Optical Short Course International

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# What's "Inside The Box"?

# Optics of Digital Projectors Weekly Newsletter

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## *Digital Micromirror Device™ in Digital Projectors*

By Michael Pate, President, OSCI

The Texas Instruments (TI) digital micromirror device or DMD™ has launched the all digital display revolution that we are living in right now and have been since 1996. In this article takes a look at the structure of how they are designed and how they work along with some of their performance parameters and limitations. We also compare some properties of the reflective DMD™ panel to the other modulator types. We also take a look at some of the concerns of the DMD™ technology and look at how they compete with some of the new modulators technologies.

**DMD™ History**

The early history[1] of the technology in 1977 began as a government funded program with deformable mirrors based upon TI's experience with night vision equipment. In 1980 an idea was proposed, by Ed Nelson, to use the device to replace the spinning polygonal mirrors in xerographic applications. This moved the program into cantilevered mirrors and finally into the flexured yoke. By 1987 the flexured yoke approach had run out of steam for printing applications. Desperation breeds Innovation!

The current DMD™ was invented in 1987 by Dr. Larry Hornbeck of the Central Research Labs of Texas Instruments. In 1989 a small team was formed to investigate using the DMD™ in display applications. They worked with the current Digital Projection International and DARPA to produce a working two line digital display by 1990. From this two line display they went quickly to 768 x 567 PAL format to a 2048 x 1152 high resolution format. For TI management these images were worth more than a thousand words and certainly more than a million bucks – They decided to form a new division called Digital Imaging Venture Project to exploit this new digital imaging technology in December 1991.

In May of 1992 TI gave a demo of the 768 x 567 format digital display. In 1994 a demo of the 2048 x 1152 3 panel system was demonstrated as an outgrowth of the DARPA contract. By early 1996 the group DVIP was renamed to Digital Imaging and by April 1996 some of the first commercial customers were shipping digital projectors using DMD's. TI made a strategic decision to provide not only the DMD™ ship but the control electronics, signal processing, illumination and imaging optics, lamp, and power supplies. This strategic decision enable customers to reach the market with products much faster which of course helped them sell into the volume applications much faster. The rest as they say is history.

Starting the count in 1996, TI has shipped 1, 2, and 5 millionth DMD™'s in December of 2001, 2003, and 2004 respectively[2] and Dr. Larry Hornbeck is on his 24$^{th}$ patent in the technology and their whole team must be in the 100's of patents awarded and submitted.

**DMD Panels**

The digital micro-mirror device or DMD™ is a reflective spatial light modulator. Being a reflective panel has some different implications than the transmissive LCD panel we look at last week's issue of <u>In The Box</u>. We learned that transmissive LCD panels are illuminated and imaged on axis or normal to the panel. The reflective DMD™ requires that the illumination and imaging are on the same sides of the panel. If the DMD™ is imaged on axis or normal to the panel this implies that the illumination must be incident on the panel at an angle, because the imaging optics or projection lens is in the way.

These illumination and imaging requirements for the reflective DMD™ panel make the optical packaging volume in front of these panels very precious space.

Let's not get ahead of ourselves. We need to take a look at how these panels work first and then we can come back to how they are used in a digital projector light engine. The current vintage DMD™ has SVGA or XGA resolution at 800 x 600 or 1024 x 768 pixels. These pixels or micromirrors are 13.68 or about 14 microns square and have the flexure hinge oriented across the corners of the mirror, see figure 1 below.

