

# Development of VHF Collinear Antennas, Matching and Feeding Techniques

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Before indulging directly to the design of VHF collinear antennas, it is worthwhile to review our antenna theory and practice of antenna home brewing. The basic principles presented in this article are standard techniques used by the radio industry to come up with finished products for commercial purposes. There is no doubt that the home brewer can similarly construct his own antenna, resulting to a finished product of equal or even better performance than the commercial ones. The beauty of home brewing is clear. It gives complete satisfaction to the builder that leads him to that great feeling of “ownership”. Some general principles of the design of collinear antennas, matching and feeding techniques are presented. These principles and techniques however can be applied to other antenna projects in mind. Actual construction techniques are left to the home brewer to use his own skills and aesthetic tendencies to produce his finished project. As long as the design and electrical characteristics are met, the finished product will perform work efficiently to provide years of service.

## The Resonant Dipole Antenna

Converse to the general notion of the few and probably many, the dipole was not named after the two split and separate wires of a standard center-fed transmitting and receiving antenna. It just happens that the half-wave antenna was split and fed at its center, hence the two separate wires of  $\frac{1}{4}$  wavelength each (see Fig. 1a).

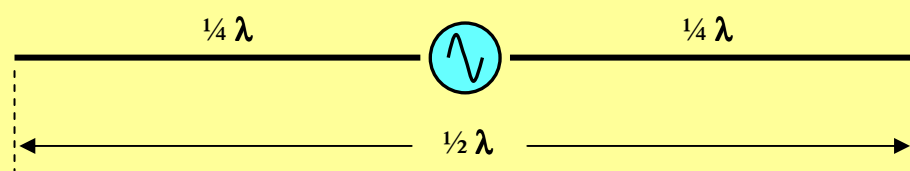


Fig. 1a. The resonant dipole antenna

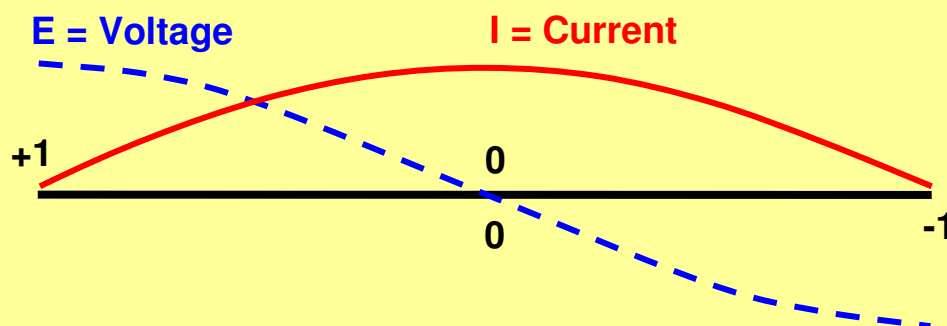


Fig. 1b. The two poles in a resonant half-wave antenna radiator

In reality, the half-wave resonant antenna has two poles (di-poles), not the two split wires. These are the electromagnetic poles at each end of the resonant radiator element that are developed along the half-wave length of wire when excited with RF energy resonant at that specific frequency. The same element also has two zeroes (See Fig. 1b).

When the voltage peaks occur at the ends of a half-wave length antenna element (and the zero crossing point is exactly at the middle of the element), this wire is said to be resonant at that particular frequency and, it will radiate efficiently!. This is because this length of wire has no residual reactive components. Otherwise, there will be no single voltage and single current peak to occur if residual reactive components exist in this wire. We can recall that any solid conductor of electricity always have a capacitance, inductance and pure resistance. And, since RF energy is a form of alternating current, the first two properties will be the major factors to influence the resonant frequency. The half-wave resonant antenna is considered as a series electrical circuit whereby, the capacitance and the Inductance of the element are imagined as connected in series. Hence, the individual reactances [capacitive reactance (- sign) and inductive reactance (+ sign)] will oppose each other (also called the vector algebraic sum of the two reactances) to equal to "Zero". This condition exist when the capacitive reactance is equal to the inductive reactance of the circuit. This is represented by the formula :

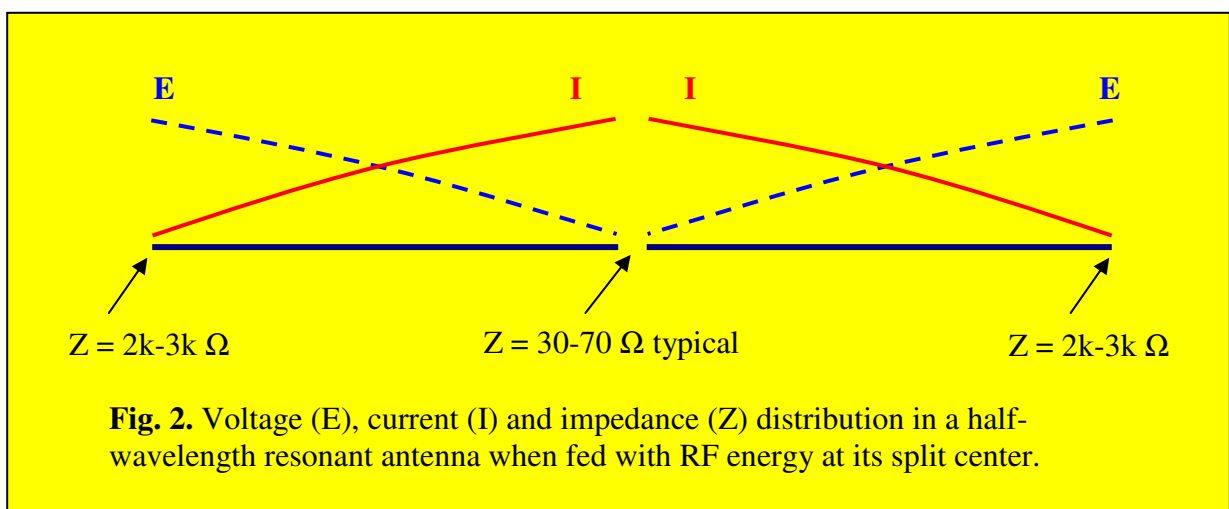
$$\text{Frequency of resonance} = 1/(2\pi FC) = 2\pi FL, \text{ or } [-X_C] + [+ X_L] = 0$$

$$\text{Based on the general resonance formula, } F_r = 1 / (2\pi \sqrt{L \times C})$$

The innate pure resistance of the element in question has very little significance to none with resonance. It is however important to note that the radiation efficiency and bandwidth of the half-wave element is a function of this electrical resistance.

