Wire Antennas For Limited Space

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Our Objectives

- Good Antennas
  - Good efficiency
  - Good predictable patterns
  - Minimal noise pickup and RFI
- Inexpensive to build
  - Wire
  - Insulators
  - Basic mechanical parts
  - Coax to feed them
  - Coax choke at feedpoint (for noise immunity)

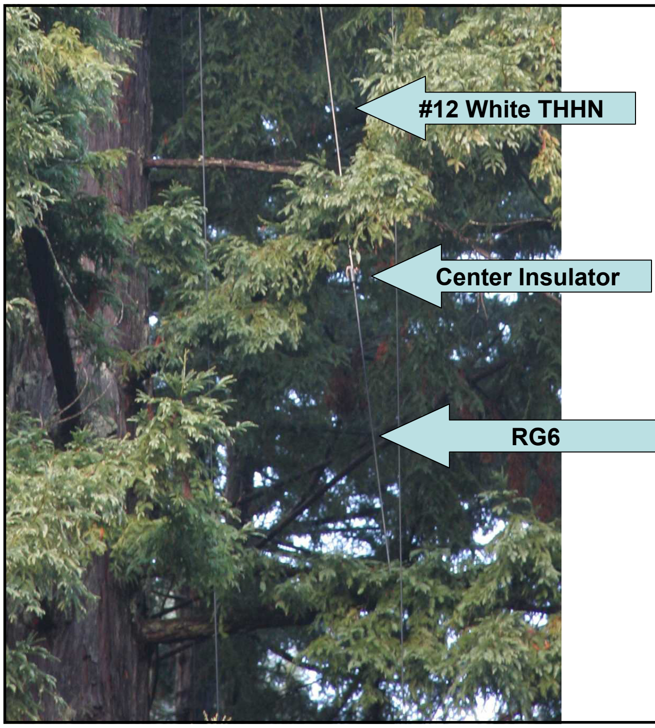
Some Possibilities

- Half-wave dipoles
  - Loading coils to make them shorter
  - Traps provide loading, fit multiple bands in same space
  - Fan dipoles fit multiple bands in same space
  - Sloping dipoles (some of the length is vertical)
  - Inverted Vee (some of the length vertical)
- Top-loaded verticals
  - Inverted L
  - Inverted Tee
- End-fed wires

How About A Vertical?

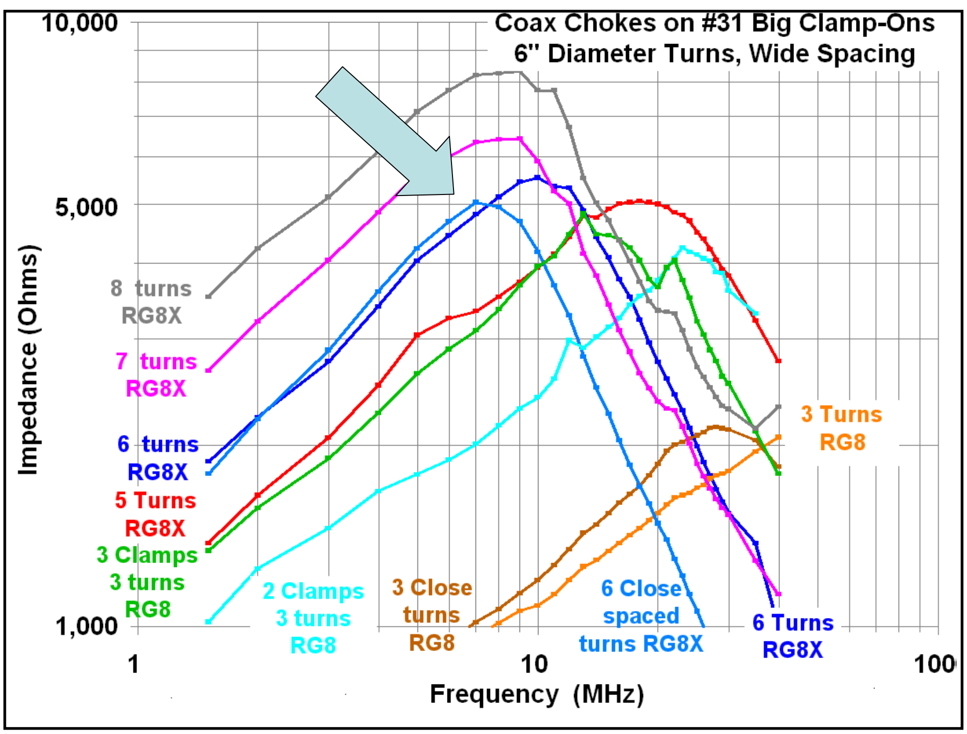
- A "good" vertical can beat a low dipole
- Low means less than about 0.3λ
  - 40 ft on 40M
  - 80 ft on 80M
  - 160 ft on 160M
- "Good" means efficient
  - Good radial system
  - Low losses (full size or top loading)
  - In the clear
  - Most commercial verticals are increasingly lossy below 30M

A Very Efficient 40M Vertical Dipole



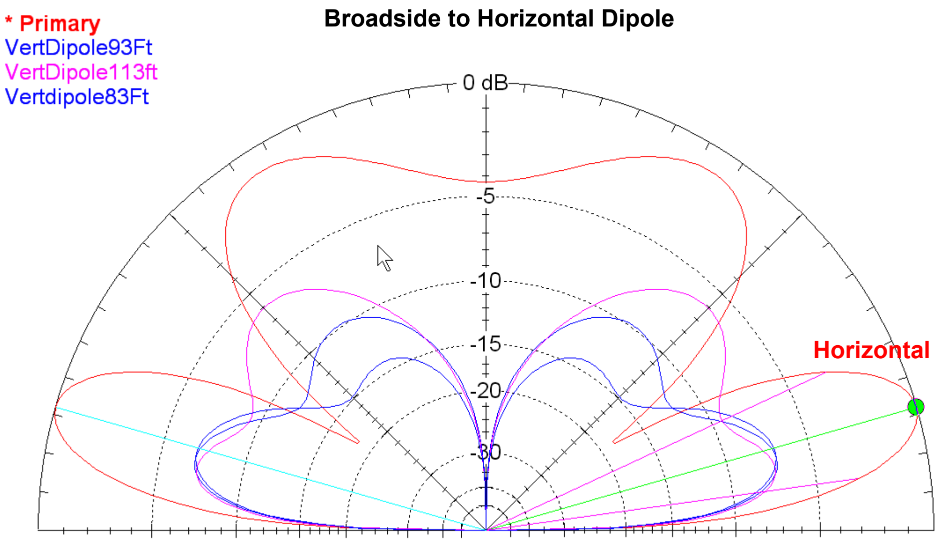
End Insulator for a 40M Dipole

- 6 turns of RG6 around a "big clamp-on" is enough for 500 watts of serious contesting
  - About 5,000Ω resistive impedance
- Two of these 6-turn chokes are needed for 1.5kW
  - About 10,000Ω resistive impedance



Coax Chokes on #31 Big Clamp-Ons
6" Diameter Turns, Wide Spacing
10,000
5,000
1,000
Impedance (Ohms)
1
10
100
Frequency (MHz)
8 turns RG8X
7 turns RG8X
6 turns RG8X
5 Turns RG8X
3 Clamps 3 turns RG8
2 Clamps 3 turns RG8
3 Close turns RG8
6 Close spaced turns RG8X
6 Turns RG8X
3 Turns RG8

Before you fall in love with a vertical dipole, compare it to a horizontal dipole!



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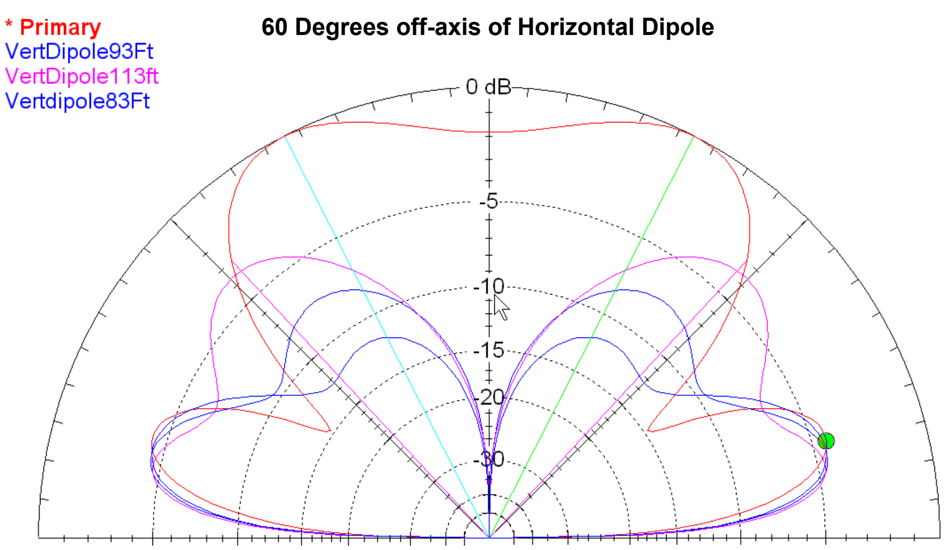
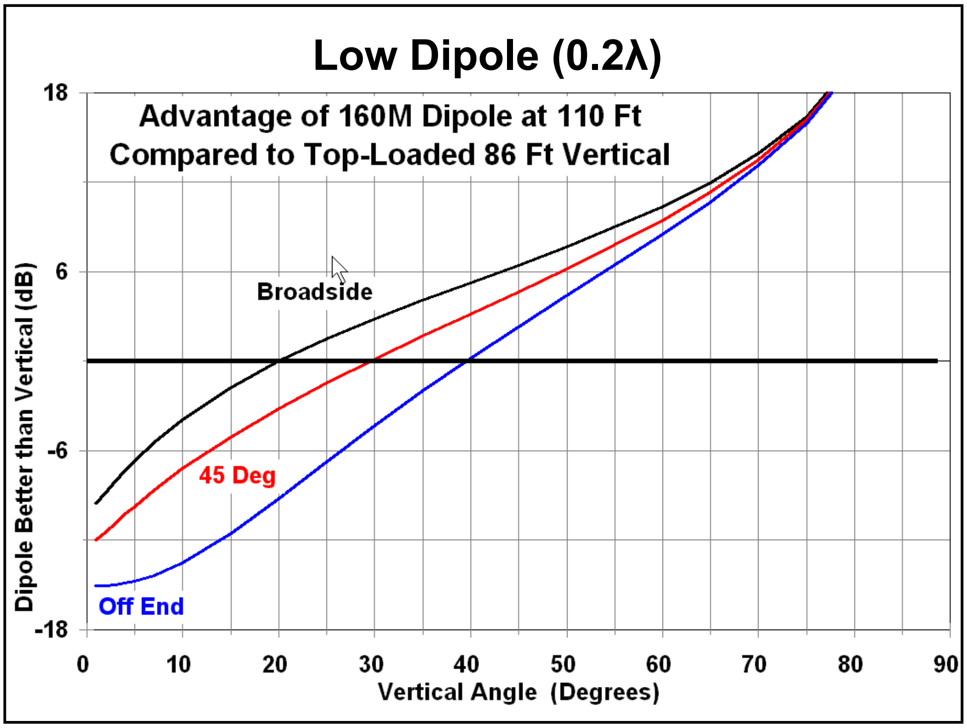


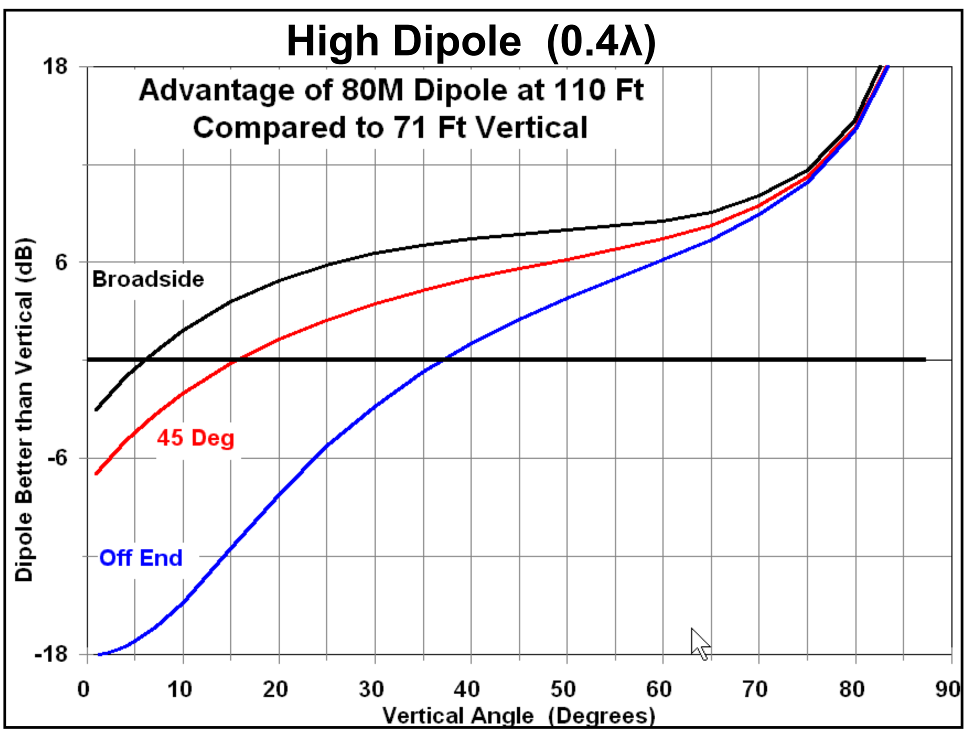
When to Use A Vertical

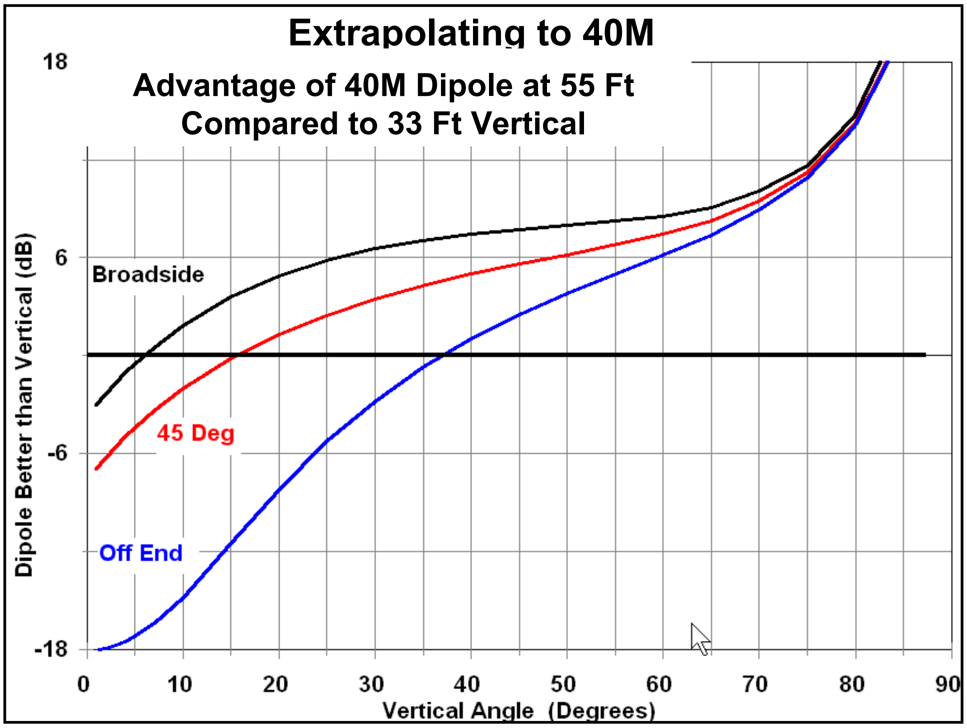
- Larger commercial verticals on 40M–10M
  - Install high, with good radial system
- Efficient wires on 160-80M
  - Low or on ground, with good radial system
  - Top loaded or full quarter wave
- A few verticals don't need radials
  - Cushcraft R7000 is center-fed, W1JR design
- To fill in nulls off ends of a high dipole

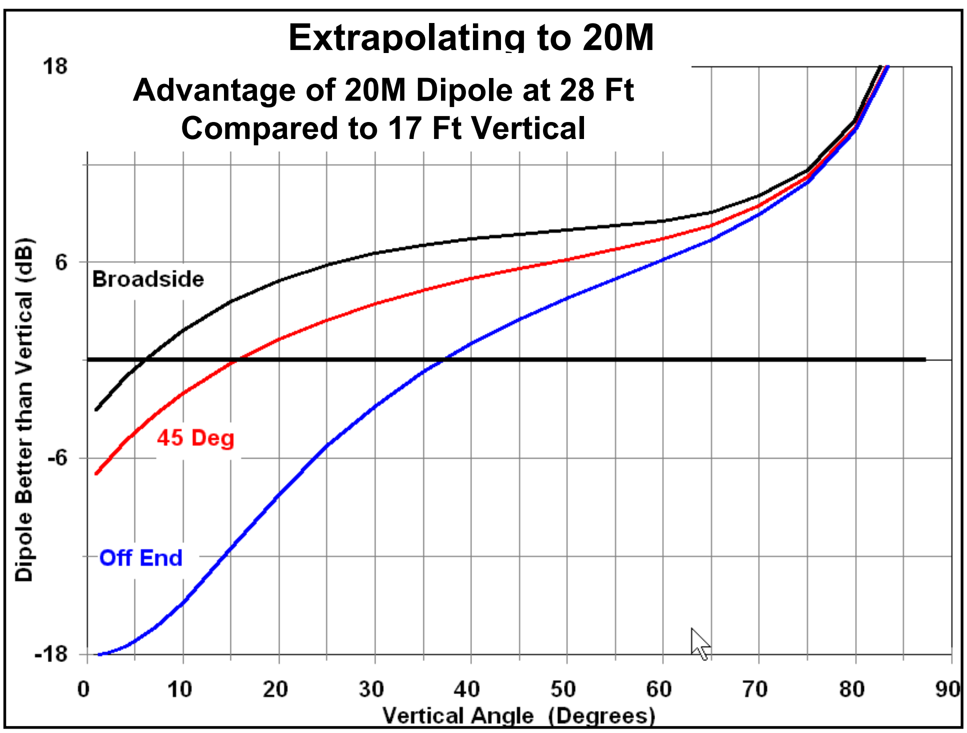
When <u>Not</u> to Bother With A Vertical

- 40M–10M when you can't mount it high and in the clear (high ground losses)
  - High means at least $\lambda/8$
- When it's physically shorter than $3\lambda/16$
- When you can't install at least three $\lambda/4$ radials for each band you want to operate
- When you can install high dipoles at right angles
  - A high dipole will beat it, even loaded or bent


Low Dipole (0.2λ)
Advantage of 160M Dipole at 110 Ft
Compared to Top-Loaded 86 Ft Vertical
Broadside
45 Deg
Off End
Dipole Better than Vertical (dB)
Vertical Angle (Degrees)
18
6
-6
-18
0
10
20
30
40
50
60
70
80
90


High Dipole (0.4λ)
Advantage of 80M Dipole at 110 Ft
Compared to 71 Ft Vertical
Broadside
45 Deg
Off End
Dipole Better than Vertical (dB)
Vertical Angle (Degrees)
18
6
-6
-18
0
10
20
30
40
50
60
70
80
90

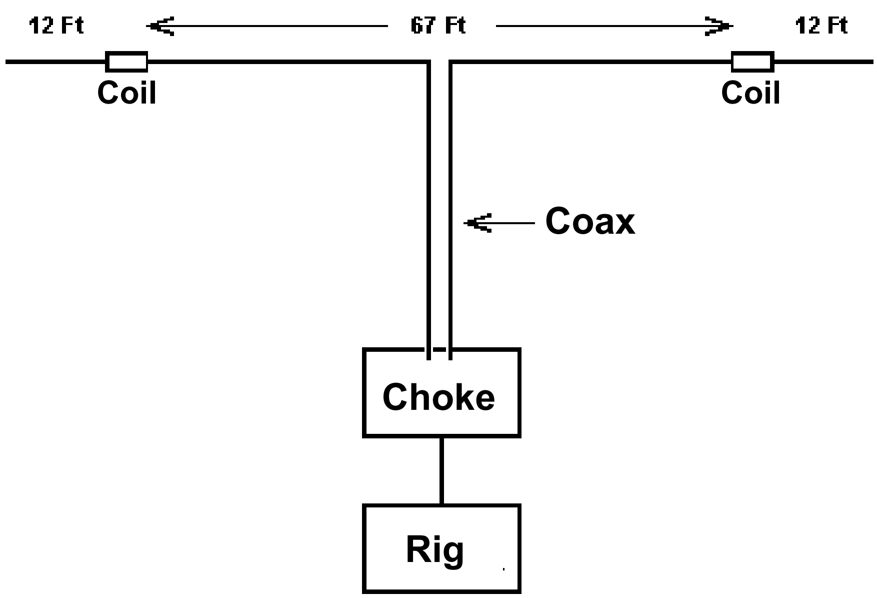

Extrapolating to 40M
Advantage of 40M Dipole at 55 Ft
Compared to 33 Ft Vertical
18
6
-6
-18
Dipole Better than Vertical (dB)
Broadside
45 Deg
Off End
0
10
20
30
40
50
60
70
80
90
Vertical Angle (Degrees)


Extrapolating to 20M
Advantage of 20M Dipole at 28 Ft
Compared to 17 Ft Vertical
18
6
-6
-18
Dipole Better than Vertical (dB)
Broadside
45 Deg
Off End
0
10
20
30
40
50
60
70
80
90
Vertical Angle (Degrees)

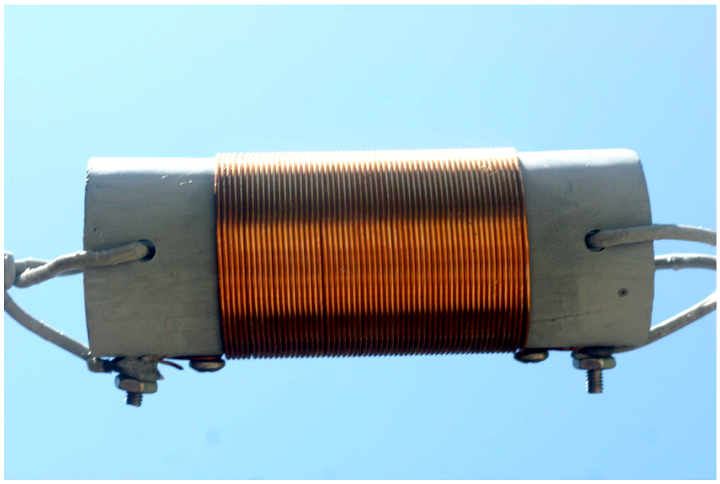
Try To Fit A Resonant Dipole First

- Well behaved pattern
- Inherently has gain in horizontal plane
- Vertical pattern depends on height
- For most QTHs
  - Higher is better on 40, 80, 160
  - Height not as important on 20-10
- Directivity tends to reduce noise
- Easy to feed with coax
  - Chokes can minimize receive noise, RFI

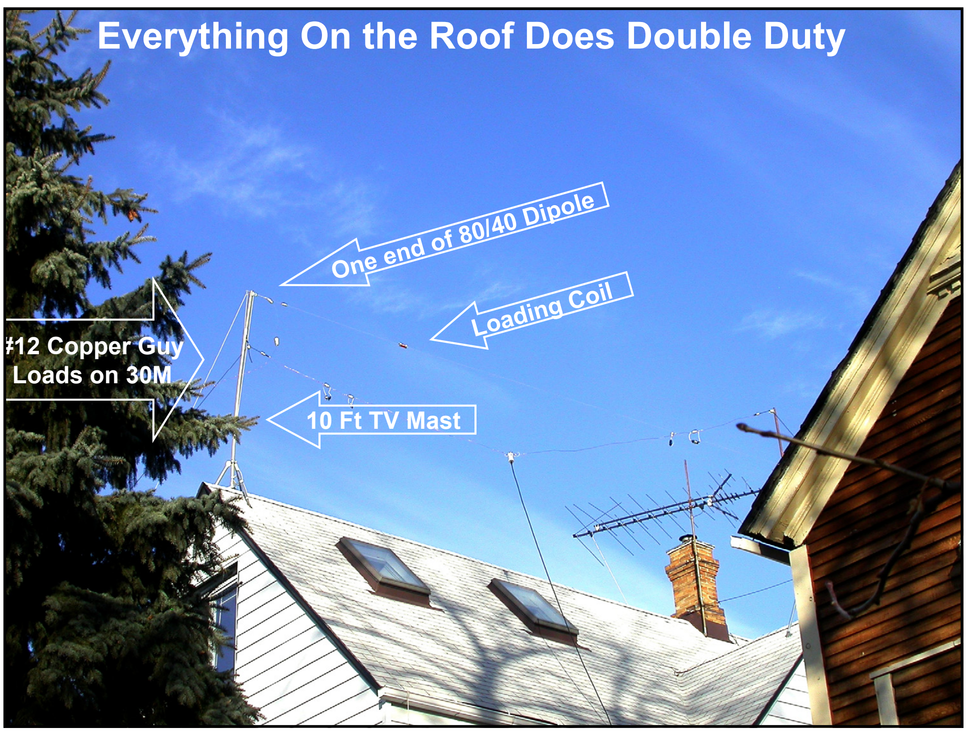
80/40 Shortened (Loaded) Dipole

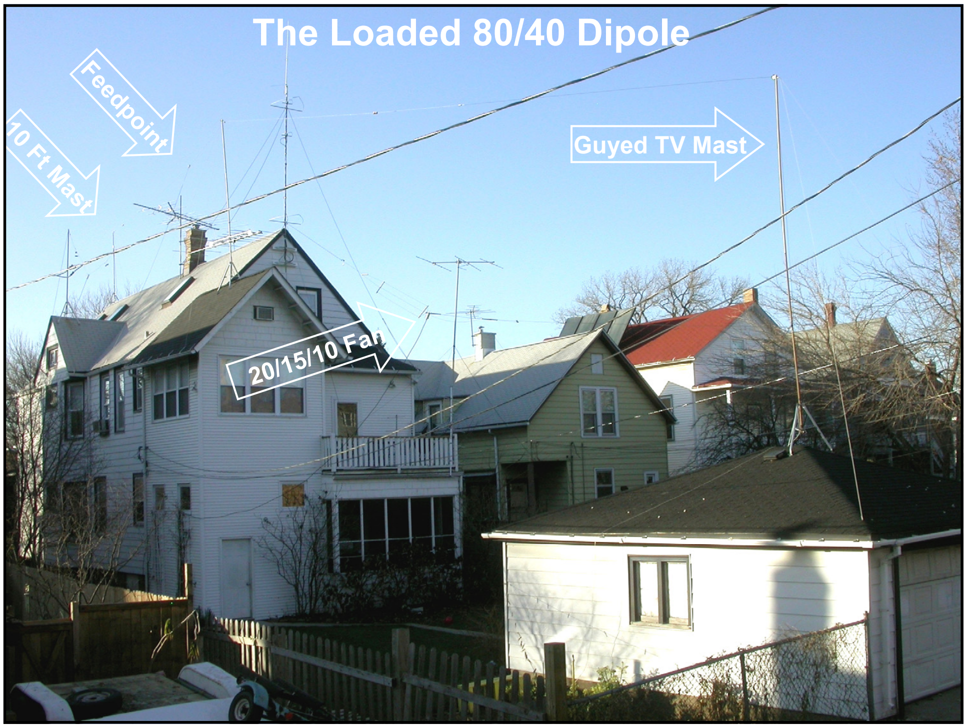


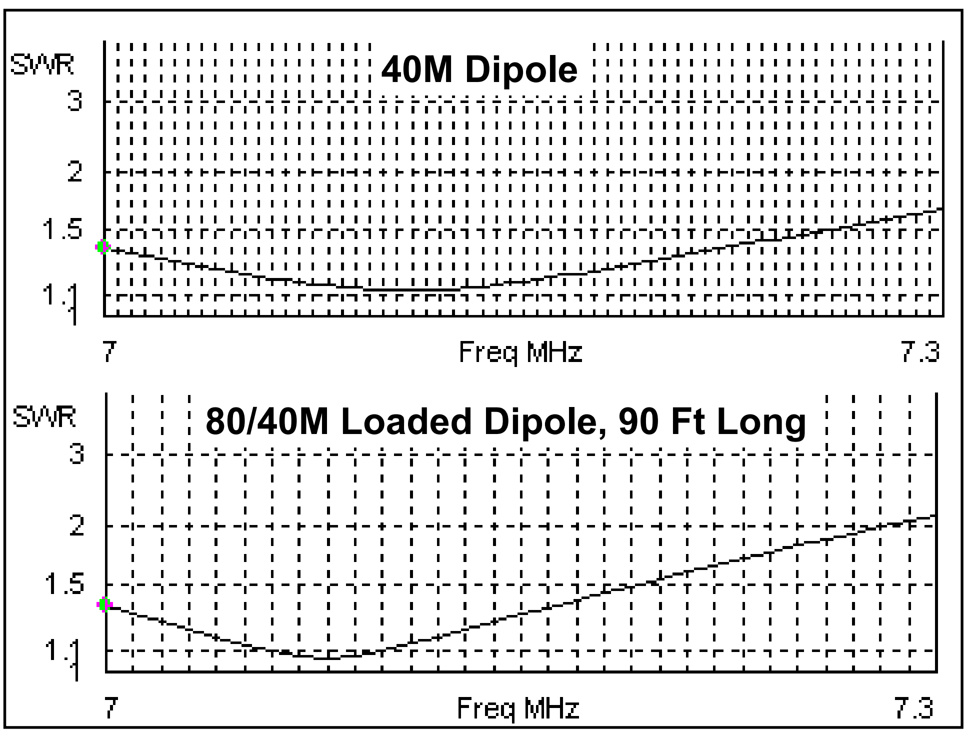
Loading Coil for short 80/40M Dipole

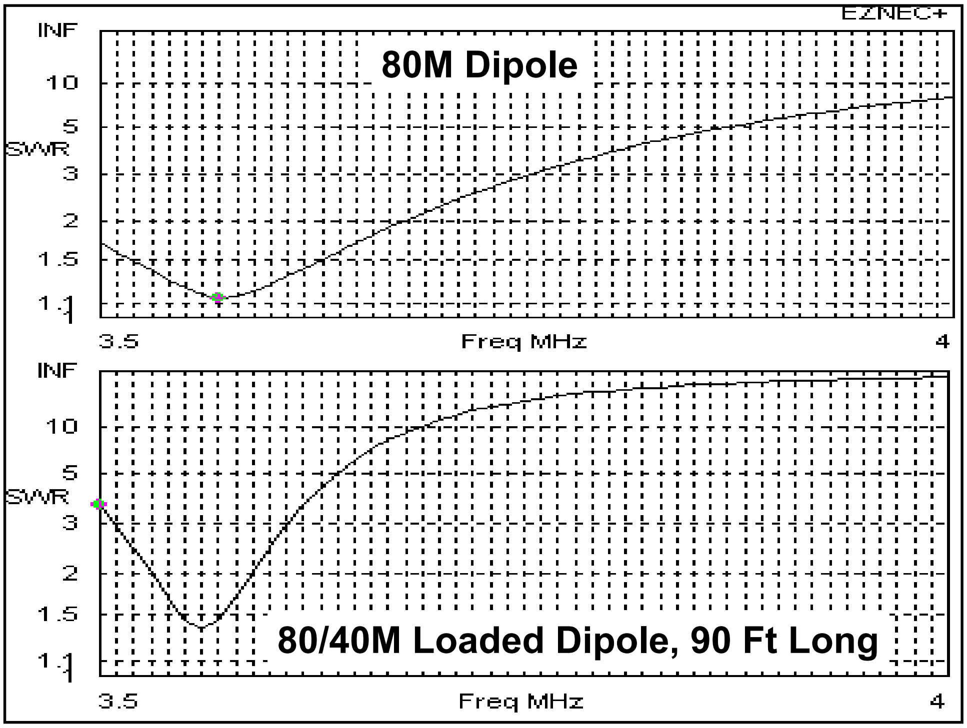


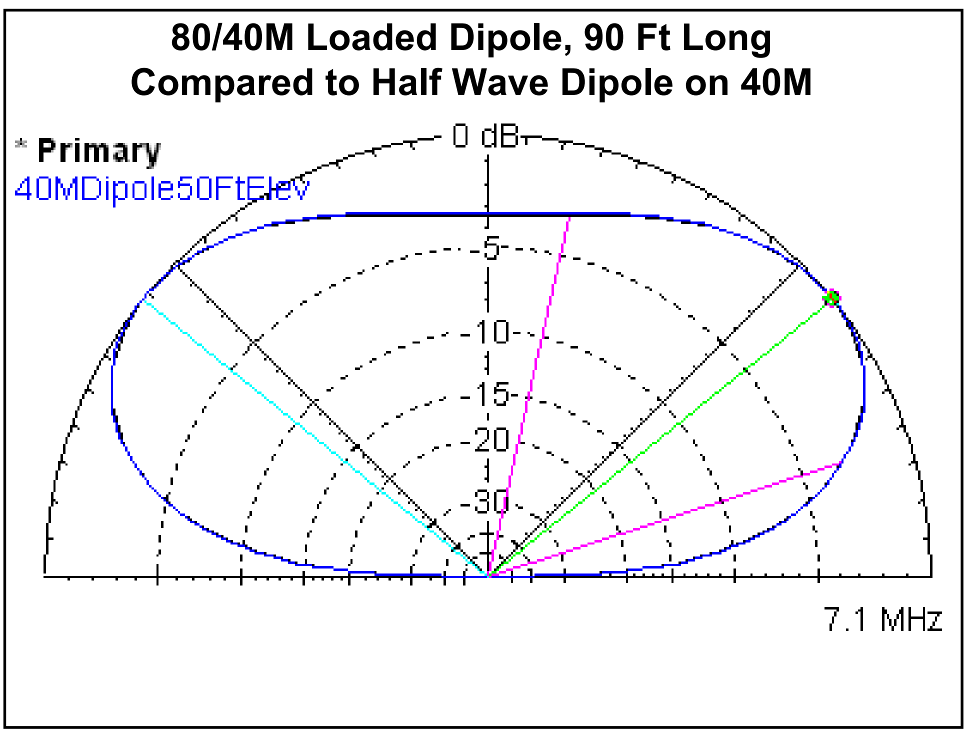
Everything On the Roof Does Double Duty



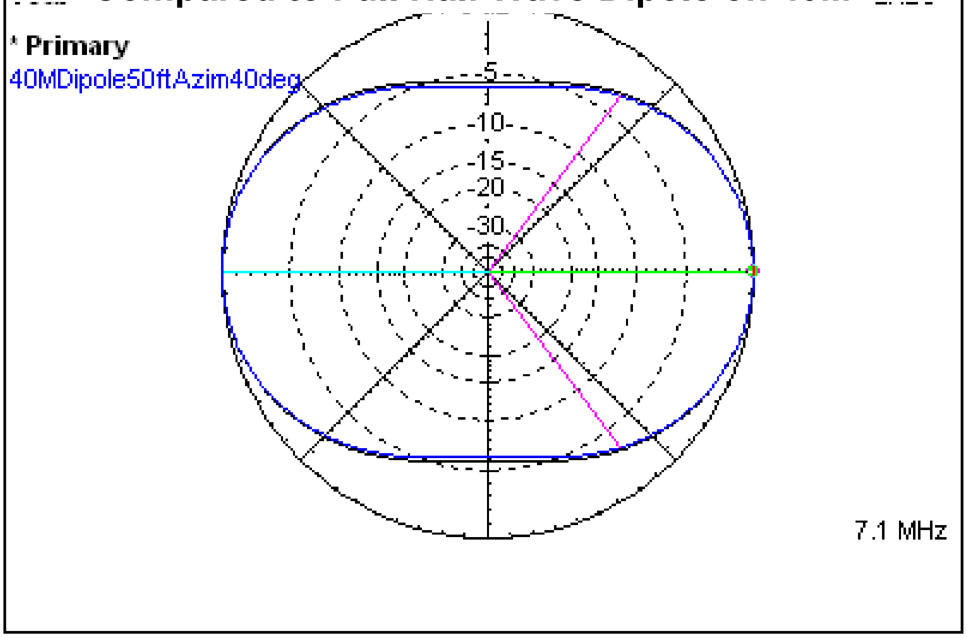

The Loaded 80/40 Dipole
Feedpoint
10 Ft Mast
Guyed TV Mast
20/15/10 Fa


40M Dipole
SWR
3
2
1.5
1.1
1
7
Freq MHz
7.3
80/40M Loaded Dipole, 90 Ft Long
SWR
3
2
1.5
1.1
1
7
Freq MHz
7.3

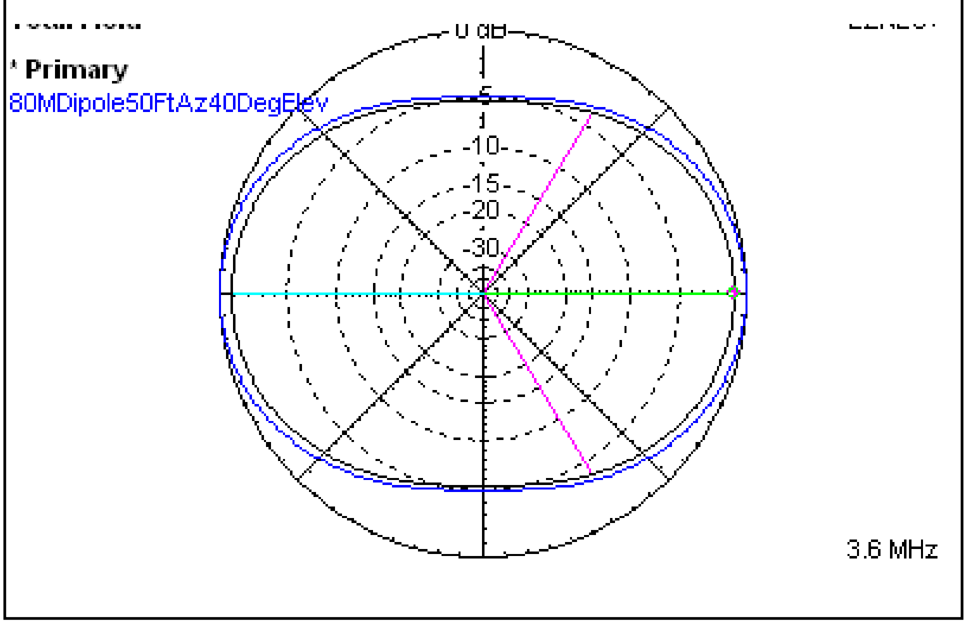

EZNEC+
80M Dipole
INF
10
5
SWR
3
2
1.5
1.1
3.5
Freq MHz
4
INF
10
5
SWR
3
2
1.5
1.1
80/40M Loaded Dipole, 90 Ft Long
3.5
Freq MHz
4


80/40M Loaded Dipole, 90 Ft Long
Compared to Half Wave Dipole on 40M
* Primary
40MDipole50FtElev
0 dB
-5
-10
-15
-20
-30
7.1 MHz

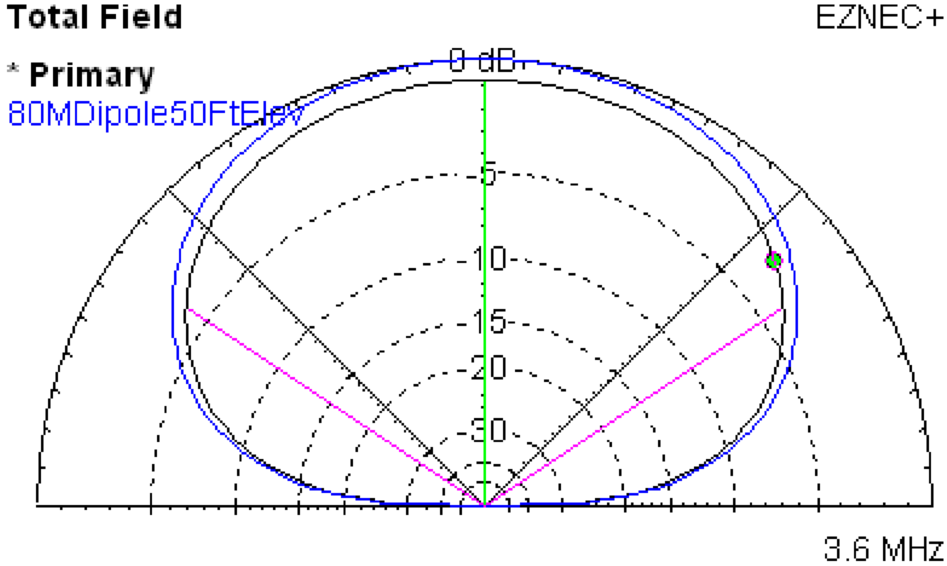
80/40M Loaded Dipole, 90 Ft Long
Compared to Full Half Wave Dipole on 40M



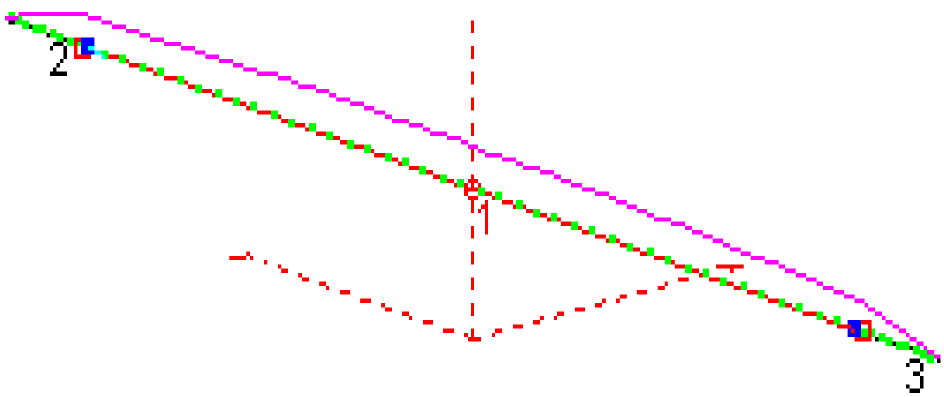
80/40M Loaded Dipole, 90 Ft Long
Compared to Full Half Wave Dipole on 80M



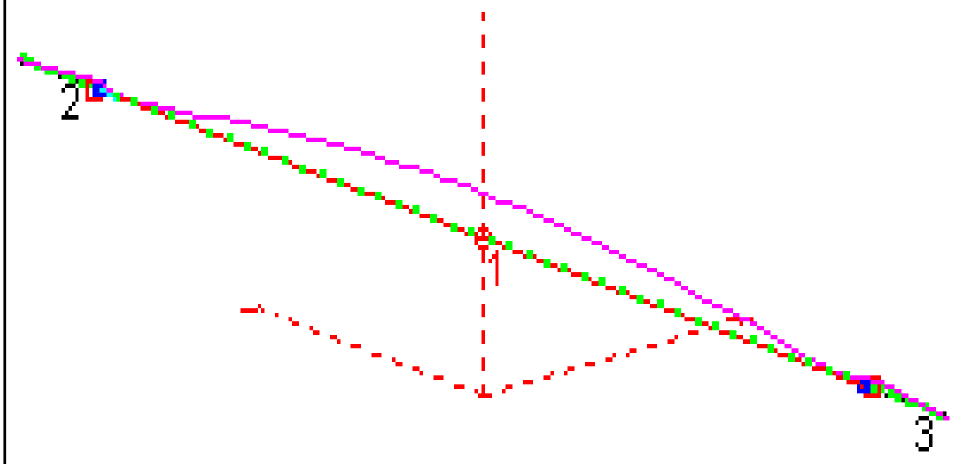
80/40M Loaded Dipole, 90 Ft Long Compared to Full Half Wave Dipole on 80M



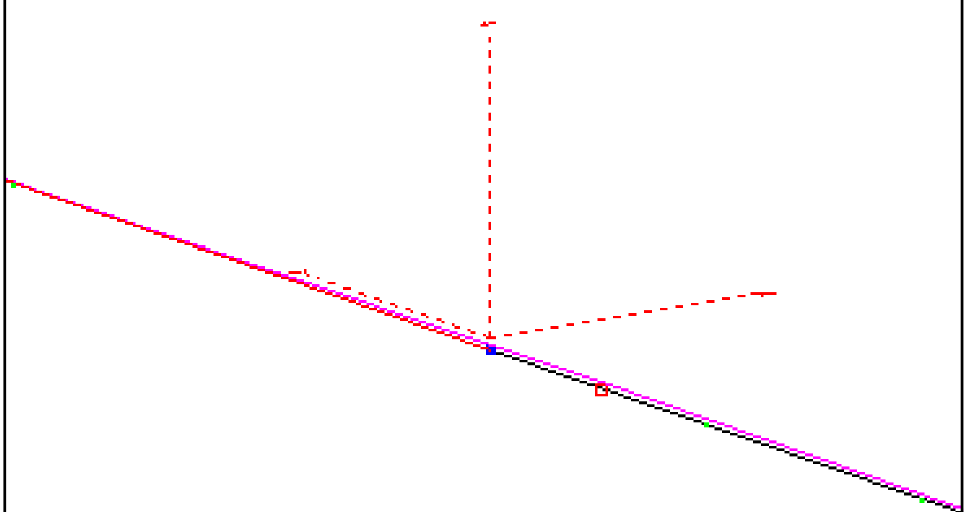
80/40M Loaded Dipole, 90 Ft Long Current Distribution on 80M



80/40M Loaded Dipole, 90 Ft Long Current Distribution on 40M



80/40M Loaded Dipole, 90 Ft Long Current Distribution on 40M

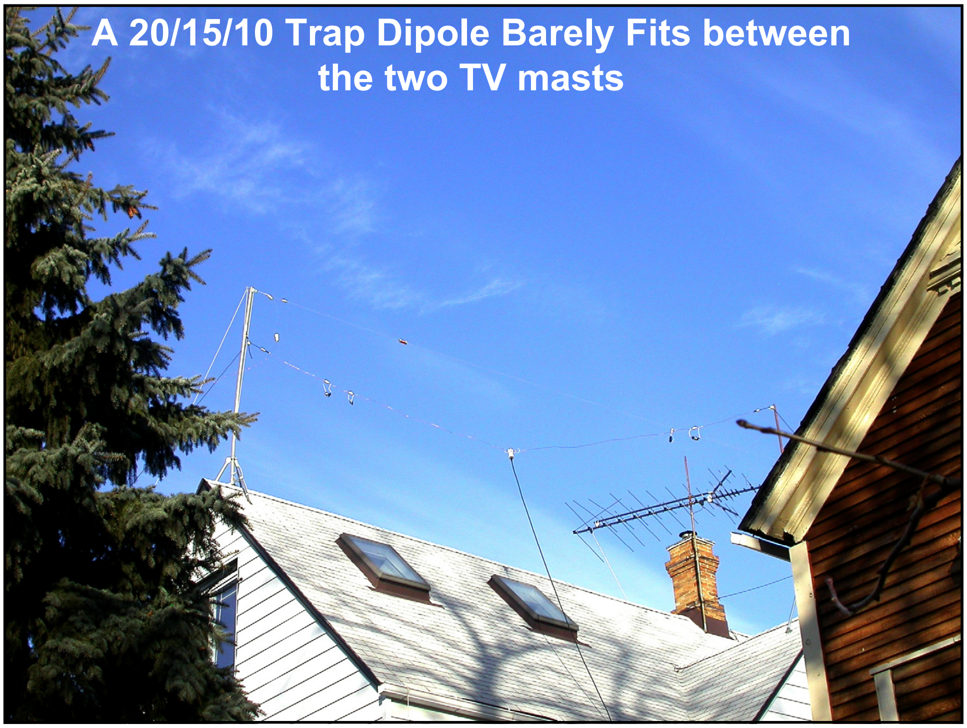


80/40M Loaded Dipole, 90 Ft Long Compared to Full Size Half Wave Dipole

- 40 Meters
  - No significant difference in gain or pattern
  - Slightly less SWR bandwidth
- 80 Meters
  - No significant difference in pattern
  - Gain about 0.8 dB lower
  - Much less SWR bandwidth
  - Greater feedline loss away from resonance

Build or Buy a Short Dipole?

- *Designing a Shortened Antenna* CT1EOJ QST Oct 2003
- Model it in NEC
  - Tweak the design for multiband coverage
- Buy from Barry, KU3X, Hypower Antenna Company (QST, Internet) 2B8040L
  - He's already done the design work



Trap Dipoles

- Traps are parallel resonant circuits
  - Below resonance, they look inductive
  - So they act as loading coils on lower bands
- A 3-band trap dipole fits in less space than a fan dipole
  - 20/15/10 is about 26-27 ft (20M dipole = 33 ft)
- Traps add some loss
  - Typically 1-2 dB
  - A lossy antenna is better than no antenna
- Traps reduce the SWR bandwidth
  - Trim lengths carefully and use a tuner!

Fitting Full-Size Dipoles Into Less Space

- Length of wire resonates the antenna
  - Very little current near the ends of a wire
  - Bending simply distorts the pattern a bit (mostly fills in nulls)
- Bend it at one or both ends
  - Has least effect on pattern or efficiency
- Bend it anywhere along its length
  - A bit more effect on pattern (fills nulls)

Fitting Full-Size Dipoles Into Less Space

- Use insulated wire
  - about 2% less wire than bare copper
- Use two or more wires in parallel ??
  - Less than 1% shorter
  - 50% better SWR bandwidth
  - Nice, but not worth the trouble
- Use bigger wire
  - #10 only 0.5% shorter than #14
  - Stronger, but shortening doesn't matter
  - Doesn't change SWR bandwidth

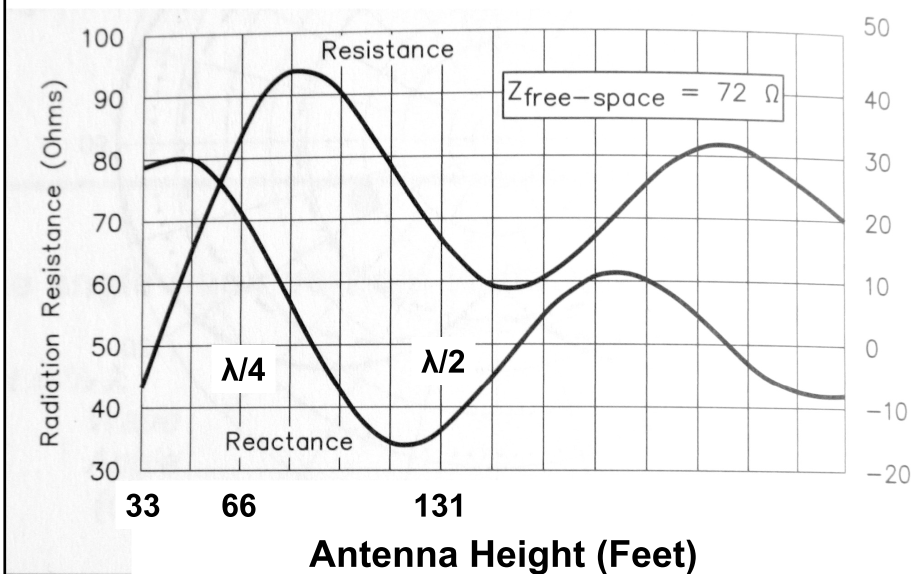
Fitting Full-Size Dipoles Into Less Space

- **Hang from one end, let it slope**
  - Keep center as high as practical
  - Skews pattern
- **Hang as inverted-V**
  - Raises angle of radiation
  - Fills in nulls off the ends
  - Efficiency still good
    - Center is high, that's where the current is!
- **As end(s) get closer to the earth (or trees), a shorter wire will resonate**
  - capacitance to earth

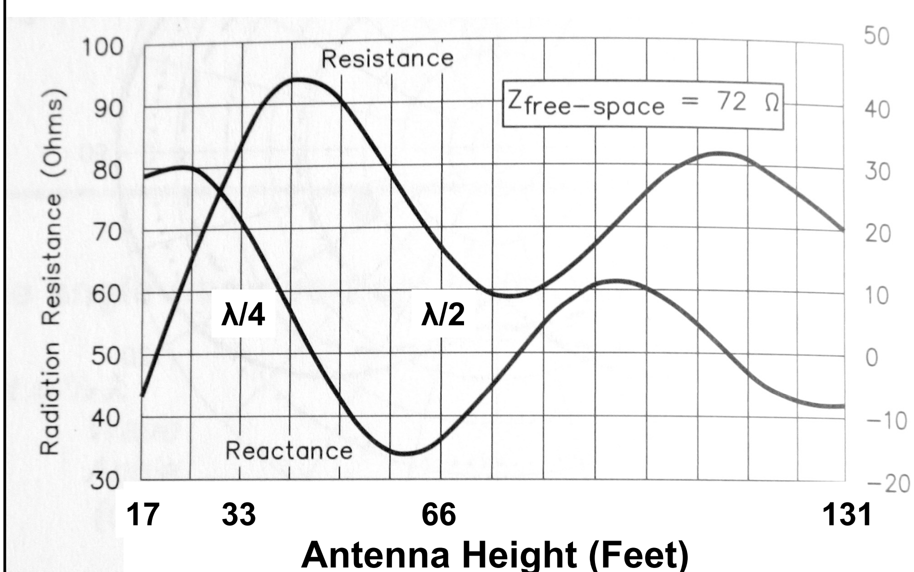
50 Ohm Coax or 75 Ohm Coax?

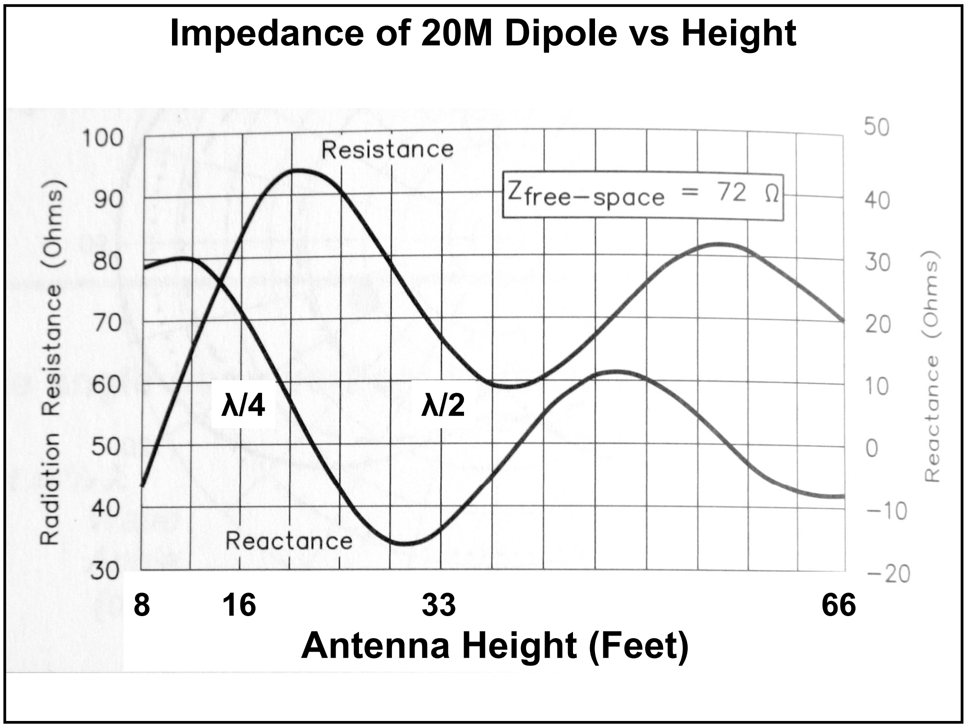
- **A Dipole in free space is a 72 ohm antenna!**
  - Proximity to earth changes the impedance
  - High dipoles are closer to 75 ohms
  - Low dipoles are closer to 50 ohms
- **Feedline SWR (and loss) depends on the match between feedline and antenna**
  - Use feedline that matches the <u>antenna</u>
- **XMTR will reduce power if mismatched**
  - Use an antenna tuner to make the rig happy

Impedance of 80M Dipole vs Height

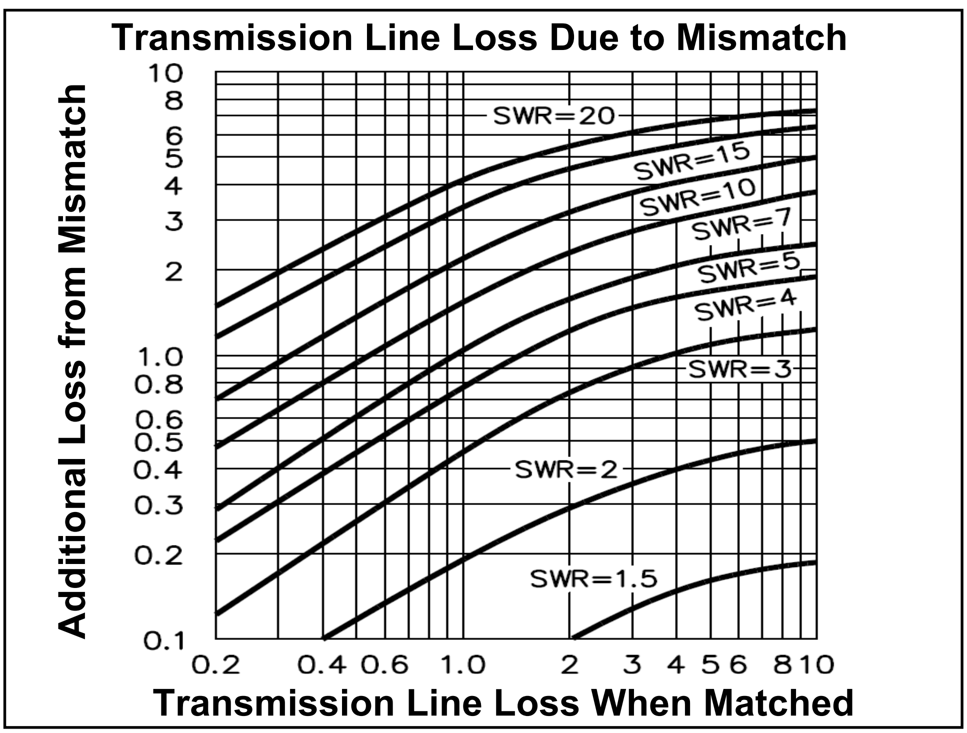


Impedance of 40M Dipole vs Height

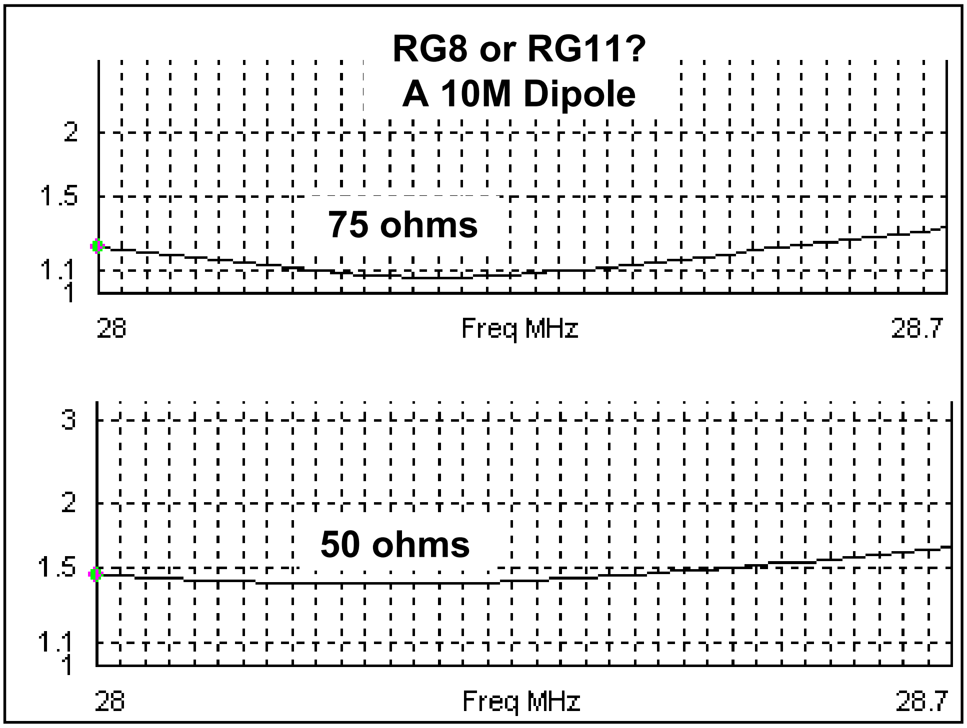


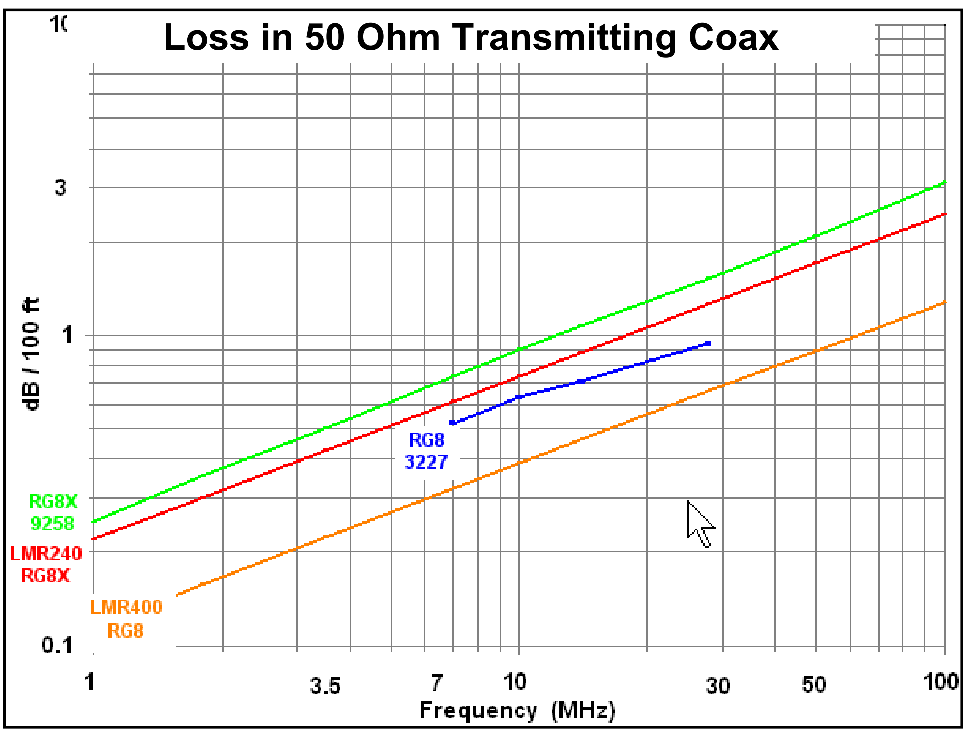


Impedance of 20M Dipole vs Height
Resistance
Reactance
Zfree−space = 72 Ω
λ/4
λ/2
Radiation Resistance (Ohms)
Reactance (Ohms)
100
90
80
70
60
50
40
30
50
40
30
20
10
0
−10
−20
8
16
33
66
Antenna Height (Feet)

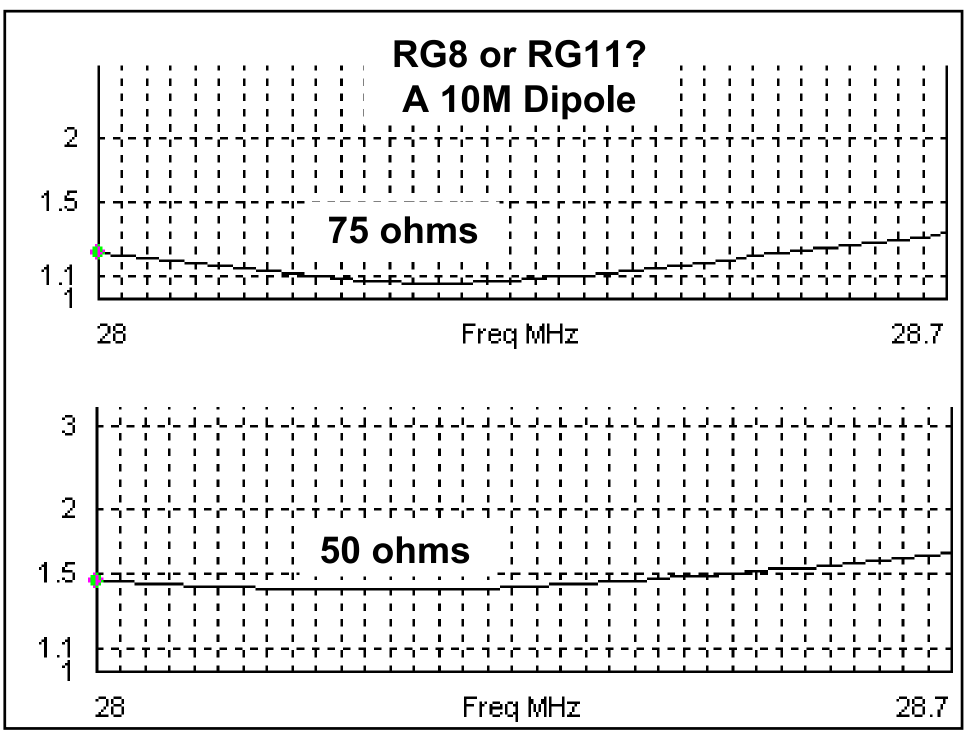


Transmission Line Loss Due to Mismatch
Additional Loss from Mismatch
SWR=20
SWR=15
SWR=10
SWR=7
SWR=5
SWR=4
SWR=3
SWR=2
SWR=1.5
10
8
6
5
4
3
2
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0.2
0.4 0.6
1.0
2
3
4 5 6
8 10
Transmission Line Loss When Matched


RG8 or RG11?
A 10M Dipole
75 ohms
2
1.5
1.1
1
28
Freq MHz
28.7
50 ohms
3
2
1.5
1.1
1
28
Freq MHz
28.7


Loss in 50 Ohm Transmitting Coax
dB / 100 ft
3
1
0.1
RG8X
9258
LMR240
RG8X
LMR400
RG8
RG8
3227
1
3.5
7
10
30
50
100
Frequency (MHz)


Loss in 75 Ohm Transmitting Coax
dB/100 ft
10
3
1
0.1
8263
RG59B
RG6
8215
RG6
1694
8213
RG11
1
3.5
7
10
30
100
Frequency (MHz)

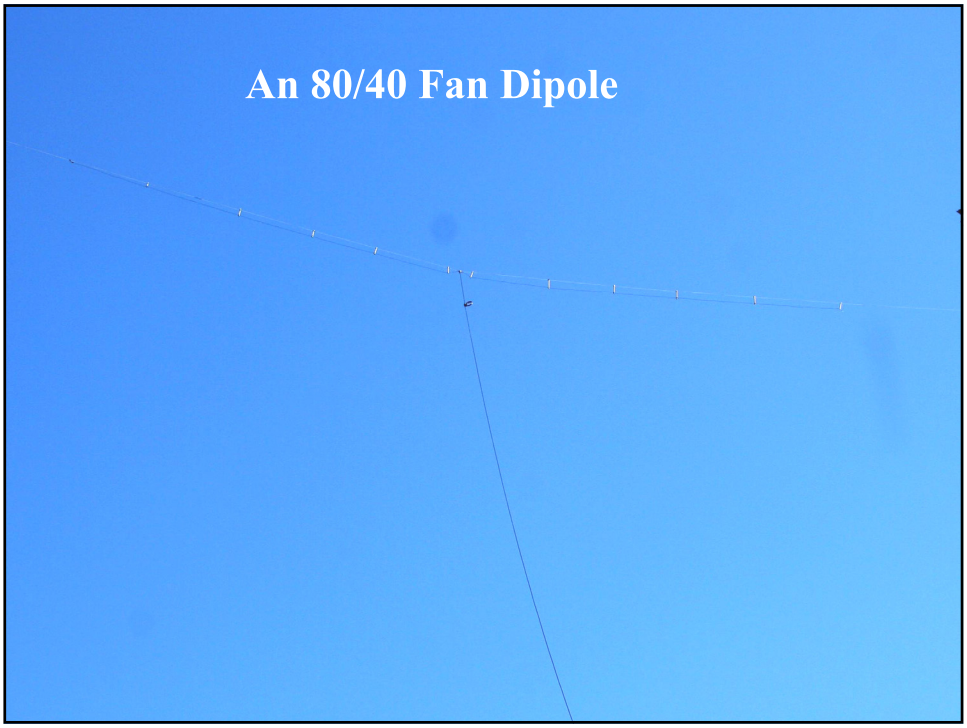

RG8 or RG11?
A 10M Dipole
75 ohms
2
1.5
1.1
1
28
Freq MHz
28.7
50 ohms
3
2
1.5
1.1
1
28
Freq MHz
28.7

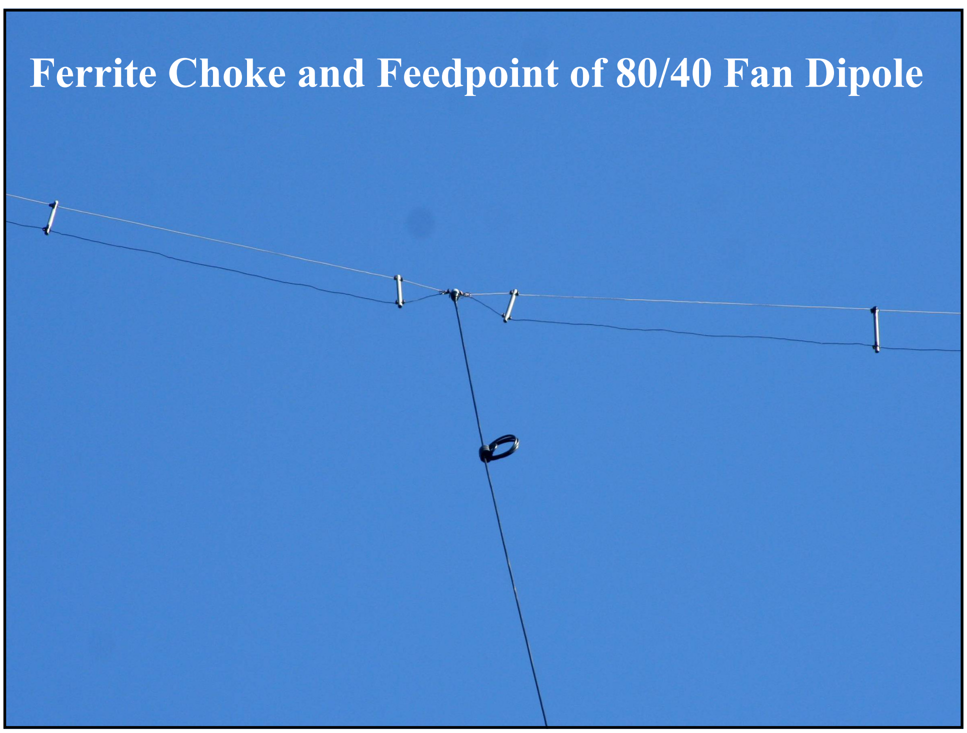
Build a Multiband Fan!

My First 20/15/10 Fan Dipole in Chicago
Only up 25 ft, but a lot of noise on E Coast


A Fan Dipole
for 20/15/10

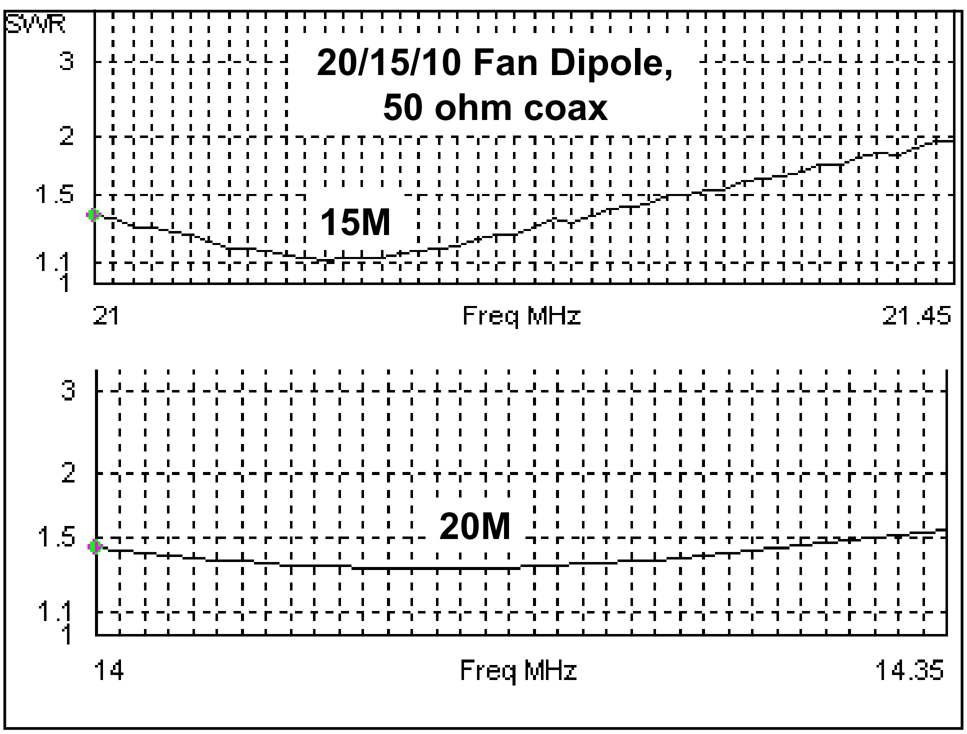

An 80/40 Fan Dipole

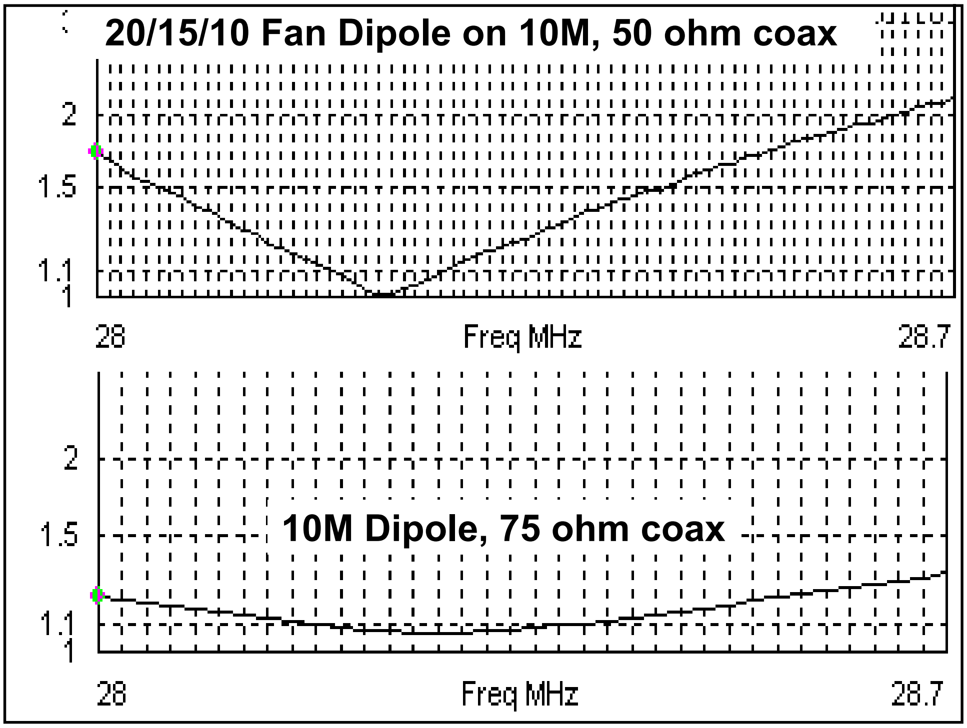

An 80/40 Fan Dipole


Ferrite Choke and Feedpoint of 80/40 Fan Dipole

Fan Dipoles – How They Work

- Same efficiency and pattern as a single dipole for each band
- Lowest frequency element has same SWR bandwidth as a single dipole
- Higher frequency elements have reduced SWR bandwidth (about 50%)
  - Length (tuning) more critical
  - Greater feedline loss at edges of band
- 20/15/10 fan looks like 50 ohms, even when very high





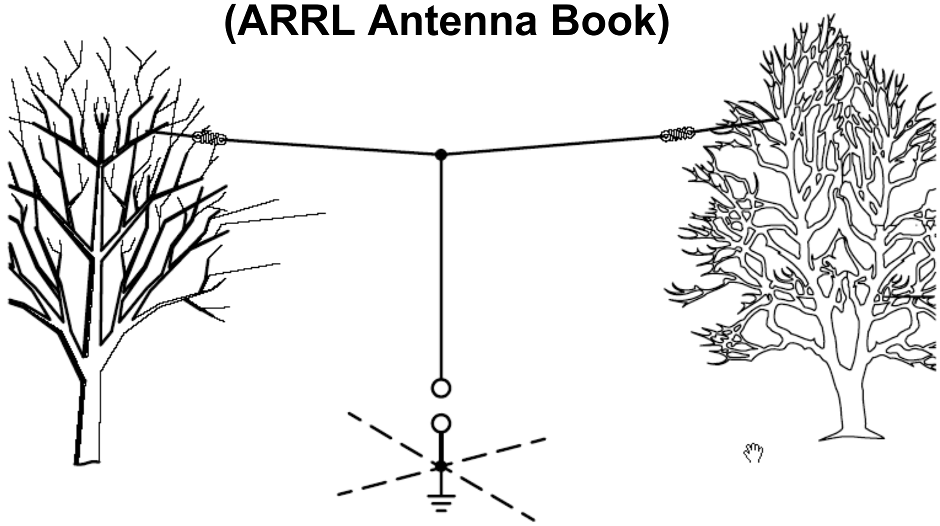
Improvising an End Fed Wire

- **Think about where most current will be**
  - **Current <u>must</u> be zero at an open circuit**
  - **Current <u>will</u> be max λ/4 (and 3λ/4) from an open circuit (low impedance, easier to match)**
    - **Could be closer if loading coils, capacitance**
  - **A high current point high and in the clear usually makes the antenna more efficient**
  - **Current must be <u>near</u> zero λ/2 (and λ) from an open circuit**
- **High current parts of antenna radiate**
- **Hight current points easier to match**

Feed A Random Wire From the End

- You <u>will</u> need an antenna tuner
- Avoid half wavelengths (high Z at the feedpoint, harder to match to XMTR)
- The lower the frequency, the greater the benefit of increased height
- You do need a radial system

A Top-Loaded "Tee" Vertical (ARRL Antenna Book)



A Top Loaded Vertical on 80/160

- Inverted L
- “Tee” – vertical
- Load it against radials or a counterpoise
- Use what you can install
  - It doesn’t need to be perfect
  - Longer/bigger is better
  - Do your best and call CQ!

A Top Loaded Vertical on 80/160

- Ideally would be quarter wave vertical
  - 70 ft on 80M
  - 135 ft on 160M
- Few of us can do that, so go as high as you can and
  - bend it in one direction (inverted L)
  - Bend it in two directions (Tee)

  so that it looks like a quarter wave to the transmitter

A Top Loaded Vertical on 80/160

- **Split the difference and load a Tee or inverted L on both 80 and 160 (w/tuner)**
  - **90-100 ft is 3/8λ on 80M, 3/16 λ on 160M**
  - **160-170 ft is 5/8 on 80M, 5/16 on 160M**

Radial Systems

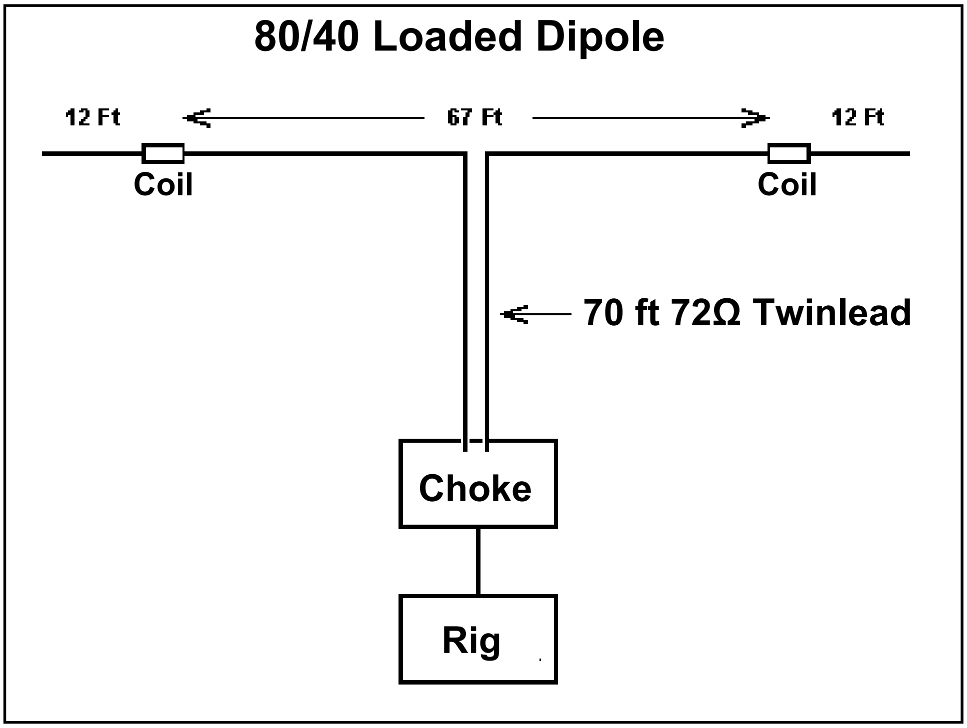
- **Provide a return for the fields and currents produced by an end-fed antenna**
- **The earth is lossy, burns transmitter power**
- **Use enough radials so that fields and current are in copper, not earth**
- **A few resonant radials work if elevated**
- **Many needed if on ground**

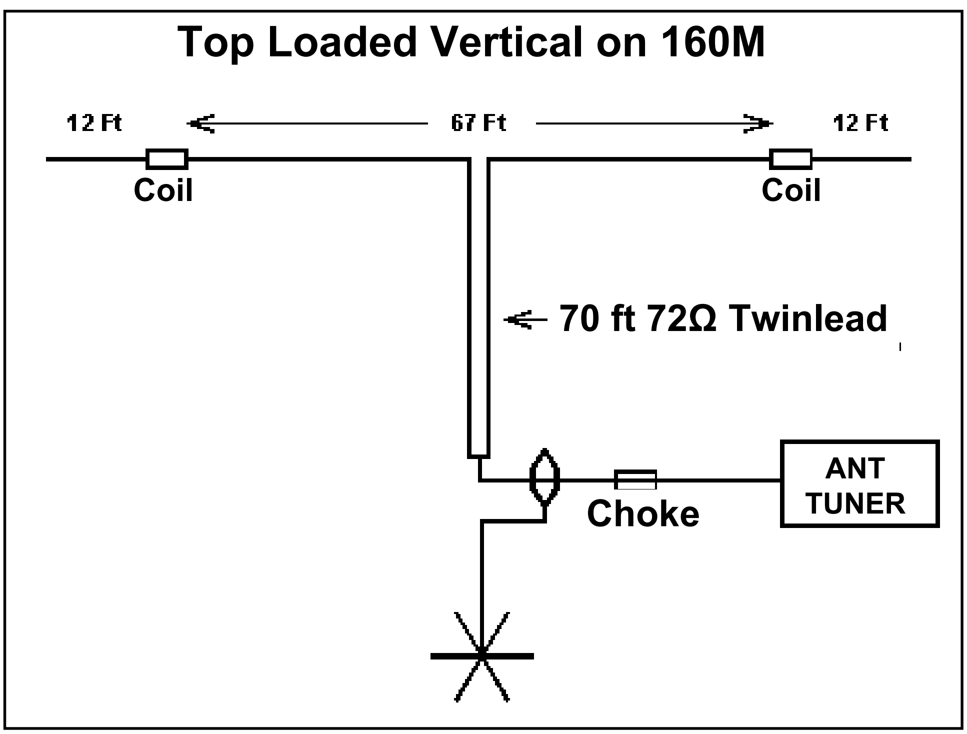
Improvising Antennas

- **Feed it against radials or a counterpoise**
  - A ground stake doesn't help
  - More wire close to the feedpoint is better
  - A lot of short wires are better than a few long ones
  - Symmetry much less important than quantity
  - Wire diameter enough it won't break
  - Do the best you can and call CQ!
- **To learn more about radial systems, study N6LF's website**

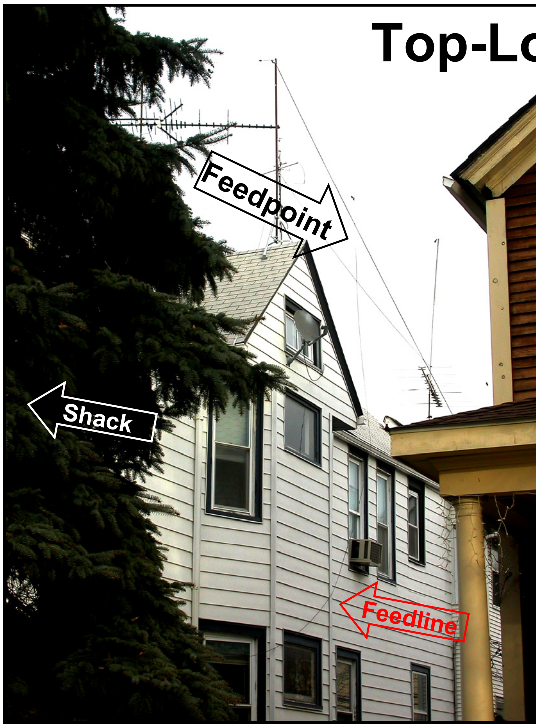
On Ground Radial Systems (ARRL Antennna Book)

Number	Length	Loss	Z
0		*10 dB ?*	*90 Ω ?*
16	0.1λ	3 dB	52 Ω
24	.125 λ	2 dB	46 Ω
36	.15 λ	1.5 dB	43 Ω
60	0.2 λ	1 dB	40 Ω
90	0.25 λ	0.5 dB	35 Ω


80/40 Loaded Dipole
12 Ft
67 Ft
12 Ft
Coil
Coil
70 ft 72Ω Twinlead
Choke
Rig

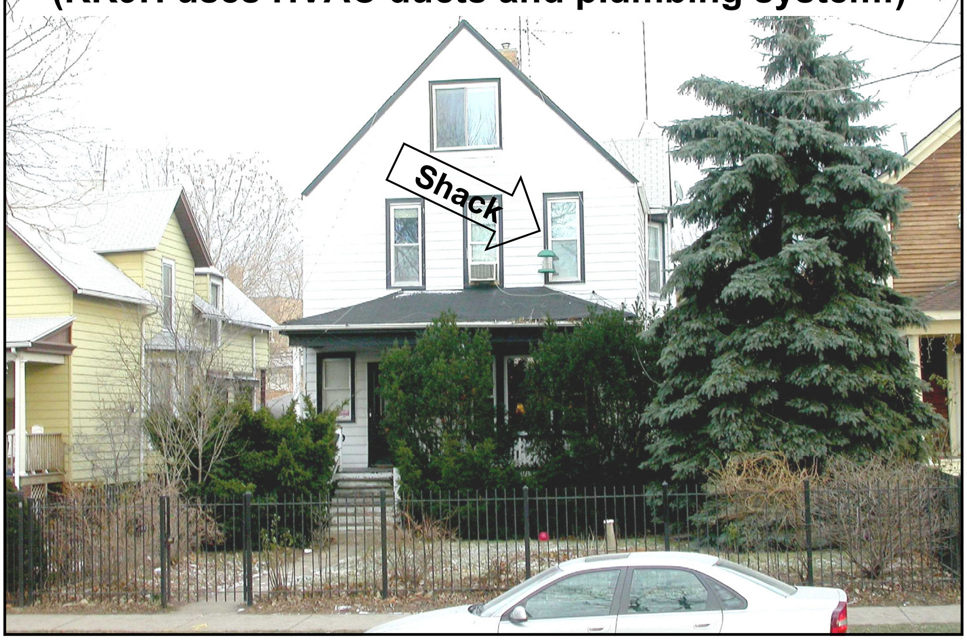

Top Loaded Vertical on 160M
12 Ft
67 Ft
12 Ft
Coil
Coil
70 ft 72Ω Twinlead
ANT
TUNER
Choke

Top-Loaded Vertical

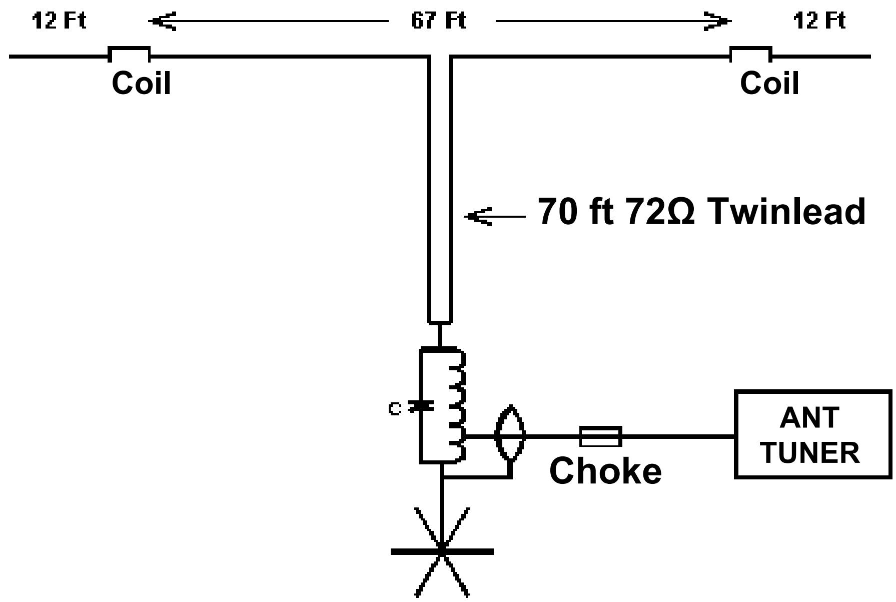


- Start with 80/40 dipole fed with twinlead
- Tie both sides together at tuner
- Feed as long wire against radials

Wrought Iron Fence was Counterpoise for Vertical (KK9H uses HVAC ducts and plumbing system!)



Loading it as A Half Wave on 80M



Building Wire Antennas

- **Use Insulated House Wire (THHN)**
  - **#10 or #12 for heavy loads, long spans**
  - **#14 for lighter antennas**
  - **#18 or even #22 for stealth!**
- **Use thimbles where wire bends to minimize stresses**
  - **The Wireman 800, 800A**
- **Avoid "Flex-Weave"**
  - **I've used a lot of it – every antenna has broken!**

Building Wire Antennas

- Don’t solder a connection that can flex
  – Soldering makes copper brittle, and it will break!
- Use Split Bolt Connectors for both mechanical and electrical connections
  – McMaster-Carr 6921K56 ($1.89 each, 25 lots)
  – Lowes, Home Depot (about $3 each)
- Tape up connections to minimize corrosion

Split Bolt Connectors at Center of a Fan Dipole

Building Wire Antennas

- End insulators – use eggs
  - RF Connection
- If you must climb to hang it, use a pulley!
  - Marine pulleys work well ($15 - $25)
- Support rope
  - UV resistance, strength, big enough to pull
  - 3/16-inch for light antennas, low tension
  - 5/16-inch for heavy ones you need to pull
  - DX Engineering, Davis RF

A Good Center Insulator is Hard to Find!

Building Dipoles

- Center Insulator
  - Mechanical Strength
  - Electrical connections
  - Weatherproof
  - Corrosion
- A Good Center Insulator is Hard to Find!
  - (You always get the other kind)
  - Wireman 801 is best of a bad lot
- Avoid commercial "baluns"
  - Wind a much better coax choke using guidelines in my Choke Cookbook

Building Fan Dipoles

- Spacers are easy to build
  - ½-inch UV-resistant PVC conduit, cut into
  - 15-inch lengths for 3-wire fans
  - 9-inch lengths for 2-wire fans
  - Separate wires by about 7 inches
  - Drill holes for wire to pass through
- For 20/15/10 fans
  - Spacer near center insulator
  - Spacer at end of 10M element
  - Spacer at end of 15M element

Building Fan Dipoles

- For 80/40 fans
  - Spacer near center insulator
  - Spacers about 6 ft apart
- Length of elements
  - Build according to usual formulas for the wire you're using, but cut a little long and trim to length after it's been in the air
  - Include all wire starting from the coax connector
  - Remember that insulated wire lowers the resonant frequency about 2%
  - I've not seen interaction between elements

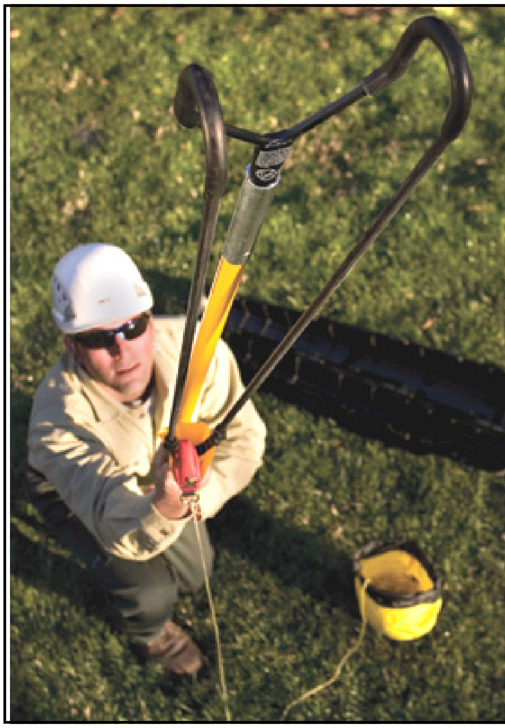
Getting Wires Into Trees

- Climb the tree, install a pulley (Best)
  - It will stay up longer, easy to change antenna
  - Allows a counterweight for wind motion
  - Least fraying of support rope
  - Climbers can be expensive ($500/day typical)
- Use a launcher
  - Put heavy fishing line over a branch
  - Pull up heavier line
  - Pull up the final support rope

- **Tennis Ball Launcher $110 - $350**
  - **Good for 200 ft**
  - **www.antennalaunchers.com**

EZ Hang Launcher
$100 - $130

http://ezhang.net



- A super slingshot on an 8 ft pole
  - 2 – 4ft sections
- Sherrill Tree Service
  - About $160 w/line and weights
  - http://sherrilltree.com
  - Good for 80 – 100 ft

Installing a Pulley with a Launcher

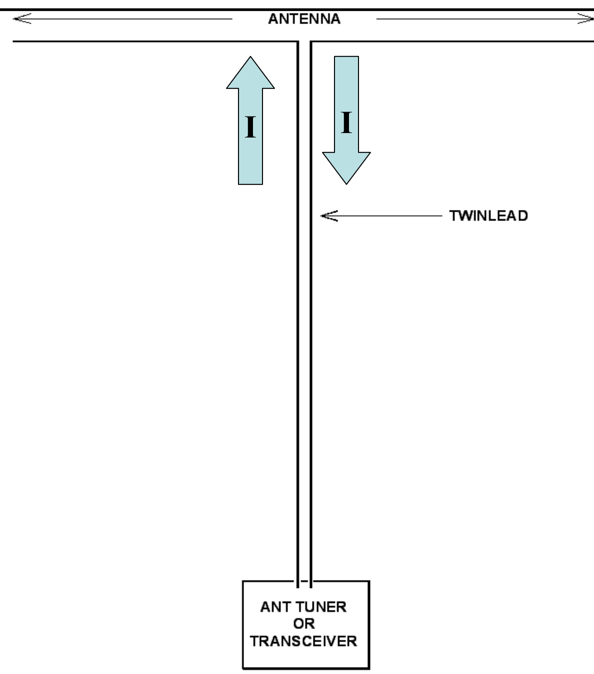
- Launch heavy fishing line over a branch
- Pull up heavier line, then final support rope
- Make a continuous loop of heavy support rope from top to ground
- Attach pulley to the loop
- Run final support rope through pulley
- Pull pulley, with support rope, up to the top
- Attach final support rope to antenna
- Now you can use a counterweight with minimal abrasion of support rope

Why Not an All Band Wire Fed with Twinlead?

Understanding Common Mode and Differential Mode Currents on Transmission Lines

Differential Mode Current

- **Transmission line carrying power from transmitter to antenna, or from antenna to receiver**
- **Signal is voltage <u>between</u> the two conductors**
- **Current flows out on one conductor and returns on the other**

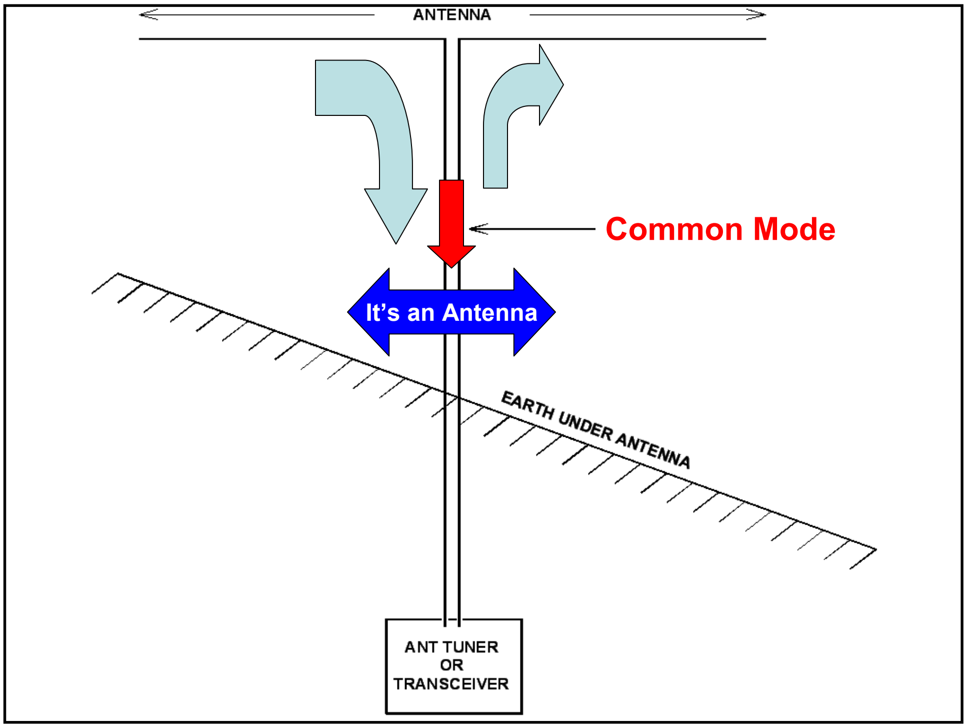


Differential Mode Current

- Transmission line carrying power from transmitter to antenna, or from antenna to receiver
- Signal is voltage <u>between</u> the two conductors
- Current flows out on one conductor and returns on the other
- Fields exist <u>between</u> the two conductors
- No radiation from ideal line
  - Field of outgoing conductor cancels field of return conductor

Common Mode Current

- Equal and flowing in the same direction on all conductors of balanced lines
- Current flows lengthwise on the line
  - No cancellation of one current by another, because they're in polarity
- Line acts as long wire antenna
  - It radiates and it receives



Ham Antennas and Balance

- Most ham antennas are <u>unbalanced</u> by their <u>surroundings</u>, even when fed by a balanced source and line

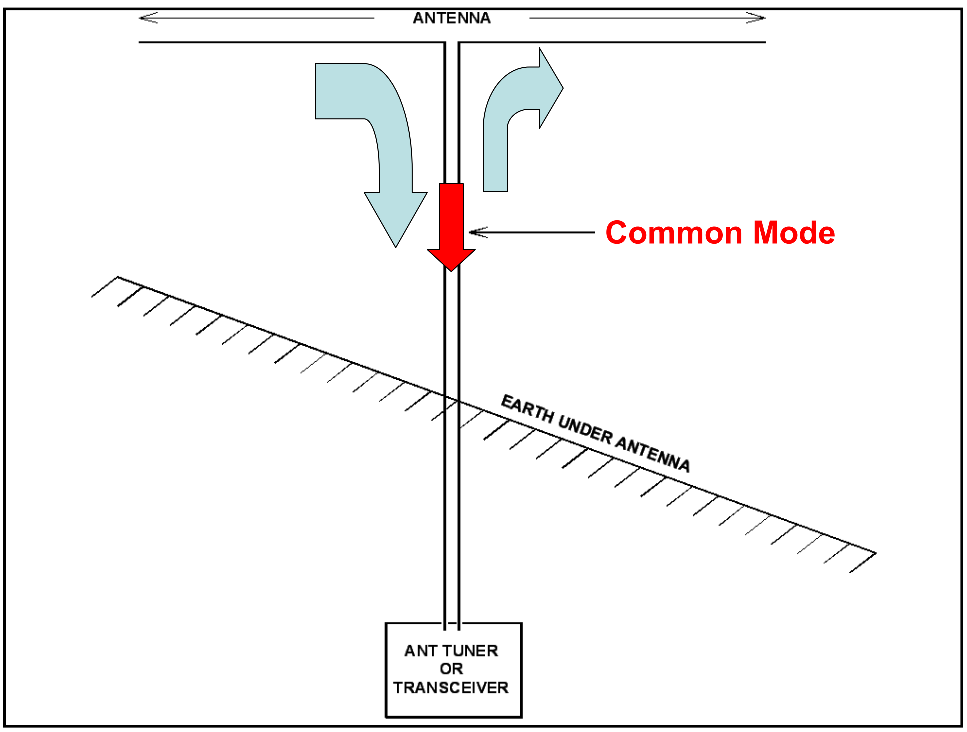
What Makes a Circuit Balanced?

