Harry A. Mills W4FD
Box 280
Bullard Route
Dry Branch GA 31020

Gene Brizendine W4ATE
600 Hummingbird Drive SE
Huntsville AL 35803

Antenna Design: Something New!

—controlled-current distribution

Antenna elements to date, whether grounded or ungrounded, are by and large composed of electrically continuous conductors whose dimensions are based on formulas related to the free-space dimensions of radio waves. The presence of standing waves and losses due to end effects have heretofore been accepted as more or less necessary in the transfer of radio frequency energy into space.

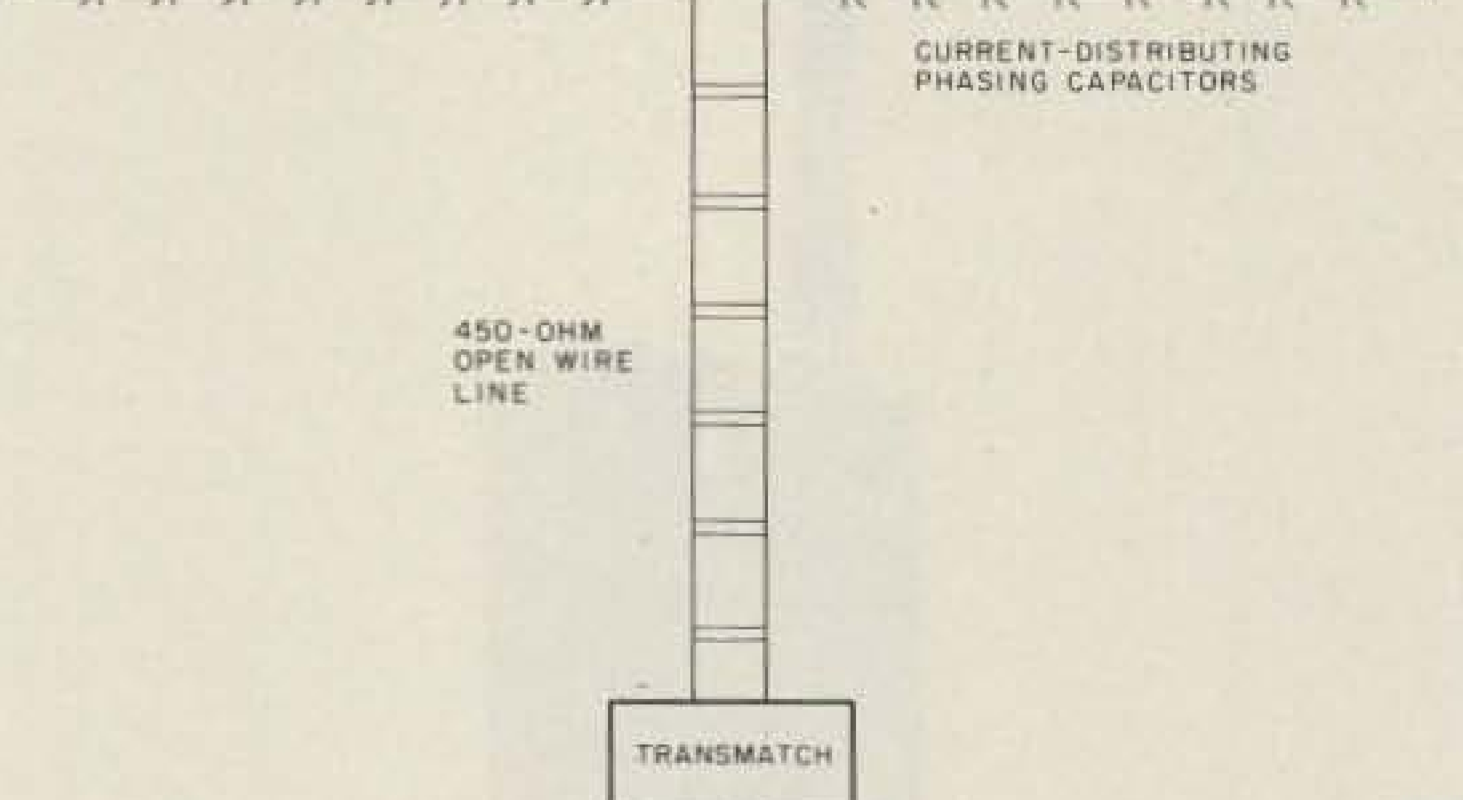

Fig. 1. Controlled-current distribution antenna general arrangement. Details of construction and adjustment are included in the text. A feedline length which is a multiple of ½ wavelength at the lowest (design) frequency is desirable.

Our thinking in this regard has changed very little since the medium of radio was discovered more than a hundred years ago.

The greatest impediment to progress in antenna development over such a long time has been the belief that an "antenna" is merely a length of wire in space, whose dimensions are locked to the operating frequency. The second problem, also linked with the first, is the notion that the antenna should sustain a standing wave. Thirdly are the problems associated with lossy end effects. There is also the excessive copper heat loss that must occur at the center of the conventional dipole. The losses due to high current (and rf field) density multiply when the usual antenna is erected as a quarter-wave vertical radiator.

But all of this was BC (before capacitors). The fact that the radiation directly from a capacitor is so minor does not justify its virtual elimination from use in antenna systems. As a device for the control of phasing, it looms as the most important consideration of all, both for pushing that antenna current to all parts of the radiator and, importantly, to distribute it in phase, so the resulting field is efficiently directed. Interestingly enough, superior results occur when the current distribution becomes more equal in the system. Lo and behold, best results are obtained upon elimination of the standing wave.

The insertion of capacitors in series with an antenna was briefly described by Terman.[1] Some ideas were added by Charman, with the advice that the technique "well deserves further investiga-

[1]Terman, *Radio Engineering Handbook*, McGraw-Hill, New York, 1943, page 773.

tion."[2] How long it has taken us to grasp the handle on this rocket, on which we may escape the prison of conventional thinking! Let us take that flight, without further delay.

It is difficult to face the fact that, for all these years, we failed to take advantage in antenna design of that most important characteristic of a capacitor, its inherent low loss. The lowly capacitor is well established as man's best friend in the design of power and audio filters over these many years. Somehow, a blind spot has prevented us from seeing it in the vital role of filtering out antenna current into a most efficient distribution pattern.

Additionally, by equalizing current throughout the radiator by use of capacitors, we realize another very important improvement. Over the years, we have tolerated that wasteful spray of high-angle radiation which occurs from the high-impedance, high-voltage portions of our antenna as though it were an unavoidable evil. In reality, a standing-wave-type radiator thrusts out energy at widely varying angles, becoming worse toward the ends. When we approach equal current along the antenna, radiation begins to focalize at a low angle. Lo and behold again, our antenna begins to perform amazingly well on DX, even when close to or near the ground. In brief, the equalized current element becomes an improved performer when substituted for the conventional dipole form in all kinds of configurations.

