Dynamic infrared scene projectors based upon the DMD

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ABSTRACT

The Micromirror Array Projector System (MAPS) is an advanced dynamic scene projector system developed by Optical Sciences Corporation (OSC) for Hardware-In-the-Loop (HWIL) simulation and sensor test applications. The MAPS is based upon the Texas Instruments Digital Micromirror Device (DMD) which has been modified to project high resolution, realistic imagery suitable for testing sensors and seekers operating in the UV, visible, NIR, and IR wavebands. Since the introduction of the first MAPS in 2001, OSC has continued to improve the technology and develop systems for new projection and Electro-Optical (E-O) test applications. This paper reviews the basic MAPS design and performance capabilities. We also present example projectors and E-O test sets designed and fabricated by OSC in the last 7 years. Finally, current research efforts and new applications of the MAPS technology are discussed.

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

1.0 INTRODUCTION

In 2001 Optical Sciences Corporation (OSC) announced the commercial availability of a family of dynamic infrared scene projectors based upon the Texas Instruments Digital Micromirror Device (DMD) which was modified for sensor test applications and projection of scenes in wavebands outside of the standard visible band. The projectors were given the trade name of Micromirror Array Projector System (MAPS) and were designed to meet the needs of customers involved with IR seeker Hardware-In-the-Loop (HWIL) simulations and IR sensor testing. The introduction of the MAPS as a commercial product was the result of an internal R&D effort begun in 1997 and a Small Business Innovative Research contract awarded to OSC by the U.S. Army in 1999. The initial SBIR Phase II development effort was completed in 2002. Since that time, a Phase II Plus contract and several Phase III contract efforts have been executed by the U.S. Government to develop customized projector systems for various test applications.

Since the introduction of the first MAPS in 2001, OSC has continued to improve the technology and develop systems for new projection and test applications. The MAPS projector technology is capable of producing very realistic dynamic scenes in the UV, visible, NIR, and IR wavebands. The projector technology offers several attractive features including high spatial resolution, high frame rates, no dead pixels, and excellent uniformity. OSC now offers a family of MAPS products including projectors, E-O test-sets, and projector engines. In addition, the projector may be customized in a variety of configurations which are tailored to specific test and simulation applications.

2.0 DMD BACKGROUND

The DMD is a micro-electromechanical system (MEMS) which has a 2-D array of individually controlled aluminum micromirrors. The DMD is the spatial light modulator in TI's Digital Light Processing™ (DLP™) systems which were introduced commercially in 1996. Figure 1 shows a 1024x768 DMD package. DLP engines are manufactured by TI and sold to OEMs for use in display products such as business projection systems, cinema, and High Definition Televisions (HDTVs). DMDs are currently commercially available in a wide variety of formats with resolutions up to 2048x1024. Several generations of DMDs have been manufactured by TI since 1996 with various technical innovations such as larger mirror tilt angle and dark metal layers for improved performance. For our applications, the primary delineation in the DMD

Figure 1: DMD Package

lineage has been the pitch spacing of the micromirrors. The initial DMDs had a micromirror pitch of 17.0μm and the mirrors tilted ±10.0° mechanically, the second generation of DMDs had 13.68μm pitch and tilted ±12.0° mechanically. The latest generation of DMDs have a micromirror pitch of 10.8μm and the mirrors tilt ±12.0° mechanically. We have primarily utilized DMDs which have micromirrors on a 17.0μm pitch and tilt ±10.0° mechanically. However, we are currently evaluating the performance of DMDs which have the 13.6μm and 10.8μm pitch for IR applications.

Each micromirror in the DMD can tilt in one of two directions depending upon the state of the underlying SRAM memory cell. With proper illumination, each mirror will reflect light into the pupil of the optical system when a "one" is written to its SRAM and out of the optical system when a "zero" is written to its SRAM. The device is therefore binary in nature. The switching speed on the individual mirrors is approximately 10 μsec. The binary image on the entire array can be updated at rates of 10,000 to 32,500 Hz (depending upon the type of DMD), and a global reset allows the entire image to be cleared in less than 20μsec. Intensity control is typically achieved using binary Pulse Width Modulation (PWM), however other techniques can also be used to generate gray levels.

3.0 KEY MODIFICATIONS 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 suitable for testing IR sensors and seekers. These issues are discussed in the following sections. All of these issues have been resolved in the design of the OSC MAPS.

3.1 Transmission of Protective Window

The DMD micromirrors are aluminum and therefore will reflect light across a broad spectrum extending well outside of the visible waveband. However, the protective window used in the DMD package is a crown glass type material, and as such, it will not transmit well at wavelengths longer than approximately 2.7μm. Therefore, for the DMD to be useful in the traditional mid and longwave IR bands (3-5μm and 8-12μm), the standard window would have to be removed and replaced with an IR transmitting window. After discussions with TI it was determined that no known IR material was compatible with their glass to metal fusing process. Therefore, we had to develop a process for removing the standard visible window and installing a window which will transmit in the waveband of choice while maintaining 100% operability of the mirrors. A process for performing this task was developed, and over the past 9 years OSC has successfully replaced the windows on over 50 DMDs while maintaining 100% mirror operability.

