

[54] **DRIVING APPARATUS FOR DISPLAY ELEMENT** 3,742,483 6/1973 Ogle..... 340/324 M  
3,761,617 9/1973 Tsuchiya et al..... 178/7.3 D

[75] **Inventors:** Tetsunori Kaji; Seiichi Murayama,  
both of Kokubunji, Japan

[73] **Assignee:** Hitachi, Ltd., Japan

[22] **Filed:** Dec. 3, 1973

[21] **Appl. No.:** 421,351

Primary Examiner—R. V. Rolinec  
Assistant Examiner—E. R. LaRoche  
Attorney, Agent, or Firm—Craig & Antonelli

[52] **U.S. CL.**..... 315/205; 178/7.3 D; 315/169 TV;  
315/208; 315/DIG. 4; 315/324

[51] **Int. CL.**..... H04n 5/66

[58] **Field of Search**..... 315/169 R, 169 TV, 200 R,  
315/201, 202, 205, 208, 291, 293, 294, 312,  
315/324, 337, DIG. 4, DIG. 7; 340/324 M;  
178/7.3 D

[57] **ABSTRACT**

A driving apparatus for a display element comprises a plurality of sources for generating pulse-width modulated pulse signals each having a different amplitude depending on its source, an adder for adding the pulse signals from the sources together and a discharge tube to which the output of the adder is applied.

