Scanned Laser Pico projectors: Seeing the Big Picture (with a Small Device)
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_Pico projectors are the latest technology to prove that big things often do come in small packages. These tiny projectors are embedded in mobile devices to provide large-screen displays that can be viewed from anywhere. This paper describes Microvision’s PicoP® display engine, a biaxial MEMS scanning laser projection technology._

It’s amazing what we carry in our pockets these days. From cell phones to iPods to PDAs, we have at our fingertips connectivity with friends and colleagues around the world, libraries of text, music, photos, videos and more.

Unfortunately, the displays that we use to view all this information are also small; they are flat-panel screens with just a few square inches of display area. No wonder that projectors that display large images from within hand-held electronic devices—pico projectors—are drawing so much attention in the tech world. With pico projectors, you can project a full-size image onto whatever is near at hand, whether it be the wall, your shirt, or a piece of paper. Pico projectors represent a core enabling technology for the future growth of portable devices.

Moreover, scanned laser pico projectors have an infinite focus that can be projected onto surfaces with any 3D depth profile and remain in focus. The possible applications are various and many. Aside from having a larger format for typical mobile applications, such as reading e-mail and sharing pictures, pico projectors could be used for impromptu business presentations or perhaps scientific visualizations.

From a business point of view, the size of the market for pico projectors is extremely large. In 2007, there were worldwide sales of more than 1 billion mobile phones, 200 million personal media players, 125 million digital cameras, and 25 million Nintendo DS handheld game devices. And it’s not just device manufacturers who stand to benefit by offering a larger-screen viewing experience. Service providers would also have the opportunity to sell bandwidth, and content providers could sell more compelling and rich multi-media content.

To enable customers to take advantage of this large market opportunity, Microvision now offers organizations the PicoP® Evaluation Kit (PEK), a turn-key development kit and support services based on the company’s ground-breaking display innovation, the PicoP display engine. The PEK provides all the necessary elements to begin exploring and designing a diverse range of laser-based pico projection applications, including displays, non-contact measurement, and image capture applications. More information and specifications about the PEK are located
What follows is a detailed description of the PicoP® display engine technology architecture, highlighting the features and benefits of Microvision’s platform technology.

**Scanned laser: A simple projector design**

The figure below shows the basic layout of Microvision’s PicoP display engine. The architecture is quite simple, consisting of one red, one green, and one blue laser, each with a lens near the laser output that collects the light from the laser and provides a very low NA (numerical aperture) beam at the output. The light from the three lasers is then combined with dichroic elements into a single white beam.
Using a beamsplitter or basic fold-mirror optics, the beam is relayed onto a biaxial MEMS scanning mirror that scans the beam in a raster pattern. The projected image is created by modulating the three lasers synchronously with the position of the scanned beam. The complete projector engine, also known as the Integrated Photonics Module, or IPM, is just 7 mm in height and 5 cc in total volume.

There are a number of advantages related to the simple design. The essence of the design is that, with the exception of the scanner, the rest of the optics engine deals with making a single pixel. All three lasers are driven simultaneously at the levels needed to create the proper color mix for each pixel. This produces brilliant images with the wide color gamut available from RGB lasers. The colors are not created sequentially and thus there is no color breakup. (In color sequential projectors, color breakup can be seen when the viewer moves his head rapidly or when the projector itself moves, as might be the case with handheld projectors.)

Direct-driving of the lasers pixel-by-pixel at just the levels required brings the advantages of better power efficiency and inherently high contrast. The efficiency is improved, since the lasers are only on at the level needed for each pixel. The contrast is high because the lasers are completely off for black pixels rather than using an SLM (spatial light modulator) to deflect or absorb any excess intensity. The single-pixel collection optics are optimized to take the particular beam properties of the red, green, or blue laser and relay it through the scanner and onto the screen with high efficiency and image quality. The pixel profile is designed to provide high resolution and infinite focus with a smooth non-pixellated image. The single pixel design also gives high optical efficiency compared to other projector technologies. With the simple optomechanical design, the electronics design becomes more challenging as some of the display complexity is moved to the electronics. This approach requires the ability to accurately place pixels and to modulate the laser at pixel rates.

_Infinite focus_

In Microvision’s PicoP display engine, there is no projection lens. The projected beam directly leaves the MEMS scanner and creates an image on whatever surface it is shone upon. Because of the scanned single pixel design, light-collection efficiency is kept high by placing the collection lenses near the output of the lasers, while the output beam NA is very low. By design, the rate of expansion of the single-pixel beam is matched to the rate that the scanned image size grows. As a result, the projected image is always in focus.

