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Using a single Spatial light modulator for stereoscopic images of high color quality and resolution

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Abstract

Since stereoscopy is a fundamental part of an immersive display, stereoscopic imaging has been part of many research papers and patents in the past. There have been different approaches developed to generate and transport the two images to the human eye. In general we can say that image generation may be done by one or two units and image encoding is done either by frequency, time or orientation.
For image generation Projectors of CRT, LCD, LCOS and DLP Type are well known. Since 3D has gained more public interest, in the past different approaches have been undertaken to simplify setups for stereoscopy. Often two projectors are used to generate stereoscopic images. But these need more maintenance than a single projector system. For a single projector, frame interleaved stereoscopic Image generation is well known for 3Chip DLP Systems using three spatial light modulators to generate the image. In this paper we describe a solution producing frame interleaved output using a single chip spatial light modulator or digital micro mirror device (DMD) allowing combining high resolution and coloring quality.

1. State of the Art

Stereoscopic imaging is realized by different approaches. We can classify them by the way the images are encoded: We know time encoded (frame or line interleaved) systems with shutter glasses, frequency encoded systems using anaglyph style glasses, frequency multiplex and wave orientated systems using polarisation [Do81].

1. 1 Encoding

1.1.1 Time encoded systems

In time encoded systems the images for the right and left eye are displayed one after another. Typically the viewer uses a shutter glass eyewear to separate the images for the two eyes. This eyewear is synchronized to the emitter and the right or the left eye of the observer. When used with CRT monitors scan line and full page modes are available. In scan line mode the image maybe swapped every scan line, in page mode the images are swapped every full frame. Since CRT Monitors are loosing market shares scan line mode is not very popular since it requires very fast shutter eyewear. Fig.1 shows the relationship between transported image and its synchronisation impulses, the control line for shutter emitters and the resulting states of the shutter glasses for a common synchronous system used with CRT based monitors and shutter eyewear. If the frequency of the alternating images in page flip mode is high enough, normally above 120Hz, the observer does not recognize some flicker. Time encoded images maybe generated by projection systems with one or two projectors. For the image generation with a single system a projector like CRT (cathode ray tube) or DLP (4) Technology can be used. LCOS Systems maybe fast enough but until now not used in this field. In [We02] Texas Instruments describes a system using a three chip DLP System with an associated quad buffer to store the images for both eyes in a front and a back buffer for each eye. Similar to the buffers of an OpenGL Stereo capable graphics board. These systems are incorporated in machines well known from Christie or Barco.

If a system with two sources is used it may need adequate blanking mechanisms presented in [Li89]. Here various rotating Shutters are used to blank the image. LC Shutters maybe another alternative for building a shutter. A two projector setup for DLP systems using the spatial light modulator or digital micro mirror device (DMD) as shutter is described in [Ho02]. In [We02] the blanking of DMD columns is used to disable the unwanted part of the image.

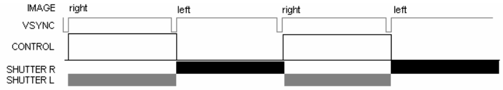

Fig1: *relation of time and transmitted images*

1.1.2 Frequency encoded systems

Simple frequency encoded systems are coding the two images using two different colors, known as anaglyph encoding. Since full colors are used for encoding the resulting image is only greyscale. Frequency multiplex - known as INFITEC – overcomes this problem and uses three frequency ranges for red green and blue light. Each range is very small and ranges for one color are close to another. In Fig.2 transmission rates are shown in relation to wavelength. A small range of red is used for the right and another range for the left eye. Both ranges should be as close as possible. So every image can be coded with its own range of red, green and blue light, not overlapping with the others color range.

