stacking broadside collinear

There are three primary types of arrays, collinear, broadside, and endfire.

Collinear is pronounced co-linear, and we may think it is spelled colinear, but the correct spelling is collinear. Collinear describes two or more things arranged in a straight line. Extended double Zepps, and two half waves in phase, are examples of collinear arrays.

Broadside is used to describe pattern in relationship to spatial area occupied by the array. While a collinear array is a broadside array, the term broadside is usually reserved for non-collinear arrangements.

Endfire arrays are arrays with elements arranged in-line with maximum radiation. Yagi antennas, W8JK arrays, and log periodic dipole arrays, are all endfire arrays.

Gain

Before analyzing stacking (broadside) or collinear antennas, we really should understand how making antenna systems larger increases gain.

Creating new nulls, at angles and directions initially having significant radiation, increases gain. The newly created null removes wasted energy in null areas, making that energy available in more desirable directions. In other words, because applied transmitter power is constant, energy formerly radiated in areas of ***significant radiation*** moves to enhance gain in other directions. This effect has nothing to do with increased area or size. It has everything to do with creating nulls, which remove power from areas with significant radiation, while not significantly increasing heat losses.

Null creation is related to the phase of two or more sources of radiation, as waves arrive at different points in space around the array. If we arrange elements spatially, and phase the elements in a way that forces a null where there is very little energy, we will not see much gain change. This is because the system is attempting to remove energy from an area lacking significant energy. The reward is small, because there is little energy to redirect to more useful angles or directions. An example of this is the quad element, as height is varied. When a horizontally polarized full-wave quad element is placed 1/2λ above ground, or multiples of 1/2λ above ground, quad gain over a dipole is minimized, or can even be negative. This is because the quad element is trying to force a null in an area that already has a deep null. Conversely, when the quad element is 3/4λ high (which produces a strong overhead field), or is in freespace, gain over a dipole is maximized. This is because, under the latter conditions, the dipole has significant energy where the quad forces a null.

This effect is sometimes called ***pattern multiplication***. Before antenna modeling software was commonly available, we often used pattern multiplication to estimate patterns and gain. Pattern multiplication remains a useful tool, helping us visualize why or how a particular array behaves in a certain way.

We should always consider patterns caused by spacing and phasing, including earth reflections, when planning optimum spacings. Optimum spacing will usually vary as element mean height, or null points created by original cells making up an array, vary. We must never assume a certain spacing always producing optimum gain, or that effective aperture somehow sets optimum broadside or collinear spacing. We will see doubling an antenna's size almost never doubles antenna gain (3dB).

I've added graphs from Jasik's Antenna Engineering Handbook throughout this article. These graphs show theoretical maximum gain of short, lossless, dipole elements when placed end-to-end (Collinear) or parallel above each other (stacked broadside).

Collinear Gain

First we have the end-to-end or *collinear* element placement gain.

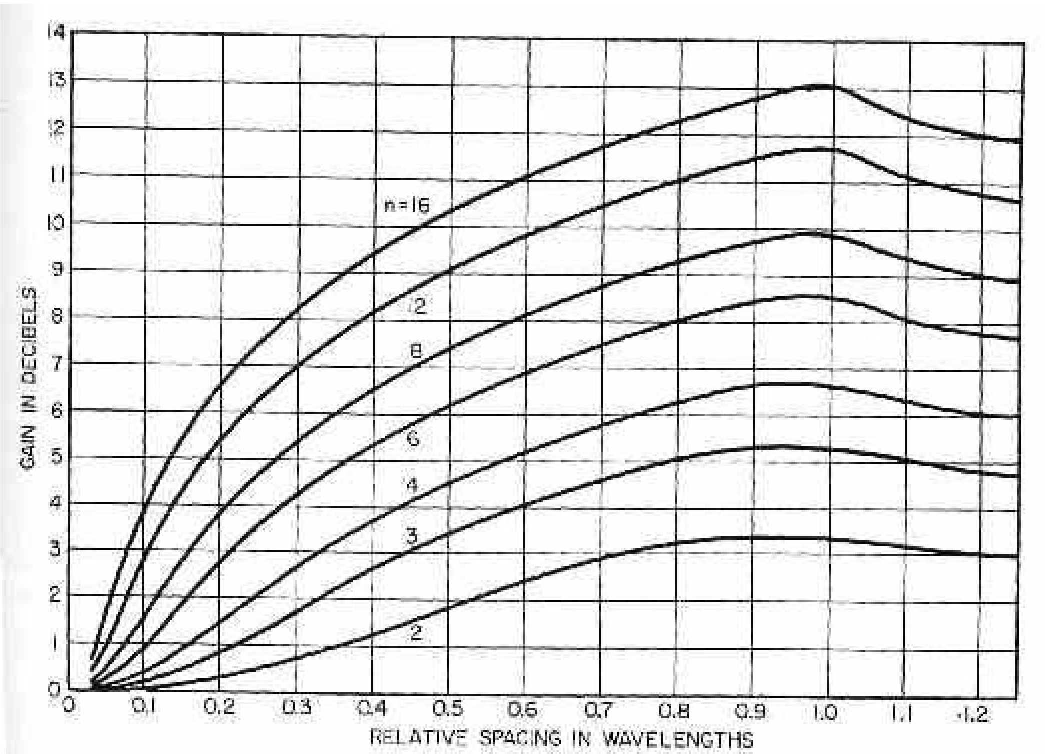
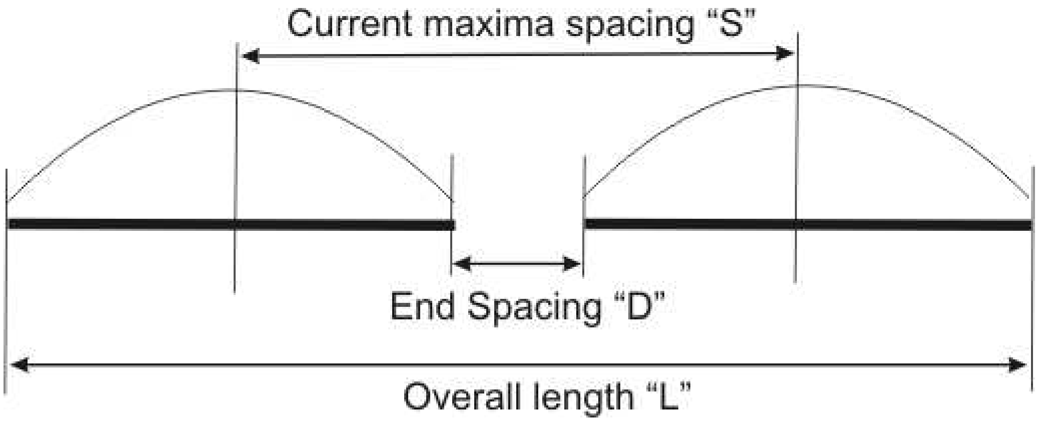


