The Radio Hotel – The Standing Wave – Rick – W5RH

We use the term SWR, or Standing Wave Ratio, as an indicator of the quality of the impedance match in our antenna systems – in reality it is the difference of the impedance match between the antenna (the load) and the transmission line (TL). Ideally, a 50 ohm coax wants to feed a 50 ohm antenna, but that is not as typical as it would seem. There is always some variation -- from very slight to quite a difference.

But, just what is the standing wave? Here is the story: Power, as a sinusoidal wave of voltage (and current) from the transmitter, is input into the TL and the wave moves down the TL to the load. If the TL's characteristic impedance(Z) and the load input feed impedance (Z) are equal (matched), all power is transferred to the load from the TL, hence more signal is radiated from the antenna – a good thing. If the TL and load are mismatched (not equal), there will be some 'reflection' of a portion of the forward wave back toward the transmitter. The greater the mismatch differential the greater the reflected wave amplitude. This reflected wave heads back toward the transmitter……(Yes, Virginia, you can have 2 waves traveling in 2 different directions on a TL.) Keep in mind that the forward wave is continuously being generated by the transmitter and the reflected wave is being reflected back toward the transmitter continuously. Because it is a closed system, these two waves, one traveling one way and one traveling the other, start to set up a pattern.

You know how when you look at, from the side, two passing trains traveling at the same speed in different directions on a parallel set of tracks….you see a "pattern" form by the coordinated moving spaces between the cars. Similarly, the two voltage waves, passing each other on the TL, set up a "pattern" wave of their own, called the "standing wave". It is "standing" because it not moving. It is not moving because the waves are each traveling at the same speed and, also, there is no shifting due to any difference in frequency. Understand, though, that the standing wave is an apparent/virtual wave -- the literal "sum" of the addition of the Forward wave's values and the Reflected wave's values generated, as they pass each other at each point on the TL.

How is the standing wave generated? Check out -- http://www.bessernet.com/Ereflecto/tutorialFrameset.htm

Years ago, Hams used a Lecher wire to measure wavelength, but you could literally see the standing wave voltage variations along the line – (Google - Lecher wire). Use the url above and change the SWR value to i.e. 2, 3, 5, 10 [hit enter] and see how the reflected wave amplitude increases and the standing wave maximum voltage to minimum voltage differential becomes greater. The Standing Wave "Ratio" then is the maximum voltage on this standing wave compared to the minimum voltage on this standing wave.

Next time "The Standing Wave Ratio"

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The Radio Hotel – The Standing Wave Ratio   Rick – W5RH

SWR – Standing Wave Ratio (always singular – never SWR's) – the ratio of the maximum voltage on the standing wave compared to the minimum voltage on the standing wave (the standing wave being created by the summation of the transmission line's incident or forward wave and the reflected wave. See 'The Radio Hotel' May 2014).

SWR is a snapshot of the quality of the match between the antenna (Load) and the feedline (TL).   The ratio is normalized around the TL's characteristic or surge impedance, so a Load with a feed impedance(Z) above the TL Z and a Load with a Z below the TL Z can both have the same SWR   For example -- TL is 50 ohms. Ant 1 Feed Z is 100 ohms so SWR = 100/50 or 2:1   Now, Ant 2's Feed Z is 25 ohms and SWR = 50/25 or 2:1.   Same SWR. Notice how the ratio is varied in order to keep the result above 1:1   So, from the SWR you can tell 'ONLY' the difference in the impedances of the TL and the Load.   It is obviously best to have the TL Z and the Load Z equal, but when they aren't, you need to know that, so you can adjust the antenna or the match.   Reducing the SWR to closer to 1:1 reduces the reflected wave amplitude and makes the whole system more efficient with less loss, etc. putting more power into the Load.   Lower SWR can also save your transmitter PA transistors, as they are not made to handle much reflected power or the fatal higher voltages generated by 'off resonance' system reactances that can occur. Most transmitters have power output reduction circuits to save the transistors, but that will lower your output power. Something you want to avoid, if at all possible, to maximize radiation.

