

A Power Meter based on the AD-8307 from Analog Devices.

This section relates to the QST paper that Bob Larkin (W7PUA) and I published in QST for June, 2001

Update, 10Mar07, 5June07

Calibration at the Frequency Extremes. 10 March 07, 5June07

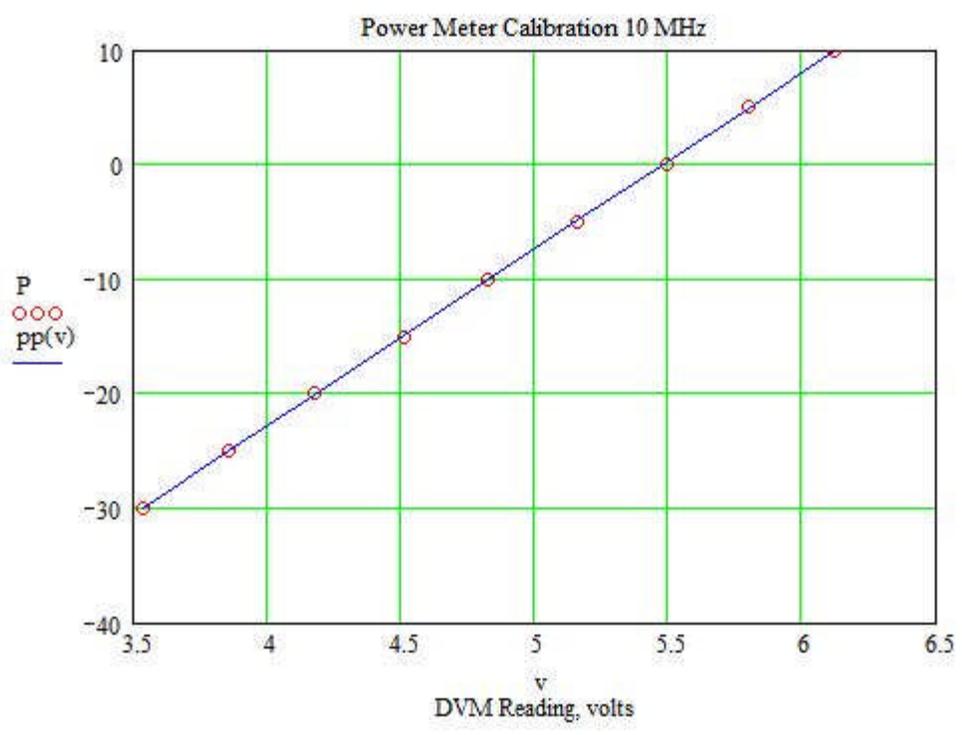
I discovered a problem with the version of the meter at w7zoi. I had been trying to build a wide frequency range return loss bridge and had seen problems at the high end, between 400 and 500 MHz, the upper limit of my instrumentation. I had been using the homebrew power meter to measure the Open to Short ratio over the 0.5 to 500 MHz spectrum. (See the bridge discussion in EMRFD.) I finally borrowed a HP435 Power meter with a 4 GHz element from a local friend to check the output accuracy of my HP8640B signal generator and to then study the accuracy of my homebrew power meter.

