June 10, 1930. O. E. BUCKLEY 1,762,956

SIGNALING CONDUCTOR

Filed Nov. 30, 1926

Fig. 1.

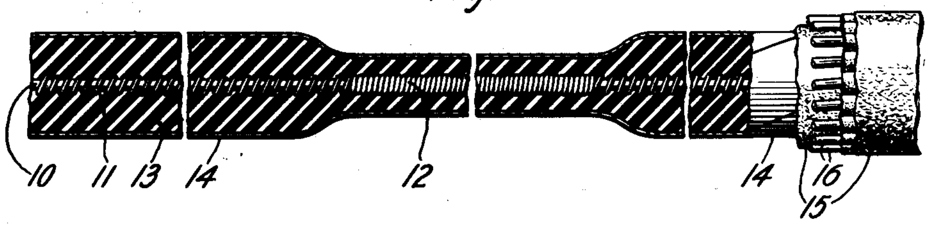


Fig. 2.

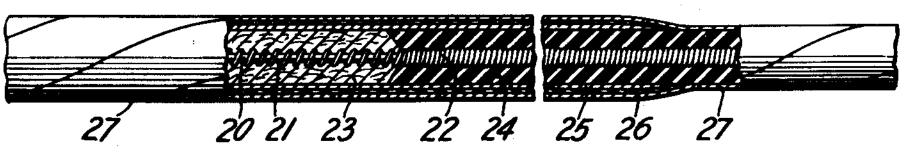


Fig. 3.

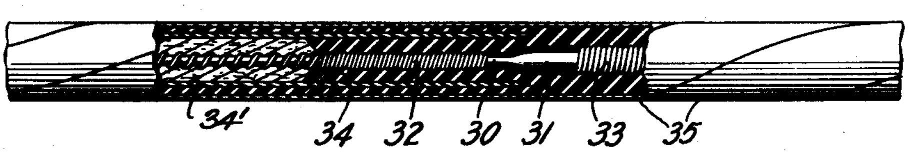
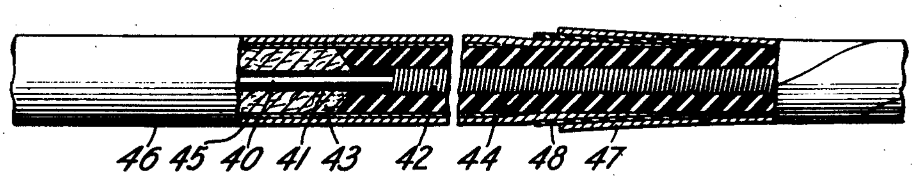


Fig. 4.



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UNITED STATES PATENT OFFICE

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SIGNALING CONDUCTOR

Application filed November 30, 1926. Serial No. 151,680.

This invention relates to signaling conductors and more particularly to loaded telegraph and telephone cables.

The general object of this invention is to secure efficient transmission of signals over a loaded cable in which the hysteresis of the magnetic material used for loading is a limiting factor in transmission.

This invention contemplates an improved construction of continuously loaded cable which is particularly applicable to very long submarine telephone cables, but which is also applicable to submarine telegraph cables. The improvement in the cable design and structure is such that an unusually large amount of power may be impressed upon the sending terminal of the cable without an undue amount of distortion due to hysteresis in the loading material. The hysteresis resistance of a uniformly loaded cable produces a proportionately greater attentuation per unit of length near the sending terminals of the cable, where relatively large current is being transmitted. A reduction of this hysteresis effect is brought about by using less loading at the terminal sections than at the mid-section of the cable as disclosed in a copending application of J. J. Gilbert, Serial No. 696,981, filed March 5, 1924. This permits impressing a larger amount of power upon the cable at the sending end than would be practicable with a uniformly loaded cable and of receiving the necessary amount of power at the other end.

Where changes in the loading are made reflection and a consequent increase in the total attenuation will occur unless the cable is so constructed that no change of the characteristic impedance occurs where the inductance changes. This invention eliminates such reflection losses by maintaining the ratio of inductance to capacitance substantially constant throughout the cable. This ratio is so maintained by changing the electrostatic capacity by the proper amount wherever the inductance is changed. Although the principles underlying this invention apply both to telephone and telegraph cables they are described more in detail and with particular reference to telephone cables in the discussion following.

The attenuation which can be permitted in a long loaded submarine telephone cable is limited by the maximum power which can be impressed at the sending end without introducing too much distortion due to hysteresis, and by the minimum power which can be received without too much interference from extraneous sources of electrical disturbance. In order to be able to telephone the greatest possible distance with a given size of cable, or in order to utilize the smallest and most economical cable to telephone a given distance, it is desirable to set the former limit as high as possible and the latter limit as low as possible. The improvement to be discussed herein refers particularly to setting the maximum sending power limit as high as possible by reducing the hysteresis near the ends of the cable and to eliminating reflection losses by maintaining a substantially uniform characteristic impedance throughout the cable.

