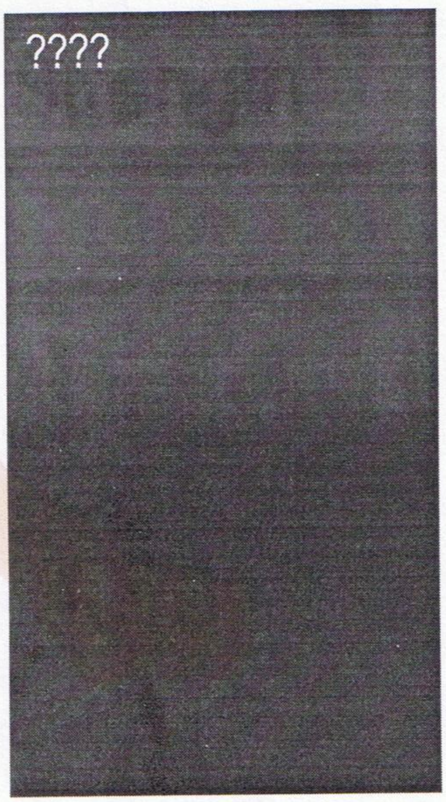
FEATURE ARTICLE

SE Nickols

Measuring RF Field Strength



In embedded products, RF techniques are becoming pervasive. Wireless technology manages to end up in everything from LANs to PDAs to telemetry systems. Sometimes embedded developers need tools for measuring RF. What if you wanted to make relative field strength measurements with ±3 dBm of accuracy? What if you wanted a broadband RF meter with a simple tuning arrangement? What if you wanted a battery-powered measurement tool that plugs into your hand-held voltmeter?

Better yet, what if you could put this handy gadget together for less than $100? Well, if that's something you could really use on your bench top, read on.

In this article, I'll describe a portable inexpensive relative field strength meter. This gadget doesn't have the accuracy of more expensive RF tools on the market. However, when tied into a DVM or data acquisition system, it can be a useful and flexible front-end building block to a more sophisticated instrument.

BACKGROUND

Recently, I've been working on wireless projects. When I invest time into learning and building hardware for a project, it is my intention to come away with tools and techniques that can be reused in future projects. The idea is to accumulate building block tools.

One project that comes to mind required the measurement of field strength emitted from a variety of small transmitters. The frequencies to be measured ranged from 300 to 450 MHz.

The application required the measurement of relative field strength for different transmitters distributed throughout a household. My employers wanted to determine a suitable transmitter for an indoor wireless appliance. They also wanted to characterize a living room environment as it affects path loss from the transmitter to a receiver.

By measuring signals at known distances, path loss for a given environment can be characterized. The goal was to capture experimental data. This data would be used for the design of a portable product that could determine the proximity of a transmitter relative to a base station receiver.

MEASUREMENT TOOL

RF field strength is measured in decibels. If you have an idea of the transmitter's output power, you can calculate path loss directly from the RF field strength as measured at the receiver. Path loss is the attenuation (reduction) of field strength caused by distance or interference.

With a direct decibel reading device you can correlate path loss and estimate proximity. RF field strength from a source is reduced at a rate based on the square of the distance involved. This is true for free space transmission loss with no reflections, obstacles, nor interference.

I needed a simple, portable, decibel meter to measure field strength without a complex tuning arrangement. It became obvious that this was the job for a broadband logarithmic amplifier. Log amplifiers convert a voltage signal input to a logarithmic equivalent voltage output on a decibel scale.

