Dec. 16, 1930. H. W. DUDLEY 1,784,825

SPEECH TRANSMISSION

Filed Sept. 5, 1929

FIG. 1.

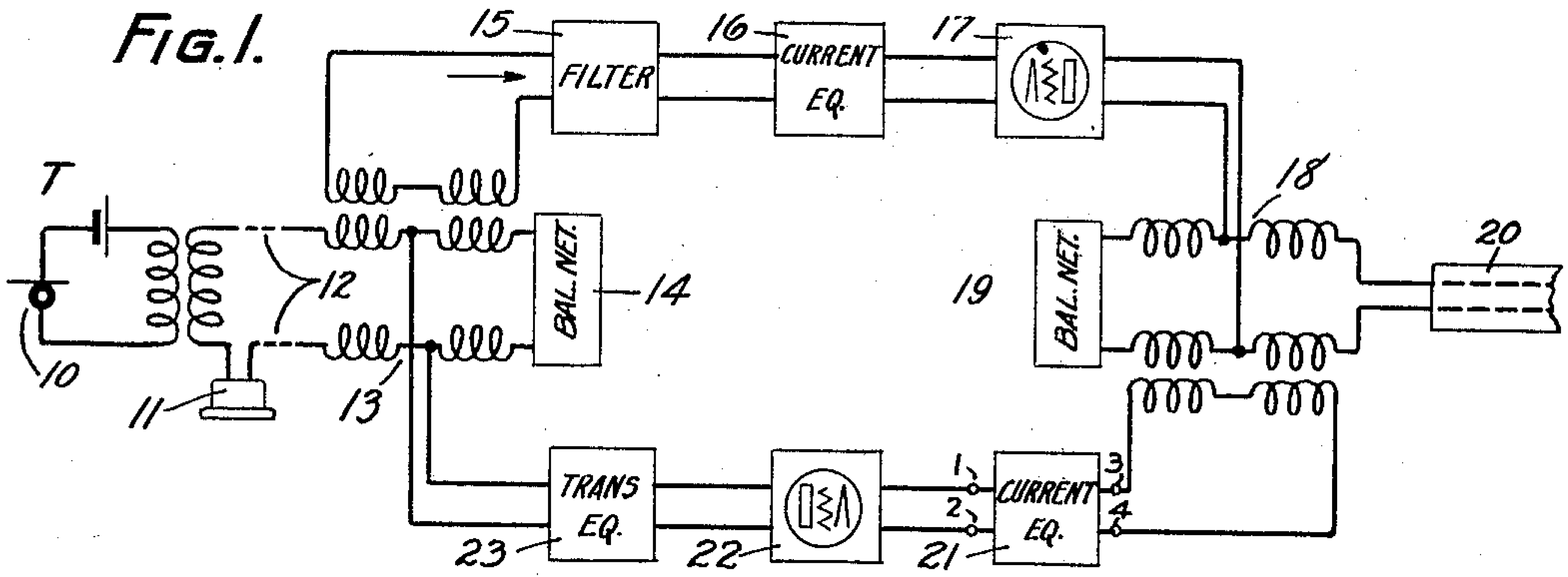


FIG. 2.

