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(54) METHODS, SYSTEMS, AND APPARATUSES FOR IMPROVING DROP VELOCITY UNIFORMITY, DROP MASS UNIFORMITY, AND DROP FORMATION

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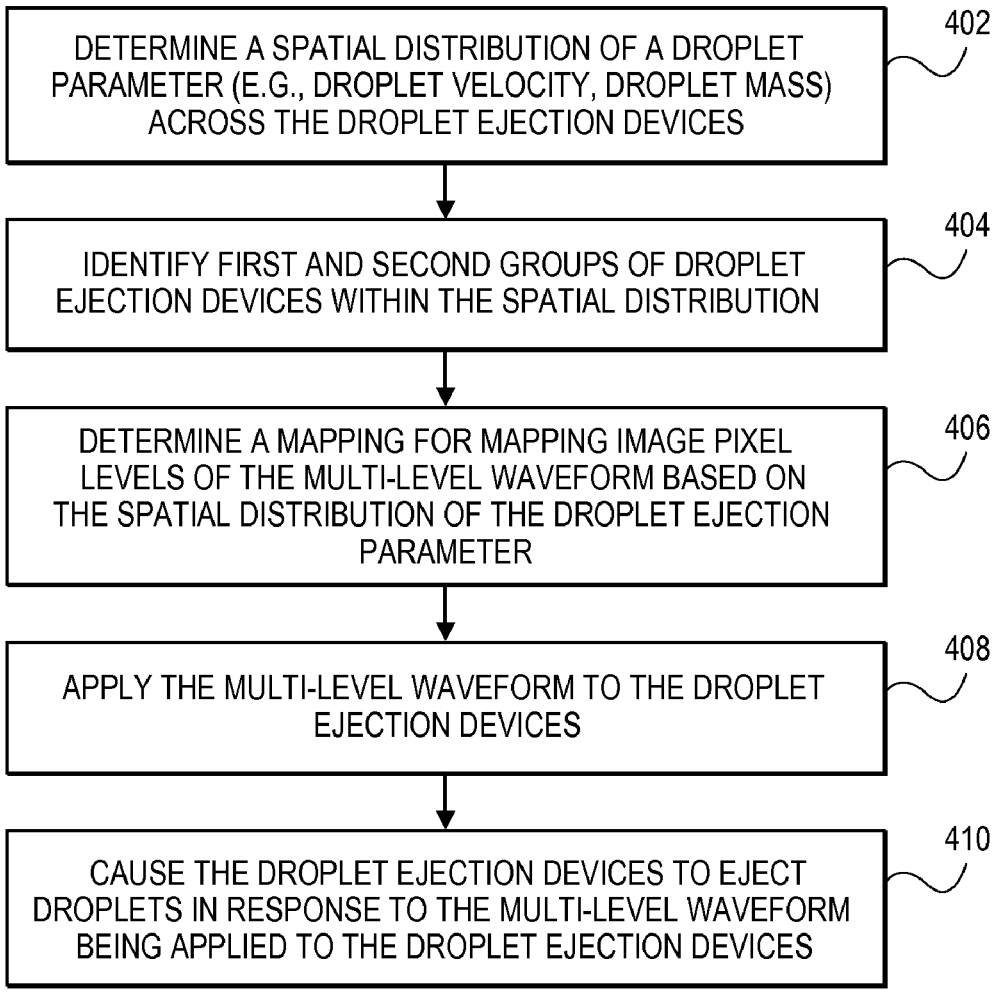
(57) **ABSTRACT**

Methods and systems are described herein for driving droplet ejection devices with multi-level waveforms. In one embodiment, a method for driving droplet ejection devices includes applying a multi-level waveform to the droplet ejection devices. The multi-level waveform includes a first section having at least one compensating edge and a second section having at least one drive pulse. The compensating edge has a compensating effect on systematic variation in droplet velocity or droplet mass across the droplet ejection devices. In another embodiment, the compensating edge has a compensating effect on cross-talk between the droplet ejection devices.



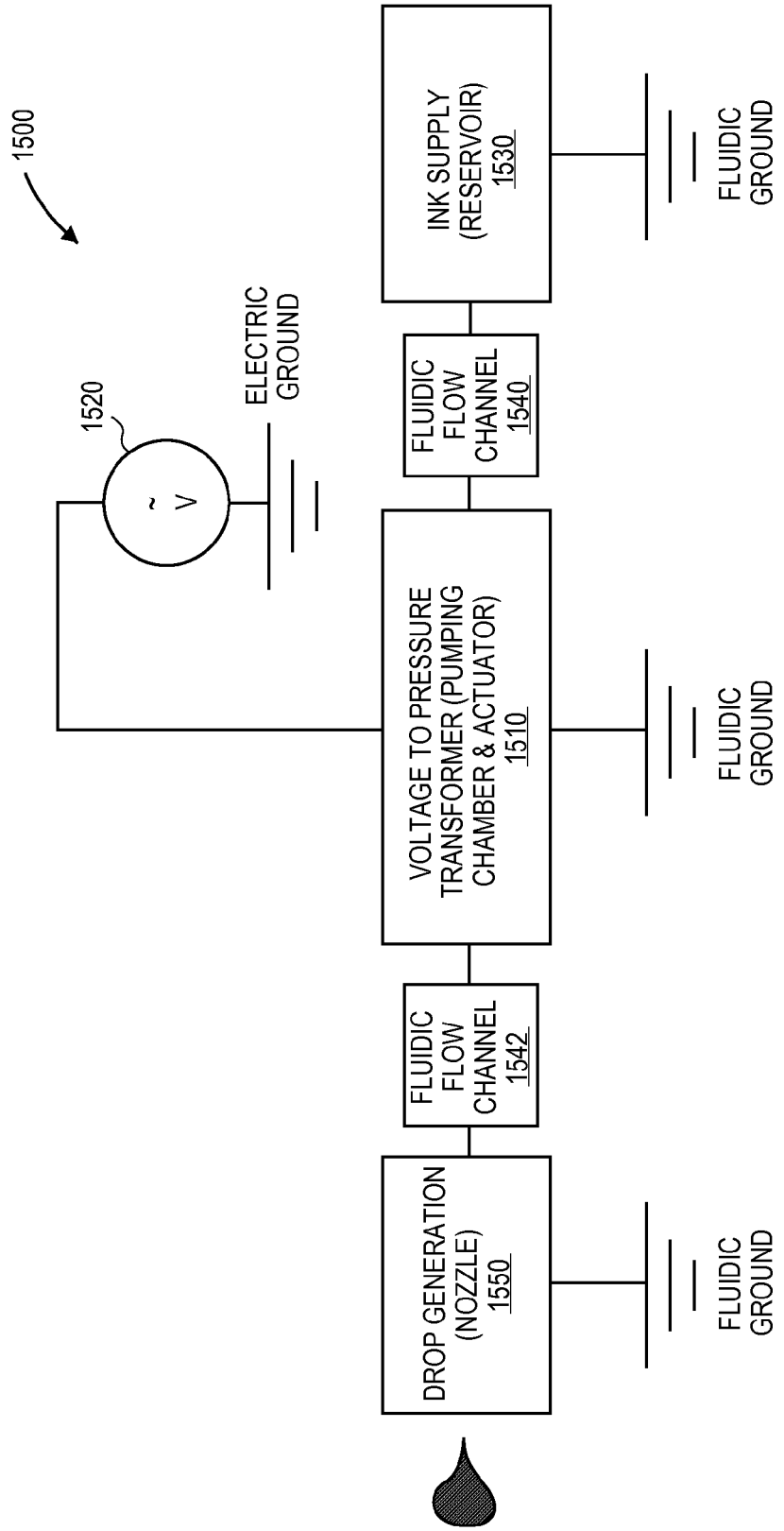

1500
1520
~ V
ELECTRIC GROUND
INK SUPPLY (RESERVOIR) 1530
FLUIDIC GROUND
FLUIDIC FLOW CHANNEL 1540
VOLTAGE TO PRESSURE TRANSFORMER (PUMPING CHAMBER & ACTUATOR) 1510
FLUIDIC GROUND
FLUIDIC FLOW CHANNEL 1542
DROP GENERATION (NOZZLE) 1550
FLUIDIC GROUND

FIG. 1

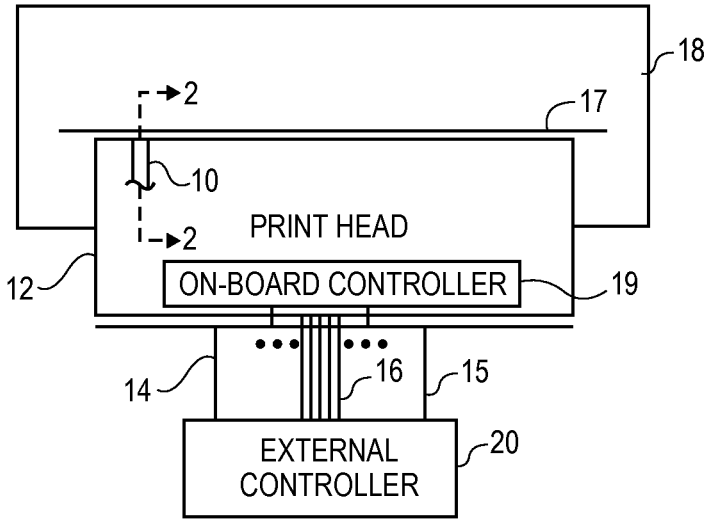

18
2
17
10
2
PRINT HEAD
12
ON-BOARD CONTROLLER
19
14
16
15
EXTERNAL CONTROLLER
20

FIG. 2

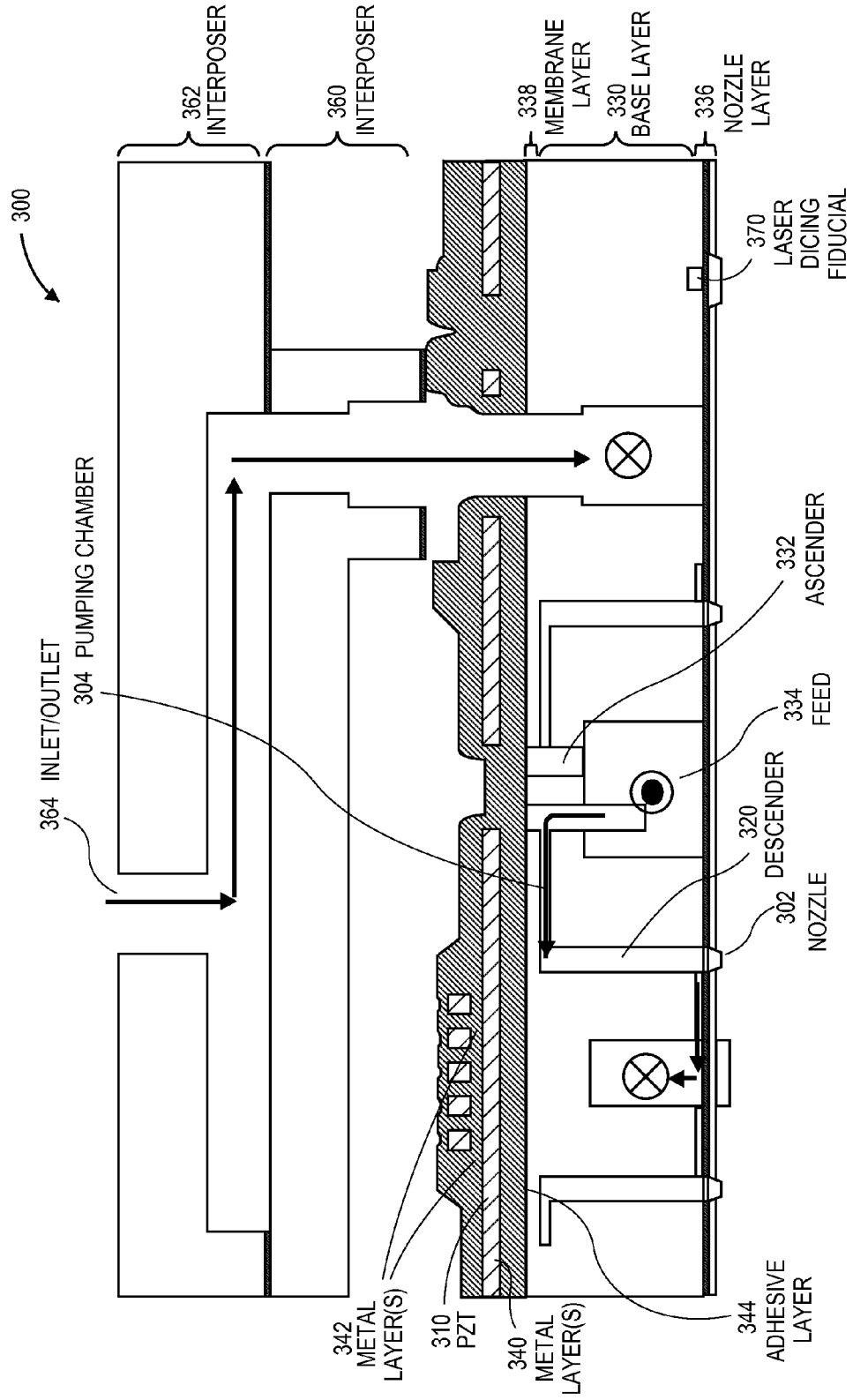

300
362 INTERPOSER
360 INTERPOSER
338 MEMBRANE LAYER
330 BASE LAYER
336 NOZZLE LAYER
370 LASER DICING FIDUCIAL
364 INLET/OUTLET
304 PUMPING CHAMBER
332 ASCENDER
334 FEED
320 DESCENDER
302 NOZZLE
342 METAL LAYER(S)
310 PZT
340 METAL LAYER(S)
344 ADHESIVE LAYER