[56] **References Cited**

**UNITED STATES PATENTS**

3,601,532 8/1971 Bitzer et al. .... 178/7.3 D

11 Claims, 12 Drawing Figures

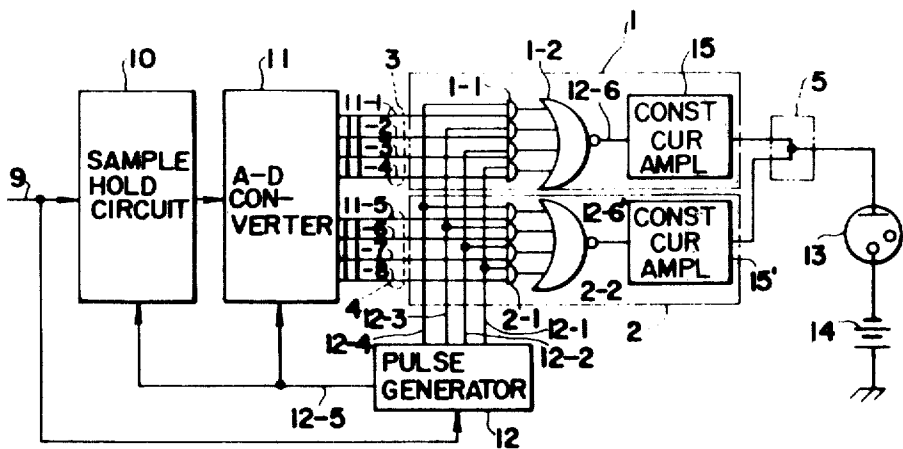


FIG. 1

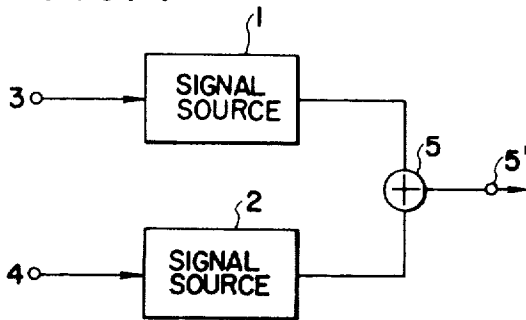


FIG. 2

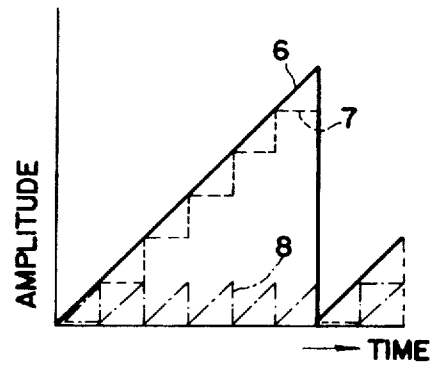


FIG. 3A

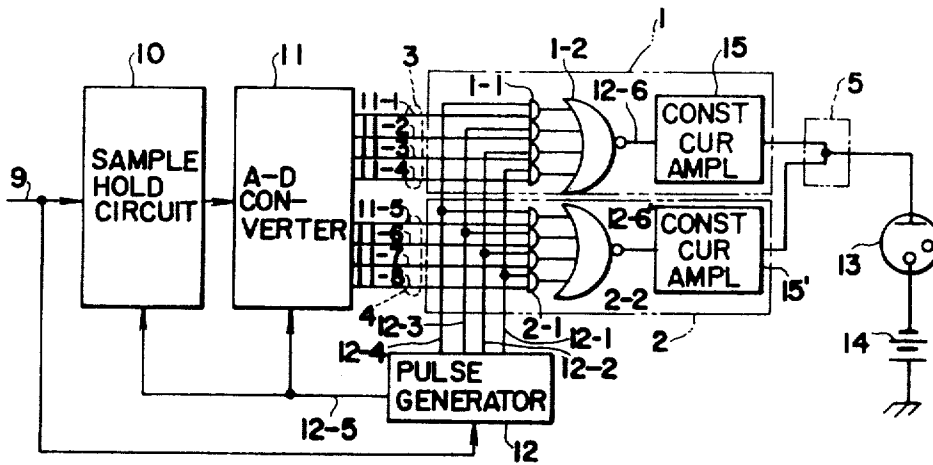


FIG. 4

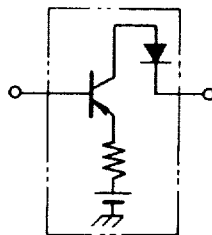


FIG. 3B

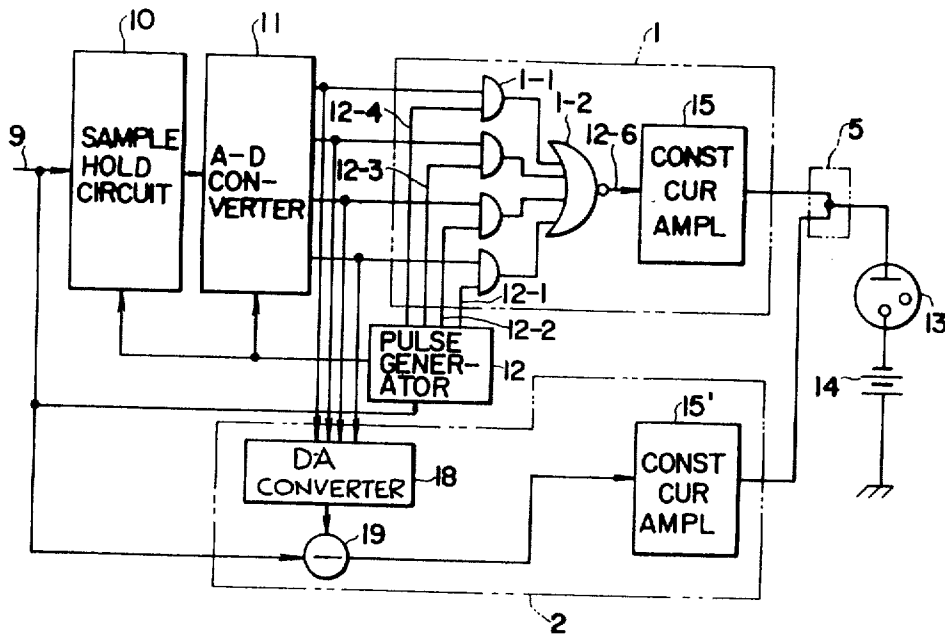


FIG. 5

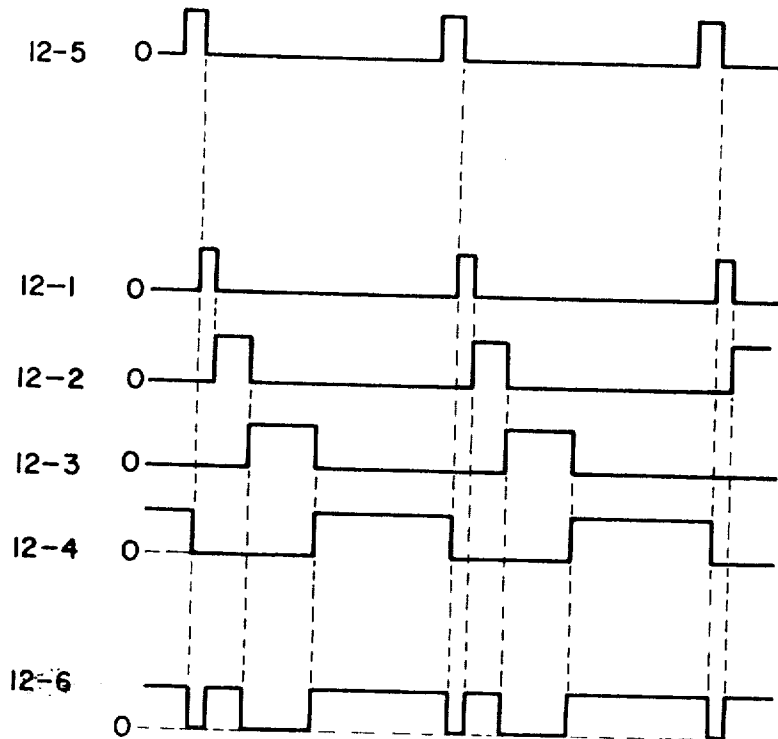


FIG. 6

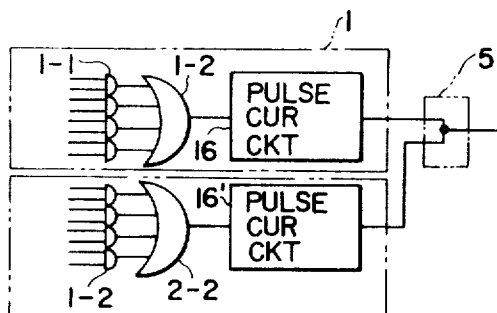


FIG. 7

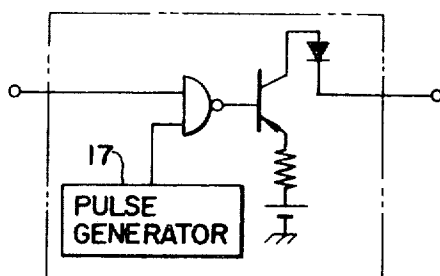


FIG. 8

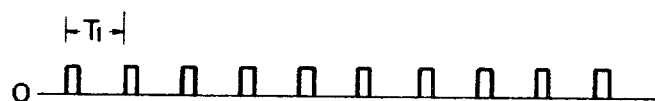


FIG. 9

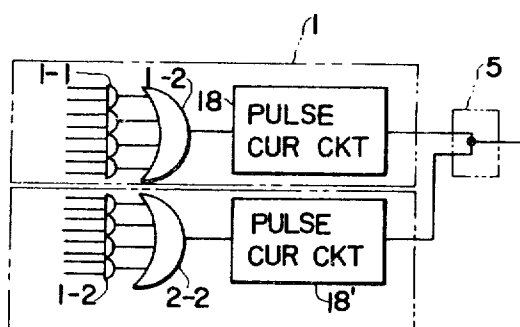


FIG. 10A

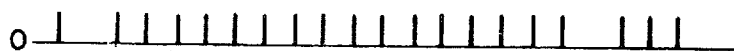
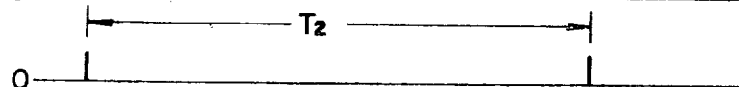


FIG. 10B



## DRIVING APPARATUS FOR DISPLAY ELEMENT

## BACKGROUND OF THE DISCLOSURE

## 1. Field of the Invention

The present invention relates to a driving apparatus for a display element and, more particularly, to a driving apparatus suitable for intensity modulation.

## 2. Description of the Prior Art

The brightness of a display element, such as one exhibiting a plasma display or electroluminescence, is determined by the product of the electric quantity applied to the display element, such as electric current or voltage, and the time required for the application of the electric quantity to the display element.

However, most of the ordinary display elements have relatively slow rise time, resulting in a slow response (the response time in these ordinary elements is usually more than  $1\mu s$ ) and, if the elements have a small electric input applied thereto, the response of the elements tends not to be stable, so that a correct response in proportion to the input quantity cannot be attained.

As a means to change the brightness of a display element, that is, to provide the display elements with brilliance or brightness modulation, various types of modulation, such as pulse-width modulation, pulse frequency modulation, and pulse-amplitude modulation, have been widely utilized for the conventional display elements. For example, the time factor of the product determining the brightness has been controlled by means of pulse-width modulation, or the magnitude of the electric quantity of the product determining the brightness has been controlled by means of pulse-amplitude modulation.

