Revised AD8307 RF Power Detector rev2.03
Based on a design by W7ZOI and W7PUA
with enhancements suggested by WØMNE

This new PCB layout of the power meter incorporates some features that should improve the isolation of the RF front end as well as allow for a more convenient installation of a shield cover over the front end.

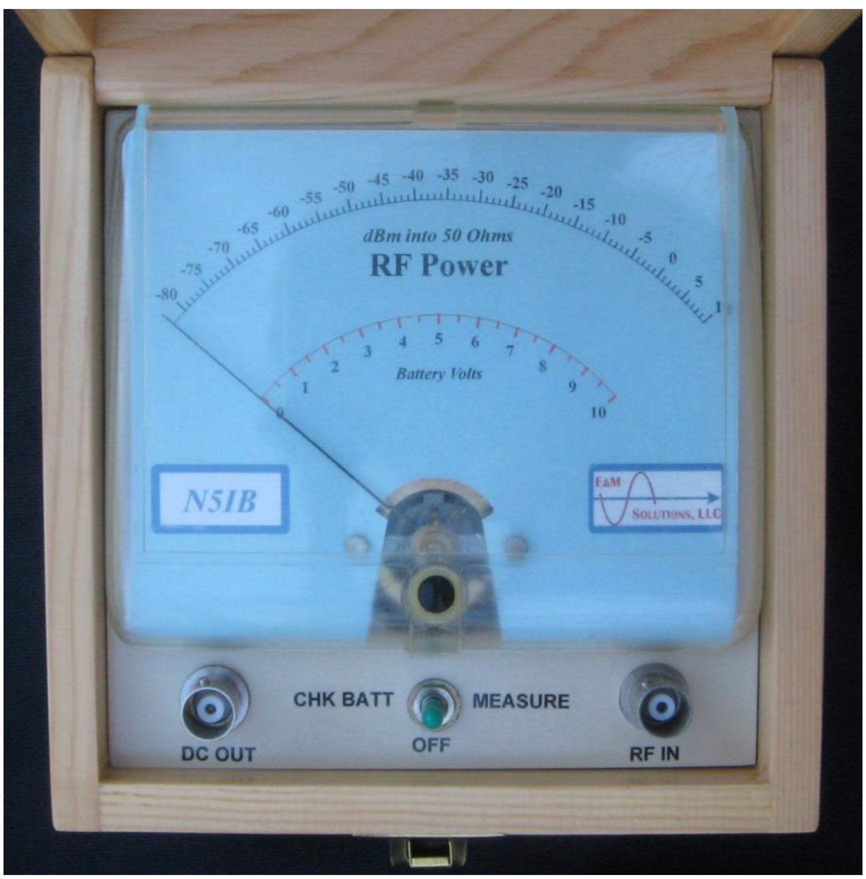
The entire RF front end is now surface mount components and all located on the top side of the board, with a continuous ground plane on the bottom side. The top and bottom ground planes under the front end are isolated from the main board ground planes, except for a single point connection on the bottom side. An unmasked border area is available on the top side, to which a shield cover can be soldered.

