Impedance, Reflections, and Transformations

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Conventional wisdom:

"My antenna is useless above 1.5:1 SWR"

(Or is it 2:1? Or 3:1?)

"Antenna tuners only make your transmitter happy."

Noooooooooo…

Waves behave just about the same in any medium!

Ripples in water
Wake from a boat
Guitar strings
Radio waves in coax line

Wave Superposition:

Waves *sum* when they intersect

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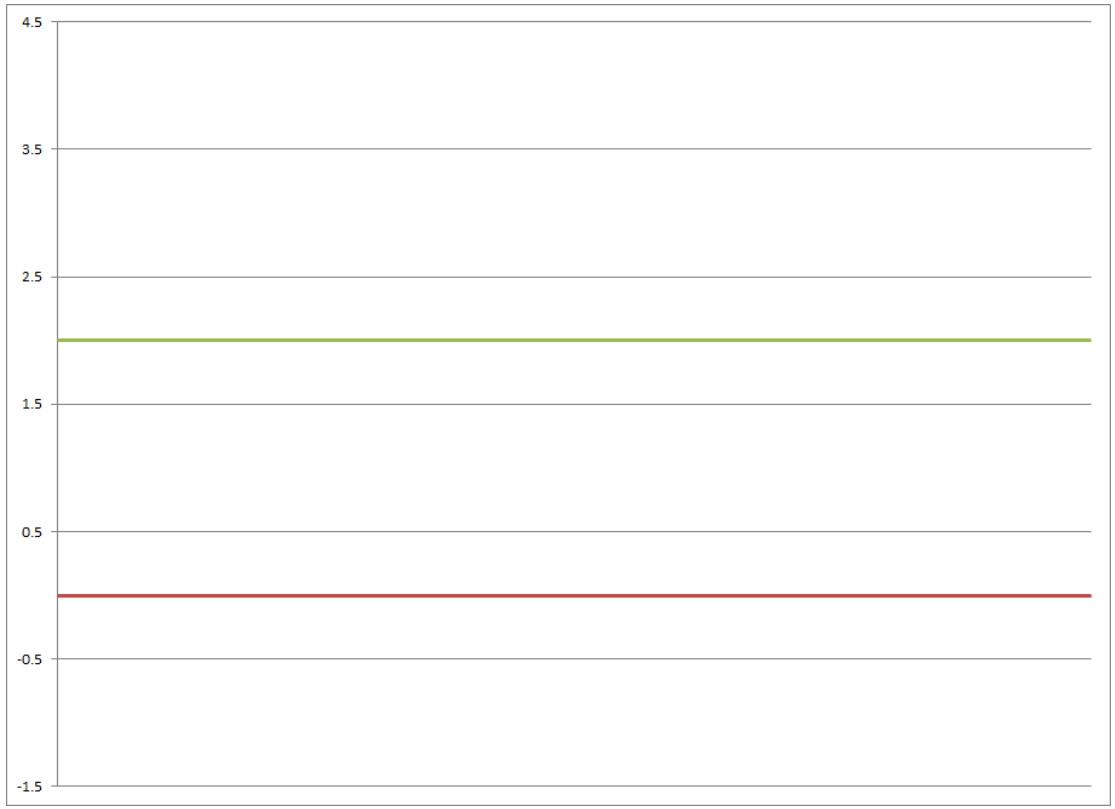
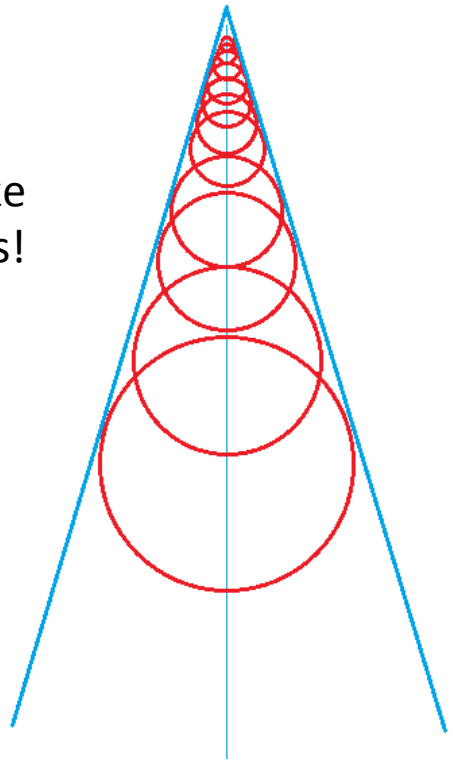


