Balanced Feed Systems with Coax

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Here are the answers to the questions of how to balance a coax feed system and tune the beam for maximum transfer of energy.

THE MOST POPULAR types of transmission lines for feeding antennas, particularly rotating beams, are Twin Lead and coaxial cable. Both types have advantages or disadvantages over one another as has been outlined elsewhere.[1]

Probably the most common fault found with the use of coax line is that the antenna becomes unbalanced to ground and the symmetry of the entire system is upset. The desirability of balance has been pointed out in other antenna articles,[2] and it is of special concern where beams are involved. Several relatively simple methods of obtaining balance using coax are possible and will be described herein. These methods have been previously discussed separately in one form or another; however, a compilation into one article, together with practical constructional and matching data, should prove to be of interest.

The Bazooka

Figure 1A is that of the well-known bazooka. At the antenna end of the transmission line a section of coaxial cable one quarter wavelength long is mounted four to six inches (not critical) from the regular feed line and parallel to it. Connections are made as indicated in the diagram. The quarter-wave line, in conjunction with the outer conductor of the regular transmission line, between points *x* and *y*, then forms a shorted quarterwave transformer and places point *x* at a high impedance to ground or to point *y*. Point *z* is also at the same impedance point and the balanced value looking into the antenna is that of the coaxial line. For the most popular cables this will be either 52 or 72 ohms.

When calculating the length of the quarterwave section, it is not necessary to consider the velocity constant (V.P.) of the cable because the dielectric in this case is the air space between the two pieces of coax.

The formula for the quarterwave bazooka section is:

$$\text{Length in feet} = \frac{246}{f_{mc}} \times .95$$

Dual Transmission Line

In *Figure 1B* two lengths of coax are run side by side all the way from the transmitter to the antenna. The outer conductors are connected at the ends of the cables, thus placing the line impedances in series and resulting in an impedance of twice that of each cable, or, in the case of 52 and 72-ohm lines, 104 and 144 ohms respectively. Both inner conductors are at the same impedance above ground and the line is balanced. Each conductor also is shielded. The ground junction of the shields at the antenna end may be connected directly to the center of the antenna.

This method of obtaining balanced feed is the simplest and is particularly good for reception. As the line is balanced for its full length with the inner conductors shielded, is not very susceptible

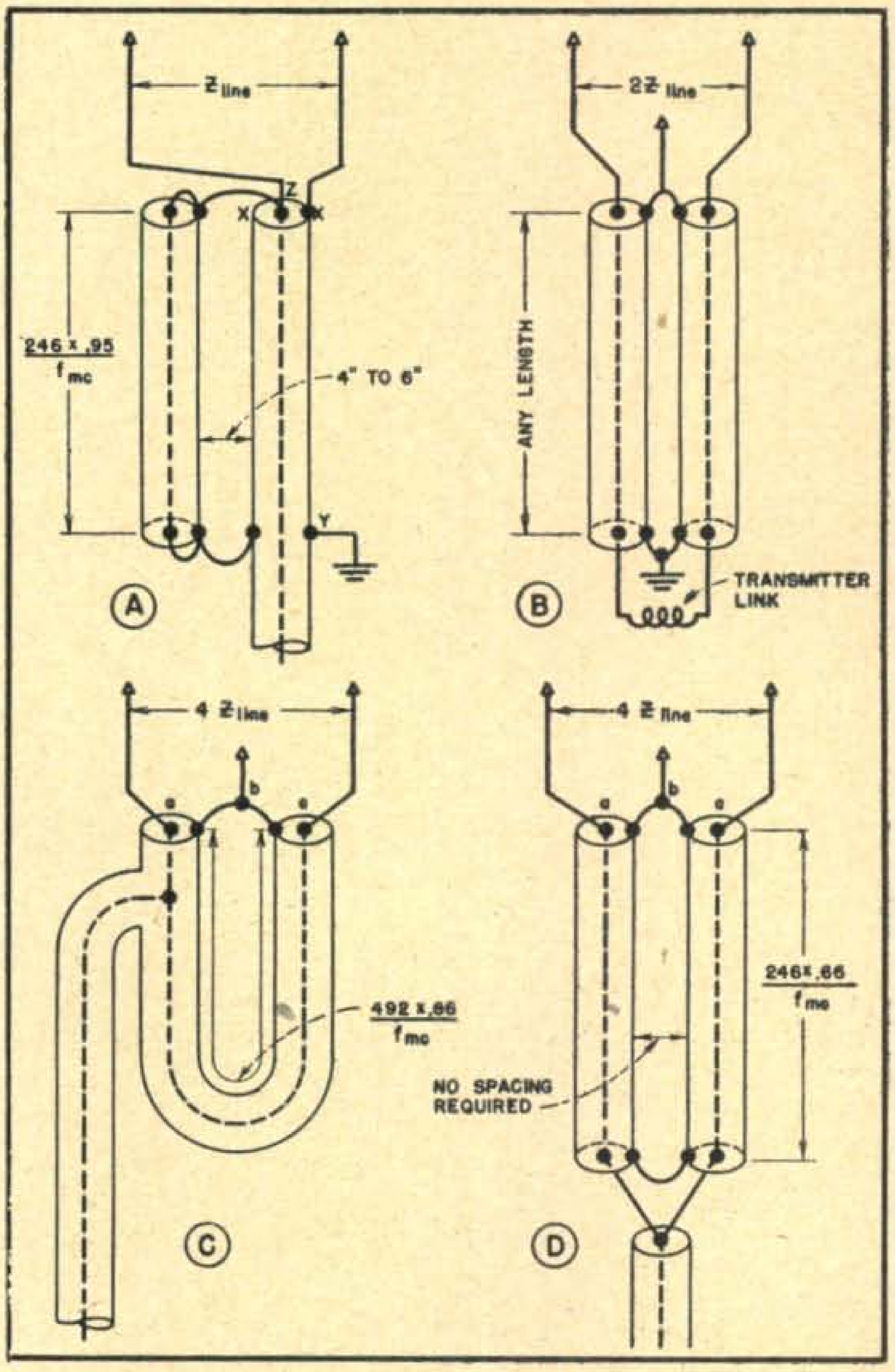

Fig. 1. Four methods using coax for balanced feed. (A) is the bazooka, (B) is dual coax, (C) is the phase inverter of impedance transformer, and (D) is a quarter-wave matching transformer.

