

Review and Applications of the Mini-Circuits PWR-6GHS+ USB Power Sensor
(Plus info on the PWR-6G+ and PWR-8GHS+ USB Power Sensors)
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Photo A: The Mini-Circuits PWR-6GHS+ power sensor

Introduction

For much of my homebrew work I need to accurately measure RF power. I've been using a home-built diode detector, but this suffers in accuracy and range at lower power levels due to the schottky diode detector voltage drop. And I must constantly calculate the actual power from the detected voltage reading. Finally, the upper power level is limited by the diode reverse breakdown voltage rating, and the frequency response is limited by my construction techniques and components used. Available ham-type power meters don't satisfy my requirements either as most aren't precision instruments. The Bird 43 has an accuracy spec of $\pm 5\%$ of full scale, so unless your reading is full-scale, accuracy can be much worse. There are digital power meters with NIST-traceable calibration giving 3-5% accuracy over their full range (Array Solutions PowerMaster, TelePost LP-100A, and WaveNode WM-2 come to mind). However, these can be pretty pricey especially if you need multiple sensors to measure RF power at HF, VHF and UHF frequencies. And then, of course, you normally can't measure low power levels (less than 1-watt) accurately with these meters. This is a problem for me as I often need to measure the power of an oscillator, mixer output, and coupler levels as well as normal high power transceivers from HF through UHF. It appeared that my best solution might be to purchase something like a used HP436A power meter with HP8482A power sensor and cable on eBay. But then I'd wind up with a used set-up with questionable accuracy for \$500-\$1000 dollars. So what to do?

Enter the Mini-Circuits PWR-6GHS+

While doing a Google search on RF power sensors, I stumbled on the Mini-Circuits PWR-6GHS+. This is a USB-powered NIST-traceable calibrated RF power sensor that uses your computer for the display. It measures average CW signal power levels from -30 dBm to +20 dBm in the 1-MHz to 6-GHz frequency range. And while it may seem pricey at \$795, it is similar in cost to a used HP/Agilent HP-436A/8482A power meter/sensor. Further, you get a one year warranty, and the ability to have the PWR-6GHS+ re-cal'd for \$99 (Mini-Circuits recommends calibrating once/year to ensure NIST traceability accuracy).

The PWR-6GHS+ consists of a power sensor unit with a male N-connector, an N-to-SMA adapter, a USB interface cable, the installation software disc, and the user manual. It has the look and feel of a high quality piece of test equipment, and the specifications reflect this as well.

The basic specifications are as follows:

Frequency Range	1MHz-6GHz
Signal type	CW, continuous
Dynamic Range	50 dB, from -30 to +20 dBm
Absolute maximum input	+27dBm RF level, 15VDC
Power Reading Uncertainty	± 0.15 dB typical, ± 0.3 dB max
Linearity	± 0.10 dB typical
Display Resolution	0.01 dB
Measurement Speed:	100ms in Low Noise mode, 30ms in Faster mode
Supported Operating Systems	Windows/Linux 32 & 64- bit operating systems

PWR-6GHS+, PWR-6G+ and PWR-8GHS+ USB Power Sensors from Mini-Circuits

The PWR-6GHS+ is very accurate and will support most home and professional lab requirements for an accurate RF power meter. Additionally, two other versions of the USB power sensor are available: the PWR-6G+ and the PWR-8GHS+. The PWR-6G+ has a slightly slower sampling speed and is limited to Windows 32-bit operating systems (XP, Vista and Windows7) but is \$100 less expensive than the PWR-6GHS+ possibly making it more attractive for hobbyist applications. However if you think you'll upgrade to a 64-bit OS, you may wish to go with the PWR-6GHS+. And certainly if you need an 8-GHz power sensor, the PWR-8GHS+ is the way to go.

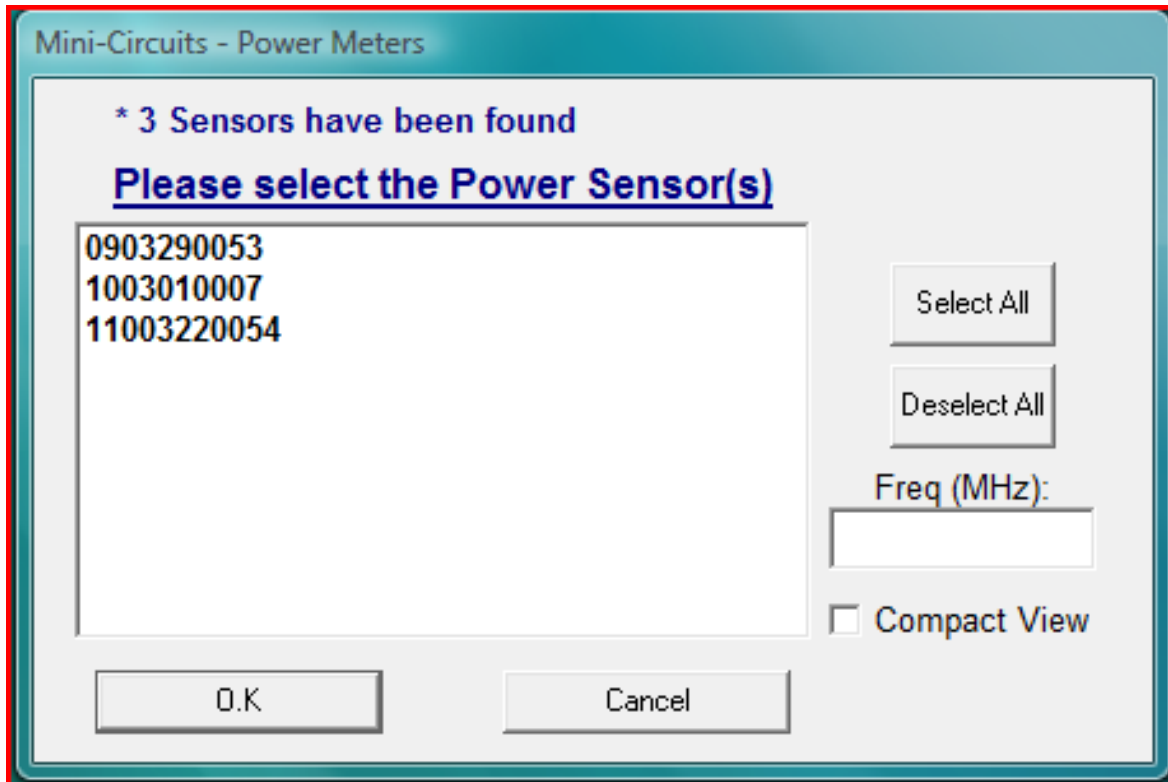
<u>Power Sensor</u>	<u>Frequency Range</u>	<u>Operating System</u>	<u>Measurement Speed</u>	<u>Price</u>
PWR-6G+	1-6000 MHz	Windows 32-bit	*300/100/60ms	\$695
PWR-6GHS+	1-6000 MHz	Windows/Linux 32/64-bit	**100/30ms	\$795
PWR-8GHS+	1-8000 MHz	Windows/Linux 32/64-bit	**100/30ms	\$TBA

