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1,781,093

CONCENTRIC CONDUCTOR SYSTEM

Filed May 23, 1929

2 Sheets-Sheet 1

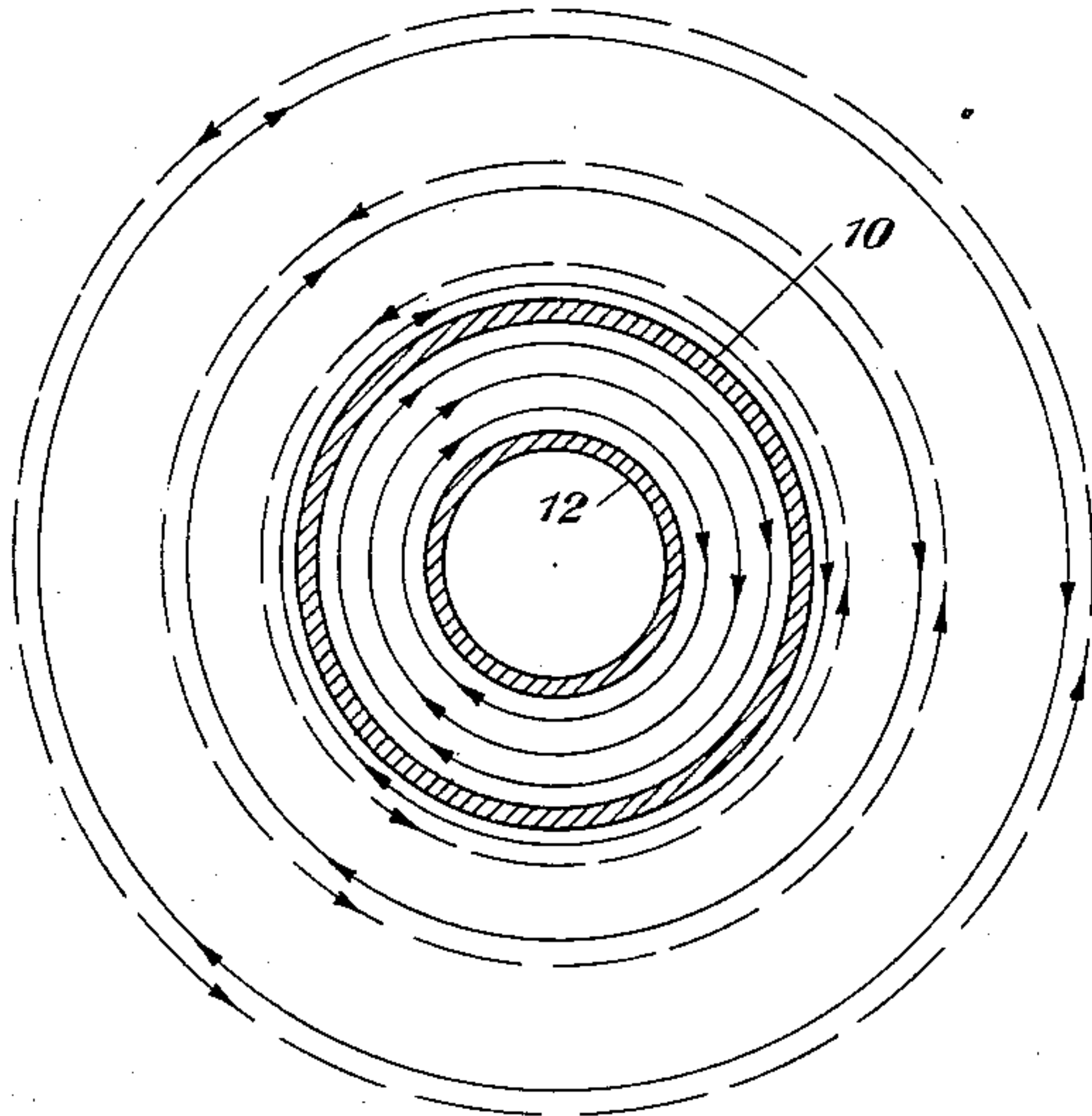


Fig. 1, Magnetic Field

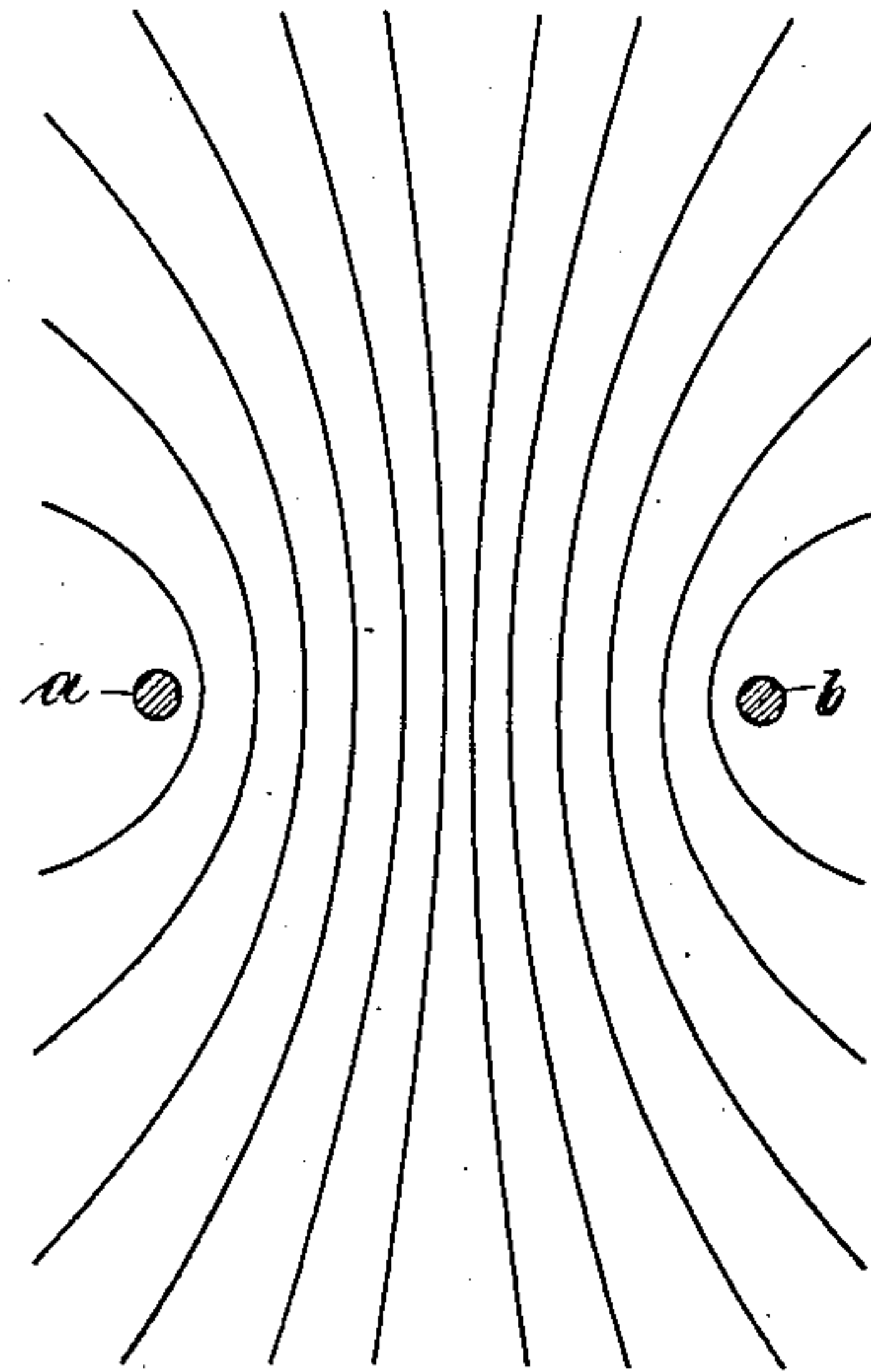


