**SWR SEMINAR** By Terry Darling **VE3CAB**

## INTRODUCTION

The purpose of this seminar is to educate us on that vague term S.W.R its use and more prevalent misuses by most of us involved in Amateur Radio, Transmission lines will be studied very briefly in order that a few basic concepts be understood about electromagnetic wave propagation through a line from the generators (transmitter) to the load (antenna).

Most of the material for this seminar was taken from QST articles entitled REFLECTIONS by Walter Maxwell J2DU, Parts 1-6 as listed in the Bibliography, The basic concepts were taken from a Communications course ELT405 of Ryerson Polytechnical institute.

I would strongly suggest that the Amateurs interesting in thoroughly understanding SWR read the QST articles as listed in the Bibliography.

## TRANSMISSION LINES

Any set of conductors which is used to carry electromagnetic energy from one place to another is deemed a transmission line* At high freq- uencies such as we use in Amateur work the signal changes so rapidly at all points on the line that the time needed for the signal to move down the line becomes great compared to the frequency of the signal voltage.,

### A Balanced Transmission Line?????

A Balanced line is one in which both conductors are the same and situated a like distance above ground, actually meaning they are both ungrounded. The use for this type of line is between an ungrounded source and load. Eg: Tv and folded dipole

The balanced transmission line looks to the source 3 (Transmitter) as shown below in Diagram 1. It exhibits series inductance, L series resistance, R, and shunt capacitance between the wires, C, as well as shunt admittance G (Admittance = fancy name for a resistor in parallel)

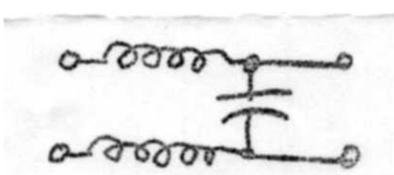


Diagram 1

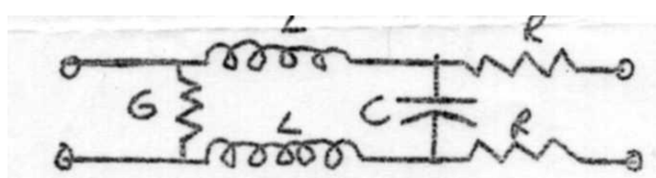



Diagram 2

Generally for high frequency work the series R and shunt G can be eliminated to give the more general representation of a Balanced Transmission line as shown In Diagram 2

### An Unbalanced Transmission Line

The best example of this type of line is the very familiar Coaxial Cable we all use. Unbalanced means that both wires are different in dimensions, and that one is grounded while the other is at a potential.

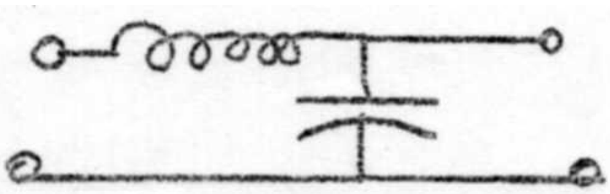


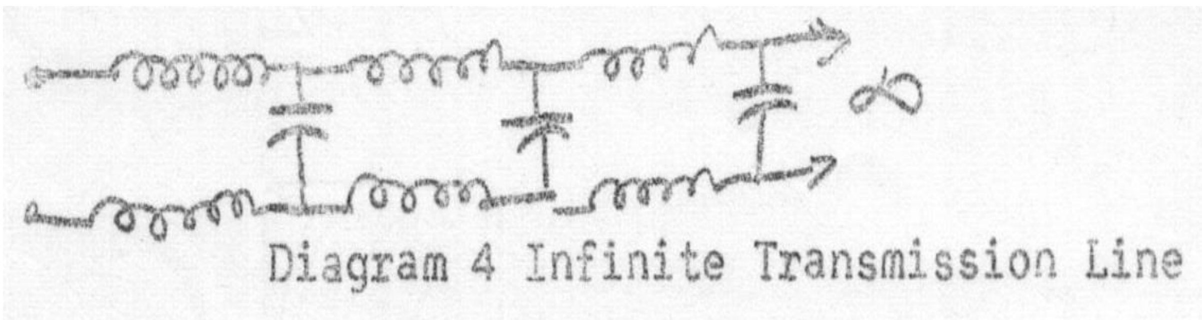
Diagram 3 Coaxial Cable Representation

In the unbalanced line, it is generally represented as assuming all the resistance occurs in one of the wires.

**(**Be careful: The word assume is made of 2 words, **ASS** and **MULE)**

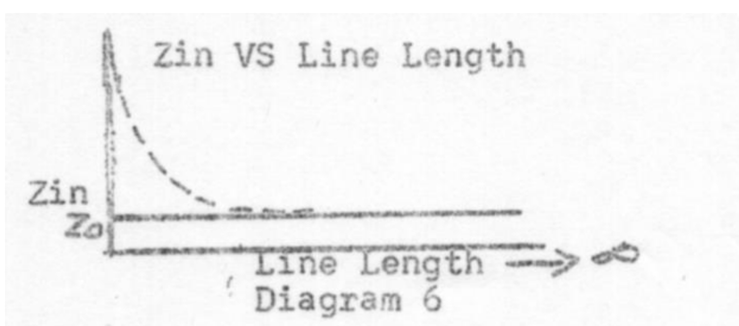
**CHARACTERISTIC IMPEDANCE**

If we "Cascade" a number of these sections together as shown in diagram 4, then we would have the true representation of an "Infinite transmission line”.




