Standing Wave and SWR

SWR or **S**tanding **W**ave **R**atio is one of the most misunderstood terms in amateur radio. Even though every antenna and transmission line book that I have seen, is quick to point that out, it still is the source of many misconceptions. To most hams with an SWR meter, SWR is whatever the meter reads and if the meter says there's no problem, (SWR is low enough) then the antenna is well. That simply isn't true. So, I will once again explain what exactly SWR is and isn't. First of all, SWR is not an antenna property or a characteristic. SWR is a measure of an antenna system. An antenna system consists at least of two parts: the antenna itself and the feedline from the antenna to the transceiver. Additionally, the antenna system may include, transformers, baluns, matching devices such as an Antenna Tuning Unit, (ATU) etc.

When a wave traveling along a transmission line (with characteristic impedance **Zo**) from the transmitter to the antenna (incident wave) encounters an impedance (**Za = Ra ±jXa**), that is not the same as **Zo** then some of the wave energy is reflected (reflected wave) back toward the transmitter. Whenever two waves of the same frequency propagate in opposite directions along the same transmission line, as occurs in any system exhibiting reflections, a static interference pattern (standing wave) is formed along the line.

In the best circumstances, we would use a 50-Ohm transmission line to connect a 50-Ohm impedance antenna to a transmitter rated at 50-Ohm output impedance. In that case, everything is matched and as long as we make sure there are no currents flowing on the coax shield, everything should work great. Since all parts of the system are matched, transmission line losses are minimized, the transmitter can operate at its designed efficiency and almost all of the power output by the transmitter will get to the antenna and be radiated.

For the purposes of quantifying reflection magnitude, we are interested in the amplitude of the voltage or the current maxima and minima. The SWR is defined as the ratio of the voltage or the current maximum to the voltage or current minimum along a transmission line as follows:

$$\mathbf{SWR = V_{max} / V_{min} = I_{max} / I_{min}}$$

SWR can be measured using either a current or voltage sensor as it is moved along the transmission line while comparing the maximum with the minimum. SWR is always greater than or equal to one. If no reflections exist, no standing wave pattern exists along the line and the voltage or current values measured at all points along the transmission line are equal. In this case, the impedance match is perfect and the SWR equals unity.

The most and convenient method to measure the SWR is using a reflectometer. This instrument comprises two power meters, one reading the incident power and the other the reflected power. Power detector directivity is possible because the incident wave voltage and current are in phase and the reflected wave is 180º out of phase.

What is SWR really? SWR is one way to register the mismatch between the ultimate load and the transmission line characteristic impedance. SWR is a measure of what conditions exist on the transmission line. Those conditions exist all along the transmission line with a little allowance for some line losses. SWR is not a measure of how well the antenna works. Low or high numbers can occur for antennas with identical far field patterns operating with essentially the same efficiency. As example: a half-wave dipole with 75-ohm resonance impedance, either fed with a coax of 50- or a 450-ohm window ladder line, will have different SWR along the transmission line; respectively 1.5 for the 50-ohm coax line and 6 for the window ladder line. But the performance of both dipoles will be practically the same when both antenna systems are properly matched to the transmitter's 50-ohm output impedance.

I want to clear up one common misconception and that is why as said above: resonance impedance (= only resistive). SWR is not simply the ratio of the antenna impedance (**Za**) to the **Zo** of the transmission line. The antenna impedance is nearly always a complex value having not only resistance but also reactance either capacitance or inductance (**jX**). Consider the following antenna impedances presented to a 50-ohm coaxial cable in **Table 11.1**.

Za	Zo	SWR
50 jX 0	50	1
75 jX 0	50	1.5
100 jX 0	50	2
50 jX 50	50	2.62
75 jX 50	50	2.42
100 jX 50	50	2.62

Table 11.1. *SWR with different antenna impedances* ***(Za)*** *and equal transmission line impedance* ***(Zo)*** *either without reactance (jX 0) or with reactance (jX 50)* ***.***

To illustrate standing wave, I modeled a 300-ohm feedline, **[11-3.EZ]**. The source is at the left and the load at the right, **Figure 11.4.** I considered four different antenna loads and two power levels:

- **Case A.** The antenna load impedance equals exactly the characteristic impedance of the transmission line Za = Zo = 300 ohms and is purely resistive. If we should measure the voltage or the current at any point along the transmission line, they should be the same. No reflected wave should be noticed and the SWR shall be 1:1.

- **Case B.** The antenna load impedance is twice the characteristic impedance of the transmission line Za = (Zo X 2) = 600 ohms and again purely resistive. If we should measure the voltage or the current at any point along the transmission line, they should differ. We should find points of maximum and minimum voltage and current. This indicates the existence of a standing wave. When we divide the maximum voltage or maximum current by the minimum voltage or minimum current we should have a ratio of 2:1 being the SWR.

- **Case C.** The antenna load impedance is twice the characteristic impedance of the transmission line but has also a reactance of jX 300 ohms. The complex antenna impedance is now 600 jX 300 ohms. If we should measure the voltage or the current at any point along the transmission line they should also differ. We should find also points of maximum and minimum voltages and current but they should differ from case B with no complex impedance. Here also, the existence of a standing wave. When we divide the maximum voltage or maximum current by the minimum voltage or minimum current, we should have a ratio of 2.58:1 as being the SWR.

- **Case D.** The antenna load impedance is five times the characteristic impedance of the transmission line but has also a reactance of jX 300 ohms. The complex antenna impedance is now 1 500 jX 300 ohms. If we should measure the voltage or the current at any point along the transmission line, they should again differ. Here also is the existence of a standing wave. When we divide the maximum voltage or maximum current by the minimum voltage or minimum current we should have a ratio of 5.05:1 as being the SWR.

The current plots of the four above models are found at **Figure 11.4** and the computed voltage, current and SWR at **Table 11.2.** When the SWR becomes rather high then the current and voltage can become extremely high in special with high power. That's why transceivers as precaution, reduce the output power when it encounters high SWR. The high current or voltage could when to high, destroy transceiver output components. Also, caution should be taken in the choice of the transmission line to withstand the high voltage.