Wave Superposition:

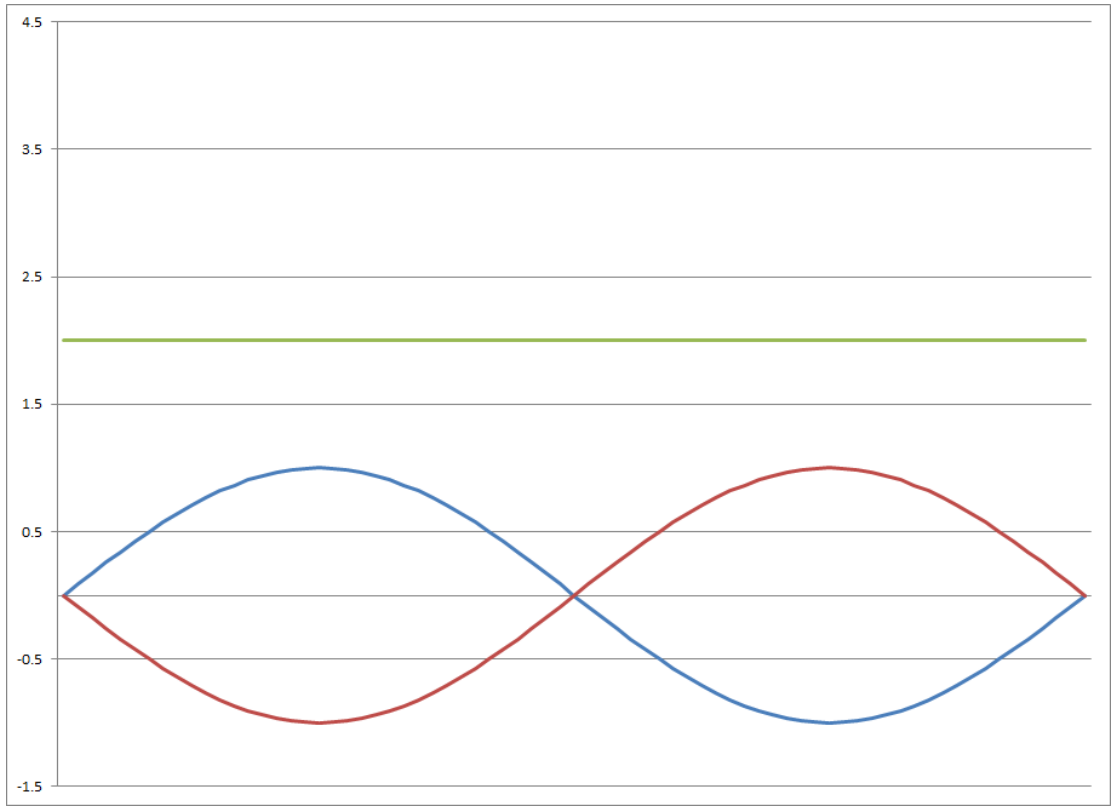
Waves *sum* when they intersect

Boat wake
Sonic booms!



Wave Superposition:

Waves *sum* when they intersect



Wave machine demo!

Shive Wave Machine

Torsion rod + weighted crossbars

Wave machine demo!

