CONCENTRIC CONDUCTOR SYSTEM

Filed May 23, 1929 2 Sheets-Sheet 1

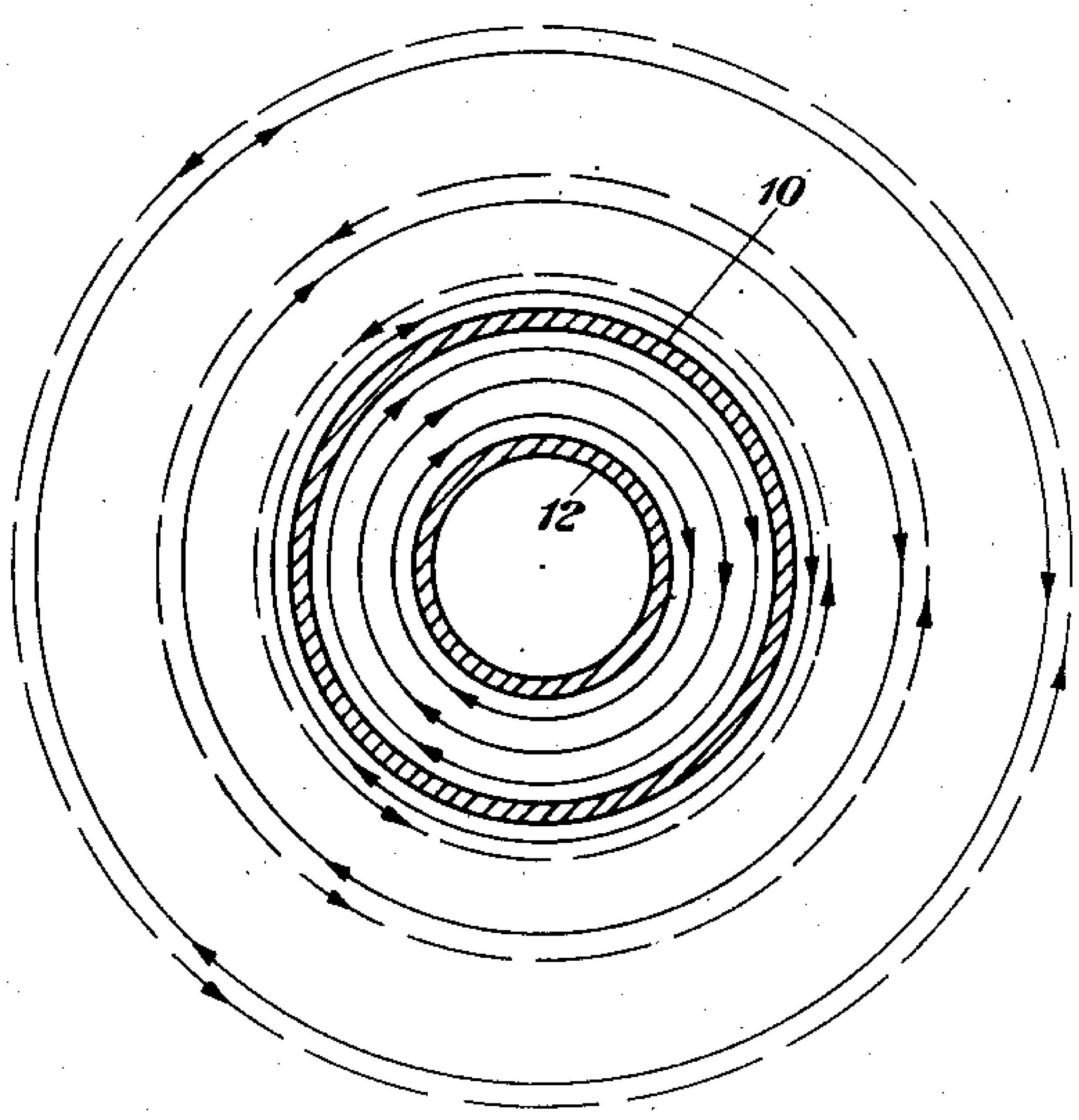

Fig. 1, Magnetic Field

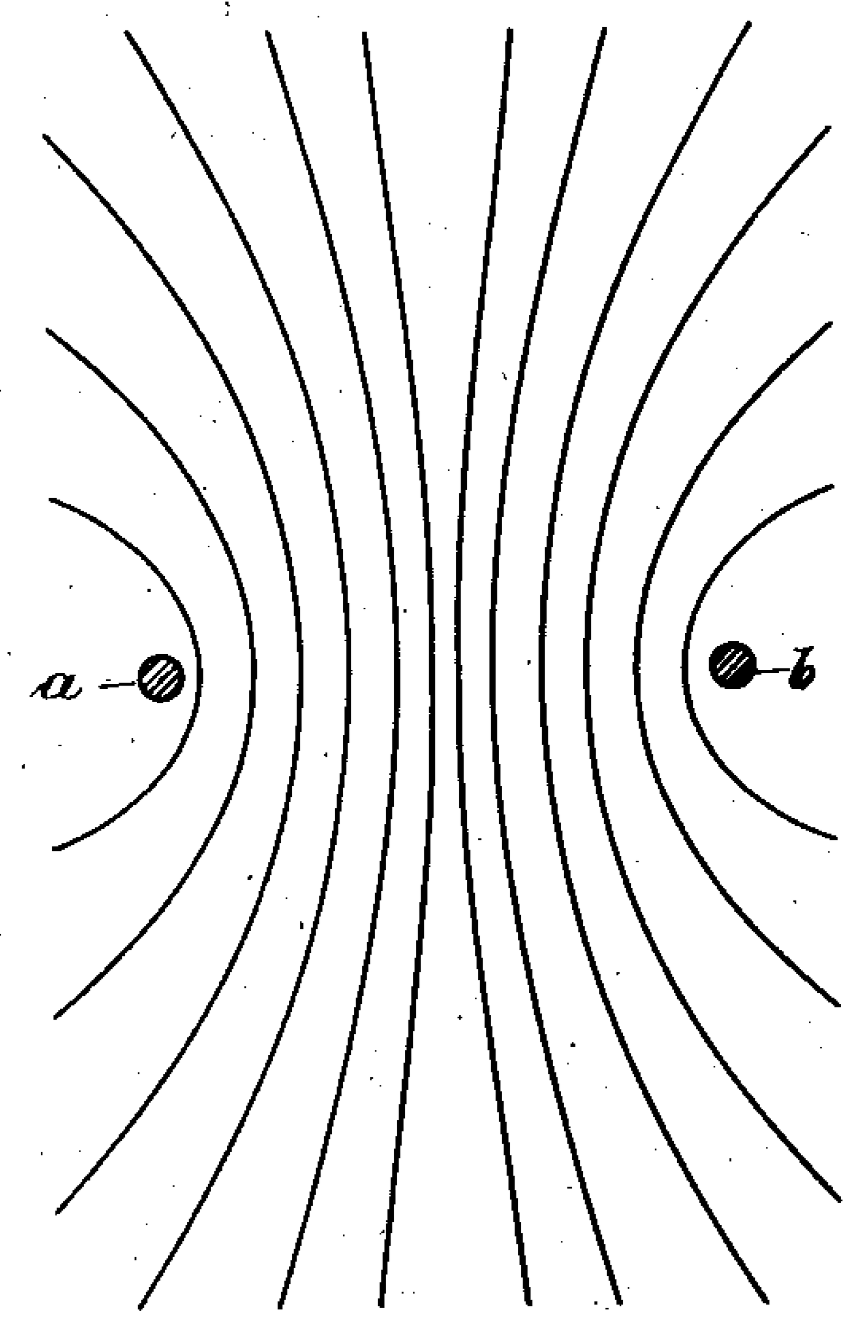

Fig. 2, Magnetic Field

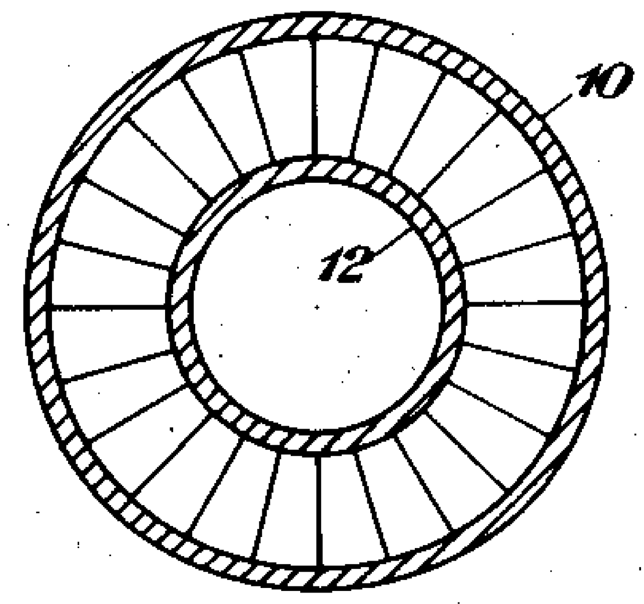

Fig. 3, Electric Field

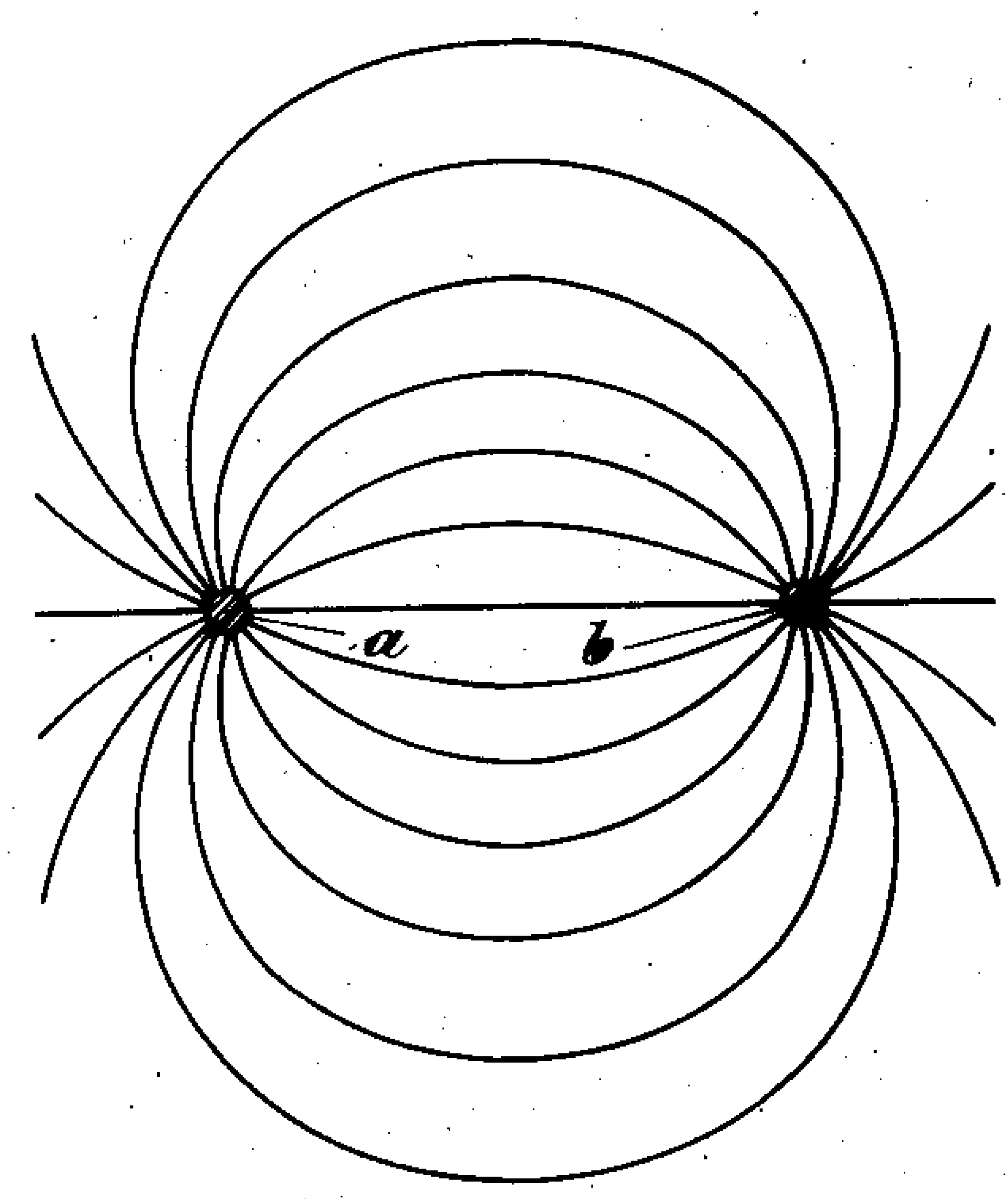

Fig. 4, Electric Field

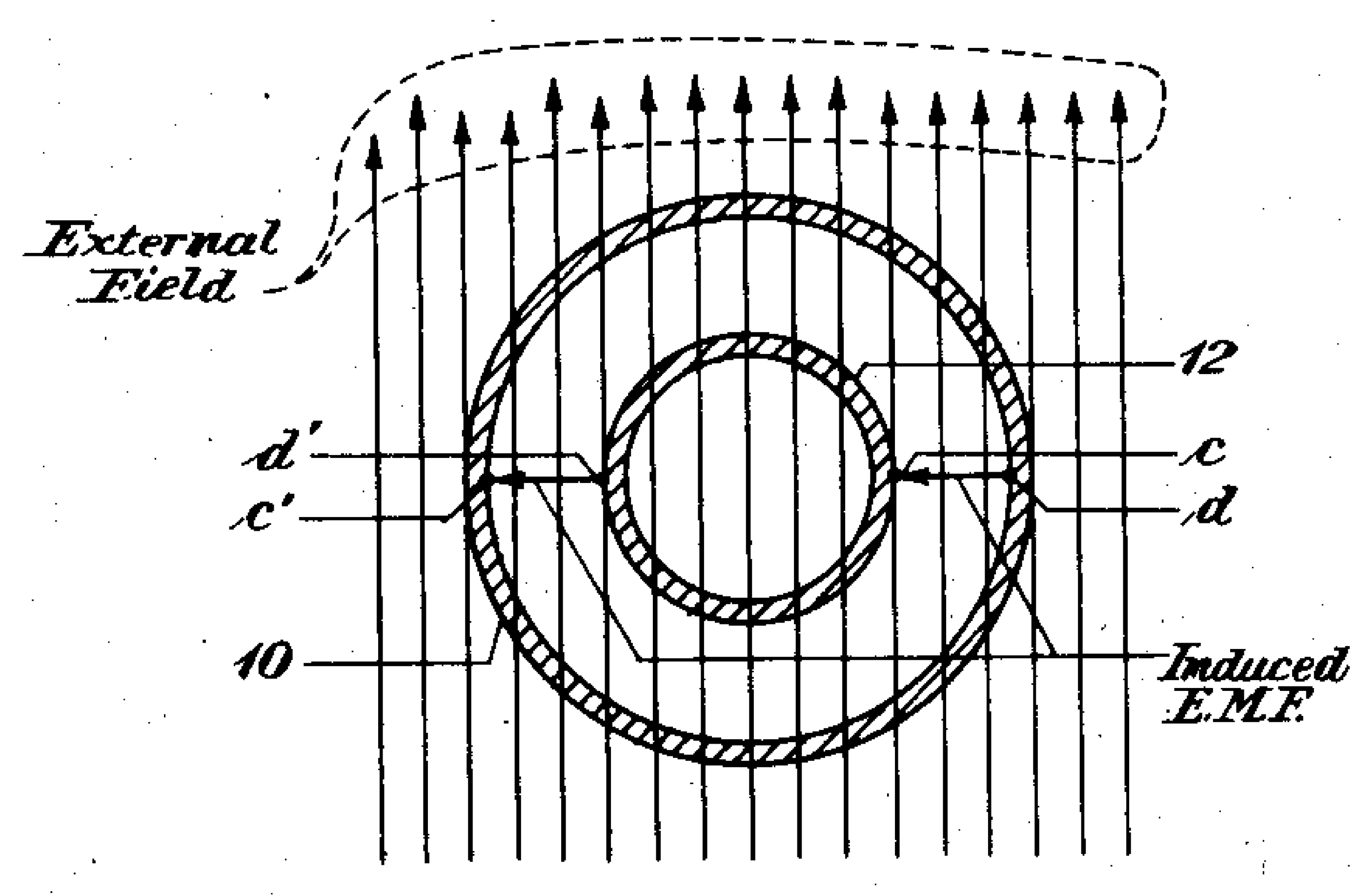

Fig. 5

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CONCENTRIC CONDUCTOR SYSTEM

Filed May 23, 1929 2 Sheets-Sheet 2

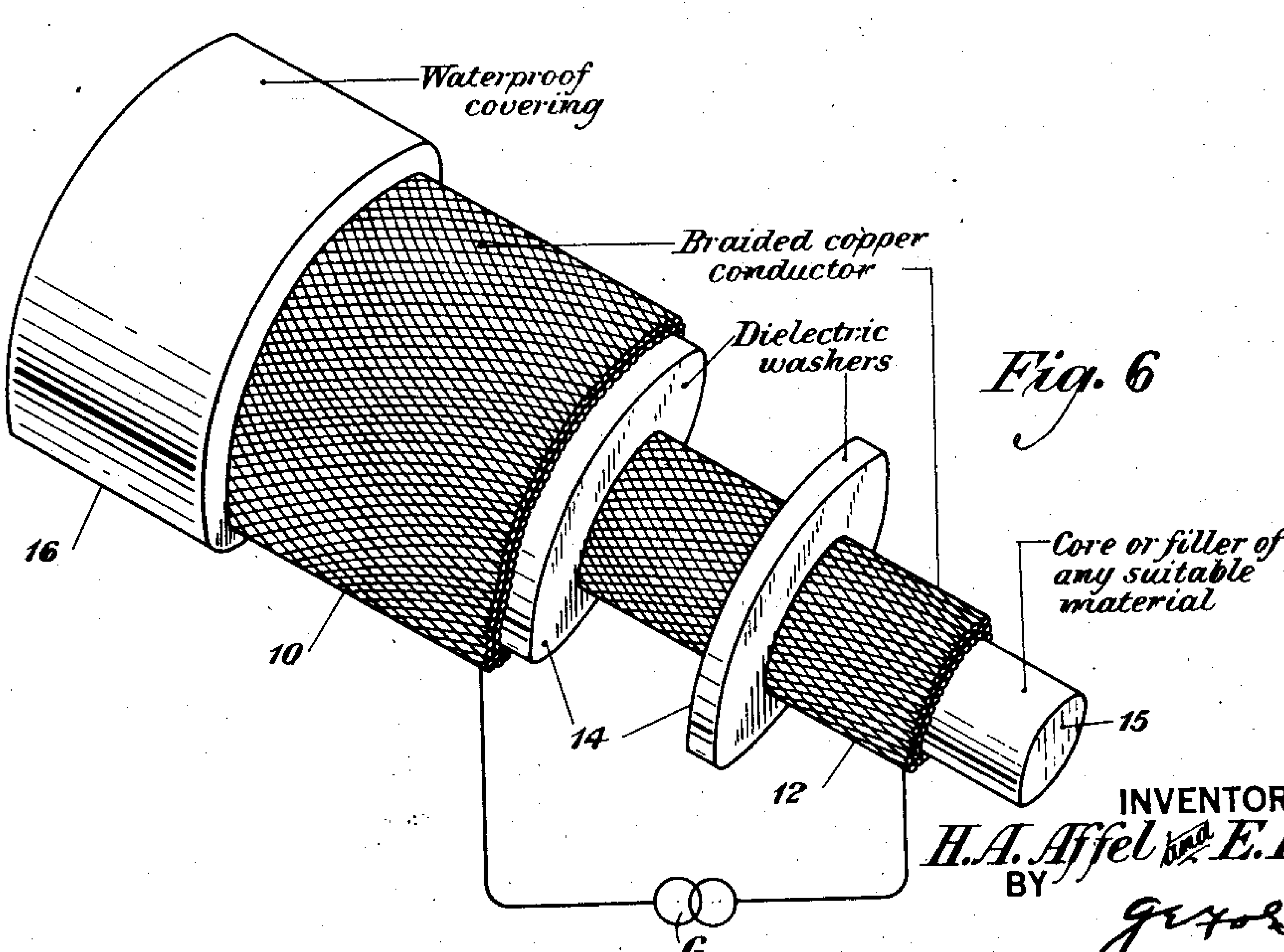

Fig. 6

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UNITED STATES PATENT OFFICE

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CONCENTRIC CONDUCTOR SYSTEM

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This invention relates to a conducting system for transmitting with small attenuation a band of frequencies whose upper limit extends well above the frequencies now employed in carrier transmission.

