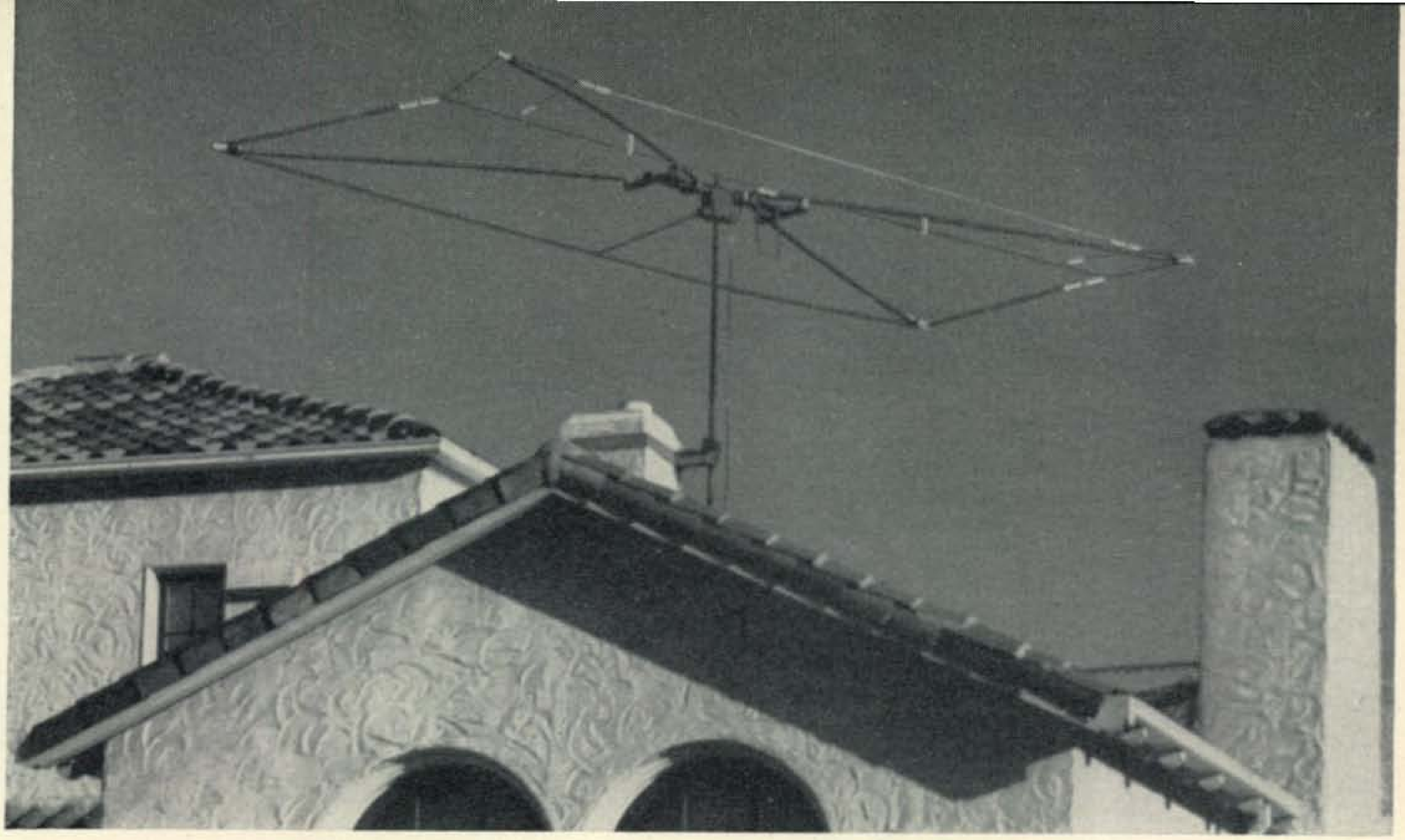

The Cobweb

C. F. BANE, W6WB*

A sure-fire snare for DX, yet 40% shorter than a conventional array, this 2-element rotary beam is the average ham's dream come true.

THIS IS THE STORY of a rather unusual beam antenna that started out purely as an experiment but, like "The Man Who Came to Dinner," is still with us!

There have been so many ingenious mechanical arrangements for beams published that there is little doubt but that our particular structural design is not original. However, this is merely a means to an end—the worth of our antenna is not in its peculiar rotary cobweb effect (so my wife says), but rather in the fact that its physical length is only about 60% of the normal beam. Coincidentally, this figures out roughly to be about one foot per meter, i.e., 20 meters, 20 feet—10 meters, 10 feet. Judging by the number of amateurs who complain of lack of space, such a shortened beam may find ready application particularly since it is also very lightweight and consequently imposes no partiular rotating problem. Ours turns nicely when driven by a pair of No. 5 Selsyns (the "slave" driving the antenna supporting shaft through a 100:1 worm and Bull-gear reduction[1]).

It is felt that further mechanical description is needless in view of the completeness of the photographs and drawings, therefore subsequent remarks will deal principally with electrical design considerations. There is reason to believe that some of the material to follow, while specifically aimed at the bean under consideration, may well apply to the design and adjustment of more conventional types.

Shortening Methods (Center Loading)

There are only a few practical methods whereby an antenna can be shortened from its normal resonant length so as to fit into some available space. The most common method is to shorten the antenna and restore resonance by inserting inductance in the center portion of the antenna. This system has been previously described in *CQ*[2]. The inductance may be in lumped form as provided by a coil or in the form of a closed-end stub. An antenna can be shortened by this method to the point where it is merely a large coil with stubs protruding from opposite ends but it is highly questionable whether such an arrangement will do much radiating. Even assuming the elements to be of reasonable length, one must take into account the fact that, as an antenna is shortened and resonated, its radiation resistance will decrease. Hence (for a constant input power), the current in the center of the antenna will increase. Bearing in mind that the total power is distributed between the radiation and loss resistance ($W = I^2(R_{rad} + R_{loss})$) it can be seen that when the radiation resistance is equal to the loss resistance, 50% of the available power is wasted. When the radiation resistance becomes very low it doesn't take much loss in the loading inductors (skin-effect, resistance at the connections, etc.), to cause trouble. Further, as the

