DLP technology – not just for projectors and TVs

Dana Dudley und Cheraina Dunn,
Texas Instruments Inc., Plano, Texas, USA

In 1996, projectors enabled with DLP (Digital Light Processing) technology first entered the market. Less than nine years later more than 8 million DLP sub-systems have shipped into data and video projectors (beamers), DLP TV sets, and digital cinema. At the heart of DLP technology is the Digital Micromirror Device (DMD), a semiconductor-based "light switch" array of thousands of individually addressable, tiltable, micromirrors. The DMD is an extremely fast spatial light modulator and lends itself for use in many applications outside the display market. Three years ago, Texas Instruments (TI) introduced a DMD developer kit that allows non-display applications access to the technology for development. Today the program continues and many new and exciting products are beginning to be introduced.

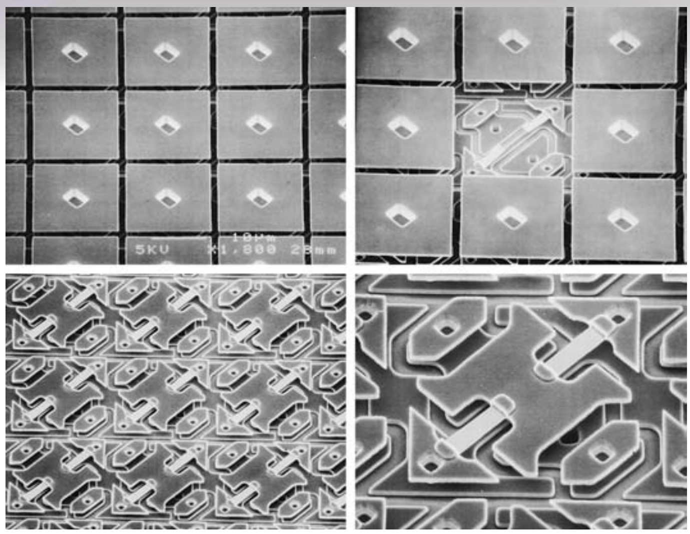

Figure 1: *Microscopic picture of a DMD. In the top left corner, a section of nine mirrors is shown. Top right: central mirror removed to expose the underlying hidden-hinge structure. Bottom left: all mirrors removed, but the hidden-hinge structures are still carrying their underlying (H-shaped) surfaces. Bottom right: close-up view of the mirror substructure. The mirror post, which connects to the mirror, sits directly on the center of this underlying surface (comp. Fig. 2)*

1 Micromirror array technology basics

The DMD is the only volume production device that is both a micro-electronic mechanical system (MEMS) and a spatial light modulator (SLM) [2]. Depending on desired resolution, it consists of hundreds of thousands of moving micromirrors that are controlled by underlying CMOS electronics (**figure 1**). The mirrors are highly reflective and used to modulate light, thus making the DMD an optical MEMS (MOEMS) as well as an SLM, and more specifically a reflective SLM. The mirrors are made to rotate to either a +12 degree or –12 degree position depending on the binary state of the CMOS memory cell that exists below each mirror (**figure 2**). The memory voltage is applied to the address electrodes, creating an electro-static attraction. When a voltage pulse is applied to the mirrors, each mirror then either stays in place or quickly rotates to its opposite state according to the memory data. Once stabilized, the mirror may be considered electro-mechanically "latched" in its desired position, and the underlying memory data may then be changed without affecting the state of the mirror.

The tiny mirrors are highly reflective, and are manufactured with submicron mirror-to-mirror gaps. This, coupled with the extremely short mirror switching time in the microsecond range, makes the technology very efficient at switching light with high precision and high optical contrast ratio [3]. This light switching efficiency does not only account for the successful application of DLP in projectors, TVs and digital cinema, but it also makes emerging applications accessible, such as lithography, data storage, and many others.

The manufacturing technology uses standard silicon wafer processing and equipment, and the mirrors are able to operate continuously at high speeds for well over 100,000 hours.

2 Fast, flexible, proven

DLP projectors and high-resolution TVs are known for having high fidelity images that do not degrade with time. This is because gray scale values in DLP pictures are created through binary pulse width modulation (PWM, i.e. the amount of time the mirror is on or off), in which intensity levels for each pixel are produced through short flashes of light whose duration is precisely controlled by digital electronics and rapid DMD mir-

