A “Refresher” on VSWR

- VSWR stands for “Voltage Standing Wave Ratio” sometimes abbreviated as just SWR.
- The subject is appropriate for all types of transmission lines.
- Note: If the transmission line is much less than $\lambda / 4$, then the analysis of “transmission line transformers” and possibly “baluns” is more appropriate.

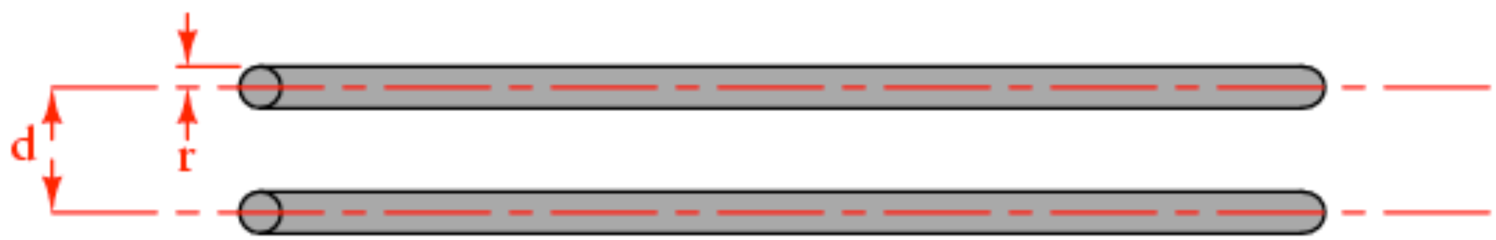
Transferring Power in Transmission Lines

- For maximum power transfer, the impedance at the load end of the line must be matched to the transmission line's characteristic impedance.

Transmission Line Characteristic Impedance

- Characteristic Impedance Z_o is Resistive.
- Z_o is fixed by the geometry of the conductors.
- Impedance of "free space" $Z_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 376.73031\Omega$

Parallel Wires



$$Z_0 = \frac{276}{\sqrt{k}} \log \frac{d}{r}$$

Where,

Z_0 = Characteristic impedance of line
d = Distance between conductor centers
r = Conductor radius
k = Relative permittivity of insulation between conductors

Typical values:
200Ω to 800Ω

Coaxial Cable

- Most common values, $Z_o = 50\Omega$, and 75Ω

$$Z_0 = \frac{138}{\sqrt{k}} \log \frac{d_1}{d_2}$$

Where,

Z_0 = Characteristic impedance of line

d_1 = Inside diameter of outer conductor

d_2 = Outside diameter of inner conductor

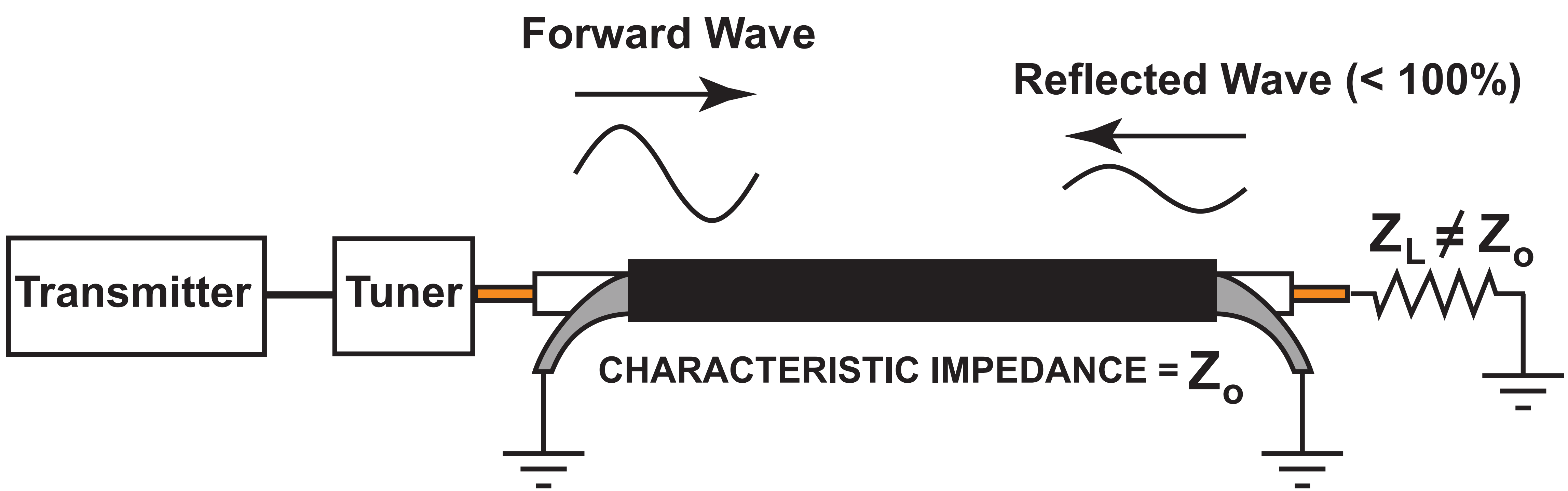
k = Relative permittivity of insulation between conductors

Typical values:

25Ω to 100Ω

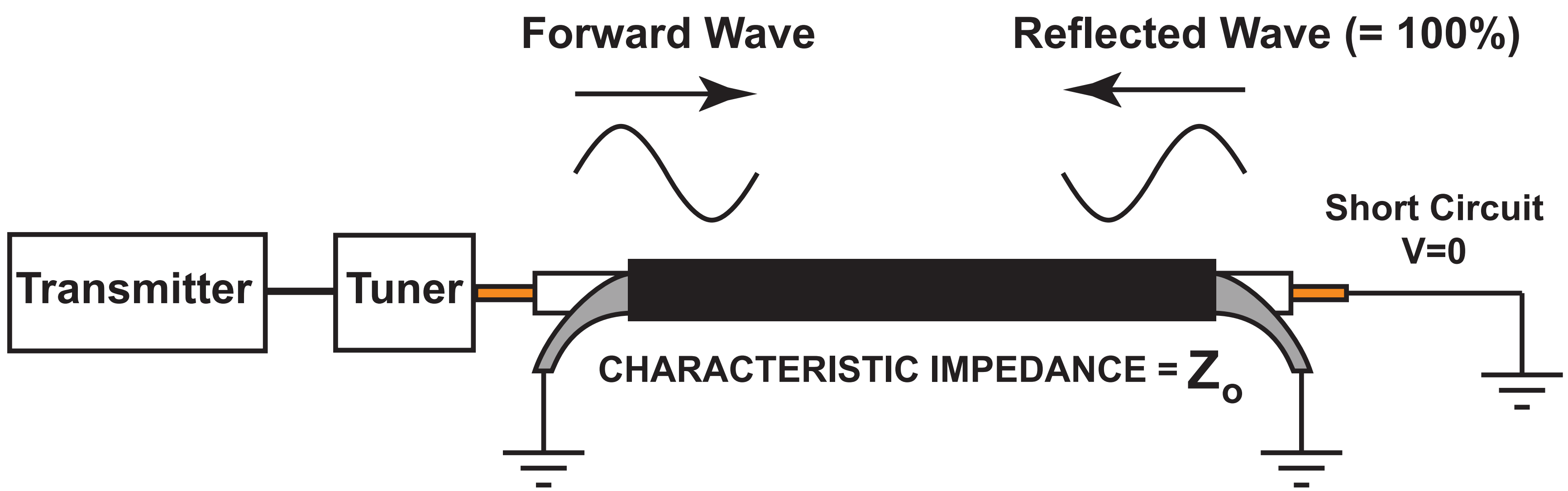
Mismatched Transmission Line

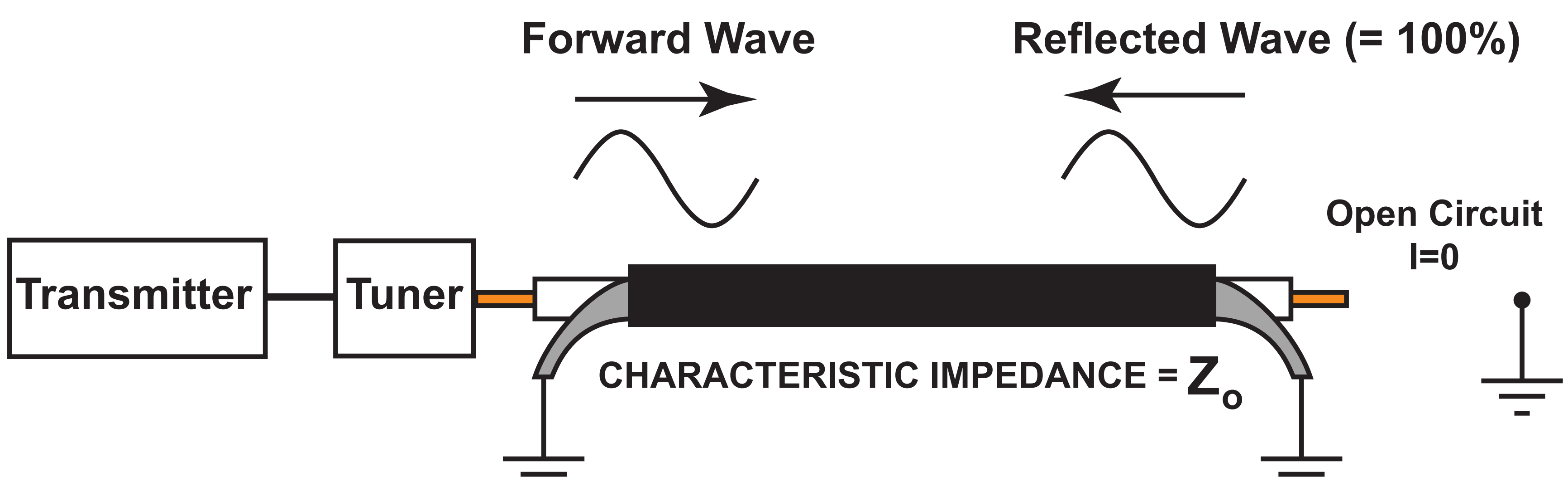
- Energy reaching the load will not be fully absorbed.
- Some of the energy is reflected back toward the source by the "impedance discontinuity."
- Splicing two transmission lines of different impedance will also cause a reflected wave.



