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Full Resolution Hologram Like Autostereoscopic Display

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SUMMARY

SYMBOLS AND ABBREVIATIONS

CRT	Cathode Ray Tube
DTI	Dimension Technologies Inc.
fL	Foot Lamberts
fps	frames per second
LC	Liquid Crystal
LCD	Liquid Crystal Display
RGB	Red, Green, Blue
SBIR	Small Business Innovation Research
SGI	Silicon Graphics Inc.
TFT	Thin Film Transistor
VGA	Video Graphics Adapter
XGA	Extended Graphics Adapter

SUMMARY

Under this program, Dimension Technologies Inc. (DTI) developed a prototype display that uses a proprietary illumination technique to create autostereoscopic hologram-like full resolution images on an LCD operating at 180 fps. The resulting 3D image possesses a resolution equal to that of the LCD along with properties normally associated with holograms, including change of perspective with observer position and lack of viewing position restrictions. Furthermore, this autostereoscopic technique eliminates the need to wear special glasses to achieve the parallax effect.

Under the program a prototype display was developed which demonstrates the hologram-like full resolution concept. To implement such a system, DTI explored various concept designs and enabling technologies required to support those designs. Specifically required were: a parallax illumination system with sufficient brightness and control, an LCD with rapid address and pixel response, and an interface to an image generation system for creation of computer graphics.

Of the possible parallax illumination system designs, we chose a design which utilizes an array of fluorescent lamps. This system creates six sets of illumination areas to be imaged behind an LCD. This controlled illumination array is interfaced to a lenticular lens assembly which images the light segments into thin vertical light lines to achieve the parallax effect. This light line formation is the foundation of DTI's autostereoscopic technique.

The David Sarnoff Research Center (Sarnoff) was subcontracted to develop an LCD that would operate with a fast scan rate and pixel response. Sarnoff chose a surface mode cell technique and produced the world's first large area π-cell active matrix TFT LCD. The device provided adequate performance to evaluate five different perspective stereo viewing zones.

A Silicon Graphics' Iris Indigo system was used for image generation which allowed for static and dynamic multiple perspective image rendering.

During the development of the prototype display, we identified many critical issues associated with implementing such a technology. Testing and evaluation enabled us to prove that this illumination technique provides autostereoscopic 3D multi perspective images with a wide range of view, smooth transition, and flickerless operation given suitable enabling technologies.

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1. INTRODUCTION

Today's computer graphics and workstation environment demands ever increasing resolution on the part of electronic displays. The need to investigate problems and design systems of ever increasing complexity lead to requirements for very high resolution electronic displays to provide an accurate real time visualization of the subjects under study. Furthermore, innovative computer graphics techniques for the visualization of complex three-dimensional phenomena are needed. Such complex 3D shapes are often difficult to interpret when displayed in perspective on a 2D screen, even when color, shading, and other monocular cues are used.

A monitor that provides high resolution and true depth perception to the scientist is both desirable and necessary in the continuing effort to achieve ever more accurate and realistic interpretation of natural phenomena. Both high resolution and 3D are now dependent upon established CRT technology. The CRT, of course, is a bulky device that takes up much desk space.

The vast majority of electronic three-dimensional imaging systems in existence are stereoscopic systems that rely on optical devices placed near the user's eyes. They operate in such a way that one eye is allowed to see one image while the other eye is allowed to see a different image. The two images are the left and right eye perspective views of a stereo pair. When the two images are presented to the appropriate eyes, an image with depth is perceived.

In the past, such devices as two eyepiece viewers, colored glasses, and polarizing glasses have been employed. Currently, the most popular stereoscopic viewing devices employ shutter glasses in combination with a CRT that displays left eye and right eye views during alternate scans.

Autostereoscopic devices display stereoscopic images that can be observed without special glasses or other optical devices worn by the user. They all employ special optics near the display that cause different perspective views of a scene to be visible from different regions of space in front of the display. These regions, called viewing zones, are arranged so that the observer will always have eyes in different zones when seated in a certain area in front of the display. Various methods of achieving this effect have been tried over the years. All have had drawbacks such as poor image quality, complexity, and limited resolution which have prevented their development into practical products.

1.1 Autostereoscopic Display Through Parallax Illumination

Dimension Technologies Inc. (DTI) has developed a type of autostereoscopic display that can overcome the major drawbacks associated with other autostereoscopic techniques. DTI's technology, called parallax illumination, has inherent geometry that gives it the capacity to produce autostereoscopic images that can be viewed from across a wide angle without sacrificing resolution or producing flicker. Unlike many of the others, DTI's technology utilizes a Liquid Crystal Display (LCD) device to create images.

1.2 The DTI Autostereoscopic Parallax Illumination System

The basic autostereoscopic imaging technique devised by DTI is called Parallax Illumination. It is very simple, easy to implement, and produces very vivid stereoscopic images without significant ghosting. It was designed specifically for use with flat panel LCD displays.

Figures 1 and 2 illustrate the basic concept of the technique. Figure 1 is a top view and Figure 2 is a magnified view of one corner of the display as seen by the observer's left and right eyes. A monochrome or color LCD is used to generate images. Images can be generated on the LCD as in conventional television, line-by-line. The LCD is a matrix of individually controllable elements (pixels) which are arranged in rows and columns. The LCD is illuminated from behind and the amount of light passing through individual pixels can be controlled such that images with gray shades or full color can be generated.
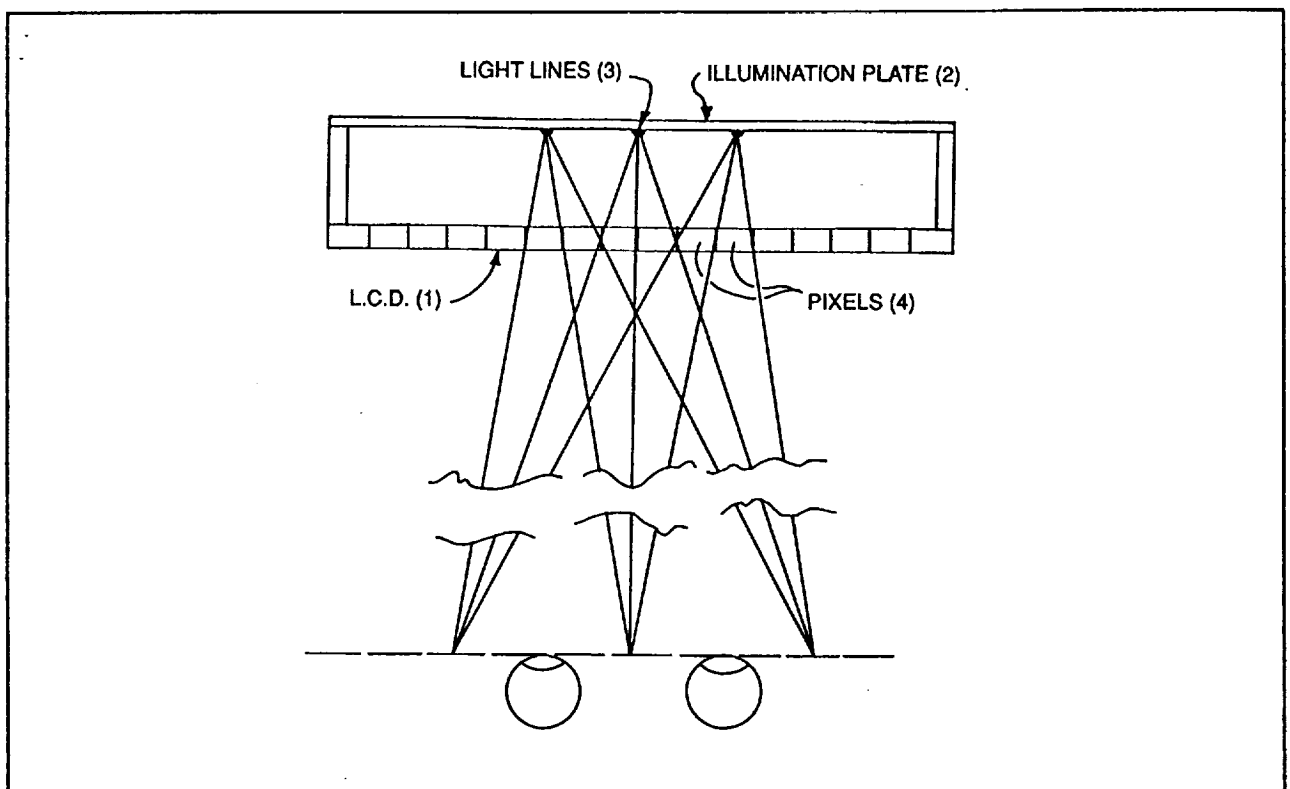

