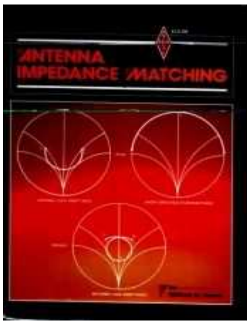

ARRL

Antenna Impedance Matching
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extraits : pages 2-27 à 2-35

The Transmission Line as an Impedance Transformer.

As its name implies, the line transformer is a short section of transmission line inserted between the antenna and the feed line. The impedance at the input to the line transformer is dependent upon a number of factors: (1) line length, (2) characteristic impedance of the line Z'_o, and (3) the impedance connected at the load end Z_a. For any set of values for these factors the input impedance is found by the general equation

$$Z_{A-A'} = Z'_o \frac{Z_a + Z'_o \tan \beta\ell}{Z'_o + Z_a \tan \beta\ell} \qquad (2\text{-}1)$$

where

$Z_{A-A'}$ = impedance at the input to the line transformer
Z_a = impedance of the antenna
Z'_o = characteristic impedance of the line transformer
$\beta\ell$ = electrical length of the line

For any length an even number of quarter-wavelengths long this becomes

$$Z_{A-A'} = Z_a \qquad (2\text{-}10)$$

For any line an odd number of quarter-wavelengths long this becomes

$$Z_{A-A'} = \frac{(Z'_o)^2}{Z_a} \quad \text{or} \quad Z'_o = \sqrt{Z_a\, Z_{A-A'}} \qquad (2\text{-}11)$$

It can be seen from Eqs. (2-10) and (2-11) that any line an even number of quarter-wavelengths long, no matter what impedance Z_a is terminating the line, the same impedance will be measured at the input terminals A-A'. On the other hand, if the line is an odd number of quarter-wavelengths long the impedance at A-A' will always vary inversely with Z_a.

For the condition where the line is properly terminated ($Z'_o = Z_a$) the input impedance $Z_{A-A'}$ will be equal to the characteristic impedance of the line Z'_o, no matter what line length is being used. This can be seen by substituting $Z_a = Z'_o$ in either of Eqs. (2-10) and (2-11).

These very important principles are used in transmission lines operated as impedance transformers. For example, consider the problem of coupling a 600-ohm line to a 50-ohm coaxial line. A quarter-wavelength line will be used as an impedance matching section as shown in Figure 2-23. It is desired to terminate the 50-ohm line with its characteristic impedance of 50 ohms in order to prevent standing waves on the line and to obtain maximum power transfer. Obviously the coaxial line cannot be connected directly to the 600-ohm 2-wire line. Therefore a device is needed which, with 50 ohms at one end, will present an impedance of 600 ohms at the other end. A quarter-wavelength line section will do this very nicely. All that is necessary is that the line section have a characteristic impedance equal to

$$Z'_o = \sqrt{Z_a Z_{A-A'}} = \sqrt{600 \times 50} = 173 \text{ ohms}$$

The action of the quarter-wavelength transformer is illustrated in Figure 2-24.

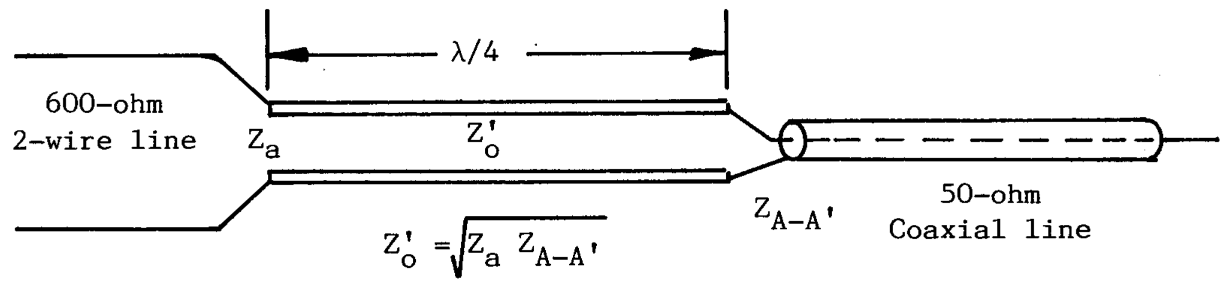

Figure 2-23. Matching with a line transformer.