Fig. 2, Magnetic Field

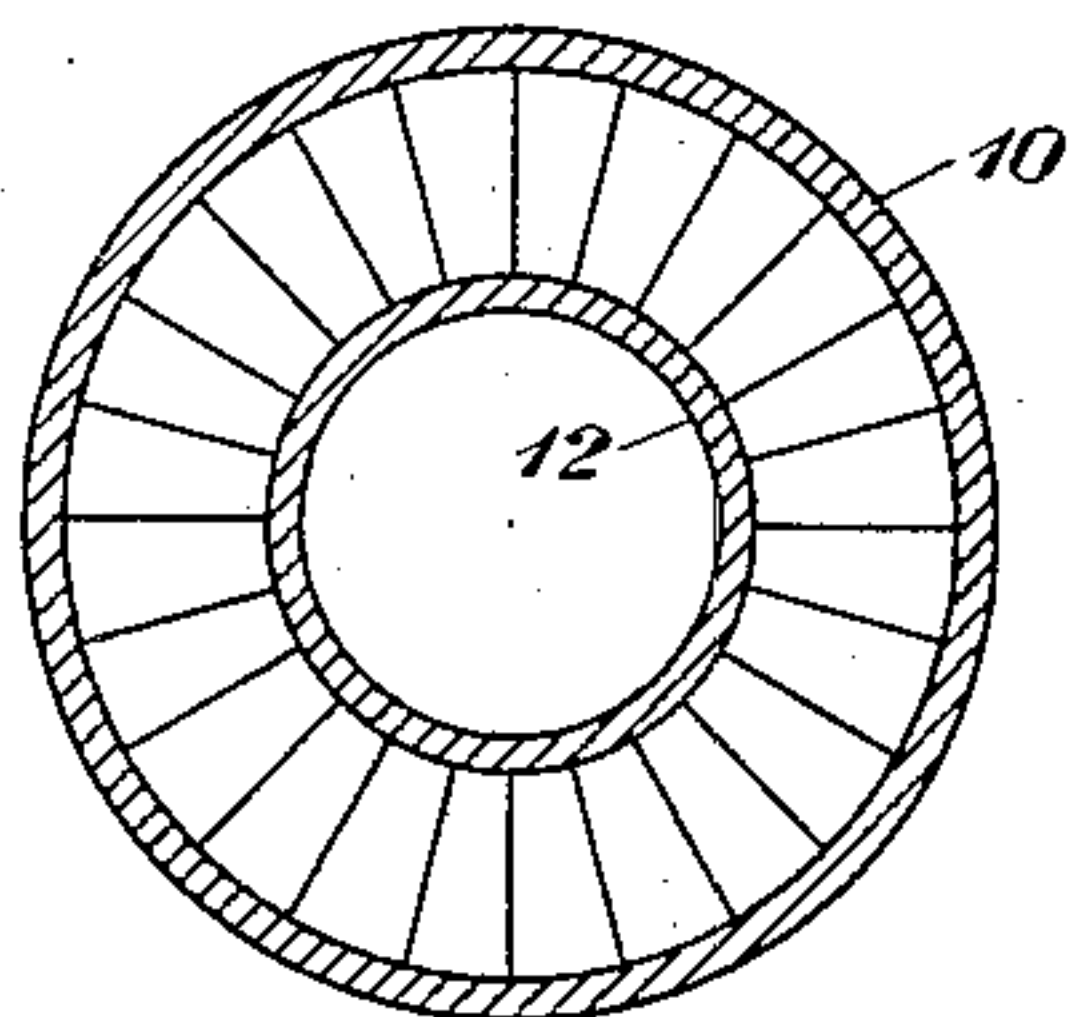


Fig. 3, Electric Field

