Electronic Cinema Using ILA® Projector Technology

R. D. Sterling, W. P. Bleha

Hughes-JVC Technology Corporation, Carlsbad, CA 92009 USA

ABSTRACT

The use of video for the replacement of 35mm film presentation (Electronic Cinema) offers many potential advantages in the production, distribution, and exhibition of motion pictures. A key enabling component for Electronic Cinema is the video projector which must provide the image quality and brightness required to replace film projection in a theatre venue.

New ILA® projectors have been developed to meet these stringent requirements. ILA® projectors provide up to 17,000 lumens, greater than 2000 TV lines of horizontal resolution, and over 1500:1 sequential contrast ratio. The unique ILA® device design has no pixel structure so that film-like images are projected.

This paper will discuss these requirements for electronic cinema and review ILA® projector technology and performance.

INTRODUCTION

Achieving the image quality required to replace film in the theatre is a significant challenge. The use of film for theatre presentations has evolved over the past century to a durable, compelling medium. In fact, possibly the only replacement for film will be to replicate the qualities that make up the "film experience", whether considered optimal from purely technical considerations. The goal of the ILA® projector in Electronic Cinema development is to provide a medium that is transparent to the artistic intent of the filmmaker. ILA® technology is ideally suited for this role. It provides a bridge from a viewer-friendly analog presentation medium to the modern digital electronic world of image creation and distribution. The ILA® device uses the CRT as an image source that creates the highest quality video displays. The ILA® device acts as an image amplifier to provide bright images and reproduce these qualities without additional artifacts such as pixelization. This paper will describe ILA® technology and its applications to Electronic Cinema.

ILA®-LIGHT VALVE TECHNOLOGY

The ILA® Light Valve (ILA-LV) is a spatial light modulator that is capable of accepting a low-intensity light image and converting it, in real time, into an output image with light from another source.[1,2] In ILA® projectors the image light sources are high resolution projection CRTs and the output light source is a xenon arc lamp. The ILA-LV, which has a clear maximum aperture of 51 X 38 mm, is designed to operate in a reflective mode so that the input CRT and output xenon light beam are incident on opposite faces of the device. By its non-light absorbing design and highly efficient optical isolation, the ILA-LV can modulate high levels of projection light of over 17,000 lumens (4:3 aspect ratio). Sequential black/peak white field contrast ratios exceeding 1500:1 are achieved using a unique high contrast mode implementation.

The cross-sectional configuration of the device is shown schematically in Figure 1. The ILA-LV embodies an amorphous silicon (a-Si) photosensor layer, a projection light blocking layer, a dielectric mirror, and a tilted homeotropically-aligned birefringence mode nematic liquid crystal sandwiched between two transparent electrodes.[3] The continuous dielectric mirror and light blocking layer separate the image input and projection functions of the ILA-LV. The dielectric mirror provides greater than 98% average reflection of the incident projection light. The light blocking layer prevents residual projection light transmitted through the dielectric mirror from reaching the photosensor. The combination of the dielectric mirror and light blocking layer give an optical isolation of $>10^6$ between the image input and projection functions.

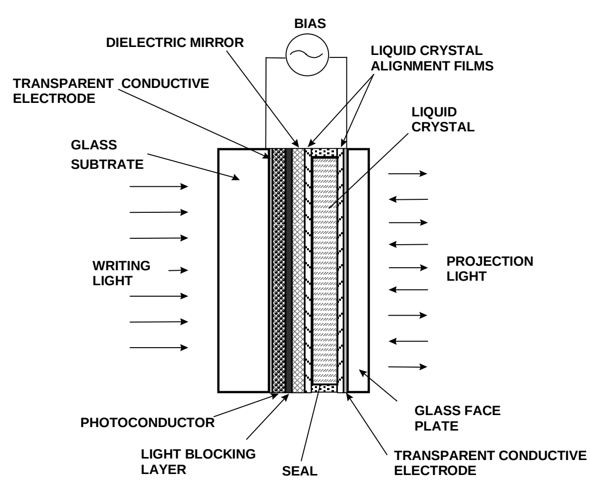

Figure 1. Cross sectional schematic of the ILA-LV

The homeotropic mode liquid crystal layer provides the high contrast observed across the visible spectrum. All layers in the ILA-LV are continuous; there are no defined pixels. In fact, the pixel information blends with neighboring pixels on all edges, exactly replicating the input CRT image. Thus images have natural MTF and the absence of image pixelization and aliasing. The high resolution is maintained by the high sheet resistivity of the component films.