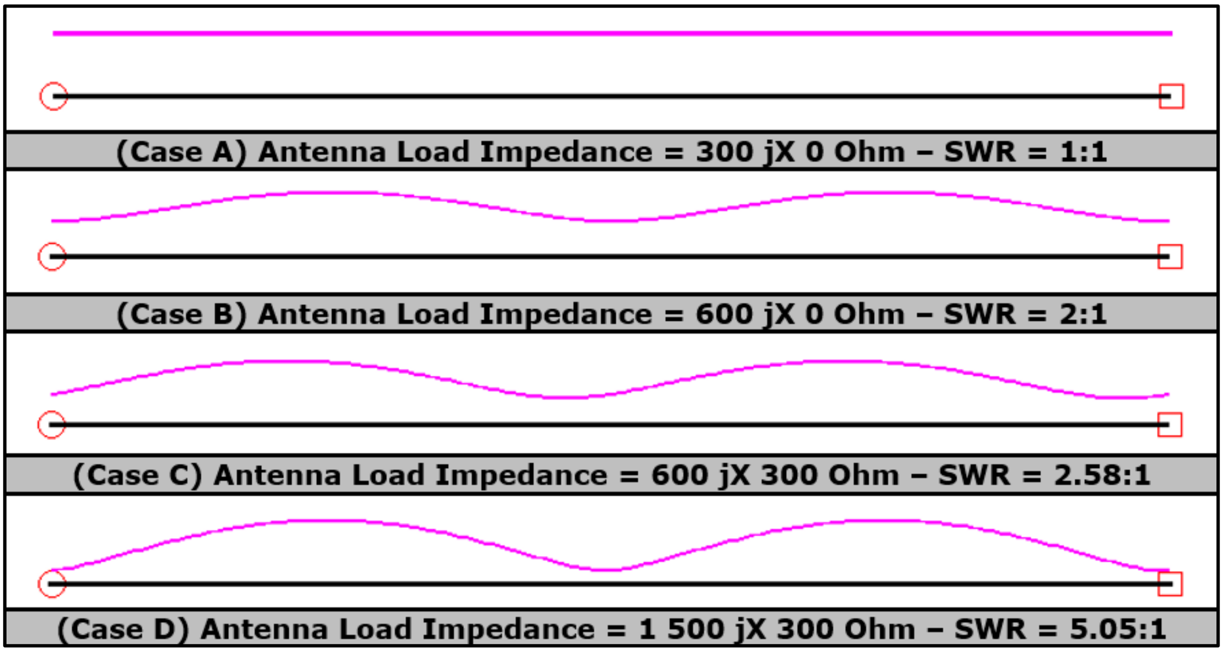

Figure 11.4. *The current along a modeled transmission line with various antenna load impedances*

Load Ohm	Power Watt	Minimum Current Ampere	Maximum Voltage Volt	Maximum Current Ampere	Minimum Voltage Volt	SWR Ratio
300 jX 0	100	0.58	173	0.58	173	1:1
300 jX 0	1 000	1.82	548	1.82	548	1:1
600 jX 0	100	0.41	244	0.82	122	2:1
600 jX 0	1 000	1.3	771	2.59	385	2:1
600 jX 300	100	0.4	273	1.05	106	2.58:1
600 jX 300	1 000	1.28	862	3.3	334	2.58:1
1 500 jX 300	100	0.26	389	1.3	78	5.05:1
1 550 jX 300	1 000	0.82	1 230	4.1	244	5.05:1

Table 11.2. *The maximum/minimum voltage and current, and the SWR obtained along a modeled feedline of 300 ohms with various load values and a power of 100 and 1000 watts.*

A mismatch between the antenna impedance, the transmission line characteristic impedance and the transmitter output impedance always leads to a standing wave and a certain SWR. Having an SWR in your antenna system is inevitable.

First, having an antenna with a load impedance equal to the characteristic transmission line impedance is not always achievable. The choice of different feedline impedances is not to great

Second, the lowest SWR is at the resonant frequency and will always increase when working more toward the frequency band edges. So, the magic 1:1 SWR (for most hams) is hard to obtain.

Having SWR in your antenna system leads to extra power losses. But even so, is having the lowest possible SWR always a concern to pursue?

Ham radio has its share of misinformation, misconceptions and misunderstandings among its participants. It seems to me that perhaps the most widespread amount of confusion stems from misunderstanding antenna and feedline operation. Why do I say this? I say this based on the air conversations and club-member meeting. I often hear something like this:

"I can't operate on the 80-meter band because I don't have room for an antenna."
"My SWR is 2.5:1 but if I can get it down to 1:1, my antenna will work much better."
"My SWR was 3.5:1 but my antenna tuner brings it down to 1.1:1."
"My antenna works best on this frequency because it is resonant here."
"My SWR is 2:1, so I lose half of my power by being reflected"
"I had to put up four dipoles so I can operate on 80, 40, 20 and 10 meters."
"IF my SWR is more than 1.5:1, it's bad."

These statements and others like them betray a lack of understanding the antenna and feedline operation. Despite of well-written and clearly explained articles about standing waves, reflected power and SWR in the past and over the years, many hams if not most, still avoid any mismatch and reflection like the plague. **"One to one all the way!"**

The SWR Myth

I don't know where all the feedline myths started. My theory and opinion is that it all started immediately after World War II. The easy availability of surplus military 50-ohm coaxial cable and shortly thereafter the appearance of do-it-yourself SWR meters started the ball rolling. Until then, most amateurs didn't even know about standing waves and if they did, they didn't seem to care about it. Every transmitter at that and before that time had a tunable Pi-filter circuit in the final amplifier stage which allowed the transfer of maximum power into the antenna system.

With the appearance of the coaxial feedline, hams began to be preoccupied with reflected power on this new type of transmission line. Almost immediately there was near universal agreement that reflected power had to be avoided like the plague. Moreover, 50-ohm coaxial cable had to be used because it doesn't radiate like open wire line. These hams failed to remember or overlooked that, before the war, hams cared not one whit about reflected power on their open wire feedline and they got along just fine.

Some hams dug into the books, but when they discovered that SWR is caused by a mismatched antenna, it only served to reinforce the myth. If a mismatched antenna causes power to be reflected down the line, they reasoned, this power obviously wasn't radiated by the antenna. Some even suggested that the reflected power got back into the transmitter tank and was dissipated in heat. Others apparently thought that reflected power just vanished. A few well-informed amateurs tried to nip these absurdities in the bud, but it was hopeless. The disease spread faster than the cure.

Let's bury the myths: first, reflected power is not lost nor does it heat up the tank circuit of your transmitter. Second, if the feedline has low loss, as it is in the case on the HF bands, the increased loss due to SWR is so small that you can forget about it.

A Closer Look at Reflection

Let's have a closer look at this amazing phenomenon of reflection. The events concerning reflection can probably be most easily described in the following manner.

Let's say the transmitter supplies 100 watts via a lossless tuner and a lossless transmission line toward an antenna with an impedance mismatch, so that 10 % of the power gets reflected. What is the scenario that takes place?

100 watts first reaches the antenna of which 10 watts is reflected. That means that 90 watts is actually radiated. The 10 reflected watts constitute the 10 % reflection due to the antenna mismatch. The reflected 10 watts reaches the tuner and sees the mismatch. Consequently, all of it gets reflected back toward the antenna. The 10 watts reaches the antenna and 1 watt of it gets reflected back down the feedline. The leftover 9 watts adds in phase to the 90 watts being radiated and the total radiation is now 99 watts. Again, the 1 watt reflected sees the mismatch at the tuner. This 1 watt is reflected and reaches the antenna whereof 0.1 watt gets reflected due to the 10 % reflection. The remaining 0.9 watt adds to the 99 watts and now 99.9 watts get radiated. This process repeats rapidly reaching the steady state and all the power ends up being radiated continuously.

Most hams do not use tuners. So, what happens to their reflected power? The reflected power triggers the mismatch protection circuit of the transmitter and reduces the output power. The power is reduced by the amount of reflection. The result is that less power gets radiated. As many hams think, the reflected power does not cause heating in the transmitter other than reducing the amount of available power. Therefore, hams who refuse to use a tuner actually prefer by implication and perhaps most unknowingly, this mode of reduced power operation. Why then is the power reduced when a certain mismatch level exits? The answer is that the reflected impedance (reflected voltage divide by reflected current) into the transmitter causes the operating voltage or current to increase beyond the design limits established for the final power amplifier transistors and associated components. It is the change in impedance (and **NOT** the reflected power as such) that causes the throttle back effect in order to protect the transistors by preventing being subject to voltage and/or current values beyond their rated specifications.

A brief explanation about the tuner: Power traveling from left to right through a tuner passes from the input to the output with no trouble along the way. However, power trying to pass through the tuner from right to left in the opposite direction gets totally reflected. It is this property that makes tuners so ideally suited to the antenna system. Rigs or antenna systems without a tuner or an equivalent network do not provide this 100 percent re-reflection of power. On the contrary, they throttle back the power when the SWR increases beyond a set limit. The rig with a tuner continues to deliver full power to the antenna regardless of the feedline SWR. The tuner-less rig does not.