### Voltage and Current Distribution in a Resonant Antenna

Let us look at the Voltage (E) and Current (I) distribution at different points of a  $\frac{1}{4} \lambda$  element in a resonant  $\frac{1}{2} \lambda$  dipole fed at its center (split), see Fig. 2 below. A voltage peak always occur at each end. This is due to the fact that the ends of the dipole are loaded with an infinite load resistance (air). Hence, RF radiations will emanate from each antenna element into the air. In short, the center of a loaded split dipole consisting of two  $\frac{1}{4} \lambda$  elements is said to have a low impedance (Z) and the end (tip) of the  $\frac{1}{4} \lambda$  elements is said to have a very high impedance.



Practically, when currents and corresponding voltages are measured along at any point in the dipole elements, the impedance at this point is,  $Z (\Omega) = E/I$ .

**PROOF (and WARNING):** It is dangerous to hold the tip of any resonant antenna while in the process of transmitting RF energy. Voltages of several hundred volts can be developed at this point. High power transmissions can jolt the living daylights of anyone touching it because more than a thousand volts exist at the open end of a resonant antenna. The voltage developed at the end of a resonant dipole antenna is,  $E = \sqrt{PR}$

The table below shows the voltages developed at the tip of a resonant dipole when driven by a transmitted RF energy.

Transmitter power (Watts)	Impednce (End of dipole)	Voltage developed at tip of antenna ( $E = \sqrt{PR}$ )
25	$Z = 3000 \Omega$	273.8 Volts
50	$Z = 3000 \Omega$	387.3 Volts
100	$Z = 3000 \Omega$	547.7 Volts
500	$Z = 3000 \Omega$	1,224.7 Volts
1000	$Z = 3000 \Omega$	1,732.0 Volts

A bare flourescent bulb will be shock ignited to glow by the RF energy when held near the tip of an actively transmitting antenna. During night driving and raining drizzles at the south expressway, I saw faintly glowing vehicle tops during those CB (11 meter band) years. No wonder! The driver was probably pushing illegally 200W into his poor little K40 antenna. This is the reason why the old man (a Missionary Ham) of HCJB in the Andes, developed the Quad antenna, to eliminate the "Corona effect" which was eating up the antenna tips of their Broadcast Station high up in the misty and humid highlands of the Andes.

### The Physical Length of the Half-wave Resonant Antenna

The radio wave will travel along this antenna element at a speed nearly as the speed of light waves (= 300,000,000 meters per second). To calculate the length of a resonant half wave element in free space for which the RF wave has to travel, We use the following formula:

$$\text{Length (in Meters)} = \frac{300}{\text{Freq (in MHz) x 2}}$$

The actual physical length of a haf-wave antenna is calculated by including a factor called "the velocity Factor". When using a wire antenna in free air, the element length is affected by this factor (= 0.95). Therefore, in practice, the formula for calculating the physical element length to be cut is:

$$\text{Length (in Meters)} = \frac{300 \times 0.95}{\text{Freq (in MHz) x 2}}$$

Antenna element lengths at frequencies in the VHF and UHF region is significantly affected by the element diameter. For instance, if the diameter of the element is 3/8 inch, the factor will be 0.94.

## Feeding RF Energy to a Resonant Dipole Antenna

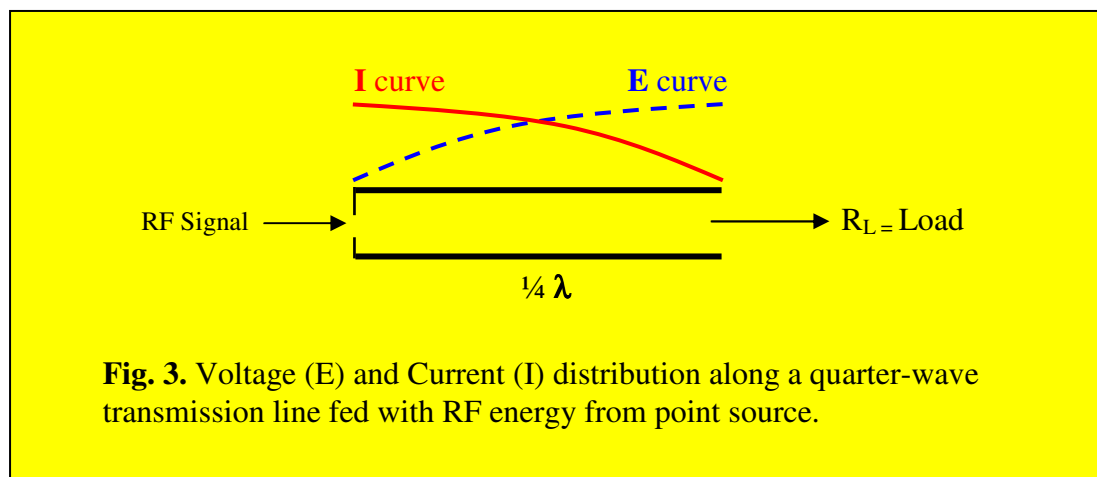
The resonant dipole can be fed with RF energy at any point along its length. First however, we must know what impedance do exist at that point. Then, make a transmission line with a characteristic impedance equal to that point to match the two (called impedance matching). This is however a very complicated exercise and abandon this technique worthy only for radio engineers. But it can be done of course if you will.

The two most common feeding techniques, and the easiest, is to feed the antenna at one end of the element (High impedance and high voltage point) called “end fed or voltage fed” and the other, which is most popular, is to split the dipole at the exact center (Low impedance and high current point) called “center fed or current fed” and use a common and readily available transmission feedline (the 50 ohm coaxial line).

## The Quarter-Wave Stub Magic

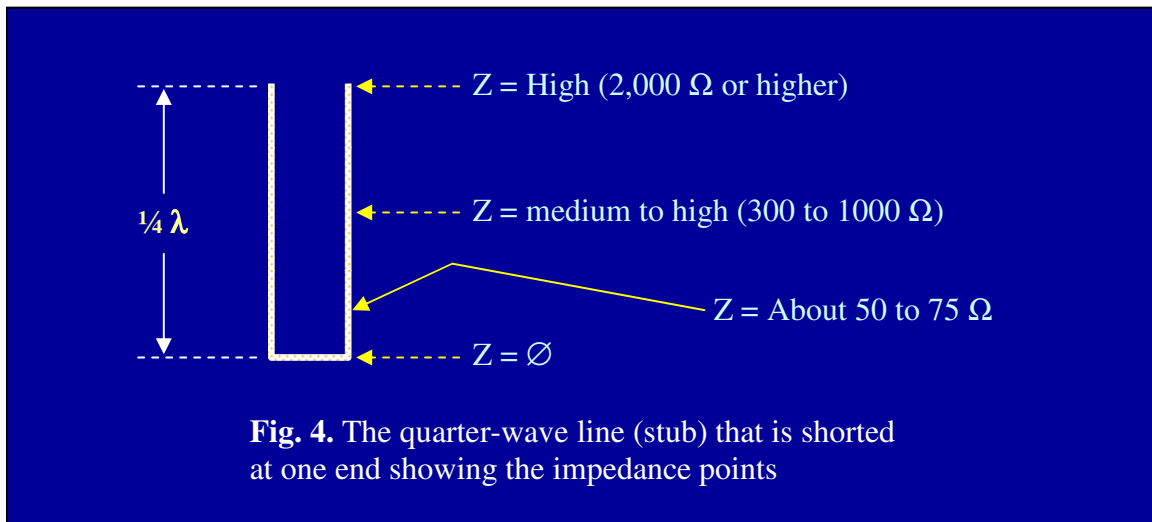
This contraption looks very innocent and appears to have no significance to new antenna homebrewers. To the Ham radio rookie, it seems that it is nothing more like a decoration for appeal purposes. It appears to have been added by someone for his antenna project so his work of art will appear different from others. Hmm... is that really the point?

