PRINCIPLES OF DIRECTIONAL ANTENNAS

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Foothill Amateur Radio Society
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AA6PZ – Amateur Ratio

Continuously licensed since 1963

Passed 20 wpm for Extra Exam using the FCC examiner's straight key

Published articles include:

Computerized Contest Duplicate Checking, QST

Build the AA6PZ Power Charger, QST cover award reprinted in ARRL Handbook

Handi-Antennas Ham Radio May 1983

AA6PZ – Career

MSEE, Purdue University

29 years designing microwave test equipment for Hewlett Packard

Currently independent consultant for medical and scientific devices

Chairman of local chapter of Antennas and Propagation Society of IEEE

AA6PZ – Amateur Radio

Conducted license classes.

Taught Radio Merit Badge for Boy Scouts

Booth duty at Maker Faire.

If you do one new thing with ham radio this year, make it sharing our hobby!

Antenna Philosophy

I’ve always thought that antennas were fun projects because typically all you needed was wire and insulators.   You don’t have to round up a bunch of different resistors and IC’s of various types and values.

I used to think that “bigger was better”. If it didn’t occasionally blow down, it wasn’t big enough. That was before moving to California and our small lots that don’t have room for an antenna to fall down “safely.”

This Presentation Will Cover:

What makes antennas directional.

Using spread sheet calculations, not specialized programs

Hopefully by the end of the hour, what happens inside the programs will be less of a mystery.

This Presentation Will Cover This

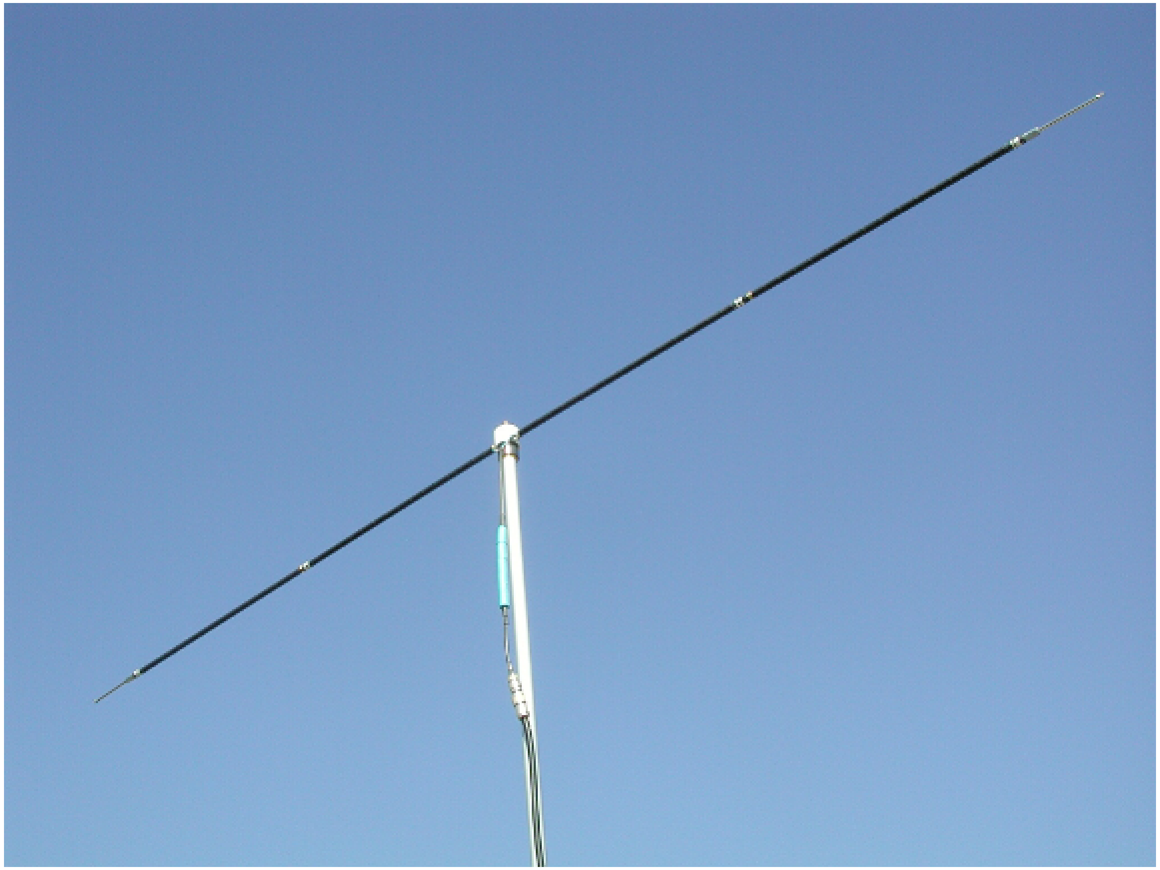
This Presentation Will Cover This

Where is this?

This Presentation Will Cover This

KGO AM by Dumbarton Bridge

This Presentation Will Cover This



This Presentation Will Cover This

This Presentation Will Cover This

Not This

Not This

Not This

This Presentation is About Directionality

I am going to focus on directional patterns

IMHO that the most important feature of antennas.

Some people are interested in matching. If all you want is a "perfect" match there are many possibilities including:

- antenna tuners
- 50 Ohm resistor

“Ideal” Unit Antenna

- Straight conductor with uniform current

“Ideal” Unit Antenna

- Straight conductor with uniform current
- Length << ¼ wavelength

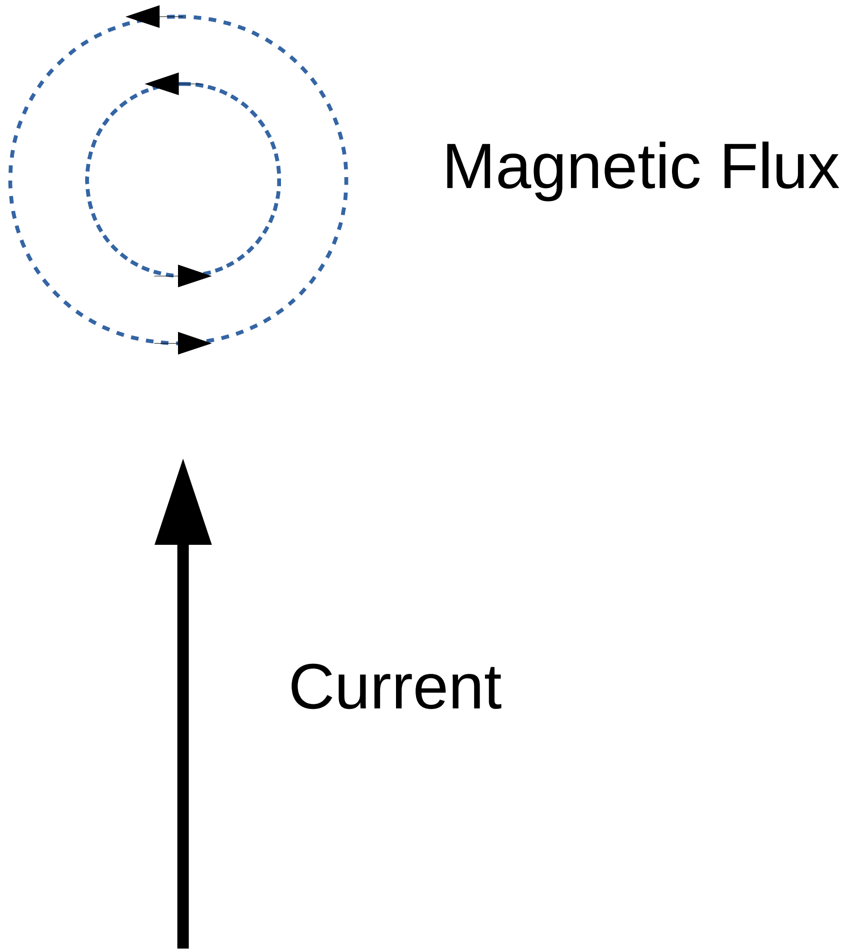
“Ideal” Unit Antenna

- Straight conductor with uniform current.
- Length << ¼ wavelength
- Easy to analyze.

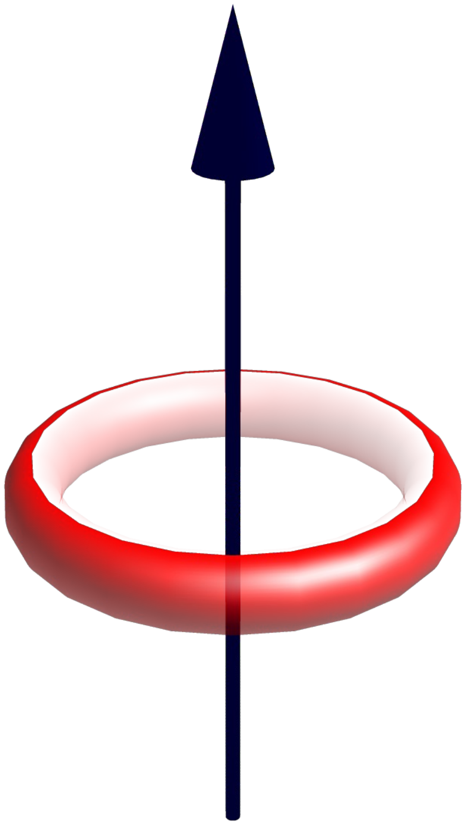
“Ideal” Unit Antenna

- Straight conductor with uniform current.
- Length << ¼ wavelength
- Easy to analyze.
- Magnetic field forms concentric circles around a wire carrying current.

Magnetic field forms concentric circles around the wire.



Magnetic field forms concentric circles around the wire.



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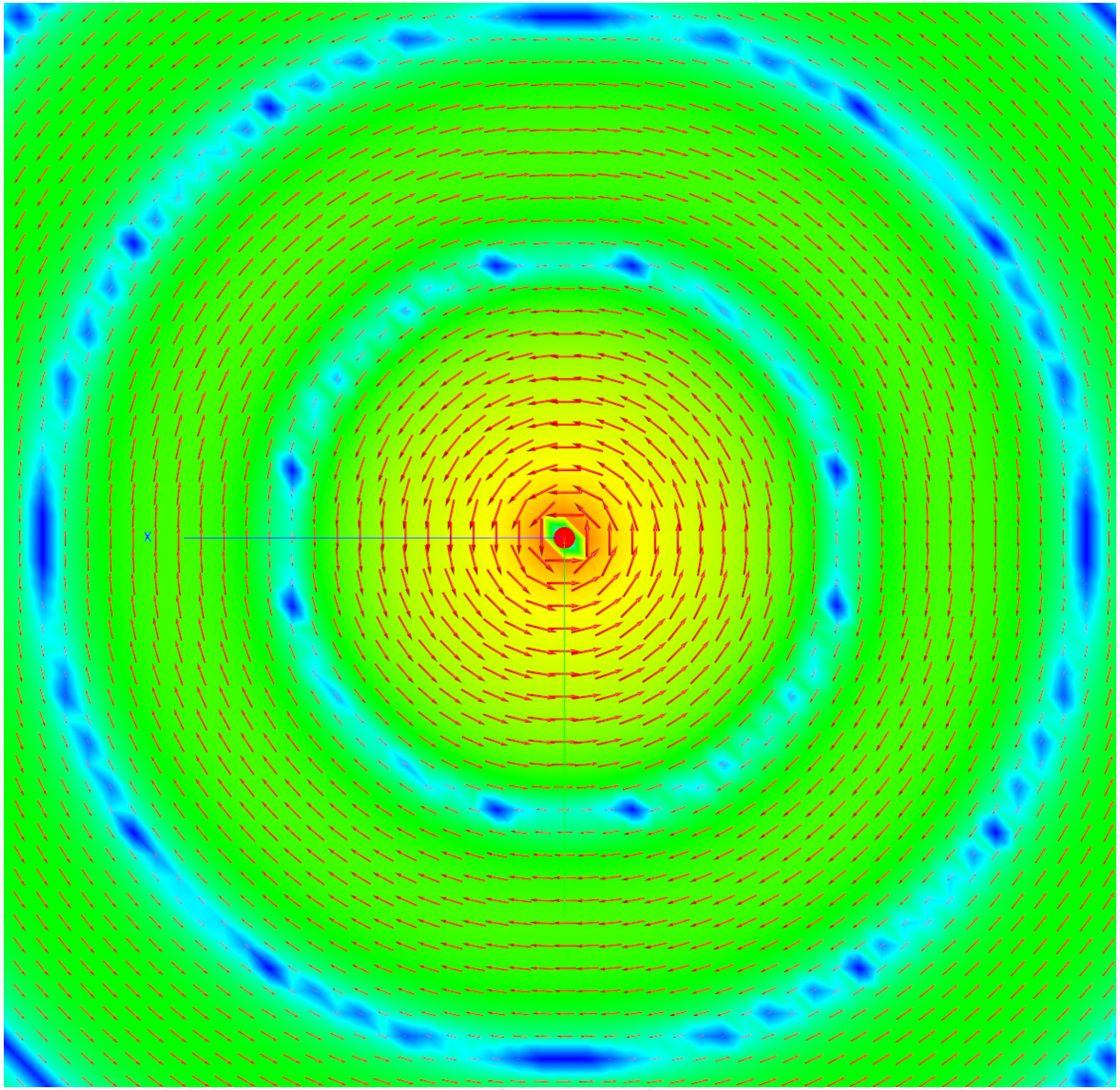


KI6BDR: TNX FR graphics

Note The Fields Alternate Directions Every Half Wavelength

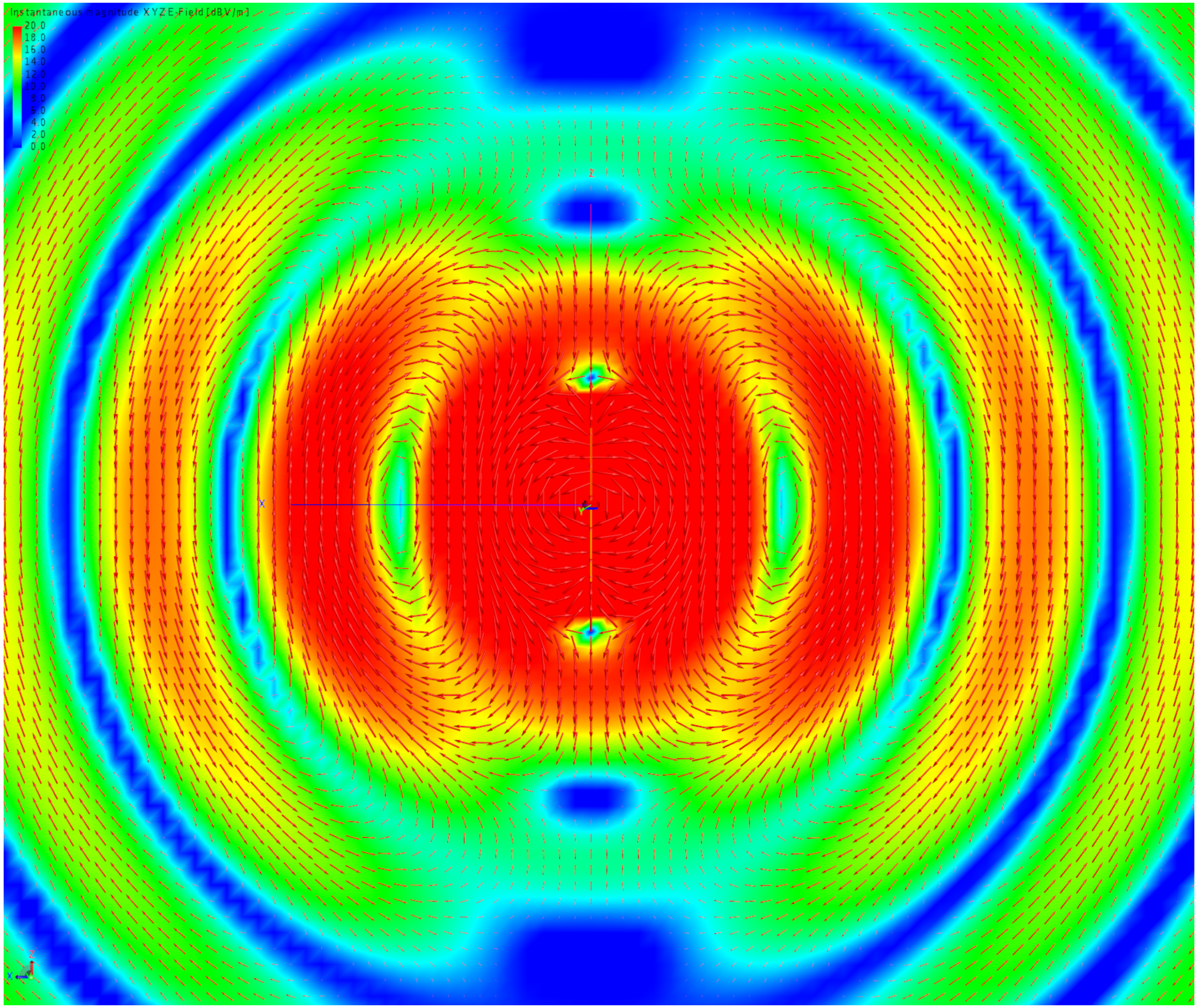
“Easy” to Model Antenna From Current and Magnetic Field

Magnetic field forms concentric circles a wire carrying current.

It is easy to define current at any place for analysis.

It is possible to measure current with an RF ammeter.

Electric Field Is More Complicated



KI6BDR: TNX FR graphics

Electric Field Is More Complicated

The electric field shape is not trivial.

Voltage is measured between 2 points.

How might one measure the voltage between the ends of a dipole?

The voltage will be affected by the geometry at the end of the conductor, but this will have minimal effect on radiation.

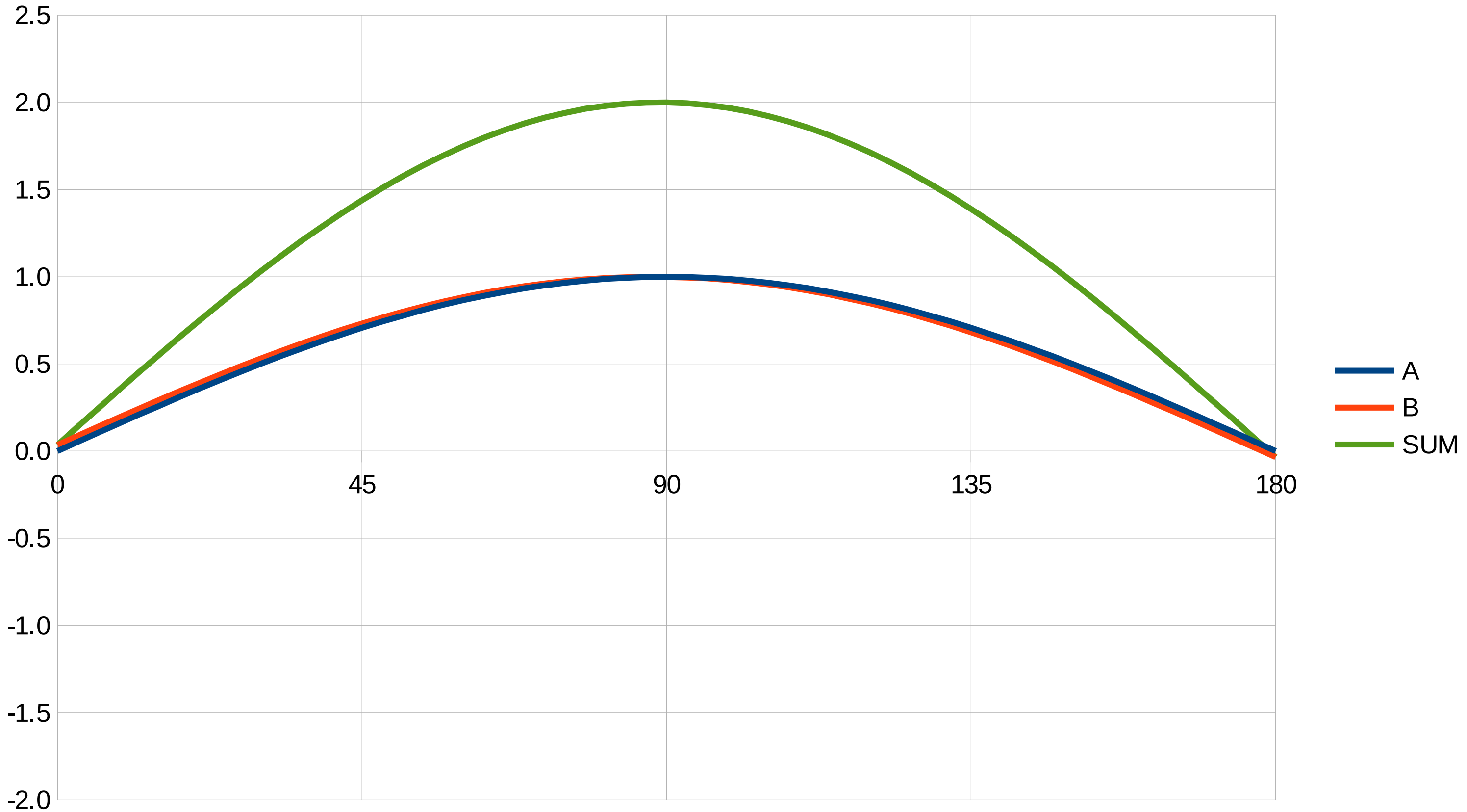
“Ideal” Unit Antenna

- Magnetic field forms concentric circles a wire carrying current.
- We can see by inspection that the fields will be symmetrical around the axis of the conductor.
- What about the other directions?