Extreme Mismatch Examples

- Heuristic argument for reflected waves...





- Since $P = V \times I$, no power is transferred to the load in either case and must be returned to the source.

OK, Now the Math

- In a mismatched transmission line, the ratio of the voltage in the reflected wave at any one point to the forward wave at the same point is defined as the "*voltage reflection coefficient,*" ρ *(rho).*

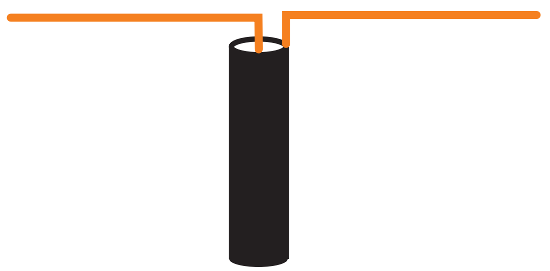
$$\rho = \frac{Z_L - Z_o}{Z_L + Z_o}$$

- In principle, this is a "complex" number if we consider reactive loads, but for the moment, we will only consider resistive loads with "real" reflection coefficients.

Some Examples

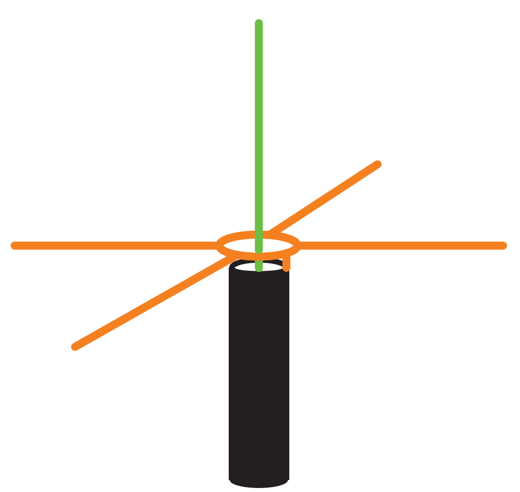
- First the feedpoint impedance of a resonant Dipole antenna in "free space" is $Z_L = 73\Omega$.

$$\rho = \frac{73-50}{73+50} = \frac{23}{123} = 0.187$$



- The feedpoint impedance of a 14 MHz Ground Plane antenna at 15 m above ground is $Z_L = 26 - j3.2\Omega \cong 26\Omega$.

$$\rho = \frac{26-50}{26+50} = \frac{-24}{76} = -0.316$$



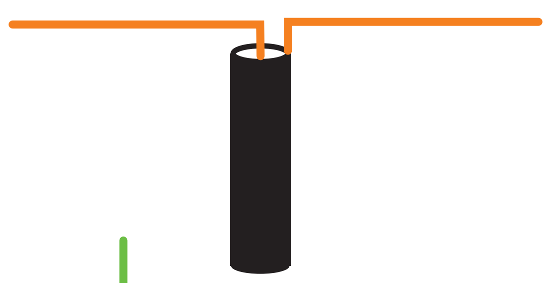
VSWR

- The VSWR is:

$$VSWR = \frac{1+|\rho|}{1-|\rho|}$$

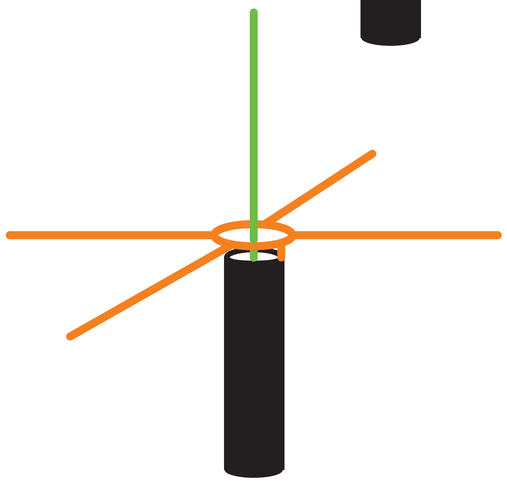
- For the resonant Dipole in free space:

$$VSWR = \frac{1+0.187}{1-0.187} = \frac{1.187}{0.813} = 1.46$$

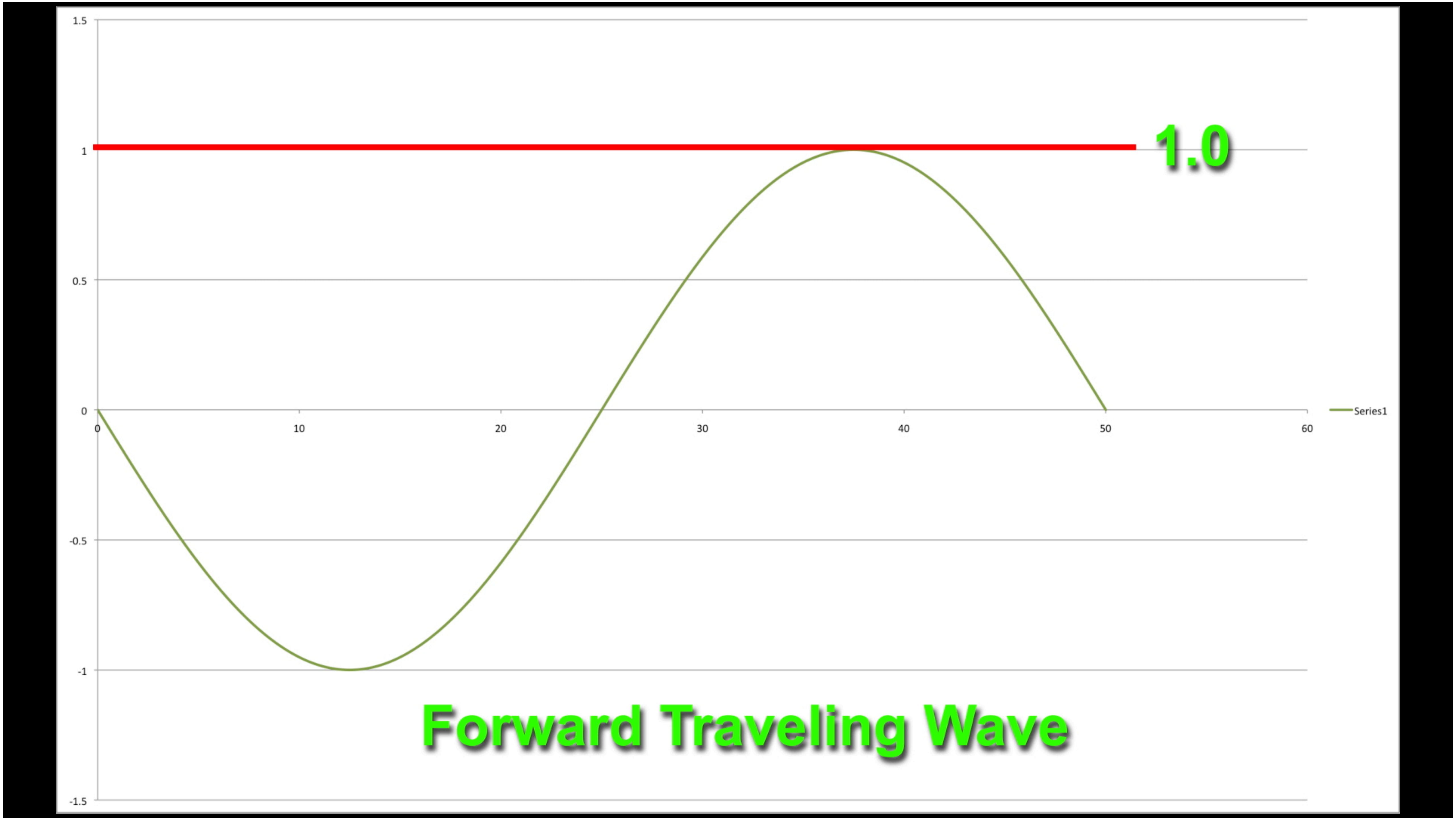


- For the 14 MHz Ground Plane:

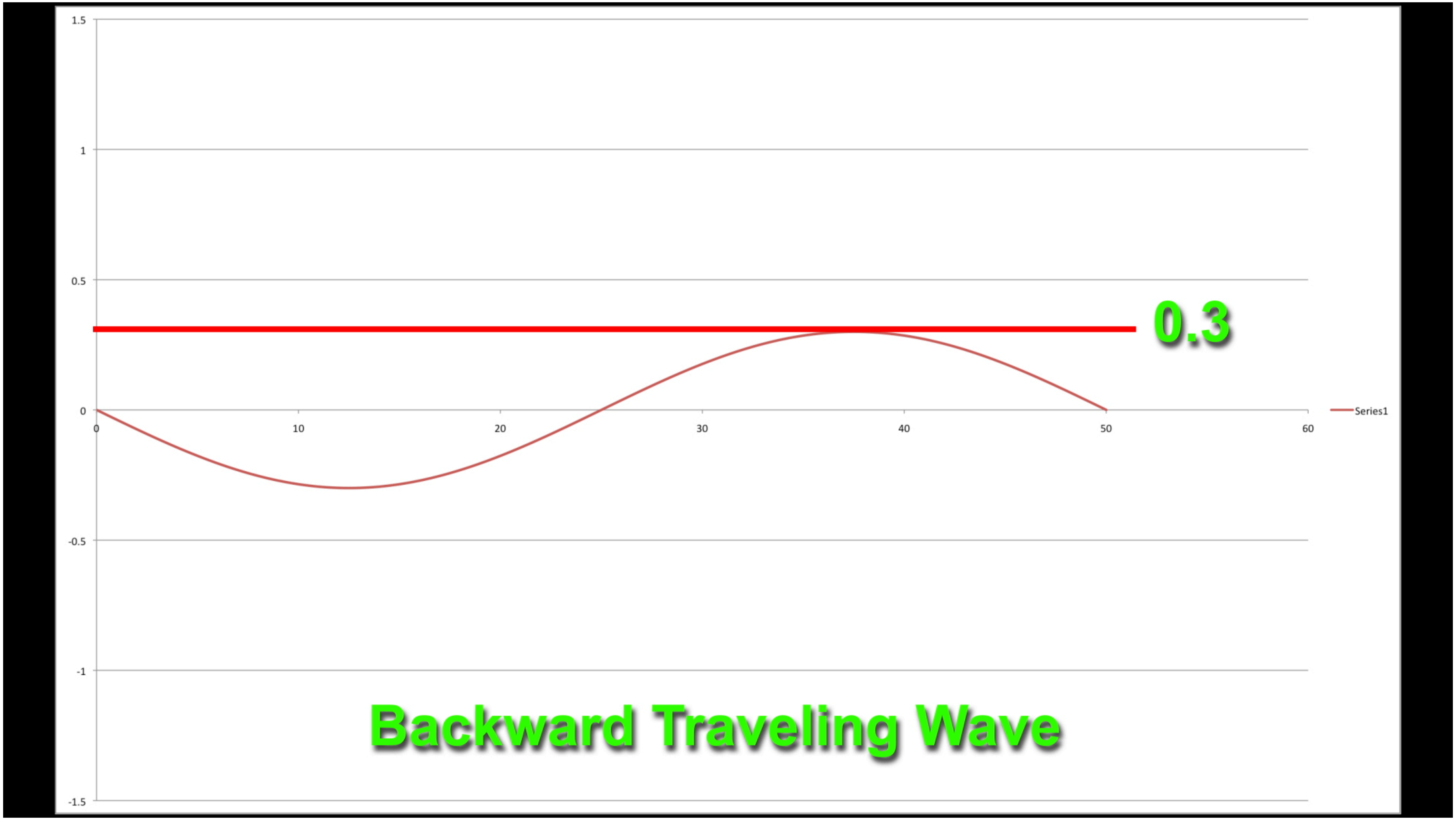
$$VSWR = \frac{1+0.316}{1-0.316} = \frac{1.316}{0.684} = 1.92$$