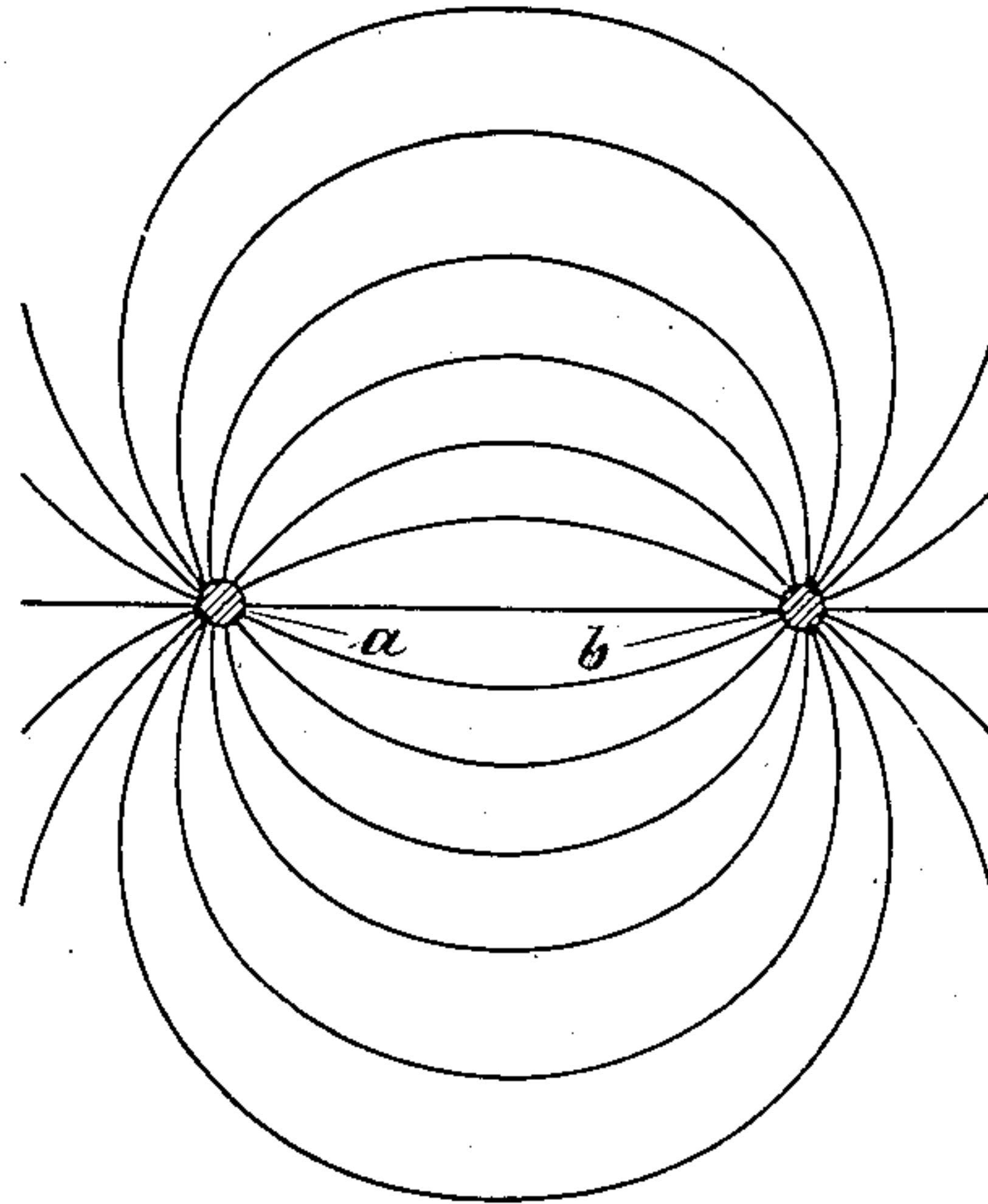


Fig. 4, Electric Field

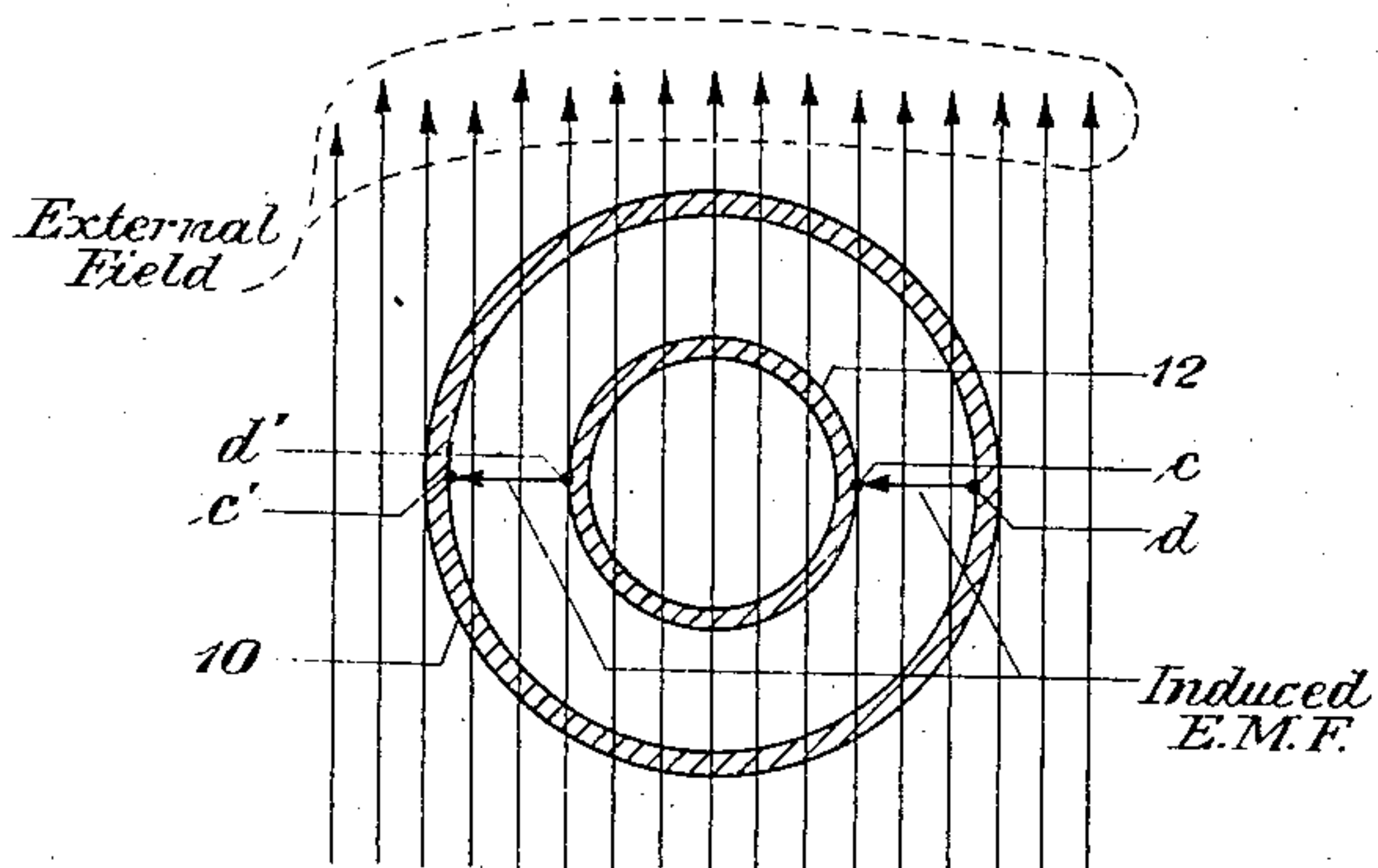


Fig. 5

