Robust, Reliable and Repairable Inkjet Print Head with Dynamic Drop Modulation Feedback for Printable Display Applications

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Abstract

With the advent of Liquid Crystal Display (LCD) and Flexible Display (FD) applications, a number of research and development companies have been pursuing mask-free digital inkjet printing processes to keep manufacture simple, low cost and environmentally friendly for instant, color filter pixelization, color filter black matrix application, polyimide coating, ball spacer, liquid crystal dispensing and light guide micro-lens deposition of back light unit and so forth. As a result, the key challenge is to not only control the drop placement accuracy but also provide sufficient drop volume uniformity control and real-time waveform modulation to meet the critical requirements. This paper focuses on the recent developments of a robust, reliable and repairable print head along with Addressable Waveform Trimming Circuit (AWTC) to enable drop placement accuracy and drop volume uniformity over 256 nozzles and 4-inch print width. Also reported is both the print head and the drive feedback system for the case of pixel-by-pixel dispense of red, green and blue Cholesteric Liquid Crystal (ChLC) which has been widely applied to bi-stable reflective display applications.

Introduction

FPD technologies mainly include Thin Film Transistor Liquid Crystal Display (TFT-LCD), Plasma Display Panel (PDP), Organic Light-Emitting Diode (OLED), Surface-conduction Electron-emitter Display (SED), and Field Emissive Displays (FED) and the flat panel market is expected to reach 100 billion US dollars in 2007 and 120 billion US dollars in 2010, led by TFT-LCD at an 83% - 85 % share [1]. The next generation display could be thin and flexible. One of major materials for flexible display is Cholesteric Liquid Crystal (ChLC) been widely applied to bi-stable reflective display applications without back light unit, alignment layer, polarizing film and color filter compared to TFT-LCD. ChLC behaves bi-stably and can reflect different light wavelength by tuning the interaction of chiral additive molecules and the nematic liquid crystal host so that low power consumption, high brightness, wide viewing angle, and sunlight readability can be achieved. Several ChCL display structures and processing methods have been reported [2-5]. There are two major approaches to form a pixel within display device. One is to pattern three sub-pixels side by side [6-9]. The other is to stack three sub-pixels [10-11]. Like color filter in TFT-LCD, ChLC layer can be digitally fabricated by piezoelectric inkjet print head. By the same token, the main challenge is to precisely control the drop volume variation and accurately deposit all the droplets.

Trident and ITRI have been involved in this area and developed Addressable Waveform Trimming Circuit (AWTC) for two print heads which are 256Jet and PixelJet shown in figure 1 and figure 2, respectively. Their unique features include (1) high reliability, (2) accurate orifice manufacture (3) replaceable orifice – chamber plates, (4) inert print head bodies, (5) individual lead for jetting performance calibration with AWTC device, and (6) highly flexible design to adapt to a wide range of drop volumes and jetting fluids [12]. The specifications are shown in Table 1.

Figure 1.

256Jet print head

Figure 2. *PixelJet print head*

Table 1. 256Jet and PixelJet specifications

	256Jet	PixelJet
# of addressable channels	256	64
Orifice spacing	0.397mm	0.743mm
Drop volume*	7-40 PL	10-60 PL
Drop velocity	5-8 m/s @ 1mm standoff	5-8 m/s @ 1mm standoff
Drive voltage	< 90 volts	< 90 volts
Straightness	< 0.5 degree	< 0.5 degree
Life expectancy	More than 90 billion jetting cycles	More than 90 billion jetting cycles

Note*: a range of drop volume can be covered by using different orifice diameters.

AWTC Device

In reality, pixel to pixel variation of display devices must be precisely controlled to ensure good display quality. Correspondingly, the inkjet nozzle to nozzle and head to head variations must also be in good control. The error source mainly comes from inherent capacitance variation of piezoelectric transducers, nozzle dimensional and positional variation, and jetting temperature variation. The AWTC has been developed and tested for differentiating drive waveform for each nozzle synchronously and then compensating for the error sources as mentioned above.

Figure 3 shows the AWTC schematic diagram. AWTC chiefly consists of high voltage switch unit, timing control unit, voltage feedback unit, and firing flow control unit. The high voltage switch unit generates individual drive waveform based on control signal from timing control unit, resistance, and each piezoelectric actuator capacitance. Timing control unit controls individual rise time, pulse width, and fall time of drive waveform.

