Harry A. Mills W4FD
Box 409 Bullard Route
Dry Branch GA 31020

Gene Brizendine W4ATE
600 Hummingbird Dr. SE
Huntsville AL 35803

The CCD Antenna—Another Look

—theoretical justification and answers to some frequently asked questions

Response to our first article (*73* for October, 1978) describing the high-gain Controlled Current Distribution antenna, has been exciting. Many telephone calls and letters have come from coast to coast, universities, and from out in the Pacific.

Enthusiastic comments and data were volunteered by Professor Arthur Erdman W8VWX of Ohio State University. His experience is quoted with his kind permission:

"My previous 14-MHz inverted dipole was 45 feet from earth at the center, and surrounded by five trees. It was fed with low-loss 300-Ohm twinlead and a tuner, and produced very poor DX results. Then, a CCD was built and substituted for the inverted dipole, at the same height and using the same tuner and feedline. The results are amazing! My DX is summarized:

14-MHz Inverted Dipole

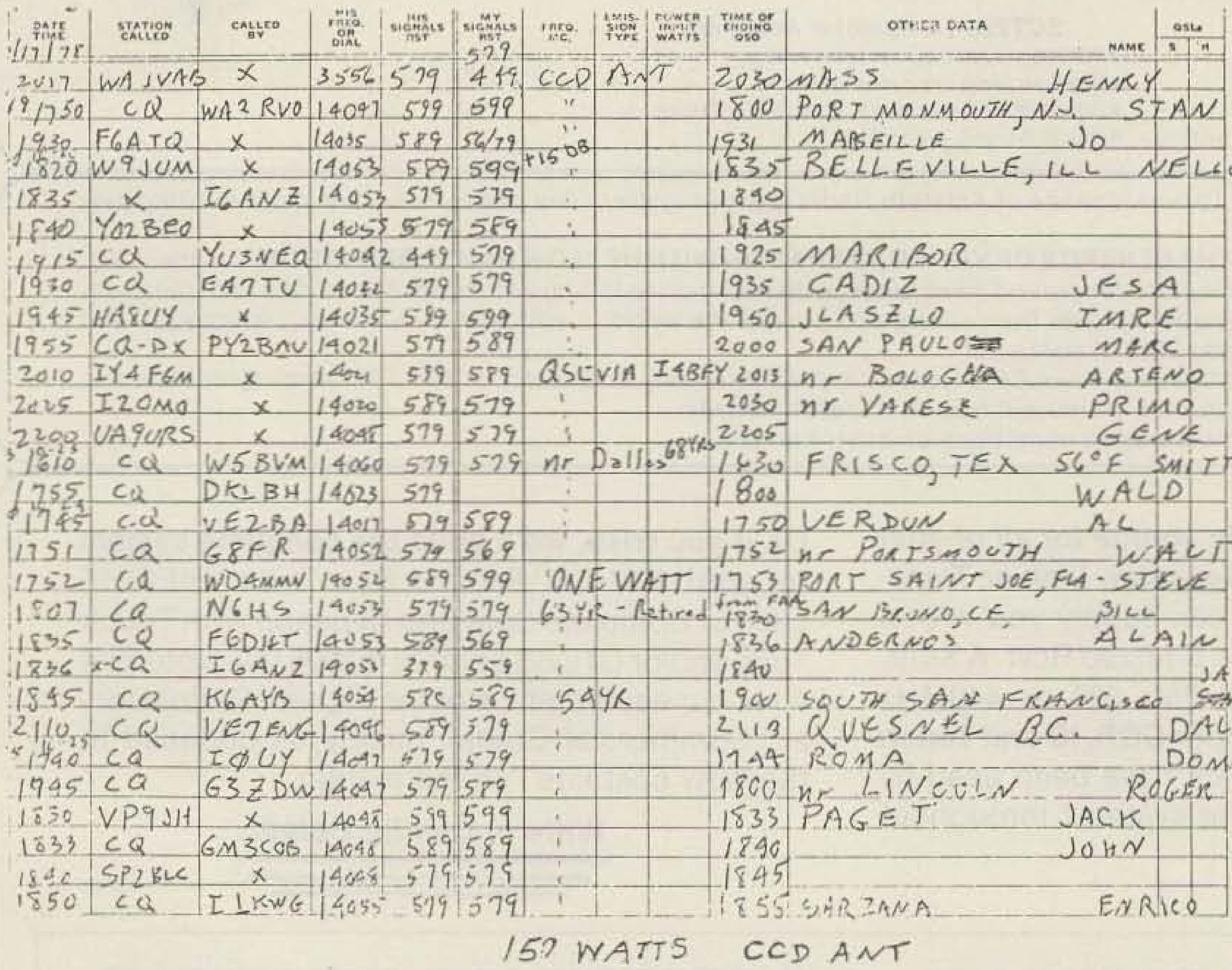
1. Could work *only* the S-9 DX stations—my reports were S-4 to S-5.
2. *Never* any answers to my DX CQs.
3. Last one in a pileup.

14-MHz CCD Antenna

1. Can work DX stations I can scarcely hear!
2. After ordinary CQs, more DX stations answer.
3. Usually 5th to 10th in large pileups!"

The Ohio State University Electrical Engineering Department feels that further research into the CCD principle is definitely justified. Professor Erdman will direct the investigation, utilizing already-written computer programs.

Additional data are presented in this article that will be helpful in constructing and understanding the superior antenna. There also is a section on theory. Finally, the questions most often asked are addressed below, in the order of most concern to those interested in the CCD's advantages.



DATE TIME	STATION CALLED	CALLED BY	HIS FREQ. OR DIAL	HIS SIGNALS RST	MY SIGNALS RST	FREQ. MC.	EMISSION TYPE	POWER INPUT WATTS	TIME OF ENDING QSO	OTHER DATA	NAME	QSL S	QSL R
1/17/78					579								
2017	WA1VAB	X	3556	579	449	CCD	ANT		2030	MASS	HENRY		
19/1750	CQ	WA2RVO	14097	599	599	"			1800	PORT MONMOUTH, N.J.	STAN		
1930	F6ATQ	X	14035	589	56/79	"			1931	MARSEILLE	JO		
1820	W9JUM	X	14053	589	599	+1508 "			1835	BELLEVILLE, ILL	NELSON		
1835	X	I6ANZ	14053	579	579				1840				
1840	YO2BEO	X	14053	579	589	"			1845				
1915	CQ	YU3NEQ	14042	449	579	"			1925	MARIBOR			
1930	CQ	EA7TU	14042	579	579	"			1935	CADIZ	JESA		
1945	HA8UY	X	14035	599	599	"			1950	JLASZLO	IMRE		
1955	CQ-DX	PY2BAU	14021	579	589	"			2000	SAN PAULO	MARC		
2010	IY4FGM	X	1400	579	589	QSL VIA	I4BFY		2015	nr BOLOGNA	ARTENO		
2025	I2OMO	X	14020	589	579	"			2030	nr VARESE	PRIMO		
2200	UA9URS	X	14045	579	579	"			2205		GENE		
18/1610	CQ	W5BVM	14060	579	579	nr Dallas	68YRS		1630	FRISCO, TEX 56°F	SMITTY		
1755	CQ	DK2BH	14023	579		"			1800		WALD		
1745	CQ	VE2BA	14017	579	589	"			1750	VERDUN	AL		
1751	CQ	G8FR	14052	579	569				1752	nr PORTSMOUTH	WALT		
1752	CQ	WD4MMN	14052	589	599	ONE WATT			1753	PORT SAINT JOE, FLA -	STEVE		
1807	CQ	N6HS	14053	579	579	63YR - Retired	from FAA		1830	SAN BRUNO, CF.	BILL		
1835	CQ	F6DKT	14053	589	569	"			1836	ANDERNOS	ALAIN		
1836	X-CQ	I6ANZ	14053	379	559	"			1840				
1845	CQ	K6AYB	14054	57C	589	59YR			1900	SOUTH SAN FRANCISCO	JACK SAN		
2110	CQ	VE7ENG	14096	589	579	"			2113	QUESNEL B.C.	DALE		
1940	CQ	IØUY	14047	579	579	"			1944	ROMA	DOMEN.		
1945	CQ	G3ZDW	14047	579	589	"			1800	nr LINCOLN	ROGER		
1830	VP9JH	X	14048	599	599	"			1833	PAGET	JACK		
1833	CQ	GM3COB	14046	589	589	"			1840		JOHN		
1840	SP2BLC	X	14048	579	579	"			1845				
1850	CQ	I1KWG	14055	579	579	"			1855	SARZANA	ENRICO		