Transmission Line Sections as Balancing Devices.

Frequently it is desired to couple energy from an unbalanced system to a balanced system, or vice versa. If a balanced system is fed directly with a coaxial line as shown in Figure 2-23, it would not be a strictly balanced system and the coaxial line would not operate normally. Currents would be present on the outer surface of the outer conductor of the coaxial line, causing it to radiate. In the interest of system performance, this condition must be avoided. A device commonly employed to maintain balance when going from a balanced system to an unbalanced one is called a "balun," an abbreviation for "balanced to unbalanced." One balun which performs the desired conversion without affecting the impedance characteristics of the system is shown in Figure 2-25. Because of its physical appearance, it is sometimes referred to as a "bazooka." When the length, $L = \lambda/4$, the outer sleeve acts with the outer conductor of the enclosed section of line to

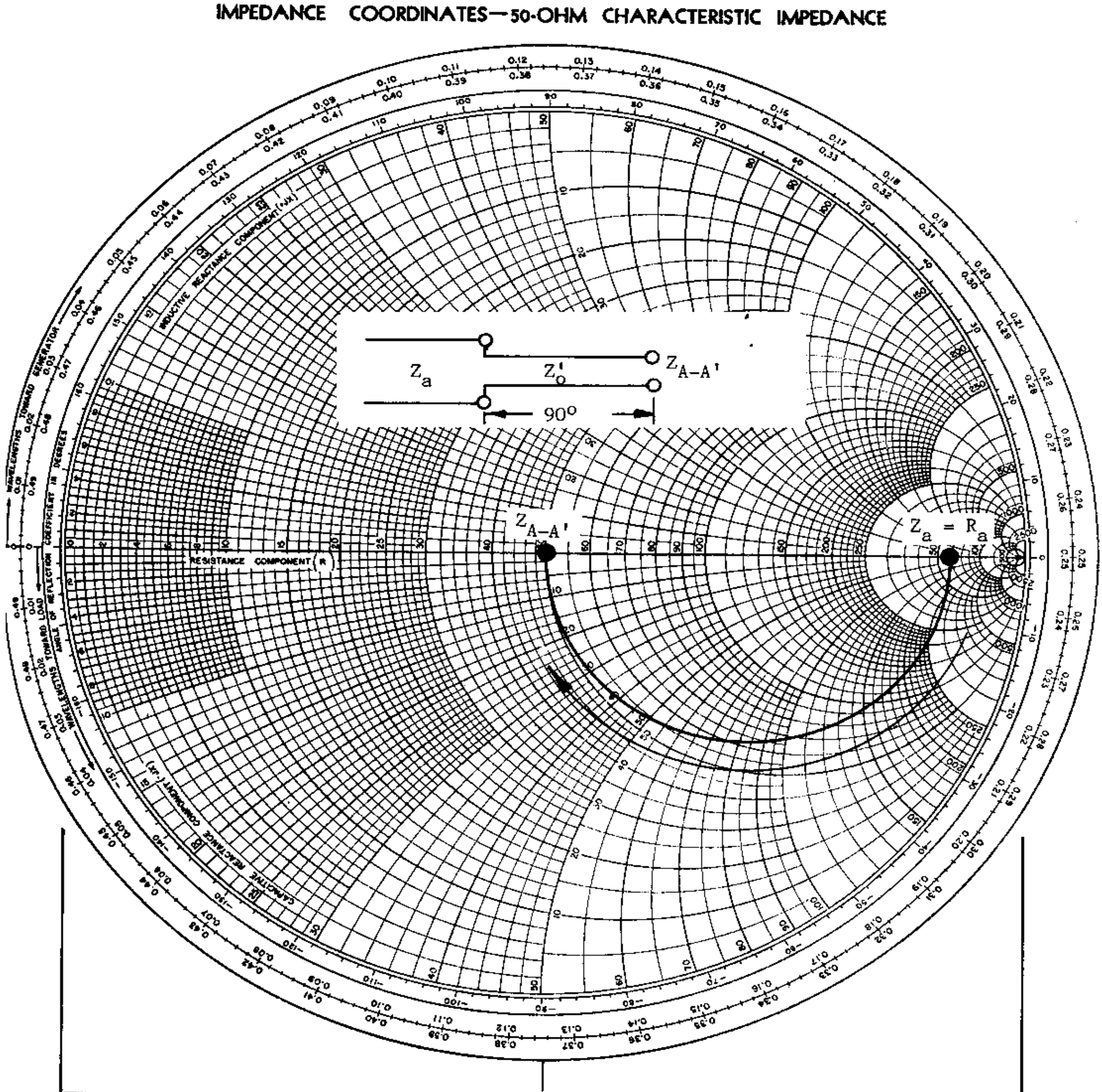

