# Imperfect Antenna, SWR & Antenna Myths

"Forward-going and reflected waves react upon each other, much as ripples in a pond when two peddles are tossed in."
William Orr, W6SAI, SK

QST, NOV 2006, PG 37-41 BY DARRIN WALRAVEN, K5DVW

QST, JULY 1979, PG 24-27 BY STAN GIBILISCO, W1GV

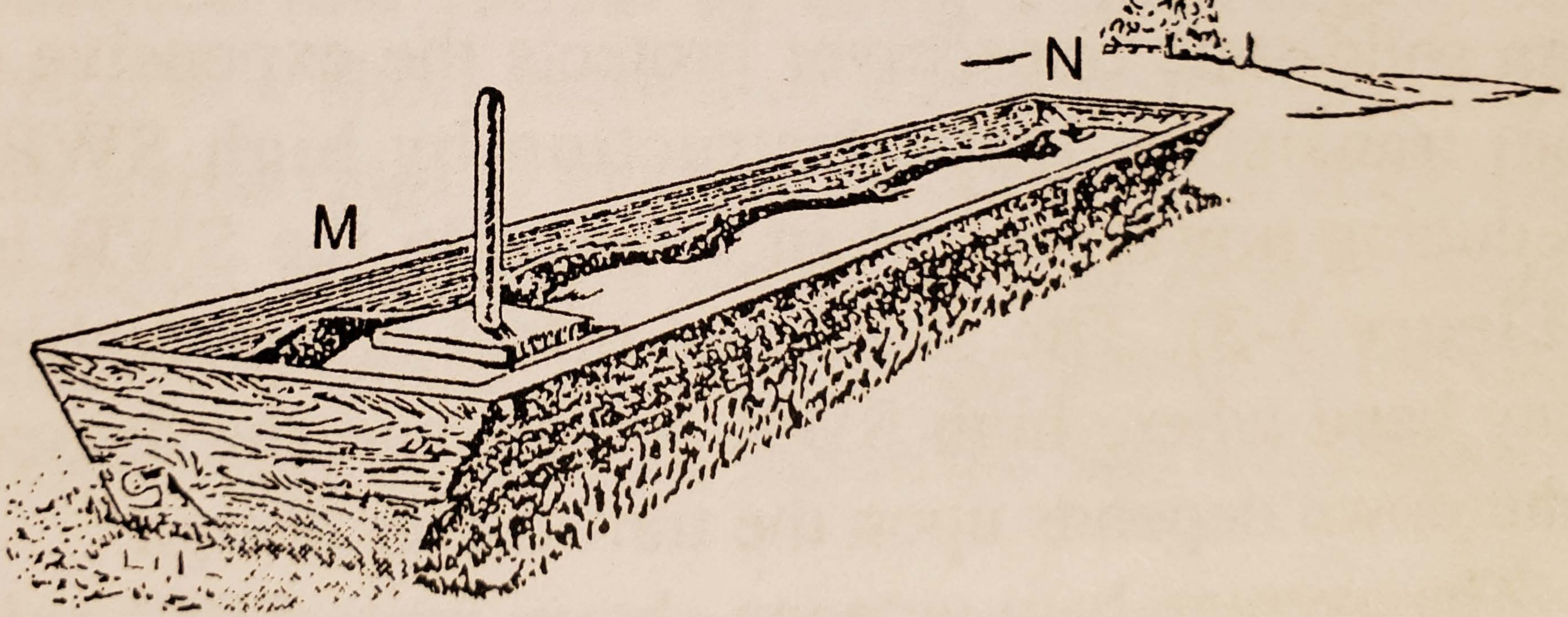
HRM, FEB 1988, PG 98 BY TM MCMULLEN, W1SL

73 MAGAZINE, FEB 1985 BY ROBERT BLOOM, W6YUY

W6SAI HF ANTENNA BOOK, 1996 BY WILLIAM ORR

ARRL ANTENNA BOOK, MULTIPLE EDITIONS

Peer Review: Bob Loving K9JU




Wave reflection is easily visualized in a water trough. When energy is applied at M by a flat paddle, a water wave travels towards the opposite end, N. A splash of water up on that end but then the wave is reflected back to the paddle end, interfering with the original wave. Science defines this as a Standing Wave. Water splashing out of the trough is not reflected back. An electrical wave operates in exactly the same way.

# Background on Standing Waves

SWR was not really understood until the early 1940s

Standing waves can be observed by a NE-2 (neon bulb) swept across 600-ohm line

Primary effort controlling of SWR > **Keep RF out of the shack and protects the transmitter**

Transmitters do not like a mismatch of impedance

**Tuner at the transmitter:** Reduce negative effects of reflected power to transmitter

**Lowering the loss of transmission line >** more energy reaches the antenna

Most reflected RF heading towards the transmitter from antenna is ultimately reflected back towards the antenna

