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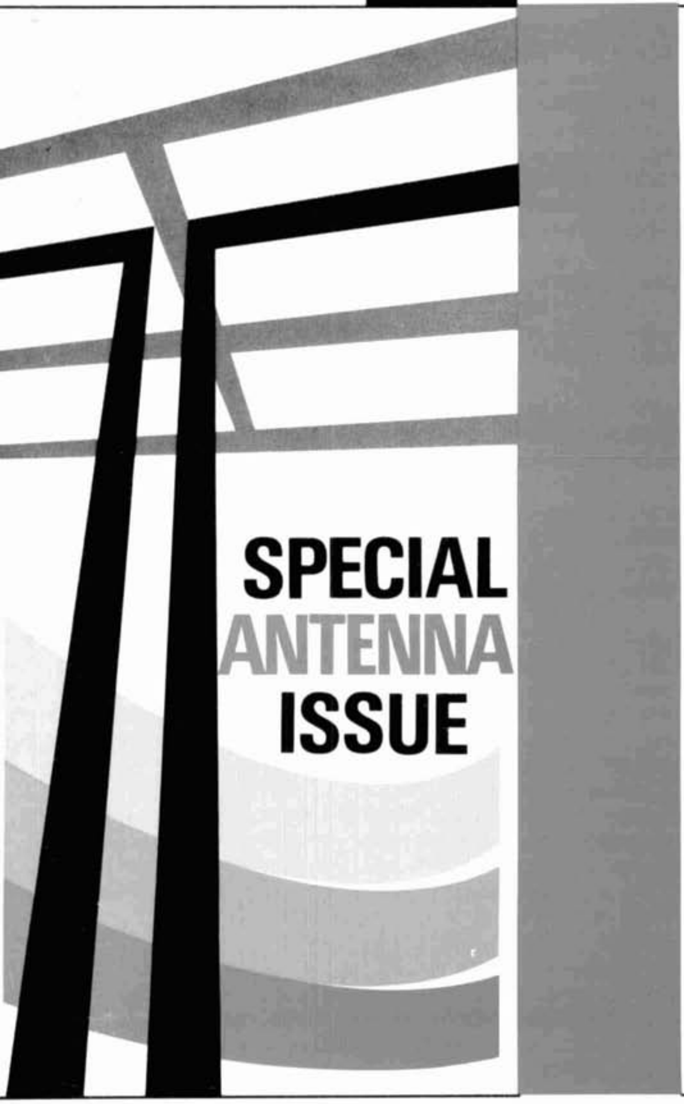

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may 1970
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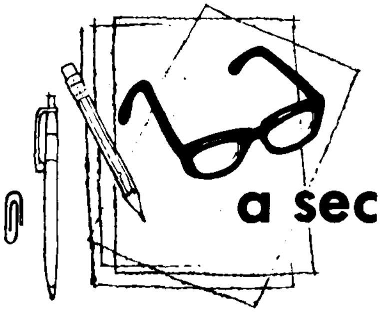

a second look

by jim fisk

If you're interested in amateur vhf fm, you've probably already heard about the new FCC docket that details proposed rulemaking concerning amateur repeaters. The docket is the result of several rule-change proposals which have been submitted by interested individuals and organizations. The FCC commissioners read these "free lance" proposals, add other information they may have at their disposal and prepare a docket which reflects what *they* feel best suits the needs of the amateur service.

The new docket, Docket 18803, has drawn strong criticism from repeater enthusiasts who feel that the restrictions it proposes would serve to make it practically impossible to legally continue operating vhf fm repeaters! The proposed frequency changes—if the docket becomes law—alone would cost amateur vhf fm enthusiasts hundreds of thousands of dollars in new crystals! Never before has the Commission tried to dictate frequencies as outlined in Docket 18803—I wonder if this portends things to come on other amateur bands?

In addition to the receiving and transmitting sub-bands proposed in Docket 18803, it is proposed that the repeater log include only the time and date of the periods the repeater is available for service, as well as entries indicating the technical and operation condition of the repeater. It is also proposed to amend the present identification rule to permit automatic repeater identification by *CW* at intervals not to exceed three minutes.

Furthermore, Docket 18803 proposes that a repeater be designed so that it will normally be activated only by means of a coded signal or other means which will effectively exclude transmissions by stations not desiring to work through the repeater, thus minimizing unnecessary transmissions and the possible resulting interference (the coded signal may consist of a single audio tone so the repeater can easily be "whistled on"). Possible interference is also cited as the reason for outlawing simultaneous re-transmissions on two or more bands and cross-band operation. The proposed receiving and transmitting sub-bands are obviously a result of the same thinking.

However, the sub-bands tend to subject the repeater user to QRM problems while purporting to protect an unknown amateur not interested in repeater operation. How unnecessary, and unworkable, especially on the 420-MHz band. The specified channel spacing is too close for most of the equipment available to amateurs. Furthermore, when the present commercial equipment is surplus and available to amateurs, some of it will be useless because it is designed to work

(continued on page 75)

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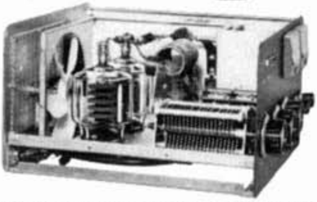

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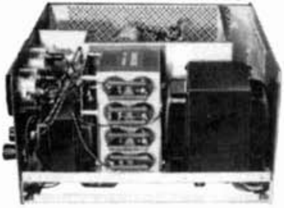

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unusual cubical-quad antennas

Four novel and interesting quad designs from overseas

Jim Fisk, W1DTY

For all practical purposes, high-performance antennas for 10, 15 and 20 meters fall into two categories: Yagis and cubical quads. Each has its pros and cons, its advantages and disadvantages, but the quad has probably been the subject of more amateur experimentation than the Yagi. The reason is simple: the quad is used primarily on the amateur bands while the Yagi sees service in commercial and military applications as well.

The cubical quad offers surprisingly high gain and excellent front-to-back ratio with a relatively short boom. Couple this with a low-angle vertical radiation pattern and you have performance that's hard to beat. However, the quad is not without its disadvantages: it's large, ungainly and offers high wind resistance. Fiberglass spreaders have solved some of the mechanical problems, but bamboo poles are still used by many, particularly overseas. Some all-metal quads have been built, but this requires careful design because of the large mass of metal in the antenna's rf field.

The antennas described below are variations on the basic quad theme - antennas that were designed to overcome some of the mechanical problems of building it, putting it up and keeping it there. These are quads that were designed with different feed systems, new supporting structures, different construction approaches - interesting cubical quad designs that have received little publicity outside the country where they originated.

english quad

One of the first variations of the basic cubical quad was G4ZU's bird-cage antenna shown in **fig. 1**. This antenna, popular in Europe a few years ago, received little notice from the American amateurs. However, it is an interesting design that solves some of the electrical and mechanical problems associated with the true quad.

Although the bird-cage uses two full-wave loops, the upper and lower sides are made from aluminum tubing bent into a "V." This simplifies the supporting structure, lowers the wind resistance and puts the low-impedance feed point near the mast. The vertical elements joining the horizontal aluminum supports are made from wire. Since the points where the antenna is attached to the vertical rotating mast are points of minimum rf voltage, insulation is simplified and weather losses are minimized. (Low-cost insulating material suggested by G4ZU includes wax-impregnated wood and bakelite.)

The stubs in the horizontal members of the antenna are used for tuning the system to frequency. It has been suggested that by increasing the vertical wires to somewhat more than ¼ wave, the antenna would resonate below the desired band. Variable capacitors could be inserted in each loop near the feed point to tune the antenna (the radiator being tuned for minimum swr, the reflector tuned for maximum forward gain).

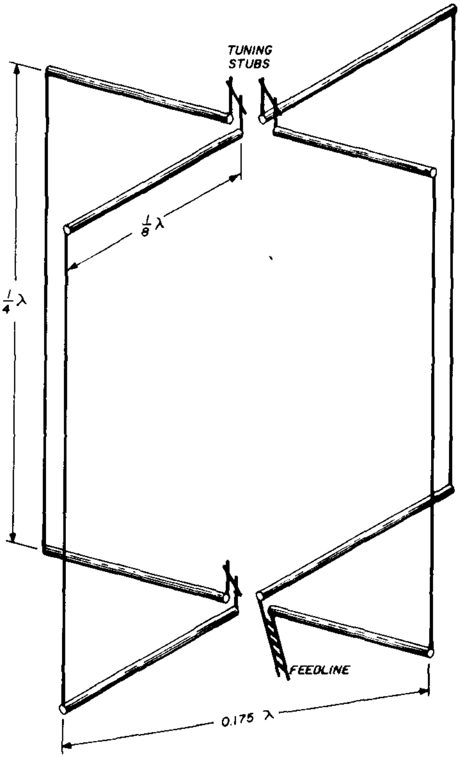

fig. 1. G4ZU's quad design simplified construction and feedline problems.

The German quad, a specialized high-gain multiband antenna designed by DJ4VM, appeared in the August, 1969, issue of *ham radio*. **Editor**

If the upper stubs are made from a ½-wavelength section of 300-ohm twin lead (at the desired 20-meter frequency), the antenna can also be used on 40 meters because the stub becomes ¼ wavelength at 7 MHz and the radiator becomes a half-wave element. The long stub can be run down inside the mast.

swiss quad

Another radical departure from conventional cubical-quad design is HB9CV's Swiss quad shown in **fig. 2.** This antenna, like G4ZU's, has been more popular in Europe than here in the States, but it's an interesting approach that offers several constructional advantages.

The horizontal elements of the Swiss quad are made from aluminum tubing, the vertical elements are no. 14 to no. 10 stranded wire, and the antenna is fed with a gamma match and coaxial line. Complete dimensions for 10, 15 and 20 meters are given in **table 1.**

The vertical elements should be initially made slightly longer than that shown in **table 1** to facilitate tuning (this lowers the resonant frequency.) Couple a grid-dip meter to the antenna, and shorten the vertical wires to raise the resonant frequency to the desired point. A slight upward bend on the upper elements will keep the vertical wires tight.

After the quad is tuned to resonance check the swr. If it is too high adjust the gamma match accordingly. Be sure to lengthen or shorten both ends of the gamma match by exactly the same amount.

When building the Swiss quad it's extremely important that the mast be securely connected to the aluminum elements *and* well grounded. Some builders have found less tuning and swr problems by insulating the horizontal aluminum elements from the mast and connecting their exact centers with wire; this wire is then connected to the mast. The elements can be simply insulated by running the elements through short sections of flexible plastic water pipe.

soviet quad

The unique three-band antenna shown in **fig. 3** consists of two wire squares approximately 12 feet on a side, spaced 114 inches apart. The top and bottom of each square is broken in the center and shunted with 300-ohm twinlead stubs that resonate the antenna on 10, 15 and 20 meters. One square is used as the radiator while the other is a reflector; the reflector is fed through a 91-inch length of 300-ohm twinlead. According to the designer, UB5UG, the antenna has 8-dB gain on 14 MHz and 10-dB gain on 21 MHz.

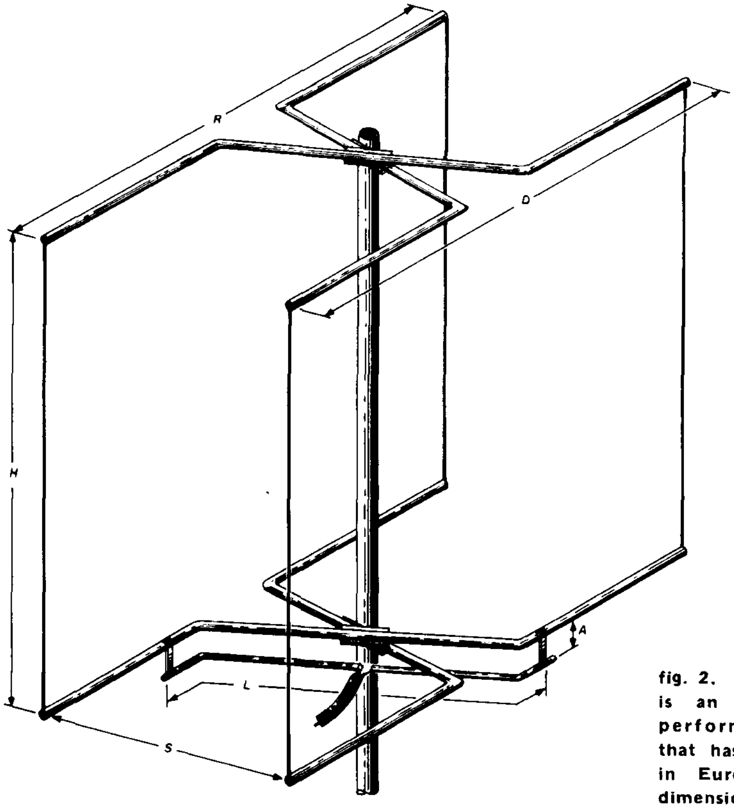

fig. 2. The Swiss quad is an unusual high-performance design that has been popular in Europe. Complete dimensions are given in table 1.

table 1. Dimensions for the Swiss quad (in inches).

frequency (MHz)	reflector horizontal (R)	radiator horizonal (D)	vertical (H)	spacing (S)	gamma length (L)	gamma spacing (A)
14.05	248	223½	236	84	188½	4¼
14.2	245	221	233	83	186½	4¼
21.05	165	149	157	56	126	2½
21.2	162½	148	155½	55½	124½	2½
28.05	124	112	118	42	94½	2
28.5	122	110	116	41½	93	2

When fed with 50-ohm coax, the swr is less than 2.7:1 on all bands. Input resistance is 30 ohms on 14 MHz, 90 ohms on 21 MHz and 80 ohms on 28 MHz. For lower swr performance, two equal-length pieces of 75-ohm coax can be used in parallel on twenty meters (equivalent impedance 37.5 ohms); for the upper two bands one piece of coax is disconnected at the transmitter. With this system the swr should be less than 1.5:1 on all bands.

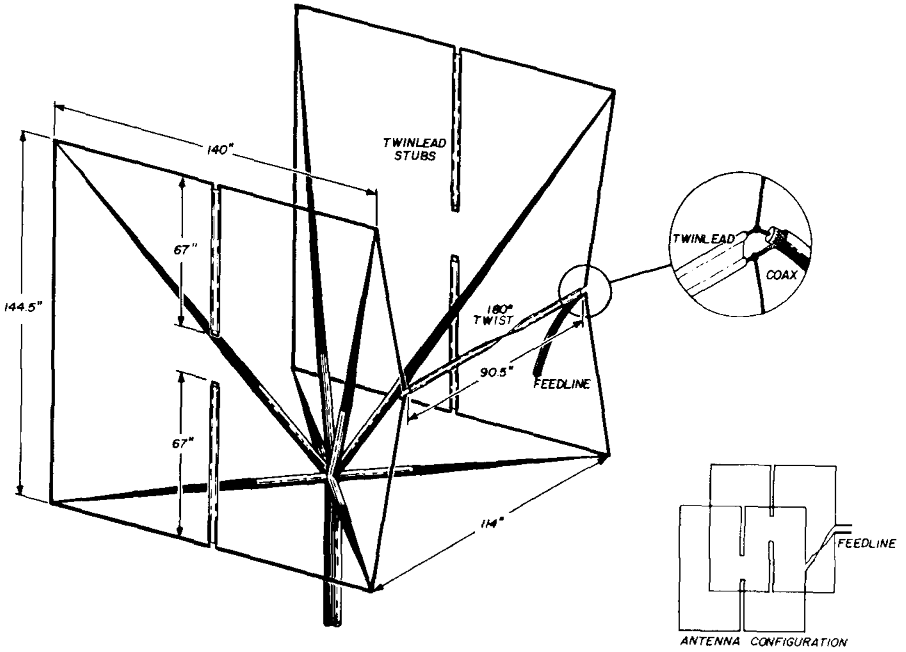

fig. 3. UB5UG's simple quad provides three-band operation. Both reflector and director are the same size.

Construction, as shown in **fig. 4** is somewhat different than that normally seen, although there is no reason a conventional quad arrangement could not be used. However, the UB5UG system doesn't use a long metal boom, and metal parts that might degrade performance are at the bottom out of the rf field.

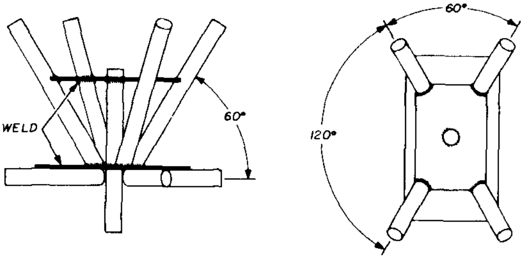

fig. 4. Construction of the spider for the Soviet quad.

Tuneup consists of adjusting the vertical 300-ohm stubs for resonance at the desired spot on the 20-meter band. Front-to-back ratio and forward gain are optimized by adjusting the length of the reflector feeder. (Be sure this feed line is twisted one-half turn.)

japanese quad

Cubical quads for 15 and 20 meters are pretty large, and some amateurs simply don't have the space to get them up into the air. The design in **fig. 5** by JA1OYY uses loading coils to reduce the size by 30% Although the original design was for 15 meters, the idea is equally applicable to other bands; suggested coil values are lised in **table 2.**

A full-sized 21-MHz quad is 11 feet, 8 inches on a side; this reduced-size unit has sides that are 8 feet, 2 inches long. The four loading coils are placed at low-current points so there is minimal effect on the radiation efficiency of the antenna. Spacing between radiator and director is 0.175 wavelength for maximum front-to-back ratio.

The loading coils consist of 11 turns no. 14 wire spaced to fill a form 1½ inches in diameter and 4 inches long. Commercial coil stock such as B&W or Airdux could also be used. The completed coils should be protected from the weather for long life and optimum performance; plastic refrigerator boxes are ideal for this purpose. Note that the coils on the bottom of the elements are equipped with alligator clips for tuneup. When the correct tap point has been found the clips can be replaced with soldered connections.

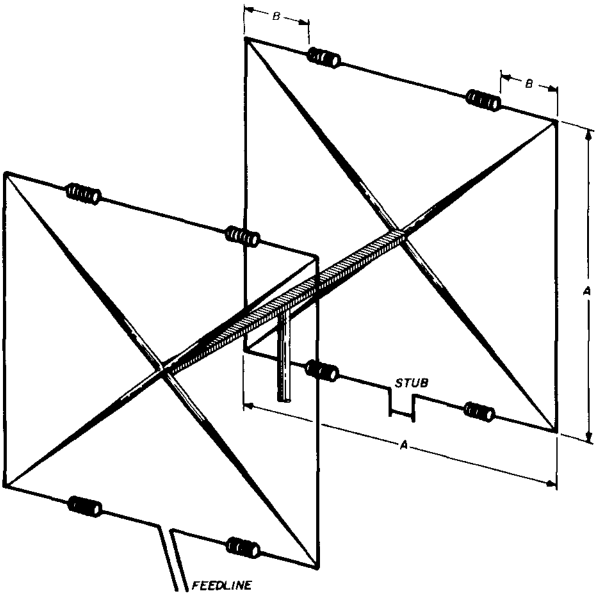

fig. 5. Miniature quad design by JA1OYY uses loading coils in the horizontal elements. Complete dimensions are given in table 2.

table 2. Construction details of the Japanese quad (in inches).

frequency (MHz)	quad side (A)	spacing	coil location (B)	coil (μH)	winding info
14	152	101	38	3.0	17½ turns no. 14, 1½" diameter, 5" long
21	98	67	24½	2.0	11 turns no. 14, 1½" diameter, 3½" long
28	77	50	19¼	1.5	9½ turns no. 14, 1½" diameter, 3½" long

Although the quad built by JA1OYY uses angle-iron spiders and wood spreaders, fiberglass poles and cast aluminum spiders will last longer. With the 21-MHz dimensions shown in **table 2** this miniature quad is resonant at 21.350 MHz (swr 1.1:1 with 50-ohm coaxial feedline); at 21.450 MHz the swr is 1.2:1 at 21.200 MHz the swr is 1.5:1.

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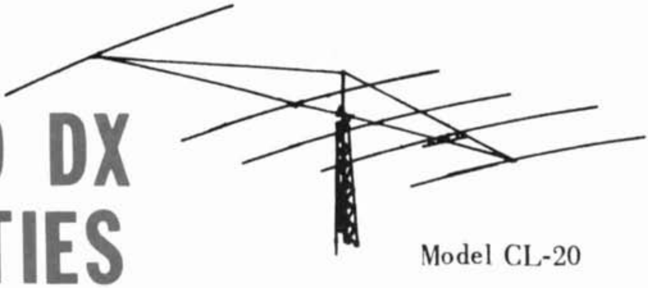

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William I. Orr, W6SAI, Eimac Division of Varian, San Carlos, California 94070

The multiband dipole is an attractive antenna for portable or Field Day operation. It's light, easy to carry and erect, and very inexpensive to build. Best of all, it's noncritical in adjustment and provides a low swr for commonly used 50-ohm coaxial transmission lines.

Simple multiband dipole antennas can take one of two forms. The most easily constructed two-band antenna consists merely of two dipoles tied in parallel at the feed point. A more sophisticated antenna uses parallel-tuned traps in series with the dipole element **(fig. 2)**.

It was desired to build a few antennas for the ARRL Field Day contest, but a search of the literature failed to provide any dimensional data or information on multiband dipole systems for the higher-frequency bands. Accordingly, several multiband dipole antennas were constructed and tested during the spring of 1968 with the hope of obtaining a suitable design before the contest began. This article covers three designs that evolved from these tests. Perhaps one of them will suit **your** Field Day requirements.

parallel dipoles

The parallel dipole shown in **fig. 1** is simpler than the trap dipole, but its use is limited to *harmonically related* bands. A parallel dipole may be built for 20 and 10 meters, because 10 meters is the second harmonic of 20 meters. However, trouble occurs when an attempt is made to use two dipoles not harmonically related. For example, a parallel dipole for 20 and 15 meters or for 15 and 10 meters isn't practical. These bands aren't harmonically related, and the dipoles have so much mutual reactance it's impossible to establish resonance without an auxiliary tuning unit. This defeats the whole purpose of the undertaking; namely, that of constructing a *simple* multiband antenna system.

For harmonically related bands, however, the lower-frequency dipole presents a high resistive impedance to the higher-frequency dipole and doesn't affect its operation to any noticeable extent. In the case of *harmonically unrelated* bands, such as 20 and 15, or 15 and 10 meters, the lower-frequency dipole is highly reactive at the higher operating frequency and introduces an intolerable degree of detuning to the higher-frequency antenna. The higher-frequency antenna doesn't influence the lower-frequency antenna to any great degree, but the lower frequency antenna—unless it presents a resistive load to the higher frequency antenna—introduces sufficient reactance at the feedpoint of the combined system to "upset the applecart."

Paralleled, harmonically related antennas detune each other to a small extent. The low-frequency dipole appears to resonate at a lower frequency and the higher frequency dipole at a higher frequency than normal. This can be compensated by trimming the dipoles to their operating frequencies.

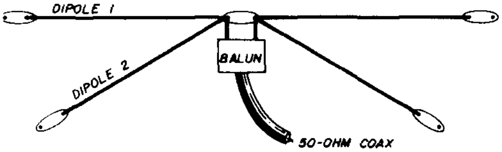


fig. 1. Parallel dipole arrangement. Two dipoles, resonant at harmonically related bands, are connected in parallel; interaction is negligible because of impedance relationships.

trap dipoles

The trap antenna operates on the principle of parallel-tuned circuits placed at critical points in the element. The tuned circuits or traps, electrically connect or disconnect the outer sections of the element as the antenna's excitation frequency is changed.

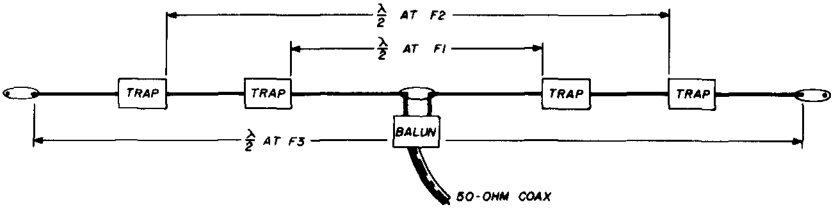


fig. 2. Trap dipole for nonharmonically related bands. Traps are parallel-resonant circuits that provide high impedance at resonant frequency and low impedance at frequencies far from resonance.