However, the use of the pulse-width modulation, pulse-frequency modulation, or pulse-amplitude modulation will cause the following disadvantages. Pulse-width modulation or pulse-frequency modulation will have a slow response action for the display elements, while pulse-amplitude modulation will cause an unstable response performance of the display elements for a lower electric input; more particularly, a low brightness region cannot be displayed exactly in proportion to the electric input.

## SUMMARY OF THE INVENTION

An object of the present invention is to provide a driving apparatus for display elements wherein the response of the display elements is quick, and the problems of unstable and variable performance in the low brightness region are solved to a considerable extent.

Another object of the present invention is to provide a driving apparatus for a display element wherein a neutral gradation of the brightness can be displayed.

To achieve the above described objects, the present invention provides a driving apparatus for driving display elements by combining the use of pulse-width modulation or pulse-frequency modulation, and pulse-amplitude modulation.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a basic diagram for illustrating the principle of the present invention;

FIG. 2 illustrates the signals used in the present invention;

FIG. 3A shows a block diagram of an embodiment of the present invention;

FIG. 3B shows a block diagram of another embodiment of the present invention;

FIG. 4 shows a circuit utilized in the embodiment of FIG. 3A;

FIG. 5 shows waveforms for illustrating the operation of the embodiment of FIG. 3A;

FIG. 6 shows a major part of the arrangement of still another embodiment of the present invention;

FIG. 7 shows circuits utilized in the embodiment of FIG. 6;

FIG. 8, FIGS. 10A and 10B show the waveforms of signals used in the circuit of FIG. 7; and

FIG. 9 shows a major part of the arrangement of a further embodiment of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a basic diagram for illustrating the principle of the present invention, in which 1 and 2 identify the signal sources for generating pulse-width modulated (or pulse-frequency modulated) output signals; the amplitude of the signals from the signal sources 1 and 2 are different from each other. 3 and 4 refer to the input terminals for the signal sources 1 and 2, respectively. 5 is an adder for adding the output signals of the signal sources 1 and 2, and 5' is the output terminal of the adder 5.

In the arrangement shown in FIG. 1, input signals which are quantization signals of analog signals are applied through the input terminals 3 and 4 to the signal sources 1 and 2 to be converted by the sources as pulse-width modulated signals having different amplitudes depending on the source. For example, the amplitude of the output signal from the source 1 is greater than that of the output signal from the source 2, so that a rough representation of the level of brightness is affected by the output from the source 1 and a minute representation of the brightness level is affected by the output from the other source 2. These two pulse-width modulated output signals from the sources 1 and 2 having different amplitudes are now applied to the adder 5 to produce, at the output terminal 5', a pulse-width modulated signal having a greater amplitude which is superimposed on the same signal with a smaller amplitude. This superimposed signal is used as a driving signal for the driving display elements.

Now, the output signals from the source 1 and 2 will be explained in more detail. If a gradation in the brightness is to be displayed in  $2^8 = 256$  degrees, the ratio between the amplitude of the output signal from the source 1 and that from the source 2 is to be  $2^4 (= 16) : 1$ , and the signals from the source 1 are assigned to the upper four bits while signals from the source 2 are assigned to the lower four bits. Thus, the sum of these two signals allocated for different bits is applied to the display element. The minimum width of a pulse, in this case, will be a sixteenth of the maximum width. If one horizontal scanning period of the signal presently used in television broadcasting ( $\approx 63.5\mu s$ ) is used as the maximum width, the minimum width will be approximately  $4\mu s$  and, therefore, the conventional display element can be properly operated with this signal. However, if only pulse-width modulation is employed as in the conventional apparatus, the minimum width of a pulse required will be  $1/256$  of the maximum width, i.e.,  $0.25\mu s$ . Accordingly, only such emission elements as emission diodes are operable with this pulse. If only

pulse-amplitude modulation is employed as in the conventional apparatus, the minimum amplitude will have to be 1/256 of the maximum amplitude, which is, in fact an extremely small amplitude for practical purposes. Thus, it is hardly possible to expect the display elements to perform in a stable and uniform manner in this very restricted region of amplitude. Also, stability must further be demanded in the wider region, so that the driving apparatus will necessarily become expensive.

