Treatise on SWR and Transmission Lines

How SWR and Transmission Line Losses Affect Radiated Power

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SWR is not the entire cause of reduced antenna power. The matched line loss of the transmission line must also be considered. This document should help dispel some rumors.

SWR

Standing Wave Ratio (SWR) reduces the power output from the antenna. That statement is almost universally accepted by every radio man. The extent to which power reduction occurs is up for debate. Some operators argue that the SWR must be reduced below 1.2:1 with no thought as to the Matched Line Loss of the transmission line. That attitude is short-sighted. It is not just SWR that reduces power, but a combination of SWR and ML (matched-line loss) that reduces the power output.

What is SWR? It stands for standing wave ratio. It is only caused by a mismatch at the antenna. Part of the incident power is reflected back toward the transmitter. The voltage at any one point along the transmission line is the algebraic sum of the forward power and the reflected power. An SWR of 3:1 means the ratio of the HIGHEST voltage to the LOWEST voltage is 3:1.

Matched-line Loss

To calculate the matched-line loss (ML), apply the formula:

$$L_M = 10 \log_{10} \frac{SWR+1}{SWR-1}$$

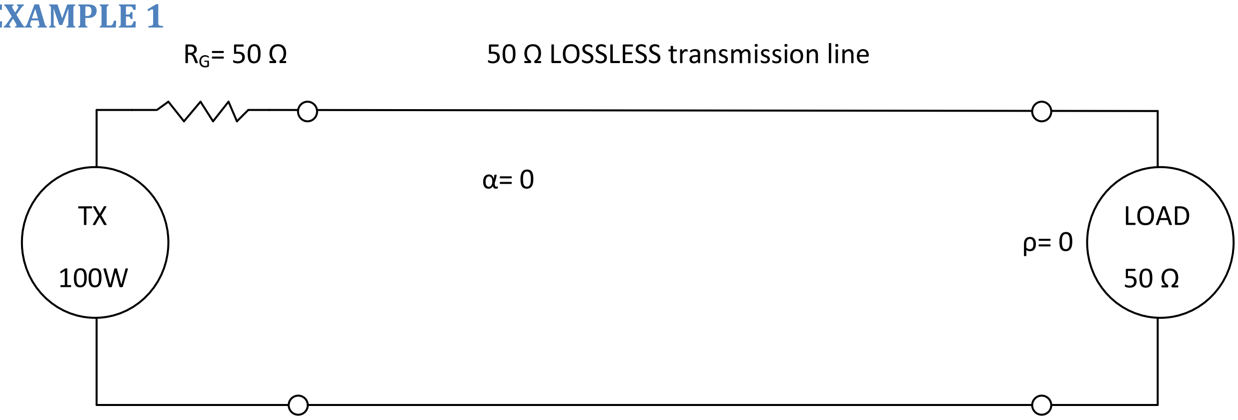
In this paper, I am going to show that the matched-line loss inherent in the transmission line is the real culprit, not the SWR. I will give you some math. None of it is very hard - just simple division and some multiplication.

Measure the SWR

The transmission line must be OPEN or SHORTED at the antenna end when you take the measurement. The reason is that when the line is open or when it is shorted, all the incident power is reflected back toward the transmitter. Use an SWR analyzer such as the MFJ-259 or MFJ-269, or use the transmitter and an SWR indicator at the output of the transmitter. The **HIGHER** the SWR reading, the **LOWER** the Matched-line loss. (See APPENDIX B)

Let’s start by assuming we have a transmission line, generator, and the load which is the antenna. The diagram is shown below.

EXAMPLE 1



Since the load is the same impedance as the transmission line, there is no reflected power anywhere in the system. Since the transmission line has no loss, all the power that is output from the generator is absorbed by the load (antenna) and is transmitted into the air.

