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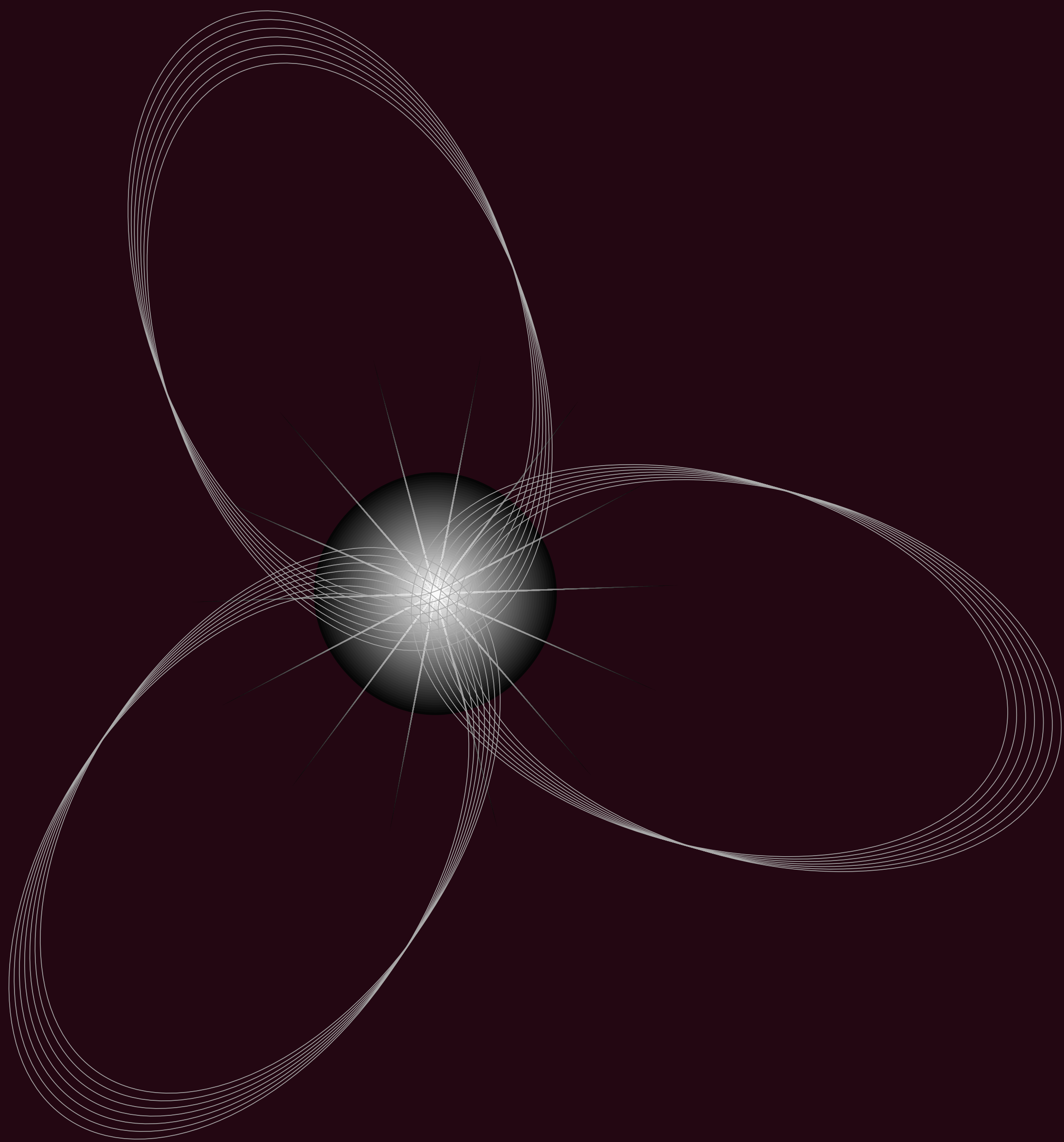
D-ILA™
The look of superior technology



D-ILA“ PROJECTOR

TECHNICAL GUIDE

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Preface

Large-screen video is fast becoming an indispensable display device for applications that require greater presence, appeal, and information distribution capabilities than is possible with conventional monitors. This shift to larger screens is mainly being facilitated by projectors, because they offer greater flexibility in terms of display size and greater compactness relative to the size of the display. At the same time, however, it is necessary that the projection device — the key component of the projector — is capable of withstanding a considerable degree of heat and light since very high levels of light are concentrated on a relatively small surface. The need for complex, advanced technology to attain high resolution further complicates the issue. Even now, engineers around the world are working to develop the next generation of high-performance projectors.

In this document we will examine the basic operating principles, features, and future prospects of D-ILA™. An understanding of these basics will both aid in the introduction of new projectors and enable current projectors to be used more effectively.

Projector Development History and Background

In the 1940s, as black-and-white TVs were fast becoming a fixture in households in America and elsewhere, the development of large-screen displays was already underway. Initially, coincident with the development of TV receivers, the primary projection method was CRT based. However, limits on light output soon led to the development of the light valve system, which made it possible to control more powerful light sources. In the 1950s, a black-and-white Eidophor system was commercialized using oil film target tubes.
In the 1960s, both projectors and TVs were converted to color systems. In the case of projectors, a configuration of three oil film target tubes was used. In the 1970s, the Talaria system was introduced. Here, color signals were multiplexed and the number of oil film target tubes was reduced. This system enabled light output of a few thousand lumens, compared to the few hundred lumens possible with CRTs. The Eidophor and Talaria devices that used oil film target tubes required large vacuum devices. This increased the size and cost, as well as requiring more maintenance, due to the chemical changes in the oil film.
By this time, however, research had already begun on the possibility of using liquid crystal for use in future flat panel displays and various display boards. By the 1980s, some manufacturers had begun applying transmissive and reflective liquid crystals to projectors. By the beginning of the 1990s, LCD projectors had been commercialized for the general market and and ILA™ projectors followed soon afterwards.
In the mid-1990s, DLP™ projectors were introduced. These used a DMD™ device, which modulated light with the mechanical vibration of ultra-small mirrors. With LCD projectors and ILA™ projectors already on the market, projection systems entered a new and much more competitive era. Table 1 lists the types of projection methods and Figure 1 shows concept diagrams for each type of projection system.