The attenuation of a loaded submarine telephone cable is given approximately by the following formula,

$$a=\frac{1}{2}\left(R_c+R_s+R_e+R_h+\frac{G}{C}L\right)\sqrt{\frac{C}{L}}$$

in which:

a is the attenuation constant,

R_c is the resistance of the central copper conductor,

R_s is the resistance of the return circuit outside the core,

R_e is the eddy current resistance,

R_h is the hysteresis resistance,

G is the leakance,

C is the capacitance, and

L is the inductance,

all per unit length. Of the several resistance factors R_c and R_s are substantially constant throughout the length of a cable of uniform construction. R_e and $\frac{G}{C}$ L vary with current near the sending end of the cable due to the change of permeability of the loading material with the magnetizing force, but otherwise are constant. R_h is of consequence only near the sending end of the cable; it decreases rapidly as the current is attenuated along the cable and throughout most of the length of the cable is quite negligible. Owing to its rapid increase with current it sets a limit to the amount of power which can be transmitted into the cable without serious distortion which would impair the quality of the telephone speech received at the other end of the cable. It is therefore desirable to decrease the factor R_h as much as possible by a modified construction near the ends of the cable, particularly if this can be done without increasing the attenuation of the cable for speech transmitted in the opposite direction.

In general, the greater the inductance due to loading the greater is R_h. Hence, one way to reduce R_h is to use lighter loading. Merely reducing the amount of inductance near the terminals of the cable, as by using less loading material, would accomplish this purpose but would have a bad effect as regards attenuation, since while one end of the cable is carrying a heavy sending current the other end is carrying a feeble received current, and at the receiving end the reduction of inductance below the optimum value chosen for the main part of the cable would increase the attenuation. Also there would be a serious loss of strength of current due to reflection at the points where the change from light to heavy loading occurs.

It is desired to prevent this reflection and to avoid an increase of attenuation, and at the same time to use lighter loading near the end to reduce R_h. The reflection will not occur if there is no change of characteristic impedance at the point where the inductance changes. The characteristic impedance is given by the formula

$$Z_o=\sqrt{\frac{R+ipL}{G+ipC}}$$

in which R is the total effective reistance, i is the $\sqrt{-1}$, and p is $2\pi f$ or with sufficient approximation for the purposes of this discussion, by the formula

$$Z_o=\sqrt{\frac{L}{C}}$$

since at working frequencies in the ordinary case R and G are small in relation to pL and pC respectively. Hence, if a smaller amount of capacitance per unit length is used on the parts of the cable near the terminals which are lightly loaded for the purpose of reducing R_h, so that the ratio $\frac{L}{C}$ is substantially the same for both the lightly loaded and heavily loaded parts of the cable, the characteristic impedance of the sections will be the same and there will be no reflection at the junction between them. Also if this is done the attenuation of the lightly loaded section will be somewhat less than that of the heavily loaded section for small currents, since the factor $\frac{C}{L}$ in the attenuation formula is not changed and since the factors R_e and $\frac{G}{C}$ L are reduced.

The capacitance may be reduced to keep the characteristics impedance, Z_o, constant either by using a thicker layer of dielectric near the terminals where the loading is light or by using a dielectric of lower specific inductive capacity. The first of these methods might be necessary where the cable goes quickly into deep water and there is no opportunity for choice of a dielectric of much lower specific inductive capacity than gutta percha or similar material which would have to be used on the deep sea section of the cable. The cable in this case would consist of a lightly loaded conductor near the terminals with the amount of added inductance increasing as the distance from shore is increased, and with thick insulation near the shore, the thickness of insulation decreasing so as to keep the characteristic impedance, Z_o, constant as the distance from shore is increased.

In cases where the cable extends a considerable distance from shore in relatively shallow water, the required decrease of capacitance may be accomplished by using in place of gutta percha an insulating material of lower specific inductive capacity such as the paper insulation commonly used with lead covered cables. The cable core in this case would consist of a conductor loaded lightly, insulated with several layers of paper and covered with a lead sheath out to as great a depth as the lead-paper type of cable is practical and beyond that point the cable core would consist of a more heavily loaded conductor with gutta percha insulation. The amount of loading in the two types of cable should be so adjusted that the characteristic impedance, Z_o, of the two types are the same. If the two types of core are made of the same diameter this would call for an amount of loading material per unit length on the paper insulated section about one-half as great as that on the gutta percha insulated section, since the specific inductive capacity of the paper and air structure is about one-half that of gutta percha.