SWR =

EXAMPLE 2

As in EXAMPLE 1, a lossless line (α = 0) is connected between a 50 Ω transmitter and a load of 150 Ω. The 150 Ω load and the 50 Ω load causes a reflection of part of the transmit voltage and power. The SWR is calculated from the formula,

$$\text{SWR} = \frac{Z_L}{Z_O}. \tag{1}$$

If Z_L is less than Z_O, then SWR = $\frac{Z_O}{Z_L}$.

The SWR is, thus, 150 / 50 = 3:1. The voltage reflection coefficient is calculated from SWR as:

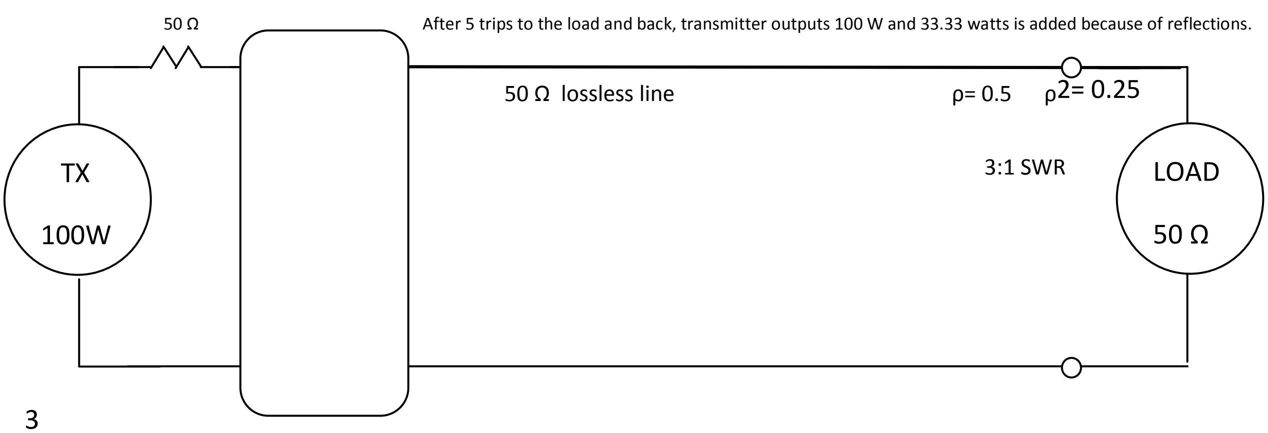
$$\rho(\text{rho}) = \frac{SWR-1}{SWR+1}. \tag{2}$$

Thus the voltage coefficient, rho, is 2/4 = 0.5. One-half of the voltage **THAT REACHES THE LOAD** is reflected back toward the generator.

How much power is reflected back toward the generator? Since power is the square of voltage in the formula E^2 / R, the power coefficient is $\rho^2 = 0.5^2 = 0.25$. So, one-fourth of the power reaching the antenna (load) is reflected back toward the generator. **Thus the antenna load accepts 75 W and 25W is reflected back toward the generator.**

NOTE: According to Walt Maxwell, W2DU, the generator reduces its output by the reflected power. The antenna accepts ALL the power put out by the generator (75W).

