HF Receiver Performance Measurements
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Introduction

How often have you wished that you could measure your transceiver's sensitivity, or at least check the S-meter readings? It turns out that you probably already have the most critical piece of test equipment in your possession.

Equipment

Generally, you need a good signal generator covering your frequencies of interest, a high frequency oscilloscope to measure the signal level, and an accurate step attenuator for precisely adjusting the signal level. Since the signal levels will be very low, the oscilloscope is normally placed at the input of the attenuator, and you rely on the accuracy of the attenuator in order to set the level. Figure 1 shows a block diagram of a typical measuring scheme.

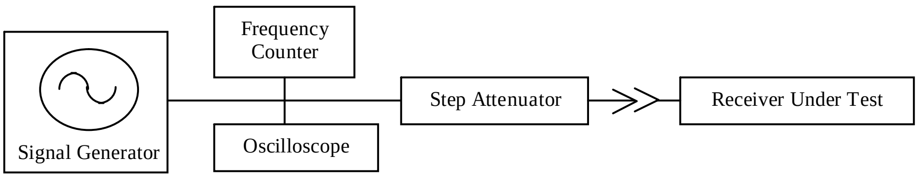


Figure 1 – Typical Receiver Measurement Setup

As you can see, this is a pretty expensive set-up that can easily cost more than the receiver or transceiver you want to measure!

Like many hams, I own an antenna analyzer. Mine is the MFJ-259B which covers from 1.8-170 MHz. In a moment of inspiration, I put my oscilloscope across the output of the MFJ-259B when it was terminated in a 50 ohm load and found that it put out 2-volts peak-to-peak across the 1.8-30 MHZ HF range. Since the bandwidth of my oscilloscope is 35 MHZ, I really couldn't accurately measure levels above 30 MHZ. So, I contacted MFJ and found out that they set the output level to 2-volts p-p, and there is an internal ALC (automatic level control) circuit inside the unit which keeps this voltage constant over the entire frequency range. From MFJ, I've verified that all of their antenna analyzers have this same 2-volts p-p ALC'd output level over their specified frequency range. If you have another vendor's antenna analyzer, you need to check with them and see what their output level and level control is like.

So what does this mean? First – it means that many of us already have a good, broadband signal generator with an internal frequency counter and a constant RF output level. And second - with a constant known output level, you really no longer need an oscilloscope!

The next item needed is a good step attenuator. A relatively inexpensive step attenuator is the MFJ-762, which has an 81-dB attenuation range, covered in 1-dB steps. This unit has an accuracy of better than 5%, and a VSWR of typically 1.1:1 from DC to 170 MHZ. But, there is a problem.

Generally you will want to inject a 50µV rms signal into a receiver, the generally accepted S9 signal level. Additionally, you want to insert lower level signal levels so as to check S-meter accuracy (is it really 6-dB/S-unit?), and check the minimum discernable signal level (MDS).

The 2V p-p signal from the MFJ-259B can first be converted to rms as follows:

$rms = 0.5V_{p\text{-}p}/2^{1/2} = 2^{-1/2} = 707$ millivolts rms

So to get a 50µV ($50x10^{-6}$ volts) signal, you need the following attenuation:

$Attenuation_{dB} = 20\log(.707/50x10^{-6}) = 83$ dB.

This is 2 dB MORE attenuation than the MFJ-762 is capable of. The simplest way to resolve this problem is to simply use two MFJ-762 attenuators in series. However, a less expensive alternative is to build your own fixed attenuators to drop the signal level into a reasonable range over which you can use a single MFJ-762 step attenuator. I first built a 52 dB attenuator, as this attenuation is high enough to get you into a reasonable measurement range with the MFJ-762, and this level of attenuation is easily achieved using standard leaded ¼-watt resistors if your measurements are limited to 160- through 6-meters. For receiver measurements above 6-meters, you should probably consider getting a second MFJ-762, as they are good to at least 170 mHz.

For Minimum Discernable Signal (MDS) level testing, you will need more attenuation. This is because the total attenuation available with the MFJ -762 and the 52 dB attenuator is about 20 dB shy of what is necessary to make an MDS measurement on most HF receivers. Therefore, I built a second attenuator which gives me an additional 30 dB of attenuation for this purpose. This is also a convenient value in that the sum of the two fixed attenuators is 82 dB, within 1-dB of the attenuation level necessary to give you a 50µV level for checking S9. The very simple schematics are shown in Figure 2, and the parts list is shown in Table 1. The 0.25-ohm resistor is made by paralleling four 1-ohm resistors.

