

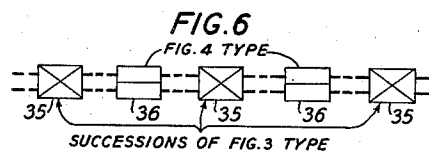
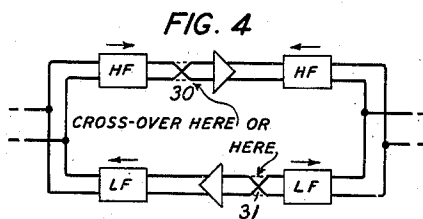
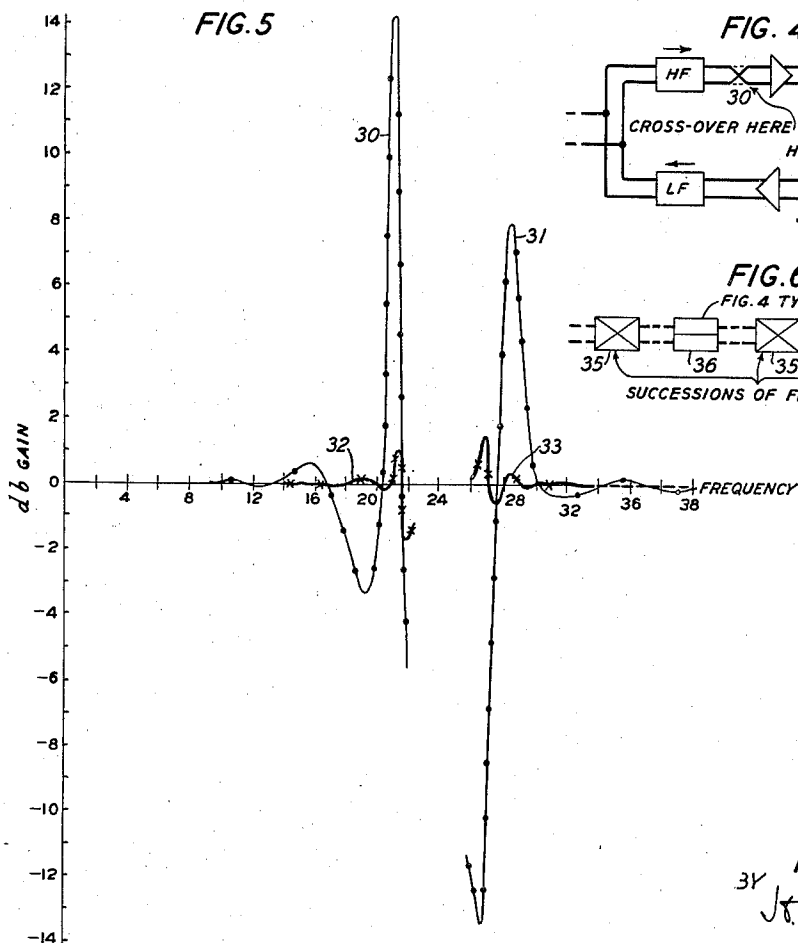
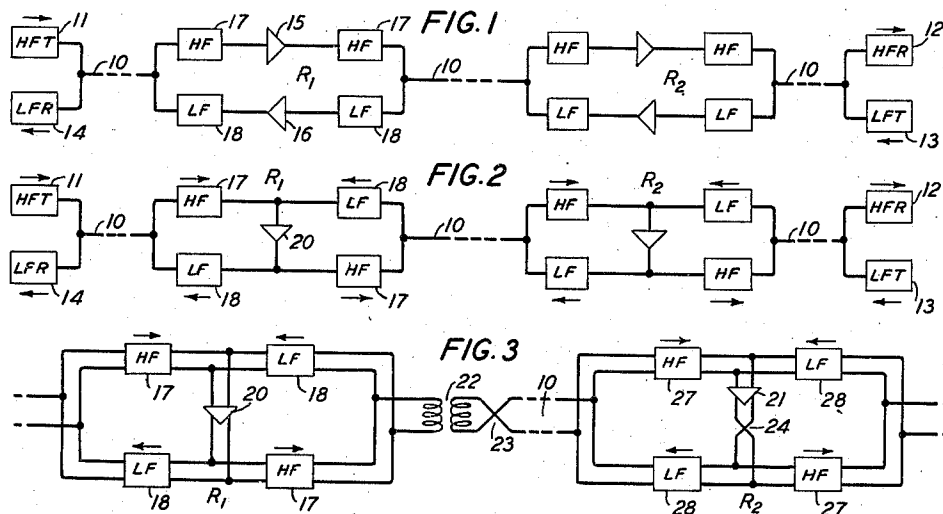
Oct. 7, 1941.