Lets go back to the split dipole. If we fold the  $\frac{1}{4} \lambda$  elements so that the elements will be parallel to each other by a certain distance, this action will convert itself into a transmission line (called open line). How? See illustration in Fig. 3 below:



If we feed the pair at one end, it looks like a launching tube. RF wave energy starts from the feed point and exits at the open end.. If we short one end (See Fig. 4), it follows that the impedance at the shorted end is Zero and the open end as high impedance point (like an insulator).

This is the basis of waveguide designs at UHF. There is no doubt that this principle can be adopted in the lower frequencies when deemed practical. Various impedance values can be determined/obtained along at any point between the shorted end and the open end (see Fig. 4).



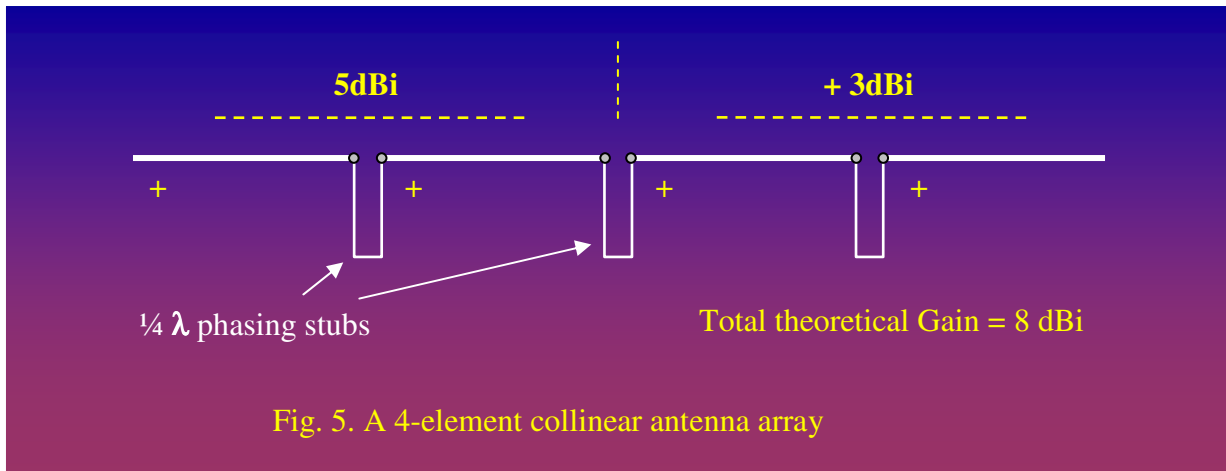
The quarter-wave stub and shorted at one end has the following electrical characteristics:

1. The open end of the stub will reverse the phase angle (180 degrees) of any RF energy passing through the line.
2. Two parallel lines close to each other will possess a characteristic impedance (depending on diameter size of the element and the distance between each.)
3. A quarter-wave shorted stub or an open ended stub is an impedance transformer. It is often called a "Universal transformer".
4. A shorted stub in one end and open at the other end is a perfect RF insulator at its design frequency (at the open end). And, a very poor insulator (almost dead short) above and below its design frequency.
5. A  $\frac{1}{4} \lambda$  shorted stub is a parallel resonant circuit, its capacitive reactance and inductive reactance are equal. This is similar to a capacitor and inductor connected in parallel to form a resonant LC circuit.
6. A quarter-wave stub is frequency sensitive and is highly selective (Used as filters). The principle is used in homebrewing high-Q cavity filters (Commonly called "duplexers") in VHF/UHF repeater systems.
7. When the shorted stub is cut to less than a  $\frac{1}{4} \lambda$  of the design frequency, it is capacitive. And when it is longer (but less than  $\frac{1}{2} \lambda$ ), it is inductive.
8. Interestingly, if the short is removed and left open, the stub acts like a series resonant circuit. It can be used as a trap filter (commonly called a notch filter)

