June 1, 1926.

1,586,894

J. J. GILBERT ET AL

SUBMARINE CABLE SYSTEM

Filed May 12, 1922

Fig. 1.

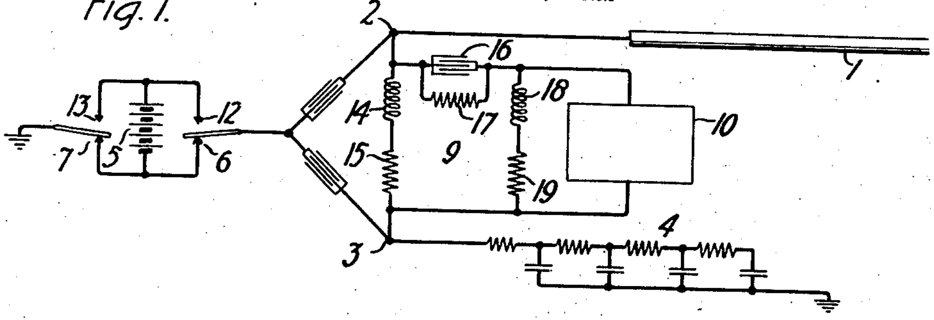


Fig. 2.

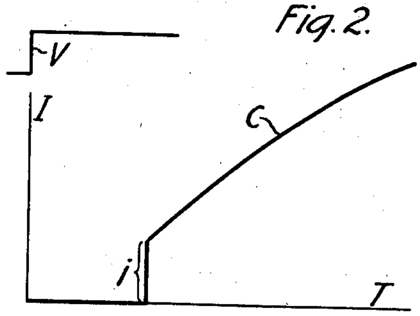


Fig. 3.

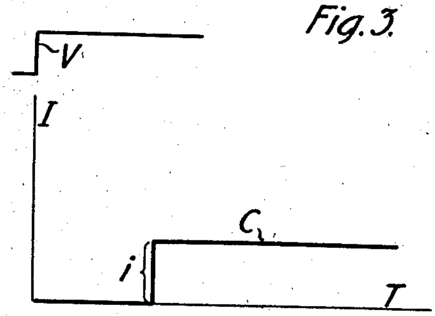


Fig. 4.

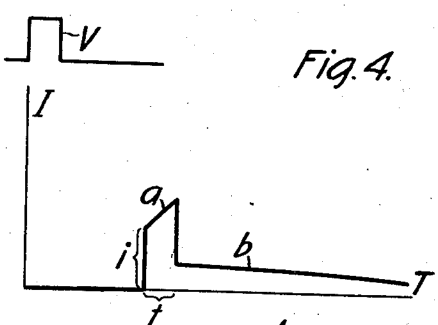


Fig. 5.

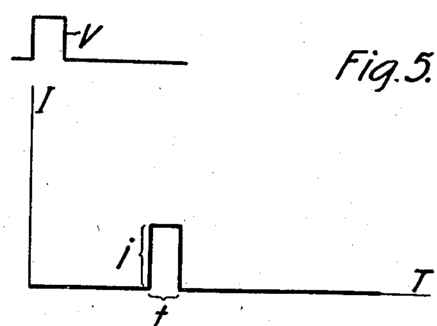


Fig. 6.

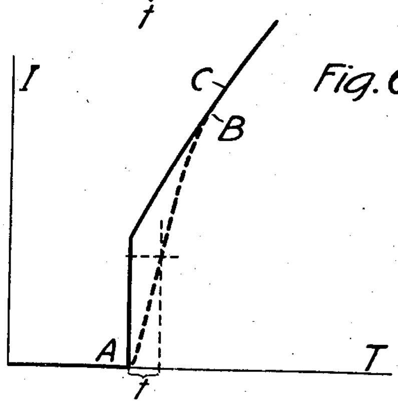
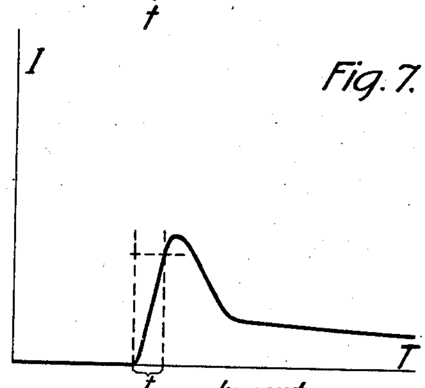


Fig. 7.



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UNITED STATES PATENT OFFICE.

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SUBMARINE-CABLE SYSTEM.

Application filed May 12, 1922. Serial No. 560,389.

This invention relates to submarine telegraph signaling.

An object of the invention is to increase the speed at which signaling can be carried on over a long submarine cable having large distributed capacity.

A further object of the invention is to compensate for signal distortion due to losses in the cable structure which are dependent upon the rate of signaling and become material at high signaling speeds.

In carrying out the objects of the invention, the usual structure of long submarine cables is modified by providing auxiliary reactive elements both throughout the length of the cable and at one or both of its terminals in such manner as to reduce signal distortion to a minimum and to permit maximum speed of signaling.