3.2 Display Timing

The most significant issue for application of the DMD to IR scene projection, and sensor testing in general, is the temporal aliasing/flicker due to PWM. The DMD is a binary device, and techniques such as temporal PWM must be used to generate interim intensity levels (gray levels) in the projected scene. In standard DLP systems, PWM is used to control the perceived 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. In standard single DMD systems PWM is used in conjunction with a color wheel to generate millions of colors. However, in sensor applications, PWM of the DMD in combination with the sensor integration time will cause effects such as intensity variations, rolling lines and flicker in the sensor output if the DMD's PWM is not synchronized with sensor's integration time. This can be further compounded by various sensor integration schemes such as rolling integration within the Focal Plane Array (FPA). OSC has addressed this issue in the MAPS by designing custom control electronics with fully programmable timing to drive the DMD in synchronization with the FPA integration. In addition, we have invested significant effort in developing firmware which will automatically synchronize the DMD with sensors which utilize a wide variety of integration or sampling schemes. Synchronized PWM is discussed in more detail in Section 5 below.

3.3 Scene Generation Interface

HWIL simulations require computer scene generators which are capable of rendering dynamic scenes in real-time with low latency, high frame rates, and good amplitude resolution. The projection system must be capable of supporting these high frame rates and amplitude resolution, and must not add any significant latency. In addition, snapshot (instead of rolling) update of the projected scene is generally preferred. The MAPS was designed to accept up to two ports of single-link DVI video. The DVI interface will support 24-bit video at up to 165 megapixels per second for each Transition Minimized Differential Signaling (T.M.D.S.) link. The MAPS utilizes a single TMDS link for each input video port, and up to two input video ports are available for the XGA and SXGA MAPS projector systems. The SXGA format MAPS can support incoming video at this maximum DVI bandwidth for an effective 239 Hz of uncompressed video. However, the XGA format MAPS currently only supports pixel rates of up to 190 megapixels per second which results in a 230Hz effective uncompressed frame rate. The video interface is fully programmable such that it can accept other formats and frame rates. For example, it is also capable of handling 8-bit video at frame rates of up to 690 Hz for the 1024x768 format. The MAPS also accepts other video formats including DVP2, RGB-HV, NTSC/PAL, and S-Video. These video formats are converted to DVI within the support electronics prior to being sent to the projector head. The electronics are designed for very low latency and the entire image is updated at the same time (snapshot update).

3.4 Optical Design

To support IR sensor testing, the MAPS optical system must be designed very differently than the standard projector applications where the image is projected onto a screen. The typical IR projector optical system is designed such that the sensor looks directly into the projector optics. The output of the projector is usually collimated at an infinite conjugate and the exit pupil is real and accessible. The exit pupil must have sufficient relief and size to over-fill the entrance pupil of the sensor under test. Of course, the optics must also transmit well over the desired IR waveband and the optical performance must be optimized over this waveband to provide good image quality. Finally, the projector optical system must be designed such that the external pupil is uniformly illuminated. Given the limited tilt angle of the mirrors, it is usually challenging to simultaneously meet the projector's FOV and pupil diameter requirements while maintaining proper illumination.

3.5 Illumination Design

The MAPS illumination system must provide sufficient energy at the exit pupil of the projector in the waveband of interest. Typically, a blackbody source is used to illuminate the DMD for IR applications. However, other sources such as high temperature thermal sources as well as IR lasers can be used. The illumination system must provide user-controlled illumination intensity such that the irradiance can be optimized for the scenario/test to be performed. At the basic level this is achieved by setting the temperature of the blackbody. More advanced systems use high-speed control of the intensity to better match the simulation requirements or to enhance the bit-resolution of the projector. Finally, the illumination optics must be carefully designed to uniformly illuminate the DMD and the exit pupil of the projector system while maximizing contrast.

3.6 Other Concerns

Prior to 2001 it was generally agreed in the IR projector community that even if the above issues could be resolved the DMD would not be useful for IR applications due to diffraction effects from the relatively small mirrors. There was some unfounded concern that the spatial resolution would be limited by this diffraction as well as the valid concern that the contrast would be reduced due to the diffraction of light by the mirrors. Fortunately, the contrast ratio reduction was not as significant as predicted, and although somewhat limited, very useful contrast ratios were achieved in the MWIR and LWIR wavebands. Given the other performance advantages of the technology, this limitation did not prevent the MAPS from being a viable IR projection technology.

4.0 MAPS DESIGN OVERVIEW

4.1 System Block Diagram

Figure 2 shows the system level block diagram and interconnections for the MAPS. As shown in the figure, the complete projector system consists of three major components - the projector head, the support electronics, and the control PC. The projector head contains the DMD, DMD drive electronics, illumination source(s), illumination source controller, and collimator lens. The support electronics chassis contains the video converter electronics, sync signal processor, and power supplies. The control PC is not required for standard operations, but can be used to monitor the status of the projector system and to set the illumination source temperature and other operational parameters of the projector system. In some later projector systems, the support electronics chassis was eliminated and its functionality was integrated into the projector head.