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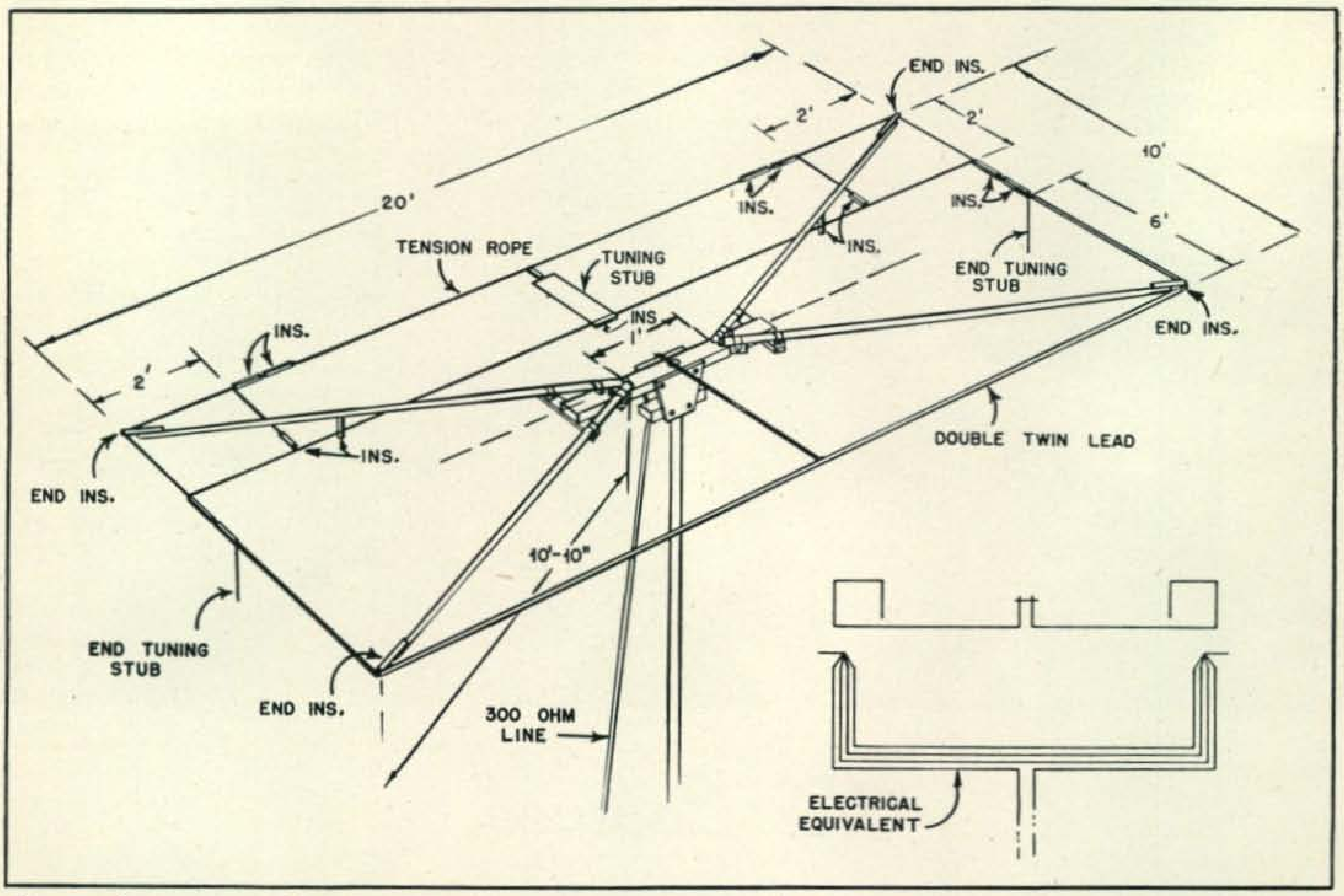
155 Saint Elmo Way, San Francisco, Calif.

[1] Hays, "Selsyn Beam Rotator," *CQ*, Feb., 1948

[2] Weichert, "The Shortened Beam," *CQ*, Sept., 1947



Support booms are of bamboo. Diameter at base averages 1¼". Diameter at tip averages 1". Center support piece is 2" x 3" x 4'. Pipe clamps are used to fasten booms to center support piece.

radiation resistance is lowered, there will be a rapid increase of voltage (and impedance), at the ends of the shortened elements. When very short elements are used corona and dielectric losses can be substantial. Anyone who has ever had occasion to load a short antenna in the 200-400 kc region will tell you that this type of loss is not to be taken lightly! These remarks are not aimed at the writer of the previous *CQ* article since his shortening of the elements was quite conservative and if our statements apply at all they do so only to a very minor degree.

End Loading

It will be obvious that an antenna shortened to a length substantially less than that for self-resonance will appear as a capacitive reactance, therefore it will be necessary to add inductive reactance (center coil or stub) in equal amount to bring the antenna to resonance. It is reasonable to expect that if we can somehow increase the capacity of the antenna we will *decrease* the capacitive reactance thereby requiring less inductive reactance (smaller coil, less losses), to restore resonance. This capacity increase can be achieved by enlarging the diameter of the conductors, or by adding plates or copper mesh at or near both ends of the antenna. This method of capacity end loading is used in the parasitic element of our particular beam by arranging the folded-back sections of the wires to form a two-foot square. This is clearly shown in one of the illustrations. By the combination of the added length gained by the folding and the end-capacity we are able to reduce the length of the center tuning stub to a negligible value, the reasons for which will be subsequently mentioned.

End Folding

One system which suffers none of the disadvantages of either of the two previously mentioned is to use the full electrical length for the elements and to condense the system by folding back a small portion of the antenna on either end. This method should closely approach the performance of non-shortened antennas since the high current center portion is completely in the clear. Present theory indicates that the portion of the antenna in which the highest current flows produces the greatest field strength. Thus in the case where a center loading coil is used, it would appear that since this high current flows mainly through the turns of the coil (which in itself contributes little to the radiated field), results might not quite equal the non-coil system. In any case, field strength measurements here indicate that there is little if any difference between a full length dipole and one in which only 60% of its length contributes to the forward (and rear) radiation (the two ends are bent back, each about 20% of the total antenna length).

No tests were made with the parasitic element as a radiator although it is felt that since the ends are folded back upon themselves, this particular geometry may be somewhat less effective than a non-bent element.

Design Specifications

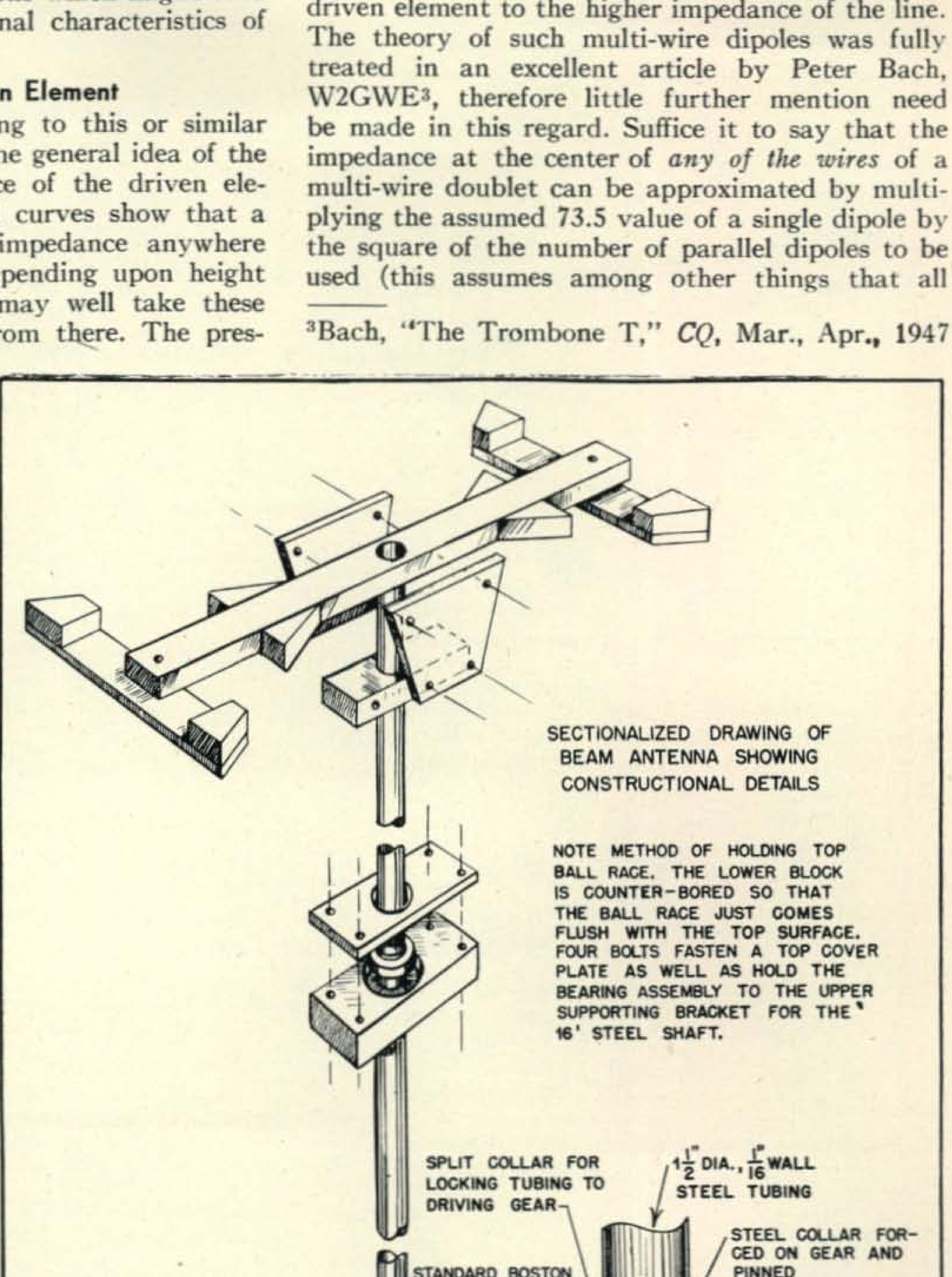
For 20-meter operation, the beam was not to exceed twenty feet in physical length; the driven element to be full electrical length but to have approximately 6' bent back on each end. The director was to be 20' long and tuned near self-resonance by forming the folded-back end sections into open circuited squares approximately 2′ on a side. Exact tuning in this latter element was to be accomplished by a center stub line not over 2′ in length. This latter requirement places the high current loop in the linear portion of the parasitic element rather than in the closed tuning stub. It was further decided to arrange all bent-back portions of radiator and parasitic element in a horizontal plane rather than to bend them up or down; this in an attempt to avoid any possibility of vertical pickup on these sections which might tend to mask the normal directional characteristics of the system.

Center Impedance of the Driven Element

In considering line matching to this or similar antennas one should have some general idea of the approximate center impedance of the driven element. The familiar published curves show that a dipole may have a center impedance anywhere between 60 and 90 ohms, depending upon height above ground, so that we may well take these figures as limits and work from there. The presence of the parasitic element spaced one tenth wavelength and tuned as a director can reduce the driven element center impedance to values somewhere between the extremes of 10 and 30 ohms. The probability of experimentally determining the exact impedance of the driven element is extremely remote, therefore, as long as we have to guess,it will be well to reduce the error as much as possible. If we take the geometric mean value of impedance of a dipole by itself (between the possible limits of 60 and 90 ohms), we come out with 73.5 (plenty close enough to the sacred value). Then, if we take the mean value of impedance of a driven element in the presence of the director (assumed to lie between 10 and 30 ohms), we arrive at a value of 17.3 ohms. Therefore our *average* ratio of drop-off in impedance due to the presence of the parasitic element can be assumed to be 4.25:1. It's a guess but as measured results show, it's not too far off to be reasonable. Some such ratio information is necessary when using multi-element dipoles as a means of matching the impedance of the antenna to some selected value of transmission line since it then becomes possible to determine the number of parallel elements that will be required to effect the necessary transformation.

Multi-Element Dipoles

Since it was our desire to use a 300-ohm balanced line to feed this beam, a multi-element folded dipole appeared to offer the best possibilities of transforming the low center impedance of the driven element to the higher impedance of the line. The theory of such multi-wire dipoles was fully treated in an excellent article by Peter Bach, W2GWE[3], therefore little further mention need be made in this regard. Suffice it to say that the impedance at the center of *any of the wires* of a multi-wire doublet can be approximated by multiplying the assumed 73.5 value of a single dipole by the square of the number of parallel dipoles to be used (this assumes among other things that all


SECTIONALIZED DRAWING OF BEAM ANTENNA SHOWING CONSTRUCTIONAL DETAILS

NOTE METHOD OF HOLDING TOP BALL RACE. THE LOWER BLOCK IS COUNTER-BORED SO THAT THE BALL RACE JUST COMES FLUSH WITH THE TOP SURFACE. FOUR BOLTS FASTEN A TOP COVER PLATE AS WELL AS HOLD THE BEARING ASSEMBLY TO THE UPPER SUPPORTING BRACKET FOR THE 16' STEEL SHAFT.

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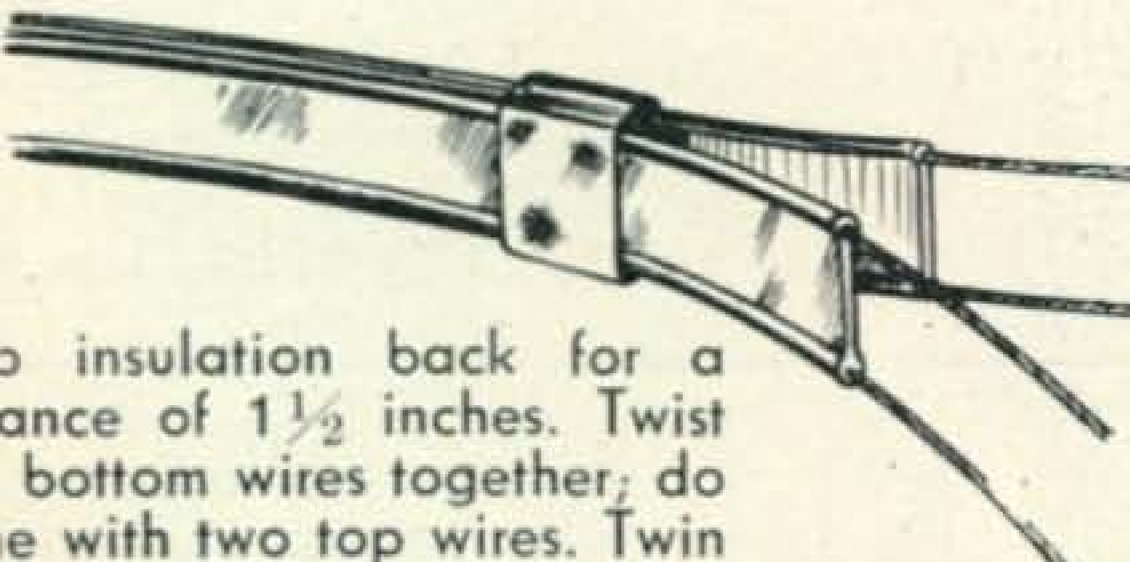
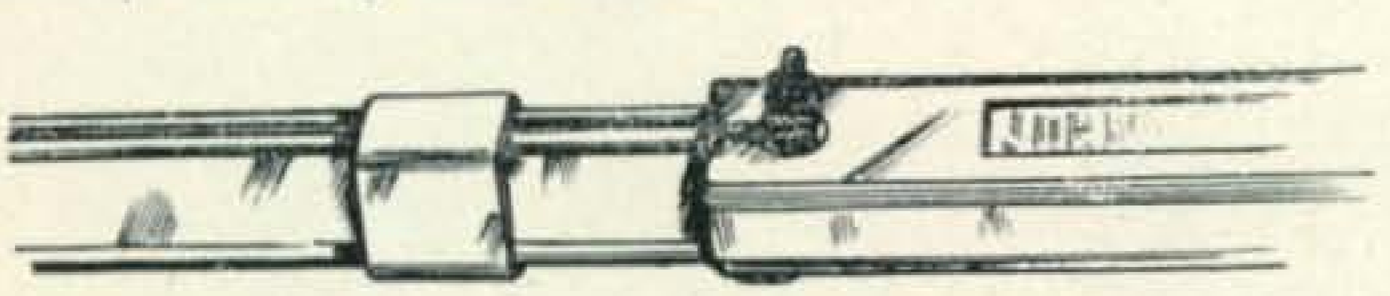
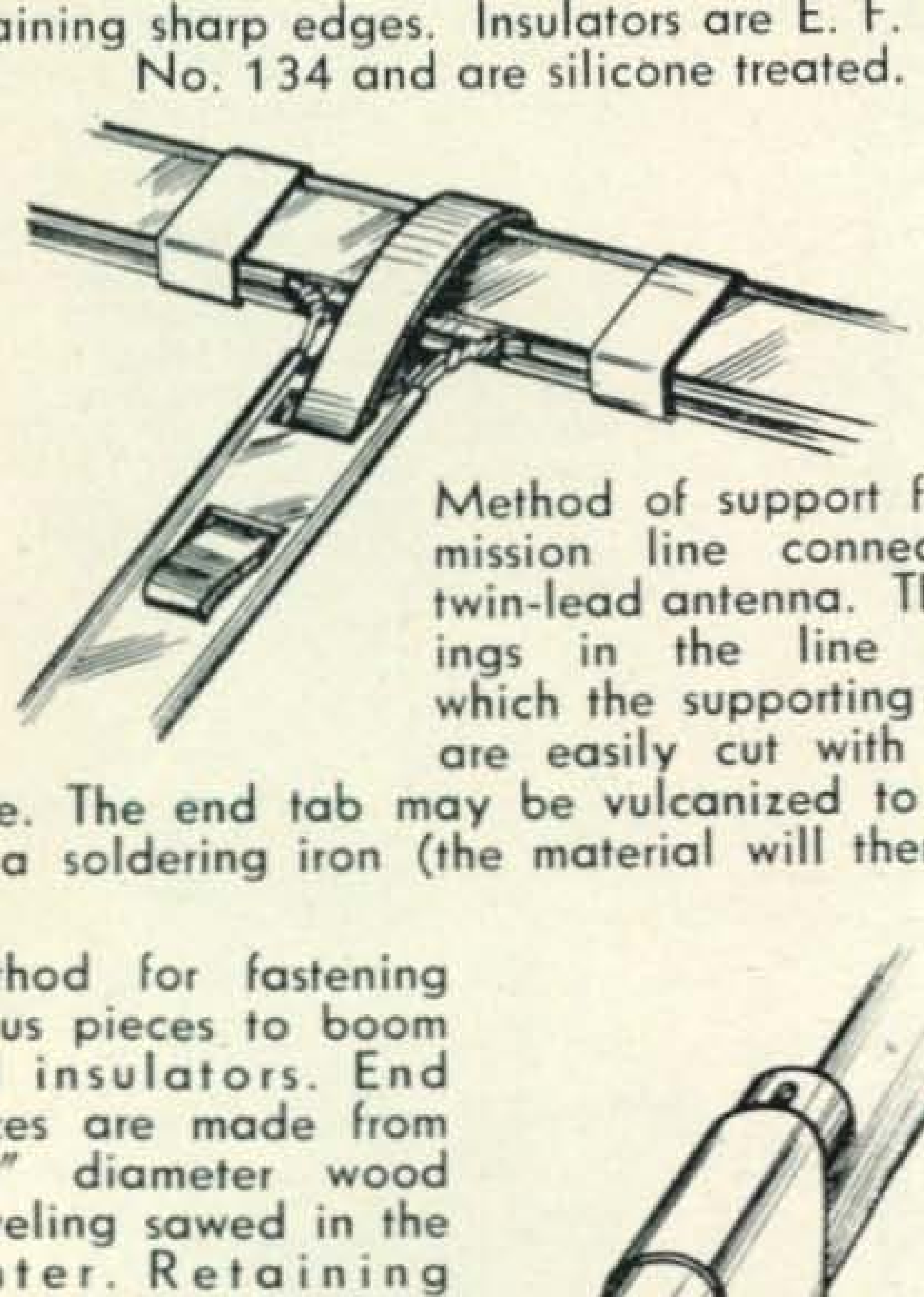
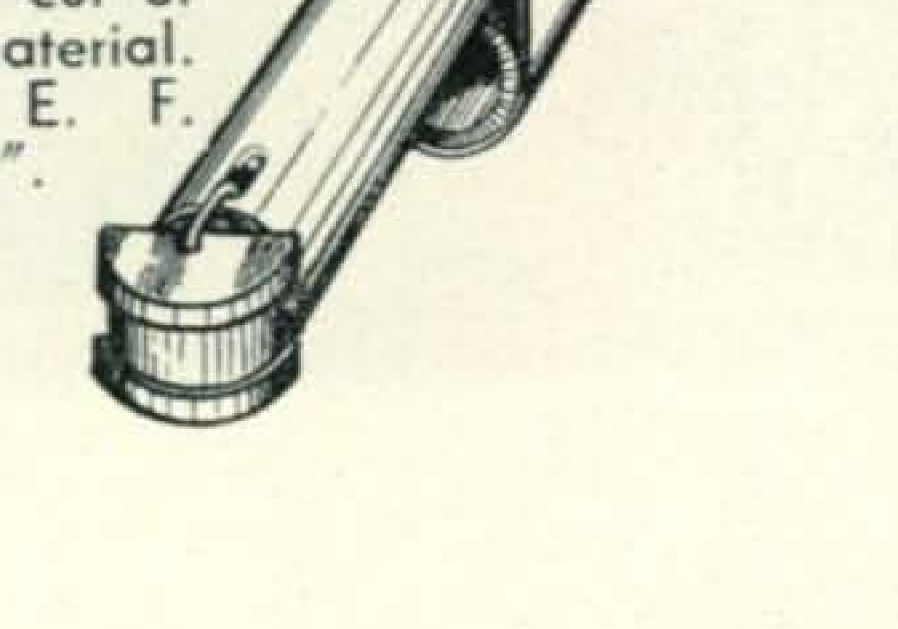
[3] Bach, "The Trombone T," *CQ*, Mar., Apr., 1947

conductors are of equal diameter, that there is no phase difference between them and that the currents are all equal). In our previously stated case, we assumed that our 73.5 ohm figure would be reduced by a ratio of 4.25 when the director was added, therefore, instead of using 73.5 we take $\frac{73.5}{4.25}$ or 17.3. Now if we arbitrarily select a four-wire doublet, the arithmetic comes out, $4^2 \times 17.3 = 275$ ohms (approx.). Thus on a guesswork basis we have set up a match for our 300-ohm line that is within 1.1 : 1 ! Oh, that it could be that simple! Measurements on the the present beam, however, show S-W-R values of less than 1.5:1 which should be quite acceptable particularly in view of the convenience of a directly connected 300-ohm line without need for matching or tuning adjustments of any kind.


Strip insulation back for a distance of 1½ inches. Twist two bottom wires together; do same with two top wires. Twin leads should be held together with tape serving each two feet.


Push bottom wire through end hole in insulator. Twist top wire as shown. Solder joint and round off any remaining sharp edges. Insulators are E. F. Johnson, No. 134 and are silicone treated.


Method of support for transmission line connection to twin-lead antenna. The openings in the line (through which the supporting tab fits) are easily cut with a sharp knife. The end tab may be vulcanized to the line by a soldering iron (the material will thermo set).


Method for fastening radius pieces to boom end insulators. End pieces are made from 1½" diameter wood doweling sawed in the center. Retaining grooves for twin-lead may be readily cut or filed in this soft material. Insulators are E. F. Johnson, 8".

Matching S-W-R

A further bit of pencil work will show that even with the widest variations apt to be encountered in practice an impedance mismatch of much over four-to-one is highly improbable. How then can we sometimes get those eight and ten-to-one S-W-R? The answer may be in the possibility that the line may be looking into a substantial reactance instead of the purely resistive impedance necessary for lowest S-W-R. The presence of the parasitic element will couple reactance into the antenna, the sign and degree of which will depend upon the spacing and the tuning (length) of the parasitic element. It is almost impossible to obtain a low S-W-R if the line looks into a complex impedance and the only practical way to correct this condition is to tune out the reactance by changing the tuning of the antenna (assuming the tuning on the parasitic element to be fixed). This applies equally to multi-wire doublets and may serve to demonstrate that in the presence of the second element they are *not* broad-band in the sense that they will not remain purely resistive over a wide frequency range. As the transmitter frequency is changed beyond the frequency to which the antenna system was initially tuned, the antenna becomes reactive as attested by the relatively rapid rise of S-W-R on the transmission line. In contrast, a four-wire folded doublet without parasitic elements is normally resistive over several hundred kilocycles, so much so in fact that it is almost impossible to locate an exact resonant frequency.

If a minimum S-W-R is sought, it will be absolutely essential that provisions are made to tune the multi-wire driven element. A check on S-W-R over a few hundred kilocycles will definitely show the resonant point of the antenna since the S-W-R will be the lowest at this frequency. The accompanying curves illustrate this point and are particularly pertinent since they are taken from the line of the antenna system under discussion. These curves indicate that the beam will work nicely over some 200 kilocycles in the 20-meter band without excessive S-W-R. It will in fact work reasonably well over the entire band (and has), but with an increase in S-W-R, which while it may not result in excessive losses does tend to make the loading on the final amplifier fussy amd critical. There is, of course, the definite possibility that the effects discussed may be exaggerated in this type of beam due to its peculiar geometry and that the rise in S-W-R off the resonant frequency of the antenna may not be so marked in other beams incorporating wider spacing.

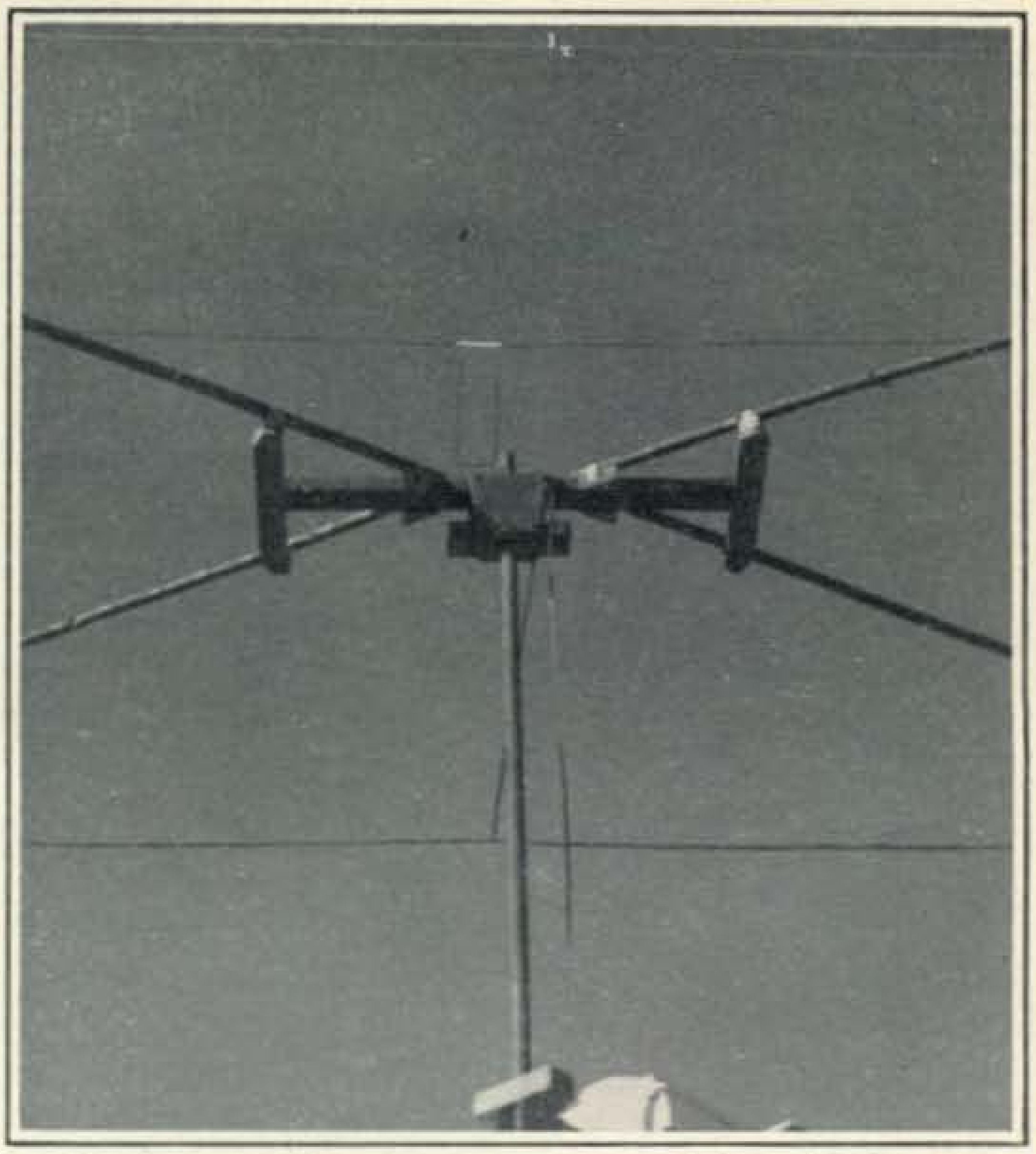
Back to the curves once again—note the effect of rotating the antenna. In one curve the *antenna* part of the beam is directly over the house; the other curve is for the director in this latter position. Unfortunately the antenna is quite close to the roof (this being a carry-over from the "experimental only" days), and it is interesting to observe that the S-W-R and resonant frequency of the antenna both change when the beam is turned so that the driven element is over the roof. The peculiarities of the two curves are no doubt due to the fact that the system is coupling into the lighting circuits of the building (an understatement!).

The Driven Element

The driven element (four-wire doublet) is made from two identical lengths of 300-ohm twin lead taped together (tape servings every two feet). The four wires on either end are joined together and one of the wires opened in the center for the 300-ohm twin lead feeder connection. Mechanically, the 150-ohm lead might be a bit easier to handle and was in fact incorporated in one of the original experimental versions of this beam. No concern need be felt as to the adjacent wire insulation since the currents in all wires are in phase, therefore there should be no potential difference between any of the wires throughout their length.[4] In an early try with the 150-ohm material, the insulation rubbed through on two of the wires and they shorted together. This, of course, made an entirely new situation as regards difference of potential and the shorted portion quickly blew through to the two unshorted wires. Result, a fused mass!

Since the two end sections of the driven element are folded back, care must be taken to insure that the twin lead does not bend around too sharp a corner at the supporting insulator (one of our early mistakes). Note that we have made supporting pieces from 1¼″ dowels so that the twin lead will have a radius around which to bend.

Insulation at and near the ends of both the parasitic and driven element is very important! Initially, the insulated twin lead looked so good that little care was taken in the antenna insulation other than at the extreme ends. This proved to be a mistake. You have no idea of the amount of r.f. on the ends of either the parasitic or driven elements until you feed about 500 watts into the system and try some sparks for yourself. The photograph of the ends of the beam will show the small tuning stubs on the ends of the double twin-lead antenna wires. These were spaced away from the end insulators about two inches and nothing more was thought about them until we took the photographs, at which time they were outlined against the sky and looked peculiarly black. The investigation that followed disclosed that the end tips were fused into nice little balls, this interesting addition being undoubtedly caused by an arc to the wire link joining the two end insulators (a distance of at least two inches)! This was enough for us; we replaced the stubs and this time let them drop at right angles to the end insulators.



Looking up at the center support. Note tuning stub. Top-ball-race with supporting block can be seen at bottom. This wood bearing housing is bolted to a steel band which fastens to the chimney. The direction in which you are looking is the only clear one at W6WB—up!

From this type of insulation breakdown and arcing with less than 1-kw input, it is not difficult to understand why the W8JK type of close-spaced beam has been falsely accused of being excellent on receive but not so good on transmit. In this type of antenna the situation is usually made even worse by using a tuned feeder with an impedance gradient of a few to many thousand ohms in a quarter wavelength. The same high voltages appear at the ends of any close-spaced beam but since most parasitic element types use no insulators at the ends, no trouble can occur from this source. It will be noted that we use feeder speaders for our end insulators; however, always two or three in series are employed and the individual insulators are Silicone treated to prevent a continuous film of moisture from forming on their surfaces. In this regard, *definitely* the transmission line should be Silicone treated if it is the conventional flat type of twin-lead. This will lessen the tendency for S-W-R rise in wet weather and here at least where it often gets quite foggy, such treatment is a "must."

The Parasitic Element

As mentioned, the parasitic element has the same unbent length as the driven element (20′), the additional resonating length being made up by a combination of folded-back and end-capacity-loaded sections. Unfortunately, folding the ends back on themselves at a spacing of only 2′ has a tendency to cancel inductance (and length), therefore an additional fold-in was required. The additional capacity on the ends so obtained makes it possible to tune the parasitic element as a director with a tuning stub approximately 18″ in length.

The previous remarks as to the importance of

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[4] Theoretically the operation of the folded dipole is altered when the parallel conductors making up the dipole are separated by a dielectric other than air. In addition to the in-phase currents flowing along the parallel conductors an out-of-phase component also flows. The V.P. of the in-phase wave will be unaltered by the presence of the dielectric but the V.P. of the out-of-phase wave will be slowed down by a factor $\frac{1}{\sqrt{K}}$ where K is the dielectric constant. Hence substantial out-of-phase energy may flow since the source does not look into a very high impedance (quarterwave stub shorted at far end) when the parallel conductors are separated by a dielectric having a dielectric constant greater than one.—Ed.

reducing loss resistance will surely apply to the tuning stub since the shorting bar for this stub is at the position of maximum current where even a small loss resistance can result in a substantial power loss. In practice, a stub was made using bare copper wire for the preliminary tuning and once the correct position for the shorting bar had been established, an identical stub was bent from insulated wire and substituted. All wire joints were first made mechanically firm, soldered, wiped, then finally coated with lacquer. It is important that that the ends of the director wires have a soldered joint in the loop where they terminate at the last insulator. Further, if appreciable power is contemplated, that these ends should be rounded off so that no sharp points exist that might aid in starting corona.

