

D-ILA projector technology: The path to high resolution projection displays

William P Bleha, PhD, JVC North America R&D Center - December 05, 2007

Introduction

The [JVC](#) D-ILA (Direct-Drive Image Light Amplifier) technology, has been at the leading [edge](#) of reflective LC micro displays (LCOS) starting with the first production SXGA+ projectors in 1998. This continued with the first QXGA 2048 x 1536 [pixel resolution](#) projector in 1999. The first demonstration of a projector of any projection technology at 4K x 2K pixels was a D-ILA projector at SIGGRAPH in 2001 in Los Angeles. In 2005 at the Aichi Expo in Nagoya Japan, JVC demonstrated an 8K x 4K D-ILA based projection system. JVC has placed in production image quality leading front projectors for home theatre, business and simulation based on these landmark projector "firsts".

Following the benchmark RS-1 in 2007 for the ultimate [HDTV](#) home theater performance, the D-ILA technology in the new DLA-RS2 packs 1920x1080 pixels a total of over 2 million pixels-on a 0.7" chip. This makes possible [display](#) of 1080p HD images at full-spec resolution of 1920 x 1080 with native contrast ratio of over 30,000:1. This is done without use of an iris which limits the range of brightness of an image. Outstanding color gamut is achieved with new color filter selections and color management techniques. The RS2 is shown in Figure 1.

LCOS technology "sandwiches" liquid crystals between a cover glass and a silicon [chip](#) with a hyper polished aluminum matrix of pixels. JVC has the most advanced version of LCOS technology with its Direct-Drive Image Light Amplifier (D-ILA), based on an innovation in digital microchip design that permits the viewer to enjoy the full range of benefits from any high quality source whether from a video deck or a [computer](#) device.

The D-ILA's innovative placement of the [CMOS](#) electronics and high density pixel array is the key to reproducing all the details in a high-definition picture. By placing the matrix addressing switches and electronics right behind (not between) the light-modulating liquid crystal layer, JVC has created a D-ILA chip with a "three-dimensional" layout. The result is a near 90% fill factor and virtual elimination of the annoying "grid" or "screen door effect," so evident in other fixed-matrix display technologies. The unique digital backplane matrix addressing [switch](#) design insures the highest level of color and [grayscale](#) rendition.

What is the end result? Wide dynamic range Images as smooth and natural as film with impeccable reproduction of all the details and information contained in the original source. What supports this high picture quality is accurate color temperature at the proper light level, high resolution, high contrast and digital gradation. Accurate color temperature is achieved with an advanced optical illumination system. High resolution is achieved using a reflective device with a high aperture ratio and high-density pixel structure, providing real resolution with invisible pixels. High contrast is achieved using vertical alignment liquid crystals of normally black operation and a high-precision wire grid optical system. In combination with the high-speed response of the vertical alignment liquid crystal, JVC's D-ILA technology makes it possible to reproduce smooth, noiseless motion pictures with clear, sharp high definition and film-like picture quality. These attributes are summarized in Figure 2.



Figure 1. RS2 D-ILA projector with full 1920 x 1080 pixel resolution and 30,000:1 contrast ratio for home theater applications

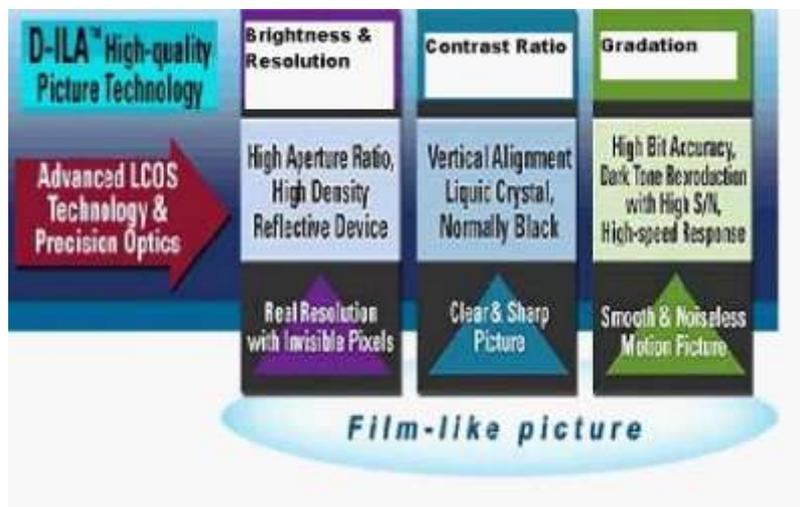


Figure 2. D-ILA Image Quality Factors

A Closer Look at D-ILA Technology

A Closer Look at D-ILA Technology

D-ILA is JVC's proprietary reflective-mode active matrix liquid crystal display LCOS technology. It offers many inherent advantages over competing technologies enabling the production of compact 3 device projectors:

- **Efficiency and Reliability**--The utilization of single crystal silicon CMOS design provides high yield, high performance direct pixel addressing backplanes. This is coupled with the high electro-optic efficiency and reliability of liquid crystal materials.
- **Ultimate High Resolution Capabilities**--High resolution capability has been demonstrated with reduction of pixel size and the increase of total resolution to 4K x 2K and in the future 4K x 8K. The future of ultra high resolution displays lies in D-ILA technology.
- **Smooth Images**--The reflective-mode device fills the display surface with closely spaced pixel elements thus minimizing a pixel border "screen door" look. In addition the liquid crystal acts to [bridge](#) adjacent pixels resulting in near structure less film-like image. This reduces the harshness of a digital image and makes the image easier for the eyes to watch.
- **Maximum Performance 3 Chip Design**--Full 3 device [RGB](#) implementation in all projectors. to give the highest dynamic range and absence of rainbow artifacts at all product levels.

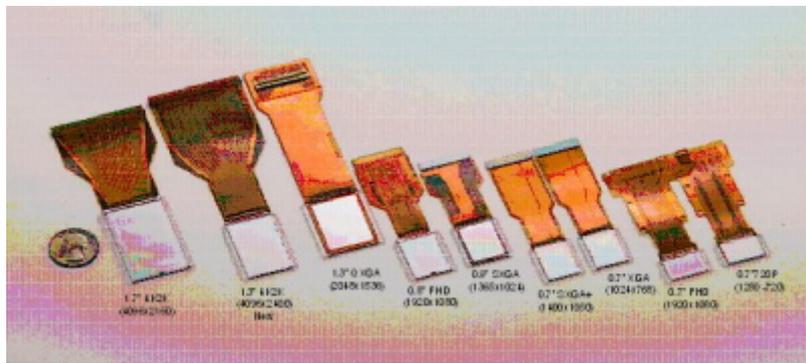


Figure 3. D-ILA device line-up: Production History

Figure 3 shows a photograph of the D-ILA display modulator types over the production history and Figure 4 the evolution of the panel and pixel [format](#) through 4 generations of refinement.

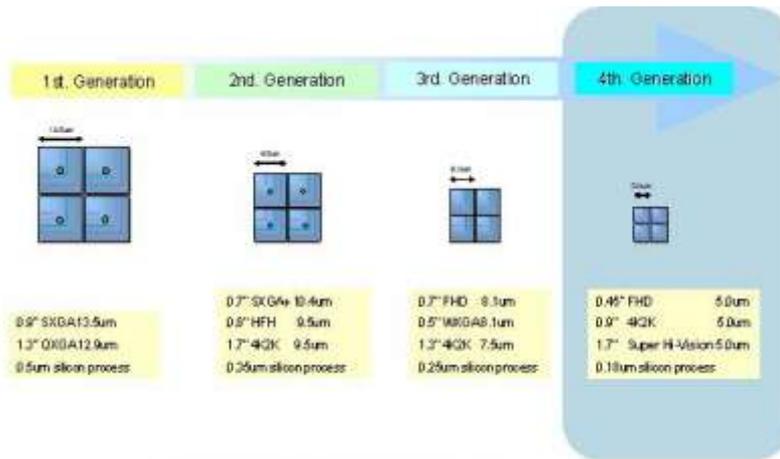


Figure 4. Evolution of D-ILA panel geometry

D-ILA Device Operation

The D-ILA device has used both analog and digital backplanes for addressing the liquid crystal layer. The new RS2 uses JVC unique digital backplane shown in Figure 5. This is compared with the [analog](#) backplane format.

With the D-ILA design, electronic signals are directly addressed to the device. The image modulators use active matrix addressing of the liquid crystal to replicate the dynamic digital [input](#) images. Each pixel is directly accessed through the x-y matrix circuitry that is located directly behind the liquid crystal layer. This means that light does not have to pass through the drive electronics since all circuitry is behind the projection light path.