It is imperative that you remember that **SWR is determined by the Load Z and the TL's characteristic Z.** The antenna feedpoint is the origin of the SWR and the position of the true SWR measurement.   SWR can be measured anywhere along the line, but loss in the line has a detrimental effect on the measurement. It causes it to be better. Better? How?   SWR can be the ratio of TL Z to Load Z, or Vmax to Vmin   or even Power forward versus Power reflected……and that is typically what we use today - Power.   We just go for max forward power and minimal reflected power.   So, where on the TL do we have the low SWR condition of 'maximum forward power versus minimum reflected power'?   At the transmitter! The forward power is at maximum and the reflected power is at minimum, as the reflected wave has occurred loss traveling from the antenna feedpoint back to the transmitter. [Note: ALL transmission lines have loss (some a lot, some very little).] Measuring the SWR at the transmitter gives you a reasonable picture of your situation, as long as you keep the loss of the TL in mind.

Take this next situation as an example of the above -- using the software **TL Details** (Google it)….. for 146.94 MHZ (WA5CYI/R), a 2 meter transceiver with a 100 foot piece of RG-58 coax connected to a ground-plane antenna. This ground-plane is 30 ohms at resonance at 146.94 Mhz.   SWR at the antenna is 50/30 or 1.66:1 SWR, but when measured at the transmitter end of the coax the SWR is 1.18:1 due to the loss in the coax.   This gives a false impression that all is OK at the antenna.   Not so and some situations are much worse than this.

Further, due to a high "matched" RG-58 coax loss of 4.6 dB at VHF, you get only 33 watts delivered to the antenna (with 100 watts out of the transmitter). With that in mind it would be much better to improve your coax quality (lower loss), so that you get more power into the Load. With lower loss, the SWR will increase at the transmitter end.   But, by knowing that the SWR is determined by the TL and Load match, you can take steps to improve that match closer to a 1:1 SWR where it really matters -- at the antenna feed point -- and put more of your transmitter power into the antenna.

Next time "SWR Measurements"

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The Radio Hotel – Measuring SWR Rick – W5RH

Measuring an antenna system's operational Standing Wave Ratio is quite easy in today's world. Not only can you measure SWR, but you can conveniently measure much more.

Typically, measurements are done with power/watt meters like the Bird 43 Wattmeter, a calibrated industry standard. It measures Forward Power and Reflected Power. That is all. From there, a forward power versus reflected power chart provides the SWR value. Some watt meters like the Diawa or MFJ meters have a crossed needle set-up – 2 independent D'Arsonval movements -- one for forward power and one for reflected power (using a Bruene-type sampling circuit). These 2 orthogonally oriented needles, with a nomograph between them, provides an easy read of the SWR value.

Recently, VNA (Vector Network Analyzer) based power meters have come into wide spread use and at a fairly low price point (thank goodness). They sample the TL (transmission line) voltage and current and then use microprocessors to perform calculations in real time and display all of the information you require: Power forward, power reflected, SWR, Return Loss (Google it), phase, impedance – vector amplitude and phase angle, plus R and +/- jx. These are perfect for analyzing not only SWR, but TL to Antenna matching, and TL characteristics (loss vs. freq or velocity factor, etc.). A bit higher in price level than a basic power SWR meter, the typical VNA based watt meter is a treasure-trove of information. [Google: Telepost LP-100A]

Whatever method of measurement you choose, there is an important point to keep in mind -- measure the SWR as close to the antenna feed point as possible to get a true reading of SWR. Of course, by knowing the TL characteristics and using a TL calculation program such as TL Details or TLW(ARRL Antenna Handbook), you can 'see' the feedpoint VSWR without leaving the ground. Measuring SWR at your transmitter output will show you what the transmitter will see, but that can be a false indictor of TL to Load match, as described in TRH May 2014.

