

March 17, 1936.

E. I. GREEN

2,034,035

CIRCUITS WITH DOUBLE CIRCULAR SHIELDS

Filed June 7, 1933

5 Sheets-Sheet 1

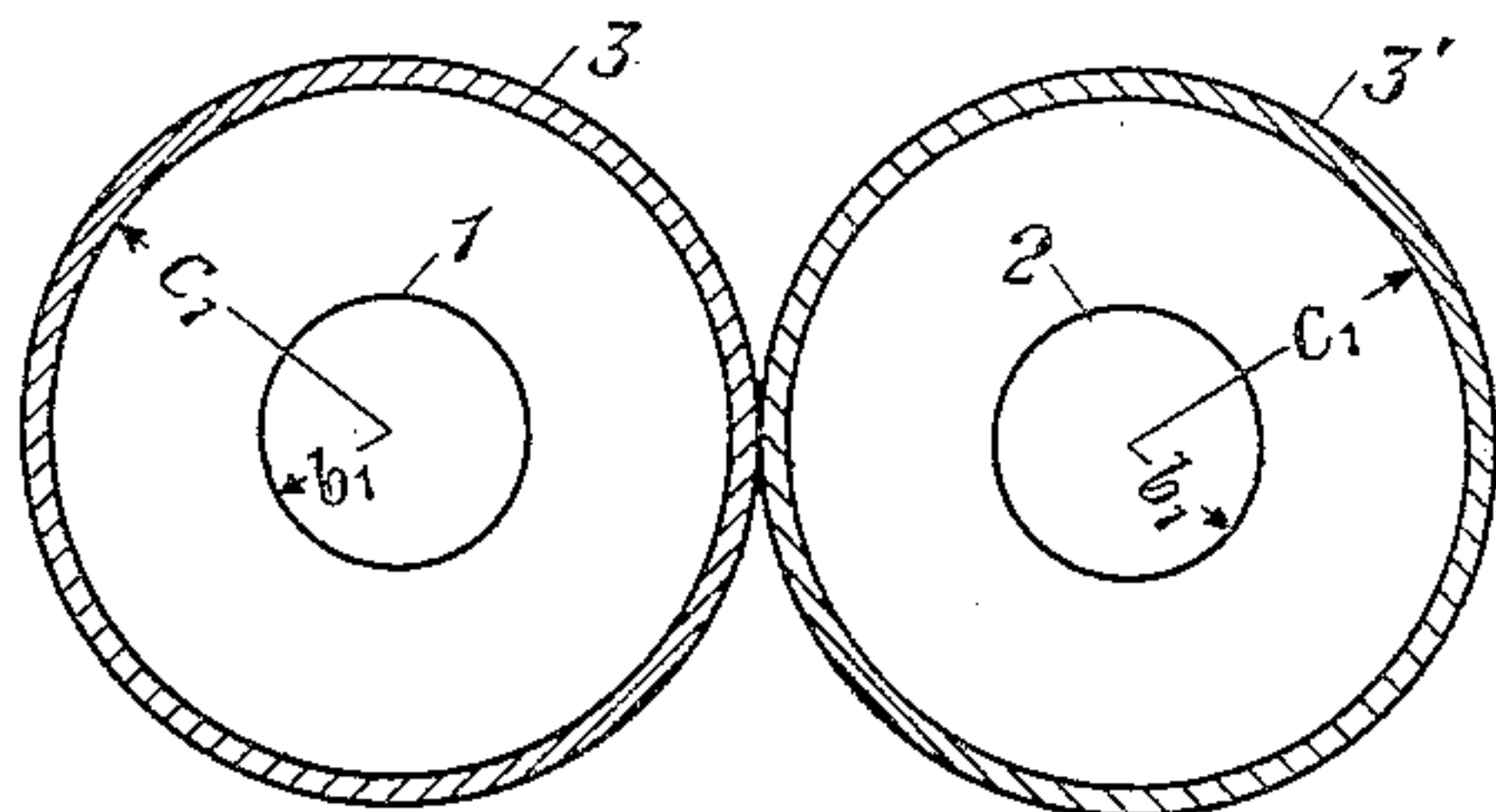


Fig. 1

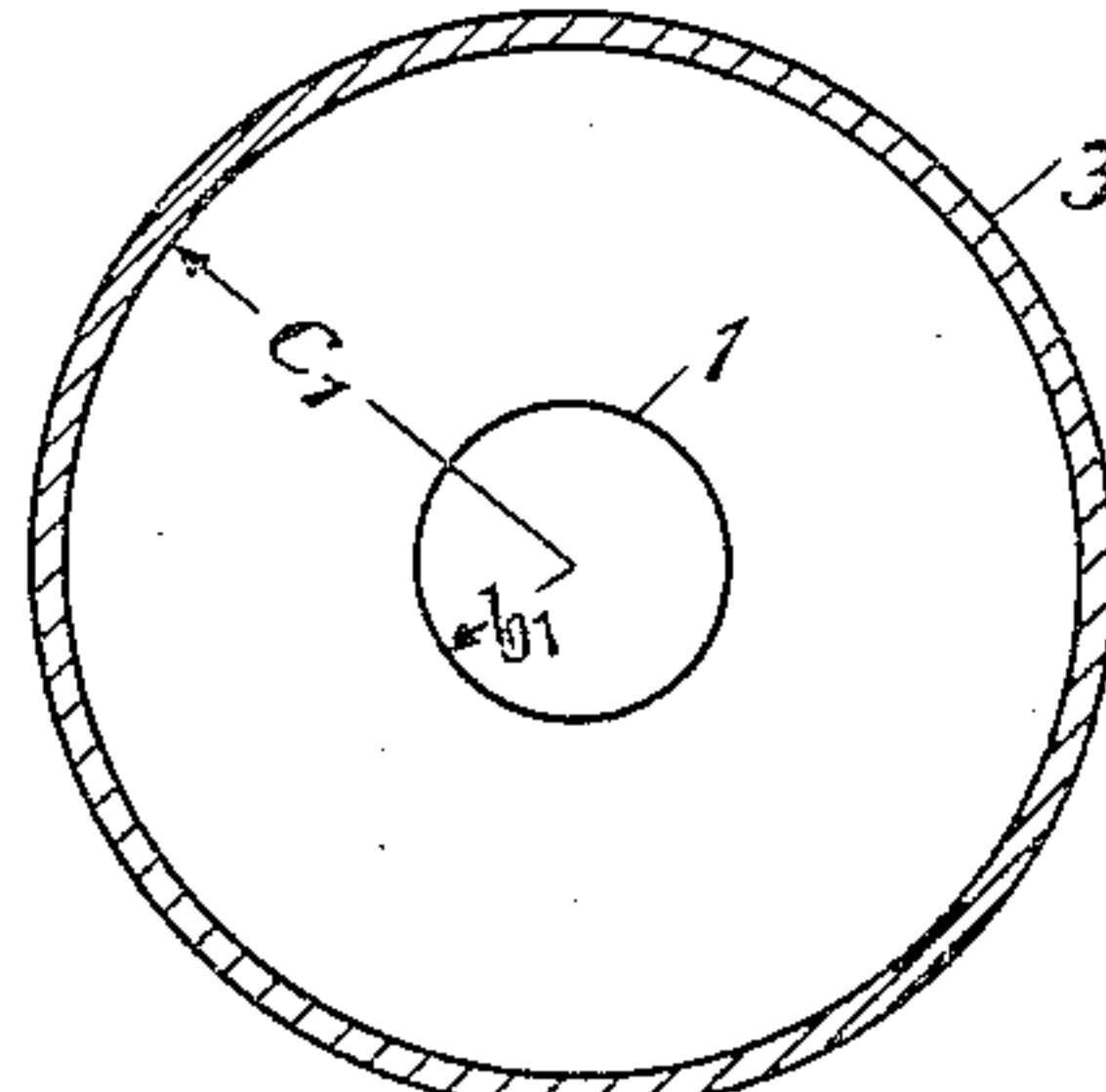


Fig. 2

