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J. J. GILBERT

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LOADED SUBMARINE CABLE

Filed Aug. 20, 1927

FIG. 1.

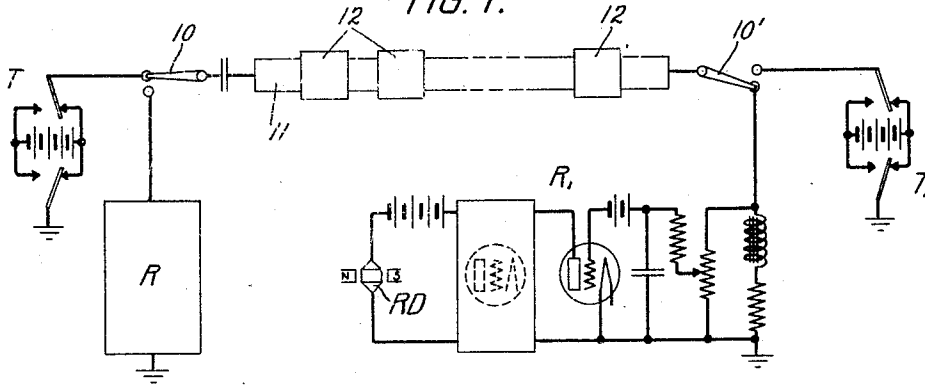


FIG. 2.

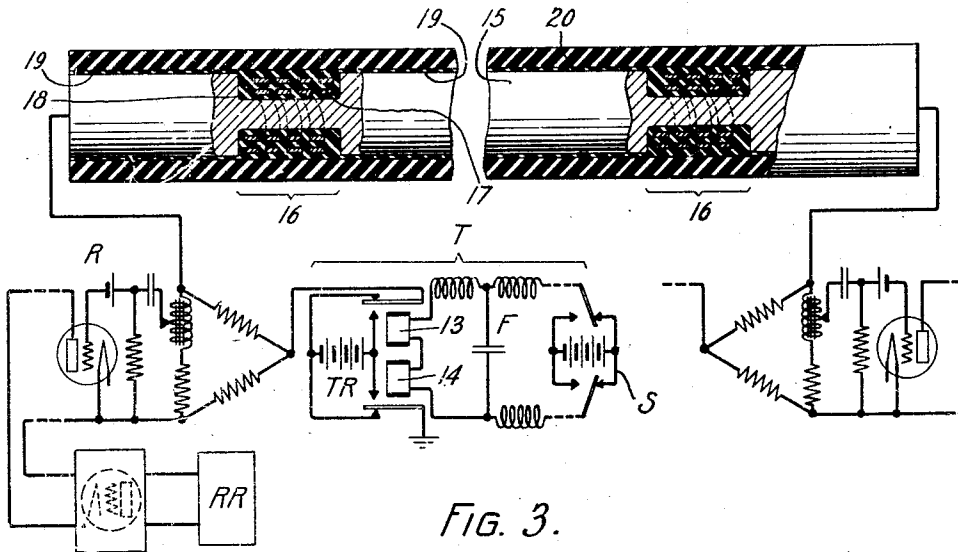
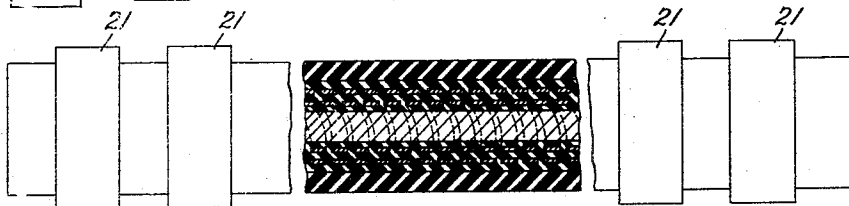


FIG. 3.



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LOADED SUBMARINE CABLE

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This invention relates to long submarine cables of the deep sea type and more particularly to coil loaded cables designed for direct current or Morse operation. For the purpose of this specification the expression "direct current transmission systems" will be used to distinguish such systems from carrier wave transmission and telephone systems.

Among the objects of the invention are, to improve direct current transmission over long submarine cables, to reduce disturbances at the receiver, to reduce duplex unbalance, to reduce dielectric losses, and to more effectively utilize magnetic loading materials.

