The Balun—
Theory and Design

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If you like your theory in short, mild doses—try this one. The author presents a very readable account of the "balun" with a discussion of its uses and applications in the ham field —Editor.

In the reduction of TVI, it has been found that the *pi* coupler tank circuit and networks help to attenuate harmonics of the carrier frequency. The *pi* coupler can be built for balanced output using twice the usual number of components which doubles the cost and complicates tuning adjustments. It is much cheaper, equally effective and easier to use the regular unbalanced *pi* network and employ a device such as the "balun" to work into a balanced transmission line or antenna. The term "balun" is a contraction of the words *bal*anced to *un*balanced transformer.

Theory

Let us start our explanation of the "balun" with a typical problem. Referring to *Fig 1a*, we have a 300-ohm balanced[1] load (transmission line and antenna) which we want to connect to a generator (transmitter) whose internal impedance is 75 ohms (a *pi* network so adjusted). Since we said the load was a balanced load we can connect the electrical midpoint or center tap to ground without disturbing the circuit as illustrated in *Fig. 1b*. Now there are two 150-ohm loads in series; one above ground and the other below ground. Stating it another way, each "hot" end of the load is of opposite polarity, or 180 degrees out of phase. Next, if we were to use some gadget to reverse the phase of one of the 150-ohm loads we could place them both in parallel. Everyone knows that two 150-ohm resistors in parallel equals 75 ohms. A 75-ohm load connected to a generator whose internal impedance is 75 ohms will result in a perfect match. This needed gadget is the balun. It consists of a half wave length section of coaxial transmission line—that's all.

In studying transmission lines as impedance matching devices there are two important and accepted facts[2]:

(1) The input impedance of a half-wave length (electrical length) section of good transmission line is equal to the terminal impedance.

(2) For such a half-wave section there is a 180 degree phase shift in the voltage and current without any change in magnitude.

Simplifying, this means that if we place a 150-ohm load at one end of a half-wave section of line and "look in" at the other end we will see 150-ohms load but it will be shifted in phase 180 degrees or completely reversed in polarity. Impedance consists of resistance and reactance. Considering a half-wave section of good line we can measure the resistance between the conductors and find it greater than a megohm. To measure the reactance along the line we could apply a source of signal through a slotted line measuring device to one end of the line leaving the other end open and measure the standing waves. Since no current is flowing across the open end, the standing waves measured is also the measure of reactance. However, to illustrate the change in polarity or phase of the reactance refer to the curve in *Fig. 2c*. If the high impedance of the open end is shunted with a 150-ohm resistor, the impedance along the line may be visualized by referring to the curve in *Fig. 2d*. Folding this half-wave section, doubling back in a "hair pin" fashion does not affect its phase reversing characteristics in any manner.

