The Extended Double-Zepp Antenna

Simple Antenna Structures Having Improved Gain and Horizontal Directivity

By Hugo Romander,* W2NB

THE questions of antenna directivity and antenna "gain" are becoming increasingly popular in discussions on antenna systems among amateurs, and it would therefore seem proper to preface an article dealing with directive antenna arrays with a warning, or perhaps a reminder, that one cannot have high gain and radiate in all directions at the same time. To most amateurs this is an obvious fact, but it may not be as well known that this principle is almost equally important in the *vertical* plane. Those of us fortunate enough to have available large open spaces in which to hang wires will find long-wire antennas, such as the "V" and the horizontal diamond, the easiest way to obtain

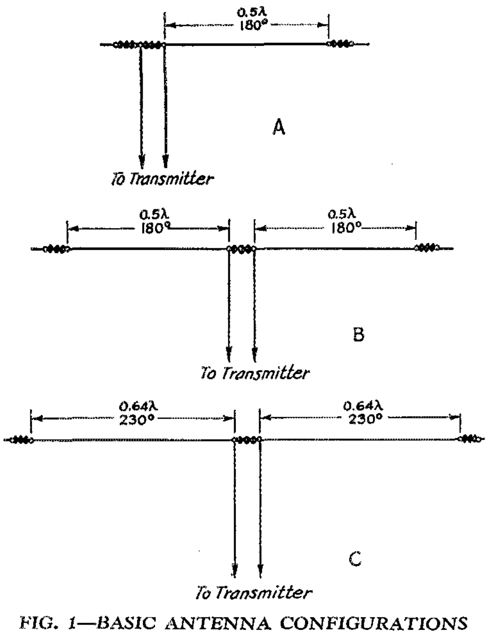

FIG. 1—BASIC ANTENNA CONFIGURATIONS
A—The half-wave Zepp; B—Double Zepp or "two half-waves in phase"; C—Extended double-Zepp.

high gain, but the radiation from such antennas is restricted in the vertical plane fully as much as in the horizontal plane. The result may well be that in the very direction such an antenna is supposed to work best, a simple horizontal doublet will put in a far better signal at certain distances.

It would seem, therefore, that the most practical antenna for a variety of distances is one with a fairly wide radiation pattern in the vertical plane.[1] The "stacking" of elements or the

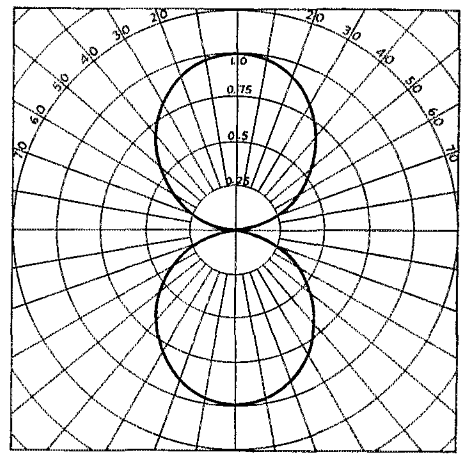

FIG. 2—HORIZONTAL PATTERN (RELATIVE FIELD STRENGTH) OF A DOUBLET HALF-WAVE ANTENNA

use of long wires is not recommended for distances under 1000 miles, except for the very short distances normally reached by the ground wave. The most universal high-gain antenna must restrict its radiation in the horizontal plane only, and its height above ground must also be considered to obtain the best compromise in the vertical plane. It is the purpose of this article to discuss the merits of a simple antenna array which combines these desirable features.

THE DOUBLET

Let us discuss, first, the simple doublet, since this antenna will serve admirably as our basis of reference or comparison. To be more specific, consider this doublet as suspended horizontally

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[1] Although this viewpoint appears to be opposed to that expressed in the article "Simple Directional Arrays Using Half-Wave Elements," by N. C. Stavrou, in May, 1938, *QST*, there is no actual conflict. As the present author points out, the broad vertical characteristic is to be preferred when the antenna is to give optimum results over short as well as long distances; the former article was concerned with long-distance transmissions, where the lowest possible angle gives best results under nearly all conditions. The type of work to be carried on naturally will be a determining factor. In any event, the simpler structures are not likely to be too sharp in either plane for satisfactory general work.—EDITOR.

