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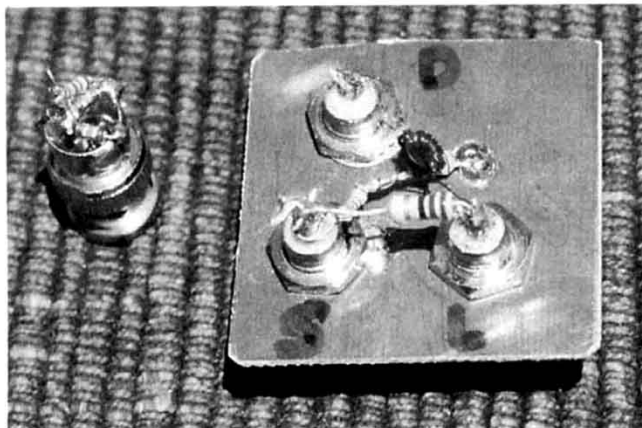
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By Jim Ford, N6JF

# Build a Return Loss Bridge



Used with your DVM, this simple bridge, diode detector and return loss techniques can help you measure cable loss and SWR at the antenna. The bridge does double duty as a hybrid combiner.

The author's homebrew return loss bridge (right) and peak-reading diode detector built on the back of a male BNC connector (left). The measured bridge directivity is: 2 MHz 24 dB, 4 MHz 26 dB, 10 MHz 28.5 dB, 30 and 50 MHz 30 dB, 146 MHz 34.5 dB.

**R**eturn loss (RL) may be a new concept to many radio amateurs. To the uninitiated it may even sound like something bad! It may surprise you, but in this case, *more loss is better*. Return loss is the decibel portion of the input power that is taken by the load; greater return loss means less reflected power and lesser SWR. In fact, when the SWR is 1:1 the return loss is infinite!

I've often thought it unfortunate that most amateurs are not familiar with return loss measurements. For some applications, return loss is easier and more useful than SWR

measurements. Let's look at a couple of examples. Suppose you know your coax loss and SWR at your transmitter, but want to know the SWR at your antenna feed point. Factoring transmission-line loss into the SWR equations is difficult, but the problem becomes a piece of cake when you use return-loss measurements. Here's the recipe:

$$RL_{Ant} = RL_{TX} - 2 L_{Coax} \quad (\text{Eq 1})$$

Where  $RL_{Ant}$  and  $RL_{TX}$  are the return losses at the antenna and transmitter, respectively, and  $L_{Coax}$  is the coax loss. All three quantities must be in decibels. You may wonder why we double the coax loss in this calculation. The reason is that the power returned by the mismatch travels through the feed line twice—once as forward power, and then again as reflected power.

Let's now consider some real numbers. Suppose the SWR measured at the transmitter is 2:1 and the coax loss is 1.75 dB. The first step of course requires us to convert SWR to return loss. We can translate between several measures of load match by reading a table (see Table 1) or applying math equations.<sup>1</sup> Table 1 shows that a 2:1 SWR equals a return loss of 9.5 dB. Plugging in the numbers, we get:

$$9.5 \text{ dB} - (2 \times 1.75) = 6 \text{ dB} \quad (\text{Eq 2})$$

The 6 dB return loss converts to a 3:1 SWR at the antenna feed point.

As you might guess, we can reverse this procedure. Suppose you want to know the SWR at your transmitter if your antenna SWR is 1.5 and coax loss is 1 dB. From Table 1, we see that a 1.5:1 SWR corresponds

to a return loss of 14 dB. This time, the calculation looks like this:

$$14 \text{ dB} + (2 \times 1) = 16 \text{ dB}$$

The SWR at the transmitter is about 1.35:1.

## A Return Loss Bridge

By now you may be wondering if it is possible to measure return loss directly. The answer is yes! You can do so with a *return loss bridge* (RLB), which some data sheets call hybrid junctions or hybrid combiners. Figures 1 and 2 show an example RLB. This basic schematic is from Wes Hayward's (W7ZOI) fine book, *Introduction to Radio Frequency Design* (ARRL Order No. 4920; see Note 1 for ordering information).

