Introduction to Antennas

Dipoles

Verticals

Large Loops

Yagi-Uda Arrays

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Introduction

What is an antenna?

- **An antenna is a device that:**
  - **Converts RF power applied to its feed point into electromagnetic radiation.**
  - **Intercepts energy from a passing electromagnetic radiation, which then appears as RF voltage across the antenna's feed point.**
- **Any conductor,through which an RF current is flowing, can be an antenna.**
- **Any conductor that can intercept an RF field can be an antenna.**

Important Antenna Parameters

- **Directivity or Gain:**
  - Is the ratio of the power radiated by an antenna in its direction of maximum radiation to the power radiated by a reference antenna in the same direction.
  - Is measured in dBi (dB referenced to an isotropic antenna) or dBd (dB referenced to a half wavelength dipole)
- **Feed point impedance (also called input or drive impedance):**
  - Is the impedance measured at the input to the antenna.
  - The real part of this impedance is the sum of the radiation and loss resistances
  - The imaginary part of this impedance represents power temporarily stored by the antenna.
- **Bandwidth**
  - Is the range of frequencies over which one or more antenna parameters stay within a certain range.
  - The most common bandwidth used is the one over which SWR < 2:1

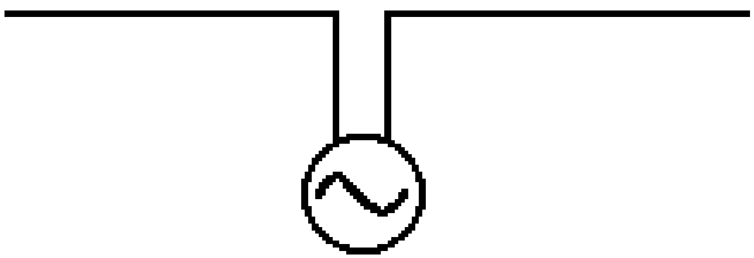
Antennas and Fields

- **Reciprocity Theorem:**
  - An antenna's properties are the same, whether it is used for transmitting or receiving.
- **The Near Field**
  - An electromagnetic field that exists within ~ $\lambda/2$ of the antenna. It temporarily stores power and is related to the imaginary term of the input impedance.
- **The Far Field**
  - An electromagnetic field launched by the antenna that extends throughout all space. This field transports power and is related to the radiation resistance of the antenna.

The Hertz Antenna
(Dipole)

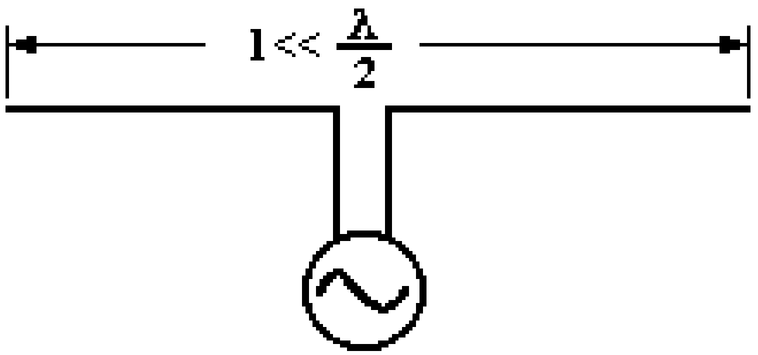
Dipole Fundamentals

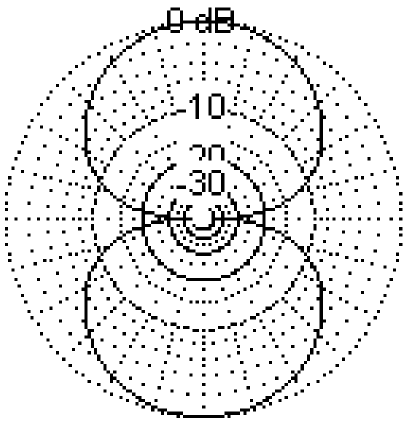
- A dipole is antenna composed of a single radiating element split into two sections, not necessarily of equal length.
- The RF power is fed into the split.
- The radiators do not have to be straight.



The Short Dipole

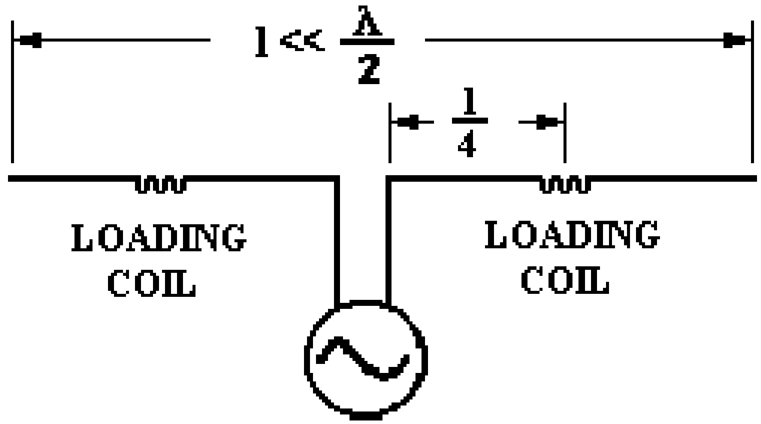
- The length is less than λ/2.
- The self impedance is generally capacitive.
- The radiation resistance is quite small and ohmic losses are high
- SWR bandwidth is quite small, < 1% of design frequency.
- Directivity is ~1.8 dBi. Radiation pattern resembles figure 8

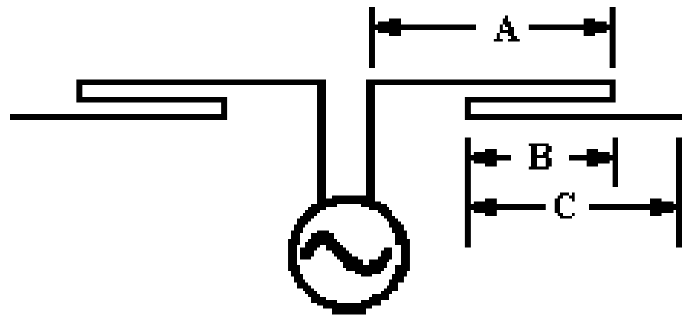




The Short Dipole

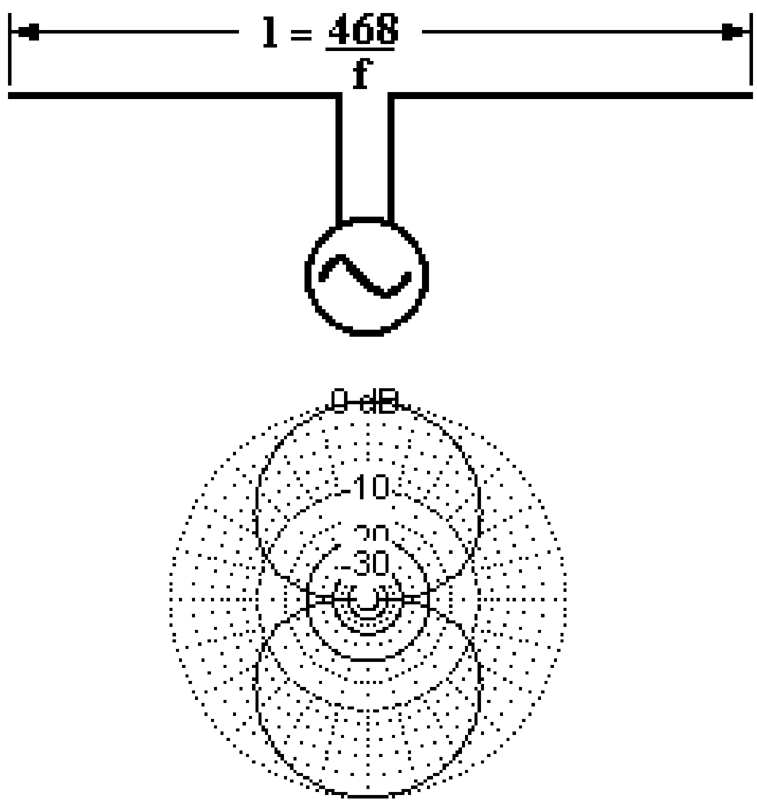
- For dipoles longer than λ/5, the antenna can be matched to coax by using loading coils
- For best results, the coils are placed in the middle of each leg of the dipole
- Loading coils can introduce additional loss of 1 dB or more
- For dipoles longer than λ/3 the antenna can be matched to coax by using linear loading
- Very short dipoles (< λ/5) require some type of matching network because Re(Zin)< 2Ω





