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(54) DRIVING CIRCUIT FOR AN INKJET PRINTHEAD

(57) The invention relates to an inkjet printing apparatus which comprises a print head, the print head in turn comprising: an ink duct; a piezoelectric element operatively coupled to the ink duct; a control device configured to control an ink drop ejection from the ink duct by actuation of the piezoelectric element. Said control device comprises: one or more current sources; one or more power supplies, wherein each of the one or more power supplies is of a different voltage level; and a switch, connected between the current source and the one or more power supplies, wherein the current source is configured to generate a current for actuating the piezoelectric element by charging and discharging, and the switch is configured to connect the current source and one of said one or more power supplies, wherein the switch is further configured to connect the current source to one of said one or more power supplies and to disconnect the current source from one of said one or more power supplies when the piezoelectric element has reached a required voltage level respectively during charging and discharging when the required voltage level is not any of the different voltage levels of the one or more power supplies. This construction allows reducing the number of power supplies and current sources needed, thereby reducing the power consumption of an inkjet printing apparatus.

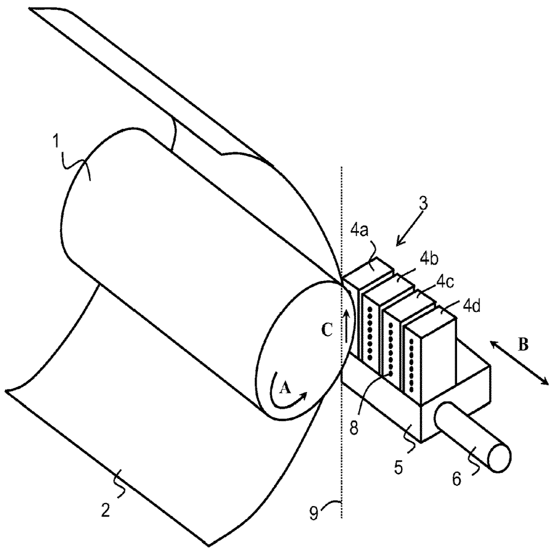

Figure 1

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Description

BACKGROUND OF THE INVENTION

[0001] The present invention generally pertains to a circuit for driving an inkjet print head.

[0002] During the execution of print processes nozzles in an inkjet print head are driven with waveforms that cause the ejection of droplets onto printing media. Those driving waveforms are generated with an electrical circuit. Said electrical circuit is responsible for a significant part of the power dissipation in an inkjet print head.

[0003] In the prior art, different solutions have been developed to reduce the amount of power dissipated in the electrical circuits of an inkjet print head. Typically, said circuits substitute a current source by a plurality of current sources, such that the amount of dissipated power is reduced. However, said plurality of current sources adds significant complexity to the hardware of the driving circuit, which increases its size.

[0004] As a consequence, it is desired to have a driving circuit with a reduced hardware complexity, such that reduced power dissipation can still be achieved without the size related drawbacks.

SUMMARY OF THE INVENTION

[0005] In an aspect of the present invention, a driving circuit for an inkjet printing apparatus according to claim 1 is provided.

[0006] In said aspect, the inkjet printing apparatus comprises a print head, the print head in turn comprising: an ink duct; a piezoelectric element operatively coupled to the ink duct; a control device configured to control an ink drop ejection from the ink duct by actuation of the piezoelectric element. Said control device comprises: one or more current sources; one or more power supplies, wherein each of the one or more power supplies is of a different voltage level; and a switch, connected between the current source and the one or more power supplies, wherein the current source is configured to generate a current for actuating the piezoelectric element by charging and discharging, and the switch is configured to connect the current source and one of said one or more power supplies, wherein the switch is further configured to connect the current source to one of said one or more power supplies and to disconnect the current source from one of said one or more power supplies when the piezoelectric element has reached a required voltage level respectively during charging and discharging when the required voltage level is not any of the different voltage levels of the one or more power supplies. This construction allows reducing the number of power supplies and current sources needed, thereby reducing the power consumption of an inkjet printing apparatus.

[0007] In an embodiment, the inkjet printing apparatus of the present invention comprises that the one or more current sources are linear current sources.

[0008] In an embodiment, the inkjet printing apparatus of the present invention comprises that the one or more current sources are voltage controlled current sources or current controlled current sources.

[0009] In an embodiment, the inkjet printing apparatus of the present invention comprises that the one or more power supplies is connected in series.

[0010] In an embodiment, the inkjet printing apparatus of the present invention further comprises one or more of piezoelectric elements; and one or more current sources, wherein the one or more power supplies and the one or more current sources are operatively connected by means of a multiplexer, the multiplexer comprising one or more input terminals and one or more output terminals, wherein each power supply is connected to a respective input terminal and each current source is connected between a respective output terminal and a respective one of the one or more piezoelectric elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will become more fully understood from the detailed description given below, and the accompanying drawings which are given by way of illustration only, and are thus not limitative of the present invention, and wherein:

Figure 1	is a schematic representation showing an inkjet printing apparatus.
Figure 2	is a schematic representation showing an ink duct assembly of an inkjet printing apparatus and its associated piezoelectric element.
Figure 3	is a schematic illustration showing a control device for charging and discharging a piezoelectric element.
Figures 4a-c	are diagrams showing voltage levels on a piezoelectric element in a process of charging and discharging of a piezoelectric element.
Figure 5	shows the circuit of the present invention for charging and discharging a piezoelectric element.

