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TRANSMISSION SYSTEM

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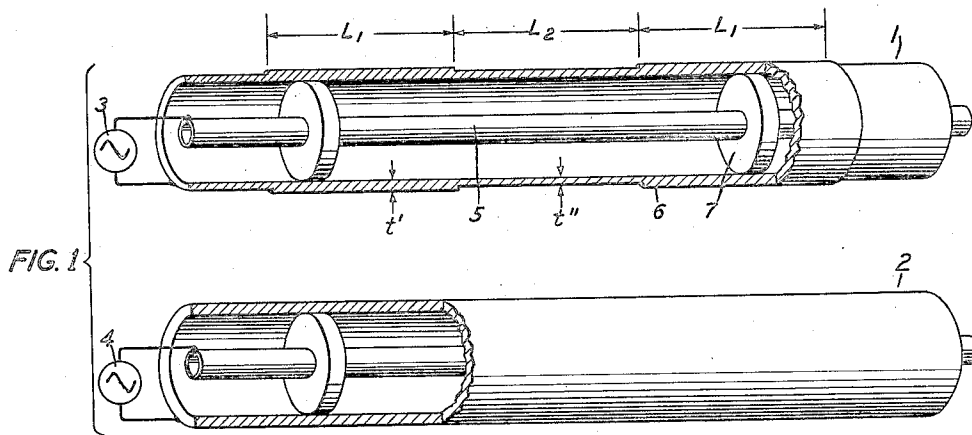
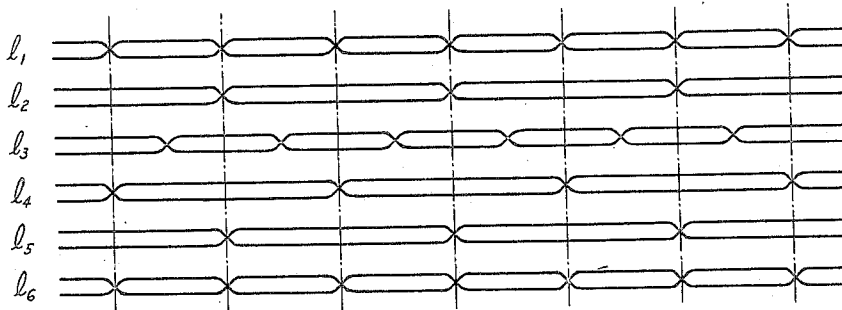


FIG. 2



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TRANSMISSION SYSTEM

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This invention relates to conducting systems for the transmission of intelligence and more particularly to such systems wherein one conductor serves as a coaxial return for another.

An object of the invention is to reduce the effect of signals in a coaxial conductor transmission line on adjacent signaling circuits. Another object is to reduce the disturbing effects of extraneous electric and magnetic fields on a coaxial conductor transmission system. A more particular object of the invention is to reduce the mutually disturbing effects of signal induction between parallel signaling circuits of the coaxial conductor type.

In another aspect, the object of the present invention is to make possible a reduction in the thickness of the return conductor of a coaxial system without permitting interference to become excessive.

A signaling line suitable for the transmission of frequencies of the order of a megacycle per second has been found to be one comprising a central conductor and a tubular or shell-like return conductor maintained in coaxial relation with the first conductor and separated from it by a dielectric that is substantially gaseous. The outer conductor, since it completely surrounds the central conductor and is normally grounded, affords almost perfect shielding against external electric disturbances. External magnetic fields, because of the arrangement of the conductors, also have little effect on the system, at least at high frequencies. Where the conductors are thick enough to be mechanically self-supporting the shielding may be so efficient, in fact, that the extent to which signals may be attenuated is determined not by the level of static and cross-talk as in other systems, but only by the resistance noise of the conducting material and interference from sources inherent in the system.

In some situations external sources of interference may be so powerful or so near the signaling line that the level of interference becomes objectionably high. Such a condition might be found, for example, where the transmission line passes in the immediate vicinity of a powerful radio broad-casting station. Where also a multiplicity of coaxial conductor pairs are brought together to form a cable as disclosed in U. S. Patent 1,978,418, October 30, 1934 to H. W. Dudley, mutual induction between circuits becomes a serious consideration, in some cases determining the frequency range that may be utilized. Increasing the thickness of the outer conductor alleviates the difficulty, but as a practical matter it is not

wholly satisfactory since the flexibility of the cable is thereby reduced and the cost of the conducting material, already the major item of expense in a system of this type, is increased.

In accordance with the present invention, it is proposed to vary from section to section along a coaxial conductor line the phase change of waves transmitted transversely through the outer conductor, in such manner that the fields created by signals in successive sections induce in adjacent circuits waves that tend to neutralize each other. Conversely, in a coaxial conductor line so designed in accordance with the invention the waves induced in the line by external fields are mutually opposing in successive sections. The required transverse phase change may be obtained by proper selection of the thickness, conductivity or permeability of the outer conductor.