The Half Wave (λ/2) Dipole

- Length is approximately λ/2 (0.48 λ for wire dipoles)
- Self impedance is 40 - 80 ohms with no reactive component (good match to coax)
- Directivity ~ 2.1 dBi
- SWR Bandwidth is ~ 5% of design frequency

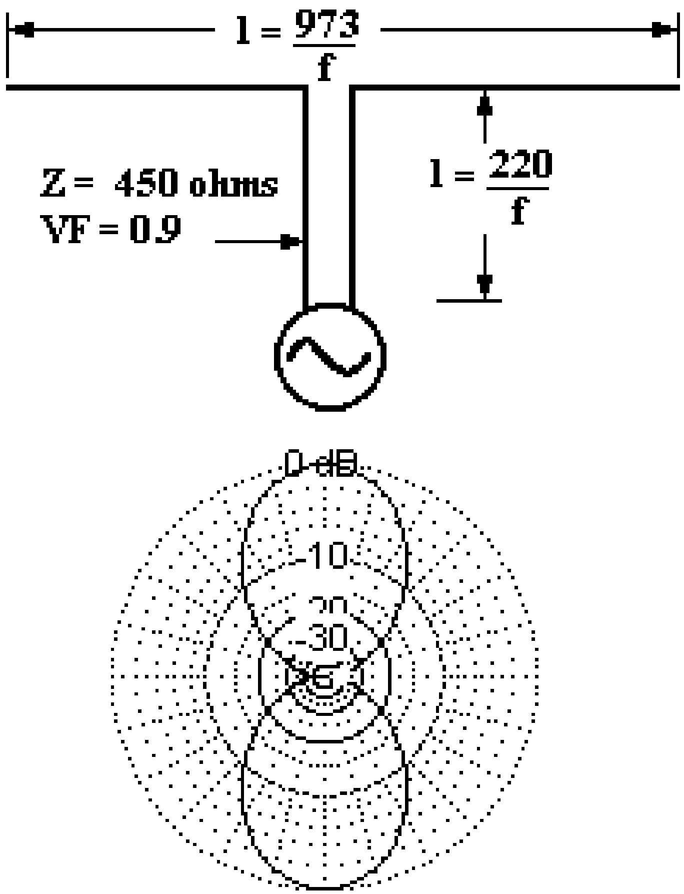


Long Dipoles

- A long dipole is one whose length is > $\lambda/2$
- The self impedance of a long dipole varies from 150 to 3000 Ω or more. A long dipole whose length is an odd multiple of $\lambda/2$ will be resonant with Zin ~ 150 Ω
- The directivity of a dipole is a maximum at a length of 1.28 λ.
- The radiation pattern becomes more complex with increasing length, with many side lobes.

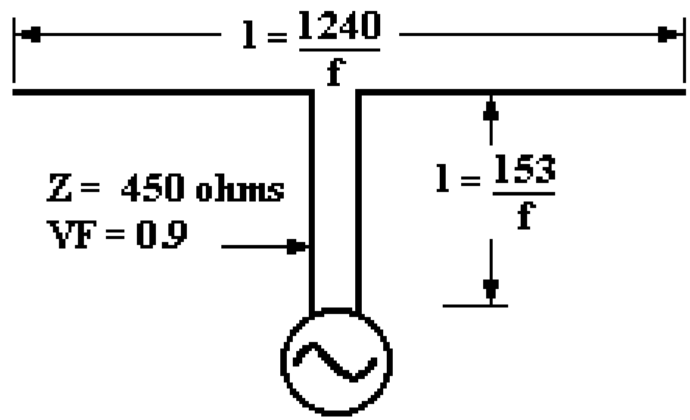
The Double Zepp Antenna

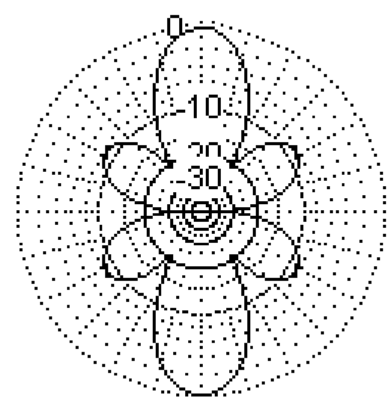
- A long dipole whose length is approximately 1λ
- Self impedance is ~ 3000 ohms.
- Antenna can be matched to coax with a 450 ohm series matching section
- Directivity ~ 3.8 dBi
- SWR Bandwidth ~ 5% of design frequency



The Extended Double Zepp

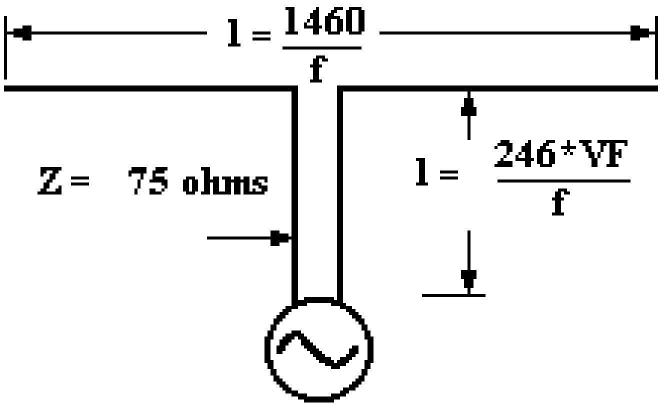
- Length is approximately 1.28λ
- Self impedance is approx. 150 -j800 ohms
- Antenna can be matched to 50 ohm coax with a series matching section
- Directivity ~ 5.0 dBi. This is the maximum broadside directivity for a center-fed wire antenna

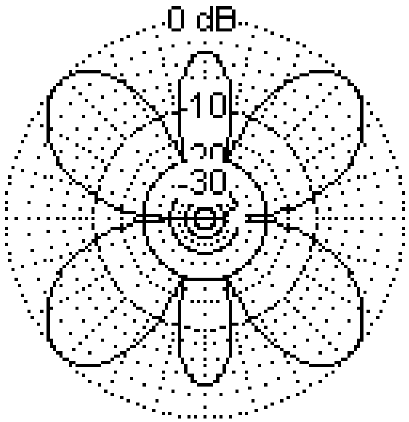




The 3λ/2 Dipole

- Length is approximately 1.48λ
- Self impedance ~ 110 ohms
- Antenna can be matched to 50 ohm coax with quarter wave 75 ohm matching section
- Directivity ~ 3.3 dBi.
- Directions of max radiation point to all areas of interest for HF DX when antenna wire runs E-W



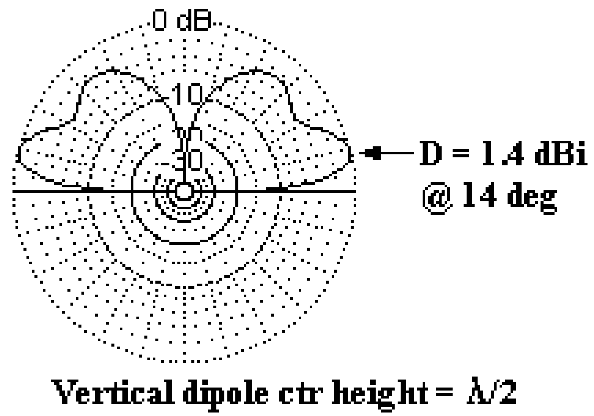


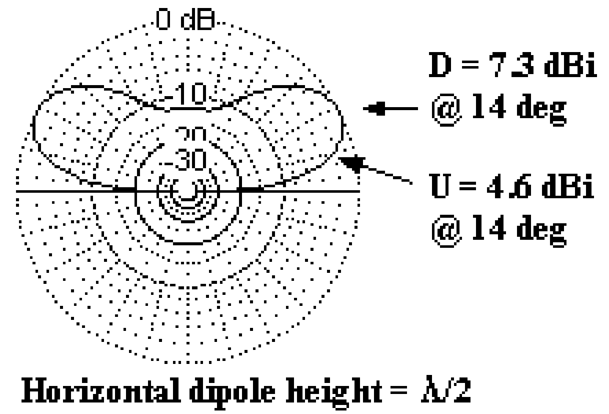
Use of a dipole on several bands

- It is possible to use a center fed dipole over a wide range of frequencies by:
  - feeding it with low-loss transmission line (ladder line)
  - providing impedance matching at the transceiver
- The lower frequency limit is set by the capability of the matching network. Typically a dipole can be used down to 1/2 of its resonant frequency.
- The radiation pattern becomes very complex at higher frequencies. Most of the radiation is in two conical regions centered on each wire
- There is no special length, since the antenna will not be resonant