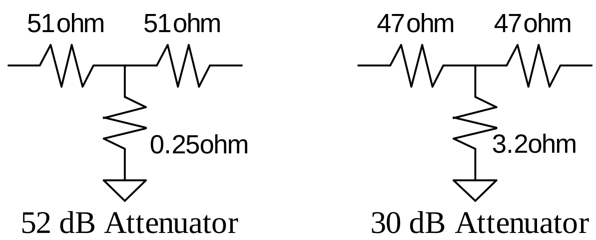


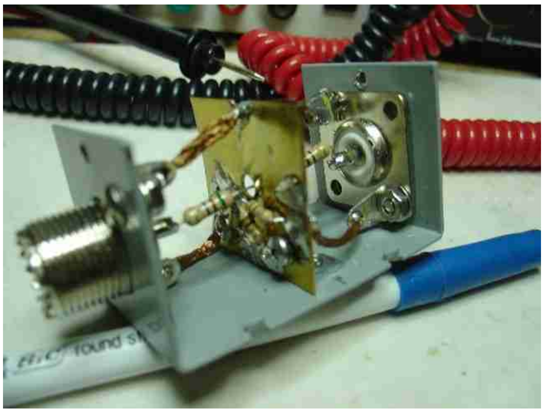
Figure 2 – Fixed Attenuators

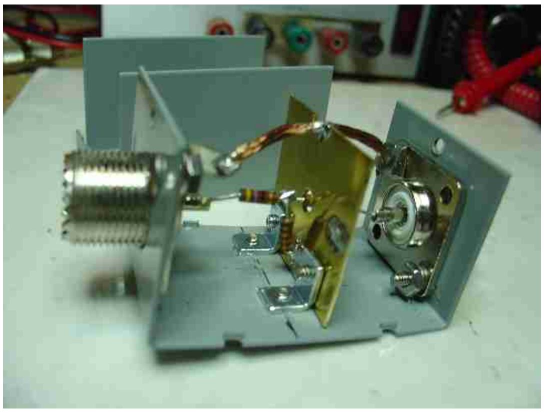
Table 1 - Attenuator Parts List (includes both 52 and 30 dB attenuator parts)

QTY	Description	Source	Price Ea
2	Small metal box	Mouser 537-M00-P	$3.63
4	1Ω ¼-watt resistor	Mouser 30BJ250-1.0	$0.22
2	51Ω ¼-watt resistor	Mouser 30BJ250-51	$0.22
1	3.2Ω ¼-watt resistor	Mouser 30BJ250-3.2	$0.22
2	47Ω ¼-watt resistor	Mouser 30BJ250-47	$0.22
4	Mounting bracket	Mouser 534-612	$0.23
4	SO-239 connector	Mouser 523-83-1R	$3.29

Miscl: #4 hardware, solder lugs, braid, brass plate

To minimize leakage across the attenuator, I included a small brass plate to isolate the input and output of the pads as can be seen in the photos. I purchased some brass sheet at my local ACE Hardware store and cut it to fit inside the aluminum box, mounting it in place with the mounting brackets called out in the parts list. Using standard 5%-tolerance components, your attenuators will be within 1-dB of the desired value assuming worst-case tolerance limits on the parts. Typically, you'll probably be within ½ dB.


52 dB attenuator


30 dB attenuator

So now, our receiver measuring setup looks like Figure 3. Assuming you have an antenna analyzer, your cost for this set-up shouldn't exceed about $100 (the cost of the step attenuator and the two home-brew fixed attenuators).

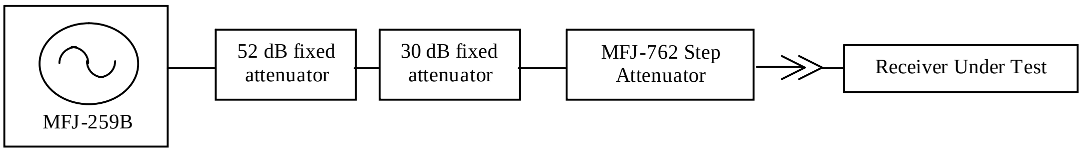


Figure 3 – Lower Cost Receiver Measurement Setup

Receiver Measurements

As discussed earlier, the two fixed attenuators will give you a 50µV signal when used with the MFJ-259B for checking the S9 S-meter reading (actually 1-dB less, but 1-dB will not be discernable on most S-meters). So to begin with, I decided to make some 20 meter measurements on my IC-703. Of course, the S-meter on the IC-703 is a relatively coarse bargraph indication. I put the 52 dB, 30 dB, and MFJ-762 attenuators in series with 0 dB selected on the MFJ-762. I'll have to admit, I was stunned when the IC-703 S-meter showed S9 – just what it should read!! The set-up and the IC-703 S-meter reading photos are shown below.

