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Baker et al.

[11] **3,784,875**

[45] **Jan. 8, 1974**

[54] **STAGE LIGHTING CONTROL UNITS**

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[30] **Foreign Application Priority Data**

May 7, 1971 Great Britain 13748/71

[52] **U.S. Cl.** **315/294**, 315/312, 315/316

[51] **Int. Cl.** **H05b 37/00**

[58] **Field of Search** 315/292, 294, 312, 315/316

[56] **References Cited**

UNITED STATES PATENTS

3,579,030	5/1971	Bentham et al.	315/294
3,004,193	10/1961	Bentham et al.	315/316 X
3,448,338	6/1969	Bentham et al.	315/312 X
3,521,124	7/1970	Bogner	315/312
3,668,467	6/1972	Isaac	315/292
3,706,914	12/1972	Van Buren	315/292 X

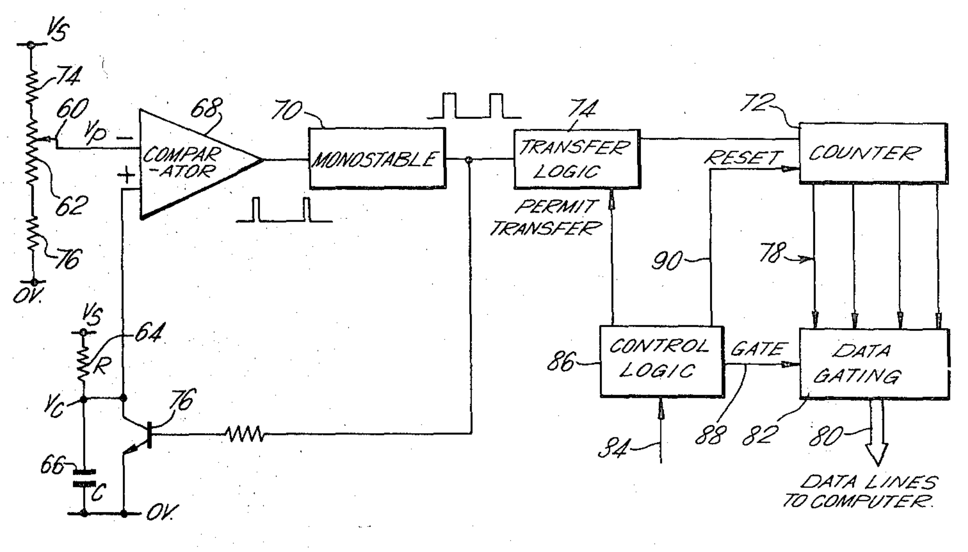
Primary Examiner—Palmer C. Demeo
Attorney—Joseph F. Brisebois et al.

[57] **ABSTRACT**

A lighting control apparatus for stage lighting and the like in which lighting values are stored and handled entirely by digital techniques, the apparatus being based on a general-purpose digital computer.

The invention also provides a novel method of controlling crossfades from one lighting state to another which is economical in its demands on data handling capacity, since it operates by defining the required changes as a given number of increments thus permitting further control to be by means of addition and subtraction only. A novel clock circuit for use in this incremental cross-fading is described.

