Optimized Design for MEMS-Based Automotive Laser Pico Projectors

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Introduction
The automotive environment is rich with displays and information systems. A constant stream of information surrounds us, some vitally important, or comforting, or entertaining, and even just informative. This is valuable, but not absolutely essential. As vehicle operators, our greatest need is critical data about the vehicle’s operation...in real time.

Car makers use a variety of technologies to provide this critical information to a driver including discrete LEDs, instrument gauges, and liquid display technology. While every vehicle model is different, this information is presented so effectively and consistently that virtually every occupant can quickly adapt and extract information from unfamiliar vehicles. This data and information can be projected virtually with a heads-up display (HUD) in the driver’s line of sight at the front of the vehicle. With the continuous improvement in display technologies, HUDs are being seen in luxury cars. As costs and sizes drop and as performance improves, these HUDs are being adapted for midsize vehicles and will soon be found in economy cars.

The newest HUD technology is implemented by moving MEMS mirrors and color lasers, also known as pico laser projectors. These laser projectors have infinite focus, readability in sunlight, superb color saturation, and small size, all of which make them an ideal medium for the automotive infotainment environment.

This article looks at modern HUD technology for automobiles and examines a new approach to laser pico projector solutions. Built around a high-performance triple laser driver, an integrated “bridge-chip” solution reduces size, cost, and design complexity compared to older TFT, CRT, and DLP technologies. And all these advances come from the benefits of laser light.

The Fundamentals of HUD Technology
At the heart of the newest HUD technology is a miniature laser projector (Figure 1), a small MEMS imaging system that projects an array of pixels onto virtually any surface. Instead of using an emitting area like TFTs and CRTs, the pico laser projector emits a beam of colored light that draws out images, instruments, and indicators. The beam scans a raster pattern similar to a CRT-based television. Individual picture elements, or pixels, are created by combining the shades and intensities of the three primary colors (see Figure 1).
Using an 8-bit DAC integrated in the MAX3601 laser driver, each individual pixel can generate 24 bits of RGB color with the rich saturation of a laser to produce over 16 million unique colors. Since the laser is emitting each color at a distinct frequency, the colors are vivid and can be “supersaturated” to get a driver’s attention. Greens are made to appear unnaturally green to stand out in a forest or jungle environment.

The combined beam is presented to the scanning MEMS mirror chip, which scans horizontally to create a scan line, then ramps vertically to combine lines into a display plane. The resulting high-definition (HD) image is refreshed at 60Hz and is always in focus—another benefit of laser technology, especially with curved windshields.

**Challenge of Driving a Miniature Projector**

In cathode ray tubes (CRT), each line starts from the left side and is returned quickly to the start of each line using a flyback mechanism (**Figure 2**). Leveraging modern digital technology, a pico laser projector sends odd lines in a forward pattern and even lines in a reverse pattern (**Figure 3**).
Figure 2. With CRTs, during blanking time the electron beam is turned off and a flyback re-retraces it for the next line.

Figure 3. With pico projectors, the lasers turn on for the entire left-to-right line draws; then turn off in the inactive video as it steps down vertically; then on again as it draws from right to left in the active video.

Another difference between CRT and pico laser projector technology is the timing variation, which depends upon the pixel’s location in the horizontal scan line. With MEMs technology, the mirrors must accelerate and decelerate at the beginning and end of each line. As the inertia of the MEMS mirror plays out, it slows down before reaching each end point, thus forcing the pixels sent with a constant pixel clock to “bunch” at the ends. Uncorrected, this pixel bunching would be seen as higher left-right edge brightness and scalar distortion (Figure 4).
Figure 4. The row of colored dots above represents MEMS pixel spacing. Because the moving mirrors are mechanical, they take time to accelerate and decelerate. This angular velocity distortion is compensated with clever techniques.

One method to correct this bunching is to create a virtual pixel and interpolate, or drop, subpixels during various segments in the scan line. In the middle of the scan line, where the MEMS mirror scans at its fastest rate, subpixels are sent as one per virtual video clock. At the edges, only every third, fourth, or fifth subpixel is sent (Figure 5).

Figure 5. At the left edge, pixels are interpolated—1 pixel per 3 subpixel clocks. In the middle, there is one pixel per subpixel clock.

The Complexities of a Traditional Laser Projector Design

Controlling each high-speed laser pixel requires a device that can turn the pixel on and off quickly, plus many high-level interfaces, resources, and functional blocks (Figure 6). The MAX3601 RGB laser driver (Figure 7) is well suited to this task because it can modulate pixel edges in as little as 1ns. Since lasers have high-capacitive and inductive loads, turning off a laser pixel is challenging. With the support of Maxim’s unique Pixel-Off Assist function, 1ns fall-off edge rates are possible. A triple-channel DAC running at 250MHz and higher ensures video speeds at HD resolutions.
Figure 6. The traditional architecture for a pico laser projector SoC requires many high-level interfaces, resources, and functional blocks.

LCDs, DLP, and other backlit technologies are challenged by nighttime and tunnel conditions where backlight leakage can create shadows and ghost images. This is not an issue with laser projectors, as the lasers light each pixel with a front-light approach. Since laser projectors add light on a pixel-by-pixel basis, except for laser bias current, power is always less than 100% full on. The power can be turned off during blanking and when the pixels are black. In this way power consumption is reduced to 80mW for an all-black scene. The MAX3601 has a multiplier DAC that can safely modulate the light output power from 1 lumens appropriate for darkness all the way up to 30k lumens in bright sunlight.

Figure 7. The integrated MAX3601 triple-laser diode driver Interfaces cleanly with our bridge-chip design, resulting in a highly integrated solution. See below discussion of the bridge-chip design.