Single pulse

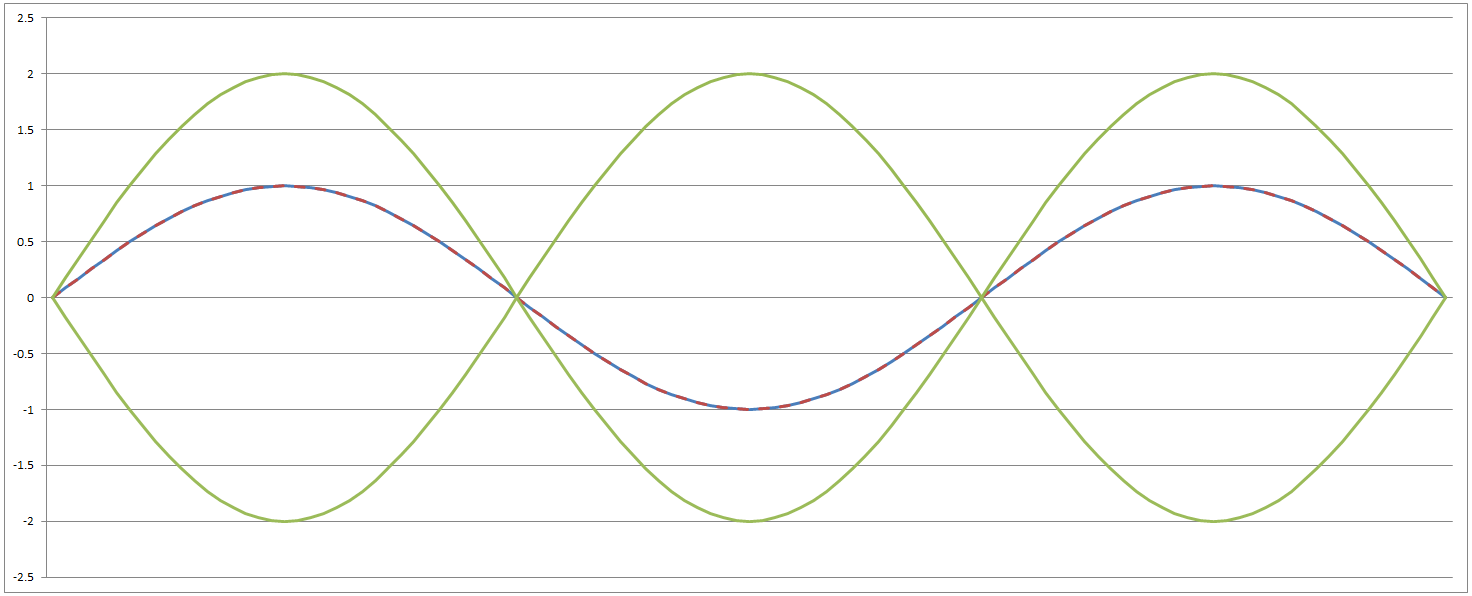
Intersecting pulses

Wave Superposition:

Standing waves!

Forward & Reverse waves identical amplitude; 100 % reflection

- peaks and troughs 2x amplitude
- nodes have zero amplitude

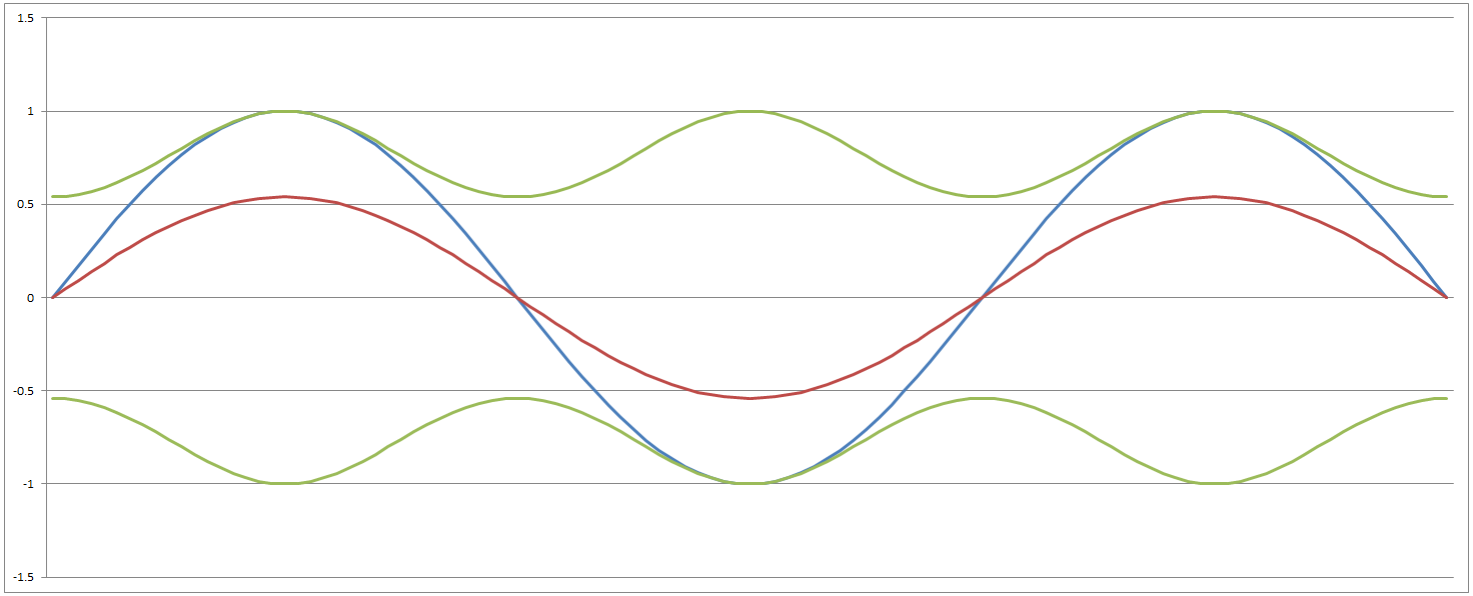


Wave Superposition:

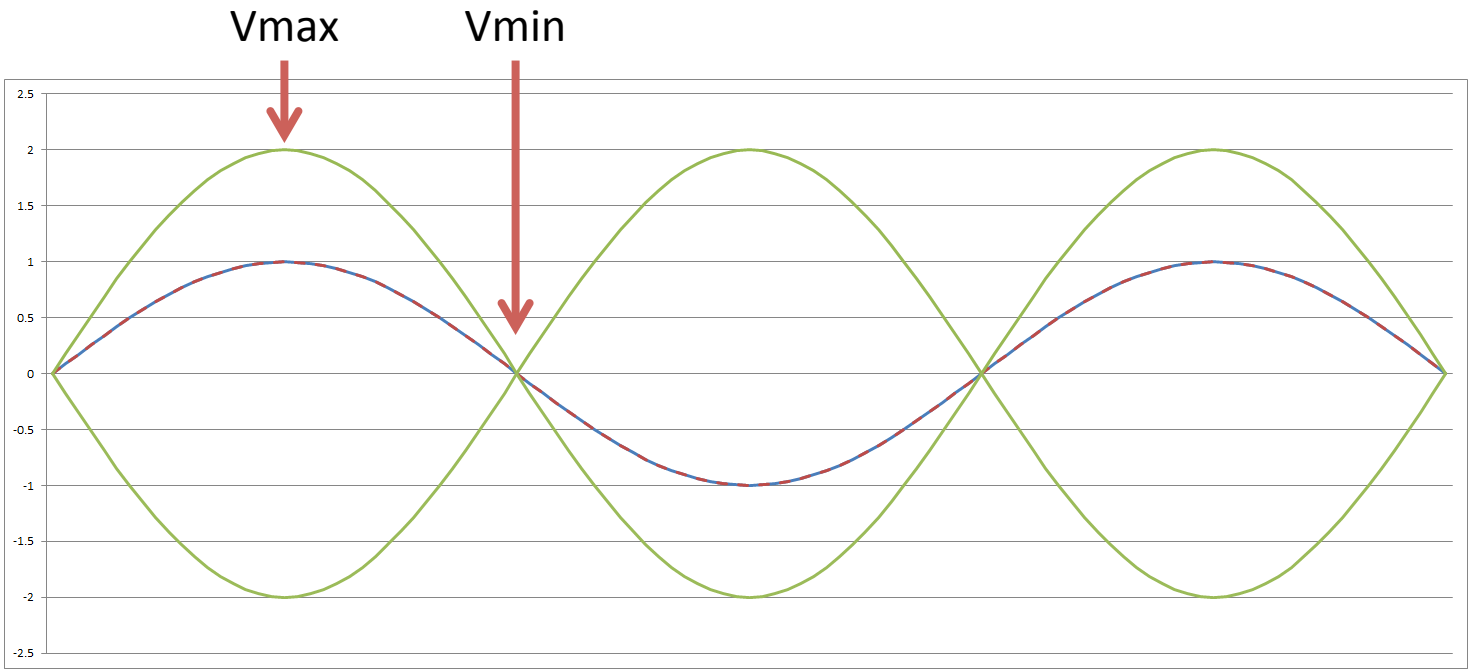
Standing waves!