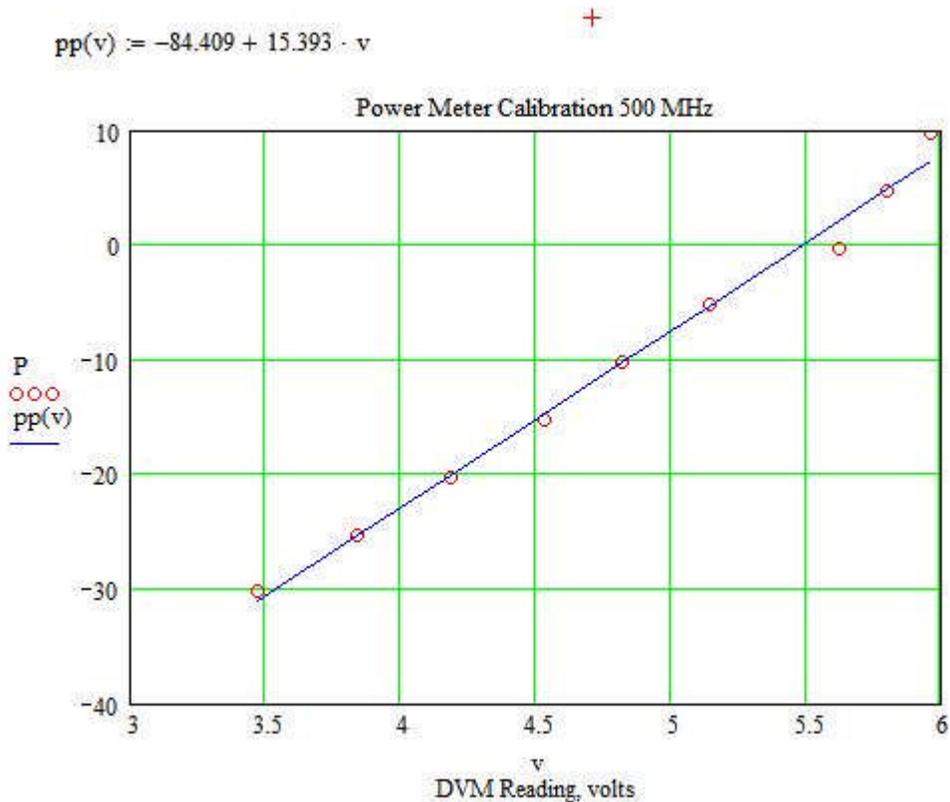
The first conclusion reached is that the HP8640B signal generator is extremely accurate with regard to output power versus that indicated by the front panel meter. The accuracy seemed to only be limited by the resolution of the meter.

This has been my experience with other HP signal generators. I checked calibration at 10 and 500 MHz, and a few frequencies between.

The other conclusion is less encouraging. I calibrated the AD8307 based power meter at several frequencies and found that the calibration was compromised at the high end. The results I got at 10 MHz and at 500 MHz are plotted below. Note that the points at the high end are not on the linear curve fit line at higher powers at 500 MHz. The points are not evenly spaced like they are at 10 MHz. The plots consist of a solid blue line, which is the equation listed, and round data markers showing the power from the generator on the Y axis and the DVM reading on the X axis. The equation was determined from a curve fitting routine in MathCad.

