COMPENSATION SYSTEM HAVING FEEDFORWARD AND FEEDBACK CIRCUITS FOR CANCELING LEADING AND TRAILING EDGE DISTORTION OF SIGNAL PULSES

Filed Feb. 23, 1966 4 Sheets-Sheet 1

Fig. 1.

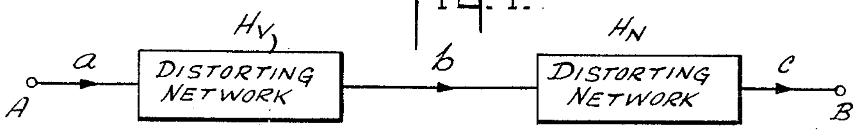


Fig. 2.

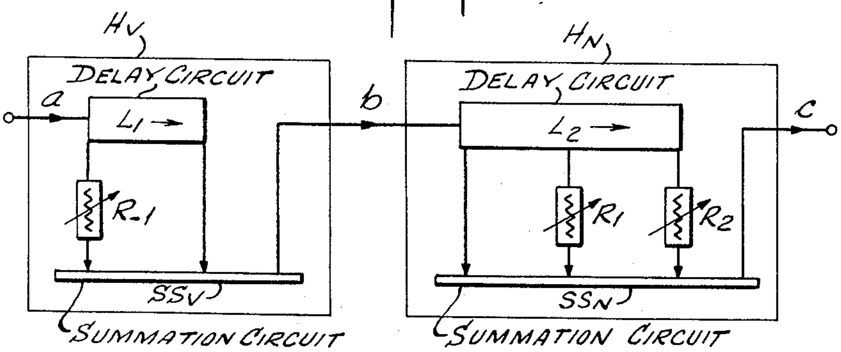


Fig. 3a.

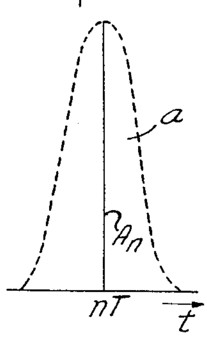


Fig. 3b.

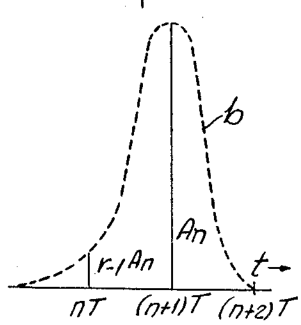
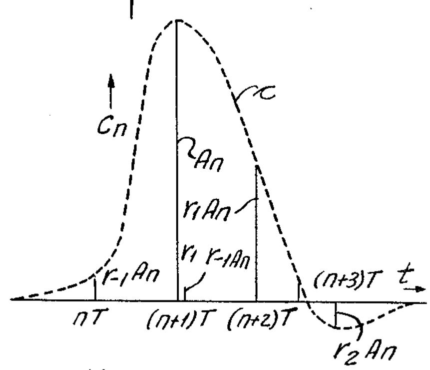
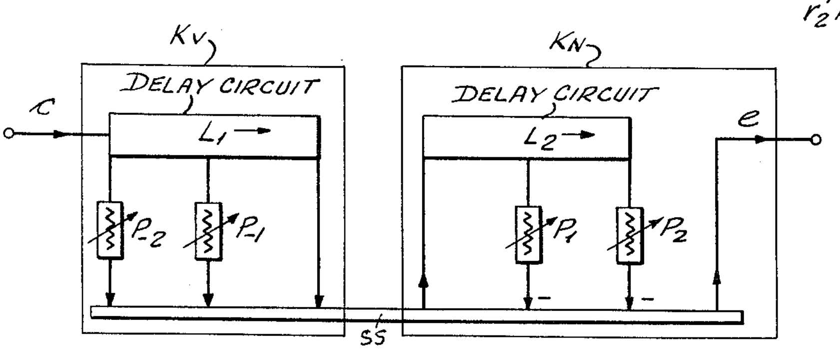


Fig. 3c.





Prior Art Fig. 4.

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Fig. 5. Prior Art

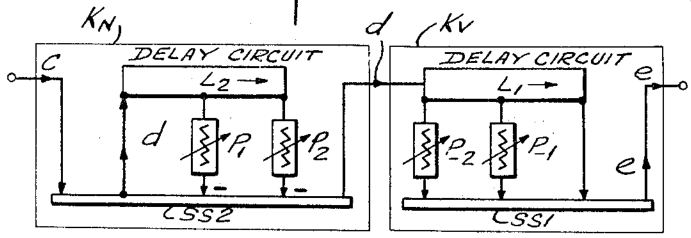

Fig. 6.

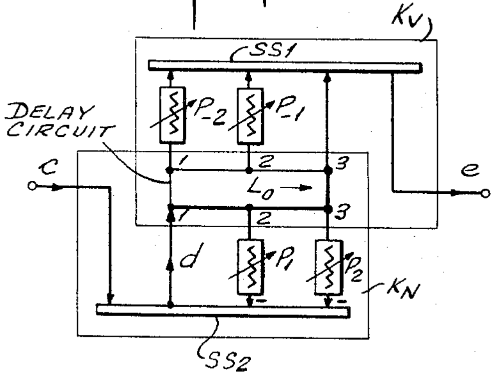

Fig. 6a.

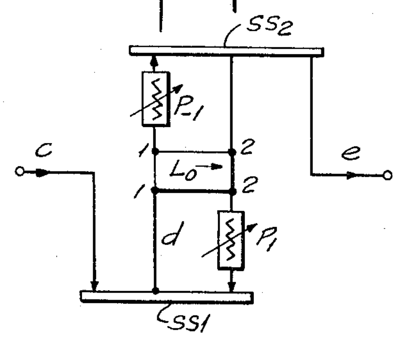

Fig. 7.

