Bob's TechTalk #4
by Bob Eckweiler, AF6C

Decibels (Part IV of IV)

Attenuators:

Often, on one band or another, you'll hear: "Larry, you're two S-units stronger than Bob at this QTH." Or "Bob, you're lighting two more bars than Larry, here." Or perhaps, "Ken you're 40 over nine here, Bob's an S-7." While these sound like good signal comparisons, their accuracy leaves much to the imagination. Most receiver S-meters are notoriously inaccurate and their sensitivity varies tremendously from band to band. How can you give a good comparative report? It's simple if you have a reasonably accurate step attenuator. Reasonably accurate step attenuators are inexpensive and easy to build for the HF and VHF bands. They can also be purchased in all sizes and flavors from companies like MFJ and Hewlett Packard.

Probably, if your rig has a built-in attenuator, you've used it to reduce strong signals or help remove interfering QRM. The step attenuator differs from a built-in attenuator in that it has 4 to 8 or more switched attenuator sections, each of which can switch in a fixed attenuation. Steps are often binary, such as 1 dB, 2 dB, 4 dB, 8 dB, 16 dB, etc. On less expensive attenuators the largest step is usually 20 dB since attenuation larger than that requires extra careful shielding. Since attenuators are usually low power devices, it is best to use one only with a radio that has a separate receive antenna line. Transmitting through most attenuators will result in smoke!

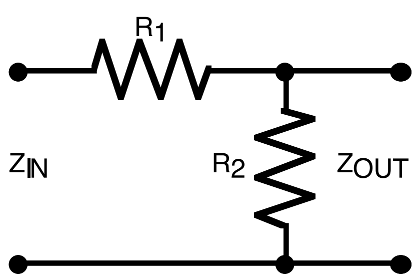
After you've installed an attenuator in the receiver antenna line, you can set all the switches to the out position and receive normally. To compare two signals, as in the first example above, wait until Larry is transmitting and then start switching in some attenuation until the s-meter reading is peaking at some convenient point; say S-6. Note the setting of the attenuator switches. Now, when Bob starts to transmit, remove (or add) attenuation until the S-meter again peaks to the same convenient point. Again note the attenuator setting. The difference between readings is an accurate report of the difference in signal strength of the two stations. The station requiring more attenuation is the stronger.

To read the attenuator, just add the dB reading of the sections switched in. For example, if Larry is an S-6 with the 16 dB and 4 dB sections switched in (20 dB total), and Bob is S-6 with the 8 dB, 2 dB and 1 dB sections switched in (11 dB total) then Larry is 9 dB stronger than Bob. If you have the chart handy from last month's ***Tech Talk***, you can report: "Larry's signal is nine dB stronger than Bob's. That's 2.8 times the voltage or eight times the power at this QTH!" When finished, be sure to switch all sections out or you'll think your receiver has gone hard-of-hearing!

If your rig has a bar-type S-meter you're at a slight disadvantage. However, with practice, the level can be adjusted so a given bar segment is just flickering at a reference point. Bar type S-meters are more rugged and cheaper than real meters, but that is where the advantage ends. The reason they are becoming so popular is the latter reason!

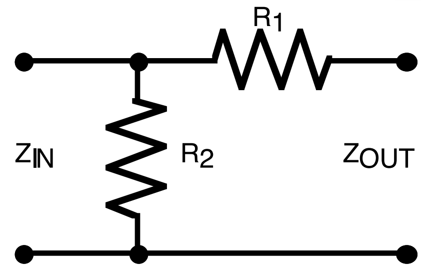
With an attenuator you can do a relative calibration of your S-meter. What you need is a steady signal source for each band. A signal generator or grid-dip meter will work. With a minimum of 3 dB set on the attenuator; adjust the signal source for full S-meter deflection. Now add attenuation until the S-meter drops to the next mark and note the change in attenuation. Continue for all desired calibration points. When you run out of attenuation, reset the attenuator back to 3 dB and readjust the signal source level until the S-meter is at the last calibrated point and continue. Always start with a minimum of at least 3 dB; the reason for this is explained later. If you are lucky to have access to a signal generator that has a calibrated output, you can even calibrate your S-meter directly in microvolts. In either case, you'll notice that the calibrations vary significantly from band to band and possibly even from one end of a band to the other.

Attenuators are commonly resistive devices that operate over a large frequency range and down to DC. They come in numerous types. Besides their attenuation value, other specifications are input and output impedance (attenuators with the same input and output impedance are called symmetrical), power capability, and balanced or unbalanced. Unbalanced attenuators are used with signals that have one side grounded (RF in coax for example). Balanced attenuators are used with balanced lines such as many audio lines and ladder-line. Figure one shows four common types of unbalanced attenuator circuits. Circuits 1a and 1b are commonly used to match two different impedances over a wide frequency range. They are often called "minimum loss pads". For any given impedance change this attenuator gives the minimum loss that can be achieved with resistive matching. Note that the circuits are bidirectional.

