When Are SWR & Reflected Power Important

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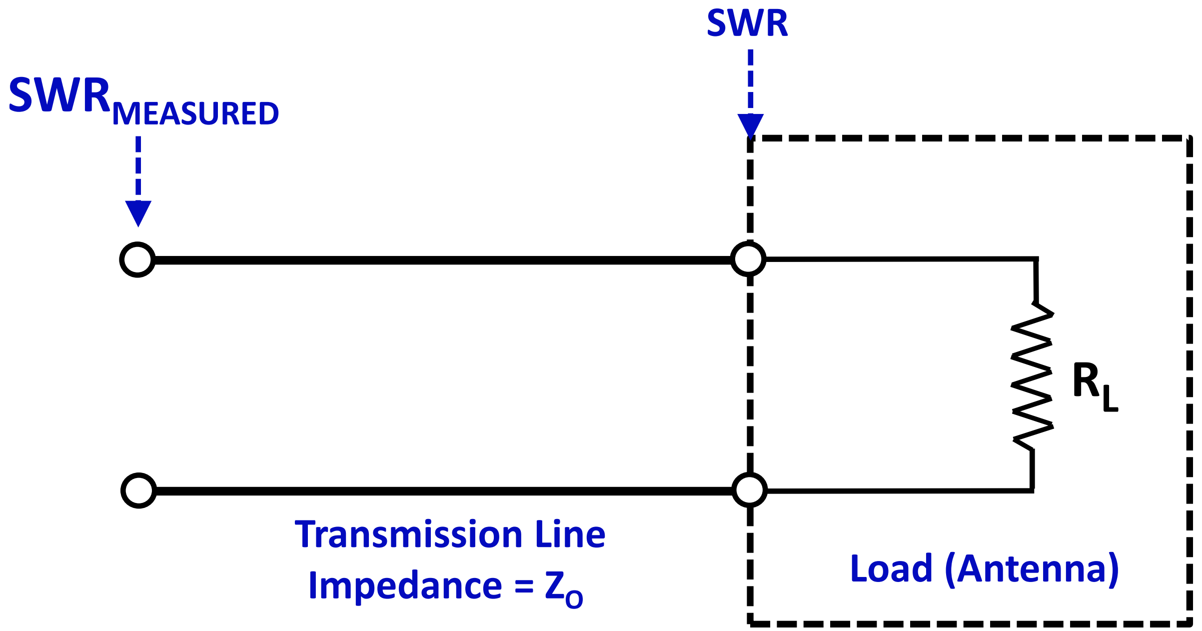
SWR Quiz

True or False:

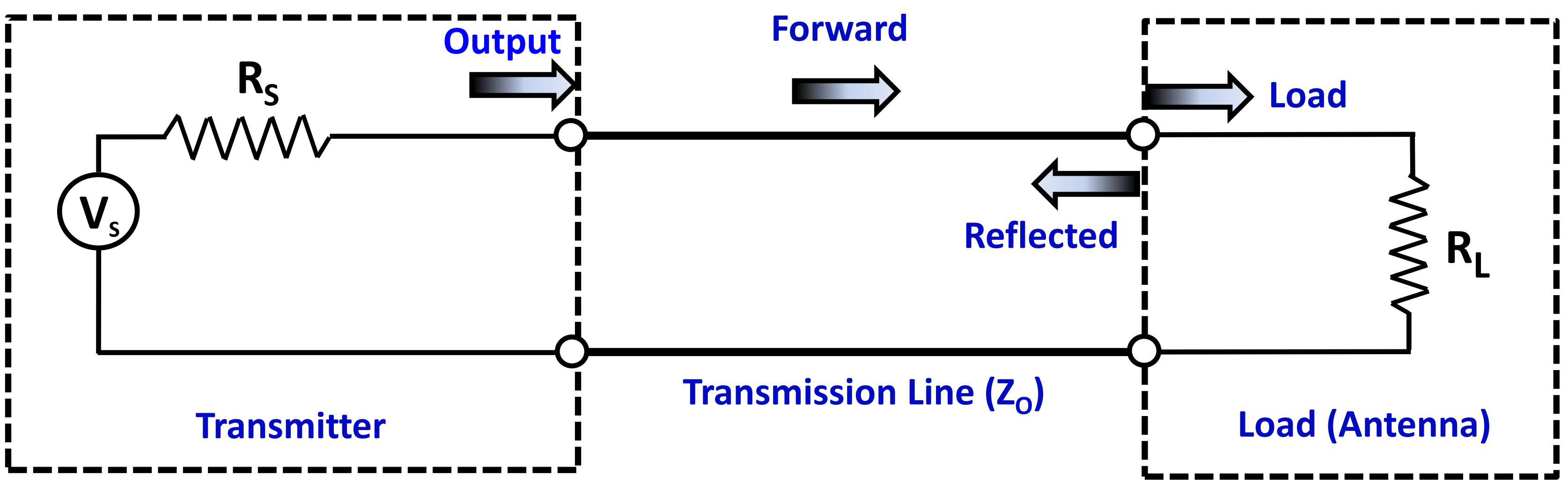
1. Low SWR ensures good performance
2. High SWR ensures poor performance
3. An antenna needs to be resonant to perform well
4. Reflected power always represents lost power
5. Reflected power flows back into the transmitter causing increased dissipation and other problems
6. It is always best to reduce SWR well below 2:1
7. Any transmission line with high SWR produces unwanted radiation
8. SWR can only be accurately determined at the antenna
9. The SWR at the transmitter can be improved by changing the length of the transmission line
10. Mobile antennas with the lowest unmatched SWR perform best
11. Antenna resonance can be determined by a simple impedance measurement at the end of any transmission line
12. The lowest SWR on an antenna always occurs at resonance

What Is SWR?



- The Standing Wave Ratio (SWR) is a measure of the impedance mis-match between a load and a transmission line
- An SWR measurement allows for a quick assessment of:
  - whether impedance matching is required
  - whether an antenna system is performing properly

Traveling And Standing Waves

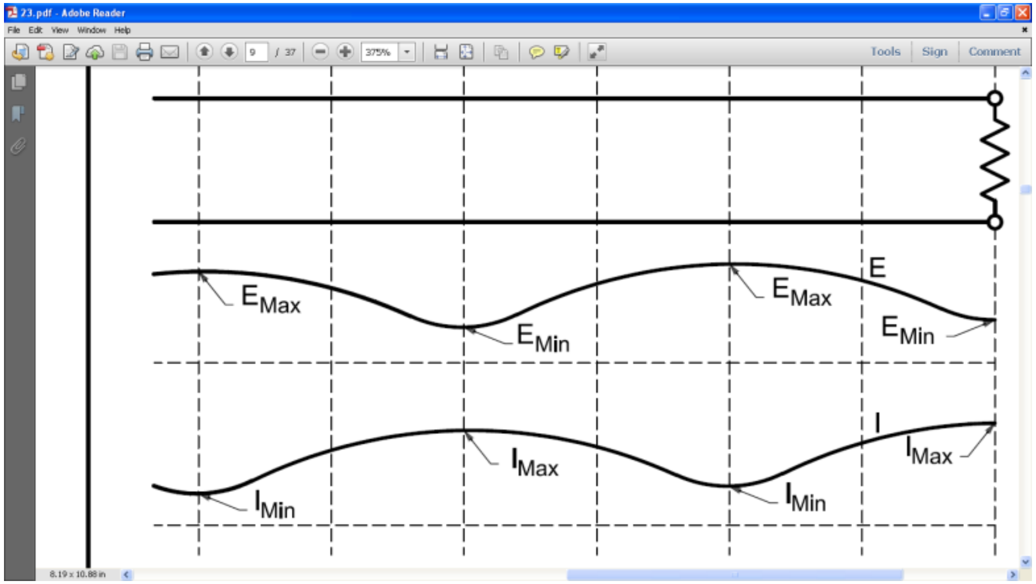


- A voltage at the input to the transmission line creates an electromagnetic (traveling) wave in the forward direction
- If the SWR = 1.0:1, the traveling wave continues on to the load
- If the SWR > 1.0:1, then:
  - A second Traveling Wave is reflected back toward the transmitter
  - A Standing Wave to be created from the interaction of the forward and reflected traveling waves

Standing Wave

- **A Standing Wave:**
  - **Is created by the interaction of the two traveling waves**
  - **Is a <u>stationary</u> amplitude modulation pattern with:**
    - **Maximums (anti-nodes) and**
    - **Minimums (nodes)**
  - **Has voltage maximums that occur at current minimums, and visa versa**

When $R_L < Z_O$:



How To Determine SWR

1. For resistive loads:

$$SWR = \frac{R_L}{Z_O} = \frac{Z_O}{R_L}$$

Ex: $$SWR\ (3{:}1) = \frac{50}{16.7} = \frac{150}{50}$$

2. Using SWR bridges, power meters & antenna analyzers:

$$SWR = \frac{1+\rho}{1-\rho}$$

Reflection coefficient (ρ) = $$\sqrt{\frac{P_R}{P_F}} = \frac{Z_L - Z_O}{Z_L + Z_O}$$

$$SWR = \frac{1 + \sqrt{\frac{P_R}{P_F}}}{1 - \sqrt{\frac{P_R}{P_F}}}$$

3. Return Loss (RL):

$$SWR = \frac{1 + 10^{\frac{-RL}{20}}}{1 - 10^{\frac{-RL}{20}}}$$

Voltage And Current Peaks Versus SWR

- On a transmission line:
  - Peak voltage increases as R_L goes above 50 ohms
  - Peak current increases as R_L goes below 50 ohms

Z_O=50Ω

Watts	Peak	SWR						
		1:1	2:1		3:1		5:1	
		50Ω	25Ω	100Ω	16.7Ω	150Ω	10Ω	250Ω
100	Emax (V_{PEAK})	100	71	141	58	173	45	224
	Imax (A_{PEAK})	2.0	2.8	1.4	3.5	1.2	4.5	0.9
1500	Emax (V_{PEAK})	387	274	548	224	671	173	866
	Imax (A_{PEAK})	7.7	11.0	5.5	13.4	4.5	17.3	3.5

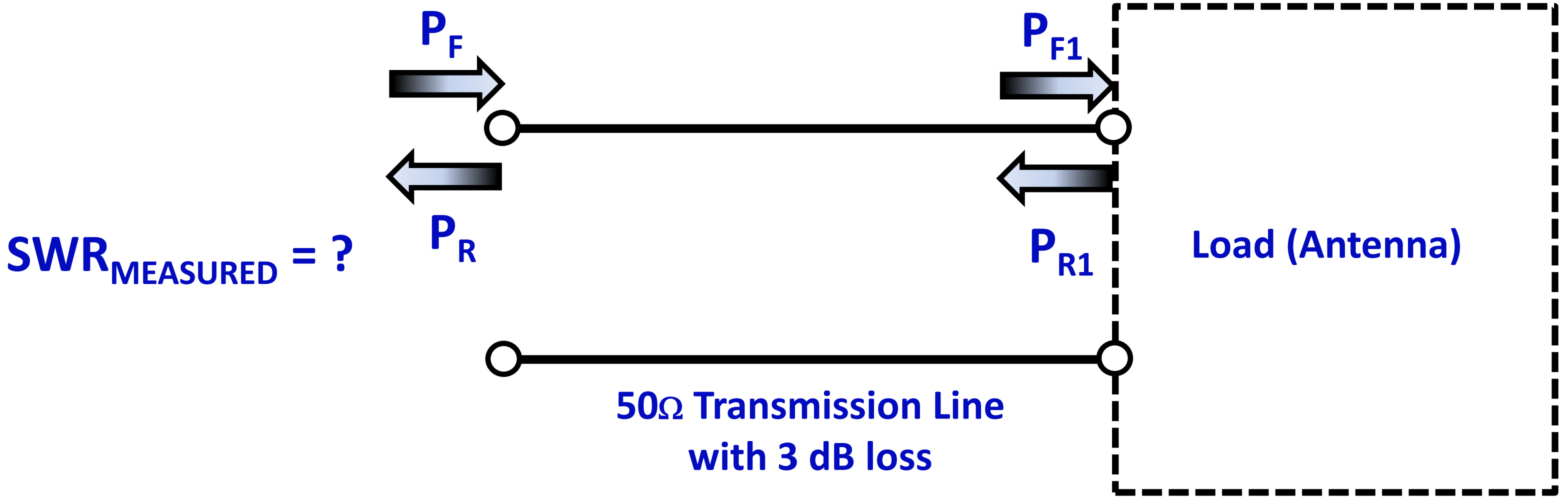
Z_O=600Ω

Watts	Peak	SWR		
		1:1	10:1	
		600Ω	60Ω	6000Ω
100	Emax (V_{PEAK})	346	110	1095
	Imax (A_{PEAK})	0.6	1.8	0.2
1500	Emax (V_{PEAK})	1341	424	4242
	Imax (A_{PEAK})	2.2	7.1	0.7

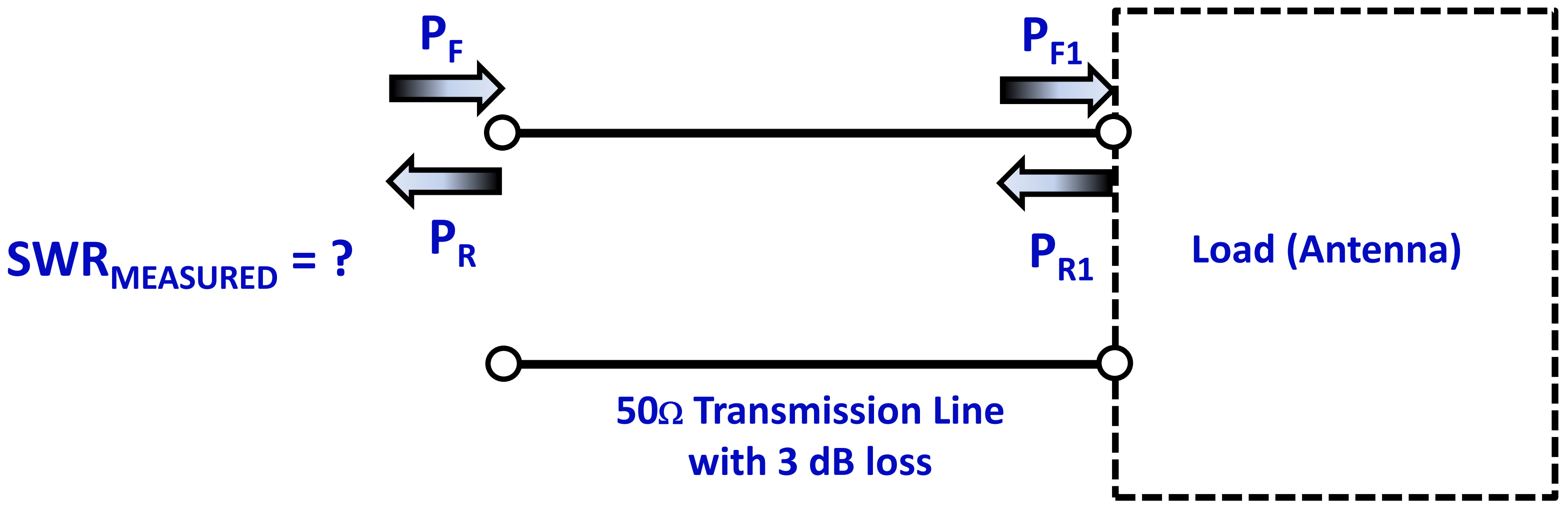
Cable	V_{PEAK}	A_{PEAK}	PWR_{MAX}
RG-58	424	?	?
RG-8	424/848	?	?

