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⑤④ **Method and apparatus for eliminating the effects of acoustic cross-talk in thermal ink jet printer.**

⑤⑦ A side-shooting thermal ink jet printer is provided with a control circuit for permitting the ejection of ink droplets from printhead orifices at only certain times after the ejection of ink droplets from other orifices in the printhead so that crosstalk between orifices through the ink supply does not degrade the quality of the subsequently ejected ink droplets. A test circuit is provided for determining the optimum multiplex periods between ejection of ink droplets from adjacent orifices.

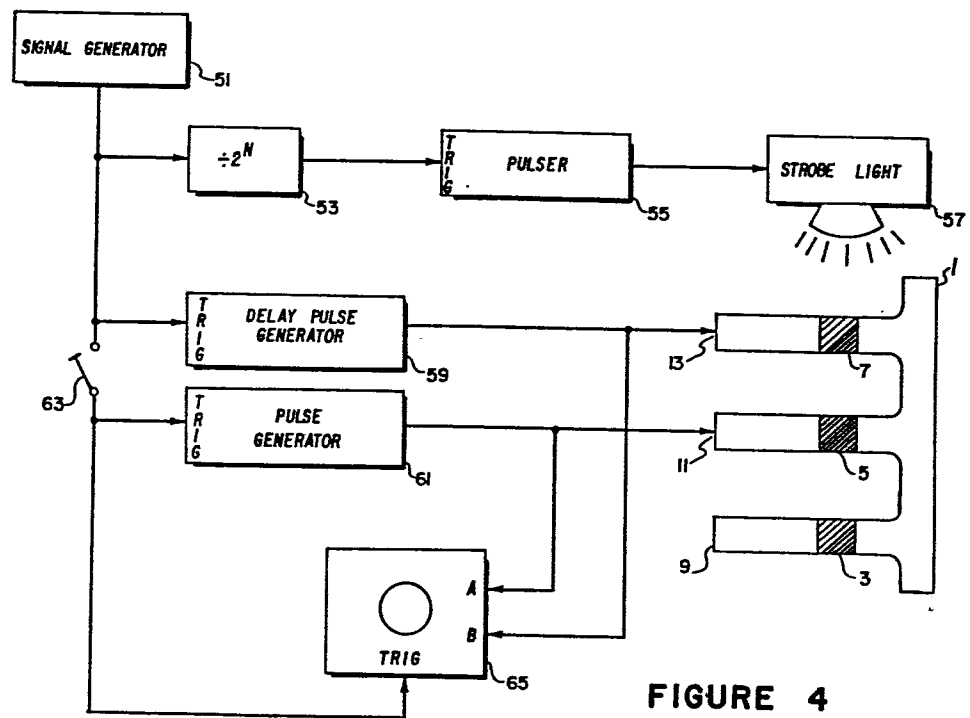


FIGURE 4

METHOD AND APPARATUS FOR ELIMINATING THE EFFECTS OF ACOUSTIC
CROSS-TALK IN A THERMAL INK JET PRINTER

This invention is concerned with thermal ink jet printers and is especially concerned with method and apparatus for eliminating the effects of acoustic cross-talk in these printers.

5 Thermal ink jet printers, as described for example in published UK Patent Application No. 2106039A are generally constructed in either an edge-shooting or a side-shooting configuration. In an edge-shooting printer the ink is ejected from an orifice which is
10 located at the end of an ink capillary. In a side-shooting printer the ink capillary essentially defines a plane and the ink is ejected from an orifice in a direction which is orthogonal to that plane.

In side-shooting printers a number of resistors
15 are located adjacent to one another on a substrate. A plate containing ejection orifices is located above the substrate such that a gap is left between the substrate and the plate. Ink is fed into this gap from one or more sides and fills the gap by capillary action. When an ink
20 droplet is demanded from a single orifice a current pulse is

applied through the associated resistor and the heating of the resistor causes a bubble to form which forces an ink droplet to be ejected from the desired orifice.

Because the various resistors and orifices of
5 a side-shooting printer are connected to a common capillary, the formation of a bubble at any resistor and the bubble's subsequent collapse causes an acoustic wave to travel through the ink in the capillary. This wave not only forces an ink droplet to be ejected from the desired orifice, but also
10 causes resonant motion of the ink menisci at the other orifices. If the amplitude of the acoustic wave is sufficiently large, unwanted ink droplets may be ejected from the other orifices. If the acoustic wave amplitude is not so large as to cause unwanted ink droplet ejection
15 the mere existence of the acoustic wave can cause problems in the ejection of subsequent ink droplets from other orifices because of the resultant menisci movements. The acoustic wave induced resonant motion of the other orifice menisci and the associated varying velocities of the ink
20 comprising these menisci cause ink droplets subsequently ejected from these other orifices to vary in both size and velocity. Such variations result in a degradation of the quality of the printed matter.