Measuring set-up

IC-703 S-meter reading with 82 dB in-line

Using the MFJ-762, I checked the S-meter readings at different setting as follows:

82 dB +	S-meter
0 dB	S9
6 dB	S8
12	S7
18	S5
20	S4
22	S0

As you can see, the S-meter tracks quite well to S7, and then gets progressively more non-linear below that. I also removed the 30 dB attenuator and looked at signals above S9. Again, the meter readings were surprisingly accurate. I measured S9+10 dB, S9+20 dB, and S9+30 dB for the corresponding levels. Again, this is looking at a fairly coarse bargraph reading.

Next I checked the preamp gain and attenuator loss in the IC-703. I checked the preamp gain by starting at the standard S-9 signal level (82 dB attenuation). Then I turned on the preamp and stepped the MFJ-762 until I was back at S9. This showed the preamp gain to be 10 dB. For the attenuator loss, I removed the 30 dB attenuator and put in 30 dB of attenuation with the MFJ-762 to again start at S9. Then I turned on the IG703 attenuator, and removed attenuation on the MFJ-762 until I was again at S9. Using this method, I found the IC-703 attenuator value to be 10 dB.

Finally, I wanted to check the MDS level of the receiver. First, I calculated the attenuation necessary to give me 0 dBm (1-milliwatt or 0.001 watt).

$P_{watts} = V^2/R$, so $V = (PxR)^{1/2} = (0.001x50)^{1/2} = 0.224Vrms$

Since the MFJ-259B puts out 0.707Vrms, the attenuation necessary to get 0.224Vrms is:

Attenuation = 20 log (0.707/0.224) = 10 dB for 0 dBm

According to the ARRL test report on the IC-703, the MDS was measured at -133 dBm. Therefore, the total attenuation necessary to reach this level is 143 dB when using the MFJ-259B (10 dB to get to 0 dBm, plus 133 dB to get to –133 dBm). However, when I put my attenuators in-line I couldn't drop the received signal below where I could hear it with my full 163 dB of attenuation! After playing around with this, I noticed that I could influence the tone level by moving my cables around, indicating that I was getting leakage from the cables. I then changed my interconnect cable from the MFJ -259B to the attenuators with a short piece of LMR-240 which is 100% shielded. Once I did this, I found that the signal disappeared with 145 dB of total attenuation, implying -135 dBm MDS. I was using the 250 hz filter in my IC-703 receiver during this testing. This is a very subjective measurement (based on my hearing), but I felt this was close enough to the ARRL measurements for my purposes. The point to be made here is that you must use well shielded cables at high level signal points within your measurement set -up.

Antenna Relative Gain Measurements

For making front-to-back and front-to-side ratio readings, you normally cannot trust your S-Meter readings due to the typical inaccuracy of most S-meters. However, you can make quite accurate readings using your step-attenuator.

First, make sure you can't transmit. Putting even a half-watt into your attenuator will probably destroy it! Now, while listening to a fixed level signal (such as a friend transmitting a CW signal), rotate your antenna to peak the S-meter on your receiver, and adjust your step attenuator for a convenient reading on your S-meter. I like to set the level to S9 if possible. Note the step attenuator setting.

Now, rotate your antenna so that the signal is off the side of your antenna, minimizing the S-meter reading. Now remove attenuation with your step attenuator. The difference between the two step attenuator readings is your front-to-side ration in dB. You can make front-to-back ratio readings exactly the same way. Finally, you can also compare the performance of different antennas using this method (such as comparing a vertical, wire antenna, yagi, etc).

Conclusion

Making many normal receiver measurements is not that difficult, however the test equipment necessary can be fairly expensive. This article has shown a simple and inexpensive way around this problem, by using a commonly already -owned antenna analyzer, an inexpensive step attenuator, and some home -built attenuators. Further, information on making relative antenna gain measurements has also been provided.