DLP™

A TEXAS INSTRUMENTS TECHNOLOGY

The Digital Display Technology of the Future

INFOCOMM '97
5-7 June 1997
Los Angeles, California USA

The Digital Display Technology of the Future

Lars Yoder
Texas Instruments Incorporated, P.O. Box 655012, MS11, Dallas, TX 75265
phone: 972-995-2377 • email: yodr@msg.ti.com

Introduction

In this information age, we are surrounded by computers, faxes, modems, pagers, and cellular telephones. These products all rely on digital technology. More recent advances have produced digital cameras, digital camcorders, digital satellite systems (DSS), and the widely anticipated digital video disk (DVD) players, which play digital source material of unprecedented image quality. And of course, who could forget the Internet, the seemingly endless forum of digitized information. Before long, digital VCRs will make their way into the homes of millions of consumers, offering yet another digital solution.

Although many of us realize the benefits of this digital technology, the majority of video displays are still based on the old analog cathode ray tube (CRT), which recently celebrated its 100th anniversary. Why would someone want to go to all the trouble of preserving digital video and graphic data only to have it converted to analog before it is viewed? Digital Light Processing (DLP™) offers a solution to this problem of unrealized image quality potential. DLP, invented by Texas Instruments, is the new digital display technology. It is the final link in the chain that makes possible a completely digital video information structure. This is especially important as TVs and PCs converge to provide central information and communication media windows.

On April 3, 1997 the Federal Communications Commission (FCC), along with the major networks, officially kicked off a plan to begin the conversion process to digital television transmission. As the U.S. embarks on a multi-year transition to digital high-definition television (HDTV), DLP brand products will be uniquely positioned as the only all-digital HDTV projection display systems available to bring viewers the best possible image quality. With DLP, consumers can enjoy the same life-like video realism that the compact disc brought to the audio industry more than 15 years ago.

Background

In 1991, Texas Instruments formed its Digital Imaging Venture Project (DIVP) to bring the radically new DLP technology to the marketplace. During the next 5 years, Texas Instruments took DLP from research project to commercial production. In 1996, leading manufacturers brought DLP to the market as the world's only digital projection systems. Today there are world class projectors available for a wide variety of applications that range from conference rooms, classrooms, and home theaters to sports arenas, auditoriums, and commercial theaters.

Digital Light Processing (DLP)

When we compare DLP to today's display technologies, it's easy to see why DLP has a promising future. Because the technology is digital, DLP is able to reproduce life-like color images with precision accuracy. Seamless picture reproduction, high brightness, inherent reliability, the ability to show PC graphics and TV video, and other DLP advantages are discussed below.

™ DLP is a registered trademark of Texas Instruments Incorporated

How DLP Works

Texas Instruments DLP display technology digitally manipulates (or processes) light to produce film-like, all-digital images. DLP integrates a projection lamp and an electronic video signal from a source such as a VCR or computer, and the processed light produces an all-digital picture.

The key to this complete digital process is the Texas Instruments Digital Micromirror Device (DMD), a thumbnail-size semiconductor light switch. The DMD consists of an array of thousands of microscopic-size mirrors, each mounted on a hinge structure so that it can be individually tilted back and forth. When a lamp and a projection lens are positioned in the right places in the system, DLP processes the input video signal and tilts the mirrors to generate a digital image.

Imagine that you are in a football stadium at night and it's half-time. All the lights in the stadium are turned off; there is a blimp floating a few hundred feet above the field. As part of the half-time show, a powerful spotlight placed at the 50 yard line blasts light into the stands. All the fans in one area of the stadium are asked by the announcer to hold up the reflective seat cushions that were in their seats before the game. Each reflective cushion has a different number on the back. The announcer asks you to tilt your seat cushion so that the light from the spotlight reflects directly up to the blimp each time your number appears on the scoreboard screen. If your number is not displayed, you are to tilt the cushion away from the blimp and direct light down to the field. Each fan in the stands now controls a pixel of light. You can imagine that if some fans reflect the light toward the blimp, an image of some sort will appear on its side [Figure 1(a)].

Now imagine a viewer looking toward the stadium and the blimp from a remote distance [Figure 1(b)]. When looking at the blimp, he or she will see an image on the side of the blimp that is generated by the sports fans tilting their reflective seat cushions and reflecting light onto the side of the blimp.

DLP technology accomplishes this same task, but it does so by processing light that is focused onto the

(a)

(b)

Figure 1. Fans in a stadium reflecting light toward a blimp. (a) Light is projected from a spotlight toward fans in the stadium. When cued by a numbered signal, these fans hold up their reflective seat cushions and tilt them toward or away from a blimp. By doing so, the fans in the stadium are reflecting pixels of light toward the blimp. The result is that the light pattern created by the seat cushions projects an image onto the surface of the blimp. (b) A distant viewer sees the image on the blimp.

