Architecture of A High Performance LED Printhead Platform

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Abstract

Océ's continuous feed printer families are developed to satisfy the ever increasing speed and quality requirements of our customers. One of the key components for higher performance in electrophotographic printing is the exposure system. Océ develops and manufactures LED printheads since many years because of their high reliability and durability. A third generation printhead platform was developed to meet highest speed and quality requirements while lowering overall cost. This was achieved by a combination of mechanical, optical, and electronical improvements.

For the mechanical part, customization of a general-purpose pick-and-place system ensured a three-sigma LED-to-LED placement accuracy of less than two microns.

The selection of a very uniform Selfoc™ lens array with high aperture but low depth of focus forced a mechanical design with minimized tolerances between LED and photoconductor surface in order to achieve optimum print resolution.

LED drivers were implemented in full custom mixed-signal CMOS technology with .35 micron design rules. An on-chip bus for data, clock, status, and control signals makes the array length scalable to arbitrary print width with minimal changes to parts. The sustained data throughput of the driver chain comes close to 2 gigabits per second. Various power and timing control settings can be configured via bus commands. Each chip autonomously performs redundancy checks to alert the controller in case of data integrity errors. Non-uniformities of light output are compensated for by individual energy calibration for each dot. Bi-level, four-level, and sixteen-level exposure modes are available. All exposure functions are controlled digitally to achieve highest precision and reliability.

Thermal management utilizes a massive heat sink onto which the heat-dissipating elements are directly bonded, and a liquid cooling system to provide for uniform temperature inside each individual print head and across all print heads of a printing system.

Former Generations

The first platform of LED print heads for electrophotographic production printers was developed under the Siemens brand. Generic resolutions of 240 and 300dpi and two different print widths were available. Print speed was up to 1 meter per second.

Figure 1 shows our first generation LED printhead with the optics unit removed.

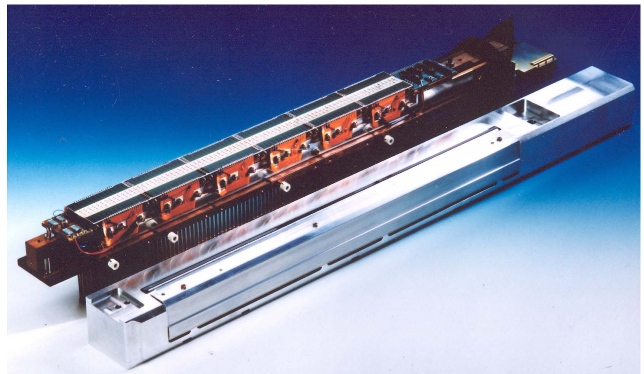

Figure 1: *First generation LED print head (1988)*

The second platform is still in use in our Océ VarioPrint 5000™ and Océ VarioStream 7000™ series. The latter achieves a linear web speed of up to 1.5 meters per second, which translates to a productivity of roughly 600 A4 pages per minute (see *Figure 2*).

Figure 2: Second generation LED print head (1997)

Third Generation LED Print Head

The new generation had to increase process speed while decreasing system cost and improving print quality. What looks like squaring the circle was achieved by streamlining the overall design and using new key components. *Figure 3* shows the main assembly of the new generation print head without optics, power supply, data interface, and cleaning unit.

