Introduction to Standing Wave Ratio (SWR)

Gordon Gibby KX4Z

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SWR is POPULAR

- For decades and decades, hams have been measuring Standing Wave Ratio (SWR)
- CB-type SWR meters abound, $15 at hamfests
- Amazon <$50 for VHF/UHF SWR meters
- SWR is present in almost every review of antennas
- Most hams want their SWR < 2:1
- What is SWR?

What is SWR?

- Have to look at RADIO WAVES (electrical/magnetic) (voltages / currents) moving along a transmission line.
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- If the line is perfectly terminated in an impedance exactly equal to the impedance of the line, ALL THE POWER IS ABSORBED by that impedance.   NO REFLECTION

Voltage and Current along perfectly terminated

- These are RADIO signals, so yes they go up and down at MHz frequencies….
- But if the line is perfectly terminated, and we took a voltmeter that measures RMS current over a few cycles – it would read the SAME VOLTAGE EVERYWHERE on this line.
- If we measured the CURRENT (RF current) along the line, it would be the SAME EVERYWHERE on this line (assuming no losses)
- No variation in RMS voltage or current.

Imperfectly terminated line

- If the load impedance is different from the LINE impedance, then when the signal hits the load, not all of it will be absorbed (at that point)
- Some will be REFLECTED.   There are complex changes in the PHASE of the reflected wave, that depend on how the impedance is mismatched.
- There can be only ONE VOLTAGE at a point in space at any given time.
- So the ACTUAL VOLTAGE at any point along the line is equal to the sum of the forward and reflected waves….

- Due to those PHASE CHANGES and the fact that these waves move as AC waves, there are complex but predictable constructive and destructive interferences between these two waves.
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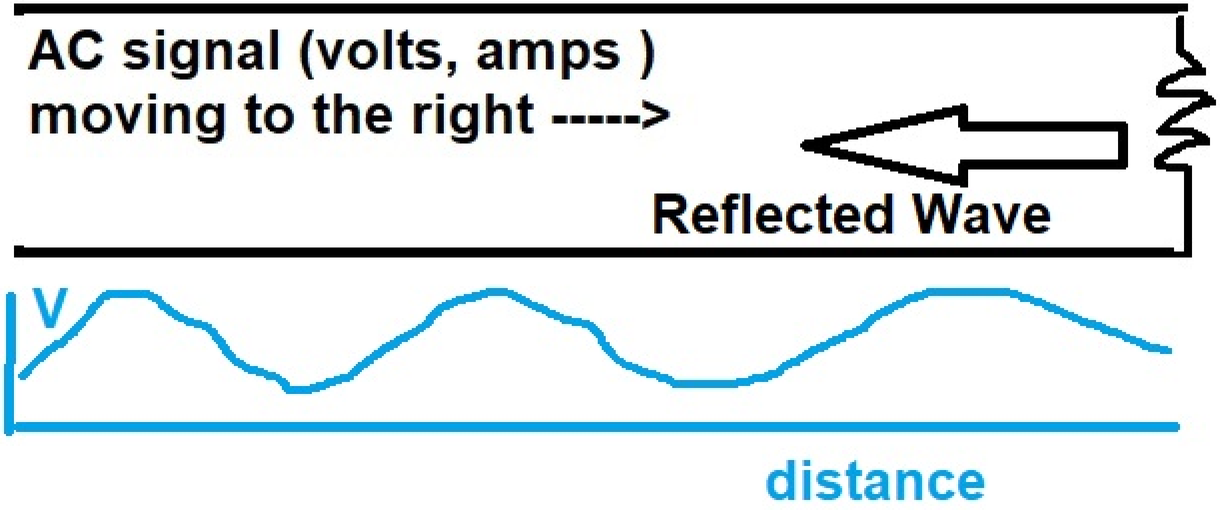
- At some points, they cause the RMS voltage to be HIGHER
- At some points, they cause the RMS voltage to be LOWER
- At some points they cause the RMS current to be higher
- At some points they cause the RMS current to be lower.

- If you were to walk along the transmission line with a voltmeter, you would discover predictable changes



The voltage at each point is a RF Sine wave of MHz frequency…. But the AMPLITUDE is what you Measure (approximately) with your Voltmeter, and you'd find that there Are evenly spaced higher and lower Voltages.

If you used a current meter, you Would find the same – but the peaks Are unlikely to coincide.