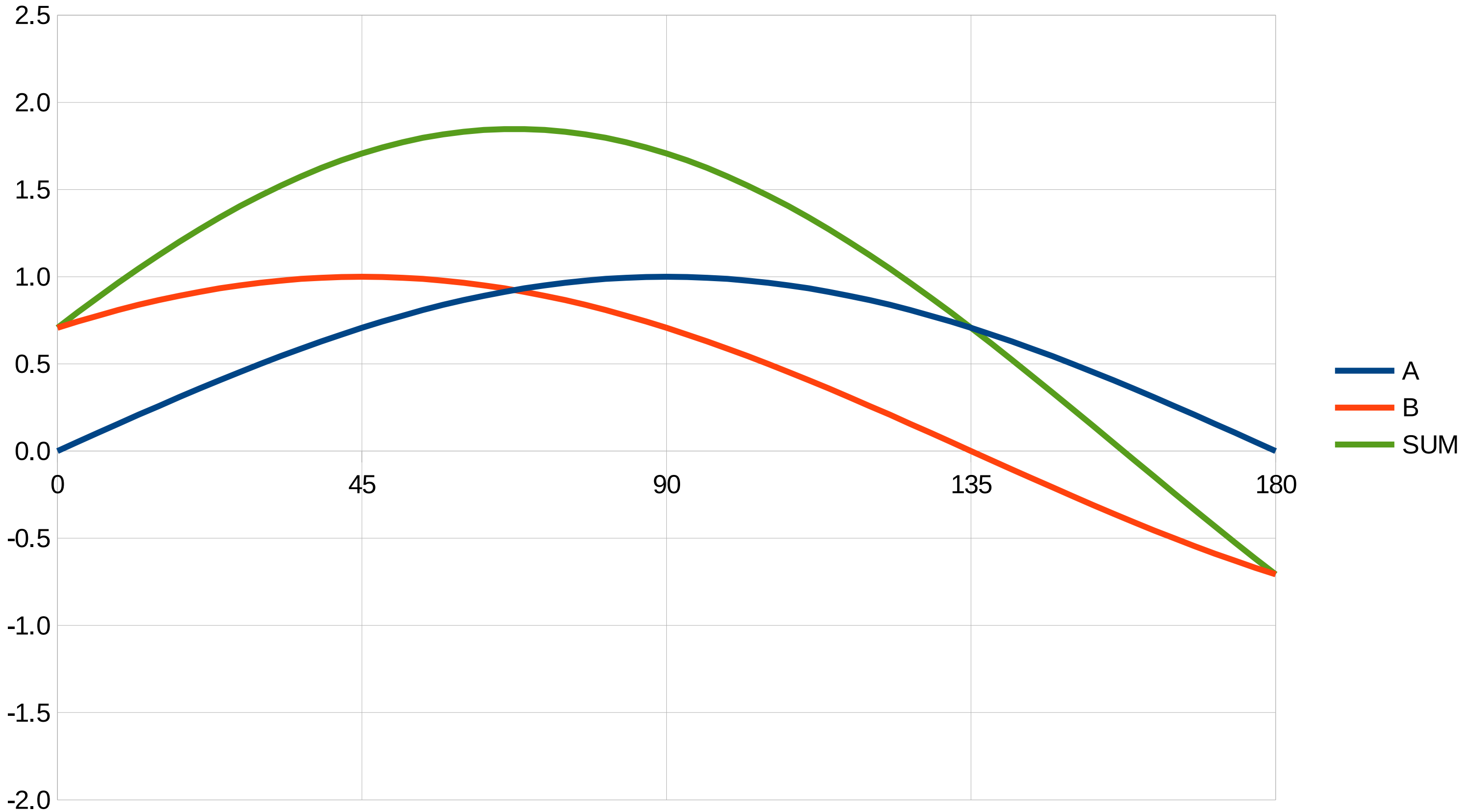
Vector Addition

- Take two sine waves of equal amplitude.
- When added, the result depends on the phase.
- If the signals are in phase, the result is double.
- If the signals are out of phase, the result is zero.

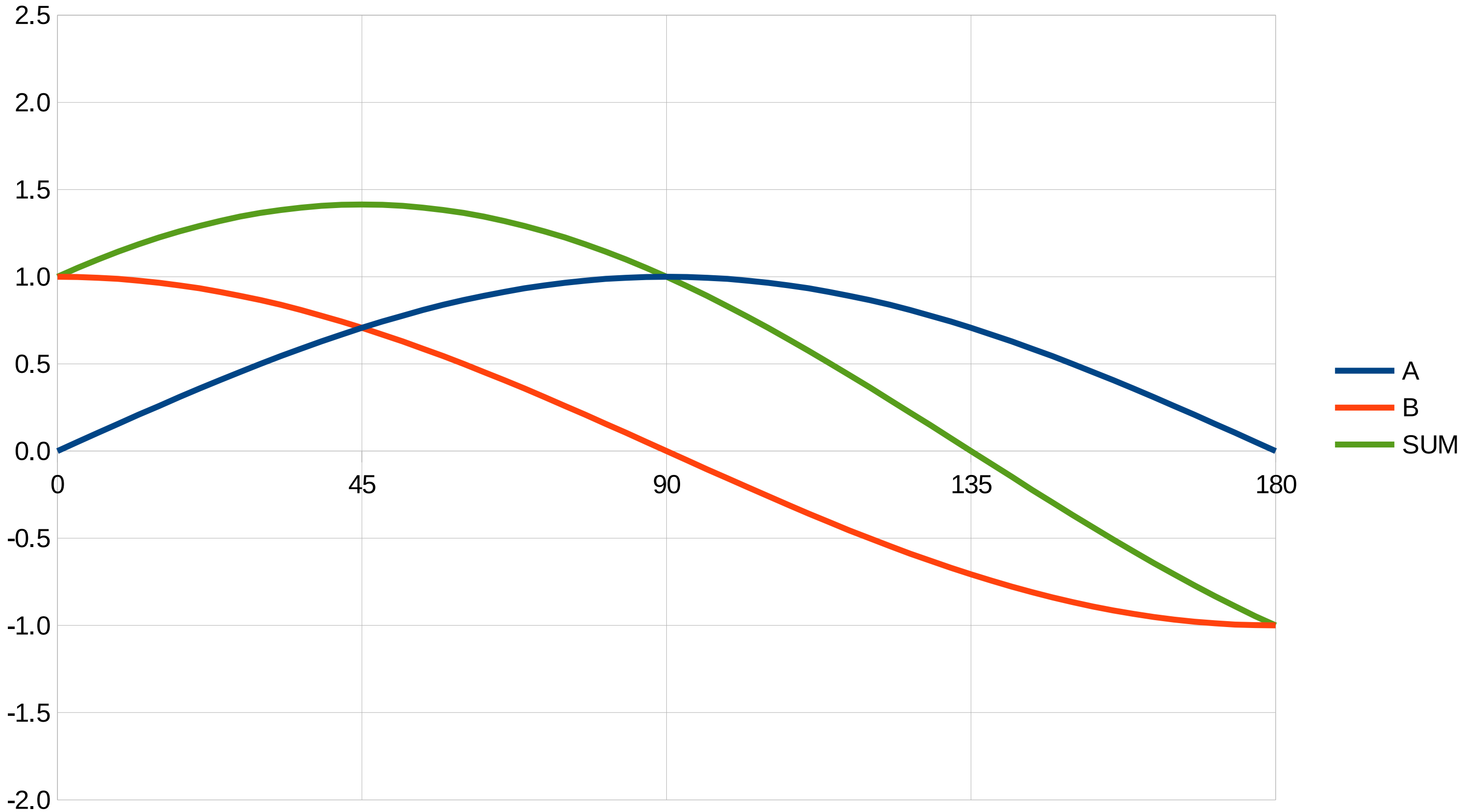
Vector Addition
In Phase



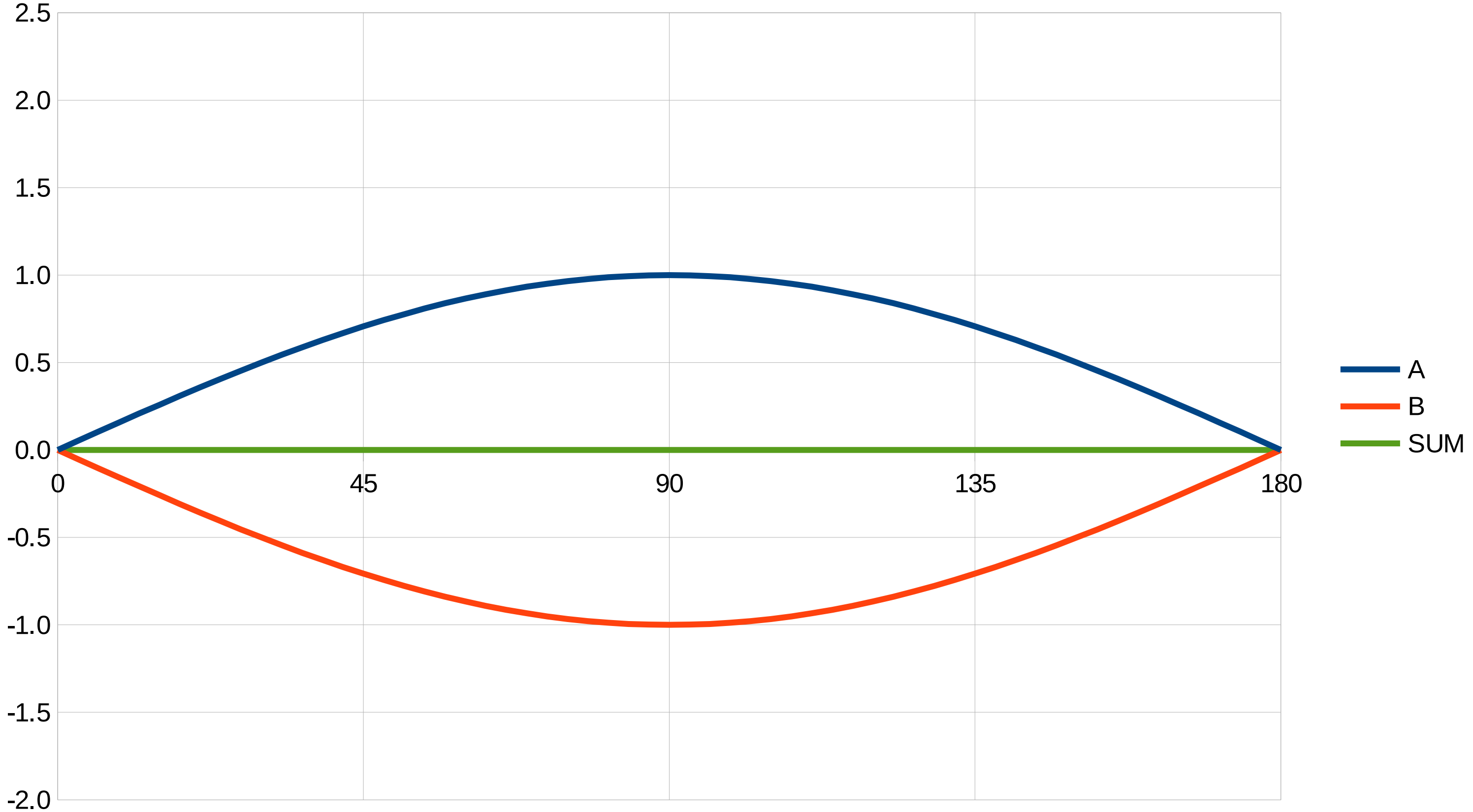
Vector Addition
45 Degree Offset



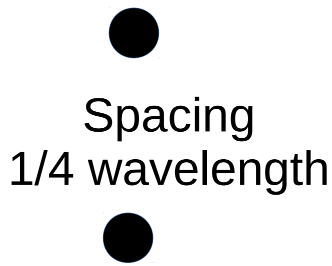
Vector Addition
90 Degree Offset

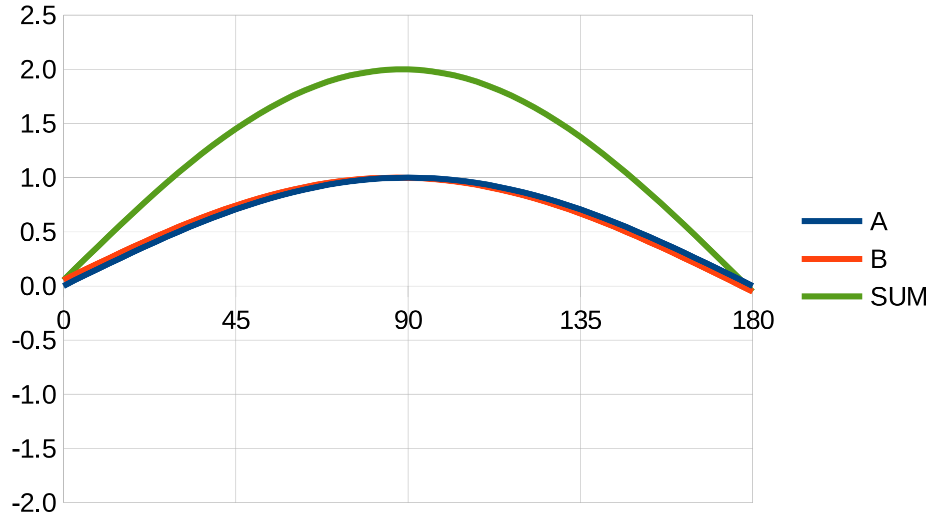


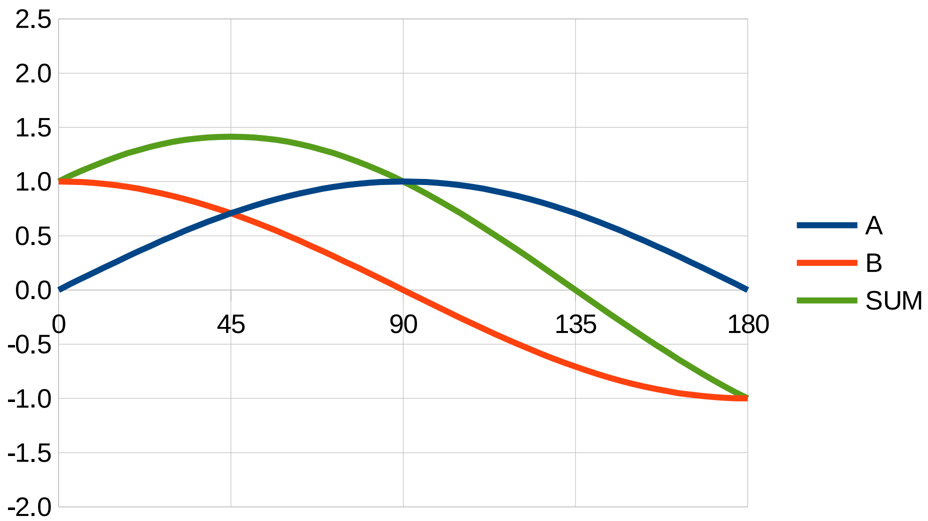
Vector Addition
180 Degree Offset



Two Unit Antennas







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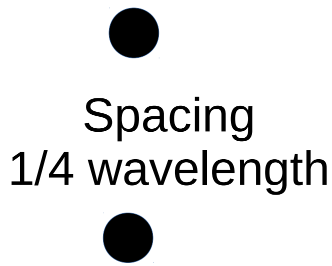

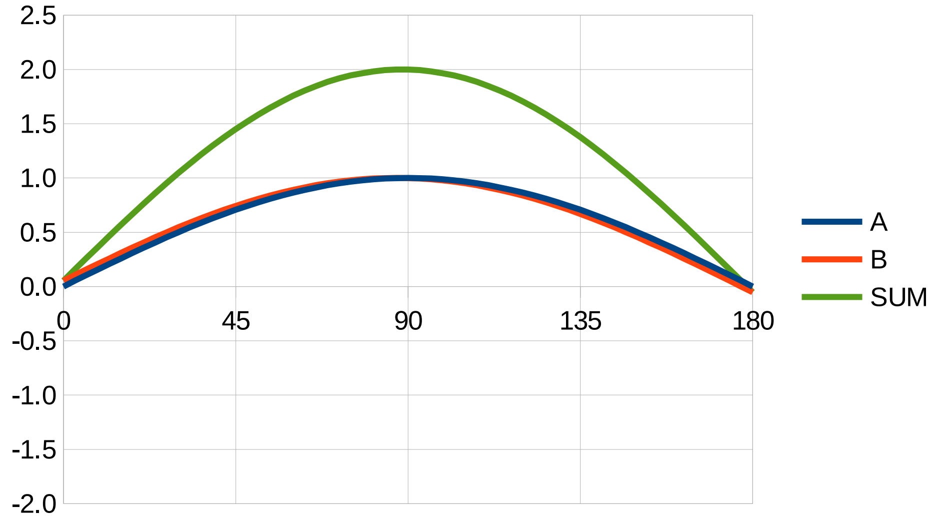

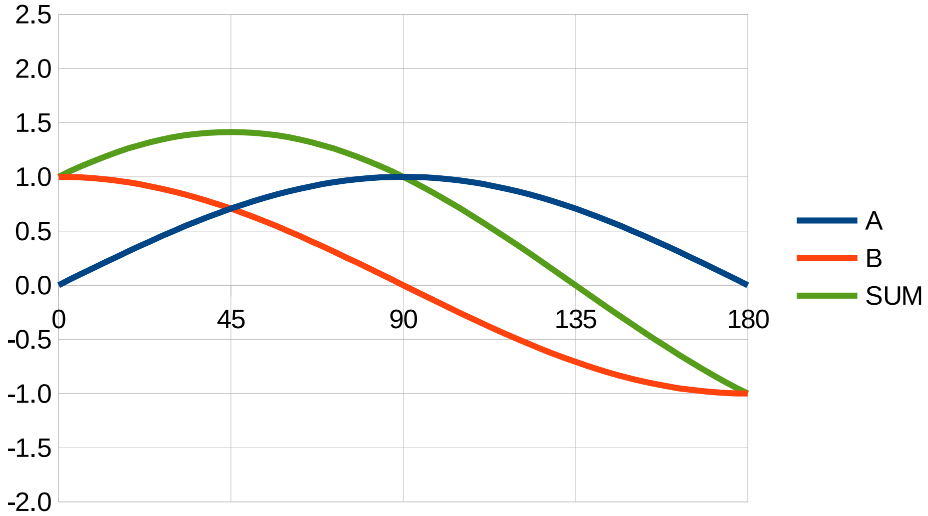

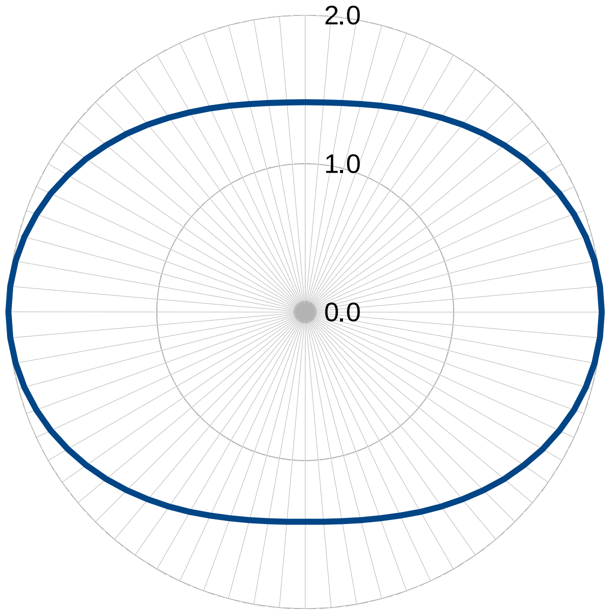

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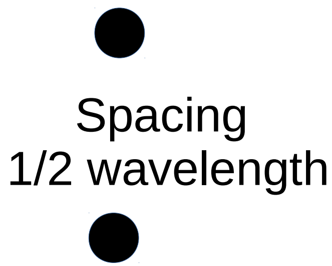
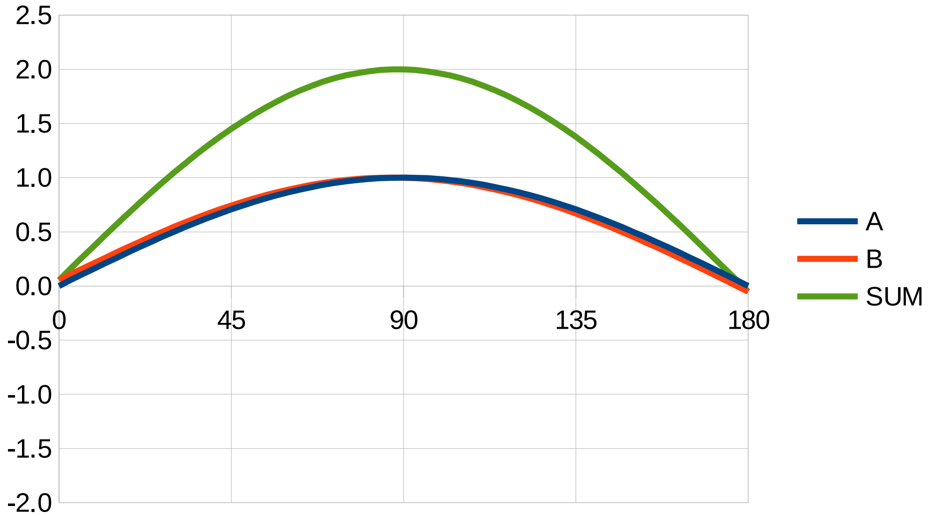
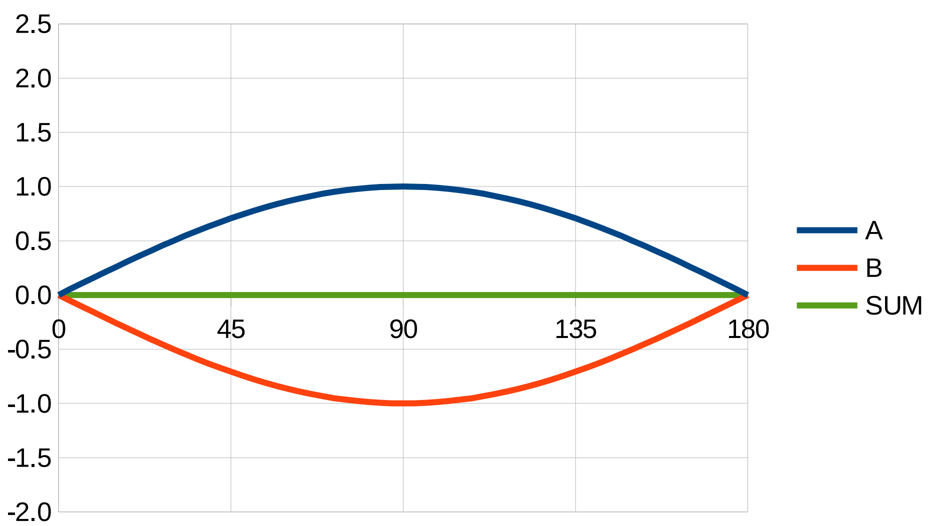
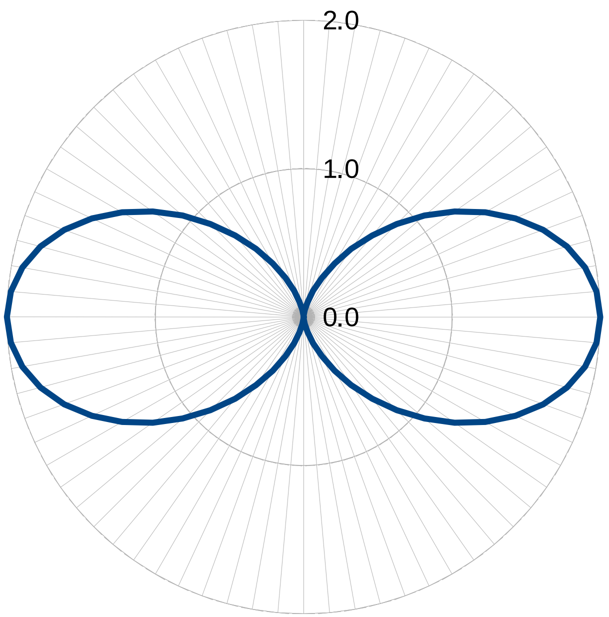




