Transmission Line Loss Calculation and Measurement (Concluded)

It has been stated in previous articles on the subject that the measured loss at radio frequencies is 50 % larger than computed values. This agrees quite well with tests made in our laboratories. The computed values increased by 50 % have been plotted in Fig. 1 for the three cases mentioned. Actual tests on the ¼ inch tube line showed the velocity of propagation to be 5 % less than that of free space.

If the two wire line is terminated in an impedance not equal to the characteristic impedance the loss is increased due to the presence of standing waves. The loss under these conditions can also be calculated from the well known transmission line equations in terms of hyperbolic functions.

$$I_S = I_R \cosh \gamma l + E_R/Z_o \sinh \gamma l$$

$$E_S = E_R \cosh \gamma l + I_R Z_o \sinh \gamma l$$

Where subscripts S and R denote sending and receiving currents and voltages respectively. Taking Z_o as a pure resistance R_o and terminating the line in a complex impedance $Z_R = E_R/I_R$

$$\text{Where } Z_R/Z_o = \frac{R_R}{R_o} + j\,\frac{X_R}{R_o} = \mathrm{a} + j\,b.$$

From these equations the input power to the line may be calculated as

$$P_i = \mathrm{a} R_o I_R^2 \left[\cosh 2al + \frac{\mathrm{a}^2 + b^2 + 1}{2\mathrm{a}} \sinh 2al\right]$$

The output power into Z_R is

$$P_o = I_R^2 R_R = \mathrm{a} I_R^2 R_o$$

The line loss in decibels is then given as $L = 10\ log_{10} P_i/P_o = 10\ log_{10}$

$$\left[\cosh 2al + \frac{\mathrm{a}^2 + b^2 + 1}{2\mathrm{a}} \sinh 2al\right]$$

If the termination is a pure resistance, then $b = o$. Also if this termination is a resistance equal to Z_o a $= 1$ and the loss is $8.68al$ in decibels. Thus if the loss is known when the line is terminated in Z_o the above relations may be used to determine the loss when the line is terminated in a value other than Z_o. In Fig. 2 there have been plotted the values of the loss in decibels for various degrees of mismatch versus the loss in decibels for the same length of line when terminated in Z_o.

In Fig. 3 there has been plotted for convenience the efficiency versus loss in decibels as calculated from the relations

$$\text{Loss } (db) = 10\ log_{10} \frac{P_i}{P_o}$$

$$\text{Eff } (\%) = 100\, \frac{P_o}{P_i}$$

This is useful in obtaining the efficiency of any length of line with any degree of mismatch. The loss of the given length of line when terminated in Z_o can be determined from Figs. 1, 4, 5 and 6 by direct ratio. For the degree of mismatch for which you desire the efficiency the loss can be found from Fig. 2 and from this loss the efficiency is read from Fig. 3. Thus, for example, 250 feet of ¼ inch copper tubing spaced 1½ inches and terminated in 60 ohms resistance has an efficiency of 90 % at 14 megacycles.

Figs. 4, 5 and 6 show the results of experimental measurement of losses on three types of lines. Fig. 4 is the ¼ inch copper tubing line computed previously. Fig. 5 is a small size coaxial transmission line made up of No. 12 wire inside of ⅜ inch copper tubing and centered by Isolantite beads spaced 1¼ inches. Fig. 6 is a type of twisted pair often used for radio frequency transmission. It consists of two No. 12 wires with a spacing approximately 5/32 inch. Each wire is rubber covered, and the two wires are twisted together and covered with an impregnated braid. The loss for this type of line increases more rapidly with frequency than the theoretical treatment would indicate. This is due to the addition of the dielectric loss of the insulation to the copper loss and skin effect.

The characteristic impedance of a coaxial transmission line is 138 $log_{10}\ r_1/r_2$ ohms.

Where r_1 is the inner radius of the outer conductor

and r_2 is the outer radius of the inner conductor.

For the coaxial line measured $r_1 = .15$ inches and $r_2 = .0404$ inches, giving a theoretical value 78.7 ohms for the characteristic impedance. The measured value is slightly less. This can be explained by the fact that the inner conductor of No. 12 wire is slightly oversized, and the capacity is increased partly by the dielectric constant of the Isolantite beads. The velocity of propagation is 15 % lower than for free space.

In the twisted pair transmission line the velocity is reduced by 35 to 40 % from the value for free space due to the increased dielectric constant.

—L. M. Craft

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The 45A Transmitter (see October Signal) has rapidly won an important place for itself. The photograph shows a group of 45A's under construction. An effort is being made to speed up production to meet the unexpected number of sales.

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