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H. NYQUIST

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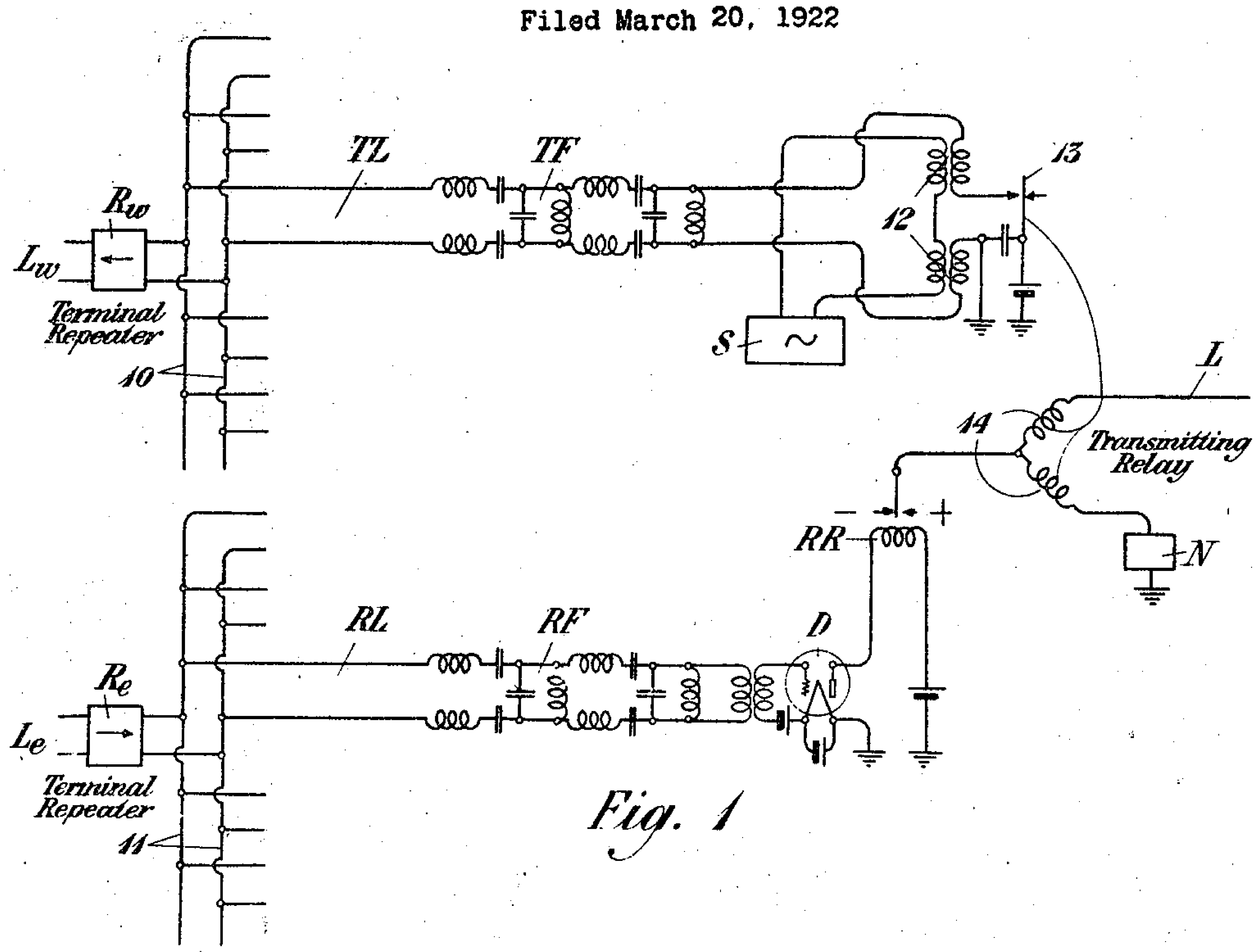

