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ANALOG PEN TRACKING ON A CATHODE RAY TUBE DISPLAY DEVICE

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ABSTRACT OF THE DISCLOSURE

Pen tracking apparatus for use with a computer-driven cathode-ray tube display is described. A pattern of beam spots on the cathode-ray tube centered about the previously determined center of the pen is within the field of view of the pen. The amplitude of the pen response to each of these spots is compared to determine in what direction the center of the spots must be moved in order to coincide with the pen center.

The invention herein described was made in the course of a contract sponsored by the U.S. Navy, Office of Naval Research.

BACKGROUND OF THE INVENTION

Many modern digital computer systems contain display equipment capable of facilitating the insertion of graphical material into memory. One such technique employs "pen tracking," a term used to denote the ability to control the electron beam of a cathode ray tube with an external "writing" device. Graphical information can be inserted using a light pen as the writing device. The use of a light-sensitive pen in this manner is an established technique for guiding the motion of a CRT beam. Through the tracking process, the pen controls the position of the electron beam by sensing the light output of the phosphor excited by this beam. To furnish a sketch to the computer, the display console is placed in the tracking mode and the operator "draws" on the face of the CRT with the light pen. The coordinates of the path described by the pen are retained by the computer to permit continuous display of the material being sketched.

In a particular prior art display equipment, pen tracking is accomplished digitally by logic within the display console itself. A light pen controls the position of the electron beam, and beam horizontal and vertical coordinates are stored in registers within the console. These registers are regularly sampled by the computer. Hardware implementation of the tracking operation in the display console frees the computer from performing this necessarily repetitive chore of tracking. In this prior art system, when in the tracking mode of operation, the scope display is interrupted every 10 milliseconds and a tracking cycle of approximately 1 millisecond duration is used to update pen position (a 10-millisecond interval between tracking cycles is about an upper limit if the beam is not to be lost when the pen is moved rapidly across the scope face). The tracking cycle consists of the generation and display of a tracking pattern centered at the last known position of the light pen as determined during the previous tracking cycle. Recalculation of present pen position is accomplished using the response of the light pen to this pattern. The tracking pattern is a small cross consisting of 32 points of light drawn on the CRT by the display console line generator. The points are plotted one at a time, starting at the center of the pattern, and incrementing out to describe the arms of the cross.

The light pen consists of a photoconductive sensor and associated electronics (one type of pen consists of a photo-multiplier tube and threshold detector, with a fiber-optic cord linking the pen and photomultiplier). When positioned over the tracking pattern described above, the pen yields an output pulse for each illuminated point of the cross which falls within its field-of-view. The console logic counts the points seen on each of the four arms of the cross and recalculates present pen position from this digital information. This position serves as the center of the new tracking cross to be generated in the next tracking cycle. The cycle takes approximately 1 millisecond to complete, hence, occupies about 10 percent of the total display time.

The time required for completion of a tracking cycle is limited by the phosphor response of the scope. Cathode ray tubes used in computer display are rewritten 30 times per second, or less, and must have a persistent phosphor in order to reduce flicker to tolerable level. Due to this light persistence, it has been found necessary that a blanking interval of about 14 microseconds exist between successive illuminated points of the cross if the pen is to make a reliable "seen"/"not seen" decision. With 64 points being illuminated in one cycle (i.e., each of the 32 points of the cross is illuminated twice: once on the outward trace of the arm, and again when returning to the center), the resulting total pattern generation time is about 1 millisecond. This represents a considerable portion of the total time available for display. As each additional console is added to the same tracking system, operating on a time-shared basis, an additional 10 percent of display time is required, and the amonut of potential display time being absorbed by the tracking operation becomes of considerable concern. The problem, then, can be very succinctly stated: the time required by the present digital technique for light pen tracking is excessive. A faster method is needed for updating the position of a pen moving over the face of a display console.

SUMMARY OF THE INVENTION

This invention is an "analog" pen-tracking technique which requires a considerable smaller tracking cycle time than the digital system described earlier. Digital tracking operates on a points-seen-or-not-seen basis, and a large number of tracking pattern points are necessary to achieve positional accuracy. The analog method differs from this in that the amplitudes of the pen responses to a small number of displayed points convey the required positional information. Rather than counting the total number of points whose responses exceed a preset threshold level, the amplitudes of the pen responses from only four points of light on the CRT are compared to provide updating of pen position.

Basic operation may be explained as follows. Initially, assume that the pen **55** is placed against the CRT **56** face and held in a fixed position while a point of light (the electron beam **57**) sweeps past. If the output signal of the pen is plotted as a function of beam position, a curve such as that shown in FIG. 1 is obtained, the exact shape depending on the pen optics. If instead, the electron beam is deflected incrementally so as to generate two points of light in the vicinity of the pen as in FIG. 2, with point **1** displayed first, followed by point **2**, two corresponding pen output voltages E1 and E2, result. The difference between these D-C amplitudes, E1–E2, provides a measure of the distance separating the pen center from the midpoint of the line joining the two displayed points. Only when the quantity E1–E2 is zero will the two points be symmetrically centered about the pen.

An analog tracking pattern can consist of four points as in FIG. 3. Point **1** is illuminated first, followed by points **2**, **3**, and **4**. With a pen placed over this pattern, the horizontal pair of points **1**, **2** provides a horizontal error voltage, ΔEh, and the vertical pair, ΔEv. Converting these orthogonal difference voltages to error distance (specifically, increments of distance along the horizontal and vertical axes of the CRT face), and adding them to the coordinates of the pattern center, establishes the position of the pen. This is accomplished by converting the error voltages to digital code (with appropriate scaling) and adding them to the digital coordinates of the pattern center, moving the cross center to this new position centers it about the axis of the pen. Repeating this "tracking cycle" at periodic intervals would permit the cross, hence the CRT beam, to follow a pen moving over the scope face. The time interval between tracking operations is utilized to display the graphical material being described by the pen.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a typical pen amplitude response curve.