The most important part of an SWR measurement is knowing what the number should be!

Transmission Line Loss And SWR Measurement



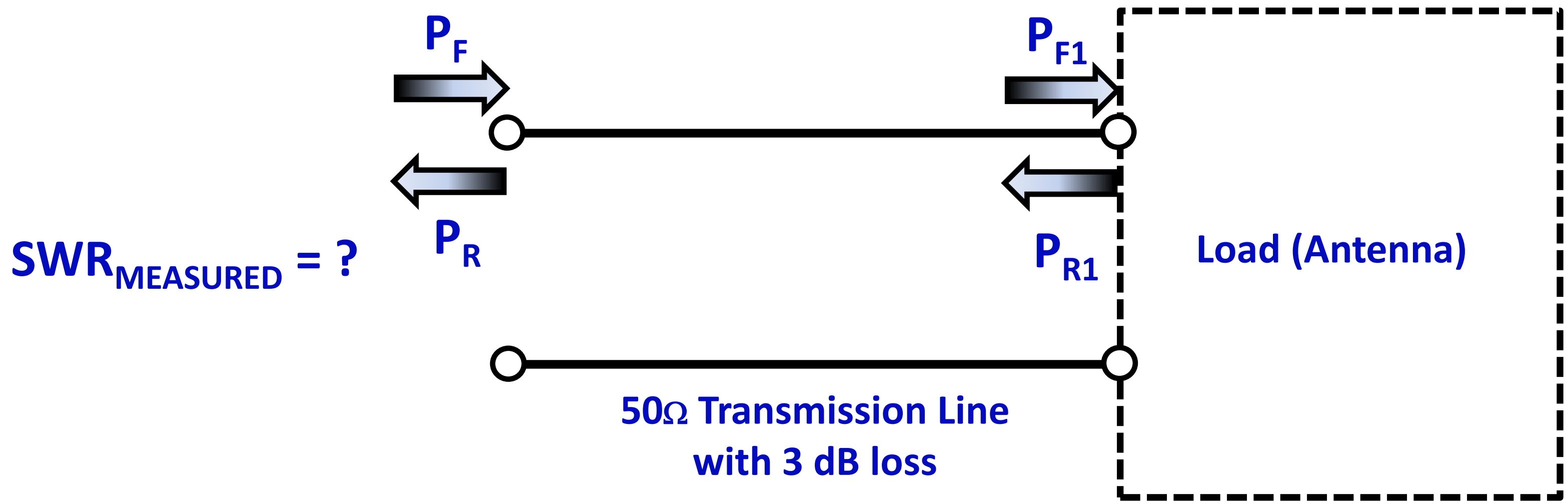
Transmission Line Loss And SWR Measurement



Load SWR = 3:1:

$SWR_{MEASURED}$ = ?

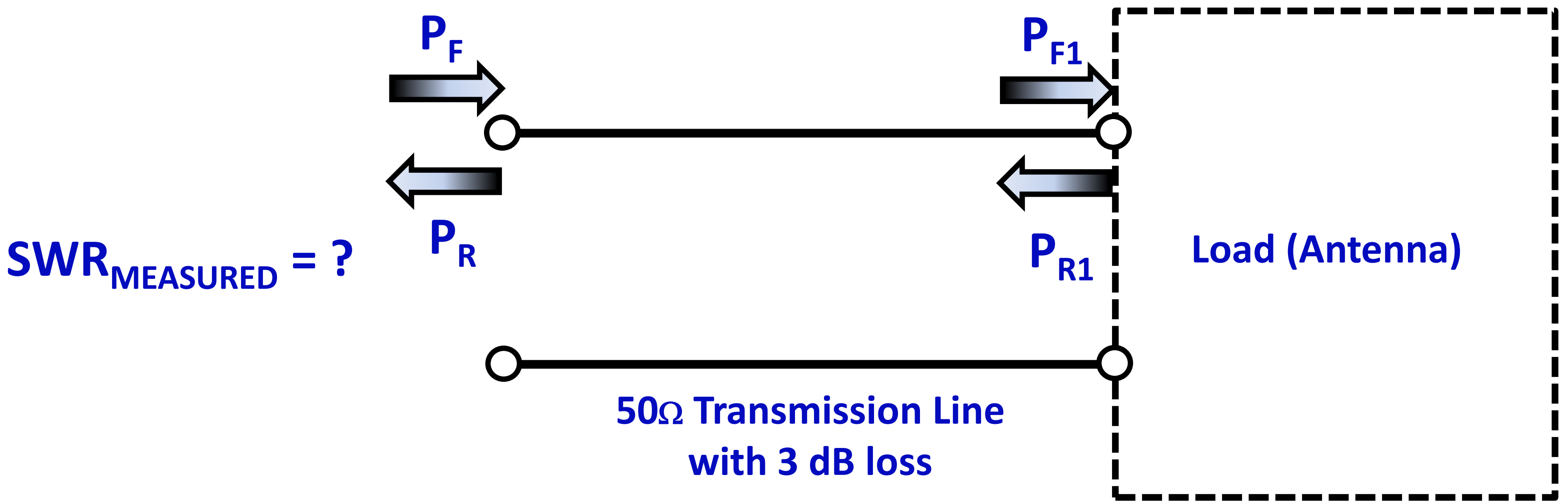
Transmission Line Loss And SWR Measurement



Load SWR = 3:1:

$SWR_{MEASURED}$ = 1.66:1

Transmission Line Loss And SWR Measurement



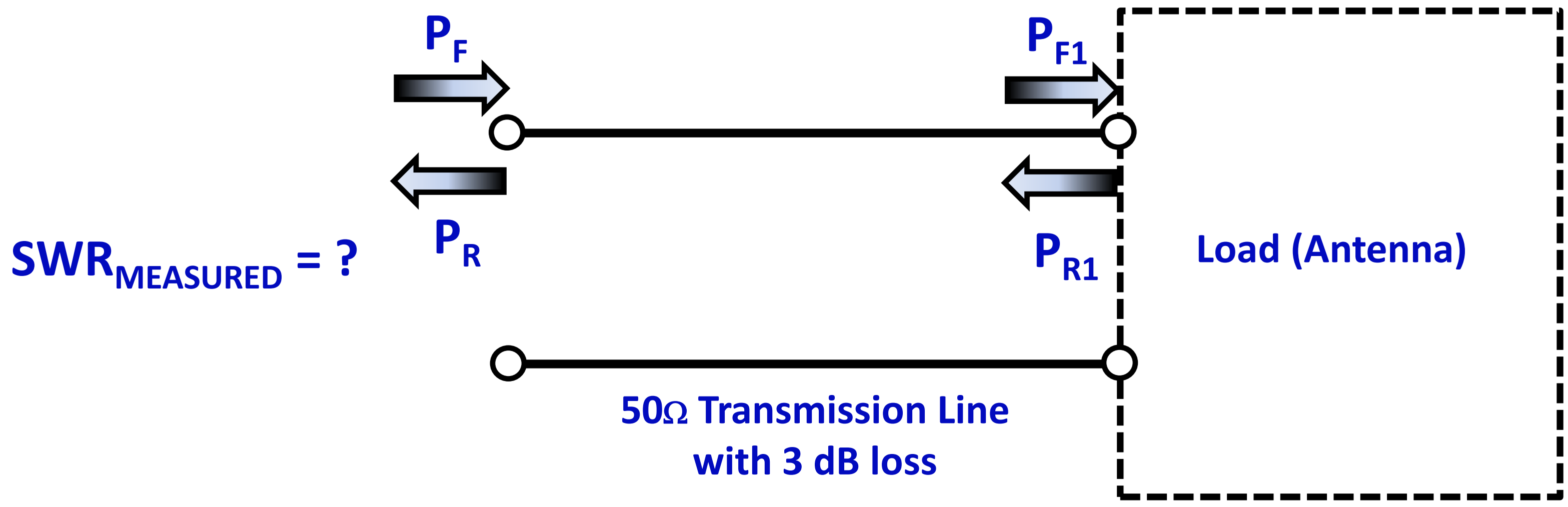
Load SWR = 3:1:

$SWR_{MEASURED}$ = 1.66:1

Load = open circuit:

$SWR_{MEASURED}$ = ?

Transmission Line Loss And SWR Measurement



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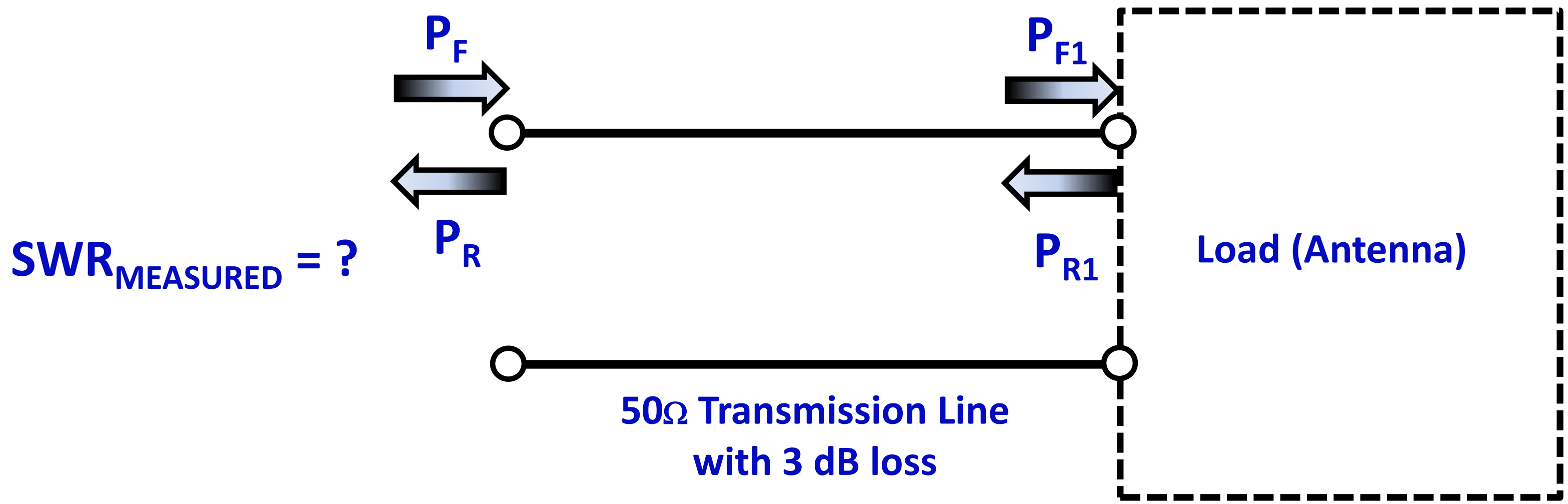
Transmission Line Loss And SWR Measurement



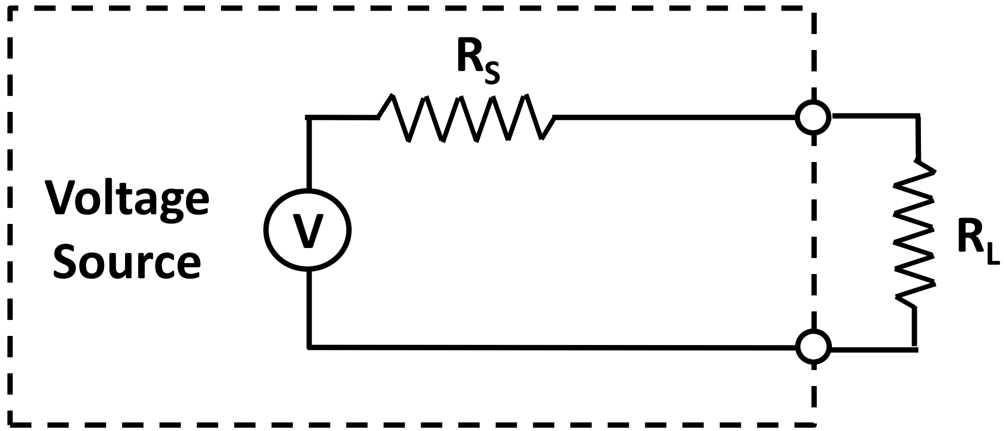
- If you know the type and length of your transmission line, TLW will give you line loss and a "corrected" SWR
- An unexplained drop in SWR may not be a good thing

Why Match?