FIG. 3

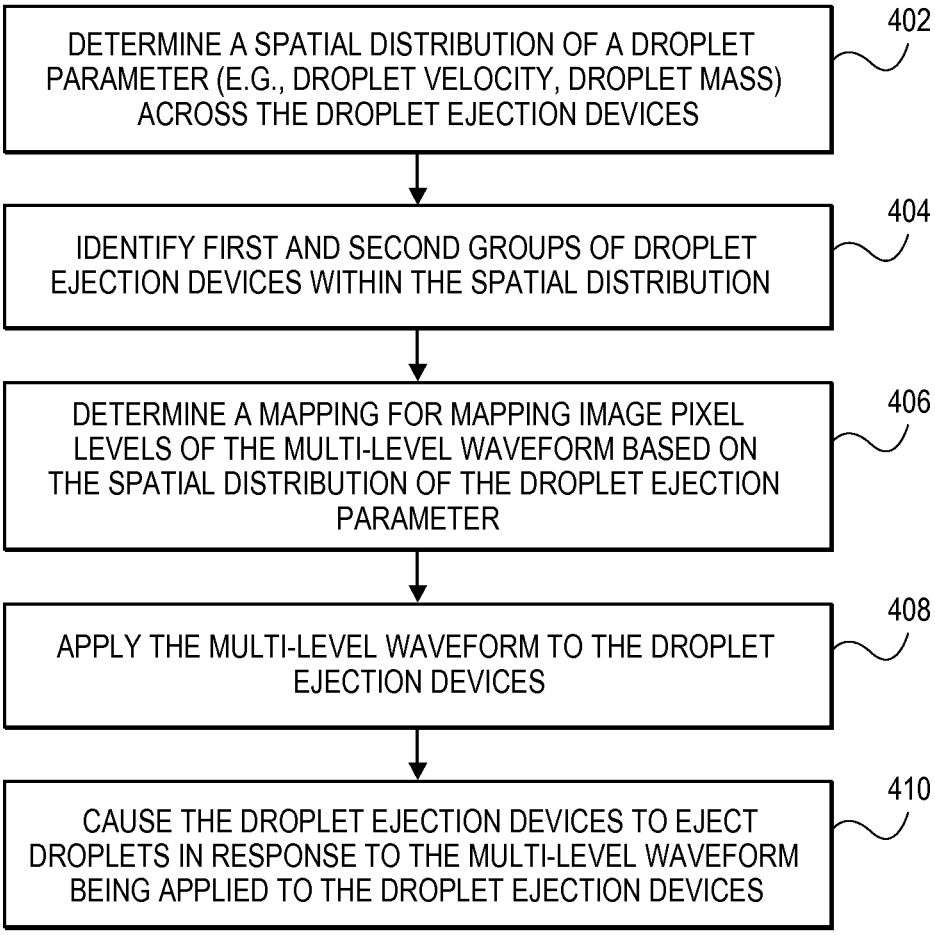

DETERMINE A SPATIAL DISTRIBUTION OF A DROPLET PARAMETER (E.G., DROPLET VELOCITY, DROPLET MASS) ACROSS THE DROPLET EJECTION DEVICES
402
IDENTIFY FIRST AND SECOND GROUPS OF DROPLET EJECTION DEVICES WITHIN THE SPATIAL DISTRIBUTION
404
DETERMINE A MAPPING FOR MAPPING IMAGE PIXEL LEVELS OF THE MULTI-LEVEL WAVEFORM BASED ON THE SPATIAL DISTRIBUTION OF THE DROPLET EJECTION PARAMETER
406
APPLY THE MULTI-LEVEL WAVEFORM TO THE DROPLET EJECTION DEVICES
408
CAUSE THE DROPLET EJECTION DEVICES TO EJECT DROPLETS IN RESPONSE TO THE MULTI-LEVEL WAVEFORM BEING APPLIED TO THE DROPLET EJECTION DEVICES
410

FIG. 4

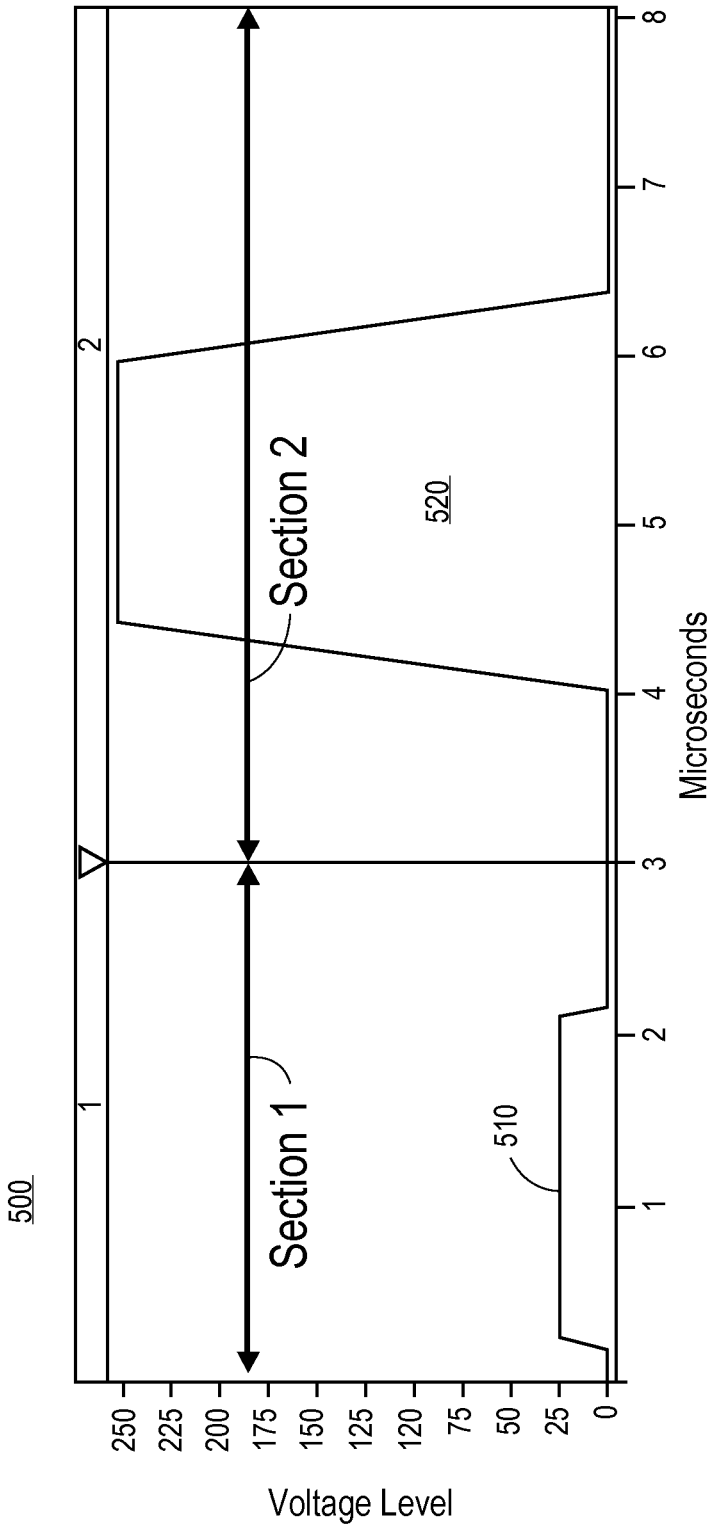

500
Section 1
Section 2
520
510
1
2
3
4
5
6
7
8
Microseconds
250
225
200
175
150
125
120
75
50
25
0
Voltage Level

FIG. 5

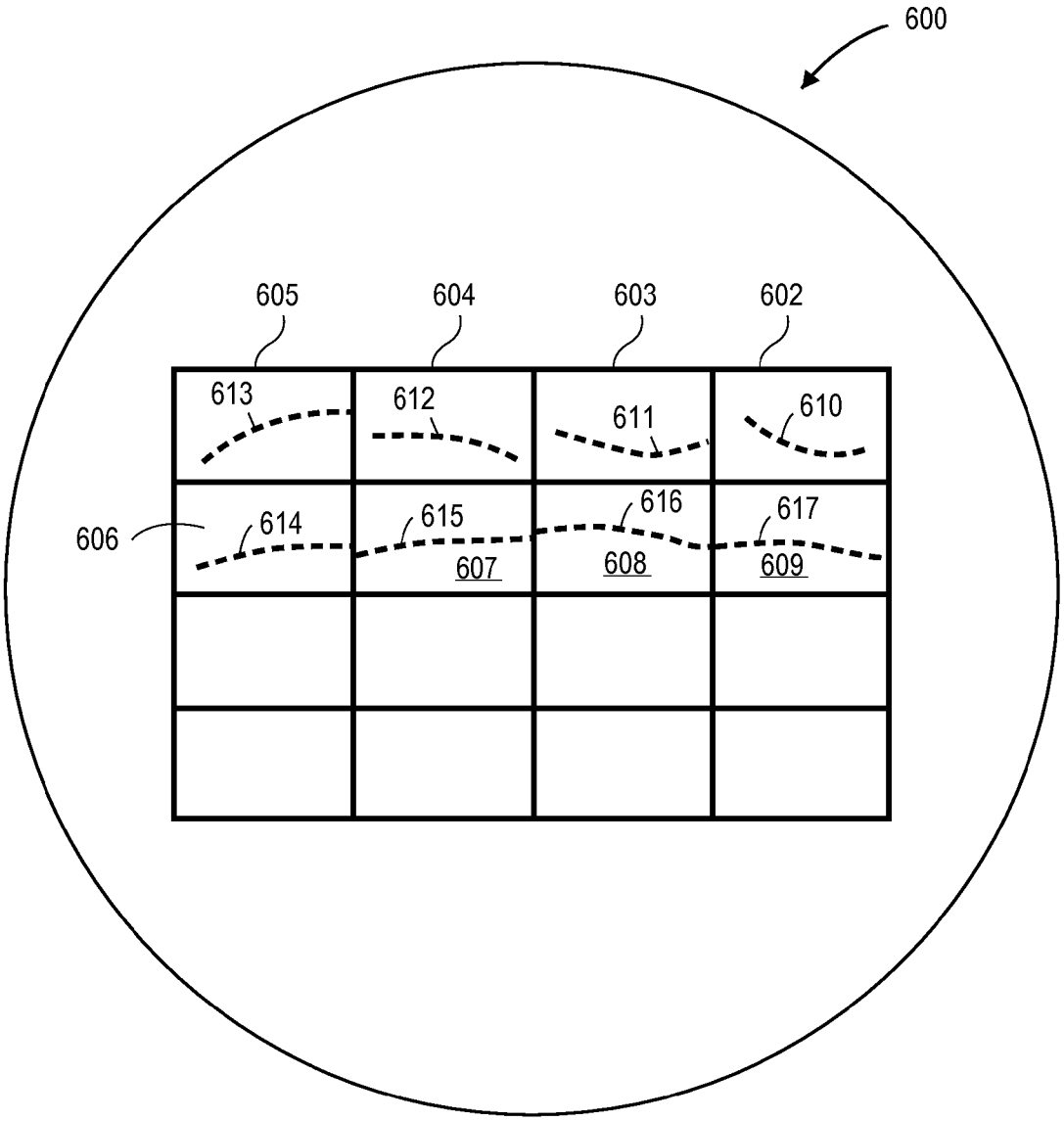

600
605
604
603
602
613
612
611
610
606
614
615
607
616
608
617
609

FIG. 6

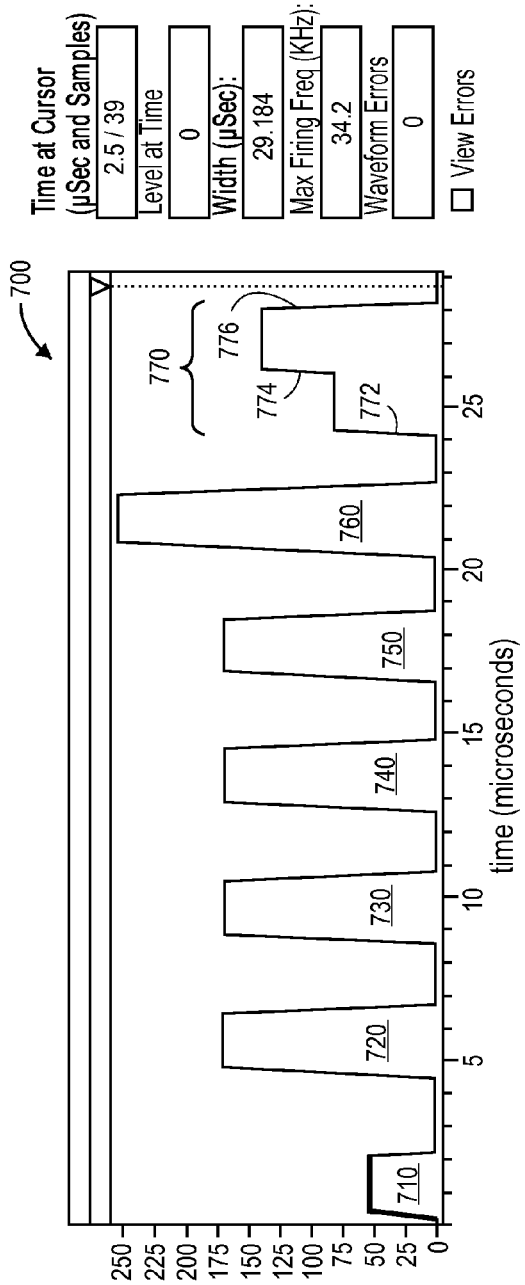

700
Time at Cursor (µSec and Samples)
2.5 / 39
Level at Time
0
Width (µSec):
29.184
Max Firing Freq (KHz):
34.2
Waveform Errors
0
View Errors
770
776
774
772
760
750
740
730
720
710
Voltage Level
time (microseconds)