DETAILED DESCRIPTION OF EMBODIMENTS

[0012] The present invention will now be described with reference to the accompanying drawings, wherein the same or similar elements are identified with the same reference numeral.

[0013] An inkjet printing apparatus is shown in Figure 1. According to this embodiment, the inkjet printing apparatus comprises a roller 1 used to support a receiving medium 2, such as a sheet of paper or a transparency, and to move it along a carriage 3 in direction A. The carriage 3 comprises a carrier 5 on which four print heads 3b, 4b, 4c and 4d have been mounted. Each print head may contain its own color, in this case cyan (C), magenta (M), yellow (Y) and black (K), respectively, but in an embodiment each print head may comprise a same substance to be applied onto the medium 2, for example.

[0014] The roller 1 may rotate around its own axis as indicated by arrow A. In this manner, the receiving medium may be moved in a sub-scanning direction C relative to the carrier 5 parallel to an axis 9, and therefore also relative to the print heads 3b-4d. The carriage 3 may be moved in reciprocation using suitable drive mechanisms (not shown) in a direction indicated by double arrow B, substantially parallel to roller 1. To this end, the carrier 5 is moved across a guide rod 6. This direction is generally referred to as the main scanning direction. In this manner, the receiving medium may be fully scanned by the print heads 3b-4d.

[0015] According to the embodiment as shown in this figure, each print head 3b-4d may comprise one or more internal ink ducts (not shown), each with its own exit opening (nozzle) 8. The nozzles in this embodiment form one row per print head perpendicular to the axis of roller 1 (i.e. the row extends in the sub-scanning direction C). According to a practical embodiment of an inkjet printer, the one or more ink ducts per print head is greater and the nozzles are arranged over two or more rows. Each ink duct comprises a piezoelectric element (not shown) that may generate a pressure wave in the ink duct so that an ink drop is ejected from the nozzle of the associated duct in the direction of the receiving medium. The piezoelectric elements may be actuated image-wise via an associated control circuit (not shown). In this manner, an image built up of ink drops may be formed on receiving medium 2.

[0016] An ink duct 13 is shown in FIG. 2 comprising a piezoelectric element 16. In the illustrated embodiment, the ink duct 13 is formed by a groove in base plate 14 and is limited at the top mainly by the piezoelectric element 16. The ink duct 13 changes into an exit opening 8 at the end, this opening being partly formed by a nozzle plate 20 in which a recess has been made at the position of the ink duct 13. When a signal generator 18 applies a signal on the piezoelectric element 16 via actuation circuit 15, the piezoelectric element 16 deforms in the direction of the ink duct 13. This produces a sudden pressure rise in the ink duct 13, which in turn generates a pressure wave in the ink duct 13. If the pressure wave is strong enough, an ink drop is ejected from exit opening 8.

[0017] FIG. 3 shows a schematic illustration of a control circuit 30 and a piezoelectric element 37 which is connected between ground and a first terminal of a current source 36. The piezoelectric element 37 may be charged by means of the current source 36.

[0018] A second terminal of the current source 36 is connected to an output terminal of a switch 35. The switch 35 is connected to one or more power supplies 31, 32, 33, 34, each delivering a voltage of x V. The power supplies 31, 32, 33, 34 are connected in series. The switch 35 has five input terminals 35a, 35b, 35c, 35d, 35e. A first input terminal 35a is connected to ground, supplying a voltage level of 0 V. A second input terminal 35b is connected to a terminal of the first power supply 31, supplying a voltage level of x V. A third input terminal 35c is connected to a terminal of the second power supply 32, supplying a voltage level of 2x V. A fourth input terminal 35d is connected to a terminal of the third power supply 33, supplying a voltage level of 3x V. A fifth input terminal 35e is connected to a terminal of the fourth power supply 34, supplying a voltage level of 4x V.

[0019] To establish ink drop ejection from the ink duct the piezoelectric element 37 needs to be actuated. Actuation is established by charging the piezoelectric element 37 via the current source 36. A pressure wave due to the actuation is strong enough to eject an ink drop from the nozzle of the ink duct as described herein-above with reference to FIG. 2. The charging of the piezoelectric element 37 is managed by the control circuit 30. The control circuit 30 comprises the current source 36, which generates a current towards the piezoelectric element 37 according to a first directed arrow 38. When the voltage difference over the piezoelectric element is increased to a predetermined maximum level, e.g. 4x V, the actuation occurs resulting in a pressure wave in the ink duct, which leads to a drop of ink being ejected from the nozzle of the ink duct.