DMD (Figure 2). At speeds greater than 1,000 times per second, the mirrors are electronically tilted. Light from a lamp is digitally reflected from the DMD, through a projection lens, and onto a screen. Color is added through a color wheel filter system.

Seamless Picture

Besides being able to generate images digitally, DLP reproduces these images in a virtually seamless fashion. The picture appears seamless because the mirror pixels used in a DLP system have very tiny spaces between them—1 micrometer gaps, to be exact. This gives DLP a fill factor, or active area, of approximately 90%. In other words, DLP comes closer than any other technology to producing an exact mirror image of an input video or graphic signal (Figure 3).

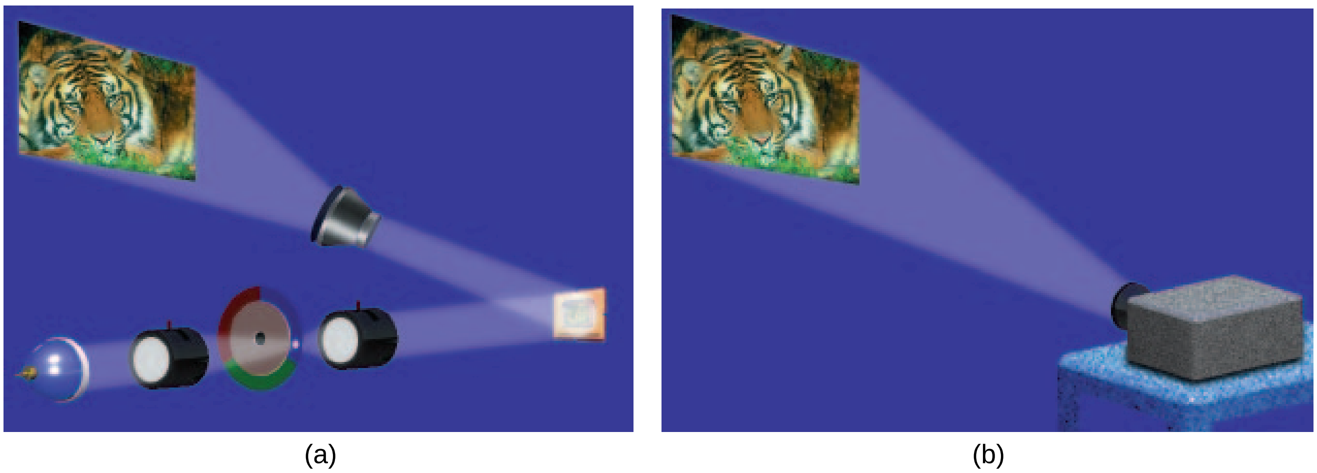

Figure 2. DLP system operation. (a) In much the same way the image was formed on the side of the blimp, DLP forms images for video. Shining light on the DMD and tilting the mirrors creates a digital image. Color is added by placing a red, green, and blue color wheel filter system in the optical path. As the wheel spins, the mirrors are tilted on for the exact amount of time required for each color. At any given instant, only one of the primary light colors is hitting the DMD, but when the filter system spins fast enough, the colors blend to create a full-color digital image. (b) A viewer sees an image on the screen from a DLP projector.