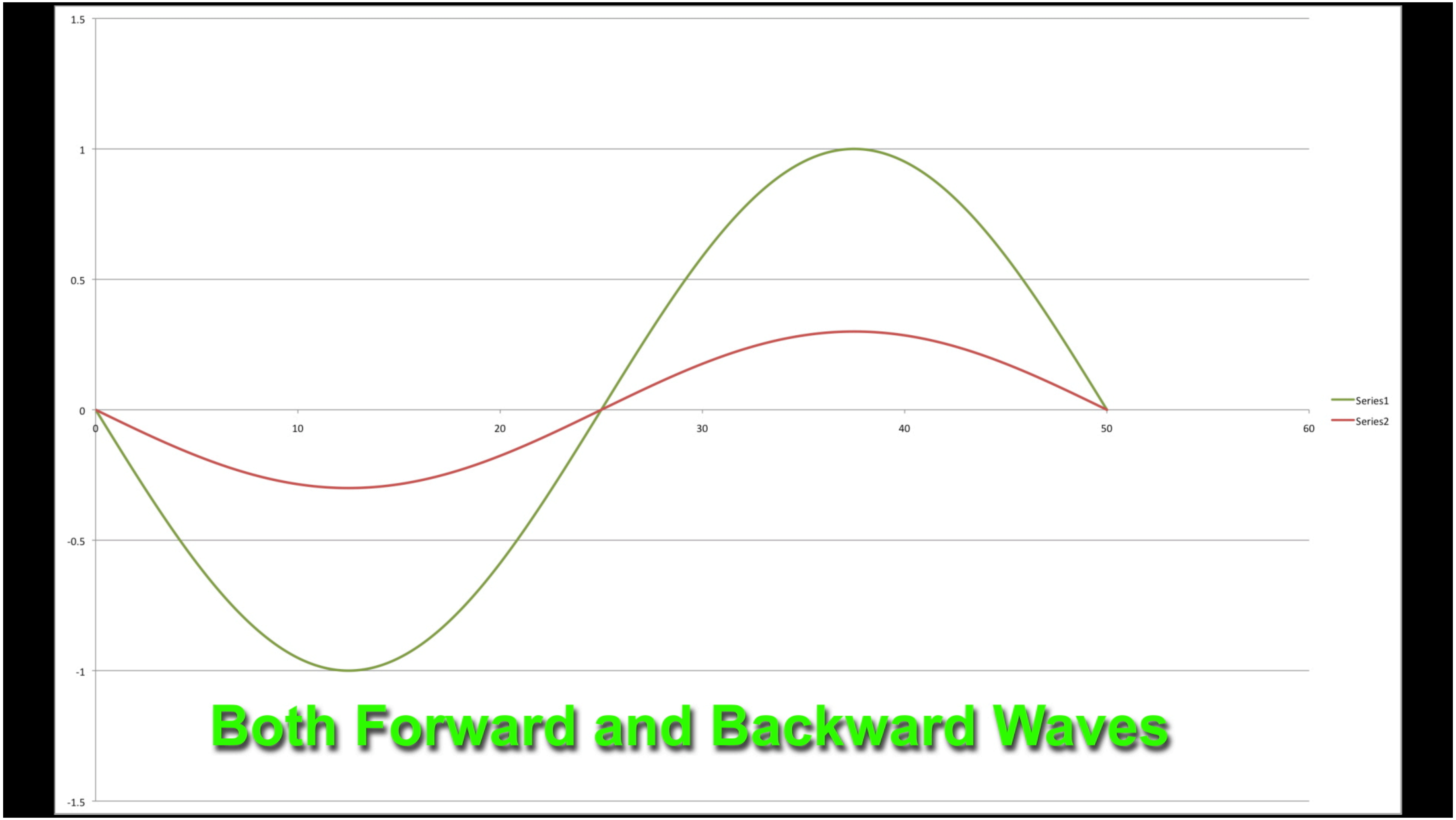
Forward Wave, Length=1λ



Reverse Wave, $\rho = -0.3$

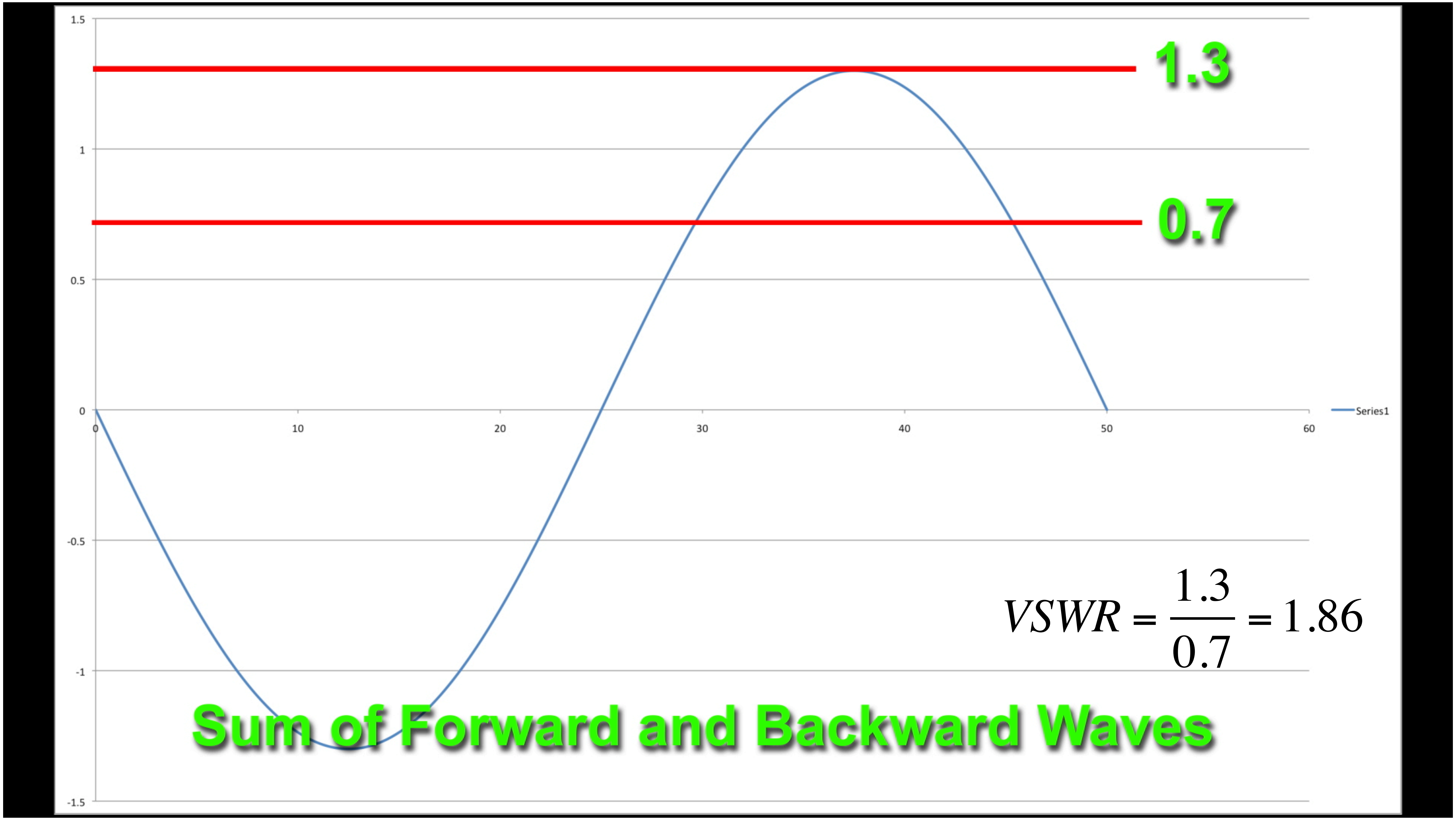


Both Waves



1.5
1
0.5
0
-0.5
-1
-1.5
0
10
20
30
40
50
60
Series1
Series2
Both Forward and Backward Waves

Now, Sum Both Waves



Formula Variations

- The Voltage Reflection Coefficient can be calculated from Forward & Reverse Powers.

$$|\rho| = \sqrt{\frac{P_R}{P_F}}$$

- Sometimes "Return Loss" is calculated:

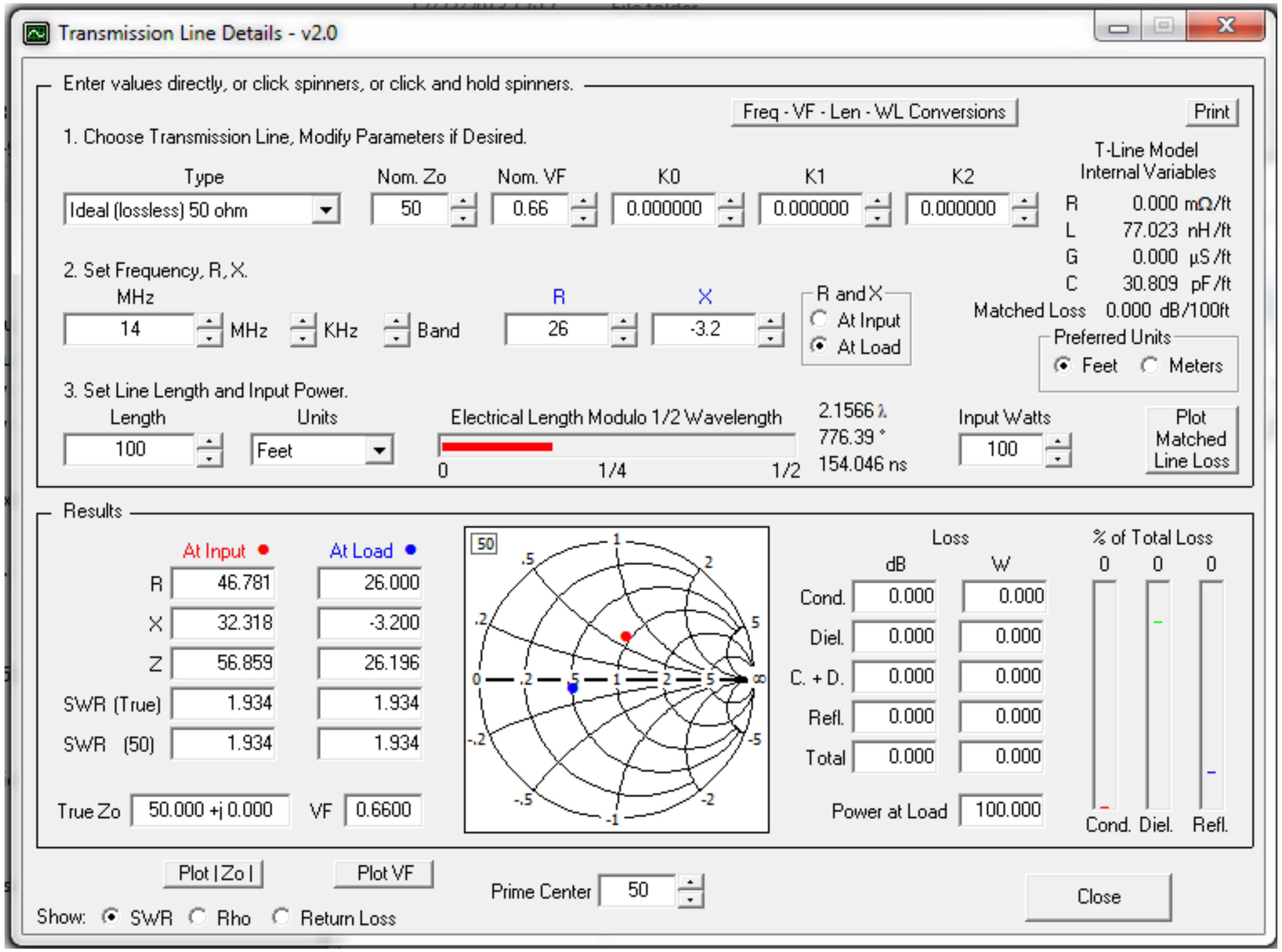
$$RL(dB) = 10\log_{10}\left(\frac{P_F}{P_R}\right) = 10\log_{10}\left|\frac{1}{\rho^2}\right|$$

$$RL(dB) = -20\log_{10}|\rho|$$

Note: Return Loss is often used when the VSWR is close to 1.0

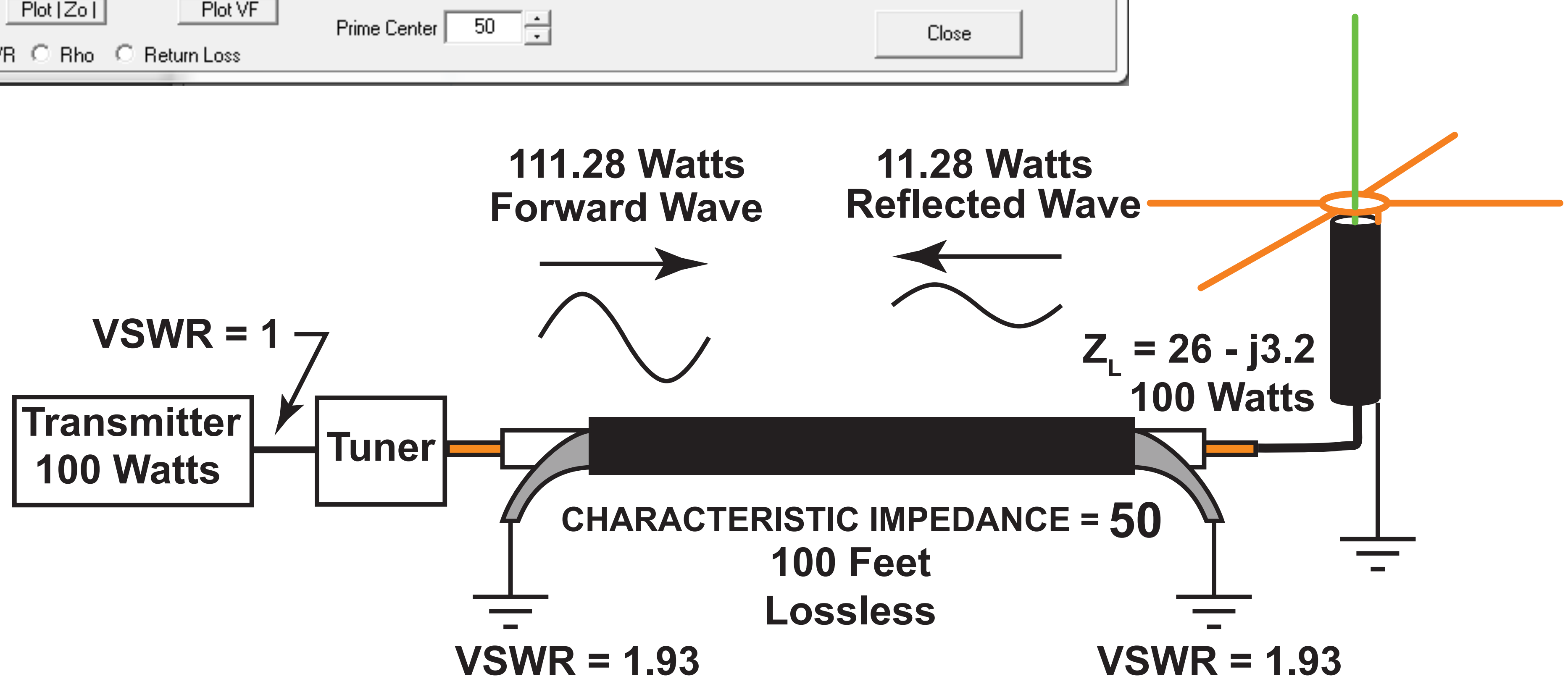
- For example:

$$\mathrm{Z_L} = 75\Omega \quad \mathrm{Z_o} = 50\Omega \quad \rho = 0.2 \quad \mathrm{VSWR} = 1.5 \quad \frac{\mathrm{P_R}}{\mathrm{P_F}} = 0.04 \quad \mathrm{RL} = 14\ \mathrm{dB}$$