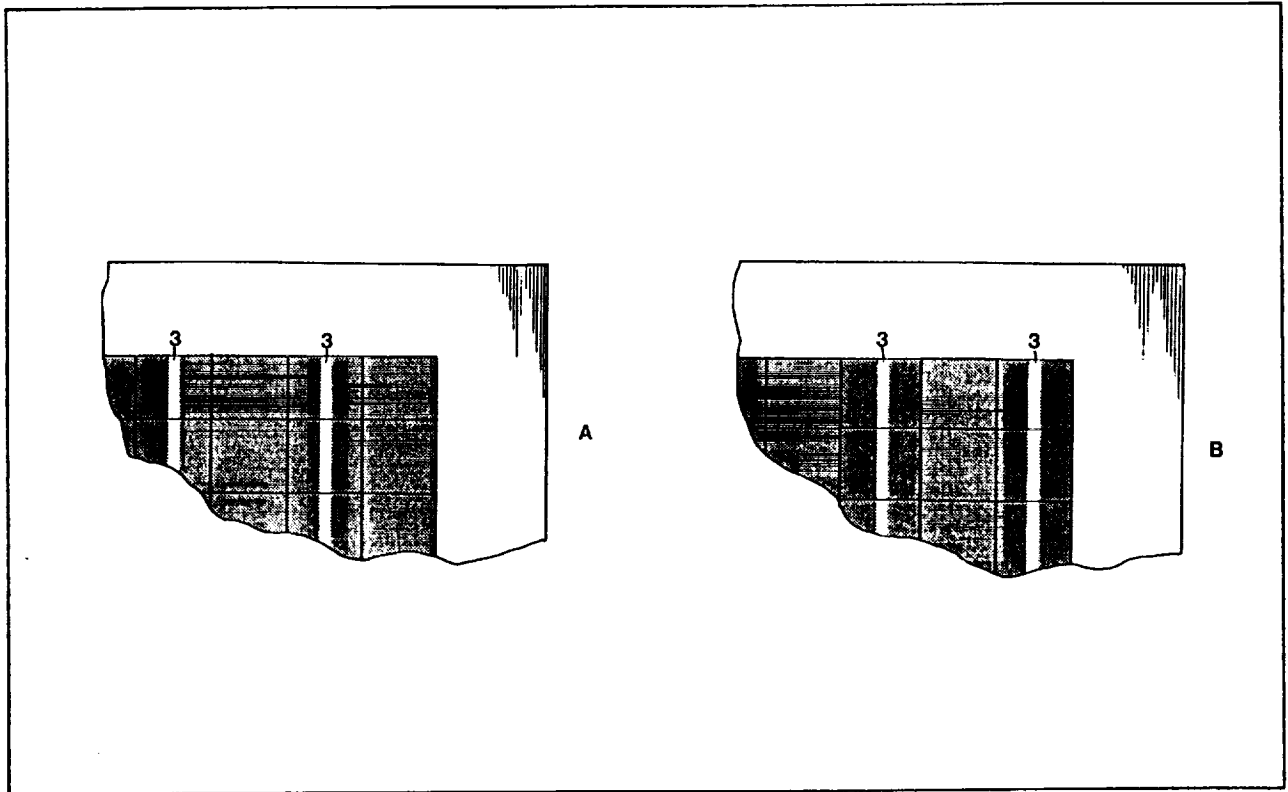**Figure 1 - Autostereoscopic Display - Top View**

Figure 2 - Autostereoscopic Display - Magnified Front View

To generate 3D images, the LCD is made to display left and right images of a stereo pair on alternate columns of pixels. The left image appears on the odd columns, while the right image is displayed on even columns. Both left and right images are displayed simultaneously, not alternately as in other systems, a feature which eliminates flicker.

As shown in the figures, a special illumination plate (2) is located behind the LCD. The illuminator generates several sets of very thin, very bright, uniformly-spaced vertical lines of light (3). The lines are spaced with respect to the LCD pixel columns (4) such that (because of the parallax) the left eye sees all the lines through the odd columns of the LCD, as shown in Figure 2A, while the right eye sees them through even columns, as shown in Figure 2B. There is a fixed relation between the LCD and the illumination plate that determines the size of the "viewing zones" shown in Figure 3, within which the light lines appear to line up correctly behind the LCD pixels. An observer's eye can see a left eye viewing zone from anywhere within the quadrilateral shaped regions marked "L" in the diagram in Figure 3, and can see a right eye view from anywhere within the quadrilateral regions marked "R" in Figure 3. Thus, as long as the observer sits in a position in which one eye is in a region labeled L and the other in a region labeled R, the observer perceives a 3D image. Note that there are several sets of these regions spaced across a plane (7) in front of the display.
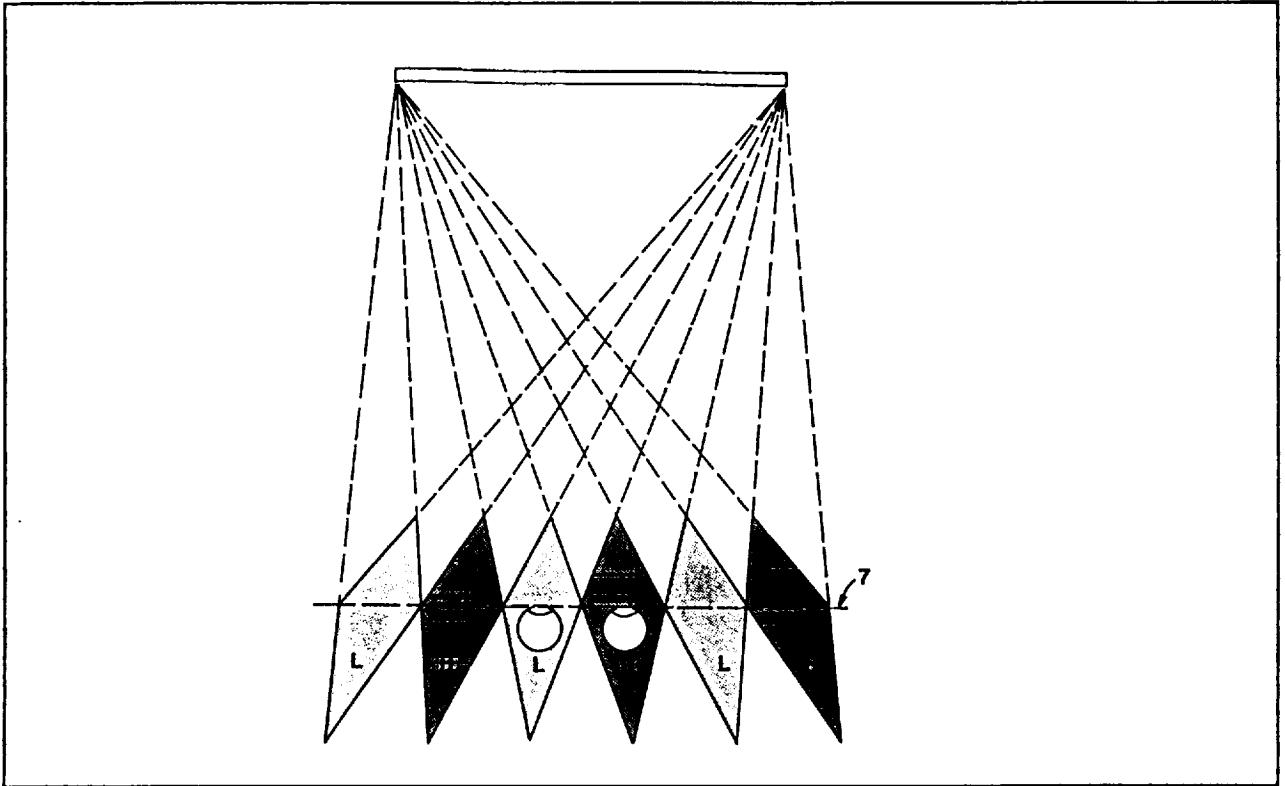
Figure 3 - Viewing Zones of an Autostereoscopic Display

1.3 A Hologram-like Full Resolution Display

As discussed above, DTI's autostereoscopic effect relies on the use of unique illumination behind an LCD, which is generated in such a way that different pixels are visible from different viewing zones in front of the display. This interaction of illumination and LCD operation provides the foundation for advanced functionality that is not present with other 3D techniques.

Advanced functionality is realized through manipulation of the light sources used to create 3D effect in synchronization with data placement on the LCD. By using two sets of light lines that alternately flash on and off, and by increasing the scan rate of an LCD, one can generate left and right eye views with the same resolution as the LCD. Given that a complete cycle of both light line sets flashing on and off is accomplished in 1/30th second or less, full resolution autostereoscopic imagery can be produced without flicker.

By using multiple sets of flashing lines and an LCD capable of many cycles in 1/30th second, more than two viewing zones can be produced in front of the display, from each of which a full resolution image with proper perspective is visible. Thus, a multiple perspective look around or hologram-like effect could be created.