One solution to this cross-talk problem, as
25 described in the above-reference UK patent application, has been to construct physical barriers between the resistor/orifice pairs. These barriers are exceedingly difficult to fabricate and limit the density with which orifices can be located on a print head and also limit the print resolution that can be obtained. Another solution has been
30 to limit the printing speed so that resonant motion of the menisci is largely decayed before a subsequent ink droplet ejection is attempted.

The present invention provides a circuit for
35 causing ink droplet ejections from a multiplicity of

orifices resident on a thermal ink jet printer by selectively energizing orifice resistors associated with said orifices, said circuit being characterized in that it comprises pattern generation means for generating a pattern signal, 5 said pattern signal indicating the specific orifice resistors to be energized; and energization means for receiving the pattern signal from said pattern generation means and for energizing the orifice resistors indicated thereby with a predetermined multiplex time period between energizations of physically adjacent orifices wherein said 10 multiplex time period is determined to substantially minimize the effects of acoustic crosstalk between adjacent orifices.

The pattern generation means preferably comprises 15 an addressable memory.

The present invention further provides a method of energizing orifice resistors of a thermal ink jet printhead, said method being characterized in that it comprises the steps of determining a multiplex time period 20 wherein a delay of said multiplex time period between energizations of physically adjacent orifice resistors substantially minimizes the effects of acoustic crosstalk between adjacent orifices associated with said adjacent orifice resistors; and energizing the orifice resistors with a 25 delay substantially equal to the multiplex time period between the energizations of orifice resistors associated with physically adjacent orifices.

The first step of determining a multiplex time period preferably comprises the steps of energizing a 30 second orifice; measuring a base ejection distance travelled by an ink droplet ejected from a second orifice associated with said second orifice associated with said second orifice resistor; energizing, at a first time, a first orifice resistor associated with a first orifice which is physically 35 adjacent to the second orifice; energizing the second

orifice resistor at a second time which is subsequent to the first time; measuring a second ejection distance travelled by an ink droplet ejected from the second orifice at the second time; and varying a difference between the first and the second times until the second ejection distance is substantially equal to the base ejection distance.

In accordance with the illustrated preferred embodiment of the present invention an apparatus for multiplexing the ejection signals supplied to the various resistors is shown. From the resonant period of the orifice menisci null times are determined at which the effect of a previous ink droplet ejection has no effect on subsequent ejections from the other orifices. The illustrated multiplexing circuit allows ink droplet ejection to occur only at such null times.

There now follows a detailed description, which is to be read with reference to the accompanying drawings, of method and apparatus according to the present invention; it is to be clearly understood that this method and apparatus have been selected for description to illustrate the invention by way of example and not by way of limitation.

In the accompanying drawings:-

Figure 1 is a perspective view depicting the interior of a three-jet side-shooting thermal ink jet printhead;

Figure 2 is a perspective view depicting the orifice face of the printhead shown in Figure 1;

Figure 3 depicts a detailed view of the resistor substrate used in the printhead shown in Figures 1-2;

Figure 4 is a block diagram of a test circuit used in measuring the null times of the printhead shown in Figures 1-3; and

Figure 4 is a block diagram of a circuit for multiplexing a 15-jet thermal ink jet printer.

Referring now to Figures 1 and 2, there are shown an interior view and an exterior view of a three-jet side-shooting thermal ink jet printhead. A substrate 1 is provided on which resistors 3, 5 and 7 are mounted.

5 Electrical connections are made to the resistors 3, 5 and 7 via conductors 9, 11 and 13, respectively, and via a ground conductor 15. Two spacers 21 are used to maintain the separation of the substrate 1 from a top 23, thereby providing a capillary channel 25 for the flow of ink from
10 either or both sides to the resistors 3, 5 and 7. Orifices 31, 33 and 35 are located in the top 23 so as to overlay the resistors 3, 5 and 7, respectively. A more detailed view of the substrate 1 is provided in Figure 3 which depicts the relative locations of the resistors 3, 5 and
15 7, the conductors 9, 11 and 13, insulation 17 and the ground conductor 15.

