BOSTON MICROMACHINES CORPORATION

Multi-DM™ Deformable Mirror System

User Manual, Rev. 5.2



This document describes the following products:

Multi-DM – Continuous Deformable Mirror
1.5 µm, 3.5 µm, & 5.5 µm Strokes

Multi-SLM – Segmented Deformable Mirror
1.5 µm & 3.5 µm Strokes

Control Electronics
Multi Driver Control Drive Electronics P/N DRV00120-03

Software
Deformable Mirror Software Development Kit (DM SDK)

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1. Multi-DM Quick Start

1.1 New -AND- Experienced Users

READ, UNDERSTAND, AND FOLLOW the Operator Safety and System Damage Warnings in Section 3, Safety Information.

1.2 For Users New to Deformable Mirrors

To learn what Deformable Mirrors are and how they are used

- Read through Section 5, System Components Overview
- Read through some of the technical information in Section 10, Reference Information
- Visit the Boston Micromachines website: www.bostonmicromachines.com

  Follow the “Education” link at the top of the page

  Follow the “Want to Learn More?” link at the bottom of the page

1.3 For Users Experienced with Deformable Mirrors and Ready to Start

TO GET READY to install your Deformable Mirror:

- Follow Section 3, Safety Information
- Follow Section 4, Introduction
- Follow Section 5, System Components Overview

TO INSTALL your Deformable Mirror:

- Follow Section 6, BMC SDK Software Installation
- Follow Section 7, Hardware Installation
- Follow Section 8, Verifying the DM Installation

2. Declarations, Certifications, and Warranty

2.1 About this Document

This manual is designed to help the reader understand, install, and operate the Multi-DM and Multi Driver. It assumes that the reader has a fundamental understanding of electronic components, electronic instruments, optics, and applicable safety procedures.

The manual describes the physical specifications of the Multi-DM and Multi Driver as well as the installation procedures that are required to use the system.

This document is available as a PDF file. Updated releases may be available by contacting moreinfo@bostonmicromachines.com.

2.2 Product Certification

Boston Micromachines Corporation certifies that the Multi-DM, Multi Driver, and all related components, are fully functional at time of shipment.

The Multi-DM included in this system has been tested and certified to function beyond the hardware limits set on the Multi Driver. Therefore, a “safety factor” need not be applied to the commands which send voltage to the mirror during normal operation.

2.3 Warranty

Any software or hardware failures due to manufacturing or inherent defects will be repaired or replaced (at Boston Micromachines’ discretion) for a period of 1 year from delivery.

For warranty questions or to initiate the warranty process, contact Boston Micromachines’ technical support at +1-617-868-4178 or techsupport@bostonmicromachines.com.

2.4 Limitations of Warranty

Warranty does not cover any damage incurred from mishandling or misuse of the DM or driver including failure due to electrostatic discharge (ESD), excessive optical intensity, or by not following the instructions included in this document.

Warranty does not cover any damage resulting from a customer’s decision to purchase or use nonstandard equipment, including but not limited to a removable window or drive electronics not sold by Boston Micromachines.

3. Safety Information

3.1 Types of Warnings in this Document

The following types of warnings are used in this document.

3.1.1 Operator Safety Warning

	Failure to observe the stated precaution(s) or perform the procedural step(s) exactly as defined, may cause serious injury or death to the operator.

3.1.2 System Damage Warning

	Failure to observe the stated precaution(s) or perform the procedural step(s) exactly as defined, may cause irreparable damage to the DM, the Driver Electronics, or associated equipment.

3.1.3 Important Information

	Take particular care to read and understand this information. It will save you time and effort and help avoid preventable errors.

3.2 Specific Warnings to Observe

The following warnings apply in a general sense throughout this document.

Additional warnings can be found at critical points in this document.

	**SHOCK HAZARD** Voltages up to 300V can be present on the deformable mirror (DM), packaging, electrodes, cable, and electronics driver. DO NOT come into contact with these items when the system is powered on.

	**DEFORMABLE MIRROR ESD DAMAGE** The DM is highly sensitive to electrostatic discharge. Always handle the DM in an electrostatically sensitive environment while wearing a Grounding Wrist Strap (shipped with system).

	**MULTI DRIVER ESD DAMAGE** The Multi Driver is highly sensitive to electrostatic discharge. Always handle the Driver in an electrostatically sensitive environment while wearing a Grounding Wrist Strap. Avoid touching any electrical interconnections.

	**MULTI-DM HAS NO USER SERVICEABLE PARTS** Do not open or disassemble in any way. Contact Boston Micromachines for any service required.

	**MULTI DRIVER HAS NO USER SERVICEABLE PARTS** Do not open or disassemble in any way. Contact Boston Micromachines for any service required.

4. Introduction

4.1 About Boston Micromachines Deformable Mirrors

Boston Micromachines (BMC) Deformable Mirrors (DMs) are advanced wavefront control devices that consist of a mirror membrane supported by an underlying actuator array.

- Each actuator can be individually deflected by electrostatic actuation, thus changing the shape of the mirror, to achieve the desired pattern of deformation.
- BMC DMs are capable of achieving high spatial resolution shapes due to high actuator count and low to no inter-actuator coupling.
- BMC DMs are available with continuous or segmented mirror surfaces.
- BMC DMs exhibit highly stable operation with no hysteresis.
- BMC provides compact, high resolution DM drive electronics that are suitable for bench-top or OEM integration.
- BMC's DM Software Development Kit (SDK), including Windows and Linux hardware drivers, software drivers for C/C++, Python, MathWorks MATLAB and National Instruments LabVIEW software, and command line and GUI based DM control applications.
- BMC's DM software is capable of operating multiple DM systems simultaneously.

4.2 Included Components

All Multi- series DMs are supplied with the following items:

- The Multi-DM Deformable Mirror.
  For detailed specifications see Section 4.3.1, Multi Deformable Mirrors.
  For detailed description see Section 5.1, System Diagram.
- The Multi Driver Control Electronics.
  For detailed specifications see Section 4.3.2, Multi Driver.
  For detailed description see Section 5.3, Multi Driver Electronics.
- The BMC Deformable Mirror Software Development Kit (SDK).
  For detailed information see Section 5.4, SDK and Demonstration Software.
- A DM- and Driver-specific configuration file.
- A DM-specific half bias flat shape data file.
- A DM- and Driver-specific System Data Sheet file.
- A USB Male A to Male Mini-B cable for connecting the Multi Driver to a PC.
- An ESD wrist strap.
- A complete set of hardware and software documentation.

4.3 Specifications

4.3.1 Multi Deformable Mirrors

DM Model Number	Multi-1.5 *	Multi-3.5	Multi-3.5L	Multi-5.5	Multi-1.5-SLM	Multi-3.5-SLM
Maximum Stroke (µm)	1.5	3.5	3.5	5.5	1.5	3.5
Actuator Pitch (µm)	300	400	450	450	300	400
Full Aperture Dia. (mm)	4.50	6.00	6.75	6.75	4.80	6.40
Active Aperture Dia. (mm)	3.30	4.40	4.95	4.95	3.60	4.80
Recommended Optical Aperture Dia. (mm)	2.70	3.60	4.05	4.05	3.60	4.80
Inter-Actuator Coupling	15%	13%	13%	22%	0%	0%
Mechanical Response time for a 100 nm step 10% - 90% deflection (µs) **	<40	<75	<75	<100	<35	<80
Avg. Step Size (nm)	< 1	< 1	< 1	< 3	< 1	< 1
Mirror Surface	Continuous Membrane Surface				Segmented Mirror Surface	
Actuator Count	140					
Actuator Layout	12 x 12 square without corners See Section 10.4, Mirror Mapping for Multi Driver DRV00120-03					
Actuator Count Across Aperture	12					
Mirror Coating	Aluminum, Gold, or Protected Silver					
Surface Quality (when driven flat)	< 30 nm RMS				< 40 nm RMS	
Protective Window (with Anti-Reflective Coating)	350-700nm, 650-1050nm, 1050-1700nm, 400-1100nm, or 550-2400nm					
Recommended Operating Temperature (°C)	-10 – 30					
Recommended Storage Temperature (°C)	-10 – 80					
Recommended Relative Humidity (%RH)	< 30					

* The Multi-1.5 is not available for new designs. New optical designs should use the Multi-C-1.5.
** High speed X-Driver option available, contact BMC for more information.

	Every deformable mirror can be safely actuated to the maximum stroke specified. No safety factor is necessary to safeguard proper function of the mirror.

	Throughout this document, unless otherwise noted, all references to, and descriptions of, the Multi-DM also apply to the Multi-SLM version.

4.3.2 Multi Driver

BMC Part Number	DRV00120-03
Computer Interface:	USB 2.0
Max Frame Rate:	8 kHz (125 µs USB packet size)
Voltage for Max Deflection	Up to 300V (device-specific)
Slew Rate	2V/µs
Slew Time to Max Deflection	Up to 150 µs (device-specific based on Max Voltage)
Resolution:	14-Bit
Dimensions (W x D x H):	9 in. x 7 in. x 2.5 in.
Power Requirements:	Chassis requires 24V, 2A Max which is supplied by AC\DC converter requiring 100-240 Volt, 1.6 A, 50-60 Hz
Output Voltage Limit	In hardware to ensure safe mirror operation

	Driver Voltage limits are specific to the specified Boston Micromachines DM. If multiple systems are ordered, DO NOT mix and match DMs and driver electronics.