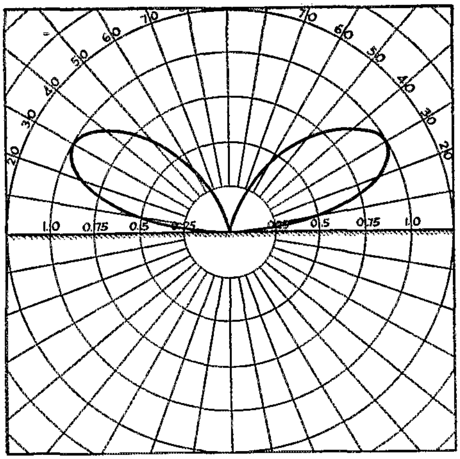

FIG. 3—VERTICAL-PLANE PATTERN FOR A HORIZONTAL ANTENNA, ½-WAVE ABOVE PERFECT EARTH IN DIRECTION OF MAXIMUM RADIATION

and fed at one end in the time-honored fashion of the Zepp feeder, as in Fig. 1A. Ignoring, for the moment, the fact that the open-ended feeder wire will be at somewhat higher potential than the other feeder wire and will therefore radiate, the horizontal radiation pattern about this doublet, if you're lucky, will be about as shown on Fig. 2. Of course, it is assumed the antenna is sufficiently remote from power-line wires and house plumbing to be unaffected by such linear conductors, since our problem is complicated enough without having to consider the mutual impedance between our doublet and the neighbor's b.c.l. antenna!

This pattern of the horizontal doublet is, no doubt, familiar to most amateurs. Less familiar, perhaps, is the vertical radiation pattern (in the direction of maximum horizontal radiation) as shown in Fig. 3. Here it is assumed that the height of the doublet above ground is one-half wavelength and that the earth has perfect conductivity. Fortunately, even the relatively low-conductivity soil and sand on Long Island reflects a high percentage of the horizontally-polarized waves radiated at angles less than 50° to the earth's surface. Such reflected waves, combining with the direct radiation from the antenna within the range of vertical angles in which we are most interested, are responsible for a maximum gain of nearly 6 db over the same doublet in "free space"; that is, without the presence of the earth.

This gift of 6 db must not be taken too much for granted, however. Consider the fact that most amateur communications at high frequencies utilize vertical angles ranging from 10 degrees to 50 degrees. That 6 db must, therefore, come from radiations reflected from the earth's surface quite some distance from the doublet, and in the desired direction of transmission. If the ground slopes sharply upward, or houses or wires are in this area, it becomes questionable, indeed, whether any great portion of the available 6 db is realized. This is especially true for the lower angles of radiation, but usually nothing can be done about this situation, so let us see if we can make up for our ground reflection losses by increasing the horizontal directivity.

THE DOUBLE-ZEPP

By the simple expedient of attaching another doublet to the open-ended terminal of the Zepp feeder, as in Fig. 1B, and hanging this doublet parallel and coaxial with the original doublet, an appreciable gain may be obtained. The horizontal radiation pattern will be as shown in Fig. 4. The gain should measure about 1.9 db, corresponding to a 55 per cent increase in power. This antenna is widely used among amateurs and is popularly known as the "double-Zepp" antenna, or "two half-waves in phase." A fair amount of gain and a reduction in interfering signals from end-wise directions is easily realized, but the gain is rather disappointing, since it would seem one is entitled to 100 per cent gain in power when doubling the number of radiating members.