Fig. 1

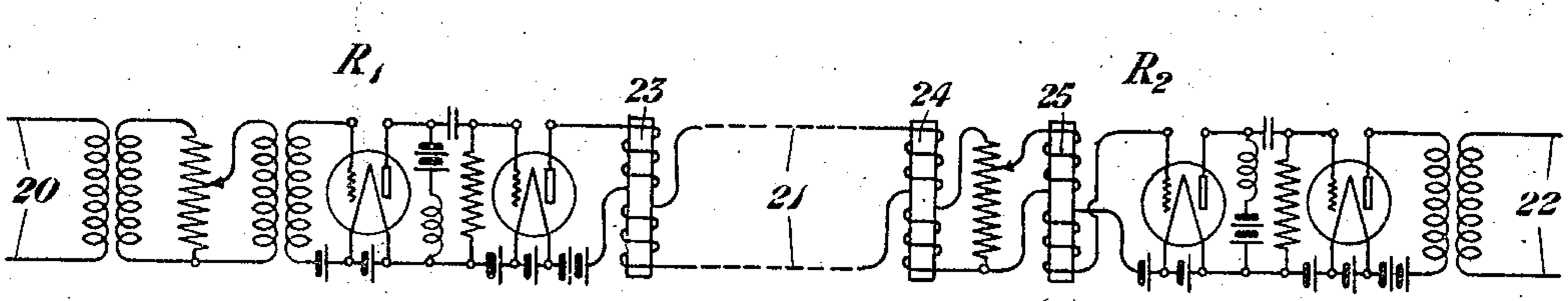

Fig. 2

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UNITED STATES PATENT OFFICE.

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MEANS FOR AND METHOD OF REDUCING INTERFERENCE.

Application filed March 20, 1922. Serial No. 545,295.

To all whom it may concern:

Be it known that I, HARRY NYQUIST, residing at Elmhurst, in the county of Queens and State of New York, have invented certain Improvements in Means for and Methods of Reducing Interference, of which the following is a specification.

This invention relates to multiplex signaling, and more particularly to means for and method of reducing interference between the channels of a multiplex signaling system.

Heretofore, in the operation of multiplex carrier systems, it has been found that the repeater tubes employed at points along the line for transmitting the carrier frequencies, where the same tube is used to transmit the frequency of a number of channels, tended to impose a limit on the number of channels that might be employed over a single circuit. This is for the reason that the tubes do not have a straight line characteristic and a certain amount of distortion occurs, which produces second harmonics of the carrier frequencies and also sum and difference frequencies. These harmonics and sum and difference frequencies, in many instances, assume such amplitudes as to cause interference in the channels whose frequencies are near those of the interfering harmonics, etc. Interference of this character becomes especially serious in a carrier telegraph system involving a large number of channels employing carrier frequencies within the usual voice range, for in such a case it is almost essential to economic working of the system that the channels be narrow and closely spaced, and that all the channels be amplified by the same repeater tube. Even where the circuit is to be used for ordinary voice transmission, the distortion, while not producing results as serious as in the case just mentioned, may be sufficiently undesirable to require correction, especially where the characteristics of the repeaters depart materially from the desired linear characteristic.

In accordance with the present invention, it is proposed to overcome this difficulty by poling successive repeaters oppositely, so that the currents under consideration will be substantially neutralized in two successive repeaters. This result may be readily accomplished by reversing the connections between the tube to one repeater and the tube to the next succeeding repeater. In this case, the harmonics and sum and difference frequencies generated by the tube of the second repeater will be substantially 180 degrees out of phase with the harmonics generated in the first repeater and will, therefore, tend to neutralize them. This will not be true for third harmonics or any distortion arising from the presence of a third power term in the repeater characteristic, but in general, components resulting from the higher power terms of the repeater characteristic are of such small magnitude that they may be neglected.

The invention may now be more fully understood by reference to the following description, when read in connection with the accompanying drawing, Figure 1 of which illustrates the arrangement of the terminal equipment of a multiplex carrier telegraph system operating within the voice range, and Fig. 2 of which illustrates the arrangement of two successive repeaters in a line associated with terminal equipment, such as that of Fig. 1.

Before discussing the theory underlying the present invention, a brief description of the circuit arrangements to which the invention appertains and of the simple change in circuit arrangement for carrying out the invention will be given.

Referring to Fig. 1, L_e and L_w designate two transmission lines operating on a four-wire basis, so that one line transmits currents in one direction and the other line transmits currents in the other direction. At the terminal station each of these lines includes a one-way terminal repeater, as indicated at R_e and R_w, and these repeaters may be of any well-known type, such, for example, as vacuum tube repeaters. The details of the circuit arrangement of the repeaters may be as shown, for example, in Fig. 2, which will be described later. The input side of the repeater R_w is associated with bus connections 10 from which branches lead through various channels, such as the transmitting channel TL. In a similar manner, the output side of the repeater R_e is connected to bus-bars 11 from which branch connections extend to the various channels such as the receiving channel RL.