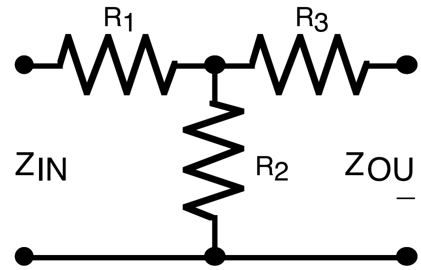


a) Unbalanced "Pad" Attenuator
$Z_{IN} > Z_{OUT}$

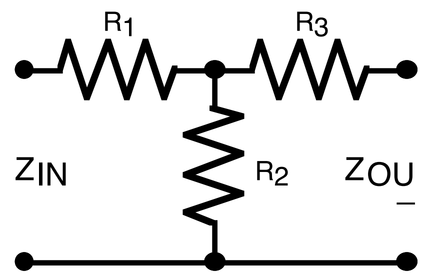
Figure 1: Unbalanced Attenuator Circuits



b) Unbalanced "Pad" Attenuator
$Z_{IN} < Z_{OUT}$



c) Unbalanced "Tee" Attenuator
$Z_{IN} <=> Z_{OUT}$
$R_1 = R_3$ for $Z_{IN} = Z_{OUT}$



c) Unbalanced "Tee" Attenuator
$Z_{IN} <=> Z_{OUT}$
$R_1 = R_3$ for $Z_{IN} = Z_{OUT}$

Figure 1: Unbalanced Attenuator Circuits Continued

The first circuit increases the impedance and the second lowers it. Circuit 1c, called the "tee", and circuit 1d, called the "pi", allow you to select the input and output impedance and attenuation independently. Often, as in the case of the step attenuator discussed earlier, the input and output impedances are symmetrical, commonly 50 or 75 ohms. The "tee" and "pi "circuits can be used interchangeably. The circuit using the most standard value of resistors is usually selected.

Figure two shows five common balanced attenuator circuits. Circuits 2a through 2d correspond to their unbalanced cousins. The series resistors are just divided equally between legs. Circuit 2e is a favorite in audio circuits; it's called the symmetrical lattice attenuator. The values for R1 and R2 can be interchanged without affecting the attenuation on this circuit only.

Calculating resistor values for attenuators is beyond the scope of this series. There are numerous books that have programs for handheld calculators and computers for calculating the resistor values for given parameters. See the side bar on nepers. Table one shows some common 50 and 75-ohm attenuator resistor values.

What is the input and output impedance of an attenuator? Since attenuators commonly work to DC you can use an ohmmeter to check them. The input impedance is just the impedance (resistance at DC) that you measure looking into the input when the output is terminated at its impedance. For a 50-ohm attenuator connect a 50-ohm resistor across the output and measure the resistance of the input. It should read close to 50 ohms too. The output impedance is just the reverse; terminate the input with its specified impedance and measure across the output terminals.

Another feature of an attenuator is that it corrects circuit impedance errors. A small attenuator, or "pad", is often used between a signal generator and circuit under test. This helps insure that the signal generator is seeing the impedance it's designed to work into. Thus it's a good idea to have a minimum of 3 dB of attenuation on when making measurements with your attenuator. That assures that the antenna looks close to 50 ohms to the receiver and that the receiver input looks close to 50 ohms to the transmission line.

If you decide to build your own attenuator here are some suggestions that will help make it a top notch unit up into the VHF region. First, attenuator sections should be shielded from each other. Printed circuit board or brass stock (available at hobby and hardware stores) can be used for shielding. Second, use the proper type switch. Cheap slide switches actually work very well due to their wiping action. If you use miniature toggle switches, use the ones that are designed for "dry switching". These usually have gold contacts and don't rely on a bit of current to keep the contacts clean. Third, keep sections that have large attenuation separated when possible. If you have two 20 dB sections, don't put them directly next to each other; put a lower value attenuator section between them to reduce unwanted coupling. Finally, keep the sections at or below 20 dB; above that leakage will limit the section's accuracy.

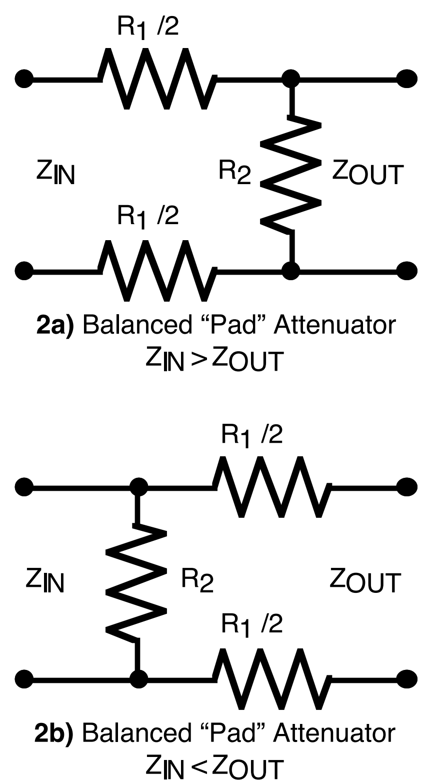
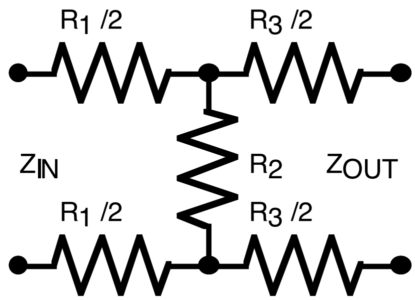


