

Dec. 15, 1931.

H. W. DUDLEY

1,836,841

ELECTRIC WAVE SIGNALING SYSTEM

Filed Sept. 30, 1930

2 Sheets-Sheet 1

FIG. 1.

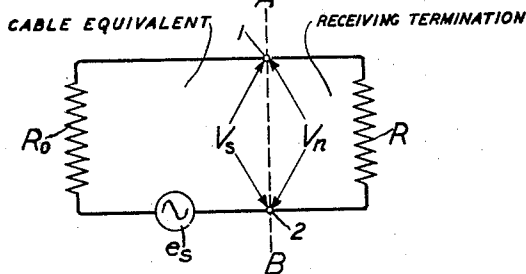


FIG. 2.

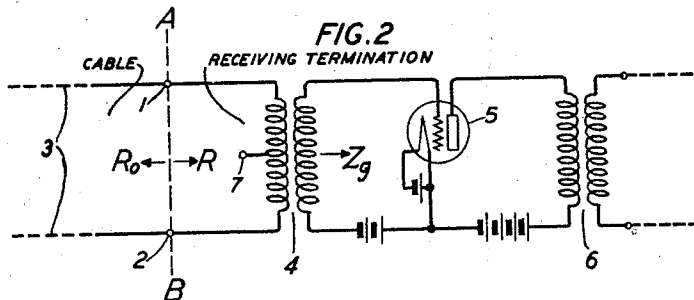


FIG. 3.

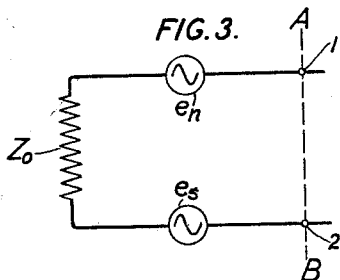


FIG. 4.

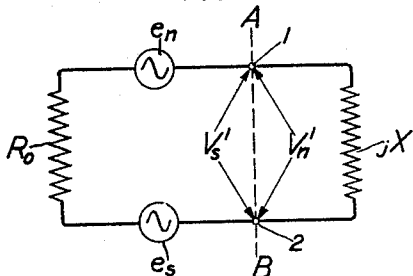
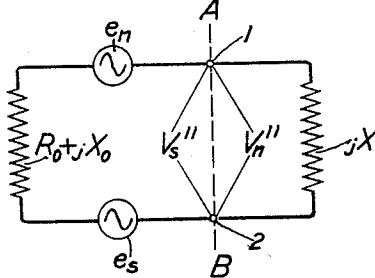


FIG. 5.



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ELECTRIC WAVE-SIGNALING SYSTEM

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2 Sheets-Sheet 2

FIG. 6.

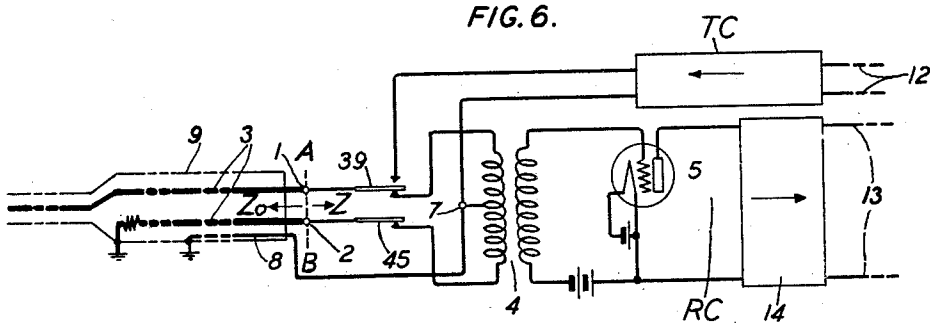


FIG. 7.