Table 1: Types of Projection Systems

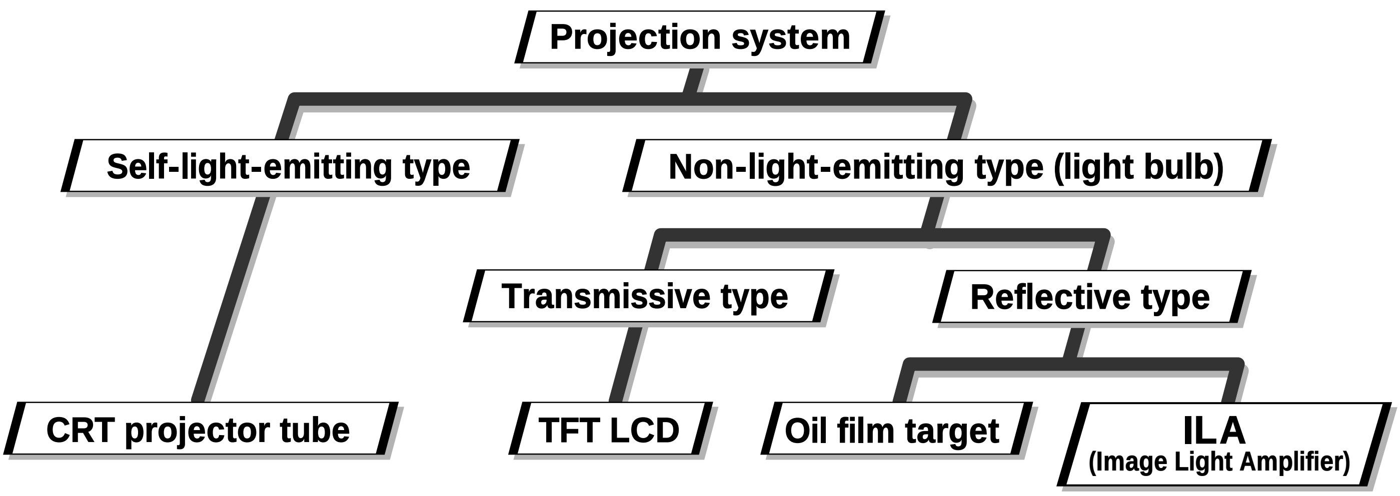
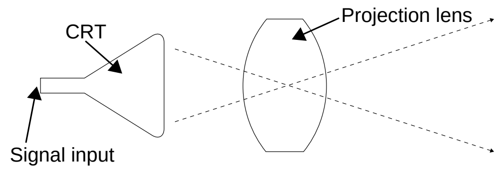
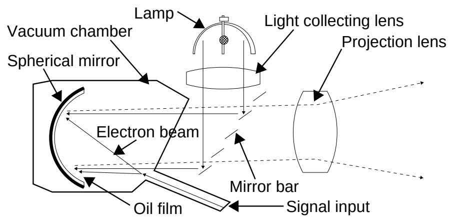
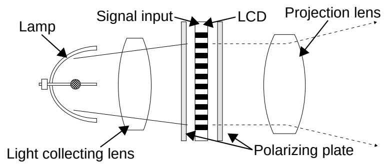
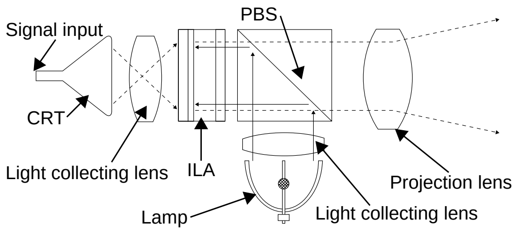
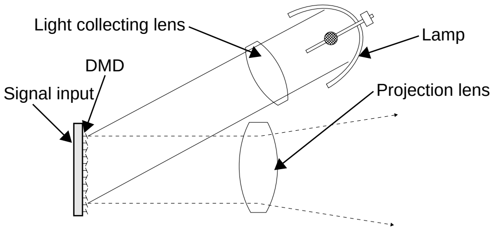


Figure 1: Concept Diagrams and Features for Each Projection System

	Configuration Concept Diagram	Features
CRT		○ Mature technology and low cost ○ No pseudo-signals with no pixels ○ Can handle specially shaped screens × Resolution and light output inversely related × Low output × Large size and weight
Oil film target type		○ Writing and reading are separated, so light output is higher ○ No pseudo-signals with no pixels ○ Can handle specially shaped screens × High device costs × Long startup time for vacuum device × High maintenance costs × Large size and weight × Deterioration in S/N ratio due to film surface characteristics
LCD		○ Can easily be made small and light ○ Can be produced at low cost ○ Easy optical configuration × Resolution and light output inversely related × Large device required for high light output × Contrast limited (horizontal orientation)
ILA		○ Provides both resolution and light output ○ No pixels and no pseudo-signals ○ Aperture ratio 100% ○ High contrast ○ Writing and reading are separated, so high light output easily produced ○ Can handle specially shaped screens × Large size and weight × Difficult to produce at low cost
DLP		○ Uses natural light, giving it a high light efficiency ratio (in principle) ○ High-speed response makes screen sequence color easy ○ Tones managed easily with digital switching operations × The device process includes mechanically moving parts and is complicated. Yields and costs are issues. × The pixel pitch is restricted, so high resolutions require larger devices. × The drive logic is complex.

Meanwhile, following the development of conventional TVs, due to the maturity of the technology and their relatively low cost, CRT projectors had for many years dominated the projector market. However, in spite of technological advances, these projectors remained plagued by insufficient light output and bulky, heavy designs. Eventually the CRT projection system was relegated to use in home projection TVs and specialist applications, while designs of other projectors were modified to incorporate to the newer systems. Similarly, the Eidophor and Talaria devices were phased out because the vacuum devices they required means that they were too large, heavy and expensive to compete with the newer systems.

From ILA™ Projectors to D-ILA™ Projectors

Around the start of the 1970s, research was carried out at Hughes Aircraft into optic writing spatial modulation devices and in the 1980s, projectors using this device came into practical use (even though they were restricted to still-picture images). Continuous improvements eventually made it possible for these devices to handle moving images and by the end of the 1990s, the technology for moving images was firmly established.

At the same time, JVC (Victor Company of Japan, Limited), was carrying out research and development on projection methods suitable for the anticipated large-screen pictures. Determining that the optic writing spatial modulation devices were optimum for this purpose, JVC's R&D focused on practical implementation of this technology. Hughes Aircraft and JVC joined forces to develop a marketable projector and in 1993 introduced the ILA™ (Image Light Amplifier) projector. This was immediately recognized in the market as the new standard for large screen projectors in the second half of the 1990s.

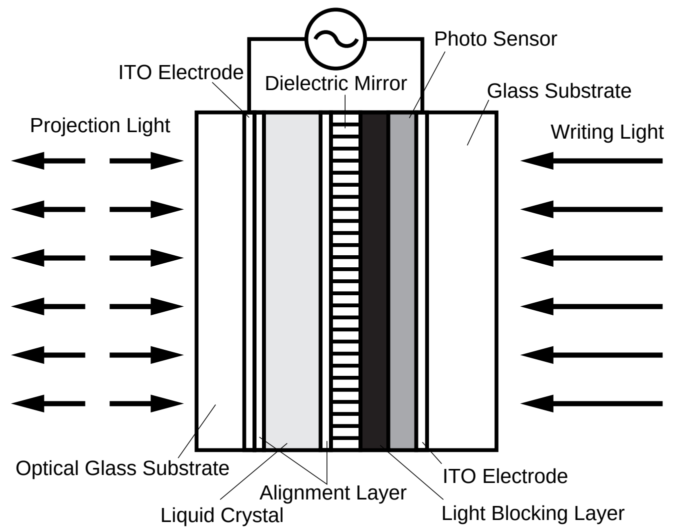
As Figure 2 shows, the ILA™ projector device is comprised of a number of layers of 0 thin-film that are sandwiched between two glass substrates. The thin-film structure has four layers: an opto-electrical conductive layer, a light cut-off film, dielectric mirrors, and liquid crystal with ultra-fine processing to generate pixels. As Figure 1 shows, the device operates with two-dimensional CRT optical images as the writing light, forms the images in the opto-electrical conductive layer, and varies the impedance of the optic-

electrical conductive layer according to the strength of the optical image. As a result, the AC voltage applied to the liquid crystal layer changes to match the optical image and optical modulation is applied to the reading light. The modulated light is branched at the PBS (Polarized Beam Splitler) surface to the light source side and the projection side linked with the strength of the writing light.
The features of the ILA™ projectors are as follows.

①The reading light that determines the optical output is reflected by dielectric mirrors, with an aperture ratio of 100%, so high brightness projection is possible.
②The writing light that determines the resolution is ultra-low, so the CRT beam size is ultra fine. Conseguently very high resolution can be easily attained.
③The liquid crystal vertical layout, once considered difficult for mass production, is mass produced for the first time, providing very high contrast.
④There is no pixel structure, so distortion-free reproduction, free of any pseudo-images is possible for all types of input signals.

In other words, by separating the light output (whose phase is easily shifted), and the resolution, the writing light and the reading light (with dielectric mirrors), this is the first technique to provide both very high light output and high resolution. Furthermore, this system has the added advantage of distortion free image combined with very high contrast. This allows superior quality images from the ILA™ projector.

Figure 2: *Basic Composition of ILA™ Device*



While ILA™ projectors are high-resolution projectors that realize light output of up to 12,000 lumens, boundary resolution of 1,600 TV lines, and contrast of over 1,000 to 1, some problematic issues remain.