Modern developments in the art of communication render it highly desirable to have available for transmission purposes a system which will transmit without undue attenuation frequencies extending from the audio frequency range well up into the radio frequency range. For example, high grade circuits are now required for the transmission of programs over telephone lines to broadcasting stations. In order to transmit musical programs it is necessary to provide circuits that will transmit a band of frequencies extending well up toward 10,000 cycles, as compared with the voice range ordinarily employed in telephony, which does not exceed about 2,750 cycles. For the best quality of transmission of music it might be desirable to transmit over telephone lines frequencies up to the audio limit, which would be in the neighborhood of 15,000 or 20,000 cycles. Modern cable circuits are not adapted for transmission of such high frequencies, and the only commercial circuits now available which would be capable of transmitting frequencies of this order would be the open wire circuits which have heretofore been employed for high frequency multiplex carrier transmission.

Even for carrier transmission, open wire lines have been found uncommercial for the transmission of frequencies much above 30,000 cycles. If, therefore, an open wire line is used for the transmission of a high grade audio frequency program involving frequencies in the neighborhood of 15,000 or 20,000 cycles, the remanent frequency range above such audio band would be so narrow as to be of little use for carrier transmission. From this standpoint, therefore, it would be highly desirable to have available a circuit which would transmit frequencies much higher than 30,000 cycles.

The modern development of television also introduces a new factor. Existing television systems which have been experimented with have been limited to the