9 Claims, 6 Drawing Figures



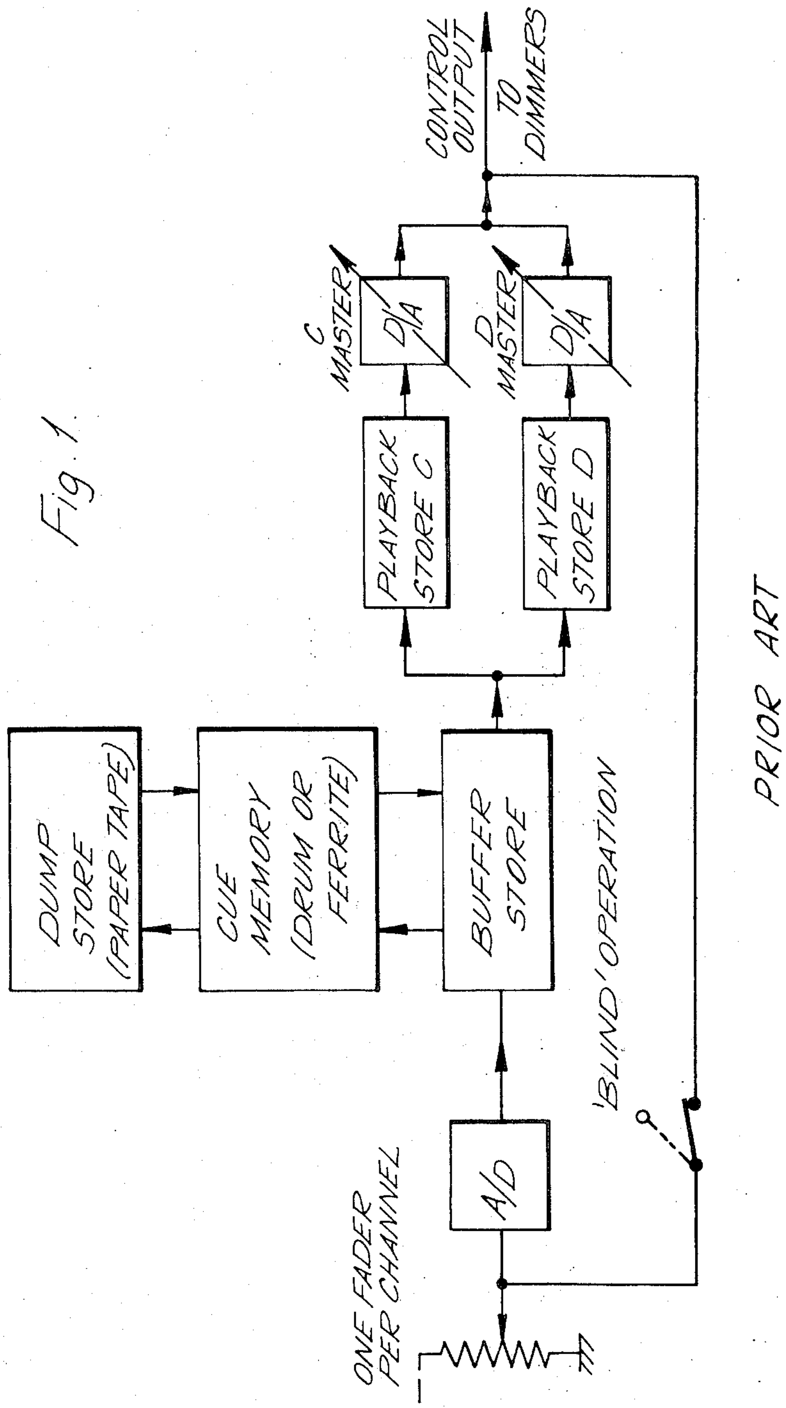


Fig. 1

PRIOR ART

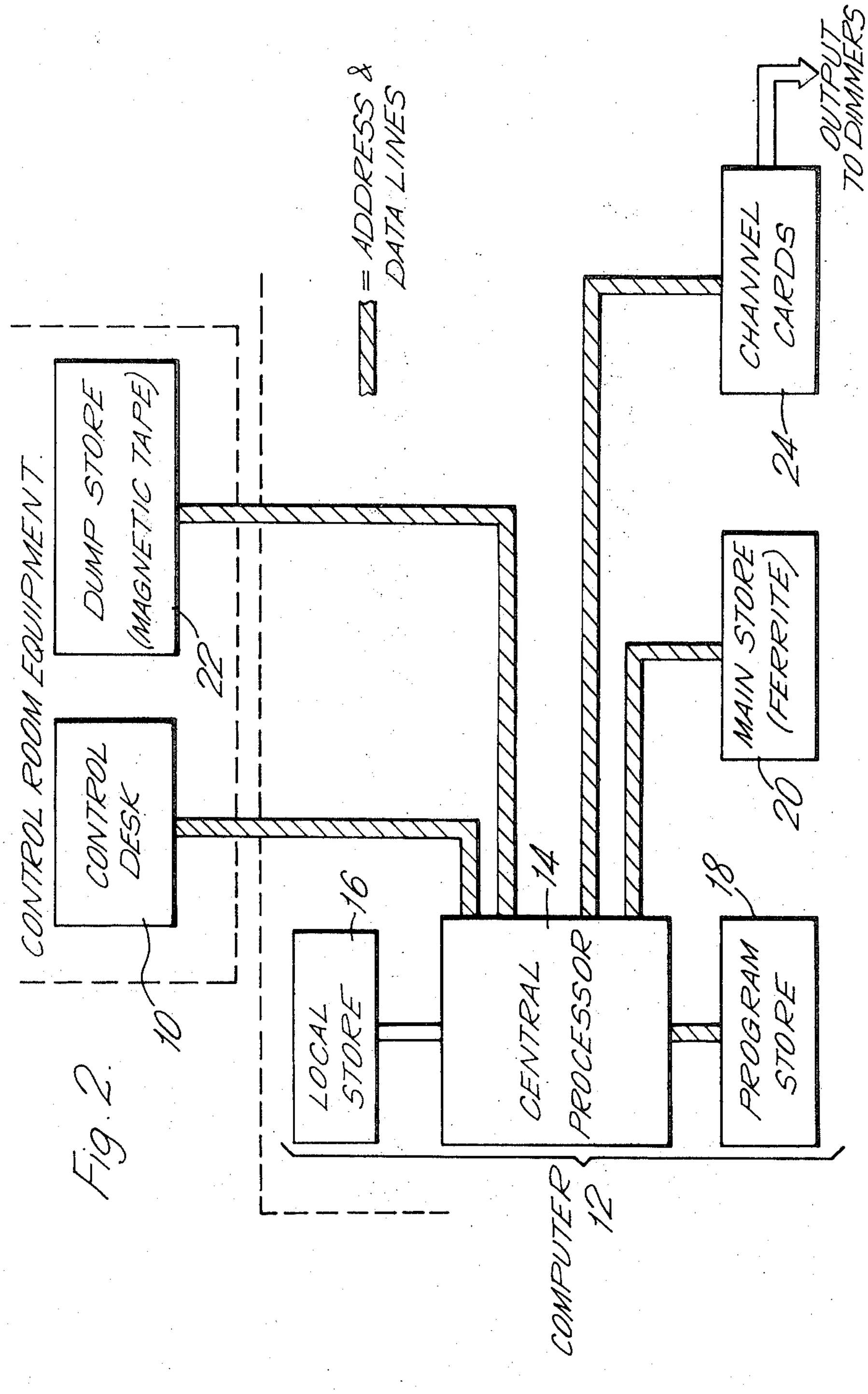

CONTROL ROOM EQUIPMENT.
CONTROL DESK
10
DUMP STORE (MAGNETIC TAPE)
22
= ADDRESS & DATA LINES
LOCAL STORE
16
CENTRAL PROCESSOR
14
PROGRAM STORE
18
MAIN STORE (FERRITE)
20
CHANNEL CARDS
24
OUTPUT TO DIMMERS
COMPUTER 12

Fig. 2.

