# Make a low-cost benchtop power meter

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With a few inexpensive ICs and passive components, you can easily make a multirange power meter suitable for use on your benchtop. The circuit in **Figure 1** measures currents from microamps to amps and voltages as high as 100V. The voltage at $V_{OUT}$, which you can monitor with a DVM, indicates the load's power. Two 9V batteries can run the circuit (±V=±9V), which has a current drain of 10 mA.

### TABLE 1—POWER METER RANGES AND SETTINGS

| $S_0$ | $S_1$ | PGA GAIN | $I_{MAX}$ | $V_{MAX}$ | $P_{MAX}$ | $V_{OUT}$ scale |
|---|---|---|---|---|---|---|
| Open | Open | 1000 | 10 mA | 100V | 50 mW | 10 mW/V |
| Closed | Open | 100 | 100 mA | 100V | 500 mW | 100 mW/V |
| Open | Closed | 10 | 1A | 100V | 5W | 1W/V |
| Closed | Closed | 1 | 10A<br>(see note) | 100V | 50W | 10W/V |

NOTE: $I_{MAX}$ may be lower, depending on the rating of $R_{SENSE}$.

The circuit performs an analog multiplication of current and voltage to calculate the power. The load that you want to measure connects between +OUT and –OUT. The supply to the load connects between +IN and –IN. The PGA amplifier ($IC_1$) produces a voltage proportional to the load current ($I_{LOAD}$) sensed across $R_{SENSE}$, which sits on the ground side of the supply. $R_1$, $R_2$, and $IC_{3D}$ generate a scaled version of the load voltage equal to $V_{LOAD}/20$. The output of $IC_1$ and $V_{LOAD}/20$ are the inputs to $IC_2$'s precision analog multiplier. $IC_2$ has a built-in scale factor of $^1/_{10}$. $R_4$, $R_5$, and $R_6$ provide additional gain. A lowpass filter at the output helps reduce noise and provides protection to $IC_2$ in case $V_{OUT}$ accidentally shorts to ground. Combining all the scaling factors gives

$$V_{OUT} = (I_{LOAD}R_{SENSE})\left(V_{LOAD}\frac{R_2}{R_1+R_2}\right)PGA_{GAIN}\left(\frac{1}{10}\right)\left(\frac{R_6+R_4}{R_5}\right) = I_{LOAD}V_{LOAD}\frac{PGA_{GAIN}}{10}.$$

The circuit works equally well for positive and negative load currents and voltages. If the load is producing rather than dissipating power, $V_{OUT}$ reads negative. The scale of $V_{OUT}$ is the same for positive and negative power readings. **Table 1** shows the ranges.

The maximum load-current setting ($I_{MAX}$) limits the output of $IC_1$ to 5V to meet head-room requirements when using 9V supplies. $D_1$ through $D_5$, $R_3$, and an LED provide a positive-current-overload warning. When the LED turns on, you should decrease the PGA's gain. A similar string of diodes with opposite polarity can monitor negative-current overloads. Make sure $R_{SENSE}$ has a sufficient rating to handle the maximum current you use. Also, remember that for high $I_{LOAD}$, there is a significant voltage drop across $R_{SENSE}$.

The maximum load voltage ($V_{MAX}$) of this circuit is 100V, limiting the voltage at $IC_2$'s input to 5V. You can adjust the ratio of $R_1$ and $R_2$ for a different $V_{MAX}$. Keep the sizes of $R_1$ and $R_2$ large to minimize current through them. Their currents add to $I_{LOAD}$ and cause an error in the power reading. $IC_{3D}$ prevents $IC_2$'s input-bias current from flowing through $R_1$ and $R_2$. The maximum power ($P_{MAX}$) setting limits $IC_2$'s output to 5V.

$IC_{3A}$ through $IC_{3C}$, $IC_{4A}$ and $IC_{4B}$, and potentiometers $R_7$ through $R_{10}$ provide offset cancellation. $R_6$ provides gain calibration. The circuit must remove various offsets and gain errors to achieve the best accuracy, which is better than ½% of full-scale over most of the ranges. If lower accuracy is acceptable, you can remove some or all of the offset cancellation circuitry. To fully calibrate the circuit:

1. Short the load (place a short between +OUT and –OUT) with $V_{IN}$=0. Adjust $R_{10}$ until $V_{OUT}$=0, which nulls the offset of the output of $IC_2$.
2. Remove the short, set PGA=1, and apply a large $V_{IN}$ with no load. Adjust $R_7$ until $V_{OUT}$=0, which nulls the offset of the $I_{LOAD}$ input to $IC_2$.
3. Set PGA=1000 and continue applying $V_{IN}$ with no load. Adjust $R_8$ until $V_{OUT}$=0, which nulls the offset of the front end of $IC_1$. If the PGA gain remains the same, $R_8$ is unnecessary because $R_7$ cancels the offset.
4. Short the load. Apply $V_{IN}$, and increase $I_{LOAD}$ until the LED starts to turn on. (For PGA=1000, $I_{LOAD}$ is 10 mA to turn on LED.) Adjust $R_9$ until $V_{OUT}$=0, which nulls the offset of the $V_{LOAD}$ input to $IC_2$.
5. Finally, calibrate the gain. Set the PGA=100, the load=2k, and $V_{LOAD}$=25V. Adjust $R_6$ until $V_{OUT}$ matches the calculated power.(DI #2250) e

