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Rotary Beam for 10 or 15: the LB-2

—eliminates nasty matching problems

My first rotary-beam antenna was a two-element, 10-meter "signal squirter" manufactured by the late M.P. Mims W5BDB. During the forty-odd years since then, I have owned many beam antennas, some homemade and some factory-made. Most of my homemade arrays used the gamma-matching system, and I always had problems during the rainy season when moisture collected on the variable capacitor plates. Another problem with both the commercial and homemade arrays was noisy reception, thought to be due to corroded electrical connections after the antenna had been on the tower for several months.

About a year ago, I began experimenting with the design of an "ultimate" antenna—one which would stand up under all kinds of weather conditions and remain in adjustment for long periods of time. At the same time, I carried out a number of experiments aimed at reducing the high noise-level problems on the 15- and 10-meter bands. The end result is the LB-2 array described here. Two of these antennas have been built—one for 15 meters and another for 10 meters. Except for size, the characteristics of the two antennas are identical and the performance of each leaves little to be desired. Although both antennas will be covered, the 15-meter array will be described in more detail.

Design Frequency (In MHz)	Radiator	Director	Spacing	Stub
21.1	Notes 1, 2	21' 4"	5' 1¼"	49"
21.3	Notes 1, 2	21' 1½"	5' 1"	48"
21.4	Notes 1, 2	21' ¾"	5' ¾"	47"
28.2	Notes 1, 3	15' 11½"	3' 10"	37"
28.6	Notes 1, 3	15' 8¾"	3' 9½"	36"
29.5	Notes 1, 3	15' 3"	3' 8"	35"

Notes

1. Radiator length will be determined by resonating and matching adjustments.
2. For 15 meters, start with a radiator (driven element) length of 22' 7" and adjust as required. See text.
3. For 10 meters, start with a radiator length of 17' and adjust as required. See text.
4. Stub dimensions are measured down the stub from the antenna end. These dimensions were taken from the prototype antennas after final adjustments were made. Actual position of shorting bar will depend upon the length of the radiator, since each interacts upon the other. Dimensions apply only to stubs made from ½" tubes spaced 3" on centers (300 Ohms Z_0).

Table 1.

Design

Why a two-element array? In the first place, I am retired and disabled and my budget is limited. Second, because of trees surrounding the ham shack, I am limited also in space. A long-boom, multi-element yagi was simply out of the question. Third, I wanted a low-cost, lightweight antenna that could be built from materials readily available at the local hardware or do-it-yourself builder's supply store, and one which could be turned by a heavy-duty TV antenna rotator. When properly designed and adjusted, the two-element parasitic array, consisting of a driven element and one parasitic director spaced 0.11 wavelengths apart, produces the highest forward gain per unit size of any type of antenna used by amateurs. The antenna described here is spaced for maximum forward gain—about 5.3 dB greater than the signal from a half-wave dipole at the same height above ground. When adjusted for maximum forward gain, the front-to-back ratio of the array is only about 7 to 10 dB.

If you wish a greater front-to-back ratio, adjust the spacing to about 0.125 to 0.150 wavelengths. Although the front-to-back ratio improves with wider spacing between the elements, the forward gain goes down to about 5.0 dB over the dipole. Nevertheless, a 5.0-dB gain will give a considerable boost to your signal on either 10 or 15 meters when it is compared with the signal from a dipole or quarter-wave vertical antenna. When the array is adjusted for the maximum front-to-back ratio, the discrimination between signals off the front and back of the array will be in the order of 15 to 17 dB.

Matching

In addition to the features listed above, I wanted a matching system that would be easy to adjust and one that would remain in adjustment for long periods of time, unaffected by the weather. After much searching and reading, I finally found a description of a "line bazooka" (balun) matching device in the Collins military technical manual, *Fundamentals of SSB*, published in 1959. A similar device was described by William I. Orr W6SAI, in the 19th edition of the *Radio Handbook*, published by Howard W. Sams & Co. This device first attracted my attention as a means of getting rid of the troublesome gamma capacitor. However, it has several other desirable characteristics, as well. As it is a shorted stub less than a quarter wavelength long, it acts as an inductance and introduces an X_L component at the driven element feedpoint. The driven element itself is adjusted to introduce an X_C component across the open end of the stub. The two reactive components tend to oppose each other as the operating frequency is made higher or lower than the array design frequency, producing a broadband effect.