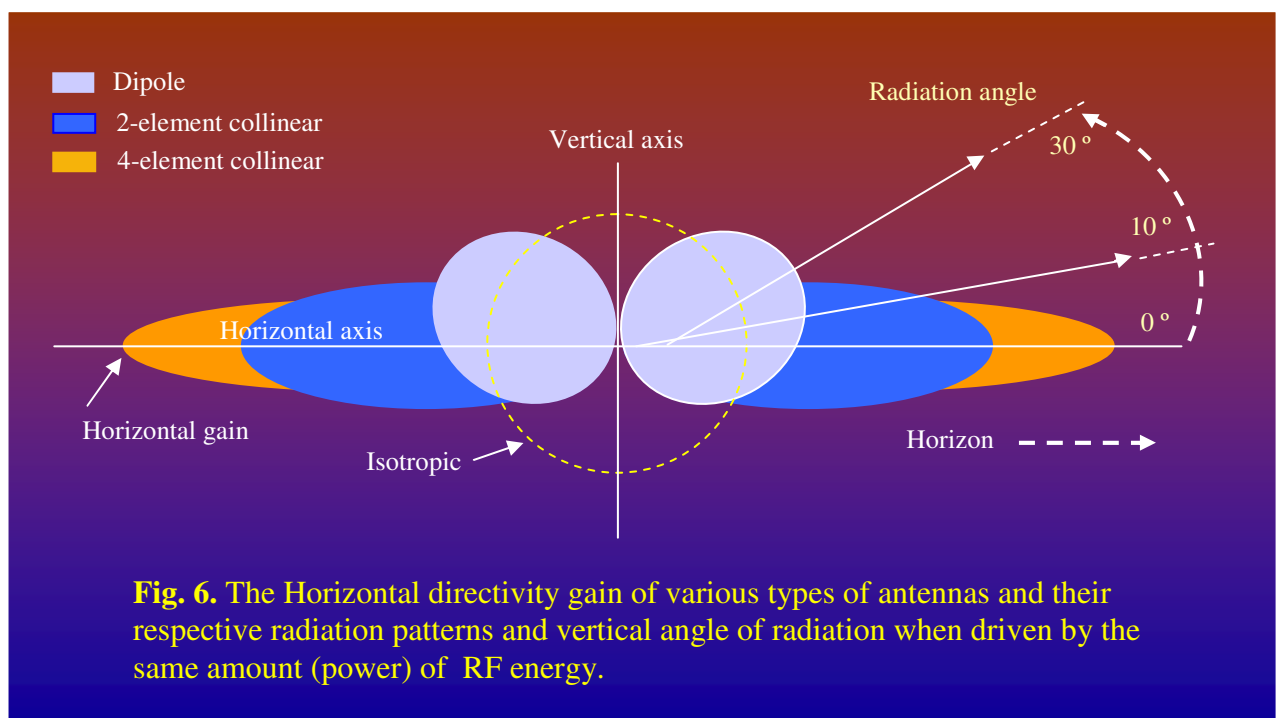
### Development of Collinear Antennas

Armed with the fundamental principles and antenna theory presented earlier, we are now ready to discuss the development of collinear antennas. It must be noted that the basic building block of this type of antenna consists of several series connected resonant half-wave radiators and make each radiator to launch the RF wave in Phase. Since the dipole has two poles (the positive pole and the negative pole), we need something to reverse the poles (Phase) of the succeeding dipole so that wave cancellation will not occur. To accomplish this phase reversal, a phase reversal line (called phasing harness or phasing stub) must be used to connect between each dipole. One such line is the shorted  $\frac{1}{4}$  wave stub. This connection is shown in Fig. 5. When several dipoles are connected in this manner, the antenna assembly is called a **collinear (or co-linear) antenna array**. This array of dipole antennas is mounted in such a manner that every element is an extension, with respect to its long axis. The primary purpose is to increase the overall gain and directivity.

In the VHF region, a collinear array is usually mounted vertically. When stacks of  $\frac{1}{2} \lambda$  elements are added one on top of the other, the gain and directivity is increased in the horizontal direction. The shorted phasing stub separates the  $\frac{1}{2} \lambda$  elements and reverses the phase angle of the RF wave developed in the next stack. This will make all the elements radiate in the same phase as the first below it, all in unison, hence the apparent gain. If another half-wave pair of elements are added, this will increase the horizontal gain by as much as 3dBi (see Fig. 5)



Any number of dipoles may be added as desired. This however will depend on available space and height limitation. In the UHF region, about eight or more can be stacked. Doubling the number of dipoles to that shown in Fig. 5 will give an additional gain and directivity of 3dBi. Bear in mind that the gains shown in Fig. 5 are based on the imaginary “Isotropic antenna” which radiates radially and of equal magnitude in all directions. All antenna models are compared to this standard antenna and the gain of a new antenna is expressed as gain over isotropic, with the term “dBi”. The gain of a resonant dipole is equal to 2.15 dBi. In standard practice and for all practical purposes, the gain of a dipole is taken as 2 dBi. Hence, if two dipoles (doubled) are arranged in a collinear configuration, the total theoretical directivity gain will be 5dBi. In practice however, the actual gain will be slightly less due to the proximity of the elements as a result of closer spacings.