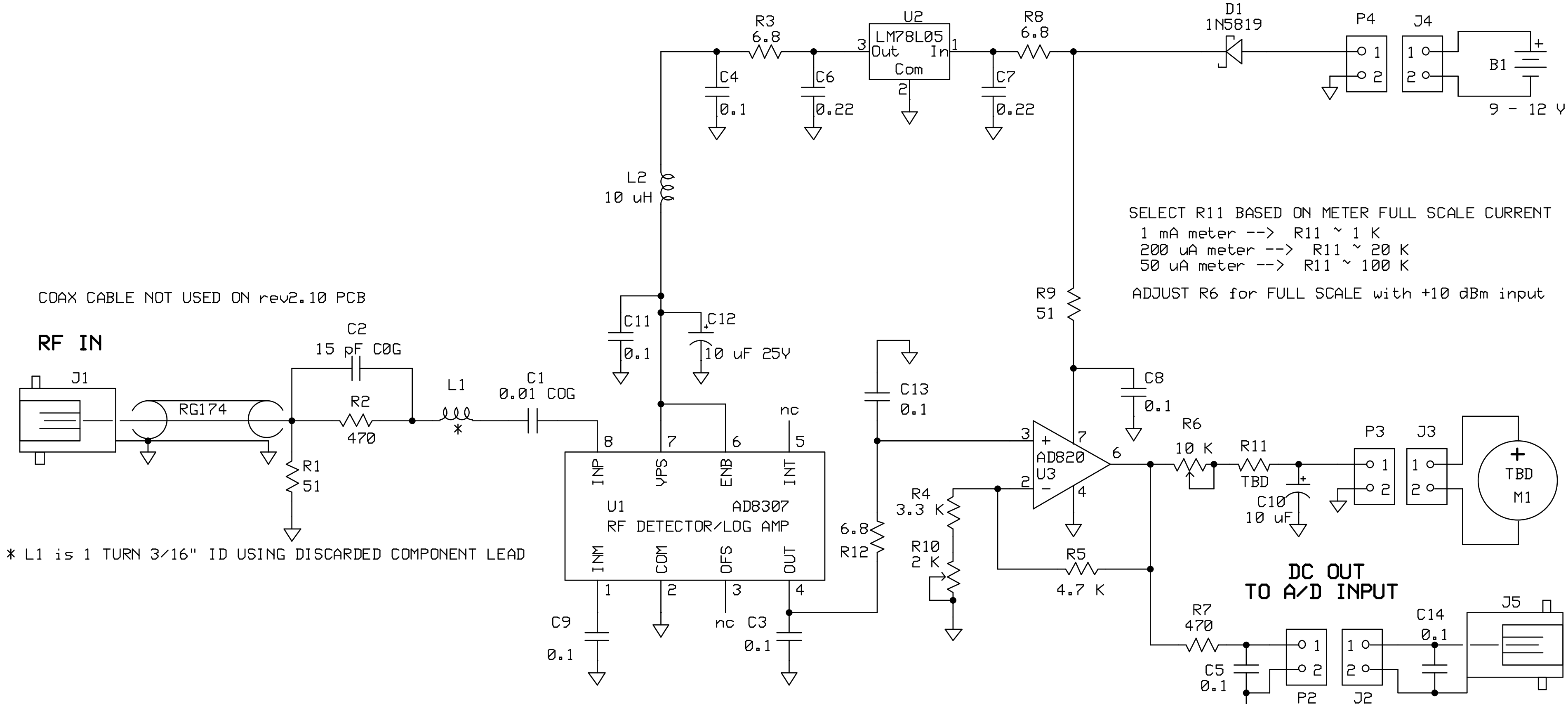
Also added is an additional resistor in series with the analog meter movement to allow for customizing the full-scale meter current for a wide variety of meter movements.

A complete schematic, bill of materials, and an approximately actual size PCB layout are shown.

Jim, N5IB

30 Jan 2014





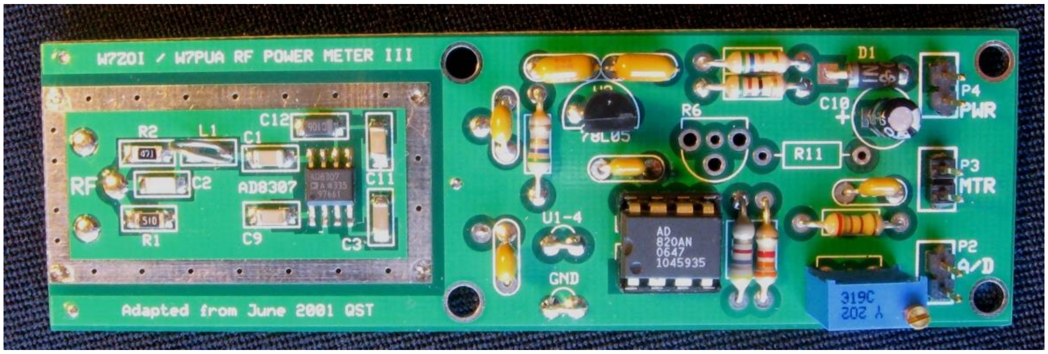
U1 V-OUT ~ 1850 mV @ -10 dBm
U1 V-OUT ~ 2100 mV @ 0 dBm
U1 V-OUT ~ 2350 mV @ +10 dBm
SLOPE 25 mV per dBm
Zero Intercept -84 dBm