In the array described here, when adjusted for a line swr of 1:1 at 21.3 MHz, the line swr was still less than 1.75:1 at either 21.0 or 21.450 MHz. If you have read about line bazookas in the handbooks, you may get the wrong impression of this device. The quarter-wavelength bazooka is used as a 1 to 1 impedance transfer device. The short line bazooka matches a coaxial line input to the approximately 18 Ohms of impedance at the center of the driven element. It also acts as a balun, since the 53-Ohm input is unbalanced (coaxial line) and the output is 18 Ohms balanced. It also acts as a decoupling device to prevent rf currents from flowing on the outside of the 53-Ohm coaxial transmission line from the antenna to the transmitter. The impedance-transfer ratio of the device, unbalanced to balanced, and its broadbanding effect depend upon the Z_0 of the stub, which, in turn, depends upon the center-to-center spacing between the two ½-inch copper tubes and the position of the shorting bar across the two conductors.

I spent much time experimenting with the size, length, and spacing of the two copper tubes that make up the matching section before the optimum dimensions were found. If the tubes are spaced too closely, the bandwidth will be narrow; if they are spaced too wide apart, the coaxial inner-conductor loop at the open end of the stub begins to exhibit inductive effects in the circuit. The surge impedance of the two ½-inch tubes, spaced 3.0 inches on centers, is about 300 Ohms. If the reader constructs the matching section exactly as described here, he will have no difficulty in making the proper matching adjustments. The most important consideration is to mount the two tubes rigidly so that the same spacing is maintained throughout their parallel lengths. To start, each tube was made 53 inches long. In this array, at the final adjustment at 21.3 MHz, the distance from the open end of the stub at the antenna feedpoint to the position of the shorting bar was 49 inches. After it was made certain that this was the correct dimension with the antenna on the tower, the shorting bar was soldered in place and the unused end of the single tube was cut off. The other tube, however, was left 53 inches long and was fitted with an SO-239 coaxial connector as shown in Fig. 2. The construction and adjustment of the matching stub will be covered later. At this time, let us discuss the construction of the boom and elements.

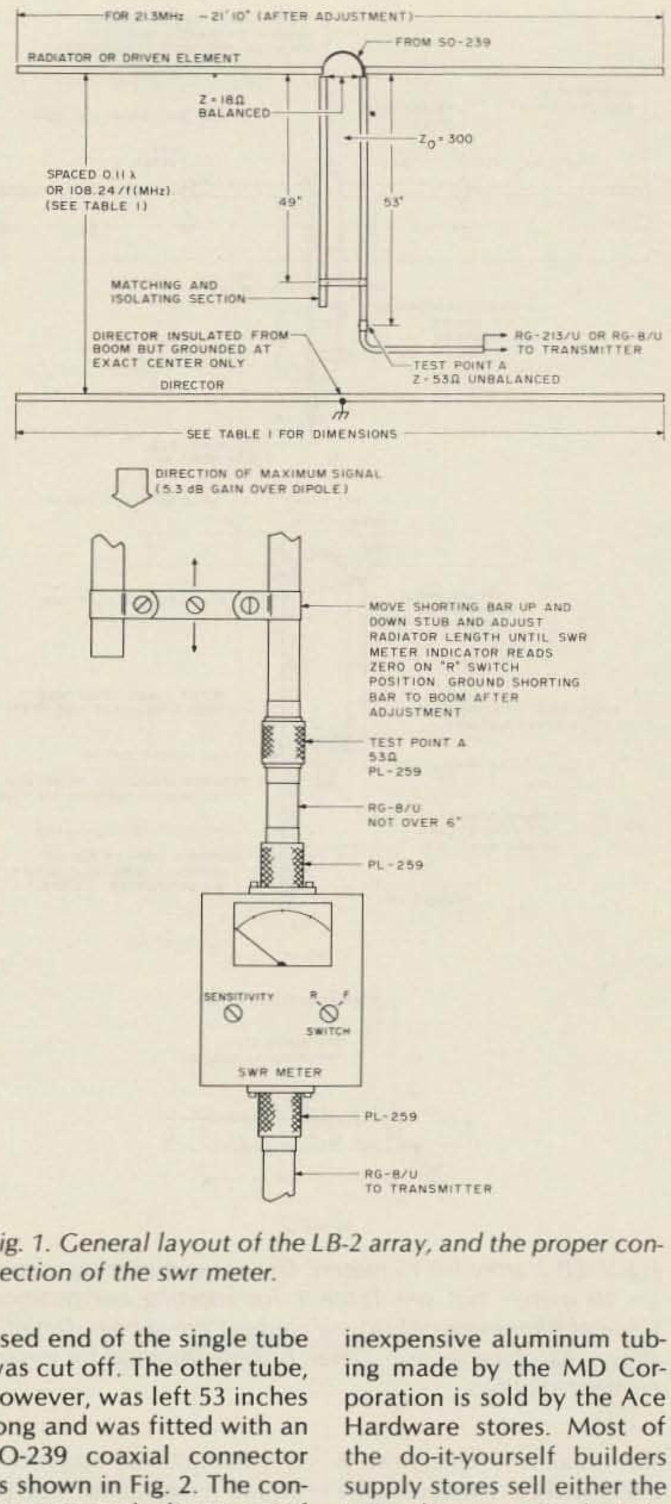

Fig. 1. General layout of the LB-2 array, and the proper connection of the swr meter.

