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APPARATUS FOR MEASURING DATA SIGNAL IMPAIRMENT

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FIG. 1

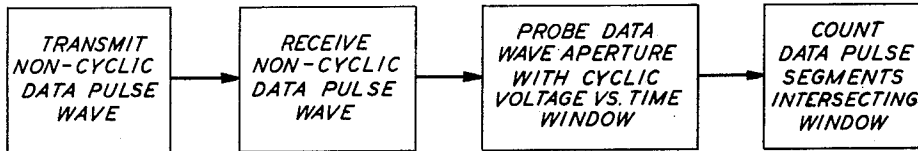


FIG. 2

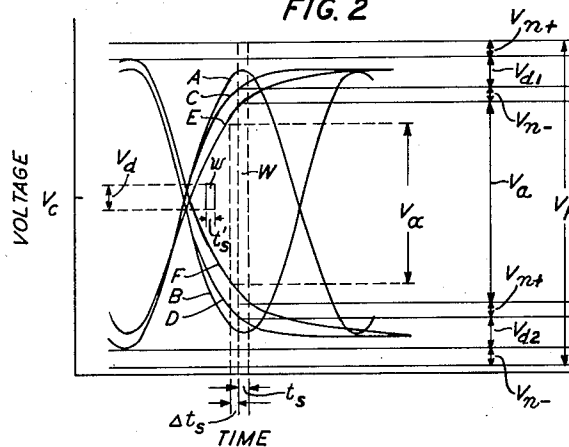
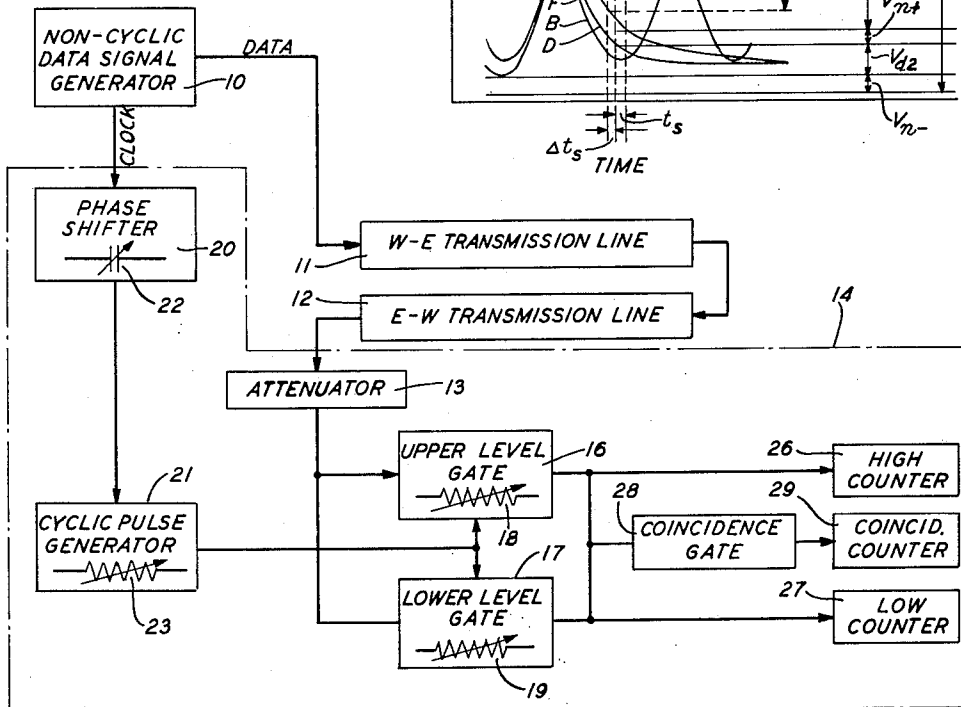


FIG. 3



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APPARATUS FOR MEASURING DATA SIGNAL IMPAIRMENT

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13 Claims. (Cl. 178-69)

This invention relates to a means for measuring the impairment of a data signal.

In data transmission systems information is transmitted in the form of a binary code comprising mark and space signals which are either positive-going or negative-going electrical impulses. Such signals are similar to ordinary telegraph signals but are characterized by bit transmission rates roughly one hundred times higher than telegraph transmission rates. The binary coded information may, in a data system, represent combinations of numbers or letters with only symbolic significance; and these combinations may not, therefore, be directly readable as the ordinary written word.