[0020] At the start of the actuation, the piezoelectric element 37 may not be charged and the switch 35 may be switched towards the first input terminal 35a. Then the current source 36 is starting to charge the piezoelectric element 37 and at the same time the switch 35 is switched towards the second input terminal 35b such that a voltage difference over the current source 36 of x V is established. A voltage difference over the piezoelectric element 37 increases. The voltage difference over the current source 36 results in power dissipation. The voltage difference over the current source 36 decreases to a level of 0 V due to the voltage difference over the piezoelectric element 37 reaching x V. As soon as the voltage difference over the current source 36 reaches a level of 0 V, the switch 35 alters the switch position from the second input terminal 35b towards the third input terminal 35c. The third input terminal 35c is supplying a voltage of 2x V By doing so, the voltage difference over the current source 36 is increased towards approximately x V and power is dissipated over the current source 36 directly after the moment of altering the switch position. The power dissipation may start to decrease again, if the voltage difference over the piezoelectric element increases further.

[0021] The current from the current source 36 is still charging the piezoelectric element 37 towards a higher voltage difference over the piezoelectric element. Power is starting again to be dissipated by the current source 36, since a voltage difference over the current source 36 is established. When the voltage difference over the piezoelectric element 37 has increased to a level of 2x V and the voltage difference over the current source 36 has thereby decreased to a level of 0 V, the switch 35 alters the switch position from the third input terminal 35c towards to fourth input terminal 35d. The fourth input terminal 35d is supplying a voltage of 3x V. By doing so, the voltage difference over the current source 36 is increased towards approximately x V, thereby dissipating power over the current source 36. Analogue to the above description, the switch 35 may be switched towards the fifth input terminal 35e supplying a voltage of 4x V. By switching towards the fifth input terminal 35e, the voltage difference over the current source will be approximately x V and the voltage difference over the piezoelectric element 37 increases to a level of 4x V. At a voltage difference of 4x V over the piezoelectric element 37, the ejection of the ink drop takes place. During a short time period the voltage difference will stay at this maximum voltage difference of 4x V.

[0022] Before a next actuation of the piezoelectric element 37, the piezoelectric element 37 needs to be discharged. To establish discharging of the piezoelectric element 37, the current from the current source 36 is altered into an opposite direction indicated by a second arrow 39 towards the switch 35. The process of discharging the piezoelectric element 37 is reversible with respect to the process of charging the piezoelectric element 37. After discharging is started, the voltage difference over the piezoelectric element 37 decreases. The voltage difference over the current source 36 is increasing and power is dissipated again. As soon as the voltage difference over the piezoelectric element 37 has decreased to a level of 3x V, the switch 35 is switched towards the fourth input terminal 35d. Since the fourth input terminal supplies a voltage of 3x V, the voltage difference over the current source 36 becomes approximately 0 V.

[0023] The switch 35 is further switched towards the third input terminal 35c, when the voltage difference over the piezoelectric element 37 has decreased to 2x V, towards the second input terminal 35b, when the voltage difference over the piezoelectric element 37 has decreased to x V, and finally towards the first input terminal 35a, when the voltage difference over the piezoelectric element 37 has decreased to 0 V.

[0024] By switching to an input terminal 35a, 35b, 35c, 35d, 35e which supplies a voltage which has a low voltage difference with the voltage present over the piezoelectric element 37, the voltage difference over the current source 36 remains below a level of the x V during charging and discharging. Thus the voltage difference over the current source 36 is limited such that the power dissipation during charging and discharging of the piezoelectric element 37 is significantly reduced. The calculation of the amount of power dissipation reduction during charging and discharging as described above is explained on the basis of FIG. 4a-4c.

[0025] The current source 36 is connected between the switch and the piezoelectric element. In a known circuit, a voltage difference over a piezoelectric element at actuation time is applied at once onto a current source. This is illustrated in FIG. 4a. In FIG. 4a a graph is shown with a voltage level represented on a vertical axis, whilst time is represented on a horizontal axis. Bold line 40 shows the voltage at an output terminal of the switch 35 (see FIG. 3) during an actuation cycle in the case of one voltage step. A dashed line 41 shows the voltage difference in time over the piezoelectric element 37 (see FIG. 3) during charging, a second dashed line 42 shows the voltage difference during discharging of the piezoelectric element. At a first point of time t0 the switch of the switch 35 is switched from ground 35a to the fifth input terminal 35e, delivering at once a maximum voltage Vmax to the output terminal of the switch 35. From the first point of time t0 until a second point of time t1 the current source 36 is charging the piezoelectric element 37 and the voltage over the piezoelectric element increases from 0 V towards the maximum voltage Vmax. From the second point of time t1 to a third point of time t2 the voltage over the piezoelectric element remains approximately constant at a maximum level Vmax in order to establish an actuation of the piezoelectric element 37. After actuation, at the third point of time t2 the current source 36 is starting to discharge the piezoelectric element 37 such that the voltage difference over the piezoelectric element 37 decreases from Vmax towards 0 V at a fourth point of time t3. The surface of the hatched area 43a is a measure for power dissipation in the current source 36 during charging of the piezoelectric element 37 and the surface of the hatched area 43b is a measure for power dissipation in the current source 36 during discharging of the piezoelectric element 37.