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1 M. J. Fein, "Coax For Your Antenna", *CQ*, Feb. '47.

to noise pickup. It has the disadvantage of requiring twice as much total cable and is subject to higher losses, especially where the length of the line is considerable.

Phase Inverter or Imepdance Transformer

Figure 1C is often mistaken for the bazooka. Actually it is a half-wave re-entrant line forming a phase inverter or impedance transformer.[2] An electrical half-wave section of line is folded so that the inner conductor at each end, *a* and *c*, may be connected to the antenna. The line from the transmitter is connected to one end of the half-wave section; shown in the drawing. The normal transmission line impedance is expressed between points *a* and *b*, and since a line composed of one or more half-waves repeats whatever appears at one end, this same value of impedance then appears between point *b* and *c*, and is 180 degrees out of phase with that at *a*. The total output impedance between points *a* and *c* will then be four times that of the coaxial line and it will be balanced. In the case of 52 or 72-ohm cables this will be 208 and 288 ohms respectively. Point *b* may be connected directly to the center of the antenna.

When calculating the length of the half-wave section, the velocity constant of the cable must be taken into consideration. For the most widely used coaxial cables (polyethylene insulation) the V.P. is .66.

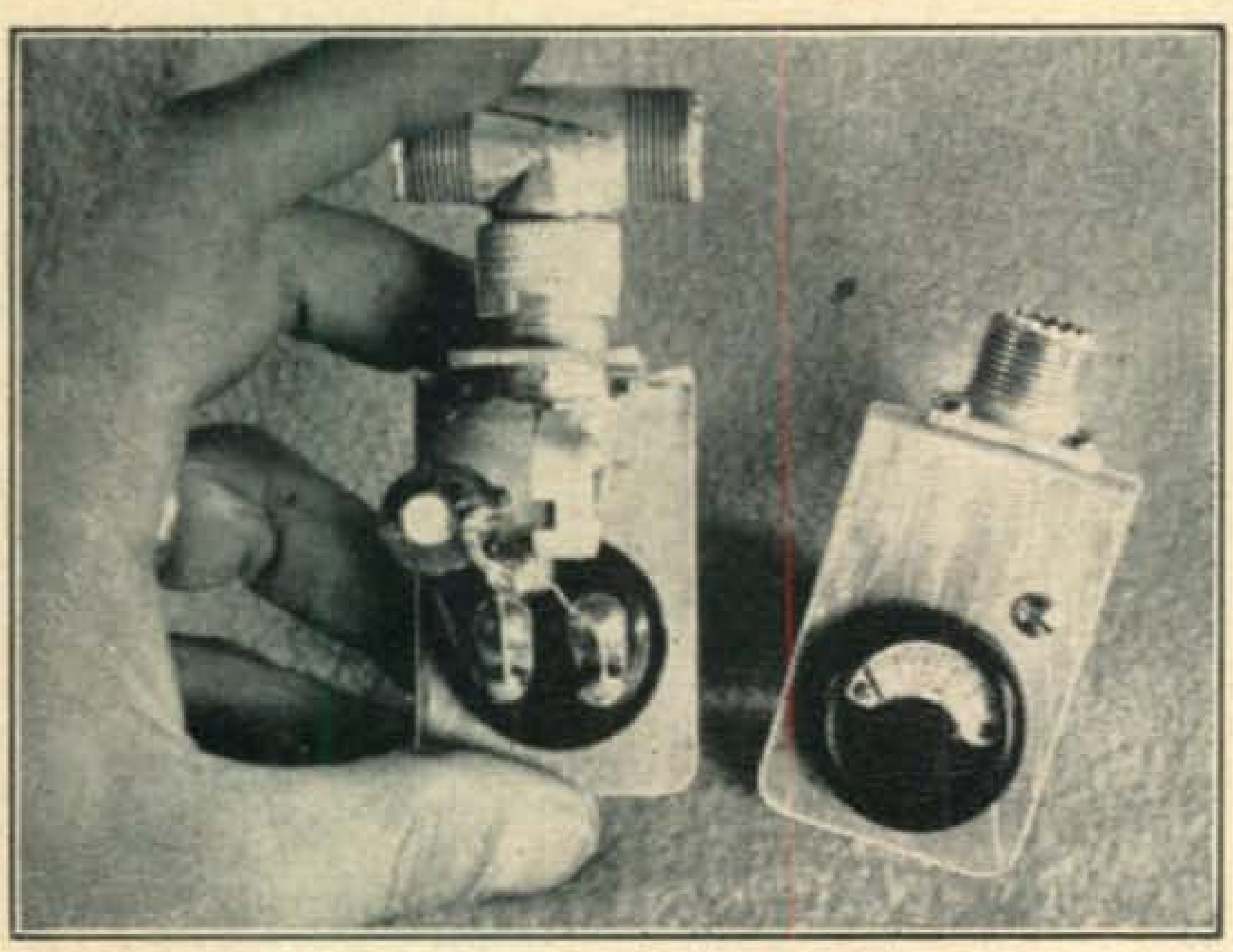
The formula for the half wave section is:

$$\text{Length in feet} = \frac{492}{f_{mc}} \times \text{V.P.}$$

It is important that the length be figured with the fittings connected at the ends of the cable. This should also include the receptacles shown in the assemblies of *Fig. 2*. Since the dielectric of the fittings is usually different from that of the cable, inclusion of their length in the calculations will still be very slightly in error. Wherever possible, the correct length should be determined using a Grid-Dipper.[3]

2 H. Bach, Jr., "The Trombone T", *CQ*, March and April '47.

3 W. M. Scherer, "Applications of the Grid-Dip Oscillator", *CQ*, Jan. '49.
W. M. Scherer, "The Improved Dipper", *CQ*, Feb. '49.