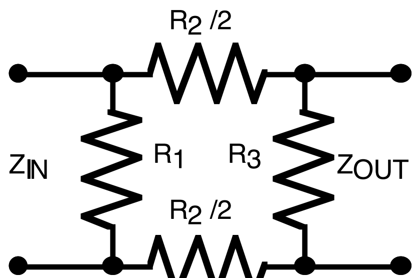
Figure 2:
Balanced Attenuator Circuits



2c) Balanced "H" Attenuator

$Z_{IN} <=> Z_{OUT}$

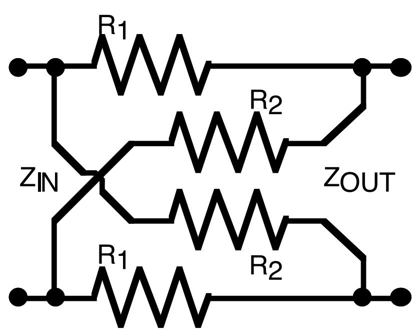
$R_1 = R_3$ for $Z_{IN} = Z_{OUT}$



2d) Balanced "O" Attenuator

$Z_{IN} <=> Z_{OUT}$

$R_1 = R_3$ for $Z_{IN} = Z_{OUT}$



2e) Balanced Symmetrical Lattice Attenuator

$Z_{IN} = Z_{OUT}$

Values of R_1 and R_2 may be interchanged

Figure 2 continued: Balanced Attenuator Circuits

Here are some references on attenuators where you can get more information, construction ideas, etc.:

Jules Gilder, *Basic Computer Programs in Science and Engineering*, Hayden Book Company, 1980, Chapter 12 "Attenuator Pads"

Pete Ostapchuk, N9SFX, *A Rugged, Compact Attenuator*, QST - May 1998, pp. 41-43, (See errata)

Reference Data for Radio Engineers - fourth edition, IT&T Corp., 1956

The 1989 ARRL Handbook, "Low Power Step Attenuators", pp. 25-36 to 25-38

50 Ohm "PI" and "O" Symmetrical Attenuators

Atten. dB	R1 & R3 Ohms	R2 Ohms
1.0	869.7	5.77
2.0	436.3	11.6
3.0	292.5	17.6
4.0	221.0	23.8
6.0	150.5	37.3
8.0	116.1	52.8
10.0	96.2	71.1
16.0	68.8	153.7
20.0	61.1	247.3

50 Ohm "Tee" and "H" Symmetrical Attenuators

Atten. dB	R1 & R3 Ohms	R2 Ohms
1.0	2.87	433.4
2.0	5.73	215.3
3.0	8.55	142.0
4.0	11.3	104.9
6.0	16.6	67.0
8.0	21.5	47.3
10.0	26.0	35.1
16.0	36.3	16.3
20.0	40.9	10.1

Table 1... Typical Attenuator Resistor Values

600 Ohm Balanced Symmetrical Lattice Attenuators

Atten. dB	R1 Ohms	R2 Ohms
3.0	3508.8	102.6
6.0	1805.7	199.4
10.0	1155.0	311.7
12.0	1002.5	359.1
20.0	733.3	490.9

Minimum Loss Pads (Reversible)

Atten. dB	Zin	Zout	R1 Ohms	R2 Ohms
5.72	75	50	43.3	86.6
13.42	300	50	273.9	54.8
11.44	300	75	259.8	86.6
7.66	600	300	424.3	424.3
14.77	600	75	561.2	80.2
16.63	600	50	574.5	52.2

Table 1 continued...
Typical Attenuator Resistor Values

Nepers:

If you decide to calculate attenuator resistor values you will likely come across the term nepers. The neper is similar to the decibel, except it is based on the natural logarithm ($\log_e$):

$$\text{Nepers} = (1/2) * \log_e (P2 / P1)$$

$$\text{dB} = [20 / \log_e(10)] * \text{Nepers} = 8.686 * \text{Nepers}$$

$$\text{Nepers} = [\log_e (10) / 20] * \text{dB} = 0.1151 * \text{dB}$$

73, from AF6C

This article is based on the TechTalk article that originally appeared in the April 2001 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.