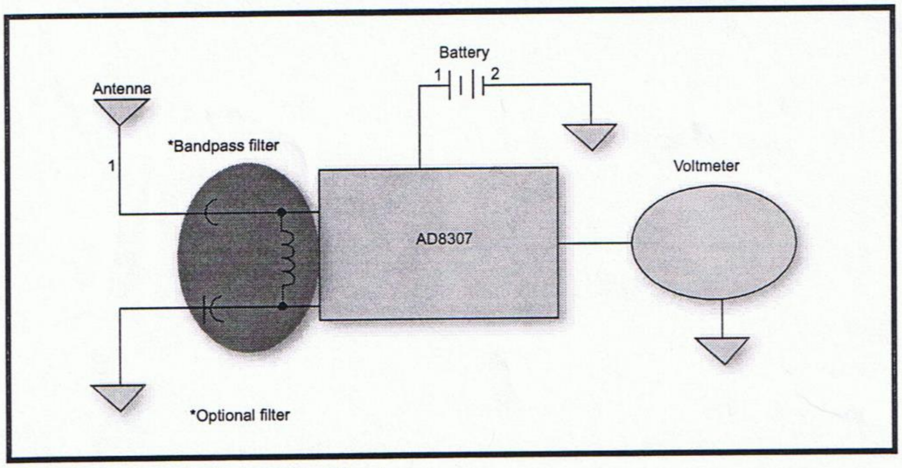


Figure 1—*Here's a block diagram of the RF meter.*

There are logarithmic amplifiers that offer a great range of sensitivity, with flat response across a wide band of frequencies. I knew a log amp attached to an antenna was the ticket; change the antenna and you tune the sensitivity to the wavelength/frequency of interest (see Figure 1). By adding a filter network following the antenna, you can improve sensitivity at a frequency of interest.

FINDING THE IDEAL LOG AMP

For me, simplicity, cost, and availability of parts are always important considerations when trying to build hardware. For this project, the requirement was a device with a flat response from 100 to 450 MHz. In addition, I wanted 0.80 dBm of dynamic range.

Analog Devices offers excellent broadband log amps; the AD8307 looked ideal for my project. The company's web site offers a useful datasheet about the AD8307. [1] This log amp has a dynamic range of 92 dB, 2.7- to 5-V at 7.5 mA operation, DC operation to 500 MHz, SO 8, and eight-pin DIP packages.

I credit Ian Hickman for giving me the idea to use the AD8307 logarithmic amplifier for my RF meter approach. [2] His article, "How Strong is Your Field," describes an RF meter for measuring antenna radiation patterns. He recommends the AD8307 with a dipole antenna arrangement for more exacting measurements.

My approach is similar, however, the circuitry is more simplistic. Analog Devices can supply you with the hardware. Evaluation boards are even better. Great datasheets help development as well.

Figure 2 shows the internal workings of the AD8307. [1] The AD8307 is composed of a cascade of six nonlinear amplifier elements. The nonlinear amplifiers perform a logarithmic conversion of wide dynamic range signals. Logarithmic amplifiers compress signals ranging from microvolts to volts into the decibel equivalent voltage. In radio work, log amps are well suited for measurement applications.

RF signal strength tends to vary widely from weak signals at distance, to strong signals that are near by. As such, RF signal strengths have wide dynamic range.

In the case of the AD8307, it measures signals as low as –75 dBm. That's a sine wave voltage amplitude of ±56 mV. The upper end of the AD8307 is 17 dBm, which means it converts a sine voltage of ±2.2 V.

Notably, the AD8307 has about 0- to 500-MHz uniform bandwidth response. Uniform response to different frequencies, is shown as log conformance. [1] Figure 3 displays the relative performance of the AD8307 at 10, 100, and 500 MHz. This device can also be used at frequencies in the audio range to 900 MHz with reduced performance.

BUILD A MEASUREMENT TOOL

Upon inspection of the AD8307 datasheet, you'll find circuit examples that can be tailored to this application. The circuit illustrated in Figure 4 is a good starting point. [1] This appeared to be a convenient starting point. Analog Devices makes working with the AD8307 easy. And, note that you can buy an AD8307 evaluation board for $50 (excluding shipping).

I went ahead and purchased the AD8307 evaluation board. This was later placed in a box. Metal boxes improve immunity to stray signals. (By the way, plastic boxes are easier to work with.) I used BNC connectors for the antenna connection and log voltage output. The evaluation board has SMA connectors at the input and output. I used an SMA-to-BNC converter to make things easy. Three 1.5-V AA batteries in series provide 4.5 V for +VS.