R-F voltmeters designed to facilitate rapid and accurate s.w.r. measurements.

The line from the transmitter should be connected as near as possible to point *a*. A "T" fitting at this junction serves satisfactorily. This is shown in the photograph.

Quarter-wave Matching Transformer

Figure 1D is similar to *Fig. 1C* in that the final result is the same. It is not as cumbersome but requires an additional means of connecting the transmission line. Two sections of cable cut to an electrical quarter wavelength are placed side by side with their outer conductors connected at each end. Their impedances are in series. This then forms a quarter-wave matching transformer having a surge impedance equal to twice that of the coaxial cable. When a transmission line of the same cable impedance is connected at the lower end of the transformer, the balanced impedance appearing between points *a* and *c* will be four times that of the line.

Calculations for the quarter-wave matching transformer should be made in the same manner as for the half-wave phase inverter of *Fig. 1C*.

The formula for the quarter-wave section is:

$$\text{Length in feet} = \frac{246}{f_{mc}} \times \text{V.P.}$$

These balancing methods may be used in a number of ways with different types of antennas. If the antenna is a half-wave dipole of 72 ohms impedance, the bazooka (*Fig. 1A*) may be connected directly to the open center of the antenna when the line used is 72 ohms. Where the antenna is a half-wave folded dipole of approximately 288 ohms impedance, the half-wave phase inverter (*Fig. 1C*) or the quarter-wave transformer (*Fig. 1D*) may be connected directly without the need for any matching system, 72-ohm coax line being employed.

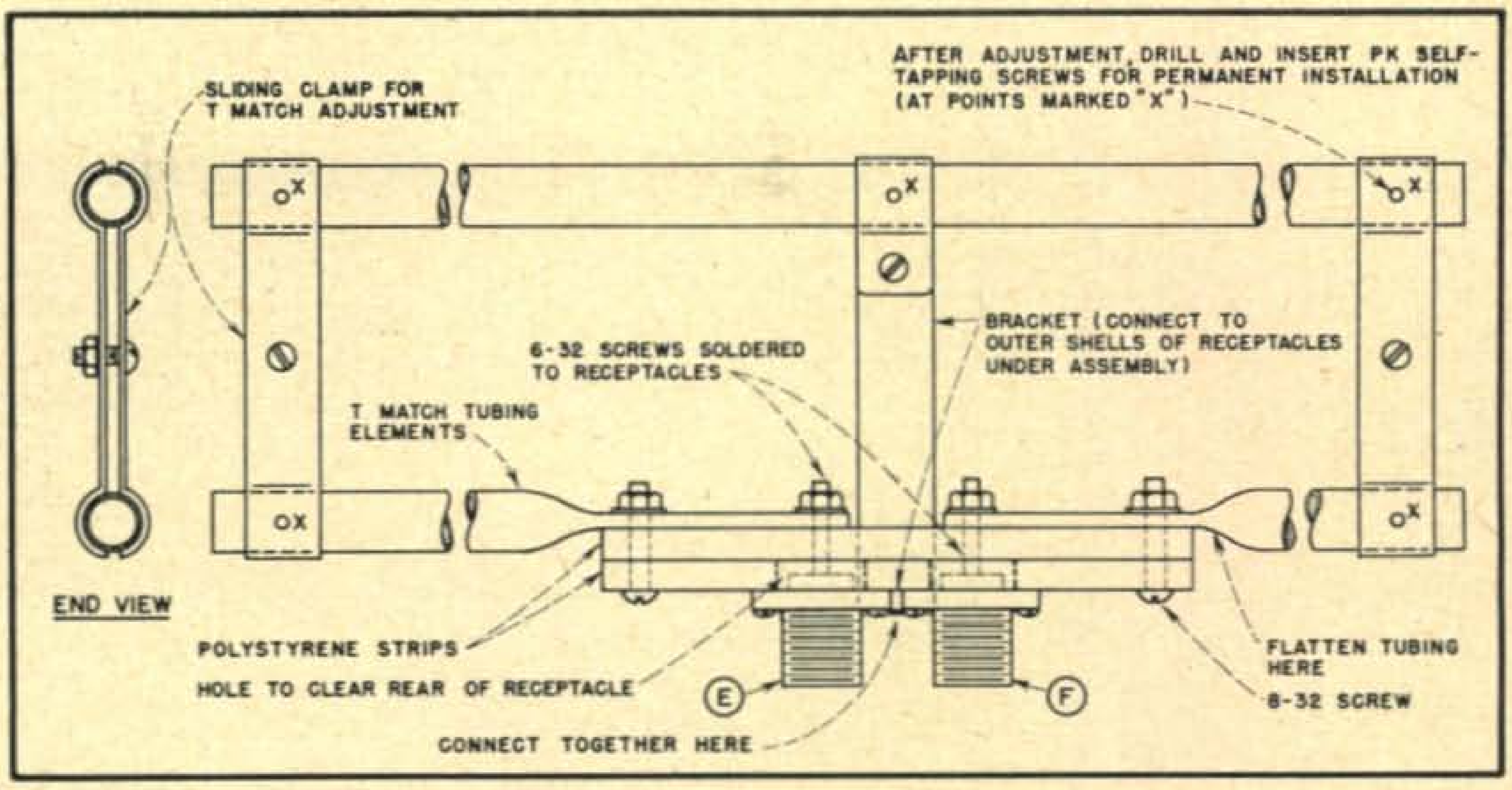
If the beam impedance is near 52 ohms, the bazooka may be used directly with a 52-ohm line; however, most amateur beams (and we are concerned mainly with beams) have an impedance lower than 52 ohms and a method of matching the higher impedance (52-288 ohms) balanced-line sections to the antenna must be utilized.