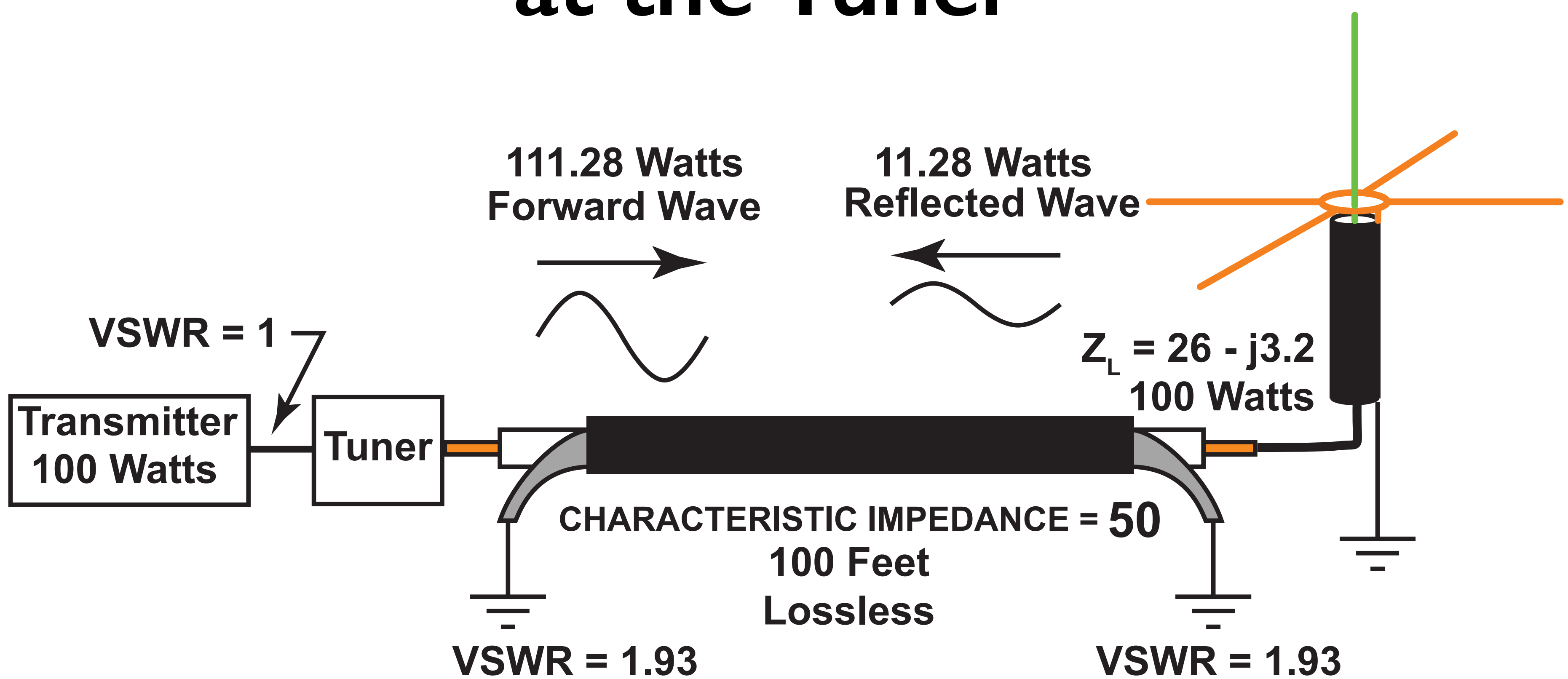


Transmission Line Details

http://www.ac6la.com/tldetails1.html



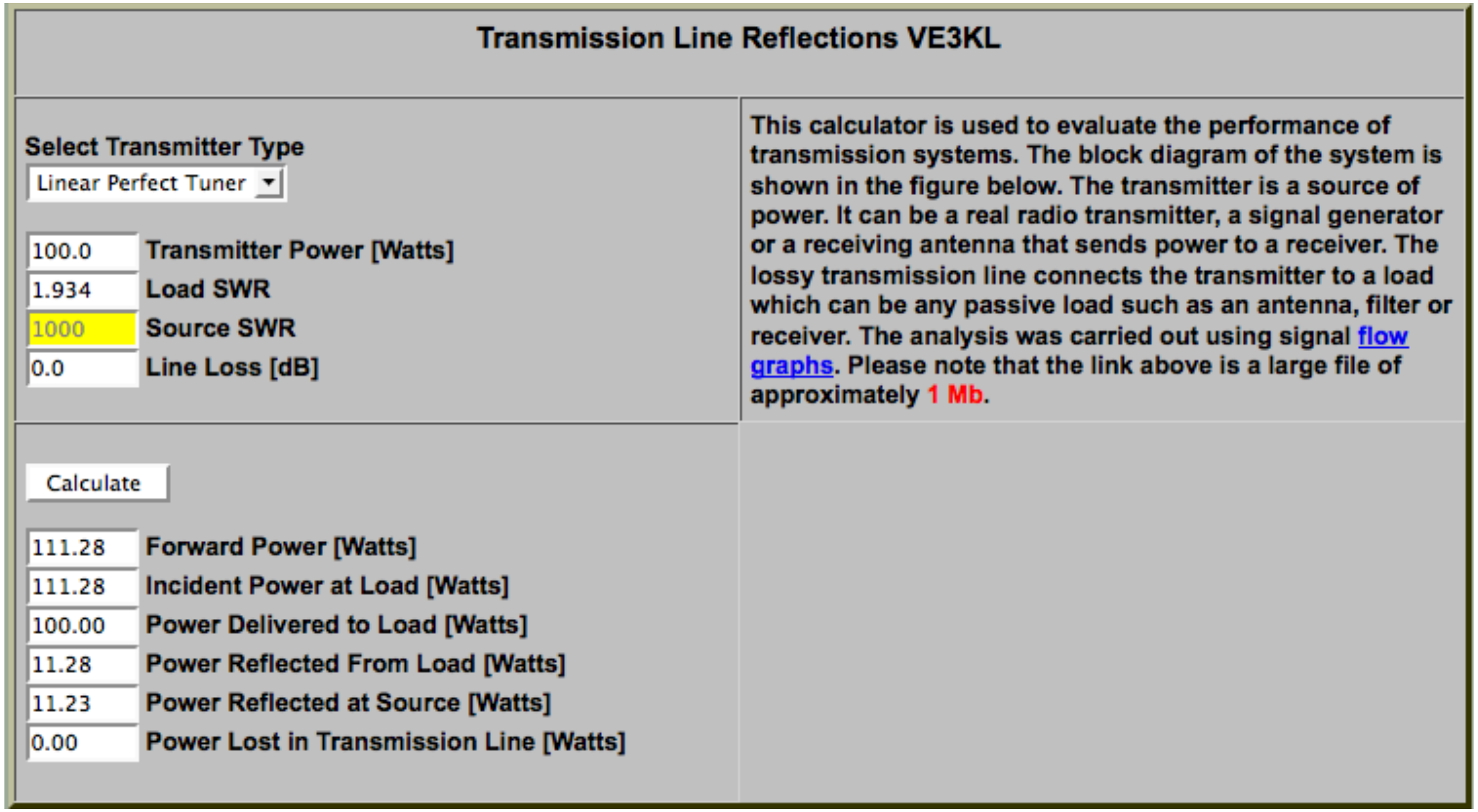
Backward Traveling Wave is Re-Reflected at the Tuner

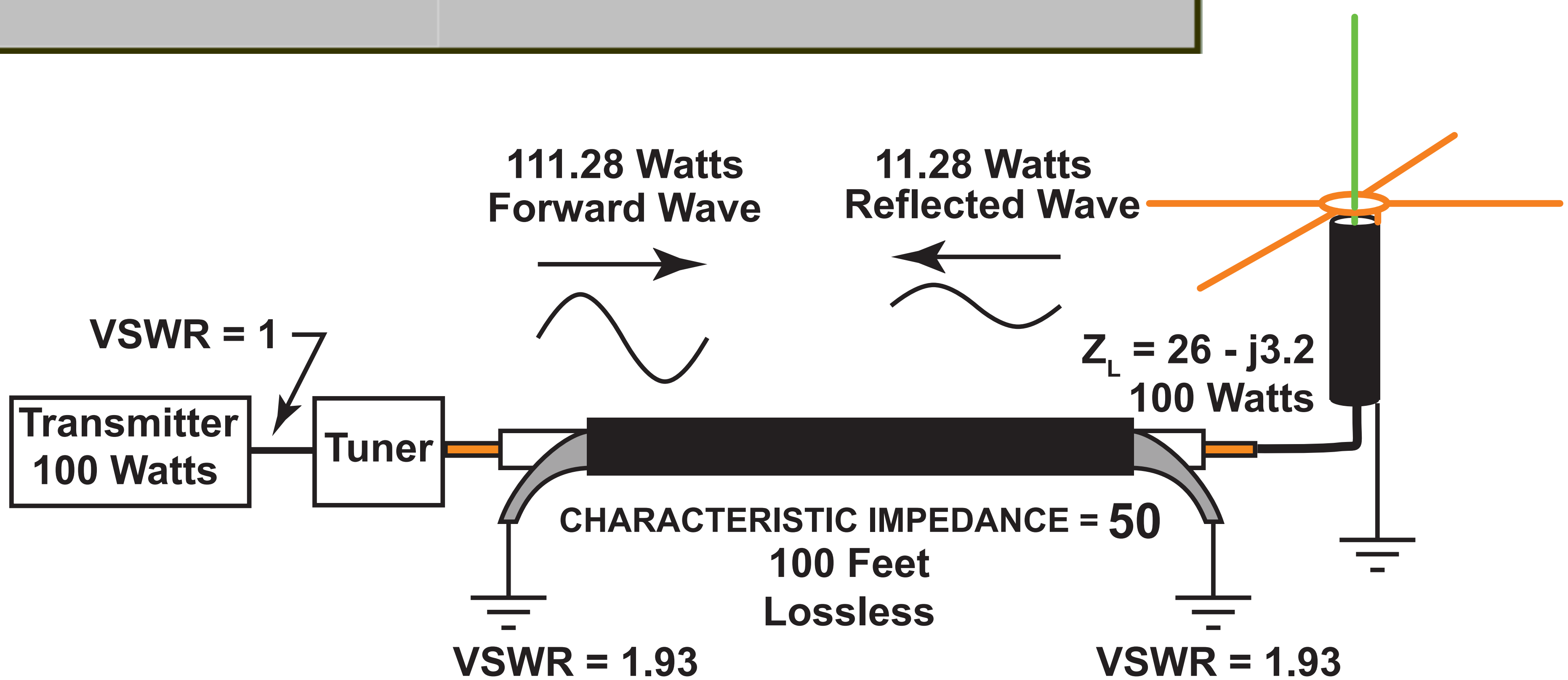


The antenna tuner adjusts the electrical length of the antenna and coax so that the reflected energy (11.28 Watts) has exactly the correct phase to be re-reflected at the antenna tuner. When the tuner is correctly tuned, no energy gets back into the transmitter.