150 WATTS CCD ANT

Fig. 1. A sample log sheet from W8VWX, while using the CCD antenna and 150 Watts input.

Testing

Previous comparisons of CCD antenna performance against a reference dipole at 7 MHz had been cumbersome, due to the sheer distances required to separate test antennas from the Ferris Model 32-B laboratory-type field-intensity measuring instrument. But to construct a valid antenna range for HF antenna measurements becomes a monumental task: building an adequate, level ground plane of suitable dimensions, maintaining constant spacing of test antennas, and clearing of vegetation.

VHF frequencies permit closer control of test conditions, due to both smaller radiators and antenna range dimensions. A Taco/Jerrold Model AIM 719-B laboratory-level field-intensity instrument covering 54 through 900 MHz and calibrated to 1 dB was purchased, and construction of a VHF antenna range was begun.

A section of level land was selected, and vegetation cleared to a radius of 63 feet (approximately 9.2 wavelengths at 144 MHz). Projecting near-future plans to test many CCD beam configurations, a ground plane twenty feet square was constructed, using close-mesh woven wire. A rigid support post for test antennas was mounted at plane-center, with a compass and means for accurately spacing radiators at specific heights above the effective ground.

Two independent power sources were provided: commercial 115-volt and lead-acid storage battery. Operation solely from the battery would quickly reveal any distortion of radiated field patterns which might result from reflections by commercial power feedlines. Also importantly, the more constant battery power would eliminate errors in pattern measurements that could result from commercial power fluctuations.

Five different designs of 2-meter CCD radiators have been used at W4FD to consistently activate repeaters 90 miles away while using one-Watt power. The CCD design selected for the initial range measurements was 7 feet long, made up of 40 sections of ¾-inch OD aluminum tubing, each 2 inches long. (Except: two sections at the feedpoint and also the two at each end are 2½ inches long.) The 38 fixed capacitors connecting these are each 24 pF.

Two identical simple dipoles were constructed of ¾-inch OD aluminum tubing, each 3′¾″ long. One serves as the reference dipole, the other as the field-meter antenna, located 9.2 wavelengths from the test antennas.

For valid comparisons of the CCD versus the reference dipole, the precise adjustment of equal input power to each is most critical, and was greatly facilitated by use of a line-to-antenna impedance-matching system which we call the "trombone match."

Some disturbing variations in field-meter readings were caused by the movement of personnel. By also applying the trombone match, immunity to such movements was achieved, and uniform readings were then possible from any convenient position.

Careful preliminary measurements were first made with power to the range supplied through a 115-volt ac line laid flat on the ground and laborously positioned at 90 degrees to the test antenna during measurement at each 10-degree point around the range. Then the ac source and line was completely removed from the range and replaced by storage battery. The same readings were again taken at each 10 degrees of azimuth for both the CCD and reference dipole test antennas, each mounted in exactly the same position. Absolutely no difference in values was found (the AIM 719-B instrument is easily read to 0.1 dB).

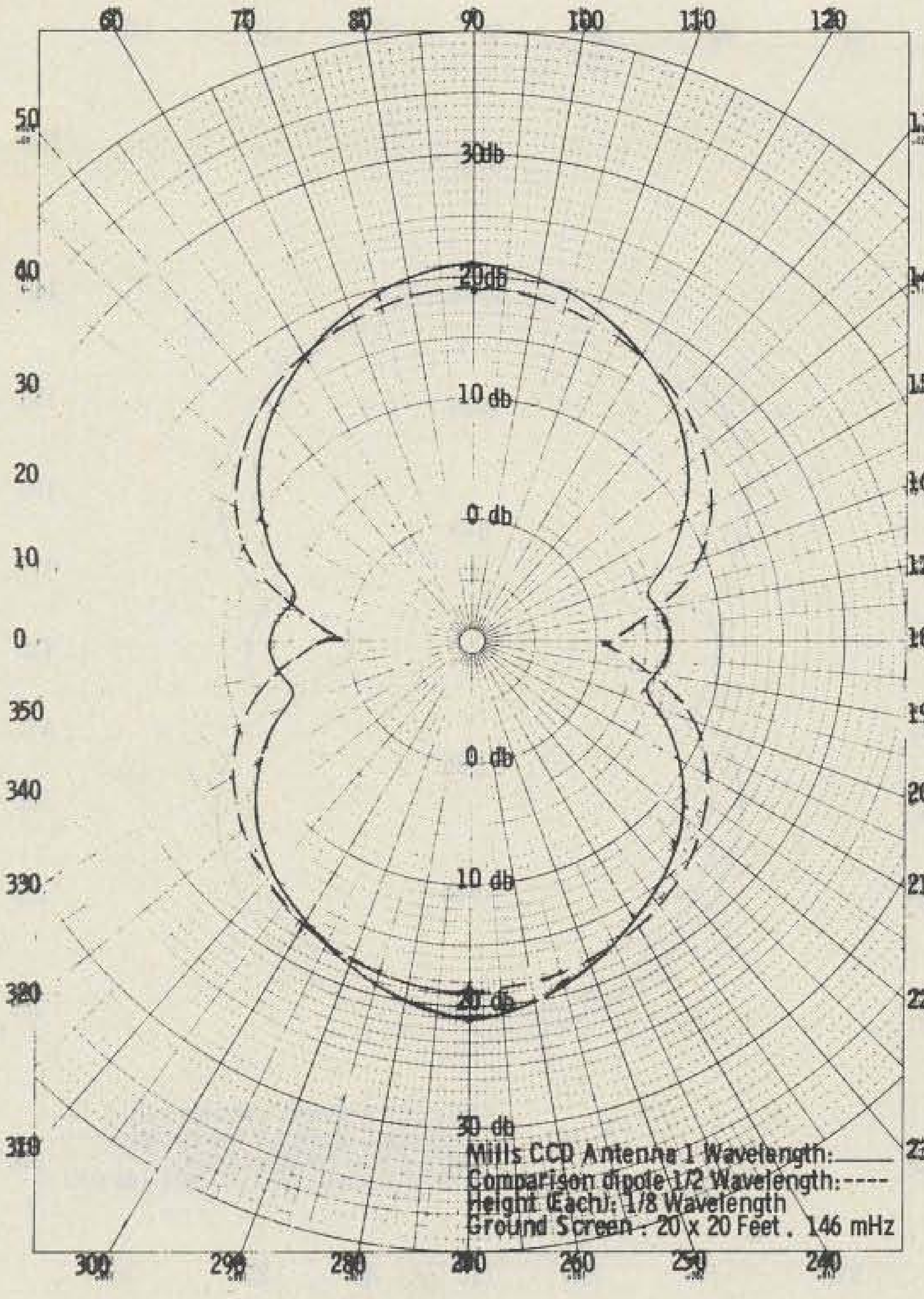


Fig. 2.