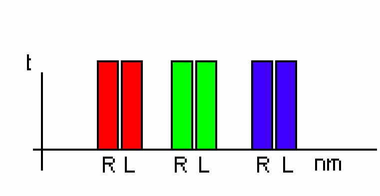

Fig.1. *frequency ranges of infitec glasses*

1.1.3. Wavelength direction encoding

Very familiar encoding methods are based on the direction of the light waves and known as polarisation. Linear polarisation achieved by placing filters in the light beam and in the glasses. Typically light is polarized in horizontal and vertical light waves, with an offset of 45 degrees. Resulting in polarisation of 45 and 135 degrees. Circular polarized light results from adding a lambda/4 retarder to the linear filter adding a rotational component to the light beam. With circular filters the rotation of the observer along the light beam is less critical.

A popular solution is to add a z-screen [Nu01] unit in front of a fast projector to change the direction of light by a liquid crystal rotator. The alternating images can now be visualized by a passive (filter only) instead of using an active (shutter glass) eyewear.

1.2. Projection Systems

We know four different types of projection systems, CRT and LCD, LCOS and DLP. CRT and LCD are well known. LCOS Technology is gaining more market shares and may become the most important system in the near future.

1.2.1 LCOS Projectors

LCOS (or LCoS) is similar to LCD (HTPS High Temperature Poly Silicon) and consists of a liquid crystal layer which sits on top of a pixelated, highly reflective substrate. Below the substrate another layer containing the electronics to activate the pixels is located. This assembly is combined into a panel and packaged for use in a projection subsystem. Currently LCOS light valves are manufactured in 1280 x 768 (720p) and 1920 x 1080 (1080p) chip configurations.

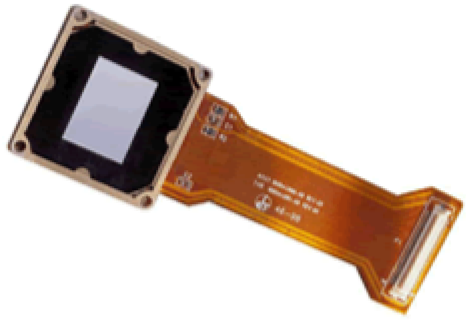

Fig. 3: *An LCOS Panel (Image by MicroDisplay)*

"LCOS is a reflective LCD display panel with high open area ratio. Basically, by placing the wiring area and switching elements under the reflection layer, there is no black matrix area – so it is possible to view a near-seamless image (Fig.4). Similar to DLP, LCOS systems can be created as 1 chip and 3 chip systems (Fig.5).

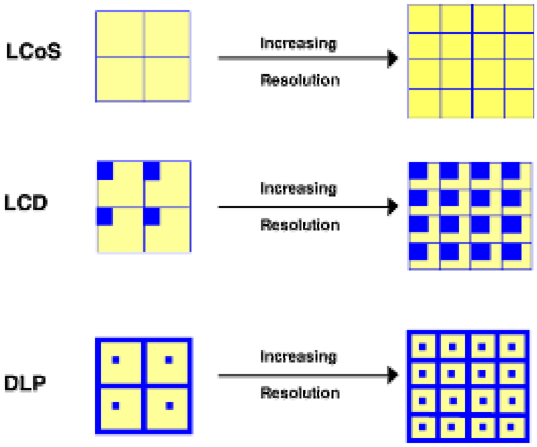

Fig. 4: *Pixel Matrixes comparison*

At the moment LCOS technology is fairly competitive in terms of price and performance advantages compared to HTPS and DMD systems. Pixels on LCOS panels can be made smaller than is possible with other micro display technologies, without compromising picture quality or manufacturability. LCOS displays can be scaled to 1080i/p resolution (1920x1080 pixels) and beyond, without increasing the size and cost of the panel and other optical components in the light engine.