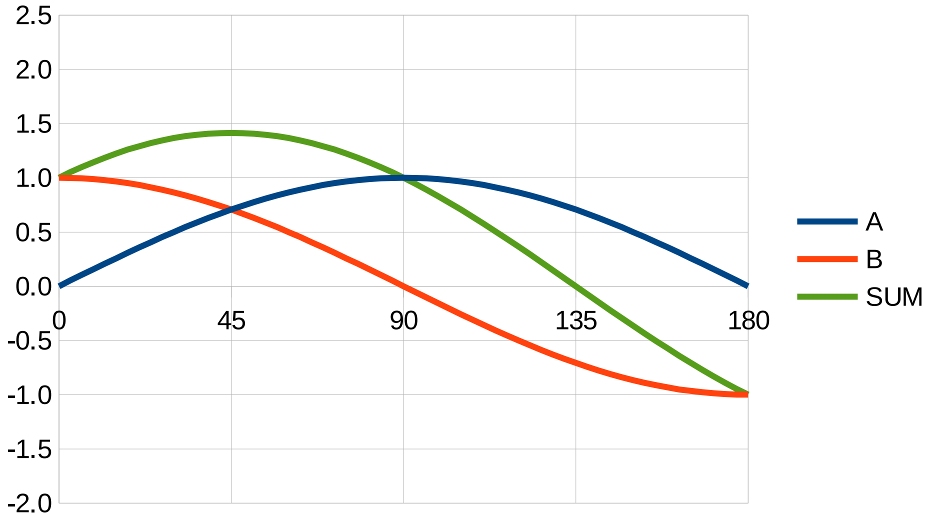


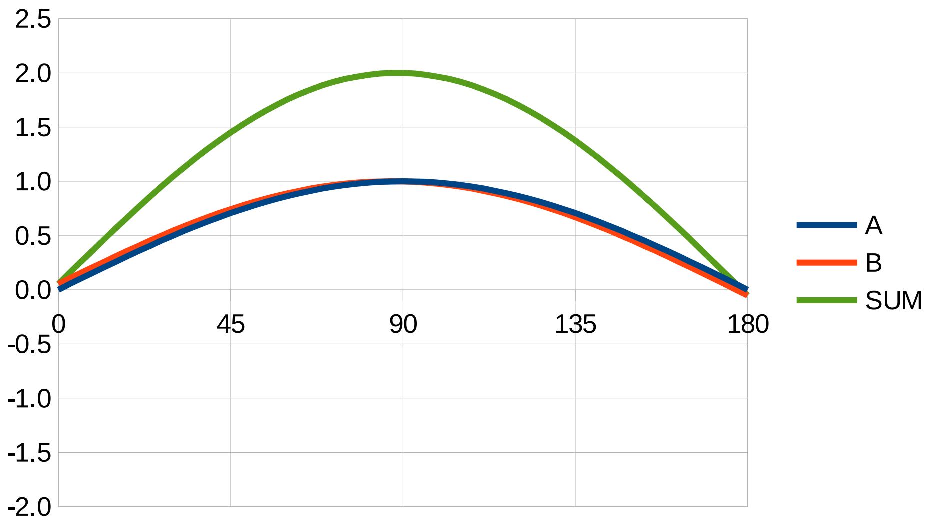


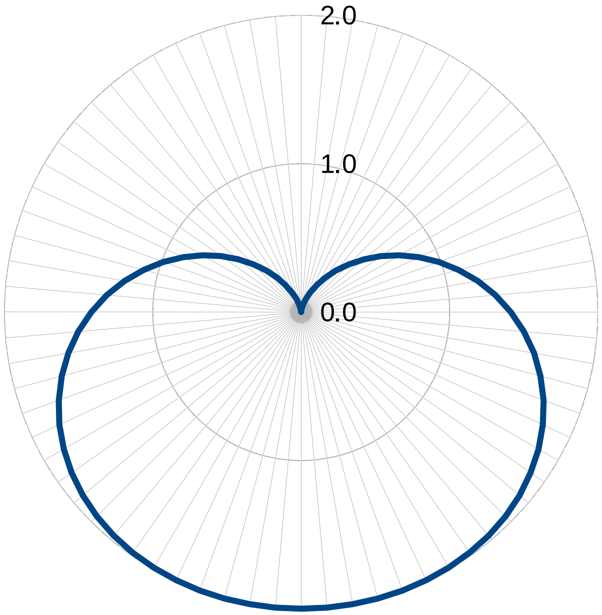
2 Unit Antennas

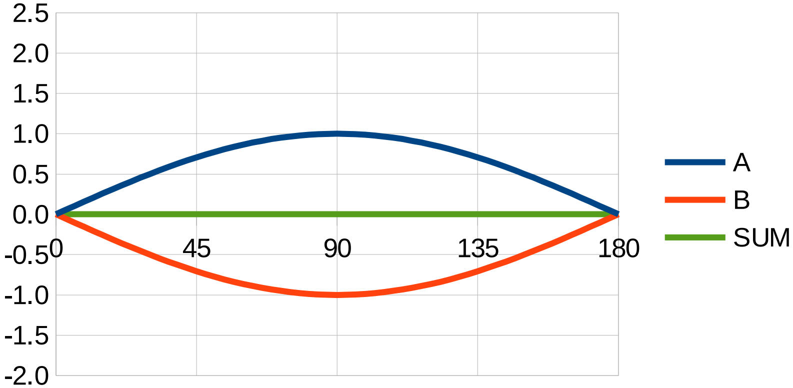
Spacing
1/4 wavelength

Phase Shift
90 Degrees

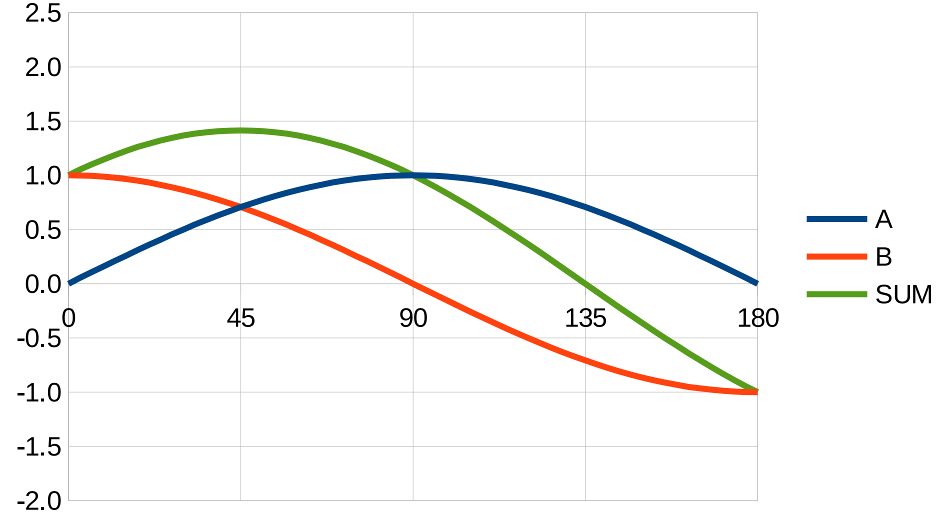






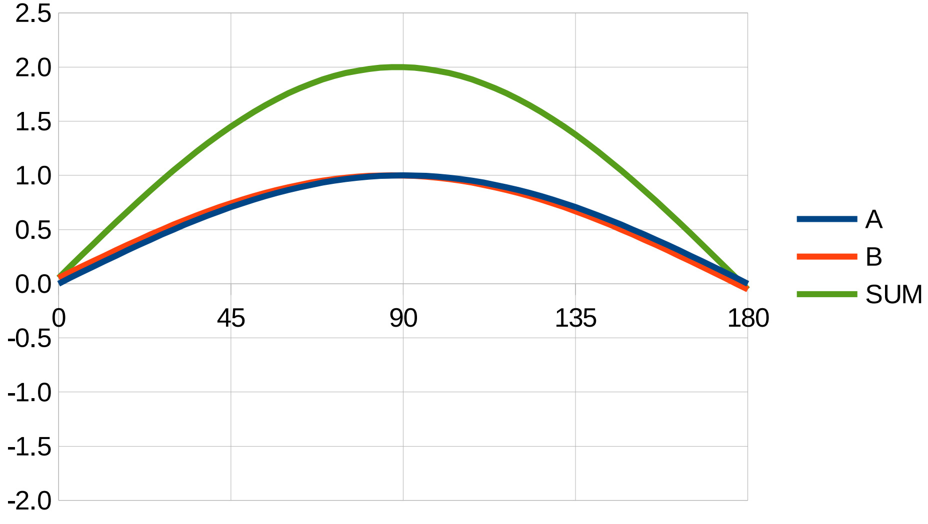


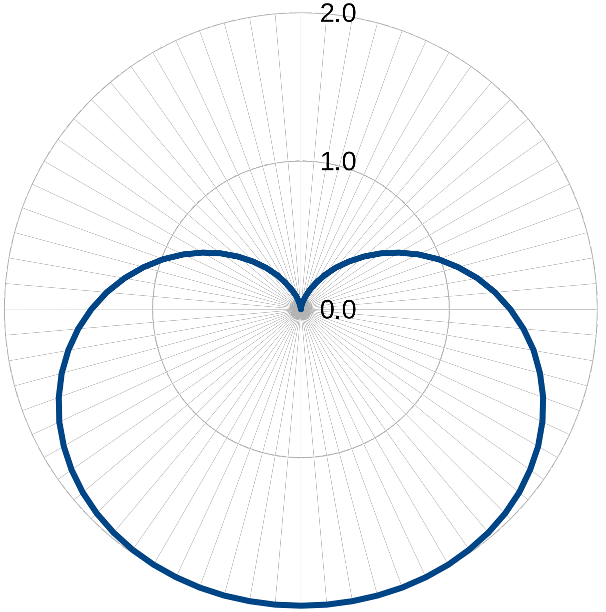
it Antennas



Spacing
1/4 wavelength

Phase Shift
90 Degrees

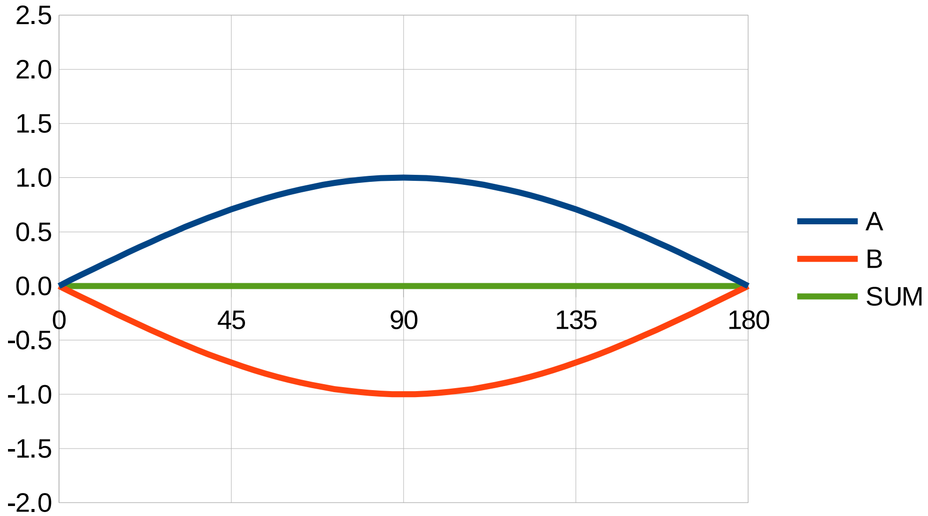


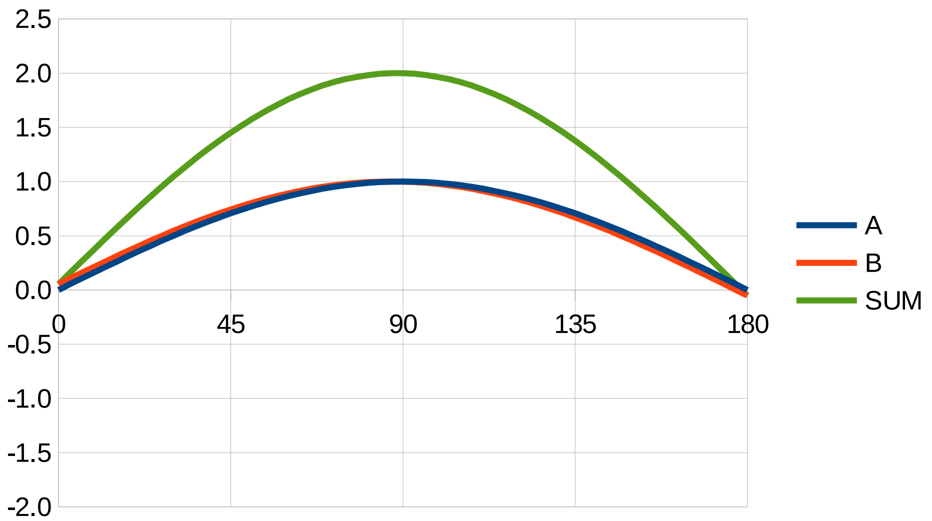


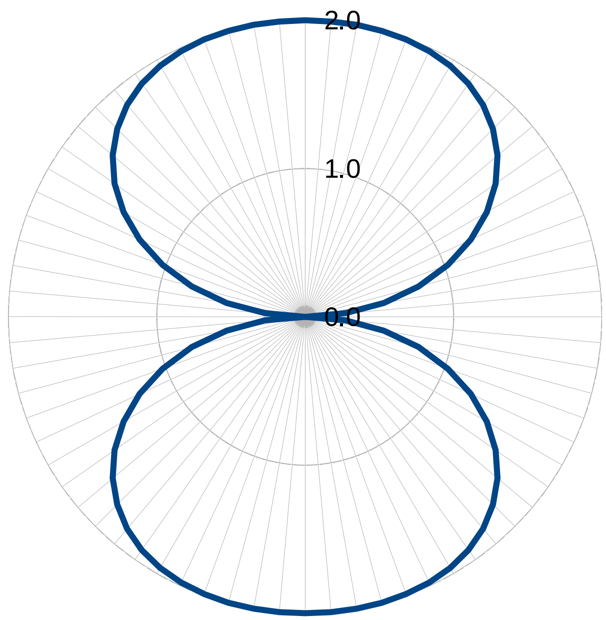
2 Unit Antennas

Spacing
1/2 wavelength

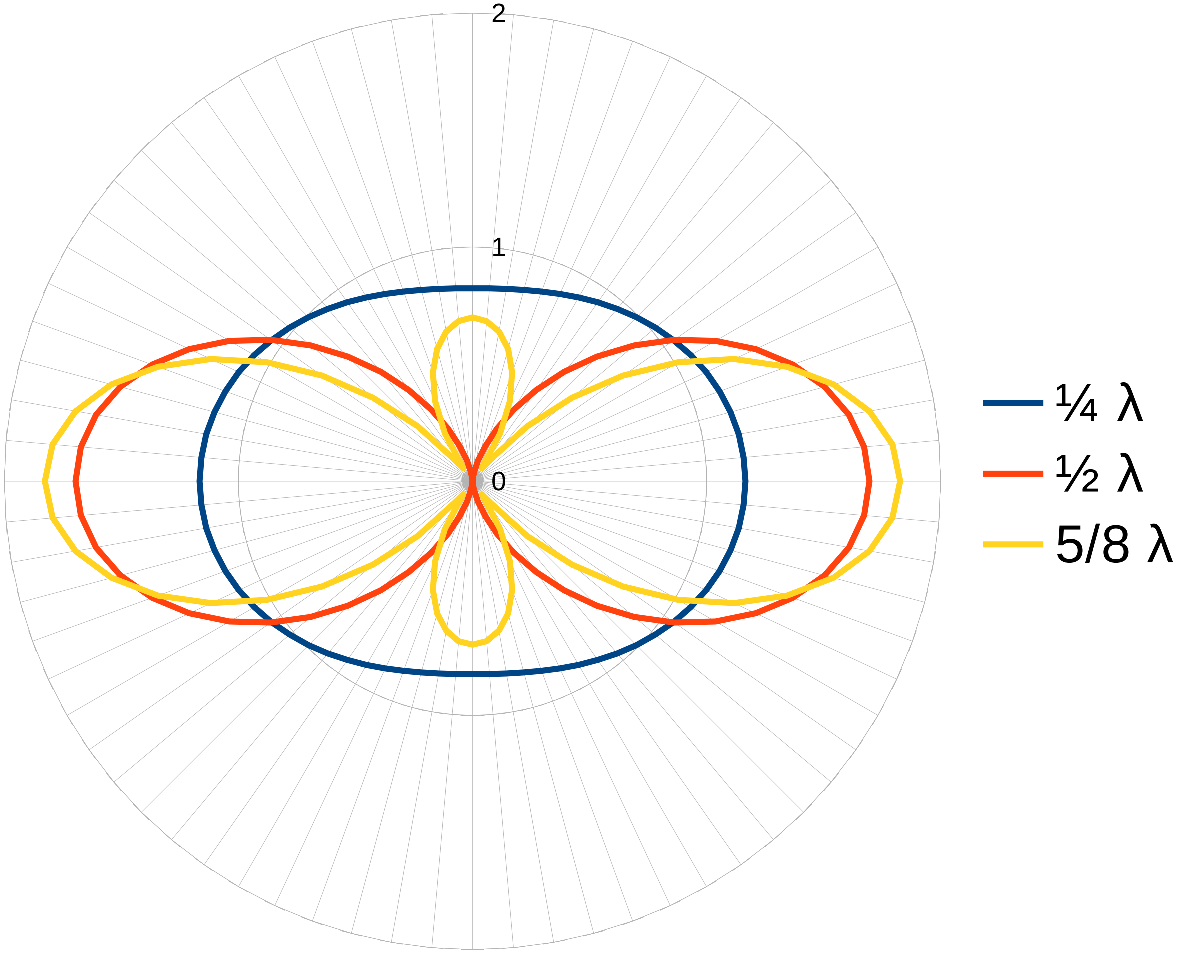
Phase Shift
180 Degrees



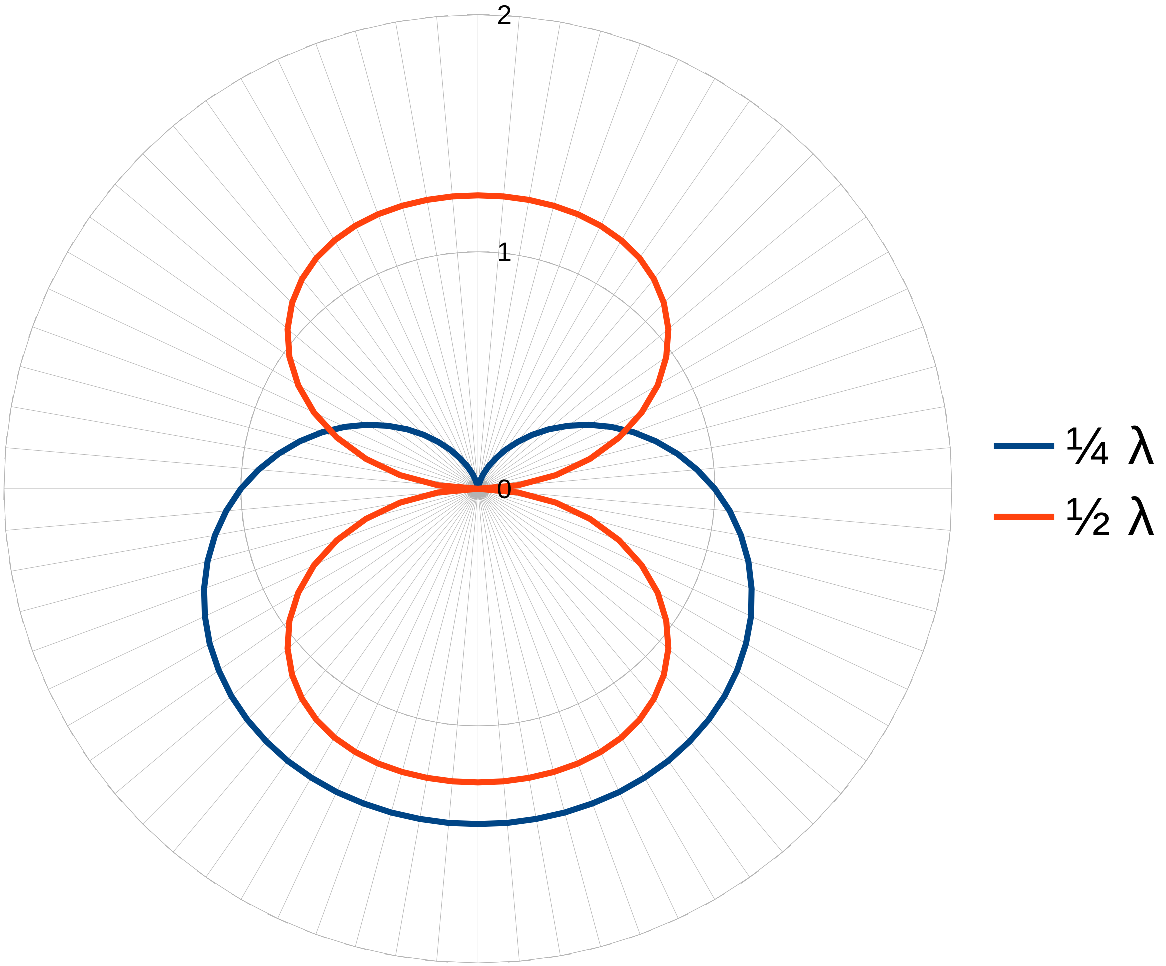