The present paper was written to encourage a breakthrough and breakaway from conventional impeding practices. Some simple theory and practical construction details are included to introduce the improved system.

Developmental Background

The controlled-current distribution (CCD) principle was recognized more than ten years ago, during the development of a compact 3-element rotary beam. Ferrites were used, not only to dramatically shorten the antenna elements, but also to provide a means whereby a special type of cored ferrite material could be used to electrically tune each element individually over a wide range of operating frequencies. Controls for tuning are conveniently located at the operating position.

The CCD principle is implicit in the basic United States patent 3,564,551, granted to W4FD on February 16, 1971, which covers the scheme whereby a dipole antenna element employing ferrite is tunable over a wide range of frequencies, in either transmitting or receiving modes, by varying the permeability of the sleeved cores. Permeability variation is accomplished by magnetically biasing the cores with controlling field current windings.

It is well known that ferrite material must be employed in rf circuits under conditions of high current and low voltage because of its inherently high dielectric properties. Previous use of this material had been limited to the middle one-third to one-half of the dipole.

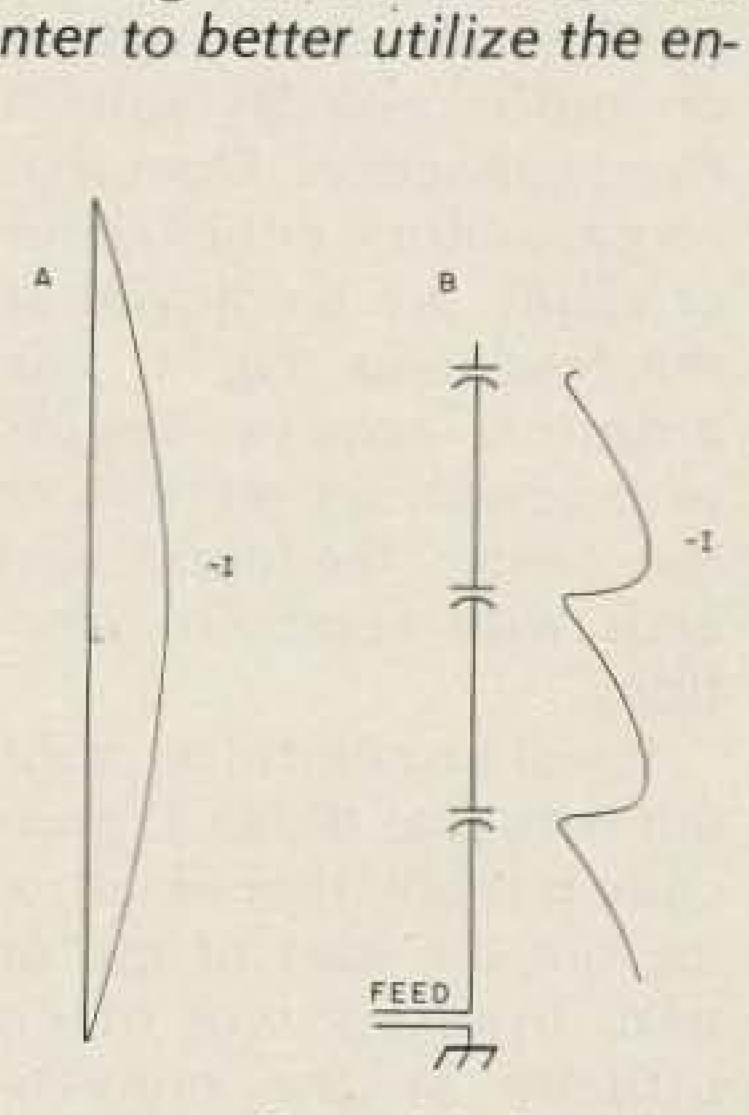

Fig. 2. (a) Conventional half-wave radiator showing the concentration of current at the middle half of the antenna. (b) Small section of a vertical CCD antenna showing current loops at each capacitor-wire section. Loop amplitudes decrease as the radiator end is approached. However, very significant improvements in gain and other features now result from expanding current distribution outward from the antenna center to better utilize the entire radiator.

To offset this limitation, a means to obtain a near-constant rf current along the conductor was conceived. This CCD scheme made it practical to utilize cored sleeves over the entire radiator and to greatly extend the frequency tuning range.

In brief, the system made possible the operation of elements as short as hundredths of a wavelength, with spacing of beam elements likewise reduced. Upward of 300 foreign countries were contacted by W4FD, under the previous call W3UZ, using the shortened ferrite antennas between the years 1959 and 1973. Moreover, many of these contacts were made while radiating from ferrite elements in a basement in Washington, DC, 5 or 6 feet below outside ground level.

Continued experimentation with the CCD scheme, following its initial use in ferrite antennas, revealed that the gain realized from conventional wire, beam, mast, or tower antennas of all types could be markedly improved by employment of the controlled-current distribution principle. In short, it improves the operation of antennas at both dimensional extremes.

The Controlled-Current Distribution Theory

It is well established that a maximum field is produced around conductors at points of maximum current. Points of high voltage and low current, conversely, produce small fields. It follows that, should some means be provided to maintain the antenna current at a constant or near-constant value along a conductor, the resulting field should translate into improved gain from the radiator. This condition of tracking the antenna current in phase would not only redistribute the excessive I^2R conductor heating loss present at the center point of peak current, but would also reduce or eliminate the dielectric end effect losses. Such a current distribution would not only make it possible to efficiently employ constant cross-section area sleeves in a ferrite radiator, but also to improve other antenna systems.

Band meters	Length feet	Section inches	Sections number	Capacitor pF	Capacitors number	"K"
160	560	140	48	1560	46	33.92
80	280	70	48	780	46	16.96
40	140	35	48	390	46	8.48
20	70	17.5	48	195	46	4.24

Table 1. Construction guidelines for CCD antennas one space wavelength long.

[2]Charman, RSGB *Bulletin*, London, July, 1961.

The problem of current distribution was resolved by cutting the antenna conductor into twenty-two or more even-numbered sections of equal length, to which were interconnected in alternate series twenty or more equally-valued fixed capacitors. Note that no capacitors, either series or shunt, are employed at the feedpoint, Fig. 1. The antenna always begins with conductor sections at the center feedpoint and ends with conductor sections.

It will be helpful to point out here that the CCD principle is really that of carrying out the idea of top or end loading, so often utilized in the conventional shortened antenna. The ultimate result is that of improving the current distribution throughout any length radiator. Control of current distribution by means of interconnected series conductor-capacitor sections with fanned end radials or large discs (but without lumped inductance in the circuit) begins at one-half wavelength for the dipole or a quarter of a wavelength for the grounded vertical. Thus, by using the horizontal dipole as a guide, it can be seen that the addition of aluminum screen discs at the ends, plus the cutting of a half-wavelength radiator into a series of alternate wire and capacitor sections, could improve both the current distribution and gain of the resultant radiator. However, this is only the beginning of the possibilities.