Transmission Line Reflections

https://www.rac.ca/tca/ReflectionsV1.html





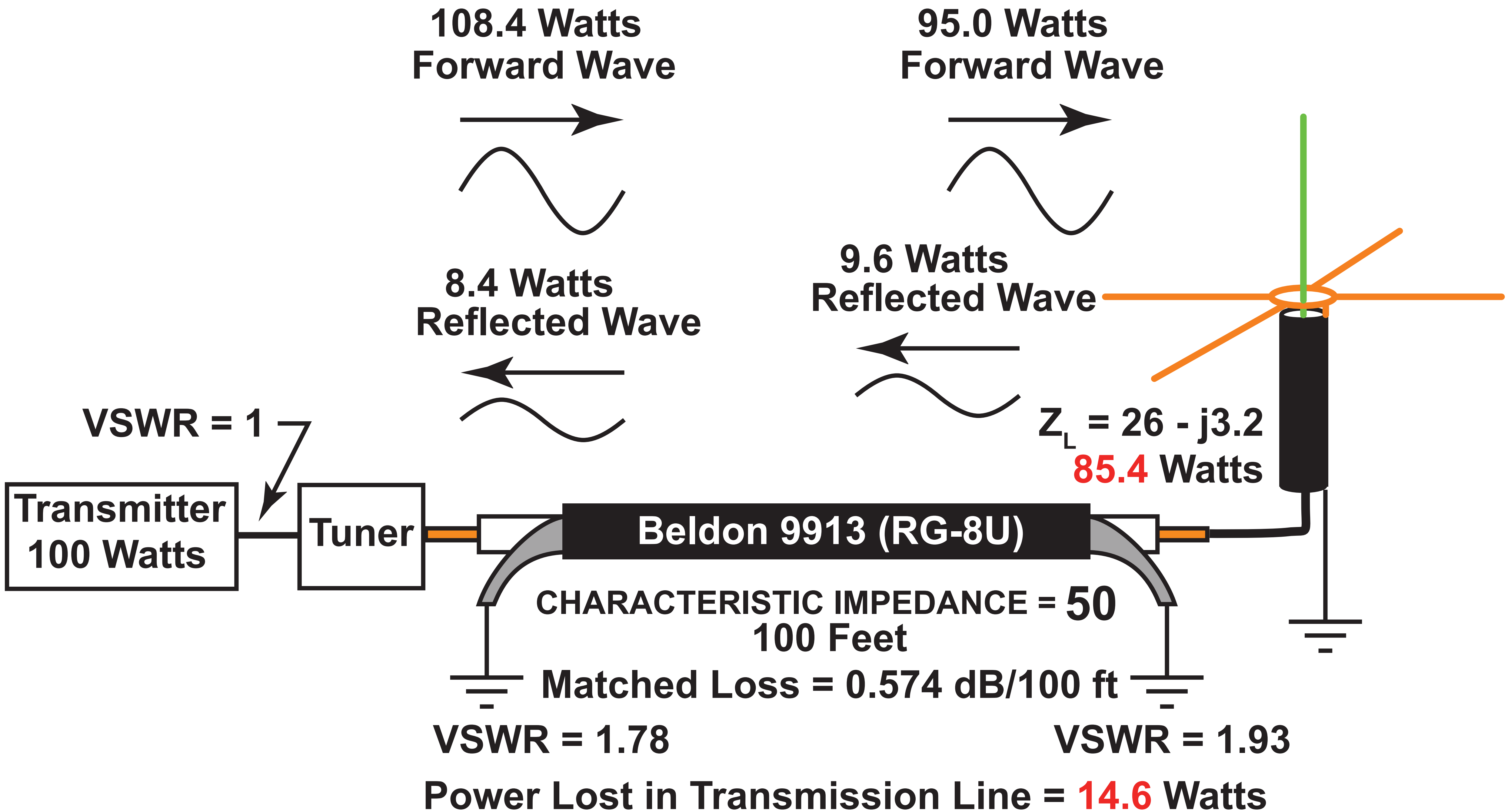
Lossy Transmission Lines

- Real transmission lines have loss.
- The loss is characterized as "matched-line loss" given as "dB per 100 feet."

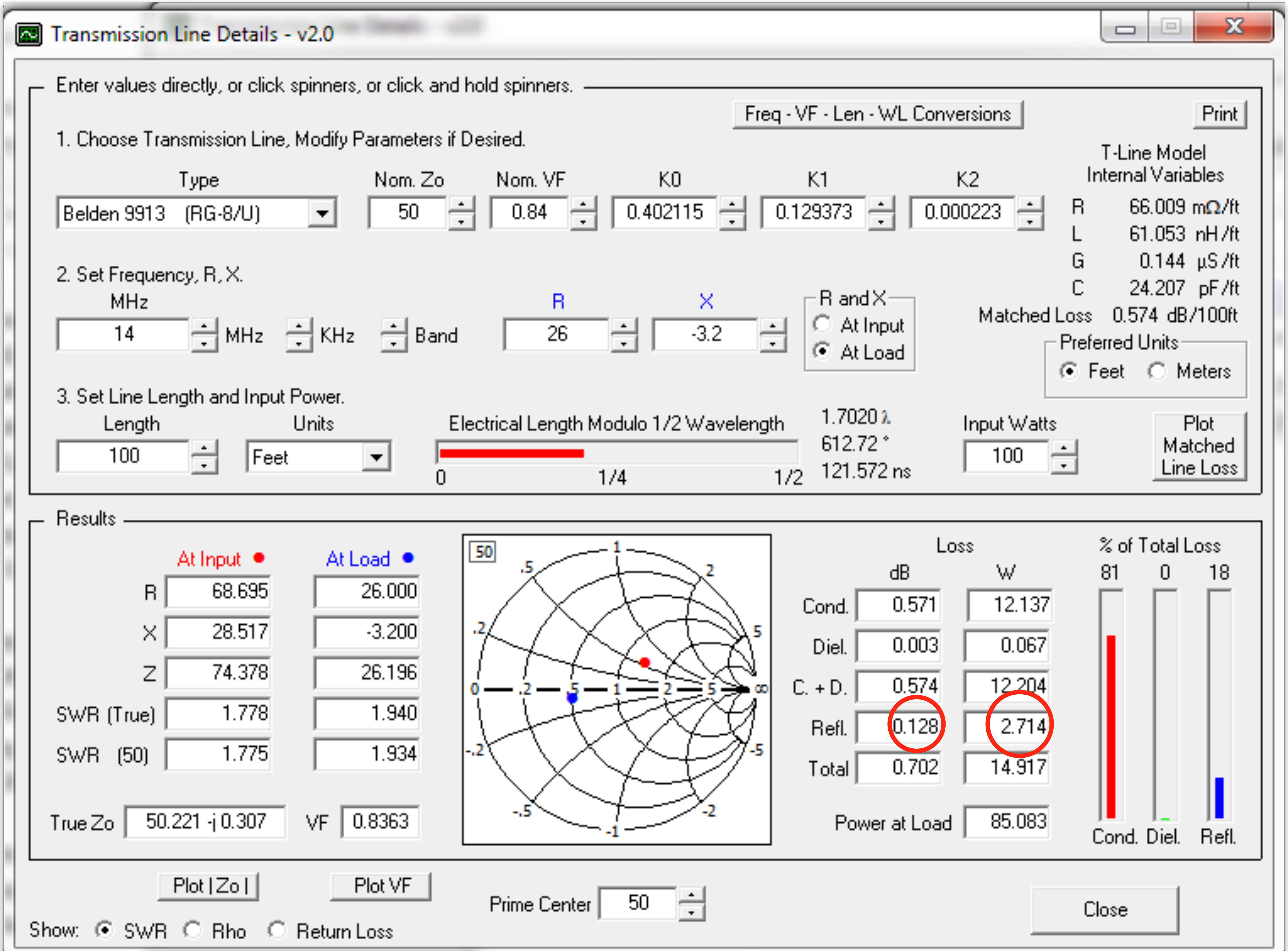
Type	Z	Loss 30 MHz	Loss 146 MHz
LMR 400 Coax	50Ω	0.7	1.5
RG-8X Coax	50Ω	2	4.5
3/4" Hardline	50Ω	0.3	0.85
551 Ladder Line	450Ω	0.3	0.77

- For example, 50 feet of LMR 400 at 146 MHz:

$$\text{Attenuation} = 1.5 \text{ x } {}^{50}\!/_{100} = 0.75 \text{ dB}$$



108.4 Watts
Forward Wave
95.0 Watts
Forward Wave
8.4 Watts
Reflected Wave
9.6 Watts
Reflected Wave
VSWR = 1
Transmitter
100 Watts
Tuner
Beldon 9913 (RG-8U)
Z
L
= 26 - j3.2
85.4 Watts
CHARACTERISTIC IMPEDANCE = 50
100 Feet
Matched Loss = 0.574 dB/100 ft
VSWR = 1.78
VSWR = 1.93
Power Lost in Transmission Line = 14.6 Watts



$$\text{Additional Loss} = 0.702\ dB - 0.574\ dB = 0.128\ dB$$

Transmission Line Reflections VE3KL

Select Transmitter Type

Linear Perfect Tuner

100.0	Transmitter Power [Watts]
1.934	Load SWR
1000	Source SWR
0.574	Line Loss [dB]

This calculator is used to evaluate the performance of transmission systems. The block diagram of the system is shown in the figure below. The transmitter is a source of power. It can be a real radio transmitter, a signal generator or a receiving antenna that sends power to a receiver. The lossy transmission line connects the transmitter to a load which can be any passive load such as an antenna, filter or receiver. The analysis was carried out using signal flow graphs. Please note that the link above is a large file of approximately 1 Mb.

Calculate

108.44	Forward Power [Watts]
95.01	Incident Power at Load [Watts]
85.38	Power Delivered to Load [Watts]
9.63	Power Reflected From Load [Watts]
8.40	Power Reflected at Source [Watts]
14.62	Power Lost in Transmission Line [Watts]

Mismatched Lossy Lines

- The net effect of high VSWR is to increase the average value of voltage and current over a matched line which increase the power loss.
- The total Mismatched Line Loss in dB is:

$$Loss(dB) = 10\log_{10}\left[\frac{a^2 - |\rho|^2}{a\left(1 - |\rho|^2\right)}\right]$$