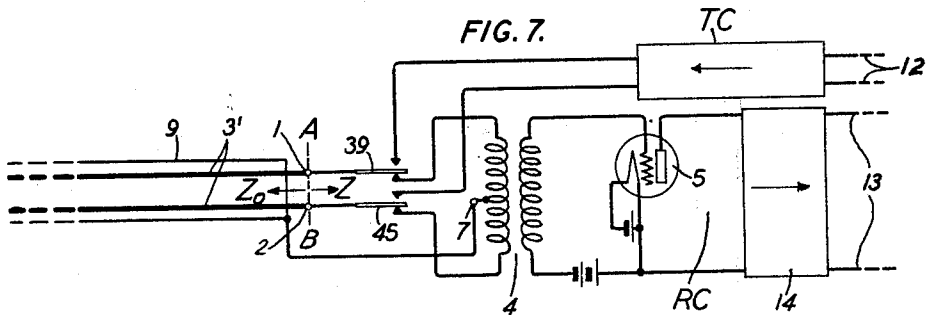
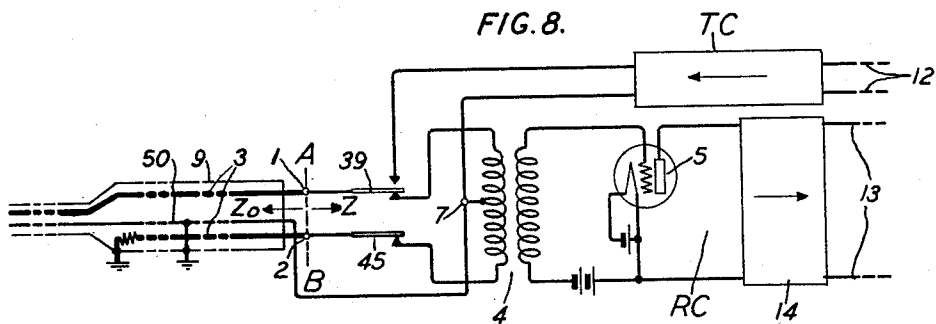
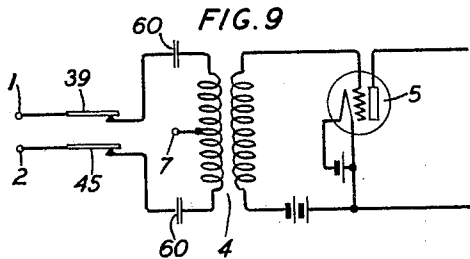


FIG. 8.



60. FIG. 9



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ELECTRIC WAVE SIGNALING SYSTEM

Application filed September 30, 1930. Serial No. 485,389.

This invention relates to signaling especially to transmission of speech over circuits such, for example, as long submarine cables.

Objects of the invention are to use such circuits efficiently and to obtain a favorable ratio of signal transmission level to resistance-noise level in such circuits.

To increase the permissible speech current attenuation at the higher essential speech frequencies in such cables without increasing the sending transmission level in the cable, in accordance with the invention it is proposed to receive the speech currents of those frequencies at a transmission level so low that the interference from the thermal agitation in the cable becomes of importance. This is feasible notwithstanding the fact that at lower frequencies, such as those in the neighborhood of the frequencies that have been used for transoceanic cable telegraphy, the level of extraneous interference may exceed the resistance noise level; because shielding effects, as for example those of the sea water and the cable armor, are much greater for the higher frequencies than for the lower frequencies, and the transmission level of the signal waves after they have traversed the cable, which has far greater attenuation at the higher frequencies than at the lower frequencies of the utilized frequency range, is higher at the lower frequencies than at the higher frequencies even though the higher frequency waves be transmitted to the cable at a level as high as, or higher than, the lower frequency waves in order to use the cable most efficiently.

The reception of the higher frequencies of the speech range under limitation of the cable resistance noise is also feasible notwithstanding the facts that the difference between the sending levels of the high frequencies and the low frequencies of the utilized frequency range should be sufficiently small to permit efficient utilization of the cable and that consequently the action of the lower frequency signal components upon the magnetic loading material of the cable produces in the upper portion of the utilized frequency range, modulation products of magnitude large compared to the cable resistance noise; because these modulation products are so greatly at-

tenuated in traversing the cable that they become small compared to the resistance noise.

Vacuum tubes are known at the present day which have sufficiently low level of tube noise to render feasible the reception under limitation of resistance noise, notwithstanding the fact that the resistance component of the iterative impedance of the cable may be as low as approximately one hundred or two hundred ohms at a frequency of 200 cycles per second or greater.