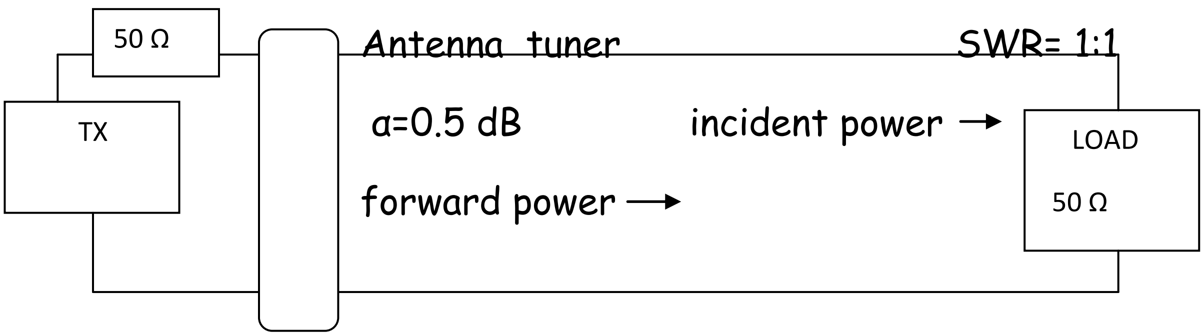
EXAMPLE 3 Conjugate match or Ant. Tuner



After 5 trips to the load and back, the Forward is 100W + 33.33 W= 133.33 W. Since we still have an SWR of 3:1, 25 % of the power reaching the load is reflected, and 75% is absorbed by the antenna. So, 100W is absorbed by the antenna and 33.33 W is reflected.

EXAMPLE 4

Again we have a 100W-50Ω transmitter putting out 100 W into a transmission line with an impedance of Z_o = 50Ω. The SWR at the load is again 3:1. Rho(ρ) is the same as Example 3, which is 0.5 and ρ^2 is 0.25. However, this time we will use a transmission line that has some loss to it. Let's assume 0.5 dB of loss, typical of 87 feet of RG-59 at 4.00 MHz.



Since we have a 1:1 SWR, 100% of the incident power is absorbed by the antenna. How do we calculate the actual power loss? It is derived by using the formula for dB

$$0.5\text{ dB} = 10 \log_{10} (P1/P2) \qquad (3)$$

But this is not the final form. We must take the antilog of both sides.

When we are through rearranging the formula, we wind up with

$$P1/P2 = 10^{-dB/10} \qquad (4)$$

$$P1/P2 = 10^{-0.5/10} = 10^{-0.05} = 89.125\text{ W}$$

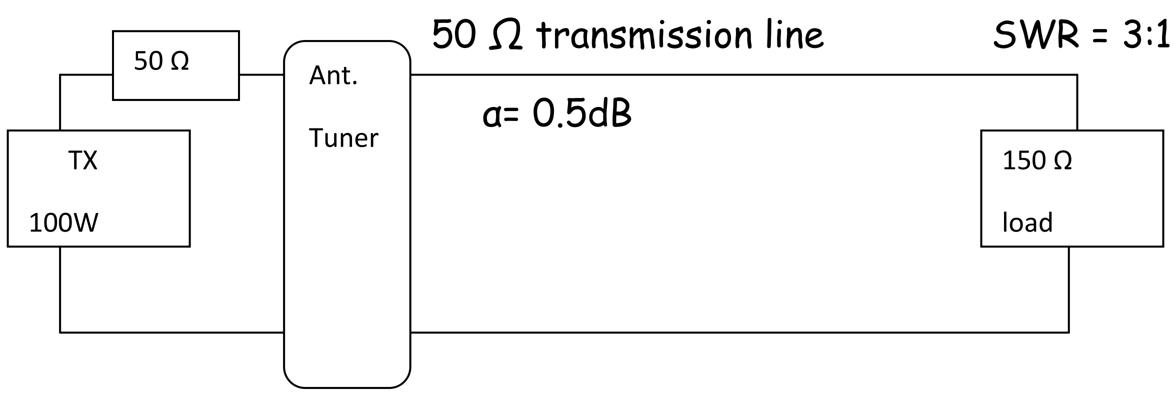
To calculate this, press SHIFT, the LOG button on the calculator. Then MINUS, and DECIMAL, ZERO, FIVE, then press EQUALS (or EXECUTE). Your answer will be 0.89125. That means you have lost

10.875 per cent through the transmission line. Starting with 100W, we have lost 10.88 W.

This means 89.125 W reaches the antenna and all of it is absorbed, since there is no SWR at the antenna.

