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E. I. GREEN

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COAXIAL CONDUCTOR SYSTEM

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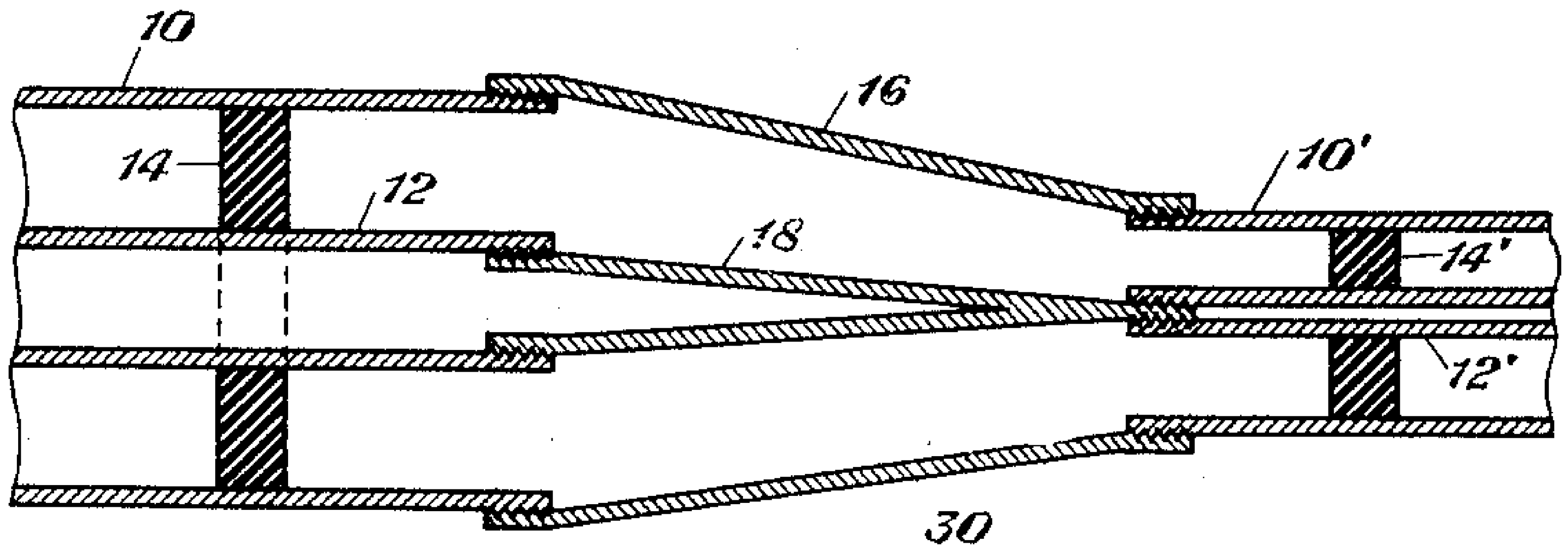