FIG. 2 shows the analog voltage developed in the pen from only two illuminated points.

FIG. 3 shows the analog tracking pattern of the illuminated points on the face of a cathode ray tube.

FIG. 4 is a functional block diagram of the analog pen tracking system.

FIG. 5 is a block diagram of the circuitry which generates the four-point pattern for analog tracking.

FIG. 6 is a block diagram of the circuitry for processing the analog difference voltage in one channel, the horizontal.

FIG. 7 is a timing diagram of the voltages at selected points of the diagrams of FIGS. 5 and 6.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIG. 4, the pen tracking circuits consist of two basic parts: the tracking pattern generator **41**, and the pen-signal processor **42**. The tracking pattern generator **41** provides synchronized horizontal G and vertical H deflection signals and intensification signals J to plot the four-point tracking pattern. It also provides timing pulses A–D to the pen-signal processing circuits **42**.

The horizontal (right-left) deflections occur first, and the right E_1 and left E_2 pen-amplitude samples are stored in sample-and-hold circuits **70**, **71** as waveforms N, O. After a delay (to allow for transients to subside), the difference amplifier **58** yields the horizontal error voltage R, which is converted to digital binary code T and loaded into the ΔX register **59** of the display system in preparation for updating the horizontal pen position register **60**.

FIGURE 4 indicates that the tracking system has an identical vertical channel which receives its inputs C, D slightly later than the horizontal channel (i.e., when the vertical deflections occur). Alternatively, one channel can be used for both horizontal and vertical error measurements if the vertical deflections are delayed until the horizontal coding operations are completed. This would take longer, but save on eqnipment. The remainder of this discussion assumes a parallel system.

Note that since the signal at the input to the analog-to-digital converter **62** is an error signal denoting how far the pen moves between tracking cycles, only a few binary digits (bits) are needed in the analog to digital (A/D) converter **62**, irrespective of the total resolution of the display surface. The number of bits and their weighting depend on the pen field-of-view, the tracking cycle repetition rate, and the desired maximum pen speed which the system is to follow. They may be varied in accordance with the parameters of a particular display and a particular light pen.

Details of the system are shown in the block schematics of FIGS. 5 and 6. Circuit waveforms are shown in the timing diagram of FIG. 7. Once the main deflection system of the display has settled to the position specified by the X pen-position register **60** and the Y register (not shown) (35 μsec. for a system that was constructed), the horizontal error is available in digital form in 25 μsec., and the vertical error (not shown) in 35 μsec. Another 35 μsec. must then be allowed for the display to return to the X, Y positions as determined by the computer **61** it was at when interrupted by the tracking cycle. Thus, the total cycle time for tracking is 105 μsec., as compared with 1 msec. for the prior art digital method.

The main deflection system comprises the magnetic beam deflection circuitry **77** (for the horizontal deflection direction) together with its analog input voltage from D/A converter **78**. The input to converter **78** will be either a horizontal digital position signal X from computer **61**, when information is being presented on the face of CRT **56** from the computer storage; or the input to converter **78** will be X register **60**, the last pen-position, when the system is in the pen track mode of operation. When in the pen track mode of operation gate **79** will be in the "on" position during the time interval represented by waveforms $F+A+B+C+D$. When not in the pen tracking mode gate **80** will be gated "on" by the complement of these waveforms so that the input X from computer **61** will be applied to D/A converter **78**.

GENERATION OF THE TRACKING CROSS

At the beginning of each tracking cycle, the information in the pen-position registers **60** is used to magnetically deflect the blanked electron beam to the position of the pen as determined by the previous tracking cycle. The tracking cross is developed using electro static deflection G, H to further deflect the beam slightly about this position, first to the right, then left, up, and down. At each position, an unblanking pulse is applied and a point of the cross is formed.

The block diagram of the tracking pattern circuitry is shown in FIG. 5. The associated waveforms are shown in the timing diagram of FIGURE 7. Initially, the pulse E starting the tracking cycle is used to trigger delay unit **63** to provide a 35 microsecond delay F, necessary to provide settling time for the magnetic deflection mode **64**. The trailing edge of this delay pulse F starts the generation of the cross. Four deflection voltages A, B, C and D symmetrical about zero volts, are generated by four monostable multivibrators (one-shot MV's **51**, **52**, **53**, **54**). These signals are combined, in pairs, in units **65**, **66** to obtain the required horizontal G and vertical H deflection voltages, and are then amplified and coupled to electrostatic deflection plates of CRT **56**. After each of the four sequential deflection plate voltages has achieved its steady state, unblanking pulses J are applied to intensity modulate the electron beam of CRT **56** and the corresponding point of the cross is illuminated. Pulses J are obtained from the leading edge of pulses A–D after shaping in combining unit **67** to provide pulses I which are then delayed in monostable MV **68** before triggering monostable MV **69**.

To accomplish the above cross generation, the four deflection one-shots **51–54** are connected in cascade, the trailing edge of the output of each circuit serving to trigger the following unit.

The leading edge of each output pulse A–D is used to initiate a delay slightly greater than the rise-time of the deflection amplifier (not shown). At the end of this delay, the unblanking pulse J occurs. The above sequence of events is detailed graphically in the timing diagram of FIGURE 7.

In addition to generating the required deflection waveform A–D the four one-shots also provide four independent circuit states which are used to control the gating of the pen output signals. For the horizontal channel gates **70**, **71** are open during states A and B as shown in waveforms Land M.