transmission of a small image of a few square inches in area, and in such image the elements of the picture making up the entire image have been relatively large, so that the picture is not well defined. The mechanical problems involved in designing a television transmitting and receiving apparatus capable of picking up and receiving with excellent definition a representation of some large scene, such as a ball game or a theatrical performance, are capable of solution by known means, but the transmission of such a picture electrically involves the transmission of frequencies from zero up to the neighborhood of 500,000 cycles, and there is no telephone circuit now available which would commercially transmit any such range of frequencies. It therefore becomes desirable to have available a conducting system which would transmit without undue attenuation a wide range of frequencies including the extremely high frequencies necessary for television, the circuit being at the same time available if necessary for the transmission of a very large number of carrier channels or for any desired number of bands of sufficient width for the transmission, without undue distortion, of high grade programs.

In accordance with the present invention, a circuit having these desirable characteristics is obtained by employing concentric conductors of relatively large diameter, one acting as a return for the other. The two conductors, which may preferably be in the form of hollow cylinders, are insulated from each other and held in proper concentric relation by any suitable means, such as spacing washers of some dielectric of low loss angle and low dielectric constant so as to introduce a minimum leakage loss between the conductors. By spacing the washers relatively far apart the principal part of the dielectric between the two conductors will be air, which, as is well known, involves substantially no leakage loss.

