

Feb. 7, 1956

O. L. PATTERSON

2,734,137

CATHODE RAY TUBE FUNCTION GENERATOR

Filed Oct. 4, 1950

2 Sheets-Sheet 1

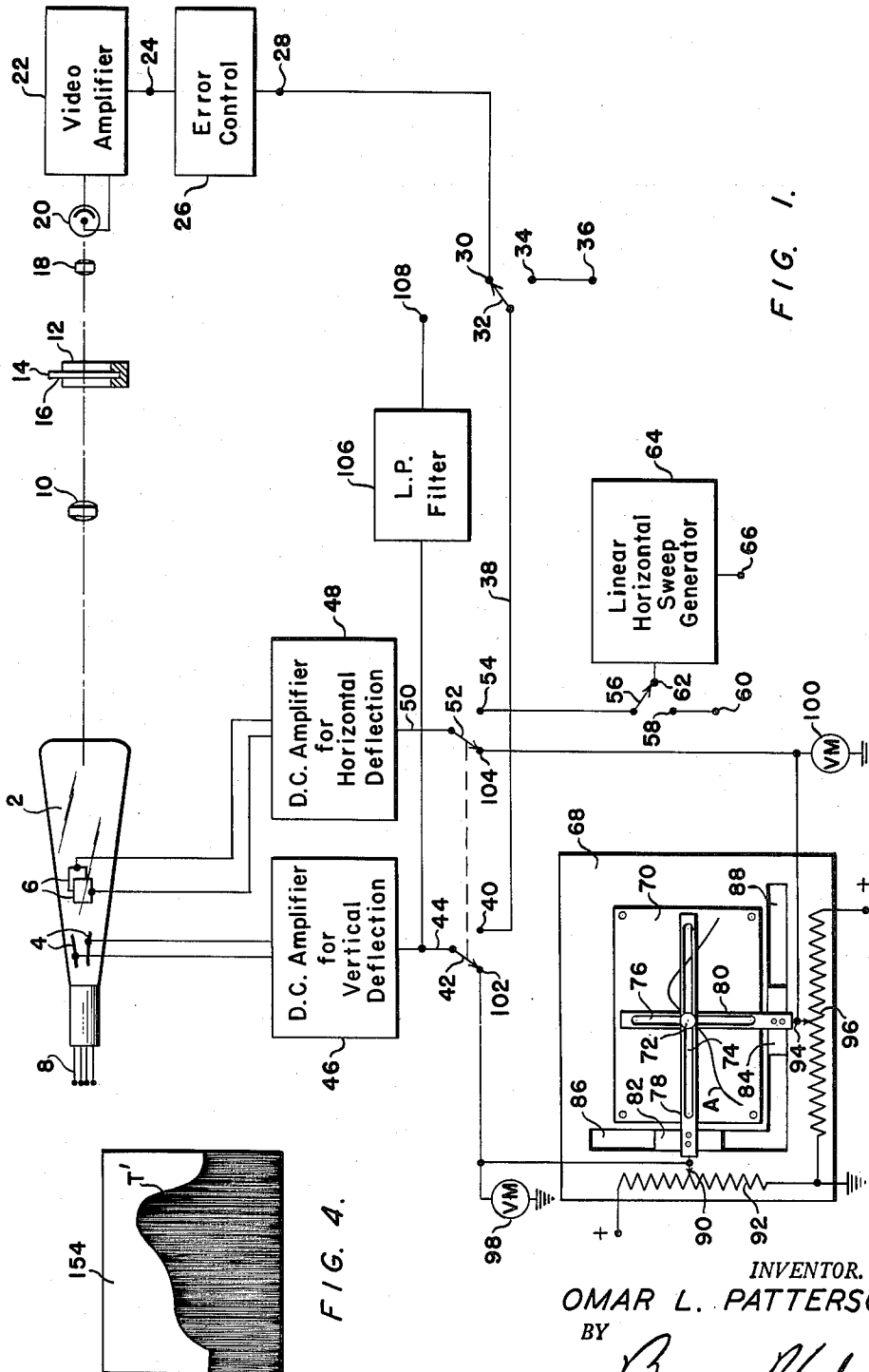


FIG 1.

INVENTOR.
OMAR L. PATTERSON
BY *Bruce & Harding*
ATTORNEYS.

