REFLECTION BRIDGE
50 KHz to 1.5 GHz
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This article presents a reflection bridge useful from 50 KHz to the neighborhood of 1.5GHz. This bridge may be used in conjunction with a vector network analyzer (VNA), in which case the use of OSL calibration makes its performance about as good as one could want. It may also be used without calibration as a free-standing bridge, as discussed below. It was designed primarily to be used with Scotty's Spectrum Analyzer with the VNA option.

The schematic of the bridge is shown in the Appendix. It consists of three parts. The first part is an input attenuator, resistive bridge, and Mini-Circuits TC1-1-13M balun, all on a single PCB. The second part is a homemade balun made with UT-47-FORM, two ferrite beads and a toroid. RG-316 could also be used, but may not have as good performance at high frequencies. This balun is terminated at the second PCB, which contains an attenuator and output connector. The finished bridge is shown in Figure 1.
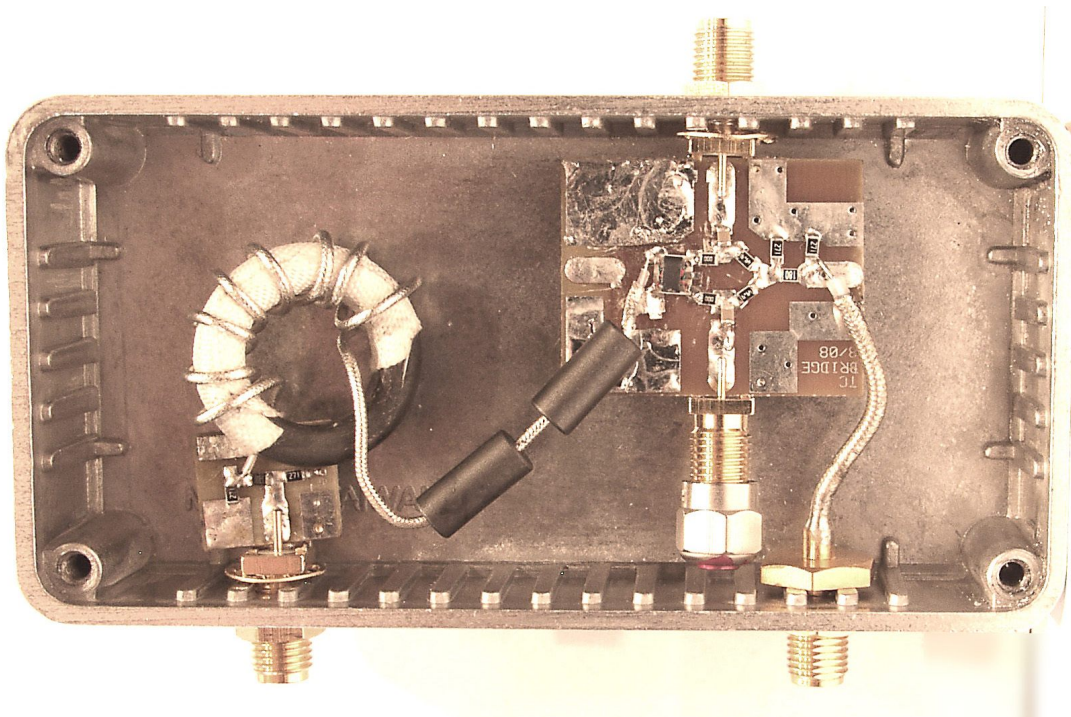

Figure 1—Assembled Bridge
DUT at top, output at lower left, input at lower right
The toroid is wrapped in tape because it is very conductive.
The enclosure is approx. 4"x2"x1"

Theory of Operation
This bridge is a standard resistive bridge, using two 49.9 ohm resistors (close enough to 50 ohms for present purposes; in fact, they need only be 1% tolerance) as the upper legs of two voltage dividers, and using the device under test (DUT) as one lower leg, and an external 50 ohm load as the other lower leg. (The external load is used to preserve symmetry, which is useful at higher

frequencies. Below a few hundred MHz, an on-board 49.9 ohm resistor can be used.) The reflection from the DUT is equal to the difference between the voltage on the DUT and on the 50-ohm reference. That difference is extracted by means of two successive baluns that function as common mode chokes to pass only the differential signal.

The trick to obtaining decent performance is to have an effective balun. The TC1-1-13M balun by itself can only obtain directivity on the order of 20 db (more on directivity below), and also has weak performance below 5 MHz. Therefore, a second balun is used to further choke the common mode signal.