A data receiver includes means for sampling each data bit and a detector for deciding whether each sample was taken from a mark or a space. However, signal impairments of different types can cause marks to be detected as spaces and vice versa. For example noise may change the amplitude of a bit sufficiently to cause an error; distortion may change the time phase of a bit with respect to the phase of the receiver sampling operation to cause an error; or a shift, or jitter, in the time of occurrence of the sample-taking operation may also cause errors. Accordingly, it is desirable to know the range of possible signal impairment in a data transmission system in order that system equipment may be designed, maintained, and adjusted to provide adequate operating margins which are consistent with the error rate which the particular system can tolerate. Since the tolerable error rate is the criterion of transmission effectiveness, it would be convenient to measure impairment in terms of the tolerable error rate. There is, however, no convenient way to recognize an error immediately after mark-space detection unless a special error checking circuit is employed or unless the transmitted signal is also reproduced at the receiver by a slave generator for comparison with the received signal.

It is possible to obtain some idea of signal impairment in data systems on a qualitative basis by superimposing upon the screen of a cathode ray oscilloscope the traces of a series of successive data pulses. The traces of superimposed mark and space pulses enclose an area, hereinafter called the data wave aperture, having a size and configuration which are a function of signal impairment due to noise and distortion. If one is observing the screen at the time of an error, a momentary reduction in the size of the aperture will be noted. However, in order to detect errors accurately in such a visual arrangement it is necessary to keep the oscilloscope screen under observation at all times. For this reason, and others, the visual method is not entirely satisfactory for determining the accuracy of mark-space detection in a data system under different conditions.

Accordingly, it is one object of the invention to measure data signal impairment.

Another object is to improve data transmission systems by determining operating margins for the systems and thereby facilitate the design of system components.

A further object is to obtain a quantitative evaluation of a data transmission system.

An additional object is to measure data signal impairment in terms of predetermined data error rates.

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These and other objects of the invention are realized.

In an illustrative embodiment which includes a particular combination of voltage-sensitive gate circuits and counting devices so arranged that only pulses of certain amplitudes will be counted. A cyclic sampling voltage generator, which is precisely synchronized with the data pulse wave, actuates the gates for a predetermined time once during each data bit. The sampling time and the gate voltage-passing amplitudes would define a rectangular area, or window, in the aperture of a synchronized oscilloscope trace of the data wave. The window may be altered in size and moved about the aperture by adjusting the sampling time and the gate voltages, and data bit samples which have instantaneous amplitudes lying in the window are counted. If the window is positioned for a sample count which bears a predetermined relationship to the tolerable error rate of the measured system, the voltage dimensions of the aperture can be determined from the gate settings. Certain other characteristics of the data wave can also be determined in a similar manner in terms of specific voltages and specific error probabilities. Features of the method which is involved in the operation of structures described in this application are disclosed and claimed in our copending application, Serial No. 171,613, filed February 7, 1962, and entitled "Method for Measuring Data Signal Impairment," which is a division of the present application.

A complete understanding of the apparatus for determining data signal impairment in accordance with the invention may be obtained upon a consideration of the following specification with reference to the attached drawing in which:

FIG. 1 is a diagrammatic representation of the steps of the method underlying the operation of the invention;

FIG. 2 is a simplified oscillogram of some superimposed data impulses for facilitating an understanding of the invention; and

FIG. 3 is a block and line diagram of an illustrative embodiment of the invention.

Referring to FIG. 1, the steps of the signal impairment measuring method in accordance with the invention include transmitting a noncyclic data pulse wave over a suitable transmission medium; receiving the same wave as altered by such transmission factors as noise, delay, and attenuation; probing the data wave aperture with a voltage-versus-time window; and counting data wave segments which intersect the window.

The received data wave, if applied to a properly synchronized cathode ray oscilloscope, might present traces similar to the simplified traces illustrated in FIG. 2 wherein traces A and B represent, during a sampling interval t_s , reference mark and space traces, respectively. That is, traces A and B are traces which are not altered by either noise or distortion. During the same interval traces C and D represent mark and space traces, respectively, which have been altered by distortion only, respectively C and D represent mark and space traces, respectively, which have been altered by distortion plus noise. Voltages V_{d1} and V_{d2} are the voltage ranges through which a data signal may be altered by distortion for some predetermined error probability criterion ϵ . The quantity ϵ is the ratio of the permissible error rate in a given period of time to the total number of data bits that occur during that same time. Voltages V_{n+} and V_{n-} similarly represent the ranges of plus and minus noise voltage excursions that may alter data signals. The voltage V_a represents the voltage dimension of the data wave aperture during the sampling interval t_s . The voltage V_p represents the maximum range of voltage which the data signal does not exceed more than ϵ of the time.