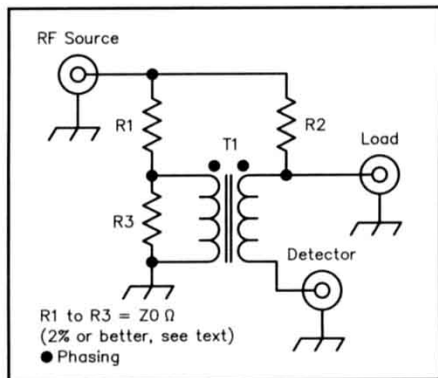


Figure 1—Return loss bridge schematic. T1 is 10 turns bifilar wound #30 AWG enameled wire on an FT-23-77 core. For best accuracy, use 1% tolerance resistors. Use either carbon-composition or metal-film resistors, but keep all leads as short as possible to preserve the useful circuit bandwidth. The cores are available from Amidon.<sup>2</sup>

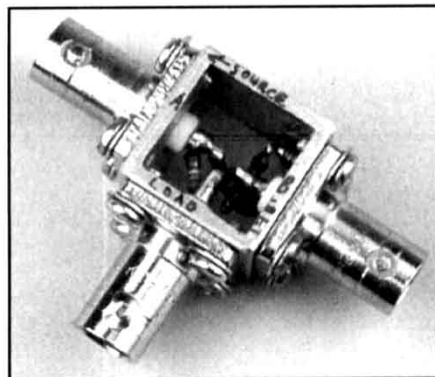


Figure 2—An RLB constructed by ARRL Lab Engineer Zack Lau, W1VT. Zack's construction minimizes lead lengths for maximum bandwidth.

<sup>1</sup>Notes appear on page 36.

## Advantages

Return loss bridges offer some advantages over a standard SWR meter. For example, an RLB can measure the mismatch at the input of a receiver or other low-power device without needing 100 W of input power. In fact, 10 mW or so, sometimes less, will do the job (depending on your detector). A signal generator will suffice for most purposes.

The return loss bridge output is RF, compatible with instruments such as spectrum analyzers or log detectors. The amplitude display of a spectrum analyzer, for example, displays dBm (dB relative to 1 mW), and the scale is therefore in decibels. The output of an RLB can therefore be viewed directly on a spectrum analyzer's log (dB) scale.

A return loss bridge can measure coax loss directly, in decibels, much more simply than the standard method (two measurements with power meter and dummy load). The coax must be either unterminated or shorted for this measurement. Figure 3 shows the setup; just connect the coax to the load port of the RLB. The actual coax loss is the return loss divided by two.

A return loss bridge is typically useful over a surprisingly wide spectrum. An RLB and a sweep generator can measure mismatch over a wide frequency range. For example, the commercially made Anzac H9 is rated for use from 2 to 2000 MHz. Such remarkable frequency coverage costs more than \$500, and the Anzac is undoubtedly more complex than the RLB shown here.

An RLB is less frequency sensitive than a reflectometer SWR meter. Reflectometers use short, coupled transmission lines to sample  $E_f$  and  $E_r$ , unlike modern, transformer-based directional couplers. The coupling of the short lines increases greatly with frequency, so the instrument sensitivity increases, too. If you have such a meter, you may have noticed that it takes the full calibration-pot (usually labeled **CAL** or **SET**) range to get a full-scale reading on 80 meters, while the same power level and setting easily pegs the meter on 20 meters. In fact, I once had a problem with a QRP transmitter that had (unknown to me) excessive harmonic output. The harmonic energy effectively filled in the SWR meter null because of the instrument's increased sensi-

tivity at the harmonic frequencies. This prevented me from seeing the match at the fundamental frequency.

Return loss bridges can also function as signal combiners. In fact, you may have noticed that the circuit for "A Hybrid Combiner for Signal Generators" in Chapter 26 of *The ARRL Handbook* is identical to an RLB! Combiners can mix two signals into one, while simultaneously isolating the two signal sources. This isolation prevents the generators from interacting and provides a two-tone test signal that is free of intermodulation and other distortion.