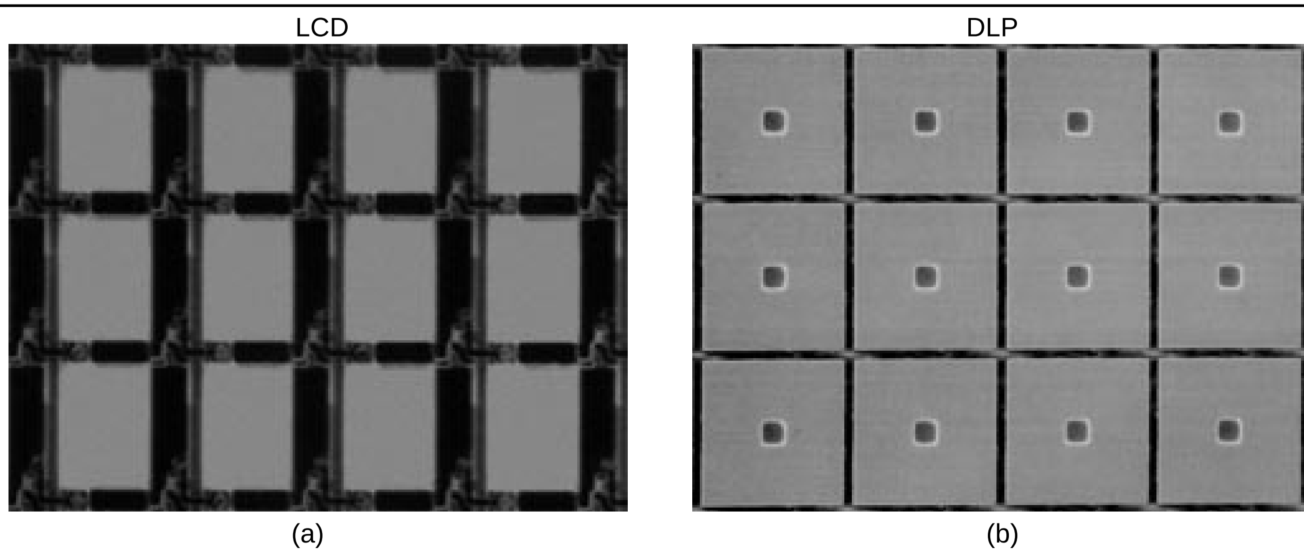

Figure 3. Actual photographs of (a) liquid crystal display (LCD) pixels and (b) DLP pixels. Projected images are made up of thousands of small pixels; DLP pixels (b) are more uniform and more closely spaced than the polycrystalline silicon (poly-Si) pixels seen in view (a). Based on a superior pixel structure, DLP offers a higher fill factor and better image quality.

Figure 4. Photograph used to demonstrate DLP's seamless picture. This digitized photograph of a polar bear was projected with both a DLP and an LCD projector to illustrate the seamless, film-like picture quality of DLP (Figure 5).

Using a super video graphics adapter (SVGA) DLP projector (800 × 600 pixels) and a leading SVGA liquid crystal display (LCD) projector, the photograph of a polar bear (Figure 4) was used to illustrate DLP's superior image quality. Figure 5(a) shows the pixelated screen-door effect common to LCD projectors. The screen-door effect is gone when the image is projected with a DLP projector [Figure 5(b)]. Rather than looking at an image as if it were behind a screen door, the viewer sees a seamless, digitally generated and projected image. Although the resolution, or number of pixels, is the same in each photograph, DLP has a higher perceived resolution because of its seamless advantage.

High Brightness

Because DLP is a reflective technology, it is far more efficient than the competing systems. This means that more light gets from the lamp to the screen—an extremely important factor in high-brightness