The operation of the printhead depicted in Figures 1 to 3 may be better understood with reference to the above-referenced UK patent application and to the
20 following discussion. In order to eject an ink droplet from, for example, the orifice 33, a current pulse is applied to the conductor 11. This current pulse flows through the resistor 5, generates heat therein and creates a bubble of steam in the ink overlying the resistor
25 5. The creation of said bubble causes the desired ink droplet to be ejected from the orifice 33. But, the expansion and subsequent collapse of said bubble also causes an acoustic wave to travel throughout the ink supply resident in the capillary channel 25. If the bubble produced is
30 sufficiently large, the ejection of spurious ink droplets from adjacent orifices 31 and 35 can also result. Even if the bubble is not quite large enough to cause spurious droplet ejection it will still cause the ink menisci within the orifices 31 and 35 to vibrate with a resonant frequency
35 and will cause the ink overlying the resistors 3 and 7 to move with some velocity.

Referring now to Figure 4, there is shown a test circuit for measuring the null times at which the ejection of an ink droplet from a thermal ink jet printer orifice will not be affected by a previous ink droplet ejection from another orifice. A signal generator 51, which may comprise a Hewlett-Packard model 3312A, generates a square wave which is received by a converter 53 and the signal rate is divided down by a factor of 2 to a variable Nth power. This divided down square wave is coupled to the trigger input of a variable delay pulser 55 such as the Hewlett-Packard model 8012B. The delayed pulse is connected to the input of a strobe light 57, for example, a General Radio model 5139A. The output of the signal generator 51 is also connected to a trigger input of a variable delay pulse generator 59 which may comprise, for example, a Hewlett-Packard model 214B. The output of the pulse generator 59 is connected to the conductor 13 which is associated with the resistor 7 and is located on the substrate 1 (shown in Figures 1 to 3). The output of the signal generator 51 is further connected through a switch 63 to a trigger input of a pulse generator 61 which may be a Hewlett-Packard model 214B. The output of the pulse generator 61 is used to drive the resistor 5 via the conductor 11. An oscilloscope 65, which may comprise a Hewlett-Packard model 1722B, has a trigger input connected to the output of the signal generator 51 and two trace inputs A and B connected to the outputs of the pulse generators 59 and 61.

The operation of the test circuit shown in Figure 4 may be understood with additional reference to Figures 1 to 3 as follows. Firstly, the switch 63 is opened and the delay of the pulse generator 59 is set to zero. Thus, the ejection rate of droplets from the orifice 35 due to the resistor 7 is some multiple of the strobe rate of the strobe light 57. The droplets ejected from the orifice

35 are observed with the strobe light 57 and a microscope (not shown). The delay of the pulser 55 is varied until the observed strobed droplets are located at some reference point. The delay of the pulser 55 is then held constant. In the next step, the switch 63 is closed causing the pulse generator 61 to pulse the resistor 5 and to cause ink droplets to be ejected from the orifice 33 at the clock rate of the signal generator 51. The delay of the pulse generator 59 is varied until null times are reached at which the droplets ejected from the orifice 35 are viewed to be at the reference point. The durations of these pulse generator 59 delays are measured on the oscilloscope 65 and are recorded as the individual multiplex periods to be used to avoid the effect of crosstalk between orifices.

The thermal ink jet printer depicted in Figures 1-3 was constructed with 0.075 by 0.075 mm resistors and orifices and with a spacing between orifices of 0.127 mm. When a water-based ink was used a miniscus resonant period of 12 microseconds was measured. When the printer of Figures 1-3 was connected to the test circuit of Figure 4, with a water based ink and a clock frequency of 2 KHz being used, it was found that individual multiplex periods of 3, 15 and 27 microseconds eliminated the effects of crosstalk between the adjacent orifices 33 and 35.

Referring now to Figure 5, there is shown a circuit for multiplexing a 15-jet side-shooting thermal ink jet printer with a multiplex period measured as discussed hereinabove. A conventional clock 71 is used to generate a square wave at a clock rate F . The output of the clock 71 is connected to a divider 77 which divides F by a factor L such that L/F is the desired multiplex period. For the three-jet printer described above with reference to Figures 1-4, the period L/F would be $(3 + 12M)$ microseconds where $M = 0, 1, 2, \dots$. The output of the divider 77 is connected

to a count input 83 of a conventional four bit counter 81.