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2 Sheets-Sheet 2

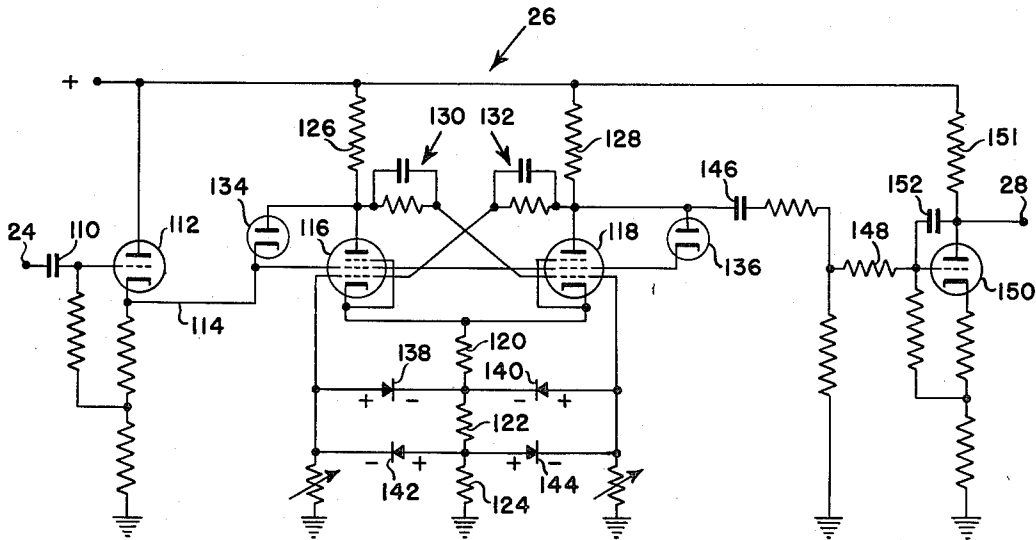


FIG. 2.

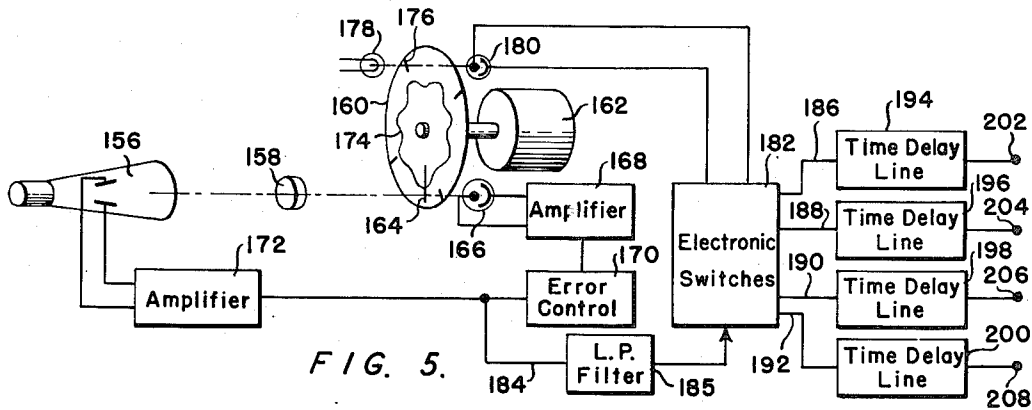


FIG. 5.

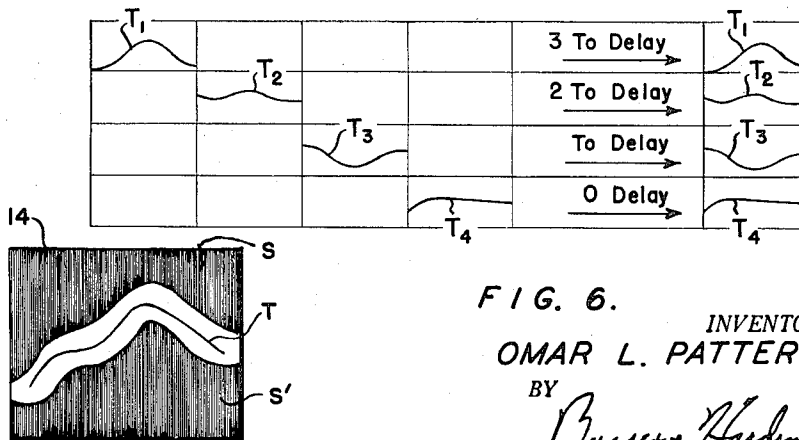


FIG. 3.

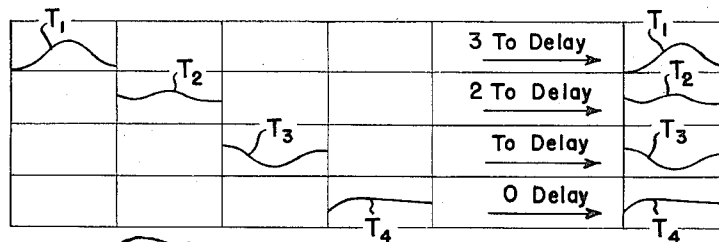


FIG. 6.

INVENTOR.
OMAR L. PATTERSON
BY *Bussard & Harding*
ATTORNEYS.

