



- (51) International Patent Classification:
H02N 2/06 (2006.01) *H01L 41/22* (2013.01)
- (21) International Application Number:
PCT/US2012/035911
- (22) International Filing Date:
30 April 2012 (30.04.2012)
- (25) Filing Language: English
- (26) Publication Language: English
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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(54) Title: SELECTING PULSE TO DRIVE PIEZOELECTRIC ACTUATOR

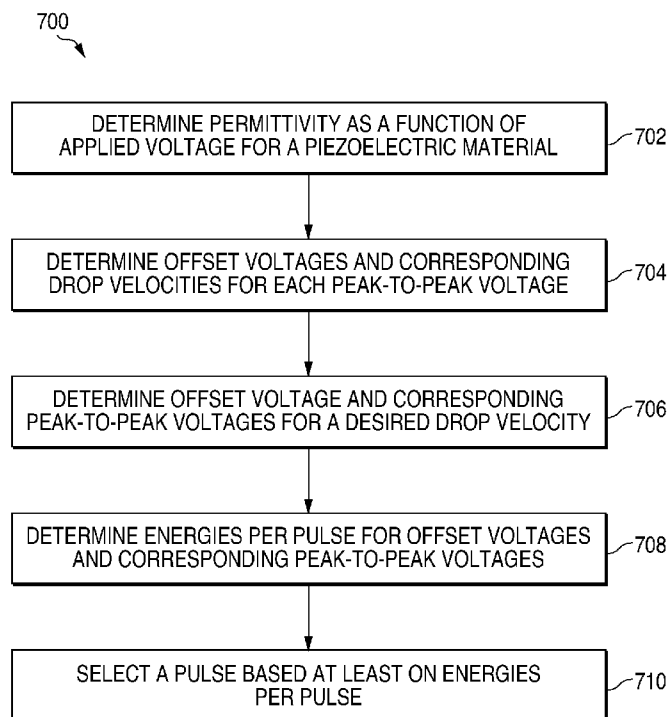


FIG. 7

(57) Abstract: A method (700) is provided for selecting a pulse for driving a piezoelectric actuator (112). The method includes determining offset voltages and corresponding peak-to-peak voltages that achieve a desired drop velocity, determining energy per pulse for each offset voltage, and selecting an offset voltage and a corresponding peak-to-peak voltage for the pulse based on at least the energy per pulse for each offset voltage.



(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

Declarations under Rule 4.17:

— as to the identity of the inventor (Rule 4.17(i))

SELECTING PULSE TO DRIVE PIEZOELECTRIC ACTUATOR

TECHNICAL FIELD

[0001] The present disclosure is related to piezoelectric inkjet printheads.

BACKGROUND

5 [0002] Drop-on-demand inkjet printers are commonly categorized based on one of two mechanisms of drop formation. A thermal inkjet (TIJ) printer uses a heating element actuator (e.g., a thin film resistor) in an ink-filled chamber to vaporize ink and create a bubble that forces an ink drop out of a nozzle. A piezoelectric inkjet (PIJ) printer uses a piezoelectric actuator on a wall of an ink-filled chamber to generate a pressure pulse that forces a drop of
10 ink out of the nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] In the drawings:

Fig. 1 is cross-sectional view of an inkjet printhead with a piezoelectric actuator on a flexible membrane of a fluid chamber in one example of the present disclosure;

15 Fig. 2 is a timing diagram of a waveform applied to the piezoelectric actuator of Fig. 1 in one example of the present disclosure;

Fig. 3 is a cross-sectional view of the printhead of Fig. 1 with the piezoelectric actuator in an actuated state in one example of the present disclosure;

20 Fig. 4 is an electronic schematic of the printhead of Fig. 1 in one example of the present disclosure;

Fig. 5 is a chart of permittivity and internal friction of a piezoelectric material in the piezoelectric actuator of Fig. 1 as a function of voltage in one example of the present disclosure;

25 Fig. 6 is a chart of displacement of the piezoelectric actuator of Fig. 1 as a function of voltage in one example of the present disclosure;

Fig. 7 is a flowchart for a method to select a pulse for a piezoelectric actuator on a

membrane of a fluid chamber in one example of the present disclosure; and

Fig. 8 is a chart of drop velocity as a function of offset voltage for a peak-to-peak voltage in one example of the present disclosure;

Fig. 9 is a chart of peak-to-peak voltage as a function of offset voltage for a drop velocity in one example of the present disclosure;

Fig. 10 is a chart of energy per pulse as a function of offset voltage in one example of the present disclosure;

Fig. 11 is a timing diagram of a waveform with the pulse selected in the method of Fig. 7 in one example of the present disclosure; and

Fig. 12 is a timing diagram of a waveform with a different offset voltage than the waveform of Fig. 11 in one example of the present disclosure. .

[0004] Use of the same reference numbers in different figures indicates similar or identical elements.

DETAILED DESCRIPTION

[0005] Fig. 1 is a cross-sectional view of a piezoelectric inkjet (PIJ) printhead 100 in one example of the present disclosure. PIJ printhead 100 may be part of an inkjet device or a microelectromechanical systems (MEMS) device. Printhead 100 includes a fluid chamber 102 defined by a flexible membrane 104 and rigid walls 106, 108, and 110. Wall 108 defines an orifice or nozzle 109. Printhead 100 further includes a piezoelectric actuator 112 fixed to flexible membrane 104. Piezoelectric actuator 112 includes a piezoelectric material 114 between electrodes 116 and 118. In one example, piezoelectric material 114 is a thin film of piezoceramic such as lead zirconate titanate (PZT). Electrodes 116 and 118 form a capacitor that, when charged, provides an electric field to piezoelectric material 114. In one example, piezoelectric material 114 has a polarization orientation that provides a motion into fluid chamber 102 when electrode 116 has a higher voltage than electrode 118. Printhead 100 typically includes multiple fluid chambers 102 with piezoelectric actuators 112.

[0006] Fig. 2 is a positive waveform 200 applied to electrode 116 (Fig. 1) of piezoelectric actuator 112 (Fig. 1) while electrode 118 (Fig. 1) is grounded in one example of the present

disclosure. Waveform 200 includes a first pulse 202 and a second pulse 204. From time t_0 to t_1 , waveform 200 is at a positive rest voltage. The rest voltage holds piezoelectric actuator 112 in an actuated state where piezoelectric actuator 112 extends into fluid chamber 102 as shown in Fig. 3. First pulse 202 occurs from time t_1 to t_2 . At time t_1 , waveform 200
5 transitions from the rest voltage to zero volts (0 V) to discharge piezoelectric actuator 112. The change from the rest voltage to 0 V causes piezoelectric actuator 112 to move away from fluid chamber 102 to draw ink into the chamber. At time t_2 , waveform 200 transitions from 0 V to the rest voltage to charge piezoelectric actuator 112. The change from 0 V to the rest voltage causes piezoelectric actuator 112 to move into fluid chamber 102 to eject a first ink
10 drop from fluid chamber 102. Waveform 200 remains at the rest voltage from time t_2 to t_3 . The duration of time t_1 to t_3 is the allotted time to print one drop onto a first pixel on a substrate before the fluidic system is in a state to be optimally responsive to a subsequent pulse.