This special property comes from dividing the task of projecting an image into using a low NA single-pixel beam to establish the focus and a 2D scanner to paint the image. In fact, the MEMS scanner plays the role of fast projection optics by producing an image that expands with a 43-degree horizontal projection angle.
This can’t be achieved in more traditional projector designs, where projection optics are used to image a spatial light modulator onto the projection screen due to conflicting constraints on the projection lens. On the one hand, a short focal length lens is needed to create an image that grows quickly with projection distance, while, on the other, the lens aperture must be kept large to maximize the projector’s brightness. This dictates the need for a fast projection lens, with F/2 lenses being typical. Depth of focus is proportional to F-stop. The tradeoff for traditional projector designs balances the rate the image grows with distance, light efficiency and depth of focus.

The figure above shows the spot size as a function of projection distance for the PicoP. Notice that the spot size grows at a rate matched to the growth of a single pixel. For comparison, the figure also includes the estimated spot growth for an imaging-type projector that has been focused for a 0.5-m projection distance. We assume a moderately fast F/4 projection lens and the focal length chosen to give the same 43° rate of growth with projection distance for the projected image. The depth of focus for an imaging-type projector is much reduced compared to the scanned laser.

To the user, this means that the imaging-type projector must be refocused as the projection distance is changed, and that portions of the image will be out of focus when one projects onto surfaces that present a range of projection distances within the image—for example, projecting onto a flat surface at an angle or onto surfaces with a significant 3D profile.

Shifting projector functions from optics to electronics
With the simplification of the optomechanical projector engine design, a greater portion of the display emphasis is shifted to the electronics. This allows the physical size of the projector engine to be minimized to fit with hand-held consumer products. The electronics, which can be integrated more straightforwardly into consumer products, take over tasks that are done optically with other projector designs. Some of the tasks that are shifted include pixel positioning, color alignment and brightness uniformity. With the PicoP, the video processor and MEMS controller have been implemented as custom ASICs that drive the IPM scan engine.

**MEMS Drive ASIC**

The MEMS Drive ASIC drives the MEMS scanner under closed loop control. The horizontal scan motion is created by running the horizontal axis at its resonant frequency—which is typically about 18 KHz for the WVGA (Wide Video Graphics Array) scanner. The horizontal scan velocity varies sinusoidally with position. The MEMS controller uses feedback from sensors on the MEMS scanner to keep the system on resonance and at fixed scan amplitude.

The image is drawn in both directions as the scanner sweeps the beam back and forth. This helps the system efficiency in two ways. First, by running on resonance, the power required to drive the scan mirror is minimized. Second, bi-directional video maximizes the laser use efficiency by minimizing the video blanking interval. This results in a brighter projector for any given laser output power.

The vertical scan direction is driven with a standard sawtooth waveform to provide constant velocity from the top to the bottom of the image and a rapid retrace back to the top to begin a new frame. This is also managed in closed-loop fashion by the MEMS controller based on position feedback from the MEMS scanner to maintain a smooth and linear trajectory. The frame rate is typically 60 Hz for an 848 x 480 WVGA resolution; it can be increased when the projector is used in lower resolution applications.

**Video ASIC**

The video processor accepts either RGB or YUV (NTSC/PAL) input. A video buffer is provided to allow artifact-free scan conversion of input video. Gamma correction and colorspace conversion are
applied to enable accurate mapping of input colors to the wide laser color gamut. A scaling engine is available for upconverting lower resolution video content.

A proprietary Virtual Pixel Synthesis (VPS) engine uses a high-resolution interpolation to map the input pixels to the sinusoidal horizontal trajectory. The VPS engine demonstrates how projector functions have been shifted from the optics to the electronics in the scanned laser paradigm. It effectively maps the input pixels onto a high-resolution virtual coordinate grid. Besides enabling the repositioning of video information with subpixel accuracy onto the sinusoidal scan, the VPS engine optimizes the image quality. Brightness uniformity is managed in the VPS engine by adjusting coefficients that control the overall brightness map for the display.

Optical distortions—including keystone, parallelogram, and some types of pincushion distortion—can be compensated by using the VPS engine to adjust the pixel positions. The VPS engine also allows the pixel positions for each color to be adjusted independently. This simplifies the manufacturing alignment of the IPM by relaxing the requirement that the three laser beams be perfectly aligned. The positions of the red, green and blue pixels can be adjusted electronically to bring the video into perfect alignment, even if the laser beams are not. This capability can also be used to compensate for some types of chromatic aberration if the PicoP is used as an engine in a larger optical system.