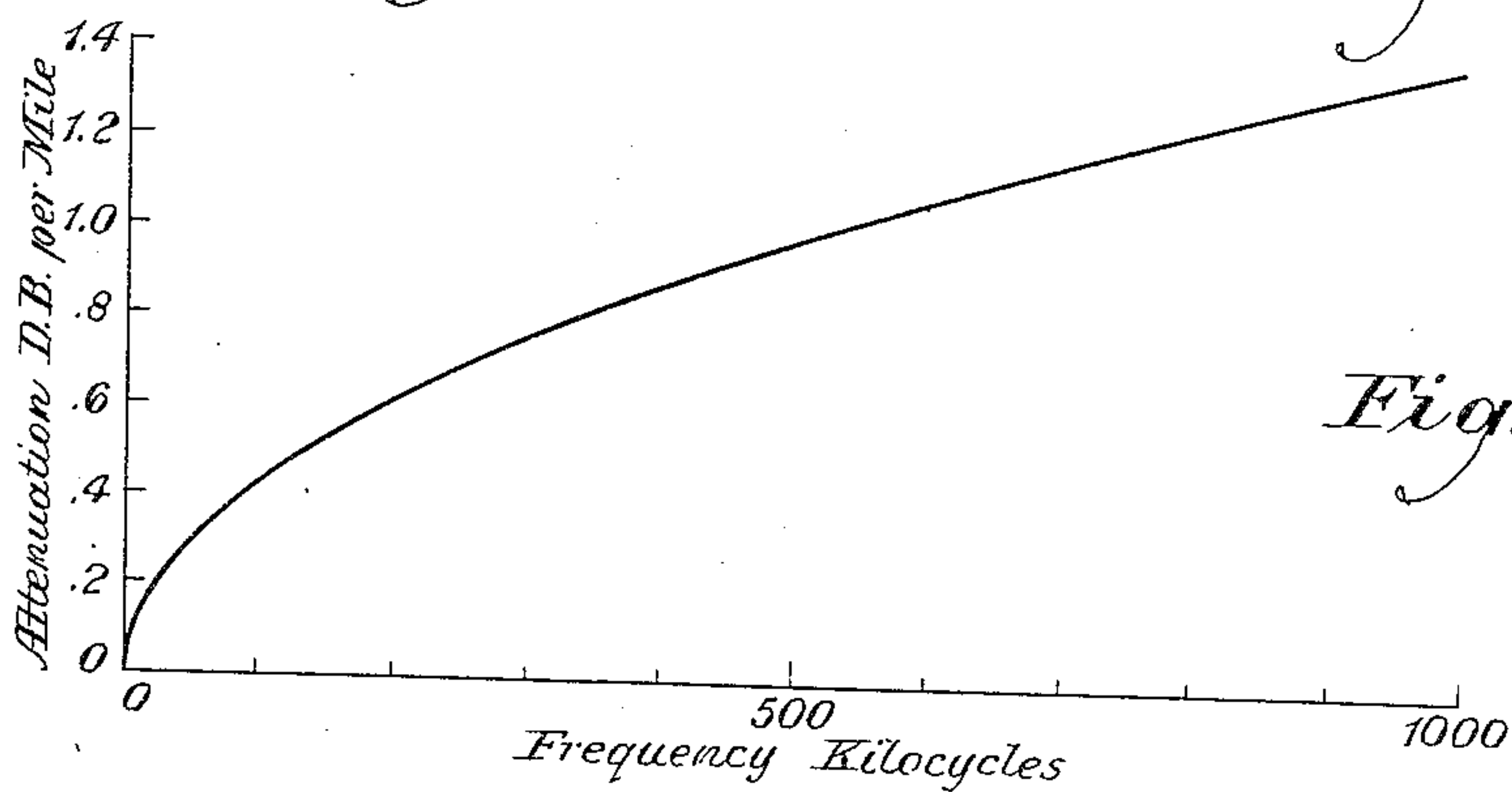


Fig. 3

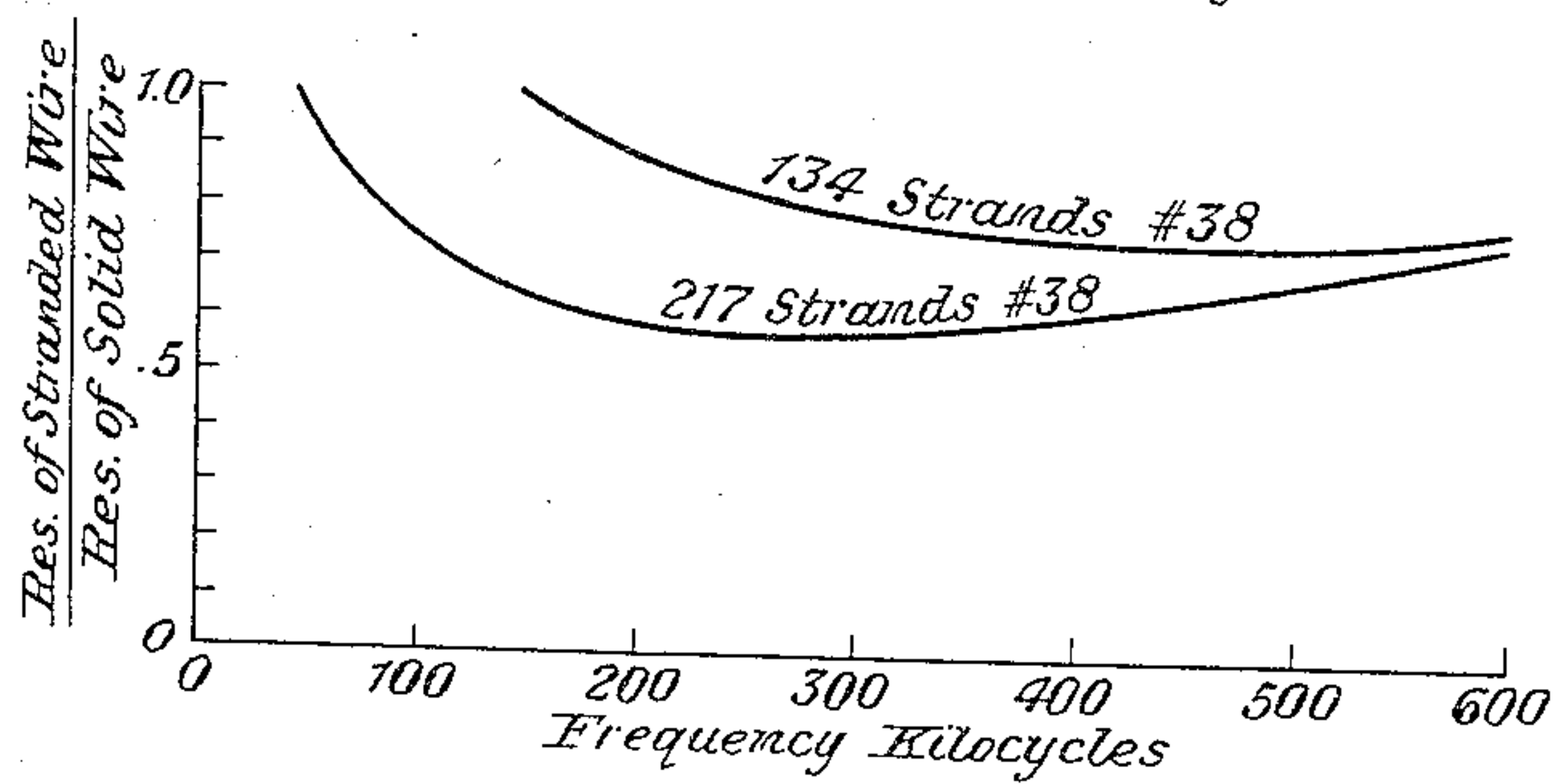


Fig. 4

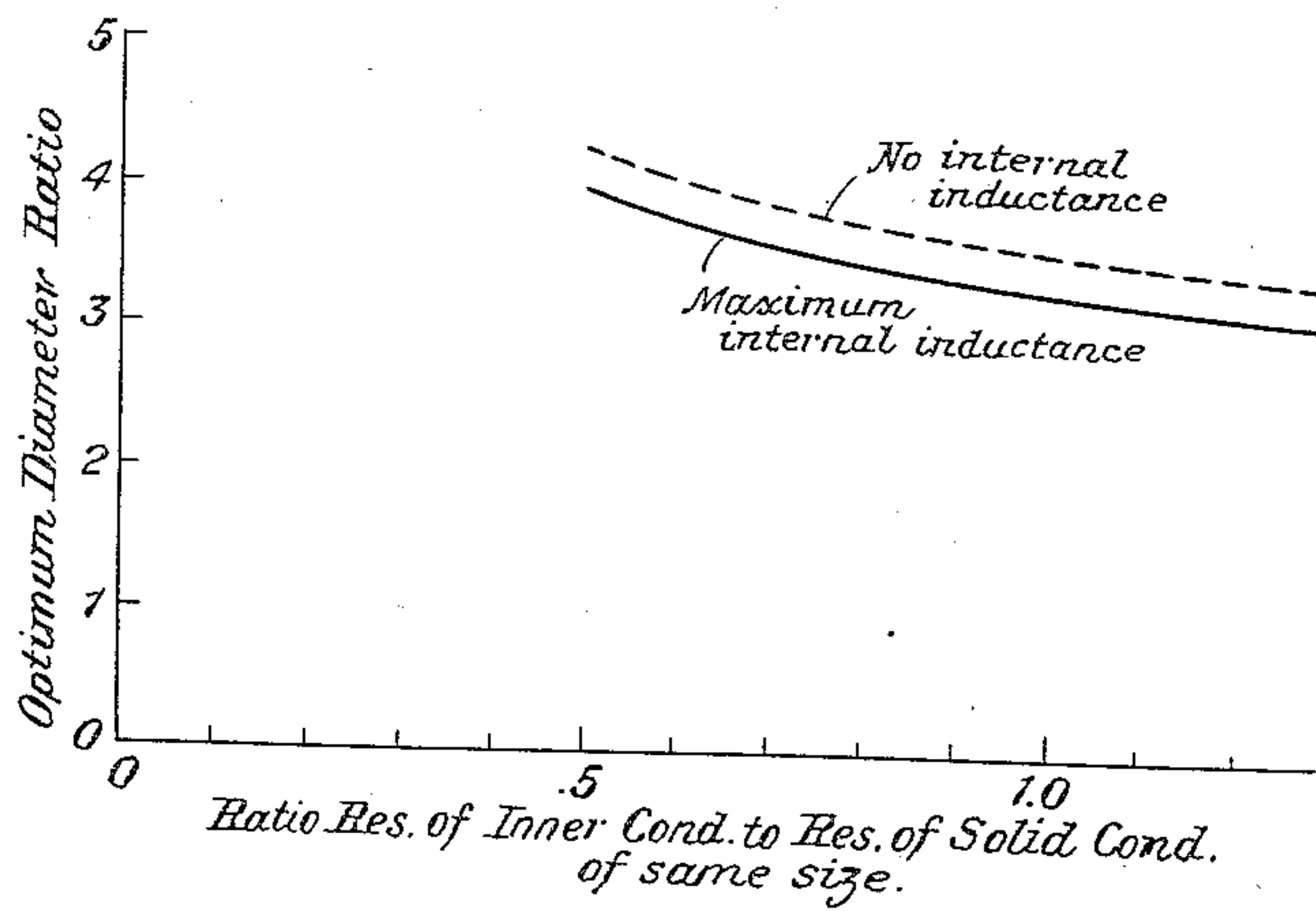


Fig. 5

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March 17, 1936.

