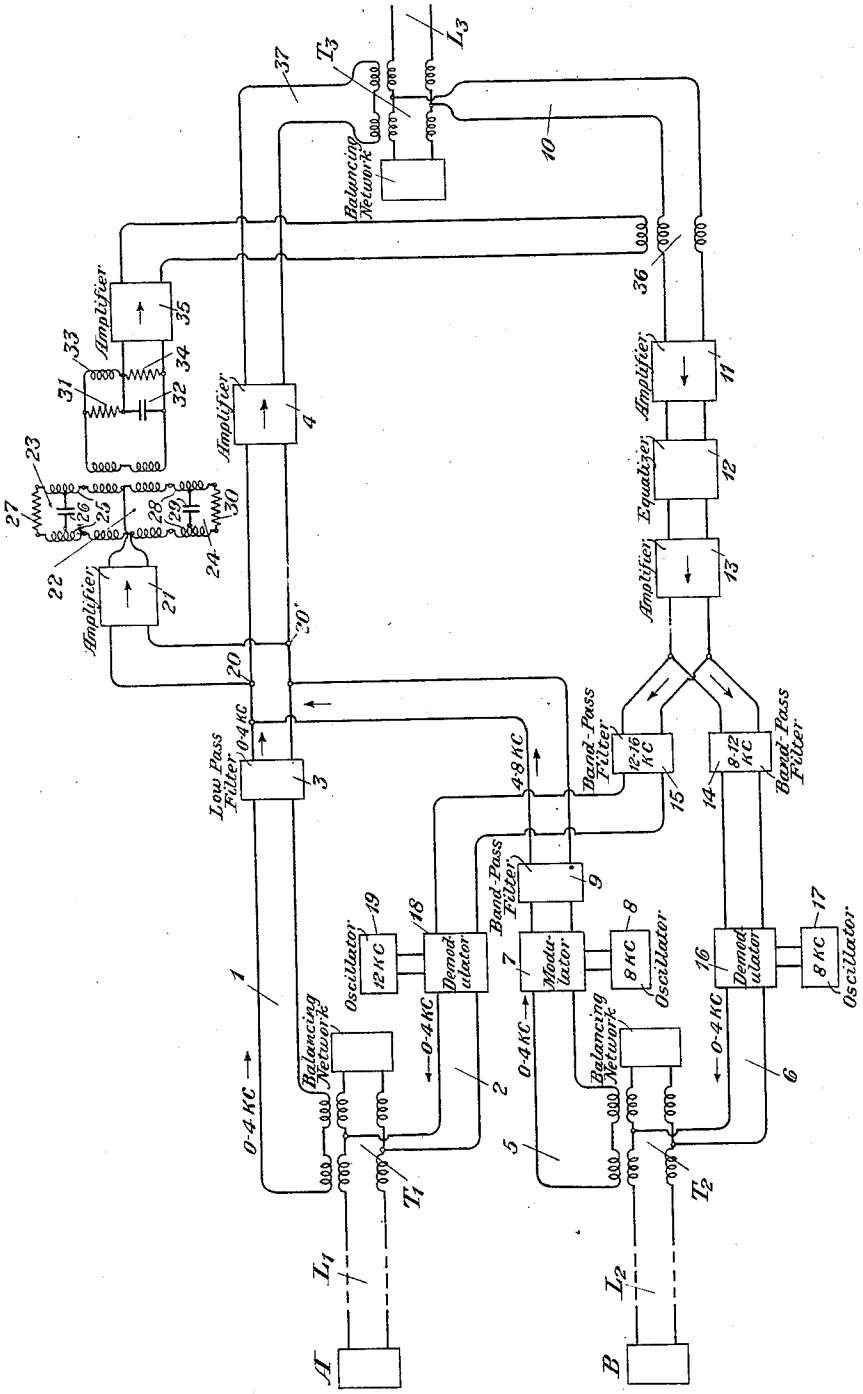
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MEANS FOR COMPENSATING FOR NONLINEAR DISTORTION IN TRANSMISSION CIRCUITS

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MEANS FOR COMPENSATING FOR NONLINEAR DISTORTION IN TRANSMISSION CIRCUITS

Application filed June 28, 1930. Serial No. 464,687.

This invention relates to means for compensating for non-linear distortion in signaling circuits, and particularly to means for neutralizing the interference created in received signals as the result of the simultaneous transmission of other signals over the same transmitting medium, which medium employs materials having non-linear characteristics.

In my copending application, Serial No. 464,686, filed June 28, 1930, I have described a system for compensating for the distortion produced by the non-linear characteristics of a transmission circuit such as a submarine cable, which system is adapted for use in connection with the operation of a single two-way signaling channel.