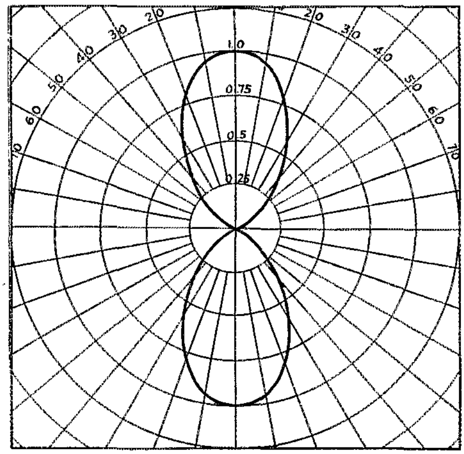

FIG. 4—HORIZONTAL PATTERN OF A DOUBLE-ZEPP OR TWO HALF-WAVES IN PHASE

The reason why only 1.9 db is realized with the double-Zepp is made clear only after a mathematical study of the situation. Briefly, the close proximity of the two doublets causes a mutual coupling between them, and this coupling (mutual impedance) has an adverse effect on the radiation resistance insofar as gain in the broadside direction is concerned. Obviously, the thing to do is to move the doublets further apart, but this complicates the method of feed. A much simpler way of obtaining increased gain was evolved by Mr. A. A. Alford, of Mackay Radio and Telegraph Company, from the principles discussed in Mr. G. H. Brown's article on broadcast antennas in the Proceedings of the I.R.E. for January, 1936. Mr. Alford presented this idea in a paper delivered at an I.R.E. meeting in Washington.

EXTENDED DOUBLE ZEPP

The gain of the double Zepp may be increased from 1.9 to 3.0 db by the simple expedient of increasing the length of each doublet until its electrical length is 0.64 wavelength instead of 0.5 wavelength. In electrical degrees the double Zepp consists of two 180-degree elements; the *extended* double Zepp for maximum gain should consist of two 230-degree elements. See Fig. 1C. In this way the power gain may be increased from 55 per cent to 100 per cent. The gain decreases rapidly for extensions beyond 230 degrees, and therefore, when operating over a band of frequencies, each of the two elements should not exceed 240 degrees for the highest frequency. The horizontal pattern for the double 230-degree Zepp is shown in Fig. 5. The vertical pattern in a plane perpendicular to the antenna will be the same as for the simple doublet.

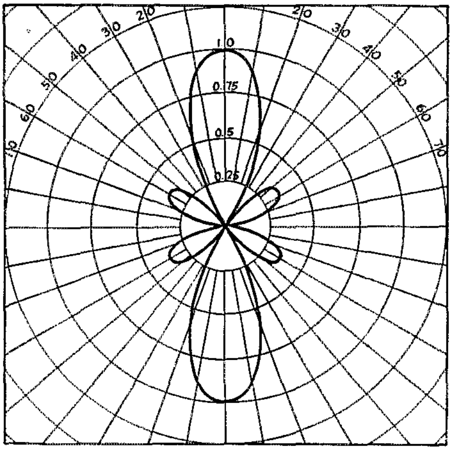

FIG. 5—HORIZONTAL PATTERN OF DOUBLE 230-DEGREE ZEPP

ANTENNA IMPEDANCE

The impedance of this antenna at the termination of the transmission line is of interest, since it has an important bearing on the standing-wave ratio of current or voltage in the line, and it will be compared with that of the ordinary double Zepp. The double 180-degree antenna presents an impedance of approximately 4400 ohms of almost pure resistance as a termination for the transmission line. This value will be slightly affected by the size of wire used in the antenna and, to a moderate extent, by the height above ground or the influence of nearby conductors, and so the "free space" value is given for No. 14 wire. With this antenna and a 600-ohm surge-impedance line the ratio of maximum to minimum current along the line will be 4400 divided by 600, or 7.3. Incidentally, the terminating resistance of the simple Zepp-fed doublet is about 12,000 ohms, resulting in a standing wave ratio of 20 on our 600-ohm line. For calculation of the surge impedance of the line the reader is referred to *The Radio Amateur's Handbook.*

The impedance at the center of the double 230-degree antenna is not a pure resistance, and hence its effect upon the transmission line will be such that maxima or minima of voltage and current along the line will not be odd multiples of a quarter wave from the antenna, as with the ordinary Zepp or double-Zepp antennas. As might be expected, the current or voltage maxima will be shifted towards the antenna, since the two doublets are longer than normal, and this shift is approximately 0.13 times the wavelength. At any rate, the antenna impedance is such that the equivalent pure resistance at any voltage maximum will be about 6000 ohms; that is, the standing-wave ratio will be 10 on a 600-ohm line.