According to the present invention, the minimum amplitude is no less than 1/16 of the maximum amplitude, which eliminates the associated difficulties of the conventional apparatuses and display elements. In FIG. 1, only two output signals from the sources are added to each other for illustrative purposes, but the present invention can also be applied when more than two output signals are added together.

In the above description, it has been assumed that both input signals supplied to the sources 1 and 2 are quantization signals, but this is not a strict requirement. Where two signal sources are used, better performance can be expected for adding the output signals from the signal sources, if at least one of the input signals is a quantization signal. However, if there is no quantization signal, it does not affect performance.

If one of the input signals is not a quantization signal, the signals shown in FIG. 2 are applied to the signal sources 1 and 2. In FIG. 2 sawtooth signals 6 are used as brightness signals, where the vertical axis shows amplitude, and horizontal axis shows time. The quantization signals are applied to the source 1, as shown by the dotted line, and analog signals 8 represented by the chain line, having an amplitude which corresponds to the difference in amplitude between the signals 6 and quantization signals 7, are applied to the signal source 2.

FIG. 3A is a block diagram of one embodiment of the present invention in which both of the signal sources 1 and 2 have quantization input signals, and a discharge tube is used as a display element. In FIG. 3A, 9 is a brightness signal input; 10 is a sample-hold circuit, and 11 is an analog-digital converter. (This will be referred to as an A-D converter hereinafter.) 1-1 is an AND gate; 1-2 is a NOR gate; 15 is a constant current amplifier. These three components constitute the signal source 1. The signal source 2 comprises an AND gate 2-1, an OR gate 2-2, and another constant current amplifier 15'. 12 is a pulse generator consisting of a component for generating a timing pulse for sample-hold circuit 10 and A-D converter 11, and another component for generating four pulse signals having different widths supplied to either of the AND gates 1-1 and 2-1. 5 is an adder; 13 is a discharge tube, and 14 is a voltage source.

In the above described arrangement, an input signal (brightness signal), e.g., video signal, is applied to the sample-hold circuit 10 in response to a timing pulse generated by the pulse generator 12 in synchronism with the synchronizing signal within the video signal. The signal stored in 10 is quantized by the A-D converter 11 and converted into eight-bit signals 3 and 4. The signal 3 being a four-bit signal having bits 11-1, 11-2, 11-3 and 11-4, in descending order of brightness, is applied to the signal source 1, while the signal 4 being a four-bit signal for lower brightness having bits

11-5, 11-6, 11-7 and 11-8 in increasing order of brightness is applied to signal source 2.

The pulse generator 12, the output signals of which are shown in FIG. 5, generates four signals 12-1, 12-2, 12-3 and 12-4 whose pulse widths are twice the preceding signal, respectively, in synchronism with the timing pulse 12-5 generated in synchronism with the said synchronizing signal, and the signals 12-1, 12-2, 12-3 and 12-4 are applied to the input terminals of the AND gates 1-1 and 2-1, respectively. The other input terminals of the AND gates 1-1 and 2-1 are supplied with the bit signals; thus the brightness is controlled by the width of the pulses. At the output of AND gates 1-1 there are obtained the AND product of the bit signal 11-1 representing the highest brightness, and the pulse signal 12-4 having a maximum pulse width, the AND product of the bit signal 11-2 representing the second highest brightness and the pulse signal 12-3 having the second maximum pulse width, and the same products are obtained in a similar manner for the remaining bit signals and pulse signals. The outputs of the AND gates 1-1 are applied to the input of the OR gate 1-2 to obtain a logical summation; similarly the outputs from the AND gates 2-1 are applied to the input of the OR gate 2-2 to obtain a logical summation. The OR gates 1-1 and 2-2 in FIG. 5 are substituted by NOR gates for inverting the polarity. Inversion of polarity at this stage is necessary, since the polarity of the signals will later be inverted in the constant current amplifier described hereinafter.

Accordingly, if the bit signals 11-1, and 11-3 are at the level "1" and when the bit signals 11-2 and 11-4 are at the level "0", the summation signal from the OR gate is a pulse signal with a changed pulse width as shown by 12-6 of FIG. 5. Similarly, a pulse signal having pulse widths corresponding to the levels of the bit signals 11-5, 11-6, 11-7 and 11-8 is obtained from the OR gate 2-2.

