Sept. 22, 1936. R. W. CHESNUT ET AL 2,054,789

COMMUNICATION SYSTEM

Filed May 26, 1934 2 Sheets-Sheet 1

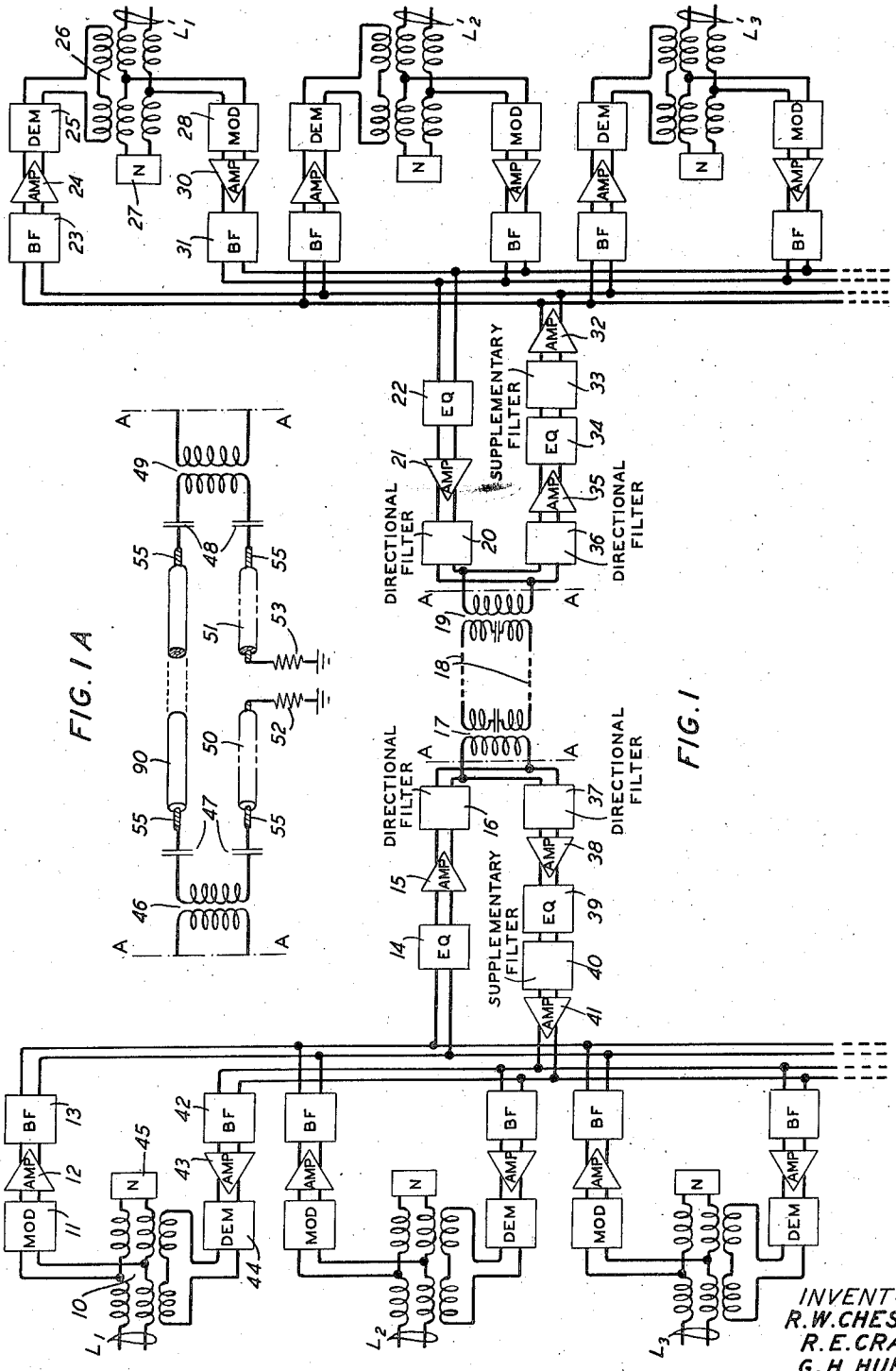

FIG. 1

FIG. 1A

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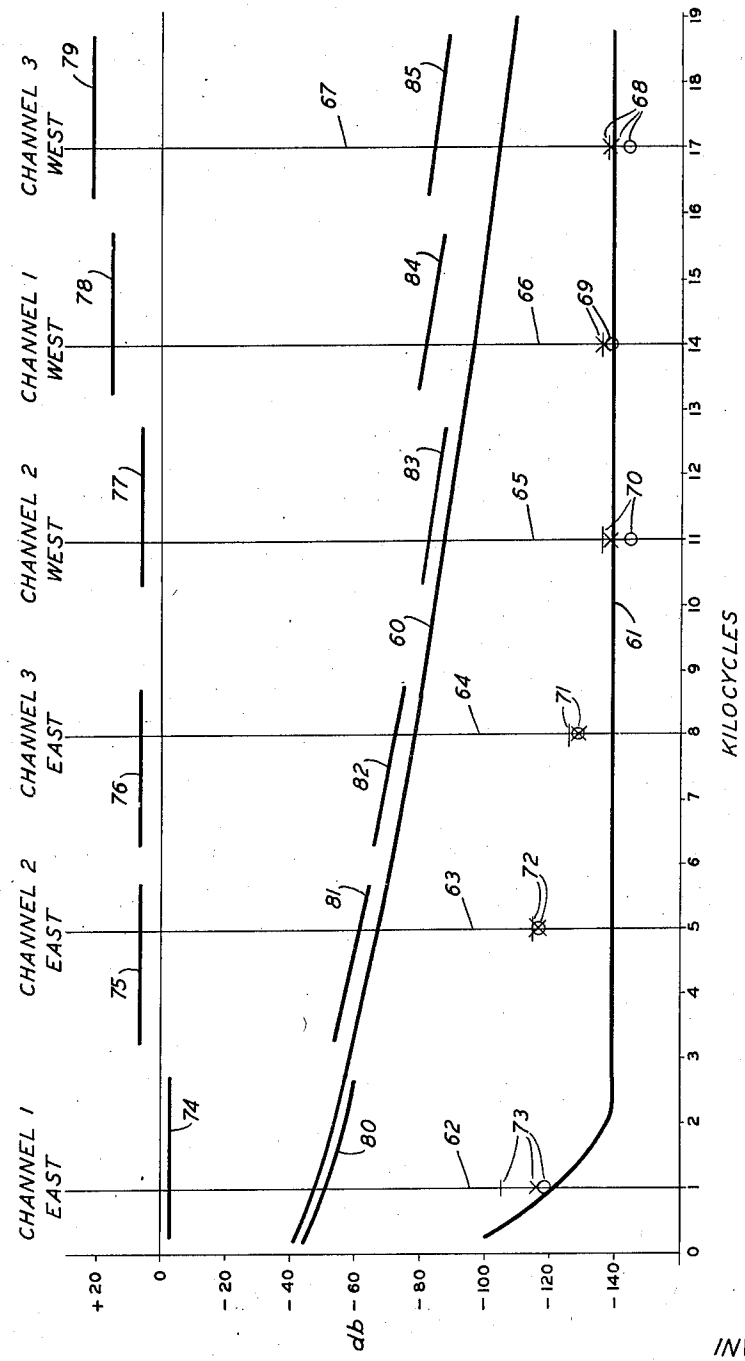
FIG. 2



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2,054,789

COMMUNICATION SYSTEM

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3 Claims. (Cl. 179—78)

This invention relates to multi-channel communication systems in which the various channels transmit signal currents at different frequencies over a single communication line and more particularly the case of a communication line which is loaded, or in which the attenuation increases rapidly with frequency or both. Such a system is a carrier current communication system operating over a long submarine cable. The invention, however, is applicable to all multi-channel carrier current communications systems regardless of whether the line furnishes a number of channels all operated in the same direction, four-wire, or two-wire two-way facilities, either exclusively or in combination.

The object of this invention is to decrease the interfering energy in relation to the received signal energy. A system operated in accordance with the method herein disclosed as compared to other methods of operating transmission systems of the type in question makes it possible to obtain more or higher grade channels from a given line or to obtain the same number and grade of channels from a line of higher attenuation and therefore of less cost. These results may also be considered therefore objects of the invention.