SWR and Matched-line Loss

Off course a transmission line is not lossless as proposed above when discussing the power reflection from the antenna toward the ATU and the power reflection from the ATU toward the antenna if a mismatch is present. Each time the power is traveling along the transmission line, either from ATU toward the antenna or from the antenna toward the ATU, it will be attenuated according to the feedline type used and its attenuation properties, (dB meter or dB feet). These values are found in tables or graphs from most transmission line manufacturers. This information is essential to determine the extra loss by SWR in your system. For example, suppose you are using 30 meters (100 feet) of RG58/A at 7 MHz. The total loss under perfectly matched conditions between antenna and feedline impedance is 1.05dB. If your SWR happens to be 1, then you already know what the feedline loss is. But if the SWR is not 1, then there will be additional loss in the line. This additional loss is called the SWR loss.

Actual and Apparent SWR

In most cases the SWR is measured at the transmitter output. However, measuring it at this point does not give an accurate reading. The actual SWR, being the quality of the match between the antenna and the feedline, must be measured at the antenna feedpoint to have accurate results. The reading you get in the station at the transmitter is the apparent SWR and is always less than the actual SWR. Sometimes the difference might be considerable.

Putting an SWR meter at the antenna feedpoint is not easily done. But there is an easier way to find out. If you know the line loss under perfectly matched conditions from the manufacture's datasheet or info from publications, then **Table 11.3** will give you the actual SWR as a function of the apparent SWR. Once you know the actual SWR as well as the line loss under perfect matched conditions, you are ready to find the SWR loss, the extra feedline loss caused by standing waves.

	1.0	1.2	1.4	1.6	1.6	2.0	2.5	3.0	4.0	5.0	6.0	7.0
0.2	1.0	1.2	1.4	1.6	1.9	2.1	2.6	3.1	4.2	5.5	6.8	8.0
0.4	1.0	1.2	1.4	1.7	1.9	2.1	2.7	3.4	4.7	6.3	8.0	9.5
0.6	1.0	1.2	1.5	1.7	2.0	2.2	2.9	3.7	5.2	7.8	10.0	x
0.8	1.0	1.2	1.5	1.7	2.0	2.3	3.1	4.0	6.0	9.0	x	x
1.0	1.0	1.2	1.5	1.8	2.1	2.4	3.3	4.3	7.0	x	x	x
1.2	1.0	1.3	1.5	1.9	2.2	2.6	3.6	4.8	8.3	x	x	x
1.4	1.0	1.3	1.6	1.9	2.3	2.8	4.0	5.5	9.9	x	x	x
1.7	1.0	1.3	1.6	2.0	2.5	3.0	4.3	6.5	x	x	x	x
2.0	1.0	1.3	1.7	2.1	2.8	3.3	5.3	8.4	x	x	x	x
2.5	1.0	1.4	1.8	2.4	3.2	4.0	8.0	x	x	x	x	x
3.0	1.0	1.4	1.9	2.7	3.7	4.9	9.8	x	x	x	x	x
3.5	1.0	1.4	2.1	3.1	4.6	6.9	x	x	x	x	x	x
4.0	1.0	1.5	2.3	3.7	6.0	10.0	x	x	x	x	x	x
4.5	1.0	1.6	2.6	4.7	7.9	x	x	x	x	x	x	x
5.0	1.0	1.8	3.0	6.0	x	x	x	x	x	x	x	x
5.5	1.0	2.0	3.4	8.5	x	x	x	x	x	x	x	x

Table 9.3. *Actual SWR as a function of matched-line loss (Vertical Axis) and the apparent SWR (Horizontal Axis). SWR values greater than 10 are indicated by an* ***x****. SWR values above 6 are accurate to about ± 0.5. As example: your transmission line has a matched line loss of 1.0 dB and your SWR meter at your transmitter output indicates 2.0, then your actual SWR shall be 2.4.*

Additional transmission line loss

Use **Table 11.4** to determine your additional transmission line loss cause by SWR. Does the result surprise you and how do you know whether or not it is significant?

	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
0.2	0	0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7
0.4	0	0	0.1	0.2	0.2	0.4	0.5	0.7	0.8	1.0	1.1	1.3
0.6	0	0	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7
0.8	0	0	0.2	0.3	0.4	0.7	0.9	1.2	1.5	1.7	1.9	2.1
1.0	0	0	0.2	0.3	0.5	0.8	1.2	1.4	1.7	1.9	2.2	2.5
1.2	0	0	0.2	0.4	0.6	1.0	1.3	1.7	1.9	2.2	2.5	2.8
1.4	0	0	0.3	0.4	0.6	1.1	1.5	1.8	2.1	2.4	2.7	3.0
1.7	0	0	0.3	0.5	0.7	1.3	1.7	2.0	2.3	2.6	3.0	3.3
2.0	0	0.1	0.3	0.5	0.8	1.3	1.8	2.1	2.5	2.8	3.2	3.6
2.5	0	0.1	0.3	0.6	0.9	1.5	1.9	2.3	2.8	3.1	3.5	3.7
3.0	0	0.1	0.4	0.6	1.0	1.5	2.0	2.5	2.9	3.2	3.7	4.0
3.5	0	0.1	0.4	0.7	1.1	1.6	2.1	2.6	3.1	3.4	3.8	4.1
4.0	0	0.1	0.4	0.7	1.1	1.7	2.2	2.7	3.2	3.5	3.9	4.2
4.5	0	0.1	0.4	0.7	1.1	1.7	2.3	2.8	3.2	3.6	4.0	4.3
5.0	0	0.1	0.4	0.8	1.2	1.8	2.3	2.9	3.3	3.7	4.1	4.4
5.5	0	0.1	0.5	0.8	1.2	1.8	2.4	2.9	3.3	3.8	4.2	4.5

Table 11.4. *Additional loss caused by standing waves. Find the line loss when perfectly matched in the vertical column; read across for the actual SWR. Find the figures that are closest to yours if yours are not exactly represented. An example: your transmission line has a matched line loss of 1 dB and your actual SWR = 2.5, then your additional SWR loss shall be 0.3 dB and your total line loss will be 1 + 0.3 = 1.3 dB. Another example: suppose a matched line loss of 2 dB with an SWR of 3, then your total loss will be 2 + 0.8 = 2.8 dB.*

In general, when the SWR loss is less than 1 dB then you are wasting your time by striving for a perfect match. A change in signal strength of 1 dB is recognized as the smallest detectable change. Therefore, in practice, anything less is nothing. A gain of less than 1 dB will not be detected by the other station under any condition. Having an SWR loss of less than 1 dB does not mean you have a good antenna. It simply means there is no point in trying to get a better match with the existing feedline.

Let's assume that an approximately coax cable length of 25 meters is a commonly used length in most antenna systems. Let's also assume we use no more than 200 watts of power. What are the differences of the transmission line loss at the 28 MHz frequency band with either RG-58 and RG-213 coax, **Figure 11.5.** From this plot, we read a loss of about 8.5 dB/100m for the RG-58 coax and a loss of 3 dB/100m for the better RG-213 coax. For a length of 25 meters this is respectively a loss of 2.125 dB and 0.75 dB. Mind, these are the losses when perfectly matched. What additional loss will we have with a so *"much worse"* SWR of 3:1? Consulting **Table 11.4** tells us that the SWR loss for the RG-58 coax will be 0.85 dB giving a total feedline loss of 2.975 dB and for the RG-213 coax 0.75 dB giving a total feedline loss of 1.025 dB. For both cables, the SWR loss is less than 1 dB and therefore minor. The respectively total loss will be either 2.125 dB for the RG8 cable and 0.75 dB for the RG13 cable which gives a difference of 1.375 dB and is hardly noticeable. This example shows how to use these data and illustrates another point as well: feedline loss is not a simple direct function of SWR.

