

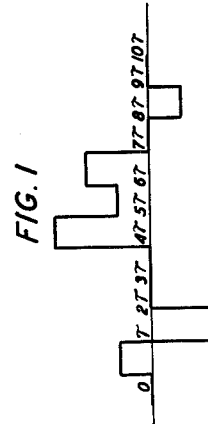
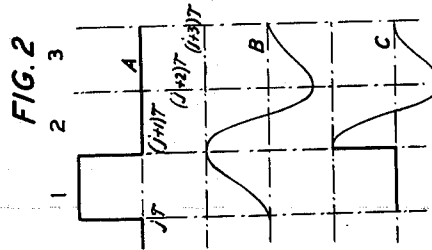
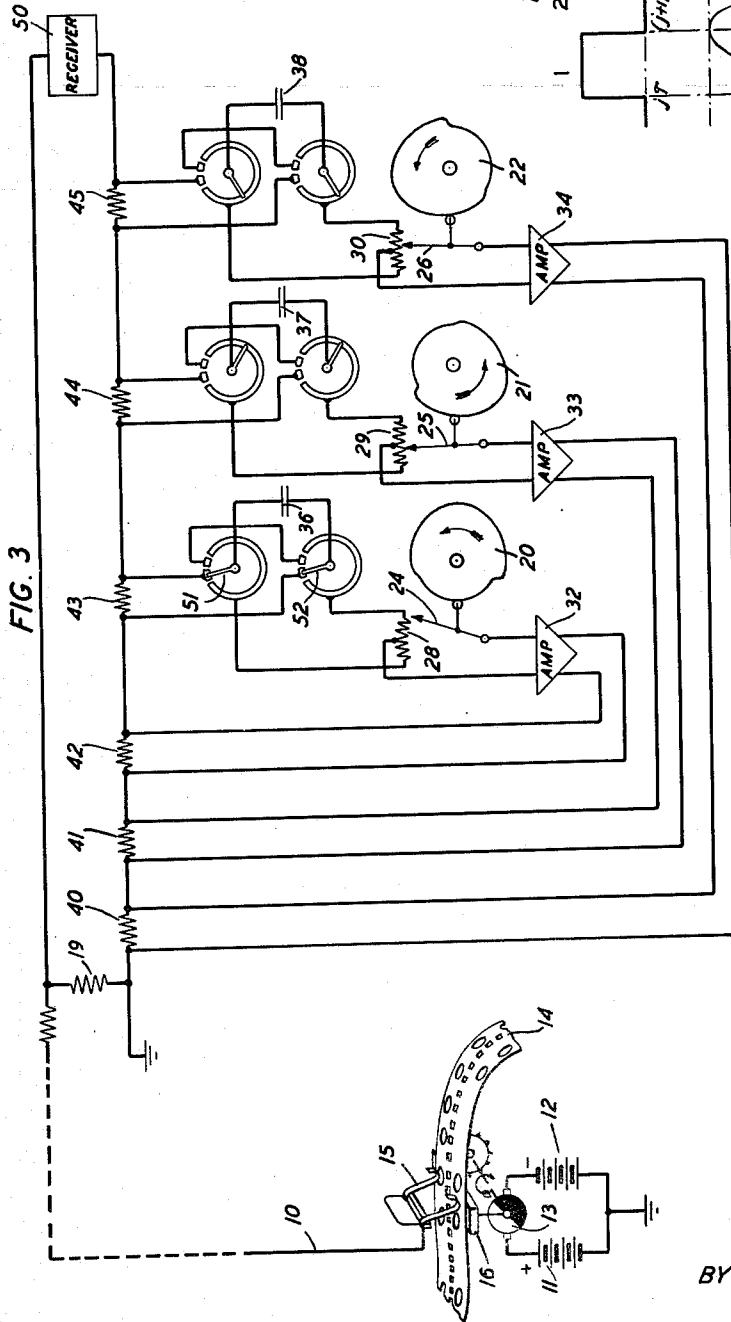
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SIGNALING METHOD AND APPARATUS

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SIGNALING METHOD AND APPARATUS

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The present invention relates to signaling through media which distort the signal waves and to method and means for compensating or correcting for the distortion to a substantial extent.

Distortion in a transmission medium is either linear or non-linear. In the former no new frequencies are produced by the transmission medium. In the latter new frequencies are produced. In the former, waves of several frequencies simultaneously present, add algebraically to give the resultant arrival wave. In the latter there is also a multiplication of wave components, and the new frequency components referred to are the products of such multiplication.

