A Broad-Band Balun For A Buck

BY WILLIAM I. ORR,* W6SAI

This article describes the construction of an inexpensive broad-band balun of the lumped constant coaxial variety. It has a 1:1 impedance transformation and will handle a kilowatt without overheating.

A BALUN is a balance-to-unbalance r.f. transformer and an extremely useful device in the field of radio communication. Known for decades in commercial practice, various forms and shapes of baluns are now being used to advantage in radio amateur antenna installations. In many instances it is common practice to connect a coaxial transmission line to a balanced transmission line or antenna system. Conversely, it is not unknown to find unbalanced (coaxial) transmission lines attached directly to the balanced circuits of receivers or transmitters. It is a poor technique to follow and untold difficulties may arise from subterfuges of this type. Such electrical mismatches, or transitions, should not be made directly since the junction between the balanced and unbalanced systems presents an electrical discontinuity in the characteristic impedance of the system. The use of a balun at such a junction permits a proper balance to be achieved and eliminates a sticky problem that can lead to all sorts of weird effects, especially when s.w.r. measurements are made. Trying to make knowledgeable s.w.r. measurements through a balance/unbalance discontinuity in your antenna system is like trying to nail a blob of Jello to the wall. It just can't be done.

*Amateur Service Dept., EIMAC, a Division of Varian Associates, Inc., San Carlos, California.

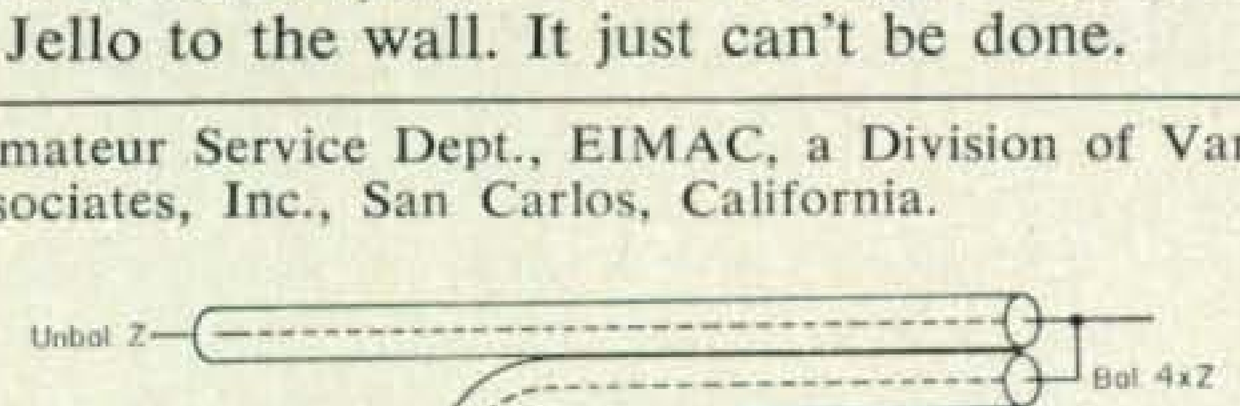

Fig. 1—A simple half-wave coaxial balun provides a 4 to 1 impedance transformation and is extremely frequency-sensitive. Good balance may be achieved over only one amateur band.

Half-wave Coaxial Baluns and Ferrite Baluns

Simple half-wave coaxial baluns have been used for years by radio amateurs to achieve a continuous junction between unbalanced and balanced systems (fig. 1). These devices may be made of a length of coaxial line and are cheap and easy to build. They are, however, decidedly frequency-sensitive and the balun length becomes quite critical at 50 mc and above. Worst of all, for the amateur wishing to match a low impedance coaxial line to a typical beam antenna (having a *lower* value of impedance than the line) the half-wave balun provides exactly the *opposite* impedance transformation. It is a step-up device rather than a step-down device. In this instance, the perfect balun would provide a balancing action with a step-down impedance ratio that would match a 50 ohm coaxial line to the driven element of a Yagi antenna which is in the neighborhood of 20 ohms or so.

The emergence of the so-called tri-band or duo-band beam in the past decade has imposed a second restriction on the "perfect" balun: it should function over a four octave range (7-29.7 mc). The half-wave balun is too frequency sensitive to do this job. Suitable broad-band baluns to cover this range may be wound on ferrite cores and will accept power levels up to 750 watts or so.[1] Ferrite cores, however, are costly and somewhat fragile and cannot be readily found in the corner radio shop.

An inexpensive and satisfactory substitute for the ferrite variety of broad-band balun is the lumped constant coaxial balun. This article describes such a balun and shows how you may build one in a few minutes for modest cost.

[1]Turrin, R., "Broad-band Balun Transformers," *QST*, August 1964, p. 33.