FIG. 7

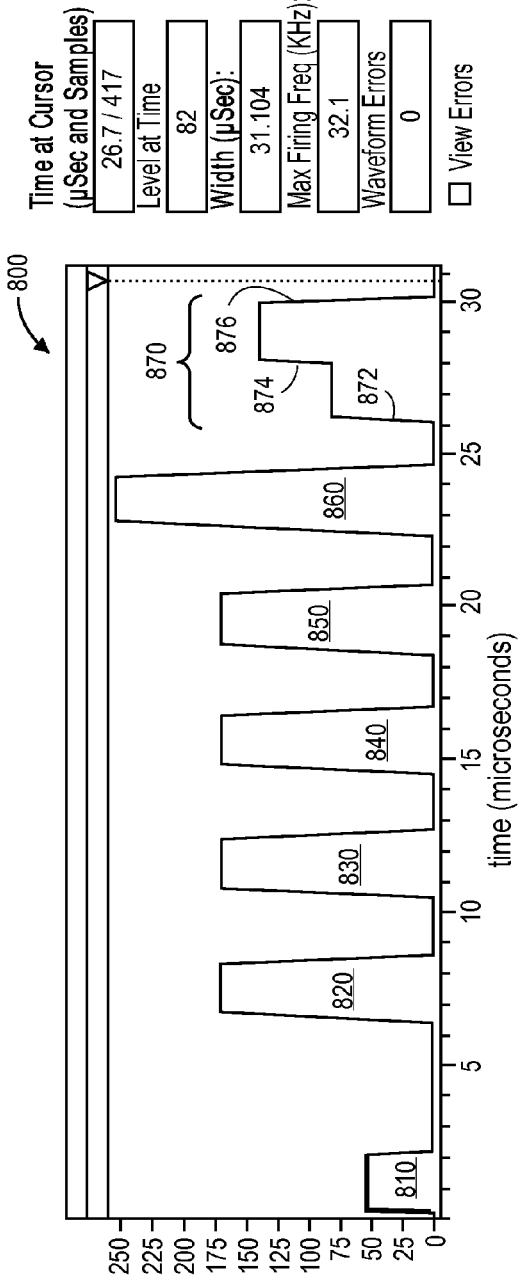

800
Time at Cursor (µSec and Samples)
26.7 / 417
Level at Time
82
Width (µSec):
31.104
Max Firing Freq (KHz):
32.1
Waveform Errors
0
View Errors
870
876
874
872
860
850
840
830
820
810
Voltage Level
time (microseconds)

FIG. 8

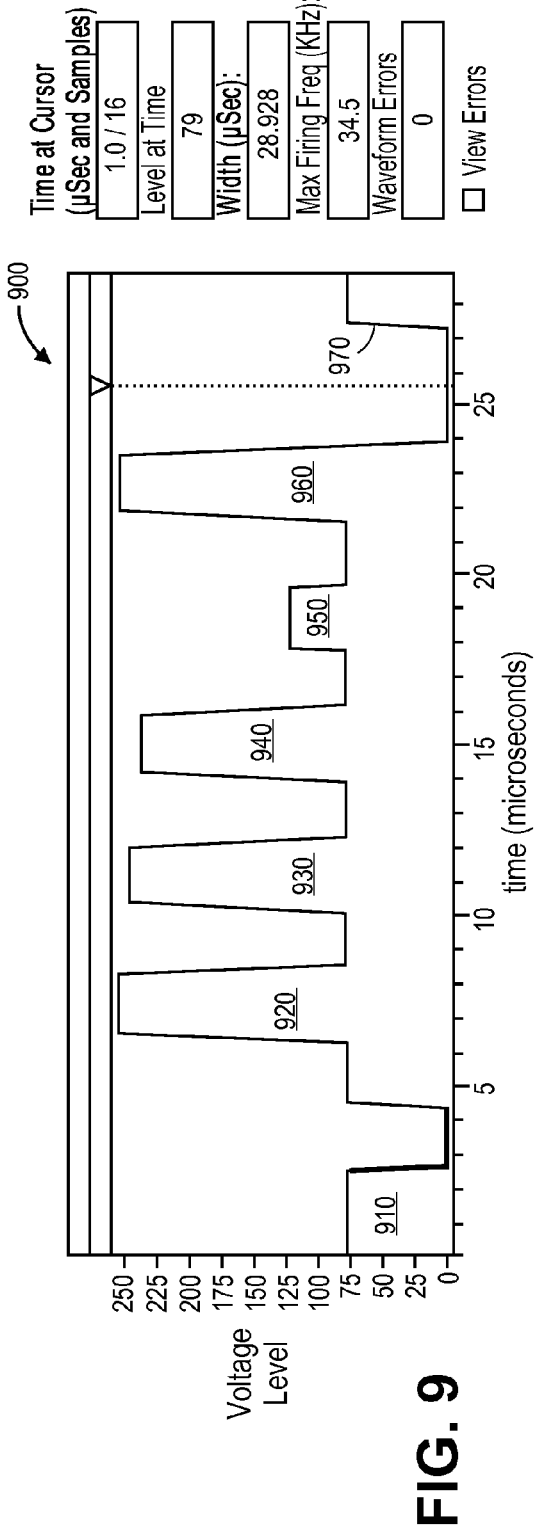

900
Time at Cursor (µSec and Samples)
1.0 / 16
Level at Time
79
Width (µSec):
28.928
Max Firing Freq (KHz):
34.5
Waveform Errors
0
View Errors
910
920
930
940
950
960
970
Voltage Level
time (microseconds)

FIG. 9

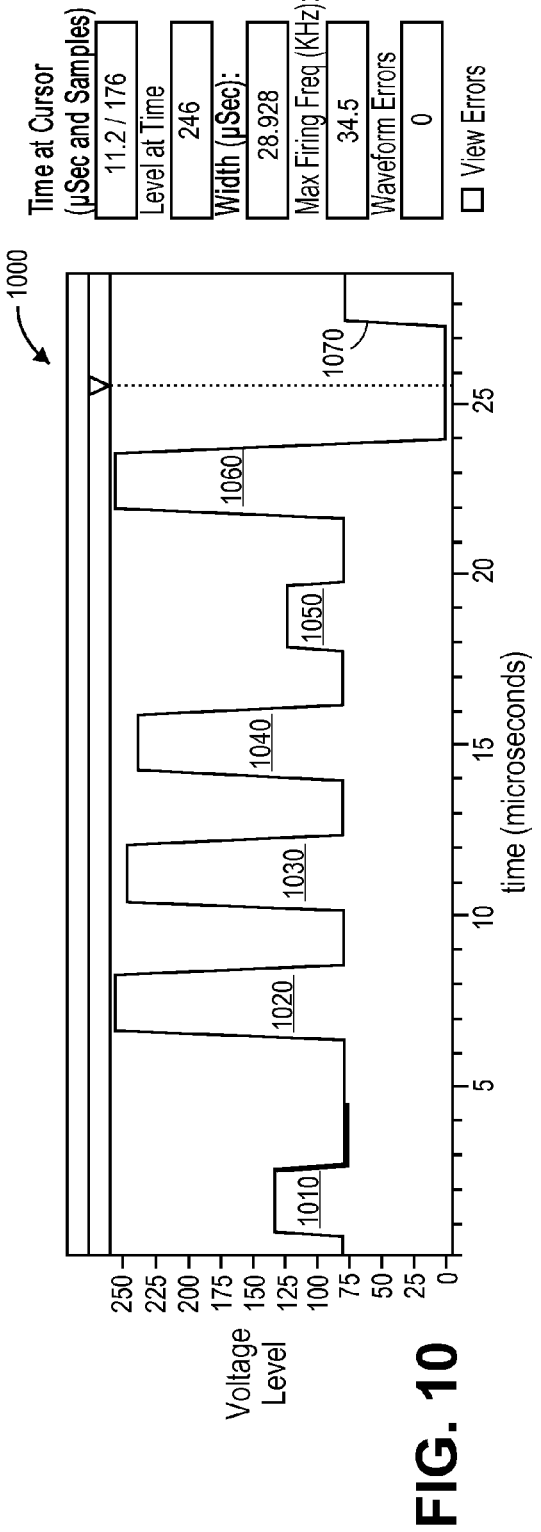

1000
Time at Cursor (µSec and Samples)
11.2 / 176
Level at Time
246
Width (µSec):
28.928
Max Firing Freq (KHz):
34.5
Waveform Errors
0
View Errors
1010
1020
1030
1040
1050
1060
1070
Voltage Level
time (microseconds)

FIG. 10

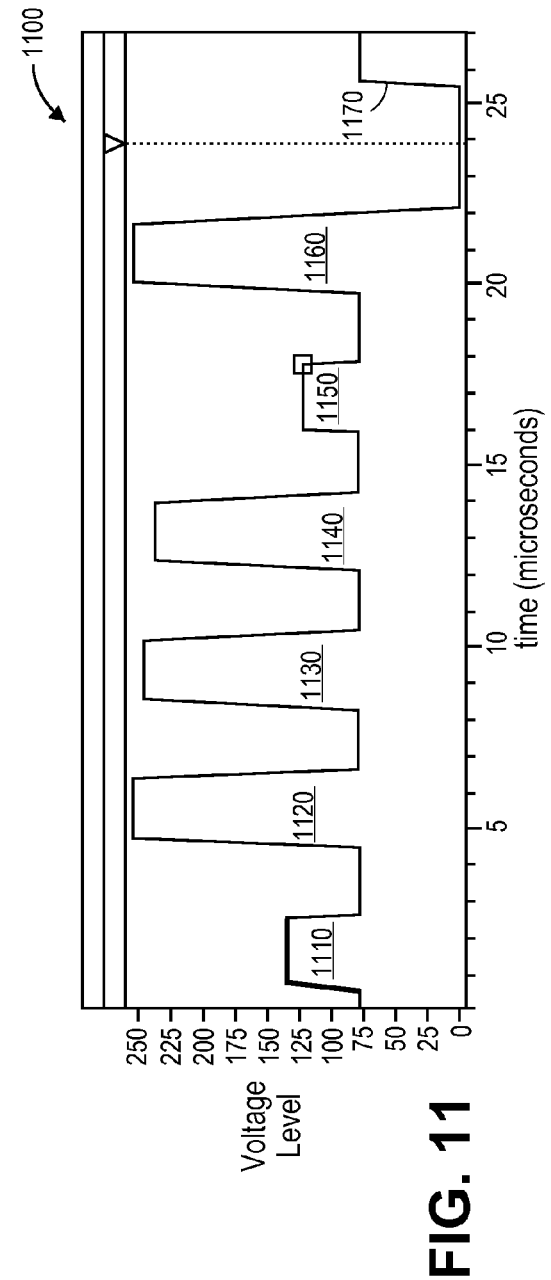

1100
Time at Cursor (µSec and Samples)
9.6 / 150
Level at Time
246
Width (µSec):
27.008
Max Firing Freq (KHz):
37.0
Waveform Errors
0
View Errors
1110
1120
1130
1140
1150
1160
1170
Voltage Level
time (microseconds)

FIG. 11

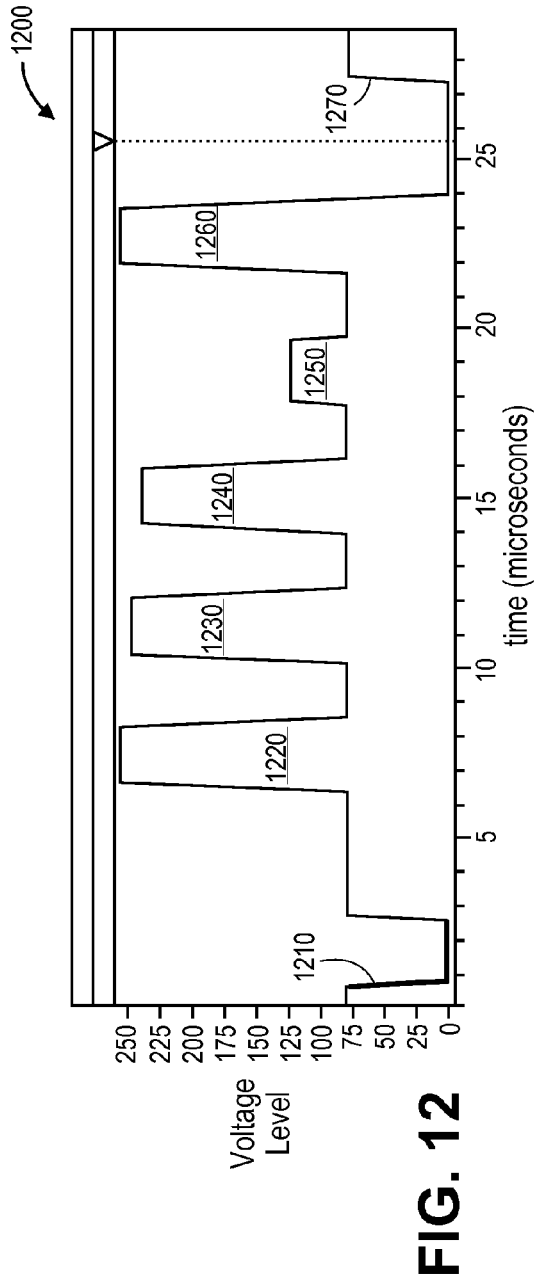

1200
Time at Cursor (µSec and Samples)
11.8 / 185
Level at Time
246
Width (µSec):
28.928
Max Firing Freq (KHz):
34.5
Waveform Errors
0
View Errors
1210
1220
1230
1240
1250
1260
1270
Voltage Level
time (microseconds)