If the sampling interval were shifted Δt_s microseconds to the left as indicated in FIG. 2, the aperture voltage would be reduced to the voltage V_a . The difference between V_a and V_c is called the jitter voltage V_j .

In a typical data receiver (not shown) the mark-space detecting apparatus would be actuated during the sampling interval t_s to determine for each of the data pulses whether the amplitude thereof is above or below a critical voltage V_c which is the nominal amplitude discriminating level of the detector in the data receiver.

In accordance with this invention, the operating margins of the measured transmission system are determined by probing the aperture of the data wave to determine the size thereof. The probing operation is carried out by creating a voltage-versus-time window of predetermined dimensions which can be varied in size and which can also be moved about as desired to scan the data wave aperture and determine the largest aperture for a given number of wave segments intersecting the window. For some purposes a large window W with the dimensions V_a and t_s may be utilized and for other purposes a small window w with the dimensions V_d and t'_s may be utilized. The number of data pulse waveforms which intersect the window in each location in a given period of time is counted, and the total count is utilized, together with the probing window location, to indicate the aperture size. The measuring method just outlined is hereinafter described in greater detail in connection with apparatus, called a "bidiameter," in accordance with the invention for carrying out the method. The word "bidiameter" is a shortened form of "binary digital aperture meter."

Referring to FIG. 3, a signal generator 10 produces a noncyclic data pulse wave which is applied to a west-to-east transmission line 11. The receiving end of the line 11 is coupled directly to the transmitting end of an east-to-west transmission line 12 to perform the measurements on a loop basis. The same measurements can also be performed on a straightaway basis as will be hereinafter described in greater detail. The receiving end of the line 12 is coupled to an attenuator 13 in the input of a bidiameter 14. The output of attenuator 13 is coupled to the common input of two gate circuits 16 and 17. Gate circuit 16 is an upper level gate and is designed in a well known manner to be responsive to the simultaneous application thereto of a conditioning pulse and a further pulse having an amplitude which is less than a first predetermined amplitude V_1 for producing an output voltage pulse. Gate 17 is a lower level gate and is designed in a well known manner to be responsive to the simultaneous application thereto of a conditioning pulse and a further pulse having an amplitude which is greater than a second predetermined amplitude V_2 for producing an output voltage pulse. The voltage V_2 may be either greater or less than V_1 depending upon the particular mode of operation of the bidiameter. The responsive levels of gates 16 and 17 may be adjusted as desired, and this fact is schematically represented in FIG. 3 by including adjustable resistors 18 and 19 within the respective blocks representing the gates. The adjustment of resistors 18 and 19 establishes the voltage boundaries of the voltage-versus-time window W employed to probe the data wave aperture. Thus, the size of the window can be adjusted and the position of the window in the voltage direction can also be adjusted.

The output of signal generator 10 includes, in addition to the noncyclic data signal, a cyclic clock voltage wave which is employed within the generator for defining the duration of mark and space intervals as is well known in the art. Further in accordance with this invention, such a clocking voltage is applied from generator 10 to a phase shifter 20 in the bidiameter 14. The output of phase shifter 20 is coupled to the input of a cyclic pulse generator 21. Phase shifter 20 is adjustable as indicated schematically by the variable capacitor 22 which is in-

cluded within the block representative thereof. The adjustment of capacitor 22 shifts the position of the probing window in the time direction.

Generator 21 produces a train of cyclic pulses for application to gates 16 and 17 in synchronism with the phase shifted clock voltage wave. The duration of each output pulse from generator 21 corresponds to the duration of the sampling time interval t_s indicated in FIG. 2. The duration of the sampling pulses is adjustable in a well known manner as schematically represented by the adjustable resistor 23 which is within the block representing generator 21. Adjustment of resistor 23 establishes the time boundaries of the voltage-versus-time probing window W .