The signaling waves traversing the outer conductor of a coaxial pair are largely concentrated at the inner surface of that conductor. They extend outward too, but with diminishing intensity, to the outer surface of the conductor and from that outer surface they extend to nearby circuits where they induce disturbing currents. The rate of transverse propagation, i. e., from the inner surface to the outer surface, is slow compared with the rate of propagation of the waves longitudinally of the conductor or through space, and the phase of the waves at the outer surface may therefore be quite different from that at the inner surface. Calculations show, for example, that in cylindrical copper shells greater than ten mils in thickness the phase shift at forty thousand cycles per second is 0.077 radian per mil. The precise transverse phase change can be controlled by varying the thickness, conductivity or permeability of the outer conductor or any combination of these three factors.

Applicant has discovered that a coaxial conductor line may be divided into a plurality of longitudinal sections and the physical properties of successive sections so chosen that the waves extending from the outer conductor of one section are in phase opposition to those extending from the outer conductor of adjacent sections. The waves induced in successive portions of nearby conductors are then likewise in phase opposition and tend to neutralize each other, thus reducing the resultant disturbing current reaching the terminals of those conductors.

Conversely, extraneous fields linking successive sections of a coaxial conductor line designed in accordance with the invention generate in the main current path of the outer conductor waves

that are mutually opposing so that the resultant disturbing effect of the field is diminished.

The principles underlying the present invention will more fully appear from the mathematical treatment herein to follow. Other objects, features, modifications and applications of the invention will also be set forth, reference being made to the accompanying drawing, in which:

Fig. 1 illustrates the invention as embodied in a single coaxial conductor line; and

Fig. 2 shows schematically the application of the invention to a plurality of adjacent coaxial conductor lines.

The factors and relations involved in the design of a coaxial conductor system in accordance with the present invention may be arrived at by considering the mathematical expression for the distributed mutual impedance between one coaxial pair and an adjacent coaxial pair.

If the "effective thickness" of the outer conductor of a coaxial pair is defined by

$$(1) \quad h = 2\pi t \times \sqrt{\lambda \mu f}$$

where t is the actual thickness of the outer conductor in centimeters and λ and μ are, respectively, the conductivity and the permeability in electromagnetic units of the material comprising the outer conductor and f is the frequency, then, if h is greater than π , the distributed mutual impedance Z_{12} between two coaxial pairs in metallic contact can be represented approximately in the following form:

$$(2) \quad Z_{12} = A e^{-2h} [\cos 2h - i \sin 2h] \text{ abohms per cm.}$$

If a single coaxial line is considered,

$$(2a) \quad Z_{12} = A e^{-h} [\cos h - i \sin h] \text{ abohms per cm.}$$

These equations for distributed mutual impedance may be derived from those found in applicant's paper on the "Electromagnetic theory of coaxial transmission lines and cylindrical shields" published in the Bell System Technical Journal, October 1934. Thus, Equation (75) of the paper referred to gives an accurate expression for the surface transfer impedance Z_{ab} which is shown in simplified form in Equation (82). In the latter equation the expression ot is the same as $h + ih$. If it be assumed that the electrical thickness h is large enough to make e^{-2h} small by comparison with unity, then $\cosh h = 2e^{-h}$ and Equation (82) becomes

$$Z_{ab} = \frac{\eta}{\pi \sqrt{ab}} e^{-h} (\cos h - i \sin h)$$

The relation to Equation (2a) is apparent.

The distributed mutual impedance of two coaxial pairs is equal to the product of the surface transfer impedances of their outer members and a quantity which depends upon the separation of the two pairs. If the two lines are alike, therefore, it follows that the expression for the distributed mutual impedance is of the form indicated in Equation (2). The quantity A lumps together several factors that are substantially independent of h .

In Equation (2) it is assumed that the outer conductors of both coaxial pairs are equally thick; if they are not equally thick, the quantity $2h$ should be replaced by the sum of the effective thicknesses of the outer conductors of the two pairs.

If we now treat the two coaxial pairs as divided into a plurality of axially successive sections, the

mutual impedance for two such sets of parallel sections can be represented, respectively, as:

$$(3) \quad P [\cos \alpha + i \sin \alpha] \text{ and } Q [\cos \beta + i \sin \beta]$$

where α is the effective thickness for one set of sections and β for the other. P and Q , representing the respective magnitudes of these vector quantities, each obviously depends on the combined thickness of outer conductors in the corresponding set of sections. P and Q are in fact very nearly proportional to $e^{-\alpha}$ and $e^{-\beta}$, respectively. Each varies also directly as the length of the section.