The output of the clock 71 is also connected to a counter 73 which counts up to a number K and then resets to 0. Thus, all of the output lines of the counter 73, 5 which are connected to inputs of a NAND gate 75, are 0 only once every K counts and the output of the NAND gate 75 is 1 only once every K counts. The output of the NAND gate 75 is connected to an input of an OR gate 79, the output of which is connected to an enable input 85 of the counter 10 81. The four outputs of the counter 81 are connected to the four inputs of a converter 89 and are also connected

to the four inputs of an OR gate 87. The output of the OR gate 87 is connected to another input of the OR gate 15 79. Therefore, the counter 81 is enabled after every K counts of the counter 73 and remains enabled thereafter only until it has itself made sixteen counts.

The converter 89, which may comprise any of a number of commercially available devices, converts the 20 four bits received from the counter 81 to a one of sixteen signal. Thus, for example, for a four bit input of 0011, the converter 89 would set the third output line high and would set all of the rest low. It should be noted that the 0th output line from the converter 89 is not used in 25 the circuit of Figure 5.

The output of the NAND gate 75 is also connected to a count input 93 of a counter 91. This means that the counter 91 presents a new output to an address input 97 of a memory 95 at a rate of F/K . The memory 95 may 30 easily be constructed as a $15 \times P$ bit (where P is the number of columns of dots desired) addressable memory from commercially available devices. Stored within the memory 95 is a representation of a dot pattern which it is desired to have printed on a recording medium. For example, if 35 it is assumed that a printhead 161 is swept horizontally

across a page and that the orifices are aligned vertically, then each serial address location in the memory 95 corresponds to a vertical column of dots to be printed on the page and the 15 bits of information resident at that 5 memory address define which of the orifices are to eject ink droplets in that column.

The 15 outputs of the memory 95, one for each bit, and the 15 outputs of the converter 89 are connected in pairs to the inputs of the 15 AND gates 99-127. The outputs of 10 the AND gates 99-127 are connected to resistor drivers 131-159, which may comprise high current pulse generators such as the Hewlett-Packard model 214B, which in turn drive the 15 resistors of the printhead 161 and cause the desired droplets to be ejected from the orifices of the 15 printhead 161.

In actual operation of the circuit depicted in Figure 5, F and L will be chosen so that L/F is the desired multiplex period. K, which is greater than $16 \times L$, is chosen so that the period K/F is the time required for the 20 printhead 161 to move horizontally between adjacent columns of dots to be printed on the recording medium. The counter 81 is only enabled once every K/F seconds for an ejection period of $15 \times L/F$ seconds duration during which ejection period the desired droplets for a specific column are 25 ejected. An orifice can only eject a droplet when both the converter 89 and the memory 95 simultaneously present high signals to the specific AND gate of the AND gates 99-127 which is connected to that orifice. Therefore, the droplet pattern desired for a specific column is stored in an 30 addressable memory location within the memory 95 and droplets are ejected from the orifices of the printhead 161 starting with the first orifice and continuing serially to the fifteenth with a multiplex period between ejections from adjacent orifices.

CLAIMS

1. A circuit for causing ink droplet ejections from a multiplicity of orifices resident on a thermal ink jet printer by selectively energizing orifice resistors associated with said orifices, said circuit being characterized in that it comprises:

pattern generation means for generating a pattern signal, said pattern signal indicating the specific orifice resistors to be energized; and

energization means for receiving the pattern signal from said pattern generation means and for energizing the orifice resistors indicated thereby with a predetermined multiplex time period between energizations of physically adjacent orifices wherein said multiplex time period is predetermined to substantially minimize the effects of acoustic crosstalk between adjacent orifices.

2. A circuit according to claim 1 and characterized in that the pattern generation means comprises an addressable memory.

3. A method of energizing orifice resistors of a thermal ink jet printhead, said method being characterized in that it comprises the steps of:

determining a multiplex time period wherein a delay of said multiplex time period between energizations of physically adjacent orifice resistors substantially minimizes the effects of acoustic crosstalk between adjacent orifices associated with said adjacent orifice resistors; and

energizing the orifice resistors with a delay substantially equal to the multiplex time period between the energizations of orifice resistors associated with physically adjacent orifices.