U. S. Patent to H. W. Dudley, 1,832,366, November 17, 1931, discloses a single channel communication system in which the transmitting volumes of the different frequencies within the single frequency band transmitted are adjusted to obtain an optimum ratio between the volume of the received frequency and the volume of the received static and other noises having that frequency. The present invention, however, relates to the discovery that the maximum allowable attenuation in any channel of a multi-channel carrier current communication system could be increased by assigning transmitting volumes to the various channels of the multi-channel system such that the receiving volumes in the various channels will be maintained at a specified ratio above the volume of the interaction products between the various channels as well as the other noise in the respective channels.

The invention may be more readily understood from the following description when read with reference to the attached drawings in which:

Figs. 1 and 1A illustrate simple multi-channel carrier current communication systems in which the invention may be practiced; and

Fig. 2 shows the manner of assigning different transmitting volumes to the transmitting currents in the different channels in accordance with this invention.

In any signal transmission system, the lowest volume to which signal energy may be allowed to fall is limited by the volume of the extraneous noises or energy in the system. The margin between the volume of the signal energy and the noise energy determines the grade of the system or channel; the greater this margin in any circuit or channel, the higher the grade of the circuit or channel. In general, new communication facilities are designed to furnish communication channels in which the margin between the signal and interfering energy will meet a specified value, depending upon the grade of circuit desired. This margin, in conjunction with the volume of the noise in a given channel, determines the minimum allowable volume of the signal in that channel. When a system consists of more than one section with repeaters connecting them, the margin between signal and noise volumes in the individual sections must be greater than for a single section system furnishing an equal grade of facilities, since the noise in each section is repeated and therefore adds to the total amount. The discussion which follows applies to a single section of a system containing one or more sections, the assumption being made that satisfactory margins will be provided in a multi-section system so that each section may be considered by itself as a single section system.

The various types of interference may be divided in two classes: (1) Those not due to operation, such as static, thermal agitation (called resistance noise), crosstalk from other signal lines carrying similar frequency bands and induction from power lines; and (2) unwanted frequenices not contained in the original signals but which are set up by signal energy applied to any channel or combination of channels. The latter are caused by the non-linear characteristics of the lines or terminal equipment which result in the production of harmonics of individual frequencies as well as of frequencies which are functions of two or more frequencies simultaneously applied to the line. The process of interaction just described is known as modulation and the resulting unwanted frequencies are modulation products.

The maximum volume at which a signal may be applied to a channel in a multi-channel communication system is limited not so much by a distortion and the generation of modulation products in the particular channel concerned, as by the volumes of the modulation products falling

in other communication channels. The most severe limitation arises in the case where one or more channels are transmitting to a line at the same terminal from which one or more channels are receiving signals in the opposite direction, thus requiring that the high volume of energy applied at one terminal of the line by those channels which are transmitting shall not set up interference in the other channels in which very low volume energy is being received from the same terminal of the line.

In the simple case of a two-channel system it is necessary to consider only the modulation products in one channel resulting from energy flow in the other. In considering the case of more than two channels, the matter is simplified by the fact that the combined interfering effect of two or more channels operating in the same direction of transmission is approximately equivalent in effect to the effect of one such channel carrying energy equal to the total energy in those channels.

In the case of a multi-channel communication system, the most efficient use of the line requires that the receiving volume of the band having the greatest attenuation be limited only by interference of the first type previously discussed. This requires that the modulation products in this channel, due to energy applied to other channels, shall not increase the noise level materially. Due to the intermittent nature of the modulation products as contrasted to the relatively steady nature of noise due to thermal agitation (resistance noise), the volume of modulation products in any speech band often may be permitted to be nearly as large as that of the resistance noise. For many cases, a volume four decibels lower than that of the resistance noise is satisfactory.

With the permissible volume of modulation products in the channel of highest attenuation as a starting point and with information regarding the relation between the volume of the modulation products produced in a given channel and the energy volumes applied to other channels and knowing the ratios between the attenuations of the various channels, the maximum transmitting volumes of the channels may be determined as described more in detail hereinafter. The difference between the sending and receiving volumes, expressed in decibels, of the channel having the highest attenuation will then be equal to the greatest attenuation that can be allowed for the desired number and grade of facilities. It follows therefore that a line built to have this maximum attenuation may be expected to cost less than any other that will give equally satisfactory performance.