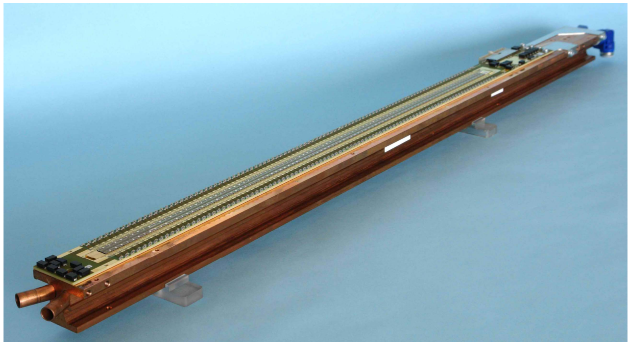

***Figure 3**: Third generation LED print head, optics removed (from 2007)*

Speed Requirements

For the new generations of printing systems, a linear speed target of more than 2.0 meters per second was set. We decided to design a flexible data path architecture with switchable bit depth per pixel, while the data transfer rate remains the same for each mode. That means where full halftone capability is required, the linear speed is the lowest, and where less halftones are sufficient, the linear speed can grow accordingly. This concept is well adaptable to the capabilities of diverse raster image processing engines and printing system architectures. *Figure 4* shows a comparison of the maximum print speed of three generations of 2-up print heads.

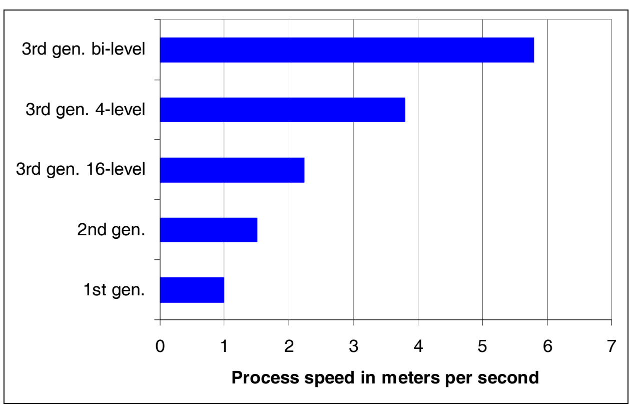

***Figure 4:** Maximum print speed of three print head generations*

Mechanical Improvements

LED array placement accuracy

Further refinement of placement accuracy was achieved by fine tuning of the existing equipment. Three-sigma accuracy improved from ±5 to ±2 microns, thereby eliminating the occasional occurrence of fine bright or dark lines in solid and halftone images.

Lens and TC alignment

Due to the small depth of focus of the SLA20D lens array, this process needed refinement of the mechanical precision of the carrier bar; new, highly precise gauges for adjusting the print head position in the printer, and new tools for lens alignment in the print head manufacturing line. The overall TC alignment tolerance between LED surface and photoconductor surface is now well below ±50 microns.

Data Path Architecture

A less complex physical interface than that of second-generation print heads was designed to leverage the capabilities of .35 micron mixed-signal CMOS switching speed. A linear, unsegmented clock and data bus across each driver IC chain became feasible. While the second-generation print heads using .8 micron design rules required eight sub-chains with separate data lines for a 20.5" device, only two ports are sufficient for the new design [1]. This architecture saved bonding pad space on each driver chip, and the main printed circuit board (main PCB) could be greatly simplified. Data traffic on the bus was significantly reduced by uploading calibration and halftone control tables into the driver chips on start-up. Because there is only one clock input for each IC chain, clock recovery by a phase-locked loop is implemented within each chip. *Figure 5* shows a schematic of the data path architecture.

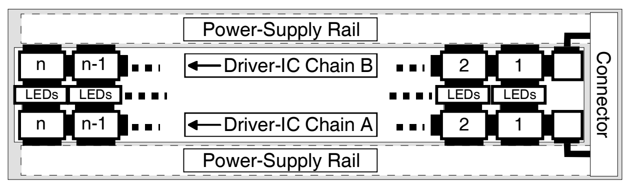

***Figure 5:** Schematic of data path architecture*

Intra-Device Data Traffic

All data traffic for one driver chain employs an 18-bit wide bus which provides for data, clock, and talk-back lines. The functions remaining for most of the main PCB area are to supply logic and LED driver power, reference voltage resistors, and some footprint for decoupling capacitors. Nevertheless the main PCB is a challenging component because of its sheer size, the precise placement of lines, and the wire-bond surface quality.