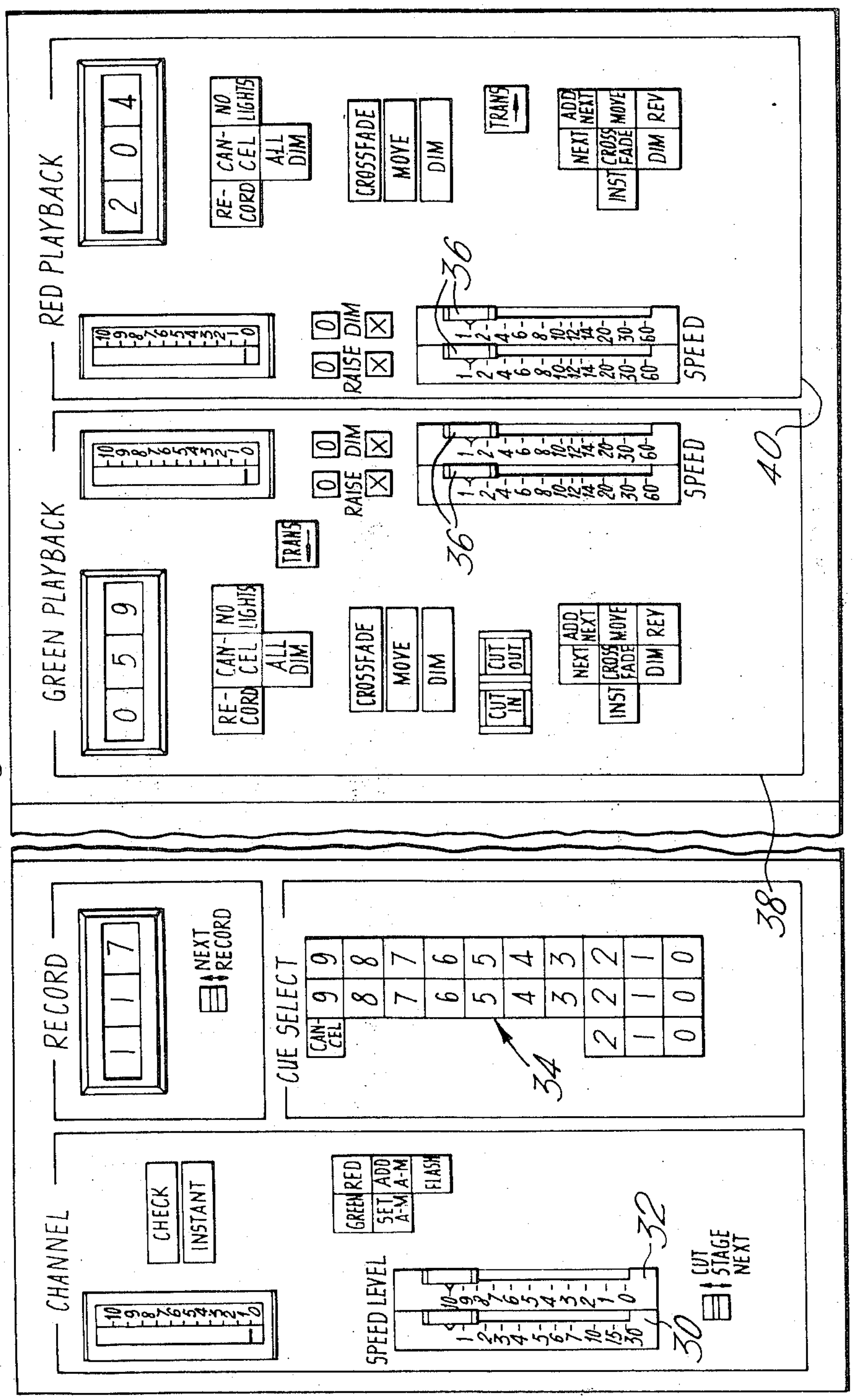
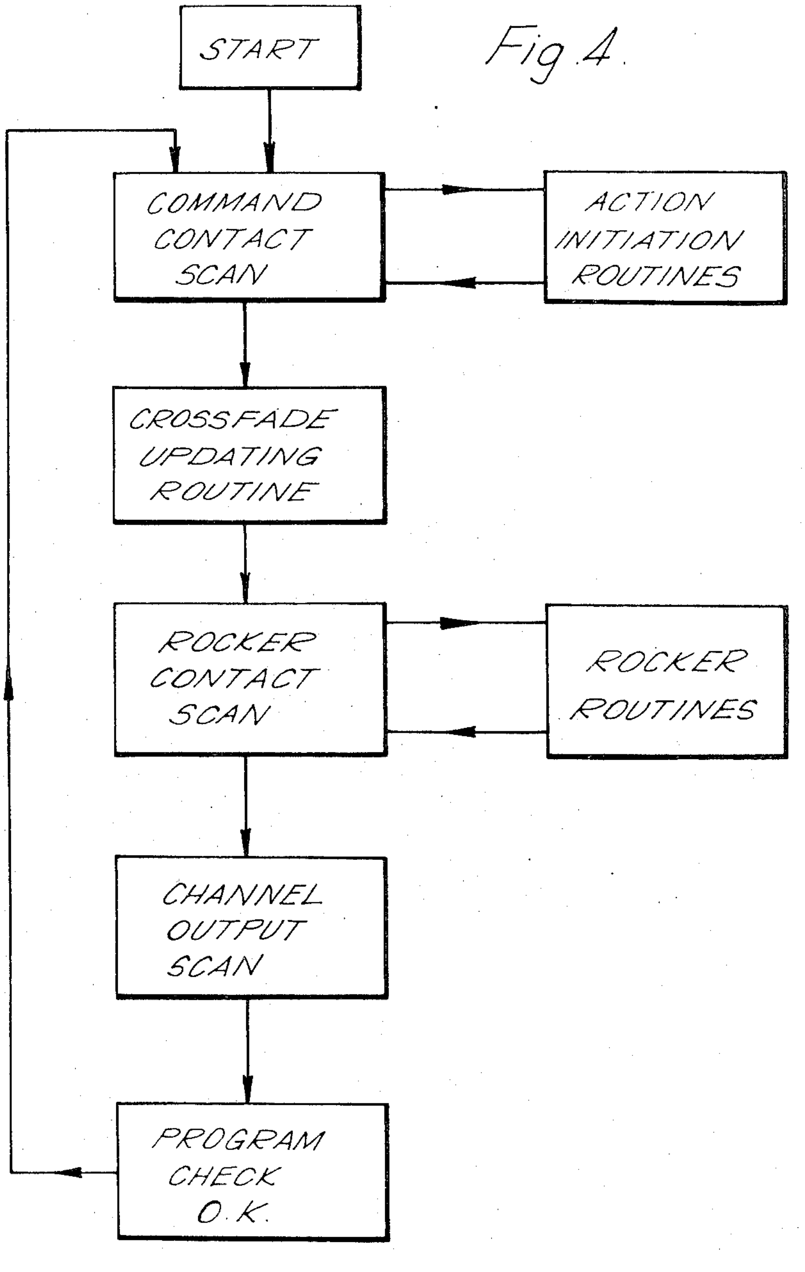

RED PLAYBACK
GREEN PLAYBACK
RECORD
CHANNEL
CUE SELECT
RE-CORD
CAN-CEL
NO LIGHTS
ALL DIM
CROSSFADE
MOVE
DIM
TRANS
NEXT
ADD NEXT
INST
CROSS FADE
MOVE
DIM
REV
RAISE
DIM
SPEED
CUT IN
CUT OUT
NEXT RECORD
CHECK
INSTANT
GREEN
RED
SET A-M
ADD A-M
FLASH
SPEED LEVEL
CUT STAGE NEXT
30
32
34
36
38
40

Fig. 3

Fig. 4.