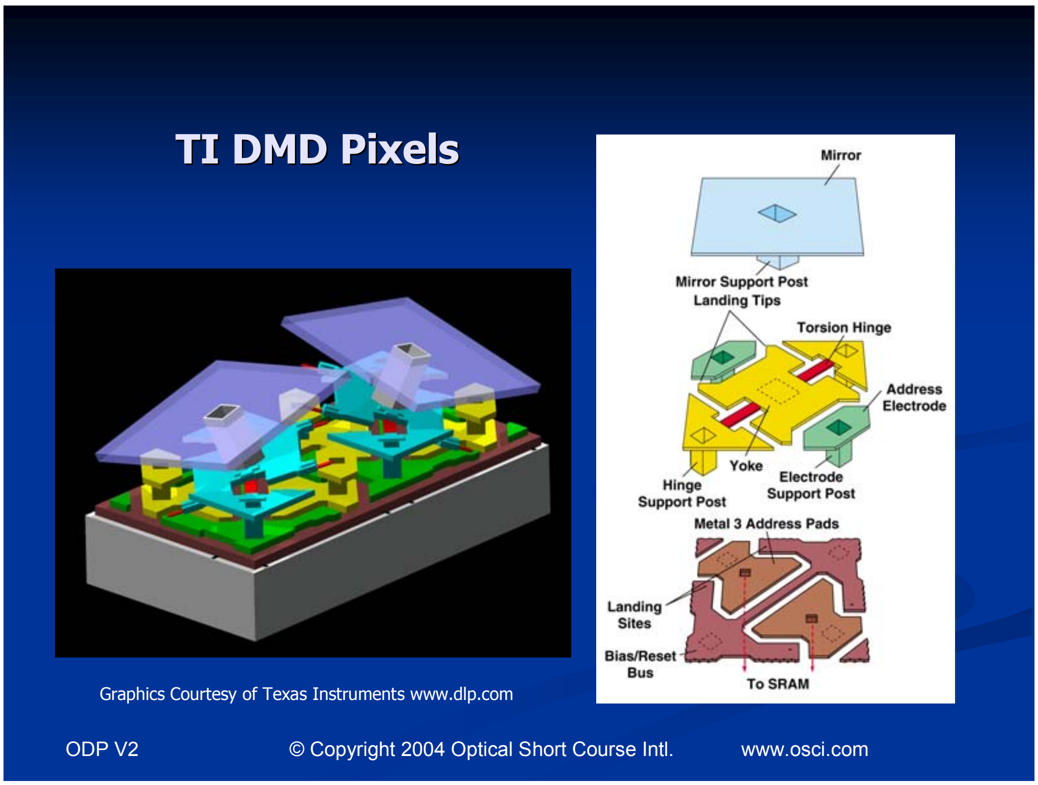


Figure 1. DMD™ Panel Cross Section View
Graphics Courtesy of Texas Instruments http://www.dlp.com
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm

We can see the structure of the DMD™ in the cross section illustrations above. We see that the whole structure is sitting on a silicon wafer substrate and then the static random access memory is patterned onto the wafer. Next the address electrodes and their support post are structured on the SRAM's. The yoke, torsional hinges, and hinge support posts are structured onto the bias reset buss. Next the mirror support post and the mirror are structured onto the yoke. The micromirrors are tilted by creating an electrical field force between the address electrode and the back of the mirror. The angle of the torsional hinge flexure and thus the mirror is fixed at +/- 10 or 12 degrees.

We can see these structures from a real device which has been magnified by a scanning electron microscope or SEM image in Figure 2. We can clearly see the hole from the mirror support post, the yoke, torsional hinges, and the address electrodes. We can also see the mirror spacing and some of the structures below the mirror. TI has continued to innovate by making progress by improving the modulator contrast by making the areas and structures below the mirrors "optically black". They call this dark metal technology and the idea is for these areas and structures to absorb any light that is not reflected by the surface of the mirror. Light that gets in between the mirrors and underneath the mirrors is a potential source of scattered and retro reflected light. If any of this unwanted light gets to the screen it will reduce the contrast ratio of the projected image.

