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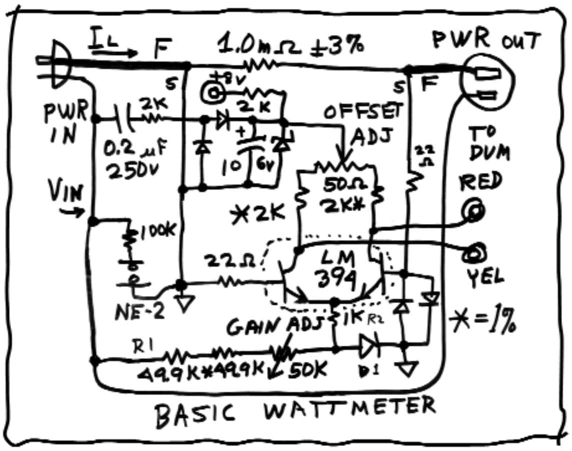
What's All This Wattmeter Stuff, Anyhow? (AKA Multiplication Stuff, Part III)

Last month, I designed a good 1-mΩ shunt *("What's All This Shunt Stuff, Anyhow?" April 29, p. 94)*. Now we'll use it in a 1.5-kW wattmeter. This one is optimized for the 80- to 130-V ac range, and for currents up to 15 A *(see the figure)*.

How does it work? When V_{IN} is positive, the current in R1 just flows to ground via D1. But when V_{IN} goes negative, the current flows through R2 to the matched transistors. If the load current I_L is zero, the balanced transistors will cause zero output.



If there's a load current, the transistors will *multiply* the I_L by V_L, acting as a balanced modulator. The "product" signal will appear at the output terminals, to be read by a floating meter. A 3-1/2-digit DMM with 200.0-mV full scale works well. An analog meter with 100- or 150-mV full scale gives poorer resolution, but it gets you started.

What shunt shall we use? Previously, I said that the copper shunt had a BIG tempco, +3300 ppm/°C. But here, the copper shunt will well compensate for the –3300 ppm/°C of the g_m of the transistors. (Nichrome with its low tempco would be *wrong*.) We won't achieve perfect gain tempco—but pretty good.

This meter resolves 1 W out of 1.501 kW, using a 3-1/2-digit DMM. If you want high resolution over a wider range, check out the multirange-version schematic in the electronic copy of this column at *www.elecdesign.com*. It uses four shunts to cover 150-, 15-, and 1.5-W ranges. If you can't attain info from the Web site, circle Reader Service No. 552 to acquire it by mail.

What's *wrong* with this wattmeter? At large currents, the multiplier cell isn't very linear. The g_m of the transistor pair falls off, according to $\tanh(V_{SENSE}/52$ mV). As the peak voltage across the shunt exceeds 10 mV, the diffamp's gain falls off by 1% or 2%, even if the average current is under 3 or 5 A. That's why I chose a 1-mΩ shunt for 15-mV "full scale" at 15 A. Calibrated at 100 V ac, its gain will be low at 80 V by about –0.1%, or high by +0.1% at 140 V. Not *too* bad.

This meter won't directly read the true power if the load draws current on only one half of the cycle. But a work-around is easy: plug in the load both forward and reversed, and take the average. Or instead, employ a big DPDT switch to reverse the output wires.

I recommend the LM394CH for the super-matched transistor pair. If that's inconvenient, make up a matched couple of 2N3904s *(http://www.national.com/rap/Story/vbe.html)*. Pair them within 0.3 mV at equal currents and temperatures, and glue them together.

The circuits in here are mostly at low voltage, but a *few* parts are at high voltage. You can put tape over the high-voltage components. If the low side of line power is connected to the wide prong, most circuitry *should* be at low voltage. But you must follow proper safety procedures while working on high-voltage circuits. Keep one hand in your pocket, etc., when you see that neon lamp glowing!

What's *right* about it? Well, it reads true V × I watts in a true rms way. It rejects reactive currents, such as capacitive or inductive currents. For example, a capacitive load, like 2 µF (rated at 200 V ac), will generate 90 VARS (reactive). But this meter reads zero because the integral over one cycle of line voltage is zero. It has low "burden"—the voltage across the shunt is normally less than 0.03% of the line voltage.

Calibration: A big advantage of this meter is that you can calibrate it with dc, without making or measuring lots of watts of precision ac power. First, disconnect the meter from line voltage. Apply +8 V dc (used only for calibration) to the +8-V jack and apply –100.6 V dc to the V_{IN} at the input line plug. Then, adjust the offset so the meter reads 0.0 mV.

Now, force 2 A dc through a calibrated 1-Ω resistor *into* the input connector prong and *out of* the output socket. Trim the gain adjust so that the meter reads $2 \times 1.01 \times (V_{IN} - 0.6 \text{ V}) \times I$. (The "2" makes up for the multiplier working just half the time.) So if you had 2.00 A × (100.6 – 0.6) volts, the meter should read 40.4 mV. Then the meter reads 20.2 mV for a true 200-W ac load—about 1% high, but right on at 6 A, 1% low for 9 A dc, 2% low for 12 A of sinusoidal load, and about 4% low for 15 A. Next, I'll check it out at PG&E's labs!

All for now. / Comments invited!
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