- **Primary reasons:**
  - **To maximize power transfer from transmitter to the antenna**
  - **Prevent activation of transmitter SWR shutdown circuit**
    - **In solid state transmitters the typical activation SWR ~ 2:1**
- Other reasons:
  - Increase usable antenna bandwidth
  - Avoid exceeding voltage or current limits of components
  - Reduce transmission line loss

How To Achieve A Match

1. **Find the value of R_L that maximizes power dissipation in R_L?**



How To Achieve A Match

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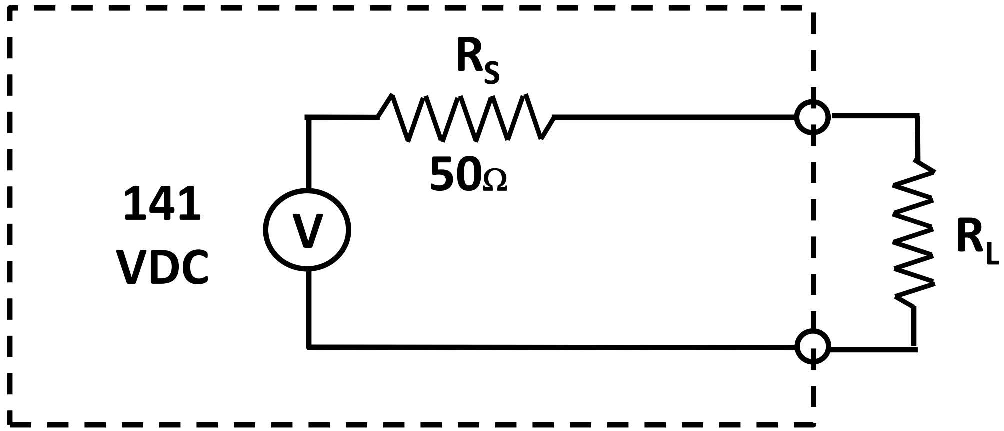
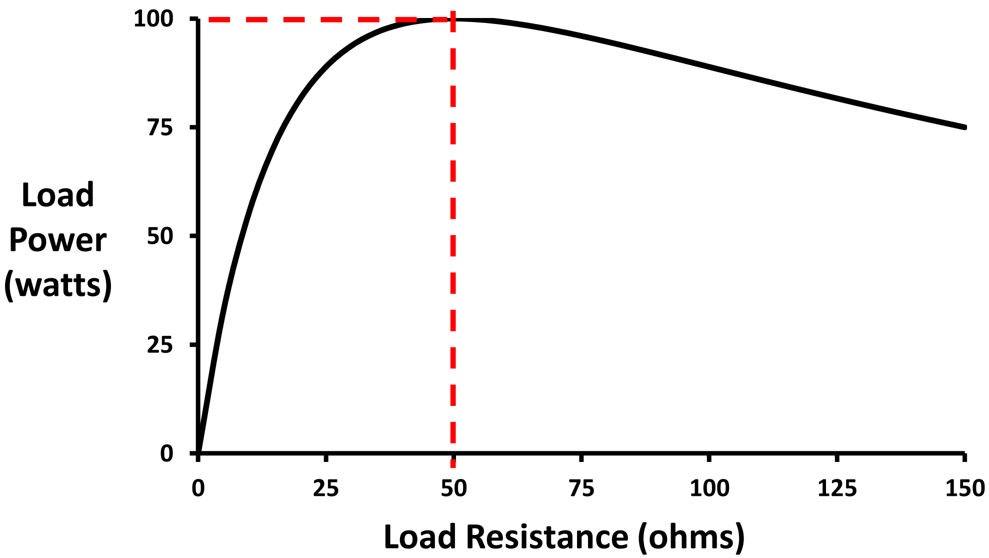


Maximum power (P_{MAX}) is dissipated in the load when $R_L = R_S$

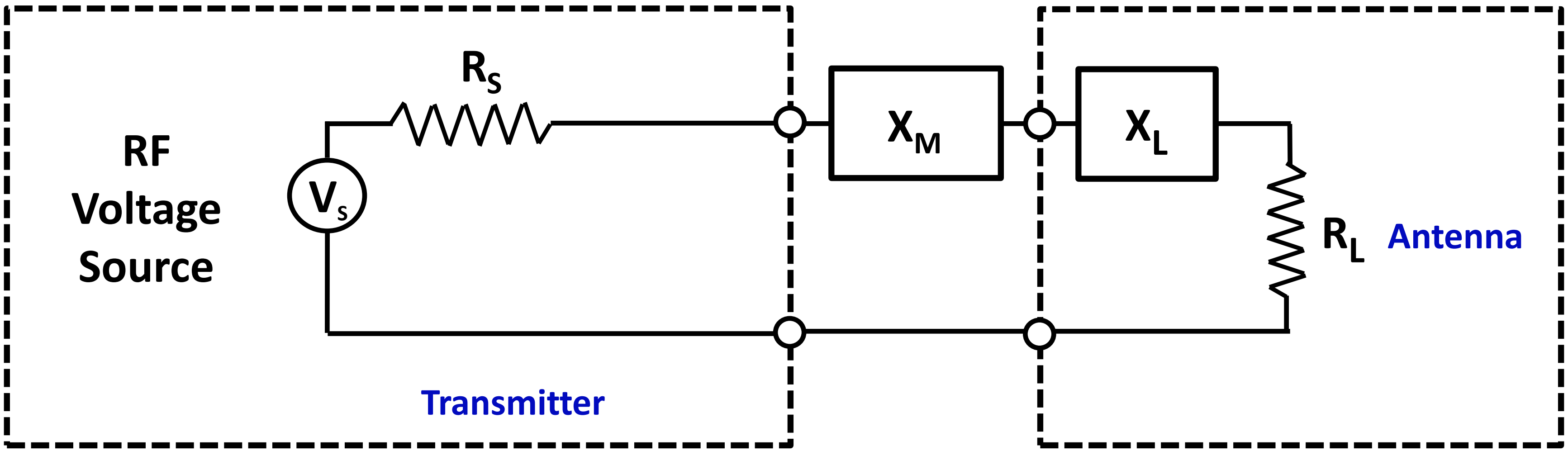


$R_L = R_S$ = "Perfect" Match

For Ham transmitters: $R_S = 50\Omega$

How To Achieve A Match

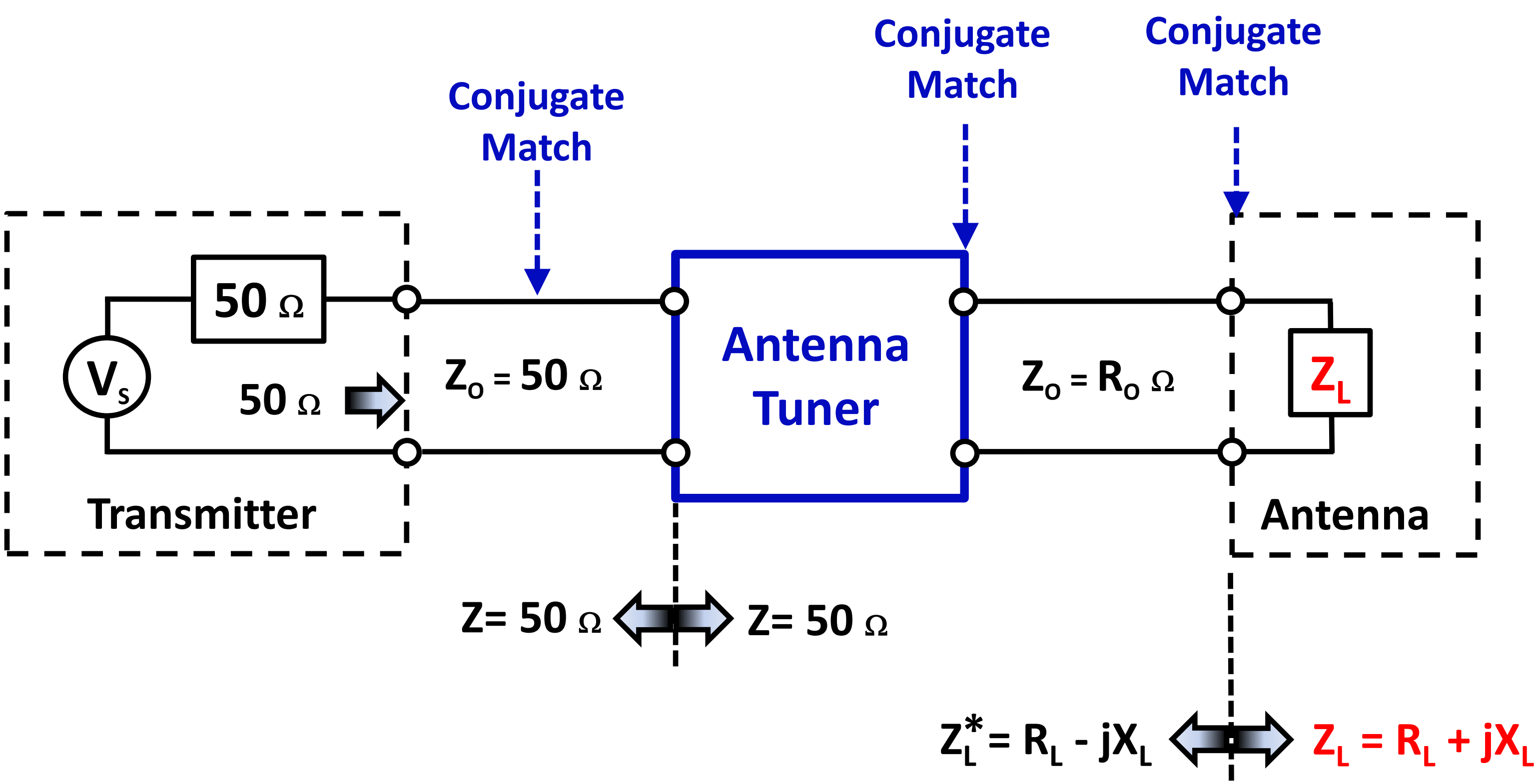
2. When RF is involved, we need to have a "Conjugate" match



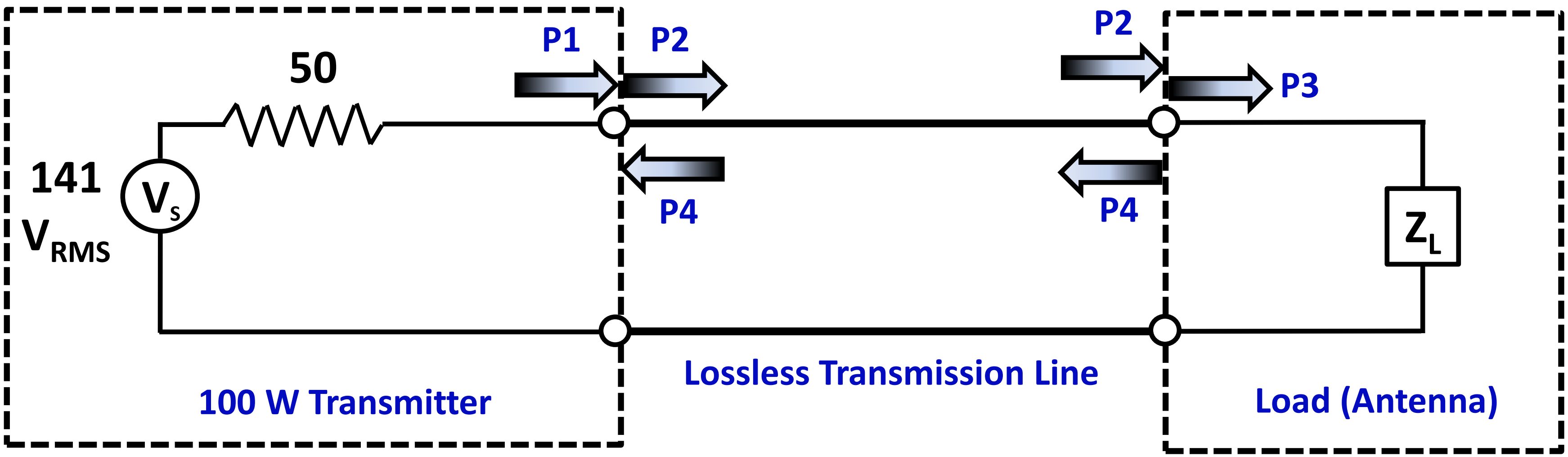
- A Conjugate match requires both:
  - $R_S = R_L$
  - $X_M = -X_L$
  - This equates to the circuit being resonant
- A Conjugate match exists at only one frequency

How To Achieve A "Conjugate Match"

- **Use an Impedance Transformer**
  - **Usually require the antenna to be resonant**
- **Use an Antenna (System) Tuner:**
  - **Antenna System includes: Antenna, Transmission Lines, Balun, etc**
  - **Antenna tuners tune the entire Antenna System to resonance**
    - **Antenna tuners do not tune the antenna to resonance**



Conservation Of Energy



- Conservation of Energy: "Energy can neither be created or destroyed"
- With a lossless transmission line, conservation of energy requires:

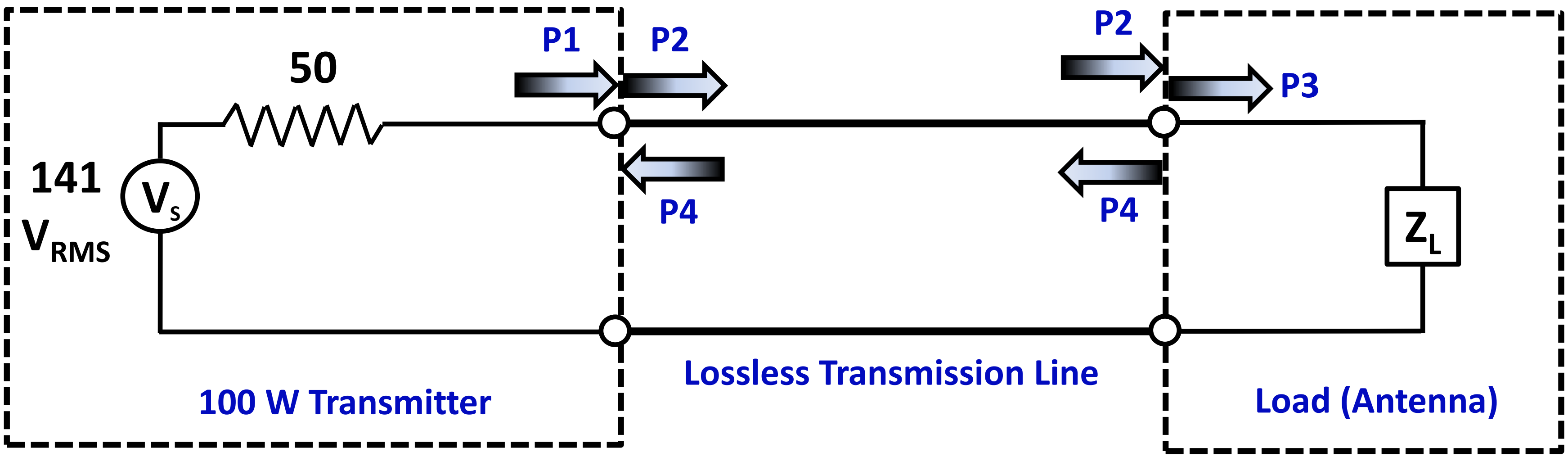
P1 + P4 = P2

P3 + P4 = P2

Therefore:

P3 = P1 (<u>regardless of SWR</u>)