Elements and Boom Construction

The first step is to locate and select the proper size aluminum tubing for the elements and the boom. In California and other states, lightweight and relatively inexpensive aluminum tubing made by the MD Corporation is sold by the Ace Hardware stores. Most of the do-it-yourself builders supply stores sell either the MD tubing or a similar tubing made by Reynolds Aluminum Corporation. This "hobby" tubing comes in either 6- or 8-foot lengths and in various diameters. Although I have seen on display only 1, 7/8, 3/4, 1/2, and 3/8-inch o.d., and 0.055-inch wall thickness tubing in the 6- and 8-foot lengths, I am informed that the Ace Hardware stores will order other sizes made by MD. For telescoping elements,

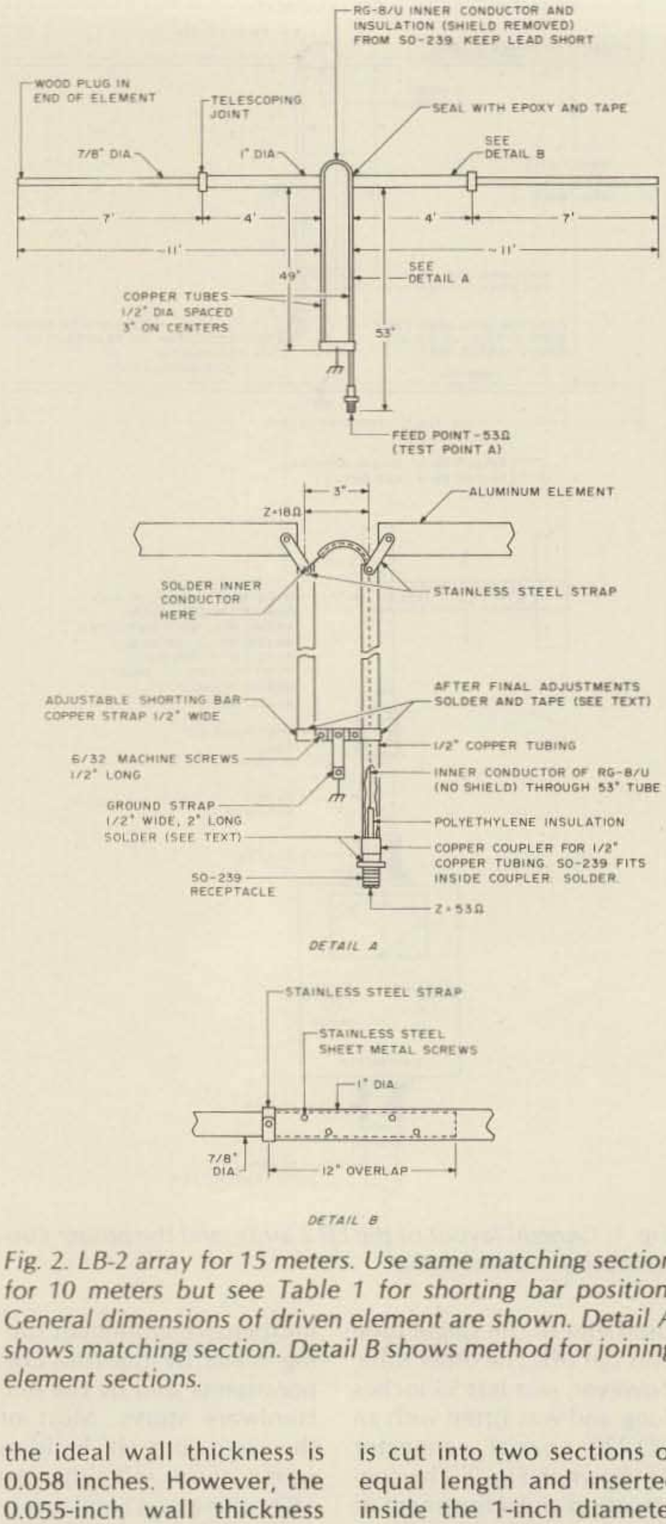

Fig. 2. LB-2 array for 15 meters. Use same matching section for 10 meters but see Table 1 for shorting bar position. General dimensions of driven element are shown. Detail A shows matching section. Detail B shows method for joining element sections.

the ideal wall thickness is 0.058 inches. However, the 0.055-inch wall thickness material will be perfectly satisfactory if the precautions given below are observed.