Some of the general features of this invention are broadly outlined above. Further objects and features will appear and a better understanding of the invention will be had in the following detailed description and accompanying drawings.

Fig. 1 is a drawing of a cable embodying this invention in which the same kind of insulation is used throughout and its thickness varied.

Fig. 2 is a drawing of a cable also embodying this invention in which different kinds of insulation are used in different sections and its thickness maintained substantially the same throughout.

Fig. 3 is a drawing of a cable also embodying this invention in which the insulation is of different kinds and its thickness varied by varying the diameter of the center conductor and its loading.

Fig. 4 is a drawing of a cable also embodying this invention in which different kinds of insulation are used and the return conductor is positioned within a lead sheath encasing the conducting and insulating members at the end sections for a distance just beyond the paper insulation and then continued outside of the lead sheath.

The arrangements shown in the several figures illustrate different ways of varying the inductance of different sections of the cable and of maintaining the ratio of inductance to capacitance, $\frac{L}{C}$, substantially constant throughout the entire length of the cable. In all cases the loading is reduced in the end sections of the cable so as to reduce the hysteresis losses and thereby permit applying a relatively large amount of power at the transmitting end as set forth above. A number of successive changes in the amount of loading may be made in a cable though only one is shown in the drawing.

The central conductor may be solid but it would preferably be stranded in accordance with the usual submarine cable construction. A return conductor may be made a part of the cable by concentrically positioning outside of the insulation surrounding the central conductor one or more conducting tapes wound with a long lay or pitch. Such a return conductor would usually be covered with an outside protecting covering of jute and armoring or other suitable materials. However, in some cases the return conductor may be placed immediately within a lead sheath used to keep water away from such insulating materials as paper and thereby reenforce the lead sheath against external hydrostatic pressure. The variation in the amount of loading may be obtained either by varying the quantity of loading material per unit of length of cable or by using loading material having different magnetic characteristics.

In the arrangement shown in Fig. 1 the inductance of different sections is varied by varying the amount of loading material per unit of length of the cable in different sections and the ratio of inductance to capacity is maintained substantially constant by varying the quantity of loading and the quantity of insulation in the different sections. The lightly loaded end sections of the cable have a larger overall diameter than the mid-section as the same kind of insulation is used throughout and the capacitance of these sections must be less than that of the central section thereby requiring more insulating material. The central conducting core 10 is wrapped with a loading wire of permalloy or other suitable magnetic material. The variation in the amount of loading at the different sections may be secured, as shown in this figure, by using loading wire of the same kind and size throughout and varying its distribution, such as, by closely winding it around the conductor in the heavily loaded mid-section 12 of the cable and by separating its convolutions to a greater extent on the lightly loaded end sections 11. Insulation 13, such a gutta percha, surrounds the central conductor and its thickness is greater on the lightly loaded end sections of the cable than at the mid-section in order to maintain the ratio of inductance to capacitance substantially constant. A return conductor 14 may be provided consisting of copper, aluminum, or other suitable material which may be in the form of several helical strips wound with a long lay around the insulation 13. Any desired protective covering, such as jute 15 and wire armoring 16, may be used.

A modified arrangement for providing a light loading for the terminal sections and a heavier loading for the mid-section of the cable and maintaining the ratio of inductance to capacitance substantially constant is shown in Fig. 2. The outside diameter of the insulation around the central conductor is substantially the same throughout and the variation of the capacitance is obtained by using insulating materials having different specific inductive capacities. The conductor 20 and its loading 21 and 22 may be arranged the same as shown in Fig. 1 to secure the relatively light loading for the end sections of the cable. The insulation 24 of the mid-section may be of gutta percha or other similar material capable of withstanding deep sea immersion. The electrostatic capacity of the gutta percha is high and the section so insulated is correspondingly heavily loaded. The end sections having lighter loading have an insulation 23 of paper or other material having a smaller electrostatic capacity than gutta percha. By properly proportioning the amounts of loading and insulation, and by using insulating material of the proper specific inductive capacity in the different sections, the ratio of inductance to capacitance of the end sections can be made substantially the same as that of the mid-section and the outside diameter of the insulation of all sections made substantially the same. Where paper insulation or any other insulation which absorbs moitsure is used it must be protected from moisture by a water-proof casing 25, such as a lead sheath. The water-proof casing is continued some miles beyond the junction between the paper and gutta percha insulated sections to form a substantially water-tight seal and prevent moisture reaching the paper insulated section. It is believed that several miles of well dried gutta percha or rubber insulated core covered with a lead sheath continuously from the paper insulated section over the gutta percha will cause the rate of penetration of the moisture to be so slow as to be negligible even after a period of many years. A separator 26, such as an insulating cloth tape, surrounds the outside of the lead sheath to prevent galvanic action between the lead and the return conductor 27. The return conductor may be made of several helical conducting strips placed upon the outside of the lead covered and the gutta percha insulated sections. Any suitable protective covering may be applied to the outside of the cable.