Each of the channels includes a band filter, for providing selectivity between the channels, a band filter TF being shown in the transmitting channel TL and a band filter RF being shown in the receiving channel RL. These band filters are of the general type known as Campbell filters, but are shown as comprising two sections, each of said sections including series resonant elements and shunt anti-resonant elements. In order to give the filter as great an impedance as possible to frequencies outside of the range which it is desired to transmit, the section of the filter adjacent the multiple connection to the bus-bars is made a full series section, as indicated. Filters constructed in this manner will have a fairly sharp cut-off and the attenuation will be very great for frequencies on either side of the limits of the band of free transmission.

The transmitting channel TL is associated through a transformer 12 with a source of carrier frequency S and the transformer 12 is connected with the channel TL in such a manner that the frequency supplied to the channel from the source S may be interrupted by means of a contact 13 of a polar transmitting relay 14, whose windings are arranged one in the telegraph line L and the other in the connection to the balancing network N. The receiving channel RL includes a detector D, which may be of any well-known type, such for example as a vacuum tube detector, and the output circuit of the detector includes a receiving relay RR whose contact is arranged to relay the received impulses to the midpoints of the windings of the polar relay 14 for transmission over the telegraph line L without operating the transmitting relay.

By means of this arrangement, telegraph signals incoming from the line L will operate the polar relay 14 to interrupt the connection of the source S to the channel TL, so that a carrier frequency interrupted in accordance with the telegraph signals will be transmitted through the filter TF to the bus-bars 10 and thence through the terminal repeater RW to the line L_w. Similar carrier frequencies transmitted in the opposite direction from a distant station will be received from the line L_e and amplified by the terminal repeater RE before being impressed upon the bus-bars 11. The frequency corresponding to the channel RL will be selected into said channel by reason of the filter RF and the detector D will then function to translate the carrier frequency into Morse signals to operate the receiving relay RR, and the receiving relay RR in turn relays the Morse signals to the receiving line RL without interfering with the terminal relay, as has already been described.

Referring now to Fig. 2, a line is disclosed which may be considered as typical of lines such as L_w and L_e. Two repeaters R_1 and R_2 are illustrated at successive repeater stations and serve to interconnect successive line sections 20, 21 and 22. Each repeater as shown comprises two tubes in tandem and a potentiometer associated with the input circuit of the first tube. A transformer associates the input of the first tube with the potentiometer, and another transformer is interposed between the potentiometer and the line section. The output of the second tube of each repeater is similarly connected with the next transmission line section by a transformer. While the circuit arrangement of Fig. 2 has been described as being used in connection with the multiplex telegraph system of Fig. 1, it is obvious that the circuit may be employed for ordinary voice transmission. In either case the distortion produced by harmonics and sum and difference frequencies of the various frequencies transmitted through the repeaters may be overcome by properly poling the repeaters in the manner about to be described. The reversal of connections, whereby the second harmonics and sum and difference frequencies of successive repeaters are caused to oppose each other, may be accomplished in several different ways. The line wires of the line section intervening between two repeaters might be transposed at any desired point, or the connections of some transformer or other piece of apparatus to the circuit might be reversed. Between the repeater R_1 and repeater R_2 three transformers 23, 24 and 25 are interposed and the poling of any one of these transformers might be reversed in order to obtain the desired result. As illustrated in Fig. 2, transformers 23 and 24 are poled in the same way, but the connections from the second winding of the transformer 25 of the grid of the first tube of the repeater R_2 are transposed, thereby reversing the poling of the transformer 25. This will result in producing second power effects in the repeater R_2 which are opposite in phase to the second power effects produced in the repeater R_1.

The reason why the simple reversal of connections above described will tend to eliminate interference due to second harmonics and sum and difference frequencies will be clear from the following theoretical discussion of the principles involved.

Suppose we are not considering distortion arising from terms higher than the second power. Then the repeater characteristic may be represented by

$$i=a+be+ce^2 \quad (1)$$

where i is the current in the plate circuit and e is the alternating voltage on the grid.