It is prudent to use a coaxial cable for the connection to the VOM. (coax-

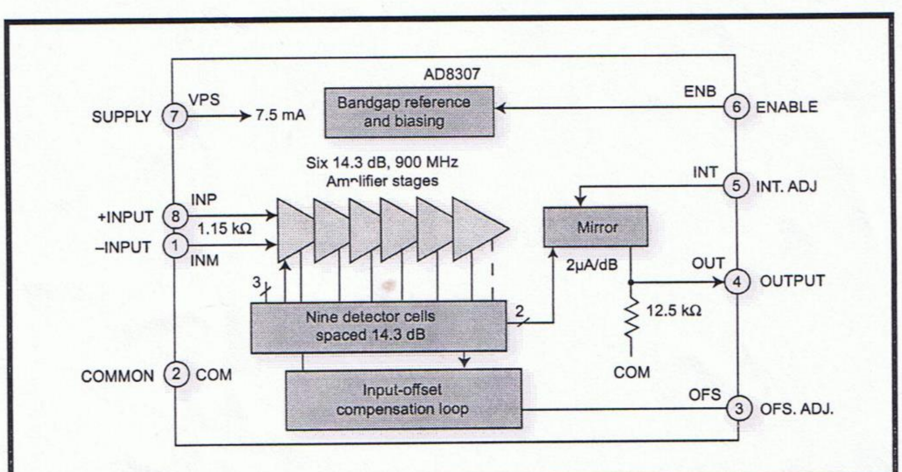


Figure 2—*Check out the internal workings of the AD8307.*

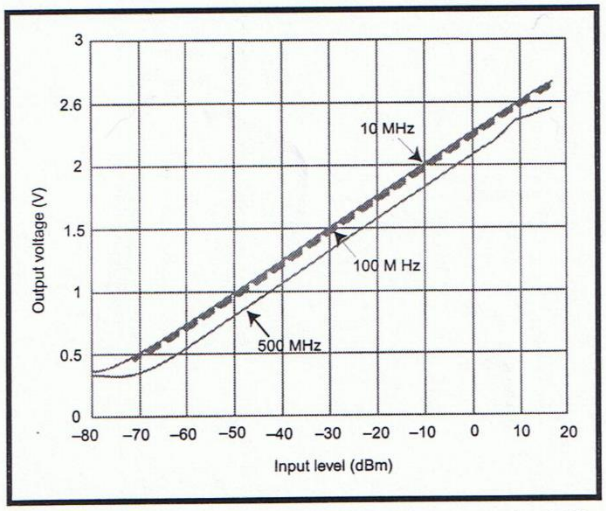


Figure 3—*Compare the logarithmic voltage output versus power input of the AD8307.*

to-banana plugs.) I used a collapsible antenna mounted on a BNC connector for the input to the circuit in Figure 4.

You can modify the circuit in Figure 4 by removing R1 and adding an inductor, LM, across pins 1 and 8 of the AD8307. Table 1 shows a table of filter values for narrowband filtering. Modify components C1, C2, and LM in Figure 4 to filter values in Table 1 when you need peak response to a given frequency.

CALIBRATING THE RF METER

Adjustment was easy with a signal generator calibrated in decibels greater than 1 mW (dBm). It is best to calibrate in an environment that has a low RF ambient background. I had access to a shield room for initial testing.

For reference signal input, I used a 300-MHz sine wave as a starting point (see Figure 5). I soldered a 9.8″ piece of 16-gauge wire to a BNC connector, and then attached it to the output of the RF generator. Using an RF signal generator calibrated in decibels greater than 1 mW, I set the initial output to 10 dBm, or 10 mW of RF output power. This method is similar to the calibration technique used by Hickman.

On the RF meter, I adjusted the length of the whip antenna to 9.8″, which is the quarter wavelength for 300 MHz. Next, I removed jumper LK2 in Figure 6. Jumper LK1 should be to position A. LK1 connects pin 6 to $+V_S$.

At close range, with antennas nearly touching, I read about 2.2 V. Figure 3 shows ideal readings versus RF power at the RF meter antenna. I could test down to 0 dBm with my RF generator. My readings were linear and in agreement with Figure 3. This setup should output about 25 mV/dBm.