$pp(v) := -84.277 + 15.384 \cdot v$ Linear regression curve fit. +



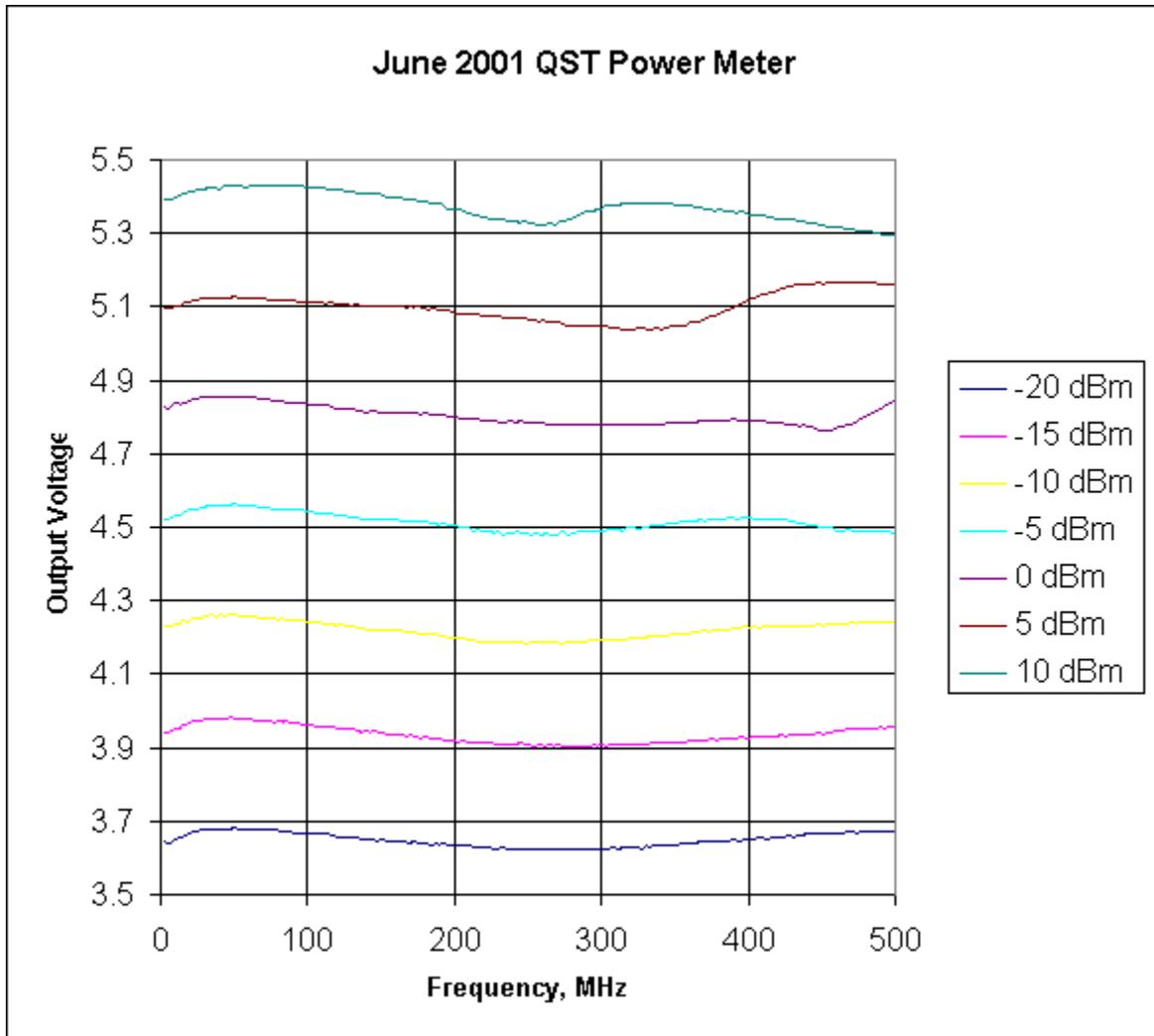


This does not mean that the power meter should not be used over the full frequency range. **However, if you are after the best results, you should do your own calibration.** I was seeing an error of about 2 dB in my 500 MHz results, which was enough to severely confuse the experiments (as well as the experimenter.) **Please don't use the calibration results listed above for your own power meter.**

Update, 5 June 07:

After the alarming results reported above, I decided that it was time to get some muscle behind the observations and I ask Bob Larkin, W7PUA, to take a look at the problem. Bob started by using the sweeper part of his HP8714B network analyzer to drive his HP power meter, an HP435A with an HP8481A sensor. The two agreed within 0.1 dB over the range of the power meter. The sweeper was found to be flat within .05 dB at powers between -20 and +10 dBm.

Bob then examined his version of the AD8307 based power meter. The sweeper has an A to D input with the ability to output digital data to a file. This was used to record the output of the 8307 power meter for later plotting. The results are shown below:



These results from W7PUA are extremely interesting. The data is reasonable at powers of -10 dBm and lower. However, the calibration becomes compromised at the high frequency end as the power is increased.

The extremely wide range of the homebrew power meter means that we still have a lot of room for measurements. All that is required is to keep the power below -10 dBm. There is some curvature to the sweeps shown above, even at low power, but this was of no consequence in the bridge measurements I was doing (mentioned above) where I was comparing results at each frequency.