The present invention resides in means for neutralizing interference produced by the non-linearity of the characteristics of the materials employed in a transmission circuit over which a plurality of two-way signaling channels are being operated at any instant.

Other objects of this invention will be apparent from the following description when read in connection with the attached drawing, showing schematically a form of embodiment of the invention.

In the drawing, L_1 and L_2 represent two transmission circuits, for example, two land lines over each of which ordinary two-way signaling may be maintained from the stations A and B, respectively, to distant stations. L_3 represents another transmission circuit such as a submarine cable over which the signals transmitted by L_1 and L_2 may be propagated simultaneously. The circuits L_1 and L_2 are connected with the cable L_3 by means of a repeater having sending and receiving paths, each of which has one or more amplifiers connected therewith. The circuit L_1 is connected by the hybrid coil T_1 with the sending path 1 and the receiving path 2. The sending path from L_1 to L_3 includes the filter 3, the amplifier 4 and one of the windings of the hybrid coil T_3, the said amplifier and winding being common to the path from L_2 to L_3. The filter 3 is adapted to pass the band represented by 0 to 4 kilocycles representing the frequency range of the signals transmitted over the line L_1.

The line L_2 is connected with the repeater by the hybrid coil T_2 in such manner that signals intended to be impressed by the line L_2 upon the repeater will pass into the path 5 while those intended to be impressed by the repeater upon the line L_2 will pass over the path 6. The path 5, which constitutes part of the sending path from L_2 to L_3, includes a modulator 7 having connected therewith an oscillator 8 whose frequency is such as to change the input frequency of 0 to 4 kc. to a band of 4 to 8 kc., which band will be transmitted by the filter 9. The transmitted band will be impressed upon the amplifier 4, common to both sending paths, together with the band that passes through filter 3.

Transmission over the cable L_3 is carried on by employing different bands of frequencies not only for the several channels but also for the oppositely transmitted signals of each channel. The signals transmitted over L_3 from its distant end will be impressed upon the receiving path 10 containing the amplifiers 11 and 13 and the transmission equalizer 12, which operate upon the received currents of both channels. The output of the amplifier 13 is connected with two branch paths, one containing the band pass filter 14 transmitting the range of frequencies from 8 to 12 kc., and the other containing the band pass filter 15 transmitting the range of frequencies from 12 to 16 kc. The band represented by 8 to 12 kc. will be impressed upon the demodulator 16, with which is associated the oscillator 17 whose frequency, 8 kc. is such as to beat the band down to the range of from 0 to 4 kc. That band will then be impressed by the path 6 upon the circuit L_2. The band of from 12 to 16 kc. passed by the

filter 15 will be impressed upon the demodulator 18. The oscillator 19, operating at 12 kc. will beat the received band to the frequency range of from 0 to 4 kc., which range will be impressed by the path 2 upon the circuit L_1.

Bridged across the sending path at the points 20, 20′ is the input side of the distortion correction circuit, which circuit includes an amplifier 21 whose output is connected with the midpoints of the line windings of the hybrid coil 22. Connected with the outer terminals of the line windings are two networks 23 and 24. Network 23 includes the inductance coils 25, the condenser 26 and the resistance 27, and similarly, network 24 includes the inductance coils 28, condenser 29, and resistance 30. One of the networks is linear, that is, the constants of its elements do not vary with current strength. The other network is non-linear, that is the values of its elements do vary with current strength. However, for very weak currents the networks 23 and 24 are equal. The third winding of the hybrid coil 22 is connected with a network comprising two branches, one containing the resistance 31 in series with the condenser 32 and the other containing the inductance 33 in series with the resistance 34. The junction between the resistance and condenser of the first branch is connected to the junction between the inductance and resistance of the second branch. Bridged across the resistance 34 is the input of the amplifier 35, the output of which is connected by means of the transformer 36 with the receiving path 10.

The manner in which the system operates to compensate for the non-linear distortion of the returned wave is as follows: Let it be assumed that two-way telephone conversation is being carried on simultaneously by the subscribers at A and B with corresponding subscribers at terminal circuits at the distant end of the cable L_3. When the subscriber at A is talking to a subscriber at the distant end of the line L_3, the current from the line L_1 will pass to the sending path 1 and will pass through the filter 3, which transmits the band ranging from 0 to 4 kc. A portion of that wave will be impressed upon the amplifier 21 but the major portion will be amplified by 4 and impressed upon the cable L_3. That signal wave, after its propagation over the cable, will be impressed upon a circuit similar to that shown in the figure, wherein, it will be selected by a filter capable of transmitting the frequency range from 0 to 4 kc., and impressed upon the line of the subscriber with which the subscriber at A is talking.