4.4 System Requirements

- Power Source for Multi Driver Power Adapter.
  NEMA 5-15R receptacle supplying 100-240 Volt, 1.6 A, 50-60 Hz
  Contact Boston Micromachines for non-North American inputs.
- PC with the following minimum requirements:
  - 64-bit Intel-compatible CPU
  - Microsoft Windows 7 or 10 (64-bit) or Linux Operating System
  - 160 MB free disk space on the Operating System drive
  - If using MathWorks MATLAB, then 64-bit Version 2008a or newer.
  - If using National Instruments LabVIEW, then Version 2012 SP1 or newer.
  - If using Python, then Version 3.5 or newer.
  - If C/C++, an integrated development environment (IDE)
    such as Microsoft Visual Studio 2010 or newer, is recommended but not required.
- Mounting for the DM Housing.
  For optical bench top setup, an optical mount for 2-inch diameter component is required. Suggested compatible mounts are listed in Section 5.7, Optical Mount (Optional, Customer-Supplied).

5. System Components Overview

5.1 System Diagram

The Multi-DM System consists of the following components.

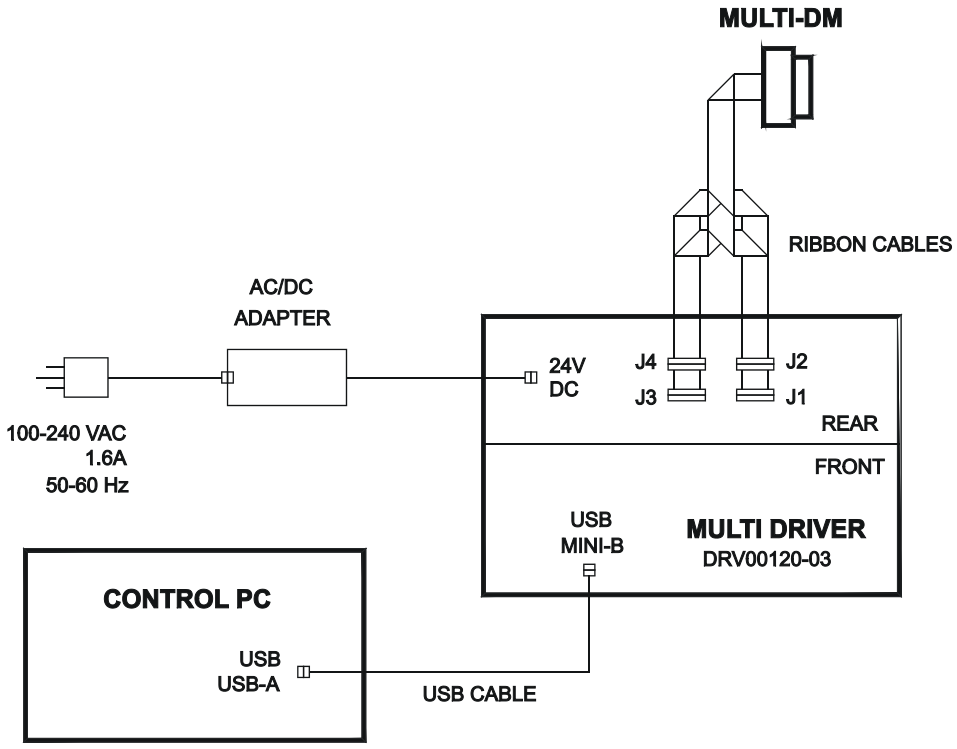


Figure 1 - Multi-DM System Diagram

Details on each of these components are in the rest of this section.

5.2 Multi-DM Deformable Mirror

The Multi-DM is a microelectromechanical systems (MEMS) device that is fabricated using polysilicon surface micromachining methods.

The Multi-DM starts with an array of electrodes on the base silicon. Over each electrode is a flexure element that is attached to a post that is attached to the underside of a floating flexible mirror surface. Each electrode and flexure element taken together are known as an actuator.

Mirror surfaces can be either continuous (without any breaks) over the entire actuator array, or segmented, with an individual segment over each actuator.

A voltage applied to the electrode will attract the flexure element, pulling on the post and the mirror directly above it, thus changing the height of the mirror surface above the actuator. Acting in concert, the actuator array can control the mirror surface to create shapes from flat to complex 3D surfaces.

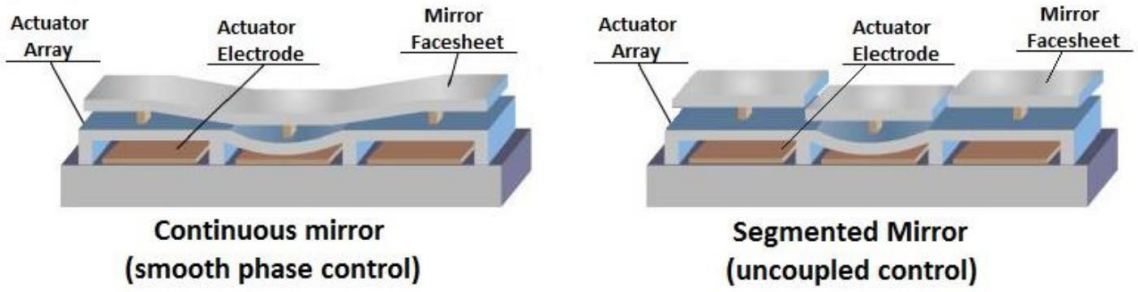
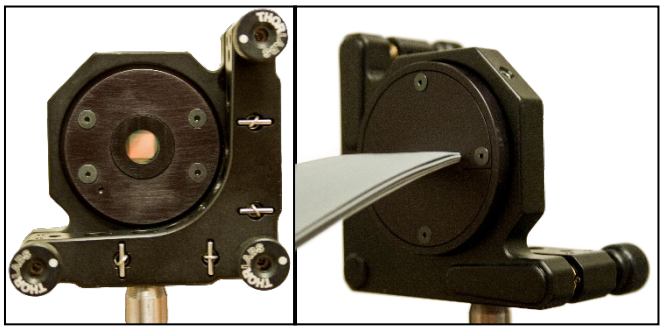


Figure 2 - Deformable Mirror Cross Sections

The DM silicon device is packaged and wire bonded to a ceramic chip carrier and the chip carrier is sealed into a windowed enclosure. The sealed chip carrier enclosure is further integrated into a rugged aluminum enclosure. Four ribbon cables extend from the rear of this outer enclosure, each terminating in DC-37 male connectors that mate to the Multi Driver electronics.

For a dimensional drawing of the DM enclosure see Section 10.3, Multi-DM Mechanical Drawing.

The DM enclosure is easily mounted in most standard 2-inch optical mounts. A sample mounting configuration is shown in Figure 3 - Multi-DM in Customer-Supplied Thorlabs KS2 Kinematic Mirror Mount. For a list of compatible optical mounts, see Section 5.7, Optical Mount (Optional, Customer-Supplied).



Front (Mirror) Side Rear (Cable) Side

Figure 3 - Multi-DM in Customer-Supplied Thorlabs KS2 Kinematic Mirror Mount

For installation and setup instructions of the DM enclosure see Section 7, Hardware Installation.

5.3 Multi Driver Electronics

The Multi-DM drive electronics provide 14-bit digital control of 140 high-voltage output channels. A host PC, connected with a USB 2.0 interface, controls each output channel independently.

For a dimensional drawing of the Multi Driver Electronics see Section 10.6, Multi Driver DRV00120-03 Mechanical Drawing.

For installation and setup instructions of the Multi Driver Electronics see Section 7, Hardware Installation.

The following sections describe the connectors, displays, and controls on the front and the rear of the unit.

5.3.1 Multi Driver Electronics Front Panel

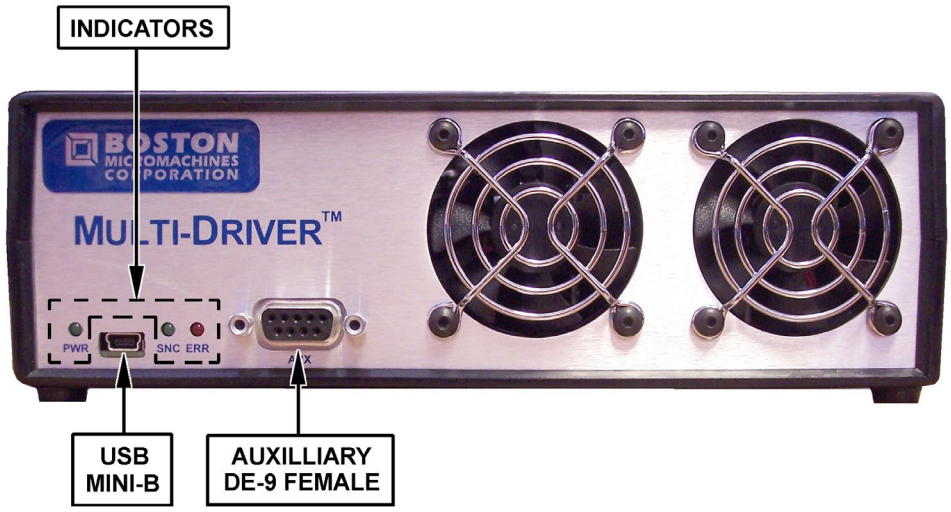


Figure 4 - Front Panel of Multi Driver

Table 1 - Front Panel Connections

Label	Type	Function
	USB 2.0 Mini-B	Data connection to the control PC.
AUX	DE-9 female	Provides timing, low voltage output, and status signals.