At the lowest operating frequency, the tuned traps have a minimum effect on the antenna, which is resonant at a frequency determined by its electrical length. The electrical length is influenced slightly by the loading effect contributed by the inductive reactance of the traps. At some higher frequency, the outer set of traps is parallel resonant. This places a high impedance between the center portion of the element and the ends beyond the traps. Thus, the element resonates at a frequency higher than that determined by the over-all physical length of the element. As the operating frequency is increased, the inner set of traps becomes resonant, effectively disconnecting a larger portion of the element from the center driven section. The length of the center section is therefore resonant at the highest operation frequency. The center section, plus two adjacent inner sections, are resonant at the intermediate operation frequency, and the complete element is resonant at the lowest operation frequency.

At the lower frequencies, the traps in the active portion of the element contribute a reactive load that makes the over-all element length somewhat shorter than that determined by formula. As a result, the lengths of the multiband trapped dipole sections must be determined by cut-and-try, since the loading contributed by the traps is difficult to determine.

The efficiency of such a system is generally established by trap- and element-tuning accuracy and by the Q of the traps. An accurately tuned multiband dipole using high-Q traps compares favorably with full-size, separate dipoles as far as efficiency and bandwidth are concerned.

20-15 meter trap dipoles

These bands aren't harmonically related, so a parallel dipole isn't practical, and a trap dipole must be used **(fig. 3)**. The dimensions are given in **fig. 3A.** The 15-meter portion is resonant at about 21.15 MHz. It's length is very close to the figure obtained from the formula given in the handbooks.

The 20-meter length is shortened by the loading effect of the 15-meter trap to 29 feet, 8 inches. The traps are about 2 inches long. This length must be included in the over-all measurement, which makes the tip sections each 3 feet, 7½ inches long.

The dipole is fed from a balun.[1] This is necessary if meaningful swr measurements are to be obtained. The feedline may be a random length of RG-58A/U for power up to 500 watts PEP, or RG-8/U for power up to 1000 watts PEP. The smaller cable is recommended for Field-Day use, as it's easier to handle than the RG-8/U.

The completed 20-15 meter trap antenna produces the swr curves shown in the chart of **fig. 3C.** At the design frequency of 14.15 MHz, the 20-meter dipole exhibits an swr of about 1.25 at the end of a half wavelength of transmission line. At the limits of the 20-meter band, the swr rises to less than 1.6. On 15 meters, at the design frequency of 21.15 MHz, the antenna exhibits an swr of about 1.09, rising to less than 1.9 the high-frequency end of the band and to 1.4 at the low-frequency end. These swr figures are well within the limits normally established

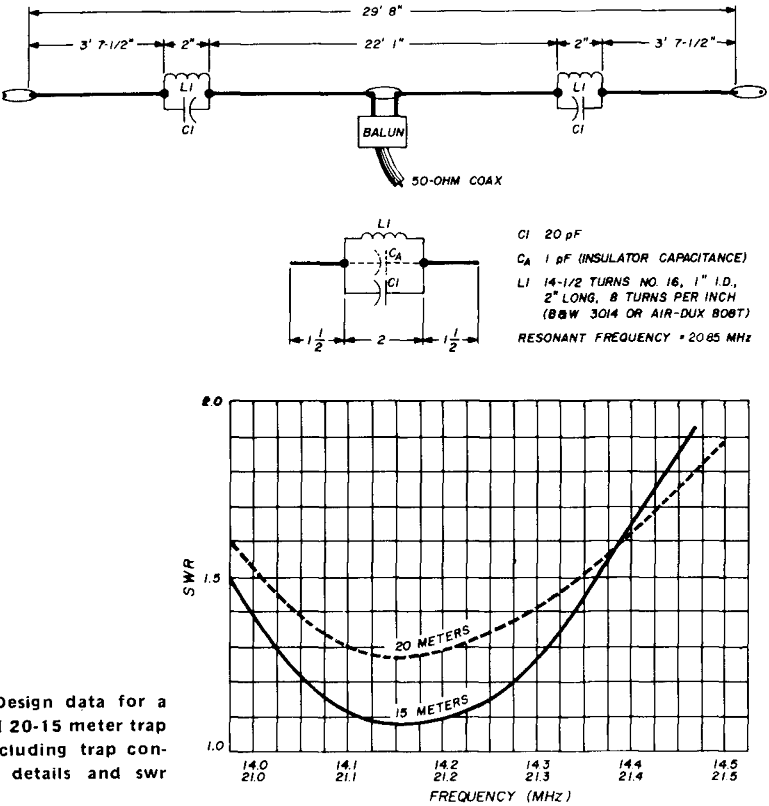


fig. 3. Design data for a dual-band 20-15 meter trap dipole including trap construction details and swr response.

for use with most transmitting equipment.

20-10 meter parallel dipole

A practical 20-10 meter parallel dipole is shown in **fig. 4.** Two separate dipoles are connected in parallel at the feed point, with their ends separated about five feet. The 20-meter dipole dimensions are normal but the 10-meter dipole is lengthened slightly to re-establish resonance, which is affected by the addition of the 20-meter section. Formulas for computing correct dipole lengths for other harmonically related bands (40 and 20 meters, for example) are given. Dipole spacing at the ends isn't critical; however, too-close spacing will detune the antennas. A separation of five feet is satisfactory for the 20-10 meter antenna system; for a 40-20 meter antenna, ten feet is satisfactory.

Again, a simple balun is placed at the antenna, as suggested for the previous antenna. Typical swr curves for the 20- and 10-meter bands are shown in **fig. 4B.** The swr remains below 1.6 across the 20-meter band and remains below 1.6 across nearly a megahertz of the 10-meter band. For the high end of 10 meters, the 10-meter dipole should be shortened about three inches at each end.

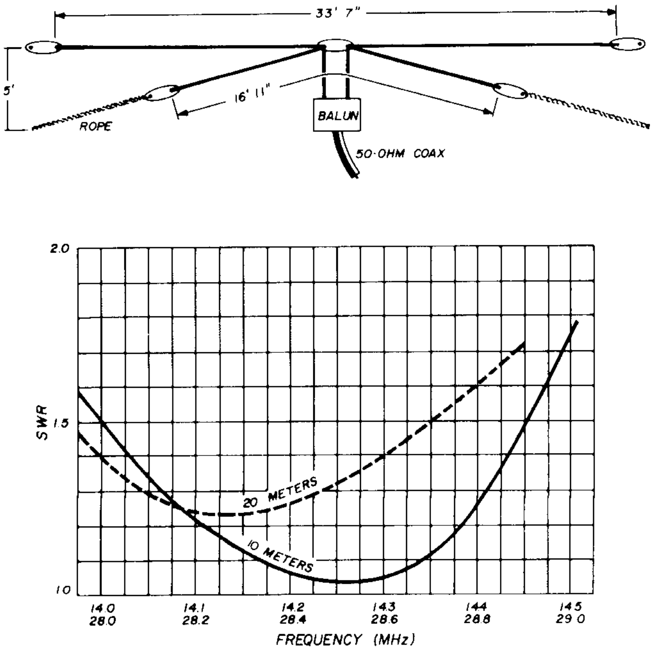


fig. 4. 20-10 meter parallel dipole design and swr as a function of frequency. No traps are needed in this inexpensive system, which can be adapted for other harmonically related bands. The length of the lower-frequency dipole (in feet) is equal to 478/f where f is a frequency in MHz; length of the higher-frequency dipole is 485/f.

a 20-15-10 meter trap dipole

The trap technique may be extended to three bands. Two sets of traps are required, one for 10 meters and one for 15 meters. Construction information for a triband trap dipole is given in **fig. 5.** While the 10-meter dimensions are normal, both antenna lengths for the 15- and 20-meter sections are shortened by trap loading. Over-all antenna length is only 26 feet, 2 inches. No matter. The antenna performs remarkably well on all three bands, and comparisons with full-size dipoles indicated little or no difference in signal strength between antennas, either on transmit or receive.

Two sets of traps decrease the operaing bandwidth somewhat, as seen from the swr curves of **fig. 5B**. However, the over-all bandwidths still permit an swr of 2.15 or less across the 20-meter band, with a minimum swr of 1.3 at the resonant frequency of 14.3 MHz. The 15-meter antenna meter swr is higher. It's close to 1.6 at the resonant frequency of 21.22 MHz, rising to about 2.4 at the lower band edge and to 2.2 at the high edge. The 10-meter swr curve is quite broad. Although not quite as good as that of a single 10-meter dipole, it's about the same as that of the parallel dipole shown in **fig. 4**. Nevertheless, the swr remains below 1.6 from the low edge of the phone band to about 28.85 MHz, and is below 2.0 to 29.0 MHz.

As in the case of the other antennas, a balun feed and 50-ohm transmission line are used.

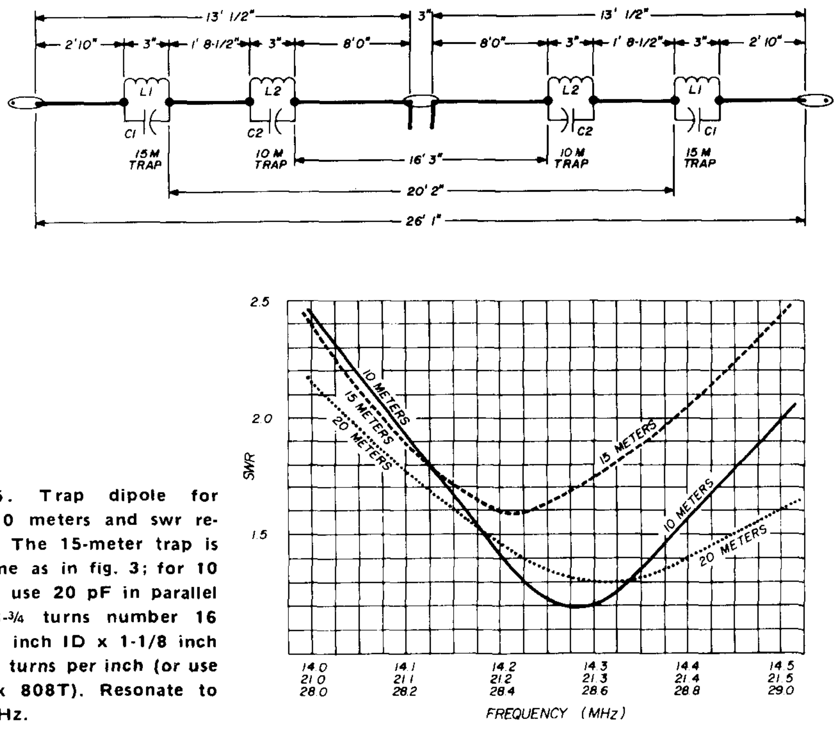


fig. 5. Trap dipole for 20-15-10 meters and swr response. The 15-meter trap is the same as in fig. 3; for 10 meters, use 20 pF in parallel with 8-3/4 turns number 16 wire, 1 inch ID x 1-1/8 inch long, 8 turns per inch (or use Air-Dux 808T). Resonate to 27.8 MHz.

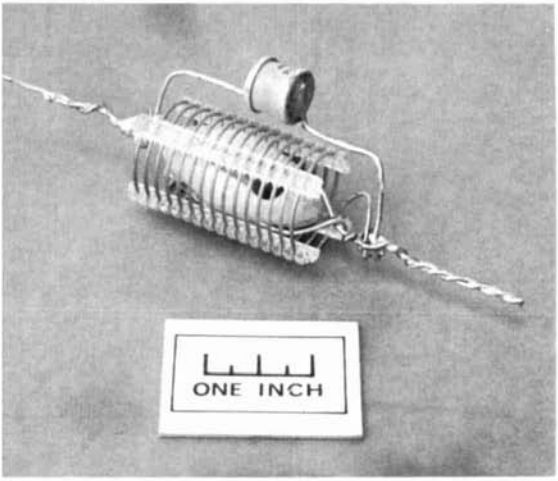
trap resonant frequency

Trap adjustment is easy if the proper procedure is used. The only instruments required are a grid-dip oscillator and a calibrated receiver. But you must know *where* to tune the traps for optimum performance.

Tradition says the traps should be tuned to the low edge of the band, or just outside the low edge. Measurements made on various trap beam antennas showed that the traps were indeed tuned in this manner. Discussions with antenna manufacturers on trap tuning have led to the conclusion that traps are adjusted in this manner merely because the competition does it, and none really knows the reason for trap adjustment–if they do, they're not saying! I saw no valid reason for this particular choice of trap resonant frequency, so I made some tests.

The tests revealed (1) there's no magic frequency to which the traps should be tuned, and (2) if the trap is tuned to resonance with the band in which it is supposed to resemble a switch, all will work as expected.

However, I noticed on repeated tests that, when the trap was tuned *lower* in frequency than the expected range of operation, the antenna bandwidth on that band was improved. In other words, tuning the trap to some frequency within the band restricted antenna bandwidth. To obtain the best bandwidth, it proved best to tune the traps somewhat *lower* than the lowest expected operating frequency.



Typical 15-meter trap. Lead length affects resonant frequency slightly, and trap should be measured with connecting leads in place.

The exact frequency to which the trap was tuned didn't seem too critical as long as both traps (for the same band) were tuned to the same frequency. Tests using tunable traps indicated good results with the 10-meter traps tuned to 27.8 MHz, the 15-meter traps tuned to 20.85 MHz, and (for 40-20 meter trap antennas) the 20-meter traps tuned to 13.9 MHz. As long as the traps were resonant *outside* the low-frequency end of the band by fifty to several hundred kilohertz, antenna action remained unchanged for all practical purposes. When the trap resonant frequency approached the operating frequency, or was higher than the operating frequency, antenna bandwidth became progressively more restricted, as shown by the measured standing wave ratio.

This seemed to be the "secret" of proper trap adjustment. Just *why* this is so I'll leave as an exercise for the reader.

trap construction

Construction of a typical trap is suggested in the photo. The trap can be built around a strain insulator, which will remove the antenna tension from the coil and capacitor. The strain insulator has measurable capacitance (about 1 pF) so it must be considered as part of the trap circuit. The coil may be placed around the insulator, with the capacitor connected around the coil.

Trap length enters into the over-all length of the antenna. A standard length of two inches is used for the traps shown here. Generally speaking, the L/C ratio of the trap is not too important; traps have been built around high-voltage ceramic capacitors of 20 or 25 pF. For power output of 500 watts PEP, the Centralab 853A-20Z ceramic capacitor is ideal. It has a capacitance of 20 pF and a voltage rating of 3 kV. Small, commercially built air wound inductors may be used for the trap coils, such as the Barker & Williamson or Air-Dux coils.

To attach the traps easily to the antenna wires, it's a good idea to add 1½-inch leads to each end of the trap. The leads may then be twisted around the antenna wires and soldered.

assembling the traps

Attach about a foot of wire to the strain insulator, then loop the wire through the insulator and back upon itself. Cut the wire to length and solder the joint. The coil may be placed over the insulator or beside it. Solder the coil leads to those of the insulator, then solder the capacitor in parallel.

trap tuning

Place the trap in a clear spot away from metal objects. Loosely couple it to a grid-dip oscillator. Check the trap resonant frequency against a calibrated receiver. As mentioned previously, the exact resonant frequency isn't important as long as it's outside the low-frequency end of the band. Both traps of the set should have resonant frequencies within about 50 kHz of each other.

weatherproofing

Moistureproofing seems to be more of a problem than building the traps. If it's guaranteed not to rain on Field Day, the traps may be used without a protective shield. An emergency rain shield may be made by wrapping the traps in kitchen plastic and stapling the plastic cover around the trap. A better shield may be made from a polyethylene "squeeze bottle," obtainable at a drug store. The best (and most time-consuming) trap shield may be made of plastic tubing with end pieces cemented into a waterproof cylinder around the trap.

Regardless of the weatherproofing method, it's imperative that the traps be protected from water, otherwise the traps will become detuned when wet and may, in fact, flash over and be destroyed.

antenna adjustment

The antenna dimensions and trap data guarantee that an antenna constructed in this fashion will *work.* A check on operation may be made by running an swr curve across the amateur bands for which the antenna is designed. The resulting curves should resemble those in this article. Note, however, that swr curves obtained *without* a balun between the antenna and the feedline are meaningless and are not representative of antenna performance.

If the swr on one or more bands indicates the antenna is resonant at a frequency other than that desired, antenna resonance may be re-established by altering the length of the antenna section in question. Adjustments shouldn't be made to the traps after once set, as too many variables will certainly lead to improper antenna adjustment.

Adjustment should be made to the highest-frequency antenna first, followed by the next lower-frequency segment. Once the 10-meter sections are of the proper length, the 15-meter sections may be adjusted, then the 20-meter section. It must be remembered that adjustments made to *one* antenna section affect the adjustments of the *lower*-frequency sections, since the higher-frequency antennas form a part of the lower-frequency ones.

Don't deliberately look for trouble, because the data and measurements given for these antennas have been tried in various installations with complete success. It can be seen, futhermore, that trap antennas can be designed for two or more frequency bands, regardless of their harmonic relationship, in the fashion outlined in this article.

power limitations

It's possible to destroy an antenna trap, as some "California kilowatt" users have discovered to their dismay. The limiting factors are capacitor flashover and coil heating. The trap construction described in this article is satisfactory for power up to 500 watts PEP in the antenna; but for the maximum amateur power rating, it's recommended that more robust components be used. For high-power construction, two Centralab type 858, 50-pF, 5-kV capacitors may be connected in series to provide a 10-kV rating. The coil could be self supporting, wound with tv aluminum ground wire or number 10 copper wire. Trap size will increase, requiring slight adjustments to the antenna sections.

reference

1. William I. Orr, "Broadband Antenna Baluns," *ham radio,* June, 1968, p. 6.

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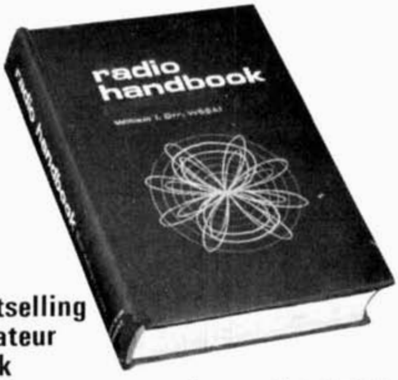

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improved triangular shaped beam antenna

Norman B. Watson, W6DL

Presented in this article is a beam antenna covering 7 through 28 MHz using triangular-shaped elements. It is simpler than similar antennas I have developed previously.[1, 2] Instead of 14 elements, only 6 are used. Little if any sacrifice in gain occurs on 21 MHz, and there's an increase in gain on 28 MHz compared with the original design.

electrical description

All elements except the 7- and 21-MHz driven element and director are closed loops (**fig. 1**). The 7-MHz beam consists of a driven element and director spaced 1/8 wavelength. The wire elements are folded in a triangular shape with sides of equal length. The bottom leg of the triangle is parallel to the earth. The driven elements are fed at the center of this horizontal side. Nominal radiation resistance of the 7-MHz antenna is 15 ohms.

The 21-MHz antenna uses the same two elements as the 7-MHz antenna. Since its operating frequency is three times the fundamental, the 21-MHz antenna's electrical length is 1.5 wavelengths. Element spacing is 3/8 wavelength. Its radiation resistance is 215 ohms.

The 14-MHz antenna is a four-element beam. Reflector, driven element, and two directors are closed triangular loops one wavelength in perimeter. The elements are spaced about 1/8 wavelength. The driven element is fed at the center of the triangle horizontal leg in the same way as the 7/21-MHz driven element.

Physically, the 28-MHz antenna doubles as the 14-MHz antenna. Electrically, however, it is two wavelengths in perimeter on 28 MHz. Element spacing is ¼ wavelength on this band. Radiation resistance on 28 MHz is 175 ohms; on 14 MHz it is 65 ohms.

directivity and gain

The beam's directivity on the four bands is given in **table 1**. Directivity, as considered here, is a measure of **beamwidth**. That is, the directivity is the power concentrated through a portion of the space around the antenna, as opposed to that from an isotropic source.

Directivity is a useful comparative parameter. It's merely necessary to plot a receiving antenna pattern using a signal source at any desired distance from the antenna, then calculate the directivity using the half-power beamwidth. The numbers in **table 1** are based on the assumption that antenna beamwidths are the same in the vertical and horizontal planes.

wire lengths

The wire lengths in **fig. 1** were determined by cut and try. The resonant frequency of the driven elements was measured at an operating height of 60 feet above ground, using an ac frequency-compensated bridge. Each antenna element is a series-resonant circuit, whose resonant frequency is a function of physical wire size and length. Capacitance is determined by the physical distance between the element and the ground, tower, houses, trees, antenna boom, and other antenna elements.

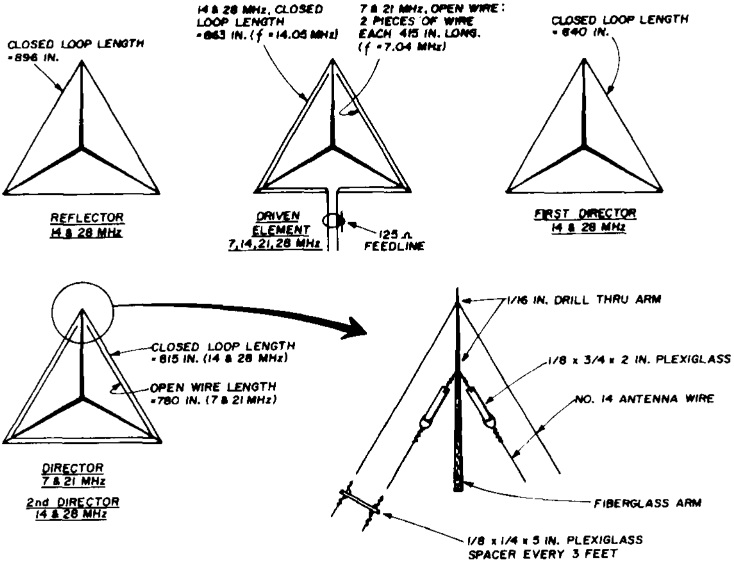


fig. 1. Layout detail of the triangular elements.

For these reasons, wire-element lengths will be affected by your antenna site and by antenna height. The antenna should have the wire lengths given in **fig. 1**. The resonant frequency of the driven elements should be measured at the operating height. (A measurement method is described below.)

If the operating frequency is unsatisfactory, it may be altered by changing the wire lengths of the driven elements. An over-all change of 13 inches will move the resonant frequency about 0.1 MHz and 0.22 MHz in the 7- and 14-MHz bands respectively. The other element lengths can remain unchanged with little effect on performance.

FREQUENCY BAND (MHz)	NUMBER OF ELEMENTS	ELEMENT SPACING (APPROX λ)	DIRECTIVITY (SEE TEXT) *	RADIATION RESISTANCE (Ω)
7	2	1/8	4	15
14	4	1/8	10	65
21	2	3/8	7	215
28	4	1/4	16	175

*AS A BASIS FOR COMPARISON, THE DIRECTIVITY OF A HALF-WAVELENGTH ANTENNA IS 1.64

table 1. Beam antenna characteristics

feed line type and tuning

A single 125-ohm shielded transmission line feeds both driven elements, which are tied together at a common feed point. The feed line is electrically one wavelength long at the operating frequency in the 7-MHz band, which makes it 2 wavelengths on 14 MHz; 3 wavelengths on 21 MHz; and 4 wavelengths on 28 MHz. A feed line that is a multiple of ½ wavelength reflects the load resistance to the input end of the line. Therefore,

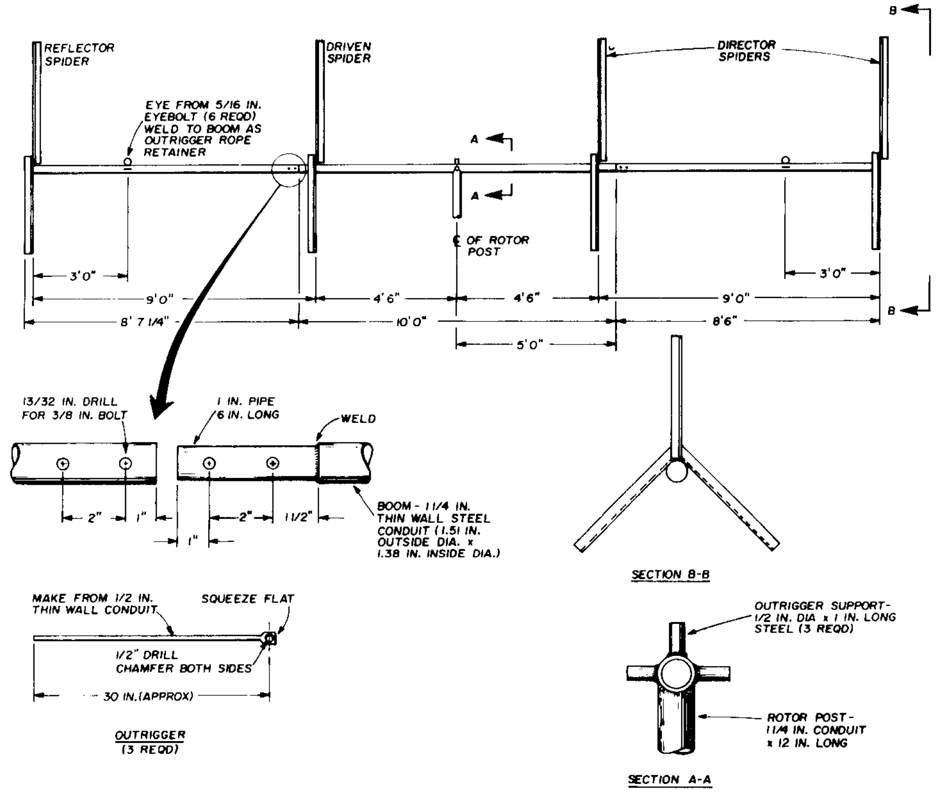


fig. 2. Construction of the boom.

the even-wavelength-multiple line makes it possible to operate the antenna on four bands with a single feed line, providing an antenna tuner is used to match the transmitter to the resistance appearing at the input end of the line. This resistance will be the antenna's radiation resistance, providing the antenna is tuned (cut) for resonance at the frequency at which the feed line is a multiple of ½ wavelength.