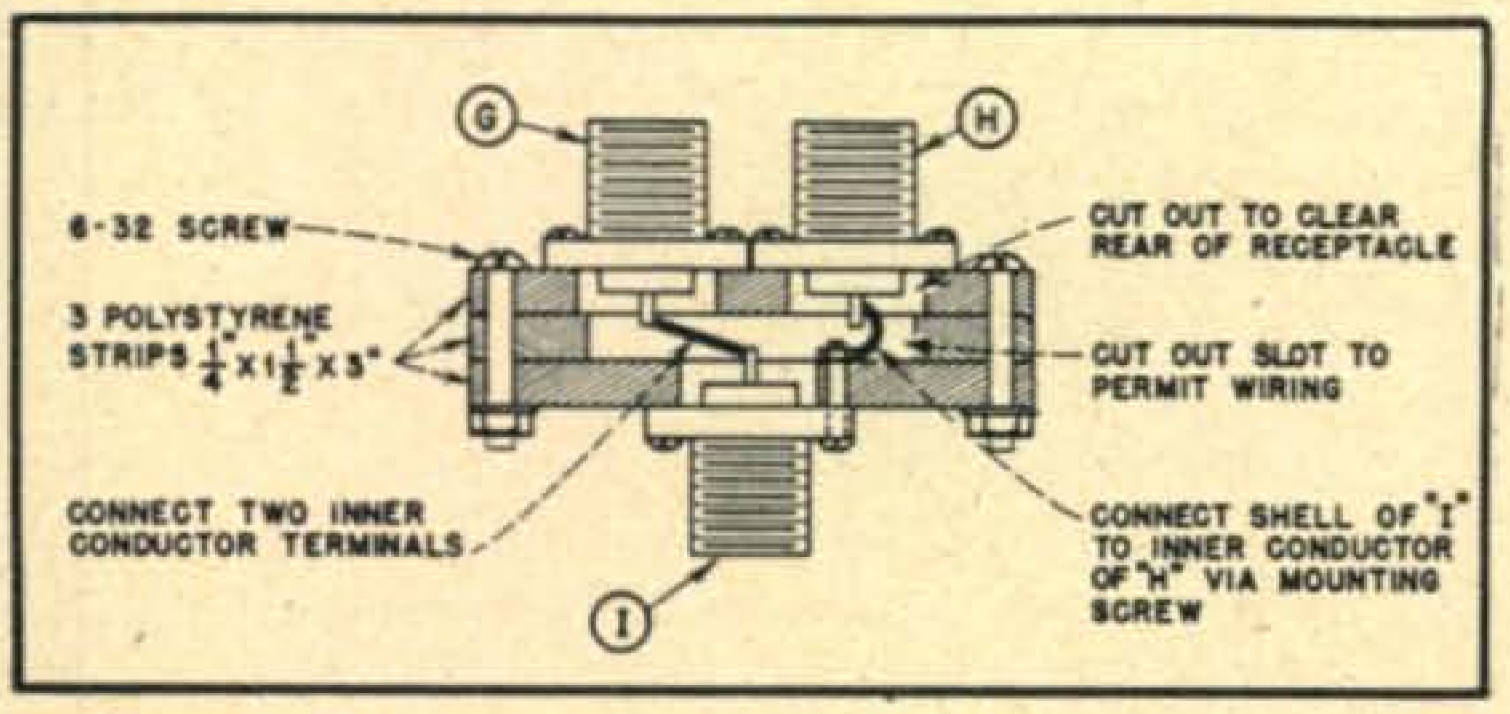
The T-match is recommended for this purpose, not only because it is simple, but also because a correct match may easily be obtained without the need to know the antenna impedance which, more often than not, is different from that of similar duplicate arrays due to differences in spacing, height above ground, nearby objects, element diameters, etc. A number of amateurs have not had satisfactory results with the T-match, claiming it is impossible to obtain a match, or that it is too critical. It is our belief that this has risen out of incorrect tuning procedures for we have found it non-critical and have been able to realize a proper match with any type of feed line or antenna when the tuning methods to be subsequently described were employed.

Simple T-Match

Figure 2A shows the constructional details for the coax fitting assembly used at the center of the T-match. The fitting also serves as the center support for the matching device.

Fig. 2A (right). Mechanical details of T-match connector and support. Fig. 2B (below). Mechanical details of coax transformer-to-transmission line coupling connector.





One inch 6-32 screws, with heads cut off, are soldered to the center conductor rear terminal of each of two female coax receptacles. The receptacles are then mounted, side by side, on the bottom of a piece of polystyrene ¼" x 1½" x 4". The outside shells of the receptacles are joined together. Another polystyrene strip, of the same size, is cemented on top of the one with the receptacles. Holes are drilled in the top strip to pass the 6-32 screws on the fittings. Polystyrene cement (Amphenol 912 coil dope) is applied around the screw holes to seal them against moisture seepage.

The ends of the tubing making up the T-match are flattened and are then bolted to the assembly as shown in the diagram. A bracket from the center of the antenna to the center of the assembly supports the entire unit. The bracket also is connected to the outer ground shells of the receptacles. After completion, the assembly is sealed with several coats of coil dope.

The tubing used for the T-matching section may be of the same diameter, or slightly smaller than that of the antenna, and it should be spaced three to five inches from the antenna. The length of the tubing is ultimately determined during the matching process, but for a start, each half may be about one-sixth the length of the antenna.

When using the dual coaxial line arrangement of *Fig. 1B*, the antenna ends of the lines are plugged into receptacles *E* and *F*. At the transmitter end, the two outer conductors should be fastened together and grounded, while the inner conductors are connected to the ends of the final amplifier coupling link. A dual receptacle device may be made up for use at the transmitter end.

If the phase inverter of *Fig. 1C* is utilized, the center male plug of a coaxial T-fitting is inserted in receptacle *E* so that the length of the T-fitting is at right angles to the length of the polystyrene strip. This may be seen in the photograph. One end of the half-wave line is connected to receptacle *F* and the other end is plugged into one of the free ends on the T-fitting. The half-wave line may be left hanging in the shape of a "U," or it may be rolled upon the boom supporting the beam elements. The transmission line is joined to the remaining free end of the T-fitting.