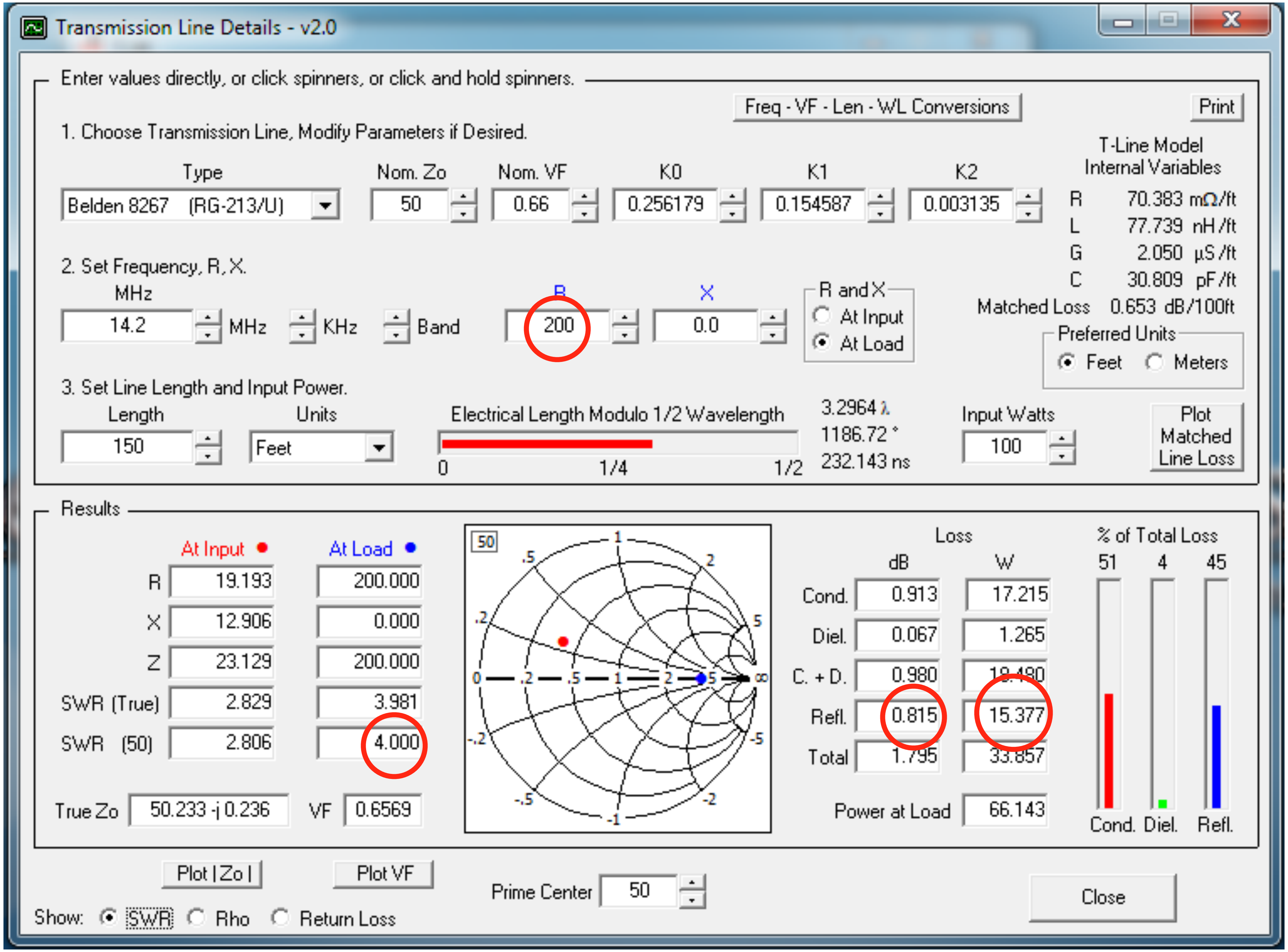
where $a = 10^{\left(ML/10\right)}$ = Matched Line Ratio

ML = Matched Line Loss in dB

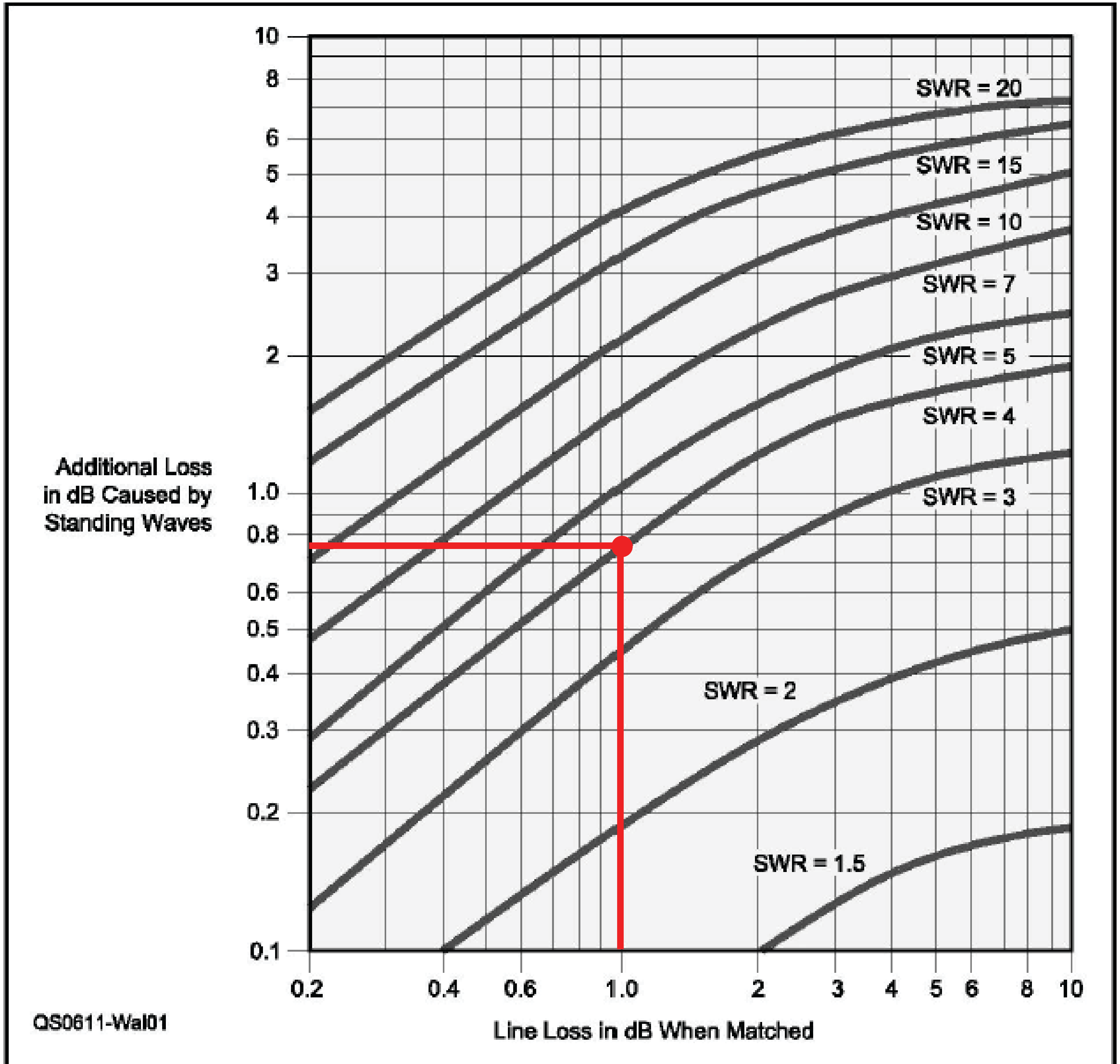
- Example: ρ=.6, VSWR=4.0, 150 feet RG-213 @ 14.2 MHz
- ML= (0.653/100)x150 = 0.980 dB)

a=1.253 Mismatched Loss=1.79 dB or and extra 0.81 dB

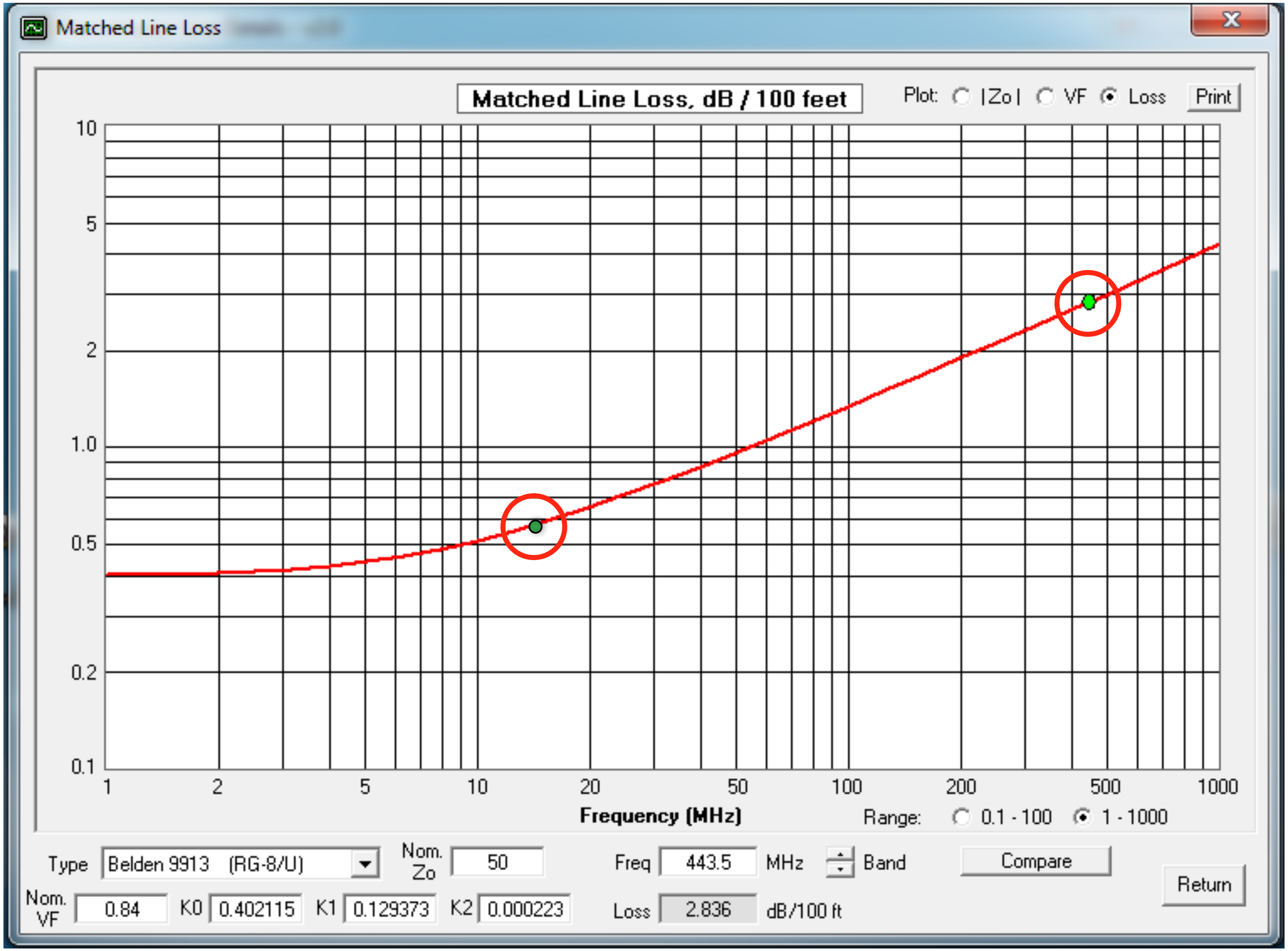
Mismatched Lossy Lines



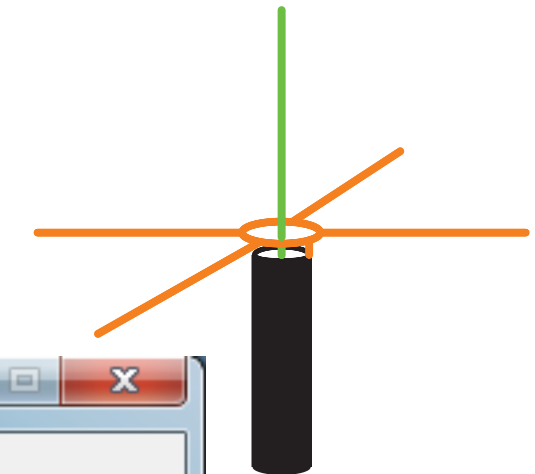
Additional Loss Caused by Standing Waves