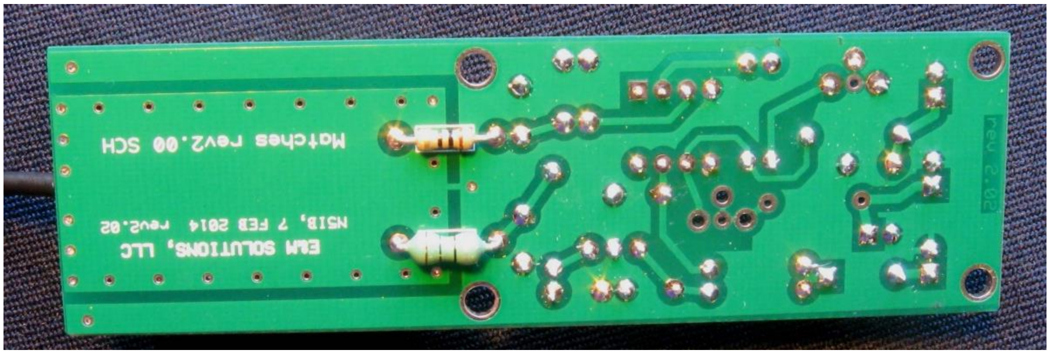
U3 GAIN = 1 + (R5)/(R4+R10)
ADJUST R10 for +5 V at pin 6 for +10 dBm input

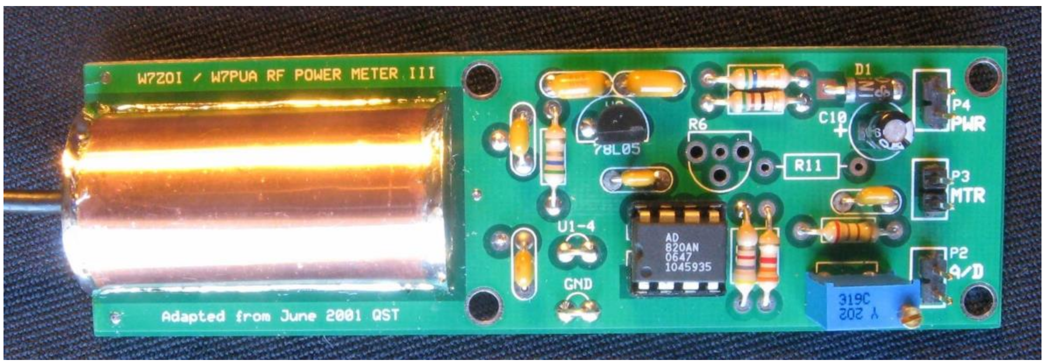
MATCHES PC BOARDS rev 2.02. 2.03 & 2.10

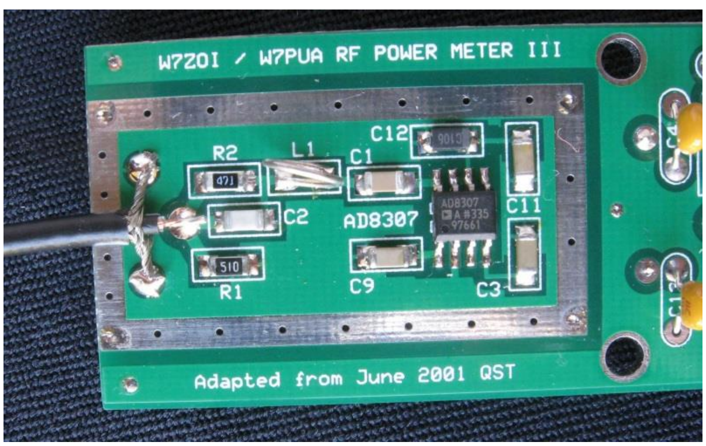
E&M Solutions, LLC		
W7ZOI, W7PUA RF Power Meter		
Design: W7ZOI W7PUA Redrawn: N5IB	Rev 2.03 6 NOV 2019	Page 1 of 1