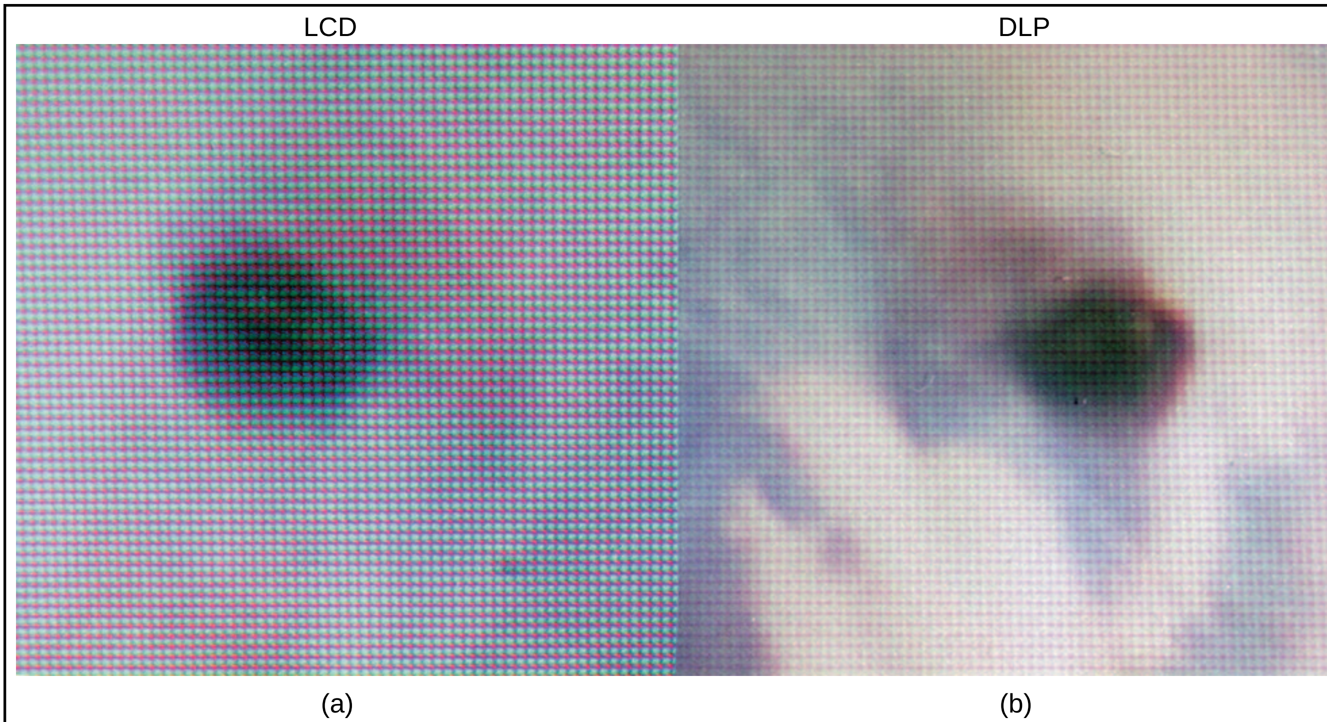

Figure 5. Actual close-up photographs of both (a), an LCD-projected image, and (b), a DLP-projected image. An SVGA poly-Si projector (a) was compared to an SVGA DLP projector (b). The photographic image of the polar bear in Figure 4 was displayed on both projectors. The LCD and DLP photos shown here were taken under the same conditions, with each projector being optimized for focus, brightness, and color. Note the high level of pixelation in the LCD photo compared to that of the seamless DLP photo. DLP offers superior, seamless picture quality because of the high fill factor and close spacing of DMD mirror pixels.

applications. In fact, thermal models predict that for a three-DMD super-extended graphics adapter (SXGA) projection system (1,280 × 1,024 pixels), 10,000 on-screen lumens can be achieved.

Reliability

DLP systems have passed a series of environmental and regulatory tests to simulate thermal shock, temperature cycling, mechanical shock, vibration, moisture resistance, and acceleration conditions. Most reliability concerns are focused on the hinges that tilt the mirrors from one position to another. To test reliability, DMDs were subjected to accelerated life cycle tests simulating approximately 20 years of use. Inspection of the devices after the testing showed no broken hinges on any of the devices. Texas Instruments has completed thousands of hours of life cycle and environmental testing to conclude that the DMD and DLP systems are inherently reliable.

Other Display Technologies

In addition to DLP, there are three other primary display technologies: amorphous silicon (am-Si) LCD, polycrystalline silicon (poly-Si) LCD, and cathode ray tube (CRT).

LCDs

An LCD acts as a light shutter. It can be best understood as a mechanism capable of modulating or controlling the amount of polarized light that can be transmitted through the panel. Improvements in LCDs have led to increases in transmissivity (light throughput), but LCD technology is still limited to an analog architecture. Am-Si and poly-Si are thin film transistor (TFT) LCDs that require a transistor to control each pixel on the LCD panel. An electric signal applied through the transistor to the LCD pixel changes the pixel's polarization. By varying the polarization, the amount of light passing though each pixel can be controlled to produce an image (Figure 6).

Amorphous Silicon LCD

Am-Si LCDs are built by depositing transistors on a large glass substrate. A transistor is located in the corner of each pixel while a thin conductive grid connects to each pixel on the panel. Pixels are made up of three individually controlled sub-pixel strips (red, green, and blue) to create a pixel capable of producing many color combinations. Am-Si panels are used to create single-panel projectors, but these projectors suffer from poor image quality due to the side-by-side sub-pixel color scheme.

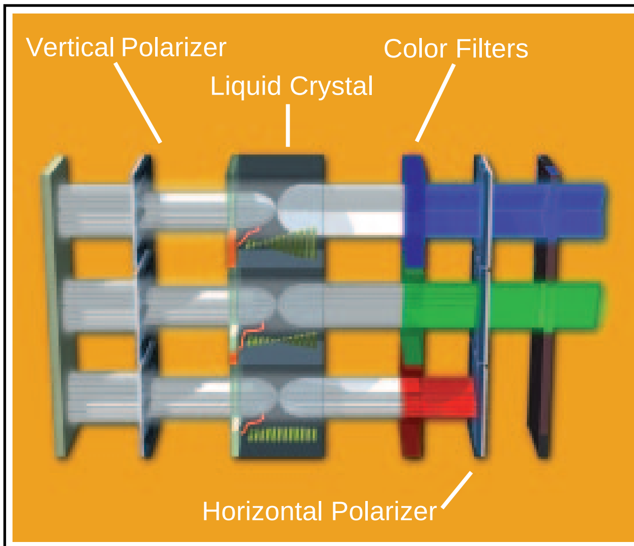

Figure 6. Three closely spaced red, green, and blue LCD sub-pixels. Light can be represented in vertical and horizontal components. If light is directed at a vertically oriented polarizer, the polarizer acts as a filter and allows only the vertical light to pass. On the other side of the system, another polarizer is positioned so that light will pass only in the horizontal direction. With no liquid crystal in the path, the first polarizer would block the horizontal light and pass the vertical. When the vertical light hits the second polarizer, it would also be blocked (because the second polarizer passes only horizontal light). The result would be complete blockage of light, producing a dark pixel. When a liquid crystal is "sandwiched" between the two polarizers, it acts as a modulator or "twister" of polarized light. By applying a voltage to the crystal, the light polarization can be altered, allowing various levels of light to pass through the system. Projection systems based on LCD technology use either a single LCD panel or three panels, one for each primary color—red, green, and blue. In the single-panel configuration shown here, small, closely spaced red, green, and blue sub-pixels make up one pixel.