Here is yet more to understand feeder line loss and reducing it to a practical minimum. The first step in the process is understanding what power loss means in practical terms. **Figure 11.6** might help. This graph compares the actual power loss (percentage) with the loss registered in decibels. If we arbitrarily let 6 dB equal 1 S-unit, then you must lose about 75% of your power before your signal goes down by 1 of those S-units. 100 meters of RG-58A/U at 14 MHz equals a loss of 5.75 dB with an SWR of 1. An SWR of 2.5 should add 2 dB and the total loss will be 7.75 dB. So, even with this rather long and coax type of feedline, your signal should go down only a little more than 1 S-unit using it on the 14 MHz band.

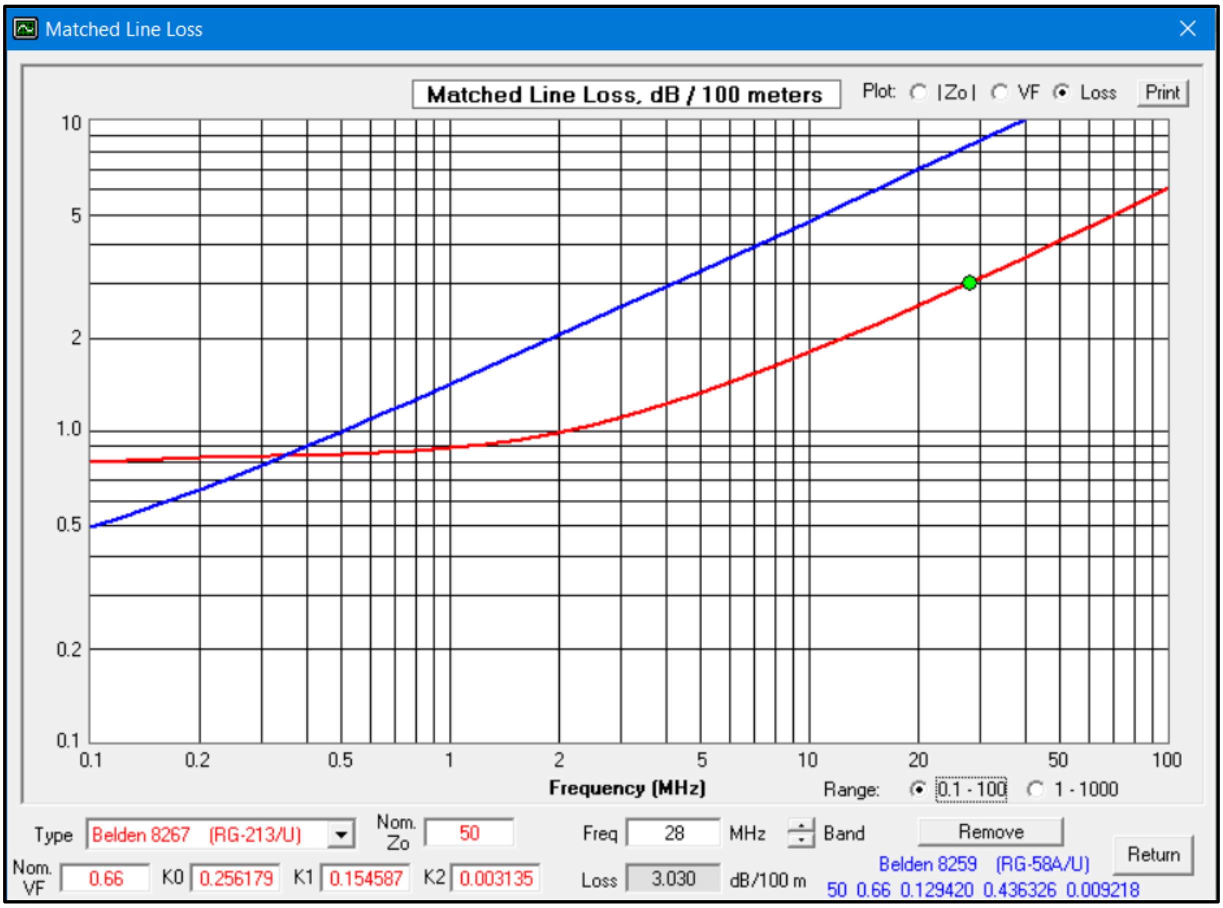

Figure 11.5. *The* ***Loss*** *of either RG-58 or RG-213 coax cable for a length of 100 meters. Note at the top-right: a plot of the chosen transmission line characteristic impedance (*Z_0*) and the Velocity Factor (****VF****), can also been displayed by checking its radio-button.*

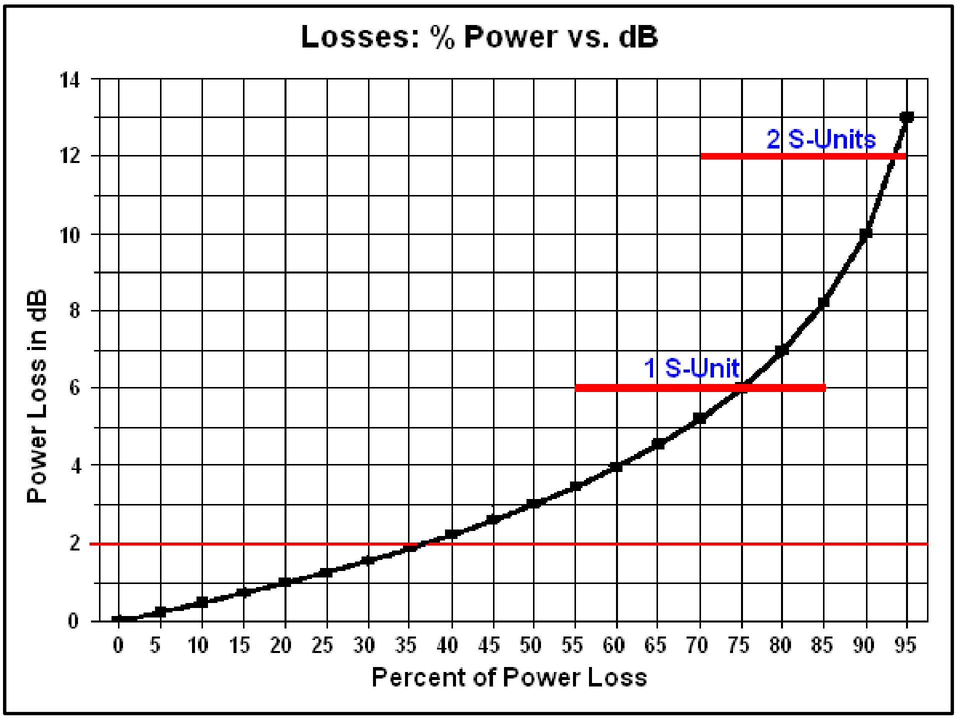

Figure 11.6. *Percentage of power loss versus loss in dB and related S-Units*

Conclusion

For all practical purposes, an actual SWR of 2.5 or better is just as good as a perfect match, as far as loss is concerned. This is apparent from examining **Table 11.4.** So, next time you try out a new antenna, don't throw your hand up in dismay and declare it is not a good one just because your SWR meter reads 2:1. Or perhaps you might think your antenna has too little bandwidth because you read an SWR of 3:1 at the band edges. Because the modern-day solid state transmitters have no tunable matching output circuit, an ATU is practically always needed to match any antenna system to the 50-ohm output impedance. I really don't understand why most amateurs dislike an ATU. Is it because they must do something extra, (is TUNING to match)? Once you are familiar with the tuning procedure, it only takes a few seconds or otherwise if this is still too much bother for you, buy an automatic ATU which needs only one push on a button to match.