Forward & Reverse waves *different* amplitude; [0 < 100%] reflection

- peaks and troughs somewhere between 1x & 2x
- nodes have *non-zero* amplitude



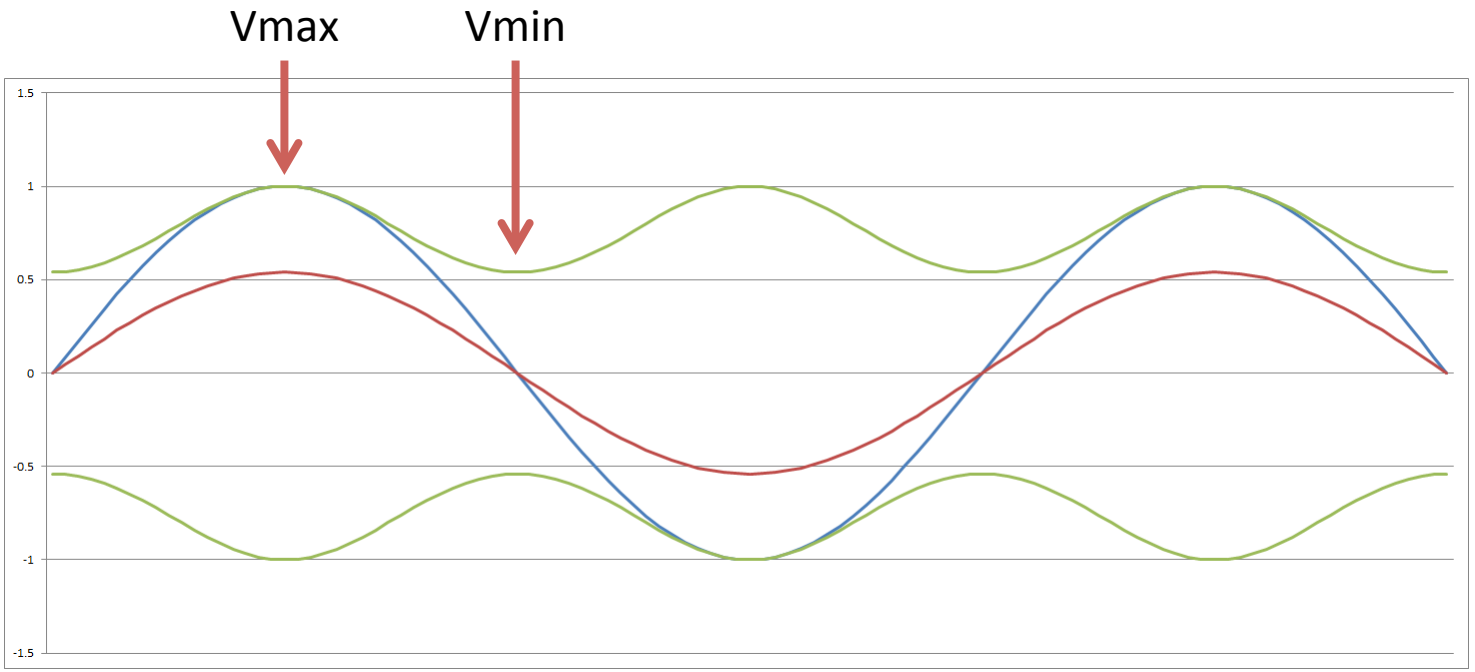
Standing Wave Ratio



100 % reflection

$$\text{Voltage SWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{2.0}{0} = \infty$$