*300ms, improves to 100ms with USB2 HUB in NORMAL mode, 60ms in Faster mode

**100ms in Low Noise mode, 30ms in Faster mode

Using the PWR-6GHS+

The same software load supports all three of the PWR-series power sensors, and the latest software version is available on the Mini-circuits website for easy download. Software installation is straightforward and just takes a few minutes. Besides reading and displaying RF power, the software also provides text file and Excel spreadsheet file outputs, max/min measurement limits, and time scheduled measurements with a Power Output vs Time graph. You can even add additional power sensors to other USB ports, and the software will read and record the data from all sensors simultaneously. When more than one sensor is detected, a dialog box opens up asking which sensors you want to monitor as shown below.



Multi-Sensor screen displaying sensor serial numbers detected. First sensor is a PWR-6G+. Second and third sensors are PWR-6GHS+.

For maximum accuracy, enter the desired measuring frequency in the measuring window screen display. The compensation is broad-band, so changing the frequency input is unnecessary unless you move more than 100 MHz. The PWR-6GHS+ also has an internal temperature sensor which compensates for temperature variations in order to keep the readings accurate. Now let's look at some applications of these power sensors.

Calibrating Attenuators

All three power sensors have a 50dB range from -30dBm to +20dBm. This means that you will require attenuators for any power measurements above +20dBm. Whether you purchase new attenuators or used attenuators, you want to ensure precision accuracy of these attenuators. After all, you have a very precise (NIST-traceable calibration) power sensor, so let's make sure our attenuators are precise as well.

All of the new and used attenuators I've looked at have very well-controlled return loss and attenuation across the bandwidth I need (1.8-450 MHz). However, the actual attenuation specifications are typically ± 0.3 to ± 0.5 dB about their nominal attenuation value. This sounds pretty good, but a ± 0.5 dB corresponds to about a 12% error, and ± 0.3 dB corresponds to about a 7% error. So if your transceiver puts out exactly 100-watts, you could measure as little as 89 watts or as much as 112 watts with a ± 0.5 dB attenuator specification. And if you cascade attenuators (probably the case), you will cascade the individual attenuator errors making the overall error much worse (or much better) than this. Because the Mini-Circuits USB power sensors have a typical measurement uncertainty of ± 0.1 dB from 1-3000 MHz, and ± 0.15 dB

across the full range, with a little care you can calibrate your attenuators so that your total uncertainty is no more than the $\pm 0.1\text{dB}$ of the Mini-Circuits USB power sensor.

In order to calibrate your attenuators, you need a good stable low level signal source. Obviously, you can use the output of any signal source you might have – as long as you ensure you won't exceed the maximum input to the power sensor. Most antenna analyzers have output levels that can be used. As examples, the typical output levels of the Array Solutions AIM4170C and VNA2180 are -18 dBm and $+7\text{ dBm}$ respectively, and $+10\text{dBm}$ for the RixExperts AA-200/230 and the MFJ-259B. As these are typical output levels, you should wait for the instrument to warm up so the actual levels are stable – after all we're going to be making measurements accurate to about $\pm 0.1\text{dB}!!$

If desired, you can build a low-level 50MHz signal source for attenuator calibration purposes. I chose 50 MHz as this gives a very good reference signal for calibrating attenuators in the 160-through 2-meter range (1.8-150 MHz). And you can build a very stable (power and frequency) 50 MHz signal source using an inexpensive 50MHz clock oscillator (less than \$2) and a few added components. Also, I am used to seeing this reference port on HP/Agilent power meters which is used in HP/Agilent power meters to calibrate their sensor heads – something that is completely unnecessary with the Mini-Circuits PWR-series of power sensors!

A 5V clock oscillator is perfect for this application, as the maximum output power will be less than $+20\text{dBm}$, the upper range on the PWR-series power sensors. Assuming the full 5V p-p power supply voltage swing and a sinusoidal output signal:

$$P = V_{\text{rms}}^2/R = (2.5/\sqrt{2})^2/50 = 0.063 \text{ watts} = +18\text{dBm}$$

Even if the output is a perfect square wave, the output power is $+21\text{dBm}$ with a full 5V p-p swing. This is above the $+20\text{dBm}$ spec'd measuring range of the PWR-series of power sensors, but still much less than the $+27\text{dBm}$ absolute maximum ratings of the sensors.

Because the output waveform of a clock oscillator is typically close to a square-wave, there is a very high 3rd harmonic content in the signal. A simple low pass filter at the oscillator output significantly improved this, resulting in 2nd and higher order harmonics greater than 30dB below the fundamental frequency as measured on my HAMMEG spectrum analyzer. As the final filtered output level was $+14\text{dBm}$, I added a 9dB attenuator to drop the output to $+5\text{dBm}$, keep a stable load on the oscillator, and provide a good 50 ohm source output. Standard leaded components were used, and all circuitry was built on a single-sided piece of pc board material (bottom side traces cut with a Dremel tool). Figure 1 shows the final schematic, with the necessary parts listed in Table 1. The L-brackets are used to support the pc board within the cast aluminum box.