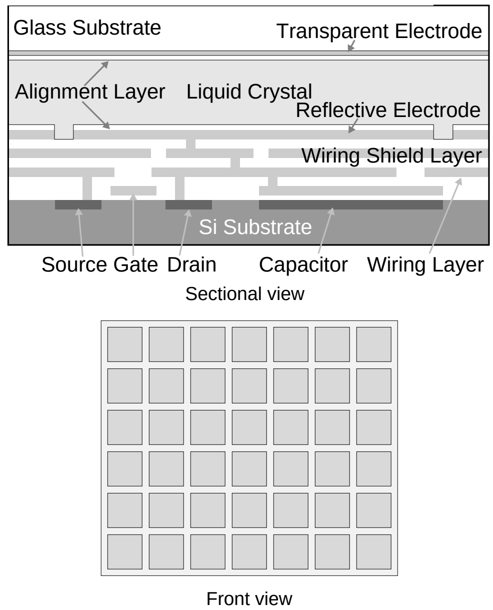
①Because the ILA™ is used as the projecting device and a CRT for the writing light, two key devices are required. As a result, costs can qucikly escalate as does size and weight.
②The writing optic image is formed with an electron beam that has a diameter, so even though the boundary resolution is high, as the optical image spatial frequency rises, the MTF (modulation transmission function) gradually decreases. This can lead to diminished legibility of very small letters.

In recent years, thanks to increases in computer capacity and speed, together with decreasing costs, presentations which include graphics and text have become commonplace. It is expected that ② above may reduce the suitability of ILA™ projectors for multimedia applications.
JVC has developed its own new projection method that resolves Issues ① and ② while retaining the high light output, high resolution, and high contrast provided by ILA™ projectors. To meet market demand for a mainstream projection technique for the 21st century, JVC introduced its "D-ILA™ Multimedia Projector" at the beginning of 1998.

Structure and Basic Operating Principles of D-ILA™

As Figure 3 shows, the basic structure of D-ILA™ devices is LCOS (Liquid Crystal on Silicon). Aluminum reflective electrodes, corresponding to each pixel, are laid out on the CMOS board making up the X-Y matrix that selects the pixel address. After this surface is flat processed, the vertical film is formed. On the other glass board, the transparent electrode layer and the vertical film are placed. The liquid crystal layer is sealed between the facing films.

Figure 3: *Basic Structure of D-ILA™ Devices*



The D-ILA™ device's reflective technique involves laying out the pixel address selection section and the light modulation section liquid crystal in three dimensions. The entire surface, except for the insulation section between pixel electrodes, is used as a reflective surface, so a very high aperture ratio is possible. Also, thanks to the high aperture ratio, high intensity light can be handled, making it easy to convert to higher light output.
The vertical orientation that has proven itself on ILA™ projectors, is used for the liquid crystal layer, so high contrast is obtained. Depending on the optical system selected, a contrast of over 1,000 to 1 is possible.

The resolution is determined by the size of the cells on the CMOS board. Given the sub-micron scaling of current CMOS memory ICs, even the pixels for full HDTV (1,920 x 1,080 pixels) can be fitted onto a CMOS board of less than 1 inch across, providing ultra-high resolution.

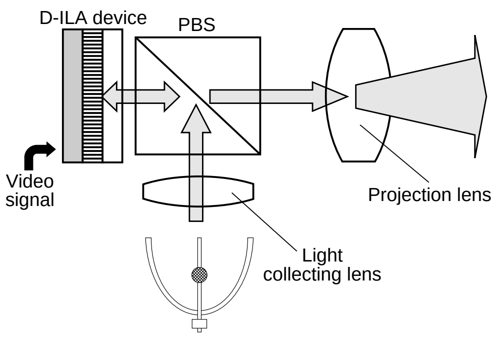
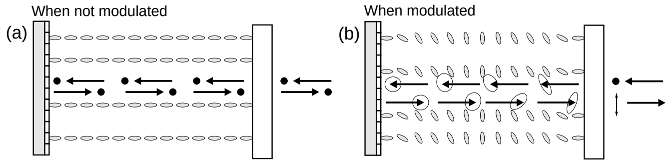


Figure 4: Basic Structure of D-ILA™ Projector

Figure 4 shows how a D-ILA™ projector operates. The natural light from the light source is separated by the PBS (polarized beam splitter) into a P wave component (light vibrating parallel to the surface) and an S wave component (light vibrating perpendicular to the surface.) The P wave component proceeds straight through the PBS. Since it is unnecessary light, it is not used. Only the S wave component reaches the D-ILA™ elements. The light that has reached the elements passes through the liquid crystal layer, is reflected by the pixel electrodes, passes through the liquid crystal layer again, and reaches the PBS. At this time, the component that was modulated in the liquid crystal layer is converted into P waves and after it has passed through the PBS, is projected onto the screen through the projection lens. On the other hand, the S wave component that was not modulated is reflected by the PBS and returns to the light source, so it does not contribute to the projection image.

Figure 5 shows the optic modulation characteristics for the vertically oriented liquid crystal. (a) is for when there is no modulation and (b) is for when there is modulation. When the input signal to the device is black, voltage is not applied to the pixel electrode, the liquid crystal layer remains in its vertical orientation (as shown in the diagram), the light axis of S wave and liquid crystal long axis are parallel, and optic modulation does not take place in the liquid crystal layer. The light input, as S waves, is output as it is (without modulation) and reflected by the PBS. As a result, this light does not reach the screen and it reproduces the black state. The high contrast characteristic of the vertically oriented liquid crystal is for black reproduction, when the liquid crystal is not modulated. This is how true black is obtained. (b) shows the state in which voltage is applied to the pixel electrode. Since the liquid crystal is the n type, the long axis tilts in the direction perpendicular to the applied electric field. At this time, the axis of the incoming S wave light and the long axis of the liquid crystal intersect. Due to the compound refraction of the liquid crystal, the light is converted into elliptically polarized light and circularly polarized light, a P wave component is generated, and the projected optical image is formed on the screen. The maximum modulation of the liquid crystal occurs when all the S waves coming into the device are converted into P waves to reproduce a white image.

Figure 5: Modulation Characteristic of Vertically Oriented Liquid Crystal



Features of D-ILA™

The features of D-ILA™ are as shown in Table 2. Because of the high aperture ratio, any rise in the temperature of the device due to photothermal conversion and any malfunctioning of drive elements due to photoelectric conversion is minimal. Therefore, it is possible to handle high intensity light. Moreover, the resolution is determined by the CMOS process scaling, as discussed above. So pixel pitches of only a few microns are possible and, as mentioned previously, the pixels for full HDTV (1,920 x 1,080 pixels) can fit onto a CMOS board less than 1 inch across. Also, the vertical orientation of the liquid crystal is fully utilized. The high light output, high resolution, and high contrast of the conventional ILA™ are retained, while shape, weight, and cost issues of the ILA™ are resolved by converting the writing method from an optical image to direct writing with electrical signals.

Table 2: D-ILA™ Projector Features

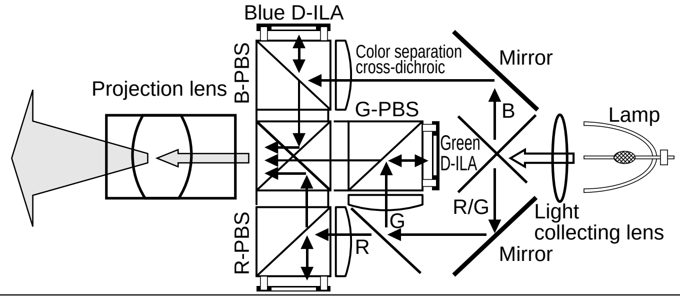
High resolution	Currently, this is the element with the highest possible density. When pixel size is the same, it provides the highest resolution; when resolution is the same, it has the smallest pixel size.
High aperture ratio	As long as the insulation between pixel electrodes is maintained, the size of the non-opening section can be minimized, so resolution can be raised with only a minimal reduction in the aperture ratio.
High light output	The aperture ratio and light output are proportional and the non-opening section is small. As a result, photothermal conversion is minimal, the light withstand level for the elements is high, and powerful light sources can be used.
High contrast	The vertically oriented crystal provides a no-modulation state, so the highest contrast of a few thousand to one can be attained for the element alone.
High-speed response	With the reflective type, light is modulated while it goes back and forth. As a result, the thickness of the liquid crystal layer is half that of the transmissive type, the electric field boundary strength gw is double, and high-speed response is possible.
Compact, lightweight	The high pixel density and high aperture ratio allows the elements to be light and compact.

