Nov. 11, 1930. H. A. AFFEL ET AL 1,781,092

CONCENTRIC CONDUCTING SYSTEM

Filed May 23, 1929 2 Sheets-Sheet 1

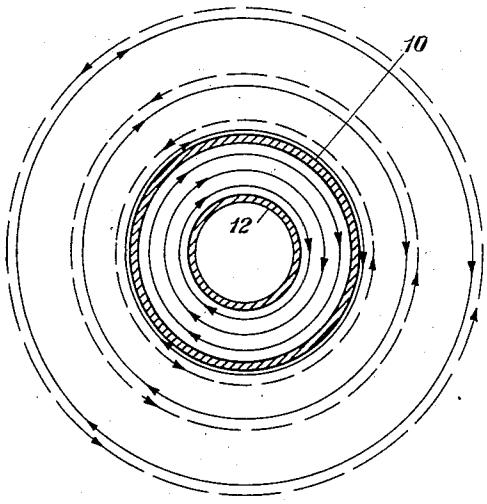


Fig. 1, Magnetic Field

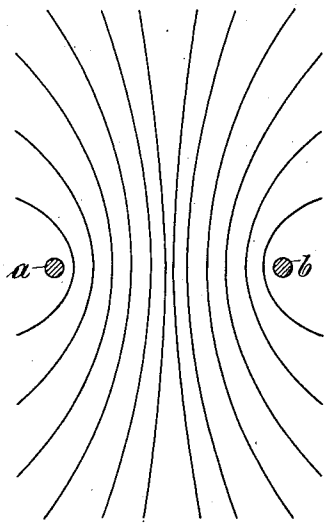


Fig. 2, Magnetic Field

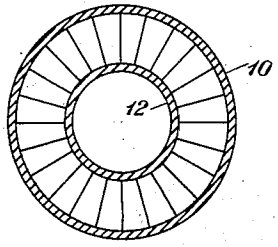


Fig. 3, Electric Field

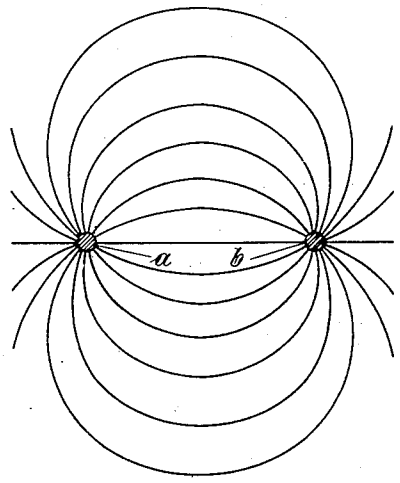


Fig. 4, Electric Field

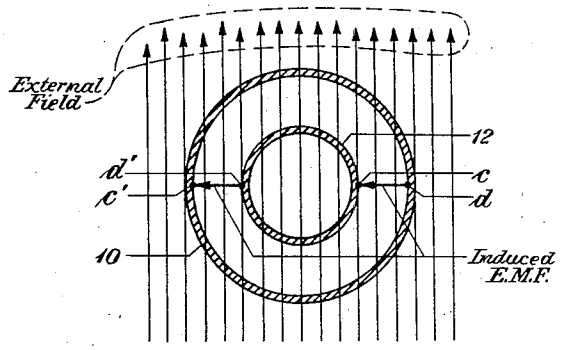


Fig. 5

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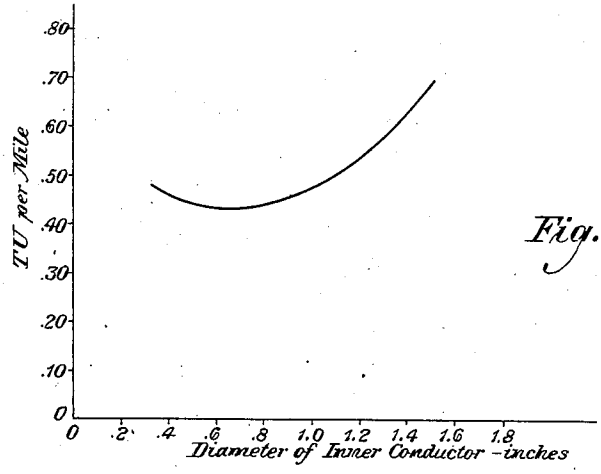