In operation, a nominal voltage of 10 V at 2 kHz is placed across the transparent conductive electrodes of the ILA-LV. Then a raster scanned CRT writing light image is focused on the amorphous silicon photosensor by an image relay lens. This lowers the impedance of the photosensor layer in proportion to the CRT light intensity. The corresponding increase in voltage transferred to the liquid crystal layer is in the form of a real-time spatially varying birefringence pattern matching the input image. The direction of a linearly polarized projection light beam is changed in direct correspondence to the birefringence pattern in systems described below.

The impedance of the photosensor, and thus the voltage pattern on the LC layer, changes in synchronism with the CRT temporal changes. The time response of the liquid crystal material, the a-Si photosensor and CRT phosphor are chosen for Electronic Cinema applications to give a response time of less than 10 msec. The same basic ILA® component is interchangeable among the R, G and B channels.

ILA® PROJECTOR TECHNOLOGY

The basic ILA® projector optical channel schematic, shown in Figure 2, is the building block for full-color systems. The input image is provided by a high resolution projection CRT. The CRT is imaged on the ILA-LV through a relay lens. A xenon arc lamp and condensing optics provides the output projection light beam which is linearly polarized by a McNeille-type polarizing beam splitter (PBS) before reaching the ILA-LV. The PBS polarizes the light to a high extinction ratio without absorption. The projection beam passes through the liquid crystal, reflects from the dielectric mirror, and passes through the liquid crystal again before returning to the polarizing beam splitter. In passing through the liquid crystal, the direction of the linearly polarized light is rotated in direct response to the level of input image modulation of the liquid crystal birefringence. The PBS then analyzes the output image from the ILA-LV, passing rotated polarized light to the projection lens and returning non-rotated light toward the lamp. Finally the projection lens focuses and magnifies the ILA-LV image on a screen.

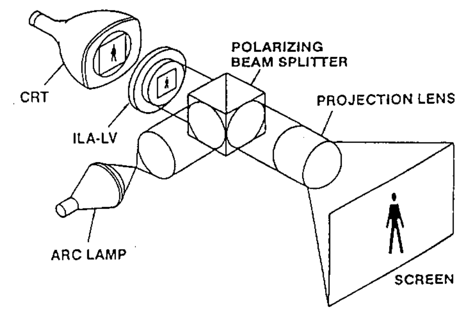

Figure 2. ILA® projector optical channel schematic

The EC300 and ILA-12K use three projection lenses for the RGB image components which are converged on the projection screen.[4] These configurations have been optimized for Electronic Cinema applications

THE EC300 AND ILA-12K PROJECTORS

The EC300 and ILA-12K three lens projector optical schematic, shown in Fig. 3, uses the three basic projector optical channels for the RGB signals. A dichroic splitter is used to separate the broad band xenon white spectrum into RGB components for the three ILA-LVs. Using a highly efficient illumination system, the ILA-12K model with a 7.0 kW arc lamp, provides 17,000 peak lumens in a 4:3 image aspect ratio.

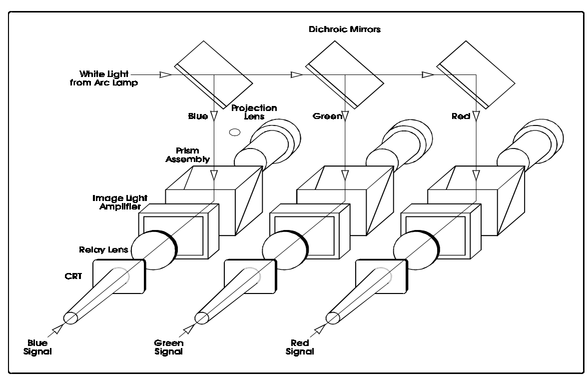

Figure 3. Optical System Schematic of EC300 and ILA-12K Projectors

The interchangeable f/4.6 telecentric projection lenses have throw-to-screen width ratios of 0.885:1, 1.5:1, 2:1, 3:1, 5:1, 7:1, 10:1 and a 2-4:1 zoom.. A 0.8 wide angle converter lens adapter is available for the 3:1 and 5:1 lenses.

