

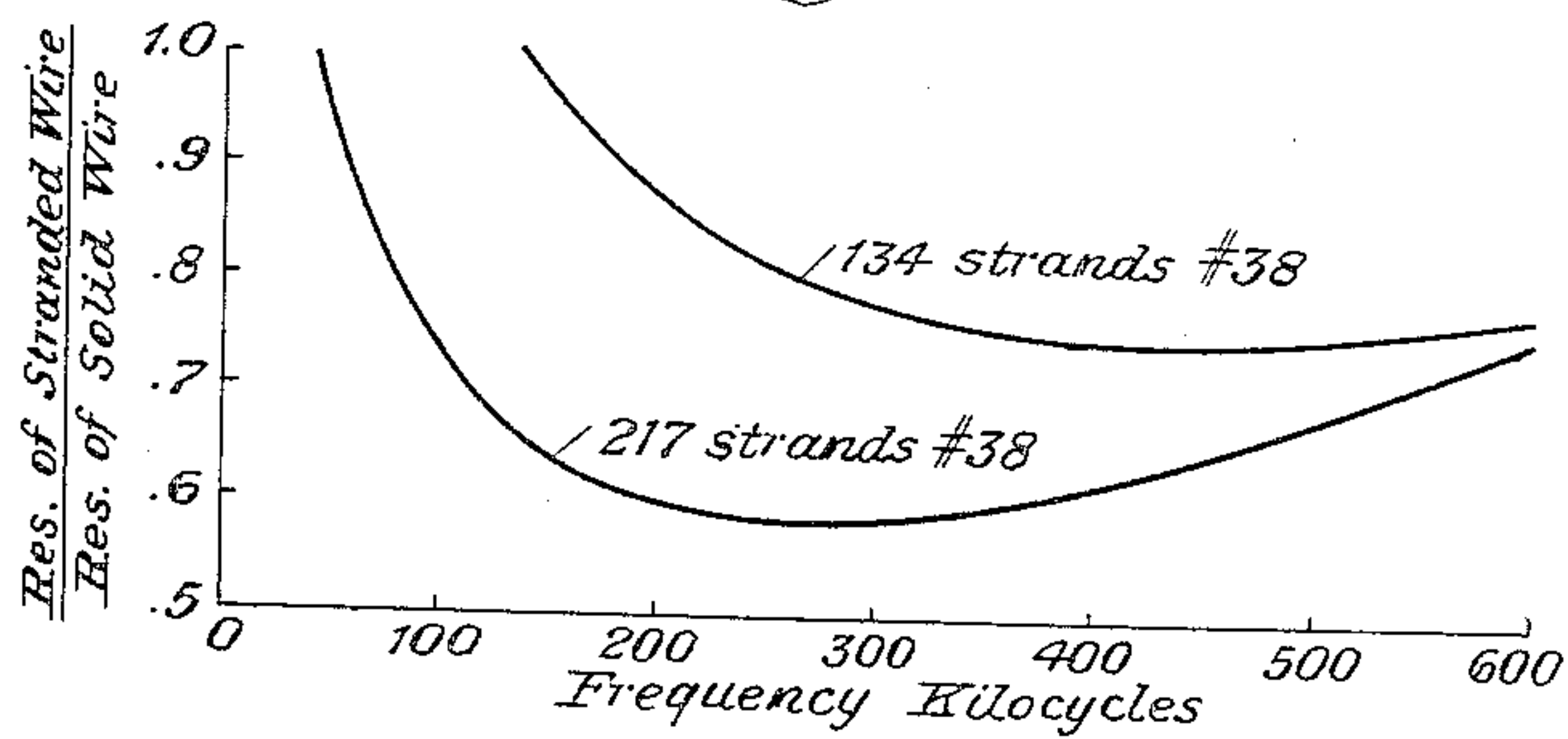
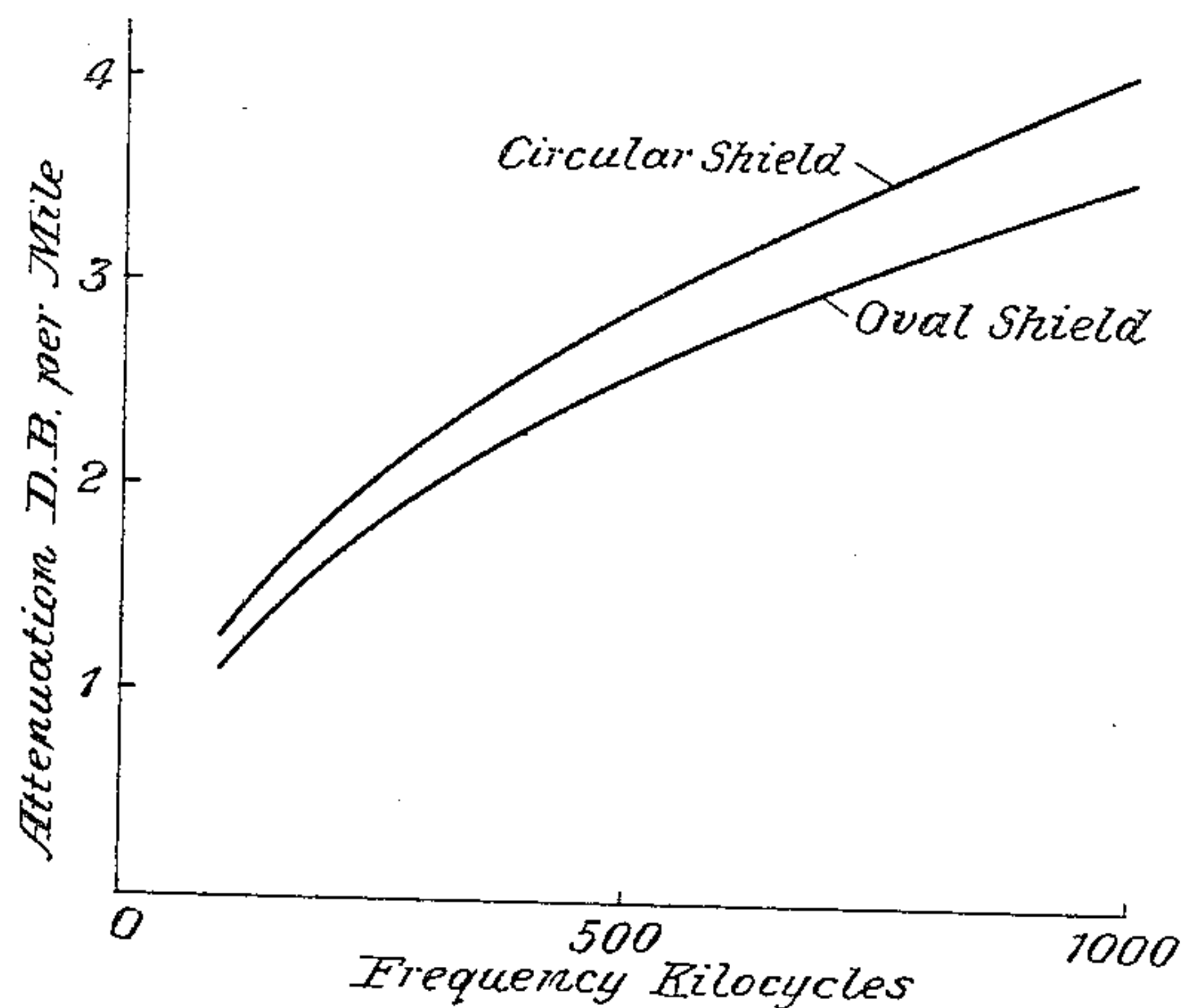
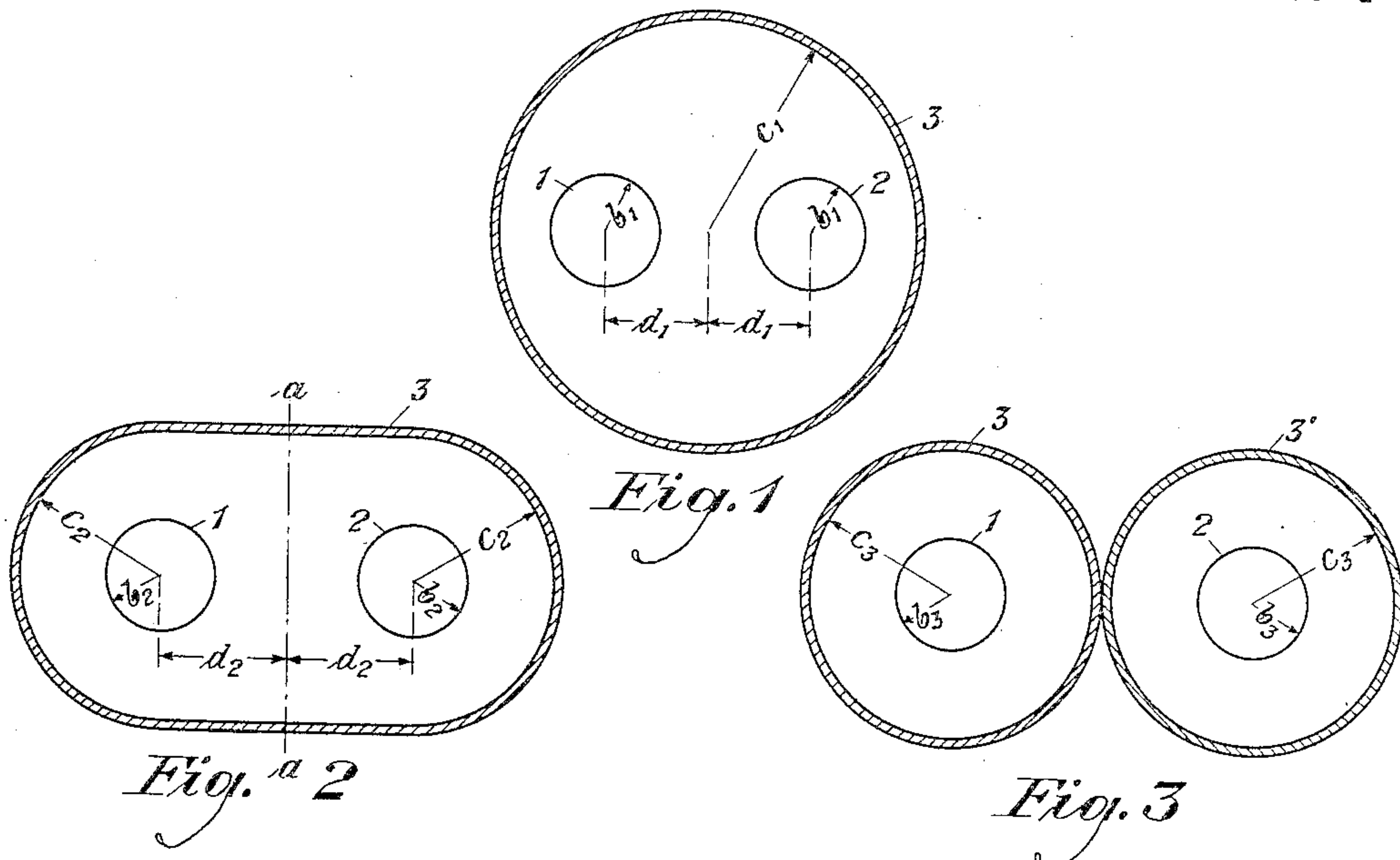
March 17, 1936.