[0007] Second pulse 204 occurs from time t_3 to t_4 . At time t_3 , waveform 200 transitions from
15 the rest voltage to 0 V to discharge piezoelectric actuator 112. The change from the rest voltage to 0 V causes piezoelectric actuator 112 to move away from fluid chamber 102 to draw ink into the chamber. At time t_4 , waveform 200 transitions from 0 V to the rest voltage to charge piezoelectric actuator 112. The change from 0 V to the rest voltage causes piezoelectric actuator 112 to move into fluid chamber 102 to eject a second ink drop from
20 fluid chamber 102 and print one drop onto a second pixel on the substrate. Waveform 200 may repeat to print additional drops onto other pixels on the substrate.

[0008] Fig. 4 is an electronic block diagram for printhead 100 in one example of the present disclosure. Printhead 100 includes a waveform source 402 that outputs a waveform to a drive integrated circuit (IC) 404, which amplifies the waveform and outputs an alternating voltage
25 V_p to electrode 116 of piezoelectric actuator 112. Waveform source 402 may be a controller or a microprocessor programmed with the waveform. Drive IC 404 also outputs a constant voltage V_c to electrode 118 to generate an electric field across piezoelectric material 114. Alternating voltage V_p may have a positive or negative offset relative to constant voltage V_c . Alternating voltage V_p has a positive offset when its low value is higher than constant voltage
30 V_c . Alternating voltage V_p has a negative offset when its low value is less than constant voltage V_c .

[0009] Energy loss per pulse in printhead 100 is primarily due to resistive heating in drive IC

400 when piezoelectric actuator 112 is charged and discharged. The energy stored in the capacitor of piezoelectric actuator 112 by the leading edge of a pulse passing through drive IC 404 is $\frac{1}{2}CV^2$, where C is the capacitance and V is the applied voltage difference. The energy discharged from the capacitor of piezoelectric actuator 112 by the trailing edge of the pulse passing through drive IC 404 is $\frac{1}{2}CV^2$. Thus, the total energy per pulse is CV^2 .

[0010] The heat dissipated by drive IC 404 may be removed by ink or some other flow through coolant. The former results in hot ink that limits the frequency of operation, causes reliability problems such as ink thickening and bubble formation, and causes thermal gradients that create non-uniform drop ejection.

10 [0011] Cold switching may be used to address the resistive heating issue. In cold switching, waveforms are generated off-board from printhead 100 and onboard electronics select which waveform to use. However, this approach limits the number of piezoelectric actuators 112 and their packing density as electrical interconnection becomes more difficult. Cold switching also limits the number of waveforms sent to piezoelectric actuators 112 to the waveforms generated by the off-board electronics. In contrast, hot switching allows for easier implementation of individualized waveforms for piezoelectric actuators 112, which provide drops with volumes and speeds having more uniformity.

[0012] Examples of the present disclosure adjust a waveform to a piezoelectric actuator to take advantage of the non-linear behavior of the permittivity (dielectric constant) and the internal friction (hysteresis loss) of the piezoelectric material. This non-linear behavior is notably pronounced in thin film piezoceramics where the electric fields may be as large as 20 megavolts per meter (MV/m). In bulk piezoceramics used in highly cyclic actuators the electric fields are generally less than 1 MV/m.

[0013] Fig. 5 is a chart of permittivity of a PZT thin film as a function of applied voltage in one example of the present disclosure. The applied voltage refers to peak-to-peak voltage where the low of the voltage is at 0 V. In other words, the applied voltage has a zero offset. PZT thin film is 2 micron (μm) thick film and it is formed on a test chip used to represent piezoelectric actuator 112 in printhead 100. The permittivity curve is obtained using the following parameters: oscillation level – 0.1 V; frequency of oscillation – 10 kilohertz (kHz); bias level – 40 V max. The measurements were performed in two steps: 1st step – voltage cycling, 20 times +/- 40V; 2nd step – voltage sweeping between 40 V and -40 V and 40 V

(with oscillation level and frequency as above). An electric field of 200 kilovolts per centimeter (kV/cm) is created by applying 40 V to a 2 μm PZT thin film.

[0014] As the applied voltage changes from -40 V to positive 40 V, the permittivity curve follows point 1, 2, and 3. When the applied voltages changes 40 V to -40 V, the permittivity curve follows point 3, 4, and 5. The cycle then repeats. Note that on the way back from 40 V to -40 V, the permittivity curve does not follow the original path from -40 V to 40 V because of electromechanical hysteresis behavior of piezoelectric material.

[0015] As the figure shows, the permittivity decreases rapidly with increasing positive voltage differences. As permittivity depends on the applied voltage, the energy for the leading edge or the trailing edge per pulse is defined as follows:

$$\int_{V_1}^{V_2} C(v)vdv = \epsilon_0(A/t)\int_{V_1}^{V_2} \epsilon(v)vdv \quad (1)$$

where $C(v)$ is capacitance as a function of applied voltage, v is voltage, V_2 to V_1 is the voltage range applied to the actuator where $V_2 - V_1$ is the peak-to-peak voltage, ϵ_0 is the permittivity of free space, A is the area of the thin film electrodes facing the piezoelectric material, t is the thickness of the piezoelectric material between the electrodes, and ϵ is the permittivity of the piezoelectric material.

[0016] Fig. 6 is a chart of average displacement of actuator 112 as a function of applied voltage with a zero offset in one example of the present disclosure. Actuator 112 is operated between a low voltage and a high voltage where the low voltage is typically 0 V. In one example, actuator 112 is driven by a baseline pulse having a 20 V voltage difference that transitions between a low of 0 V and a high of 20 V to produce an average displacement of 82.6 nanometers (nm). Displacements of the same magnitude can be achieved using other pulses that are offset from 0V. In one example, the same magnitude of displacement is produced with a first pulse having a 21 V voltage difference that transitions between a low of 5 V and a high of 26 V (shown as box 602), a second pulse having a 27 V voltage difference that transitions between a low of 10V and a high of 37 V (shown as box 604), and a third pulse having a 39V voltage difference that transitions between a low of 15 V and a high of 54 V (shown as box 606).