FIG. 12

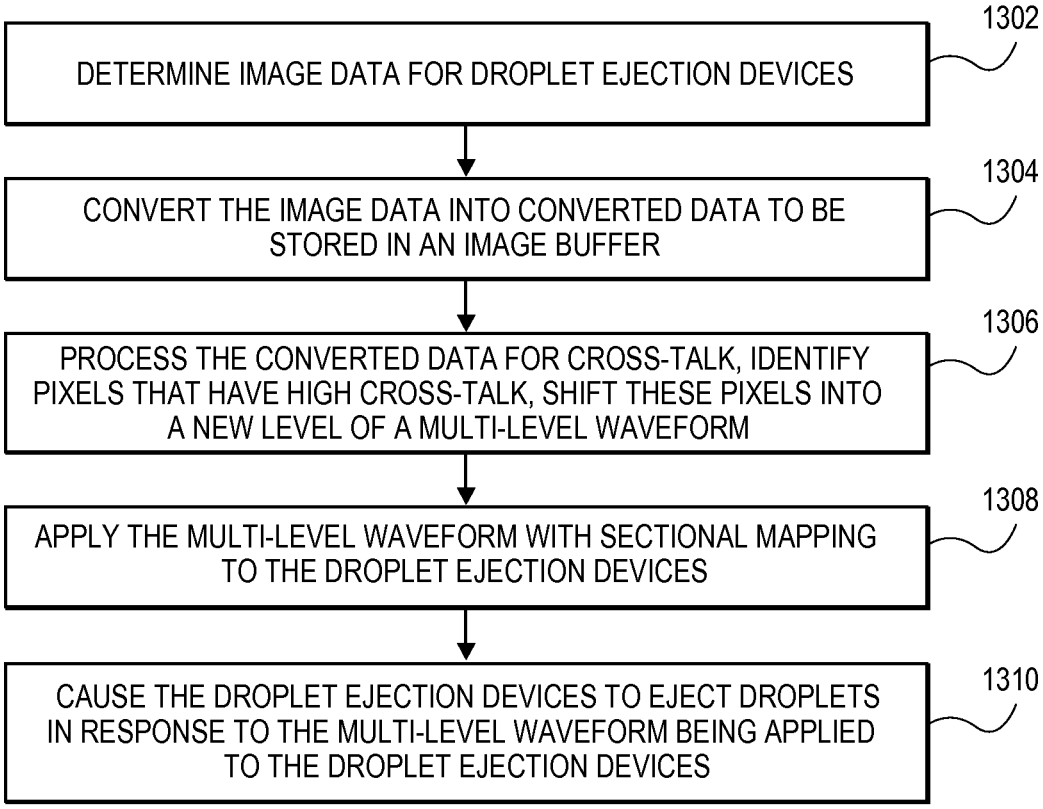

DETERMINE IMAGE DATA FOR DROPLET EJECTION DEVICES
1302
CONVERT THE IMAGE DATA INTO CONVERTED DATA TO BE STORED IN AN IMAGE BUFFER
1304
PROCESS THE CONVERTED DATA FOR CROSS-TALK, IDENTIFY PIXELS THAT HAVE HIGH CROSS-TALK, SHIFT THESE PIXELS INTO A NEW LEVEL OF A MULTI-LEVEL WAVEFORM
1306
APPLY THE MULTI-LEVEL WAVEFORM WITH SECTIONAL MAPPING TO THE DROPLET EJECTION DEVICES
1308
CAUSE THE DROPLET EJECTION DEVICES TO EJECT DROPLETS IN RESPONSE TO THE MULTI-LEVEL WAVEFORM BEING APPLIED TO THE DROPLET EJECTION DEVICES
1310

FIG. 13

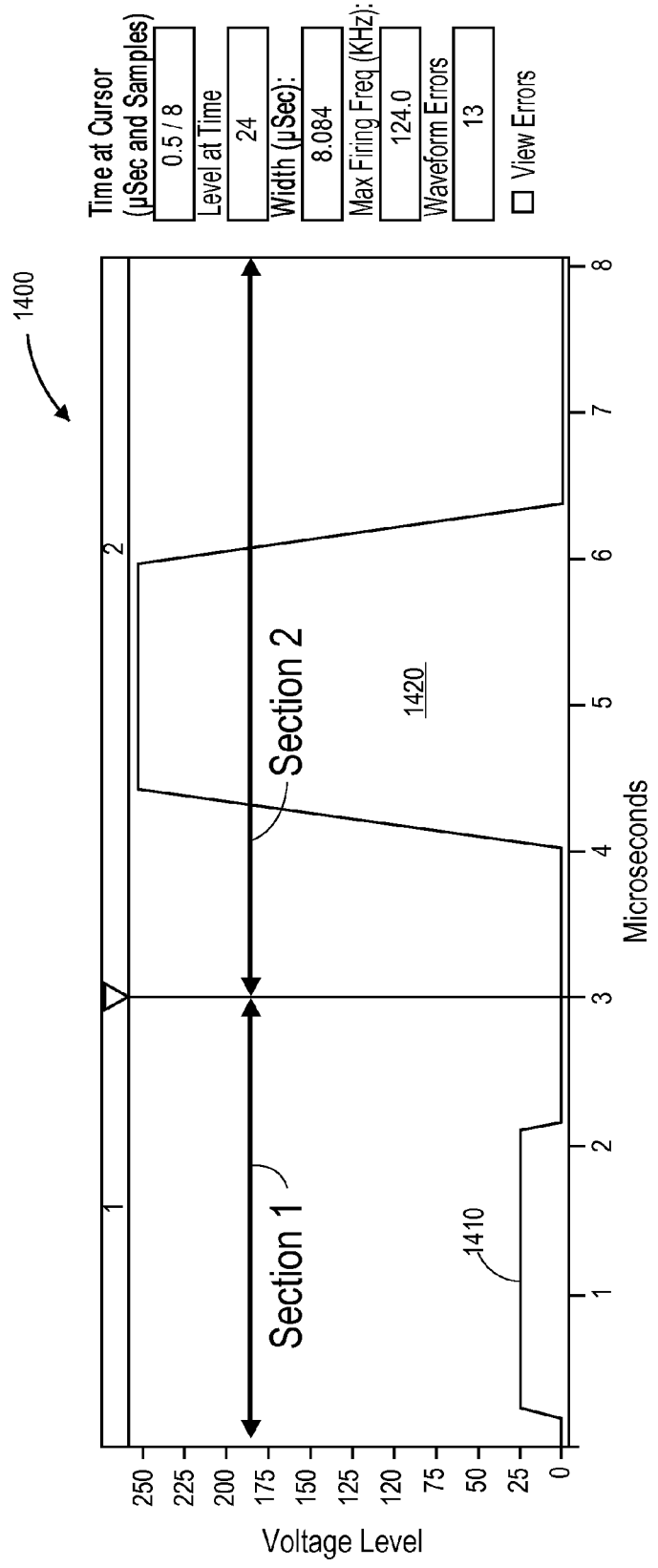

1400
Time at Cursor (µSec and Samples)
0.5 / 8
Level at Time
24
Width (µSec):
8.084
Max Firing Freq (KHz):
124.0
Waveform Errors
13
View Errors
Section 2
Section 1
1420
1410
Voltage Level
Microseconds