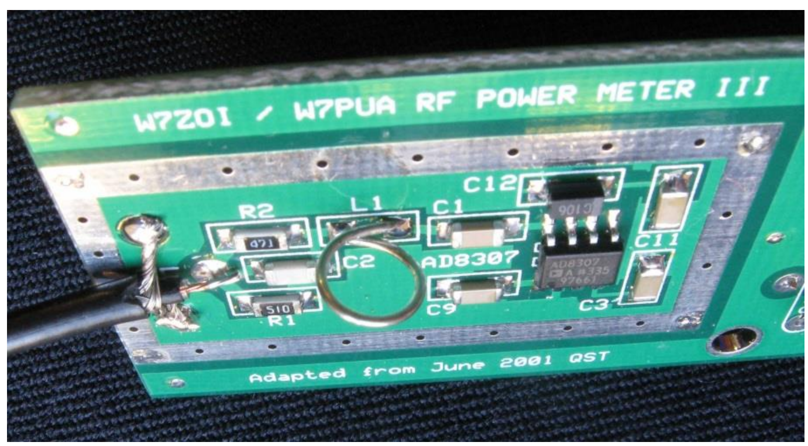
W7ZOI W7PUA AD8307 RF Power Meter rev2.00		
Bill of Materials 17 February 2014		
Matches Schematic rev2.00 and PCB Layout rev 2.02		
		Mouser catalog number
	The following are surface mount components	
C1	0.01 uF 50V SMT 1206, C0G preferred	77-VJ1206A103JXAAT (C0G)
C2	15 pF 50 V SMT 1206 NP0 or C0G preferred	77-VJ1206A150JXACBC
C3, C9	0.1 uF 10% 50 V SMT 1206	80-C1206C104K5R
C12	10 uF 16 V 10% Tantalum V SMT 1206	74-593D106X9016A2TE3
R1	51 ohm 5% SMT 1206	71-CRCW120651R0JNEA
R2	470 ohm 5% SMT 1206	71-CRCW1206J-470-E3
U1	AD8307 log amp RF power detector SOIC8	584-AD8307AR
	The following are conventional leaded, through-hole components	
C4, C5,	0.1 uF 100V ceramic 0.2" lead space	80-C322C104K1R
C6, C7	0.22 uF 50 V ceramic 0.2" lead space	594-K224K20X7RF53H5
C10	10 uF 25 V electrolytic radial leads 0.1" lead space	667-EEU-HD1H100B
D1	1N5819 Schottky barrier rectifier, axial leads	625-1N5819-E3/53
J1	BNC panel mount jack, may also use for D/A output from J4	523-112424
J2, J3, J4	2 pin, 0.1" spaced, female header connector	538-70107-0001 (shell)
L1	1 turn 3/16" inside diameter using discarded resistor lead	n/a
L2	10 uH molded inductor, 10%, axial leads	542-78F100-RC
M1	analog meter movement, 1 mA preferred	junk box/hamfest/ ALL Electronics #
P2, P3, P4	2 pin, 0.1" spaced male header, cut from breakaway strip	571-41033210
R3, R8,	6.8 ohm 5% 1/4 W carbon film	291-6.8-RC
R4	3.3 K ohm 5% 1/4 W carbon film	291-3.3K-RC
R5	4.7 K ohm 5% 1/4 W carbon film	291-4.7K-RC
R6	10 K ohm trimmer potentiometer	858-64YR10KLF
R7	470 ohm 5% 1/4 W carbon film	291-470/AP-RC
R9	51 ohm 5% 1/4 W carbon film	291-51/AP-RC
R10	2 K ohm trimmer potentiometer	858-64YR2KLF
R11	1/4 W 5%, value TBD depending on meter movement used: 1 mA movement - 1 K 200 uA movement - 20 K 50 uA movement - 100 K	
U2	LM78L05 +5 V 100 mA linear regulator TO92	512-LM78L05ACZ
U3	AD820 single channel FET input op amp DIP8, other rail-to-rail in/out single supply amplifiers may be substituted - the pinout is standard: e.g. CA3160, OPA344, LT1077, LT1677, LMC661 (CMOS), MAX4484 (SMT)	584-AD820ANZ
B1	9 volt alkaline or lithium battery, with battery clips and leads	123-5006-GR (clip only)