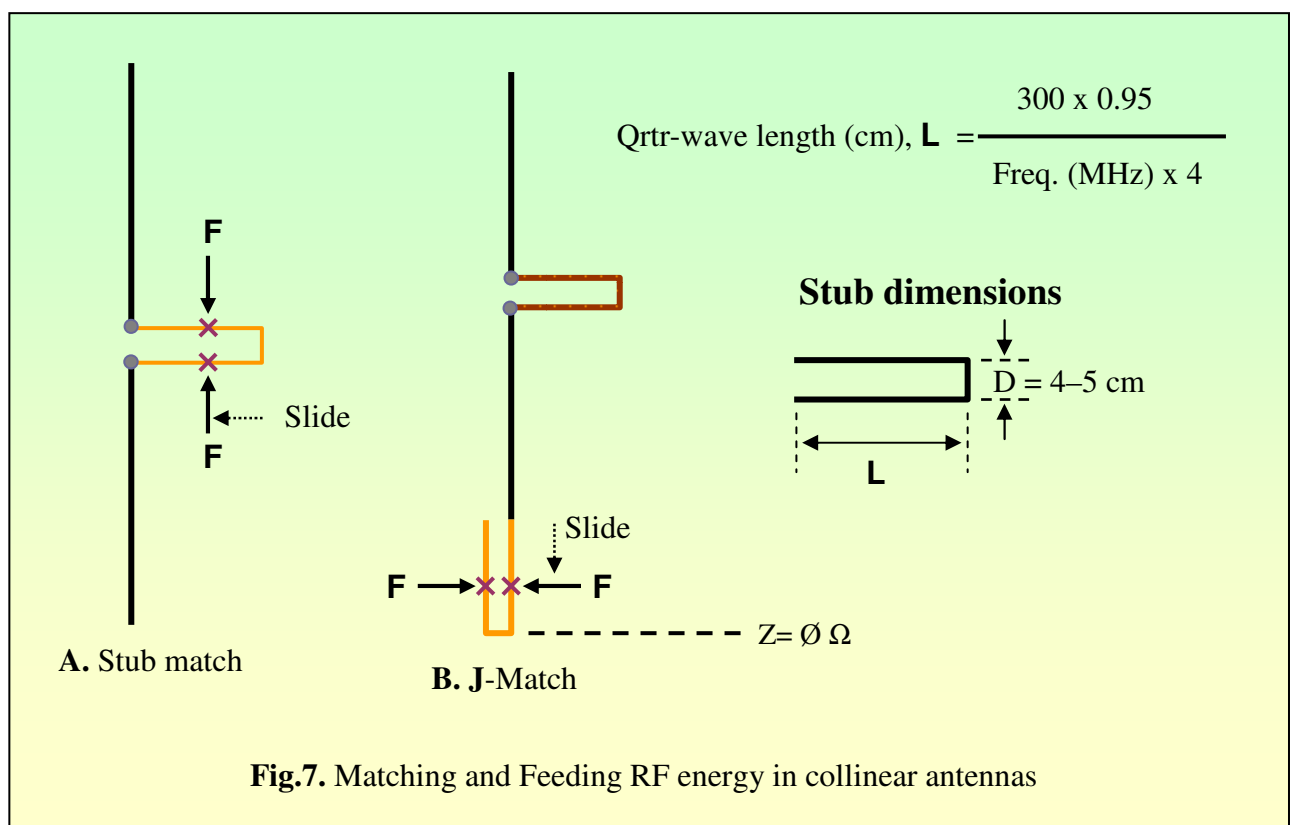


It must be emphasized that the term antenna gain, be it vertical and or Horizontal gain, does not mean that the power of the source is increased. Rather, the apparent gain is due to the manipulation of the radiation pattern (lobe) to be concentrated in a direction from the point source towards infinity (See Fig. 6, not drawn to scale but to emphasize radiation angle and horizontal gain). Adding extra elements in a collinear fashion where the array is closely spaced will touch and disturb the aperture of each. Thereby resulting to a distorted pattern, vertically and horizontally. Controlled manipulation such as the collinear array will result to a combined constriction and elongation of the lobes and the reduction of the vertical radiation angle. This effect increases the power density which is confined within the boundaries of the orientation of the resulting lobe and is measured in  $\mu$ Volts induced in a standard monitor antenna, 1 meter long. Due to the horizontal gain, the usable field intensity (called signal strength) can extend to farther distances from its point source. It follows that antennas with higher horizontal gain can reach stations farther towards the horizon compared to a single dipole and with the same RF power fed to each. Antennas with high vertical radiation angles in the VHF and UHF region and beyond, is for the satellites, airplanes and birds only!

### Matching and Feeding RF Energy to the collinear Antenna

From the earlier discussions, it is surmised that the reader can now predict and or correctly select where the feedpoint will be for the collinear antenna shown in Fig.5. A quick glance to the dipole and the quarter-wave stub provides the clue.

Think of a 2-element collinear dipole with the phasing quarter-wave stub connected (see Fig.7A). We said earlier that the shorted end has zero (or neutral) impedance. We can therefore use the same stub to inject RF energy in this quarter-wave line. The shorted  $\frac{1}{4} \lambda$  stub is useful when loading the feed point of antenna systems with unknown high feed impedance. It is a balanced line and must be loaded also with balanced transmission lines (twin-lead 300  $\Omega$ , 600  $\Omega$  or any other open line). Using an unbalanced coaxial line (RG58 or RG8 cable) to feed the stub requires a Balance to Unbalance contraption, called "BALUN". Connect separately the transmission line leads to each leg (marked F) of the phasing stub.



**Fig.7.** Matching and Feeding RF energy in collinear antennas

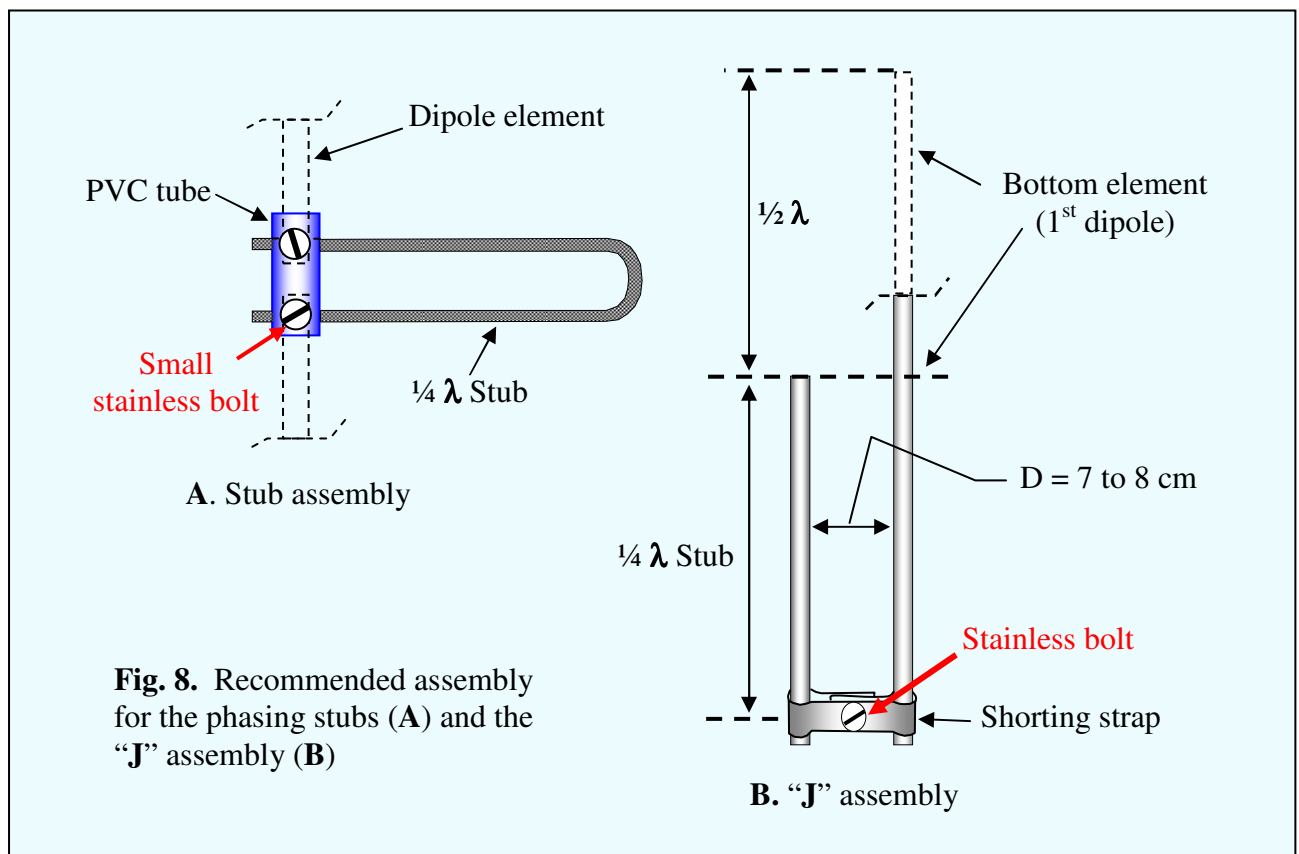
To match the line, say  $300 \Omega$ , to the  $300 \Omega$  point in the stub, you have to slide the connection point from Zero (shorted end) to a distance equal to  $300 \Omega$  impedance. Use an antenna analyzer or SWR meter to find the correct match.. This is when the VSWR reading is lowest. If the dipoles are equally resonant, VSWR readings at the correct matching point and frequency will be 1:1 ratio or thereabout.