SAMPLING AND STORING OF PEN SIGNALS

The pen sensor **55** may be the conventional light pen such as previously described or may be a "beam pen" which relies on capacitive pickup to detect the electron beam itself, rather than the light it creates when it impinges on the face of the CRT **56**. The "beam pen" is described in the AFIPS Proceedings—Fall Joint Computer Conference, 1965, in an article by D. H. Haring. The desirable feature of the beam pen is that its output is independent of phosphor decay time. An undesirable feature is that the beam pen field-of-view response curve is considerably broader than that of the light pen because the charge generated impingement of the beam can be detected over an area larger than that occupied by the illuminated spot. The difference in outputs E_1, E_2 for a given displacement of the pen axis from the centerline of spots **1**, **2** is therefore less for the beam pen than for the light pen. The beam pen, in a stationary situation, produces a pulse-to-pulse output fluctuation equal to approximately ten percent of the D-C output amplitude.

With the beam pen **55** placed over the tracking cross, four output pulses K will occur during each track cycle, their amplitudes depending on the proximity of the pen to each of the cross dots **1**, **2**, **3** and **4**. The first two pulses E_1, E_2 are used to determine the horizontal pen position error; the remaining two pulses, the vertical error. The horizontal and vertical channels of this pen-tracking system are identical in design and performance. After the pen output pulses E_1, E_2 corresponding to the horizontal arm of the cross have been processed, an identical procedure is followed with respect to the vertical arm. The only difference existing between the two channels is the final destination of the binary error signal generated by each circuit. The horizontal channel loads this information into the ΔX register **59**; the vertical channel, into the ΔY register (not shown). In view of this duplication, only one channel, the horizontal, is described in detail.

The circuitry required for the processing of the pen **55** responses E_1, E_2, to the horizontal arm, points **1**, **2**, of the tracking cross is shown in block form in FIGURE **6**. The output of the beam pen amplifier **72** is coupled to an emitter follower **73** to provide the required current gain and source impedance for the sampling stages **70**, **71**. The output of the emitter follower **73** (the pen response corresponding to each point of the cross) is applied to the inputs of the two channels. The horizontal channel, with which we are concerned here, commences with two parallel analog gates **70**, **71**. During each tracking cycle, four pulses K are received from the beam pen. The first two E_1, E_2, are the responses to the horizontal arm of the cross, the initial pulse corresponding to the right dot **1**; the second, to the left dot **2**. While the first point **1** of the cross is being illuminated, and the corresponding beam pen pulse E_1 generated, the deflection multivibrator one-shot **51** is in its unstable state, producing a +10-volt, 5-microsecond wide pulse A. This pulse, in addition to providing the deflection for the first point of the tracking cross, is used as the control signal L at the first analog gate **70**. Gate **70** is opened for this 5-microsecond duration and permits passage of the first pen output pulse E_1 to hold circuit **75**. Potentiometer **74** is initially adjusted to ensure that the maximum amplitude of the pen pulses is less than the gate control signal L.

Diode D_1 and capacitor C_1 serve as a peak detector and hold circuit **75**. When gate **70** turns off, C_1 is charged to the peak amplitude of the first pen output pulse E_1. During the remainder of the tracking cycle, C_1 remains essentially charged at its peak value. Performance of the second analog gate **71** is identical. One-shot **52** generates the control voltage N, and hold capacitor C_2 is charged to the peak value of the second pen output pulse E_2. (Similarly, the analog gates of a vertical channel would

At this point in the analog tracking cycle, the two sampling capacitors C_1, C_2 hold the peak amplitudes N, O of the pen responses E_1, E_2 to the two horizontal points **1**, **2** of the cross. The difference between these amplitudes N, O is the error voltage specifying the distance separating the center line of points **1**, **2** and the axis of the pen **55**, and is obtained with the difference amplifier **58**. Each sampling capacitor C_1, C_2 is coupled to this amplifier through a Darlington-pair emitter follower **76**. This configuration provides sufficient isolation of the holding capacitors C_1, C_2 to prevent excessive discharge before subtraction occurs.

Emitter followers **81**, **82** couple the outputs of the difference amplifier **58** having waveforms P, Q respectively to diode OR gate **83**. One output of amplifier **58** is also coupled to Schmitt trigger **91** which serves to load the horizontal sign bit of ΔX register **59**. Diode gate **83** couples the positive-going output of difference amplifier **58** to analog gate **84**. Gate **84** remains closed until the output transient of gate **83** has decayed to zero. At this time, gate **84** is opened by gate control one-shot MV **85** which is triggered by the trailing edge of waveform D. The output voltage waveform R of gate **84** is coupled to A/D converter **62** through filter circuit **86** comprising an envelope detector **87** and low pass filter **88**. Filter circuit **86** reduces noise produced by small variations in beam-pulse amplitudes due to the electron-beam and the CRT phosphor. Also, since the small signal detected by the pen undergoes considerable amplification prior to insertion in the tracking circuitry, stray signals picked up in an early stage can contribute significantly to the output and must be filtered to reduce their influence.

The binary bits b_0, b_1, b_2, of digital output T of converter **62** are stored in the ΔX register **59** together with the binary sign bit S. The information is transferred through gate **89** to X register **60** after the X and Y tracking information has been obtained. The pulse U from load one-shot MV **90** turns on gate **89** for a time sufficient to shift the X information into the X register **60** (only a few microseconds). The shift pulse U occurs about 5 microseconds after input signal gating waveforms A–D have terminated.

Although specific embodiments of the present invention have been depicted, it is obvious that numerous additions and substitutions may be made without departing from the spirit and scope of the invention. Accordingly, the invention should be deemed limited only insofar as it is restrictively defined in the following claims.