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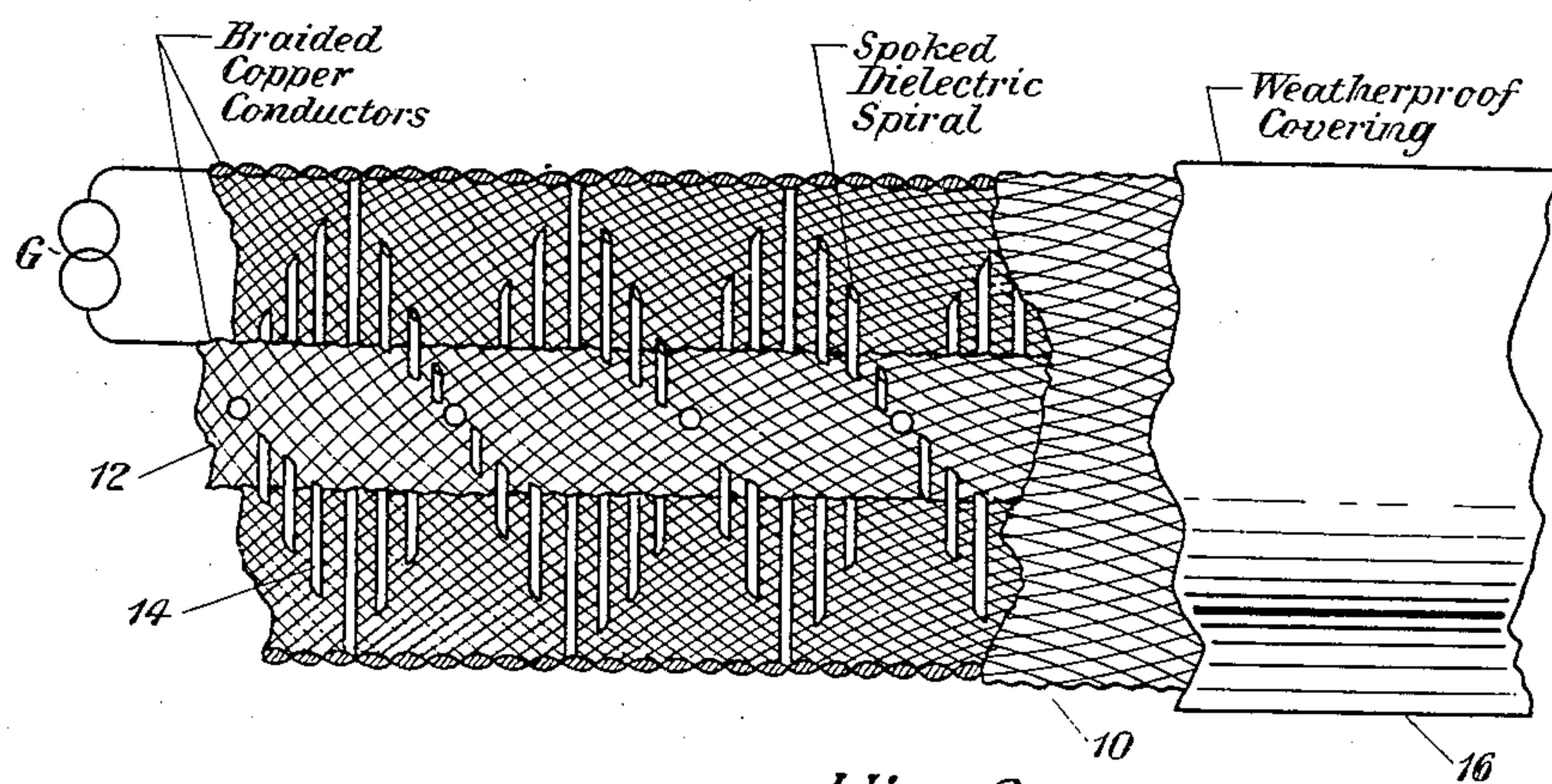


Fig. 6

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CONCENTRIC CONDUCTOR SYSTEM

Application filed May 23, 1929. Serial No. 365,523.