The ARRL Laboratory uses combiners with a pair of signal generators for receiver dynamic-range tests. You can perform such tests at home with an RLB. To obtain a two-tone signal, connect signal generator A to the **SOURCE** jack and signal generator B to the **DETECTOR** jack. The two-tone output appears at the **LOAD** jack. Chapter 26 of *The ARRL Handbook* describes the complete procedure under "Receiver Performance Tests."

## Disadvantages

Probably the biggest disadvantage of this return loss bridge is that you cannot leave it in the transmission line during normal station operation. There is no straight through path from source to load as most directional couplers for SWR meters. In fact, the RLB has a 6 dB loss from the source to the load. The RLB resistors must dissipate 75% of your transmitter power. For 100 W operation the resistors would be too large for a practical RLB, and losing 75% of your transmitter's output power to a return loss bridge is simply not acceptable to most amateurs.

An RLB has only one output port (**DETECTOR**). Most directional couplers have separate forward and reverse outputs, so they can simultaneously measure both forward and reverse power.

## Theory and Operation

For a 50  $\Omega$  ( $Z_0 = 50 \Omega$ ) system all three resistors should also be 50  $\Omega$ . When the **LOAD** port connects to 50  $\Omega$ , the voltages at the **LOAD** port and the R1-R2 junction are equal, resulting in no RF output. In other words the bridge is balanced. T1 serves as a balun; it allows unbalanced measurement of the RF output.

When the **LOAD** port is either open or short circuited, the voltage output from the bridge is maximum. This maximum output is the reference point (0 dB RL) against which we measure the return loss when an antenna, etc is the load. For example, if an open-circuit voltage of 1 (E1) drops to 0.1 V (E2) with the load connected, the reflection coefficient,  $\rho$ , is (E2/E1) 0.1, return loss is 20 dB and SWR is 1.22:1 (from Table 1).

The output from the **DETECTOR** port is RF. How do you measure RF of this small power level? There are several solutions. You can use an oscilloscope to measure the peak voltage.<sup>3</sup> Even if you don't have the latest oscilloscope, yours may be adequate. Only the level *change* from open to loaded circuit concerns you; absolute accuracy is not necessary. If you can get near-full-scale deflection on any range, it should work okay. So, even a 50 MHz 'scope should work just fine—even at 2 meters.

An RF micropower meter would also work. Some surplus power meters—such as an HP431 or HP432—are available at reasonable prices, but beware! Often their RF sensor cable is missing or the power head is defective—having been destroyed by an overload (10 mW, maximum, for some models). If you are measuring power, don't forget to find the RL by using the proper column of Table 1.

You can also measure return loss with a diode detector, as shown in Figure 4. The detector and a DVM measure the peak RF voltage. The forward voltage is that with the **LOAD** port open; the reflected voltage is that with the load attached. Diode detectors are not very linear at low power levels, but that is not important if a measured calibration curve relates the dc output voltage to the RF power input. This detector has more than enough accuracy for use with a return loss bridge. This article's lead photo shows that small parts permit us to build the detector *inside* a UHF or BNC connector. It's possible to calibrate a diode detector for good accuracy, but you don't need extreme accuracy to measure power *ratios*.<sup>4</sup> You can use the data in Figure 4 for yours and avoid the calibration. Beware! Keep lead lengths as short as possible to preserve detector bandwidth. Larger connectors can degrade performance by requiring longer leads.

## Caveats

Directivity, the isolation between the **SOURCE** and **DETECTOR** ports, is a key measure of directional-coupler or return-loss-bridge performance. We measure directivity in decibels, and more than 20 dB is desirable. Poor directivity in an RLB shows up as RF leakage at the detector port, even with a perfect load (remember, we want no output).<sup>5</sup> Directivity serves as a floor for mismatch measurements. With 20 dB of directivity, we can measure no more than 20 dB RL; the minimum measurable SWR would be about 1.2:1. With 30 dB of directivity, we could measure an SWR of about 1.07:1.