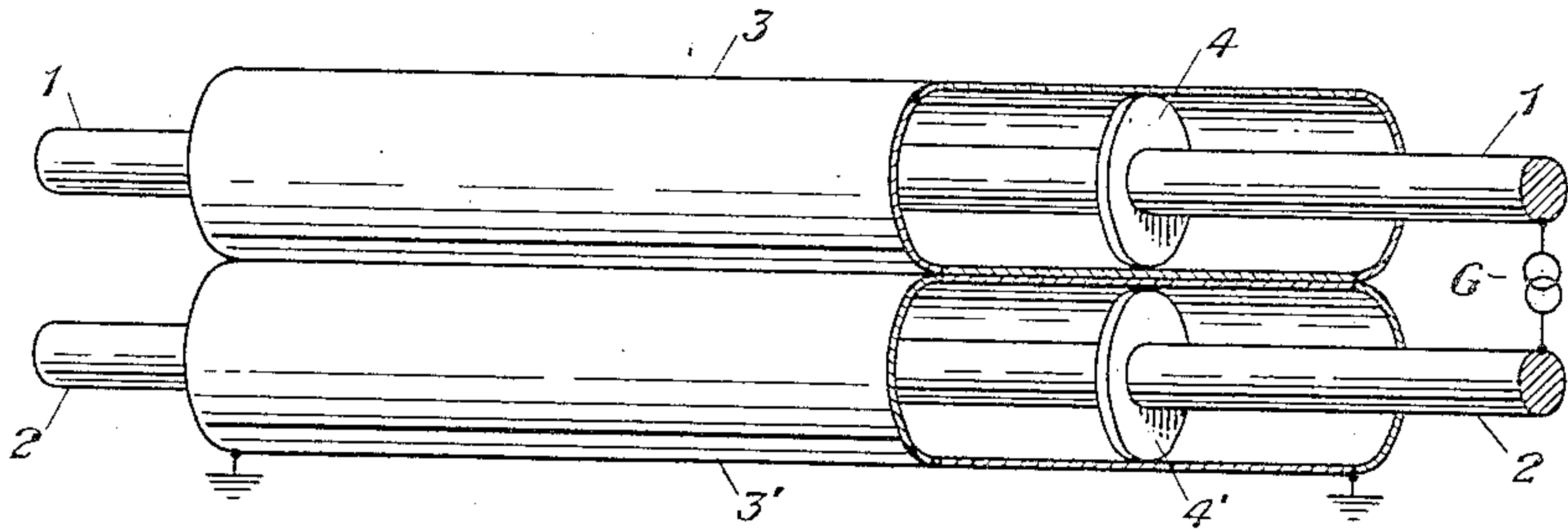
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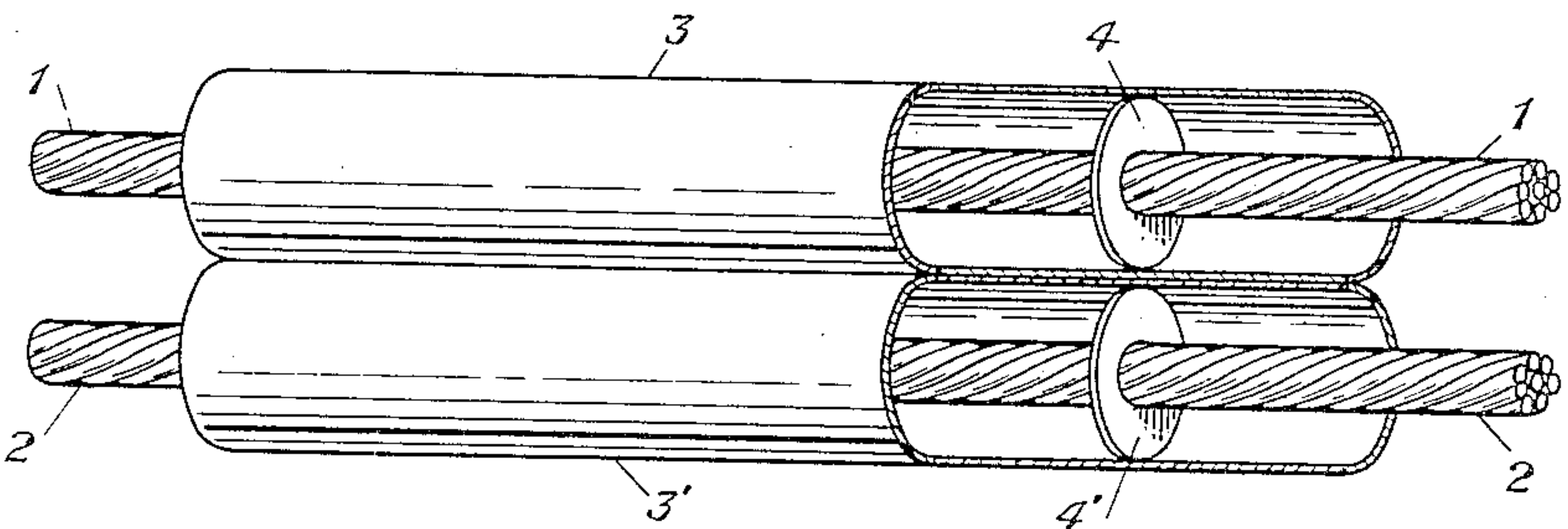
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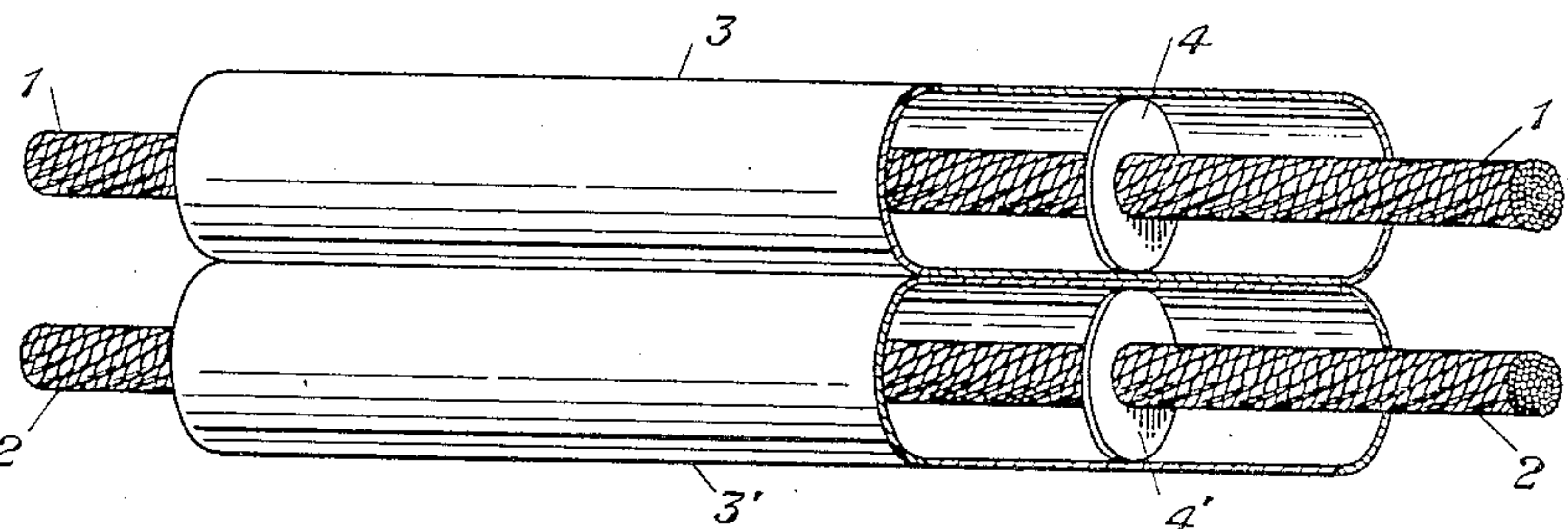
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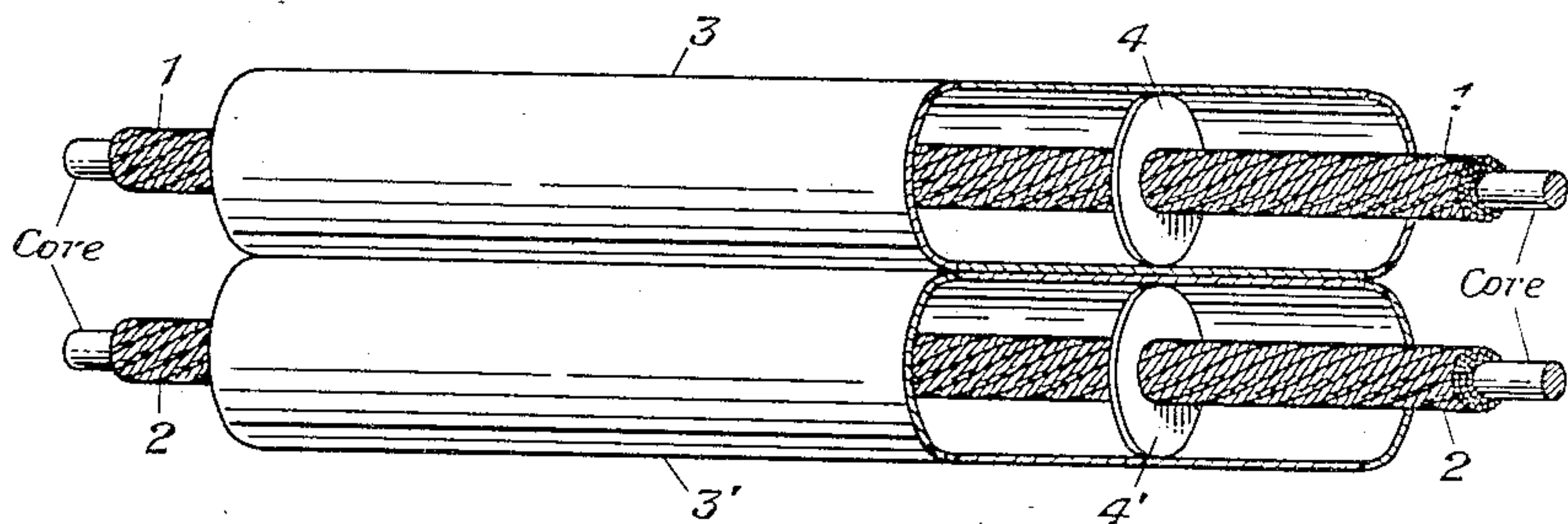
*Fig. 6*



