SWR for the hobbyist Ham

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Nov 4 2021

Impedance first

- Before we dive into SWR, we have to first talk about IMPEDANCE (AC version of OHMS, which includes both resistance and reactance).

What Impedance Means

- Impedance is the ratio of VOLTAGE divided by CURRENT.
- There is only ONE impedance at any given component or place in a circuit.
- If you divide the measured voltage by the measured current at that point or across/through that component, there is a SINGLE answer.
- An impedance is a single value. It can’t have multiple values simultaneously. Your station end of the transmission line has ONE impedance at any given frequency, not multiple.

- No matter WHAT crazy transmission line and antenna you choose to use, and no matter WHAT frequency you are using…..
- THERE IS EXACTLY ONE IMPEDANCE at your transmitter end of that transmission line when you pick a frequency and decide to put power into that line. It doesn't matter whether 100mW, 1 W or 1 kilowatt.
- ONE IMPEDANCE.

- Your transmitter “generally” prefers that it “sees” 50 ohms.
- If you have a well matched antenna, you’ll probably see 50 ohms.
- If you have a really lossy coax...you’ll STILL see 50 ohms even if the antenna is terrible! (Lots of manufacturers take advantage of that deceptive fact.)
- If your transmitter sees 50 ohms it will be happy. Whether or not anyone hears you….that’s another story!

Damage to the transmitter?

- It is **complicated** to explain what happens ***to your transmitter*** if your transmitter DOESNT see 50 ohms, but in general it is likely to
  - Not be as happy (extreme cases, may be damaged)
  - Not put out as much power (fancy solid state rigs will “foldback the power” specifically to avoid the possibilty of damage because their simple transformer outputs do not adjust well to poor SWRs)
  - Calculating exactly what happens to the transmitter is beyond the scope of this talk. Part of the problem is that the transmitter’s source impedance may NOT be 50 ohms…. **Suffice it to say that higher/lower voltages or higher/lower currents than the transmitter expected….are possible. Try to keep the impedance that the transmitter “sees” somewhere within a factor of 2-3 either way from 50 ohms.**

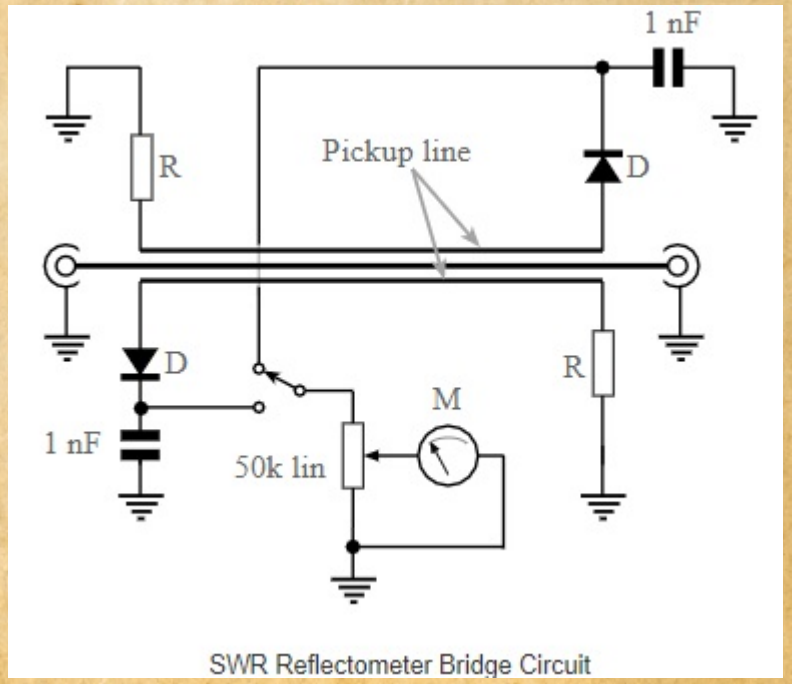
Damage to transmitter

- Older TUBE transmitters had a TUNABLE pi network that can SOMEWHAT adjust to a non-50-ohm load….but we still had occasional arcing on the air-variable capacitors (little damage)
- Newer SOLID STATE transmitters may see voltages beyond the Vceo rating of the transistor...causing catastrophic damage if not for the FOLDBACK circuitry….
  - Designers usually include foldback, or in very simple designs depend on manufacturer statements that even infinite SWR is OK if supply voltage is <= X volts.

Why is SWR ubiquitous?