Conservation Of Energy

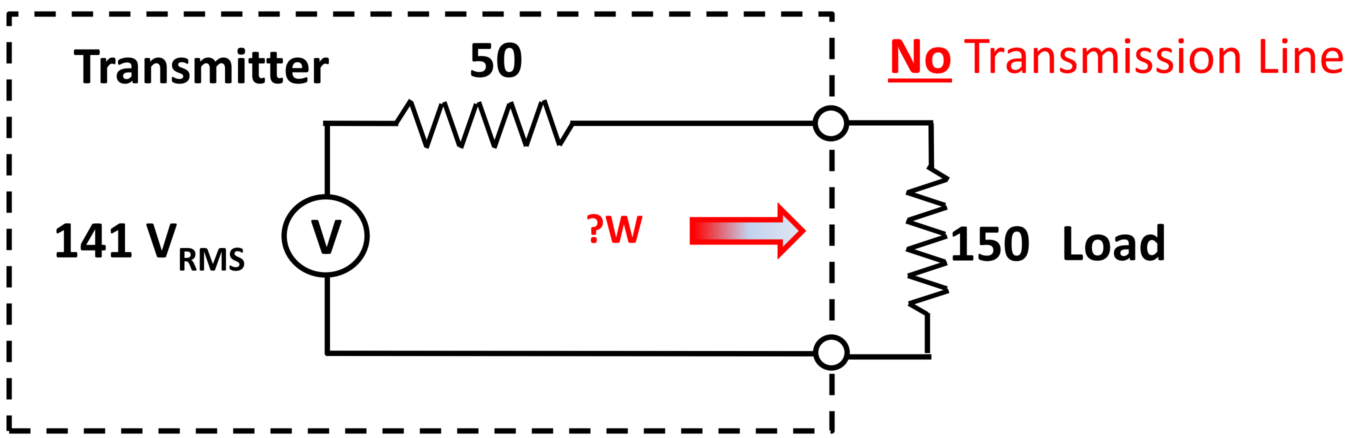


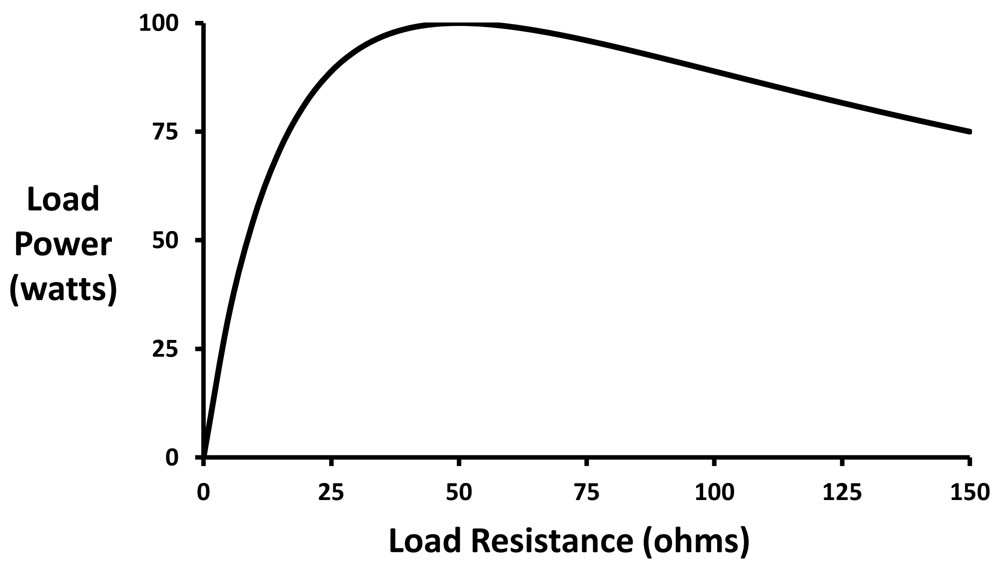
All power generated by the transmitter is radiated by the antenna, regardless of the SWR!

(Assuming negligeable losses in the transmission lines)

Effect Of Mis-Match On Transmitter Output Power

- Assume 100 watt transmitter and SWR = 3:1





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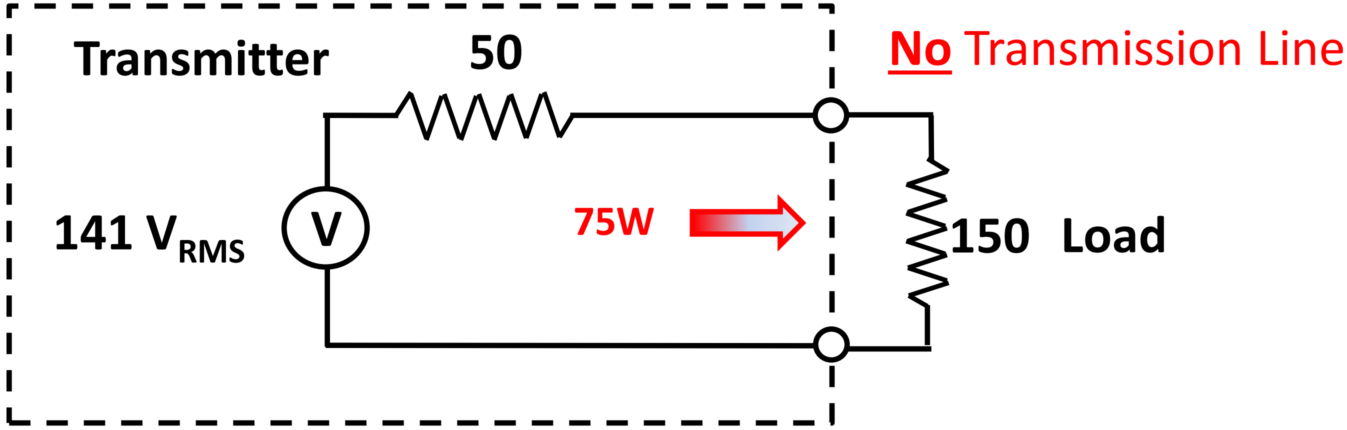
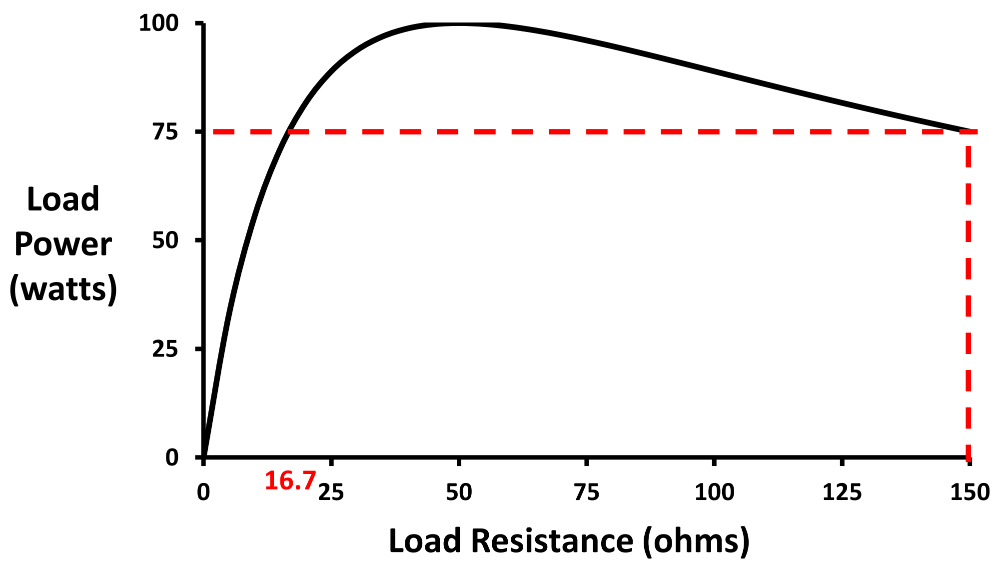
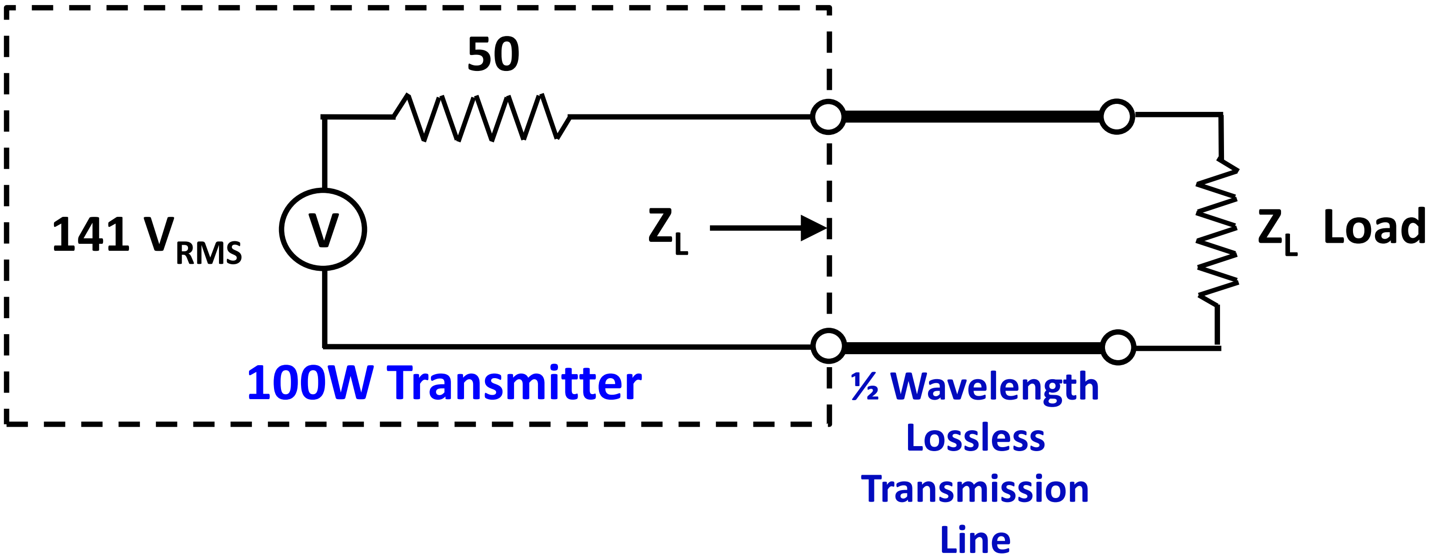




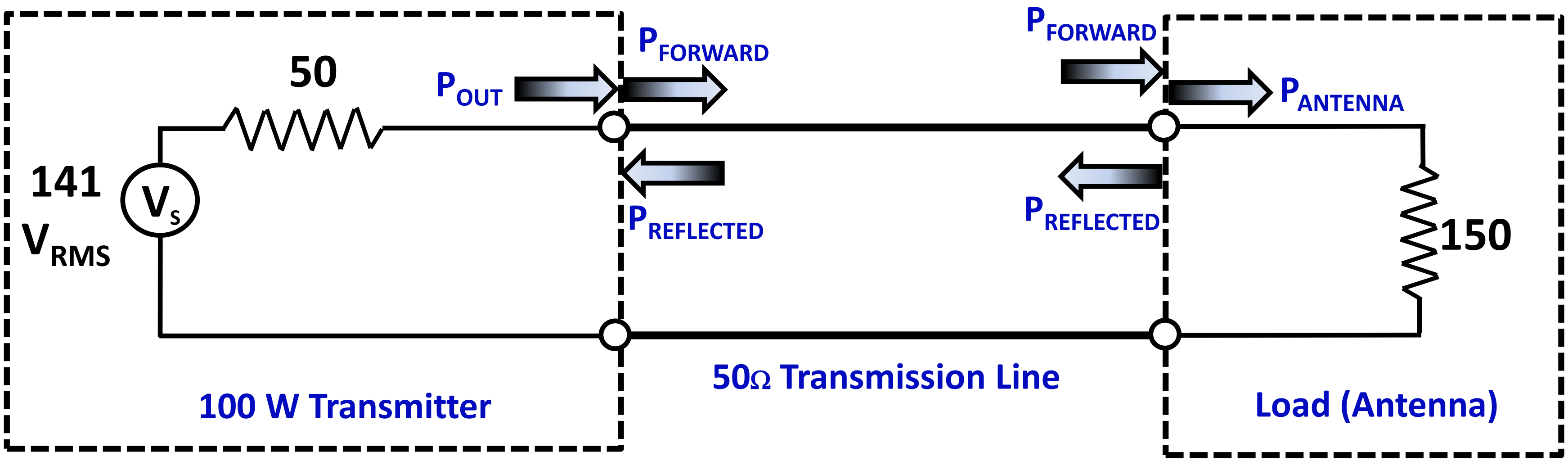
The 100 W transmitter can only deliver **75 watts** into a 3:1 SWR due to the <u>impedance mis-match</u>

Effect Of Mis-Match On Transmitter Output Power



- A ½ wavelength (elecrical length) lossless transmission line causes the transmitter to see Z_L as a load
  - The final results do not depend on this condition

How To Calculate Dissipated & Reflected Powers



- **With a 150 ohm load at the end of a 50 ohm lossless transmission :**

$$\text{Reflection coefficient} = \rho = \frac{R_L - 50}{R_L + 50} = \frac{150-50}{150+50} = 0.5$$

$$\text{Reflected power} = \rho^2 \times P_{FORWARD} = 0.25 \text{ X } P_{FORWARD}$$

$$\text{Power transferred to the antenna} = (1-\rho^2) \times P_{FORWARD} = 0.75 \text{ X } P_{FORWARD}$$

What Happens To The Reflected Power?