According to present practice in submarine telegraph cable signaling no attempt is made to inductively load the cable to compensate for distortion of the signal produced by distributed capacity of the signaling conductor. Due to this distortion the rate of signaling must be kept very low. Many forms of continuous and lumped inductive loading have been suggested, but until recently iron was considered the only suitable material for such loading. A nickel-iron alloy has now been discovered which has remarkably high permeability at the low magnetizing forces utilized in submarine signaling and also other valuable properties, such as high resistivity and small hysteresis effect. The discovery of this alloy, which has been appropriately termed permalloy, and a study of its possibilities as a loading material, at once offered the prospect of greatly increasing permissible signaling speeds. In connection with the development of the permalloy loaded cable subsequently undertaken, difficult problems arose due largely to the new range of frequencies employed. It was not known what degree of loading would give best results or how great a part should be played by the terminal shaping apparatus, if such indeed were necessary, until after an experimental cable had been designed and built. The present invention was the outgrowth of this development. For a more complete description of the new nickel-iron alloy, reference is made to a publication entitled "Permalloy—an alloy of remarkable magnetic properties" by H. D. Arnold and G. W. Elmen, published in the Journal of the Franklin Institute, May 1923.

For a complete understanding of the invention reference is made to the following specification with the accompanying drawing in which Fig. 1 shows terminal apparatus for a submarine cable and Figs. 2 to 7, inclusive, are arrival curves and curves representing received signal current.

The cable 1 is shown by way of example as terminating in the well known duplex bridge arrangement in which sending battery 5 is connected between the ground and the apex of the bridge and the shaping correcting network 9 hereinafter described is connected between two conjugate points 2 and 3 of the bridge and to the amplifying or receiving instruments 10. An artificial line 4 forms one arm of the bridge and balances the cable 1. Signaling is accomplished by keys 6 and 7 in the ordinary manner, positive impulses being transmitted to the line by the closure of dot-key 6 upon contact 12 and negative impulses by closure of dash-key 7 upon contact 13. The cable 1 is inductively loaded preferably by providing a spiral wrapping of permalloy tape a few mils in thickness about the conductor. The wrapped conductor is covered with a layer of insulation, such as gutta percha. A wrapping of jute is preferably placed outside the gutta percha, a sheathing of spirally arranged steel wires is placed over the jute and other layers of jute laid upon the sheathing. The return circuit for the signaling conductor is through the sheathing and sea water.

The theory of a submarine cable such as that just described under ideal conditions, in which the four parameters, resistance, inductance, capacitance and leakance, which may be denoted respectively by R, L, C and G, are constant at all frequencies, indicates that if unit voltage were applied at one of the cable terminals beginning at time $t=0$, the current received at the other terminal would vary in the manner shown in Fig. 2, in which the curve C is the arrival curve for the impressed voltage V of the form shown at the top of the figure, I representing received current and T elapsed time. In the special case known as the distortionless cable, where the relation R C=L G holds, the arrival curve is of the form shown in Fig. 3. If the current I is sufficient to operate the recording instrument, pulses of very short duration can be transmitted over the cable. The form of such a pulse as it arrives at the receiving end can be easily determined for either the ideal cable or the distortionless cable from the arrival curves of Figs. 2 and 3 respectively. For instance, the shape of the pulse obtained by impressing unit voltage at the sending end for a short interval t is shown in Fig. 4 for the ideal cable and in Fig. 5 for the distortionless cable. The pulse received from the distortionless cable is an exact copy of the transmitted pulse greatly attenuated. For the other cable the distortion at a, b for the received pulse is comparatively small and can be diminished by decreasing the duration of the pulse. Thus, the distortion of signals transmitted over a loaded cable of the ideal form can be decreased without loss of amplitude by increasing the speed of signaling, a close approximation to the conditions encountered on a distortionless cable being possible.

The cable parameters, however, are not entirely independent of the frequency, and the variations involved in high speed signaling, such as is contemplated for use with permalloy loaded cables, becomes very material. The pulse represented in Figs. 4 and 5 may be considered as corresponding to a signal dot, the dash being of the same duration but opposite in polarity.

The transmitted telegraph message, consisting of a succession of such pulses, may be considered as composed of sinusoidal currents of all frequencies from zero to infinity added together, the relative amplitudes of the various components being determined by the character and arrangement of the signal pulses. It is found that in order to best preserve the legibility of the message, it is necessary to preserve the amplitude relations of all components up to a certain frequency which can be termed the "signal frequency". This frequency bears a definite relation to the frequency of the shortest pulse of the signals, the relation depending on the code and method of reception used. In the case of the standard cable code with recorder working the signal frequency is roughly equal to the fundamental frequency encountered in a succession of alternate dots and dashes. The components of frequencies higher than the signal frequency up to roughly twice the signal frequency may be reduced in amplitude, the reduction increasing with the frequency, without waking the signal unintelligible, although the less these higher frequencies are reduced the more easily legible is the signal.