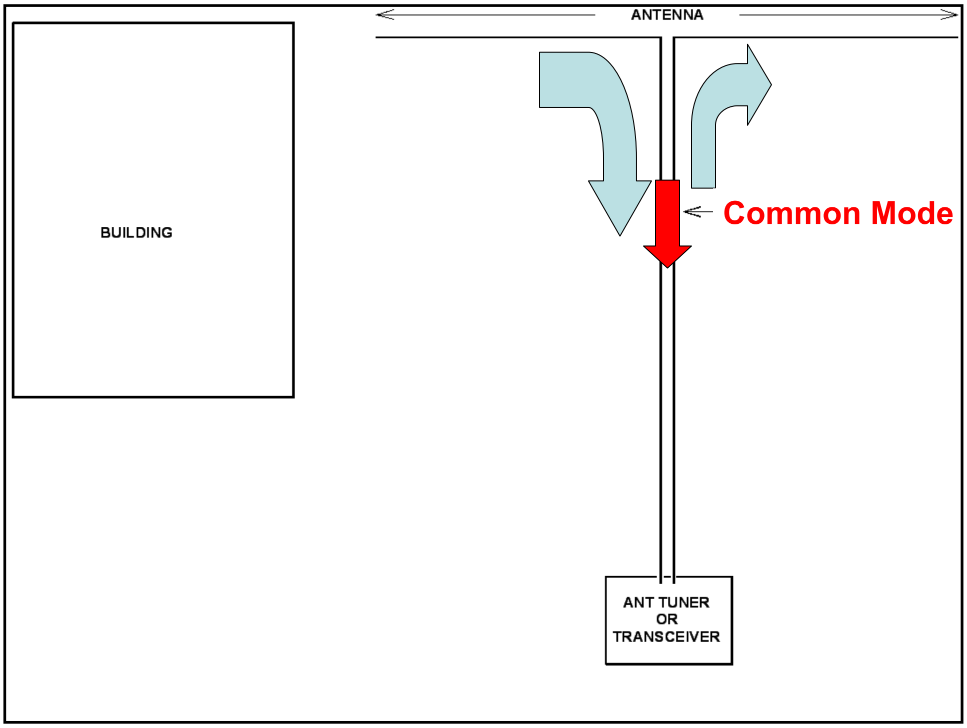
What Makes a Circuit Balanced?

- **The impedances of each conductor to the reference plane are equal**
- **Balance is not defined by voltage or current**
- **Imbalance impedances cause unbalanced currents**

Ham Antennas and Balance

- **Most ham antennas are <u>unbalanced</u> by their <u>surroundings</u>, even when fed by a balanced source and line**
  - Unequal capacitances to nearby conductors
  - Unequal inductive coupling to nearby conductors
  - Trees, buildings, towers, terrain
  - Feedline comes off at an angle
  - Coax is not a part of these imbalances

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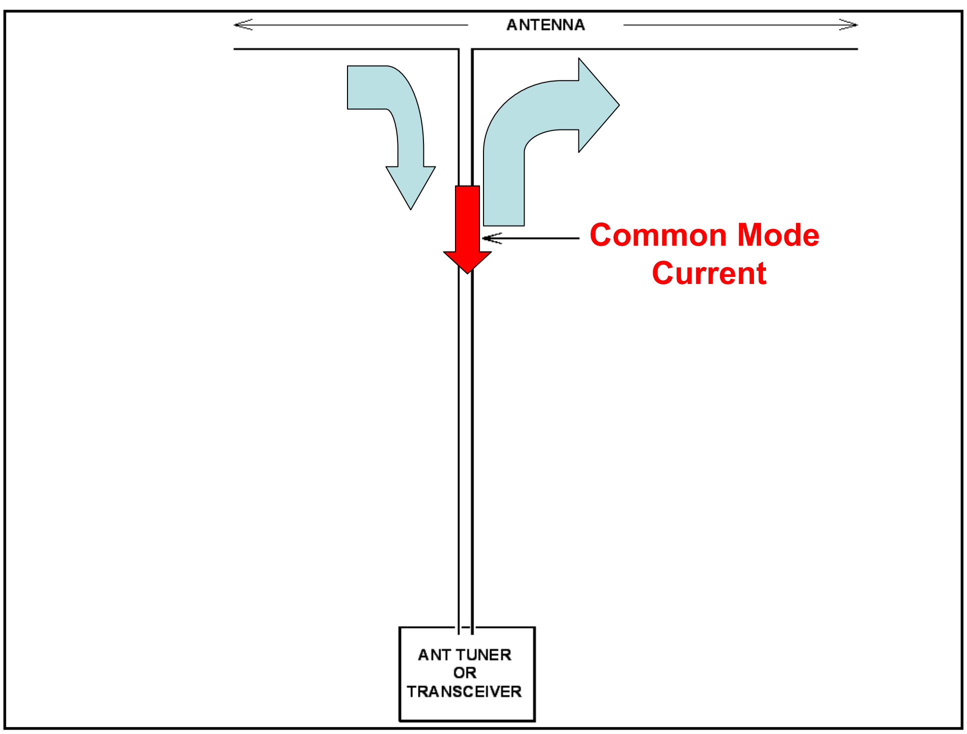
BUILDING
Common Mode
ANT TUNER
OR
TRANSCEIVER


ANTENNA
Common Mode
Current
ANT TUNER
OR
TRANSCEIVER

Unbalanced Antennas and Lines

- **If the antenna is unbalanced**
  - **Unequal voltage and current to earth**
  - **Unequal currents on the feedline**
  - **The difference is common mode current, and it radiates from the line**
- **<u>Coax</u> did not cause the imbalance in these antennas!**
- **Coax simply adds to the imbalance**

The Fields around Coax and Twinlead are Very Different

Coax is Special

- **All the differential power (and field) is confined <u>inside</u> the coax**
- **All the common mode power (and field) is <u>outside</u> the coax**
- **<u>A ferrite core surrounding coax sees only the common mode power (and field)</u>**

Coax is Special

- **Skin effect splits the <u>shield</u> into two conductors**
  - **<u>Inner</u> skin carries <u>differential</u> mode current (the transmitter power)**
  - **<u>Outer</u> skin carries <u>common</u> mode current (the current due to imbalance)**

Twinlead Has Leakage Flux from Differential Current

- **This leakage flux is not confined to the region between the conductors, but instead spills to the area immediately surrounding the conductors**
- **Leakage flux causes very little radiation, but it will cause heating in a lossy medium!**
  - **Like a ferrite core**

How Much Leakage Flux?

- **Depends on mutual coupling between conductors**
  - **Depends on conductor-to-conductor spacing**
  - **How close together can conductors be?**
- **Coupling coefficient of 60-70% typical**
  - **30-40% leakage flux in best balanced cables**
  - **50% or more in ladder line**

We'll talk more about all this later on

Now We Can Talk About Common Mode Chokes!

What’s a Common Mode Choke?

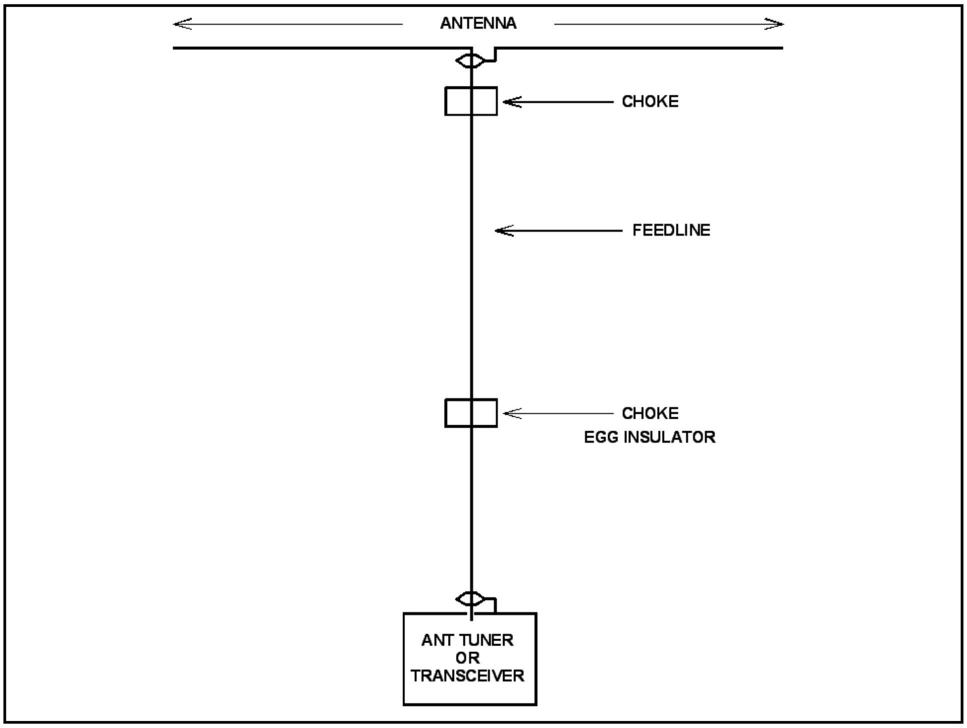
- A circuit element that reduces common mode current by adding a high impedance in series with the common mode circuit
  - Reduces radiation from the cable
  - Reduces reception by the cable

Some Common Mode Chokes

- **A coil of coax at the antenna**
- **A string of ferrite beads around coax (Walt Maxwell, W2DU)**
- **Multiple turns of transmission line through a toroid (Joe Reisert, W1JR) or stack of toroids (W1HIS, K9YC)**
- **Most 1:1 “baluns” are common mode chokes**

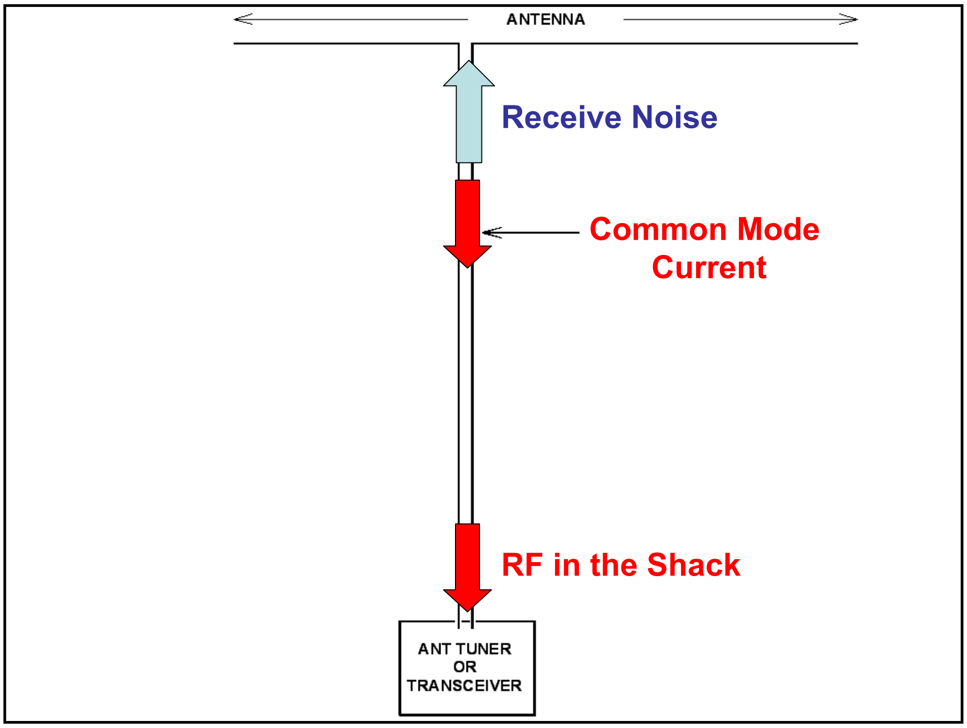
Some Common Mode Chokes

- **Some 2:1, 3:1, and 4:1 “baluns” are also common mode chokes**
  - **But the few I’ve measured aren’t very good common mode chokes**



Why Transmitting Chokes?

- Isolate antenna from its feedline
- Reduce receive noise
- Keep RF out of the shack
- Minimize antenna interaction
  - SO2R, Multi-multi
  - Dipole feedline and vertical antenna



"Strings of Beads" (W2DU, W0IYH Baluns)

A String of Different Beads

K9YC Chokes (Improvements on W1JR, W2DU Designs)

Why Not Twinlead?

- **You can't put a choke on it!**

So:

- **More receive noise**
- **More RF in the shack**
- **More RFI to your neighbors**
- **More antenna interaction**
- **More loss when it's wet**

References

- **A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing** Self-published tutorial (on my website)
- **Transmitting Chokes** (Power Point pdf) (on my website)
  Applications notes, tutorials, and my AES papers are on my website for free download
  http://audiosystemsgroup.com/publish

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- ***Ferroxcube Catalog and Applications Notes* More online from another great manufacturer of ferrites. http://www.ferroxcube.com**