

Measuring Microwave VSWR or Return Loss

Paul Wade W1GHZ ©2026

w1ghz@arri.net

Hams obsess about VSWR (Voltage Standing Wave Ratio), a measure of RF power from a mismatched antenna reflected back down a transmission line. This is important at HF, where many hams use non-resonant wire antennas on multiple bands, a compromise usually requiring an antenna tuner to match the antenna for low VSWR and protect the radio or amplifier from damage due to high VSWR.

At microwave frequencies, professional engineers use Return Loss (RL) rather than VSWR; a different format for the same measurement. Return loss is the ratio of forward (transmitted) power to power reflected from an antenna or other load, in dB. It measures the loss in dB for the reflected signal, so a high RL indicates less reflected power and therefore a better VSWR. A return loss of 20 dB (VSWR = 1.22), or only 1% of the power reflected, is usually considered adequate. At the higher microwave frequencies, a RL of 15 dB (VSWR = 1.43) or even 10 dB (VSWR = 1.92) may be acceptable. There are several reasons for this tolerance:

- Many commercial microwave designs are broadband, creating some variation over frequency – hams operate in narrow frequency ranges.
- Tuning is difficult at the higher microwave frequencies – an antenna tuner would have too much loss.
- Measuring small amounts of reflected powers at microwaves is difficult.

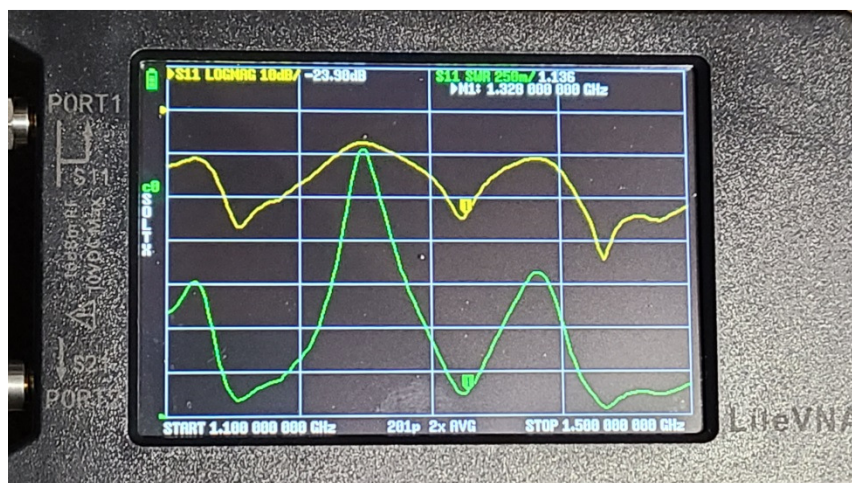


Figure 1 – Return Loss (yellow trace) and VSWR (green trace) displayed simultaneously by a TinyVNA measuring a WA5VJB log-periodic antenna around 1296 MHz. The scale values are not clear but the traces follow the same reflected power pattern with frequency.

Note: To be precise, the yellow trace is actually $|S_{11}|$, the magnitude of S-parameter S_{11} , which is Return Loss with the opposite sign. Return Loss decreases as VSWR increases.

Measuring VSWR or Return Loss

The straightforward way to measure return loss is with a directional coupler, which separates a sample of only the power traveling in one direction. The 10 GHz directional couplers shown in Figure 2 are marked with a direction arrow – a sample of power traveling in that direction is available at the top connector. Reverse the coupler to sample the other direction. The amount of coupled power is the coupling factor – the three on the left are marked 10, -20, and -30 dB, the amount of coupled energy relative to the energy passing through (sign seems to be arbitrary depending on manufacturer). One watt passing through a 30 dB coupler yields one milliwatt at the coupled port on top.