FIG. 5-22. Gains to be expected from a collinear (omnidirectional) array of short-dipole elements. The gain is relative to that of a single element.

The "Relative Spacing In Wavelengths" in the graph (fig 5-22) above is the ***current-maximum*** spacing of the elements, not element "tip" or "center" spacing.

Gain for two collinear 1/2λ (or shorter) dipole elements peaks with ~0.9λ (wavelength) spacing. Radiation is caused by current, and so areas of maximum current are where radiation primarily occurs. With a 1/2λ dipole in each element, the dipole center spacing below would be 0.9 - .25 - .25 = 0.4λ. The overall array length would be .9 + .25 + .25 = 1.4λ



With two dipoles placed end-to-end at the center with almost no end spacing, spacing of current maximums (S) would be .25+.25=.5λ. Overall length would be twice that of a single dipole, or 1λ. Maximum theoretical gain for this spacing is found on the graph above, at the crossing of the vertical 0.5 RELATIVE SPACING IN WAVELENGTHS and intersection of "curve 2" (the two-element curve), as just under 2dB over a single element. Gain would be less than 2dB over a single element in ANY collinear antenna using 1/2λ or shorter elements with very small element end spacings (D). Despite what is commonly claimed, doubling the number of elements and doubling array length does ***not*** increase gain 3 dB.

A ***collinear*** two-element antenna, using half-wave dipole elements, has 3dB gain over a single dipole when dipole current maxima spacing (S) is .75λ. This is .25λ D, or 1.25λ overall L in the case of 1/2λ dipole elements, for 3 dBd gain. Keep in mind 3dB is not the maximum obtainable gain for two elements. Maximum theoretical gain is about 3.25 dBd, and for 1/2λ dipole elements, occurs at about 0.9λ S current maxima spacing, or 1.45λ L overall length.

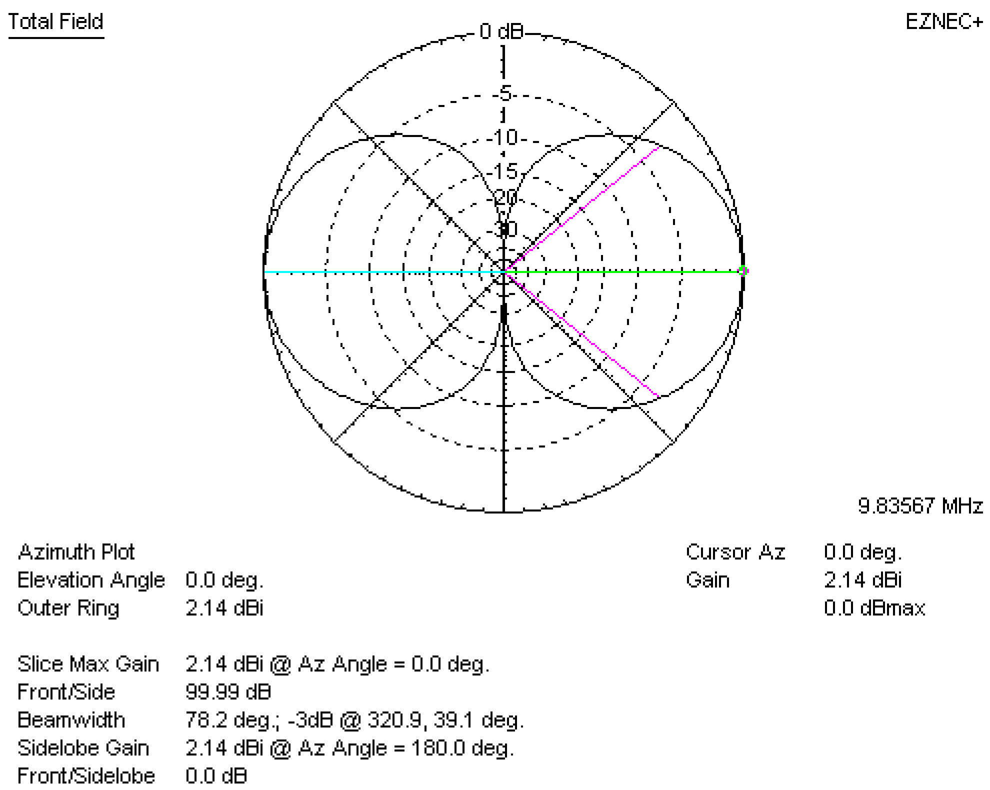
Doubling gain again (3dB more gain, for a total of ~6dB), over the two-element case, requires a minimum of ***four*** collinear elements. The array would be 2.75λ long, or 5.5 times the overall length of the initial dipole.