If we could apply and measure an input current and voltage to the terminals of the input then we could calculate the input impedance from the relationship that Zin = Input voltage/current. This measurement would give us the characteristic impedance of the particular line we were measuring which includes the series L, R, and shunt C.

We would find that as we added many of these sections on the effect on the input impedance would be much smaller than the previous section. Obviously then, the input impedance is approaching a finite X value, as the length of the line approaches Infinity. The limit that this line approaches is called The Characteristic Impedance of the line.




The characteristic impedance of a coaxial cable (ZO) can be pre-deter-mined by a formula which uses the diameters of the inside and outside conductor diameters.

**TERMINATION OF LINE BY R=ZO**

Wave motion and energy conditions can be examined on any section of line terminated by R=ZO. As in the case of an infinite line, energy travels down the line, but now, except for the small amount of energy that is attenuated in the resistance of the line, all the energy is delivered to, and dissipated by the load* maximum energy is transferred from the source to the load. In this case there is NO reflection of energy. As far as the source is concerned the line appears infinite because it sends out energy and does not see it again. In summary, any line terminated by a resistive load equal to the characteristic impedance acts as an infinite line:

a) Input impedance-ZO and is resistive
b) No reflections occur on the line
c) Current and voltage are in phase
d) Maximum energy transfer from source to load

**STANDING WAVES ON TRANSMISSION LINES**

We will now consider what happens if we terminate the line with a load which is not the same as ZO As the wave is launched down the line it will begin as if the line appeared infinite. However, the wave will find discontinuity which causes a disturbance in voltage and current distribution. 2 possible cases of discontinuity we can throw at the transmitter are explained.

**1) REFLECTIONS ON AN OPEN ENDED LINE**

If our transmission line was left open at the other end, it would have a load impedance of infinity. The first waves of voltage and current as our transmitter is turned on would have voltage a current in phase with each other. (ie: both peaks would occur at the same time.) The in-phase relationship of these waves will remain the same until they encounter a difference in impedance between the two wires.

As the current reaches the open end it must collapse to zero because there is no place for the electrons to flow. We all should know from our electrical theory that a current must establish a magnetic field. We also know that as an electric field collapses about a conductor a voltage is induced in the conductor. Since the current at the open ended transmission line collapses to zero, a voltage is induced in the wires at the open end. This voltage acts as a "reverse" generator and sets up new current and voltage waves that travel back from the open end toward the transmitter. THIS is called REFLECTION. Since current is a minimum and voltage is a maximum at the open end, then the two waves are said to be 90 electrical degrees out of phase with each other.

The beginning of the two waves (voltage and current) which start back toward the transmitter have the same polarity as the incident wave which travels from the transmitter to the open end even though the two are varying in magnitude at the output end, they will always add to form AC voltages and currents that are the sum of both the incident and reflected waves. In summary at the output end or **any** OTHER POSITION on the line there is a constant AC voltage and current that is the sum of the travelling waves mentioned.

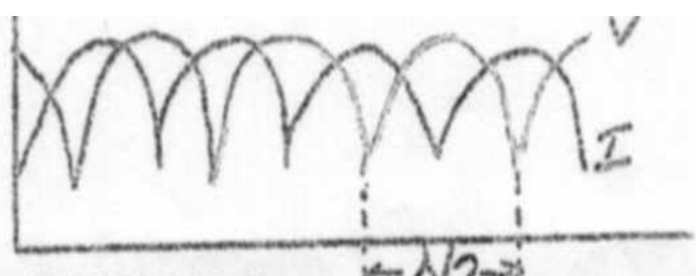



DIAGRAM 5
Standing Waves On an Open Ended Line

The Standing waves are stationary on the line as the name standing implies. If we could measure the voltage or current on the line we would find that the max, and minimum would occur a half wavelength apart as shown in the above diagram 5.

**2. REFLECTIONS ON A SHORT CIRCUITED LINE**

Since a short circuit is a condition of zero resistance, the current at the end of the line has a value maximum. Even though the voltage will have a minimum value, reflection will occur because none of the energy of the incident wave is absorbed by the short circuit. Voltage and current are 90 electrical degrees out of phase with each other as in the previous case but the current is maximum at the load end while the voltage is a minimum.

3. **REFLECTIONS ON A LINE TERMINATED OTHER THAN BY AN OPEN OR SHORT CCT**
When a transmission line is terminated other than by #1 or **#2** conditions the situation will be somewhere between the two. There will be incident and reflected waves on the line resulting in standing waves of voltage and current, unless of course the termination satisfies the condition RLoad=ZO Diagram 6 shows the RMS voltages and currents on a transmission line on which there are no standing waves.