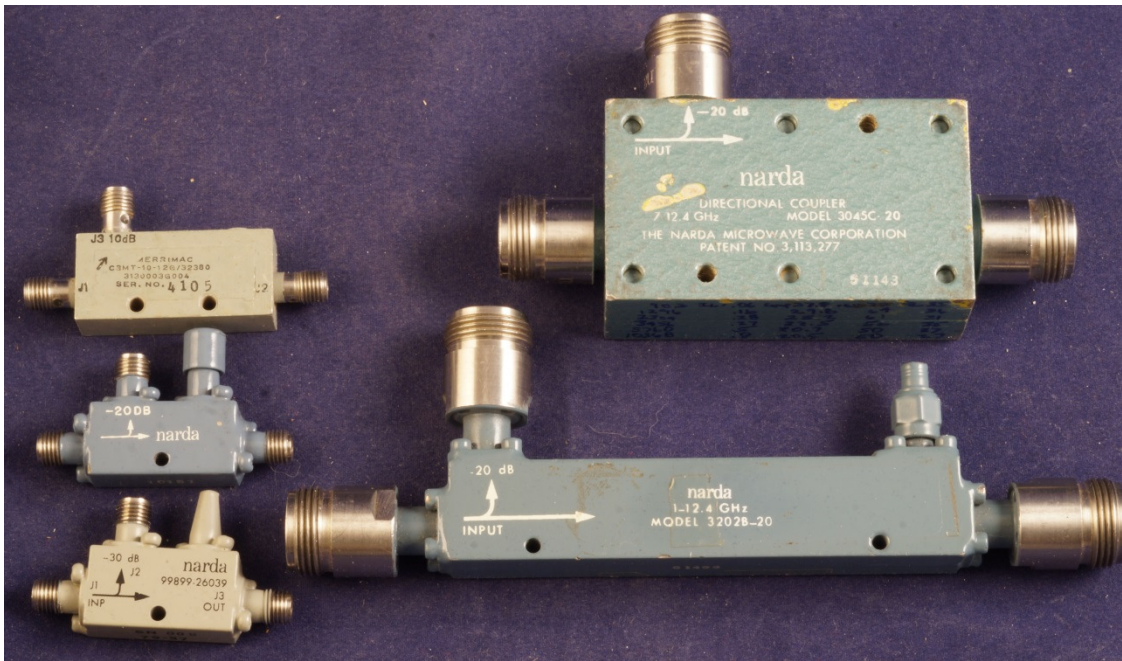


Figure 2 -Coaxial directional couplers for 10 GHz. Arrows indicate the coupling direction, and the coupling factor is marked near the top connector.

To properly measure RL, we must be able to measure RF power, which is one of the basics for microwaves. A good power meter is ideal, but even the simple one such as the Analog Devices AD8317 described in **QST** Microwavelengths for April 2023 will suffice for approximate results. Other USB power meters can be found on ebay at reasonable cost.

The actual measurement is made at low power, by adding an attenuator between the signal source and the directional coupler. With the directional coupler oriented for reflected power, an RF short circuit is placed on the output, which causes 100% of the power to be reflected and measured at the coupled port, reduced by the coupling factor. Then the short is replaced by the antenna or load and coupled power measured; the difference in dB is the return loss. The signal source providing RF might change power output with a large change in impedance, particularly with a short, so it should be isolated with an attenuator or isolator at the input to the directional coupler. I found that a 6 dB pad works as well as an isolator.

The coupled power levels can be quite low when making measurements at modest power levels, perhaps 0 dBm; a 20 dB return loss with a 30 dB coupler reduces the coupled power to -50 dBm, difficult to measure with most power meters. A 10 dB or even a 6 dB directional coupler would provide more convenient levels when measuring with modest power. A good microwave power meter can only measure power down to perhaps -30 dBm, so it would not be able to measure RL greater than about 20 dB with a 10 dB coupler. Of course, it would still be safe to increase the power a bit, to $+10$ dBm or so, perhaps with a small amplifier. Higher powers might risk damaging a power amplifier if testing high VSWR, and radiating high power in the shack is a bad idea.

The separation of the two directions by a directional coupler is not perfect, limiting accuracy. Directivity is a measure of the separation, or leakage, between forward and reverse directions. A directivity of 20 dB implies that the leakage is only 20 dB down, so the return loss with no reflections would only be 20 dB. The coaxial directional couplers in Figure 2 are only specified for directivity of 15 or 20 dB, depending on the version, over the design band. I've tested a few, and the best was 23 dB at 10.368 GHz. These couplers are designed to provide a uniform coupling factor over an octave or greater bandwidth, requiring design compromises that probably affect directivity. They are intended for monitoring output power or for monitoring reflected power for high VSWR due to failures, not for precise measurements. A few directional couplers with better directivity are available for the lower microwave bands.