E. I. GREEN ET AL
CIRCUITS WITH NONCIRCULAR SHIELDS

2,034,034

Filed June 7, 1933

4 Sheets-Sheet 1



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2,034,034

CIRCUITS WITH NONCIRCULAR SHIELDS

Filed June 7, 1933

4 Sheets-Sheet 2

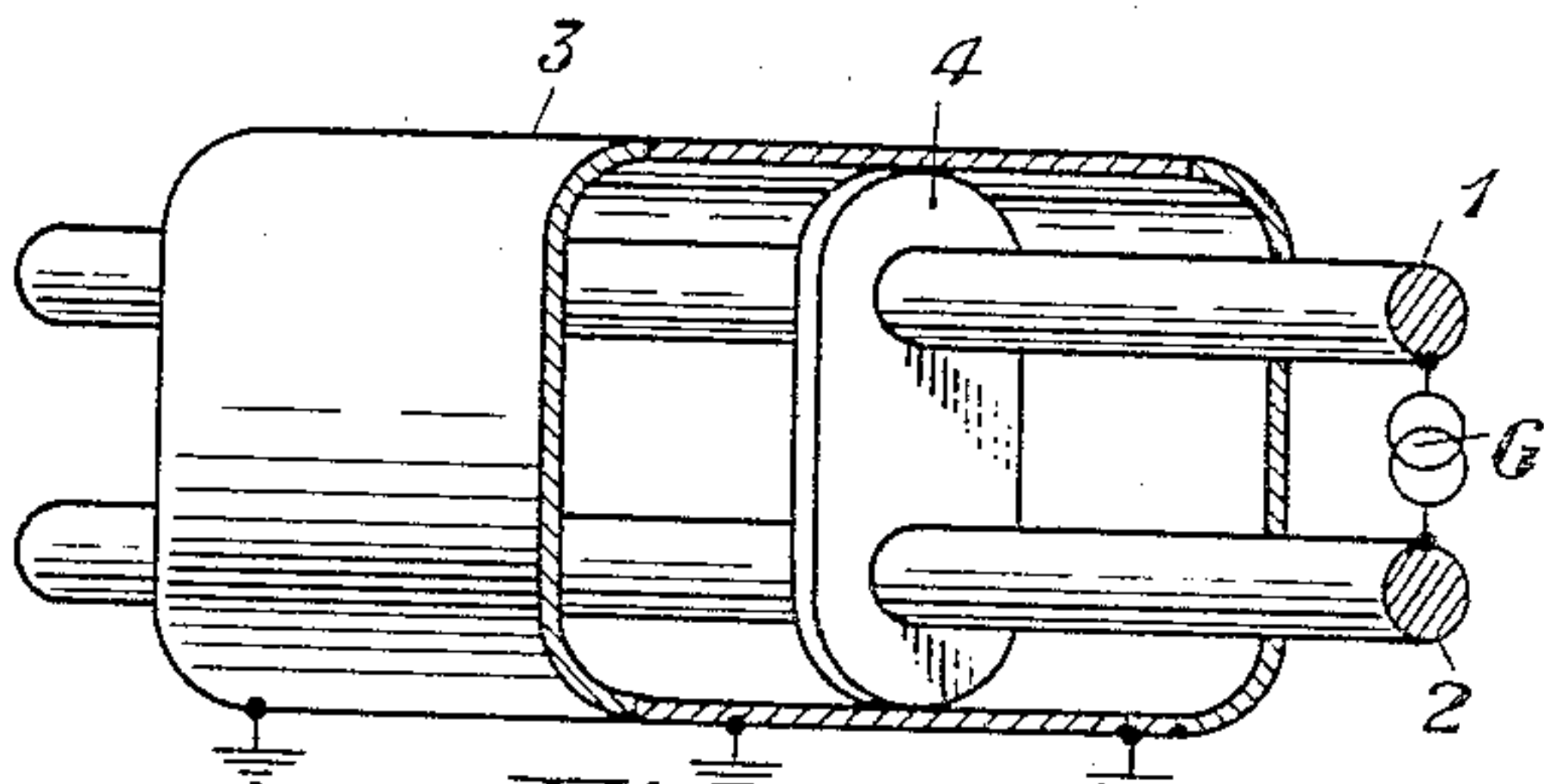


Fig. 6