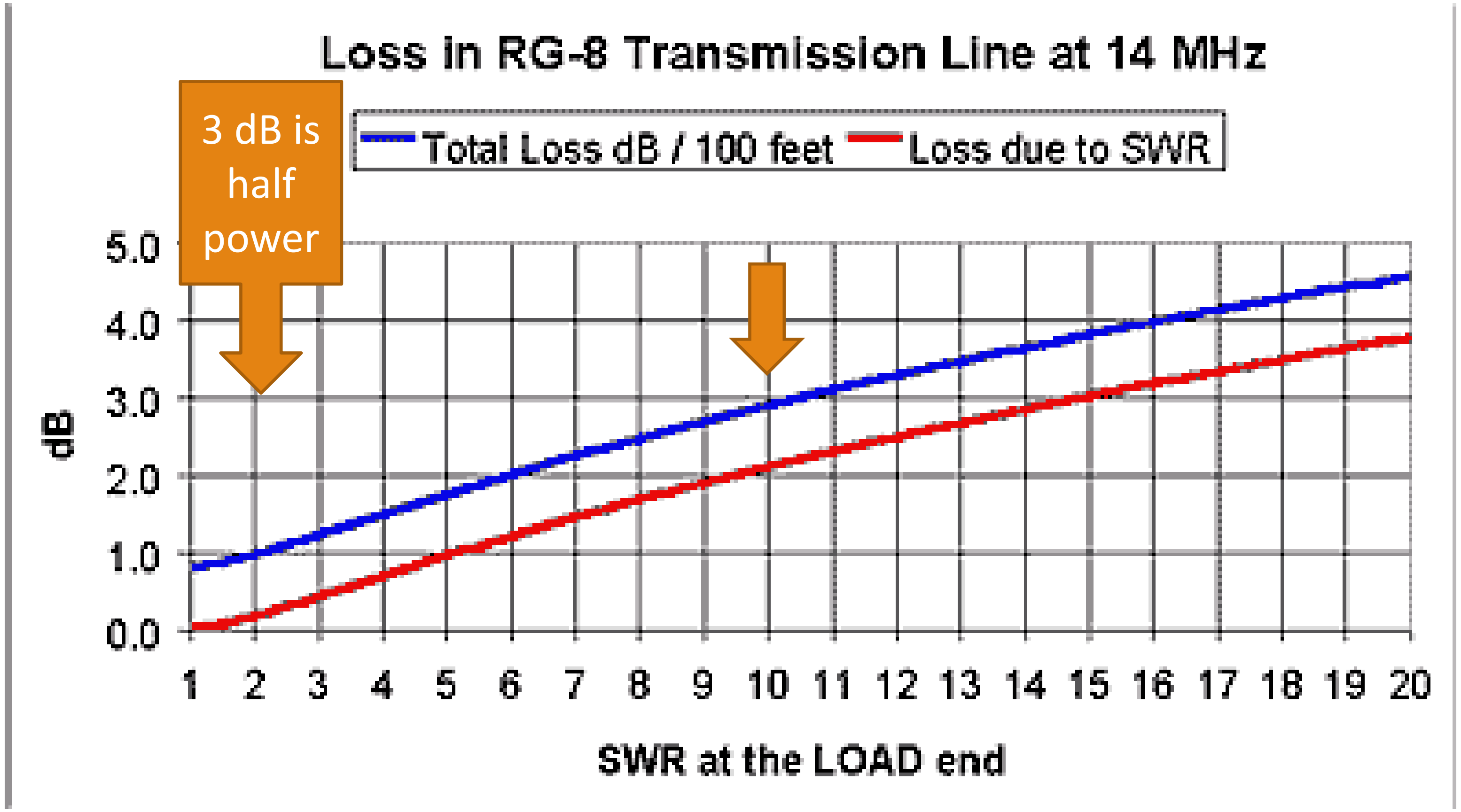
# Mis-matched Antenna

- **A mis-matched antenna tends to look like Reflected Power is subtracted from Forward Power**
- **Most power not used by the antenna is lost by heat in the transmission line**
- **Most modern radios automatically compensate for high SWR by reducing power output to save the finals**
- **Example: 20-meter antenna w/100 ft of RG8 coax**
  - Assume SWR 3:1 at the antenna, results in a loss of only 0.27 dB or 6.4% of the power plus the coax loss (~1 dB)
  - Remember, the lost power mostly occurs within the transmission line
  - For 100W transmitter, only 75W would ultimately be available to the antenna
  - For high SWR, the transmitter may compensate by reducing power also

NEXT SLIDE SHOWS THIS GRAPHICALLY (SWR 10:1 at ANTENNA)

# Loss due to transmission line & SWR 10:1

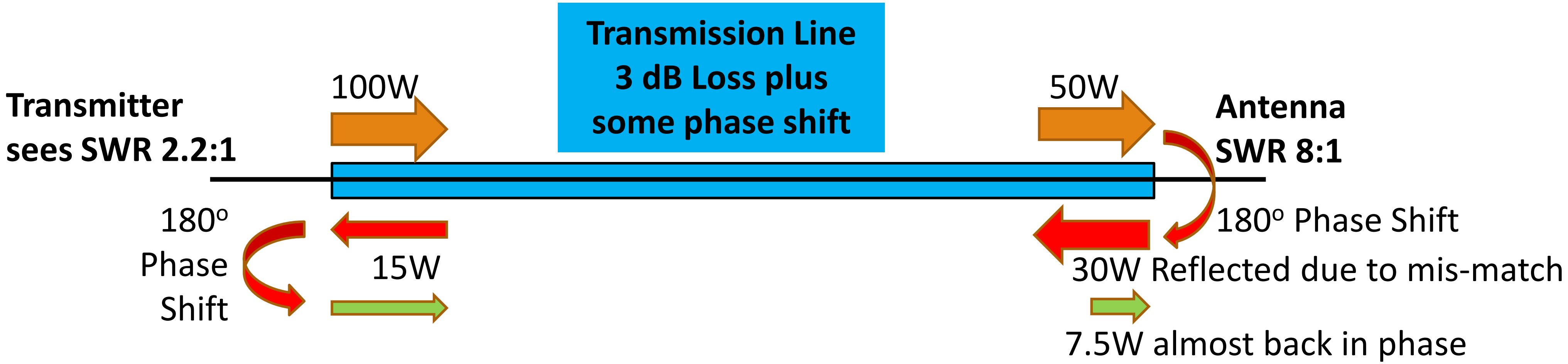
- For each 100 feet of RG8 loss will be one half power assuming SWR at the antenna is 10:1 (blue line).
- If coax were RG174, RG58 or RG8X the loss will be even greater.