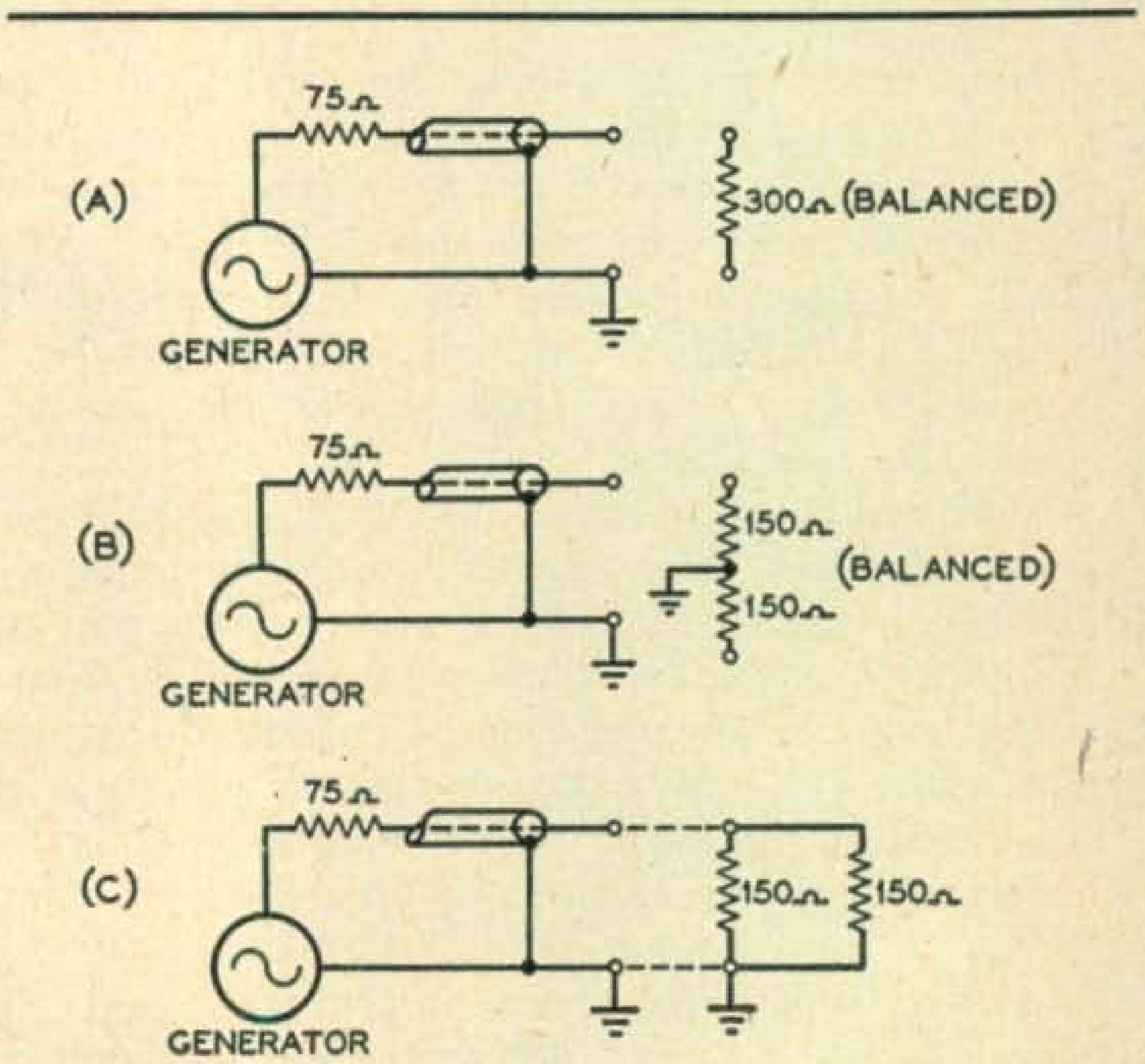

Fig. 1. The basic problem is how to connect a 300-ohm balanced line to a 75-ohm unbalanced line.

[1] ARRL, "Radio Amateur's Handbook", 28th Edition 1951, p. 56

[2] King, Mimno and Wing, "Transmission Lines, Antennas and Wave Guides", McGraw-Hill Book Co., 1945, p. 44

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Going back to *Fig. 1b* apply this balun to one of the 150-ohm loads as shown in *Fig. 3a.* The balun reverses the phase of half of the load or 150 ohms and places it in parallel, in phase, with the other half of the load, resulting in an equivalent load of 75 ohms. Since the ends of the section's outer conductor are connected to ground points, they may also be connected together as presented in *Fig. 3b.*

It should be pointed out that the balun, while being a balanced to unbalanced transformer, is also an impedance transformer with a 4:1 ratio. It can be used at other impedances such as 200:50 ohms or 600:150 ohms. The balun is a linear device and may be used to transmit energy in either direction. It works equally well with the balanced terminals connected to a balanced transmitter output in order to couple to a lower impedance unbalanced antenna, such as a quarter wave vertical whip.

The balun is just as effective as a balancing device at the third and other odd harmonics. This accounts for the use of the balun that the television industry has made in matching TV receivers to some antennas.

Designing a Balun

In designing a balun the length of the coax must be the electrical half-wave length which is less than a half-wave length in free space. It is determined by:

$$\text{half-wave length} = \frac{492 \times V_f}{f} \text{ (in feet)}$$

where f = frequency in megacycles
V_f = Velocity factor of the line used.