An alternative, more accurate calibration technique is to attach the RF meter to the RF generator through a veriable attenuation block. The meter is very sensitive. After I came out of the shielded room, the meter showed levels of signal detection based on location. For example, the testing that was done at an apartment near a cell site antenna indicated about 1 V of signal. This was a –50-dBm signal as measured as ambient signal strength. Using a front-end tuning arrangement will improve immunity to stray signals and sensitivity to desired signals.

DECIBEL SCALE EXPLAINED

The decibel scale is convenient for quantifying signal strength. Table 2 shows the common decibel unit expressions. Decibels are a logarithmic way of representing relative power levels. The basic unit is the bel (10 decibels). Two power levels, P_1 and P_2, are said to differ by bels (B):

$$B \equiv \text{Log}_{10}\left(\frac{P_1}{P_2}\right) \qquad [1]$$

For example, consider two power levels, $P_1 = 6$ W, and $P_2 = 3$ W. Using this equation, you can say that:

$$D = 10\ \text{Log}_{10}\left(\frac{6}{3}\right) = 10\ \text{Log}_{10}(2) = 3 \cdot 01 \approx 3\ \text{dB} \qquad [2]$$

where P_1 is 3 dB greater than P_2.

For measuring power in communications systems, a reference level is established and all measurements are compared to that reference level. One milliwatt is a convenient number. Now, you may use the dBm scale. If you used 1 W as a reference, it would be dBw. For any value you want to compare to this reference, divide the value to be compared by 1 mW. [3]

Let's say the transmitter emits about 1mW of RF power. Dividing 1 mW by 1 mW equals 1.This is called a log ratio of one. Using the next formula, you may convert 1 mW to its equivalent on the decibel scale:

$$\text{dBm} = 10\ (\log 10 \times 1) = 0\ \text{dBm}$$

Going back to Figure 3, you now have a means to compare the voltage output of the RF meter to the decibel scale. You can relate this to received power at the antenna on the decibel

FC (MHz)	ZIN (W)	C1 (pF)	C2 (pF)	LM (nH)	Voltage gain (dB)
10	45	160	150	3300	13.3
20	44	82	75	1600	13.4
50	46	30	27	680	13.4
100	50	15	13	330	13.4
150	57	10	8.2	220	13.2
200	57	7.5	6.8	150	12.8
250	50	6.2	5.6	100	12.3
500	54	3.9	3.3	39	10.9
10	103	100	91	5600	10.4
20	102	51	43	2700	10.4
50	99	22	18	1000	10.6
100	98	11	9.1	430	10.5
150	101	7.5	6.2	260	10.3
200	95	5.6	4.7	180	10.3
250	92	4.3	3.9	130	9.9
500	114	2.2	2	47	6.8

Table 1—*Filter values for narrowband sensitivity.*

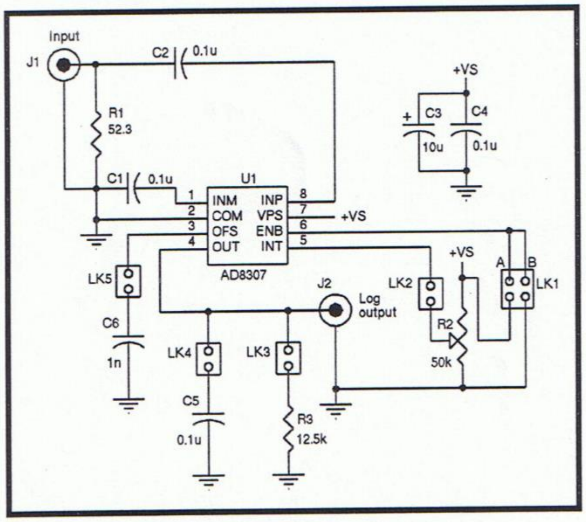


Figure 4—*The schematic of RF meter shows all the details.*

meter. Figure 6 is a simple look-up table for comparing relative values on the decibel scale.

INTERPRET VOLTAGE READINGS

Using a test setup as described, you can move away from the RF source and measure power at a distance. Let's say you get a 1-V reading from the RF meter. The frequency setting of the RF source is 300 MHz. And the power setting is adjusted to 10 dBm (10 mW).