Here's a procedure for tuning the antenna-feed line system:

1. Decide on the frequency at which optimum efficient is desired. This will be influenced by whether cw or phone operation is contemplated for the greater portion of time.

2. Calculate the approximate electrical length of feed line needed for operation at the desired frequency. Consider the line's velocity factor and the distance from transmitter to antenna feed point. (A discussion of velocity factor is contained in the ARRL Handbook.) Add a couple of feet to the calculated length as a safety factor, and cut the line.

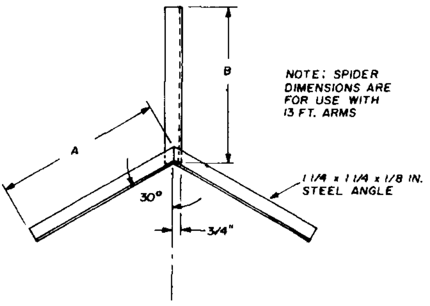
3. Short circuit one end of the line, and connect the antenna bridge to the other end. Determine the frequency at which a null occurs with the bridge set to zero. Cut the line, a little at a time, until the bridge nulls at the desired operating frequency. The greater the number of half wavelengths in the line, the less will be the frequency change per inch of length removed.

4. Run the line from the operating position up the tower and out the antenna boom to the driven element spider. From the driven element spider, the line can hang free to where it's attached to the driven elements. Connect the feed line to **both** driven elements, not to just one. (Interaction exists between all elements on this antenna as with any beam.)

5. Connect the bridge to the operating-position end of the transmission line. Raise the tower and antenna to the operating height. Find the bridge null that indicates the antenna resonant frequency. Alter the antenna driven element length to bring its resonant frequency to the desired operating frequency. Antenna radiation resistance will be reflected at the bridge-end of the line when antenna resonant frequency is the same as that at which the transmission line is a multiple of an electrical half wavelength.

6. Connect the bridge to the antenna tuner output. Set the bridge to the antenna radiation resistance of one of the bands. Tune the antenna tuner to the operating frequency for the band, as indicated by a null of the bridge. Record the tuner dial settings for use when changing bands. Repeat the procedures for each band.

fig. 3. Spider.



ELEMENT	A (INCHES)	B (INCHES)
REFLECTOR	26 1/2	27
DRIVEN	20	21
DIRECTORS	16	17

construction

My original 4-element beam was in use for three years. The experience gained over this period has resulted in simpler construction of the beam described here. Except for a few pieces of scrap Plexiglas, all materials can be found in the Sears mail-order catalogue. Simple hand tools are required, and some welding is necessary. The advantage of welded construction has been proven with my original large beam. No failures have occurred in three years of storms howling in from the Pacific Ocean.

The 27-foot boom is constructed from three 10-foot lengths of 1¼-inch thin-wall steel conduit **(fig. 2)**. The center section is 10 feet long. Cut off the two end sections with a hacksaw or tubing cutter at 8 feet 6 inches and 8 feet 7 inches respectively. Weld a 6-inch length of 1-inch pipe to each end of the center section to serve as a joint. Assemble the sections using 3/8-inch stainless-steel bolts.

The four spiders are constructed as shown in **fig. 3.** Clamp the two "A" legs to a piece of scrap wood before welding: make sure the angles are correct. Then clamp the "B" leg to the assembly and weld. Next, weld the spiders to the boom. The "V" joint of the spider sets on top of the boom (section B-B, **fig. 2**). Three different spider lengths, **fig. 3**, are used to save material and weight.

Weld a 12-inch length of 1¼-inch conduit to the center boom section to support the beam on the rotor. Don't increase the length of this center section as a means of increasing the beam height above ground. The 12-inch long rotor section is strong enough to withstand high winds with ice. It can be made longer for attachment to a rotor located down in the tower, providing an upper bearing is located within 6 inches of the boom.

Cut three one-inch-long pieces from a ½-inch bolt, and weld them to the top and sides of the boom to support the outriggers as shown in **fig. 2.** Cut three pieces 31 inches long from a 10-foot length of ½-inch thin-wall conduit for outriggers. Squeeze the end of the outrigger together in a vise and drill a ½-inch hole through the flat section. The 3/8-inch outrigger rope will be threaded through these holes when the beam is assembled. Cut the eyes off of six 5/16-inch eyebolts, and weld the eyes to the boom as shown in **fig. 2.** The outrigger ropes will be fastened to these eyes. After welding and drilling are completed on the boom and outriggers, they should be hot-dip galvanized. Galvanizing is nominal in cost. The entire job won't cost more than four or five dollars, and galvanized parts will last for many years.

All that remains to be made now are the antenna-to-feedline connector plate, **fig. 4,** and the Plexiglass insulators and spreaders, as shown in **fig. 1.** Cut a notch in each end of the spreader to fit over the antenna wire, and drill a hole in each end for wiring the spreader to the antenna.

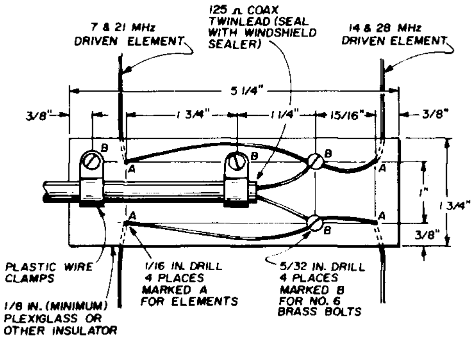


fig. 4. Antenna-to-feedline connector plate.

Automobile hose clamps are used to fasten the fiberglass arms to the spiders. Twenty-four clamps are required. Solid braid polyethylene rope is used for the outriggers. It won't stretch, so no turnbuckles are required. Polyethylene rope is used extensively for boats and can be obtained from the Sears mail order catalogue. Three pieces, each 23 feet 6 inches long by 3/8-inch diameter are required. After cutting, fuse the end over a gas flame.

Thirteen-foot-long fiberglass arms are used for wire spreaders. Twelve are required. Obtain the most rigid arms you can find. They should be at least ½-inch diameter at the small end and 1-3/8-inch diameter at the large end. The arms I used are marketed by Kirk Electronics and manufactured by U. S. Fiberglass.

assembly

After the boom and outriggers are galvanized, assemble the boom section on the ground. Clean any excess zinc from mating sections and bolt holes.

If you have a tilting tower, as I do, assembly is very straightforward. Assemble the fiberglass arms to the two center section spiders. With one set of arms resting flat on the ground, string the antenna wires and make the solder joints. Tilt the tower down and attach the boom to the rotor. Raise the center section out of the way. Assemble the fiberglass arms to the two end section spiders, with the arms flat on the ground and the boom section joint pointing upward. String the wires on the end element supports. Tilt the tower down, and bolt an end section to the center section. Tie the three outrigger ropes to the boom eyes. The length of outrigger rope given allows a foot at each end for tying to the eyes.

Raise the antenna, rotate the boom 180°, and tilt the tower down again. Thread the outrigger ropes through the outriggers and insert the outrigger tubes over the ½-inch-diameter retainers. Raise the tower so the second end section can be attached to the boom. Tie the outrigger ropes to the second set of eyes. The side outrigger ropes need only be snugly tight with the boom straight. The top outrigger may have to be readjusted after the tower has been raised to ascertain if the boom is level.

If you have a rigid or crank-up tower, you're on your own for an assembly method.

If you'd like to start building a less complex antenna than this beam, try only the driven frame. Feed it in the same manner as described above. It will function as an excellent four band antenna.

I'll be glad to help serious builders with further technical information.

references

1. Norm Watson, W6DL, "Triangular Loop Antenna," *QST*, April, 1968.
2. Norm Watson, W6DL, "Triangular Loop Beams," *73*, May, 1968.

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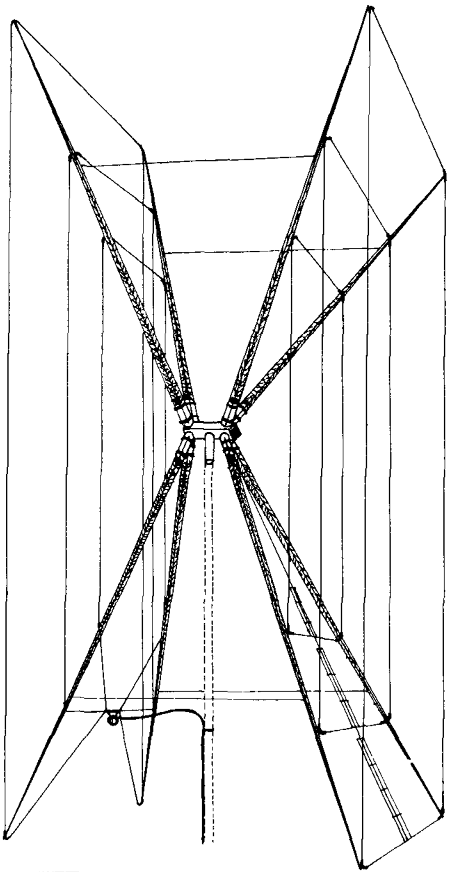

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80 meters vertical beam antenna

George Cousins, VE1TG

Just "getting Out" on 80 meters calls for nothing too elaborate in the way of antennas. But to **really** get out, to the tune of working a world-wide DX as a matter of course, calls for something a bit special. The antenna described here is the result of a fair amount of experimentation and construction on the part of Bill Shearman, VE1AX, whose DX countries total on 80-meter ssb is well over the magical 100 mark.

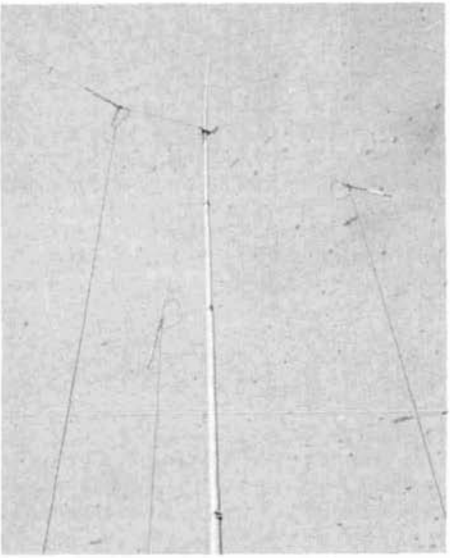
To say it's a two-element beam conjures up ghastly thoughts of huge towers and monstrous drooping elements, but this beam is vertical, which makes all the difference in the world. For one thing, it's unobtrusive. It sits right in the middle of a subdivision and is not particularly noticeable. Being a quarter-wave vertical, the elements are only about 60 feet high. Although this may seem a lot, by using small-diameter masts the problems of height and weight become quite reasonable.

elements

The antenna at VE1AX consists of two identical 48-foot aluminum masts topped with a 12-foot fiberglass whip of the type used for marine transmitters. Any suitable combination of aluminum or steel tubing, tv masts, etc. could be used; but both verticals must be identical. The masts must be insulated from ground, which Bill did by using commercially built tripod mounts. But here again, traditional ham ingenuity should come to the rescue with such alternates as wooden posts, power line standoff insulators, or even Coke bottles, as I remember seeing in another article.

broadbanding

To make the antenna broadband, a three-wire cage encloses each mast. **Fig. 1** and the photo show that these wires extend out from the mast about eight feet, and are connected to the mast at a point about fifteen feet from the top. (The exact point isn't critical.) Then they extend downward to the base of the mast. The upper arms of the cage connect to strain insulators, which are connected to the guys. The lower ends of the wires are also connected to strain insulators, which are in turn tied to the base mounting. This arrangement keeps the cage neat and taut. All the cage wires are connected electrically to the base of the vertical element and fed in parallel with it.



One of the vertical beam elements. Loops near insulators are bridge wires connecting horizontal and vertical cage wires.

A small loading coil is connected in series with the coaxial cable feeding the base of each vertical, and a movable tap is used to adjust the element for optimum performance.

ground system

Like all vertical antennas, the secret of this one is the ground system. The old axiom of, "the more, the better," couldn't be more true. Bill's philosophy is to lay out every bit of spare wire he can get his hands on, and the ground under and around the array is a maze of everything from hookup wire to braided ground strapping. At this writing, well over 1000 feet of radials have been laid out, but there will likely be more by the time you read this! Each little bit helps put the signal where it will do the most good – low down, and a long way out.

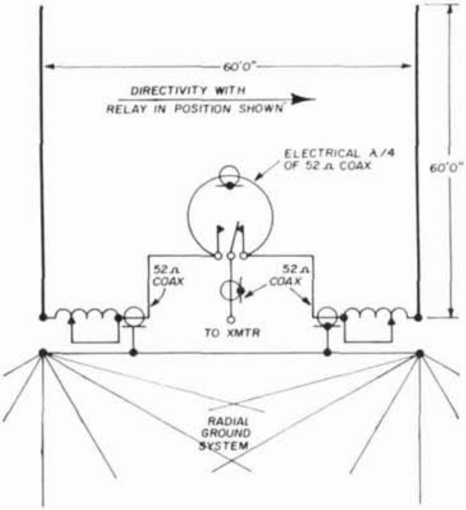


fig. 1. General construction of the array. Loading coils are made from commercial coil stock or home wound, approximately 35 turns, 2½ inches in diameter, close-spaced.

orientation and feed

The two verticals are mounted in line with the direction most wanted. In other words, to work European stations from the East coast, the elements should be mounted in a northeast/southwest line.

Each element is fed with 52-ohm coax. Both pieces are cut to exactly the same length. However, a third piece, an **electrical** quarter-wave-length long, is inserted in series with one vertical, thus making it act as a reflector. This produces a significant gain in the forward direction and a very considerable front-to-back ratio. By using a relay or coax switch, this extra piece of coax can be switched from one vertical to the other, therefore instantly reversing the directivity of the array. Bill has found this feature to be very valuable and quite disconcerting to those on the other end of the contact.

tuning

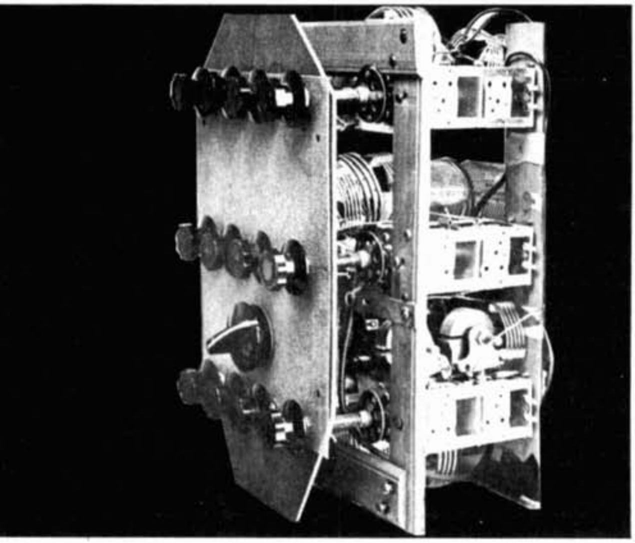
Tune-up of the array was checked with some General Radio test equipment, but for those with more meager means (almost all of us), each element can be tuned separately by using an swr bridge and adjusting the tap on the loading coil for minimum swr. This should be very close to 1:1 at the chosen operating frequency. The loading coils are mounted in small water-tight metal or plastic containers at the base of the elements.

results

Results have been excellent as might be expected. Front-to-back ratio is sufficient to knock down most of the W and VE interference. This, with the forward gain, gives a very significant boost to DX signals. While gain measurements are always tricky, it appears that gain in the order of 3 to 5 dB is reasonable, while actual on-the-air reports (compared with a well-tuned dipole) have been so good as to be considered a bit far-fetched. However, signals received with excellent strength on the other side of the world from VE1 can attest to the performance of the array.

ham radio

Final check by VE1RK (left) and VE1AX. Test equipment is GR 1606-A rf bridge with 1212-A null detector and a 1330-A bridge oscillator.



antenna tuner for optimum power transfer

How to increase radiated and received power using the correct impedance transformer

George A. H. Bonadio, W2WLR, 373 East Avenue, Watertown, New York

In my article on the construction of diversity antennas,[1] I stressed the importance of using the proper antenna tuner. My antennas, because of their inherent low reactance, will work with almost any tuner. But to obtain maximum power transfer, and hence maximum efficiency, you should use what I'll call a "compatible" tuner.

A compatible tuner will transfer power from source to load regardless of load reactance. Conversely, an "incompatible" tuner, although it will transfer power, is inefficient because it doesn't account for reactance.

Both tuner types are discussed in this article. Data is presented to show you how to build a compatible antenna tuner—the most efficient deivce for transforming power from transmitter to load.

an example

Suppose you wish to transfer power from a 52-ohm coaxial cable to a balanced load **(fig. 1)**. The load might have inductive and capacitive reactances that exceed the resistive component **(fig. 1B)**.

A whip antenna, for example, could have a resistive component of, say, 0.5 ohm **(fig. 2)**. Its reactance could be 360 ohms capacitive. To obtain maximum power transfer, you'd need a reactance of opposite sign and equal magnitude. In this example a huge coil would be required, whose skin resistance might be 9.5 ohms. This would result in a 10-ohm series circuit consisting of 0.5 ohm radiation resistance (across which useful power is dissipated) plus 9.5 ohms (across which power is wasted). The circuit's efficiency would be only 5 percent.

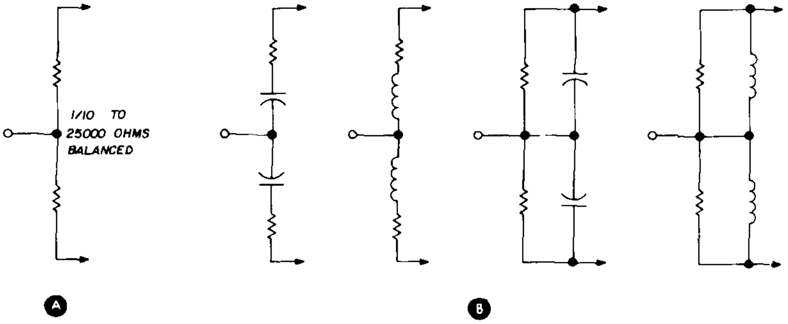
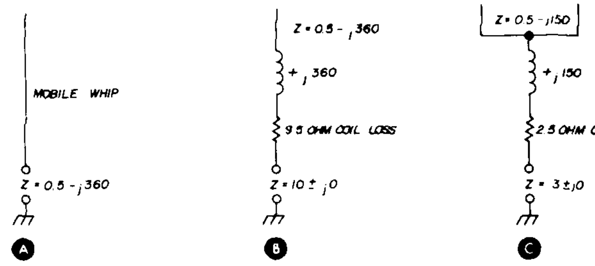


fig. 1. The tuner problem. Load at A is resistive; a tuner working into it will transfer power with minimum loss. A tuner working into loads in B must compensate for reactances.

If a second whip antenna is added, as in **fig. 2C**, the capacitive reactance is reduced to about one-half, and only 2.5 ohms of skin loss occurs in the compensating inductance. Three times as much power is then available for radiation. This idea might be extended to four balanced whips with interesting results.

fig. 2. Reactance compensation. Antennas must be resonant to accept power. This is shown in B, with 95% power loss in the coil. Antennas in C can provide 3 times as much radiated power.



The important thing to remember is that if the ratio of reactance to resistance is high in the tuner, the compensating element may have to be physically large with consequent losses.

power factor

A definition of power factor is the ratio of active (or true) power to reactive (apparent) power. It's generally expressed in percent. Your power company spends a lot of money in its generating equipment to overcome power-factor losses. A corollary in amateur work would be an antenna tuner that delivers only a fraction of the available power to the load. For example, I once had a tuner that delivered only ten percent of its input power to the load on some bands. This is a 90-percent loss, or 10 dB into and out of the tuner.

If the voltage peak doesn't agree with

the current peak in your tuning apparatus, a correction is needed. This is usually accomplished by tuning. If the tuner doesn't compensate properly for reactance, you've got problems.

incompatible tuners

Perhaps you're using one of the tuners shown in the examples of **fig. 3.** It may work beautifully into a dummy load, but its efficiency will suffer from power-factor loss when working into a reactive load.

Consider the load resistance shown in **fig. 1A.** This is a purely resistive load; voltage and current are in phase, and most of the power is dissipated as useful energy. The loads shown in **fig. 1B** contain reactance. Unlike the power company, you don't have a reserve source of power to pump into the load—your generator, which is your final amplifier, is probably working at full output.

To compensate for the reactance, your final will have to supply, say, 100 volts at zero current; the resistive portion of the load will accept 100 volts at 1 ampere. The 100 volts at zero current is so-called "wattless power." Why accept a 3-dB reduction in your transmitted signal or the same loss of received signal power? The compatible tuner is the answer.

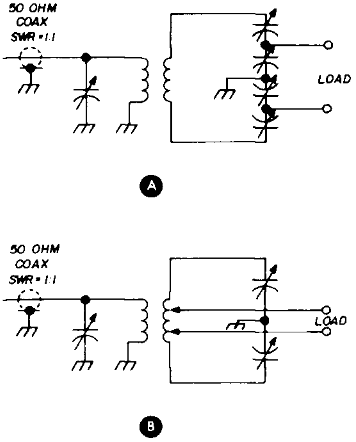


fig. 3. "Incompatible" tuners. Regardless of unity swr, load reactances can cause power-factor loss that wastes energy.

compatible tuners

Don't be misled by a standing-wave ratio of 1. This doesn't prove you don't have a power-factor problem. An incompatible tuner can produce an swr of unity just about as well as a compatible tuner, regardless of load reactance. Neither tuner will *tune* differently, but a compatible tuner will deliver *full* power to its load **(fig. 4).**

tapped constants

You can always tap down on tuner coils and capacitors. If the tuner feeds a resistive load, it will transfer power with minimum loss. If, however, you tap across the tuner with a capacitor, power will circulate in the capacitor and will be returned to the load -sheer waste. The same reasoning applies to a tapped inductance. In general, there's an even chance that only 3 dB, or half your available power, will be delivered to the load if your tuner has the configuration of those in **fig. 3A** or **3B.**

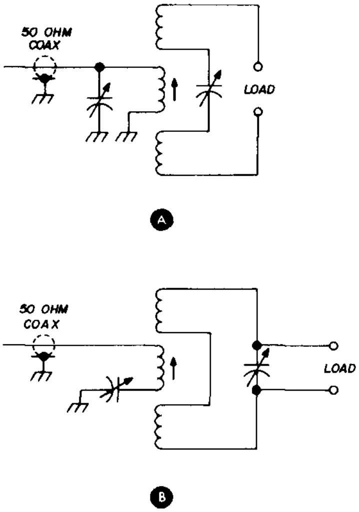


fig. 4. "Compatible" tuners. Either will handle the load reactance. Note that feeders in B are connected directly to the capacitor.

In the compatible tuner, you always load across the lumped inductive and capacitive reactances. No tapped elements are used. A tuner using differential capacitors, as in **fig. 3A** is electrically equivalent to tapping down on the inductance **(fig. 3B)**.

series solution

If line reactance and resistance are in series with a compatible tuner, all reactances cancel, and the system will be resonant. The series solution works fine if the tuner sees a balanced load of under 500 ohms. If the load is much higher, your coils will be so large you may want to change the design.