The mutual impedance of the two sets of sections in tandem is

$$(4) \quad [P \cos \alpha + Q \cos \beta] + i[P \sin \alpha + Q \sin \beta]$$

the magnitude of which may be expressed as:

$$(5) \quad \sqrt{P^2 + 2PQ \cos (\alpha - \beta) + Q^2}$$

The last equation shows that the magnitude of the total mutual impedance is:

(A) Maximum, if the difference between α and β is zero or any even multiple of π ; and

(B) Minimum, if this difference is π or any odd multiple of π .

In the second case, that giving minimum coupling, the magnitude of the total mutual impedance is equal to $P - Q$. P and Q can be made equal and the coupling thereby reduced to zero by properly relating the lengths of the two sections. Specifically, the lengths of the sections having mutual impedances P and Q , respectively, should be in the ratio of e^α to e^β . Thus, the lesser shielding efficiency of the section having the smaller effective thickness is compensated by lesser length, so that the magnitudes of the mutual impedances of the two sections are made equal.

Continuing to confine our attention to the case of two parallel coaxial conductor pairs, cross-talk will be a minimum, then, when in one section the sum of the effective thicknesses of the two outer conductors differs by π or an odd multiple thereof from the sum of the effective thicknesses of the two outer conductors in the next successive section.

Mathematically expressed:

$$2\pi t' \sqrt{\lambda' \mu' f} - 2\pi t'' \sqrt{\lambda'' \mu'' f} = \pi$$

$$t' \sqrt{\lambda' \mu'} - t'' \sqrt{\lambda'' \mu''} = \frac{1}{4\sqrt{f}}$$

or if

$$\lambda' = \lambda'' \text{ and } \mu' = \mu''$$

$$t' - t'' = \frac{1}{4\sqrt{\lambda \mu f}}$$

This condition permits a wide latitude in design, ranging from the case (1) where one outer conductor is uniform in electrical and physical thickness throughout its length and the other conductor is divided into a plurality of sections each differing in electrical thickness from the two adjoining sections by π or an odd multiple thereof, to the case (2) where the outer conductors of both pairs vary in electrical thickness, and in identical manner, from section to section along the line, successive sections of each outer conductor in this case differing from each other in electrical thickness by

$$\frac{\pi}{2} \text{ or by } \frac{\pi}{2} + 2\pi k,$$

where k is an integer.

It should be clear from a consideration of Case (1) that a coaxial pair to which a system of quasi-

transposition has been applied as there set forth will be immune not only from adjacent untransposed signaling pairs but also from such sources of interference as nearby radio transmitters. This is true because the interfering waves can be assumed to arrive in substantially the same phase at each pair of successive sections within that portion of line seriously affected.

Case 1 is illustrated in Fig. 1 of the drawing. Two coaxial conductor lines, 1 and 2, are shown, each connected to a respective source 3, 4 of high frequency signaling waves. The wave sources may be, for specific example, the terminal circuits of a multiplex two-way carrier telephone system operating over a frequency range of from fifty to five hundred kilocycles per second as described in U. S. Patent 1,978,419, October 30, 1934 to H. W. Dudley. Line 1, comprising central conductor 5, outer conductor 6, and separators 7, is indicated as being quasi-transposed at intervals, whereas line 2, similar in other respects, is not.

The quasi-transposition system is designed to be of maximum effectiveness at some frequency in the lower portion of the signaling spectrum, let us assume for purposes of further discussion, the lowest frequency, fifty kilocycles per second. The average length of the sections may be chosen almost at will, the only limitation being that there be a sufficient number of sections per wave-length at fifty kilocycles that within any section the system shall not lose its effectiveness by reason of phase reversal in the longitudinal transmission.

Assume that the outer conductor of the quasi-transposed line is a copper tube 50 mils in thickness in one section. The effective thickness h' is, as given by Equation (1),

$$h' = 2\pi \times .050 \times 2.54 \sqrt{\lambda \mu \times 50000}$$

The effective thickness h'' of the adjacent section is determined by the condition

$$h' - h'' = \pi$$

$$h'' = h' - \pi$$

$$2\pi t'' \sqrt{\lambda \mu f} = 2\pi t' \sqrt{\lambda \mu f} - \pi$$

Solving this equation for t'' , the actual thickness of the conductor,

$$t'' = \frac{2\pi t' \sqrt{\lambda \mu f} - \pi}{2\pi \sqrt{\lambda \mu f}}$$

$$= t' - \frac{1}{2\sqrt{\lambda \mu f}}$$

$$= .050 \times 2.54 - \frac{\sqrt{1724}}{2\sqrt{1 \times 50000}} = 0.0342 \text{ cms.}$$

or $t'' = 13.5$ mils.