In the array shown in Fig. 2, a single 8-foot length of 1-inch o.d. tubing is used to make the two halves of the driven element center section. To increase the mechanical strength of the split driven element, a 6-foot length of 7/8-inch o.d., 0.055-inch wall tubing is cut into two sections of equal length and inserted inside the 1-inch diameter sections. To further improve the mechanical strength of the driven element, a hardwood dowel, about 18 inches long, is sanded down to a tight fit and driven into each 7/8-inch section before the driven element is assembled. This arrangement permits the use of heavy-duty standoff insulators with 1/4-inch machine screws through each element section without introducing any appreciable mechanical weakness at the point of mounting.

The two driven element end sections are 7/8-inch o.d. tubes, 8 feet long and with a wall thickness of 0.055 inch. As the adjusted overall length of the driven element will be about 22 feet for 21.3 MHz, there is a telescoping overlap of about 12 inches where each half of the center section and its end piece join. The hobby aluminum tubes are manufactured with a dull oxidized finish that is a poor conductor of electricity at radio frequencies. This finish must be removed from the inside of the larger tubing and from the outside of the smaller tubing where the two pieces join; this is done easily with sandpaper and steel wool. To remove the finish from the inside of the larger tubing, wrap a piece of sandpaper around a wood dowel, or use a round file, and work it up and down inside the tube until the inner surface is bright and clean. The ends of the 1-inch tubes are slit with a hacksaw for a distance of about two inches, as shown. Before inserting one tube inside the other, coat both contacting surfaces with an antioxidizing compound and wipe each surface with a clean, dry cloth or paper napkin. Leave only a thin film of the compound on each surface. The compound is sold under various brand names and is available in 5-oz tubes at most electrical supply houses.

During the preliminary adjustments, the two tube sections are maintained in good electrical contact by placing a stainless steel strap-type hose clamp around the slit end of the larger tubing and drawing it tight. After the final adjustments are complete, a half dozen 3/8-inch stainless steel sheet-metal screws are inserted through both tubes and arranged in a spiral around the larger tube for a distance of three or four inches to ensure a permanent electrical and mechanical joint. Finally, all joints are tightly wrapped with plastic vinyl tape to prevent the entry of moisture.

After the final adjustments of the driven element and the shorting bar, the shorting bar is soldered in place with a propane torch. When soldering the copper tube containing the coaxial cable inner conductor, do not use excess heat at the junction, as this might melt the polyethylene insulation and cause the inner conductor to short circuit to ground. To check the inner conductor for a possible short circuit after soldering, disconnect the inner conductor lead at point B and measure between the end of the disconnected lead and ground (boom). The ohmmeter should indicate an open circuit. The main transmission line from the transmitter should be disconnected from the antenna before making this test. The center point of the shorting bar is grounded to the boom through a short length of 1-inch-wide copper strap.

The director element is not split at the center, so a smaller diameter center section is used. In the prototype array, the director center section is a single 8-foot piece of 7/8-inch o.d. tubing. To add mechanical strength and to prevent wind vibration, two 3-foot long wood dowels are sanded down to a close fit and one is inserted in each end of the 7/8-inch tube. When the two dowels are pushed down toward the center, about a foot of clearance is left at each end of the director center section for insertion of the 3/4-inch o.d. end pieces. The ends of the 7/8-inch tube are slit, and both tubes are cleansed of the oxidized coating as described above. Join together the center section and end pieces in the same manner as described above for the driven element.

Please note that the director is mounted on standoff insulators and does not follow the usual "plumber's delight" type of construction where the element is mounted directly on the boom. The insulated director element is then grounded to the boom at the exact center of the element. This type of construction is believed to be one of the reasons for the low noise level of the 15- and 10-meter antennas. The method of mounting the director element on the standoff insulators, however, is somewhat different from that of the driven element. The mounting details are shown in the photograph and drawings.

During the early stages of this antenna project, both the driven element and director lengths, and the spacing between them, were made adjustable. Unless you are building the array for greatest front-to-back ratio, there is no point in having so many variables in the system that it leads only to unnecessary complications in the adjustments. For the maximum-forward-gain version, the optimum director length for 0.11-wavelength spacing between the elements is equal to 450/f, where f is the frequency in MHz. In the 21.3-MHz array described here, the overall director length is fixed at 21 feet and 1 inch. The 0.11-wavelength spacing is also fixed, at 61 inches. The only variables left are the driven element length and the position of the shorting bar on the stub.

