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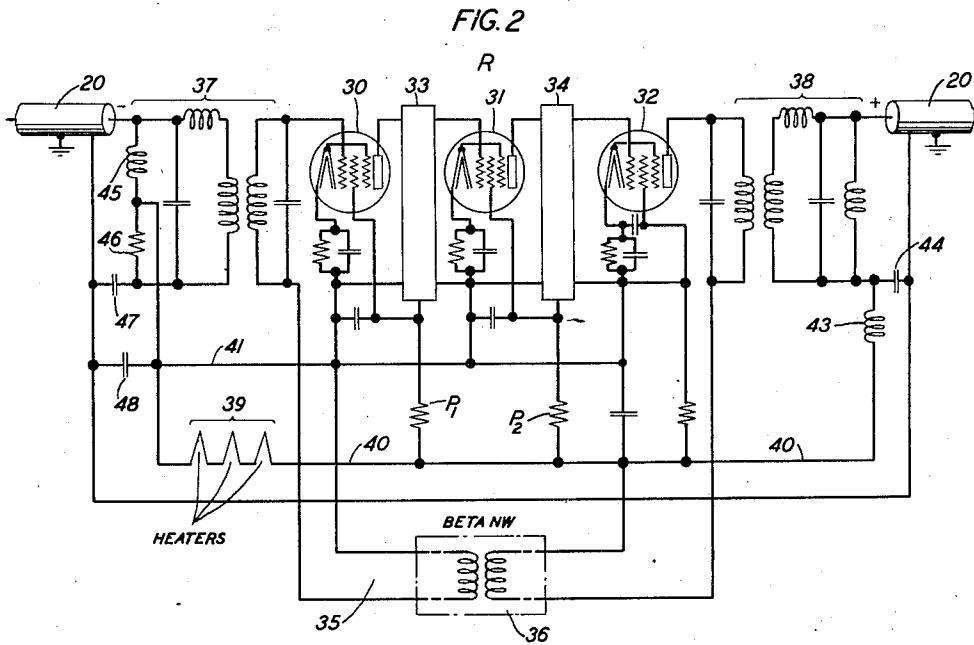
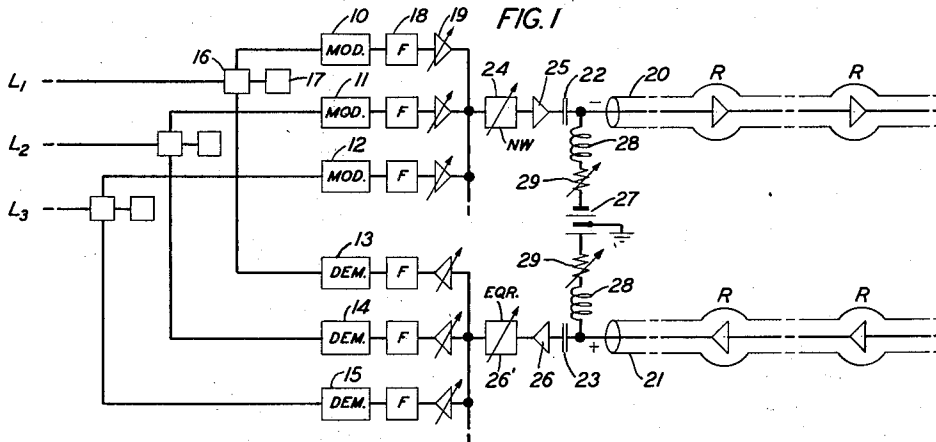
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2,342,544