As mentioned, the 2m range was fitted with a flat, close-mesh ground plane 20 by 20 feet square, and the new Taco/Jerrold Model AIM 719-B laboratory-level field-intensity instrument, which covers 54 through 900 MHz and is calibrated to 1 dB, was used. In order to eliminate the possibility of pattern distortion by proximity of the transmiting equipment, an excavation underneath the ground plane contained the TS-700 SP 2-meter transceiver and power source.

The new range will be used to make vertical pattern slice measurements at varying angles, equidistant from ground, to reveal the low-angle characteristics which are so vital to DX communications. It also will be used to study the effects of adding capacitive loading discs at the CCD radiator ends, to extend current flow even more to the antenna ends. Following this, measurements will be made of patterns radiated from multi-element CCD arrays, showing the gains and advantages which can be obtained when employing all-driven or parasitic elements. The trombone match will be utilized to provide equal power division to driven array elements.

Some Theory

An antenna is a transducer for coupling rf energy into space. Its function is analogous to that of a loudspeaker and its system of baffling which functions to couple low frequency energy into the air to achieve efficient sound reproduction.

Over many long years, we have become accustomed to regard space as being "empty." This is because early scientists and physicists advanced a medium theory whereby radio and other magnetic energy

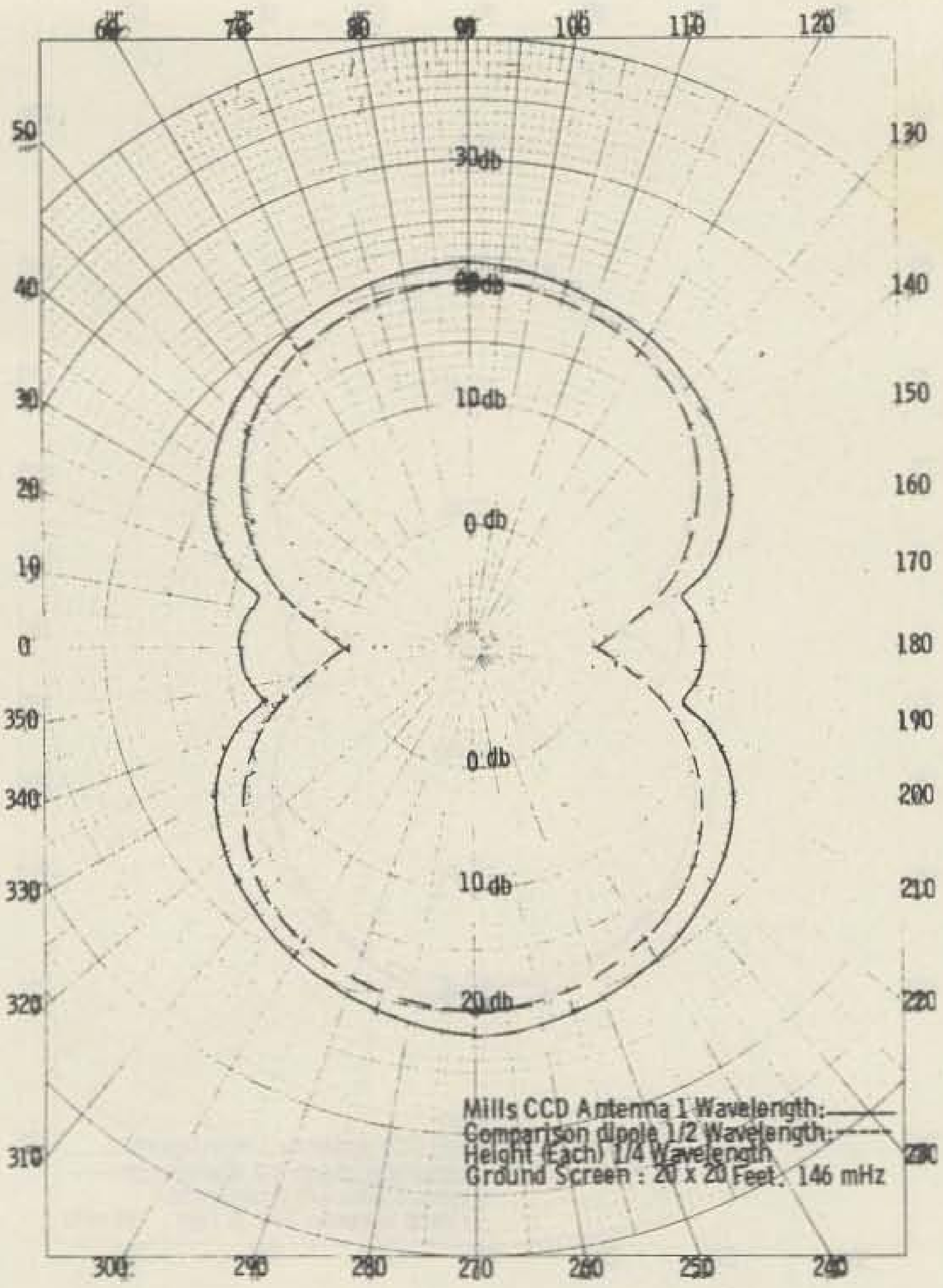


Fig. 3.

fields traveled through the "ether," an unfortunate choice of words, which suggested that propagation was through a medium of gas. That concept has fallen into disuse. However, the vast radiation energies now known to be resident in space provide ample reason fc, keeping an open mind to any new explanation of electromagnetic theory.

We express an opinion that consideration should be given to the theory that light itself, that ever-present photon, may be the medium through which many forms of radiations are propagated through space. Some known facts lending credence to this theory include: 1) Light is known to have definite mass (as does any "solid") a determinant in its velocity which is 186,000 miles per second (the same velocity as other known radiations). 2) Light is "bent" by the presence of intense magnetic fields, as theorized by Dr. Einstein and proven by actual tests. 3) The sun's light rays, interacting with our planet, form ionized radiation around it. 4) Light may be said to be "modulated" by vortical changes in the temperature of the light-emitting body, as sunspots create intense magnetic fields which occasionally disrupt communications as far away as our planet. 5) Stars throughout the universe emit light; even planets may be said to emit photons, although the level is below the detection threshold of human eyesight. (Light is present, even in the darkest cave, only our unaided eyes are not sensitive enough to detect its low level). 6) A photon is a single quantum of electromagnetic energy. Maxwell's equations form the basis of classical electromagnetic theory, but quantum theory requires that we postulate the existence of photons to carry the energy of electromagnetic radiation. Quantum field theory pictures the coulomb forces and magnetic forces between particles as being associated with a kind of photon exchange beween particles. The pressure of sunlight is very small. It has, however, been observed to have a measurable effect on the orbits of earth satellites, particularly on that of the large satellite *Echo I*, launched in 1960.[1]

Questions and Answers

Q. My real estate seems too small for the CCD antenna dimensions given. What are my options?

A. Several space-saving arrangements are possible without reducing CCD efficiency. When mounted as an inverted dipole, much less ground space is required. Also, since the new design is a low-impedance device with greatly reduced high-voltage points, it may be arranged effectively in a zigzag configuration. Another space-saving plan is to mount the middle portion horizontally and allow the ends to hang vertically. This latter scheme will add vertical polarization to the composite pattern, which is beneficial during some propagation conditions. When antennas for different bands are desired but space is limited, they may be efficiently fed by a single feedline. The low-Z property of the CCD renders it very tolerant to nearby trees and structures, with much less detuning and losses than is experienced with a conventional dipole. This factor reduces the space requirements, and, surprisingly, a CCD radiator performs very well on DX when only 7 feet above ground. So, the importance of tall supporting towers is greatly reduced and most city lots will accommodate 14-MHz and higher frequency CCD antennas which will rival a rotary beam in performance.