High performance multi-scan electronics drive the RGB projection image input CRTs. The CRTs have a 132 mm diagonal raster with a full width at half maximum spot (FWHM) size of 85 µm. Automatic synchronization is provided continuously from 15 to 90 kHz horizontal scan frequency and 45-120 Hz vertical scan frequency. Thus, cinema applications can utilize multiples of 24 frames vertical scan frequency up to 72 Hz directly. The video bandwidth is 150 MHz (-3db). A fully digital on-screen convergence system is used to provide greater than 0.1% convergence accuracy. Vertical and horizontal image keystone correction of $\pm 15^0$ and $\pm 2^0$ respectively is provided electronically. Raster formats can be switched directly from over the range required for cinema from 4:3 (1.33:1) to 2.4:1.

The high contrast mode contrast ratio, measured with sequential black and white fields, is greater than 1500:1 in the EC300 and ILA-12K. The high contrast mode incorporates a quarter wave plate between the ILA-LV and the polarizing beam splitter to improve the extinction ratio of the PBS for projection light rays not on the optical axis. With a nine square checkerboard pattern, the average contrast ratio measured at the center of the squares is greater than 250:1. A factory adjustable, fixed three point gamma correction corrects for the non-linearity in the output response of the ILA-LV and CRT and allows selection of the gamma characteristic for a given application. The desired gamma function is a function not only of the input signal, but also of the viewing ambient.[5]

PERFORMANCE OF ELECTRONIC CINEMA ILA® PROJECTORS

Luminous Output

ILA® projectors project up to 17,000 lumens in a 4:3 aspect ratio from xenon lamp sources. In an electronic cinema applications with a 16:9 aspect ratio, the projector will provide >12 ft-L of center peak brightness on a 40 feet wide, 1.3 gain screen. This conforms to SMPTE standard 196M. Thus, ILA® projectors cover the brightness required for a vast majority of theatre screen sizes.

Modulation Transfer Function

The total limiting horizontal resolution (5% MTF) of the EC 300 and ILA-12K projectors is greater than 2000 TV lines. In the study of Kaiser et. al.[6] 35 mm theatre release print film was measured to have a horizontal limiting resolution (5% MTF) of 2035 TV_L. In exhibition the 35mm film resolution is further reduced from this value by horizontal and vertical jitter of the film moving through the gate. Thus the ILA® projected image is comparable in resolution to the theatre release 35 mm film. The shape of the MTF is also similar to film in comparison to pixelated displays where spatial artifacts occur.

Contrast Ratio

High contrast ratio is key to giving a film-like experience in Electronic Cinema.[7] ILA® projectors achieve their sequential high contrast ratio of >1500:1 by combining a continuous, specular ILA® image source with polarized light. The use of polarized light can give the highest contrast ratios in optical systems because the use of cross-polarization is very effective in stopping rejected light from reaching the projection screen. This is critical as very small values (<0.1%) of rejected light reaching the viewing screen seriously compromise the contrast ratio.

Systems, which create contrast between the bright and dark states by deflecting or scattering light, have to resort to more onerous methods to eliminate the remnant of deflected or scattered light from reaching the projection screen through the system exit pupil. Typically, the modulator is not smooth due to pixel edges and other spatial non-uniformities such as mirror support mechanisms that can scatter light. This is a significant problem for Electronic Cinema applications where a very high sequential contrast ratio (>1000:1) is required to create a film-like image.

Temporal Response

The time envelope of the video decay in ILA® projectors is determined by the decay convolution of the a-Si input image photosensor and the liquid crystal layer. Continuous analog gray scale levels are generated intermediate to the dark and light levels in direct response to the input image. This provides a temporally integrated picture that is very natural to the eye. Importantly, each gray level covers the complete temporal span so that noise or scintillation is not visible to the viewer. In comparison, the use of a time multiplex system in binary-mode mirror systems divides the frame time interval into on-off segments according to the average brightness or gray level required.