4. A method according to claim 3, characterized in that the first step of determining a multiplex time period comprises the steps of:

energizing a second orifice;

5 measuring a base ejection distance travelled by an ink droplet ejected from a second orifice associated with said second orifice resistor;

energizing, at a first time, a first orifice resistor associated with a first orifice which is physically
10 adjacent to the second orifice;

energizing the second orifice resistor at a second time which is subsequent to the first time;

measuring a second ejection distance travelled by an ink droplet ejected from the second orifice at the
15 second time; and

varying a difference between the first and the second times until the second ejection distance is substantially equal to the base ejection distance.

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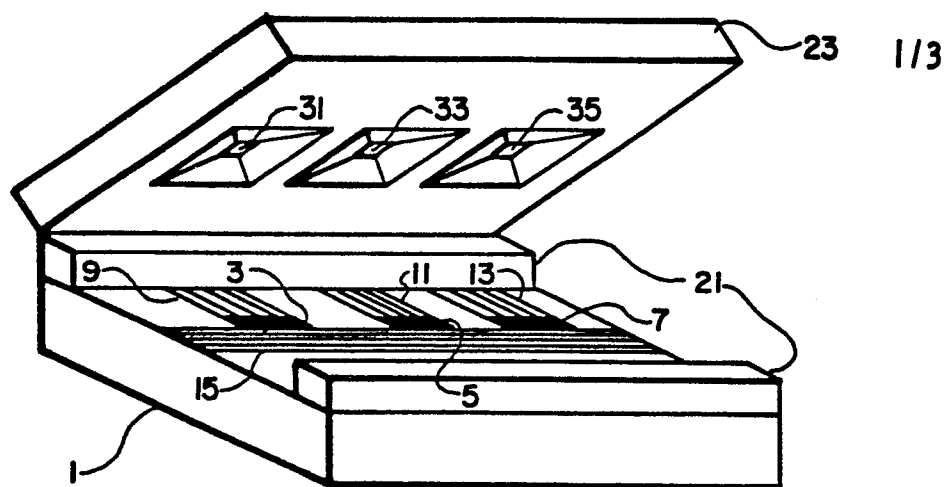