Table 2 - Front Panel Indicator LEDs

Label	Color	Function
PWR	Green	**When lit solid green**, indicates that the power cable is plugged in and the system is turned on.
SNC	Green	**When lit solid green**, indicates frame synchronization and that data is being sent from the computer.
ERR	Red	**When lit solid red**, indicates a USB input buffer error. This is usually caused and cleared by the host software. **When lit blinking red**, indicates that the temperature in the Multi Driver enclosure has exceeded 50° C and the high voltage supply in the Multi Driver will automatically shut off. For additional details on the ERR LED see Section 10.8, Multi Driver Dataflow and Error Detection.

5.3.2 Multi Driver Electronics Rear Panel

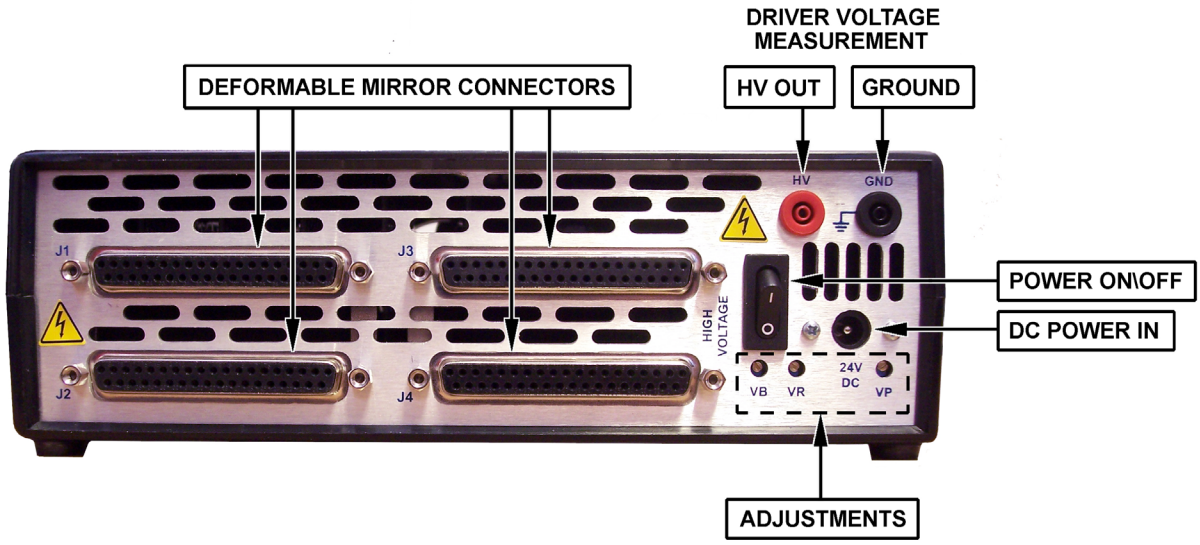


Figure 5 - Rear Panel of Multi Driver

Table 3 - Rear Panel Switches

Label	Type	Function
I O	Toggle	Press I to turn the Multi Driver on Press O to turn the Multi Driver off

Table 4 - Rear Panel Connections

Label	Type	Function
J1-J4	DC-37 Female	Outputs to the Multi-DM.
24VDC	6mm Coax	24VDC input from external power supply.
HV	2mm Safety Sheathed Jack	High voltage output terminal. Use to measure Driver maximum voltage.
GND		Ground terminal. Use to measure Driver maximum voltage.



J1 through J4 connectors:
High voltages may be present.
Only make connections with the Multi Driver off.



DO NOT use the HV and GND connections unless specifically instructed to do so by a Boston Micromachines technical representative.



HV and GND connectors:
High voltages may be present.
Only make connections with the Multi Driver off.

Table 5 - Rear Panel Adjustments

Label	Type	Function
VB	Pot	Amplifier Bias Current Limit Adjustment
VR	Pot	Voltage Reference Adjustment (Range of Digital to Analog Converters)
VP	Pot	High Voltage Output Rail Adjustment (Maximum Voltage Supplied to DM)



DO NOT adjust the VB, VR, or VP controls unless specifically instructed to do so by a Boston Micromachines technical representative.

5.4 SDK and Demonstration Software

Along with the DM and Multi Driver, a USB flash drive is supplied that includes the following files:



By default, the DM and Multi Driver system ships with an SDK and applications for Microsoft Windows 64-bit operating systems.

A Linux SDK is also available, contact Boston Micromachines for details.

- DMSDK-Setup-<version number>.exe, a self-executing installation program that installs the following components:
  - Software drivers for programming the DM in the C or C++ programming language.
  - Software drivers for programming the DM on the MathWorks MATLAB and National Instruments LabVIEW platforms.
  - DMShapes, a graphical user interface application that can load a shape from a Command Map file, set the entire DM to a particular value (piston), or set actuators individually (poke) or sequentially (play).
  - BMCLoadShape, a command line application that reads a shape from a Command Map file and applies it to the DM.
  - A full set of documentation in PDF and HTML format.
  - Hardware drivers for the Multi Driver so that it will be recognized by Windows when it is connected to the PC.
- The DM Profile file, a configuration file that is matched to a unique DM and Driver combination.
- The DM Half Bias Flat Map file, a Command Map that drives the Deformable Mirror surface to a plane.
- The User Manual for the DM (this document) in PDF format.
- A DM- and Driver-specific System Data Sheet file in PDF format. This contains full system specifications, system test results, command vs. deflection curves, and interferometric surface data.

For software installation instructions see Section 6, BMC SDK Software Installation.

5.5 USB Cable

A 6.5 ft (2 m) long USB 2.0 Type A male to Type Mini-B Male cable is supplied for connecting the Multi Driver to the control PC.

5.6 ESD Wrist Strap

An ESD wrist strap is supplied with all systems.



To prevent electrostatic damage, a properly grounded ESD wrist strap MUST be worn at all times while handling the DM or Multi Driver electronics.

5.7 Optical Mount (Optional, Customer-Supplied)

The Multi DM must be rigidly mounted in your optical system.

If you are not designing a custom mounting in your system, note that the Multi DM housing fits many standard 2-inch optical mounts from select manufacturers.

Several optical equipment manufacturers produce mounts that are well suited for the Multi- DM. The following mounts are known to work well.

- Thorlabs KS2 - Ø2" Precision Kinematic Mirror Mount, 3 Adjusters
  http://www.thorlabs.com/thorproduct.cfm?partnumber=KS2
- Thorlabs KS2D - Ø2" Precision Kinematic Mirror Mount,
  2 Differential Adjusters, 1 1/4"-80 Adjuster
  http://www.thorlabs.com/thorproduct.cfm?partnumber=KS2D

6. BMC SDK Software Installation

	Make sure to complete the BMC SDK software installation per this section BEFORE attaching the Multi Driver. Installing the Multi Driver first can result in errors during installation.

This section contains the following topics:

Section 6.1, BMC SDK Software Installation Instructions

Section 6.2, Device-Specific File Installation

Follow the procedures in each section in the order shown.

	The procedures in this section describe installation of the Windows version of the BMC SDK. If you have the Linux version of the SDK, refer to the installation instructions that were supplied with it.

	As with all software installations, before starting make a drive image, backup the operating system configuration, or set a Windows Restore Point to aid in recovery in case of any errors during the installation.

6.1 BMC SDK Software Installation Instructions

The BMC SDK software consists of hardware and software drivers, GUI and command line applications to control the DM, and a full set of documentation.

For a full description of the contents of the SDK software see Section 5.4, SDK and Demonstration Software.

To install the BMC SDK Software:

1. Verify the computer meets the minimum hardware and software requirements. For the detailed requirements see Section 4.4, System Requirements.

2. Verify there is no existing installation of the BMC SDK software. To do this check in **Control Panel**, **Programs and Features**.

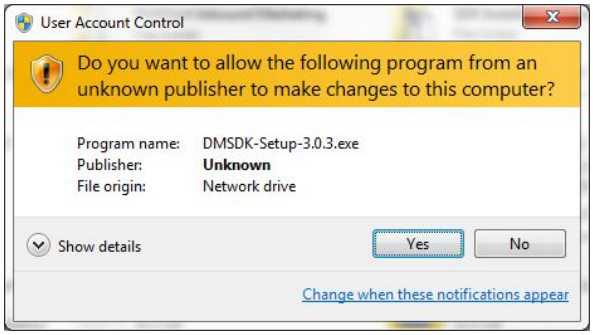
   If there is an existing installation, continue with this procedure. You will be presented with an option screen where you can select Remove.

