6.4: *Invited Paper:* Fully Digital D-ILA^{TM} Device for Consumer Applications

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Abstract
JVC[1] has developed a fully digital driving D-ILA device, which inherits the advantages of conventional D-ILA such as contrast ratio greater than 5000:1, high efficiency, high resolution and high reliability. The all-digital drive offers substantial reductions in system cost and excellent picture quality has been achieved.

1. Introduction
Recently, large displays are becoming very popular all over the world, especially in Japan and in the US markets. The market share of the flat panel displays such as PDP and LCD is increasing rapidly. Also the market share of microdisplay type rear projection TVs using DLP or HTPS is increasing rapidly and is replacing CRT products. Unfortunately, LCOS type projection TVs haven't taken off yet, although expectations have been high.

JVC announced last August that JVC had developed new D-ILA (Direct-Drive Image Light Amplifier). (Fig. 1) D-ILA is a kind of LCOS type device, and has superior features such as high contrast ratio, high efficiency, smooth image and high reliability under intense illumination light [1]. But so far, D-ILA has been limited to high-end professional applications [2]. The new 720P device is targeted at consumer applications and employs a fully digital driving method.

For consumer market applications, such as rear projection TVs, system cost is one of the most important issues. To address this need, JVC has formed a strategic partnership with Aurora Systems to develop the new all digital 720P D-ILA. This partnership combines the all-digital silicon back-plane and driver technology [3] designed by Aurora Systems with the vertically aligned Nematic (VAN) liquid crystal technology developed and manufactured by JVC.

So far, many people have tried to drive Liquid Crystal (LC) digitally, but until now, they have not obtained good picture quality and reliability at the same time. The liquid crystal they used was mainly ferroelectric crystal (FLC) which must respond to driving pulses individually. Although FLC materials have fast response times (100us) this is still insufficient for rendering accurate grayscale without using other measures such as modulation of the light [4] or spatial dithering technologies.

Our approach is to use Nematic liquid crystal, which has relatively slow response time compared with its shortest driving pulse width. This approach using Nematic liquid crystal was reported by K.H Kang et al [5], but they did not achieve sufficient grayscale.

Our target is to reproduce the high picture quality and the high reliability of conventional analog D-ILA and to make it possible at an affordable price.

[1] Victor Company of Japan, Limited: Its Website is http://www.jvc-victor.co.jp/english/global-e.html.

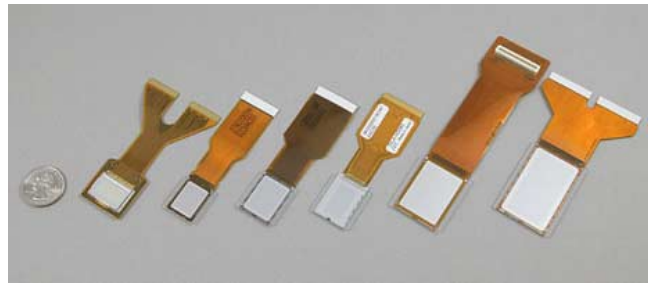

Fig. 1 The lineup of D-ILA devices. From right side, 4K2K 1.7inch, QXGA 1.3inch, FHD (1920x1080) 0.82inch, SXGA 0.9inch, SXGA+ 0.7inch, and the fully digital D-ILA device (Left side.)

2. Fully Digital D-ILA Device
2.1 Specifications
The Device specification is shown on Table 1.

Its diagonal is 0.70 inches. The pixel pitch is 12 micron and there are 1280x720 pixels in the display area. The electrical addressing employs a PWM (pulse width modulation) driving method. The fill factor of the device is nearly 93 percent, which is designed to produce a smooth bright image.

Table 1. The device specification

Device diagonal	**0.70 in.**
Driving method	**Digital (PWM)**
Number of Pixels	**1280 x 720**
Aspect ratio	**16:9**
Pixel Pitch	**12 micron**
Fill factor	**93 %**
Contrast (device only)	**5000:1**

2.2 Device Structure
The fundamental device structure is the same as conventional D-ILA, and the device consists of a glass substrate and a silicon back-plane and between them a liquid crystal layer. The liquid crystal we use is negative dielectric Nematic type, which is aligned for vertically (VAN mode), and is designed to respond to the average RMS voltage of the PWM signal.

We employ high speed SRAM as the silicon back-plane, which is specially developed by Aurora Systems Inc.

Unlike conventional analog 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 are given from outside of the back-plane.