Polycrystalline Silicon LCD

Polycrystalline silicon LCD, more commonly referred to as poly-Si, is a very popular LCD technology for projection display. These LCDs are fabricated at high temperatures on quartz substrates. Poly-Si LCD panels are much smaller than am-Si panels. They have smaller transistors and greater fill factors as well, but to date, poly-Si panels are monochromatic (meaning they don't have the color stripping found in am-Si panels). Color is created in poly-Si projectors by using three separate LCD panels, beam-splitting mirrors, and a prism system. White light is split into red, green, and blue components. Each component of light is directed to its own LCD panel, where the light modulation occurs. The modulated light is then recombined by a prism so that the pixels from each panel are overlaid on each other to produce a color image. The challenge for these three-panel poly-Si projectors is the precision alignment that is necessary to make the separate red, green, and blue image planes converge to produce a uniform, aligned picture.

Cathode Ray Tube Technology

Cathode ray tube technology is used in nearly all of today's computer monitors and televisions. Electron beams are scanned back and forth and directed at a phosphor-emitting surface. When electrons hit this surface, light is emitted. By scanning the beams at rates faster than the eye can detect, a full image can be created.

The problem with CRTs is that they are not digital but analog displays. CRT technology probably will be replaced in the future by emerging LCD and DLP technology. In addition to being based on an old, analog technology, CRTs also lack the brightness necessary for many larger screen applications. Further brightness limitations arise when CRT projection systems attempt to drive higher resolution video signals. The CRT's brightness decreases as resolution increases, limiting the CRT's potential as an optimal solution for HDTV. Because a CRT display system usually relies on three electron guns (Figure 7), one for each primary color (red, green, blue), it also requires constant alignment and tweaking for optimum picture quality. This leads to increased setup time and maintenance costs during a product's lifetime (Figure 7).

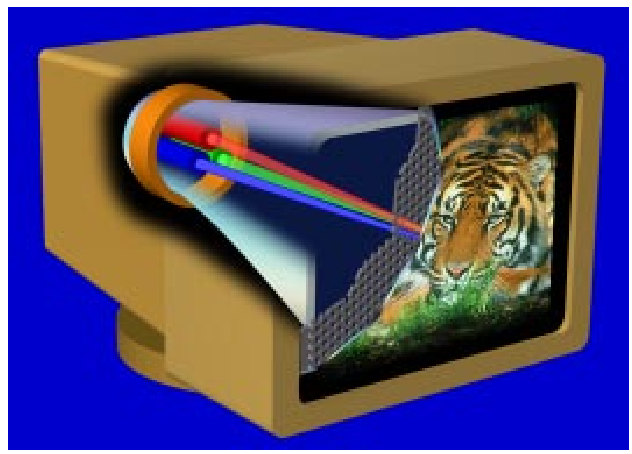

Figure 7. The CRT monitor. Input video or graphic signals are sent to three electron guns at the back of the monitor's cathode ray tube. Each electron gun shoots a stream of electrons, one for each of the primary colors. The intensity of each stream is controlled by the input signal. The beams pass through a shadow mask to keep them precisely aligned. When the electrons strike the phosphors coating the inside of the screen, the phosphors emit light. A magnetic deflection yoke bends the paths of the electron streams so that they sweep from left to right and top to bottom in a process called raster scanning. The screen is usually redrawn, or refreshed, 60 or more times a second.

Summary

More and more of today's information is created, edited, and transmitted in the digital domain. The majority of existing display technologies are analog and limit the full potential of digital video. At present, DLP is the only digital projection solution available to produce an entirely digital video infrastructure. As PCs and TVs converge and the digital HDTV infrastructure begins to take form, DLP offers consumers the maximum benefit of digital source material by producing life-like, digitally projected images of unprecedented picture quality. The colors are truer and brighter, the pictures seamless. Because it is a reflective technology, DLP images will become brighter and brighter as resolutions increase. Texas Instruments has also gone to great lengths to ensure that the DLP technology is inherently reliable by subjecting it to numerous environmental and regulatory tests.

Using DLP technology, leading manufacturers are bringing world class projectors to the market to serve a wide variety of digital display applications. DLP is the new digital video technology. Welcome to the future of digital high-definition projection display!

BIBLIOGRAPHY

[1] E. Baumann, "The Fischer Large-Screen Projection System," *J. SMPTE*, Vol. 60, pp. 344-356 (April 1953).