The Antenna Aperture Concept

One aperture can be conveniently defined, for the purposes of this article, as the in-space dimension of a half wavelength at a particular frequency. By this definition, the conventional thin-wire dipole, because of its end-effect characteristic, may be said to have an aperture of about 0.95. Antennas constructed of tubing or cylindrical elements have an even smaller aperture.

Aperture as a concept involves the idea of exposure to a wavefront. The idea may be referred to a slot antenna, cavities, or even to the raster of a television picture scan. In a sense, all radiating systems which present an exposure which is less than a wavefront in free space distance may be said to suffer from a degree of "wavefront distortion." In other words, the full potential of the wave-sweep or scan is not present in a transmitting or receiving antenna of contracted dimensions.

Real exposure efficiency, or maximum aperture usage, begins at the point where an in-phase equal-current coverage fills the conductor or slot medium.

Exposure efficiency begins in a smaller way with the CCD scheme, plus element end or top capacitance loading, and emerges more or less full-blown with antenna lengths of two apertures or more.

The improvement in gain that can be effected through the use of a constant-current distribution arrangement can be illustrated with the 5/8-wavelength horizontal antenna. This radiator produces its peak gain at this length partly because of the trade-off between an increasing out-of-phase component and its expanded aperture. Gain begins to decrease at antenna lengths above and below the 5/8-wavelength figure.

It is customary to provide the 1/8 wavelength (extending the ½-wave dipole) by loading the antenna with a non-radiating series inductor. However, inductors introduce substantial losses. Therefore, any trade-off scheme to increase gain through the use of either inductor or capacitors should favor the inherently lower-loss capacitor. Moreover, the CCD principle can be employed not only to eliminate the loading inductor losses, but also to effectively distribute the current so that resonance is restored to the ½-wavelength value. Not only is the out-of-phase component effect greatly reduced, but the resultant current distribution can be made phase-aiding also. Furthermore, the trade-off limitation at the 5/8-wavelength dimension disappears, and the way is opened for continued increase of aperture, in phase, with increasing antenna length.

Controlled-Current Distribution Principles

The CCD process can be more easily visualized by comparing it to full-wave rectification of a multi-phased alternating current to iron out the ac ripple component. No rectification of the rf in the antenna element is, of course, taking place in the CCD system. However, in the alternate conductor-capacitor arrangement, as values of capacitors are progressively increased and wire length in each section is decreased, within reason, the rf standing-wave "ripple" along the antenna will tend to smooth out. The better the distribution of the current, approaching a true in-phase condition, the more effective the antenna. The capacitance loading discs employed serve the purpose of carrying uniform distribution of current nearer to the radiator's very end.

An illustration of current patterns through the X_C and X_1 components is shown in Fig. 2(b). A vertical radiator is depicted, so that positive X_1 and negative X_C values may be shown right and left respectively. The wire sec-

Date	Time DST	Antenna	Height in feet	Ferris 32-B level, dB
7-2-77	1:45P	#4 CCD	60	20 Relative
		REF	60	15
	2:10P	#7 CCD	60	20
		REF	60	15
7-4-77	7:20P	#4 CCD	60	20
		REF	60	15.5
7-5-77	10:56A	#4 CCD	60	20
		REF	60	15
7-14-77	10:40A	#4 CCD	60	20
		REF	60	15

Test antenna specifications:
#4 CCD—150 feet overall, 36-inch sections, 390 pF caps.
#7 CCD—136 feet overall, 38-inch sections, 390 pF caps.
Reference model 67 feet overall. A conventional dipole.
All three antennas normal to a bearing of 45 degrees true, and the standard Ferris model 32-B antenna.
All inactive antennas were floated during each reading.

Table. 2. CCD comparative field intensity measurements.

