Addressable Waveform Modulation for Ink-Jet Printing Realized by Self-Feedback Circuit

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Abstract

Definitely, the ink-jet fabrication is an expectable technology for the field of display and semiconductor, like the fabrication of color filter, the forming of metal circuit, the dispensing of liquid crystal, and further continuous manufacture of flexible display etc. Why it hesitates to pace forward? The obstacle lies across is the jetting quality control, especially for the pixel-to-pixel variation. As minimum requirement for those applications, the 10% pixel variation is the threshold. In this article, an electrical controller was designed to differentiate waveform for each nozzle synchronously, to compensate the nozzle cell deformation and pressure drag loss during inkjet firing at high voltage and high frequency. The controller senses the variation of jetting fluctuation caused by pressure, temperature, and combined with the real observation analysis results, as a feedback circuit to modulate the driving waveform for each nozzle at versatile inks and environmental situations. It composed of a high voltage control block to drive each nozzle, a FPGA chip to multiplex all the high voltage output, an A/D converter to transfer analog signal to digital signal into FPGA, a differential signal input to FPGA as feedback to correct analog output, a real-time tracking of jetting quality to verify the nozzle-to-nozzle variation. By this design, the pixel-to-pixel variation can be acceptable and adaptable with the sharply environmental change.

Introduction

The challenge of ink-jet fabrication relies on the control the nozzle-to-nozzle (N2N) and head-to-head (H2H) variation during printing process. It results the pixel defect, discontinuous line presence, white omission, and even the uniformity problem, causes the hard to promote this technology into real fabrication. The innate fluid behavior of ink-jet printing is the Rayleigh instability described by Rayleigh [1], Its behavior is the drop enlarges surface to afford the driving energy by moving bulk molecules to surface), and release the driving energy by shrinking drop surface. Due to the characteristics, the jetting quality will be affected by the pressure drop within flow channel, the temperature difference along nozzle to nozzle, on-the-fly jetting environmental condition, and the variation due to the imperfect fabrication of nozzles.

To get minimum deviation between jetting drops, Kiguchi [2] proposed a precision control of menisci during the printing. It first pulled motion to the ink menisci by the waveform, keeping all menisci the same shape before droplet ejection, and then a forceful eject motion is applied. In this control, it can effective reduce the variation caused by ink evaporation, but it can not sense the variation caused by the temperature and pressure fluctuation, and the on-the–fly drops difference due to environmental condition variation. Kobayashi et al. [3] adopted a switch pulse generator to switch on and switch off the waveform, to trim the individual driving energy into the element of print head, and improve the N2N variation from ±20% down to ±5%.

To meet the requirement of emerging applications of ink-jet printing [4-8], in this paper, we integrated the analog circuit and operational amplifier circuit, as a self-feedback compensation mechanism to calibration the N2N and H2H variation by tuning the individual waveform. Also, under this compensation mechanism, the temperature variation, pressure variation, and the drop volume, jetting velocity variation all were included to as input correction factors. It also discussed the 128-nozzles head module driving circuit with individual analog output to each element of head.

Circuit Structure & Driving Methodology

Two major methodologies can be used for driving piezoelectric print head. The first and the simpler one is the direct driving. It inputs the high voltage (generally up to 100V) and high current driving energy into the piezoelectricity element of head. In this design, a chip can operate at high voltage and output high current is needed, and it is hard to implement the driving waveform has different setting for each nozzle, due to the board dimension size limitation. Alternatively, if one considered the piezoelectric element equiv to electrical capacitance, and control the charge timing by switch on and switch off only. Compare with first method, the latter has the advantage of compact size, and an individual modulating for each nozzle can be feasible However, this control method will be sensitive to the consistence of the piezoelectricity of nozzles, and an extra modulation for the switch timing is needed.