START
COMMAND CONTACT SCAN
ACTION INITIATION ROUTINES
CROSSFADE UPDATING ROUTINE
ROCKER CONTACT SCAN
ROCKER ROUTINES
CHANNEL OUTPUT SCAN
PROGRAM CHECK O.K.

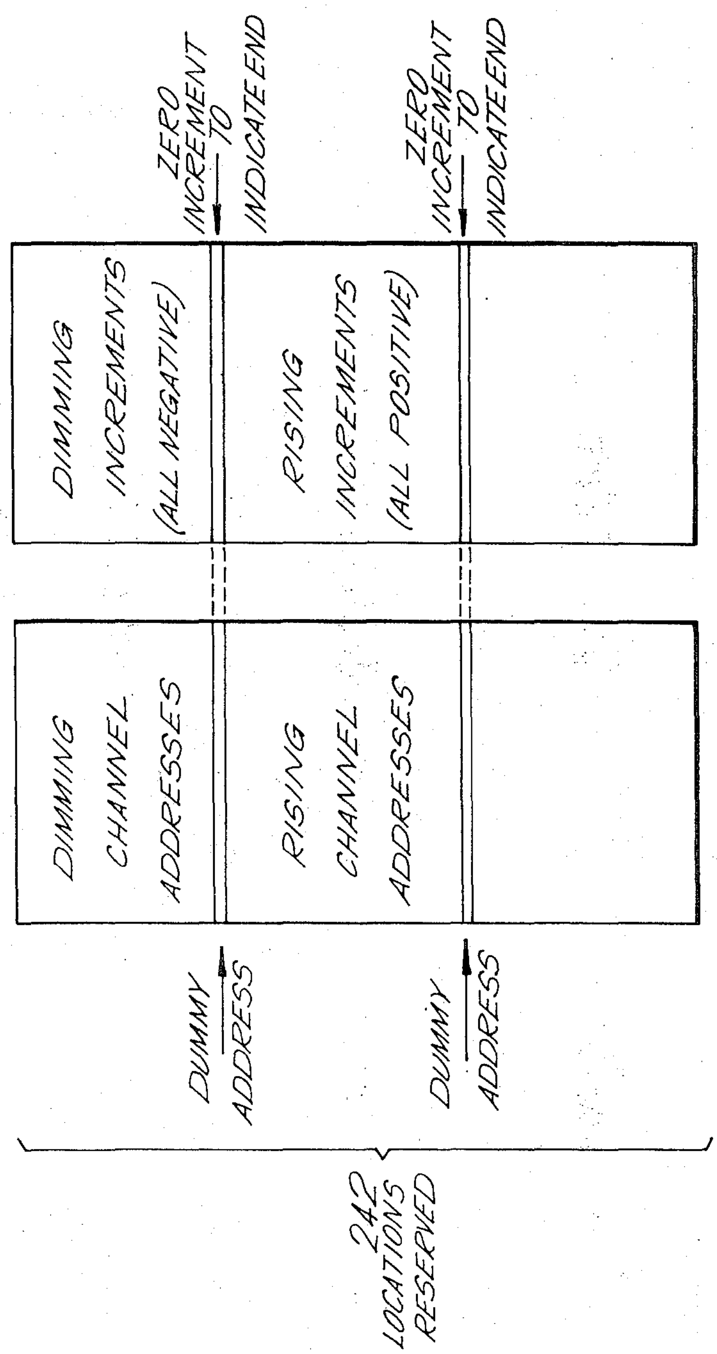
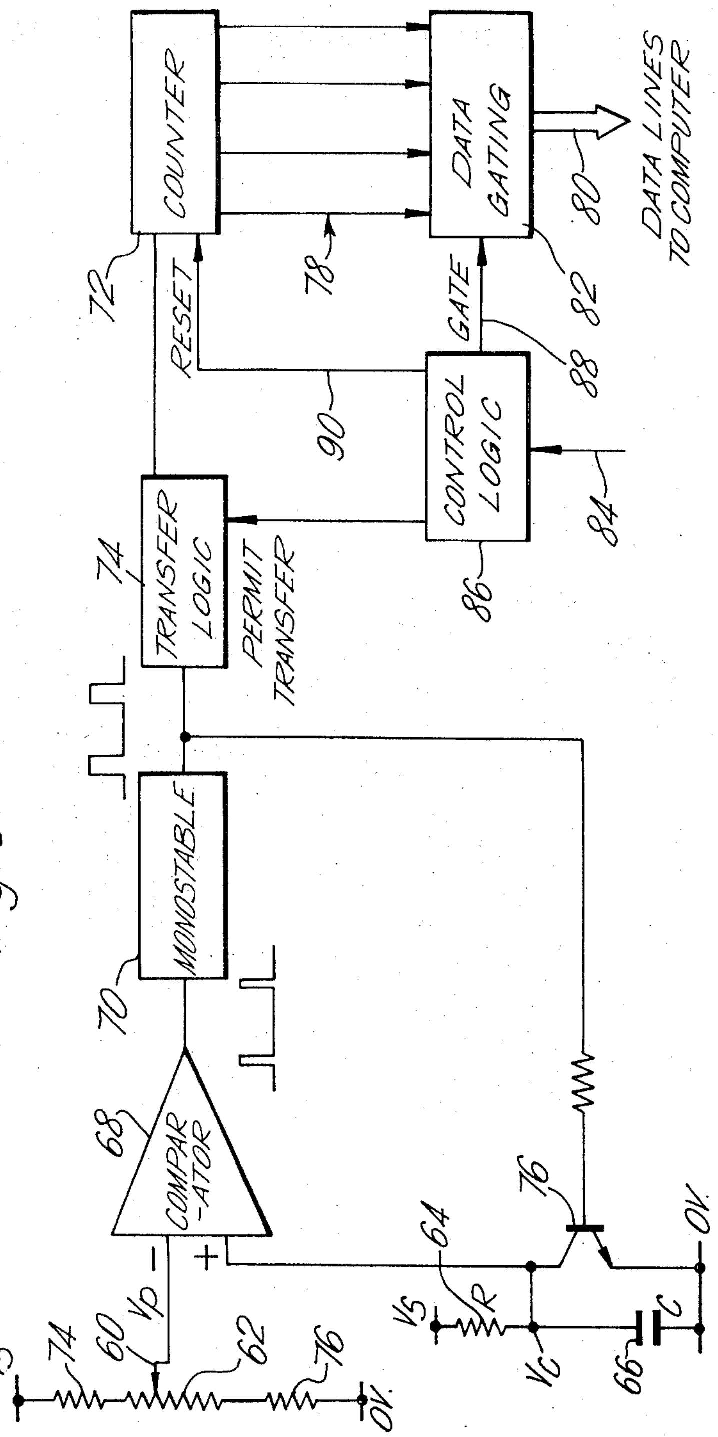