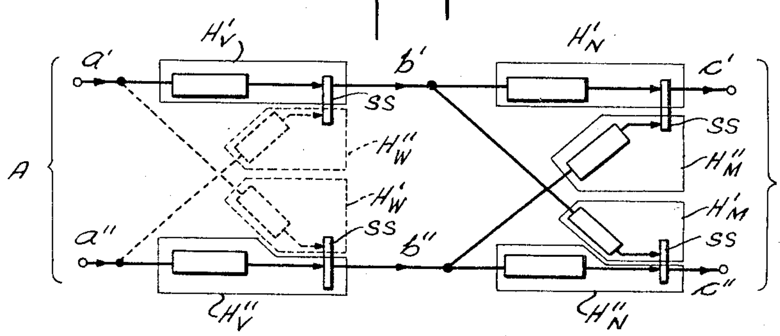

Fig. 9.

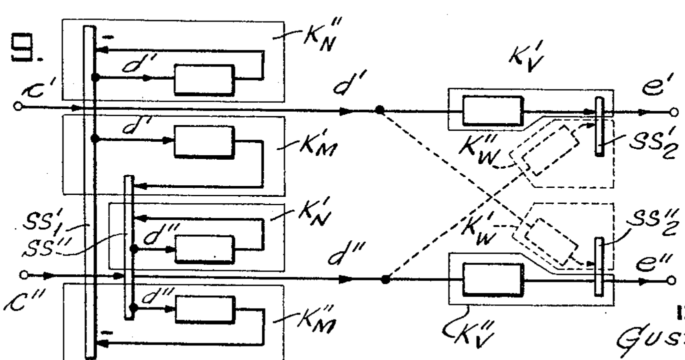

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Fig. 8.

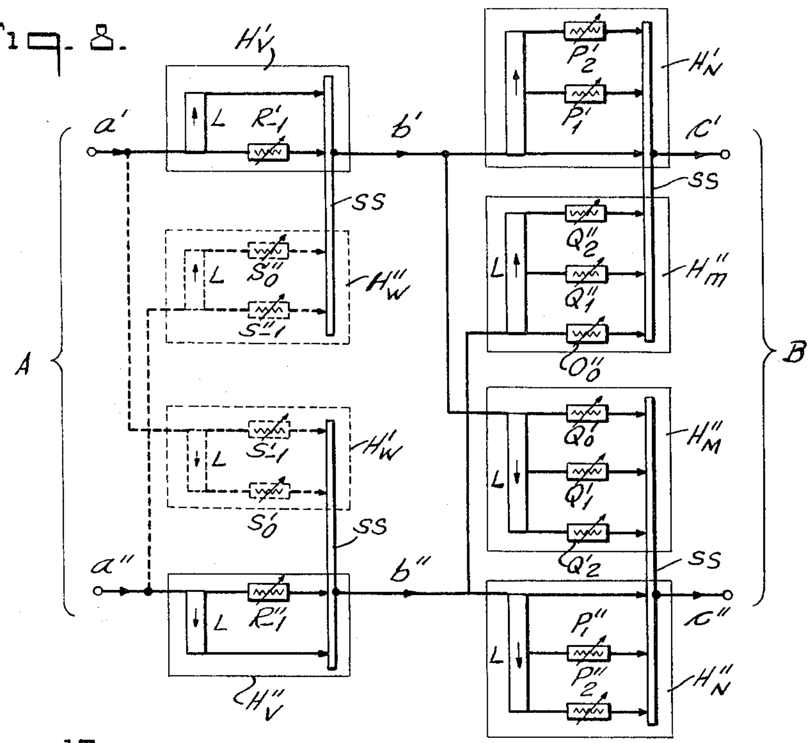

Fig. 10.

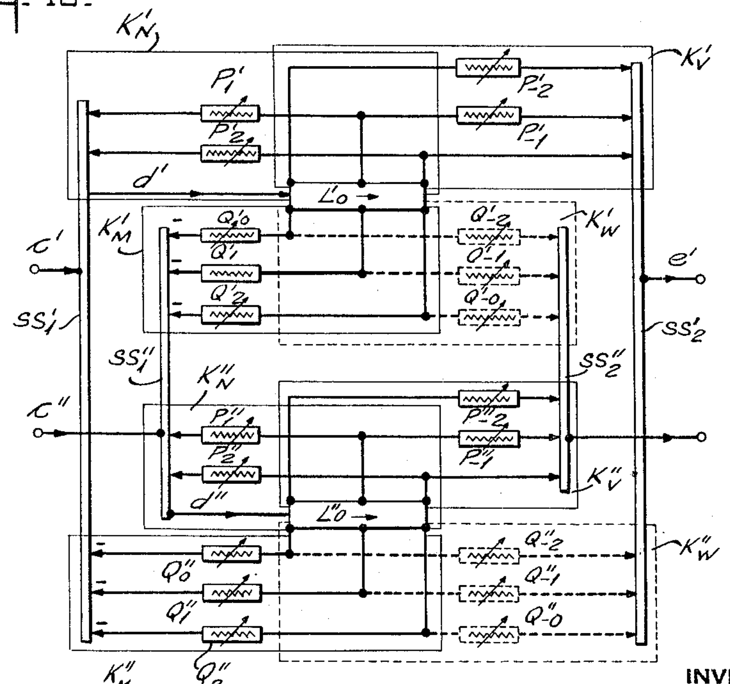

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Fig. 11a.

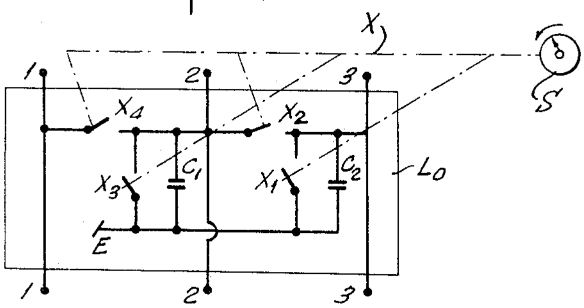


Fig. 12a.

C1	C2	C3	C4
E	3	2	1
1	E	3	2
2	1	E	3
3	2	1	E

Fig. 11b.

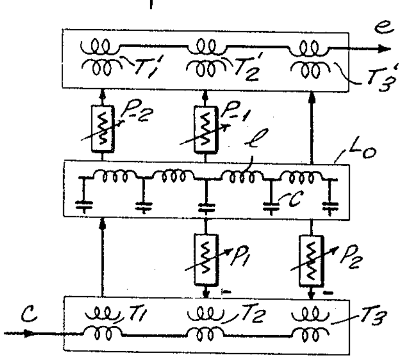


Fig. 12b.