Thus, pulse signals, having modified pulse widths 12-6 and 12-6', are obtained from the OR gates 1-2 and 2-2, to be applied to the input of the constant current amplifiers 15 and 15' which, as shown in FIG. 4, respectively, comprise a transistor, a voltage source connected in series with the emitter of the transistor, a source resistor and a diode connected to the collector of the same transistor. In this arrangement, the value of the source resistor of the amplifier 15 is 16 times as great as that of the amplifier 15', and the amplitude of the output current of the constant current amplifier 15 is 16 times as large as that of the constant current amplifier 15'.

Pulse signals 12-6 and 12-6' from the OR gates 1-2 and 2-2 are respectively applied to the base of the transistor to produce an output signal at the collector which passes through the diode. The signals thus finally obtained from the diodes are the pulse signals from the signal sources 1 and 2. These pulse signals are added to each other in the adder 5 (which is placed at the junction point of the outputs of the constant current amplifiers 15 and 15'). The summation pulse signal is applied to the cathode of the discharge tube 13. Thus, the amplitude ratio of the output signals from the signal sources 1 and 2 is 16:1, the pulse width of the minimum current being 1/16 of that of the maximum current. Consequently,  $2^8 = 256$  degrees of brightness gradation can be obtained.

The description of FIG. 3A has been limited to the arrangement in which the input signals of the signal sources 1 and 2 are both quantization signals, but the present invention can apply to those arrangements in which only one of the input signals is a quantization signal, as has been explained in relation to FIG. 2. In this case, analog signals have to be obtained from either of the signal sources 1 and 2 in the embodiment of FIG. 3A. FIG. 3B shows an embodiment in which analog signal is obtained from the signal source 2. This arrangement of FIG. 3B is the same as that of FIG. 3A except the arrangement of signal source 2. The signal source in FIG. 3B comprises a digital-analog converter 18 (which will be referred to as D-A converter hereinafter), a subtracter and a constant current amplifier 15'. The operation described in relation to FIG. 2 is carried out with this arrangement of the signal source 2. A pulse signal from the A-D converter 11 is applied to the D-A converter 18 to produce a corresponding analog signal for the quantization signal, which is applied to one of the input terminals of the subtracter 19. To the other input terminal of the subtracter 19 video signal 9 is applied, and a signal representing the difference between the above-mentioned analog signal and the video signal 1 is obtained from the subtracter 19. The difference signal is to be the signal 8 of FIG. 2, for instance. The difference signal is applied to the constant current amplifier 15' and the same operation is carried out as described previously.

For pulse-number modulation, a similar result is obtained with the present invention. Now an embodiment utilizing pulse-frequency modulation will be described.

Referring to FIGS. 3A and 3B, the signal sources 1 and 2 have been already described in the case of pulse-width modulation. In the case of pulse-frequency modulation, the signal sources 1 and 2 may have either different amplitude or different pulse frequency. In the first case, an embodiment in which the sources have different amplitudes is illustrated by FIG. 6.

In FIG. 6, pulse current circuits 16 and 16' replace the constant current circuits 15 and 15' of FIG. 3, and the remainder of arrangement is the same as in FIG. 3. However, it should be noted that inversion of polarity is not carried out by the OR gates 1-2 and 2-2 in FIG. 6. The pulse current circuits 16 and 16' generate pulse-frequency modulated signals under the control of the pulse-width modulated input signals from the OR gates 1-2 and 2-2. The amplitude ratio of the currents of the pulse current circuits 16 and 16' is set at 16:1. The arrangement of each of these pulse current circuits is shown in FIG. 7.

As is shown in FIG. 7, a pulse current circuit comprises a NAND gate, a pulse generator 17 for supplying a pulse to one input of the NAND gate the output of which is connected to the emitter of the transistor; a source resistor is connected in series with the emitter and voltage source, and a diode is connected to the collector of the transistor. The pulse current circuits 16 and 16' adjust the amplitude ratio of the output currents to a ratio 16:1 by means of the source resistors. The pulse generator 17 generates pulse signals shown in FIG. 8, which are applied to one of the inputs of the NAND gate. The pulse-width modulated signal from the OR gates 1-2 and 2-2 is applied to the other input of the NAND gate. The frequency of pulse signals over a given period of time, shown in FIG. 8, changes corresponding to the pulse width of the pulse-width modu-

lated signal; therefore, a pulse-frequency modulated signal is obtained from the NAND gate. The amplitude of the pulse-frequency modulated signal is determined by the value of the source resistor connected to the emitter of the transistor. This pulse-frequency modulated signal output from the pulse current circuits 16 and 16' is applied to the discharge tube through the adder 5. The period  $T_1$  of the pulse signals in FIG. 8 generated by the pulse generator 17 must be equal to or less than the pulse width of the pulse signal 12-1 in FIG. 5 which controls the brightness.

