Collinear Phased Antennas for the HF Bands

Need a good-performing wire antenna? A collinear phased array could be just what you're looking for!

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The thrill of chasing DX is an integral part of Amateur Radio. With the increase in sunspot activity, there's more DX fun every day! Unfortunately, newcomers (and some old-timers) sometimes think that the only way to work DX is with the aid of costly towers, rotators and beams. This article shows you how to design and build an effective DX antenna called a collinear phased array. Collinear antennas are easy and inexpensive to construct, and if you already have a dipole or an inverted V, you already have many of the materials you'll need.

Collinear-Array Fundamentals

Basically, a collinear array is nothing more than two or more radiating elements that are strung together, end to end.[1] The radiating elements are usually a half wavelength long, but other lengths can be used. Fig 1 shows a collinear array that is composed of three half-wave, center-fed dipoles. If the three transmission lines that lead from the common feed point in Fig 1 to the centers of each dipole are the same length, the currents in all three dipoles will always be traveling in the same direction at a given time (the three dipoles are in phase). The term *collinear* is used because the radiating elements are arranged geometrically in a straight line.

If the three dipoles shown in Fig 1 are fed in phase, the fields created by the dipoles will also be in phase. At a distant receiving antenna in a direction perpendicular to the array elements, the energy radiated by the three dipoles adds, creating a received signal that is stronger than if only one dipole was used. This principle also applies to the reception of incoming waves: A perpendicular incoming wave strikes all three dipoles at the same time. The signals induced in the dipoles add in phase, making the received signal stronger than if only one dipole was used. The theoretical gain of a collinear phased array over a half-wave dipole is 1.9 dB for an array with two elements, 3.2 dB for a three-element antenna and 4.3 dB for an array with four elements.

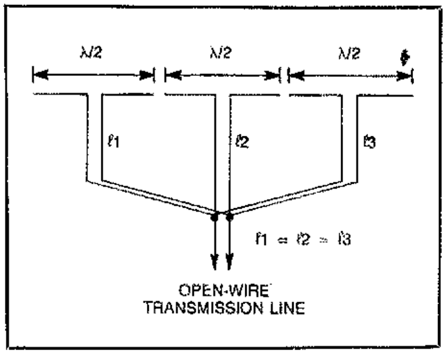

Fig 1—A three-element, collinear phased array fed with equal-length sections of open-wire line. (This is the simplest way to feed a collinear array.) See text.

Table 1

Number of wavelengths of open-wire transmission line required to connect two to five elements to a common feed point

Number of elements	*Wavelengths of transmission line*
2	1.5
3	3.0
4	5.0
5	7.5

Feeding Collinear-Phased Arrays

The use of multiple feed lines as shown in Fig 1 has the advantage of ease of construction and tuning. The only things you need to tune this antenna system are a tape measure, a transmitter and an SWR bridge. The use of multiple feed lines has several *disadvantages*, however. Feed lines should run perpendicular to the antenna for at least a half wavelength before turning any corners. This can be an unsightly mess, difficult to implement (depending on the installation) and, most of all, costly. Table 1 shows the minimum amount of parallel-conductor transmission line that is necessary to connect multiple elements to a common feed point.

The preferred methods of feeding collinear phased arrays are shown in Figs 2 and 3. Fig 2 shows the feed system for an antenna with an odd number of elements, and Fig 3 is that for an antenna with an even number of elements. The advantage of these feed methods is that only one feed line is required, and its length isn't critical. In general, the feed methods shown in Figs 2 and 3 are less costly, easier to construct, and visually unobtrusive. The disadvantage is that some means (such as an RF noise bridge) is required to adjust the quarter-wave phasing lines.

The short arrows next to the antenna elements in Figs 2 and 3 indicate the direction of current flow during half of a cycle of the applied signal. During the following half cycle, all currents flow in the reverse direction. In a long, continuous wire, the direction of current flow reverses every half wavelength. Figs 2 and 3 show that all currents in the radiating sections are in phase.

The short vertical sections shown in Figs 2 and 3 are quarter-wave phasing stubs. The current flowing on one side of a stub is equal in amplitude to the current flowing on the other side at every point along the length of the stub. Because the currents flow in opposite directions, their magnetic fields cancel, and the stub does not radiate. The current amplitude is not constant along the length of the stub: The current is at a minimum at the top of the stub, and reaches a maximum at the bottom of the stub.

Both voltage- and current-feed methods are shown in Figs 2 and 3. Voltage feed is so named because the antenna is fed at a

[1] Notes appear on p 32.