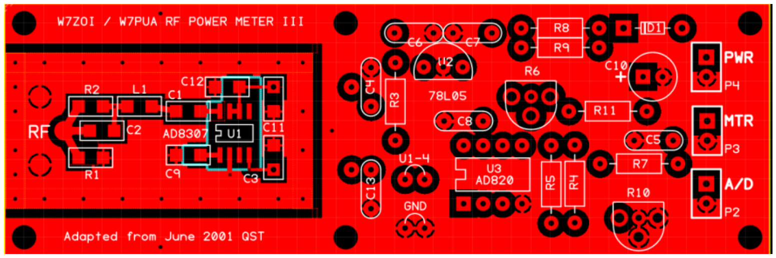




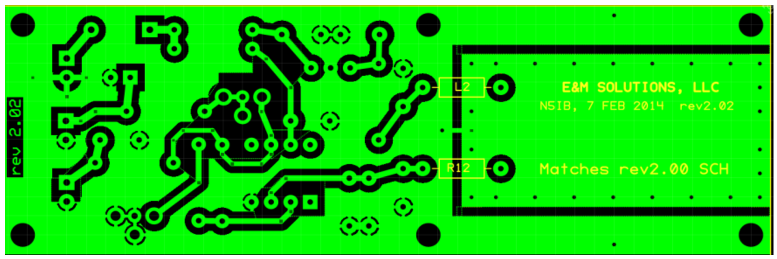
Note: In the above photo, R6 and R11 are not yet installed. The values of these components may vary depending on the sensitivity of the optional analog meter movement. They should be chosen to allow full scale meter deflection when the output of U3 is 5.0 V.

Approximately actual size 3.925" x 1.150"