Dipole Polarization

- On the HF bands dipoles are almost always horizontally polarized. It is not possible to get a low angle of radiation with a vertical dipole (electrically) close to the earth
- Reflection losses are also greater for vertically polarized RF
- The height of the support required for a vertical dipole can also be a problem

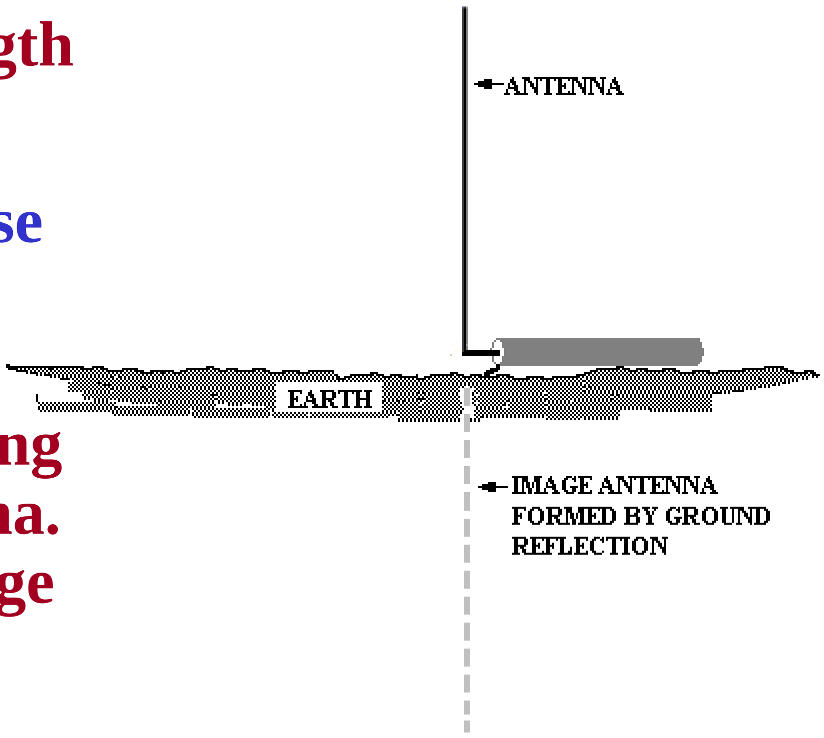




The Marconi Antenna
(vertical monopole)

Vertical Fundamentals

- **A vertical antenna consists of a single vertical radiating element located above a natural or artificial ground plane. Its length is < 0.64λ**
- **RF is generally fed into the base of the radiating element.**
- **The ground plane acts as an electromagnetic mirror, creating an image of the vertical antenna. Together the antenna and image for a virtual vertical dipole.**



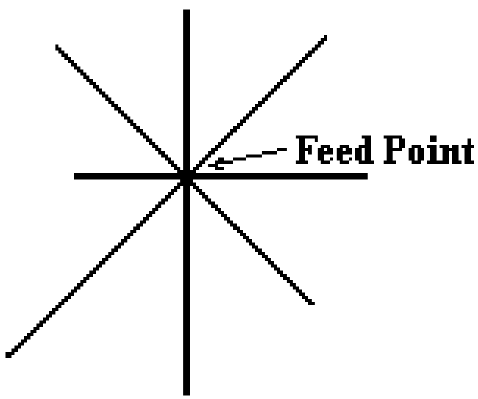
The Importance of the Ground

- **The ground is part of the vertical antenna, not just a reflector of RF, unless the antenna is far removed from earth (usually only true in the VHF region)**
- **RF currents flow in the ground in the vicinity of a vertical antenna. The region of high current is near the feed point for verticals less that $\lambda/4$ long, and is ~ $\lambda/3$ out from the feed point for a $\lambda/2$ vertical.**
- **To minimize losses, the conductivity of the ground in the high current zones must be very high.**
- **Ground conductivity can be improved by using a ground radial system, or by providing an artificial ground plane known as a counterpoise.**

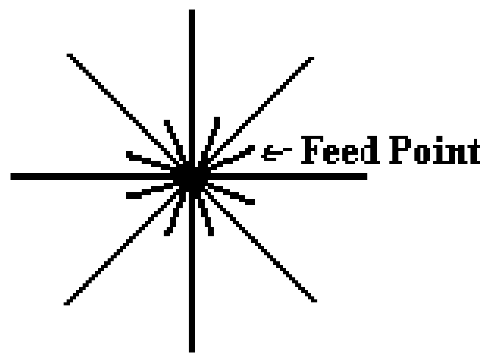
Notes on ground system construction

- Ground radials can be made of almost any type of wire
- The radials do not have to be buried; they may lay on the ground
- The radials should extend from the feed point like spokes of a wheel
- The length of the radials is not critical. They are not resonant. They should be as long as possible
- For small radial systems ($N < 16$) the radials need only be $\lambda/8$ long. For large ground systems ($N > 64$) the length should be $\sim \lambda/4$
- Elevated counterpoise wires are usually $\lambda/4$ long

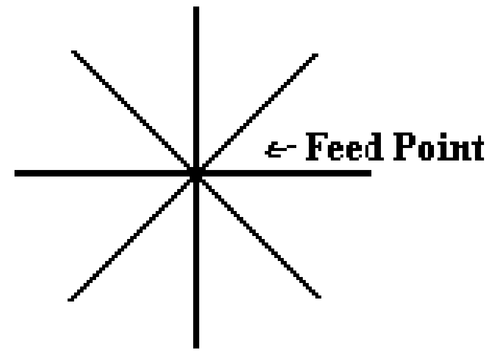
Radial/Counterpoise Layout



Ground Radial System
with random length
radials on ground



Ground Radial System
with extra short radials
in high current region

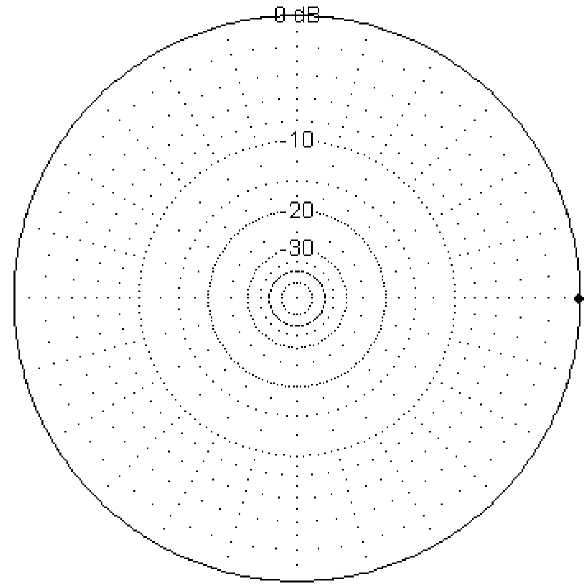


Elevated Counterpoise
using λ/4 radials

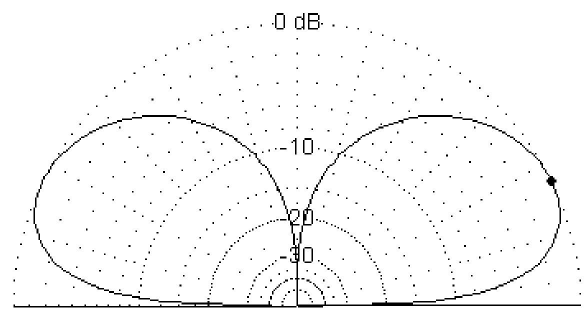
- **Note: The radials used in a counterpoise are not grounded !!**