- Notice that the voltage minimums aren’t likely to be 0
- These are called “standing waves” – but they aren’t RF waves themselves-- they are just the waxing and waning of the AMPLITUDE of the RF waves combining at each point.
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- The ratio of the peak voltage to trough voltage is call VSWR. (or just “SWR”)
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- There is only one IMPEDANCE at any give point, because there is only one VOLTAGE and only one CURRENT at any given point.
- The ratio of the VOLTAGE (amplitude) the CURRENT (amplitude) is called the IMPEDANCE.   It can be resistive (in phase) reactive (way out of phase) or both (in between phases)
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- *****THE IMPEDANCE WILL CHANGE ALL ALONG THE LINE****

- While the IMPEDANCE changes all along the line (where the current gets wiped out, the impedance is HIGH; where the voltage gets wiped out, the impedance is likely to be LOW)
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- THERE IS ONLY ONE STANDING WAVE RATIO FOR THE ENTIRE LINE (assuming minimal losses)

Supreme Advantage

- The supreme advantage of SWR is that it stays constant and can be measured ANY WHERE CONVENIENT on the line.
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- You can't do that with impedance.   In order to find the impedance of the antenna, you ideally need to be on a ladder right at the feedpoint….and then you would be INTERFERING with it, anyway.
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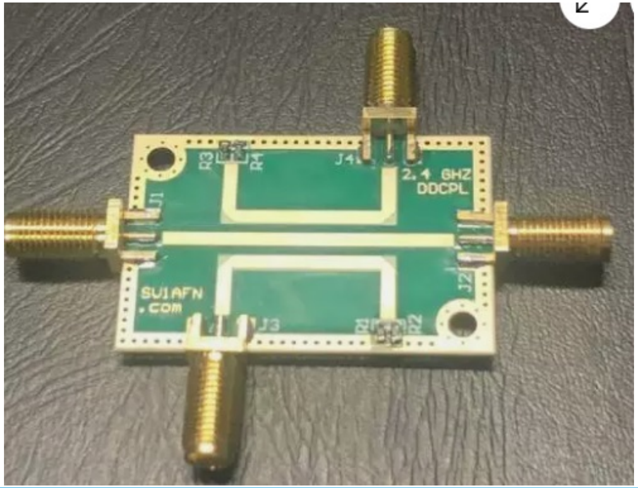
- This is why SWR is so incredibly popular.   It is convenient.

EASY, TOO!

- Furthermore, measuring SWR turns out to be relatively EASY also, while measuring impedance (including phase shifts) is TRICKY.
- DIRECTIONAL COUPLER



- The magic of setting up a parallel transmission line next to the real one – and terminating it either toward the antenna or toward the transmitter, mysteriously (lotta MATH!!) allow you to “sample” how much power is in that forward wave(s), and how much is in the reverse wave(s)
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- Simple CB SWR meters used the same thing – just larger – and literally just were using painted calibration marks to compute SWR

- Suppose we have a cheap voltmeter and we can use it to measure the the sample of the forward or reflected wave.
- Lets suppose we adjust the voltmeter so the forward wave reads “full scale” on an arbitrary voltage scale; and using the same scale, the reverse wave reads “half scale”
- Remember $P = V^2/R$? Power is proportional to SQUARE of V
- So the reflected power as a fraction is $(1/2)^2 / 1^2 = (¼) / 1 = ¼$
- 25% of power is reflected under the voltages we measured...


SWR
1
1.5
2
3
CAL
POWER

Lets run through the formula

$$\text{SWR} = \left(\frac{1 + \sqrt{\frac{P_r}{P_f}}}{1 - \sqrt{\frac{P_r}{P_f}}} \right)$$

SWR = (1 + $(0.25)^{1/2}$) / (1 – $0.25^{1/2}$) =

(1 + 0.5) / (1 - 0.5)

= 1.5 / 0.5 = 3.0 SWR

- With 25% of the power reflected at the antenna
- The reflected VOLTAGE amplitude will be HALF the forward
- That is why you use the cheap CB SWR meter the way you do:
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- Set it for forward, and bring it to full scale
- Flip it to reverse, and read the SWR off the funny scale which does the “formula” for you.

IT TURNS OUT

- There are many other ways to measure SWR.
- SWR is ALSO equal to the ratio of the load impedance to the transmission line impedance
- (or if that is less than one, take the inverse until you get a number bigger than one)
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- So a 200 ohm antenna has a 4:1 SWR on a 50ohm transmission line.

- So an antenna analyzers measures the IMPEDANCE and then uses that to calculate SWR

