Introduction

To date only optical character generators (Fig. 1) comprising a laser or laser diode, polygon mirror, acousto-optical modulator and lens system have been used to expose the photosensitive layers in electrophotographic printers with a print performance in excess of 100 pages (DIN A4) per minute. However, these character generators, which are generally referred to as laser systems, are limited in terms of performance capability (print speed x resolution x print width). They also have a relatively large unit volume and are maintenance-intensive.

Advances in semiconductor technology, in particular the integration of up to 128 light dots on a single gallium-arsenide chip and further enhancements in mounting and packaging techniques, have made it possible to develop so-called static LED character generators to the series production stage. Unlike laser-beam character generators which perform serial exposure (scanning) of a line, LED character generations feature parallel exposure. In principle all light dots of an LED row are exposed simultaneously, each dot having a separate light source (LED) (Fig. 2).

Today's known LED Character Generators

LED print heads of various designs have been known for a number of years from the lower end of the range of electrophotographic printers (up to approx. 40 ppm). The performance capability of these systems is governed by the following characteristics:

- Maximum current per LED, typically 5 mA
- Serial or parallel serial data transmission restricts the data transfer rate (typically 10 Mbit/s)
- Uniformity of light intensity when new and over the full lifetime (typically ± 15 % when new, ± 25 % after aging)
- Typical resolutions of 240, 300, 400 dpi
- Typical lifetime of 1000 hours
- Complete system: failure of a single LED results in system rejection (no repairs possible)
- Overall length limited, typically up to 300 mm

The High-Performance LED Character Generator

In order to ensure that LED character generators can also be used in electrophotographic printers at the top end of the range, an LED character generator meeting the following requirements had to be developed:

- Print speed > 200 ppm
- Print width > 2 x DIN A4 (approx. 420 mm)
- Resolution 240, 300, 600 dpi
- Maintenance-free and adjustment-free system
- Repairability
- Lifetime > 10,000 hours
- Uniformity of light energy over the full lifetime and all LEDs

Fig. 1: Laser-Beam Character Generator
1 Laser, 2 Mirror, 3 Lens system, 4 Acousto-optical modulator, 5 Lens system, 6 Polygon mirror, 7 Mirror, 8 Mirror, 9 Photoconductor drum

Fig. 2: LED Character Generator
1 LED-array, 2 Logic and driver IC, 3 Heat sink, 4 Optical system, 5 Housing, 6 Photoconductor drum

Fig. 3: Siemens LED Character Generator
1 Interconnection, 2 BUS multilayer circuit, 3 LED array, 4 Logic and driver IC, 5 Air-flow/protective shield system, 6 Selfoc optic, 7 Photosensor, 8 Photosensor drive, 9 Power supply connection, 10 Module, 11 Air-flow duct, 12 Signal connector
How were the requirements met? (Fig. 3)

- Print speed > 200 ppm
  a) Development of an LED array with 64 LEDs integrated light dots with a light power of 7 μW/mA and LED current of up to 10 mA per LED.
  b) Optimum packaging in terms of thermal properties as a result of the LEDs being soldered onto a copper base material.
  c) Development of a logic and driver chip with 16-bit parallel data transfer rate of 20 MHz.

- Print width > 2 x DIN A4 (approx. 420 mm)
  a) The character generator comprises a high-precision base material on which modules are mounted in a row.
  b) A module is the smallest testable and replaceable unit.
  c) Different print widths can be achieved by arranging varying numbers of modules in rows.

- Resolution of 240, 300, 600 dpi
  The modular construction and multi-row arrangement of light windows on the LED array enable the individual components to be used for various resolutions. Various LED arrays were designed for this purpose.

- Maintenance-free and adjustment-free system
  Packaging is so precise that the character generators are mechanically compatible and do not require adjustment in the unit. A movable protective shield and air-flow system in addition to a self-monitoring system make it maintenance-free.

- Repairability
  If the self-monitoring system detects the failure of one or more LEDs, individual modules can be replaced at the factory.

- Service life of character generator and uniformity of light energy
  A self-monitoring and control system capable of compensating all exposure errors over the specified service life of more than 10,000 hours was developed.

Self-Monitoring System for Automatic Detection and Compensation of Exposure Errors due to Component Tolerances and Aging Effects

Achieving superior print quality requires the photosensitive layers to be exposed with a very high degree of uniformity. i.e. the LED character generator must as far as possible emit uniform light energy at all light dots. Basically the following disturbance factors are involved:

- Different quantum efficiency levels (luminous efficiency) of the individual LEDs within an LED array;
- Differences in brightness of the LED arrays;
- Temperature dependence of LED luminous efficiency;
- Variable light transmitting capacity of the Selfoc optic over the print width as a consequence of the fiber-optic arrangement;

Differences in aging of the LEDs within a character generator since statistically the individual LEDs are not turned on with the same frequency in standard print programs.