Coil or lumped loading of aerial lines, especially carrier telegraph lines and telephone conductors has been practiced to a considerable extent. No parallel development of coil loaded direct current telegraph cables of the deep sea type has taken place. Numerous difficulties have been recognized as preventing such development, one of which is the difficulty of manufacturing and laying on the seat bottom a coil loaded cable. Each coil not only involves a large additional expense but introduces additional probability of breakage or of insulation failure and thereby imperils the whole project. For this reason it is extremely desirable that the number of coils employed in a coil loaded direct current submarine cable be such as will enable transmission and reception to be carried on satisfactorily but that no greater number be used.

It has long been known that one can simulate a continuously loaded conductor with any desired degree of approximation by spacing properly designed loading coils sufficiently close together. Rules for loading telephone and carrier current conductors have been formulated and applied extensively with entire success. By experiment, it has been determined that the usual rules for loading telephone and carrier conductors do not fulfill the conditions of effective high speed direct current telegraph transmission over

long submarine cables. In accordance with modern practice, amplifiers of great gain are employed for amplifying the impulses received over such cables and under such conditions the usual loading practices result in troublesome phenomena at the receiver. These phenomena are due partly to reflection from the coils in the vicinity of the receiving end and partly to an accumulation of reflections as the signal is transmitted over the cable. Such reflections have been styled "filter oscillations". In duplex transmission similar phenomena occur in connection with the operation of the local receiver. However, this is a secondary consideration and the invention relates primarily to reduction of the effects of filter oscillations at the receiver.

As stated above, it is known that a lump loaded line may be made to simulate a smooth loaded line within any desired degree of approximation. In telephone practice, this rule is carried into effect by employing 8 or 9, or in some cases, slightly more or slightly less, coils per wave length at the highest frequency to be transmitted. Although the use of various extremely large numbers of coils per wave length has been theoretically discussed for the purpose of showing mathematically the degree of exactitude to which a smooth line may be approximated, such a greater number has been regarded as simulating a smooth line with unnecessarily great precision. The usual practices for loading telephone and high frequency carrier lines are not applicable to direct current telegraph transmission over long deep sea cables because the phenomena of filter oscillations introduce new considerations.

For direct current telegraph operation it is usual to define the "signaling frequency" as the fundamental frequency of a series of alternate positive and negative impulses of unit length. This definition is used here. It is usually considered, in modern submarine cable telegraph practice, that it is necessary to

transmit with attenuation not excessively greater than the signaling frequency all frequencies up to $1\frac{1}{2}$ times the signaling frequency. Frequencies higher than this may be and usually are considerably attenuated. This assumption is a rather approximate one, however, because the attenuation curve of an actual cable rises steadily and at an increasing rate in passing to higher frequencies from the signaling frequency. It is possible to calculate or measure the attenuation for any given frequency but difficult to say at what frequency the attenuation becomes so great as to render the energy of that frequency negligible. Assuming $1\frac{1}{2}$ times the signaling frequency to be the highest frequency to be transmitted, it would be proper, in accordance with telephone practice, to load the cable so that the theoretical cut-off frequency would be about 2 to $2\frac{1}{2}$ times the signaling frequency, the particular value depending upon the quality of the telephone loading system chosen for comparison. This would necessitate about 7 to 10 coils per wave length. However, such coil spacing for long submarine cables employed for direct current telegraph transmission leads to difficulties on account of the filter oscillations hereinbefore mentioned. Such filter oscillations, corresponding to the most fundamental form of transmitted signal, that is, an abrupt change in D. C. voltage applied to the cable, consist of a train of oscillations superposed on the usual arrival curve, the period and amplitude of the successive elements of the train being of successively decreasing magnitude. The first $\frac{1}{2}$ cycle, or more accurately $\frac{1}{2}$ wave, of such oscillations produces the principal difficulty at the receiver. A large component of the energy of this $\frac{1}{2}$ wave is concentrated in a frequency region corresponding roughly to $\frac{1}{3}$ the theoretical cut-off frequency. With a coil spacing of 7 to 10 coils per wave length, a large part of the energy of these oscillations falls within a range close to the signaling frequency. The trouble due to this source is aggravated by the modern tendency to the use of high gain amplification. However, by employing from 15 to 20 coils per wave length the cut-off frequency may be caused to fall between 5 and 6 times the signal frequency and the energy of the troublesome $\frac{1}{2}$ wave of the filter oscillation will consist largely of energy of frequency just above $1\frac{1}{2}$ times the signaling frequency and may be suppressed by selective circuits or other means. In practice the attenuating property of the cable for such energy and the use of selective circuits at the receiver to discriminate against it both have a beneficial effect. The number of coils per wave length (because of the economic considerations discussed above) should be the least possible consistent with reducing to a permissible value the amplitude of the first $\frac{1}{2}$ wave of the filter oscillations.

