The Effects of VSWR on Transmitted Power

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• What is VSWR and Why Should I Care?

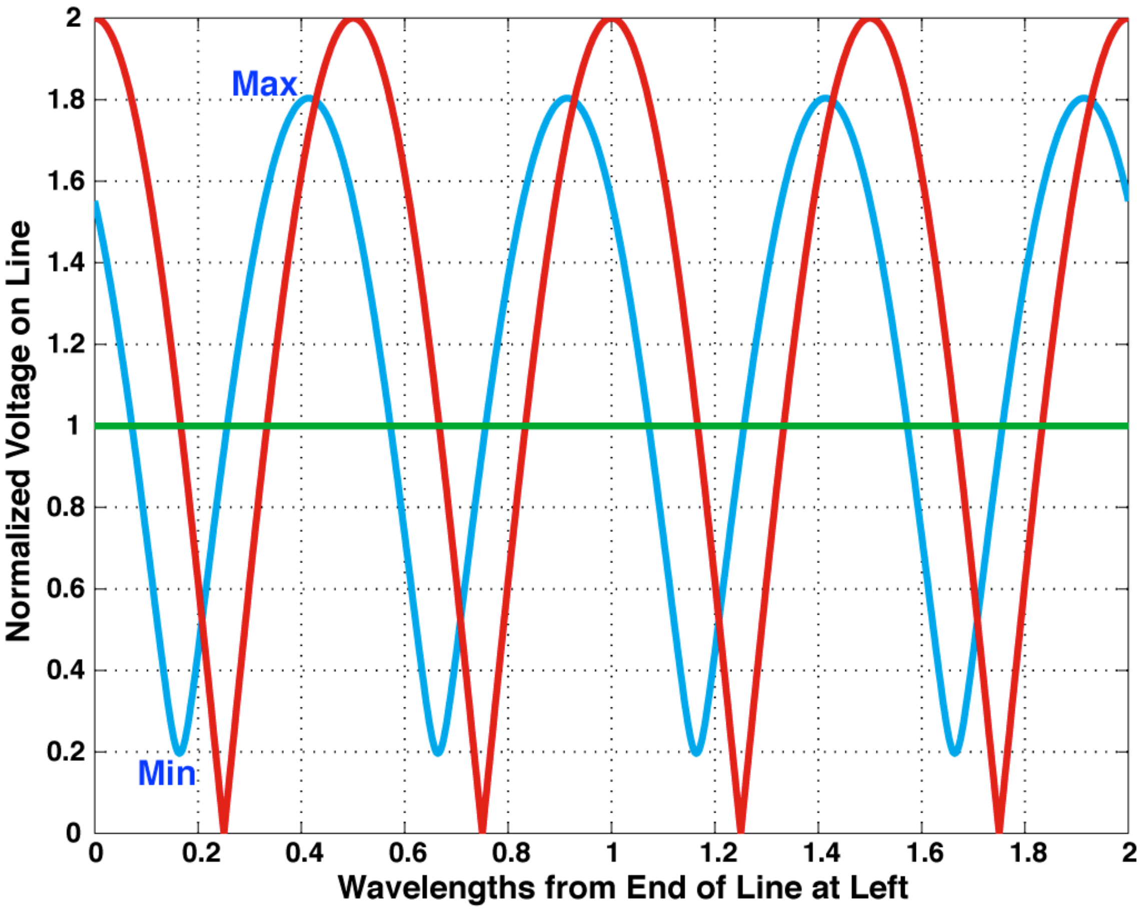
An ocean wavetrain traveling toward shore carries energy toward the beach. If it runs up onto a gently sloping beach, all of the energy gets absorbed, and there are no waves traveling back offshore. If instead of a sloping beach a vertical seawall is present, then the incoming wavetrain gets completely reflected, so that no energy is absorbed at the wall. The interference between the incoming and outgoing waves in this case produces a "standing wave" that doesn't look like it is traveling at all; the peaks stay in the same spatial positions and just go up and down.

The same phenomenon happens on a radio or radar transmission line. In this case, we want the waves on the line (both voltage and current) to travel one way and deposit their energy into the desired load, which in this case may be an antenna where it is to be radiated. If all the energy gets reflected (for example, by an open or short circuit) at the end of the line, then none gets absorbed, producing a perfect "standing wave" on the line. This is a bad, undesired situation. In fact, when the power meant to be radiated comes back into the transmitter at full strength, it will usually burn out the electronics there.

It doesn't take an open or short circuit to cause a reflected wave. All it takes is a mismatch in impedance between the line and the load. If the reflected wave is not as strong as the forward wave, then some "standing wave" pattern will be observed, but the nulls will not be as deep nor the peaks as high as for a perfect reflection (or complete mismatch).