I am fully aware that I may have rubbed some amateurs the wrong way as I explained about the SWR myth. Why are they so persistent? I have no definitive answer. Perhaps hams have not understood the subject sufficiently well. Perhaps they don't believe what they read. Perhaps they are influenced more by what they hear from their colleague hobbyists. Some are hard believers of their SWR misconception and may never be convinced to the contrary.

Of course, there may be good reasons for having a low SWR. Where to match for the best result in your antenna system and its circumstances is also important to consider.

How Important is Low SWR

QRO, High Power Operators

Above we learned that the extra loss caused by a rather high SWR was low for the HF bands. However, care should be taken when using high power, in particular with power from 1Kw and higher. When using this high power, the voltage at curtain points along the transmission line can reach rather high levels. The higher the SWR the higher the maximum voltage can reach and the higher the risk of damage the coax cable. A voltage flash-over between the two conductors and damaging the dielectric of the cable is not a unique event.

Even more, I know of a fact and saw with my own eyes. A friend OM replaced his coax cable because water was soaked into the cable. When removing the faulty cable, he discovered that the cable outer jacket was heavily burned through at several places. So, what happened? Using 1.5Kw power and due to a rather high SWR at some bands, the voltage at the maximum level node points made a flash-over to the metal tower construction along where the cable was taped. **Note:** the antenna was a sloping longwire spanned from the top of a self-supporting mast.

QRO operators must keep in mind and be prudent about the very high voltage sometimes involved. 5000 volts and higher is not a rarity with high power levels and standing waves. Good quality coax is a must, not to reduce the SWR loss but to withstand the high voltage occurring.

QRP, Very Low Power Operators

QRP operators often work on the differences between no registration on the S-meter and a faint tick of the needle. That is in the 1 dB differential range between no signal and something that can be heard and copied. Even though 1 dB represents about a 20% power loss, that 20% can be composed of lots of little losses that add up. Hence, it pays within certain practical limits, to minimize every potential power loss, including the minimal SWR loss.

VHF – UHF Operators

The matched line loss with coax transmission lines is rather higher when compared between the HF band frequencies and the VHF or UHF frequencies. **Table 11.5a** and 11.**5b** shows the loss for a cable length of 30 meters:

- The matched loss
- The extra loss with respectively a SWR of 2:1 and 3:1
- The total loss with respectively a SWR of 2:1 and 3:1
- The power finally reaching the antenna at the feedpoint to be radiated with 100 Watts delivered to the feedline at the transmitter output.

For the VHF and UHF bands, the matched loss and the cable length is most important. The extra loss when having standing waves is of course higher compared to HF bands but not that high that most hams think. Anyway, most VHF or UHF antenna are matched already as much as possible at the feedpoint itself to an impedance of 50 ohms and thus little SWR will be noticed.

The choice of the coax feedline type at VHF and UHF frequencies is certainly important. If you need rather long lengths, then choose at least RG-213 or better such as ECOFLEX-10 or ECOFLEX-15. To illustrate the effect a long transmission line at VHF can make, I witnessed the following case. I have a 5/8 vertical at a height of 25 meters with an RG-213 coax feedline of 35 meters length and another 5/8 vertical at a height of 4 meters with an RG-58 coax feedline of 4 meters length. I noticed for local communication, the antenna at low height using the higher lossy RG-58 coax, performed better than the higher installed antenna with the less lossy RG-213 coax. What are the feedline loss figures for both antennas? For the higher antenna, the computed loss is 2.75 dB and for the low height antenna only 0.85 dB. That 1.9 dB was quite noticeable as mentioned for local communication. The high height antenna was only better for long distance communication locations which were not in sight with the one with lower height.

Band MHz	Matched loss	SWR loss 2:1	SWR loss 3:1	Total loss 2:1	Total loss 3:1	Power Matched	Power SWR 2:1	Power SWR 3:1
28	1.11	0.21	0.55	1.32	1.66	77.5	73.7	68.2
50	1.50	0.26	0.66	1.76	2.16	70.6	66.6	60.6
144	2.68	0.36	0.92	3.04	3.60	53.9	49.58	43.7
420	4.93	0.46	1.3	5.39	6.23	32.1	28.9	24.7

Table 11.5a. *Losses at various bands with 30 m RG-58 coax.*

Band MHz	Matched loss	SWR loss 2.1	SWR loss 3:1	Total loss 2:1	Total loss 3:1	Power Matched	Power SWR 2:1	Power SWR 3:1
28	2.09	0.33	0.82	2.42	2.91	61.7	57.2	51.1
50	2.85	0.37	0.94	3.22	3.79	51.8	47.6	41.8
144	5.07	0.46	1.13	5.53	6.20	31.1	27.9	23.9
420	9.32	0.50	1.23	9.82	10.55	11.7	10.4	8.8

Table 11.5b. *Losses at various bands with 30 m RG-213 coax.*

SWR with ATU

The lower the power you are using, the more vital that all that precious power reach the antenna. You want the power your transmitter produces to be radiated by your antenna and not lost by the feedline. If you thought the job of the **A**ntenna **T**uning **U**nit

(ATU) in your transceiver, or sitting right next to it, was to ensure that as much of the power as possible gets to the antenna, you could be in for a nasty surprise. It is not very widely realized that the best place for the antenna matching unit is at the antenna feedpoint and not at the transmitter.

Most radio hams appreciate the need to use an antenna tuner at HF, so that their transceiver transmits into a 50-ohm load and sees an SWR close to 1:1. Most hams today have an antenna tuner sited right next to the transceiver or even built into it. What is often not known or appreciated is that using an ATU at the transmitter does not solve the problems caused by a high SWR. It merely fools the transmitter into thinking that the antenna is matched to 50 ohms. Of course, this is important for most solid-state final stages, which do not like working into a high SWR and which will reduce the output power to a safe level if there is a big mismatch. The ATU did help your PA by seeing a matched load but did not take away the standing waves in your feedline.

Whatever mismatch exists between the antenna and the feedline; whatever SWR is measured without the ATU in circuit, this mismatch still exists whether your ATU has "*matched*" the antenna system or not. Most hams think that once they have tuned their antenna system to 1:1 or as close as possible, they have removed the standing wave on their transmission line. This is absolutely not true. An antenna tuner does not tune your antenna at all; even its name says so. A better name is Transmatch because this unit matches one impedance; the one at the end of your transmission line to the transceiver output impedance which is 50 ohms.

The choice of feedline impedance compared to the antenna feedpoint impedance plays, of course, a significant role to the standing waves on the feedline, the total loss and final power to be radiated. Let's make a study with the program ***"Transmission Lines Details"*** from Dan Maguire (see its *"ReadMe"* text below) and take a 40-meter dipole with an impedance 75 ohms at resonance frequency. As an example, I compute respectively the impedance, the SWR at the load and the input and the various losses with either a 50-ohm impedance coax (RG-58) or 75-ohm impedance coax (RG-59). The results are shown in **Table 11.6a, 11.6b.** The "TLDetails" windows of the different frequencies within the 40-meter band can be found in the additional document **[TLDetails.pdf].** See **Figure 11.7** for such a program window-screen to find out where to set and consult the more interesting program inputs and outputs. From the two tables, we notice that the lowest reflection loss is with the RG-59 (75-ohm) coax. In other words, the closer the match between the feedline impedance to the antenna feedpoint impedance, the lower the losses.