[2] R.J. Gove, "DMD Display Systems: The Impact of an All-Digital Display," Society for Information Display International Symposium (June 1994).

[3] L.J. Hornbeck and W.E. Nelson, "Bistable Deformable Mirror Device," *OSA Technical Digest Series, Vol. 8, Spatial Light Modulators and Applications*, p. 107 (1988).

[4] W.E. Nelson and L.J. Hornbeck, "Micromechanical Spatial Light Modulator for Electrophotographic Printers," *SPSE Fourth International Congress on Advances in Non-Impact Printing Technologies*, p. 427 (March 20, 1988).

[5] L.J. Hornbeck, "Deformable-Mirror Spatial Light Modulators (Invited Paper)," Spatial Light Modulators and Applications III, *SPIE Critical Reviews*, Vol. 1150, pp. 86-102 (August 1989).

[6] T.J. Sheerer, W.E. Nelson, and L.J. Hornbeck, "FEM Analysis of a DMD," *Seventeenth Nastram User Colloquium, NASA Conf. Pub. 3029*, p. 290 (1989).

[7] J.B. Sampsell, "An Overview of Texas Instruments Digital Micromirror Device (DMD) and Its Application to Projection Displays," *Society for Information Display Internatl. Symposium Digest of Tech. Papers*, Vol. 24, pp. 1012-1015 (May 1993).

[8] L.J. Hornbeck, "Current Status of the Digital Micromirror Device (DMD) for Projection Television Applications (Invited Paper)," *International Electron Devices Technical Digest*, pp. 381-384 (1993).

[9] J.M. Younse and D.W. Monk, "The Digital Micromirror Device (DMD) and Its Transition to HDTV," *Proc. of 13th International Display Research Conf. (Late News Papers)*, pp. 613-616 (August 31-September 3, 1993).

[10] J.B. Sampsell, "The Digital Micromirror Device," *7th ICSS&A*, Yokohama, Japan (1993).

[11] J.M. Younse, "Mirrors on a Chip," *IEEE Spectrum*, pp. 27-31 (November 1993).

[12] J.M. Younse, "DMD Projection Display Technology (Invited Talk)," IEEE Multimedia Symposium, Richardson, TX (April 19, 1994).

[13] M.A. Mignardi, "Digital Micromirror Array for Projection TV," *Solid State Technology*, Vol. 37, pp. 63-66 (July 1994).

[14] K. Ohara and R.J. Gove, "DMD Display and Its Video Signal Processing," The Institute of Television Engineers Japan 1994 Annual Convention, ITEC '94, Saga, Japan (July 1994).

[15] V. Markandey, T. Clatanoff, R. Gove, K. Ohara, "Motion Adaptive Deinterlacer for DMD (Digital Micromirror Device) Based Digital Television," *IEEE Trans. on Consumer Electronics*, Vol. 40, No. 3, pp. 735-742 (August 1994).

[16] J.M. Younse, "Commercialization of Digital Micromirror Display Technology," Conference for Commercialization of Microsystems, Banff, Alberta, Canada (September 13, 1994).

[17] V. Markandey and R. Gove, "Digital Display Systems Based on the Digital Micromirror Device," SMPTE 136th Technical Conference and World Media Expo (October 1994).

[18] D.W. Monk, "Digital Micromirror Device Technology for Projection Displays," EID Exhibition & Conference, Sandown, UK (October 26, 1994).

[19] R.J. Gove, V. Markandey, S. Marshall, D. Doherty, G. Sextro, and M. DuVal, "High Definition Display System Based on Digital Micromirror Device," International Workshop on HDTV (HDTV'94), International Institute for Communications, Turin, Italy (October 1994).

[20] J.B. Sampsell, "An Overview of the Performance Envelope of Digital Micromirror Device Based Projection Display Systems," *SID 94 Digest*, pp. 669-672 (1994).

[21] C. Tew, L. Hornbeck, J. Lin, E. Chiu, K. Kornher, J. Conner, K. Komatsuzaki, and P. Urbanus, "Electronic Control of a Digital Micromirror Device for Projection Displays (Invited Paper)," *IEEE*

International Solid-State Circuits Digest of Technical Papers, Vol. 37, pp. 130-131 (1994).

[22] D. Monk and R. Gale, "The Digital Micromirror Device for Projection Display (Invited Paper)," *Microelectronic Engineering*, Vol. 27, pp 489-493 (1995).

[23] G.A. Feather and D.W. Monk, "The Digital Micromirror Device for Projection Display," IEEE International Conference on Wafer Scale Integration, San Francisco, CA (January 18-20, 1995).

[24] W.E. Nelson and R.L. Bhuva, "Digital Micromirror Device Imaging Bar for Hardcopy," Color Hardcopy and Graphic Arts IV, *SPIE*, Vol. 2413, San Jose, CA (February 1995).