Figure 2-24. A 600-ohm load is matched to 50 ohms by the action of a quarter-wavelength line transformer.

form a quarter-wavelength coaxial section, causing a high impedance to exist between points 1 and 2. The result is little or no shunt path to ground from 2 to 1, no division of current at junction 2 and, consequently, equal currents in each conductor of the twin line 2 and 3. Since the currents in the twin line are equal and 180 degrees out of phase, the voltages to ground are also equal and 180 degrees out of phase, which then results in a balanced operation.

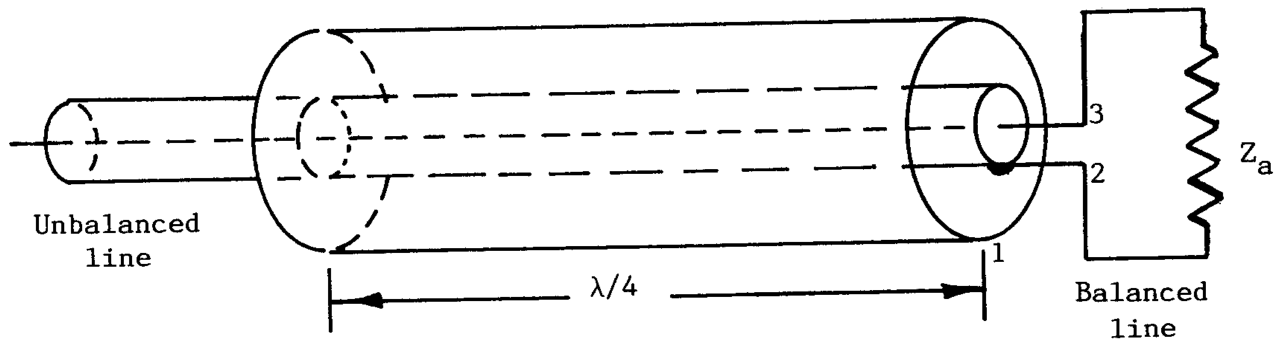

Figure 2-25. Bazooka type balun with a 1:1 impedance transfer.

The impedance between points 1 and 2 remains high only when the length L is near one-quarter wavelength long. Consequently, this type of balun provides good performance over a relatively narrow band of frequencies of about 10 percent. Where wide band operation is required, the "double bazooka" type balun, shown in Figure 2-26, may be used.