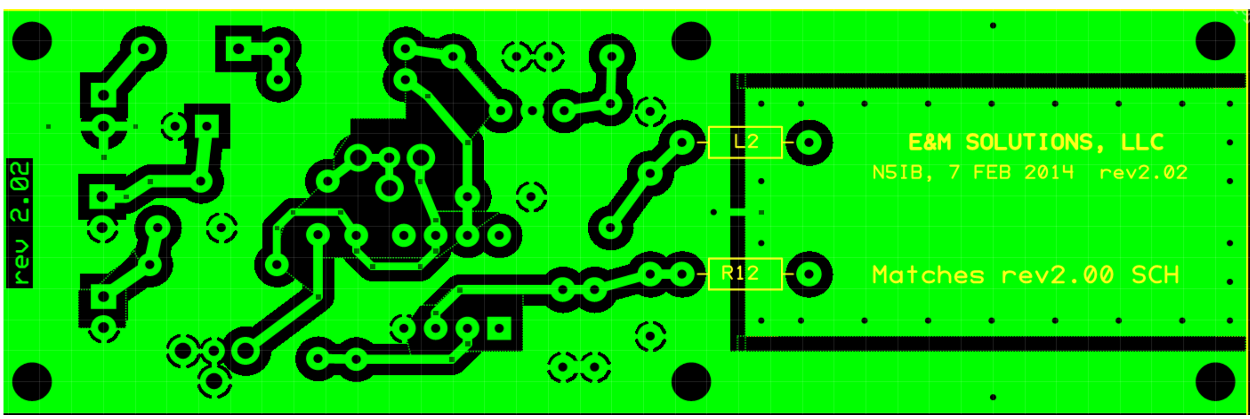
Top copper

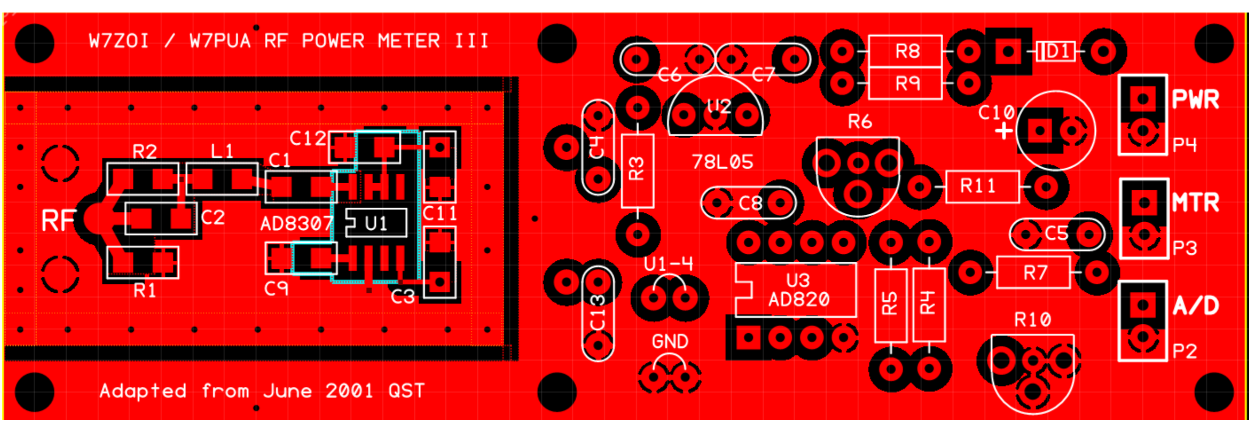


Bottom copper



Not to scale, for parts placement reference





Calibrating the RF Power Meter

The AD08307 RF power detector is a logarithmic device, meaning its voltage output is directly proportional to the logarithm of the RF power applied to its input. As a result its output is a linear response in units of decibels. For RF measurements the preferred unit of measure is the **dBm**, which is defined as decibels with respect to a reference level of 1 milliwatt (0.001 W). To convert dBm to a voltage it is necessary to know the load resistance to which the power is being delivered. A load resistance of 50 ohms is the most common in ham radio applications. The table below shows a few power levels in dBm, along with the corresponding powers and voltages across a 50Ω load.

RF Power in dBm	RF Power	RF rms voltage across a 50Ω load
+37	5 W	15.8 Vrms or 44.7Vpeak-peak
+10	10 mW	707 mVrms or 2Vpeak-peak
+3	2 mW	316 mVrms
0	1 mW	224 mVrms
-3	0.5 mW	158 mVrms
-10	0.1 mW	70.7 mVrms or 20 mVpeak-peak
-20	0.01 mW	22.4 mVrms
-30	0.001 mW or 1.0 µW	7.07 mVrms
-60	0.000001 mW or 0.001 µW	0.224 mVrms or 224 µVrms
-70	0.0001 µW or 0.1 nano watt	70.7 µVrms
-120	0.001 pico watt	0.224 µVrms

The AD-8307 is capable of measuring over at least the entire shaded range above. The last row represents an RF signal level which would be considered a relatively weak signal in a ham radio receiver, while the top row represents a QRP transmitter power output.

The AD-8307 data sheet specifies that the output voltage of the device changes by about 25 mV for each 1 dBm change in RF input power. The rate of change of output voltage is called the **slope**. Furthermore, its minimum detectable power (the **noise floor**) should be about −78 dBm into a 50Ω load. However, the output voltage will not be zero at the noise floor. The hypothetical power level at which the output voltage would actually fall to zero should be about −84 dBm. This hypothetical level (which can never be reached) is called the **intercept**. Algebra students should quickly recognize the terms **slope-intercept** and begin to visualize a straight-line graph of voltage and power.

The slope, intercept, and noise floor are not absolute, precise parameters. They differ somewhat from device to device due to manufacturing variations. From the data sheet, the table below shows the typical range of these parameters.

	Typical minimum	Nominal value	Typical maximum
Slope	23 mV/dBm	25 mV/dBm	27 mV/dBm
Intercept	-87 dBm	-84 dBm	-77 dBm
Noise Floor	*not specified*	-78 dBm	*not specified*

In addition to the RF detector (U1), the circuit described in this document includes an operational amplifier (U3) and potentiometer (R10) which can change the slope of the measurement response, but not the intercept. An additional potentiometer (R6) allows accommodation for various analog meter movements. This makes it easier to use the AD-8307 with different sorts of analog or digital meter displays, or computer analog-to-digital inputs. The calibration process involves determining the intercept and setting the slope of the response.

There are several ways to calibrate a power meter of this circuit configuration. We'll touch on them in turn, in order of increasing accuracy. In each case the potentiometer R10 can be adjusted to fine-tune the slope of the detector response. Using the component values that are shown on the schematic (R4=3.3K, R10=2K) the voltage gain of the U3 amplifier can be adjusted from roughly 1.9 to 2.4, meaning that the slope of the response at the output of U3 can be varied from a minimum of about 45 mV per dB, to a maximum of about 60 mV per dBm. A larger range of adjustment could be provided by changing the resistor values, keeping R5 between about 2K and 20K

$$voltage\ gain = \frac{R5}{R4 + R10} + 1, \qquad slope \cong gain \times 25 \frac{\text{mV}}{\text{dBm}}$$

Zero Point Calibration

As the name implies, this method does not require any signal source of a known power level. We simply naively presume that the AD-8307 will perform according to its nominal specifications and carry on.