Fig. 1

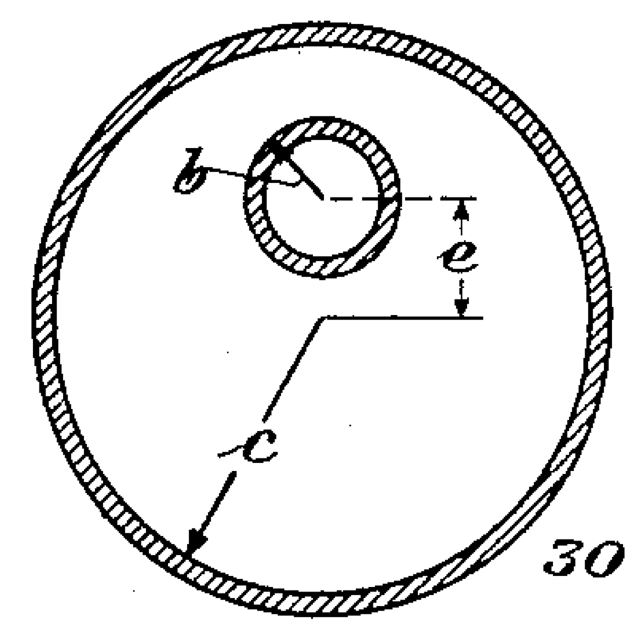


Fig. 2

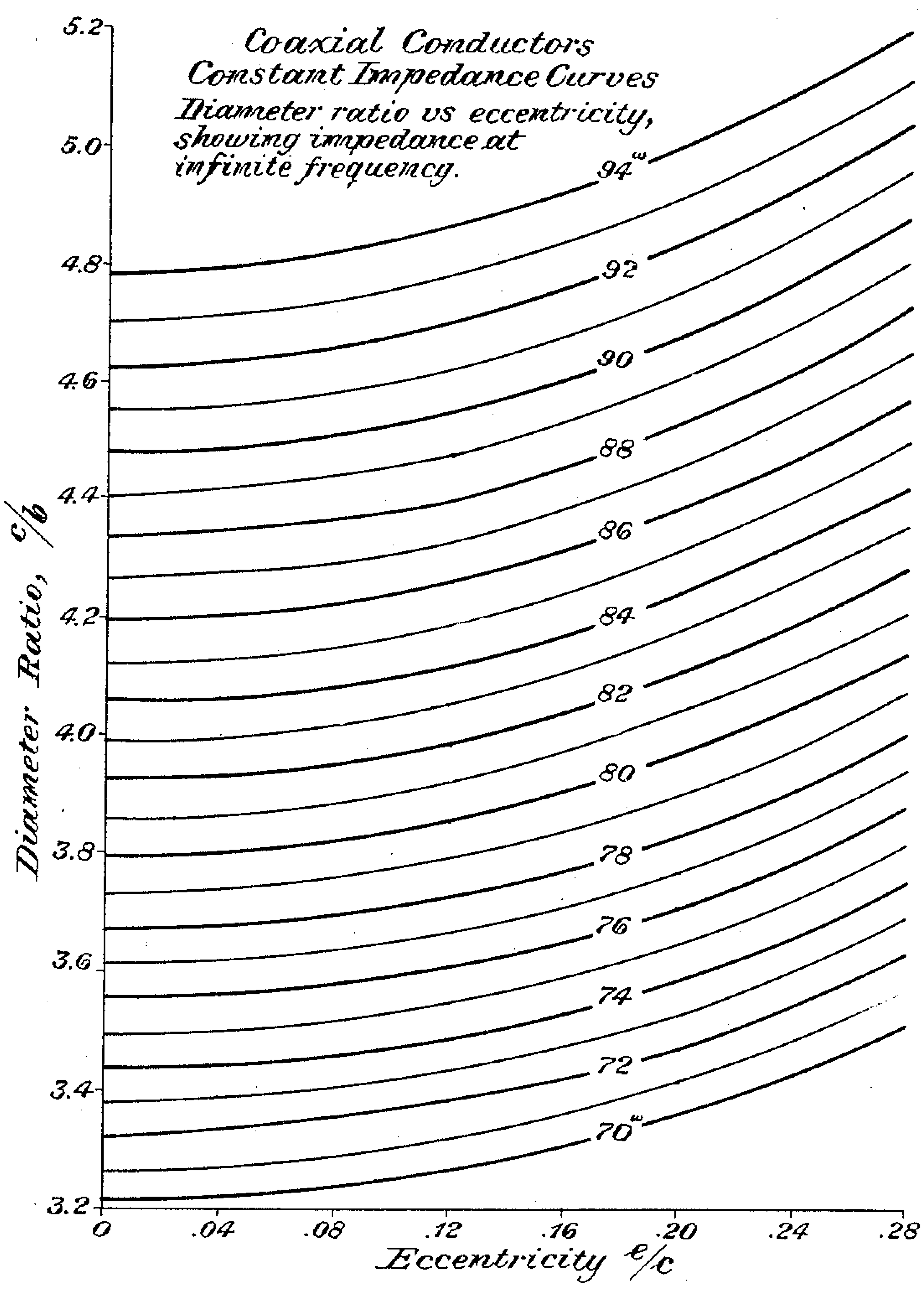


Fig. 3

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## COAXIAL CONDUCTOR SYSTEM

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Application April 9, 1931. Serial No. 528,929

7 Claims. (Cl. 178—44)

This invention relates to coaxial conductor systems, and more particularly to arrangements for connecting or terminating coaxial conductor systems of different sizes and of different eccentricities without introducing impedance irregularities.