2-Element Driven Arrays
Broadside

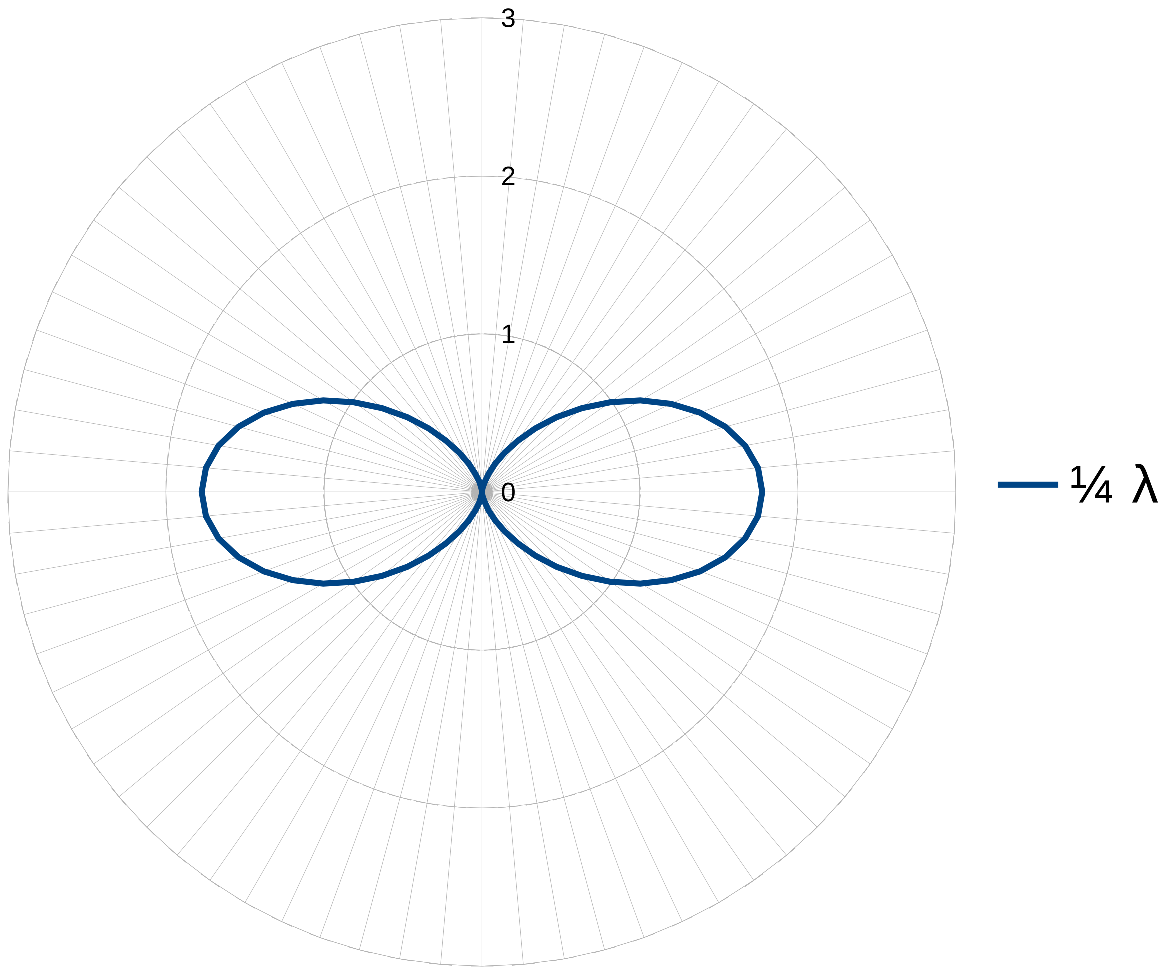


2-Element Driven Arrays
Endfire



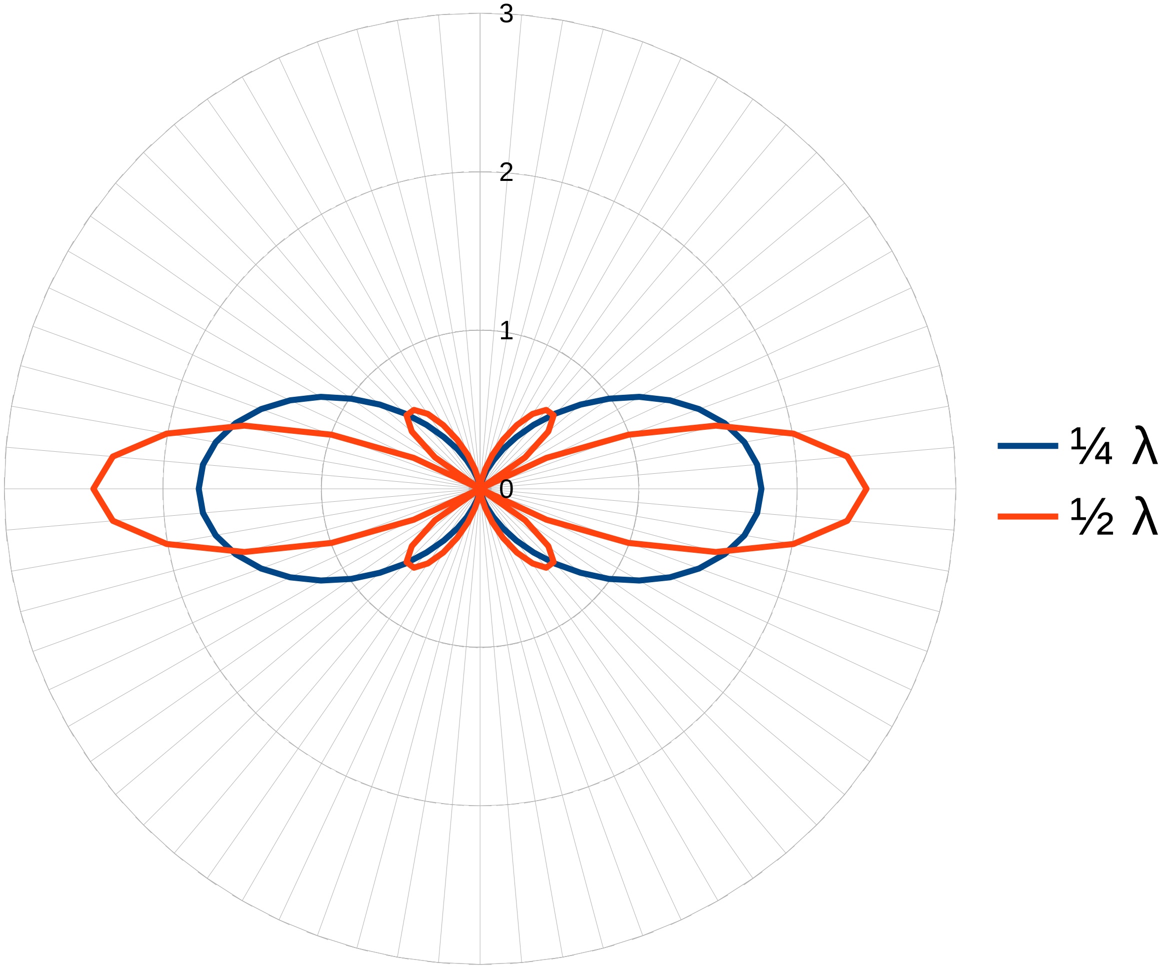
4-Element Driven Arrays

Broadside



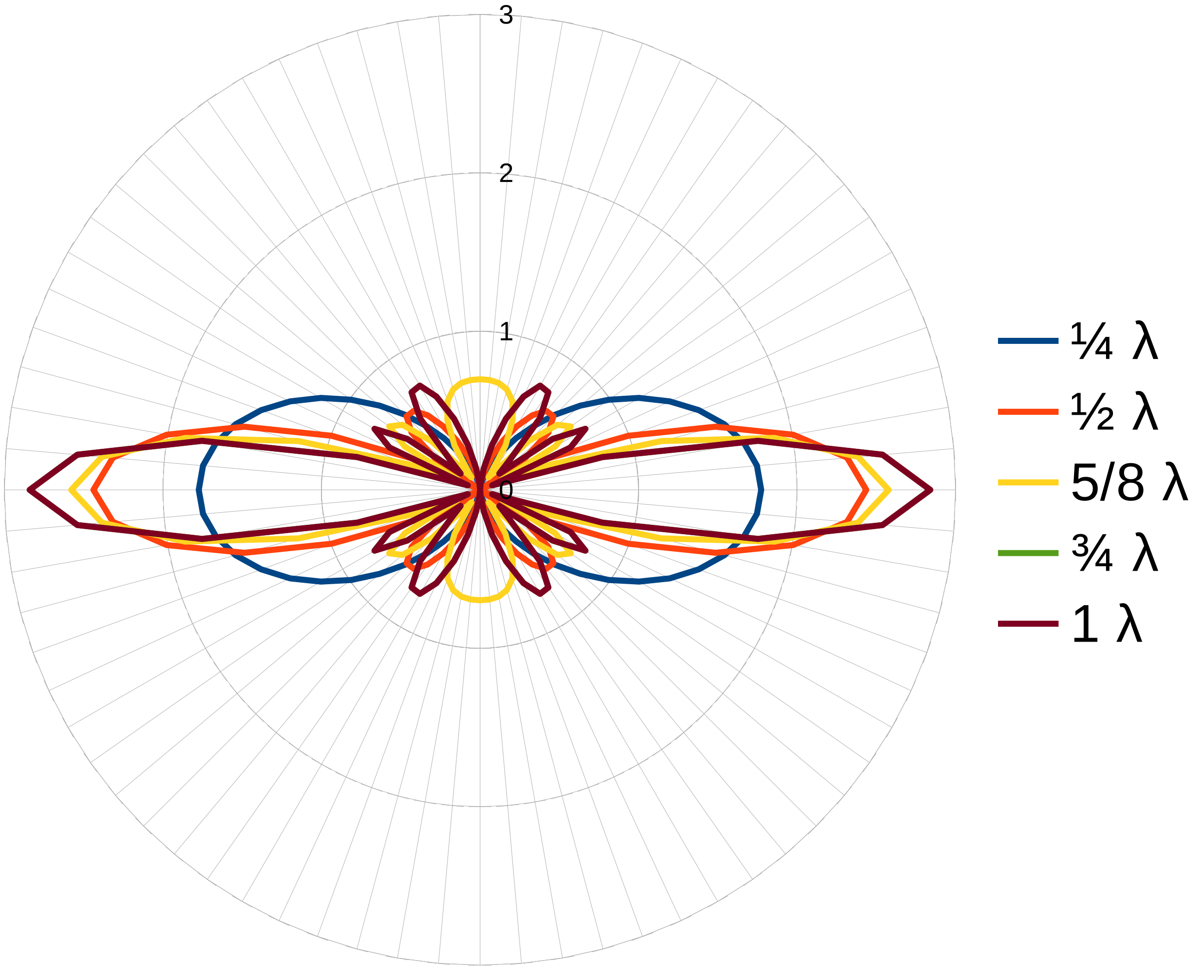
4-Element Driven Arrays

Broadside



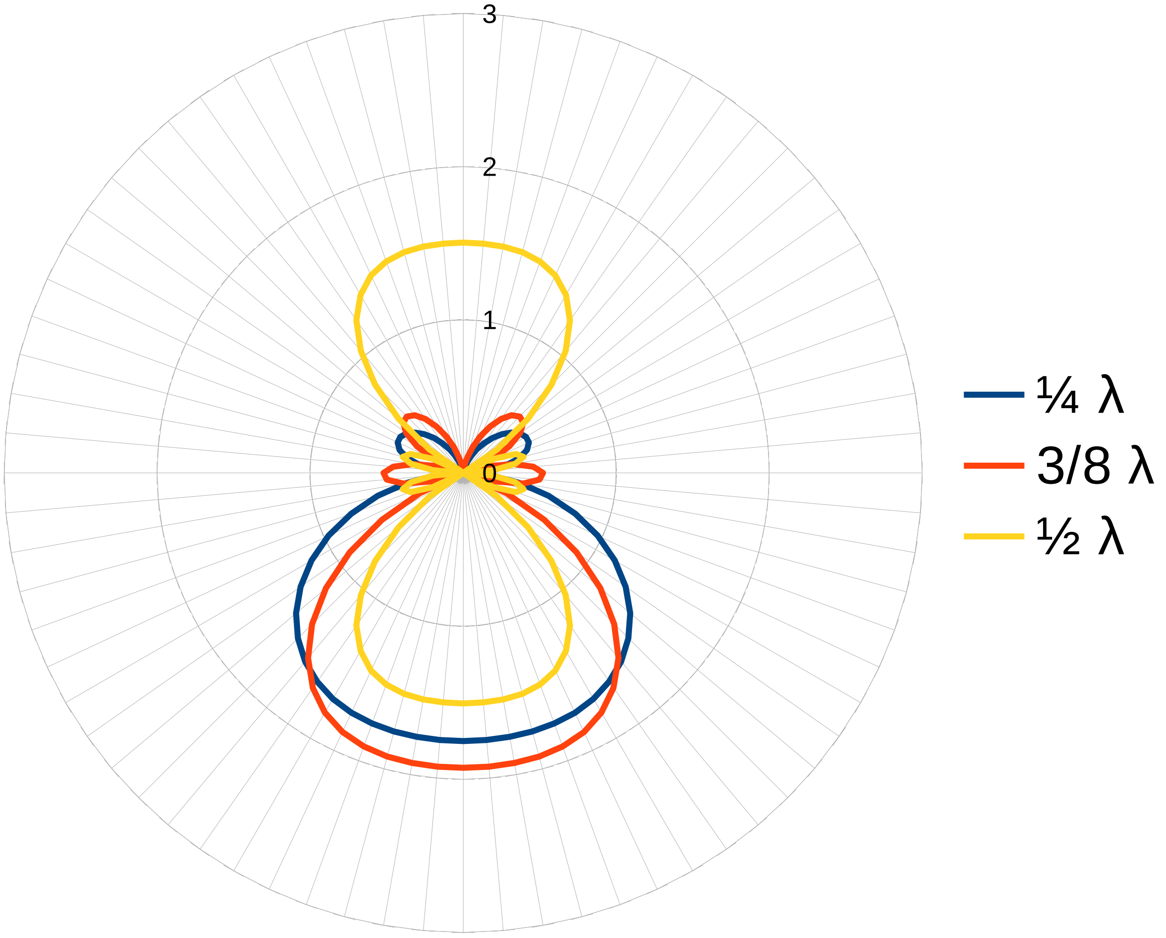
4-Element Driven Arrays

Broadside



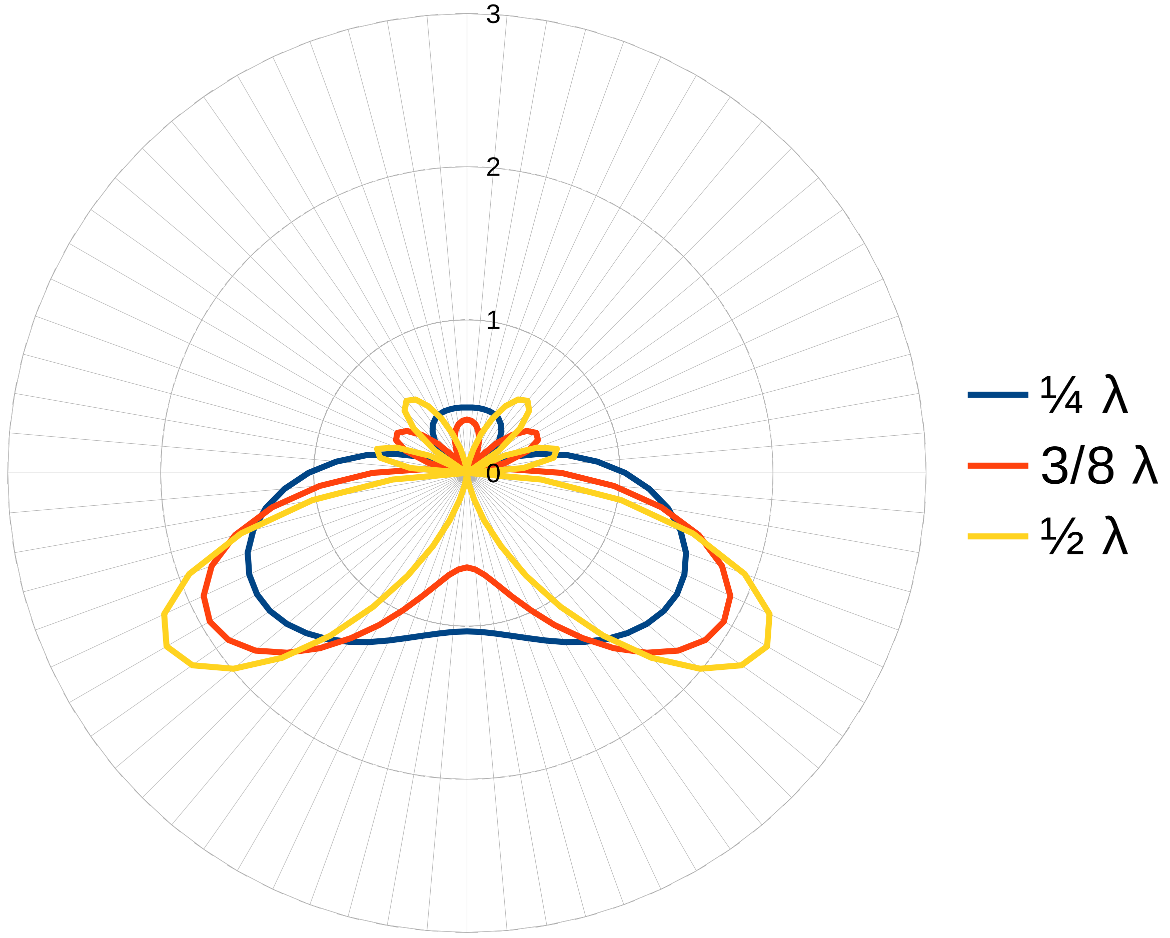
4-Element Driven Arrays

End Fire



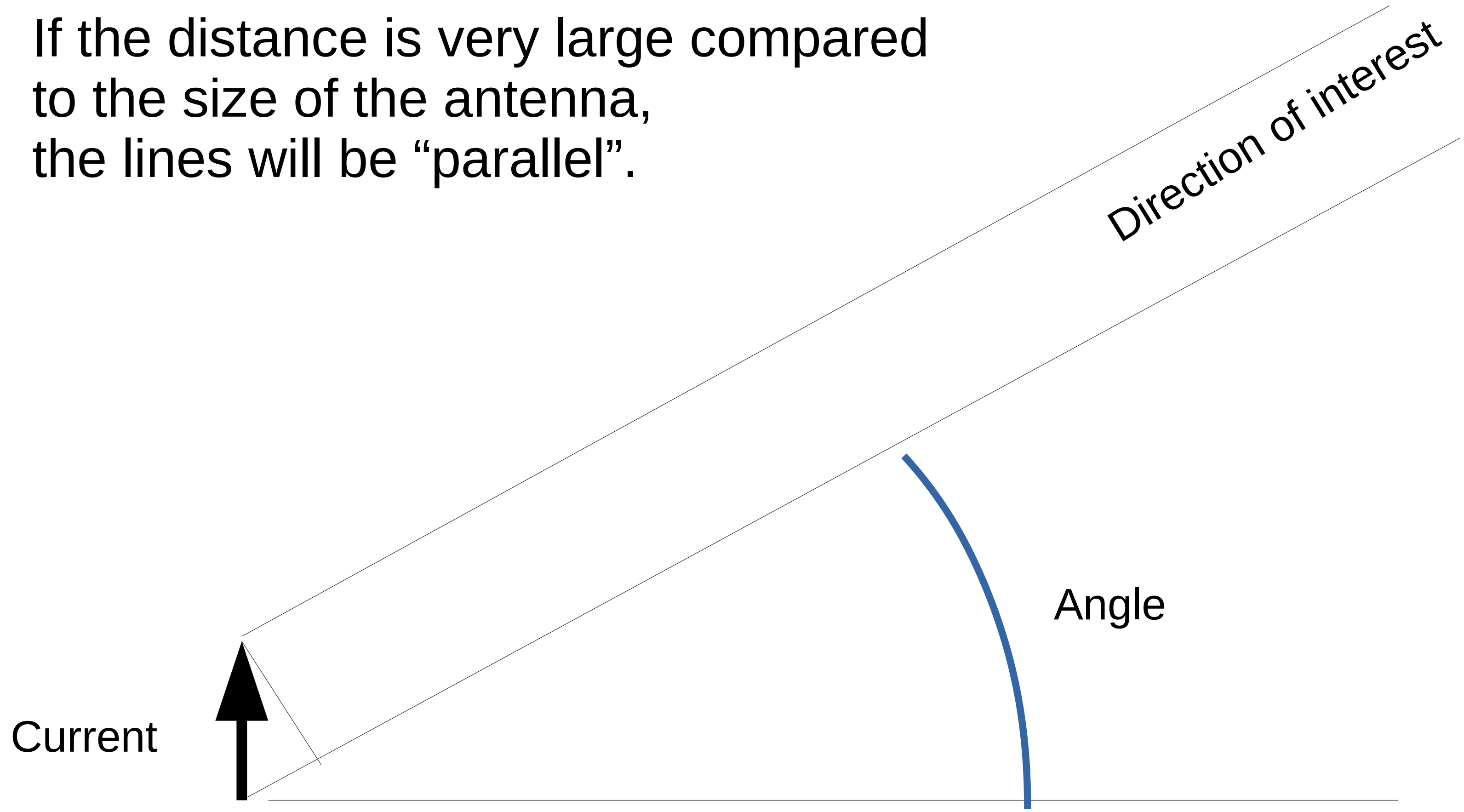
4-Element Driven Arrays

Off Axis

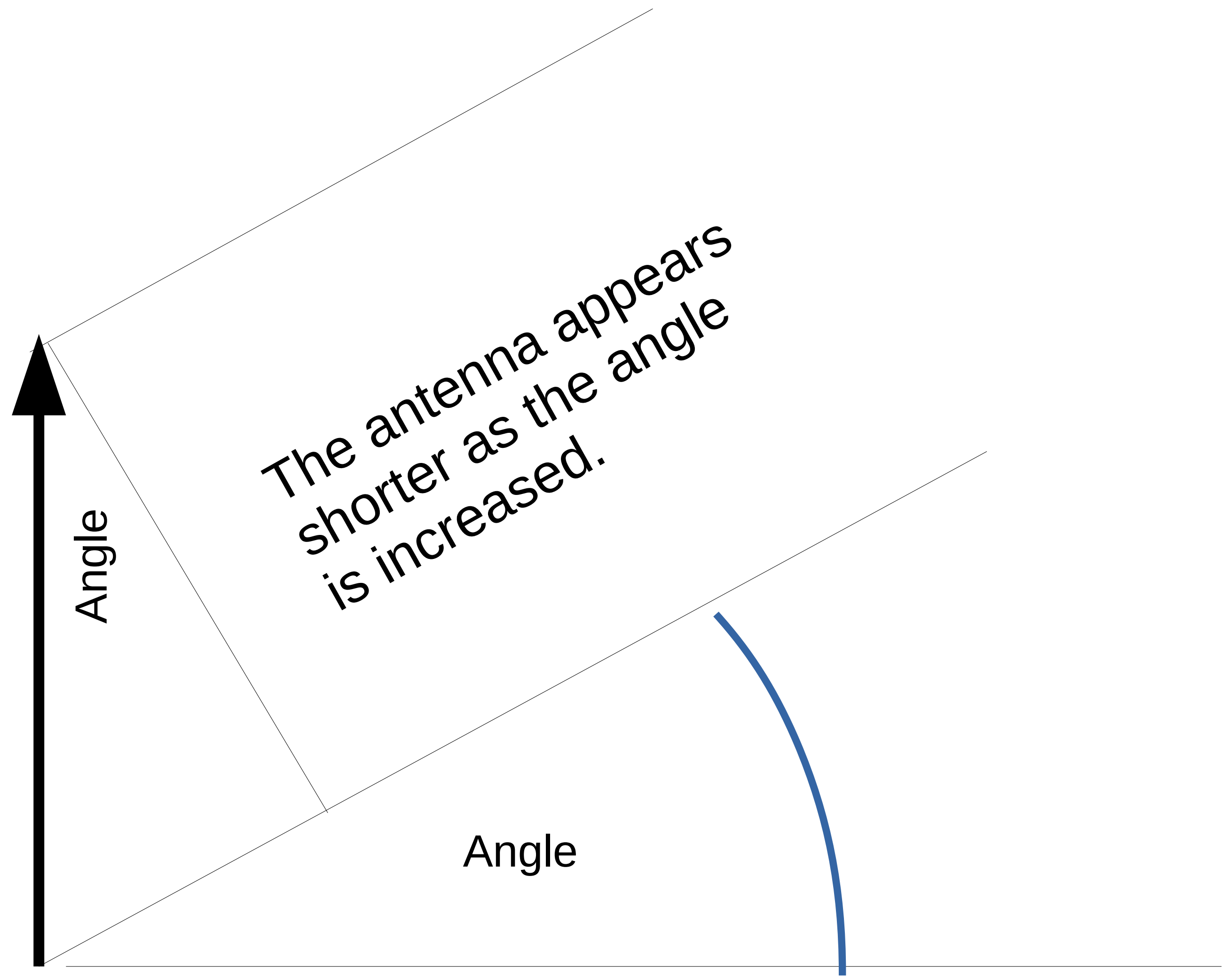


Geometry of Different Angles

If the distance is very large compared
to the size of the antenna,
the lines will be “parallel”.