Fig. 5. CROSSFADE DATA.
(FOR 240 CHANNEL SYSTEM)

Fig. 6


COUNTER
DATA GATING
DATA LINES TO COMPUTER
80
82
78
72
RESET
GATE
88
90
CONTROL LOGIC
84
86
TRANSFER LOGIC
74
PERMIT TRANSFER
MONOSTABLE
70
COMPAR-ATOR
68
76
64
OV.
R
C
VS
VC
66
VP
60
74
62
76
VS
OV.

STAGE LIGHTING CONTROL UNITS

This invention relates to stage lighting control units. Such units are used to control the illumination produced on a set in theatrical, television or similar fields, and are required to control the illumination provided by a number of lighting channels both individually and in some situations en bloc.

The development of stage lighting control units has been directed from the beginning towards greater flexibility of operation, with a corresponding increase in the freedom of the operator from restrictions in technique imposed by limitations of the mechanical and electrical systems at his disposal. More recently, the trend of development has been towards units which are capable of recording entire lighting cues in some form of memory (originally mechanical, but later magnetic) so that a set of lighting cues constituting a lighting plot can be stored and the stored plot subsequently re-played without the need for manual presetting of the dimmer controls. Changes of cue in this type of unit are effected by cross-fading from one cue memory to the next.

An example of this type of system is illustrated by the embodiment described in our U.K. Patent Specification No. 1,220,815. FIG. 1 of the accompanying drawings depicts a simplified schematic of this arrangement. During playback (performance) cues are read back alternately into Stores C and D. A modulating device allows the outputs from these two stores to be multiplied by any factor between 0 and 1 by the setting of corresponding "mastering" controls. The setting of these controls can therefore be used to mix the outputs from the two stores, perform crossfades, etc.

However, since the introduction of the equipment described in the aforementioned U.K. Patent, a number of features have been scrutinised with a view to achieving improved performance/cost ratios.

One of the first areas for scrutiny was the channel fader lever which has conventionally been used on manual preset controls and has been similarly adopted in systems of the type described in U.K. Patent Specification No. 1,220,815. As a means of temporarily setting and storing a dimmer level, the fader lever is many more times expensive than alternative digital solutions. An all digital approach would avoid the necessity for costly analogue to digital interface circuits associated with each fader lever. The fader lever also presents difficulties from the operational point of view. The live performance is rarely completely predictable, being subjected as it is to continuing artistic improvement and modification as well as to human errors. The lighting operator must therefore be able to quickly modify a previously recorded stage lighting level without attracting the attention of the audience. Using the fader lever this entails careful matching of the fader lever output to the previously recorded dimmer level before the change can be executed. One solution to this problem has already been described in U.K. Patent Specification No. 1,083,408 namely the use of a rocker switch which can either be used as a command control to raise or lower a particular channel level at a pre-set rate or alternatively as a means of channel identification operated in association with a single level setting means or common command buttons which can instruct the circuit to be flashed on or off for identification purposes during rehearsal. The operation of this control in one embodiment of the system described in this specification is outlined later. However, the principal feature of the rocker control is that it provides essentially digital information which can be interpreted by a digital system without the necessity for costly interface circuits.

A more extensive use of digital techniques is embodied in a system known as Q File invented by A.A. Isaacs described in U.K. Patent Specification No. 1,171,914. A multiplexed arrangement is used throughout which enables a common set of basic logic circuits to carry out similar functions in turn to each channel. Thus a number of recorded lighting states can be logically added or subtracted to produce a composite scene made up from a number of sub-groups of lighting. Dimmer levels are set by means of a single multiplexed fader lever which is assigned to one channel by means of a numerical keyboard. Furthermore, during a fade, output levels are changed by means of computed increments or decrements to the original lighting state. This computation is performed by a combination of analogue and digital techniques. A further advantage is that if the fade process is interrupted then the digital levels at the time of interruption can be immediately used as the starting point for the computation of a new fade. This permits processional fades to be carried out i.e. a fade to a new cue can be started before the previous one has been completed.

The embodiment described in U.K. Patent Specification No. 1,171,914 is based on an arrangement of digital and analogue circuits designed specifically for the purpose required. In other words, it is a system based on hardware logic.

Such a system has obvious drawbacks in that the use of hardward logic makes it difficult to facilitate the incorporation of additional or modified operational facilities.

It has been proposed to overcome this problem by the use of a stored program computer in a lighting control. At least one such system has been built in which a computer retrieves and files lighting data. However, crossfading from one cue to the next is still, in this prior system, handled by conventional analogue techniques.

An object of the present invention is therefore to enable the use of a digital computer to control all aspects of a lighting system, including the dynamic requirements of crossfading.