Figure 4 - Hologram-like Autostereoscopic Display - Top View

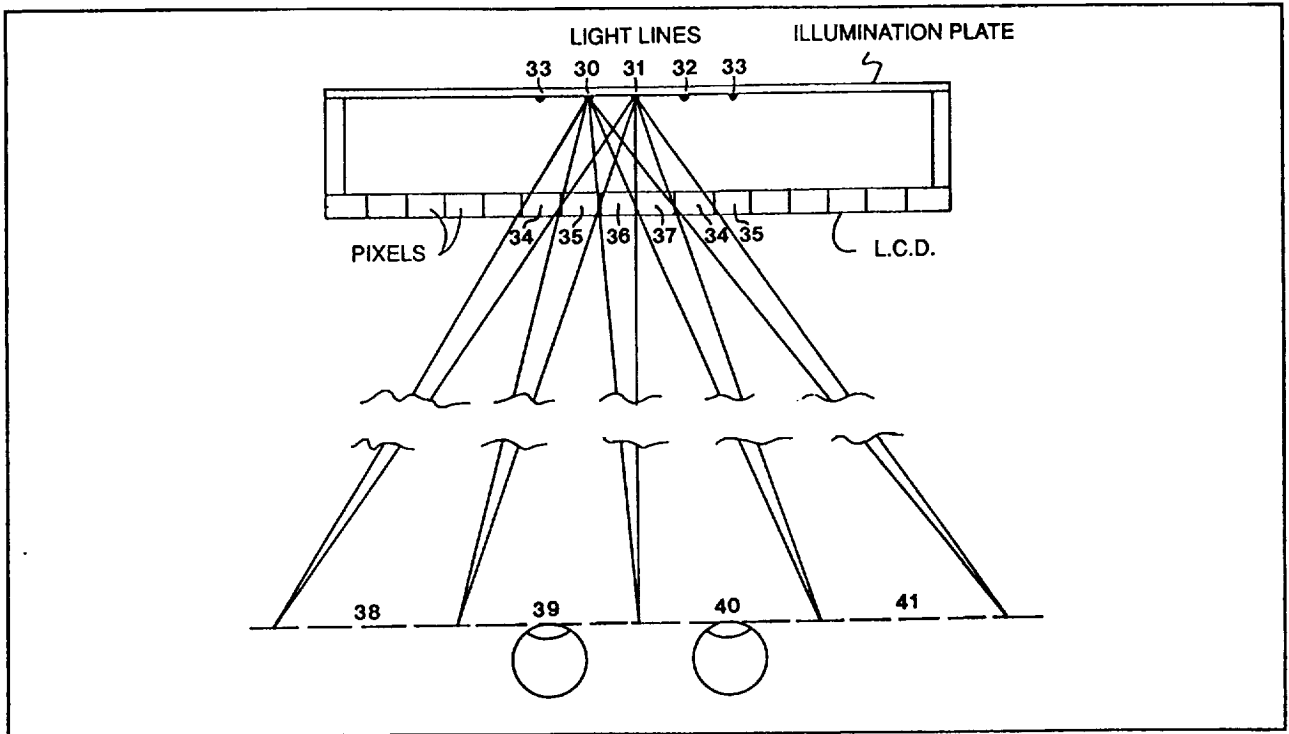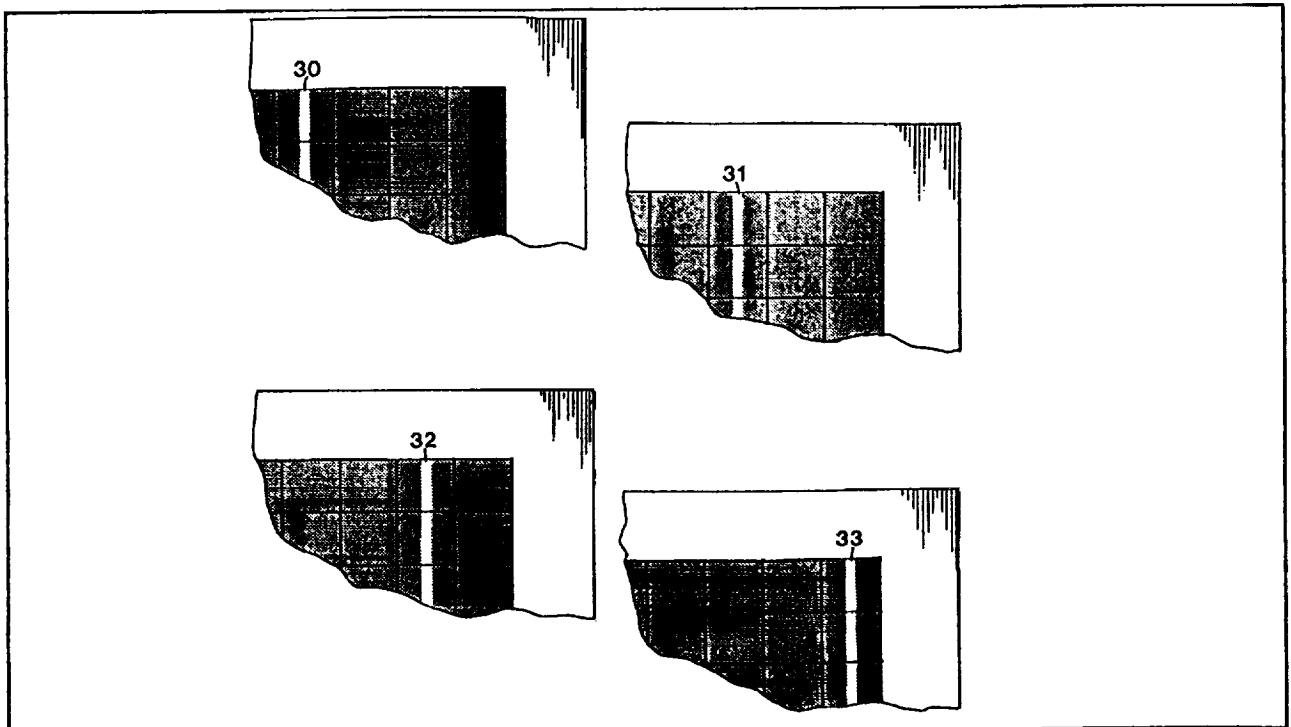**Figure 5 - Hologram-like Autostereoscopic Display - Magnified Front View**

The operation of the hologram-like concept is illustrated in Figures 4 and 5. Figure 4 is a top view and Figure 5 is a close-up view of the display as it is seen from one of the viewing zones. In theory, any number of zones may be produced. The four zone system was selected to provide a simple illustration of the geometry involved. The prototype described later produces six zones.

Here four different sets of light lines are used (30 - 33). The members of each set are spaced apart by a little more than the width of four pixel columns, so that light from each set passes through four columns (34 - 37) in front of it, to four viewing zones (38 - 41) spaced evenly in front of the display. The sets flash on and off successively, so that at any instant only one set of lines is on. First set 30 flashes, then set 31, then 32, then 33, and then the cycle starts over with set 30. Ideally, the entire flash cycle should be completed in 1/30th second or less.

When lines 30 are on, they are visible through pixel columns 34 from any point within zone 38; they are visible through columns 35 from any point within zone 39; and so on. While set 30 is on, pixel columns 34 are made to display part of a perspective view of a scene as it should look from the center of zone 38; columns 35 are displaying a slightly different perspective view of the same scene as it should appear from the center of zone 39; columns 36 display part of the scene as it should appear from the center of zone 40; and columns 37 display part of the scene as it should appear form the center of zone 41. Figure 5A shows how the display looks from zone 38 when lines 30 are on.

When lines 30 turn off and lines 31 turn on, these new lines are visible through columns 35 from zone 38; through columns 36 from zone 39; through columns 37 from zone 40; and though columns 34 from zone 41. Between the time that line sets 30 turn off and sets 31 turn on, the image on the LCD changes, so that when set 31 comes on, columns 35 are displaying new parts of the perspective view appropriate to zone 38; columns 36 are displaying parts of the image appropriate to zone 39; columns 37 are displaying parts of the image appropriate to zone 40; and columns 34 are displaying parts of the image appropriate to zone 41. Figure 5B shows how the display looks from zone 38 when lines 31 are on.

As can be seen in Figures 4 and 5, when successive sets of lines come on, an observer's eye in zone 38 will see the lines successively through pixel columns 34, 35, 36, and 37. Thus, through each successive cycle, the eye sees a light line behind all the columns of pixels; and as the LCD changes, a complete full resolution image is built up column by column. Likewise, an eye in zone 39 will see the light lines appear successively through columns 35, 36, 37, and 34. An eye in zone 40 will see the lines appear behind columns 36, 37, 34 and 35, and an eye in zone 41 will see the lines successively behind columns 37, 34, 35, and 36.

A full resolution image will thus be visible from each zone. However, the images visible from each zone will be different from each other, each being a perspective view appropriate to the zone from which it is seen.

Although the previous discussion assumes that the light lines are turned on and off in sequence from left to right, any sequence in fact can be used, as long as the proper pixel columns are displaying the proper image segments for each light line set.

Several viewing zones must be generated to achieve a smooth look around effect as the observer moves across the zones, and at the same time provide a wide viewing area. The narrower the viewing zones, the smaller the displacement between adjacent perspective views of a given image and the less noticeable the transition between them.

However, the narrower the zones, the more of them one must generate to cover the desired viewing area. The number of zones that can be produced and thus the width of the viewing area and the smoothness of look around depend on the speed of the LCD. An LCD must be used that is capable of addressing its pixels and changing their state completely within a very short period of time.

1.4 Phase I Proof-of-Concept

A proof-of-concept breadboard display using this illumination technique behind a low resolution ferroelectric LCD was demonstrated in 1991 during an SBIR Phase I program sponsored by NASA's Ames Research Center. Given the feasibility demonstrated in Phase I, the SBIR Phase II program was designed to focus on the visual performance and image quality possible by using the DTI autostereoscopic hologram-like full resolution illumination technique, along with an assessment of enabling technologies.