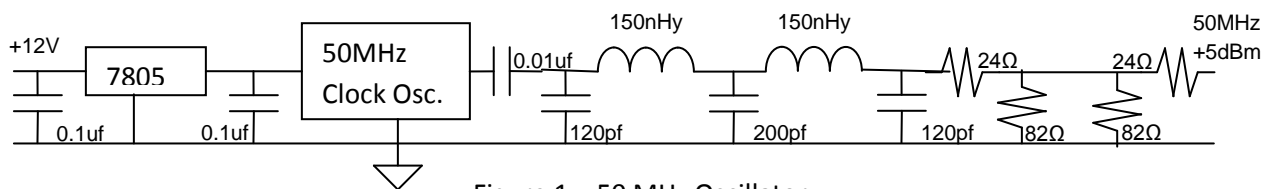


Figure 1 – 50 MHz Oscillator

Table 1: Parts List

<u>QTY</u>	<u>Description</u>	<u>Mouser Part Number</u>
2	0.1uf capacitor	581-SR211C104KAR
1	7805 regulator	511-L7805ACV
1	2.1mm DC jack	163-1060-EX
1	50MHz oscillator	520-TCF5000-X
1	0.01uf capacitor	581-SA101C103KAR
2	120pf capacitor	581-SR151A121JAR
1	200pf capacitor	81-RPE5C2A201J2P1Z03
2	150nHy inductor	542-9230-00-RC
2	24 Ω resistor	271-24-RC
2	82 Ω resistor	271-82-RC
1	Cast AL box	563-CU-5123
1	N-male chassis conn.	523-172118
3	#4 L-brackets	534-621
7	#4 screws & lockwashers	

The N-connector and DC jack holes are easily drilled in the cast aluminum box with a step drill. I drilled and tapped #4 screw holes for the RF connector, and I drilled #4 clearance holes for the L-brackets. I chose an N-male connector as most attenuators have N-female connectors on one or both ends. Obviously, you can use whatever connector you'd like. Photo B is an inside look at the completed oscillator, and Photo C shows the fully assembled view. Finally, Photo D shows the measured output of the completed 50 MHz source.



Photo B: Internal view of the 50 MHz reference oscillator. Pretty simple!

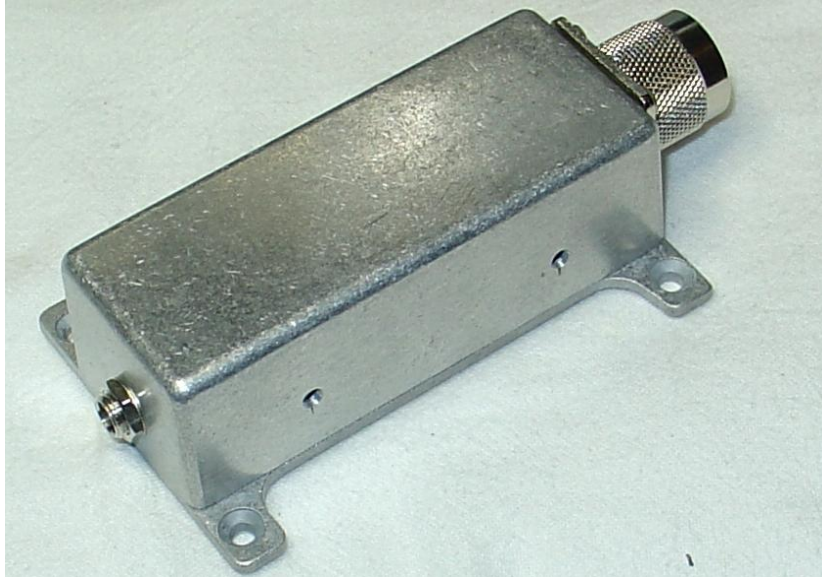


Photo C: The completed 50 MHz reference oscillator

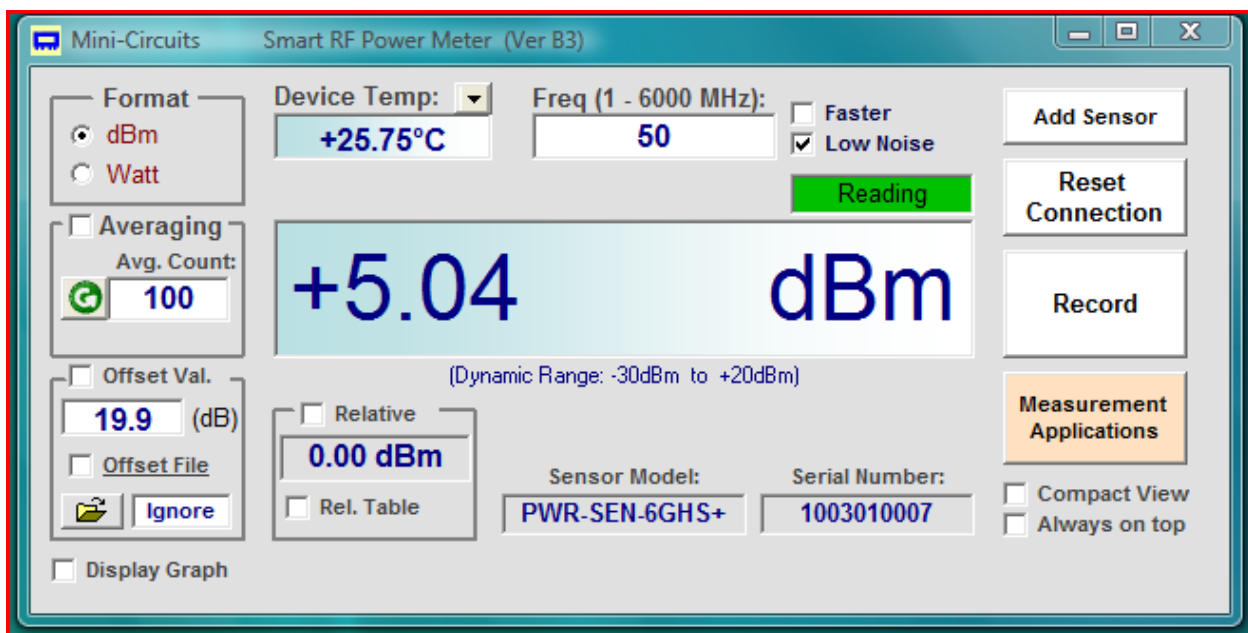


Photo D: Measured output of the 50 MHz source

Calibration Procedure

With +5dBm output, we have a 35dB range for measuring attenuators. The PWR-series of power sensors are most linear from -30dBm to +5dBm (± 0.1 dB) though linearity from +5dBm to +20-dBm isn't bad either (± 0.15 dB). I found that in most cases, I could find lower attenuation value attenuators that could handle higher power levels at very reasonable prices on eBay. So it makes sense to cascade lower attenuation/high power attenuators with appropriate lower power level attenuators. Therefore, the 35dB measuring range is plenty good. I use a 20dB 150-watt attenuator and a 20dB 2-watt attenuator for the majority of my applications as these are perfect for measuring the output power of my 50- and 100-watt transceivers (see Photo E). I also have a variety of 10dB, 6dB and 3dB attenuators for flexibility in measuring various power levels.