[0026] The current source 36 is connected between the switch and the piezoelectric element. In a known circuit, a voltage difference over a piezoelectric element at actuation time is applied at once onto a current source. This is illustrated in FIG. 4a. In FIG. 4a a graph is shown with a voltage level represented on a vertical axis, whilst time is represented on a horizontal axis. Bold line 40 shows the voltage at an output terminal of the switch 35 (see FIG. 3) during an actuation cycle in the case of one voltage step. A dashed line 41 shows the voltage difference in time over the piezoelectric element 37 (see FIG. 3) during charging, a second dashed line 42 shows the voltage difference during discharging of the piezoelectric element. At a first point of time t0 the switch of the switch 35 is switched from ground 35a to the fifth input terminal 35e, delivering at once a maximum voltage Vmax to the output terminal of the switch 35. From the first point of time t0 until a second point of time t1 the current source 36 is charging the piezoelectric element 37 and the voltage over the piezoelectric element increases from 0 V towards the maximum voltage Vmax. From the second point of time t1 to a third point of time t2 the voltage over the piezoelectric element remains approximately constant at a maximum level Vmax in order to establish an actuation of the piezoelectric element 37. After actuation, at the third point of time t2 the current source 36 is starting to discharge the piezoelectric element 37 such that the voltage difference over the piezoelectric element 37 decreases from Vmax towards 0 V at a fourth point of time t3. The surface of the hatched area 43a is a measure for power dissipation in the current source 36 during charging of the piezoelectric element 37 and the surface of the hatched area 43b is a measure for power dissipation in the current source 36 during discharging of the piezoelectric element 37.

[0027] FIGS. 4b-4c show diagrams, each diagram comprising a graph of the voltage level on a vertical axis against time on a horizontal axis, output through an output terminal of the switch 35 (see FIG. 3) between the start time of charging the piezoelectric element 37 (see FIG. 3) and the end time of discharging the piezoelectric element 37. The graph is forming two so-called voltage ladders. A voltage ladder may comprise voltage level steps to be applied through the switch 35 to the current source 36 (see FIG. 3) either in a process of charging the piezoelectric element 37 or either in a process of discharging the piezoelectric element 37. FIG. 4b shows a graph of two voltage ladders 44, 45, each voltage ladder comprising two voltage level steps. The voltage at an output terminal of the switch 35 is represented by bold line 48 which follow in discrete steps a dashed trapezoidal curve 49. At the beginning of a first step, at a first point of time to a first voltage V is set, for example by switching the switching device to the third output terminal 35c. During the time period between the first point of time to and a second point of time t the piezoelectric element 37 is charged and the voltage difference over the piezoelectric element 37 increases from 0 V towards V. V. At the beginning of a second step, at the second point of time t a second voltage V is set, for example by switching the switching device to the fifth output terminal 35e. The first and second voltage are selected such that V = 1/2 V_{max}. During the time period between the second point of time t and a third point of time t the piezoelectric element 37 is charged and the voltage difference over the piezoelectric element 37 increases from V_1 V towards V_{max} V. The dashed trapezoidal curve 49 represents the voltage over the piezoelectric element 37 during the actuation cycle. Since the total surface of the hatched areas 44a, 44b, 45a, 45b is a measure for power dissipation in the current source 36 during the actuation cycle, the power dissipation in the current source 36 is approximately halved in the case of two voltage level steps as may be calculated when comparing the total surface of the hatched areas 43a, 43b in FIG. 4a with the total surface of the hatched areas 44a, 44b, 45a, 45b in FIG. 4b. FIG. 4c illustrates an embodiment comparable to the embodiment illustrated in FIG. 4b. FIG. 4c shows two voltage ladders 46, 47, each voltage ladder comprising four voltage level steps according to the configuration shown in FIG. 3 whereas the embodiment of FIG. 4b comprises two voltage level steps. The operation of the embodiment of FIG. 4c is however essentially similar to the operation of the embodiment of FIG. 4b. In the case of four voltage level steps each input terminal 35a-35e of the switch 35 is used during charging of the piezoelectric element 37. At the beginning of a first step, a first voltage V is set. At the beginning of a second step, a second Voltage V is set. At the beginning of a third step, a third Voltage V is set. At the beginning of a fourth step, a fourth Voltage V is set. The first voltage V, the second Voltage V, the third Voltage V and the fourth voltage V are selected such that V=1/2 V =1/3 V=1/4 V_{max}. Since the surface of hatched areas 46a, 46b, 46c., 46d, 47a, 47b, 47c, 47d is a measure for power dissipation in the current source 36 during the actuation cycle, the power dissipation in the current source 36 is approximately quartered in the case of four voltage level steps per voltage ladder as may be calculated when comparing the total surface of the hatched areas 43a, 43b in FIG. 4a with the total surface of the hatched areas 46a, 46b, 46c., 46d, 47a, 47b, 47c, 47d in FIG. 4c. In general, it may be easily calculated that the original amount of power dissipation as shown in FIG. 4a in the current source 36 is divided by approximately n, where n represents the one or more voltage level steps per voltage ladder. One may conclude that a minimum of no power dissipation takes place in the ideal situation of an infinite number of voltage level steps. In that case an adjustable power supply may be used. However in practice, a disadvantage of an adjustable power supply may be that the internal power dissipation is relatively large, such that power dissipation is moved from the current source towards the adjustable power supply. One or more voltage level steps may be calculated to optimize the amount of power dissipation reduction on the basis of power dissipation in the current source and power dissipation in the power supplies used in the driver circuit.