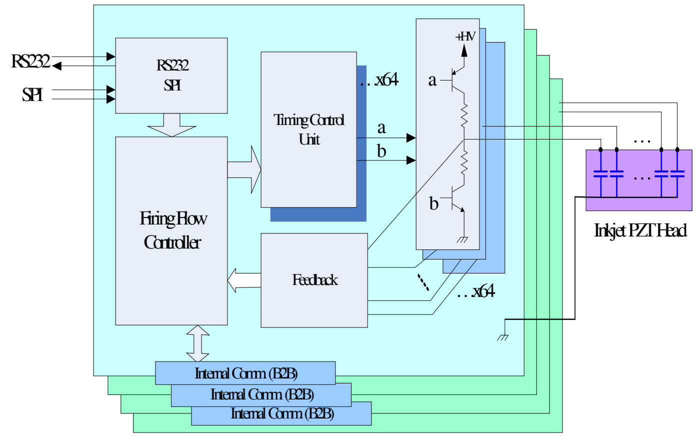


Figure 3. *AWTC schematic Diagram*

Self-tuning vs. User-tuning

The firing flow control unit enables two calibration mechanisms as shown in Figure 4.

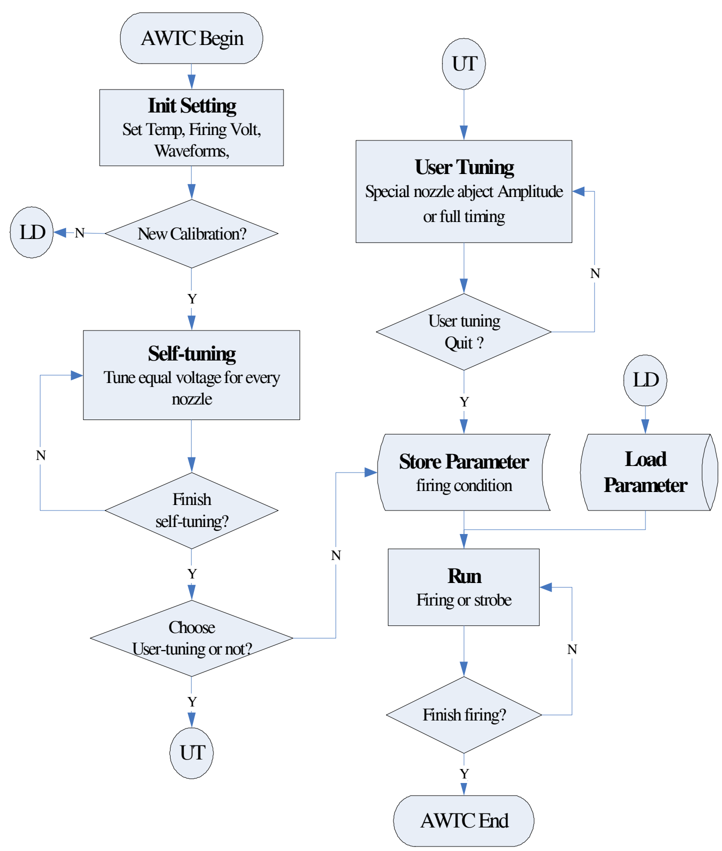


Figure 4. *AWTC calibration flow chart*

One is defined as self-tuning calibration. The firing flow controller automatically tunes all piezoelectric actuators to the same setting drive voltage through feedback circuit. The purpose is to compensate for inherent capacitance variation for each nozzle. The other is defined as user-tuning calibration. Due to other variations for example, jetting temperature variation or nozzle diameter variation, the user-tuning calibration is intended to adjust specific nozzles. Thus, in the end, sufficient drop volume uniformity can be efficiently achieved.

Real-time Voltage Feedback Unit

Real-time voltage feedback unit ensures the precise desired drive voltage applied to individual piezoelectric actuator with inherent capacitance variation. As shown in Figure 5, the yellow line stands for a driving signal. The blue line is the voltage curve acting on the piezo-transducer during charging, holding and discharging. The green line indicates the real-time feed back voltage.