3. Insert the supplied USB Flash Drive into an available USB Port.

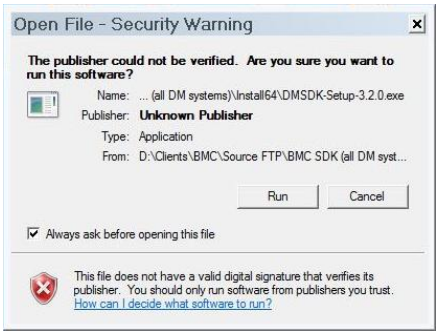
4. On the **Desktop** open **My Computer**, or Click **Start** then **My Computer**.

5. Browse to the USB Flash Drive which may appear in the Navigation Pane as either **USB DISK** or **Removable Disk**.

6. In the file window locate the file **DMSDK-Setup-** <version number>**.exe**, then double-click on the file name.
   - In Windows 10 the **User Account Control** dialog will appear.
   - In Windows 7 the **Open File - Security Warning** dialog will appear.



Windows 10
User Account Control dialog



Windows 7
Open File - Security Warning dialog

This dialog is to confirm that you want to allow a program from an unknown publisher to make changes to the computer.

To install the BMC SDK Software (continued):

7. To allow the installation program to continue:
   - In Windows 10 click **Yes**.
   - In Windows 7 click **Run**.

   A few windows will display quickly as the files are being unzipped and prepared. Then the **BMC SDK - InstallShield Wizard - Welcome Screen** will display.

   Note: If the software is already installed then you will be presented with the **BMC SDK - InstallShield Program Maintenance** dialog. Click **Remove**. When the removal completes restart the installation.

8. Click **Next**.

   The **BMC SDK - InstallShield Wizard - License Agreement** dialog will display.

9. Select **I accept the terms in the license agreement** then click **Next**.

   The **BMC SDK - InstallShield Wizard - Readme Information** dialog will display.

10. Read the information, then click **Next**.

    Note: To access the Readme Information text after installation, go the **C:\Program Files\Boston Micromachines\Doc** folder and locate the file **ReadMe.txt**.

    The **BMC SDK - InstallShield Wizard - Ready to Install the Program** dialog will display.

11. Click **Install**.

    The BMC SDK will start to install.

    When complete the **BMC SDK - InstallShield Wizard - InstallShield Wizard Completed** dialog will display.

12. Click **Finish**.

The BMC SDK installation is now complete.

Proceed to the next section to copy the device specific files to the PC.

6.2 Device-Specific File Installation

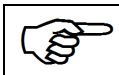
There are two configuration files specific to the device you have that must be copied from the USB Flash Drive to specific folders in the BMC software folder.

- **The DM Profile file.**
  This is a configuration file that is matched to a unique DM and driver combination. The Profile file name contains the serial number of the supplied DM device in the format of <DM_Serial_Number>.dm. This file must be copied to the **Program Files\Boston Micromachines\Profiles** folder.
- **The DM Flat Map file.**
  A Command Map that drives the Deformable Mirror surface to a plane, so that it can be used as an optically flat surface during optical alignment. The Flat Map file name contains the serial number of the supplied DM device in the format <DM_Serial_Number>_FLAT_MAP_COMMANDS.txt. This file must be copied to the **Program Files\Boston Micromachines\Shapes** folder.

For more information on Flat Maps and Profiles, see Section 10.1, Glossary.

To copy the Device-Specific Files to their proper locations:

1. Insert the BMC SDK software USB Flash Drive into an available USB Port.
2. On the Desktop open My Computer, or click **Start** then click **My Computer**.
3. Browse to the USB Flash Drive which may appear in the Navigation Pane as either **USB DISK** or **Removable Disk**.
4. In the file window, select and copy the Profile file **<DM_Serial_Number>.dm**.



The filename may not be identical to that of the serial number that is noted in the data sheet or on the label of the DM.
This is due to the 11-character requirement of the filename in the software.

5. Browse to, and paste the file in, the **Program Files\Boston Micromachines\Profiles** folder.
6. Browse back to the USB Flash Drive.
7. In the file window, select and copy the Flat Map file **<DM_Serial_Number>_FLAT_MAP_COMMANDS.txt**.
8. Browse to, and paste the file in, the **Program Files\Boston Micromachines\Shapes** folder.

The software installation is now complete.

Proceed to the next section to install the DM and Multi Driver hardware.

7. Hardware Installation

☞	Make sure to complete the BMC SDK software installation per Section 6 BEFORE attaching the Multi Driver. The Multi Driver hardware driver was copied to the PC by the SDK installation. Connecting the Multi Driver before this is done will result in driver installation errors.

To install the Multi-DM hardware:

1. Mount the Multi-DM in your optical setup.

   If you are using a bench top optical setup, note that compatible optical mounts are listed in Section 5.7, Optical Mount (Optional, Customer-Supplied).

2. Position the Multi Driver such that the cables from the Multi-DM can reach the rear panel and the cable from the PC can reach the front panel.

⚠	**SHOCK HAZARD** Voltages up to 300V can be present on the Multi Driver. Make all connections with the Driver off and the power cord disconnected. DO NOT come into contact with the rear panel connectors when the Driver is on.

3. Plug the four Ribbon cables from the Multi-DM labeled J1 through J4 into the four DC-37 female connectors labeled J1 through J4 on the back of the Multi Driver. Match the labels on the cable connectors to the labels on the Driver connectors.

☞	All four cables must be attached and detected by the Multi Driver in order to activate the high voltage power supply.

4. Connect the Multi Driver to the PC using the supplied USB cable as follows:
   a) Plug the smaller end of the cable into the USB Mini B connector on the front of the Multi Driver.
   b) Plug the larger end of the cable into a USB Type A port on the PC.

5. Connect power to the Multi-Driver as follows:
   a) Connect the AC power cord to the Multi Driver power transformer brick.
   b) Connect the transformer brick DC power out cord to the Multi Driver.
   c) Plug the AC power cord into a 100-240V wall receptacle.

☞	The Multi Driver is supplied with a power cord with a standard NEMA 15-P plug. Contact Boston Micromachines for cordsets for non-North American applications.

To install the Multi-DM hardware (continued):

6. If the host PC is not powered up, power it up now.
   Allow the Windows operating system to fully start.

7. Power up the Multi Driver by flipping the switch on the back of the unit.

   Compatible Windows operating systems will install the driver files automatically. First the message **Installing device driver software** will appear in the system tray. Then the message **Cambridge Innovations Multi DM Driver USB Device** will display.



For Microsoft Windows installations only:

The Multi Driver will appear in the Device Manager under the Universal Serial Bus Controllers node as Cambridge Innovations Multi DM Driver USB Device.

This device is displayed in Device Manager only when the Multi Driver is turned on and connected to the PC.

The hardware installation is now complete.

Proceed to Section 8, Verifying the DM Installation.

8. Verifying the DM Installation

After installing the hardware and software:

- The operation of the Driver and DM should be verified.
- Any alignment(s) required by the optical system design can be performed

	Make sure to complete the BMC SDK software installation per Section 6 and the hardware installation per Section 7 BEFORE verifying the installation.

	The procedures in this section describe using applications that are only supplied with the Windows version of the SDK. If you have the Linux version of the SDK, refer to the instructions that were supplied with it.

	The procedures in this section use the DMShapes application to control the shape of the DM surface. For additional details on using this application see Section 9, DMShapes Software Overview

This section contains the following topics:

Section 8.1 Verification Tools
Section 8.2 Verifying the Installation
Section 8.3 Performing Angular Alignment
Section 8.4 Performing Positional Alignment

8.1 Verification Tools

The following software, shape, and hardware tools are used in the verification and alignment processes.

8.1.1 Software Tools

Boston Micromachines supplies two programs to directly control the DM. They are all installed by the SDK installation program.

- **DMShapes** is a graphical user interface application that can load a shape from a text file and apply it to the DM, set the entire DM to a single value, or set actuators individually. For detailed information see Section 9, DMShapes Software Overview.
- **BMCLoadShape** is a command line application that reads a shape from a Command Map file and applies it to the DM. For detailed information on BMCLoadShape see BMC Document No. D02-00025, Boston Micromachines Getting Started With C/C++ in the **Program Files\Boston Micromachines\Doc** folder.

8.1.2 Shape Tools

Three types of alignment are possible, although not every application will require all of them. Each type of alignment requires a particular shape to be formed by the mirror.

- Angular alignment requires a flat mirror surface.
- Centering and rotational alignments require some type of regular geometric pattern or shape.

The following table summarizes these requirements.

Type of Alignment	Mirror Shape Required	Command Map
Angular (of DM surface)	Flat surface	The Flat Map File supplied with all DMs
Centering (X and Y)	Cross, square, etc.	Supplied with Multi and Kilo DMs
Rotation	Cross, square, etc.	For other DMs created by user

All Shape files are located in the **Program Files\Boston Micromachines\Shapes** folder and can be loaded in the DMShapes application from the **Shapes** list.