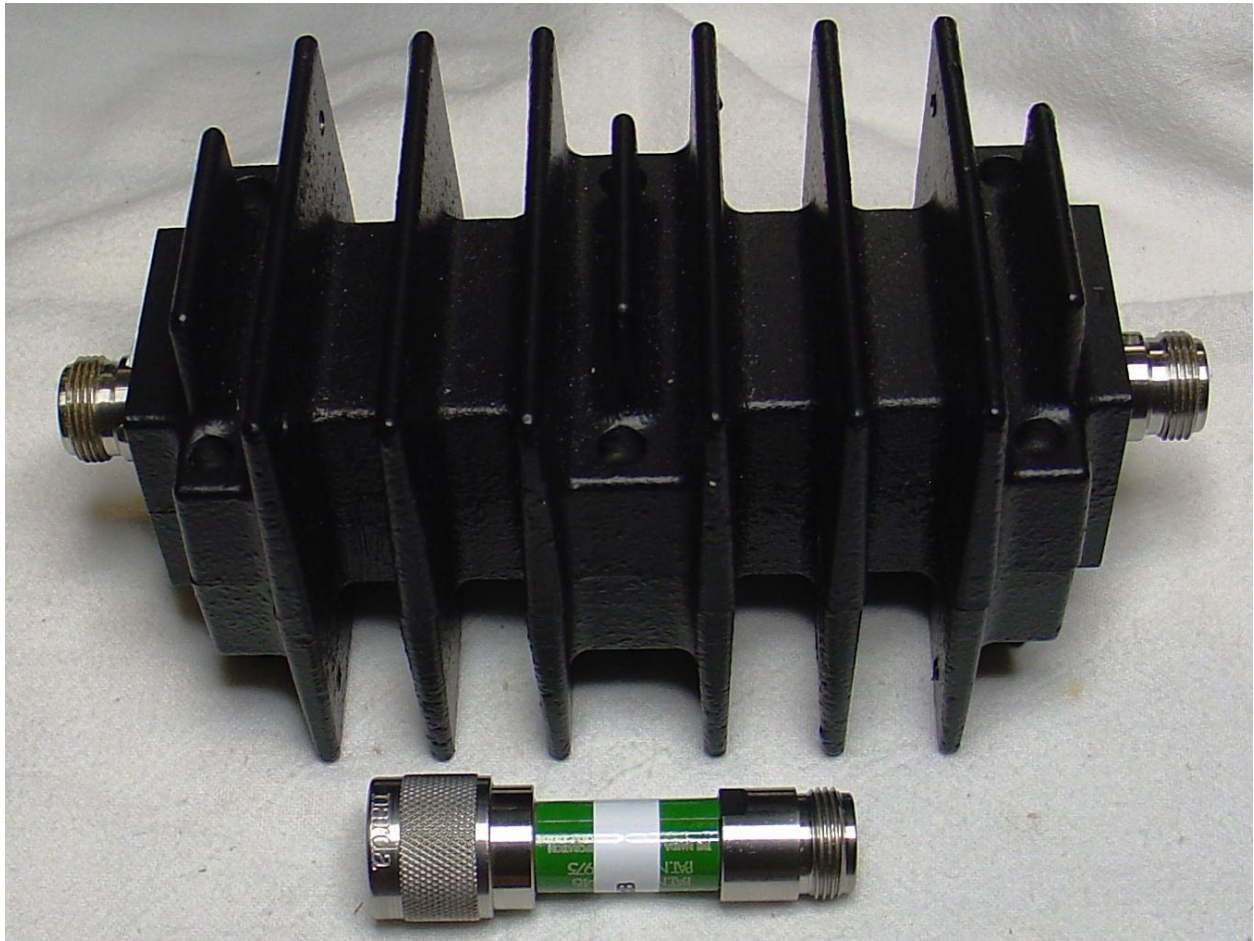


Photo E: 20dB 100-watt and 20dB 2-watt attenuators

Measuring the attenuators is a snap with the PWR-6GHS+. Because of the “Relative” measuring capability, the actual output power of the signal source is not important – only that the output level remains stable during the measurement. Just connect the PWR-6GHS+ directly to your low level frequency source and check the “Relative” and then “dB” boxes on the display. Now anything connected between the PWR-6GHS+ and the signal source will read out exactly in dB.

For this exercise, I used the 50 MHz source to calibrate my attenuators. As I am working on a 222 MHz coupler design, I also checked the attenuation with my RigExperts AA-230 antenna analyzer at 222 MHz and found no difference in the attenuation values measured at 50 MHz. This makes sense because these surplus attenuators are spec'd to at least 3GHz, so variation in attenuation between 50 MHz and 222 MHz should be unnoticeable. Photo F shows the reading after checking the “Relative” and “dB” boxes on the PWR-6GHS+ screen with the PWR-6GHS+ connected directly to the 50 MHz source. Photos G and H show the attenuator installed and actual measured attenuation, respectively, of my high power attenuator. And Photo I shows the measured attenuation of my 2-watt 20 dB attenuator.

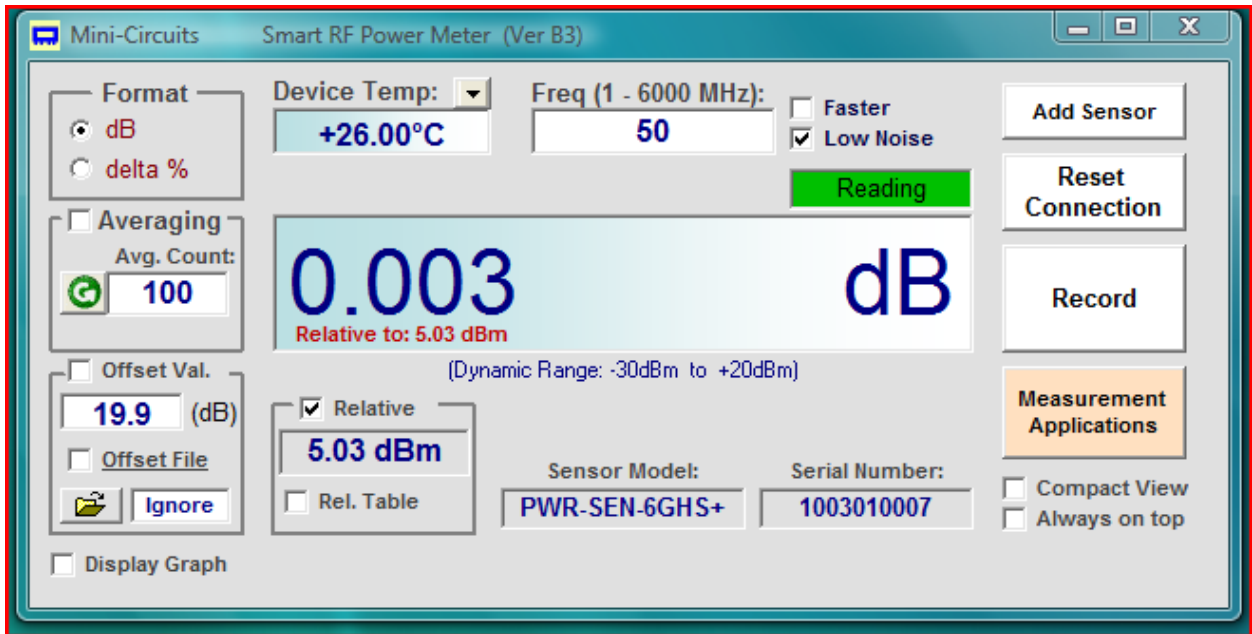


Photo F: Relative” and “dB” boxes checked with PWR-6GHS+ connected to 50 MHz source