The boom is made from 2-inch aluminum irrigation tubing cut to a length of 66 inches. If you cannot find the irrigation tubing in your area, use 1-1/2-inch electrical conduit (EMT) or thin-wall steel TV mast material. After the boom is cut to length, remove all burrs and sharp edges with a file, sandpaper, and steel wool. To add strength to the aluminum tubing boom, a 12 inch long wooden dowel or plug, only slightly smaller than the inside diameter of the tube, is inserted inside the boom and pushed down toward the center. Secure the plug in place with a flathead wood screw driven through the aluminum into the wood. A similar but shorter wood plug is inserted in each end of the boom and secured in the same manner. The purpose of the wood plugs is to permit the use of automotive muffler clamps to secure the element assemblies to the boom without crushing the comparatively fragile aluminum tube. Searching for a source of the wooden plugs, I found a supply of old-fashioned hardwood kitchen rolling pins at a local supermarket. These happened to be of exactly the proper diameter for a snug fit inside the boom. One rolling pin was used for the center plug and the other was cut in half to make the two end plugs.

In addition to the wooden plugs inside the boom, I also used three 8-inch pieces of 2-inch i.d. electrical conduit (EMT) over the aluminum boom—one piece at the central balance point and one at each end of the boom. The inside diameter of the conduit is large enough so that the sections can be rotated by hand. The muffler clamps used for mounting the element assemblies and the rotor mount on the boom are placed around the conduit sections. During the preliminary adjustments, these conduit sections can be secured with a single sheet-metal screw through the conduit and aluminum tubing walls into the wooden plug. When the array is

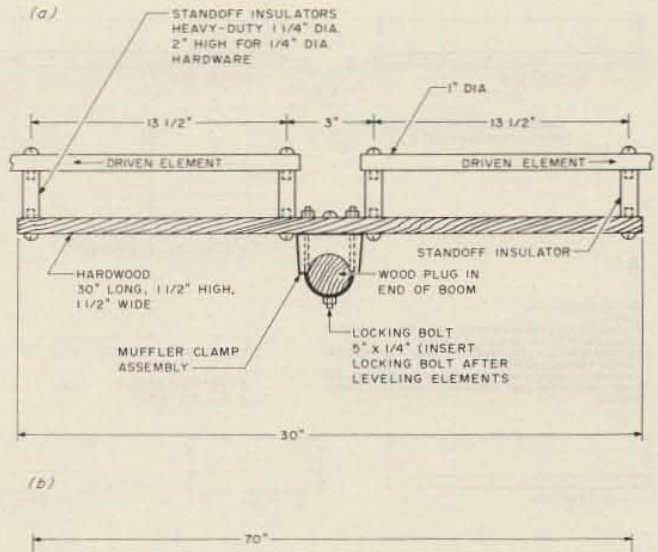

Fig. 3. (a) Driven element mounting details. (b) Director driven element details. Detail A shows element-to-angle construction technique.

placed on the tower, the conduit sections can be rotated on the boom to level the elements and place them in the same horizontal plane. After the elements have been leveled, secure them in this position by inserting several sheet-metal screws through the metal and into the wood inserts.

Resonating and Matching Adjustments

The preliminary resonating and matching adjustments may be carried out with the array suspended only a few feet above the ground. An 8- or 10-foot wooden stepladder functions very well as a support if the array is lashed to the top and kept level during the adjustments. Place the stepladder and array in an open space, away from buildings, trees, wires, or other antennas. Point the director toward empty space, if possible. Keep the ends of both elements away from any objects, particularly those made of metal. During the adjustments, the presence of your body in the field of the antenna will affect the adjustments and the instru-