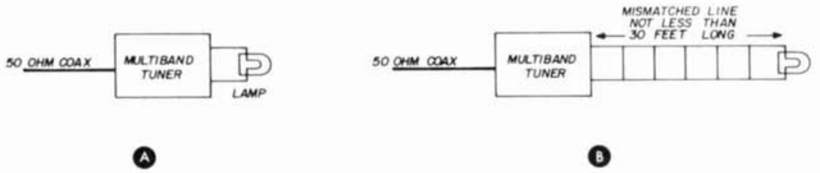


fig. 5. Test circuits. "Compatible" tuner, A, will show same lamp brilliance on all bands. An "incompatible" tuner, with feed line connected as in B, will not deliver full power to the lamp on some bands.

parallel solution

Perhaps your load is higher than 500 ohms. In this case, you can connect a capacitor in parallel with the load impedance **(fig. 4B)**. While this circuit has low peak voltage, it has high circulating current. A smaller coil will waste power because of the current. The changeover at 500 ohms is a matter of economy, physical space, and wavelength.

practical circuits

To build a practical compatible tuner, measure line resistance and reactance, then plot the data. You can determine sizes of the constants from a table hookup. Then all you have to do is wind the coil, cut it and solder. It works right the first time.

proof test

Disconnect your antenna feeders from the tuner. Connect a lamp in place of your antenna feeders **(fig. 5A)**. Tune your transmitter into the load, then change bands. If you're using a compatible tuner, lamp brilliance won't change much from band-to-band.

Now connect the same lamp load as shown in **fig. 5B.** Excite the load, starting at the lowest-wavelength band, then progress through the shortest-wavelength band, If you're using an incompatible tuner, you'll find that the bulb won't light well on most bands.

In my next article, I'll show how to build a simple homemade tuner that can be used as an outboard device to compensate for reactance in an incompatible tuner. I'll also discuss feedpoint measurement using the substitution bridge methods.

reference

1. George Bonadio, W2WLR, "Construction of High-Frequency Diversity Antennas," *ham radio,* October, 1969, p. 28.

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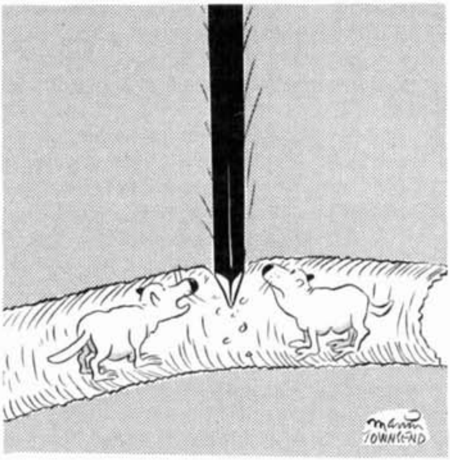

"Watch your head! Our ham friend is putting in a new ground rod."

the isotropic source and practical antennas

Antenna performance is explained in terms of the imaginary free-space isotropic radiator

Ray Griese, K6FD

The isotropic antenna is an imaginary concept as basic to antenna theory as Ohm's law is to circuit theory. Over the years, Ohm's law has been expanded into many forms of circuit theory that are hardly recognizable to those with limited experience. But the most complex forms can be traced back, step by step, to E=IR. The relationship between the isotropic antenna and advanced antenna theory is similar. Unfortunately, very little has been written about the isotropic antenna on the basic level for use by radio amateurs. Perhaps this article will help those who desire a keener insight into operation and performance of antennas.

antennas in free space

The isotropic antenna is considered as a point source of electromagnectic radiation. It is the simplest form an antenna can take. In fact, it is so simple no one has managed to build one for electromagnetic waves, although it has been approximated for sound waves. The difficulty is that a point-source antenna must have zero dimensions. Such an antenna, of course, is impossible to construct by any known method. But even so, this nice bit of fiction can be easily approximated for many practical purposes. For example, a 7-MHz antenna located 100 km in space will *look* like a point source even though it isn't. The errors introduced by the size of the antenna are too small to matter at that distance for almost all areas of interest. In most calculations, a distance of 100 km isn't necessary to make an antenna look like a point source of radiation. This distance can be just a few wavelengths in some instances without introducing intolerable errors. The free-space radiation pattern of the isotropic antenna is shown in **fig. 1.** The antenna radiates in all directions: east, west, north, south, up and down. There is no inherent directivity, and this is exactly what the name implies: *iso* meaning everywhere the same; *tropic* meaning no matter how it is turned.

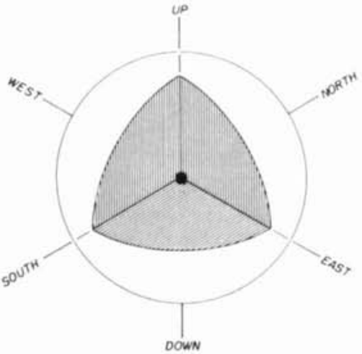

fig. 1. Radiation pattern of the isotropic antenna in free space.

power and voltage measurements

Antenna engineering involves measurements in addition to those of frequency, phase, resistance and resonance. Two of these measurements are power density in watts per square meter (W/m^2) and electrical field strength in volts per meter (V/m). Both can be derived by using the isotropic antenna for demonstration.

Imagine that the isotropic antenna is located in the center of a spherical balloon whose surface is everywhere 1 meter from the antenna **(fig. 2)** and that the antenna is radiating 1 kW. All of the radiated power must pass through the surface of the balloon, and it is easy to calculate how much power passes through each square meter of its surface The surface of a sphere is $4\pi R^2$. With a radius of 1 m, it is 12.57 m^2. Therefore, the power passing through 1 m^2 of surface is 1000/12.57, or 79.5 W. If the balloon is inflated until the radius is 10 m, the surface area will be increased 100 times, the area will be 1257 m^2, and the power passing through 1 m^2 will be 0.795 W. It can be seen that free-space loss in power, in its progress from source to oblivion, is due to the spreading of the wave. The mathematical relationship is $P = 1/D^2$, where D is the distance from source to point of measurement. Thus, the power passing through a unit area is inversely proportional to the square of the distance from the source.

In actual antenna-pattern and field-strength measurements, the instruments read out in voltage rather than power. The conversion from W/m^2 to V/m is related by

$$e = (377P)^{1/2}$$

where

e is V/m
P is W/m^2
377 is a constant*

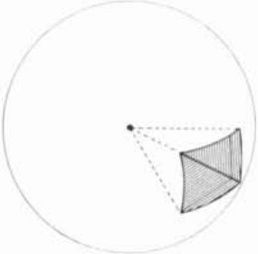

fig. 2. Radiated power passing through 1 square meter of spherical surface.

Returning to the spherical balloon example, if W/m^2 is converted to V/m, the field strength at D = 1 km is 0.173 V/m. This is usually expressed as 173 mV/m in antenna literature. It is the free-space field of 1 kW at 1 km from an isotropic source. Sometimes referred to as "unattenuated free-space field strength," it means that nothing is in the path between antenna and measuring equipment that

*The number 377 is the product of 120π which is the resistance of free space. **Editor.**

will introduce measurement errors.

directional characteristics

Engineers use antenna directional characteristics to maximize radiation at the angles of elevation and azimuth required for the station's coverage. The principle uses vector addition of the radiated fields. This principle is well covered by antenna texts, so it will not be discussed further. But the use of the isotropic antenna in lieu of an actual antenna simplifies the problem to some degree, and it is helpful to look at it in this manner.

Suppose the isotropic antenna is ½ wavelength above a perfectly conducting and reflecting plane. Measurements of the radiated field will show that the spherical pattern has been distorted by the reflecting plane; the pattern is depicted in **fig. 3.** Radiation upward is zero, because the reflected wave is reversed in phase and cancels the downward radiation. Radiation horizontally along the plane is also zero, because the reflected wave is reversed in phase, and the sum of the direct and reflected wave is zero **(fig. 3)**.

The path length of a wave reflected 30 degrees above the ground plane is ½ wavelength longer than that radiated directly from the isotropic antenna. The additional ½ wavelength adds 180 degrees of phase change. This, plus the 180-degree phase reversal due to reflection, brings the two waves back in phase, and they add. The sum is twice the value of either direct or reflected wave, resulting in 6-dB gain. If the wave from the isotropic antenna is horizontally polarized, then its pattern cross section is similar to that of a dipole located ½ wavelength above a perfectly conducting plane.

the dipole

The directive property of the dipole is caused by wave cancellation and addition similar to that of the isotropic antenna above a perfectly conducting plane. Suppose the dipole consists of two isotropic antennas spaced ½ wavelength apart. At a distant point on the axis line, the radiation from one would arrive 180 degrees out of phase with the other, and would cancel the fields. At right angles to the axis line between the two isotropic antennas, the fields would arrive at the same time, in phase, and would add, thus making a lobe of maximum radiation. Minimum radiation, of course, would be along the axis of the line between the two isotropic antennas.

The field of a dipole is almost exactly like this. The difference is caused by power distribution along the antenna. If the dipole were cut into an infinite number of isotropic antennas whose power and phase were identical to that of the dipole, and the fields of all of these isotropic antennas were added, the result would be the field pattern of the dipole. Thus, the inherent directivity of the dipole exhibits a gain 2.1 dB above that of the isotropic antenna. The gain is not 6 dB, because it is generated in a different manner than that of the isotropic above the reflecting plane; it is the sum of many fields of many amplitudes and phases and not the sum of two fields of equal amplitude and identical phase. However, when the dipole is placed horizontally ½ wavelength above a perfectly conducting plane, the maximum lobe will be the sum of the direct and reflected fields, and the gain will be 6 dB. This gain, plus the dipoles's 2.1-dB inherent directivity will result in 8.1-dB gain above the isotropic antenna. This pattern is the familiar double-lobe pattern as shown in **fig. 4.**

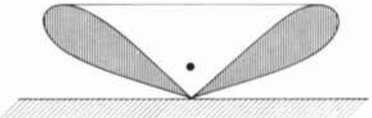

fig. 3. Cross section of the radiation pattern from an isotropic antenna ½ wavelength above a perfectly reflecting plane.

the real world

A perfectly conducting and reflecting ground plane is hardly ever available. The average soil has much less than ideal reflecting capabilities. Losses from this source distort the neat, geometric patterns shown in the textbooks.

Another interesting conclusion results from the reflection phenomenon. Suppose the antenna is erected over the world's worst location—the soil absorbs all the radiation, and reflection is zero. The field strength of the maximum lobe will be one-half the ideal value—a 6 dB loss. The minima will disappear, and the gain at those angles can be 10 to 20 dB, which may or may not be useful in transmission and reception.

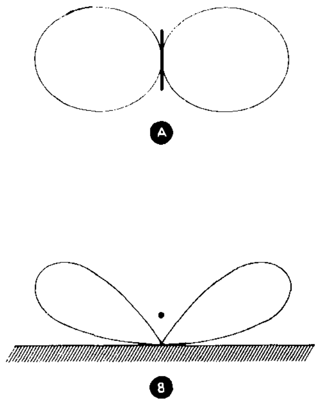

fig. 4. Radiation pattern of a dipole located ½ wave above a perfectly reflecting plane; horizontal pattern is shown in A, vertical pattern in B.

grounded antennas

Grounded antennas also respond to the isotropic antenna concept. Suppose the isotropic antenna is located directly on the perfectly reflecting and conducting plane. The antenna is so close to the reflecting plane that no phase reversal of any kind exists. The pattern will be a hemisphere, because no radiation will exist downward through the reflecting plane. Assuming 1 kW is still being used, in free space 500 W will be radiated above the equatorial line in **fig. 1**, and 500 W below. When on the ground, 1 kW will be radiated upward, and the power gain will be 3 dB.

Vertical grounded antennas exhibit a modified 3-dB gain factor because of their finite length. Radiation from the bottom tends to generate the isotropic pattern, while that from the top tends to create maxima and minima, because the top is some distance above the reflecting plane. Grounded antennas shorter than 5/8 wavelength exhibit more gain toward the horizon than the sum of the 3-dB and free-space directivity gain. The extra gain comes from increased directivity at low vertical angles, because the wave is vertically polarized, and the direct and reflected waves add. There is no phase change with reflected vertical polarization.

Again considering the vertical antenna situated over the world's worst ground, maximum loss will be 3 dB! It is important to have the vertical antenna as far as possible from nearby structures.

It is also important to have a low-resistance ground connection. Vertical antennas usually have a feed-point resistance from a few ohms to a few hundred ohms. A ground-rod may have a ground contact resistance of 200 ohms; a 36-ohm antenna connected to such a ground would receive only about 1/6 of the delivered power—5/6 is used to heat the ground rod.

radiation pattern and ground conductivity

Ground reflection varies with different soils. The amplitude and phase of the reflected wave depend on the angle of incidence, soil conductivity, and soil dielectric constant. The radiation pattern of grounded verticals in the high-frequency bands may be radically different from that anticipated. These verticals can be improved by using two or more ¼-wavelength ground-plane radials. On vhf bands and higher, vertical antennas are many wavelengths above ground, so the effects of soil conductivity and dielectric constant are minimized.* The maximum gain from a vertical antenna several wavelengths above a perfectly conducting

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*However, a simulated ground plane, consisting of ¼-wavelength radials, is essential for vertical ¼ wave vhf antennas. **Editor.**

table 1. Directivity power gains of common antennas radiating 1 kW.

antenna	power gain (numerical)	power gain (dB)	$\mu W/m^2$ at 1 km	$\mu W/m^2$ at 1 mile	mV/m at 1 mile	mV/m at 1 km
dipoles, free-space conditions						
isotropic	1.00	0	79.5	30.6	107.5	173
1/16 wave	1.50	1.76	119	46	131.5	212
1/4 wave	1.54	1.86	122	47	133	214
1/2 wave	1.64	2.14	130	50.3	138	222
5/8 wave	1.74	2.39	138	53.5	142	228
monopoles, grounded, perfectly reflecting ground, vertical polarization						
isotropic	2.00	3.00	159	61.2	152	244
1/16 wave	3.00	4.76	239	92	186	300
1/4 wave	3.30	5.18	262	101	195	314
1/2 wave	4.84	6.84	385	148	236	380
5/8 wave	6.53	8.14	518	201	275	442
dipoles, ½ wave above perfectly reflecting ground, horizontal polarization						
isotropic	4.00	6.00	318	122	215	346
1/16 wave	6.00	7.76	477	184	263	424
1/4 wave	6.12	7.86	487	188	267	429
1/2 wave	6.53	8.14	520	201	276	443
5/8 wave	6.92	8.39	552	213	283	456

ground is more than 6 dB. Gains for several antennas, modified by the ground plane, are given in **table 1.**

physically small antennas

An interesing feature about antennas is that a small antenna can radiate a large amount of power, but physical limitations prevent this from being done efficiently. One limitation is antenna conductor resistance. As the antenna is shortened, radiation resistance decreases to a point where most of the power is dissipated in heat rather than radiation. Some large vlf antennas, for example, radiate only about 5 percent of the power delivered to them. On the hf bands efficient operation, say in excess of 50 percent, is possible by using a dipole that's small compared to a wavelength. The practical limit is in the vicinity of 1/16 wavelength. The radiation resistance will probably be between 0.5 and 1.0 ohm. With care, a 160-meter dipole can be constructed that is as small physically as a 20-meter dipole. A small, center-fed dipole is much more effective on the 2- and 3-MHz bands than a short, grounded vertical *without a low-resistance ground.*

avoiding losses

Poor antenna performance is caused by pattern formation disturbed by improper construction, improper feeding, or distortion from nearby objects. Poor ground connections in vertical antennas don't apply to horizontal dipoles. The difficulty with the latter is due to losses at the element ends, which carry high voltage. The best way to avoid these losses is to use plastic guys or insulators with low leakage paths. The antenna should be carefully tuned and matched to its transmission line.

conclusions

The isotropic antenna concept clearly shows why any practical antenna's field is highest near the antenna. For best results, the antenna should be as clear as possible from obstructions, and ohmic losses should be a small fraction of the antenna's radiation resistance. If all resistances that dissipate power uselessly are reduced to an absolute minimum, the amount of radiated energy can be increased by increasing antenna radiation resistance.

ham radio

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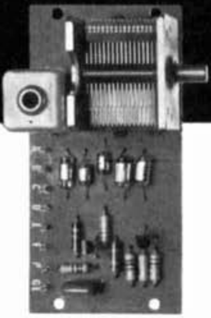
These four modules, MX1, AA1, VO1 and TX1 are completely wired and assembled circuit boards to custom build a 40-80 meter CW transceiver. Use the VO1 for a transmitting and receiving VFO. The MX1 converts signals directly to audio. Crystal provision in the TX1 allows Novice use. AA1 amplifier drives head phones.

MR1, set of four modules, with instructions **$29.95**

MX1—Synchrodyne detector-converter uses dual gate MOSFET for high sensitivity, low noise and effective reduction of overload. Selectivity 2KHz. 2″ × 4″ circuit board. Power +12 VDC @ 3 ma.

AA1—Integrated circuit audio amplifier has 100 db gain. Response shaped 200-2500 Hz. Output impedance 1000 ohms. Drives high impedance headphones. 2″ × 4″ circuit board. Power +12 VDC @ 9 ma.



VO1—40-80 meter oscillator-buffer. Drift less than 100 Hz. Output 2 volts R.M.S. Low impedance. Designed for use with MX1 or TX1. 2″ × 4″ circuit board. Power +12 VDC @ 15 ma.

TX1—Crystal oscillator and power amplifier. Tapped toroidal coils cover 80-40-20 and 15 meters. Final amplifier power input 2 watts. 2″ × 4″ circuit board. Power +12 VDC @ 250 ma.

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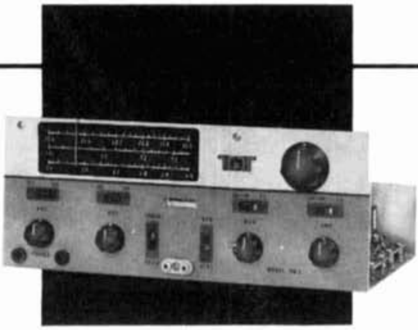

POWER-MITE 1 The MX1, AA1, VO1, and TX1 modules are wired into a bandswitching 80-40 meter CW transceiver. Front panel controls: On-off, Transmit-Receive, Receiver Resonate, VFO-Crystal, Bandswitches, Oscillator tuning, Final Resonate. A meter is provided to monitor final amplifier current.

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PM2 (with case)	**$54.95**

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AC5—Low power antenna tuner. Matches random length twin lead or open wire line fed antennas. 10 watts maximum.	**$8.95**
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underground coaxial transmission lines

Underground coaxial transmission lines offer a number of advantages — here's the correct way to do it

Bob Ruyle, W0FCH, 420 Steinway Road, Lincoln, Nebraska 68505

Have you ever considered putting that coax lead-in underground? It has an aesthetic influence on the wife and the neighbors and if properly installed has some advantages over the old aerial installations. The number one item of consideration is advance planning. This is absolutely necessary to make sure you don't run into gas lines, telephone cables

Author Ruyle getting ready to install an underground cable run.

or power lines that may be buried in the area.

First draw a sketch of the exact location the cable will occupy and use it to check city drawings of the area before making the trench. Keep the sketch with your equipment manuals for future reference.

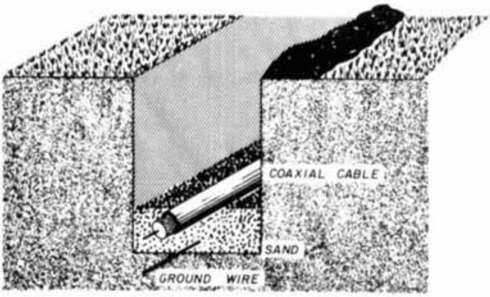
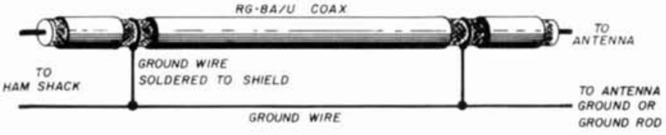


fig. 1. Cable trench. Sand provides drainage and discourages rodents.

choosing cable

The next step is to choose the proper cable. Check manufacturers specifications for information on their cable; they will tell you which should be buried and which should not. The cable may or may not be armored. Armored cable should be used in areas where gophers and other rodents are a problem. However, when cable is installed as shown in **fig. 1** armored cable is not a necessity. Make sure you have enough cable to install it without a splice. (Splicing *can* be done, but great care must be taken to keep the moisture out.)

fig. 2. External ground wire protects the coax against lightning damage. It shouldn't be more than a foot away from the coax.



the trench

Your next step is to dig the trench. Dig it 18 to 24 inches deep and 4 to 12 inches wide. If the terrain is rough increase the depth to 30 inches or more. Put 2 or 3 inches of sand in the bottom of the trench. (see **fig. 2**). The cable is placed on top of the sand. If you think you might need more cable in the future you can put a length of plastic conduit in the trench to allow for cable pulling at a later date.

Buried cable is subject to lightning just as exposed cable is so a shield wire or a no. 4 AWG aluminum wire is recommended. Lay the wire beside or above the buried cable but not more than one foot away. The wire, just as the cable, *should not be spliced.* To be effective the shield wire must be connected to the outer shield of the coax cable at both ends as shown in **fig. 2.** (If the cable is spliced then the ground wire should be connected to the splice point as well.)

Sand is poured into the trench on top of the cable and the ground wire to a depth of 2 to 3 inches. The sand provides proper drainage to keep the cable dry and discourages underground rodents from chewing on the cable. The sand also protects the cable from rocks that may work their way up thru the soil.

Before refilling the trench be sure to check the coax for damage by attaching a dummy load to the end and running swr checks at spot points on each of the amateur bands. With a high-quality dummy load the swr should be 1:1.

ham radio

integrated swr bridge and power meter

A novel application of a toroid as a sensor for a built-in swr and peak power monitor

Lloyd M. Jones, W6DOB, 17,779 Vierra Canyon, Salinas, California 93901

The instrument described in this article is designed to replace the various sizes and shapes of the black box known as the "swr bridge." The instrument, which I call an integrated swr bridge and power meter, performs all the functions of the usual swr bridge plus a few more—yet it occupies only about two cubic inches. Components will fit nicely in the space next to the rf output connector in most equipment. With the integrated swr bridge and power meter installed in your transmitter or transceiver, you can dispose of your regular swr bridge and use the parts for other projects.

The instrument is in the line at all times. It consumes only a few microwatts and doesn't disturb the circuit in which it's connected. In addition to measuring swr, the bridge measures peak power, monitors voice peaks, and indicates normal voice-power output. With a noninductive dummy load, you can check transmitter neutralization under full power.

The schematic is shown in **fig. 1**. The indicator can be your S-meter or plate-current meter. The meter sensitivity can be between 1 mA and 25 mA. A fixed resistor for R4, or a variable resistor controlled from the front panel, can be used to set peak meter reading to any desired value.

circuit development

This circuit may be well-known to some readers, but I don't recall seeing it in this application. A schematic of a 50-MHz, 40-watt cw transistor transmitter in the RCA Transistor Manual[1] uses a vswr bridge to back- bias a driver stage for excitation control to the final amplifier. When the vswr is high, drive decreases to maintain the final amplifier transistor within ratings.

The RCA diagram, reproduced in **fig. 2**, suggests the possibility of adding another coil on the toroid. Thus the circuit could be used to indicate forward and reflected power with reasonable accuracy.

construction

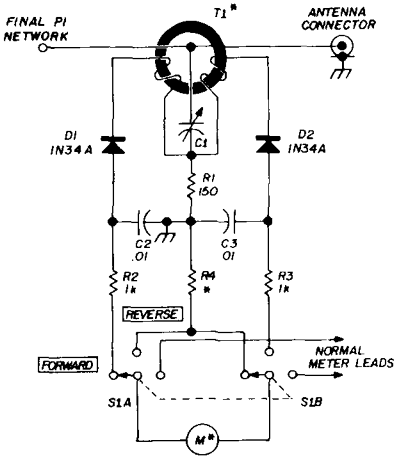
Toroid cores of one-half inch I.D. were used; a possible source is Amidon Associates.* The windings are made by twisting two lengths of No. 26 enamelled wire about 12 inches long. Wind the twisted pair to occupy ten turns around the core, then apply a coat of coil dope. Untwist about two inches from the ends, remove the insulation, identify each end with an ohmmeter, then connect the two windings in series **(see fig. 3)**.