[0028] FIG. 5 shows the circuit of the present invention for charging and discharging a piezoelectric element. FIG. 5 shows a schematic illustration of a control circuit 50 and a piezoelectric element 57 which is connected between ground and a first terminal of a current source 56. The piezoelectric element 57 may be charged by means of the any of the current sources 56a, 56b, 56c, and 56d.

[0029] The switch 55 is connected to one or more power supplies 51, 52, 53, each delivering a voltage multiple of V (x integer times V). The switch 35 has four input terminals 55a, 55b, 55c, and 55d. A first input terminal 55a is connected to ground, supplying a voltage level of 0 V. A second input terminal 55b is connected to a terminal of the first power supply 51, supplying a voltage level of x V. A third input terminal 55c is connected to a terminal of the second power supply 52, supplying a voltage level of 2x V. A fourth input terminal 55d is connected to a terminal of the third power supply 53, supplying a voltage level of 3x V. It can be observed in FIG. 5 that there is a current source for each voltage level needed, 0, HV1, HV2, and HV3. In order to illustrate the functioning of the present invention, input terminal 55b, current source 56b, and first power supply 51 have been eliminated, which does not allow directly connecting a piezoelectric element to be charged or discharged until it reaches voltage level HV1. It can be observed in FIG. 5 that slope 57 cannot be performed anymore by connecting the piezoelectric element to power supply 51 of a voltage level HV1. Instead, the circuit of the present invention is configured to utilize switch 55 to connect the piezoelectric element reaches the required voltage level HV1. In this way, slope 58 can be used to replicate slope 57, thereby allowing a reduction in power sources, which in turn leads to a reduction in power consumption of the inkjet apparatus of the present invention.

[0030] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

Claims

1. An inkjet printing apparatus, comprising:

a print head, the print head comprising:

an ink duct;
a piezoelectric element operatively coupled to the ink duct; and
a control device configured to control an ink drop ejection from the ink duct by actuation of the piezoelectric element, the control device comprising:

one or more current sources;
one or more power supplies, wherein each of the one or more power supplies is of a different voltage level; and

a switch, connected between the current source and the one or more power supplies, wherein the current source is configured to generate a current for actuating the piezoelectric element by charging and discharging, and the switch is configured to connect the current source and one of said one or more power supplies, wherein the switch is further configured to connect the current source to one of said one or more power supplies and to disconnect the current source from one of said one or more power supplies when the piezoelectric element has reached a required voltage level respectively during charging and discharging when the required voltage level is not any of the different voltage levels of the one or more power supplies.

2. The inkjet printing apparatus according to claim 1, wherein the one or more current sources are linear current sources.

3. The inkjet printing apparatus according to claim 1, wherein the one or more current sources are voltage controlled current sources or current controlled current sources.

4. The inkjet printing apparatus according to claim 1, wherein the one or more power supplies is connected in series.

5. The inkjet printing apparatus according to claim 1, the inkjet printing apparatus further comprising:

one or more of piezoelectric elements; and
one or more current sources, wherein the one or more power supplies and the one or more current sources are operatively connected by means of a multiplexer, the multiplexer comprising one or more input terminals and one or more output terminals, wherein each power supply is connected to a respective input terminal and each current source is connected between a respective output terminal and a respective one of the one or more piezoelectric elements.