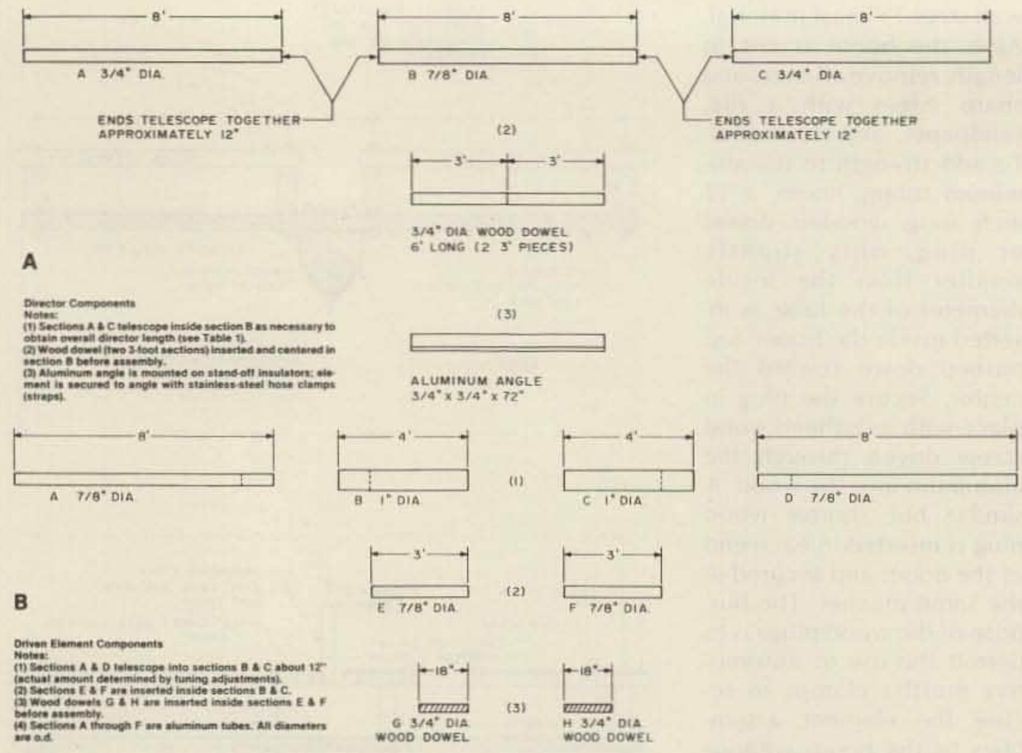

Fig. 4. Components for (a) director and (b) driven element.

ment readings. When adjusting sensitive arrays close to the ground, I usually use two swr meters—one at the point where the transmission line connects to the array and another at a point one-half wavelength down the line from the antenna. To obtain a true reading, walk out of the field of the antenna after making an adjustment and read the swr meter at a distance or at the half-wave point.

To start, adjust the driven length to 476/f, where f is in MHz, not including the 3-inch gap at the center. For 21.3 MHz, the length of each half of the driven element will be about 11 feet, 2 inches. The exact length at this point is not extremely important, but make sure that the two halves are exactly equal to each other. Now, beginning at the end of each 1-inch center tube section, scratch marks one inch apart on the 7/8-inch end sections in the direction of the tips. Four or five marks will be sufficient. Make the same number of marks on each end section. Adjust the shorting bar to a position about 36 inches down the stub from the antenna and tighten it just enough to make good contact with the copper tubes. Connect an swr meter in series with the coaxial line at the point where it joins the stub SO-239 connector. If you have a second swr meter, put in a pair of PL-259 plug connectors exactly 15 feet, 3 inches (for RG-213/U, RG-8/U, and 21.3 MHz) down the line from the SO-239 connector at the antenna, and insert the second meter at this point. Adjust the test signal to the proper frequency.

Adjust the signal level and the swr meter sensitivity to indicate exactly full scale in the "forward" position. Switch the swr meter(s) to indicate the "reverse" or "reflected" signal level. With the array adjusted as described, the reflected signal level probably will be less than full scale, but is not likely to be zero. Now, very carefully adjust each end section by telescoping it into the 1-inch center section the distance of one inch (one mark). Make sure that each end section is telescoped exactly the same amount so that the array will remain in electrical balance. While observing the swr indicator, move the shorting bar up and down the stub for the deepest indicator null. Alternately, adjust the driven element overall length, maintaining electrical balance, and the shorting bar position until the swr meter indicates zero in the reflected signal position. At this point, tighten the two stainless steel clamps around the driven element but do not insert the sheet-metal screws yet.

If it is possible, raise the antenna to about 24 feet above the earth and observe the change, if any, in the swr meter indicator. I use a wooden pole for a tower. An overhanging arm at the top of this pole was fitted with a rope and pulley so that the array could be pulled up to any height above ground. When the array was raised from 8 feet to 24 feet, the line swr at 21.3 MHz changed from 1:1 to 1.4:1. After several trial adjustments of the driven element length, the line swr was reduced to 1.2:1 at 21.3 MHz. The antenna was then lowered to the ground and the sheet-metal screws were inserted in the driven element. The entire joint was then wrapped with plastic vinyl tape. After the antenna was installed on the tower, the shorting bar was adjusted for a 1:1 swr at 21.3 MHz and soldered in place.