8.1.2.1 Flat Map

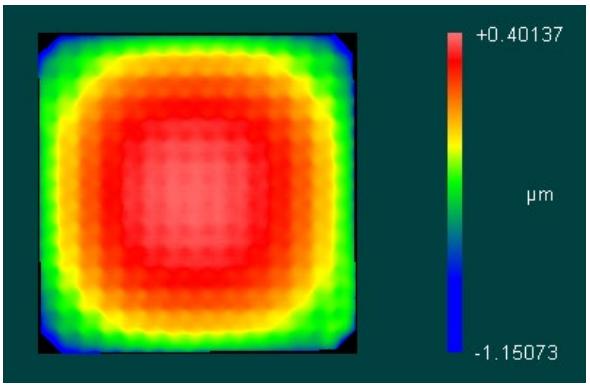
All un-powered DMs, as fabricated and supplied, have a low order curvature.

The DM surface can be driven to be optically flat using a specific type of Command Map called a Flat Map. A Flat Map can establish a flat surface at any position within the travel of the DM actuators.

A half bias (50% deflection) Flat Map is supplied with each DM.

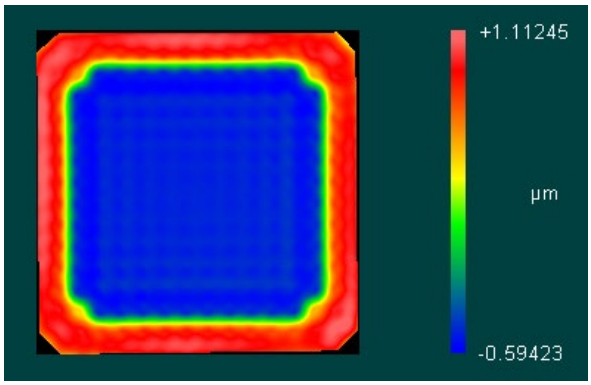
Loading this map will establish a planar surface with the specified surface quality of less than 30 nm RMS at the approximate mid-point of the actuator travel.

The effect of applying this Flat Map to a continuous DM is shown in Figure 6 - The Effect of a Flat Map on a Multi-DM.



Continuous Multi-DM Surface un-powered

Segmented Multi-DM Surface is similar



Continuous Multi-DM Surface with half bias Flat Map applied

Segmented Multi-DM Surface is similar without sloped edge (yellow shaded area)

Figure 6 - The Effect of a Flat Map on a Multi-DM

8.1.3 Hardware Tools

8.1.3.1 The Multi Flat Setup Mirror

The Multi Flat Setup Mirror Assembly is a form-fit compatible unit to the Multi-DM, where the active MEMS mirror is replaced with a simple static mirror.

It can be used during setup and angular alignment to prevent shock and electrostatic discharge (ESD) damage to the sensitive MEMS element of the Multi-DM.

8.2 Verifying the Installation

Verifying the installation is done by sending software commands to the DM and visually monitoring its response.

Typically, DMShapes is most easily used to verify the installation. The balance of this section documents using that application.

To verify the actual operation of the DM, first move all of the actuators to each end of their travel, then actuate each of them individually.

Keep in mind when manipulating and observing the DM:

- Zero (0) on the Piston corresponds to no actuator deflection, and thus the DM mirror is in its relaxed un-powered state.
- One (1) on the Piston corresponds to maximum actuator deflection, and thus the DM mirror is in its maximum deflected state.

8.2.1 Verify the actuator's operational limits

1. Turn on the Multi Driver, start the DMShapes application, and load the Profile for the Multi Driver and the DM.
2. Set all the actuators to the top limit of their motion by doing one of the following:
   - On the toolbar click the **Zero** button.
   - Move the Piston to 0.

   The actuators in the display will all turn blue.
3. Visually verify the actuators all move together the same distance.
4. Set all the actuators to the bottom limit of their motion by moving the Piston to 1.

   The actuators in the display will all turn red.
5. Visually verify the actuators all move together the same distance.



How you verify this motion is dependent upon your application and optical setup. If technical assistance is necessary, contact Boston Micromachines.

8.2.2 Verify the control of individual actuators

1. Turn on the Multi Driver, start the DMShapes application, and load the Profile for the Multi Driver and the DM.
2. Set all of the actuators to the top limit of their motion by doing one of the following:
   - On the toolbar click the **Zero** button.
   - Move the Piston to 0.

   The actuators in the display will all turn blue.

   The actuators on the DM will all go to the top of their motion and the mirror will return to an un-deflected state.
3. On the toolbar click the **Play** button.

   Starting with Actuator 0, each actuator will move to the 0.8 position, then move back to the 0 position. This will continue with the next actuator until all have been moved.
4. As this process takes place, visually verify each actuator moves down and then returns to an un-deflected state and that no other actuators are moving.

   This will appear to be a single actuator-sized depression that moves through the mirror. Refer to the Actuator Map in Section 10.4.

System verification is now complete and you can begin to align the DM.

8.3 Performing Angular Alignment

Angular alignment refers to the direction of an axis perpendicular to the DM surface.

Angular alignment requires the surface of the DM to be flat. This can be done with the DM driven flat with the Flat Map file or by replacing the DM with the Setup Mirror Assembly

To perform the angular alignment of the DM using the Flat Map File

1. Turn on the Multi Driver, start the DMShapes application, and load the Profile for the Multi Driver and the DM.
2. Load the Flat Map for the DM.
3. Adjust the angle of the DM surface as necessary.

To perform the angular alignment of the DM using the Setup Mirror Assembly

1. Install the Setup Mirror Assembly in place of the DM.
2. Adjust the angle of the DM surface as necessary.
3. Replace the Setup Mirror Assembly with the DM.

8.4 Performing Positional Alignment

Positional alignment refers to the displacement and rotation of the X and Y coordinate system of the actuators.

Positional alignment requires a discernable shape to be formed by the DM surface. Typically this can be deflected actuators at the corners, or deflected actuators forming a cross, or some other type of regular pattern of deflected actuators.

1. Turn on the Multi Driver, start the DMShapes application, and load the Profile for the Multi Driver and the DM.
2. Load the desired shape file.
3. Adjust the displacement position or rotation of the DM as necessary.

9. DMShapes Software Overview

This section is a reference for the graphical user interface application DMShapes.

DMShapes is a graphical user interface application that can load a shape from a Command Map file, set the entire DM to a particular value (piston), or set actuators individually (poke) or sequentially (play).



DMShapes functions only to send commands to the DM.
It does not read the state of the DM. When using DMShapes, the state of the mirror must be monitored through direct observation.

This section contains the following topics:

9.1 The DMShapes Window

9.2 Using the DMShapes Application

9.3 Using DMShapes with Multiple DMs

9.1 The DMShapes Window

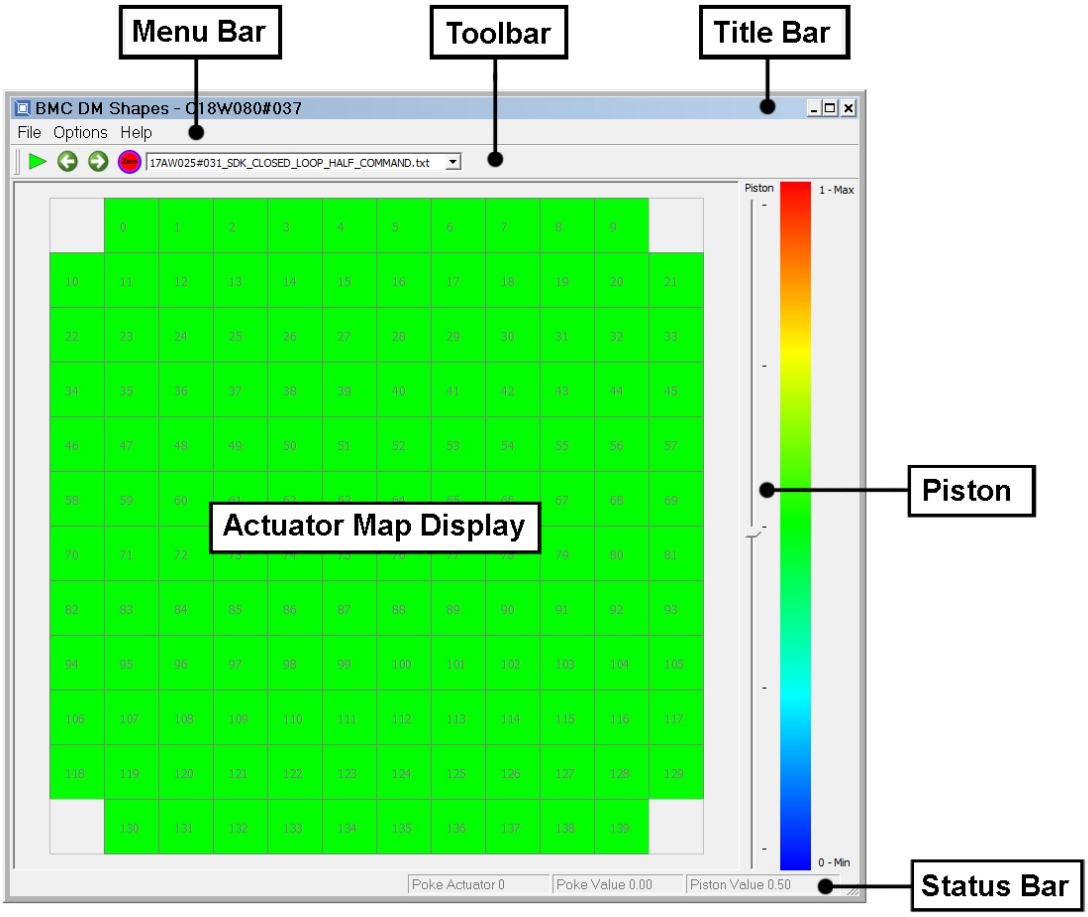


Figure 7- DMShapes Window

Title Bar

Displays the program name and the serial number of the DM specified by the currently loaded Profile. This is the file name of the currently loaded Profile.