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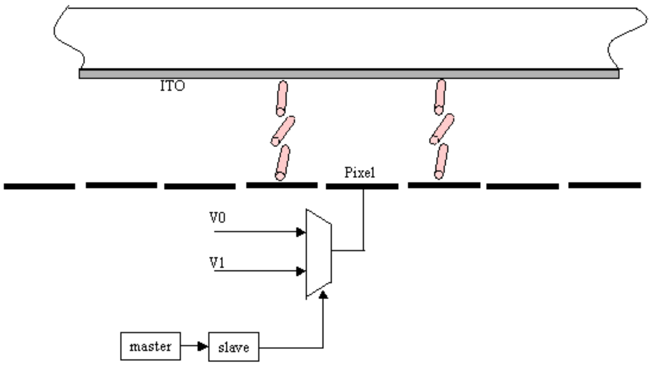

Fig. 2 The cross-section of the digital D-ILA

2.2 Driving Principle

The fundamental driving procedure consists of two steps, data addressing and driving LC. Firstly, 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 bitplane image is written to the pixel SRAM of the digital D-ILA through the frame buffer.
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.

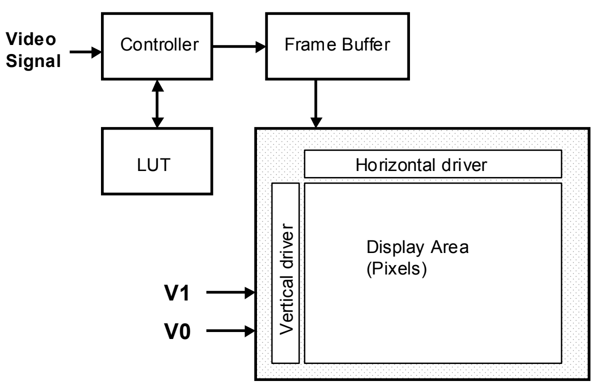

Fig. 3 Driving Block Diagram

After data-addressing step is finished, the next step is to drive the liquid crystal. We use three voltage signals, V0 and V1 and ITO voltage. 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, we can adjust the threshold voltage of the device and the maximum voltage according to each device.
Our device has over 40 subframes. Under this configuration, we can handle 24 bit planes and set each bit plane length freely, so in theory there are 2^24 gray scale steps. In practice we use a combination of bit sequence that allows over 1024 addressable states to be generated. The 40 subframe we achieve is significantly larger than 10 to 12 typically achieved in PDP displays. Consequently we are able reproduce fine gray scale.
In this driving scheme, the LC is driven by high frequency that approximates a square wave running at a few kilohertz. This is significantly higher than that of analog devices, 60 or 120Hz.

3. Characteristics of the device

3.1 The performance of the device

3.1.1 Uniformity

We can observe no cross talk image, reflection and ghost image 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. This means that we have eliminated the need to calibrate voltages for row or column drivers. This greatly simplifies system design and helps reducing system cost.
It also eliminates the influence of light leakage, and it improves the uniformity of the picture and the reliability of the device.

3.1.2 Efficiency of the device

The polarization conversion efficiency (PCE) of VAN liquid crystal shows almost 100%, and it will allow us to obtain a very high bright display. The pixel gap is as small as 0.4um and therefore the device has a high aperture ratio, 93 percent, and smoother picture are achieved compared with transmissive LCDs.
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 PMS voltage. The influence of digital drive to the maximum output light was very small and was almost the same as analog driving.

3.1.3 High Contrast Ratio

The one of the benefit to use VAN mode is its 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 readily achieved in all colors. The contour graph of our device shows good contrast even without any compensation. (Fig. 4)

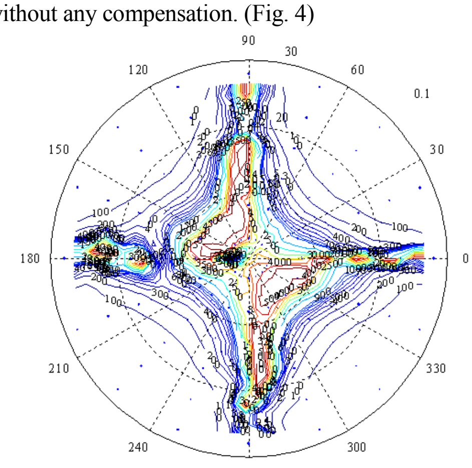

Fig. 4 The contrast ratio of the device

We could obtain more than 5000:1 contrast ratio after proper compensation of the residual birefringence of the liquid crystal. Fig. 5 shows a sequential contrast ratio of Blue and Green devices measured in an optical system with F2.4 while each device is driving. As previously mentioned, in our device the threshold level is strictly determined by the V1 and V0 and ITO voltage. So, it is easy for our digital device to get high contrast after gamma calibration.