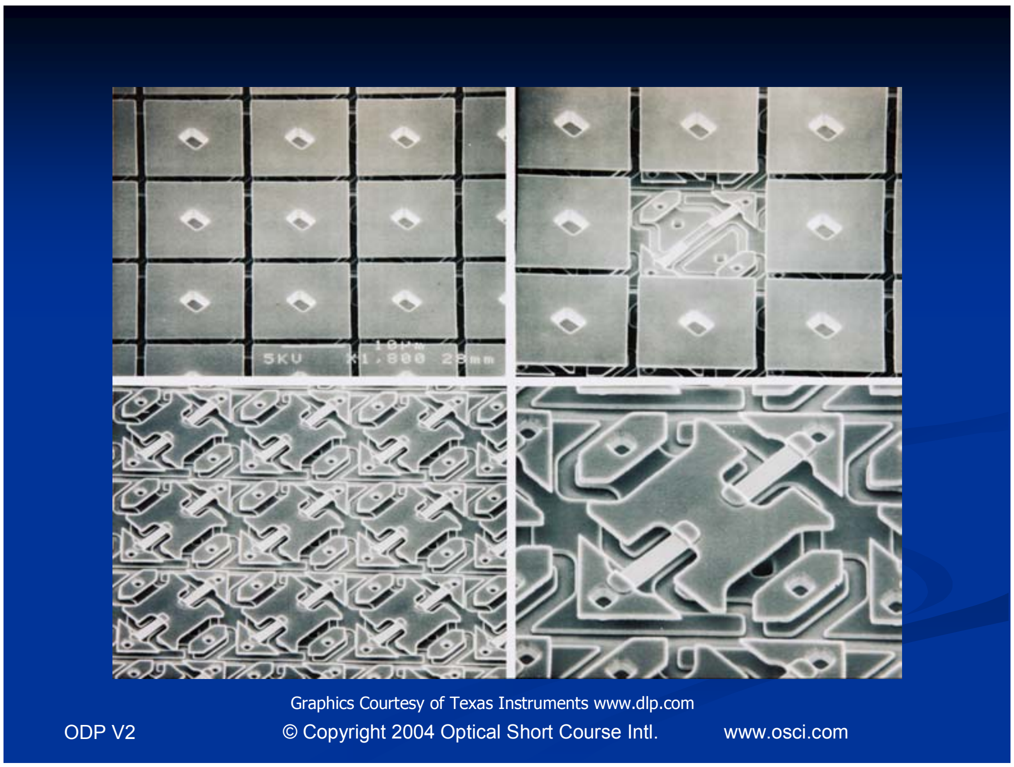


Figure 2. SEM of DMD™ Mirrors, Yoke, Torsional Flexure, Address Electrodes
Graphics Courtesy of Texas Instruments http://www.dlp.com
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm

You can see that the mass and resulting inertia of the yoke and mirror are low which means that the switching speed of the DMD™ is fast at tens of microseconds. Recall from last week that the switching speed of the LCD is tens of milliseconds, so the DMD™ is much faster. The DMD™ encodes the amount of light for each pixel by using a technology called binary-weighted pulse width modulation. One frame or time unit of a data (like MS Word or PowerPoint) or video can be divided into 8 bits or 256 steps of light. This scale goes from black (no light reflected from that pixel during the frame) to white (256 steps or full on for the total time of one frame) in 256 steps of grey.

It is important to understand how the DMD™ spatial light modulator works in the illumination and imaging system of a digital projector. In Figure 3 we can see the key subsystems we need to understand the modulator operation. We have the lamp and illumination system that illumination the spatial light modulator; recall that we discussed these subsystems in detail in an earlier version of In The Box. We also can see the projection lens assembly and know that the projection lens assembly has an entrance pupil that the illumination must pass through if it is to get to the projection screen. We can also see the light absorber or light dump. In the illustration of Figure 3, below we can see two pixels of the DMD™ array or mirrors. The pixel on the left is oriented in the on state at -12 degrees so that the illumination from the lamp and illumination system is reflected by the Micromirror so that the light passes through the entrance pupil of the projection lens assembly and out onto the screen.

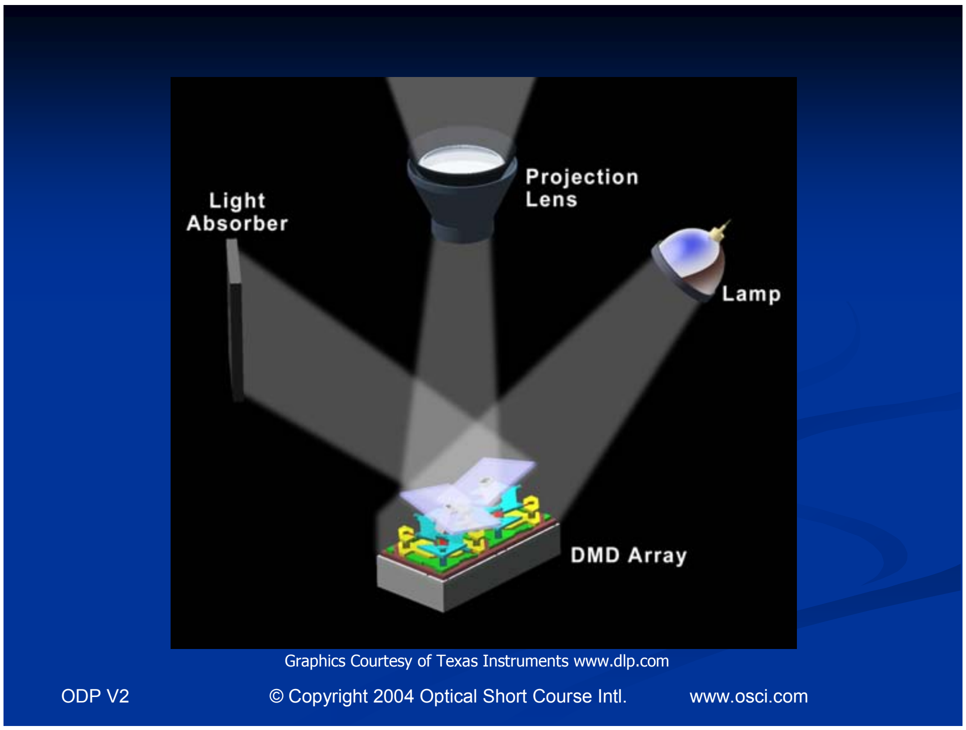


Figure 3. LCD Panel Principle of Operation
Graphics Courtesy of Texas Instruments http://www.dlp.com
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm

We can see that the pixel on the right is oriented in the off state at + 12 degrees so that the illumination from the lamp and illumination system is reflected from the Micromirror and into the light dump or absorber. The pixel on the left will be white and the pixel on the right will be black. If we want the pixel to be some shade of grey we just have to add the appropriate pulse width modulated light from the pixel during the time period of the frame.

In order to achieve color with a single chip DMD™ light engine we can use a sequential color filter wheel in the illumination path. The color filter wheel might have red, green, blue, and white angular segments that follow each other sequentially in time. Because the color filter wheel is synchronized to the DMD™ chip, see a previous issue of In The Box on color filters, the correct color image can be displayed in sequence on the screen to display a colored image. In Figure 4 we can see the single panel light engine layout.

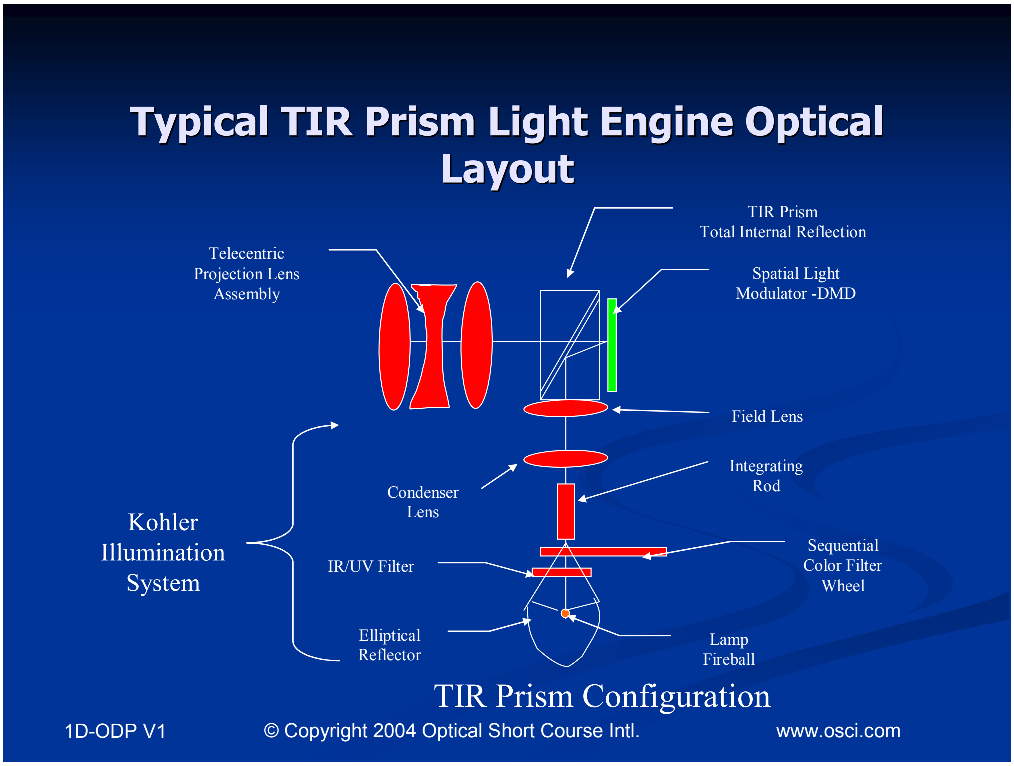


Figure 4. Single Panel DMD Light Engine Layout
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm

**Other DMD™ System Design Features**

As we can see in Figure 5 below the fill factor is about 87% for DMD™ panels so this means that we are wasting 13% of the light due to the mirror spacing and via holes in the center of the mirror. This is an improvement over the LCD fill factor but not as good as the impressive 92% fill factor of LCoS panels.

Panel optical efficiency is another area where the DMD™ panels excel over the other spatial light modulator technologies. The panel optical efficiency is defined as putting 100 units of light into a modulator and if all the pixels are turned full on how much light is reflected or transmitted by the panel. This will include reflection and transmission of the modulator pixels, window anti-reflection coatings, glass absorption, scatter, diffraction, etc; basically all of the optical affects are taken into account. The DMD™ has an optical efficiency of about 60% where LCD and LCoS are much lower.