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 did not exceed 2,500 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 ordinarily adapted for transmission of such high frequencies, and the only commercial circuit 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 carried 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 without undue attenuation 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 readily 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 because of the enormous attenuation involved at frequencies above about 30,000 cycles. 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 may be insulated from each other and held in proper concentric relation by means of a spiral insulating arrangement comprising a series of spokes passed transversely through the inner conductor and arranged spirally along the inner conductor with their outer ends acting as supports for their outer conductor. Preferably the inner conductor, and, if desired, both conductors, may be constructed of a large number of fine wires of conducting material insulated from each other by some suitable insulating enamel and braided together to form

flexible cylinders. If desired the insulating spokes may be mounted in their spiral positions and extended transversely through the inner conductor during the process of braiding. By the use of this form of insulating separator between the two conductors the principal part of the dielectric between the conductors will be air which, as is well known, involves substantially no leakage loss.

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 will be practically negligible. Moreover, the nature of the circuit is such that even though the outer conductor be grounded it will not be subject to interference from ground currents. This enables the conductor to be laid directly on the metallic supports of an overhead cable system or underground in a conduit without any external insulation. 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 drawing, 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 drawing, 10 designates an outer conductor which may be in the form of a thin cylindrical shell constructed either of solid conducting material or of a large number of fine wires of conducting material, each insulated from the other by a suitable enamel coating and woven or braided together. A second conductor 12 is mounted concentrically with the outer conductor 10, the inner conductor likewise being constructed of braided fine wires insulated from each other by enamel or other insulating coating. One of the 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.

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 of air since air introduces no dielectric. Accordingly, the two conductors are held in proper concentric relation and out of electrical contact with each other by means of a series of spokes or thin rods 14 of dielectric material, these spokes being passed transversely through openings or interstices between the wires of the inner conductor 12, and the successive spokes being arranged spirally along the inner conductor with their outer ends extending outwardly to support the outer conductor. The successive spokes 14 should be separated as far as possible from each other and the pitch of the spiral in which the spokes are arranged should be made as large as possible consistent with mechanical strength. The spokes should also be composed of some dielectric material 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. Pyrex glass or isolantite is a suitable material for the spokes 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 spokes 14 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 will therefore be apparent that even if the dielectric material of which the spokes 14 is composed is not the most perfect from the standpoint of low loss angle and small dielectric constant, the attenuation due to the insulating member may still be practically negligible.

As will be explained later, a conducting system of this type will be practically free from external interference even though the outer conductor is grounded. Since, therefore, 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, the flexible construction of

the system due to the braided arrangement of the conductors and to the spirally mounted insulating supports of spokes especially adapts it for mounting in overhead cable hangers or in underground cable conduit.

5 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, as the frequency becomes higher more and more of the current tends to flow at or near the surface of the conductor, 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 at 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, such as described in connection with the present invention, if both conductors are in the form of thin hollow shells of conducting material, the conductors offer 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, in a concentric conductor system, the current at higher frequencies tends to flow more and more at the inner surface of the outer conductor and at the outer surface of the inner conductor, due to the well known skin effect. If, however, two cylindrical conducting shells are formed of a large number of fine wires insulated from each other but braided together so that the wires loop in and out toward and from the common center of the two conductors, the current can no longer follow along the adjacent skins or surfaces of the two cylinders but is compelled to follow the wires of which the cylinders are composed, with the result that both the conducting material adjacent the inner surface of the outer cylinder and that at the outer surface of the outer cylinder will be used for conducting the current at high frequency, and the same holds true for the inner conductor. This accordingly reduces the skin effect very materially with the result that while the component of the attenuation which is due to the conductor resistance may increase to some extent with frequency, the rate of increase is very much less than in the case of an open wire line.