**Only 50 watts of power reaches the antenna**

ARRL Antenna Handbook

# Transmission Line Loss vs. SWR




KEY TAKE AWAY: The reflected power has been attenuated by 2X 3dB, ie., 6 dB and this means a SWR at the transmitter is 2.2:1 with the SWR at the antenna is actually 8:1.

# SWR and the Tuner Fix

- The SWR meter reads the amount of reverse power in a coax and converts that number to a value defined as SWR (Standing Wave Radio)
- Adding a tuner at the transmitter does not change the SWR caused by a mis-match
- The job of the tuner is to present a suitable load to the transmitter to **MAKE IT HAPPY**
- Reflected power is power unable to be absorbed by the antenna and thus not converted to electro-magnetic energy which is thus not radiated
- Per M. Walter Maxwell in his book Reflections: Transmission Lines and Antennas says: **"… the tuner obtains a match, by all reactances throughout the entire antenna system being canceled, including that of the off-resonant antenna, thereby tuning it** (the <u>antenna system</u>) **to resonance."**

# What is Voltage Standing-wave Ratio (VSWR)? Let’s just call it SWR!

1. Place a voltage meter at the end of the coax on a perfect 50-ohm load and see max reading
2. Move the meter along the line and there will be maximums (Emax) and minimums (Emin)
3. Definitions: VSWR = Emax/Emin and ISWR = Imax/Imin
4. All transmission lines have loss:
   a. The line conductor presents a loss to the signal with greater loss as the frequency increases (skin effect)
   b. Dielectrics in the manufacture of the cable has loss with some having more and some less
   c. Given enough power with a high loss transmission line and high SWR > the cable smokes
5. SWR loss is basically a factor of the load impedance not equal to the cable/antenna impedance
   a. The voltage and current will be out of phase if the antenna and line impedance do not match
   b. This is defined as “feed-line mismatch loss”
   c. A perfect load impedance and matching transmission line offers a “flat line”, defined as a conjugate match
   d. **An antenna can only be a perfect (1:1) match at exactly one frequency (or a harmonic)**

# How does an SWR meter work?

- The meter measures the difference between the RF voltage (E) and current (I) at **its location** in the transmission line.
- SWR meters will only be totally accurate if the transmitter and transmission line impedance are the same and the load is purely resistive (no reactive component)
- The reactance of the antenna (which changes with frequency) also has an effect of the transmission line match to the transmitter, thus the metered SWR can change with frequency

# SWR Metering Methods

- All VSWR meters use a diode to convert RF to DC and then filter to average out peaks
- Voltage (E) and current (I) both maximum = matched TX to Line to Antenna
- Reversing the meter in/out ports allow both forward and reflected power to be read
- A perfectly matched antenna to a transmission line and the SWR reads 1:1 {MATCHED}
- SWR is calculated by taking a measurement with a perfect resistive dummy load in place of the antenna, then with the antenna connected - compare the results:
  - Resistive 50-ohm dummy load should show 1:1 when connected
  - Antenna should show <2:1 SWR at the transmitter when connected
  - Higher than 2:1 at the transmitter likely requires transmitter to reduce power (or just shut down)

REMEMBER: The tuner at the transmitter output "fools" the radio into allowing full power to be sent only to the tuner input!