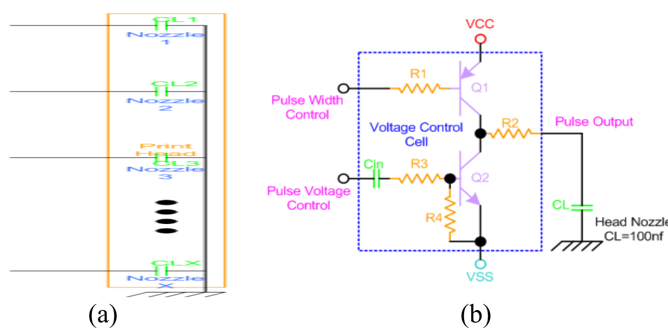

Fig. 1 (a)-(b) Equivalence circuit and the control diagram for print head

In Fig.1(b), a trapezoidal drive voltage waveform is supplied to the common electrode of each PZT and individual electrodes are connected to ground through a switch device, and a negative waveform is output. In operation, the initial state is in switch off and the "Pulse Width Control (PWC)" and "Pulse Voltage Control (PVC)" both keep at low voltage level. Then follow with a charge state, the Q1 transistor tuned "ON" to charge piezoelectricity device until the PWC was set at high level. For operation of jetting, the PVC will set at high level and make the piezoelectricity device discharging until the PVC fell to original off state, and completed a cycle operation. Fig.2(a) shown a timing sequential relation in detail.

It is notable that the resistance R2 and equivalence capacitance CL determined the charging and discharging speed. At same operation for each piezoelectricity device, however, the different between the nozzles will cause the capacitance variation (i.e, CL), and make the fluctuation between nozzles, the N2N variation. As indicated in Fig.2(b), even though the same triggering pulse, but the difference of CL made the output waveform in distinguishable.

To correct the variation mentioned before, in Fig.3, a self-feedback circuit to scan every nozzle cell is operated. At beginning, the control system got a feedback reference CL by the A/D converter. Then the system scans the output of each cell to examine if its value is same as the reference CL output by a comparison device. After scanning, all the information will record and modulate the PWC to determine the driving waveform, and an ideal tuning process is completed.

Waveform Trimming & Calibration

Even though the driving waveform for each nozzle has carefully calibrated as the same, however, the discharging time existed the time lag between nozzles for the difference of piezoelectricity deformation, the jetting temperature, the back pressure of ink chamber, and the jetting environmental conditions. Therefore, in this paper, a mechanism was designed to shift the output waveform to tune this difference. The first step is to build up reference timing. Then follow the similar step, scan each nozzle and establish a timing look-up table and correct it. As presented in Fig.4, the left figure has a lag compared with the reference waveform output. The treatment is to advance the trigger time of the trigger pulse, and an ideal consistence waveform can be realized. Fig.5(a)-(b) summarized the self-feedback mechanism and demonstrated the tuning process. Fig.5(a) indicated the piezoelectric capacitance difference came from manufacturing variation. For example, one nozzle is at 100nf and the another nozzle is at 150nf. It shown the same driving setting will cause different response output, at the voltage of -92V and -70V. In Fig.5(b), adopted the self-feedback mechanism and considered trigger shifting method, the output will in perfectly match with the desired profile, and the nozzle-to-nozzle variation can be significant reduced.

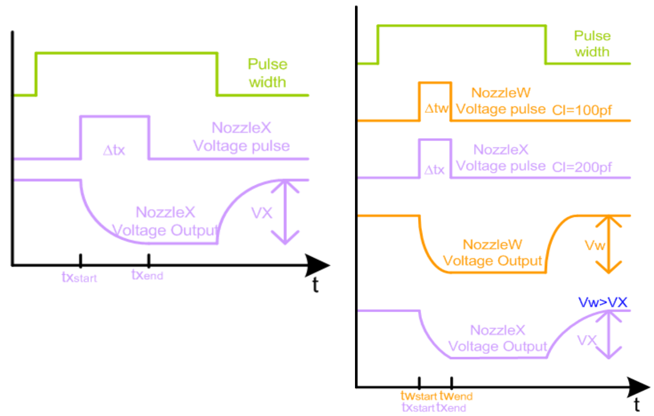

Fig.2(a)-(b) (a) The sketch of generating a negative analogy waveform trigged by a pulse for piezoelectricity device. (b) the difference of CL made the output waveform in distinguishable when system gives the same triggering pulse .