1.5 Phase II Objectives

To ascertain the technical and commercial feasibility of a real time hologram-like full resolution autostereoscopic display, the following objectives were set forth for the Phase II program.

(1) Develop a prototype to allow visual evaluation and performance testing of DTI's autostereoscopic hologram-like full resolution technique.

(2) Advance the state-of-the-art in LCD, illumination, and electronics technology as necessary to build a display prototype using DTI's autostereoscopic hologram-like full resolution illumination technique.

(3) Evaluate the ability to create multiple perspective views and the smoothness of the transition between the views.

(4) Gather baseline data on visual performance factors such as flicker and beta movement visibility for the prototype system.

(5) Evaluate enabling technologies to assess future implementations of the technology.

In order to satisfy the objectives, a prototype system was designed with the following considerations:

Minimum specifications/constraints:

- 180 Hz LCD operation to support multiple zone formation.

- Illumination and optics design to support six perspective views and five stereo zones.

- Minimum brightness of 20 foot lamberts to enable flicker and jitter tests.

- Image generation via Silicon Graphics R,G,B interface.

- Near real time data throughput to allow static and dynamic imagery evaluations.

- Typical display system parameters such as display size, resolution, color, and power efficiency were not critical for evaluation of the technique at this point and were thus subject to device availability, ease of development and Phase II budget/time constraints.

2. SYSTEM DESIGN OVERVIEW AND REQUIREMENTS

The following is an overview of the major subsystems making up the prototype display system. Figure 6 diagrams the basic system architecture. Each subsystem is described and critical requirements are discussed.
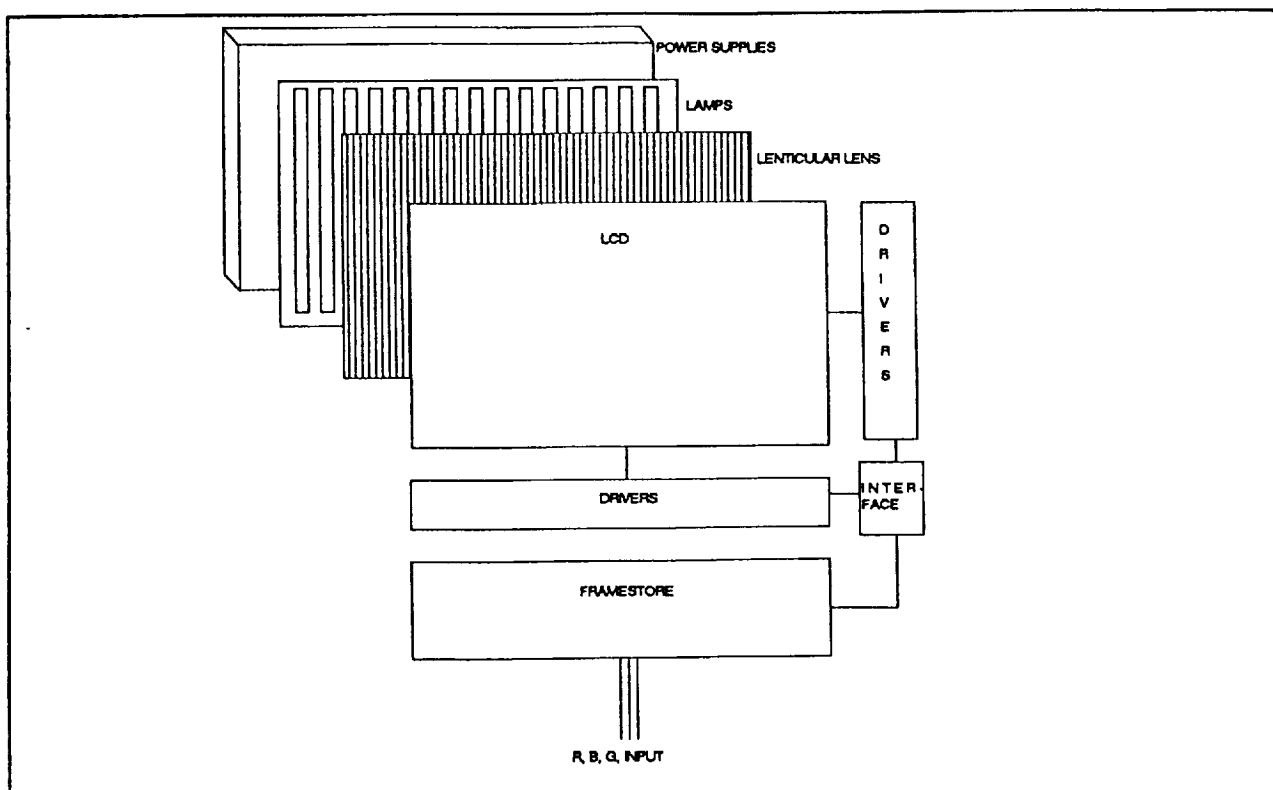
Figure 6 - Hologram-like Autostereoscopic Display - Major Components

2.1 Parallax Illumination System

The purpose of the parallax illumination system is to generate the set of six flashing light lines behind the LCD. This can be accomplished by means of six sets of vertically oriented linear light sources situated in a plane behind a lenticular lens sheet, which focuses light from the light sources into a large number of light lines on a diffuser mounted behind the LCD. Thus the parallax illumination system has two major subsystems: the illumination system (light sources, drivers and synchronization electronics) and the optics system (lenticular lens and diffusers). Each of these systems works in conjunction with the image generation to produce the full resolution autostereoscopic hologram-like effect.

If ideal system components were available, the image would be formed instantly on the LCD, leaving the complete time between images for illumination of the image with the light lines. Each set of light

lines would be generated simply by turning one set of vertical lamps on. Unfortunately lamps and LCD components are not fast enough to operate in the simplistic mode just described. In reality three actions must occur during each field to form an image and make it visible to the observer. First, the pixels of the LCD must be addressed in a column by column fashion from left to right. Second, all the pixels must have time to completely change state to form the next image, including the very last ones addressed. Note that the pixels at the left, having been addressed earlier, will complete their change earlier than the pixels on the right side. Third, the lamps must be turned on and then off again before the next address of the LCD begins.

In many situations, it is desirable to include a forth step in which the existing image is completely erased before the LCD is scanned again to form the next image. All these actions must occur within 1/180th second to avoid objectionable display flicker, yielding six fields and thus one complete full resolution image, every 1/30th second. If the 1/180th second were divided equally between the first three actions described above, roughly only 1/540th second, or 1.85 ms, could be allowed for each of the actions: the LCD scan, the pixel changes, and the lamp flashes. Such scan and pixel response values are far faster than those associated with typical TFT LCDs. Means are thus needed to relax these speed requirements.

One way to overcome the speed problem requires that portions of the display (for example, 1/4 the columns) be written and illuminated in sequence. New data is applied to the LCD starting at the left side of the display and proceeding to the right side. Once an image is written, there is a pause, and then the next image is written. As an image is written the illumination sequence is as follows:

(1) After the first 1/4 columns have been addressed, and the pixels within them have all changed to form the new image, illuminate those columns until the first column is written with new data again.

(2) After the image has formed on the next 1/4 columns, illuminate those columns until the next 1/4 of the columns are written with new data.

(3) Continue as above illuminating each group of 1/4 columns as the image is formed in those columns.

Using this scheme, the address, pixel change, and illumination periods can all be overlapped, with different actions potentially occurring in different parts of the display at the same time. The LCD address rate from side to side can actually take up all of the 1/180th second period if desired. This leaves 4.12 ms between the time when the last pixels of any section are addressed and the first pixels of that section are addressed again. This time must be divided between pixel response and the lamp flash. If time were divided evenly between the two for example, 2.06 ms would be allotted to each.

Since typical pixel response times tend to be on the slow side, it makes sense to allocate most of the 4.12 ms to pixel response, with a

much shorter period left over for illumination. In practice, how short the lamp flash can become is often limited by brightness considerations, not the theoretical lower limits to light source turn on and turn off periods (i.e. the shorter the duration of the lamp flash, the lower the total amount of light that is being emitted during a given flash cycle, and thus the lower the brightness). At the start of the project, DTI discussed technical requirements and performance constraints with LCD and light source manufacturers. Values of 5.6 ms (1/180th second) for the LCD address, 3.5 ms for pixel response time and 300 μs for lamp flash were specified and agreed to by the manufacturers.

2.1.1 Illumination System

Light Sources - Per requirements, the light sources should be capable of turning off to on or vice versa in at most 300 μs, but preferably less to provide the maximum amount of time possible at peak brightness. Also, the light sources should be configurable into multiple sets for the formation of six viewing zones and these sets must fit within the physical space of the display.

The light sources must be bright enough to provide at least 20 fL of white light illumination to the image.

Synchronization Control - The illumination of the LCD must be synchronized with the formation of the image on the LCD such that the correct sets of lamps turn on with the appropriate section of the LCD being displayed and off prior to the next section being addressed.

2.1.2 Optics System

The optics system focuses the light from the lamps into vertical light lines behind the LCD in such a way that the light from one set of lamps forms one set of light lines, while the light from the other sets of lamps form other sets of light lines. The light lines are focused onto a diffuser situated behind the LCD in order to achieve illumination evenness.