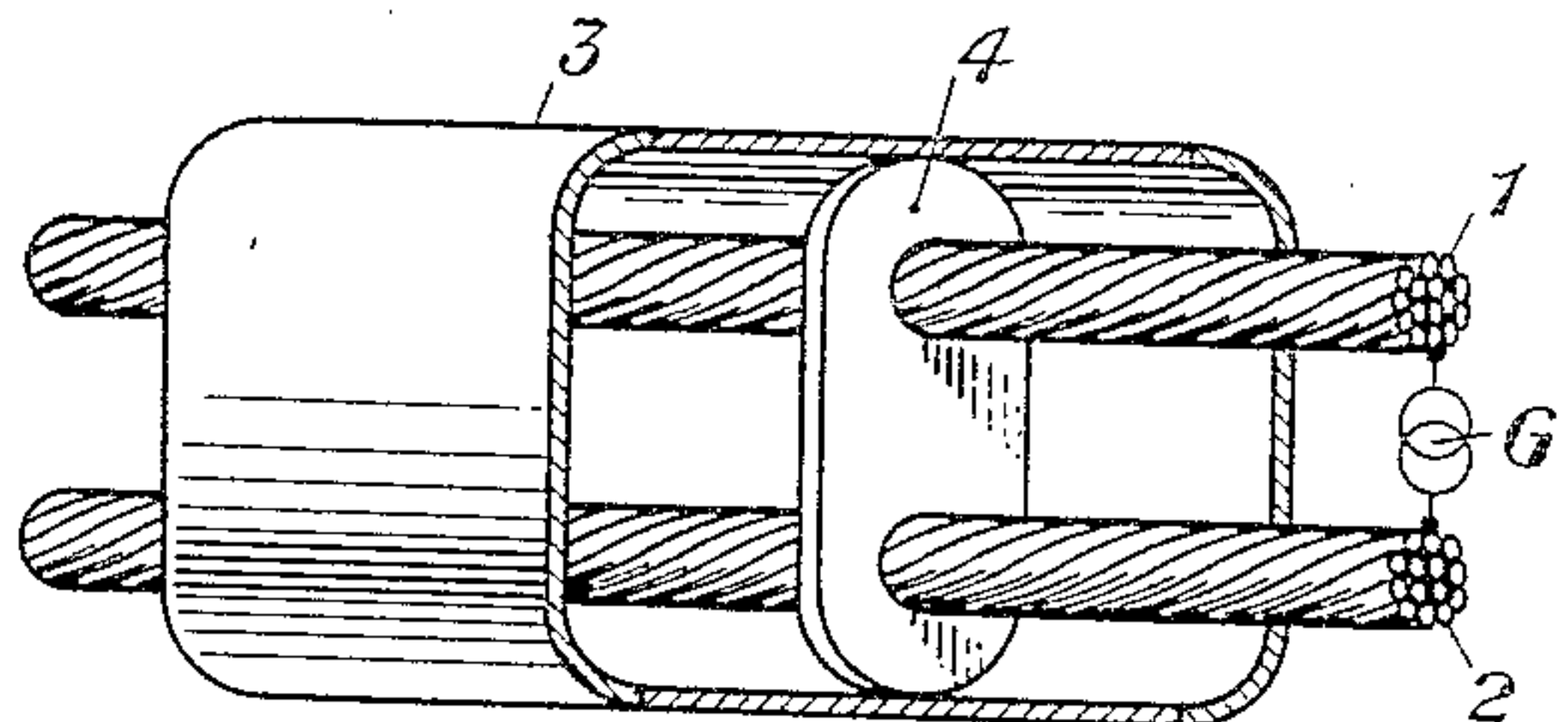


Fig. 7

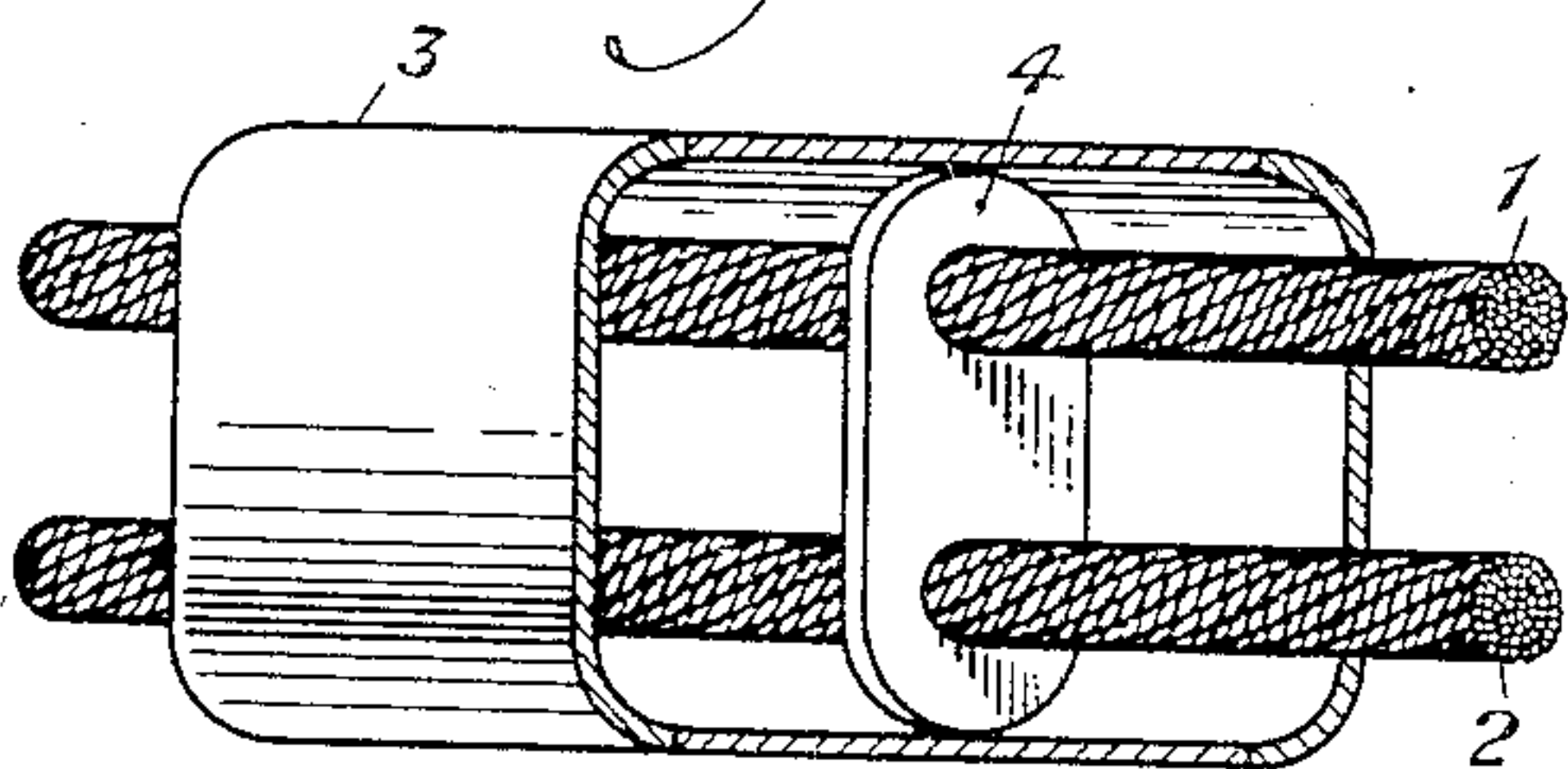


Fig. 8

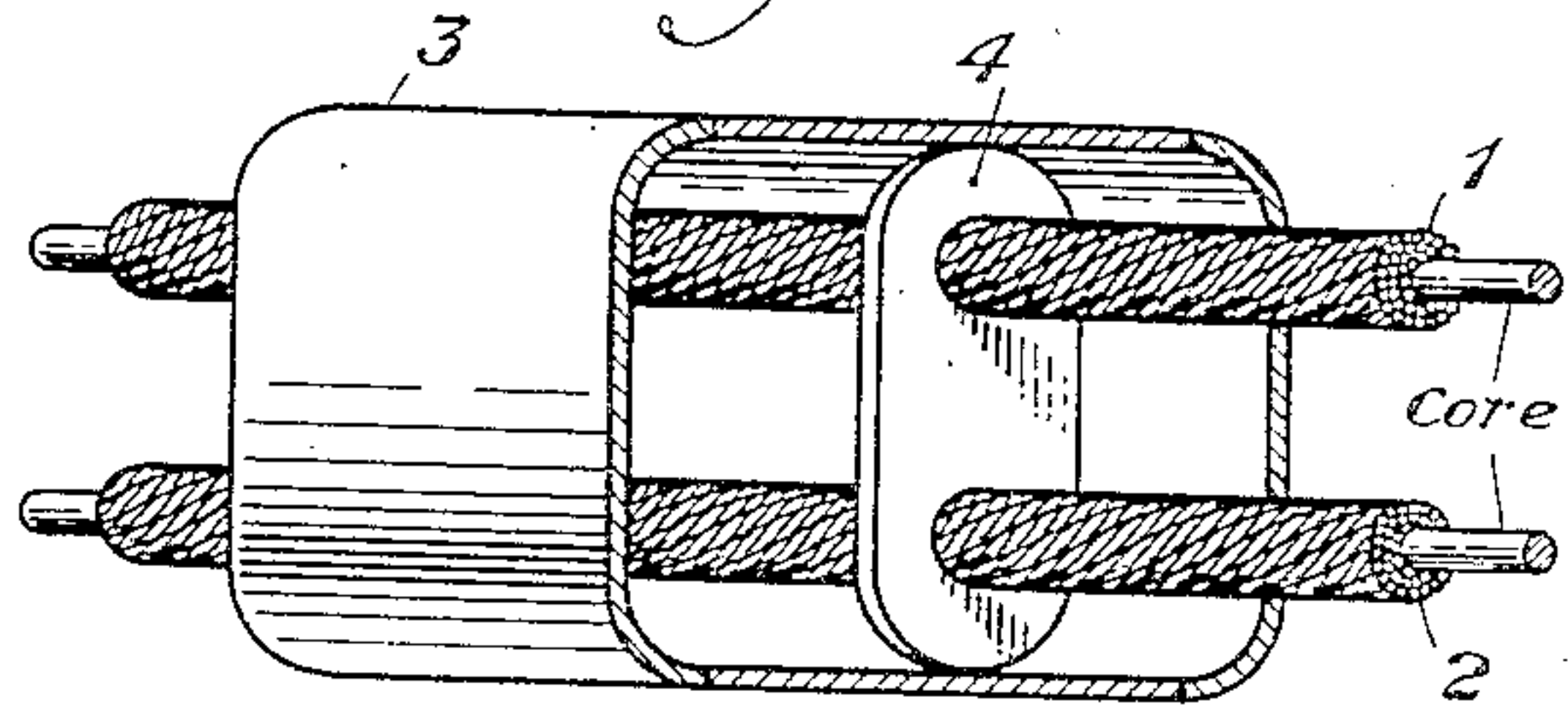


Fig. 9

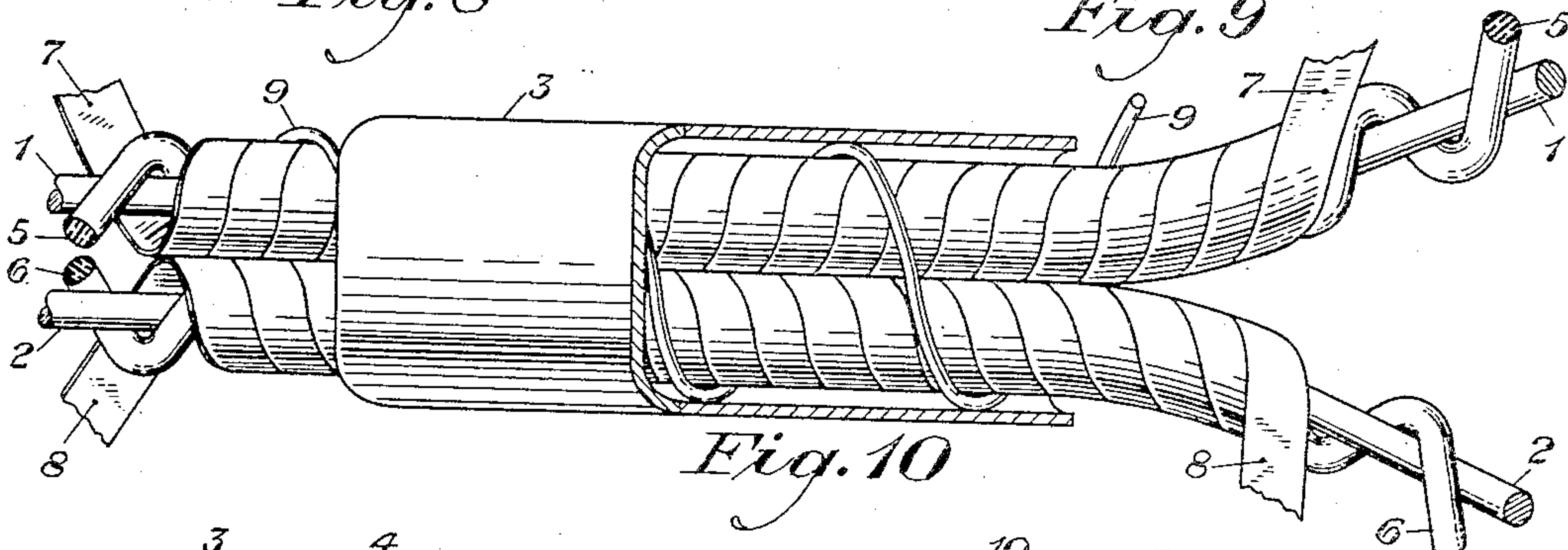


Fig. 10

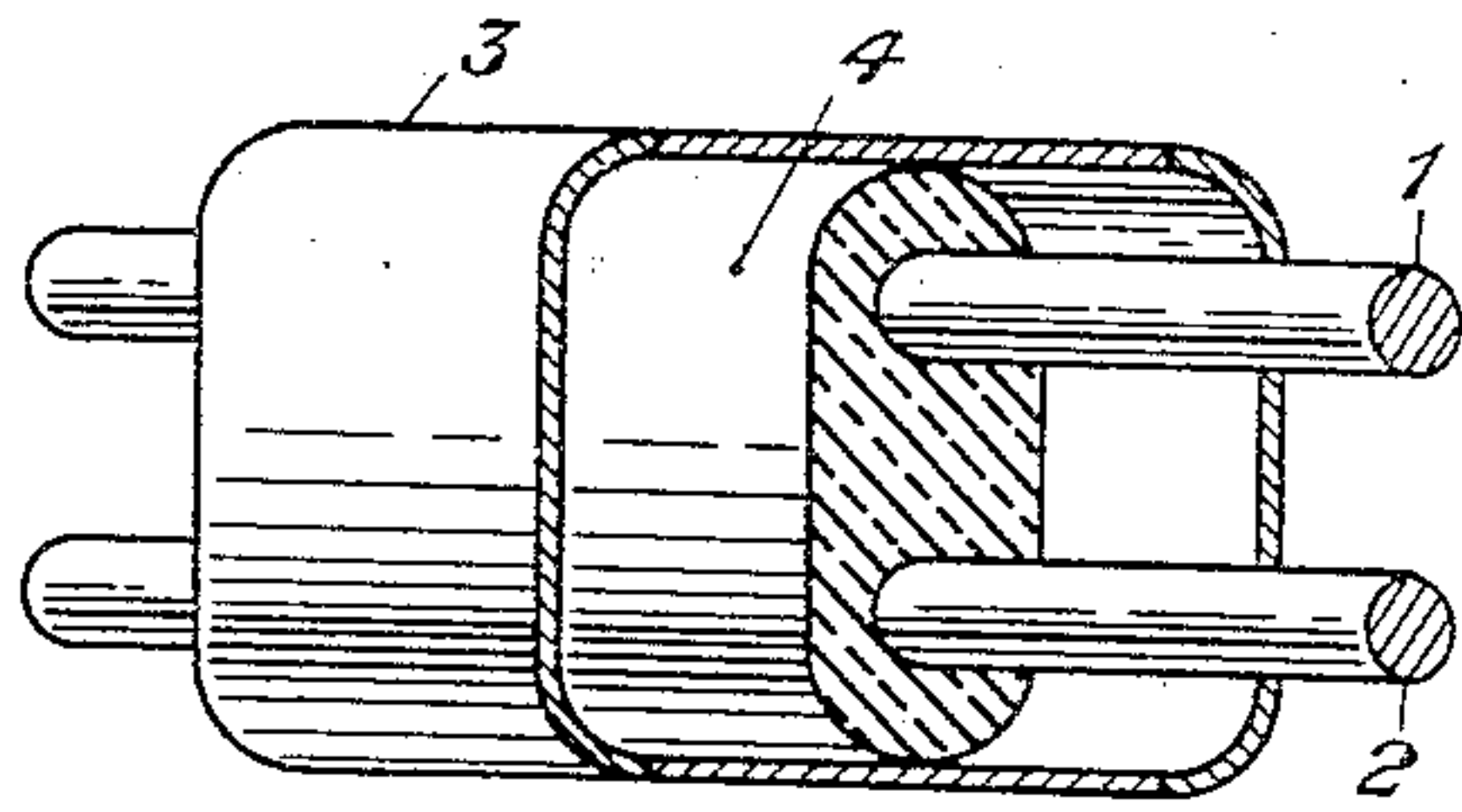


Fig. 11

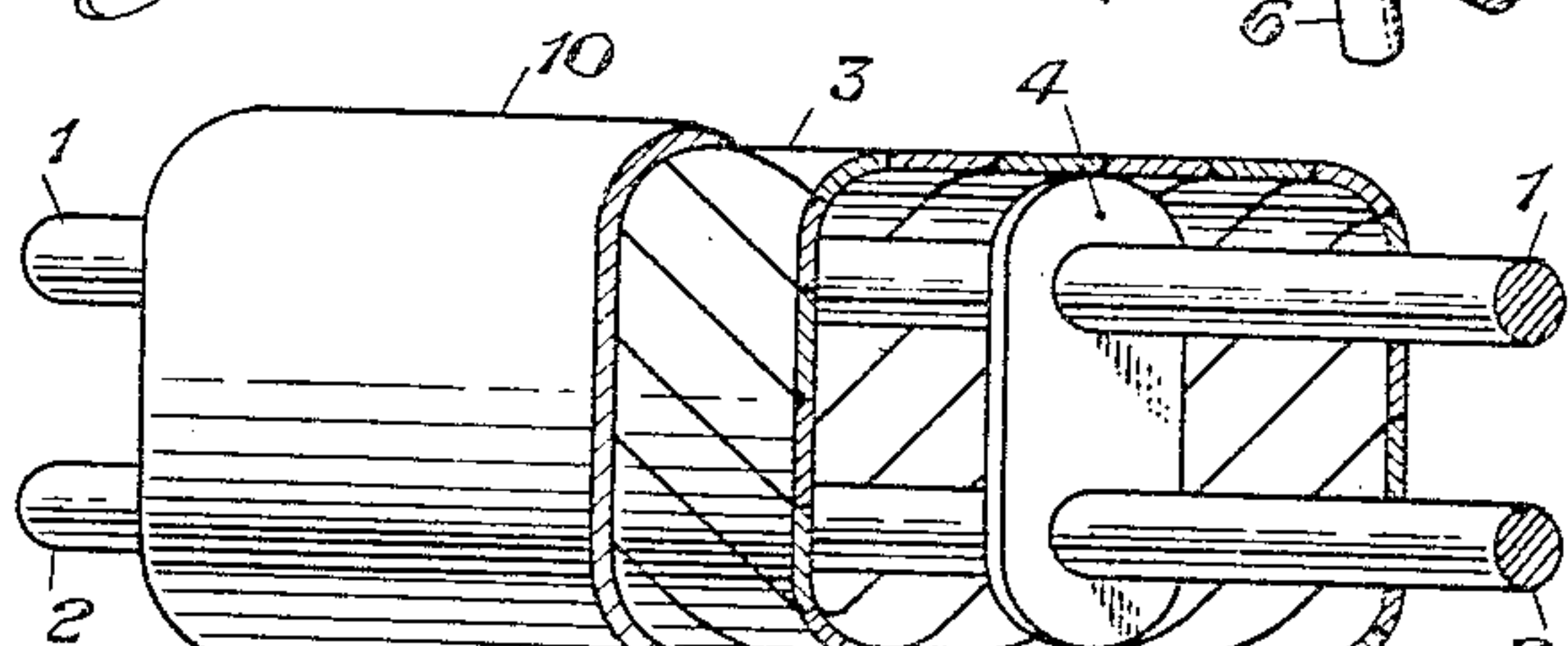


Fig. 12

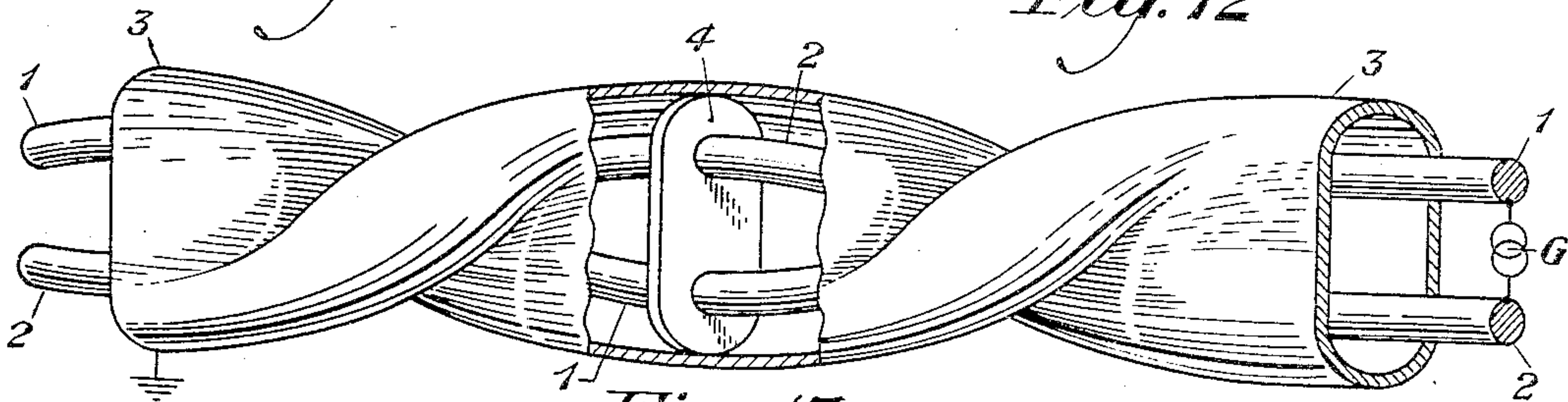