LCOS technology is still relatively expensive compared to LCD and DLP, but with Intel stepping up mass production this year that can be expected to change. According to Intel, in 2005 it will be possible for the cost of a single-panel LCOS light engine to drop below the cost of DLP and LCD light engines. " (MicroDisplay)

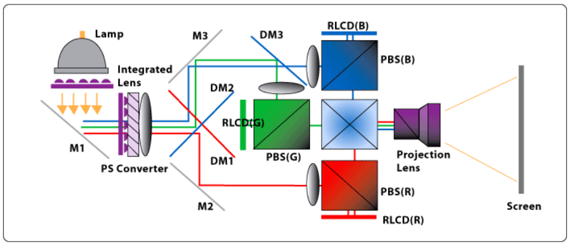

Fig.5: *3 Chip LCOS (courtesy of MicroDisplay)*

Because small LCOS panels can have much faster switching times than big LC Panel cells, it is possible to have fast LCOS units used in single LCOS Projectors.

It maybe possible to use LCOS for stereoscopic application like DMD Systems. There are some TV Vendors that will present LCOS single chip Rear Projection TV (RPTV) in the near future.

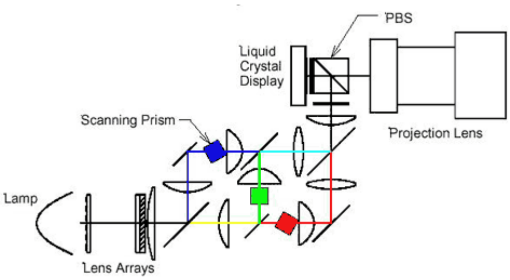

Fig. 6: *single panel reflective LCD Projector [Sh04]*

Fig.6 shows a single LCOS projector using a technique of rotating prisms to generate three color stripes in an LCOS panel instead of using a color wheel.

1.2.2. DLP

"The base of Digital Light Processing (DLP) technology from Texas Instruments Inc. is the Digital Micro mirror Device (DMD) (Fig.7) from Texas Instruments described in [**Ho91**] by Hornbeck in 1991.

Fig.7: *0.9" DMD Chip, Image by TI*

The DMD chip is a micro electro mechanical system (MEMS) consisting of an array of bistable mirrors fabricated over a CMOS memory substrate. Projection systems based on this technology vary in configuration and include one-chip, two-chip and three-chip DMD Designs.

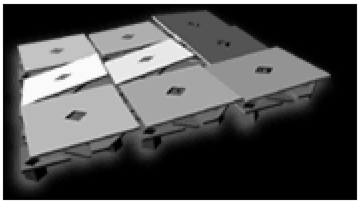

Fig.8: *DMD Chip, Micromirrors. (TI)*

Single-chip projector systems utilize a single DMD chip and a color wheel to display full color images. The DMD chip reflects light passing through the color wheel either through the projection lens system onto a screen or back through the color wheel into the light source. Since the DMD chip consists of thousands of tiny micro-electromechanical mirrors, the chip itself does not regulate color. For this reason color wheels that consist of at least three primary colors (e.g. red, green, and blue) is used to modulate the light source color. The color is modulated at a rate faster than it is recognized by the human eye, thereby causing a full color effect. The intensity if the light that is reflected by each pixel (micro-mirror) of the DMD is controlled by a pulse-width modulation scheme. This scheme is more fully described in [Do98]. The DMD Chip consists of a complicated micro mechanical mirror system constructed over a CMOS memory substrate. The DMD chip is described in [Ho89]. To display a single image frame from a video or computer source on the DMD chip, mirror state information is written to the CMOS substrate of the DMD chip in Block or groups. Once a block off memory is written, each mirror above the block is updated to its new state. This process continues block by block until each mirror in the chip is updated. At the end of a frame, all mirrors on the chip are reset to the "OFF" position at the same time. That is, each mirror is directed to reflect light back into the optical source. The fact that all mirrors on the DMD chip are reset to "OFF" at the end of a chip update makes the DMD chip eminently suitable as a light valve for 3D stereoscopic projection systems.[We02]"

Fig.9 illustrates a typical single chip DMD Projector optical design as described in [Sh04]. In this design an elliptic mirror and condenser lens projects light through the color wheel into an integrator rod. A second condensing lens gathers light from the integrator rod. Two reflecting prisms are used to reflect this light onto the DMD chip, that in turn reflects light out through the
Projection optics.