Q. Why is one full wavelength at the lowest operating frequency used instead of some shorter length?

A. At approximately one physical wavelength, a desirable condition such as cancellation or near-cancellation of the wire section inductive reactance by the capacitive reactance of the next adjoining capacitor in the series chain results. Also, a great reduction of end effects occurs when the overall radiating system is made resonant. Reflections from the radiator ends are markedly reduced, so that a traveling wave may move efficiently from the transmission line and the radiator into space.

Q. I have a number of capacitors on hand other than the values specified in the guidelines table. May these be used efficiently in a CCD antenna?

A. Yes, definitely. It is necessary only to adjust section wire lengths and the number of sections 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, finding K for 7 MHz from Table 1 in original article: 470 pF/8.48 = 56. Overall antenna length (from Table 1) is 140 feet or 1680 inches.

Next, find the length of each wire section: 1680/56 = 30 inches. The number of capacitors is always 2 less than the number of wire sections; 54 in this example.

Q. How many capacitors are necessary in the CCD, and should they have a high-voltage rating?

A. There is no set number of capacitors required. Within practical reason, the larger the number of capacitors used, the more uniform the current distribution and the more effective the radiator. In general, 40 to 60 fixed capacitors will provide very effective current smoothing throughout the antenna. (Upward of 1,000 capacitors have been successfully employed at W4ATE.)

Best broadside gain results when all capacitors are of equal capacitance. When as many as 40 capacitors are connected in series with wire sections of the CCD radiator, the rf voltage applied across each individual capacitor is quite small (typically under 80 volts, even with 1 kW input to the final amplifier). This permits the use of conventional-sized polycarbonate (most stable), polystyrene (lightest weight), silvered mica, mica, dipped mylar®, and other low-loss capacitors. The capacitance tolerance should be within 5%, which narrows the off-the-shelf choice to the first three types named. Wider tolerance capacitors may be used provided that they are selected by accurate measurement to the 5% tolerance required. Any units selected should have substantially strong wire leads or terminals.

Q. What type of antenna will perform best inside a building or attic (assuming no metallic Faraday shielding is present)?

A. Definitely, the CCD type of radiator. It should be remembered that the high-voltage, high-impedance characteristics that exist over the large outer portion (away from the center) of the conventional dipole produce high dielectric loss in the radiator even though the walls, ceiling, and roof are of dry wood and shingles. Therefore, design your antenna as a current-operated device free from points of high voltage throughout, and the dielectric losses from the surroundings will be greatly reduced. W4FD had these advantages amply demonstrated while working DX with attic CCD antennas on 10, 15, and 20 meters under the previous call W3UZ, in Washington, DC.

The increasing trend toward condominium and apartment living with their restrictions against outdoor antennas, presents another application where an indoor CCD will provide performance which is much superior to the conventional indoor dipole. Even where outdoor antennas are employed, very little dielectric loss will occur when the CCD antenna is strung through trees or shrubbery.

Q. Why does the CCD antenna produce good signals and provide good DX reception at heights of only six to eight feet (albeit down about 10 dB from one elevated to ½ wavelength) whereas a simple dipole at the same low level usually does not?

A. This is a question for which all the answers are not yet formulated. However, it is believed that there are several reasons for the improved performance of the CCD at very low elevations. First, it is known that low-angle radiation (the requirement for DX) occurs in the center, highest-current portion of the conventional dipole, and for the simple horizontal dipole at low heights, the radiation resistance is known to drop off very rapidly, nullifying most if not all of the low-angle radiation. Not only is the dipole then coupled closely to its ground "image" but the "hot spotting" center current produces excessive ground losses, as does the dielectric end effect. That energy which would have been reflected at least partially at lower angles (assuming a ½-wavelength height) is sporadically reflected at higher angles, chiefly useful for close-in communications.

In sharp contrast, the low-mounted CCD antenna

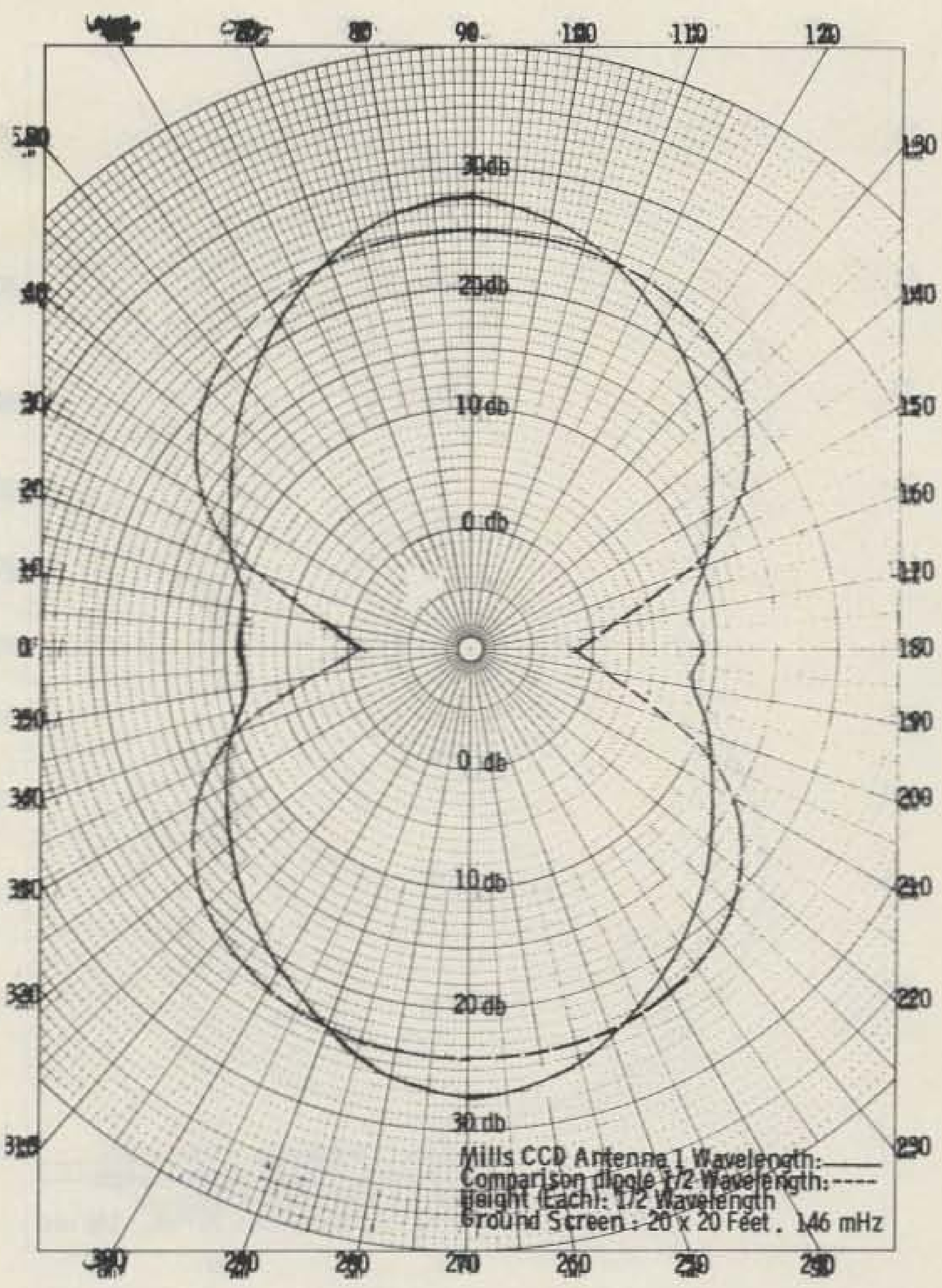


Fig. 4.