- Now that you know how SWR is measured, and why it is useful, what can you do with it?
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- It allows you to optimize power transfer into a mismatched transmission line – you or a computer adjust a matching network until the impedance is “transformed” to 50 ohms – giving you an apparent SWR of 1:1   (The SWR alone the line is unchanged by this wizardry – only your radio thinks it is better.)
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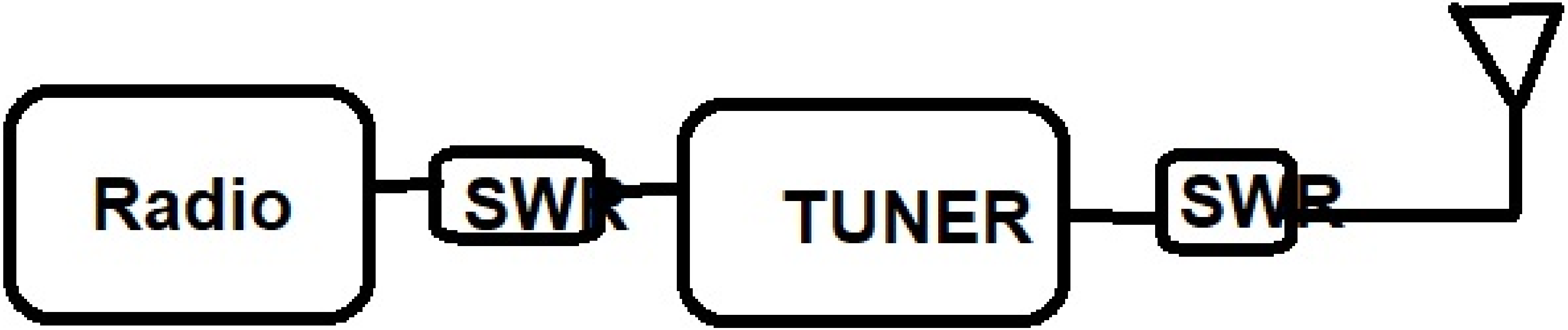
Where to put the SWR meter?



Impacts of SWR

- Reflection → changes in impedance at every point on line
- Impedance seen by transmitter can be very different from 50 ohms
- Higher impedance seen = higher voltages on transmitter components. Possible immediate destruction of marginal MOSFETs or Transistors. Possible breakdown of capacitors
- Lower impedance seen = possible overheating and destruction of marginal MOSFETS or transistors, possible damage to inductors

Inflexible Transformers

- Many solid state transmitters’ finals produce very low impedance power (e.g. multiple amperes of RF current at 12V) – only a few ohms!
- Depend on step-UP transformers to couple into 50 ohms
- Transformers: fixed impedance ratio
- Much lower transfer into even SWR of 2:1!
- Often “fold-back” circuits to protect MOSFETS etc.
- Some MOSFETS built to withstand (specified up to 20:1 SWR!)

How did TUBES do it?

- Yesteryear amplifiers used very high voltages and low currents, operating at thousands of ohms impedance.
- Required impedance transformation DOWN to 50 ohms.
- Favorite solution: pi network (looks like Greek letter π)
- Typically two air-gap rotatory variable capacitors – could match reasonably well into SWRs 3:1 or so (efficiency starts to drop)
- If unexpected high voltages? $\rightarrow$ ARC announces and little damage

Signal Purity

- Modern transmitters use extensive LOW PASS FILTERS to remove harmonics caused by semiconductor non-linearities
- Older transmitters slightly more linear and PI NETWORK also reduced harmonics (inherently low-pass)
- Intermodulation Distortion often lower on tube transmitters than solid state
- Compensatory “pre-distortion” in high end solid state amplifiers improving their performance
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What happens to reflected power?

- Long running argument
- Can be visualized in more than one way.
- **Impedance**: There is only one IMPEDANCE at any point. A mismatched system presents a non-50-ohms impedance to amplifier. Power transfer may be reduced, voltage or current stresses in amplifier may result, reduced power output.
- **Wave**: If amplifier, like transmission line, presents 50 ohms, then the reflected wave coming to the transmitter will be partially absorbed by the transmitter and partially RE-REFLECTED. This helps explain why “forward” power may be unexpectedly LARGER THAN EXPECTED in bad SWR systems.

Transmission Line Effects

- SWR results in larger voltages & currents at various points along the line, generally → increased dielectric and ohmic losses.
- AIR is much less lossy than PLASTIC
- COAX has the most losses, especially SMALL DIAMETER
- Older Window Line or Open Transmission Line mostly AIR so little loss even with HIGH SWR's. Use tuner to match, who cares?
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Examples

- Dipole hung high in trees
- Fed with 450-ohm window line (very low loss unless coated with ice)
- Low-loss air-capacitor tuner with huge-wire inductors manually tuned
- Transmitter sees 50 ohms (happy).
- Works well on multiple bands!
- Higher losses in modern auto-tuning antenna “tuner”

Matching

- Directional YAGIs at both HF and VHF/UHF can present lower impedances than 50 ohms due to parasitic element coupling
- Multiple solutions (delta, gamma etc match) – generally involve connection “farther out” from center to get to higher impedance point and possibly LC type transform made by hardware
- Combining multiple antennas (“stacked arrays”) handled by using ¼ wave coax transformers to get impedances where they need to be

FOR MOST PEOPLE: Focus on LOSSES

- Using Coax – if antenna has reasonably low SWR (<2.5) then at HF decent coax, modest distance (100ft) reasonably low loss
- If wild antenna impedances, switch to lower-loss transmission line and find a way to match into what you get!
- Our 9:1 non-resonant antennas are a COMPROMISE that have some loss but with LOW LOSS FERRITES can deliver useful performance
- Our 49:1 resonant antennas approx 1-1.5 dB loss on resonant bands
- Guanella 4:1 baluns incredibly low losses.
- Dummy Loads have low SWR! Lossy systems (“comet vertical”) have their place but know what you are doing!