To increase the ratio of signal level to resistance noise level, in accordance with the invention it is proposed to terminate the cable in an impedance giving a value of such ratio substantially greater than would be obtained by terminating the cable in an impedance equal to that of the cable. It is shown hereinafter that this can be accomplished by terminating the cable in, for example, a substantially pure reactance or an impedance substantially greater than the characteristic impedance of the cable. Wave reflections at the termination are not objectionable, in view of the high attenuation of the cable and low level of the waves which have traversed the cable.

The terminating impedance may be a substantially pure reactance comprising a network of reactance elements connecting the cable with the input electrodes of a receiving vacuum tube amplifier, the network including the effective grid cathode impedance of the tube and having a transmission-frequency characteristic such as to favor transmission of certain frequencies which it is desired to utilize as compared to lower frequencies, in order to prevent such lower frequencies from producing in the receiving amplifier objectionable modulation products of frequencies lying in the upper portion of the utilized frequency range.

In broad aspects the invention is not limited to cable telephony, but is capable of various applications.

Other objects and features of the invention will be apparent from the following description and claims.

In the drawings; Figs. 1, 3, 4 and 5 are circuit diagrams for facilitating explanation of the invention; Fig. 2 shows a circuit em-

bodying one form of the invention; Figs. 6, 7 and 8 show cable systems illustrating applications of the invention to different forms of cables; and Fig. 9 shows a circuit that can be substituted for a portion of the circuits of Figs. 6, 7, and 8 to form modifications of those circuits.

In Fig. 1, R_o represents the iterative impedance of a line or circuit, as for example a transoceanic telephone cable at the left of the dotted line A—B. R represents the receiving terminating impedance for the circuit. For instance the voltages across R , i. e. the voltages across the terminals 1 and 2 may be applied to the grid and cathode of a receiving vacuum tube amplifier. Then if e_s is the signal voltage across the cable terminals on open circuit, the signal voltage across R is

$$V_s = \frac{e_s R}{R_o + R} \quad (1)$$

Assuming R_o and R to be substantially resistances or else to have the same impedance angle, the effective voltage across R caused by resistance noise is

$$V_n = K \sqrt{\frac{R_o R}{R_o + R}} \quad (2)$$

in which K is constant as R is varied. The nature and effects of resistance noise caused by thermal agitation of electrons in conductors is described for example in the copending application of O. E. Buckley and J. B. Johnson, Serial No. 266,423, filed March 31, 1928, allowed April 15, 1930.

As regards resistance noise, the signal-to-noise ratio r is

$$r = \frac{V_s}{V_n} = \frac{e_s}{K} \sqrt{\frac{R}{(R_o + R) R_o}} = \frac{K'}{\sqrt{1 + \frac{R_o}{R}}} \quad (3)$$

in which K' is independent of R .

It is usual to terminate the line in R_o to prevent reflections. Calling the value of r for this case r_o as a reference value,

$$r_o = \frac{K'}{\sqrt{2}} \quad (4)$$

The improvement G obtained in r by changing to any other value of R can be expressed in decibels as

$$G = 20 \log_{10} \frac{r}{r_o} = 10 \log_{10} \frac{2}{1 + \frac{R_o}{R}} \quad (5)$$

From (5) it is seen that if $R < R_o$, G is negative, while if $R > R_o$, G is positive. For positive value of R the largest value of G is for $R = \infty$ and is

$$G_2 = 10 \log_{10} 2 = 3. \quad (6)$$

As regards resistance noise, a 3 db improvement in the signal-to-noise ratio is then ob-

tained if the cable is left effectively on open circuit. This will cause reflection at the end of the line, but in the case of a transoceanic telephone cable, for example, the reflected current will be of such small value as to be negligible in its effects.