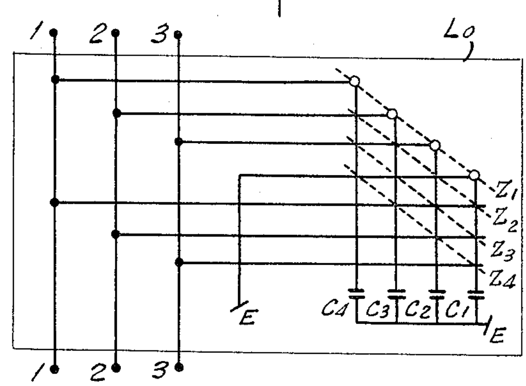


Fig. 13.

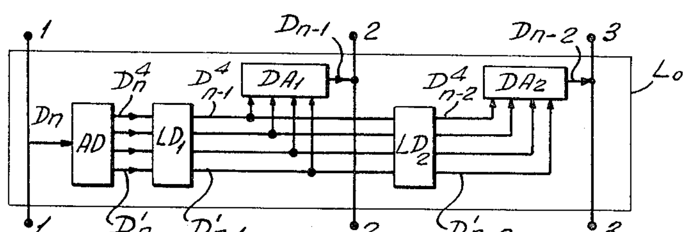


Fig. 14a.

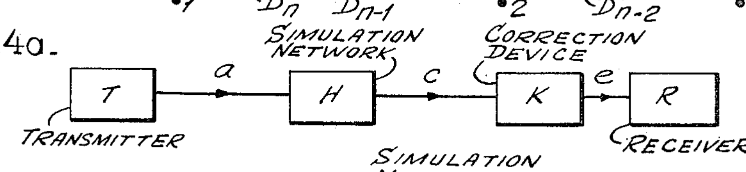
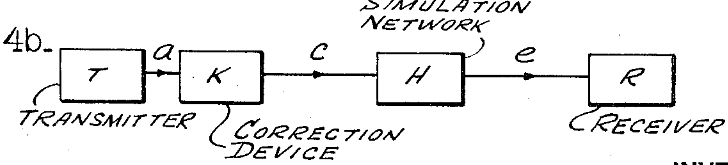


Fig. 14b.



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COMPENSATION SYSTEM HAVING FEEDFORWARD AND FEEDBACK CIRCUITS FOR CANCELING LEADING AND TRAILING EDGE DISTORTION OF SIGNAL PULSES

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Claims priority, application Switzerland, Feb. 26, 1965, 2,705/65
8 Claims. (Cl. 333—20)

ABSTRACT OF THE DISCLOSURE

In signal transmission by means of equi-spaced signal pulses through a transmission path subjecting the pulses to widening or dispersion involving both leading and trailing disturbing components preceding and following, respectively, a signal pulse, both the leading and trailing distortion is eliminated or minimized by a compensator comprising a single delay device having at least one input and at least one output coupling point, further means being provided for passing the pulses to be corrected from said input to said output coupling point with the difference in transit time of said device between said coupling points being equal to the spacing intervals between the signal pulses. In order to compensate for the trailing distortion components, there is provided a unidirectional feedforward circuit, in respect to the signal passing direction through said device, between said input and said output coupling points, and in order to compensate for the leading distortion components, there is provided a unidirectional feedback circuit, in respect to the signal passing direction through said device, between said output and said input coupling points. By the further provision of suitable amplitude control and polarity adjusting devices in both said feedforward and feedback circuits, there is achieved a substantial cancellation of both the leading and trailing disturbing signal components by the use of a single delay device. If the signal pulses are distorted by two or more disturbing components spaced by intervals equal to the pulse spacing intervals, compensation of all components, both leading and trailing, may be effected by providing said device with a corresponding number of coupling points, spaced as to transmit time by differences equal to the pulse spacing intervals and connected to individual feedforward and feedback circuits each including its own amplitude control and polarity adjusting device.

The present invention relates to distortion compensation in electrical pulsed signal transmission by means of equi-spaced signal pulses modulated in accordance with the variations of a signal or information to be transmitted.

In the transmission of modulated electric signal pulses through a transmission path or channel, the unavoidable linear distortion, as a result of the frequency-dependent amplitude and/or phase variations produced by the transmission channel, has the effect of both broadening or increasing the width of the pulses as well as changing the instantaneous or peak amplitudes thereof. As a consequence, the received pulse signals at a receiving station start prematurely in respect to their peak value or exhibit an increased rise time, this distortion being referred to as leading pulse distortion for the purpose of this specification, and, in addition, the pulses are retarded relatively to their peak values or in reaching the final zero value, the latter distortion being hereafter referred to as trailing pulses distortion for the purpose of this specification. As a further result of the leading and trailing distortions,

amplitude distortion or variation of the peak values of the pulses may occur to a greater or lesser extent.

Where the pulses are transmitted with constant spacing intervals, such as in pulse amplitude modulation or pulse code modulation transmission, the leading and trailing distortions of the pulses may give rise to undesirable interference or crosstalk in that each pulse of a transmission signal pulse series carries with it interfering leading and trailing pulses or components liable to encroach upon the preceding and next following pulse or pulses, aside from the resultant amplitude or peak value distortion of the pulses referred to hereinbefore.

Moreover, it may be difficult, if not impossible, depending upon the extent or degree of the prevailing distortions, to segregate the individual pulses clearly, aside from the difficulty to determine their original amplitude accurately and faithfully at the utilization or receiving station.

One way of resolving the resultant problem in pulse signal transmission of the referred-to type is the utilization at the receiving station of means to restore the distorted pulses to their original shape and amplitude, at least to such an extent as to enable a clear and satisfactory identification and subsequent demodulation of the received signal pulses.

Various means and devices have already become known in the past for effecting a solution of the foregoing problem all of which involve the provision of a delay device or network at the receiving station for the production of compensating or correcting signals or pulses adapted to cancel or suppress the interfering pulse or signal components. All of the known devices operate to compensate or correct either the leading distortion or the trailing distortion only of the received pulses, the elimination of the trailing distortion alone being sufficient in certain limited cases for the desired purpose. In all other cases, separate cascaded delay or compensating arrangements are required, to sequentially correct or eliminate both the leading and trailing distortion of the received signal pulses. Arrangements of the latter type are relatively costly aside from other obvious defects and disadvantages.