Fig. 6

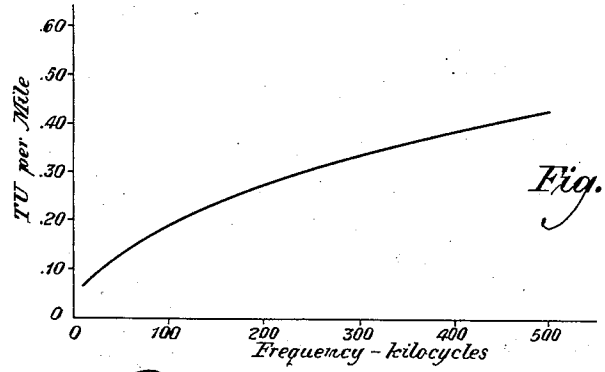


Fig. 7

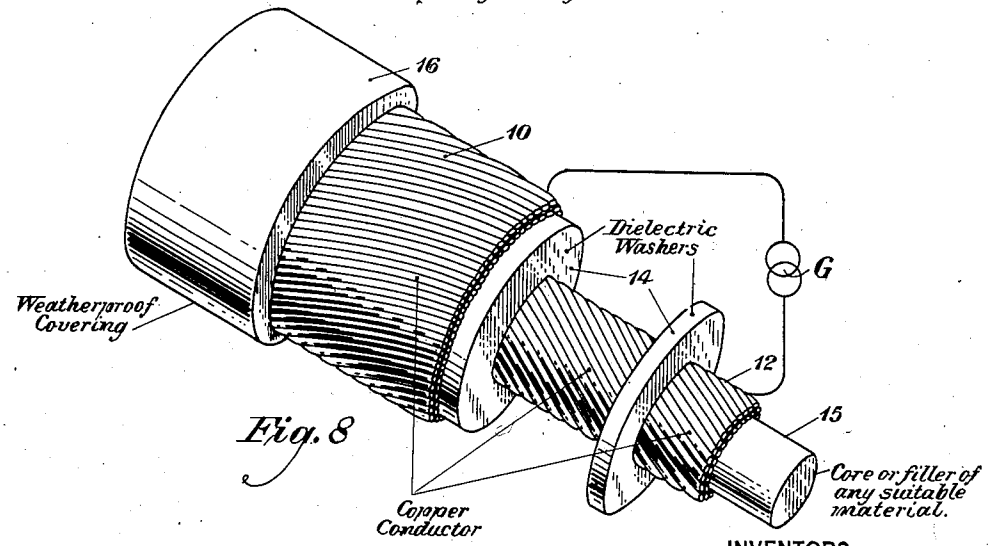


Fig. 8

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UNITED STATES PATENT OFFICE

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CONCENTRIC CONDUCTING SYSTEM

Application filed May 23, 1929. Serial No. 365,522.

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 about 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 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 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 remnant 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 inner conductor is formed by spirally winding a plurality of wires about a suitable core, thus forming in effect a hollow conducting shell. A plurality of spacing washers of some suitable dielectric are mounted upon the inner shell to form a support for the outer conductor. These washers should preferably be composed of a dielectric of small 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. The outer conductor may be formed by spirally winding a plurality of wires over the outer surfaces of the supporting washers to form in effect an outer conducting shell. If desired, both the inner and outer conducting shell may comprise a plurality of layers of wire in order to obtain the desired conductivity and mechanical rigidity. A waterproof covering will then surround the entire surface of the outer conductor to protect the system from moisture, this waterproof covering being of any type used for a similar purpose in cable construction.

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 7 are curves illustrating the principles of the invention; and Fig. 8 is a perspective view in partial section of a portion of the concentric conductor arrangement.

Referring to Fig. 8 of the drawing, 10 designates the outer conductor, 12 the inner conductor, 14 a plurality of dielectric washers for separating the two conductors, 15 a core upon which the inner conductor is mounted, and 16 a waterproof covering for encasing the entire construction. 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. The inner conductor is formed by spirally winding one or more layers of copper or other conductive wire upon the core 15 to form, in effect, a relatively thin conducting shell. Upon this shell the spacing and insulating washers 14 are mounted. The outer conductor is then formed by spirally winding one or more layers of conductive wire over the outer surfaces of the spacing washers to form in effect an outer conducting shell. The waterproof covering which surrounds the outer conductor may be of any known type such, for example, as is used in ordinary cable construction and is intended to serve the dual purpose of mechanical protection and prevention of the entrance of water into the interior of the system.

In order that the attentuation may be small at high frequencies, the leakage loss between the conductors 10 and 12 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 leakage loss. Accordingly, the dielectric washers 14, which hold the two conductors in proper concentric relation and out of electrical contact with each other, are arranged so as to be separated from each other a suitable distance, and they should also be as thin as possible consistent with the required mechanical strength. Preferably these washers should 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, may be used for the insulating washers 14.

In this connection it should be noted that since the conducting system is rendered watertight by means of the waterproof covering, the insulating washers may be maintained dry and free from dirt or contamination, so that the leakage losses 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.

Since, 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, it is possible to mount the concentric conductor arrangement upon the metallic supports of an ordinary overhead cable construction or to per-

mit the arrangement to be buried directly in the ground or laid in a conduit such as might be employed for underground cable, even though the outer layer of waterproofing material be nothing more than a lead shield. In either case the construction of the two conducting shells of spirally wound wire has the advantage that the final construction is as flexible as the ordinary telephone cable, and it may be installed and maintained in the plant in the same way as a cable.