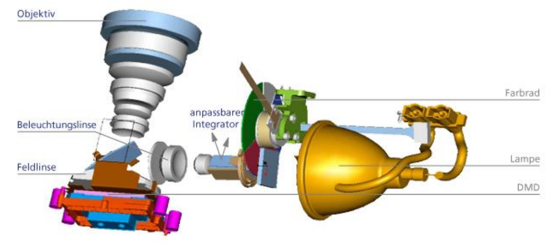

Fig.9: *DLP Projector, (Image by ZEISS)*

1.3. Combinations for Stereoscopic Viewing

In Table1 we have summarized combination of singe and dual projector setups with encoding techniques.

SOURCE	ENCODER					
Single	Linear	circular	Infitec	Observer Shutter	Source Rotator	Source Shutter
CRT				X	X	
LCD						
DLP	X	X	X	X	X	
LCOS						
Double						
CRT	X	X	X	X		X
LCD	X	X	X	X		X
DLP	X	X	X	X		X
LCOS	X	X	X	X		X

Table1: *Encoding combined with projector types*

In [Di02] Divelbiss shows the use of Color Wheels in combination with circular filters for a DLP Projector. DLP Projectors maybe realized with different color wheels using three (Red, Green and Blue), four (RGB and White), six (RGB, RGB) or eight (RGBWRGBW) segments (Fig.10). He separates the Segments in each with left and right polarisation to generate two images. A striped image is used as a source. In parallel the even or odd columns have to be blanked or doubled to display an image at a time while the color wheel changes orientation from right to left rotation during each color synchronously.

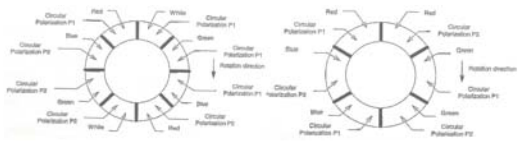

Fig.10: *Different color wheels, from [Di02]*

Frequency multiplex maybe used with any type of projector if the desired wavelength is produced by the lamp and transmitted by the filters of the projector. An advanced color correction system may be needed to generate good color impressions.

A combination of circular filters with LCD is difficult. Typically the polarisation of Red and Blue Light is orthogonal to Green light. Special filter sets maybe used to rotate the green light and apply circular polarisation afterwards or special projectors which avoid beam splitting in two orthogonal light beams.

In single projector Systems a Shutter maybe used with fast projectors only (CRT, DLP, LCOS). We do not know systems of LC or LCOS projectors to be fast enough to swap images at 8 or 10ms. State of the Art of LC Panels maybe 8ms for full on off contrast but nor for any greyscale contrast [KU05]. In Dual Projector setups it is possible to combine almost any encoding technique with any type of projector.

1.3.1 Discussion

It is beyond the scope of this article to judge about the known encoding techniques, projector styles and many possible combinations. It is well known, that some combination maybe perfect for one, whilst not perfect for another setup.

Our intention was to find a stereo solution as simple as possible while maximizing resolution and throughput. For a simple setup we prefer only single projector systems. Having a look at Table 1 shows that at this time only DLP based systems maybe used for this. In the near future the described techniques may apply to LCOS systems, since DLP and LCOS are similar in many points.

2. Current Stereo DLP solutions

A DLP System as described by Texas Instruments [Se91] consists of an Interface and the projection display. The interface accepts input from any source, which maybe scaled and converted in scan frequency (scan conversion) and thus stored in a Ram Buffer. The projection display consists of a formatter, the DMD chip and associated high Speed RAM. The input from the interface is stored in this RAM and reorganized suiting the needs of the image generation by the DMD.