Fig. 2 shows an example of the receiving amplifier connection that can be used. The cable 3 has its terminals 1 and 2 connected to the primary winding of an input transformer 4 whose secondary winding is connected to the grid and filament of a receiving amplifier vacuum tube 5. The output transformer 6 for the amplifying tube 5 has its secondary winding connected to the remainder of the receiving circuit, which may include other amplifiers, equalizers, filters and any apparatus suitable for the receiving channel terminating the cable. In this figure the impedances R and R_o correspond to those of Fig. 1. Designating the number of turns in the primary winding of the input transformer of Fig. 2 as t and the number in the secondary winding as T ,

$$R = \left(\frac{t}{T}\right)^2 Z_o \quad (7)$$

in which Z_o is the grid-to-filament impedance of tube 5. If R is to be infinite

$$\left(\frac{t}{T}\right)^2 Z_o$$

must be infinite. It is not practicable to realize this condition. Furthermore, if R be made large by increasing

$$\frac{t}{T}$$

a point is reached where the tube noise which is independent of

$$\frac{t}{T}$$

becomes the determining noise. So a compromise should be made, and a value of

$$\frac{t}{T}$$

chosen to give a minimum noise from the addition of the thermal noise and tube noise. If R is made eight times R_o all but .5 db of the 3 db applying for $R = \infty$ is obtained. Vacuum tubes are known which are sufficiently quiet so that it is entirely feasible to obtain approximately this improvement (2.5 db) by having R several times R_o or greater, the exact amount of the improvement obtained depending upon how quiet a tube is used, as well as upon how great R is made.

The ratio of signal level to resistance noise level can also be made to approximate that for the open circuit condition of the cable by making the termination substantially pure reactance; for terminating in reactance does

not alter the open-circuit signal-to-resistance noise ratio since both the signal and the resistance noise come from the line, the terminating reactance contributing to neither.

The circuit of Fig. 3 is thus the equivalent of the line of iterative impedance Z_0 , the signal and resistance noise voltages in Z_0 being indicated at e_s and e_n respectively; and when the line is terminated in a reactance, these voltages (at any frequency) are treated the same so that the same ratio of signal-to-resistance noise holds. Therefore, terminating the line in a pure reactance has the same effect, as regards signal-to-resistance noise ratio, as terminating the line in an infinite resistance. This can also be shown as indicated below, by reference to Figs. 4 and 5.

Fig. 4 shows a circuit equivalent to a line or cable having its iterative impedance the resistance R_0 with a termination of reactance jX . Here the signal voltage magnitude V'_s across terminals 1 and 2 is

$$V'_s = e_s \frac{X}{\sqrt{R_0^2 + X^2}} \quad (8)$$

The resistance noise voltage V'_n across terminals 1 and 2 is equal to the square root of the resistance component of R_0 and jX in parallel, i.e.,

$$V'_n = K \sqrt{\frac{R_0 X^2}{R_0^2 + X^2}} \quad (9)$$

$$V'_n = KX \sqrt{\frac{R_0}{R_0^2 + X^2}}$$

From (8) and (9),

$$\frac{V'_s}{V'_n} = \frac{e_s X}{\sqrt{R_0^2 + X^2} KX \sqrt{R_0}} = \frac{e_s}{K \sqrt{R_0}}; \quad (10)$$

but for the reference condition in which the terminating impedance is a resistance R_0 equal to the line impedance R_0 , it may be seen from Fig. 1 and (1) and (2) that

$$V_s = \frac{e_s}{2}, \quad V_n = K \sqrt{\frac{R_0}{2}}, \quad \text{and}$$

$$\frac{V_s}{V_n} = \frac{e_s}{\sqrt{2K \sqrt{R_0}}} \quad (11)$$

From (10) and (11) it is seen that the signal to-resistance noise ratio is 3 db better with the line terminated in a pure reactance than with the line terminated in a resistance equal to the line resistance.

Fig. 5 shows a circuit equivalent to a line or cable having a reactance component X_0 in its impedance and with the reactance termination jX . Here the line impedance is $R_0 + jX_0$. The signal voltage magnitude V''_s across terminals 1 and 2 is

$$V''_s = \frac{e_s X}{\sqrt{R_0^2 + (X + X_0)^2}} \quad (12)$$

The resistance noise voltage V''_n across ter-

minals 1 and 2 is equal to the square root of the resistance component of $R_0 + jX_0$ and jX in parallel, i. e.,

$$V''_n = K \sqrt{\frac{R_0 X (X + X_0) - R_0 X_0 X}{R_0^2 + (X + X_0)^2}} = KX \sqrt{\frac{R_0}{R_0^2 + (X + X_0)^2}} \quad (13)$$