Development of color projectors

Figure 6 shows the configuration of a three-D-ILA™ projector. The first and second "fly-eye" lens plates and the PS composite plates sandwiched between them convert the natural white light of the light source into S wave. This raises the operating efficiency of the light source and improves the uniformity of the amount of light on the screen at the same time. Subsequently, the light is separated into RGB (red, green, blue) components through color photospectrometry and each color is input to the corresponding PBS. The S wave component, reflected by the PBS, becomes the P wave component modulated by the liquid crystal as shown in Figure 4 and discussed above. Only this component passes through the PBS, while the RGB is synthesized by the cross-dichroic prism, and projected onto the screen as a color image through the projection lens.

The three-panel projector is the most fundamental method for handling color. This is a system in which the light utilization efficiency is high and projector performance, color reproduction, contrast, and resolution are determined directly by the device characteristics. On the other hand, tiny differences in registration and uniformity among the R, G, and B devices can directly influence the picture quality. Since three devices are required and color separation and color synthesis optical systems are necessary, this can lead to high cost and large size. Therefore, although the three-panel system is suitable for professional use, it is not suitable for consumer systems which require lower prices. In order to develop an affordable consumer-level system, it is necessary to reduce the number of devices and further reduce the size and cost of the optical systems.

Figure 6: Structure of Three-D-ILA™ Projector



Single D-ILA™ Color Projector

Methods proposed for reducing the number of devices include (i) surface sequencing that multiplexes the colors on the time axis and (ii) simultaneous point sequencing that multiplexes the colors in space.

Surface sequencing synchronizes with the field frequency and applies the RGB light sequentially. It has the advantage that the device resolution is output as is, but it requires that the field drive frequency is three times the incoming frequency. Also, due to time difference, color mixing, field flicker, etc., pseudo-signals can occur easily, depending on the color disruption and drive conditions.

The point sequence method allocates each pixel within the screen and features simultaneous equations. Color disruption, color mixing, and flicker are less likely to occur and quality equivalent to that of a three-panel type projector, can be obtained. However, three times the number of pixels are required relative to the resolution, making ultra-high density devices indispensable.

The problem with both methods is with the basic principle; that is, if the colors are simply multiplexed, the light utilization efficiency drops to 1/3. For single D-ILA™ projectors, the high-density characteristic of the device itself is utilized. By combining this with a hologram color filter, it has been possible to develop single D-ILAs™ that minimize the drop in light utilization efficiency. These were first shown in late 1999 and introduced to the market during 2000 in the form of consumer projection TVs.

Figure 7 shows basic principles of the structure and color multiplexing for the D-ILA™ hologram device used in the single-panel system. The pixel electrodes are formed on the CMOS IC board and the device comprises an orientation film, liquid crystal layer, and transparent electrodes. This is the same as for D-ILA™ devices. However, by placing a hologram color filter (HCF) on top of the transparent structure, the RGB point sequence is established for each pixel.

This hologram raises the diffraction efficiency for the incoming pure white light with the aim of improving the light utilization efficiency and making the light come in at an angle. As the figure shows, after the light is split into RGB components and passes through the liquid crystal layer, it is concentrated on each pixel electrode by the diffraction wavelength dependence. The RGB light is reflected by the pixel electrodes, passes through the liquid crystal layer again, and arrives at the HCF. Since this light comes into the HCF at a right angle, it passes through the HCF with almost no diffraction effect. While the light is passing back and forth through the liquid crystal layer, it is optically modulated according to the input signal level — the same as with D-ILA™ devices — and projection light corresponding to that amount is created.

When shifting to the color system, this device requires three times as many pixels as the required resolution. All this can be made possible thanks to the high density characteristics of D-ILA™.

Figure 7: Structure of D-ILA™ Hologram Device

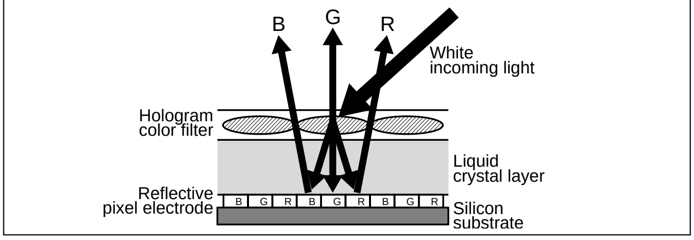


Figure 8 shows the configuration of the single D-ILA™ projector with the D-ILA™ hologram device. The light from the light source travels via the cold mirror, the visible light component is concentrated by the light collecting lens, aligned as a straight-line polarized light component at the incoming-side PBS, and input to the D-ILA™ hologram device at an angle. Only the light that has been optically modulated in the device passes through the output-side PBS and is projected onto the screen through the projection lens.

Figure 8: Basic Structure of Single D-ILA™

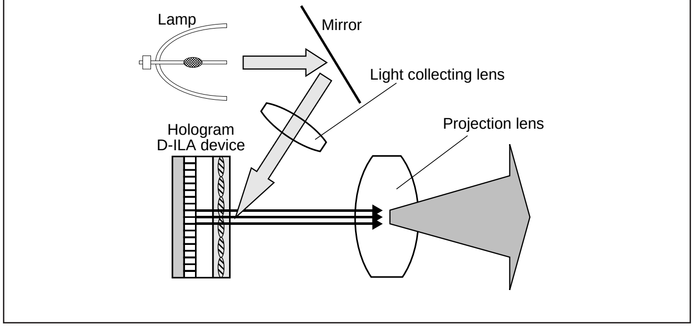


Table 3 gives the specifications for the currently used D-ILA™ device and the D-ILA™ hologram device.

The hologram device attains a horizontal pixel pitch of 22.8/3 = 7.6µm, enabling the highest density level and securing an aperture ratio of 88%. The contrast makes use of the vertical orientation and reaches a few thousand to one for the device itself. Though it depends on a combined optical system, it is possible to secure a contrast ratio of 1,000:1 in a projector.