λ /4 Vertical Monopole

- **Length ~ 0.25λ**
- **Self impedance:**
  Z_S ~ 36 - 70 Ω
- **The λ /4 vertical requires a ground system, which acts as a return for ground currents. The "image" of the monopole in the ground provides the "other half" of the antenna**
- **The length of the radials depends on how many there are**
- **Take off angle ~ 25 deg**



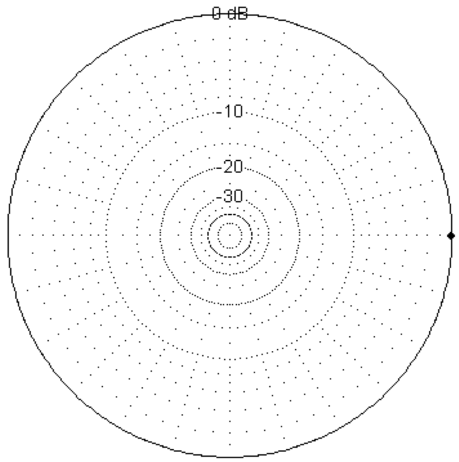
Azimuth Plot



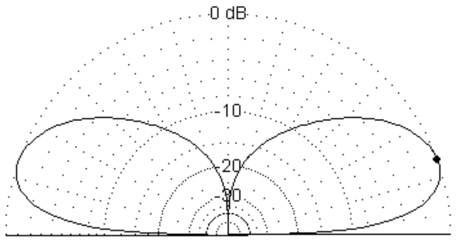
Elevation Plot

λ /2 Vertical Monopole

- **Length is approximately 0.48λ**
- **Self impedance ~ 2000 Ω**
- **Antenna can be matched to 50 ohm coax with a tapped tank circuit**
- **Take off angle ~ 15 deg**
- **Ground currents at base of antenna are small; radials are less critical for λ/2 vertical**



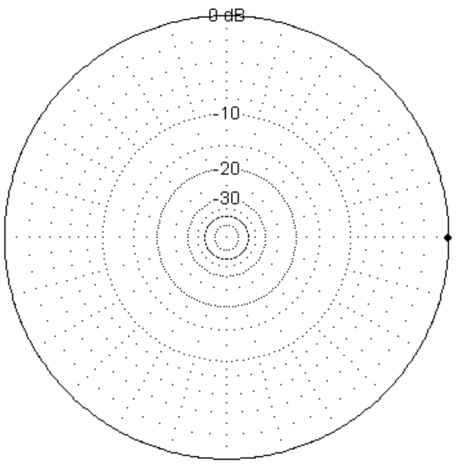
Azimuth Plot



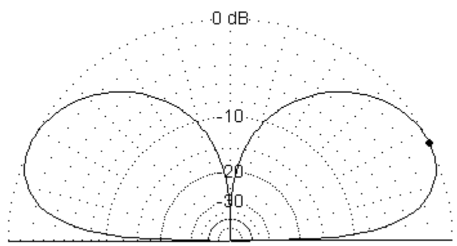
Elevation Plot

Short Vertical Monopoles

- **It is not possible for most amateurs to erect a λ/4 or λ/2 vertical on 80 or 160 meters**
- **The monopole, like the dipole can be shortened and resonated with a loading coil**
- **The feed point impedance can be quite low (~10 Ω) with a good ground system, so an additional matching network is required**
- **Best results are obtained when loading coil is at the center**



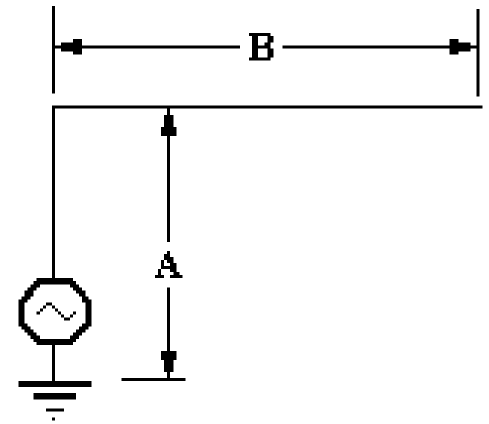
Azimuth Plot



Elevation Plot

Inverted L

- The inverted L is a vertical monopole that has been folded so that a portion runs horizontally
- Typically the overall length is ~ 0.3125λ and the vertical portion is ~ 0.125λ long
- Self impedance is ~ 50 + j200Ω
- Series capacitor can be used to match antenna to coax



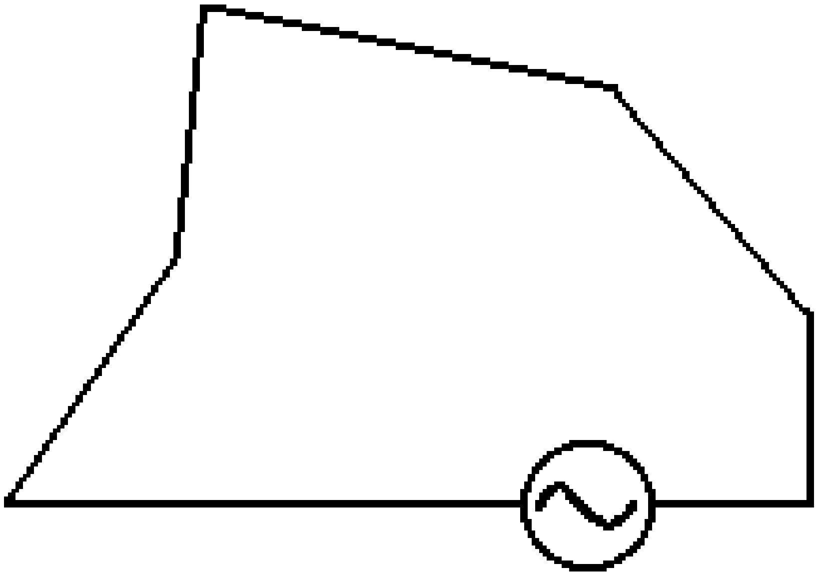
Use of a Vertical Monopole on several bands

- **If a low angle of radiation is desired, a vertical antenna can be used on any frequency where is is shorter than 0.64 λ :**
- **The lower frequency limit is set by the capability of the matching network and by efficiency constraints.**
- **The ground system should be designed to accommodate the lowest frequency to be used. Under normal circumstances, this will be adequate at higher frequencies**

The Large Loop Antenna

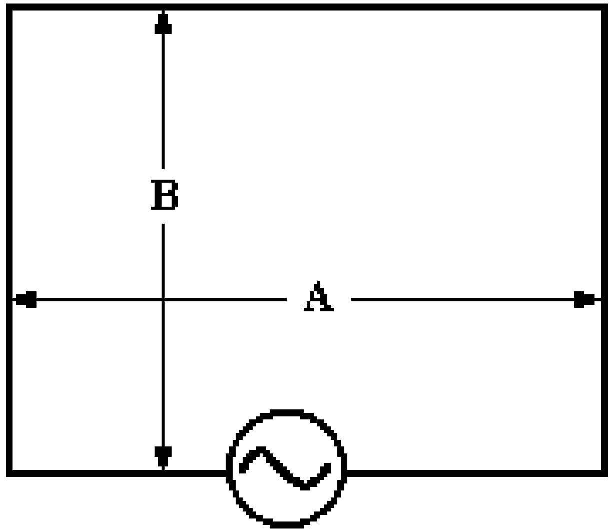
Loop Fundamentals

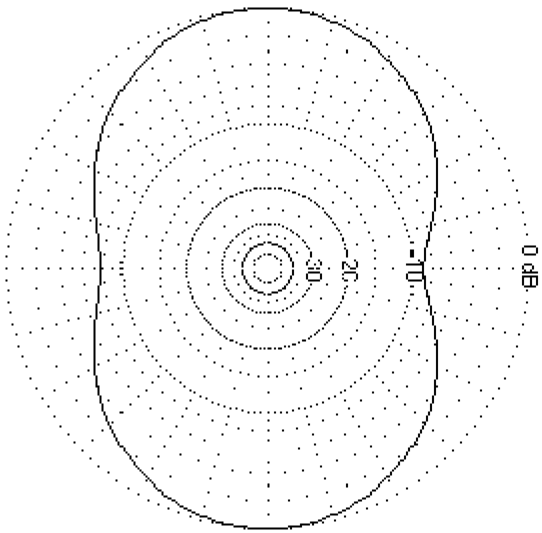
- A large loop antenna is composed of a single loop of wire, greater than a half wavelength long.
- The loop does not have to be any particular shape.
- RF power can be fed anywhere on the loop.