[0017] In each of the three pulses, the average capacitance is decreased over the higher applied voltages so the energy per pulse and the dissipated heat are reduced. However, this is offset by increases in the energy per pulse and the dissipated heat caused by the higher voltage difference. Compared to the baseline pulse, the first pulse produces approximately
5 30% reduction in the average capacitance and the energy per pulse, 10% increase in the energy per pulse due to the increase in the voltage difference. Thus the first pulse has a net decrease of approximately 20% in the energy per pulse compared to the baseline pulse. The 30% reduction in average capacitance is estimated by comparing the average of the capacitances at 5 V and 26 V against the average of the capacitances at 0 V and 20 V.

10 Instead of estimating the reduction in average capacitance, the actual reduction in capacitance may be determined by integrating the capacitance over the applied voltages using formula (1) and the permittivity curve in Fig. 5. The 10% increase in energy per pulse is determined by squaring the voltage differences and calculating their differences.

[0018] The second pulse produces approximately 17% reduction in the average capacitance
15 and the energy per pulse, 82% increase in voltage difference. Thus the second pulse has a net increase of approximately 65% in the energy per pulse. Like the second pulse, the third pulse produces a net increase in the energy per pulse. Thus, the first pulse has the optimum offset from 0V based on the shape of the permittivity curve in Fig. 5 and the displacement in Fig. 6.

[0019] In the examples above, the same actuator displacement is used to select a waveform
20 with energy savings. Instead of displacement, drop velocity may be used in other examples of the present disclosure to select a waveform with energy savings.

[0020] Fig. 7 is a flowchart for a method 700 to select a waveform for a piezoelectric actuator of a fluid chamber in one example of the present disclosure. Method 700 may begin in block 702.

25 [0021] In block 702, permittivity as a function of applied voltage for a piezoelectric material is determined. The result may be represented by a formula, a table, or a chart as shown in Fig. 5. The piezoelectric material used in method 700 may be part of a test chip used to represent piezoelectric actuator 112 in printhead 100. The test chip may be made on the same wafer as piezoelectric actuator 112 but with bigger bond pads and dimensions so it is easy to
30 take measurements. Block 702 is followed by block 704.

[0022] In block 704, the relationship between offset voltage and drop velocity is determined

for a set of peak-to-peak voltages. In other words, offset voltages and corresponding drop velocities for each peak-to-peak voltage is determined. Fig. 8 shows the chart for one peak-to-peak voltage (e.g., 24.5V) in one example of the present disclosure. Block 704 is followed by block 706.

- 5 [0023] In block 706, the results of block 704 are filtered to determine the relationship between offset voltage and peak-to-peak voltage for a constant drop velocity. In other words, offset voltages and corresponding peak-to-peak voltages for a constant drop velocity is determined. Fig. 9 shows the chart for the desired drop velocity (e.g., 10 meter per second) in one example of the present disclosure. In another embodiment, the chart of Fig. 9 is
- 10 generated by selecting a constant drop velocity and then varying the offset voltage and peak-to-peak-voltage to generate combinations that produce the constant drop velocity. Block 706 is followed by block 708.

- [0024] In block 708, the energy per pulse is determined for each offset voltage. The energy per pulse is calculated by integrating formula 1 using the permittivity values determined in
- 15 block 702. Fig. 10 shows energy per pulse for offset voltages (and their peak-to-peak voltages) in one example of the present disclosure. Block 708 is followed by block 710.

- [0025] In block 710, a pulse is selected as the pulse for piezoelectric actuators 112 based on its energy per pulse and its offset voltage. Note that the pulse with the lowest energy per pulse may not be selected since the jetting behavior may not be desirable. For example, Fig.
- 20 10 shows a negative offset voltage of -8V provides the lowest energy per pulse, and Fig. 9 shows the corresponding peak-to-peak voltage of about 24 V. However, such a negative offset voltage would exceed the coercive field of the piezoelectric material, which is about -4 V, and raise concerns about reliability. Furthermore, different bias voltages may cause small satellite droplets ejected along with a large drop of ink or puddling of ink around the lip of
- 25 the nozzle. Thus energy per pulse has to be balanced against avoiding undesirable jetting properties. For example, a positive offset voltage of 2 V providing the third lowest energy per pulse may be preferred, which has a corresponding peak-to-peak voltage of about 31 V.

- [0026] The selected pulse may be programmed or hardwired into waveform source 402, such as a controller or a microprocessor, of printhead 100. The same waveform may be applied to
- 30 multiple piezoelectric actuators 112 in the same or other printheads 100 when they have the same design and manufacture. The same waveform may be adjusted to account for design

and manufacture variations, so it may be applied to multiple piezoelectric actuators 112 in the same or other printheads 100.

[0027] Fig. 11 is a waveform 1100 with the pulse having the peak-to-peak voltage and offset voltage determined in method 700 (Fig. 7) in one example of the present disclosure. From time t_0 to t_1 , waveform 1100 is at a positive rest voltage V_2 set to the high value of the pulse determined in method 700. Rest voltage V_2 holds piezoelectric actuator 112 in an actuated state so piezoelectric actuator 112 extends into fluid chamber 120. A first pulse 1102 occurs from time t_1 to t_2 . At time t_1 , waveform 800 transitions from rest voltage V_2 to offset voltage V_1 equal to the low value of the pulse determined in method 700 to discharge piezoelectric actuator 112. The change from rest voltage V_2 to offset voltage V_1 causes piezoelectric actuator 112 to move away from fluid chamber 120 to draw ink into the chamber. At time t_2 , waveform 1100 transitions from offset voltage V_1 to rest voltage V_2 to charge piezoelectric actuator 112. The change from offset voltage V_1 to rest voltage V_2 causes piezoelectric actuator 112 to move into fluid chamber 102 to eject a first ink drop.

[0028] In Fig. 11, the period from time t_1 to t_9 is the allotted time to print one drop of ink on one pixel on a substrate. In one example, a single pulse is used to print one pixel so waveform 1100 remains at rest voltage V_2 from time t_2 to t_9 (shown in phantom from times t_3 to t_4 , t_5 to t_6 , and t_7 to t_8). In another example, a double or triple pulse is used to print one pixel so waveform 1100 remains at rest voltage V_2 from time t_2 to t_3 and a second pulse 1104 occurs from time t_3 to t_4 as shown in Fig. 11. At time t_3 , waveform 1100 transitions from rest voltage V_2 to a low voltage V_3 to discharge piezoelectric actuator 112 (Fig. 1). In one example, low voltage V_3 is the same as offset voltage V_1 . In another example illustrated in Fig. 11, low voltage V_3 is higher than offset voltage V_1 . At time t_4 , waveform 1100 transitions from low voltage V_3 to rest voltage V_2 to charge piezoelectric actuator 112. Second pulse 1104 is timed to be in phase with the motion of piezoelectric actuator 112 to eject a second ink drop that combines with the first ink drop in flight to form a single pixel on a substrate. Waveform 1100 remains at rest voltage V_2 from time t_4 to t_5 .