Having determined the thickness of the sections, it now remains to determine the relative lengths of adjacent sections. We have indicated that the lengths should be in the ratio $e^{h'} : e^{h''}$. That is, for the illustrative case assumed,

$$\frac{L'}{L''} = \frac{e^{h'}}{e^{h''}} = e^{h' - h''} = e^{\pi} = 23.14$$

When the effective thickness h is less than π , the formula for the mutual impedance is:

$$Z_{12} = B \cosh^2 (h + ih)$$

where B is independent of the thicknesses of the outer conductors. The phase of the mutual impedance, it will be seen, changes with effective thickness. Hence, again, the transverse phase change in successive sections of the coaxial con-

ductor line may be adjusted in accordance with the invention to reduce interference.

Since electrical thickness depends upon frequency, the complete elimination of interference is obtained only at some one particular frequency. If the coaxial pairs are designed to give the most complete neutralization of interference at the lowest frequency of the signaling range, where interference is ordinarily most severe, then as the frequency increases the reduction in the neutralizing effect is compensated for by the general increase in the shielding effect of the outer conductor. The length of the section, as previously observed, should be small compared with the length of the lowest frequency wave.

Complete quasi-transposition can be effected at a plurality of frequencies, however, if conductor sections of more than two different thicknesses are employed. Thus if two non-identical pairs of sections balanced at some one frequency are connected in tandem, they can be so designed as to be mutually balanced at some second frequency.

A composite outer conductor consisting of two or more layers of material having different electromagnetic constants may be designed to provide the desired phase change, in this case due account being taken of the reflection taking place between different media. Iron, lead or aluminum, for example, might be deposited electrolytically on the surface of a hollow copper cylinder, or the material might be provided in tape form and wrapped about the outer conductor. The latter construction is preferred where the outer conductor is a composite one, as shown, for example, in U. S. Patent 2,018,477, October 22, 1935, to J. F. Wentz.

Where the invention is to be applied to reduce cross-talk between a plurality of coaxial conductor lines in close proximity to each other the lengths of the sections in each line should not be the same as those of the paralleling sections in the adjacent lines, else the effect of a phase reversal in one line may be offset by the effect of a similar phase reversal in another line. In general, the desired result may be obtained by employing different lengths of sections in the several lines or by disposing the sections in accordance with schemes analogous to those employed for the transposition of open-wire lines.

Fig. 2 shows schematically a system of quasi-transposition that might be employed in the case of a six-pair cable. The transposition points therein indicated represent the junctions of the several sections of the conductors. Obviously, the system of transposition may be varied or extended in accordance with the number of conductors in the cable.

Although in the foregoing discussion it has been assumed that successive sections of outer conductors are so designed that the interfering electromotive force from one section is exactly in phase opposition to the interfering electromotive force from an adjoining section, it is clear that a reduction in interference will be obtained so long as there is any relative phase difference between these waves. Other modifications and adaptations of the specific system that have been disclosed herein for purposes of illustration will occur to those skilled in the art and they are intended to be embraced by the appended claims.

In the claims the term "effective thickness" has the significance indicated by Equation (1).

What is claimed is:

1. A high frequency signaling system comprising a coaxial conductor transmission line divided into a multiplicity of successive sections, the effective thickness of the outer conductor of said line in adjacent sections differing by π or an odd multiple thereof, at the lowest signaling frequency transmitted.

2. A high frequency signaling system comprising a coaxial conductor transmission line, the material comprising the outer conductor of said line being uniform in conductivity and permeability and the thickness of said outer conductor differing in successive sections of said line by

$$\frac{1}{4\sqrt{\lambda\mu f}}$$

where λ and μ are the conductivity and permeability, respectively, of said material and f is the signaling frequency at which interference is most severe.

3. A high frequency signaling system comprising a coaxial conductor transmission line, the thickness of the outer conductor of said line and the electromagnet constants of the material comprising said outer conductor being so related in successive sections of said line that the effective thickness of said outer conductor varies from sec-

tion to section and waves induced in one of said sections from an external interfering source are opposed by other waves induced in adjacent sections from said source.

4. A multiplex carrier telephone signaling system comprising two adjacent coaxial conductor transmission lines, both of said lines being divided similarly into a plurality of successive sections, the combined electrical thickness of the two outer conductors of said lines differing in successive sections by π or an odd multiple thereof at the lowest signaling frequency transmitted, the length of said sections being a fraction of a wave-length at said lowest signaling frequency.

5. A high frequency signaling system comprising a plurality of pairs of parallel coaxial conductor transmission lines, each of said lines being divided into a plurality of sections of which adjoining ones are unequal in electrical thickness, the electrical thickness at a predetermined signaling frequency and the lengths of all of said sections being so interrelated that inter-pair induction in one section of each of said lines is counteracted by inter-pair induction in another section of the same line.

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