2.1 Stereo DLP

In [We02] Werner explains in detail how a stereoscopic setup for a DLP system should be designed.

The input from two sources has to be multiplexed and scan rate converted. The alternating images are then fed in the formatter unit.

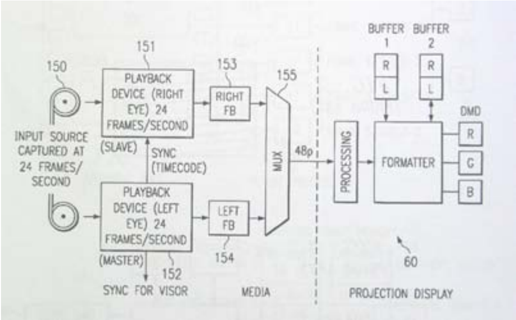

Fig.11: *Stereo DLP 3 Chip, [We02]*

Instead of a double buffer it is equipped with a quad buffer storing an image for each eye. The images are then alternating transported to the three DMD units with approx 100Hz. In reality the formatter in the figure has to be replaced by three formatters and associated RAM working in parallel. It is clear that input frame rates may not be as high as output to the DMD since the Quad Buffer maybe read out multiple times before a new image pair has made its way through the Formatter interface.

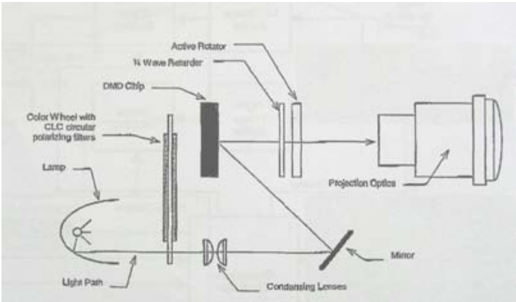

Fig.12: *Stereo single chip with column blanking. [Di02]*

In [Di02] Develbiss shows a system based on a single chip DLP System using a column blanking or column doubling technology to transport two images by using a vertical striped image. Resulting in only half of the resolution per image. A complex 3D processing unit converts any input image in a column interleaved format in the native resolution of the DMD to avoid any scaling by the formatter.

Fig. 12 shows a simplified diagram of the light path: The light may pass the DMD and some columns maybe blanked or doubled to show only right or left part of the image at a time. Images are then processed alternating using standard shutter eyewear. Additional retarder and LC rotators maybe used to view images with passive style glasses.

Another actual available solution is the Infocus DepthQ Projector using a SXGA 800x600 DMD for display of 120Hz Stereo images. The unit accepts frame interleaved signals. This is possible by using currently available chipsets for higher resolutions and using the increased bandwith for displaying more images of lower resolution.

2.2. Discussion of state of the art stereo solutions

The Solution from Werner uses a costly three DMD design and optics and the solution of Develbliss reduces resolution turning an expensive high resolution device into a low resolution projector. The pre-processing of the Data may add additional costing to the unit. Additionally image processing in the DMD Formatters may add significant errors to the column interleaved source image.

The 3Chip DLP solution suffer from another important problem: Since it accepts only one video source with multiplexed input it is difficult to assign two different sources, e.g. different computers of a cluster, to the projector. This (normally) degrades performance of a graphic board by factor two. Additional Hardware maybe used to multiplex two inputs adding additional costs.

Because of the limited bandwidth of the Formatter and the associated memory it is not possible to transmit images at a rate of 120Hz into the system and out of the formatter to the DMD at higher resolutions. The mechanism known by the DephQ Projector allows only low resolutions.

Higher resolutions incorporate doubling the speed of the Memory, which is already fast RAMBUS, and doubling the processing power of the Formatter ASIC. It is not expected to have a chipset with higher throughput for mass production available whilst it has to compete against simple LCD and LCOS units in a very price sensitive market.