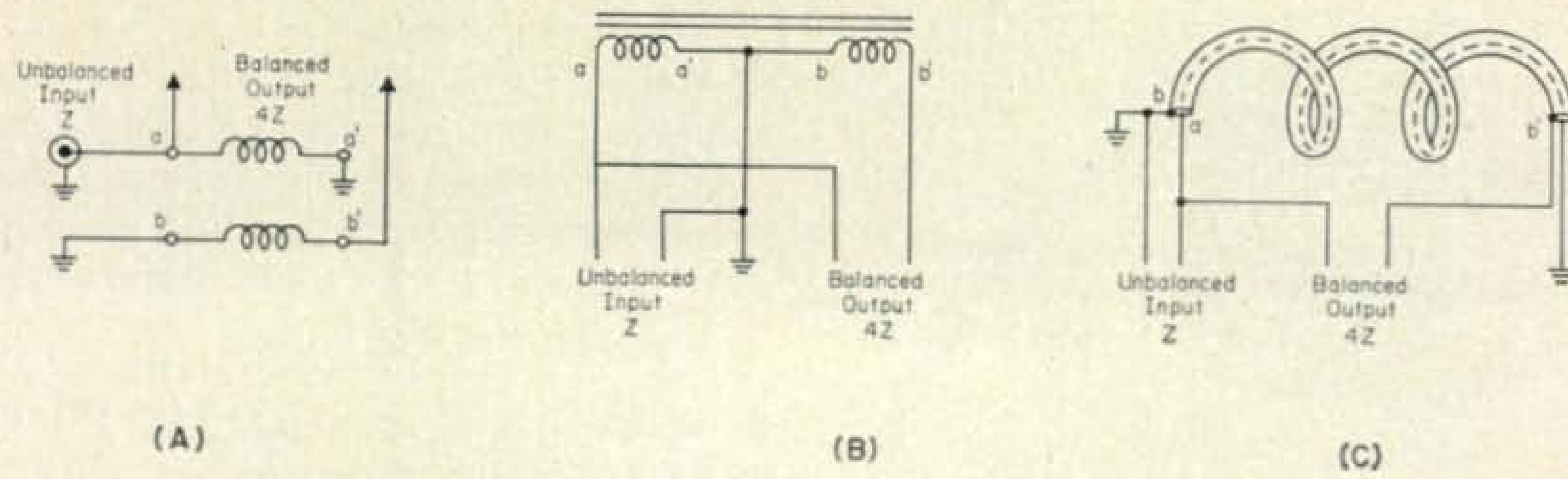

Fig. 2—The 4 to 1 balun coil may be visualized as a form of TV "ladder transformer" (A), or as a audio inductor (B) with the input fed to one-half the winding. Balanced output is taken across the complete winding. An equivalent r.f. transformer makes use of a section of coaxial cable (C) which is equivalent to a coaxial winding. The coaxial cable is approximately an electrical quarter wavelength at the center frequency of the balun.

The Broad Band Coaxial Balun

A simple, efficient and effective broad-band balun may be constructed from a length of coaxial line, suitably tapped and wound into a coil. The transformation can be made to be unity (one-to-one), thus providing a balanced 50 ohm termination for a 50 ohm coaxial line, suitable for most tri-band beam antennas. Alternatively, a "Hair-pin" matching device may be used to transform the 50 ohm balanced termination to a lower value.[2]

The broad-band coaxial balun is shown in the drawings and illustrations and consists of a section of 50 ohm coaxial line wound on a 6¾ inch diameter form. The balun acts as a transmission line transformer at the high frequency end of the operating range and as tightly coupled inductors at the low frequency end of the range. The over-all passband is about 6 to 32 mc, and is limited at the low frequency end by the inductance of the windings, and at the high frequency end by transmission line resonances.

Operation of the broad-band coaxial balun may be seen from the analogy shown in fig. 2. This is the sketch of a simple 4:1 coaxial balun. (A). It is also known as a ladder transformer in TV *lingo*. This balun may be compared to a push-pull audio inductor, with the exciting voltage fed to one-half of the winding and the output voltage taken across the complete winding. If both windings have an equal number of turns, the output voltage will be twice the input voltage and will be balanced with respect to ground. As the ratio of the output and input impedances of this device is a function of the square of the ratio of the output to the input voltage, the impedance transformation is 4:1 (step-up).

[2]Orr, W., *Beam Antenna Handbook*, 2nd Edition, Radio Publications, Wilton, Conn.

The 1:1 Coaxial Balun

A version of the broad-band coaxial balun is shown in fig. 3 wherein a 1:1 transformation ratio (unity) may be realized. The balun is pictured as having three windings (or two windings, with one winding tapped at the center to obtain a half-voltage point) as shown in the audio inductor analogy.

Each half-winding of this inductor has one-half the input voltage impressed across it. The full input voltage is impressed across both halves of the winding, and one output tap is placed at the center of the winding. The other output tap is taken from the proper end of the "third" winding which has one-half the impressed voltage across it. By proper polarization of the windings the output voltage will be balanced to ground. This version of the coaxial balun provides a 1:1 (unity) transformation from an unbalanced to a balanced state and is a very handy device to have around the amateur station!

