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H. NYQUIST

DISTORTION CORRECTION FOR TRANSMISSION LINES

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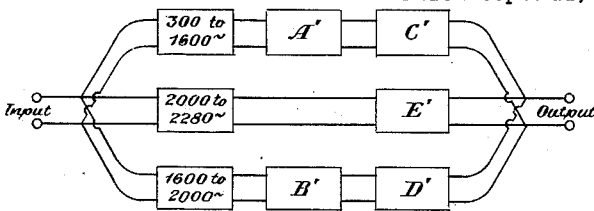


Fig. 1

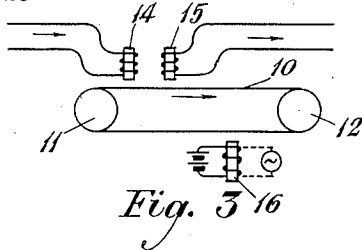


Fig. 3

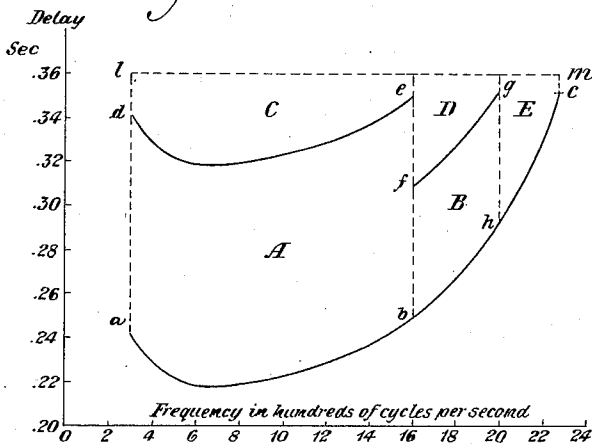


Fig. 2

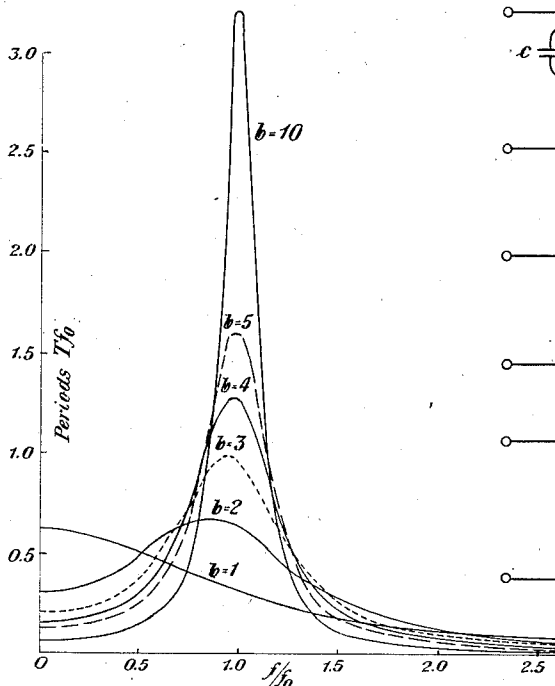


Fig. 5

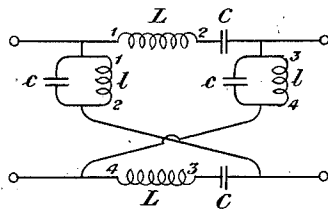


Fig. 4a

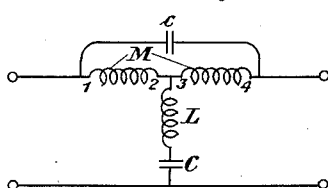


Fig. 4b

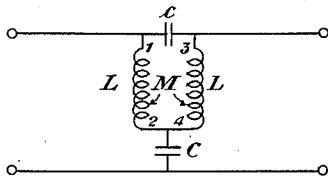


Fig. 4c

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UNITED STATES PATENT OFFICE.

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DISTORTION CORRECTION FOR TRANSMISSION LINES.

Application filed September 11, 1926. Serial No. 134,930.

This invention relates to the correction of distortion in transmission lines, and more particularly to a method and means for correcting for the difference in time of transmission and in the attenuation of the components of a complex wave, such as an electrical signal wave, over a transmission line.

In transmission lines such as are used for signalling purposes, the velocity of transmission and the attenuation depend on the frequency, and as a result the various components making up the initial wave form are changed in magnitude and phase, resulting in a substantial distortion which becomes greater as the length of the line is increased.

Various attempts have been made to correct for this distortion, this being commonly accomplished by the introduction of electrical networks of such characteristics as to introduce additional delay and attenuation in those portions of the frequency spectrum in which these are low, and by suitable design of the electrical networks it is possible to give a transmission line a practically uniform characteristic throughout that portion of the frequency spectrum of interest. Such correction networks are illustrated in my application, Serial No. 751,146, filed November 20, 1924.