Fig. 13

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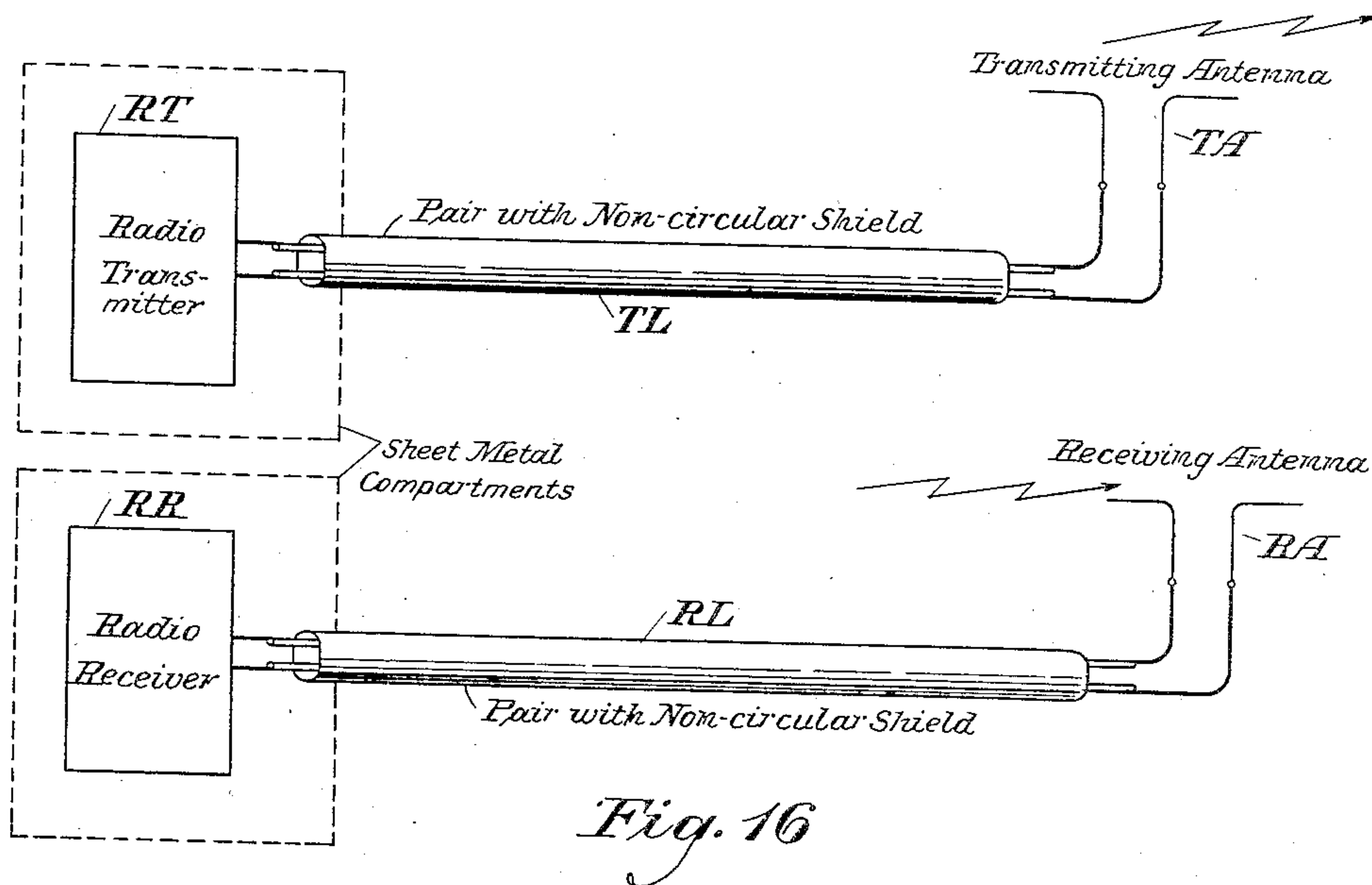
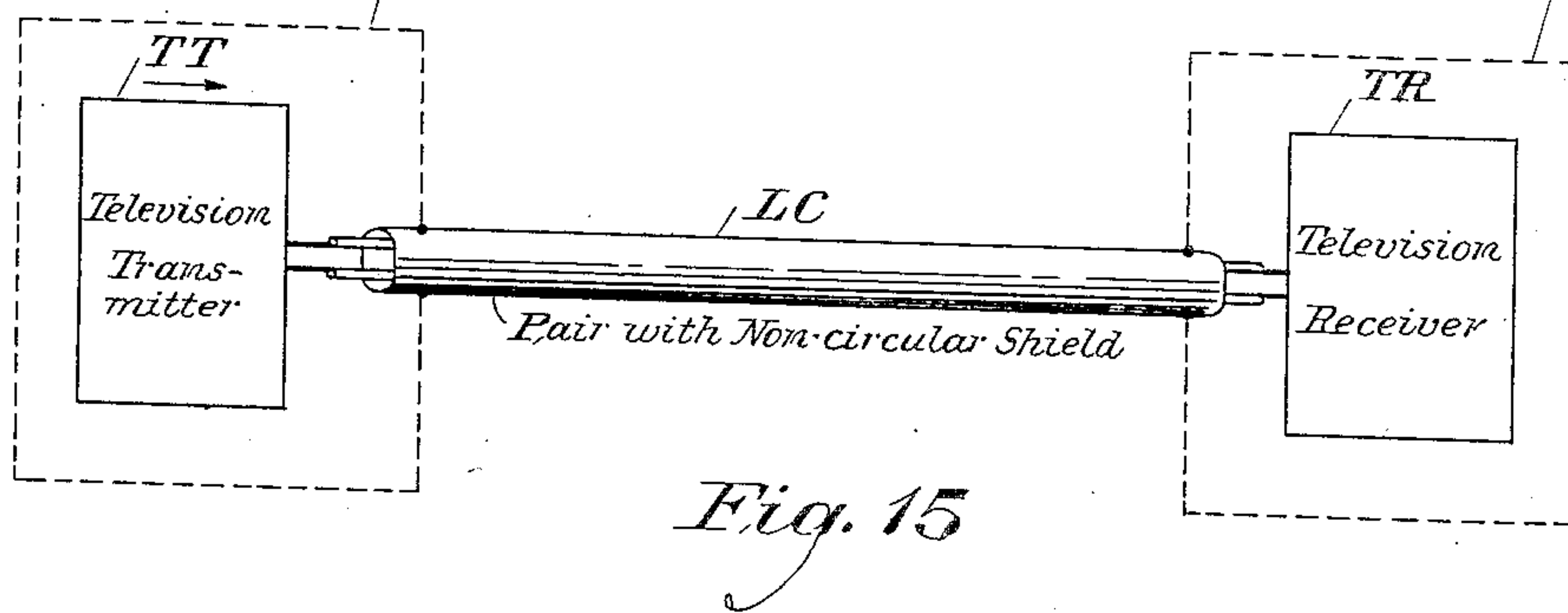
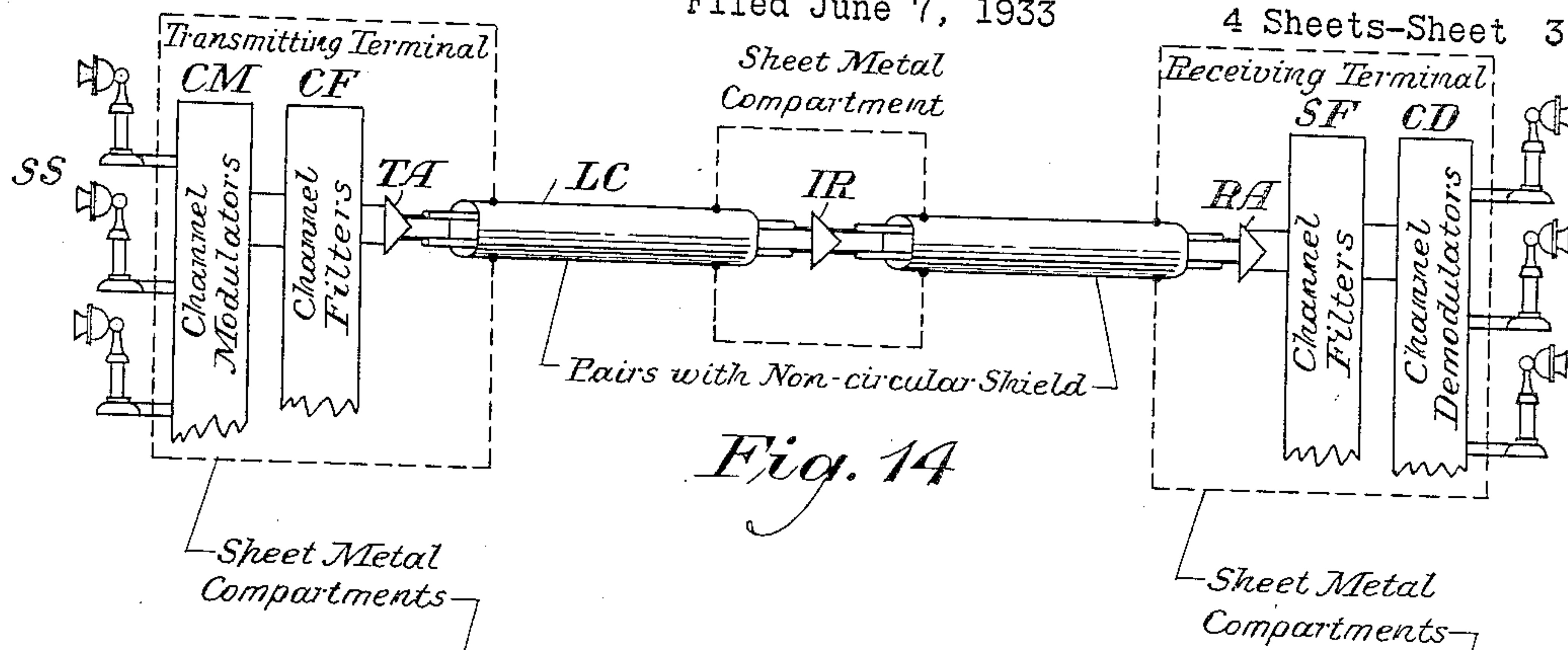
E. I. GREEN ET AL

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CIRCUITS WITH NONCIRCULAR SHIELDS