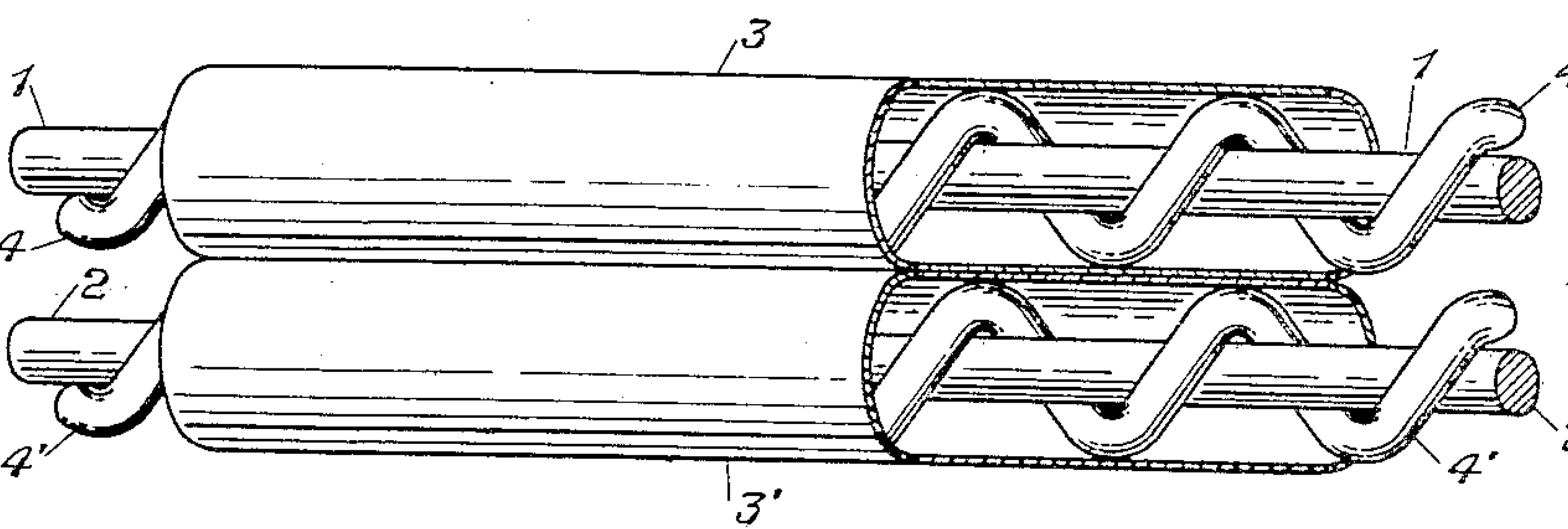
*Fig. 7*



*Fig. 8*



*Fig. 9*



*Fig. 10*

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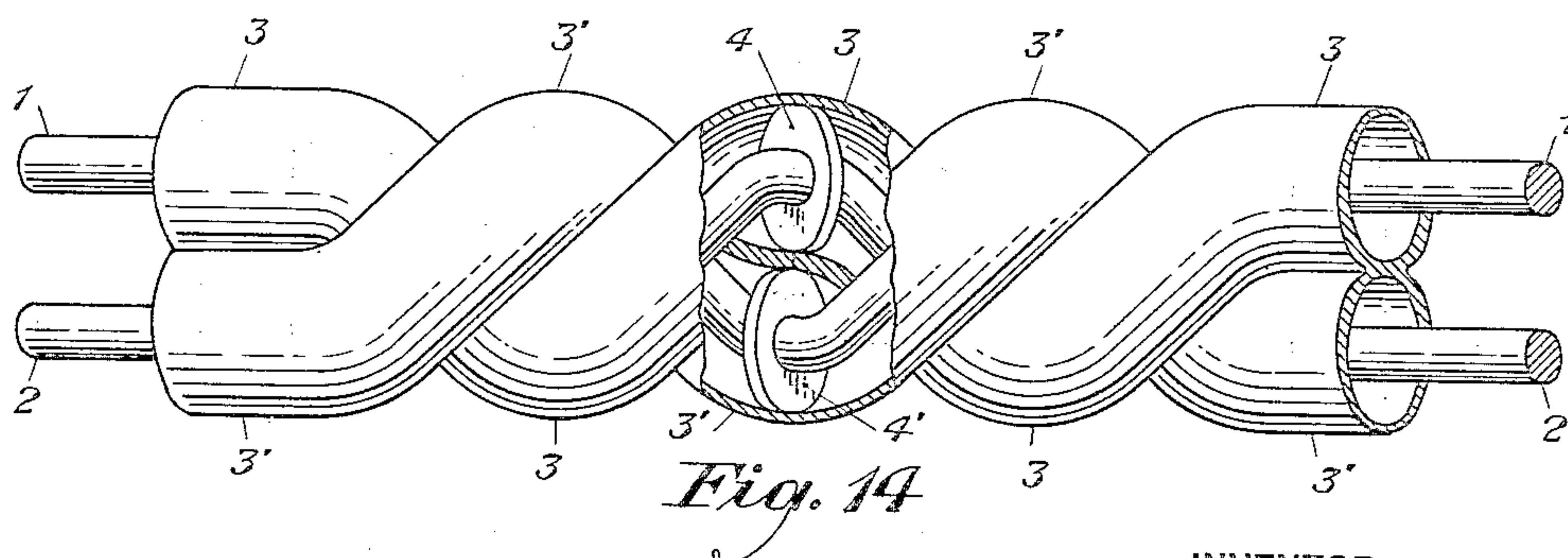
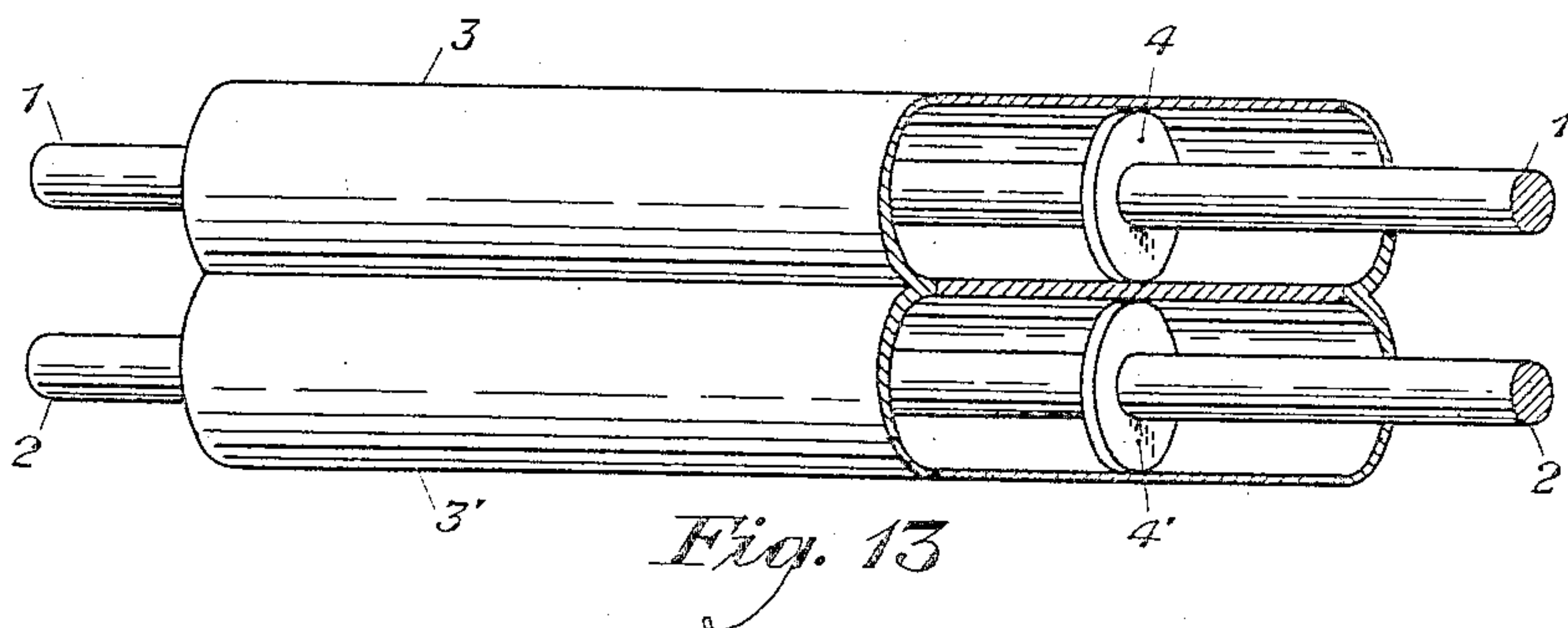
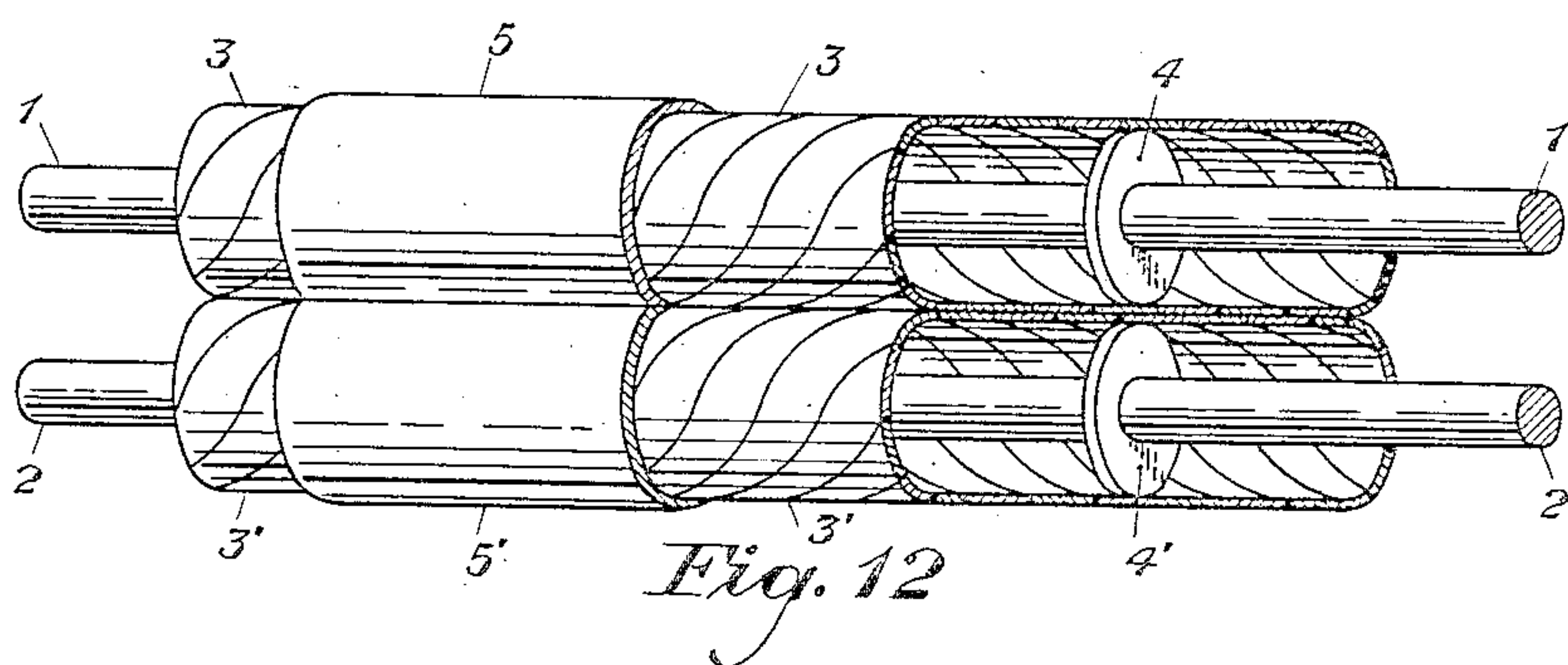
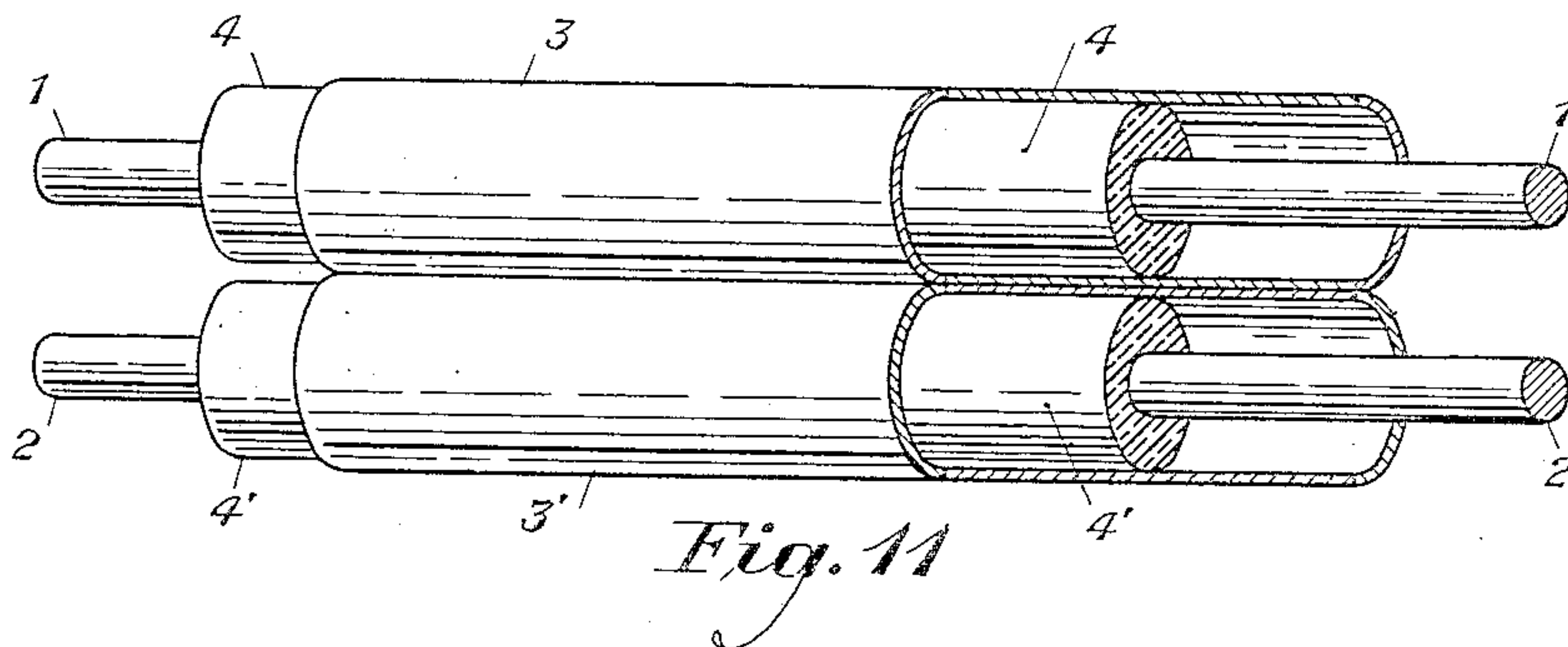
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CIRCUITS WITH DOUBLE CIRCULAR SHIELDS