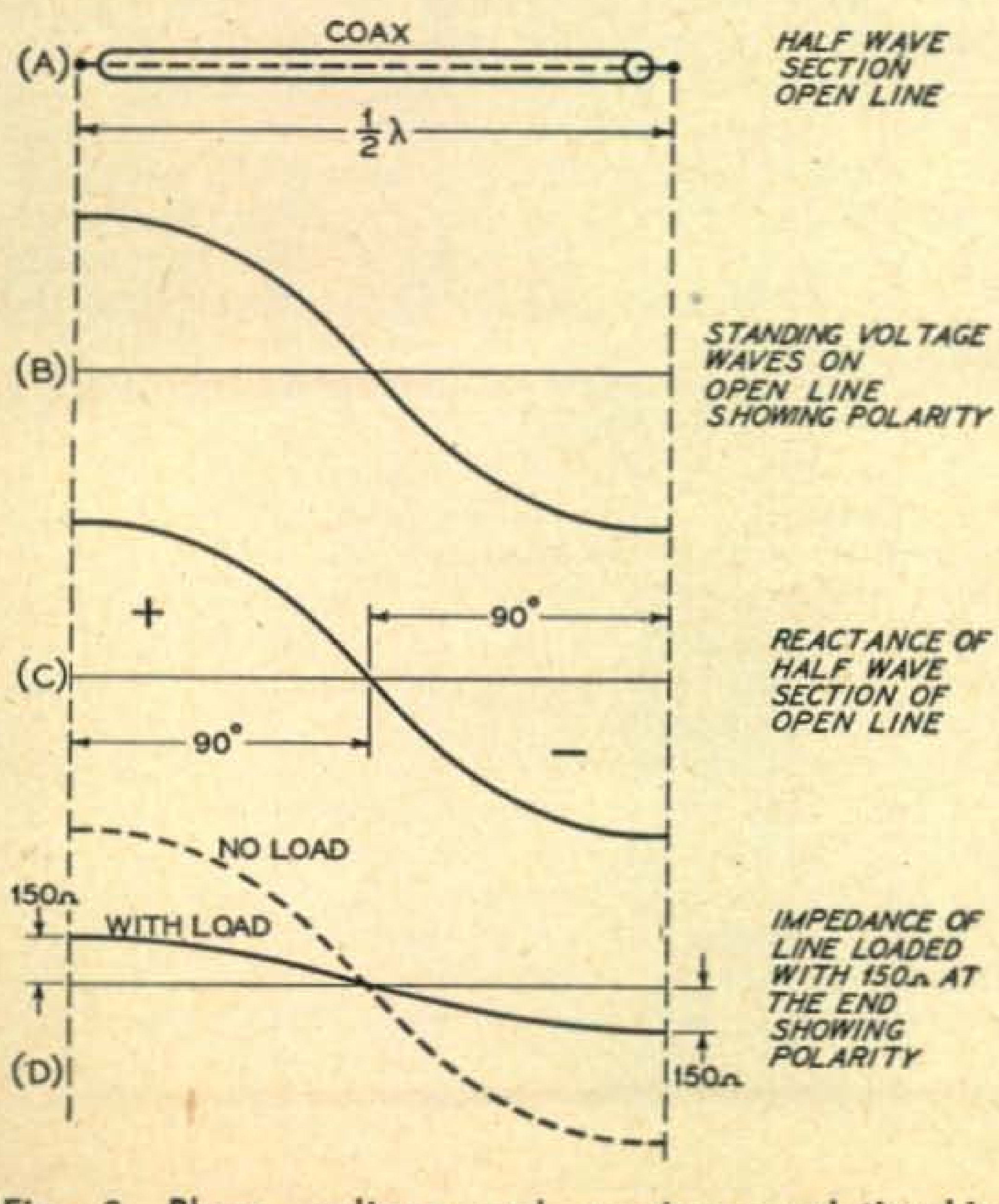

Fig. 2. Phase, voltage and reactance relationships along a half-wave coax line.