From (12) and (13)

$$\frac{V''_s}{V''_n} = \frac{e_s}{K \sqrt{R_0}} \quad (14)$$

but for the reference condition in which the terminating impedance is equal to the line impedance, the signal voltage V_s across terminals 1 and 2 is

$$\frac{e_s}{2},$$

and the resistance noise voltage V_n across these terminals is

$$V_n = K \sqrt{\frac{R_0}{2}},$$

and

$$\frac{V_s}{V_n} = \frac{e_s}{\sqrt{2K \sqrt{R_0}}} \quad (15)$$

From (14) and (15) it is seen that for the circuit represented by Fig. 5 as for the circuit represented by Fig. 4, the ratio of signal to resistance noise is 3 db better than were the line terminated in an impedance equal to its own impedance.

Similarly it can be shown that for any cable impedance Z_0 the 3 db improvement over the matched impedance condition can be obtained by making the terminating impedance either a substantially pure reactance or a resistance high in comparison to the cable resistance. Where the terminating resistance is not high, the termination should be as nearly as convenient a pure reactance; and where the termination is not a substantially pure reactance, its impedance should be substantially higher than (and preferably at least several times as high as) the resistance of the cable.

If the receiving terminal is of the balanced type, for example as shown in Figs. 6 to 8 the midpoint 7 of the primary winding of transformer 4 should be earthed. For instance, in Fig. 6 it is grounded to the cable armor wires 9 and the sea water through a sending sea earth conductor 8. This figure shows a transmitting channel TC for transmitting signals, for example, speech currents, from line 12 to the cable, and shows a receiving channel RC for transmission from the cable to the line 13. (For simplicity, only one end of the cable is shown. The termination of the cable at the other end of the cable may be like the termination shown in this figure, i. e. the two ends of the cable may be terminated in the same way.) The channel

RC includes the transformer 4 and tube 5 and apparatus shown as a block 14 which may include equalizing means, amplifying means, filtering means and other suitable apparatus. The directions of transmission in TC and RC are indicated by the arrows in those channels. The lines 12 and 13 may be the two sides of a four-wire circuit, and the system may be for example of the type disclosed in my copending application Serial No. 473,853, filed August 8, 1930. One of the cable conductors 3 is shown as a receiving sea earth or cable balancing return circuit of the type described in J. J. Gilbert Patent 1,654,328, December 27, 1927. The single core cable and its sending and receiving sea earths may be for example as disclosed in the copending application of A. M. Curtis, Serial No. 382,011, filed July 29, 1929, (corresponding British Patent 339,288, Feb. 26, 1931) which claims a cable with such sea earths. For instance, the cable may be continuously loaded as described in that application and the sending sea earth 8 may be a non-loaded sea earth of a few miles in length whereas the receiving sea earth may be relatively long and may be continuously loaded and may have a proper terminating impedance at its sea end.

Switches 39 and 45 are shown to indicate that, as described in my application Serial No. 473,853 referred to above, during receiving these switches connect terminals 1 and 2 to the primary winding of transformer 4 and the switch 39 opens the circuit between the transmitting channel and the cable core, whereas during transmitting the switches 39 and 45 disconnect the transformer 4 from the cable and the switch 39 connects the transmitting channel to the cable. Thus, during receiving the impedance of the transmitting channel as seen from the cable is substantially infinite, or in other words the impedance of the transmitting channel is not attached to the cable during receiving. The transmitting channel then does not interfere with proper receiving termination of the cable for obtaining a favorable signal-to-resistance noise ratio as explained above in connection with Figs. 1 to 5.