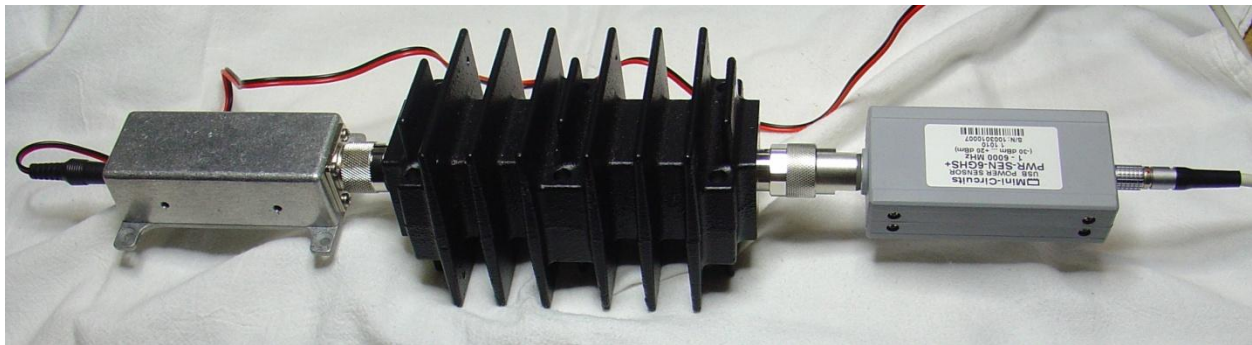


Photo G: Attenuator installed in measuring set-up

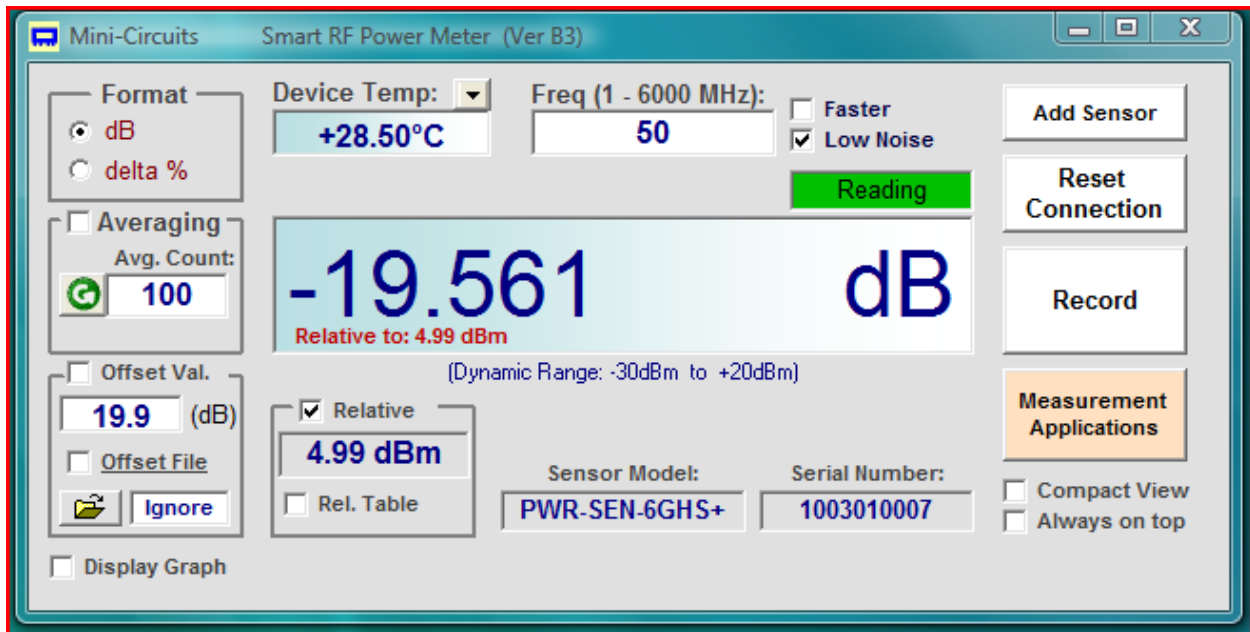


Photo H: Actual measured attenuation of 100-watt 20dB attenuator

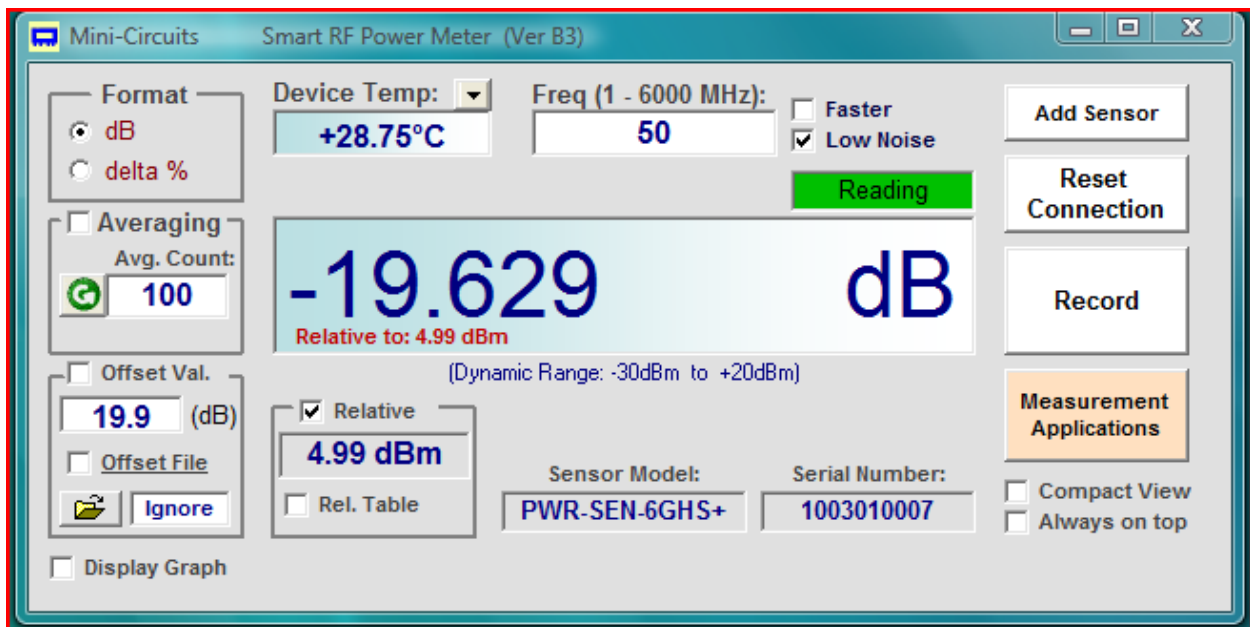


Photo I: Actual attenuation of the 20dB 2-watt attenuator

The last thing I did was to measure the loss of the coax cable and connectors that interface my Jetstream 220 MHz transceiver to the attenuators. This is a 5-foot section of LMR-240 with N-connectors on both ends. I measured 0.25 dB attenuation at 222 MHz using my RigExpert AA-230 and the PWR-6GHS+. This leaves a total attenuation from the transceiver of $0.25 + 19.56 + 19.63 \text{ dB} = 39.44 \text{ dB}$. Next I connected the transceiver to the calibrated set-up and measured the power output. I simply input the 39.44 dB total attenuation in the "Offset Value" box which permits reading the output of the transceiver directly in watts. As you can see in Photo J, the

measured value of 50.4 watts is pretty much right-on with the spec'd typical output power of 50 watts of the Jetstream transceiver.

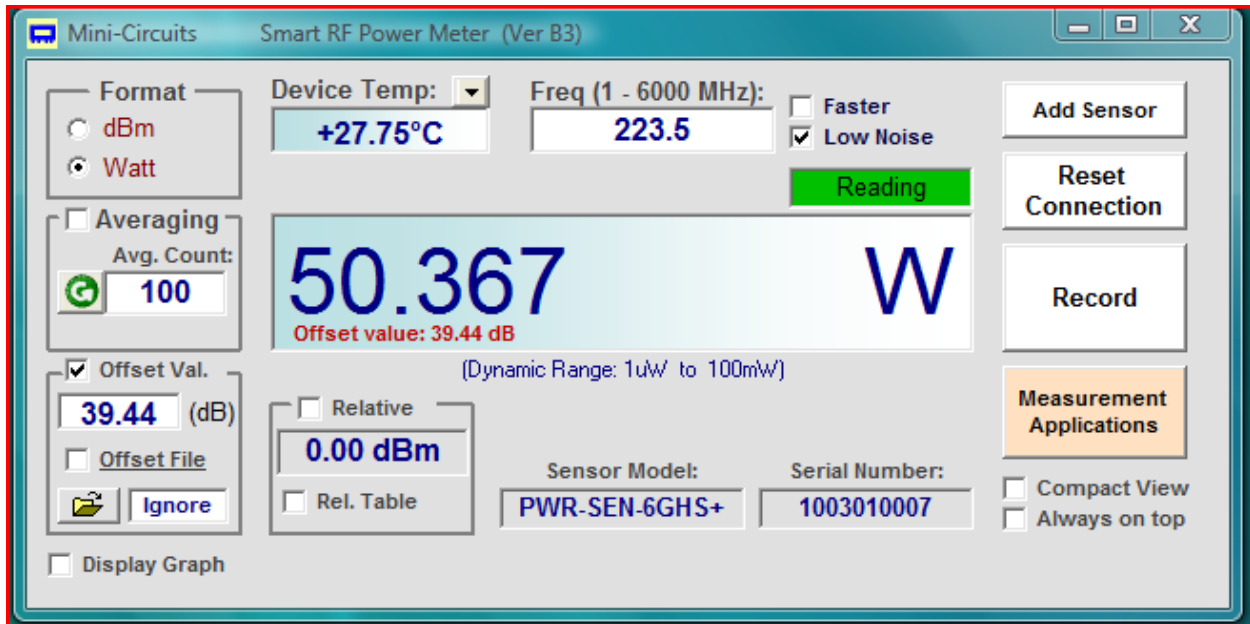


Photo J: Measured output power of Jetstream 222 MHz transceiver.

Measuring Return Loss