Accordingly, an important object of the present invention is the provision of an improved distortion compensating device or network of the referred-to type for correcting both the leading and trailing distortion in a pulsed signal transmission system which device is both simple in design and construction as well as efficient in operation and may be produced at relatively low cost.

A more specific object of the invention is the provision of an improved distortion compensating device of the referred-to type utilizing a single delay device or network for the compensation or suppression of both the leading and trailing distortion components of the pulses in a pulse signal transmission system.

Another object of the invention is the provision of a pulse distortion correcting system of the referred-to type suitable for suppressing distortion directly originating in a first transmission channel as well as distortion originating from a neighboring transmission channel due to mutual coupling obtaining between said channels.

The invention, both as to the foregoing and ancillary objects as well as novel aspects thereof, will be better understood from the following detailed description, taken in conjunction with the accompanying drawings forming part of this specification and in which:

FIG. 1 shows in block diagram form a normally distortion-free signal transmission path including a pair of substitute devices or networks for the simulation or artificial production of leading and trailing pulse distortion, representing the conditions of an actual transmission channel or circuit;

FIG. 2 shows, in greater detail and by way of example, a pair of distorting networks embodied in the transmission channel of FIG. 1;

FIGS. 3*a*, 3*b*, and 3*c* illustrate, respectively, an original pulse signal, the same signal subjected to leading distortion, and after additional trailing distortion by the networks of FIG. 2;

FIG. 4 shows a general distortion compensating network of known construction for correcting a distorted pulse signal, such for instance of the type according to FIG. 3*c*;

FIG. 5 shows a modification of FIG. 4;

FIG. 6 shows the improved distortion compensating network constructed in accordance with the principles of the invention;

FIG. 6*a* shows a simplified compensating system of the type of FIG. 6;

FIG. 7 shows, in a manner similar to FIG. 1 and in block diagram form, a pair of mutually coupled transmission channels embodying networks or devices for the production of both direct and mutual distortion, leading as well as trailing, of the pulses transmitted through said channels;

FIG. 8, being analogous to FIG. 2 shows, more clearly and by way of example, the delay devices of FIG. 7 for producing both single-channel (direct) and double-channel (mutual) distortion of the signal pulses;

FIG. 9 shows, in general block diagram form, a system for compensating the distortion produced by the substitute networks of FIGS. 7 and 8;

FIG. 10 illustrates in greater detail and by way of example, a practical realization of a compensating system according to FIG. 9;

FIG. 11*a* shows one form of a charge-transfer delay device or network suitable for use in connection with the invention;

FIG. 11*b* shows an example of a passive delay network suitable for carrying into effect the invention;

FIG. 12*a* shows a switching sequence table for the device according to FIG. 11*a*;

FIG. 12*b* shows another embodiment of charge-transfer delay device suitable for use in connection with the invention;

FIG. 13 shows, in block diagram form, a delay device embodying an analog-digital and digital-analog converter;

FIG. 14*a* is a block diagram of a transmitting system comprising a signal transmitter, a receiver and distortion compensator according to the invention; and

FIG. 14*b* is a diagram similar to FIG. 14*a* and showing a modification of the latter.

Like reference characters denote like parts and magnitudes throughout the different views of the drawings.

With the foregoing objects in view, the improved distortion correcting system or network according to the invention, according to one aspect thereof, involves generally the provision of a pulse delay device, such as a delay line or the like storage and delay network, having an input and an output for passing therethrough a series of signal pulses to be corrected, said device having a delay time substantially equal to a whole number, including unity, multiple of the spacing interval between the pulses. There is furthermore provided at least one feedforward circuit branch between said input and said output and at least one feedback circuit branch between said output and said input, suitable current amplitude and polarity control means being inserted in said branch circuits, whereby both leading and trailing distortion of the pulses may be corrected or compensated by the aid of a single or delay device or network.

In its simplest embodiment, the delay device may have a delay time equal to a single pulse spacing interval for the correction of leading and trailing pulse distortion originating from a single preceding and following pulse in a series. Where distortion caused by more than a single adjoining pulse, i.e. both leading and trailing, is to be corrected, the delay device has a total delay time equal to a multiple of a pulse spacing interval with suitable tap or intermediate coupling points being provided upon said device spaced by a pulse spacing interval, for deriving properly timed feed forward and feedback correcting signals or pulses. In this case, that is, where more than one correcting or compensating pulse is involved, the latter are combined by a pair of summation circuits or networks supplying the correcting pulses or signals for both the leading and trailing distortion correction, respectively, from the common delay device or network, in a manner as will become further apparent as the description proceeds. The proper transmission directions in the feedforward and feedback circuits or branches may be achieved either by the use of a uni-directional delay device or by the provision of uni-directional conducting devices in the circuits, such as amplifiers, rectifiers, etc.

Referring more particularly to FIG. 1, there is shown an equivalent circuit of a distorting transmission channel connecting a transmitting point A with a receiving point or station B by a distortion-free transmitting path or circuit including a pair of cascaded leading and trailing distortion producing devices or networks H_V and H_N, respectively, designed to result in a distorted received pulse signal *c* from an original transmitted signal *a* simulating the actual distortion conditions prevailing in an ordinary transmission line or channel, in the manner more clearly illustrated by FIGS. 3*a*–3*c*. This simulation of an actual transmission channel is presented for explanatory purposes, to afford a better understanding of the design and operation of the distortion compensating device described in the following.

This distortion producing networks H_V and H_N of FIG. 1 may consist of a first and second delay device or network L_1 and L_2, FIG. 2, from which the leading and trailing distorting pulses or components are derived through suitable adjustable amplitude control and polarity adjusting devices R_{-1}, R_1 and R_2 in the example illustrated. The derived distorting signals are combined in the summation circuits or devices SS_V and SS_N of the networks H_V and H_N which are connected in cascade, to first produce a signal *b* from the signal *a* subjected to leading distortion in H_V and to thereafter subject the signal *b* to trailing distortion in the device H_N, to result in the final signal distorted *c*. The delay times of the networks or systems L_1 and L_2 correspond substantially to the intervals T between the pulses being transmitted, or whole-number multiples thereof.