SUBMARINE CABLE TRANSMISSION

Filed April 18, 1942

2 Sheets-Sheet 1



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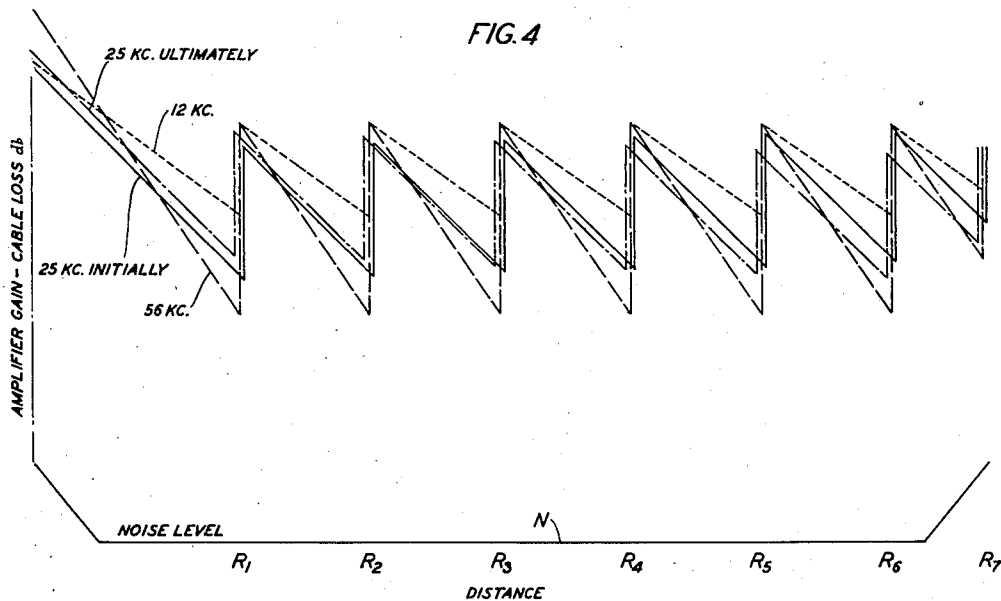
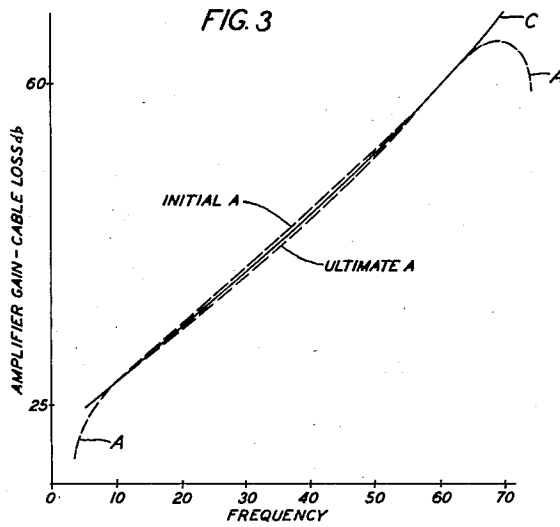
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2,342,544

SUBMARINE CABLE TRANSMISSION

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Application April 18, 1942, Serial No. 439,497

7 Claims. (Cl. 178-44)

The present invention relates to deep-sea cable transmission, involving sea-bottom repeaters, or to similar types of transmission.

The invention has particular application to the general type of system disclosed and claimed in Buckley-Jacobs Patent 2,020,297, November 12, 1935, in which one or usually many repeaters would be incorporated in a deep-sea cable for reinforcing the signal waves sent over the cable. A broad frequency band accommodating several carrier telephone channels or even a practical television range is contemplated.

As explained in the Buckley-Jacobs patent, long life repeaters would be used in order to minimize as far as possible the necessity of having to pick up the cable and repeaters for replacements of tubes, etc. Since tubes operating over periods of years gradually lose gain, provision has to be made for maintaining suitable amplification performance taking this loss of tube gain into account. One way of meeting this situation is to provide a remote gain control for the sea-bottom repeaters as was done in the system of the patent. If the system were operated under conditions of varying cable attenuation, some form of remote gain control would be essential especially where many repeaters are used in tandem, since a small decrease in line attenuation might otherwise result in dangerously high over-all gain of the system. It should be noted by way of example that such systems may use fifty or so repeaters in tandem on the basis of 40-mile spacing and a 2000-mile span.

A sea-bottom system, however, is by circumstances a constant attenuation system since it operates at a constant temperature and, therefore, the resistance of the copper core remains at the same value indefinitely. This fact makes it practical to use constant gain repeaters.

