Measuring Return Loss with an oscilloscope and a Return Loss Bridge (RLB)

An RF return loss bridge (RLB) is a wide band bridge which can be used to check the impedance of antennas, coaxial cables, and filters, etc. The ARRL Handbook defines return loss as:

> "*a measure of how closely one impedance matches a reference impedance in phase angle and magnitude. If the reference impedance equals the measured impedance level with a 0°phase difference, it has a return loss of infinity.*"

For Ham radio applications This impedance is usually 50-ohms. The INPUT port is normally connected to a test frequency (an RF oscillator or tracking generator from a spectrum analyzer). The DET (detector) is usually connected to an oscilloscope or spectrum analyzer. A RLB is ideal for measuring filter response because return loss measurements are a more sensitive measure of pass band response than insertion-loss measurements.

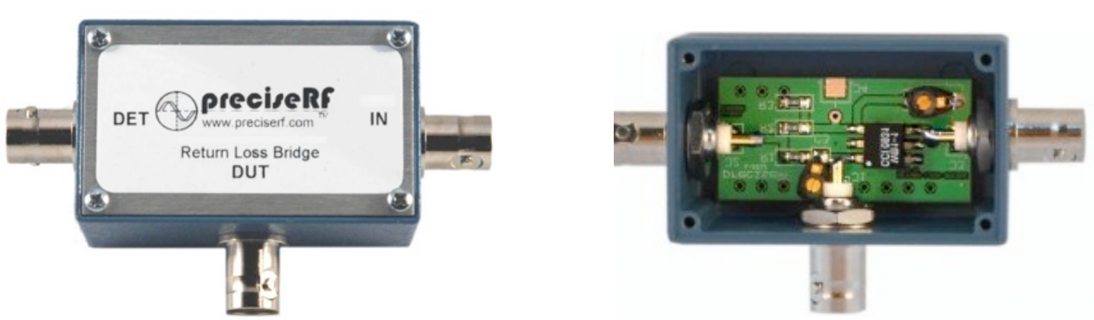

Figure 1. Return Loss Bridge

An RF Return-Loss Bridge

Figure 1. The RLB-I (internal reference – three ports) is a high performance RLB. It is carefully designed specifically for Ham radio applications. It uses a wide band 1:1 minia-

ture SMD 750 MHz transformer. The bridge reference resistors are precision 50 ohm SMD devices. The circuit board employs computer optimized 50-ohm strip line technology.

How to measure return loss with an oscilloscope

There are a number of ways to measure return loss. The method described below relies only on the accuracy of a low-cost step attenuator and removes the scope and signal generator accuracy uncertainty.

> Note: For maximum accuracy, the oscilloscope input impedance should be 50-ohms (this may require an external 50-ohm feedthrough terminator) the step attenuator should be 50-ohms and the signal generator should be 50-ohms as well.

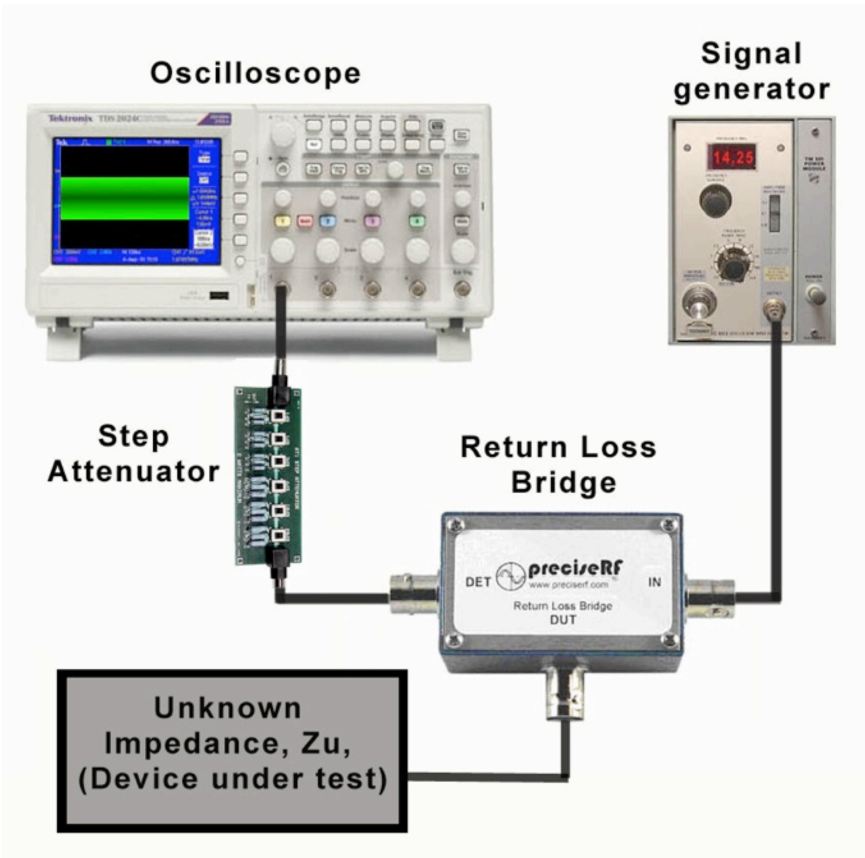

Figure 2. Return loss measurement setup

1. See Figure 2 above. Apply the output of the signal generator to the RF INPUT port of the RLB. It may be necessary to attenuate the generator output to avoid overloading the device under test.