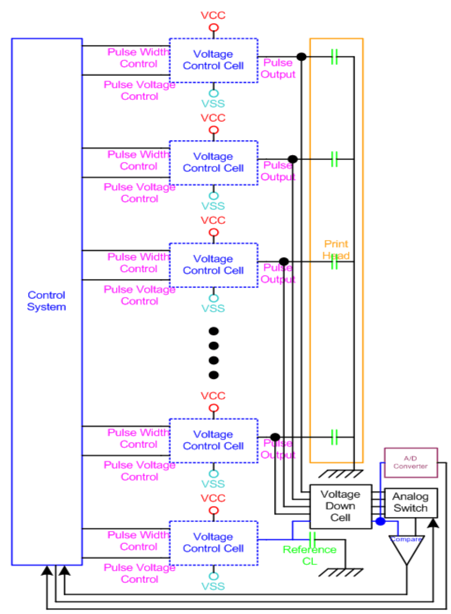

Fig. 3 The self-feedback diagram and its circuit layout.

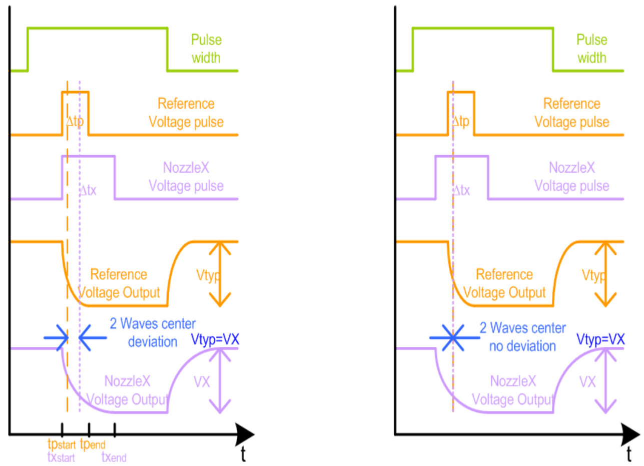

Fig. 4 The trigger shifted to tune the output waveform.

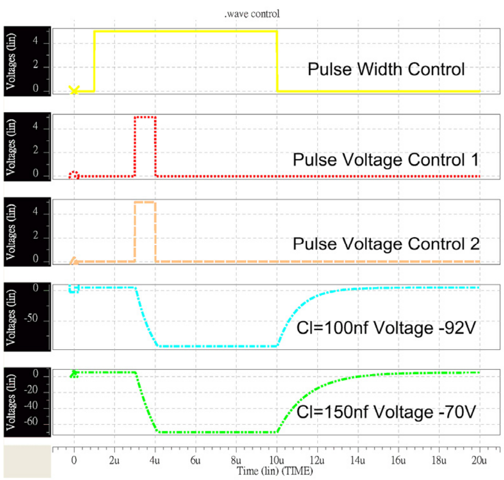

Fig. 5(a) Simulation result without self-feedback and trigger shift mechanism.

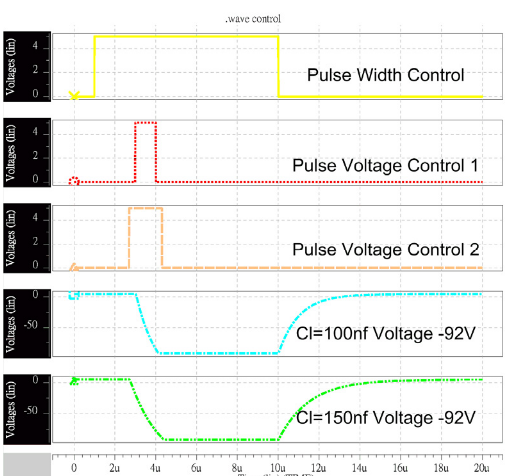

Fig. 5(b) Simulation result with self-feedback and trigger shift mechanism.

Conclusion

This article disclosed a new methodology in design the driving circuit for piezoelectric device. The electrical controller was designed to differentiate waveform for each nozzle synchronously, to compensate the nozzle cell deformation and pressure drag loss during inkjet firing at high voltage and high frequency. The controller senses the variation of jetting fluctuation caused by pressure, temperature, and combined with the real observation analysis results, as a self-feedback circuit to modulate the driving waveform for each nozzle at versatile inks and environmental situations. By this design, the pixel-to-pixel variation can be acceptable and adaptable with the sharply environmental change.

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