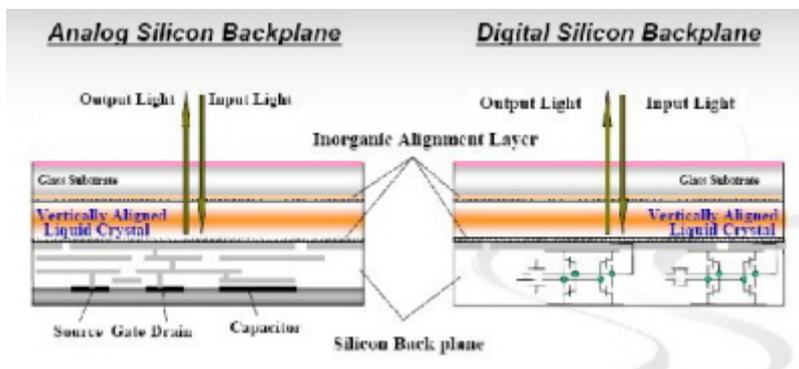


Figure 5. Schematic of Analog and Digital Backplane D-ILA Device

Digital Backplane

D-ILA Device: Digital Backplane

The specification of the full HD 1920 x 1080 digital backplane D-ILA used in the RS-2 projector is shown in [Table 1](#).

Diagonal display size	0.7-inch (17.8mm)
Resolution (H x V)	1,920x1080 (2,073,600 pixels)
Aspect ratio	16:9
Pixel pitch	8.0 μm
Aperture ratio	89%
Pixel Drive Method	Pulse Width Modulation (PWM)
Contrast Ratio (per device)	> 40,000:1
LCD mode	Vertically Aligned Nematic (VAN)
Alignment layer	Optically stable inorganic alignment layer

Table 1 Full HD digital backplane D-ILA device specification

Device Structure

The fundamental device structure is the same as conventional analog D-ILA. The liquid crystal is used in a vertically aligned nematic (VAN mode), and responds to the average RMS [voltage](#) of the pulse width modulation (PWM) signal over the [frame](#) time. High speed [SRAM](#) is used in the silicon backplane.

Unlike conventional analog LCOS devices this new back plane does not require charge [storage](#) at the pixel or any special light blocking layers. The drive voltages used by all pixels are common and originate from outside of the backplane.

Digital D-ILA Operation Principle

The fundamental driving procedure consists of two steps, data addressing and driving LC. First, the input signal is processed by the [controller](#) and turned into bit-plane format. In this step, a lookup table is used to determine the correct bit sequence for a target gray level. The first [bit](#) plane image is written to the pixel SRAM of the digital D-ILA through the frame buffer. The digital D-ILA driving [block diagram](#) is shown in Figure 6.

The pixel memory has only "on" or "off" information. The information of the pixel is stored in the master [memory](#) and then is transferred to the slave memory. This configuration enables data to be transferred to a pixel at the same time that the previously loaded data is being displayed.

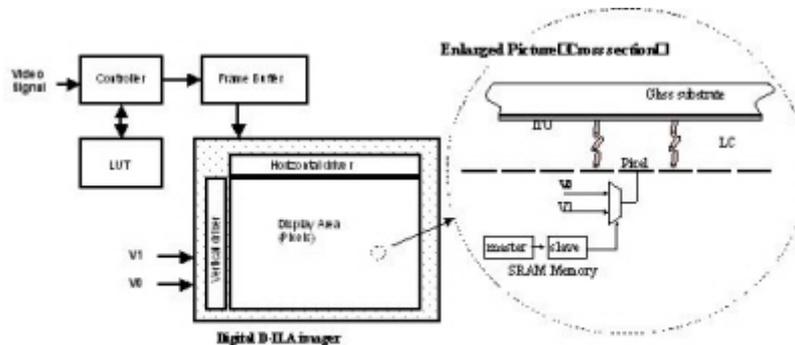


Figure 6. Digital backplane D-ILA driving block diagram

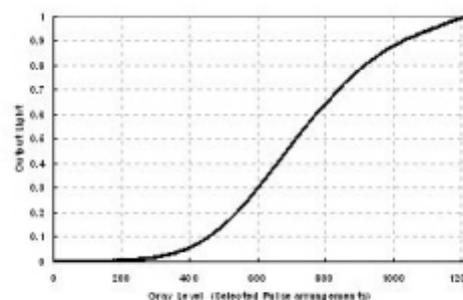


Figure 7. Electro optical transfer characteristic of D-ILA with digital PWM activation

After the data-addressing step is finished, the next step is to drive the liquid crystal. Three voltage signals, V0 and V1 and ITO voltage are used. These voltages are applied to all pixels of the display area at the same time so that every pixel can be driven by the same condition. The V0 signal and the V1 signal are selected by the SRAM information of the pixel. The liquid crystal driving voltage is given by ITO voltage "V1 or ITO voltage "V0. Thus, the threshold voltage of the device and the maximum voltage according to each device can be adjusted.