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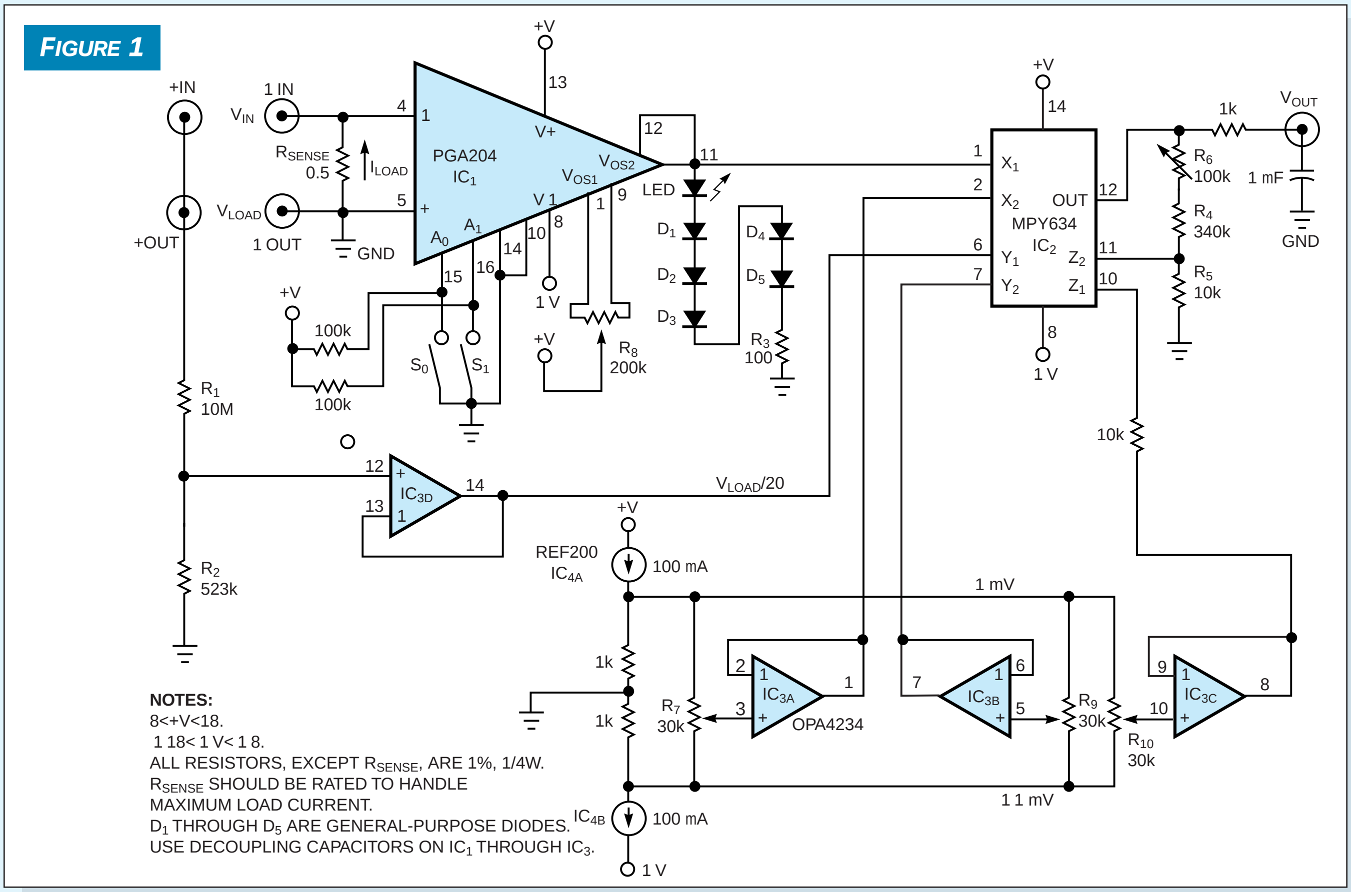
**FIGURE 1**



NOTES:
8<+V<18.
1 18< 1 V< 1 8.
ALL RESISTORS, EXCEPT $R_{SENSE}$, ARE 1%, 1/4W.
$R_{SENSE}$ SHOULD BE RATED TO HANDLE
MAXIMUM LOAD CURRENT.
$D_1$ THROUGH $D_5$ ARE GENERAL-PURPOSE DIODES.
USE DECOUPLING CAPACITORS ON $IC_1$ THROUGH $IC_3$.

A programmable-gain amplifier, an analog multiplier, and a handful of other active and passive components implement a benchtop, multirange power meter.