Setting potentiometer R10 at mid-range (1 K) should yield a slope of about 52 mV per dBm. If the 8307's intercept is close to the nominal −84 dBm, then the input RF power in dBm should approximate the formula

$$\text{dBm} = \frac{V_{out}}{52\ \frac{\text{mV}}{\text{dBm}}} - 84\ \text{dBm}, \qquad \text{where } V_{out} \text{ is the voltage at U3 pin 6, in millivolts}$$

For example, suppose you applied an unknown RF level to the input of the 8307 and measure 3.900 V at U3-6. The RF power would be

$$\frac{3900\ \text{mV}}{52\ \frac{\text{mV}}{\text{dBm}}} - 84\ \text{dBm} = -9\ \text{dBm}, \qquad \text{or } 0.126\ \text{mW}$$

Single Point Calibration

If a signal source of accurately known power level is available, calibration can be improved. The signal ideally should be of a level near the upper end of the measurement range, between -10 and +10 dBm or so. Do not exceed +10 dBm so as to not overload the 8307. The frequency is not especially critical, but something in the middle of the intended measurement band is best. The 8307 itself can measure from DC up to 500 MHz. In this particular circuit, because of the capacitively coupled input, the lower end is a few hundred kHz. For typical ham radio HF (1.6 to 30 MHz) measurements, 10 MHz or so would be fine.

Apply the known reference signal to the 8307 input and measure the output voltage at U3 pin 6. We will again presume that the intercept is the nominal −84 dBm. We can then calculate a slope as

$$slope = \frac{V_{out}}{P_{in} - (-84\ \text{dBm})}, \qquad \text{where } V_{out} \text{ is in mV and } P_{in} \text{ is in dBm}$$

For example, suppose the known reference signal has a level of +3 dBm, and the voltage at U3-6 is measured as 4.65 V

$$slope = \frac{4650\ mV}{+3\ dBm + 84\ dBm} = 53.4\,\frac{\text{mV}}{\text{dBm}}$$

Here's where the adjustability afforded by R10 becomes useful. If R10 is tweaked until the U3-6 voltage becomes 4.350 V, then the slope would become a nice round number:

$$slope = \frac{4350\ \text{mV}}{+3\ \text{dBm} + 84\ \text{dBm}} = 50.0\frac{\text{mV}}{\text{dBm}}$$

Now, for some unknown RF input level, the power in dBm would be

$$\text{dBm} = \frac{V_{out}}{50\,\frac{\text{mV}}{\text{dBm}}} - 84\ \text{dBm}$$

Two Point Calibration

If an input signal can be provided at two known power levels an even better calibration can be performed, for now it will be possible to calculate both the slope and the intercept from direct measurements. The two reference levels should be at the same frequency, and would be best if one were near the upper end of the power range and the other lesser in level by 30 to 50 dBm or so.

The reference signals could be obtained from a signal generator with an accurately calibrated output, or the two levels could be measured with a calibrated oscilloscope. An alternative is to have a single known level, then insert an attenuator of known loss in order to create the other signal level.

Suppose you have a 10 MHz source whose output is accurately known to be −10 dBm into 50**Ω**. You also have available a 30 dB attenuator, so that a −40 dBm signal can be produced by inserting the attenuator. You measure U3-6 as 3.75V for −10 dBm input, and 2.28V for −40 dBm input. Then

$$slope = \frac{V_{out1} - V_{out2}}{P_{in1} - P_{in2}} = \frac{3750\ \text{mV} - 2280\ \text{mV}}{(-10\ \text{dBm}) - (-40\ \text{dBm})} = 49\,\frac{\text{mV}}{\text{dBm}}$$

Recall from before, when we assumed the nominal −84 dBm intercept:

$$slope = \frac{V_{out}}{P_{in} - (-84\ \text{dBm})}$$

Now, since we have a freshly calculated slope, we can replace the assumed intercept value of −84 dBm with a variable for which to solve. We can use either pair of P_{in} and V_{out}, for example:

$$49\frac{\text{mV}}{\text{dBm}} = \frac{2280\ mV}{-40\ dBm - (intercept)}\ , \qquad \text{then,}\quad intercept = -40\ \text{dBm} - \frac{2280\ \text{mV}}{49\frac{\text{mV}}{\text{dBm}}} = -86.5\ \text{dBm}$$

With these freshly calculated values for both the slope and intercept we can calculate any other power level simply by measuring the V_{out} voltage at U3-6.

$$\text{dBm} = \frac{V_{out}}{49\ \text{mV/dBm}} - 86.5\ \text{dBm}$$

Once again, R10 can be tweaked to bring the slope value to some convenient round number, if desired.