Building the 1:1 Coaxial Balun

The 1:1 broad-band balun may be simplified by making the whole device out of a single length of coaxial line as shown in fig. 4 and 5. Symmetry of placement of the various "coils" is thus insured and the cost of the coax is negligible. The "single" winding portion of the balun is made of a shorted section of the coaxial line which, in reality, is merely a continuation of the original "dual" winding. Sounds complicated? Well, it really isn't . . . here's how you do it.

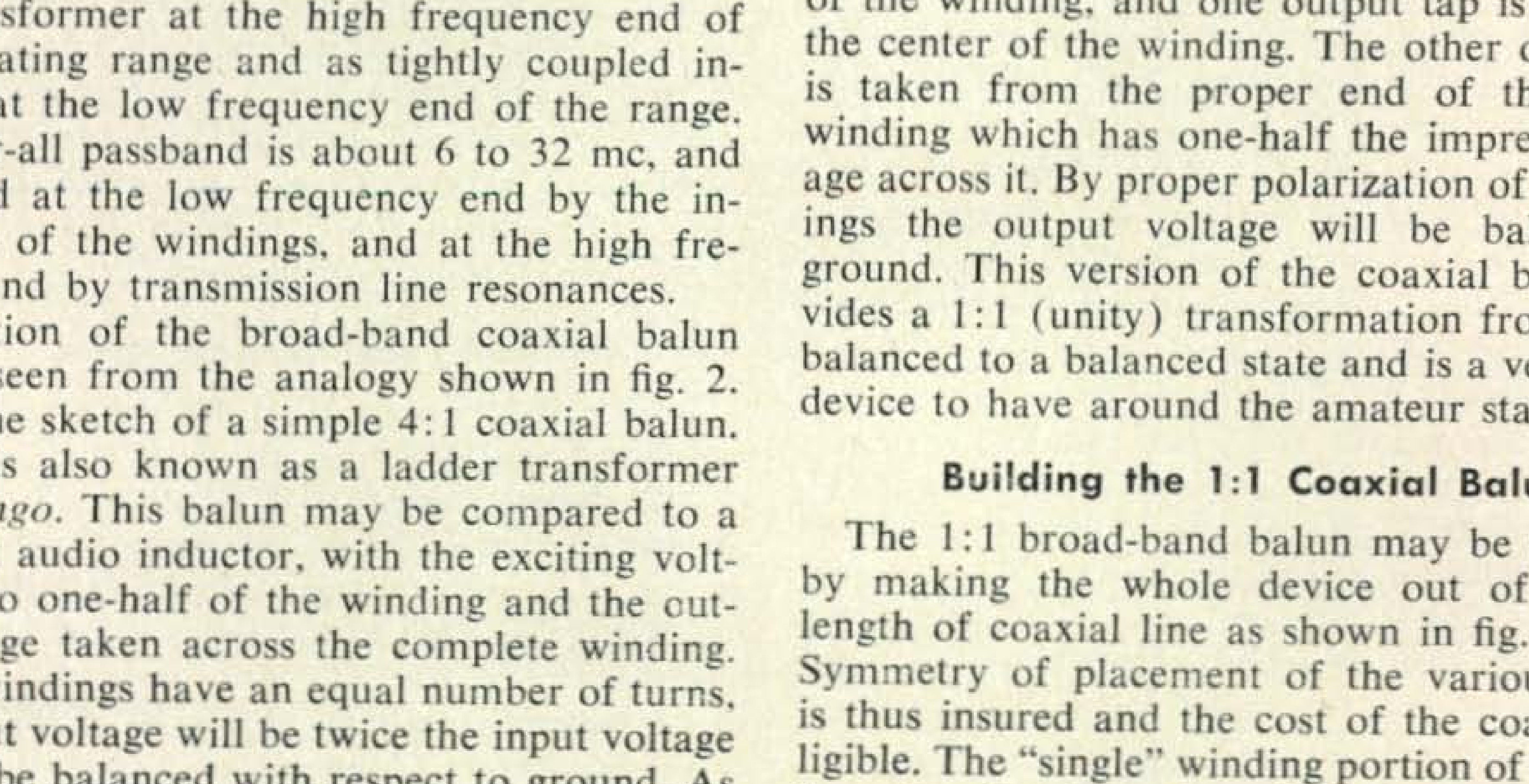

Fig. 3—The 1 to 1 balun coil has three windings (A) or may be visualized as an audio inductor having three equal coils as in (B). Voltage across each coil is equal and proper polarization of the windings provides output voltage balanced to ground. An equivalent r.f. transformer requires three windings, two of which may be made of a length of coaxial cable. The third winding may be a single section of wire, but is often made of the outer conductor of a coaxial line in order to preserve symmetry as shown in (C). In this case, the outer and inner conductor may be shorted together.