In Fig. 7, similarly, the switches 39 and 45 are shown to indicate that during receiving the effective impedance of the transmitting channel TC as seen from the cable is substantially infinite, and during sending the transformer 4 is disconnected from the cable and the transmitting channel TC. The system shown in this figure is like that of Fig. 6, except that the cable is of the twin-core type for example, and there being no sending sea earth such as 8 of Fig. 6, the transmitting channel (during sending) is connected across the cable conductor 3' instead of between a cable conductor and the sending earth ground. The manner of connecting the twin-core cable to the transmitting channel

and the receiving channel is in general that disclosed in the Curtis application referred to above. The transmitting channel need not be actually disconnected from the cable conductors 3' at switches 39 and 45 during receiving, but may instead be opened on the primary side of an output transformer (not shown) for the channel TC, as shown in the Curtis application mentioned above, provided the impedance of that channel as seen from the cable and from the transformer 4 is made substantially infinite during receiving. (As in the case of Fig. 6, so also in the case of Fig. 7 and in the case of Fig. 8 described below, only one end of the cable has been shown, and the two ends of the cable may be terminated in the same way.)

Fig. 8 shows a circuit like that of Fig. 6 except that the cable is of the concentric return type, the concentric return path being indicated at 50. Any suitable type of concentric return cable may be used. By using a concentric return conductor cable of the type disclosed in the copending application of O. E. Buckley, Serial No. 392,351, filed September 13, 1929, which has magnetic material of high initial permeability shielding the central cable conductor and the concentric return conductor, it becomes unnecessary to employ a balancing sea earth and the system can then be as indicated in Fig. 7, one of the cable conductors then being a concentric return conductor, however, instead of a twin core conductor, and the ground connection to point 7 being omitted.

In Figs. 6, 7 and 8 the transformer 4 can have a high step-up ratio and the primary-to-secondary impedance of the transformer, i. e. the receiving impedance Z facing terminals 1 and 2 from the right, can be made a substantially pure resistance. The transformer 4 can be made to have sufficiently low mutual inductance to give it lower transmission efficiency for the low frequencies of the utilized frequency range than for the higher utilized frequencies, to act as an equalizer for discriminating against the low frequencies. This is of advantage since the attenuation of the cable is not only very great but is of a higher order of magnitude for the higher frequencies of the essential speech range than for the lower frequencies of the utilized range and at terminals 1 and 2 the transmission level of these lower frequency components arriving over the cable is so much greater than the transmission level of the higher frequencies that modulation products generated in the tube 5 by the lower frequency signal components and falling in the frequency range of the higher frequency signal components may seriously interfere with proper reception of the higher frequency signal components unless equalization of the character mentioned is effected before the signals ar-

iving over the cable are transmitted to the tube 5.

As explained in my copending application, Serial No. 390,491, filed September 5, 1929, now Patent 1,784,825, granted December 16, 1930, the equalization of the received speech currents may be achieved to some extent by a predistortion of the transmission at the sending end, whereby the high frequency speech currents are increased in intensity relatively to the low frequency components; but the degree of equalization that can be effected in that way is limited since the cable loading material limits the input power capacity of the cable. That is, the modulation products caused by the magnetic loading material of the cable limit the load capacity of the cable and require that for the most efficient use of the cable the speech current components should be substantially equalized in intensity before transmission to the cable. Moreover, the noise from extraneous sources may be sufficiently great at low frequencies in the utilized frequency range to require that the low frequency signal components emerge from the cable at transmission levels higher than those required for the higher signal frequencies by resistance noise, noise from extraneous sources, cable modulation and tube noise. The waves in the upper portion of the speech range are transmitted to the cable at the lower transmission levels permitted by the interference from resistance noise and the waves in the upper portion of the speech range are transmitted to the cable at the highest transmission levels permitted by the interference from the modulation produced by the loading material, these level adjustments being obtained in any suitable manner, for example as described in my Patent 1,784,825 referred to above or in my application Serial No. 473,853 referred to above. My Patent 1,784,825, just mentioned, claims the equalization at both the input to the cable and the input to the receiving amplifier and also claims an equalizer constituted of reactance elements at the receiving end of the system.

If desired condensers 60 may be inserted in series with the primary winding of transformer 4 in Figs. 6, 7 and 8, as indicated in Fig. 9, to form with the mutual inductance of the transformer 4 a high pass filter, with a cutoff frequency of approximately 300 cycles for example, primarily to keep out earth currents; or the transformer may effect equalization over the utilized frequency range as described above, the series condensers however assisting in this equalization by discriminating against low frequencies of the utilized range and cooperating with the transformer to give very high attenuation for the frequencies below approximately 300 cycles for example.