As to the relation between the volumes of the modulation products and those of the applied energy causing the modulation products, the results of a number of investigations show that a change in the total volume of the applied energy, expressed in decibels, above or below a suitable reference volume causes a greater change in the volume, also expressed in decibels above or below the reference volume, of the modulation products. The ratio between such changes may be designated by the symbol "*a*", "*a*" being, in general, greater than unity. It is found that "*a*" is substantially constant (for a given line) over the ranges of applied energy volumes usually encountered. From the foregoing, it will be seen that the volume M of the modulation products in a particular channel will bear a definite relation to the volume I of the applied energy in another channel when the volumes are expressed in terms of decibels above or below a suitable reference volume. If the applied energy is adjusted to reference volume, the volume of the modulation products will be a definite number of decibels lower, depending upon the type of line or equipment causing the modulation and the frequency bands of the channels concerned. This difference in volume is called the modulation constant, M_c, for the particular conditions concerned. For various values of I, the volume of the modulation products M will be equal to $aI-M_c$. For some other channels affected by modulation products due to energy applied to another group of channels, the ratio and modulation constants may be different, although not radically so, and we may have

$$M'=a'I'-M_c'$$

The ratios k, k_1, k_2, etc., between the attenuations of the various channels may be approximated by using the ratios obtained from the attenuation-frequency characteristic of a cable of the type which it is contemplated may be used.

It is proper to note that the procedure herein described should be repeated after the first determination is made, until the assumptions made regarding "*a*", M_c and k are made consistent with the size of cable indicated by the result of the application of this procedure.

As an example of the determination of the optimum operating volumes, as well as of the maximum attenuation that will permit a specified grade of transmission, the case of a line carrying only two channels will be described first. For simplicity, it may be assumed that both channels are operated on a two-way basis, thus furnishing two independent circuits and requiring that the interference from one channel into the other be very small.

The specified margin between speech energy and noise may be designated as S, expressed in decibels. Assuming that the cable or line and terminal apparatus is adequately shielded from extraneous interference, the noise volume in the channel having the highest attenuation may be determined from fundamental data on resistance noise and amplifier noise. This volume may be designated as N decibels below reference volume, i. e., —N. With the margin of four decibels between noise and modulation products, as described above, the latter must not be higher than —N—4. If this volume is due to the application of energy at the volume I in the other channel, then it follows that

$$aI-M_c=M=-N-4 \qquad (1)$$

and

$$I=\frac{M_c-N-4}{a} \qquad (2)$$

The above expression gives the input volume of the channel of lesser attenuation, which is the lower of the two frequency bands under consideration, since the attenuation increases with frequency.

If the attenuation of the higher channel is designated by A, expressed in decibels, the attenuation of the lower band will be kA. The receiving volume in the lower band will be $I-kA$ and the allowable level interference will be $I-kA-S$. Where S is the specified margin between the volume of the received signals and the noise and modulation products, if the input level of the upper channel is designated by I', it follows that:

$$a'I'-M_c'=I-kA-S \qquad (3)$$

In this expression only I' and A are unknown. However, I' may be expressed in terms of A, since the input volume of the upper channel is A decibels above the receiving volume, which is S' decibels above the noise volume which is —N, so that:

$$I'=A+S'-N \quad (4)$$

Now, susbtituting the values for I and I' from (2) and (4) in (3) and solving for A, we have:

$$A=\frac{\left(M_c'+\frac{M_c}{a}\right)+\left(a'-\frac{1}{a}\right)N-a'S'-S-\frac{4}{a}}{a'+k} \quad (5)$$

In most cases M_c' and M_c, S' and S, and a' and a are substantially equal. In addition, a has been found to be about equal to 2 for the volumes ordinarily employed in communication circuits. Making these substitutions in (5) we have:

$$A=\frac{1.5M_c+1.5N-3S-2}{k+2} \quad (6)$$

This is the highest attenuation of any channel (usually the channel operating in the highest frequency range) of the system and by substituting it in (2) and (4) the transmitting volumes may be easily obtained.

In a multi-channel carrier system having more than two channels the procedure for determining the maximum allowable attenuation and the input volumes is much the same. Modulation products from channels which operate always in the same direction as the particular channel under consideration usually may be neglected, as may also the products from the opposite bound channel which forms the other half of the same two-way circuit. It is necessary, however, to consider the effect of all other opposite bound channels transmitting simultaneously while speech energy is being received on the channel in question. This may be done by assigning differences in volume roughly proportioned to the attenuations of the channels and considering the combined volume as being concentrated in one channel. With a little experience it is practicable to select the two channels which have the greatest influence in determining the maximum allowable attenuation. After determining the attenuation by the procedure herein described, the effects of the various channels upon each other may be checked and such minor adjustments made as will permit the attenuation to be increased to the maximum value. The chief adjustment applies to the assignments of the differences in volumes of the like-bound channels.