The new bus architecture saves a lot of work when print heads for various print widths have to be built. No complex data shuffling is needed to adapt to a different length; only a few parts have to be redesigned.

LED Driver IC Architecture and Technology

The migration of functions formerly performed by the controller back-end and the main PCB forced a highly complex mixed-signal design for the driver IC. A state machine was designed to control the various mode and state transitions during power-up, printing, error polling, temperature sampling, and control parameter update phases. Several clock domains had to be provided to overcome the restraints to some function blocks. *Figure 6* shows a schematical block diagram of the architecture. The .35 micron mixed-signal CMOS process chosen satisfies the speed and driver current requirements at clock speeds beyond 100 MHz and single LED driver current of up to 6 milliamps.

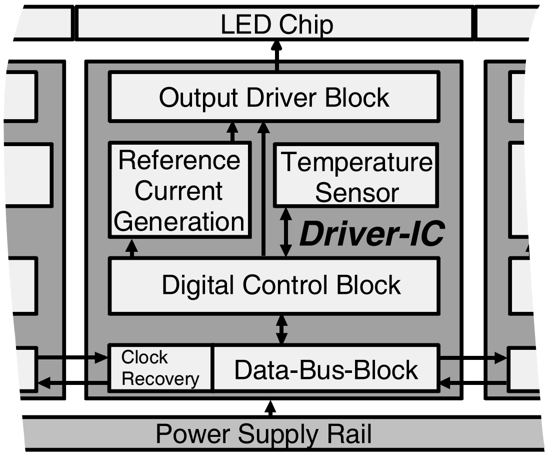

Figure 6: *Block diagram of driver IC*

Precision power and timing control

One of the building blocks for excellent power control is a good power supply. A switching power supply of our own design delivers up to 20 amps of logic and 80 amps of driver supply current with utmost stability. The direct mounting of the power supply PCB to the carrier/heat sink bar gives two advantages: excellent heat dissipation and low inductance. All the way from the PCB to the driver ICs, planar, low-inductance leads provide for negligible ripple and voltage drop. The back side of the main PCB carries a 200 micron copper layer for LED driver current supply; a special bonding layer keeps it at 50 micron distance to the carrier/heat sink bar which also acts as ground potential for LED arrays and drivers.

Still more sophistication is needed to switch thousands of LEDs in fully arbitrary fashion without causing cross-talk or voltage break-down. All state-of-the-art design features have been implemented into the driver design, including shunt transistors for ultimate switching precision as required by the target engines. Slew rate control of the LED drive pulse suppresses higher-harmonic oscillations which would lead to deviations of the integral pulse energy and, consequently, pattern dependent print artefacts. *Figure 7* shows a typical plot of the integral energy versus triggered pulse duration.

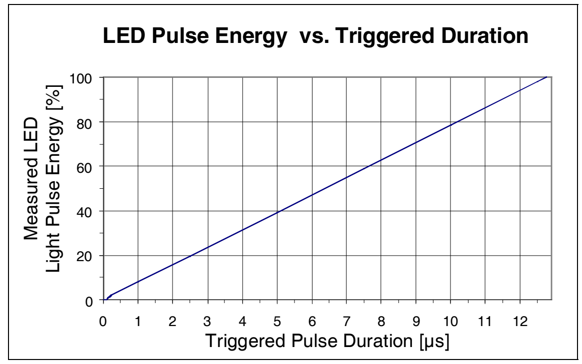

Figure 7: *Plot of pulse energy vs triggered duration*

Data integrity monitoring feature

The driver IC logic continuously performs integrity checks of print data and local status information and reports the results to the print controller via the talk-back channel. This feature ensures detection of any data related image distortion and enables the printing system to react accordingly.