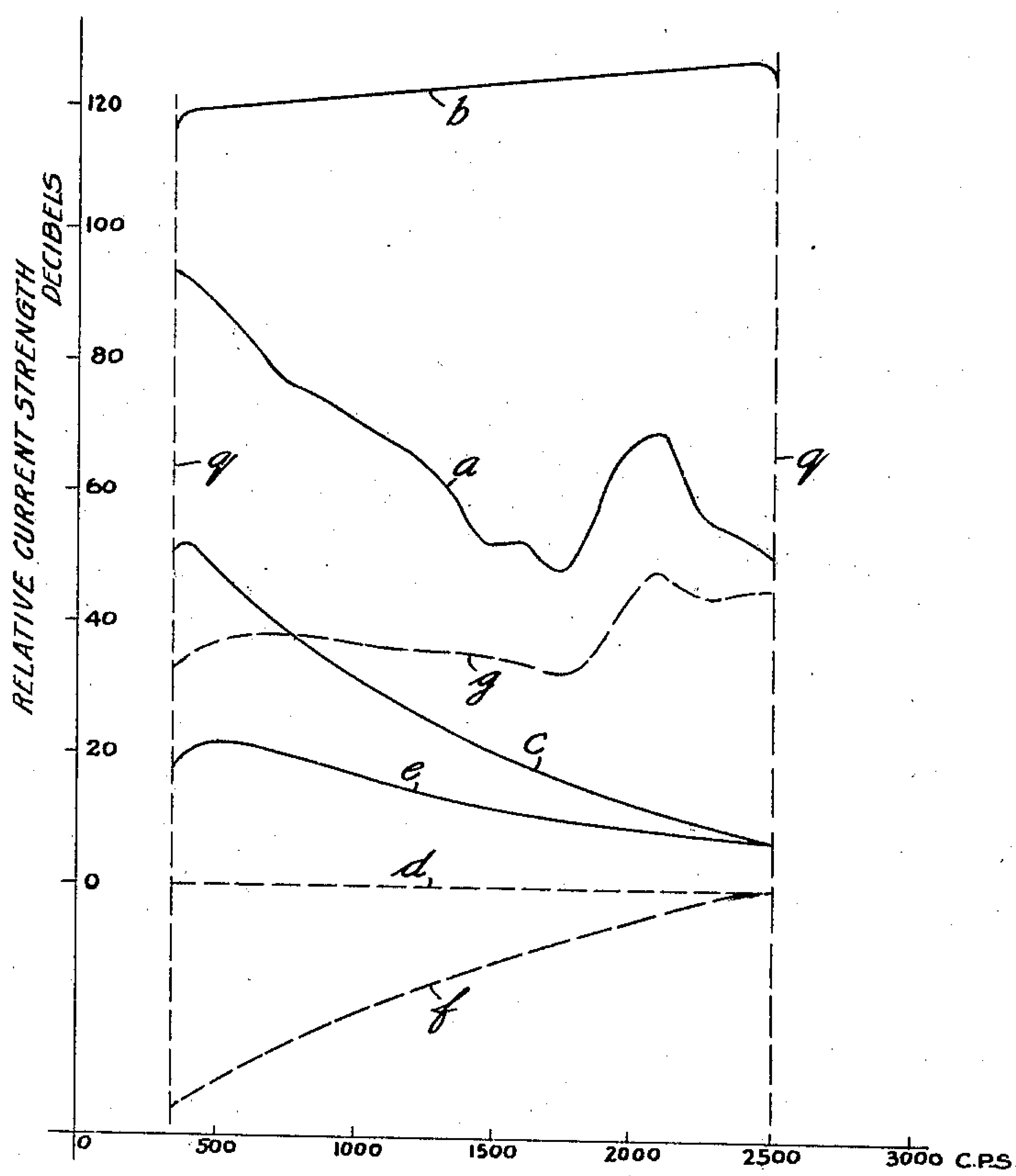


FIG. 3.

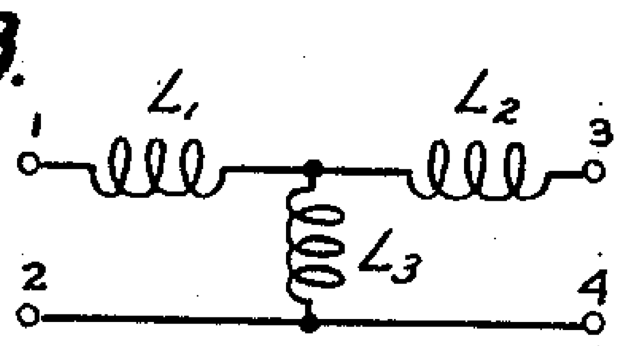
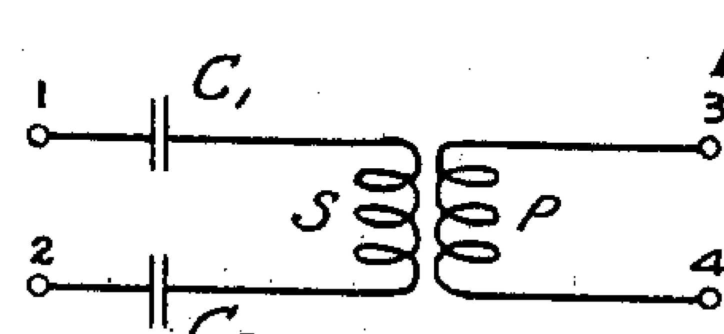


FIG. 4.



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Patented Dec. 16, 1930

1,784,825

UNITED STATES PATENT OFFICE

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SPEECH TRANSMISSION

Application filed September 5, 1929. Serial No. 390,491.

This invention relates to signaling systems and more particularly to the reception of speech currents transmitted over long submarine cables.

An object of the invention is the more efficient utilization of receiving amplifiers associated with a long submarine cable.

Another object is to increase the signal to noise ratio in speech transmission over highly attenuating circuits.

A further object is the diminution of noise producing currents in the receiving circuits of a long telephone cable, particularly with respect to noise currents due to the thermal agitation of the electrons in the electrical conductors.