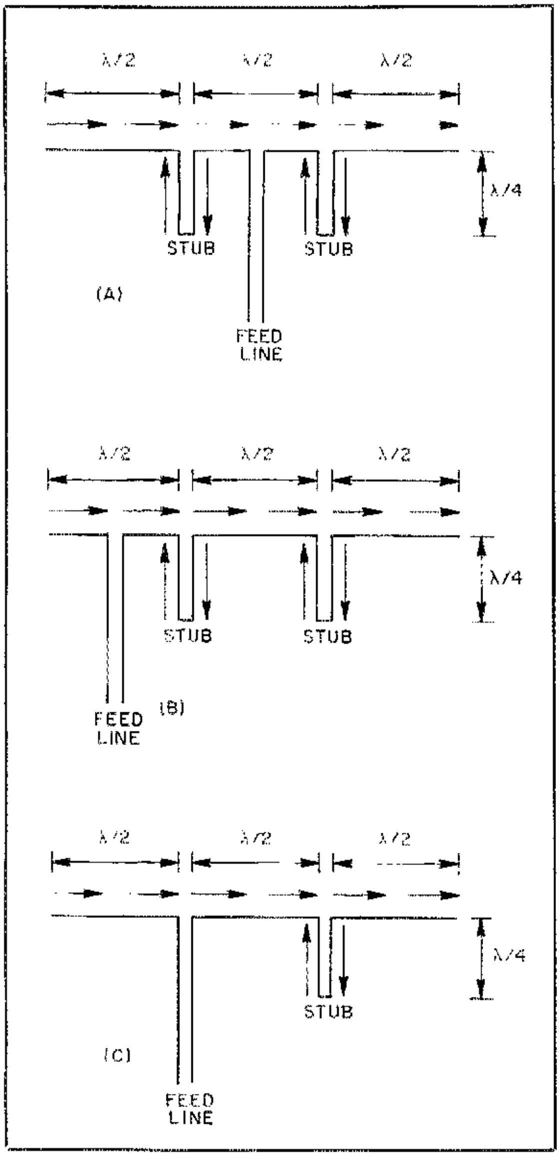

Fig 2—Feeding an odd number of collinear elements. At A, balanced current feed. At B, unbalanced voltage feed. At C, current feed.

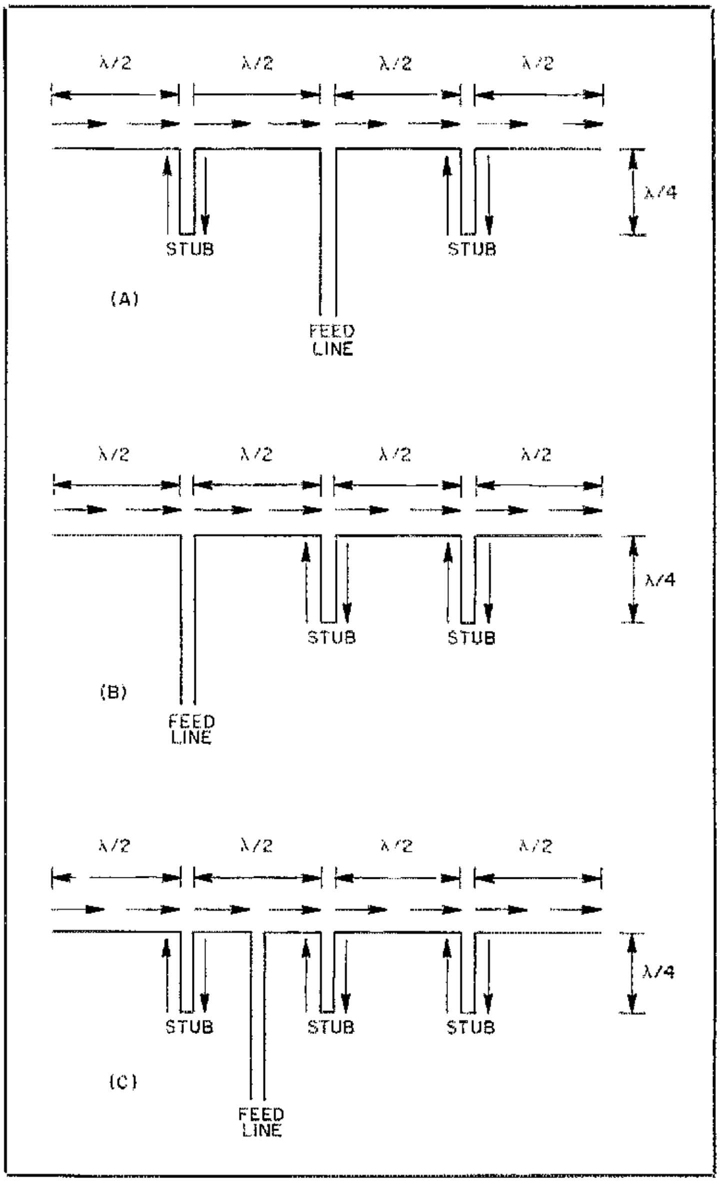

Fig 3—Feeding an even number of collinear elements. At A, balanced voltage feed. At B, unbalanced voltage feed. At C, current feed.

point of maximum voltage (minimum current). Current feed is feed at a point of maximum current (minimum voltage).