Suppose further that there is no phase shift in either the line or the repeater,—that is, no shifting of the phase with respect to frequency, so that all of the carrier frequencies of the different channels (or all of the component voice frequencies in the case of vocal transmission) at all parts of the circuit have the same relative phase with which they started out. Now let us consider the action of a wave made up of two frequencies of equal amplitude. Such a wave may be expressed

$$e_1=E(\cos p_1t+\cos p_2t) \quad (2)$$

where p_1 and p_2 represent 2π times the frequencies of the individual carrier waves (or two component voice frequencies). Substituting from equation (2) in equation (1), we have

$$i=a+be_1+ce^2_1=a+bE(\cos p_1t+\cos p_2t)+cE^2(\cos p_1t+\cos p_2t)^2. \quad (3)$$

In equation (3) the constant a represents a direct current term which is not transmitted through the transformer in the output of the repeater from the line section to the next repeater. The expression

$$bE(\cos p_1t+\cos p_2t)+cE^2(\cos p_1t+\cos p_2t)^2 \quad (4)$$

represents the alternating current component flowing in the output circuit of the amplifier. Now, the voltage impressed upon the grid of the succeeding amplifier will depend upon the attenuation and other constants of the various electric elements through which this current is transmitted, but it will have the same form as the current flowing in the output circuit of the amplifier and will be proportional to the algebraic expression (4). Consequently, the voltage applied to the grid of the succeeding amplifier may be expressed

$$mbE(\cos p_1t+\cos p_2t)+mcE^2(\cos p_1t+\cos p_2t)^2 \quad (5)$$

where m is a factor representing the relation between the voltage applied to the grid of the succeeding amplifier and the current flowing in the output circuit of the preceding amplifier. If we analyze the expression (5) it will be seen that the first term thereof is of the same form as the voltage impressed upon the grid of the preceding amplifier as given by equation (2), the only difference being that the term in equation (5) is multiplied by the factor mb. If this factor be made equal to unity the first term of equation (5), (which represents the voltage applied to the grid of the succeeding tube) will be identical with the voltage applied to the grid of the preceding tube. The factor b is a term depending upon the amplification of the preceding tube, but the factor m depends upon the transmission characteristics of the line and is also controlled by the adjustment of the potentiometer in the input circuit of the grid of the succeeding amplifier. By proper adjustment of the potentiometer the factor mb may be made unity, and we then have as the alternating voltage on the grid in the second repeater the expression

$$e=\pm E(\cos p_1t+\cos p_2t)\pm\frac{cE^2}{b}(\cos p_1t+\cos p_2t)^2 \quad (6)$$

In equation (6), the plus sign is read if there is no reversal of the connections or if there is an even number of reversals of the connections, and the minus sign is read if there is an odd number of reversals.

The setting of the potentiometer of the succeeding amplifier determines the gain thereof. When the potentiometer is so set that the factor mb becomes unity, the gain of the succeeding amplifier will be practically equal to the loss in transmission between the amplifiers. In making this statement (which is only approximate) it should be remembered that in equation (4) the expression

$$bE(\cos p_1t+\cos p_2t)$$

is the term representing the amplified component corresponding to the original wave, and the only term with which we are concerned in amplification. If we had a perfect amplifier, that is, an amplifier having a straight line characteristic, the second power term

$$cE^2(\cos p_1t+\cos p_2t)^2$$

and other higher power terms would not be present at all. Even in the practical case now under consideration, where a slight amount of distortion does actually occur, the second power term is quite small as compared with the first power term. Consequently, it is quite justifiable to say in connection with equation (6) that, since the first power term of the right-hand side of said equation is identical with the original wave of equation (2), the voltage impressed upon the grid of the succeeding tube is practically equal to the voltage impressed upon the grid of the preceding tube. Therefore, the gain of the repeater is substantially equal to the loss in the line.

The characteristic of the second repeater may also be represented by an equation similar to equation (1). Hence we have, by substituting the values given by equation (6) in the equation corresponding to equation (1) for the second repeater,

$$i=a\pm bE(\cos p_1t+\cos p_2t)\pm cE^2(\cos p_1t+\cos p_2t)^2+c\left[E(\cos p_1t+\cos p_2t)+\frac{cE^2}{b}(\cos p_1t+\cos p_2t)^2\right]^2 \quad (7)$$

Equation (7) represents the space current in the second repeater. The expression in brackets in equation (7), when squared, becomes

$$E^2 (\cos p_1t + \cos p_2t)^2 + \text{terms in } E^3 \text{ and } E^4. \quad (8)$$

Hence the space current takes the form

$$i = a + bE (\cos p_1t + \cos p_2t) + 2cE^2 (\cos p_1t + \cos p_2t)^2 + \text{terms in } E^3 \text{ and } E^4 \quad (9)$$

where there is an even number of reversals. Where there is an odd number of reversals, the space current takes the form

$$i = a - bE (\cos p_1t + \cos p_2t) + \text{terms in } E^3 \text{ and } E^4. \quad (10)$$