[0029] When a triple pulse is used to print one pixel, a third pulse 1106 occurs from time t_5 to t_6 . At time t_5 , waveform 1100 transitions from rest voltage V_2 to a low voltage V_4 to discharge piezoelectric actuator 112. In one example, low voltage V_4 is the same as offset voltage V_1 or low voltage V_3 . In another example illustrated in Fig. 11, low voltage V_4 is higher than offset voltage V_3 . At time t_6 , waveform 1100 transitions from low voltage V_4 to

rest voltage V_2 to charge piezoelectric actuator 112. Third pulse 1106 is timed to be in phase with the motion of piezoelectric actuator 112 to eject a third ink drop that is timed to combine with the first and the second ink drops in flight to form one drop on one pixel on a substrate. Waveform 1100 remains at rest voltage V_2 from time t_6 to t_7 .

5 **[0030]** In one example, a cancellation pulse 1110 occurs from time t_7 to t_8 . At time t_7 , waveform 1100 transitions from rest voltage V_2 to a low voltage V_5 to discharge piezoelectric actuator 112. In one example as shown in Fig. 11, low voltage V_5 is higher than offset voltage V_4 . At time t_8 , waveform 1100 transitions from low voltage V_5 to rest voltage V_2 to charge piezoelectric actuator 112. Cancellation pulse 1110 is timed to be out of phase with
10 the motion of piezoelectric actuator 112 to dampen the motion of piezoelectric actuator 112. Waveform 1100 remains at rest voltage V_2 from time t_8 to t_9 .

[0031] Time t_9 is the start of a time period allotted to print another pixel on the substrate. A first pulse 1110 in this time period occurs from time t_9 to t_{10} . At time t_9 , waveform 1100 transitions from rest voltage V_2 to offset voltage V_1 to discharge piezoelectric actuator 112.
15 At time t_6 , waveform 1100 transitions from offset voltage V_1 to rest voltage V_2 to charge piezoelectric actuator 112. Waveform 1100 may repeat with additional pulses as described for time t_1 to t_9 .

[0032] Fig. 12 is a waveform 1200 with the pulse having the peak-to-peak voltage and another offset voltage determined in method 700 (Fig. 7) in one example of the present
20 disclosure. Waveform 1200 is similar to waveform 1100 (Fig. 11) but for a different (e.g., higher) offset voltage V_1 .

[0033] Various other adaptations and combinations of features of the examples disclosed are within the scope of the invention. In one example, piezoelectric material 114 has a polarization orientation that provides a motion into fluid chamber 102 when a negative
25 waveform is applied to electrode 116 and electrode 118 is grounded. The negative waveform may mirror waveform 1100 in Fig. 11. Numerous examples are encompassed by the following claims.

CLAIMS

What is claimed is:

Claim 1: A method (700) for selecting a pulse to drive a thin film piezoelectric actuator (112), comprising:

determining offset voltages and corresponding peak-to-peak voltages that achieve a desired drop velocity;

determining energies per pulse for the offset voltages and the corresponding peak-to-peak voltages; and

selecting an offset voltage and a corresponding peak-to-peak voltage for the pulse based on at least the energies per pulse.

Claim 2: The method of claim 1, wherein the selecting the offset voltage and the corresponding peak-to-peak voltage is based on the energies per pulse and corresponding offset voltages.

Claim 3: The method of claim 1, wherein the selecting the offset voltage and the corresponding peak-to-peak voltage is based on the energies per pulse and avoiding satellite droplets and puddling.

Claim 4: The method of claim 1, further comprising determining permittivity of a piezoelectric material over a voltage range.

Claim 5: The method of claim 4, wherein determining the offset voltages and the corresponding peak-to-peak voltages comprises:

determining offset voltages and corresponding drop velocities for each peak-to-peak voltage; and

selecting offset voltages from the offset voltages and the corresponding drop velocities for each peak-to-peak voltage that include the desired drop velocity.

Claim 6: The method of claim 1, wherein an energy for a leading edge or a trailing edge per pulse is defined as follows:

$$\int_{V_1}^{V_2} C(v)vdv = \epsilon_0(A/t)\int_{V_1}^{V_2} \epsilon(v)vdv$$

where $C(v)$ is capacitance as a function of applied voltage, v is voltage, V_2 to V_1 is a voltage range applied to a piezoelectric material, ϵ_0 is the permittivity of free space, A is the area of electrodes facing the piezoelectric material, t is a thickness of the piezoelectric material between the electrodes, and ϵ is a permittivity of the piezoelectric material.

Claim 7: The method of claim 6, wherein the piezoelectric material is part of a test piezoelectric actuator.

Claim 8: The method of claim 1, wherein an offset voltage is a voltage from a low of the pulse applied to a first piezoelectric electrode to a constant voltage applied to a second piezoelectric electrode.

Claim 9: The method of claim 1, further comprising programming the pulse into a waveform source (402) for the piezoelectric actuator.

Claim 10: The method of claim 1, wherein the thin film piezoelectric actuator is part of an inkjet device (100) or a microelectromechanical systems device (100).

Claim 11: A method (700) to select a pulse to drive thin film piezoelectric actuators (112), comprising:

determining a relationship between values of an offset voltage and values of a drop velocity for each value of a peak-to-peak voltage on a test thin film piezoelectric actuator;

determining a relationship between the values of the offset voltage and values of peak-to-peak voltage for a desired value of the drop velocity;

determining values of energy per pulse for corresponding values of the offset voltage and peak-to-peak voltage; and

based on at least the values of the energy per pulse, selecting corresponding values of the offset voltage and the peak-to-peak voltage for the pulse.

Claim 12: The method of claim 11, wherein the selecting the corresponding values of the offset voltage and the peak-to-peak voltage is based on the values of the energy per pulse and the values of the offset voltage.

Claim 13: The method of claim 11, wherein the energy for a leading edge or a trailing edge per pulse is defined as follows:

$$\int_{V_1}^{V_2} C(v)vdv = \epsilon_0(A/t)\int_{V_1}^{V_2} \epsilon(v)vdv$$

where $C(v)$ is capacitance as a function of applied voltage, v is voltage, V_2 to V_1 is a voltage range applied to a piezoelectric material, ϵ_0 is the permittivity of free space, A is the area of electrodes facing the piezoelectric material, t is a thickness of the piezoelectric material between the electrodes, and ϵ is a permittivity of the piezoelectric material.

Claim 14: The method of claim 13, further comprising determining the permittivity of the piezoelectric material over the voltage range on the test thin film piezoelectric actuator.

Claim 15: The method of claim 11, wherein the offset voltage is a voltage from a low of the pulse applied to a first piezoelectric electrode to a constant voltage applied to a second piezoelectric electrode.

