Paper 21.3: D-ILA ™ Technology for Electronic Cinema

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Abstract

The D-ILA™ is a reflective mode liquid crystal active matrix image modulator utilizing a single crystal CMOS backplane (LCOS). Projectors utilizing the D-ILA have been developed for applications from home theatre to auditoriums. Advancements in D-ILA technology lead to new projectors to meet the requirements of electronic cinema. This paper will review DILA technology and the application to an electronic cinema projector.

1. Introduction

Cinema history was made in 1999 with the first ever showing of first run Hollywood movies via electronic projection technology. "Star Wars: Episode I" (LucasFilms) and "An Ideal Husband" (Miramax) were exhibited in the New York and Los Angeles areas for one month. Two JVC ILA® projectors (and two Texas Instruments DLP™ projectors) were used for the four "Star Wars" screenings and two ILA projectors only were used for the two "Ideal Husband" screenings.

Following this initial event, JVC is leading the way to the next generation of higher-resolution large screen projection displays for electronic cinema applications with the continuing development of D-ILA technology. The D-ILA technology builds on the high luminance, high resolution ILA™ Super Projectors that established new standards of video image excellence over the past decade

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The goal of ILA/D-ILA Electronic Cinema projector development has been, and continues to be, to provide a visual medium that is transparent to the artistic intent of the film maker. ILA/D-ILA technology is ideally suited for this role. ILA technology provided a high brightness analog image close to motion picture film quality based on the use of the CRT as an image source for the image amplifying liquid crystal modulator. With the development of the D-ILA by JVC, the CRT image source is replaced by a high resolution, high pixel density active matrix CMOS image source to drive the same liquid crystal modulator. Thus the high quality of the ILA image is combined with a high performance digital image source to provide maximum stability, ease of operation and maintenance, and reproducibility of image quality for the cinema environment. And significantly the D-ILA is the most advanced technology to duplicate the present cinema experience while providing a direct path to the higher quality cinema projectors in the future.

Figure 1. The First D-ILA Projector: The Model G1000

Figure 2. DLA-M4000L D-ILA Projector

With the benchmark G1000 D-ILA projector shown in Figure 1, the path to the future of compact ultra-high resolution displays began in 1998. Now new projectors, the DLA-G15/G20, and the DLA-M4000L shown in Figure 2, carry the D-ILA technology to higher performance

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D-ILA is JVC's proprietary reflective-mode active matrix liquid crystal display commonly referred to as LCOS (liquid crystal on single crystal silicon). LCOS displays promise to revolutionize the high-resolution projection display market both in virtual personal displays and in personal workstations and group projection displays. This is based on the inherent advantages of LCOS display design and manufacture over competing technologies:

- Wide spread capability of foundries for fabrication of the single crystal silicon backplane for the display modulator. Design rules for LCOS displays are not typically at the state of the art; thus foundries are well established and their capital costs are largely amortized. The investment for BEOL "(back-end of the line)" LC processing is minimized by the use of processes and equipment developed for the high volume flat panel LCD market. This leads to lower cost/pixel in display production than any other emerging technology.
- The unique high performance and small dimensions of single crystal silicon backplane circuitry allows a high level of integration of driver and processing circuitry. This is coupled with the high electro-optic efficiency and reliability of liquid crystal materials.
- Adaptability and scalability: With LC technology, in contrast to micromirror technology, pixel size and aspect ratio can be readily adjusted to meet optical system requirements. In fact, designs have been fabricated that change pixel size and shape on a single device over the area of the device to correct for optical system aberrations and viewing screen contours. For electronic cinema, anamorphic designs are readily accommodated.
- High performance reflective-mode displays fill the display surface with closely spaced pixel elements thus minimizing the pixel border "screen door" look of transmissive LCD displays. This becomes a critical requirement for electronic

cinema when the display modulator must be magnified to a 40 feet width and viewed from only 10 feet away. The close spacing of the pixels and the ability to block the reflected projection light from the circuitry also allows high luminous output to cover the gamut of applications.

- Thermal stability: the silicon backplane can be thermally controlled across the entire aperture for stability and reliability in operation. Ultra-bright systems using xenon arc lamps sources are possible.