Unsolder the transmitter rf lead from the chassis connector and slip the toroid coil over the lead. Shim the toroid around the lead so that the coil can't possibly touch the rf lead. (I used a ½-inch length of polyethylene cut from RG-58/U coax and slipped it onto the rf lead; this provided a snug fit for the toroid.) Resolder the rf lead to the chassis connector. The lead from capacitor C1 **(fig. 1)** should be connected to the rf line within ½ inch of the toroid.

Cut a piece of phenolic board about 1 x 2 inches. A guide for laying out the parts is shown in **fig. 4**. If you'd like to go the modern route, etch the circuit as shown. Mount the parts as suggested in **fig. 4**. Bend the leads on the back side to join with other leads that are twisted together, cut off excess, and solder. Be sure to form solder connections close to the board, so that bushings about ¼ inch long will hold the board away from the mounting surface to avoid short circuits.

Attach three wires, preferably a 3-conductor shielded cable, to the board output. Route the cable to the meter and dress the cable to avoid the amplifier's rf field. Ground the cable shield at both ends.

The switch selects either forward or reflected power, or the circuit normally connected to the meter (marked A and B, **fig. 1**). If you don't wish to mount the switch on the panel of your equipment, the switch can be remotely located.



*SEE TEXT

fig. 1. Schematic of the integrated swr bridge and power meter. Capacitor C1 is a 1.5-8 pF trimmer (Erie 539); S1 is a Mallory 22F134 wafer switch. Components occupy only two cubic inches.

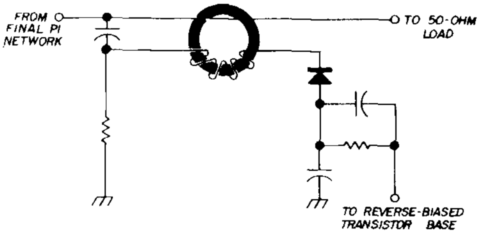


fig. 2. Circuit in the RCA Transistor Manual from which the design was developed.

adjustment and calibration

When wiring is complete and checked, connect a dummy load to the transmitter. Adjust R4 and/or the carrier power to give a full-scale meter reading in the FORWARD position. Position the switch to REFLECTED. The reading should be noticeably lower.

When making adjustments, remember that high voltages are present in the vicinity of the circuit board. Keep clear of high voltage circuits and use an *insulated* tuning wand for all adjustments.

Adjust C1 for a minimum meter reading, which should be very close to zero. Check the adjustment of C1 on all bands. Capacitor C1 tunes out the reactance of

*Amidon Associates, 12033 Otsego Street, No. Hollywood, California 91607. Part no. T-80-2; price 60c each plus 25c handling; minimum order $1.00.

the toroid coil. If the dummy load is *nonreactive on all bands*, C1 shouldn't have to be changed with band switching.

Remove the dummy load and connect the antenna. Adjust the transmitter for full power, adjusting R4 as you tune to give a full-scale reading on the meter with the switch in the FORWARD position. Now switch to REFLECTED. The meter should read 1/10 full scale or less at the antenna resonant frequency if the antenna is matched to 50 ohms.

A rough indication of swr may be had by calibrating the meter (scale 0-100) as follows: 50 = 3:1, 25 = 1.5:1, 12.5 = 0.75:1, 6.25 = 0.37:1, and 3.1 = 0.19:1.

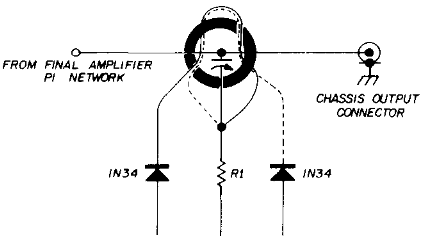


fig. 3. Method of series connection for T1 windings. Only two turns are shown for clarity.

If you adjusted C1 using a 50-ohm dummy load, then changed to a 75-ohm transmission line, C1 should be readjusted for minimum meter reading using a 75-ohm dummy load.

peak-power measurement

As I mentioned at the beginning of this article, this instrument serves admirably as a peak-power measuring device. All that's required for this use is to choose a value for R4 for your particular transmitter input power (**table 1**). If your transmitter is rated at 180 watts input, for example, the value shown for an input of 200 watts would be adequate for R4. The output power will be some fraction of full-scale meter indication, of course.

If you decide to use a switch with another set of contacts, a fixed resistor could be used for R4 to indicate power output, and a variable resistor could be used to allow full-scale meter indication of swr with reduced power.

table 1. Values of resistor R4 for different transmitter powers and meter sensitivities.

transmitter input power (watts)	meter movement 1 mA	500 μA
100	7500	15k
200	15k	27k
300	18k	33k
500	22k	47k
600	27k	56k
1000	47k	91k

conclusion

I've found this circuit indispensable for checking the resonance of my mobile whip antenna. With the switch in the REFLECTED position, I can adjust the whip antenna length for a minimum meter indication at the desired frequency.

Perhaps some of the more enterprising manufacturers of transmitters and transceivers will incorporate this instrument in future models. The small cost should make it worthwhile.

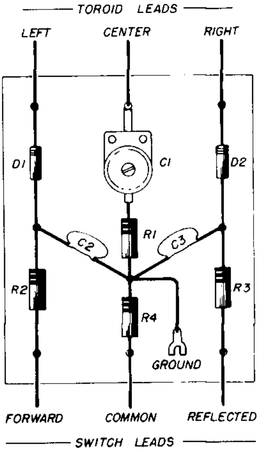


fig. 4. Suggested parts layout on phenolic board.

references

1. "RCA Transistor Manual," Radio Corporation of America, Electronic Components and Devices, Harrison, New Jersey, January, 1967 edition, pp. 504-505.

ham radio

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some reflections for reflected power

Transmission-line standing-wave ratio seems to be a topic for much debate — here are some interesting views on the subject

Walter H. Anderson, VE3AAZ

A UA9 I worked recently said he was using a Zepp antenna. It occurred to me that at least one generation has passed since the Zepp was, by far, the most popular ham antenna (see **fig. 1**). We didn't realize it then, but the Zepp's standing wave ratio probably ran as high as 30:1. However, history shows that the Zepp put out a good signal. Thus, it would seem that the Zepp didn't really have the side effects we hear attributed to high swr nowadays: high plate dissipation, radiation loss and all the rest.

I don't suggest we dismantle our beams and go back to Zepps. Rather, I propose to show that transmission-line theory, properly understood, is free of the contradictions that seem to arise when discussing swr, reflected power, line losses and other phenomena associated with antennas and feed systems.

transmission-line length

The relationship between electrical and physical length is significant when discussing transmission-line characteristics. For example, the RG-8/U coax for my 14-MHz antenna, is about 94 feet long. Its velocity factor is 2/3, which means the velocity of the signal traveling on the line is 2/3 of what it would be in free space. The line's electrical length is 94 x 3/2, or about 140 feet (two wavelengths). A signal requires 14.25×10^{-8} second or 1/7 microsecond to travel the line's length **(fig. 2)**.

Let's look at it another way. Suppose the letter H is sent at 12 wpm. In the time required to make just one dot, an electrical signal would make 3.5×10^5 round trips on the line. In this sense, the line is extremely short.

The transition of a conductor from a simple connecting wire to part of a transmission line is said to occur when circuit length exceeds 0.1 wavelength. Therefore most antenna transmission lines are electrically long and must be analyzed in terms of transmission-line theory.

In the first part of the discussion the line is assumed to have zero loss. Lossy lines are considered later from a practical viewpoint.

line reflections

The characteristic impedance, Z_0, of a transmission line is the impedance which, at the line's termination, will absorb all the energy in the line. This is never realized in practice, because it's impossible to construct a line with constant impedance along its length.

What happens if the load impedance doesn't equal line impedance and some energy is reflected?

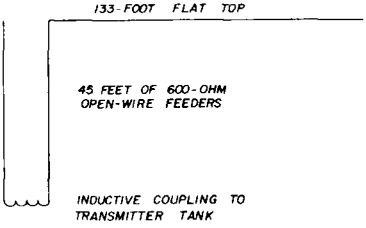

fig. 1. The classic Zepp. A very popular antenna years ago despite a standing wave ratio that sometimes was quite high.

It's unlikely that the source and line impedances will be exactly equal. Thus, any energy reflected from the load will travel down the line to the source to be reflected again toward the load. This repeats until the wave's amplitude becomes too small to be of interest.

The waves moving from source to load and from load to source are called the incident and reflected component, respectively. If the sum of any two waves is measured at any point on the line, the result would be a single standing wave. Thus, no matter how many *individual* waves are in the forward or reflected component, a standing-wave measurement will describe what's happening on the line at the point of measurement.

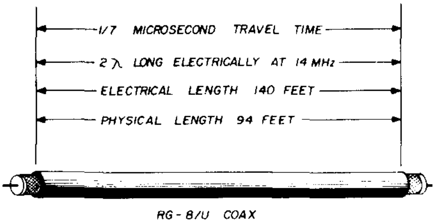

fig. 2. Relationship between signal travel time and line length for a typical coax line.

standing wave ratio

Various instruments have been devised to sense the waves traveling from source to load and vice versa. The indicators (meters) on such instruments are calibrated for forward and reflected power. While these meters indicate in watts, we shouldn't regard the readings as we would usually use the word "watt." The only *real* power is the difference between forward and reflected indications on these instruments.

If a standing-wave pattern is made for voltage and some reflected power exists, the voltages will combine in phase at a voltage maximum and be out of phase at a voltage minimum. The ratio of these quantities is the voltage standing wave ratio. In a lossless line, the power passing a given point will be the same as that passing any other point. Therefore, at points of voltage maximum, current will be minimum, and vice versa. It therefore follows that current and voltage swr can be used interchangeably.

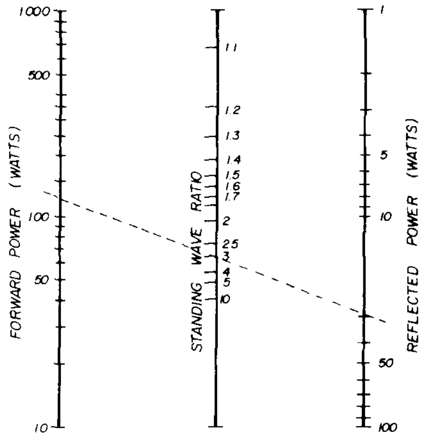

fig. 3. Nomograph for finding swr for various values of forward and reflected power.

Forward power, reflected power, and swr are related by

$$\text{swr} = \frac{1 + \sqrt{\frac{\text{Pref}}{\text{Pfwd}}}}{1 - \sqrt{\frac{\text{Pref}}{\text{Pfwd}}}} \qquad (1)$$

common misconceptions

Up to this point the transmission line has been assumed lossless. This isn't true in practice although it's closely approximated in modern coax cable and open-wire lines operating below vhf.

Occasionally someone writes an article based on the graph shown in **fig. 4**, which was adapted from reference 1. The reasoning runs this way: if the terminating impedance is 100 ohms on a 50-ohm line, then the ratio of reflected-to-forward power is 1/9. So only 8/9 of the power is absorbed by the load, which means a reflection loss of 10 $\log_{10}$ 9/8 = 0.5 dB. The fallacious conclusion is that such a condition leads to a *reduction* in radiated power and possibly an increase in plate dissipation of the amplifier tubes. Viewed in proper perspective, this is insignificant in practical applications.

lossy lines

Let's now use reflection loss in its proper sense. Consider a very lossy line with Z_0 = 50 ohms and a loss of 20 dB overall. If 60 volts are applied to the input, 1.2 amperes will flow. Thus 72 watts enter the line. At the load end the power will be down 20 dB, or down to 0.72 watt. If the load is, say, 100 ohms and reflected power is 1/9 forward power, the reflected power will be 0.08 watt, and only 0.64 watt will be absorbed by the load. The 0.08 watt will return to the source, suffering another 20-dB loss, arriving at the source at 0.0008 watt. This tiny amount of power will hardly affect conditions at the sending end.

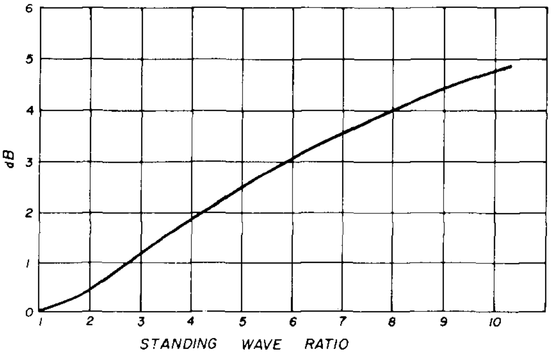

fig. 4. Reflection loss on a transmission line with increasing swr.

This is the justification for saying that the line looked like 50 ohms even though its termination was not 50 ohms. The significance is that the line loss is great; *not* that reflection loss exists.

Generalizing, we can say this about lossy lines:

1. The swr at sending and receiving

ends is different; the load end always exhibits the higher swr.

2. Power into the line equals the sum of line losses and power delivered to the load.

3. Reflection loss is only meaningful when line losses are so large that load changes don't modify the line's input impedance and thus cause a change in power into the line.

4. The lost power is not distributed evenly over the line, but is much greater nearest the source.

approximate line loss

All lines have some loss. This is because standing waves of current stress the line at certain points. A rough guide of line loss as a function of swr is shown in **fig. 5**. An approximation of the loss can be made by shorting the line at the antenna, obtaining an swr reading and plugging it into the following equation:

$$\text{Line loss in dB} = \log_{10} \frac{\text{swr} + 1}{\text{swr} - 1} \qquad (2)$$

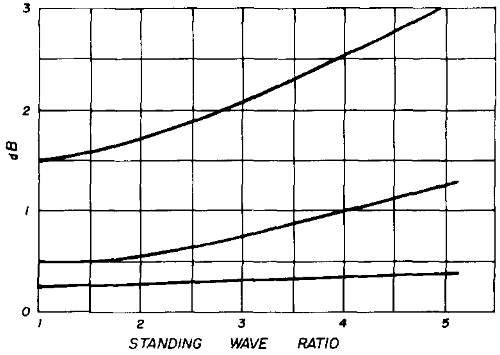

fig. 5. Transmission line loss with increasing swr.

the Zepp again

Let's return for a moment to the good old days. Imagine a pair of 210's feeding a Zepp antenna that has a 30:1 standing wave ratio. Sixty watts would be a reasonable output for 100 watts input, leaving 40 watts for plate dissipation and tank-circuit losses. The forward power would, however, be 480 watts, and the reflected power would be 420 watts. (Check the numbers in **Eq. 1** if you doubt it!)*

If there is no harm in high reflected power as far as *power delivered* to the antenna is concerned, then why all the fuss about high swr? We'll explore this and other fascinating topics next.

transmitter specifications

Quoting from published data on two popular transmitters,

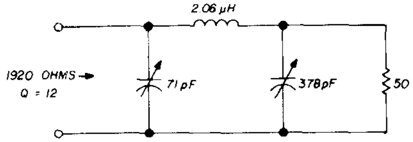

fig. 6. Typical pi network values for 14 MHz.

Collins 32S3: "Rf output impedance 50 ohms with not more than 2/1 swr."

B&W 6100: "Output impedence – will match 30-100 ohm resistive load."

These statements require some interpretation, since what is referred to in both cases is the *load* impedance, *not* the output impedance, which is what one would measure looking back into the transmitter output terminals. Also it's not a matter of matching (equalling or duplicating) anything; it's a matter of what impedance is appropriate as a load. As for the Collins, the statement *could* perhaps mean that as long as the resistive component was 50 ohms you could have up to 2/1 swr. What it undoubtedly *does* mean

---

*The forward and reflected power could also be 48 and 42 watts, or 4800 and 4200 watts respectively. Knowing the old 210 triode, 48 and 42 watts would probably be more realistic. **Editor.**

is that you can cope with any load impedance that has less than 2/1 swr on a *50-ohm basis.* As for the B&W, it appears that no reactance whatever is permissible, even though the swr can be about two or so. This suggests that the line must be trimmed to exact quarter-wave multiples.

If a low-pass filter is used, it would be difficult to meet the specifications without laboratory facilities. Perhaps these statements about loading are not intended to be taken this literally; however, the point remains—this is the way they are published.

line sending-end impedances

When the reflected power is not zero (swr is not 1), and the line is of random length, the reflected voltages and currents may have any phase relationship when they combine with the forward voltages and currents at the sending end. Thus, the impedances at the transmitter end of the line may vary within certain limits, depending upon line electrical length. **Table 1** lists some of these possibilities, all on a 50-ohm basis.

Table 1 shows that if you have a line with a known swr and put an rf bridge at the sending end, the impedance will fall in the corresponding column. The antenna's terminal impedance will also appear in the column. Note that the swr = 1 column has only one entry, while entries in the other columns are theoretically limitless. However, no impedance in any one column appears in any other.

So if you have a line with an swr greater than one, you can lengthen or shorten the line and change its impedance at the sending end. But you can never hit 50 ohms pure resistance, even though the *resistive component* may be 50 ohms plus some reactance.

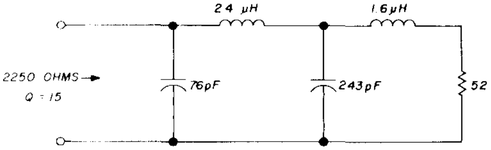

fig. 8. Typical pi-L network circuit values for 14 MHz.

Published transmitter specifications are undoubtedly intended to encourage the operator to keep the swr low so that the transmitter is presented with a load impedance near 50 ohms.

output networks

Most modern transmitters use pi networks in the output. A common misconception is that these networks can transform any imaginable impedance to that required by the final amplifier plate circuit.

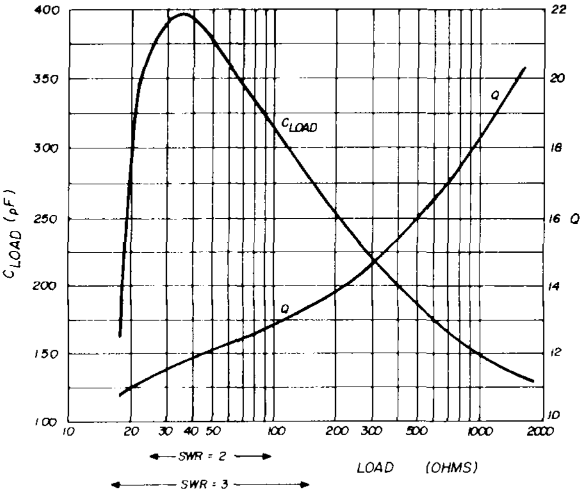

fig. 7. Pi network loading capacitance and Q as functions of output loading resistance.

For example, consider a pi network designed to be used between parallel 6146's and a 50-ohm load. These tubes should work into a load of about 1920 ohms at a Q of about 12. The circuit is shown in **fig. 6**. The tank inductance is generally fixed, but the two capacitors are variable to maintain the proper load impedance despite external load changes.

What happens when the load is changed and the capacitors are adjusted to maintain correct tube plate impedance is shown in **fig. 7**. In this case, we face an impossible task when loads are lower than 17 ohms or higher than 1800 ohms. Also, even when we're well within the range of possible impedances, the loading capacitor must be varied widely, which is certain to influence harmonic response. Circuit Q also changes, and this will affect the output waveform, although probably not seriously. The only way to avoid this is to present the transmitter pi network with an impedance close to 50 ohms, i.e., a load with an swr close to unity.

When I was writing this article, Bill Orr's article on pi an pi-L networds came along.[2] Taking these parameters (input impedances = 2250 ohms; Q = 15; load impedance = 52 ohms) at 14 MHz, **fig. 8**, a similar investigation was made. The results, **fig. 9**, indicate that the pi-L will work somewhat more smoothly over a wider range. However, a limit still exists for the load impedances that can be handled; 10 ohms is now the lower limit.

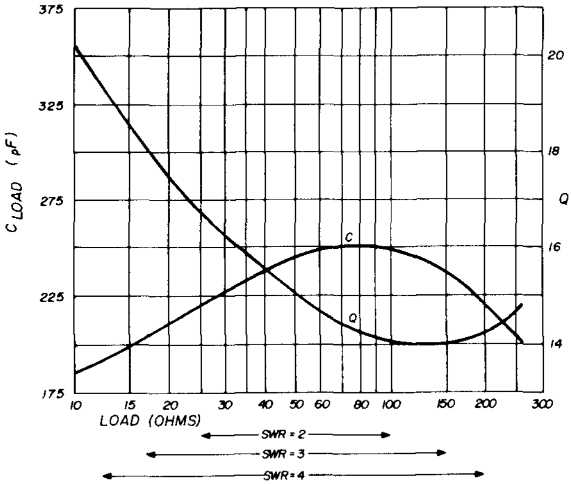

fig. 9. Changes in pi-L network parameters for various loads.

To sum up,

1. Low reflected power means low swr.
2. An swr close to one means impedances close to 50 ohms.
3. Impedances close to 50 ohms mean that the transmitter can operate near its design center.

antenna relays

Let's now go back to **table 1** and compute some currents and voltages on the basis of 1 kW being sent down the line. This is depicted in **table 2**. At the higher swr's the "average" currents and voltages will be higher. This, of course, means greater line losses, as described earlier.

Most modern stations use some form of antenna changeover device for vox or fast cw break-in. Consider the antenna relay. Assuming worse-case conditions, the relay could be in the line at the point of maximum current. If the relay is rated at "1 kW for swr = 1," it's really rated at 4.48 amperes of contact current **(table 2)**. If the number in **tables 1** and **2** for resistance and current are substituted in the equation for power, you'll find that the power presented to the relay is 1 kW for an swr of either 1 or 2. However, the maximum current at an swr of 2 is 6.32 amperes. So if a relay with a maximum contact-current rating of 4.48 amperes is operated at the current maximum point in the line with a 2:1 swr, the relay's true *power* rating will be $(4.48)^2$ x 25 ohms, or 500 watts. Clearly, such a "power rated" relay should be derated for maximum power-handling capability of

table 1. Possible line impedances for standing wave ratios between 1 and 2.

swr	1	1.5	2.0
$\frac{Pref}{pfwd}$	0	$\frac{1}{25}$	$\frac{1}{9}$
possible impedances	50	60 +j20 60 - j20 33.333 37.5 + j12.5 375 - j12.5 75 50 + j20.4 50 – j20.4	75 + j35 75 – j35 25 40 + j30 40 – j30 100 50 + j35.3 50 – j35.3

note: the highest purely resistive impedance is 50 x swr; the lowest purely resistive impedance is 50/swr.

table 2. Voltage and current as a function of swr with forward power = 1000 watts.

swr	1	1.5	2
I_{max} (amps)	4.48	5.48	6.32
I_{min} (amps)	4.48	3.65	3.16
V_{max} (volts)	224	274	316
V_{min} (volts)	224	183	158

1000/swr watts. This is, in itself, a good argument for a low swr.

antenna tuners

It's easy to dispense advice on obtaining a low swr, but it's much more difficult to specify remedies for curing high swr's. If you must live with kinky antenna impedances, then you might consider using an antenna tuner. If air dielectric capacitors and silver-plated inductors are used, power loss from the tuner will be negligible. An antenna tuner will allow the impedance presented to the transmitter to be close to 50 ohms, and transmitter specifications will be satisfied. Such a tuner also pays dividends when receiving.

In **fig. 10** the antenna is assumed to represent a load resistance of 25 ohms (swr of 2). The antenna is connected to either transmitter or antenna tuner through a lossless line two wavelengths long.

Suppose we accept the idea of reciprocity, so that the same antenna will have a source resistance of 25 ohms when receiving. Also assume that the receiver's input resistance is 50 ohms (actually, in many receivers input resistance is close to 300 ohms).

In **figs. 10A** and **10C**, where no tuner is involved, line swr will be 2 and 1 respectively. In **fig. 10B** the tuner will transform the load so that 50 ohms is presented to the transmitter, and the short length of line between tuner and transmitter will have an swr of 1.

If tuner settings are unchanged and the receiver is switched in **(fig. 10D)**, the swr on the main transmission line will increase to 2:1! What may be even more difficult to accept is that the power delivered to the receiver will *increase*—not much, true, but an increase nevertheless.

The reason that more power goes down the line in **fig. 10D** than in **fig. 10C** is because an impedance match exists at the antenna terminals in **fig. 10D**.

conclusions

Transmission lines with low inherent losses should be used. Disregard reflected power as *power* and think of it as contributing to higher standing wave ratios.