The present invention deals only with linear distortion. In linear systems of some types and ranges of constants, the phase and amplitude distortion may be excessive, resulting in arrival waves of forms that are different from that of the sent impulses during the period corresponding to the duration of the sent impulse and that also persist beyond the time corresponding to the duration of the sent impulse. If, then, two impulses are sent out with an interval of no impressed current between them, the arrival current or voltage wave may, for example, not fall to zero between the wave portions corresponding to the two sent impulses, but the receiver may have applied to it a voltage of some value more or less all the time, rendering reception of discrete impulses difficult. The arrival wave resulting from a single sent impulse may even extend over into or beyond the time interval corresponding to the next sent impulse, and for a sent impulse of given polarity the arrival wave may undergo reversals of polarity during times later than the time corresponding to the duration of the sent impulse. An impulse applied to the system may give rise to transient effects which have the appearance of a whole succession of impulses.

The portion of the arrival wave which persists beyond the period of duration corresponding to that of the sent impulse is termed "intersymbol" interference. It is the part of the wave which tends to fill up the interval between the sent impulses when the current or voltage should fall to zero.

An object of the present invention is to reduce intersymbol interference.

The manner of carrying out this and other objects of the invention, as well as an understanding of the invention and its various aspects and objects, will be had from the following detailed description taken in connection with the accompanying drawing, in which

Figs. 1 and 2 show diagrams of wave forms to be used in the description, and

Fig. 3 is a simplified schematic circuit diagram

of one system embodying the invention by way of example.

It is theoretically possible according to the invention to transmit signals over any physical transmission system at any speed and in such manner that the message at the receiving end has the same duration as the message at the sending end. The theoretical possibility is based on the assumed validity of ordinary circuit theory. Practically, an attempt to obtain exceedingly high speed would run into difficulties due to the electronic effects.

It is to be understood throughout the discussion that only real physical systems are under consideration; no ideal apparatus, such as filters which absolutely suppress certain bands of frequencies, are postulated. The transmission system proper, that is aside from the sending and receiving apparatus, is assumed to be linear.

To simplify the exposition, consider first direct current telegraphy with machine sending so that accurately timed signals of equal impulse duration are sent. At the sending end of the system any message expressed, say, as a potential-time curve, is constant in each of the time intervals $0 < t < \tau$, $\tau < t < 2\tau$, $2\tau < t < 3\tau$, . . . , but the constant value may be different in different intervals. From the physical point of view there is no difference between one message and several successive messages; hence there is no loss in generality in confining the discussion to a single message.

The quantity τ , the duration of a signal element at the sending end, is quite arbitrary, but in the case of any one particular system it is set once for all. It is understood that the constant value which the curve has in any one interval is limited to one of a finite number of possible values, including the value zero. There is no loss in generality in assuming that the message has the value zero for all negative values of t . A simple example of such a message is shown in Fig. 1.

Now consider the single element of the sent message which occupies the interval $j\tau < t < (j+1)\tau$, where j is zero or an arbitrary positive integer. This element is shown at A in Fig. 2, and it will be denoted by $f_0(t-j\tau)$. This element will give rise to a particular elementary current wave at the receiving end which will be denoted by $f(t-j\tau)$. (The delay in the transmission system has been neglected here. This amounts to using different zeros of time at the two ends of the system.) The important properties of the latter function are that it vanishes for $t < j\tau$, that it has appreciable values for some values of t greater than $(j+1)\tau$, and that its form differs more or less widely from that of $f_0(t-j\tau)$. A typical example of $f(t-j\tau)$ might have a form somewhat like that shown at B in Fig. 2. Each element of the message at the sending end will give rise to such an elementary current at the receiving

end, having the proper magnitude (including sign) and position in time. The algebraic sum of these elementary current waves is the received signal wave. It is clear that the form of the received signal wave will differ from that of the sent signal wave, both because the different elementary current waves overlap (intersymbol interference) and because each of them individually differs in form from the corresponding element of the sent message. This difference between the forms of the sent signal and the received signal makes the interpretation of the received signal more or less difficult.

Consider the function $f_1(t-j\tau)$ which is obtained from $f(t-j\tau)$ by making the function equal to zero in the interval $j\tau < t < (j+1)\tau$. In the case in which $f(t-j\tau)$ is as shown at B in Fig. 2, the function $f_1(t-j\tau)$ is as shown at C in Fig. 2. It is easy to imagine a machine which would generate a current wave having the form $f_1(t-j\tau)$. For example, this could be done by a properly shaped template driving a contact over a rheostat. Such a machine will be called a corrector. Assume that at the receiving end there are as many correctors, say N , as there are intervals of length τ in which $f(t-j\tau)$ is appreciably different from zero. Assume that the first corrector is set to generate the currents $C_{11}f_1(t)$, $C_{12}f_1(t-N\tau)$, $C_{13}f_1(t-2N\tau)$, . . . , that the second corrector is set to generate the currents $C_{21}f_1(t-\tau)$, $C_{22}f_1(t-\tau-N\tau)$, $C_{23}f_1(t-\tau-2N\tau)$, . . . , that the third corrector is set to generate the currents $C_{31}f_1(t-2\tau)$, $C_{32}f_1(t-2\tau-N\tau)$, $C_{33}f_1(t-2\tau-2N\tau)$, . . . , and so on, where the C 's are, for the present, arbitrary constants.