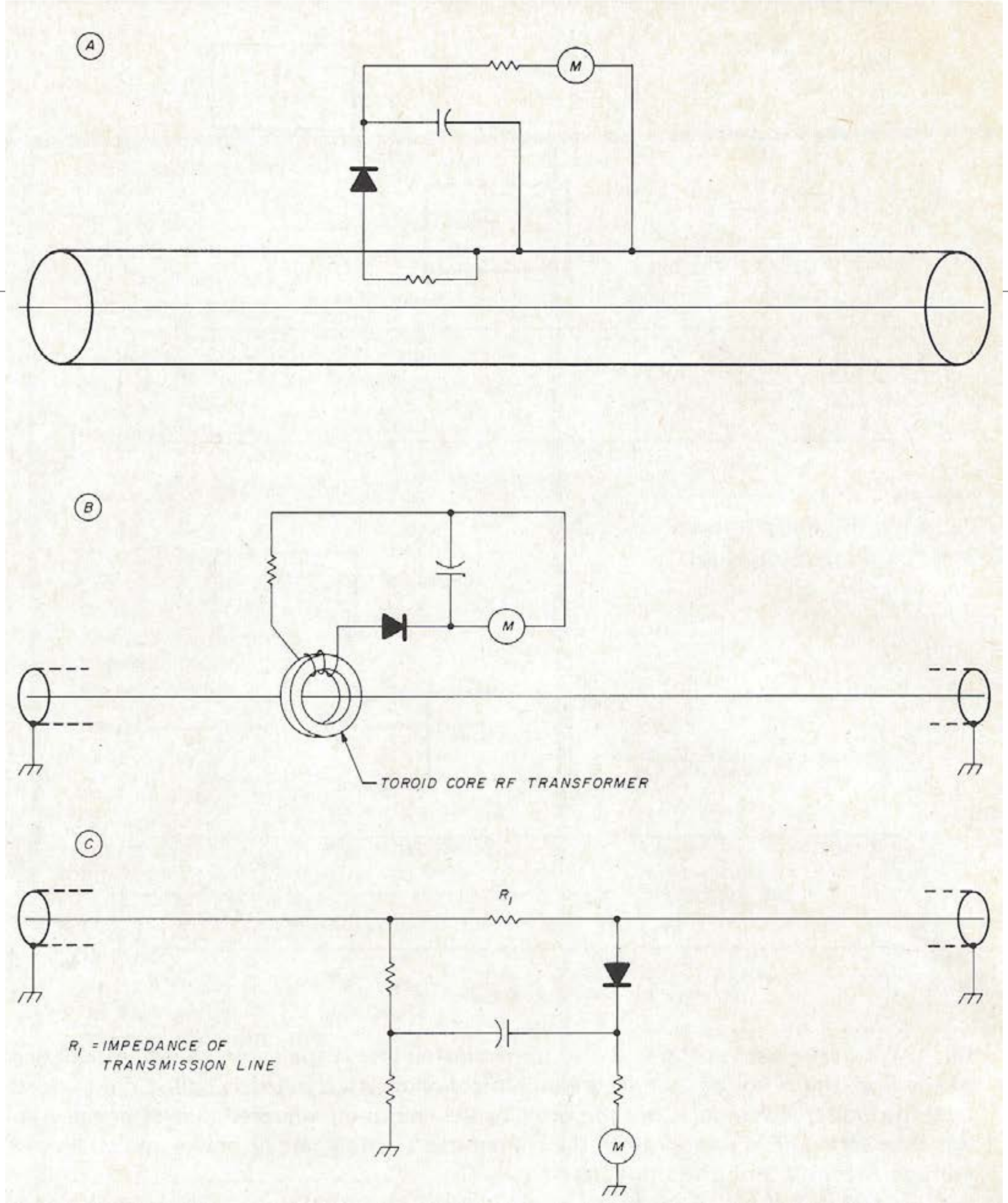
# Amateur Radio VSWR Meter

Current-pickup-loop samples the rf current in the transmission line:

A. Coax shield is tapped at two places and resulting voltage compared

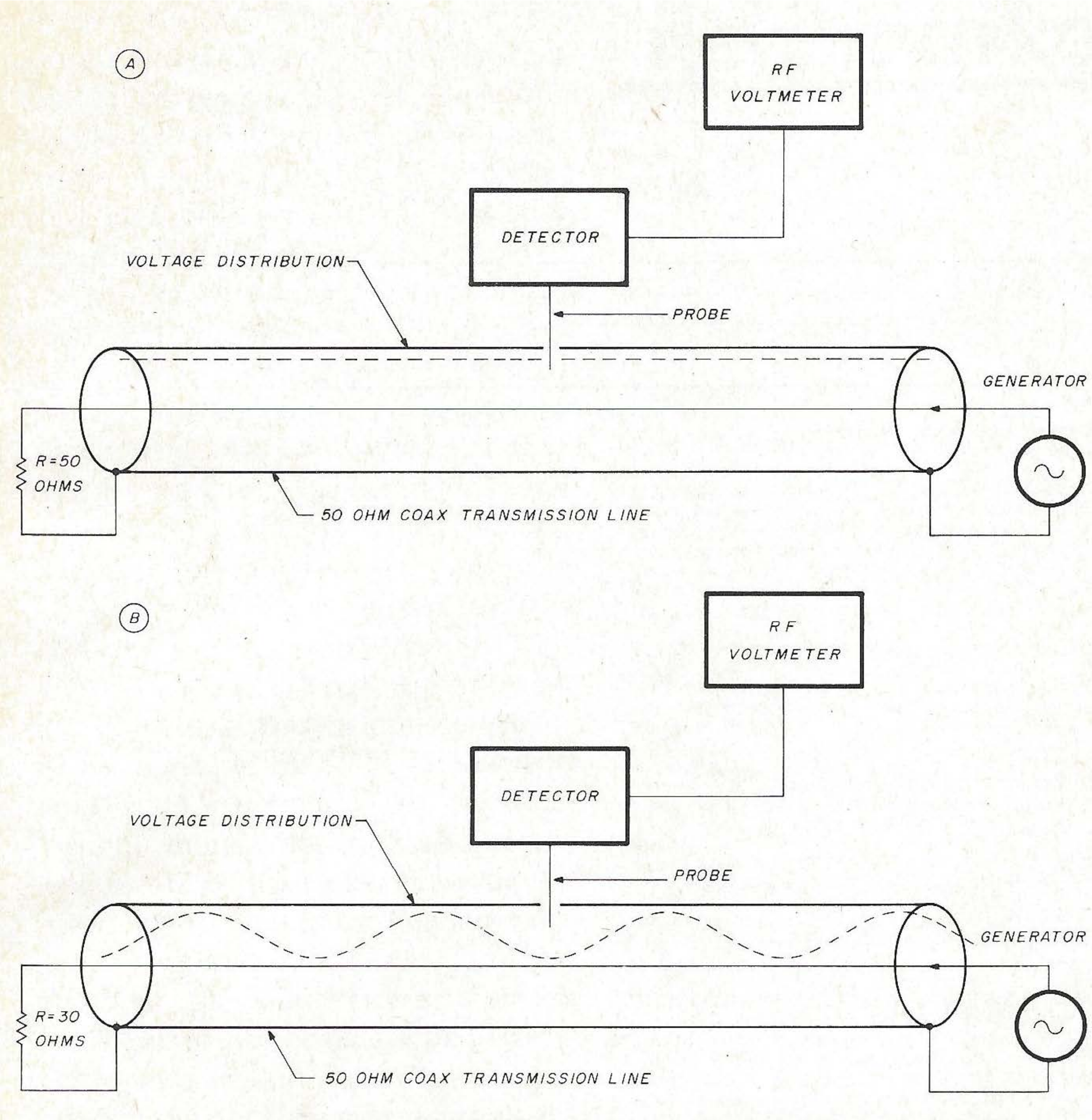
B. Current toroid transformer measure current flowing on the shield