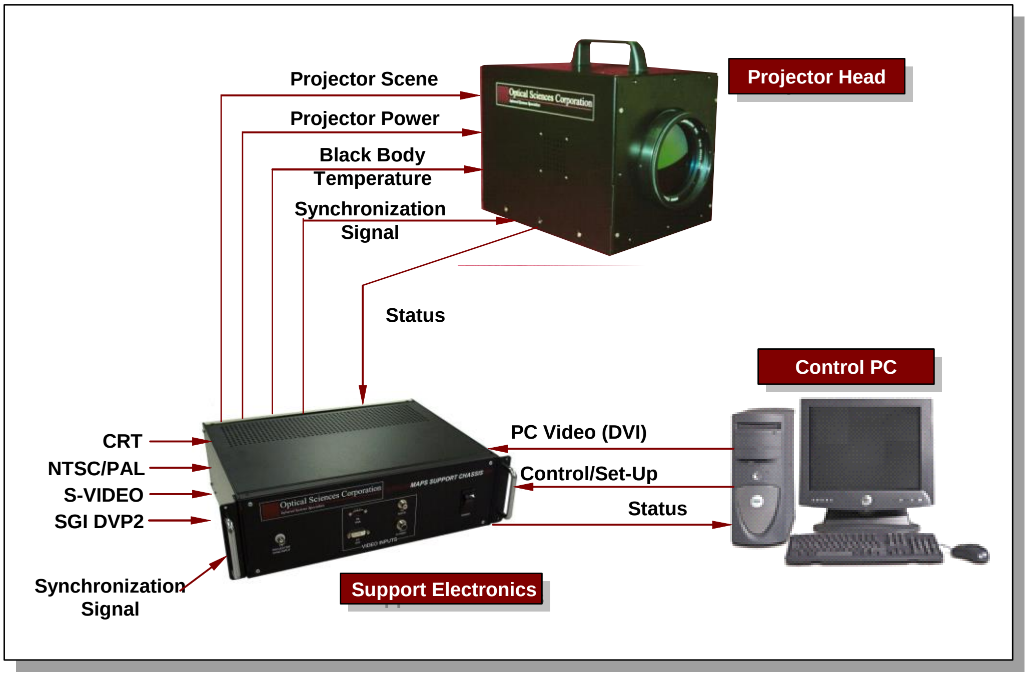

Figure 2: MAPS Block Diagram

4.2 MAPS Projector Head

The projector head contains the DMD, DMD cooler, DMD drive electronics, illumination source(s), illumination source controller, illumination optics, and collimator lens. The design of several of these subsystems is discussed in the following sections.

4.2.1 Modified DMD

Figure 3 shows some of the array formats used in MAPS projectors. The smallest array is an SVGA (800x600) format, the mid-sized array is an XGA (1024x768) format, and the largest array is an SXGA (1280x1024) format. All of these arrays have a 17µm mirror pitch which is the type of array we have primarily used for IR projectors.

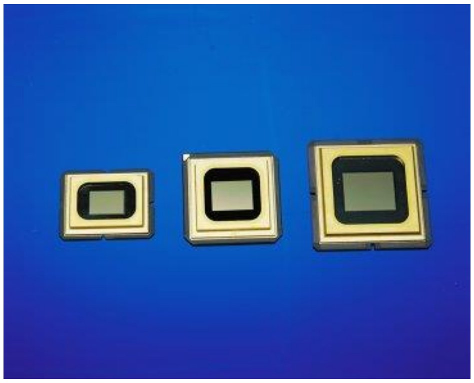

Figure 3: SVGA, XGA, and SXGA DMD Packages

We are currently characterizing the performance of the latest generation of DMDs which have the 13.6µm and 10.8µm mirror pitch in the MWIR and LWIR spectral bands. Included in this evaluation is the latest 1080p format (1920x1080) DMD. We have successfully operated both MWIR and LWIR 1080p DMD, and we are currently measuring the contrast ratio in these wavebands. Our characterization will include measurement of the spectral radiance and spectral contrast of each DMD format over the 3-14µm spectral band.

4.2.2 DMD Cooler

The internal DMD electronics generate heat in the chip substrate and the device is slightly emissive. Therefore, an active cooling system is used to cool and stabilize the temperature of the DMD to reduce and stabilize the minimum apparent temperature of the MAPS in the IR. Temperature stabilization provides the necessary calibration repeatability and stability for the projector. The DMD cooling system consists of a thermo-electric cooler, heat sink, and closed-loop temperature controller. The user can control the DMD operating temperature via the MAPS control software within a certain range of temperatures typically below ambient, but above the dew point of the internal environment.