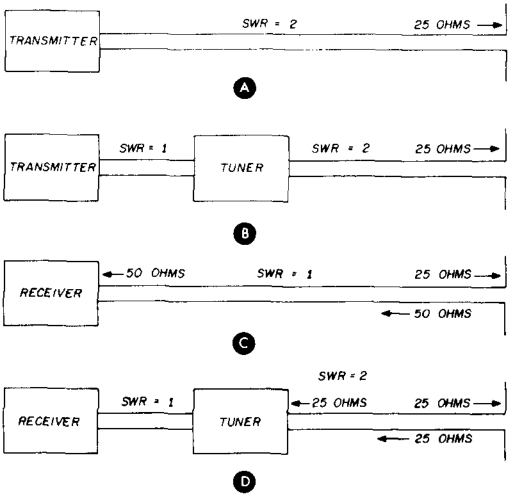

fig. 10. Examples of what happens when using an antenna tuner for transmitting and receiving. Line impedance is 50 ohms in all cases; line is 2 wavelengths long.

An antenna tuner is worthwhile for both transmitting and receiving, especially when transmitting swr is high.

Beware of claims by electronic equipment manufacturers. Power-rated devices for antenna changeover functions and published specifications for transceiver or transmitter output swr requirements can be misleading.

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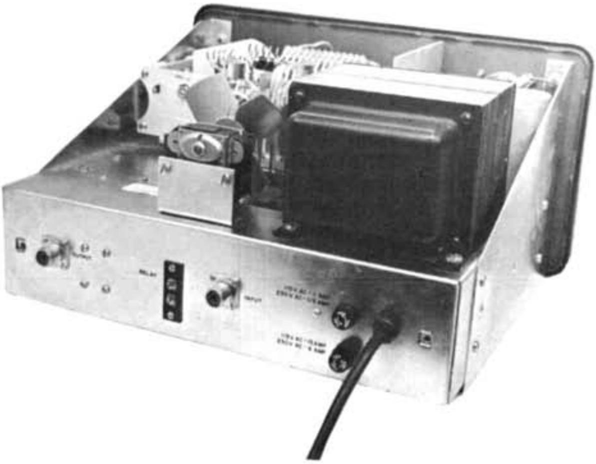

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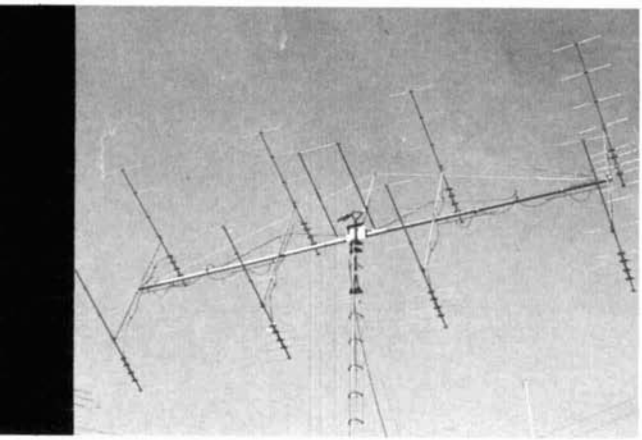


photos by W6BUR

a practical 144-MHz moonbounce antenna

Here's a practical moonbouncing antenna that provides outstanding performance for tropo contacts as well

Ken Holladay, K6HCP, 7733 Rainbow Drive, San Jose, California

Earlier this year a radical new antenna design—the log-periodic yagi or LPY—was introduced to vhf amateurs[1,2]. This new antenna has some interesting characteristics that should interest any vhf enthusiast: broad bandwidth and relatively high gain. The 9-element two-meter Swan log-periodic Yagi* features 4-MHz bandwidth and 11.5 dB gain. And, unlike some commercial antennas, these characteristics hold from one antenna to another.

Both broad bandwidth and high gain are important for long-haul tropo work or moonbounce. Four of the Swan LPY antennas will give 17- to 18-dB gain, and eight of them are capable of successful moonbouncing. The array of eight Swan LPY antennas described in this article is being used for serious moonbounce work, and is a tremendous performer over long-haul tropo paths as well.

*Available from Swan Antenna Company, 646 North Union Street, Stockton, California 95205.

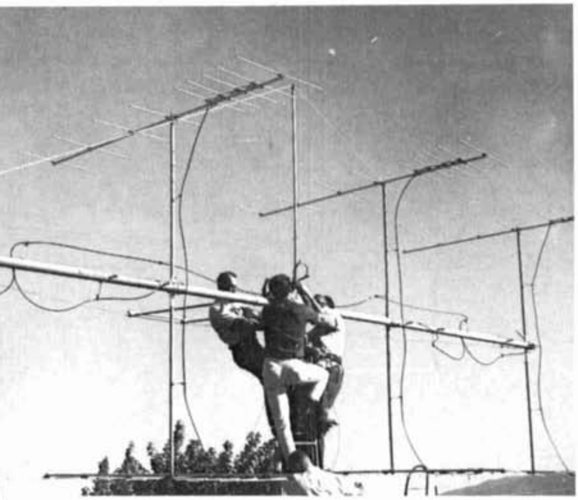
construction

I am not going to describe the mechanical portions of the antenna in any great detail because locally available materials will pretty much dictate how you build your own array. Briefly, however, this antenna uses a 30-foot section of 3-inch aluminum irrigation pipe for the main boom. (4-inch aluminum would be better if it is available.) The LPY supports are made from 10-foot sections of 1-inch diameter tv masting.

The elevation system is made from two pieces of 3/8-inch thick aluminum plate, hinged at the bottom. The 3-inch boom is mounted on the side of the plate and the tower mast is mounted on the other. A worm gear and motor drive lowers and raises the plate, changing the vertical elevation angle of the array. I'm not going to provide exact details of the elevation drive because it was built up from surplus parts as we went along, more devised than designed.

Be sure to keep the boom from sagging. I used nylon rope for my installation, and it seems to be satisfactory. *Do not* use hemp; it shrinks when wet.

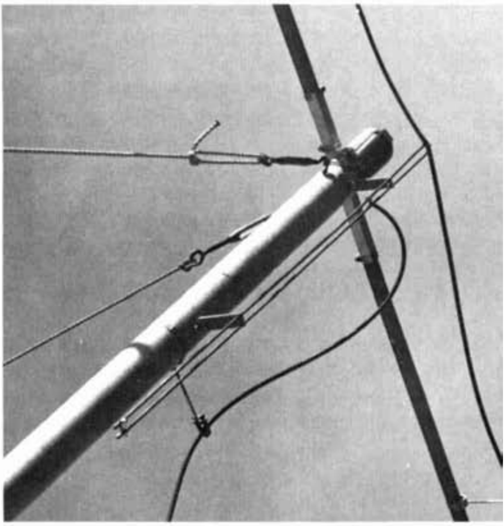
There's not much room at the top the tower. Left to right: K6MYC, WA6MIA and K6HCP; WA6UAP below.



feeding it

The feedpoint impedance of the Swan LPY antennas is 110 ohms. This is not too convenient for 50-ohm coax, but the matching system shown in **fig. 1** works well. High quality 300-ohm feedline is used throughout the matching system. (Belden 8275 is highly recommended.) All the lines are cut to multiples of one-half wave-length; the exact electrical length is determined by grid dipping a half-wavelength section and using it as a standard for the half-wave multiples. This is the method described by W1HDQ in the ARRL "Radio Amateurs VHF Manual" (page 182).

Corrective stub for feeding two of the LPY antennas.



I must stress the importance of using half-wave multiples in the feed system. When this antenna was first put up half-wave multiple feedlines were not used and matching was very difficult; in addition, the lines were heavily influenced by surrounding objects. The half-wave multiple lines eliminated these undesirable effects.

Each pair of LPY antennas is connected through a 1-wavelength section of line to a corrective matching stub; these matching stubs are adjusted to match a 300-ohm line. Each *pair* of matching stubs is then connected through a half-wavelength line to a common standoff point. These two junctions are connected through 2-wavelength lines to another corrective stub, located at the center of the array. This latter stub is adjusted to match the characteristic impedance of the feedline you're using. My array is fed with 300-ohm Belden 8275.

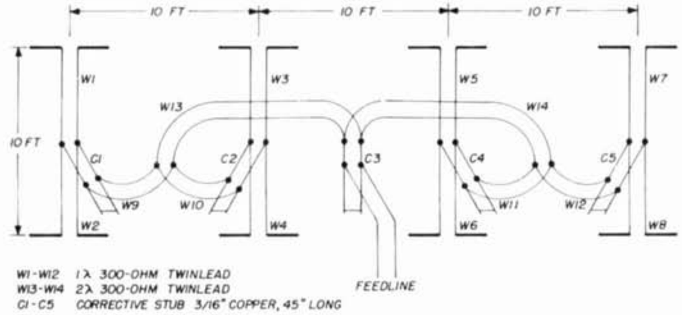


fig. 1. Matching feed harness for the practical 144-MHz moonbounce antenna.

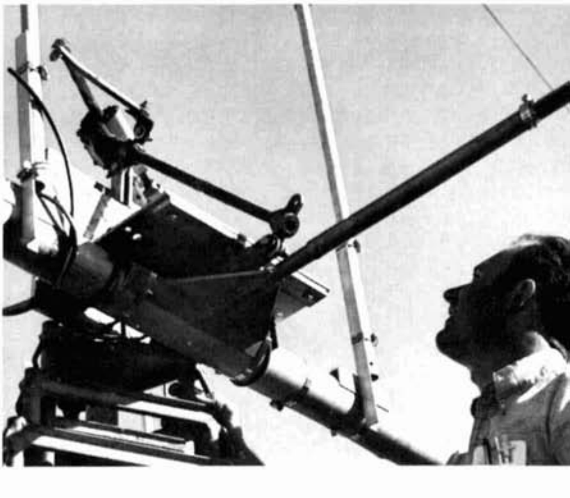
A balun must be used for adjusting each matching stub. I used the one described in *QST*[3] (also in the ARRL vhf handbook, page 183). Don't use the flexible coax type because they are not very predictable. For adjusting the stubs on my array I used a 50- to 300-ohm balun, an inexpensive low-power swr meter and a Gonset Communicator at 144 MHz. The swr meter does not read true swr accurately at 144 MHz, but it does null when terminated with a 50-ohm load.

The matching stubs are 45-inches long and made from 3/16-inch hard-drawn copper that I found at one of the local scrap yards. If you don't have any material for these stubs, you can buy aluminum ones from Cush-Craft*. If you don't want to put up an array as large as eight LPY antennas, the matching scheme will also work for two or four LPYs.

performance

On-the-air performance of the 8-LPY array has turned out just as expected. In the first two weeks of operation, K6MYC and I ran extensive tests and found that this array is 3 to 4 dB below his colinear.[4] I can hear my own echos off the moon, as well as those of K6MYC's. I have worked W1FZJ/KP4, almost worked SM7BAE, and my moonbounce signals have been heard in Australia.

K6MYC inspects the elevation system.



*Cush-Craft, 621 Hayward Street, Manchester, New Hampshire 03103.

For those of you who would like to try 144-MHz EME, I think this is the most practical antenna to come along. If you're a little more daring, an array of 16 LPY antennas should be really tremendous.

I would like to thank Ed, WA6MIA, Pat, WA6UAP, George, W6BUR, Glen, WB6VYM, and especially Mike, K6MYC—without his enthusiasm and mechanical talents this array would never have gotten off the ground.

K6MYC makes the final adjustments.

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ham radio

receiving antennas

A discussion of special purpose antennas for receiving — including some novel ideas for improved performance on the lower bands

Robert L. Nelson, K6ZGO

It has become popular among amateurs, commercial and military stations to use the same antenna for receiving as that used for transmitting. In fact, amateurs have gotten so hooked on the idea that we have completely overlooked the tremendous advantages that specially-designed receiving antennas can offer. Take the forty-meter phone band as an example: the difficulty is not so much in getting your signal out as it is trying to dig the other station's signal out of the QRM. Wouldn't it be nice to have a receiving antenna that could null out the interference while simultaneously maintaining reception of the desired station? Sure, you *can* build a full-size Yagi and stick it up 70 feet in the air, but how many amateurs have that kind of money? Or room?

On forty meters you can probably work almost anybody you can hear with just a little power even if you use a simple vertical (or dipole) antenna. Why not use the vertical for transmitting and build a small, easily rotatable, *receiving* antenna that can make listening to forty a lot more enjoyable?

the receiving system

The trouble with most antenna books is that they talk only about antennas. That seems reasonable enough until you realize that the important characteristics of a receiving antenna can't be specified without considering both the antenna and the entire receiving system. You have to look at receiver noise as well as the electrical noise that the antenna sees.

A basic receiving system is shown in **fig. 1.** It consists of an antenna, a transmission line and a receiver. The antenna acts as a transducer between the impinging electromagnetic waves, (containing both signal and noise) and one end of the transmission line; the transmission line provides a path to the receiver. The receiver amplifies and detects both signal and noise, adds some noise of its own and presents the result to the listener.

The basic receiving system problem is to maximize the ratio of signal power to noise power at the receiver output. SNR, the output signal-to-noise power ratio is defined thus:

$$SNR = \frac{S_o}{N_o} \qquad (1)$$

where S_o is the available output signal power and N_o is the available output noise power. If we had a perfect antenna, transmission line and receiver SNR would be the same as the ratio of the signal and noise powers as they propagate through space. This is the ultimate SNR, and you can't do any better.

There are three basic types of noise that make up the noise contribution to this ultimate SNR: atmospheric noise, cosmic noise and man-made noise. Atmospheric noise is generated by the electrical discharges that attend the hundreds of thunderstorms going on around the world. In the high-frequency portion of the spectrum (3-30 MHz) this noise energy is propagated by the ionosphere and is more evident below 30 MHz.

Cosmic noise is generated by the stars, and most reaches the earth from staggering distances; cosmic noise tends to dominate the noise picture between 20 and 200 MHz.

Man-made noise is just what the name implies. It represents the rawest form of pollution of the electromagnetic spectrum. Even in quiet locations this noise is often dominant over others in the region from 10 to 100 MHz, although these figures are highly variable; in less fortunate locations man-made noise may completely cover the high-frequency spectrum. Typical man-made noise generators are electric motors, neon lights and insufficiently shielded rf generation equipment.

You can't improve the ultimate SNR, but let's see what happens when we add a lossy transmission line or a noisy receiver to the system. The free-space signal and noise are attenuated equally as they pass through the lossy transmission line; thus the SNR at the receiver end of the line is identical to the ultimate SNR. However, at this point noise is contributed by the receiver; the result at the receiver output is a degraded SNR.

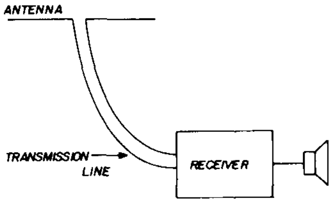


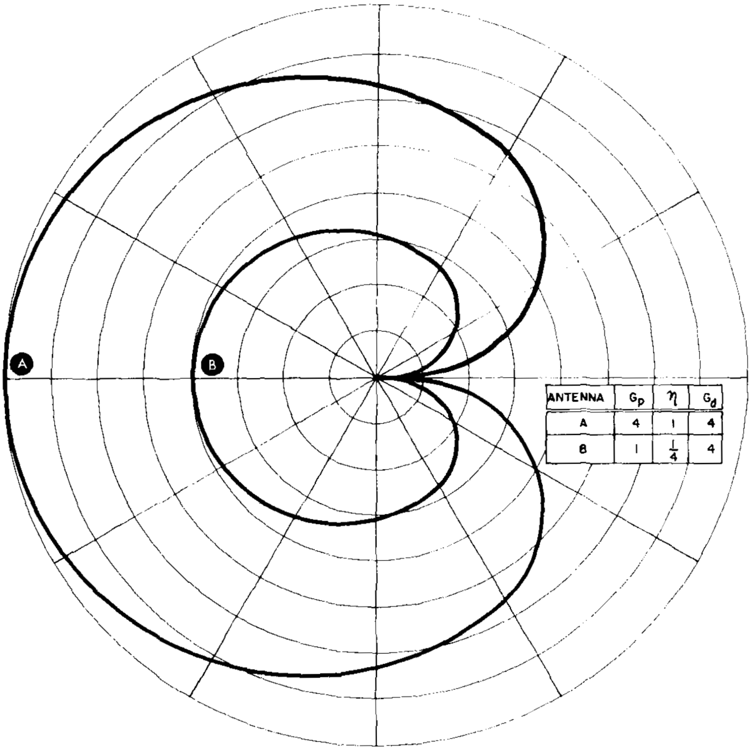
fig. 1. Basic receiving system consists of an antenna, the transmission line and a receiver.

antenna theory

At this point let's review some basic antenna theory and define directive gain, power gain, radiation efficiency and capture area of an antenna. Reference 1 gives an even more simplified treatment of basic antenna theory if you need it.

Power gain. Most simply this can be defined, in the receiving sense, as the ratio of signal power received from a distant station with a directive array, divided by the power received with a perfectly non-directional (i.e., isotropic) antenna. It has the symbol G_p.

Directive gain, G_d, is a measure of the directivity of an antenna. It can be thought of most simply as a measure of the *shape* of the antenna radiation pattern. The radiation patterns of two different antennas are shown in **fig. 2.** Since the shape (but not size) of their radiation patterns is identical, they both have the same directive gain. But the power gain of antenna A is four times that of antenna B. We'll come back to this in a moment.



ANTENNA	G_p	η	G_d
A	4	1	4
B	1	$\frac{1}{4}$	4

fig. 2. **Comparison of two antennas with identical directive gains.**

Every antenna has some losses. That is, if the antenna is used for transmitting, part of the transmitter output power will be burned up in heat losses due to resistance in the antenna. When the antenna is used for receiving, a portion of the received signal (and noise) power is burned up in the same lossy parts. These power losses are due to resistive elements present in the antenna (such as the resistance of wire, tubing and traps) and also due to ground losses and the like in the environment surrounding the antenna. The cumulative effect of these losses can be lumped into *loss resistance,* R_l. The useful signal power (transmitted or received) can be represented as resistance R_r; this is the radiation resistance. The resistive equivalent circuit of a resonant antenna consists of R_l in series with R_r. The *radiation efficiency* of an antenna is defined as:

$$\eta = \frac{R_r}{R_r + R_l} \qquad (2)$$

where η is the symbol for radiation efficiency. If the transmitter output power is multiplied by η, the result is the amount of useful radiated signal power. Power gain and directive gain are related by:

$$G_p = \eta G_d \qquad (3)$$

This accounts for the size difference in the radiation patterns of antennas A and B in **fig. 2.**

Now we come to "capture area." If an impinging electromagnetic wave has a power density D_p, then the power from the wave which is available at the antenna terminals is:

$$P_{av} = AD_p \qquad (4)$$

where P_{av} is the available power and A is the antenna capture area. Capture area is the effective frontal area which the antenna presents to the passing electromagnetic wave and is related to the gain of the antenna by:

$$A = G_p \frac{\lambda^2}{4\pi} = \eta G_d \frac{\lambda^2}{4\pi} \qquad (5)$$

where λ is the wavelength at the frequency of operation.

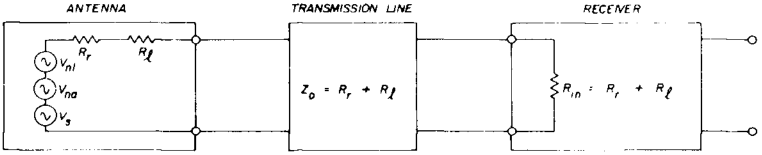


fig. 3. Equivalent circuit of the basic receiving system. V_{nl} is the antenna noise voltage, V_{na} is the external noise voltage, V_s is the signal voltage and Z_o is the characteristic impedance of the line.

the over-all system

With this background we are ready to redraw **fig. 1** into a complete schematic **(fig. 3).** Now we can determine the effect that antenna radiation efficiency has on receiver output SNR, and we can put some limits on this important characteristic.

Since a practical transmission line attenuates both signal and noise in equal proportions, transmission line loss has no effect on system output SNR as long as it is small enough that external noise dominates receiver noise. Remember that the important thing in the receiving sense is a high receiver output SNR. We can even put on a number on how much we can reduce antenna efficiency for a given degradation of SNR. For example, if the antenna efficiency is reduced until the system output SNR is 1 dB less than the ultimate SNR, the minimum required η is:

$$\eta = \frac{T_o + LT_r}{0.26T_a + T_o} \qquad (6)$$

in decibels:

$$\eta db = 10 \log_{10}(T_o + LT_r) - 10 \log_{10}(0.26T_a + T_o) \qquad (7)$$

In these equations T_o is the reference temperature (room temperature, 270° Kelvin), T_r is the receiver noise temperature, T_a is the effective noise figure of external sources, and L is transmission line loss (L = 2 if line loss is 3 dB).

The receiver noise temperature is related to receiver noise figure by:

$$f_r = 1 + \left(\frac{T_r}{T_o}\right) \qquad (8)$$

where f_r is the receiver noise *factor* (f_r = 2 if noise figure is 3 dB).

The effective noise temperature of external sources, T_a, is related to an "antenna noise factor" by:

$$f_a = \frac{T_a}{T_o} \qquad (9)$$

where f_a is the antenna noise *factor* (f_a = 4 if antenna noise figure, F_a is 6 dB). Data on F_a are available for the entire world in reference 3.

Eq. 6 and **7** give the *minimum* required for less than 1 dB over-all loss in output signal-to-noise ratio. Increasing beyond

If you are interested in the derivation of **eq. 6** and **7**, send a self-addressed, stamped envelope plus 50 cents to cover Xerox costs to the author; a copy of the mathematical work will be sent to you. *editor* this value provides absolutely no more than a 1-dB increase in SNR. In **fig. 4** the minimum efficiency defined by **Eq. 6** and **7** is plotted against antenna noise figure for representative values of transmission line loss and receiver noise figure.

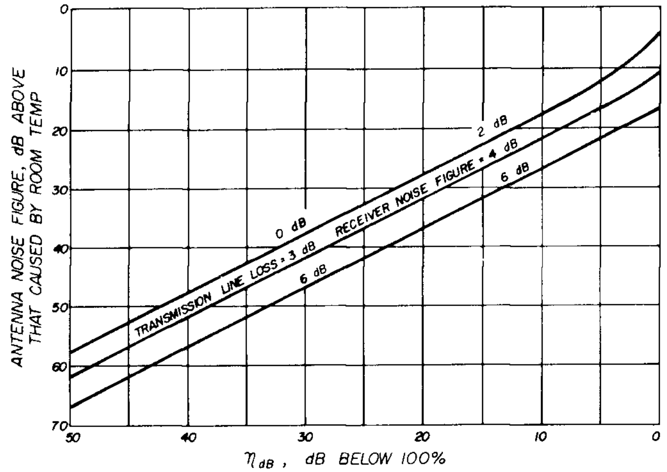


fig. 4. Required minimum receiving antenna efficiency required for 1 dB degradation of system output signal-to-noise ratio, plotted as a function of antenna noise figure.

Unfortunately, the three essential antenna characteristics—size, radiation efficiency and bandwidth—are mutually conflicting. That is, you cannot build an antenna with simultaneous high efficiency, small size and wide bandwidth. If two of these characteristics are essential to a given design, the third must be sacrificed. For example, if you want a small wideband antenna, then it must be relatively inefficient. If both efficiency and bandwidth can be sacrificed then the size of the antenna can be very small.

If external noise is inherently much greater than receiver noise (as it is in the high-frequency portion of the spectrum and below) antenna efficiency can be traded for small size and wide bandwidth. If wide bandwidth is not important, as in single-band amateur use, then the size can be reduced still further, and extremely small antennas can be practical. It is important to note here that we have not compromised directivity. Since we have only reduced radiation efficiency, the directive gain is unaffected even though the power gain may be less than unity.

We may have an antenna with a radiation pattern like antenna B in **fig. 2**—a perfectly satisfactory antenna for high-frequency use. In fact, not only is antenna B perfectly satisfactory, it will provide almost exactly the same system output SNR as antenna A, the efficient (and larger) antenna.

Antenna B in **fig. 2** shows how increasing directive gain increases output SNR. Compared to an isotropic antenna, antenna B receives an identical amount of signal power, but off the back and sides where only noise exists it is less sensitive. As the back and side sensitivity is reduced further to increase directivity, SNR increases in direct proportion because of decreased received noise. Remember, if the system is external-noise limited, antenna directive gain governs output SNR, not power gain.

antenna noise figure

The antenna noise figure, F_a, is a measure of all external noise sources combined: atmospheric, cosmic and man-made. When designing a high-frequency antenna, you have to look at the magnitude of the external noise expressed by F_a to determine the required antenna efficiency. In fact, what must be found is the *minimum* expected antenna noise figure, so the realistic minimum required η

can be calculated. The minimum value of F_a for the frequency range from 1 to 100 MHz is shown in **fig. 5.** Actually this is the cosmic-noise floor; noise figure less than the values shown in **fig. 5** will seldom be observed.

