Basics of Wire Antennas
Part I – Horizontal Antennas

Presented to the
Stamford Amateur Radio Association

by

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About the only "truths" there are about antennas

- ALL real-world antennas are a series of compromises.

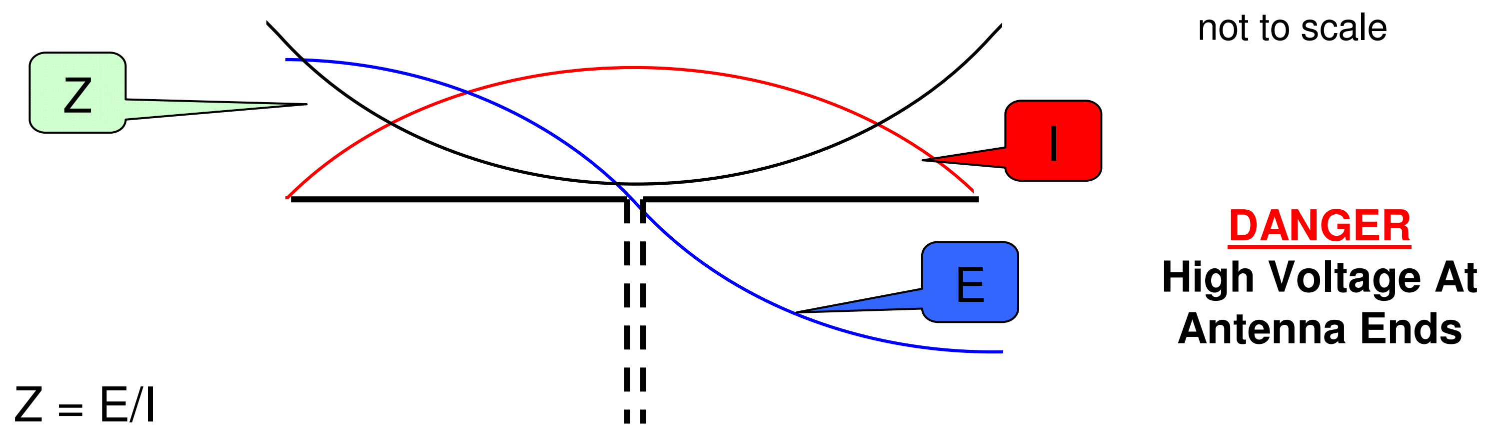
- EVERYTHING is relative.

  - There is no one metric (e.g. SWR) that represents whether an antenna is "good" or "bad".
  - A given value for a metric (e.g., 1:1 SWR) is neither "good" nor "bad" by itself.

- Antennas obey the laws of physics. There are no magic bullets, secret formulas, special sauces, or patented shortcuts that violate those laws.
- Don't ask if an antenna is "good" or "bad", rather ask:

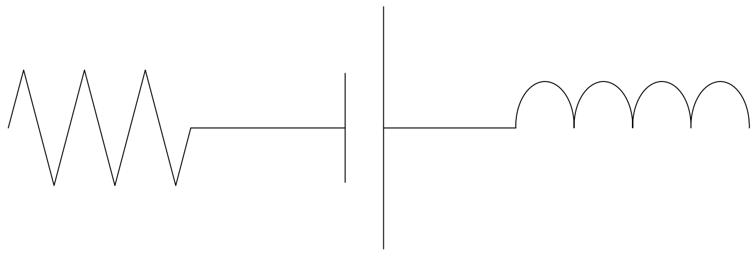
> Is it the most effective antenna I can put up given my planned operating frequencies, planned power, budget, space available, restrictions, and surroundings?

All other things being equal, a ½ wavelength (λ/2) antenna is the basis for effective signal radiation



- The current, voltage, and impedance curves ("waves") are constant – which means that the radiation fields are constant
  - They are referred to as "standing waves"
- The current is maximized, and thus the radiation fields
- We refer to the antenna as being a "resonant length"
- **Integral multiples of λ/2 are also "resonant lengths" and maximize signal strength (all other things being equal)**
- Note that the impedance varies depending on where the feedpoint is located
  - About 50 ohms at center, about 4000 ohms at ends