Thus, the response speed required for the display elements can be reduced by the arrangement above-described to a sixteenth of that required in the arrangement where only pulse-width modulation or pulse-frequency modulation is utilized for brightness modulation. The minimum amplitude in this arrangement is 16 times as large as that in the arrangement where only pulse-amplitude is utilized as a means for brilliance modulation, resulting in a more stable and uniform performance in the low brightness region.

With the application of the present invention, a much improved brightness display of neutral gradation can be achieved.

An embodiment where in the amplitudes of the output signal from the signal sources 1 and 2 are the same, but their respective pulse number are different will be explained.

A major portion of this embodiment is shown in FIG. 9. In FIG. 9, pulse current circuits 18 and 18' replace the constant current amplifier 15 and 15' of FIGS. 3A and 3B, and the remainder of the arrangement is the same as in FIGS. 3A and 3B. Therefore, the embodiment of FIG. 9 has the same arrangement as in FIG. 6, except that the pulse current circuits 16 and 16' are replaced by the circuits 18 and 18'. The detailed arrangement for the pulse current circuits 18 and 18' are similar to those of FIG. 7. The pulse current circuits 18 and 18' generate output signals having different pulse number under the control of the pulse-width modulated signal, in contrast to the output signals of equal amplitudes generated in FIG. 7, where the values of the source resistors are equal. The ratio of pulse numbers obtained by the pulse current circuits 18 and 18' in FIG. 9 is 16 to 1. For this reason, the waveforms of the pulse signals generated by the pulse generating circuit 17 of FIG. 7 are diversified, as shown in FIGS. 10A and 10B. The waveform of the pulse signal shown in FIG. 10A corresponds to the pulse current of circuit 18', and the waveform of FIG. 10B the pulse frequency of which is a sixteenth of that of the waveform of FIG. 10A corresponds to the pulse current of circuit 18. The period  $T_2$  for the pulse signal shown in FIG. 10B must be equal to or less than the pulse width of the pulse signal 12-1 of FIG. 5, as described previously. The pulse-frequency modulated output signals, thus obtained from the pulse current circuits 18 and 18', are applied through the adder 5 to the discharge tube.

As described above, brightness modulation for display elements can be made stable and uniform in the region when the input electric quantity is small, according to the present invention.

While we have shown and described several embodiments in accordance with the present invention, it is understood that the same is not limited thereto but is susceptible of numerous changes and modifications as known to a person skilled in the art, and we therefore

do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are obvious to one of ordinary skill in the art.

What we claim is:

1. An apparatus comprising:

a display element;

first means for quantizing input signals representing the degree of brightness to which said display element is to be energized;

second means for digitizing the output from said first means;

a plurality of first AND gates to one of whose input terminals signals corresponding to predetermined upper bits within the output signals from said second means are applied;

a plurality of second AND gates to one of whose input terminals signals corresponding to predetermined lower bits within the output signals from said second means are applied;

third means for generating pulse signals varying in width within a predetermined range;

fourth means for applying simultaneously said pulse signals in the increasing order of their pulse width to the other input terminals of said first and second AND gates;

first and second OR gates to which the output signals from said first and second AND gates are applied, respectively;

fifth and sixth means to which the output signals from first and second OR gates are applied, for respectively generating output signals having different respective amplitudes;

seventh means for adding the outputs from said fifth and sixth means, together; and

means for supplying the output of said seventh means to said display element.

2. An apparatus according to claim 1, wherein each of said fifth and sixth means respectively comprises:

a transistor,

a resistor element which is connected in series with the emitter of said transistor,

a voltage source which is connected between said resistor element and ground, and

a diode which is connected to the collector of said transistor, and

wherein the respective outputs from each of said OR gates is applied to the base of said transistor.

3. An apparatus according to claim 1, wherein each of said fifth and sixth means comprises:

an AND gate to one of whose input terminals the output from said OR gate is applied,

a pulse generator for applying pulse signals having a given period to the other input terminal of the AND gate,

a transistor to whose base the output from the AND gate is applied,

a resistor element connected in series with the emitter of said transistor,

a voltage source connected between said resistor element and ground, and

a diode connected to the collector of said transistor, and wherein the magnitude of the output can be varied with said resistor element.