A type of repeater which can be made to have a nearly constant insertion gain notwithstanding wide variations in tube gain is the stabilized feedback repeater disclosed and claimed in H. S. Black Patent 2,102,671, December 21, 1937. The present invention utilizes these stabilized feedback repeaters as sea-bottom repeaters and the design is such as to stabilize the gain as far as possible so as to minimize the effect on repeater gain of the loss of gain by the tubes due to aging or other causes of tube deterioration. There are other important advantages, known in themselves, of using stabilized feedback repeaters, one such being the reduction of intermodulation between the currents in the different channels.

While the use of stabilized feedback amplifiers

in the repeaters removes the necessity of providing a remote gain control to compensate for loss of tube gains, the compensation secured by the stabilized feedback is not the same at all frequencies throughout the transmission band but is less complete near the middle of the band than near the band edges. The reason for this is implicit in the theory of the stabilized feedback amplifier as given in Black's patent and elsewhere in the published art so that it suffices here merely to state the fact that as the tubes lose their gain with time the insertion gain of a repeater is almost perfectly compensated for by the feedback action at those frequencies at which the phase shift around the feedback loop is in the vicinity of 90 degrees or 270 degrees but is less perfectly compensated for at frequencies at which the phase shift departs from those values. Also in accordance with established stabilized feedback amplifier design, these phase angles of 90 degrees and 270 degrees occur at or near the edges of the transmission band, the middle part of the band usually being located in the vicinity of 180 degrees loop phase shift on the frequency phase shift plot.

In accordance with the present invention the repeater gains are preshaped to take account of the less complete compensation for loss of tube gain in the middle portion of the transmission band so that as the tubes eventually lose gain the departures from best performance due to that cause are kept within narrower limits.

The nature and objects of the invention will appear more fully from the following detailed description of an illustrative application of the invention in a submarine cable system and from the drawings, in which

Fig. 1 is a block diagram of one terminal of a two-way deep-sea cable installation of a type to which the invention is applicable by way of example;

Fig. 2 shows in simplified schematic diagram the circuit of one repeater in the cable; and

Figs. 3 and 4 show graphs to be referred to in the description.

Fig. 1 shows in single line schematic three telephone lines L_1 , L_2 and L_3 leading up to the carrier terminal apparatus represented by the modulators 10, 11, 12 and demodulators 13, 14, 15, connection to these being made through branches of the usual hybrid coils and line balances such as 16, 17. There may be any number of such lines feeding into a cable system, such as twelve lines, this figure being suggested by the twelve-channel blocks at present in use in connection

with commercial carrier telephony. The side-band filters for separating the various conversational waves from one another are shown at 18 and terminal amplifiers are indicated at 19. The transmitting channels lead into eastward cable 20 via equalizing network 24, amplifier 25 and coupling capacity 22, and the receiving channels are derived from westward cable 21 through coupling capacity 23, amplifier 26 and compensating equalizer network 26'.

Each cable has included in its repeaters R at spaced intervals in accordance with the disclosure and teaching of the Buckley-Jacobs patent. Energizing current for these repeaters is supplied over the cables from the two shore ends, one source being indicated at 27 connected to the cable cores through filters indicated by the inductances 28, and through regulating resistances 29. A similar source oppositely poled is at the opposite end. Since the present invention is not dependent upon or limited to detailed matters of cable system design for its practice but is applicable generally to repeated systems which may differ widely from one another, only a general disclosure is made as to the cable system, by way of example.

It will be apparent that the opposite terminal of the system will be the counterpart of the terminal shown, the receiving line connections in that case leading from cable 20 to the telephone lines and the transmitting branches of such lines leading to cable 21.

In Fig. 2 one repeater R inserted between sections of cable 20 is shown as including three pentode tube stages 30, 31, 32 with suitable interstage networks 33, 34. A negative feedback path 35 is provided from the output of the last stage to the input of the first stage and includes the beta network 36. Suitable input and output coupling circuits are shown at 37 and 38, respectively, each including a transformer and certain reactance elements which may be used to assist in shaping the insertion gain.