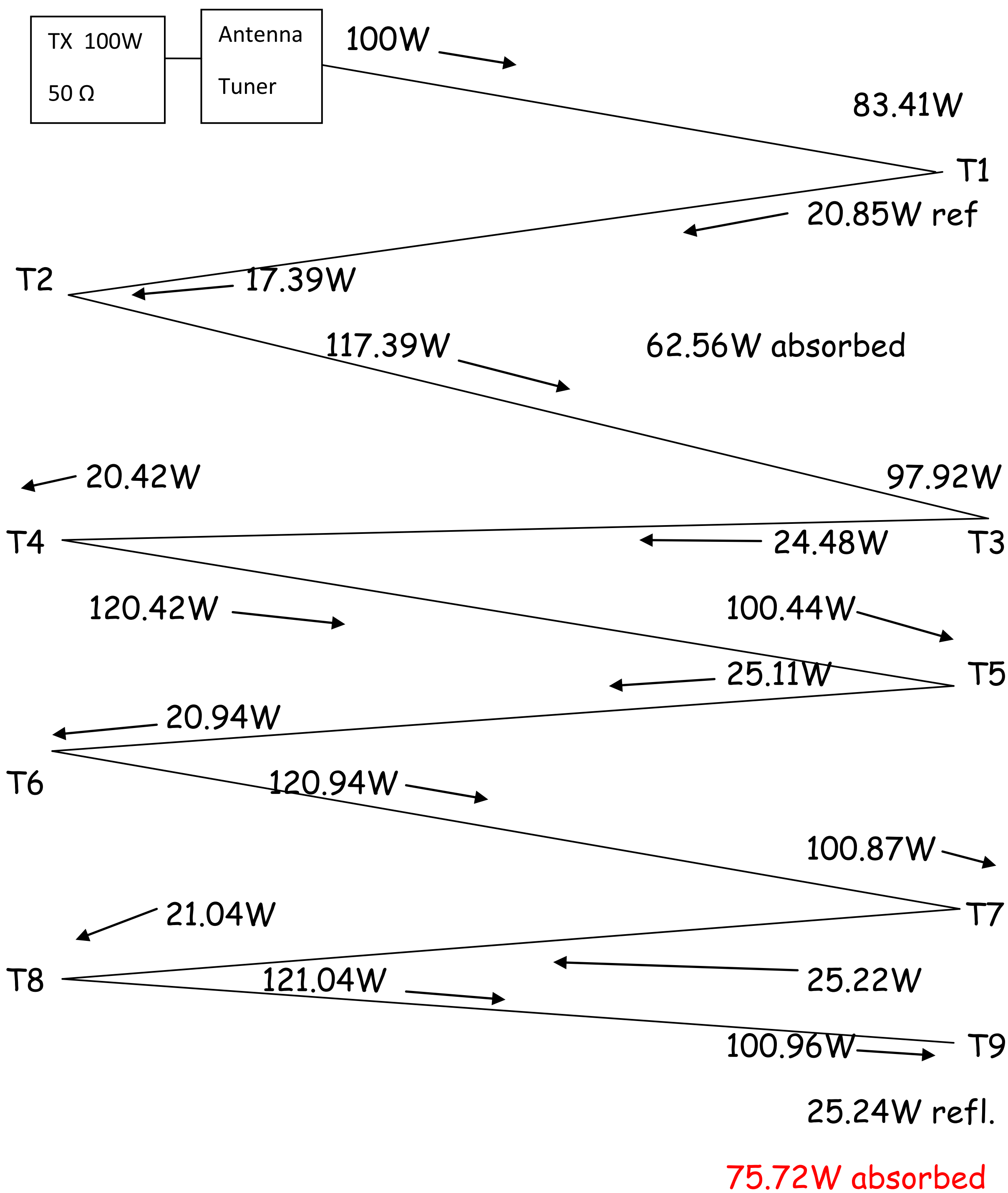
EXAMPLE 5

Example 5 combines transmission line loss with an SWR of 3:1. Again, the line input is matched to the transmitter.



We already know the loss in the transmission line from EXAMPLE 5. If the transmitter is putting out 100W, 83.41 W gets to the antenna as incident power due to the 0.5dB (+ 0.288dB) loss in the line (SEE APPENDIX A). Since we have a 3:1 SWR, 25% of that is reflected back toward the transmitter. This reflected power suffers the same 0.788dB loss on its trip to the transmitter. 17.39 W reaches the transmitter-line input match point and is added to the 100W output of the transmitter. A bounce diagram is shown below.