The array will produce over 6dB gain by using more than .75λ current maxima spacing. If the array has .95λ element current maxima spacing, the array of four elements would have optimum gain of 6.7dB with an overall physical length of 3.35λ.

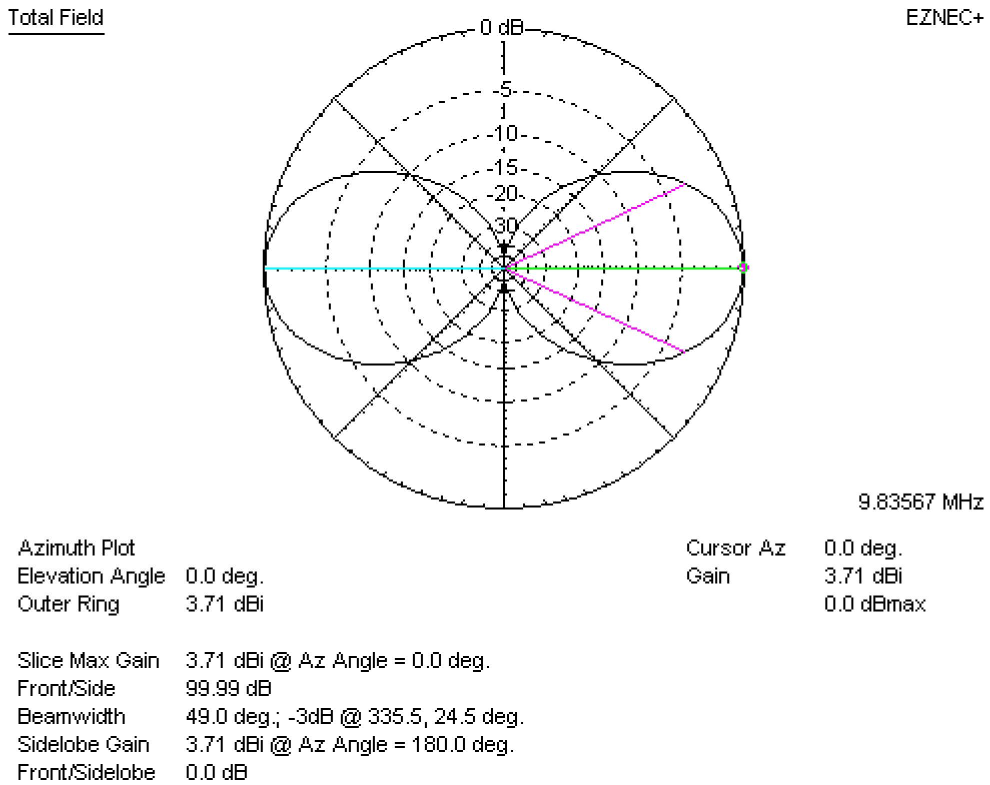
The more elements the array has, the further individual elements must be spaced for optimum gain. Doubling physical size while doubling the number of elements will not double the gain.

EXAMPLE OF COLLINEAR

Using EZNEC, we see the gain of a lossless dipole in freespace is 2.14 dBi.



Adding a second collinear element with close end-to-end spacing, which doubles antenna size, we have:



We now have 3.71-2.14 = 1.57dBd gain. We doubled antenna size, but gain increased only 1.57 dB. Looking at Jasik's collinear gain graph, we find close agreement. Current maximum spacing "S" in the model is 0.5λ, and maximum theoretical gain predicted in Jasik's graph is about 1.75dB:

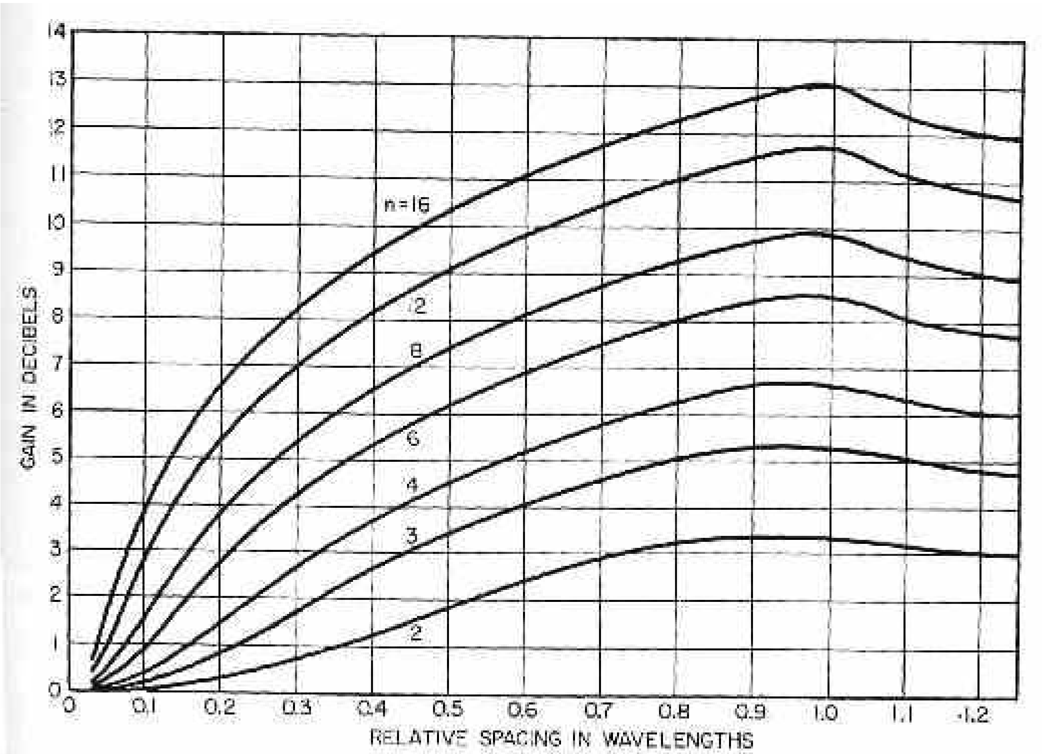
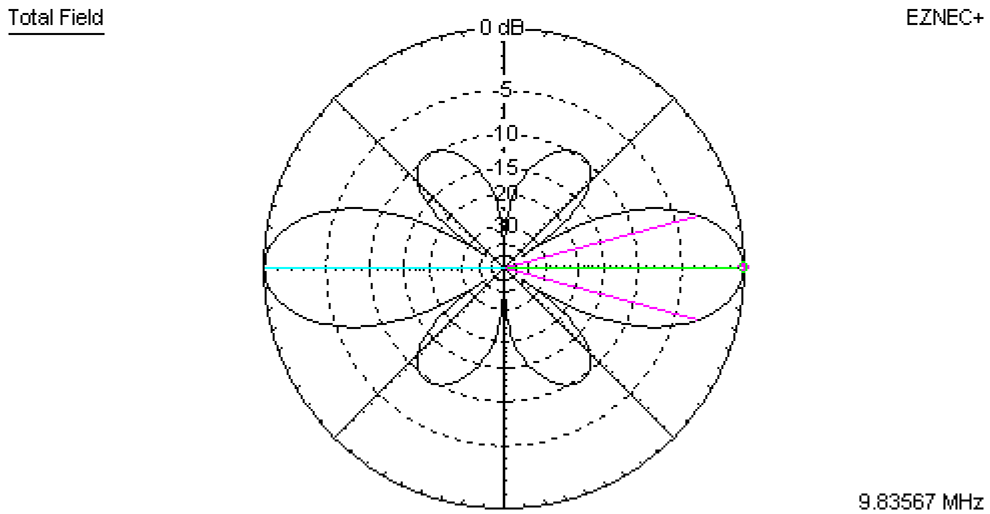


FIG. 5-22. Gains to be expected from a collinear (omnidirectional) array of short-dipole elements. The gain is relative to that of a single element.

Increasing spacing S to 0.9 wavelengths should produce maximum gain for two lossless collinear dipole elements. EZNEC shows, for full-size dipoles:



Azimuth Plot
Elevation Angle 0.0 deg.
Outer Ring 5.37 dBi

Cursor Az 0.0 deg.
Gain 5.37 dBi
0.0 dBmax

Slice Max Gain 5.37 dBi @ Az Angle = 0.0 deg.
Front/Side 99.99 dB
Beamwidth 30.0 deg.; -3dB @ 345.0, 15.0 deg.
Sidelobe Gain 5.37 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe 0.0 dB

We now have 5.37-2.14 = 3.23 dBd gain. This is in close agreement with Jasik's graphs. A 3dB gain increase requires a 2.6 times antenna area increase, and this is with simple dipoles. Generally, as individual elements or cells (groups) of elements making up an array become more directive, optimum spacing distance increases.

Earth Influences on Azimuth-focused Gain

When an antenna with azimuthal or compass-heading directivity increase is placed above earth, pattern multiplication and gain is not largely affected by earth. It is still possible to nearly obtain full theoretical gain at any height. This is because the earth is not trying to force a null where the array is also trying to create a null.

Broadside Arrays

Broadside array usually describes elements or cells or elements placed parallel and one above the other. The graph below shows ***OPTIMUM or maximum possible gain***, not the actual gain an array might have. The graph below is for *1/2*λ *dipole* elements (or shorter) in freespace. Stacked Yagis would, in general, require wider spacing to produce maximum possible gain, and almost always produce less than the theoretical maximum gain increase shown below. This is because a Yagi generally has a significant null off the antenna's forward lobe. The differently located nulls, or reduced energy level in areas where dipoles normally have significant radiation, change optimum broadside stacking distance.

Optimum broadside stacking distance increases with more directive elements or cells. This is why a pair of multi-element Yagis stacked requires wider spacing than a pair of dipoles, and why less maximum stacking gain is possible with the Yagi than we might obtain with stacked dipoles. Think of it this way, if the antenna is already narrow there is less unwanted energy available to move to the main lobe.

Here is the optimum gain graph for dipoles in freespace:

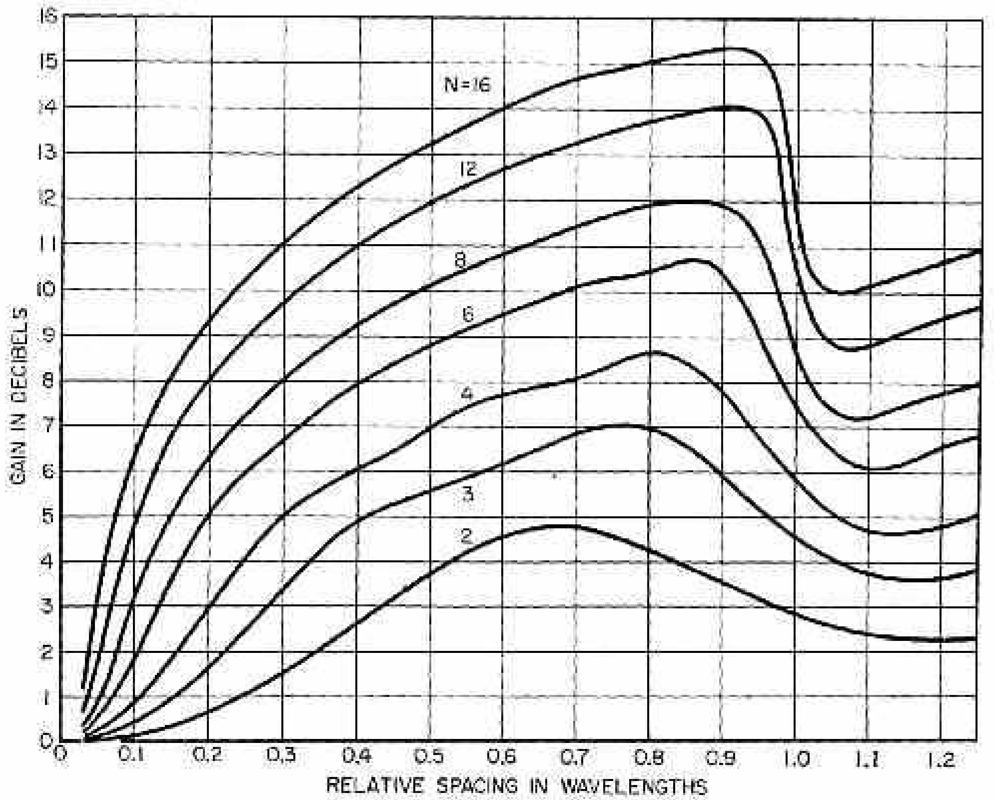
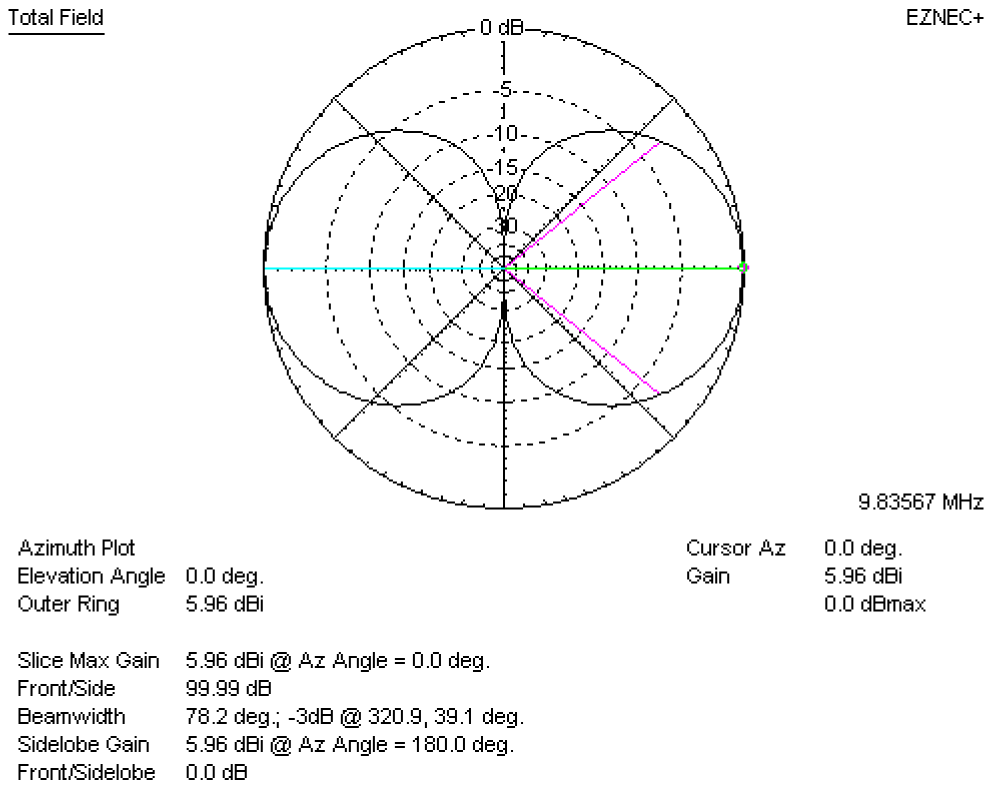


FIG. 5-10. Gains* to be expected from a single array (no reflector) of broadside elements.

We can see maximum gain occurs at .675λ stacking height. The stacking gain is 4.8db, not 3dB as we often see claimed. Again the more elements the narrower the pattern, and the narrower the pattern the wider spacing must be between elements for maximum gain.

EZNEC Comparison

Here is the freespace EZNEC plot of two stacked (broadside) dipole elements:

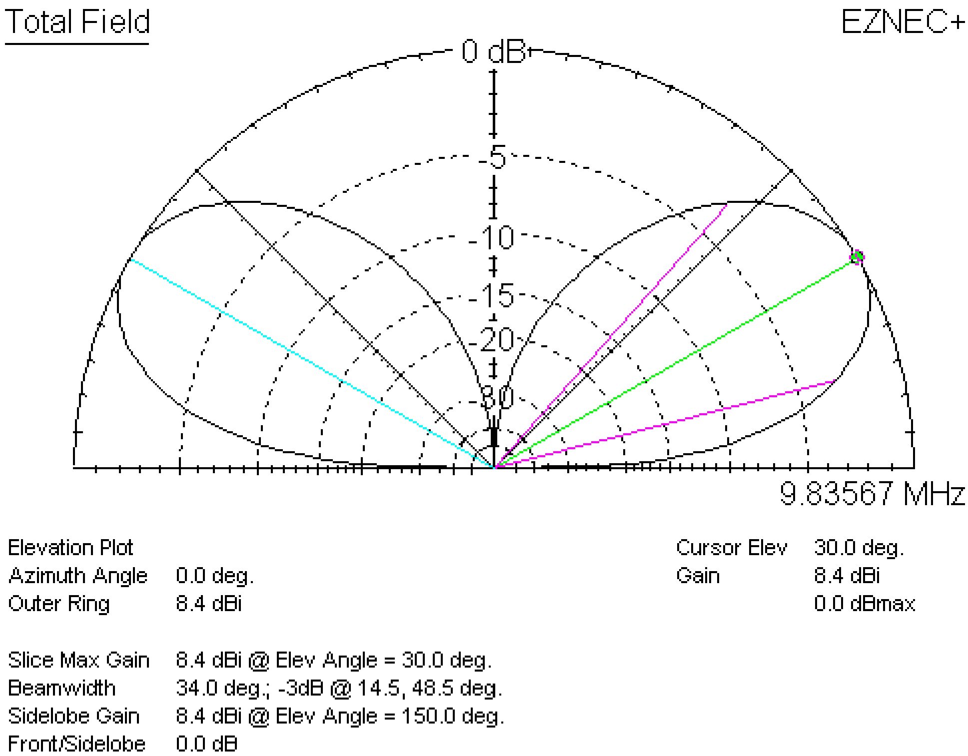


Compared to a lossless dipole in freespace, gain is 5.96 - 2.14 = 3.82 dBd. This agrees with the graph from Jasik.

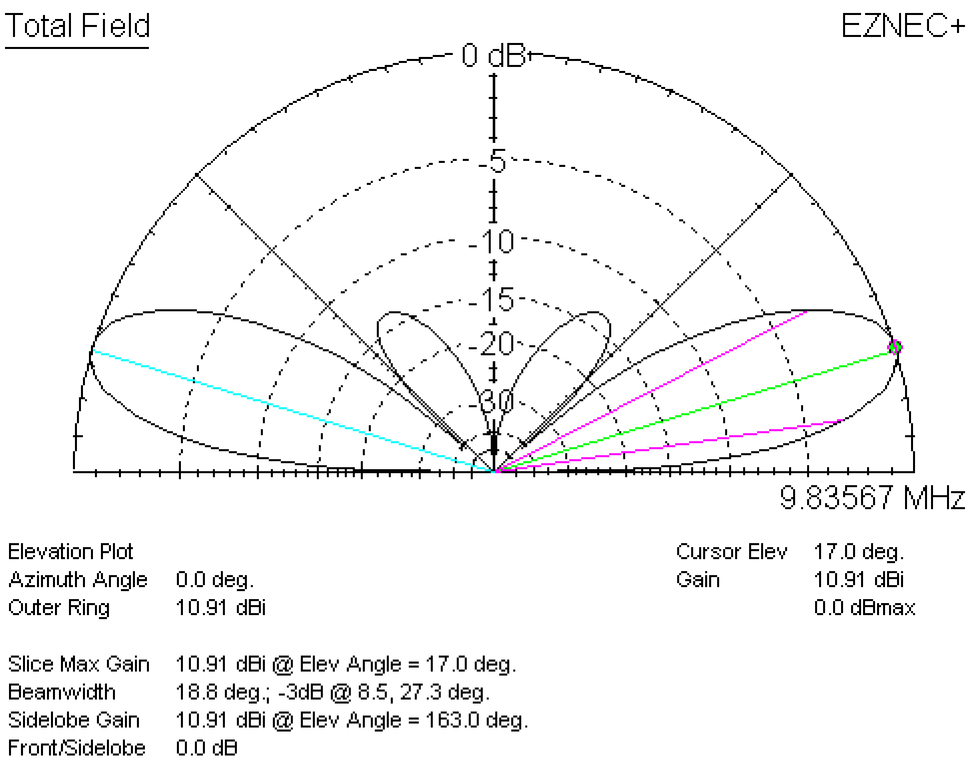
Earth Influences on Elevation Patterns

The presence of earth influences optimum stacking distance. This is because the earth is trying to force a null in the same area or areas that elevation stacking is also influencing. The earth can be considered a second element, and before computer modeling, this influence was often visualized and calculated by using fields from an imaginary "image antenna" placed down in the earth. The "image antenna" was not something that actually existed, but was a tool for calculating elevation patterns in the presence of earth. If we search old textbooks and handbooks, the image antenna often appeared.

If we have a lossless dipole at 1/2λ over perfect earth, we have this basic gain:

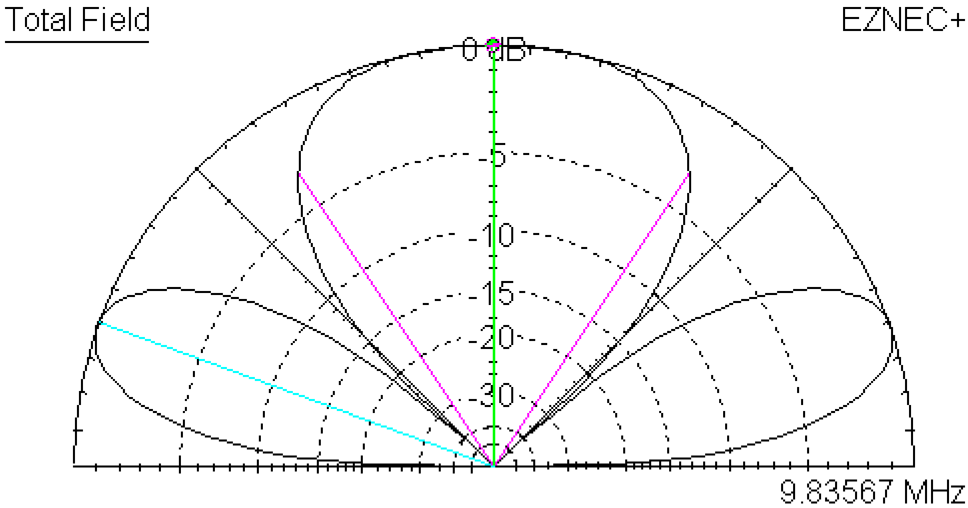


For a single lossless dipole, 1/2λ over perfect earth, gain is 8.4 dBi. Now let's watch when we stack the dipoles at the same 1/2λ wave stack spacing:



The system now has 10.91 - 8.4 = 2.51 dBd gain. Freespace stacking gain was 3.82 dBd, stack gain is about 1.3 dB less.