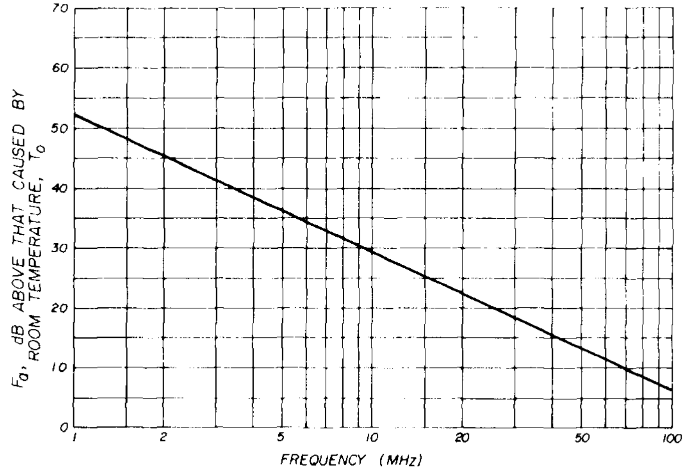


fig. 5. Minimum antenna noise figure, due to galactic noise, as a function of frequency.

minimum required efficiency

If we combine **fig. 4** and **5** we can plot the required minimum antenna radiation efficiency at any frequency; this is the value which we must use in our design. At 7 MHz for example, with 3-dB transmission-line loss and a 4-dB receiver noise figure, minimum efficiency is −21 dB. This means that the radiation resistance of the antenna can be less than 1% of the total antenna output (or input) resistance. Loss resistance, R_l, can exceed ratiation resistnace, R_r, by a factor of 100 to 1!

This is a long way from the usual amateur receiving antenna and offers a terrific amount of design freedom. On the 160-meter band (1.9 MHz) with negligible line loss and a 2-dB receiver noise figure, loss resistance can exceed radiation resistance by nearly 10,000 to 1!

As wavelength increases high radiation resistance becomes more and more difficult to achieve with small antennas and losses increase. However, with the increas-

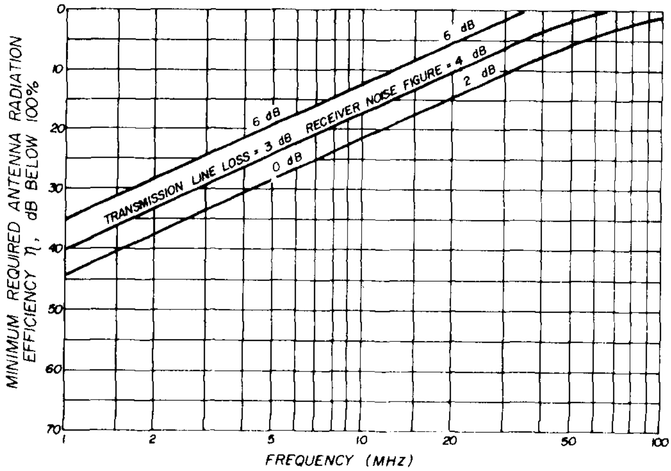


fig. 6. Minimum required receiving antenna efficiency required for 1 dB degradation of system output signal-to-noise ratio, plotted as a function of frequency.

ing external noise at lower frequencies, lower efficiencies can be tolerated, so radiation efficiency can be traded off for small size.

With smallness comes the ability to rotate the antenna. Thus we can build small directive receiving antennas that can be turned, even at 160 meters. This can make the difference between a marginal contact and armchair copy.

local man-made noise

Man-made noise has ruined many contacts, especially on the high-frequency bands. Every active amateur who uses a vertical antenna on 40 meters can remember any number of contacts that were prematurely interrupted by automobile ignition noise or a neighbor's electric shaver. Let's examine the characteristics of man-made noise to see if there is a way to discriminate against it.

Man-made noise is characterized by predominantly vertical polarization, imbalance with respect to ground and an electric field form. Therefore, an unbalanced, vertically-polarized, electrical-field antenna is an inviting target—a quarter-wave vertical is ideal in this respect. On the other hand, an antenna which is horizontally polarized, magnetic-field sensitive and balanced with respect to ground discriminates against man-made noise but is no less sensitive to the desired far-field signal. Therefore it gives a higher system SNR.

It is not usually necessary for a receiving antenna to have all three of these desirable properties. If the antenna is balanced and magnetic-field sensitive, or balanced and horizontally polarized, it will usually discriminate against local noise to an acceptable degree.

dipole antenna

The half-wave center-fed dipole can be miniaturized to provide a good receiving antenna simply by helically winding the two sides and adding a capacitive hat (**fig. 7**). This antenna, if mounted horizontally, will be horizontally polarized, electrical-field sensitive and balanced with respect to ground, and will discriminate rather well against local noise.

The over-all length of this antenna can be about six feet for all bands between 160 and 20 meters, although the number of turns on the helix will differ from band to band. Specific data for helical antenna design is given in reference 4. The antenna can be tuned with a grid-dipper or antennascope and fed with 72-ohm twin-lead.

If coax is used a balun should be used to preserve balance and electrical symmetry. The capacitive hats can be one to three feet in diameter and made of stiff wire; the helix can be one to two inches in diameter. This antenna will have the same radiation pattern as a full sized dipole (a figure 8 in the horizontal plane) so it has two nulls that can be used to reduce interfering signals.

If two of these antennas are spaced a short distance apart, say 0.05λ, and fed so that the phase difference between the antennas plus the spacing equals a half wavelength or 180°, exciting things begin to happen. This is the basic end-fire array formula and results in a radiation pattern similar to antenna B in **fig. 2.** A 3-dB increase in SNR will result, and the front-to-back ratio will be quite good.

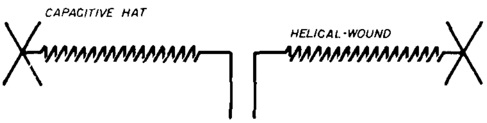


fig. 7. Construction of a helical dipole, end loaded with capacitive hats.

the loop

Another antenna that can be used for receiving is the loop. A small loop antenna is primarily magnetic-field sensitive and balanced with respect to ground (if the plane of the loop is vertical the antenna is vertically polarized). For use on the 160-through 20-meter bands, a suitable loop can be from 2 to 3 feet in diameter; typical layouts are shown in **fig. 8.**

In **fig. 8A** the upper capacitor is used to resonate the loop; the resonant transformer is used to match the impedance of the loop to that of the transmission line. A match can also be obtained with the capacitive divider shown in **fig. 8B**. The *loop itself can be made from one (or several)* turns of wire or tubing. A good description of a loop antenna for receiving on 160 meters is given in reference 7.

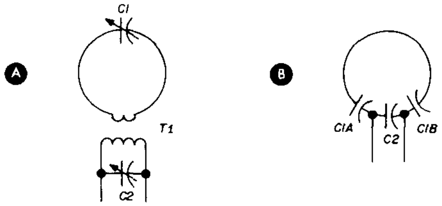


fig. 8. Loop antennas. In A C1 resonates the ***loop; C2 tunes the matching transformer T1. In*** **B C1 and C2 form a capacitive divider for matching to the feedline, and also resonate the loop.**

There is no reason why two or more loops cannot be phased the same as dipoles. The result will be a cardioid radiation pattern and an increased SNR. Loop spacing can be from 0.02 to 0.05λ, a little closer than dipoles; this is because the near field of a loop is more confined than that for a dipole.

Both the small dipole and small loop are fairly narrowband antennas so it is wise to use an antenna coupler between the transmission line and receiver. The antenna can then be peaked up at band center and the antenna coupler tuned for maximum response as the receiver is tuned across the band.

summary

I have obtained good results with both a helical dipole and an untuned five-foot-long dipole with a capacitive hat when worked through an antenna coupler. However, the helical arrangement is somewhat better.

It is beyond amateur means to actually measure the radiation efficiency of an antenna, but there is a simple test which determines if an antenna has sufficiently high radiation efficiency to be a good receiving antenna. Simply hook the antenna up to the receiver; and if there is a significant increase in noise at the *receiver output then the antenna efficiency* is high enough.

At radio frequencies there is a complicated relationship between antenna size and radiation resistance. What it boils down to is this: if the greatest dimension of a linear antenna is greater than about four feet, and the area enclosed by a loop is greater than about two square feet, the result will be sufficiently high radiation efficiency.

It has been found through experience that when sky-wave circuits open up atmospheric noise levels increase to the point that antenna efficiency can be reduced another 20 dB at frequencies below 10 MHz. Since the sky-wave circuit is the rule for most amateur contacts the data of **fig. 6** can be modified accordingly.

I hope this article has tickled your imagination enough to send you to the workshop, latest issue of *ham radio* in hand. Small antennas can do a superior *receiving* job on our high-frequency bands so give them a try.

references

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ham radio

ground plow

This tool simplifies the installation of large radial systems that are required for efficient vertical antenna systems

Jim Ashe, W1EZT

As I was working in the library one day, researching a science article, I came upon a "ground plow." Now, what would you use a ground plow for? I wondered. I read.

The vertical antenna is a popular low-angle radiator; it is simple to build and very adaptable to multiband work. Lots of amateurs use vertical antennas, and I certainly would myself, if I had a place to put it. But if you want to build a really good vertical antenna, you wind up with a rather difficult grounding problem.

some notes about grounding

An efficient vertical antenna *must* have an excellent ground system. Since it extends up into the air, there seems to be very little relation to the earth it rest upon, but actually the vertical antenna is *one-half of a dipole* **(fig. 1)**. *The other* half is a mirror image in the earth, made up of the electrical effects of heavy ground currents. But soil typically has a fairly high resistivity, and, outside tidal salt flats, the total ground resistance is too high for efficient grounding from a mere copper-clad steel ground rod. Much of the energy intended for the antenna is lost in the earth around it.

There is another way of looking at this **(fig. 2)**. Starting at the coax input cable, we find a complete circuit through the antenna's radiation resistance and its ground resistance. Current flows in loops around antenna circuits, just as in wire circuits, and in this case it flows from the cable center conductor, through the tower, into space, back to ground, and returns to the cable.

Some of the applied energy is radiated into space. This is accounted for in our diagram by the "radiation resistance," which can actually be measured as the antenna's radiated power divided by the square of the applied current. This is the familiar $W = I^2R$ equation. The radiated power can also be viewed as the product of current through, times voltage across, the radiation resistance. But this is not easily measured since the current that sees the radiation resistance also sees the

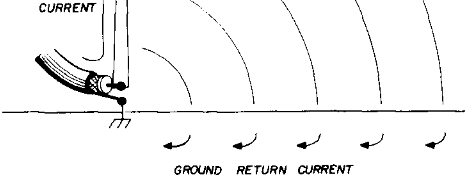


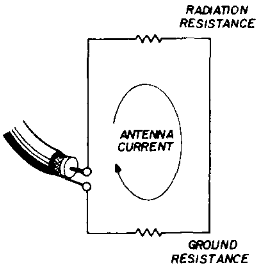
fig. 1. Radio-frequency current flows into space from the tower and returns to the ground terminal.

ground resistance and our measurements will indicate the total voltage across both resistances. (**Fig. 2** supposes we are operating at resonance, where inductive and capacitive reactances balance out.)

Rf current flowing through the earth dissipates power in direct proportion to the ground reisitance. If ground resistance is equal to radiation resistance, one-half of the power reaching the antenna is lost. This applies to incoming signals, too. Since it is easier to make a lossy ground than a lossy antenna tower, this invisible part of the system is far more than a minor detail. If our antenna system is inefficient, we probably have to fix an inefficient ground.

It turns out that ground losses are really serious only near the tower. The losses decrease as the square of the current, which in turn falls off faster than inversely as the distance. At a part of a wavelength away from the vertical radiator, up to a few wavelengths at vhf, the current is low and the losses also low. We need a good ground surface only near the tower.

fig. 2. Since the same current flows through both antenna and ground-return resistances, applied power is divided between the resistances. If the radiation and ground-return resistances are equal one-half the applied power is wasted as heat in the earth.



A broadcast engineer's rule-of-thumb indicates how good this ground surface must be: "A radial ground system consisting of 120 quarter-wavelengths of copper wire will have an effective resistance of 2 ohms." Very few amateur ground systems will meet this spec, but by comparison one or two ground rods may be terribly inadequate.

Probably a great many amateur ground systems have resistances of 20 ohms or more; and that is in the radiation resistance ballpark for large vertical antennas. *If the tower's electrical length is reduced* the radiation resistance falls too as shown in **fig. 3**. This suggests a short antenna on 80 and 160 meters may have a radiation resistance in the one- to- ten-ohm ballpark! If you are thinking of serious communicating and particularly any DX work, it's very likely you need to put in *some time on your ground system.*

the ground plow

Would you dig ditches to install a *hundred and twenty radials* four to twelve inches in the ground? I am afraid I wouldn't. At 80 meters that would be about 7200 feet, or twenty feet per day for a year. The wire is probably not much of a problem, and for this application I'd try the power company, junk yards, surplus dealers, and other such sources for good used copper wire. It needn't be all the same size but should be around number 10 or so for adequate strength.

The pros put down a good ground plane with a ground plow (**fig. 4**). Its sharpened leading edge digs down into the ground until the skids or wheels at the ends of the main frame are riding along the surface. A tractor pulls the plow, but it should not be so close that it yanks the plow out of the ground. One or two chimney blocks or some cinder blocks serve as weights, and you walk

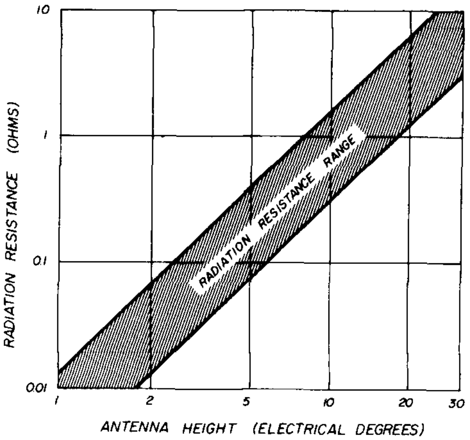


fig. 3. Radiation resistance of short vertical antennas.

along behind guiding it in a reasonably straight line but around rocks and obstacles. Your helper rides the tractor, which

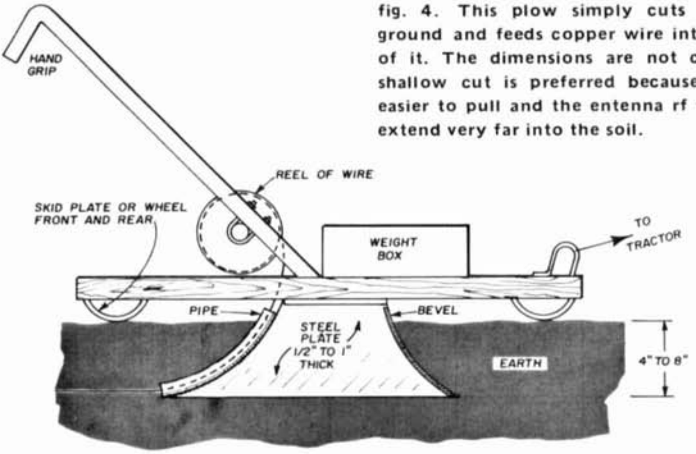


fig. 4. This plow simply cuts a slit in the ground and feeds copper wire into the bottom of it. The dimensions are not critical, but a shallow cut is preferred because the plow is easier to pull and the entenna rf field does not extend very far into the soil.

for a shallow cut in good soil could be a small garden variety. Extra weight may be required on the driving wheels. With this gear an 80-meter ground plane should go down in a half day.

How about making the plow? This is easy if there is a welding shop nearby. Since the plow will be used rarely it can be assembled from scrap iron. A cutting torch will cut inch thick iron like wax and can rough out the bevel too. Then the bevel is finished with a hand grinder and the rest of the frame, skids, and etc. welded on. The finished plow can be carried around in a station wagon. A key point, of course, is to make this a small group or a club project, rather than do it all yourself.

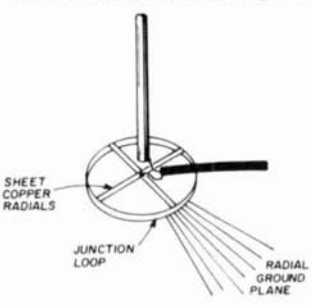


fig. 5. A simple junction loop assembly with radials connected to a ring rather than to the tower. This provides a reliable structure and avoids problems with big bundles of heavy copper wire.

finishing up

Unless you are using a gamma match your tower will rest on an insulator in the center of the ground plane. Broadcast practice is to have a heavy expended-mesh screen in this area since the voltage and current levels are very high, but you can get by with some two- or three-foot sheet copper radials to carry the ground return currents.

Outside the radials there is a continuous ring of copper pipe or more copper strips. Two to four copper-clad steel rods are driven into the earth around the ring's perimeter. These serve two purposes: they hold the ring in place and serve as an additional channel for carrying lightning strikes into the earth. Your antenna is likely to be hit by lightning at least once every year or two, and if you are in certain parts of the Midwest or Florida, you can expect frequent fireworks.

The radials are brought to the circular ring, rather than to the tower itself, and connected by soldering or brazing. This finishes the job, and you will have an effective ground system that will enhance communications.

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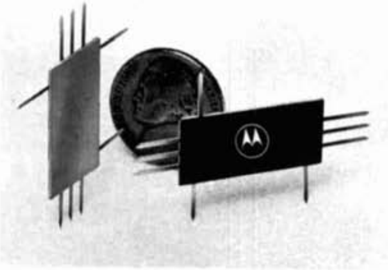

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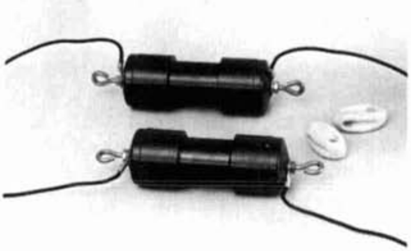
multi-band antenna



The Bomerang II antenna system is designed for 80 and 40 meters, but when tuned properly, it will also perform satisfactorily on 20, 15 and 10 meters. The antenna system consists of 108 feet of copper wire, two high-strength lightweight traps, a 1:1 balun, hardware and insulators. All hardware is stainless steel or copper and the traps are encased in impervious polyvinylchloride.

This antenna is usually erected in the popular inverted-V configuration, but sometimes it is installed as a flat-top. Because of the low weight of the system and the low wind profile of the traps, number 16 copper wire may be safely used; number 12 or 14 may be used for high strength. Suitable number 16 wire, such as Belden 8074, (126 feet) costs about $3.00.

The Boomerang II antenna system, rated at 2 kW PEP ssb, complete with balun, less wire, is $22.95. Boomerang II without balun is $12.95; the AB1 Boomerang 1:1 balun is $10.95. All prices postpaid in the U. S. A.

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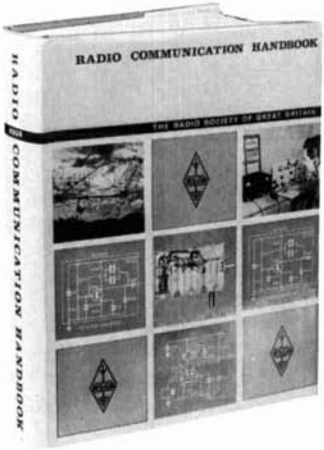

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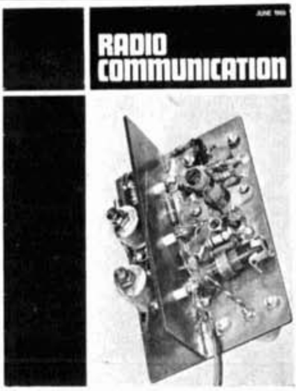

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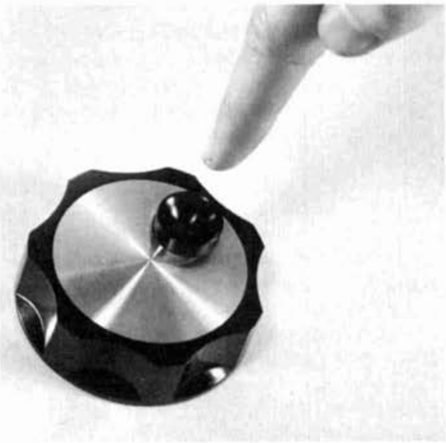

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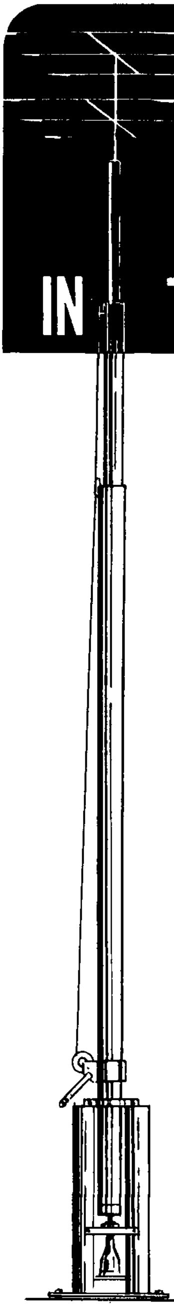

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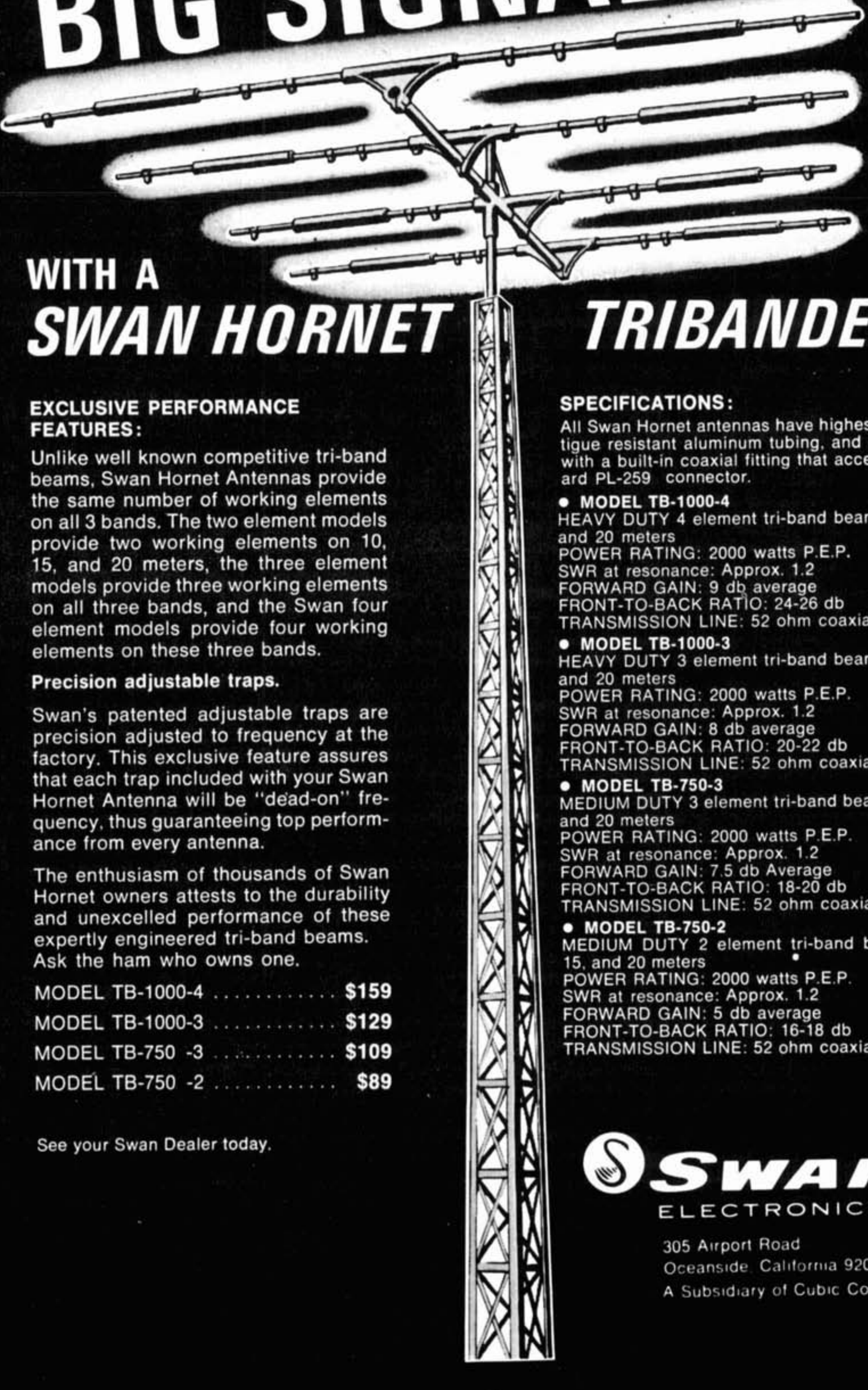

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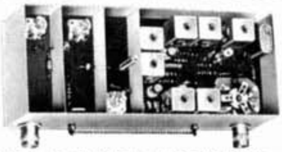
All units contained in silverplated, brass enclosures. Stripline 432 MHz circuits. Silverplated, glass-epoxy printed circuit boards throughout. All solid-state. From West Germany. Literature upon request.