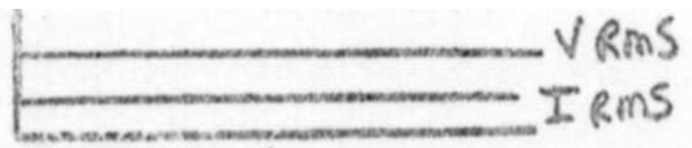


DIAGRAM 6

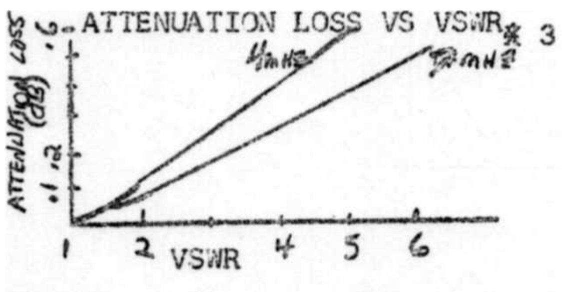
**THE STANDING WAVE RATIO**
The optimum condition for transmission line and load combinations is one in which the maximum values of voltage and current along the line are equal to the minimum values. No reflections present) A figure of merit which indicates how close we are to the optimum condition is defined as the standing wave ratio which is simply the ratio of maximum voltage to minimum voltage or maximum current to minimum current. Note on diagram 5 that the minimum of both the voltage and current will not = 0. Note from diagram 6 that the ratio of maximum to minimum voltage or current is the same, or 1:1, the ideal case, ideal ONLY meaning that standing waves are not present, or in other words the line has been terminated by Rload = ZO.

***WHAT* HAPPENS TO REFLECTED POWER???**
The amount of reflected power lost is not dependent on the SWR alone. The attenuation factor for the specific feedline must also be included. Note this very important point: The ONLY reflected power lost is the amount dissipated in the line because of the attenuation, the remainder returns to the load. That is to say it is re-reflected back to the load from the transmitter. As the SWR increases the amount of reflected power increases but ALL of it returns back to the load anyway EXCEPT for the little which is attenuated in the line as it goes back and forth between the transmitter and antenna many times depending on the degree of mismatch. The higher the SWR the more times re-reflections occur.

From the viewpoint of amateur communications, it can be shown mathematically and easily verified in practice that the difference in power transferred through any coaxial line with an *SWR* of 2:1 is imperceptible compared to having a perfectly matched 1:1 termination, no matter what the length or attenuation of the line, and that many typical feedlines (coaxial) that we use in the HF bands with an SWR of 3 or 4 and often as high as 5 to 1 have an equally imperceptible difference.

What is being said, then, is that the lower the feedline attenuation the higher the values of SW that can be permitted as far as not losing much power is concerned. ONCE again "All reflected power reaching the source is returned to the load as part of the incident wave. The only power lost is because of the line attenuation, during its return to the source and once again during its return to the load (antenna).

Diagram 7 below shows the effect of S7/R on line loss at 4 and 7 Mhz for a 100 ft. section of RG8 for typical SWR values.




In a typical realistic case where the attenuation is .5db (175 feet of RG8 at 4Mhz or 85 feet at 14 Mhz.) if the load were perfectly matched to the line SWR = 1:1 the 100 watts delivered would be attenuated to 83.13 watts during travel to the load. But with a 3:1 mismatched load the additional one-way attenuation (due to SWR) is 0.288….83.41 watts is delivered to the load. This means that with an SWVR of 3:1 we only lose 5.72 watts due to an increase from a perfectly matched load VSWR of 1:1 to one causing a mismatch 3:1. Is it really worth reducing the SWR to 1:1???

**SO WHY WORRY ABOUT SWR?**
**Dielectric Breakdown**
As far as Amateur work is concerned;, we need not be concerned about dielectric breakdown with RG8u coaxial cable and the legal power limit we are confined to. That will occur in commercial work (*or by using a KW with a high VSWR on RG58*) with a high VSWR, is that the voltage peaks along the line will be substantially increased. As the voltage peaks increase with increasing VSWR, a point will be reached in which arcing over will occur between the centre conductor and the braid. This is the same effect as applying a voltage far in excess of the rated value on an electrolytic capacitor which will break the dielectric down and destroy the capacitor. Just in passing, a general rule of thumb is that the peak voltage on a transmission line with SWVR greater than 1:1 will = sqr root of the matched value of peak voltage at SWR = 1:1.

**TRANSMITTER DAMAGE**
As was previously explained, reflected power does not flow back into the transmitter and cause heating and other damage. The damage blamed on reflections is caused by improper output-coupling adjustment not by the SWR.
Tube overheating is caused by either or both of the following things:
1) over-coupling and
2) reactive loading indicative of improper tuning.

Tank-coil heating and arc overs occur because a rise in Q of the circuit is caused by under-coupling. With manipulation proper output coupling can be achieved no matter how HIGH the SWR.
The transmitter doesn't see an SWR but only an impedance resulting from it. The impedances can be matched quite well in some transmitters without concern for the SWR.

References
1973 Apr Jun Aug Oct Dec QST
Walter Maxwell April 1973 QST pp35-40
Ryerson Polytechnical ELT 405 Communication Systems