The energizing current passes through the conductor 40 conductively connected between the cores of the opposite cable sections and includes in series the heaters 39 of the amplifier tubes. The cathodes are connected through usual grid bias resistance-condenser circuits to the conductor 41, while the screens and plates are connected, in some cases through potential reducing resistances, to the conductor 40 on the more positive potential side of the heaters so that the plate and screen voltages are derived from the potential drop across the heaters. Leads P₁ and P₂ are connected through resistances to lead 40 for supplying plate and screen voltage to tubes 30 and 31. A similar connection is made for the screen of tube 32, the plate of this stage getting its voltage through the beta network.

Suitable filtering is supplied to separate the energizing current from the signals, including inductance 43 and capacity 44 at the output side and the constant-resistance bridge or lattice network composed of inductance 45, capacity 47, cable impedance and cable-balancing impedance represented as resistance 46 for simplicity. An additional shunt capacity filtering element is shown at 48. The circuit details that have been mentioned do not in and of themselves form any part of the present invention, although the invention does involve the use of some suitable form of circuit design and the repeater of Fig. 2 is given as illustrating the best type known to applicant at the present time.

In Fig. 3 the solid line curve C is a plot of assumed attenuation characteristic of a section 20 of submarine cable leading up to some one repeater R, such as that in Fig. 2. It is possible by known methods of amplifier design to provide a repeater of the type shown in Fig. 2 which will have a gain characteristic A closely fitting this attenuation characteristic throughout the transmission band, extending for example from 12 kilocycles to 60 kilocycles in this example. Such amplifier characteristic will depart from the solid line characteristic below the lower band edge and above the upper band edge as shown, but the portion of the gain characteristic throughout the band can be made to lie along the solid line curve as closely as may be desired. The general method of design to be followed for this purpose is that given in H. W. Bode Patents 2,123,178, July 12, 1938, and 2,242,878, May 20, 1941. Since in the present case resistance noise is more significant than tube noise, the general conditions to be assumed in the repeater design are those indicated in Fig. 3 of the latter Bode patent. The equalization for line attenuation may be entirely in the transformer or input and output coupling circuits, or it may be divided between these and the beta network. There is considerable latitude in this respect since it would even be possible to provide an equalizer in the line ahead of or following the amplifier to provide the required equalization although this would be less preferred.

In accordance with the present invention, instead of designing the repeater to have a gain characteristic exactly matching the attenuation characteristic of the cable over the band, the match is made at both edges of the band but the gain curve lies slightly above the attenuation curve in the middle portion of the band as indicated by the dotted curve marked Initial A. For any one repeater the departure would be less than actually indicated, the showing being greatly exaggerated for illustration. As the tubes lose gain over a period of, say, the first ten years, the middle portion of the gain curve will sag and the match between the attenuation and gain curves will be closer. During a further period of aging, such as the second ten years, the gain curve will continue to sag in the middle and reach the position Ultimate A (exaggerated), this corresponding to about the end of the useful life of the repeater when it would normally be expected to be replaced. If the same assumptions be made except that Initial A be assumed to coincide with curve C, the Ultimate A would depart from C in the central portion by something like twice the extreme departure of either Initial A or Ultimate A in the case first assumed. Instead of making the stable gain points just at the edges of the band they may be just inside the edges so that at the edges a reverse effect to that described with respect to the middle part of the band takes place, the gains at the extreme edges being made initially slightly less than the cable attenuation and approaching the cable attenuation as the tubes begin to lose gain.

Fig. 4 is a level diagram for a cable including a number of repeaters in tandem. It shows in another way the same effects as discussed in connection with Fig. 3. The band edges are at 12 kilocycles and 60 kilocycles while the frequency at which the repeater gain changes most with tube gain is taken as 25 kilocycles. The points of greatest gain stability are at 12 kilocycles and 56 kilocycles. The gains and losses for these three frequencies are plotted. There

would, of course, be a whole family of similar curves, one for each frequency but the three that are given show the extremes between which the other curves would lie. The gains introduced by the repeaters are shown by the vertical lines while the cable losses are given by the sloping lines. The gains of all the repeaters are assumed alike for any one frequency but the gains increase with increasing frequency as in Fig. 3. The noise level is indicated by curve N below the saw-tooth curve and it slopes upwardly at both ends to indicate that the noise level is higher near shore where the shielding effect of the shallow water is less.