Comparing equations (9) and (10), it will be seen that the term

$$2cE^2 (\cos p_1t + \cos p_2t)^2$$

is missing in the latter case. As this second power term is responsible for the production of second harmonics and sum and difference frequencies, it follows at once that by reversing the connections between successive repeaters so as to obtain a current in the output circuit of the second repeater, as represented by equation (10), the second harmonics and sum and difference frequencies will be suppressed. That the expression

$$(\cos p_1t + \cos p_2t)^2$$

is responsible for the second harmonics and sum and difference frequencies will be apparent from a simple algebraic transformation, by which this expression reduces to the following:

$$\cos p_1t + \cos p_2t)^2 = \cos^2 p_1t + 2 \cos p_1t \cos p_2t + \cos^2 p_2t = \frac{1 + \cos 2p_1t}{2} + (\cos [p_1 + p_2]t + \cos[p_1 - p_2]t) + \frac{1 + \cos 2p_2t}{2} \quad (11)$$

Analyzing the four terms on the right-hand side of the equation (11), it will be seen that the first and last of these four terms represent second harmonics of the frequency p_1 and p_2, while the second and third terms represent the frequencies corresponding to the sum and difference of these two frequencies, respectively.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated, without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a multiplex system in which a plurality of carrier frequencies are simultaneously transmitted through successive repeaters in a transmission line, the method of eliminating second harmonics and sum and difference frequencies produced by the distortion of the repeaters, which consists in impressing the several carrier frequencies on successive repeaters in opposite phase relation.

2. In a multiplex system in which a plurality of carrier frequencies are transmitted through successive repeaters in a transmission line, the method of eliminating second harmonics, which consists in impressing the several carrier frequencies on successive repeaters in opposite phase relation.

3. In a multiplex system in which a plurality of carrier frequencies are simultaneously transmitted through successive repeaters in a transmission line, the method of eliminating sum and difference frequencies, which consists in impressing the several carrier frequencies on successive repeaters in opposite phase relation.

4. In a multiplex system in which a plurality of carrier frequencies are transmitted through successive repeaters in a transmission line, the method of eliminating even power components due to the distortion of the repeaters, which consists in reversing the connections between successive repeaters.

5. In a multiplex carrier system, a transmission line, means for transmitting a plurality of carrier frequencies over said transmission line, a plurality of repeaters included in said transmission line, the connections of the successive repeaters being so arranged with respect to each other that the carrier frequencies will be impressed upon each succeeding repeater in opposite phase relation to that in which they were impressed upon the preceding repeater of the series.

6. In a multiplex carrier system, a transmission line, means for transmitting a plurality of carrier frequencies over said transmission line, a plurality of repeaters included in said transmission line, the connections of each successive repeater being reversed with respect to the repeater immediately preceding, whereby the carrier frequencies will be impressed upon each repeater in opposite phase relation to that in which they were impressed upon the preceding repeater.

7. In a transmission system in which a frequency is transmitted through successive repeaters in a transmission line, the method of eliminating second harmonics of the transmitted frequency, which consists in impressing the transmitted frequency on successive repeaters in opposite phase relation.

8. In a signaling system in which a range of frequencies is transmitted through successive repeaters in a transmission line, the method of eliminating second harmonics and

sum and difference frequencies produced by the distortion of the repeaters, which consists in impressing the various transmitted frequencies within the range upon successive repeaters in opposite phase relation.

9. In a signaling system in which a range of frequencies is transmitted through successive repeaters in a transmission line, the method of eliminating frequencies corresponding to the sums and differences of component frequencies within the transmitted range, which consists in impressing the frequencies to be transmitted upon successive repeaters in opposite phase relation.

10. In a signaling system in which a range of frequencies is transmitted through successive repeaters in a transmission line, the method of eliminating even-power components, due to the distortion of the repeaters, which consists in reversing the connections between successive repeaters.

11. In a transmission system, a transmission line, means for transmitting a band of frequencies over said transmission line, a plurality of repeaters included in said transmission line, the connections of the successive repeaters being so arranged with respect to each other than the component frequencies of the band will be impressed upon each succeeding repeater in opposite phase relation to that in which they were impressed upon the preceding repeater of the series.

12. In a transmission system, a transmission line, means for transmitting a band of frequencies over said transmission line, a plurality of repeaters included in such transmission line, the connections of each successive repeater being reversed with respect to the repeater immediately preceding, whereby the component frequencies of the band will be impressed upon each repeater in opposite phase relation to that in which they were impressed upon the preceding repeater.

In testimony whereof, I have signed my name to this specification this 18th day of March, 1922.

HARRY NYQUIST.