The impedance of the signal source also limits RLB accuracy. Any differences among

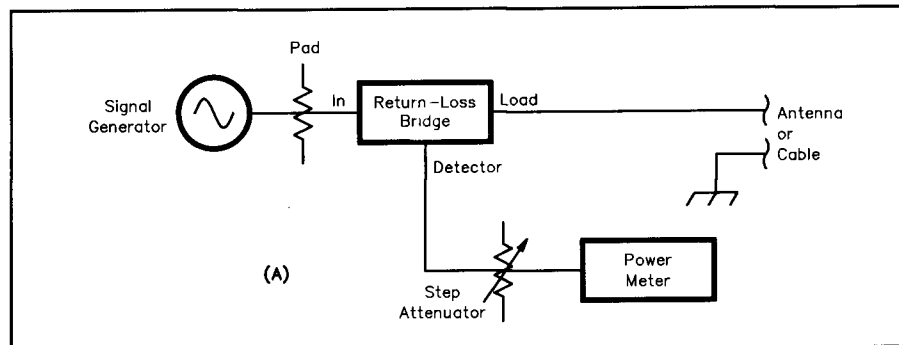


Figure 3—An RLB test setup to measure antenna-system match or coax loss.

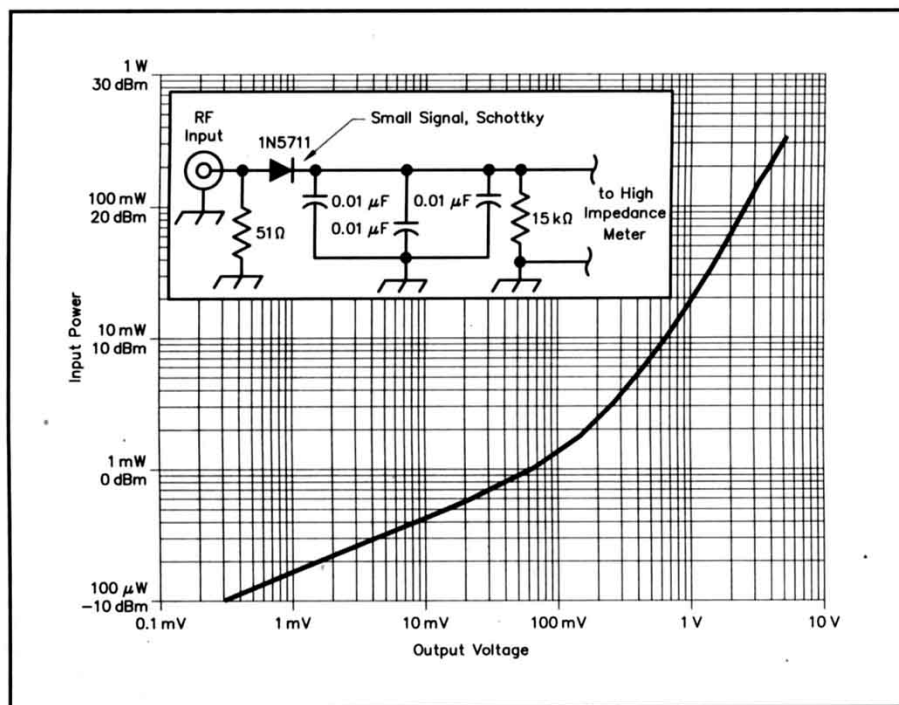


Figure 4—Schematic of the author's diode detector and the detector's calibration curve. All data was taken at 30 MHz. Unless otherwise specified, use  $\frac{1}{4}$  W, 5% tolerance carbon composition or film resistors.

the source and R1 through R3 (usually 50  $\Omega$ ) unbalances the bridge, changes the open/short circuit 0 dB reference output and degrades accuracy. Most good signal generators are sufficient in this respect, but if you

suspect yours you can improve it. Connect a 3 or 6 dB attenuator in line between the signal generator and the RLB. This improves the return loss of the generator by 6 or 12 dB, but also reduces the available signal level.

### Conclusion

It is much easier to measure and work with mismatch and attenuation in terms of return loss, rather than SWR. Return loss will probably never replace traditional SWR measurements, but knowledge of both techniques can be very helpful. Despite some limitations, a return loss bridge is a very good way to measure mismatch (especially for low-power applications) and coax loss. With its additional ability as a hybrid combiner, this circuit—just four parts—can be a versatile and valuable addition to your test bench.