The device has over 50 sub frames. Under this configuration, 24 bit planes can be established and each bit plane length can be determined freely, so in theory there are 224 gray scale steps. In practice a combination of bit sequence that allows over 10 bit, 1024 addressable states, is used. Thus a gray scale can be reproduced without image contouring found in time sequential operation devices.

In this driving scheme, the LC is driven by high frequency that approximates a square wave running at several kilohertz. This is significantly higher than that of analog devices, 60 or 120Hz. This contributes to the high reliability of the D-ILA devices. The transfer characteristic is shown in Figure 7 and the [output illumination](#) in a frame from the pulse width modulation in Figure 8.

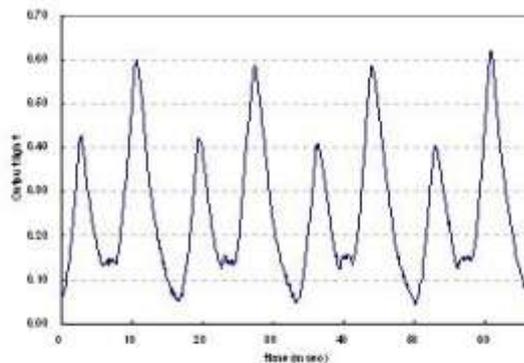


Figure 8. Projection output light at the 128 gray level as a function of frame time. There are two light pulses per frame.

D-ILA Device Characteristics

D-ILA Device Characteristics

Uniformity

No cross talk image or reflection and ghost image is observed in the picture, because the full digital driving principle eliminates these analog artifacts. In addition the SRAM [architecture](#) provides excellent voltage uniformity across the active area of the panel, and consequently it has good uniformity throughout the picture area.

It also eliminates the influence of light leakage, and it improves the uniformity of the picture and the reliability of the device.

Liquid Crystal Alignment

Vertically aligned nematic (VAN) LC alignment allows high device contrast ratio across the entire visible light spectrum range since, in a tunable birefringence operational mode, 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 using a broad spectrum projection light source. The liquid crystal molecules are aligned almost perpendicular to the surface with a small pre-tilt angle at off state. A low pre-tilt angle is an important factor in achieving high contrast ratios and good quality in the projected image. Figure 9 shows a schematic of the VAN liquid crystal alignment. There is a range of pre-tilt angles best suited for producing a high contrast ratio and a good uniform image without LC disclination. With optimized pre-tilt the intrinsic device contrast ratio for a $i_c^{1/2}/2.4$ optical system is greater than 40,000:1. As shown in Figure 9, the molecules are rotated away from the perpendicular state by the electric field from the pixel corresponding to input image signal.

JVC pioneered the use of LC alignment methods that use no organic layers. Thus high stability is achieved under conditions that degrade organic layers and cause short operating lifetimes. The JVC inorganic liquid

crystal alignment method shows no degradation in the accelerated test. In the graph the voltage holding ratio of the liquid crystal (VHR) is used as a figure of merit for the stability of the alignment method. Over 100,000 hours of operating life are indicated.

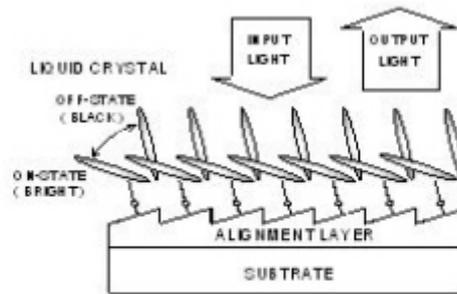


Figure 9. VAN LC alignment used in D-ILA devices

The polarization conversion efficiency (PCE) of VAN liquid crystal is highly efficient--approaching 100%. The D-ILA device also has a high aperture ratio of 89%. In digital driving, LC is driven by pulses so the LC molecule is always moving and the output light intensity is also changing. But in the bright state, all most all pulses are "on", therefore it is driven as if it is driven by RMS voltage level.