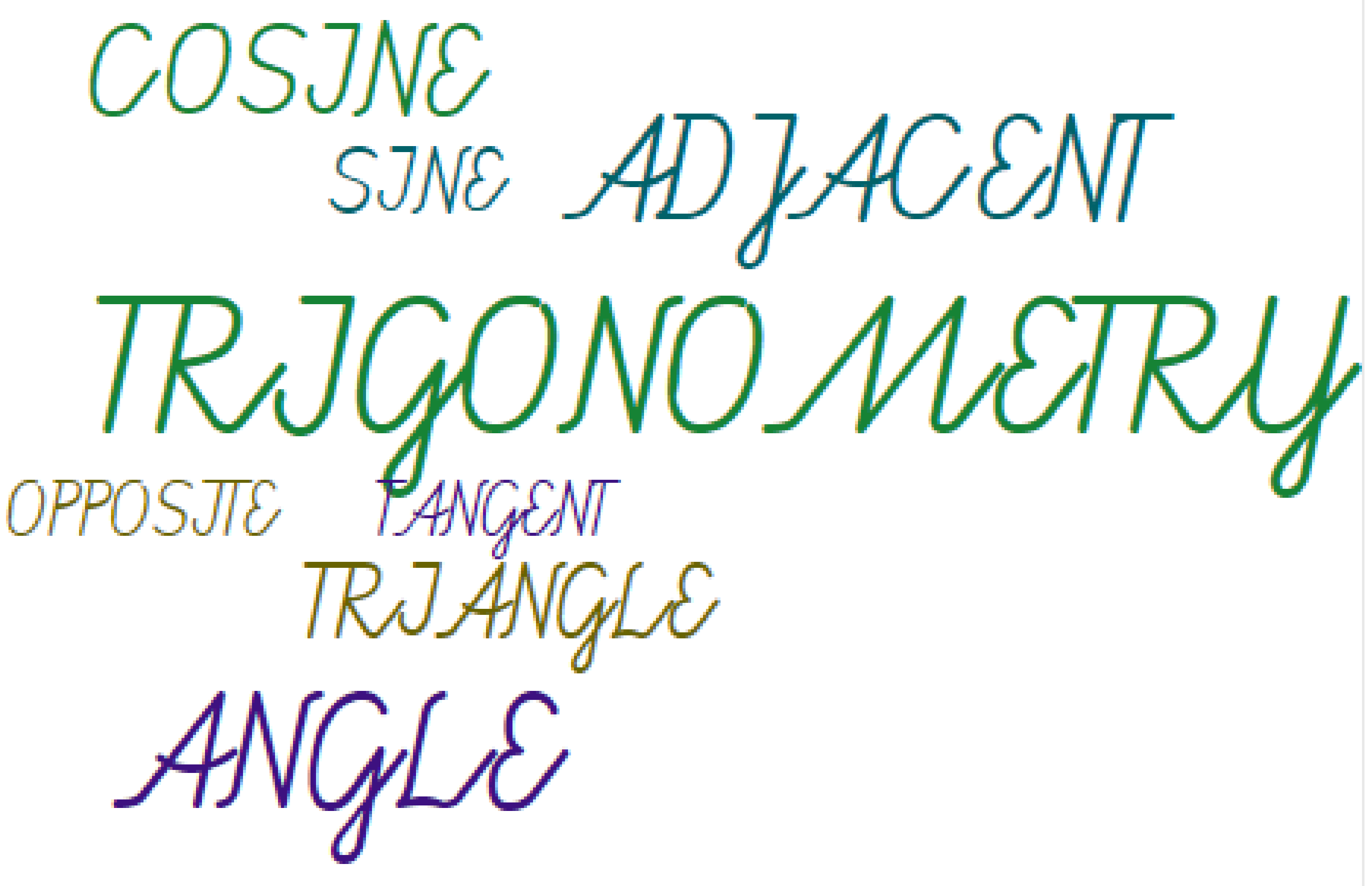
Geometry of Different Angles



What is Relation Between Angle and "Shortening" of the Antenna?

Trigonometry is the part of math that considers the relations between angles and sides of triangles.

What is Relation Between Angle and "Shortening" of the Antenna?

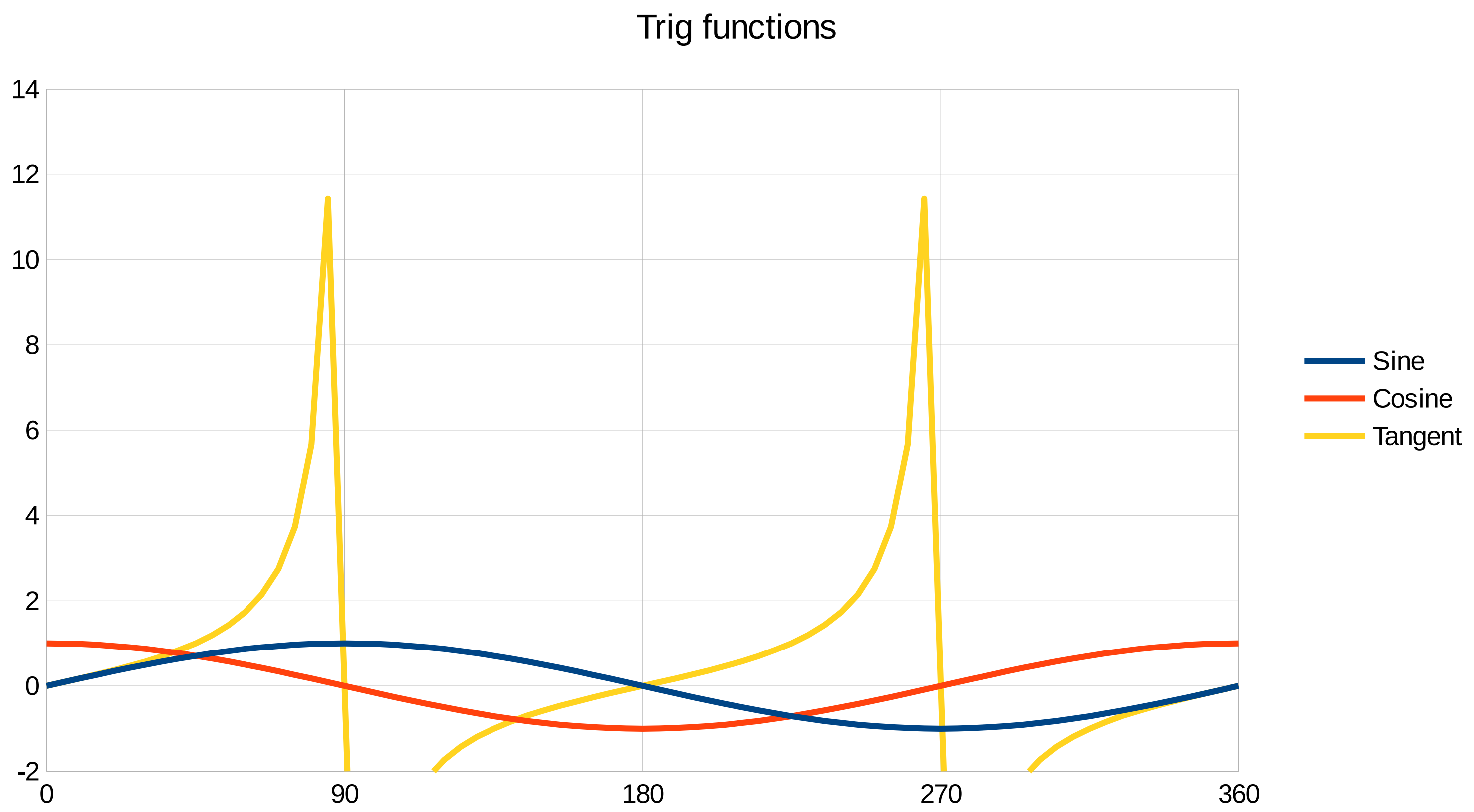


What is Relation Between Angle and "Shortening" of the Antenna?

There are several relations between the various sides and angles of a triangle:
sine,cosine, tangent ...

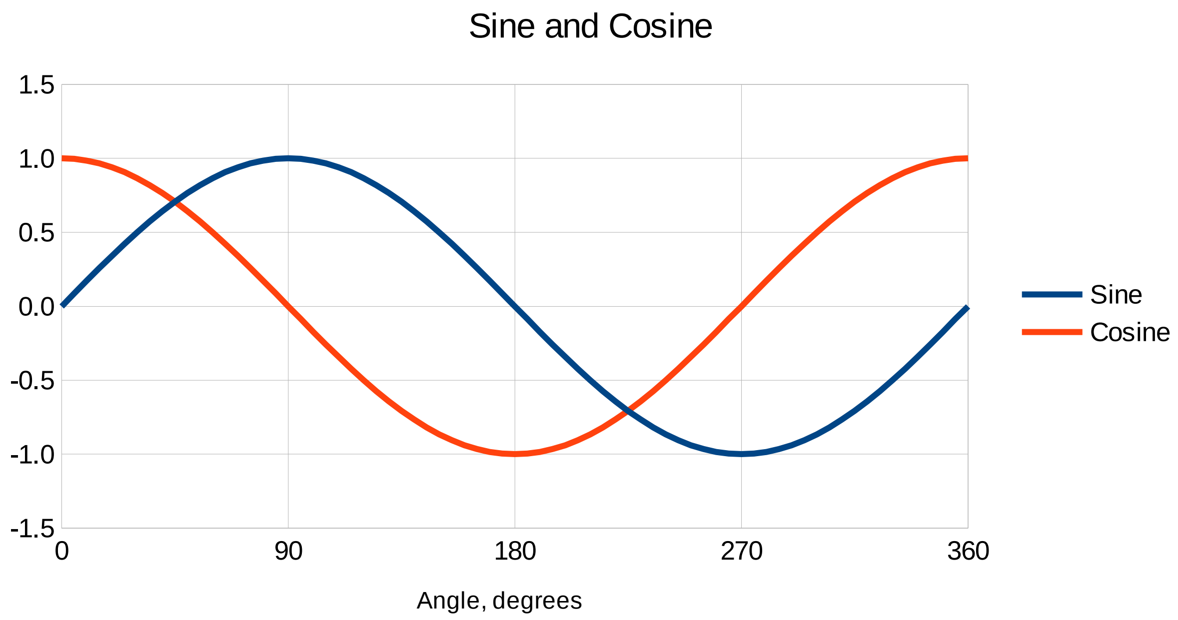
We need one that goes between values of 1 and 0.

What is Relation Between Angle and “Shortening” of the Antenna?



We need a function that goes between 0 and 1. Obviously not the tangent function!

What is Relation Between Angle and "Shortening" of the Antenna?



Cosine, if the angle is measured perpendicular to the antenna.

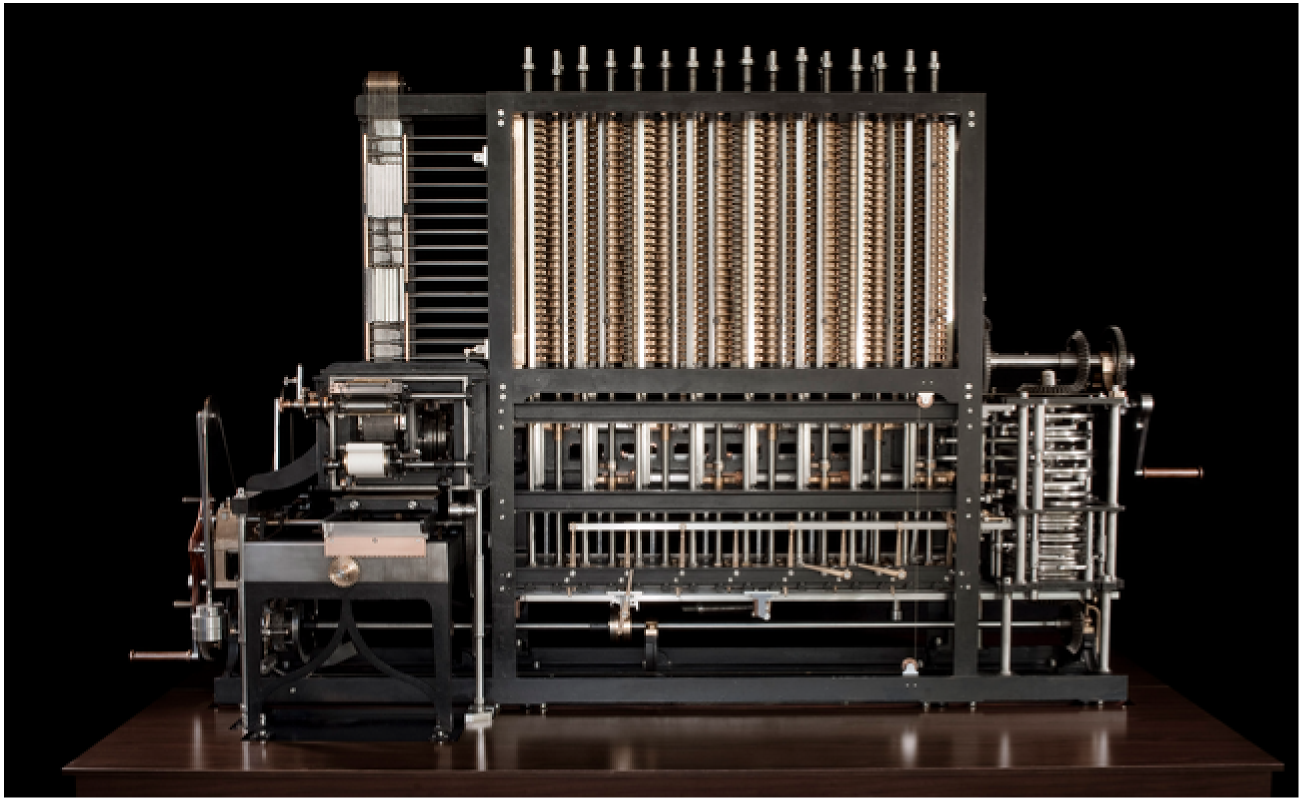
(Might also use the sine function if the angle is measured parallel to the antenna.)

What is Relation Between Angle and "Shortening" of the Antenna?

Isn’t it amazing that the functions we need for this antenna problem are the same functions we use in circuits.

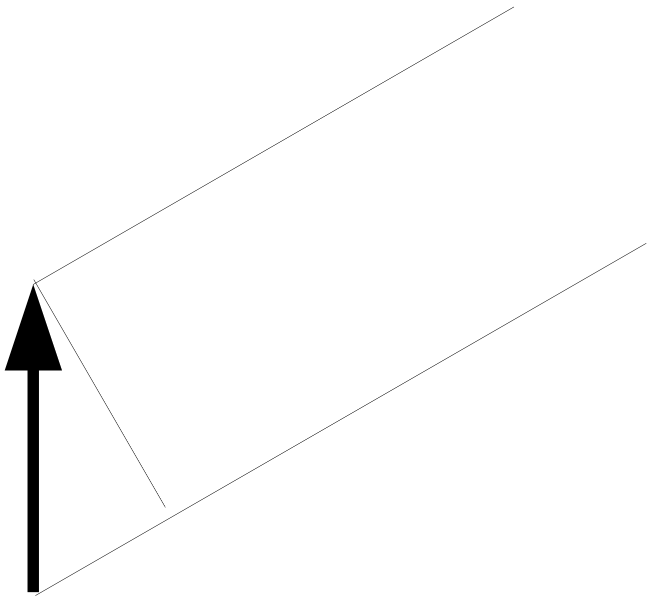
Personally, I am somewhat in awe of the mathematicians who studied and examined these formulas with no clue how useful they would be in future centuries.

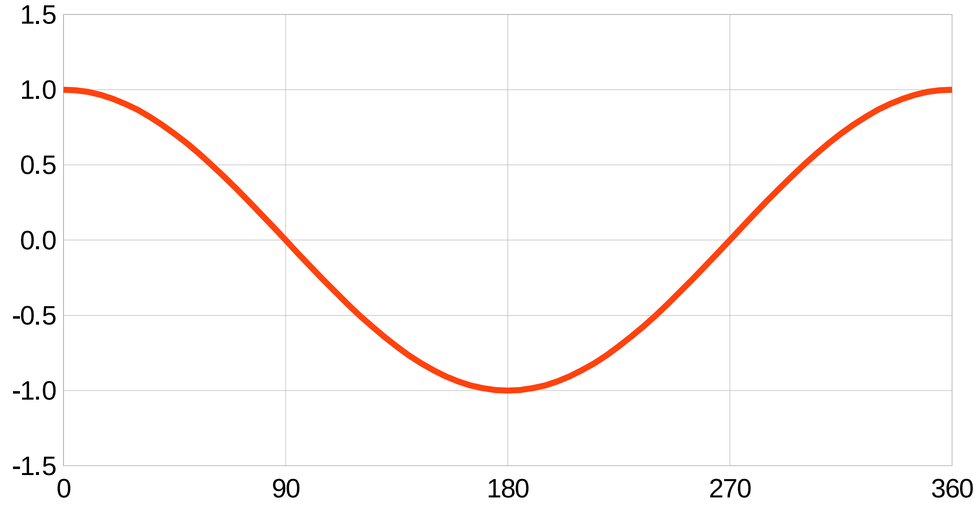
How to Calculate Cosine Function



This mechanical computer was designed by Charles Babbage in the early 1800's. It took until 2002 to build it.

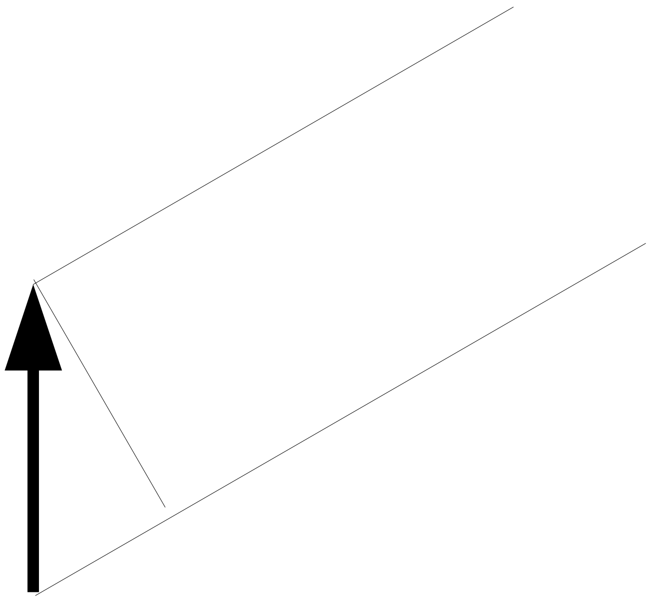
Relation Between Angle and Apparent Length of Antenna

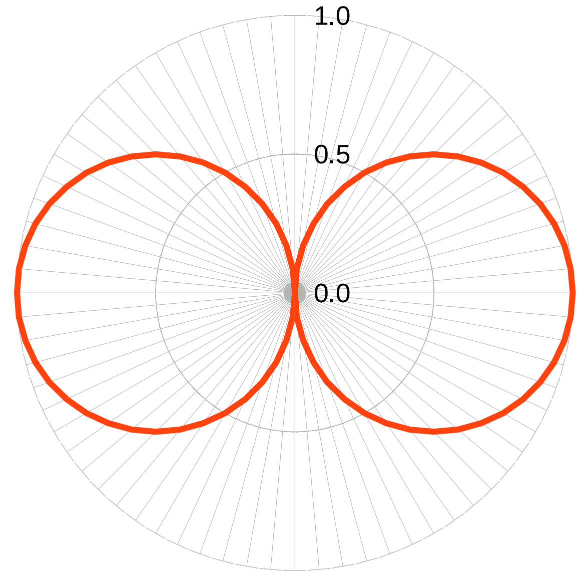




Viewed from different angles, the antenna appears shorter as the cosine of the angle.