By following the procedure described above and repeatedly adjusting the assumed values to be consistent with the result of the determination, the final determination will give attenuation and volume data from which the final design of cable structure may be worked out and the optimum operating conditions secured, with the result that the cable will cost the least of any that will give the desired number of circuits, each of which will be of substantially the same grade.

In order to further illustrate the principles of this invention, its application to a typical multi-channel carrier communication system will now be described with reference to Figs. 1 and 2. L_1, L_2 and L_3 represent three communication channels which transmit and receive signals to and from lines L'_1, L'_2 and L'_3, respectively. Since all the lines are substantially equivalent, the detailed structure will be described for lines L_1 and L'_1 only. Starting with L_1 the signals enter the hybrid coil 10 and pass through to modulator 11. The balancing network 45 provides an impedance balance with the line L_1 so that signals from demodulator 44 will not be transmitted to modulator 11. The incoming signals from line L_1 therefore pass to modulator 11 and are modulated thereby and are then amplified by amplifier 12. They then pass through the band pass filter 13 to the equalizer 14. Signals from the other lines L_2 and L_3 pass through similar equipment to equalizer 14 where they all pass through equalizer 14, amplifier 15 and directional filter 16 to transformer 17 and then over line 18 to terminal transformer 19, directional filter 36, amplifier 35, equalizer 34, supplementary filter 33, amplifier 32 to band pass filters where they are separated to their respective channels. The signals from channel L_1 are selected by band pass filter 23 and then pass through amplifier 24, demodulator 25 and hybrid coil 26 to line L'_1. In a similar manner, signals from line L'_1 pass through hybrid coil 26, modulator 28, amplifier 30, band pass filter 31 where they are joined by similar signals from lines L'_2 and L'_3. All the signals then pass through equalizer 22, amplifier 21, directional filter 20, line transformer 19, line 18, terminal transformer 17, directional filter 37, amplifier 38, equalizer 39, supplementary filter 40 and amplifier 41. Here the signals from L'_1, L'_2 and L'_3 are again directed to their respective lines by band pass filters. Thus the signals from L'_1 pass through filter 42, amplifier 43, demodulator 44 and hybrid coil 10 to line L_1. Fig. 1A shows specific details of line 18 when it is a submarine cable. In this case, transformer 17, line 18 and transformer 19 are replaced by transformer 46, condensers 47, submarine cable 90, sea earth cable 50 and balancing network 52, condensers 48, transformer 49, sea earth cable 51 and balancing resistance 53. If desired, loading material 55 may be applied to either the submarine cable 90, sea earth cables 50 and 51 or to both submarine cable and balancing sea earth cable as is desirable. Although the invention is shown as applied to a sea earth connection, it may be equally well applied to a concentric return cable system.

Thus, in this system shown in Figs. 1 and 1A there are six channels employed, three of which transmit currents in one direction while the other three transmit currents in the opposite direction and are combined to form three two-way, four-wire channels.

In designing and operating such a system in accordance with this invention, the noise conditions and variations of attenuation of the cable with frequency are first investigated. The attenuation versus frequency characteristic of such a cable is illustrated by curve 60 of Fig. 2. The attenuation of the cable is, of course, positive. Thus curve 60 shows the output volume from the cable when a reference volume input is applied to the input of the cable. A typical curve showing the level of the natural noises by resistance and interference versus frequency of such a system is shown by curve 61 of Fig. 2. Next, the number and width of the frequency bands are selected and assigned to the appropriate channels. Thus, in Fig. 2 the three lower channels transmit the signals East, that is, from lines L_1, L_2 and L_3 to lines L'_1, L'_2 and L'_3, respectively, while the three upper frequency bands carry the signals in the reverse direction from L'_1, L'_2 and L'_3 to L_1, L_2 and L_3, respectively. Then some reference frequency, usually the frequency which corresponds to the 1000 cycle frequency of the original current is chosen in each channel. These frequencies are