The optics consist of a lenticular lens sheet with vertically oriented lenticular lenses that focus light from the lamps onto the diffuser. The lenticular lenses must be positioned very precisely and have closely matching focal lengths in order to form light lines that are aligned precisely and accurately with the LCD pixels. The light lines must have a pitch that is slightly wider than the width of six LCD pixel columns (for the six zone case), in order for the light lines to appear to line up behind the proper pixel columns within viewing zones of the specified width at the specified distance from the screen. Furthermore this pitch must be maintained precisely across the whole LCD. Any individual light line can be allowed to deviate from its ideal position with reference to an edge line by no more than about 1/10 pixel width, to avoid brightness discontinuities and shadows. In addition, the light lines must be imaged at a precise distance behind the LCD in order that the plane where the viewing zones are widest is approximately 76.2 cm from the screen.

Precise alignment of the light lines to the LCD pixels had to be accommodated. Alignment requirements are dependent mainly on the size of the LCD and the size of the pixels. For the LCD used under the program, once the light lines were positioned they could not be allowed to shift laterally by more than one fifth of a pixel width. This is to insure that the viewing zones remain centered in front of the display to within 1.2 cm. In addition the line array as a whole could not rotate by more than the amount necessary to cause the top or bottom of the line to be displaced by more than 1/10 pixel width from vertical. This is necessary to avoid widening of the areas at the edges of the viewing zones where moire shadows and double images are seen. The lenses also had to be positioned relative to a diffuser with an accuracy of .005 cm, in order to provide sharply focused light lines. Therefore, a solid mounting with a precise alignment mechanism had to be designed for the lens.

2.2 LCD System

2.2.1 LCD

The LCD system accepts RGB video data, converts it into digital data and displays it in the form of six composite fields. The LCD has to provide faster pixel response times (3.5 ms) and faster address times (180 Hz) than those present on any commercially available TFT LCD. The LCD also must function in a column scan as opposed to the conventional row scan in order to allow the 1/4 segment address scheme.

2.2.2 Framestore

The framestore acts as a buffer and data translator between the image generation system and the LCD display. Input data from the image generation system is at a rate of 60 frames per second. Each of these frames contains 2 images. The framestore captures this video data a row at a time, digitizes it, stores it, and formats the data out to the LCD a column at a time. The framestore generates and sends control signals to the LCD to control the operation of the LCD's shift registers, flush sequence and column driver functions. The framestore also controls the lamp flash sequence with the data placement on the LCD.

2.3 Image Generation System

The image generation component is comprised of the hardware and software necessary to render images for the prototype display. Several design constraints were imposed given available hardware and software at DTI. The following requirements/design constraints were set forth.

• An entry level Silicon Graphics Indigo workstation (R3000A RISC CPU) will be used. This provides a platform for rendering 1024 by 768 resolution graphic images with 8-bit color.

• Wherever possible standard Silicon Graphics routines, specifically those in the SGI image rendering Graphics Library, are to be used.

- Images are to be rendered as R,G,B video data to a Graphics Display Window on the workstation monitor.

- Custom software is to be written to allow application programs to render six appropriate perspective views given x,y,z data of an object to be rendered.

- Custom software and images are to be developed to support component level validation, system testing, and demonstration.

3. SYSTEM COMPONENT SPECIFICATIONS

The following detailed specifications are presented for each component critical to the operation of the prototype system.

3.1 Parallax Illumination System

3.1.1 Illumination System

After examining the most promising options available, a configuration of individually controlled flashing fluorescent lamps was chosen. The main reason for choosing this configuration was its ability to meet the requirements for on/off speed, brightness, white light illumination, and its ability to be configurable as multiple sets.

Given the speed of the LCD, an illumination system capable of generating six sets of light lines to produce six sets of viewing zones was designed.

The illumination system that was built consisted of 24 vertically oriented fluorescent aperture lamps spaced across the rear of the LCD as shown in Figure 6. Six lamps were used for each of the four groups of 200 columns on the LCD. An opaque mask with slot apertures in front of each lamp was situated directly in front of the lamp bank to ensure that light did not escape from areas other than the lamp apertures.

The sub components for the illumination system had the following key specifications:

(1) **Lamps** - The lamps were specified to be .7 cm in diameter with .32 cm wide apertures to provide maximum brightness within the aperture. Given the LCD and optics transmittances, the lamps were required to emit roughly 13,500 fL from their apertures in order to meet the minimum brightness specifications of 20 fL after the light passes through the optics, diffuser, and LCD. The lamps contained a fast responding phosphor, a blend of GTE phosphors 283 and 2461, that turns off or on in less than 300 μs.

(2) **Lamp Drivers** - In order for control versatility of the illumination array, each fluorescent lamp had to be individually driven. A commercially available lamp driver which operates from 28 Vdc and provides a 50 kHz voltage to the lamp was chosen. The lamp driver vendor tested the lamps designed for this project and modified the standard lamp driver to suit this application. Key specifications for the lamp driver were:

- Input voltage 28 ± 10% Vdc
- Open Circuit Output voltage 365 Vrms
- Output Current limited to 200 ma ± 5 ma
- Efficiency 80% at full load
- Frequency 50 kHz

(3) **Synchronization Control** - As the image was formed in a group of columns, one of the lamps for that group turned on and stayed on until the group was reset in preparation for the next image. As

each new image was formed, a different one of the six lamps turned on. This continued until all six lamps behind each group of 200 columns has been turned on and off. The lamp timing was synchronized to the framestore circuitry that sent data to the LCD.

3.1.2 Optics System

The Optics system had to image light from the 24 vertical light sources of pitch 1.017 cm and width of .7 cm located 10.4 cm behind the lens into 812 narrow vertical light lines, with the precise pitch requirements described below, on a diffuser mounted behind the LCD.

In order to produce light lines with the required position accuracies, a very precise lens array was needed. Given a lens radius of .20 cm provided by an existing mold cutting stylus, the required average pitch of the lenses was .12993 cm, with an allowable random position error of .00006 cm. Fortunately, these tolerances were well within the capabilities of current lenticular lens fabrication technology. A lens was fabricated, tested, and found to have properties extremely close to those specified. Upon mounting in front of a lamp bank situated at the proper distance, light lines of the required pitch were produced by the lenslets and furthermore different lines resulting from different lamps were superimposed on one another.

In addition, in order to maximize brightness and prevent uneven illumination, the optics were specified to transmit 90% of the impinging light with variation in transmittance across the display of less than ± 5%. In order to minimize unwanted reflected and scattered light which can cause ghost images to be visible, the use of anti-reflective glass substrates for the lens was investigated and implemented.

The sub components for the optics system had the following key specifications:

(1) **Lenticular Lens** - The most critical specification for the lenticular lens was the pitch and focal length of the lenses. Light lines with a width of at most .006 cm had to be generated behind the LCD pixel layer. For use with this LCD, the required light line pitch was .02510 cm (.1506 cm for every sixth line), with a random position error of any line with regard to a reference edge line of no more than ± .00002 cm allowed. To avoid undesirable visual effects, the light lines had to be parallel to the LCD pixel columns to within 51 arc seconds and overall lateral position errors of no more than ± .006 cm were tolerated.

(2) **Diffuser** - The diffuser specifications were not critical. Only a weak diffuser was needed. The diffuser had to be strong enough to wash out unwanted bright areas in regions that were illuminated by two lamps, yet weak enough that the reflected light off the diffuser did not contribute to ghost image visibility.

(3) **Mounting/Alignment** - A lens mount was designed that attached directly to the LCD assembly and contained manually operated adjustment mechanisms for position and rotational adjustments to the required accuracy.

3.2 LCD System

3.2.1 LCD

Standard LCDs are updated at a 60 Hz rate (16.7 ms) but their pixels take several frame intervals to fully change to the new state. This is not a problem in normal applications because the image is changing at a much slower rate than 60 Hz.

The challenge for this project was to create an LCD that was addressed and had pixel response times several times faster than common off-the-shelf devices. Since the number of viewing zones and the quality of look around images depends on the speed of the LCD, a device with as much speed as possible was desired. Since this technology was a stepping stone to a commercial grade product, an adequate contrast ratio and gray scale were also important.

The David Sarnoff Research Center (Sarnoff) was selected as subcontractor to develop the custom LCD. After exploring several alternatives, Sarnoff concluded that a version of an existing experimental 400 x 800 resolution Sarnoff LCD with very fast operating speeds could be built using a surface mode configuration proprietary to Optical Shields Inc.

Experimentation with single cells as well as the LCD itself prior to integration with the electronics led to the expectation that address rates of close to 180 Hz, pixel response times of .5 ms off and 3.5 ms on, a contrast ratio of up to 25:1, and a maximum transmittance of nearly 25%, could be achieved.

Due to the response behavior of the liquid crystal material, the response time in transitions between gray shades would normally be much longer than transitions between full on and full off. To overcome this problem, a drive scheme was implemented whereby all 200 columns in successive 1/4 horizontal sections of the LCD were driven to the opaque state prior to the address of each section in a column by column fashion. Thus in successive fields pixels never changed from one gray level directly to another; instead they always started from full off at the beginning of each field. Response times from full off to any gray level are nearly equal to the response times to full on (3.5 ms).