Accordingly, one aspect of the present invention provides a lighting control apparatus for controlling dimmers of a plurality of lighting channels, comprising a digital computer including a lighting cue memory for recording series of dimmer control signals, each such series constituting a lighting cue, manual control means for selecting any given cue memory location for providing output signals to the dimmers to produce a lighting effect corresponding to the lighting cue in that location, the computer being arranged to compute, when said means is operated to recall a new lighting cue, a succession of outputs which cause said output signals to move over a period of time from their existing levels to the levels recalled by said operation.

According to a further aspect of the invention, there is provided apparatus for controlling dimmers of a number of lighting channels, comprising a digital computer including a lighting cue memory for recording series of dimmer control signals, each such series constituting a lighting cue, manual control means for selecting any given cue memory location for providing output signals to the dimmers to produce a lighting effect corresponding to the lighting cue in that location, a manually operable control member for setting the speed of crossfading from one cue to a following cue selected by said control means, a clock arranged to produce pulses at a rate determined by the setting of said control member, and a resettable counter arranged to receive pulse from the clock, the computer being arranged to operate, when said means is operated to recall a new lighting cue, to initially compute a list defining the sense of change of illumination in each channel and the magnitude of each of a predetermined number of equal increments into which the necessary change is divided, and thereafter to increase the output signals of the channels sequentially by adding a respective number of increments equal in number to the count held in the counter, the counter being reset on completion of each cycle of computation.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. **1** relates to the prior art, as has been described;

FIG. **2** is a block diagram illustrating the components of the apparatus and their relationship to each other;

FIG. **3** shows the operator's control desk;

FIG. **4** is a flow chart of the computer main program loop;

FIG. **5** depicts the organisation of part of the stored data; and

FIG. **6** is a circuit diagram of a clock and counter arrangement used in this embodiment.

As is well known in the stage lighting art, individual light sources such as spots and floods are patched together to form a number of channels each controlled by a dimmer, usually a thyristor arrangement. A channel may have from one to a large number of light sources, and a given light source may form part of more than one channel. By suitably controlling the dimmers, a given lighting state or effect, also referred to as a lighting cue, is achieved.

Referring now to FIG. **2**, the present embodiment includes a control desk **10** (which will be described in more detail below) connected to a computer **12**. The computer **12** is a small general-purpose computer, specifically a PDP **11** by Digital Equipment Corporation, and comprises a central processor **14**, a local store **16** and a program store **18** and is connected to a ferrite core main store **20**, as is all well known in the art. Also connected to the computer **12** is a magnetic tape read/write unit **22** which acts as a dump store. The computer **12** controls the dimmers (not shown) via channel circuit cards **24**.

The electrical connections between these various units are by means of a conventional address and data line structure such as is used to provide the standard means of interconnection between a computer and its peripherals. Operationally, the system hardware can be considered as performing the functions of a very fast telephone exchange. However, in this case there is a simplification in that only the computer can do the "ringing up" of numbers, or addresses as they are normally called. When an address has been called up, transfer of data may take place either from the computer to the hardware or vice versa. This method of operation is basically an extension of the internal operation of the computer. In order to allow for varying time delays which can occur dependent on the length of interconnecting cables, an electrical "handshake" system is used to secure the transfer of data before the computer moves on to the next address. Again this principal is a conventionally accepted computer technique.

Thus in operation, the computer controls the high speed telephone exchange and can manipulate and process the data it receives.

The control desk **10** of FIG. **2** comprises a main desk shown in FIG. **3** and a rocker panel (not shown) which carries a number of rocker switches or rockers, one for each channel. Each rocker switch can be depressed at one end to raise the lighting level of the channel, and at the other to lower it, and the rockers act in conjunction with controls **30, 32** on the master desk which determine the speed of this movement and its upper limit. A number of cues (in this case 250) can be built up in this way and each recorded in the main store **20** at a location identified by a one number zero to 299 entered by a keyboard **34.** The remaining controls may be generally designated "action" controls since they determine record, playback and crossfade actions. These actions are all controlled by the computer **12** which generally recycles on a program loop shown in FIG. **4.** When any of the action controls or rockers is operated, this is detected during the appropriate scan period and the computer branches to a subroutine to give effect to it. These routines are straightforward and it is easily within the capabilities of a person skilled in the computer art to arrange the recording and recall of cue data, and the like.

The essence of the invention lies in solving the problem of handling a cross-fade (i.e. a move from one cue to another in a given time) digitally, and the solution according to the invention will now be described.

In order to respond to any of the Rockers or Action controls, the computer is programmed to interrogate each in turn. This is accomplished by addressing contacts in blocks of ten, whence 0/1 data representing the ON/OFF conditions of the controls is transmitted back to the computer along the data bus.

As far as the operator is concerned, response to the operation of a control must appear to be almost instantaneous, which means that any control must be interrogated at least once every 50 milliseconds or less. During a digital crossfade, it is important to minimise the size of the increments of decrements applied to each dimmer control signal output, otherwise the lighting discontinuities will be apparent to the eye. The applicants have found that for crossfades of longer than 10 seconds, output increments of dimmer control voltage must be restricted to 1/256 of full output. This conclusion is based on the theatre requirement to operate over a very wide range of illumination levels and assumes that the dimmer control characteristic is also suited to this application.

For crossfades of less than 10 seconds, larger discontinuities can be tolerated provided that outputs are updated at least once every 30 milliseconds. This ensures that the response time of the lamp (typically 100–200 milliseconds) and the eye's persistence of vision have an overall "smoothing" effect upon the control signal discontinuities.

As the result of this analysis, it was concluded that a main programme loop of the form shown in FIG. **4** should be adopted. Furthermore, in order to satisfy all of the foregoing requirements, the programme loop must on average be completed in less than 30 milliseconds.

The crossfade requires each channel to be updated on the basis of the following equation.

Output at time $t = X + t/T(Y-X)$

Where

X = dimmer lever at the start of a crossfade.

Y = required dimmer level at the end of the crossfade.

T = the set crossfade time.

t = elapsed time.