Relation Between Angle and Apparent Length of Antenna





Viewed from different angles, the antenna appears shorter as the cosine of the angle.

“Ideal” Unit Antenna

- Straight conductor with uniform current.
- **Length << ¼ wavelength**
- Easy to analyze.
- Magnetic field forms concentric circles a wire carrying current.
- **“Hard” to build. The current at the ends must go somewhere!**

“Ideal” Unit Antenna

The black line represents a conductor.
The red line represents the current along the conductor.

BUT most real antennas have ends that are open!

More Realistic Antenna

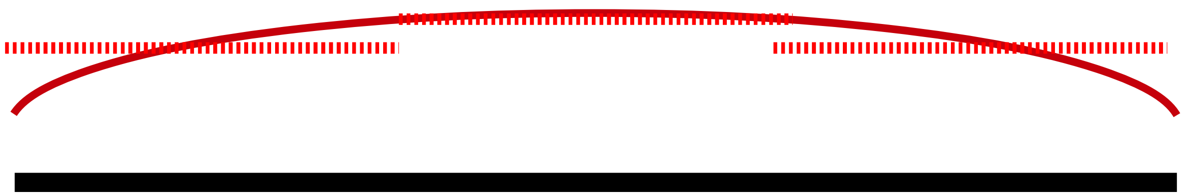
- Combine several unit antennas to simulate a dipole.
- Different current in each segment to approximate a sinusoidal distribution.
- At each angle, must combine the signal from each segment with regard to the phase shift caused by distance.
- How many segments?

More Realistic Antenna

The current is zero at the ends.

The real world current magnitude has a sine wave shape.

More Realistic Antenna

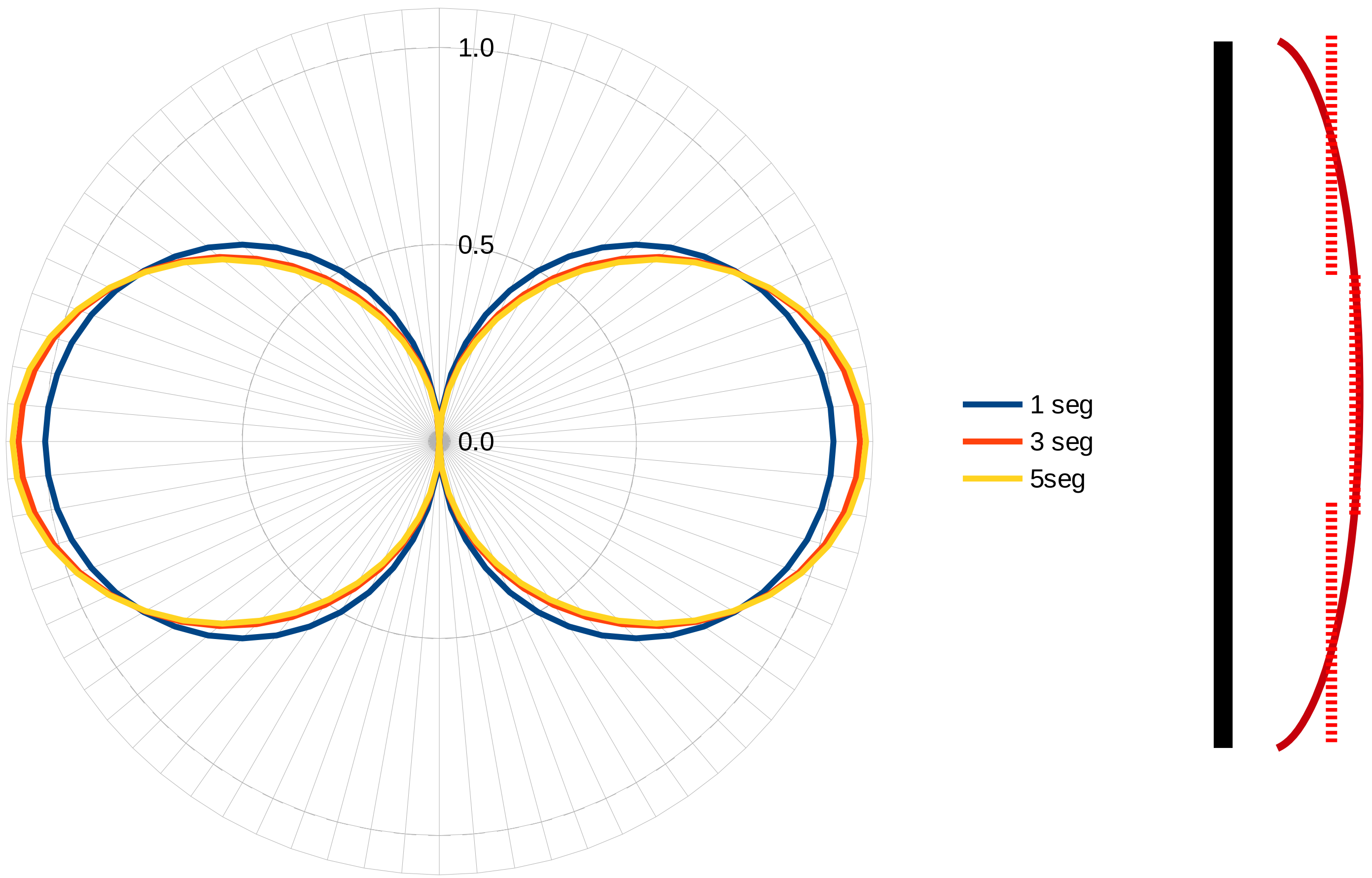


Model the real conductor with several “unit” antennas.

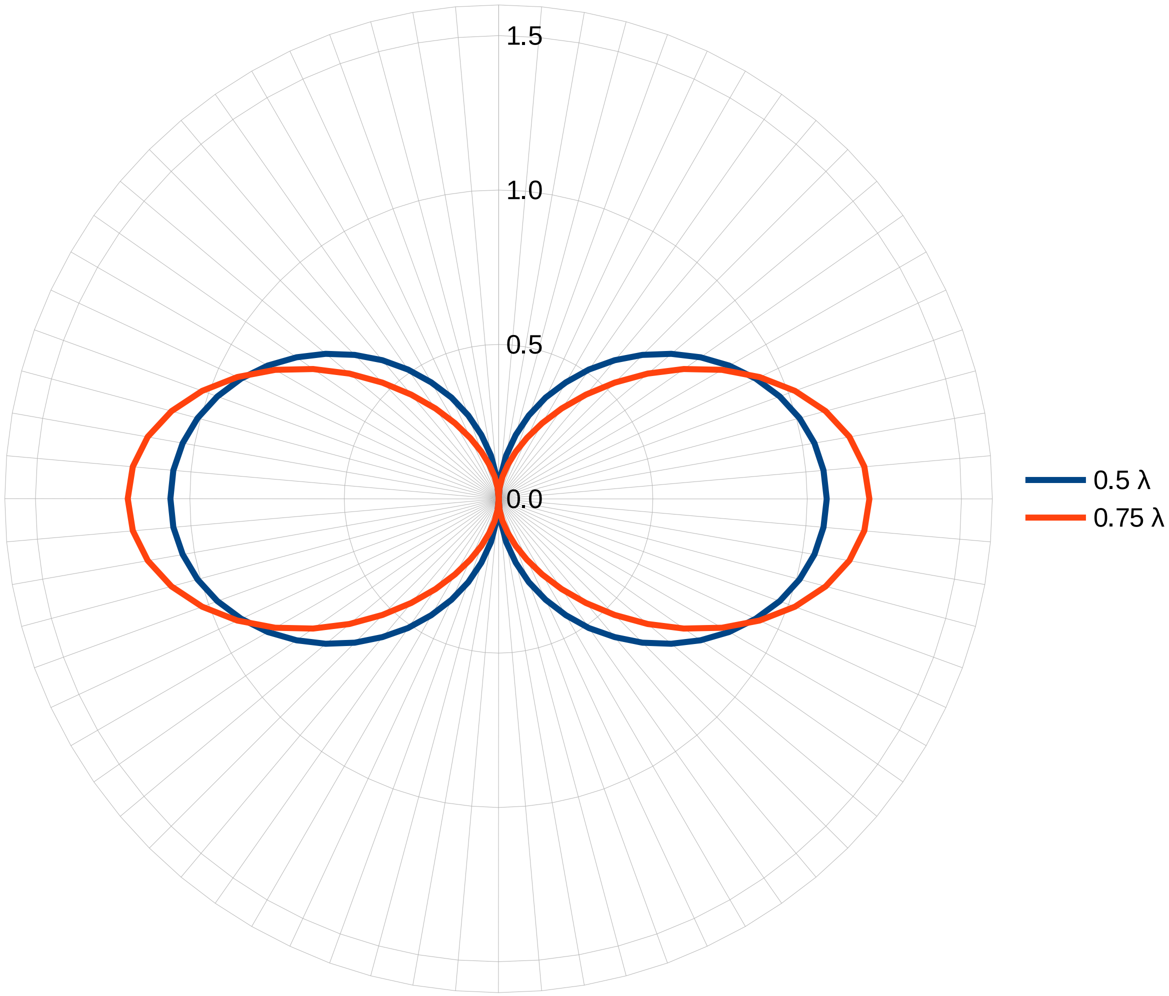
Computational Numeric Accuracy

- Lots of academic work has been done on how many segments to use, including more complicated segments.
- Most computer languages limit calculations to typically 4 or 5 digits. If a model has too many segments, the numbers from each segment get rounded off, limiting the accuracy .
- Spread sheets naturally do lots of digits, like 15.