Knowing the standing-wave ratio, it becomes an easy matter to calculate the input resistance to the transmission line if it was cut, let us say, at any current maximum. Thus, for the simple Zepp-fed doublet, this resistance would be 600 divided by 20, or 30 ohms. For the ordinary double-Zepp antenna this resistance would be 600 divided by 7.3, or 92 ohms. For the double 230-degree antenna this resistance would be 600 divided by 10, or 60 ohms. Those who do not use correcting stubs or other methods to obtain a "flat" line (standing wave ratio of 1), but who cut their transmission lines at the maximum current point after the manner of the "tuned feeder," will find these figures useful in calculating the power output of their transmitters.

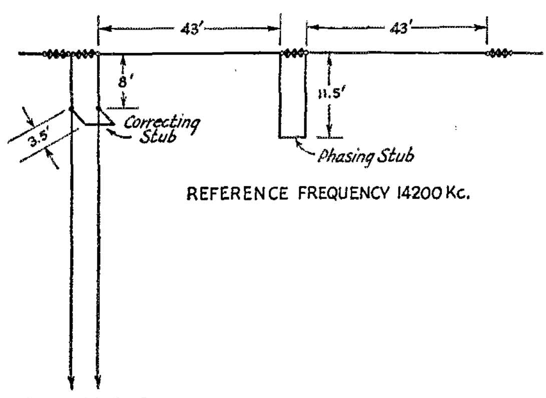

FIG. 6—END-FED DOUBLE 230-DEGREE ZEPP WITH 600-OHM NON-RESONANT TRANSMISSION LINE

However, the use of flat lines, in amateur circles usually referred to as untuned lines, is becoming increasingly popular as their merits are more generally known, and the figures given are essential in calculating the length and position, for example, of a correcting stub, the latter being one of the simplest devices for reducing the standing-wave ratio to unity. A discussion of the use of the correcting stub may be found on page 307 of the *Handbook* (15th edition) where a table indicates the lengths and positions of the stub for various standing-wave ratios. The shorted stub or "loop" will generally be most practical, and some idea of dimensions may be obtained from the fact that when using the double 230-degree Zepp on 14,200 kc. the stub should be 3.5 feet long; that is, it should be composed of the same kind of wire as is used in the transmission line, this wire being 7 feet long and bent to form a U-shaped rectangle with a width equal to the transmission line. At the frequency mentioned, where each extended doublet is 43 feet long, the correct location for the stub will be about 8 feet from the antenna.