In the patent of E. I. Green, No. 1,841,493, granted January 19, 1932, the relation of the characteristic impedance of the coaxial conductor system to the ratio of the diameters of the conductors is developed. In said application it is shown how this relationship may be taken advantage of to join two concentric conductor systems of different sizes without impedance irregularity. The invention of said application, however, involved the assumption that the concentric conductor was truly concentric, that is, there was no eccentricity of the conductors.

The present invention involves the further fact that the impedance of a concentric conductor system is also a function of the eccentricity of the conductors, the eccentricity being defined as the ratio of the distance between the centers of the two conductors to the inner radius of the outer conductor. Thus, it will be seen that we have two variables upon which the characteristic impedance depends: (1) the ratio between the inner diameter of the outer conductor and the outer diameter of the inner conductor and (2) the eccentricity. By varying either or both of these factors a concentric conductor system may be given any desired characteristic impedance. If two concentric conductor systems of different types are to be connected together without impedance irregularity, either variable of either or both circuits may be changed so that the characteristic impedances of both circuits will be the same.

As a practical matter it will generally be found that the eccentricity of the circuit is to be fixed by certain structural considerations, and adjustments to obtain any desired impedance can be most practically made by variation of the diameter ratio. For example, if two circuits of different sizes are to be joined together, it will generally be found that the eccentricity of the smaller circuit will be more pronounced than for the larger circuit. So, also, where a section of concentric conductor is curved, a certain amount of eccentricity may be introduced. This eccentricity in any section may be taken care of by varying the diameter ratio of the two conductors of either the more eccentric section or the less eccentric section to which it is to be joined.

The invention will now be more fully understood from the following description, when read in connection with the accompanying drawing in which Figure 1 shows how two sections of concentric conductor of different sizes and eccentricities may be joined, Fig. 2 being a sectional diagram illustrating particularly what is meant by eccentricity, and Fig. 3 being a series of curves showing the relationship of the impedance to the two variable factors of eccentricity and diameter ratio.

Referring to Fig. 1, 10 designates the outer cylindrical conductor of a large concentric conductor section and 12 designates the inner concentric conductor of the section. The two conductors are spaced by dielectric rings or spacers such as shown at 14 and which may be strung along the conductors at suitable intervals to give the necessary mechanical strength. Similarly, 10′ and 12′ designate the outer and inner conductors of another section of concentric conductor separated by spacers such as 14′. This last mentioned concentric conductor section is of smaller size than the sections shown at the left of Fig. 1 and the eccentricity is greater, that is, the inner conductor is off center with respect to the axis of the outer conductor by a greater amount than in the case of the conductor section shown at the left. The two sections of concentric conductor may be joined in any suitable manner as, for example, by means of tapered or conical unions 16 and 18 screwed to the ends of the conductors, as shown. The inner conductors 12 and 12′ may, if desired, be solid wires instead of hollow tubes as shown.

The characteristic impedance of a coaxial circuit varies with the ratio between the diameters of the two conductors and also with the eccentricity of the circuit, the eccentricity being customarily defined as the ratio of the distance between the centers of the two conductors to the inner radius of the outer conductor. Thus, referring to Fig. 2 of the attached drawing, the eccentricity is given by the ratio

$$\frac{e}{c}.$$

Let us consider the nature of the dependence of the coaxial circuit impedance upon each of these variables. The impedance of a coaxial circuit at high frequencies is given by the expression:

$$Z_o=\sqrt{\frac{L}{C}} \qquad (1)$$

where L=the inductance per unit length, and
C=the capacity per unit length.

For perfect centering, the capacity C is:

$$C=\frac{.08941}{\log_e \frac{c}{b}} \text{ mf. per mile} \quad (2)$$

while the inductance for no eccentricity is given by:

$$L=.3219 \log_e \frac{c}{b} \text{ milli-henries per mile} \quad (3)$$

where $c$ is the inner radius of the outer conductor, and $b$ is the outer radius of the inner conductor. These formulas may be obtained from pages 72 and 109 of "Calculation of Alternating Current Problems" by L. Cohen.