Contrast Ratio

The one of the benefit to use VAN mode is its ultra-high contrast ratio, which is essential to get good picture quality. The residual retardance of the VAN [mode](#) is very small and so the dark state of the D-ILA is achromatic and very high contrast is achieved in all colors. More than 20,000:1 sequential contrast ratio can be obtained with compensation of the residual birefringence of the liquid crystal. Figure 10 shows the process development steps that lead to the high reflectivity and contrast ratio.

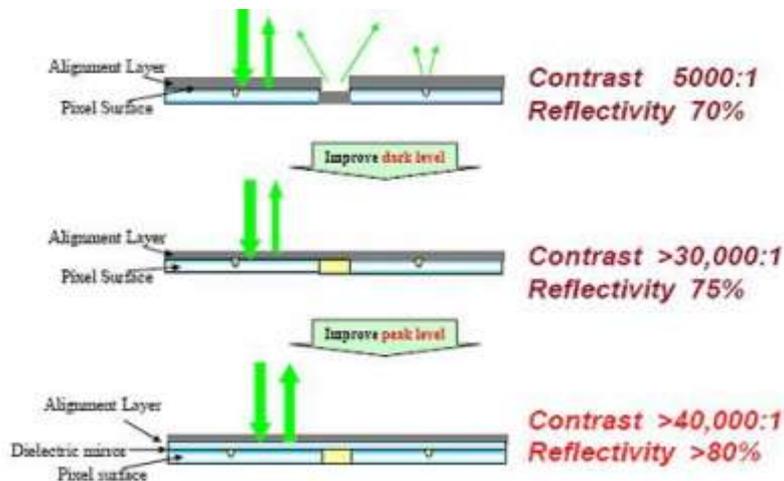


Figure 10. Process refinement of D-ILA leading to higher efficiency and contrast ratio

Gray Scale

A VAN nematic liquid crystal layer is used, whose response time is slow compared with the duration of the least significant bit (LSB). In this configuration, the output of LC shows non-linear characteristics, which is suitable to display subtle gray levels. On the other hand, in the bright state, it can produce more light as by driving many pulses. It works as if by RMS voltage. Because of increased sub-frames, a smooth gray scale is obtained (Figure 7). Furthermore, driving the nematic liquid crystal by pulse voltage has an advantage that the output light shows non-linear characteristics. The high contrast and large number of sub frames allows subtle gray scale in the dark state to be accurately replicated. A smooth picture without utilizing error diffusion or dither technologies, which are used in PDP and DLP, is possible.

Digital driving can control precise gray scale. A gamma curve is established with a calibration method, and 1024 pulse arrangement (10bits) out of 224 selectable patterns to express 10 bit gray scale are selected.

Characteristics - continued

Gamma characteristics and Stability

The gamma curve is established by selecting pulse arrangements to fit a desired curve. The stability under various environments is very important for consumer applications.

The advantage of using VAN mode is that the dark state and the white state are very stable, and the influence is occurred only in the middle of gray level. This is because that the E-O characteristics of VAN mode, V_{th} and V_{max} , are very stable with wide range of temperature. At the dark state and bright state, all pulses are driven equally so that these portions aren't affected by LC response time. In the middle of gray level, some pulses are driven, and the output light will be modulated by the response of liquid crystal cell. The amount of modulation can be reduced by the driving pattern.

Response time

Another advantage of using digital driving is response time in moving pictures.

In the newly developed digital driving method, we intentionally insert black portions between each frame time in most of the gray levels. The driving voltage is relatively high compared with the analogue drive and so the response time is faster as predicted by the relationship $T \sim 1/V^2$. Furthermore, the same drive voltages are used for all gray levels, so we achieved excellent response time for moving images.

MTBF of D-ILA Device

The ruggedness and reliability of the D-ILA modulator has been demonstrated in actual operation in the field since production started in 1998. Table 2 summarizes the MTBF performance.

