drop in a foot of heavy power wires. The LCD meter and op amp consume about 10 milliamps, hardly enough to notice. The only slight problem I have found is that the zero drifts slightly; since the sensor operates on magnetic fields, it senses changes in stray and residual magnetic fields when no current is flowing.

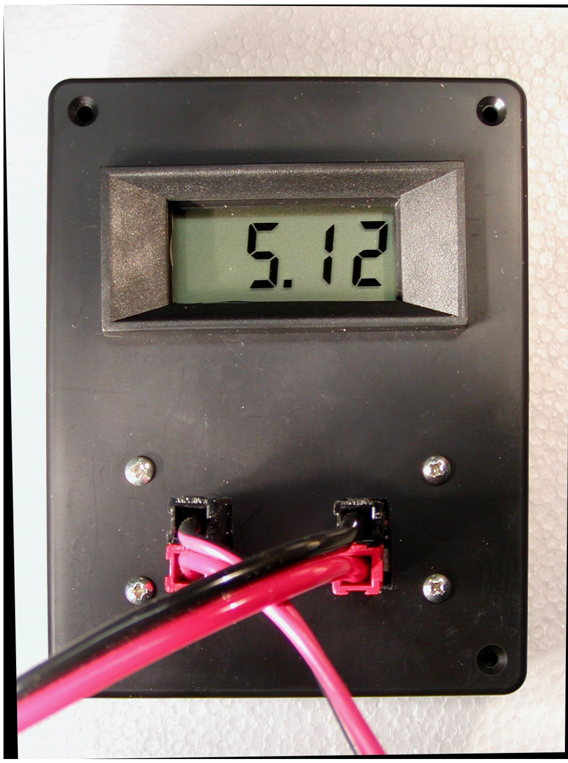


Figure 4

Figure 5

Operation is not limited to 12 volts circuits. The circuit shown should operate up to 28 volts, as long as all the capacitors are rated for 50 volts or higher. For completely isolated operation, the meter and op amp could use an ordinary 9-volt battery – the Allegro sensor is rated for 3KV isolation. The response is fast enough to for AC as well as DC current; with the high isolation, one could be used to monitor AC power[1]. If 50 amps isn't enough, higher current sensors are available, as well as bigger PowerPole connectors.

This simple project allows measurement of high currents with no losses due to voltage drops. It doesn't do anything fancy, like calculate power – you'll just have to multiply by the voltage. The Hall-effect current sensor is an interesting bit of technology that stimulated the project.

1. J. Bachiochi, "Intelligent Current Sensing," *Circuit Cellar*, March 2004, pp. 74-77.