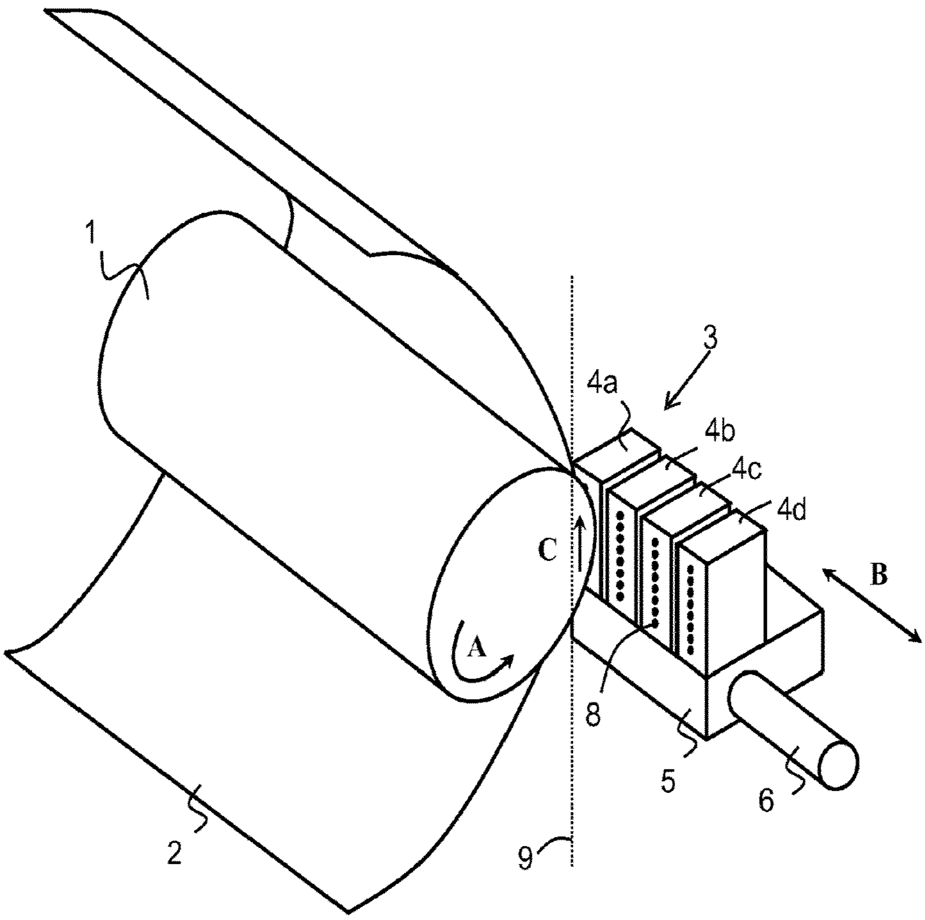

Figure 1

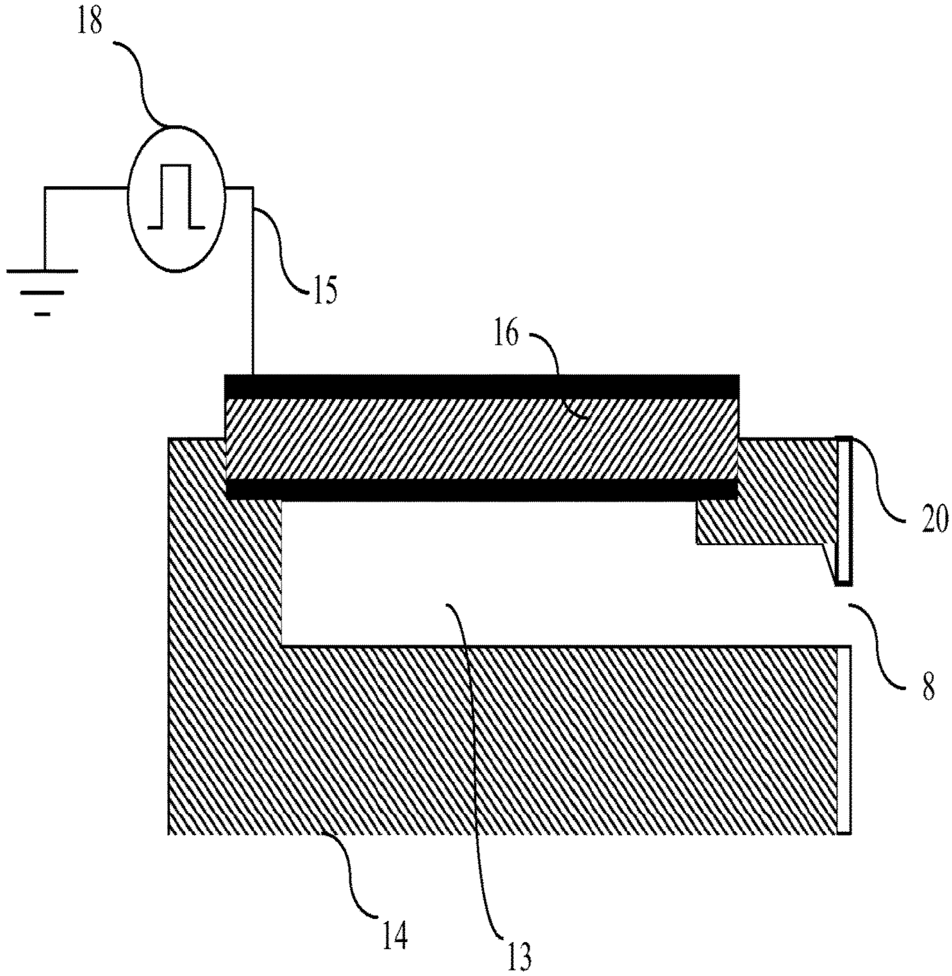

Figure 2

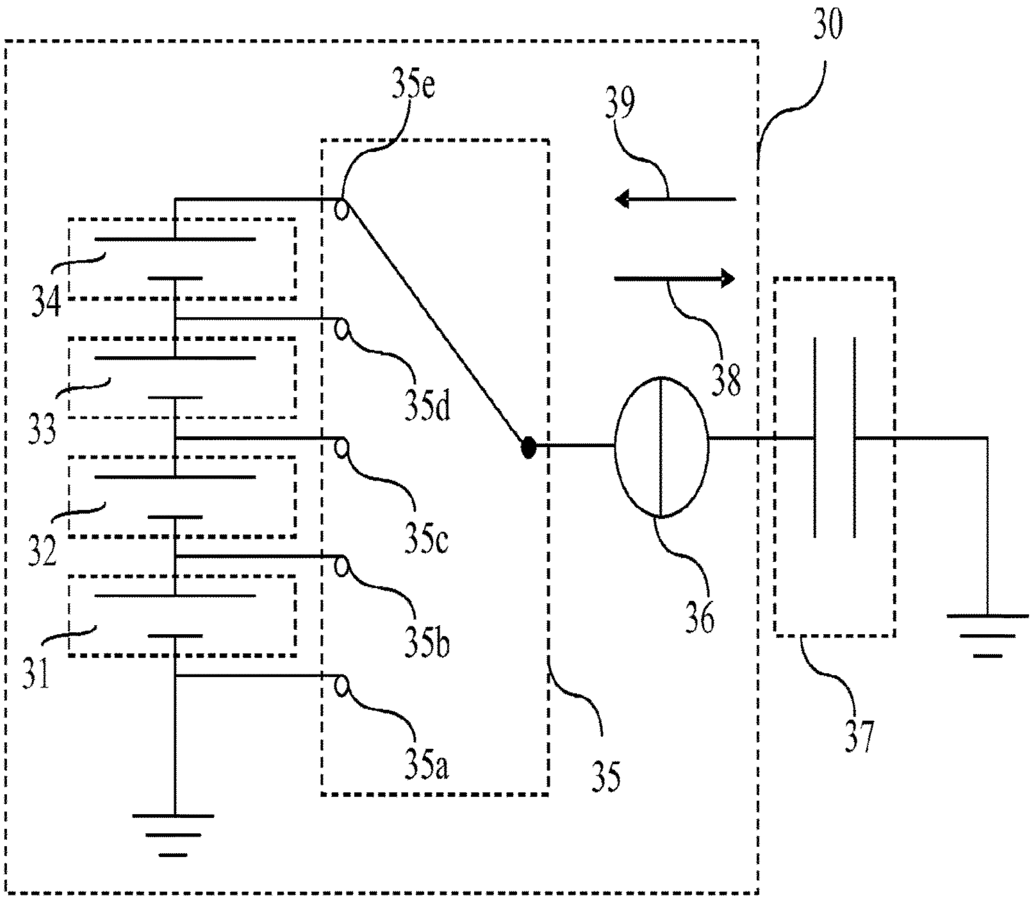

Figure 3

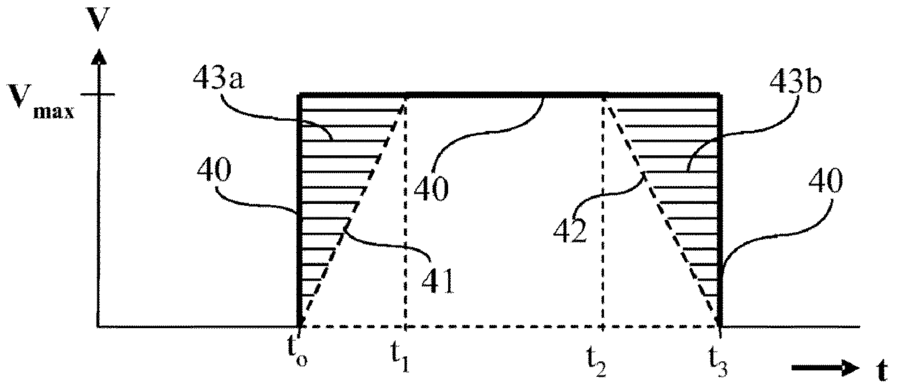

Figure 4a

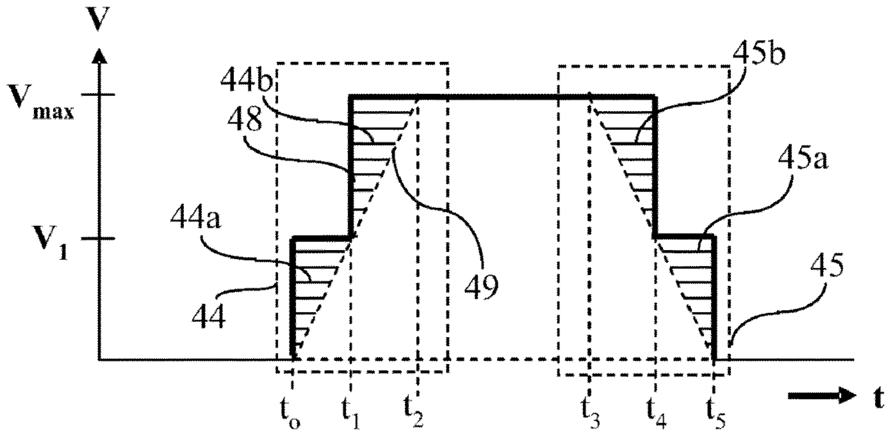

Figure 4b

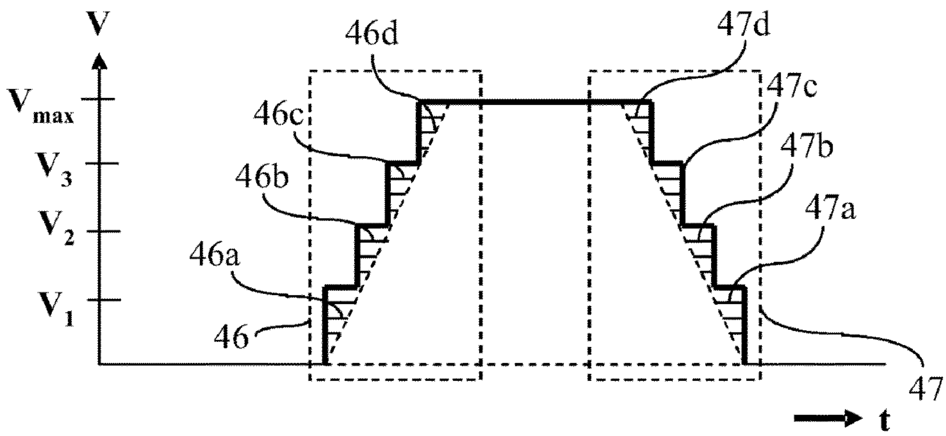

Figure 4c

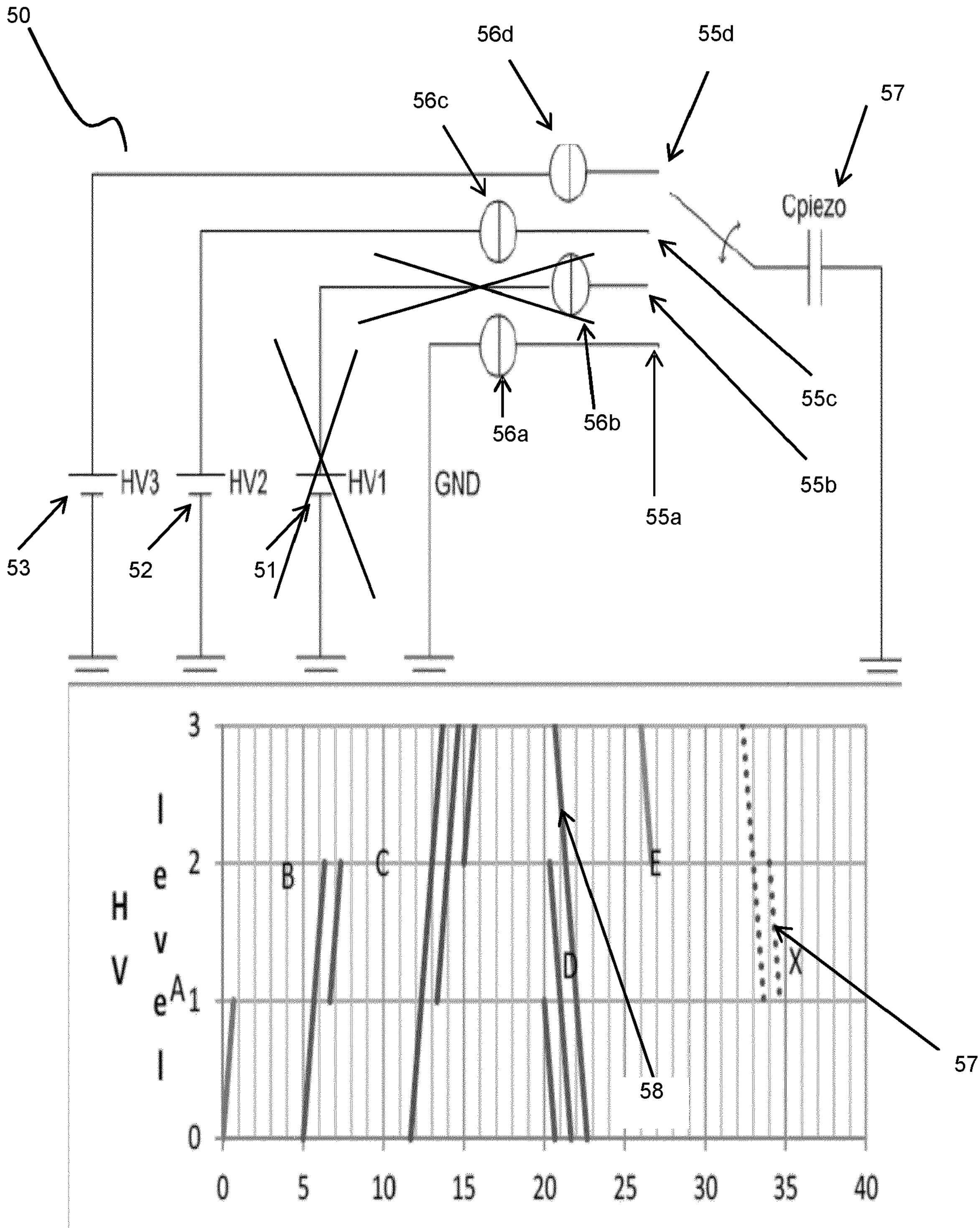
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Figure 5

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EUROPEAN SEARCH REPORT

Application Number
EP 20 21 5239

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 352 645 A1 (OCE TECH BV [NL]) 10 August 2011 (2011-08-10) * paragraphs [0001] - [0032]; figures 1-8a * -----	1-5	INV. B41J2/045
A	EP 1 470 921 A1 (SHARP KK [JP]) 27 October 2004 (2004-10-27) * paragraphs [0002] - [0124]; figures 1-8 * -----	1-5	
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A	US 2013/162307 A1 (BHATTACHARYA ANINDYA [US] ET AL) 27 June 2013 (2013-06-27) * paragraphs [0036] - [0069]; figures 1-9 * -----	1-5	
			TECHNICAL FIELDS SEARCHED (IPC)
			B41J

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	25 May 2021	Bitane, Rehab

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 21 5239

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25-05-2021

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