Starting at the extreme left of the figure, the signal input levels are higher than at the repeater points to provide adequate margin over the higher noise level near shore. There is also preequalization as indicated by the fact that the level is highest at 56 kilocycles and lowest at 12 kilocycles. This can be obtained by use of the shaping network 24 or by variably adjusting the gains of the transmitting terminal amplifiers 19 of Fig. 1 or partly by each means. When the first repeater R_1 is reached the 56-kilocycle component is attenuated to a much lower level than the other frequency components, and the repeater gain is shaped to raise both edges of the band to the same outgoing level for application to the succeeding cable section. This action is repeated at each repeater station throughout.

Two level diagrams are shown for 25 kilocycles, corresponding to the Initial A and Ultimate A discussed in connection with Fig. 3. Initially the repeater gains at 25 kilocycles are slightly in excess of the cable loss at this frequency. Consequently, the input level at 25 kilocycles is correspondingly lowered as indicated. This can be done either by adjustment of the predistorting network 24 or by adjustment of the transmitting amplifiers 19 or both. Since for best reception the power in each speech channel should arrive at the output of the intermediate repeater at which the levels are highest, it is necessary to start out with just enough lower level at 25 kilocycles to offset the additional gain which this frequency component will experience in the repeater string so that it will come out at the last repeater at the same level as the other frequencies. This is indicated in the diagram by the upward slope toward the right of the bottoms of the graph for 25 kilocycles initially.

As the repeaters lose gain in the middle of the band, the input level is raised by the operating attendants until it ultimately becomes (for 25 kilocycles) the level indicated by the curve, 25 kilocycles ultimately. In this case the repeater gains are slightly smaller than the cable attenuations at 25 kilocycles so that the tips of the graph are sloping downwardly toward the right.

The last repeater R_7 is on shore and may comprise amplifier 26 and compensation network 26' of Fig. 1, so that this repeater is accessible for adjustment. Its gain characteristic is adjusted with time to be greater ultimately than initially at the middle part of the band in order to give an arrival wave that is undistorted for either the initial, ultimate or intermediate conditions discussed.

It will be noted that a considerable range of adjustment can be made in the input level at the middle of the band without either trespass-

ing upon the permissible noise margin or exceeding the overload point of the repeaters. In practice the levels would be changed at both ends to such values as to secure best signal transmission with minimum interference.

While for simplicity all repeaters have been assumed alike, it is within the invention to build certain repeaters with special characteristics to have a rectifying effect on the cumulative characteristic of a number of intervening repeater sections. In laying a cable, for example, it may be desirable every so often to include such a special repeater designed to compensate for measured irregularities in the portion of the system already put down.

The method of operating that has been disclosed with respect to the 25-kilocycle wave could, of course, be followed to some extent with respect to the entire band. It was assumed for simplicity and for the sake of comparison that the gains at the band edges exactly equal the losses over the entire life period, but if this is not the case due either to incomplete stabilizing of the gain or to changes in attenuation, considerable compensation can be made by adjustment of input levels with whatever coincidental adjustment of receiving level is necessary. In general, the initial gain should be slightly greater than the initial attenuation as pointed out in the case of the middle portion of the band.

For illustration, a repeater such as has been disclosed may have initially a negative feedback of 40 decibels or more throughout the transmission band and the insertion gain at 60 kilocycles may be 60 decibels or higher, these values being given by way of example and not as limiting. This initial order of magnitude of feedback should be sufficient to reduce the changes in insertion gain to the order of four-tenths of a decibel when the feedback has decreased 15 decibels.