Claim 16: The method of claim 11, further comprising programming the pulse into waveform sources (402) of the thin film piezoelectric actuators.

Claim 17: The method of claim 11, wherein the thin film piezoelectric actuators are parts of inkjet devices (100) or microelectromechanical systems devices (100).

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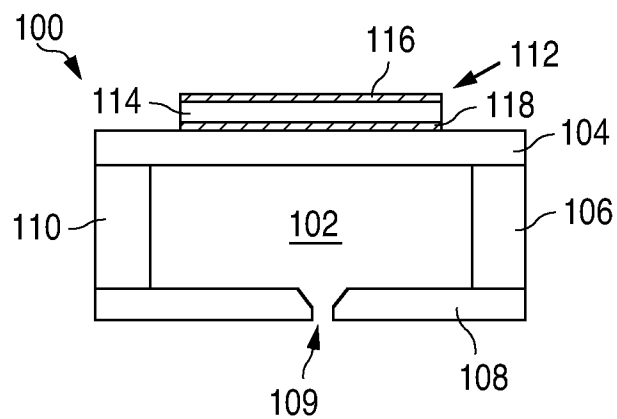


FIG. 1

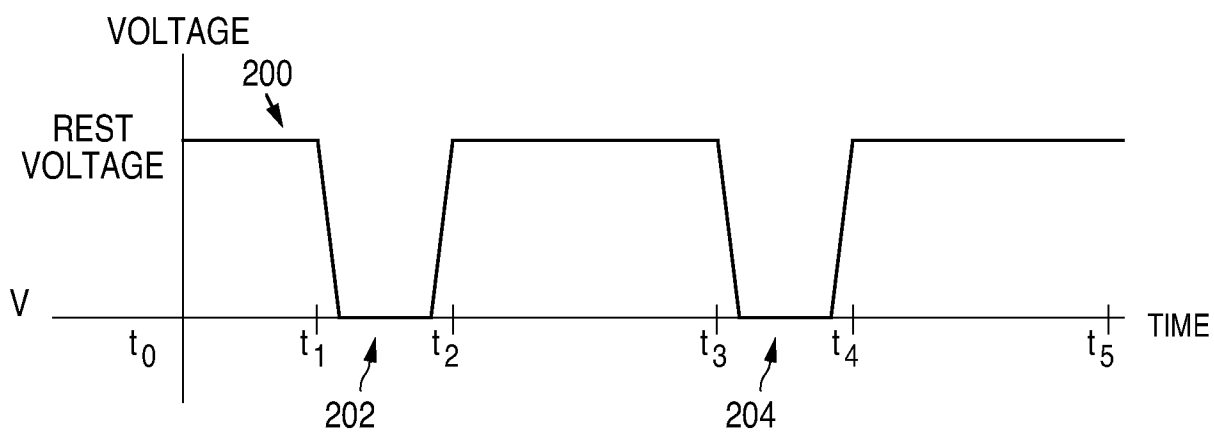


FIG. 2

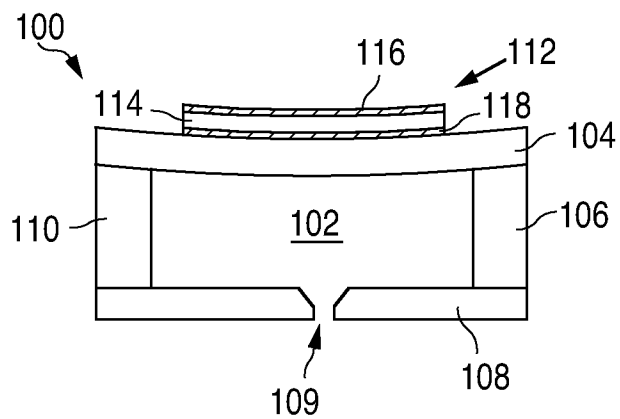
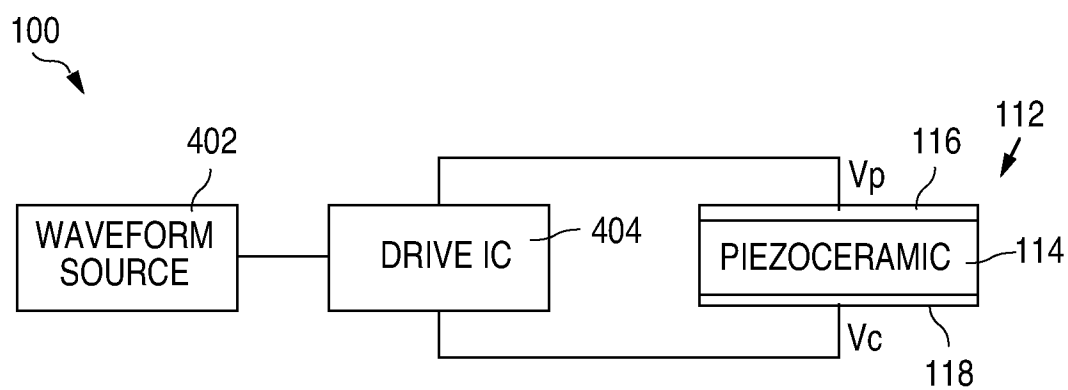
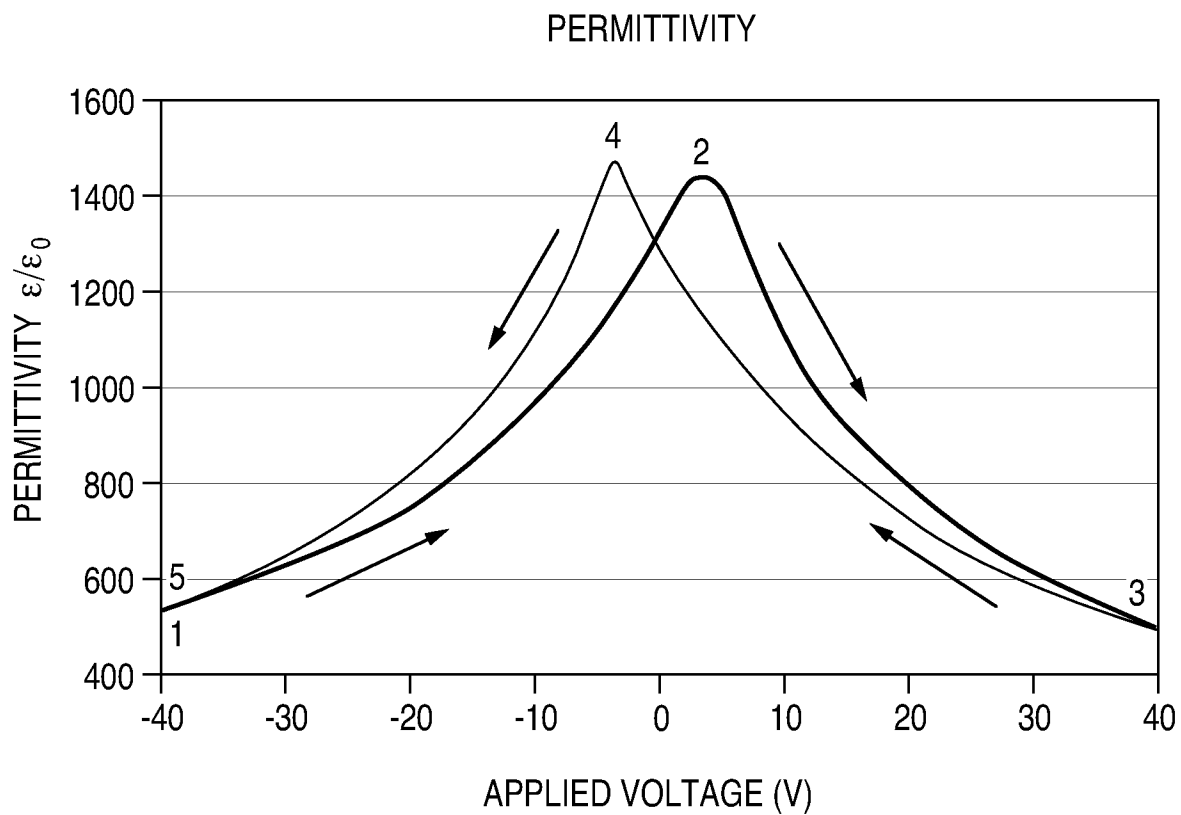