Filed June 7, 1933

4 Sheets-Sheet 3



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E. I. GREEN ET AL

2,034,034

CIRCUITS WITH NONCIRCULAR SHIELDS

Filed June 7, 1933

4 Sheets-Sheet 4

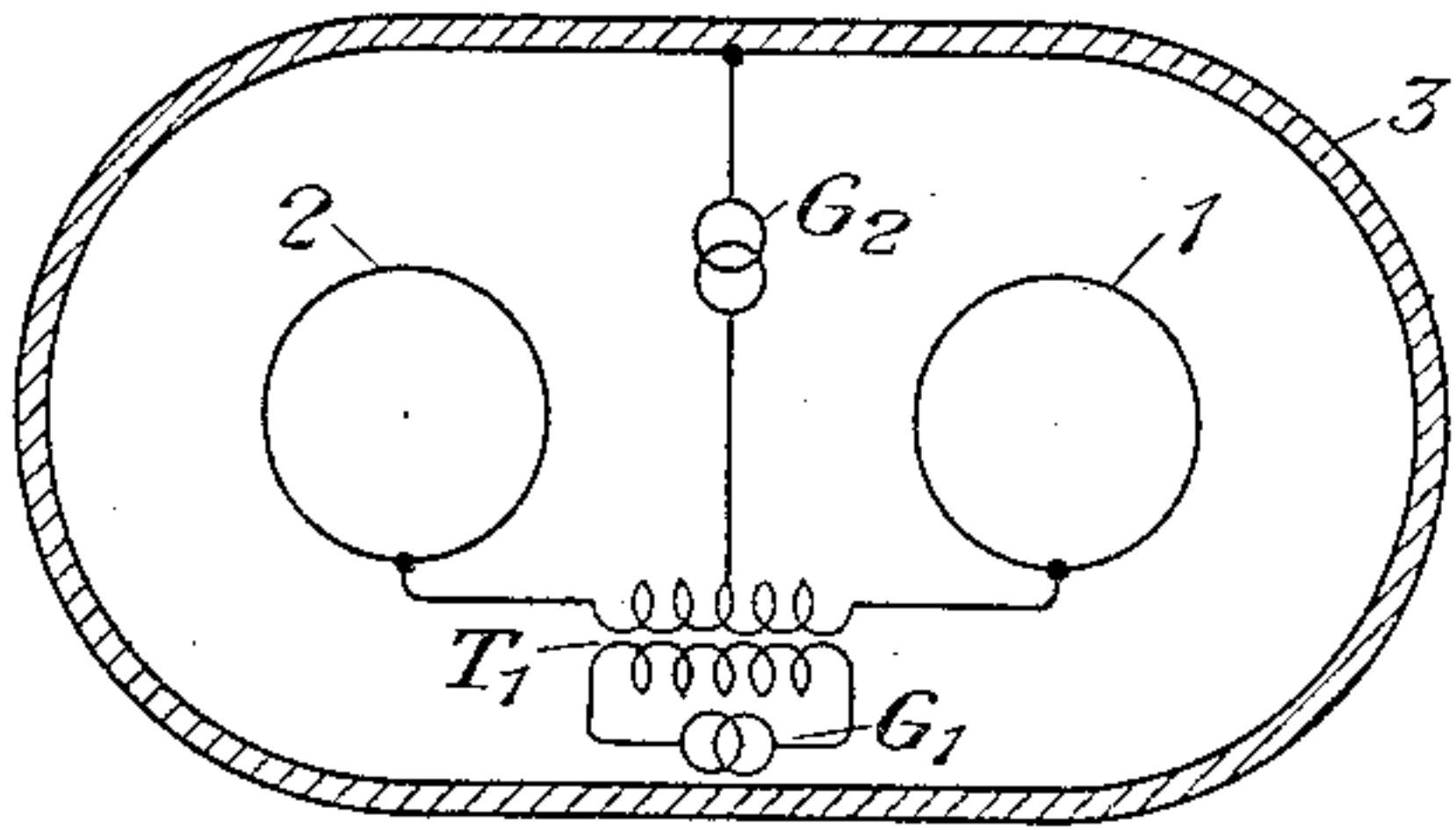


Fig. 17

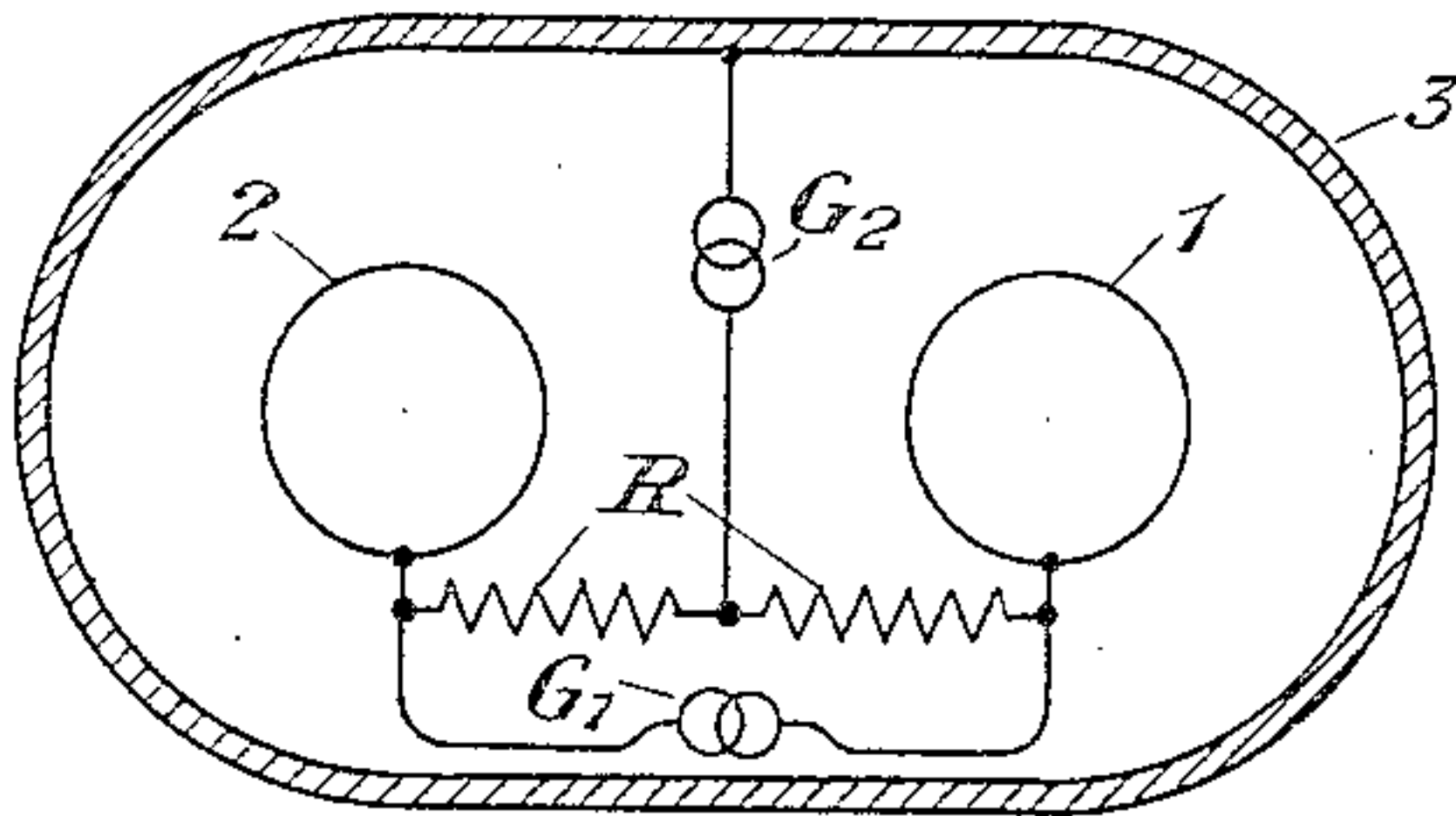


Fig. 18

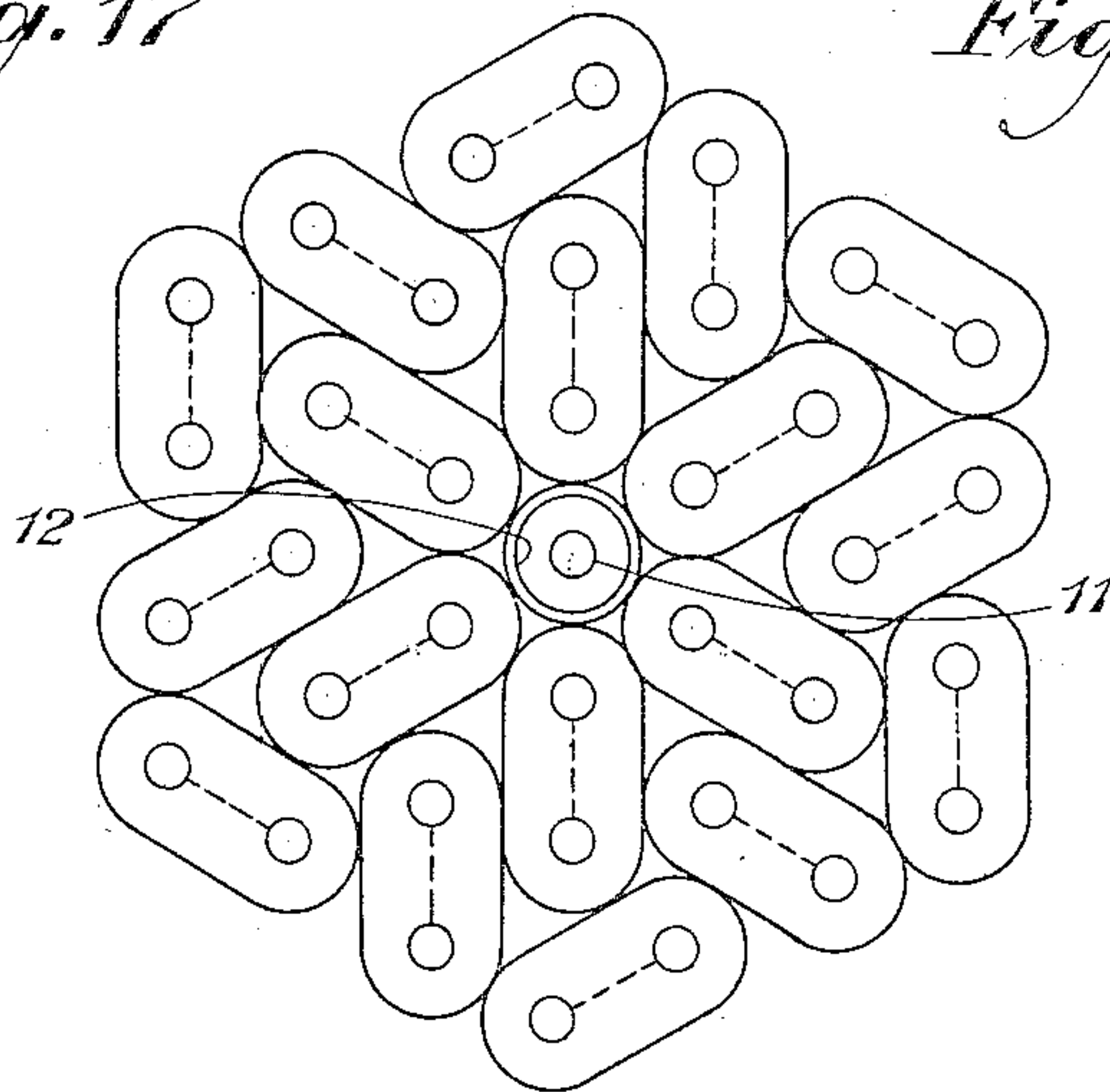


Fig. 19

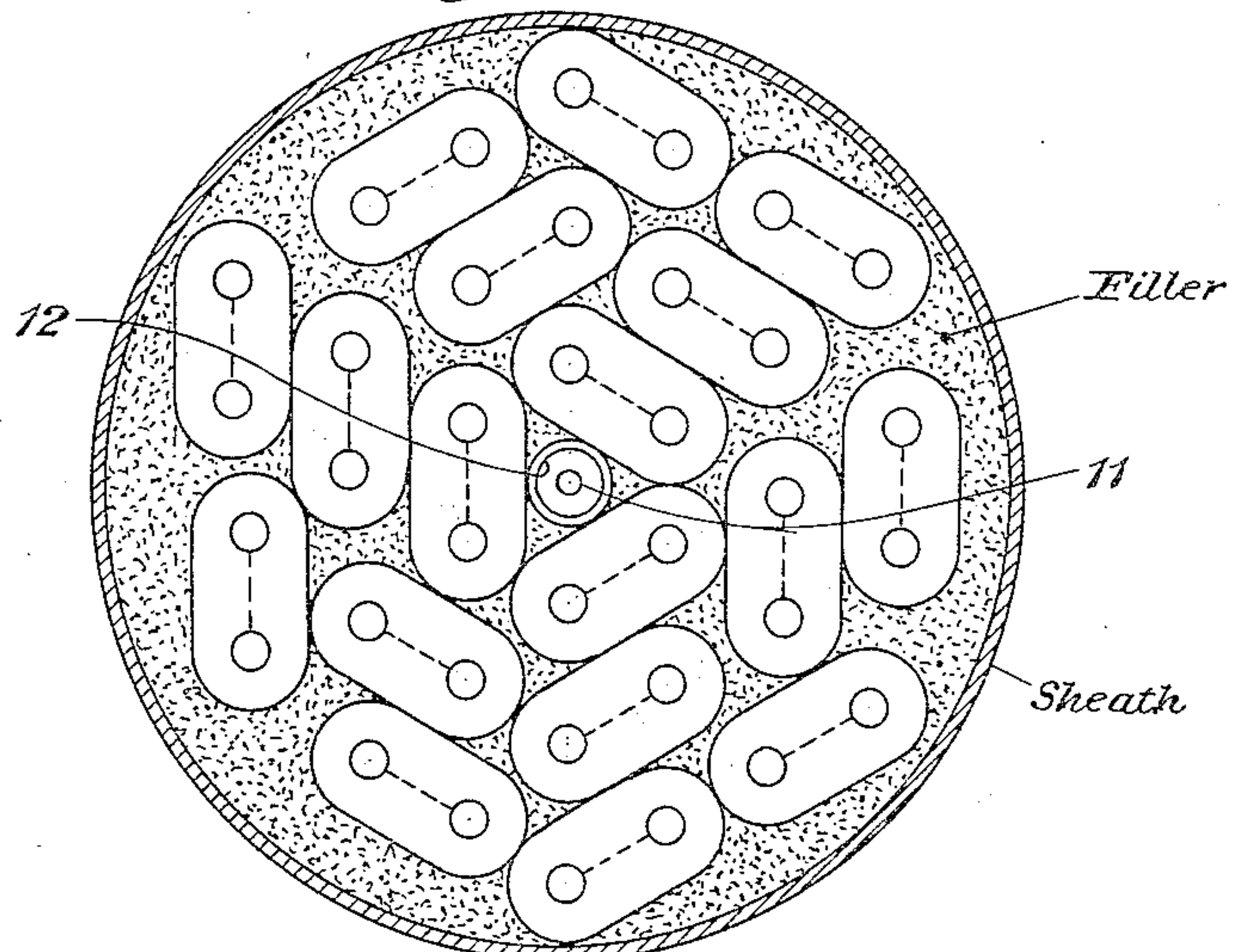


Fig. 20

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UNITED STATES PATENT OFFICE

2,034,034

CIRCUITS WITH NONCIRCULAR SHIELDS

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Application June 7, 1933, Serial No. 674,764

16 Claims. (Cl. 178—44)

This invention is concerned with electrical transmission circuits and especially with circuits comprising a pair of conductors surrounded by an individual shield. A particular object of the invention is to obtain a transmission circuit which has the properties of low attenuation and substantial freedom from interference over a wide band of frequencies.

In determining the type of transmission circuit to be used for the transmission of high frequencies or broad bands of frequencies, there are two important characteristics to be considered: (1) the susceptibility of the circuit to external disturbances, such as crosstalk from nearby circuits, and interference or noise from other outside sources, and (2) the high-frequency attenuation, which should be kept as low as is consistent with securing a desirable size and favorable mechanical properties. In some applications there is a further characteristic which may be of importance, namely, that the circuit should be balanced with respect to ground.

In accordance with the present invention it is proposed to enclose a pair of conductors in a conducting shield which acts to prevent external electromagnetic and electrostatic high-frequency disturbances from causing disturbances in the circuit of the pair, and conversely to prevent the currents transmitted over the pair from causing disturbances in external circuits. Since the effectiveness of such an enclosing shield decreases with decreasing frequency, it is proposed to transmit over the pair in a balanced manner in order to reduce the effect of interference which may pass through the shield at low frequencies. It is also proposed to dispose the shielded pair of conductors relatively to other similar circuits in such a manner as to reduce the interference which might enter at low frequencies.