2. Connect the bridge DETECTOR port to an oscilloscope through a step attenuator and leave the (DUT) port of the bridge open circuited.

3. Set the step attenuator for a relatively high level of attenuation of approximately 40 dB, and note the oscilloscope deflection.

4. Adjust the signal generator level and the oscilloscope vertical VOLTS/DIV setting for a convenient six divisions of amplitude as observed on the oscilloscope display.

5. Now connect the unknown impedance of the device under test to the bridge DUT port. The scope reading will decrease.

6. Adjust the step attenuator to produce the same reading obtained when the DUT port was open circuit. The difference between the two measurements is the return loss, measured in dB (as taken from the attenuator setting).

Example: Assume the step attenuator initial setting was 40 dB with six divisions of vertical signal displayed. After connecting the device under test to the DUT port, the step attenuator has to be adjusted to 10 dB of attenuation in order to get as close to six divisions of vertical deflection as possible. The difference between 40 dB and 10 dB is 30 dB. The return loss in this example is 30dB.

Accuracy Limitation

Since most low cost step attenuators have only 1dB of resolution, you may not be able top exactly match the initial divisions of the displayed signal. Thus, the accuracy is limited to about 1 dB. If greater accuracy is required, a spectrum analyzer and or precision RF power meter, or a very high accuracy oscilloscope may have to be employed.

Bridge Operation

By way of operation, the reference internal impedance (50-ohm) is compared to the DUT impedance. If the impedances are exactly equal, than the detector output will be essential zero (0). In practice this never happens. Most bridges have residual return loss from 30-40 dB (1000-1 to about 10,000-1).

The unknown impedance measured by this technique is not limited to amplifier inputs. Coax cables attached to a load, an antenna, a filter, or any other fixed impedance device can be characterized by return loss.

What is return loss

You may want to skip reading this section if all that interests you is the practical aspects of measuring return loss. Thanks to feedback from our customers, clarification as to the exact definition of return loss, particularly whether it should be expressed as a positive or negative quantity is useful.

I believe that return loss when expressed as a relative quantity, such as a dB, is a positive quantity, and when expressed as power as in dBm, it can be either positive or negative regardless whether or not it is measuring an active or passive device.

Notwithstanding the foregoing, there are a number of experts such as Dr. Trevor S. Bird, editor of the IEEE Antennas and Propagation Transactions, who have published articles addressing the science behind return loss measurements. Yet confusion still prevails. The internet provides a great deal of information, some of it questionable, so, for those interested, I suggest they research this issue on their own and draw their own conclusion.

Nonetheless, Wikipedia defines return loss as follows:

> *"..In telecommunications, return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB);*

$$RL(\mathrm{dB}) = 10\log_{10}\frac{P_\mathrm{i}}{P_\mathrm{r}}$$

where RL(dB) is the return loss in dB, P_i is the incident power and P_r is the reflected power. Return loss is related to both standing wave ratio (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Return loss is used in modern practice in preference to SWR because it has better resolution for small values of reflected wave.

Sign

Properly, loss quantities, when expressed in decibels, should be positive numbers. However, return loss has historically been expressed as a negative number, and this convention is still widely found in the literature. Taking the ratio of reflected to incident power results in a negative sign for return loss;

$$RL'(\mathrm{dB}) = 10\log_{10}\frac{P_\mathrm{r}}{P_\mathrm{i}}$$

where RL'(dB) is the negative of RL(dB). Return loss is identical to the magnitude of Γ when expressed in decibels but of opposite sign. That is, return loss with a negative sign is more properly called reflection coefficient. The S-parameter S_{11} from two-port network theory is frequently also called return loss, but is actually equal to Γ. Caution is required when discussing increasing or decreasing return loss since these terms strictly have the opposite meaning when return loss is defined as a negative quantity...”

See figure 3 below. Remember, a dB is a relative value and dBm are actual power levels. dBM can be either positive or negative. When using a return loss bridge, the detector port displays the reflected power from a device under test. When displaying this value on a spectrum analyzer, assuming the reference level is set to zero dBM, the reflected power from a device as measured from the detector port can very well be less than zero dBm. As a result, negative values may be shown if the output power is less than zero dBm. Remember, zero dBm is not zero power.