The Ham's typical goal is to get the antenna system to have an SWR of, close to, 1:1 -- meaning maximum power into the antenna for maximum radiation (and reception strength). This can be obtained with proper antenna adjustment, TL matching, low loss coax, etc. At HF frequencies SWR concern is less critical, as the inherent system losses are not so high (they certainly can be though). But, at VHF and UHF frequencies is it best to be as close to 1:1 and even then you have significant "matched loses" that will occur if best practices on TL choice are not followed. One last bit of warning: be wary of antenna systems that require you to use a longer than necessary length of coax (in order to get the SWR down, at the transmitter). This requirement screams "LOSS".

Next time "Antenna Bandwidth and SWR"

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The Radio Hotel –Antenna Bandwidth & SWR   Rick – W5RH

Over the past 4 submissions of The Radio Hotel I have talked about SWR. What generates it, what it is and how it is measured. In all of these discussions I have stated that the SWR is an indicator of the differential of impedances at the junction of the TL - transmission line and the Load – the antenna (commonly known as the feed point). Since the TL is always of a predetermined surge impedance (i.e. 50, 75, 300, 450, 600 ohms), the antenna feed impedance (Z) is the most significant side of that equation. Our desire is to have the antenna have the same Z as the TL. Fine, but Ham's have bands of HF frequencies to work on and not just a single frequency. Because of this, a dipole being "resonant and a close match" in the middle of the band, will not be resonant or matched at the ends of the band.

Just what is the range of the feed Z of a dipole over a typical band of frequencies? And how does this "change in feed Z" influence the SWR? Let's take a look.

Using EZNEC, I modeled a full length dipole -- ½ wavelength off the ground and resonant at the middle of the band. I charted the feed Z and SWR at that center frequency and also at both ends of the band. The chart below shows the values for 160, 80, 40, 20 and 10 meters. (the other bands 30,17,15,12 are quite narrow and vary very little). The dipole is modeled with #12 solid wire, stretched horizontally above the Earth.

Band	Center MHz	Feed Z ohms	SWR	Low MHz	Z	SWR	High MHz	Z	SWR
160	1.90	71	1.4	1.8	65 –j93	4.53	2.0	77+j103	4.72
80	3.75	71	1.4	3.5	65 –j109	5.63	4.0	80 +j123	5.87
40	7.15	72	1.45	7.0	69 –j27	1.75	7.3	74 +j40	2.14
20	14.20	72	1.45	14.0	70 –j12	1.49	14.35	74 +j24	1.74
10	28.50	73	1.51	28.0	70 –j13	1.5	29.1	75 +j35	1.99

You can see, as the frequency bands go higher, the narrower the bands and the less frequency change from band edge to band edge. The SWR "swing" has a diminishing width. 160 and 80 (with the most bandwidth change of any band) are the tough bands to match with a single resonant point system. Their SWR swing from the lowest frequency to the highest frequency is quite wide -- i.e. 5:1 thru 1.4:1 at mid-band and then back up to 5:1 again. To cover the whole 160 or 80 meter bands, some hams use open wire TL's and an ATU, while others use wider bandwidth antennas like cage dipoles or multiple wires in parallel, each cut for different portions of the band.

The higher frequency bands, 20 meters and up, stay under 2:1 SWR for the whole band and are, therefore, easily matched with 50 ohm coax across the whole band. For these bands, you can just use an "in shack" tuner to trim the matching so the transmitter puts out the full tilt wattage for which it is built. Unmatched line loss remains fairly low at these low SWR ratios. Thank goodness.

The above cursory study is what happens with resonant wires on the band of design choice and use. But what happens on a single dipole that is used on other bands? The SWR goes wild at times, especially on the even harmonics. Matching networks/ATU's are implemented. What happens in those matching networks and what happens on the transmission lines? That will have to wait until next month.

Next Time: Matching, reflections and the magic of wave mechanics.

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The Radio Hotel –Matching within the Antenna System Rick – W5RH

The whole premise of paying attention to the antenna system's SWR is to lessen the losses within the antenna system and, therefore, provide the maximum amount of power out (and reciprocally, reception strength in).