C. Bridge using a in-line resistor (same value as transmission line impedance) allows resulting voltages to be measured at both ends of one leg



# Commercial VSWR Meter

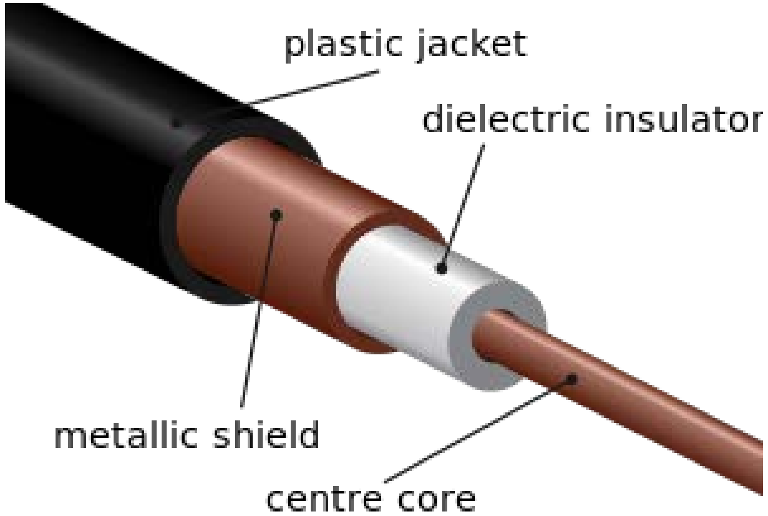
A. Detector has a stub placed in a transmission line to sense the signal in the test line
B. If voltage across the line is constant, the line is called FLAT (purely resistive & no reactance), transmission line then matches transmitter impedance
C. With a 30-ohm load, voltage across the length of the line varies so reflected out of phase voltage interacting with the transmitter output is the result

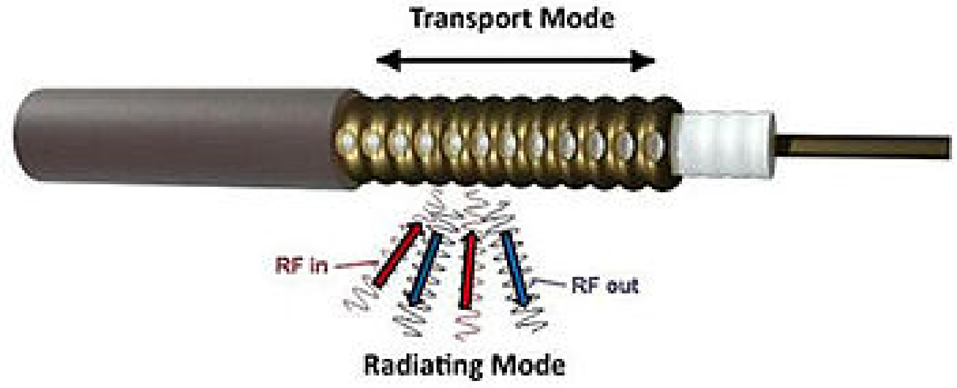


# Can SWR meter provide meaningful readings?

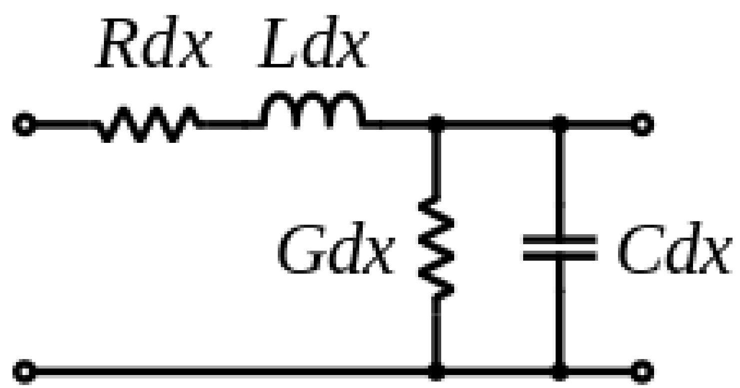
- Transmission line length always has an effect on SWR readings, even on the best meters
- A SWR meter only reads one frequency at a time though harmonics could interfere with the ability to show the ratio
- Add different lengths of 1/8th wavelength cable segments between the measuring point and the meter to see how length of cable changes the readings
- Add an exact ½ wavelength cable for the frequency being measured, the SWR should the same
- Placing a >30 dB harmonic filter between the transmitter and the SWR meter will improve the accuracy of the readings
- SWR readings on frequencies >28 MHz are less than meaningful

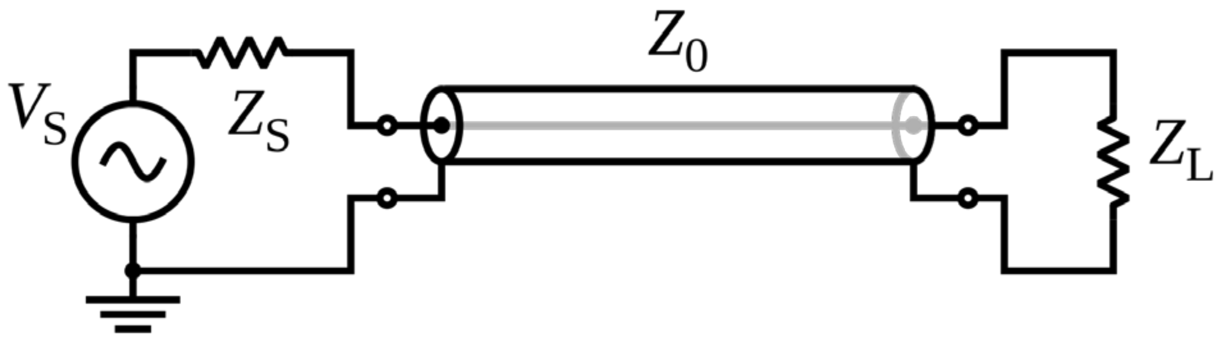
# Types of Coax Transmission Lines




# RF Transmission Line Attenuation




- ❑ At higher frequencies skin effect increases the effective series resistance, Rdx
- ❑ Only a thin layer of each conductor is utilized to carry the signal
- ❑ The dielectric properties of inner insulation of the center conductor defines the conductance, Gdx
- ❑ Gaps or holes in the outer shield allow some signal to leak away from the coax which is measured as loss
- ❑ **Total attenuation is a result of loss of the dielectric material, resistive losses of the conductors, signal loss through the cable shield and cable connectors**