When measuring an actual antenna, the reflected power combines with the leakage; depending on the relative phase, the total can be either higher or lower, adding uncertainty to the result. With a directivity of 20 dB, accurate measurements of low VSWR are limited by this error. A return loss of 20 dB means that 1% of the power is reflected. If the directivity is also 20 dB, the leakage power is also 1%. Depending on the phase relationship, the total coupled power could add, to 2% (apparent RL = 17 dB), or cancel to zero (apparent infinite RL, VSWR = 1.000).

Marki Microwave has an online calculator¹ that generated Figure 3, showing possible error range with directivity of 20 dB (yellow vertical line) when measuring a VSWR of 1.25 – return loss anywhere between 13.5 dB (VSWR = 1.5) and 40 dB (VSWR ~1.0). Anything in this range is good enough, but attempting to tune something using a directional coupler with directivity of 20 dB or less would be futile. Don't bother with those tuning screws. Anything measuring a return loss of 15 dB or better is probably better than 10 dB, and possibly much better, good enough to use. Anything much worse probably has a problem worth investigating.

With directivity of 40 dB (blue vertical line), the error is quite small, so we can believe the measurements.

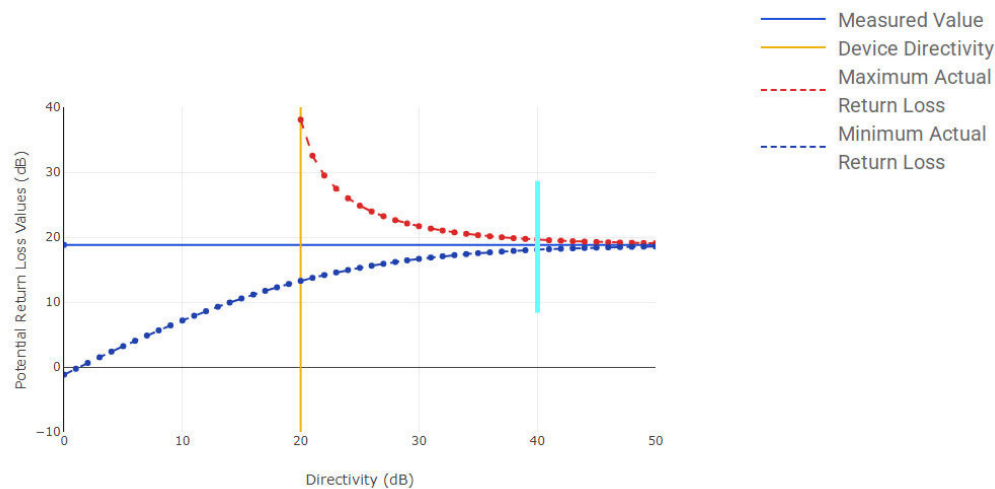


Figure 3 – Marki Microwave Return Loss Error Calculator showing error range measuring return loss of 19 dB using directional couplers with directivity of 20 dB (yellow line) and 40 dB (blue line)

The directional couplers in Figure 2 are specified to operate over X-band, 8-12 GHz, except for the one in the lower right, marked 1-12 GHz, a very useful range. The others will work fine at lower frequencies with reduced coupling factors (less coupled power). Couplers designed for lower frequencies often have better directivity, often 25 dB, with a few specified for 30 dB, over their operating range. But I wonder about those HF VSWR meters we use to get the VSWR down to 1.00?

VNA

More accurate measurement of VSWR or Return Loss at microwaves requires a calibrated VNA (Vector Network Analyzer). The VNA compensates for the errors in its internal directional couplers by computer correction based on a calibration procedure, involving an RF short, RF open, and accurate termination.

For frequencies up to 6 GHz, the handheld LiteVNA (Figure 1) is a very affordable solution, with additional capabilities beyond measuring VSWR or RL, at a price lower than many antenna analyzers. An IEEE paper² has a comparison up to 3 GHz of the the LiteVNA to a professional VNA costing 150 times as much, quoted here: “The Nano VNA performs well against the E5061 Keysight ENA. The word *fantastic* comes to mind, given the price. The Nano was able to achieve decent results on every measurement we threw at it, and mostly with adequate accuracy.”

Above 3 GHz, the LiteVNA64 works to 6 GHz with reduced dynamic range and a higher noise floor. It is still a really useful instrument, adequate for nearly all amateur needs. A small handheld instrument

that you can take to the antenna or problem, even up the tower, is much more useful than a big heavy box. If you drop it off the tower, the repair cost is not too painful – just replace it.