On most Ham Radio antenna systems you have an antenna that is nominally 50 ohms feed Z, coax that is nominal 50 ohms characteristic Z and a transceiver that has been designed to output into a 50 ohm system. All components are then closely matched, providing a nominal 1:1 SWR. Recall that, even in a perfectly matched condition that there are "matched" system losses. For one, coax is inherently lossy. Just how lossy is dependent on the coax type. *(Google: coax attenuation chart W4RP)*

As seen last month (TRH Sept 2014), even within the confines of 80 Meters the SWR can vary widely. Also, depending on the antenna feedpoint location the SWR can be very high. For example, with a ½ wl end fed wire, the antenna feed Z is greater than 1K ohms creating a 20:1 SWR. Another example is a center fed, multi-band dipole that is used on the second harmonic or other non-resonant bands. The feed Z could vary between 10 ohms and 2K ohms and be very reactive, hence generating a 50 ohm SWR of greater than 40:1. For all of these examples, some type of impedance "matching" is required.

Matching can be provided anywhere along the TL (transmission line). This matching is accomplished by a network of lumped inductive and capacitive components. *(Google: impedance matching).* The network could be a manually adjusted L, Pi or T network or it could be a fully automatic ATU "Antenna Tuning Unit" (or Coupler) operating remotely at the antenna feedpoint. (*Google: antenna tuner and antenna coupler*) Matching right at the antenna feedpoint is best, as it causes the TL to see a load that is matched to its' characteristic impedance (i.e 50 ohms for coax, 600 ohms for open wire line, etc.), so maximum transfer of power happens and only the matched TL loss is incurred (plus a bit of loss within the matching network itself).

You could move the matching network down the TL toward the transmitter to some physically convenient point (like on the ground) or, as most Hams do, move it all of the way back to shack end of the TL. But if you do, then the effect of the feedpoint mis-match will cause increased loss due to a higher SWR on the TL between the matching network in the shack and the antenna feed point at the other end of the TL. (Note: This is why Hams, implementing this "in shack" configuration, will use open wire or parallel wire transmission line between the ATU and the antenna – open wire line has much lower loss than coax.)

If the ATU provides a match of 1:1 right at the transmitter, then the transmitter will see 50 ohms and it will dump full allotted power into the matching network, which will then transfer most of that power into the TL (some loss in the matching network will occur). This power will then travel on the TL to the antenna, see the feedpoint mis-match and reflect a portion of the Forward power (see TRH May). The Reflected wave heads back to the matching device in the shack and is then, due to complementary wave mechanics, reflected back toward the load. All the while, losses will occur on both the forward and reflected waves traveling back and forth, hence the increase in loss, over the matched TL loss, when a greater than 1:1 SWR is on the TL. Matching in the shack is common practice and can be made efficient with the use of the proper TL/feedline and the properly sized matching network.

Understand antenna system characteristics (i.e. antenna feed impedance and matching network type and location within the system) and their affect on TL losses is most important for implementing the best system for your particular situation. This is what **The Radio Hotel** is trying to accomplish; to provide you with a baseline knowledge about the TL--transmission line. TL's can be a bit of a gray area for some Hams. Let's hope after the past few months that it is less gray.

Next month -- The last piece to the SWR/Matching puzzle.

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The Radio Hotel – Reflected Reflections -- Rick W5RH

What occurs when an Antenna Tuner is placed in the transmission line –TL at some point? What happens to the reflected power that is sent back towards the transmitter from the mis-matched antenna load? Is it lost, is it absorbed, is it radiated…. just what happens? The answers to these questions lies in the organized confluence of complementary impedances, phasing and wave mechanics. There is much more detail than TRH has space to deal with, but I can give you the cursory, 20,000 foot perspective.