By means of the construction above described, therefore, I have the one component

of the attenuation which is due to leakage losses or the so-called "shunt effect" 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 loss, while the other component of the attenuation, namely, that due to the conductor resistance or so-called "series effect" is very much reduced as compared with the ordinary type of conducting system for any given frequency.

The form of construction herein disclosed also has the advantage that it does not produce material interference in a neighboring circuit and, conversely, is 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 is 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 outer 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 are also prevented from causing interference. This is because the skin effect in the outer conductor furnishes protection against such fields.

As has been previously stated, the concentric conducting system is free from external interference even though the outer conductor be grounded, and hence there is no necessity for insulating the outer conductor from metallic supports in case it is mounted like an overhead cable, or from ground in case it is placed in a conduit. The reason for this is that a ground return circuit is noisy, due to the fact that a wire supported above ground forms with the ground a loop to pick up stray fields. But from the diagram of Fig. 5 it is evident that if the outer conductor such as 10 is grounded so that it in effect becomes a ground return for the tube 12, it is only the space between the two concentric conductors that acts as the loop to pick up stray fields. Hence, as has been just explained in connection with Fig. 5, substantially no interfering currents are induced in the conductors 10—12.

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. In general it has been found that if the cylindrical conductor is made thick enough to satisfy the mechanical requirements, the electrical resistance is not a limiting factor in the attenuation at high frequencies. This is due to the skin effect, which, as previously described, causes the current to crowd to the outer surface of the inner conductor and the inner surface of the outer conductor as the frequency increases, thereby rendering the remaining cross-sectional area of little utility for carrying current.

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. At high frequencies R 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 decreases 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. This is due to the absence of coupling to external fields and results in a very low noise level. On an open wire circuit the level could not be allowed to go below -50 transmission units, while with the concentric conductor system it might be permitted to fall as low as -80 transmission units. If the repeaters are adjusted to give an output of +10 transmission units this would result in a repeater spacing of thirty-six miles for the open wire circuit and 210 miles for the concentric return circuit. It appears to be impractical to devise a transmission system for an open wire circuit at such high frequencies, and the high frequency cross-talk would limit its use to one circuit on a given lead. Due to the absence of couplings to other circuits this limitation would not apply to the tubular conductor system, and any desired number of such conductor systems might be mounted upon the same pole line or carried in adjacent conduits without undue interference.

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 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 limit 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 conductive system for the communication of intelligence, two concentric conductors of cylindrical form, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor.

2. In a conductive system for the communication of intelligence, two concentric conductors of cylindrical form, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor with their outer ends supporting the outer conductor.

3. In a conductive system for the communication of intelligence, two concentric conductors of cylindrical form, the inner of said conductors being in the form of a conductive shell comprising a plurality of insulated wires woven together so that each wire weaves in and out toward and from the center of the shell, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor.

4. In a conductive system for the communication of intelligence, two concentric conductors of cylindrical form, the inner of said conductors being in the form of a conductive shell comprising a plurality of insulated wires woven together so that each wire weaves in and out toward and from the center of

the shell, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor with their outer ends supporting the outer conductor.

5
10 5. In a conductive system for the communication of intelligence, two concentric conductors of cylindrical form, both of said conductors being in the form of a conductive shell comprising a plurality of insulated
15 wires woven together so that each wire weaves in and out toward and from the center of the shell, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor.

25 6. In a conductive system for the communication of intelligence, two concentric conductors of cylindrical form, both of said conductors being in the form of a conductive shell comprising a plurality of insulated
30 wires woven together so that each wire weaves in and out toward and from the center of the shell, and insulating means for separating the conductors electrically and maintaining them in concentric relation, said means comprising spoke-like members of dielectric material passing transversely through the inner conductor so that successive spoke-like members are arranged spirally along the conductor with their outer ends supporting the
40 outer conductor.

In testimony whereof, I have signed my name to this specification this 20th day of May, 1929.

HERMAN A. AFFEL.