What is claimed is:

1. Pen tracking apparatus of the type comprising a cathode ray tube,
   - means for intensity modulating a beam of electrons within said tube,
   - a pen responsive to the effect produced by the electron beam impact on the face of said tube,
   - said pen having an axis,
   - said pen having an output which diminishes with the distance between said axis and said beam impact position,
   - means for deflecting said beam in response to a stored signal and a second signal,
   - means for providing said stored signal to said deflecting means to cause said beam to deflect to the position of the pen axis determined during the previous tracking cycle,
   - means for providing a sequence of pulsed second signals at the time said stored signal is applied to deflect the beam incrementally about its stored pen axis position,
   - means for providing intensifying pulses to said intensity modulating means in time coincidence with said pulsed second signals to provide a plurality of beam impingements on said face spaced in time and space from each other,
   - said pen being responsive to said beam impingements to

provide a plurality of output signal pulses in sequence,

wherein the improvement comprises,

means for determining the difference in amplitude and sign of said output pulses to obtain an error signal proportional to the position of the axis of said pen with respect to the non-incrementally deflected beam position,

means for adding said error signal to said stored signal to provide a new stored signal corresponding to the actual location of said pen axis to complete the tracking cycle.

2. The apparatus as in claim 1 wherein

said sequence of pulsed second signals deflects said beam in orthogonal directions to provide two points of beam impingement on said face along each direction,

said pen being responsive to said beam impingements to provide output signals,

means for determining the difference in amplitude and sign of said output signals from impingement points along one direction to provide a first error signal,

said stored signal comprising first and second component signals each to deflect said beam along one of said orthogonal directions,

said first component signal deflecting said beam along the same direction as said first error signal,

means for adding said first error signal to said first component signal to provide a signal corresponding to the pen axis position in said one direction,

means for determining the difference in amplitude and sign of said output signals from impingement points along the remaining orthogonal direction to provide a second error signal,

means for adding said second error signal to said second component signal to provide a signal corresponding to the pen axis position in said orthogonal direction.

3. Apparatus as in claim 1 wherein

said deflection means comprises means for deflecting said beam in a first direction and a second means for deflecting said beam in a second direction,

said pulsed signals comprising a first and second pulsed signal,

means for applying a first signal to said first deflection means,

means for applying a second signal to said second deflection means,

said first signal providing a pair of points of impingement of said beam on the face of said tube in said first direction,

said second signal providing a pair of points of impingement of said beam on the face of said tube in said second direction,

wherein the improvement comprises,

means for detecting the amplitudes of the pen responses to said first direction beam impingements,

means for determining the difference in amplitude and sign of said first direction pen response amplitudes,

means for providing said amplitude and sign of said first direction amplitude difference to said first deflection means to deflect said beam along said first direction toward the axis of said pen,

means for detecting the amplitudes of the pen responses to said second direction beam impingements,

means for determining the difference in amplitude and sign of said second direction pen response amplitudes,

means for providing said amplitude and sign of said second direction amplitude difference to said second deflection means to deflect said beam along said second direction toward the axis of said pen.

4. Apparatus as in claim 3 wherein

said first and second directions are orthogonal.

5. The apparatus of claim 1 wherein

said pulsed second signals deflect said beam about its stored pen axis position to form a pattern of four impact points each equally spaced from said stored pen axis position and from each other,

two of said points lying along a first line,

the other two points lying along a second line orthogonal to said first line,

means for comparing the amplitude of said pen outputs produced by said points along said first line to provide a first error signal,

means for determining the amplitude of the component of said stored signal which produces the deflection of said beam along said first line,

means for adding said first error signal to said first line component,

means for comparing the amplitude of said pen outputs produced by said points along said second line to provide a second error signal,

means for determining the amplitude of the component of said stored signal which produces the deflection of said beam along said second line,

means for adding said second error signal to said second line component.

6. The apparatus of claim 1 wherein

said cathode ray tube has a phosphorus coating on its face,

said electron beam impingement on said phosphor coated face producing light output,

said pen being responsive to said light output to provide an electrical output signal diminishing with distance from the point of light output to the axis of said pen.

7. The apparatus of claim 1 wherein

said electron beam impingement on said cathode ray tube face produces an electrical charge at the point of impact,

said pen having an input responsive to said charge to provide an electrical output signal diminishing with distance from the point of impact to the axis of said pen.

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Jan. 26, 1971 F. FLORET ET AL 3,559,182