Every antenna looks like a circuit of resistance, capacitance, and inductance



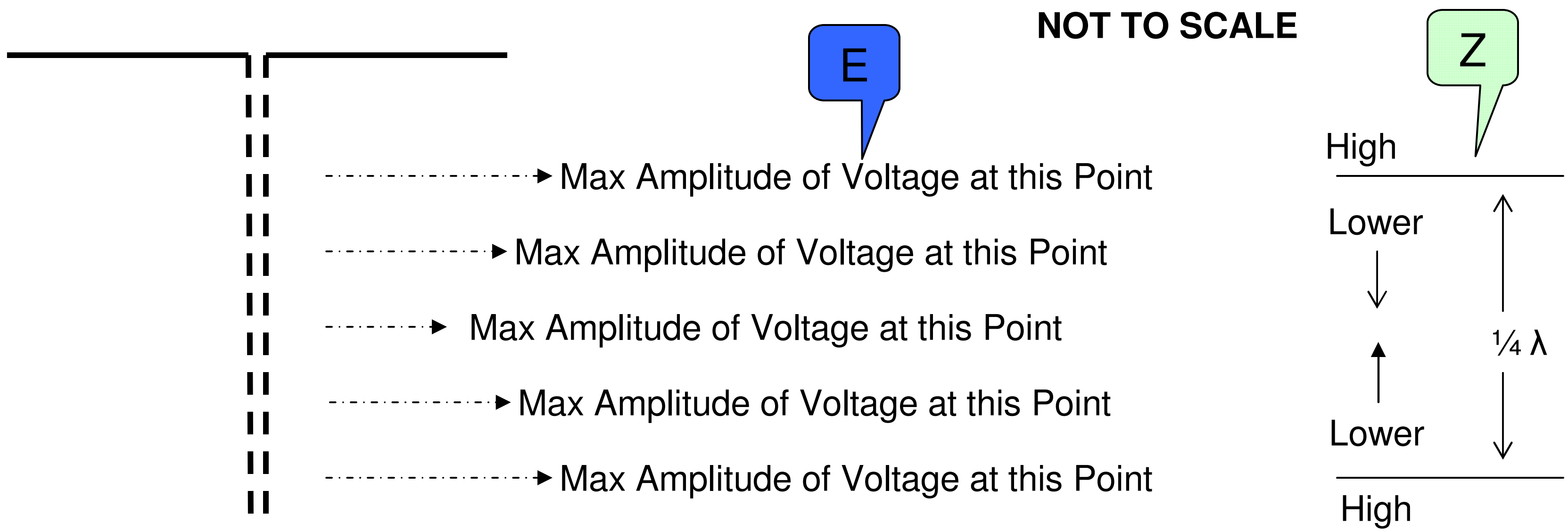
$X_L = 2*Pi*F*L$

$X_C = 1/(2*Pi*F*C)$

$Z = R + \sqrt{(X_L**2) - (X_C**2)}$

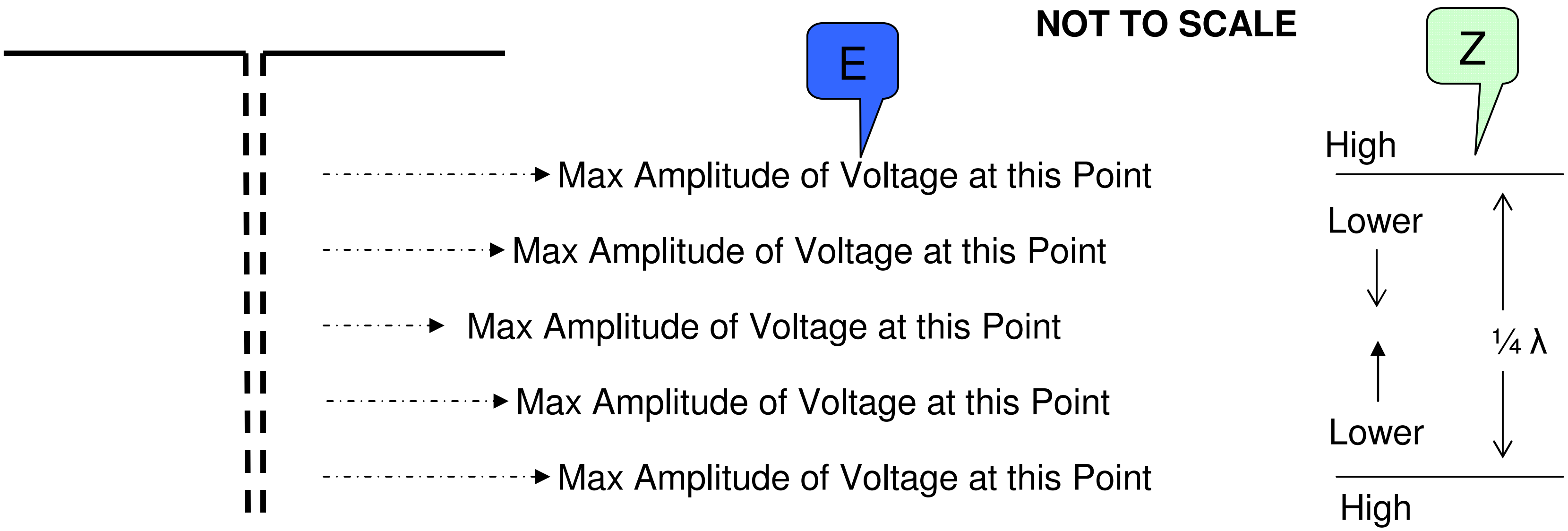
- Impedance of the antenna impacted by factors such as:
  - **Length (resonant vs. non-resonant)**
  - Design/geometry
  - Height above ground
  - Things around the antenna
- Lowest impedance when inductive impedance and capacitive impedance cancel each other out
  - Antenna is said to be “resonant” or “at resonance”
- Additional capacitance and/or inductance can be added to an antenna to change the characteristic impedance
  - Does NOT make the antenna a resonant length
  - All other things being equal, a resonant length antenna at resonance will be more effective than a similar non-resonant length antenna at resonance

When there is an impedance mismatch, power is reflected back down the feedline from the antenna



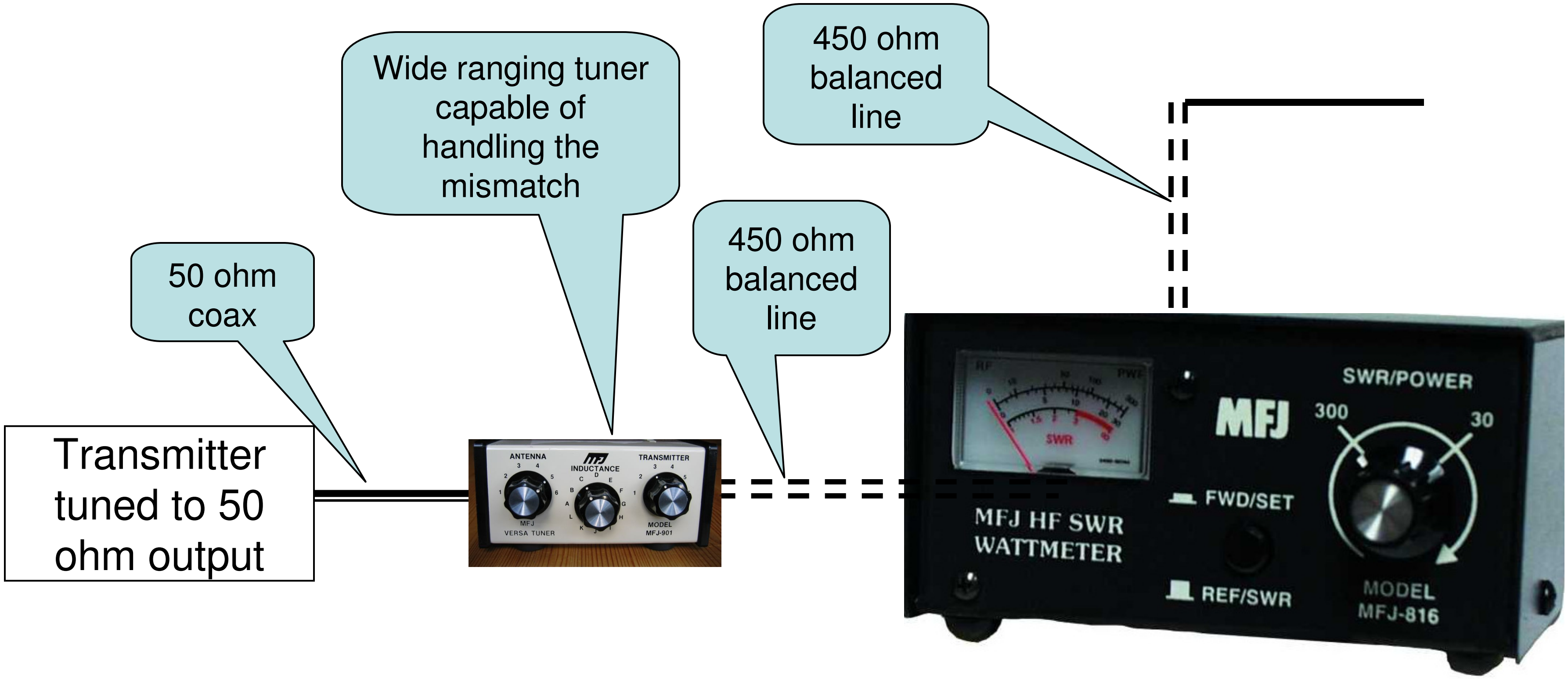
- Power coming back down the feedline mixes with power coming up the feedline to create a set of complex standing waves along the feedline
  - The highest amplitude of the voltage at certain points along the feedline will be different than the highest amplitude of the voltage at other points along the feedline
  - Impedance will range from low to high in periods of $\lambda/4$
  - Note: not necessarily a pure sine wave function, do not expect sine wave-like distributions of voltage or impedance along the line

SWR (VSWR) tells you how much of mismatch in impedance there is between different parts of the antenna system (transmitter, feedline, antenna)



- Voltage Standing Wave Ratio (VSWR):
  - Measures the ratio of highest maximum voltage amplitudes along the feedline to the lowest maximum voltage amplitudes along the feedline
    - 1:1 means no difference in max amplitude, indicates no mismatch in impedance
    - >1:1 means there is a difference in max amplitude which only comes about due to a mismatch
- Higher the SWR, the less signal radiation
  - Power dissipated in feedline and transmitter instead of radiating signal
  - Danger to the transmitter
  - Well-cooked transmission line (keeps the snow off the line)

Warning: Many modern SWR meters measure relative to 50 ohms no matter where they are in the system



- What will the SWR meter read in the above situation??
  - Hint: 450/50 = 9
- In this case note the FWD/SET – REF/SWR button