The more obvious approach to this computation would involve multiplication. However, with the constraints placed on programme cycle time, this could only be achieved by using an expensive computer equipped with a fast multiplication facility.

Thus although (as has been previously mentioned), a computer has been used previously to handle lighting control cues, the apparent complexity and expense has so far deterred the incorporation of a digital crossfade.

However, a much simpler solution was achieved as the result of a novel approach to the crossfade computation which will now be described. The computation is carried out in two parts. In the first, the normal program cycle is interrupted whilst information is computed and tabulated. The program then returns to its normal cycle during which the tabular information is used to update channels during the crossfade period. It is more important to minimise the time for the latter computation rather than for the initial tabulation since a slight delay in starting an action is more acceptable than discontinuities appearing during the updating of channel levels.

Whilst Rocker and Action controls are inactive, the program cycles quiescently through the routine outlined in FIG. 4, cycle time for a 360 channel system being in the region of 20 milliseconds. Immediately a crossfade action button is operated, the quiescent program cycle is interrupted. The required end of fade conditions are placed in an active computer store labelled the Destination Store. The Destination level for each channel is then compared with the current output and the difference (Δ) is determined for each moving channel. If we now divide each fade into 256 equal time intervals, then the fade can be progressed by adding (or subtracting) at each time interval, the appropriate fade increment ($\delta=\Delta/256$ etc.). In general, it will be different for each moving channel.

In practice, the division by 256 is carried out in a single computer operation cycle by exchanging the more significant (8 bit) byte in a 16 bit word for the less significant byte. All the fade increments are then placed in an active computer store (Increment Store) as are the numbers of all those channels required to move during the fade (Channel Number Store). The general stacking organisation is depicted in FIG. 5 from which it can be seen that increasing channels are segregated from decreasing channels. These stored tabulations are sometimes referred to as the Movement List.

Having prepared this information which may take any-thing up to 60 ms for a 360 channel system, the computer can now return to the main program loop of FIG. 4.

The system is equipped with four fade time levers **36** to enable RAISE and DIM fade times to be set independently on each of the two play back controls (see FIG. 3). Each fade time lever is coupled to a clock which produces 256 pulses during the time period set on the scale of the respective fade time lever **36**. Each clock output is connected to the input of a respective elapsed time counter, the output of which can be addressed, read and cleared to zero by the computer. Once the movement list has been prepared, the computer returns to the main program loop. Each time the crossfade up-dating routine is entered, the incremental counters are in turn addressed, read and set to zero. The number D in the DIM's counter is read first and this establishes the decrement to be applied to each of the corresponding channels namely $D \times \delta$. The DIM counter is set at zero immediately after it has been read and number D noted. The up-dating of the channel level is then performed by D successive subtractions of the stored decrement . The RAISE counter is similarly read and increments added to those channels being raised. Crossfade updating is carried out with reference to the movement list (see FIG. 5) and only the moving channels listed are processed. Furthermore the separate stacking of positive and negative increment permits each group to be processed independently in conjunction with the appropriate incremental counter output.

The system has two independent sets of playback controls, known as GREEN and RED respectively. These have identical sets of action controls on the master desk, designated **38** and **40** in FIG. **3**. The Green crossfade updating routine is carried out first followed immediately by RED crossfade updating.

Each time the computer program enters the crossfade updating routine, the count read from each elapsed time counter will depend not only on the fade time set but on the time taken for the program to complete the loop. The average program cycle is never longer than 30 milliseconds so that for a fade time in excess of 10 seconds, an incremental counter reading of either 1 or 0 will be received at each crossfade update. For crossfade times of less than 10 seconds, with a 360 way system, each counter output will be greater than 1 since the average program cycle time may be as long as 30 milliseconds particularly if a large number of channels is involved in the movement list. Furthermore the incremental counter has a maximum capacity of 8 which facilitates the selection of a crossfade time as short as 1 second without overloading the counter. Nevertheless, the asynchronous nature of the design allows the system to compensate for these varying conditions. In particular, the arrangement permits the simple interleving of four independent fade computations i.e. the RAISE and DIM fades of both RED and GREEN playbacks. The absence of complex interrupt or synchronisation facilities makes for a simple, flexible design which is readily adapted to meet the varying tasks which the computer is required to undertake. Thus if additional Rocker or Action controls are required, they can be readily serviced in the main program loop, there being no critical constraints on timing or synchronisation.

A number of different types of crossfade are possible viz:-

1. CROSSFADE, in which all channels move to the levels recorded in the next cue.
2. MOVE, in which all channels move to the new level except those for which the new level is set at zero; these channels stay constant. This simplifies a change where only a small number of existing channels are altered.

3. DIM, in which the channels identified in the new cue are reduced to zero.
4. ALL DIM, in which all channels move to zero.
5. REVERSE, in which all channels move from their existing state to the last cue.
6. INSTANTANEOUS — when operated with any of (1) to (5), the required change takes place instantaneously.

It will be appreciated that (2) to (6) above are special cases of CROSSFADE which are provided simply for operational convenience.

From the programming point of view, the main differences between these actions occur in the initial setting up routine which interprets the contents of NEXT and DESTINATION stores according to the particular action called for. Otherwise, the determination of fade increments and the updating routine remains as previously described. The REVERSE action only involves changing the contents of the destination store during its initial routine. At each crossfade update routine, the signs of the increments are inverted so previous increments are now subtracted etc.

The crossfade computation is the most important of the system functions since the method chosen establishes the flexible asynchronous approach to executing all the system functions. The novel design of the associated clock and incremental counter will now be described.

Referring to FIG. 6, the appropriate manual control 36 (FIG. 3) moves the slider 60 of a linear potentiometer 62 connected across a supply voltage Vs, to give a variable control voltage Vp. The same supply voltage Vs is applied across a resistor 64 and capacitor 66 in series. The voltage Vc across the capacitor C follows the law

$$Vc = Vs\ (1-e^{-t/RC})$$

where

t is the time elapsed from Vc = 0

R is the value of the resistor **64** and

C is the value of the capacitor **66**

The capacitor voltage Vc is fed to one input of a comparator **68** whose other input receives the control voltage Vp. When Vc reaches the value of Vp, the comparator output goes positive and triggers a monostable circuit **70.** The resulting output pulse from the monostable circuit **70** passes to a counter **72** via a gate **74** and to the base of a transistor **76** shunting the capacitor **66** to earth. The counter **72** therefore counts up, while the capacitor **66** is discharged to Vc = 0, and the cycle is restarted.

