Dynamic IR Scene Projector
Based Upon the Digital Micromirror Device

D. Brett Beasley, Matt Bender, Jay Crosby, Tim Messer, and Daniel A. Saylor
Optical Sciences Corporation
www.opticalsciences.com
P.O. Box 8291
Huntsville, AL 35808

ABSTRACT

Optical Sciences Corporation has developed a new dynamic infrared scene projector technology called the Micromirror Array Projector System (MAPS). The MAPS is based upon the Texas Instruments Digital Micromirror Device (DMD)™ which has been modified to project images which are suitable for testing sensor and seekers operating in the UV, visible, and IR wavebands. The projector may be used in several configurations which are optimized for specific applications. This paper provides an overview of the design and performance of the MAPS projection system, as well as example imagery from prototype projector systems.

Keywords: Infrared, Scene Projection, Digital Micromirror Device, Simulation, FPA testing, Hardware-in-the-loop.

1.0 INTRODUCTION

Optical Sciences Corporation (OSC) has developed a new dynamic IR scene projector technology called the Micromirror Array Projector System (MAPS) which is based upon the Texas Instruments Digital Micromirror Device (DMD™). This projector technology is capable of producing very realistic dynamic scenes in the UV, visible, and IR wavebands. The projector technology offers several attractive features including high spatial resolution, high frame rates, no dead pixels, and excellent uniformity. The projector may be used in several configurations which are tailored to specific applications. OSC has successfully demonstrated three prototype configurations of the Micromirror Array Projector System (MAPS) operating in both binary and pulse width modulation (PWM) mode. These configurations include a one-DMD MWIR projector, a two-DMD MWIR projector, and an IR and visible Dynamic Sensor Test Set (DSTS).

2.0 DIGITAL MICROMIRROR DEVICE™ BACKGROUND

The DMD is a micro-electromechanical system (MEMS) which has a 2-D array of individually controlled aluminum micro-mirrors. The DMD is the spatial light modulator in TI's Digital Light Processing™ (DLP™) system. DLPs are manufactured by TI and sold to OEMs for use in display products such as business projection systems. DMDs are currently commercially available in formats up to 1024x768, and 1280x1024 DMDs are expected to reach the market in the near future. Figure 1 shows a 1024x768 DMD package, and Figure 2 is an SEM image of the micromirrors with a grain of salt on the surface of the device.

As depicted in Figure 3, each micromirror in the DMD can reflect light in one of two directions (±20° optical) depending upon the state of the underlying memory cell (SRAM). With proper illumination, each mirror will reflect light into the pupil of the optical system when a "1" is written to its SRAM and out of the optical system when a "0" is written to its SRAM. The device is therefore binary in nature. The switching speed on the individual mirrors is approximately 10 usec. In commercially available visible projector systems, intensity control is achieved by binary Pulse Width Modulation (PWM). The binary image on the array can be updated at a rate of approximately 5000 Hz, and a global reset allows the entire image to be cleared in less than 20 usec.

Figure 1 – DMD

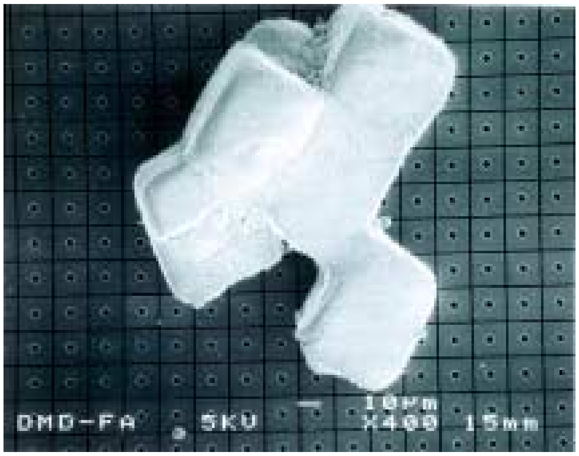

Figure 2: DMD with Grain of Salt on Surface

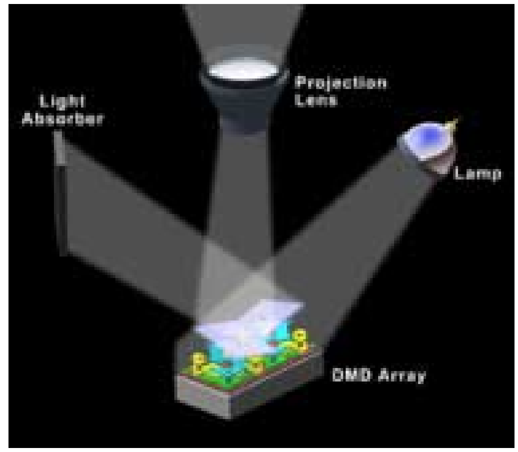

Figure 3: DMD Illumination

3.0 ISSUES FOR APPLICATION OF THE DMD TO IR PROJECTION

Because the DMD was designed for visible projection and human perception, several technical issues had to be addressed for it to be used as a dynamic IR scene projector. These issues included temporal aliasing due to PWM, limited dynamic range due to diffraction of the small mirrors, exit pupil illumination, and spectral transmission of the window covering the DMD. All of these issues have been addressed in the OSC design.