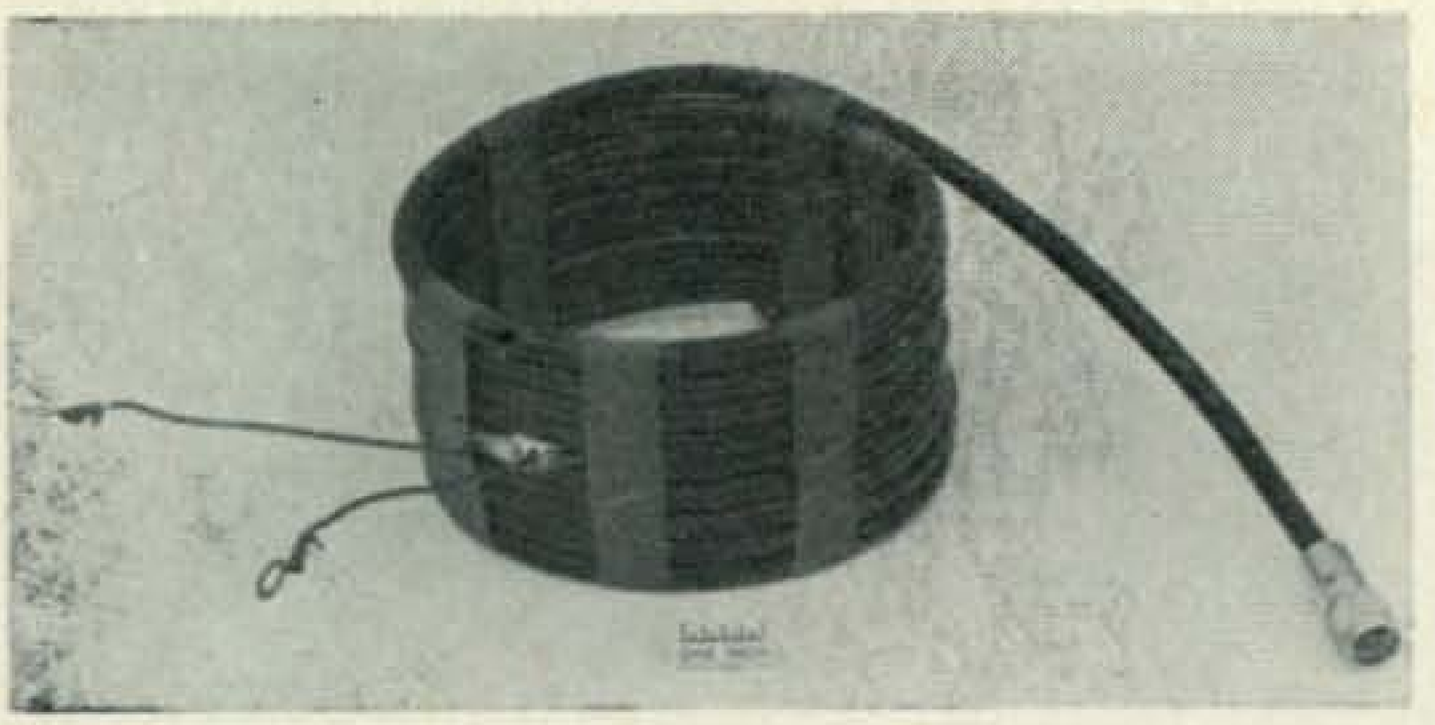

Fig. 4—A coaxial balun made by WA6JSA. A single length of coaxial cable was wound on a suitable form and fixed in position with vinyl tape. The balanced connections at the center of the winding are made by short lengths of #12 wire, and the "top" end of the coil has a PL-259A plug affixed to it for connection to the station transmission line.

The balun is simply a coil of 50 (or 52 ohm) coaxial line. The old favorite RG-8/U or its new noncontaminating cousin RG-8A/U may be used. Alternatively, the new 50 ohm non-contaminating RG-213/U is satisfactory. Any of these cables will produce a sturdy balun that will handle a kilowatt-plus (over two kilowatts p.e.p.) of power without overheating. The new RG-213/U is recommended over the others for reasons that will be discussed later.

A section of coaxial cable 16′6″ long is to be wrapped into a coil whose inside diameter is 6¾ inches. This length of line will permit 9 turns to be made, with an inch or two left at each end of the coil for connections. The physical mid-point of the length is found and at this point the outer plastic cover and the outer, flexible shield of the line are broken. The plastic cover is trimmed back for an inch on each side of the break and the copper outer braid is trimmed back and cut about one-half inch each side of the center point to allow the connections shown in fig. 5 to be made. The inner conductor is *not* broken. (To prevent ambiguity, the "shorted" section of line is termed the "bottom" and the unshorted section is termed the "top," as shown in fig. 3.) Wire leads are now soldered to the outer shield at both ends of the "top" section. The shield of the "bottom" section is soldered to the inner conductor at both ends of the line. When this is completed, mark the free end of the "bottom" winding so that it is readily identifiable and securely solder the center joints of the line. Cover this joint with waterproof, vinyl tape, allowing the connecting leads to extend from the taped joint.