The manner in which that distant subscriber's voice is transmitted to the subscriber at A will be understood if we first trace the path of transmission from the subscriber at B to the distant subscriber with which he intends to talk, since the principle of frequency translation is involved in both cases. When the subscriber at B talks over the line L_2, the speech currents ranging from 0 to 4 kc. will pass into the sending path 5 and be impressed upon the modulator 7 wherein they will modulate oscillations of 4 kc. from the source 8. The band pass filter 9 is designed to pass the upper side-band, namely, 4 to 8 kc., which is impressed upon the cable L_3 after being amplified by 4. At the distant end that band will be selected by a band filter of suitable range, the speech band of 0 to 4 kc. will be detected and impressed upon the circuit of the subscriber with which subscriber B is talking. The speech currents of the subscribers at the distant end are transmitted over the cable by two side-bands, 8 to 12 kc. and 12 to 16 kc., respectively. Those side-bands will pass into the receiving circuit 10 and when amplified by 11, equalized as to frequency by 12, and further amplified by 13, will be impressed upon the two-branch circuits containing the filters 14 and 15. Filter 14 will pass the band ranging from 8 to 12 kc., which band will be beaten in the demodulator 16 with oscillations of 8 kc., thereby producing the speech band of 0 to 4 kc. That band will be impressed by the path 6 upon the line L_2 and transmitted to the subscriber at B. The other branch circuit containing filter 15 will transmit the band ranging from 12 to 16 kc. That band will be beaten in the demodulator 18 with oscillations of 12 kc. so as to produce the speech band of 0 to 4 kc. that will be impressed by the path 2 upon the line L_1 for transmission to the subscriber at A.

When the transmitted waves representing frequencies ranging from 0 to 8 kc. are impressed by the sending circuit 37 upon the cable L_3 for transmission thereover, the impressed voltage represented by that transmitted wave produces an interferring wave by virtue of the non-linearity of the characteristics of the materials employed in the cable. Each element of the loading material and of the dielectric throughout the entire length of the cable produces distortion, which effect is cumulative throughout the cable. The interfering wave produced by each element travels in both directions along the cable, and since all waves travel with substantially the same velocity, the contribution to the total distortion of the transmitted wave made by all elements of the non-linear materials combines in phase. The part of the interfering wave that travels to the distant end of the cable, causes no great concern since it is, of course, greatly attenuated as the result of its propagation. The portion of the interfering wave that returns to the sending end of the cable is of considerable importance because of its effect upon the signaling waves that have been impressed upon the distant end of

the cable and therefore are greatly diminished by attenuation as the result of being progagated over the cable.

The components of the distortion returned from the successive elements do not add up in phase but are shifted by amounts which depend upon the distances of these elements from the sending end of the circuit.

I have found that the distortion introduced into a signaling wave arising from the non-linearity of the characteristics of the materials of an infinitely long line, equals the distortion received from the first unit length of line divided by the expression

$$(n+1)\alpha + i2\omega T$$

where α is the attenuation per unit length,

$$i = \sqrt{-1},$$

ω is the frequency in radians, T equals B/ω, which is the delay per unit length, and n is the power of the distortion which should be determined experimentally for the particular materials used for the cable. An harmonic analysis of the received wave when a pure sine wave of suitable value is applied to the sending end, may be used to determine n which equals the order of the highest harmonic present.

Since the distortion that would be produced in the channels represented, for example, by 8 to 16 kc. as the result of their transmission over the cable would be the same as the distortion created by a unit length of material at the sending end divided by the expression given above, it is possible to create a plurality of networks by which a neutralizing wave of the same magnitude and shape as the interfering wave may be obtained, and to impress that neutralizing wave upon the receiving path in phase opposition to the wave representing the distortion. Such networks are shown in connection with the distortion correction circuit. As pointed out hereinbefore, the networks 23 and 24 are intended to produce a wave of the same magnitude and shape as the interfering wave produced by the non-linearity of the characteristics of the unit length of cable connected with the sending path 37. Accordingly, one of the two networks 23 and 24 is linear and the other is non-linear to the same extent as the first unit length of cable is non-linear. The network made up of the resistances 31 and 34 and the condensers 32 and inductance 33 is intended, together with amplifier 35, to produce the same effect upon the resultant wave created by the networks 23 and 24 as the remainder of the cable produces upon the interfering wave created by the unit length connected with the transmitting circuit 37. That is, the wave which emerges from the hybrid coil 22 should next be divided by the expression $(n+1)\alpha+i2\omega T$. This is accomplished by suitable design of the four elements 31, 32, 33, 34, as follows: The two resistances are made equal to each other, and, say to the quantity R. Make $L=CR^2$ and

$$\frac{R}{L}=\frac{(n+1)}{2T}\alpha.$$

Accordingly, we will have in the output of the amplifier 35 a neutralizing wave that is of the same magnitude and shape as the distortion produced upon the signaling waves in the receiving path 10 by the interfering wave created in the cable L_3 as the result of transmitting over that cable the waves impressed thereon by the circuit 37. Accordingly, such distortion effect will be eliminated and the received waves representing the bands from 8 to 16 kc. that pass into the branch circuits will be substantially free from distortion arising from the non-linearity of the characteristics of the materials employed in the cable.

