An Alternative Architecture for High Performance Display

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Abstract

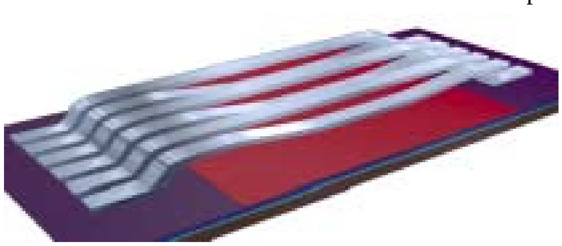
The Grating Light Valve (GLV™) technology is being used in an innovative system architecture to create a high resolution projected image by optically scanning a linear array of GLV pixels. We will discuss the real-time video processing used to optimize the performance of this unique architecture for applications such as Home Theater and Electronic Cinema.

Introduction to the GLV Technology

The Grating Light Valve technology is a means for creating a high-performance spatial light modulator on the surface of a silicon chip. It is based on simple optical principles that leverage the wavelike behavior of light, using diffractive interference as the basis for discriminating between *on* and *off* pixel states. A GLV array is fabricated using conventional CMOS materials and equipment, adopting techniques from the emerging field of Micro-Electromechanical Systems (MEMS). Pixels are comprised of a series of identical mechanical structures, fabricated using very few masks and processing steps. The end result is a unique combination of high performance, reliability, and low cost at production volumes.

Optical Principles of GLV Pixels

A GLV pixel is an addressable diffraction grating created by moving microscopic planar structures. A typical GLV pixel consists of an even number of parallel, dual-supported "ribbons" formed of silicon nitride and coated with a reflective aluminum top-layer

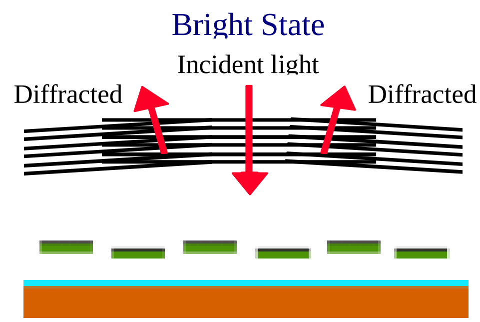


(Figure1).

Figure 1: Typical GLV pixel showing alternate ribbons being addressed.

These ribbons are suspended above a thin air gap allowing them to move vertically relative to the plane of the surface. The ribbons are held in tension, such that in their unaddressed state, the surfaces of the ribbons collectively function as a mirror. A GLV pixel is addressed by inducing a voltage potential between the top of the ribbons and the substrate, thereby deflecting alternate ribbons. Viewed in cross-section (as in Figure 2), the up/down pattern of reflective surfaces creates a square-well diffraction grating [1].

Figure 2: Diffractive (bright) state of a GLV pixel



The GLV device uses digitally-generated signals to generate specific drive voltages for each pixel, achieving precise variable control over the proportion of light that is reflected or diffracted.

The Scanned Linear GLV Architecture

The Scanned Linear GLV Architecture was presented for the first time at SID '98 [2]. In contrast to a 2-D array made up of physical pixels that correspond to each bright or dark spot in the final image, the Scanned Linear GLV Architecture consists of a linear array of physical GLV pixels oriented along a vertical column of image data. Once per image refresh, this linear array is optically scanned across the screen to produce a complete two-dimensional image. During one scan, each pixel writes successive values corresponding to one entire row of image data. In this way, a single scan of the linear GLV array creates the complete image (Figure 3).

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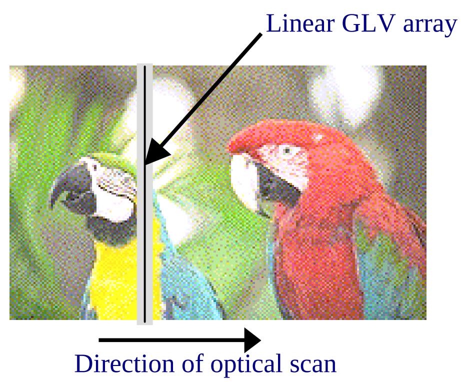

Figure 3: The Scanned Linear GLV Architecture

Modulator Requirements

Considering the fundamental advantages of a scanned linear architecture, why doesn't everyone use one? Such an architecture imposes severe performance criteria on the spatial light modulator used. Specifically, the spatial light modulator must meet three fundamental requirements:

1. It must be capable of extremely fast switching speeds.
2. It must be capable of withstanding very high optical power density.
3. It must be capable of rendering continuous tone gray scale

The GLV technology has unique performance advantages in each of these areas. Thus, we believe that *only* the GLV technology can support the Scanned Linear Architecture for high quality, high-resolution images, such as those required for HDTV and Electronic Cinema.