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2,734,137

CATHODE RAY TUBE FUNCTION GENERATOR

Omar L. Patterson, Media, Pa., assignor to Sun Oil Company, Philadelphia, Pa., a corporation of New Jersey

Application October 4, 1950, Serial No. 188,291

10 Claims. (Cl. 250—201)

This invention relates to method and means for producing a cyclically repetitive arbitrary wave form as a function of time or voltage and to apparatus involving said wave form producing means. In particular the invention relates to the use of conventional cathode ray oscilloscope tubes for this purpose involving a minimum of complexity of apparatus and high accuracy independent to a high degree of the characteristics of said tube.

Proposals have heretofore been made to produce wave forms through the use of conventional cathode ray oscilloscope tubes by providing a mask over a portion of the face of such tube, the mask having a contoured edge conforming to the function to be generated. A photocell is provided responsive to the exposure of the spot produced on the oscilloscope tube screen. The photocell through a suitable circuit was arranged to deflect the beam (for example, vertically) in such fashion that if the intensity of illumination on the photocell was too great the beam would be deflected in a direction to be further masked, while if the illumination was insufficient a reverse deflection would occur to increase the exposure of the spot produced by the beam. A properly controlled horizontal sweep of linear or other form was used with the result that the spot would follow the edge of the mask. The vertical deflecting potential during the sweep would then correspond to the function represented by the edge of the mask.

The last mentioned method of function generation, however, has various disadvantages and in particular is rather inaccurate due to non-linearity of the deflection characteristics of the tube and aberrations of the electron optics of the tube. In view of this a mask could not be cut having its ordinates linearly related to the ordinates of the function to be generated with any expectation of substantial accuracy of wave form generation, and to secure even reasonable accuracy it would be necessary to exercise considerable trial and error in mask cutting with measurements of the function generated prior to each new approximation to the proper mask shape.

In accordance with the present invention there is also used a simple cathode ray oscilloscope tube with conventional low cost circuitry and a high degree of accuracy is attained substantially independent of non-linearity in deflection sensitivity of the tube and of aberrations of the tube's optical system. In brief, the invention involves the utilization of the cathode ray oscilloscope tube to produce a photographic plate or film image which is developed and then used in the reproduction by the same oscilloscope tube. By doing this and by having the plate or film located precisely in the same position during both its formation and reproduction the function generated is essentially independent of the non-linearity and aberrations just referred to. The record thus produced is permanent and usable repeatedly with the same tube when high accuracy is desired; however, the record may also be used with reasonable accuracy in conjunction with similar tubes having their deflection sensitivities properly adjusted, the assumption being then made that the optics of the repro-

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ducing tube are essentially similar to the optics of the recording tube.

If a linear time sweep is used for both recording and reproduction it will be evident that the produced function will correspond to the original and will be a function of time. However, alternatively, the record may be produced by a linear time sweep and then for reproduction there may be used a sweep function which is a non-linear function of time. In such case it will be evident that the generated function will be a function not of time but of the sweep function which is in turn a function of time. Thus it will be evident that various complex functions may be generated.

Through the use of low persistence phosphors high frequency sweeping may be provided with generation of repetitive functions at high frequency or alternatively rapid rise times may be properly reproduced at lower frequencies.

While time of development of the photographic image represents a disadvantage, the photographic development is simpler than the cutting of a mask. Furthermore, if adjustments are desired it is easy to modify the trace on the photographic film or plate by what amounts to photographic retouching.

As will appear hereafter the original trace which is photographed may be manually drawn. However, the photographic record may also be made if desired by applying a particular electrical wave form of either repetitive or transient type to the oscilloscope tube whereupon if desired the wave may be measured on a plotting board. The functional relationships of two waves may also be ascertained in similar fashion.

Furthermore, as will become apparent, one or more generators of the type indicated may be used to provide input functions for differential analyzers or other computing apparatus.

It is also possible as will appear hereafter to provide superposition of functions using delay lines with the utilization of a single cathode ray oscilloscope tube and associated apparatus.

Further objects of the invention relate to improved methods and apparatus for the following of a trace by the spot of a cathode ray oscilloscope.

The various general objects of the invention relate to the attainment of the results indicated above. These and other objects of the invention particularly relating to details of construction and operation will become apparent from the following description read in conjunction with the accompanying drawings, in which:

Figure 1 is a diagram indicating one form of the improved function generator;

Figure 2 is a wiring diagram showing the details of the error control portion of the apparatus indicated in Figure 1;

Figure 3 is an elevation showing a typical photographic record such as is produced and used in the generator;

Figure 4 is an elevation showing an alternative type of photographic record which may be produced and used in the generator;

Figure 5 is a diagram illustrating the fashion in which a plurality of wave forms may be simultaneously generated using a single cathode ray oscilloscope tube; and

Figure 6 is a diagram explanatory of the operation of the apparatus of Figure 5.