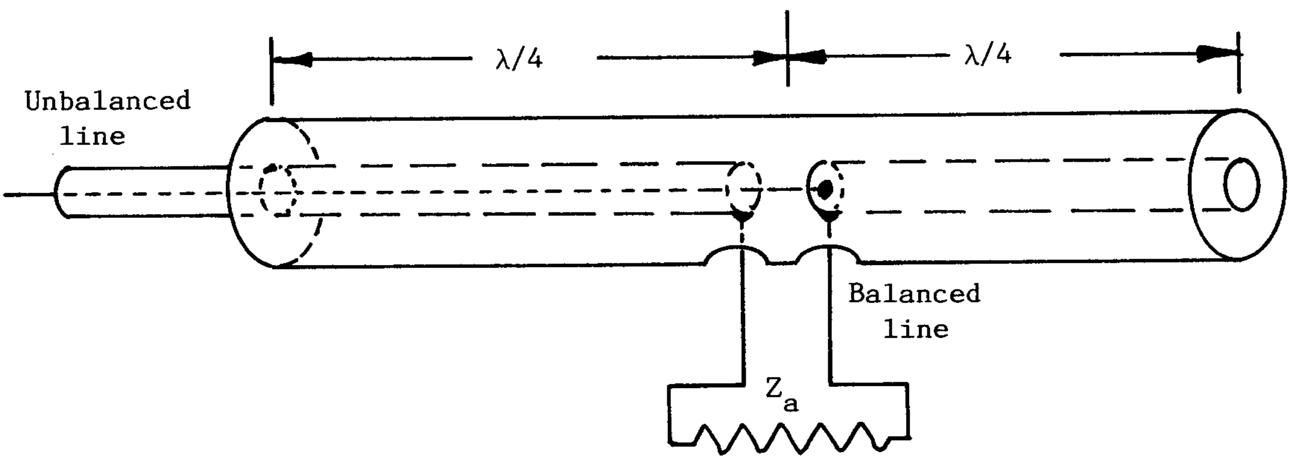

Figure 2-26. Double bazooka type balun with 1:1 impedance transfer.

A balun, the performance of which is superior to those just described, is shown in Figure 2-27. This type of balun functions similarly by preventing undesirable currents from flowing along the outside of the coaxial line. Here, however, this is accomplished by a cancelling effect rather than choking off the current as with the one-quarter wavelength sleeve section.

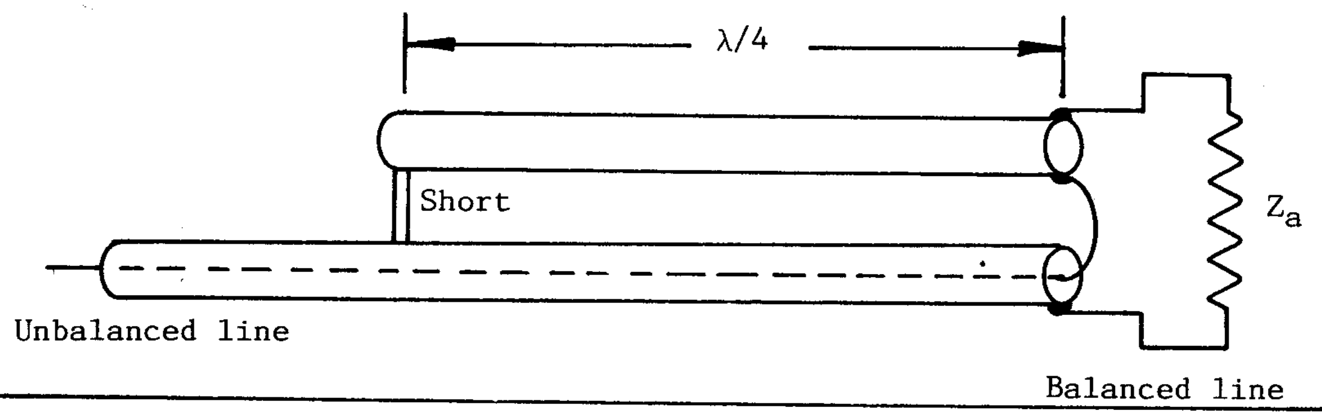

Figure 2-27. Parallel-conductor type balun with 1:1 impedance transfer.

It is frequently desirable to operate the balun at other than a quarter-wavelength in order to take advantage of the shunt reactance it presents to the load for impedance matching purposes. From the discussion on the transmission line section as a parallel-resonant circuit, it becomes apparent that the impedance characteristics of the shorted line section can be utilized here. Since the impedance of a center-fed half-wave dipole antenna resembles those of a series resonant circuit, the combined effect of the balun and the dipole result in a wider frequency range of operation where the reactance is negligible.

A balun which provides a fixed impedance transformation of 4:1 is shown in Figure 2-28. Advantage is taken of the fact that a half-wavelength section of line repeats its load but with a 180-degree phase reversal in voltage. Thus the voltages to ground from each side of the load impedance Z_a will be equal and 180 degrees out of phase, resulting in a balanced operation.