Now consider the reception of the message. There is no intersymbol interference during the interval $0 < t < \tau$; the current during that interval depends only on the magnitude of the first element in the sent message. Consequently, any particular measurement on the current during that interval, say of its integral over the interval or of its magnitude at the center or latter end of the interval, gives complete knowledge of the first element of the sent message. Let this measurement set the first corrector to generate the current $C_{11}f_1(t)$, where C_{11} is given a value proportional to the magnitude of the first element. This setting is maintained until $t = (N+1)\tau$ when the corrector is reset in a manner to be described presently. The current generated by the corrector can be subtracted from the received signal wave, with the result that all signal elements following the first are freed from the intersymbol interference due to the first. The second element in the received signal is now free from intersymbol interference, and any particular measurement on it will determine the magnitude of the second element in the sent signal. Let this measurement set the second corrector to generate the current $C_{21}f_1(t-\tau)$, where C_{21} is proportional to the magnitude of the second element. This setting is maintained until $t = (N+2)\tau$. When the current generated by the corrector is subtracted from the received signal the signal is freed from intersymbol interference due to the second element. This process is continued until all of the correctors are in operation.

After $t = N\tau$ there is no need to continue the correction for the intersymbol interference due to the first element. Hence, the measure of the $(N+1)^{\text{th}}$ element of the signal is caused to set the first corrector to generate the current $C_{12}f_1(t-N\tau)$, where C_{12} is proportional to the

magnitude of the $(N+1)^{\text{th}}$ element, and this current is subtracted from the signal wave to eliminate the intersymbol interference due to that element. Likewise, the determination of the magnitude of the $(N+2)^{\text{nd}}$ element is caused to set the second corrector to eliminate the intersymbol interference due to that element. And so the process continues.

In this way the message can be received without intersymbol interference and interpreted. It is to be noticed particularly that the transmission characteristics of the transmission system have no effect on the speed of signaling, and that the only way in which they enter is in their controlling influence on the number and construction of the correctors, within the limitations noted above in case of exceedingly high signal speeds. Furthermore, it is to be noted that the duration of the corrected received signal is precisely equal to that of the sent signal. Hence we have the proposition: it is possible, using only apparatus which is in principle easily constructed, to signal through any transmission system at any speed and in such a manner that the time required to receive and interpret the message is equal to the time required to put the message on the line.

The foregoing general description of the principle of the invention having been given, a practical embodiment of the invention in the form of a telegraph system will now be described as illustrated in Fig. 3.

This figure shows a transmitting station at the left and a receiving station at the right, connected by the line 10, which may be a land line or a submarine cable. Oppositely poled batteries 11 and 12 have a common ground and their ungrounded poles are connected to the brushes of a rotating commutator 13 carrying on its same shaft a drive for a sending tape 14 which is assumed to be punched to represent signals. Brushes 15 reach through the punched holes and make contact with metal platen 16 causing a positive or a negative impulse to be sent to line depending on the position of commutator 13 when a hole in the tape is underneath a brush 15. This showing of the sender is merely symbolic and is intended to represent any suitable type of which many are known in the art. With the type of sender indicated, a space is denoted by zero current, a dot by one polarity of current and a dash by the opposite polarity. The duration of all the symbols is the same.

A positive impulse as sent is of the form shown at A in Fig. 2. As received, the impulse is assumed to have the form shown at B. This represents intersymbol interference extending throughout two signal intervals after the interval corresponding to the sent signal. Hence three correctors of the type above discussed are provided at the receiving station.

These are shown as comprising rotating cam mechanisms and associated elements, the cams being shown at 20, 21, and 22. As these cams rotate they cause contacts 24, 25, and 26, respectively, to move along potentiometer resistances 28, 29, and 30 for impressing correcting impulses on the amplifiers 32, 33 and 34. The potentiometers derive their voltages from condensers 36, 37, and 38 in a manner to be described.