Bounce diagram



The steady-state value is reached in approximately 5 trips to and from the load. What is the result in decibels? Well, apply formula (3) above.

$$dB = 10 \log_{10} (75.72/100.96) = -1.25 \text{ dB}$$

This is only a little over 1/6 of an S-Unit and no-one can tell you are putting out 75W instead of 100W.

What does the tuner do when you adjust the reflected power to zero? The tuner sets up a conjugate match at the match point and by doing so adjusts the phase of the reflected wave and the forward wave. That is, both are in phase. So, both voltages are in phase with each other and add together. The reflected power adds to the Forward power and moves toward antenna.

CONCLUSION

As an amateur, what can you take away from this discussion? Number 1, an SWR of 1:1 is not absolutely necessary. You may be able to tolerate an SWR of 2:1, 3:1, or even 6:1 depending on the matched-line loss of your transmission line. Your loss depends on the SWR AND the matched line loss. Use the transmission line that has the least loss.

2. Use a tuner. This allows you to use one antenna from 160M – 10M. This does depend on the length of the antenna, of course. There are lengths you should avoid, and these are documented in the ARRL Handbook.

3. Getting your SWR below 2:1 is just not worth the effort most of the time. Many tower climbers have died trying to get the SWR down below 2:1. A 2:1 SWR is only about 11% reflected power. If using a tuner, 89 watts vs. 100 watts is not discernable on the air. This is only -0.45 dB.

4. If operating with a low matched loss transmission line and antenna tuner, you can tolerate a high SWR. I operated my ICOM 718 recently with a 6:1 SWR and NO TUNER. The radio obviously cut back the power, but it did not burn the radio up and the other guys on the Navy-Marine Corps MARS net could not tell I had any reduced power output. Since I used a low-loss cable (about 20 feet of RG-8X), the additional loss from the SWR was negligible.

Hopefully, you now know exactly how much loss you will encounter when operating with a higher than "normal" SWR and that SWR is not the culprit it has been made out to be.

One of my pet peeves is someone saying, "All the tuner does is match the transmitter to the feedline." When you read that from someone, just go somewhere else. The person making that statement really does not know what is going on.

The absolute bottom line

1. Use a tuner at the line input so you can use one antenna for all HF frequencies. The modern commercial tuners have an estimated 0.01 dB of loss, so tuner inefficiency is not a legitimate reason for not using a tuner. I can say with confidence you will always get more power output with a tuner than without one.