Operation
To use the bridge as a free-standing device to measure return loss, an input signal is connected to the input and the output is connected to a spectrum analyzer. An "open" standard is connected to the DUT port, and the output level is recorded. A "short" standard is then connected to the DUT port, and the output level recorded. The average of the open and short output levels becomes the reference level for that frequency. Various DUTs can then be attached to the DUT port, and the output level recorded. The difference between the DUT output and the reference level (obtained from averaging the open and short), expressed as a positive number in db, is the return loss of the DUT. That return loss measures the reflection received from the DUT relative to the signal sent to the DUT. For example, if the average of the open and short is -12 dbm, and the output with the DUT attached is -30 dbm, then the measured return loss is 30-12=18 dbm. (Error will be discussed later.)

The bridge may be used with a vector network analyzer, in which case the use of Open-Short-Load (OSL) calibration will greatly improve accuracy. In addition, the VNA will be able to measure the phase of the reflection, which enables it to determine S-Parameters.

Performance
The quality of a reflection bridge is measured primarily by its directivity. Directivity is the amount of indicated return loss with a 50-ohm load. There should be no reflection in that situation, so the return loss should be infinite. For use with a VNA directivities of 20 db or better are acceptable, and anything over 30 is nearly perfect. For free-standing use without calibration, a directivity of 30 db will allow measurement of actual return losses up to 30 db, with some uncertainty (more on that later).

Another measure of quality is the difference between the open and short output levels. Ideally, the magnitude of the reflection with an open and shorted DUT should be equal. A discrepancy between them may indicate that the DUT port does not present a good 50-ohm impedance to the DUT. When directivity is good and the open and short are close to one another, the DUT port impedance is likely very close to 50 ohms.

Figure 2 shows the measured directivity and open/short for the bridge. Note that while we subtract the short output from the open output to determine open/short, we are subtracting db levels so the resulting difference actually represents the ratio of the open and short outputs. Hence the label "open/short". For use with OSL calibration, open/short magnitudes as high as 3 are still workable. For use with manual measurements, open/short magnitudes under 1 essentially create a measurement error of only half that magnitude. Thus, in the wide area where open/short is under 0.5 db, the manual measurement error would be only 0.25 db.
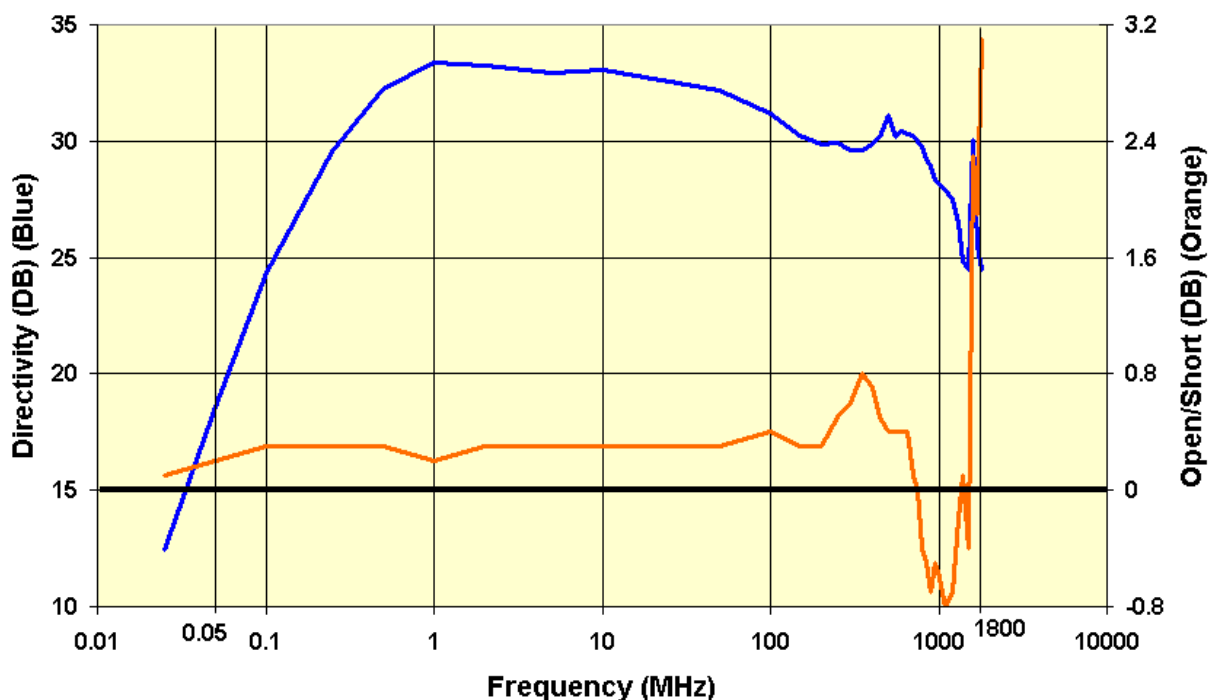
Figure 2—Directivity and open/short

Figure 2 shows that the directivity is good from about 50 KHz to 1.8 GHz, and is excellent from 1 MHz to 1 GHz. The open/short value exceeds 0.5 db at only a couple of small peaks for frequencies below 1.5 GHz.