As has been previously pointed out, no insulation between the outer conductor and any external conductor is necessary in order to prevent interference. The insulation of the system, so far as it affects transmission, is confined entirely to the space between the two concentric conductors. Consequently, by making the external conductor waterproof, the leakage due to the dielectric of which the washer 14 is composed will not change with wet weather, and the surfaces of the dielectric washers will not deteriorate with time due to accumulations of dirt or other foreign substances. The leakage loss of the system will therefore be confined to that leakage loss which will be due to the dielectric material of which the washers are composed when the washers are new, clean and dry. If reasonable good dielectric material is employed, the leakage loss due to the supporting washers will be practically negligible, and if a material of low loss angle and dielectric constant is used, such for example, as pyrex glass, the factor of attenuation which is due to leakage will be so small as to be practically negligible. In ordinary open wire line construction (which has the lowest attenuation at high frequencies of any type of construction now employed in telephone practice) the attenuation due to leakage losses has been very large, and in wet weather becomes enormous. With the present type of construction this factor of the attenuation becomes of little importance, and any attenuation due to this factor is fixed and unchangeable with variations in weather conditions.

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. With a system of concentric conductors, such as described in connection with the present invention, both 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 a system of concentric conductors such as herein disclosed, 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 well known skin effect. The result is that while that component of the attenuation which is due to the conductor resistance increases 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, we 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, while the other component of 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 12 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 is 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 inner conductor 12, it is only the space between the two concentric conductors that acts as the loop to pick up stray fields. Hence, as has just been 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 conductor 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 values of electrical resistance and mechanical strength. In general, it has been found that if the conducting shells are made up of spirally wound wire of such thickness and wound in a sufficient number of layers 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 or proximity 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 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.

Fig. 6 is a curve showing how the attenuation varies with diameter of the inner conductor at 500,000 cycles, with the inner diameter of the outer conductor fixed at two and one-half inches. This curve shows a minimum attenuation of .43 transmission units per mile for an inner conductor diameter of about .7 inch. As will be clear from the curve, either an increase or decrease of the diameter of the inner conductor from the foregoing value results in an increase in the attenuation. In Fig. 7 is shown a curve of the attenuation at various frequencies of a concentric conductor system whose outer conductor has a diameter or two and one-half inches and the inner conductor has the optimum diameter of about .7 inch. It will be observed from this curve that while the attenuation increases with frequency, the slope of the curve is not steep and the increase in attenuation is very much less than would be the case for an open wire line.

At 500,000 cycles the attenuation per mile of a 165-gauge open wire circuit with a spacing of 12 inches between wires is about 1.67 transmission units, which compares with .43 transmission units per mile for the concentric conductor system. The advantages of using the latter are even greater than would appear from these figures 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 concentric 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 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 limit without using a very expensive loading system. A cable circuit could not conceivably be loaded 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 conductors connected one as a return for the other, each conductor being in the form of a shell of conductive material and the two conductors being arranged concentrically one inside the other, means to prevent moisture from entering the interior of the outer conductor, the inner conductor being formed by winding a plurality of conducting filamentary structures about a core, 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, and said outer conductor being formed of a plurality of conducting filamentary structures wound about said insulating means.

2. In a conducting system for the communication of intelligence, two conductors connected one as a return for the other, each conductor being in the form of a shell of conducting material and having a diameter large as compared with its wall thickness so that its attenuation will be relatively small at high frequencies, said conductors being arranged concentrically one inside the other, means to prevent moisture from entering the interior of the outer conductor, the inner conductor being formed by winding a plurality of conducting filamentary structures about a core, 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, and said outer conductor being formed of a plurality of conducting filamentary structures wound about said insulating means.

3. In a conducting system for the communication of intelligence, two conductors connected one as a return for the other, each conductor being in the form of a shell of conductive material and the two conductors being arranged concentrically one inside the other, means to prevent moisture from entering the interior of the outer conductor, the inner conductor being formed of at least one layer of conducting wire wound about a core, 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, and said outer conductor being formed of at least one layer of conducting wire wound about said insulating means.

4. In a conducting system for the communication of intelligence, two conductors connected one as a return for the other, each conductor being in the form of a shell of conducting material and having a diameter large as compared with its wall thickness so that its attenuation will be relatively small at high frequencies, said conductors being arranged concentrically one inside the other, means to prevent moisture from entering the interior of the outer conductor, the inner conductor being formed of at least one layer of conducting wire wound about a core, 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, and said outer conductor being formed of at least one layer of conducting wire wound about said insulating means.

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

HERMAN A. AFFEL.
ESTILL I. GREEN.