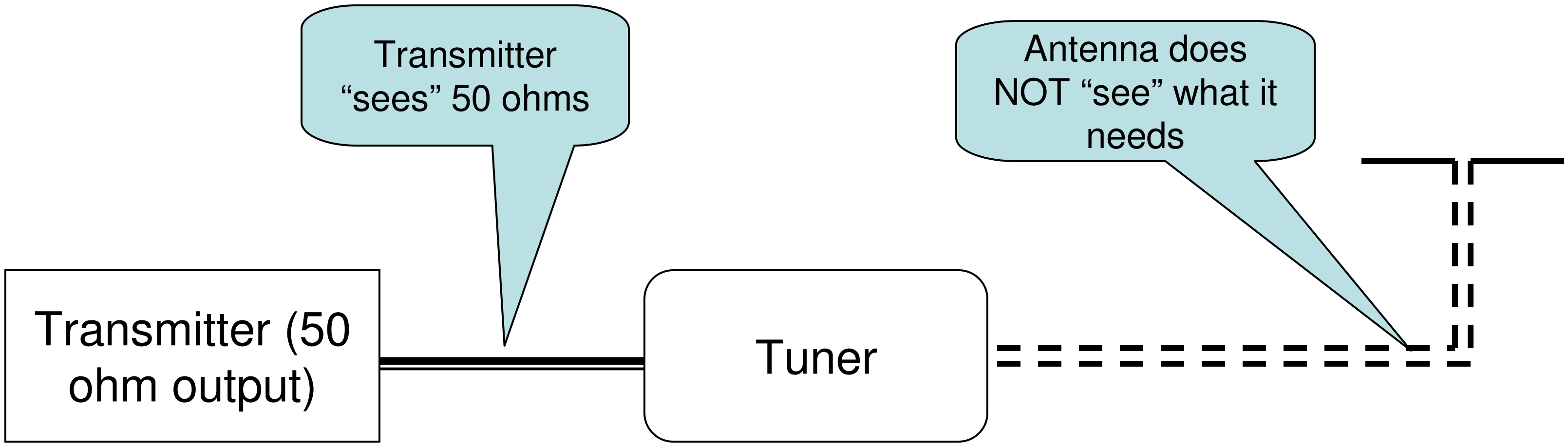
Tuners, baluns/ununs, and matching networks are used to bring down SWR

- Tuners
  - Internal vs. External
  - Automatic vs. Manual
- Baluns (Balanced to Unbalanced)
  - Ladder line, window line, etc. are balanced in that they have similar currents on both wires; coax is unbalanced in that the currents are not the same on center conductor and on shield
  - Essentially transformers
  - Ratio indicates extent of mismatch they can handle (e.g., 4:1, 9:1, 1:1)
  - Current (adjusting) vs. voltage (adjusting)
- Ununs (Unbalanced to Unbalanced)
  - Same as Baluns but targeted at unbalanced line to unbalanced line
- Matching Networks (complex circuitry)
  - Different types
  - Different ratios
- They compensate for impedance mismatches but do NOT make the antenna a resonant length

Tuners: Internal vs. Rig-Specific vs. External

- Internal tuners typically have narrow range
  - Vendor: 10:1
  - Accepted Reality 5:1
  - Tested Reality 3:1
- Same with most rig-specific tuners (e.g., AT-897)
  - Elecraft an exception
- External tuners may have much wider range, depending on design, component sizes
  - Vendor: 100:1
  - Accepted Reality: Possibly as high as 100:1, usually at least 20:1
  - Tested Reality: Possibly as high as 100:1, usually at least 20:1
- In general, the bigger the components, the more it can handle

"… but my internal automatic tuner says it's giving me a 1:1 …"



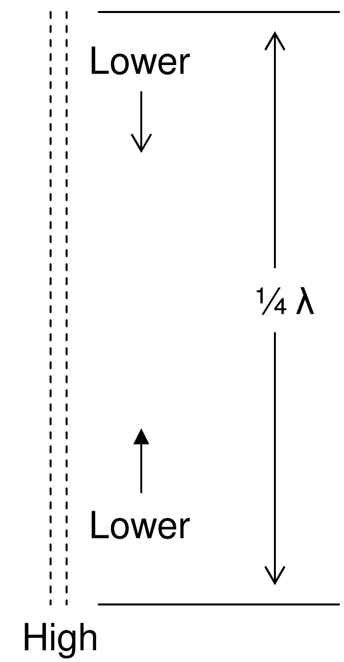
- Internal automatic tuners (and most rig-specific external automatic tuners) answer one question only:

  "What is the transmitter seeing?"

  - They don't ask what the antenna is seeing
  - Also true of some other external automatic tuners (look at size, components, price)
- Symptoms:
  - No QSOs
  - Low receive levels after tuning
  - Low power outbound of the tuner

Balanced feedline is often used as part of the matching network, especially in multiband antennas …

- Different impedances along the feedline
  - Can tap in at a point of lower impedance (e.g., end-fed Zepp, G5RV)
  - For example, in end-fed Zepp, impedance at the feedpoint of the antenna may be 4000 ohms, but at various points along the feedline, the impedance is as low as 200 ohms.
    - By tapping into the feedline at the 200 ohm points, the transmitter will see a 4:1 mismatch, and not an 80:1 mismatch
    - Use tuner to get from the 200 ohm (4:1) down to 50 ohms (1:1)
- Balance feedline has a lower loss per 100’ than coax
  - Not that much less lossy *when everything matches*
  - But much less lossy when the SWR is high (as much as 10db)
  - EXCEPT WHEN IT GETS WET



… but is a pain in the a** to use (relative to coax)

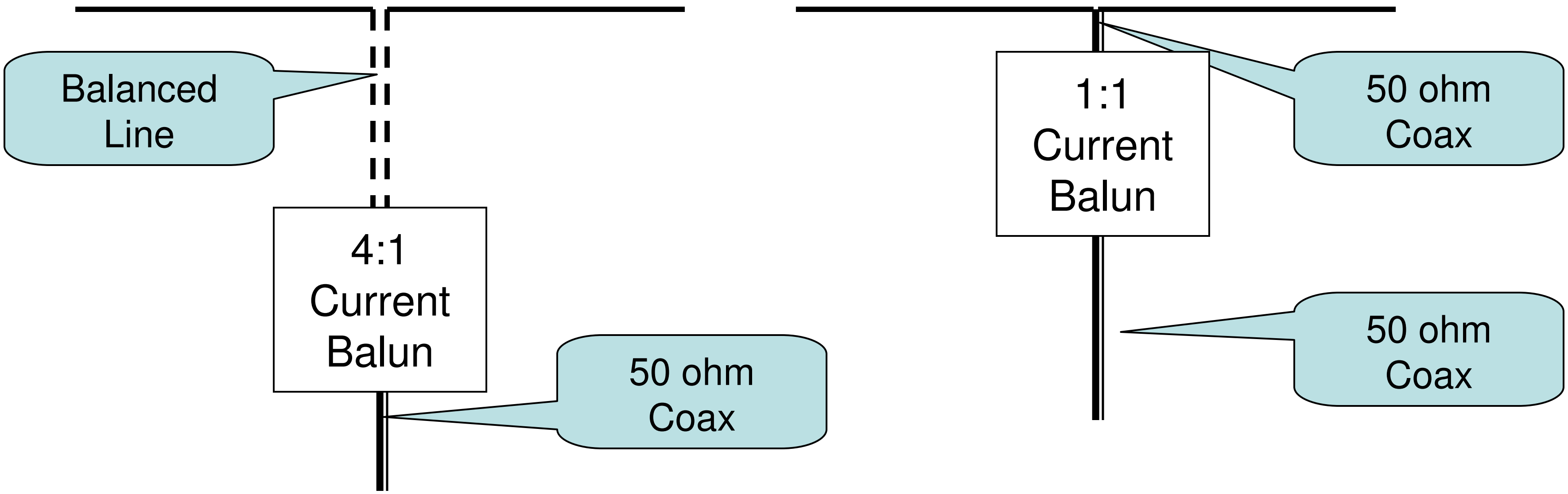
- Must be kept away from metallic objects (e.g., rain gutters, chain-link fences, aluminum siding)
  - SERIOUS potential for arcing/shorting
  - SERIOUS impact on antenna performance
- More potential to create RFI, especially when being used to match to a higher impedance antenna
- Must leave antenna at right angle
- Should not parallel the antenna at any point
- Cannot be buried in the ground or run through most types of protective conduit
- Many antenna designs call for a specific lengths, which may not be convenient
- Need to wax every six months or so