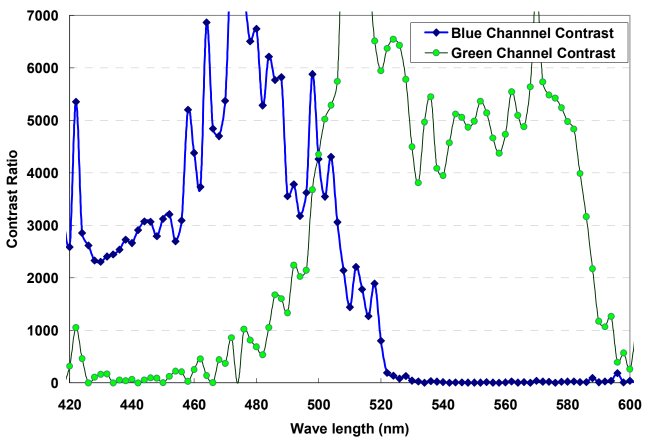

Fig. 5 Sequential contrast ratio of the digital D-ILA

3.1.4 Gray Scale

We use a Nematic liquid crystal cell, whose response time is too slow compared with the duration of the least significant bit (LSB). In this configuration, the output of LC shows non-liner 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, we are able to achieve smooth gray scale. The results for this are shown in Fig. 6 and demonstrate a big improvement over the results reported previously [5]. Furthermore, the high contrast and large number of sub frames allows subtle gray scale in the dark state to be accurately replicated. Smooth picture without error diffusion or dither technologies, which are usually used in PDPs and DLP, is possible.

Digital driving can control precise gray scale. We can make a gamma curve using a calibration method, and select 1024 pulse arrangement (10bits) out of 2^24 selectable patterns to express 10 bit gray scale.

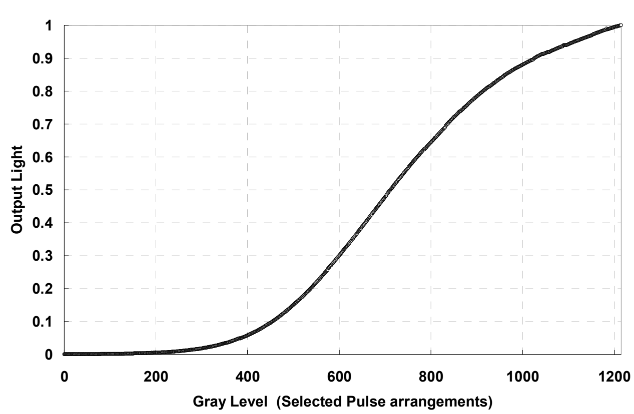

Fig. 6 Electro Optical Curve at Digital Driving

3.1.5 Gamma characteristics and Stability

When we set up a gamma curve, we select pulse arrangements to fit a desired gamma curve. Its 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. It's because that the E-O characteristics of VAN mode, Vth and Vmax, 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. We use this technology and get stable performance without controlling the temperature within a few degrees C.

3.1.6 Response time

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

It is well known that charge storage type display shows blur effect when the picture moves [6]. Most liquid crystal devices use charge storage to maintain voltage across the pixel. Many researchers are developing methods to improve LC response time in order to improve moving picture quality. A widely reported method is to over drive the pixel [7]. Also it is well known that moving picture quality is greatly improved when the picture is driven to black within a frame [6].

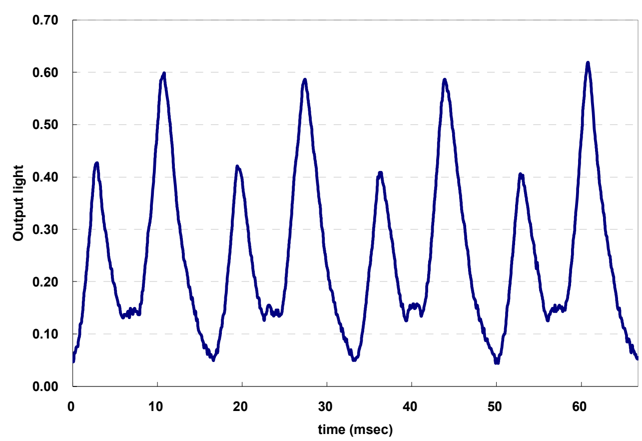

Fig. 7 Measured output light response at 128 gray level

In the newly developed digital driving method, we intentionally insert black portions between each frame time in most of the gray levels. (Fig. 7) The driving voltage is relatively high compared with the analog 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.