Electrical Height

Most amateurs believe that the higher the antenna, the better its performance, especially for DX work. I have found, however, that a height above ground from about a half wavelength to a five-eighths wavelength appears to be best for my location when working European DX. W6TYH is located in the foothills of the Sierras at about 500 feet elevation. In the direction of Europe, the Sierras are about 7,000 feet high. Low-angle radiators, such as vertical arrays, give very poor results toward Europe when compared with the little two-element parasitic arrays. The best signal reports from Europe on the 15-meter band were obtained when the array was about five-eighths wavelength above the earth. To establish the electrical height at five-eighths wavelength, a 1.5-Ampere thermocouple rf ammeter was inserted in series with the 50-Ohm transmission line at the point where it is connected to the SO-239 receptacle. The rf power input to the line at the transmitter was held constant while the array was raised and lowered. The maximum rf current was indicated when the array was about 28 feet above the earth. This also has proved to be an effective height for working European DX across the Sierras. Apparently, the vertical angle of the radiated signal is just right for the wave to clear the high mountain ranges to

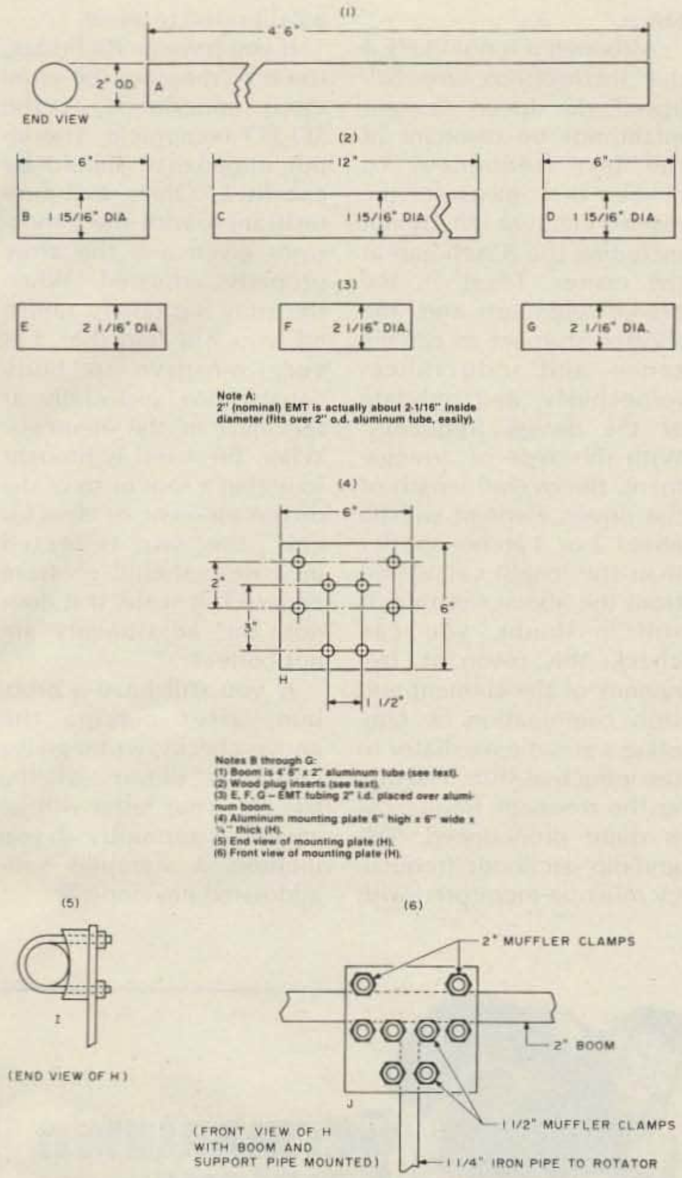

Fig. 5. Boom assembly and mounting details.