The output of gate 16 is coupled to the input of a counter 26 to produce an indication of the number of data pulse samples having amplitudes which are less than the high voltage limit of the probing window. The output of gate 17 is coupled to the input of a second counter 27 which produces an indication of the number of data pulses having amplitudes which exceed the low voltage limit of the probing window. In addition, the outputs of both gate 16 and gate 17 are applied to the input of a coincidence gate 28 which has the output thereof coupled to a third counter 29. If more convenient, of course, a single counter could be employed with appropriate switches for connection to any one of the gates 16, 17 or 28. Counter 29 produces an indication of the number of data pulses which have amplitudes of sufficient magnitude to actuate both counters, i.e. amplitudes which lie between the voltage limits of the probing window W .

Considering now one aspect of the operation of the apparatus in FIG. 3, the resistors 18 and 19 are adjusted to produce a probing window W of a desired amplitude, such as V_a . That is, the critical response voltage of gate 16 is adjusted so that this gate can be actuated only by data voltages which are less than the upper voltage level of aperture voltage V_a . The critical response voltage of gate 17 is adjusted so that gate 17 can be actuated only by data voltages which are greater than the lower voltage level of aperture voltage V_a . Resistor 23 is adjusted to fix the width of window W by setting the duration of the sampling pulses from generator 21. Capacitor 22 is adjusted to position the window W at the desired point in the data wave aperture by shifting the time phase of the clock frequency voltage with respect to the data wave prior to the application thereof to generator 21.

The noncyclic data signal from generator 10 is applied via the transmission lines 11 and 12 and the attenuator 13 to one input of each of the gates 16 and 17. The clock voltage is applied via phase shifter 20 to actuate the cyclic sampling pulse generator 21 for producing sampling pulses of t_s microseconds' duration at a predetermined time during each successive data bit. The sampling pulses are applied in multiple to a second input of each of the gates 16 and 17 to condition the gates for actuation in response to certain data pulse amplitudes as hereinbefore noted. Data bits having sample amplitudes which are less than the lower voltage limit of the probing window W actuate gate 16 only, and gate 16 produces an output to drive the counter 26. Samples which exceed only the lower voltage limit of the probing window W actuate both gate 16 and gate 17, and these gates drive counters 26 and 27, as well as the coincidence gate 28 and counter 29. Samples which exceed both voltage limits of the probing window W actuate gate 17 only, and only counter 27 is operated. When the voltage levels on the gates are adjusted such that the counts on counters 26 and 27 are equal for a given period of time, it is then known that mark and space bits are making approximately equal contributions to the total number of traces intersecting window W . The count indicated on counter 29 during the same interval indicates the amount of impairment produced by the particular transmission factors, or, stated differently, the count is an indication of the error rate

that can be expected in the measured system if the system relies upon the utilization of the entire window height corresponding to the voltage V_a .

By adjusting the critical response voltages for gates 16 and 17, it is possible to obtain different relations between the counts indicated by the respective counters 26, 27, and 29 to indicate different characteristics of the data wave as will be hereinafter described in greater detail. Likewise, the position of the probing window can be moved about as hereinbefore described to explore the size of the data wave aperture. Such exploration determines the size of the aperture with respect to a predetermined tolerable error rate for the measured system. These items of information may then be employed to assess the operating condition of the system to determine whether or not repairs or adjustments should be made. The information may also be employed to establish design requirements for the transmission equipment in order to simplify the equipment and to make maximum use of available operating margins and still produce detected data signals with a predetermined degree of accuracy.

The apparatus of FIG. 3 is adapted for loop measurements as has been hereinbefore noted. Straightaway measurements can be performed if the line 12 is removed from the circuit and the clock voltage which drives phase shifter 20 is supplied to the output end of line 11 via a separate transmission channel and the bidiameter is connected to the output end of line 11.

Once a performance criterion ϵ has been determined for a particular data system, the single bidiameter 14 of FIG. 3 can be employed to determine:

$$\text{Total transmission Impairment (TTI)} = -20 \log_{10} \frac{V_a}{V_p} \quad (1)$$

$$\text{Noise transmission Impairment (NTI)} = -20 \log_{10} \frac{V_p - 2V_n}{V_p} \quad (2)$$

$$\text{Distortion transmission Impairment (DTI)} = -20 \log_{10} \frac{V_a + 2V_n}{V_p} \quad (3)$$

$$\text{Timing uncertainty Impairment (TUI)} = -20 \log_{10} \frac{V_j}{V_p} \quad (4)$$

The various voltages which are indicated in Equations 1 through 4 have been hereinbefore defined in connection with FIG. 2. By way of explanation of the significance of the different impairments, the total impairment TTI would be zero if both the noise and distortion were zero because the aperture voltage V_a would then be equal to the peak-to-peak voltage. The size of the aperture is reduced as impairment increases. Noise impairment NTI is a figure that is indicative of the reduction in operating margin as a result of noise alone. Distortion impairment DTI is a figure that indicates the extent of reduction in operating margin due to such factors as delay and attenuation which exist in the transmission path. The noise, aperture, and peak-to-peak voltages already measured are employed to calculate distortion impairment. Timing uncertainty impairment TUI is an indication of the impairment that may result if the time phase of sampling signals in a data receiver is subject to shift or jitter. The above-listed expressions for impairment can be translated into practical numerical values by means of measurements made with a bidiameter.