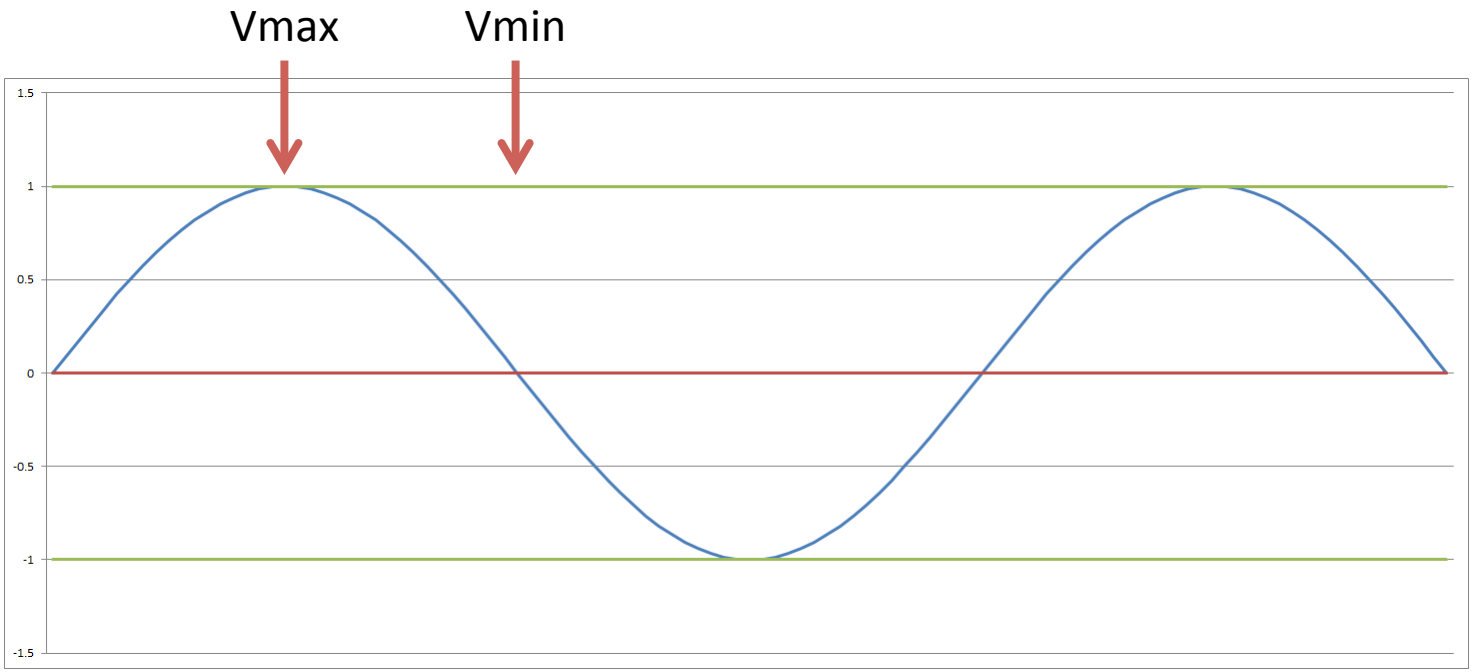
Standing Wave Ratio



[0 < 100] % reflection

$$\text{Voltage SWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1.0}{0.54} = 1.85{:}1$$

Standing Wave Ratio



0 % reflection (100% absorption!)

$$\text{Voltage SWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1.0}{1.0} = 1{:}1$$

Reflections come from impedance mismatches

Standing waves come from reflections

Big impedance mismatch = big standing wave ratio

True in radio, water, mechanical!

Four ways to determine SWR

VSWR = $V\downarrow max \ / \ V\downarrow min$

ISWR = $I\downarrow max \ / \ I\downarrow min$

SWR = $1+\sqrt{(P\downarrow fwd \ / P\downarrow refl \ )}/ \ 1-\sqrt{(P\downarrow fwd \ / P\downarrow refl \ )}$

SWR ~= $(Z\downarrow 0 \ / Z\downarrow load \ )\uparrow \pm$

Use the one simplest to measure

Wave machine demo!

Standing waves

Reflections at load

Reflections at line discontinuity

Impedance transformation

Reflected power is real power

Reflects and re-reflects until lost to heat or absorbed by load

High-loss line will dissipate reflected power faster than low-loss line

What does this mean for radio?

What does this mean for radio?

Lecher lines demo!

50 Ohm TX (FT-817 0.5W 147.55 MHz)
4:1 half-wave coax balun
200 Ohm open wire line (1/8” brass rods, 1/3” on center)
Changeable loads

Directional power indicators

Voltage indicators

Power measurement @ RX

Lecher lines demo

Matched condition: dummy load

Directional power indicators show forward power
No reflected power

Voltage indicators equally bright along entire length of transmission line

No meaningful received power

Lecher lines demo

Mismatched condition: open circuit

Directional power indicators show forward power
100% reflected power

Voltage indicators show standing waves!
High & low voltage points 90 degrees apart
Repeats every ½ wavelength

No meaningful received power

Lecher lines demo

Mismatched condition: short circuit

Directional power indicators show forward power
100% reflected power

Voltage indicators show standing waves!
High & low voltage points 90 degrees apart
Repeats every ½ wavelength

Phase shifted compared to open circuit!

Lecher lines demo

Mismatched condition: ½ wave dipole

~ 3:1 SWR

Directional power indicators show forward power
Some reflected power

Voltage indicators show standing waves!
High & low voltage points 90 degrees apart
Repeats every ½ wavelength

SWR not as severe as open or short

Note signal at receiver

Lecher lines demo

Mismatched condition: full wave dipole

~ 11.5:1 SWR

Directional power indicators show forward power
Much reflected power – Severe mismatch, feeding at high voltage point

Voltage indicators show standing waves!
High & low voltage points 90 degrees apart
Repeats every ½ wavelength

SWR pretty bad

Note signal at receiver

Received signal strength

3:1 SWR

vs

11.5:1 SWR

Received signal strength

3:1 SWR

vs

11.5:1 SWR

Only a few dB difference, not catastrophic!
Why???

Received signal strength

Low-loss line!

Reflected signal re-reflects

Eventually radiates

Minus some heat loss

Can we make it better?

Impedance transformer – antenna tuner!

½ wave dipole: 4.7 pF shunt cap 23.2 cm from load

(or 73.2 cm…)

Full wave dipole: 1.9 pF shunt cap 56.4 cm from load

(or 106.4 cm…)

Note received signal strength!

