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TRIPLE CONCENTRIC CONDUCTOR SYSTEM

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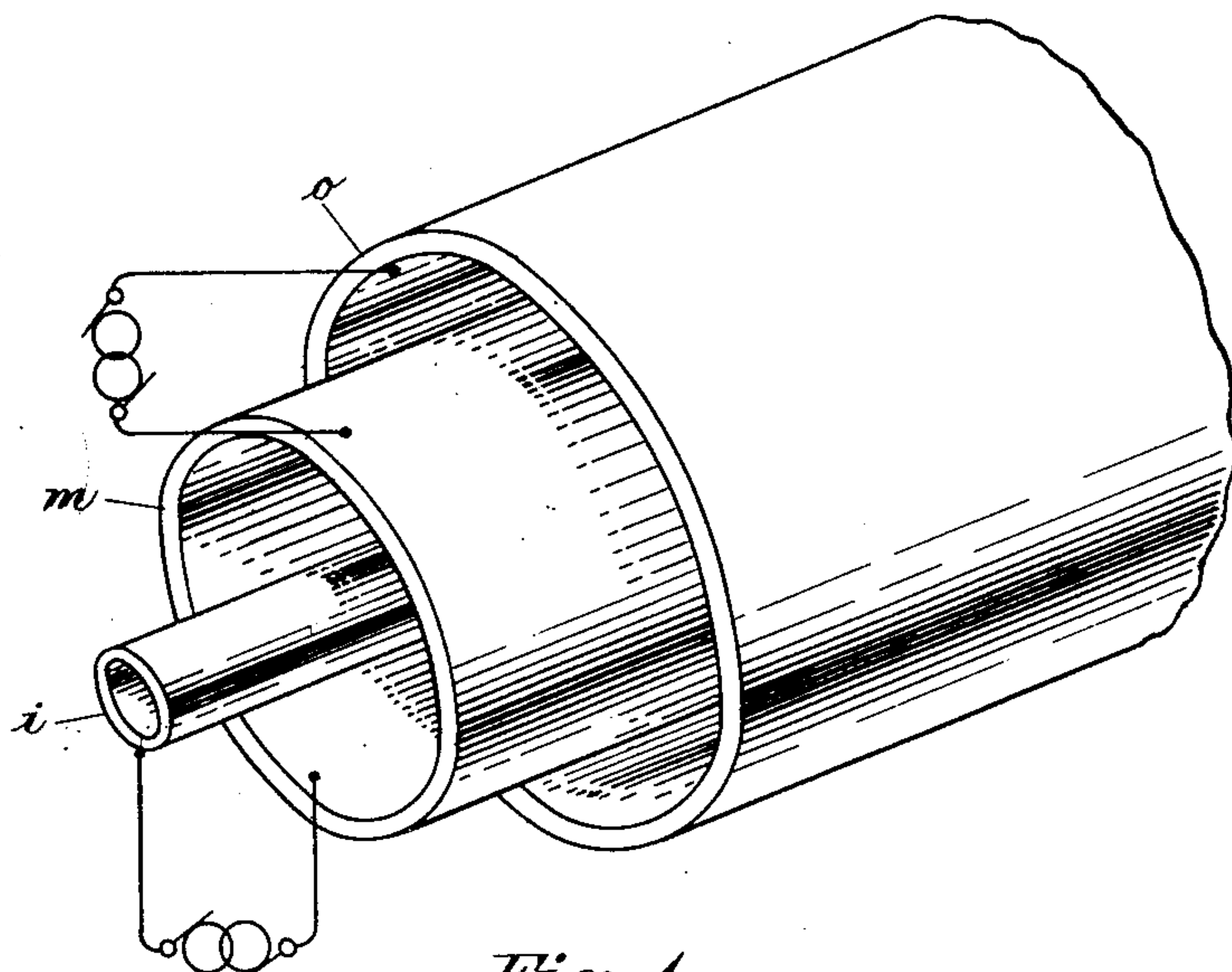