In order to reduce the high-frequency attenuation of the shielded circuit, it is proposed to secure low shunt losses by employing a dielectric having a small power factor and to reduce the series losses in the conductors by employing an insulating medium having a low dielectric constant. Accordingly, it is proposed in one embodiment of the invention to utilize a substantially gaseous dielectric between the conductors of the pair and between these conductors and shield. The invention comprehends also, however, the use of non-gaseous dielectric material to insulate the conductors from one another and from the sheath.

A particular object of the invention is the provision of a configuration of conductors and shield

which for any given size of shield will minimize the high-frequency attenuation of the circuit. A feature of the invention is the employment of a non-circular shield for this purpose.

More broadly, the invention is concerned with systems in which balanced pairs with individual non-circular shields are utilized for the transmission of high-frequencies or wide bands of frequencies.

The satisfactory transmission of television images with good definition requires the transmission of a frequency band which may extend from zero frequency to hundreds or perhaps thousands of kilocycles. If, for example, it is desired to transmit, with a total of 24 reproductions per second, an image containing 40,000 picture elements, there is required a frequency band of approximately 500 kilocycles in width. Still wider frequency bands may be necessary for representing with adequate detail such scenes as a theatrical performance or an athletic event. A television band of such width might be transmitted directly over a shielded pair designed in accordance with the principles of the invention, or it might be shifted to a higher frequency position in order to avoid the necessity of transmitting the extremely low television frequencies over the line.

Moreover, by the application of multiplexing, the wide frequency bands obtained from a shielded pair which is designed in accordance with the invention may be used to provide substantial numbers of narrower frequency bands suitable for other communication purposes, as, for example, for telephone circuits which may require bands of about 2,500 cycles in width, for high quality program circuits which may require bands extending up to 10,000 cycles or higher, for high-speed facsimile transmission, or for other services.

Also, it is frequently desirable in radio transmission to employ an antenna which is balanced with respect to ground rather than to transmit or receive between antenna and ground. Such, for example, is the case when using a diamond antenna or a horizontal dipole antenna. A balanced shielded pair of the type described herein is especially adapted for connecting such balanced antennas with radio transmitting or receiving apparatus, inasmuch as such a pair may be designed to have low attenuation and substantial immunity from external interference at the frequency or frequencies employed for radio transmission.

These and other objects and features of the

invention will now be more readily understood from the following description when read in connection with the accompanying drawings, in which Figure 1 is a cross-sectional diagram of a pair of conductors surrounded by a circular shield; Fig. 2 represents a cross-sectional diagram of a pair with non-circular shield; Fig. 3 is a cross-sectional diagram of a shielded circuit comprising two sets of concentric conductors; Fig. 4 is a curve showing the estimated high-frequency attenuation for a pair of wires with non-circular shield; Fig. 5 is a graph showing the improvement in high-frequency resistance obtained by two specific designs of stranded conductors; Fig. 6 represents a view of a transmission structure designed in accordance with the invention, this structure consisting of a pair with non-circular shield; Figs. 7 to 13 show various other structures embodying the principles of the invention, Figs. 14 to 16 typify arrangements of apparatus which may be used in association with a circuit derived from a pair with non-circular shield; Figs. 17 and 18 illustrate methods of effecting transmission over a structure with non-circular shield; and Figs. 19 and 20 illustrate methods whereby structures designed in accordance with the invention may be laid up in cable form.

A form of construction which has been suggested as being suitable for a shielded and balanced transmission circuit is indicated by the cross-sectional diagram of Fig. 1. This structure comprises two conductors, 1 and 2, which are surrounded by a circular shield 3. Such a construction is the subject of the copending application of E. I. Green and H. E. Curtis, Serial No. 674,763, filed June 7, 1933 and that of E. I. Green, H. E. Curtis and S. P. Mead, Serial No. 674,762, filed June 7, 1933. In these applications methods have been described for proportioning and spacing the conductors in order to obtain minimum attenuation. As indicated in Fig. 1, b_1 represents the radius of either conductor, c_1 the inner radius of the shield, and d_1 the distance from the axis of the shield to the axis of either conductor.

Consideration of the circular form of shield in Fig. 1 shows that it approaches fairly close to the conductors at the two sides while it is quite well removed from them at the top and bottom of the figure. This means that the capacity of the circuit is greater (and the impedance correspondingly less) and the losses in the shield are greater than would be the case if the shield could be kept at a more nearly uniform distance from the conductors. Consequently, a lower high-frequency attenuation might be obtained if, while keeping the total area circumscribed by the shield unchanged, the shield were modified to an oval or elliptical form with the conductors located on the major axis of the oval or ellipse. Further consideration, however, indicates that a still better result might be secured with such a shape as that shown in Fig. 2, where the shield consists in effect of a semi-circular portion placed around the outside of each conductor and two straight portions connecting the semi-circular portions, each conductor being coaxial with the surrounding semicircular portion. In Fig. 2, 1 and 2 represent the conductors, and 3 the shield, while b_2 is the radius of each conductor, d_2 is the distance from the center of the shield to the center of either conductor, and c_2 is the inner radius of that portion of the shield which is concentric with either conductor. To obtain a circuit which is

balanced with respect to ground, the conductors 1 and 2 may be used one as a return for the other. The shield 3 may be grounded if desired.

The proportioning of the arrangement of Fig. 2 in order to obtain optimum transmission results will now be considered. It has been found that for many purposes the cost of a transmission circuit may be considered as roughly proportional to the space occupied by the circuit. This applies particularly if the circuit in question is one of a number of circuits which are formed up into a cable. Accordingly, it is desirable to determine the configuration of a shield of the type shown in Fig. 2 which will give minimum high-frequency attenuation for a given cross-sectional area.

This problem divides into two parts, first, the case in which the conductors are solid or are otherwise constructed in such a manner that the high-frequency currents travel along the surfaces of the conductors, and, second, the case in which the conductors are composed of insulated strands which are interwoven so as to distribute the high-frequency currents throughout the cross-section of the conductors. The first of these cases will now be taken up.

Comparing Fig. 1 and Fig. 2 it is clear that for equal areas enclosed by the shields in the two cases

$$\pi c_1^2 = \pi c_2^2 + 4c_2d_2 \quad (1)$$

It has been shown in the application of Green, Curtis and Mead, Serial No. 674,762, previously referred to, that for the configuration of Fig. 1 when using solid conductors or their equivalent, minimum high-frequency attenuation is obtained for a given inner diameter of shield when the value of the ratio

$$\frac{d_1}{c_1}$$

is made approximately .46.

It is of interest to consider the factors which determine the value of this ratio. If the dielectric losses are neglected (on the assumption that these can be made small) the sources of loss in a shielded balanced pair are (1) the loss in the conductors, including the proximity effect loss, and (2) the loss in the shield. These losses appear in the familiar expression for the attenuation in the term

$$\frac{R}{2Z_0}$$

where R is the resistance contribution of the conductors and the shield, and Z_0 is the high-frequency characteristic impedance of the circuit. Obviously the attenuation may be reduced either by decreasing the effective resistance R or by increasing the impedance Z_0 . However, changes in the configuration generally affect both R and Z_0 , so that the problem is one of obtaining the balance between the different factors which gives minimum attenuation. The factors involved may be listed more specifically as follows:

1. The increase in losses due to proximity effect (i. e., the tendency of the high-frequency currents to avoid those parts of the conductors which are farthest from each other) as the spacing between conductors is reduced.
2. The increase in eddy current losses in the shield as the spacing between conductors is increased so as to bring them in closer proximity to the shield.
3. The change in the high-frequency charac-

teristic impedance of the circuit. This impedance reaches a maximum when

$$\frac{d_1}{c_1}$$

equals approximately .486, and decreases as the spacing is varied from that value. Since the high-frequency impedance varies inversely with the capacity and directly with the inductance, the spacing of .486 represents also the condition for minimum capacity and maximum inductance.

Those factors having now been examined which determine for the configuration of Fig. 1 the conductor spacing

$$\left(\frac{d_1}{c_1}\right) \div .46$$

which gives minimum high-frequency attenuation for a given cross-sectional area, the corresponding problem in the case of Fig. 2 may be considered.

Comparison of Figs. 1 and 2 indicates that since c_1 in Fig. 1 is measured to the center of the shield, the counterpart of the ratio

$$\frac{d_1}{c_1}$$

for Fig. 1 becomes

$$\frac{d_2}{c_2 + d_2}$$

for Fig. 2. Thus, a change in conductor spacing in Fig. 2 differs from a similar change in Fig. 1 in that in the case of Fig. 2, in order to maintain a constant area within the non-circular shield, c_2 must be changed whenever the conductor spacing is changed.

In order to obtain further light on this problem, it is convenient now to refer to the circuit arrangement illustrated in Fig. 3. This diagram represents two pairs of coaxial conductors placed side by side. A shielded transmission circuit which is balanced to ground is obtained by using 1 and 2 as conductors and 3 and 3', which are assumed to be in contact, as the shield. In this figure b_3 designates the radius of each conductor and c_3 , the radius of either half of the shield. A transmission circuit of the type shown in this figure is the subject of the copending application of E. I. Green, Serial No. 674,765, filed June 7, 1933. It is shown in that application that minimum high-frequency attenuation is obtained for a circuit of this kind when the ratio

$$\frac{c_3}{b_3}$$

is made approximately 3.59.

Now it will be observed that Fig. 3 bears a strong resemblance to Fig. 2. The similarity is emphasized if there is drawn in Fig. 2 the line $a-a$ to represent an imaginary mutual plane midway between the two conductors. Inspection of these two figures will make it clear that for a given cross-sectional area of the shield the minimum capacity (and hence maximum high-frequency characteristic impedance) will result for Fig. 2 when the conductors are separated by less than twice the distance c_2 . This is because the greater capacity between the conductor and the middle portion of the wall $a-a$ is offset by the smaller capacity between the conductor and those portions of the wall adjacent the shield 3. The shape of Fig. 2 is such that the conductor spacing giving minimum capacity and maximum impedance can be determined

graphically to a very good degree of approximation. The problem of finding minimum capacity is evidently one of balancing the change in capacity at the middle of the mutual plane as the conductor spacing is changed against the change in capacity occurring at the top and bottom of the mutual plane. By graphical methods it may, therefore, be determined that the condition giving minimum capacity (also maximum high-frequency impedance and maximum inductance) for a given cross-sectional area in Fig. 2 is that the conductor spacing

$$\frac{d_2}{c_2 + d_2}$$

should equal approximately .47.

One further step is required to determine the condition giving minimum high-frequency attenuation for a given cross-sectional area in Fig. 2. It has been seen in Fig. 1 that to obtain minimum high-frequency attenuation, the spacing is shifted from the value of .486 (corresponding to maximum impedance) to a value of .46. In Fig. 2 the shift from the spacing giving maximum impedance to that for minimum attenuation should be smaller inasmuch as the rate of change of the shield losses as the spacing ratio is changed is greater than in Fig. 1. Careful study indicates that the spacing giving minimum high-frequency attenuation for a given cross-sectional area in Fig. 2 may be written with a close degree of approximation:

$$\frac{d_2}{c_2 + d_2} \div .46 \quad (2)$$

On combining Equations (1) and (2), it is found that for equal areas in Figs. 1 and 2

$$c_2 \div .69c_1 \quad (3)$$

$$d_2 \div .59c_1 \quad (4)$$

Having determined the optimum spacing between conductors for Fig. 2, it is now of interest to determine the optimum size of conductors, or, more properly speaking, the value of the ratio

$$\frac{c_2}{b_2}$$

which results in minimum high-frequency attenuation for a given cross-sectional area. Comparison of Figs. 2 and 3 indicates that the optimum value of the ratio

$$\frac{c_2}{b_2}$$

in Fig. 2 should be fairly close to the optimum value of 3.59 for

$$\frac{c_3}{b_3}$$

and further, that the departure should be on the side of a slight increase in the ratio

$$\frac{c_2}{b_2}$$

A comparison of Figs. 1 and 2 throws added light on the matter. The optimum value of the ratio

$$\frac{c_1}{b_1}$$

in Fig. 1 is approximately 5.4. Now if $c_2 = .69c_1$, the corresponding ratio for Fig. 2 would be approximately 3.75. Inspection of the two figures indicates that the optimum ratio for Fig. 2 should not be far from this value of 3.75. It seems,

therefore, that for practical purposes the optimum value of

$$\frac{c_2}{b_2} \approx 3.7 \quad (5)$$

It is interesting to note that the optimum proportioning ratios for Fig. 2 at high frequencies are independent of the frequency, the size of the conductors, and other variables. It will be obvious that the high-frequency attenuation of the system can be reduced by increasing the size of the shield, keeping

$$\frac{c_2}{b_2} \text{ and } \frac{d_2}{c_2}$$

fixed. The size of the shield will ordinarily be determined by such considerations as the maximum frequency to be transmitted over the circuit and the maximum allowable attenuation at that frequency.