H. S. BLACK

2,258,275

REPEATERED TRANSMISSION SYSTEM

Filed Aug. 3, 1940



INVENTOR
H. S. BLACK
3Y
J. A. Bingen

ATTORNEY

UNITED STATES PATENT OFFICE

2,258,275

REPEATERED TRANSMISSION SYSTEM

Harold S. Black, Elmhurst, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 3, 1940, Serial No. 350,478

5 Claims. (Cl. 178—44)

The present invention relates to carrier wave transmission and to the reduction of distortion in repeaters in which different frequencies are used for opposite directions of transmission over the system.

In such a system, directional filters are used at a repeater point to establish separate repeating paths through the repeater for the opposite directions of transmission. Either a single amplifier may be used in common for both directions of transmission or a separate amplifier may be used for each direction, both arrangements being known in the art.

In repeaters of this kind it has been found that a small amount of feedback takes place around the amplifier through one or more of the filters passing one range of frequencies and through one or more of the filters passing the other range of frequencies, commonly a low-pass filter and a high-pass filter. In the pass range of the lower frequency band, for example, the high-pass filter does not have infinite attenuation, hence a small transmission passes through it. If the phase of the waves so fed back had some fixed negative value at all frequencies, such as 180 degrees, this feedback might not be a disadvantage or might even be a definite advantage. The phase characteristic of the filters, however, goes through wide variations within the frequency limits of one directional band and produces a corresponding variation in the gain, giving rise to troublesome irregularities in the gain frequency characteristic of the repeater. To eliminate these irregularities in a single repeater would require a costly filter design even if it were possible to meet the requirements in particular cases by filter design. In a system with tandem repeaters of identical design these irregularities become cumulative.

The present invention eliminates or reduces the effect of these irregularities in successive repeaters by causing them to occur in respectively opposite phase in successive repeaters whereby they tend to neutralize each other. This method does not impose new requirements on filter design and results in economy and improved operation.

The nature of the invention and its various features and objects will be made clear in the following detailed description in connection with the drawing in which:

Fig. 1 is a block diagram of a long repeatered line using repeaters of the two-amplifier type;

Fig. 2 is a similar diagram of a line using repeaters of the single-amplifier type;

Fig. 3 shows in schematic form the circuit of

two adjacent repeaters of the single-amplifier type with the invention incorporated;

Fig. 4 is a similar but partial diagram embodying the invention in the case of a two-amplifier repeater;

Fig. 5 shows curves illustrating the improvement obtainable by use of the invention; and

Fig. 6 shows a contemplated arrangement for cases using a large number of repeaters in tandem.

In Fig. 1 the long line 10 has a high frequency transmitting circuit 11 at its west terminal for transmitting currents in a relatively high frequency range over the line to the distant east terminal where they are received in the high frequency receiver circuit 12. Similarly, the east station has a low frequency transmitter 13 for transmitting waves comprised in a relatively low frequency range over the line to the west station for reception in the low frequency receiver 14. The waves may, for example, consist of signals in a plurality of carrier channels comprised in two mutually exclusive frequency ranges as is common in the art, the high group transmitting west to east and the low group transmitting east to west.

At intermediate points are repeaters, two only of which are shown at R_1 and R_2 . These are similar and each comprises an eastward amplifier 15, a westward amplifier 16 and directional filters, such as the high-pass or band-pass filters 17, 17 and the low-pass or band-pass filters 18, 18, all as in the prior art.

In Fig. 2 the layout is the same except that each repeater comprises a single amplifier 20 for amplifying in common the waves transmitted in both directions. In this case the arrangement of the directional filters has to be altered, as shown. This type of system also is known in the art.