For long lines, the cost of a sufficiently large number of sections to introduce the necessary delay or correction may become prohibitive and the object of this invention is to provide a method of and means for doing this which is more economical than the use of electric circuits. I accomplish this by obtaining part of the correction by a mechanical delay device such as a phonograph, a telegraphophone or other equivalent means, and then obtaining the remainder of the necessary or desirable correction by a limited number of sections of electric networks. A further object of my invention then is to obtain the major portion of correction for such a transmission line by economical and convenient mechanical means and to confine the use of electrical sections to the final correction.

In a long transmission line there is quite commonly excessive delay in certain portions of the frequency spectrum which introduces special difficulties to the problem. In this invention I overcome such difficulty by the method of splitting a wide transmission band of frequencies into several narrow bands by means of filters, equalizing separately each band by suitable phase and attenuation equal-

izers, and finally recombining the separate bands in a single circuit. In the case of very long circuits, where the delay required in the equalizing apparatus is very great, it may be possible to select, by means of filters, one or more parts of a band where a great and approximately constant delay may be utilized. This part of the total delay may be obtained by various substitute electro-mechanical devices referred to above and which may be mentioned here more specifically. For example, one might use any of the following devices: (a) A phonograph, when reproducing needle follows recording needle after a given time and recording and reproducing attachments are connected so as to operate from or work into an electric circuit, respectively; (b) a telegraphophone of the kind now well-known in the art and referred to more specifically in Figure 3 of the accompanying drawing, to which further reference will be made below; (c) the speaking tube described in my application, Serial No. 127,934, filed August 7, 1926.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which Figure 1 shows the manner of splitting up the frequency spectrum for a given transmission line and means for correcting each narrow band; Fig. 2 shows a delay characteristic curve of a long transmission line and the application of the arrangement of Fig. 1 towards its correction; Fig. 3 gives one form of mechanical delay device for the purpose mentioned heretofore; Figs. 4^a, 4^b and 4^c represent typical forms of lattice-type networks useful for the final correction; and Fig. 5 shows curves giving the delay characteristics of such networks.

In order to explain the invention and to illustrate how the reduction in the number of electrical networks may be accomplished, let us assume that it is desired to use the method of this invention in correcting distortion on a certain 2000-mile No. 19-gauge loaded side circuit. The delay-versus-frequency relationship for this circuit is shown by the curve *a*, *b*, *c* of Fig. 2. Suppose that for our special purpose it is desired to transmit a band from 300 to 2300 cycles. It is then seen from Fig. 2 that a constant delay of .1 of a second added from 300 to 1600 cycles raises that portion of the delay curve to *d*, *e*, and the area covered by the lifting of this portion

of the curve gives the area A which is equal to 130 units, the unit here being an arbitrary one. A constant delay of .06 seconds added from 1600 to 2000 cycles gives the curve *f*, *g* and in being so lifted the curve covers the area B equal to 24 units. If now, in Fig. 1 the transmission line is divided into three portions extending, respectively, from 300 to 1600 cycles, 1600 to 2000 cycles, and 2000 to 2300 cycles, by means of accurate sharp cut-off filters, we may then introduce electro-mechanical devices A' and B', as shown in Fig. 1, in the channels transmitting the two lower frequency bands so as to yield a resultant delay given by the curve *d*, *e*, *f*, *g*, *h*, *c*.

Having thus corrected for the major portion of the delay, it will now be feasible to correct each of the three channels of Fig. 1 still further with electrical networks so as to take care of the delay represented by the areas C, D and E of Fig. 2 yielding such resultant delay as may be desirable, which, in general, would be a straight line, as indicated by *l*, *m* of Fig. 2. This correction may be accomplished by any suitable electrical networks such as are indicated in Fig. 1 by C', D' and E', and it will be convenient at the same time to make these electrical networks of such form as to equalize for variable attenuation throughout the frequency spectrum in which we may be interested.

Certain forms of networks for phase correction are shown in Figs. 4^a, 4^b and 4^c, which may be made electrically equivalent by giving proper values to the reactances, one form of network being more convenient in certain cases than in others. These electrical networks are explained in detail in my copending applications, Serial No. 751,146, filed November 20, 1924, and Serial No. 90,656 of February 26, 1926, which applications relate specifically to the correction for transmission lines, the correction being obtained by electrical networks. In Fig. 5, there is shown a group of curves giving the delay characteristics of such networks in terms of the natural frequency of the members of the networks of Figs. 4^a, 4^b and 4^c. The delay characteristic for any one of these networks, as explained in my co-pending applications, may be controlled, and this is indicated in Fig. 5 by the curves having different values for a parameter *b*, which is determined by the relative magnitudes of the inductances and the capacities in the network in question. By the choice of one or more of these networks of given characteristic, it is possible to introduce almost any desired delay in any portion of the frequency spectrum, and by the choice of a plurality of these networks, with the same or different values for the parameter *b*, it is possible to introduce almost any desired delay at any frequency or band of frequencies. The area under each of the curves of Fig. 5 has the property of being equal to