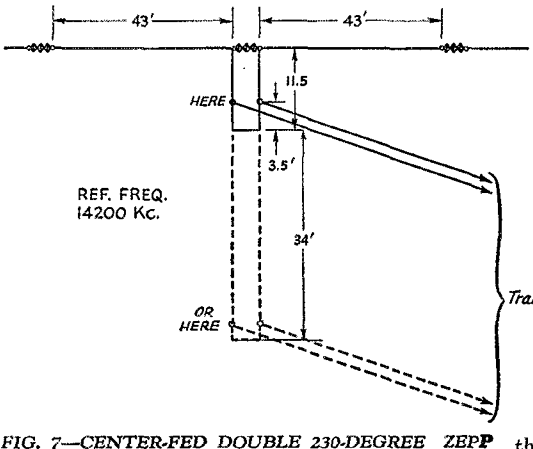

FIG. 7—CENTER-FED DOUBLE 230-DEGREE ZEPP WITH 600-OHM TRANSMISSION LINE

Ordinarily the best place to introduce power into an antenna is at a point symmetrically located with respect to the opposite ends of the system. This will not always be practical, because of space limitations, and hence it may become necessary to feed the extended double-Zepp antenna at one end in true Zepp fashion. Some sacrifice in gain will result, due, for the most part, to unequal distribution of current between the two doublets and to radiation from the feeder because it has an unbalanced load. Physical dimensions of feeder, extended doublets, and phasing stub are shown in Fig. 6. Note that the phasing-stub length is shorter than a quarter wavelength, but by an amount not exactly equal to the extension of each doublet beyond a half wavelength. This discrepancy is due to interaction between the doublet wires and the wires of the phasing stub. Again a reference frequency is given to simplify calculation of lengths at other frequencies by inverse proportion. The figures given should be regarded as approximation, and tests made individually to determine dimensions and positions of important elements.

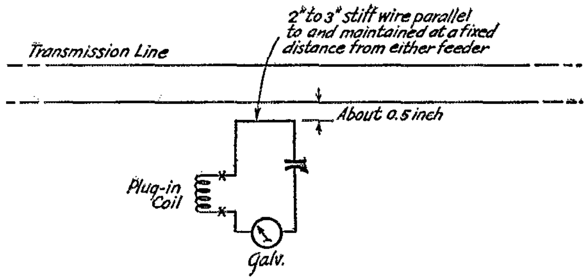

FIG. 8—PORTABLE LINE-CURRENT INDICATOR

ANTENNA ADJUSTMENTS

One of the most effective methods of adjusting an antenna system is to use the transmitter to excite, at the desired frequency, another antenna stretched out, perhaps temporarily, at least 8 or 10 feet from the ground. This "exciter" antenna should preferably be at least one-half wavelength away from the antenna to be adjusted. If the two are parallel to each other, so much the better. Using the end-fed extended double-Zepp antenna as an example, the first consideration is the length of each doublet, and this brings up the problem of "end-effect." We have approximately solved this by cutting our doublets 5 per cent short of the theoretical length. Actually the end-effect, which normally exists only at the ends of the antenna, depends on the wire size and the size of the insulator fitting (if metal caps are used), as well as the frequency. Moreover, the end-effect does not vary quite as rapidly as a direct function of the wavelength, so that if an end-effect of 1 foot is correct at 14,200 kc., it is more nearly 1.5 feet than 2 feet at 7100 kc.

The theoretical "uncorrected" length of each half of an extended double-Zepp antenna at 14,200 kc. is 44.3 feet. The end-effect may be no more than 1 foot, but since it is better that the antenna be a little too short than too long, let's make the correction 1.3 feet, so that each half will be exactly 43 feet long. At the center insulator which separates the two halves a "stub" must be connected, if the system is to be end-fed. Now,

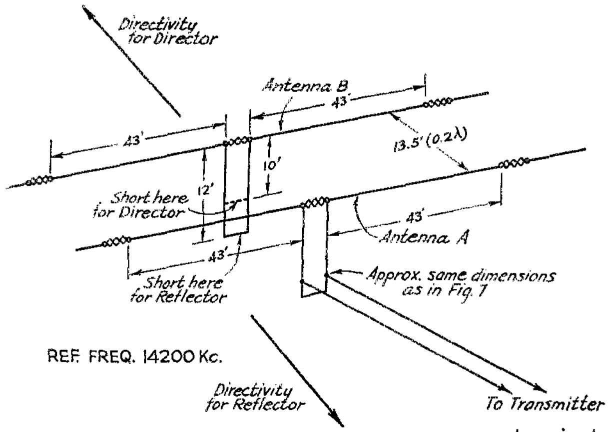

FIG. 9—DOUBLE 230-DEGREE ZEPP WITH PARASITIC REFLECTOR-DIRECTOR

this stub will take the form of a transmission line shorted at the end opposite from the antenna, and for the frequency under consideration its shortest length will be about 12 feet. Since it is our intention to make this transmission line somewhat longer than the anticipated proper position of the short in order to permit locating the correct position by sliding the short up or down, and furthermore since 12 feet will ordinarily not bring the probable correct shorting point at a convenient distance from ground, it will be more practical to add any multiple of a half wavelength (34 feet) to the transmission line and do the shorting experiment at a point along the line accessible from the ground.

