Technology White Paper

Nanosecond Light Pulses

Breaking the Boundaries of High-Speed Imaging

nano drive™

New integrated LED drivers, able to deliver full power to a light in 500 nanoseconds or less, improve the performance, precision, and repeatability of high-speed imaging systems.

smart vision lights

smartvisionlights.com
sales@smartvisionlights.com

Smart Vision Lights
5113 Robert Hunter Dr.
Norton Shores, MI 49441
Phone: 231-722-1199

Nanosecond Light Pulses Illuminate the Frontier of High-Speed Imaging

While the meaning of "high speed" may seem self-evident in the context of machine vision, the term has no fixed definition independent of a particular application. It simply means that an imaging system can capture relevant data accurately and repeatably within the window of an extremely brief event, whether that be a packaged product whizzing by an inspection station, an automotive crash test, or droplets issuing from a printer cartridge.

Engineering a high-speed imaging system demands several design considerations beyond what conventional machine vision applications require. Those considerations include camera trigger latency, how field of view (FOV) influences shutter speeds, and calculating the exposure times necessary to freeze rapidly moving objects in time. Proper illumination is another important factor to consider, as it can help ease or even eliminate other design issues at higher image capture rates.

"Proper illumination" — another term more easily defined within the context of an application — means more than simply applying enough light at the correct wavelength or angle. The pulsed light sources typically used for high-speed imaging applications must achieve full brightness with a degree of speed, precision, and repeatability that can challenge even conventional LED light sources.

To address this, designers have created new LED drivers that can deliver full power to a light in 500 nanoseconds (ns) or less. The benefits extend beyond faster strobe times to also include higher output and precision control over sub-microsecond pulse shapes.

Faster Is Not Always Better

Traditionally, xenon strobes and pulsed LED light sources have been the favored solutions for freezing part motion in high-speed imaging applications. Xenon flashlamps are brighter in terms of absolute photon output, and their light pulses when strobed typically last from 15 to 30 microseconds (µs), though they can pulse as low as 250 ns if necessary. To date, the shortest pulses that conventional LED lights can effectively deliver are in the low microsecond range.

LEDs offer several advantages over xenon lamps, however, including greater ruggedness, lower maintenance, and longer lifetimes. LEDs also emit within a narrower spectral range than xenon sources, which can enhance the contrast and visibility of key features in an image.

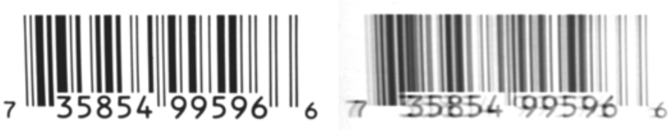
As solid-state light sources, LEDs can be overdriven to provide higher intensities versus constant operation. This involves pulsing an LED at a higher current for a brief period and switching it off for a specific rest time. As power increases, this provides a diminishing return in output, however. LEDs are typically overdriven at 4–10 times their rated currents to provide 3–8 times the rated output. In extreme cases, 10 times more output is possible. Operating at these high powers can limit the LED's duty cycle, however. For example, an LED light with a 10% duty-cycle limit in overdrive mode can be strobed for 1 millisecond (ms) but then must remain off for another 9 ms before it can be strobed again.

Compared to xenon lamps, LEDs provide better control over the duration, intensity, and shape of each pulse. This is important because the absolute intensity of a light source has less bearing on image capture than the flux density — the number of photons per unit area projected within the target FOV per one second of time.

In addition, the comparatively compact form factor of LED lights enables them to be positioned closer to the target. Applied to light, the inverse square law states that intensity decreases in proportion to the square of the distance. This decline relative to distance permits smaller LED heads positioned closer to the target to overcome their lower absolute intensity versus xenon lamps. In practical terms, this means they can achieve comparable or even better illumination than xenon sources and higher flux density across the FOV.

Banishing Blur

A vision system's ability to freeze motion in an image is a function of how precisely and quickly it puts photons to pixels. The faster the motion, the more challenging this becomes. A common goal is for each pixel of a camera sensor to detect one point on an object. If the point is moving too quickly relative to the camera's exposure time, it may be captured across multiple pixels. The resulting pixel blur causes poor image data. The best image quality will limit pixel blur to 1 pixel (px) or less, although this level of performance is not always necessary.



A vision system's ability to freeze motion in an image is a function of how precisely and quickly it can put photons to pixels. Vision system design typically assigns a certain number of pixels to ensure accurate capture of a corresponding point on a moving object, such as a narrow bar of a UPC bar code. This helps the designer calculate system features such as exposure time, FOV, and the illumination necessary to avoid pixel blur. Photo courtesy of Omron.