one of the arbitrary units heretofore mentioned, of which there were 130 in the area A. By using *n* such sections, the total delay throughout the frequency spectrum as a whole will be equal to *n* units. It is apparent, therefore, that in order to obtain the total correction corresponding to the curve *a*, *b*, *c* of Fig. 2, a large number of sections would be required, but having obtained the major portion of the correction by mechanical means, a relatively few number of sections of the electrical networks will be necessary to take care of the balance of the correction.

The saving in the number of sections of electrical networks due to this substitution can be computed for any case. In the particular one in hand, let us again suppose that the delay of the total transmitted band, 300 to 2300 cycles, is first equalized by means of *N*₁ sections of electrical network without splitting the bands by means of filters. In this case, we will have the relation

$$N_1 = A + B + C + D + E + n_1 \quad (1)$$

where *n*₁ is the area under the total delay curve of *N*₁ sections which occurs outside of the range of 300 to 2300 cycles. If, now, the areas A and B are taken care of electro-mechanically, we need only the following number of sections of electrical networks to take care of the areas C, D and E, respectively,

$$N_c = C + n_c \quad (2)$$

$$N_d = D + n_d \quad (3)$$

$$N_e = E + n_e \quad (4)$$

where *n*_c, *n*_d and *n*_e are the areas under the delay frequency curves lying outside of the transmitted bands of the respective channels. Thus, the saving *S* in total sections of electrical networks is

$$S = N_1 - N_c - N_d - N_e \quad (5)$$

$$= A + B + n_1 - n_c - n_d - n_e \quad (6)$$

$$= 154 + n_1 - n_c - n_d - n_e \quad (7)$$

It is economical to make *n*₁, *n*_c, *n*_d and *n*_e as small as possible by properly selecting the values of *b* and *f*₀ for the various sections of electrical networks, this being possible as is seen by the curves of Fig. 5. Thus, the total saving in electrical sections of distortion correction networks obtained by using the electro-mechanical devices amounts to about 154 sections.

As indicated above, the mechanical delay may be obtained by any one of a variety of mechanical devices, of which only one need here be illustrated. Fig. 3 shows such a mechanical delay device, this consisting of a telegraphophone which comprises a magnetizable wire or ribbon 10, moving continuously in any suitable manner, such as over wheels 11 and 12. Adjacent to this moving wire, is a recording magnet 14, which is connected to the incoming channel of one branch of Fig. 1. A second magnetic winding 15 then picks up

and reproduces the signal, transmitting it to the output terminals of this same channel. By moving the reproducer 15 to or from the recorder 14, any desired delay may be obtained. Instead of moving the magnets, obviously the same result could be accomplished by changing the velocity of the moving wire or ribbon. An electro-magnet 16 adjacent the wire should be provided for wiping off the record and placing the wire in condition for operation on again reaching the recorder 14. This electro-magnet may be excited by a direct current source or a high frequency alternating current source, as is preferred.

Having introduced the mechanical delays A and B in two of the channels, and having made the final correction by means of the electrical networks, the three channels of Fig. 1 may then be brought together, and the signal allowed to proceed into a single output channel.

While I have described this invention in connection with specific apparatus, it is to be understood that the invention should not be so limited, but that it is capable of numerous modifications without departing from the spirit of my invention.

What is claimed is:

1. In a transmission system, the method of correcting for delay irregularities which consists in making the large portion of the delay correction mechanically and the final portions electrically.

2. In a transmission system, the method of correcting for delay and attenuation irregu-

larities which consists in correcting for the main portion of the delay mechanically and in correcting for the attenuation and the final portions of the delay electrically.

3. In a transmission system, the method of correcting for delay irregularities which consists in dividing the transmission channel into a plurality of parallel branches, dividing the frequency spectrum among these branches according to extent of delay, making the main delay correction in each branch mechanically and the final delay correction in each branch electrically.

4. In a transmission line to be corrected for delay irregularities, a section of said line divided into a plurality of parallel branches, a wave filter in each section adapted to pass a definite frequency band, mechanical delay devices in each branch adapted to correct for most of the delay, and electrical networks in each branch adapted to correct for the remainder of the delay.

5. In a transmission line to be corrected for delay irregularities, a section of said line divided into a plurality of parallel branches, means in each branch adapted to pass a definite frequency band only, mechanical delay devices in a branch carrying a band with large delay and electrical delay devices in various branches to correct for smaller delays.

In testimony whereof, I have signed my name to this specification this 10th day of September, 1926.

HARRY NYQUIST.