Therefore, any "standing wave" is an indication of an imperfect condition, with part of the power meant for radiation being returned because of a mismatch. If there is no mismatch with only a forward traveling wave, then there is no standing wave; i.e., the voltage at any point on the line is the same as it is everywhere else. A long time ago, clever electrical engineers devised simple methods to measure the presence and strength of a standing wave on a transmission line or waveguide, and use this to gauge the quality of the match. Once detected, one can decide whether it is strong enough to worry about, and whether to fix the source of the mismatch. ***The intensity of the standing wave is referred to as the "Voltage Standing Wave Ratio", or VSWR.***

There are four quantities that describe the effectiveness of transferring power from a line to a load or antenna: the VSWR, the reflection coefficient, the mismatch loss, and the return loss. These are all inter-related, and they are defined and demonstrated in this document. For now, to obtain a feeling for their meaning, we show them graphically on the next figure. This graphs three conditions: (1) line connected to a matched load; (ii) line connected to a short monopole antenna that is not matched (antenna input impedance is 20 – j80 ohms, compared to the transmission line impedance of 50 ohms); (3) the line is open at the end where the antenna should have been connected.



$$VSWR \equiv \frac{Max}{Min}$$

Red Curve: **Standing wave on line with open circuit at left end (antenna terminals)**

[This is very bad: no power transferred past end of line]

Load Impedance = ∞

Reflection Coefficient = 1

VSWR = ∞

Mismatch Loss = $-\infty$ dB

Return Loss = 0 dB

Blue Curve: **Standing wave on 50-ohm line into short monopole antenna**

[This is not too good; power into load or antenna is down –4.5 dB from that available traveling down line]

Load Impedance = 20 – j80 ohms

Reflection Coefficient = 0.3805 – j0.7080

Absolute Value of Reflection Coefficient = 0.8038

VSWR = 9.2

Mismatch Loss = - 4.5 dB

Return Loss = -1.9 dB

<u>Green Curve</u>: **Standing wave on 50-ohm line with matched 50-ohm load at end**

[This is perfect; no standing wave; all power goes into antenna/load]

Load Impedance = 50 ohms
Reflection Coefficient = 0
VSWR = 1
Mismatch Loss = 0 dB
Return Loss = $-\infty$ dB

- **Formal Definition of VSWR and SeaSonde Measurements**

The voltage component of a standing wave in a uniform transmission line consists of the forward wave (with amplitude Vf) superimposed on the reflected wave (with amplitude Vr). Reflections occur as a result of discontinuities, such as an imperfection in an otherwise uniform transmission line, or when a transmission line is terminated with other than its characteristic impedance.

If you are interested in determining the performance of antennas, the VSWR should always be measured at the antenna terminals itself rather than at the output of the transmitter. Because of ohmic losses in the transmit cabling, an illusion will be created of having a better antenna VSWR, but that is only because these losses damp the impact of an abrupt reflection at the antenna terminals.

Since the antenna is usually located some distance from the transmitter, it requires a feed line to transfer power between the two. If the feed line has no loss, and matches both the transmitter output impedance and the antenna input impedance, then the maximum power will be delivered to the antenna. In this case the VSWR will be 1:1 and the voltage and the current will be constant over the whole length of the feed line.

Return loss is a measure in dB of the ratio of power in the incident wave to that in the reflected wave, and we define it to have a negative value.

Return loss = $10 \log(P_r / P_i) = 20 \log (E_r / E_i)$

For example if a load has a return loss of -10 dB, then 1/10 of the incident power is reflected. The higher the return loss, the less power is actually lost.

Also of considerable interest is the mismatch loss. This is a measure of how much the transmitted power is attenuated due to reflection. It is given by the following relation:

Mismatch Loss = $10 \log (1 - \rho^2)$

For example, from Table #1 an antenna with a VSWR of 2:1 would have a reflection coefficient of 0.333, a mismatch loss of -0.51 dB, and a return loss of -9.54 dB (11% of your transmitter power is reflected back).

Table#1

VSWR	Return Loss (dB)	% Power / Voltage Loss	Reflection Coefficient	Mismatch Loss (dB)
1	∞	0 / 0	0	0.000
1.15	23.1	0.49 / 7.0	0.07	.021
1.25	19.1	1.2 / 11.1	0.111	.054
1.5	14.0	4.0 / 20.0	0.200	.177
1.75	11.3	7.4 / 27.3	0.273	.336
1.9	10.0	9.6 / 31.6	0.316	.458
2.0	9.5	11.1 / 33.3	0.333	.512
2.5	7.4	18.2 / 42.9	0.429	.880
3.0	6.0	25.1 / 50.0	0.500	1.25
3.5	5.1	30.9 / 55.5	0.555	1.6
4.0	4.4	36.3 / 60.0	0.600	1.94
4.5	3.9	40.7 / 63.6	0.636	2.25
5.0	3.5	44.7 / 66.6	0.666	2.55
10	1.7	67.6 / 81.8	0.818	4.81
20	0.87	81.9 / 90.5	0.905	7.4
100	0.17	96.2 / 98.0	0.980	14.1
∞	.000	100 / 100	1.00	∞

Formulas:

VSWR = Emax/Emin =(E_{frd} + E_{ref})/(E_{frd} - E_{ref})

Where:
E_{max} = maximum voltage on the standing wave
E_{min} = minimum voltage on the standing wave
E_{frd} = incident voltage wave amplitude
E_{ref} = reflected voltage wave amplitude

VSWR =(1 + ρ)/(1 - ρ)

Where:
ρ is the reflection coefficient of the antenna (absolute value of voltage reflection)

Return loss = 10 log(P_r / P_i) = 20 log (E_r / E_i)

Ideally, with a perfect 1:1 VSWR there would be no reflected power. Consequently the return loss on the feed line would appear to be infinite.

From the SeaSonde monitor below, you will get the forward and reflected power: