a technical discussion

The Cubical Quad

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The cubical quad is a natural development of the folded dipole. Observe Fig. 1. This is a folded dipole. The input impedance is approximately 300 ohms. Now stretch the sides of the folded dipole out so the included angles formed are 90 degrees. Fig. 2. This is now a quad, and the input impedance is approximately 125 ohms. Continue to stretch the sides out and we finally have a shorted half wave line, with an input impedance of approximately zero ohms at resonance. Fig. 3.

We are interested in the quad wire, stretched only half way out, so that a square is formed. As noted above, the input impedance of this configuration is approximately 125 ohms. Now add a reflector ⅛ wavelength (about 8 feet) behind the radiator portion, and the input impedance drops to approximately 75 ohms, a good match for RG11U co-ax.

The power gain of the radiator portion of the quad only approximates 1 db over a dipole. The power gain of a quad with a reflector approximates 7-8 db over a simple dipole. With a properly adjusted reflector stub, or coil, the F/B ratio approximates 25 db. The F/S ratio is even higher.

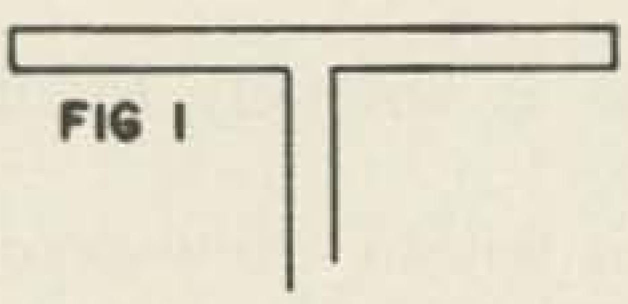


FIG 1

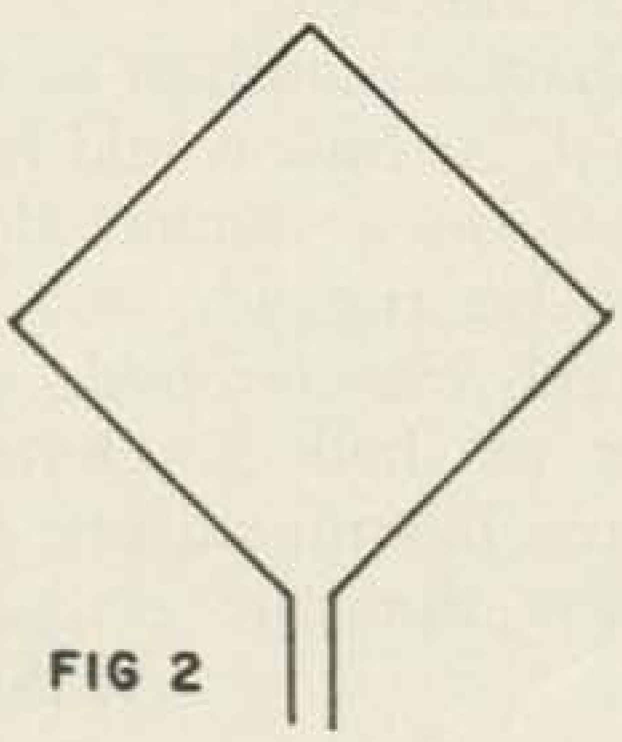


FIG 2


FIG 3

L.T.

The Q of a cubical quad is low. The Q is the ratio of the reactance of an antenna to it's radiation resistance. The advantage of a low Q antenna is that it is less frequency selective, and therefore easier to feed. If the SWR of a quad is, or approaches 1:1 at resonance in the middle of an amateur band, then the SWR rises very slowly as the transmitter is tuned towards the ends of a band. This is a distinct advantage.

It must be understood that the figures mentioned above concerning F/B ratios and gain figures, may vary considerably from those mentioned, due to local conditions. They may be greater or less. The height above an effective ground, the presence of nearby objects, etc., all affect these figures, either for better or for worse.

The half power point of a quad is approximately 75 degrees. It is truly a broad band beam. Of course, the F/B ratio will vary as the quad is tuned away from resonance, but it varies rather slowly, and may be considered as good at any place in the amateur band, if the quad is resonated at the center of the band.

The total length of wire for a 20 meter quad should be 844" for the 15 meter quad 575 inches, and for the ten meter quad 414 inches.

These figures change somewhat when a quad is built for three bands on a single framework, as shown in the diagram, Fig. 4. In general, the sides of the quad for 20 and 10 should be modified somewhat, and made somewhat less, due to the fact that the 10 and 20 quad wires are pulled in to the feed point of the 15 quad. This reduction, in the case of the 20 meter quad is about 4 inches per side less and in the case of the 10 meter quad, the reduction in length is approximately 2 inches. If this is not done, the bands in question will resonate somewhat lower in frequency. This will not materially effect the operation, however, and may be ignored in the practical case.

14.0-40 ohms	14.2 -70	14.4 -80
21.0-50 ohms	21.22-50	21.35-50
28.0-50 ohms	29.0 -50	30.0 -80

Fig. 5

The quad is particularly suited to multiband construction, as shown in Fig. 4. A single framework will hold all three quads very nicely. In fact, the three band model is more rigid than a single quad. There is no noticeable reaction between quads when the multiband quad is used.

A single feed line may be used to feed all three quads, and no switchover system is needed or desired. The input impedance, as measured on a three band single feed line system, is as shown in Fig. 5. This indicated that the feed line may be either RG8U or RG11U. Use 8U if xmtr output x req. The SWR on the three bands has been measured as indicated in Fig. 6.

A quad may also be constructed for 40 meters, but the size is such that it first must be determined whether or not there is room for erection. The length of a side would be approximately 35 feet and the boom length would be 16 feet.

The reflector portion of a quad must resonate at approximately 5% lower than the radiator. This may be accomplished by the use of either a tuning stub, or a reflector coil. The reflector coil is compact, and needs no arrangement for holding the ends. A stub is somewhat easier to tune correctly, but is more cumbersome, and needs an arrangement for holding the stub in place. A stub arrangement is a likely arrangement for a single quad, but the coils are much superior for a three band quad, due to the complicated lash up necessary where three stubs are used. A reflector coil may consist of several turns of wire wound on a one inch diameter, non-hygroscopic tube. The same wire as used for the quad elements may be used for the coils. No. 14, enamelled copper wire is recommended, as it will carry a full kilowatt with ease.

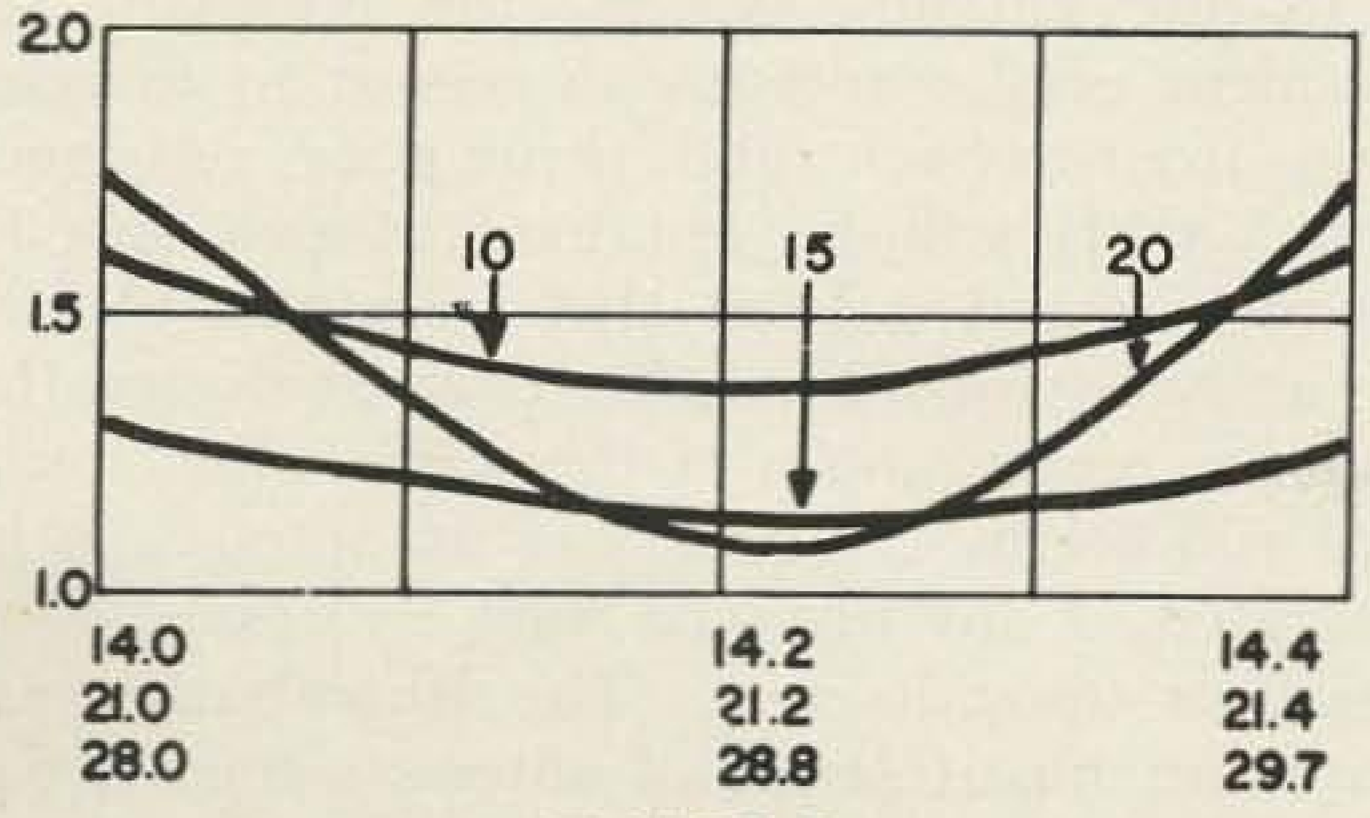


FIGURE 6 L.T.

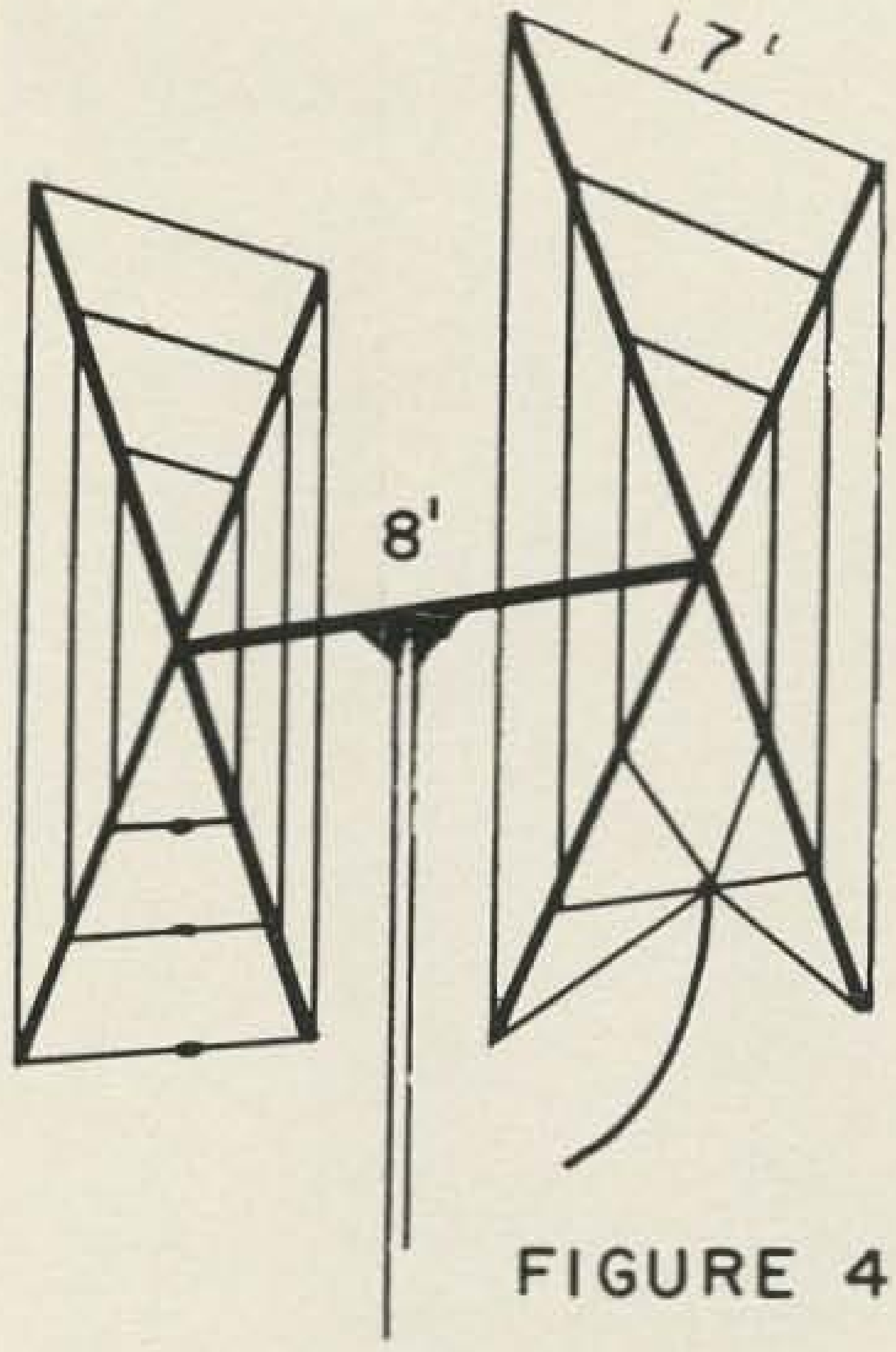
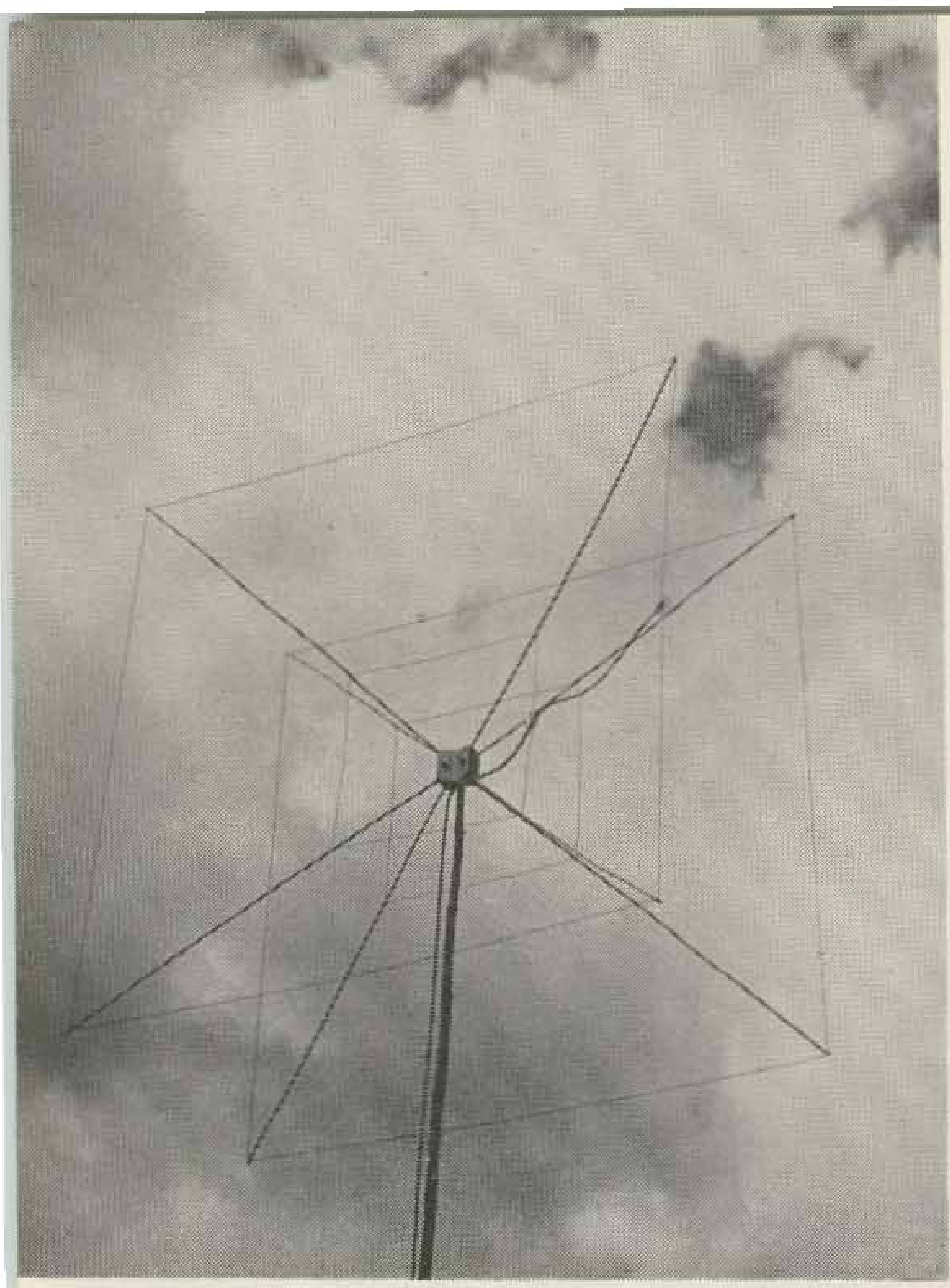


FIGURE 4 L.T.

Quad spreaders may be either of bamboo or fiberglass. The bamboo spreader will last for several years if properly treated with several coats of alkyd resin enamel. Another way to treat bamboo is to spiral wrap it with plastic tape, wrapping from the small end. It is well to dab the bolts which hold the quad wires with a bit of roofing cement to prevent entry of water in this case.

Fiberglass spreaders are of course, ideal for spreader arms. They deteriorate but little from the weather. They are even lighter than the bamboo, and are extremely resistant to lateral stresses, although they can be crushed by dropping a heavy weight on them. Of course, they are absolutely straight, while bamboo is not. They are more expensive, of course. They need no treatment against the weather whatsoever. Bamboo should be bought in 20 foot lengths, and cut to the 12½ feet necessary for the spreader arms, in order to have a reasonably large tip at the outer end. Curved washers should be used to fasten the bamboo or fiberglass to the end spider, and they should also be used in either the bamboo or fiberglass where the quad wires cross. This distributes the pressure of the bolts over a greater area than if flat washers were used.

A quad is truly an outstanding performer on the amateur bands. It possesses all the desirable qualities of a good beam, namely, reasonably low cost, good gain, good F/B ratio, and low Q tuning characteristics. It is an easy beam to feed, and seldom, if properly made and adjusted, exhibits appreciable reactance at the load. Check the signals, on the air, of amateurs using cubical quads. They are almost invariably outstanding. . . . W4YM



A Two Band VHF Quad

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Photo credit: Bob Jensen W6VGO

The Quad is no longer a "new" antenna but it is showing every sign of never becoming an old antenna. The unique structure and performance of these beams has made them a subject and the objects of continuing interest to radio amateurs. In short, the quad seems to be here to stay. The first cubical quad was devised by W9LZX while he was associated with missionary radio station HCJB near Quito, Equador. That first quad was cut for an International Short Wave band and was beamed on the United States; later W9LZX, using the call HC1JB, used a quad on the 20 Meter ham band. The rest is a part of amateur radio history. The quad caught on and has snowballed to become one of the most popular DX antennas in the world.[1] The simplicity and efficiency of this antenna type makes it an excellent array for the high frequencies and it is finding increased favor as a VHF radiator and collector.[2]

A most casual survey of antennas for HF and VHF will reveal those qualities that are sought by the amateur who intends to build his own beam. An antenna that is attractive is one that will render reasonably consistent results and which can be constructed and used with a minimum of folderol. The Quad is such an array. In its simplest form, a quad is a one wavelength driven loop with an adjacent parasitic reflector. The reflector is spaced from one-tenth to one-quarter of a wavelength behind the tuned square and caused to be self resonant at a frequency about 5% lower than that of the Antenna element. This combination will produce a two element beam that is capable of a 5 db forward gain, a front-to-back ratio of 15 or more decibels and a low radiation angle.

In any antenna system, the optimum adjustment of the antenna in regard to forward gain, front-to-back ratio, drive point resistance and VSWR will be obtained at one specific frequency and only at that frequency. When an array is worked at other than its design frequency, compromises of the above characteristics will occur. The ability of an antenna to be operated at any distance from its design point depends upon its type. The Rhombic is perhaps the most tolerant of antennas since it can be operated over a 2 to 1 frequency range. A quad will perform very well from 3% below its design frequency to 5% above that frequency and it is for this reason that quad frequency placement is often toward the low end of the amateur band for which it is cut.

The light weight VHF quad shown in the photographs and diagrams was designed to provide a simple two band beam that would offer a reasonable measure of gain, an effective degree of directivity and economy of construction. The true "cubical" quad has a spacing between the driven element and the reflector of one-quarter wavelength; this gives the array a cuboid outline. As a practical matter, the cubical quad is more difficult to build and will render less forward gain than some other quad forms. Field tests have indicated that the element spacing that will give the highest gain—5.7 db—is one-eighth wavelength.[1] $\lambda/8$ pacing can be developed without a boom and is the spacing used in this VHF quad. The plywood spreader support used in its construction causes the relative spacing of each antenna in this array to be the same. In a free-space situation where a quad's environment is perfect and its reflector is properly tuned, the amount of space between the driven element and its reflector is the principal drive point resistance determinant. This means that under certain conditions one transmission line can be caused to match, or nearly match, either of several driven elements.[3] This is possible just as it is possible to work more than one dipole from a single feedline when the dipoles are suspended at a proper height above the ground.[4] Ordinarily, we could expect the $\lambda/8$ spacing between the elements of this VHF quad to create a radiation resistance of about 60 ohms. This impedance figure presupposes that the ground is moderately conductive and that foreign objects such as trees, power lines, the mast, guy lines and other quad elements exert no influence over the behavior of the quad. Such a model situation seldom, if ever, exists and for that reason the feed point impedance of each driven element is considered to be in the neighborhood of 52 ohms.

Construction

The construction of this quad begins with the spreader support block. Two identical plywood plates (Fig. 1) are glued together with Weldwood cement to make one strong unit. The dimensions of each plate can be drawn on the ¾" plywood stock to facilitate the sawing. Any kind of fine toothed saw can be used to make these cuts but a tilt-head sabre saw or a table saw will make this work fast and easy. The tongue of wood that remains after the slot cuts have been made can be removed by scoring and delaminating with a wood chisel or a sharp screwdriver. Square blocks are not used to make the spreader support because they will not produce the desired aspect ratio when the plates are assembled. The corners are trimmed to make flat surfaces for the drilling of the spreader socket holes. These holes, which should be made after the spreader diameters are known, should be piloted with a small drill prior to the final boring. Slight drilling errors at this stage of the construction will be magnified into larger errors when the spreaders are mounted—so much care and enough time should be spent here. In the building of the prototype of this quad, the holes were made with an electric hand drill and a small liquid level was used to make sure that the drill was perpendicular to the work. After the plywood block is completed and the cement has set, the holes for the U-bolt mast clamp can be drilled. The U-bolt can have a throat size of 1¼ to 1⅜ inches and must be at least 3¼ inches long. The "V" saddle formed by the joined plywood plates serves as the other half of the mast clamp as shown in Fig. 2.

The spreaders used in this quad are made of bamboo. These particular bamboos are 4 foot plant stakes which are standard nursery items

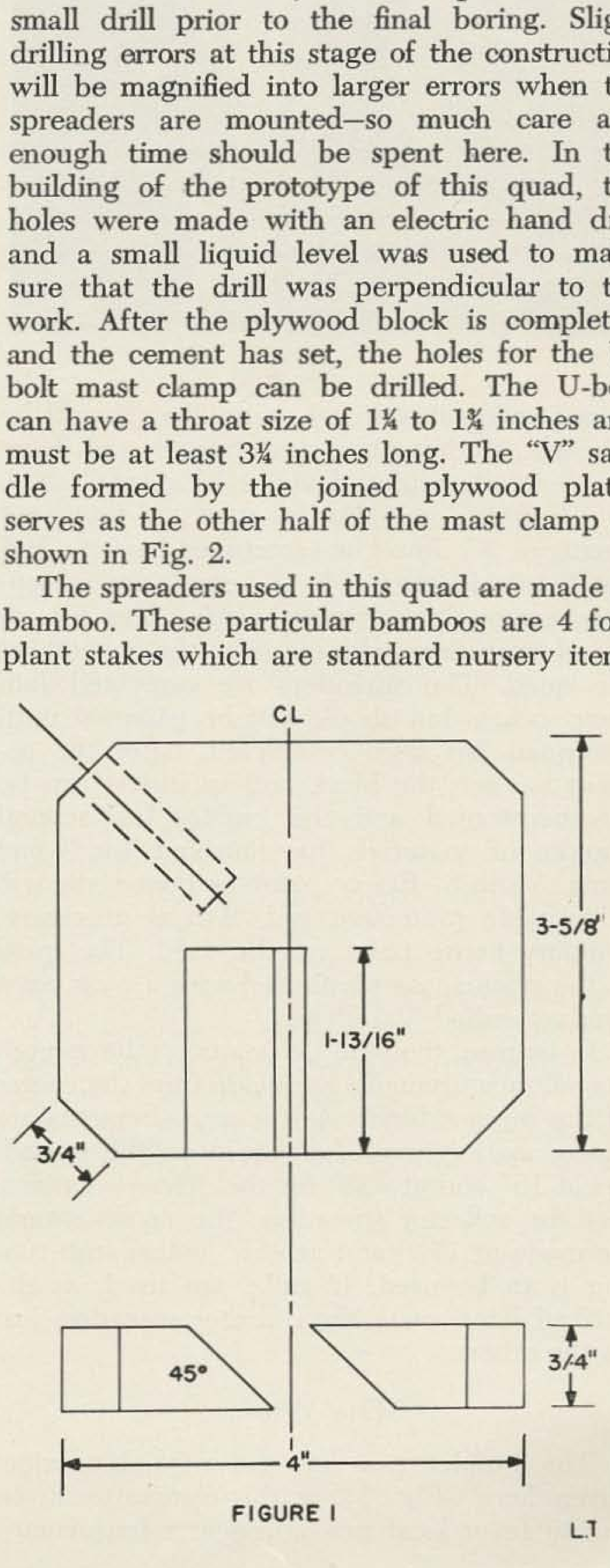

FIGURE I

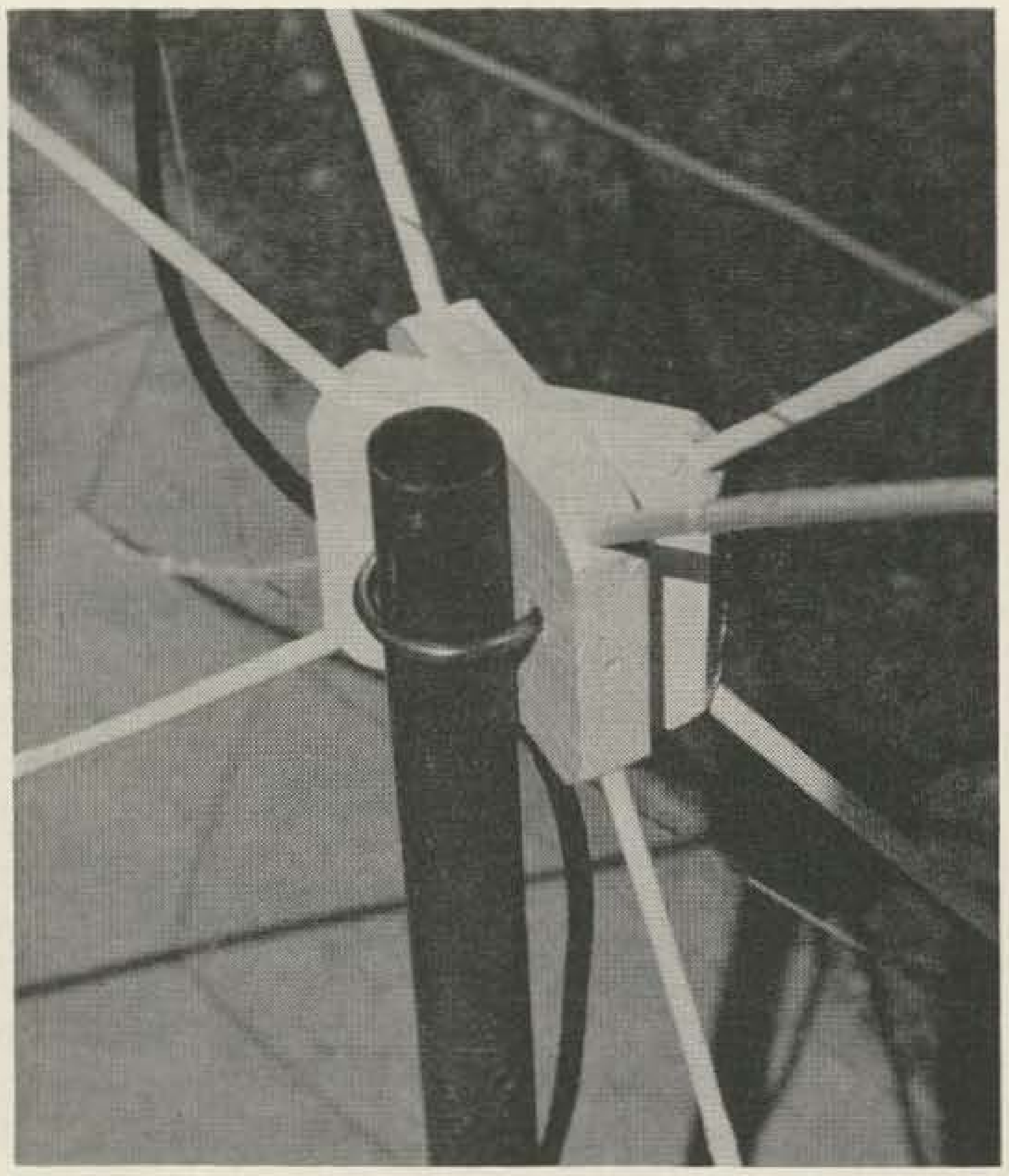

Fig. 2

priced at about a nickel each. They should be selected so that they are straight and have base end diameters of about ⅜". Dowel stock of ¼" to ½" can also be used. A four foot length of ⅜" dowel is sometimes hard to find but 8 foot lengths of 7/16" stock are reasonably common at lumber yards. The use of dowel spreaders will increase the weight of the quad. The spreaders are cemented into their sockets but should not be trimmed until the quad has been completed. After the cement has set, the block and spreaders can be weatherproofed and the builder has several choices of materials for finishing the wood parts. Varnish, Epoxy paint or boat resin will all provide protection and, if it is necessary, ordinary house paint can be used. The quad in the photos was plasticized with a west coast product called Varathane.

In figuring the wire tie points on the spreaders, all measurements are made from the center of the support block. As the measurements are made, marks should be placed on the spreaders at 15" and at 43½" for the driven elements. For the reflector spreaders, the marks should be made at 15¾" and at 45½" unless stub tuning is to be used. If stubs are used, as described later, mark the reflector spreaders just as the others.

The Wires

The builder can use the wire dimensions given here (Fig. 3) or the elements can be cut to favor local net or repeater frequencies. The inch is handy for VHF use and will lead to less annoyance than will the use of feet and decimal fractions of the foot; to compute the length, in inches, of each side of a driven element: the design frequency, in megacycles, is divided into the constant 2976. The reflectors of this beam are stubless and their dimensions are based upon dead reckoning. That is, each reflector is made 5% longer than its associated antenna element. This method of reflector construction was chosen for the following reasons. An oversized reflector can be made up, installed and used with no instrumentation; the absence of a stub will avoid any distortion of the radiation and collection patterns that sometimes occurs with stub use; the oversized reflector will increase the *effective aperture* of each quad section and will enlarge the capture area of each of the antennas. Stubs can, of course, be used to artificially lengthen the reflectors and their use in quad construction is common. When stubs are used they should be in the form of 3" open wire ladders which are closed at their bottom ends. The stubs can be insulated and separated with three-inch plastic spreaders or the old stand-by: dowels which have been boiled in wax or paraffin. The stubs are inserted into the centers of the bottoms of the reflector wires.

Using solid or stranded wire of #16 to #20 gauge, the antenna and reflector squares should be carefully planned. After being freed of kinks and having been stretched slightly, the wires can be measured and marked off with nail polish. The wire marks should be made at those points that will become corners when the loops are attached to the spreaders. Each

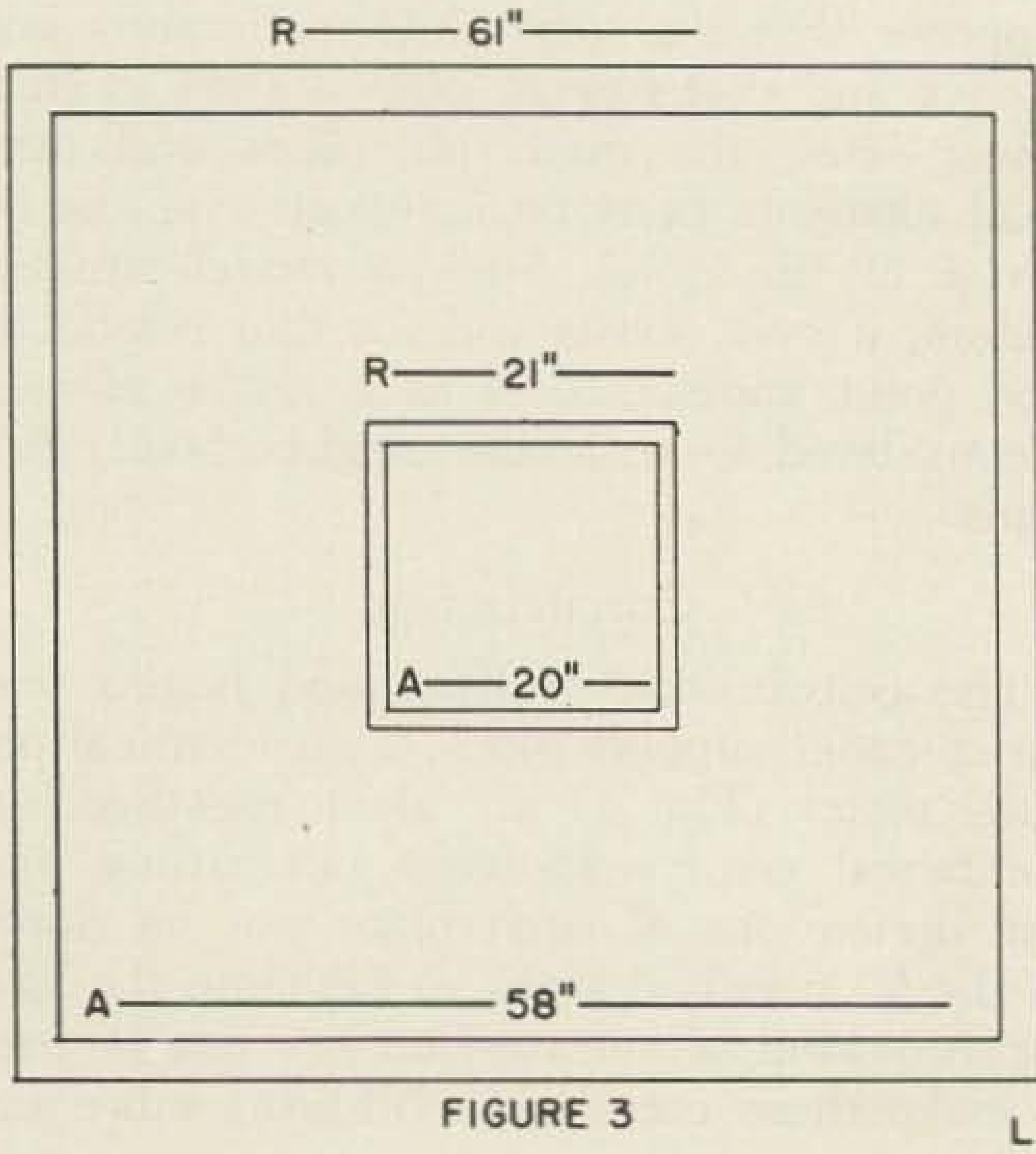

FIGURE 3

wire element is attached to the spreaders with 15 pound test soft monofilament fishing line. A series of clove hitches and square knots can be used to secure each wire corner to its proper spot on the spreader. It's easier and neater when the monofil is tied to the spreader first. After the monofil is trimmed, the ends can be burred with a hot cigarette to prevent unraveling. The insulators used at the feed points of the driven elements should be small and light. 1" slugs of plastic, drilled to accept the wires, will work fine and a toothbrush handle will furnish enough insulators for the whole project. The drive points can be waterproofed by enclosing them in small plastic boxes as shown in Fig. 4; the boxes can be sealed with model cement.

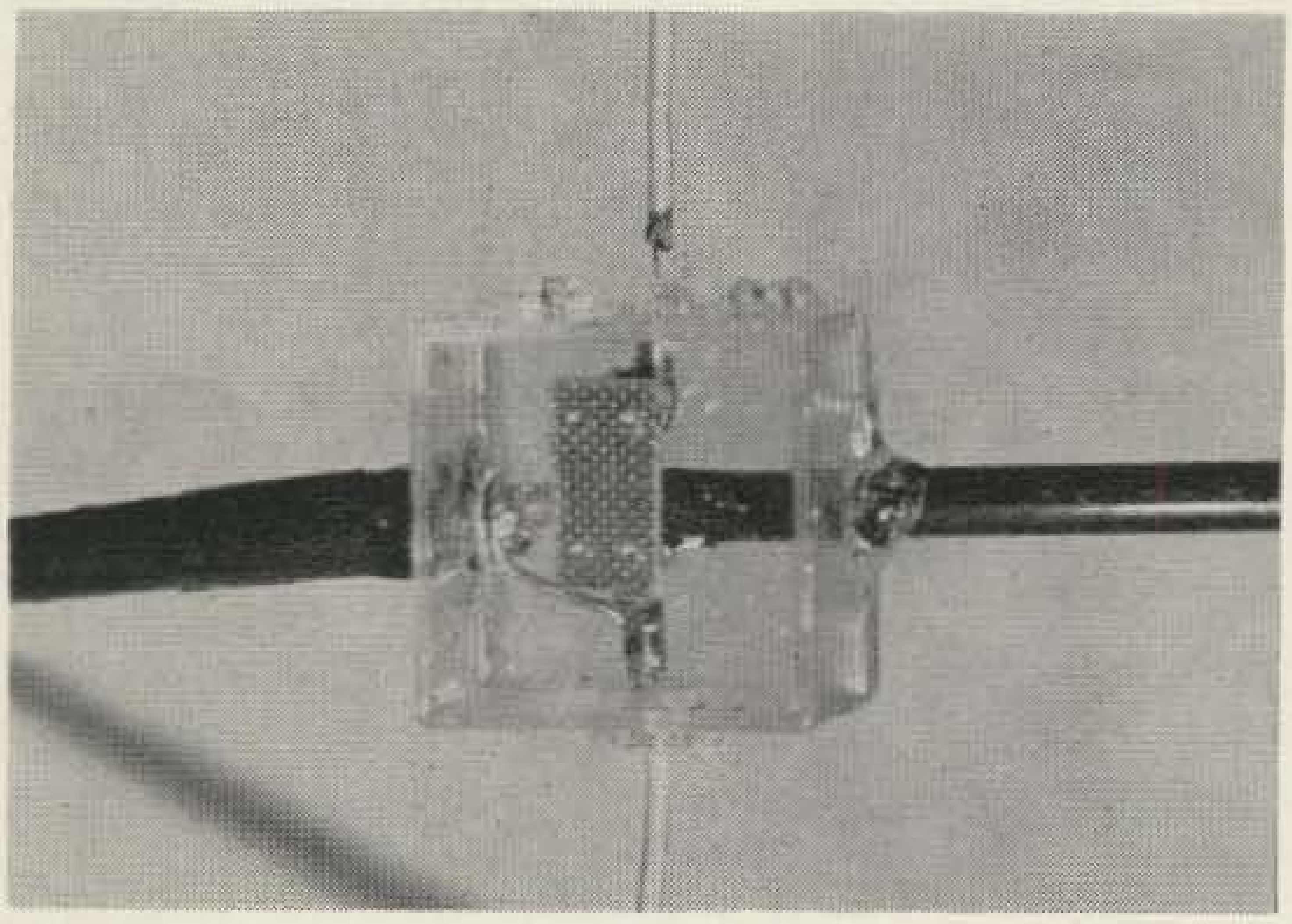

Fig. 4

This quad is light and is not very big but it will be found that element attachment goes easier if the block and spreaders are supported while this work is being done. If the block is clamped to a section of mast and the mast is held horizontally in a bench vise, it will be possible to walk around the spreaders to make the wire ties without too much difficulty. The 2 Meter elements should be attached first. Another way is to position the quad frame on the seat of a kitchen chair so that the ends of the spreaders will be free for work. When the 6 Meter wires are tied to the spreaders, it is possible that the marks on the wires will miss the marks on the spreaders by as much as an inch. This can happen due to small sawing or drilling errors or because one or more of the spreaders is slightly crooked. Such small errors won't affect the performance of the array. After all of the wire elements have been attached, a 30" monofil stay should be tied between the spreaders—from the front to the back—at each 6 Meter corner. The monofil stays will add no appreciable weight and will true up the quad frame geometry and stabilize

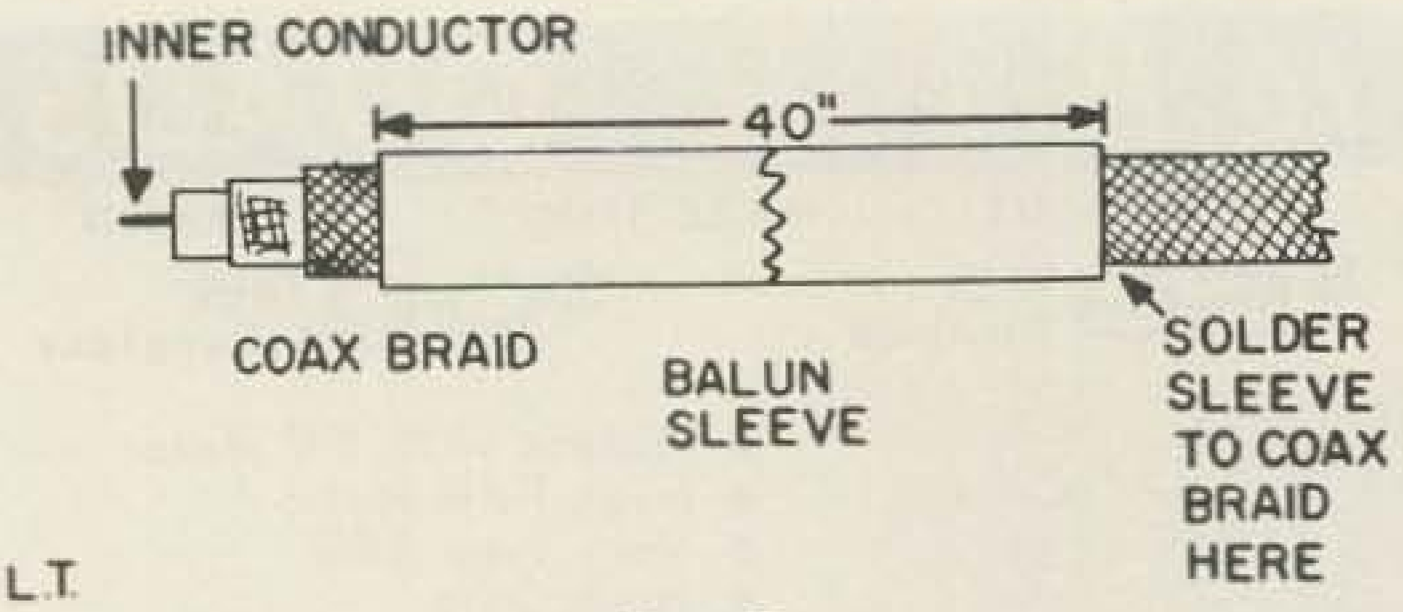

Fig. 5

the antenna mechanically.

The Feedline

We are all familiar with the classic transductance equation in which the generator, the line and the load all possess the same characteristic impedance and in which there are no balanced-to-unbalanced problems. Under such an arrangement, the only losses that are incurred are the natural losses imposed by the rf resistance of the feedline. Unfortunately, this ideal situation is rarely enjoyed by the radio amateur. Feeding quads is like feeding other antennas in that it is sometimes necessary that we use devices or tricks in order to get the rf energy to and from the quad's feed points with a minimum of loss. The quad is a balanced antenna and should be treated as such; this means that the most elementary form of transmission line that may be used with the antenna is a two conductor balanced affair such as open wire or twin-lead. For the sake of convenience, however, coaxial cable is more often used. The use of coax at the transmitter end is simplicity itself since it is usual but necessary that the cable be connected to the pi-net matching circuit, or the output link, of the rig. But when coax is used, two bugbears present themselves: it becomes necessary that some form of balun be employed to satisfy the balanced quad; and coaxial line losses are high—particularly at VHF.[5] Practical solutions to these problems exist and they will be partially catalogued here. The builder has the choice of several functional feed methods and it will be assumed that the quad will be used with an unbalanced shack termination in both the transmitter and the receiver.

The simplest and roughest way to feed a quad with coax is to cause the antenna to display a radiation resistance at each of its driven elements that will approximately match the impedance of the coax and then just solder the braid and inner conductor to the driven wires where they are brought together at a common insulator. This drive method ignores the fact that the quad is a balanced array—but it works. In fact, it works better than it has a right to. Many quads are fed this way at the High Frequencies and they turn in creditable performances. The drawbacks to this arrangement include: feedline radiation, deceptive SWR readings and a directive skew in the radiation pattern. Where such a feed method is used, feedline radiation can be reduced by the use of a coaxial "balun." This is an electrical quarter wave of coax formed into a king sized doughnut and bound with tape. This type of "balun," which is really more of an rf choke, is situated near the driven element feed point. The extra loss introduced by this device is not attractive at VHF and it is not particularly recommended.

The Gamma match is an excellent system for meeting both the impedance matching and the unbalanced-to-balanced problems that go with quad feeding. This tuned transformer is described in detail in the ARRL *Handbooks* and in the W6SAI book, *All About Cubical Quads*. The most satisfactory single-line feed method for the multiband quad revolves about the use of the Gamma match and it will produce the lowest true voltage standing wave ratio that can be obtained. The Gamma matching procedure is, however, lengthy and complex and requires some things not found at every hamshack; a crank-up tower, good instrumentation, waterproof variable capacitors and much time and patience.

The Sleeve Balum,[1, 6] which is recommended for this 6 and 2 quad, is handy as a transmission line modifying device. (Fig. 5). Sometimes called the "Bazooka," this type of balun will change a coax from an unbalanced cable into a balanced line without transforming the impedance greatly as does the "Trombone" balun. To feed a quad with a sleeve baluned single coax is possible if the quad is for one band or if it is built for two bands having a 3 to 1 wavelength relationship. 40 and 15 meters for example. This is feasible because $\lambda/4$ on 40 is ¾ of a wavelength on 15; thus sustaining the "odd number of $\lambda/4$" requirement of the sleeve balun's electrical dimensions. The same concept allows the practical, if not exact, use of a 6 meter sleeve at both 6 and 2 meters. The balum sleeve is the same length, 40", whether it is made with RG 8 U or RG 58 A/U because each cable has a velocity factor

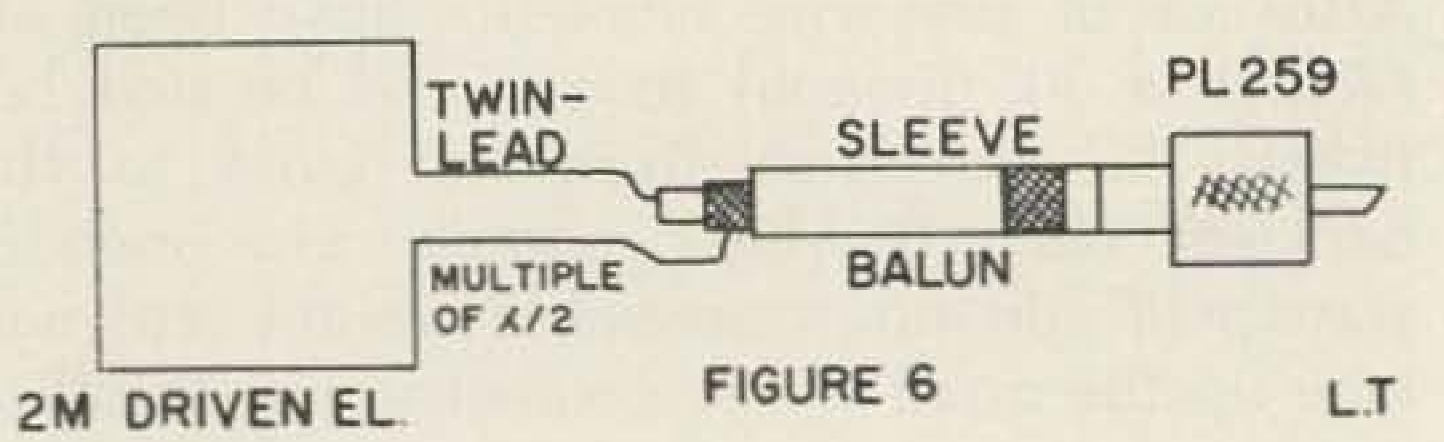

FIGURE 6

of dot sixty-seven (.67) and an electrical quarter-wave is 67% of a yardstick quarter-wave. The sleeve can be made of woven braid of the type often used for flexible bonding straps. Getting a Meter of braid to slip on a coaxial cable can be quite a tussle and it's easier if the braid is put on in several short lengths and joined with solder after the sleeve is completed. At the builder's option, the sleeve can be made by winding bare copper wire upon the coax in the manner of a long coil. The sleeve bottom is soldered to the coax braid and should then be waterproofed with pre-warmed plastic insulating tape. If the quad is built for 2 Meters only, make the balun sleeve 13½" long. When coax is used entirely, the sleeve is installed at the load end of the line; but if the line run exceeds 60 or 70 feet the coaxial losses will become high, especially at 144 mc.

An inexpensive and more efficient line can be made of open wire or twin-lead. In this arrangement, the balun is made up and used at the shack end of the system as indicated in Fig. 6. The balanced output of the coax is connected to the open wire as shown. The common types of twin-lead or open wire obviously will not impedance-match either the quad or the balun; so the line must be cut to a multiple of an electrical half-wave.[7] The velocity factor of household twin-lead is .82 and a 300 ohm line can be any multiple of 95". Typical lengths might be 47′ 6″ or 63′ 4″. Clearly, the tuned line will not be right on the nose for each band, so the following procedure is suggested: make the twin-lead line 8 inches longer than its computed length and check the SWR on each band as the balun connection point is tapped back toward the computed "mark." This way, the feedline can be trimmed to a spot that will be compatible with each of the driven elements. Open wire lines are affected by environment and should be transposed—by twisting—to cancel the effects of nearby conductive objects. Twin-lead can be treated with silicone compound so that moisture will not cling to upset the qualities of the line.

It is also possible to feed the antennas by using open wire and a pair of "Trombone" baluns.[8] This method requires a balun at both the sending and the load ends of the line. The use of a multiple λ/2 wire line and balun combination can cause the drive point impedance to be mirrored to the transmitter and good transconductance will be obtained.

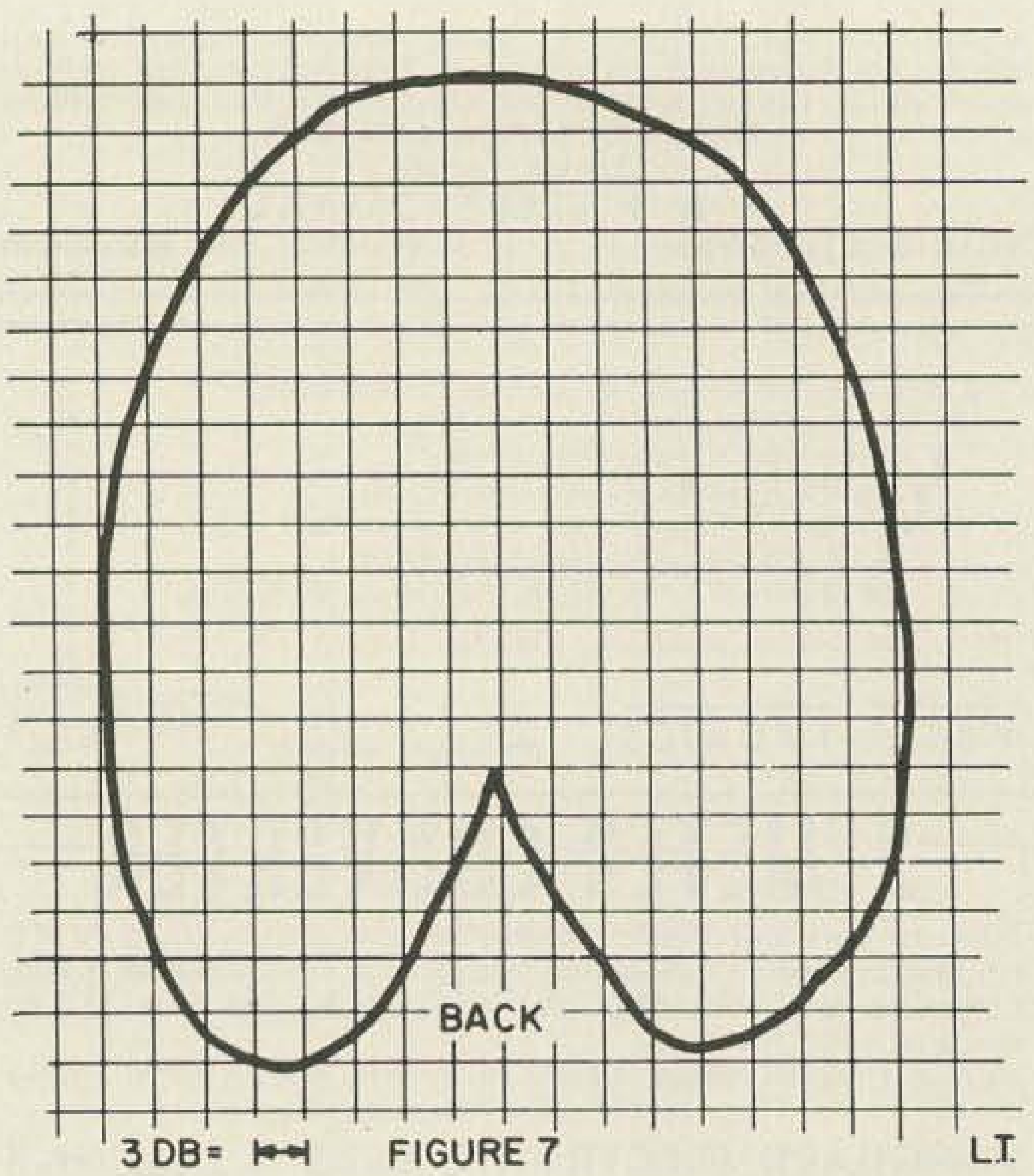

FIGURE 7

Feedline Connection

The balance corrected load end of the feedline is soldered to the 2 Meter driven element. A 20" length of coax is connected from the 2 Meter drive point to the 6 Meter driven wire. It may seem strange to use an unbalanced coax for this link but if open wire were used here, the 6 Meter driven element would see the open wire link as an extension of itself. This would cause the antenna to be self resonant considerably below its design frequency. The coax link is less than λ/4 at six meters and thus does not assert its character and becomes two pieces of wire—one inside the other.

SWR

The most familiar indicator of the feedline to antenna impedance match is the old boomerang factor—SWR. If a quad is operated with an SWR in excess of 2:1, two things will occur; the directivity will get soft and line losses will be higher. A high SWR will create an rf loss factor that increases as the line is lengthened. In a very long line, the standing wave ratio can be deceptively low because of the line loss presented to the returning reflected signal by the long line.[9] The design frequency SWR's of this quad were checked as the quad was being fed with a line and balun made of 30 feet of RG58 A/U. The signal sources were a modified Collins MBF and a Gonset Communicator II. Readings of 1.25:1 and 1.65:1 were obtained at 6 and 2 meters, respectively, on a Heath Kit AM 2 reflectometer which was strapped for 50 ohms.

Adjustment

This quad has been built for vertical polarization because it is very popular in the Los Angeles area. If horizontal polarization is desired, feed the driven elements in the centers of their bottoms instead of their sides. If the antennas are fed at a corner, oblique polarization will result.

If the quad is built with the pre-cut oversized reflectors, adjustment is not intended. It should be realized, though, that the optimum front-to-back ratio and forward gain relationships may not occur precisely at the design frequencies. When 3" wide stubs are used, they should have initial lengths of 9" for Six and 3" for Two Meters. The stubs can be experimentally shortened, if F/B improvement is sought, by shortening the stub with a shorting bar made with a crocodile clip at each of its ends. Such tests are more easily conducted with the receiver tuned to a properly polarized carrier which is several miles away and which is free of reflections from mountains or other objects that can obscure the polarity and the directivity of the sent signal. It will be found that the directivity patterns of this antenna will be different from those charts which have been published for horizontally polarized quads. One of the most noticeable characteris-

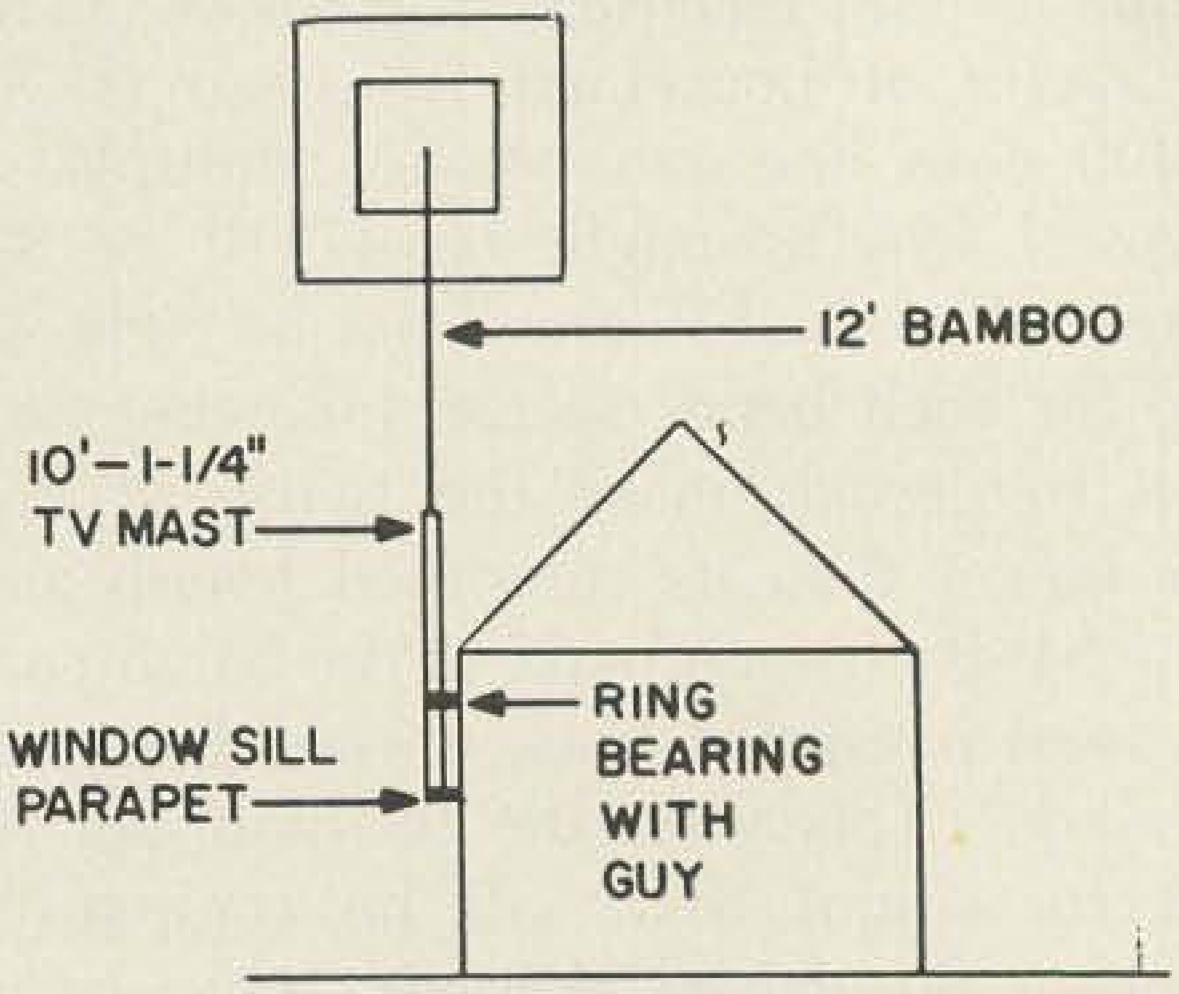

FIGURE 8

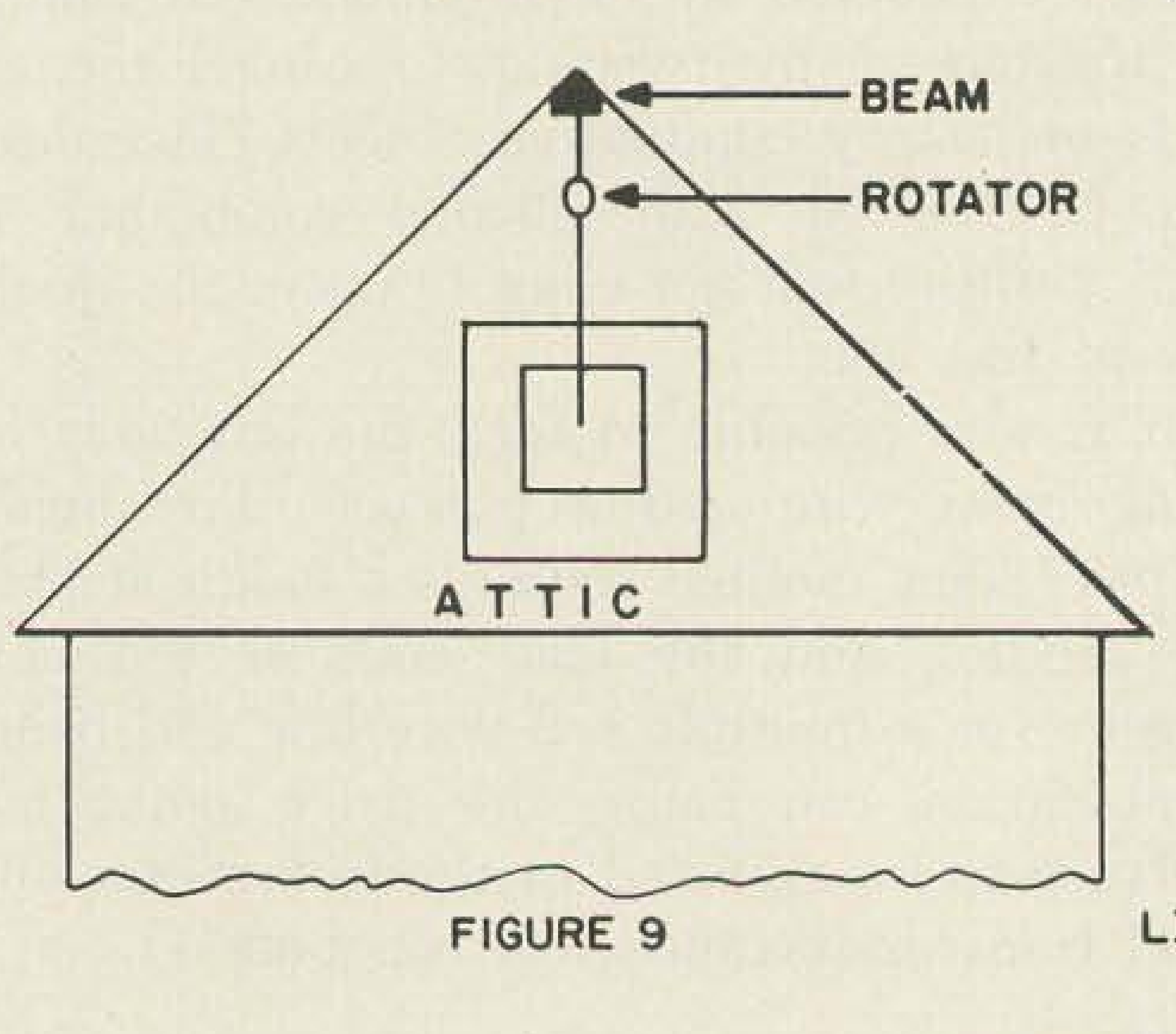

FIGURE 9

tics of any horizontally polarized array is its dramatic front-to-side ratio; but this effect is not as pronounced in the vertically polarized quad. This 6 and 2 meter antenna has a cardiode pattern as shown in the graph of Fig. 7. This collection pattern was plotted on six meters over a clear optical path between Mount Wilson and the San Fernando Valley. In this case, the receiving equipment used was a Hallicrafters SX 110 and a Vanguard converter. The reflectors were not adjusted in any way and Fig. 7 shows the kind of directivity that can be expected by the builder. As compared with the front, signals fall off 15 to 20 db on the sides and back; the slot in the center of the back may be as much as 42 db deep. This rejection slot is handy for excluding unwanted signals and can be used to prevent receiver overload when strong locals are being worked. When making tests for front-to-back and front-to-side ratios, the checks should be made under several path conditions before any major correction is applied to the antenna. Misleading readings can be obtained due to the many factors which may disguise the true performance of the array. If your station receiver has no "S" meter for making these comparisons, the antenna can be checked by sending to a station having such an indicator. A field strength meter can be used for checking the quad but it should be at least 500 feet away from the transmitting site.

Masts

The light weight and small size of this array permits a variety of support systems to be used to get it up to a useful height. The operating parameters of this quad require that it be at least one half-wave above the ground, or a metal roof. This works out to be only ten feet at six meters and presents no real problem. The quad in the photos is worked on a 12 foot bamboo pole which has a 10 foot length of TV mast ferreled onto its bottom end. This combination is manually rotated in a pipe socket which was driven into the ground just outside the shack window. This arrangement requires no guys and is easily dismantled for Mountain Topping and other field work. Another support and rotation method which suggests itself is the use of an upstairs window sill parapet as the mast support. (Fig. 8). With this arrangement, the mast should be bearing guyed as it passes the eave of the roof. The short turning radius of this 6 and 2 beam allows it to be used within an attic as seen in Fig. 9. The builder can attach this quad to a previously erected fixed or rotating mast as the antenna is being assembled. Construction of the array is carried out as described earlier except that the reflectors are left off. They are added after the quad has been clamped to the mast. A motorized or lanyard operated flip-flop arrangement can be employed if frequent polarity changes are desired.

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