Collinear phased arrays work best if they are balanced (equal signal amplitudes flow on both sides of the antenna at a given time). Therefore, current feed is preferred for an antenna with an odd number of elements (Fig 2A). The feed-point impedance of a current-fed antenna is slightly over 300 Ω and provides a reasonable match to 300- or 450-Ω open-wire transmission line. Voltage feed is preferred for an antenna with an even number of elements (Fig 3A). The feed-point impedance of a voltage-fed antenna is over 1000 Ω. If a particular installation requires an off-center feed, current feeding is the preferred method because of its more favorable feed-point impedance.

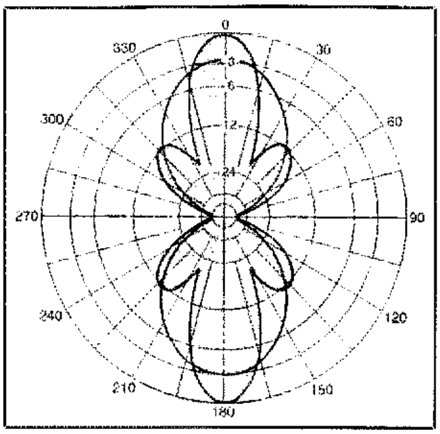

Fig 4—Radiation patterns of center-fed collinear phased arrays. The unshaded pattern is for an antenna with two elements; the shaded pattern is for a four-element antenna.

Radiation Patterns

Collinear phased arrays are bidirectional. In addition to some minor lobes, they produce two major lobes perpendicular to the antenna wire. The more elements the antenna has, the more narrow the major lobes (and the more numerous the minor lobes). Fig 4 shows the radiation pattern for collinear phased arrays with two and four elements. In addition to the coverage provided by the major lobes, the minor lobes usually provide adequate coverage for local communication.

Construction

The first step in constructing a collinear phased array is to decide the directions of the major lobes and how many elements the antenna should have. This depends on the location of the desired DX, whether or not these locations all lie in (or close to) a straight line and how much room there is at the installation site. If the desired DX locations all lie in (or close to) the same direction (or 180° from each other), the antenna can be built with many elements, assuming that the necessary space is available. On the other hand, if the desired DX is fairly spread out, the wider major lobes of an antenna with fewer elements may be more desirable.

If the gain and directivity of a three-element array is desirable but there isn't enough space for it, and if there is more than the required amount of space for a two-element array, an extended double Zepp (EDZ) should be considered. The EDZ—a special case of the two-element collinear phased array—has a gain of approximately 3 dB over a half-wave dipole, and is only 1.28 λ long. For information on this antenna, see *The ARRL Antenna Book* and *QST*.[2]

Collinear phased arrays work best if they are erected parallel to the ground. This means that a support is needed at each end—the higher the support, the better. If minimizing cost is important, or if less directivity is desired, the antenna can be erected as an inverted V. If this is done, the apex angle should not be less than 90°. The antenna may have to be raised and lowered several times during construction and tuning, so it is a good idea to use support structures with pulleys, as shown in Fig 5. The antenna can then be raised and lowered easily with halyards.

Materials

The radiating sections of the array should be constructed from no. 12 or 14 copper-clad steel wire, such as Copperweld™. The extra strength of steel wire is desirable because the antenna must bear the weight of the phasing stubs and transmission line. If minimizing cost is important, the antenna can be built from no. 12 insulated copper wire (the kind used for house wiring). If copper wire is used, however, the antenna may not stay up during severe weather, and the conductors may stretch excessively if they're not well supported.

The radiating sections of a collinear phased array must be an *electrical* half wavelength long, which means that they will be slightly shorter than the calculated value given by the equation

length (feet) = 468 ÷ f (MHz) (Eq 1)

There are two methods that can be used to find the correct electrical length for the materials being used; both start with the same step. Calculate the length of a half wavelength of wire using Eq 1. Use a frequency at the center of the desired band for this calculation.