4.2.3 Custom DMD Drive Electronics

The DMD drive electronics are located in the projector head assembly at the rear of the DMD. The drive electronics were custom designed to provide the features necessary to support sensor testing and synchronized PWM. They are FPGA-based which allows flexibility in modifying/adding features for new applications. Figure 4 is a photograph of an SXGA format DMD drive electronics board taken with the DMD mounted on the board and operating. An actual image can be seen on the DMD, and the two DVI video connectors can be seen the left side of the photograph.

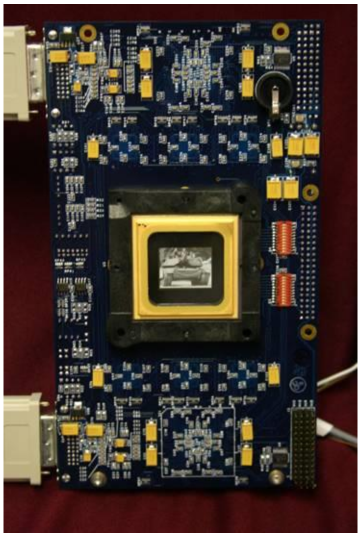

Figure 4: SXGA Drive Electronics Board

4.2.4 Illumination Source

The DMD is illuminated by a source which emits radiation in the waveband of interest. Because the DMD is capable of generating scenes in any waveband from the UV to LWIR, the illumination source may be one of several types of sources. For IR applications, extended area blackbody sources are typically used. More advanced systems use high-speed control of the intensity to better match the simulation requirements or to enhance the bit-resolution of the projector. OSC has also developed a dual-blackbody configuration for IR applications. In this configuration a cold blackbody is used to illuminate the off-side of the DMD, which improves the contrast and reduces the minimum apparent temperature. In addition to improving the minimum apparent temperature, the dual-blackbody configuration also allows differential control of the blackbodies which is useful for precision testing of IR sensors. For visible and NIR applications a halogen bulb source is typically used. For visible color applications a metal halide lamp and color wheel are used to illuminate the DMD with three sequential colors of light.

4.2.5 Optical System

The projector optical system includes the illumination optics and the collimating optical assembly. The illumination optics condense and relay the energy from the illumination source onto the DMD at the proper angle of illumination. They are designed to completely and uniformly illuminate the DMD and the exit pupil of the projector system. The collimating optical assembly collimates the image of the DMD at an infinite conjugate. Figure 5 shows an example MWIR collimator assembly. The effective focal length of collimator and the size of the DMD determine the projector's FOV. Key parameters for the collimator are EFL, object (DMD) size, pupil diameter, and pupil relief. Most users desire a pupil diameter and FOV combination which drives the collimator f/# lower than f/4. The design of the collimator and illumination system becomes increasingly difficult as the f/# is reduced. However, we have successfully (albeit somewhat reluctantly) built systems with f-numbers as low as f/1.4.

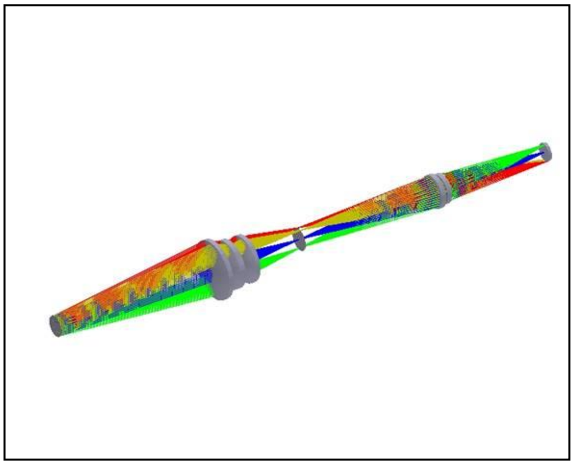

Figure 5: Example Collimator

4.3 Support Electronics

The MAPS support electronics are typically housed in a standard 3U 19 inch rack mount chassis. A standard support electronics chassis can be seen in Figure 2. The functions of the support electronics include:

- Receive the video from either a DVP2, DVI, RS-170/PAL, RGB-HV (CRT), or S-video source
- Convert/digitize the video and send to the DMD drive electronics
- Receive the input sync signal and modify as commanded by the user via software
- House the power supplies for the electronics and illumination sources
- Transmit status and receive control commands to/from the computer via the serial interface

For some systems the functionality of the support electronics is included in the projector head to reduce the overall size of the system and simplify the system to a single chassis with power, video, and control inputs.

4.4 Control Computer and Software

The MAPS control software will run on any Microsoft Windows-based PC. This software allows the user to control and monitor the projector operational parameters via the computer's serial interface. Figure 6 shows one of the windows from the control software. The top-half of this window allows the user to set the dual-blackbody source temperatures and load a calibration file which will set the blackbody temperature required to generate the desired apparent temperature. The bottom half of the window displays the status of the blackbody sources and the other parameters of the projector system. The control software also includes a video setup screen and a synchronization setup screen. The video setup screen allows the user to perform a variety of functions on the incoming video such as image flips and intensity scaling. The synchronization setup screen allows the user to generate a sync signal or modify an incoming sync signal as necessary to synchronize to the UUT.