SYSTEM FOR TRACING SYMBOLS ON VISUAL INDICATOR WITH ORTHOGONAL SWEEP

Filed Dec. 20, 1967 7 Sheets-Sheet 1

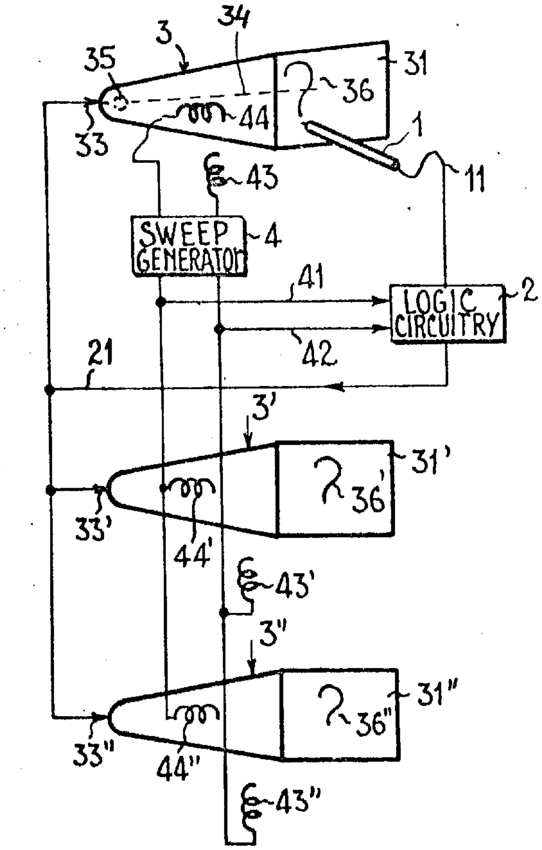

FIG 1

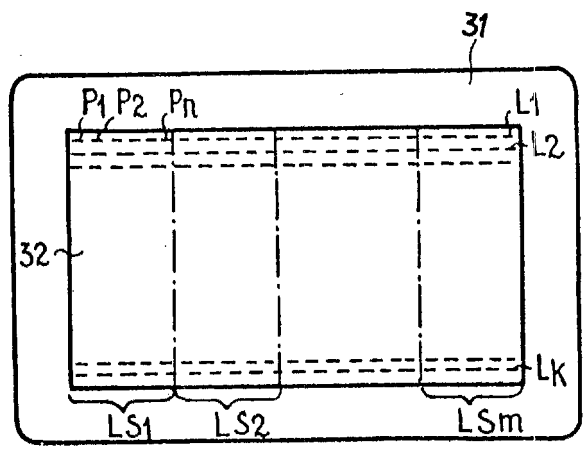

FIG. 2

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SYSTEM FOR TRACING SYMBOLS ON VISUAL INDICATOR WITH ORTHOGONAL SWEEP

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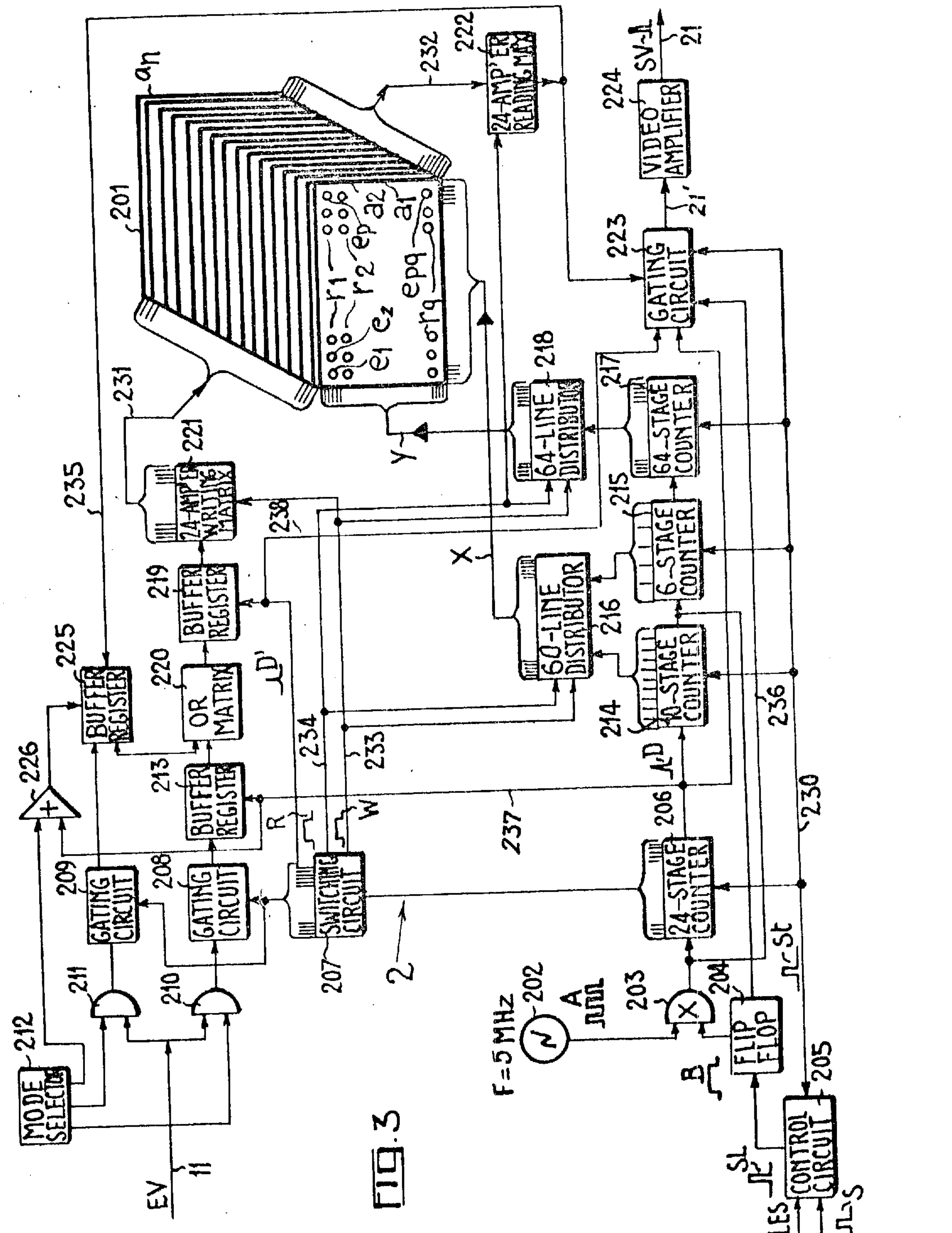

FIG. 3

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SYSTEM FOR TRACING SYMBOLS ON VISUAL INDICATOR
WITH ORTHOGONAL SWEEP