TLDetails shows the impedance and reflection coefficient parameters (SWR, reflection coefficient magnitude Rho, or Return Loss RL in dB) at both ends of a transmission line and the details of power loss in the line.
In addition to numeric results, impedance points are shown on a Smith chart and loss components are shown on bar charts.
Includes characteristics for approximately 100 built-in line types.
You can modify these values to see how small changes affect the results or to specify custom lines.
All program inputs may be changed directly or you can use spin buttons to make the changes.

There is no separate help file but you can see brief tips by hovering your mouse over any of the non-obvious text boxes.
For additional information see the TLDetails web page at http://www.ac6la.com/tldetails.html.
TLDetails must be run with a screen size of 800x600 or greater, 640x480 is not supported.

Transmission Lines Details *program ReadMe text-file.*

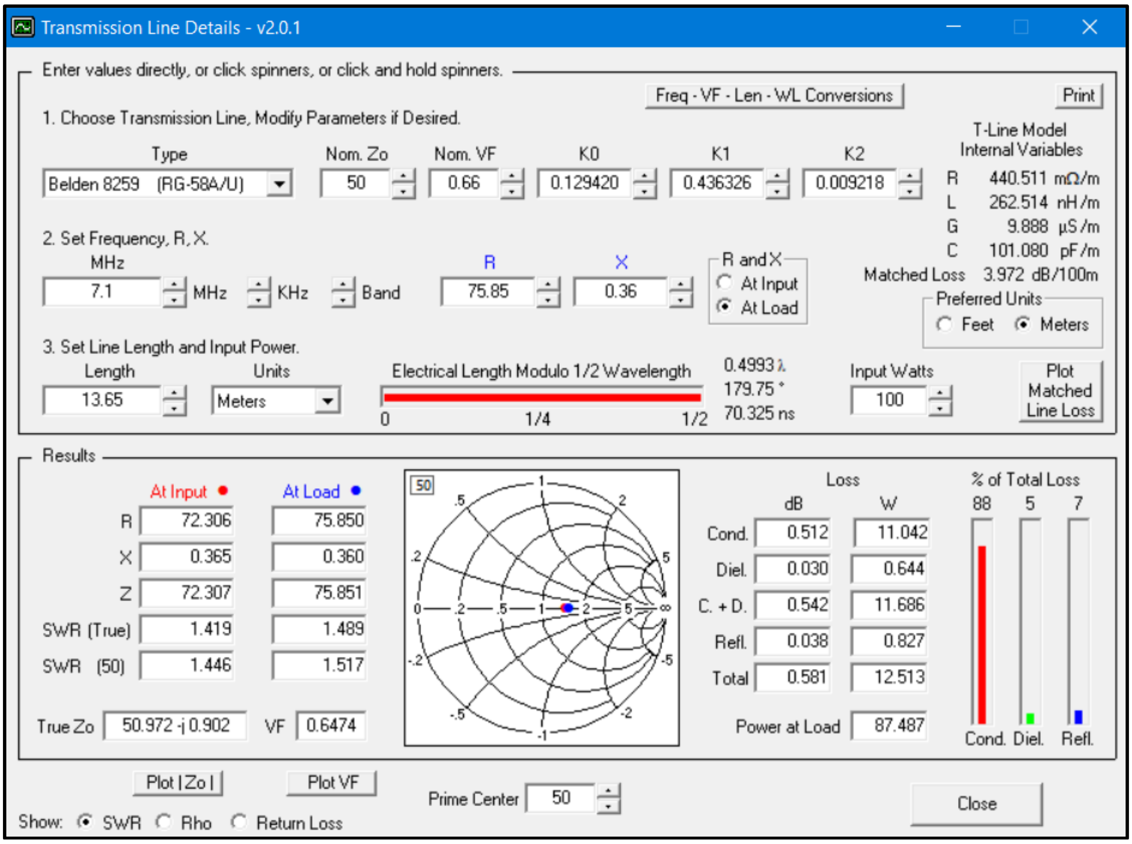

Figure 11.7. *TLDetails program window. The top area shows the dialog boxes, at the bottom area the results.*

Freq MHz	Imp R jX	SWR at Input	SWR at Load	Loss Refl. dB	Loss Total dB	Power at Load Watt	Loss Cond. + Diel. %	Loss Refl. %
7.00	71.10 -22.51	1.541	1.636	0.064	0.602	87.049	89	11
7.05	73.96 -11.06	1.464	1.538	0.042	0.583	87.446	93	7
7.10	75.85 +0.36	1.419	1.489	0.038	0.581	87.487	93	7
7.15	77.79 +11.78	1.508	1.596	0.051	0.595	79.371	91	9
7.20	79.73 +23.17	1.665	1.789	0.077	0.624	86.626	88	12
7.25	81.76 +34.57	1.867	2.044	0.117	0.666	85.792	82	18
7.30	83.79 +45.94	2.099	2.347	0.169	0.719	84.741	77	23

Table 11.6a. *Computed values with a RG58 (50-ohm) coax feedline for a 40-meter band dipole with resonance feedpoint impedance ±75 ohms and input power 100 W.*

Freq MHz	Imp R jX	SWR at Input	SWR at Load	Loss Refl. dB	Loss Total dB	Power at Load Watt	Loss Cond. + Diel. %	Loss Refl. %
7.00	71.10 -22.51	1.301	1.338	0.019	0.450	90.150	96	4
7.05	73.96 -11.06	1.129	1.144	0.004	0.437	90.423	99	1
7.10	75.85 +0.36	1.019	1.021	0.000	0.434	90.489	100	0
7.15	77.79 +11.78	1.166	1.187	0.005	0.440	90.368	99	1
7.20	79.73 +23.17	1.330	1.371	0.017	0.454	90.079	96	4
7.25	81.76 +34.57	1.510	1.579	0.037	0.475	89.639	92	8
7.30	83.79 +45.94	1.703	1.808	0.064	0.503	89.068	87	13

Table 11.6b. *Computed values with a RG59 (75-ohm) coax feedline for a 40-meter band dipole with resonance feedpoint impedance ±75 ohms and input power 100 W.*

Bandwidth and SWR

The bandwidth percentage is the greatest at the 80-meter band (13.3 %). Using an 80-meter band antenna over the entire bandwidth will certainly give high SWR values at the band edges when the antenna is resonant at the middle of the band. For example: a dipole with a 60-ohm feedpoint impedance at resonant frequency 3.75 MHz. **Table 11.7a** summarizes the impedance, the SWR and losses when the dipole is fed with 30-meter RG-213 coax cable. As can be noticed, rather high SWR values occur toward the band edges. But even with the high SWR at these edges the power loss is maximal 26% or 1.35 dB. With a quality ATU it is easy to match the high SWR to the transmitter's 50-ohm output preferring a SWR of 1:1. You don't need to fiddle with the dipole with any construction tricks to make the bandwidth flatter or trying to get lower SWR at the band edges. The best you might achieve with getting lower band edges SWR is a gain of approximately 0.5 dB.

If you should take a 450-ohm ladder feedline instead of a coax line, the SWR shall be much higher, but the actual power reaching the antenna shall be higher. The reason is the lower loss of such a 450-ohm ladder feedline, **Figure 11.7b**.