Configuration	Life-time coefficient	Actual performance data	Life-time
IC	10% decreasing rate of MOS amplification ratio (grs) (Degradation of transistor characteristic by hot electron)	110 years at 15V (120 years at 50 degree C)	Over 10 years
LC	Timing of 10% degradation in LCD holding rate by UV element	574,200 Hrs at 0.1mW/cm ²	Over 10 years
Sealing material	Reduce by half time of adhesion strength by UV light	Over 8 years at room temperature storage	Over 8 years
ACF connection	Insulation resistance of terminal 100 ohms, connecting resistance over 300 ohms	Over 100,000 Hrs at 85 degree C, 85% moisture	Over 100,000 Hrs

Table 2. MTBF of D-ILA modulator components

D-ILA Projector System Technology

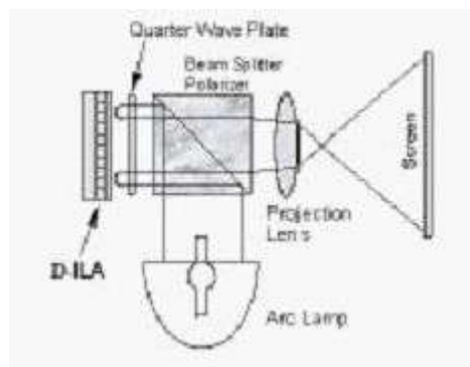


Figure 11. Optical Schematic of Basic D-ILA Projector

A schematic of the optical system to read the image on a single D-ILA device is shown in Figure 11. This shows the basic operation for a single D-ILA which can be R, G or B. The light from the arc lamp is separated into two linear polarization states by the polarizing beam splitter (PBS) before it reaches the D-ILA. One state is reflected by the [interface](#) in the PBS and reaches the D-ILA device. To remove residual retardance and thus improve the contrast ratio of the PBS, a wave plate retarder is inserted between the PBS and the D-ILA. The polarized light is then reflected by pixel electrode and modulated by the liquid crystal

again, thus receiving the gray scale image information. Finally the image is magnified and focused on the viewing screen by the projection lens.

Third Generation Optical System for the RS-2

Third Generation Optical System for the RS-2

D-ILA projector technology has advanced to improve compactness, luminous efficiency, and contrast ratio with each succeeding generation of projector. The RS1 and RS2 use this new system to make a quantum jump in system contrast ratio.

Figure 12 shows the optical schematic of the third generation full color RGB system using state of the art Moxtek wire grid polarizers. Wire grid polarizers polarize light by a two dimensional array of parallel wires with period below the wavelength of visible light. A schematic of wire grid polarizer operation is shown in Figure 13. These high performance elements replace the solid glass PBS used in earlier projectors (Figure 11) allowing contrast ratio of the optical system alone in excess of 50,000:1. The white projection light from the high intensity light source (UHP-type lamp) is collimated and sent to an integrator and polarization recovery optical elements. The integrator improves the uniformity of the illumination across the aperture of the D-ILA modulators and the polarization recovery element rotates some of the orthogonal polarization state to the state used for projection. The beam is then split into RGB components by dichroic filter plates, and sent through the wire grid PBS beam splitters above to the D-ILA devices. The image-modulated output projection light from the 3 D-ILAs is analyzed by the same PBS elements and combined by a crossed dichroic prism, which transmits the full color image to the projection lens. The projection lens images and magnifies the converged RGB image components on to a projection screen.

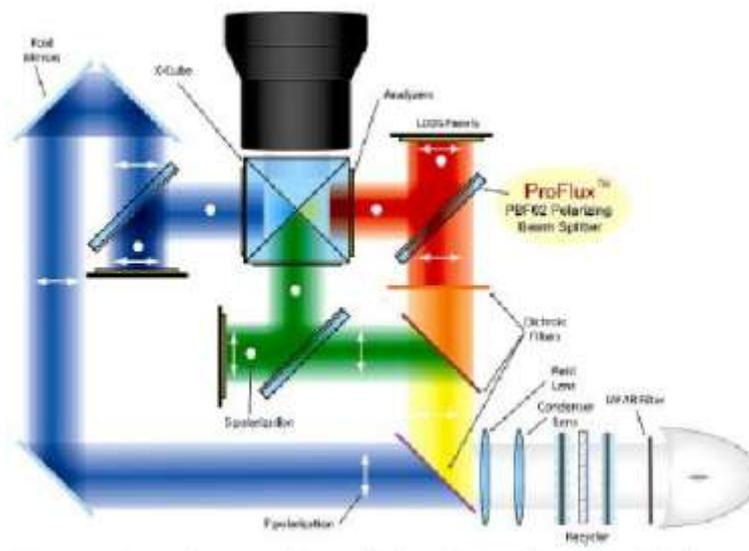


Figure 12. Three panel optical engine using Moxtek ProFlux wire grid polarizer polarizing beam splitters