Cost savings by less power dissipation, cooling concept

Overall power dissipation significantly contributes to the cost of a print head. The dominant parameters here are LED efficiency and transmission factor of the imaging optics. Both determine the drive current and switch-on time for individual LEDs to generate a pixel on a given photoconductor surface. Good cooling is essential for a long life print head in a production printing system, because heat compromises both the efficiency and the life span of LEDs. In order to get the most value from our new architecture, we selected the SLA20D imaging optics from Nippon Sheet Glass Co., which offers three times the transmission of the legacy product SLA12A. The drivers can handle up to 6 milliamps which is sufficient for speeds beyond 2 meters per second with normal-efficiency GaAsP LEDs and our standard photoconductor materials. The theoretical speed limit comes close to 6 meters per second with AlGaAs-based LEDs.

Power dissipation of a print head impacts the size of the power supply, the dimensions of the driver chip, and the size of the cooling device. In our case, a cost reduction of roughly 30% was achieved by the combined effect of all three factors. For example, we were able to change the cooling system from an expensive custom device to low-cost off-the-shelf components for personal computers in our VarioStream 8000 and 9000 series. Temperature sensors on the driver ICs are polled via the talk-back bus for temperature control and overheat protection in case of a liquid leak.

As cooling ducts we use copper tubes fitted into grooves along the sides of the carrier bar, which proved as a very cost-effective solution. Multiple print heads are linked in a way that results in minimal temperature differences between heads, thereby eliminating misregistration between their respective images [2].

Uniformity compensation

A dual compensation scheme is used to align the pulse energy output of all LEDs in a printhead. After final assembly and burn-in, the LED current of all driver ICs is tuned digitally to deliver a pre-set threshold light power output for their respective LEDs. In a second step, the standard pulse width of each single LED is tuned to deliver the same amount of light energy per pulse. This can be done with an accuracy of ±0.5%.

Global light control

Two parameters govern the amount of light the print head has to deliver for correct photoconductor discharge: PC sensitivity and print head temperature. The effect of both is compensated for via a control loop which adjusts the light pulse width up and down in small steps, if required. An on-chip multiplier calculates the correct switch-on time from calibration data and the global light control parameter which is transmitted via the data bus.

Multi-level exposure control

The new platform was designed to be as flexible as possible; therefore three exposure modes have been implemented: bi-level, quad-level, and sixteen-level, according to one, two, or four bits per pixel transmitted to the printhead. During initialization of the print head, look-up-tables are loaded into the driver ICs for multi-level gamma correction. While printing, the driver IC logic is processing look-up-table entries with global light control and uniformity compensation parameters on the fly to deliver preset values for all exposure count-down timers. For a 20.5 inch wide 600 dpi print head operating at two meters per second this translates to more than one billion integer multiplications per second.

Conclusion

A new high-speed LED print head platform was developed using state-of-the-art precision tools, full custom mixed-signal CMOS driver ICs with refined light control functions, precise light calibration, and high-transmission optics. The fully digital data interface and exposure control saves cost on the electronic part, while less power dissipation saves cost on the power supply and cooling system. The new data path architecture makes it easy to adapt to various print widths with minimum effort.

References

[1] European Patent Specification 0 827 613 B1.
[2] German Patent Specification 196 12 642 C1.

Author Biography

Wolfgang Schullerus studied Mechanical Engineering at Munich Technical University, where he received his diploma in 1979. He has been working in non-impact printing technologies ever since, most of the time in DOD ink-jet technology with Siemens AG. Since 1996 he is working with Océ Printing Systems GmbH in Poing, Germany, where he heads a printer technology laboratory. He is responsible for the development of LED print heads and other electrophotographic components.

Klaus Pachonik studied Electrical Engineering at Munich Technical University, receiving his diploma in 1993. After 2 years as a freelancer in audio engineering, he joined the printer division of Siemens Nixdorf AG in 1995. In 1996 he changed to Océ Printing Systems GmbH in Poing, Germany, where he is responsible for the electronics of the LED print heads and their high-speed data interfaces.