FIGURE 1

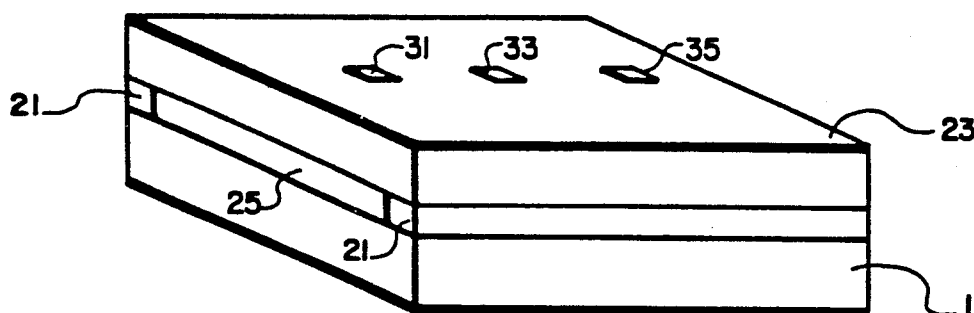


FIGURE 2

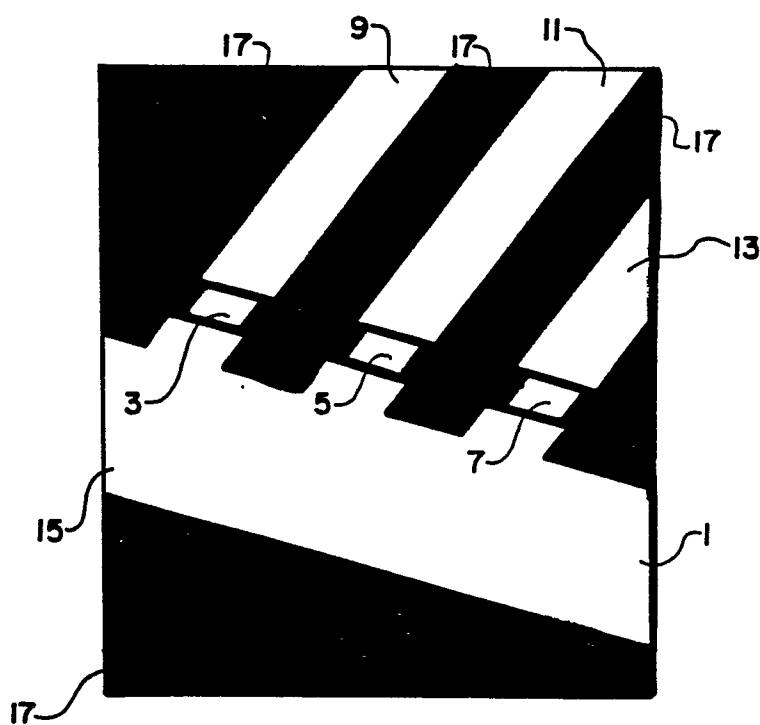
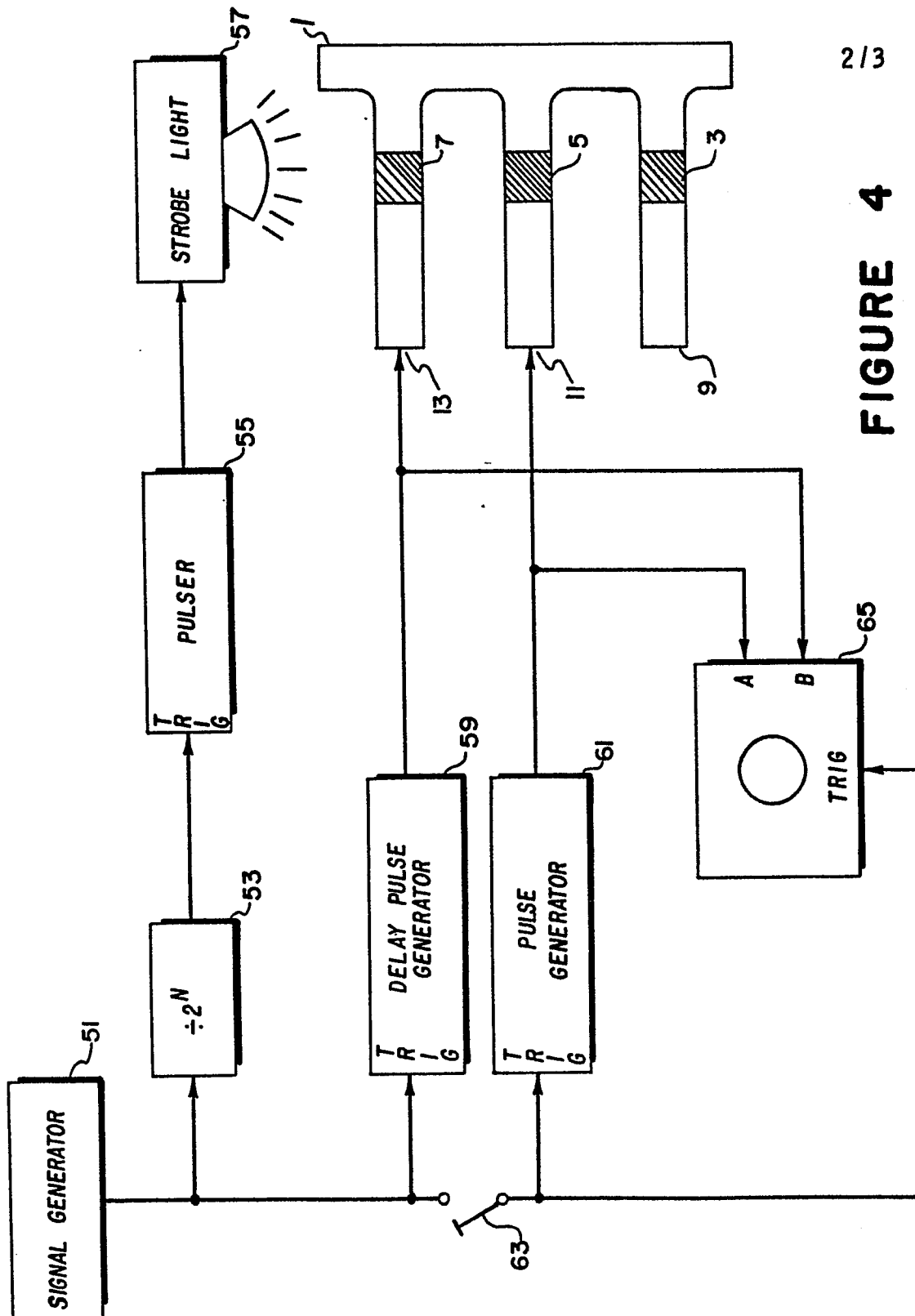


FIGURE 3

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**FIGURE 4**