FIG. 14

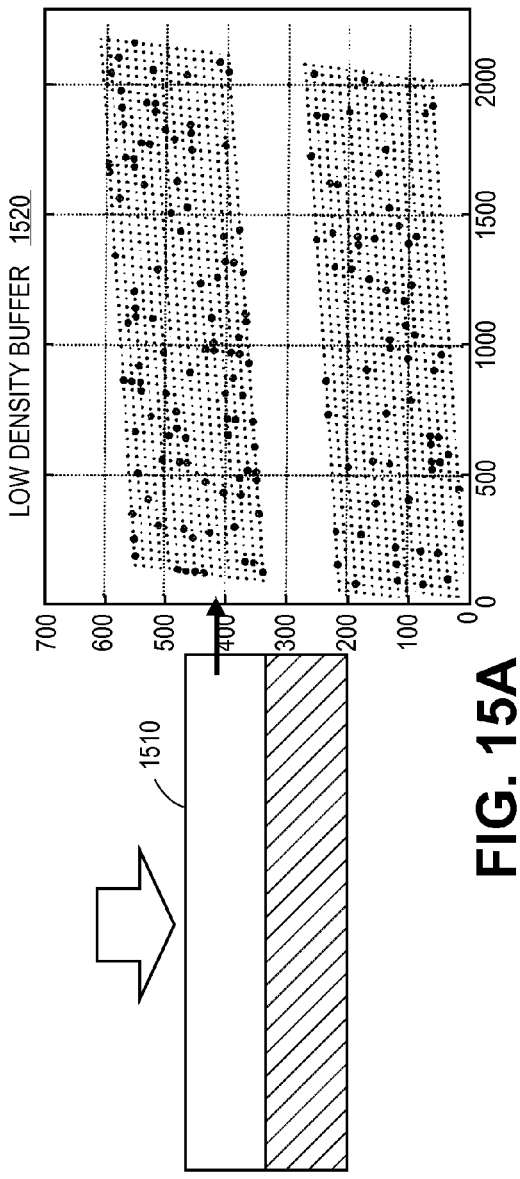


FIG. 15A

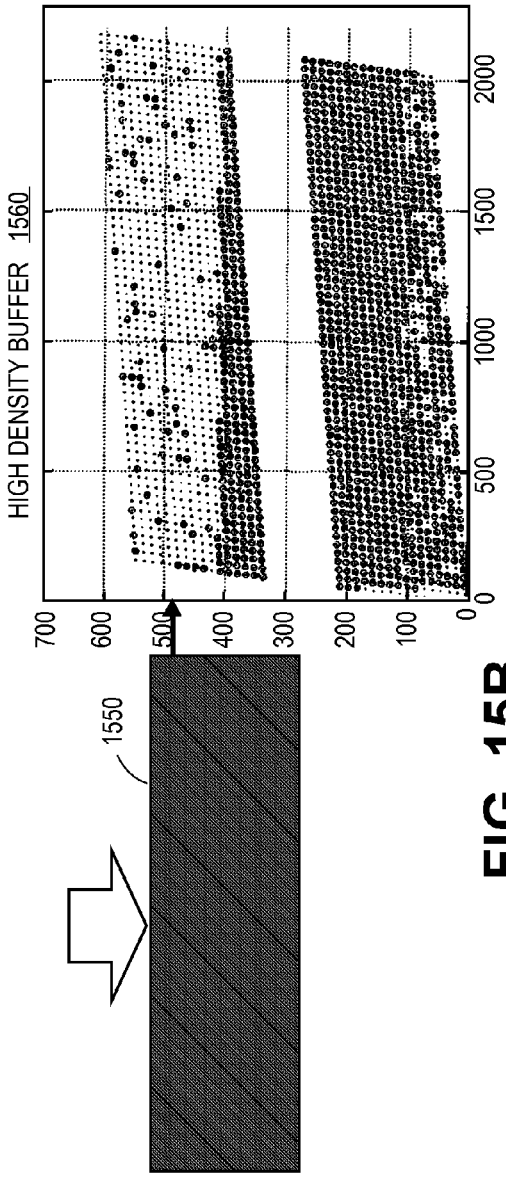


FIG. 15B

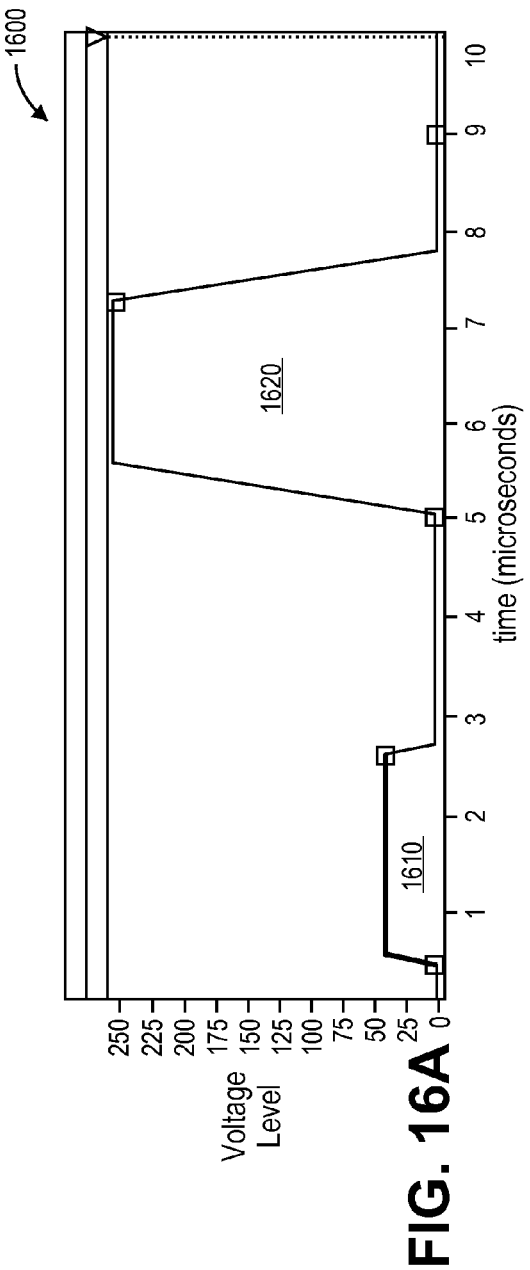


FIG. 16A

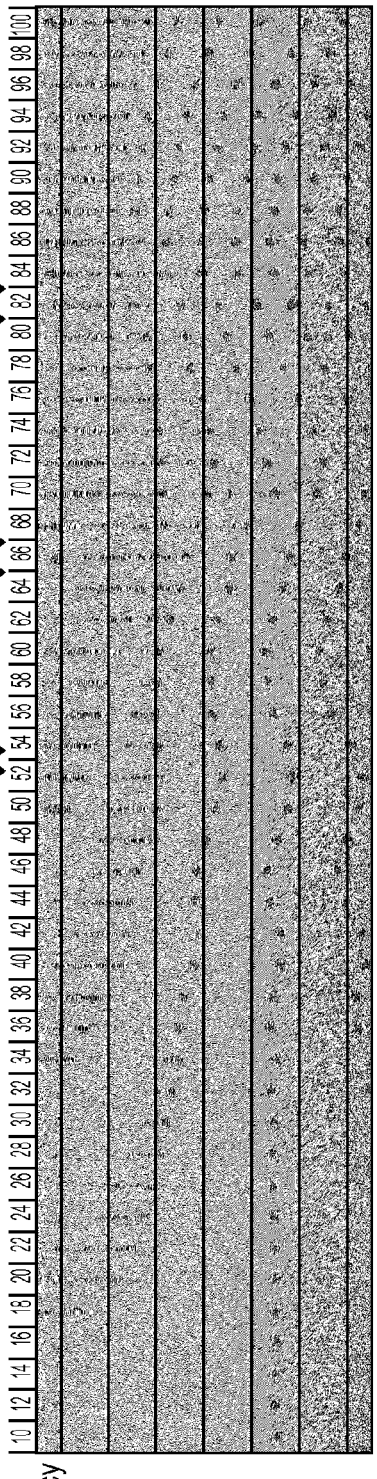


FIG. 16B

FIG. 17A

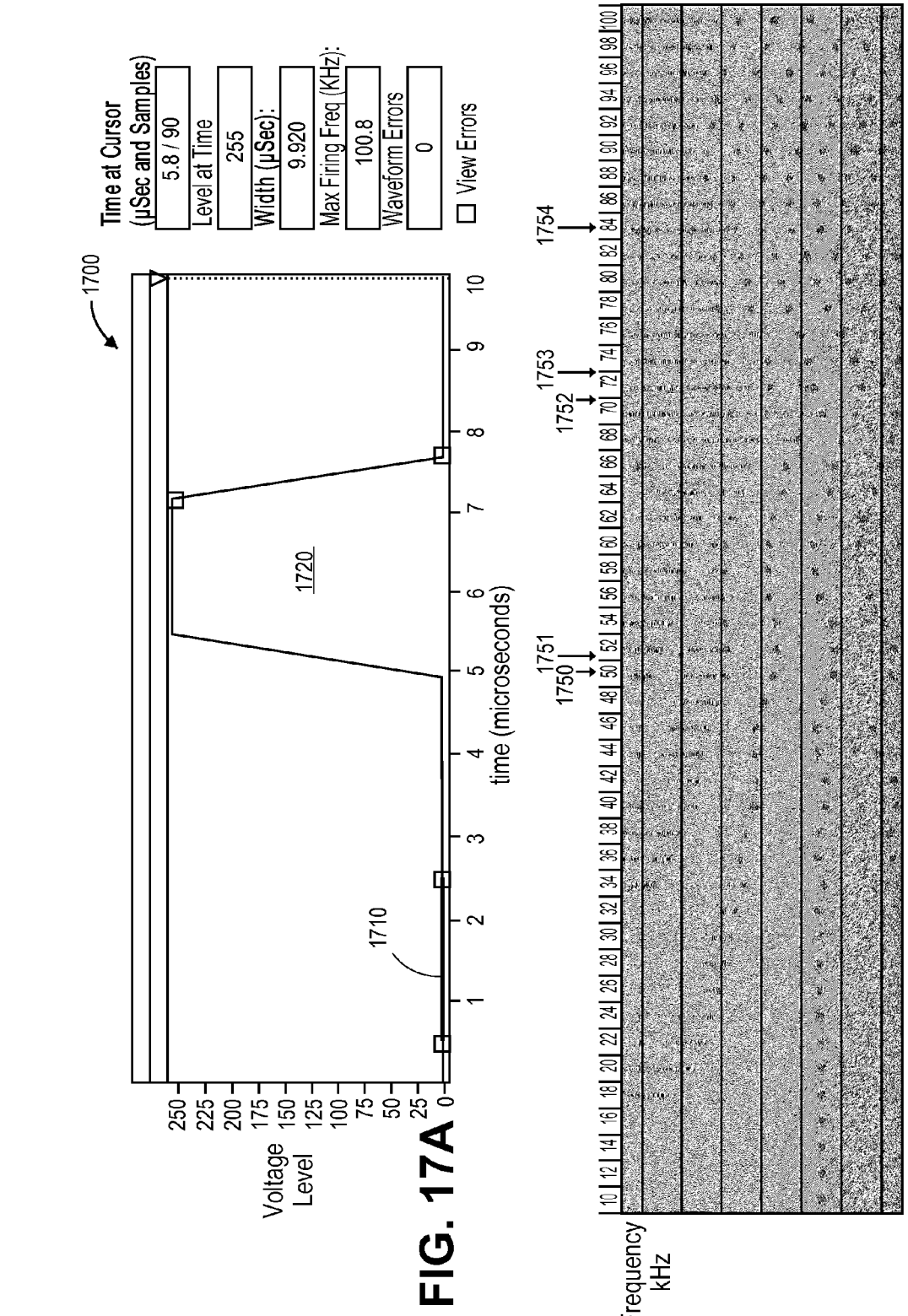


FIG. 17B

FIG. 18A

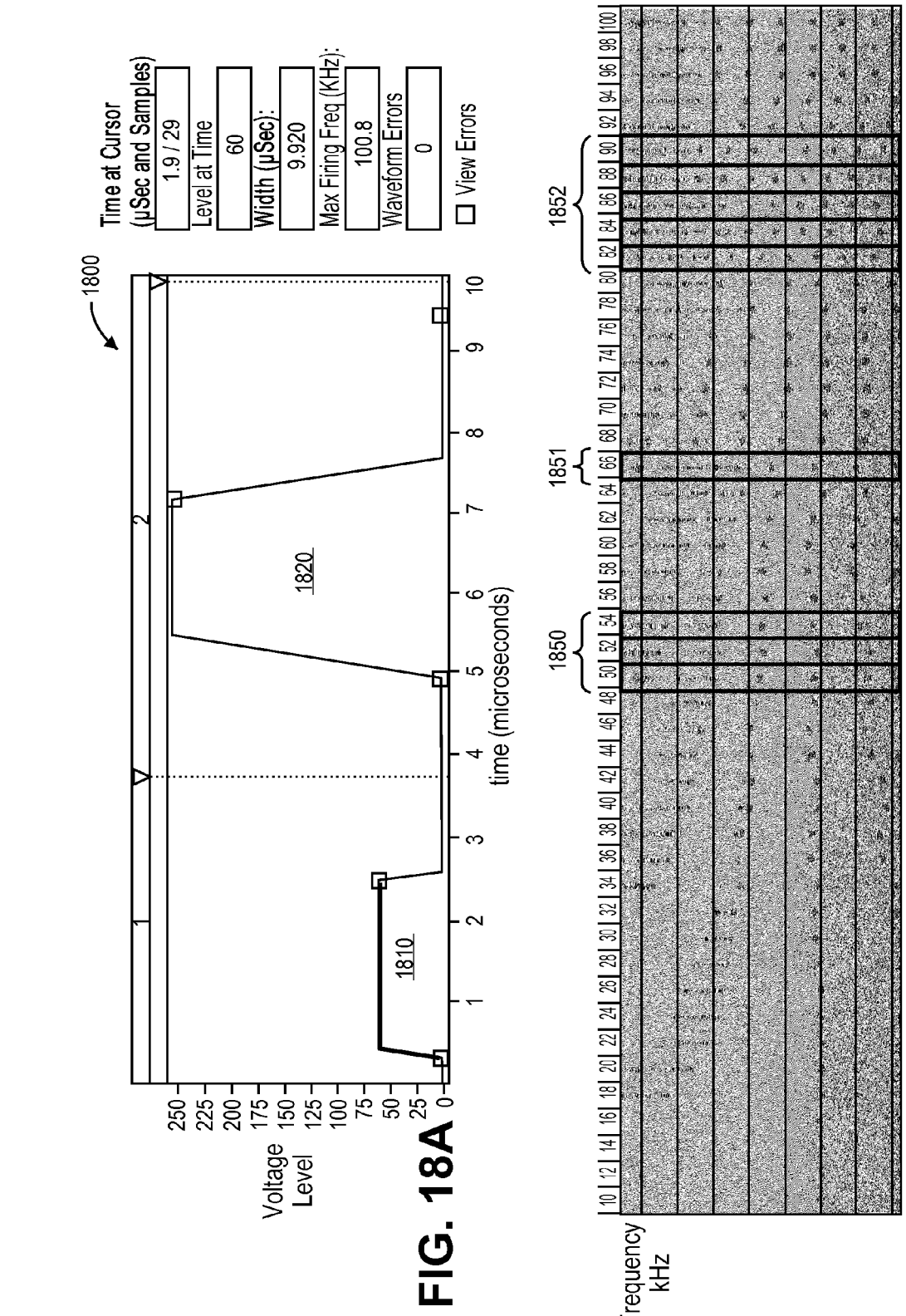


FIG. 18B

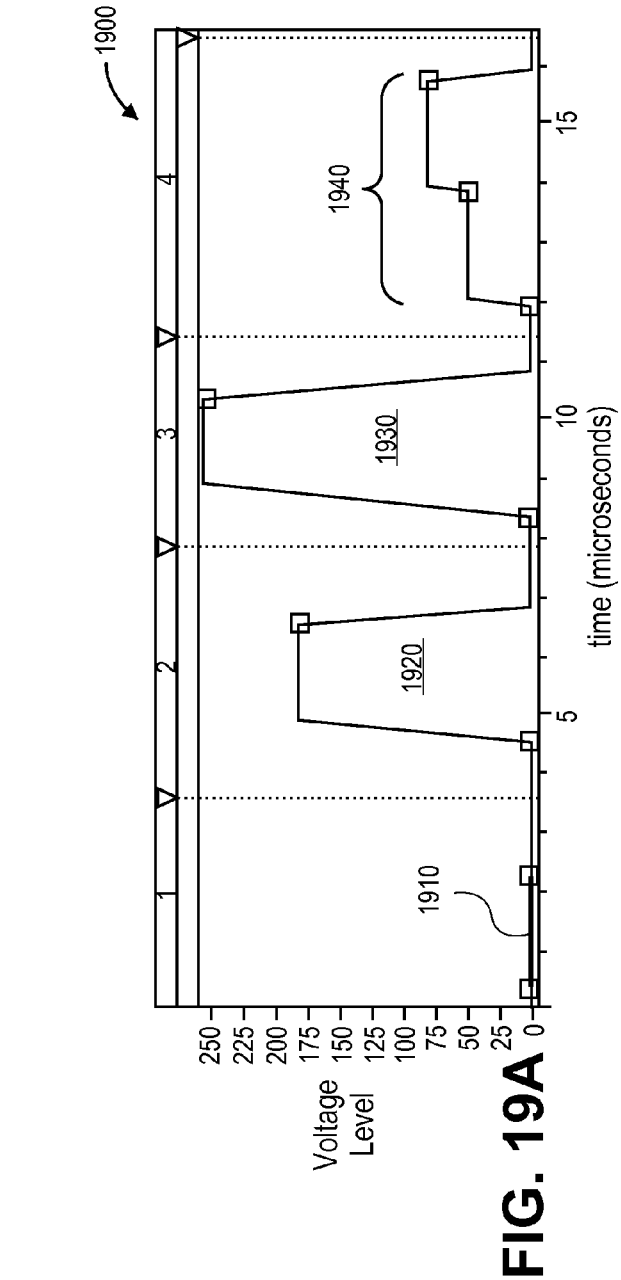


FIG. 19A

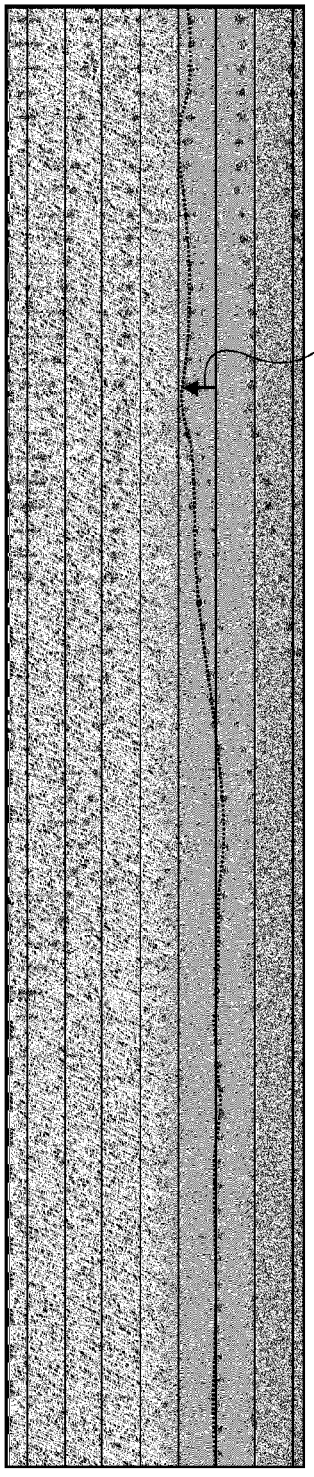


FIG. 19B

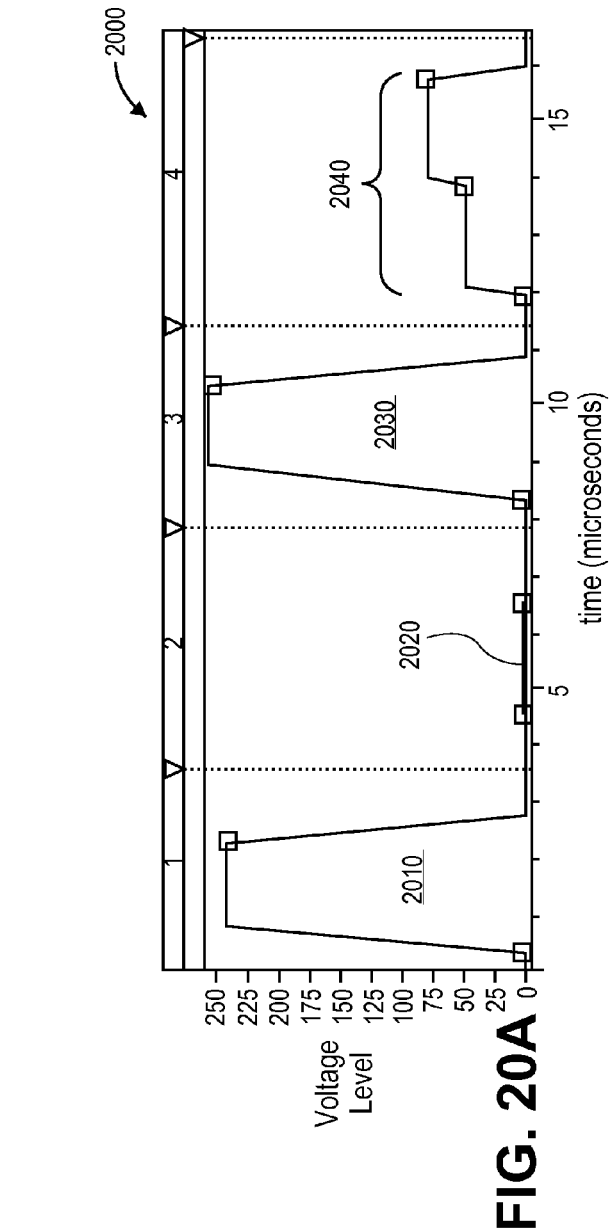


FIG. 20A

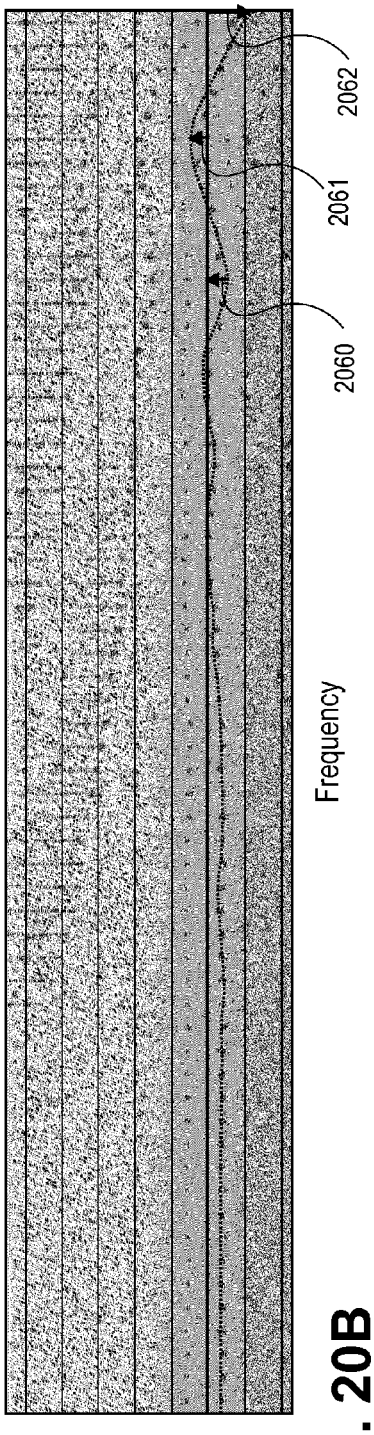


FIG. 20B

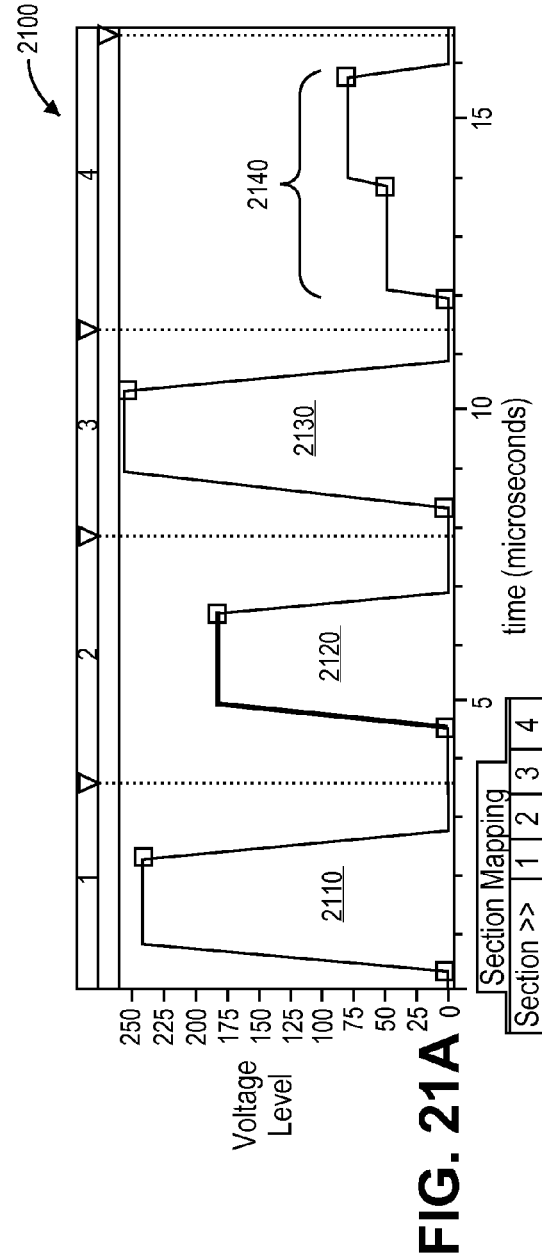


FIG. 21A

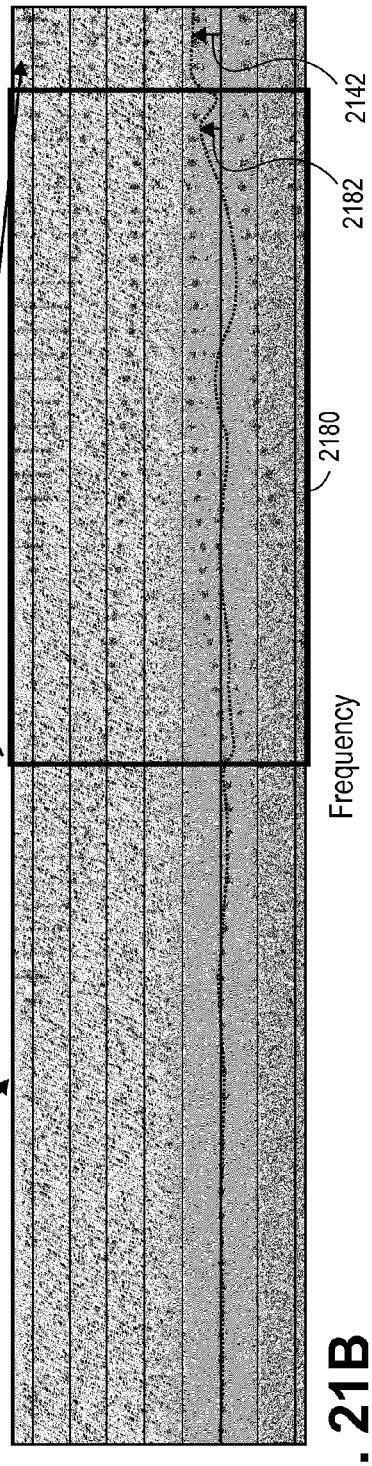


FIG. 21B

METHODS, SYSTEMS, AND APPARATUSES FOR IMPROVING DROP VELOCITY UNIFORMITY, DROP MASS UNIFORMITY, AND DROP FORMATION

TECHNICAL FIELD

[0001] Embodiments of the present invention relate to droplet ejection, and more specifically to applying compensating pulses via multi-level image mapping to improve drop velocity uniformity, drop mass uniformity, and drop formation.

BACKGROUND

[0002] Droplet ejection devices are used for a variety of purposes, most commonly for printing images on various media. Droplet ejection devices are often referred to as ink jets or ink jet printers. Drop-on-demand droplet ejection devices are used in many applications because of their flexibility and economy. Drop-on-demand devices eject one or more droplets in response to a specific signal, usually an electrical waveform that may include a single pulse or multiple pulses. Different portions of a multi-pulse waveform can be selectively activated to produce the droplets.

[0003] Droplet ejection devices typically include a fluid path from a fluid supply to a nozzle path. The nozzle path terminates in a nozzle opening from which droplets are ejected. Inkjet print heads exhibit highly coupled electrical, mechanical, and fluidic behavior and are sensitive to non-uniformities that arise from manufacturing variations, cross-talk, loading, and natural frequency response. Thus, non-uniformities in drop velocity and mass distribution exist across a print head having a large number of closely spaced nozzles. It is desirable to lower the impact of these non-uniformities on output pattern quality. Previous approaches include tightening manufacturing tolerances or additional electronics such as amplifiers and switches to drive various nozzles using separate waveforms to compensate for variations. However, these previous approaches are more expensive to implement because of the additional electronics and also require more time for separate waveforms.

SUMMARY

[0004] Methods and systems are described herein for driving droplet ejection devices with multi-level waveforms. In one embodiment, a method for driving droplet ejection devices includes generating a multi-level waveform having a compensating edge that is associated with at least one pulse in the multi-level waveform. The compensating edge is selected based on a spatial distribution of a droplet parameter and has a compensating effect to compensate for systematic variation across the droplet ejection devices. The method includes using the multi-level waveform in at least one of the droplet ejection devices to eject one or more droplets.

[0005] In another embodiment, a method for driving droplet ejection devices includes determining image data for the droplet ejection devices, converting the image data into converted data to be stored in an image buffer having first and second levels, processing the converted data to determine cross-talk affected data, and applying the multi-level waveform to the droplet ejection devices. The multi-level waveform includes a first section having at least one compensating edge and a second section having at least one drive pulse. The at least one compensating edge has a compensating effect to compensate for cross-talk variation across the droplet ejection devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which:

[0007] FIG. **1** illustrates a block diagram of an ink jet system in accordance with one embodiment;

[0008] FIG. **2** is a piezoelectric ink jet print head in accordance with one embodiment;

[0009] FIG. **3** illustrates a piezoelectric drop on demand print head module for ejecting droplets of ink on a substrate to render an image in accordance with one embodiment;

[0010] FIG. **4** illustrates a flow diagram of a process for driving droplet ejection devices within a print head or ink jet system with a multi-level waveform to compensate for systematic variation of at least one droplet parameter across the droplet ejection devices in accordance with one embodiment;

[0011] FIG. **5** shows a multi-level waveform **500** in accordance with one embodiment;

[0012] FIG. **6** illustrates a wafer with multiple dies and corresponding spatial distributions of drop velocity in accordance with one embodiment;

[0013] FIG. **7** shows a multi-level waveform **700** with a compensating pulse in accordance with one embodiment;

[0014] FIG. **8** shows a multi-level waveform **800** with a compensating pulse in accordance with one embodiment;

[0015] FIG. **9** shows a multi-level waveform **900** with a compensating pulse in accordance with one embodiment;

[0016] FIG. **10** shows a multi-level waveform **1000** with a compensating pulse in accordance with one embodiment;

[0017] FIG. **11** shows a multi-level waveform **1100** with a compensating pulse in accordance with one embodiment;

[0018] FIG. **12** shows a multi-level waveform **1200** with a compensating pulse in accordance with one embodiment;

[0019] FIG. **13** illustrates a flow diagram of a process for driving droplet ejection devices within a print head or ink jet system with a multi-level waveform to compensate for cross-talk between droplet ejection devices in accordance with one embodiment;

[0020] FIG. **14** shows a multi-level waveform **1400** in accordance with one embodiment;

[0021] FIG. **15***a* illustrates converting image data into a low density buffer in accordance with one embodiment;

[0022] FIG. **15***b* illustrates converting image data into a high density buffer in accordance with one embodiment;

[0023] FIG. **16***a* illustrates a 1 bit waveform with a compensating pulse in accordance with one embodiment;

[0024] FIG. **16***b* illustrate a frequency response graph with drop formation issues at certain frequencies;

[0025] FIG. **17***a* illustrates a 1 bit waveform with a compensating pulse in accordance with one embodiment;

[0026] FIG. **17***b* illustrate a frequency response graph with drop formation issues at certain frequencies;

[0027] FIG. **18***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment;

[0028] FIG. **18***b* illustrate a frequency response graph with drop formation issues at certain frequencies;

[0029] FIG. **19***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment;

[0030] FIG. **19***b* illustrates a frequency response graph with frequency response variation in one embodiment;

[0031] FIG. **20***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment;

[0032] FIG. **20***b* illustrates a frequency response graph with frequency response variation in one embodiment;

[0033] FIG. **21***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment; and

[0034] FIG. **21***b* illustrates a frequency response graph with frequency response variation in one embodiment.