The Challenge of 1080p

Of the numerous HDTV standards defined by the ATSC, the 1080p specification (1920 x 1080 pixels with progressive scan) provides the highest image quality for large screen HDTV and Home Theater applications. However, due to prohibitive bandwidth requirements and modulator costs, it is not surprising that systems today are adopting the 720p (fewer pixels) or 1080i (interlace scan) standards.

Traditional displays fall into one of two system architectures. The first is the scanned beam approach (exemplified by CRT technology) where a bright spot of light on the screen is swept horizontally across a series of separate scan lines to display a complete 2D raster. Consider the ramifications of supporting the 1080p standard with this approach. Over two million pixels (1920 x 1080) need to be updated each screen refresh by a single drive channel. At a 60Hz refresh rate to avoid flicker and 10-bits/pixel, a single drive channel would have to be capable of supporting ~ 1.5 Gbit/s bandwidth. This is a daunting task for system electronics. Furthermore, there is an inherent trade-off between effective resolution and scan rate. Higher pixel counts require higher scan rates, resulting in pixel smearing and an overall lower effective resolution.

The second traditional display architecture is the 2D panel (exemplified by LCD, DMD, LCOS and most other emerging display technologies) where one physical pixel is fabricated for each point in the image. System bandwidth is not the limiting issue for supporting 1080p with this approach, since the row or column drivers must typically only supply data at the *line rate*. 1080 lines per refresh at 60Hz and 10 bits/component requires only ~ 650 Kbit/s, orders of magnitude lower bandwidth than the scanned beam approach. However, the architecture requires more than two million active pixels that must be fabricated and yielded within acceptable tolerances. Thus, the complexity of the 2D panel and its associated manufacturing costs prohibit these 2D architectures from cost-effectively supporting the 1080p standard.

The Scanned Linear GLV architecture leverages the unique capabilities of the GLV technology to make 1080p practical by supporting both low modulator cost and low system bandwidth. With this approach, only 1080 physical pixels are fabricated to render a complete 1920 x 1080 image-- three orders of magnitude fewer pixels than the 2D approach. In addition, because this scanned linear architecture uses such a small array, many GLV device candidates can be fabricated on a single silicon wafer with high production yields and low costs. Regarding system bandwidth, the architecture requires only 1080 drivers that supply data at the *column rate*. 1920 columns per refresh at 60Hz and 10-bits/component requires only 1.2M bit/s bandwidth, three orders of magnitude lower than the scanned beam approach.

Video Processing Architecture for a Scanned Linear GLV Projection System

Silicon Light Machines has developed a 1080p projection display prototype based on the Scanned Linear GLV architecture. The system receives 1080p video data at 24 or 30 fps via a standard SMPTE 292M serial digital interface. The electronics architecture supports the following system performance:

- 1920 x 1080 resolution
- Up to 120 Hz refresh, progressive scan
- 10 bits/channel R,G,B

While leveraging many traditional video-processing techniques, we have also developed several processing steps that are unique to a scanned linear architecture.

This paper describes a complete electronics system that is suitable to support a GLV-based 1080p projection display, as implemented in our current prototype projection system.

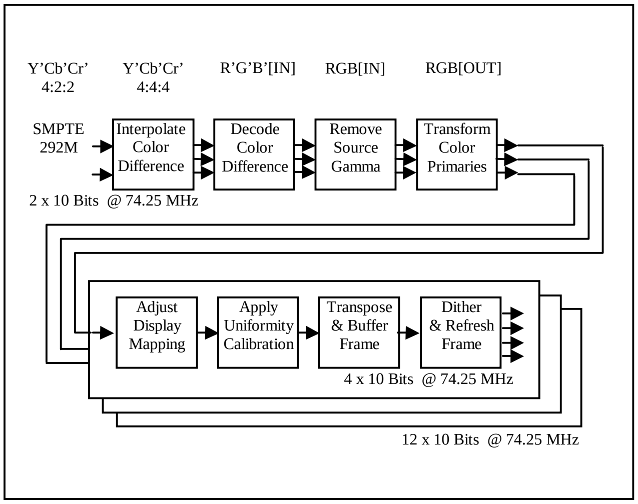

Figure 4: Video processing architecture for a Scanned linear GLV system.