Has SWR changed?

Is the transmitter happy?

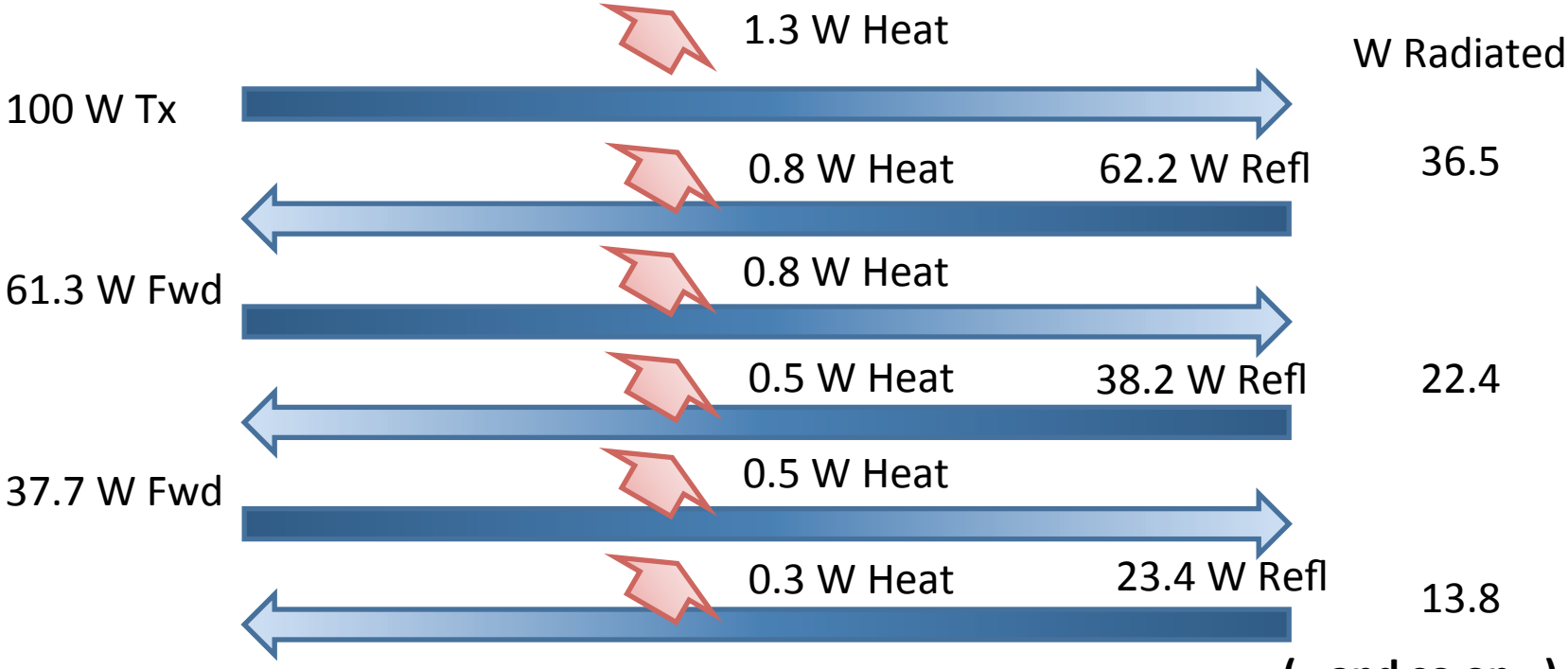
Is the transmitter fooled?

Is the *receiver* happy and fooled?

Reflected power is real power – let it radiate!