The Rectangular Loop

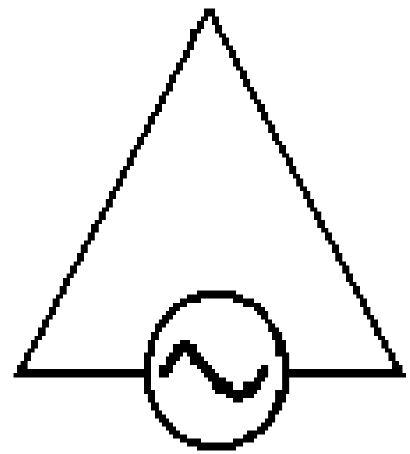
- The total length is approximately 1.02 λ.
- The self impedance is 100 - 130 Ω depending on height.
- The Aspect Ratio (A/B) should be between 0.5 and 2 in order to have $Z_s \sim 120\ \Omega$.
- SWR bandwidth is ~ 4.5% of design frequency.
- Directivity is ~2.7 dBi. Note that the radiation pattern has no nulls. Max radiation is broadside to loop
- Antenna can be matched to 50 Ω coax with 75 Ω λ /4 matching section.

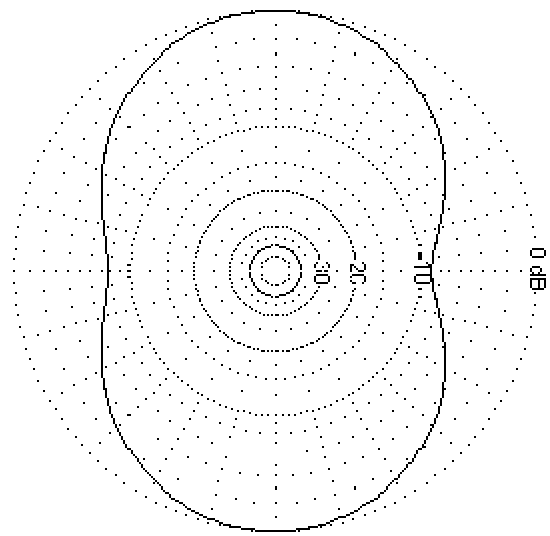




The Delta Loop

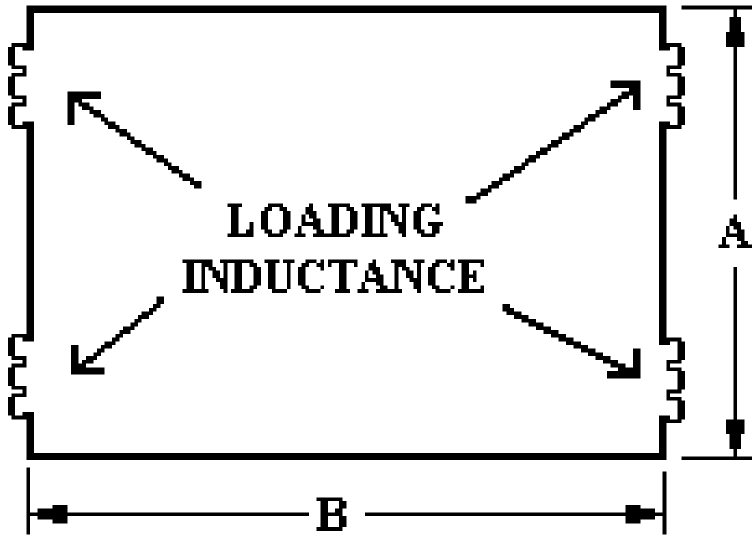
- **A three sided loop is known as a delta loop.**
- **For best results, the lengths of the 3 sides should be approximately equal**
- **The self impedance is 90 - 110 Ω depending on height.**
- **Bandwidth ~ 4 %**
- **Directivity is ~2.7 dBi. Note that the radiation pattern has no nulls. Max radiation is broadside to loop.**
- **Antenna can be matched to 50 Ω coax with 75 Ω λ /4 matching section.**





Reduced Size Loops

- Loops for the low HF bands can be inconveniently large.
- Loading can be used to shorten the perimeter of the loop
- Directivity ~ 2 dBi
- SWR Bandwidth is ~ 2.5% of design frequency
- Radiation pattern is almost omnidirectional
- Input impedance is ~ 150 Ω. Can be matched with 4:1 balun

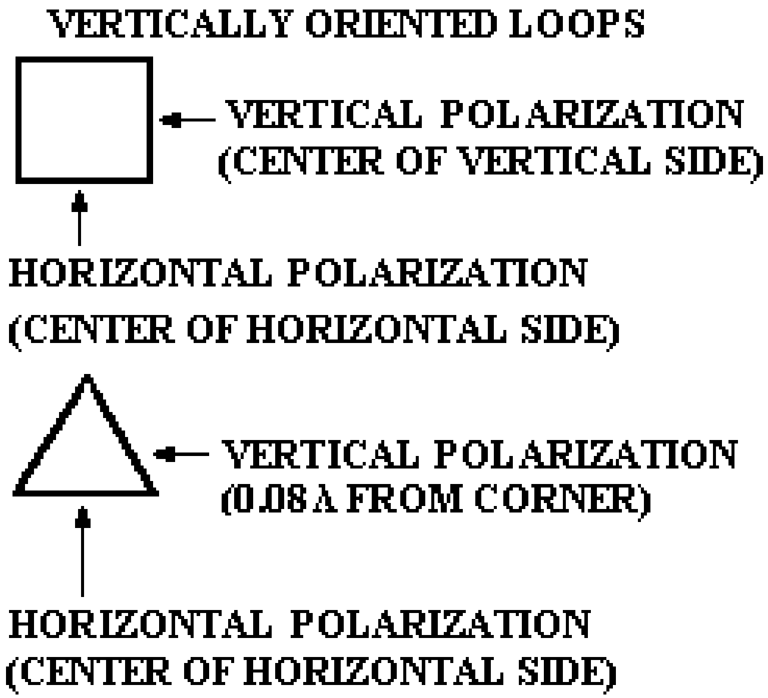


Harmonic Operation of Loops

- A loop antenna is also resonant at integral multiples of its resonant frequency.
- The self impedance of a 1λ loop at these multiples of the resonant frequency is 200 - 300 ohms.
- The directivity is lower on harmonic frequencies
- Vertically oriented loops will have high angles of radiation on harmonic frequencies.
- Horizontally oriented loops will have lower angles of radiation on harmonic frequencies.

Polarization of Loop Antennas

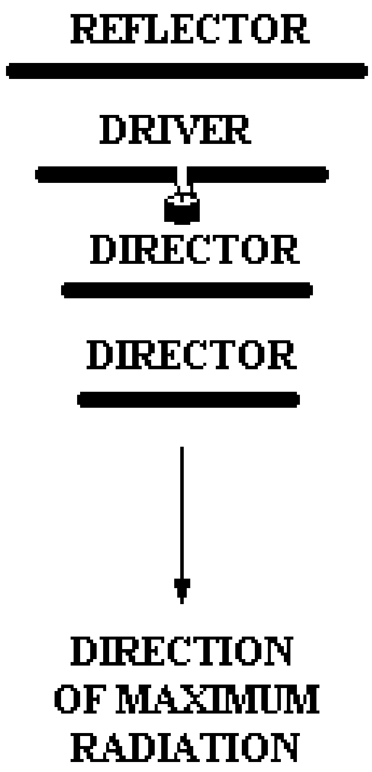
- The RF polarization of a vertically oriented loop may be vertical or horizontal depending on feed position
- Horizontally oriented loops are predominantly horizontally polarized in all cases.
- Vertical polarization is preferred when antenna is low