Many hobbyists have an antenna analyzer or vector network analyzer which permits accurate measurement capability of SWR or return loss up to about 170-200 MHz. However, measuring return loss above this frequency range normally means investing in much more expensive equipment. Of course, the reason you'd need to measure SWR/return loss above 2-meters is because you have a 220 MHz or 440 MHz radio - so you do have a signal source. With your transceiver as a signal source, you can easily measure return loss using a broadband directional coupler. For measuring return loss, you want a directional coupler with high directivity, as the directivity limits your return loss measurement ability. I found that the relatively inexpensive Mini-Circuits ZFDC-20-5N coupler is perfect for virtually all of my return loss measurement requirements, as this coupler has a typical directivity of greater than 30dB from 1.8-450 MHz.

The Mini-Circuits ZFDC-20-5N is spec'd for a maximum input power of about 2-watts, so size your attenuator to keep the total power below this amount. To measure return loss using a directional coupler, the Figure 2 test set-up is used.

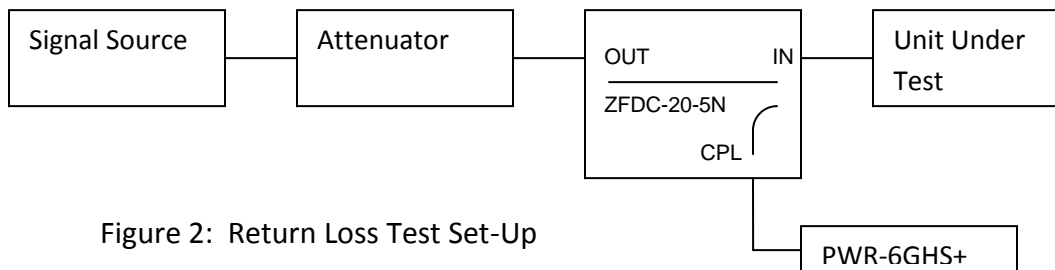


Figure 2: Return Loss Test Set-Up

You'll note that we're feeding the signal into the output port of the directional coupler. This is correct, as we want only the reflected signal from the unit under test to couple out to the PWR-6GHS+. I.e., the reflected signal becomes the input to the directional coupler, as we're measuring the "loss" of the "return" signal – Return Loss!