DETAILED DESCRIPTION

[0035] Methods and systems are described herein for driving droplet ejection devices with multi-pulse waveforms. In one embodiment, a method for driving droplet ejection devices includes generating a multi-level waveform having a compensating edge that is associated with at least one pulse in the multi-level waveform. The compensating edge is selected based on a spatial distribution of a droplet parameter and has a compensating effect to compensate for systematic variation across the droplet ejection devices. The method includes using the multi-level waveform in at least one of the droplet ejection devices to eject one or more droplets.

[0036] Sources of drop velocity variation within an inkjet module include variation within a jet, jet to jet variation, and fluidic cross-talk. The within jet variation is dependent on a frequency response of the jet, image type, and print speed. The jet to jet variation can be caused by systematic variation due to manufacturing tolerances (e.g., piezoelectric properties or thickness variation). Fluidic cross-talk between jets depends on an image pattern.

[0037] Multi-level or multi-section waveforms can be designed with a velocity control compensating pulse to compensate for these variations in drop velocity. The velocity control compensating pulse can accelerate or decelerate drop velocity. Systematic variations such as jet to jet can be addressed using image pixel levels to apply compensation pulses as appropriate to selected jets. Frequency and cross-talk related variations can be addressed dynamically in a similar manner with image pixel levels. Various types of compensating pulses can be developed to correct drop mass variation as well.

[0038] The waveforms of the present application include a non-drop-firing portion to provide a compensating effect to compensate for drop velocity variation, drop mass variation, cross-talk, and drop formation variation between droplet ejection devices.

[0039] FIG. **1** illustrates a block diagram of an ink jet system in accordance with one embodiment. The ink jet system **1500** includes a voltage source **1520** that applies a voltage to pressure transformer **1510** (e.g., pumping chamber and actuator), which may be a piezoelectric or heat transformer. An ink supply **1530** supplies ink to a fluidic flow channel **1540**, which supplies ink to the transformer. The transformer provides the ink to a fluidic flow channel **1542**. This fluidic flow channel allows pressure from the transformer to propagate to a drop generation device **1550** having orifices or nozzles and generate one or more droplets if one or more pressure pulses are sufficiently large. Ink level in the ink jet system **1500** is maintained through a fluidic connection to the ink supply **1530**. The drop generation device **1550**, transformer **1540**, and ink supply **1530** are coupled to fluidic ground while the voltage supply is coupled to electric ground.

[0040] FIG. **2** is a piezoelectric ink jet print head in accordance with one embodiment. As shown in FIG. **2**, the 128 individual droplet ejection devices **10** (only one is shown on FIG. **2**) of print head **12** are driven by constant voltages provided over supply lines **14** and **15** and distributed by on-board control circuitry (on-board controller) **19** to control firing of the individual droplet ejection devices **10**. External controller **20** supplies the voltages over lines **14** and **15** and provides control data, logic power, and timing over additional lines **16** to on-board control circuitry **19**. Ink jetted by the individual ejection devices **10** can be delivered to form print lines **17** on a substrate **18** that moves under print head **12**. While the substrate **18** is shown moving past a stationary print head **12** in a single pass mode, alternatively the print head **12** could also move across the substrate **18** in a scanning mode.

[0041] In one embodiment, a print head (e.g., print head **12**) includes an ink jet module that includes droplet ejection devices to eject droplets of a fluid and control circuitry (e.g., on-board controller **19**) that is coupled to the droplet ejection devices. During operation, the control circuitry drives the droplet ejection devices by applying a multi-level waveform to the droplet ejection devices. The multi-level waveform includes a first section having at least one compensating edge and a second section having at least one drive pulse. The compensating edge has a compensating effect to compensate for systematic variation in a droplet parameter (e.g., droplet velocity, droplet mass) across the droplet ejection devices of the print head.

[0042] At least one of the control circuitry and a controller (e.g., external controller **20**, a processing system, etc.) execute instructions or perform operations to determine a spatial distribution of a droplet ejection parameter across the droplet ejection devices and determine a mapping for mapping image pixel levels of the multi-level waveform based on the spatial distribution of the droplet ejection parameter. Alternatively, a different processing system provides the spatial distribution of the droplet ejection parameter and determines a mapping for mapping image pixel levels of the multi-level waveform based on the spatial distribution of the droplet ejection parameter. The spatial distribution of the droplet ejection parameter can include a spatial distribution of a droplet velocity across the droplet ejection devices. The spatial distribution of the droplet ejection parameter can include a spatial distribution of a droplet mass across the droplet ejection devices. At least one of the control circuitry and controller execute instructions or perform operations to identify first and second groups of the droplet ejection devices within the spatial distribution and to convert pixels in the second group into a second level of the multi-level waveform while pixels in the first group remain in a first level of the multi-level waveform. The compensating edge or pulse may cause an increase or a decrease in drop mass of droplets ejected by the droplet ejection devices. The compensating edge or pulse can reduce a frequency response variation of droplets ejected by the droplet ejection devices.

[0043] In another embodiment, a print head includes an ink jet module that includes droplet ejection devices to eject droplets of a fluid and control circuitry coupled to the droplet ejection devices. During operation, the control circuitry drives the droplet ejection devices by applying a multi-level waveform to the droplet ejection devices. The multi-level waveform includes a first section having a compensating pulse with a compensating effect to compensate for cross-talk across the droplet ejection devices and a second section having at least one drive pulse. At least one of the control circuitry and the controller determine image data for the droplet ejection devices, convert the image data into converted data to be

stored in an image buffer having first and second levels, and process the converted data to determine cross-talk affected data. Processing the buffer data for cross-talk includes identifying pixels that are affected by cross-talk. At least one of the control circuitry and the controller execute instructions to shift the identified pixels that are affected by cross-talk into a third level of the image buffer. The at least one compensating edge or pulse increases or decreases a drop velocity of the droplets ejected by the droplet ejection devices.

[0044] FIG. **3** illustrates a cross-section view of a piezoelectric drop on demand print head module for ejecting droplets of ink on a substrate to render an image in accordance with one embodiment. The module **300** has a series of closely spaced nozzle openings from which ink can be ejected. Each nozzle opening **302** is served by a flow path including a pumping chamber **304** where ink is pressurized by a piezoelectric actuator **310**. Other modules may be used with the techniques described herein.

[0045] A piezoelectric (PZT) actuator **310** sits on top of the ink pumping chamber. When pressured by the piezoelectric actuator, ink flows from the ink chamber through the descender **320** and out of the KOH nozzle opening **302** (as indicated by the arrows). Furthermore, a base silicon layer **330** of the module body in the print head defines an ascender **332**, a feed **334**, and the pumping chamber **304** as shown in FIG. **3**. Ink flows from the feed into the pumping chamber as indicated by the arrows.

[0046] A nozzle portion is formed of a silicon layer **336**. In one embodiment, the nozzle silicon layer **336** is fusion bonded to the base silicon layer and defines. A membrane silicon layer **338** may be fusion bonded to the base silicon layer, opposite to the nozzle silicon layer.

[0047] One or more metal layers **340** and **342** on or below the PZT layer **310** are used to form a ground electrode and a drive electrode. The metallized PZT layer is bonded to the silicon membrane by an adhesive layer **344**. In one embodiment, the adhesive is polymerized benzocyclobutene (BCB) but may be various other types of adhesives as well. Interposers **360** and **362** provide an inlet/outlet **364** into an opening of the membrane layer and the base layer. The base layer and nozzle layer provide a laser dicing fidicial **370**. Multiple jetting structures can be formed in a single print head die. In one embodiment, during manufacture, multiple dies are formed contemporaneously.

[0048] A PZT member or element (e.g., actuator) is configured to vary the pressure of fluid in the pumping chambers in response to the drive pulses applied from the drive electronics (e.g., control circuitry). For one embodiment, the actuator ejects droplets of a fluid from a nozzle via the pumping chambers. The drive electronics are coupled to the PZT member.

[0049] FIG. **4** illustrates a flow diagram of a process for driving droplet ejection devices within a print head or ink jet system with a multi-level waveform to compensate for systematic variation of at least one droplet parameter across the droplet ejection devices in accordance with one embodiment. The operations of the process may be performed with control circuitry, a controller, a processing system, or some combination of these components. In one embodiment, the process for driving the droplet ejection devices includes determining a spatial distribution of a droplet parameter (e.g., droplet velocity, droplet mass) across the droplet ejection devices of a print head or ink jet system at block **402**. The process identifies first and second groups of droplet ejection devices within the spatial distribution at block **404**. For example, for the droplet velocity parameter, the first group may include droplet ejection devices that eject droplets with a faster droplet velocity and the second group may include droplet ejection devices that eject droplets with a slower droplet velocity. For the droplet mass parameter, the first group may include nozzles that eject droplets with a heavier droplet mass and the second group may include nozzles that eject droplets with a lighter droplet mass. The process may include determining a mapping for mapping image pixel levels of the multi-level waveform based on the spatial distribution of the droplet ejection parameter at block **406**. Determining the mapping may include converting pixels in the second group into a second level of the multi-level waveform. The pixels in the first group can remain by default with a first level of the multi-level waveform or can be mapped into the first level. The process applies the multi-level waveform to the droplet ejection devices at block **408**. The multi-level waveform includes a first section having at least one compensating edge or at least one compensating pulse with a compensating effect to compensate for systematic variation of the droplet parameter across the droplet ejection devices and a second section having at least one drive pulse. The process causes the droplet ejection devices to eject droplets at block **410** in response to the multi-level waveform being applied to one or more of the droplet ejection devices at block **408**.

[0050] In one embodiment, a pressure response wave that is caused by the at least one compensating edge, which may be a compensating pulse or multiple compensating pulses, is in resonance (i.e., in phase) or approximately in resonance with respect to pressure wave(s) of the at least one drive pulse. Alternatively, a pressure response wave that is caused by at least one compensating edge, which may be a compensating pulse or multiple compensating pulses, is approximately in anti-resonance (i.e., out of phase) with respect to the pressure response waves of the at least one drive pulse. A peak voltage of the compensating edge or compensating pulse may be less than a peak voltage of the at least one drive pulse. A pulse width of the compensating pulse may be similar to a pulse width of the at least one drive pulse.

[0051] A compensating edge or a compensating pulse is designed to not eject a droplet. The compensating edge or the compensating pulse also has a lower maximum voltage amplitude in comparison to drive pulses to avoid ejecting a droplet.

[0052] In one embodiment, each droplet ejection device ejects additional droplets of the fluid in response to the pulses of the multi-level waveform or in response to pulses of additional multi-level waveforms. A waveform may include a series of sections that are concatenated together. Each section may include a certain number of samples that include a fixed time period (e.g., 1 to 3 microseconds) and associated amount of data. The time period of a sample is long enough for control logic of the drive electronics to enable or disable each jet nozzle for the next waveform section. In one embodiment, the waveform data is stored in a table as a series of address, voltage, and flag bit samples and can be accessed with software. A waveform provides the data necessary to produce a single sized droplet and various different sized droplets. For example, a waveform can operate at a frequency of 20 kilo-Hertz (kHz) and produce three different sized droplets by selectively activating different pulses of the waveform. These droplets are ejected at approximately the same target velocity.

[0053] FIG. **5** shows a multi-level waveform **500** in accordance with one embodiment. Section 1 of the waveform includes a compensating pulse **510** and section 2 includes a drive pulse **520**. Section 1 corresponds to a time period of approximately three microseconds of the waveform and section 2 corresponds to approximately the remaining five microseconds of the waveform. The compensating pulse **510** has a compensating effect to compensate for systematic variation across the droplet ejection devices of a print head. The time period from a firing of the compensating pulse to a subsequent firing of a drive pulse may be approximately a resonance time period.

[0054] Table 1 shows a sectional mapping for the waveform **500**.

TABLE 1

Section Mapping			
	Section No.		
	1	2	Other non-drop forming waveform (NOT SHOWN)
No Print (Level 0)	OFF	OFF	ON
Level 1	OFF	ON	Optional
Level 2	ON	ON	Optional

[0055] FIG. **6** illustrates a wafer with multiple dies and corresponding spatial distributions of drop velocity in accordance with one embodiment. The dies **602-608** include a respective spatial distribution of drop velocity **610-617**. The spatial distribution of drop velocity has a systematic signature that is dependent on die location on the wafer **600**. The compensating pulse discussed herein is designed to compensate for systematic drop velocity variation across different die locations. In one embodiment, each die location corresponds to a different print head. For example, the die **602** includes a distribution of drop velocity **610** that decreased from left to right across the die in general. The droplet ejection devices that correspond to slower drop velocities of the distribution of drop velocity **610** can be compensated with a compensating pulse to accelerate the drop velocity for these droplet ejection devices and reduce the systematic drop velocity variation.

[0056] FIGS. **7-12** illustrates different types of multi-level waveforms for correcting systematic drop velocity or drop mass variations across droplet ejection devices. FIG. **7** shows a multi-level waveform **700** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating pulse **710** (e.g., located in section 1), drive pulses **720-760** (e.g., located in section 2), and a non-drop-firing portion **770** includes a jet straightening edge **772** having a droplet straightening function and cancellation edges **774** and **776** having an energy canceling function. The drive pulses cause the droplet ejection device to eject a droplet of a fluid. The compensating pulse **710** has a compensating effect to compensate for systematic variation across the droplet ejection devices. The compensating pulse by itself does not fire a droplet. The compensating pulse **710** adds energy to the droplet ejection device to increase the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating pulse to a subsequent firing of a drive pulse may be approximately in resonance with a resonance time period of the drive pulses.