# VSWR (at Transmitter) vs Reflected Signal

| VSWR | Reflected Voltage | Reflected Power | VSWR | Reflected Voltage | Reflected Power |
|---|---|---|---|---|---|
| 1.0:1 | 0 | 0 | 1.8:1 | 29% | 8.2% |
| 1.1:1 | 5% | 0.2% | 1.9:1 | 31% | 9.6% |
| 1.2-1 | 9% | 0.8% | 2.0:1 | 33% | 11.0% |
| 1.3-1 | 13% | 1.7% | 2.5:1 | 43% | 18.4% |
| 1.4:1 | 17% | 2.8% | 3.0:1 | 50% | 25.0% |
| 1.5:1 | 20% | 4.0% | 4.0:1 | 56% | 36.0% |
| 1.6:1 | 23% | 5.3% | 5.0:1 | 67% | 44.4% |
| 1.7:1 | 26% | 6.7% | 10.0:1 | 82% | 67.0% |

# Cable Loss Related to SWR

- Assume a long lossy transmission line and an antenna mismatch
- VHF, 100 feet of RG8X line results in about 4.5 dB of cable loss under matched conditions
- If SWR were 2:1, the added loss: 0.4 dB
- If SWR were 3:1, the added loss: 1.0 dB
- If SWR were 4:1, the added loss: 1.8 dB

Somewhat minimal loss.