In accordance with the present invention, the attenuation due to the skin effect is decreased by forming the hollow cylindrical conductors of a plurality of fine wires insulated from each other by some suitable coating and braided together in such a manner as to form a hollow tube. Various methods of braiding hollow tubes are known. For example, a hollow tube may be constructed by the use of a basket weave, or the tube may be constructed by weaving in the manner common in the construction of the fabric covers for telephone cords and electric light cords. A method of braiding has also been employed for producing hollow tubes of braided wire to be used as metallic shields for groups of conductors in a cable. Any of these methods may be used in producing the hollow cylinders of the present invention, the essential requirement being that the wires, in braiding, be weaved inwardly and outwardly toward and from the center of the cylinder. If this is done, the current at high frequencies cannot confine itself to the skin or surface of the cylindrical conductor but will, as it passes along, flow through all portions of the cylinder wall. The inner conductor, instead of being a hollow tube of stranded wires, may be a solid strand of insulated wires which are interwoven in the manner described above.

A conducting system such as above outlined has a number of advantages. It may be made waterproof, with the result that the leakage losses between the conductors (which in the case of ordinary open wire construction vary greatly with weather conditions and at high frequencies contribute very substantially to the attenuation) may be made small and constant. Furthermore, the increase in conductor resistance with frequency due to the skin effect is relatively small, so that the increase in the attenuation component due to resistance is much less rapid than for ordinary open wire construction. Also, the form of construction is such that interference from nearby circuits and noise coming from external sources may be made practically negligible. Also, the velocity of transmission will be substantially uniform for all frequencies.

The invention will now be more fully understood from the following description when read in connection with the accompanying drawings, of which Figures 1 to 5 are curves illustrating the principles of the invention, and Fig. 6 is a broken section of a portion of the conducting system in accordance with the present invention.

Referring to Fig. 6 of the drawings, 10 designates an outer conductor cylindrical in form which may be made up of a large number of relatively small wires each insulated from the other in some suitable manner, as, for instance, by coating the wire with an insulating enamel, and the wires being braided together in such manner that each individual wire weaves inwardly and outwardly toward and from the center of the cylindrical conductor. A second conductor 12 constructed of braided wire in the same manner as the conductor 10 is mounted concentrically with said outer conductor 10. One of the cylindrical conductors acts as a return for the other and not as a mere shield, this fact being indicated by the conventional representation of a source of alternating electromotive force G with its terminals connected to the two conductors. The conductor 12 may be a hollow tube as shown, with a core or filler 15 of any suitable material, or it may be a solid strand of insulated interwoven wires.

In order that the attenuation may be small at high frequencies, the leakage loss between the conductors must be as small as possible. As the leakage loss is due to the nature of the dielectric interposed between the conductors, the dielectric should be principally gaseous. Accordingly, the two conductors are held in proper concentric relation and out of electrical contact with each other by means of spaced dielectric washers 14. These washers should be separated from each other a suitable distance and should be made as thin as possible consistent with the required mechanical strength. They should also be composed of some dielectric of small loss angle and low dielectric constant, since if these conditions are obtained, the leakage loss (which in the ordinary open wire system comprises a large part of the attenuation) may be made so small as to be practically negligible. For example, hard rubber, or preferably pyrex glass or other good insulting material, may be used for the insulating washers 14. In this connection it should be noted that as the outer shell may be made watertight by a suitable waterproof cover 16, the insulating washers will be maintained dry and free from dirt or contamination so that the leakage loss will not increase or change with time. In ordinary open wire construction where the insulators are exposed to the air and to the action of the elements, the insulators become coated with a film of relatively high resistance conductive material which introduces large leakage losses, and these leakage losses are enormously increased when the external surfaces of the insulators become wet. If it were possible to maintain an open wire line with its insulators in the dry and clean condition which characterizes them when they come from the factory, the attenuation component due to leakage would be so small as to be negligible.

It is possible to mount the concentric conductor arrangement upon the metallic support of an ordinary overhead cable construction or to permit the arrangement to be buried directly in the ground or laid in a conduit such as might be employed for underground cable and the flexible construction of the system due to the braided arrangement of the conductors especially adapts it for mounting in overhead cable hangers or in underground cable conduit.

In the ordinary type of conductor system, either open wire or cable, where one solid wire acts as a return for another solid wire, the component of the attenuation which is due to the skin effect is of great importance at high frequencies. As is well known, where a solid conductor is employed, more and more of the current tends to flow at or near the surface of the conductor as the frequency becomes higher, so that the conductive material near the center of the conductor takes but little part in the action at high frequencies. As a consequence, the conductor resistance increases with frequency as a smaller and smaller part of the cross-section of the conductor is usefully employed. If the same amount of conductor material is arranged in the form of a relatively thin shell, the resistance in any given high frequency is very much reduced because now more nearly all of the material of the conductor is usefully employed in transmitting current. In a system of concentric conductors in which the cylindrical walls are composed of continuous conducting material, the two conductors, being in the form of thin hollow shells, offer a much less resistance at high frequencies due to the skin effect for the same amount of conductive material than in the case of an ordinary transmission circuit consisting of two solid wires. In fact, with such a system of concentric conductors, the current at higher frequencies tends to flow more and more at the inner surface of the outer conductor and the outer surface of the inner conductor, due to the skin effect.