In Fig. 3 a more detailed showing is given of two adjacent repeater stations R_1 and R_2 of Fig. 2. Repeater R_1 is shown provided with a transformer 22 on the side facing repeater R_2 , which could be omitted except for permitting a cross-over at 23 without disturbing the grounding conditions at the repeaters. Repeater R_2 is like R_1 except for the cross-over at 24 which could as well be on the input side of amplifier 21 instead of on the output. The cross-over at 24 is made in accordance with the invention, which also allows for and may comprise the cross-over at 23 as will presently be explained.

Considering the repeater R_1 in greater detail, the amplifier 20 has two separate circuits traceable from its output to its input, each through a

pair of filters 17 and 18. If these filters were designed to have infinite attenuation in the opposite frequency band, there would be no feedback through them. In practice the attenuation of each filter in the pass-band of the other is very large but is still finite so that there is a slight amount of feedback from the output to the input of the amplifier 20. This feedback would not be objectionable if the phase shift were the same at all frequencies and had some fixed value in the neighborhood of 180 degrees. In practice, however, the phase shift around the repeater loop may vary over a range of 2 or 3 complete cycles (i. e., 4π to 6π radians) within the band of each of the filters. This causes fluctuations in the repeater gain. For example, when the feedback is in phase, the gain is slightly increased; when the feedback is in phase opposition, the gain is slightly decreased and at other values of phase shift the gain is changed correspondingly. While these changes in gain are small and in the case of a single repeater might be negligible, the cumulative gain changes in several or, more especially, a very great number of successive repeaters may be enough to be objectionable.

The fluctuations in gain as calculated for two repeaters in tandem under conditions that may be considered typical are shown by the light line curves 30, 31 of Fig. 5, in which the lower frequency band extends from 10 to 22 kilocycles and the upper frequency band extends from 26 to 38 kilocycles. The phase shift variations and the resulting gain fluctuations are most pronounced in the region near the cut-off of each filter.

These fluctuations are a form of distortion since they result in amplitudes that are too great at some frequencies and too small at some frequencies to correspond to the actual frequency amplitude relations of the signal. As indicated above, they are produced by the circulating currents around the amplifier through one high-pass filter and one low-pass filter in series. By providing the cross-over at 24 in accordance with the invention in alternate repeaters, the resultant gain fluctuations of two tandem repeaters can be reduced to some such size as is indicated by the heavy line curves 32, 33 of Fig. 5. This results from the fact that the gain fluctuations in the two repeaters are thrown into phase opposition or approximately so.

A quantitative measure of the reduction in the required circulating current margin and, therefore, of the amount of attenuation that must be provided in each filter in the pass range of the opposite filter, can be obtained from regarding the problem as a feedback amplifier problem, in which μ is the gain of the amplifier and β is the feedback factor and in which in this case $\mu\beta$ is numerically quite small and in the ideal case, where the filters had infinite attenuation in the loss range, would be zero. If $\mu\beta$ is finite, the repeater gain will be the amplifier gain divided by the quantity $|1-\mu\beta|$ or $(1+\mu^2\beta^2-2\mu\beta \cos \theta)^{1/2}$ where θ is the phase shift around the loop and, as stated above, may go through 2 or 3 cycles or more within the range of one filter. Assigning extreme values of ± 1 to $\cos \theta$, the total range of fluctuation, N , in gain is seen to be

$$N = \frac{1+\mu\beta}{1-\mu\beta}$$

If we reverse the phase of the amplifier in the

repeater loop at alternate repeaters in accordance with this invention, we have as the gain of the repeaters with cross-over as at 24 in Fig. 3, a gain which is the amplifier gain divided by $|1+\mu\beta|$, or the sum of the gains of the two repeaters R_1 and R_2 is equal to

$$\left| \frac{2G}{1-\mu^2\beta^2} \right|$$

where the amplifier gain in each case is G . If we assign extreme values of ± 1 to $\cos \theta$ for this case, the total range of the gain fluctuations about the amplifier gain for both repeaters in tandem has the value

$$\frac{1+\mu^2\beta^2}{1-\mu^2\beta^2}$$

If the total range of fluctuations in gain of two tandem repeaters when the cross-over is used is to be the same as the total range of the fluctuations of the same two amplifiers without the cross-over, the $\mu\beta$ value with cross-over can be found by equating the total range of fluctuations for the two cases, identifying $\mu'\beta'$ with the case using the cross-over and $\mu\beta$ with the other case, whence it is found that

$$\mu'\beta' = \frac{\mu^2\beta^2}{2}$$

or converting to decibels

$$20 \log \mu'\beta' = 40 \log \mu\beta - 6$$

which shows that the circulating current margin expressed in decibels is reduced approximately one half by the use of the reversal of polarity. This is another way of saying that the decibel filter loss or decibel discrimination need be only approximately half as great when reversal of polarity is used. Where the phase reversal in alternate repeaters is not used, the requirement of high filter attenuation to reduce the circulating current margin is usually very much more stringent than the corresponding requirement placed on the filter by the condition that the repeater must not sing. Accordingly, it is seen that any substantial reduction in the circulating current margin is very significant and very valuable from the standpoint of filter design.