Freq MHz	Imp R jX	SWR at Input	SWR at Load	Loss Refl. dB	Loss Total dB	Power at Load Watt	Loss Cond. & Diel. %	Loss Refl. %
3.500	44.53 -123.5	6.203	8.375	0.979	1.350	73.288	27	73
3.525	45.93 -111.1	5.399	6.966	0.787	1.159	76.576	32	68
3.550	47.38 -98.55	4.633	5.730	0.615	0.988	79.656	37	62
3.575	48.84 -86.50	3.951	4.710	0.469	0.844	82.340	44	56
3.600	50.36 -74.16	3.318	3.824	0.342	0.718	84.765	51	48
3.625	51.91 -62.11	2.768	3.097	0.238	0.615	86.793	61	39
3.650	53.52 -49.44	2.268	2.469	0.150	0.529	88.539	72	28
3.675	55.16 -37.23	1.861	1.979	0.085	0.465	89.842	82	18
3.700	56.84 -25.15	1.531	1.595	0.040	0.421	90.764	91	9
3.725	58.57 -12.74	1.275	1.304	0.011	0.393	91.344	97	3
3.750	60.35 -0.32	1.175	1.192	0.001	0.383	91.569	100	0
3.775	62.18 +11.91	1.319	1.354	0.002	0.387	91.468	99	1
3.800	64.05 +24.15	1.564	1.633	0.019	0.406	91.075	95	5
3.825	65.97 +36.29	1.856	1.975	0.049	0.437	90.429	89	11
3.850	67.95 +48.65	2.190	2.379	0.091	0.480	89.541	81	19
3.875	69.97 +60.78	2.549	2.828	0.141	0.532	88.477	73	27
3.900	72.06 +73.26	2.943	3.342	0.202	0.594	87.214	66	34
3.925	74.19 +85.44	3.347	3.891	0.270	0.663	85.847	59	41
3.950	76.39 +97.88	3.773	4.498	0.345	0.740	84.341	53	47
3.975	78.64 +110.2	4.203	5.141	0.426	0.821	82.766	48	52
4.000	80.94 +122.5	4.635	5.821	0.511	0.908	81.132	44	56

Table 11.7a. *Values over the entire* 80-meter band with RG-213 coax and resonance frequency 3.75 MHz

Freq MHz	Imp R jX	SWR at Input	SWR at Load	Loss Refl. dB	Loss Total dB	Power at Load Watt	Loss Cond. & Diel. %	Loss Refl. %
3.500	44.53 -123.5	10.282	10.833	0.171	0.215	95.174	20	80
3.750	60.35 -0.32	7.198	7.470	0.098	0.143	96.769	31	69
4.000	80.94 +122.5	5.871	6.056	0.080	0.126	97.138	36	64

Table 11.7b *Values of the* 80-meter band with 450-ohm window line and resonance frequency 3.75 MHz.

Feedline length and SWR

Another often stated misconception among some radio hams is: "You can get a lower or acceptable SWR by trimming the feedline length." This is wrong! At anywhere along the feedline, the SWR should be practically the same value. The only small difference that might occur is depending on the line loss of the feedline and resulting in an "Actual" and "Apparent" SWR, see **Table 11.3**. When you can bring the SWR down or up significantly by changing the feedline length, then there is definitely something wrong with your SWR meter or you have current flowing on the outside coax cable shield. To demonstrate the impedance value and SWR variations at the end of a feedline with certain length difference, I computed these values with the above mentioned program TLDetails. The computed results are found in **Table 11.8.** The antenna feedpoint impedance was taken as 150 jX 0 and the coax cable length was respectively increased by 10 degrees wavelength. The results with an RG-213 coax at 3.5 MHz are found at the left columns. The at the right columns display the results with a hypothetical lossless transmission line. From this table, we can notice that the apparent SWR is decreasing very slightly with increasing feedline length. As can be seen, you can't trim your SWR to a match value suitable for your transmitter output. Even worse, the longer the length you make the feedline the higher the power loss.

Degrees	WL	R	X	Z	SWR	Loss dB	Power W		R	X	Z	SWR
0	0.000	150	0	150	2.96	0	100		150	0	150	3
10	0.027	121.6	-54.6	133.3	2.94	0.008	99.82		120.8	55.1	132.8	3
20	0.055	78.7	-66.4	103.0	2.93	0.019	99.57		77.5	66.4	102.0	3
30	0.083	51.2	-58.0	77.2	2.91	0.035	99.2		50.0	-57.7	76.4	3
40	0.111	35.9	-46.2	58.5	2.89	0.058	98.6		34.8	-45.7	57.5	3
50	0.139	27.4	-35.0	44.4	2.88	0.089	97.9		26.3	-34.6	43.5	3
60	0.166	22.4	-25.2	33.7	2.86	0.128	97.1		21.4	-24.7	32.7	3
70	0.194	19.7	-16.3	25.6	2.84	0.174	96.1		18.6	-15.9	24.5	3
80	0.222	18.3	-8.2	20.0	2.83	0.225	94.9		17.1	-7.8	18.8	3
90	0.250	17.9	-0.4	17.9	2.81	0.278	93.8		16.6	0	16.6	3
100	0.277	18.6	7.3	20.0	2.80	0.330	92.7		17.1	7.8	18.8	3
110	0.305	20.3	15.3	25.4	2.78	0.379	91.6		18.6	15.9	24.5	3
120	0.333	23.5	23.8	33.5	2.77	0.423	90.7		21.4	24.7	32.7	3
130	0.361	28.8	33.1	43.9	2.75	0.460	89.9		26.3	34.6	43.5	3
140	0.389	37.8	43.2	57.4	2.74	0.490	89.3		34.8	45.7	57.5	3
150	0.416	53.0	53.2	75.1	2.72	0.512	88.8		50.0	57.7	76.4	3
160	0.444	78.6	58.4	97.9	2.71	0.529	88.5		77.5	66.4	102.0	3
170	0.472	114.5	45.1	123.1	2.70	0.539	88.3		120.8	55.1	132.8	3
180	0.500	136.0	-0.2	136.0	2.68	0.547	88.1		150	0	150	3

Table 9.8. *Resonant R = 150 ohms with RG-213 Zo = 50.634 –jX0.616 at 3.5 MHz*

As we can note from **Table 11.8**, a transmission line is a continuous impedance transformer. Two characteristics are eye catchers. Impedance values repeat the values of the antenna feedpoint every 180 degrees, (with a little adjustment for line losses). The other magic mark along the line is the ¼ wavelength or the 90-degree point. At this point the reactance is minimal and changes in the other direction. The reactance now departs by approximately the same degree in the other direction. This 90-degree property can be used as a series matching system.

Series Matching.

A series matching system consists of several elements: a load impedance **(Z_L)**, a characteristic impedance of a transmission line to be match to the load **(Z_o)**. **Figure 11.8a** shows the elementary quarter-wavelength transformer section connected between the transmission line and the antenna load. This transformer is a kind of Regier series matching method as handled in **"Chapter 6: Transmission Lines"** and also sometimes called a **Q section**. When designed correctly, this transmission line transformer is capable of matching the normal feedline impedance Z_S to the antenna feedpoint impedance Z_L. The key factor is to have available a piece of transmission line that have an impedance of:

$$Z_O = \sqrt{Z_L * Z_S}$$

The key limitation to all series section matching systems is that they are frequency specific. Since all are composed of length of transmission line that will be specified in electrical degrees, the physical length of the Q section lines will vary with frequency. In most cases, the effective operating bandwidth of these systems will be quite sufficient to cover any of the ham bands. However, they are not broad-banded systems as a well-designed impedance transforming balun or unun.