An LCD with the following properties was chosen:

*   Resolution: 400 rows by 800 columns
*   Active area: 20.3 cm by 15.24 cm
*   Transmittance: 15% minimum

Since the LCD had to be capable of forming at least 180 completely different images every second, the following properties were also specified:

*   Element Response Time: 3.5 ms maximum
*   Address rate: 5.6 ms (1/180th sec)
*   Contrast Ratio: 25:1 minimum

3.2.2 Framestore

The framestore acts as a buffer and data translator between the computer generating graphic images and the hologram-like LCD display. The framestore captures 60 images per second from each of the RED, GREEN and BLUE video channels from a computer and sends them to the LCD at the rate of 180 LCD frames per second.

The framestore receives the computer data, stores it and outputs the data to the LCD in the LCD format (32 bit data words) organized to give multiple perspective zones.

There is complete independence between the writing of data into the framestore and the reading of data from the framestore. The data transfer rate from the framestore to the LCD can be varied from 96 to 180 frames per second (16 to 30 complete images per second).

The framestore provides the illumination system with information allowing lamp control circuitry to turn lamps on and off in the proper sequence at the proper time.

3.3 Image Generation System

Using the SGI Indigo Workstation, Graphics Library, existing 3D image data and rendering programs as a foundation, custom software was developed to meet stated objectives.

DTI developed a multiple perspective stereo tool kit to be accessible by application programs used to render 3D objects. The tool kit is comprised of a number of routines designed to accept a perspective number (1-6) and calculate the appropriate settings for the graphics library rendering matrices. The tool kit specifically sets the projection matrix, and color (R,G,B) to the appropriate values for the perspective view being rendered.

Application rules were developed to work in conjunction with the tool kit. Application programs are to define the Graphics Window as 768 (h) by 800 (w) positioned leftmost on the monitor. This provides an area large enough to render the six perspective views. Three views are rendered in the top 384 by 800 portion and the other three in the bottom 384 by 800 portion. By setting the view port to the top portion of the graphics window for perspective views four through six or the bottom portion for views one through three, an image is rendered in the appropriate location. Also, Graphics Mode must be set to RGB mode to allow the segregation of views through color. Given three colors and two view ports, six individual perspectives can be written to the graphics window.

When interfaced to the prototype, the framestore is designed to recognize: perspective one as the green component of the bottom 384 by 800 portion of the 1024 by 768 RGB datastream, perspective two as the red component of the bottom portion, perspective three as the blue component of the bottom portion, perspective four as the green component of the upper portion, perspective five as the red component of the upper portion, and perspective six as the blue component of the upper portion.

Custom software and images were developed to support component level validation, system testing, and demonstration. These include:

- Single zone images sized to a configuration of 400 rows by 200 columns with gray level and zone placement control. These were designed for LCD and parallax illumination system testing.

- Test images such as full white screen, black screen, gray bars, alternating white and dark bars for the testing of transmittance, uniformity, gray level performance, crosstalk, and contrast.

- Various wireframe and text images for image quality observations such as transition smoothness, perspective view analysis, and stereo acuity.

All software code is written in Silicon Graphics C.

4.0 SYSTEM COMPONENT TESTS

In order to validate the specifications of the components that make up the display system, individual component evaluations along with system integration tests were performed. The following are the results of those tests.

4.1 Parallax Illumination System

4.1.1 Illumination System

(1) **Lamps** - The lamps were tested and found to be in conformance with their specifications for both performance and physical dimensions. The lamps were measured to have a response time of 300 μs as required. The phosphors exhibited a slightly pink color when they first came on, but this could easily be corrected to a more uniform white color with a weak filter. The lamps had brightness variations from lamp to lamp on the order of 1% - 3% when measured with a photometer. The overall brightness of the array after transmission through the LCD was 23 fL which met the specified value of 20 fL.

(2) **Lamp Drivers** - The lamp drivers were tested and found to be in conformance with their specifications for both performance and physical dimensions.

(3) **Synchronization Control** - The lamp bank allowed for adjustment of lamp turn on and turn off times to experiment with and optimize visual results in terms of illumination evenness and gray shading. It also allowed for variation in the sequence in which the lamps are flashed. In fact for some of the illumination testing, the lamp flash rate and the sequence of lamp flashes was changed from a left to right flashing order to various pseudo random sequences in order to evaluate visual performance.

4.1.2 Optics System

(1) **Lenticular Lens** - The lenticular lens had to be replicated in low expansion epoxy from a brass mold. Since the tolerances are so precise, a test lens was made from a small test mold first, and its pitch and focal length were measured directly. The radius and focal length were also calculated indirectly from tests during which the lens was used to form viewing zones of correct size and distance using two lamps positioned at the correct spacing from each other and the lens, and a lithographic mask to simulate the LCD. These tests verified that the lens was within specification.

A full size mold was then made, and lens replicas made from it. The lens was not measured directly, but rather was inspected visually for blemishes and defects, then installed behind the LCD and spacings between the lamps, lens, and LCD adjusted. The lens formed viewing zones of the correct width and distance from the LCD with the lamps very close to the predicted optimum positions, thus demonstrating that the lens complied to specifications.

(2) **Diffuser** - Visual inspection revealed no blemishes or
discolorations that would degrade image quality. The diffuser was
put in place to insure that unwanted bright areas of the
illumination were washed out. The diffuser did indeed perform
this function.

(3) **Mounting/Alignment** - The lens mount proved to perform adequately.
The system was aligned easily and remained aligned throughout
testing and evaluations. Mechanisms were integrated into the
mounting to lock down the optics once they were correctly aligned.

4.2 LCD System

4.2.1 LCD

The LCD subcontractor processed two lots of active matrix substrates.
As the substrates were experimental in nature, none of the panels
operated 100%. The panel chosen for experimentation provided
sufficient operation to both evaluate the hologram-like look around
technique and the fast liquid crystal technique embodied in the LCD.

The panel chosen performed as follows:

- Address Speed: 180 Hz
- Measured Pixel Response: .5 ms (Full CLEAR to 90% DARK)
                            3.5 ms (Full DARK to 90% CLEAR)
- Measured Contrast Ratio: 46:1
- LCD Transmittance: 15:1

The LCD possessed some **visual anomalies** that hindered its performance,
especially in the area of flicker evaluation. They include:

- The second group of 200 columns have a synchronization problem and
  flash which results in a visual artifact of flicker in the group.

- There is a gross LCD flicker present which is due to LCD
  nonuniformity. There are clusters of pixels that operate
  differently from surrounding pixels. The pixels are sensitive to
  backplane voltage such that their transmissivity varies as a
  function of the backplane polarity. The result is a pulsing
  effect at the backplane reversal rate due to the change in
  brightness of groups of pixels throughout the LCD.

- A third anomaly is a warm up condition that causes image sticking
  (DC offset) approximately three minutes after turn on. The
  hypothesis for the cause of the problem may be that there is some
  form of DC voltage offset which is preventing the pixels from
  completely erasing the previous images.

- A fourth anomaly is the nonuniformity of the pixel response which
  eliminates the ability to generate gray levels and also results in
  slow pixel response.

4.2.2 Framestore

The framestore required some debugging and modification in order to work as specified. One problem was the synchronization to the Indigo system. Since the image source was high speed, non standard video data from an Indigo work station, there were synchronization problems to properly digitize the data. The solution to this required the location of a new video sync IC that could operate at the high speed required. A second problem encountered was the image to lamp coordination. To make the correct lamps come on behind the correct data required coordination of two microprocessors plus a great deal of high speed logic. Debugging of both processors firmware and the logic were required to get the correct data illuminated. Also debugged were the RAM clock pulses. The RAM used to buffer the video data was operating running at max speed during writing of data. To operate consistently, careful shaping of the write clock pulses was required. This could only be done once the complete system was up and running. After these problems were resolved, the framestore operated correctly and the data was presented in the correct format to the correct columns and flashed the corresponding lamps.

4.3 Image Generation System

The image generation system functioned as designed and was able to produce the test and demonstration imagery necessary to validate the prototype display. During integration testing it became desirable to observe the six individual perspective images simultaneously as they were being integrated and displayed on the prototype.

Through the use of a second video monitor and an Indigo video adaptor board (#D5-IVID-2.0), we were able to view the images as separate top and bottom R, G, B images and as six perspective views on the prototype. This proved to be very beneficial during system debug and synchronization optimization.

4.4 Integrated Components Test

Assembly of the Lamps, Optics, and LCD was completed and the system was debugged, and tested. Initial observations indicated that all elements were operating in synchronization. The system was able to generate, capture and synchronize high speed image data to the LCD and illumination. The complete prototype system operated with the following characteristics:

Display Size

The active area of the display is approximately 20.3 cm x 15.24 cm as dictated by the LCD.

Display Chromaticity

The display is black and white.

Imagery Capability

Images can be displayed in either static or dynamic mode through user controls. Images can also be positioned on this display through the user controls. Imagery consists primarily of wire frame and text objects rendered with two pixel width thickness. The use of the two pixel wide images allowed for brighter images to be displayed.

Gray Level

There is no gray level performance with the system due to nonuniformity in the pixel response (see LCD anomalies). An attempt was made to show 32 gray levels, but the LCD was not able to render them.