With all this done and with the Zepp feeder *not* attached to the main antenna (why not use it to feed the exciter antenna?), power may be fed to the exciter antenna and with a sensitive r.f. instrument connected in the short on the "stub," a position of the short may easily be found where maximum current flows. This assumes that the main antenna has been hauled up into its normal operating position. Note this maximum-current position of the short and measure in exact multiples of one-half wavelength from this point towards the antenna, thus arriving at the nearest point to the antenna at which a short may be placed. This will give the shortest possible center stub. Of course, it is not necessary that the center stub be made that short, since very little loss will be incurred if it is left a half-wave or even a wavelength longer—that is, if the wire is not smaller than No. 14. The Zepp feeders may now be attached to either end of the antenna, as it is now ready for operation.

The method of adjusting the center stub just outlined is also useful where it is desired to feed any of the antenna forms discussed above with an untuned transmission line—that is, a transmission line terminated by its surge impedance. Using the example cited in the previous paragraph, let us assume the point of maximum current through the short has been found and, after soldering a piece of wire across the line at this point, the extra length of transmission line is chopped off. The two-wire line from the transmitter may now be tapped in above this shorted end of the stub, and it is only a question of position of the feeder tap from the shorted end to terminate the line properly. See Fig. 7. This point will be approximately 3.3 feet from the short for a 600-ohm transmission line. Of course, when all this is done, we will have the same transmission line with correcting stub discussed earlier in this article.

LINE-CURRENT MEASURING DEVICES

The same principle holds true for the double-Zepp and for center feeding the simple doublet, the only ambiguous point being that of knowing when the transmission line from the transmitter is connected at the right distance from the closed end of the stub. The transmission line will be properly terminated when there is no appreciable variation in voltage or current along the line, and hence some method must be used which will detect any variation in voltage or current. Simplest of all is the old-fashioned wood-covered lead pencil, for with this device bright arcs may be drawn from either wire and the voltage at any one point judged by comparison with the voltage

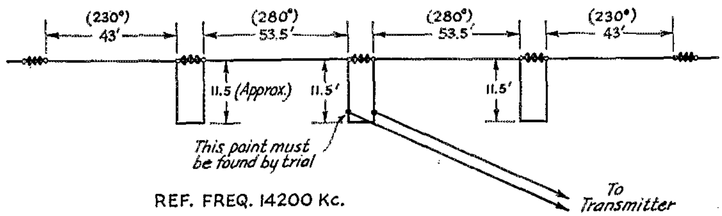

FIG. 10—FOUR-ELEMENT ARRAY WITH 230-DEGREE ELEMENTS

at another point. This method has the disadvantage of being both crude and liable to error due to the presence of second or higher-order harmonics in the output from the transmitter. A little better is the small neon bulb, but this is also a voltage-operated device and subject to harmonic distortion. Then there is the current-squared galvanometer with a few small turns of wire connected to its terminals, these turns being coupled to either line. This device is quite good if

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keep the loading at the proper value immediately upset the tracking. A half-wave 3.5-Mc. voltage-fed antenna tapped directly on the final plate tank coil through a 50-$\mu\mu$fd. variable condenser could be used maintaining satisfactory tracking throughout the 7- and 14-Mc. bands. The adjustment of loading by means of variation in the capacity of the coupling condenser did not upset the tracking. Over the wider 3.5- and 28-Mc. bands, however, even this did not solve the problem. Thus far, the most convenient coupling device seems to be the pi-section network. This adds two controls, but, if they are located near the frequency control dial, resonance in the final amplifier and loading may be controlled very conveniently. At any rate, we're going to put the system to work in our present transmitter which now has 8 controls. We figure the elimination of five of them will be well worth the few necessary changes.