Above 6 GHz, accurate measurement becomes more difficult – a VNA is either big, heavy, and expensive, or big, heavy, and old. Measurements in waveguide can be difficult with a VNA, since a transition from coax to waveguide has discontinuities that add uncertainty. Calibration on the waveguide side would work, but there are few calibration standards – an open circuit is not possible, since an open waveguide is an antenna. There are waveguide calibration kits but I've never seen one, and most VNAs don't come with a waveguide calibration routine.

Waveguide Directional Couplers

At 10 GHz most electronics uses coaxial connectors, but antennas are based on waveguide, even if they have coax connectors. Higher frequencies are nearly all waveguide. At 10 GHz and above, waveguide directional couplers are available. The long broadwall couplers shown in Figure 4 are excellent, much better than any coaxial coupler. The Hewlett-Packard HP752 series, from an era when HP made excellent waveguide hardware^{3,4}, have directivity better than 40 dB over the full waveguide bandwidth and provide excellent results. And they did the design with slide rules – no EM modelling software.

I recently acquired an HP X752C for 10 GHz (10 dB coupling) at a hamfest and am really pleased at being able to make stable and reliable measurements. It works so well that I bought the HP K752C for 24 GHz on ebay which works better than anything I have used for that band. Similar surplus couplers from other manufacturers are probably copies – a traditional microwave engineering technique.

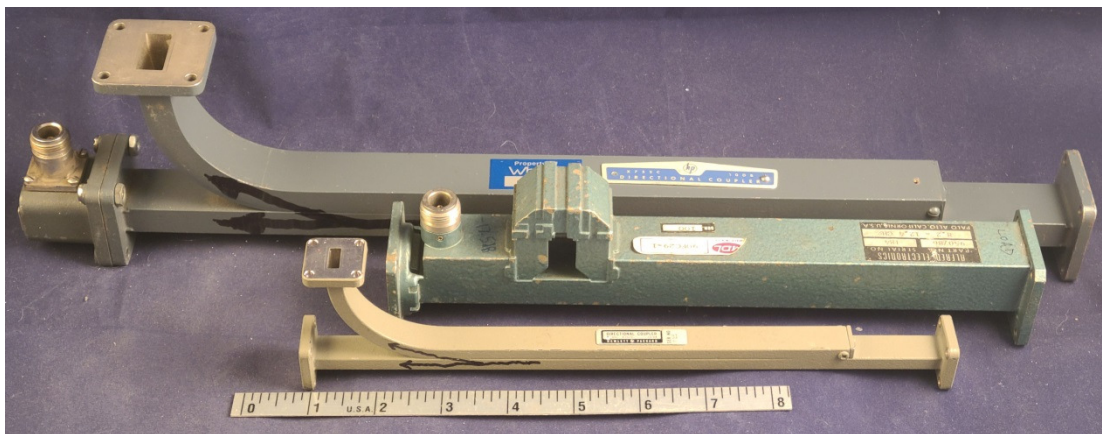


Figure 4 - Waveguide broadwall directional couplers, including two WR-90 models for 10 GHz (top and middle) and a WR-42 for 24 GHz (bottom). The arrows indicate coupling direction, which is opposite from coaxial couplers.

The Alford WR-90 directional coupler in Figure 4, probably from an old microwave test set, also has very good directivity. I don't fully understand the inchworm-shaped coupling section.

We still have the problem of measuring very small powers. A 10 dB directional coupler, a 6 dB isolation pad, and return loss of 30 dB adds up to 46 dB of loss, or -46 dBm with 0 dBm from a signal generator. The lowest scale on my power meter is -25 dBm, and that is a bit drifty. Perhaps I could measure 15 dB return loss near the bottom of the lowest scale.

A good Spectrum Analyzer can measure smaller signals. My TinySA has about 30 dB less sensitivity on the 10 GHz range than lower frequency ranges, with a default noise floor around -30 dBm. Reducing the RBW (Receive Band Width) to 30 KHz knocks the noise floor down to around -5 dBm – usable, but with slow display times. That’s not good enough if you only have a 20 or 30 dB coupler. Otherwise, back to the big, heavy, and old – this time a spectrum analyzer.