Winding the Balun Coil

The next step is to wind the modified coaxial cable into a coil having an inner diameter of 6¾ inches. Your ingenuity will stand you in good stead at this point. It is possible to "air wind" the coil using small wooden strips as braces.[3] After making a few baluns using this technique, using a hand-made form built up of dowel rods pushed into holes drilled in a board, I suddenly discovered a near-perfect coil form of the proper diameter. Gray, *Polyvinyl Chloride (P.V.C.)* plastic pipe of various diameters are available from plumbing supply houses and an eight-inch length of this material makes a nice, permanent coil form that may be bolted directly to the boom of the beam antenna.

[3]WA6JSA used an empty gallon cider jug for his coil form.

Let's assume you have a chunk of the proper diameter P.V.C. plastic pipe. Wind your prepared coaxial line on the form for a trial run, and you'll end up with slightly more than nine turns. Using three hands hold the winding in place and mark the nine-turn end-points on the form with a pencil.

It is necessary to fasten the coaxial coil to the form. The easiest way to do this job is to remove the winding and drill small holes through the wall of the form at each end of the winding (previously marked with pencil) and lash the ends of the coaxial line to the form with heavy twine or lacing cord. Using the pencilled end point marks, it is simple to determine where the holes should be drilled (one on each side of the ends of the cable). The coax may then be rewound on the form and lashed in place. If all went well, the center tap of the coaxial line will be at the center of the coil; that is, there should be exactly 4½ turns each side of the center tap.

The last step is to connect a grounding jumper from the "top" end of the coil braid to the braid at the "bottom" end of the winding. The jumper should have reasonably low inductance. I use a ½ inch wide copper strap for this connection, scrounged from the junk box. Solder the jumper in place at both ends and your balun is completed (The jumper goes from a to b^1 in Fig. 3C: a common ground connection.)

Using the Coaxial Balun

This balun should be mounted on the boom of your beam antenna close to the feed point of the driven element. It is designed to match an unbalanced 50 or 52 ohm coaxial line to the center of a split, driven element and should not be used with such shunt-fed system as gamma matches or the like. The balun may be mounted to the boom by means of a pair of small right-angle brackets. Connections from the center balun terminals to the driven element should be made with short lengths of copper strap or heavy wire. The coaxial transmission line attaches to the input ("top") terminations of the balun, and the ground (outer braid) is grounded to the boom of the antenna and the common ground of the balun coil. That's all there is to it!

In addition to providing a good match for a "tri-band" beam, the coaxial balun works well with a single band beam. The so-called Inductomatch or Hair-pin system may profitably be employed in this instance.[2]

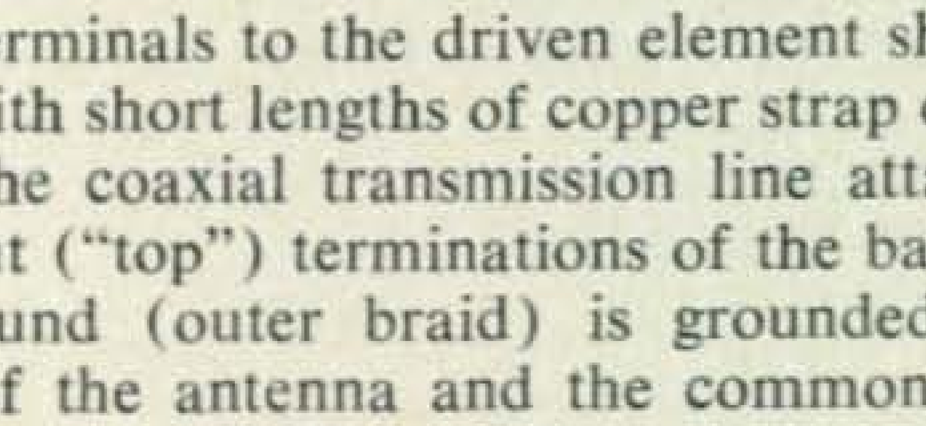

Fig. 5—A sketch of the center junction of the balun coil.