- **It is EASY to measure**. A directional coupler can be made by lining up two wires parallel to a small portion of your transmission line's center conductor. Terminate opposite ends with 50-100 ohms and add diodes opposite sides, feed a meter and you have an SWR meter!

https://www.electronics-notes.com/articles/antennas-propagation/vswr-return-loss/vswr-reflectometer-bridge-circuit-simple.php



SWR Reflectometer Bridge Circuit

Cheap, too!

- HF directional coupler SWR meters are generally $10-$15 at hamfests. Inside there are literally three parallel wires just like in the schematic, a couple of diodes, and the meter.
- For VHF/UHF the dimensions just have to SHRINK.
- Professional directional couplers even at microwave work BASICALLY the same way….just with waveguides instead of wires I think.
- (There is an alternative technique that uses RF transformers to sample voltage & current….another talk…..)

ONLY consistent value on line

- SWR is the **ONLY thing that stays constant** all the way along a transmission line.

WHY?

- With a mismatched antenna (Z of the antenna not equal to Zo of the transmission line) there are REFLECTED WAVES that move backwards on the transmission line.
- They variously ADD or SUBTRACT from the forward voltage/current as they move backwards, just like overlapping ripples in a lake interfere (constructively and destructively) with other ripples.

Bounce back from the end

- Forward wave comes from transmitter, heads to antenna.
- Poor match at antenna – not all power accepted – left over power REFLECTS and starts travel BACKWARDS
- The two waves (forward & reflected) interfere with each other ALL ALONG THE LINE – sometimes raising the voltage, sometimes lowering, sometimes raising the current, sometimes lowering.

Wild Things

- At each distance along the line, the RATIO OF VOLTAGE TO CURRENT (the impedance at that point) is literally different from the next point…..
- The IMPEDANCE is CHANGING along the length of a mismatched transmission line.
- The (total) VOLTAGE is CHANGING along the length of a mismatched transmission line.
- The (total) CURRENT is CHANGING along the length of a mismatched transmission line.
- These CHANGES sit “still”. You could measure them with a voltmeter! They are “STANDING” “waves”.

ONE THING is constant

- The Standing Wave Ratio (easy measurement, tough mathematical explanation….) is THE SAME EVERYWHERE ON THE LINE (unless the line is quite lossy)
- So it doesn’t matter WHERE you measure it, the SWR will be the SAME on a transmission line (if it isn’t quite lossy).
- THAT makes SWR a whale of a lot more useful.

- Constant along the line.
- Easy to measure with simple instruments
- CHEAP to measure with simple instruments

- Hams have ALWAYS gravitated toward the SWR as a result.

What IS standing wave ratio?

- Multiple equivalent definitions.
- Simplest: ratio of the antenna impedance to the transmission line impedance (typically 50 ohms but not always)
- If you measured the voltage at every point along the line, it is also the ratio of LARGEST to the smallest voltage you found.
- If you measured the current at every point along theline, it is also the ratio of the LARGEST to the smallest current...

In terms of forward/reflected POWER:

- Formula is a little more complicated…

- How the heck does a $15 hamfest SWR meter do all that? The secret is in how they make the markings on the meter…..that formula is why the SWR meter has such an odd non-linear set of markings, and **why 3:1 is always halfway up….**

$$\mathrm{SWR} = \frac{1 + \sqrt{P_r / P_f}}{1 - \sqrt{P_r / P_f}}.$$

HALFWAY IS ALWAYS 3:1

- SWR meters (and cheap RF Power meters) are ALWAYS basically VOLT METERS. They measure VOLTAGE, forward, reverse, or total.
- Lets take the case of reflected voltage = 50% of forward voltage.
- There is only ONE impedance at any given point.
- No matter WHAT that impedance is, Power = V^2/Z
- If the reflected voltage is half the forward voltage, then the reflected POWER is ¼ of the forward power...

Exactly as suspected….

$$\mathrm{SWR} = \frac{1 + \sqrt{P_r / P_f}}{1 - \sqrt{P_r / P_f}}.$$

SWR = 1 + sqrt(1/4)