Wire Grid Polarizer

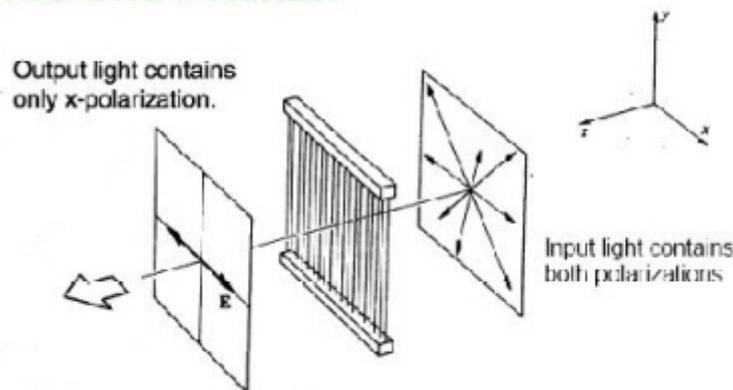


Figure 13. Schematic of Wire Grid Polarizer operation

4K x 2K Development

4K x 2K Development

A 4K image contains a significant increase in image information as shown in Figure 14. Now the ability to create 4K motion images through computer animation, scanned film or through capture directly with digital sensor cameras has progressed rapidly. Also the ability to transmit high [bandwidth](#) real-time data has matured. This is revolutionizing fields from the cinema to visualization to simulation. To meet the challenge of displaying these images in many different venues, JVC is demonstrating a new compact 4096 x 2400 pixel projector with 10,000:1 contrast ratio and 3500 lumen output. The new 4K D-ILA device, with a diagonal of 1.27 inches is the second generation 4K D-ILA after the pioneering 4K first demonstrated in 2001.

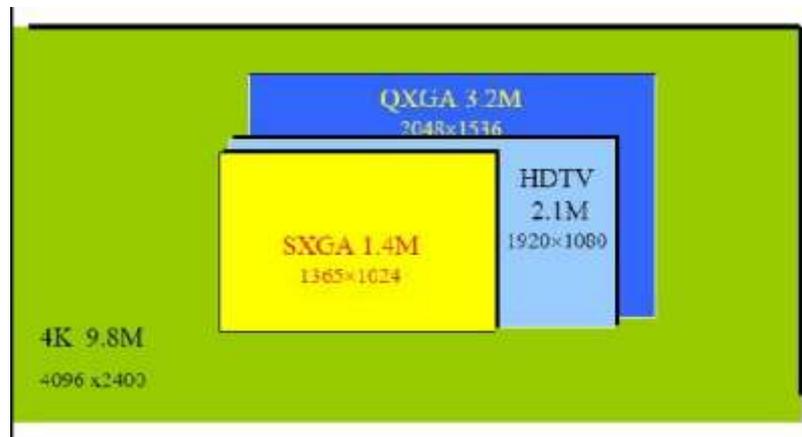


Figure 14. Comparison of image formats showing significant increase in 4K image presentation

A Bright Future

D-ILA technology has always been in the forefront of leading the way to higher projection display resolution and film-like dynamic imagery. The demonstrated versatility of the D-ILA design indicates that this technology will continue to lead the way to 8K x 4K resolution and beyond. The future will see a broadening base of D-ILA applications as the new illumination technologies such as LED, laser, and system concepts including true holographic 3D display will provide the basis for display realism in many different venues.

Dr. William P. Bleha is the Senior Research Scientist of the JVC North America R&D Center, ILA Technology Group, in Cypress, California. He is involved at JVC in the research and development of D-ILA_{1/2} technology for projection displays. He received his PhD in solid-state physics at the University of Illinois-Urbana-Champaign. After receiving his degree he joined the Hughes Aircraft Co Research Labs in Malibu CA where he was involved in applying the emerging liquid crystal technology to projection display devices and systems, and optical data processing. He was awarded the 1986 Rank Prize for Opto-Electronics in London for his role in the invention and development of the Image Light Amplifier (ILA) at the Hughes Aircraft Co. In 1992 he joined Hughes-JVC Technology Corp., which demonstrated the first digital cinema projection. He is the author of over 50 publications and 18 patents. In 2005, he received the Karl Ferdinand Braun Prize from the Society for Information Display for outstanding contributions to display technology. Dr. Bleha is a Fellow of the Society for Information Display (SID) and the Society of Motion Picture and Television Engineers (SMPTE). He can be reached at wpbleha@jvc.com