4. An apparatus according to claim 1, wherein each of said fifth and sixth means comprises

an AND gate to one of whose input terminals the output from said OR gate is applied,

a pulse generator for applying pulse signals having a given period to the other input terminal of the AND gate,

a transistor to whose base the output from the AND gate is applied,

a resistor element connected to the emitter of said transistor,

a voltage source connected between said resistor element and ground, and

a diode connected to the collector of said transistor, and wherein the pulse frequency of the pulse signals from said pulse generator can be changed within one period of said pulse signal.

5. An apparatus comprising:

a display element;

first means for quantizing input signals representing the degree of brightness to which said display element is to be energized;

second means for digitizing the output quantization signal from said first means;

a plurality of AND gates to one of whose input terminals respective pulse output signals corresponding to predetermined upper bits within the digitized quantization signal are applied;

third means for generating pulse signals varying in width within a predetermined range;

fourth means for applying simultaneously respective pulse outputs from said third means to one input terminal of said AND gate, to the other of whose input terminals the pulse outputs for the predetermined lower bits within the digitized quantization signals are applied in the increasing order of their pulse width;

fifth means for measuring the difference of said quantization signals and said input signals;

an OR gate to which the outputs from said AND gates are respectively applied;

sixth means, to which the outputs from said fifth means and said OR gate are applied, for converting the signals applied thereto into respective separate output signals, the amplitudes of which are at different prescribed values; and

means for supplying the output from said sixth means to said display element.

6. A driving apparatus for a display element comprising:

a plurality of input terminals to which input signals, corresponding to the degree of brightness to which said display element is to be energized, are coupled;

a plurality of signal sources, coupled to said plurality of input terminals, each of which signal sources generates, in response to said input signals coupled thereto, a pulse-width modulated signal representative of the degree of brightness to which said display element is to be energized;

first means, coupled to said plurality of signal sources, for amplifying the respective pulse-width modulated signals from said signal sources by respectively different degrees of amplification, thereby providing separate pulse-width modulated signals having different amplitudes;

second means, coupled to said first means, for summing the respective separate pulse-width modu-

9

lated signals having different amplitudes, to produce a summation signal; and

third means, coupled to said second means, for supplying said summation signal to said display element.

7. A driving apparatus according to claim 6, wherein each of said plurality of signal sources includes a signal source which generates analog signals representative of the difference between said input signals and a quantized representation of said input signals.

8. A driving apparatus for a display element comprising:

a plurality of input terminals to which input signals, corresponding to the degree of brightness to which said display element is to be energized, are coupled;

a plurality of signal sources, coupled to said plurality of input terminals, each of which signal sources generates, in response to said input signals coupled thereto, a pulse-frequency modulated signal representative of the degree of brightness to which said display element is to be energized;

first means, coupled to said plurality of signal sources, for amplifying the respective pulse-frequency modulated signals from said signal sources by respectively different degrees of amplification, thereby providing separate pulse-frequency modulated signals having different amplitudes;

second means, coupled to said first means, for summing the respective separate pulse-frequency modulated signals having different amplitudes, to produce a summation signal; and

third means, coupled to said second means, for supplying said summation signal to said display element.

10

9. A driving apparatus according to claim 8, wherein each of said plurality of signal sources includes a signal source which generates analog signals representative of the difference between said input signals and a quantized representation of said input signals.

10. A driving apparatus for a display element comprising:

a plurality of input terminals to which input signals, corresponding to the degree of brightness to which said display element is to be energized, are coupled;

a plurality of signal sources, coupled to said plurality of input terminals, each of which signal sources generates, in response to said input signals coupled thereto, a pulse-frequency modulated signal representative of the degree of brightness to which said display element is to be energized;

first means, coupled to said plurality of signal sources, for producing a plurality of separate output signals, having respectively different numbers of pulses, in accordance with the respective pulse-frequency modulated signals generated by said plurality of signal sources;

second means, coupled to said first means, for summing said separate output signals to produce a summation signal; and

third means, coupled to said second means for supplying said summation signal to said display element.

11. A driving apparatus according to claim 10, wherein each of said plurality of signal sources includes a signal source which generates analog signals representative of the difference between said input signals and a quantized representation of said input signals.

\* \* \* \* \*

40

45

50

55

60

65