stretches out the antenna current to the very ends of the radiator (when end-loading capacity-producing discs are added). Now the antenna current is no longer bunched at the center portion, but tends to produce a focus or aggregation of lower-angle currents across the radiator. When the CCD is mounted at widely varying heights, the center feedpoint impedance variation is only a fraction of the excursions produced when the height of a simple dipole is changed the same amount.

During actual tests, DX beyond three or four thousand miles has been worked with the CCD antenna lying flat on the ground, although the reported level is then down 20 to 30 dB. Field Day hams take note!

Q. How does the bandwidth of the CCD antenna compare with the conventional dipole bandwidth?

A. A CCD antenna which contains near or equal capacitance values and wire section lengths has a three to four times wider bandwidth than the usual dipole counterpart. Extremely wide bandwidths have been attained (at some sacrifice in gain) when the capacitor values and radiator section lengths are made progressively smaller, beginning at the feedpoint and with the smallest values at the radiator ends. This form of CCD results in a reflection-free radiator with waves *traveling* in only one direction from the feedline, through the antenna and into space, *without* standing waves. Measurements show that voltage and current disappear at the antenna ends. This configuration has produced a UHF radiator that is matched across 340 to 550 MHz.[2]

Q. What are the antenna resistance (load impedance) characteristics of the CCD antenna?

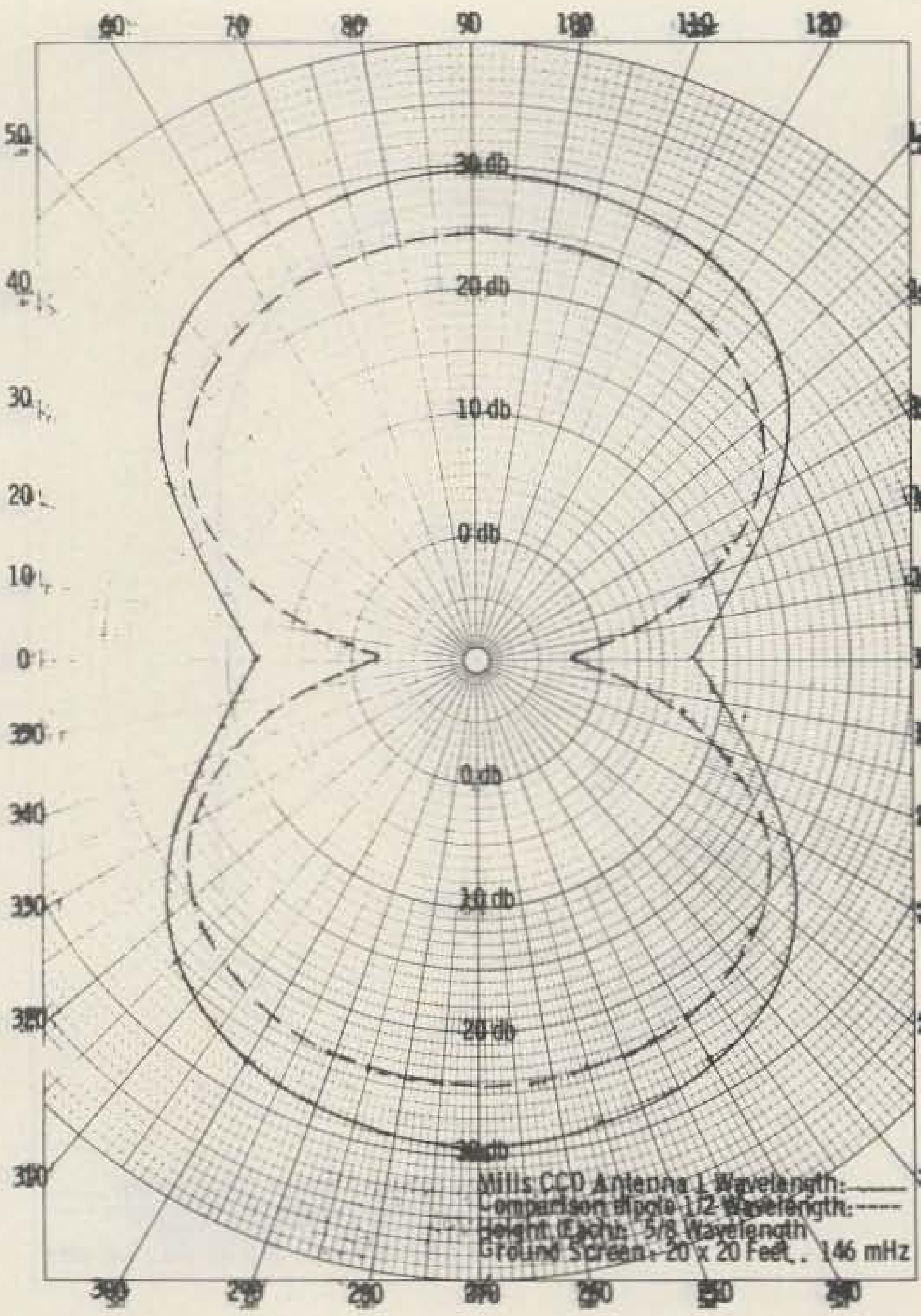


Fig. 5.

A. The load impedance of a conventional horizontal dipole (antenna resistance at resonance) may vary as much as 10 times or more, with wide variations in antenna height. The controlled-current distribution antenna resistance change is only a fraction of this for the same variations in height. Indeed, the main determinant of the antenna resistance will be the design selection of the wire section lengths and capacity values, together with any loading screens employed at the radiator ends. With capacitor and wire section values within the ranges covered by the formula, antenna resistance values around 250 Ohms may be expected.

Thus, 300-to-450-Ohm, open-wire balanced line used with a transmatch will work well with very long transmission line lengths. For shorter lines, 50-to-73-Ohm coaxial line with a 4-to-1 balun at the antenna terminals works quite well. The very high ratio of radiation resistance to loss resistance and the greater aperture of the CCD produce a much greater signal than can be realized with the conventional dipole design.

Q. How effective is a 160-meter horizontally-polarized CCD antenna, both as a nighttime skywave radiator and a ground-wave daytime antenna?