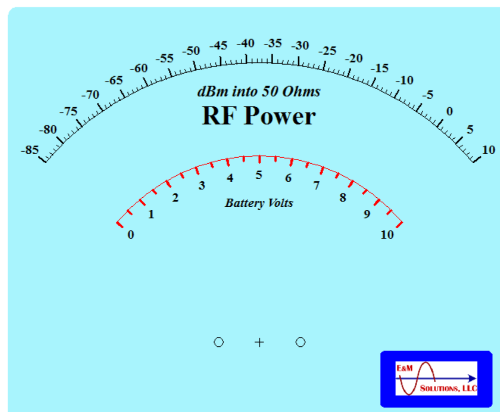
Multi Point Calibration

About the best calibration possible will be achieved if it's possible to apply several input signals of known power levels and use the power of **least-squares-approximation** mathematics to calculate the slope and intercept. The result will be the best possible estimate of those parameters than can be made from the given data. While it's possible to hand calculate a least-squares, the procedure is best left to computers. It is very simply accomplished with an Excel or OpenOffice spreadsheet. You simply apply a series of known RF input signal levels, measure the corresponding U3-6 voltages, enter the data into the spreadsheet and out pops the slope and intercept.

One way to get a series of known levels it with the calibrated signal generator or oscilloscope mentioned earlier. Another way is to use a single, fixed signal source and a series of attenuators, or a step attenuator.

No need to go to excess, if you can provide perhaps ten different accurately known levels, roughly evenly spread out over the range from perhaps +3 dBm to −60 dBm, a very good calibration indeed can be achieved.

An example Excel spreadsheet can be found at this link: https://qsl.net/n5ib/



Adjusting R10 to use an analog meter movement

Resistor R11 and potentiometer R6 are included to accommodate analog meter displays. The current through a meter movement will depend upon those resistances, the internal resistance of the meter movement, R_{int}, and V_{out}, the voltage at U3-6.

$$I_{meter} = \frac{V_{out}}{R_{int} + R11 + R6}$$

The internal resistance will depend on the full-scale current for the movement. For example, most 1 mA meter movements have an internal resistance of about 1000 Ω.

The goal is to adjust R6 for a full scale deflection of the meter when the RF input power is at the top of the measurement range – usually +10 dBm. The zero-deflection value will then correspond to the intercept as determined above.

Note that the noise floor is *above* the intercept. This means that whenever the circuit is powered on, there will always be a small deflection of the meter, even with no signal applied to the input. This will be the noise floor for that particular instrument. It will depend upon the characteristic of the individual detector chip, the level of shielding, and the local RF environment.

The image above shows a customized meter face created with the *Galva* software that has a battery check scale as well as the RF power scale. http://www.f5bu.fr/galva-about/

Using the power meter to measure higher powers

The maximum power that should be applied to the input of the AD-8307 is about 50 mW (17 dBm) but the measurement linearity begins to suffer for inputs greater than about 10dBm (10 mW). Therefore, 10 mW should be considered the upper limit for the meter.

To measure higher powers an attenuator or power tap must be used. For example, if a 30 dB attenuator is inserted between the RF source and the power meter, the upper limit would now be +40 dBm (10 W). It is important to note that the attenuator or power tap must be capable of safely dissipating essentially the entire power of the RF source. The usual small attenuators are generally rated for no more than 1 watt, so cannot be used at the 5 W or 10 W level.

One possible method is to connect the RF source to a robust dummy load capable of handling its full power. A voltage divider is then connected in parallel with the dummy load to reduce the signal to the power meter.

The circuit below has proved to be satisfactory. Most of the input power is dissipated in the dummy load, so relatively small wattage resistors may be used for the divider. It provides 30 dB of attenuation and allows powers up to 10 W to be measured. Simply add 30 dBm to the reading of the power meter. For best results the dummy load and the voltage divider should be housed in separate shielded enclosures.