To measure return loss, begin by leaving the IN port of the coupler open. Now all power will be reflected and you can read this reflected power level with the PWR-6GHS+. As we're using a 20dB coupler, the reflected power will be about 20dB below the maximum power being transmitted. I.e., if your signal source is putting out 100 milliwatts after the attenuator (+20dBm), then the reflected power you should read is about 1-milliwatt (0dBm). This is your reference level, which is not really critical. Now check the "Relative" and "dB" boxes on the PWR-6GHS+ screen and connect your antenna or other device that you want to measure. You will now read return loss directly on the PWR-6GHS+. Pretty easy!

As an example, I wanted to see how well a 1/4-wave 147 MHz antenna might work at 445 MHz, where the antenna is close to 3/4-wavelength (actually it is a little short at 445 MHz). I measured a 1.5:1 SWR at 147 MHz using my RigExpert AA-230 antenna analyzer, which corresponds to a 14 dB return loss. Now while I don't have an antenna analyzer at 445 MHz., this is not a problem since I have the PWR-6GHS+ and a ZFDC-20-5N coupler. My actual test set-up is shown in Figure 3 below:

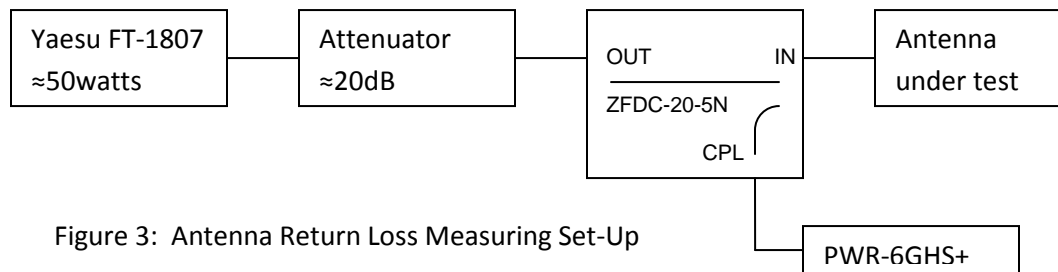


Figure 3: Antenna Return Loss Measuring Set-Up

The 20dB attenuator limits the signal level into the ZFDC-20-5N coupler to about 1/2-watt. First I left the IN port of the coupler open so that all power is reflected. The total reflected power coupled to the PWR-6GHS+ was +6.57 dBm as you can see in Photo K below. I didn't bother to precisely measure the attenuators, coupler coupling, transmitter output power and cable losses as I was only interested in relative readings that are necessary for the return loss measurement. However, the numbers make sense:

50 watts = +47dBm. Less 20dB attenuator = +27dBm. Less 20 dB coupling of the reflected signal = +7dBm. As you can see, this is very close to the actual measurement, and it is also well above the -30dBm threshold of the PWR-6GHZ+ so as to give us good return loss measurement range.

I checked the "Relative" and "dB" boxes on the PWR-6GHS+ display to set this as the reference reflected power level.

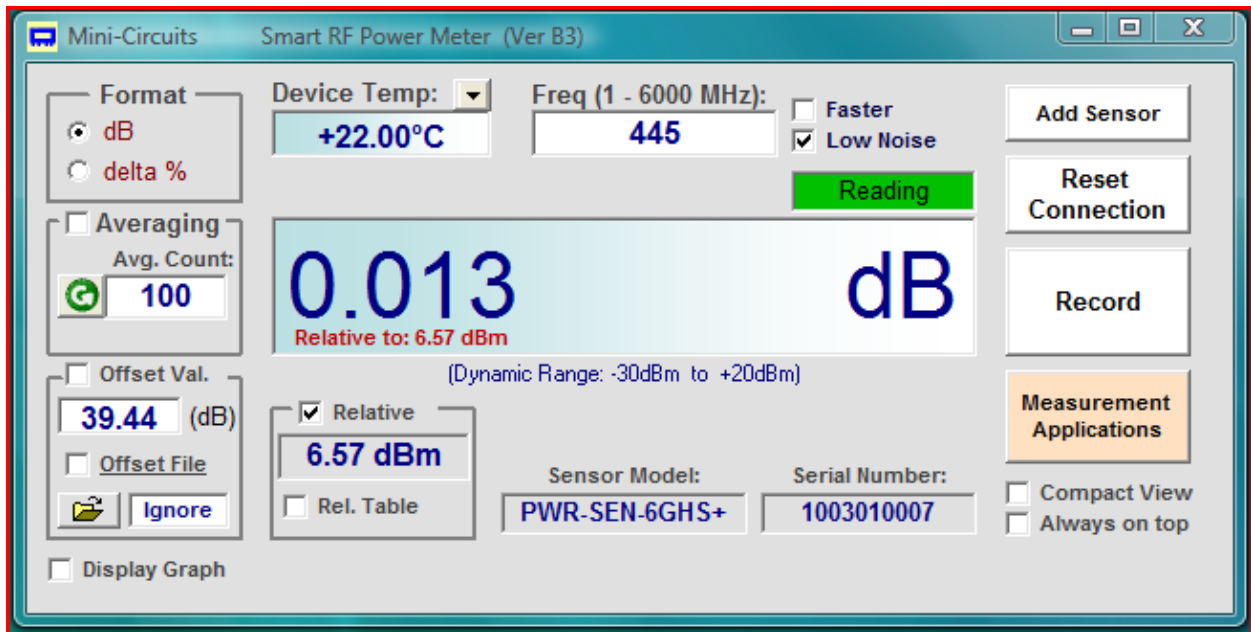


Photo K: Reference reflected power: Coupler IN port open-circuited (+6.57dBm actual power)

Next I connected a good 50 ohm termination to verify that the overall set-up is good enough to measure return loss. An excellent termination is the Mini-Circuits KARN-50+ which is only \$12 and has a return loss >40dB through 4 GHz. Photo L shows a measured return loss of 27 dB, which corresponds to an SWR of 1.09:1. This return loss is a function of the coupler directivity, the load return loss, and the coupler port return loss. The measured 27dB return loss is good enough for our purposes.