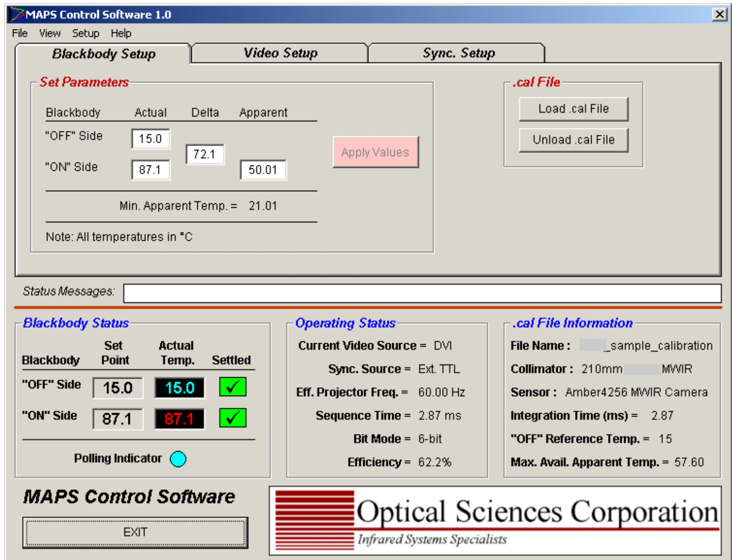

Figure 6: MAPS Control Software

5.0 SYNCHRONIZATION FOR SENSOR TESTING

5.1 Binary Mode

In its most basic mode, the DMD can be operated in a single-bit "flickerless" manner. In this mode, binary images can be generated at very high frame rates and there is no minimum integration time required for the UUT. In binary mode the MAPS is typically 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. It should be noted however, that the latest DMDs do not appear to need the rest time, and OSC has delivered systems which are capable of running for short periods of time without the rest time.

5.2 Synchronized PWM

Because the DMD is a binary device, gray scale intensities must be generated by PWM or some other technique such as half-toning or modulation of the illuminator. 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 duration of time. For sensor test applications, temporal aliasing will occur if the PWM is not synchronized properly with the sensor integration. OSC has developed the technique of synchronized PWM to address this issue. The synchronized PWM technique was implemented in MAPS by designing custom DMD drive electronics to drive the DMD in synchronization with the FPA integration. Figure 7 shows the basic technique of PWM where the entire PWM sequence occurs during the sensor integration time. As shown in the image, the PWM sequence time is exactly equal to the integration time of the sensor. The concept shown in the figure is what we refer to as "one-shot" mode. That is, the sequence is executed during the sensor integration and the mirrors are off during other times. This mode is best utilized when a sync signal from the sensor is available. An alternate mode for synchronized PWM is what we refer to as "continuous" mode. In this mode the sequence time is still exactly equal to the integration time of the sensor. However, the PWM sequence is repeated continuously. Even though the projector is on during the non-integrating time, the result is the same as the one shot mode. This mode is useful when a sync signal is not available from the sensor or when the sensor utilizes a rolling integration scheme.

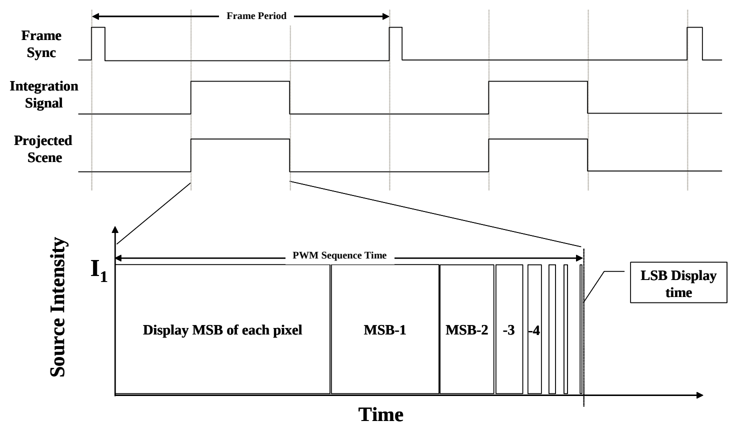

Figure 7: Synchronized PWM Timing in "One-Shot" Mode

In a HWIL simulation it is also important to update the video frame projected by the DMD at the appropriate time. If not performed properly, the sensor can perceive parts of two frames within one sensor frame which will cause errors in the simulation. Thus, the projector must be properly synchronized with not only the sensor integration, but also the sensor frame update. Exact details on how this is accomplished in the projector is beyond the scope of this paper, however the MAPS firmware has been designed to update the scene at the appropriate time for various modes of operation.