The next step in using the first method is the construction of a half-wave dipole that uses the same antenna wire and insulators that will be used in the construction of the collinear antenna. Connect a 50- or 75-Ω transmission line to the dipole, and raise the antenna into position. Good-quality transmission line is not necessary for this test; an old piece of RG-58 or RG-59 will work fine. A balun is not required either. Resonate the dipole by pruning equal amounts off each end for best SWR. Once the dipole is resonant, it can be lowered and measured to determine the correct length for the half-wavelength elements.

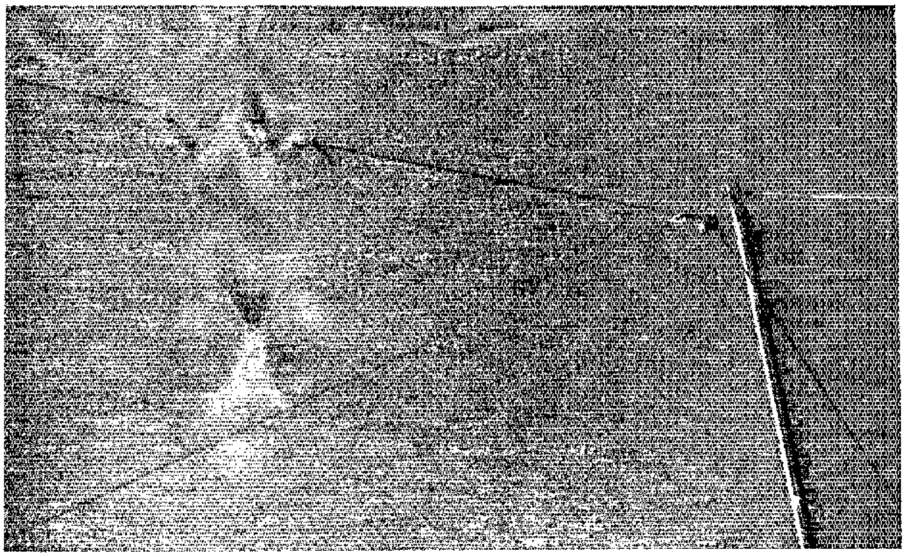

Fig 5—Supporting mast for a collinear phased array. The guy cable that pulls in the same direction as the antenna prevents the mast from bending backward when tension on the antenna is released.

Fig 6—A coiled quarter-wave phasing stub constructed from no. 12 insulated copper wire.

The second method for determining the proper element length is similar to the first, except that you'll need to build a full-wave dipole and then prune it for resonance at half of the desired center frequency. (You can only use this method if half of the desired center frequency falls in an amateur band.)

The first method is preferred if you are building a current-fed antenna, because the test dipole can be used as an element of the collinear array. The second is the preferred method when constructing a voltage-fed antenna, for the same reason. Once an electrical half wavelength has been determined, the radiating elements for the collinear antenna can be cut and assembled. A word of caution is in order here: The ends of the radiating elements are points of high voltage. If you intend to use high power (1 kW or more), large insulators, such as those shown in Fig 5, should be used. If large insulators aren't available, or if cost must be minimized, two smaller insulators in series can be substituted.

The Phasing Stubs

The quarter-wave phasing stubs can be constructed from almost any type of wire. If the antenna is to be fed with less than 100 W, 300-Ω TV twin lead can be used. If higher power levels are anticipated, no. 14-conductor, 1-inch spaced, balanced transmission line can be used. Wide-spaced line such as this can, however, be hard to resonate because of its low Q. It is also more expensive than no. 12 insulated copper wire.

The phasing stub shown in Fig 6 is constructed from no. 12 insulated-copper house wire: Two quarter-wavelength pieces of wire are twisted tightly together. No. 14 zip cord could also be used to make the phasing stubs. Figs 2 and 3 show the phasing stubs hanging straight down, but this is visually obtrusive. (To make the stubs even less noticeable, make them of wire with blue or clear insulation.) Because the stubs don't radiate, they can be coiled, as shown in Fig 6.[3] This lowers their resonant frequency a bit, so coil them *before* pruning them to resonance.

To resonate the phasing stubs, an RF noise bridge is required. Any of the commonly available commercial units work fine for this.[4] Connect the bridge's unknown input to the end of the phasing stub that will eventually connect to the radiating elements. Leave the other end of the stub open. An open quarter-wave transmission line behaves like a series resonant circuit. Follow the instructions that come with your bridge for finding the resonant frequency of a series resonant circuit. The actual resonant frequency should be lower than the calculated value. Prune each stub until it is resonant at the antenna's center frequency, and then attach it to the radiating elements. Solder together the wires at the other end of the stub.