The resistance of the cable includes an effective resistance due to hysteresis and eddy currents in the loading material, eddy currents in the core conductor and in the return conductor and hysteresis in the armor wires. Each of these losses is a function of the frequency. Another loss which has been found to be of considerable magnitude is that occasioned by the so-called skin effect in the armor wires and the surrounding sea water, but more particularly in the former. As the frequency increases it appears that more of the return current is confined to the armor wires and less to the sea water and the part in the water is confined to a much thinner surrounding layer. Dielectric hysteresis loss also varies with the frequency.

The signal frequency now in use with oceanic telegraph cables is of the order of 10 cycles per second, while the signal frequency used with permalloy loaded cables of the same length is several times as great and may be six or seven times as great. In the former case the range of frequencies involved in the transmission of an easily legible signal is from 0 to 12 or 15 cycles and possibly in a few instances the range is slightly greater than this. The above mentioned variable resistance and dielectric losses are entirely negligible in this range. If, for example, a signal frequency of 30 cycles per second is used with permalloy loaded cable, the range of frequency components involved is from 0 to 60 or more cycles. The variable resistance and dielectric losses become quite material over a large portion of this range. When a signal frequency of 60 cycles per second, which it is now thought will be a preferred frequency, is used, the frequency range will extend from 0 to 120 or more cycles and the variable resistance and dielectric losses will play a still greater role in the transmission of signals.

Because of this variation of certain of the parameters the curve of received current differs from that for the ideal case in that instead of rising instantaneously to the value I it rises more gradually, as shown by the broken line portion of the curve in Fig. 6. Signals transmitted over such a cable will therefore not be free from distortion, the received impulse then taking the form shown in Fig. 7. In Figs. 6 and 7 received current is represented on a larger scale than in Figs. 2 to 5.

Moreover, on account of the finite slope of the portion A, B of the arrival curve if the length of a single signaling pulse is decreased below a certain value t, which represents the time required for the arrival current to reach the value necessary to operate the receiving instrument, the amplitude of the pulse will be too small to be recorded. There is therefore a limit to the speed at which signals can be received. This limit can be raised by means which will cause the portion A, B of the received current curve of Fig. 6 to more nearly approach a vertical position, that is to have an increased slope. According to this invention this object is accomplished by providing shaping apparatus to act upon the transmitted signals before or after transmission through the cable which will counteract the effect of the variable losses in the cable and give to the received signal a form that approximates that of the signal received from a distortionless cable. The required correction is seen to be of the same general form as that necessary to compensate for capacity distortion in unloaded cables. It is well known that an electrical network of the form shown in Fig. 1 is suitable for correcting distortion of this character. In putting the invention into practice, therefore, this network may be employed but other suitable forms of correcting apparatus may, of course, be used if desired. The form shown comprises inductance 14 and resistance 15 in shunt to the receiving apparatus, capacity 16 with shunted resistance 17 in series relation with respect to the receiving apparatus, and a second shunt circuit comprising inductance 18 and resistance 19.

What is claimed is:

1. In combination, an inductively loaded telegraph signaling cable having an arrival curve with a head or front slightly inclined to the vertical and a tail or rear portion having a greater inclination to the vertical, the variation from the vertical of said head portion being due to those losses in the cable which are dependent upon frequency, terminal shaping apparatus for varying the form of the arrival curve to produce a head more nearly vertical, and terminal apparatus for forming, impressing upon said cable and receiving current signal impulses at such a rate that received impulses will be greater in amplitude than without the use of said terminal shaping apparatus.

2. The combination with a submarine cable conductor, of magnetic material distributed along said conductor to compensate in part at least for the distributed capacity thereof, and terminal-shaping means cooperating therewith to compensate in part at least for distortion introduced by said loading material.

3. The combination with a long inductively loaded submarine cable, of terminal apparatus for high speed transmission and reception, and terminal apparatus for compensating in part at least for signal distortion produced by return-circuit losses which are dependent upon frequency and are of maximum importance only in high speed signaling.

4. The combination of a long submarine conductor with a metallic sheath having a lower total resistance than said conductor and forming the return circuit in part at least, and terminal apparatus for signaling and receiving at such high rates that distortion due to skin effect in said metallic sheath becomes material, and terminal apparatus for compensating in part at least for said distortion.

5. The combination with a long insulated signal conductor, of terminal apparatus for signaling and receiving at rates at which distortion due to losses in the insulation become appreciable, and terminal apparatus for compensating in part at least for said distortion.

6. The combination with a long signaling conductor, of magnetic loading material associated therewith, terminal apparatus for signaling and receiving at rates at which material signal distortion is produced by losses dependent upon frequency and due to eddy currents in the loading material, and terminal apparatus for compensating in part at least for said distortion.

7. The combination with a long signaling conductor, of magnetic loading material associated therewith, terminal apparatus for signaling and receiving at rates at which material signal distortion is produced by losses dependent upon frequency and due to hysteresis in the loading material, and terminal apparatus for compensating in part at least for said distortion.

8. The method of receiving high speed telegraph signaling impulses over a long continuously loaded conductor, which consists in first shaping the received signaling currents to correct for the distortion due to dissipation effects consequent on high speed operation, and then applying said currents to operate the receiving apparatus.

In witness whereof, we hereunto subscribe our names this 10th day of May A. D., 1922.

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ALLISON A. CLOKEY.