The transmitter as it stands will make an excellent single-control driver for any high-power final amplifier. If higher power is desired, however, it would seem advisable to gang at least the final amplifier's grid circuit tuning along with the exciter tuning. About the only practical limit to the number of stages which may be ganged is reached when the number of condensers in the gang reaches the point where serious mechanical back-lash results from the accumulation of spring in the flexible couplings.

The Extended Double-Zepp Antenna

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one is careful to use constant coupling to the wire, but its disadvantages are that coupling between the meter and line is both inductive and capacitive, causing the meter to read differently according to how it is held up to the line, and that the meter will also be influenced by harmonics.

The most satisfactory device seems to be a sensitive galvanometer in a miniature tuned circuit coupled to the line. Such a device combines sensitivity with freedom from harmonic distortion, but the effects of capacity are still there to some extent. The tuned circuit should therefore be carried along the line with its position relative to the plane of the two wires maintained constant. See Fig. 8. Checking along one of the two wires only is usually sufficient, but if one suspects an unbalance exists, the other line should also be checked. If the antenna system is reasonably symmetrical, unbalanced currents will most likely be due to improper coupling to the transmitter, but that is another story. At any rate, if a current maximum (voltage minimum) appears at the junction of transmission line and stub, the connection to the stub is too near the shorted end, and if the current is a minimum the opposite, of course, will be true. If the current maximum or minimum (assuming standing waves actually exist) does not occur near the stub, there has been a slip-up somewhere in the procedure, for this will be evidence that the stub itself did not tune the antenna to resonance.

PARASITIC ELEMENTS

The use of spreaders several feet in length to support each end of a "flat-top" antenna composed of two wires is again becoming popular, and for a good reason. Gains of around 5.5. db for a bi-directional array and around 7 db for a uni-directional array are thus made possible. One of the most promising arrangements is that of two double-230-degree antennas supported parallel to each other only 0.2 wavelength apart, as illustrated in Fig. 9. Antenna A is excited by the transmitter using the same technique as when exciting a single double-230-degree antenna. Antenna B may be tuned by proper positioning of a short on its stub to become either a director or a reflector. In fact, this stub might be extended by multiples of a half wavelength to enter the operating room where, by means of a single switch the shorting position may be changed from that corresponding to a director to the position corresponding to a reflector, thus reversing the directivity of the antenna system. Information as to the gain of such an antenna system when one antenna is used as a director is not available, but when it is used as a reflector and adjusted to give a *minimum* signal to the rear, the signal forward will be 7 db better than a simple doublet, and the signal backwards will be 7 db less than from a doublet, resulting in a front-to-back ratio of 14 db. Adjustment of the reflector shorting bar should be on the basis of minimum backward signal from the antenna, or minimum signal received from a station in that direction when using the antenna system for reception, since this adjustment can be made more accurately than one resulting in maximum front signal. This will minimize QRM for both transmitting and receiving. The same principles hold true when adjusting the auxiliary antenna for use as a director.

If adjustments of the auxiliary antenna are to be made when transmitting and an ammeter is temporarily inserted in the shorting bar, minimum backwards signal will occur for the reflector when the short is moved slightly further from the antenna than that position corresponding to maximum current through the short. For the director, optimum conditions will be obtained when the short is slightly closer to the antenna than the maximum shorting current position. From this it can be seen that the proper adjustment of the auxiliary antenna is quite critical and certainly very important. Since field strength instruments are not generally available, a receiver fitted with a signal strength indicator of some sort located within a few miles of the antenna and in the desired direction should prove to be the next best thing. Connecting your own receiver to the antenna, with the other fellow transmitting, is perhaps even more practical in search for that minimum-signal adjustment.