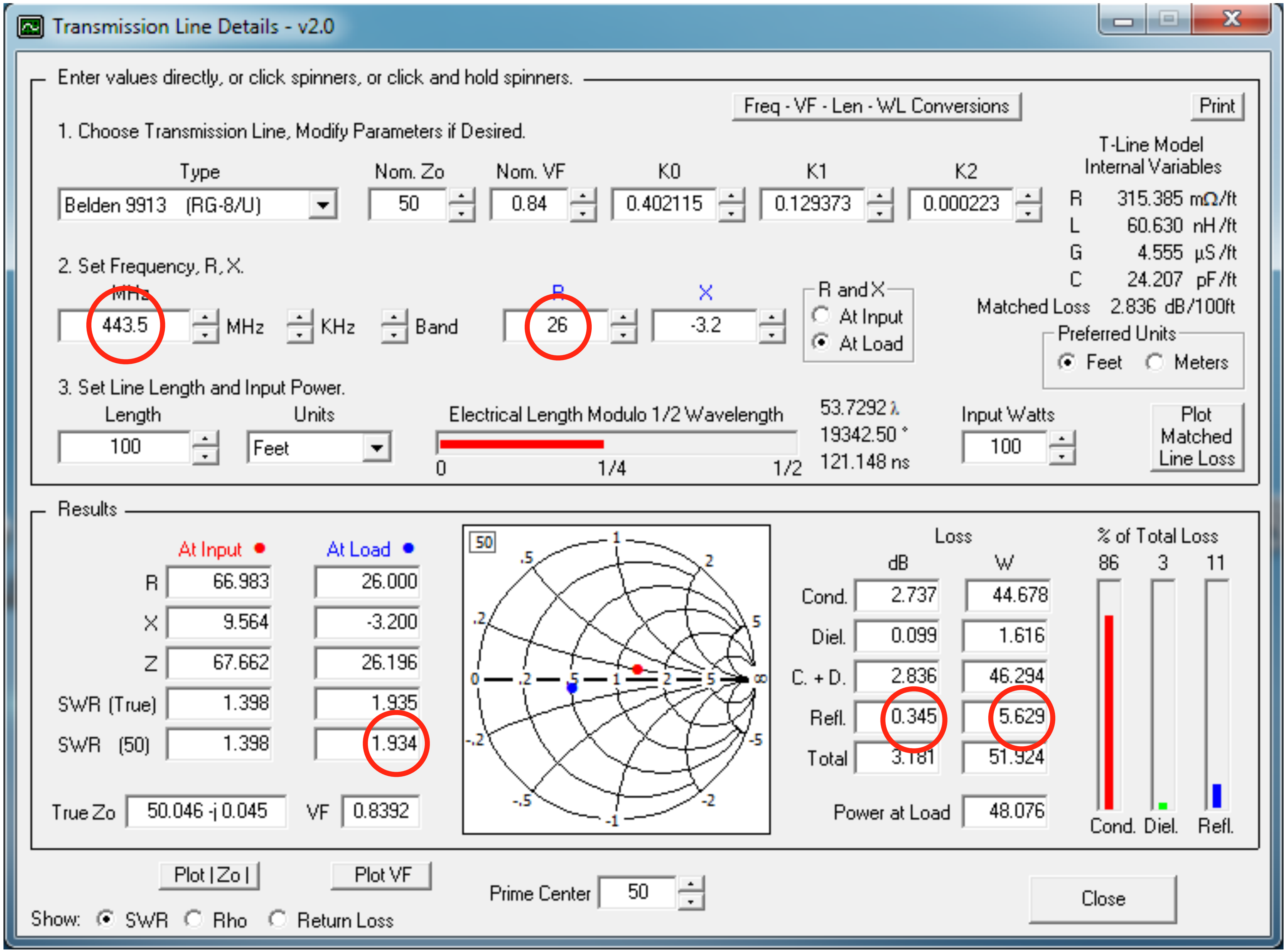


RG-8U at 443.5 MHz



RG-8U at 443.5 MHz





VSWR at the Input of a Lossy Line

- Because of the losses in a transmission line, the measured VSWR at the input of the line is less than the VSWR measured at the load end of the line.

$$VSWR_{Input} = \frac{a + |\rho|}{a - |\rho|}$$

- Example

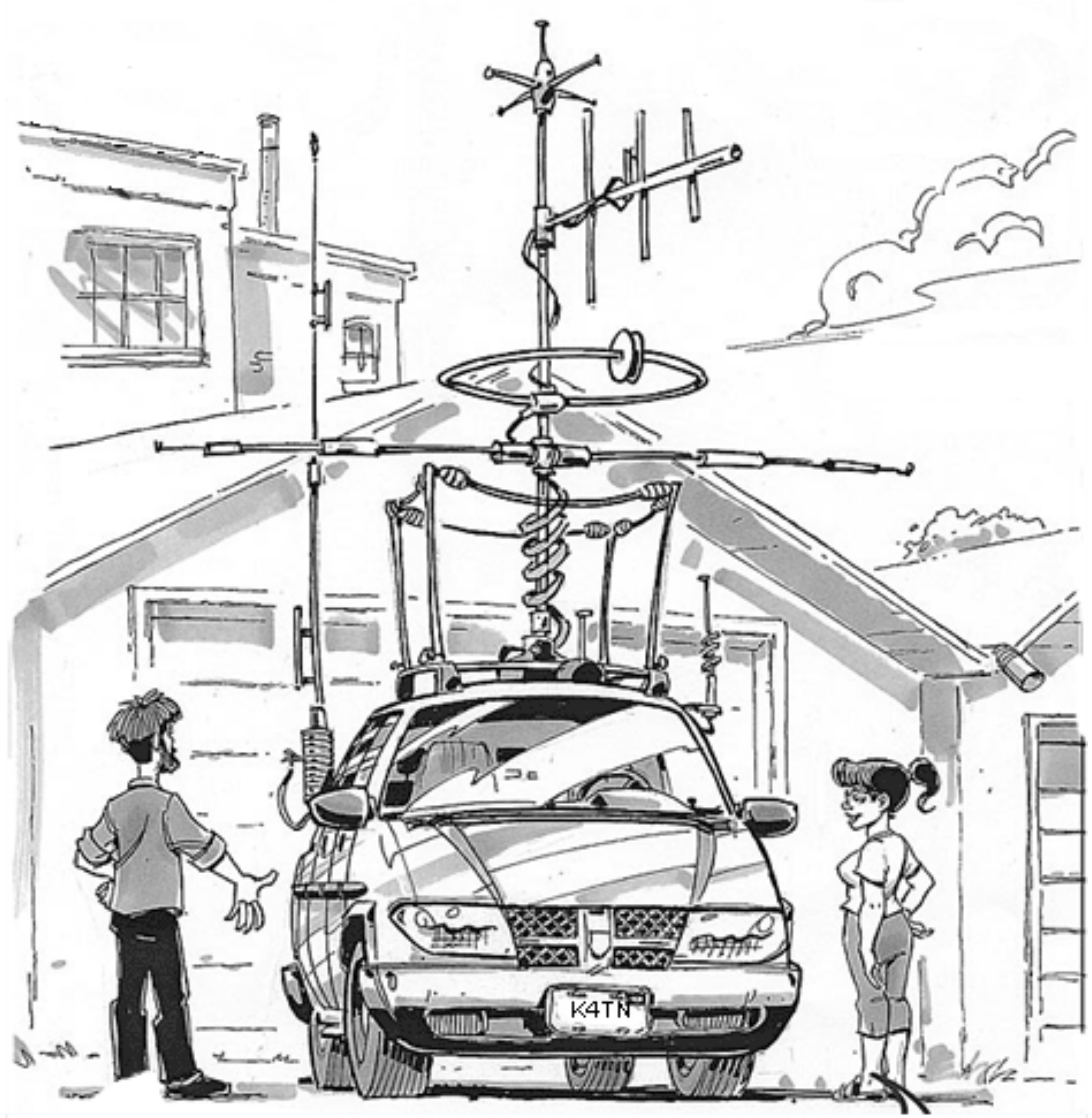
  250 feet of RG-8X @ 30 MHz (ML=2.0 dB x 2.5 = 5.0 dB) with a VSWR at the load of 6:1

$$|\rho| = 0.71 \quad a = 3.16 \quad \text{VSWR}_{Input} = 1.58$$

- Even with the load-end open or shorted, e.g. $|\rho| = 1$

$$VSWR_{Input} = \frac{3.16+1}{3.16-1} = {}^{4.16}\!/_{2.16} = 1.92$$

Now you can explain everything about your antennas!



Here is a good article to help: *http://www.hamuniverse.com/wc7iswr.html*