The third choice is to downconvert to a lower frequency where we have more dynamic range. We likely already have the downconverter in a transverter. The low frequency receiver can be the TinySA, an RTL-SDR dongle, or an SDR receiver – most of them display power reasonably accurately, and we only need differences, not absolute power.

Swept frequency measurements often provide more insight. Since a VNA does this well, I was thinking of a way to adapt it when I realized that my big heavy one can measure loss with very high dynamic range. I connected Port 1 to the input of the coupler and Port 2 to the coupled port of the HP752C waveguide directional coupler. The displayed S_{21} , the loss between Port 1 and Port 2, is about 15 dB with a short and 55 dB with a good HP waveguide load, over a 500 MHz band around 10.25 GHz. The difference is 40 dB, the expected return loss. With a waveguide sliding load, small differences around 40 dB RL are seen as the load is moved. Voila – a waveguide VNA!

The only problem was seen with a homebrew sliding short – the loss varied a few dB with position and with frequency. I suspected the changing load on the internal generator, so I added an isolator at the coupler input. This reduced the variation with the sliding short to 0.8 dB. The variation was the same with a 6 dB attenuator. (You may have noticed that I suggested isolation above – that was written after this experience.) For comparison, I tried a coaxial sliding short on the VNA after proper calibration with coax standards – the variation was 0.3 dB. It would take a lot of work to find whether the variation is due to directivity and other errors or due to imperfections in the sliding shorts.

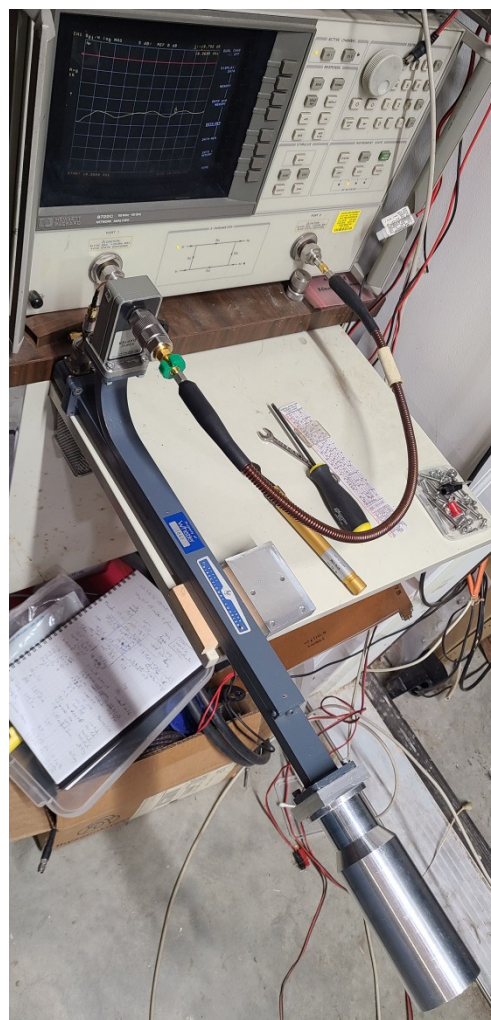


Figure 5 – Using waveguide directional coupler with VNA

Cross-guide Directional Couplers

Another type of waveguide directional coupler is the cross-guide coupler, shown in Figure y for WR-90 and WR-42 waveguide. These couplers have a little better directivity than coaxial couplers, but not nearly as good as broadwall couplers. When I machined some⁵ of this style for 24 and 47 GHz a few years ago, I find that the coupling holes between the two waveguides could be optimized for high directivity over a narrow frequency range – fine for ham bands.