First, to accomplish an impairment determination, the desired probability of error ϵ for satisfactory system operation is decided upon; and then the noise voltages V_{n+} and V_{n-} must be measured. With no signal on the transmission lines 11 and 12, and while receiving noise only, resistor 18 is adjusted so that gate 16 is responsive to samples below a voltage which is less than a zero-signal reference voltage level, and resistor 19 is adjusted so gate 17 is responsive to samples above a voltage which is more than the same reference level. Then each of the resistors 18 and 19 is further adjusted until the output from its associated gate produces pulses to the respective

counters in sufficient number to correspond to a performance criterion equal to $\epsilon/2$ for the measured system. The voltage input levels of gates 16 and 17 at which this condition occurs are then equal to V_{n-} and V_{n+} , respectively, and the total of these two voltages is V_n , the critical noise voltage, i.e. the voltage range through which noise can change the amplitude of a data pulse without increasing the probability of error beyond the probability criterion ϵ of the measured system.

Next, to determine the peak-to-peak voltage V_p , signal is applied to the input of line 11. There appears at the output of line 12 the signal, plus noise, plus distortion. Resistor 18 is adjusted until the count on counter 26 indicates that gate 16 is responsive to a fraction $\epsilon/2$ of the data sample pulses, i.e. until $\epsilon/2$ of the pulses have magnitudes less than the critical response voltage of gate 16. Resistor 19 is similarly adjusted until the count on counter 27 indicates that $\epsilon/2$ of the pulses have magnitudes greater than the critical response voltage of gate 17. The difference between the response voltages of the two gates 16 and 17 is then the voltage V_p . By substituting into Equation 2 the values for V_n and V_p just determined the noise transmission impairment NTI can be readily calculated.

To determine aperture voltage V_a , resistors 18 and 19 must be readjusted while receiving signal, plus noise and distortion. The criteria for adjustment this time are that the counts shown by counters 26 and 27 must be equal to one another and that the count shown by counter 29 must be equivalent to the predetermined permissible error rate for determining the error probability ϵ . This time the difference between the response voltages of gates 16 and 17 is the aperture voltage V_a . Upon substituting this value for V_a , and the previously determined values for V_p and V_n , into Equations 1 and 3, the values for total transmission impairment TTI and for distortion transmission impairment DTI can be calculated. In the case of total impairment, the indication on counter 29 will be to an experienced operator a direct measure of signal impairment. The higher the sample count indicated by counter 29 in this mode of operation, the greater is the impairment for any given aperture size.

To determine the value of jitter voltage V_j , capacitor 22 is adjusted to provide a new sampling interval Δt_s . The previously described procedure for determining aperture voltage V_a is now repeated to determine the reduced aperture voltage V_a in interval Δt_s . The difference between V_a and V_a is equal to the jitter voltage V_j , the reduction in aperture voltage due to shift, or jitter, in the sampling time. Upon substituting the voltages V_j and V_p into Equation 4 the impairment due to timing uncertainty TUI can be calculated.

Although the invention has been described in connection with particular illustrative structure, it is to be understood that additional embodiments and modifications will be apparent to those skilled in the art and are included within the scope of the invention.

What is claimed is:

1. A bidiameter for measuring the aperture of a data wave, said bidiameter comprising means receiving a non-cyclic voltage wave envelope including pulses occurring at a predetermined cyclic rate, said pulses having peak amplitudes included in either one of two adjacent amplitude ranges corresponding to binary code representations, voltage sensitive gating means connected to said receiving means, a counter connected for actuation in response to pulses from the output of said gating means, and means biasing said gating means for passing to said counter only those pulses having peak amplitudes within a third amplitude range which overlaps portions of both of said first and second ranges.