The most significant issue for application of the DMD to IR scene projection is the temporal aliasing due to PWM. The PWM technique controls the intensity of each pixel by setting the percentage of time each mirror is in the "on" position within a given time frame. A sensor with a long integration time (relative to the switching speed of the mirrors) will perceive an intensity of each pixel which is related to the amount of time each mirror is in the on position. The standard electronics in the DLP projector systems are designed to generate three 8-bit colors at a 60-85 Hz frame rate using PWM. Thus, it takes approximately 5.5 msec to generate an 8-bit PWM image. If a sensor has an integration time of less than 5.5 msec. (such as most InSb FPAs), it will perceive temporal aliasing when viewing a DMD with standard electronics. A rolling integration scheme within the FPA will also contribute to the aliasing problem. The OSC projector design has addressed this issue by designing custom control electronics to drive the DMD in synchronization with the FPA integration and by using other configurations to eliminate the need for PWM.

A second concern for application of the DMD to IR scene projection is the reduction in contrast due to the diffraction of light by the mirrors. Because the mirrors are not significantly larger than the wavelength of light, potentially significant diffraction of the light reflected from the DMD may occur. Because the tilt angle of the mirror is limited to 20 degrees this diffraction will reduce the contrast ratio of the device as the wavelength of the light increases. In the visible band, a contrast ratio of 400:1 is typical. Although the contrast ratio drops to ~90:1 in the MWIR, this still provides a very good apparent temperature range. The dynamic range of a DMD projector system can be optimized in the illumination design, however for our applications, the optics must also be designed to uniformly illuminate the exit pupil of the system.

Another significant issue for application of the DMD to scene projection for bands other than the visible is the transmission of the window covering the DMD. The window material used in the DMD will not transmit wavelengths significantly outside the visible band such as the MWIR band. Therefore, an IR transmitting window had to be installed on the DMD. OSC has developed a technique for removing the visible window and installing a window which will transmit in the waveband of choice. OSC has successfully replaced the windows on several DMDs with IR transmitting windows, while maintaining 100% operability of the mirrors.

4.0 MICROMIRROR ARRAY PROJECTOR SYSTEM

OSC has developed a DMD-based IR projector which is capable of generating realistic IR images for advanced testing of IR seekers, sensors, and FLIRS. Applications of the projector include hardware-in-the-loop testing, portable test sets, built-in testing, production line testing and training. The MAPS is capable of operating in two modes: flickerless binary and PWM. In binary mode, the projector is virtually flickerless, with only a brief reset occurring each frame to prevent hinge memory in the micromirrors. The projector is compact and can be produced at a low-cost compared to other IR projector technologies.

4.1 MAPS Design

The projector consists of a customized DMD, illumination source, collimating optics, and custom drive electronics. A photograph of the system is shown in Figure 4. The DMD was modified for use in the IR by replacing the standard window with an IR transmissive window. A technique for replacing the window without the loss of any mirrors was developed by OSC. OSC has modified several DMDs which have 100% mirror operability. The DMD has a format of 848x600, and a binary frame rate of 4065 Hz. A broadband IR source is used for illumination and was designed to ensure that the exit pupil was uniformly illuminated. The prototype system includes an f/4 MWIR collimator which has an exit pupil relief of 18 inches. The custom drive electronics were designed to be programmable such that any combination of gray scales, frame rate, and PWM frequencies (within the capabilities of the DMD) can be generated.

In its most basic mode, the DMD can be operated in a single-bit “flickerless” control. In this mode, binary images can be generated at high frame rates and there is no minimum integration time required for the UUT. In binary mode the MAPS is projecting the scene for ~97% of the frame time. During the remaining 3% of the frame time the mirrors are allowed to go to a “rest” state to prevent hinge memory. The timing of this rest event can be synchronized to the UUT so that it occurs during a time when the sensor is not integrating or during the “flyback” time of a scanning sensor. The rest time can actually be eliminated if necessary, however the lifetime of the device may be reduced. Give the reported MTBF lifetimes of greater than 100,000 hours for these devices, this would probably not be a problem for most applications.