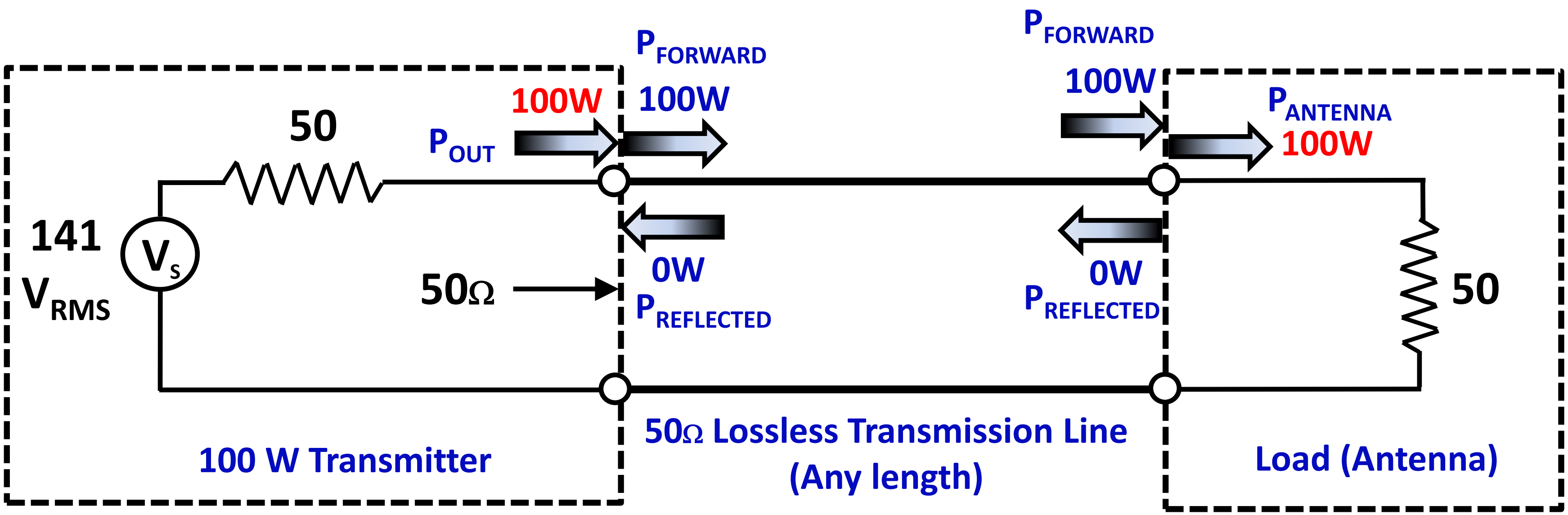
Only 3 cases to consider:

1. **A perfect match**

2. **A Mis-Match**

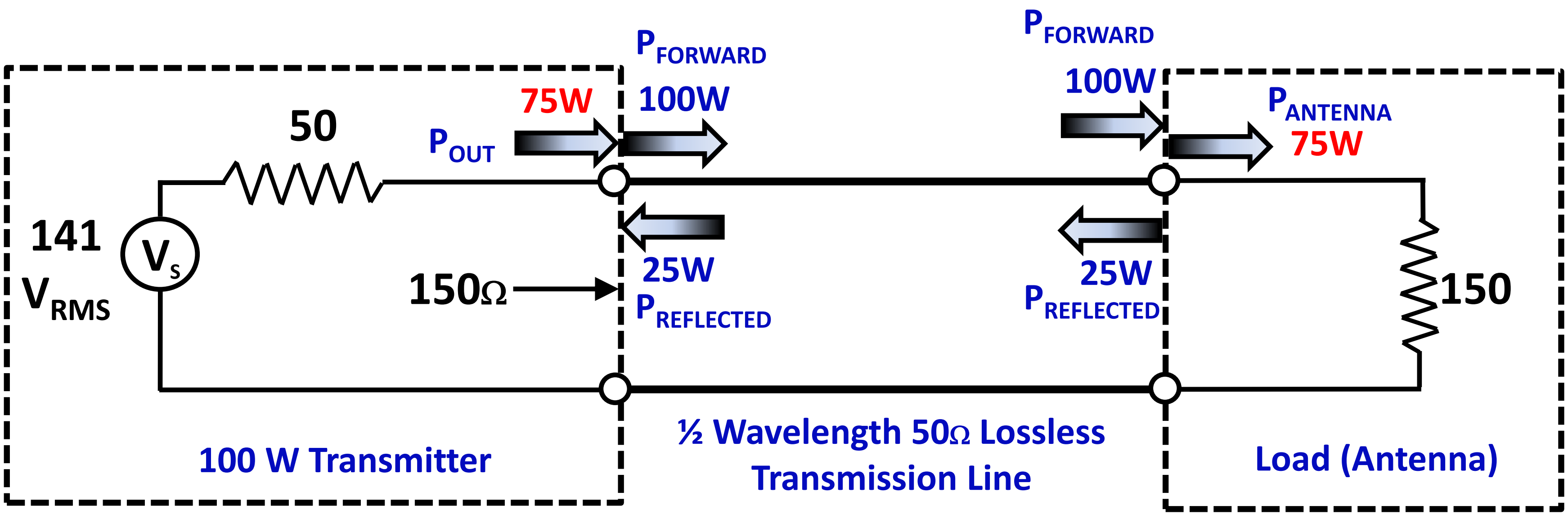
3. **A Mis-Match tuned to a Conjugate Match**

Case 1: Perfect Match



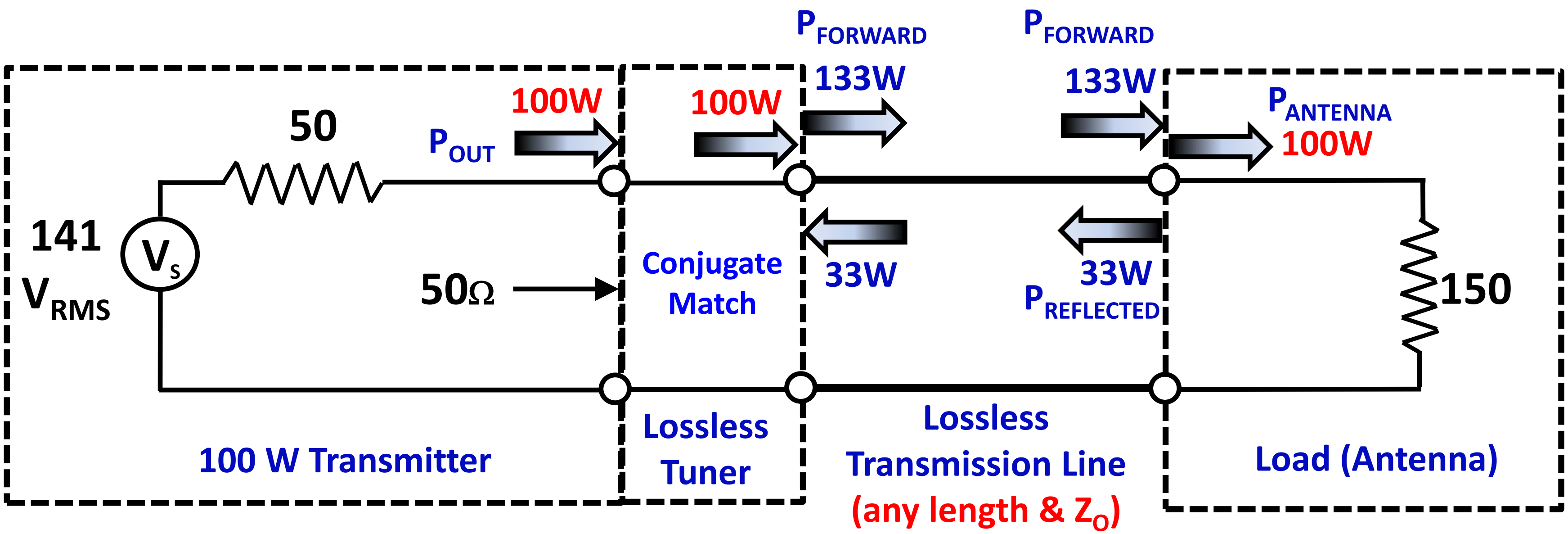
- The transmitter sees a perfect match (50Ω load) and generates it's max available power => P_{OUT} = 100W
- All 100W generated by the transmitter is dissipated in the load
  - $P_{ANTENNA} = P_{OUT} = P_{FORWARD}$ = 100W
- With perfect match $\rho = 0$ => $P_{REFLECTED}$ = 0W

Case 2: Mis-Matched load (SWR = 3:1)



- Because of the ½ wavelength line the transmitter sees a 150 ohm load
- Because of the 150 ohm load, P_{OUT} = 75W
- All of the power generated by the transmitter (75W) is dissipated in the load (ie, radiated by the antenna), $P_{ANTENNA}$ = 75W
- At the Antenna: $P_{FORWARD} = P_{ANTENNA} /0.75$ = 100W
  - $P_{REFLECTED} = 0.25 \times P_{FORWARD}$ = 25W
- At the Transmitter:
  - Conservation of Energy requires: $P_{FORWARD} = P_{REFLECTED} + P_{OUT}$ = 25 + 75W = 100W
  - The 25W reflected from the load is re-reflected at the transmitter, adds to the transmitter power and returns to the load
    - Reflected power is not lost or dissipated in the transmitter
    - Reflected power equals the power not generated by the transmitter

Case 3: A Mis-Match Tuned To A Conjugate Match



- The transmitter sees a perfect match => P_{OUT} = 100W
- All of the power generated by the transmitter (100W) passes thru the tuner, enters the transmission line and is dissipated in the load => $P_{ANTENNA}$ = 100W
- At the Antenna:
  - $P_{ANTENNA}$ /0.75 = 133W
  - $P_{REFLECTED}$ = 0.25 x $P_{FORWARD}$ = 33W
- At the Transmitter:
  - Conservation of Energy requires: $P_{FORWARD}$ = $P_{REFLECTED}$ + P_{OUT} = 33 + 100W = 133W
  - The 33W reflected from the load is re-reflected at the transmitter, adds to the transmitter power and returns to the load
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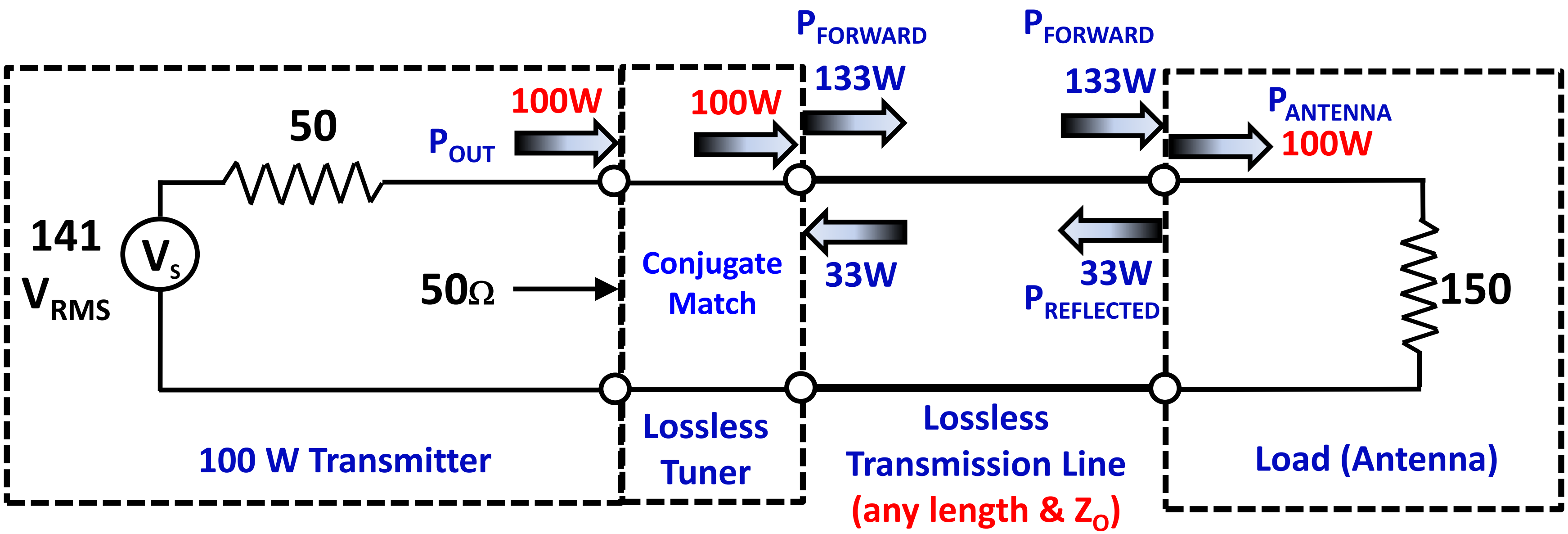
Case 3: A Mis-Match Tuned To A Conjugate Match



Note: The transmitter is NOT generating 133 watts!

What Happens To The Reflected Power?

Case 1: A perfect match generates no reflected power:

1) This allows the transmitter to generate it's maximum power
2) All of the power generated by the transmitter is dissipated in the load

Case 2: A Mis-Match does two things:

1) The transmitter sees a mis-match as a load
   - This causes the transmitter to generate less than maximum power
   - The amount of power reduction exactly equals the reflected power
2) ALL power that was reflected from the load is re-reflected at the transmitter
   - All of the power generated by the transmitter is dissipated in the load
   - NO reflected power is lost
   - The power not dissipated in the load equals the power not generated by the transmitter

Case 3: A Conjugate Match does two things:

1) Presents a perfect match to the transmitter
   - This allows the transmitter to generate it's maximum power
   - All of the power generated by the transmitter is dissipated in the load
2) ALL power that was reflected from the load is re-reflected at the transmitter
   - NO reflected power is lost

Measured Results

- P_{OUT} = 300 watts from a tube type amplifier
- Three Cases:
    1. Perfect Match (SWR = 1:1)
    2. Mis-Matched load (SWR = 3.1:1) still tuned for 50Ω load
    3. Mis-Matched load (SWR = 3.1:1) tuned to a conjugate match

CASE	WATTS					
	MEASURED			THEORETICAL		
	P_F	P_R	P_{LOAD}	P_F	P_R	P_{LOAD}
1	300	0	300	300	0	300
2	300	70	230	300	75	225
3	375	100	275	400	100	300
				373*	93*	280*

*0.3dB Tuner Loss Included

SWR Quiz

True or False:

1. Low SWR ensures good performance
2. High SWR ensures poor performance
3. An antenna needs to be resonant to perform well
4. Reflected power always represents lost power
5. Reflected power flows back into the transmitter causing increased dissipation and other problems
6. It is always best to reduce SWR well below 2:1
7. Any transmission line with high SWR produces unwanted radiation
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9. The SWR at the transmitter can be improved by changing the length of the transmission line
10. Mobile antennas with the lowest unmatched SWR perform best
11. Antenna resonance can be determined by a simple impedance measurement at the end of any transmission line
12. The lowest SWR on an antenna always occurs at resonance

Question 1: Low SWR ensures good performance

- **Ground mounted resonant ¼ wave monopole (vertical)**
  1. With **100+ radials** over good ground has:
     - Radiation resistance = 32 ohms
     - Ground loss = 1 ohm
     - Antenna input resistance = 33 ohms
     - Input **SWR = 1.6:1**
     - **Efficiency > 95%**
  2. With **4 radials** over good ground has:
     - Radiation resistance = 32 ohms
     - Ground loss = 18 ohms
     - Antenna input resistance = 50 ohms
     - Input **SWR = 1.0:1**
     - **Efficiency ≤ 63%** (signal strength down ≅ 2 dB)
       - The lost power is being dissipated in the ground
- **Lowest SWR does not ensure best performance**

Transmission Line Loss

- **<u>Net</u> transmission line loss is the sum of two losses:**
  - **Matched line loss: Loss in dB when SWR = 1.0:1**
  - **Mis-matched line loss: Additional line loss in dB due to SWR >1:1**