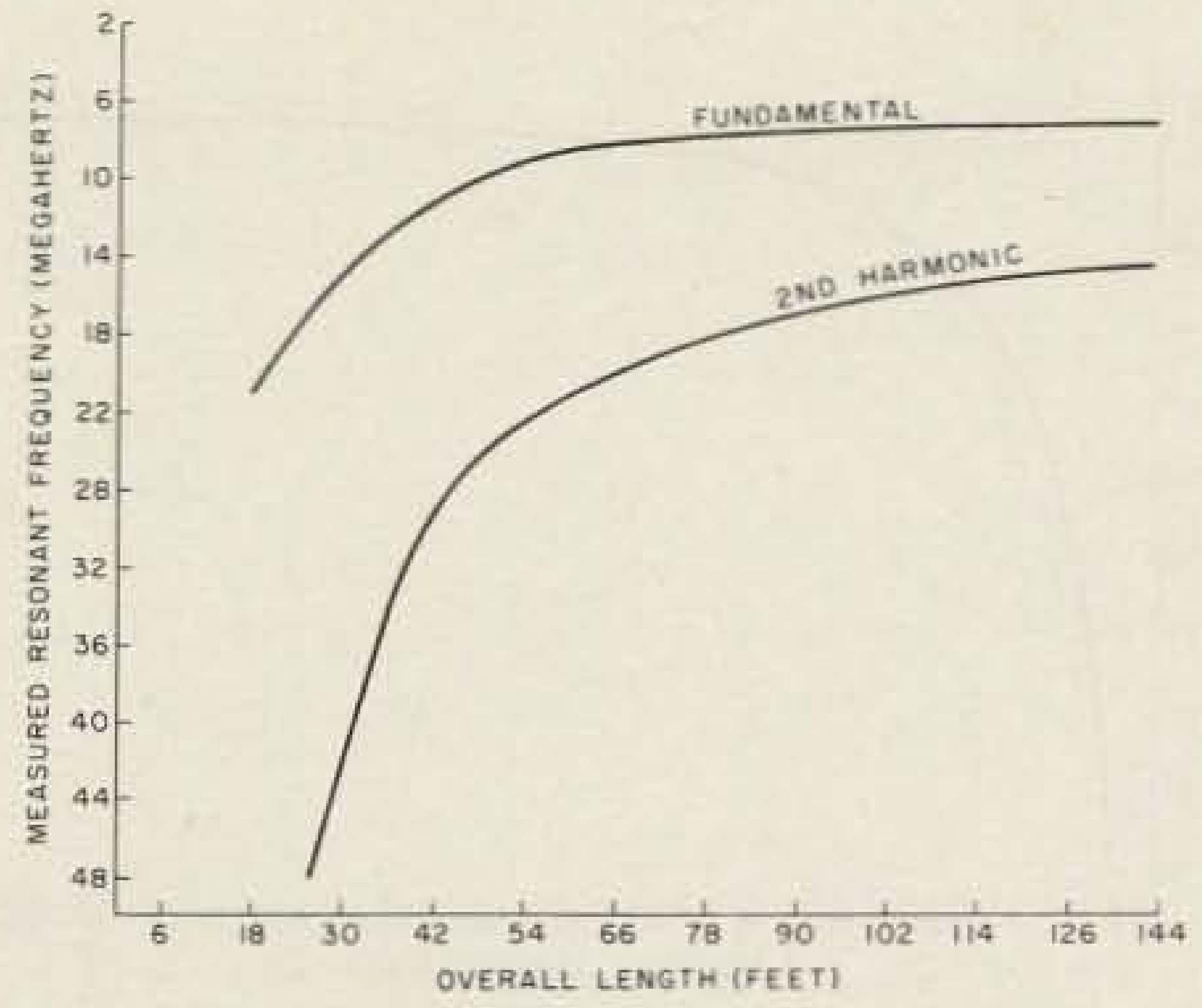

Fig. 4. The Mills controlled-current distribution antenna. Graph made from data taken during assembly on July 20, 1977. Section length—11 inches; capacitors—1500 pF; number of capacitors—160; dip meter—Millen Solid. For exact measurement data, see Table 4.

most efficient use of the available ground space.

One startling characteristic of the CCD antenna is its almost complete immunity to the effects of close-by nonresonant conductors or semiconductors. In one test, consistent S-9 reports on 7 MHz were received by W4FD from stations in Miami, Cincinnati, New Orleans, and Louisville with the CCD antenna lying flat on the ground during a soaking rain. With the CCD arranged in a square, again flat on the ground and under several inches of snow, I2CUV reported a signal of 549 on January 28, 1977. A two-wire nonradiating feeder 9 feet long was used, and no arcing was found along the radiator with an input of 500 Watts.

Advantages of the CCD Antenna

1. Greater gain.
2. Great reduction or elimination of end effects.
3. Higher antenna resistance.
4. Full use of antenna element—no nodes.
5. Lower radiation angle—good DX radiator.
6. No high voltage points—can be laid on tree limbs.
7. Good field day antenna—works well at only 8 feet up.
8. No phase-inverting stub required.
9. Can be made any convenient length for available space.
10. Improved broadband characteristics.
11. Improved broadside radiation at early harmonics—good harmonic antenna.
12. Current distribution effects lower losses in both antenna and ground.
13. Very effective for quads, deltas, etc.
14. Changes in height produce progressively less relative changes in antenna resistance as the number of capacitors and overall length are increased.
15. Harmonic operation becomes more and more effective as the number of capacitor units is increased and the conductor sections are proportionately shortened. Rule of thumb shows that, for a given overall antenna length, shortening the wire sections by one half doubles both the number and the capacitance values of the fixed capacitors required. Broadside pattern characteristics are proportionately improved at both the fundamental and harmonic frequencies with an increasing number of sections.

Length overall (feet)	Fundamental (MHz)	2nd harmonic (MHz)	3rd harmonic (MHz)	4th harmonic (MHz)
6	46	125		
12	30.1	86	140	
18	22	63.5	104	
24	17.8	57	83.5	
30	14.4	42.5	71	
36	13	36.6	59.5	
42	11.5	31.7	52.6	
48	10.5	28.4	48	
54	9.9	25.5	40.8	
60	9.3	23.5	38	
66	8.9	21.6	35	
72	8.65	19.8	32.5	
78	8.3	18.5	30	
84	8.1	17.3	28.3	
90	7.9	16.15	26.35	
96	7.8	15.5	25	34
102	7.7	14.6	23.6	32.5
108	7.6	14.1	22.4	30.4
114	7.5	13.4	21.3	29
120	7.35	12.9	20.3	27.9
126	7.25	12.4	19.2	26.4
132	7.15	12.0	18.3	25.4
138	7.1	11.7	17.8	24.5
144	7.05	11.4	17.15	23.1
*150	7.0	11.3	16.0	21.8

*Table 3. Measured CCD antenna fundamental and harmonic resonances versus overall length, as measured during construction. The graph in Fig. 3. was plotted using these values. *With 2-foot square aluminum screens attached to each end during last measurement.*

CCD Disadvantages

1. Increased cost because of the added wire, capacitors, and insulators.
2. Greater care in construction and testing.
3. Requires more erection space than is available to some amateurs.
4. In CCD antennas for 3.5 MHz and lower, the capacitors should be protected from static charge by shunting resistors. If a cluster of CCDs is used, only the longest one needs this protection.

These are really minor inconveniences in contrast to the fifteen overwhelming benefits listed above. The old adage, "Every nickel spent on the antenna is worth more than a dollar spent on the station gear," was never truer. Give that good rig a chance with an equally good antenna!

Comparative Field Intensity Measurements of the CCD Antenna

At the W4FD antenna range, carefully controlled gain measurements are made using a laboratory standard Ferris model 32-B field intensity meter, fitted with its standard 41-inch antenna. Power to both the plates and filaments is regulated to 1 percent. The laboratory equipment is

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tion is distributed X_1, comprising most of the radiator, and the X_c contributes only minor power in the radiation process.

Contrasting the CCD features to another type of long antenna, the collinear array, its performance superiority is readily apparent. When several one-wavelength CCD radiators are configured as a collinear array, no longer are the usual 180-degree phase-shifting stubs required at one-half wavelength intervals along the radiator. Stubs are only needed to separate each one full electrical wavelength, thereby reducing the number of stubs by one-half in a given array.

The simplified and improved antenna will prove to be outstanding in gain for 2 meter and higher frequency applications and particularly in color television, where a broadband response is mandatory.

The user of the CCD will be especially pleased with its performance as a vertical radiator. The longer his CCD with respect to the electrical half wave, the less will be the need for the labor-consuming radials which are so important to the conventional standing-wave system. Since current is nicely distributed throughout the radiator, no longer are we troubled by the heavily-concentrated field and resulting lossy ground-return currents directly at the vertical antenna base. The heavy field around the base becomes less and less as the antenna is lengthened to one-half wavelength and performs quite well with shorter radials. At one wavelength, we realize a low-angle radiator par excellence and may dispense with the radial plow.

The user will be most agreeably surprised when he learns that the almost uniform distribution of current throughout the CCD not only provides a more favorable antenna resistance at the fundamental frequency (usually double), as compared to the conventional dipole, but also the current distribution at the second harmonic will be only a few hundred Ohms (usually less than 450), provided he utilizes 50 or more distribution capacitors. Moreover, most of the radiation will occur broadside to the antenna, as has been found during operation at the fundamental frequency.

Elaborate measurements and adjustments could be performed, measuring antenna resistance and resonant frequency with rf bridge and detector, while adjusting end-loading capacitor screen discs to the exact diameter. However, in practical application, such elaborate tailoring is not justified, because the antenna will generally be used over a wide range of frequencies.