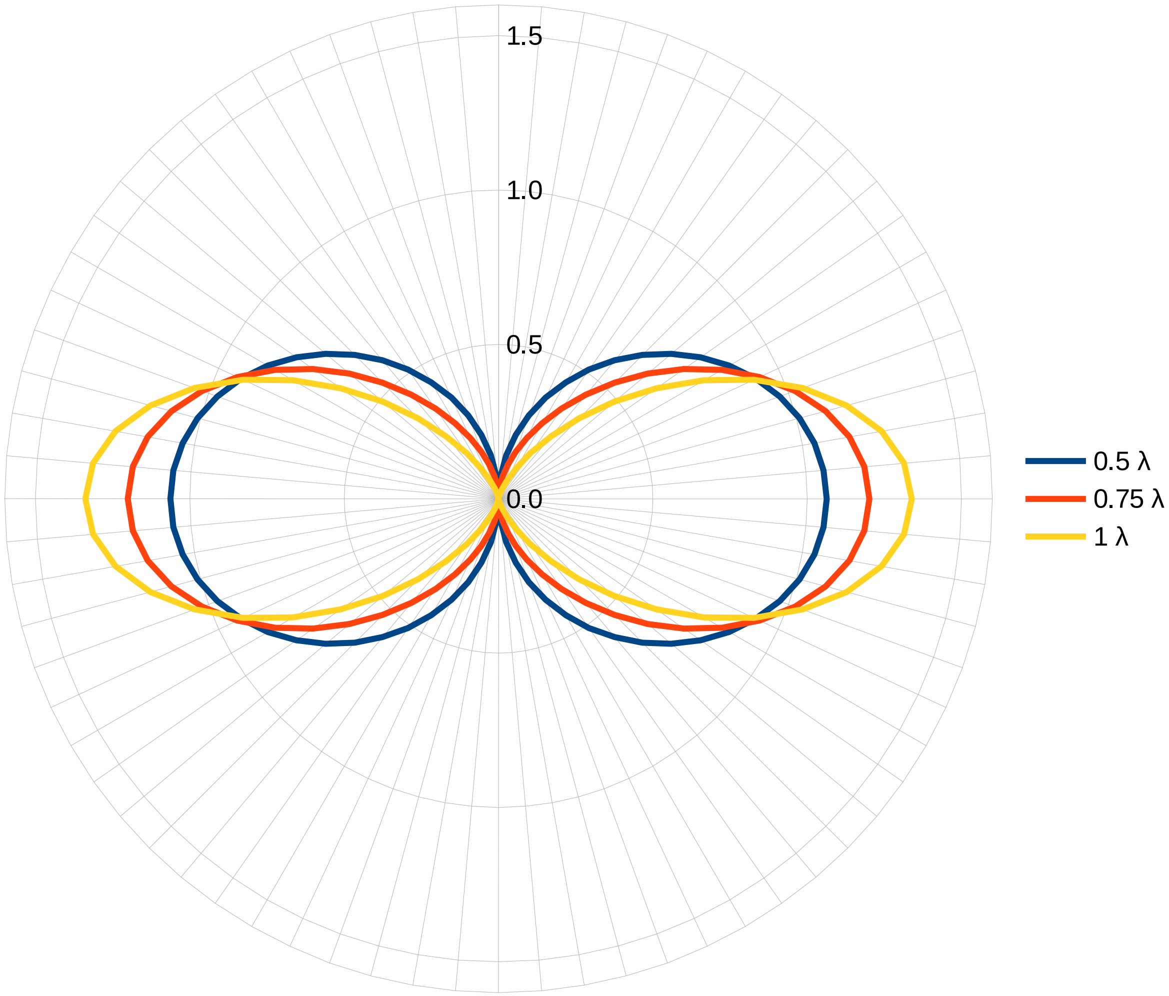
½ Wave Dipole Antenna



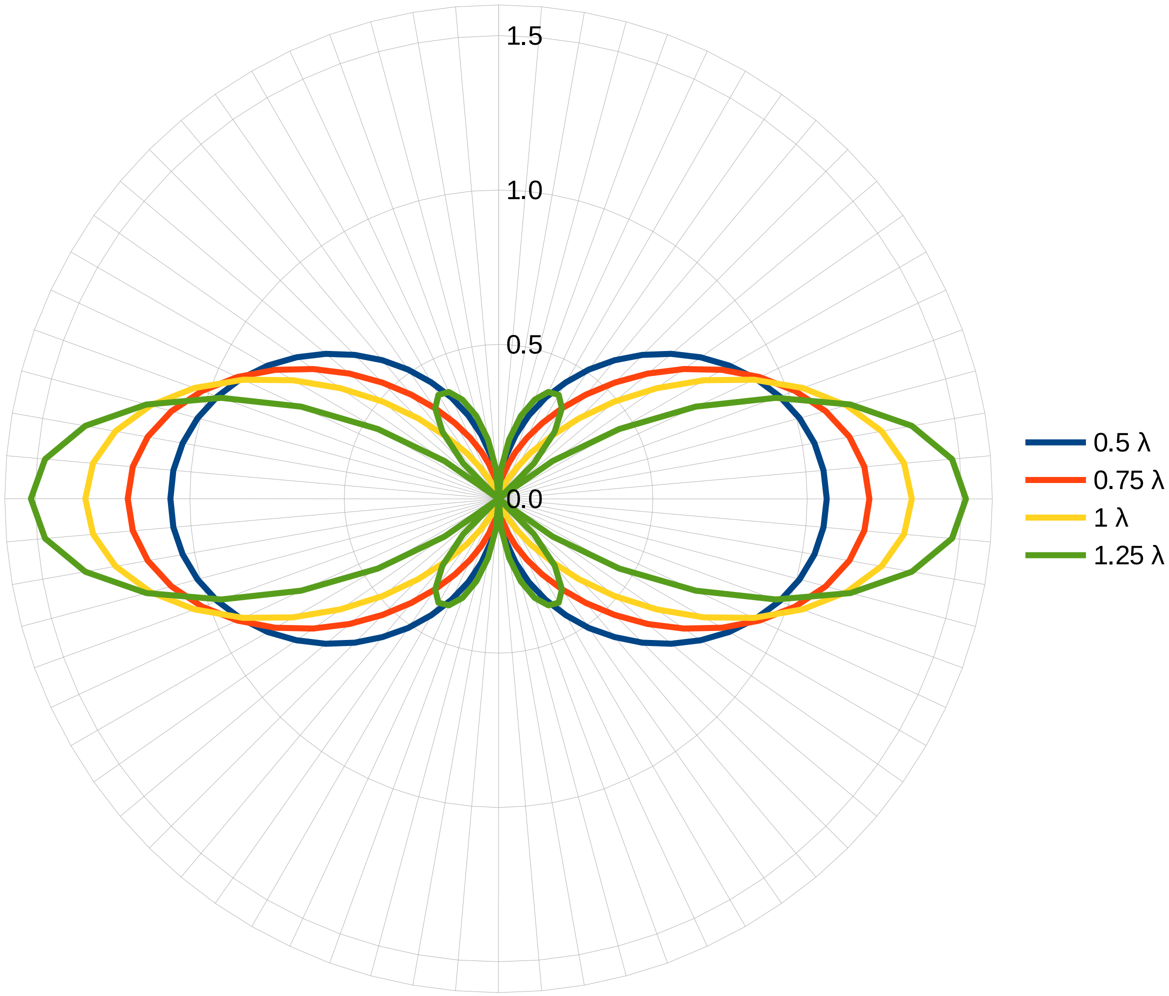
Dipole Antennas



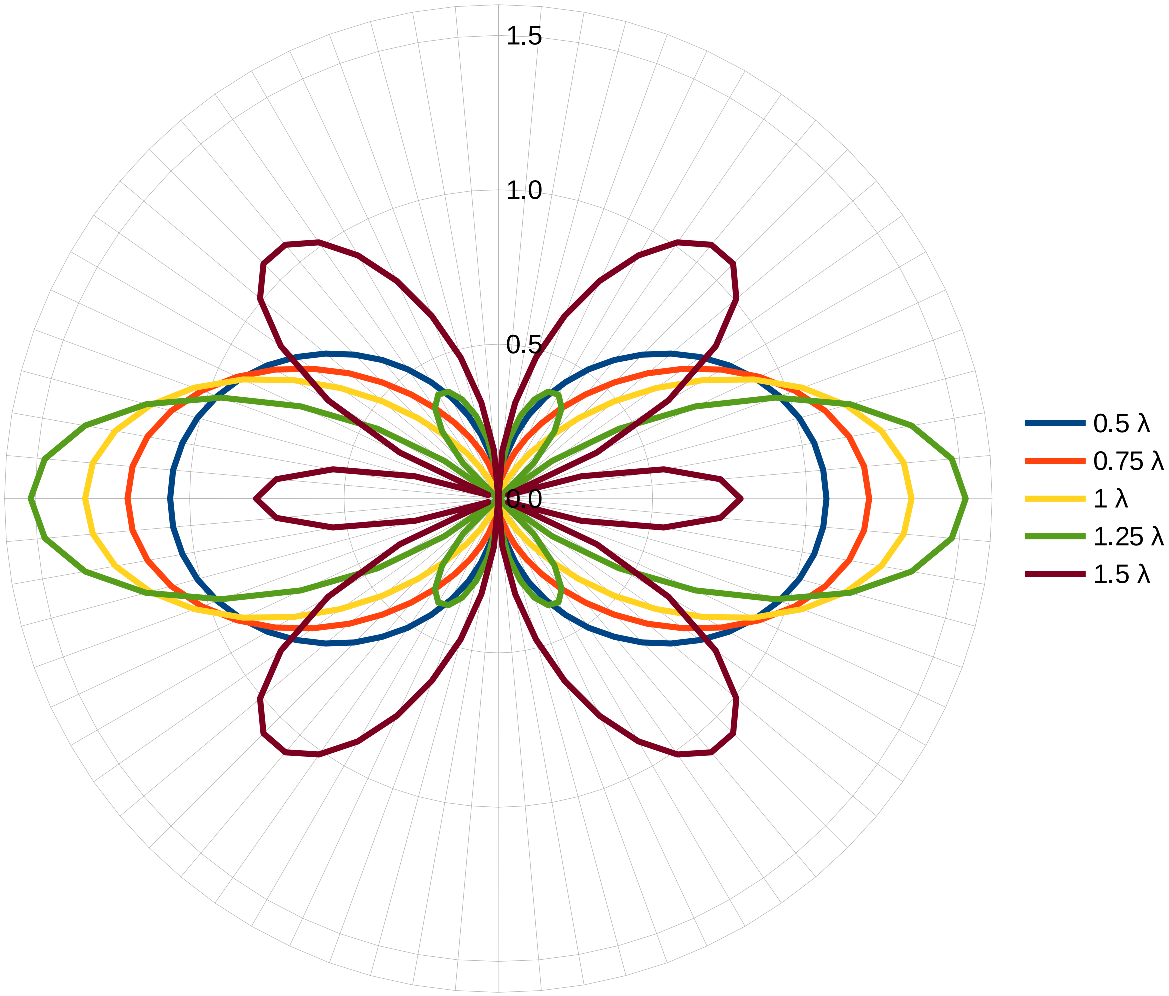
Dipole Antennas



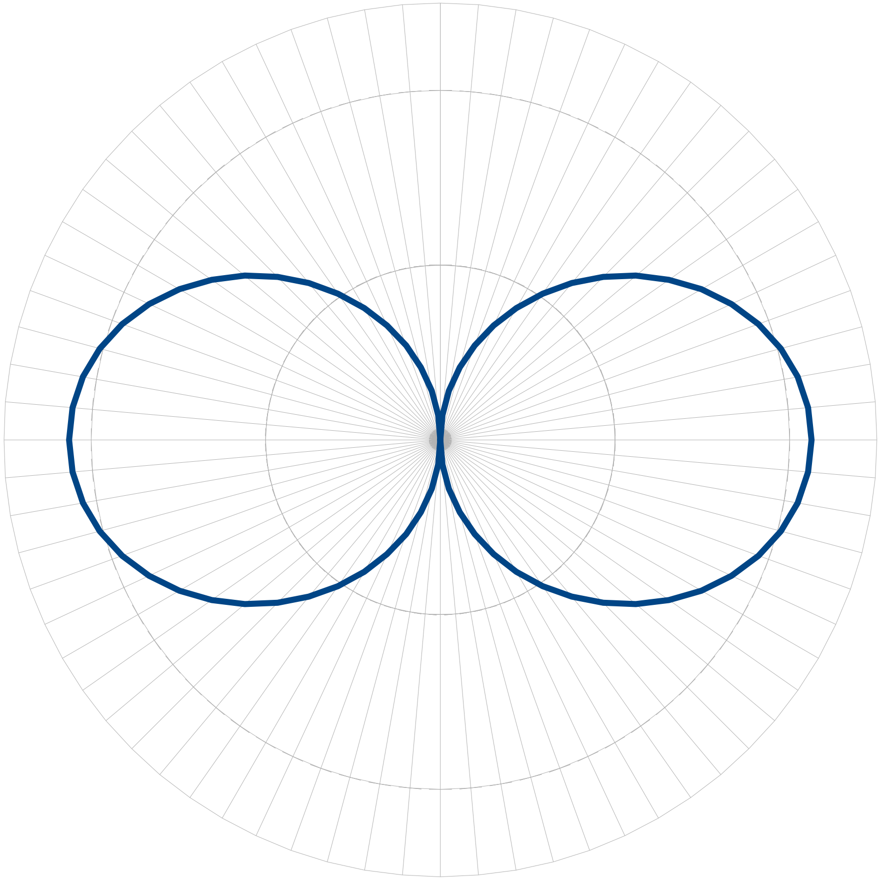
Dipole Antennas



Dipole Antennas

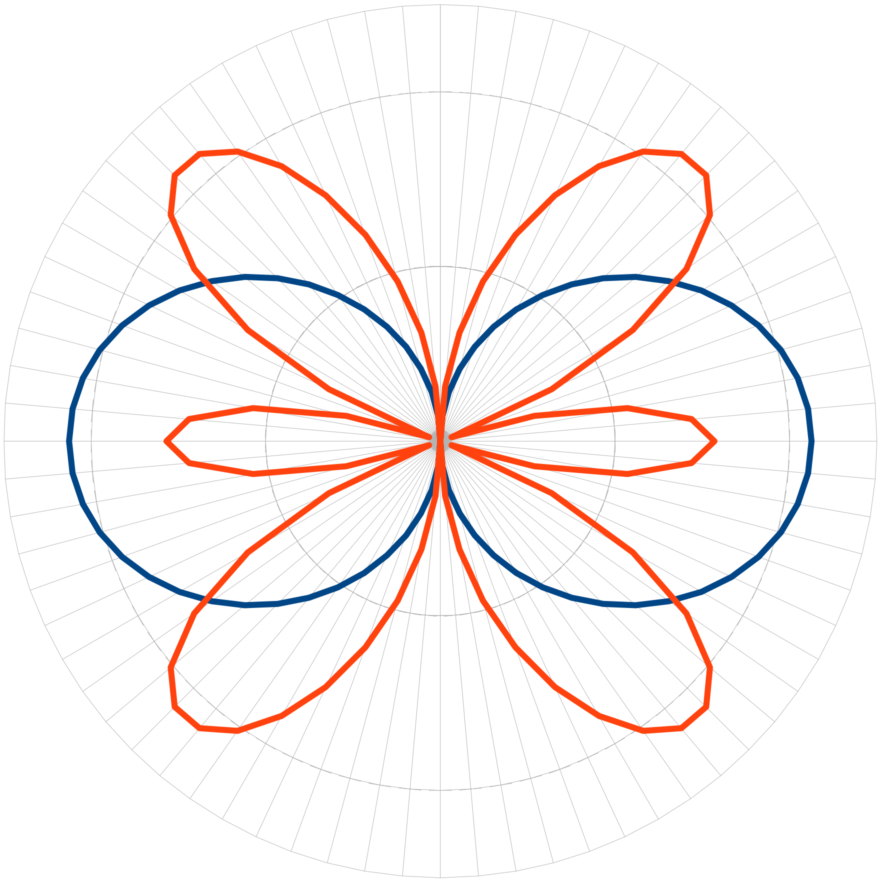


Multi-Band Dipole Antennas



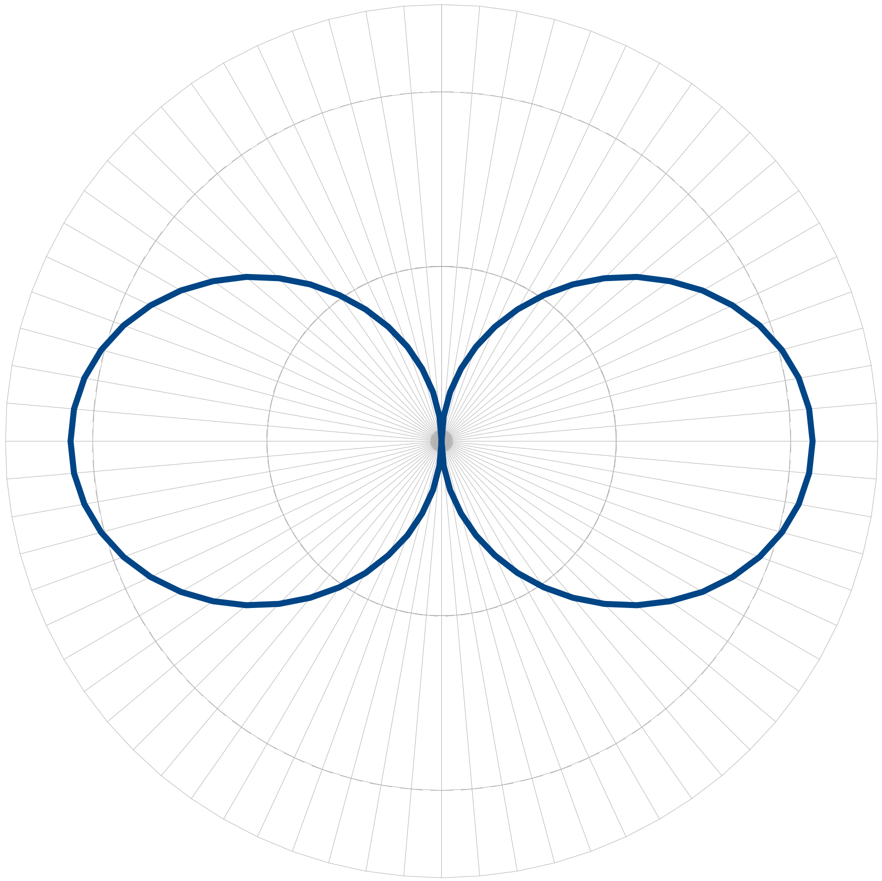
Horizontal Pattern of
Half-wave Dipole on 40 Meters

Multi-Band Dipole Antennas



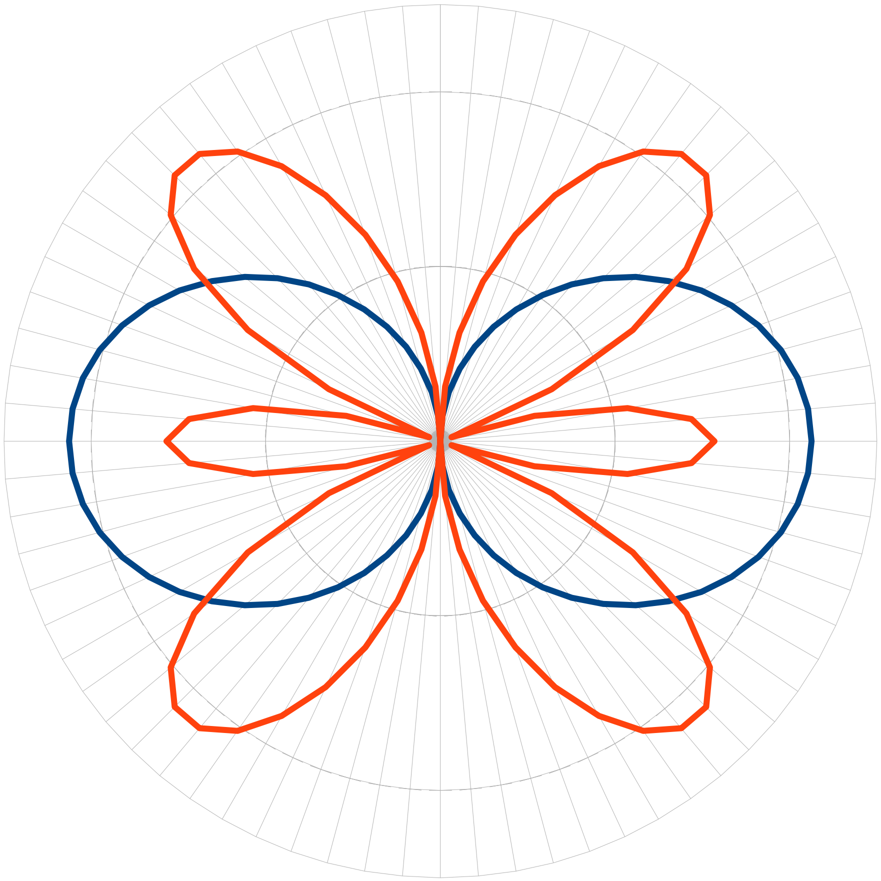
Horizontal Pattern of
Half-wave Dipole on 40 Meters
Same Antenna on 15 Meters

Another Multi-Band Antenna



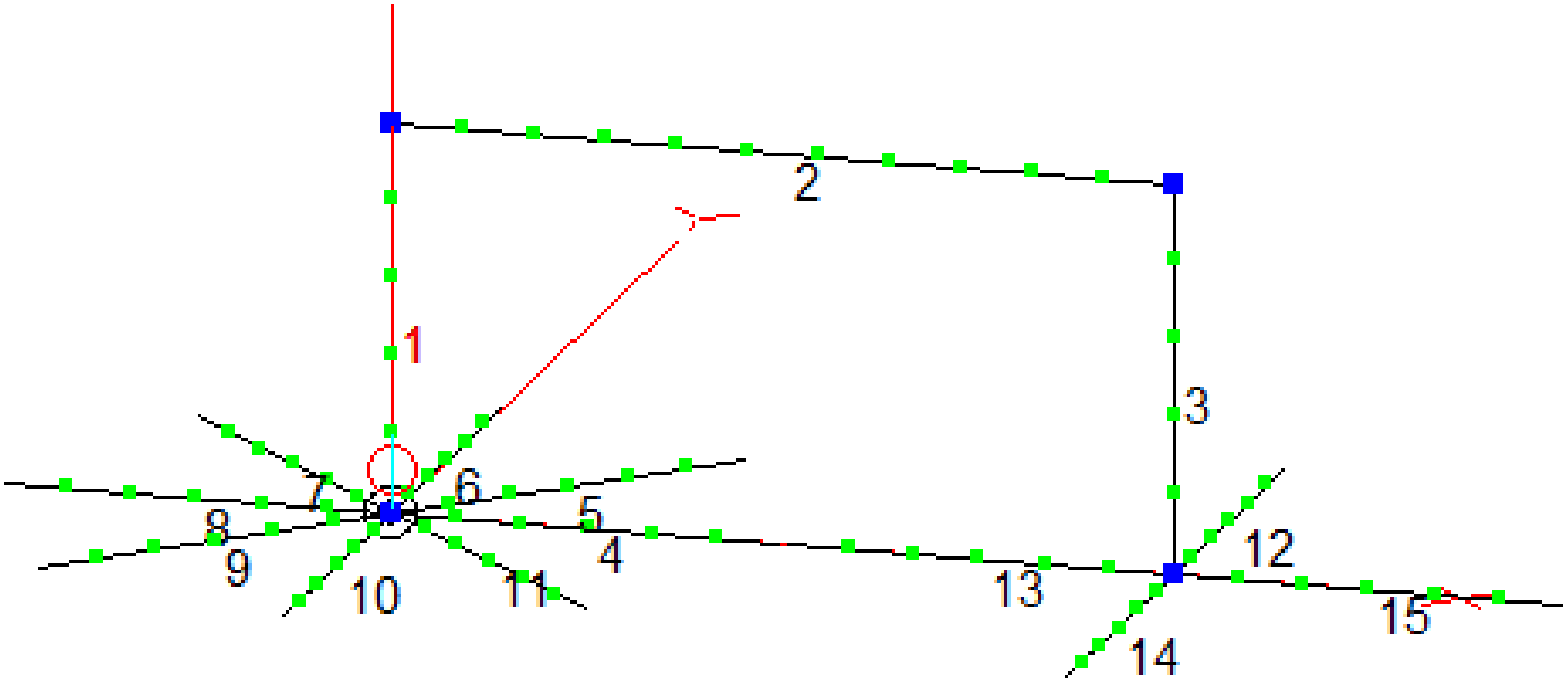
Vertical Pattern of
Half-wave Dipole on 2 Meters

Another Multi-Band Antenna



Vertical Pattern of
Half-wave Dipole on 146 MHz
Same Antenna on 440 MHz

Field Day Antenna for 40 MTRS



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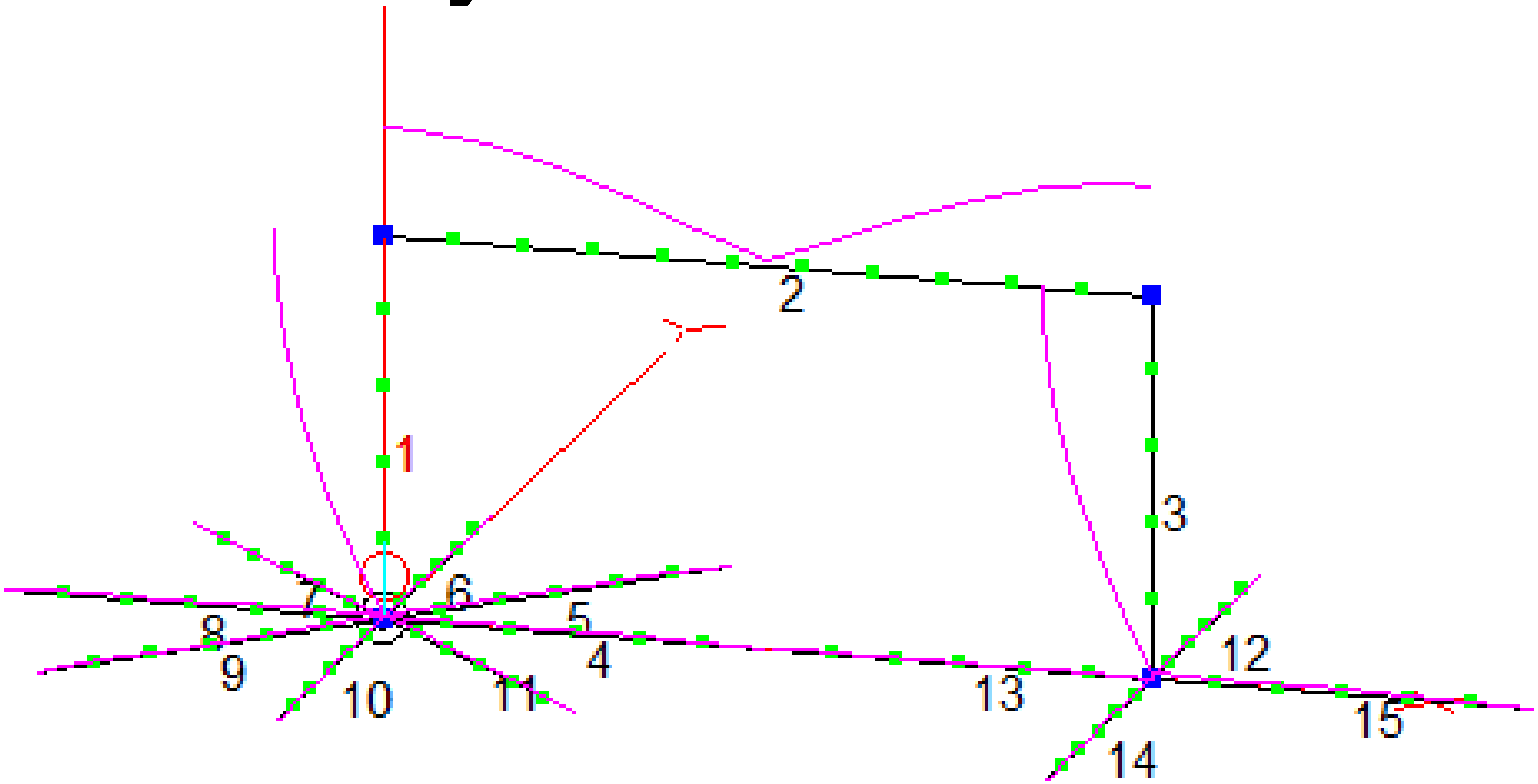

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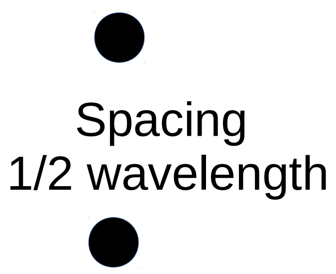

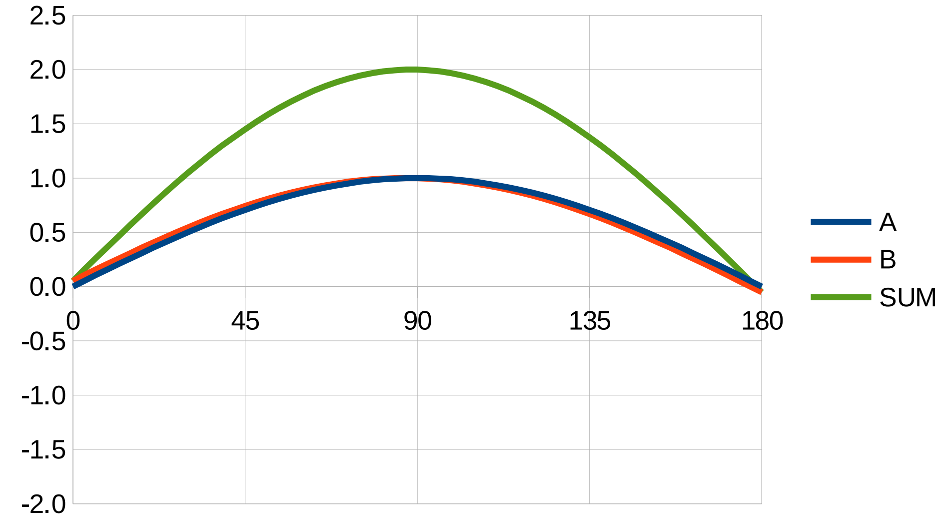

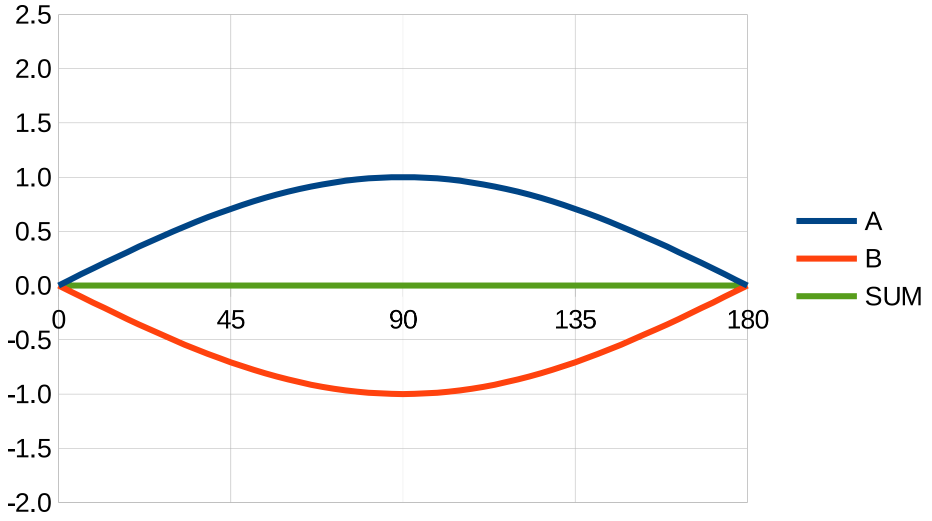

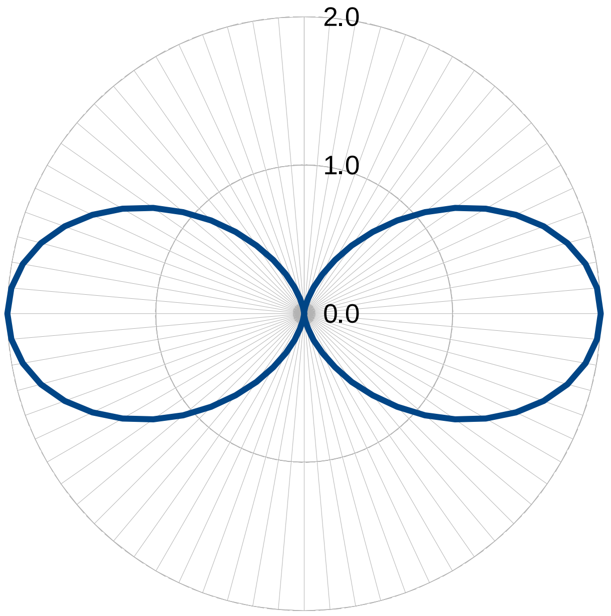

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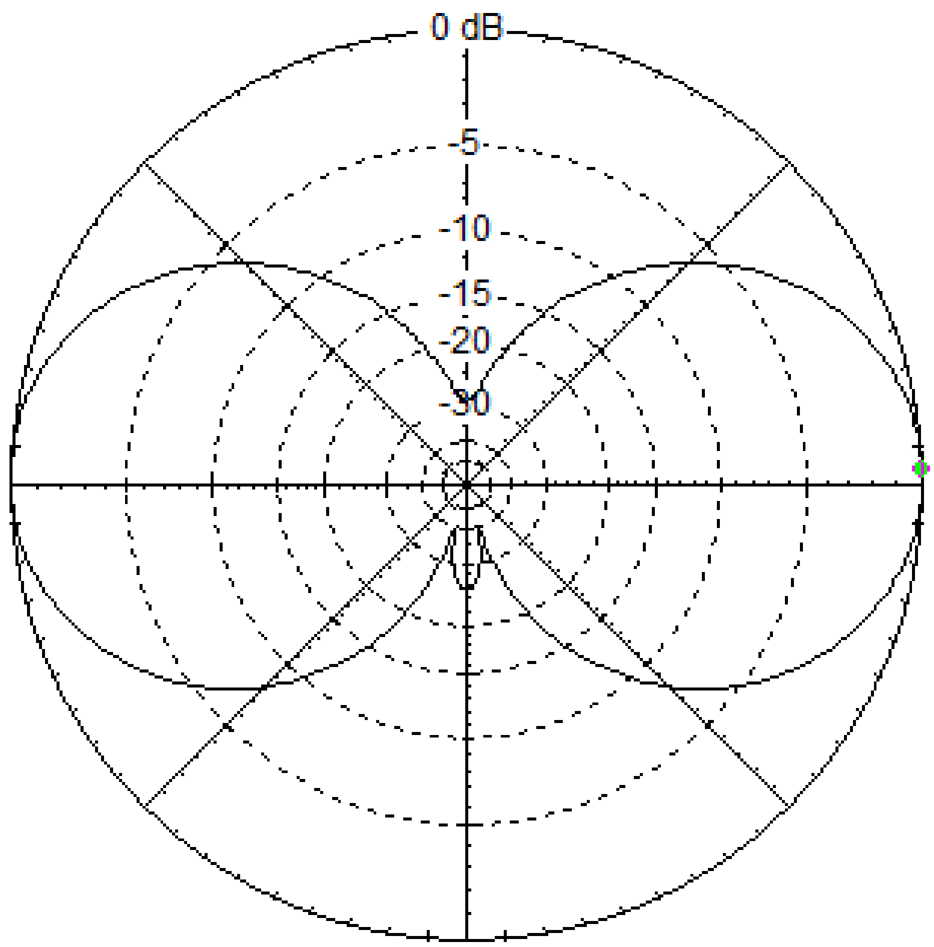