High-speed inspection applications often specify the allowable threshold for pixel blur, and vision engineers design systems accordingly. There are two fundamental — and complementary — approaches to design. Traditionally, engineers used the following formula to calculate the minimum exposure time required to avoid a specified pixel blur:

$$\text{pixel blur} = (\text{line speed} * \text{exposure time}) * (\text{image size/FOV})$$

So, assuming that pixel blur can equal no more than 1 px, for example, it is possible to calculate exposure time by plugging in other known quantities. If the engineer knows that the line speed is 3000 millimeters per second (mm/s), the image size is 1960 x 1080 px (using the pixel count in the direction of travel, or 1960 horizontal in this case), and the camera's FOV is 100 millimeters (mm), then:

$$1 \text{ px of blur} = (3000 \text{ mm/s} * X \text{ seconds}) * (1960 \text{ px}/100 \text{ mm})$$

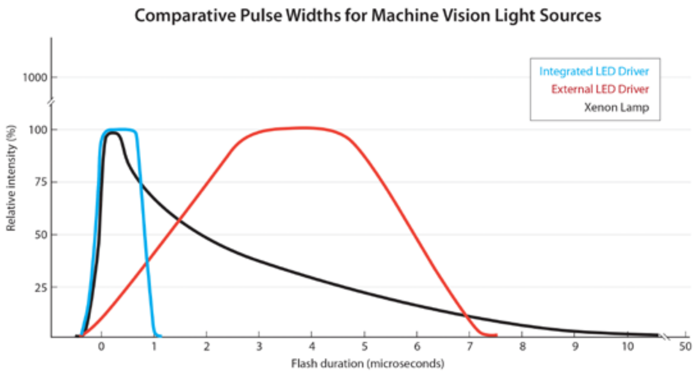
This works out to an exposure time of 0.000017 seconds, or 17 µs.

Exposure time is one side of the system design coin. Illumination is the other. The faster a feature of interest moves through a camera's FOV, the more quickly the camera's shutter needs to open and close to freeze it in time. As shutter speed increases, the target needs to be more brightly illuminated to ensure proper exposure at each pixel.

Widening the aperture of the camera will help it capture more light. But this decreases depth of field, which can be problematic in some applications. Similarly, increasing camera gain can brighten output, but this also amplifies image noise. Achieving high intensity and evenly distributed illumination across the scene at short exposure times remains the best solution for machine vision applications in which image quality determines success.

The Impact of Pulse Rate and Shape

Given the limited number of ways in which a camera system can be tweaked to gather more light during short exposure times, it is advantageous to illuminate the object of interest more intensely. As pulse lengths decrease to accommodate shorter camera exposure times, the shape of each pulse — the time it takes the LED to reach full intensity and then switch off — becomes increasingly important. Measured in intensity over time, an LED light pulse should exhibit a square shape, which indicates that the die is achieving full output power more quickly. This ensures that an LED is not still "rolling on" when the camera shutter opens but is illuminating the target with its full intensity. Otherwise, pixel blur can begin to creep in.



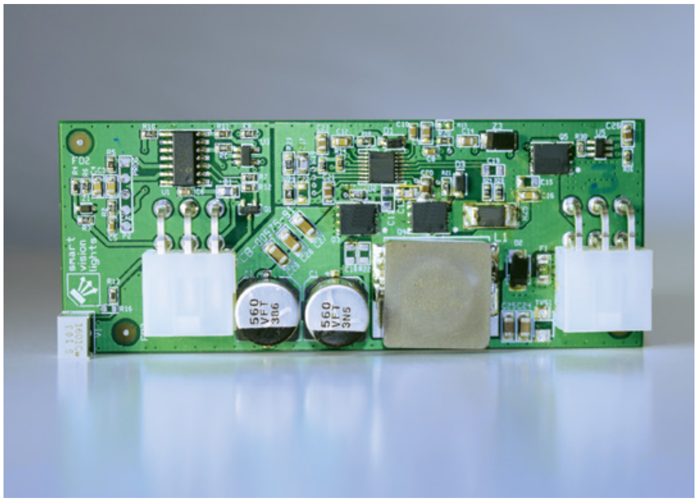
The shape of a light pulse is as important as its absolute intensity. Though xenon lamps (black line) can emit comparatively higher intensities and shorter (25 µs) pulses than LEDs, only 10% of their light is effective due to poor pulse control and fast off times. LED sources with external controllers (red line) are capable of emitting more controlled pulses than xenon sources. However, inescapable parasitic impedances of external wiring contribute to broader pulses with sloped edges, resulting in system jitter (shaded area) and blurred images at fast exposure times.

Contrast the performance of these sources with the controlled pulse shape from LED designs that integrate driver and controller in close proximity on the motherboard (blue line). This architecture eliminates impedances from wiring and allows the LED to achieve full power in the 300–500 ns time frame and to deliver repeatable, high-intensity pulses with durations in the microsecond range.

While delivering full intensity more quickly is necessary to achieve sharp, microsecond light pulses, the key benefit of this capability is greater control and precision when syncing a light pulse to a camera's exposure time. Conventional LED systems designed for high-speed imaging can deliver pulses in the same microsecond duration using external controllers. However, the physics of such systems introduces inescapable latency issues that dull the edge of that square pulse shape. The longer the cable, the greater the impact from latency. Even a 2-foot cable connecting driver and light source will impose significant parasitic impedances that contribute substantially to system jitter and extend the rise to full intensity.