How the CCD Antenna Differs

It has long been assumed that, because radio frequency energy becomes an accurately measurable standing wave in free space, the radiating element itself should be dimensionally designed to also contain a standing voltage wave. This locked-in concept, far from having basis in fact, is one of the bottlenecks to the realization of greater efficiency and versatility in antenna design and construction.

Here are features wherein the improved CCD antenna departs radically from the usual dipole. First, we select the wire section length desired and then determine what capacity in picofarads is necessary to partially cancel the inductive reactance of the wire sections.

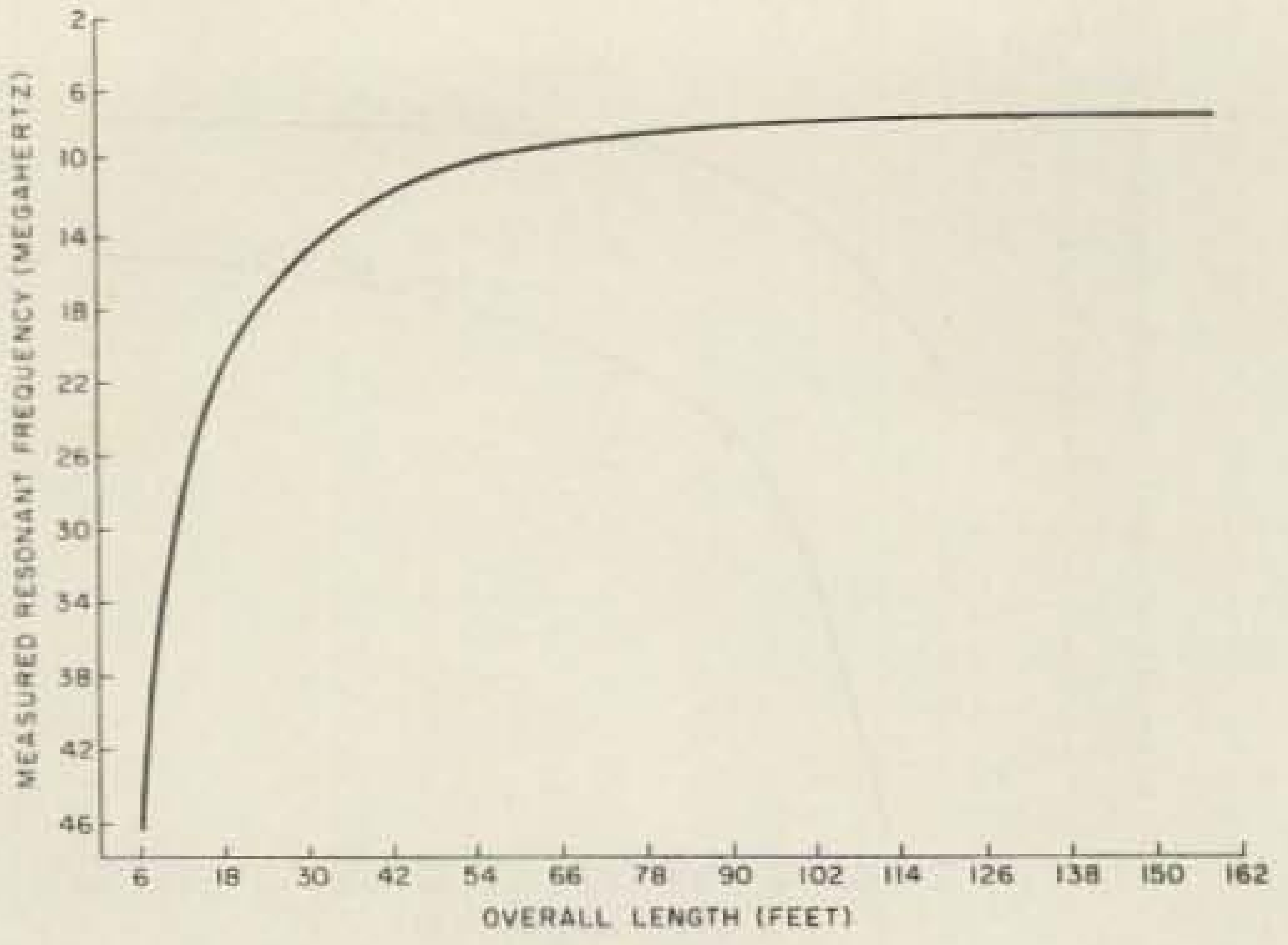

Fig. 3. The Mills controlled-current distribution antenna. Measurements were taken during assembly on March 24, 1977. Sections—3 feet; capacitors—silver mica 390 pF (50 each); dip meter—Millen Solid; coupling turns—8. For exact measurement data, see Table 3.

Too low a capacity will create too high a capacitive reactance in Ohms and thereby over-cancel the inductive reactance of the wire section. Conversely, incorporating capacitors of too small a value will prevent ever achieving resonance, regardless of how many sections are added. The X_1 to X_c ratio is the key to proper CCD antenna performance. If the difference is too small, we will require an impracticable number of wire sections and series capacitors to obtain resonance at the desired frequency, and the magic of controlled-current distribution disappears.

The superior characteristics of the controlled-current distribution system become apparent when the radiator overall length is extended to one electrical wavelength and beyond. The end-loading discs may then be eliminated, except in instances where it is desired to feed the antenna at some point considerably off center. In such cases, the use of a disc is recommended only at the shorter end. When off-center feed is employed, a balun should be inserted between antenna and feedline to isolate the feedline circulating currents and to maintain balance. Since the antenna impedance along its length is practically constant, no feed problems should be experienced at any point, provided that balancing techniques are employed.

The broadbanding characteristics of the CCD radiator are remarkable, increasing in proportion to antenna length. Since standing waves are now conspicuous by their absence in the conventional sense, the need for a phase-inverting stub (which limits bandwidth in the collinear array) no longer exists. In one fell swoop, controlled-current distribution removes both a long-standing obstacle to broadbanding and also the wire loss introduced by the stub.

Heretofore, the capacitor has not been employed to any great extent directly in antenna elements. It is passive insofar as its contribution to the radiation process. However, its low losses and its ability to control current distribution, and hence phasing, give it a unique place in antenna design. Importantly, it provides the antenna designer with flexibility in tailoring his radiating system for the housed in a permanent isolated building located normal to the test antennas and 56 wavelengths distant (at 7 MHz). A 67-foot-long dipole, for comparison, is mounted parallel with the CCD antennas and is elevated 60 feet.

Two identical separate drivers and finals are carefully matched for equal outputs and feed identical impedance-matching networks and transmission lines to the antennas being compared. To minimize the effects of fading, provision is made for rapid alternate switching between the two antennas being compared, both while transmitting and receiving. See Table 2.