3. Solution

A single projector as known by Barco or Christie maybe more expensive than two off the shelf single Chip DLP systems with modifications for active stereo. Especially interesting is the fact that they provide two separate inputs, thus allowing to be driven by two computers, maximizing frame rates.

3.1. Double projector solution

As we have shown in [Ho04] and it is assumed by Develbliss in [Di02] it is possible to generate an image of full quality at half of the frame time. This is possible because Micro mirrors are now operated at double data rate (DDR) instead of a single data rate (SDR). DDR DMD's have been developed to increase color quality and color wheel speed to avoid rainbow effects. These effects result from the fact that the color generation is realized with pulse width modulation of the mirrors. In a simple scheme colors maybe reproduced by bit weighting of the color bits. In the simple case the bit weights are corresponding to

the bits exponent. So the MSB (which maybe bit 7) takes ½ frame time, while bit 6 enables a mirror for ¼ of the frame time and so on.
In reality color sequence generation is a very difficult process and bits are split through the frame time to achieve a better distribution of light flashes over time take into account the human's visual system. Since speed of the Mirrors is limited, the number of colors and the resulting image update rate are limited. With SDR DMD's color range was full 24Bit, but some people recognized color flicker at low brightness levels or rainbow effects from slow color wheels. With DDR DMD's the color space is now 30Bit and the flicker is reduced.

It is easy to see that the application of SDR color sequence program with DDR DMD at double speed allows using only ½ of the frame time with color quality of 24Bit known from SDR DMD's.

As we stated in [Ho04] a synchronized array of DLP Projectors maybe used to drive a projection for a virtual environment. In this application we use two projectors for one Screen and blank one projector alternating. Synchronisation of Projectors is possible by driving the Formatter at the same data rate and phase for all connected projectors. We achieved this by synchronizing the output of the scan conversion buffer of the connected projectors.

Fig.14 shows a typical projector setup, with an attached electronic shutter which is realized by blanking the DMD. The scan converter (here LEHK-II), which is present in any projector with its associated VRAM, is not to be messed up with the memory associated to the formatter on the formatter board!

The scan converter at the interface board is mainly used for image pre-processing, such as scaling, scan line and frame rate conversion and the interface to many different input signals. Usually this unit drives the connected formatter with a fixed frame rate at 50 or 60Hz.

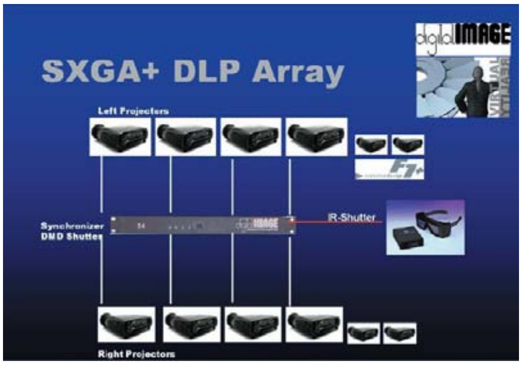

Fig. 13: *Synchronized DLP Array*

Synchronizing the clocks of the scan converters leads to a synchronized output to the formatter board of the connected DMD system and thus to a synchronized operation of all DMD Systems in the array. Whilst obtaining synchronisation, all color wheels operate at the same speed and the same phase. (Fig 13)

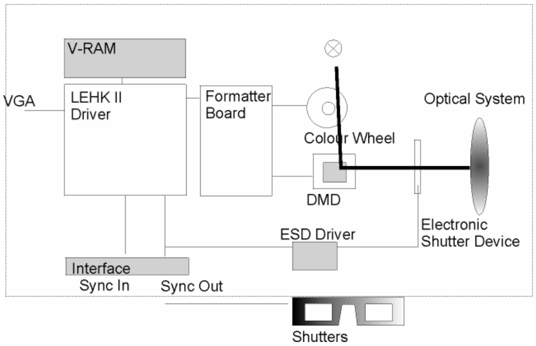

Fig. 14: *Standard single DMD projector with associated shutter and synchronisation*

A sample installation is shown in Fig. 15. It shows a 4 Sided virtual environment called "DAVE" using 8 synchronized DLP projectors in an array. Other installations of this type were used to build power walls with two or three segments.