Menu Bar

Contains commands for loading and saving Command maps and setting program options. For detailed information see Section 9.1.1, The DMShapes Menu Bar.

Toolbar

Contains commands to poke and reset individual actuators and a menu to select a Command Map to apply. For detailed information see Section 9.1.2, The DMShapes Toolbar.

Actuator Map Display

Displays the actuator grid with the color-coded value currently being applied to each actuator and allows changes to individual actuators. For detailed information see Section 9.1.3, The DMShapes Actuator Map Display.

Piston

Displays a scale and a slider and allows changes to the entire array of actuators. For detailed information see Section 9.1.4, The DMShapes Piston.

Status Bar

Displays information on the last selected actuator and current piston setting. For detailed information see Section 9.1.5, The DMShapes Status Bar.

9.1.1 The DMShapes Menu Bar

The DMShapes Menu Bar contains the following commands.

Command	Description
File > Open DM	Loads a user selected Profile file
File > Open Driver Map	This command is not used
File > Load Calibration	Loads a user selected Calibration file Used with open loop calibration only
File > Save Shape As...	Saves the current shape settings to a user selected file name Note that Administrator permissions are required to save this file to the Shapes folder.
Options > Show Grid	Shows or hides a grid pattern separating the actuators
Options > Apply Offsets	Applies the offsets defined in the current Calibration file Used with open loop calibration only
Help > About	Displays a dialog showing the program version

9.1.2 The DMShapes Toolbar

Note that the DM Toolbar can be floated, repositioned, and hidden.

Icon	Label	Description
	Play	Press to initiate a sequence to poke all actuators in sequence starting with actuator number 0 and ending with the highest numbered actuator. The poke, just poked, and final actuator values after the operation completes depend upon the starting state as follows: • If the actuators have been set to a single value by the piston or by the Zero button and no individual actuators changed from that value, then the Play operation pokes each actuator at 0.8 then returns it to its previous value. • If the actuators have been set to a single value by the piston or by the Zero button and one or more individual actuators changed from that value, then the Play operation sets all actuators to the current piston value, then pokes each actuator at 0.8 then returns it to its previous value. When the entire cycle completes, all previous actuator values are restored. • If a Command Map has been applied, with or without any individual actuator values manually changed, then the Play operation sets all actuators to the current piston value (0.25), then pokes each actuator at 0.8 then returns it to its previous value. When the entire cycle completes, all previous actuator values are restored. As this command pokes each actuator at 0.8, it has no effect if all actuators have been set to 0.8 by the Piston or a Command Map.

The DMShapes Toolbar (continued)

Icon	Label	Description
	Poke Previous	Press to apply the value of the current actuator to the actuator one lower in number, i.e. poke it. The poked actuator then becomes the current selection. The values of the original actuator and the other non-poked actuators after the poke depend upon the starting state as follows: • If the actuators have been set to a single value by the piston or by the Zero button, with or without any individual actuator values manually changed, after the poke all other actuators, including the previously selected one and any that had been changed from the Piston or Zero value, are returned to the Piston value. • If a Command Map has been applied, with or without any individual actuator values manually changed, after the poke all other actuators including the previously selected one are set to the current Piston value (0.25). If the lowest (0) actuator is selected, the next one will wrap to the highest numbered actuator. Note this command does not update the Poke Actuator and Poke Value in the Status bar. As this command changes the value of an actuator to the value of an adjacent actuator, it has no effect on that actuator if the adjacent actuator had the same value. It may however change the values of the original and other actuators.
	Poke Next	Same as Poke Previous except in the opposite direction, i.e. applies the value of the current actuator to the actuator one higher in number. If the highest actuator is selected, the next one will wrap to the lowest (0) numbered actuator.
	Zero	Sets all actuators to 0.

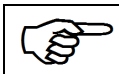
The DMShapes Toolbar (continued)

Icon	Label	Description
	Shape File List	Displays the name of the most recently applied Command Map (unless one has been saved in the current session). When the program is first opened, the list box will default to show the first file in the Shapes folder even though it is not applied to the DM. To apply a Command Map, open the list and select the desired file. • The selected Shape file will load in the application. • The Actuator Display will refresh with the values in the Shape file. • The proper commands will be sent to the DM. • The Piston value will be set to 0.25 (although this has no effect on the DM). If changes are made to actuator values in the actuator window the Command Map shown is no longer applicable but remains displayed. If a Command Map saved with the **File>Save Shape As** command, the new Command Map file will appear in the Shape File list but the Shape File displayed in the list box will default to show the first file in the Shapes folder. If a Command Map is added to the Shapes folder while DMShapes is open it will not appear in the list until DMShapes is restarted.

9.1.3 The DMShapes Actuator Map Display

The Actuator Map Display area contains a graphical representation of the DM actuators.

The actuator array is shown with each actuator numbered.
Surrounding mirror segments without actuators are not shown.



Note that the display does not reference the orientation in the DM housing.
For that orientation see Section 9.2, Multi-DM Mechanical Drawing.

A grid delineating the actuators can be toggled on and off using the menu command Options > Show Grid.

The displacement value currently being sent to each actuator is displayed using the color spectrum that is shown in the Piston Color Bar.

- Blue represents a zero displacement (un-powered) command being sent.
- Red represents a maximum displacement (full stroke) command being sent.



The Actuator Map does not display the actual deflection of the DM actuators, but rather the deflection commands being sent to each individual actuator by the Multi Driver.

- **For continuous DMs**, the actual displacement is determined by the magnitude of the command sent to the actuator with an offset caused by inter-actuator coupling. For a detailed explanation of this effect see Section 10.10, Deflection and Inter-Actuator Coupling.
- **For segmented DMs**, the actual displacement is determined only by the magnitude of the command sent to the actuator.

The actual state of the mirror must be monitored through direct observation.

Within the map, each actuator can be individually controlled. Click on an actuator to display a spin box that allows you to set the actuator value by clicking the up or down arrows or by direct keyboard entry. The value is immediately applied to that actuator on the DM.

The actuator value must be a 2-place decimal between 0 and 1 inclusive.
To set values with greater precision, up to a 14-bit value, use a Command Map or MathWorks MATLAB, National Instruments LabVIEW, Python, C or C++ program control.

9.1.4 The DMShapes Piston Area

The Piston Area consists of a single control and a static display.

- The Piston Slider controls the displacement of all of the DM actuators at once. Dragging this slider will immediately change all actuator values, including any that were applied manually or through a Command Map selection, to the value of the slider. Possible values are 0 through 1 inclusive and there are tick marks at 0.25 increments.



Using the Piston to set all actuators to the same value does not ensure that the DM is as completely planar die to the DM's inherent low order curvature.

To ensure the DM is planar use the supplied Flat Map. For the procedure on how to do this see Section 8.3, Performing Angular Alignment.

- The Color Bar is a chromatic key display of how individual actuator displacement is represented in the Actuator Map.
  - Blue represents a zero displacement (un-powered) command being sent.
  - Red represents a maximum displacement (full stroke) command being sent.

9.1.5 The DMShapes Status Bar

The **Status Bar** is located at the bottom of the DMShapes window and displays the following information.

- The left side of the Status Bar displays the most recent error message.
- The Poke Actuator value displays the number of the actuator most recently selected by the user. Note that this value does not update during Play or Poke operations initiated from the Toolbar.
- The Poke Value value displays the displacement value being sent to the actuator most recently selected by the user. Note that this value does not update during Play or Poke operations initiated from the Toolbar, changes made by the Piston, nor changes made by selecting a Command Map file.
- The Piston Value value displays the displacement value specified by the Piston. Note that this value is not necessarily being sent to all of the actuators on the DM unless the last user input was to set the Piston value (and thus all actuators have the same value).

9.2 Using the DMShapes Application

9.2.1 To Start DMShapes

- On Windows: Click **Start**, then click **All Programs**, then click **Boston Micromachines**, then click **DMShapes**.
- On Linux: From the Run dialog or your preferred terminal emulator, run "/opt/Boston Micromachines/bin/DMShapes" (with quotes)

  When the application opens:
  - The last specified Profile will be loaded.
  - There will be no Command Map (shape) loaded.

9.2.2 To Load a Profile

1. On the **Menu Bar**, click **File**, then click **Open DM**.

   The **Find DM Profile** dialog will display with the **C:\Program Files\Boston Micromachines\Profiles** folder open.
2. Locate and select the Profile file that was supplied with your DM.
   The Profile file name should contain the serial number of the attached DM device.
3. Click **Open**.

   The selected Profile will load in the application.

   The serial number of the DM specified by the currently loaded Profile will display in the DMShapes Title Bar. This is the file name of the currently loaded Profile.

   The Actuator Map specified by the profile will display.