designated by lines 62, 63, 64, 65, 66 and 67 in Fig. 2. Then, from Equation (6) maximum attenuation A for the highest channel, that is, channel No. 3, may be determined since N is given by curve 61, M_c and k are constants of the cable structure and S is specified or determined by the required performance of the system. Then, having determined this factor, A the transmitting volume in the lower channels is next determined. Since, as pointed out above, the modulation products in the highest channel should not exceed the noise level but should be at least four decibels below this noise level, as shown by the circle at 68 in Fig. 2, the sending level in the lower two channels, channels No. 1—East and No. 2—East may be determined by Equation (2). It must, however, be remembered that this volume is the combined volume of both of these channels transmitting at the same time. In a similar manner the transmitting volume for the top channel, channel No. 3—West may be determined in accordance with Equation (4). In a similar manner the transmitting levels in the other channels may easily be determined. These volumes are shown by lines 74, 75, 76, 77, 78, and 79 in Fig. 2. The receiving levels then may be determined by subtracting the attenuation of the cable from these transmitting volumes and are shown by lines 80, 81, 82, 83, 84, and 85. Then, by subtracting the specified margin S from these receiving volumes the permissible noise level is obtained and is illustrated by the short horizontal lines at 73, 72, 71, 70, 69, and 68 of Fig. 2. It is noted that this permissible noise volume is above the natural noise shown by curve 61 and the modulation products which are shown by the circles also designated by 73, 72, 71, 70, 69, and 68 and also the combined volume of this noise and the modulation products which are illustrated by the cross at 73, 72, 71, 70, 69, and 68 of Fig. 2. As shown at 73, there is a considerable margin between the cross and the horizontal line showing that the actual noise volume is somewhat below the permissible volume of this noise so that this channel provides a higher grade circuit. If it is desired, or if this margin should be too large in any channel, the transmitting volumes may be again readjusted in accordance with these formulae by slightly redesigning the cable and changing the constants M_c and k as pointed out above, until all the channels provide substantially the same grade of transmission.

If circuits of different grades are desired, suitable values of S may be used for the particular channels concerned and data obtained permitting the design of the most economical cable for the particular conditions specified.

In addition to the procedure described, different combinations of opposite bound channels to form circuits must be investigated to secure the most economical results, due to the facts that (1) the interaction between opposite bound channels of the same circuit may be allowed to be greater than in the case of channels of different circuits, and (2) the interaction may be different for different combinations of frequency bands.

The above description which describes several specific embodiments of the invention merely illustrates the features of the invention but does not restrict or limit the scope of the following claims which define the invention.

What is claimed is:

1. A loaded submarine cable of greatly varying attenuation with frequency designed to transmit a plurality of bands of frequencies, each band corresponding to a different channel of communication, in combination with terminal apparatus for applying message currents of those frequencies thereto, characterized in this, that said terminal apparatus includes means for applying the message currents to the respective bands at such a volume that the receiving volume in each band is at a substantially uniform margin above the combined noise induced by currents in other bands and noise produced from all other sources.

2. In a multi-channel carrier current deep sea communication system in which message currents of a plurality of bands of frequencies, each band providing a communication channel, may be simultaneously transmitted in both directions over said various channels comprising a submarine cable of varying attenuation with frequency, loading means incorporated in said cable for reducing the attenuation of said cable, terminal apparatus for transmitting and receiving message currents to and from said cable, means for transmitting the message currents to the various channels at such volumes that the modulation products induced into the higher attenuation channels when combined with the resistance noise will not appreciably increase the volume of the interference over that due to resistance noise alone, and such that a specified margin is maintained between the message current volume and the volume of the combined noise and modulation products in each channel.

3. In a multi-channel carrier current deep sea communication system in which message currents of a plurality of bands of frequencies, each frequency band of which provides a communication channel, may be simultaneously transmitted in the same and opposite directions over the various channels comprising a submarine cable, the attenuation of which increases rapidly with frequency, terminal apparatus for transmitting and receiving message currents to and from said cable, means for increasing the maximum allowable attenuation which comprises means for adjusting the transmitting volumes of the various channels so that modulation products induced into the channels having the higher attenuations when combined with the noise of these channels will not appreciably increase the volume of the interference in the channels, and so that a specified margin is maintained for each channel between combined volume of the noise and the modulation products and the volume of the message currents therein.

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