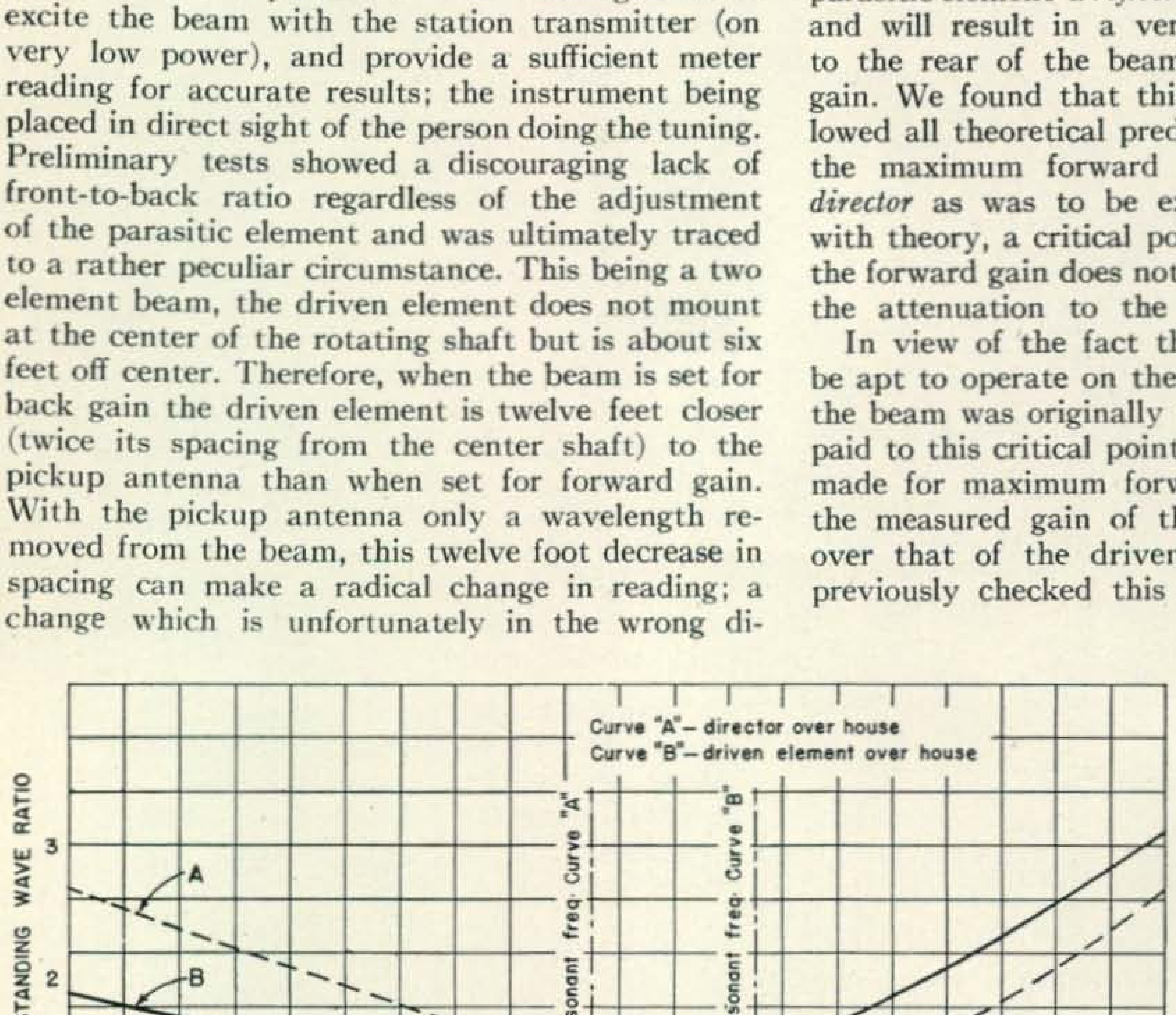
Tuning

Several attempts were made to tune the beam with the assistance of on-the-air stations. For the greater part these were not successful particularly as regards forward gain adjustments. If the maximum forward gain of the antenna is about 4 db and an S point on the receiver meter represents about 6 db (maybe), the *best* one could expect would be little more than half an S point change; hardly sufficient in view of changing line voltage and other parameters. It was finally decided to set up a field strength antenna as far removed from the beam as possible (about one wavelength in our case), and to run a long feed line from this antenna (to which a thermo-galvanometer could be connected). It is possible with this arrangement to excite the beam with the station transmitter (on very low power), and provide a sufficient meter reading for accurate results; the instrument being placed in direct sight of the person doing the tuning. Preliminary tests showed a discouraging lack of front-to-back ratio regardless of the adjustment of the parasitic element and was ultimately traced to a rather peculiar circumstance. This being a two element beam, the driven element does not mount at the center of the rotating shaft but is about six feet off center. Therefore, when the beam is set for back gain the driven element is twelve feet closer (twice its spacing from the center shaft) to the pickup antenna than when set for forward gain. With the pickup antenna only a wavelength removed from the beam, this twelve foot decrease in spacing can make a radical change in reading; a change which is unfortunately in the wrong direction as regards back-to-antenna readings.

The problem was solved by taking readings on the driven element alone with the parasitic element open at the stub and subtracting the difference in readings so obtained with the antenna rotated 180 degrees. This correction factor was then applied when normal front-to-back meaurements were undertaken. The obvious correction would have been to move the pick-up antenna farther away so that the twelve foot differential in driven element spacing (to pick-up antenna), would be negligible in comparison to the total distance. In our case this was impossible without cloud hooks. Although tuning procedure is very conventional one or two comments may be helpful. At the start, open the stub in the parasitic element then put a small amount of power into the antenna (use very loose coupling to the final amplifier and make certain that the latter is carefully resonated). Solder a pair of heavy wires to a flashlight bulb and use this as the shorting bar on the stub of the parasitic element (an r-f ammeter can also be used). Slide the bridge along until the bulb passes *through* a definite maximum then return to the point of greatest lamp brilliancy. The final amplifier should then be re-resonated and this operation repeated. This position of maximum represents self-resonance of the parasitic element and assuming that the adjustment has been made at the frequency to which the beam is to be tuned, will give a definite check on whether or not the end loading on the parasitic element is sufficient to result in a small tuning stub. This self-resonant point makes the parasitic element a *reflector* (with one tenth spacing), and will result in a very substantial attenuation to the rear of the beam but very little forward gain. We found that this beam rather closely followed all theoretical predictions as to patterns and the maximum forward gain was achieved as a *director* as was to be expected. Again consistant with theory, a critical point can be located where the forward gain does not drop too badly but where the attenuation to the rear increases markedly.

In view of the fact that we would hardly ever be apt to operate on the exact frequency to which the beam was originally tuned, little attention was paid to this critical point and all adjustments were made for maximum forward gain. At this setting the measured gain of the beam was about 4 db over that of the driven element alone. We had previously checked this driven element against a

(*Continued on page 101*)



Curves showing S-W-R vs frequency for four-wire folded doublet working into a 300-ohm line (2-element beam). Note the change in S-W-R and shift in resonant frequency as either antenna or director are directly over a portion of the roof.

the second harmonic is short-circuited, and for most practical purposes, eliminated.

Although there may be second harmonics in many push-pull amplifiers, all of them will not radiate this energy. It must be understood that the second harmonic voltage, due to common series impedance, will be quite low, because the stray inductance is low. Trouble can be expected when the total length of the antenna and feeders is near to an odd number of quarter wavelengths at the harmonic frequency, and the feeders have a fairly high capacity to ground. Then it takes but a few volts to fully excite the antenna, and radiate a great deal of power.

Incidentally, an antenna coupler can not be depended upon to get rid of second harmonic radiation from a push-pull amplifier. In the tests conducted at the author's station, the antenna coupler had almost no effect.

The first suspicion of the "push-push" effect came when a test was made with one of the final tubes removed. When this was done, the fundamental signal dropped but slightly, while the second harmonic almost dropped out completely. More work, with the aid of several cooperating amateurs, unveiled what is believed to be a new understanding of an old problem. Even harmonics do not necessarily cancel out in a push-pull stage.