The half-wavelength balun can be used with the line transformer arrangement of Figure 2-23. Since $Z_{A-A'}$ is now 200 ohms instead of 50 ohms, the impedance Z_o' of the line transformer must be

$$Z_o' = \sqrt{Z_a \; Z_{A-A'}} = \sqrt{200 \times 600} = 346 \text{ ohms}$$

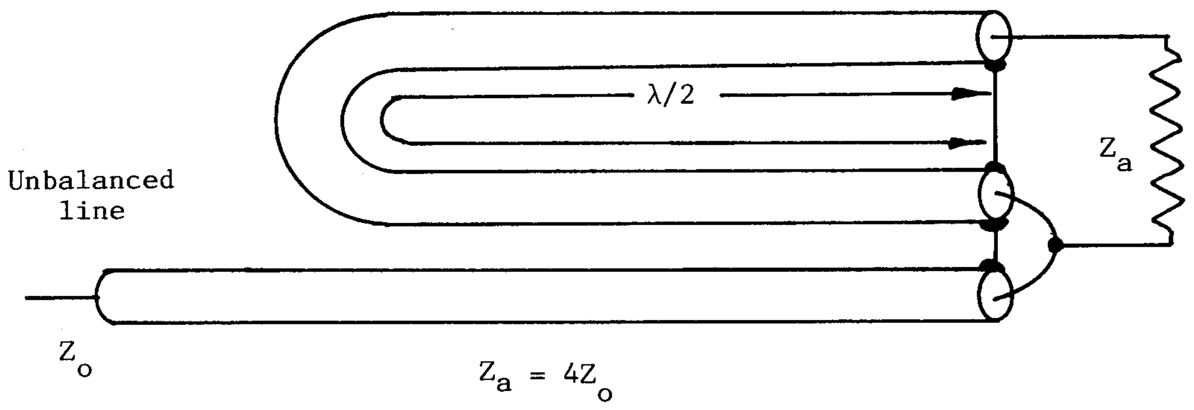

Figure 2-28. Half-wave balun with 4:1 impedance transfer.

It is not the purpose of this discussion to describe all possible balancing devices which may be employed in antenna systems. Those described here, however, are the more basic types and are representative of those commonly employed.

Lines With Attenuation.

If we were able to sample the energy propagating along a lossless line we would find that the SWR radius is constant. For instance, if we measured a SWR magnitude of 2.8 at the antenna terminals we would still have a magnitude of 2.8 at the generator terminals regardless of the line length. However, in real life, all lines have attenuation. This attenuation causes the incident wave to be attenuated as it travels toward the antenna and again as it returns.as a reflected wave after reflection. It is evident that the SWR resulting from these two components varies in amplitude along the line. If the line is very long and the attenuation constant high, the reflected wave will be very small and the line will appear to be terminated in its characteristic impedance. This attenuation will be manifested as a spiraling inward towards the center of the Smith chart of the impedance point.

For this particular example, the length of line is 0.200 wavelength long with an attenuation of 1.4 dB. The load impedance is R = 1.65 and jX = 2.2. This value is plotted as Z_a in Figure 2-29. From the scale of attenuation at the bottom of the Smith chart, it is found that Z_a lies on a circle of constant attenuation corresponding to a value of about 1.8 dB. Travelling clockwise along this constant attenuation circle 0.200 wavelength we arrive at a second impedance point Z_b which corresponds to R = 0.28 and jX = -0.67.

Since the line attenuation is 1.4 dB, we now know that the input impedance Z_c when found will correspond to a point on another attenuation circle of constant attenuation of 1.4 dB higher than 1.8 dB at a distance 0.200 wavelength from the antenna. This 1.4 + 1.8 = 3.2 dB level is represented by another constant attenuation circle on the Smith chart of Figure 2-29. Point Z_c specifies the input impedance for this particular example. Its coordinates are R = 0.52 and jX = -0.57. Unfortunately the "in 1 dB steps" scale is not numbered. (See Figure 2-29). Assigning the number "0" to the first mark just under the scale designation, the subsequent marks can be numbered out to 15 dB.

It should be emphasized that point Z_b corresponds to an impedance point that would have prevailed had the line been without attenuation and with attenuation point Z_c as moved along the dashed spiral from Z_a to Z_c. If the lossy line were infinitely long the dashed line in Figure 2-29 would spiral to the center of the Smith chart and point Z_c would be R = 1.0 and jX = 0.

The use of attenuators or resistive pads to reduce the high SWR encountered with small low frequency receiving antennas is a common and accepted practice. Figure 2-30 illustrates the effect of attenuation on SWR.