5.3 Bit Resolution Limitations

The length of the sensor integration time determines the maximum number of bits of resolution which can be generated. Longer sensor integration times allow more intensity levels to be achieved. Figure 8 shows the minimum integration time (PWM sequence time) required to generate N bits of resolution for the XGA format DMD. 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. The MAPS electronics are capable of monitoring the input sync signal and adjusting the PWM sequence timing automatically to match the integration time and maximize the bit resolution with only one sync period of lag. Because of the DMD's binary nature and the stability of the master clock, the intensity levels are very accurate and linear. Figure 8 also shows the maximum DMD, video input, and system frame rates as a function of the number of bits displayed. As shown in the table the frame rate can be limited by either the DMD sequence time or the video clock rates depending upon the number of bits displayed.

1024x768 DMD Display Timing

		Max Frame Rate (Hz)		
Image Mode	*Min. Sequence Time (us)*	*DMD Display*	*Video Input*	*Total System*
1bit	128.0	7812.5	4800.0	4800.0
2bit	236.8	4223.0	2400.0	2400.0
3bit	390.4	2561.5	1600.0	1600.0
4bit	585.6	1707.7	1200.0	1200.0
5bit	841.6	1188.2	960.0	960.0
6bit	1353.6	738.8	800.0	738.8
7bit	2377.6	420.6	685.0	420.6
8bit	4425.6	226.0	600.0	226.0
9bit	8521.6	117.3	533.0	117.3
10bit	16796.8	59.5	480.0	59.5
11bit	33347.2	30.0	436.0	30.0
12bit	66444.8	15.1	400.0	15.1
13bit	132643.2	7.5	369.0	7.5
14bit	265036.8	3.8	343.0	3.8
15bit	529824.0	1.9	320.0	1.9
16bit	1059395.2	0.9	300.0	0.9

Figure 8: Bit Resolution Limitations

5.4 Bit Resolution Enhancement

OSC and others have developed numerous concepts for enhancing the number of bits which can be generated in a given amount of time. These concepts fall within several general categories. One technique for enhancing the bit resolution is to combine multiple DMDs into a single image. The output of each DMD would be weighted/attenuated appropriately to generate the desired bit levels. This provides a significant performance increase at the expense of size and complexity. A second technique is to modulate/attenuate the illumination source in synchronization with the DMD displaying individual bit planes. This technique is very fast but requires an illumination system in which the source intensity can be changed very rapidly. Using this technique, each bit can potentially be generated in 100 microseconds or less. A third general category for bit enhancement is super-pixelling or the combination of several mirrors into one effective pixel. This can increase amplitude resolution at the expense of spatial resolution. Finally, hybrid techniques which combine one or more of these three concepts can be utilized to enhance bit resolution.

6.0 MAPS PERFORMANCE

6.1 Performance Summary

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

Parameter	Performance
Spectral Range	UV to LWIR available. Determined by illumination source and optics.
Format	800x600 (SVGA) 1024x768 (XGA) 1280x1024 (SXGA) 1920x1080 (1080p)
Pixel Pitch	17µm, 13.6µm, or 10.8µm
Maximum Binary Frame Rate	4065 Hz. (SVGA) 10,000 Hz. (XGA) 7,500 Hz. (SXGA) 23,000 Hz (1080p)
Address Mode	Snapshot
Max. Duty Factor	~97% typical 100% for short durations
Amplitude Resolution	1-24 bit programmable.
Contrast Ratio (17µm mirror pitch)	400:1 Visible ~250:1 MWIR 15:1 LWIR (Normal Mode) 110:1 (Special Mode)
Max Apparent Temperature	>800K (Dependent upon source selected)
Pixel Operability	100%
Spatial Uniformity	>99.8%
Video Interfaces	DVI, RGB-HV, NTSC, PAL, S-Video, DVP2
Max 24-bit Video Frame Rate (unpacked)	100 Hz. (SVGA) 230 Hz. (XGA) >230 Hz. (SXGA)
Max 8-bit Video Frame Rate (packed DVI)	690 Hz. (XGA and SXGA)

Table 1: Micromirror Array Projector System Performance Summary

6.2 Apparent Temperatures

The maximum and minimum apparent temperatures of the IR-MAPS are dependent upon the illumination source temperature. OSC has collected apparent temperature data on numerous systems, and it has remained very consistent. Figure 9 shows the maximum and minimum apparent temperature of a MAPS operating in the MWIR band as a function of illumination source temperature. Figure 10 shows the maximum and minimum apparent temperature of a MAPS operating in the LWIR band as a function of illumination source temperature. Note that the LWIR data is shown for two modes of operation - normal mode (NM) and special mode (SM). The special mode of operation is a technique of operating the DMD which utilizes a diffraction effect to significantly enhance the contrast in the LWIR band under certain conditions.