A. The results from testing the 160-meter CCD under these conditions will agreeably surprise many readers. Nighttime performance was as good or better than with the best of conventional antennas. Our mutual friend John Sharpe W5AB at Houston, Texas, is broadside on the southwest lobe of the W4FD 160-meter CCD, and reported both CW and SSB signals were never below S9. He further reported that 90% of the time the signal was 20 to 25 dB over S9. Contacts were made on two different nights on 1808 kHz, with the same reports. The power input was 100 Watts to the Swan 160X equipment. Daytime coverage has been 80 to 100 miles with the same input power.

Q. Is there a value of radiation resistance in Ohms which, if maintained, will produce optimum radiating efficiency?

A. This question has been of great interest to us for some time. Although no firm answer has yet been formulated, there are indications suggesting such a possibility. The following is intended to arouse interest among members of the amateur fraternity, to encourage experimentation along these lines.

Assuming that light may indeed be the medium in which signals are propagated through space and that the intrinsic impedance of space itself is 377 Ohms, would a continuous radiation resistance of 377 Ohms (or even crossing through this impedance value many times), produce optimum coupling efficiency to the radiator? This is a most intriguing question.

The radiation resistance of the simple dipole sweeps through 377 Ohms only twice. It occurs a number of times in the collinear antenna and even more in the rhombic. Each type of antenna produces an ascendingly improved efficiency. The CCD antenna produces scores of sweeps through 377 Ohms. Aside from any theoretical considerations, tests with the multi-section CCD suggest that there may be some optimum (if continuously maintained) radiation resistance such as 377 Ohms.

Q. How may I determine that capacitors out to the very end of my CCD antenna are all functioning?

A. In a properly constructed CCD (wire lengths and capacitors correct according to formula), defective capacitors will be revealed by exploring the radiator with any simple voltage or current indicator while *low* power is applied. The indicator may be a hand-held neon or fluorescent lamp, a miniature dipole feeding a solid-state diode and sensitive dc current meter, or a dip meter in the diode mode. Starting at the feed point, be sure that an indication of rf is present while the indicator is moved out to the extreme end of each half of the CCD. If a point is reached where no indication is obtained, the last capacitor passed over may be defective. If, however, an rf indication is lost at *both* ends of the antenna and at approximately the same distance from the feedpoint, the wire section lengths may be shorter or the capacitors may be larger than specified by the formula. Both values should be carefully verified.

Also, it is possible that one is attempting to operate the CCD below its resonant frequency, in which case it functions as a high-pass filter, preventing rf from traveling beyond a few sections from the feedpoint.

To explore this possibility, temporarily feed twice the design frequency, i.e., 14 MHz to a 7-MHz CCD, and repeat the preceding rf probing tests. If indications of rf are then obtained out to the radiator ends, the capacitors are functioning, and steps must be taken to resonate the CCD to a frequency near the low-frequency end of the design band, as described earlier.

Wire sections which are shorter than specified by formula will prevent rf from reaching the antenna ends because the X_C will be much larger than the X_L. Also, when wire sections which are too short are used, one may continue to add any number of sections and never achieve resonance! This can be very baffling and discouraging until the importance of making X_L approximately equal to X_C is realized.

Q. Will you please furnish the calls of some successful builders of the CCD antenna so that I might contact them and profit from their experiences?

A. Yes; we believe that the following constructors will willingly share their ideas regarding the CCD when you furnish an SASE:

K2GGN, W2IMU, W2SVJ, W4DNX, W4KIX, W4OQT, W4KXC, W8VWX, WD4DSX, AC5P, K8AA, AA6US, WB8RGN, and KK4X.

Q. Can the CCD antenna be operated at harmonics of the fundamental frequency?

A. Yes. But please note that the positive inductive reactance, X_L, and the negative capacitive reactance, X_C, move in diametrically opposite directions, when the exciting frequency is changed, to a series circuit such as the CCD. Therefore, harmonics as we are accustomed to regard them, will *never* occur close to whole number multiples. For example, in a reasonably well-balanced chain of alternate wires and capacitors in series, with fundamental resonance at 14 MHz, a second "harmonic" indication at average antenna height occurs at slightly over 1.6 times the fundamental frequency.

These relationships between fundamental and "harmonic" frequencies in a typical, balanced CCD are shown graphically in Fig. 1 of our previous article. In another example (from the same graph), in order to produce a second harmonic near 28 MHz, a CCD radiator would necessarily have a fundamental resonance near 17 MHz. In a futuristic example, the harmonic of a CCD designed for the new 18-MHz band falls neatly near 28.9 MHz!

Actually, this offbeat harmonic relationship provides a great advantage in practical operation. Instead of the wide swings in load impedance experienced with a conventional dipole when changing from even to odd harmonics, the CCD user employing a transmatch will find relatively small changes in loading. Moreover, the effects of improved current distribution and smoothing out of the broadside radiation field pattern will carry over to the second and third frequency multiples.

Q. Is there a simple formula or formulas which I may use in a step-by-step manner to calculate with reasonable accuracy, the design parameters for a CCD operating at any frequency within the HF bands?

A. Definitely yes.

Formula 1. $S-2 = fC/59.35$, where $S-2$ = number of capacitors, S = number of wire sections, and f = resonant frequency in megahertz. (Note: 59.35 is an empirically derived constant.)

Formula 2. $L_T = 984/f \times 12$, where L_T = total length in inches (for 1 wavelength) and f = resonant frequency in megahertz. 984 is double the usual 492 because the CCD is one wavelength overall.

Formula 3. $L_S = L_T/S$, where L_S = length of sections in inches, S = number of wire sections (from Formula 1), and L_T = total length in inches (for one wavelength).

These three simple formulas can be combined in a single comprehensive formula. However, it has been found that less confusion results when specific parameter values are determined by using the formulas in the above order. A sample calculation is contained in the answer to the following question.