Filed June 7, 1933

5 Sheets-Sheet 3



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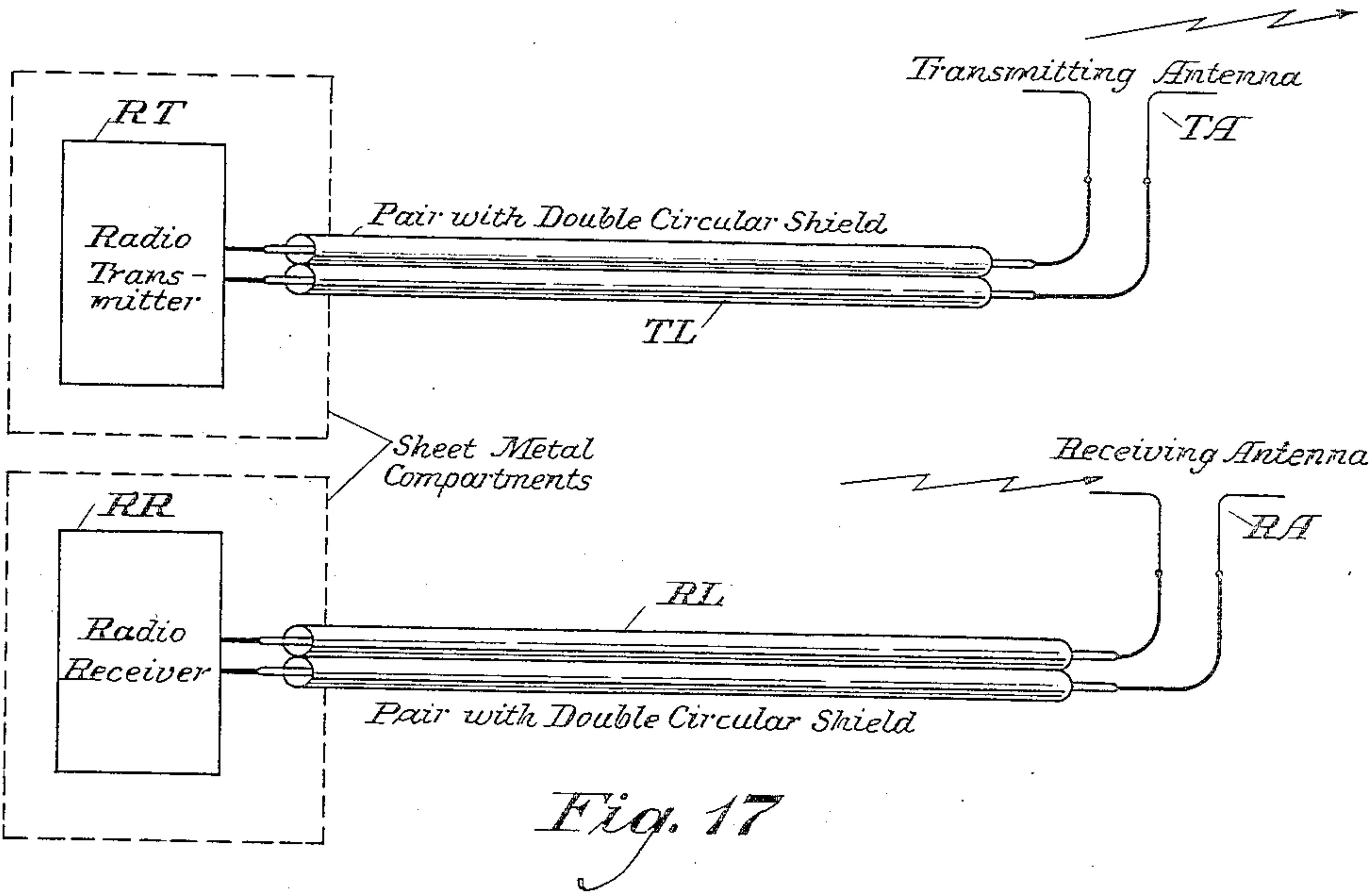
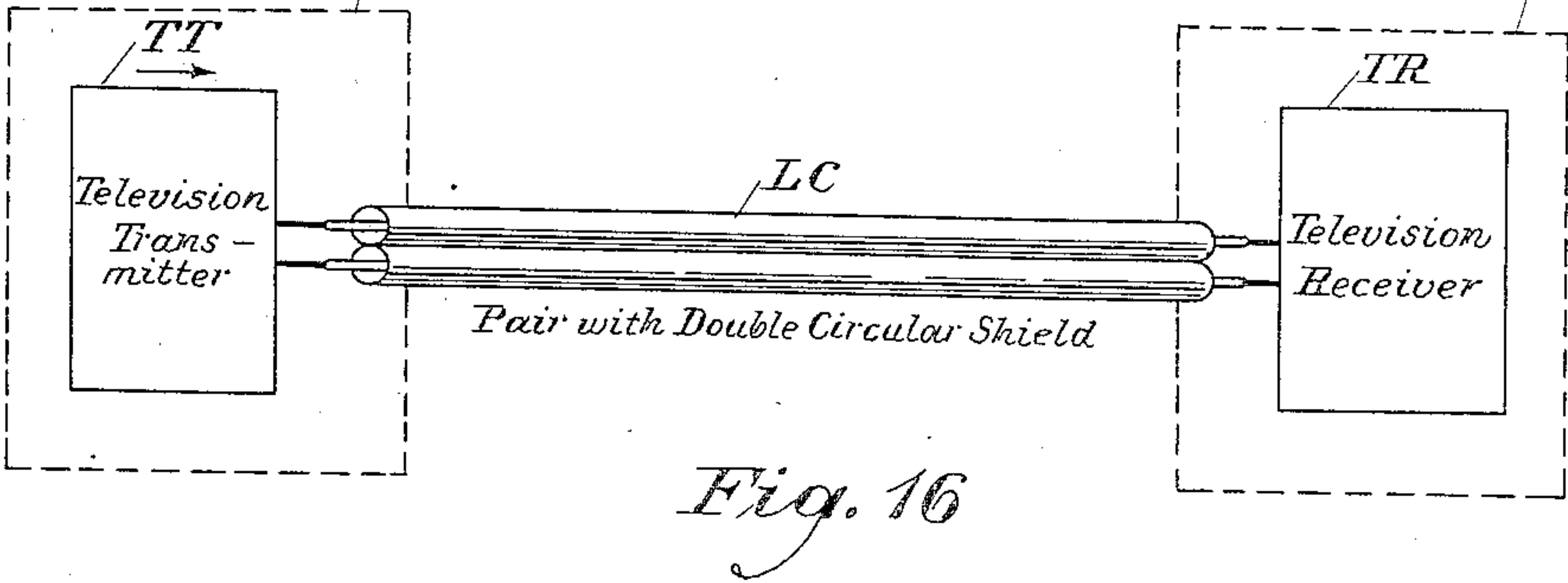
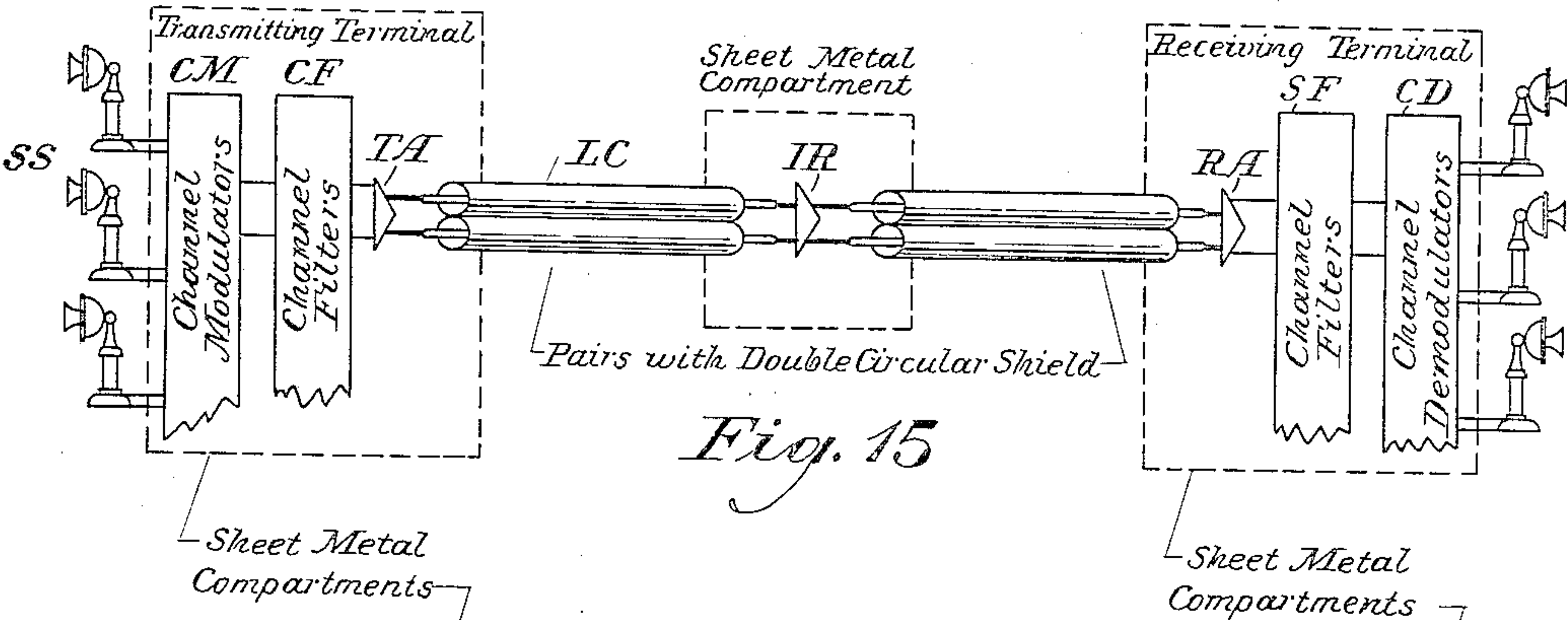
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CIRCUITS WITH DOUBLE CIRCULAR SHIELDS