This rule of 15 to 20 coils per wave length applies to the case where unit impulses are transmitted and received. In accordance with a more modern type of system, the speed of transmission is effectively doubled by setting the signaling frequency at such a value that impulses of twice unit length are the least which are transmitted over the cable and actuate the receiving relay or other receiving device. Single impulses of effective amplitude are not received but are produced at the receiver by regeneration. In such a system the signaling frequency for the purposes of the present invention and in so far as the receiver is concerned will be that at which alternations of impulses of twice unit length are transmitted. The signaling frequency corresponding to the unit impulses is disregarded and the frequency of transmission as established by the shortest impulses which are actually received at the receiver is regarded as the signaling frequency for the purposes of this invention.

An advantage of coil loaded cables is increased ease in constructing an artificial line. In the present instance the artificial line will preferably have the number of coils per wave length exactly the same as in the cable conductor.

In general, with coil loaded cables, duplex balance is facilitated by the ease with which an artificial line may be constructed to balance the cable. Reflections from cable loading coils may be neutralized by corresponding reflections from coils of the artificial line which will be of the same amplitude and can by careful design be made to have the same phase, within a desired degree of approximation.

Inasmuch as the filter oscillation phenomena at the receiver are due partly to reflections from coils in the vicinity of the receiving end and partly to an accumulation of reflections as the signal is transmitted over the cable, it would be permissible to use greater coil separation at the mid-portion of the cable than near the terminals. However, if greater spacing is used at the mid-portion the spacing in the terminal sections should be reduced to compensate for it.

The word "coil" is used in the preceding discussion in the usual sense. It may be desirable, however, to provide an inductance lump consisting of a straight conductor a few hundred or a few thousand feet in length continuously loaded with several layers of loading material in the form of wire or tape helically applied. These inductance lumps should be of a total diameter over the copper conductor and loading equal to the diameter of the non-loaded core. Of the total length a portion less than $\frac{1}{2}$ and preferably about $\frac{1}{10}$ should consist of continuously loaded portions. These "coils" or "inductance lumps" should be uniformly spaced a

distance of $1/20$ or $1/15$ wave length. With such an arrangement the cable structure will be uniform and mechanically much easier to manufacture and lay than is the case with coils of diameter larger than the main cable structure.

One advantage of such an arrangement is that the magnetic material may be worked at a higher flux density for a given current. This will result in increased inductance in the case of some magnetic materials. However, magnetic materials are known (these being described in Elmen Patent, 1,715,647, granted June 4, 1928), which have constant permeability for a magnetizing force up to several c. g. s. units. They comprise compositions of iron, nickel and cobalt, with or without other ingredients, heat treated to develop the desired constancy of permeability. By using elongated coils loaded with several layers of such magnetic materials, the portion of the magnetization curve which is straight may be much more effectively utilized than in the case of conductors continuously loaded throughout. This is done by making the flux density greater in the loading material than in the case of continuous loading throughout.

It is desirable to employ insulating materials of leakance lower than that of gutta percha immediately adjacent the conductor of a high speed submarine cable. The greater part of the energy losses in the dielectric take place in the region immediately adjacent the conductor and in the case of the lump loaded structure just described where a large portion, for example $9/10$ of the conductor is non-loaded, advantage can be taken of this fact to apply a layer of such low leakance material immediately adjacent the unloaded portion of the conductor. In the case of continuously loaded conductors, the application of such a layer of material is more difficult on account of the necessity of completely surrounding the loading material by a semi-fluid pressure equalizing medium. Of course, the material of the lowest leakance which it is feasible to apply should be applied to the loaded portion of the conductor to serve as a pressure equalizing medium for the loading material.

Artificial lines for balancing conductors loaded with from 15 to 20 coils per wave length may be conveniently constructed with a corresponding number of coils per wave length. To the extent that filter oscillations set up in artificial lines are troublesome, the use of the invention may be advantageous in causing their reduction.

Since accuracy of duplex balance is largely dependent upon balancing a few hundred miles of the cable near the terminals, the form of construction employing coil loaded end sections and a continuously loaded intermediate portion offers considerable advantages.

In this case, actual coils instead of inductance lumps, formed by continuously loaded sections, are preferred. The design is such that the impedances at the junction of the two kinds of cable are matched as accurately as possible over the range of frequencies to be transmitted.