It will now be of interest to determine at least approximately the value of high-frequency attenuation which results for the circuit of Fig. 2 when the values given in Equations (2) and (5) are used. It is evident from an inspection of Fig. 2, which has actually been drawn using the values given in (2) and (5), that the capacity of a circuit with this proportioning is very close to, but slightly greater than, the capacity of a coaxial circuit of the type shown in Fig. 3 and having

$$\frac{c_3}{b_3} = \frac{c_2}{b_2}$$

The capacity of this coaxial circuit is given by the formula

$$C = \frac{\epsilon}{4 \log_e \frac{c_2}{b_2}} \text{ abfarads per cm.} \quad (6)$$

where ϵ is the dielectric constant. The capacity of the circuit of Fig. 2 with optimum proportioning may be set down as follows with a small degree of error:

$$C = \frac{1.015\epsilon}{4 \log_e \frac{c_2}{b_2}} \text{ abfarads per cm.} \quad (7)$$

Insertion of numerical values indicates that the capacity for the circuit of Fig. 2 is about 13 per cent less than that for Fig. 1. Since the high-frequency characteristic impedance varies inversely with the capacity, the circuit in Fig. 2 will have an impedance about 13 per cent higher than that of Fig. 1. Also, the high-frequency inductance of the circuit of Fig. 2 will be about 13 per cent higher than that of Fig. 1.

With regard to the resistance of the circuit of Fig. 2, a comparison with Fig. 1 indicates that the losses introduced by the sheath will be less than in Fig. 1 because of the greater separation of the conductors from the sheath. The proximity effect in Fig. 1 for the case of solid conductors has been shown to be small owing to the reaction of the sheath currents. In Fig. 2 a larger proximity effect may be anticipated. It is probably on the conservative side to assume that the resistance reduction due to lower sheath losses is balanced by the resistance increase due to proximity effect, and that the resistances of the two circuits are equal. On this basis the high-frequency attenuation of the circuit of Fig. 2 would be lower than that of Fig. 1 by the amount

of the reduction in capacity, i. e., about 12 per cent.

Fig. 4 shows a curve for the high-frequency attenuations of the circuits of Figs. 1 and 2 on this basis, derived on the assumption that the inner diameter of shield in Fig. 1 is one-half inch and that the two circuits occupy the same cross-sectional area. It will be noted that at a frequency of 1,000 kilocycles the attenuation of the pair with non-circular shield is approximately 3.6 db per mile. Hence, if repeaters having a gain of 60 db each were connected in the circuit, these could be spaced at intervals of about 17 miles.

The case where the conductors in Fig. 2 are composed of insulated strands will now be considered. As will be pointed out later, such stranding may be accomplished in various ways. Ordinarily the purpose of stranding would be to reduce the resistance of the conductors at high frequencies by counteracting the tendency of the currents to concentrate on the surface of the conductor, and to increase the internal inductance of each conductor. Both of these results tend to decrease the high-frequency attenuation. Stranding may also be advantageous from the standpoint of obtaining a flexible structure.

In order to counteract the tendency of the currents to concentrate on the surface of the conductor at high frequencies it is essential that the insulated strands be passed back and forth toward and from the center of the conductor. With a suitable method of stranding the high-frequency current may be distributed substantially uniformly over the cross-section of the conductor.

The high-frequency resistance of the one stranded conductor alone (in abohms per centimeter) may be written as

$$\frac{n}{b_2} \sqrt{\frac{f}{\lambda}}$$

b_2 being the radius of the conductor, f the frequency in cycles, λ the conductivity (approximately 5.8×10^{-4} abmhos per centimeter cube for copper), and n the ratio of the resistance of the stranded conductor to the resistance of a solid conductor of the same diameter at the frequency f .

The value of n for a conductor that is stranded in such a manner that the current density is uniform throughout its entire cross-section can be obtained from a formula by S. Butterworth, published in the Philosophical Transactions of the Royal Society of London, vol. 222, p. 57. Equation (85) therein should be modified by the omission of the two terms which involve D^2 when it will read

$$R' = R_0 \left[\left(1 + \frac{\alpha^2}{2} \right) (1 + F) + \frac{2S^2 \delta^2 G}{d_0^2} \right] \quad (8)$$

In this formula F and G are certain functions which are given in graphical and tabular form in the article referred to; the other symbols are as follows: S =number of strands, δ =diameter of each strand, α =angle of twist, and d_0 =overall diameter of stranded wire. This formula gives the A. C. resistance of one stranded conductor in abohms per centimeter. The high-frequency resistance R_1' of a solid wire is given by the expression

$$\frac{1}{b_2} \sqrt{\frac{f}{\lambda}}$$

The value of n may be determined by dividing R' by R_1' .

Fig. 5 shows how the value of n varies with frequency for two assumed conditions of stranding. It will be observed that the value of n may be made considerably less than unity at frequencies in the vicinity of 500 kilocycles or above. By the use of Formula (8) the stranded conductors may be designed so as to have as low a value of n as practicable at the maximum frequency to be transmitted over the circuit.

As pointed out below, it would be possible, instead of filling up the complete conductor cross-section with insulated strands, to arrange the strands in an annular cross-section, the stranding being carried out in such a way that the path of any individual strand would extend between the outer and inner circumferences of the annulus. If the conductors are stranded in this or some other manner the value of n may be determined by computation or experiment.

In the application of Green and Curtis, Serial No. 674,763, it is shown that when the conductors in Fig. 1 are completely stranded, for the values of n ordinarily realizable in practice, the minimum high-frequency attenuation will be obtained when the spacing ratio

$$\frac{d_1}{c_1}$$

is given a value of from .41 to .42 and the ratio of radii

$$\frac{c_1}{b_1}$$

approximately 5.0. Comparison of Figs. 1 and 2 indicates that inasmuch as the losses in the shield are lower in Fig. 2, the spacing ratio

$$\frac{d_2}{c_2 + d_2}$$

in Fig. 2 should be slightly larger than

$$\frac{d_1}{c_1}$$

in Fig. 1. It is clear, however, that this ratio should be closer to the value of .41 or .42 than to the value of .47 which gives maximum circuit impedance for Fig. 2. A reasonable range of working values for different values of n would appear to be from .42 to .43.

As in the case of solid conductors, the optimum ratio of radii for the case of stranded conductors can best be determined by comparison of Figs. 2 and 3. In the co-pending application of E. I. Green, Serial No. 674,765, it is shown that when the conductors in Fig. 3 are stranded, the ratio of radii

$$\frac{c_3}{b_3}$$

which gives minimum attenuation ranges from about 3.3 to 4.3, depending upon the value of n .

In view of the close resemblance of Figs. 2 and 3, the ratio

$$\frac{c_2}{b_2}$$

for Fig. 2 should evidently be very close to this range of values. Another check on the optimum ratio is obtained by comparison with Fig. 1, for which the ratio

$$\frac{c_1}{b_1}$$

should be approximately 5.0. The corresponding value of the ratio

$$\frac{c_2}{b_2}$$

in Fig. 2 would be approximately 3.6. It is not necessary to determine the optimum value of

$$\frac{c_2}{b_2}$$

with a high degree of accuracy inasmuch as, for reasonable departures from the optimum, the attenuation will not be appreciably increased. For the values of n obtained in practice, results closely approaching the optimum will be obtained in the range of values

$$3.3 \leq \frac{c_2}{b_2} \leq 4.3 \quad (9)$$

It is now of interest to compare the attenuation of the circuit of Fig. 2 when using stranded conductors with that of Fig. 1 for stranded conductors. Considerations similar to those which have been set forth for the case of solid conductors make it evident that the capacity of the circuit of Fig. 2 with stranded conductors should be about 12 per cent less than that of Fig. 1 and the inductance and high-frequency impedance about 13 per cent greater than for Fig. 1.

Since the stranding of the conductors eliminates proximity effect, there remains only the sheath loss to be added to the resistance of the conductors themselves. Inasmuch as the sheath losses are lower in Fig. 2, the resistance of the circuit of Fig. 2 will be lower than for Fig. 1, the actual amount depending on the value of n . For ordinary working values of n it is thought that the resistance of Fig. 2 with stranded conductors may be of the order of 10 to 15 per cent less than that of Fig. 1 for stranded conductors.

It follows from the above that the high-frequency attenuation of the circuit of Fig. 2 with stranded conductors will be of the order of 20 to 30 per cent lower than that of the Fig. 1 circuit with stranded conductors, the actual difference depending upon the nature of the stranding.

The foregoing derivation of the proportioning of a circuit with non-circular shield in order to obtain minimum high frequency attenuation has largely been directed toward the cases where the insulating medium is largely gaseous so that the dielectric constant is substantially unity and a leakage conductance substantially zero. It can be shown, however, that the optimum proportioning will remain substantially unchanged for other types of dielectric. Thus if the space between conductors and shield is filled with a homogeneous non-gaseous dielectric as, for example, rubber or oil, the ratios giving minimum high-frequency attenuation should be the same as for a gaseous dielectric. This will also be the case when a mixture of dielectrics is employed, for example, a combination of gaseous and non-gaseous dielectrics provided that the arrangement of the dielectric is such as not to distort the path which would be assumed by the dielectric flux if the dielectric medium were entirely gaseous. Where a combination of dielectrics is employed in such a manner as to produce such distortion of the flux both the ratios for optimum proportioning may be changed to some extent, but, in general, characteristics approaching the optimum will be obtained for the values which have previously been set forth.

Some of the fundamental principles of the invention having now been set forth, consideration may be given to types of structures in which these principles may be incorporated. Fig. 6 represents a view of a transmission structure

consisting of a pair with non-circular shield. In this figure, 1 and 2 represent two solid conductors which are held in position with respect to one another and the non-circular shield 3 by insulating spacers 4 or other suitable devices. The conductors of the pair are connected one as a return for the other, as is indicated conventionally by the generator G. If desired, the shield 3 may be grounded as indicated on the drawings.

The conductors 1 and 2 may be of such a type that currents of frequencies well above the audible range travel substantially on the outer surfaces of the conductors. For example, the conductors may be solid wires or may be tubular. If tubular conductors are employed, their wall thickness will ordinarily depend upon mechanical rather than electrical considerations, since only a very thin wall is required. Also, the conductors may consist of a cylindrical assembly of conducting strips, tapes, ribbons, wires or the like which are not insulated from one another. Such a form of construction might be particularly desirable where a flexible structure is required. One construction of this type is indicated in Fig. 7, the conductors 1 and 2 in this case being composed of uninsulated wires stranded together.

As has already been pointed out, it may be found advantageous to construct the conductors 1 and 2 of a number of strands, filaments, tapes or the like which are insulated from one another and are interwoven or braided together in any of various ways. In this manner there may be obtained a reduction in the high-frequency resistance of the conductors and an increase in their internal inductance, both of which tend to reduce the high-frequency attenuation of the circuit. In order to obtain these results it is essential that the insulated strands be passed back and forth toward and from the center of the conductor.

With a suitable method of stranding, the high-frequency current may be distributed substantially uniformly over the cross-section of the conductor. One method of securing this result is to strand the conductor in a manner similar to that used in the manufacture of rope. Thus, several individual strands (for example, three) would first be twisted together; next several of these groups would be twisted together to form larger groups and several of the larger groups would be twisted together, the process being continued until the desired total number of strands is obtained. If the stranding interval or pitch is made different for the successive twisting operations, it will be found that with such a method any one strand in going along the conductor travels a path back and forth between the center of the conductor and its periphery. A structure employing conductors stranded in this manner is illustrated in Fig. 8.

Instead of being twisted together as described above, the strands might be interwoven or braided in other ways so as to produce the desired effect. Also, it would be possible, as already noted, to employ an annular cross-section for the insulated strands, the core of the conductor being filled up with some non-conducting material such as jute, or with a conducting material such as copper or steel to provide strength or rigidity. The stranding might preferably be designed in such a way that the path of any strand would extend between the outer and inner circumferences of the annulus. A structure employing stranded

conductors having an annular cross-section of this kind is illustrated in Fig. 9.

Any of various forms or shapes may be employed for the insulation between the two conductors and between conductors and sheath. One possible arrangement would be to use a continuous spirally applied string or strip of dielectric material around each conductor and another spirally applied string to separate them from the shield. An arrangement of this type is illustrated in Fig. 10, where 5 and 6 are strings of insulating material wrapped spirally around the conductors, 7 and 8 are thin strips of insulating material covering the conductors and the spirally wrapped strings and 9 is a spirally applied string separating the conductors from the shield. Generally, it will be desirable that the amount of insulating material be a minimum in order that the dielectric between the two conductors may be largely gaseous. In some cases, however, it will be found advantageous to use a dielectric which is wholly or partly non-gaseous, as, for example, rubber insulation. A structure with a dielectric of this kind is shown in Fig. 11. For the insulation arrangements that would ordinarily be employed in practice, the optimum configuration of the circuit will be approximately the same as for the assumed condition of a gaseous dielectric.

The shield surrounding the two conductors, instead of being formed of a single tube, might consist of a cylindrical assembly of conducting strips, tapes, wires, ribbons or the like. Such forms of construction might be particularly advantageous where a flexible structure is desired. One construction of this kind is illustrated in Fig. 12, where the shield consists of a number of spiral segments formed into a tube. If desired the shield may be surrounded by a water-proof sheath or covering 10, which may be composed of lead, rubber or other suitable material.

In connection with the shield, it may be noted that, in addition to performing an electrical function by protecting against inductive effects, it may be useful in affording mechanical protection to the circuit and thereby permitting the use, to a very considerable extent, of an air dielectric. Due to skin effect the high-frequency currents will penetrate only a little way into the shield, so that the electrical requirements are satisfied by a very thin shield. Consequently, the thickness of the shield will ordinarily be determined by mechanical considerations and will usually be such that it does not enter into the problem of determining the optimum configuration of conductors and shield.