It has been pointed out in certain prior art patents that reversal of polarity of alternate repeaters is effective in reducing certain types of distortion in systems having tandem repeaters. See, for example, Nyquist Patent 1,570,770, January 26, 1926, and Peterson Patent 1,927,070, September 19, 1933. The cross-over at 24 has the effect of reversing the polarity in this sense and of effecting reduction in modulation in the manner disclosed in those patents. If, however, in any particular case it is wished not to have the polarity of alternate repeaters reversed so far as the effect on cumulative modulation is concerned, a second cross-over can be made at some point such as 23 which cancels the effect on modulation of the reversal at 24 but still leaves the effect of the reversal at 24 so far as circulating currents in the repeater loop are concerned.

Fig. 4 shows how the reversal of polarity may be made, as at 30, for reduction of cumulative effects of circulating currents in the repeater loops in the case of a two-amplifier, two-way repeater. In this case repeaters should be considered in groups of four, the first and third being unpoled, the second poled at 30, Fig. 4, and the fourth at 31, Fig. 4. Instead of making

the cross-over on the input side of the amplifier it could be on the output side, if desired, and it will, of course, be understood that it can be made in either side of the repeater circuit.

In some cases using a large number of repeaters, it is contemplated that a succession of single-amplifier repeaters (Fig. 3 type of arrangement) would be alternated with a two-amplifier repeater (Fig. 4 type of arrangement) which could be continued to whatever extent desired or necessary. This is indicated in Fig. 6 in which each box 35 represents a chain of repeaters of the single-amplifier type with cross-overs as described in connection with Fig. 3, while each box 36 represents a two-amplifier repeater. These latter would be ordinarily used in sets of four if maximum use of the cross-overs is used. Other arrangements will occur to those skilled in the art, depending upon particular requirements of given installations.

The invention places no restriction on the type of amplifier used. For example, an amplifier of the stabilized feedback type disclosed in H. S. Black Patent 2,102,671, December 21, 1937, may be used.

The invention is not to be construed as limited to the details of the embodiment which has been disclosed but its scope is defined in the claims which follow.

What is claimed is:

1. In a two-way transmission system, using a high frequency band for one direction of transmission and a low frequency band for the opposite direction of transmission, repeaters in tandem in said system each comprising an amplifying path for one direction including filters having a pass range corresponding to the high frequency band and an amplifying path for the opposite direction including filters, having a pass range corresponding to the low frequency band, where-

by similar undulations occur in the over-all gain frequency characteristic of each amplifier due to feedback effects through certain of said filters, and means to reduce the cumulative effect of such undulations in said system comprising means included in certain of the repeaters to cause said undulations to have respectively opposite phase in succeeding repeaters.

2. A combination according to claim 1 in which said means comprises cross-overs in the amplifying paths of alternate repeaters.

3. A combination according to claim 1 including single-amplifier repeaters in which the same amplifier cooperates in known manner with the filters to amplify in common the waves transmitted over the system in both directions, and in which a cross-over is made at the terminals of the amplifier, within the repeater, in the case of alternate repeaters.

4. A combination according to claim 1 in which successions of single-amplifier repeaters, with cross-overs in the alternate repeaters of each succession, have inserted between them a two-amplifier repeater, and an internal cross-over in every second one of said two-amplifier repeaters.

5. In combination, a repeated system for transmitting different frequency bands in opposite directions, a succession of spaced repeaters of the single-amplifier type, each provided with directional filters for separately transmitting the oppositely directed waves between the line and the input and output terminals of the single amplifier in the case of each repeater, and an internal cross-over in alternate repeaters at the terminals of the respective amplifier to reduce cumulative effects of variations in gain due to variations in phase characteristic of the filters.

HAROLD S. BLACK.