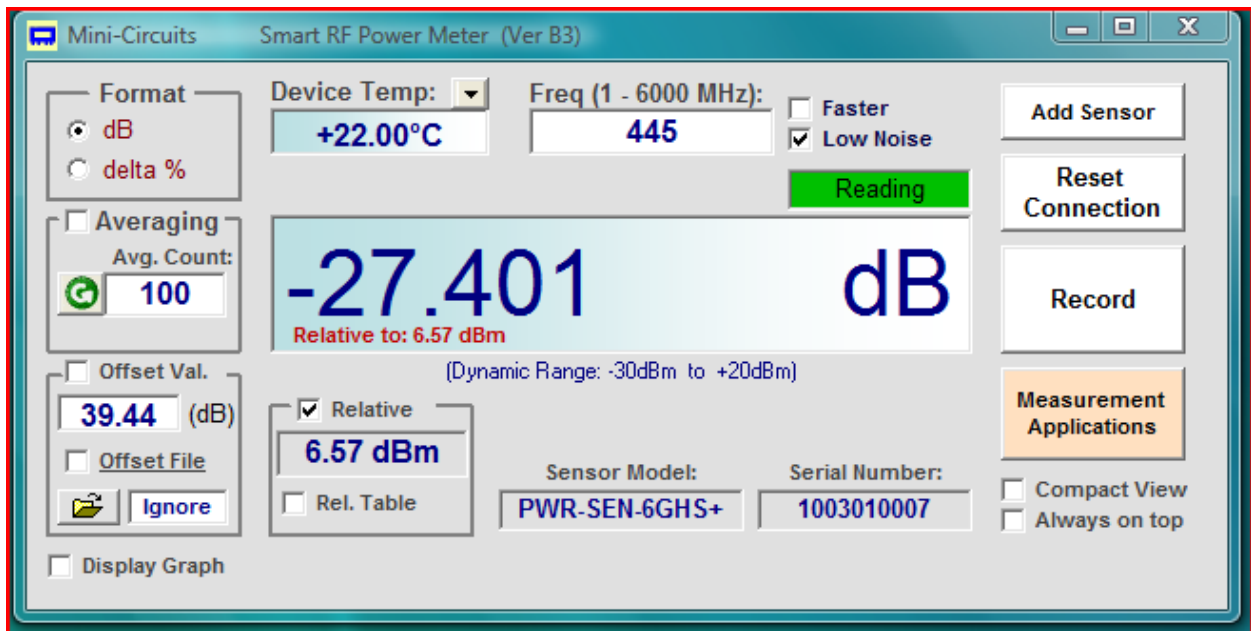


Photo L: Return loss of 50 ohm load connected to IN port of the coupler

Finally, I connected my antenna feed-line to the IN port of the coupler. As you can see in Photo M, the return loss of the 147 MHz antenna at 445 MHz is 6.6dB, or about a 2.8:1 SWR. This is not great, but it is within the load range of many UHF transceivers.

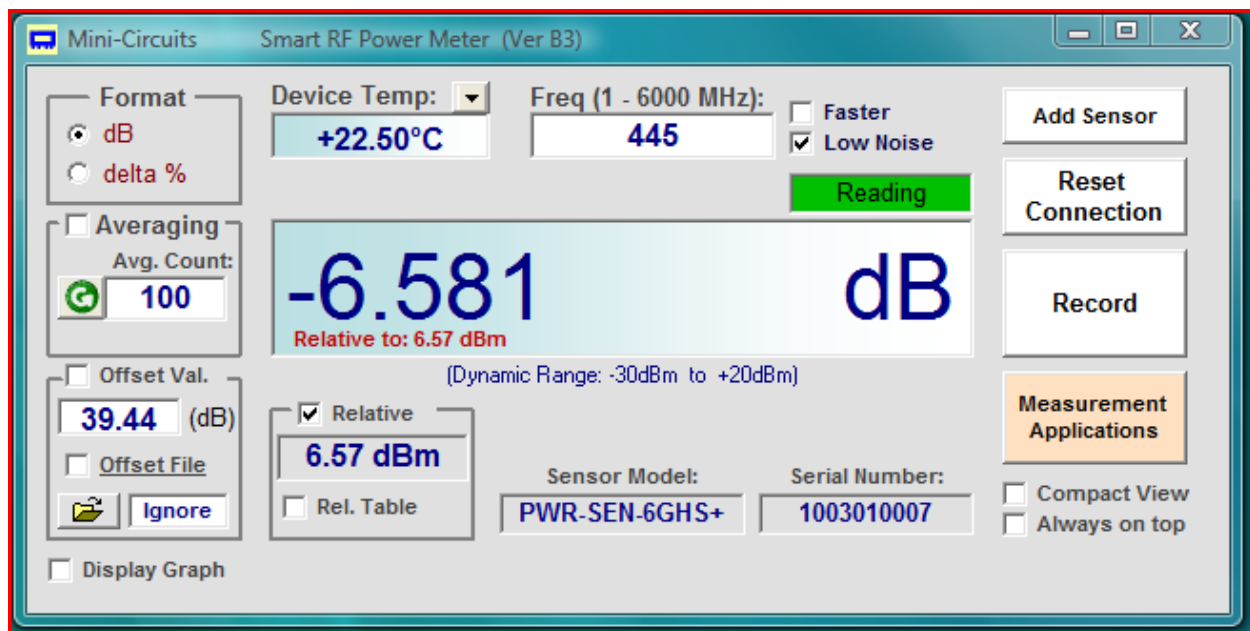


Photo M: Return loss of the 147 MHz antenna measured at 445 MHz

Final Thoughts

I've described some basic measurements that are easily accomplished with the Mini-Circuits PWR-6GHS+ USB power sensor. I'm sure other applications will come to mind as you work with this instrument. Obviously you can measure coupler directivity (OUT to CPL with IN terminated on the Mini-Circuits ZFDC-20-5N). And because of its wide and linear dynamic range, one could use the PWR-6GHS+ with a low level variable frequency source to measure filter performance (insertion loss, filter shape factor, in-band ripple, ultimate rejection, and filter return loss using a coupler). A very flexible instrument indeed!

Conclusion

The Mini-Circuits PWR-6G+/6GHS+/8GHS+ USB power sensors are reasonably priced, highly accurate, very broad-range power meters that are equally useful in a commercial lab or the home experimenter's set-up. And because your laptop takes care of all display information, no other external equipment is required other than the power sensor head – even if you need multiple sensors and data recording. For more information on these USB power sensors, you can view all documentation at www.minicircuits.com.