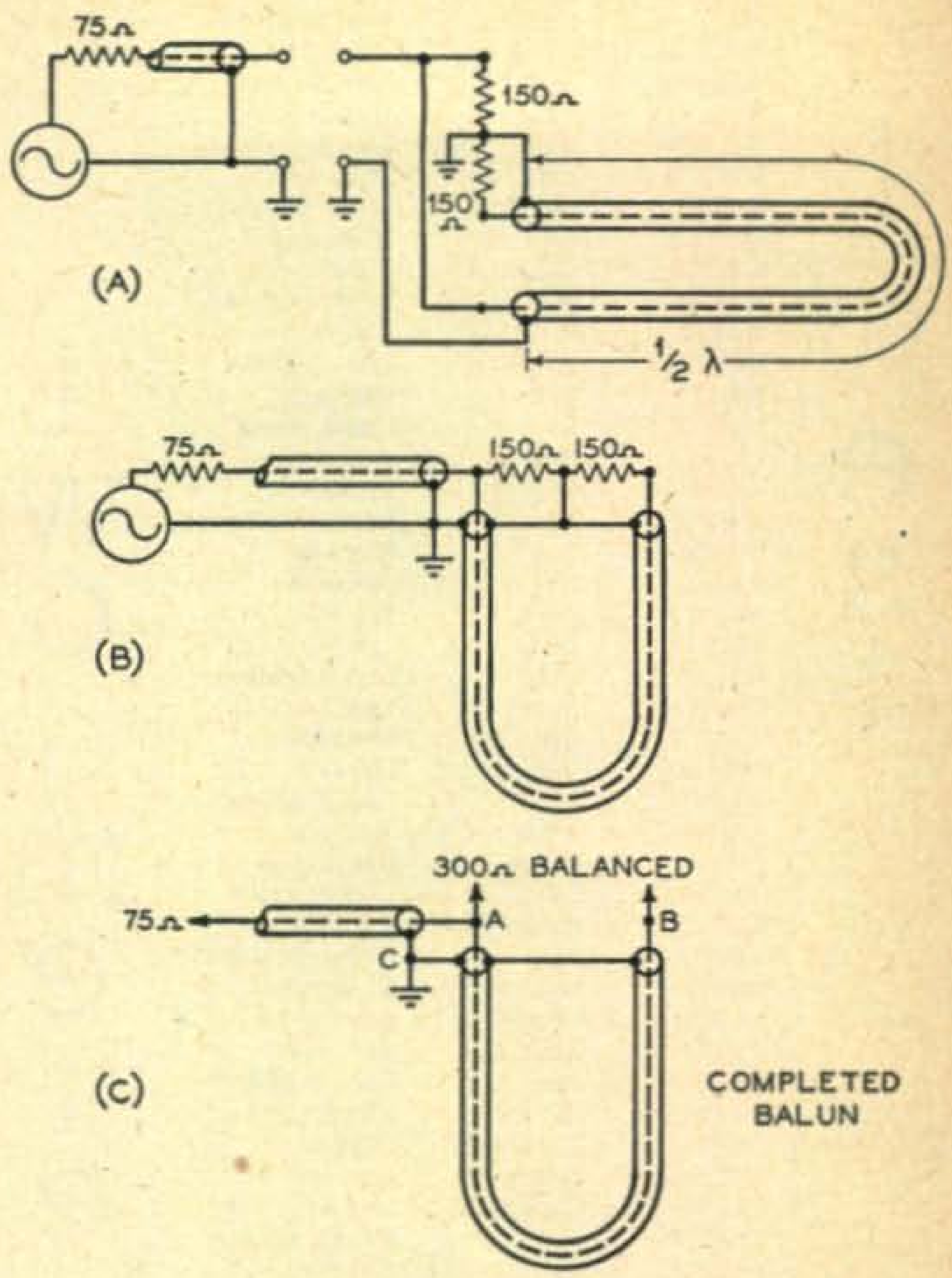

Fig. 3. Physical derivation of the "balun."

The velocity factor for various coaxial transmission lines are given in most handbooks[3]. Choosing 14.2 megacycles as an example, the length of RG 8/U cable is:

$$1/2\ \lambda = \frac{492 \times 0.66}{14.2} = 22.8 \text{ feet}$$

For 29.5 mc the length of coax is:

$$1/2\ \lambda = \frac{492 \times 0.66}{29.5} = 11 \text{ feet}$$

The half-wave length section of line is measured from connection *A* to connection *B* in *Fig. 3c.* The outer conductor should extend reasonably close to these connections *A* and *B.*

Any of the popular coaxial lines may be used in a balun for any 4:1 ratio of impedances. Since many hams work with 300-ohm balanced lines (fixing the input impedance to the balun at 75 ohms), RG 59/U cable is generally preferred for feeding the unbalanced connections. However, RG 59/U cable is not likely to handle more than 680 watts at 30 mc without overheating. The low impedance unbalanced terminals may be connected to any length of coaxial cable whose characteristic impedance (Z_o) is equal to or reasonably close to the desired value, or it may be connected directly to the transmitter. In like manner the balanced

[3]ARRL, "Radio Amateur's Handbook", 28th Edition, 1951, p. 319

(Continued on page 68)

11. Donald H. Mix, W1TS, "The Novice One-Tuber," QST, p. 18, May 1951.
12. Richard M. Smith, W1FTX, "A Single-Control Low-Power Transmitter," QST, p. 11, Jan. 1951.