If the quarter-wave transformer of *Fig. 1D* is to be used, the antenna ends of the two lines making up the transformer are connected to both receptacles *E* and *F*. The transmission line ends are connected to receptacles *G* and *H* shown in *Fig. 2B*. This assembly is made up in the same manner as that of *Fig. 2A*. Correct connections for the receptacles are indicated in the drawing. The transmission line from the transmitter is plugged into receptacle *I*.

A permanent installation of the bazooka of *Fig. 1A* has not been made by the writer, but plug-in assemblies, similar to those already described, could be devised together with some mechanical means of spacing the bazooka lines.

Adjusting the T-Match

One of the most important requirements for perfectly matching any feed system to any antenna, for the attainment of near unity standing wave ratio and a maximum transfer of power to the antenna, is that the antenna be resonant at the desired operating frequency. This can not be stressed too strongly, for it is impossible to obtain a perfect match with the antenna incorrectly tuned. This is one big reason why many amateurs are unable to realize a satisfactorily low s.w.r.

Several methods may be employed to resonate the antenna. It may be accomplished quickly and accurately using a Grid-Dipper. The length of the beam elements should first be set approximately according to formula. The T-matching section should be installed on the antenna element, but all coax cable should be disconnected. If any difficulty is encountered in obtaining a resonant dip on the

Grid-Dipper due to low antenna *Q*, large diameter elements, etc., connect a crystal diode and a 0-1 ma meter (or smaller) in series between the two halves of the T-section as shown in *Fig. 3*. Couple

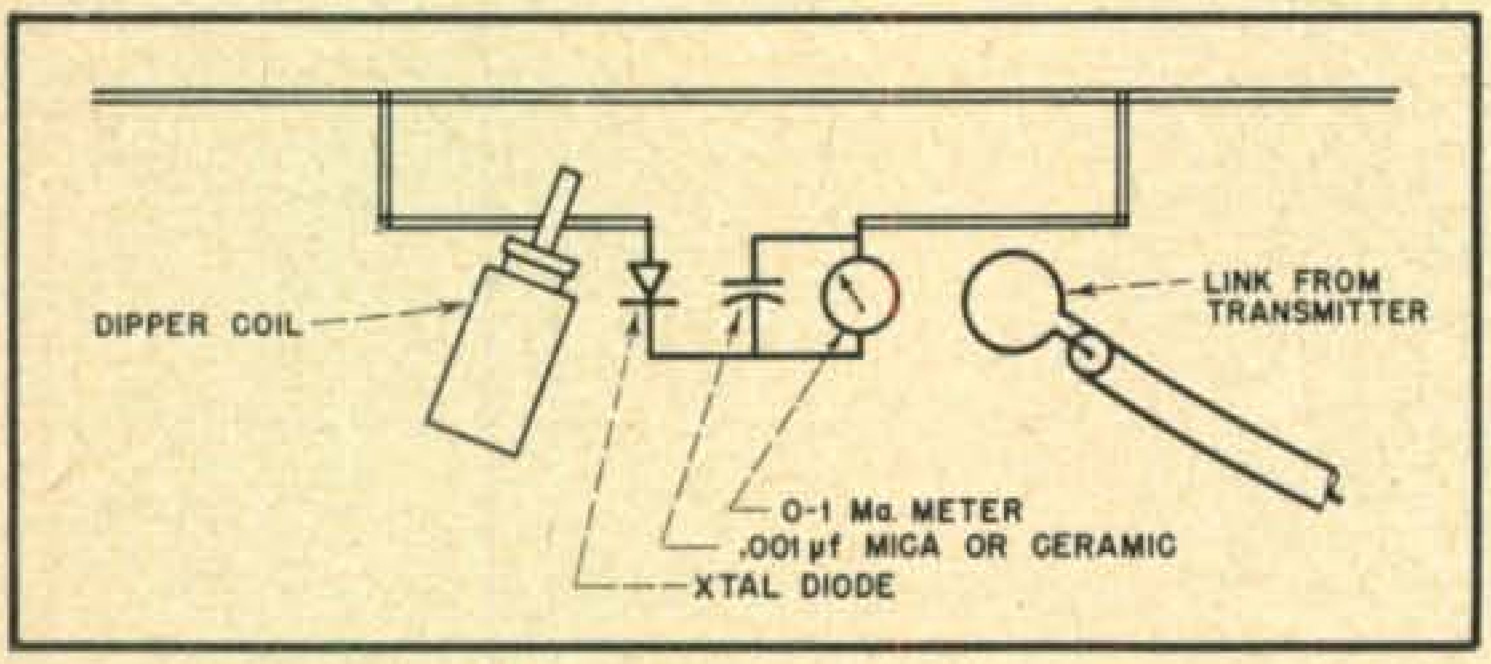


Fig. 3. Method of employing grid dip oscillator for T-match element tuning adjustments.

the Dipper (used as a signal generator) to the antenna or T-section, and tune the antenna for maximum reading on the antenna meter at the desired frequency.

If a Grid-Dipper is not available, this same method may be employed by replacing the Dipper with a coupling link of one or two turns connected to the transmitter via the regular feed line. The physical position of the link must remain fixed while tuning the antenna.

Resonating the antenna by shock excitation before the parasitic elements are installed is not recommended, because the resonant frequency will shift considerably upon installation of the other elements. This is true especially with close-spaced beams. Neither is shock excitation recommended with reflector and director elements installed and purposely detuned. Later, adjusting these elements to correct length will materially shift resonance.