[25] E. Chiu, C. Tran, T. Honzawa, and S. Namaga, "Design and Implementation of a 525 mm^2 CMOS Digital Micromirror Device (DMD) Chip," *Proc. 1995 International Symposium of VLSI Technology Conf.*, p. 127, Taipei, Taiwan (1995).

[26] B.R. Critchley, P.W. Blaxtan, B. Eckersley, R.O. Gale, and M. Burton, "Picture Quality in Large-Screen Projectors Using the Digital Micromirror Device," *SID 95 Digest*, pp. 524-527 (1995).

[27] G. Sextro, T. Ballew, and J. Iwai, "High-Definition Projection System Using DMD Display Technology," *SID 95 Digest*, pp. 70-73 (1995).

[28] M.R. Douglass and D.M. Kozuch, "DMD Reliability Assessment for Large-Area Displays," *Society for Information Display International Symposium Digest of Technical Papers*, Vol. 26 (Applications Session A3), pp. 49-52 (May 23-25, 1995).

[29] G. Feather, "Digital Light Processing™: Projection Display Advantages of the Digital Micromirror Device™," 19th Montreux Television Symposium (June 1995).

[30] J.M. Younse, "DMD Microelectromechanical (MEMS) Technology (Keynote Address)," Society of Experimental Mechanics (SEM) UACEM Conference, Worcester, MA, (July 6, 1995).

[31] J.M. Younse, "DMD Display Technology (Invited Talk)," Naval Research Center, Washington, DC (September 5, 1995).

[32] G. Hewlett and W. Werner, "Analysis of Electronic Cinema Projection With the Texas Instruments Digital Micromirror Device™ Display System," 137th SMPTE Technical Conference, Los Angeles, CA (September 6-9, 1995).

[33] J.M. Younse, "DMD Display Technology (Invited Talk)," U.S. Government's Large Display Working Group Meeting, NUWC, Newport, RI (September 21, 1995).

[34] T. Hogan, J. Hortaleza, "Low Temperature Gold Ball Bonding for Micromechanical Device Interconnections," Ultrasonic Industry Association, Columbus, OH (October 18, 1995).

[35] J.M. Younse, "Projection Display Systems Based on the Digital Micromirror Device (DMD)," SPIE Conference on Microelectronic Structures and Microelectromechanical Devices for Optical Processing and Multimedia Applications, Austin, TX, *SPIE Proceedings*, Vol. 2641, pp. 64-75 (October 24, 1995).

[36] L.J. Hornbeck, "Digital Light Processing and MEMS: Timely Convergence for a Bright Future (Invited Plenary Paper)," *Proc. SPIE*, Vol. 2639, Micromachining and Microfabrication Process Technology, p. 2 (1995)—Abstract Only. Color reprint of complete paper available. Call 1-888-DLP-BYTI (1-888-357-2984).

[37] W.E. Nelson, "Tutorial on Optical Printheads," IS&T Eleventh International Congress on Advances in Non-Impact Printing Technologies, Hilton Head, SC (October 29, 1995).

[38] L. Yoder, "The Fundamentals of Using the Digital Micromirror Device (DMD) for Projection Displays," *Proc. International Conference on Integrated Micro/Nanotechnology for Space Applications*, sponsored by NASA and Aerospace Corp., Houston, TX (October 30-November 3, 1995).

[39] J. Iwai, G. Sextro, "High-Definition Projection System Using DMD Technology," IEEE 1995 International Workshop on HDTV and the Evolution of Television, Taipei, Taiwan (November 15-17, 1995).

[40] G. Deffner, "Eye Movement Recordings to Study Determinants of Image Quality in New Display Technology," *Eye Movement Research*, pp. 479-490, J.M. Findlay, R. Walker, and R.W. Kentridge (eds.), Elsevier, Amsterdam (1995).

[41] D. Fritsche, V. Liu, V. Markandey, and S. Heimbuch, "Integration of Today's Digital State With Tomorrow's Visual Environment," *Proc. SPIE*, Vol. 2650, Projection Displays II, pp. 9-17 (1996).

[42] V. Markandey, T. Clatanoff, and G. Pettitt, "Video Processing for DLP Display Systems," SPIE Photonics West '96, San Jose, CA (January 27-February 2, 1996).

[43] R. Howell and M. Mignardi, "Fabrication of the Digital Micromirror Device (Invited Paper)," SID Displaywork 1996, Manufacturing Technology Conference (February 7, 1996).

[44] J. Florence and L. Yoder, "Display System Architectures for Digital Micromirror Device (DMD) Based Projectors," *Proc. SPIE*, Vol. 2650, Projection Displays II, pp. 193-208 (1996).

[45] V. Markandey, G. Hewlett, and G. Pettitt, "Digital Light Processing: The Convergence of Television and Computer Display," *30th SMPTE Advanced Technical Conference 1996 Proceedings*, pp. 150-160 (1996).