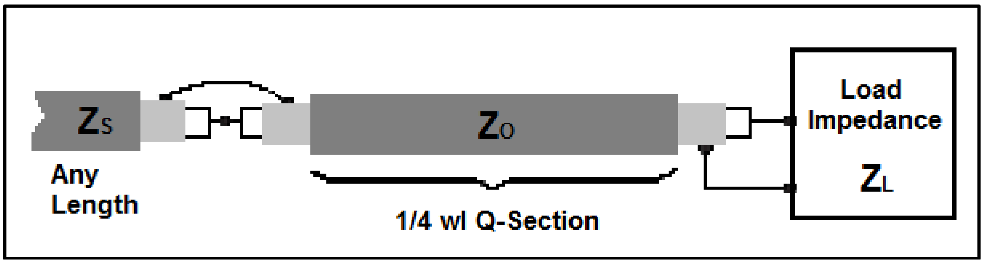

Figure 11.8a. *A ¼ wavelength Q Section impedance transformer.*

As example: a single loop antenna has approximately a load impedance of Z_L **= 120 jX 0** ohm at resonance, **[11-4.EZ]**. This impedance is ideal to use a series-matching system to match this load impedance to a Z_S of **50-Ohm** of the transmitter output load and mostly used transmission coax line. The needed ¼ wavelength Q section could be easily made of RG-11 or RG-59 with 75-ohm characteristic impedance, **Figure 11.8b.**

$$Z_o = \sqrt{120 * 50} = \sqrt{6000} = 77 \text{ ohm}$$

Computing the SWR-50 with the program TLDetails results to nearly 1:1. Even when the load impedance should swing between 100 to 140 ohms and reactance component of 40 jX to -40 jX the SWR-50 should be low (1:1.5) and manageable by the transmitter output circuit.

We can also model a 75-Ohm TL feedline of ¼ wavelength between the antenna feedpoint and a source on a virtual segment, **[11-4-1.EZ]** or even add a length of 50-Ohm coax from this virtual segment toward the rig, **[11-4-2]**. Find the SWR-50 plots of both models in **Figure 11.8c**.

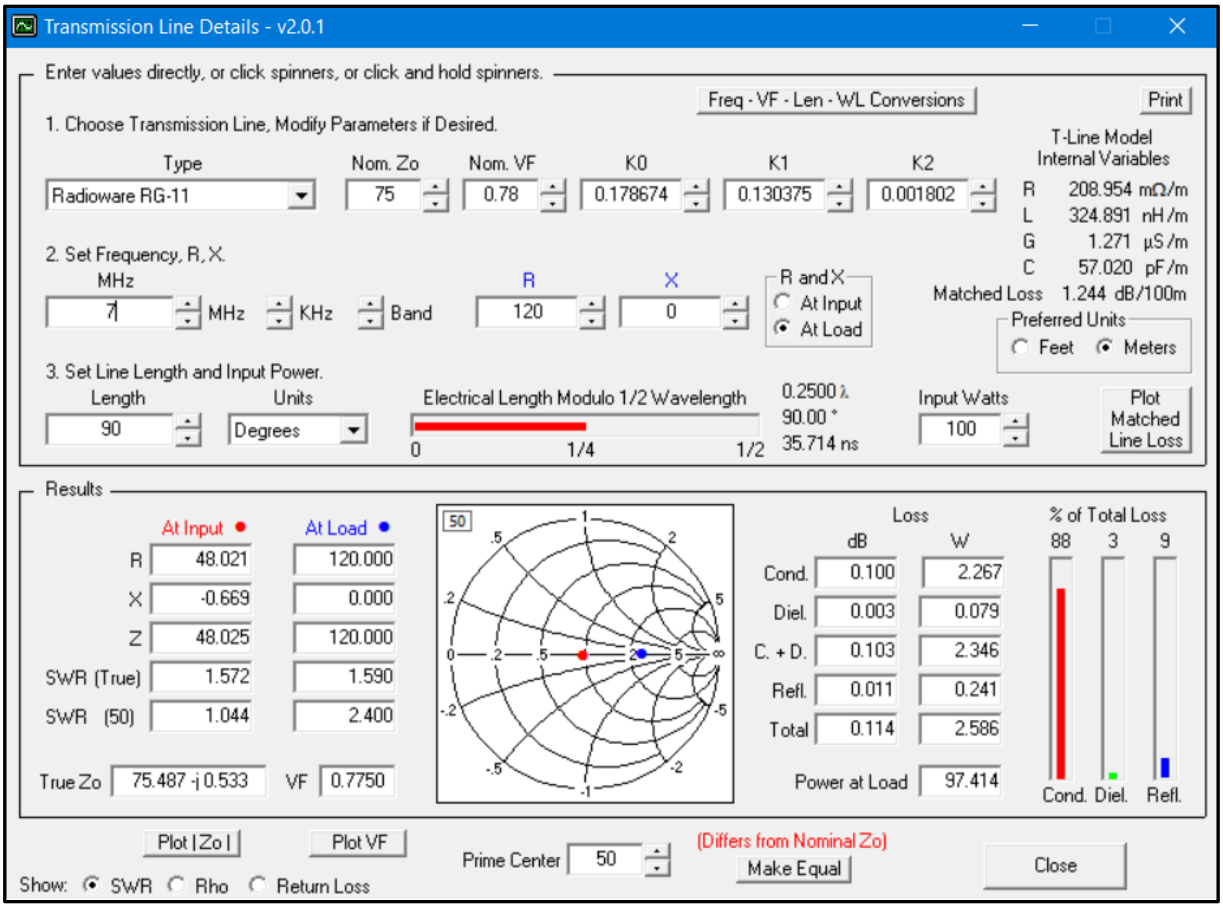

Figure 11.8b. *Transforming an antenna load impedance of 120 jX0 ohm to a 50-ohm coax (RG-213) and 50-ohm transmitter output, with a ¼ wavelength (90 degrees) transformer section of 75-ohm characteristic impedance (RG-11).* ***Note:*** *compare the At Input data with the At Load data.*

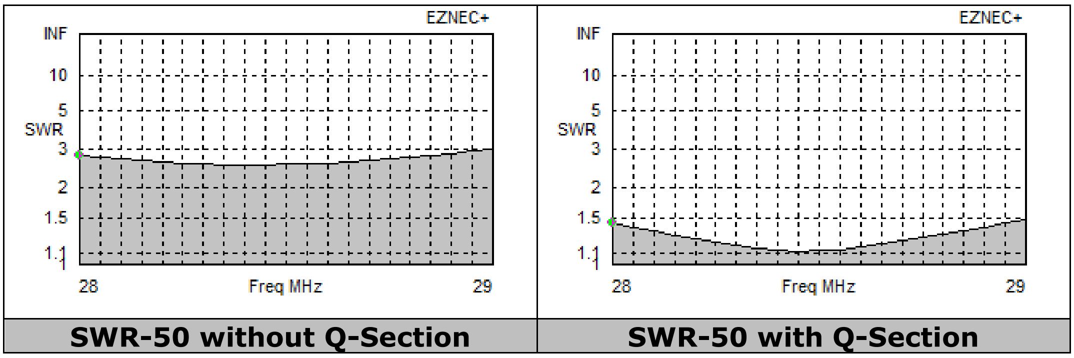

Figure 9.8c. *Both SWR-50 plots of single quad loop: without or with 75-Ohm ¼ wl Q-section.*