By forming the cylindrical conductors of a plurality of braided wire strands each insulated from the other in accordance with the present invention, the skin effect will be still further reduced. The individual wires making up a given cylindrical conductor may be braided together in any one of a number of known ways to produce a hollow tube. For example, the method of braiding known as "basket weave" may be used, or the wires may be braided together in the manner commonly employed in the construction of the fabric covers for telephone cords, electric light cords and the like. Another method of braiding the wires is that employed for the construction of the braided wire tubes which are used as metallic shields for a group of conductors in a cable. In short, any known method of braiding the wire may be employed so long as the individual strands are woven in and out toward and from the center of the resulting hollow cylinder. If this is done and the strands are insulated from each other by suitably coating them with insulating enamel or the like, the current at high frequencies can no longer flow at the skin or surface of the cylinder but is forced to follow the path taken by the individual wire. The result is that the current flows at high frequencies just as at low frequencies substantially throughout the cross-sectional area of the cylinder.

By means of the construction above described, therefore, we have the one component of the attenuation which is due to the conductor resistance or so-called "series effect" very much reduced as compared with the ordinary type of conducting system for any given frequency, while the other component of attenuation, namely that due to leakage losses or the so-called "shunt effect" is reduced to practically negligible proportions by reason of the fact that the dielectric between the conductors is very largely of air, and such other dielectric as is employed introduces but little leakage. The result is that a concentric conductor arrangement employing the braided or woven wire as herein described can be used for the transmisison of exceedingly high frequencies without substantial attenuation, and the braided construction, furthermore, has the advantage of rendering the conductor flexible so that it may be readily inserted in cable ducts or overhead cable hangers.

The form of construction herein disclosed also has the advantage that it does not produce material interference in a neighboring circuit and, conversely, may be made substantially free from interference from nearby circuits and noise coming from external sources.

In order to understand this more clearly it should be remembered that the interference between any two circuits is due to the fact that the one circuit lies within either the electric field or the magnetic field or both, of the other circuit. Considering first the magnetic field, let us consider two conductors *a* and *b* circular in cross-section and arranged side by side, one acting as a return for the other. These conductors are shown in section in Fig. 2. The lines of force due to the magnetic field surround each conductor and are crowded together in the space between the two conductors. Any other conducting system introduced at a point where the conductors of such other system will be cut by these lines of force will have induced therein cross-talk from the conductor system *a—b*. If, now, we have two conductors 10 and 12, as shown in Fig. 1, in the form of hollow shells concentrically arranged and the one acting as a return for the other, each conductor has lines of magnetic force surrounding it, each successive line of force being of larger radius and all of the lines, due to the current flowing in the particular conductor, such as 12, being external thereto. As the current flows in one direction through the conductor 12 and in the opposite direction through the conductor 10, the lines of magnetic force due to the current through the conductor 12 are in one direction, as indicated by the arrows, while those due to the current flowing in the conductor 10 are in the opposite direction. Now, an inspection of Fig. 1 shows that some of the lines of force due to the current in the conductor 12 are within the conductor 10, but none are within the conductor 12. On the other hand, all of the lines of force due to the current flowing in the conductor 10 are external to said conductor, and the two magnetic fields produced by the currents flowing in the two conductors tend to oppose each other outside of the conductor 10. The resultant field of magnetic force external to the conductor 10 is, therefore, very small, and the only effective magnetic field lies within the space between the two conductors. Since the external magnetic field is very small it is obvious that another conductive system external to the conductor 10 will not receive any appreciable amount of cross-talk interference from the conducting system 10—12.

In so far as the electric field is concerned, the distribution of the field in the case of two parallel conductors *a* and *b* is as indicated in Fig. 4, so that any external conductor which is cut by the lines of electric force between *a* and *b* will have cross-talk induced therein. In the case of the two concentric conductors 10—12, however, the electric field set up due to currents flowing in the two conductors is entirely between the adjacent surfaces of the two conductors, as indicated in Fig. 3. No external conductor can possibly be cut by any of the lines of the electric field due to current flowing in the conductor 12 and returning in the conductor 10, or vice versa, and hence so far as the electric field is concerned, no possible external interference can take place.

The concentric arrangement not only has the advantage that it produces substantially no external field to interfere in other circuits, but it may be practically free from interference due to any external source. For example, referring to Fig. 5, let us assume that some external force produces a field as represented by the arrows. The lines of force cutting the two concentric conductors produce differences in potential between points of the two conductors. For example, consider the points *c* and *d*, the one on the other surface of the conductor 12 and the other on the inner surface of the conductor 10. The lines of force cutting the two conductors produce an induced E. M. F. between these points in the direction and having the value indicated by the arrow *c*—*d*. Since the same number of lines of force cut the two conductors on the opposite side of the diagram, a difference in potential indicated by the arrow *c′*—*d′* will be produced between the two points *c′* and *d′*. The induced potential *c*—*d*, however, tends to produce a current flow equal to and opposite that induced by the difference of potential at *c′*—*d′*, so that a balance is obtained. Due to the symmetry of the conducting system with respect to the cutting lines of force, all differences in potential induced between any other two points of the two conductors will be balanced by similar differences of potential induced at corresponding points on the opposite side, so that if the interfering field is evenly distributed through the cross-sectional area of the conducting system (as would be the case where the interfering source is not too near the system) substantially no interfering effect would result in the conducting system 10—12.