Laser colors are continuously monitored to ensure a consistent color over a wide variety of temperatures and to ensure safe laser conditions. Color sensors are also used to compensate for brightness under daylight, shade, or nighttime conditions. Since the laser is always in focus, complex and costly optics do not consume valuable space in a light engine. Consequently, the laser projector fits into the tightest of spaces in the smallest of vehicles. Because today's HUD architecture uses seven or more devices for this color presentation, the space that it saves becomes exponentially more valuable.

Bridging Worlds: a Bridge Chip Offloads Real-Time, Demanding Processing

In a traditional laser projector, the video-laser controller SoC has nearly the same horsepower as the host SoC controller. It also has a similar-sized video frame buffer, and GPU functionality. Pico projector functionality can consume a processor's bandwidth with simultaneous, demanding real-time tasks. Traditional designs send data from the video frame buffer memory to a pico projector processor's frame buffer memory, then to be parsed out line by line to the MEMS mirror. This is redundant and inefficient.

It is time to eliminate this redundancy and to rebalance the cost, power, and workload of each key component. A bridge chip brings back the balance.
By using the bridge chip (Figure 8) in a pico laser projector, the data flow is streamlined and efficient. Two video frame buffers are reduced to one. Real-time events are offloaded to the bridge chip, no longer burdening the SoC with performance-draining interrupts. Cost and power are reduced. The SoCs' GPU handles the memory addressing of the FIFO-LIFO scan line inversion and compensates for MEMS inertial motion. The work load is balanced.

That is the theory. Fine, but where to start? Let's look at the projector SoC's functions and determine how to better parcel them. Both the host SoC processor and the video processor have 6MB frame buffer memories, so we can eliminate that memory and replace it with a few line buffers. This will require careful timing between the high-speed video input and the much slower line video rate of the MEMS mirror; it is especially critical across the various resolutions needed to support this HUD application. The bridge chip ensures that the line buffer is always full while also checking that the host SoC is powered down or minimal key functions are activated, both to save system power.

Interrupting the SoC to handle mundane real-time tasks and service predictable interrupts causes higher SoC power consumption during idle time. This is wasteful because a bridge chip is better suited to handle real-time tasks. A bridge chip maximizes system efficiency.

The host SoC is ideally suited to handle GPU tasks such as scaling; color correction; white balancing; dewarping (to compensate for the curved surface of a windshield or the pin-cushioning effects from a flying spot architecture); and sending data to fill the bridge chip's line buffer. Reversing the memory addressing from left to right and right to left is a simple tasks done by the SoC with a few lines of code. This SoC will preprocess this data and send it to the bridge chip without needing to know MEMS timing needs.

A tiny microprocessor or state machine embedded in the bridge chip handles simple housekeeping chores and gives a designer the flexibility to add custom features.

This four-chip solution built around the bridge chip creates a highly integrated and programmable pico laser projector that connects to standard video interfaces like HDMI and VGA. It handles all projector-related tasks. But can we shrink the design even more?
Figure 8. A four-chip pico laser projector solution can be implemented with a bridge chip, but a more highly integrated solution would be even better.

For applications requiring even higher integration, such as mobile phones and other small consumer devices, the bridge chip can be combined with other functions. For example, let’s make the bridge chip programmable to accommodate distance sensing; barrel distortion correction; mirror acceleration and deceleration compensation; intensity, color, and vibration stabilization. Hardware blocks for dithering, zigzag raster scanning, Endian video data alignments, variable resolution and brightness controls, and power management top off the wish list. Let our processor-driven core run hardware algorithms in software fast enough to refresh a virtually solid flicker-free image. Now the prior four-chip solution can be condensed into one (Figure 9).

Figure 9. This next-generation highly integrated bridge chip is reduced to a one-chip solution for a pico laser projector.

Conclusions
Pico laser projectors are being embedded into smartphones, tablets, laptops, wearable computers, and automotive HUD displays. With over half a million HUDs shipped in automobiles in 2013 and the growth rate estimated to be 20% to 30% for at least the next five years, the OEM requests to save HUD space and cost are understandable. A highly integrated bridge chip, like the solutions in Figures 8 and 9, will significantly offload a host processor and reduce the space, power, chip count, and processing resources needed.

A CPU-centric bridge chip for a HUD pico laser projector enables quality peripheral integration and a fast processor to run algorithms in software. This bridge-chip approach reduces hardware, power, and complexity. It provides flexibility for new ideas and approaches for the HUD.

What about the future? Pico laser projectors, using the flying spot architecture, will extend their functionality into 3D camera and gesture applications. These will be available in PCs and tablets by late 2014 followed by HUD devices in cars.
Soon, drivers will merely wave a hand at their Infotainment console to turn up the radio volume or switch to a different channel. Their eyes will stay safely on the road looking through their laser HUD. A highly integrated bridge-chip for a pico laser projector and a reference design will give more companies access to this technology for quicker, creative, and profitable uses.

About the Authors

Mike Roberts joined Maxim seven years ago as a business manager, and is now an Executive Business Manager. Mike has six patents. He attended the Fachoberschule in Nurnberg, Germany, and got his BSEE from Iowa State University in the U.S. He has an MBA from the University of Dallas. Mike loves to spend time with his family and friends. He flies planes, rides motorcycles, and does CNC machining and 3D printing. And of course, he also loves designing electronics.

Walter Chen joined Maxim Integrated in 2000 as a product definer and is now a senior applications engineer with the title of Senior Principal Member of Technical Staff. Walter is very interested in mixed-signal processing and has 15 U.S. patents, including one while with Maxim. He has a BSEE from Polytechnic University, an MSEE from Cal Tech, and a Ph.D. in EE from Polytechnic University.