Color Difference Interpolation & Decode

The SMPTE 292M serial digital input contains luma (lightness) for all pixels and chroma (red and blue color difference) for odd pixels. The even pixel chroma values are generated by FIR filtering the red and blue chroma input. The luma and chroma are decoded into red, green, and blue with gamma using multipliers and adders. The decoder can support any 10-bit standard such as ITU-R BT.601 or SMPTE 240M.

Source Gamma Removal & Color Primaries Transform

The gamma removal and color transformation are combined to allow a 9K x 16-bit table to take the place of three nonlinear mappings and nine multiplies. This approach supports an arbitrary change of color primaries and any 10-bit gamma standard such as ITU-R BT.709 or SMPTE 240M. We use 16-bit table entries to maintain the human-perceived signal quality while RGB is expressed in linear intensity. The table outputs are added and rounded to yield linear RGB for the system primaries. The current system uses solid-state RGB lasers as illumination sources, so it is capable of displaying a much wider color gamut than SMPTE RP 145. The table entries can be modified to change the whitepoint and/or to interpret highlights, depending on whether the input is standard video for HDTV or a custom transfer intended to produce a more film-like experience.

Display Mapping/Gamma Adjustment

This step maps RGB intensity to the GLV intensity-voltage characteristic. Conventional spatial light modulators that create grayscale values through digital pulse width modulation have an inherently linear optical response. However, the inherent GLV electro-optic response creates a natural, continuous grayscale with wide dynamic range that is well matched to the human visual system (Figure 5). This is similar to the gamma response of a CRT but with a better gamma near black, an advantage that is particularly noticeable in dark scenes. This enables us to remap source/display gamma without a tradeoff in dynamic range or sacrifice in image quality, visible as contouring.

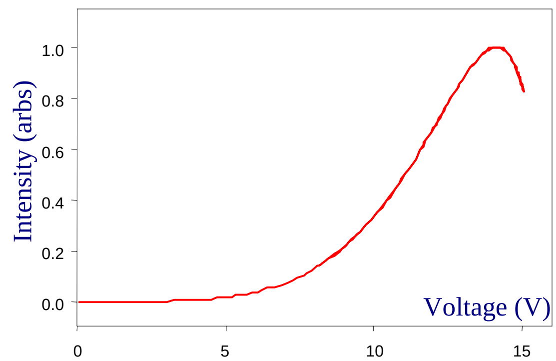

Figure 5: GLV non-linear electro-optic response

Data Calibration

The electro-optic response of a GLV pixel is remarkably uniform because it is based on a simple and repeatable system of electrostatic (attractive) and mechanical spring (restorative) forces. Due to this mechanical simplicity, the GLV response is highly predictable and can be mathematically calculated from relatively simple models. If only a few data points near the peak intensity and maximum slope of the I/V response curve are collected, the rest of the curve can be calculated with a high degree of accuracy. Since the linear GLV array uses only a small number of physical pixels, each pixel can be exercised and the data necessary to fully calibrate the complete image can be collected using a simple optical integrator and single point detector. This simplicity enables a calibration technique that can efficiently measure all sources of variation within a system (particularly non-uniformities introduced by the system optics) and adjust the response of each pixel to show the highest quality image at all times [3].

The electronic circuitry required to effect uniformity calibration can be implemented at minimal cost and complexity. We think that such a calibration system can be used to maintain a level of image uniformity not possible with 2D arrays. Since there are only 1080 drive channels, only 1080 values need to be loaded into look-up-tables, as compared with two million required for a comparable 2-D array.

Row/Column Transpose & Frame Rate Multiply

The SMPTE 292M input is row-centric, meaning the video data is presented sequentially by row. Since the scanned linear GLV system as currently implemented scans left to right by column, a frame buffer is used to store data by rows and transpose it into column data for display. Since higher refresh rates produce better image quality, the frame buffer accepts progressive data at the source rate and sends it out at a faster rate for display. The frame buffer in the current system typically reads data in at 24 or 30 fps and refreshes the display up to four times the input rate.