2. D-ILA Device

2.1 D-ILA Description

With the D-ILA, JVC has developed a technology that combines the high performance of the Hughes-JVC ILA® technology with active matrix direct electronic addressing. The D-ILA technology is a reflective liquid-crystal design where electronic signals are directly addressed to the device.[2-4]

The D-ILA X-Y matrix of pixels is configured on a CMOS substrate using planar processes standard in IC technology. Each pixel is covered, except for a small border, with an aluminum reflective pixel electrode. The driving transistor is connected to this reflective pixel electrode. The homeotropic (vertically aligned) liquid crystal is sandwiched between the reflective pixel electrode and continuous transparent ITO electrode. The thickness of the liquid crystal layer is ~3 micrometers. The liquid crystal material has a negative dielectric constant necessary for homeotropic alignment and low viscosity for video-rate response. The voltage applied to the selected pixel of the matrix makes the liquid crystal above the pixel change birefringence and thus modify the polarization state of the projection light in the D-ILA. The video rate response of the D-ILA is less than 16msec as shown in Figure 3.

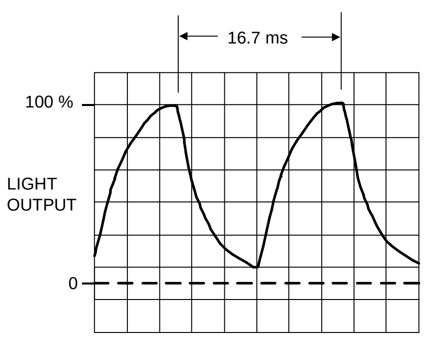


Figure 3. Time Response of D-ILA. The Rise and Decay Times Total <16msec.

2.2 D-ILA Formats

In Figure 4 the two current production formats of D-ILA modulators are shown. The first modulator (used in the G1000 and DLA-M4000L) has a 23mm diagonal with 1365 (H) x 1024 (V) pixels in a 4:3 array. The DLAG15/G20 and DLA-M4000L incorporate 3 of these modulators. The pixel period is 13.5 micrometers horizontal and vertically. The interpixel spacing is 0.5 micrometer. The second modulator, called the SD-ILA, is used for a single full color modulator home theatre rear projection display. This image modulator has an array of pixels with 31mm diagonal (1280 (H) x 1028 (V) with each pixel comprised of RGB sub-pixels for a total of 3840 (H) x 1028 (V) sub-pixels. Each sub-pixel has a period of 7.6 micrometers (H) and 14.8 micrometers (V). This is by far the most advanced image modulator in production today. The SD-ILA is combined with a unique holographic color filter shown in Figure 5 to create the full color single modulator projection display.

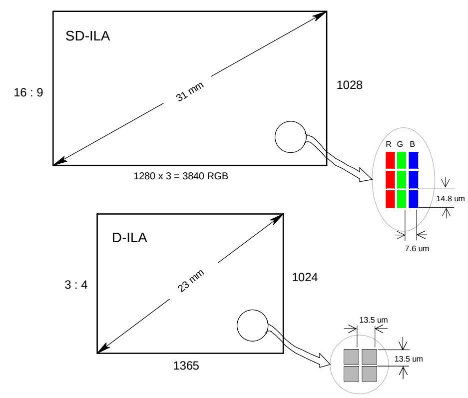
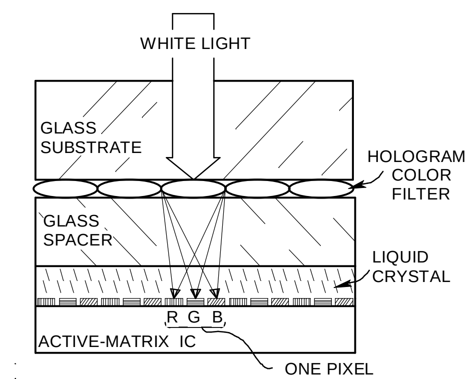


Figure 4. D-ILA Modulator Pixel Formats



Optical Function of Holographic Color Filter

The reflectivity and light blocking structure of the silicon CMOS substrate are important factors in achieving projected images with high luminous output. The pixel electrodes of the D-ILA devices have an aperture ratio of greater than 90%, and have high intrinsic reflectivity. The insulating layers formed between each metal layer are made flat and smooth by chemo-mechanical polishing techniques. The final aluminum pixel mirror approaches a reflectivity of 91%. Based on analysis of light blocking and thermal loading, it will be possible to possible to produce projection systems using D-ILA devices with greater than 15,000 lumens required for the large screen electronic cinema.