FIG. 3

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**FIG. 4****FIG. 5**

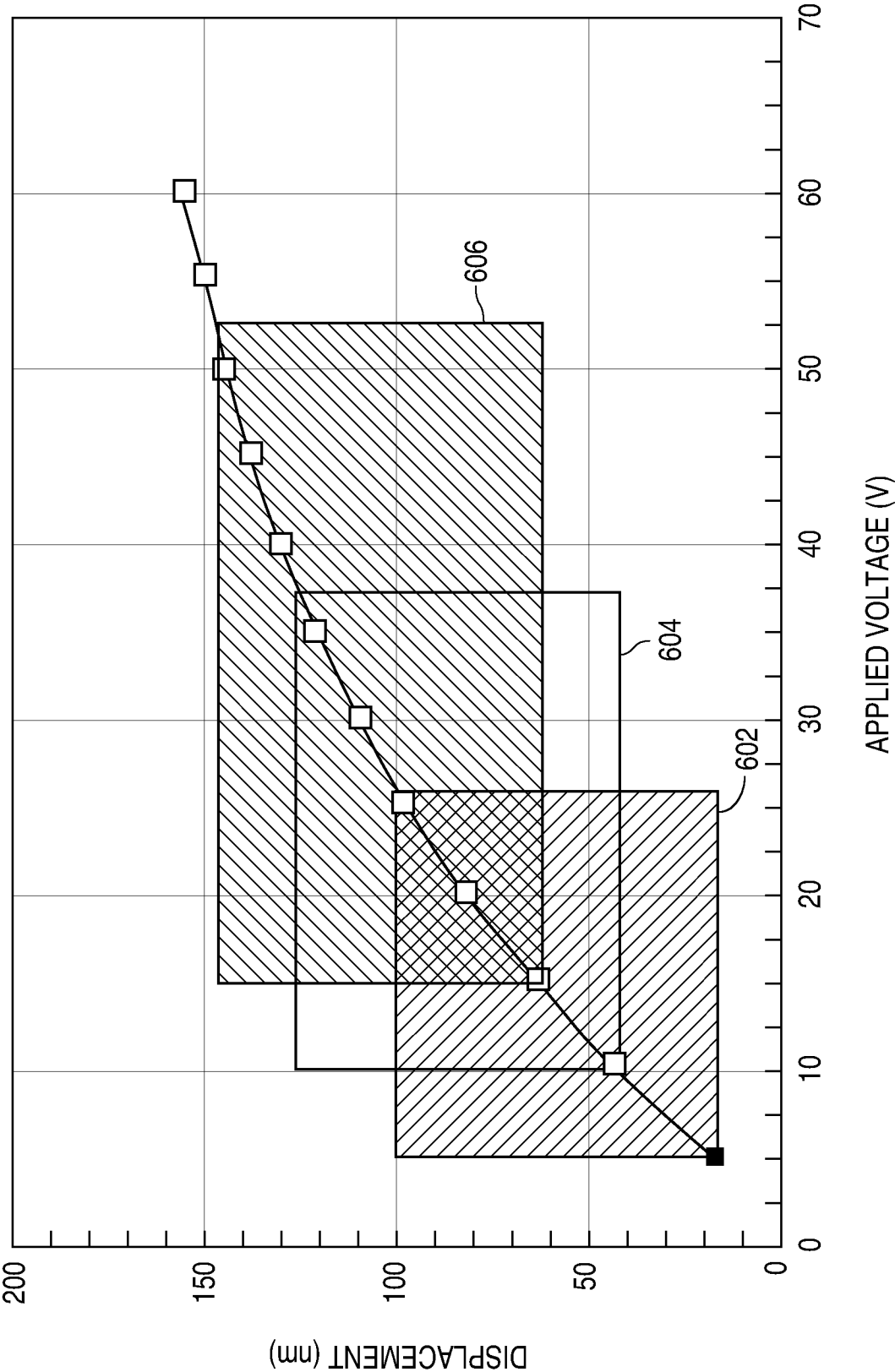
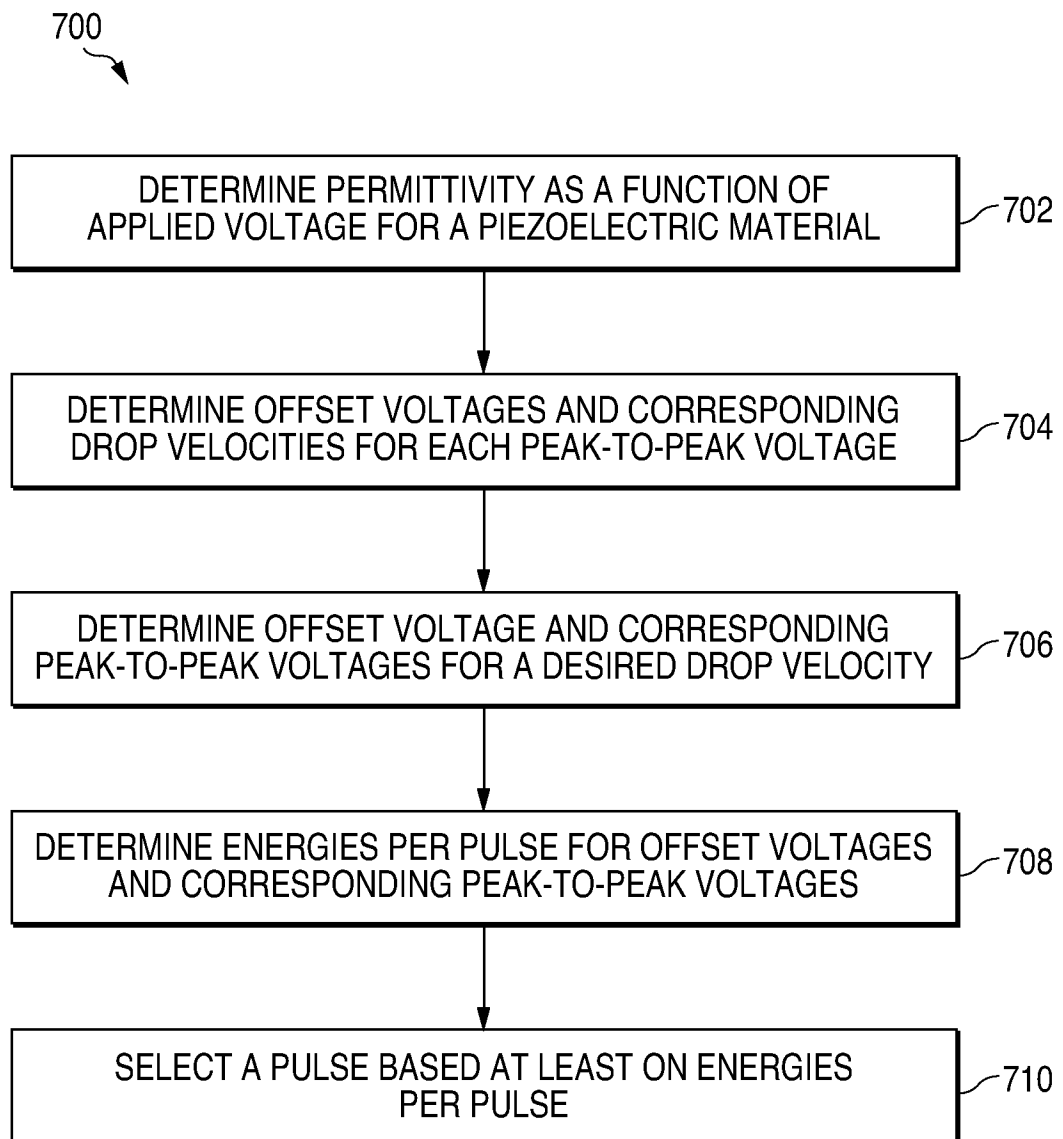