There are several lessons that become apparent from this study. Our measurements are only as good as the calibration we use with our instruments. If we really need accurate results, we had better figure out a way to calibrate our homebrew measurement gear. The assumption that a compensation done at one power level will extend to others is not valid. (The compensation in question here is the input RLC network preceding the AD8307 detector chip.)

This is especially true with something as grossly nonlinear as a logarithmic detector. We could have detected some of the problems with careful application of a step attenuator. This refined and updated data is not a condemnation of the AD8307. Rather, it is just an observation that the part is limited in its capability. It is still a spectacular integrated circuit. This is a reminder of why we build spectrum and network analyzers that use mixers to do the more refined measurements.

Many thanks to Bob for the enlightening measurements!

The Analog Devices AD-8307 is now available from DigiKey Electronics. Also, look at the Analog Devices web site, for you may qualify to get a sample. Analog Devices has become the leader in the industry in recent times in the way they provide engineering samples and we thank them for this policy! 2 June 2004, 10 March 07.

What is a power meter?

Seems like an odd question considering that we are answering it two years after the paper appeared in QST. Nonetheless, it struck me that it was a question worthy of comment.

A power meter in the sense that we talked about it in our paper is an instrument with a built in termination. RF power is applied to the input jack and the power delivered to the termination, usually 50 Ohms, is indicated on the meter.

Our power meter used either an internal analog meter movement or an external digital voltmeter. While many manufacturers have built and sold power meters, those most familiar to the amateur radio community are from Hewlett-Packard. We call this instrument a "lab power meter."

A popular instrument in the RF world is the "in-line power meter." This equipment, typified by boxes manufactured by Bird, usually includes a built in directional coupler. The combination is capable then of measuring the flow of power in a transmission line. By reversing the instrument, power flow in a reverse direction can be measured, allowing impedance match to be evaluated.

Often, in-line power meters are capable of operation at the high power levels associated with transmitters. The in-line power meter does not include a termination.

The lab power meter can certainly be used with an outboard directional coupler for transmission line measurements. It can also be used, with couplers or taps, to measure transmitter level powers during operation. But the lab instruments are more often used during the development of circuits. That was the dominant application for our instrument. If you are interested in an in-line power meter, we recommend the design by Roy Lewallen presented in QST for Feb, 1990. This paper is included on the EMRFD CD.

2 Dec 2003, 10March07.

Errata:

18July01 wh

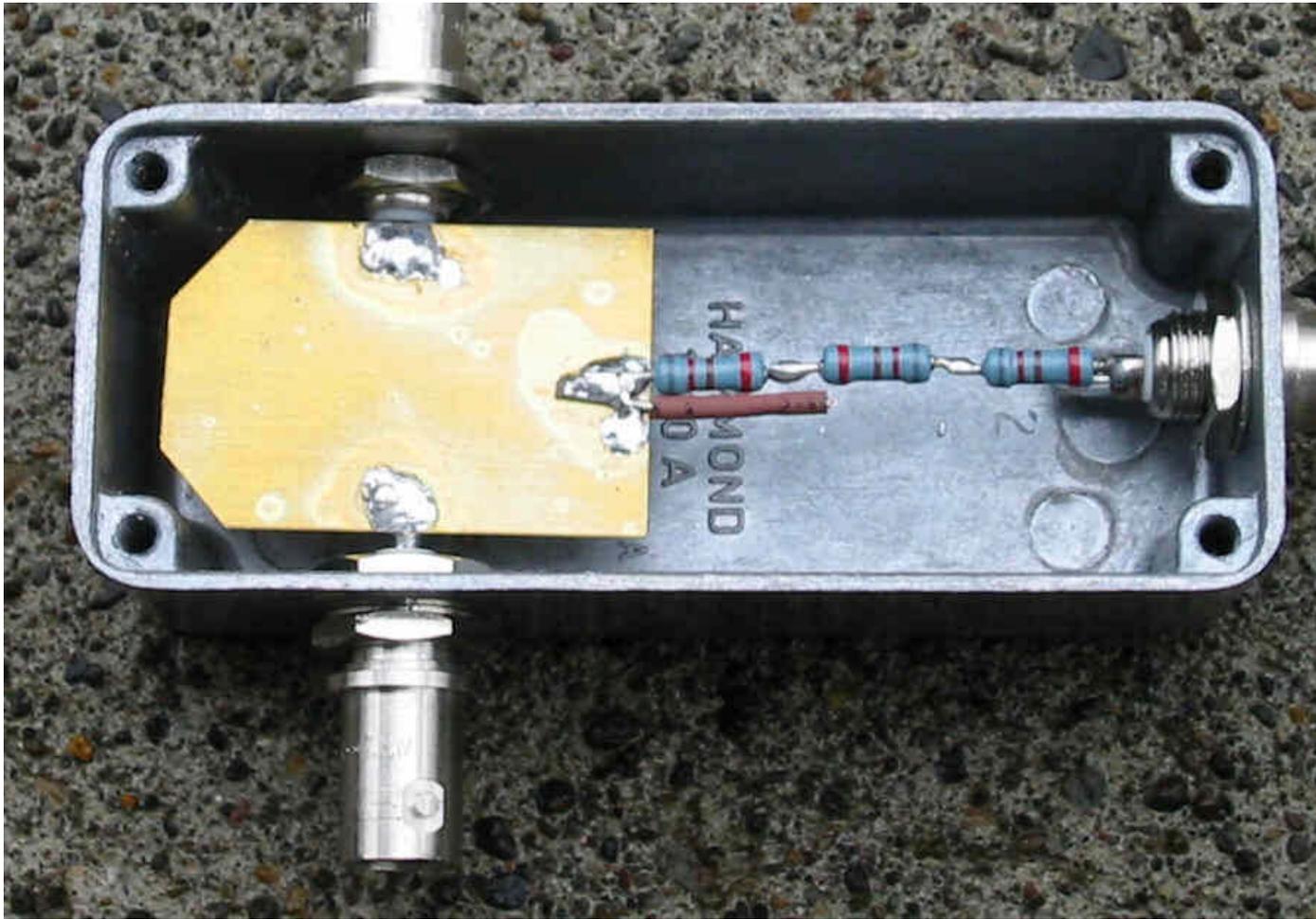
The power meter paper from the June 2001 issue of QST (coauthored with Bob Larkin, W7PUA) had a couple of errors:

1. There was an error in the main schematic, Fig. 1. The IN and the OUT labels on U2, the 78L05 regulator should be interchanged.
2. In Fig. 6: The 10 dB pad is used between the tap attenuated output and the power meter. It does not go between the power meter and the DVM as was indicated.

A Tap with BNC Connectors.

Some readers have built the power meter tap with BNC connectors. This is the way I built mine. But there is often a problem, for some BNC connectors will protrude well into the box, leaving no room for the large brass transmission line section. There is a simple solution. Use two nuts with each BNC connector.

This then puts the BNC center connector nearly flush with the surface. This is shown in the following photo. An even better solution would use flange mount BNC connectors, available from DigiKey or Mouser, among other sources.



Calibrating your power meter.

I got a couple of notes from folks who had trouble with the equation we used with a DVM to read power. This is a calibration that the builder must do for his or her power meter. The procedure is shown below:

Power meter calibration.

We did two measurements with a signal generator at 10 MHz. With an input from the generator of 0 dBm, the DVM read 5.40 volts. Decreasing the generator to -10 dBm, the DVM read 4.70 volts.