The Yagi-Uda Array

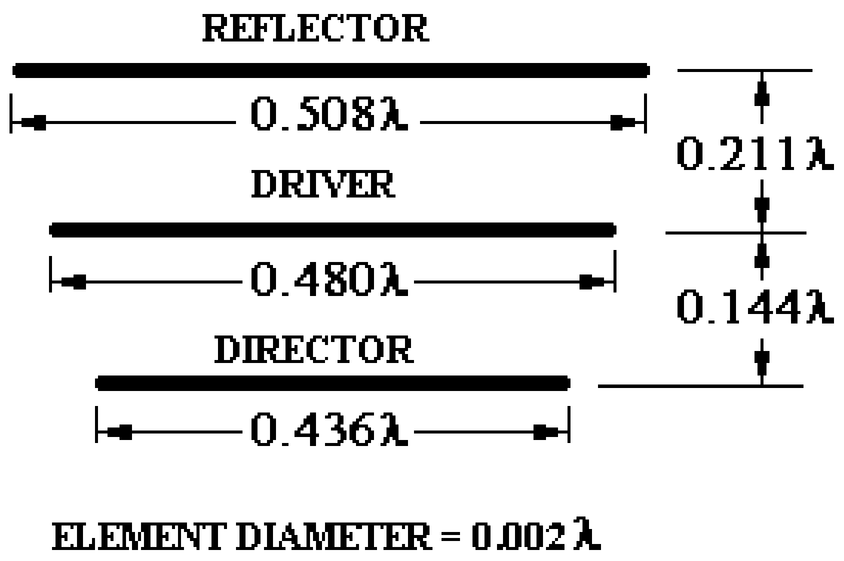
Yagi Fundamentals

- A Yagi-Uda array consists of 2 or more simple antennas (elements) arranged in a line.
- The RF power is fed into only one of the antennas (elements), called the driver.
- Other elements get their RF power from the driver through mutual impedance.
- The largest element in the array is called the reflector.
- There may be one or more elements located on the opposite side of the driver from the reflector. These are directors.



Yagi Array of Dipoles (yagi)

- This type of Yagi-Uda array uses dipole elements
- The reflector is ~ 5% longer than the driver.
- The driver is ~ 0.5λ long
- The first director ~ 5% shorter than the driver, and subsequent directors are progressively shorter
- Interelement spacings are 0.1 to 0.2 λ



Typical yagis (6 m and 10m)

The 2 element Yagi

- **The parasitic element in a 2- element yagi may be a reflector or director**
- **Designs using a reflector have lower gain (~6.2 dBi) and poor FB(~10 dB), but higher input Z (32+j49 Ω)**
- **Designs using a director have higher gain (6.7 dBi) and good FB(~20 dB) but very low input Z (10 Ω)**
- **It is not possible simultaneously to have good Z_{in}, G and FB**

The 3 element Yagi

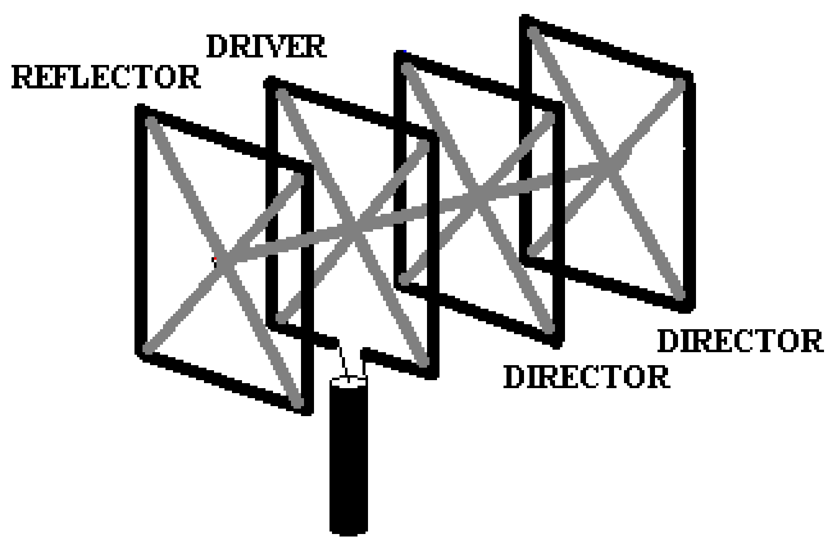
- **High gain designs (G~ 8 dBi) have narrow BW and low input Z**
- **Designs having good input Z have lower gain (~ 7 dBi), larger BW, and a longer boom.**
- **Either design can have FB > 20 dB over a limited frequency range**
- **It is possible to optimize any pair of of the parameters Z_{in}, G and FB**

Larger yagis (N > 3)

- There are no simple yagi designs, beyond 2 or 3 element arrays.
- Given the large number of degrees of freedom, it is possible to optimize BW, FB, gain and sometimes control sidelobes through proper design. (although such designs are not obvious)
- Good yagi designs can be found in the ARRL Antenna Book, or can be created using antenna modeling software

Yagi Array of Loops (quad array)

- This Yagi-Uda array uses rectangular loops as elements.
- The reflector's perimeter is ~ 3% larger than the driver's.
- The driver's perimeter is ~ 1λ
- The first director's perimeter is ~ 3% smaller than the driver's, and additional directors are progressively smaller.
- Interelement spacings are 0.1 to 0.2 λ.



Advantages of a Quad Array

- **Fewer elements are needed - gain of a 2-el quad is almost equal to a 3 el yagi in terms of FB and G**
- **Quad loops can be nested to make a multiband antenna without lossy traps.**
- **The input Z of quads are much higher than yagis, simplifying matching (50 – 90 Ω vs 12 – 40 Ω).**
- **At equal heights, the quad has a slightly lower takeoff angle than a yagi.**
- **Quads can be constructed from readily available materials (bamboo poles, wire).**

Disadvantages of a Quad Array

- **A quad occupies a much larger volume than a yagi of equal performance.**
- **Quad loops are more susceptible to icing damage.**

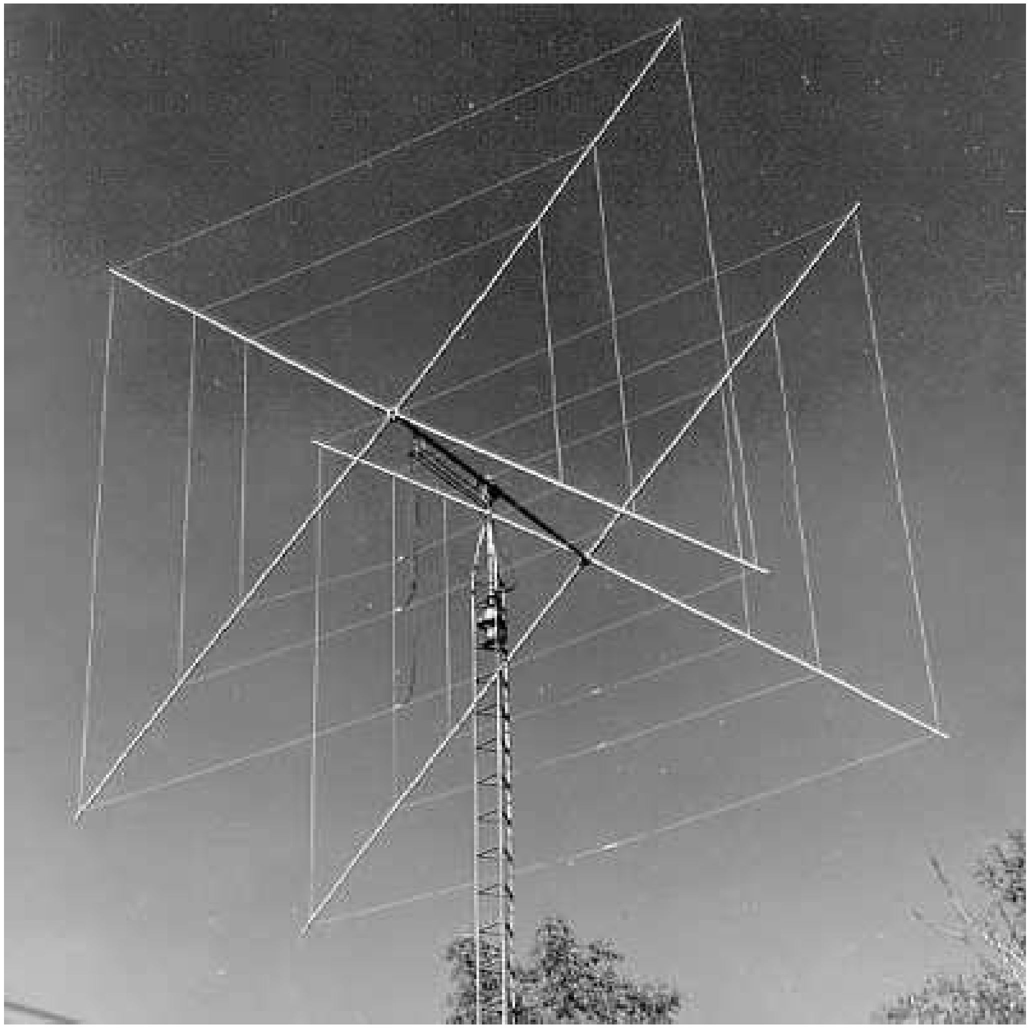
The 2 element Quad

- The parasitic element is a reflector
- Gain is 6 – 7 dBi depending on element separation.
- Zin is ~ 50 Ω for spacing of λ/8 and ~ 100 Ω for spacing of λ/6.
- FB is 15 – 20 dB.