The mode of applying the invention is described in further detail by reference to the accompanying drawings in which Fig. 1 represents a system in accordance with the invention designed for transmitting in one direction at a time;

Fig. 2 represents a modified form of the invention adapted for duplex operation; and

Fig. 3 represents a cable loaded with loading coils near the terminals and continuously in the middle portion.

In Fig. 1 a switch 10 serves to transfer manually or automatically the cable terminal back and forth between a transmitter and a receiver and the switch 10' performs the same function at the distant terminal. The transmitters T and T₁ are any ordinary type and the receivers R and R₁ are equipped with thermionic amplifiers and any suitable recording device RD. The cable 11 is provided with inductance coils 12 spaced apart $1/20$ to $1/15$ wave length at the frequency of transmission determined by the sending of alternate positive and negative impulses of unit length by the transmitter.

The wave length at a desired signaling frequency can be determined with sufficient accuracy by known methods. In the case of a 2000 mile cable having 70 milli-henrys inductance and .36 microfarads inductance per nautical mile the coil spacing at 80 cycles signaling frequency should not be greater than four nautical miles, but preferably slightly less than this.

Fig. 2 is arranged for duplex operation. The transmitter T comprises an impulse sender S which is connected to a transmitter relay TR by means of a filter network F. The relay TR is actuated by windings 13 and 14. Filter F suppresses impulses of unit length for which reason the relay TR is actuated only by impulses of twice unit length and impulses of unit length are not impressed upon the cable conductor. The receiver comprises a vacuum tube amplifier with suitable correcting networks incorporated therein having its output circuit connected to a regenerative relay RR. The regenerative relay operates in a well known fashion to interpolate or restore the impulses of unit length suppressed by the filter F employed in connection with the transmitter. The cable comprises long unloaded sections 15 and short continuously loaded sections 16. The loaded sections are spaced apart about $1/20$ to $1/15$ wave length at the fundamental signaling frequency impressed upon the conductor by the relay TR. The loaded sections function

as inductance lumps or loading coils and are loaded with several layers of magnetic material 17 applied helically in the form of wire or tape. The copper core of the loaded portions is reduced in diameter and the loading material is of such thickness that the total diameter of the loading material is just equal to the diameter of the loaded portions. The loading material may be a nickel-iron alloy for example, or preferably a magnetic alloy of iron, nickel and cobalt with or without other ingredients and heat treated to have a constant permeability up to a magnetizing force of 2 or 3 gauss, more or less. The loading material is thoroughly impregnated with bitumen 18 or other suitable pressure equalizing substance. On the unloaded copper core may be applied a thin layer 19 of vulcanized or depolymerized rubber or other material having a leakance lower than that of gutta percha. The entire core including the loaded and unloaded portions may be surrounded by a layer 20 of gutta percha or other suitable insulation. The entire cable is surrounded by jute and armored in the usual fashion.

In Fig. 3 is illustrated a cable with end sections loaded with coils 21, 21 and an intermediate continuously loaded section. The coils may be of any suitable type but for duplex working are preferably relatively short coils as distinguished from elongated inductance lumps. For one-way operation the coils may be short coils or loaded sections such as 16, 16 of Fig. 2. The cable is designed so that the impedances of the coil or lumped and continuously loaded portions are matched within the band of essential frequencies to be transmitted. The loading coils are spaced 15 to 20 per wave length and the coils of a balancing artificial line are similarly spaced in the head end portion of the line but further out may have some other suitable spacing if desired.

The details of the invention and modes of its application in practice have been described. The novel features inherent therein are set forth in the appended claims.

What is claimed is:

1. A submarine cable in which a portion near the ends is magnetically loaded by means of loading coils and a portion near the central part is magnetically loaded by magnetic material wrapped about extended and relatively long portions of the central conductive core.

2. A submarine cable section comprising a central conductive core having relatively small portions of the core continuously loaded with magnetic material, the loaded portions being uniformly spaced apart and constituting less than one-half the total length of the cable section in which the diameter of the loaded portion of the conductive core is reduced as compared to that of the unloaded portion, whereby the total diameter of the

core plus the loading material of the loaded portions approximates that of the unloaded portions.

3. A submarine cable signaling system in which impulses of unit length produced at the transmitter are too attenuated at the receiver to be effective and are reproduced by regeneration, in which the cable is loaded with from 15 to 20 coils per wave length at the signaling frequency determined by the transmission of alternate positive and negative impulses of twice unit length.

In witness whereof, I hereunto subscribe my name this 17th day of August, A. D. 1927.

JOHN J. GILBERT.