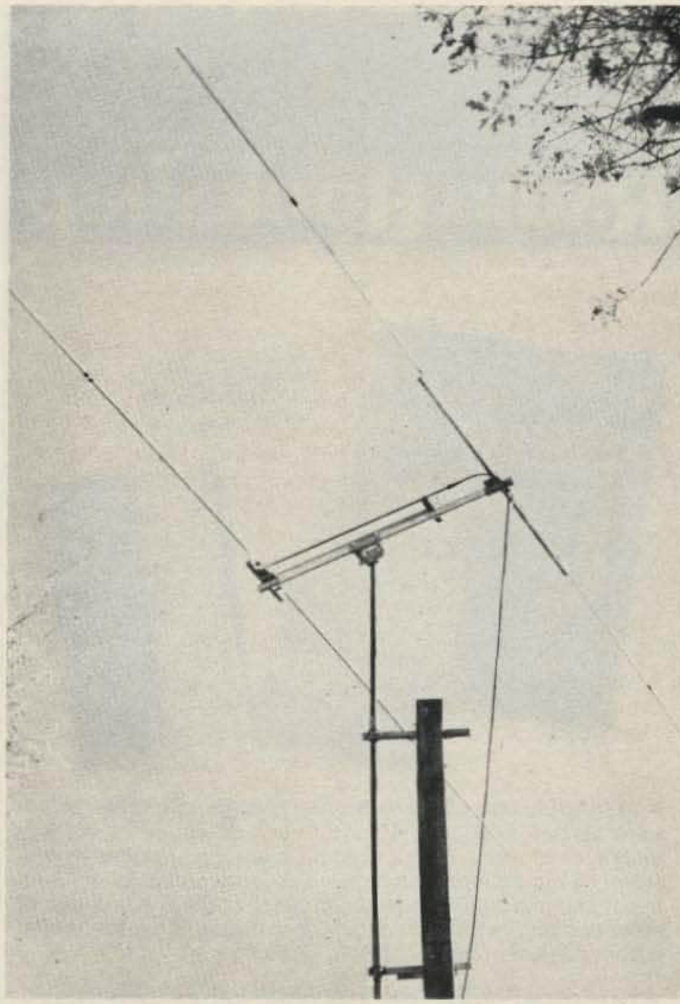

Fig. 6. LB-2 15-meter array. The split driven element is at the left in this photo. The director element, right, is insulated from the boom but grounded to it at the exact center to reduce noise pickup. Note coax line connection at end of 53-inch tube. As shown, maximum radiation will be toward the right. Maximum gain (over a half-wave dipole) is 5.3 dB. The rotator (not shown) is an AR-22 heavy-duty TV type.

the north and east.

Operating Performance

After almost half a century of amateur and professional radio communications experience, it requires outstanding performance in an antenna or a piece of ham gear to cause me to become enthused. I can truthfully say that I am delighted with the performance of the little two-element 15- and 10-meter antennas. The real worth of any antenna, as far as I am concerned, is proved by what it will do when I am competing with a dozen other stations for a rare DX contact. Many times when the competition was fierce, the DX station came back to W6TYH, and I have the QSL cards to prove it. During the past few months that the antennas have been in use, I have had good signal reports from all parts of the world. Most of the time, the PEP input to the transmission line was only 175 Watts. The antennas also work very well for reception, a signal standing up from the background noise like the proverbial "sore thumb."

Troubleshooting

This antenna design has been proved to be sound and, if the dimensions and adjustment procedures are carefully followed, absolutely no trouble should be experienced in obtaining top performance from either of the two arrays. However, some of us are like the new bride who burned water trying to boil it, and somebody will get into trouble with the array and write to me.

The most common problem is difficulty in getting the line swr down to 1:1 at the design frequency. In one case, the trouble was caused by harmonics of the test signal appearing in the line. The use of a low-pass filter in the transmission line at the signal source eliminated the problem.

Do not be tempted to change the spacing of the copper tubes in the matching section, or use different diameters from those specified. I have been through all this and it is not only tricky but very frustrating. Remember that this is a balanced driven element and feed system; when adjusting the overall length of the driven element, make sure that both halves are adjusted exactly the same amount. Mount the matching section tubes on standoff insulators about 6 inches above the boom and make certain that each copper tube is spaced the same distance from the boom to equalize the distributed capacitance.

Although it is not likely if the instructions are followed, the driven element might not be resonant at the test frequency. To check, first measure the overall element length, not including the 3-inch gap at the center. Together, the driven element and the shorted stub act as capacitance and inductance, respectively, and resonate at the design frequency. With this type of arrangement, the overall length of the driven element will be about 2 or 3 inches shorter than the length calculated from the above formula. If still in doubt, you can check the resonant frequency of the element and stub combination by coupling a grid-dip oscillator to the inductive stub. The dip, at the resonant frequency, is quite pronounced. The grid-dip oscillator frequency must be monitored with a calibrated receiver.

If you have an RX bridge, use it to measure the array input impedance at the SO-239 receptacle. The input impedance should be exactly 53 Ohms and pure resistance, with the dimensions given and the array properly adjusted. When the array is properly adjusted, you will find that it is very sensitive to body capacitance, especially at the ends of the elements. When the hand is brought to within a foot or so of the driven element or director end, the swr reflected indication should go from zero to full scale. If it does not, the adjustments are not correct.

If you still have a problem after making the above checks, write, giving complete details of the trouble. Your letter will be answered promptly if you include a stamped self-addressed envelope. ■