Another arrangement for reducing the loading of the end sections of the cable and at the same time maintaining the ratio of the inductance to capacitance substantially constant throughout the entire length of the cable is shown in Fig. 3. In this arrangement the diameter of the conductor in the end sections 30 is somewhat smaller than in the mid-section 31. The lighter loading on the end sections may be obtained by using a loading wire 32 of smaller diameter than the loading wire 33 on the mid-section. The loading material of all sections may be closely wound as shown and the difference in amount of loading obtained, as shown, by using loading wire of different diameters, or of different magnetic characteristics. In this arrangement the outside diameter of the central core of the end sections is made less than that of the mid-section and more room within a given diameter for the insulation is provided near the end sections than at the middle section thereby making the capacitance of the sections near the end relatively smaller even with the same kind of insulating material as that in the middle section. The insulating material 34 may be of gutta percha or rubber throughout. The insulating material 34′ in the end section may be of paper or other material having a smaller electrostatic capacity than gutta percha. The return conductor 35 is spirally applied in long lay around the outside of the insulation, the entire cable being protected by any desired protective covering.

In Figs. 1, 2 and 3 the return conductor has been arranged on the outside of the insulation where the insulation is impervious to moisture and on the outside of the lead sheath where the insulation was protected from moisture by a water-tight sheath. A somewhat modified arrangement of positioning the return conductor where a water-tight sheath is required is shown in Fig. 4. Another arrangement of varying the loading in different sections is also shown. The central conductor 40 is lightly loaded by having one layer of loading wires 41 on the lightly loaded sections and more than one layer of loading wires 42 on the heavily loaded section. The lightly loaded sections are covered with an insulating material 43 having a smaller specific inductive capacity than the mid-section which is covered with an insulation 44 having a higher specific inductive capacity. The arrangement of the loading and insulating material is so proportioned that the ratio of inductance to capacitance of all sections is substantially constant. The return conductor 45 in the end sections consists of copper or other material spirally wound around the insulated conductor for a distance somewhat beyond the junction between the paper and gutta percha insulation. The waterproof casing 46, such as a lead sheath, extends some miles beyond the junction of the paper and the gutta percha insulated sections and for most of the distance beyond this junction it is in intimate contact with the gutta percha insulation so as to form a water-tight seal. The return conductor 45 extending from the shore end of the cable to a distance somewhat beyond the paper insulation is continued over the mid-section by the helical strips 47 surrounding the insulated central conductor the same as in the arrangement shown in the other figures. An insulating tape separator 48 is placed between the metal casing 46 and conductor 47 to prevent galvanic action. Special metallic connection may be made between sections 45 and 47 of the return conductor or the necessary electrical connection may be obtained through the surrounding sea water and the lead sheath.

In the submarine cable extraneous interfering electrical disturbances may be picked up by the cable and means have been devised for reducing such interference to a minimum. The effect of these disturbances may be diminished by using a special sea-earth termination which is immersed at a depth beyond which the effect of disturbances picked up are negligible. The effect of the electrical disturbance at a lesser depth is made negligible by a sea-earth connection such as disclosed in U. S. Patent 1,678,184, granted to John J. Gilbert on July 24, 1928, and in British Patent 280,440, accepted Feb. 2, 1928. Either of these methods may be applied in connection with this invention. In order to reduce the terminal interference to a minimum it will in general be desirable to use a balanced twin core out to a depth of water where the effect of extraneous electromagnetic disturbance is greatly reduced; one conductor of the twin serving as the main cable conductor, and the other as a seat-earth conductor, the latter may be terminated in an impedance to balance the main cable conductor beyond the termination of the connection of the sea-earth. In case a paper insulated end section is used, this twin core may be included wholly or partly in the paper insulated section; if only partly it will in general be desirable to use separate lead sheaths around each of the paper insulated sections, the junction of each with its gutta percha insulated section being similar to that described above for a single conductor. If the twin core is wholly included in the paper insulated section, then it will be possible to use a single lead sheath around the two paper insulated conductors, this sheath continuing beyond the point where one of the conductors is terminated in an impedance, the structure beyond that point being like that disclosed for a single conductor. The latter arrangement in which a single lead sheath covers both of the conductors of the twin core sections has the advantage of enclosing the terminating impedance of the sea-earth conductor in the same lead sheath.