Table 3: Device Dimensions

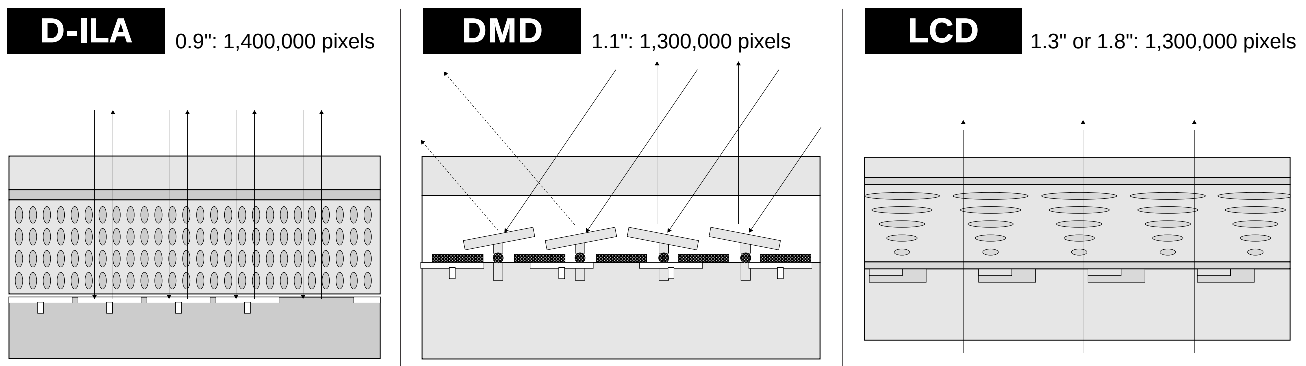
	D-ILA device	D-ILA hologram device
Pixel size (diagonal)	0.907 inch (4:3)	1.22 inch (16:9)
Number of pixels	1,365 x 1,024 dots	1,280 (x3) x 1,028 dots
Pixel pitch	13.5x13.5 µm	22.8/3=7.6 µm
Aperture ratio	93%	88%
Contrast ratio (theoretical)	>2,000:1	>1,000:1
Response speed	Rising + falling < 16 ms	Rising + falling < 16 ms

Comparison with Competitive Systems

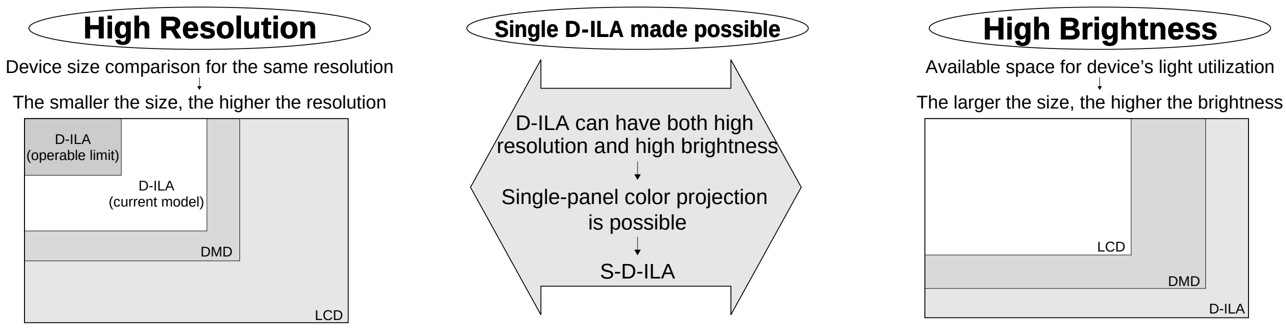
Figure 9 shows the composition of current mainstream projection devices and Table 4 compares the performance of the various methods with the triple color method. DLP™ switches the double stable angle of micro-mirrors digitally to modulate the light path and reproduces tones according to changes in light. Since natural light is used as is, high light utilization efficiency can be expected. However, there is a strong relationship between mirror weight and the twisted hinge, restricting pixel size flexibility. It is estimated that the best pixel pitch that can currently be attained is from a few µm to 20+µm. Shifting to higher resolutions will require larger chip surface areas and is expected to cause deterioration of pixel yields and make mass production difficult.

LCDs use transmissive light, so the optical configuration of the system is relatively simple. Even with a triple system, the device can easily be made compact and lightweight and low cost can be attained. On the other hand, since transmissive light section, the address lines, signal lines, and drive elements are all laid out on the same surface, an increase in the number of pixels will decrease the aperture ratio. Because in this system, resolution and light output generally have an inverse relationship, it is more appropriate for mobile and portable units than for ultra-high resolution and ultra-high brightness.

Figure 9: Structure of Each Projection Device



	D-ILA	DMD	LCD
Device	• Liquid crystal polarized modulation • Analog gradation • Uses polarized light (PS composition is needed) • Ultra high density • Ultra high aperture ratio	• Micro mirror angle modulation • Digital gradation • Uses natural light • Limited pixel pitch • High aperture ratio • Yield difficulty	• Liquid crystal light modulation • Analog gradation • Uses polarized light (PS composition is needed) • Low density • Low aperture ratio
Optical system	• Reflective type • Quasi-shurilen separation • Close relationship between cone angle and device angle (More freedom of F value, High light efficiency ratio) • 3P composition • Middle light path length	• Reflective type • PBS separation • Inverse relationship between cone angle and contrast (Telecen system, Limited F value, Phase compensation) • 3P/4P composition • Long light path length	• Transmissive type • Polarization plate separation • Inverse relationship between light amount and temperature of polarization plate (Adoption of intake side PBS, Large device size) • 4P composition • Short light path length



As mentioned above, because D-ILA™ has pixel densities and aperture ratios superior to other systems, it is possible to produce ultra-high light output and ultra-high resolution. Also, by using the high density characteristic, the size of the pixel chip can be reduced compared to other units at the same resolution. This means that this system is applicable to portable and mobile systems. The D-ILA™ system is considered ideal for the high-resolution era of the 21st century.

Table 4: Performance Comparison for Different Systems

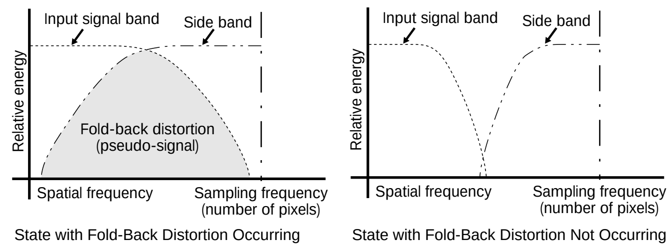
	D-ILA	DLP	LCD
Resolution	Excellent (1365 x 1024)	Good (1280 x 1024)	Fair (1280 x 1024)
Aperture ratio	Excellent (93%)	Excellent (91%)	Fair (65%)
High pixel density	Excellent (7 µm pitch)	Good (17 µm pitch)	Fair (25 µm pitch)
High light output	Excellent (10 klm or more possible)	Excellent (10 klm or more realized)	Good (larger pixels for higher output)
Light efficiency ratio	Good (Polarized light)	Excellent (Natural light)	Good (Polarized light)
Contrast ratio	Excellent (Vertical orientation)	Good	Fair
Ease of optical configuration	Good	Good	Excellent (Transmissive type)
Element cost(yield)	Good	Fair	Excellent
Response speed	Good	Excellent	Good
Real time characteristic	Good	Fair (Frame memory)	Good
Development to single-panel projector	Excellent	Good (Surface sequence)	Fair (Larger pixels)

D-ILA™ Picture Reproduction

① High-resolution

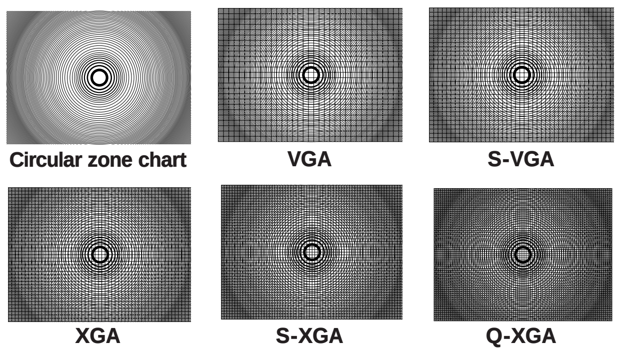
Naturally, the larger the screen, the greater resolution is required. Current resolution requirements can generally be separated into that for computer displays centering on text and graphics on the one hand and video displays on the other. Even for computer displays, S-XGA level resolution can be supported adequately. At the workstation level, most requirements for U-XGA resolution can be handled. On the other hand, for video displays, although full support for 720p/1080i is hoped for with the future standardization of HDTV, this has not yet been commercialized.
To respond to the need for high-resolution displays and display various types of signals from different multimedia applications, many projectors use a resizing technique with pixel density conversion. However, if the projector resolution is insufficient, the display image is compressed and information is lost Also, even if the resolution is greater than that of the input signals, resampling can generate pseudo-signals called fold-back distortion.
Figure 10 shows this state. The spatial frequency of the input signal and side-band components generated with the sampling frequency which corresponds to the projector's pixels are mixed in. This results in the generation of a pseudo-signal (shown with diagonal lines) that produces fold-back distortion when converted into low-band components. This appears as moire and jaggedness and causes drastic deterioration of the picture quality.