Fig.14: *important person in the virtual environment "DAVE".*

Fig. 15 shows an color test image of a modified projector of a double projector solution. The projector runs with 120Hz, 50% shutter closed, gamma correction circuit. The image was shot through a rear projection screen.

Fig. 16 shows the color bar of the modified projector. The resulting image has a high color resolution. The image shows a rear projection of the color bar at 120Hz, with 50% shutter closed.

Fig.15. Test image

Fig.16. color range test image

3.2. Single projector solution

As discussed before a two projector system is not the optimal solution. Since it uses two light sources it produces images of different colors.

Instead of using two DMD's and blanking each DMD for half of the frame time it is optimal to use a DMD in turn for right an left, or even more, images generated by different formatters. Since the DMD is a complete digital device it maybe shared by two image sources by switching data bits. A high resolution DMD receives its Data via a 128 Data Bus at a speed of 60MHz, with data on rising and falling edges of the clock signals. This results in an effective data rate of approx 120MHz.

In our proposed solution the output of the Formatter is not connected to a DMD directly as shown in [Se91]. Instead it is connected to a high speed bus circuit, well known for memory switches in computers. (Fig.17). Switching between the two, or even more, formatter outputs enables us to transmit at least two images during frame time.

While keeping images synchronized at the input side, a switching between the images is uncritical.

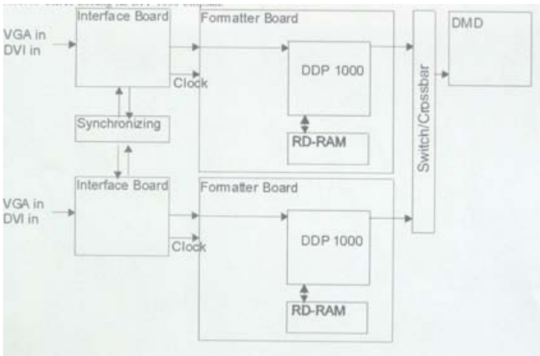

Fig.17. *Formatters driving a single DMD Chip*

Since the DMD appears to the Formatter as a simple RAM circuit and only write operations are performed, the circuit is completely invisible for the attached Formatters.

Fig. 18 shows a projector unit which has been used for active stereo in a dual projector setup and will be used for active single projector stereo.

In the case of the shown projector the complete projector electronic circuit is placed on a single board. The output of the Formatter is routed via flex cables to the DMD sub installation. The proposed high speed crossbar can be easily installed in-between the board and the Flex Cable assembly reducing production costs.

3.1 Conclusion

The proposed solution has some advantages against the presented state of the art:
- It provides a single DMD solution and so reducing the hardware costing.
- It is capable of accepting input at full 60Hz frame rate for the right and left channel, resulting in 120Hz throughput.
- It can deliver high quality colors.
- It works with the highest resolutions available
- Because of its two inputs it can accept signals from two different sources, e.g. computers to maximize the output in a visualisation cluster.
- A simple demux maybe used for accepting page flipped input if necessary at low costs [Ho01].
- The necessary synchronisation maybe realized in the projector as shown in [Ho04] with no extra cost.
- Using active (time based) image encoding eliminates the need of special material for screens and surfaces.

The result is a very portable projector for high resolutions to build any kind of virtual environment.

Fig.18. *Projector used for active stereo*

3.2 Additional options

When using more than two formatters we can mix any signals at any time into the data stream to the DMD. This mixing of signals may include stripe sets for measurement and scanning purposes or can include even more images for more participants. So one projector may accept two, three or even more sources.

4. Patent information

The presented solutions are part of international patents held by digital IMAGE.

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