2.3 Liquid Crystal Alignment

Homeotropic alignment of the liquid crystal allows a high device contrast ratio in the visible light spectrum range since, in a homeotropic tunable birefringence mode,[5] the birefringence of the liquid crystal is near zero at the threshold off-state voltage. This allows the theoretically highest contrast ratio for any liquid crystal device. The liquid crystal molecules are aligned almost perpendicular to the surface with a small pre-tilt angle at the off state. A low pre-tilt angle is the most important factor in achieving high contrast ratios and good quality in the projected image. There is a range of pre-tilt angles best suited for producing a high contrast ratio and a good uniform image without disclination. This is about a 1° pre-tilt. With this pre-tilt the intrinsic D-ILA image modulator contrast ratio for an $f/4.8$ optical system is greater than 2000:1

This high D-ILA contrast ratio is ultimately limited by the optical system of the projector, in particular the polarizing beam splitters (PBS). In order to achieve a much higher contrast ratio, the use of a quarter wave plate "super contrast mode"[6] can be used to eliminate a geometric cause of contrast ratio degradation in the polarizing beam splitters. This is discussed in the D-ILA projector technology section. D-ILA devices have achieved greater than 1500:1 sequential contrast ratio in an optimized optical system using the super contrast mode with both xenon and laser illumination.

3. D-ILA Projector Technology

The professional D-ILA projectors have 3 modulators for R, G, B image color components. Each modulator has its own PBS. The modulated output projection light from the 3 D-ILAs is combined by a crossed dichroic prism, which transmits the full color image to the projection lens for imaging on the projection screen.[7] Figure 6 shows the optical schematic of the DLA-M4000L projector including the input xenon arc lamp, optical integrator, and dichroic splitter that sends the RGB light components to the respective D-ILAs. The DLA-M4000L optical system uses a 1.6kW xenon lamp instead of the 400W lamp in the G1000. Both systems use the 0.9 inch 1365x1024 pixel D-ILA modulator. The optical system of the DLA-M4000L is designed to accommodate a larger D-ILA (33mm diagonal) that will be required for electronic cinema resolution.

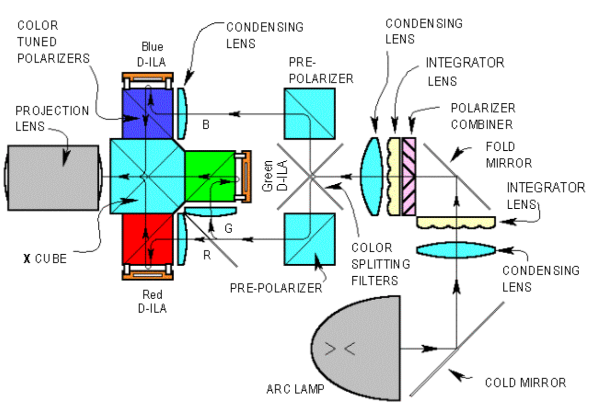


Figure 6. DLA-M4000L Optical System Schematic

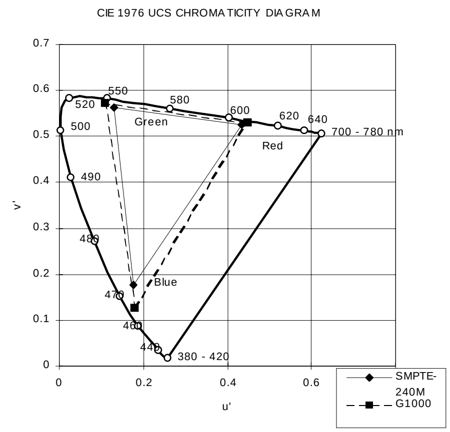


Figure 7. Color Gamut of G1000 D-ILA Projector

The color gamut is shown is Figure 7. The color is reproduced at 8 bits per color. The color reproduction corresponds closely to SMPTE 240M. Optimization of the color gamut will be achieved for electronic cinema projectors by expanding the color reproduction to 10-12 bits per color and increasing the gamut of the color dichroic filters.