The use of the shield will ordinarily make it possible where desired to allow the signals transmitted over the pair to drop down to a minimum level determined by the noise due to thermal agitation of electricity in the conductors. Hence, the shield facilitates the spacing of intermediate amplifiers in the circuit at wider intervals than would otherwise be possible.

It has been proposed in connection with the circuit of Fig. 1 that the conductors be transposed at frequent intervals in order to reduce the possibility of interference into or from the circuit at low frequencies where the shield is less effective. Such transposition can readily be accomplished for the circuit of Fig. 1 by twisting the two conductors helically about the axis of the shield. It is evident that a transposition arrangement of this kind is not suitable for a structure of the type represented in Fig. 2, since the twisting of the conductors with respect to the shield would

bring them in contact with or in too close proximity to the shield. However, if it should be desired to transpose the circuit of Fig. 2 in order to improve its characteristics at low frequencies, this can be done by the method illustrated in Fig. 13, where the entire structure consisting of conductors and non-circular shield is twisted about its axis. Such twisting has, of course, the possible disadvantage of increasing the space which may be occupied by the structure if it is to be laid up in a cable with other structures.

The structures which have been illustrated in Figs. 6 to 13, comprising conductors surrounded by non-circular shields, may be employed as transmission media for various types of transmission systems. Some of the systems which may be used in this manner are illustrated schematically in Figs. 14 to 16.

Fig. 14 is a diagram of a multiplex carrier telephone system including the channel modulating and demodulating equipment, the filter apparatus required for segregating the different channels and the amplifying apparatus at the terminals and at intermediate points along the line. In this figure voice-frequency currents derived from the instruments SS are applied to individual modulators as indicated by CM which convert them to carrier frequencies. The wanted sidebands are selected by channel filters CF and may, after passing through the amplifier TA, be applied to the line section LC comprising a pair of wires with non-circular shield designed in accordance with the invention. At suitable points in the line repeaters such as IR may be inserted. At the receiving end the incoming carrier channels may, after being amplified in the receiving amplifier RA, be separated by means of the channel filters SF and be brought again to voice frequencies in channel demodulators as indicated by CD. The arrangement as shown serves for transmission in one direction and a duplicate arrangement would be provided for the opposite direction of transmission.

Fig. 15 is a diagram of a television system in which the line circuit is provided by a pair of conductors having a non-circular shield. In this diagram TT represents the television transmitting apparatus by means of which the television signals are applied to the line circuit LC. The transmitting apparatus may be such as to furnish to the line a band of frequencies extending from approximately zero frequency to a high frequency determined by the degree of image definition which it is desired to obtain. If desired, however, this apparatus may also include modulating equipment whereby the television band of signals is shifted to a higher position in the frequency spectrum. At the receiving end the television receiving apparatus TR takes the band of signals delivered by the line and converts it into the desired image, this apparatus including whatever demodulating apparatus may be required to shift the frequency position of the television band in a manner reverse to that employed at the transmitting end. The arrangement illustrated serves for a single direction of transmission and may be duplicated for the opposite direction of transmission. It is obvious that other signals as, for example, those from voice channels, may be combined with the television signals for transmission over the line.

Fig. 16 is a diagram of a radio transmitting system in which the connection from the transmitting apparatus to the transmitting antenna is secured by means of a pair with non-circular

shield and the connection between the receiving antenna and the receiving apparatus is similarly obtained. In this diagram RT designates radio transmitting apparatus and TL a transmission circuit for connecting this apparatus to the transmitting antenna TA, while RA designates a receiving antenna whose output is transmitted over the receiving circuit RL to the radio receiving apparatus RR.

The terminal apparatus and amplifiers which may be used in connection with a transmission line such as previously described may be shielded from electrical interference from outside sources by surrounding them with sheet metal compartments. These compartments may be connected to the shield of the transmission line if desired. Such compartments are illustrated in Figs. 14, 15 and 16.

The arrangements thus far described have contemplated the use of the structure with non-circular shield for providing a balanced transmission circuit in which the conductors 1 and 2 are employed one as a return for the other. If desired, it would be possible to derive from the same structure an independent transmission circuit by connecting the conductors 1 and 2 in parallel and using the sheath as a return. Figs. 17 and 18 illustrate two different methods of deriving two independent transmission circuits, one balanced and one unbalanced, from the structure of Fig. 2. In Fig. 17, the generator G_1 is connected to the conductors 1 and 2 through a transformer T_1 , thus providing a balanced to ground circuit. Generator G_2 is connected between the electrical midpoint of the conductors 1 and 2, provided by a center tap on the secondary of transformer T_1 and the shield, providing a second circuit, the latter being unbalanced to ground. In Fig. 18, the generator G_1 is connected directly to the conductors 1 and 2 providing a balanced to ground circuit. An unbalanced to ground circuit is obtained by connecting a generator G_2 between the shield and the midpoint of a resistance R shunted across the generator G_1 .

Figs. 19 and 20 illustrate methods in which structures of the type shown in Figs. 2 to 11 may be laid up in cable form. In the lay-ups illustrated the various circuits are so disposed with reference to one another as to tend to minimize the coupling which would exist between them at low frequencies where the shielding is only partially effective.

It will be noted in Figs. 19 and 20 that the oval shields do not extend to the center of the cable. This center space may be left empty or may be filled with jute, paper or other similar material. It may be utilized by filling it with pairs of wires or by placing a coaxial conductor in it. In Figs. 19 and 20 a coaxial conductor is shown in the center of the cable, 11 and 12 being the inner and outer conductors, respectively.

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

What is claimed is:

1. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a high frequency transmission path, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent

thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, the interaxial separation of said conductors being less than the diameter of said semi-circular portions, said conductors and shield being insulated from one another, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied.

2. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a high frequency transmission path, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, the interaxial separation of said conductors being less than the diameter of said semi-circular portions, said conductors and shield being insulated from one another by a substantially gaseous dielectric, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied.

3. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a high frequency transmission path, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, the interaxial separation of said conductors being less than the diameter of said semi-circular portions, said conductors and shield being insulated from one another, said conductors being of such a type that conduction of currents whose frequencies are substantially above the audible range takes place substantially on the surface of said conductors, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied.

4. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a high frequency transmission path, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said

conductors is surrounded coaxially by a semi-circular portion of said shield, the interaxial separation of said conductors being less than the diameter of said semi-circular portions, said conductors and shield being insulated from one another, each of said conductors consisting of a plurality of conducting strands insulated from one another, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied.

5. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, a flattened conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another; the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being less than the ratio which gives maximum characteristic impedance of the circuit, and approximately equal to

$$\frac{d_1}{c_1}$$

where, in a system of cylindrical conductors surrounded by a circular shield and designed for minimum attenuation, $2d_1$ is the separation between conductors and c_1 is the radius of the shield; and the ratio of the inner diameter of either semi-circular portion of said shield to the outer diameter of each of said conductors being of the order of magnitude of

$$\frac{c_3}{b_3}$$

where, in a system of cylindrical conductors each surrounded by its own individual shield and designed for minimum attenuation, c_3 is the radius of the shield and b_3 is the radius of the conductor; and the high frequency attenuation of the circuit having a flattened shield being a minimum for the cross-sectional area included within said shield.

6. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, a flattened conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another by a substantially gaseous dielectric; the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being less than the ratio

which gives maximum characteristic impedance of the circuit, and approximately equal to

$$\frac{d_1}{c_1}$$

5 where, in a system of cylindrical conductors surrounded by a circular shield and designed for minimum attenuation, $2d_1$ is the separation between conductors and c_1 is the radius of the shield; and the ratio of the inner diameter of
10 either semi-circular portion of said shield to the outer diameter of each of said conductors being of the order of magnitude of

$$\frac{c_3}{b_3}$$

15 where, in a system of cylindrical conductors each surrounded by its own individual shield and designed for minimum attenuation, c_3 is the radius of the shield and b_3 is the radius of the conductor; and the high-frequency attenuation of the circuit having a flattened shield being a minimum for the cross-sectional area included within
20 said shield.

25 7. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, said conductors being of such a type that con-
30 duction of currents whose frequencies are substantially above the audible range takes place substantially on the surface of said conductors, a flattened conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions
35 joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another;
40 the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being less than the ratio which gives maximum characteristic
45 impedance of the circuit, and approximately equal to

$$\frac{d_1}{c_1}$$

50 where, in a system of cylindrical conductors surrounded by a circular shield and designed for minimum attenuation, $2d_1$ is the separation between conductors and c_1 is the radius of the shield; and the ratio of the inner diameter of
55 either semi-circular portion of said shield to the outer diameter of each of said conductors being slightly larger than

$$\frac{c_3}{b_3}$$

60 where, in a system of cylindrical conductors each surrounded by its own individual shield and designed for minimum attenuation, c_3 is the radius of the shield and b_3 is the radius of the conductor; and the high frequency attenuation of the
65 circuit having the flattened shield being a minimum for the cross-sectional area included within said shield.

70 8. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, each of said conductors consisting of a plurality of conducting strands insulated from one another, a flattened conducting shield surrounding
75 said conductors, said shield comprising two por-

tions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially
5 by a semi-circular portion of said shield, said conductors and shield being insulated from one another; the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the
10 length of each flat portion of said shield being less than the ratio which gives maximum characteristic impedance of the circuit, and approximately equal to

$$\frac{d_1}{c_1}$$

15

where, in a system of cylindrical conductors surrounded by a circular shield and designed for minimum attenuation, $2d_1$ is the separation between conductors and c_1 is the radius of the
20 shield; and the ratio of the inner diameter of either semi-circular portion of said shield to the outer diameter of each of said conductors being of the order of magnitude of

$$\frac{c_3}{b_3}$$

25

where, in a system of cylindrical conductors each surrounded by its own individual shield and designed for minimum attenuation, c_3 is the radius
30 of the shield and b_3 is the radius of the conductor; and the high frequency attenuation of the circuit with the flattened shield being a minimum for the cross-sectional area included within said shield.

35 9. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section, and flat portions joining the
40 ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another, the ratio of
45 the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield, being approximately in the range between .42 and .46 and the ratio of
50 the inner diameter of either semi-circular portion of said shield to the outer diameter of each of said conductors being approximately in the range between 3.3 and 4.3.

55 10. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, said conductors being of such a type that con-
60 duction of currents whose frequencies are substantially above the audible range takes place substantially on the surface of said conductors, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section, and flat portions joining the
65 ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another, the
70 ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being approximately .46 and the ratio of the inner diameter of
75

either semi-circular portion of said shield to the outer diameter of each of said conductors being approximately 3.7.

11. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, each of said conductors consisting of a plurality of conducting strands insulated from one another, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section, and flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another, the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being approximately in the range between .42 and .43 and the ratio of the inner diameter of either semi-circular portion of said shield to the outer diameter of each of said conductors being approximately in the range between 3.3 and 4.3.

12. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, said conductors being of such a type that conduction of currents whose frequencies are substantially above the audible range takes place substantially on the surface of said conductors, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section, and flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another by a substantially gaseous dielectric, the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being approximately .46 and the ratio of the inner diameter of either semi-circular portion of said shield to the outer diameter of each of said conductors being approximately 3.7.

13. An electrical transmission circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other, each of said conductors consisting of a plurality of conducting strands insulated from one another, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section, and flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another by a substantially gaseous dielectric, the ratio of the interaxial separation of said conductors to the inner diameter of either semi-circular portion of said shield plus the length of either flat portion of said shield being approximately in the range between .42 and .43 and the ratio of the inner diameter of either semi-circular portion of the shield to the outer diameter of each of said conductors being approximately in the range between 3.3 and 4.3.

14. An electrical transmission structure comprising a pair of cylindrical conductors, one of said conductors being connected as a return for the other, a conducting shield surrounding said

conductor, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another, means for connecting said conductors in series to form a high frequency transmission circuit, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied, and means for connecting to the electrical center of said pair of conductors for establishing an independent high frequency transmission circuit between said pair of conductors in parallel as one conductor and said shield as the other conductor.

15. An electrical transmission structure comprising a pair of cylindrical conductors, one of said conductors being connected as a return for the other, a conducting shield surrounding said conductors, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, said conductors and shield being insulated from one another, means for connecting said conductors in series to form a balanced to ground high frequency transmission circuit, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied, and means for connecting said pair of conductors in parallel for establishing an unbalanced to ground high frequency transmission circuit between said pair of conductors and said shield.

16. In an electrical transmission system, a line circuit comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a high frequency transmission path, a conducting shield surrounding said conductors, said shield and conductors being insulated from one another, said shield comprising two portions of semi-circular cross-section with flat portions joining the ends of said semi-circular portions and tangent thereto and so disposed that each of said conductors is surrounded coaxially by a semi-circular portion of said shield, the transmission path formed from said cylindrical conductors acting one as a return for the other having connected thereto apparatus for applying thereto and receiving and utilizing therefrom a band of signal frequencies whose range is many times that of the audible range, said path with its associated shield acting to transmit without excessive attenuation the band of frequencies so applied, and repeaters at intermediate points in said line circuit for amplifying the range of frequencies transmitted.

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