Fig. 1

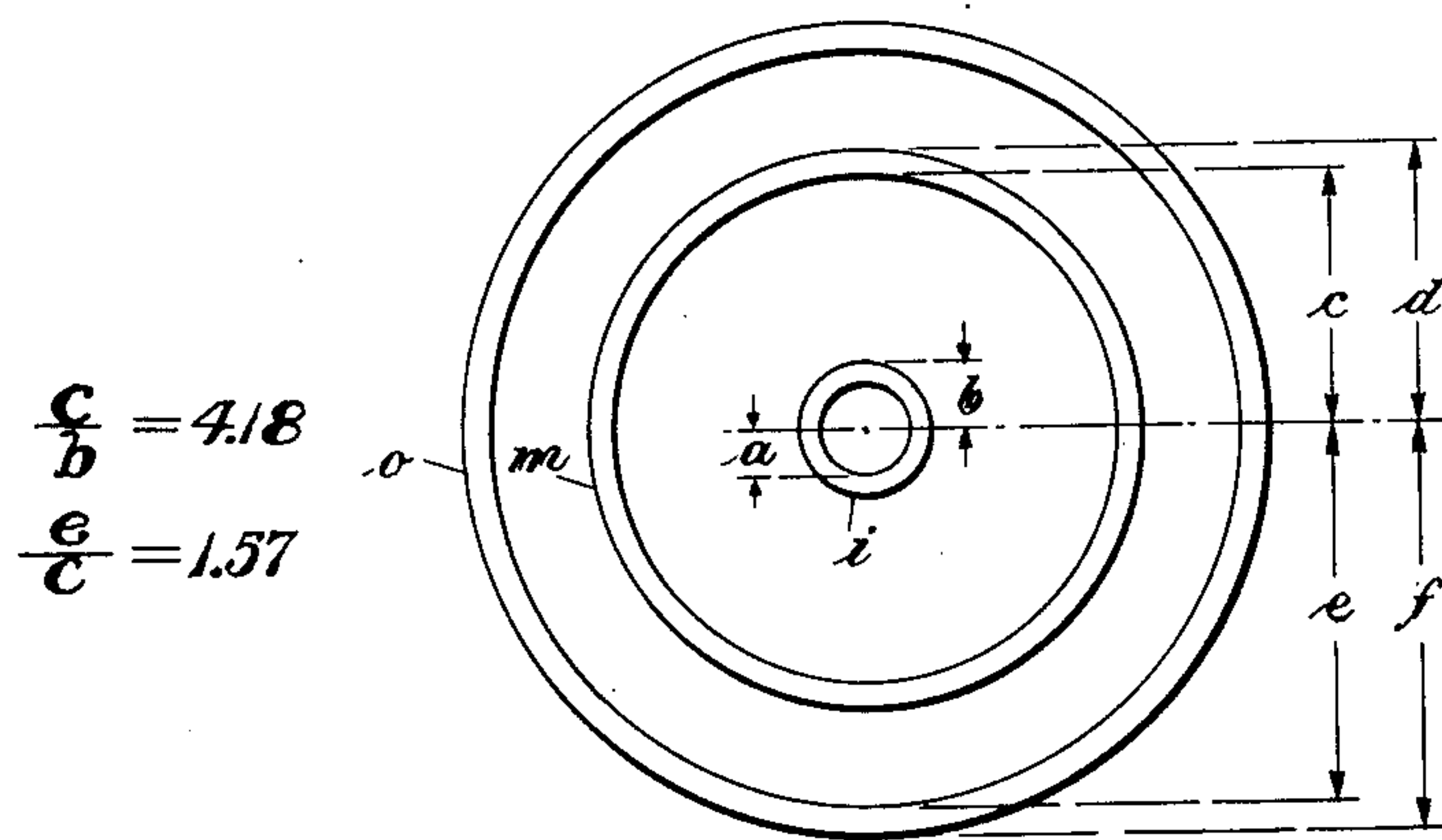


Fig. 2

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TRIPLE CONCENTRIC CONDUCTOR SYSTEM

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This invention relates to concentric conductor systems, and more particularly to a system in which more than two concentric conductors are employed.

5 It has been proposed that an arrangement of three concentric cylindrical conductors of different sizes may be employed as a transmission medium. Where any two concentric conductors are connected so that one acts as a
10 return for the other, due to the skin effect at high frequencies the current tends to crowd to the adjacent surfaces of the two conductors. In other words, the current flow concentrates at the inner surface of the outer of
15 the two conductors and at the outer surface of the inner conductor. It is, therefore, possible in a triple conductor system to use the middle and inner conductors as one circuit and the middle and outer conductors as an
20 independent circuit. At high frequencies the two circuits will be effectively separated since the currents of one circuit will flow on the inside of the middle conductor and those of the other circuit on the outside of the mid-
25 dle conductor.

The present invention is concerned with the discovery that the two independent circuits thus formed may be so constructed as to have the same attenuation and that such at-
30 tenuation will have a minimum value for any given diameter of the outside conductor if the concentric conductors have certain diameter ratios.

The invention will now be more fully understood from the following description when read in connection with the accompanying drawing, Figure 1 of which shows schematically the general arrangement of a concentric conductor system of three conductors, and
40 Fig. 2 of which is a cross-section of the triple conductor system to show the diameter relations.

