Transmission Lines

The quarter-wave section—how its impedance-inverting qualities are used to make it a matching transformer, an insulator, or to balance junctions of unlike lines

By **ROBERT C. PAINE**

BEFORE radio communication went to its present high frequencies we used to think of a transformer as two coils of wire wound together on an air or iron core. But at the higher frequencies used today, a transformer can be just a pair of heavy conductors (a section of transmission line or co-axial cable). This is the *quarter-wave transformer* or *Q-section*, as it is used by hams.

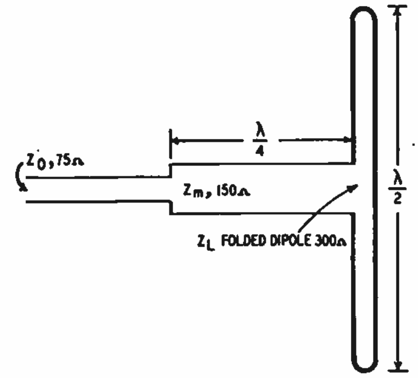

Fig. 1—A quarter-wave matching transformer.

The first two articles in this series (December, 1948, and February, 1949) described several uses of transmission-line sections for impedance matching. The quarter-wave transformer converts the ratio between the impedance connected to one end and its own impedance to the reciprocal of this ratio at the other end of the transformer. Fig. 1 is an example. The characteristic impedance Z_m of the quarter-wave transformer (determined by the diameter and spacing of its wires) is 150 ohms. The impedance of the folded dipole connected to one end of the transformer is 300 ohms. The ratio, therefore, of the antenna to the transformer impedance is 2. Since the reciprocal of 2 is ½, the impedance at the other end of the transformer is one-half Z_m: 150/2, or 75 ohms. A 75-ohm line can be connected to this 75-ohm impedance, the net effect being to match the 75-ohm line to the 300-ohm antenna. This use of the Q-section is common in FM and TV practice when the receiver input is designed to match a 75-ohm line.

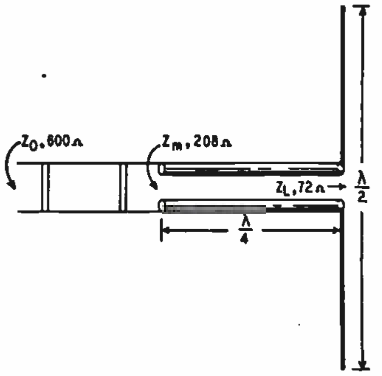

Fig. 2—The Q-section is well known to hams.

The radioman often has to find the correct impedance of a quarter-wave transformer to match two known impedances. If the input or line impedance is called Z_o, that of the quarter-wave matching transformer Z_m, and the load impedance Z_L, the formula is:

$$Z_m = \sqrt{Z_o Z_L}$$

In other words, simply multiply the input and load impedances together and take the square root (the geometric mean of the two values) for the impedance of the matching section.

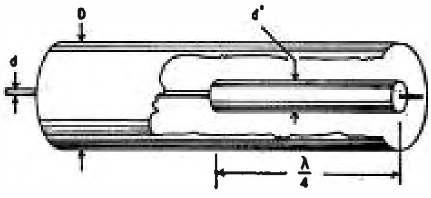

Fig. 3—A co-axial quarter-wave section.

Since the characteristic impedance of a line is usually nearly pure resistance, the quarter-wave transformer can match it only to a load that is also pure resistance. The impedance of any kind of load as seen at the points in the standing wave (see earlier articles in this series) where the voltage is at a minimum (node) or maximum (antinode or loop) is pure resistance. If the load happens to be reactive and not pure resistance, the transformer should be located at one of these points. At a voltage antinode the resistance equals the standing wave ratio times the characteristic impedance, or s.w.r. × Z_o. At a voltage node the resistance equals Z_o/s.w.r.