Filed June 7, 1933

5 Sheets-Sheet 4



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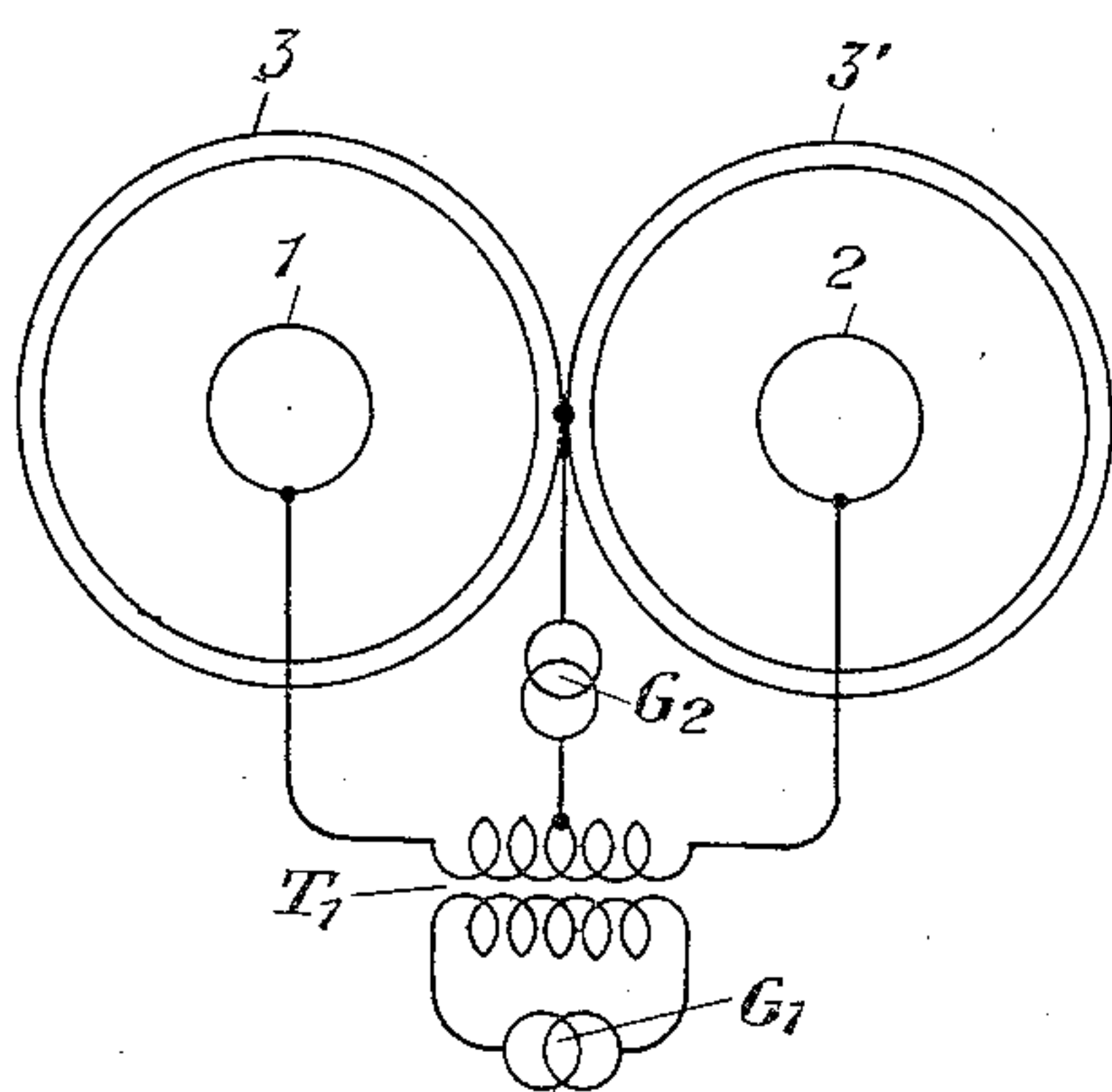
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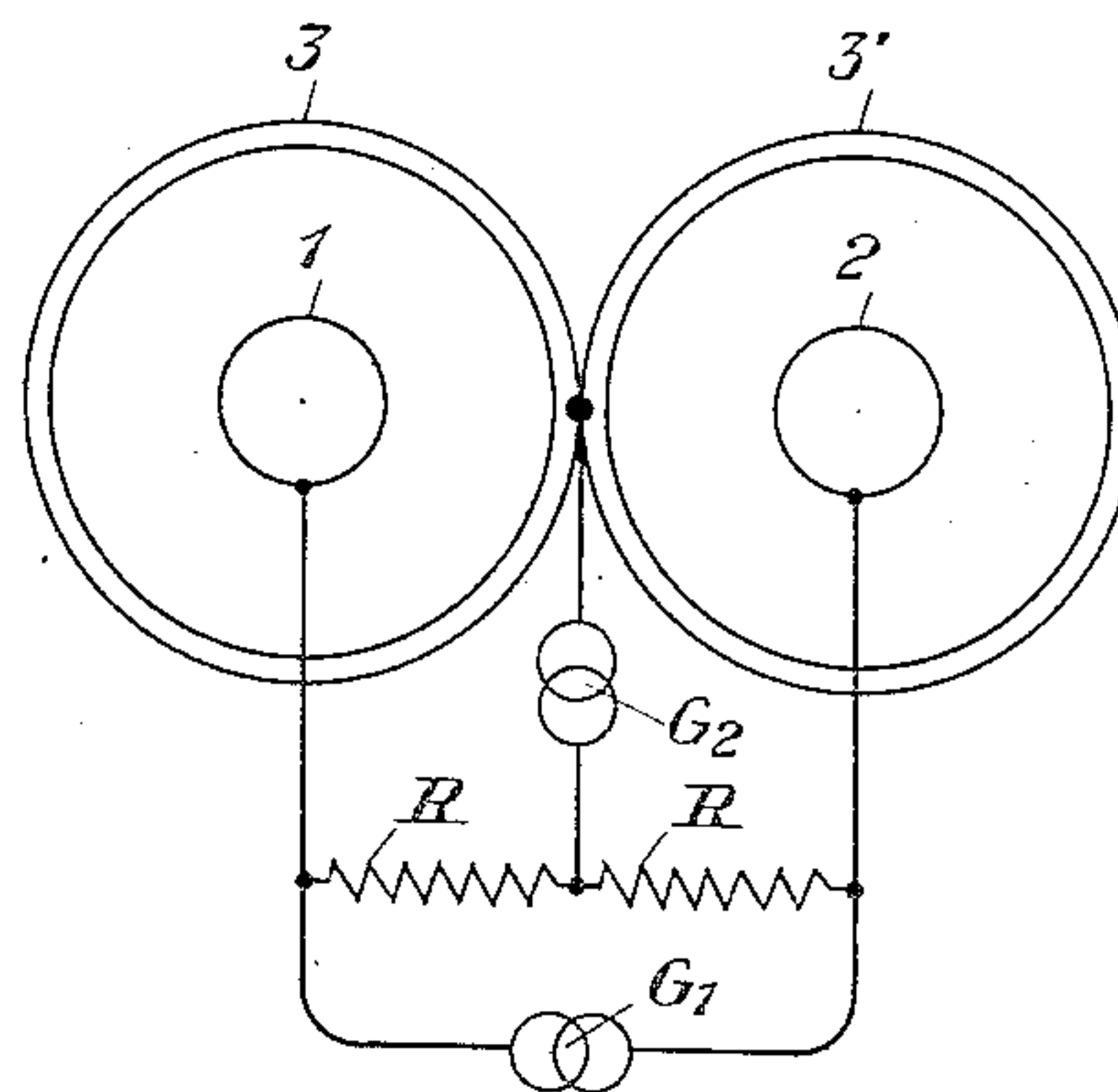
CIRCUITS WITH DOUBLE CIRCULAR SHIELDS

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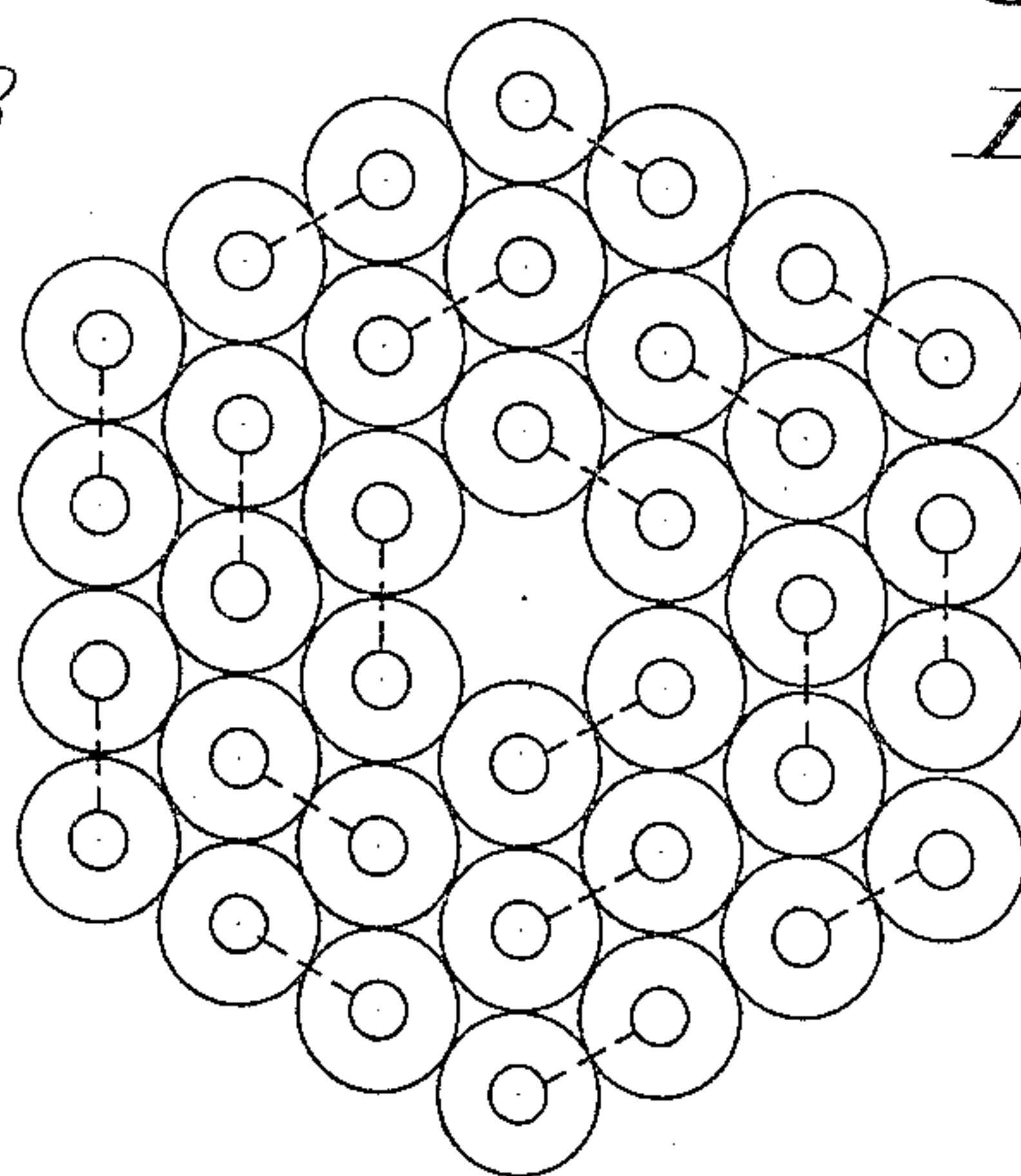
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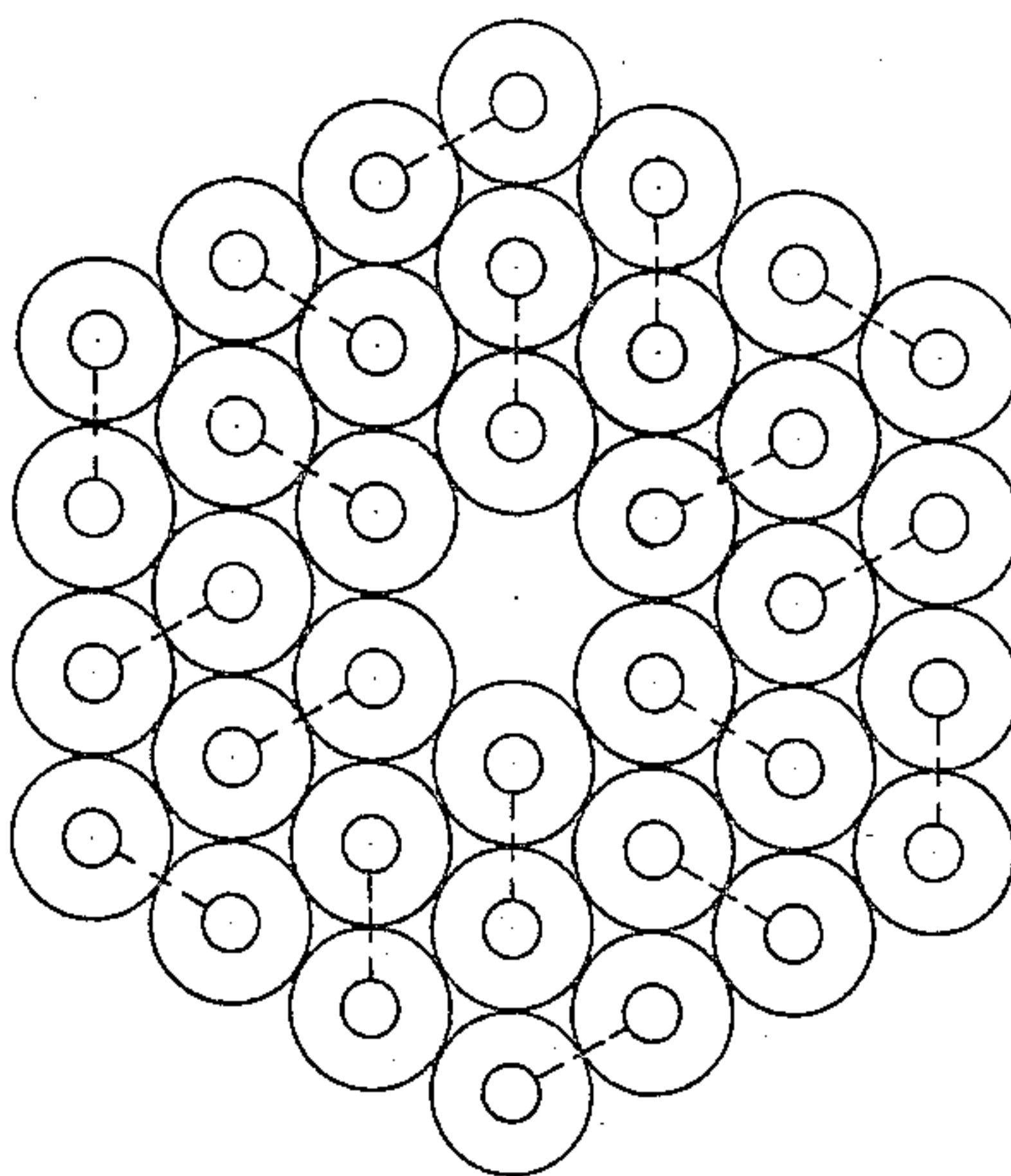
*Fig. 18*