Because of PMW driving, our digital D-ILA device may have some moving artifacts like PDP, DMD and other digitally addressed devices have. It is strongly related to the pulse arrangements. We have successfully reduced these artifacts an acceptable level for consumer applications.

3.2 Other Advantages

3.2.1 Silky Image

Because of the reflective device, the image that comes from the device has very smooth and silky image. It's due to the fact that we have a very high aperture ratio and almost all of the display surface is used for displaying images. We have no spacers in the display area so that we can produce very smooth picture throughout the display area.

3.2.2 Productivity

In analog devices, such as conventional D-ILA, it is essential to block strong illumination light in order to prevent undesirable voltage shifts of the pixel electrode. So, conventional analog devices include a light shield structure between the pixel electrodes and transistors. This added complexity can limit the yield of the silicon back-plane. The digital device does require any special design features to control stray light and so the device structure is simplified. Therefore, the digital device yield is expected to be higher than conventional analog devices.

The calibration of systems is simplified by the digital approach and so the production time is greatly reduced.

3.2.3 High reliability

The 720P D-ILA uses a vertical aligned Nematic liquid crystal that incorporates specially developed inorganic alignment film. This alignment film shows excellent stability under very high illumination light conditions [8] and does not suffer from the problems reported [9][10] in devices that utilize conventional alignment material such as Polyimide. Long lifetime is an extremely important requirement for consumer applications and the JVC VAN cell technology meets this need.

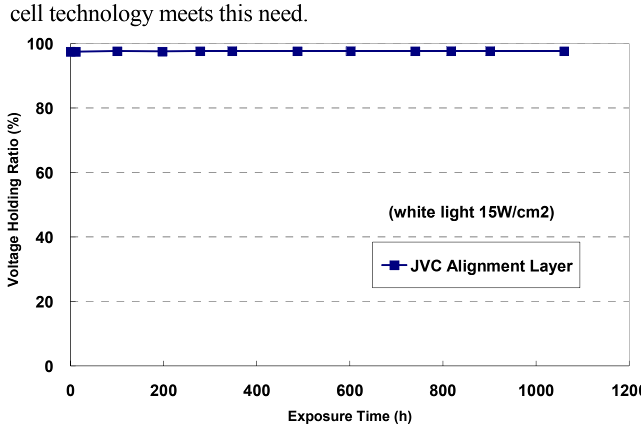

Fig. 8 Photo-stability of the alignment layer [8]

4. Rear Projection TV

Our device is intended for a 3-panel system, so that it produces high output compared with other single or two-panel system. It enables high output light, and we can select it for improving other characteristics such as viewing angle of the projection image, larger display area or power consumption of the system.

We are launching RPTV using the fully digital D-ILA 720P device this year. These are 52-inch model and 61-inch model. The RPTV has a high efficiency optical system that will produce more than 5lm/W with 110W long life lamp. The total luminance is expected to be more than 500cd/m^2 with a contrast ratio more than 1000:1.

Both models feature JVC's exclusive Digital Image Scaling Technology (D.I.S.T) that upconverts the signal to deliver sharper images and JVC's Four-Point Color Management and other picture technologies, with which people can enjoy large screen program with high picture quality and vivid color.

Fig. 9 Rear Projection TV model using the digital D-ILA

5. Conclusion

The all-digital drive eliminates problems with analog noise, cross talk and ghost images. Additionally the voltage uniformity across the panel is excellent and there is no need for compensation circuits on row/column drivers. This greatly simplifies the system electronics and results in significant system cost reductions.

This development is a major change in direction for JVC in order to provide a more cost effective product. JVC intends that all future D-ILA devices for consumer products will be of this new digital technology. We are planning to introduce the first product for the consumer market, such as a rear projection TV, in 2004.

6. Acknowledgements

We'd like to thank Mr. Yoshikawa of Aurora Systems for supporting our development, and express great thanks to Mr. Nakagaki of JVC for useful discussions and leading us.

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