Referring to Figure 1 there is indicated at 2 a cathode ray oscilloscope tube of conventional type desirably having a low persistence phosphor. The vertical deflecting plates are indicated at 4 and the horizontal deflecting plates at 6. The conventional focussing, intensity, heater and other connections are indicated at 8 and are supplied from a conventional oscilloscope circuit. A lens 10 is arranged in the axis of the oscilloscope tube to project

an image of the spot from the screen upon the sensitized surface 16 of a photographic plate or film 14 supported in a holder 12. The arrangement of the physical parts of the apparatus should be such as to maintain accurately fixed the relationships of the tube 2, lens 10 and holder 12, the latter being so arranged as to receive and hold precisely in position the sensitized element 14 which, for the purpose of securing maximum accuracy, is desirably a sensitized plate. Film however, may be used preferably with aligning holes for the reception of pins to maintain it accurately positioned and render it capable of being returned to its initial position after removal therefrom. As will be apparent hereafter, it is of importance that the sensitized element after development may be located precisely in the position in which it was exposed for the making of a trace thereon.

One of the surfaces of the sensitized element 14 should be formed as a diffusing surface or, alternatively, the sensitized element may be associated with a diffusing translucent surface as may be provided by ground glass. Beyond the element 14 there is provided the collecting lens 18 to project the image of a spot from this diffusing surface on the cathode of a photocell indicated at 20.

Instead of projecting the image of the spot on the sensitized element upon the photocell, it has been found very satisfactory to use a sensitized element of small area and to merely back it up with a photocell, thus eliminating lens 18. As will appear hereafter, variation of level of illumination of the photocell by the exposed spot is not particularly important so that the arrangement just described is quite practical.

In order to provide sufficient sensitivity the photocell 20 generally should be of multiplier type. In any event it is associated with a conventional video amplifier 22 which provides its output at terminal 24 to an error control 26 which will be hereafter more fully described with reference to Figure 2. The output terminal 28 of the error control is connected to the contact point 30 of a single-pole double-throw switch 32, the other contact point 34 of which is connected to a terminal 36 for the application of an external arbitrary voltage. The switch 32 is connected through line 38 to the contact point 40 of a single-pole double-throw switch 42 which is connected through line 44 to the direct current amplifier 46 for vertical deflection of the beam of the cathode ray tube. A similar direct current amplifier 48 is provided for horizontal deflection of the beam and receives its input through connection 50 from a single-pole double-throw switch 52, the contact 54 of which is connected through switch 56 alternatively to contact point 58 and terminal 60 for the application of any desired horizontal sweep or to the contact point 62 which is connected to the conventional linear horizontal sweep generator 64 having a synchronizing connection 66 for the reception of a synchronizing signal.

The video amplifier 22, the amplifiers 46 and 48 and the linear horizontal sweep generator 64 may be conventional and are accordingly not described in detail.

For the purpose of providing vertical and horizontal deflection for the tracing of a curve on the sensitized member 14 there is provided the manually operable arrangement shown at the lower left of Figure 1.

A board 68 provides a support for a sheet 70 on which there may be traced and followed a curve A corresponding to the wave form to be generated. A stylus 72 adapted to be moved to follow the curve A has sliding mounting in the slots 74 and 76 of members 78 and 80 provided with cross heads 82 and 84 mounted to slide in rectangular directions in guideways 86 and 88 in the board. The cross head 82 carries the contact 90 of a linear potentiometer 92 connected between a positive potential source and ground. Similarly the cross head 84 carries a contact 94 of a linear potentiometer 96 also connected between a positive voltage supply and ground. It will be evident that the arrangement just described pro-

vides, when the stylus 72 follows a curve such as A potentials at contacts 90 and 94 which are linearly related respectively to the ordinates and abscissae of curve A. Suitable voltmeters 98 and 100 may be provided to indicate these potentials. The contact 90 is connected to the contact point 102 of the switch 42 heretofore described while the contact 94 is connected to the contact point 104 of the switch 52 also heretofore described.

The connection 44 is joined to the input of a low pass filter 106 which has a cut off higher than the maximum frequency component of the output wave form, the output terminal of this filter being indicated at 108. As will appear hereafter the output at connection 44 is in the form of the wave to be reproduced having superimposed thereon a high frequency saw tooth wave form which is filtered out by the filter 106, leaving the wave form desired.