More specifically, each of the distorting networks H_V and H_N comprises a delay line or the like L_1 and L_2, respectively, an input of each said lines, and an output in the form of a summation device or circuit SS_V and SS_N, respectively. The summation circuit of each line is connected to a plurality of points of the respective delay line spaced by distances corresponding substantially to the spacing intervals of the pulses to be distorted, with suitable amplitude control and polarity adjusting devices R_{-1}, R_1 and R_2 being inserted in the branch circuits between the summation circuits and associated delay lines, excepting either the branch farthest from the input of the line, as in H_V, for the production of the leading distortion of the pulses, and the branch circuit being closest to the input terminal of the line, as in H_N, for the production of the leading distortion of the pulses respectively.

Thus, considering the distorting circuit as a parallel network comprising a direct branch in the main signal path and a shunt branch including the delay device in parallel to said main branch, the signal attenuator and polarity adjusting device is inserted either in series with the main branch as in H_V, FIG. 2, to produce leading pulse distortion, or in series with the shunt branch as in H_N, to produce trailing pulse distortion, respectively.

FIGS. 3*a*–3*c* more clearly illustrate the distortion of the pulses by the networks of FIG. 2, it being assumed that the original signal or transmitted pulse *a* has an instantaneous amplitude or peak value A_n in accordance with

FIG. 3*a*. Leading distortion in H_V, FIG. 2, then produces from the signal *a* a signal *b* in accordance with FIG. 3*b*, signal *b* having an instantaneous peak A_n at the instant $(n+1)T$ and an instantaneous value $r_{-1}A_n$ at the instant nT, wherein r_{-1} represents the coupling or transmission coefficient of the coupling device R_{-1}. In a similar manner, trailing distortion of the signal *b* in H_N results in the final signal *c*, FIG. 3*c*, the latter having a value r_1A_n at the instant $(n+2)T$, a value r_2A_n at the instant $(n+3)T$, the latter being assumed as negative in the example illustrated compared with r_1A_n, and an instantaneous or peak amplitude $A_n+r_1r_{-1}A_n$ with r_1 and r_2 again representing the transmitting coefficients of the devices R_1 and R_2, respectively, in the manner shown and further understood from the drawing.

With the pulses *c* being distorted, such as in the manner shown in FIG. 3*c*, to simulate the conditions of an actual transmission line or circuit, the problem now arises of producing once again from the signal *c*, having instantaneous values C_n, C_{n+1}, C_{n+2}, C_{n+3}, a non-distorted signal *a* having a peak amplitude A_n, FIG. 3*a*.

As can be readily seen from the foregoing, distortion of the signal *c* can be removed or corrected by means of a compensating device or network being similar to the distorting network of FIG. 2 and shown specifically in FIG. 4.

In the latter, wherein K_V represents the leading distortion compensator and K_N represents the trailing distortion compensator, it has been assumed that the pulses have been subjected to both leading and trailing distortion by more than one preceding and following pulse, respectively, with the control devices P_{-1} and P_{-2} assumed to compensate the leading distortion (negative subscripts) and the control devices P_1 and P_2 assumed to compensate the trailing distortion of the pulses (positive subscripts), respectively. Besides, the polarities of the correcting pulses are indicated, in the drawing, by way of examples, by the minus signs adjoining the arrows leading from P_1 and P_2.

An important factor in the arrangement according to FIG. 4, with the summation devices of both lines L_1 and L_2 being combined into a common device or circuit SS, is the sequence of the delay lines or systems L_1 and L_2, that is, such that compensation is first effected of the leading distortion of the pulses and thereafter of the trailing distortion. In other words, in the system according to FIG. 4 different signals are applied to or present, at a given instant, at the inputs of the delay devices L_1 and L_2.

It can be shown that distortion may also be corrected or removed by means of a modified arrangement of the compensator as shown in FIG. 5, wherein, in contrast to FIG. 4, the trailing distortion of the input signal is first of all compensated in K_N comprising the delay network L_2 and the summation circuit SS_2, whereupon the resultant intermediate signal *d* is freed from its leading distortion in K_V comprising the delay line L_1 and summation circuit SS_1, to obtain a final distortion-free signal *e*. In other words, in FIG. 5 separate delay lines as well as separate summation circuits are required for the suppression of both the leading and trailing distortion components of the pulses, it being of particular significance here that the input signals to both delay circuits L_1 and L_2 are identical, being derived from the same summation device or bus bar SS_2.

It is thus possible, in the manner described, to correct or compensate both leading and trailing distortion of a pulse signal by the proper design of the delay devices L_1 and L_2, as well as of the transmission coefficients and polarities of the devices P_{-1}, P_{-2}, P_1 and P_2 to correspond to or be properly related to those of an equivalent or substitute network simulating the transmission path to be corrected.

According to the improvement of the present invention, the same effect and results described in the foregoing are achieved with a simplified distortion compensating network or arrangement as shown by FIG. 6, wherein both delay lines L_1 and L_2 of FIG. 5 are combined into a single line or delay device L_0. More specifically, the circuit of the invention comprises the common delay line or device L_0 for removing or correcting both the leading and trailing distortions of an incoming signal *c*. The system for the removal of the trailing distortion, comprising the devices P_1 and P_2, and summation circuit SS_2, is again designated by K_N as in FIG. 5 and framed in a corresponding fashion in FIG. 6. The circuit and adjustment of this part of the network are identical to those shown in FIG. 5, whereby the intermediate signal *d* also appears at the input of the delay line L_0 in FIG. 6.

The delay system for removing the leading distortion designated in FIG. 5 by K_V is associated with the same delay line or device L_0 in FIG. 6. Again, the signal *d* is derived from the delay line or system L_0 as in FIG. 5 via the output devices P_{-1} and P_{-2} and fed to the summation circuit SS_1. As a consequence, the final output signal *e* of the device according to FIG. 6 is the same as the output signal in FIG. 5 and, accordingly likewise corresponds, except for negligible departures, to the original non-distorted signal *a*.