The “Q” of the stub is very high. This is the reason why the phasing shorted stub used in collinear antennas is preferred (the Ringo ranger II is an example) rather than using parallell resonant capacitors (C) and inductors (L). These LC components have lower Q-values due to circuit losses of low quality materials used. Stub matching is however not very practical (but highly possible) in the HF frequencies. For shorter wavelengths, like in the VHF and UHF band region and beyond, stub matching is a common Radio Engineering practice. It it is also cost effective.

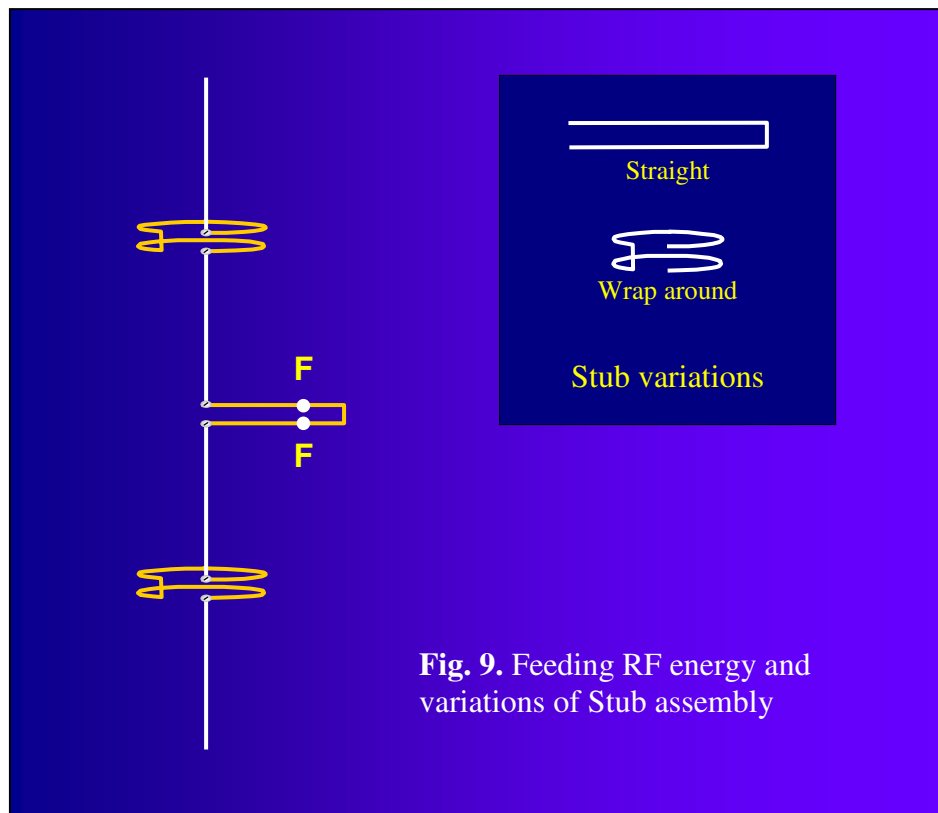
The **J-match** (or open end stub match) feeding technique as shown in Fig. 7B is another example of the practical uses of the stub. Simple and efficient, this was popularized by the MARS...ians south of Metro Manila in the mid-1980's. This matching and feeding technique is the ID of the J-pole design. The 2-element collinear shown in Fig.7B is end fed by a quarter-wave stub at the bottom of the collinear dipoles to form the familiar “Super J” mentioned in many amateur antenna handbooks. The matching is accomplished by using tha same procedure as in the stub match mentioned above.

### Construction and Mounting Techniques

Beginning at the VHF region and above, the dipole elements can be small diameter aluminum tubing or heavy guage copper wires. They are stacked by using plastic insulators where the element and stub meets. However, this author has built a 2-element collinear antenna (The Super “J”) for the DX1MK repeater following the J-match with considerable success. Here, the elements were separated by a small diameter blue PVC tubing as shown in Fig. 8A below.



Selecting which stub to feed RF energy is a choice for the homebrewer. In Figure 5, the 4-element collinear has three stubs. Any of the three can be fed but the best choice will be the second stub from the bottom if the antenna is erected vertically. This is for better balance of RF currents between the lower and upper dipoles resulting to better radiation pattern. The quarter wave stubs can be connected straight as is or another variation, is to bend the stub to wrap around the axis of the dipoles (see Fig. 9).



**Fig. 9.** Feeding RF energy and variations of Stub assembly

In the case of the J-match, the only choice to feed RF energy will be the bottom end of the first dipole. The length of this dipole can be extended a quarter wavelength further down and then a shorting strap (See Fig. 8B) is installed at this point to connect the open leg of the J element. This element can be of the same diameter as in the dipole element to make a strong structure to match and connect the transmission line.

**Mounting** – The collinear antenna shown in Fig. 5 will serve as a good repeater antenna, cost effective and can be easily repaired or reconstructed after a damaging typhoon. It can be mounted vertically with acceptable structural strength by mounting the whole structure in fiberglass tubing. The other feature of this antenna is that it can be electrically grounded at several points. By examining the antenna assembly, the various grounding points are the center of each dipole and the shorted ends of each stub. These are the neutral points and can all be grounded to a metal tower. These neutral points can serve as structural mounting points for bracing against the side of the tower. Bear in mind however that such mounting technique will distort the radiation pattern if a metal mast will be used. When mounted like this, the pattern will be cardioid with almost zero response directly behind the tower. The minimum distance from the axis of the dipoles and metal mast must not be less than one quarter wavelength of the operating frequency. All other possibilities is left to the homebrewer's imagination.