The variable position of these segments in the position in the time interval can be observed under some conditions as periodic intensity variations in flat fields.

Also, if the motion in the video picture occurs at a rate that is out of phase to the video time frame the bit map representing the moving object is out of phase with the true object position. This is illustrated in the case of vertical bars moving horizontally across the screen, which results in actual image breakup.

Colorimetry

The colorimetry of the ILA® projector is selected to exceed the requirements of SMPTE 240M and more closely match film, as shown in Figure 4. Specially tuned dichroic filters divide the xenon light spectrum into the requisite RGB components.

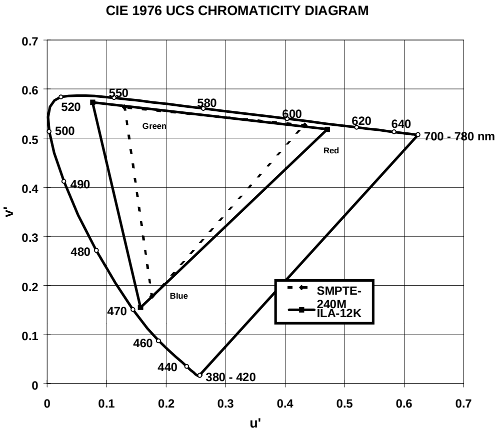

Figure 4. Comparison of Colorimetry of ILA® Projector and SMPTE 240M

SUMMARY

The specification for the ILA® Electronic Cinema Projector is summarized in Table 1. ILA® projectors provide a unique combination of high picture quality and brightness and multi-scan rate capability. The lack of pixelization creates temporal and spatial image continuity not achievable with other technologies. This has already allowed ILA® projectors to be used effectively for demanding applications in large screen video/graphics presentations. Now ILA® Projectors have been used to show the promise of Electronic Cinema as a viable replacement for film in the theatre. As the other technical and business issues that will allow Electronic Cinema to enter the market are resolved, ILA® projection engineering will continue to advance to provide projection products as durable as the film projectors they will replace.

TABLE 1 -Specification of ILA® Projectors for Electronic Cinema

Aperture aspect ratio range (Continuously variable)	1.33:1 to 2.4:1
Projection xenon arc light source Power (kW)	7.0
Luminous output (lumens) center full white at 5600 K	17,000
Horizontal raster freq. (kHz) automatic synchronization	15-90
Vertical raster freq. (Hz) automatic synchronization	45-120
Video bandwidth, (MHz), (-3db)	150
Keystone correction range Horizontal Vertical	± 2° ±15°
Contrast ratio, sequential High contrast EC mode	>1500:1
Source Compatibility	2500(H) x 1340(V)
Resolution, (TV lines)	> 2000

REFERENCES

1. T.D. Beard, W.P. Bleha, S.Y. Wong, 1973, “AC Liquid-Crystal Light Valve,” Appl. Phys Lett. 22, 90.

2. R.D. Sterling et al, 1991 “Video-Rate Liquid-Crystal Light-Valve Using an Amorphous Silicon Photoconductor,” SID International Symposium Digest of Technical papers/Volume 21/SSN- 0097-966x, p.327.

3. A.M. Lackner et al, “Photostable Tilted-Perpendicular Alignment of Liquid Crystals for Light Valves,” op cit, p. 98.

4. W.P. Bleha, June, 1993, “Image Light Amplifier Technology for High Definition Large Screen Projection Electronic Display,” Symposium Record of the 18th International Television Symposium-Montreaux.

5. Charles A. Poynton, “Gamma and Its Disguises,” SMPTE Journal, 1993, p. 1099.

6. Arthur Kaiser, et al, “Resolution requirements for HDTV,” Television: Journal of the Royal Television Society, Vol. 22, p. 68.

7. Laurence J. Thorpe, “HDTV and Film-Digitization and Extended Range,” SMPTE Journal, 1993, p. 486.