While the invention has been described as embodied in a particular form, it is capable of embodiment in other and different forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, the said line employing a material having a non-linear characteristic, of a repeater connected with the said line, having a sending path for impressing upon the said line signals for transmission thereover, and a receiving path for the reception of signals from the said line, each of said paths having an amplifier therein, and a distortion correction circuit connected with the said sending path and having means to produce a neutralizing wave that closely approximates in magnitude and shape the interfering wave produced by the non-linearity of the characteristics of the materials of the line when a signaling voltage is impressed thereon by the said sending path, and means to apply the said neutralizing wave to the received signals so as to substantially reduce the effect of the interfering wave thereon.

2. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, the said line employing a material having a non-linear characteristic, of a sending circuit and a receiving circuit, each having an amplifier therein, a network to balance the said line, a hybrid coil connecting the said sending circuit and the said receiving circuit to the said

line, and a distortion correction circuit connected between the sending circuit and the receiving circuit, having means to amplify a portion of the current of the sending circuit, means to produce a neutralizing wave substantially similar in magnitude and shape to the interfering wave created by the non-linearity of the characteristics of the materials of said line, and means to impress said neutralizing wave upon said receiving path in phase opposition to the interfering wave.

3. In a system for reducing the distortion produced by the non-linearity of the charactertistics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, the said line employing a material having a non-linear characteristic, of means to impress signaling currents upon the said line for transmission thereover, means to receive from the said line signaling currents distorted by the non-linearity of the characteristics of the materials used in the said line, and means to create from the said impressed signaling currents a neutralizing wave similar to the distortion introduced into the received signaling currents and to impress said neutralizing wave upon the said receiving means in phase opposition to the distortion in the received signals.

4. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line of a terminal circuit having input and output branches conjugately connected with the said line, and a distortion correction circuit connected between the said input and output branches and including a plurality of networks adapted to produce a resultant wave similar to the distortion produced by the unit length of the said line adjacent to the said terminal circuit, a network adapted to modify the said resultant wave in accordance with the effect produced by the remainder of the said transmission line, and means to apply the resultant wave as thus modified to the output branch in phase opposition to the distortion effect produced in the received signal waves as a result of their propagation over the said transmission circuit.

5. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, of a terminal circuit having an input branch and an output branch conjugately connected to the said line, and a distortion correction circuit connected between said input and output branches, having means to create from a portion of the current in the input branch a neutralizing wave similar in shape and equal in magnitude to the interfering wave produced in the received signals by the non-linearity of the materials employed in the said line, and means to oppose said neutralizing wave and said interfering wave.

6. In a distortion correction circuit, the combination with a source of potential of an amplifier connected therewith, a pair of networks of equal impedance connected in parallel across the output of the said amplifier, one of said networks using materials having linear characteristics and the other employing materials having non-linear characteristics, a third network connected differentially with the said pair of networks to effectively divide the resultant wave produced by the said pair of networks by the factor $(n+1)\alpha+i2\omega T$, where n is the power of the distortion, $i=\sqrt{-1}$, α is the attenuation constant, ω is the frequency in radians and T is the delay constant.

7. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, of a terminal circuit having an input branch and an output branch conjugately connected with the said transmission line, a plurality of trunk circuits connected conjugately to the said input and output branches, certain of said branches including means to change the frequency of the waves traversing the said branches, and a distortion correction network connected between said input and output branches and including a plurality of networks adapted to produce a resultant wave similar to the distortion produced by the unit length of the said transmission line adjacent to the said terminal circuit, a network adapted to modify the said resultant wave in accordance with the effect produced by the remainder of the said transmission line, and means to apply the resultant wave as thus employed to the output branch of the terminal circuit in phase opposition to the distortion effect produced in the received signal waves.

8. In a system for reducing the distortion produced by the non-linearity of the characteristics of the materials employed in the transmission line of a multi-channel signaling system, the combination with a transmission line over which two-way signaling by a plurality of channels is maintained, of a terminal circuit having input and output branches, a plurality of trunk circuits each connected conjugately to the said input and output branches and a distortion correction

circuit connected between said input and output branches to create and to impress upon the output branch a neutralizing wave substantially like but in phase opposition to the distortion created in the received signal wave by the said transmission line.

In testimony whereof, I have signed my name to this specification this 26th day of June, 1930.

HARRY NYQUIST.