The DMD™ panels are able to put the most screen lumens per panel of the three technologies. In the market we can find DMD™ projectors putting out 4000 screen lumens per panel in the large venue three chip digital projectors.

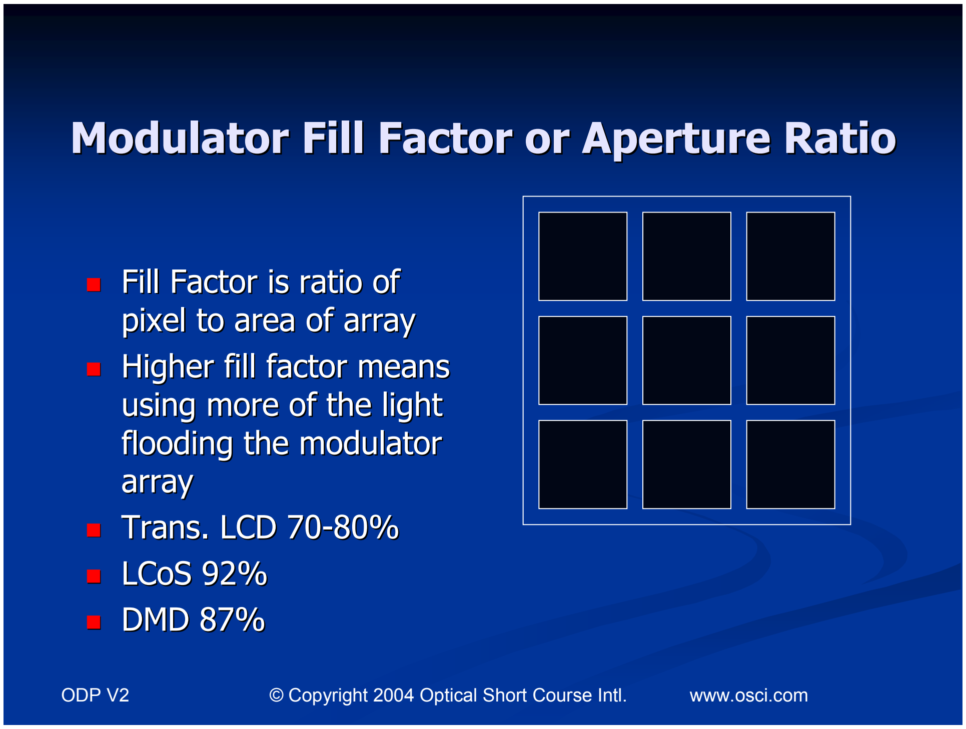


Figure 5. Modulator Fill Factor
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm

**Concerns of DMD™ Technology**
Cost, Cost, Cost. Because the DMD™ fabrication process is basically a silicon fabrication and lithography process it has the same cost and yield issues as semiconductors fabrication. If we want to drive the cost down we need to put more chips on a wafer, this means smaller pixels and smaller chip diagonals – of course this is the wrong direction for illumination designers we want bigger diagonals for a larger étendue so we can pump more lumens through the system from the lamp. The yield is difficult because for an XGA chips we need to have 786,432 essentially perfect mirrors, yokes, flexures, landing pads, and SRAM CMOS electronics on the chip so that it will perform well for years.

The DMD™ has no direct competition like the LCD and LCoS panel manufacturers do, they only have these substitutes to compete with in digital projector light engines. There are no DMD™ used in sub US$900 projectors it is all LCD panels, and three panels at that. Maybe the DMD™'s shouldn't play in this low cost space and they should stick to the middle and higher end of the product spectrum. What do you think?

**Summary**
We took a brief look at the history of the DMD™ within TI research labs and understand that it took about 14 years to get the technology ready for market. Since 1992 the Digital Imaging business of TI has continued to grow at a very fast rate. They have sold over 5

million DMD™ chips since 1996 to date. We looked at the micromechanical structure of how these devices are built and addressed. We discussed the principle of operation in a digital projector light engine and how the mirror reflects light into the lens for an on pixel and out of the lens for an off pixel. These devices are pulse width modulated to achieve the grey levels and work with a sequential color filter wheel to create color images. In the system performance area we understand that DMD™'s have a high optical efficiency and can deliver the most screen lumens per panel of the three major modulator types. The big concerns with DMD™'s is that they are inherently a silicon fabrication process and that TI has no direct competition and these factors keep the cost of the chips high.


1. From Cathode Rays to Digital Micromirrors: A history of electronic display technology, Larry J. Hornbeck, July-September 1998, TI Technical Journal, Pgs. 7 – 46.
2. http://www.dlp.com/about_dlp/about_dlp_story.asp


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