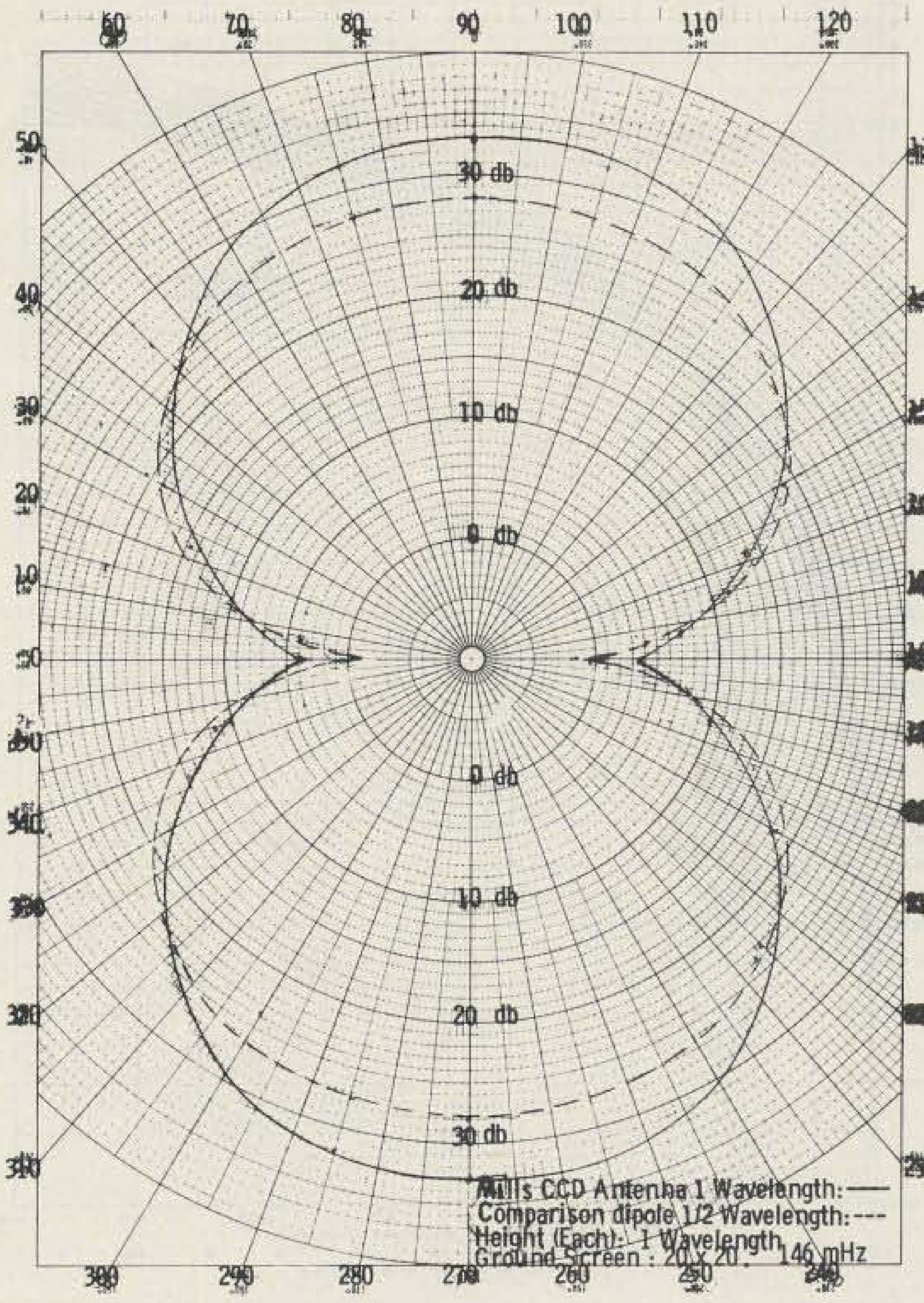


Fig. 6.

Q. I have on hand 50 fixed mica capacitors, each 390 pF in value. Do I have enough of them to construct a 7-MHz CCD antenna, assuming that I have a sufficient amount of #14 copper wire? *How do I determine all antenna dimensions?*

A. Applying Formula 1: $S-2 = (7\ \text{MHz} \times 390\ \text{pF})/59.5 = 46$ capacitors. Then, $S = 46+2 = 48$ wire sections.

Applying Formula 2: $L_T = (984/7\ \text{MHz}) \times 12 = 1686.85$ inches overall length.

Applying Formula 3: $L_S = 1686.85/48 = 35.14$ inches, the length of the sections.

In summation, we have 46 fixed capacitors, each 390 pF, 48 wire sections, each 35 inches long, and a total CCD antenna length of 1686.8″ or 140.57 feet.

Wire sizes 18, 16, and 14 all have a sufficiently small length-to-diameter ratio when utilized at the 7-MHz operating frequency.

Q. Can the CCD antenna be operated effectively on frequencies either above or below its resonant frequency?

A. It should be recognized at the outset that this type of radiator is a very broad characteristic type of high-pass filter. It will perform well at all frequencies above its resonant point, but should not be used on amateur bands whose frequencies fall *below* resonance. The broadband nature of this antenna is such that it will operate most efficiently on the lowest frequency band for which it is designed, even in instances where resonance occurs at or near the high frequency end of a band. It is most desirable that the CCD be made resonant within the

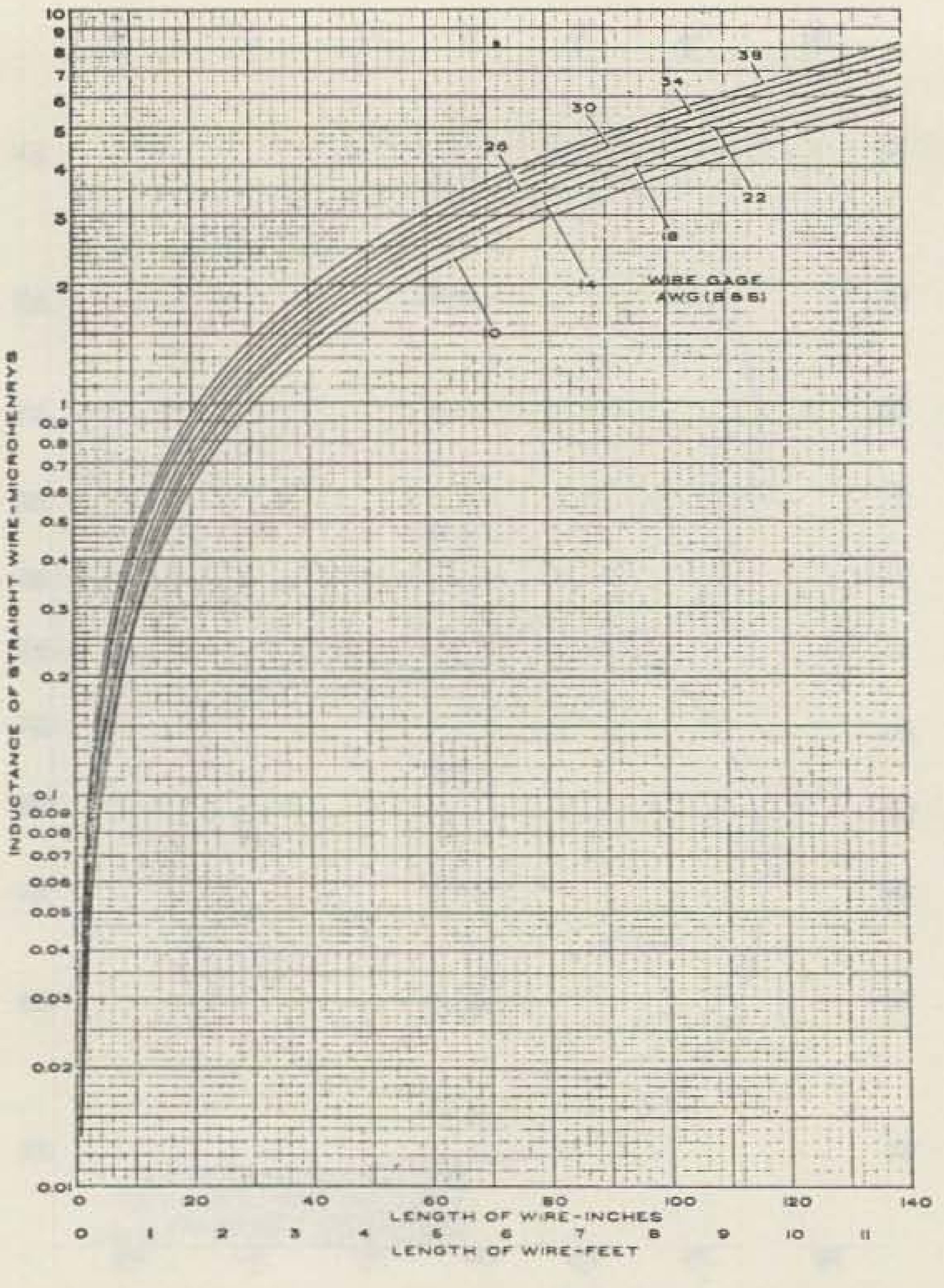


Fig. 7. Graph for determining the self-inductance of straight lengths of wire.

lower frequency half of the band.