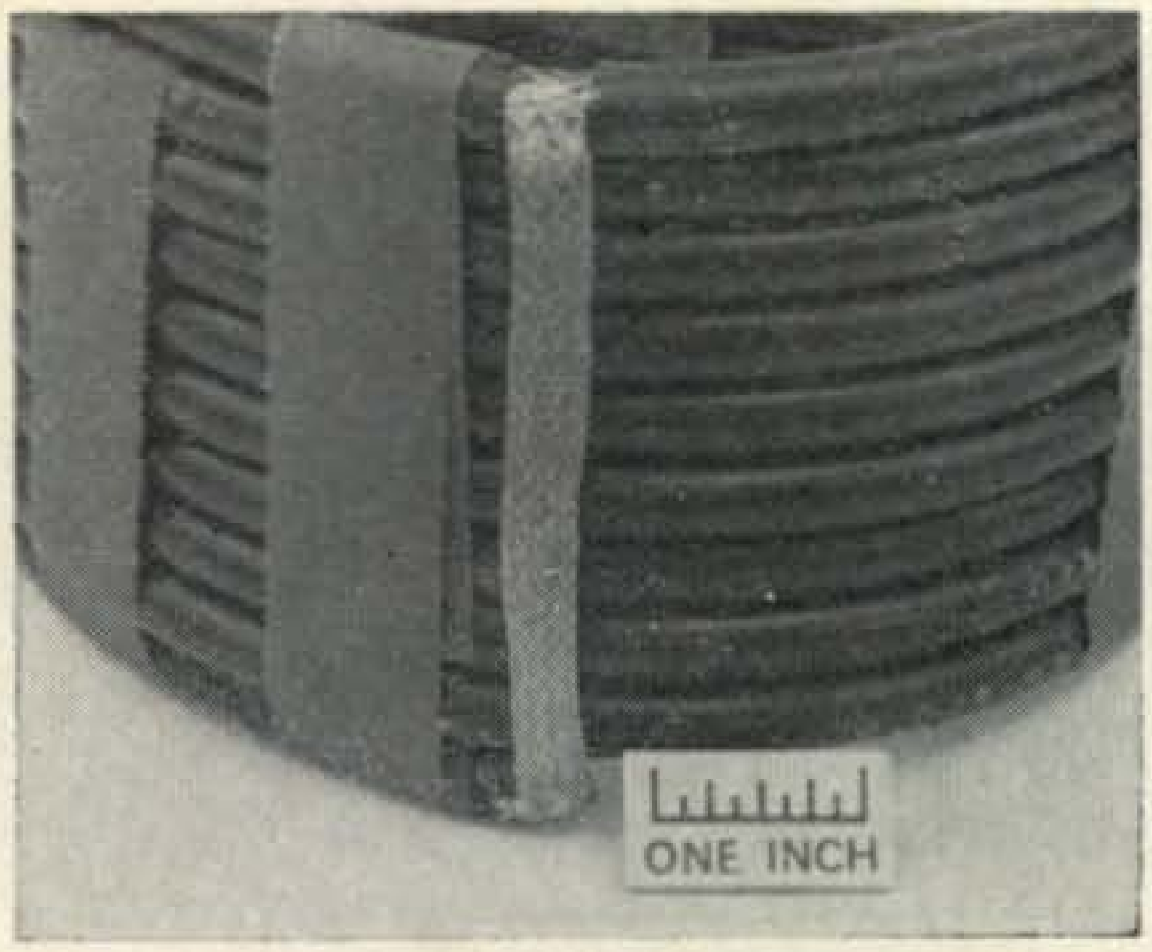

Fig. 6—The outer conductor of the balun coil is jumpered to itself at each end of the coil. This is a common ground point and may be connected to the metal boom of the beam antenna. A short length of copper braid was used in this balun, but a length of copper strap may also be used.

Electrical Characteristics of the Coaxial Balun

A frequency run of a typical coaxial balun is shown in fig. 7, made under laboratory conditions with an *R-X* meter. Using RG-213/U line (a nominal 50 ohms) the balun presented various input impedances when terminated in a 50 ohm non-inductive load. At 7 mc, the input impedance of the balun was about 55.2 ohms. At 14 mc the input impedance had dropped to 53.3 ohms, and was measured as 51.8 ohms at 21 mc. Minimum impedance occurred at about 24 mc and was measured as 51.5 ohms. At 30 mc, the balun input impedance had risen to about 52 ohms. The balun proved to be slightly reactive, having an input capacitance of about 15 mmf above 11 mc. Below 11 mc the capacitance rose gradually and smoothly to 35 mmf at 7 mc.