In the transmission of speech currents over submarine cables of trans-oceanic length new problems are encountered due to the high degree of attenuation in the cable and to the fact that intermediate repeaters cannot be inserted between the ends of the line. One of the principal difficulties arises out of the fact that the various elements of the system tend to generate noise currents, the energy of which is distributed more or less uniformly through the range of audible frequencies, and which, therefore, cannot be eliminated by any form of discriminating circuit. In the space discharge amplifiers associated with the cable the noise currents are due to the statistical variations of the emission and are known as the "small-shot" effect. The intensity of these currents increases with the amount of amplification in the receiving amplifier. In the electrical conductors of the system the thermal agitation of the electrons gives rise to other noise currents having a uniform energy distribution, the noise E. M. F. in a given conductor being proportional to the square root of its resistance. For good reception it is necessary that the energy level of the speech currents should be considerably higher than that of these noise currents. This is achieved primarily by increasing the speech input power by means of amplifiers and by applying inductive loading to the cable conductor. Another difficulty arises from the fact that the attenuation in the cable is not only very great, but differs greatly for low and for high speech frequencies, the latter being the more strongly attenuated. This difference in attenuation, together with the fact that in normal speech by far the greater part of the energy is concentrated at the low frequencies, tends to produce so great a difference in the intensities of the received currents that a receiving amplifier designed to raise the high frequency components to their normal level would be greatly overloaded by the low frequency currents and, consequently, would introduce a large amount of distortion. For the most efficient utilization of the receiving amplifier it is desirable that the received speech currents before amplification should be equalized in intensity, at least to such an extent as will enable all components to be amplified without overloading.

The equalization of the received speech currents may be achieved to some extent by a pre-distortion of the transmission at the sending end, whereby the high frequency speech currents are increased in intensity relatively to the low frequency components. However the degree of equalization that can be effected in this way is limited by the fact that, due to the loading, the cable has a limited input power capacity and, for its most efficient utilization, requires that the speech current components should be substantially equalized in intensity at this point also. In accordance with this invention equalization of the speech current intensities is effected at the input end of the cable and also at the output end thereof, that is, at the input of the receiving amplifier. In this way both the cable and the receiving amplifier may be utilized to their best advantage without the introduction of distortion due to overloading.

A feature of the invention is the use of only reactance elements in the speech intensity equalizer at the receiving end of the system. By the elimination of resistance from this portion of the system the introduction of additional thermal agitation noise is avoided and, to some extent the uniform noise of the cable is diminished.

The invention thus contemplates broadly two main features; first, the equalization of the speech current intensities at the inputs of those portions of the circuit which are productive of distortion when overloaded and, second the use of purely reactive circuits for this purpose at the points where the energy level of the transmitted signals is very low.

The nature of the invention will be more fully understood from the following description, illustrated by the accompanying drawings, of a system in which it is embodied. Of the drawings,

Fig. 1 is a schematic lay-out of a four-wire terminal circuit in accordance with the invention arranged for connecting a cable to a land line;

Fig. 2 shows the characteristics of the current intensity distribution at various points in the system; and

Figs. 3 and 4 illustrate different forms of equalizers suitable for use at the receiving end of the system.

In Fig. 1, T denotes a subscriber's telephone set comprising a microphone 10 and a receiver 11. The subscriber's set is connected by means of a land line, denoted by 12, to the hybrid coil 13 and balancing network 14, at which point the circuit is divided into separate channels for transmission and reception respectively. The transmitting channel comprises a band pass filter 15, the purpose of which is to exclude all speech frequencies save those necessary for clear reception. The transmission range of this filter is preferably from about 400 c. p. s. to 2500 c. p. s., the very strong low frequencies not essential to clear articulation being thereby excluded, and also those high frequencies which would be too strongly attenuated in the cable to be utilized at the receiving end. Following the filter is a current intensity equalizer 16, and following this is a power amplifier 17. The function of the current equalizer is to bring all of the frequency components of normal speech to about the same energy level before amplification. Its transmission characteristic is based on the normal frequency distribution of speech energy as described by Crandall, Sounds of Speech, Bell System Technical Journal, Vol. IV, No. 4, October 1925. Preferably the equalizer is made to favor the high frequency components slightly since these are of greatest importance for good articulation. From the amplifier the transmission path passes to a second hybrid coil 18 to which is connected the cable 20 and a balancing network 18 therefor.

Currents received from the cable enter the hybrid coil 18 and pass into the receiving circuit which comprises in succession a current intensity equalizer 21, an amplifier 22, and a transmission equalizer 23. From the transmission equalizer the currents pass to hybrid coil 13 and thence to the subscriber's set T. The terminal apparatus at the other end of the cable is a duplicate of that shown in the figure and hence need not be reproduced.