Q. What effect does height-above-ground have on the radiated pattern of the CCD antenna?

A. Although complete pattern data has not yet been obtained and analyzed, preliminary measurements made with a commercial field-intensity instrument at the 2-meter range indicate that the sharper pattern lobes occur when the CCD is elevated 1/2λ or higher. At heights of 5/8λ and above, side levels (off the radiator ends) are 22 to 24 dB below the broadside lobes. Dropping the height from 1/2λ to 1/8λ gradually collapses the major broadside lobes. At the 1/4λ height, the broadside-to-side radiation differs by slightly more than 12 dB. At 1/8λ elevation, the difference is even less. See Figs. 2 through 6 for various elevations.

It is interesting to note that the off-end radiation begins to increase markedly below 1/4λ height, and can become almost equal to the broadside value as the elevation is reduced below 1/8λ.

These preliminary measurements were made with both the test antennas and the field-intensity instrument antennas horizontal to flat ground, well in the clear and at the same height. The probing point was 5λ away. A groundplane screen had been installed at this time.

The test CCD antenna was rotated through 360 degrees and field-intensity readings were taken at each 15-degree interval between full broadside and 30 degrees. Between 30 and 0 degrees, readings were recorded at each 7.5 degree point. Directly off the CCD ends, minor lobes were noted which were approximately 1 dB above the minimum skirt levels of the side radiation. A power input of 1 Watt at 146 MHz was used during all pattern measurements.

Q. What are the advantages gained by the use of capacity-loading disc screens at the ends of a CCD radiator?

A. Although the use of loading discs is not essential to efficient operation of the CCD, some of the valuable refinements are increased radiation resistance, improved broadbanding, improved current distribution, almost complete elimination of end effects, and final adjustment of resonant frequency.

In particular, more current will then flow in the very ends, resulting in a more efficient radiator. Wire screens are recommended over solid discs, for reduced wind resistance. For the 7-MHz band, 16-inch diameter discs are suitable, the diameter increasing in inverse proportion to frequency, for other bands.

The constructor will find that the added discs cause a slight lowering of the antenna's resonant frequency. By adding the discs one at a time and noting a slight frequency decrease with each addition, a positive indication is obtained that all sections are functioning.

A CCD is installed as an inverted dipole at W4ATE, where it is found convenient to replace the discs with small fixed capacitors soldered between the radiator ends and the supporting wire, which is grounded. The desired value of capacitor may be determined by the temporary use of two variable capacitors which may be adjusted for proper operation and then replaced with fixed capacitors.

When loading discs are not employed, it is suggested that the two outer wire sections be dimensioned about 50% longer than the others.

Q. Is there a method whereby a directional array of multi-elements can be optimally adjusted at a particular frequency, or even changed to another band within a few minutes without conflicting reactions?

A. Definitely, yes, where the CCD antenna system is utilized in directional arrays. The method involves a full tuneup of all the radiating elements (CCD or conventional) directly from the operating position, with a simple means for power division to the individual elements. The scheme eliminates the troublesome common-point junction bottleneck and uses an inexpensive tube or solid-state amplifier feeding each antenna element to permit rapid system tuning without interaction problems, which many amateurs already recognize with conventional systems.

Q. Is there a method, particularly adaptable to solid-state linear amplifiers and to transmatch tuners, whereby the conventional, cumbersome wide-spaced tuning capacitors can be eliminated from tank, and the open-end or toroidal coils be henceforth ferrite-loaded and five or six amateur band tanks placed in the area now occupied by one tank?

A. Fortunately, yes. The method involves a controlled-voltage distribution (CVD) system, a blood brother of the CCD scheme developed at the same time. The basic plan is very much like the CCD in that capacitive loading is utilized.

Q. Although my CCD antenna usually produces a stronger signal than my reference test antenna, there are times when my reference antenna produces the stronger signal. Why is this?

A. It is well known that

under certain conditions of sunspot activity and other circumstances in which the Earth's field-ionization pattern is altered (as caused by the sun's activity), the usual ionized layers existent at a particular time of day can become greatly changed. Signals normally bent to Earth by the reflecting action of one or more ionized layers may, because of alterations in the usual layer heights and thickness, be reflected to a higher or lower angle than usual.

Since the CCD antenna is known to produce a considerably lower reflection angle, any circumstance which changes the reflection angle from the ionized layer(s) at which the antenna maximizes, will necessarily produce a weaker signal. Many amateurs who use both horizontal and vertical radiators often find that one or the other polarization produces a stronger signal. Since the CCD antenna's radiation angle can be even lower than that produced by either of the aforementioned conventional antennas, it not only becomes a very helpful third form of advantage, but, on occasion, can receive signals otherwise not even detected. Also, several observers have noted that under most circumstances the CCD antenna will produce the least signal fading.

Q. How may I determine the inductive reactance of straight-wire sections, for further experimental study?

A. This information does not appear in standard wire tables, but may be derived after the inductance value is calculated according to the formula $L = l(2\log 4l/d - 3/2)10^{-3}$, where L = self-inductance, l = length of wire in centimeters, and d = diameter of wire in centimeters. However, the design chart in Fig. 7 more readily provides the self-inductance values of various copper or aluminum wire sizes useful for CCD antenna construction.

For example, to find the inductive reactance at 7 MHz of a piece of #14 copper wire which is 35 inches long, first locate 35 inches along the bottom of the chart. Trace directly up to the curve for #14 wire. From that point, go to the left edge of the chart and read approximately 1.33 μH.

Last, insert this value into the usual formula, $X_L = 2\pi fL$, where f is frequency in MHz and L is inductance in microhenrys:
$X_L = (6.2832)(7)(1.33) = 58.4$ Ohms.

Q. Can a CCD dipole be used as a basic element or building block for more complex arrays?

A. Yes. The CCD principle may be employed in most existing systems and configurations with improved efficiency. The resulting radiation patterns will be different from those with conventional arrays.

Final Remarks

We are grateful for the enthusiasm and suggestions of commercial antenna engineers and many amateurs who have phoned or written: Frank K8AA, for comparison tests with 7-MHz European stations, using less than one-Watt input to his CCD, Ben W5TM, for suggesting static protection resistors across the phasing capacitors, the encouraging notes of Dick W2IMU and Art W8VWX, and for useful construction ideas from the imaginative mind of Larry AA6US.

Larry's experience is typical of CCD builders: "Out here in Los Angeles, I suffer from the "copper curtain" syndrome. California kilowatts wipe out fellows using 100-200 Watts like myself. Oh, we can rag chew with ZLs across the Pacific, but spanning the long overland haul to Europe was unheard of for me. But last night on 14 MHz, I was reading a TA2 in Turkey and G3 stations on the inverted-dipole, 7-MHz CCD antenna. I could not hear them at all on either my 14-MHz dipole or a 130-foot, all-band doublet up 60 feet. Also, when using the CCD my signal reports are usually two S-units above my tried and true 7-MHz double-extended Zepp."■

References

1. Shortley and Williams, *Principles of College Physics*, Prentice-Hall, Englewood Cliffs NJ, 1967, pp. 593, 833, and 858.
2. Hallen, *Electromagnetic Theory*, Chapman & Hall, also Wiley & Sons, New York, 1962, pp. 501-504.

Fig. 8. CCD antenna design chart for a 1-wavelength element. Use curve 1 for wire-section length, and use curve 2 for number of wire sections and capacitor value. The number of capacitors is two less than the number of sections. (Curves derived at 7 MHz.)

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