**However, this is not the complete story!**

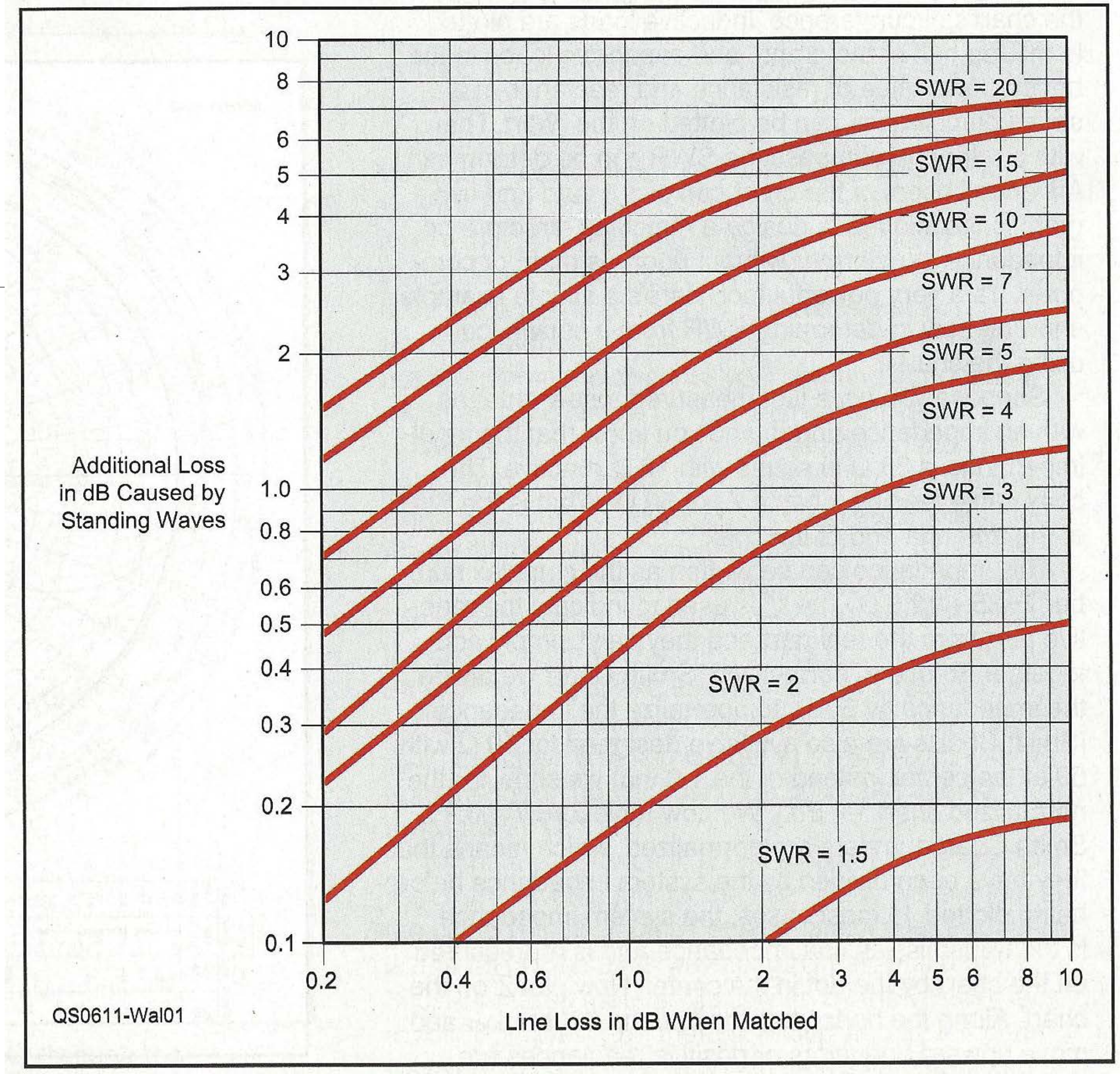



Chart from ARRL Handbook

# Real Effects of Cable Loss

- The real loss to the RF TX energy: How much the antenna actually radiates!
- Assuming 2:1 SWR at the transmitter, now see what the real SWR is at the antenna
- Looking at the graph to the right and see the cable loss of 4.5 dB
- The equivalent SWR at the antenna with 4.5 dB cable loss is: ~20:1
- Remember, at 10:1, 67% of the power is reflected back