Several arrangements of loading have been shown to obtain different amounts of inductance for various sections of the cable, and also several arrangements of insulation have been shown to obtain different amounts of capacitance for the different sections; and certain specific combination or association of these arrangements have been shown in the several figures for obtaining a substantially constant ratio of inductance to capacitance. Other arrangements for varying the inductance and the capacitance, and combinations for maintaining the ratio of inductance and capacitance throughout a given cable substantially constant are possible. Obviously it would be within the scope of the invention to employ different kinds of loading material at the same time that different amounts are used and the same is true of the insulation. As many loading changes may be made as are desirable to give the effect of tapering the amount of loading towards the ends of the cable. The specific construction of a given cable would usually be determined by the physical and operating conditions to be met, and also by the cost of materials and manufacturing operations.

What is claimed is:

1. A loaded submarine cable having loading of different values of inductance per unit of length for some sections than for others, and having insulation for giving said cable sections different values of capacitance per unit of length, the loading and the insulation being so proportioned that the ratio of the inductance to capacitance in each section of the cable is substantially the same per unit of length for all sections.

2. A loaded submarine cable having different values of loading for some sections than for others and insulation giving different values of capacitance for some sections than for others, the said different values of loading being obtained by using different amounts of loading material and the said different values of capacitance being obtained in part, at least, by using insulation of different electrostatic characteristics, and the amounts of loading and of insulation of each section being such that the ratio of inductance to capacitance for each unit of length of each section of the cable is substantially the same.

3. A loaded submarine cable having different values of loading for some sections than for others and insulation such that the product of its thickness and dielectric constant is different for some sections than for others, the said different values of loading being obtained in part, at least, by using materials having different magnetic characteristics and the said different values of said product being obtained in part, at least, by using insulation materials having different electrostatic characteristics, and the amount of loading and of insulation in each section being so proportioned that the ratio of inductance to capacitance for each unit of length of each section of the cable is substantially the same.

4. A loaded submarine cable having different values of loading for some sections than for others and insulation giving different values of capacitance for some sections than for others, the said different values of loading being obtained, by using materials having different specific inductances and the said different values of capacitance being obtained in part, at least, by using insulating materials having different specific inductive capacities and the amounts of loading and of insulation in each section being so proportioned that the ratio of inductance to capacitance for each unit of length of each section of the cable is substantially the same.

5. In a loaded submarine cable comprising a central conductor, loading material associated therewith and insulating material surrounding the central core, the said loading material and the said insulating material being different in different portions of said cable but proportioned to maintain the ratio of inductance to capacitance constant throughout the entire length of the cable.

6. A loaded submarine cable having sections with different amounts of loading and with different amounts of insulation, the values of said amounts being so changed with respect to each other in each section that the ratio of the inductance due to the loading to the capacitance due to the insulation is substantially constant for all said sections.

7. In a loaded submarine cable comprising a central conductor, loading material associated therewith, insulating material surrounding said central conductor and said loading material, a water-tight covering for said insulation, and a return conductor arranged on the inside of said covering on sections of the cable where the insulating ma-

terial is pervious to water and on the outside of said covering on sections of the cable where the insulating material is impervious to water.

8. In a loaded submarine cable comprising a central conductor, loading material associated therewith, insulating materials of different electrostatic characteristics surrounding said central conductor and said loading material, a water-tight covering for said insulation, and a return conductor arranged on the inside of said covering on sections of the cable where the electrostatic characteristic of the insulating material is of one value and on the outside of said covering on sections of the cable where the electrostatic characteristic is of another value, said return conductors being interconnected electrically through the surrounding sea water and said water tight covering.

9. A joint for connecting a cable section insulated with plastic material to a section insulated with fibrous material such as paper and covered with a waterproof metallic covering, comprising a section insulated with a continuation of the plastic material and having the lead covering continued over said plastic material for a considerable distance.

10. A loaded submarine cable having more lightly loaded sections near the terminals than in the middle, and insulation of relatively low specific inductive capacity in the sections at and near the terminals and insulation of relatively high specific inductive capacity in the middle sections, the amounts of loading and insulation in each section being so proportioned that the ratio of inductance to capacitance for each section of the cable is substantially the same.

11. A loaded submarine cable as set forth in claim 10 characterized in this that the insulation at and near the terminals is paper and that in the middle sections is gutta-percha.

In witness whereof, I hereunto subscribe my name this 29th day of November, A. D. 1926.

OLIVER E. BUCKLEY.