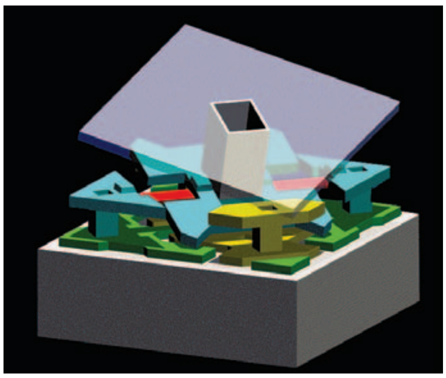

Figure 2: *DMD schematic showing mirror in a tilted state*

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***Figure 3:** XGA resolution DMD (1024 x 768 pixels) as used e.g. for beamers*

ror transitions. Although the eye cannot follow this short burst timing, humans are able to discern small changes in time duration by integrating the average amount of light emitted from pixels in an array, which are thus effectively acting as an array of high precision A/D converters.
Because of this link between picture fidelity and light modulation speed, TI engineers are continually pushing DLP technology to higher mirror speeds and data bandwidths. This continuous pursuit of more and more speed is precisely what makes the DMD so sought after for use in many other applications – many of which do not require gray scale but instead are all about optical rendering of binary information. DMDs are currently able to display 10-15 thousand binary information frames each second. For a XGA DMD with 768 rows of 1024 mirrors (**figure 3**), that's about 10 gigabits/sec.
This high speed binary light processing capability makes DLP technology unique – so much so that for many years TI has been approached by photonics inventors and system developers who have had interesting ideas for new DMD applications and products. During that time TI elected to focus on the projector markets and not to dilute its resources on new applications. Now that significant projector market share and resulting business success have been achieved, TI increasingly seeks to enable non-projector applications and products.
In order to maximally address the wide variety of new opportunities, a line of flexible products has been created and made broadly available to developers. This DMD Discovery product family features the DMD and a set of flexible support chips that allow the developer to define their own data formats and mirror timing.

3 Grayscale dynamics and frame rate influence DMD timing

With the flexible support chips, a wide range of frame rates and intensity depth can be achieved. **Figure 4** describes the maximum achievable frame rate as a function of pulse width modulation (PWM) bits that can be displayed within one frame. The 0.7 XGA LVDS DMD correlated with this figure is organized into 16 mirror sections, allowing each mirror section to be latched independently. This enables an LSB (Least Significant Bit) bit plane to be displayed for a shorter duration than the ~60 µs full array load time, while still maximizing "exposure" duty cycle and brightness. In this phased reset mode the minimum LSB period is ~14 µs as determined by the mirror transition and settle time (compare **figure 5**) plus the time required to reload the mirror section with new data. For binary (black-and-white only, no gray) operation the LSB is equal to full array load time (~60 µs) unless partial array operation is used. Binary frame rates up to 16,000 and 70,000 frames/second can be achieved for full array (1024 x 768) and partial array (<175 rows) operation, respectively. Note that advanced techniques are typically used in DLP projector products to create shorter expose times than the ~14 µs described above, resulting in increased bits/frame, but with slightly reduced duty cycle and brightness.

4 Emerging applications

With availability of the general purpose DLP development kits (**figure 6**) over the last two years, the market is now starting to see new emerging DMD applications. The applications are broad and include volumetric display, scientific and medical instrumentation, and industrial applications as diverse as lithography, watermarking, engraving, and optical communications.

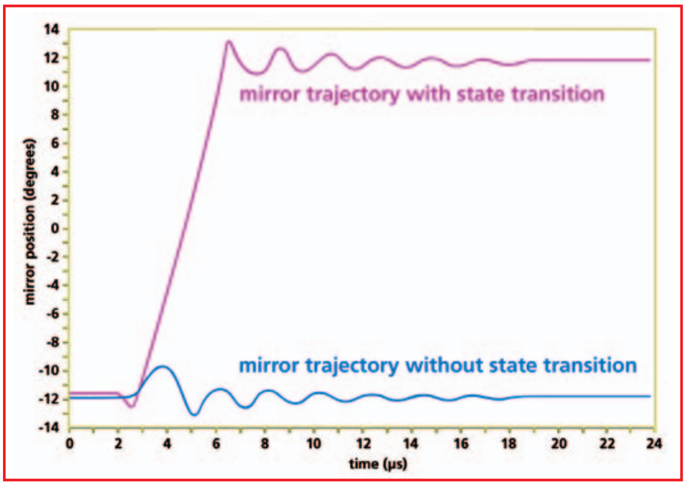

***Figure 5:** Mirror trajectory with and without state transition*

4.1 3D displays

One new DLP application is in volumetric displays, in which the DMDs are used to render 3-dimensional images that appear to float in space without the use of encumbering stereo glasses or headsets. Actuality Systems' "Perspecta" product [4] creates 10" diameter 3D imagery within a transparent sphere, that allows observers to walk around an interactive 3D image to achieve a 360° perspective (**figure 7**). Three DMDs, one for each primary color, project binary color images onto a rotating screen, creating over 100 million voxels (volume