### Notes

<sup>1</sup>The 1997 ARRL Handbook (ARRL Order No. 1743) contains more information on return loss bridges and hybrid combiners in Chapter 26. You can also find a more detailed mathematical discussion of transmission lines and their associated losses in Chapter 24 of *The ARRL Antenna Book* (18th ed., ARRL Order No. 6133). If you're like me, however, you'll be happy to learn that mathematics beyond simple arithmetic is unnecessary to appreciate or apply return loss.—Ed. ARRL publications are available from your local ARRL dealer or directly from ARRL. Mail orders to Pub Sales Dept, ARRL, 225 Main St, Newington, CT 06111-1494. You can call us toll-free at tel 888-277-5289; fax your order to 860-594-0303; or send e-mail to [pubsales@arrl.org](mailto:pubsales@arrl.org). Check out the full ARRL publications line on the World Wide Web at <http://www.arrl.org/catalog>.

<sup>2</sup>Amidon Inc, 3122 Alpine, Santa Ana, CA 92704; tel 714-850-4660, fax 714-850-1163.

<sup>3</sup>The detector load impedance must match that of the RLB, 50  $\Omega$  here.

<sup>4</sup>A discussion of improving diode-detector sensitivity appears under "RF Power Measurement" (pp 146-148) in ARRL's *Solid State Design for the Radio Amateur* by Wes Hayward, W7ZOI, and Doug DeMaw, W1FB (ARRL Order No. 0402). The 1997 ARRL Handbook Tandem Match circuit (pp 22.36 to 22.42) uses op amps to compensate for diode nonlinearity. John Grebenkemper's, K16WX, QST article (Jan 1987, pp 18-26) fully describes the technique. For purchasing information, see Note 1.

<sup>5</sup>Make sure to use an accurate load for this measurement. If you use the same resistor as used for R2, the stray reactances will cancel, and erroneously increase the directivity measurement.—Ed.

Jim was first licensed as WV6AXA in 1958, when he was 15. He upgraded to General a few months after getting his Novice "tickey" and remained a General operator until 1965, when he upgraded to Extra class. Ham radio started his career in electronics, and after completing his bachelor degree (a BS in electronics industrial technology from Cal State Long Beach), Jim's first job was in digital design. He had been a digital designer for almost 20 years with many of the local defense companies, when he had an opportunity to join an RF group. There was no trauma in the change because of Jim's Amateur Radio experience. After the defense cutbacks, Jim became an electronics instructor at a local community college. He finds teaching a rewarding experience. You can contact Jim by mail at 2415 College Dr, Costa Mesa, CA 92626 or by e-mail at [jimford@netcom.com](mailto:jimford@netcom.com)

QST

Table 1

$\rho$ ,  $\rho^2$ , Return Loss and SWR

$\rho$ (V)	$P_r/P_t$ ( $\rho^2$ )	RL (dB)	SWR
0.00	0.00	$\infty$	1.00
0.05	0.00	26.4	1.10
0.09	0.01	20.8	1.20
0.10	0.01	20.0	1.22
0.13	0.02	17.7	1.30
0.15	0.02	16.5	1.35
0.17	0.03	15.6	1.40
0.20	0.04	14.0	1.50
0.23	0.05	12.7	1.60
0.25	0.06	12.0	1.67
0.26	0.07	11.7	1.70
0.29	0.08	10.9	1.80
0.30	0.09	10.5	1.86
0.31	0.10	10.2	1.90
0.33	0.11	9.5	2.00
0.35	0.12	9.1	2.08
0.40	0.16	8.0	2.33
0.45	0.20	6.9	2.64
0.50	0.25	6.0	3.00
0.55	0.30	5.2	3.44
0.60	0.36	4.4	4.00
0.65	0.42	3.7	4.71
0.70	0.49	3.1	5.67
0.75	0.56	2.5	7.00
0.80	0.64	1.9	9.00
0.85	0.72	1.4	12.33
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