Filed Dec. 20, 1967 7 Sheets-Sheet 3

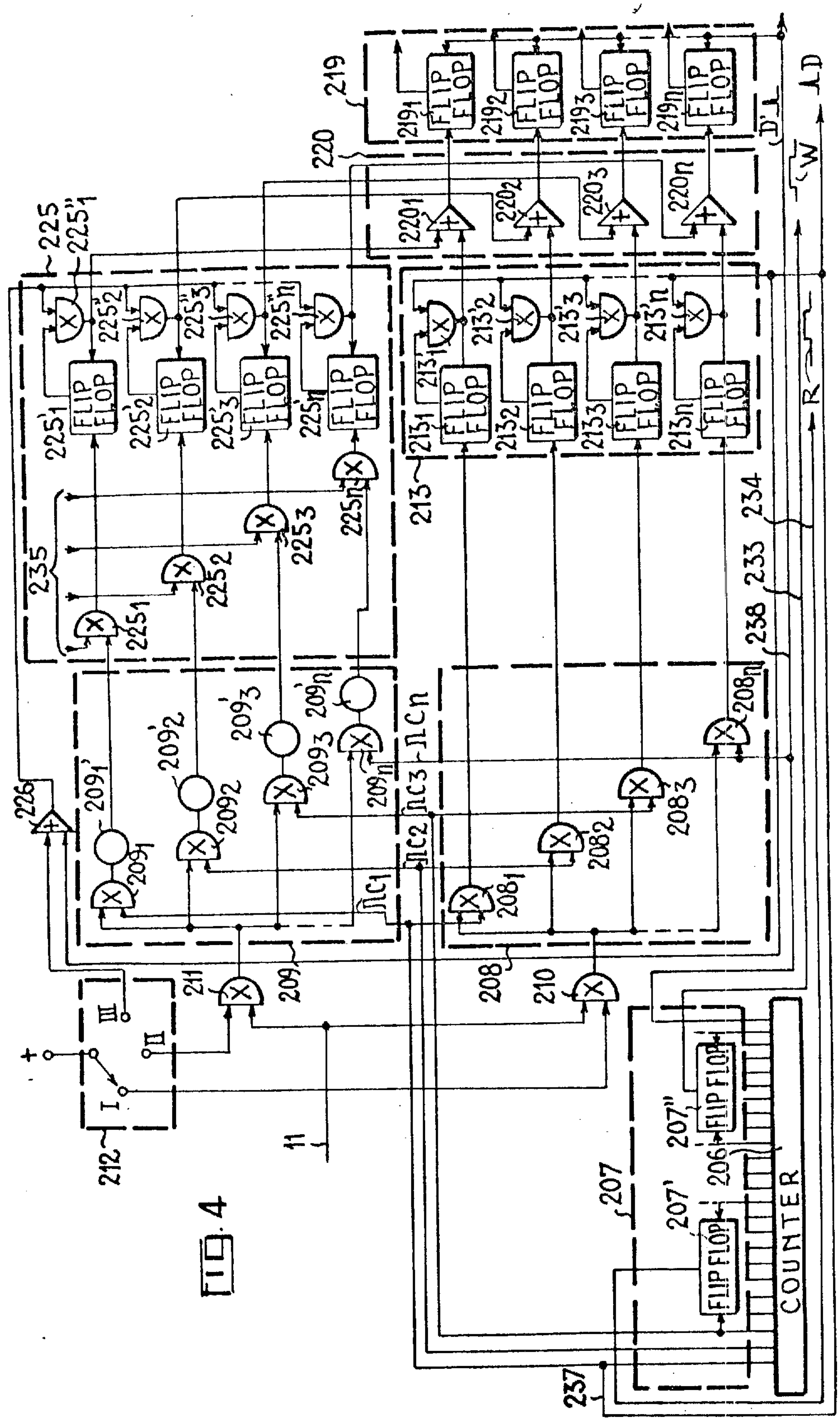

FIG. 4

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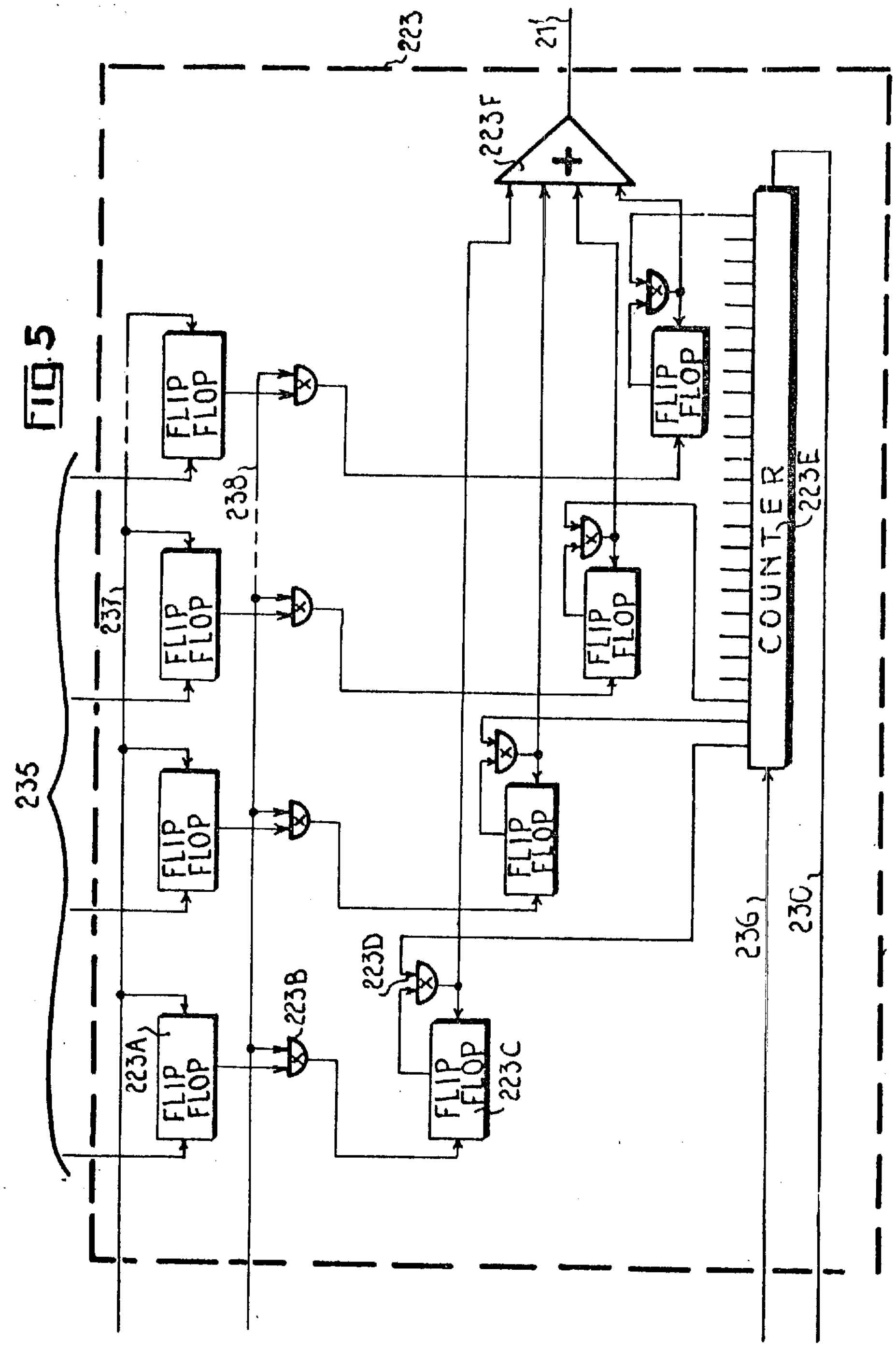