When buying an antenna, watch for these words

"…an external wide ranging tuner is recommended/required…"

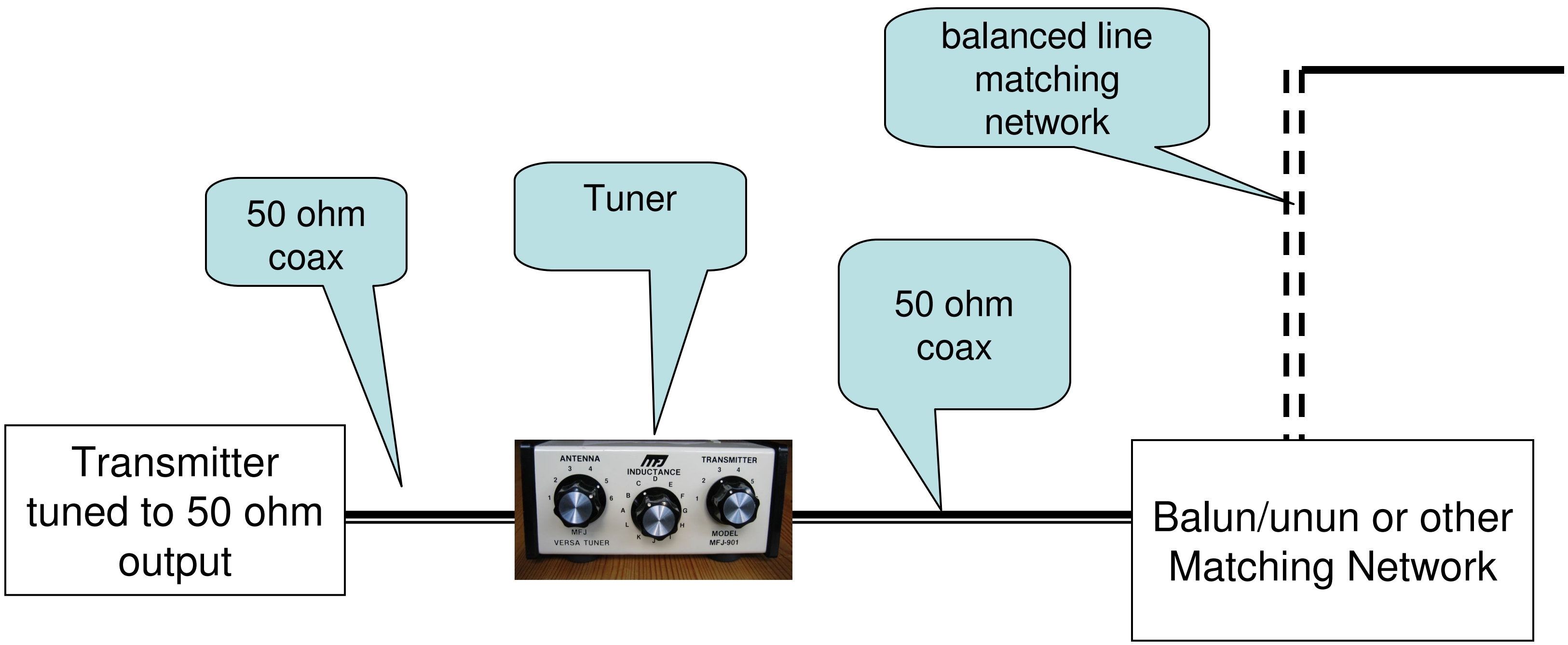
- For example, from the AlphaDelta "Problem Solvers for Wire Antenna Installations"
  - "Attic Installations. We have many successful customer reports of attic installations, particularly with the Model DX-EE ….. an external wide range tuner is usually required for proper SWR operation."
- What they mean: SWR is going to be > 10:1
- How do we know?
  - Because transceiver vendors claim 10:1 capability for an internal tuner
  - If an external, wide range tuner is required, then it must mean more than 10:1
- NOT necessarily a problem
  - Can your tuner/balun/matching network handle it??

All other things being equal, it is best to have the tuner/balun/unun/matching network where the mismatch occurs, but that can be difficult …



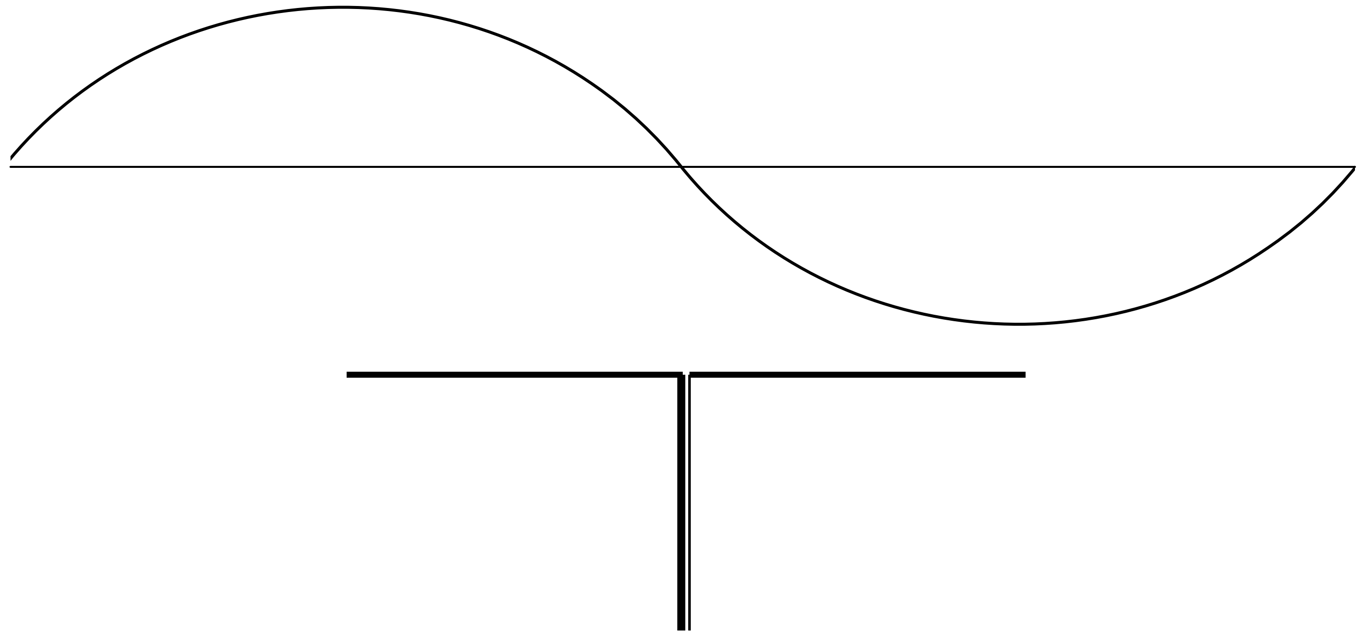
- Remote tuners are expensive, and difficult to hang onto dipoles
- Many multiband antennas have a different feedpoint impedance for each band in use