Matched Line Loss

SWR on transmission line = 1.0:1

23.pdf - Adobe Reader

File Edit View Window Help

22 / 37 100% Tools Sign Comment

dB/100 ft

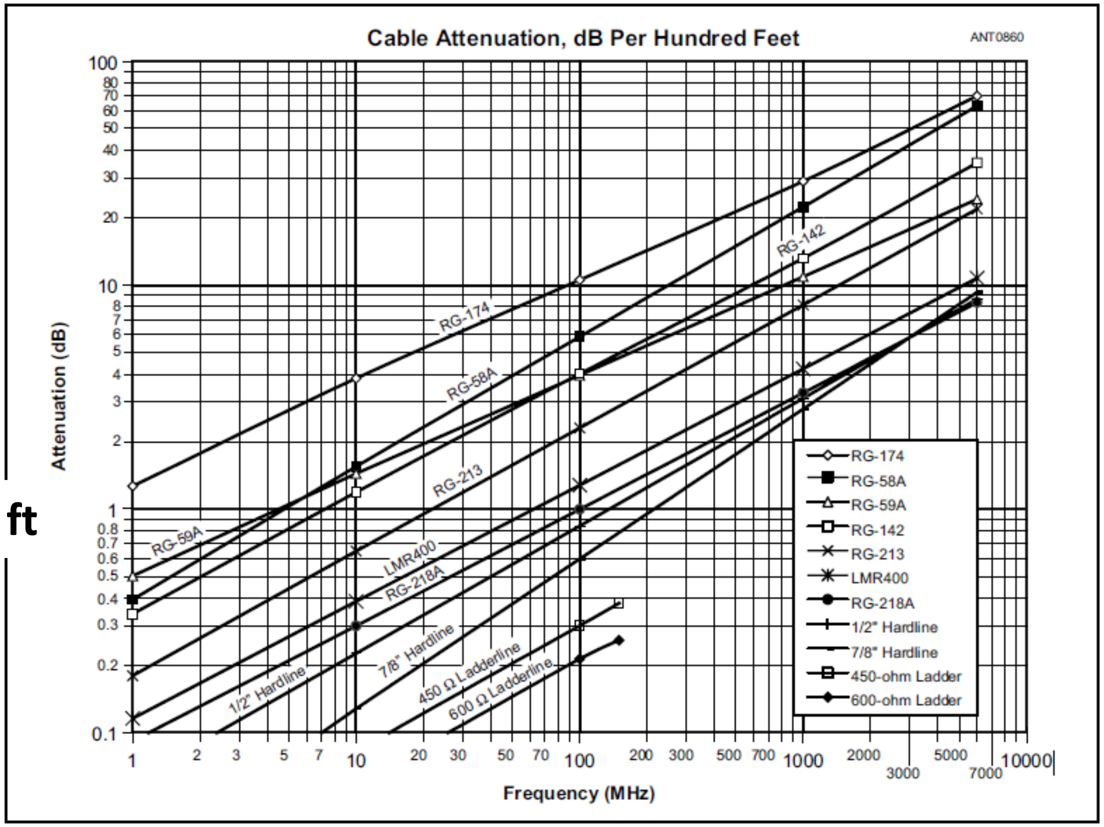
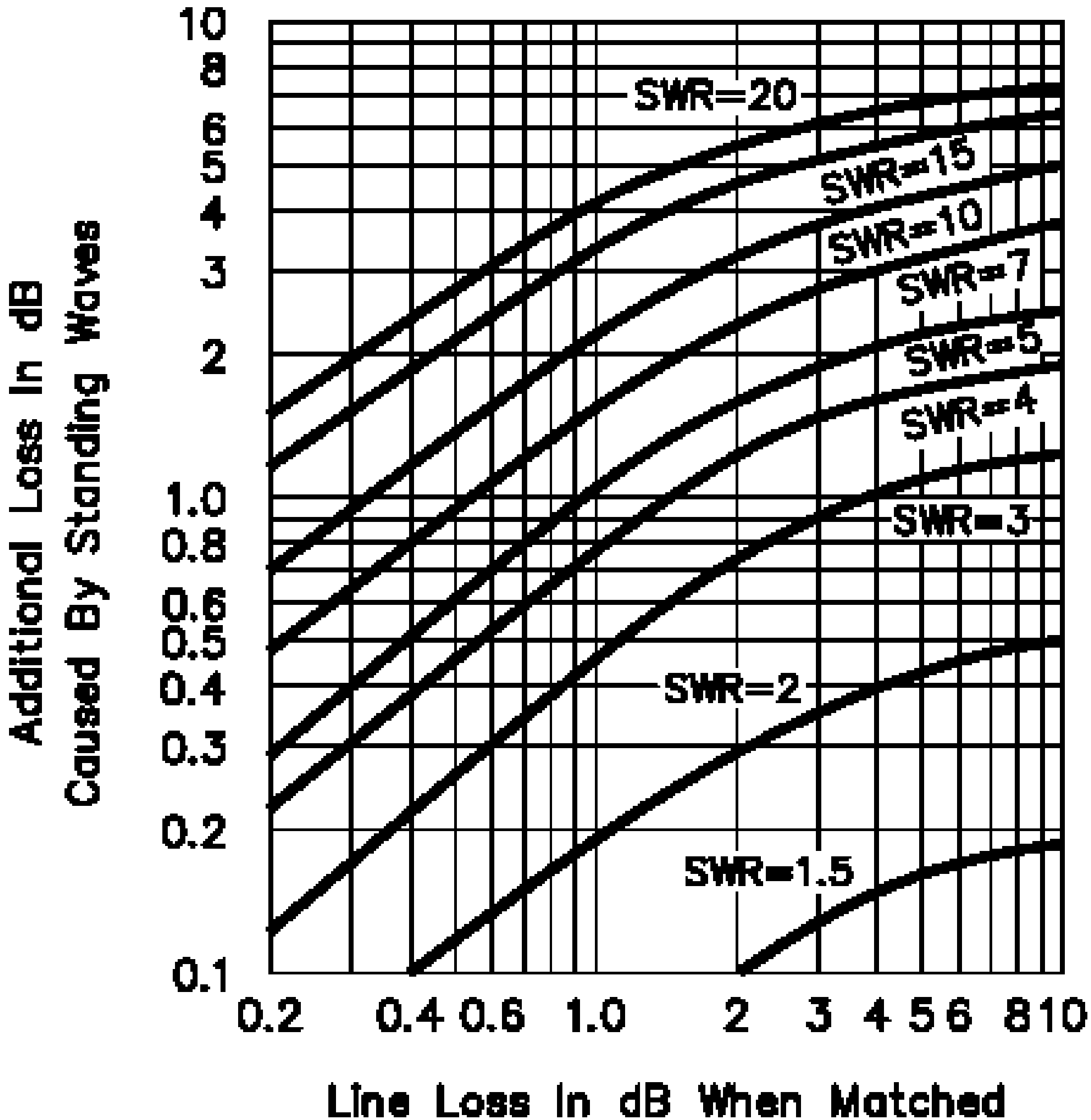


Figure 23.24 — Nominal matched-line attenuation in decibels per 100 feet of various common transmission lines. Total attenuation is directly proportional to length. Attenuation will vary somewhat in actual cable samples, and generally increases with age in coaxial cables having a type 1 jacket. Cables grouped together in the above chart have approximately the same attenuation. Types having foam polyethylene dielectric have slightly lower loss than equivalent solid types, when not specifically shown above.

Mis-Matched Line Loss

SWR on transmission line > 1.0:1



Mis-Matched Line Loss

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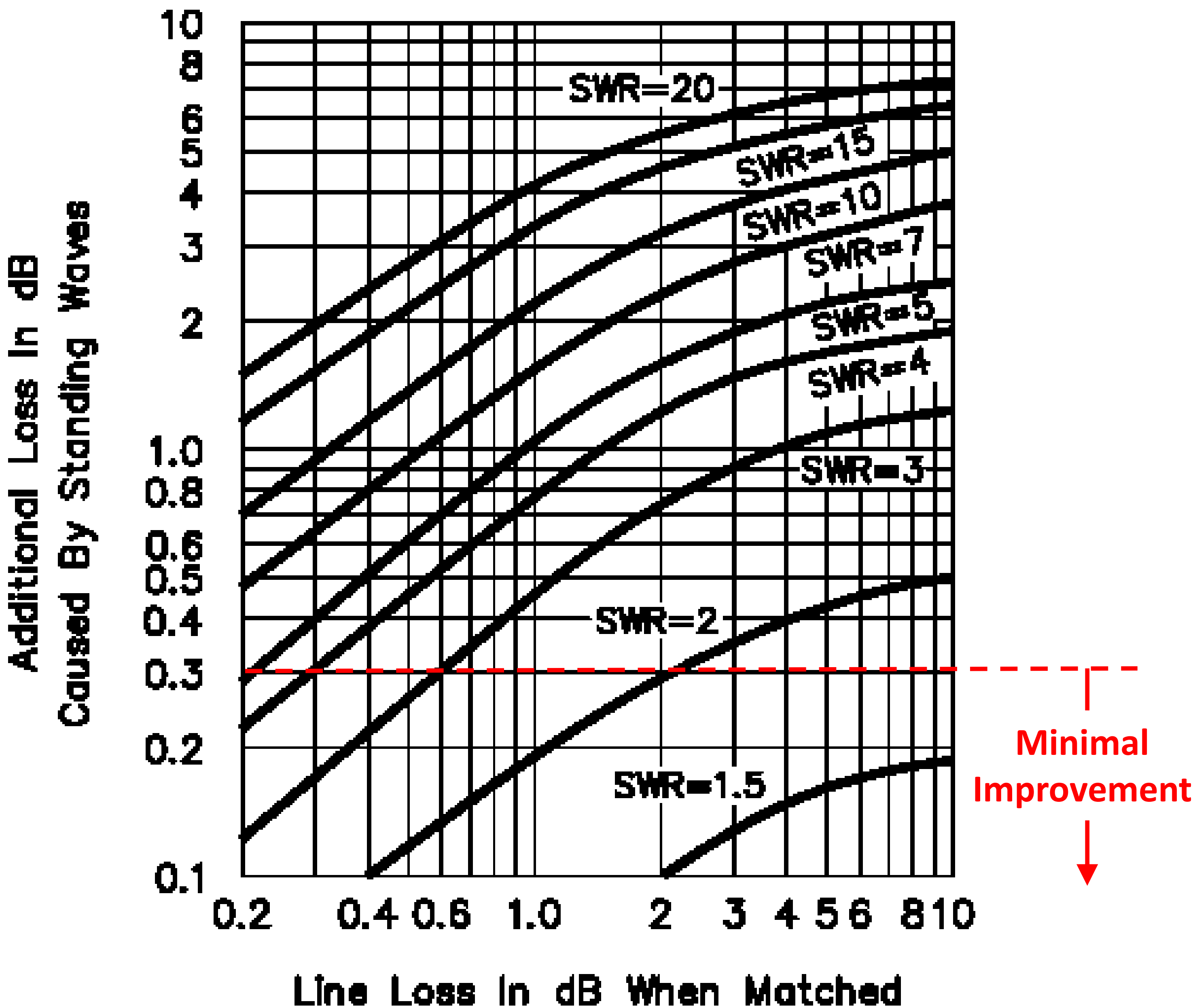
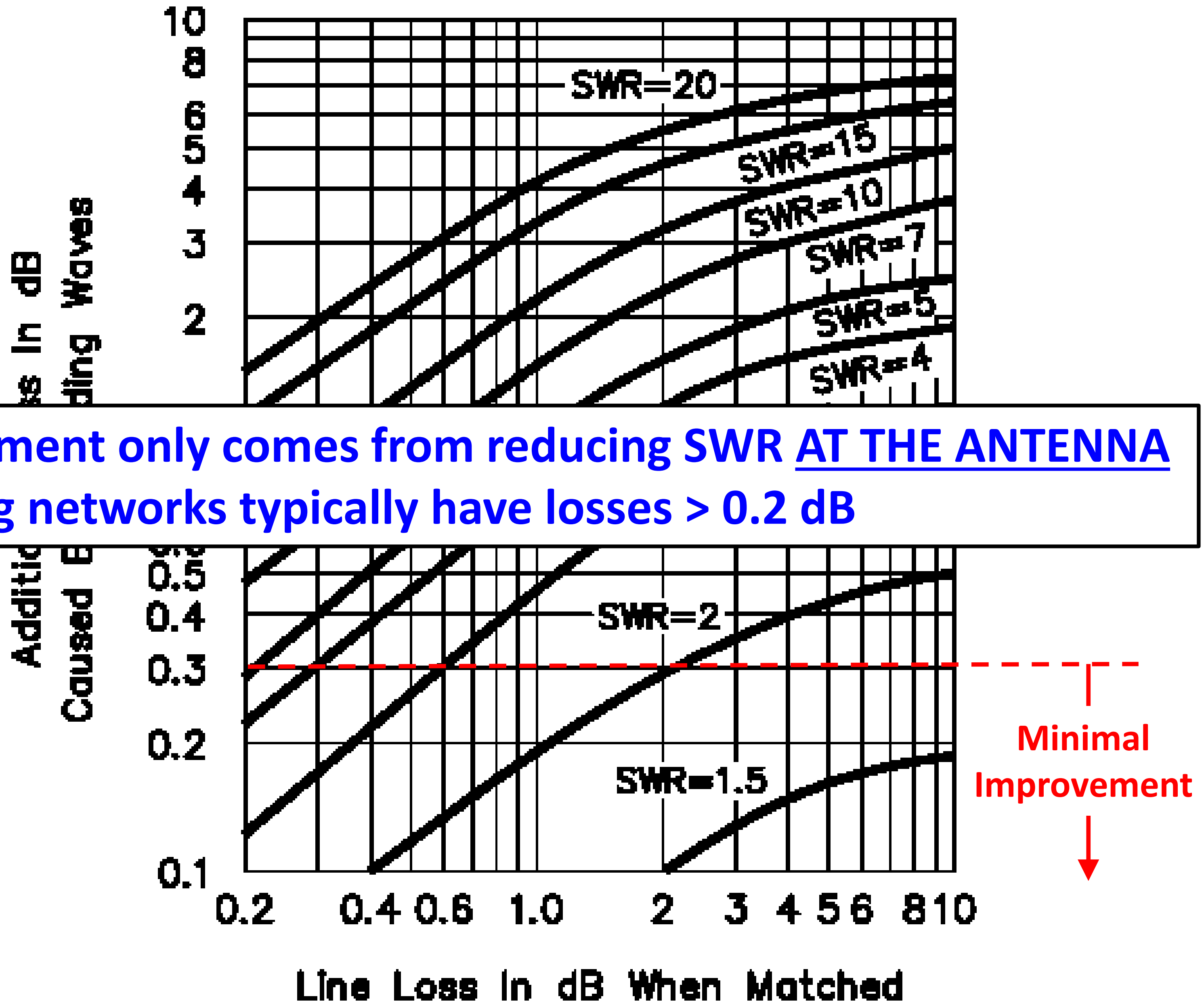