An Antenna Tuner, aka Matching Network – MN, is a variable RF transformer that matches the impedance (toward the load) seen at its' output, to the impedance (toward the xmitter) seen at its' input. When matched, you get the maximum amount of power transferred. In the RF world this match is called a "conjugate match", which is 1) making the R values of these two impedances equal; and 2) providing the complement of the imaginary, or j term, in the impedances. For example: if Zout=150 +j50 ohms then the MN provides the complement of 150 –j50 ohms -- mathematically called the "complex conjugate". Hence the name for the match: conjugate match. This complex conjugate matching causes a "maximum power transfer condition". (Google "Conjugate Match" and "Maximum Power Transfer Theorem").

This matching can be accomplished using many network types; the choice is dependent on where the network is applied. At the antenna, you can have Gamma matches, Hairpins, stubs, etc. If it is located within the TL, you can have L, T, and Pi…networks (named after the shape the network elements take in the schematic). These networks are what are inside those "tuners" from MFJ, Palstar, LDG, SGC, etc.

The MN, by setting up this complementary impedance match, also produces complementary wave mechanics and wave phase interactions that cause the reflected waves coming back from the antenna to be "re-reflected" at the MN and then to add, in phase, with the forward going waves continuously traveling toward the antenna from the transmitter. These "reflected reflections" create a "circulating current" of forward and reflected voltage and current waves on the TL. (For a complete (in depth) explanation of this process, Google "Another look at Reflections K6MHE" go to page 24 and read section <u>Reflection Mechanics of Stub Matching</u> – Walt Maxwell explains this process in intimate detail.)

Simple proof that all of the reflected power is truly re-reflected is the observation that the SWR on the TL, from the load to the MN, is something greater than 1:1, but from the MN to the rig it is 1:1, a matched condition. When the SWR is 1:1 there is no reflected power. Zero, Zip, Nada! All power input from the transmitter (except for TL and MN loss) is transferred to the antenna system. The term "reflection gain" is used by Maxwell for this situation where reflected power is added to the forward power, creating, literally, a higher forward power level to the antenna than what the transmitter outputs.

Summary. What does all of this mean to us Hams? First, it shows us that our antennas, TL-feed lines and MN-matching networks are indeed a "closed system" where one change affects the whole system, etc. Second, now that we know that all the power is re-reflected and eventually makes it to the antenna to be radiated and the only losses are the matched TL losses and the minimal MN losses, then the thing to concentrate on is to lessen the TL losses and the MN losses by using lower loss coax/feedline and a more efficient MN.

If everything is implemented properly, the losses incurred will be minimal and you will get maximum power out to the antenna and stronger signals into your receiver. Coax can be used, as it is convenient, but when dealing with multi-band antennas or unmatched antennas on tuned feeders, then it is best to use open wire line or ladder line to lower the loss. The SWR might be higher, as these balanced feedlines run characteristic impedances of 400 ohms and up, but the overall losses incurred will be lower than with coax.

For this series, we started out 6 months ago defining SWR and ended up this month discussing the results of complementary wave mechanics on the TL. A lot of RF thru the proverbial RF bridge (HI). I hope you go back and reread the past 6 columns in order to make sense of what is happening on your TL and understand why it all works as it does and why in the end we get Reflected Reflections. Enjoy – Rick – W5RH

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The Radio Hotel– SWR/Matching & Learning More by W5RH

In the past 7 months I have tried to show how the antenna system's components all work together and how they interact. The Radio Hotel column's subjects all centered around the SWR – Standing Wave Ratio. Much more detail in the system's workings needs to be understood in order to get a complete picture. Back in the 80's, when I was relearning RF electronics, it took me quite awhile for all of this to make sense with all of the interactions that are happening. I truly hope that it takes you much less time than I. Once you understand the theory it's great, as you can immediately apply that knowledge to any antenna system situation and understand what that system is trying to accomplish and how it is doing it. Another nice thing is that you will stop worrying so much about SWR and the "bad things" that it brings. You will take care of what you can using the best components and just operate.