	If the selected Profile does not match the type of Driver attached, if the driver has not been connected to the PC, or if the driver has not been turned on, an error message will display.

9.2.3 To Load a Shape (Command Map)

- In the **Shapes** list, click to select a Shape file.

  The selected Shape file will load in the application.

  The Actuator Display will refresh with the values in the Shape file.

  The proper commands will be sent to the DM.

  The Piston value will be set to 0.25 (although this has no effect on the DM).

9.2.4 To Change All Actuators

- In the **Piston Area**, click and drag the slider to the desired value, then release.

  As you move the slider:

  - In the Actuator Map display, all actuators will change to the color for that value.
  - In the Status Bar the Piston Value will update.
  - The value will be immediately applied to the actuators on the DM.

9.2.5 To Set All Actuators to 0

- On the **Toolbar**, click the **Zero** button.
  - In the Actuator Map display, all actuators will change to the color for 0 (blue).
  - In the Status Bar the Piston Value will update to 0.00.
  - The value will be immediately applied to the actuators on the DM.

9.2.6 To Change a Single Actuator

1. Click on the actuator.

   In the Status Bar the Poke Actuator Value will update.

   A spin box will display with the current value of the actuator shown.
2. In the spin box, set the desired value by doing one of the following:
   - Click the up or down arrows.
   - Enter the value on the keyboard.

   As you change the value:

   - In the Actuator Map, the display for that actuator will change to the color for that value.
   - In the Status Bar the Poke Value will update.
   - The value will be immediately applied to that actuator on the DM.

9.2.7 To Poke All Actuators in Sequence

- On the **Toolbar**, click the **Play** button.

  All actuators, starting with Actuator 0 and ending with the highest number actuator, will be poked in sequence

  The poke, just poked, and final actuator values after the operation completes depend upon the starting state as follows:

  - If the actuators have been set to a single value by the piston or by the Zero button and no individual actuators changed from that value, then the Play operation:
    - Pokes each actuator at 0.8 then returns it to its previous value.
  - If the actuators have been set to a single value by the piston or by the Zero button and one or more individual actuators changed from that value, then the Play operation:
    1. Sets all actuators to the current piston value.
    2. Pokes each actuator at 0.8 then returns it to its previous value.
    3. When the entire cycle completes, all previous actuator values are restored.
  - If a Command Map has been applied, with or without any individual actuator values manually changed, then the Play operation:
    1. Sets all actuators to the current piston value (0.25).
    2. Pokes each actuator at 0.8 then returns it to its previous value.
    3. When the entire cycle completes, all previous actuator values are restored.

	As this command pokes each actuator at 0.8, it has no effect if all actuators have been set to 0.8 by the Piston or a Command Map.

9.2.8 To Poke a Single Actuator

Note that this command has no effect if the current and adjacent actuators have the same value.

1. Click to select an actuator.
2. Poke the next actuator in one of the following ways:
   - To poke the actuator one higher in number, on the **Toolbar** click **Poke Next**.
   - To poke the actuator one lower in number, on the **Toolbar** click **Poke Previous**.

The following occurs:

- The value of the actuator originally selected is applied to the adjacent (either higher or lower) actuator.
  - If the lowest numbered actuator (0) was the selected actuator, the Poke Previous operation will wrap to the highest numbered actuator.
  - If the highest numbered actuator was the selected actuator, the Poke Next operation will wrap to the lowest numbered actuator.
- The value of all other actuators may change depending upon the starting state as follows:
  - If the actuators have been set to a single value by the piston or by the Zero button, with or without any individual actuator values manually changed, after the poke all other actuators, including the previously selected one and any that had been changed from the Piston or Zero value, are returned to the Piston value.
  - If a Command Map has been applied, with or without any individual actuator values manually changed, after the poke all other actuators including the previously selected one are set to the current Piston value (0.25).
- The poked actuator becomes the current selection.
- In the Status Bar the Poke Actuator and Poke Value are not updated.



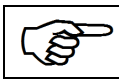
As this command changes the value of an actuator to the value of an adjacent actuator, it has no effect on that actuator if the adjacent actuator had the same value.

It may however change the values of the original and other actuators.

9.2.9 To Save a Shape

1. On the **Menu Bar** click **File**, then click **Save Shape As...**
2. The **Save Shapes As** dialog will display.
3. Browse to the **C:\Program Files\Boston Micromachines\Shapes** folder.
4. In the **File Name** box enter a name for the shape file.
5. Click **OK**.

   The current actuator values will be saved in a new Shape file.
   Unless specified a .txt file name extension will be used.



Windows requires Administrator access to save to any subfolder of C:\Program Files.

   The **AOShapes** dialog will display.

6. In the AOShapes dialog:
   - To return to the DMShapes application click **OK**.
   - To go to the directory where the shape was saved click **Open**.

9.2.10 To Find the Program Version

- On the Menu Bar click **Help**, then click **About**.

  The DMShapes dialog will display with version information for the application and the SDK. Please provide this information when contacting Boston Micromachines for support.

9.2.11 To Close DMShapes

- On the Menu Bar click **File**, then click **Quit**.

  The driver output for all actuators will be set to 0.

  All actuators will return to their un-powered state.

  The DMShapes application will close.

9.3 Using DMShapes with Multiple DMs

The controlling PC can operate more than one DM and Driver combination by using additional instances of DMShapes.

The quantity of attached Drivers is limited by the type of Driver interface.

Interface	Driver Type	Maximum Quantity
USB	Multi Driver	Multiple, only limited by the number of available USB ports
Fiber via S/X-CL™ PCI Express Card	Kilo Class, S Class, and X-CL Class	One

Each instance of DMShapes will connect to the Multi Driver and DM that is specified by the Multi Driver serial number in the Profile file that is loaded. For DMs purchased prior to January 1, 2018, contact Boston Micromachines to enable this functionality.

To connect a single PC to multiple DMs:

1. Install the BMC SDK on the PC per Section 6.1, BMC SDK Software Installation Instructions.
2. Install the DM specific files for each DM per Section 6.2, Device-Specific File Installation.
3. Connect each of the DM and Driver combinations per the appropriate instructions.
4. One at a time, verify each DM and Driver combination per the appropriate instructions.
5. For each DM and Driver combination you want to control:
   a) Open an instance of DMShapes.
   b) Load the Profile file for that DM and Driver combination.

   The Profile contains both the interface type (USB or PCIe) and for Drivers with USB interfaces, the serial number of the Driver.

   - For Profiles that specify a USB interface, the application will connect to each Driver connected to a USB port, verify the serial number of the connected Driver, and, if verified correctly, will control the DM attached to that Driver.
   - For Profiles that specify a PCIe interface, the application will connect to the Driver connected to the PCIe card (if installed), and control the DM attached to that Driver.



DO NOT use the same Profile in more than one instance DMShapes.
Unexpected results will occur.

10. Reference Information

This section contains the following topics:

Section 10.1 Glossary
Section 10.2 Help File Locations
Section 10.3 Multi-DM Mechanical Drawing
Section 10.4 Mirror Mapping for Multi Driver DRV00120-03
Section 10.5 DM Apertures
Section 10.6 Multi Driver DRV00120-03 Mechanical Drawing
Section 10.7 Multi Driver Auxiliary Output DE-9 Details
Section 10.8 Multi Driver Dataflow and Error Detection
Section 10.9 System Performance
Section 10.10 Deflection and Inter-Actuator Coupling

10.1 Glossary

Actuator

An **Actuator** is a microelectromechanical systems (MEMS) element comprised of an electrode attached to a silicon substrate and a flexure element attached to a post that is attached to the underside of a mirror surface. A voltage applied to the electrode attracts the flexure element, thus changing the height of the mirror surface above the actuator. Actuators in a DM are configured in an array. Acting in concert, this actuator array can control the mirror surface to create shapes from flat to complex 3D surfaces.

Actuator Map

A convention for relating the actuator positions on a DM with respect to the order in which they are listed in a **Command Map**. The sequence of deflections in a **Command Map** are mapped to the DM actuators in the sequence the DM actuators are listed in the Actuator Map. Actuator Map files have the file name extension **.map** and are stored in the **Program Files\Boston Micromachines\Map** folder. A DM of a particular size may have more than one Actuator Map corresponding to different packaging (e.g. cable pin out) configurations.

Amplifier Slew Rate

The rate at which output voltage of the high-voltage amplifier signal from the driver electronics move from one output level to another output level, expressed as a change in voltage per unit time.

Amplifier Slew Time

The time it takes the output voltage of the high-voltage amplifier signal from the driver electronics to move from their current state to a new state. The **Amplifier Slew Time** is the difference between the start and end voltages divided by the **Amplifier Slew Rate**.

Command Map

A set of deflections used to drive a Deformable Mirror surface to a specific **Shape**. A Command Map for a particular DM model must conform to the defined **Actuator Map** for that DM. A Command Map must contain a deflection value, even if zero, for each actuator in the DM array. Command Map files have the file name extension .**csv** or **.txt** and are stored in the **Program Files\Boston Micromachines\Shapes** folder.