It is thought that the construction can best be understood by tracing through the operative steps. For simplicity it will be assumed that the first impulse is being received over the system and that, therefore, there is no intersymbol in-

interference to begin with. The impulse of form B in Fig. 2 is received over the line 10 and passes partly through resistance 19 to ground and partly through the resistances 40 to 45 inclusive and receiver 50, actuating the latter. At some suitable instant in the arrival interval, for example, near the center, switches 51 and 52 pass over fixed contacts connected across resistance 43 placing a charge on condenser 36 of a voltage corresponding to that of the received impulse. Immediately thereafter in their counter-clockwise movement switches 51, 52 connect condenser 36 across resistance 28, which is so high as not to cause appreciable discharge of the condenser during the correcting period. At this time, that is, during the signal arrival interval designated interval #1 in Fig. 2, cam mechanism 20 is operating over a circular portion of its surface and contact 24 is held off the end of resistance 28 so that no voltage is impressed on amplifier 32. Referring to curve C, Fig. 2, zero correcting voltage is being developed during interval #1. At the end of this interval, however, a high region on cam 20 begins to move contact 24 along resistance 28, applying initially a relatively high voltage to amplifier 32, the amplified output of which is impressed on the resistance 42 in such phase as just to nullify the intersymbol voltage represented at B, Fig. 2. As cam 20 continues to move contact 24 along resistance 28 a voltage is developed in the input to amplifier 32 which follows in magnitude and sign the form of the correcting curve C, Fig. 2. Reversal of sign occurs when contact 24 passes the center of resistance 28 at the end of interval #2. Toward the end of interval #3, switches 51, 52 place a short circuit across condenser 36 and discharge it in preparation to receive a new charge when these switches connect it again to line resistance 43.

If only the one impulse had been sent as assumed in the three intervals that have been considered, condensers 37 and 38 would not receive any charge from the line and cam mechanisms 21 and 22 would be of no effect. However, with successive impulses on the line these mechanisms operate in succession in the same manner as has been described of cam 20 and its associated elements. The sequence of events is then as follows: The first signal element is free from intersymbol interference. Cam 20 as described generates correcting potentials for intervals #2 and #3. This insures that interval #2 is free of intersymbol interference. If interval #2 contains a received signal element, cam 21 and associated mechanism generates correcting currents for intervals #3 and #4, leaving interval #3 free. If interval #3 contains a received impulse, cam mechanism 22, etc., corrects intervals #4 and #5, leaving interval #4 free of interference. Cam mechanism 20, etc., then can operate as before to correct intervals #5 and #6, leaving interval #5 free, and so on.

While the invention has been illustrated and described as applied to a telegraph system, it is not to be construed as limited to any particular type or form of signaling system, since it is capable of general application as demonstrated in the discussion heretofore given. Its application in practice to systems employing complicated wave forms is limited only by the difficulty of providing correctors of sufficient num-

ber and complexity to effect the necessary correcting operations.

One important aspect of the invention is the secrecy of transmission which it makes possible. The transmission band of the line may be made so narrow in comparison with the speed of signaling that the intersymbol interference will be sufficiently great to make the signals incapable of intelligible reception without the aid of specially constructed correctors in the general manner herein disclosed.

What is claimed is:

1. The method of signaling over a medium which produces linear distortion in the transmitted waves comprising determining the characteristic distortion of an arrival wave in the intersymbol intervals only, producing at a receiving point a compensatory type of wave, and opposing the compensatory wave to the arrival wave to reduce intersymbol interference.

2. In a signaling system, means at a sending station to impress impulses of current on a line in a succession of signal time intervals for transmission thereover, said line producing linear distortion in the transmitted impulses such that the arrival wave resulting from a sent impulse of one polarity is prolonged beyond the time interval corresponding to the sent impulse and over into the time interval corresponding to the next sent impulse and undergoes a reversal of polarity, and means at a receiving station on said line for substantially annulling the prolonged effect of such an arrival wave beyond the time interval corresponding to the sent impulse.

3. The method of secret signaling over a system producing linear distortion but negligibly small non-linear distortion comprising transmitting at a signaling speed so high that the intersymbol interference effectively masks the signals and at a distant receiving point of said system reducing the intersymbol interference sufficiently to enable the signals to be interpreted.

4. In a system for transmitting signal impulses with linear intersymbol distortion, means at a receiving point for producing a voltage wave corresponding in magnitude and polarity to the intersymbol interference produced by each elemental signal impulse to be received and means for combining received waves with said produced waves in such phase as to compensate the intersymbol interference while preserving the signal impulses.

5. In a signaling system producing linear distortion in transmitted waves, means at a receiving point for producing waves of magnitude and form predetermined from the distortion characteristic of the system, means determining the operation of said first means in the interval corresponding to that in which a signal impulse is being sent, and means causing said first means to begin to operate to neutralize received waves at the end of said interval.

6. In a signaling system producing linear distortion in transmitted waves, means at a receiving point timed in its operation to receive a voltage from the line during the interval corresponding to the interval of a sent impulse and to produce therefrom a wave similar in shape to the distortion, and means opposing such produced wave to the received wave to compensate such distortion.

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