THE COBWEB

(*from page 22*)

conventional-length two-wire folded dipole mounted at the same height and as near as possible to the same position. W6RBQ and W6ERS at about two miles could detect no difference in the two antennas. This check was made inadvertantly since we thought at the time that we had a beam only to find subsequently that the parasitic element was so hopelessly short as to have negligible effect!

Perhaps we can keep someone else from making the same error if we confess that in our initial setting of the tuning stub we neglected to open this stub at the ends. Therefore the meter was shunted and merely became less sensitive as we moved it toward the closed portion of the stub. The final effect, however, was most realistic and totally deceiving. When the bottom of the stub was opened and the adjustment procedure repeated, it was found that the length had to be increased another 14″ in order to find the resonant point. Since this resulted in a stub about 4′ long, the present end-capacity-loading was devised as a means of reducing the stub to its present length of approximately 18″.

Summary

It is not easy to evaluate the relative merits of any beam since there are so many factors that must be taken into account. Judged from a standpoint of gain, this beam measures up to within about 1 db from the theoretical predicted maximum. This is, of course, merely in a horizontal plane and does not take into account gain at higher angles. From the shape of patterns produced with different adjustments of the parasitic element we can state that this beam appears to duplicate the patterns obtainable with full-length types. It is likewise capable of deep and precise end nulls when adjusted for the type of pattern in which such nulls appear. No compromise has been made as regards the feed system and the S-W-R is very satisfactory when the antenna is properly adjusted. This method of using parallel twin lead to obtain a suitable impedance value at the center of one of the parallel elements offers good possibilities to the users of conventional beams with tubing elements. There is no particular reason why one or two sections of twin-lead cannot be fastened to a tubing element; the connections to the existent element being made at or near the ends and the transmission line connection made to one wire of the twin lead. This should be particularly effective where the tubing element is closed in the center as in the familiar Plunbers Delight beams.

So in summary—The Cobweb:

Come up into my parlor said the Spider to the Fly
I'd like to show you something even Barnum would deny.
He says this thing works broadside—regardless of the bends,
If he tries it any shorter, it will work right off the ends!

SELSYN BEAM ROTATOR

(*from page 28*)

gear crank must be used in the shack to overcome the inertia of the beam. Several methods of showing direction and azimuth will probably occur to you at this point. In our particular case we use a great circle map on San Francisco located where an extension shaft from the selsyn will protrude through the center. A pointer attached to this shaft indicates the direction of the beam antenna.

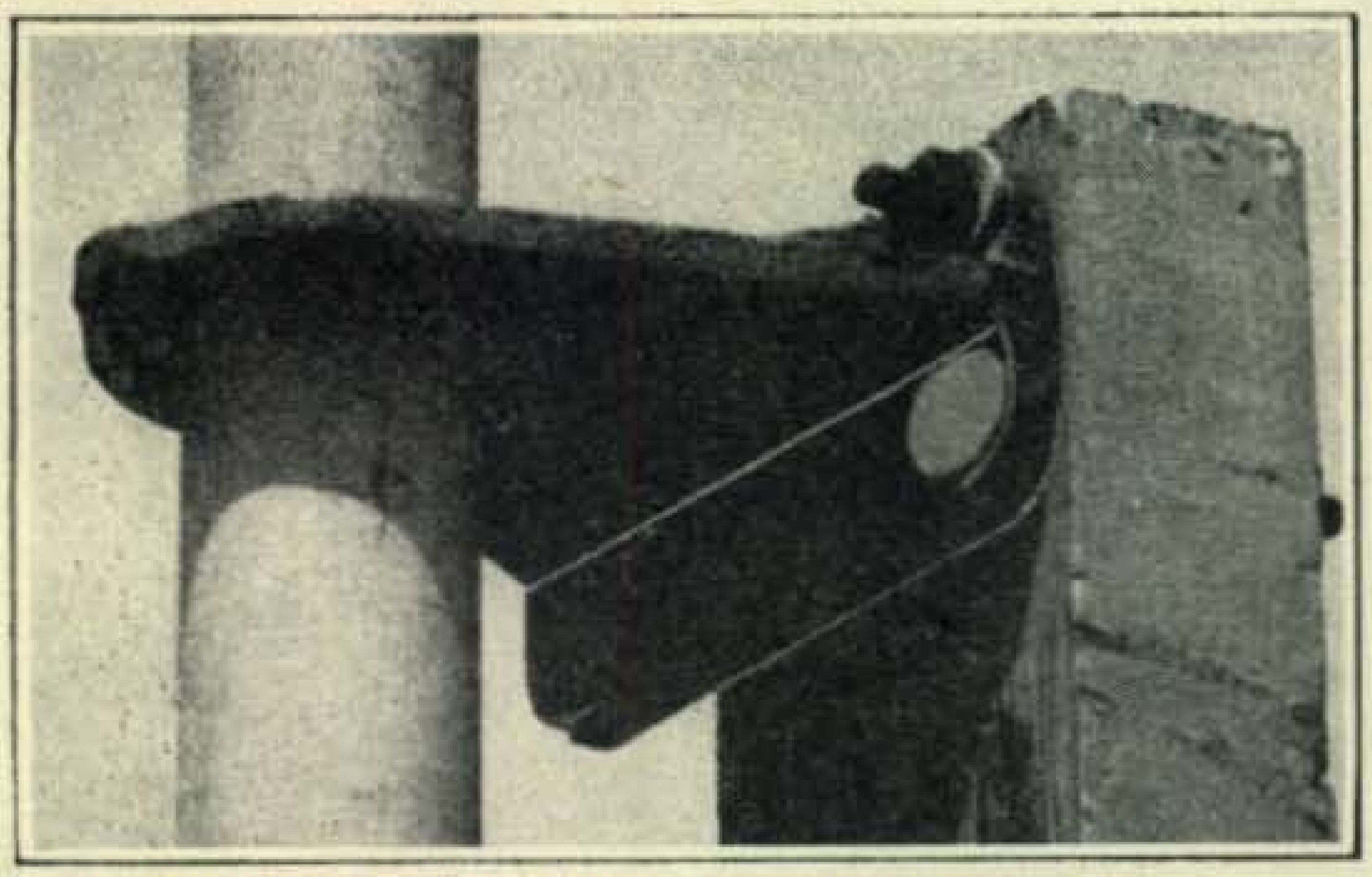


Fig. 3. The Bendix type heavy duty selsyns come complete with two heavy mounting brackets. One of these can be removed and used as the upper bearing for the rotating steeltube. The bracket is supported by a 2x4.

It will probably also be found necessary to incorporate a brake of some sort at the base of the beam to stop it from rotating too much in the wind. This should be one of the electrical solenoid operated type working on the 110-volt a-c line. These relays are currently being advertised and are inexpensive. They should be connected as shown in *Fig. 1* so that when the selsyns are energized for rotation, the solenoid plunger will automatically release the brake band around the steel tube at the base of the beam. The brake band will then be reset when the a-c current is shut off.