In other words, in FIG. 6, the input signal *c* applied to SS_2 and passed, in the direction of the arrow, to SS_1 through L_0 is corrected at point **1** of L_0 by the feedback signals of both P_1 and P_2, to remove the trailing distortion from the signal in the manner pointed out, or to produce an intermediate signal *d* which is then, in turn, corrected at point **3** of L_0 by the forward feed signals of both P_{-1} and P_{-2}, to remove the leading distortion from the signal *d*, to result in the final corrected signal *e*.

If the delay device L_0 is of the unidirectional type, as indicated by the arrow and constructed for instance as shown by FIGS. 11*a* and 12*a*, the feedforward and feedback circuits may be connected in the manner shown. If, on the other hand, the delay device is of the bidirectional type, as shown by FIG. 11*b*, suitable unidirectional conducting devices (amplifiers, diodes, etc.) may be inserted in the circuits, as indicated by the additional arrows adjoining the summation circuits.

FIG. 6*a* shows a simplified compensator arrangement according to the invention for the special case where the signal pulses *c* to be corrected have been subjected to both leading and trailing distortion by a single preceding and following pulse only, whereby the line L_0 may have a length corresponding to a single spacing interval between the pulses, compared with the line L_0 of twice said interval in FIG. 6.

With reference to the removal or suppression of the amplitude distortion, let it be assumed that the amplitude values transmitted by the coupling members R_{-1}, R_2, R_3 for the leading distortion of the system L_1 of the FIG. 2 are designated by r_{-1}, r_1, r_2. In this case, it may be calculated that the following coupling factors will result in a substantial compensation of the leading distortion in K_V of both FIGS. 5 and 6:

$$p_{-1}=r_{-1} \text{ and } p_{-2}=r^2_{-1}$$

In order to compensate for the trailing distortion, the same coupling factors $p_1=r_1$ and $p_2=r_2$ may be used in K_N as in the simulation H_N of the transmission channel of FIG. 2. This, in turn, leads to an instantaneous value E_n of the output signal *e* substantially agreeing, with the exception of a small error, with the instantaneous values A_{n-1} of the original signal, being three steps in advance, as follows:

$$E_n=A_{n-3}+r^3_{-1}\cong A_{n-3}$$

The error r^3_{-1} is in general comparatively small, that is, the amplitude distortion is reduced to a negligible value. If required, the error may be further reduced by an increase of the number of stages of the delay device.

The transmission system may comprise several parallel transmission channels with a certain amount of mutual coupling obtaining between neighboring channels. These couplings produce additional distortion, which may be likewise corrected by the improved compensating means according to the invention.

FIGS. 7 and 8 illustrate, by way of example, the simulation of two adjacent transmission channels, connecting a transmitter A with a receiver B, with the input signals of the channels being designated by a' and a'', and with the output signals being designated by c' and c'', respectively. Each channel comprises a leading distorter H'_V and H''_V and a trailing distorter H'_N and H''_N, respectively as in FIG. 1. Again, if there is mutual coupling between the channels, a distinction must be made between the leading and trailing mutual distortions,, the occurrence of which is represented by the additional distorting circuits or networks H'_W, H''_W and H'_M, H''_M, respectively.

Experience has shown that the leading distortion acting on a neighboring channel usually is of little importance in practice. The corresponding networks H_W are accordingly indicated by dashed lines in FIGS. 7 and 8, as also are the corresponding correction networks K_W in FIGS. 9 and 10. From the intermediate signals b', b'', trailing distortion in H_N and H_M produce the final distorted or output signals c' and c'' of the transmission channels.

In FIG. 8, which substantially corresponds to FIG. 7, the various distorting networks H_V, H_N, H_W and H_M are shown in greater detail and by way of example, the direct leading distortion couplings being designated by R'_{-1} and R''_{-1}, the direct trailing distortion couplings being designated by P'_1, P'_2 and P''_1, P''_2, the leading mutual distortion couplings being designated by S'_0, and S'_{-1} and S''_0, S''_{-1} and with the trailing mutual distortion coupling being designated by Q'_0, Q'_1, Q'_2, and Q''_0, Q''_1, Q''_2, respectively.

FIG. 9 shows in general block diagram form a distortion correcting system for removing the leading direct and mutual distortions by the networks K'_N, K''_N and K'_M, K''_M, and for removing the trailing direct and mutual distortion by the networks K'_V, K''_V and K'_W, K''_W, respectively, to convert the received distorted signals c' and c'' into the final distortion-free signals e' and e'' via the intermediate signals d' and d'', respectively.

FIG. 10 shows, by way of example, a more detailed distortion compensating system according to the invention embodying two delay lines L'_0 and L''_0 only for the removal of all the direct and mutual distortions, both leading and trailing, from the signals c' and c'', the leading and trailing distortion couplings for one channel being designated by P'_{-1}, P'_{-2} and P'_1, P'_2, the leading and trailing distortion couplings for the other channel being designated by P''_{-1}, P''_{-2} and P''_1, P''_2, the mutual leading and trailing distortion couplings for the first channel being designated by Q'_{-0}, Q'_{-1}, Q'_{-2} and Q'_0, Q'_1, Q'_2, and the mutual leading and trailing distortion couplings of the second channel being designated by Q''_{-0}, Q''_{-1}, Q''_{-2}, and Q''_0, Q''_1, Q''_2, respectively. Connection of the coupling devices with the associated delay devices L'_0 and L''_0 and summation circuits SS'_1, SS''_1, SS'_2 and SS''_2 is substantially the same as in FIG. 6, whereby to provide direct leading distortion compensators K'_N, K''_N, direct trailing distortion compensators K'_V K''_V, mutual leading distortion compensators K'_M, K''_M, and mutual trailing distortion compensators K'_W, K''_W, respectively, in the manner shown and understood from the foregoing.

If no leading distortion between the channels has to be taken into account, the distorting networks H_W indicated by dashed lines in FIGS. 7 and 8 may be omitted, as may be the distortion-removing networks K_W indicated in dashed form in FIGS. 9 and 10.