*Fig. 19*



*Fig. 20*



*Fig. 21*

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## UNITED STATES PATENT OFFICE

2,034,035

## CIRCUITS WITH DOUBLE CIRCULAR SHIELDS

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American Telephone and Telegraph Company,  
a corporation of New York

Application June 7, 1933, Serial No. 674,765

18 Claims. (Cl. 178—44)

This invention is concerned with electrical transmission circuits and especially with circuits comprising a pair of conductors surrounded by a 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 wide 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 or 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 circuit in a balanced manner in order to reduce the 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 may 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 the shield. The invention comprehends also, however, the use of non-gaseous dielectric material between the conductors and the shield.

A particular object of the invention is the provision of a configuration of conductors and shield which will minimize the high-frequency attenu-

ation of the circuit. A feature of the invention is the employment of a double circular shield for this purpose.

More broadly, the invention is concerned with systems in which circuits derived from pairs of conductors with double 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 reproducing 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 con-



nection with the accompanying drawings, in which Figure 1 is a cross-sectional diagram of a pair of conductors surrounded by a double circular shield; Fig. 2 represents a cross-sectional diagram of a pair of coaxial conductors; Fig. 3 is a curve showing the high-frequency attenuation for a pair of wires with a double circular shield; Fig. 4 is a graph showing the improvement in high-frequency resistance obtained with two specific designs of stranded conductors; Fig. 5 shows curves for determining the proportioning of a structure comprising a pair of stranded conductors with double circular shield; Fig. 6 represents a view of a transmission structure embodying some of the principles of the invention, this structure consisting of a pair of conductors with a double circular shield; Figs. 7 to 14 show various other structures, each comprising a pair of conductors with double circular shield; Figs. 15 to 17 typify arrangements of apparatus which may be used in association with a circuit derived from a pair with a double circular shield; Figs. 18 and 19 illustrate methods of effecting transmission over a structure with non-circular shield; and Figs. 20 and 21 illustrate methods whereby structures designed in accordance with the invention may be laid up in cable form.

The coaxial type of circuit as shown diagrammatically in Fig. 2 is well known in the art and its advantages for the transmission of high frequencies and wide bands of frequencies have been set forth elsewhere. A characteristic of the coaxial circuit, however, which makes it unsuited for certain applications is its unbalance with respect to ground. It has already been pointed out, for example, that such a characteristic may be disadvantageous in a transmission circuit which is to be associated with a radio antenna which is balanced to ground.

In order to realize the transmission advantages of the coaxial type of structure and at the same time secure a circuit which is balanced to ground, it is proposed in accordance with the present invention to employ an arrangement which may be thought of as consisting of two pairs of coaxial conductors placed side by side, the inner conductors being used for the transmission circuit and the outer conductors as a shield. Such an arrangement is illustrated in Fig. 1 where 1 and 2 are used as the conductors, and 3 and 3', which are assumed to be in contact, as the shield. In this figure  $b_1$  designates the radius of each conductor and  $c_1$  the radius of either half of the shield. Similar designations are used for the corresponding quantities in Fig. 2.

For some applications the arrangement of Fig. 1 might be employed without any consideration of the particular proportioning which results in minimum high-frequency attenuation for a given cross-sectional area. It has been found, however, 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 especially 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 for the circuit of Fig. 1 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.

Referring to the coaxial circuit of Fig. 2, the high-frequency resistance, inductance and capacity of this circuit, which may be designated  $R_2$ ,  $L_2$  and  $C_2$ , respectively, may be approximately represented by the following well-known formulas:

$$R_2 = K_0 \sqrt{f} \left( \frac{1}{b_1} + \frac{1}{c_1} \right) \quad (1)$$

$$L_2 = K_1 \log_e \frac{c_1}{b_1} \quad (2)$$

$$C_2 = \frac{K_2 \epsilon}{\log_e \frac{c_1}{b_1}} \quad (3)$$

where  $K_0$ ,  $K_1$  and  $K_2$  are constants,  $f$  is the frequency in cycles per second and  $\epsilon$  is the dielectric constant of the insulating medium.

Since the circuit between conductors 1 and 2 in Fig. 1 may be considered to consist of two coaxial circuits the high frequency resistance and inductance  $R_1$  and  $L_1$  for Fig. 1 are each double the corresponding values for Fig. 2, while the capacity  $C_1$  is half that for Fig. 2. In other words:

$$R_1 = K_3 \sqrt{f} \left( \frac{1}{b_1} + \frac{1}{c_1} \right) \quad (4)$$

$$L_1 = K_4 \log_e \frac{c_1}{b_1} \quad (5)$$

$$C_1 = \frac{K_5 \epsilon}{\log_e \frac{c_1}{b_1}} \quad (6)$$

where  $K_3$ ,  $K_4$  and  $K_5$  are constants.

Now, the high-frequency attenuation of the circuit of Fig. 1 may be closely approximated by the following formula:

$$\alpha = \frac{R_1}{2} \sqrt{\frac{C_1}{L_1}} + \frac{G_1}{2} \sqrt{\frac{L_1}{C_1}} \quad (7)$$

where  $G_1$  is the leakage conductance of the circuit. Let it be assumed that the dielectric is largely gaseous so that the leakage conductance may be assumed to be zero.

If the cross-sectional area occupied by the circuit is to be constant, the value of  $c_1$  may be assumed constant. Hence, on substituting the values for  $R_1$ ,  $L_1$  and  $C_1$  in (7), these results the following:

$$\alpha = K_6 \frac{\left( 1 + \frac{c_1}{b_1} \right)}{\log_e \frac{c_1}{b_1}} \quad (8)$$

where

$$K_6 = \frac{K_3 \sqrt{f}}{2} \sqrt{\frac{K_5 \epsilon}{K_4 c_1}} \quad (9)$$

On minimizing (8) with respect to

$$\frac{c_1}{b_1} \quad (10)$$

it is found that the condition for minimum high-frequency attenuation in the circuit of Fig. 1, for a given cross-sectional area occupied by the circuit when using solid conductors or their equivalent, is

$$\frac{c_1}{b_1} = 3.59 \quad (11)$$

Fig. 3 shows the high-frequency attenuation



for a circuit of the type shown in Fig. 1, assuming that the value of  $c_1$  is 0.5 inch and that the ratio

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

is that which gives minimum attenuation. It will be noted that at a frequency of 1,000 kilocycles the attenuation of the pair with double circular shield is approximately 1.4 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 43 miles.

The case where the conductors 1 and 2 in Fig. 1 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 counteract the tendency of the high-frequency currents to concentrate on the conductor surface and hence to decrease the resistance and increase the internal inductance of each conductor at high frequencies. Both of these results tend to decrease the high-frequency attenuation of the circuit. 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 conductors surface 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 cm.) may be written

$$\frac{n}{b_1} \sqrt{\frac{f}{\lambda}}$$

where  $b_1$  and  $f$  have the same significance as before,  $b_1$  being in centimeters,  $\lambda$  is the conductivity (approximately  $5.8 \times 10^{-4}$  abohms per cm. cube for copper) and  $n$  is the ratio of the resistance of the stranded conductor to the resistance of a solid conductor of the same diameter at the same frequency.

The value of  $n$  for a conductor which 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, page 57. Equation (85) therein should be modified by the omission of the two terms which involve  $D^2$ , when it will read:

$$R' = R_0 \left[ \left( 1 + \frac{\alpha^2}{2} \right) (1 + F) + \frac{2S^2 \delta^2 G}{d_0^2} \right] \quad (10)$$

This formula gives the A. C. resistance of one stranded conductor in abohms per cm. The high-frequency resistance  $R_1'$  of a solid wire is given by the expression

$$\frac{1}{b_1} \sqrt{\frac{f}{\lambda}}$$

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

Fig. 4 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 kc. or above. By the use of formula (10) 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.