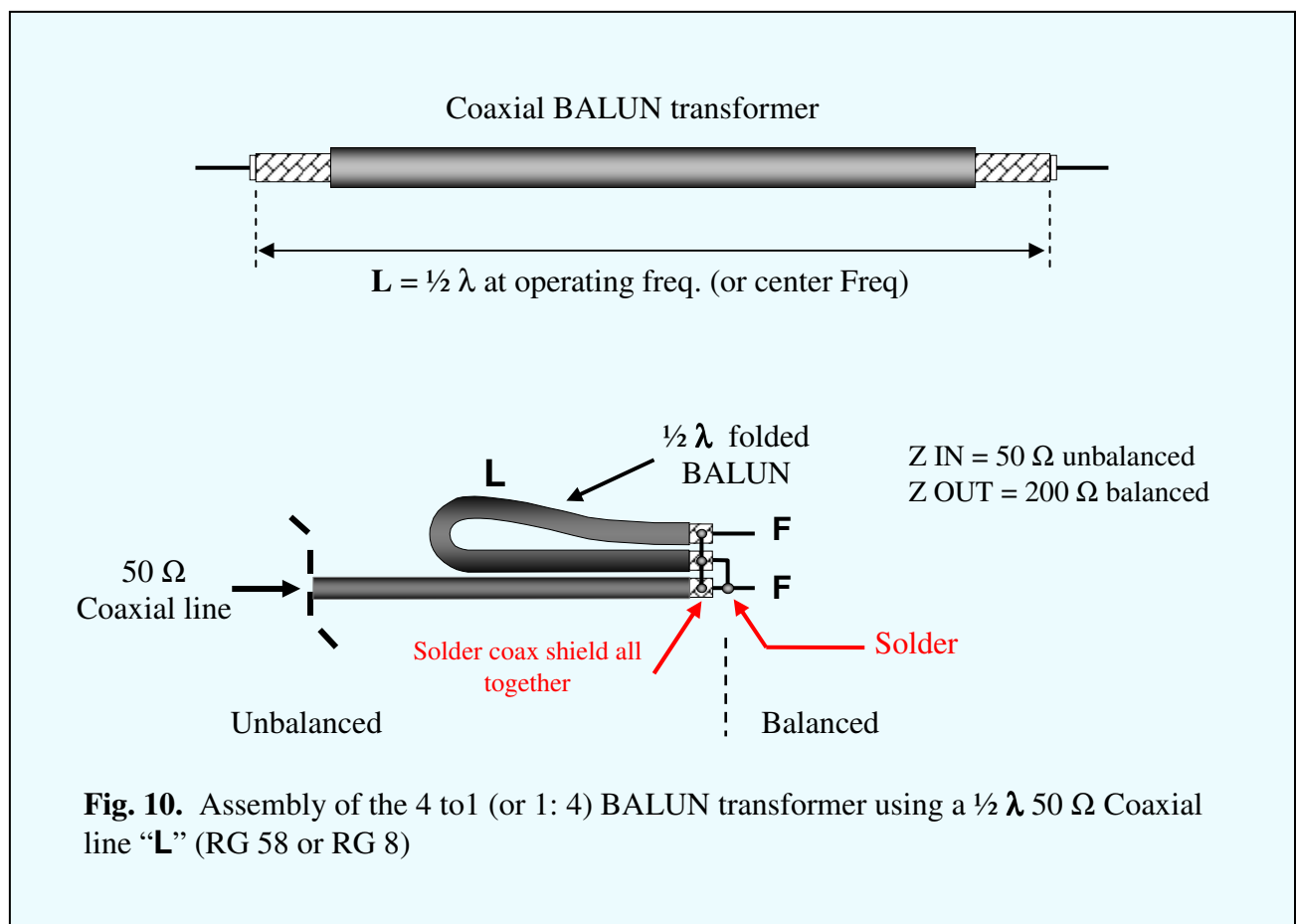
### Final Tuning and feeding Guidelines

Like any other antenna construction project, a good construction practice is to follow the following guidelines:

1. Select your radiator element to suit your design and application parameters. (how you will use the antenna and how you will mount it)
2. Cut the antenna elements to resonate at your desired center frequency before adjusting the matching point. Make a 2-element first and trim/tweak tune the antenna pair with the stub connected. The dipoles and the stub will interact, so tune them well to resonance before adding the other elements. The first 2-elements will guide you to duplicate the additional elements.
3. Do not attempt to adjust the matching feedpoint with the hope of reducing VSWR readings if the dipoles are not tuned (resonated) to the desired operating frequency. By doing so, you will not be able to achieve the expected design gain. and radiation pattern.
4. Ensure a good and strong electrical connection between dipoles and the phasing stubs
5. The collinear antenna, as designed, requires a balanced line. If you use a coaxial transmission line to feed the antenna, you must use a BALUN (see Fig. 10) between the transmission line and the feed point. Otherwise, the radiation pattern will be distorted due to the RF currents going back to the transmission line via the coax shield.

A BALUN transformer can be easily made from the same coax transmission line by cutting an electrical one-half wavelength and then folded to form the transformer (see Fig. 10). The balanced output impedance at the feed terminals will be 4 times that of the characteristic impedance of the unbalanced Coax transmission line being used. This length (in centimeters) can be found by using the following formula:

$$\text{Half wavelength "L" (cm)} = \frac{300 \times 0.66 \times 100}{\text{Freq. (MHz)} \times 2}$$