The error control 26 is detailed in Figure 2. The input from terminal 24 is delivered through condenser 110 to a cathode follower arrangement comprising the triode 112 and suitable cathode resistance which, in turn, provides an output through connection 114 to the bistable multivibrator comprising the pentodes 116 and 118. The circuit of this bistable multivibrator or scaling circuit is substantially conventional except for certain limiting arrangements which appear therein. The cathodes of pentodes 116 and 118 are connected together and to ground through a series of resistances 120, 122 and 124. As is usual an essentially constant current flows through these resistances. The anodes of the pentodes are respectively connected to the positive potential supply line through resistances 126 and 128 and criss-cross connections between each anode and the grid of the companion tube are provided by the resistance-capacitance networks indicated at 130 and 132. Connection 114 is to the screens of the pentodes 116 and 118. Diodes 134 and 136 arranged as illustrated are connected between the screens and the anodes of the pentodes. In order to provide voltage limitation there are connected between the grids of the pentodes and the junction points of the resistances 120, 122 and 124 the crystal diodes 138, 140, 142 and 144 polarized as indicated. The result is that the potential of a control grid cannot rise above the potential of the junction point of resistances 120 and 122 and cannot fall below the potential of the junction point of the resistances 122 and 124. In this fashion limited, substantially square waves are emitted when the bistable multivibrator is thrown from its one stable condition to the other. A negative pulse on the line 114 serves to trigger the multivibrator in the usual fashion.

The output of the multivibrator is delivered from the anode of pentode 118 through condenser 146 and a resistance network including the resistance 148 to the grid of triode 150. A resistance 151 connects the anode of triode 150 to the positive potential supply line and there is connected between the anode and grid of triode 150 the condenser 152, the arrangement being such that the circuit of this triode constitutes an integrator which provides a triangular output with the amplitude of its excursions dependent upon the time of duration of the respective stable states of the multivibrator.

The operation of the described system is as follows:

The predetermined wave form A may be either drawn to a desired scale on the sheet 70 or more accurately may be plotted thereon while the plotter observes the readings of voltmeters 98 and 100 to determine the position of the stylus 72 corresponding to the ordinates and abscissae of points on the wave form which may be known. If a point by point plotting is thus effected by reference to the voltmeters there may follow such plotting the drawing of a smooth curve, if the wave form is desirably smooth, or of broken lines, or the like, if otherwise, between the plotted points. In any event by the use of accurate voltmeters it will be evident that the curve may

be provided on the sheet 70 so as to eliminate any errors of linearity of the potentiometers 92 and 96.

Following the production of the desired curve, the switches 42 and 52 are located in their left-hand positions illustrated in Figure 1 and there is placed in the holder 12 a sensitized photographic element 14 of the type described. If now the operator follows one or more times the curve A by the stylus 72, the light spot of the oscillograph tube will trace on its screen a curve corresponding to the curve A and the image of the spot will be projected to expose the sensitized element. The tracing may be carried out sufficiently slowly to produce the desired exposure in one tracing of the curve, or if a denser exposure is desired the curve A may be repeatedly traced.

The exposed element 14 may then be developed to a high contrast to produce a curve such as T in Figure 3 representing the trace corresponding to the original at A. This image is then fixed and otherwise finished in conventional photographic fashion.

Generally it will then be desirable to cover regions above and below the trace T with photographic opaque coating such as indicated at S and S' in Figure 3, leaving a transparent region of limited extent both above and below the trace T.

The wave form may now be reproduced by the apparatus, the developed photographic record being placed therein in the position occupied during exposure. Assuming that a direct reproduction of the precise wave form originally drawn is to be effected, the switch 56 is located in its right-hand position illustrated in Figure 1 to be connected to the linear horizontal sweep generator 64. The switches 42 and 52 are also located in their right-hand positions. The switch 32 is located in its upper position indicated in Figure 1.

Operation of the apparatus then occurs in the following fashion:

An initial impulse may be imparted to the light spot of the oscillograph tube to cause it to move vertically so that its projected image on the photographic member 14 moves correspondingly vertically. As the spot crosses the trace T an impulse will be transmitted from the photocell 20 through the video amplifier to the error control. Assuming that the number of stages in the video amplifier is such that the obscuring of the spot momentarily by the trace T gives rise to a negative trigger pulse at the input to the scaling circuit, the scaling circuit will be thrown to its alternative stable position producing a square wave output which through the integrator will produce an excursion of the spot projected on the record member 14 in an opposite direction. As the spot again crosses the trace T the scaling circuit will again be flipped causing, through the integrator, a reversal of the movement of the spot. As these excursions in reverse direction occur, with reversal after each passage of the projected spot across the trace T, the horizontal sweep will be moving the spot horizontally. The result is that the spot will follow the trace T zig-zagging across this trace at a high frequency. The circuit adjustments should be so set that this frequency of reversal is substantially greater than the highest frequency which it is desired to reproduce, and preferably constants are so chosen that the spot image departs very little from trace T above and below the same; i. e., the amplitude of the zig-zag wave should be small in the interest of maximum accuracy of reproduction. The potentials applied for vertical deflection are transmitted through the filter 106 which will cut off the frequency of the triangular zig-zag wave so that there will be reproduced at terminal 108 a smoothed output corresponding to the original trace A. As will be evident by adjustment of the frequency of the horizontal sweep the repetitive frequency of this output may be adjusted to any desired value short of the situation in which high frequency components of the original

wave would be lost by their rise beyond the cut-off point of filter 106.