FIG. 6

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**FIG. 7**

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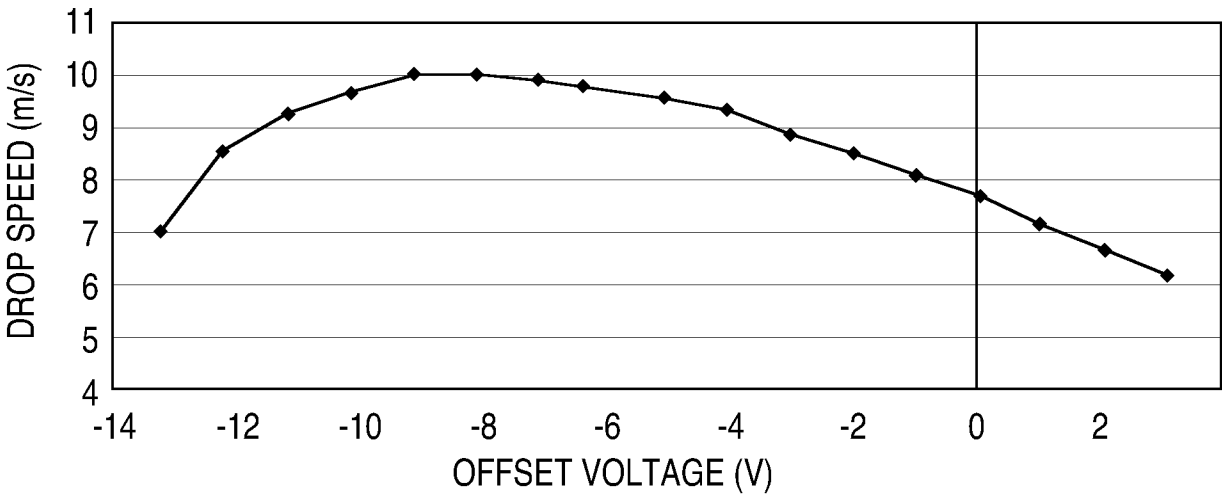


FIG. 8

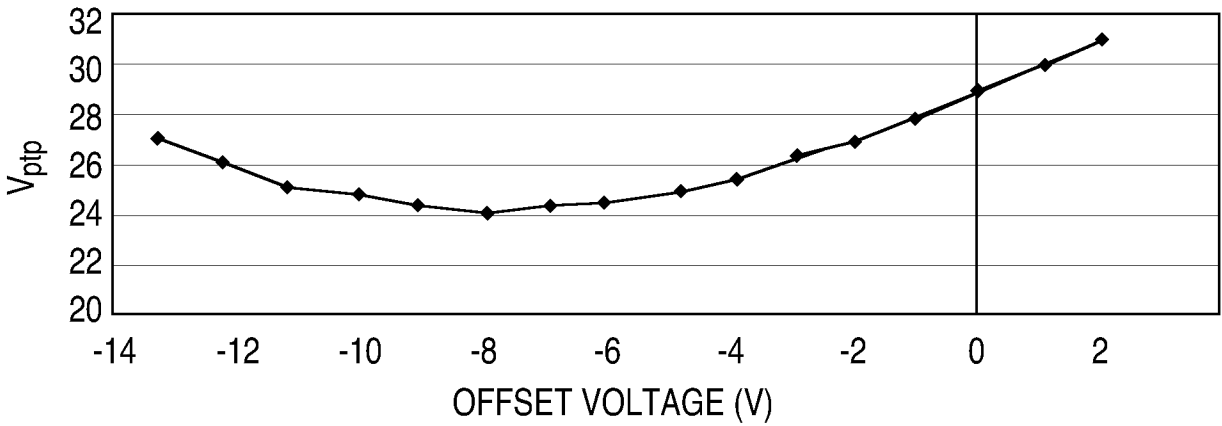
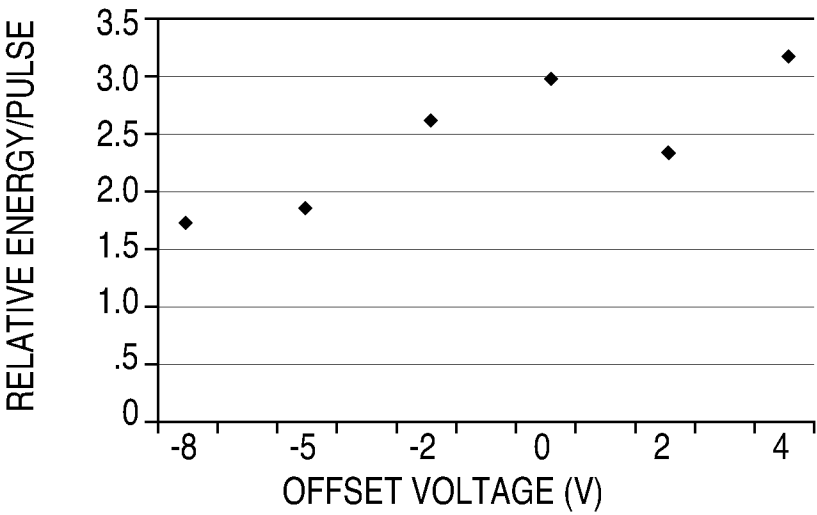