Substituting these values for L and C in (1), we find the familiar expression for the approximate impedance at high frequencies with no eccentricity as follows:

$$Z_o=60 \log_e \frac{c}{b} \text{ ohms} \quad (4)$$

Let us now consider the effect of eccentricity upon impedance. Referring to "Alternating Currents" by A. Russell, vol. I, page 166, we find that:

$$C=\frac{.08941}{\cosh^{-1}\left(\frac{c^2+b^2-e^2}{2bc}\right)} \text{ mf. per mile} \quad (5)$$

This formula may be rewritten as follows:

$$C=\frac{.08941}{\cosh^{-1}\left[\frac{1}{2}\frac{c}{b}+\frac{1}{2}\frac{b}{c}-\frac{1}{2}\left(\frac{e}{c}\right)^2\frac{c}{b}\right]} \text{ mf. per mile} \quad (6)$$

showing that it involves only the two variables of eccentricity

$$\left(\frac{e}{c}\right)$$

and diameter ratio

$$\left(\frac{c}{b}\right)$$

and does not depend upon the absolute dimensions of the circuit.

Russell does not give a formula for determining the relation between the inductance and eccentricity. This relation may, however, be determined as follows: At high frequencies, the velocity of propagation may be assumed practically constant. Since the velocity depends upon L and C, it is clear from (2) and (3) that this constant is:

$$V=\frac{1}{\sqrt{LC}}=186{,}400 \text{ mi. per sec. (approx.)} \quad (7)$$

If C is now given the value indicated by (6), we find from the constant velocity assumption that the value of L is:

$$L=.3219 \cosh^{-1}\left[\frac{1}{2}\frac{c}{b}+\frac{1}{2}\frac{b}{c}-\frac{1}{2}\left(\frac{e}{c}\right)^2\frac{c}{b}\right] \quad (8)$$

while the value of the high frequency impedance is:

$$Z_o=60 \cosh^{-1}\left[\frac{1}{2}\frac{c}{b}+\frac{1}{2}\frac{b}{c}-\frac{1}{2}\left(\frac{e}{c}\right)^2\frac{c}{b}\right] \quad (9)$$

Thus the value of $Z_o$ is given in terms of the two variables of diameter ratio and eccentricity. Fig. 3 of the attached drawing indicates a range of variations in the high frequency impedance due to these two variables, a number of curves of equal high frequency impedance being plotted against the coordinates of diameter ratio and eccentricity.

This dependence of the high frequency impedance upon the eccentricity and diameter ratios suggests that in any section of line where the eccentricity must for any reason differ from the eccentricity in the adjoining section, an impedance irregularity may be avoided by choosing the proper diameter ratios for the two sections. Thus, referring to Fig. 3 of the drawing, a circuit with a diameter ratio of 3.90 and an eccentricity of 16 per cent is seen to have the same impedance (80 ohms) as a circuit with a diameter ratio of about 3.80 and an eccentricity of 4 per cent. The proposal is, therefore, that the coaxial line be designed upon the basis of a constant high frequency impedance, the condition for this being that the right hand member of Equation (9) shall equal the desired constant impedance.

Where it is desired to connect the two sections of concentric conductor as shown in Fig. 1, the diameter ratio or the eccentricity of one of the conductor sections or both may be varied to give the conductor sections any desired characteristic impedance and both characteristic impedances may, of course, be made the same so that the two sections may be joined without impedance irregularity.

Differences in eccentricity at different parts of the line may result from the constructional requirements. Changes in the dimensions of the circuit would very likely be one of the principal causes of changes in eccentricity. While the clearances and tolerances necessary for the conductors and insulators may be smaller for a small coaxial circuit than for a large one, nevertheless the ratio of these clearances and tolerances to the circuit dimensions will be greater in the case of the smaller circuit. Hence a small coaxial circuit must in general have much greater eccentricity than a large one, and the proposal is to offset this by adjusting the diameter ratio as discussed above. Other causes of differences in eccentricity for different line sections might be the use of curved construction in some sections, flexible construction in others, etc.

Since in a practical case the situation will be usually one in which one of the conductor sections has a certain amount of eccentricity which is fixed by structural conditions and the other section has little or no eccentricity, the desired impedance values will usually be obtained by adjustment of the diameter ratio of one of the conductor sections, usually the one whose conductors are eccentric. In general, eccentricity of the conductors is undesirable and the necessary equality of impedance would not ordinarily be obtained in practice by varying the eccentricity.