**There is almost no RF energy getting to the antenna with high loss coax!**

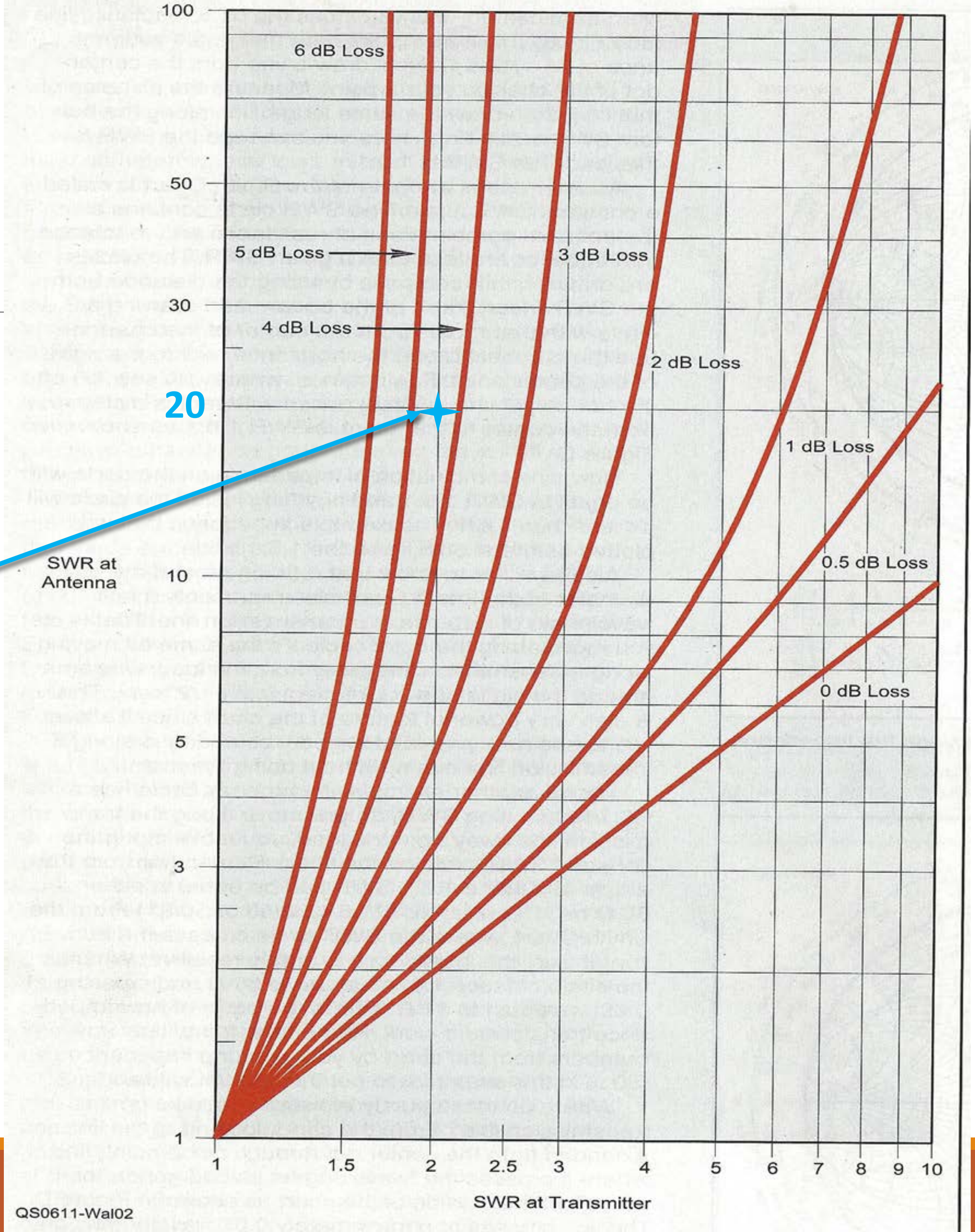


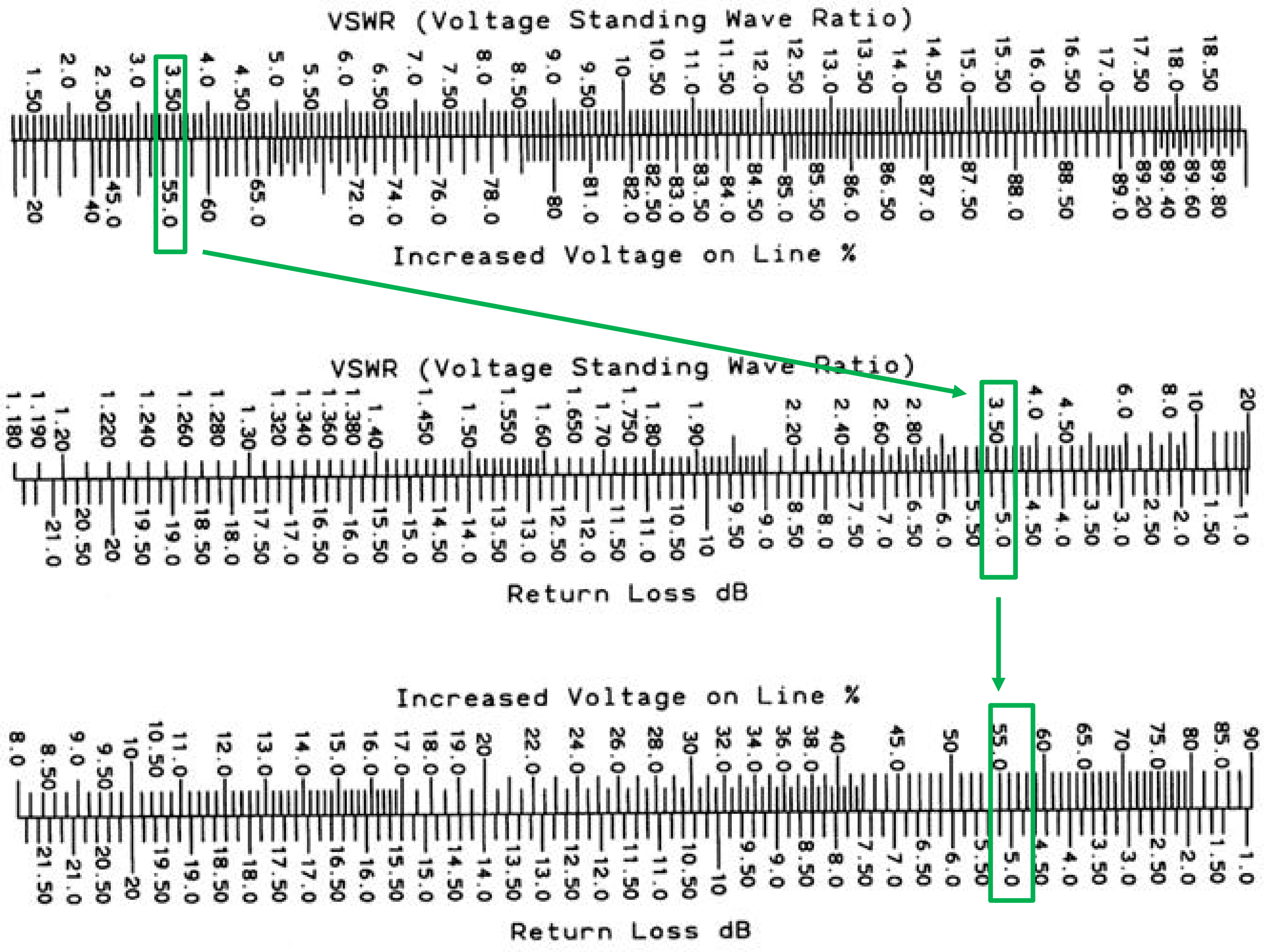

Chart from ARRL Handbook

# Now, Look at the voltage on the transmission line!

**As SWR increases on a transmission line, the result is an increase of the peak voltage which might cause insulation breakdown under high power.**

**Note: Example shows a 55% increase in voltage with high SWR.**

**A 1.5 kW transmitter using a 50 ohm transmission line produces 388 volts peak. With high SWR this could reach upwards of 776 peak voltage.**



# SWR using an Antenna Analyzer

- Can easily show SWR on multiple frequencies as it has is own RF exciter
- Antenna system measured must <u>not</u> utilize feedline as part of the antenna
- Adjusting the frequency to find the lowest reading allows user to then determine the antenna resistance
- One can quickly know where the antenna has highest and lowest SWR
- Antenna can be trimmed and/or adjusted to provide the best overall match
- Some meters actually graph the sweep and show the antenna resonant points

# SWR vs. External Interference

- High SWR does not by itself cause TVI
- If arcing were to occur due to high enough mis-match, this could be the interference generator
- The effects of high SWR on parts of the RF system:
  - Can create unwanted harmonics
  - Can cause RF on the outside of the coax to be present in the shack
- Depending on the mis-match:
  - Some transmitters can go into oscillation at an unpredictable frequency
  - A skewed radiation pattern of the antenna may also result when high SWR is determined
- An antenna exhibiting high SWR at the transmitter due to impedance mismatch can be a source of RF in the shack – a possible means of reducing the effect is the use of a choke (current balun)
  - A coil of closely spaced coax: >7 turns about 10 feet of 50-ohm coax
  - 50 closely spaced ferrite beads with coax threaded through multiple times

# Lessons Learned – Page 1

1. A FLAT LINE (conjugate match) operates with the least power loss
2. SWR is a negligible factor below 30 MHz, assuming SWR at the antenna is <2:1
3. Actual transmission line loss is a huge factor above 30 MHz
4. High SWR when using high power (>100W) can result in failed transmission line due to increased voltages
5. Impedance changes with and repeats every ½ wavelength of transmission line
6. SWR should be 1:1 when transmission line is terminated in its characteristic impedance with a like resistor and 2:1 when resistor is doubled in value

# Lessons Learned – Page 2

7. High SWR (>6:1) at the transmitter can cause the final amplifier to be de-tuned unless a tuner is used to protect it.
8. High loss coax does reduce the actual power at the antenna.
9. Placing a tuner at the output of the power amplifier makes the output finals tuning look into the correct impedance (50-ohms) and the maximum power is delivered to the transmission line.
10. Use of a current balun (choke) at the antenna will reduce negative effects of currents flowing on the outside of a coaxial transmission line.