[46] D. Monk, "Digital Light Processing With the Digital Micromirror Device," Electronic Displays '96, Chemnitz, Germany (April 24-25, 1996).

[47] G. Pettitt, A. DeLong, and A. Harriman, "Colorimetric Performance Analysis for a Sequential Color DLP Projection System," SID '96, San Diego, CA (May 1996).

[48] R.G. Fielding, M. Burton, and T. Bartlett, "Colorimetry Performance of a High Brightness DMD Based Optical System," SID '96, San Diego, CA (May 1996).

[49] M.R. Douglass and C. Malemes, "Reliability of Displays Using Digital Light Processing," SID '96, San Diego, CA (May 1996).

[50] L. Yoder, "DLP, The State of the Art in Projection Display," SID '96, San Diego, CA (May 1996).

[51] L.J. Hornbeck, "Digital Light Processing: A New MEMS-Based Display Technology (Keynote Address), "*Technical Digest of the IEEJ 14th Sensor Symposium*, pp. 297-304, Kawasaki, Japan (June 4-5, 1996).

[52] L. Yoder, "The TI Digital Light Processing Tech: Putting it to Work Now," *Advanced Imaging Magazine*, pp. 43-46 (June 1996).

[53] L.J. Hornbeck, "Digital Light Processing and MEMS, Reflecting the Digital Display Needs of the Networked Society (Invited Plenary Paper)," *SPIE Europto Proceedings*, Vol. 2783, pp. 2-13 Besancon, France (June 12-13, 1996).

[54] R.L. Knipe, "Challenges of a Digital Micromirror Device: Modeling and Design," *SPIE Europto Proceedings*, Vol. 2783, pp. 135-145 (June 12-13, 1996).

[55] V. Markandey and G. Hewlett, "Digital Light Processing: A DSP Powered Multimedia Display," *DSP & Multimedia Technology*, Vol. 5, No. 4 (July/August 1996).

[56] L.J. Hornbeck, "Digital Light Processing and MEMS: An Overview (Invited Paper)," *Digest of IEEE/LEOS 1996 Summer Topical Meetings, Optical MEMS and Their Applications*, WA3, pp. 7-8, Keystone, CO (August 5-9, 1996).

[57] F. Skaggs, "Automatic Testing of the Digital Micromirror Device (DMD)," *Digest of IEEE/LEOS 1996 Summer Topical Meetings, Optical MEMS and Their Applications*, WB2, pp. 11-12, Keystone, CO (August 5-9, 1996).

[58] W.E. Nelson, "Digital Light Processing for Color Printing (Invited Paper)," *Digest of IEEE/LEOS 1996 Summer Topical Meetings, Optical MEMS and Their Applications*, WC3, pp. 19-20, Keystone, CO (August 5-9, 1996).

[59] M. Mignardi, R. Howell, "The Fabrication of the Digital Micromirror Device," EF/SEMI Conference, Commercialization of Microsystems '96, Kona, HI (October 6-11, 1996). Proceedings in progress.

[60] L.J. Hornbeck, "Digital Light Processing for Projection Displays: A Progress Report (Invited Paper)" *SID EuroDisplay '96, Proceedings of the 16th International Display Research Conference*, pp. 67-71, Birmingham, England (October 14-18, 1996).

[61] L.J. Hornbeck, "DLP (Digital Light Processing) fur ein Display mit Mikrospiegel-Ablenkung," *Fernseh-und Kino-Technik*, pp. 555-564, Berlin, Germany (October 1996) — In Color.

[62] M.S. Brennesholtz, "Light Collection Efficiency for Light Valve Projection Systems," *Proc. SPIE*, Vol. 2650, Projection Displays II, pp. 71-79 (1996).

[63] L.J. Hornbeck, "Digital Light Processing for High-Brightness, High-Resolution Applications," *Electronic Imaging, EI '97*, San Jose, CA (February 10-12 1997).

[64] J. Florence, R. Miller, and T. Bartlett, "Contrast Ratio in DMD-Based Projection Systems," SID '97, Boston, MA (May 1997).

[65] Digital Light Processing World Wide Web site: http://www.ti.com/dlp

1-888-DLP-BYTI
(1-888-357-2984)
http://www.ti.com/dlp

Texas Instruments Digital Video Products Group
P.O. Box 655012, MS 24
Dallas, Texas 75265-5012

Texas Instruments England Limited
800 Pavilion Drive
NorthHampton Business Park
NorthHampton NN47YL, England U.K.

Texas Instruments Japan Limited
Aoyama Fuji Building
3-6-12 Kita-Aoyama Minato-ku
Tokyo 107

Product # DLP-0031

A TEXAS INSTRUMENTS TECHNOLOGY