The Q-section transformer

As an example of the Q-section used by amateurs, take a half-wave dipole of 72 ohms impedance to be coupled to a 600-ohm line of parallel wires supported on insulating spreaders. The required impedance of the Q-section equals $\sqrt{72 \times 600} = 208$ ohms. Two ½-inch-diameter tubes spaced 1½ inches between centers would give this impedance, as calculated by the formula for impedance of parallel conductors given in the December installment of this series. This Q-section is shown in Fig. 2. On co-axial lines at ultra-high frequencies the quarter-wave transformer may be in the form of a sleeve over the center conductor. Fig. 3 shows the end of a co-axial line with such a sleeve transformer. The characteristic impedance of the co-axial line depends on the ratio D/d of the inside diameter of the outer sheath to the outside diameter of the center conductor. Then the impedance of the line can be decreased for the last quarter-wavelength by making the inner conductor larger (d') to form a quarter-wave transformer. This sleeve forms a section of lower impedance than the rest of the line.

The quarter-wave transformer is a quarter-wavelength only at a given frequency and functions properly only in a relatively narrow band near this frequency. To pass a wider band the transformer may consist of a series of two or more sections in graduated impedance steps. The more steps used, the wider the band transmitted. The author has shown elsewhere[1] how to compute these steps logarithmically. Fig. 4 shows a two-step multiple transformer for connecting a 50-ohm line to a 70-ohm load. This two-section transformer practically eliminates standing waves in the range 70 to 110 mc. (s.w.r. = 1.03). If a single-section transformer were substituted the s.w.r. would be 1.13 in this range.

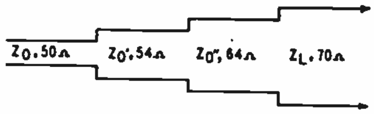

Fig. 4—Sample wide-band matching section.

Insulators and bazookas

If the quarter-wave section is short-circuited at one end it shows an infinite impedance at the other end (for an ideal, no-loss line). Actually the input impedance can be made very high, as explained in the second of this series of articles, making it possible to use such a section as a metallic support or "insulator" for an ultra-high-frequency line or antenna[2].

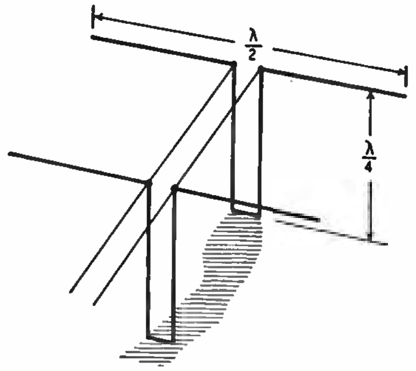

Fig. 5—Showing how to use copper insulators.

Fig. 5 shows two elements of a directional array of dipoles, with connecting transmission line, supported by such metallic insulators. Some radar systems use large arrays of these elements. The same principle is applied to co-axial lines at ultra-high frequencies to support the center conductor, as shown in Fig. 6. The supporting pillar is a quarter-wavelength long, and is soldered or otherwise solidly connected to the outside conductor. If a sleeve is used over the center conductor also, as shown, a broader band of frequencies can be transmitted.

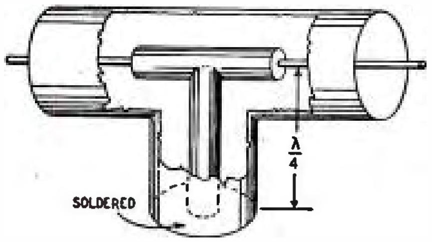

Fig. 6—The quarter-wave insulator in co-ax.

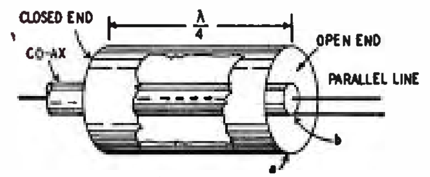

Fig. 7—Bazooka between co-ax and open line.