Referring to Table 3, 1 V represents –50 dBm, or 10 nW. Now, you can conclude that the path loss, or attenuation, from the transmitter to the receiver is –60 dBm.

The current circuit configuration gives about 25 mV/dBm. Perhaps in the future, I'll design a microcontroller to convert the AD8307 voltage output to direct decibels greater than 1-mW readings.

The hand-held RF meter gives you the ability to measure RF power at distance. Now that you have an understanding of the decibel scale, converting decibels back to watts can be useful when you want to know how much power you are receiving at what distance.

Figure 7 shows a model for a RF power source attached to an antenna. The antenna has a gain (G) based on length. This source, separated by distance r from the receiver, will emit an electromagnetic field. The receiver will convert the field to power.

For the RF meter, the antenna length is selected to be a quarter of the wavelength of the RF signal to be measured. Portable antennas are most efficient when they are at quarter, half, or at full length of the wavelength involved.

Wavelength (in air) in centimeters can be calculated as 30,000/frequency in megahertz. For 300 MHz, you get 30,000/300 = 100 cm. The quarter wavelength is 25 cm. A simple formula quarter wavelength in centimeters is 7500 /frequency in megahertz.

The receiver has an antenna area. It is conceptually easier to consider this as the length of antenna and area of the ground plain under the antenna. In this case, I used an antenna length of 9.8″ = 25 cm. For simplicity I ignored the ground plane. I used the antenna area as its width multiplied by its length. And, 1 cm × 25 cm determines the antenna area value. In this case, you get 25 cm² (0.25 meters²).

Because I used a quarter wavelength of the RF generator used in calibration, the transmit antenna gain is estimated at 0.25.

The Friis formula is useful for modeling antenna gain, area, path length (r), and power levels. [4] This formula calculates probable proximity from the transmitter to receiver. If you know the transmitted power and receiver gain, you can estimate the approximate distance.

$$\text{Preceiver} = \text{Ptransmitter} \times \text{Gain} \left(\frac{\text{area}}{4\pi r}\right)^2 \quad [3]$$

Received power (in decibels with the AD8307) diminishes as a square root of the distance from the transmitter.

Because you can actually measure power at the RF meter, you can rearrange the Friis formula to solve for r:

$$r = \text{Gain} \times \frac{\text{wavelength}}{4\pi \times \sqrt{\dfrac{\text{Ptransmit}}{\text{Preceiver}}}} \quad [4]$$

Suppose the transmit power is 1 mW and the RF meter reads 1 V. According to Figure 7, –50 dBm is 0.00001 mW at the RF meter. Calculating for r tells you that the RF source is approximately 6.25 meters from the RF meter (line of site). Of course, this is an example; results may change given the broad band sensitivity of the RF meter results may change.

Unit	Definition
dBV	dB change relative to a volt
dBW	dB change relative to a watt
dBmv	dB change relative to a millivolt—common in CATV
dBm	dB change relative to a millwatt— common in RF
dBK	dB change relative to a kilowatt—common in broadcast
dBu	dB change relative to a microvolt—common in broadcast
dBc	dB change relative to carrier (voltage or power)

Table 2—*Log terms and notations are displayed here.*

To achieve this reading in free space, you would need prefect conditions. Any extra RF source would have to be less than –50 dBm. Also, you would assume you have no multi-path (reflections of the original source) signals to interfere with the reading.

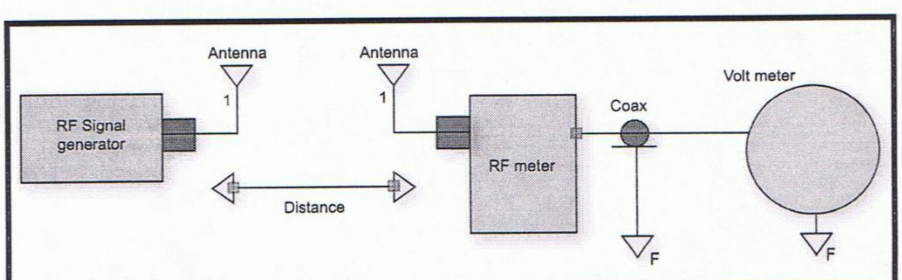


Figure 5—*To set up your test, follow this diagram.*

I found that measuring decent proximity is achievable if a 1-mW transmitter is no more than 30′ away and there are no metals objects at quarter wavelengths or longer than the wavelength of transmission frequency. For short-range applications such as RF tags, garage door openers, and wireless networks, the RF meter can determine path loss from the source.