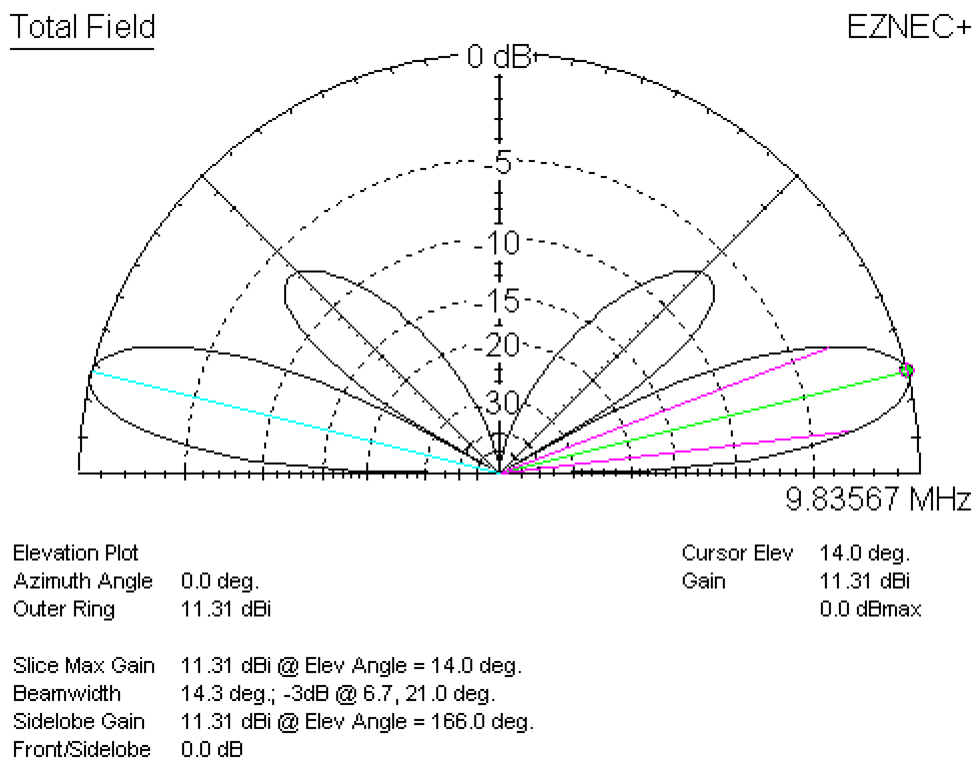
Moving the dipole to 3/4λ height, we have the following dipole pattern and gain:



Elevation Plot		Cursor Elev	90.0 deg.
Azimuth Angle	0.0 deg.	Gain	8.05 dBi
Outer Ring	8.05 dBi		0.0 dBmax

Slice Max Gain	8.05 dBi @ Elev Angle = 90.0 deg.
Beamwidth	67.0 deg.; -3dB @ 56.5, 123.5 deg.
Sidelobe Gain	8.04 dBi @ Elev Angle = 160.0 deg.
Front/Sidelobe	0.01 dB

This is 8.05dBi gain, now with significant energy where the stack would force a null. Adding the second broadside element, in the stack, we have:



Gain is now 11.31 dBi, or 3.26 dBd (dipole at 3/4λ).

Summary

I hope these graphs help dispel the myth that doubling number of elements, or doubling array size, doubles gain (3dB gain). Things are not that simple, and things almost never follow that rule.

1.) Doubling elements or array size does not guarantee doubling (3 dB more) gain. That's a myth, because it is almost never true.

2.) The narrower initial antenna pattern is, the wider stacking distance generally becomes for maximum gain improvement. This does, in some very rough way, relate to effective aperture.

3.) Optimum stacking distance for gain is virtually never 1/2λ, it is almost always wider.

4.) Optimum stacking distance can be very wide for arrays with multiple sharp-pattern antennas, or cells, in the array.

5.) Maximum gain occurs only when a null is forced in an area that formerly contained significant energy levels. If the original element or cell of elements has a null where the stacking distance tries to force a new null, maximum gain increase is reduced.

6.) Height above ground affects antenna pattern, and because of that, height also affects optimum stacking distance.

7.) Determining optimum stacking height or distance requires a model that includes earth, as well as feedline and conductor losses.

Feed Systems

The optimum feed system is generally a distributed or branching type of feed system. There are many articles suggesting feed systems, so I'll only point out a few places where caution should be applied.

One error is using long lengths of 75-ohm line to co-phase two 50-ohm elements. An odd-quarter wavelength 75-ohm line transforms impedances because the line is mismatched, and has standing waves. If the line is lossless with a perfect 50 0j ohm load, the 75-ohm SWR all along the 75-ohm line is 1.5:1. This means, at odd-quarter wave distances, line impedance becomes 1.5*75 = 112.5 0j ohms. Two of those impedances in parallel are 56.25 ohms. Unfortunately, the required coaxial cable physical length means elements must ether be less than 1/2λ apart, or we must use longer feedlines from the Q-sections to element centers.