The DUT port should ideally present a 50-ohm impedance to the DUT. If any part of the reflection reaching the DUT port is itself reflected back to the DUT, the measurement of the reflection will be inaccurate. When the bridge is used with a VNA, calibration will correct for this error, unless it becomes unreasonably large. For free-standing use of the bridge, DUT port return losses of 30 db or better are acceptable. The open/short value can be used as a guide to whether return loss is getting out of hand, though the correlation is not perfect. Open/short magnitudes under 0.8 should present no problem.

Measuring Return Loss Manually
A reflection bridge can be used to measure return loss manually, as described above under "Operation". The question arises as to how accurate such measurements are, given the lack of OSL calibration, which a VNA would perform. First, consider how much accuracy is needed. Return loss indicates the amount of power reflected by the DUT. Generally, if the DUT has return loss of 30 db or better (higher), it is reflecting so little power that it does not really matter exactly how little it is. Or in terms of impedance, return loss of 30 db or better means the impedance of the DUT is close enough to 50 ohms that it can be considered to be 50 ohms. For example, resistances between 47 and 53 ohms have return losses of 30 db or higher.

On the other hand, if a DUT reflects half or more of the power reaching it, we may just consider it to be unacceptable, without having to know exactly how much it reflects. A DUT with a return loss of 3 db or worse (lower) reflects at least half the power reaching it.

So if we know the return loss is higher than 30 db or lower than 3 db, that may be all we need to know. And even for values in the 3-30 db range, errors of several db may not be meaningful.

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The one situation where precision might be useful is to determine the exact impedance of the DUT, for example in order to devise an impedance matching network to adjust it to 50 ohms. However, because return loss is a scalar value, we cannot determine the exact impedance even if we knew the exact return loss. Phase information would be required. Our manual use of the bridge provides only scalar information, and is effectively a "scalar network analyzer", as opposed to the fancier "vector network analyzers", which provide phase information. The absence of phase information in return loss generally makes it pointless to try to determine return loss precisely.

With that background, what error can we actually expect? Consider the frequency range 250 KHz to 800 MHz. First, the open/short discrepancy creates some error. Ideally, we would use the bridge output with an open DUT as the reference to calculate return losses for large resistances, and the output with a shorted DUT to calculate return losses for small resistances. But we don't know what resistance we are measuring, so we use the average of the open and short values. That creates a possible error equal to half the open/short difference. In our case, this difference reaches a maximum of 0.8 db, so the error is 0.4 db. It is conceivable that the calculation for reactive devices might involve larger error; we don't have phase information so we can't be precise about that. But our open/short and directivity levels are so well behaved that I would not expect there to be additional error for reactive devices. But let's say the total error from the open/short discrepancy may equal 0.5 db. Let's increase that to 1 db to allow for error in the measurement of the bridge output.

Second, directivity essentially indicates a bogus reflection that is present even when there is no real reflection from the DUT. If the DUT actually produces a reflection, the bogus reflection may add to or subtract from that reflection, depending on phasing. So the bogus reflection may cause us to measure too much or too little reflection. If we assume directivity of 30 db (pretty close for 250 KHz-800 MHz), we can actually calculate the extent of maximum error in our measurement. I won't describe the process here, but Figure 3 illustrates the relationship between our return loss reading and the possible range of values of the actual return loss.