2. A pulse transmission evaluation test set comprising means receiving a noncyclic voltage wave envelope which includes pulses occurring at a predetermined rate, said pulses having peak amplitudes lying in either one of two

adjacent amplitude ranges, voltage sensitive gating means comprising a first gate connected to said receiving means, means biasing said first gate to be nonconducting in the absence of pulses with peak amplitudes which are less than a first amplitude level included in a first one of said two ranges, a second gate connected to said receiving means, means biasing said second gate to be nonconducting in the absence of pulses with amplitudes in excess of a second amplitude level included in the other of said two ranges, said first level being higher than said second level, and counting means connected to the outputs of said gates for registering pulses with amplitudes in predetermined portions of said amplitude ranges.

3. The transmission test set in accordance with claim 2 in which said counting means comprises first and second counters connected to the outputs of said first and second gates, respectively, for actuation in response to pulses passed by the corresponding gate, and each of said bias means includes means adjusting said levels to produce a predetermined relationship between the indications of said first and second counters.

4. The transmission test set in accordance with claim 2 in which said counting means comprises a coincidence gate having two input connections coupled to the outputs of said first and second gates, respectively, and a counter connected to the output of said coincidence gate for indicating the number of pulses passed by said voltage sensitive gating means and having peak amplitudes between said first and second levels.

5. The transmission test set in accordance with claim 2 which comprises in addition means generating cyclic pulses at said predetermined rate, and means applying the output of said generating means to said bias means for said first and second gates to block both of such gates except during the same predetermined interval of each of said noncyclic envelope pulses.

6. In a test set for evaluating electric pulse transmission systems in which information is represented by the presence or absence of pulses in successive time slots, means receiving a noncyclic voltage wave envelope which is synchronized at a predetermined rate, amplitude sensitive gate means connected to said receiving means, means enabling said gate for predetermined intervals at approximately said predetermined rate to pass samples of said envelope, means adjusting said gate means to reject signal envelope samples with peak amplitudes in predetermined amplitude ranges, and counter means totaling signal envelope samples passed by said gate means.

7. A test set for evaluating pulse transmission systems, said test set comprising means sampling a signal pulse wave at a predetermined rate which is independent of signal wave configuration, adjusting means in said sampling means for confining the passage of signal samples to those samples having peak magnitudes in at least one certain magnitude range, and a counter indicating the numbers of samples passed in said ranges.

8. In a test set for evaluating a pulse transmission system having a predetermined permissible error rate ϵ , means receiving signals from said system, signal-responsive gate means connected to the output of said receiving

means for sampling said signals in adjustable amplitude ranges, means recurrently enabling said gate means at a predetermined rate to sample said signals, counting means connected to be actuated by the output of said gate means, and means adjusting said ranges for producing predetermined relationships between counts in said counting means and said error rate ϵ .

9. The test set in accordance with claim 8 in which said gate means comprises a first gate responsive to signal amplitudes below a first voltage level, a second gate responsive to signal amplitudes above a second voltage level, and said adjusting means controls the relative magnitudes of said levels.

10. The test set in accordance with claim 9 in which said counting means comprises a first counter connected to said first gate and a second counter connected to said second gate, said first level is smaller than said second level, and said adjusting means sets the values of said levels so that the counts in said counters bear the same predetermined relationship to said error rate ϵ .

11. The test set in accordance with claim 9 in which said gate means further comprises a coincidence gate connected to the outputs of said first and second gates, said counting means comprises first and second counters connected to the outputs of said first and second gates, respectively, and a third counter connected to the output of said coincidence gate, and means in said adjusting means fixing said first level higher than said second level and further fixing their values so that the counting rate of said third counter is equal to said error rate ϵ and substantially equal counting rates are produced by said first and second counters.

12. The test set in accordance with claim 11 which comprises in addition means shifting the phase of said recurrent enabling means with respect to said signals.

13. In a test set for evaluating a pulse transmission system having a predetermined error rate, signal waves in said system being characterized in that if traces of plural sequential portions of said waves and of more than one pulse interval in duration were superposed in synchronism they would define a trace aperture, means exploring the limits of said aperture in terms of said error rate, said means comprising signal-responsive sampling means operating at a predetermined rate to sample said signal waves, counting means connected to be actuated by the output of said sampling means, means adjusting the maximum and minimum response levels of said sampling means to make the rate of operation of said counting means over a predetermined time interval no greater than said error rate, and phase shift means changing the phase of operation of said sampling means with respect to said signals.

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