In addition, it should be possible for the LED character generator to be matched to various print speeds. For this purpose the illumination energy of the individual dots should be adjustable over a wide range.

This whole complex of problems was resolved as a result of the systematic development of a self-monitoring and control system for the LED arrays, which is able to compensate for all exposure errors. This compensation system covers three subareas:

1) LED driver IC with integrated correction-data memories and freely selectable operating point.
2) Facility allowing automatic exposure measurement of each LED light dot and forming an integral part of the character generator (self-monitoring system).
3) Intelligent, microprocessor-controlled processing of the illumination data, including calculation of correction data and control of the LED driver ICs.

The function of the automatic exposure adjustment facility is described below:

Since the exposure energy of a light dot is the product of the LED light power and exposure time, both the exposure time of an LED and its brightness can be varied to set the energy released to a specific value. The light output power of an LED can be adjusted linearly via the conducting-state current supplied by the driver chip.

The central chip in the adjustment system is the specially developed driver IC for the conducting state current of the LEDs. In this IC the functions of print information transmission are linked with those of exposure tolerance compensation. An IC of this type drives 64 LEDs and offers the following options, among other things (see Fig. 2):

1) The print information (light dot on/off) is loaded into a 4 x 16-bit data register via a parallel 16-bit data bus.
2) A programmable current source (Q1 to Q64) is activated for an exposure cycle with each active data bit. Each current source drives a single LED with a current pulse whose length (exposure time T) and amplitude (current intensity I) are programmable.
3) In order to compensate for the differences in light power within a connected LED array, each of the 64 single LEDs can be turned on with an individual exposure time, i.e. the on-time is short for bright LEDs and correspondingly longer for weaker LEDs. Initially this ensures that the emitted light energy levels (I x T x power) within an LED array are adjusted to the same value. The actual on-time of each single LED is set by linking the external time-base signal (TB), which is identical for all LEDs, with the individual corrected exposure time for each LED. This correction value is stored in the driver IC with 3-bit resolution (ST3 to ST6).
4) The current intensities of all current sources (Q1 to Q64) of an IC are identical. The amplitude of the current intensity is set externally using analog means via a control voltage (Vx), which is the same for all driver ICs. As with the timing of the current sources, the parameter of current can also be linked with an individual current correction value for each driver IC. This correction value is stored in the driver IC with 6-bit resolution (SI). This allows batch variations in the LED arrays to be offset, i.e. each LED array in the character generator can be operated at an individual current intensity level.
5) The external setting options for the time base (Tp) and driver current (VI) allow the exposure level for the entire character generator to be matched and varied within wide limits in line with the printer requirements.

The integrated exposure measurement system in the character generator operates as follows:

The integral photodetector cell (see Fig. 3) in the housing of the character generator is mounted on a movable carriage; it is driven by a motor and can be moved along the Selfoc optic. In this way each individual LED light dot can be measured. All light dots are measured automatically. All of the measured values are digitized and stored in the main memory of the microprocessor-based controller.

Measured-value acquisition and the integrated correction functions in the driver IC are controlled and processed by the microprocessor-based controller of the character generator. Consequently, fully automatic exposure adjustment can be performed now (see Fig. 5).

In printing mode the current correction values (stored in the non-volatile RAM) are then loaded into the memories of the driver ICs prior to initiating printing.

Since the light power of the LEDs is also temperature-dependent, dynamic exposure adjustment is performed in addition to the static correction measures described above. The temperature of the LED arrays is measured by means of a built-in sensor in the LED modules. The correlation between temperature and exposure is known, so this disturbance factor can also be compensated for by tracking the driver current (VI).

Fig. 4: Schematic representation of compensation function of driver IC

Technical Highlights of the Driver IC (VLSI):
- Combination of analog and digital functions
  in 1.5 μm CMOS-Technology
- Chip size 21 mm²
- 18,000 gate functions
- 200 bit memory
- 16 bit parallel data bus
- 10 MHz data clock
- 21 bit clock, address and control bus
- 6 bit D/A converter
- Analog output: programmable constant-current sources up to 30 mA for each of the 64 channels
- 119 bonding pads for input/output signals and power supply

Fig. 5: Exposure before and after correction