… as a result, many antenna systems include both a tuner and either a balun/unun or matching network



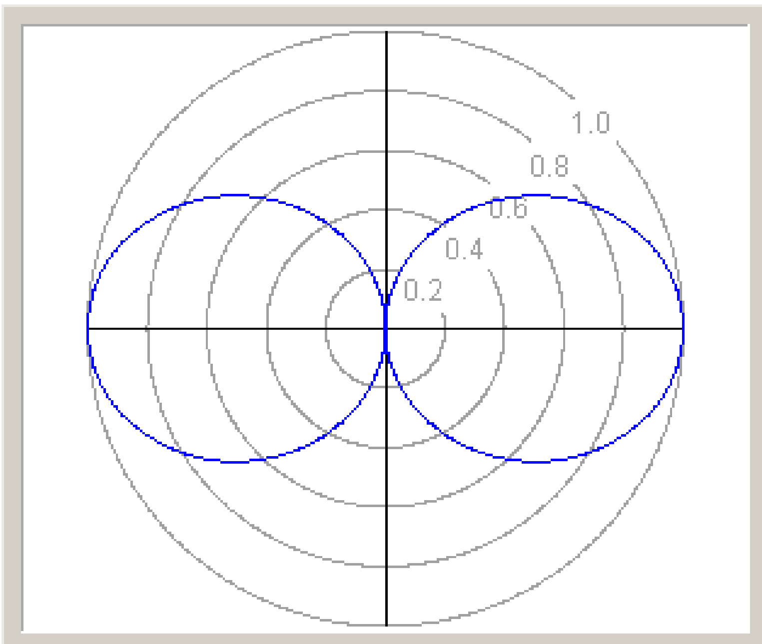
- Depending on the antenna, the tuner may be only for touch-up (okay for internal tuner) or may have to do some serious, wide-ranging matching

The basic ½ λ, monoband, resonant-length, center-fed dipole (two poles) is two ¼ λ components

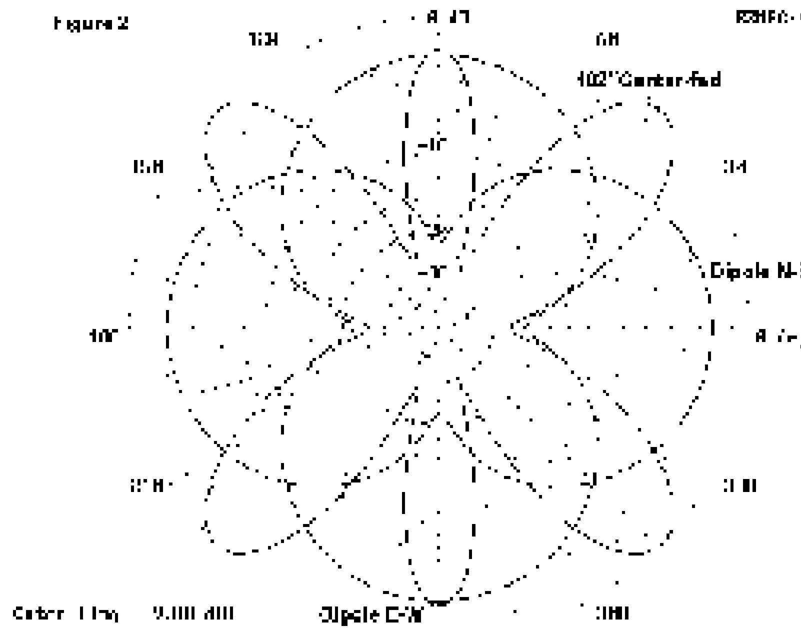


- Signal happens as a result of energy potentials between the two “poles”
  - Something to “push against”
- Impedance at feedpoint is about 50 ohms
- In theory, feedline should be ½ λ or integral multiple, but …
  - Usually can get a low enough SWR
  - A basic tuner will overcome most feedline length issues

Propagation for the ½ wavelength, resonant length, center-fed dipole

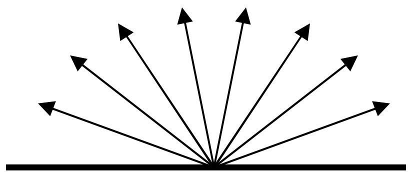


Propagation at least ½ λ above RF ground

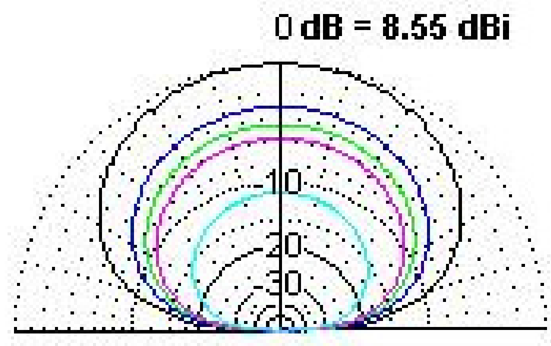


As the antenna gets lower than ½ λ above RF ground, it forms lobes and eventually becomes omnidirectional

Take-off angle is the angle above ground of maximum radiation



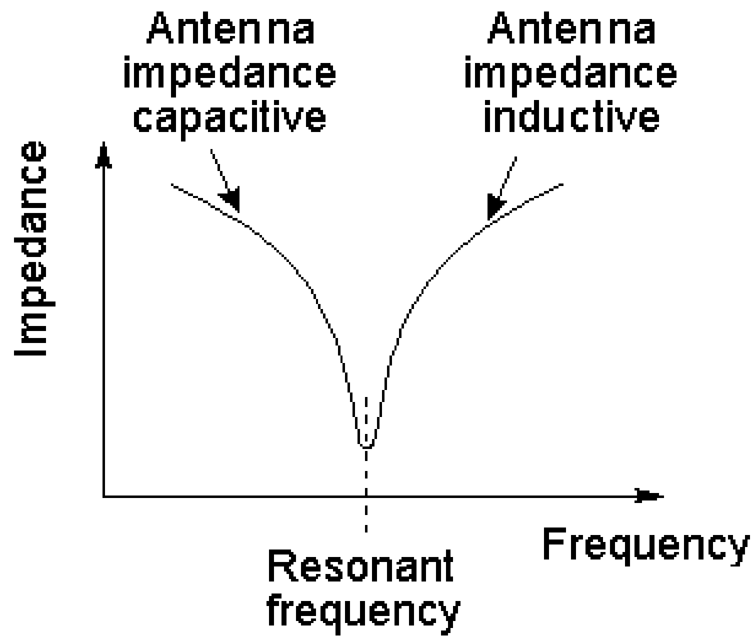
Take-off angle for dipole more than ½ λ above ground is "moderate"



As the dipole is brought lower than ½ λ above ground, the take-off angle increases until the antenna becomes NVIS

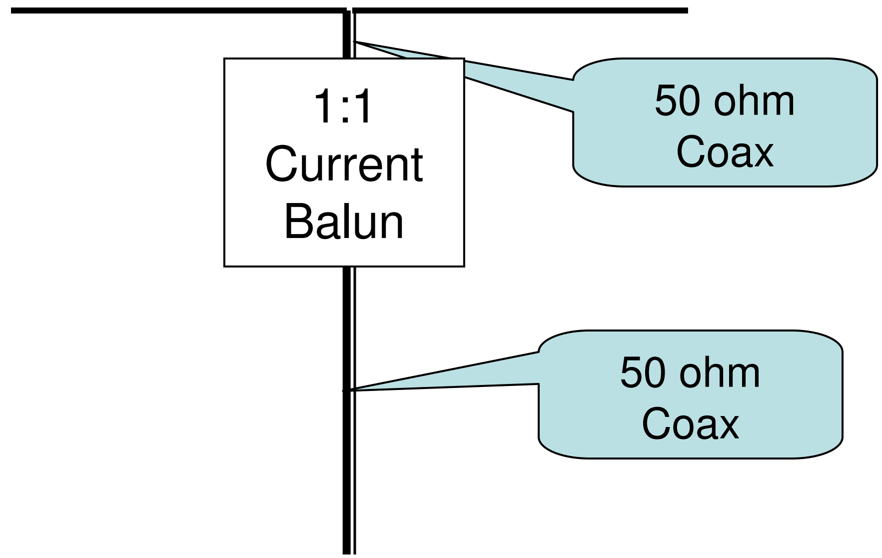
- The lower the take-off angle, the better for DX
- Is a lower take-off angle always better?
  - Hurricane Net on 14.3
  - Communication between Stamford and Hartford
  - NVIS (Near Vertical Incidence Skywave)
- NVIS not terribly effective at frequencies higher than 7MHz (40m)

Bandwidth typically limited on 160 and 80



- Bandwidth generally defined as range of frequencies with < 2:1 SWR
- Both bands are very wide as a percent of the mid-point
- 10 meters may also be a problem, depending on design

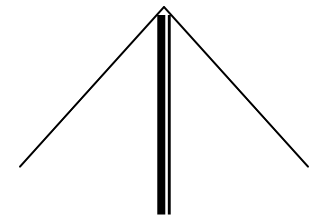
Since there are two poles, the voltages and currents are balanced on each leg



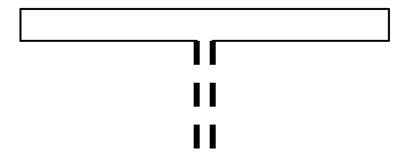
- Balanced antennas should be fed by balanced line
  - But balanced line isn't 50 ohm
- Because coax is not balanced, it is best to put a 1:1 current balun (technically an unun) between the feedline and the antenna
  - Note: best if closest to the antenna
  - Issue is current coming back down the feedline without the unun
    - Can use ferrite beads and/or coiled coax to prevent

Other “horizontal” 1/2 λ dipoles that are ¼ λ per side

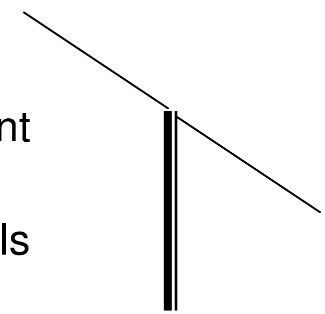
- Inverted V
  - Essentially the same as basic dipole, but saves lateral space
  - Slightly lower impedance
  - Slightly lower take-off angle



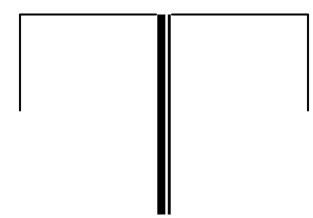
- Folded Dipole
  - Typically 300 ohms, needs 4:1 balun and tuner
  - Higher bandwidth than straight dipole
  - Good multibander



- Slopping Dipole
  - Nominally 75 ohms but can vary greatly depending on environment
  - Propagation favors direction of slope
  - NOT the AlphaDelta slopers, which are essentially sloping verticals (only half the dipole) and rely on tower or radial system for the other pole



- Inverted U
  - Keep middle 60% of antenna flat, allow ends to droop
  - Typically 30 ohms impedance
  - Very close to flat dipole



DANGER

High Voltage At Antenna Ends

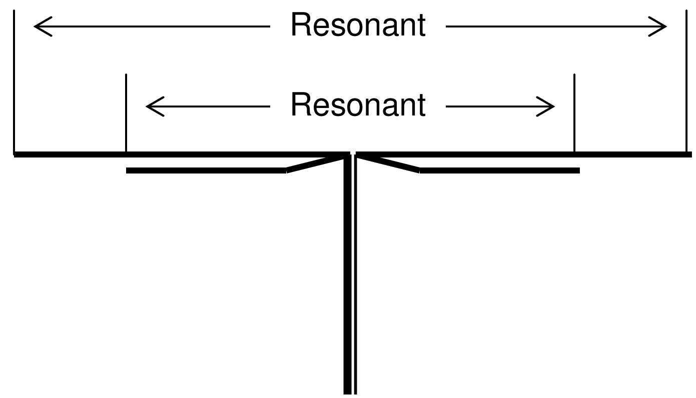
Dipoles cut for one band can be used on other bands

- 3.6MHz – odd harmonics, low feedpoint impedance, generally should not require tuner except for "touch-up"
  - x5 = 18.0MHz (17 meters)
  - x7 = 25.2MHz (close enough to 12 meters)
- 7.1MHz
  - x3 = 21.3MHz (15 meters)
  - x7 = 49.7 (just about 6 meters)

- 3.6MHz – even harmonics, high feedpoint impedance, requires tuner and/or matching network
  - x2 = 7.2MHz (40 meters)
  - x4 = 14.4MHz (near 20 meters)
  - x6 = 21.6MHz (near 15 meters)
  - X8 = 28.8MHz (10 meters)
- 7.1MHz
  - x2 = 14.2MHz (20 meters)
  - x4 = 28.4MHz (10 meters)

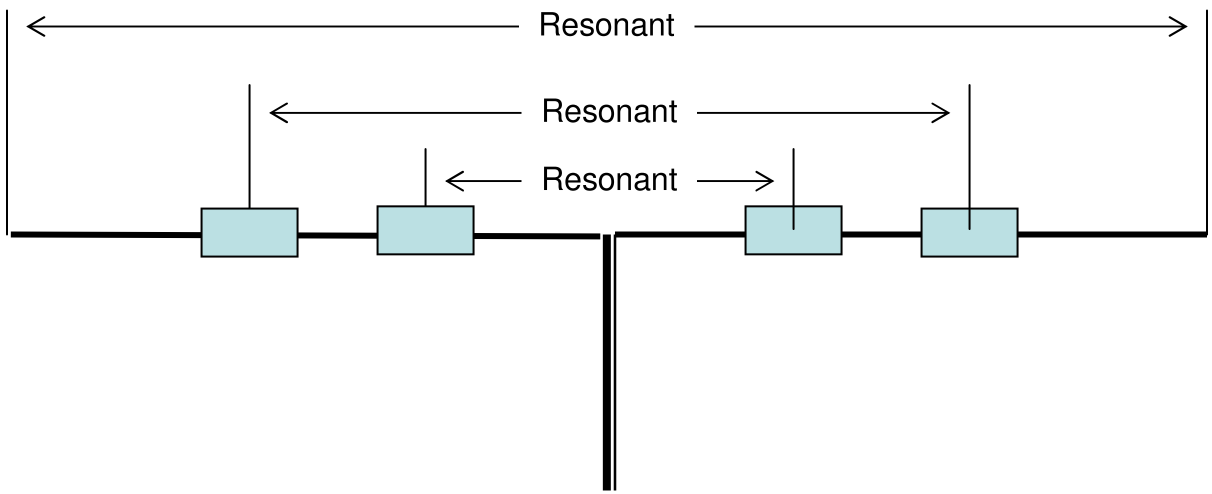
- General rule of thumb: For center-fed dipole, odd number harmonics (integral multiples) have low impedance at center point, even numbered harmonics have high impedance at center point
- External, wide-ranging tuner required for even harmonics
- With good tuner, can often go one band lower (e.g., use a ½ λ 80 meter dipole on 160)
- Note that harmonics of 3.9MHz are out of the the ham bands

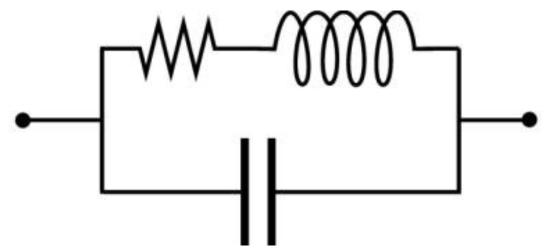
Parallel-connected multi-band dipoles simply use multiple antennas all tied to the same feedline



- The transmitter sees a resonant length at the operating frequency
  - Only the specific antenna for the band in use shows a low impedance. The others, being non-resonant, show a much higher impedance
    - Electricity always wants to flow via the lowest impedance
- Can be fed with 50 ohm coax
- Acts like a monoband dipole

Trap dipoles use circuits (traps) that electrically connect or disconnect outer sections of the antenna, depending on operating frequency

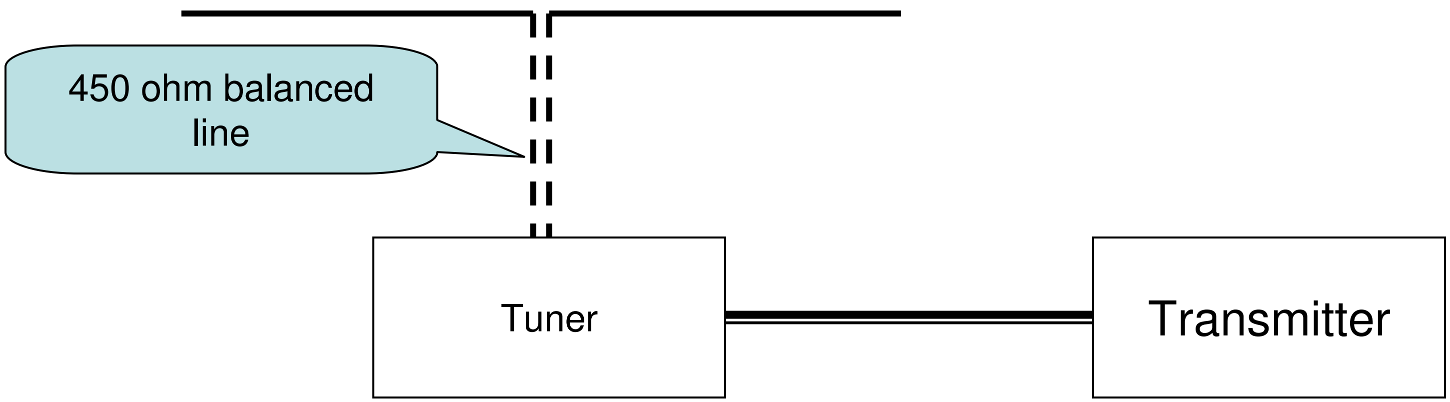




Typical Trap

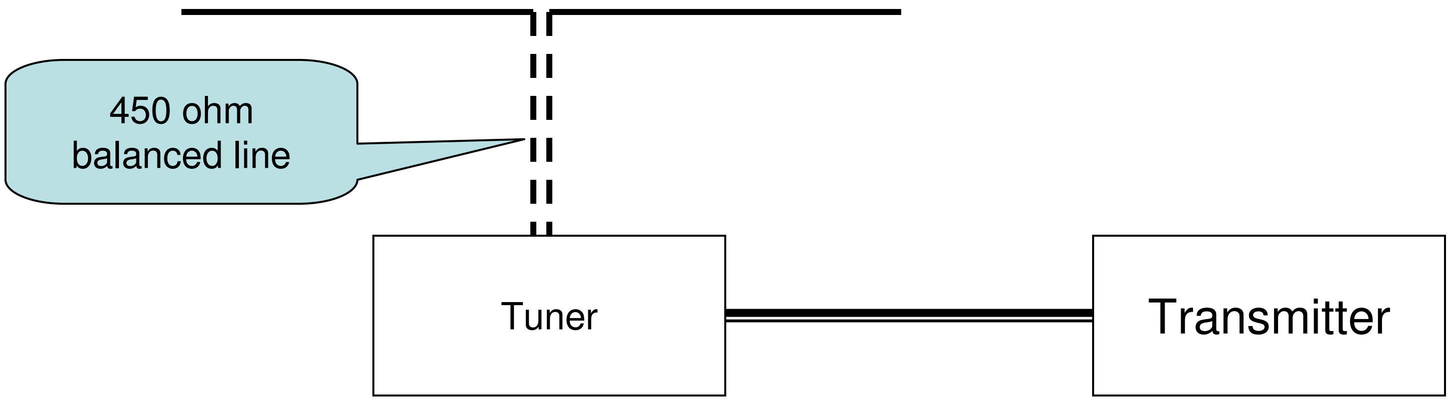
- The transmitter sees a resonant length at the operating frequency
  - The traps make the antenna look the correct length for the band in use
    - Often some losses because the traps are not perfect in limiting length
  - Traps are an inductor and capacitor in parallel that have very high impedance at the frequency being blocked
- Typically fed with 50 ohm coax
- Acts like a monoband dipole

The “center-fed” Zepp is a multiband antenna that is ½ λ on the lowest band



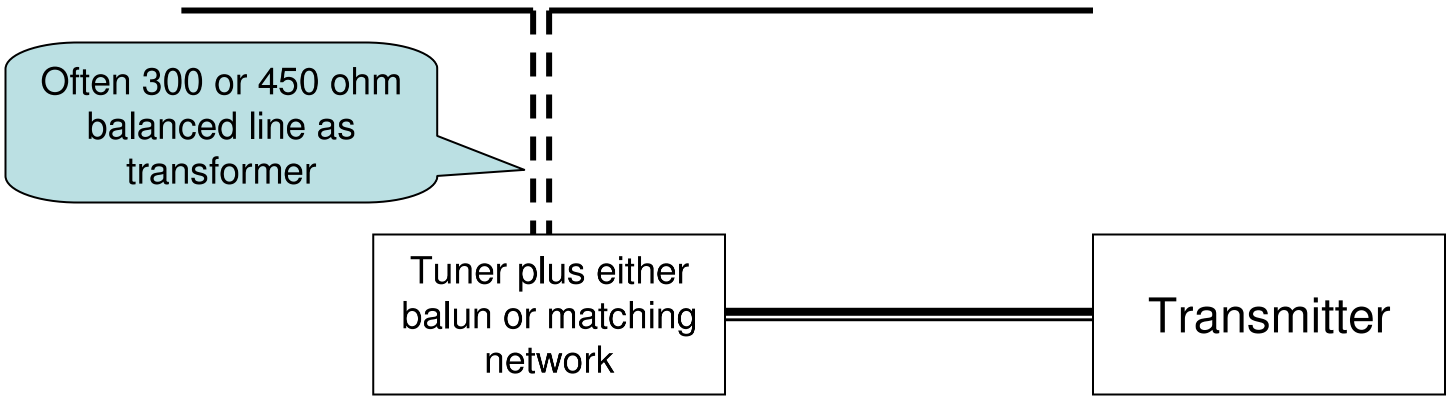
- Antenna at about ½ λ for lowest frequency in use (e.g., 127 -135 ft for 80 meters)
  - May be difficult to tune and may require very specific lengths of balanced line
  - May have current on the feedline, resulting in RF and RFI if the antenna is not a resonant length
  - Need to avoid ¼ wavelength length of feedline (or integral multiples)
  - Need an external, wide-ranging tuner
  - Balanced line serves as transformer, balun not desirable
- Fairly low take-off angle, complex propagation pattern with lobes and nulls