FIG. 5

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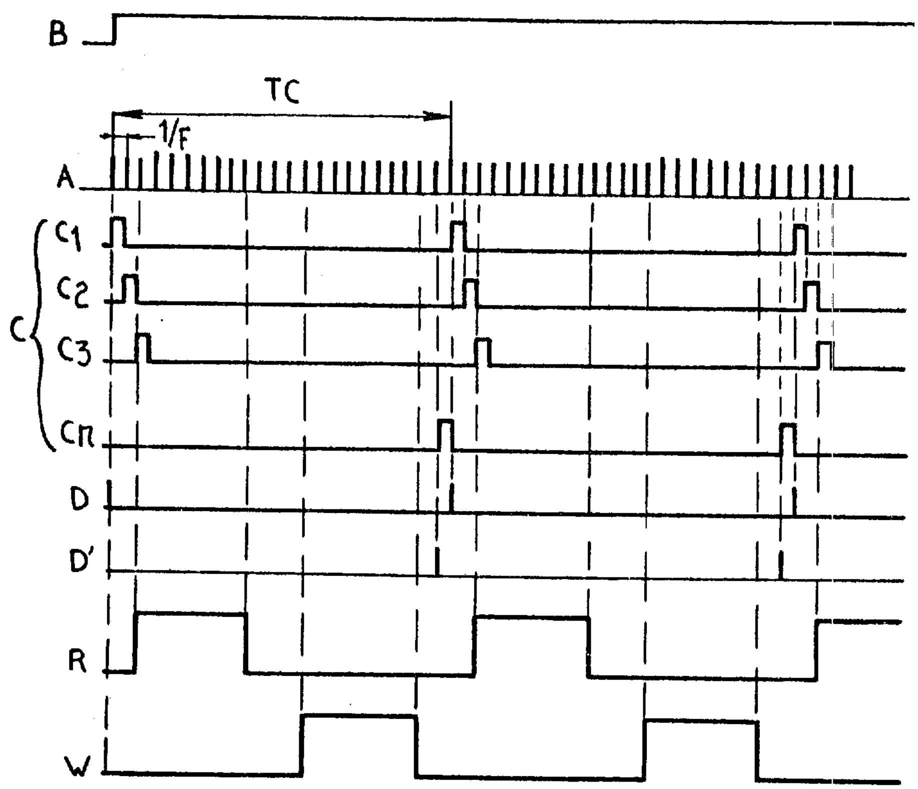

Fig 6

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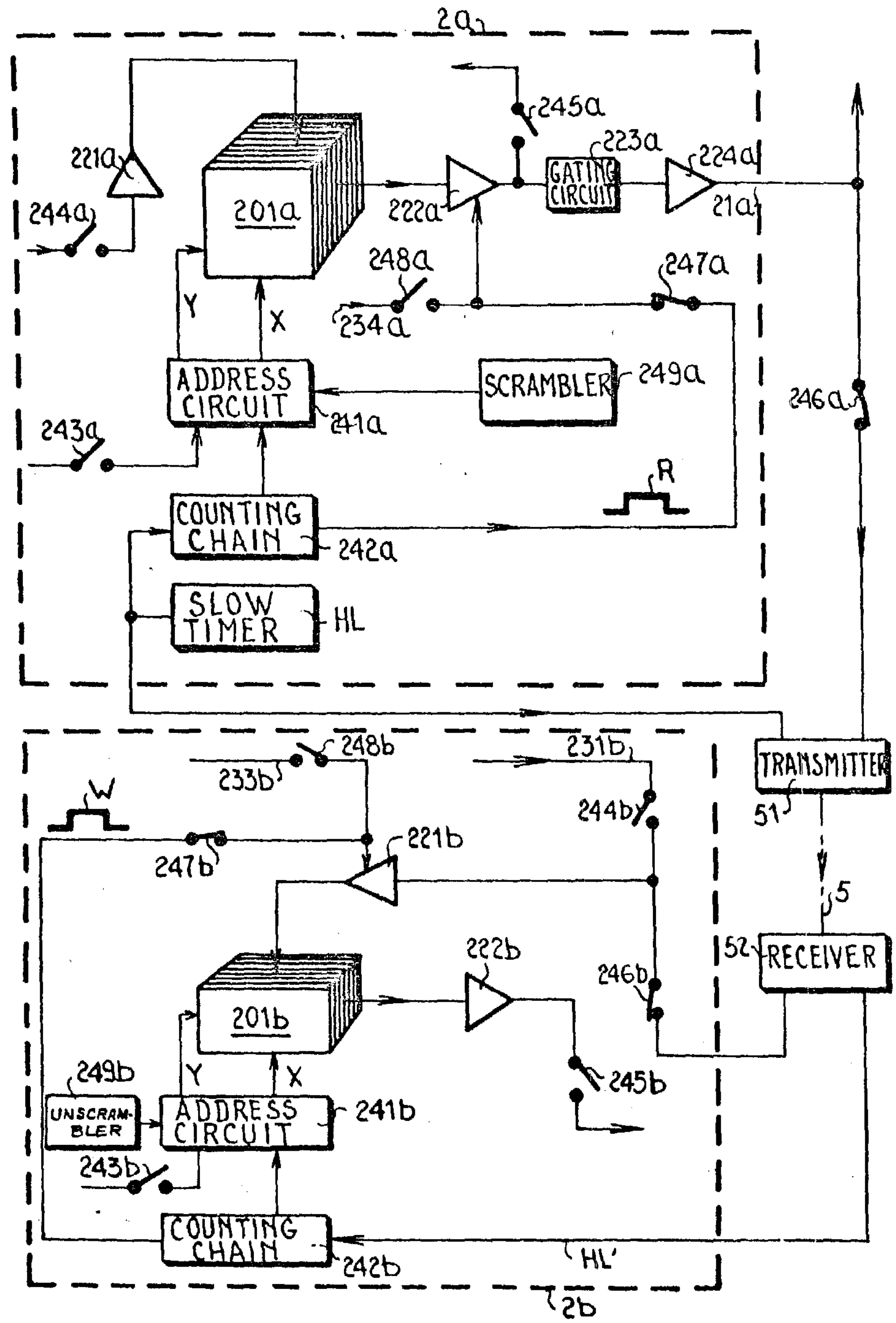