Figure 10: Pseudo-Signals due to Sampling



The only methods to eliminate this are either (i) a complete in-phase state or (ii) to use the sampling theorem shown in the figure and sample with a spatial frequency of at least double the input signal (display with resolution 2x or greater).
The in-phase state means a display of 1:1 with the number of pixels for S-XGA input. Also, when displaying XGA input using the number of pixels for S-XGA, the edges are not displayed and the pixels are displayed 1:1. For this reason, many projectors have a function that allows the resizing mode to be switched off. On the other hand, when the resolution of the projector itself is lower than that of the input signals, it is impossible to display images without the generation of pseudo-signals.
The pictures in Figure 11 show the stage of generation of pseudo-signals depending on the resolution, using a circular zone chart — a typical pattern with various spatial frequencies. As can be seen from this reproduced image, it is not simply enough that the projector resolution be equal to or greater than the resolution of the input signals. Rather it must be sufficient to ensure that pseudo-signals are not generated when input signals are reproduced.

Figure 11: Specific Example of Pseudo-Signals (Example of moire due to circular zones)



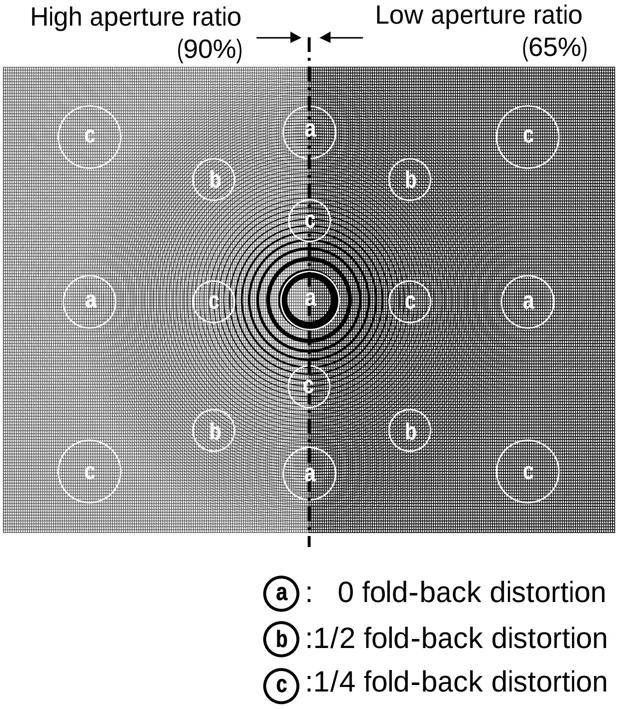
Considering the variety of multimedia signal formats, it is obvious that higher and higher resolution will be needed to completely avoid the generation of pseudo-signals. The high-density configuration of D-ILA™ is ideal for this.

② High aperture ratio

We have already mentioned how a high aperture ratio is good for high light output because it improves light efficiency and minimizes light absorption. It also has a major impact on the quality of reproduced pictures. For example, when the input signal is all white, if it is projected with a low aperture ratio, lattice stripe noise and extraneous pseudo-signals will be generated in the original picture. Therefore, the higher the aperture ratio, the fewer the artifacts so that the image reproduced will be smoother.
The circular zone chart (discussed above) in Figure 12 shows how the aperture ratio affects the amount of fold-back distortion (pseudo-signal) that appears in the reproduced image. On the left, we can see the image condition when the aperture ratio is 90%, and on the right, we see the results when the aperture ratio is 65%. It is obvious that the higher the aperture ratio, the less fold-back distortion occurs. 1/2 fold-back distortion is significantly reduced, and there is almost no 1/4 distortion whatsoever at the high aperture ratio.
The impact of fold-back distortion on the reproduced image also depends on the frequency of the band that the distortion is folded back to; the lower the band, the lower the picture quality. Here again, a device with a high aperture ratio that produces minimal

1/2 or 1/4 fold-back distortion is definitely advantageous.
The D-ILA™ device allows a high aperture ratio to be maintained even when resolution is increased. With both high resolution and high aperture ratio, the D-ILA™ device is much better at reducing fold-back distortion than other types of devices.

Figure 12: Fold-Back Distortion Status At Different Aperture Ratios



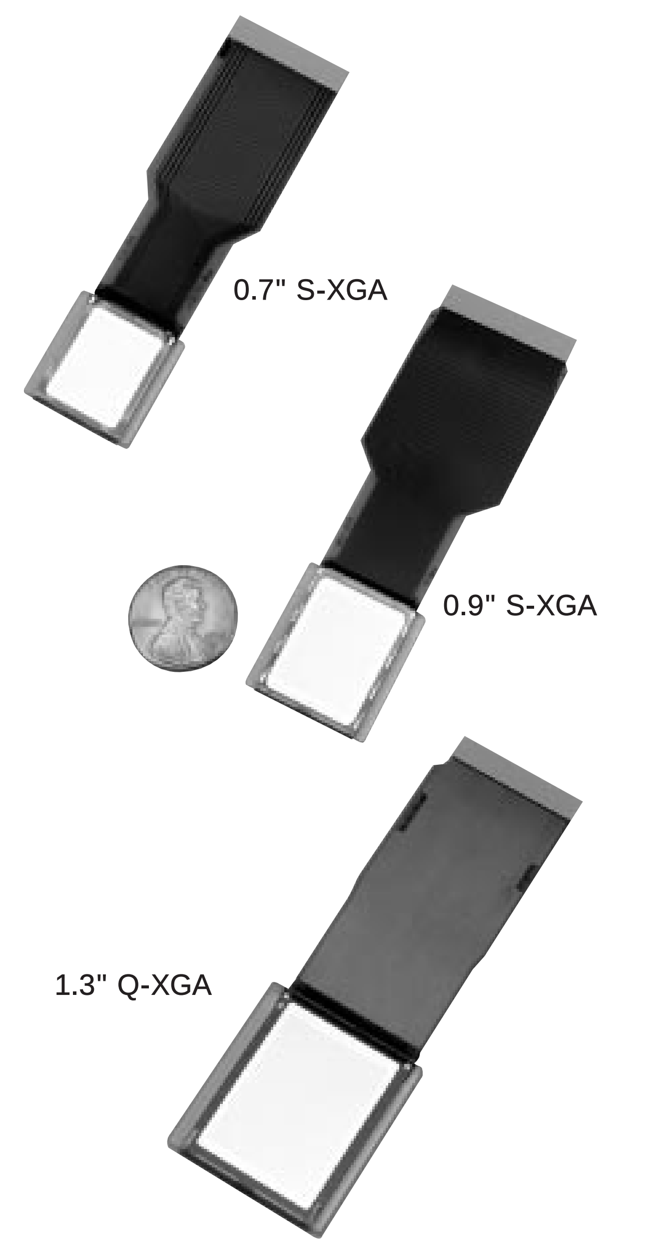
③ Contrast

Generally, text and other information can be viewed adequately at a contrast ratio of 50:1 or higher. Most audiences will accept a contrast ratio of 100:1 or higher for text and data. This is the case when the peak signal is displayed at 100% on the screen. However, if viewing a dark video source (a night-time scene, for example), the peak signal level falls below 1/3 and the contrast on the screen falls below 1/3, reducing contrast ratio. This is the main reason that many data projectors, which are used mainly for text display, set their contrast ratios between 100:1–200:1. However, nowadays with video images begining to be incorporated frequently in computer-based presentations, even data projectors are starting to need the same level of contrast required in a video system. Under these circumstances, it is necessary that the projector components themselves offer high-contrast performance. Again, D-ILA™, with its vertically oriented liquid crystals, which has a high contrast of a few thousand to one, provides an excellent solution for future development.