It may again be shown by calculation that, in order to remove a substantial amount of the distortion, the following coupling values p_{-1}, p_{-2} may be used advantageously for the leading distortion removers K'_V and K''_V:

$$p'_{-1}=r'_{-1};\ p'_{-2}=r'^2_{-1}$$
$$p''_{-1}=r''_{-1};\ p''_{-2}=r''^2_{-1}$$

As a consequence, there are obtained the following instantaneous values of the corrected output signal:

$$E'_n=A'_{n-3}+r'^3_{-1}A'_n\cong A'_{n-3}$$
$$E''_n=A''_{n-3}+r''^3_{-1}A''_n\cong_{n-3}$$

The factors r^3_{-1} may in general be neglected, that is, the instantaneous values E_n of the received and corrected signals correspond with a high degree of accuracy to the instantaneous values A_{n-3} three steps in advance of the transmitted signals.

In the device according to FIG. 10, a single delay system in each case, L'_0, or L''_0, is sufficient to correct for leading and trailing distortion within a channel, and these systems additionally serve to correct for coupling distortion between the channels, whereby to result in quite a considerable reduction of parts or apparatus compared with the known compensating devices or systems according to the prior art.

FIG. 11*a* shows, by way of example, an active unidirectional delay device, operating on the principle of electric charge storage and transfer and being suited for the purposes of the invention. In the arrangement shown, the terminals **1**, **2**, **3** correspond to those of the device L_0 of FIG. 6. In operation, let it be assumed that the capacitors C_1 and C_2 have been charged to a definite instantaneous value of a signal pulse to be delayed or transmitted. The electronic switches X_1-X_4 are now briefly closed one after another in rapid sequence, such as by means of an electron beam distributor X cooperating with said switches as indicated schematically by the dot-dash lines x, in a manner first to discharge the capacitor C_2 via X_1, to subsequently transfer the charge of C_1 to C_2 via X_2, and to finally completely discharge C_1 via X_3 and to recharge the same via X_4 to the instantaneous voltage appearing at the terminal **1** at the commencement of a new operating or switching cycle. As a consequence, provided the use of a sufficiently high switching frequency compared with the pulse recurrence frequency, the instantaneous values of the applied pulse signals will be delayed by the sequential charging and discharging of the capacitors C_1 and C_2, to provide suitable correcting signals or pulses at the terminals **1**, **2**, **3** in the manner described and understood from the foregoing. If desired or necessary, additional capacitors and associated charging and discharging switches may be interposed between the capacitors C_1 and C_2, to increase the number of incremental charges and transfers, or resulting delays of the pulses being transmitted.

FIG. 11*b* is a circuit diagram a distortion compensator according to the invention utilizing a passive bidirectional delay line or circuit L_0 comprised in a known manner of series inductances **1** and parallel capacities c, the input signal c being applied to and the feedback signals being derived from said line through coupling transformers T_1, T_2, T_3 via feedback regulators P_1, P_2, and the output signal e and feedforward signals being derived from said line through coupling transformers T'_1, T'_2, T'_3, respectively, and via feedforward regulators P_{-1}, P_{-2}, in substantially the same manner as in FIG. 6. In this case, the polarities of the correcting signals or pulses may be simply controlled by the proper winding sense or connection of the coupling transformers.

A further example of an active delay system suitable for use in connection with the invention is shown by FIG. 12*b*. In this figure, the connections disposed on z_1, as indicated by the circles in the drawing, are first closed by electronic switches, so that the voltages on the terminals **1**, **2**, **3** appear across the capacitors C_4, C_3, C_2. During the next step of switching, the connections disposed on z_1 are opened and the connections disposed on z_2 closed. The voltages previously appearing on **1**, **2** now appear at 2, 3. At the same time, the capacitor C_2 being discharged via E and C_1 is connected to the terminal 1. The connections on z_3, z_4, z_1 . . . are closed in further steps and in periodic sequence, whereby to cause the stored quantities to change over each time from 1 to 2 and from 2 to 3, respectively. Thus, in the case of this switching system, the storage capacitors $C_1 - C_4$ are connected in cyclic sequence, according to the program of FIG. 12*b*, to the terminals 1, 2, 3 and E.

In the examples of FIGS. 11*a* and 12*b*, each instantaneous signal value is stored in analog form as a voltage of corresponding amplitude. According to an improved feature of the invention, as shown in FIG. 13, the instantaneous signal values applied by way of the terminal 1 may be converted, prior to their being stored, into digital pulse trains by binary coding in the analog-digital converter AD, whereby they provide, for instance, simultaneous output pulses D^1_n–D^4_n at the output of AD. The latter pulses are then stored by one interval in the digital delay device LD at the output of which will appear the simultaneous pulses D^1_{n-1}–D^4_{n-1} coordinated to the preceding instantaneous value D_{n-1}. This instantaneous value thus appears at the output of the digital-analog converter DA, and is derived via terminal 2. The instantaneous value D_{n-2}, which is delayed by a further step, is generated in the same manner in LD_2 and DA_2 and appears at terminal 3.

The device shown in FIG. 6 may naturally also be constructed in digital fashion. In this case, the input signal *c* is changed into digital form by known means and the output signal *e* is re-converted into analog form. The regulators P_{-2}, P_{-1}, P_1, P_2 then take the form of product forming circuits or networks in which the signals derived in binary form via 1, 2, 3 are multiplied in accordance with the rules of digital calculation, with each of the respective coupling values likewise being provided in binary form. In this case, the summation circuits SS_1 and SS_2 are also constructed in accordance with the rules of binary addition.

It should finally be noted that digital or coded signals may also be utilized in connection with a delay device according to FIG. 12*b*. In this case, the terminals 1, 2, 3 may be replaced by four connections via which corresponding coded pulse trains are introduced and derived, respectively, instead of the analog signals. The capacitors C_1, C_2 . . . must also be replaced by four capacitors, and likewise the change-over points disposed on z_1, z_2. This enables the corresponding coded pulse trains, designated by D^1_n . . . D^4_n in FIG. 13, to be stored instead of the single analog signals, designated by D_n in the figures. Finally, the digital delay system may use other known storage or delay devices, such for example, as magnetic ring stores, taking the place of the storage capacitors.