Length overall (feet and inches)	Fundamental (MHz)	2nd harmonic (MHz)	Number of capacitors
20' 8"	19.1	57	24
25' 7"	16.6	48	30
32' 7"	13.2	36.4	42
38' 9"	11.5	30.9	50
47' 5"	10.25	26.5	60
58' 2"	9.45	22.2	70
74' 2"	8.85	19.2	80
82' 5"	8.5	18	90
90' 7"	8.2	17.2	100
98' 9"	8.0	16.4	110
106' 11"	7.85	15.8	120
115' 1"	7.6	15.4	130
123' 3"	7.4	15.0	140
131' 0"	7.2	14.6	150
139' 0"	7.05	14.15	160

Table 4. Fundamental and harmonic resonances versus overall length for a CCD antenna containing 160 capacitors, as measured during the assembly phase. The graph in Fig. 4 was plotted from these values. Note: Frequency measurements for the 131- and 139-foot lengths are extrapolated, due to unavoidable circumstances during construction.

Overseas Signal Reports

The results of DX tests and transmission and reception have favored the CCD by between 5 and 7 dB over the reference dipole. On good DX nights, reports on 7 MHz CW have been 10 to 20 dB over S9 from Europe and Asia to W4FD using 500 Watts.

CCD Construction Guidelines

Several methods of assembling the capacitor/wire sections have been employed successfully. These have included: (1) bridging the components across small strain insulators; (2) utilizing spacing insulators salvaged from large coaxial transmission lines; (3) encapsulating the components inside a light plastic tube (Figs. 5 and 6); and (4) spiraling dual wires about a nylon rope and taping each capacitor for waterproofing (Fig. 7).

The construction method selected depends upon individual siting problems. The major requirements are: (1) mechanical strength sufficient to support the antenna during wind and icing conditions, and (2) protection of components from moisture, salt water, etc. Obviously, a CCD mounted within an attic would have less stringent requirements.

Method (4) above was developed by W4FD and has proven very effective in situations where the assembled radiator must be dragged through tree branches or over rugged terrain during erection. This method of assembly will be described later in detail because the CCD, for the first time, opens the door for successful antenna operation in treetops and in many other sites which have been found unfavorable for other antenna systems.

The types of capacitors preferred are polystyrene, silver mica, or mica, in that order. Capacity tolerance should be 5%, and the dc working voltage may be 200 volts, due to the relatively small rf voltage imposed across each unit in the CCD application, even at the legal power limit. Polystyrene capacitors provide the advantages of stability, excellent sealing, small size, and lightest weight. Capacitors of wider labeled tolerance are equally satisfactory, provided they are selected for the recommended tolerance by means of an rf Q-meter or bridge.

Lightning and static charge protective chokes were originally used across each capacitor. These may produce random resonance indications which are misleading during dipmeter measurements which are necessary to adjust the CCD antenna to resonance. For that reason, the substitution of 1-Watt, 20 to 50k Ohm resistors is recommended.

Proper capacitor values lie between the two extremes which were mentioned above, the key to efficient CCD performance being the condition of partial cancellation of wire section positive X_1 by the negative reactance X_C. A range of useful values and wire section dimensions is included in Table 1. A simple mathematical equation can now be established in which the CCD series capacitors can be equated to a certain K value for each band. For example, if you have 26 five-foot sections (with 24 capacitors) in the antenna series string and find that 270 pF per capacitor is proper for resonance at 7.0 MHz, then:

$K = 270/24 = 11.25.$

This is, of course, the effective series capacity of the string. But, more importantly, we can use this K figure for determining fairly closely what capacitor value to use within other bands and with different wire section lengths and capacitor values. As indicated above, both the capacitance and wire section lengths are indirectly proportional to the operating frequency (i.e., K for 3.5 MHz would be around 22).

CCD antennas for higher frequencies may be designed by ratioing capacitors and wire section length from the data in Table 1. Similarly, the builder may completely fill his available land space by scaling the wire and capacitor sizes.

If capacitor values not shown in Table 1 are available, they may also be used to construct an efficient CCD antenna. It is only necessary to adjust

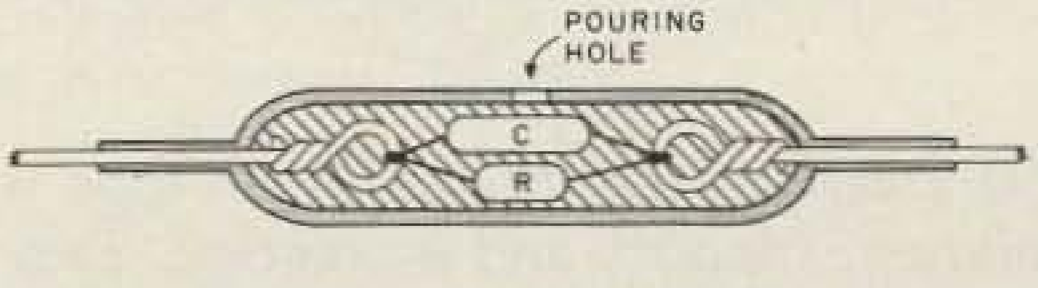

Fig. 5. CCD capacitor/resistor assembly encapsulated inside plastic hot and cold water pipe. See text for construction details.