Summary: The Future of D-ILA™

The key advantage of the D-ILA™ system is that it enables the highest density pixel integration, making it suitable for high resolution picture reproduction. Also, even at higher resolutions, there is almost no drop in the aperture ratio, so very high light output is possible. Because the D-ILA™ system provides both high light output and high resolution, it meets all the performance requirements of projectors. Moreover, D-ILA™'s other benefits — such as higher contrast with vertical orientation, and smaller size with high pixel density — make it the ideal projection solution for large-screen display systems.
Figure 13 shows the current state of D-ILA™ devices and prototypes such as an HDTV-ready single-panel hologram D-ILA™, Q-XGA mode for full HDTV, as well as a device with 4000x1000-pixel capability. These examples make it abundantly clear that the D-ILA™ system has enormous potential for development. It is safe to say that D-ILA™ is the only current system that can handle even higher performance.
When commercialization of D-ILA™ began, the system offered S-XGA resolution capability. This is still more than sufficient to meet the majority of current market demands for high resolution and high picture quality, but it is only natural that picture performance requirements will continue to rise. In order to meet this market demand, JVC is working to boost D-ILA™ performance to conform with future needs and form the basis of the next generation of large-screen image systems.

Figure 13: Various Types of D-ILA™ Devices



Reference Materials (Illumination & Optics)

Current projectors reproduce a projected image by modulating the angle and polarization of the light emitted by the light source according to the input signal. This means that the illumination optical system used to concentrate the light from the lamp and the characteristics of the lamp used in the light source are two of the most critical element technologies in the projector. This document discusses the general theory of the lamp and the illumination optical system in order to provide a better understanding of how a projector works.

Light source characteristics

The characteristics required of lamps are; 1) high light emitting efficiency, 2) emission of light flux with the brightness point diameter required for treating the light source as a point light source, 3) wide enough spectrum for good color performance, and, 4) long service life. In addition to the usual important factors — such as small size, light weight, and low cost — safety, ease of handling, impact on the environment, and a broad range of other diverse factors must be taken into account.
Typical lamps used in projectors include Xenon lamps, metal halide lamps (below MH), and ultra-high-pressure mercury lamps (below UHP). All three types use short-arc type electrical discharge tubes that provide high brightness and are nearly point light sources.
The table shows typical performance for these lamps, as well as for a halogen lamp — the basic type of white incandescent lamp.
The figure shows the light spectrum characteristics for these lamps and for natural daylight.

Xenon lamps are electric discharge lamps that emit light by discharging electricity in high-pressure Xenon gas that is at 10–15 atmospheres at normal temperature and 30–40 atmospheres when the lamp is lit.
Xenon lamps have the following advantages.
①The light spectrum characteristics are continuous and close to sunlight in the visible light spectrum. Color performance is extraordinarily good.
②The brightness is high and the lamp is nearly a point light source.
③Instantaneous lighting and re-lighting are possible.
④The light spectrum distribution is stable over time, as well as when the power fluctuates occur.
⑤High-power types are possible.

Xenon lamps have the following disadvantages.
①A rare gas is used, so costs are high.
②Service life is shorter than for MH and UHP lamps, making running costs high.
③The pressure inside the lamp is high even at normal temperatures and care is required when handling.
As can be seen in the figure, these characteristics — especially the color spectrum characteristics that are similar to natural daylight — make Xenon lamps a popular choice in projectors that emphasize the quality of the reproduced images, as well as in large projectors that require very high illumination.

MH lamps are electrical discharge tubes that add a variety of metal halides to high-pressure mercury. Vaporization pressures are at least 10 atmospheres when the lamp is lit. The mercury primarily functions as an impact gas and contributes to lamp voltage stability.
The light emission spectrum is primarily the work of the bromine and iodine metal halides.
MH lamps have the following advantages.
①Diversity, because the spectrum characteristic and color temperature can be selected by choosing the appropriate metal halide.
②Long service life is possible.
③The light emission efficiency is comparatively high.

MH lamps have the following disadvantages.
①The spectrum characteristics change as the lamp starts up and over time.
②The brightness is lower than for Xenon and UHP lamps (making it difficult to use these lamps as point light sources).
③Characteristics can vary considerably due to the addition of multiple chemical compounds.
Given these characteristics, MH lamps are frequently used in medium-size projectors where light output and color performance of at least a certain level are required.

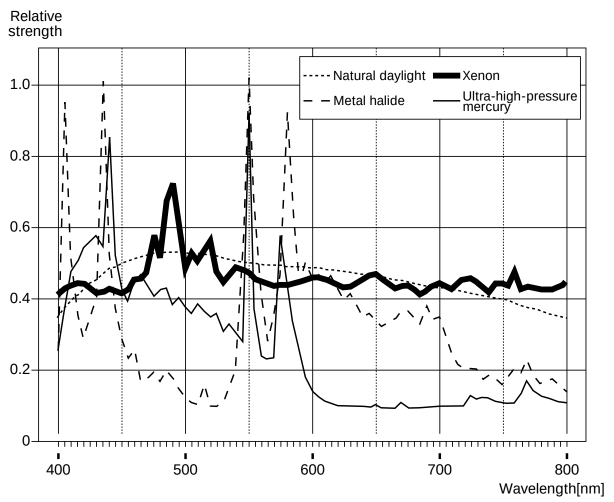
UHP lamps are electric discharge tubes that emit light with ultra-high-pressure mercury. Vaporization pressures are at least 100 atmospheres when the lamp is lit. By taking advantage of the fact that the continuous spectrum increases when the luminance spectrum of the mercury vapor discharge tube is given ultra-high pressure, these lamps have the following advantages.
①Short arcs can be attained easily and the lamp can create a point light source.
②Manufacturing costs are low and, because the effective service life is long, running costs are low.

UHP lamps have the following disadvantages.
①The long-wavelength spectrum is severely insufficient and it is difficult to reproduce warm colors.
②Only low-power types are possible, so this type of lamp is not suited to very high light output. Given these characteristics, UHP lamps are frequently used in comparatively inexpensive projectors.

Table: Representative Characteristics by Lamp Type

	Xenon	Metal halide	Ultra-high pressure mercury (UHP equivalent)	Halogen
Power	100W - 6000W	100W - 1000W	100W - 220W	50W - 2000W
Light emission efficiency	30-50 lm/W	60-80 lm/W	100 lm/W	20-28 lm/W
Brightness	1000 cd/mm^2	200-300 cd/mm^2	1000 cd/mm^2	60 cd/mm^2
Color temperature	5600 K	5000 K-7000 K	7000 K-8000 K	2800 K-3200 K
Arc length	1-3 mm	1.5-3.5 mm	1-1.5 mm	–
Starting time (stable)	A few seconds	30-50 seconds	30-50 seconds	Instantaneous
Light modulation	Possible (No color temperature change)	Not possible	Not possible	Possible (Large change in color temperature)
Change in color temperature with time	Ultra-small change	Relatively large change	Small change	Change
Change in light output over time	Decrease with time	Decrease with time	Slightly decrease with time	Decrease with time
Service life	1000-1500 H (light output half-reduction)	1500-2000 H (light output half-reduction)	2000-5000 H (remaining ratio)	100-500 H (depends on usage conditions)

Figure: *Light Source Spectrum Characteristic*



In general, Xenon lamps are used for high light output and high color performance, UHP lamps for low price and compact size, and MH lamps for applications that fall somewhere in between. However, as performance of the lamps themselves is improving it is possible that projector performance will be revolutionized in the near future by even higher brightness points (point light sources), higher efficiency, and higher color performance. Lamps are one of the most critical components of projectors.

Illumination optical system

① Uniform illumination

Various improvements allow more effective and uniform illumination of the projection device with the light from the lamp. In addition to optimization of reflectors and light collecting lenses, light pipes and integrators made up of fly eye lenses have been used for dramatic performance improvements.