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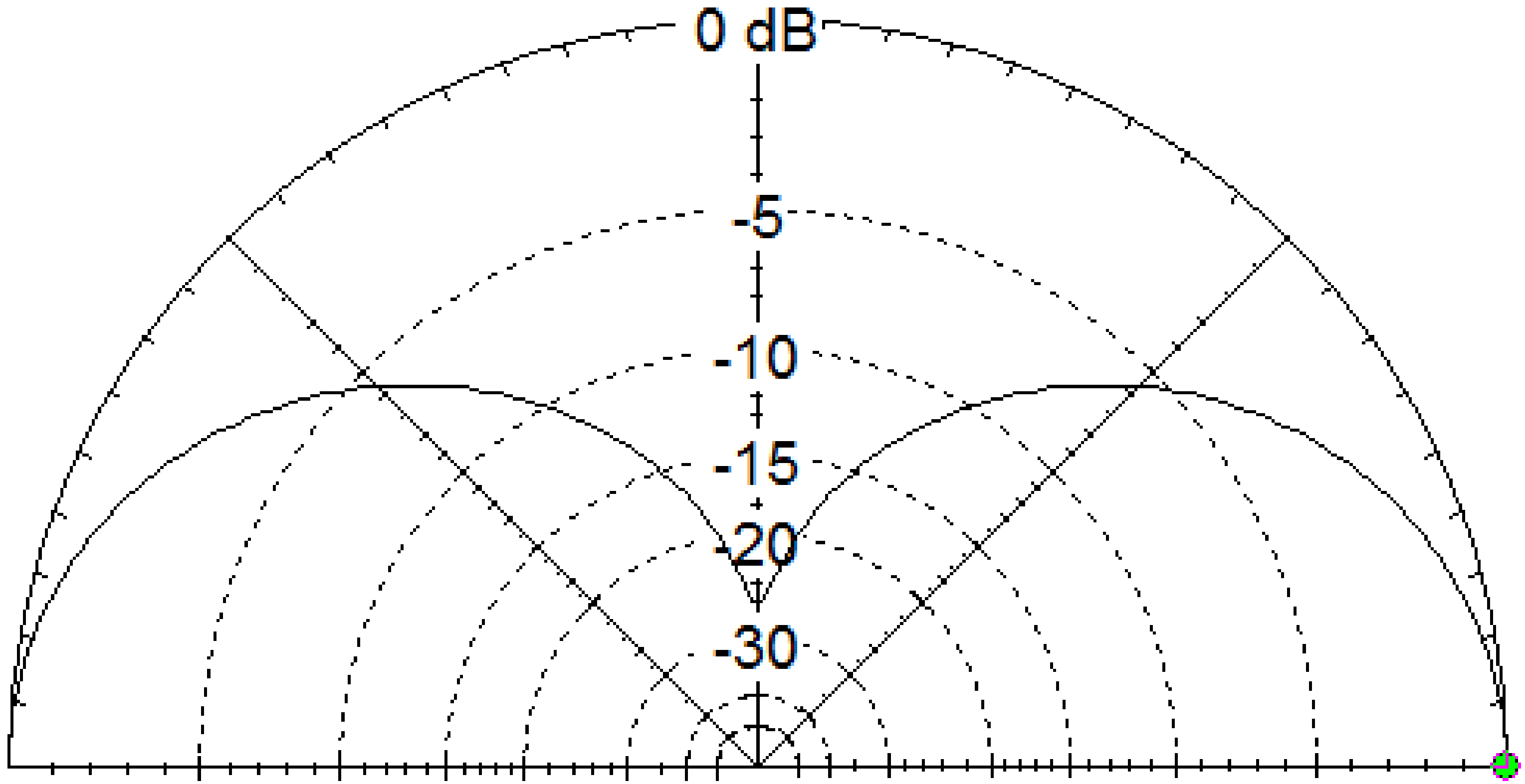

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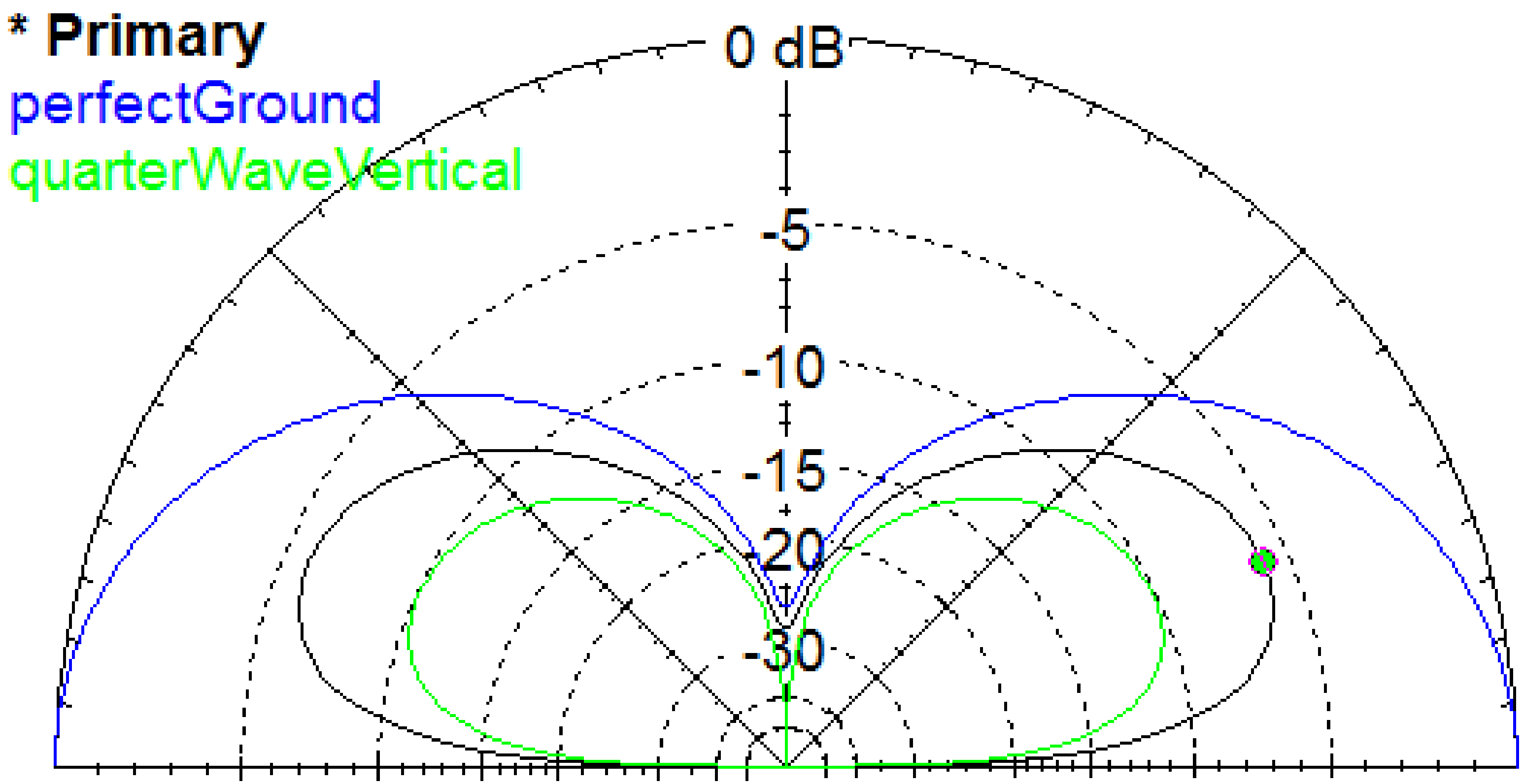

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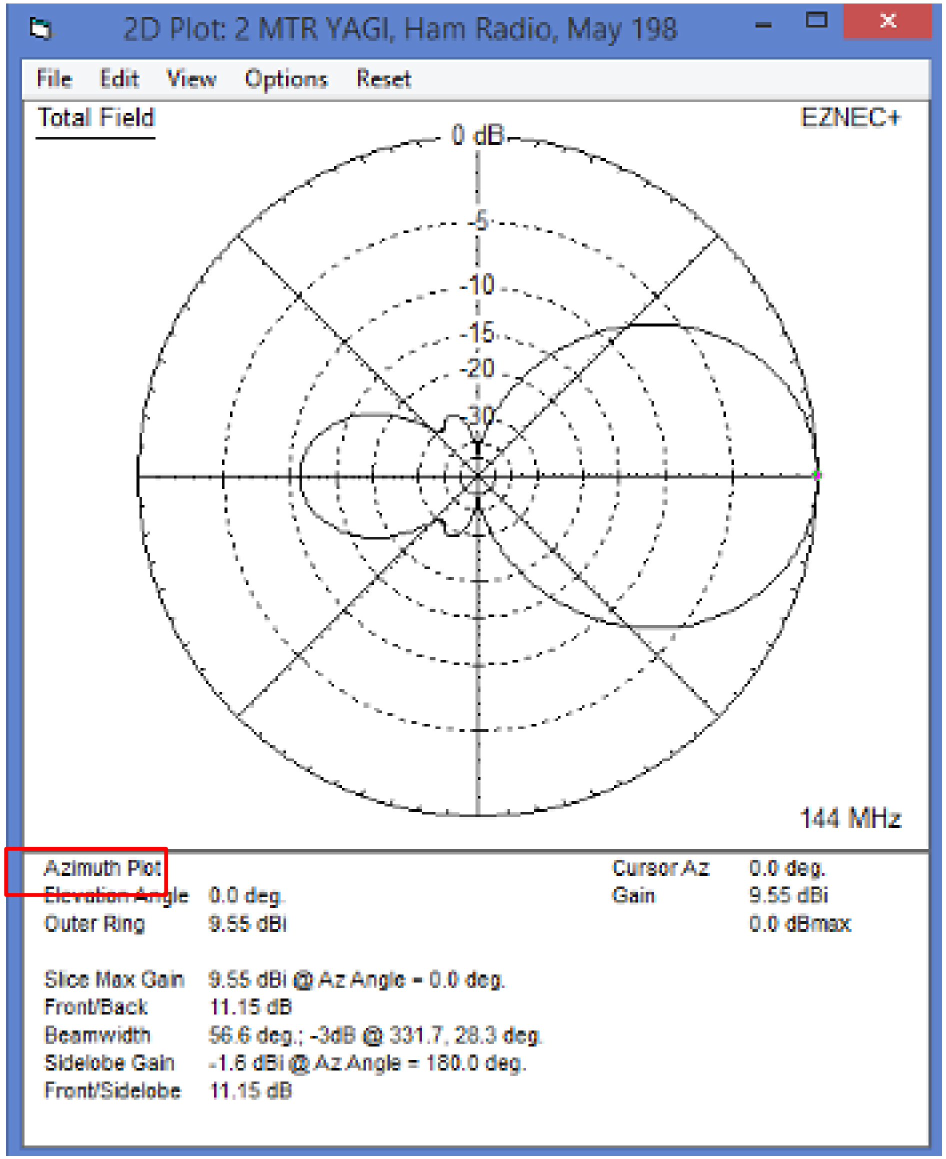
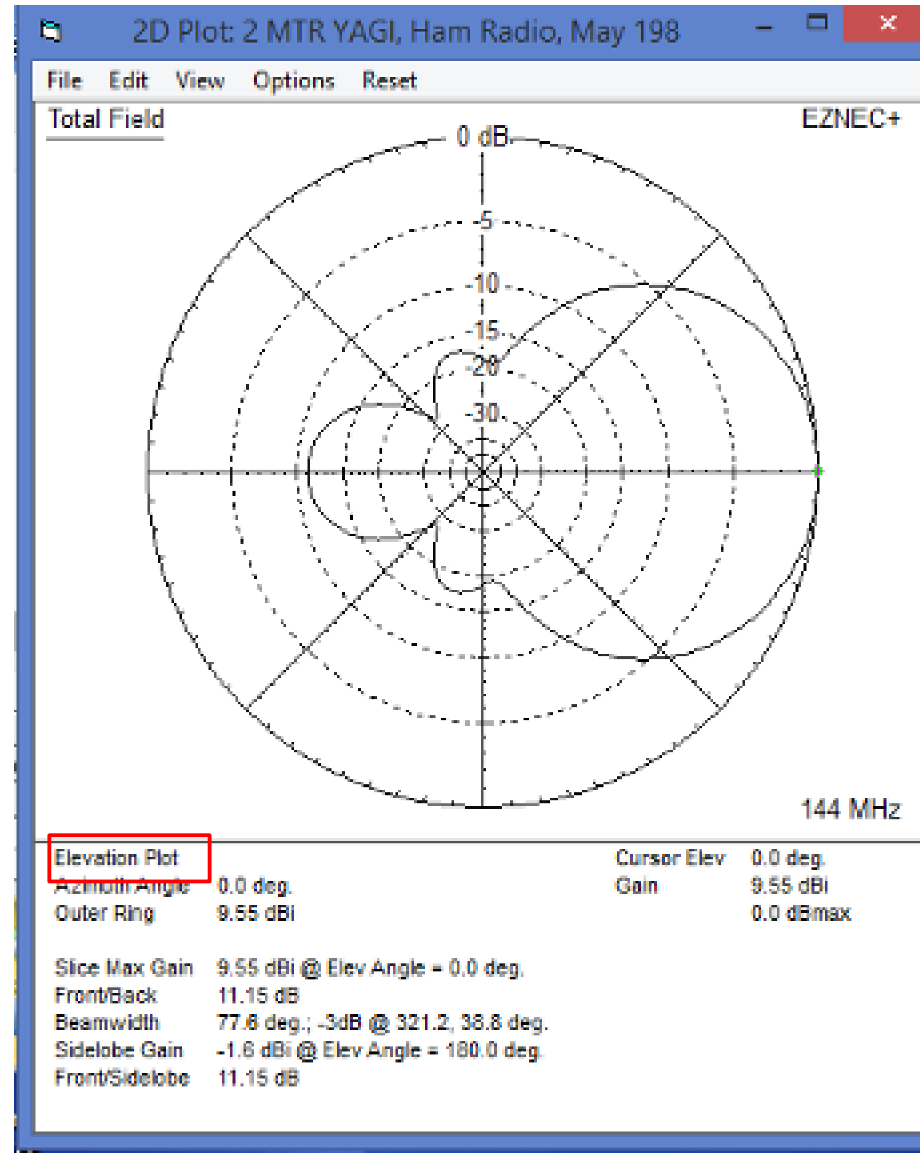
- **Why bother?**

Yagi-Uda Arrays

- No feedlines between elements simplifies construction.
- More gain per volume than driven elements
- **Used by lots more hams than driven arrays.**

Yagi-Uda Arrays





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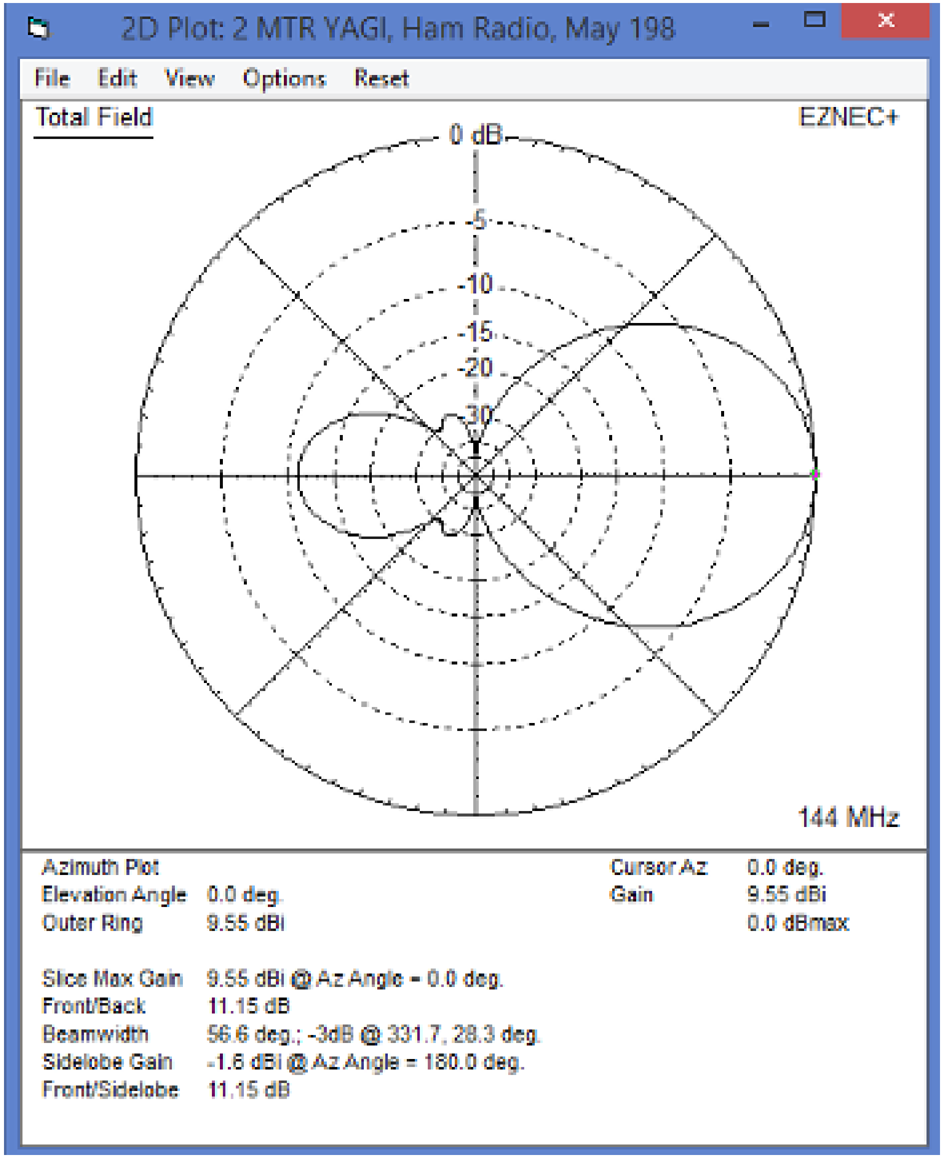

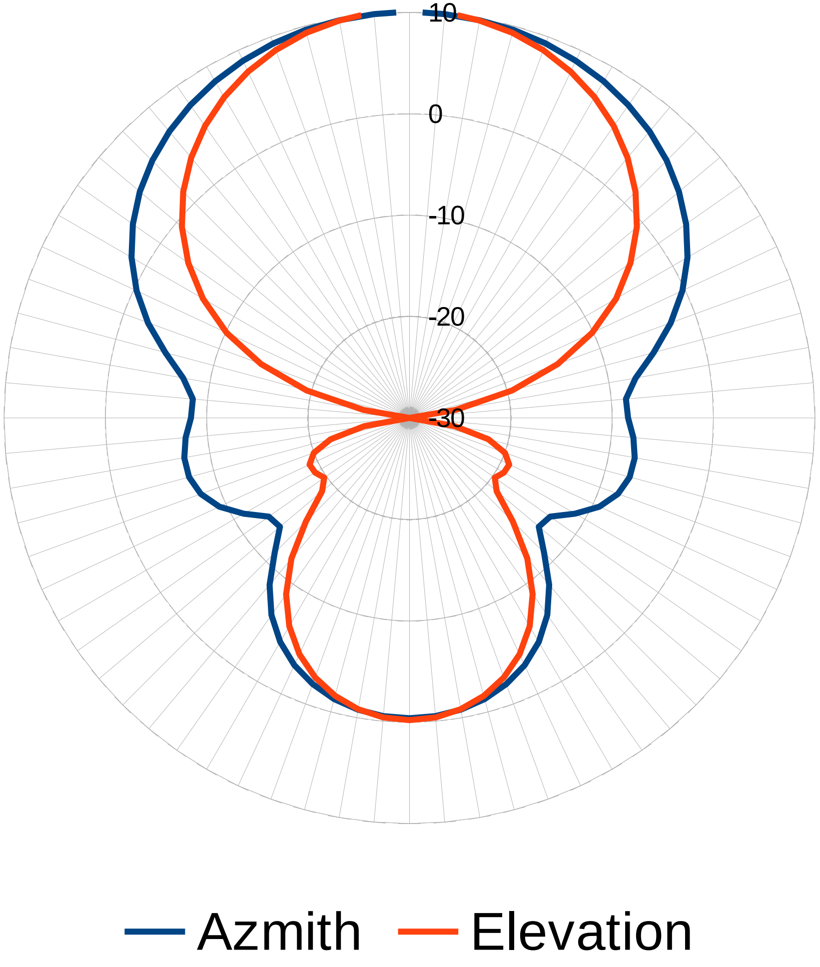

Comment on Driven Arrays

- Previously we analyzed arrays, buy saying that the currents were equal and of a certain phase. The real world is more complicated.

- Yagi antennas demonstrate that elements within ¼ wavelength can strongly couple to each other.

- If you build a driven array with close-spaced elements, expect there will be coupling. Just connecting ¼ wave transmission line probably won't achieve the intended equal magnitude with 90 degree delay.

Questions?