The presence of the auxiliary antenna only 0.2 wavelength away from the driven antenna and adjusted properly for maximum forward or backward radiation will obviously affect the radiation resistance and impedance of the driven antenna. As a result, if the auxiliary antenna is left open-circuited and the stub on the driven antenna is adjusted in accordance with the method previously given, this adjustment will not be correct when the auxiliary antenna is, in turn, properly tuned. Moreover, the impedance of the driven antenna will differ slightly according to whether the auxiliary antenna is tuned as a director or as a reflector. If quick change from reflector to director is contemplated, some sort of compromise is indicated in the adjustment of the stub on the driven antenna.

From a practical standpoint, however, the adjustment of the auxiliary antenna should be made first, be it reflector or director, with the driven antenna excited by the two-wire transmission line without a correcting stub. This may require temporary adjustment of the transmission-line length, either physically or by means of series coils or condensers, to bring a low-impedance point at the coupling coil to the transmitter in order to load the latter satisfactorily. In fact, if the line length from antenna to transmitter is not more than a wavelength or so, the reduction in line losses resulting from the use of a correcting stub is hardly worth the trouble of installing it. The point is, if a "flat" line is desired, adjustments of the stub at the driven antenna should not be made until after the auxiliary antenna has been tuned to give the desired radiation pattern.

LARGER COLINEAR ARRAYS

Now let us suppose our backyard is big enough to hang up more than two doublets end to end. An interesting possibility would be a four-element array of 230-degree elements. But here the principles of the extended double-Zepp must be carefully considered in designing the length of each element and the length of the phasing stub separating them. The actual arrangement will be as shown in Fig. 10. Both degrees and dimensional designations are used to indicate the electrical and physical length of each element. The length of the stubs indicated is approximate only and must be adjusted for best results. The lengths of the various antenna elements as shown, however, may be assumed correct. The transmission line can be tapped on to any of the stubs, but connection to the center one will give the greatest gain.

The principle of the design shown for four elements is to provide the same separation in space between each doublet center as is provided between the two doublet centers in the double-230-degree antenna. Each phasing stub will, of course, be considerably shorter than a quarter wavelength, and when adjusting their length to tune the whole antenna to resonance, all three stubs must be made the same length; that is, if one is shortened two inches, the other two must also be shortened by two inches, assuming they were all the same length to start with.

This may prove to be an awkward and tedious method of adjustment, but the procedure may be simplified by adjusting the length of the center stub only as a first approximation. The use of an "exciter" antenna temporarily rigged nearby is assumed. If it is found the center stub must be shorter than the other two stubs by 3 feet, for instance, in order to obtain maximum current through its shorting bar, the other two stubs should be shortened by 1 foot and a new position found for maximum current through the center stub. This new position should correspond closely to equal length for all three stubs. This procedure of tuning the four-element array should be followed even though a stub at the center will not be used, finally, its place being taken by the transmission line itself. Such a connection will result in standing waves along the line and it will have to be "tuned" to permit easy coupling to the transmitter or receiver.

The horizontal pattern of the four-element array just described will have two major lobes at right angles to the antenna and several minor lobes of small amplitude. The gain in actual practice has proved to be greater than anticipated, and probably is more than 7 db. The major lobes will be much narrower than for the double-230-degree antenna, thus requiring more careful "aim" in erecting the array, or provisions for swinging it about. It is assumed this array, as well as the others described, is hung horizontally. It may be hung vertically, of course, but the possible restrictions due to sharp directivity in the vertical plane should then be considered. In general, the horizontally polarized antenna will prove most practical, chiefly because the ground reflection usually encountered with vertically-polarized radiations is inferior, and because high masts are not often available.

The adjustment of the antennas described in this article may seem a bit involved as compared with the simple doublet or the double-Zepp antenna, but the extra gain thus made available should make their use worth while. For that matter, the double-230-degree antenna need not be tuned at all, its construction being made in accordance with the dimensions given and the transmission line tuned to fit the transmitter. In this respect the simplest of all directive antennas, size and gain also taken into consideration, is the extended double-Zepp.