Next, a standing-wave-ratio meter should be procured for use during the tuning and matching process. The schematic of the one used by the writer is shown in *Fig. 4*. It is simple, non-critical, and has been found to be accurate. A 150-μa meter is used in the instrument to increase its sensitivity and thereby permit the employment of the Grid-Dipper as the signal generator. This makes available a variable frequency source of r.f., which is really a necessity during any matching process. It also makes available an r-f source of low power to minimize useless QRM. The instrument is calibrated by adjusting the r.f. input level until the meter reads full scale when no load is connected to the transmission line terminals. When a load resistor (½-watt carbon) equal to that of *R* is placed across the output terminals, the meter reading should drop to zero. Load resistors of other values equal to 1.5 x *R*, 2 x *R*, 3 x *R*, etc., are then placed across the terminals and the meter readings are noted. The standing wave ratio is equal to: $\frac{R_{load}}{R}$, where *R* is equal to the line impedance as shown in *Fig. 4*. It is not necessary to calibrate the meter for any s.w.r. higher than 3:1. Actually, we are interested only in obtaining a close to unity ratio which is the case when the s.w.r. meter reads zero. No provision has been included in this meter for use with open radiators lacking a d.c. return path, since all our work has been done with closed radiators. A d.c. return may be obtained by placing an r.f. choke across the transmission line terminals and adding capacitance, equal to that of the choke, across *R*.

Originally some doubt existed as to the accuracy of this type of s.w.r. meter, because several of the local boys had difficulty in getting consistent readings. A reading of unity could be obtained but changing the length of the feed line resulted in a high s.w.r. reading. This, of course, should not occur if the s.w.r. were really unity. The same erroneous results were found when using non-inductive resistive loads in place of the antenna at the end of the transmission line. Since this also happened when using several different instruments utilizing the same circuit and with different antenna installations, it was decided to prove the instrument by checking for standing waves through some other method; namely, measuring the voltage across the line at quarter-wave intervals.

If an open-wire line or Twin Lead were to be used, no problem would have been involved in obtaining readings across the line; however, with coax some means was required to reach the inner conductor in order to connect the r.f. voltmeter. This was solved by inserting coaxial T-fittings at the desired points in the line. This then permitted a connection to the inner conductor. The circuit for the voltmeter is shown in *Fig. 5*. A 0-1 ma meter in series with a crystal diode is connected to the inner conductor through a 3-12 $\mu\mu$f variable ceramic capacitor. The other side of the meter is connected directly to the outer conductor of the line. The setting of the variable capacitor determines the sensitivity of the device. For convenience, two such meters were used and the variable capacitors were adjusted for identical meter readings when the instruments were connected across the same point in the line.

To determine the presence of standing waves, the meters are inserted in the line, via the T-connectors, one-quarter wavelength apart. The meters will read the same when the standing wave ratio is unity, but, under some conditions, even when standing waves are present, it is possible for the meters to read alike. To check this, another section of line one-eighth wavelength long is inserted. If

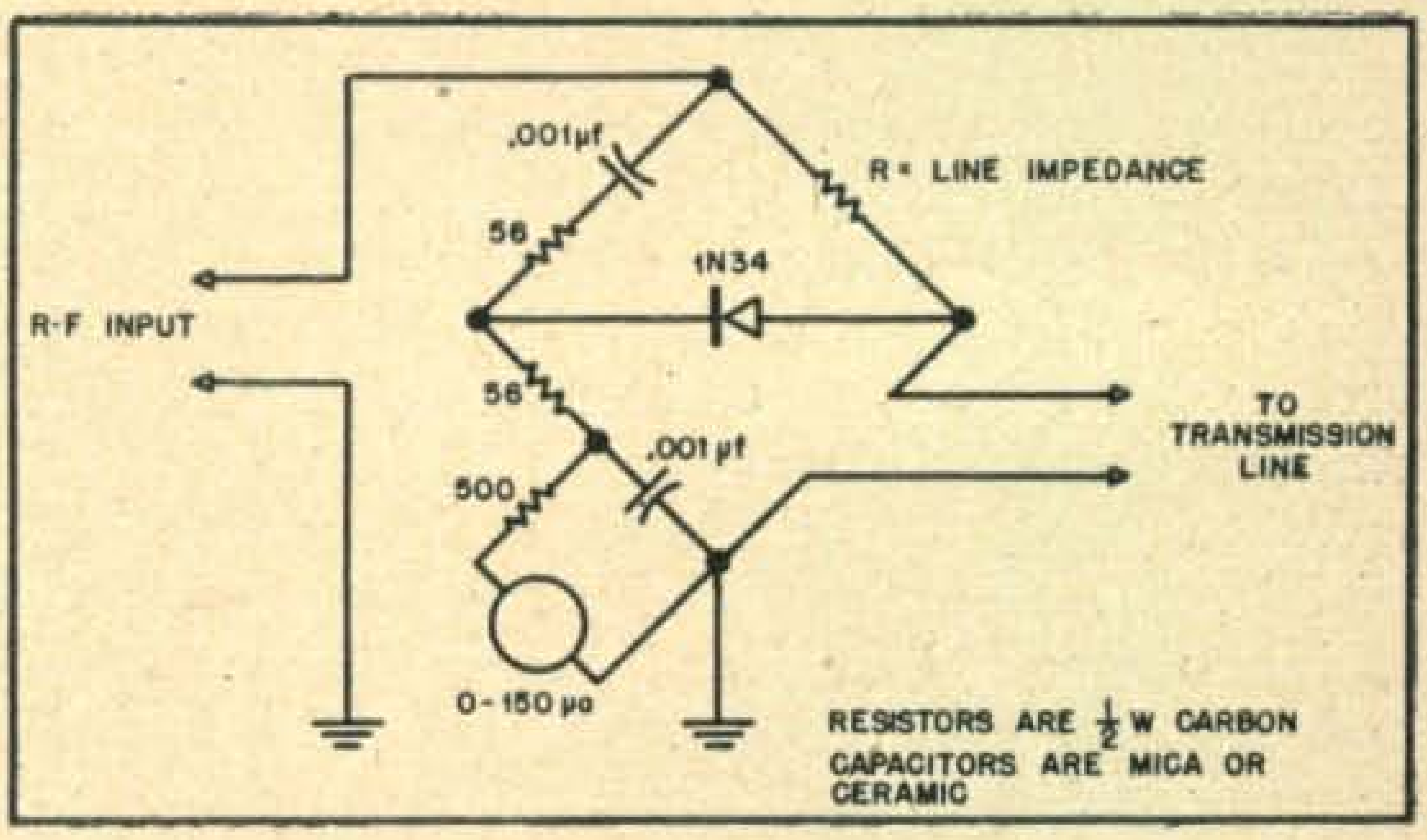


Fig. 4. Standing-wave-ratio meter used in tuning and matching tests.