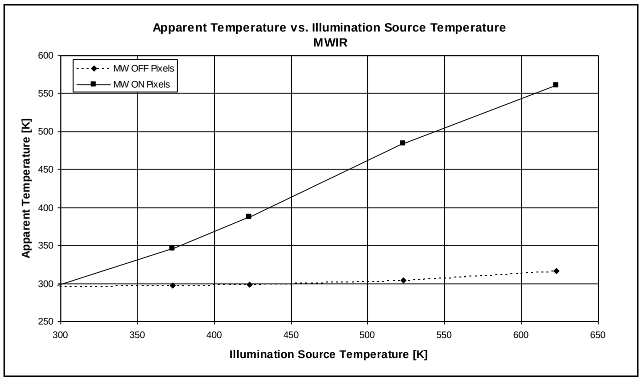

Figure 9: MWIR Apparent Temperature

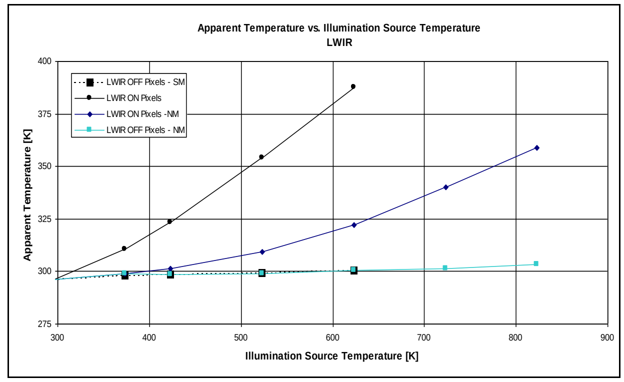

Figure 10: LWIR Apparent Temperature

6.3 Contrast

Contrast ratio is an important performance parameter for any type of spatial light modulator. It is defined as the ratio of the ON and OFF state difference radiances, each obtained by subtracting the surrounding's radiance from the relevant projected radiance. By definition, the contrast ratio is unity when the projector is OFF, and may assume an infinite value provided that the OFF state projected radiance matches that from the designated surroundings. [1] The equation for contrast ratio is:

$$ContrastRatio = \frac{L_{on} - L_{Background}}{L_{Off} - L_{Background}}$$

When utilizing the 17μm DMDs, the contrast ratio of the MAPS has been consistently tested to be >250:1 in the MWIR waveband. The contrast ratio of the MAPS in the LWIR has been consistently tested to be >15:1 in normal mode and >110:1 in special mode. Preliminary test data for a later generation 13.6μm DMD has indicated that contrast ratios in excess of 330:1 can be achieved in the MWIR.

6.4 Sample Images

Sample images collected from a MWIR MAPS and a LWIR MAPS are shown in Figures 11 and 12. The image in Figure 11 was projected by a SVGA MWIR MAPS operating at 6 bits of amplitude resolution and collected by a 320x240 InSb FPA camera. The image in Figure 12 was projected by a SVGA LWIR MAPS operating at 8 bits of amplitude resolution and collected by a 320x240 uncooled bolometer array camera.

Figure 11: MWIR SVGA Collected by 320x256 InSb FPA camera

Figure 12: LWIR SVGA Collected by 320x240 Uncooled Bolometer Array Camera

7.0 EXAMPLE MAPS PROJECTORS

7.1 FMS-Mounted MWIR Projector

Figure 13 shows one of our early XGA MAPS projectors mounted on the outer axis of a 5-axis Flight Motion Simulator (FMS) in a HWIL simulation facility.

Figure 13: FMS-mounted MWIR projector

7.2 Two-Color MWIR Projector

Figures 14 and 15 show a two-color MWIR scene projector. Figure 14 is a schematic of the system which shows how two MAPS projectors are optically combined into a single optical aperture, and Figure 15 is a photograph of the final system. This projector is designed for HWIL simulation and testing of a wide FOV two-color sensor. Unique features of this system include: synchronized dual-band MWIR projection; bands aligned to within 1 pixel; maximum apparent temperature of 850K; FOV greater than 90°x90°; and, 100 foot separation between the projector head and support electronics. Special design consideration was given to preventing ghosting and leakage between bands.

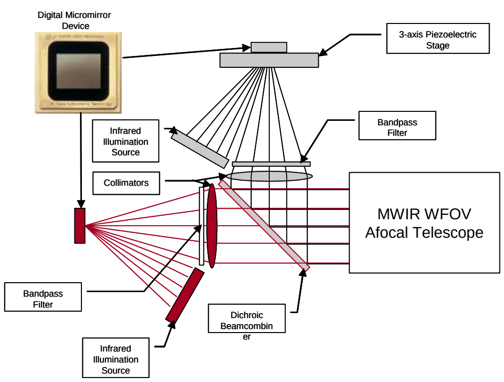

Figure 14: Schematic of two-color MWIR projector

Figure 15: Two-color MWIR projector

7.3 FMS-Mounted Dual-FOV LWIR Projector

Figure 16 is a CAD solid model and Figure 17 is a photograph of a dual-FOV LWIR projector which was designed for mounting on a 5-axis FMS. A unique feature of this system is interchangeable collimators with identical pupil relief and mechanical interfaces which allows the customer to easily change the projected FOV for different seekers. Key performance parameters include a weight less than 30kg and a FOV changeable from 7.9° x 5.9° to 10.3° x 7.7°.