The time for each cycle is the width of the pulse from the monostable circuit **70** plus the charging time of Vc and Vp. Rearranging the expression above for Vc thus produces a logarithmic function for cycle time. Resistors **74** and **76** are small fixed resistors and prevent the invalid conditions of the capacitor charging in zero and infinite times respectively. The speed control lever **36** has two logarithmic scales calibrated respectively in seconds and minutes (fade time). The component values are so chosen that 256 clock pulses are generated in the set fade time.

The binary coded output of the counter **72** is interrogated at intervals by the computer **12.** The time taken by the computer **12** to do this is short in comparison with the cycle time of the clock circuit. However, to prevent the computer **12** accessing during a pulse from the monostable circuit **70** and thus losing a pulse or producing two pulses, extra logic circuits are provided. The output from the counter **72** on output lines **78** is connected to data lines **80** to the computer via a data gating circuit **82.** An output signal on line **84** from the computer **12** causes a control circuit **86** to generate an enabling gate pulse on line **88** to gate the counter output to the data lines **80,** immediately followed by a reset signal on line **90** to the counter **72.** During these gate and reset periods the gate **74** on the input to the counter **72** is inhibited by the control circuit **86.**

An advantage of the above timing circuit or clock is that very few components are required to control the accuracy of the timing. These are the resistor **64** and capacitor **66** which must be of high stability and the potentiometer **62** whose ratio must be stable.

Different time ranges may be obtained by switching in different values for resistor **64.**

From the embodiment described, it will be apparent that the invention provides an elegant solution to the problem of providing a digital lighting control apparatus in which the entire control including crossfading is handled by an on line digital computer. This solution gives great flexibility and permits many easy modifications to the embodiment described.

For example, in a theatre the control desk is typically in the backstage area, but it is frequently desired to have additional "stalls" control in the audience area. The present invention allows a stalls control to be simply added, the computer then merely scanning both control desks during its main program loop.

Another modification made possible by the invention replaces the many (typically 240) rockers to be replaced by a simpler control layout. The control desk is provided with a keyboard by means of which the operator can select any channel, and with a handwheel driving a rotary digital encoder. To alter a channel lighting level, the operator selects that channel on the keyboard and then moves the handwheel in one direction to raise the light level and in the other to lower it. The digital encoder outputs a pulse for each given angle of rotation with an indication of the sense of the rotation and these pulses are simply added to or subtracted from the stored level for that channel. Digital encoders of this type are well known in many fields, for example in the numerical control of machine tools. With such an arrangement the program for the action controls is unchanged — only the program for level setting requires to be rewritten.

Other modifications are of course possible within the scope of the invention as defined in the appended claims.

We claim:

1. A lighting control apparatus for controlling dimmers in a plurality of channels, comprising:

A. a digital lighting-cue memory means for recording a plurality of series of dimmer control signals, each such series constituting a lighting cue,

B. manual control means responsive to a manual input for selecting any given location in the lighting-cue memory means by providing electrical output signals to the dimmers to cause the dimmers to produce a lighting effect corresponding to the lighting cue stored in that location, and

C. digital computation means responsive to operation of said manual control means for digitally computing a succession of incremental electrical signals which act upon said electrical output signals to cause a value of the output signals to move over a period of time from their levels which existed before said manual input to the levels recalled from the memory location by the operation of the manual control means.

2. Apparatus according to claim 1, in which the digital computation means performs an initial computation identifying those channels in which said output signal value must change from an existing level to a different level required by the new cue and thereby compiles a "movement list" identifying these channels and the sense and magnitude of the necessary changes in value, the movement list being subsequently used to compute said succession of outputs.

3. Apparatus according to claim 2, in which the digital computation means defines said magnitude as a predetermined number of equal increments.

4. A lighting control apparatus for controlling dimmers in a plurality of channels, comprising:

A. a digital lighting-cue memory means for recording a plurality of series of dimmer control signals, each such series constituting a lighting cue,

B. manual control means responsive to a manual input for selecting any given location in the lighting-cue memory means by providing electrical output signals to the dimmers to produce a lighting effect corresponding to the lighting cue stored in that location,

C. a manually operable control member for setting the desired speed of cross-fading from one cue to a following cue selected by said control means,

D. a clock responsive to said control member to produce electrical pulses at a rate determined by the setting of said control member,

E. a resettable counter connected to receive said electrical pulses from the clock, and

F. digital computation means responsive to the operation of said manual control means for computing a list defining the sense of change of illumination in each channel and the magnitude of each of a number of predetermined equal increments into which the necessary change is divided, and also responsive to the counter to subsequently increase the value of said electrical output signals of the channels sequentially by adding a respective number of said increments equal in number to the count held in the counter, the counter being reset each time all channels have been so incremented.

5. Apparatus according to claim 4, including further manually operable control means to provide signals representing desired levels of illumination of selected lighting channels as inputs to the lighting-cue memory means.

6. Apparatus according to claim 4, in which the clock comprises a resistor and capacitor arranged in series across a voltage source, a computer having one input connected to receive the voltage on the capacitor and its other input connected to receive a voltage determined by said control member, a monostable circuit triggered by the comparator output changing sign, and means responsive to the output of the monostable circuit for discharging the capacitor.

7. Apparatus according to claim 6, in which the voltage determined by the control member is derived from the slider of a linear potentiometer, the potentiometer being connected across said voltage source and its slider being mechanically coupled to said control member.

8. Apparatus according to claim 6, in which said means for discharging the capacitor comprises a transistor whose emitter - collector path is connected in shunt across the capacitor and whose base is connected to receive the output of the monostable circuit.

9. Apparatus according to claim 4, in which the digital computation means includes a binary shift register for computing the magnitude of said increments by dividing the required change by a constant which is a power of 2.

* * * * *