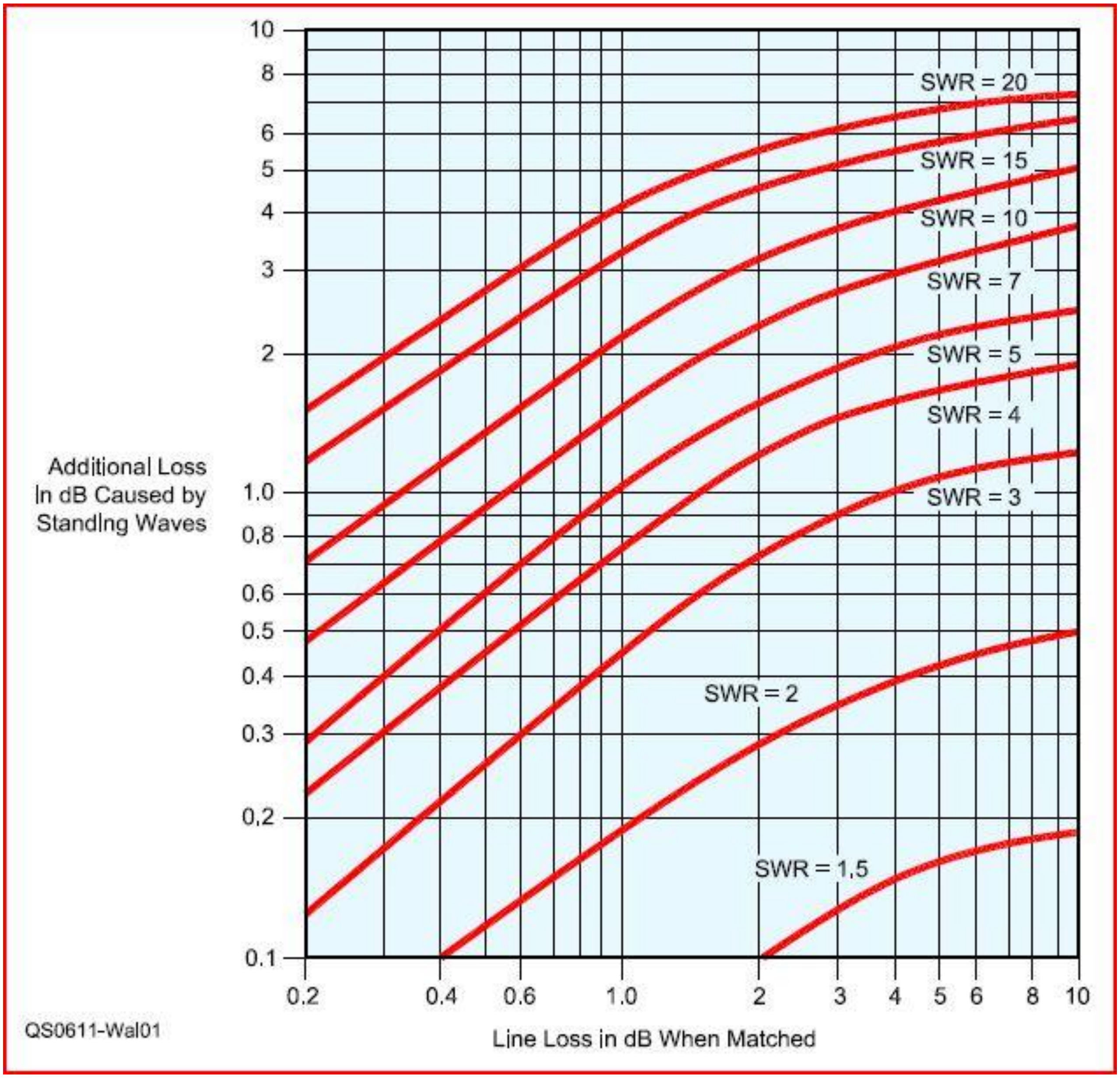
2. Use the lowest loss transmission line possible. For the average amateur using coax, that means LMR-400. For ladder line, use 450 Ω or 600 Ω line with a balanced-line tuner. If you have a very low SWR, you can tolerate high SWR. However, high SWR can cause high voltages, high enough to puncture the dielectric in coax cables.

3. A lot of information is on the internet. I hope your interest in this subject is piqued enough that you want to study this subject in more depth. Some of it is good, but some is not so good. There are electrical engineering lectures and course material that are free to watch on the Internet.