In FIG. 14*a*, there is shown, in block diagram form, a complete transmission channel including a signal transmitter T and a signal receiver. The distortion correction device K is arranged at the receiving end or station that is, following the distorting transmission channel indicated by H. Alternatively, the distortion correcting device K may also be disposed at the transmitting end as shown by FIG. 14*b*, whereby the pre-distorted signals *c*, appear at the input of the transmission system H. In this case distortion is also completely removed from the received signal in the manner described, the sequence of the networks H and K having no effect if correctly designed or matched to the transmitted signal *a*.

A certain disadvantage of the arrangement according to FIG. 14*a* is the fact that any interference appearing in the received signal *c* will be amplified by the action of the pulse correction device K. The cause of this undesired phenomenon resides in the fact that the signal *e* at the output of the correction device, for example in FIG. 6, corresponds not only to a definite instantaneous value of the applied interfering signal, but rather to the sum of the values of several preceding interference signals. This disadvantage is avoided with the device according to FIG. 14*b*, since, in the absence of a correction at the receiving end, only the instantaneous value of the received interference is contained at any particular time in the signal *c*. There is nevertheless the disadvantage in this case that it is somewhat more difficult to adjust the correction device, since the corrective action at the transmitting is less easily recognized.

In certain cases, the correction may also be subdivided and it is then advantageous to arrange for a coarse correction at the transmitting end and for fine correction at the receiving end, respectively.

There is thus provided by the invention a relatively simple and efficient distortion correcting system or device for removing both leading and trailing pulse distortion in a pulse signal transmission system. The invention, while being of special use in pulse amplitude modulation by suppressing or minimizing amplitude distortion and improving the quality of the signal transmission, equally applies to either transmission systems utilizing equi-spaced pulses for the prevention of crosstalk, such as in time-division multiplex transmission, or generally for the reshaping or restoring of the pulses distorted by a transmission line or channel.

In the foregoing the invention has been described in reference to a specific illustrative device or embodiment. It will be evident, however, that variations and modifications, as well as the substitution of equivalent elements or circuits for those shown herein for illustration, may be made without departing from the broader scope and spirit of the invention as set forth in the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than in a restrictive sense.

I claim:

1. A pulse distortion correcting system for use in electric signal transmission by means of equi-spaced signal pulses, preceded and followed, respectively, by both leading and trailing distorting components, comprising in combination:

(1) a single delay device having at least one input and one output coupling point with means for passing the pulses to be corrected from said input coupling point to said output coupling point,

(2) the difference in transmit time of said device between said coupling points being equal to the spacing intervals between said signal pulses,

(3) at least one unidirectional feedforward circuit, in respect to the signal passing direction through said device, between said input and said output coupling points,

(4) at least one unidirectional feedback circuit, in respect to the signal passing direction through said device, between said output and said input coupling points, and

(5) current amplitude control and polarity adjusting means in both said feedforward and feedback circuits,

(6) to substantially cancel, in the output of said device, both the leading and trailing distorting components of said signal pulses.

2. A pulse distortion correcting system as claimed in claim 1, said delay device including analog-digital converting means to convert instantaneous signal values of the pulses to be delayed into digital pulse trains, digital storage and delay means to delay said digital pulse trains, and digital-analog converting means to re-convert the delayed digital pulse trains into corresponding analog signal values.

3. A pulse distortion correcting system as claimed in claim 1, said device having a transit time equal to a multiple of the pulse spacing interval, additional feedforward and feedback branch circuits connected to intermediate coupling points of said device spaced in respect to the

signal transit time from each other and said input and output coupling points by intervals equal to the pulse spacing interval, respectively, and further current amplitude and polarity control means inserted in said additional circuits.

4. A pulse distortion correcting system as claimed in claim **3**, said delay device being comprised of an artificial delay line.

5. A pulse distortion correcting system as claimed in claim **3**, said delay device being comprised of a plurality of storage capacitors in cascade and periodic switching means to sequentially charge one capacitor by instantaneous signal values of a pulse to be delayed and to transfer the charge stored to the next following capacitor at a switching frequency being high compared with the pulse recurrence frequency.

6. A pulse distortion correcting system for use in electric signal transmission by means of equispaced signal pulses, preceded and followed, respectively, by both leading and trailing distorting components, said system comprising in combination:

(1) a single delay device having an input and an output coupling point,

(2) a first summation device having a first input with means to apply thereto the signal pulses to be corrected, a second input, and an output connected to the input coupling point of said delay device,

(3) a second summation device having a first input connected to the output coupling point of said delay device, a second input, and an output with means to derive therefrom the corrected signal pulses,

(4) a plurality of unidirectional feedforward circuits connected between the input coupling point and at least one intermediate coupling point of said delay device, on the one hand, and the remaining input of said second summation device, on the other hand,

(5) a plurality of unidirectional feedback circuits connected between the output coupling point and at least one intermediate coupling point of said delay device, on the one hand, and the remaining input of said first summation device, on the other hand,

(6) the difference in transit time in said delay device for the signal between adjacent input, intermediate and output coupling points thereof being equal to the spacing intervals of said signal pulses, and

(7) current amplitude control and polarity adjusting means in each of said feedforward and feedback circuits,

(8) to substantially cancel, in the output of said second summation device, both the leading and trailing distorting components of said signal pulses.

7. In combination with a multi-channel transmission system comprising at least two channels, each including a distortion correcting network according to claim **6**, means to correct mutual distortion between neighboring channels comprising additional first and second sets of compensating (feedforward and feedback) circuits for the delay devices in each said channels, corresponding connecting points of the compensating circuits of the additional sets of the delay device of one channel being cross-coupled with corresponding connecting points of the compensating circuits of the additional sets of the delay device of the other channel.

8. In a pulse distortion correcting system according to claim **7**, wherein the delay device in each said channels is provided with a first pair of sets of compensating circuits designed to correct direct distortion, both leading and trailing, originating in the respective channels, and wherein each delay device is further provided with a second pair of sets of compensating circuits being mutually cross-coupled and designed to correct at least the mutual trailing distortion between the channels.

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