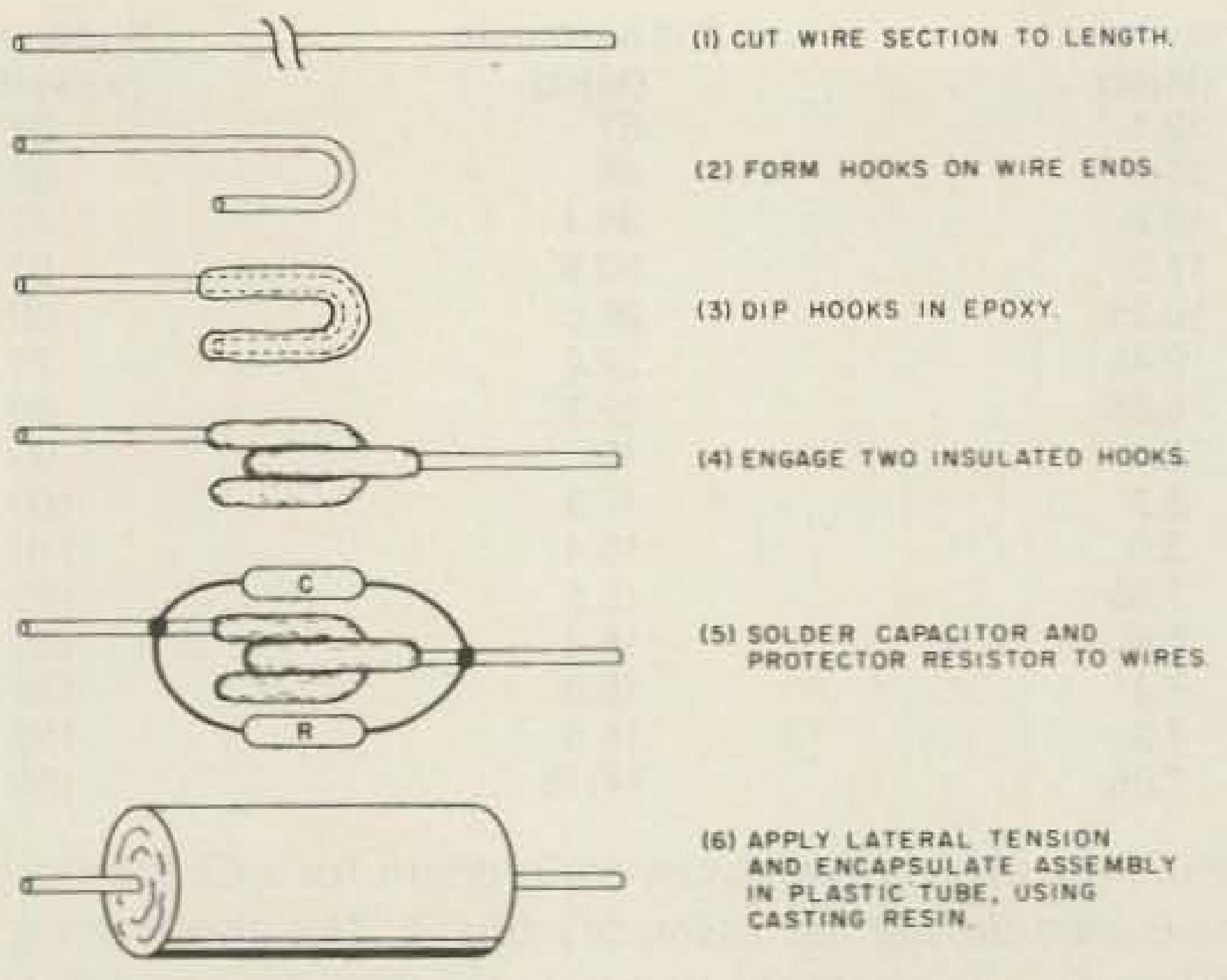

Fig. 6. Steps for constructing one type of rugged weatherproof capacitor/resistor assembly.

section wire lengths and numbers proportionately. For example, suppose that 470 pF capacitors are on hand, and a 7 MHz CCD is desired.

First, find the even number of wire sections required: 470 pF/8.48 ("K" for 7 MHz) = 56 wire sections. The overall antenna length is 140 feet (from Table 1) or 1680 inches. Then, find the section wire lengths: 1680/56 = 30 inches. The number of capacitors is always 2 less than the number of wire sections, or 54 in this example.

Harry's Magic Rope Trick

At his 40-acre antenna range on a 400-acre plot, Harry W4FD solved the special problem of raising controlled-current distribution antennas to the tops of the living 100-foot-plus Georgia pine trees which God so helpfully provided.

First, a 20-pound weight monofilament fishing line is shot from a spinning reel, over the trees, using a 45-pound pull bow. The arrow is weighted at the front by taping on a 14-inch length of ¼-inch-diameter steel rod. This added weight pulls the arrow and line to the ground after clearing the trees.

A 250-foot length of 40-pound-weight nylon cord is employed as an intermediary step. This cord, wound on a spool, is placed in a topless cardboard box. The cord end is then secured to the end of the monofilament line, following its removal from the arrow. The monofilament line is then pulled back through the tree by means of the reel (attached to the bow), until the forward end of the unwinding nylon cord is retrieved. The heavier nylon cord is then used to pull the antenna through the tree branches. The last step is simply a matter of rewinding the nylon cord on its spool until the forward end of the antenna is retrieved. (Note: It will usually be found best to lay the antenna out at the site in the form of two arm-wound coils, assuming you are using a center feedline. The pulling operation of antenna ends through the trees will then involve releasing one antenna coil at a time, working out from the center.)

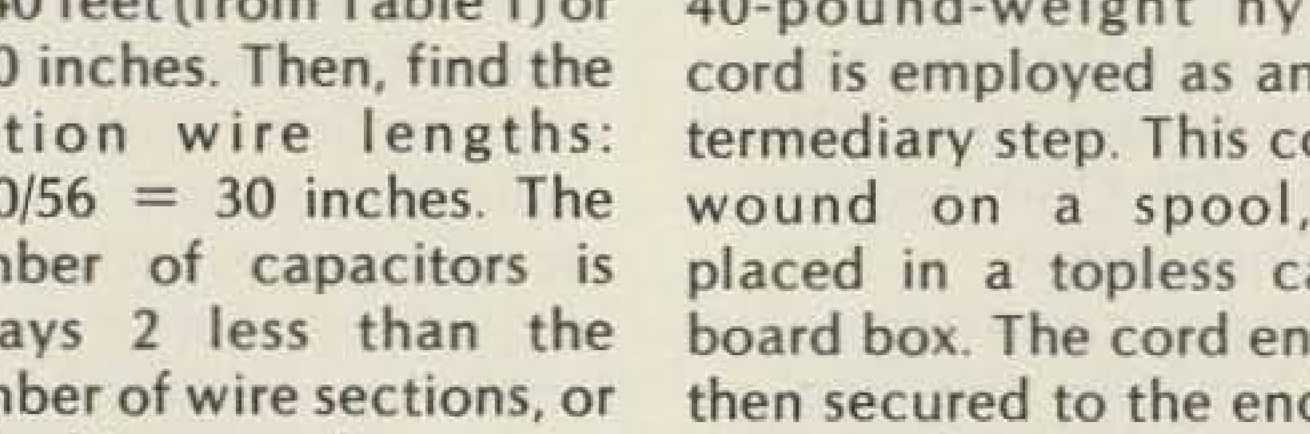

Fig. 7. CCD antenna assembly on nylon rope which provides insulation, support, and protection. Two wires are spiralled in opposite directions around the rope. The capacitor, resistor, and connections are protected against weather and rough usage with vinyl electrical tape.

To withstand the stress of dragging the capacitor/line sections through the tree branches, W4FD designed a special type of CCD antenna. A single continuous nylon rope of ¼-to 3/8-inch diameter provides all insulation and serves as a messenger to protect the antenna components during erection and also to provide a rugged support after the antenna is pulled into its operating position. In this form, the CCD becomes a versatile antenna which may be quickly unreeled for rigorous use in military, amateur field day, or emergency services.

General Construction

Two wires are paralleled in each section, spiralled in opposite directions about a continuous nylon rope. The use of two wires provides symmetry and improved performance. Electrically, the wire ends of each section are joined together and attached to the adjacent capacitor/wire section assembly, as in Fig. 7.