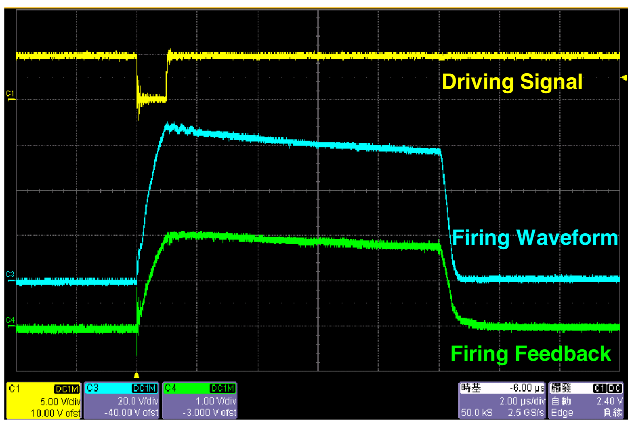


Figure 5. *Drive waveform feedback control*

ChLC case study

A multi-color ChLC panel has been digitally fabricated by inkjet printing as shown in Figure 6. The print head needs to be heated up to 80 ^{0}C to bring ChLC ink down to reasonable viscosity range for inkjet printing. A drop volume control experiment has been conducted with Trident 256Jet along with AWTC on ChLC ink material. Figure 7 shows a drive waveform.

The drop volume was measured by the image method (see Figure 8). Table 2 shows the experimental result (T2 and T3 keep constant).

Figure 6. *Multi-color ChLC panel digitally fabricated by inkjet printing*

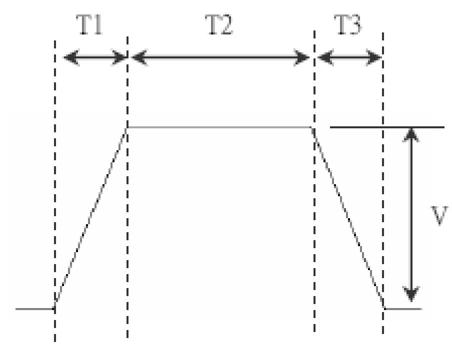
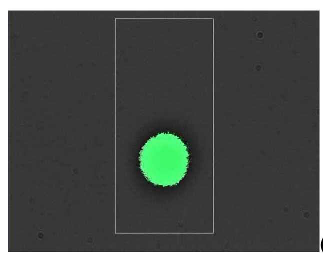
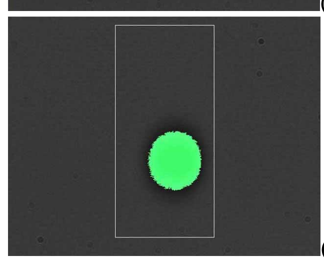


Figure 7. *Drive waveform diagram*



(a) T1= 100 counts; V=21.0v



(b) T1= 110 counts; V=22.2v

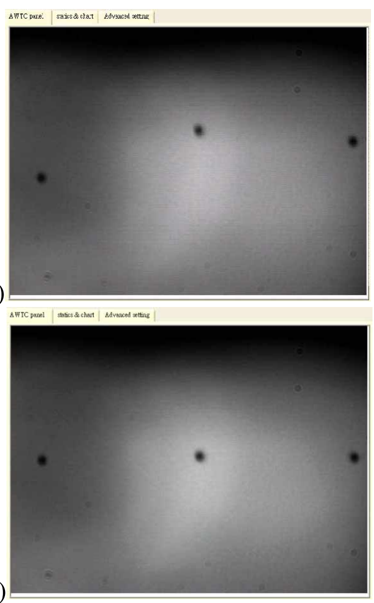
Figure 8. *Drop volume measurement*

Table 2: Experimental data

Rise Time (T1)	Voltage (V)	Drop Volume
100 counts**	21.0v	54.18 pl
110 counts	22.2v	56.29 pl
120 counts	23.0v	61.22 pl
130 counts	24.0v	65.69 pl

Note**: different count means different rise time.

AWTC uses an internal counter to modulate rise time (T1) and thus control drive voltage (V). Based on experimental data in Table 2, ten counts can control drop volume variation within 4% at V=21.0 volts. Also Figure 9 shows drop velocity uniformity over three jets before and after trimming.



(a) (b)

Figure 9. *(a) before trimming; (b) after triming*

Conclusion

Trident's piezoelectric inkjet technology has unique features which make these print heads along with AWTC ideal for flat panel display fabrication and they include:

1. Highly flexible design can be adapted to a wide range of application (different drop volume and jetting fluid viscosity).
2. Replaceable CPOP extends print head life and reduce the cost.
3. Drop volume variation can be controlled within ± 2% with AWTC.
4. Inert print head body is compatible with a wide range of jetting fluids.
5. The jetting print width can be up to 4 inches.

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Author Biography

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