Mis-Matched Line Loss

SWR on transmission line > 1.0:1



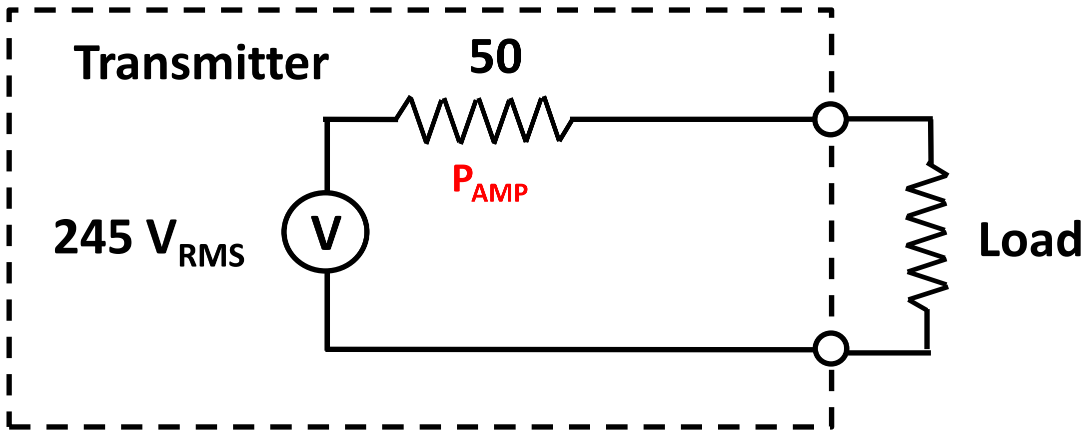
- Improvement only comes from reducing SWR <u>AT THE ANTENNA</u>
- Matching networks typically have losses > 0.2 dB

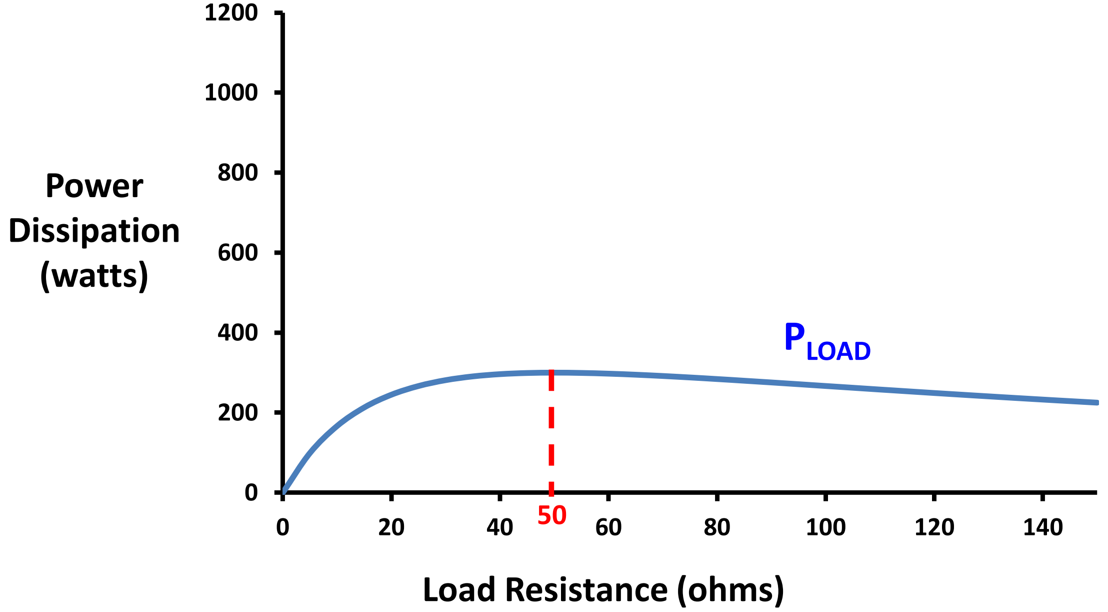
Question 2: High SWR ensures poor performance

- **Feed options for a 14 MHz resonant dipole with 50 ohm R_{IN}:**
  1. 100 feet RG-58 (no tuner):
     - **SWR** on line **= 1.0:1**
     - Transmission Line Matched loss = 1.9 dB
     - Transmission Line Mis-Matched loss = 0 dB
     - **Oveall Efficiency** $\simeq$ .98 x .65 $\simeq$ **64% (~1/3 S Unit)**
  2. 100 feet 450 ohm ladder line with tuner at transmitter:
     - **SWR** on line **= 9:1**
     - Transmission Line Matched loss $\simeq$ 0.1 dB
     - Transmission Line Mis-Matched loss $\simeq$ 0.3 dB
     - Tuner loss $\simeq$ 0.5 dB
     - **Oveall Efficiency** $\simeq$ .98 x .97 x .93 $\simeq$ **89%**
- **High SWR does not ensure poor performance**

Effect Of Mis-Match On Transmitter Dissipation

- Assume 300 watt transmitter:





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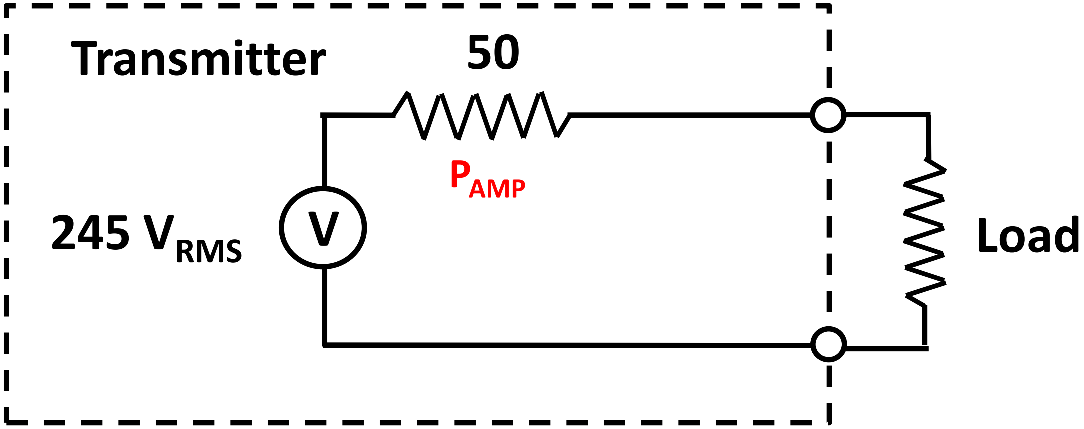

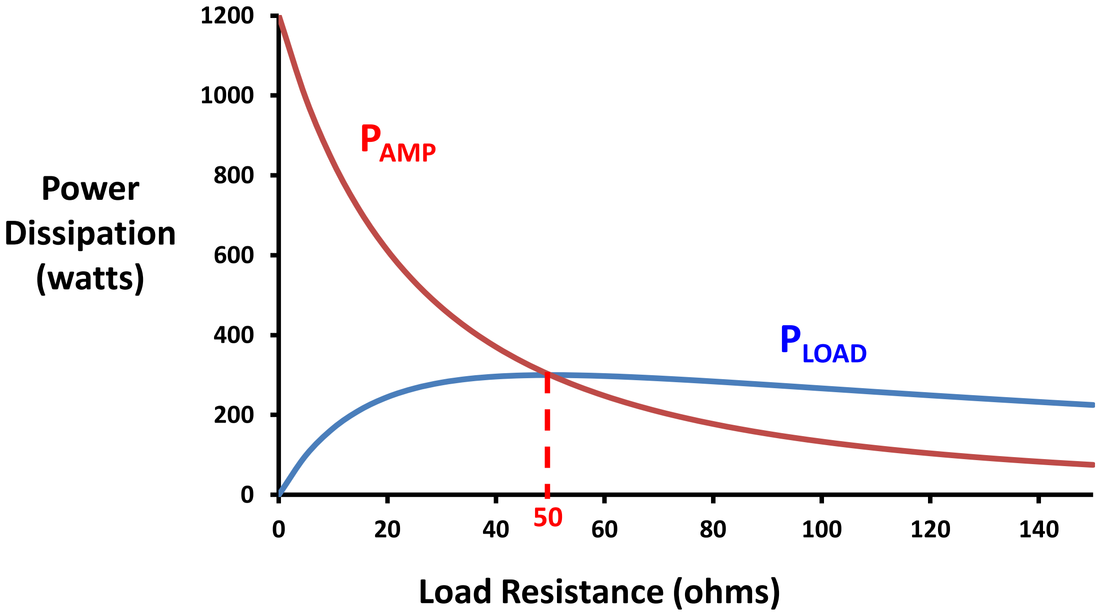

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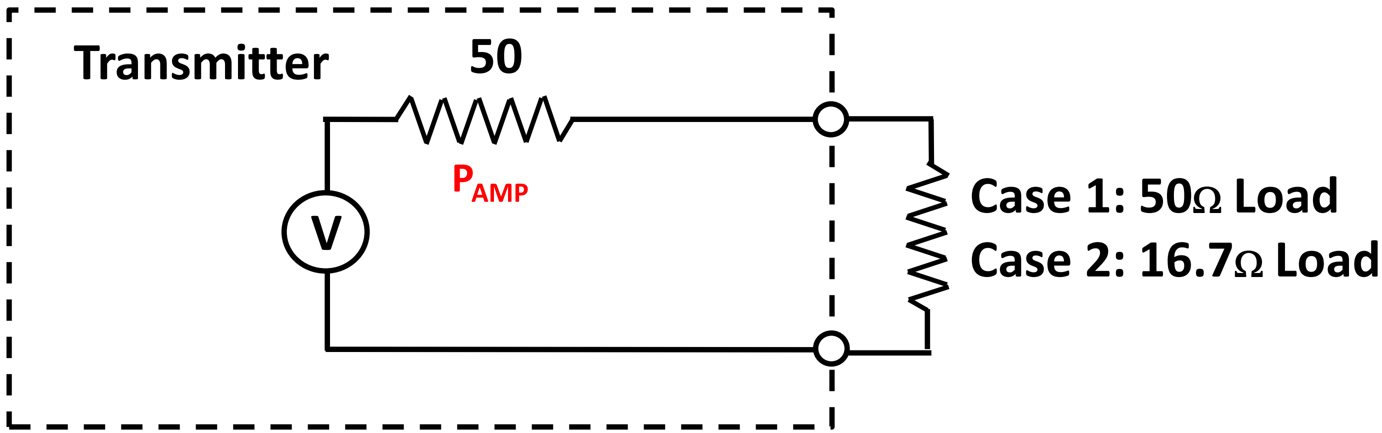
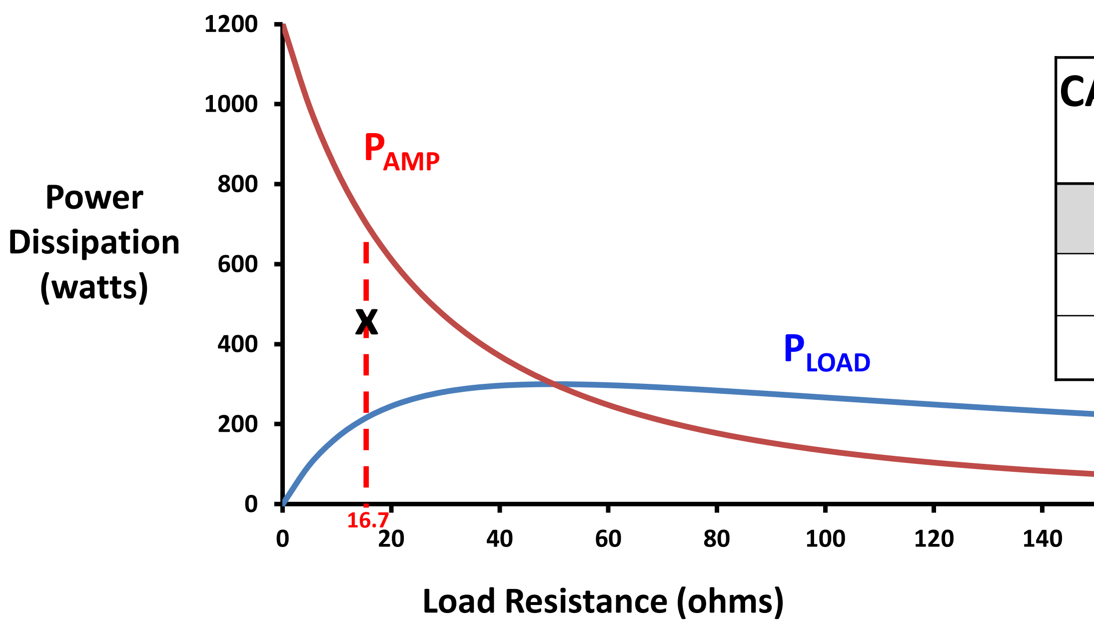
- **Assume 300 watt transmitter:**





Tube Amplifier @ P_{OUT}= 300 W

CASE	P_{IN} WATTS	DISSIPATION WATTS		EFFICIENCY %
		P_{AMP}	P_{LOAD}	
1	620	320	300	48
2	690	460	230	33

The transmitter puts out 70W less, but disspates 140W more

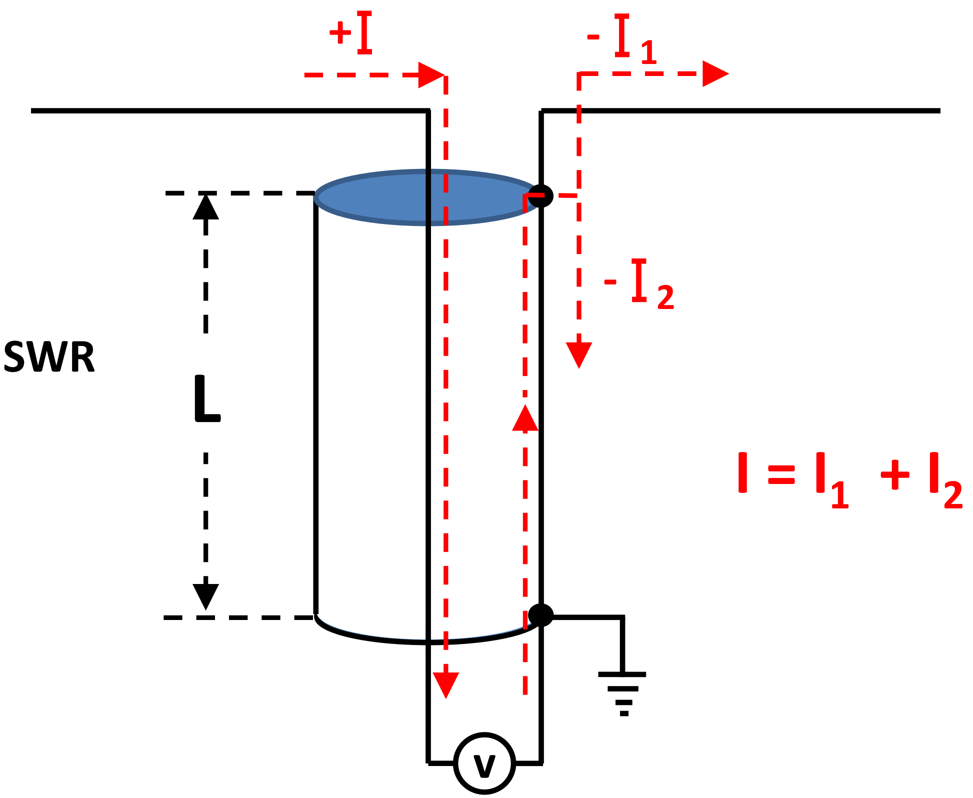
Unwanted Transmission Line Radiation

- Properly terminated transmission lines do not radiate (theoretically)
- Balanced transmission lines feeding <u>un</u>balanced antennas can radiate
  - Example: Off center fed dipole fed with ladder line
- Unbalanced (ie, coaxial) transmission lines feeding balanced antennas can radiate
  - Example: Dipole fed with coax (Tri-pole)
    - Amount of radiation is related to I_2