Let us consider a triple conductor system comprising an inner conductor i , a middle
45 conductor m and an outer conductor o coaxially arranged as shown in Figs. 1 and 2. The proposition is to use the middle and inner conductors, for example, as one circuit, and the middle and outer conductors as another.
50 This is rendered possible due to the skin ef-

fect which, as already stated, causes the currents of one circuit to flow at high frequencies on the inside of the middle conductor and the currents of the other circuit to flow on the outside surface of said conductor, the re-
55 turn currents of the two circuits flowing at the inner surface of the outer conductor and the outer surface of the inner conductor, respectively.

The diameter of the outer conductor is
60 usually determined by practical considerations, such as the size of conduit ducts or of overhead cable rings, and likewise the thickness of the conductor walls will ordinarily be determined by mechanical considerations.
65 It is desirable that the attenuation of the circuit derived from the middle and inner conductors should be the same as that of the circuit derived from the middle and outer conductors, since this condition would give equal
70 repeater spacings and equal frequency ranges on the two circuits. Assuming the foregoing conditions, let us determine the diameter relations for the triple conductor system which will make the attenuation of the two circuits
75 equal and make this attenuation a minimum for a fixed total amount of conductor material.

Let a and b be the inner and outer radii respectively of the inner conductor i , c and d
80 the corresponding radii of the middle conductor m and e and f the inner and outer radii of the outer conductor o . Bearing in mind that under the assumed conditions the current flow is concentrated at the adjacent sur-
85 faces of the conductors constituting a given conducting system, the following formulae may be used at high frequencies for the conducting system comprising the middle con-
90 ductor m and the outer conductor o :

Resistance of middle conductor=

$$R_m = K \frac{\sqrt{F}}{d} \quad (1)$$

Resistance of outer conductor=

$$R_o = K \frac{\sqrt{F}}{e} \quad (2)$$

Linear inductance=

$$L = K_1 \log \frac{e}{d} \quad (3)$$

Linear capacity=

$$C = \frac{K_2}{\log \frac{e}{d}} \quad (4)$$

where K , K_1 and K_2 are constants and F is the frequency. It will be noted that the outer radius of the outer conductor and the inner radius of the middle conductor do not appear in the formulæ.

The attenuation at high frequencies is:

$$\alpha_1 = \frac{R}{2} \sqrt{\frac{C}{L}} + \frac{G}{2} \sqrt{\frac{L}{C}} \quad (5)$$

where R , L , C and G are the linear resistance, inductance, capacity and leakage inductance, respectively. Let us assume, first, that air insulation is employed between the conductors and that $G=0$. We have, then:

$$\alpha_1 = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{R_m + R_o}{2} \sqrt{\frac{C}{L}} \quad (6)$$

Substituting the values given by Equations (1) to (4) inclusive, in Equation (6) we obtain:

$$\alpha_1 = \frac{K \sqrt{F}}{2} \left(\frac{1}{d} + \frac{1}{e} \right) \sqrt{\frac{K_2}{K_1}} \frac{1}{\left(\log \frac{e}{d} \right)^2} \quad (7)$$

Letting

$$K_3 = \frac{K}{2} \sqrt{\frac{K_2}{K_1}},$$

Equation (7) becomes:

$$\alpha_1 = K_3 \sqrt{F} \left(\frac{1}{d} + \frac{1}{e} \right) \frac{1}{\log \frac{e}{d}} \quad (8)$$

Similarly, the attenuation of the circuit formed by the middle and inner conductors may be expressed:

$$\alpha_2 = K_3 \sqrt{F} \left(\frac{1}{b} + \frac{1}{c} \right) \frac{1}{\log \frac{c}{b}} \quad (9)$$

The amount of conductor material per unit length is:

$$M = \pi(b^2 - a^2) + \pi(d^2 - c^2) + \pi(f^2 - e^2) \quad (10)$$

Let us assume that the thickness of the three conductors is the same, or in other words, that

$$b - a = d - c = f - e = t = \text{constant} \quad (11)$$

Let us also assume that t is small in comparison with the radii of the conductors, so that

$$b \doteq a, d \doteq c \text{ and } f \doteq e$$

where the symbol $\doteq$ denotes approximate equality. We then have

$$M \doteq 2\pi t(b + c + e) \quad (12)$$

or, if

$$K_{10} \frac{M}{2\pi t},$$

M being assumed constant,

$$b + c + e = K_{10} \quad (13)$$

Whence

$$\frac{b}{c} + \frac{e}{c} + 1 = \frac{K_{10}}{c} \quad (14)$$

Since d is approximately equal to c , Equation (8) may be rewritten

$$\alpha_1 = K_3 \sqrt{F} \frac{1}{c} \left(1 + \frac{c}{e} \right) \frac{1}{\log \frac{e}{c}} \quad (15)$$

which from (14) becomes

$$\alpha_1 = \frac{K_3 \sqrt{F}}{K_{10}} \left(\frac{b}{c} + \frac{e}{c} + 1 \right) \left(1 + \frac{c}{e} \right) \frac{1}{\log \frac{e}{c}} \quad (16)$$

or, letting

$$y = \frac{e}{c} \text{ and } x = \frac{c}{b}$$

$$\alpha_1 = \frac{K_3 \sqrt{F}}{K_{10}} \left(\frac{1}{x} + y + 1 \right) \left(\frac{1}{y} + 1 \right) \frac{1}{\log y} \quad (17)$$