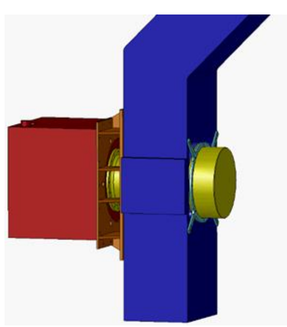

Figure 16: LWIR projector mounting to FMS

Figure 17: Dual-FOV LWIR FMS projector

7.4 Ultraviolet (UV) Projector

Although most of our systems have operated in the IR, NIR, and visible wavebands, we have recently completed development of a UV MAPS system. Figure 18 is a photograph of this system which was designed for HWIL simulation and testing of a wide FOV UV sensor. Unique features of this projector are operation in the “solar-blind” UV waveband, a very wide FOV, and a custom LED-based illumination source for very large dynamic range. Key performance parameters include a total dynamic range of 10^7 and high-speed illumination control.

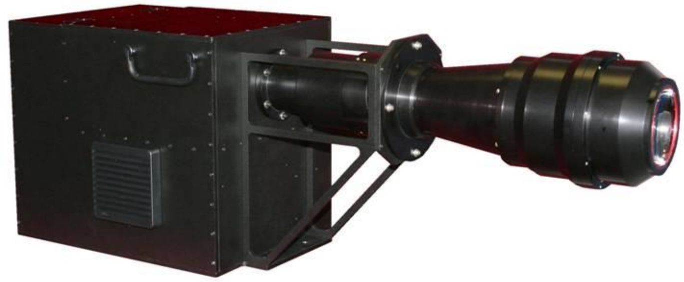

Figure 18: WFOV UV projector

8.0 EXAMPLE ELECTRO-OPTICAL TEST SETS

8.1 Multi-spectral E-O Test Set

Figure 19 is a schematic representation of MAPS-based multi-spectral E-O test set developed by OSC for the U.S. Army. The test set is transportable E-O test instrument which is capable of both static scene projection of classical E-O test patterns and dynamic real-time scene projection. This test set is capable of providing stimulation in the visible monochrome, visible color, NIR, MWIR, and LWIR wavebands. In order to optimized performance in multiple wavebands it includes three interchangeable DMD engines: visible, NIR, and IR. It also includes three interchangeable Illumination sources: visible/NIR monochrome, visible color, and IR (blackbody). The appropriate DMD engine and source can easily be installed by user depending upon test needs. It also includes a motorized rotary stage to rotate DMD engine with respect to the main module for some specific classical E-O tests. Figure 20 is a photograph of the system without the collimator installed.

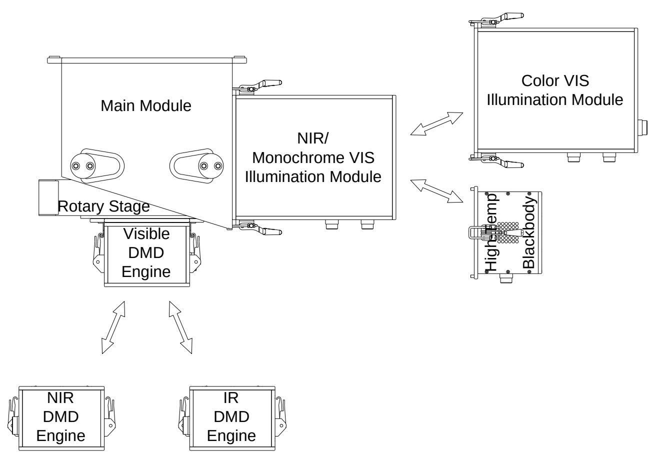

Figure 19: Schematic of a multi-spectral E-O test set

Figure 20: Multi-spectral E-O test set

8.2 Ruggedized FLIR test set

Figure 21 is a photograph of a ruggedized LWIR FLIR test set developed by OSC which was designed for “flight line” testing of aircraft FLIR. It contains a sealed inner chamber to protect it from contaminants and moisture, and it is designed to operate over a wide temperature range. No support chassis is required and it can operate on multiple types of AC input power.

Figure 21: Ruggedized FLIR test set

9.0 CURRENT RESEARCH EFFORTS

OSC is currently developing an IR hyperspectral projector system based upon the MAPS. The projector is being designed to test current and future imaging spectrographs which operate in the MWIR and LWIR wavebands. It will be capable of projecting real-time, high-fidelity, MWIR & LWIR hyperspectral scenes that are synchronized and co-registered. As a part of this effort we are characterizing the spectral radiance and contrast of several types of DMDs and formats (including the 1080p format), such that the optimum DMD can be utilized in the projector system.

10.0 ACKNOWLEDGMENTS

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11.0 REFERENCES

1. O. M. Williams, ″Imaging Infrared Projector Design″, Final Report of Key Technical Area 18, Subgroup W Technical Panel WTP-5, TTCP, (1995)

12.0 TRADEMARKS