Another important effect to be obtained by stranding is an increase in the internal inductance of the conductor. With a solid wire, the current at high frequencies crowds to the surface, so that the internal inductance is so small as to be practically negligible. With a stranded conductor, a substantial amount of internal inductance may be obtained. With a completely stranded cross-section, this internal inductance becomes very nearly equal to the D. C. internal inductance of a solid wire, which is .5 abhenry per cm. For a stranded conductor of annular cross-section, the internal inductance would evidently lie somewhere between this value and zero, depending upon the dimensions of the annulus. The value of internal inductance of a conductor of annular cross-section, assuming that the current density is uniform, is given by the following formula:

$$L_i = \frac{1}{2} - \frac{1}{\rho^2 - 1} + \frac{2 \log_e \rho}{(\rho^2 - 1)^2} \text{ abhenries per c. m.} \quad (11)$$

where  $\rho$  is the ratio of the outer to the inner radius of the annulus.

The improvement in high-frequency attenuation which may be obtained in the circuit of Fig. 1 by using stranded conductors may be taken advantage of in either of two ways:

1. If it is desired to obtain a given attenuation at a certain frequency, the diameter of the outer conductor and hence the amount of conductor material and the space occupied may be considerably reduced, or

2. If the diameter of the outer conductor be held fixed, the frequency at which a given attenuation is obtained may be increased.

By using a stranded inner conductor it is possible to obtain a reduction of about 40 per cent. in the space occupied by the circuit or an increase of about 80 to 90 per cent. in frequency range.

Knowing the values of the resistance ratio  $n$  and the internal inductance  $L_i$  which may be secured by stranding, the next step in the design of the circuit of Fig. 1 with stranded conductors is to determine the proportioning of the circuit for minimum attenuation. Using the basic attenuation Formula (7), the attenuation of the circuit with stranded conductors, assuming zero leakage, may be written as follows:

$$\alpha = \frac{K_7(1 + nx)}{\sqrt{2(\log_e x)^2 + L_i \log_e x}} \quad (12)$$

where  $x$  equals

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

and  $K_7$  is a constant. In order to determine the optimum ratio of radii

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

which will give minimum attenuation, Equation (12) should be minimized with respect to  $x$ .



This procedure shows that the minimum attenuation is obtained when the following relation is satisfied:

$$\frac{2nx \log_e x}{nx+1} = \frac{4 \log_e x + Li}{2 \log_e x + Li} \quad (13)$$

The values of  $x$  obtained from this expression are plotted in Fig. 5, where the solid curve is based on the assumption that the internal inductance of each stranded conductor is equal to the D. C. internal inductance of a solid wire (.5 abhenry per centimeter), while the dotted curve assumes that the internal inductance of each stranded conductor is zero. For a completely stranded cross-section the lower curve (solid) is substantially correct, while for annular stranding the value of the optimum ratio of radii will lie somewhere between the two curves. It will be seen that the values for the ratio of radii as given in Fig. 5 depart quite materially from the value of 3.6 which obtains in the case of solid conductors, so that in order to utilize the stranded conductors most effectively, it is necessary to design the circuit in accordance with the Formula (13) or the corresponding curves.

The foregoing derivation of the proportioning of a circuit with double 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 ratio 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 the ratio 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 of conductors with double circular shield. In this figure 1 and 2 represent two solid conductors which are held in position with respect to one another and the shields 3 and 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 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 for the conduction of the high-frequency currents.

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 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. 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 conductor cross-section. One method of securing this result is to strand each 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 inner and outer circumferences of the annulus. A structure employing stranded conductors of annular cross-section is illustrated in Fig. 9.

Any of various forms or shapes might be employed for the insulation between the conductors and shield. One possible arrangement would be to use a continuous spirally applied string or strip of dielectric material around each conductor. An arrangement of this type is illustrated in Fig. 10 where 4 and 4' represent insulating strings spirally applied around the solid conductors 1 and 2. Generally it will be desirable that the amount of insulating material be a minimum in order that the dielectric may be largely gaseous. In some cases, however, it will be found advantageous to use a dielectric which is partly or wholly 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 op-



tinum configuration of the circuit will be approximately the same as for the assumed condition of a gaseous dielectric.

The shields surrounding the two conductors instead of consisting of solid tubes might each consist of a cylindrical assembly of conducting strips, tapes, wires, ribbons or the like. Such a form of construction might be particularly advantageous where a flexible structure is desired. One construction of this kind is illustrated in Fig. 12, where each shield consists of a number of spiral segments formed into a tube. If desired, the shield may be surrounded by a waterproof sheath or covering 5, which may be composed of lead, rubber or other suitable material.

Moreover, the two separate shields might be combined into a single "double barreled" shield as illustrated in Fig. 13.

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 comparatively thin shield. Consequently, the thickness of the shield will ordinarily be determined by mechanical considerations.

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

It has been noted that the shielding of the circuit in Fig. 1 is less effective at the lower frequencies. If it is desired to transpose the circuit in order to improve its characteristics at low frequencies, this can be done by the method illustrated in Fig. 14 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 14, comprising conductors surrounded by double 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. 15 to 17.

Fig. 15 is a diagram of a multiplex carrier telephone system including the channel modulating and demodulating equipment, the filtering 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 double 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 re-

ceiving 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. 16 is a diagram of a television system in which the line circuit is provided by a pair of conductors having a double 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. 17 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 double 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. 15, 16 and 17.

The arrangements thus far described have contemplated the use of the structure with double 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 shield as a return. Figs. 18 and 19 illustrate two different methods of deriving two independent transmission circuits, one balanced and one unbalanced, from the structure of Fig. 1.

In Fig. 18 the generator  $G_1$  is connected to the conductors 1 and 2 through the transformer  $T_1$ , providing a balanced to ground transmission circuit. Generator  $G_2$  is connected between the electrical midpoint of the conductors 1 and 2, 75



provided by a center tap on the secondary of transformer  $T_1$  and the shield 3—3', providing a second circuit, the latter being unbalanced to ground. In Fig. 19 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 3—3' and the midpoint of a resistance  $R$  shunted across the generator  $G_1$ .

It should be noted also that either conductor may be used with its own half of the shield to obtain the usual type of coaxial circuit. The arrangement as shown, therefore, affords a wide degree of flexibility with respect to the types of transmission circuits which may be derived therefrom.

Figs. 20 and 21 illustrate methods in which structures of the type shown in Figs. 6 to 14 may be laid up in cable form. The go and return conductors of each double circular shield circuit are shown connected by dotted lines. In the lay-ups illustrated the various circuits are so disposed with reference to one another as to tend to minimize the electrical coupling which would exist between them at low frequencies where the shielding is only partially effective.

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 arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated by a substantially gaseous dielectric from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces acting to transmit without excessive attenuation the band of frequencies so applied.

2. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, and insulated therefrom 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces acting to transmit without excessive attenuation the band of frequencies so applied.

3. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors being of such a type that currents whose frequencies are substantially above the audible range travel substantially on the surface of said conductors, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated by a substantially gaseous dielectric, from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces acting to transmit without excessive attenuation the band of frequencies so applied.

4. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors consisting of a plurality of conducting strands insulated from one another, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated by a substantially gaseous dielectric from an individual cylindrical conducting inner surface for each conductor which is concentric with respect to the enclosed conductor, 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces acting to transmit without excessive attenuation the band of frequencies so applied.

5. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement of said conductors having such configuration that each of said conductors is surrounded by and insulated by a substantially gaseous dielectric from an individual cylindrical inner conducting surface for each conductor which is concentric with respect to the enclosed conductor, said shielding arrangement being of such thickness as to render said circuits substantially immune from inter-



ference from external sources at frequencies substantially above the audible range, 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces acting to transmit without excessive attenuation the band of frequencies so applied.

6. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the ratio of the inner diameter for each shielding surface to the outer diameter of the conductor which it encloses being such that the high-frequency attenuation of the circuit formed of the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

7. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the proportioning of the diameters of each of said conductors with respect to the diameter of the shielding surface surrounding it being such that the high-frequency attenuation of the circuit formed of the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

8. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors being of such type that the conduction of currents whose frequencies are substantially above the audible range takes place substantially on the surface of said conductors, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the proportioning of the diameter of each of said conductors with respect to the diameter of the shielding surface surrounding it being such that the high-frequency attenuation of the circuit formed by the two conductors connected one as a return

for the other is a minimum for the cross-sectional area included within both shielding surfaces.

9. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors consisting of a plurality of insulated conducting strands, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the proportioning of the diameters of each of said conductors with respect to the diameter of the shielding surface surrounding it being such that the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

10. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor and insulated therefrom by a substantially gaseous dielectric, the proportioning of the diameters of each of said conductors with respect to the diameter of the shielding surface surrounding it being such that the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

11. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the ratio of the inner diameter of each shielding surface to the outer diameter of the enclosed conductor being approximately in the range between 3.3 and 4.3, whereby the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

12. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors being of such a type that currents



whose frequencies are substantially above the audible range travel substantially on the surface of said conductors, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the ratio of the inner diameter of each shielding surface to the outer diameter of the enclosed conductor being approximately 3.59, whereby the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

13. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors consisting of a plurality of conducting strands insulated from one another, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, the ratio of the inner diameter of each shielding surface to the outer diameter of the enclosed conductor being approximately in the range between 3.3 and 4.3, whereby the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

14. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, said conductors being of such a type that currents whose frequencies are substantially above the audible range travel substantially on the surface of said conductors, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor and insulated therefrom by a substantially gaseous dielectric, the ratio of the inner diameter of each shielding surface to the outer diameter of the enclosed conductor being approximately 3.59, whereby the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

15. An electrical transmission circuit comprising two cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, each of said conductors consisting of a plurality of conducting strands insulated from one another, a conducting shielding arrangement for said conductors having such configuration that each of

said conductors is surrounded by an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor and insulated therefrom by a substantially gaseous dielectric, the ratio of the inner diameter of each shielding surface to the outer diameter of the enclosed conductor being approximately in the range between 3.3 and 4.3, whereby the high-frequency attenuation of the circuit formed by the two conductors connected one as a return for the other is a minimum for the cross-sectional area included within both shielding surfaces.

16. An electrical transmission circuit comprising a pair of cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of the said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces 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 shielding arrangement as the other conductor.

17. An electrical transmission circuit comprising a pair of cylindrical conductors arranged side by side and spaced apart, one of said conductors being connected as a return for the other to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by and insulated from an individual cylindrical inner shielding surface for each conductor which is concentric with respect to the enclosed conductor, means for connecting said conductors in series forming a balanced to ground transmission path, 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 extending from approximately zero to a frequency many times the upper limit of the audible range, said path with its associated shielding surfaces 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 unbalanced to ground high frequency transmission circuit between said pair of conductors in parallel as one conductor and said shielding arrangement as the other conductor.

18. A plurality of electrical transmission structures arranged to form a cable arranged side by side and spaced apart, each of said structures



5 comprising two cylindrical conductors, one of said conductors being connected as a return for the other to form a circuit to transmit without undue attenuation a range of frequencies extending from zero to a frequency many times the upper limit of audibility, a conducting shielding arrangement for said conductors having such configuration that each of said conductors is surrounded by an individual cylindrical inner

shielding surface for each conductor which is concentric with respect to the enclosed conductor and insulated therefrom by a substantially gaseous dielectric, each pair of conductors forming a transmission path being disposed with reference to other pairs forming paths in such manner as to minimize the electrical interference between paths. 5

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