Return Loss Range
vs RL Reading
Directivity=30 db
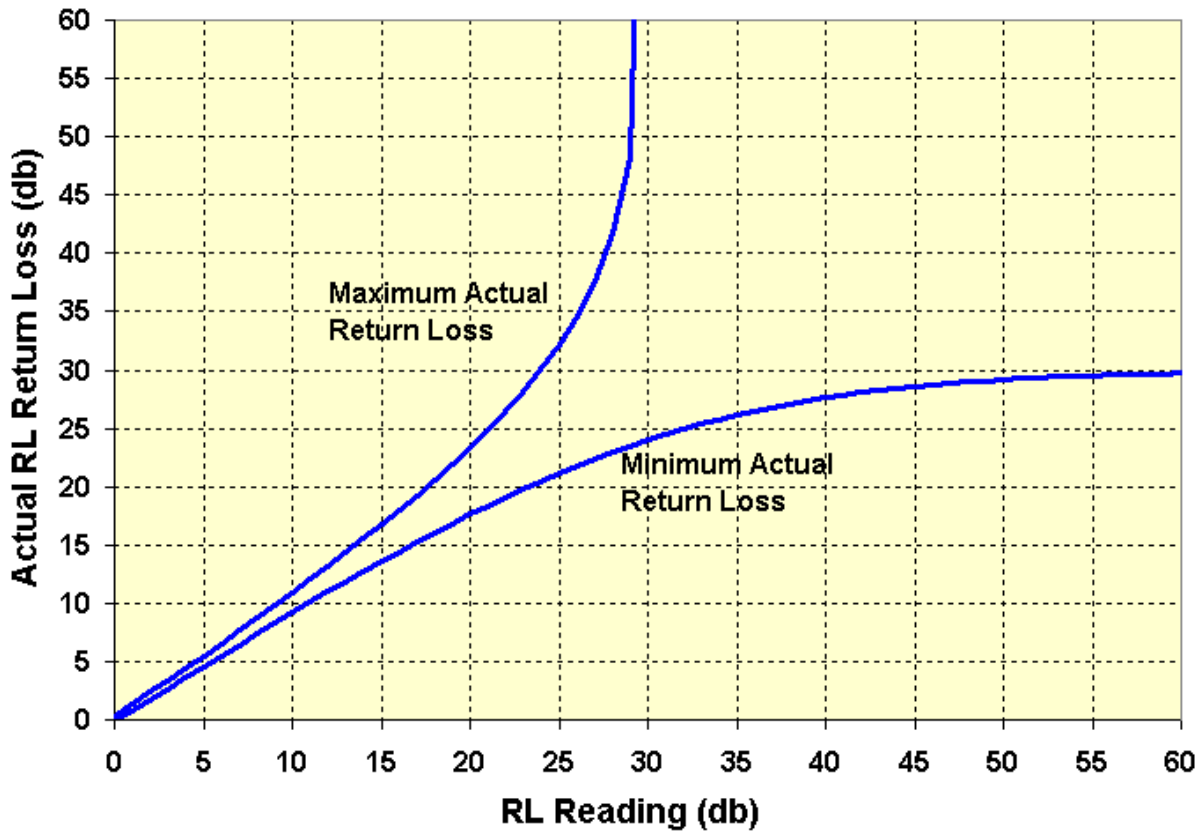
**Figure 3—Possible actual return loss values for a given return loss reading.
For example, a reading of 20 db indicates the true return loss lies above 17 db
and below 23 db.**

Figure 3 shows that we can determine return losses with reasonable accuracy if they are below 20 db. Once the return loss reading rises to 30 db and higher, we can say with confidence that the return loss is at least some minimum value (24 db for a reading of 30 db), but there is no limit to what the maximum might be. That may seem like unacceptable error, but remember that for large return losses we frequently only need to know that the return loss exceeds some threshold, without caring how far it exceeds the threshold. If we get a very large reading, like 60 db, we can be sure the true return loss is at least 30 db but can't pin it down any more precisely; but that may be all the information we need.

Remember our 1 db uncertainty resulting from the open/loss discrepancy, combined with error in measurement of the bridge output. For readings above 20 db, that error is dwarfed by the uncertainty created by directivity. For readings near zero, it becomes significant. For very low readings, indicating highly reflective DUTs, there are additional possibilities for error. It is probably good practice to proceed as follows:

1. For readings below 5 db, assume a 1 db error.

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2. For readings of 5 db to 25 db, use the graph in Figure 3 to estimate the possible error, and add 1 db.

3. For readings above 25 db, use the graph in Figure 3 to estimate the minimum possible return loss, and assume there is no ceiling to how high the true return loss may be.

APPENDIX—Schematic
Note: Brass strip is not needed once mounted in a metal enclosure

All resistors are 1%

Tape taroid before winding

8-9 turns (only three shown)

FB1

Ferrite FT-87-W or Steward LFB090050-000

FB-43-1801 (x2) or FB-43-401 (x4) or BN-43-801 (x4)

1/2" Brass strip soldered to bottom ground plane of PCB 1 and 2

Note: Coax braid is connected to lower side

Note: Best high frequency performance is obtained with UT-47_FORM coax, but RG-178 or RG-316 will work adequately if the FB-43-801 cores are used.

Reflection Out

PCB 2

R7 18

R6 270

R8 270

coax

DUT

T1

TC1-1-13M

coax

C1 1u

C2 1u

R4 49.9

R5 49.9

REF (50-ohm load)

R2 18

R3 270

R1 270

IN

PCB 1