4. Future D-ILA Electronic Cinema Projector Development

As the state-of-the-art SD-ILA technology graphically illustrates, multi-mega pixel displays are possible with very compact D-ILA modulators. Thus it will be possible in the future to reach projection display resolutions, while maintaining highest picture quality, equivalent to 70mm film. These remarkable developments will bring electronic projection technology into many new areas of image display. And by using the latest developments of IC and LC technology, D-ILA systems will be produced with the highest performance and yields and the lowest cost/pixel of any technology.

4.1 D-ILA Electronic Cinema

The two fundamental measures of image quality that are related directly to the image modulator design are the resolution and contrast ratio. If the image modulator cannot provide superior performance in the resolution/contrast ratio areas, it is impossible to create a film-like image for electronic cinema. This requirement is illustrated in Figure 8 where the image resolution/contrast ratio space is shown. The electronic cinema quality region requires a resolution greater than 2 million white pixels (6 million RGB sub pixels) and contrast ratios exceeding 1000:1.

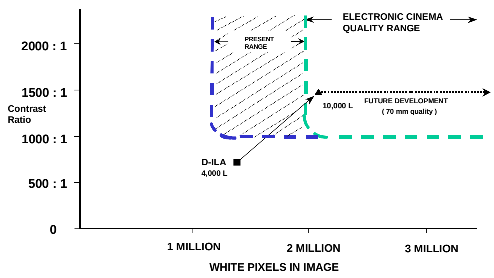


Figure 8. The Evolution of D-ILA Technology to Electronic Cinema Image Quality

The D-ILA image modulator and projector system is moving into this quality region. As reviewed before, new D-ILA developments include the SD-ILA modulator now in production with 3.8 million RGB sub-pixels (to create 1280 x 1028 white pixels) on a single full color image modulator. Other developments at JVC include a QXGA-D-ILA with 2048 x 1536 pixels on the modulator. Use of three modulators for the RGB channels will result in a 3 million while pixel projected image. Thus the minimum for electronic cinema quality resolution will soon be exceeded.

The contrast ratio improvement is taking place through the transfer of the high contrast optical system techniques used for the electronic cinema ILA projectors to D-ILA projectors. This is possible because of the close similarity of the liquid crystal light modulating systems of the ILA and D-ILA.

4.2 Laser Illumination Sources

The xenon arc lamp has become the standard light source for film-based projection and high brightness electronic displays. Emerging laser light sources promise improved image quality through improved MTF and color gamut. The polarization properties of the laser output and the low divergence of the beam lead to improvements in efficiency for small aperture birefringent liquid crystal devices such as the D-ILA.

While the application of lasers to projection displays has been reported for over 20 years, only recently has progress been made in practical laser sources. These lasers show full-color visible performance with greatly improved electrical-to-light efficiencies. The full visible spectrum sources – diode pumped solid state lasers – have been used as the illumination light source for a projector using the 23mm SXGA D-ILA image modulators.[8] The results showed a sequential contrast ratio of 1330:1 and increases of 2-5 times in the modulation at high spatial frequencies in the projected images. The color gamut area was twice as large as the SMPTE 240M color space and actually two-thirds the total area inside uniform color space spectrum locus. Speckle was maintained below visible threshold for a display at SMPTE cinema standard brightness (12 Ft-Lamberts). An efficiency of ~21/watt was achieved for the 3000 lumen display. While scaling the lasers to higher outputs remains to be achieved, there is solid progress toward the near-term application of laser illumination sources in D-ILA projectors for electronic cinema.

5. Summary

The events of the past year indicate that electronic cinema will eventually replace 35mm film projection in first-run movie theatres; but many complex technical and business issues still need to be resolved.

In the projection arena the 1999 showings indicate that audiences will accept electronic projection instead of film. However, many technical/artistic analyses of these showings still saw the need for further improvement. One area is improved resolution. The D-ILA Electronic Cinema Projector under development can provide the additional required resolution while maintaining film-like contrast ratio and color saturation. This development, along with the stability and eventual low cost of the D-ILA, will provide the best path to the electronic cinema implementation.

6. References

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