Many older sources also recommend a non-1/2 λ center-fed Zepp for multiband use



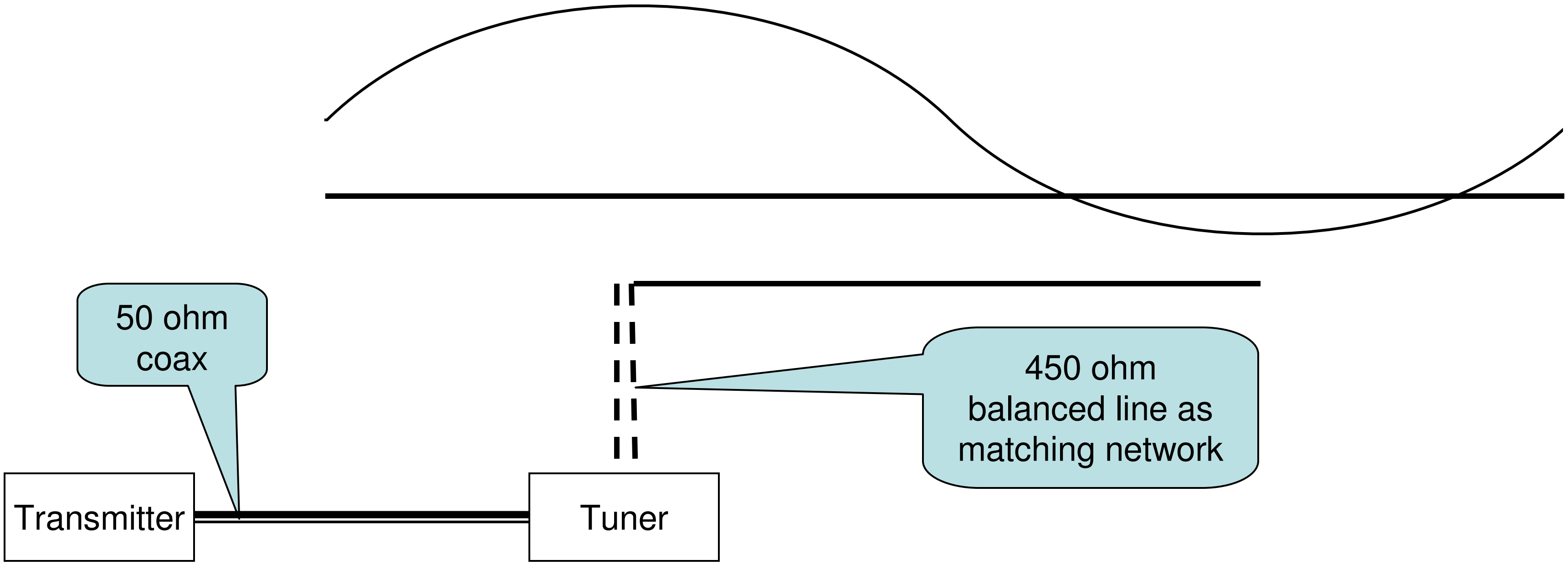
- Non-1/2 λ antenna + non-1/2 λ balanced line
  - Easiest to tune if antenna + balanced line = 110’, 133’, 177’, or 212’
  - Length of balanced line must be shorter than length of antenna
  - Length of antenna must be at least ¼ λ on lowest frequency in use
  - Effective but not as effective as dipole because antenna not a resonant length
  - Current on the feedline, RF and RFI issues – need good choke
  - Complex propagation pattern, good take-off angle
- The G5RV is a specific example of this type of antenna
  - 102’ antenna, 31’ 450 ohm balanced line, >70’ coax
  - Most antennas sold as G5RVs are not, in fact, G5RVs

Off-Center Fed (OCF) multi-band antennas are a variation of the center-fed Zepp, and generally use a ½ λ length



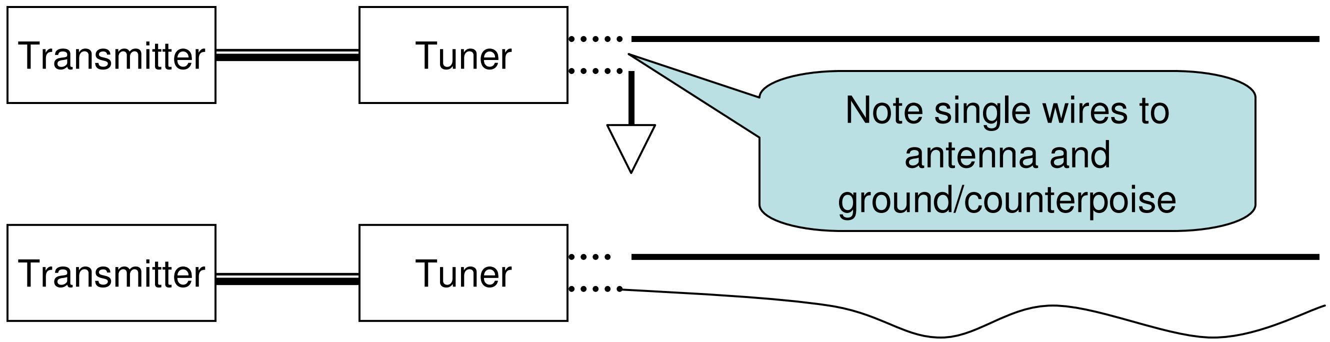
- In theory, the feed point has “about” the same impedance on each ham band covered
  - In reality, significant differences between different bands
  - Need a good tuner in addition to the balun/matching network/balanced line feedline
  - Length of balanced line often not as critical as with G5RV if used with balun or matching network
  - Propagation may be more dipole-like, take-off angles similar to standard dipole
- Can be more effective than G5RV (depending on design and quality)

The end-fed Zepp is ½ λ with balanced line as a matching network



- High impedance at end requires matching network using 450 ohm balanced line as a **transformer**
- Easy to install, inexpensive, but can be tricky to tune
- Can have serious issues with RFI and RF voltage in the balanced line if antenna not resonant
- Some multiband designs call for antenna that is not resonant length on any band

The end-fed random length long-wire is purposely a non-resonant length and feeds against either ground or counterpoise



- Best if at least ½ λ, generally longer
- Impedance is something "reasonable" (e.g., 450 ohms) that can be matched with a good tuner or matching network
  - Tables of useful "random lengths" available on internet
- Can be very effective
- Tends to be a bit directional in direction of the wire
- Note that the tuner/balun/matching network should be near the ground connection/counterpoise
  - If counterpoise should be ¼ λ on frequency in use