What is claimed is:

1. A repeater for insertion in a submarine cable comprising a stabilized feedback vacuum tube amplifier, means providing a large enough feedback ratio in said amplifier to give complete compensation near the edges of the used transmission frequency band for variation in tube gain with aging of tubes, throughout the expected life of said repeater, and equalizer means in said repeater for shaping the insertion gain frequency characteristic of said repeater to an approximate match of the attenuation frequency characteristic of a section of said cable, said equalizer means causing said match to be practically complete at two frequencies near the two edges of the used transmission band but causing the gain characteristic to exceed the attenuation characteristic in the middle portion of the band by an amount equal to about one-half the expected reduction of insertion gain of the repeater in the middle portion of the band due to aging of the tubes over the expected life of said repeater.

2. In a deep-sea cable installation having a certain transmission frequency band, a vacuum tube amplifier for insertion at a point in said cable, said amplifier having a gain stabilizing feedback of sufficiently great feedback factor to maintain the gain substantially constant throughout a given portion of said transmission frequency band notwithstanding large changes in tube gain, whereby the change in insertion gain within said portion of the transmission frequency band due to tube deterioration with age

is reduced to a given small amount over a given period of many years, and shaping means causing said amplifier to have an initial insertion gain throughout said portion of the transmission frequency band in excess of the cable loss by substantially one-half said given small amount to compensate in advance for such deterioration in tube gain over said given period.

3. A submarine cable for transmission of signals occupying a band of frequencies, said cable composed of sections with repeaters inserted between successive sections, said repeaters each having a gain stabilizing feedback of sufficiently great feedback factor to maintain the insertion gain substantially constant with time notwithstanding substantial loss in tube gain, said repeaters having initial gains closely matching the attenuation of the adjacent cable section near the edges of the band but sufficient excess gain in the middle portion of the band to allow for eventual small sagging of insertion gain in the middle portion of the band due to deterioration of the repeater tubes with age.

4. In a deep sea cable installation including repeaters whose gain is substantially constant with time over part of the transmission frequency range and variable with time over another part of the transmission frequency range, the method of operation comprising predistorting the input waves to maintain the level of waves impressed on said cable substantially constant over the first-mentioned part of the range and to progressively vary the level of waves impressed on said cable over the other-mentioned part of the range in inverse relation to the changes in repeater gain over that part of the range.

5. In a deep-sea cable installation including repeaters whose gain is substantially constant with time near the edges of the transmitted frequency band but whose gains decrease with time at frequencies within the band, the method of controlling transmission comprising initially setting the gains of the repeaters to equal the cable attenuation at or near the edges of the band and

to be slightly in excess of the cable attenuation at frequencies within the portion of the band in which the gain is subject to change with time, and initially predistorting the input waves to provide slightly lower input level of waves into the cable for the mentioned frequencies within the band than for the band edges and increasing the input level of waves into the cable at the mentioned frequencies to compensate for the decrease in repeater gains at those frequencies with time.

6. A repeater for sea-bottom installation in a deep-sea cable comprising a stabilized feedback vacuum tube amplifier having such a large feedback factor as to maintain the insertion gain substantially constant notwithstanding changes of tube gain, at two stable points coinciding substantially with the edges of the transmission frequency band, and equalizer means in the repeater for sloping the gain frequency characteristic of the repeater to match the loss frequency characteristic of the cable at said two points, said means causing the repeater gain to exceed the cable loss in the middle portion of the band by about one-half the gain reduction of the repeater in the middle portion of the band due to aging of the tubes throughout the assigned life of the repeater.

7. A repeater for insertion in a submarine cable comprising a stabilized feedback discharge tube amplifier, and equalizer means in said repeater for causing the repeater to have a gain frequency characteristic closely matching the attenuation frequency characteristic of the cable at approximately the two edges of the transmission frequency band but at a frequency slightly within the band near at least one edge while lying slightly above the cable characteristic over the main portion of the band and slightly below the cable characteristic at said one edge of the band, by such an amount at each frequency in the band as to offset in part the eventual decrease in repeater gain with time at the various frequencies in the band.

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