In the aforementioned patent of E. I. Green, No. 1,841,473 a method is given for obtaining the same high frequency impedance in two coaxial conductor sections both of which have perfect concentricity, the dielectric constant of the insulating medium differing, however, for the two sections. The high frequency characteristic impedance of either section for this case is

$$Z_o=60\frac{1}{\sqrt{K}}\log_e \frac{c}{b} \quad (10)$$

where K is the weighted average dielectric constant of the insulating material. If now we have two sections of coaxial circuit for which the dielectric constant differs and which have different amounts of eccentricity, the high frequency characteristic impedance of either section will be

$$Z_o = 60\frac{1}{\sqrt{K}}\cosh^{-1}\left[\frac{1}{2}\frac{c}{b}+\frac{1}{2}\frac{b}{c}-\frac{1}{2}\left(\frac{e}{c}\right)^2\frac{c}{b}\right] \quad (11)$$

Suppose that it is desired under these conditions to secure the same impedance in the two sections. Usually the choice of insulating material and the amount of eccentricity will be dictated by physical considerations, so that the desired result may be most easily obtained by properly adjusting the diameter ratios in the two sections in accordance with Equation 11.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a transmission system, two conductor sections each comprising cylindrical conductors arranged one within the other, and the characteristic impedance of each section being a function of two physical characteristics of the section, (a) the eccentricity of the conductors and (b) the ratio of their diameters, one said physical characteristic of one of the sections being so related to the other physical characteristic of said section that both sections will have substantially equal characteristic impedances, and means for interconnecting said sections.

2. In a transmission system, two conductor sections each comprising cylindrical conductors arranged one within the other, and the characteristic impedance of each section being a function of two physical characteristics of the section, (a) the eccentricity of the conductors and (b) the ratio of their diameters, the diameter ratio of one of the sections being so related to the eccentricity of the section that both sections will have substantially equal characteristic impedances, and means for interconnecting the sections.

3. In a transmission system, two adjacent line sections each comprising two separate conductors arranged one inside the other, the conductors in the two sections having different amounts of eccentricity and the diameter ratios of the two sections being such that the characteristic impedance at high frequencies is substantially the same for each section.

4. In a transmission system, two adjacent line sections each comprising two separate conductors arranged one inside the other, the conductors in the two line sections having different amounts of eccentricity, the dielectric constant of the insulating material being different for the two sections and the diameter ratios of the two sections being such that the characteristic impedance at high frequencies is substantially the same for each section.

5. In a transmission system, two conductor sections each comprising two cylindrical conductors arranged one inside the other, the values of the dielectric constant of the insulating medium, the ratio of the inner radius of the outer conductor to the outer radius of the inner conductor, and the ratio of the interaxial separation of the inner and outer conductors to the inner radius of the outer conductor in each of said sections being such that both sections will have substantially equal characteristic impedances at high frequencies.

6. In a transmission system, two conductor sections each comprising two cylindrical conductors arranged one inside the other, the values of the dielectric constant of the insulating medium, the inner radius of the outer conductor, the outer radius of the inner conductor, and the interaxial separation of the inner and outer conductors in each of said sections being such that both sections will have substantially equal characteristic impedances.

7. In a transmission system, two conductor sections each comprising two cylindrical conductors arranged one inside the other, the values of the dielectric constants of the insulating media, the inner radii of the outer conductors, the outer radii of the inner conductors, and the interaxial separations of the inner and outer conductors in said sections being related in accordance with the formula

$$\frac{1}{\sqrt{K_1}}\cosh^{-1}\left[\frac{1}{2}\frac{c_1}{b_1}+\frac{1}{2}\frac{b_1}{c_1}-\frac{1}{2}\left(\frac{e_1}{c_1}\right)^2\frac{c_1}{b_1}\right]=\frac{1}{\sqrt{K_2}}\cosh^{-1}\left[\frac{1}{2}\frac{c_2}{b_2}+\frac{1}{2}\frac{b_2}{c_2}-\frac{1}{2}\left(\frac{e_2}{c_2}\right)^2\frac{c_2}{b_2}\right]$$

where $K_1$, $b_1$, $c_1$, and $e_1$ are, respectively, the dielectric constant of the insulating medium, the outer radius of the inner conductor, the inner radius of the outer conductor, and the interaxial separation of the inner and outer conductors in one of said sections, and $K_2$, $b_2$, $c_2$, and $e_2$ are the corresponding quantities in the other of said sections.

ESTILL I. GREEN.