So, the final step in this series on SWR is for you to extend your knowledge beyond that given in **The Radio Hotel** over the past 7 months. This is where you come in and take over with some extracurricular reading material. I will recommend 3 of my favorite books about transmission lines and the "system" that are worth their weight in knowledge gold:

1) <u>ARRL Guide to Antenna Tuners</u> – Joel Hallas – W1ZR ARRL 2012 (very practical)
2) <u>Reflections</u> (1, 2 or 3) – Walt Maxwell (particularly applicable Ham Radio based theory)
   (the free 1967 QST series will do just fine)
3) <u>Antennas , Transmission Lines and Wave Guides</u> -- King, Mimno and Chen (1947)
   (includes -the secret ingredient of the infamous W5GI "Mystery Antenna")

(Note: I have also compiled a listing of a substantial bibliography of the articles I read and referenced to write this series on SWR. You can find that list on the BVARC.org website – Click on the "Tech Articles" page link in the Home page left side listing then on that page find **The Radio Hotel Bibliography.pdf**)

If any of the above books don't quite do it for you, there are many others, like the ARRL Antenna Handbook (any issue, 1939 to the present). You should realize that one author might sound like jibberish, but another explaining the same thing, will grab you with clarity. Some enjoy Hemmingway, others like Bill Bryson. Choose an author and writing style that suits your knowledge fancy. (This is a hobby, not a graduate course) If you are like me you will not "get it" on the first read (I do hope you do though). I take the advice of the late Dr. Richard Feynman about understanding: take one sentence, or fact, at a time, understand it, and then build on it and its' interaction with the next fact.

Some software would be good too. There are 2 TL application calculators that I can recommend. TLW, by Dean Straw, from the ARRL – usually on the Antenna Handbook DVD. Also TL Details, by Dan Maguire, AC6LA, downloadable ZIP file from the web at http://www.ac6la.com/tldetails1.html . Both of these applications are really sweet TL calculators and they will show you a whole lot about transmission lines and matching. Little by little…step by step…inch by inch….it will all start to make sense. Good luck.

Finally, if I had a bit of wisdom to impart about antennas it would be 2 things -- 1) that antennas should always be looked at as a "system" consisting of transmission lines, matching networks and the antennas themselves; and 2) a firm grasp of the fundamental principles and characteristics of antennas and transmission lines is absolutely essential for it to all make sense. If a working knowledge of antenna systems is what you want, then find yourself an "Antenna Elmer" who can answer your questions and banter with you knowledgeably in discussion.

I hope you have enjoyed this first series in **The Radio Hotel**. (If not, please, let me know your comments) I hope to start up again soon and talk specifically about antennas. Why they work, how they work and their varying characteristics. Here's hoping that you get a good antenna or transmission line book from Santa. Happy Holidays to you and yours, whichever holiday you celebrate. 73…..Rick – W5RH

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The Radio Hotel SWR Series Bibliography-- W5RH

For the 2014 series on SWR and Antenna Matching, I used the following references and encourage you to chase them down and read them to gain more intimate knowledge and understanding of transmission lines and matching.

Articles:

The Why's of Transmission Lines – George Grammer – W1DF
QST Jan, Feb and March 1965 (ARRL On-line Archives)

My Feedline Tunes My Antenna – Byron Goodman – W1DX
QST Nov, 1991 (ARRL On-line Archives)

Losses In Feedlines – Byron Goodman – W1DX
QST Dec. 1956 (ARRL On-line Archives)

Web Sites:

HF Balanced (Transmitting) Systems – www.G4NVH.net Tech. Resources

Books:

Radio Antenna Engineering – LaPorte (available on the web)
Chapter 4 – Radio Frequency Transmission Lines

Reflections – Walt Maxwell – any edition (1,2 or 3 – even online, QST 1967)

TC 9-64 Communications Electronics Fundamentals – US Army – July 2004
www.us.army.mil

Antennas, Transmission Lines and Wave Guides – King, Mimno and Chen (1947)

ARRL Guide to Antenna Tuners – Joel Hallas – W1ZR ARRL 2012

Should you have any questions about the articles or the references given, please, give me a call or an e-mail.

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