FIG 7

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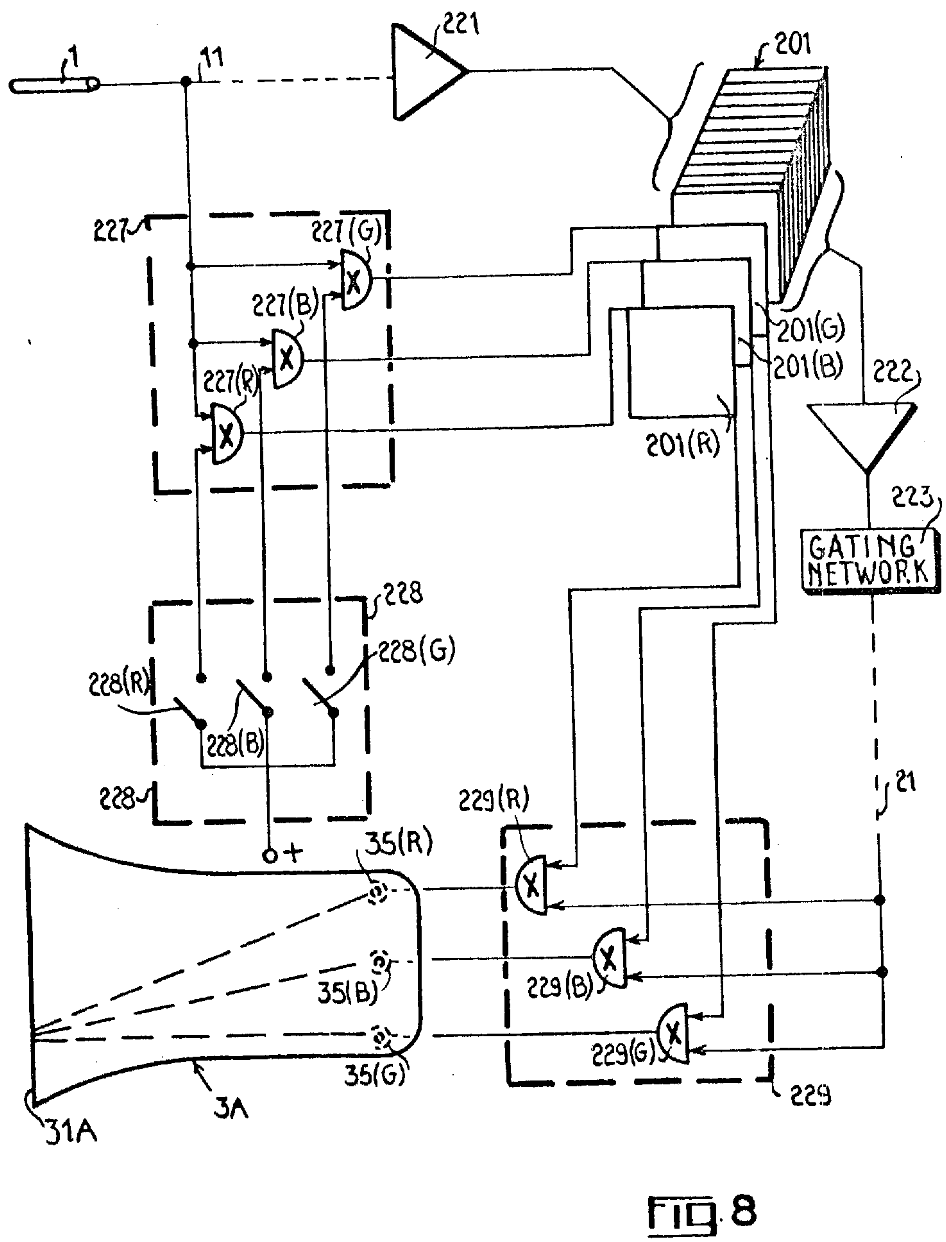

FIG. 8

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