Larger Quads (N>2)

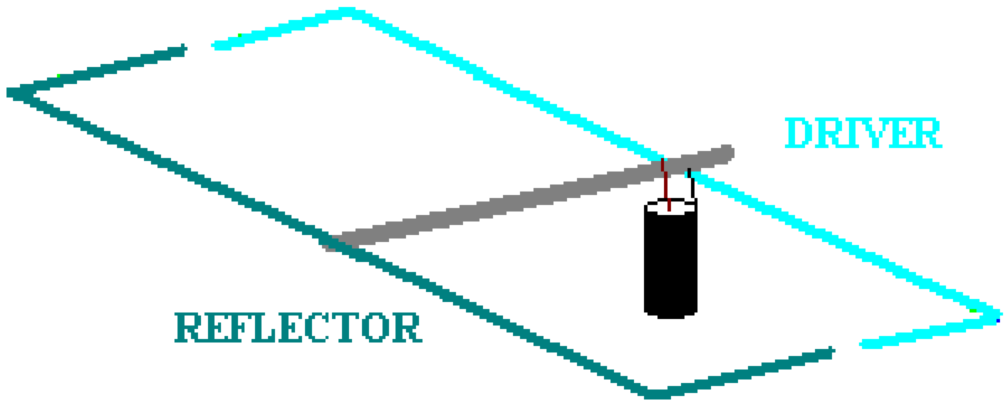
- Gain is 9 dB or, depending on interelement spacing and number of directors
- FB ratio can exceed 20 dB.
- Proper choice of element length results in much larger BW than a comparable yagi
- Optimization of Zin is not needed. Most designs have Zin between 35 and 80 ohms.
- Large quad designs are not as well developed as large yagi designs – more experimentation is required.

2 element 3 band Quad Array



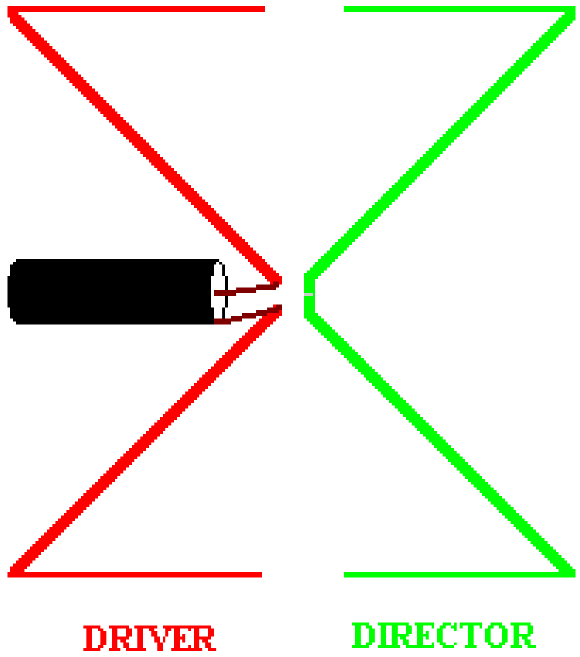
The Moxon Rectangle

- This is a 2-el Yagi-Uda array made from dipoles bent in the shape of a U
- The longer element is the reflector.
- The Input Z is 50 Ω – no matching network is needed.
- Gain ~ 6 dB, FB~ 25-30 dB (better than 2 el yagi or quad)
- More compact than yagi or quad
- Easily constructed from readily available materials



The X-Beam

- This is a 2-el Yagi-Uda array made from dipoles bent in the shape of a M
- The longer element is the driver, and the shorter is the director
- The Input Z is 50 Ω – no matching network is needed.
- Gain ~ 5 - 6 dB, FB~ 12-18 dB (similar to 2-el yagi)
- More compact than yagi or quad
- Easily constructed from readily available materials



Antenna Design Tables

Design Table: Short Dipole

λ/4 dipole with inductive loading

BAND	LENGTH OF ANTENNA (# 14 copper wire)	INDUCTANCE OF THE LOADING COIL (μH)
160 (1.83 MHz)	133 ft 10 in	90.0
80 (3.6 MHz)	67 ft 2 in	43.1
75 (3.9 MHz)	62 ft 0 in	39.4
40 (7.1 MHz)	34 ft 0 in	20.2

0.36 λ dipole with linear loading

BAND	LENGTH A (# 14 wire)	LENGTH B (# 14 wire)	LENGTH C (# 14 wire)	WIRE SPACING)
80 (3.6 MHz)	32 ft 3 in	16 ft 1 in	32 ft 5 in	4.5 in
75 (3.9 MHz)	30 ft 1 in	15 ft 1 in	30 ft 2 in	4.0 in

Design Height: 60 ft. Feed point impedance: 40 Ω

Design Table: Half Wave Dipole

BAND	LENGTH (# 14 copper wire)
160 (1.83 MHz)	255 ft 9 in
80 (3.8 MHz)	123 ft 2 in
40 (7.1 MHz)	65 ft 11 in
30	46 ft 3 in
20	33 ft 0 in
17	25 ft 10 in
15	22 ft 1 in
12	18 ft 9 in
10 (28.4 MHz)	16 ft 6 in

Design Table: Double Zepp

BAND	LENGTH OF ANTENNA (# 14 copper wire)	LENGTH OF MATCHING SECTION (450 Ω LINE VF = 0.9)
160 (1.83 MHz)	531 ft 8 in	120 ft 3 in
80 (3.8 MHz)	256 ft 1 in	57 ft 11 in
40 (7.1 MHz)	137 ft 1 in	31 ft 0 in
30	96 ft 1 in	21 ft 9 in
20	68 ft 8 in	15 ft 6 in
17	53 ft 9 in	12 ft 2 in
15	45 ft 10 in	10 ft 4 in
12	39 ft 0 in	8 ft 10 in
10 (28.4 MHz)	34 ft 3 in	7 ft 9 in

Design Table: Extended Double Zepp

BAND	LENGTH OF ANTENNA (# 14 copper wire)	LENGTH OF MATCHING SECTION (450 Ω LINE VF = 0.9)
160 (1.83 MHz)	677 ft 7 in	83 ft 7 in
80 (3.8 MHz)	326 ft 4 in	40 ft 3 in
40 (7.1 MHz)	174 ft 8 in	21 ft 7 in
30	122 ft 6 in	15 ft 1 in
20	87 ft 6 in	10 ft 10 in
17	68 ft 6 in	8 ft 6 in
15	58 ft 5 in	7 ft 2 in
12	49 ft 8 in	6 ft 2 in
10 (28.4 MHz)	43 ft 8 in	5 ft 5 in

Design Table: 3λ/2 Dipole

BAND	LENGTH OF ANTENNA (# 14 copper wire)	LENGTH OF MATCHING SECTION (RG11 Z=75 Ω VF =0.66)
160 (1.83 MHz)	797 ft 10 in	88 ft 9 in
80 (3.8 MHz)	384 ft 3 in	42 ft 9 in
40 (7.1 MHz)	205 ft 8 in	22 ft 11 in
30	144 ft 2 in	16 ft 0 in
20	103 ft 0 in	11 ft 6 in
17	80 ft 8 in	9 ft 0 in
15	68 ft 9 in	7 ft 8 in
12	58 ft 6 in	6 ft 6 in
10 (28.4 MHz)	51 ft 5 in	5 ft 9 in