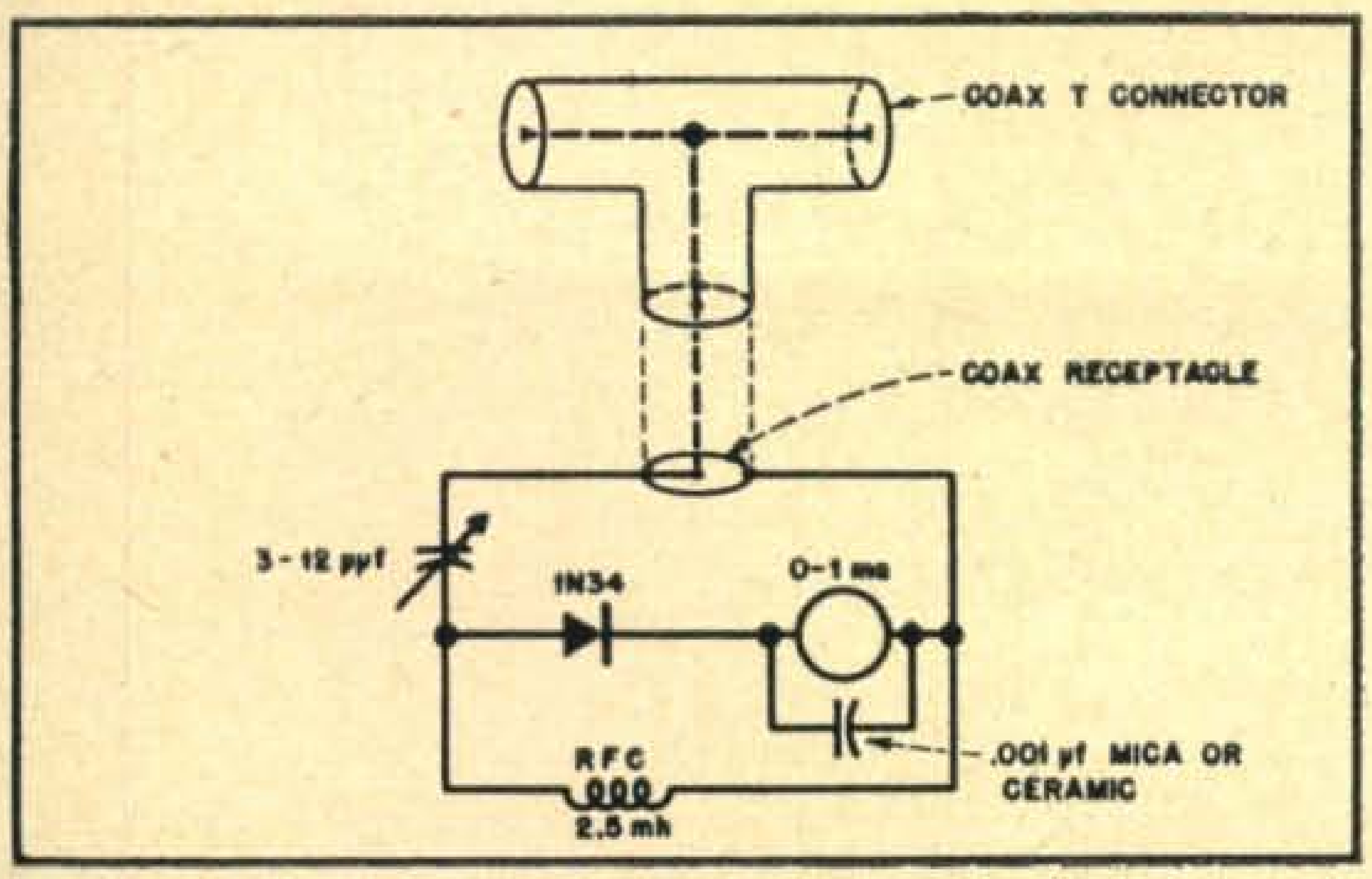


Fig. 5. Circuit of r-f voltmeters used for coax line measurements.

the s.w.r. is really unity, the meters will still read identically. This latter step is also necessary when using the regular s.w.r. meter, as will be mentioned later. Inserting the voltmeters at various points along the line caused no noticeable change in s.w.r.

Now, upon checking with the preceding arrangement, the same fallacious results were experienced as when using the s.w.r. meter. This called for some measurements of the surge impedance of the coaxial cable itself. This turned out to be 72 ohms instead of 52 ohms. Yes, the cable was unmarked and it had been sold to the same group of amateurs as 52-ohm line. Motto: Be careful when purchasing coaxial cable unless it has been marked by the manufacturer!

With the s.w.r. meter functioning correctly connect the balanced feed line to the T-match section. Couple the input of the s.w.r. meter to a variable source of r.f. such as a Grid-Dipper, standard signal generator, or v.f.o. controlled transmitter of low power. It is best to employ a variable source of r.f. because it will readily facilitate checking antenna resonance as the tuning process advances. The coupling to the r.f. source should be adjusted for maximum reading on the s.w.r. meter.