Zone Location

Viewing zones are formed at a 50 cm distance from the screen. When the user sits 50 cm from the screen, the left eye is immersed in a full left eye view, and the right eye in a full right eye view. The viewing zone distance was originally planned for a location of 76 cm, but during integration it was set at 50 cm. Due to the overall screen size, it was set at 50 cm so that the user would perceive a larger screen size than would be perceived at 76 cm. This distance can be changed by effectively changing the optical spacing of the light lines to the LCD.

Full Resolution

Using this look around technique, images are produced at full 800 x 400 resolution.

Multiple Perspective Views

The system produces six separate perspective views with each zone being approximately the width of normal interpupillary distance (6.35 cm). This allows a viewer's eyes to be positioned with one eye seeing one of the six perspectives while the other eye sees a different but complimentary perspective view. The six zones provide five stereo pairs spanning 36 cm in front of the display. Two other 36 cm wide groups of six perspectives and five stereo pairs are also displayed to the left and right of the center section to support multiple viewers; however, the outermost zones in these two sections were not fully formed as a result of the viewing angle formed by the 50 cm zone location. At a zone location of 76 cm, the viewing angle would allow the outermost zones to be fully formed.

In spite of several anomalies, the integrated prototype functioned adequately to allow visual evaluation and performance testing of DTI's autostereoscopic hologram-like full resolution technique.

5. SYSTEM PERFORMANCE TESTS

The following are the critical areas of system performance which were tested and evaluated.

5.1 Look Around Smoothness

The goal of any hologram or look around technology is seamless transition between perspectives. How far out of the screen images can extend and still provide smooth looking "look around" instead of sudden jumps in perspective as one moves from zone to zone could affect the design of future displays. Such sudden jumps could prove to be annoying to the user and might also result in difficulty in keeping the images fused during head movement. Strictly speaking, perfectly smooth transitions between perspective views can only be achieved if equivalent points of adjacent views are never displaced by more than about .5 minutes of arc relative to one another, the limit of human visual resolution, when observed from the desired viewing distance. Previous observations with the Phase I bench model had indicated that much larger displacements between one image and the next were hardly noticeable, unless one was looking for them. Other researchers have achieved visually acceptable results with displacements of many minutes of arc.[1,2]

A series of subjective observations, by ten test subjects, of lines of letters extending into and out of the screen revealed that for the display as currently configured, a displacement of up to .25 cm from one image to another was small enough that the image changes as one moved between zones on average were barely noticeable. Much greater displacements, though noticeable, did not produce difficulty in fusing the images. When asked whether the sudden image changes were annoying or obtrusive, test subjects overwhelmingly stated that they could not really tell unless they were engaged in some task with the display or were looking at some application specific image. A .25 cm distance subtends an angle of about 17 minutes of arc. A left eye and right eye image point separated by .25 cm represents a point in image space located 2 cm behind or in front of the screen when the screen is viewed from 50 cm. This suggests a rule that might apply to the ideal future display. A sufficient number of zones should be provided so that no part of any image anywhere within the image volume, which typically would extend several centimeters behind and in front of the display surface, is displaced by more than 17 minutes of arc as seen from two adjacent viewing zones. If the stereo volume extends 25 cm beyond the screen, and the screen is viewed from a more typical distance of 76 cm, that implies that viewing zones should be no more than .67 cm wide. If such thin zones were to cover the area covered by the present six zones (36 cm wide), fifty-four zones would be required. Generating images for such a large number of zones would require an LCD that operates at 1620 Hz. This is nine times the current 180 Hz rate for the six zone case. Thus, a very fast LCD would be required to provide seemingly smooth look around across a wide area for a typical image. However, it is apparent that perfectly smooth look around throughout the viewing volume is not absolutely necessary for easy image fusion, so compromising smoothness in the interest of using fewer viewing zones over a wider area seems possible. This is a very preliminary conclusion, and further research

should be done to quantify this trade-off between smoothness and number of viewing zones.

5.2 Image Crosstalk (Ghosting)

The presence of Image Crosstalk (Ghosting) which is the faint visibility of the images intended for zones adjacent to the ones where the eyes are currently positioned, due to scattered light or incomplete pixel changes, was low. Ghost images of perspective views adjacent to the one being measured were found to be 5% as bright as the proper image. A level of 5% is very good for this system. Ghost images of views intended for more distant zones were invisible. Since the ghost images were partly due to improper functioning (slow turn off) of some pixels due to a fault in the driver electronics, we expect that ghosting levels can be improved.

5.3 Tests of Flicker and Beta Movement Visibility

At the start of the program the visual effects resulting from this type of illumination system were unknown. The system, involving illumination from six sets of interlaced lines, is considerably different from the type of illumination normally seen on displays, even interlaced CRTs. Of greatest importance is how fast the display has to operate to avoid visual artifacts. This determines the number of full resolution images that can be generated with a given LCD in a given frame and thus the number of independent perspective views that can be generated. It was felt that two classes of artifact would be visible, namely ordinary flicker, and a theater marquee effect, which is called beta movement.

To test for flicker, beta movement, and other possible effects, subjects were allowed to view the illumination system operating alone without the LCD, as the lamp flash rate and the sequence of lamp flashes was changed from a left to right flashing order to various pseudo random sequences. There were six lamp sequences evaluated and those are shown in Table 1. Each of the four sections of the LCD operates with the same sequence.

Based on subjects' comments and descriptions of the effects they were seeing, the visual phenomena were grouped into three types: flicker, beta movement, and a less well defined phenomena best described as "vibrating" or "unsteady" light lines.

Flicker refers to the typical area-wide flicker that is most visible on the periphery of the visual field and at slow speeds, and is least visible at the gaze point and at high speeds.

The critical flicker frequency was about the same for all the sequences tested, near 36 Hz, with a total variation of +7%, -8% from the mean. Theory predicts a critical flicker frequency value of 30 Hz for this technique. This is a percent deviation of 9.1% and is well within acceptable values. Some sequences produced less noticeable flicker than others and the sequences are rated in Table 1. The best sequence for elimination of flicker appeared to be Sequence C, but they were all so close that the sequence did not seem to be a deciding factor. It is postulated that small variations in lamp brightness cause higher critical flicker frequencies due to variations in

overlapping light lines from the individual lamps. By changing the sequencing of the lamps, the variations in brightness will change also and could be the reason for different values of critical flicker frequency for different sequences. It is believed that these critical flicker frequencies can be lowered by better equalizing the brightness of the lamps. More focused research in this area would need to be performed in order to gather more precise data on the lamp evenness.

Beta movement refers to the illusion that causes sequentially flashing light sources to appear as steadily moving light sources, as do the light bulbs on an old fashioned theater marquee or the LEDs in a modern moving message sign.

Eight subjects were tested for Beta movement. 100% of the subjects observed the elimination of Beta movement at their critical flicker frequencies with Sequence E (See Table 1).

Flash Sequences B and C eliminated Beta movement visibility for all subjects except at very slow flashing speeds. A future design would incorporate the best possible flash sequence that would minimize both Beta and Flicker visibility. Further research with regards to this trade off is warranted.

The **vibration** effect is less evident, but tends to be visible to some degree throughout the frequency range tested and is most evident near the gaze point.

The vibration effects were less noticeable, and seem at this point to be traceable to variations in lamp brightness, resulting in variation in brightness between adjacent lines. It does not appear to be a function of the sequence used. This analysis would be part of further research into lamp illumination evenness versus flicker visibility.

Since these effects were unknown at the time of initial prototype design, a design was set forth that utilized Sequence A with regard to the data placement on the LCD and thus precluded the ability to randomize the sequences once integrated with the LCD. Tests were performed using Sequence A to gather baseline data using the LCD.

Beta movement is present when a white screen is displayed. It was not apparent with the wire frame imagery. The use of the white screen image provided as close a representation of the illumination system alone which is where the beta movement was identified. Future designs should use a sequence that minimized this effect such as Sequence E.

Flicker tests with the LCD were inconclusive due to the visual anomalies of the LCD. Based on theory, there is no reason to suspect that the choice of sequence will affect flicker in any large degree. Further analysis focused in this area would provide more substantial data to verify this hypothesis.

Vibration effects which are thought to be caused by uneven illumination were not perceived in the integrated system. Thorough evaluation was not possible due to other LCD anomalies.

SEQUENCE	FLICKER	BETA	VIBRATION
A. 1 2 3 4 5 6	6	6	2
B. 1 3 5 2 4 6	2	2	2
C. 1 3 5 6 4 2	1	2	2
D. 1 2 3 6 5 4	5	5	2
E. 1 6 2 5 3 4	2	1	2
F. 1 6 3 4 2 5	5	5	2
1 = Best Performance, 6 = Worst Performance			

Table 1 - Lamp Sequence Visual Performance Rating Table

6. TECHNOLOGY EVALUATIONS

Although the breadboard display proved several key concepts necessary for the implementation of the display, certain developments must occur to embody these concepts in a form suitable for commercial products. Discussions are being held with several vendors, with the goal of perfecting the key components and embodying them in commercially viable form. The following are discussions on the technological status of enabling technologies.

6.1 Parallax Illumination System

The key components for the illumination system of a full resolution hologram-like look around display use standard technology, and for the most part already exist in forms suitable for use in products.