What is claimed is:

1. The method of signaling through a circuit having attenuation of different orders of magnitude for currents of different frequencies, which comprises transmitting over said circuit signaling waves of said frequencies at transmission levels such that the waves of the frequencies most highly attenuated are received under limitation of the resistance noise of the circuit.

2. The method of signaling through a submarine cable having resistance noise, and having other interference decreasing with frequency, and having attenuation increasing with frequency, which comprises transmitting over said cable signaling waves of frequency range and transmission levels such that waves of the higher frequencies are received under limitation of said resistance noise and waves of lower frequency are received under limitation of said other noise.

3. A transoceanic submarine telephone cable system comprising a long cable loaded with magnetic material of high permeability at low magnetizing forces, said cable having attenuation increasing with frequency, and means for transmitting to said cable speech waves in the upper portion of said range at the lowest transmission levels permitted by the interference from the resistance noise of the cable, and speech waves in the lower portion of the utilized speech frequency range at the highest transmission levels permitted by interference from modulation in said loading material.

4. The combination with a signaling circuit which attenuates signals to a level so low as to be limited by the interference from the resistance noise of the circuit, of a terminating impedance therefor having such magnitude and phase angle as to render the ratio of signal level to resistance noise level substantially greater than were the terminating impedance equal to the circuit impedance which it faces.

5. The combination with a signaling circuit which attenuates signals to a level so low as to be limited by the interference from the resistance noise of the circuit, of a terminating impedance therefor having such magnitude and phase angle as to render the ratio of signal level to resistance noise level of the circuit and the terminating impedance approximately 2.5 decibels greater than were the terminating impedance equal to the circuit impedance which it faces.

6. The method of receiving signals under limitation of resistance noise of a signaling circuit, which comprises transmitting the waves from the circuit to a receiving impedance differing from the circuit impedance in such manner as to render the ratio of signal level to resistance noise level substantially greater than were the receiving impedance equal to the circuit impedance.

7. The method of receiving signals under limitation of resistance noise of a signaling circuit, which comprises transmitting the signals from the circuit to a receiving impedance having a substantially greater phase angle than the impedance of the circuit. 75
 8. The method of receiving signals under limitation of resistance noise of a signaling circuit, which comprises transmitting the signals from the circuit to a receiving impedance of substantially greater magnitude than the impedance of the circuit. 80
 9. The combination with a signaling circuit which attenuates signals to a level so low as to be limited by the interference from the resistance noise of the circuit, of a substantially purely reactive terminating impedance for said circuit. 85
 10. The combination with a signaling circuit which attenuates signals to a level so low as to be limited by the interference from the resistance noise of the circuit, of a terminating impedance for the circuit which is substantially greater than the impedance of the circuit which it faces. 90
 11. The combination with a loaded transoceanic submarine telephone cable circuit which attenuates speech signals to a level so low as to be limited by the interference from the resistance noise of the circuit, of a terminating impedance for said circuit which is at least several times as great as the circuit impedance which it faces. 95
 12. The combination with a signal transmitting cable which attenuates signals to a level so low as to be limited by the interference from the resistance noise of the cable of a terminating impedance therefor which is substantially pure reactance. 100
 13. The combination with a signal transmitting cable which attenuates signals to a level so low as to be limited by the resistance noise of the cable, of a terminating impedance therefor of magnitude at least several times as great as the iterative impedance of the cable at the highest frequencies of the utilized frequency range. 105
 14. The combination with a signal transmitting cable which attenuates signals to a level so low as to be limited by the resistance noise of the cable, of a substantially purely reactive terminating impedance therefor comprising a transformer and a vacuum tube, said transformer having its primary winding connected to the cable and its secondary winding connected to the input electrodes of said vacuum tube. 110
 15. The combination with a signal transmitting cable which attenuates signals to a level so low as to be limited by the resistance noise of the cable, of a substantially purely reactive terminating network therefor having high attenuation for a range of frequencies and low attenuation for higher frequencies, said network comprising a vacuum tube and reactance elements connected between said cable and the input electrodes of said vacuum tube. 115
- In witness whereof, I hereunto subscribe my name this 29th day of September, 1930. 120
- HOMER W. DUDLEY. 125
- 130