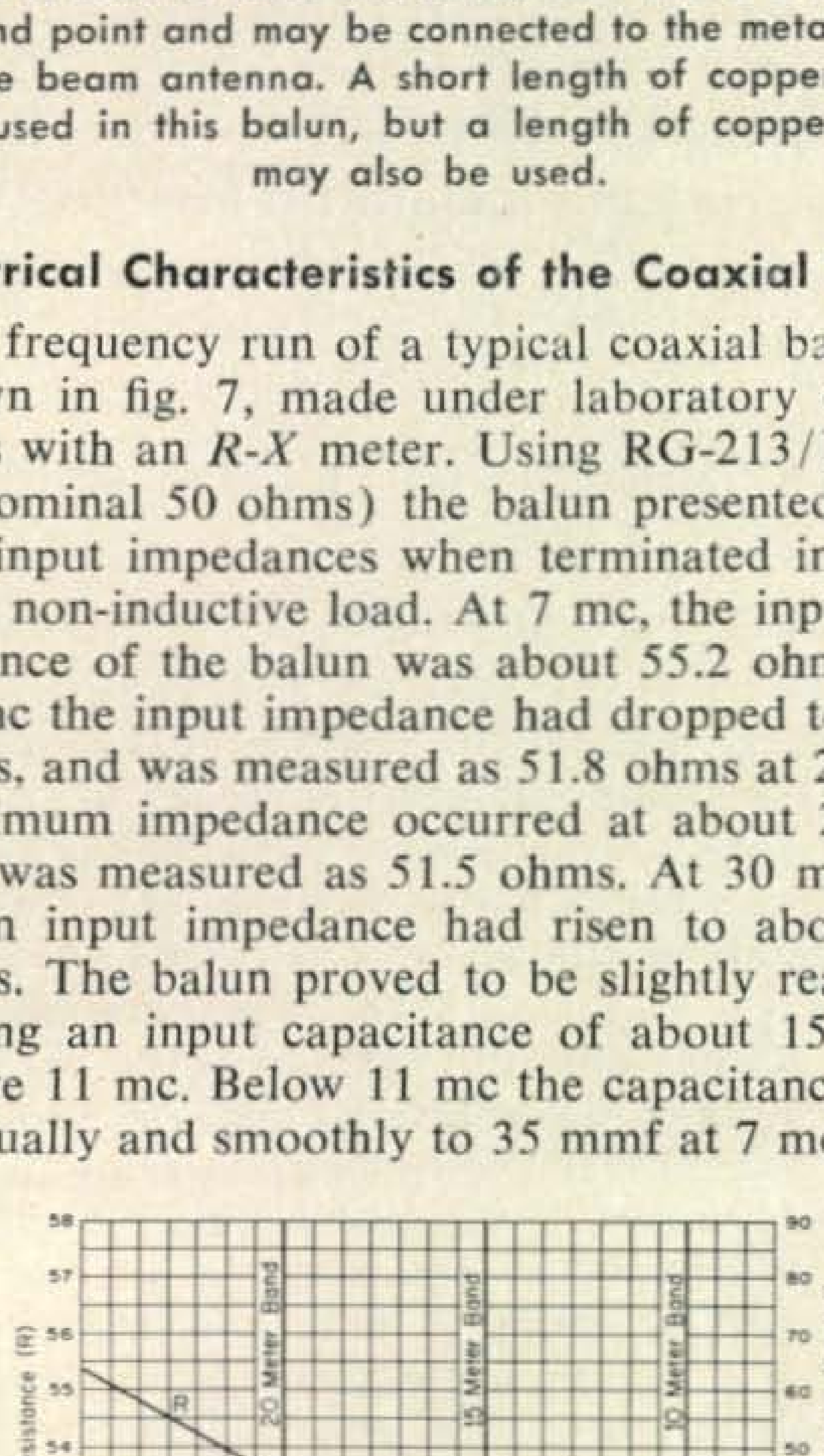

Fig. 7—Frequency run of a typical coaxial balun terminated in a nonreactive load of 50 ohms presents a load to the transmission line that varies between 55.2 ohms at 7 megacycles and 52 ohms at 30 megacycles. The input is very slightly reactive, as seen from the capacitance curve. This performance is several orders of magnitude better than many inexpensive balun devices on the amateur market. Although designed for the 14-30 megacycle range, the balun exhibits excellent characteristics at 7 megacycles. Performance starts to deteriorate above 35 megacycles or so. If the balun is wound of RG-8/U (52 ohm cable), the resistive curve is displaced upwards about 2 ohms, but retains the characteristic shape shown. The actual capacitive reactance at the input terminals of the balun is judged to be somewhat lower than shown by curve (C) as about 5 mmf of residual capacitance was inherent in the measuring device.

The very slight variations in input reactance are "washed out" when the driven element is in place and properly adjusted. Slight adjustments (and by "slight" I mean an inch or so) to the driven element of the beam can reduce the s.w.r. on the transmission line at beam resonance well below the capability of a good s.w.r. meter to detect appreciable flow of reverse current.

It was noticed that when RG-8/U line was used for the coil (a nominal 52 ohms) the resistance measurements of the balun were a consistent one to two ohms higher than when 50 ohm RG-213/U line was used for the coil. As the balun seemed to provide a line termination somewhat higher than the impedance of the line of which it was wound, it was felt that use of the slightly lower impedance line for the coil was justified. The reason for the slight impedance transformation is obscure, but it could be caused by minor imperfections in the coil or by variation in the actual impedance of the particular chunk of coaxial line used for the coil. Practically speaking, either RG-8/U, RG-8A/U or RG-213/U coaxial line may be used with little or no observable effect in operation.