The meter performs to theory when the source is constant and not modulated. Decibels greater than 1-mW readings appear to go down with amplitude shift keying (e.g., garage door openers).

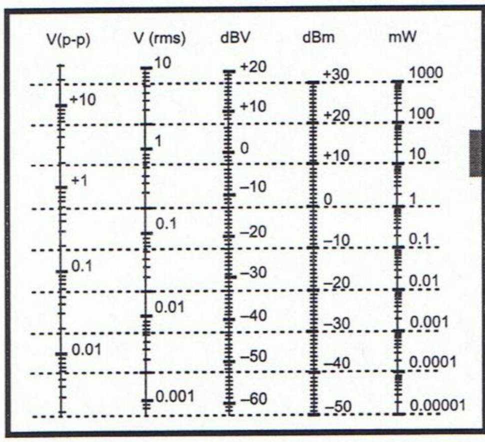


Figure 6—*Get your necessary information from the log scale look-up table.*

FINAL NOTES

I recommend you read more information to get the full picture. Antenna theory is not a trivial subject. I'll keep the topic open and perhaps write another article in the future.

A later article would include more details about antenna design and system modeling. Mathcad or Matlab would be ideal for such a model. An important question to answer is how modulation affects the reading from the RF meter.

Until then, have fun with the AD8307! ◼

Author's Note: I would like to thank Analog Devices for the use of the graphics from its datasheets.

SE Nickols biography. Two to three sentences about yourself including your education, current position, technical hobbies, and e-mail readers may use to reach you.

Log ratio	Wattage	dBm	Voltage from RF meter (–60 dBm pathloss)
0.00001	0.00000001 W	–50 dBm	1 V
0.0001	0.0000001 W	–40 dBm	1.25 V
0.001	0.000001 W	–30 dBm	1.5 V
0.01	0.00001 W	–20 dBm	1.75 V
0.1	0.0001 W	–10 dBm	2 V
1	0.001 W	0 dBM	2.25 V
10	0.01 W	10 dBm	2.5 V

Table 3—*Values for path loss/attenuation can be tabulated as shown.*

REFERENCES

[1] Analog Devices, AD8307 data sheet

[2] I. Hickman, "How strong is your field?" Electronics World, November 1998.

[3] R. Boylestad, "Introductory Circuit Analysis." Prentice Hall, Saddle River, New Jersey, August 1999.

[4] D. Rutledge, "The Electronics of Radio," Cambridge University Press, Cambridge, England, August 1999.

SOURCE

AD8307 Evaluation board
Analog Devices, Inc.
(800) 262-5643
(781) 329-4700
www.analog.com

RESOURCE

C. Scott, "How to cheat with dBs... an intuitive approach," www.scott-inc.com/html/dbtalk.htm, 1999.

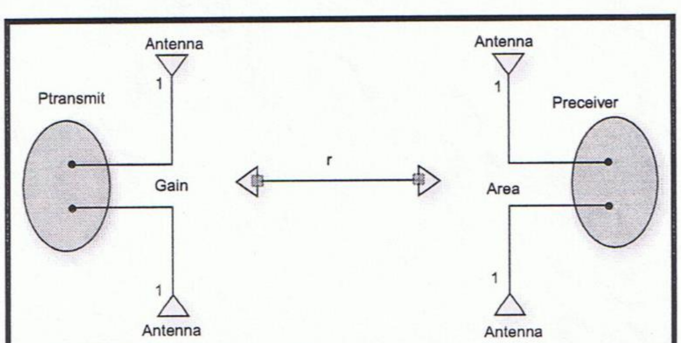


Figure 7—*This model demonstrates the transmitter and receiver system.*