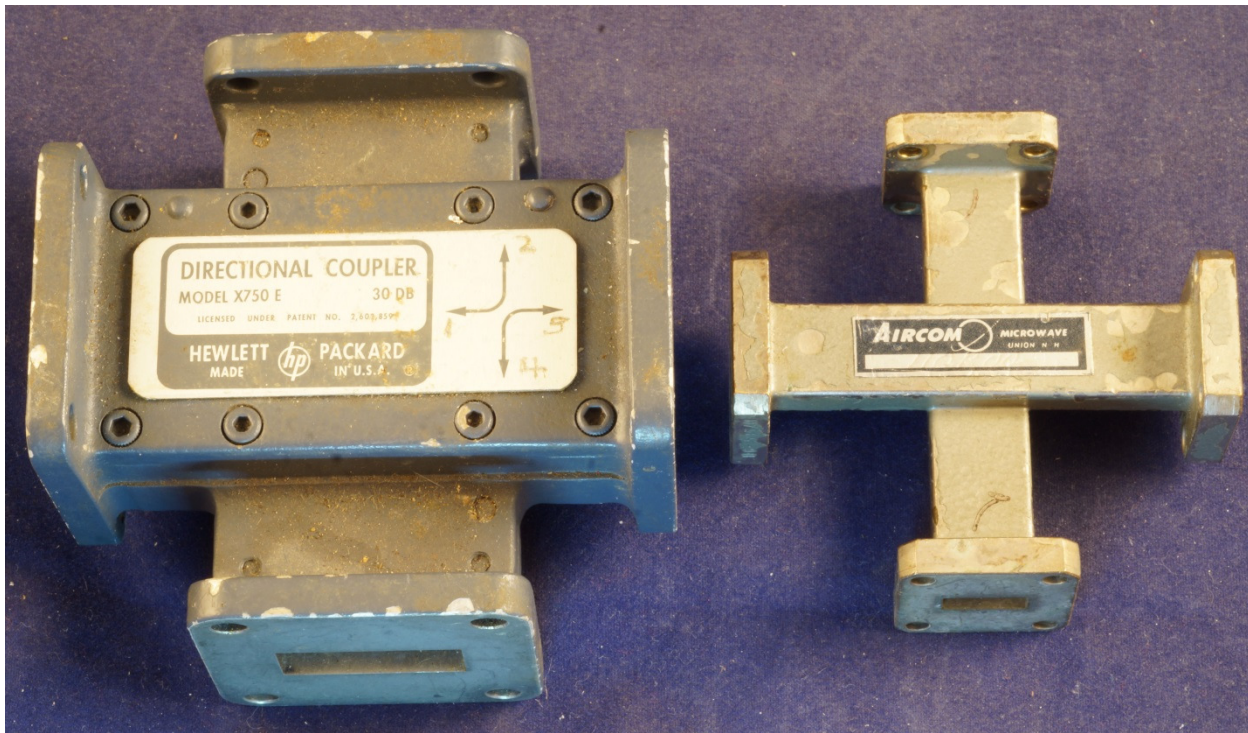


Figure 6 – Waveguide cross-guide directional couplers in WR-90 and WR-42

Cross-guide couplers are only available with small coupling factors, -20 to -50 dB, intended for power measurement and high VSWR protection. The straight paths, horizontal and vertical in the photo, are plain waveguide so the power handling capability is only limited by the waveguide limit, hundreds of kilowatts.

Slotted Line

Before the VNA, slotted lines were used for impedance measurement, and still might be the most accurate technique for waveguide, especially at the higher microwaves⁶. A short probe is inserted in the center of the broad wall of the waveguide and moved along the guide to detect the standing wave pattern and find minimum and maximum values. The magnitude of the standing wave, the ratio of maximum to minimum, is the VSWR (Voltage Standing Wave Ratio). The phase of the impedance is found by the phase shift compared to a short circuit (minimum shift).

The same power problem exists with the slotted line. The probe must be relatively short or it will affect the standing wave being measured, so very little energy is coupled to the probe. Traditionally, a diode detector was used with a 1 KHz modulated signal source, so that the detected signal could be amplified by a narrowband audio amplifier. When I was a young technician, we made slotted-line measurements at 1.2 GHz using a General Radio oscillator that probably provided at least a ½ watt.

Today, we have better solid-state detectors. I have used an AD-8317 detector for a 10 GHz slotted line, and a higher frequency one at 24 GHz shown in Figure 7, using the the Hittite 124131-2 detector. The spectrum analyzer or heterodyne technique could also work well here.