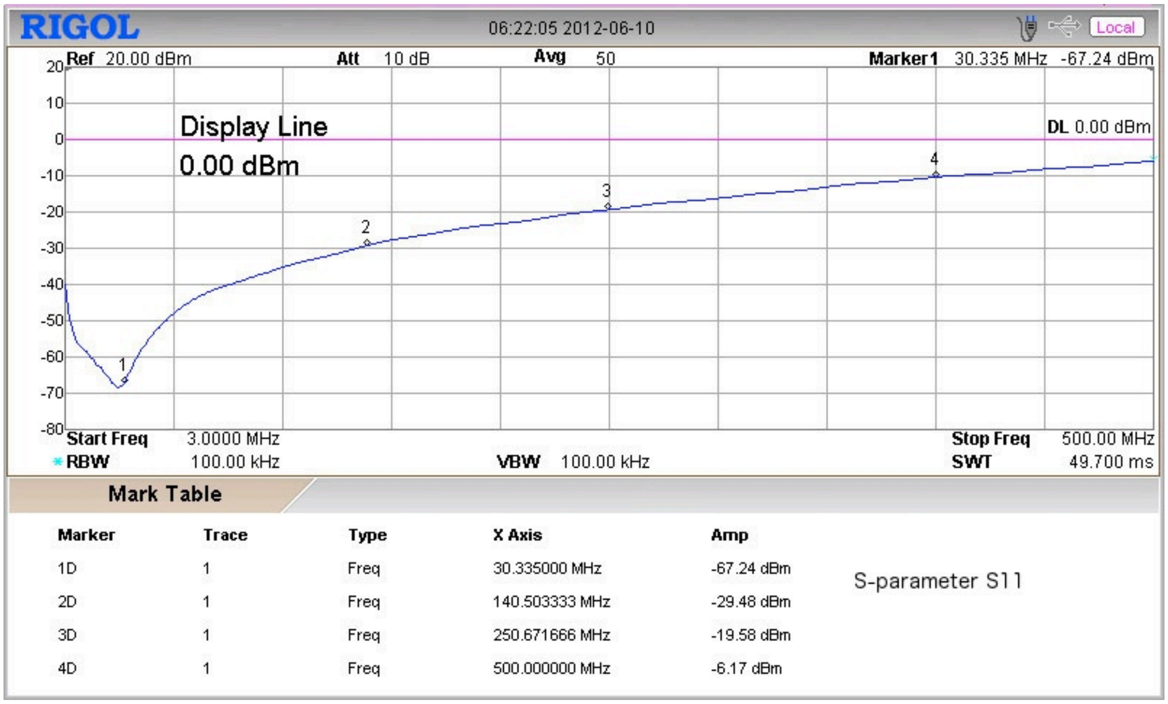

Figure 3. Reflected power expressed in dBm

You don't have have to make these calculation manually. At the time of this writing there were a number of online SWR and Return loss calculators available free on the Internet. See below:

http://www.microwaves101.com/encyclopedia/calvswr.cfm

http://cgi.www.telestrian.co.uk/cgi-bin/www.telestrian.co.uk/vswr.pl

http://chemandy.com/calculators/return-loss-and-mismatch-calculator.htm

Return Loss versus VSWR

Return Loss (dB)	VSWR	Reflection Coefficient, Γ	Mismatch Loss (dB)	Reflected Power (%)	Forward Power(%)
1	17.39	0.891	6.868	79.43	20.57
2	8.72	0.794	4.329	63.10	36.90
3	5.85	0.708	3.021	50.12	49.88
4	4.42	0.631	2.205	39.81	60.19
5	3.57	0.562	1.651	31.62	68.38
6	3.01	0.501	1.256	25.12	74.88
7	2.61	0.447	0.967	19.95	80.05
8	2.32	0.398	0.749	15.85	84.15
9	2.10	0.355	0.584	12.59	87.41
10	1.92	0.316	0.458	10.00	90.00
11	1.78	0.282	0.359	7.94	92.06
12	1.67	0.251	0.283	6.31	93.69
13	1.58	0.224	0.223	5.01	94.99
14	1.50	0.200	0.176	3.98	96.02
15	1.43	0.178	0.140	3.16	96.84
16	1.38	0.158	0.110	2.51	97.49
17	1.33	0.141	0.088	2.00	98.00
18	1.29	0.126	0.069	1.58	98.42
19	1.25	0.112	0.055	1.26	98.74
20	1.22	0.100	0.044	1.00	99.00
21	1.20	0.089	0.035	0.79	99.21
22	1.17	0.079	0.027	0.63	99.37
23	1.15	0.071	0.022	0.50	99.50
24	1.13	0.063	0.017	0.40	99.60
25	1.12	0.056	0.014	0.32	99.68
26	1.11	0.050	0.011	0.25	99.75
27	1.09	0.045	0.009	0.20	99.80
28	1.08	0.040	0.007	0.16	99.84
29	1.07	0.035	0.005	0.13	99.87
30	1.07	0.032	0.004	0.10	99.90
31	1.06	0.028	0.003	0.08	99.92
32	1.05	0.025	0.003	0.06	99.94
33	1.05	0.022	0.002	0.05	99.95
34	1.04	0.020	0.002	0.04	99.96
35	1.04	0.018	0.001	0.03	99.97
36	1.03	0.016	0.001	0.03	99.97
37	1.03	0.014	0.001	0.02	99.98
38	1.03	0.013	0.001	0.02	99.98
39	1.02	0.011	0.001	0.01	99.99
40	1.02	0.010	0.000	0.01	99.99