Designing Nanosecond LED Drivers

Integrating the driver and controller in close physical proximity to each other on an LED's motherboard eliminates the need for external wiring and ensures that high-current pulses from the driver are delivered directly to the LED across comparatively short, impedance-controlled printed circuit board traces. Smart Vision Lights took such an approach with the development of its NanoDrive™ driver to minimize resistance and parasitic electrical losses from external cables. LED lights featuring NanoDrive are thus capable of quickly delivering tens of amps to the die to achieve full power in 500 ns or less with comparable off time. Applied to high-speed imaging, NanoDrive light sources permit incredibly short image acquisition times and precision timing that would be impossible to achieve using LED sources driven by external controllers and wiring.



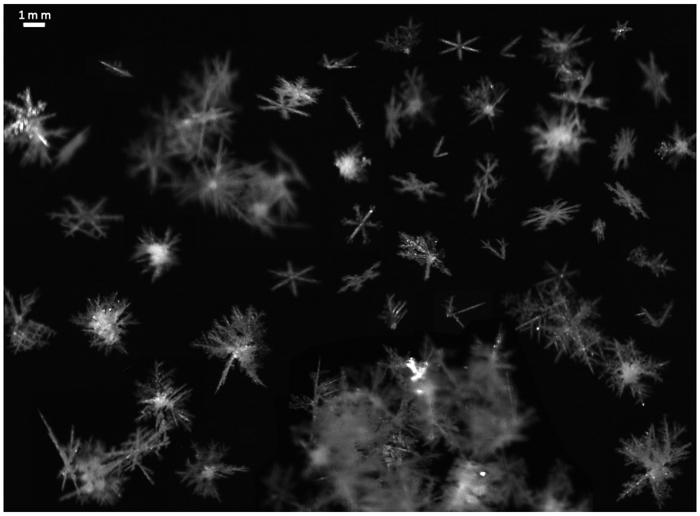
Integrating the LED and driver in close physical proximity to each other on the motherboard helps ensure that high-current pulses from the driver are delivered directly to the LED across comparatively short, impedance-controlled printed circuit board traces. Such an approach enables Smart Vision Lights' NanoDrive to quickly deliver tens of amps to the die to achieve full power in 500 ns or less with comparable off time.

LEDs powered by this advanced new driver technology can be configured to enable sub-microsecond pulse edges and to maintain 1 µs pulse widths. At a 10% duty cycle, such configurations are capable of 100,000 strobes per second. Additionally, faster on/off rates help compensate for latency issues during asynchronous operation, wherein a camera shutter is triggered by an external source, such as an approaching product tripping a photosensor.

The higher pulse rate and better control of integrated LED drivers such as the NanoDrive promise to enable accurate and repeatable high-speed image capture at substantially shorter exposure times.

Nano Pulses in Practice

Consider a high-speed application in which the camera must scan UPC or EAN-13 bar codes on parts moving up to 150 inches (3.8 m) per second, with a rate of up to 50 parts per second.



By enabling shorter, brighter LED pulses with edge resolution in the microsecond range, Smart Vision Lights helped one climatologist capture high-resolution images of falling snowflakes in broad daylight. More importantly, the precise control over pulse shape made it possible to capture such images with a comparatively low-cost CMOS camera system. Photo courtesy of Professor Aaron Kennedy, University of North Dakota.

Assume that the narrow bar width is 13 mil (0.013 inches) and that at least 2 px per thin bar are assigned to capture it for consistent decoding. However, to further ensure consistent decoding at such speeds, the tolerance for pixel blur is established at 0.5 px.

These specifications translate to an image pixel size of 0.0065 inches and a desire to keep motion-induced blur under 0.00325 inches. At 150 inches per second, the narrow bar of the code would traverse that half pixel within 0.0000216 seconds, or 21.6 µs.

Accurately scanning codes without pixel blur at that speed is a challenge with conventional cameras, which have a minimum exposure time in the range of 50 µs or longer. The minimum strobe durations of externally driven LED light sources present a further hindrance to such fast exposure times. Not only will parasitic cable impedances limit resolution to the microsecond range but such sources offer limited ability to deliver significant current for short intense bursts.

All these issues can be resolved by an LED driver that delivers full power with rise and fall times under 1 µs while allowing tens of amps to reach the LEDs for the main duration of the pulse. The duty cycle of such an LED design would exceed 50 pulses per second.

Conclusion

For all the sophistication underlying built-in LED drivers capable of pulse-edge resolutions measured in nanoseconds, the end benefit is simplicity. A competent vision designer can apply complex trigger schemes, expensive cameras, or software tricks to optimize image capture at extremely high speeds. Such solutions, however, always face the headwinds of an end user's cost-benefit analysis.

By enabling shorter, brighter pulses characterized by on/off times in the nanosecond range, new advanced LED drivers will boost both accuracy and throughput for high-speed inspection applications. Importantly, the greater control they afford will also help streamline the design, implementation, and cost of these systems.

Smart Vision Lights thanks Omron's Microscan Group for providing the details relevant for our hypothetical bar-code scanning application.