[0057] FIG. **8** shows a multi-level waveform **800** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating pulse **810** (e.g., located in section 1), drive pulses **820-860** (e.g., located in section 2), and a non-drop-firing portion **870** includes a jet straightening edge **872** having a droplet straightening function and cancellation edges **874** and **876** having an energy canceling function. The compensating pulse **810** has a compensating effect to compensate for systematic variation across the droplet ejection devices of a print head. The compensating pulse **810** reduces energy to the droplet ejection device to decrease the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating pulse to a subsequent firing of a drive pulse (e.g., leading edge of compensating pulse to leading edge of drive pulse, falling edge of compensating pulse to falling edge of drive pulse) may be approximately out of phase (anti-resonance) in comparison to a resonance time period of the drive pulses.

[0058] FIG. **9** shows a multi-level waveform **900** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating pulse **910** (e.g., located in section 1), drive pulses **920-960** (e.g., located in section 2), and a cancellation edge **970** having an energy canceling function. The drive pulses cause the droplet ejection device to eject a droplet of a fluid. The compensating pulse **910** has a compensating effect to compensate for systematic variation across the droplet ejection devices. The compensating pulse by itself does not fire a droplet. The compensating pulse **910** adds energy to the droplet ejection device to increase the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating pulse to a subsequent firing of a drive pulse may be approximately in anti-resonance with a resonance time period of the drive pulses.

[0059] FIG. **10** shows a multi-level waveform **1000** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating pulse **1010** (e.g., located in section 1), drive pulses **1020-1060** (e.g., located in section 2), and a cancelation edge **870** having an energy canceling function. The compensating pulse **1010** has a compensating effect to compensate for systematic variation across the droplet ejection devices. The compensating pulse **1010** reduces energy to the droplet ejection device to decrease the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating pulse to a subsequent firing of a drive pulse (e.g., leading edge of compensating pulse to leading edge of drive pulse, falling edge of compensating pulse to falling edge of drive pulse) may be approximately out of phase (anti-resonance) in comparison to a resonance time period of the drive pulses.

[0060] FIG. **11** shows a multi-level waveform **1100** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating pulse **1110** (e.g., located in section 1), drive pulses **1120-1160** (e.g., located in section 2), and a cancellation edge **1170** having an energy canceling function. The drive pulses cause the droplet ejection device to eject a droplet of a fluid. The compensating pulse **1110** has a compensating effect to compensate for systematic variation across the droplet ejection devices of a print head. The compensating pulse by itself does not fire a droplet. The compensating pulse **1110** adds energy to the droplet ejection device to increase the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating pulse to a subsequent firing of a drive pulse may be approximately in resonance with a resonance time period of the drive pulses.

[0061] FIG. **12** shows a multi-level waveform **1200** with a compensating pulse in accordance with one embodiment. The waveform includes a compensating edge **1210** (e.g., located in section 1), drive pulses **1220-1260** (e.g., located in section 2), and a cancelation edge **1270** having an energy canceling function. The compensating edge **1210** has a compensating effect to compensate for systematic variation across the droplet ejection devices. The compensating edge **1210** adds energy to the droplet ejection device to increase the drop velocity and drop mass of one or more of the subsequent driving pulses. The time period from firing the compensating edge to a subsequent firing of a similar edge of a drive pulse (e.g., falling edge of compensating pulse to falling edge of drive pulse) may be approximately in resonance in comparison to a resonance time period of the drive pulses.

[0062] A same sense cancellation pulse (or cancellation edge(s)) as illustrated in FIGS. **7** and **8** is preceded by a cancel edge delay, which has a voltage level that is similar to a voltage level of one or more delays between drive pulses. An opposite sense cancellation pulse (or cancellation edge(s)) as illustrated in FIGS. **9-12** is preceded by a cancel edge delay, which has a voltage level that is different than a voltage level of one or more delays between drive pulses. The voltage level of the cancel edge delay is in the opposite direction, relative to the bias level or level between fire pulses, compared to the fire pulse.

[0063] FIG. **13** illustrates a flow diagram of a process for driving droplet ejection devices within a print head or ink jet system with a multi-level waveform to compensate for cross-talk between droplet ejection devices of a print head or ink jet system in accordance with one embodiment. The multi-level waveforms may have 4 levels for a bit depth of 2, 8 levels for a bit depth of 3, etc. In one embodiment, the process for driving the droplet ejection devices includes determining image data at block **1302**. The process converts the image data into converted data to be stored in an image buffer at block **1304**. For example, the image buffer will contain level 0 and level 1 with level 1 being for printed pixels of the image data. The process may include processing the converted data for cross-talk at block **1306**. Processing the converted data may include identifying pixels that have high cross-talk and shifting them into a new level 2. For example, converted data that forms a low density image may have low cross-talk while converted data that forms a high density image may have high cross-talk. The image data can be printed and the drop velocity can be measured for the printed pattern. The data from the printed pattern that corresponds to slower drop velocity can be shifted into level 2. The process applies the multi-level waveform with sectional mapping to the droplet ejection devices at block **1308**. The multi-level waveform includes a first section having at least one compensating edge or at least one compensating pulse with a compensating effect to compensate for cross-talk between the droplet ejection devices and a second section having at least one drive pulse. The process causes the droplet ejection devices to eject droplets at block **1310** in response to the multi-level waveform being applied to the droplet ejection devices at block **1308**.

[0064] In one embodiment, a pressure response wave of the at least one compensating edge or at least one compensating pulse is in resonance (i.e., in phase) or approximately in resonance with respect to pressure wave(s) of the at least one drive pulse. In another embodiment, a pressure response wave of at least one compensating edge or at least one cancelation pulse is approximately in anti-resonance (i.e., out of phase) with respect to the pressure response waves of the at least one drive pulse. A peak voltage of the compensating pulse may be less than a peak voltage of the at least one drive pulse. A peak voltage of the cancellation pulse may be less than a peak voltage of the at least one drive pulse.

[0065] FIG. **14** shows a multi-level waveform **1400** in accordance with one embodiment. Section 1 of the waveform includes a compensating pulse **1410** and section 2 includes a drive pulse **1420**. Section 1 corresponds to a time period of approximately three microseconds of the waveform and section 2 corresponds to approximately the remaining five microseconds of the waveform. The compensating pulse **1410** has a compensating effect to compensate for cross-talk between the droplet ejection devices. The time period from one firing the compensating pulse to a subsequent firing of drive pulse may be approximately a resonance time period.

[0066] Table 2 shows a sectional mapping for the waveform **1400**.

TABLE 2

Section Mapping			
	Section No.		
	1	2	Other non-drop forming waveform (NOT SHOWN)
No Print (Level 0)	OFF	OFF	ON
Level 1	OFF	ON	Optional
Level 2	ON	ON	Optional

[0067] FIG. **15***a* illustrates converting image data into a low density buffer in accordance with one embodiment. The image data **1510** is converted into converted buffer data and then stored as a low density buffer **1520**. For a sparse pattern as illustrated in FIG. **15***a* no correction or compensation is needed.

[0068] FIG. **15***b* illustrates converting image data into a high density buffer in accordance with one embodiment. The image data **1550** is converted into converted buffer data and then stored as a high density buffer **1560**. For a dense pattern as illustrated in FIG. **15***b* real time analysis or pre-processing is needed to determine a number of droplet ejection devices fired for a given buffer. If the nozzles in a certain nozzle pattern are adjacent to each other, then cross-talk will likely occur and modify the drop velocity (e.g., slow the drop velocity). In such patterns, pixels are shifted to level 2 and printed with a compensating pulse to compensate for the cross-talk. Note that the compensating pulse can add energy and increase drop velocity. Increasing an amplitude of a compensating pulse increases drop velocity until a desired or optimal drop velocity is obtained. Alternatively, the compensating pulse can reduce energy in the waveform and decrease drop velocity. Decreasing an amplitude of a compensating pulse decreases drop velocity until a desired or optimal drop velocity is obtained.

[0069] The at least one compensating edge or compensating pulse can correct for drop mass and velocity non-uniformities as well as drop formation non-uniformities. Drop formation affects print head sustainability. Prior approaches that use image preprocessing increase voltages, which causes more drop satellites or sub-drops, and damages a print head over time.

[0070] FIG. **16***a* illustrates a 1 bit waveform with a compensating pulse in accordance with one embodiment. The 1

bit waveform **1600** includes a prepulse or compensating pulse **1610** and a drive pulse **1620**. The compensating pulse **1610** adds energy to the waveform. This waveform may be susceptible to drop formation issues at certain frequencies as illustrated in FIG. **16***b* in one embodiment. The arrows **1650-1655** indicate drop formation issues for certain frequencies in kHz.

[0071] FIG. **17***a* illustrates a 1 bit waveform with a compensating pulse in accordance with one embodiment. The 1 bit waveform **1700** includes a prepulse or compensating pulse **1710** and a drive pulse **1720**. The compensating pulse **1710** does not add energy to the waveform. This waveform may be susceptible to drop formation issues at certain frequencies as illustrated in FIG. **17***b* in one embodiment. The arrows **1750-1754** indicate drop formation issues for certain frequencies in kHz.

[0072] FIG. **18***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment. The 2 bit waveform **1800** includes a prepulse or compensating pulse **1810** and a drive pulse **1820**. The compensating pulse **1810** adds energy to the waveform. This waveform reduces drop formation issues as illustrated in FIG. **18***b* in one embodiment. The compensating pulse is associated with a first section while the drive pulse is associated with a second section. The first section is mapped to level 2 while the second section is mapped to level 1 or 2. Drop formation is improved by applying the prepulse to level 2 and applying level 1 with the drive pulse by itself to the frequency ranges 1850-1852 as indicated in FIG. **18**B.

[0073] A more uniform frequency response can be obtained using different combinations of waveform sections depending on jetting frequency. Thus, a frequency dependent variation in drop velocity and drop volume can be reduced.

[0074] FIG. **19***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment. The 2 bit waveform **1900** includes a prepulse or compensating pulse **1910**, drive pulses **1920** and **1930**, and a non-drop-forming portion **1940**. This waveform has a frequency response variation as illustrated in FIG. **19***b* in one embodiment. The compensating pulse is associated with a first section, the drive pulse **1920** is associated with a second section, and the drive pulse **1930** is associated with a third section. The frequency response graph **1950** illustrates a 2 pulse drop created by sections 2 and 3. The arrow **1960** illustrates a frequency response variation induced by an increase in frequency from left to right of the graph **1950**.

[0075] FIG. **20***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment. The 2 bit waveform **2000** includes a prepulse or compensating pulse **2020**, drive pulses **2010** and **2030**, and a non-drop-forming portion **2040**. This waveform has a frequency response variation as illustrated in FIG. **20***b* in one embodiment. The compensating pulse is associated with a second section, the drive pulse **2010** is associated with a first section, and the drive pulse **2030** is associated with a third section. The frequency response graph **2050** illustrates a 2 pulse drop created by sections 1 and 3. The arrows **2060-2062** illustrate a frequency response variation induced by an increase in frequency from left to right of the graph **2050**.

[0076] FIG. **21***a* illustrates a 2 bit waveform with a compensating pulse in accordance with one embodiment. The 2 bit waveform **2100** includes a compensating pulse **2120**, drive pulses **2110** and **2130**, and a non-drop-forming portion **2140**. This waveform has a frequency response variation as illustrated in FIG. **21***b* in one embodiment. The compensating pulse is associated with a second section, the drive pulse **2010** is associated with a first section, and the drive pulse **2130** is associated with a third section. The frequency response graph **2170** illustrates a 2 pulse drop created by sections 1, 2, and 3 with grayscale (multi-level) printing. The level 2 section mapping is used for lower frequencies and the highest frequencies as indicated with the arrows **2143** and **2144**, respectively. The level 3 section mapping is used for intermediate frequencies as indicated with the region **2180**. The arrows **2142** and **2182** illustrate a smaller frequency response variation induced by an increase in frequency from left to right of the graph **2170**.

[0077] The waveforms of the present disclosure can be used for a wide range of operating frequencies to advantageously provide different droplets sizes with improved velocity and mass control. The waveforms also provide improved droplet formation with reduced frequency response variation for improved print head sustainability.

[0078] It is to be understood that the above description is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

1. A method, comprising:

generating a multi-level waveform having a compensating edge or a compensating pulse that is associated with at least one pulse in the multi-level waveform, the compensating edge or pulse is selected based on a spatial distribution of a droplet parameter and has a compensating effect to compensate for systematic variation across a plurality of droplet ejection devices; and

using the multi-level waveform in one of the plurality of droplet ejection devices to eject one or more droplets.

2. The method of claim **1**, wherein the spatial distribution of the droplet parameter comprises a spatial distribution of a droplet velocity across the plurality of the droplet ejection devices.

3. The method of claim **1**, wherein the spatial distribution of the droplet parameter comprises a spatial distribution of a droplet mass across the plurality of the droplet ejection devices.

4. The method of claim **1**, further comprising:

determining the spatial distribution of the droplet parameter across the plurality of droplet ejection devices of a print head or an ink jet system;

determining a mapping for mapping image pixel levels of the multi-level waveform based on the spatial distribution of the droplet parameter;

identifying first and second groups of the plurality of the droplet devices within the spatial distribution; and

converting pixels in the second group into a second level of the multi-level waveform while pixels in the first group remain in a first level of the multi-level waveform.

5. The method of claim **4**, wherein the compensating edge or pulse increases or decreases a drop velocity of the droplets ejected by the second group of droplet ejection devices.

6. The method of claim **1**, wherein the compensating edge or pulse improves drop formation of droplets ejected by the droplet ejection devices.

7-25. (canceled)

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