While the foregoing explanation only applies to fields perpendicular to the axis of the conducting system, field components parallel to the axis may also be prevented from causing interference.

In order that a conducting system such as herein disclosed may have as small attenuation as possible at high frequencies, the diameters of the two concentric conductors should be made as large as possible. However, due to practical considerations it may be desirable that the system should be of such character that it might be used in existing cable ducts or in connection with present aerial cable construction. For these reasons, in practice it is convenient to make the diameter of the external conductor not much greater than about two and five-eighths inches, if the conductor is to be used in the existing telephone plant. For economical reasons the thickness of the conductors should be made as small as is consistent with securing proper electrical characteristics and mechanical strength.

As the outer conductor is, or at least can be made watertight, the leakage losses can be reduced to very low values by the use of pyrex or other insulation where mechanical support is necessary, with the largest possible air space between the two conductors. Under these circumstances the leakage loss will not change with weather conditions. For zero leakage (a condition which would be approximately obtained) the attenuation equals

$$R/2\sqrt{C/L}$$

at high frequencies, where R represents the resistance, C the capacity and L the inductance. From this expression it is evident that the values of R and C should be as small as possible. For a given thickness of conductor the value of R at high frequencies is inversely proportional to the diameter of the conductor, and hence the attenuation will be smaller at any given frequency the larger the diameter of the conductor. The capacity C also is an inverse function of the diameter and decreases as the difference between the diameters of the inner and outer conductors increases. Consequently, if the diameter of the outer conductor is fixed, as the diameter of the inner conductor increases from some small value the resistance of the conducting system decreases, while at the same time the capacity increases. The decrease in resistance tends to reduce the attenuation, while the increase in capacity tends to increase the attenuation. For a given diameter of the inner conductor these two effects balance and the attenuation becomes a minimum.

At 500,000 cycles the attenuation per mile of a concentric conductor system as described above will be very much less than the attenuation of a 165-gauge open wire circuit. There is a further advantage in using the former on account of the lower levels to which the current may be attenuated before a repeater is necessary.

It follows, therefore, for the transmission of frequencies up to 500,000 cycles an open wire circuit would be quite unsuitable, whereas the concentric conductor system would carry frequencies as high as 1,000,000 to 2,000,000 cycles or even higher, without undue attenuation. A carrier telephone system could be operated over such a conductor with as many as one to two hundred two-way channels, allowing 5,000 cycles for each channel in each direction. This is comparable to the number of circuits which might be obtained from the pairs of wires in a cable of equivalent size. Any particular circuit in the cable could not be used for the transmission of frequencies much above the ordinary telephone range, and hence could not be employed for the transmission of musical programs involving frequencies up to the audio without using a very expensive system. It is impracticable to arrange a cable circuit to transmit frequencies high enough for good television transmission. The concentric conductor system, on the other hand, may be employed for either program transmission or television.

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

What is claimed is:

1. In a conducting system for the communication of intelligence, two concentric conductors, each conductor being in the form of a shell of conductive material comprising a plurality of insulated wires so interwoven that each wire is passed back and forth toward and from the center of the shell, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

2. In a conductive system for the communication of intelligence, two concentric conductors, one of said conductors being in the form of a shell of conductive material comprising a plurality of insulated wires so interwoven that each wire is passed back and forth toward and from the center of the shell, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

3. In a conductive system for the communication of intelligence, two concentric conductors, each conductor being in the form of a shell of conducting material comprising a plurality of insulated wires braided together to form a hollow tube, the wires being so braided as to be woven inwardly and outwardly toward and from the center of the tube, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

4. In a conducting system for the communication of intelligence, two concentric conductors, one of said conductors being in the form of a shell of conducting material comprising a plurality of insulated wires braided together to form a hollow tube, the wires being so braided as to be woven inwardly and outwardly toward and from the center of the tube, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

5. In a conducting system for the communication of intelligence, two concentric conductors, one of said conductors comprising a plurality of insulated wires so interwoven that each wire is passed back and forth toward and from the center of the system, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

6. In a conducting system for the communication of intelligence, two concentric conductors, each of said conductors comprising a

plurality of insulated wires so interwoven that each wire is passed back and forth toward and from the center of the system, and insulating means for separating the conductors electrically and for maintaining them in concentric relation, said insulating means being so formed that the dielectric between adjacent surfaces of the conductors will be principally gaseous.

In testimony whereof, we have signed our names to this specification this 20th day of May, 1929.

HERMAN A. AFFEL.
ESTILL I. GREEN.