Collinear phased arrays should be fed with balanced transmission line. At output power levels of 100 W or less, if the line length is not too great, 300-Ω TV twin lead can be used. TV twin lead is too lossy for long runs, though, and it can't handle high power. For runs of more than 1 λ and/or high-power applications, transmission line with no. 14 (or heavier) conductors should be used. If this is unavailable, or if cost is being kept to a minimum, a suitable transmission line can be made from two lengths of no. 12 or 14 copper wire. Keep the wires 1 inch apart with plastic-sheet or weatherproofed-wood spacers attached at 6-inch intervals along the length of the line.

If the antenna is current fed and has been designed and built correctly, the transmission-line SWR should be less than 3:1. The SWR on a voltage-fed antenna will be higher. With a short, low-loss transmission line, a high SWR can be tolerated. If, however, the line length is more than 1 λ and low-loss line isn't used, a matching stub may be required. Information on stub matching with transmission lines can be found in *The ARRL Antenna Book*.[5]

Because of the SWR-protected final amplifiers in today's solid-state, broadband rigs, antenna tuners are needed with most antennas—including collinear phased arrays—to present a suitable SWR to such radios. If you use a tuner that doesn't have a balanced-line output, connect the feed line to a 4:1 balun and run a short piece of coax from the balun to the tuner. If a tuner is used, a collinear array can be used on bands other than the one that it is designed for, with some sacrifice in performance.

A Collinear-Phased Array in Action

I constructed my antenna for 21.225 MHz, the center of the 15-meter band. The antenna has four elements, is voltage fed through a home-brew L-network tuner, 50 feet of RG-213 coax, a 4:1 balun and 20 feet of open-wire transmission line. The antenna height is 30 feet, and the wire is oriented in a southwest/northeast direction. The major lobes point toward the middle of South America and Japan.

I tested the antenna during the 1988 *CQ* WPX SSB contest, in which I worked many stations in South America and Asia. Signal reports were quite good. After the contest, I had lengthy QSOs with several stations in South America and Japan, during which I received signal reports indicating that the collinear works about as well as a three-element triband Yagi. I also made some contacts with stations in Eastern Europe, Australia and New Zealand. Although signal levels off its ends are lower, the antenna is not totally useless in these directions.

With the aid of a tuner, my 15-meter collinear is useful on other bands. I used the antenna on 40 and 80 meters during the WPX contest, and I worked stations all over the US with my 100-W signal.

Conclusion

After constructing and using the 15-meter collinear antenna as described in this article, I have come to the conclusion that, for my needs, it is probably the best-performing antenna for the money. Like many hams, when I first got started in ham radio I put up a multiband dipole and fed it through a tuner. Because of this exercise, two guyed masts, antenna wire, transmission line, a balun, a tuner and some insulators were already on hand. I borrowed an RF noise bridge, so the only parts I had to buy for this project were the wire for the phasing stubs and a few insulators. In total, I spent less than $10—a *lot* less than I'd have to spend to put up a small Yagi!

Acknowledgment

I thank Dr Stephen I. Long, AC6T, for loaning me his RF noise bridge.

Douglas Fouts was first licensed at age 11 in 1968. He has held the calls WN6ZKU, WA6TDY, and KI6QR. Through Amateur Radio, he became interested in electronics, which has become his profession. Doug has worked for Burroughs Corp (now Unisys) as a design engineer, and is now a PhD candidate in Electrical and Computer Engineering at the University of California at Santa Barbara.

Notes

[1] For more information on collinear-array theory, see G. L. Hall, ed, *The ARRL Antenna Book*, 15th edition (Newington: ARRL, 1988).

[2] See note 1 and J. Reh, "An Extended Double Zepp Antenna for 12 Meters," *QST*, Dec 1987, pp 25-27. Also see J. Reh, "Extended Double Zepp Calculations," *QST*, Aug 1988, p 51.

[3] At any point along the stub, most of the energy is concentrated close to and between the conductors. Therefore, coiling the stubs does not degrade their performance. See J. D. Kraus and K. R. Carver, *Electromagnetics*, 2nd edition (New York: McGraw-Hill, 1973), pp 520-521.

[4] Palomar Engineers, MFJ and Heathkit® all make RF noise bridges.

[5] See note 1, Chapters 26 and 28.

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The February issue of *QEX* includes:

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- "RF Power FETs—Their Characteristics and Applications," Part 2, by H. O. Granberg, K7ES. With RF power FETs turning up in Amateur Radio circuits at an ever-increasing rate—make sure you don't fall behind the times. Learn about the advantages and disadvantages of modern power MOSFETs (as compared to bipolar transistors) in this fact-filled article.
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