Tri-pole:

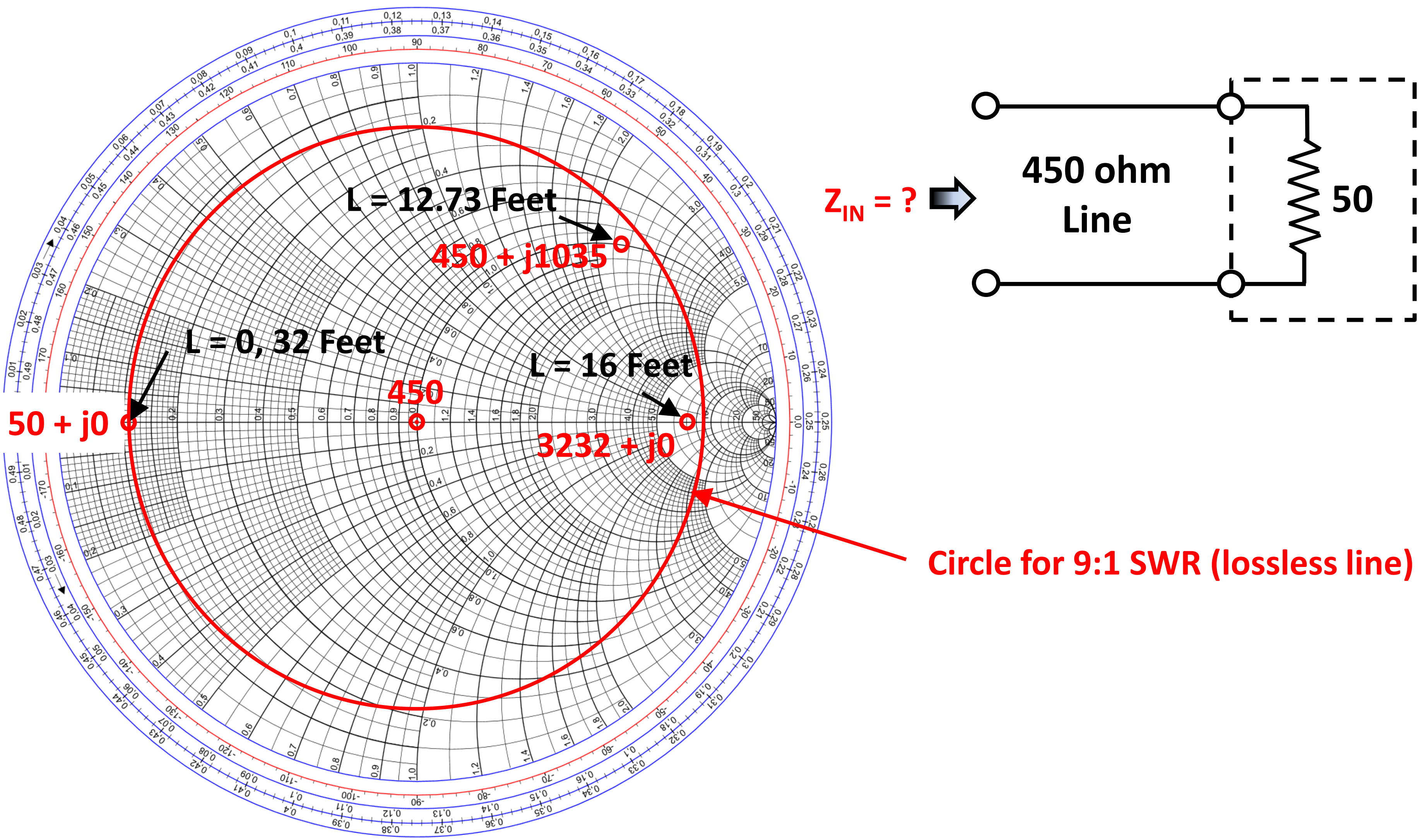
Changing L:

- does not change SWR
- does change I_2



Input Impedance And SWR

- Changing line length changes Z_{IN}, not the SWR
  - $Z_{IN} = Z_L$ at ½ wavelengths (regardless of SWR)
- Can only determine resonance at ¼ wave line lengths



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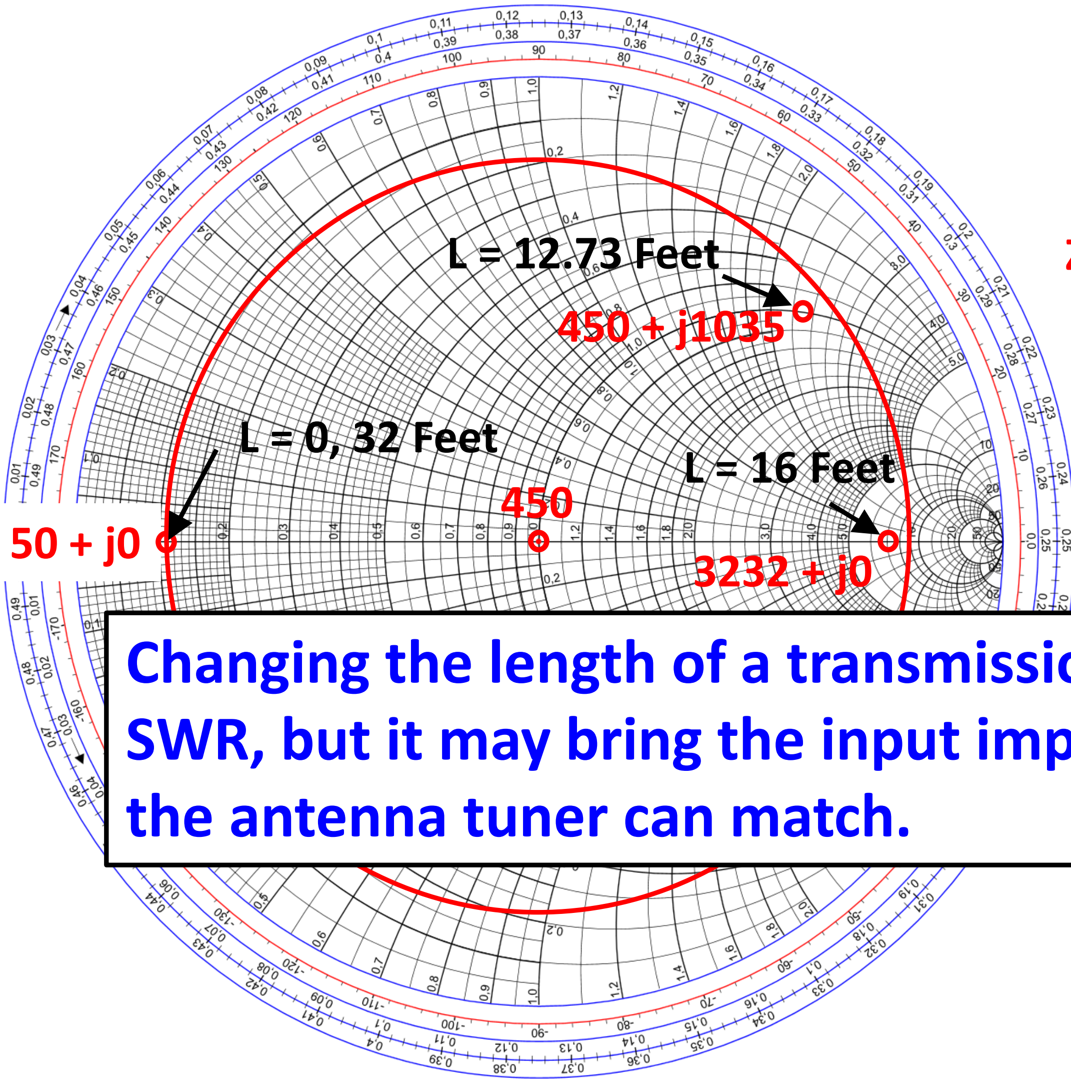
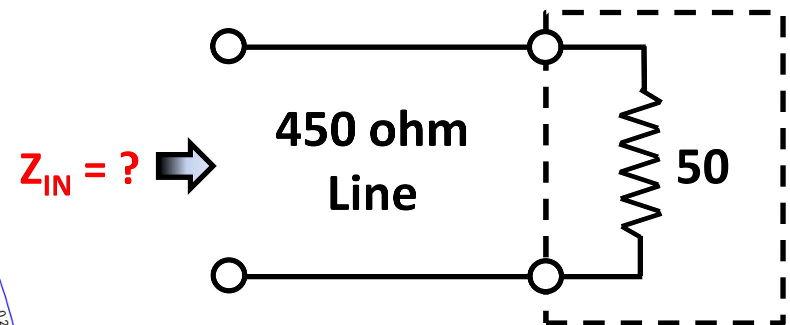
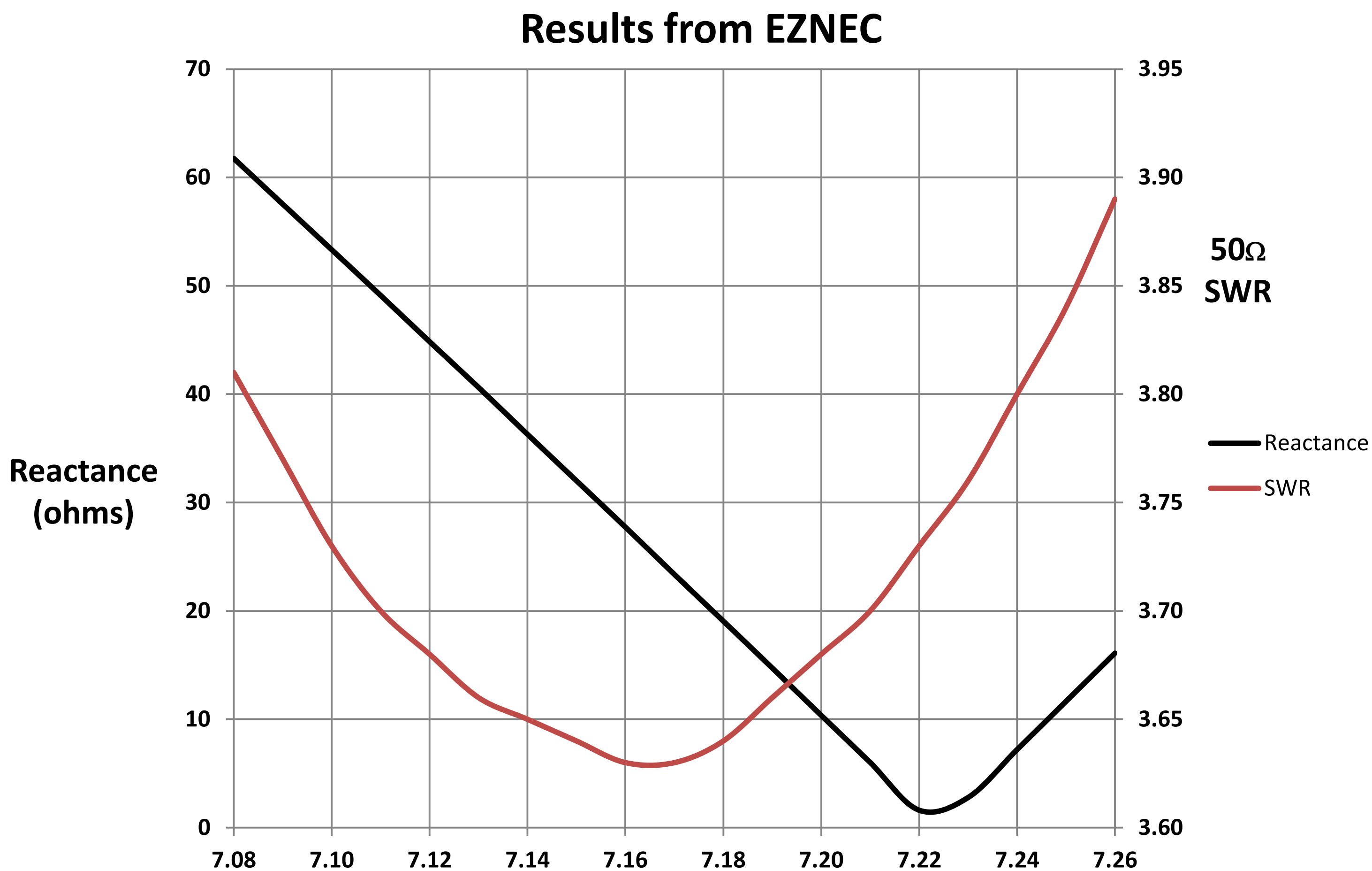




Changing the length of a transmission line will not change the SWR, but it may bring the input impedance into a range that the antenna tuner can match.

40M Off Center Fed Dipole



Resonance and lowest SWR do not always occur at the same frequency!

SWR Quiz

All answers are False

True or False:

1. Low SWR ensures good performance
2. High SWR ensures poor performance
3. An antenna needs to be resonant to perform well
4. Reflected power always represents lost power
5. Reflected power flows back into the transmitter causing increased dissipation and other problems
6. It is always best to reduce SWR well below 2:1
7. Any transmission line with high SWR produces unwanted radiation
8. SWR can only be accurately determined at the antenna
9. The SWR at the transmitter can be improved by changing the length of the transmission line
10. Mobile antennas with the lowest unmatched SWR perform best
11. Antenna resonance can be determined by measurements at the end of any transmission line by a simple impedance measurement
12. The lowest SWR on an antenna always occurs at resonance

Important Points

1. **Reflected power is <u>NEVER</u> lost**
   - **Reflected power is never dissipated in the transmitter**
   - **The power not radiated by an antenna is equal to the reflected power, which is equal to the power <u>NOT GENERATED</u> by the transmitter**
2. **All of the power generated by the transmitter is radiated by the antenna (ignoring tuner and line losses)**
3. **Forward power exceeds transmitter power whenever SWR>1:1**
4. **Reducing SWR below 2:1 yields negligeable increase in power radiated from an antenna**
5. **Low SWR does NOT ensure good performance**
6. **High SWR does NOT ensure poor performance**
7. **An antenna does NOT need to be resonant to perform well**
8. **Good tutorial on SWR: www.hamuniverse.com/wc7iswr.html**