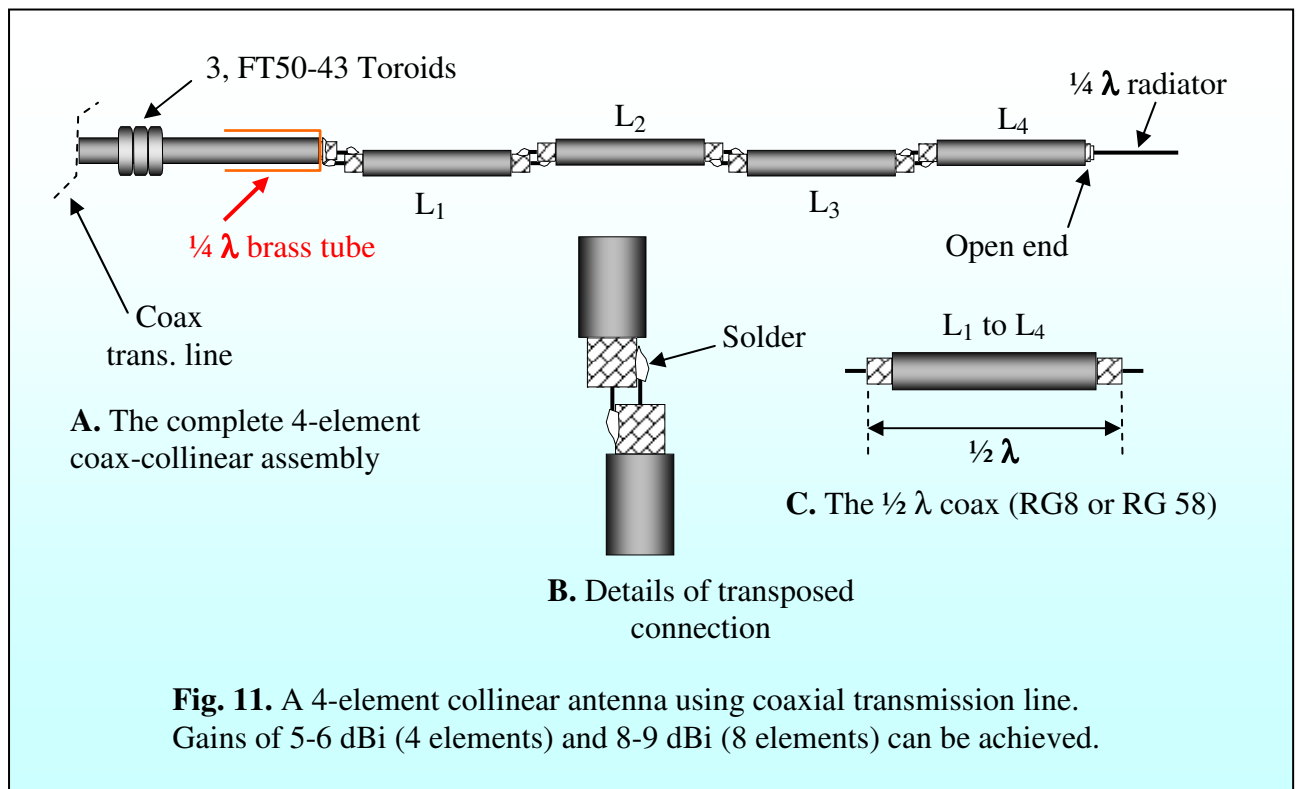


Fold the half-wavelength line and connect (solder) all the shield together to the shield of the transmission line. Finally, terminate and solder the center lead of one end to the center lead of the transmission line as shown in Fig. 10. The remaining open end and the center lead of the transmission line cable marked as “F, F” will serve as the balanced terminals to feed the signal to the collinear antenna. Use electrical tape to bind tightly the transformer in parallel with the transmission line.

## Other Unique Features of Collinear Antennas and variations

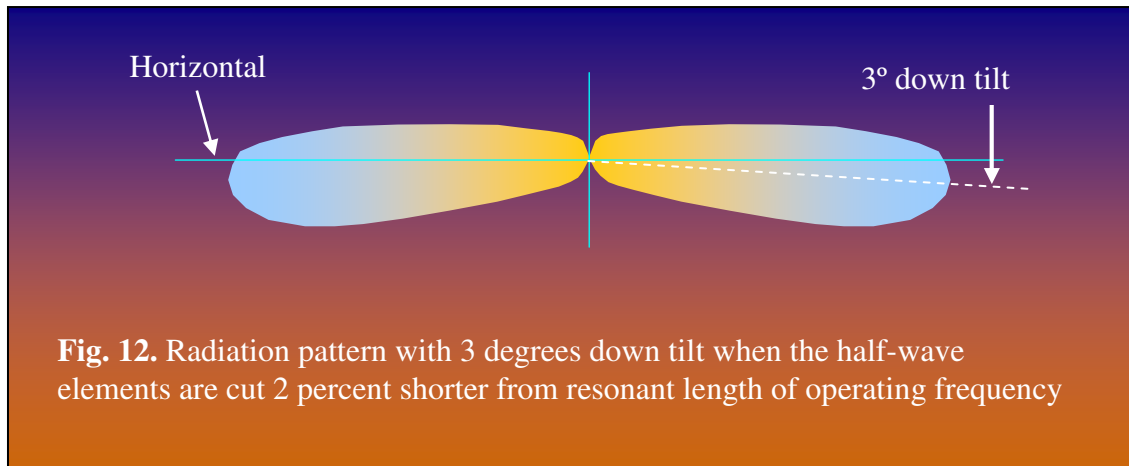
From the basic development of the collinear design, there are numerous variations available today. The dipole and the quarter-wave stub is the building block of these antennas. By using the same principle, other structural designs can be developed. It only requires the prolific imagination of the experimenter. The overall gain of a collinear antenna is terrific. Thanks to the inventor, Mr. Franklin, hence its original name “Franklin antenna”. When the axis of the antenna array is oriented in the horizontal plane, the radiation pattern is bi-directional like a very much elongated figure 8. But when the axis is oriented in the vertical plane, the pattern is omni-directional with extremely low angle of radiation, the main lobe of which is perpendicular to its axis.

A very interesting variation in design is the use of ordinary coaxial transmission lines as the radiating elements. The coax can be used to make a collinear antenna array. There are a number of homebrew projects that originated from the design of several hams, notably by, Mike Collis/WA6SVT, N1HFX, and variations by Rick/W7LPN. The construction of this antenna requires the transposition of the feed system to make the dipoles radiate in phase. This antenna is shown in Fig.11. A coaxial transmission line is cut to half-wavelength dipoles and then connected end to end by transposing the inner leads and coax shield alternately from one dipole stack to the next to radiate RF energy in Phase. At the end of the last dipole, a quarter-wave radiator is connected to the center lead. The construction details are shown in Fig. 11A, B and C. The collinear coaxial antenna shown in Fig. 11 was homebrewed by this author based on these designs, less the toroids (we used a coil choke current BALUN). This is a variation adopted by the Making Amateur Radio Society as a standby repeater antenna, the performance of which was impressive.



The length of the quarter-wave radiator at the top and the brass tubing is calculated as true  $\frac{1}{4} \lambda$  in free space (No velocity factor). The whole assembly can be hanged inside a blue PVC tubing for weather protection and mounted vertically.

The power gains claimed by the original authors using this technique are; 4-elements = 3.5 dBd, 8-elements = 6 dBd and 18-elements = 9 dBd, referenced to a dipole (a “dBd” is gain over a dipole which is equal to 2.15 “dBi” over isotropic). One additional characteristic of this type of antenna is that the radiation pattern can be tilted downwards from horizontal by as much as 3 degrees by reducing the calculated half-wave element lengths 2 percent shorter (see Fig.12). Repeaters that are located at very high elevations can take advantage of this tilted pattern to improve repeater access (down-link and up-link) by mobiles and base stations, located far down down below the repeater site.



**Performance:** When the 4-element coax-collinear antenna was used with the DX1MK repeater during emergency (usually after a damaging typhoon), 10 watts of RF feeding the transmission line gave S-9 to full scale reports for mobiles scrambling at the UP Diliman and SM City North EDSA area in Quezon City. In the Makati concrete Jungle, mobiles negotiating the traffic jams and side streets reported DX1MK signals jumping but Q-5, between S-3 to S-7. All base stations around these areas reported full scale signals all the way. This YSL (Yari Sa Laguna) antenna can also sniff weak signals that my home station using a home brewed 2-bay log periodic yagi could not hear. At that time, the QTH of the DX1MK repeater was about 350 feet above sea level somewhere facing north, among the rolling hills at the side of mount Makiling. And my Home Station’s QTH is at the floor of this magnificent Makiling mountain, about 50 feet above sea level. The Makiling VHF repeater is 60 kilometers south of Makati City.

In the UHF amateur band (70 cm), collinear antennas with 8 to 16 elements are top performers combining high gain and omni-directional coverage. If you try these collinear antennas for use at your home QTH base station (be it VHF or UHF), be prepared to hear stations you never heard before. And, If you hear them, you can work them!

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## The Amateur is Considerate

... He never knowingly uses the air in such a way  
as to lessen the pleasure of others.

\_\_Paul M. Segal