The system can also be programmed for varying PWM frequencies to match the integration time of the sensor. The longer the sensor integration time, the more intensity levels that can be achieved. As an example, a typical integration time for an InSb FPA camera is 3 msec. With this integration time, the DMD can generate 128 (7-bits) intensity levels. Because of the DMDs binary nature, the intensity levels are very accurate and linear.

Figure 4: Micromirror Array Projector System

4.2 MAPS Performance

Table 1 below summarizes the performance characteristics of the MAPS projector.

Parameter	Performance
Spectral Range	UV to LWIR available. Determined by illumination source and optics.
Format	848x600
Pixel Pitch	17 um
Maximum Binary Frame Rate	4065 Hz.
Address Mode	Snapshot
Max. Duty Factor	~97%
Amplitude Resolution	1-24 bit programmable.
Contrast Ratio	~90:1 MWIR
Max Apparent Temperature	>800K (Dependent upon source selected)
Pixel Operability	100%
Spatial Uniformity	>99.8%
Size	8.5”x9.0”x10.5”
Interfaces	PC (CRT), DVI, NTSC, S-Video
Power Consumption	7W – DMD, 50W - System

Table 1: Micromirror Array Projector System Performance Summary

It should be noted that the maximum apparent temperature is dependent only upon the illumination source and may be increased by increasing the source temperature. Figure 5 shows the apparent temperature of the on and off pixels of a DMD in the 3-5 um band as a function of illumination source temperature. To-date we have illuminated the DMD with source temperatures up to 523 K. At this temperature, the MWIR relative radiance is ~40:1 and the contrast ratio is ~93:1.

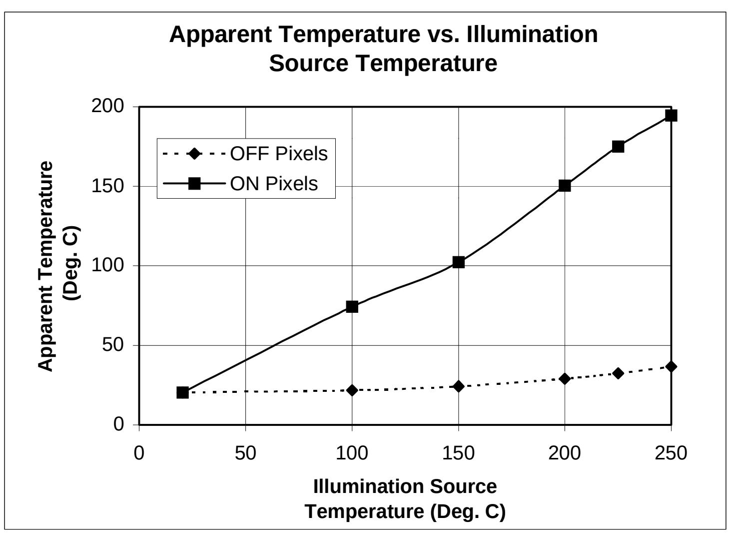

Figure 5: Apparent Temperature vs. Illumination Source Temperature

Four example images collected from the prototype IR DMD projector system operating in PWM mode are shown in Figures 6, 7, 8, and 9. The projector was programmed for 6 bits of amplitude resolution in a ~3.0 ms time period. The images were collected with a 320x240 InSb FPA camera operating at 60 Hz and set to an integration time of ~3.0 msec.

Figure 6: Sample PWM IR DMD Imagery

Figure 7: Sample PWM IR DMD Imagery

Figure 8: Sample PWM IR DMD Imagery

Figure 9: Sample PWM IR DMD Imagery

5.0 Dynamic Sensor Test Set

OSC has developed a second configuration of the DMD-based IR projector called the Dynamic Sensor Test Set (DSTS). This system is designed for automated high speed testing of visible and IR sensors. The DSTS is designed to replace the static target plates and choppers used on industry-standard test collimators. The DSTS is capable of performing standard tests such as MTF, MRTD, and NEΔT at very high speed, as well as advanced dynamic tests such as seeker tracking and correlation. The DSTS is a dynamic scene projector which can be operated in binary or PWM mode. Applications of the projector include any sensor test application which currently uses static test plates, but needs higher speed or dynamic scene capability.