As the figure shows, a light pipe is a square pillar that repeatedly and completely reflects incoming light on its glass surfaces. This converts the light flux distribution that is non-uniform, at the incoming surface, into a uniform light flux distribution at the pipe outgoing surface. At the same time, the light utilization efficiency is improved through efficient conversion that matches the light pipe outlet surface shape to the shape of the surface to be illuminated.

As the figure shows, an integrator comprises two fly eye plates (FEP) of micro lenses.

The light coming from the lamp via the reflector is input to FEP1. The images on each of the micro lenses pass through the micro-lenses of FEP2 and are projected onto the projection device. In other words, the light source image of one lamp is split as many ways as the number of micro lenses on FEP1 to improve the equivalent uniformity. Also, the integrator converts the light to a shape similar to the shape of the projection device and thus improves the light utilization efficiency of the illumination system.

The integrator (see below) is frequently used in combination with polarization conversion elements (primarily with D-ILA™ and LCD projectors which use polarization conversion),while the light pipe is used with DLP™ projectors (which use natural light).

Figure: *Light Pipe Concept Diagram*

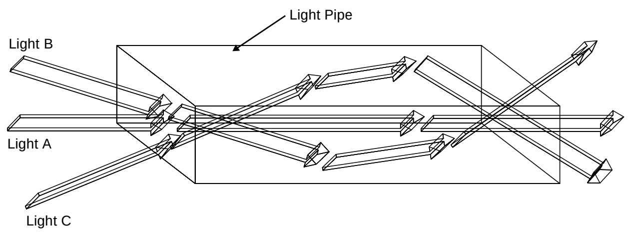


Figure: *Integrator Diagonal View Concept Diagram*

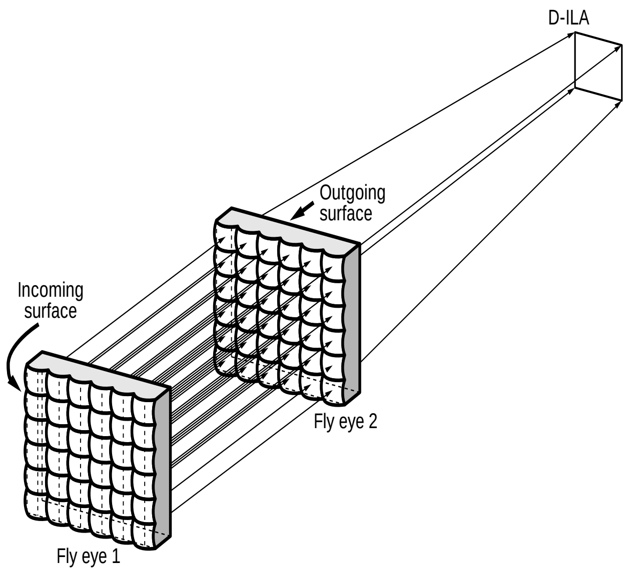
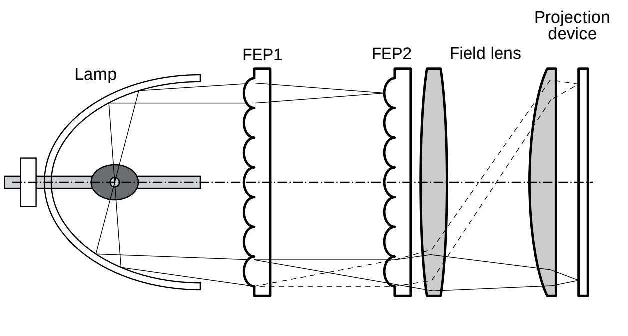


Figure: *Integrator Sectional Diagram*



② *Polarization conversion elements*

In projection systems that utilize light modulation through the multiple refraction of liquid crystal, the light from the light source is divided into two directions of perpendicularly polarized components. Only one of the polarized components is used; the other, unused polarized components, become extraneous and light utilization efficiency drops. In order to improve light utilization efficiency, the extraneous light is converted into useful polarized light with a light polarization conversion element. Figure A and Figure B show typical configurations for polarization conversion elements. In each system, the light input section of the polarization conversion element is divided into multiple sections and light polarized in one direction passes through each split surface. The reflected polarized light has its polarization converted 90° at a 1/2-wavelength plate. This is converted to light with the same polarization at the output surface of the light polarization conversion element.

Figure A shows the polarization conversion method using ultra-small PBS. The light coming from FEP1 of the integrator (discussed above) is collected so that light collection sections and non-collection sections repeat at equal intervals. This light is input to the polarization conversion element. In the polarization conversion element, the P wave (component polarized parallel to the paper surface) of the light, coming in from light collection sections, passes through the ultra-small PBS. It is then converted to S waves (light polarized perpendicular to the paper surface) by a 1/2-wavelength plate and output. On the other hand, S waves input at the ultra-small PBS are reflected by mirror surfaces and output to the non-collection sections. As a result, S waves are output to the entire surface as light whose polarization has been converted. This improves light utilization efficiency.

Figure B uses one PBS prism. The S waves (component polarized perpendicular to the paper surface) in the light coming from FEP1 of the integrator, (discussed above), are reflected at the PBS surface and input to FEP2, where sections with and without 1/2-wavelength plates repeat. The S waves reflected at the PBS pass through FEP2 as is. The P waves (component polarized parallel to the paper surface), on the other hand, are converted to S waves by 1/2-wavelength plates located in front of FEP2. As a result, the light from FEP2 is S wave light over the entire surface, so light polarization conversion is obtained.

Figure A: *Polarization Conversion Element 1*

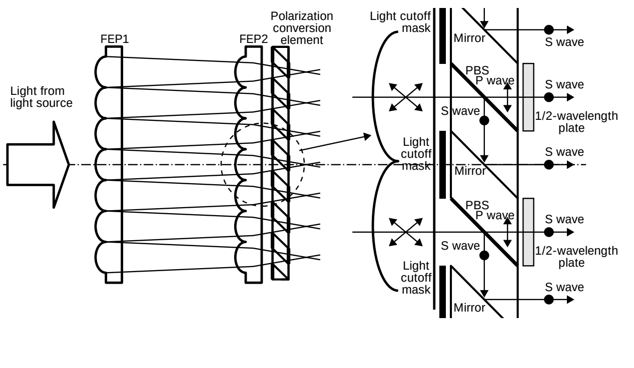
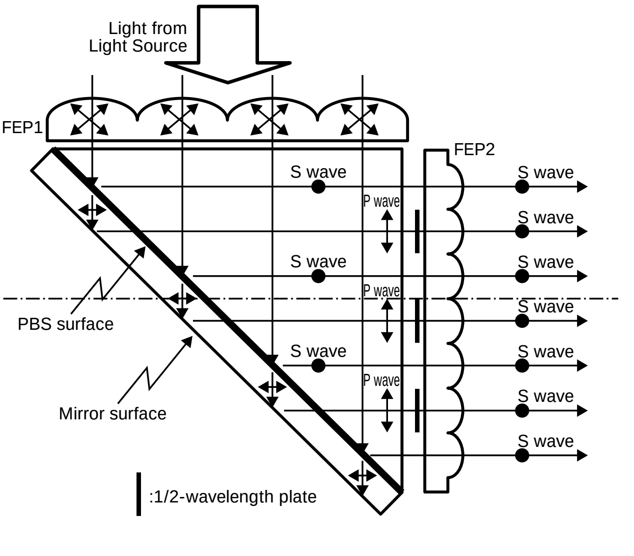


Figure B: *Polarization Conversion Element 2*



Although the light utilization efficiencies of current projectors vary greatly according to the brightness (point light source characteristics) of the light source and the size of the projection device, light utilization efficiency is still limited to about 20 percent even when well-matched parameters are used. In order to raise light utilization efficiency, the efficiency of the illumination optical system and the lamp light emission needs to be improved even more.

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