Likewise, it is found that

$$\alpha_2 = \frac{K_3 \sqrt{F}}{K_{10}} \left(\frac{1}{x} + y + 1 \right) (x + 1) \frac{1}{\log x} \quad (18)$$

Since the two attenuations α_1 and α_2 are to be equal, we find that

$$\frac{x + 1}{\log x} = \frac{\frac{1}{y} + 1}{\log y} \quad (19)$$

The problem is to find the values of x and y which satisfy (19) and make the attenuation a minimum. A mathematical solution is difficult. A satisfactory solution may be secured, however, by approximate methods. A range of values may be assumed for x and for each of these a corresponding value of y which satisfies (19) may be found either graphically or by successive computations from tables. Upon substituting these different pairs of values for x and y in Equation (18) the particular values which give minimum attenuation are found. These values are

$$x = \frac{c}{b} \doteq 4.18 \quad (20)$$

$$y = \frac{e}{c} \doteq 1.57 \quad (21)$$

When the diameter ratios are near these optimal values the change of attenuation

with changing diameter ratio is not large, so that some degree of departure from the exact values of (20) and (21) can be introduced while still keeping the attenuation a minimum for all practical purposes.

The use of insulating spacers to keep the conductors in concentric relation will have some effect upon the diameter ratios required for minimum attenuation, but these insulators can be spaced at fairly great intervals, and their effect will then be practically negligible. Likewise it should be noted that while certain simplifying assumptions have been made in determining the optimal diameter ratios, reasonable modifications can be made in these assumptions without changing the validity of the above conclusions.

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. A triple conductor system comprising inner, middle and outer conductors concentrically arranged with the middle and outer conductors constituting one transmission system and the inner and middle conductors constituting an independent transmission system, the diameters of the three conductors being so related that for a given amount of conductor material and a given size of outer conductor the attenuations of the two independent transmission systems will be a minimum.

2. A triple conductor system comprising inner, middle and outer conductors concentrically arranged with the middle and outer conductors constituting one transmission system and the inner and middle conductors constituting an independent transmission system, the diameters of the three conductors being so related that for a given amount of conductor material and a given size of outer conductor the attenuations of the two independent transmission systems will be the same and have a minimum value.

3. A triple conductor system comprising inner, middle and outer conductors concentrically arranged with the middle and outer conductors constituting one transmission system and the inner and middle conductors constituting an independent transmission system, the ratio of the inner diameter of the outer conductor to the outer diameter of the middle conductor, and the ratio of the inner diameter of the middle conductor to the outer diameter of the inner conductor, being such that for a given amount of conductor material and a given size of outer conductor the attenuation for the two independent transmission systems will be a minimum.

4. A triple conductor system comprising inner, middle and outer conductors concentrically arranged with the middle and outer

conductors constituting one transmission system and the inner and middle conductors constituting an independent transmission system, the ratio of the inner diameter of the outer conductor to the outer diameter of the middle conductor, and the ratio of the inner diameter of the middle conductor to the outer diameter of the inner conductor, being such that for a given amount of conductor material and a given size of outer conductor the attenuations of the two independent transmission systems will be equal and will have minimum values.

5. A triple conductor system comprising inner, middle and outer conductors concentrically arranged with the middle and outer conductors constituting one transmission system and the inner and middle conductors constituting an independent transmission system, the ratio of the inner diameter of the outer conductor to the outer diameter of the middle conductor being substantially 1.57, and the ratio of the inner diameter of the middle conductor to the outer diameter of the inner conductor being substantially 4.18.

6. A triple conductor system comprising inner, middle and outer conductors concentrically arranged, with the middle and outer conductors comprising one transmission circuit and the inner and middle conductors comprising an independent transmission circuit, the ratio of the inner diameter of the outer conductor to the outer diameter of the middle conductor being substantially 1.6, and the ratio of the inner diameter of the middle conductor to the outer diameter of the inner conductor being such as to make the attenuation of the inner circuit substantially the same as that of the outer circuit.

In testimony whereof, I have signed my name to this specification this 29th day of January, 1930.

ESTILL I. GREEN.

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