A section of line a halfwave long shows the same impedance at both ends. Thus if it is shorted at one end, it shows zero impedance at the other end; or if it is open at one end, it shows infinite impedance at the other (for a no-loss line). The quarter-wave metallic insulator at twice the frequency for which it is intended is a half-wave section and shorts the line. This frequency is the second harmonic of the generated frequency, so the quarter-wave section can also serve to suppress the second harmonic while freely passing the fundamental.

The co-axial type of line is essentially unbalanced to ground. If it is directly connected to the balanced parallel type of line or to a balanced load, unbalanced currents flow along its outer surface, resulting in undesired radiation or pick-up of interference. To avoid this condition, special transformers known as *bazookas* are used.

One type of bazooka is shown in Fig. 7. A sleeve a quarter-wave long is placed over the end of the cable. One end is closed and the other open. The cable passes through the closed end, and the outer sheath is soldered or otherwise secured to the bazooka sleeve. The sheath of the co-axial cable then forms the inner conductor of a co-axial line of which the sleeve is the outer conductor. Since the sleeve is a quarter-wave long and it is shorted to the line sheath at one end, the impedance between points a and b is high. The sleeve is effectively the grounded element; since the end of the actual line sheath is separated from it by high impedance, it is effectively isolated from ground and may be connected to one side of a balanced parallel-wire line.

A different form of bazooka is used to feed a dipole from a co-axial line. This is shown in Fig. 8. Here the bazooka is reversed and the outer surface of the sleeve itself radiates and becomes the lower half of a dipole of which d (connected to the center conductor) is the upper half. The inverted quarter-wave insulator separates this radiating surface from the outer surface of the co-axial sheath and keeps an unbalanced current from appearing upon it.

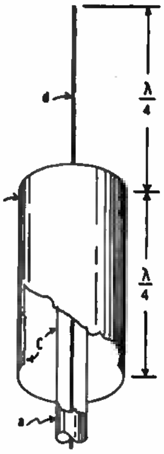

Fig. 8—The bazooka-principle antenna.

It should be pointed out that in all of the above figures dimensions have been purposely distorted to show more clearly the principles described.

References:

[1] Robert C. Paine, **Broad Band Quarter-wave Transformers** *Radio News* (Radio-Electronic Engineering Ed.) pg. 14, July, 1947.

[2] Robert C. Paine, **Metallic Insulators for Broad-Band Transmission**, *Radio News* (Radio-Electronic Engineering Ed.) pg. 9 April, 1947.

30-KV NEGATIVE VOLTMETER

The inverted-tetrode voltmeter, so called because the functions of the grid and plate are reversed, is designed to measure high negative voltages developed by low-current sources. This circuit, described in *The Review of Scientific Instruments*, measures up to 30,000 volts with an input impedance of 10,000,000 megohms. Its operation is based on the fact that current flowing in a positive grid circuit can be controlled by the plate voltage. In this circuit, a large change in plate voltage produces a small change in grid current when the grid voltage is held constant. The voltage to be measured is applied between the plate and ground—with the negative side connected to the plate. The meter in the grid circuit measures changes in grid current and may be calibrated in kilovolts.

The screen grid is grounded to shield the control grid from the plate and thereby lower the transconductance of the tube. R2, R3, R4, and R5 provide a bucking voltage to cancel the grid current that flows through the meter with zero plate voltage. R2 zeros the meter.

Degeneration provided by the cathode resistor RC improves the linearity of the grid-current plate-voltage relationship and further reduces the transconductance. RC is adjusted for full-scale deflection at 30 kv.

The 4-125A is a transmitting-type tetrode with a 125-watt plate dissipation rating. It handles positive plate voltages up to 3,000 volts. HK257's, 813's, 8001's, and similar tubes can be used in adaptations of this circuit. It will be necessary to experiment with the value of the cathode resistor to get the lowest usable grid-current plate-voltage relationship. The bucking voltage must be adjusted to limit the current through the meter.

This v.t.v.m. is useful in measuring the output of voltage multipliers, radio-frequency and kick-back power supplies, and other low-current high-voltage sources of the types commonly used in cathode-ray and velocity-modulated circuits.