Design Table: Ground Radials for λ /4 Vertical Monopole

No OF RADIALS	LENGTH OF RADIALS (in wavelengths)	GROUND RESISTANCE (ohms)
4	0.0625	28
8	0.08	20
16	0.10	16
24	0.125	10
36	0.15	7
60	0.2	4
90	0.25	1
120	0.40	<<1

- **Radial wires may be in contact with earth or insulated**
- **Wire gauge is not important; small gauge wire such as #24 may be**
- **The radial system may be elevated above the earth (this is known as a counterpoise system)**

Design Table: λ /4 Vertical Monopole

BAND	LENGTH OF MONOPOLE (#14 wire)
160 (1.83 MHz)	127 ft 10 in
80 (3.60 MHz)	65 ft 0 in
75 (3.90 MHz)	60 ft 0 in
40 (7.10 MHz)	33 ft 0 in
30	23 ft 1 in
20	16 ft 6 in
17	12 ft 11 in
15	11 ft 0 in
12	9 ft 5 in
10 (28.4 MHz)	8 ft 3 in

Design Table: $\lambda/2$ Vertical

BAND	LENGTH OF MONOPOLE (#14 wire)
160 (1.83 MHz)	255 ft 8 in
80 (3.60 MHz)	130 ft 0 in
75 (3.90 MHz)	120 ft 0 in
40 (7.10 MHz)	66 ft 0 in
30	46 ft 2 in
20	33 ft 0 in
17	25 ft 10 in
15	22 ft 0 in
12	19 ft 0 in
10 (28.4 MHz)	16 ft 6 in

Design Table: Short(λ/8) Vertical Monopoles

BAND	LENGTH OF MONOPOLE (#14 wire)
160 (1.83 MHz)	67 ft 2 in
80 (3.60 MHz)	34 ft 2 in
75 (3.90 MHz)	31 ft 6 in
40 (7.10 MHz)	17 ft 4 in

For base loading an inductive reactance of j550 Ω is req'd
For center loading and inductive reactance of j1065 Ω is req'd

Design Table: Inverted L

BAND	LENGTH A	LENGTH B	MATCHING CAPACITANCE
160 (1.83 MHz)	67 ft 2 in	100 ft 9 in	410 pF
80 (3.6 MHz)	34 ft 2 in	51 ft 3 in	220 pF
75 (3.9 MHz)	31 ft 6 in	47 ft 3 in	200 pF
40 (7.1 MHz)	17 ft 3 in	26 ft 0 in	110 pF

Design Table: Rectangular and Delta Loop

BAND	LENGTH OF ANTENNA (# 14 copper wire)	LENGTH OF MATCHING SECTION (RG-11 75 Ω VF = 0.66)
160 (1.83 MHz)	549 ft 4 in	88 ft 8 in
80 (3.6 MHz)	279 ft 2 in	45 ft 1 in
75 (3.9 MHz)	257 ft 8 in	41 ft 7 in
40 (7.1 MHz)	141 ft 7 in	22 ft 7 in
30	99 ft 1 in	16 ft 1 in
20	70 ft 9 in	11 ft 5 in
17	55 ft 6 in	8 ft 11 in
15	47 ft 4 in	7 ft 8 in
12	40 ft 4 in	6 ft 6 in
10 (28.4 MHz)	35 ft 5 in	5 ft 8 in

Design Table: Inductively Loaded Loop

BAND	LENGTH A	LENGTH B	LOADING INDUCTANCE (4)
160 (1.83 MHz)	60 ft 0 in	90 ft 0 in	63 μH
80 (3.6 MHz)	35 ft 6 in	45 ft 9 in	30 μH
75 (3.9 MHz)	28 ft 2 in	42 ft 3 in	27 μH
40 (7.1 MHz)	15 ft 5 in	23 ft 2 in	15 μH

The loop is vertically oriented, with the lower wire approximately 10 feet above ground

Design Table: 2-el yagis

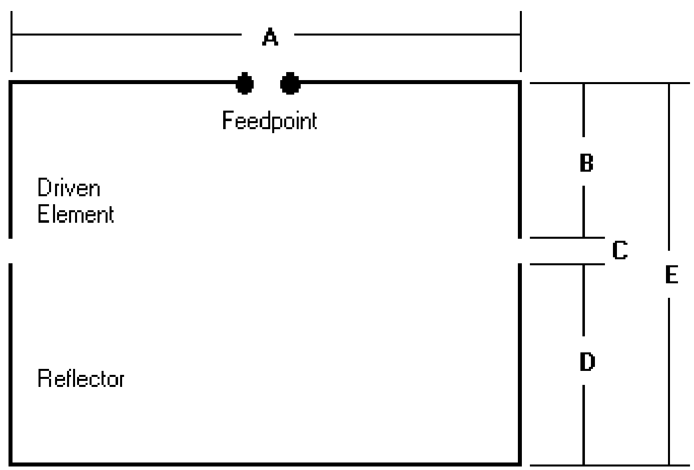
		Element Lengths (in)			Element Pos. (in)		
Band	Element Dia. (in)	Ref.	Drv.	Dir.	Drv.	Dir.	Notes
6m	0.5		117.4	108.2		11.6	G=6.7dB FB=21dB Z=9
6m	0.5	116.2	114.5		34		G=6.2dB FB=10dB Z=32+j49
10m	0.875		207	191		20.5	G=6.7dB FB=21dB Z=9
10m	0.875	205	202		52		G=6.2dB FB=10dB Z=32+j49
12m	1.00		235.5	217.5		23.5	G=6.7dB FB=21dB Z=9
12m	1.00	233.5	230		59		G=6.2dB FB=10dB Z=32+j49
15m	1.125		277	256		27.5	G=6.7dB FB=21dB Z=9
15m	1.125	274.5	270.5		70		G=6.2dB FB=10dB Z=32+j49
17m	1.375		330	305		33	G=6.7dB FB=21dB Z=9
17m	1.375	327	322		83		G=6.2dB FB=10dB Z=32+j49
20m	1.75		414	382		41	G=6.7dB FB=21dB Z=9
20m	1.75	410	404		104		G=6.2dB FB=10dB Z=32+j49

Design Table: 3-el yagis

		Element Lengths (in)			Element Pos. (in)		
Band	Element Dia. (in)	Ref.	Drv.	Dir.	Drv.	Dir.	Notes
6m	0.5	119.75	113	103	49.5	83.5	G=7.4dB FB=24dB Z=45
6m	0.5	115.25	113.5	107.25	32	64	G=8.0dB FB=38dB Z=15
10m	0.875	210.5	199.5	181	87	147	G=7.4dB FB=24dB Z=45
10m	0.875	204	201	190	57	114	G=8.0dB FB=38dB Z=15
12m	1.00	240.5	226.75	206.75	99.5	168	G=7.4dB FB=24dB Z=45
12m	1.00	232	228.75	216	65	130	G=8.0dB FB=38dB Z=15
15m	1.00	282.5	266.5	243	117	197	G=7.3dB FB=24dB Z=45
15m	1.00	273	269	254	76.5	153	G=7.9dB FB=38dB Z=17
17m	1.25	331	312	285	137	231	G=7.3dB FB=24dB Z=45
17m	1.25	319	305	298	89	179	G=7.9dB FB=34dB Z=15
20m	1.375	423	399	364	175	295	G=7.3dB FB=24dB Z=45
20m	1.375	423	399	364	175	295	G=8.0dB FB=38dB Z=15

Design Table: Moxon Rectangle

		Dimensions (in)				
Band	Element Dia.	A	B	C	D.	E
2m	#14	29.25	4.125	1.125	5.5	10.75
6m	#14	85.5	12.625	2.625	16	31.25
10m	#14	150.75	22.75	4.125	28.125	55
12m	#14	172.25	26	4.75	32	62.75
15m	#14	202.75	30.75	5.5	37.75	74
17m	#14	238	36.25	6	44.25	86.5
20m	#14	303	46.5	7.5	56	110



Design Table: X-Beam

	Element Dimensions (in)		
Band	A	B	C
2m	16.000	8.753	7.625
6m	46.750	25.500	22.125
10m	82.125	44.875	39.000
12m	93.750	51.250	44.500
15m	110.250	60.250	25.250
17m	129.250	70.625	61.250
20m	165.000	90.125	78.250