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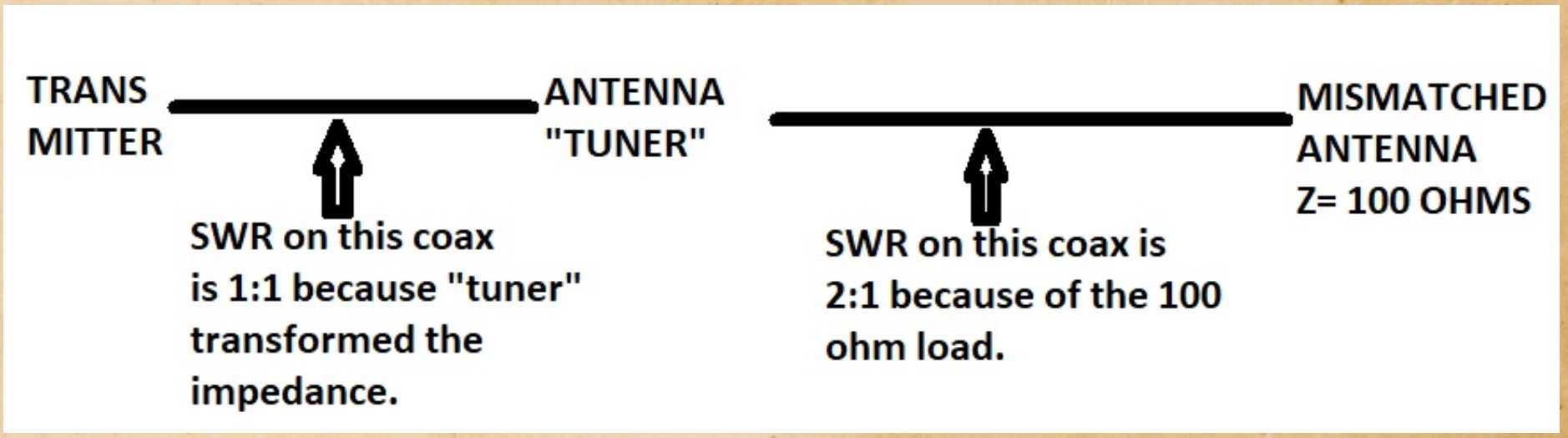
1 - sqrt(1/4)

= (1+ 1/2)/(1-1/2) = 3

- The cheap SWR meter simply reads RATIOS of the forward and reflected VOLTAGES from its simple directional coupler. (3 parallel wires)
- It is CALIBRATED (markings on the dial) to do the complicated math presented earlier.

Reading total power?

- To read TOTAL POWER it simply has a resistive voltage divider, diode rectification and a voltmeter that is calibrated in WATTS……
- But THAT PART (total watts) is ONLY accurate when the Z is actually 50 ohms…..which only occurs if
  - A) you have a perfect SWR
  - B) or you measure the power on the 50 ohm side of a well functioning antenna tuner that TRANSFORMS it to 50 ohms.


TRANS
MITTER
ANTENNA
"TUNER"
MISMATCHED
ANTENNA
Z= 100 OHMS
SWR on this coax
is 1:1 because "tuner"
transformed the
impedance.
SWR on this coax is
2:1 because of the 100
ohm load.

Two Options

- Most people want their SWR measurement on the LEFT coax to see how well the tuner did, and what their transmitter “sees” The power measurement has a chance of being accurate.
- If you put your SWR meter on the RIGHT side coax...you’ll see the true swr going to your antenna (may not be pretty…..) but your power measurements will be completely out of whack.

Losses on Lines

- Coax losses go WAY UP when there is a high SWR (because the higher voltages induce more dielectric loss, and the higher currents induce more ohmic losses in the conductors)
- If you use a long COAX line going to a weird antenna….despite your excellent antenna tuner you may have turned most of your output power into HEAT in the transmission line.
- That is why we have worked so hard to help members MATCH AT THE ANTENNA with 4:1 or 49:1 baluns for different feed points (keep swr on coax feedline reasonable)

Non resonant antennas….

- For RANDOM LENGTH antennas (wild SWRs) smarter to use BALANCED TRANMISSION LINE (not coax) and a tuner….much lower losses on balanced window line than with coax….
- Unless it gets ICE on it...

- RESONANT antennas: lower SWRs on line, coax OK
  - If really well done, may not need tuner.
  - I went years and years before I ever owned a tuner...
- NON-RESONANT (random length) antennas: higher SWRs on line, window line better choice – TUNER REQUIRED.
- BOTH WORK! I use both routinely….

Lossy Line?

- The reflection comes at the ANTENNA.
- If the line is really lossy, not only is there less “forward” left to reflect, but the amount reflected gets attenuated badly on the trip back!
- Net result: at the transmitter end of the line you think the SWR is “fine”

EXAMPLE: VERY LOSSY TRANSMISSION LINE FEEDING POOR MATCH

100 watts starts out forward

25 watts makes it to antenna

TX  ANT

Only 5 watts of reflected makes it back to transmitter end....and the SWR meter says you're almost PERFECT!

Almost ALL of it is reflected (20 watts reflected Actual SWR = 17)