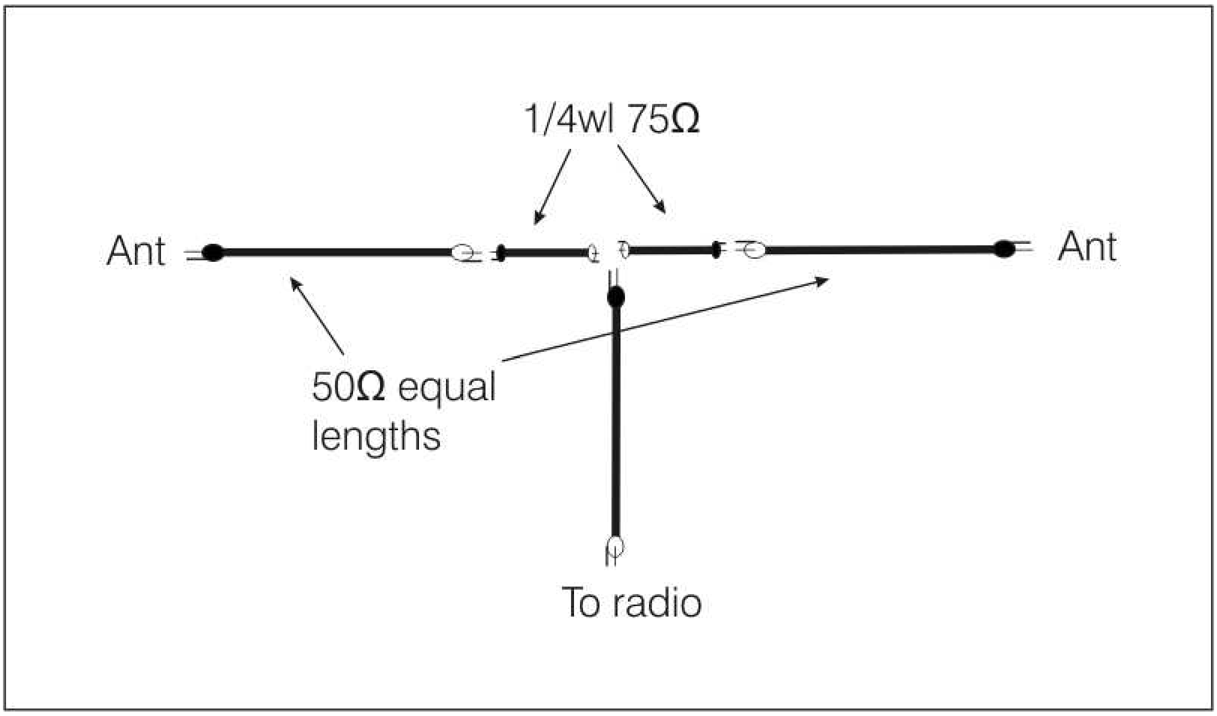
Many articles make the Q-section longer than λ/4, such as 3λ/4 or 5λ/4. We should be careful doing this, for two reasons:

1. Losses increase because mismatched sections are longer
2. Bandwidth decreases because there are multiple mismatched sections in series

Consider the case of a line 5λ/4 wavelengths long. Such a line has five 90-degree sections in series. If frequency changes 2%, it causes a 2% error in each λ/4 section. Errors in each of the five sections add, and now the total line error is 10%. The Q-section not only has additional loss, it also has reduced bandwidth.

Using a 50-ohm section from each element to its respective Q-section, so each Q section only needs to be λ/4 long, will always increase bandwidth and often decrease losses. It is also not difficult to implement. My 6-meter Yagi stack uses 50-ohm equal length lines to the Q-sections, which are only λ/4 long. Length of the 50-ohm sections does not matter, so long as they are equal, because the 50-ohm sections are matched, and essentially have a 1:1 VSWR. If I make a velocity factor error, or change frequency, or have 75-ohm line losses, errors and/or problems are 5 times less!

I'm not forced to have feedlines between the antennas that can only be changed in multiples of λ/2, such as λ/4, 3λ/4, 5λ/4, and so on. I can use two equal length 50-ohm feedlines that are any physical length that reaches, with the only attention to detail the quarter wavelength 75-ohm Q-sections. This greatly reduces cable cutting errors because the long lines are matched, and only need to be equal lengths of the same cable stock.



Where do we use stacking and collinear gain most effectively?

We use broadside stacking and collinear gain most effectively in Curtain Arrays like the Lazy H antenna. You can read more about Curtain Antenna Arrays on my **Sterba Curtain Lazy-H antenna page**.

Arrays over Earth

Unless we remove energy from an area that had significant energy, antennas cannot produce gain. If an antenna has a wide area with no radiation at all, and we designed a system to force a null totally within that same area, there would be no gain at all. The pattern must be narrowed to increase gain, and it must be narrowed in a way that does not increase heat losses faster than it concentrates electromagnetic radiation.

Earth focuses energy in the elevation plane, creating one or more nulls in elevation pattern. Height above earth, as well as quality of earth, controls the nulls formed by earth reflections. For somewhat flat earth, nulls formed by the presence of earth are all in the elevation plane of the pattern. In most cases, azimuthal beamwidth, or compass directivity, is largely unaffected by antenna height. For this reason, azimuth pattern multiplication, or gain increase by focusing in what we consider "compass direction", is largely unaffected by height above earth or changes in stacking spacing. We saw this above in the relationships between actual gain with height or vertical spacing of the antenna or antennas, and gain changes with changes in horizontal spacing or area occupied by the antenna elements.