6.1.1 Illumination

Fluorescent aperture lamps have proven to be sufficiently bright and are capable of strobing at a sufficiently fast rate for a full resolution 3D hologram-like display.

DTI is exploring the development of fluorescent illuminators using flat fluorescent lamp technology which is capable of emitting light from many small channels molded or etched into a substrate. This configuration would allow a much thinner display to be constructed through the use of a larger number of light sources spaced closer to the optics and LCD. It is also expected to be considerably more reliable than a large number of individual tubes.

An alternate possibility is the use of a small number of serpentine lamps. Each of these lamps might take the place of several short fluorescent tubes behind each section of the LCD. Such lamps can now be made in small diameters (less than .3 cm) and with apertures.

Generally, the thinner and more closely packed the channels or lamps are, the thinner one can make the display. This is due to the basic geometry of the system. The distance, d, between the lamps and the lenticular lens is given by the formula $d = p \times r$, where p is the pitch, or center to center separation between any two lamps of the same set, which are on at the same time, and r is the focal ratio of the lenticular lenslets, in other words their focal length divided by their width. As an example of the sort of thickness that can be achieved in an ideal system, if eight viewing zones are to be generated, and the thinnest possible channel or lamp is .25 cm wide, then $p = 1.2$ cm at minimum. The smallest reasonable value for r might be 1, which leads to a lamp to lens distance of as little as 1.2 cm.

6.1.2 Optics

Lenticular lens manufacturing is a mature technology. Lenticular lenses of sufficient precision can be made in any size likely to be necessary for use with LCDs of typical display size and resolution. This includes the emerging 43 cm to 48 cm VGA and XGA LCDs.

6.2   LCD System

6.2.1   Direct View LCDs

Currently, there are no off-the-shelf LCDs of suitable size and performance to support this hologram-like look around technique for direct view applications. Under this program significant advances were made with regard to the liquid crystal technique that could make an off-the-shelf solution a reality.

Sarnoff achieved very fast address rates and pixel turn on and turn off times through use of a surface mode LCD, using polycrystalline silicon driver electronics. Polysilicon driver electronics allow very fast address rates commensurate with the pixel response times, combined with fewer interconnections than other TFT technologies and more reliable operation. Address speeds of just under 180 fps were achieved. The response times possible with liquid crystal materials are typically dependent on the thickness of the LC layer, which is determined by the spacing between the glass plates of the LCD. To achieve the speeds required for a full resolution multi perspective look around display, one would normally have to use a very thin spacing, on the order of a few microns. However, maintaining this spacing over the surface area of a typical display would be difficult if not impossible. One alternative is to use a surface mode LC material, in which only a thin layer near one of the liquid surfaces is active. Thus, the high speeds associated with a thin LC layer are achieved without having to make the overall LC layer thickness thinner than usual. Easy to maintain glass spacings can be used. Pixels response times of 3.5 ms to full on and .5 ms to full off were achieved using this type of material.

Unfortunately, the response times between gray shades will still be considerably slower than the response times between full on and full off and vice versa. Response times between full off and gray shades, however, tend to be as fast as response times to full on. Therefore, a drive scheme was implemented in which 1/4 width sections of the LCD were quickly driven to full off (opaque) in sequence, just prior to addressing. This ensured that each image would be erased before the next was written; all pixels would start from the full off condition at the beginning of each field, and would reach the various gray levels or full on at approximately the same time.

Although gray level performance using this scheme could not be evaluated under this program, Sarnoff remains confident that adequate gray level performance can be achieved. In fact one panel from the two lots processed, although not suitable for evaluation, did perform with full gray level performance.

The next logical step is to embody the fast LC technology in a "production quality manufactured" AM TFT panel. This would isolate the fast LC recipe from TFT manufacturing anomalies and allow a true preproduction prototype display to be developed. This effort will require collaboration between DTI, Sarnoff and a to be determined LCD manufacturer.

6.2.2 Projection LCDs

Projection grade LCDs and other types of light valves are emerging with suitable performance characteristics to support this hologram-like look around technique in a projection implementation. One VGA resolution device is now available off the shelf. These LCDs are all currently small devices being developed for field sequential color projection display systems, such as projection televisions. Field sequential color illumination, which produces color images using a monochrome LCD that is illuminated with red, then green, then blue light in sequence, requires an LCD that operates at least at 180 fps, to avoid flicker. One California company now markets such an LCD, a 1.72 cm diagonal reflective VGA resolution device. It uses standard TFT LCD technology and achieves its fast speed through fast LC material in combination with a very thin cell gap, which is easy to maintain over such a small area. A partner in the European Flat Panel Display joint venture has produced and demonstrated a similar 5.0 cm diagonal 180 fps transmissive LCD in the laboratory.

Two other companies, in the U.S. and the U.K., are developing and marketing low resolution (256 x 256) samples of ultra fast reflective ferroelectric LCDs. They are also developing higher resolution versions for eventual use in displays. These LCDs have pixel response times on the order of .1 ms, and can be addressed at rates of several thousand frames per second. The very high speed is used to achieve an adequate gray scale; since ferroelectric LC material is bi-stable, the pixels can be turned to the full on or full off states, but not in between as is required for gray scale. Gray scale is achieved by turning individual pixels off partway through a standard 1/60th second frame. The very fast address rates used allow any of the pixels to be turned off during any one of several dozen time periods during each frame, thus allowing a wide range of gray scale.

In addition to LCDs, a few other companies are developing Digital Micro-mirror Devices (DMDs), which work by deflecting tiny mirrors (one for each pixel), thus causing light to either enter or miss a projection lens. These devices are also small and very fast, since they achieve gray scale in the same manner as the ferroelectric LCDs. High resolution 2048 x 1152 devices have been made in the laboratory.

DTI is actively evaluating the technical and commercial feasibility of a projection implementation for hologram-like look around displays.

6.3   Image Generation System

Computer graphics technologies have been and will continue to rapidly advance in both hardware and software capabilities. The burgeoning area of virtual reality has also brought an increased awareness of the importance of stereo viewing. This has resulted in increasing availability of stereo rendering capabilities in graphics applications.

Regarding the hardware interface requirements, advancements in LCD interface technology are resulting in decreased development times and improved capabilities. During this program, DTI has developed a

prototype system which can interface to virtually every 1024 by 768 resolution video format being commercially used. Development efforts under this program have also increased DTI's level of expertise in this area. We see no technology barriers in this area of system development.

7. CONCLUSIONS

The optical and illumination techniques for producing dynamic parallax illumination which results in multiple perspective hologram-like imagery are sound and have been proven to clearly produce the visual effect.

This conclusion is supported by the data gathered on zone creation, critical flicker frequency, beta and vibration visual artifacts, multiple zone transition smoothness, performance trade offs, component specification and system synchronization. Visual support is embodied in the prototype display which allows an observer to view full resolution look around 3D images within a wide area in front of the display without any special glasses or other viewing aids.

The future of the autostereoscopic technique for producing multiple perspective look around imagery is being hindered by LCD technology. This LCD technology barrier is evident in the results of this program although significant advancement was made under this program towards removing this impediment.

Two technical approaches exist for the future of this technology. The first being a continuation of the direction established under this program. Paramount to the success of this approach is the development of a larger, higher resolution, full color LCD with the required address speed and pixel response to support the concept. To address this development DTI is actively pursuing LCD manufacturers to collaborate with the David Sarnoff Research Center in the fabrication of a commercially viable LCD.

The second technical approach takes advantage of available and emerging display devices that have the required address speed and pixel response to support the concept. These display devices however are designed for projection applications and as such will not accommodate the direct view optics and illumination components currently designed and validated under this program. Based on cursory analysis, and results of an SBIR Phase I feasibility program to assess projection techniques for DTI's autostereoscopic process, DTI believes multiple perspective hologram-like imagery from a projection based system is feasible. DTI will actively pursue this direction in parallel with the direct view approach.

8. REFERENCES

1. Borner, R., "Autosteroskopische 3-D-Systeme mit Zwischenbildern in Linsensrastergrossbildschirmen" (Autostereoscopic 3-D System with intermediate images on a large format lenticular screen), *Fernseh- und- Kino- Technik*, Vol. 44, number 7, 1990.

2. McCartney, D. J. et. al., "Telecommunications Applications for 3-D Imaging Systems." *Proceedings of the SPIE*, Vol. 1915, Stereoscopic Displays and Applications III, 1993. pp. 29-35.

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16. Abstract

Dimension Technologies Inc. (DTI) developed a prototype display using a proprietary illumination technique to create hologram-like full resolution images on an LCD. The resulting 3D image has a resolution equal to that of the LCD along with properties associated with holograms, including change of perspective with observer position and lack of viewing position restrictions. To develop this display, DTI explored concept designs and enabling technologies for: a parallax illumination system with sufficient brightness and control, an LCD with rapid address and pixel response, and an interface to an image generation system. Results demonstrate that the techniques for creating multiple perspective imagery are sound and clearly produce the visual effect. Data has been gathered on zone creation, critical flicker frequency, visual artifacts, zone transition smoothness, performance trade offs, component specifications and system synchronization. Visual support is embodied in a prototype display which allows an observer to view full resolution look around 3D images within a wide area in front of the display without any special glasses or other viewing aids.

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