If the length L of the transmission line and its attenuation A are known, then its effect upon the load SWR can be determined from

$$SWR_L = \frac{1}{\tanh\left[\tanh^{-1}(1/SWR_M) - AL\right]} \qquad 2\text{-}12$$

where

SWR_L = SWR at the load end

SWR_M = measured SWR at input end

AL = Attenuation loss

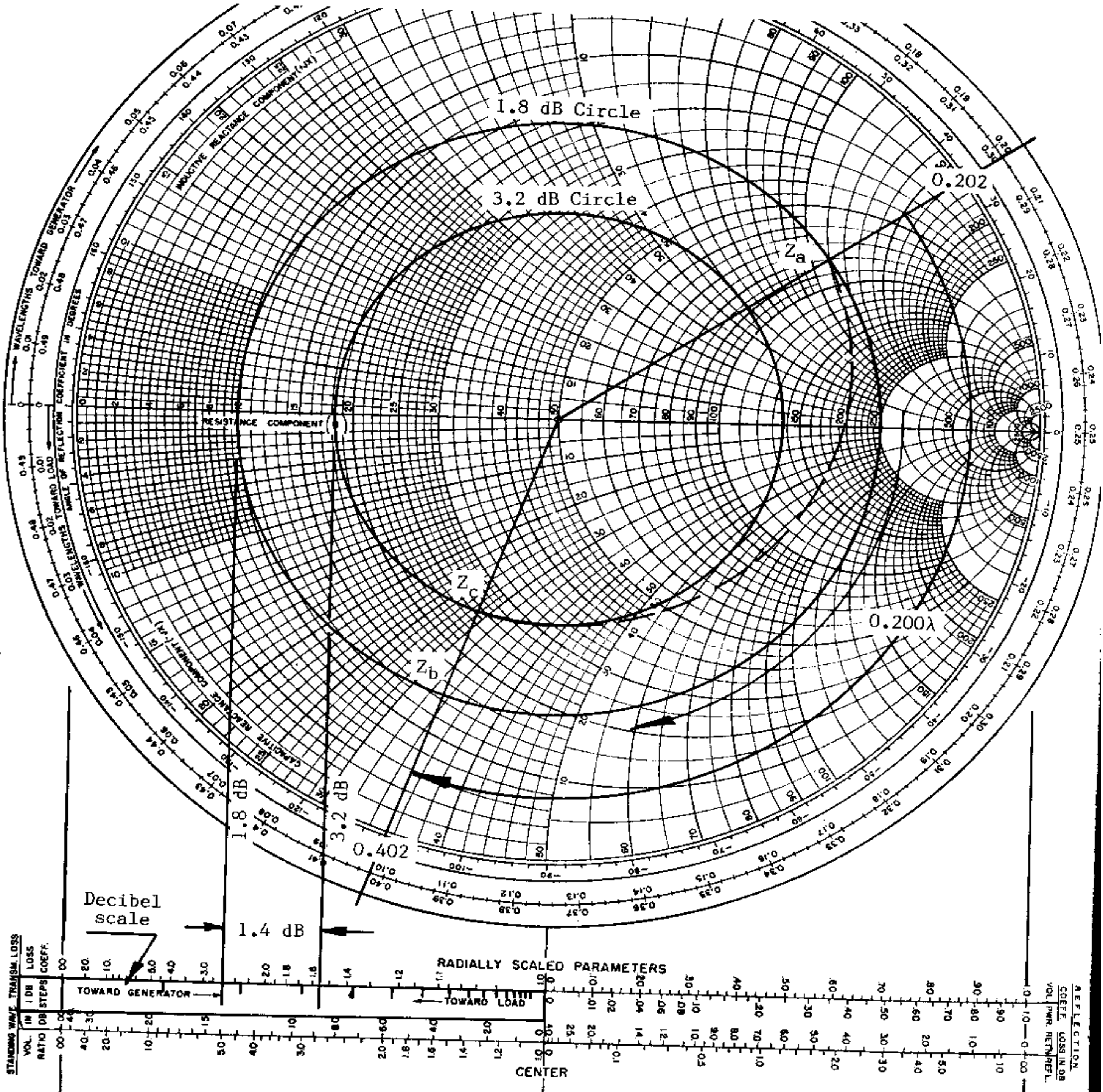

Figure 2-29. Effect of line attenuation on input impedance.