There's no reason why a low power version of this device could not be made out of RG-58/U, or a high power version (heaven forbid!) out of RG-17/U. The only precaution is that the chosen coaxial line should not be coiled less than about ten times the diameter of the line, or else "cold flow" of the plastic dielectric will permit the center conductor to gradually drift with time, eventually causing an internal short in the cable.

Those amateurs who have attempted to run s.w.r curves, or make measurements, on a tribander beam directly fed with a coaxial line

[*Continued on page 107*]

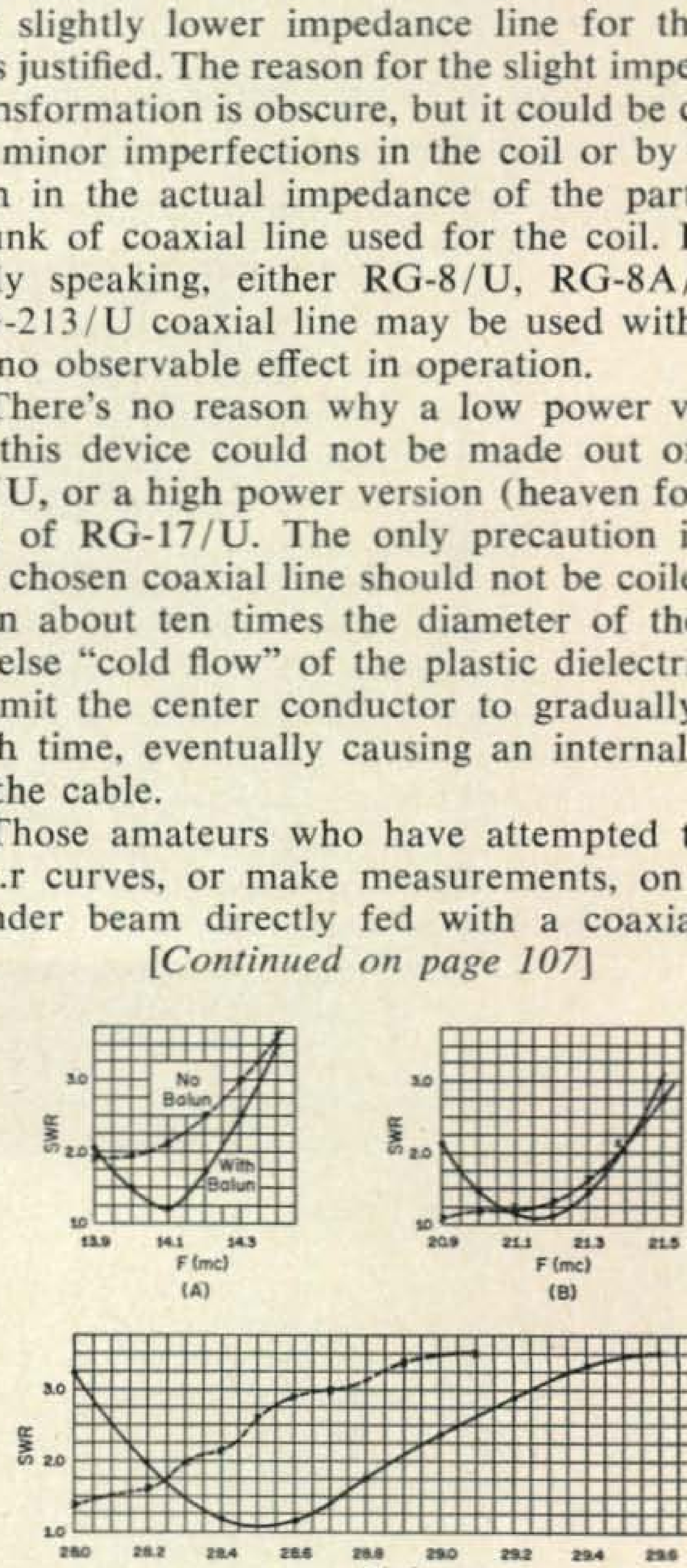

Fig. 8—S.w.r. curves on a "tri-bander" beam antenna with and without the coaxial balun coil. (A) 14 mc: Without the balun (dotted line), the s.w.r. measured worse than 2:1 across the band, with no indication of antenna resonance. The s.w.r. curve could be altered by changing length of line between measuring device and antenna. Balun coil reduced line effect and provided a normal indication of antenna resonance. (B) 21 mc: Resonance curve was emphasized by use of coaxial balun. (C) 28 mc: Without the balun, resonance curve was poorly defined, with s.w.r. running over 3:1 at 29 mc. Use of balun reduced s.w.r. across phone band, with antenna resonance indicated near 28.5 mc.