The AD8307 is "log linear," so the power in dBm will be linearly proportional to the DVM voltage. The equation is of the form

$$P(\text{dBm}) = A + B \cdot V(\text{DVM})$$

We use the data to form two equations in two unknowns:

$$P_1 = A + B \cdot V_1 \quad \text{Eq. 1}$$

$$P_1 = 0 \quad V_1 = 5.4$$

$$P_2 = A + B \cdot V_2 \quad \text{Eq. 2}$$

$$P_2 = -10 \quad V_2 = 4.7$$

We subtract Eq. 2 from Eq. 1 to get

$$(P_1 - P_2) = B(V_1 - V_2) \quad \text{resulting in} \quad B = \frac{(P_1 - P_2)}{V_1 - V_2}$$

We insert this in Eq. 1

$$P_1 = A + \frac{(P_1 - P_2)}{V_1 - V_2} \cdot V_1 \quad \text{and solve this for A to get}$$

$$A = P_1 - \frac{(P_1 - P_2)}{V_1 - V_2} \cdot V_1 \quad \text{We place the P and V values into the equation for the final result, our "calibration" equation:}$$

$$P(\text{dBm}) = -77.143 + 14.286 \cdot V(\text{DVM})$$

Assume we do a measurement and obtain a DVM reading of 2.75 volts. The equation generates a power of -37.9 dBm.

Application Hints for the Power Meter. (May 26, 2002)

A. How Strong are Signals from an Antenna?

The power meter we have described is capable of seeing very weak signals. Some builders have been confused by the residual reading when no signal is applied to the meter, and have been further confused by the response they see in the meter when even a short wire is attached as an antenna. The obvious question then is, "Just how strong are signals from a normal amateur radio antenna?"

A series of experiments was performed. Our spectrum analyzer was used for the measurements, for this allows us to isolate the frequencies in use as well as the power of the signals. Our main HF antenna at this writing consists of inverted V dipoles for 40 and 20 meters, paralleled on a single coaxial feedline. The center is up about 35 ft. A transmatch at the shack end was tuned to 14 MHz. The resulting system was then attached to the spectrum analyzer input through a short length of coax cable.

These experiments were first done on a Saturday morning (May 25, 2002 at 1700Z.) A CW contest was happening with numerous signals in the 20 meter band. We found that the stronger of these had a strength between -60 and -55 dBm. Listening to a receiver while watching the analyzer allowed us to identify these as coming from the US W0 and W6 districts, a typical distance of perhaps 1000 miles. While loud, these signals were not nearly as strong as we sometimes see.

We then widened the span. There were many strong signals in the 15 MHz International SW Broadcast area with strengths in the -55 dBm region. We found some similar signals around 18 MHz. The higher ham bands had signals, but none with large strength. This probably changed later in the day. It is common to see signals of around -30 dBm or even more from local stations, especially during contests. Although rare with my modest antennas, skywave signals can sometimes become this loud.

Keep my location in mind: The Pacific Northwest is a pretty calm and quiet place for loud signals. The folks on the U.S. East coast will experience much larger signals than we do, RF that originates in Europe. (KK7B logged over a dozen countries with a crystal set from the Upper Peninsula of Michigan.) And the folks in Europe are in the most difficult situation, for they are relatively close to these large transmitters.

By far the strongest signal I saw with my spectrum analyzer was the local Channel 2 TV. The video carrier at around 56 MHz was -15 dBm on peaks.

Attaching the power meter to the antenna tuner produced an indication of -14 dBm. Recall that the power meter will respond to signals to beyond 500 MHz while the spectrum analyzer is preselected with a 70 MHz low pass filter. We have strong signals at TV channels 6, 8, and 10, plus numerous FM broadcast stations, although Channel 2 dominates. Most of these broadcast transmitters are a few miles away.

The power meter is capable of seeing signals below -70 dBm. As such, the power meter **MUST** be well shielded. Moreover, the sources being measured should also be shielded, or the power meter must be preselected. I sometimes disconnect all antennas from my gear when doing measurements.