The relative values of the current intensities at different points in the circuit are shown by the curves of Fig. 2 in which the abscissæ are proportional to frequency and the ordinates to the logarithms of the energy. The relative values of the energies are plotted in terms of the standard unit of transmission, the Decibel, and, since the scale is logarithmic, an arbitrary zero is taken which will be explained later. Curve *a* represents the normal frequency distribution of speech energy and corresponds to the energy of transmitted currents at the input of equalizer 16. The limits of the frequency range are represented by dotted lines *g* and *g'* corresponding to the cut-off frequencies of filter 15. Curve *b* represents the distribution of energy at the output of amplifier 17, the change in the shape of this curve from curve *a* being due to the characteristic of equalizer 16 and its elevation in the energy scale being due to the amplifier. The shape of curves *a* and *b* will of course differ for different speakers, but, if equalizer 16 is designed in accordance with the ascertained average of a large number of voices, the differences will not be excessive and, by virtue of the upward slope given to curve *b*, the high frequency components of most voices will be brought up to the desired level. Curve *c* represents the energy distribution of the currents at the receiving end of the cable or at the input of receiving equalizer 21. Curve *d* represents the uniformly distributed thermal agitation noise of the cable itself, the level of this curve being taken arbitrarily as zero since it represents a value below which the level of the received currents must not fall. After passing through the equalizer 21 the received current distribution is represented by curve *e*. It is not necessary that complete equalization should be obtained at this point but only such degree as will enable all of the frequencies to be handled by amplifier 22 without overloading. Substantially complete equalization may however be provided for if desired.

Assuming that the equalizer 21 is not itself productive of thermal agitation noise, the noise level at the amplifier is indicated by curve *f*, curves *e* and *f* differing from curves *c* and *d* by the same amount so that the ratio of signal to noise is maintained. The effect of amplifier 22 and equalizer 23 is to raise the level of the received currents and to restore their energy distribution to the normal represented by the curve *a*. At the same time the noise currents represented by curve *f* are amplified and an additional constant quantity is added by the small-shot effect in the amplifier, the resultant noise currents being thereafter distorted by equalizer 23 to have the energy distribution represented by curve *g*.

Suitable constructions for the equalizer 21 are illustrated in Figs. 3 and 4, the terminals 1, 2, 3 and 4, thereof corresponding to the corresponding terminals indicated in Fig. 1. In Fig. 3 the circuit comprises a series-shunt inductance combination comprising series inductances L_1 and L_2 and shunt inductance L_3 connected therebetween. By the shunting action of L_3 the low frequencies are attenuated to a degree inversely proportional to the frequency, the degree of attenuation being limited by the series inductances. The circuit shown in Fig. 4 comprises a loose coupled transformer having a primary winding P and a secondary S and having capacities C_1 and C_2 connected in series with the secondary. Discrimination against the low frequencies is due to the looseness of the coupling between P and S also to the impedance variation of capacities C_1 and C_2. The characteristic may be controlled to give any desired degree of discrimination by varying the inductances and the coupling of P and S and by varying the capacities C_1 and C_2.

No resistance elements are used in the equalizer 21 and, if the inductances and capacities are constructed with a view to avoiding energy dissipation, the equalizer will be substantially free from thermal agitation noise.

It is to be noted that in the circuit described the currents in the cable input are substantially equalized in intensity, in consequence of which the currents at the output end have a relatively smooth distribution corresponding roughly to the attenuation characteristic of the cable. This simplifies the design of the equalizer 21 since only a continuous decrease of attenuation with frequency is required, such as can be obtained by the circuits of Figs. 3 and 4.

The function of the equalizer 23 is to compensate the transmission characteristic of the circuit as a whole. Primarily its attenuation must be complementary to that of equalizer 16 together with such part of the cable attenuation as is not compensated by equalizer 21. In addition, however, this equalizer may be made to compensate attenuation irregularities due to the other sources and to effect phase or velocity compensation if desired. Since it is located at a point of high energy level it does not introduce noise currents of perceptible magnitude.

What is claimed is:

1. A telephone system comprising a submarine cable of trans-oceanic length, transmitting and receiving amplifiers therefor, and in combination therewith circuit means for equalizing the current intensities of normal speech at the input of the transmitting amplifier, circuit means for equalizing the intensities of the received currents at the input of the receiving amplifier, and an equalizer in the output circuit of the receiving amplifier for equalizing the transmission of the system as a whole.

2. A telephone system in accordance with claim 1 in which the received current equalizer comprises only reactive impedance elements.

3. The method of receiving highly attenuated speech currents which comprises equalizing the intensities of the received currents of different frequencies at low energy level, amplifying the equalized currents uniformly and thereafter restoring the frequency distribution of the energy to normal.

4. A system for receiving telephone currents transmitted over a long submarine cable comprising in combination an amplifier, circuit means for equalizing the intensity of the received speech current components at the input of said amplifier and a transmission equalizer in the output of said amplifier for restoring the energy distribution of the speech components to normal.

5. A system in accordance with claim 4 in which the input equalizer comprises only reactive impedance elements.

In witness whereof, I hereunto subscribe my name this 3rd day of September, 1929.

HOMER W. DUDLEY.