5.1 DSTS Design

The projector consists of a single customized DMD, three illumination sources, relay optics, a standard test collimator, and custom drive electronics. A photograph of the system is shown in Figure 10. The DMD was modified for use in the IR, visible, and UV by replacing the standard window with a BaF_2 window. The DMD has a format of 848x600, and a binary frame rate of 4065 Hz. The system was designed to allow the user to manually select between a visible and IR source. Two broadband IR sources are used for illumination when the system is in IR mode. One source illuminates the mirrors in the on position and typically is set to a temperature higher than ambient. The second IR source illuminates the mirrors in the off position and is typically set to temperatures below ambient. Both blackbody temperatures are controlled via a PC RS-485 interface, and may be controlled in absolute or differential temperature mode. A single quartz halogen source is used to provide illumination in the visible mode. The image of the DMD is relayed to the focal plane of the standard test collimator using an all reflective 1:1 relay system. The resolution of the relay exceeds the resolution of the standard OAP collimator off-axis and is diffraction limited across the entire FOV of the DMD. The use of the relay allows the DSTS to be used with existing collimators without modification. The custom drive electronics were designed to be programmable such that any combination of gray scales, frame rate, and PWM frequencies (within the capabilities of the DMD) can be generated. For generation of standard test patterns such as bar targets, the binary mode is used. If gray scale targets are desired, then the system can be switched to PWM mode and synchronized to the UUT.

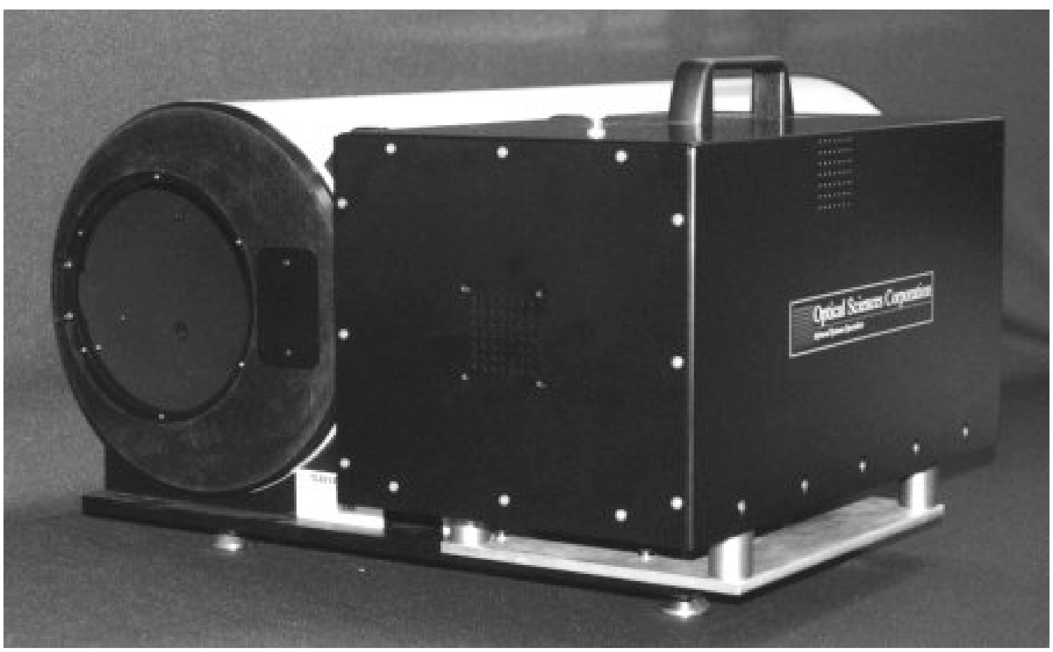

Figure 10: Dynamic Sensor Test Set

5.2 DSTS Performance

Table 2 below summarizes the performance characteristics of the DSTS projector.

Parameter	Performance
Spectral Range	Visible to LWIR available. (Switchable sources)
Format	848x600
FOV	Dependent upon collimator FOV
Object Size	14.4x10.2 mm.
Pixel Pitch	17 um
Maximum Binary Frame Rate	4065 Hz.
Address Mode	Snapshot
Max. Duty Factor	~97%
Amplitude Resolution	1-24 bit programmable. Binary and PWM modes selectable
Contrast Ratio	~90:1 MWIR
MWIR Apparent ΔT Range	-10°C to +55° C
Pixel Operability	100%
Spatial Uniformity	>99.8%
Size	8.5”x9.5”x16.5”
Interfaces	PC (CRT), DVI, NTSC, S-Video
Power Consumption	7W – DMD, 100W - System

Table 2: DSTS Performance Summary

7.0 ACKNOWLEDGMENTS

This work was sponsored by the US Army Aviation and Missile Command's Research, Development, and Engineering Center under contract DAAH01-00-C-R093. The authors would like to thank Mr. Alex Jolly, Mr. Bill Sholes, Mr. Scottie Mobley, and Mr. Jim Buford, all of USAAMCOM, for their support of our efforts. The authors would also like to thank our colleagues at OSC, Ms. Ivette Dennison, and. Mr. Tracy Reynolds, for their support.

8.0 TRADEMARKS

Digital Micromirror Device, DMD, Digital Light Processing, and DLP are registered trademarks of Texas Instruments Incorporated.