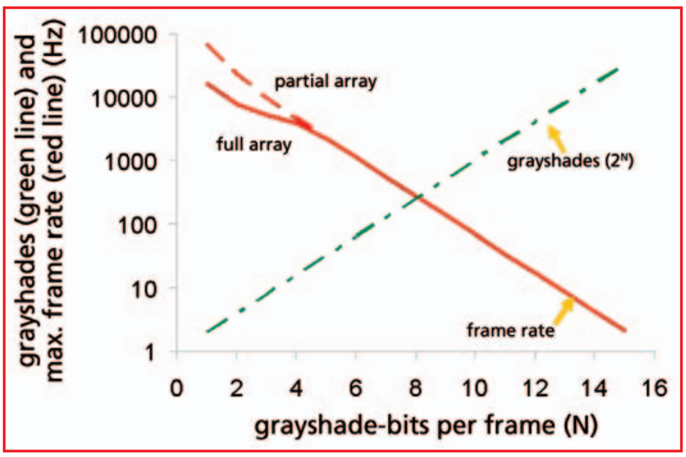

***Figure 4:** Maximum frame rate as a function of digital bits and resulting intensity levels (grayshades) possible within one frame time for the 0.7 XGA LVDS DMD using the Discovery 1000 digital controller*

Figure 6: *DMD Discovery 1100 developer kit*

pixels, 3D pixels) with spatial dithering to create hundreds of colors. The DepthCube display from LightSpace Technologies [5], is a 19.5″ computer graphics display with a 3-DMD system projecting 2D images sequentially on 20 back-to-back liquid crystal panels, generating 15.3 million voxels and over 32,000 colors.

The vastly different operation method of each of these systems demonstrates both the performance and versatility of DLP technology. 10 gigabit/sec of DMD light switching capability gives the system developer the ability to make tradeoffs over a wide range of color fidelity and 2D frame rates.

4.2 Scientific instrumentation

A programmable spectral processor called LambdaCommander was recently brought to market by Newport Corporation [6]. In this instrument, light from an optical fiber is spectrally dispersed across the DMD by a grating, and the mirrors are used to spatially attenuate specific wavelengths prior to being recombined into an output fiber. This allows input broadband radiation to be customized in real time to virtually any output spectral profile. Applications included sub-nanometer spectral shaping, fiber sensing, spectral gain flattening, optical coherence tomography, optical filter testing, and advanced telecommunications development.

This is the first of what is hoped to be a number of important scientific instruments to use the DMD as a spatial or spectral filter. Someday, real time multi-spectral imaging systems based on DMD (or multiple DMDs) will be used to image (and maybe even treat) cancer and should also have application in machine vision and remote sensing.

For years the DMD has been considered for use in confocal as well as other forms of microscopy. In these applications, individual or groups of DMD mirrors are addressed to shape or scan the illumination or collection aperture of an optical microscope, thus acting as a dynamic slit or pinhole and eliminating the need for cumbersome and low performance mechanical scanning. With the new availability of DMD electronics designed to support user-defined high speed binary switching, revolutionary products in the microscopy area are expected to reach fruition in the near future. Imagine the multispectral imaging capability described above coupled with the ability to optically section tissue through confocal microscopy. Now, combine this with the ability to do this through an endoscope (another DMD-enabled application known to be in work), and you can imagine an extremely powerful and versatile medical imaging system that would save lives and money.

Although medical imaging tends to excite many of us, a number of new DMD applications will find use in scientific labs, manufacturing, and maybe even security. DLP-enabled 3D metrology is expected to emerge in the near term. In an instrument from Vialux called z-Snapper (**figure 8**), the DMD is used to rapidly project a series of grid patterns on an object while a CCD camera synchronously captures the reflected patterns. The surface topology of the object can then be calculated from the contour patterns of the reflected images. This rapid 3D image capture capability should not only find its way into research labs, but, because of the DMD speed capabilities, also real time inspection and security.

5 Summary

DLP technology is well proven and firmly established in a variety of projection display products, due to the brilliant image quality that it enables. At the heart of this technology is the DMD, a dense array of hundreds of thousands of tiny switchable mirrors, whose switching speed, contrast ratio, and broad spectral capability are unsurpassed by any other spatial light modulator. Many new DMD applications beyond projection displays are emerging, and are being enabled through general use DMD products that are commercially available. These DMD-based innovations will result in a portfolio of exciting new products. It's a challenge not to try to predict which of these applications will be most successful. TI will instead try to enable as much activity as possible by making the DLP technology available and easy to use. It's possible that the most important DLP application is likely one that no one has yet conceived.

Figure 7: *Perspecta® Spatial 3-D Display, projecting a volumetric image of a heart chamber using the software package IDL (Image courtesy of Actuality Systems, Inc. Burlington, MA, USA, copyright 2004, David Shopper)*

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Figure 8: *Based upon Texas Instruments' DMD, the z-Snapper® is a novel high-speed 3D camera from Vialux that captures three-dimensional surface contour (330 000 data points per measurement) at a recording time comparable with standard CCD cameras [7]*

Author contact:

Dana Dudley   Cheraina Dunn
Texas Instruments Inc. - DLP Catalog Products
6550 Chase Oaks Blvd.
Plano, TX 75023, USA
Tel. +1/214/567-0833
Fax +1/214/567-7949
eMail: cvick@ti.com
Internet: www.dmddiscovery.com

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