Scanning horizontally has several benefits. First, it requires a smaller and less expensive linear GLV array (1080 pixels vs. 1920 pixels, a 44% pixel count reduction). Second, this smaller modulator allows additional system cost savings, such as smaller recombination and projection optics, smaller look-up tables, etc. Lastly, a horizontal scan also enables electronic support for variable aspect ratios (Figure 5). For example, a horizontal scan system can easily change from 4:3 to 16:9 for HDTV or from flat (1.85) to cinemascope (2.35) for electronic cinema, without requiring anamorphic lenses or complex scaling algorithms that tend to degrade image quality.

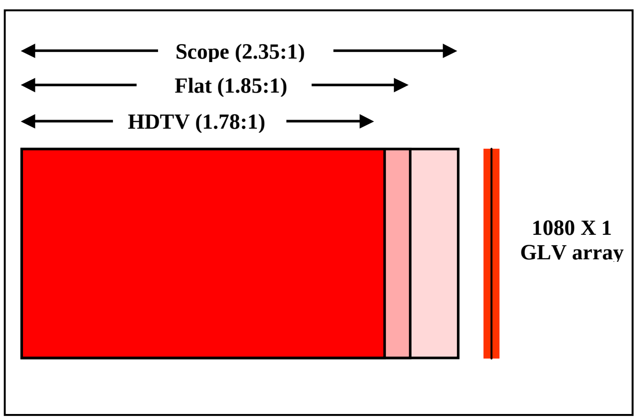

Figure 5: A horizontally scanned linear system supports high resolution and variable aspect ratios.

Frame Dither and Refresh

By refreshing the display 3 or 4 times per frame, we can achieve 1.6 or 2 additional effective bits of grayscale through dithering. Our current prototype system uses conventional drivers, similar to those that might be used as LCD column drivers. Through temporal dithering, the system exploits the GLV device's inherent speed and the novel scanned line approach to achieve 10-bit grayscale using simpler and lower cost 8-bit drivers. For example, suppose the display needs to show the 10-bit grayscale value of 201.75. Using 8-bit drivers and temporal dithering, the system would display the refresh sequence below. Because we dither only the least significant bit(s), no flicker is perceived.

	Bit width	Value
Data Input	10	201.75
Subframe 1	8	201
Subframe 2	8	202
Subframe 3	8	202
Subframe 4	8	202
Perceived Output	10	201.75

System Throughput

After serial to parallel conversion, SMPTE 292M provides 10 bits of luma and 10 bits of chroma at 74.25 MHz. Chroma interpolation outputs 10 bits of chroma red and 10 bits of chroma blue. Color difference decode and color primary transformation yields 10 bits each of RGB. Four pixels at a time are output from the frame buffer to support a higher frame rate output. The system is synchronous at 74.25 MHz. Although 8-bit drivers support 10 bits of dynamic range in the current system, the system electronics have been designed to support two additional bits should we decide to support 12 bits of dynamic range in the future.

The Scanned Linear GLV Architecture Provides a Practical Soultion for 1080p

The ATSC defined the 1080p standard as the highest level of HDTV image quality, intended to provide a theater-like experience in the home. Unfortunately, traditional display architectures cannot cost-effectively deliver this level of performance. CRT projectors are limited in light output and face prohibitive bandwidth requirements, and 2D panels face prohibitive modulator manufacturing costs. Only the Scanned Linear GLV Architecture can leverage the unique capability of the GLV technology to support both low modulator cost and low system bandwidth to make 1080p projection displays practical home theater and Electronic Cinema applications.

References

[1] D.T. Amm and R.W. Corrigan, "Optical Performance of the Grating Light Valve™ Technology," Projection Displays V Symposium, SPIE Proceedings Volume EI 3634-10, San Jose CA, February 1999.

[2] D.T. Amm and R.W. Corrigan, "Grating Light Valve™ Technology: Update and Novel Applications," SID Symposium, Anaheim, CA May 1998.

[3] R.W. Corrigan, D.T. Amm, P.A. Alioshin, B. Staker, D.A. LeHoty, K. Gross, B. R. Lang, "Calibration of a Scanned Linear Grating Light Valve™Projection System," SID Symposium, San Jose CA, May 1999.