Preselector filters for experiments are easily realized. A simple low pass filter with a 30 MHz cutoff is easy to design and build and does wonders when only HF measurements are being done. Alternatively, one can build a tunable preselector. A single tuned circuit with high insertion loss can do wonders in isolating signals, although frequent re-tuning is inconvenient. Such a filter can be built with a 365 pF air variable capacitor and a toroid core. The core is filled with wire and placed in parallel with the variable capacitor. An input link is then added: A single turn of wire (just one pass through the core) is attached to a coaxial connector. Another connector and single turn is added to form an output port.

In one example, we used a T68-2 core filled with #26 wire. The resulting filter could be tuned from 2.02 to 10.7 MHz and had an insertion loss of 9.5 dB. When this was tuned to 3.5 MHz, the filter provided 68 dB additional rejection of a 7 MHz signal. Tuning was sharp enough that a vernier dial would have been useful!

Another core, a T68-6A, contained 20 turns. This inductor provided tuning from 5.7 to 29.6 MHz with frequency dependent insertion loss of 2 dB at 15 MHz. Single turn input and output links were again used. At the other end of the spectrum, we used a low permeability ferrite core for the AM broadcast band. A FT-50-61 core was wound with 52 turns of #30 wire. (Don't bother with a -43 core!) This L tuned to 547 kHz at maximum C with an insertion loss of 3.5 dB. IL dropped at the high end of the tuning range, near 3 MHz.

B. Residual Indication

The Power meter that we described in QST will show a residual reading, even when the circuitry is in an RF tight box and nothing is connected to the input connector. The indication for my meter is around -80 dBm. Let's assume this was **NOISE** coming from an input resistance attached to the box. The available power from such a resistance would be kTB where k is Boltzman's constant, T is temperature in Kelvin, and B is bandwidth in Hz. The bandwidth of this meter is about 500 MHz. The T is around room value, or 300 K, and k is $1.38E-23$ Joules/Kelvin. (Recall that Watts is Joules/sec and 1/seconds is Hz.) kTB is then about $2E-12$ watts = $2E-9$ milliwatts, or -87 dBm. Allowing a noise figure of a few dB, this residual is nothing more than the input noise of the integrated circuit.

C. Hints for Using the Power Meter

With the difficulties mentioned, the builder can easily conclude that the meter's extreme sensitivity is it's own worst enemy. In many cases this may be true. The user needs to be careful in applying the instrument. Here are a few hints:

1. Don't even think about building the meter in anything but a shielded box. Even if you live in the most remote part of the world, this won't work.

2. Work in a coaxial environment with sources shielded if you are trying to measure weak signals. The stray RF will only be a problem when it can get to the input connector.

3. If you become frustrated with the low life of the batteries and want to use an external power source, be extremely careful in the way that DC power is routed to the instrument. A high quality feed-through capacitor is recommended, with additional decoupling. (Incidentally, Bob and I used commonly available parts where possible, which included 9 volt batteries, 78L05 regulators, LM358 op-amps. But the basic AD8307 will function well at lower voltages. Other regulators are available, as are other op-amps. A version of this meter operating from 2 or 3 AA cells should be quite practical, offering economy and isolation.)

4. Use characterized preselection filtering when possible. You will have to measure and account for the insertion loss of this, but that should be easy, for the power meter is the critical tool needed for such an evaluation.

5. As you perform measurements, continually think about the measurement process, keeping the difficulties in mind. An input attenuator is always a wonderful tool. If you insert a 10 dB pad in the input line and the indicated response drops by 10 dB, the measurement is probably viable. But if the response changes by less than 10 dB, stray RF is probably getting into the system AFTER THE PAD. (Incidentally, this can be a wonderful scheme for evaluating distortion in systems.)

New variations.

Builders should be sure to look at the excellent power meter presented by Bob Kopski, K3NHI, in the May/June 2002 issue of QEX. Nice job Bob!

Also, take a look at the version designed and built by Roger Hayward, KA7EXM. This info is in the May/June 2005 QEX and the June 2005 QST. This power meter uses a PIC processor for some added features.