432 MHz Dual Gate MOSFET Converter, Model DGTC 1702. Noise figure: 3.2, cross mod. 80 mV min., gain 5-20 db, I.F. 144-146 MHz. T-match output attenuater. **$69.00**

Braun

144/432 MHz Transverter, Model TTV 1270. Transmitter input: 50 mW to 1.2 Watts. Efficiecy: 60%. Receiver noise figure: 8. No antenna switching required. Simply connects between two-meter AM/FM/CW transceiver and 432 MHz antenna. Requires 12 Volts in "Receive" only. **$47.50**

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only in repeater systems with exactly 5-MHz channel spacing.

Other paragraphs in the docket concern attendance at the repeater transmitter or at an authorized *fixed* control point, and limiting power input (to repeaters) to 600 watts.

Although the proposed rules have the effrontery to suggest that they won't duly inhibit the growth of useful repeater systems, how can a system possibly grow when all of the parameters are initially specified? The amateur regulations have traditionally been more permissive than restrictive—a policy that has bred initiative and inovation. Development of interlinked repeaters, multiband systems, tv and wideband data repeaters, command-control systems and telemetry will be stifled by the rules proposed in Docket 18803, as will experimentation, one of the mainstays of amateur radio.

There's still time to do something about Docket 18803, but you've got to stand up and be counted *now.* All of our vhf fm readers should already have received a copy of the docket which went out several weeks ago, along with the comments of our fm editor, Jay O'Brien, W6DGO, and a resume of related ideas generated at a recent meeting of the California Amateur Relay Council. If you haven't seen a copy of this material, but would like one, simply send me a stamped self-addressed envelope and I'll put a copy in the return mail.

Comments on Docket 18803 must be filed by May 15, 1970, with reply comments on or before June 1, 1970, so you don't have time to dilly-dally. Remember that comments to FCC proposals must include an original and fourteen copies (complete filing details are included with the Docket 18803 mailing piece from *ham radio*). With the abundance of office copiers that one finds today, those 14 copies shouldn't pose too much difficulty to the amateur who is really interested in contributing his ideas.

Jim Fisk, W1DTY
editor

New!

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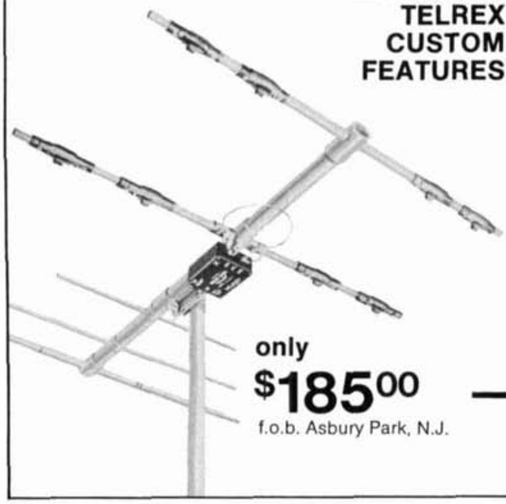
Featuring Balun Fed 5 Element TRI-BAND®
Model TB5EC/1KWP - 10-15-20M Single Trans Line Array



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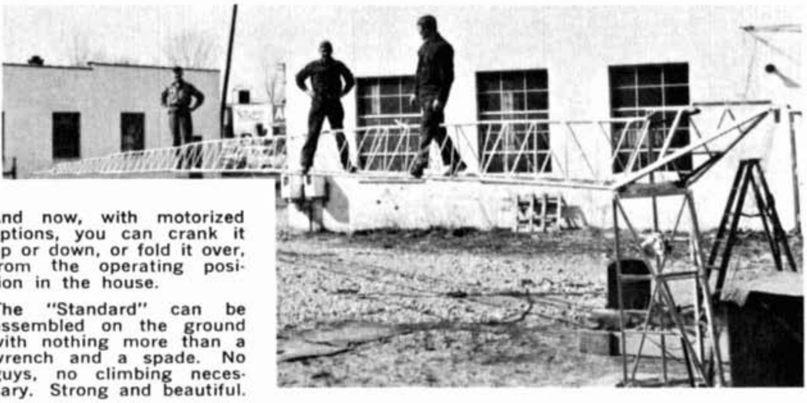

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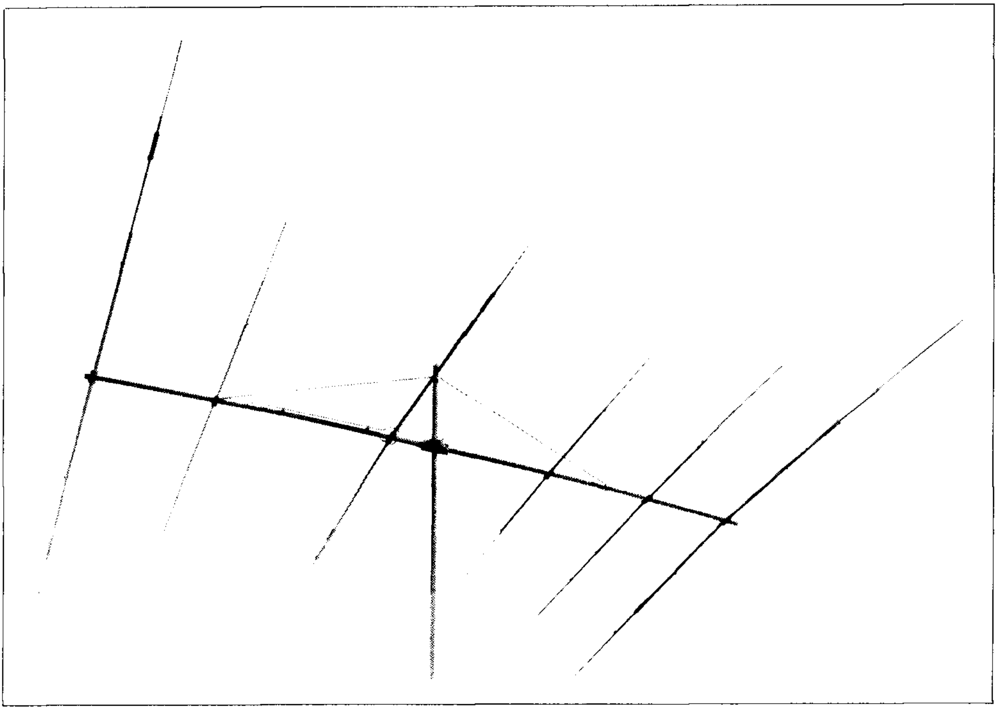
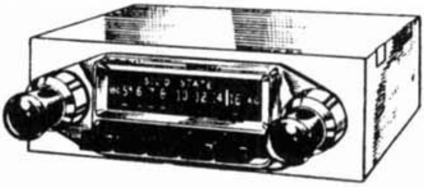


TRANSISTOR AUTO RADIOS



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1916 QST'S wanted. Especially May and June. Any unreasonable price paid! Ted Dames, W2KUW, 308 Hickory Street, Arlington, N. J. 07032.

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WANTED: September 1968 issue of Ham Radio. Name price! WA9JMY, 1420 West Bolivar Ave., Milwaukee, Wisconsin 53221.

QSL'S. SECOND TO NONE. Same day service. Samples Airmailed 25¢. Ray, K7HLR, Box 331, Clearfield, Utah 84015.

GREENE DIPOLE CENTER INSULATOR . . . see ad page 96, September 1969 Ham Radio.

COMMERCIAL LICENSE EXAMS: Second $18.00; First $24.00; Sample questions; Price list $1 refundable. Ebco Enterprises, P. O. Box 432, Sparks, Nevada 89431.

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THE TRI-STATE AMATEUR RADIO SOCIETY announces its Twenty-third Annual Hamfest to be held Sunday, July 12, 1970, at the 4-H Youth Rural Center on Highway 41 North. Advance registration $1.50 and $2.00 at the door. For details contact Jack Young, K9LAU, P. O. Box 492, Evansville, Indiana 47703.

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SOMERSET COUNTY HAMFEST — The 5th SCARC Annual Hamfest will be held Sunday, June 7 at the Casebeer Grove 4 miles north of Somerset, Pa. on US Route 219. Registration starts at noon. Rain or Shine — Free tables indoors for swap-shop. Write K3YVS, 719 Division Street, Berlin, Pa. 15530.

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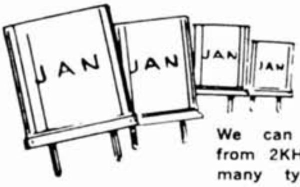
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FOR SALE: SQUIRES-SANDERS SS-1R, SS-1S, SS-1V (factory reconditioned March, 1970), $60. KWM2, 516F2, $695. 312B4, $135. 312B5, $275. 30LI, $375 & $400. T4X (Drake reconditioned Aug., 1969), AC3, $350. 32S3 #13540, 516F2, $615. HX500, $200. HT32B **OR** HT33A, $250. 75A2, vernier knob, spkr, "B" slicer, $185. Collins: HRO-50T, ABCD coils, "B" slicer, spkr, $175. F455J-05, F455J-08, F455FA-15, $45 each; F455Y-60 (for 75S1/2/3), new, $25. 516F2 (sealed carton), $130. National VFO-62, $20. B 6 W 6100 (SSB), $250. HA-1 keyer, vibro-keyer, $75. 4CX-1000-A (factory sealed bags), $95. R4A (Drake reconditioned Dec., 1969), $295. SR34 (6 & 2 meters), $150. Lafayette HA410, whip, mike, mount, $90. NCX3, ACPS, mike, $175. Hewlett-Packard: 416A ratio meter & manual, $85; 130B 'scope (needs LV xformer), manual, $100. Clegg 66'er (2 each), $125 each. HW32A, HP23A, mke, spkr, $145. Transformer, 115 V/870 VCT @ 1.13 A/ 906 VCT @ .280 A, $10. Telex HMY-2 headset, new, $5. HW12, ACPS, mike, $125. James W. Craig, W1FBG, 29 Sherburne Avenue, Portsmouth, N. H. 03801.

TOUCHTONE DIAL equivalent from Denmark. Ten button, convertible to all twelve with data included. State color: beige or black, limited number green. 12VDC required for oscillator operation. $16.00 postpaid USA. J. O'Brien, W6GDD, 6606 5th Street Rio Linda, CA 95673.

FOR SALE: HW-12 with calibrator, $80. HW-22, $70. Globe King 500A (500W, a-m and CW), $125. Gonset 913A 500-watt 6M linear, $200. Gonset 910C 6M Sidewinder (a-m, CW and ssb) with ac and dc supplies, Laff 100W linear plus many extras, $360. Gonset 2M 100W linear w/spare 826s, $90. Gonset Communicator III 6M, $115. 6M Ameco Preamp, $10. Eico 720 90W CW transmitter, $55. Tecraft 6M converter with supply (7-11 MHz out), $35. Knight R-100A gen'l coverage receiver, $60. Heath vfo VF-1, 10-160M, $15. Eico 23-channel CB transceiver, $75. Heath HX-30 6M transmitter (a-m, CW and SSB), $140. Heath HA-20 175W 6M linear, $110. Factory-sealed Ameco PT preamp, $55. Heath Sixer, w/crystals and mike, $35. Ameco 6M converter with power supply, $15. Swan 14C dc module, $50. Drake factory-sealed DC-4 12 Vdc supply, $105. Factory-sealed Ameco OCMW monitor, $12. Westcom noise blanker for Swan 250, $20. Gonset 6M G-50, $160. Ham-M rotator, $105. Factory-sealed 24-hour Pennwood clock, $14. All items fob. Tom Dittrich, WB2LZD, 605 Broad St., Endicott, N. Y. 13760.

FOR SALE: Heathkit TX-1 Apache Transmitter with S.B. 10 adapter, new tubes, excellent. $175.00. Ed, K8VIR, 106 Hartz Drive, Holly, Michigan 48442.

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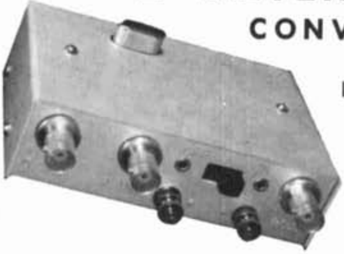

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MAYFLOWER 70 AWARD has been instituted by the Committee governing The Cheshire Homes Amateur Radio Network Fund, to commemorate the 350th Anniversary of the Sailing from Plymouth of The Pilgrim Fathers for America. The object of this Award is to continue our efforts to provide Amateur Radio Equipment to the Homes which care for the incurable sick and permanently disabled. All profits from this Award will be devoted to this purpose, no Member of the Committee will receive payment or reward for his services. The Award is open to all Amateur Radio Operators and SWL's throughout the World from January 1, 1970. No time limit. Any Band or Mode. No QSL Card required. But a certified copy from Log Book must be sent. Operators in the U.S.A. must submit proof of ONE contact with an Amateur Radio Station operating from Plymouth, England. SWL's as above but Reception of ONE Amateur Station. The cost of Certificates is ONE DOLLAR which includes Postage by surface mail. Forward all claims to: W. M. Clarke, G3VUC, Fillace Park, Horrabridge, Yelverton, Devon. PL20-7TE, England.

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THE SOMERVILLE, MASS. AMATEUR RADIO CLUB, WA1MHN, will be operating from the summit of Mt. Washington, N. H., the highest point in the northeast, the weekend of May 23-24, 1970. Operation will be from 1800-2000GMT both days according to this schedule: SSB-21.375, 28.650; AM-50.274, 145.470; FM-449.050. Any station establishing two-way contact with WA1MHN on two different bands will be eligible for a special certificate upon receipt of a request for it and 25¢ for printing and mailing charges. Contact K1YUB, 19 Cambria Street, Somerville, Mass. 02143.

The **FOURTH ROCK RIVER HAMVENTION** will be presented by the Rock River Radio Club of Dixon, Illinois, on May 17, 1970 from 9 a.m. to 5 p.m. at the Lee County 4H Center, Amboy, Illinois, located at the intersection of highway 52 and 30. Advanced ticket price is $1.00; at the door $1.50. Many prizes, plenty of food and fun. Talk in freq. of 3950 and 50.4 MHZ. Mail check to Carl Karlson, Nachusa, Illinois, 61057, W9ECF.

THE MILLIWATTER is a non-profit monthly QRPP (5 watts or less) newsletter. Operating news, QRPP construction projects, technical info, low power WAS standings, etc. For sample copy send address and stamp to Mike Czuhajewski, WA8MCQ, Route 3, Paw Paw, Mich. 49079.

SECOND OLD TIME HAMFEST sponsored by the Indian Hills Radio Club. Sunday, May 10, 10 a.m. to ?? at Slovenian Social Home, 20713 Recher Ave., Euclid, Ohio. Mobile, CW, Homebrew Contests. Swap & Shop. Prizes. XYL Activities. Speakers. Buffet Dinner by advance reservation only $3.00. Hamfest $1.50 in advance or $2.00 at the door. WA8MHW, 1504 Maple Grove Road, So. Euclid, Ohio 44121.

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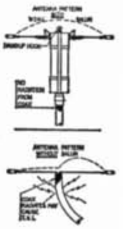

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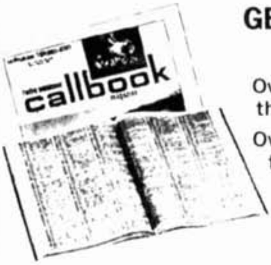

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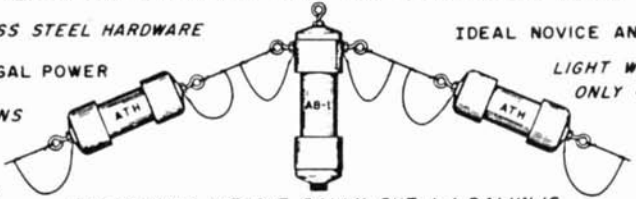

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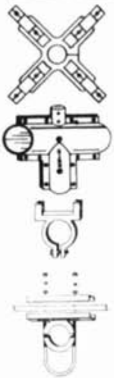
KIRK ANTENNA HARDWARE



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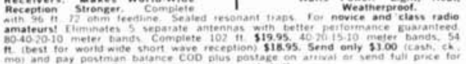

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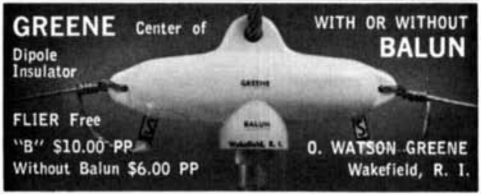
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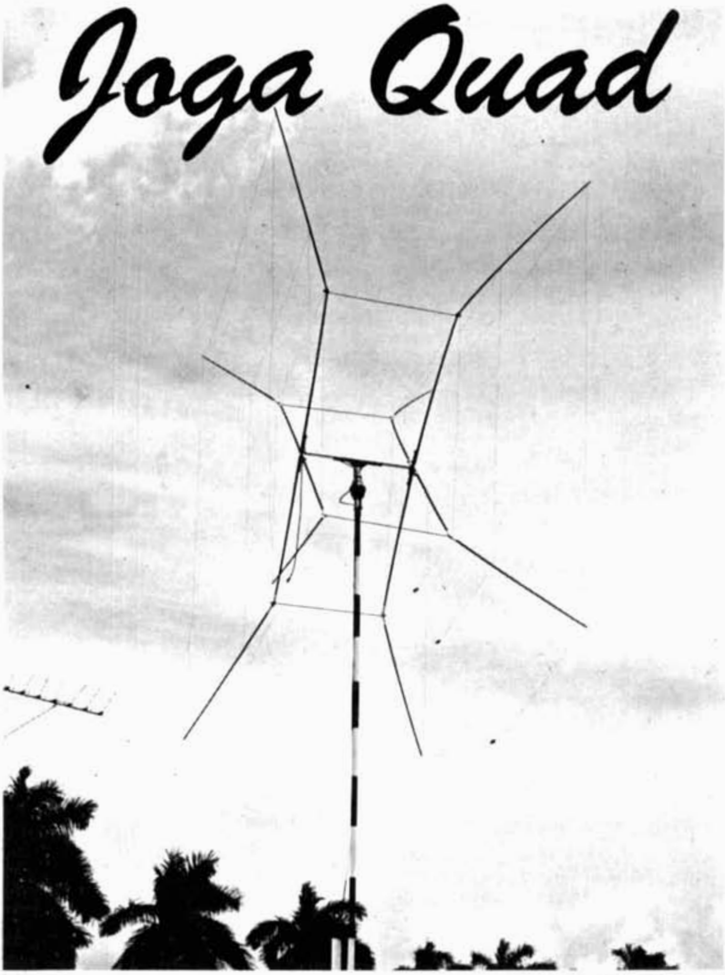
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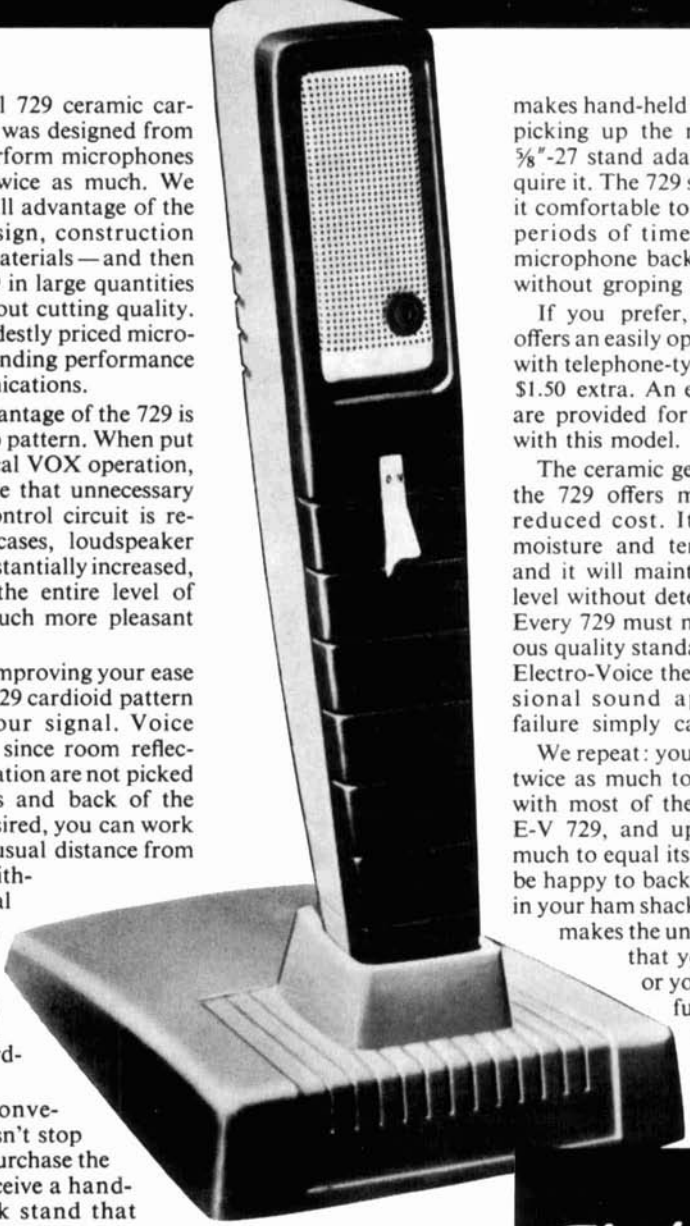
Unless you pay $\$30^{\underline{00}}$ or more, you can't buy a microphone as good as the E-V 729...for only $\$\mathbf{16}^{\underline{20}*}$!



The E-V Model 729 ceramic cardioid microphone was designed from the start to outperform microphones selling for over twice as much. We did it by taking full advantage of the most modern design, construction techniques, and materials—and then producing the 729 in large quantities that cut cost without cutting quality. The result is a modestly priced microphone with outstanding performance for voice communications.

The biggest advantage of the 729 is its cardioid pickup pattern. When put to the test of critical VOX operation, you'll quickly note that unnecessary tripping of the control circuit is reduced. In most cases, loudspeaker volume can be substantially increased, as well, making the entire level of your operation much more pleasant and effective.

But more than improving your ease of operation, the 729 cardioid pattern also improves your signal. Voice quality is crisper, since room reflections and reverberation are not picked up from the sides and back of the microphone. If desired, you can work at up to twice the usual distance from the microphone without losing essential audio clarity. This working flexibility simply cannot be matched by an omnidirectional microphone, regardless of price.

And the 729 convenience story doesn't stop there. When you purchase the Model 729 you receive a handsome slip-in desk stand that makes hand-held operation as easy as picking up the microphone, plus a ⅝"-27 stand adapter should you require it. The 729 shape and size make it comfortable to hold, even for long periods of time. And putting the microphone back in its base is done without groping or fumbling.

If you prefer, the Model 729SR offers an easily operated rocker switch with telephone-type contacts for only $1.50 extra. An extra set of contacts are provided for controlling a relay with this model.

The ceramic generating element of the 729 offers many advantages at reduced cost. It is impervious to moisture and temperature changes, and it will maintain its high output level without deterioration for years. Every 729 must meet the same rigorous quality standards that have made Electro-Voice the standard in professional sound applications where failure simply cannot be tolerated.

We repeat: you have to pay at least twice as much to find a microphone with most of the advantages of the E-V 729, and up to three times as much to equal its performance. We'll be happy to back up our claims right in your ham shack. For Electro-Voice makes the unequivocal guarantee that you must be satisfied or your money will be refunded. Write for free E-V catalog and list of the E-V distributor nearest you.

**Model 729 amateur net. Model 729SR (illustrated) $17.70 amateur net.*

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