It will be evident that if the record trace T is made as aforementioned the output will correspond very precisely to the original traced curve A entirely independently of the aberrations and non-linearities of the oscilloscope tube, the amplifiers, or the optical lens system. This result, of course, follows from the placement of the record member 14 in the same position for both recording and reproduction. It may, in fact, be noted that while a low persistence phosphor is desirable, the system is more tolerant, in its operation, of longer persistence, as compared with a system which requires the oscilloscope spot to ride, partially obscured, the edge of a mask. For a given persistence phosphor, therefore, higher reproduction frequencies are possible.

The purpose of the opaque coating provided over the areas S and S' may now be described. If in the excursion of the projected spot upwardly across the trace T it should happen that before reversal it passed over a speck of dust, or there occurred some other possible electrical disturbance which might be equivalent to opacity in its effect on the error control, the projected spot might continue to move upwardly rather than be reversed to move downwardly across the trace. In order to insure reversal the opaque coating is provided to form an edge above the trace which will produce occultation of the spot and effect reversal whereupon after the spot again crosses the trace the zig-zag following of the trace should continue in normal fashion. The same effect, of course, occurs if the spot travels too far downwardly, the reversal then occurring when it crosses the upper edge of the lower area S' of the opaque coating. It will be evident that this same effect of maintaining the spot normally on the trace may be attained by electrical limiting means which will reverse the spot whenever the vertical deflection potential becomes either too high or too low. The same type of operation may be effected electrically by providing that if the excursion in a given direction occurs for more than a limited period a reversal will occur. In such fashion proper tracing is, in general, securable, the uncontrolled excursion merely providing a momentary transient which is at such frequency as to be eliminated in any case by the filter 106 without substantial deviation from the true wave form. It may be noted furthermore that it would generally be probable that such an improper excursion of the spot would only occur through one cycle if occasioned by some electrical disturbance as compared with a speck of dirt physically on the member 14.

The record may be made otherwise than as illustrated in Figure 3, for example, as illustrated in Figure 4. In this case vertical deflection of the spot is under control of a high frequency signal, the frequency being much greater than the period of tracing or formation of the record so as to give complete exposure of the entire area under the curve. If the vertical deflecting potential is then limited by the output, for example, from the plotting board there will be produced a blackened area upon development which, as illustrated in Figure 4, will have the sharp upper boundary T' having the form of the function being recorded. Devices for limiting the excursions of a high frequency potential are well known and need not be described.

In using the developed record of the type illustrated in Figure 4, the error control should be of a type different from that illustrated in Figure 2 and may be of the monostable multivibrator type in which an impulse signal produced by an upward excursion of the spot across the boundary T' will throw the multivibrator to its unstable state from which it will return after the lapse of a predetermined interval. The result would then be a zig-zag path of the spot following the boundary T' in the form of an approximately rectangular wave, the upper limits of which may be slightly above the boundary T'

while the lower excursions of this wave below the boundary T' will depend upon the difference of potential of the output circuit provided between its stable and unstable states. In this case the output may be taken from a peak voltmeter having a time constant such as to smooth out a zig-zag output and give a response corresponding to its peak values.

It will be evident that in accordance with the invention the record may be of various other types produced and scanned in various fashions. For example, the vertical deflection of the spot may well be through such distance as to cover the complete vertical extent of the record, with the use of time demodulation in accordance with known practices to determine when the spot crosses a boundary such as T or T'. Various other expedients will be apparent to those skilled in the art as capable of being used for the proper reproduction of a wave form following the principles of the invention. Desirably avoided, however, is the provision of an arrangement in which the reproduction depends upon some predetermined partial occultation of a spot by a boundary. By utilizing signals produced when the spot crosses a boundary much better results may be secured.

Irrespective of the type of record which is made and reproduced and irrespective of the fashion in which it is made and/or reproduced it will be evident that the invention involves the important aspect that the record may be both made and reproduced in precisely the same relationship to the cathode ray oscilloscope 2 so as to eliminate any non-linearities or aberrations in the system.

There has been described above the making of a record through control of vertical and horizontal potentials by the operation of the stylus 72. However, it is also possible to make a record of an external voltage applied to the terminal 36 if the switch 32 is in its lower position engaging contact point 34 with the switches 42 and 52 in their right-hand positions. The external voltage wave may be thus recorded photographically whether it is of transient form or repeated form. In this case also it will be evident that if reproduction is effected with the plate 14 in the same position in which its record was made the reproduction will be essentially independent of non-linearities or aberrations in the system.

The apparatus may also be used for the accurate measurement of a wave form applied in the recording to the terminal 36 as last described. Assuming such a wave form to be recorded on the record member 14, it will be evident that with the switches 42 and 52 in their left-hand positions the potentiometer contact 94 may be fixed to correspond to any abscissa and then the vertically movable contact 90 may be moved to that point at which the spot projected on the record member 14 will be occulted which may be signalled by the tripping of the error control, there being in such case associated with the scaling circuit a neon tube or other indicator to show the triggering of this circuit. If the contact 90 is then moved vertically until such tripping is noted the voltmeter 98 will give an accurate measurement of the ordinate of the wave form corresponding to the particular abscissa chosen. Here again it will be evident that the measurement made is independent of non-linearities and aberrations in the system.