The above does not include all transmitters described in these magazines, but are representative, and it is suggested that the Novice read as many of them as possible, before deciding on which to build to obtain the "feel" of good design. Also consult **Radio and ARRL Handbooks.**

RADIO TELETYPE

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The R.D., during its rotation, connects contact 16 to the five selector magnets, one after the other. Any mark signal received during this period will switch B+ to contact 16, and energize whichever selector magnet happens to be connected at that instant. The selector magnets are trip affairs and require only a short pulse to trip them. Thus the letter "Y", which consists of mark signals on the first, third, and fifth pulse, will cause the first, third, and fifth selector magnets to trip, thereby moving levers 1, 3, and 5 into the mark position. These levers select the letter "Y", since they are notched like a key and the letter "Y" is the only letter that matches the notches of levers 1, 3, and 5 in the mark position and levers 2, and 4 in the space position.

When the R.D. rotates to the seventh position it connects contact 12 (which is always B+, no matter which way the polar relay is) to the print magnet L6. This magnet allows the motor in the printer to print the selected letter and to set up the selector magnets again ready for tripping on the next letter.

Shall I repeat that all again?

THE BALUN

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connections may be connected to any length of balanced transmission line or directly to an antenna whose input is balanced and reasonably close to the proper impedance. In many instances connecting the balun directly to the antenna enables one to use a single coaxial cable to feed an antenna, keeping standing waves from appearing in the outer conductor, and, in turn, aiding in the reduction of TVI.

It is suggested that the balun be strung out, doubled back upon itself as shown in the sketch and then have as few additional folds as possible. It is not recommended that it be coiled up to be placed in a small box.

Conclusions

In conclusion, the advantages of the balun are as follows:

(1) It matches a balanced transmission system to an unbalanced one.

(2) It is also a 4:1 impedance transforming device.

(3) It works well over a wide band of frequencies.

(4) It can be used to aid in the reduction of TVI by coupling to balanced or unbalanced TVI reducing filters, by enabling the use of an unbalanced *pi* network or tank circuit with a balanced antenna system and by reducing unbalanced currents and standing waves on transmission lines.

(5) It is easily and cheaply built.

It does have two disadvantages, however:

(1) It is not a multiple band device for more than a single amateur band as it requires a separate design for each band.

(2) It gets to be quite long in dimensions for the low frequency bands such as 3.5 megacycles.

No attempt is made here to explain the "BAZOOKA", which is closely akin to the balun. The bazooka is considerably more difficult for most hams to construct.

YL'S FREQUENCY

(from page 34)

At that time they were living in Waikiki. Then they moved to the big island of Hawaii and lived at the Inter-Island telephone station on a ranch 5000 feet above sea level, 13 miles from the nearest town. Johnny did his best to get her to study for her ticket, but Dell insisted it was a "man's" hobby.

"Not too long after that," says Dell, "Johnny took me for a ride and to my surprise stopped at a home I had never seen and told me, 'come, I want you to meet someone.' Even though I was thinking what nerve he had and I would never do anything like that at home, I obeyed. A very attractive woman greeted us and invited us into her ham shack. It was Ella, KH6FD, known all over the world. She was wonderful and operated her rig for a couple of hours for us. When she told me she talked to Maine, my home QTH, I couldn't stand it any longer as I already was getting homesick."

Because of Ella, Dell started studying "so hard I dreamed code and theory." The RI was coming to Hilo the following month. Dell tried the exam, missed the code, but later took Class C and in another six months passed her Class B. She got her Class A two years ago.

Johnny built her a 50-watt rig and a cubical quad antenna, and KH6TI was on the air from Hawaii for ten months, then from the Island of Maui for a year, and for the last year and a half from Waikiki. She now has a 90-watt rig on all bands, phone and c.w., but is still using the quad.

"Ella was right about talking to Maine," says Dell. "I have had 186 contacts with W1BEU in Fairfield, Maine; 150 with W1DPX in Mystic, Conn., and 202 with W4NOV in Apex, N.C. So you see it isn't so far from Hawaii to the East Coast!"

"Anything can happen in ham radio and I love it," adds Dell. She has proof, too. Enclosed with her letter was a photograph of the most unusual QSL "card" she ever received—a turtle shell which was sent to her by KB6AR on Canton Island, and imprinted with their calls! It is 7 feet around and so big they hang it on the outside of the house.

With that Dell says "Aloha from Hawaii."

And we'll say "ge-wa-pa" from New Mexico—33, *W5RZJ.*