Construction Details

1. Test every capacitor for value, within 5%. The CCD will fail to operate properly with even a single defective capacitor. Form the capacitor leads in a straight line, pointing away from the capacitor body.

2. Cut sections of soft-drawn #17 or #18 enameled copper wire into lengths appropriate for the desired frequency of operation (see Table 1 for dimensions). Add one inch more to each wire section end for connections. Scrape clean the one-inch portions for soldering.

3. Arrange a comfortable work position for anchoring, stretching, and assembling one antenna section at a time. (W4FD uses two vises spaced on a workbench.)

4. Allow sufficient rope at each end for tying the finished CCD to its supports, and stretch the first rope section preparatory to applying the two wires. Anchor a single end of the wire to the rope using vinyl tape.

5. Simultaneously twist-wind the two wires about the rope in a crisscross (spiralling turns in opposite directions) manner, making 12 or 14 turns for the typical 5-foot section. The number of crossover turns is not critical. The purpose is to provide snug adherence of the wire to the rope. Experiment with the first section until you are satisfied with your technique.

6. Wrap two turns of both cleaned ends of the antenna section wires around a capacitor lead and one protector resistor lead close to the unit bodies.

7. Solder the two wrapped wires, ensuring that solder flows onto all wires and penetrates the joint. Well-soldered connections are essential to proper CCD performance; therefore, do not solder until all joints are clean.

8. Hold the capacitor and attached #17 wire sections snugly against the rope and apply one layer of vinyl plastic tape, starting on the rope about 2 inches from the capacitor/resistor ends. Lap the tape one half of its width for each wrap. Continue taping over the capacitor and resistor until the remaining capacitor/resistor leads are just exposed.

9. Wrap two other previously cleaned #17 (next section) wires around the exposed capacitor/resistor leads, and solder well, ensuring that the solder flows onto all joining surfaces. (Note: All soldered connections must have smooth surfaces to eliminate any sharp projections of wire or solder which could puncture the waterproofing tape during erection.)

10. Apply a final wrapping on the entire capacitor/resistor assembly, starting on the rope about one-half inch beyond the end of the first taping. Continue taping until the leads are covered at both ends. (Note: An alternate method to taping may utilize heat-shrinkable tubing of a suitable diameter.)

This method of assembling the CCD on a taut rope, plus the crisscross winding of the #17 wire sections, will ensure, if carefully done, that no strain will be placed on the component pigtail leads during normal service.

Encapsulated Assembly Construction

The second Mills CCD antenna was built by W4ATE, as shown in Fig. 5. Thin-wall hot/cold plastic water pipe and the liquid casting material were purchased at Sears. The #18 copperweld wire and polystyrene capacitors are stocked by Burstein-Applebee, 3199 Mercier St., Kansas City MO 64111.

Construction Steps

1. Cut wires to the length selected from Table 1, allowing sufficient material to form anchoring loops at each end.

2. Form simple loops at each end and solder the wrapped turns (to prevent any movement after final assembly).

3. Solder a protector resistor across each capacitor, without heat damage to either. Do not trim the capacitor leads. (Note: Care must be observed during the following steps to avoid breakage of small component leads.)

4. Wrap one capacitor and one resistor lead around the antenna wire loop, and solder well. Repeat, until capacitors and resistors are soldered to one end of each antenna wire section to be used in the entire CCD antenna.

5. Saw the hot/cold pipe into 2-inch lengths. Drill a 3/8-inch hole near the center of each (encapsulating liquid is poured into the hole later). (Note: Patience and coordination are required in the next step. A few practice runs are suggested using scrap pipe and wire.)

6. Soften one end of the pipe for ½ inch by inserting a small soldering iron. Caution: This operation must be performed outdoors, or in a well-ventilated room to avoid breathing the fumes.

After the pipe end becomes completely soft, the pipe is centered over the capacitor/resistor assembly. The softened pipe end is clamped flat in a vise so that the loop wrap portion is embedded in the softened pipe.

Again, this step requires patience, but careful execution will result in a strong and permanent antenna with no exposed connections. Repeat until a capacitor/resistor and pipe section is installed on one end of each wire section.

7. Assemble the antenna sections, using the same techniques as in step 6, to close the remaining pipe ends.

8. Seal all pipe ends temporarily with masking tape, to prevent any leakage of the encapsulating liquid.

9. Mix clear plastic casting liquid and catalyst in a small paper cup. (A convenient pouring spout is formed by creasing the cup edge.) Fill the pipe cavity completely, tilting it to free any trapped air bubbles. This will flow the liquid around the wire anchor loops to provide a solid, one-piece assembly. The filled pipe may be handled freely, after temporarily sealing the pouring hole with masking tape. Repeat until all assemblies have been poured.

10. After completely hardening, the masking tape may be removed. Any obvious voids or openings noted should be filled with the potting liquid.

Adjustments

Every CCD antenna constructed must be resonated by adding or subtracting complete sections while the frequency is being monitored with an accurate dip meter. The overall CCD lengths shown in Table 1 are intended as guidelines, which may be modified to achieve resonance at the frequency desired. An equal number of sections must be added or removed at each end of the radiator in order to maintain system balance. It is desirable that resonance occurs at the low-frequency end of the operating (design) band. This condition will also improve performance of higher-frequency harmonic operation.

During adjustment, the CCD may be suspended at a convenient 5 or 6 feet above ground. Due to its minimal end-effect characteristics, much less change in resonant frequency will occur upon being raised to its final operating height. A temporary coil is installed at the antenna feedpoint for coupling to the dip meter. Eight turns are suggested as a starting value, which should be reduced wherever possible for best measurement accuracy.

Inspection of the graphs in Figs. 3 and 4 reveals a very slow lowering of the fundamental frequency as the design goal is approached during assembly. This could prove to be frustrating to the builder who is assembling his first CCD. To enable the builder to better anticipate reaching the desired frequency and antenna length, frequent measurement of higher harmonic resonances will prove helpful. Optimum performance occurs at the length where the addition of more sections produces little or no change in the resonant frequency. Operation at lengths which fall along the knee of the graph is to be avoided. Final adjustment to resonance must be made while observing dip-meter indications at the fundamental frequency.

The Future

Future work will expand into the use of ferrite elements and CCD principles in minibeams, the improved performance found to result from the application of controlled-current distribution in loop-element beams, and the superiority of driven-element CCD arrays over parasitic configurations.

Preliminary tests with CCDs using very short sections (10 inches at W4FD and 5.73 inches at W4ATE) promise an improved antenna for underwater submarine communications.

Laboratory-type field intensity studies, as stated above, plotting at a microwave range, mathematical modeling, and computer analysis can unlock further secrets of the CCD principles. Meantime, we radio amateurs are in as unique a position as always, with 300,000 testing sites in this country alone, to again improve man's profoundly important instrument, communications.■