FIG. 9

FIG. 10



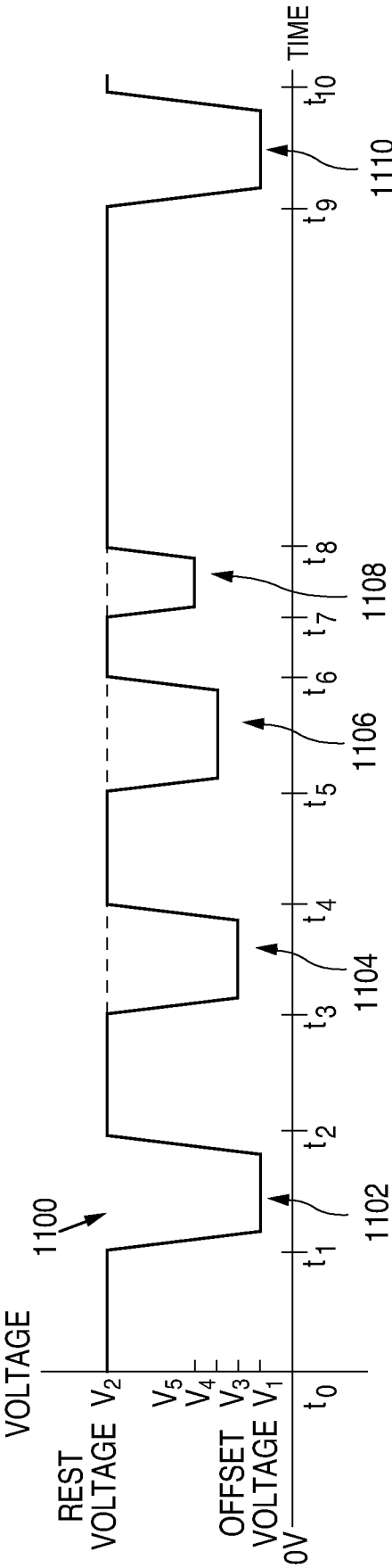


FIG. 11

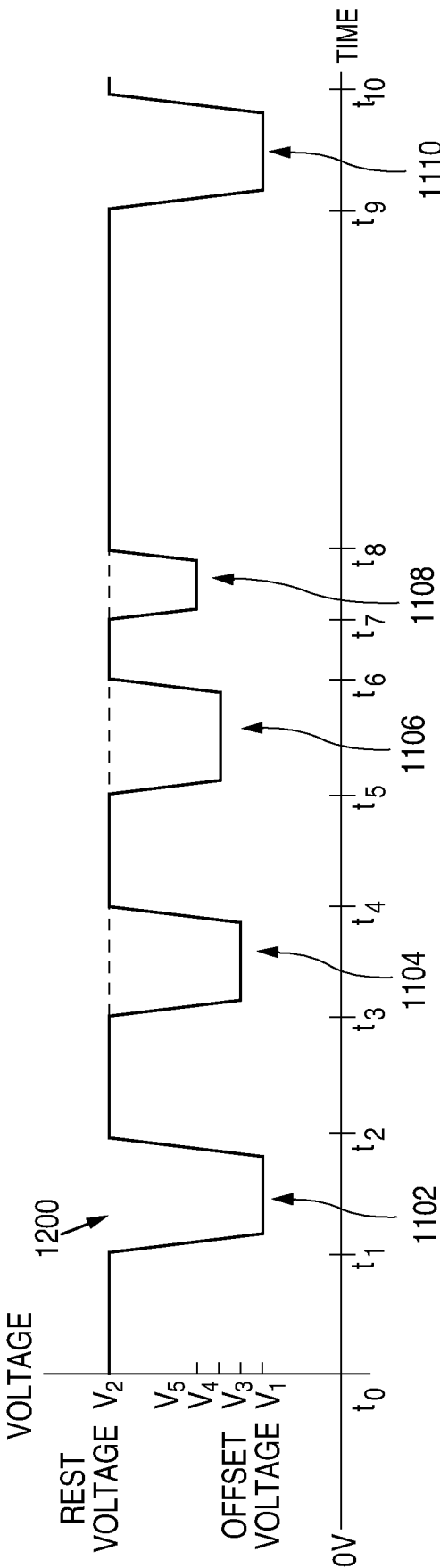


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/035911**A. CLASSIFICATION OF SUBJECT MATTER****H02N 2/06(2006.01)i, H01L 41/22(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02N 2/06; G01D 18/00; B41J 2/15; B41J 2/04; B41J 3/04; B41J 29/38; B41J 2/045; B41J 2/01; H01L 41/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: drop velocity, pulse, piezoelectric, inkjet printing, waveform

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009-0289983 A1 (WILLIAM R. LETENDRE, JR. et al.) 26 November 2009 See paragraphs [0005]-[0007], [0033]-[0057], claim 1 and figures 11C-14.	1-17
A	US 2005-0212840 A1 (AKIRA IRIGUCHI) 29 September 2005 See abstract, paragraphs [0033], [0055]-[0068], claim 1 and figure 8.	1-17
A	US 2002-0067390 A1 (YICHUAN PAN et al.) 06 June 2002 See abstract, paragraphs [0046]-[0048] and figure 6.	1-17
A	US 04872028 A (WILLIAM J. LLOYD) 03 October 1989 See abstract, column 4, line 37 - column 7, line 36 and figures 2-3.	1-17
A	JP 2000-043248 A (TEKTRONIX, INC.) 15 February 2000 See abstract, paragraphs [0010]-[0024] and figures 1-5.	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

27 August 2013 (27.08.2013)

Date of mailing of the international search report

28 August 2013 (28.08.2013)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/035911

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