The terminal 60 provides for the introduction of a horizontal sweep voltage which may not be linear but may, for example, be sinusoidal or of any other form. Assuming that a record member is made through the use of a plotting board by following a wave shape such as A with the stylus, the reproduction which is effected by feeding another wave form to the terminal 60 will involve the production of an output which is one function of a second function of time, the form of the first function being that of the curve A, while the form of the second function just mentioned will be that of the sweep function applied to the terminal 60. It will be evident

that in this fashion the apparatus may be operated as a computer to give rise to quite elaborate derived functions.

Not only does the apparatus have the important property noted above of performing its operations independently of non-linearities and aberrations of the apparatus but it has other important advantages over devices heretofore proposed and used. The developed photographic record is permanent. The circuits associated with the oscilloscope tube are simple and without critical characteristics. The spot size may be kept very small. The signal provided is of substantial magnitude and the video gain requirements of the pick-up amplifier are reasonable.

It will be evident also that the photographic records may be retained to provide a library of functions which will be very precisely reproduced by a particular cathode ray oscilloscope tube by which they were recorded and will provide at least good approximations for other tubes having reasonably similar characteristics including similar aberrations. Accordingly, if particular results are to be checked or duplicated in the future there is no necessity for the repeated drawing of the function involved.

It may be noted that the apparatus is particularly adapted to the determination of a wave form which will, when introduced into some complex system, produce a particular desired output wave form. Such a problem, for example, exists in determining the wave form to be applied to a magnetic deflection system in television apparatus to produce a desired output in the way of deflection of the spot. Trail and error may be easily carried out, if desired, by actually tracing in ink a curve on a record member such as 14 with retracing of the curve on another record member with variations which by study would seem to be in the direction of producing more desirable results. A photographic record member may, of course, be retouched for the same purpose.

It will be evident that the systems of the type described are particularly adaptable for use singly or multiply in differential analyzers or other computers and in particular in analogues in which functions of an experimentally determined nature must be introduced. As is well known in the art, functions appearing as electrical potentials or currents varying with time may be subject to algebraic and other processes such as differentiation and integration and may be combined with other functions in numerous fashions. It will be evident that the types of apparatus described are particularly susceptible to such uses. The foregoing is particularly true when the computing apparatus is of a cyclical type performing its operations repeatedly in successive cycles which may be relatively short in duration, in view of the high speed of response of the types of systems described.

The type of apparatus described is relatively simple, so that duplication or multiplication in complicated computers would not be prohibitive. But it is easily possible to utilize a single apparatus for the reproduction of functions which should simultaneously exist in the computer, for example, in a particular sub-period of a period of repetition of a computer of the cyclically operated type.

Figures 5 and 6 particularly indicate what has just been mentioned. At 156 there is indicated a cathode ray oscilloscope similar to that shown at 2 in Figure 1. In this tube, however, as will be evident the horizontal deflection plates are not used for sweeping purposes but would only be used for properly locating the spot horizontally. An image of the spot on the oscilloscope screen is projected by a lens 158, corresponding to lens 10, upon a disc 160 which is in the form of a sensitized photographic element in the form of a film or plate mounted on the shaft of a synchronous motor 162. 164 indicates the path of the projection of the oscilloscope spot on the element 160. Behind the element 160 at the location of path 164 is a photocell 166 similar to photocell 20 which is connected to a video amplifier 168, in turn connected to an error control 170, the output of which is

delivered through amplifier 172 to the vertical deflecting plates of the oscilloscope tube 156. Except for the mechanical arrangements, what has just been described may be similar to what has been described in connection with Figure 1.

A trace 174 corresponding to T of Figure 3, may be recorded as in the case of apparatus previously described on the photographic element 160 which is then developed and fixed. During the plotting of the curve 174 the horizontal variation may be secured by controlling mechanically the angular rotation of the disc past the line in which the projection of the spot moves. On the periphery of the disc there may be then marked, for example, radial lines 176 delimiting various segments of the curve 174 which has heretofore been referred to as a continuous one. However, continuity would not be normal in this apparatus and, instead, the complete curve 174 would be made up in the form of segments each of which would correspond to a separate function, all of which functions are later to be reproduced in the same period of time.

The markings 176 are arranged to occult the light from a lamp 178 falling on a photocell 180 which controls an electronic switching arrangement illustrated at 182. This arrangement may be conventional, consisting of a repetitive counting system controlling a number of electronic switching tubes corresponding to the number of functions to be simultaneously reproduced and incorporated in the curve 174. The input to the electronic switches is from the error control 170 through connection 184 including the low pass filter 185 corresponding to 106 of Figure 1.