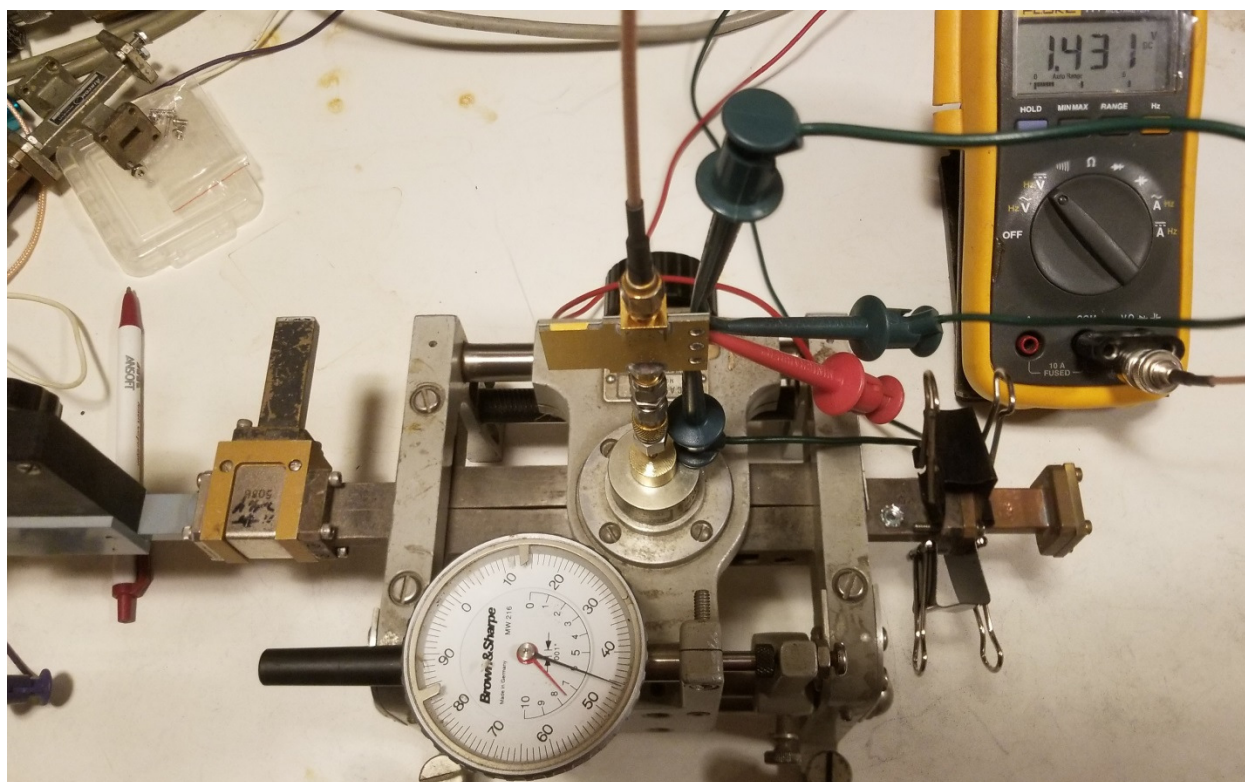


Figure 7 – WR-42 slotted line for 24 GHz with solid-state detector. Dial indicator measures distance precisely.

Summary

Measuring return loss, or VSWR if you prefer, accurately is more difficult at microwave frequencies, and more so at 10 GHz and above. Unless you are designing something or making major modifications, it often doesn't matter. Most microwave antenna designs are based on waveguide and will work well without tuning if dimensions are reasonably close. Measurement of return loss is not essential but offers some assurance; many hams have been successful without it. Whether you can measure accurately or not, don't obsess with perfection, embrace good enough and get on the air.

Notes:

1. <https://markimicrowave.com/technical-resources/tools/return-loss-error-calculator-for-directional-couplers-and-bridges/>
2. N. Hunt, J. Scott and L. Streeter, "Nano Versus Commercial [Educator's Corner]," *IEEE Microwave Magazine*, vol. 24, no. 4, pp. 88-95, April 2023
3. "More About the *-hp-* Precision Directional Couplers," *Hewlett-Packard Journal*, Jan-Feb 1953. (found at Internet Archive, <https://archive.org>)
4. "A Precision Directional Coupler Using Multi-Hole Coupling," *Hewlett-Packard Journal*, March-April 1952. (found at Internet Archive, <https://archive.org>)
5. P. Wade, "Waveguide Cross-Guide Directional Couplers," *Proceedings of Microwave Update 2019*, ARRL, 2019.
6. "A Micrometric 12-40 KMC Waveguide Slotted Line with Interchangeable Sections and Untuned Probe," *Hewlett-Packard Journal*, Sept-Oct 1956. (found at Internet Archive, <https://archive.org>)
7. D. Jorgensen and C. Marki, "Directivity and VSWR Measurements," <https://markimicrowave.com/technical-resources/white-papers/directivity-vswr-measurements/>