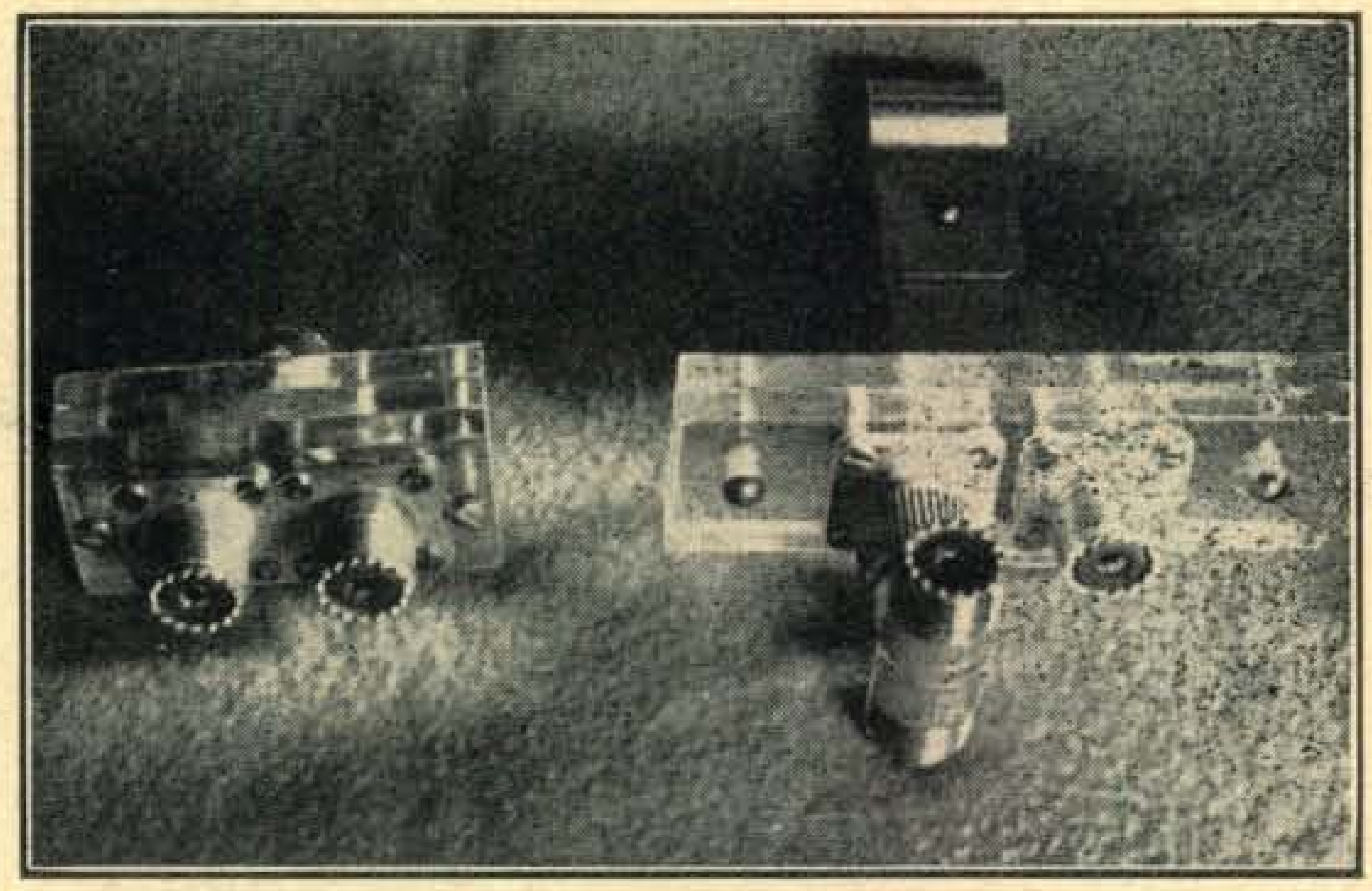
Then connect the transmitter end of the transmission line to the output of the meter. Vary the frequency of the r.f. generator to the point where a decided dip occurs in the s.w.r. meter reading. The frequency at this point should be near that of the antenna resonant frequency established earlier. Adjust the length of the T-match sections by sliding the end clamps an inch or two at a time toward or away from the center of the antenna until the s.w.r. meter reads as near zero as possible. The length of each leg in the T-match should be adjusted equally. After each adjustment, the frequency of the r.f. generator should be shifted for the greatest s.w.r. meter dip, because the resonant point may shift slightly after each adjustment. If, after the s.w.r. has been brought down to as near unity as possible, the frequency is other than that desired, the antenna length should be accordingly altered and the T-match pruned until near unity s.w.r. is found at the desired frequency. Under certain conditions it is possible for the s.w.r. meter to indicate unity even though this may not be the case. Therefore, as a final check, an eighth-wavelength section of cable should be inserted in the line and, if the s.w.r. is really unity the reading on the meter will not change.

It will be noted that we have mentioned unity or near-unity standing wave ratio. To many readers this may appear far fetched in view of the unsuccessful attempts by many amateurs to realize this condition; however, in the numerous tests made, using the methods described above, no difficulty was encountered in easily obtaining an s.w.r. of 1.1 to 1 and better.

Varying the frequency of the r.f. source will produce some interesting results in changes of s.w.r. An idea may be had as to how broad the antenna system is for a given s.w.r. On the average we have found conventional 28-mc parasitic beams to vary from unity to 2:1 over about 400 kc and run up to about 3:1 or 4:1 over a range of 1 mc.

As a final adjustment the parasitic elements should be adjusted for maximum forward gain or best front-to-back ratio, whichever is desired. The customary methods of so doing are satisfactory but for one very important exception; namely, that if the correct s.w.r. is to be maintained, the antenna must be checked and re-adjusted for resonance after each parasitic element adjustment. This could be quite a time consuming operation, but the time may be considerably reduced if a receiver with an S-meter is employed as the field strength meter to permit the use of the low power source of r.f. while the s.w.r. meter is connected in the line. Antenna resonance may then be quickly checked after each adjustment by noting the frequency at which the s.w.r. meter dips or is at unity. Final readjustments of the T-match may be required following the tuning of the other elements.

As a "final final" check, the beam should be rotated through its full 360 degrees to note the changes in s.w.r. or antenna resonance. Unless the beam is entirely in the clear in all positions, some shifts in s.w.r. and resonance will most likely be noticed due to detuning effects of nearby objects. Unfortunately nothing can be done about this condition, but it is not likely to seriously affect antenna performance.



Fittings designed to facilitate connection of coax lines to antenna. The one to the right, designed for a T-match, is illustrated in Fig. 2A; to the left is the coupling shown in Fig. 2B.