Scenario

144 MHz 15 feet 450 Ohm window line
52 Ohm antenna 8.5:1 SWR 63% reflection
0.054 dB (1.3%) loss per 15 feet



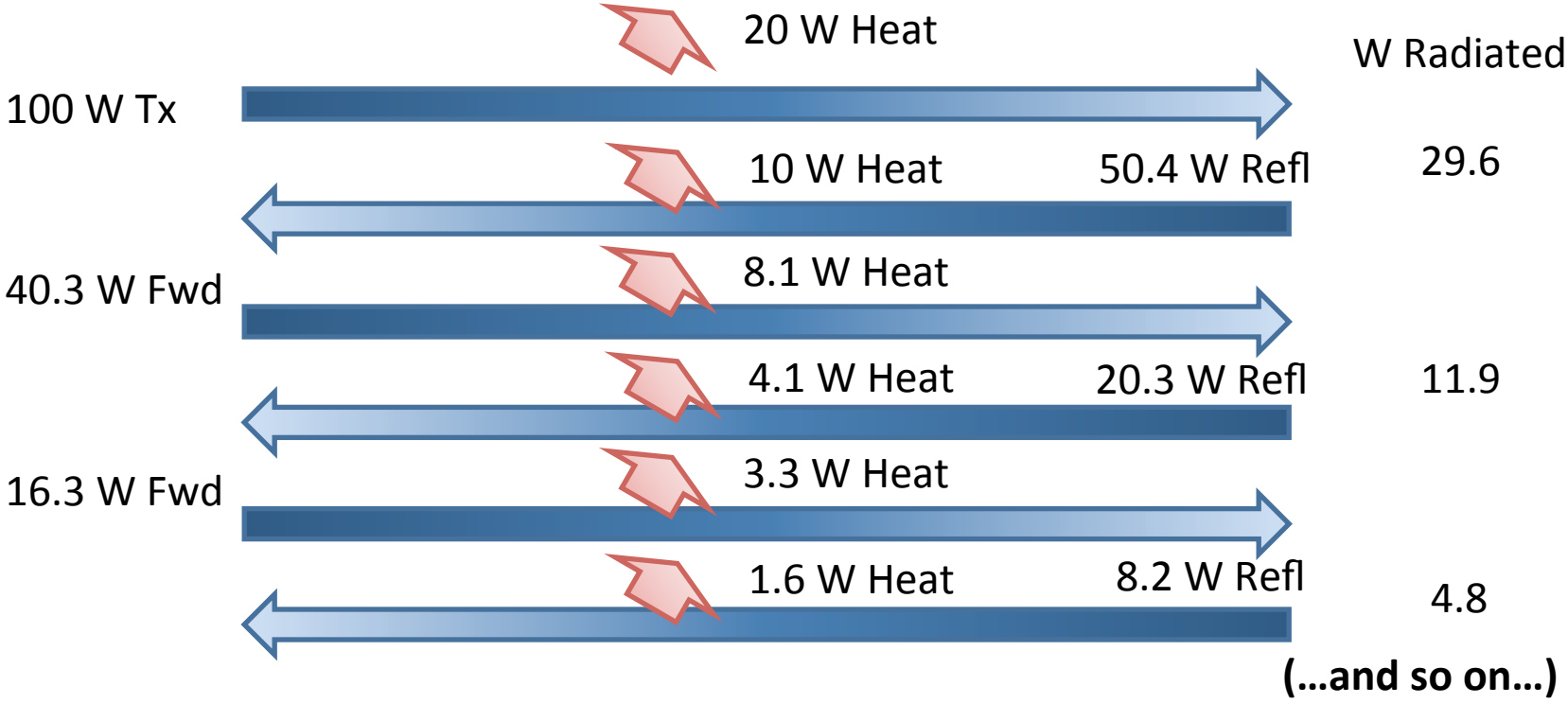
Total 93.8 W radiated – 6.2% lost to heat!

Scenario

144 MHz 15 feet RG-58

425 Ohm antenna 8.5:1 SWR 63% reflection

1 dB (20%) loss per 15 feet



Total 49.6 W radiated – 50% lost to heat!

Lecher Line Demo

Let's make it lossy

Change Tx line dielectric to water

Place thawed otter pops on high voltage points.

Note received signal strength!

Lesson: line loss is everything

Every antenna is multi-band dipole if your feedline is low-loss!

This was common pre-coax.

SWR meters can tell us something important, but can also make us lazy & uncreative.

SWR meters can trick us – where are we measuring?

SWR: Where do we measure?

Most SWR meters are really directional power meters

SWR = $1+\sqrt{(P\downarrow fwd\,/\,P\downarrow refl\,)}/1-\sqrt{(P\downarrow fwd\,/\,P\downarrow refl\,)}$

If measuring in shack, reflected power is attenuated by line loss!

With 15 ft RG-58
8.5:1 SWR at antenna will look like 4:1 in shack!

Low reflected power / low SWR reading does NOT necessarily indicate an efficient antenna!

How to have a perfect SWR reading

Transmit into a dummy load

Use several hundred feet of crummy old coax

Saturate your coax braid with water

(Does your SWR reading get better over time? You have a problem.)

How to have a perfect SWR reading

Put a tuner as close to your antenna as possible – probably NOT on your desk!

Run lowest-loss line you can manage from tuner to antenna

Window line is okay when it's dry

Homemade ladder line is a cheap & simple project

Acknowledgements

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Now play with the fun toys!

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