Comments are welcome

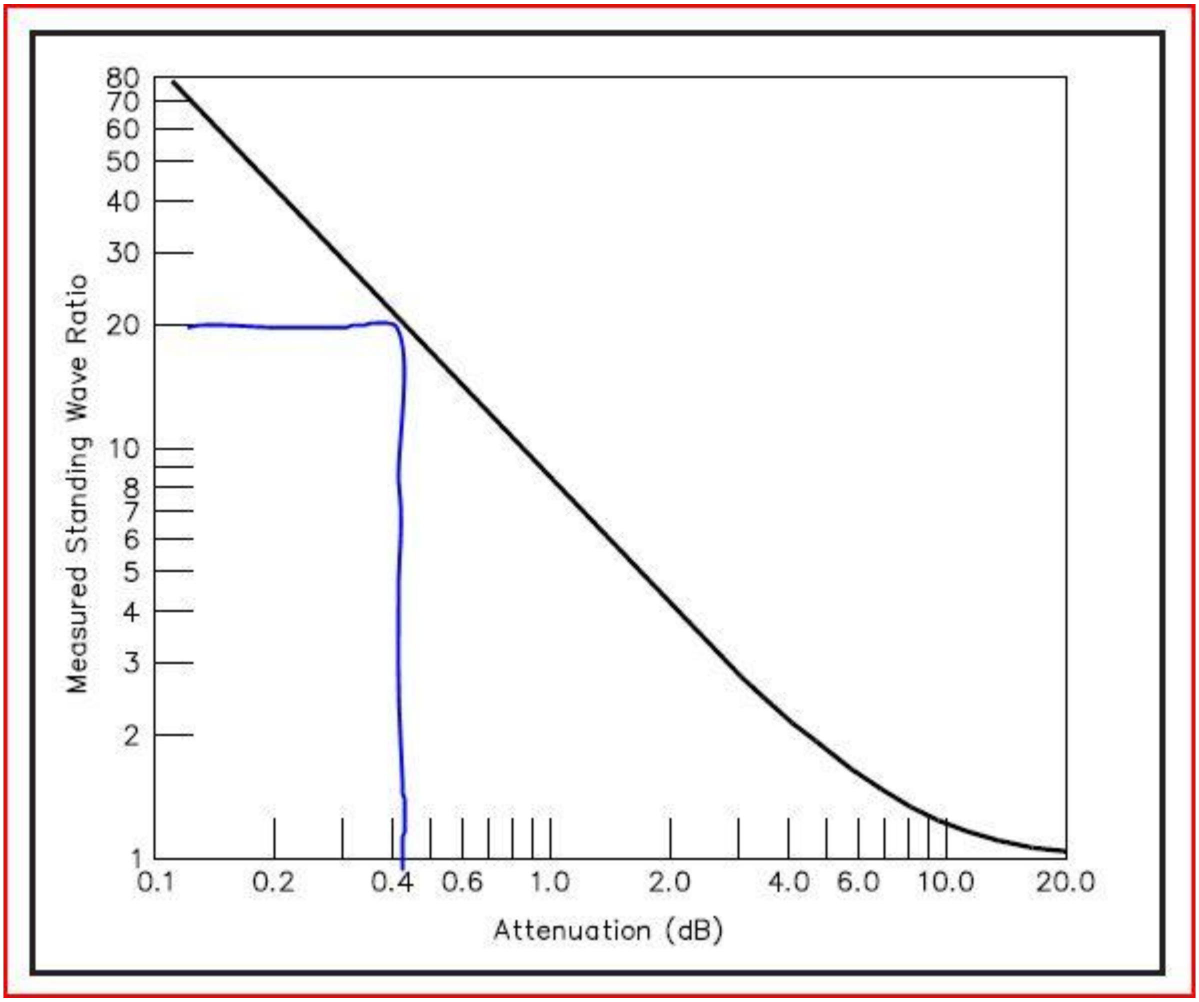
Please send your comments to aa5xo (at) arrl.net.

APPENDIX A



Additional loss on a transmission line due to SWR

APPENDIX B



Start at the SWR measurement on the left. Move horizontally across to the right until you hit the black diagonal line. Move from there to the bottom Attenuation (dB) line. This is the Matched-line loss.

For a measured SWR of 20:1, the matched-line loss is about 0.42 dB.

References

1. Maxwell, M. Walter, W2DU, (1990), *REFLECTIONS, Transmission Lines and Antennas*, The Amateur Radio Relay League, Newington, Connecticut.
2. Chipman, Robert A. , 1968, *Transmission Lines* (Schaums Outline Series) , McGraw-Hill, retrieved from http://archive.org/details/TheoryAndProblemsOfTransmissionLines.
3. Jennings, Lawrence E., WB5IZL, *Quick Coax Test*, QST Magazine, August 2012, Pg. 44.
4. DeVoldere, John, ON4UN, Chapter 6, The Feedline and the Antenna, retrieved from: http://vss.pl/lf/06.pdf