Mapping from digital video coding to laser drive is performed by the Adaptive Laser Drive (ALD) system. The ALD is a closed-loop system that uses optical feedback from each laser to actively compensate for changes in the laser characteristics over temperature and aging. This ensures optimum brightness, color and grayscale performance. Unlike other display systems, optical feedback is incorporated to ensure optimum color balance and grayscale.

**Components**

**Biaxial MEMS scanner**

The biaxial MEMS scanner is made using standard bulk silicon MEMS fabrication processes. The WVGA pico projector scanner has a scan mirror diameter of approximately 1 mm, and it produces an active video scan cone of 43.2° by 24.3°.

The scanner uses moving-coil actuation with a single drive coil, which can be seen on the vertical
scan frame in the photo with just two drive lines as shown. The single coil design simplifies the fabrication of the MEMS scanner and reduces the number of required interconnects. The MEMS die is housed in a package with small magnets that provide a magnetic field oriented at approximately 45° to the scan axes. A single composite drive signal is applied that contains the superposition of the fast-scan horizontal drive at the resonant frequency of the horizontal mirror motion and the 60 Hz vertical drive sawtooth waveform.

The mechanical design of the MEMS scanner allows motion along only the two orthogonal scan directions. Mechanical filtering, resulting from the different mass and flexure stiffness governing horizontal and vertical motion, sorts the drive signals by frequency content, inducing the 18 KHz resonant motion of the horizontal axis and the 60 Hz sawtooth motion of the vertical axis. Piezo-resistive sensors provide scan mirror position feedback to the MEMS controller ASIC to maintain closed loop accuracy of the desired scan mirror motion.

Lasers

Technology for the red and blue lasers in the PicoP leverages the technology of similar lasers that are used for the optical disk storage industry. The wavelength requirements are shifted somewhat, but the basic technology is the same—GaAlInP red laser diodes and GaN blue laser diodes.

Pico projectors incorporate green lasers as well. Prior to the push for laser projectors, green lasers had not been used for any similar high-volume applications. The technology for the green laser in the PicoP is based on infra-red lasers developed for the telecom industry, the other massive market for laser technology. Robust near-infra-red laser diodes with very high modulation bandwidths are combined with a frequency-doubling crystal, usually periodically-poled lithium niobate, to produce a green laser that can be directly modulated. With an eye toward the burgeoning pico projector industry, several companies, including Corning and OSRAM, are ramping up production of suitable green lasers.

The choice of which wavelength to use for the lasers is based on two considerations. First is the response of the human eye (the photopic response) to different wavelengths. This response is a somewhat Gaussian-looking curve that peaks in the green-wavelength region and falls off significantly in red and blue. The amount of red and blue power needed to get a white-balanced display varies rapidly with wavelength.

For example, eye response increases by a factor of two when the wavelength is changed from 650 nm (the wavelength used for DVD drives) to 635 nm. This allows the required laser power to drop by the same factor, making a projector that is lower power. Similarly, the blue laser should be chosen to have as long a wavelength as possible. Currently, blue lasers in the range of 440 to 445nm are the best practical choice. As the industry grows, longer wavelengths in the range of 460 to 470 nm may become a better option.
The second consideration is color gamut. Since the photopic response is peaked all through the green wavelength range, the green wavelength should be chosen where it will be most useful for enhancing the color of the display. Green lasers at 530 nm are a good choice for maximizing the color gamut.

The ability to directly modulate the lasers is at the heart of the scanned laser pico projector technology. Pixel times at the center of the WVGA scanned display are on the order of 20 ns. Lasers therefore need modulation bandwidths on the order of 100 MHz.

**A path forward**

The first generation of pico projectors are being launched this year. These super-small, low-power projector systems will open up the display bottleneck for mobile devices, allowing information to be accessed and shared more easily from portable devices. With the high volumes expected, there is great market opportunity for key components such as red, green and blue lasers.

The scanned laser projector paradigm provides a path forward to higher-resolution projectors without growth in size. Unlike fixed pixel-based projector technologies—in which increased resolution means growth in the number of pixels in the array—the single-pixel, single-scan-mirror nature of the PicoP engine remains the same, even as the resolution of the projected display increases.

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**[References and Resources]**