The outputs from the switches are delivered through connections 186, 188, 190 and 192 to the time delay lines 194, 196, 198, and 200 respectively from which outputs are delivered at respective terminals 202, 204, 206 and 208.

The operation of the system just described may be made clear by considering Figure 6. The curve 174 which is subjected to scanning by the spot image may be considered to be made up of the separate functions T₁, T₂, T₃ and T₄ which follow each other in serial fashion. These various functions are switched to respective delay lines which have delays related to the period T₀ of duration of each of the functions and corresponding to 3T₀, 2T₀, T₀, and 0.

(The last, of course, is merely a direct connecting line, and has been referred to as a time delay line merely for generality, since all of the functions may, if desired, be subject to additional delays.)

As will now be evident the use of the switching arrangement and the delay lines will result in the emission at the various terminals of all of the functions during the same period which will correspond to the period in which the function T₄ is generated.

It will thus be evident that a single oscilloscope assembly may be used for the generation of a number of functions which are to be simultaneously supplied to an apparatus such as a computer. This, of course, presupposes that the active part of the cycle of repetition of the computer is sufficiently short so that its inactive portion will accommodate properly the serial generation of all of the functions to be provided.

It will be evident from the foregoing that numerous variations may be made in the embodiments of the invention without departing from the scope thereof as defined in the following claims.

What is claimed is:

1. The method of function generation utilizing cathode ray oscilloscope apparatus providing an illuminated dot deflected in accordance with electrical signals introduced to said apparatus, which method comprises mounting a sensitized photographic element in the path of said dot, electrically producing deflection of said dot to record on said element a latent line image, providing from said element a member providing a visible line having the shape

and size of said latent line image, mounting said member with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of recording, and electrically producing deflection of the dot provided by said apparatus under control of photoelectric means arranged, in response to illumination from said member due to said dot, to cause said dot to follow a path related in predetermined fashion to said visible line.

2. The method of function generation utilizing cathode ray oscilloscope apparatus providing an illuminated dot deflected in accordance with electrical signals introduced to said apparatus, which method comprises mounting a sensitized photographic element in the path of said dot, electrically producing deflection of said dot to record on said element a latent line image, providing from said element a member providing a visible line having the shape and size of said latent line image, mounting said member with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of recording, and electrically producing deflection of the dot provided by said apparatus under control of photoelectric means arranged, in response to illumination from said member due to said dot, to cause said dot to follow said visible line.

3. The method of function generation utilizing cathode ray oscilloscope apparatus providing an illuminated dot deflected in accordance with electrical signals introduced to said apparatus, which method comprises mounting a sensitized photographic element in the path of said dot, electrically producing deflection of said dot to record on said element a latent line image, providing from said element a member providing a visible line having the shape and size of said latent line image, mounting said member with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of recording, and electrically producing deflection of the dot provided by said apparatus under control of photoelectric means arranged, in response to illumination from said member due to said dot, to cause said dot to follow a zig-zag path along and crossing said visible line.

4. The method of function generation utilizing cathode ray oscilloscope apparatus providing an illuminated dot deflected in accordance with electrical signals introduced to said apparatus, which method comprises mounting a sensitized photographic element in the path of said dot, electrically producing deflection of said dot to record on said element a latent line image, providing from said element a member providing a visible line having the shape and size of said latent line image, mounting said member with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of recording, electrically producing deflection of the dot provided by said apparatus, and producing an electrical output from photoelectric means arranged for response to illumination from said member due to the relationship of said dot to said visible line.

5. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, said second means comprising a sweep generator and photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to cause said dot to follow a path related in predetermined fashion to said

visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

6. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, said second means comprising a sweep generator and photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to cause said dot to follow said visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

7. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, said second means comprising photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to cause said dot to follow a path related in predetermined fashion to said visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

8. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first manually controlled means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, said second means comprising a sweep generator and photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to cause said dot to follow a path

related in predetermined fashion to said visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

9. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first manually controlled means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, said second means comprising photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to cause said dot to follow a path related in predetermined fashion to said visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

10. In combination, cathode ray oscilloscope apparatus providing an illuminated dot and having terminals for the reception of signals for deflection of said dot, means for mounting a sensitized photographic element in the path of said dot, first means for introducing signals to said terminals for the deflection of said dot for the production thereby of a latent line image on said element, said mounting means serving also for the mounting of a member providing a visible line having the shape and size of said latent line image with said visible line occupying relative to said apparatus the position which was occupied by said latent line image at the time of its production, second means for introducing signals to said terminals for the deflection of said dot, photoelectric means constructed and arranged, in response to illumination from such mounted member due to said dot, to provide an electrical output having values functionally related to the ordinates of said visible line, and switching means for alternatively and selectively providing to said terminals either signals from said first means or from said second means.

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