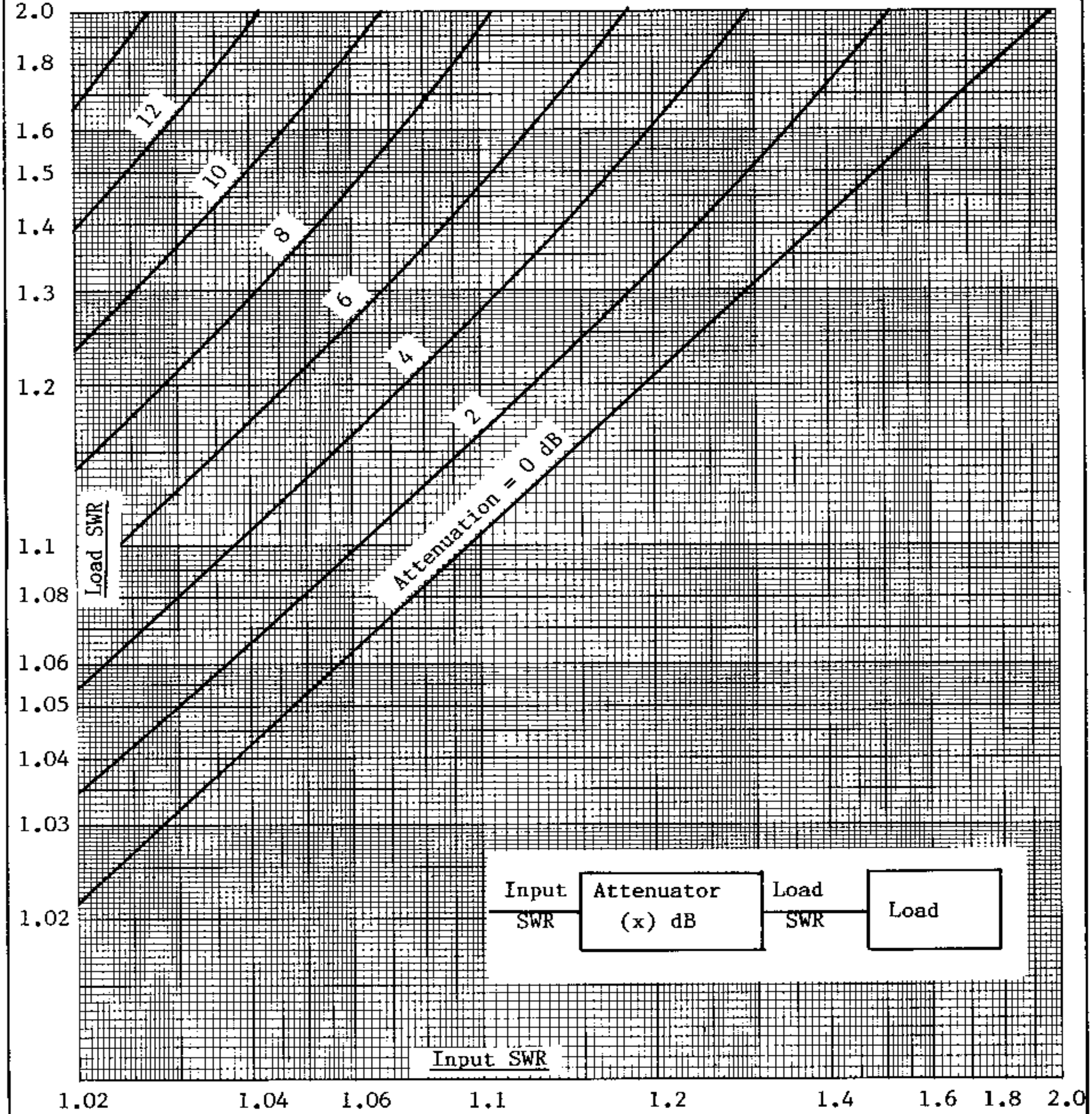

Figure 2-30. Effect of attenuation on standing wave ratio.