Continuous DM

A Deformable Mirror where the reflective mirror surface extends continuously (without any breaks) over the entire actuator array. In Continuous DMs, actuator arrays can be linear, square grid, or other type of pattern. Coupling between the mirror surfaces over adjacent actuators is typically between 13 to 22 percent of the desired deflection.

Data Latency

The time between when the PC first starts sending a Frame of data to the Driver and when the Driver has processed that data and is ready for another Frame. The Data Latency is inversely proportional to the Frame Rate.

Glossary (continued)

Deformable Mirror (DM)

A microelectromechanical systems (MEMS) device consisting of a reflective mirror surface whose position is controlled by an array of miniature electro-mechanical actuators under the reflective surface.

DM System

A DM and Driver combination.

Driver

A Driver is an electronics module that sends high voltage signals to the actuators on a DM. The driver is controlled by a PC through a digital interface such as USB or CameraLink and appropriate PCIe adapter card. Each series of DMs typically has a standard and one or more high speed Driver options.

Flat Map

A type of **Command Map** that drives the Deformable Mirror surface to a plane that is parallel to the silicon wafer base. Flat Maps for a DM are established by Boston Micromachines through interferometric analysis and are unique and custom to only that DM-Driver combination. Boston Micromachines typically supplies a Flat Map with each DM at 50% deflection for use in establishing a mirror surface for optical alignment and calibration. The Flat Map file has a .txt file name extension and as with all **Command Map**s is stored in the Program Files\Boston Micromachines\Shapes folder.

Frame Rate

The number of Frames of data that can be sent in a given time interval, expressed as frames per second. The Frame Rate is inversely proportional to the Data Latency.

Frame Size

The amount of data required to define all actuators on a DM.

Low Order Curvature

A relatively small deviation from flatness in a low-order Zernike shape.

Mechanical Response Time

The time it takes an actuator to move a given distance, typically measured and specified as the 10% - 90% deflection time in µseconds for a 100nm step.

Play

To move actuators in sequence, typically by applying a value from the previous actuator.

Poke

To move a single actuator.

Glossary (continued)

Profile

A configuration file that is matched to a unique DM and Driver combination. A Profile contain information such as DM array size, actuator mapping (by referencing an external **Actuator Map** file,) voltage limits, the driver PC interface type, and other settings. Profile file names contain the serial number of the DM device to which they apply. Profile files have the file name extension .dm and are stored in the Program Files\Boston Micromachines\Profiles folder.

As installed, the Profiles directory contains generic profiles for demonstration purposes. These generic profiles contain correct actuator mapping and limit driver output to 150 volts to protect mirrors from overvoltage conditions.

Segmented DM

A Deformable Mirror where the reflective mirror surface is segmented and the number of mirror segments is equal to or less than the number of actuators in the entire actuator array. In Segmented DMs, actuator arrays can be linear, square grid, or other type of pattern. Coupling between the mirror surfaces of adjacent segments is zero.

Mirror segments in Segmented DMs can be controlled by one or more actuators.

- With one actuator per mirror segment, the segment can move in a single direction.
- With two actuators per mirror segment, the segment can move in a single direction and tilt in one plane.
- With three actuators per mirror segment, the segment can move in a single direction and tilt in any plane.

Shape

The physical configuration of the deformable mirror. The DM's shape is controlled by the deflections contained in a **Command Map** sent to the DM actuators in the sequence specified in the **Actuator Map**.

System Latency

A measure of the overall performance of the DM and Driver system. System Latency is comprised of **Data Latency**, **Amplifier Slew Time**, and the DM **Mechanical Response**.

10.2 Help File Locations

File	Location
Multi-DM System User Manual	C:\Program Files\Boston Micromachines\Doc
LabVIEW Getting Started	C:\Program Files\Boston Micromachines\Doc
MATLAB Getting Started	C:\Program Files\Boston Micromachines\Doc
Python Getting Started	C:\Program Files\Boston Micromachines\Doc
C/C++ Getting Started	C:\Program Files\Boston Micromachines\Doc
C/C++ API	C:\Program Files\Boston Micromachines\Doc\html
Python API	C:\Program Files\Boston Micromachines\Doc\python\html
LabVIEW Getting Started	C:\Program Files\Boston Micromachines\LabView

10.3 Multi-DM Mechanical Drawing

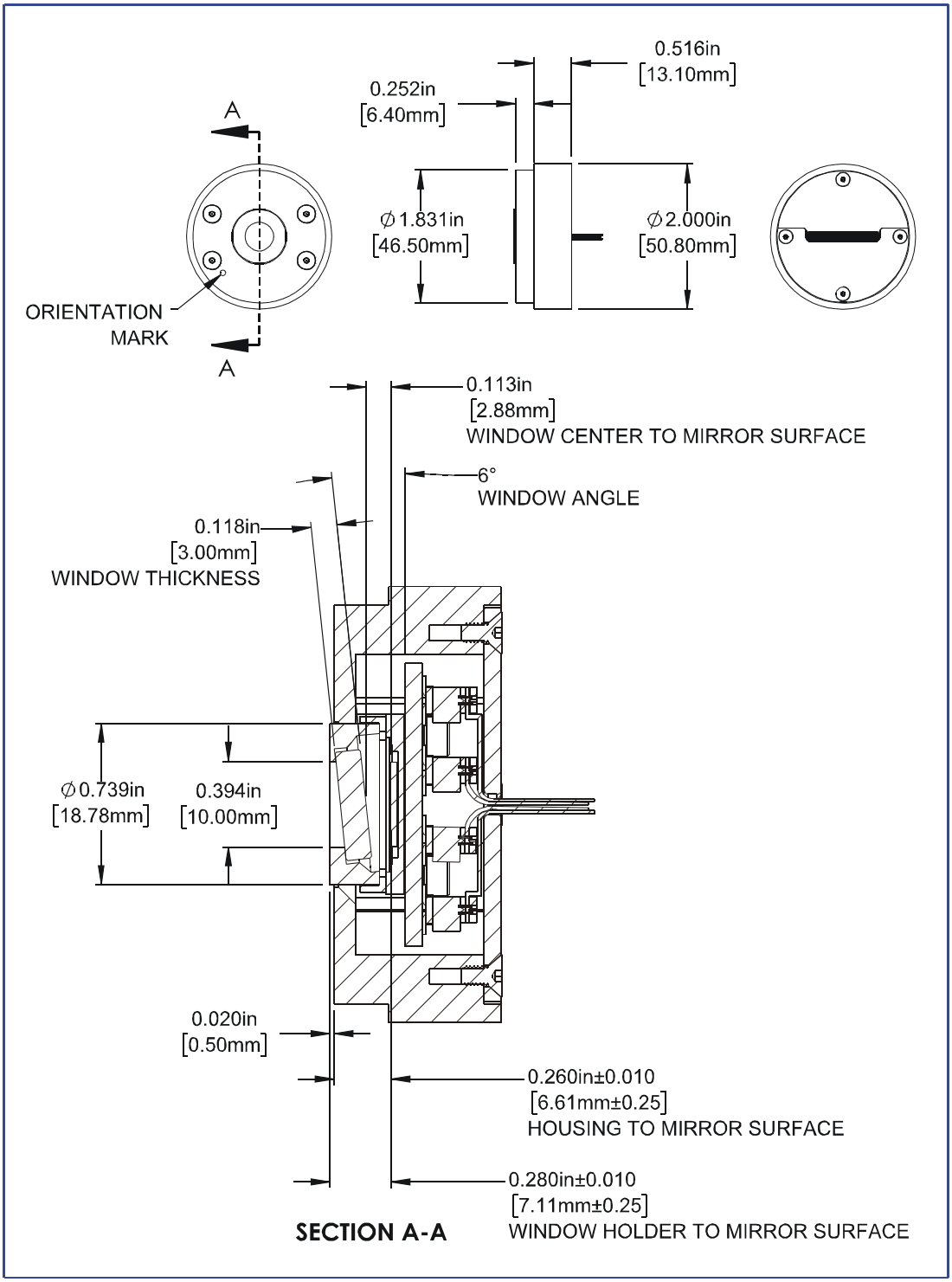


Figure 8 - 10.3 - Multi-DM Mechanical Drawing

10.4 Mirror Mapping for Multi Driver DRV00120-03

The actuator numbers on the Multi-DM are designated per Figure 9 - DM Actuator Map.

- The radial orientation of the actuator array to the DM housing is indicated by the orientation mark on the mirror side of the housing.

☞	Note that in some cases this may differ from the orientation shown in DMShapes.

- Actuator numbering starts at zero (0).
- The active actuator grid is surrounded by 2 rows of inactive actuator-sized mirror elements represented by grey in the Actuator Map.

☞	Deflecting the entire array, but not these edge rows, can provide a "raised edge", often useful as a reference point for centering and positional calibration.

    - On Continuous DMs these mirror elements are continuous within the actuated area.

☞	Completely surrounding actuators on the edges of the active array with mirror surfaces tends to constrain them in a manner similar to actuators within the array that are always surrounded by adjacent mirror surfaces. This contributes to making these edge actuators respond more like Actuators within the array.

    - On Segmented DMs these elements are segmented just like those within the actuated area.

- When using a continuous DM, the displacement of a single actuator at the edge of the active actuator array should follow the Command vs. Deflection chart for a single actuator included with the specific serialized DM.

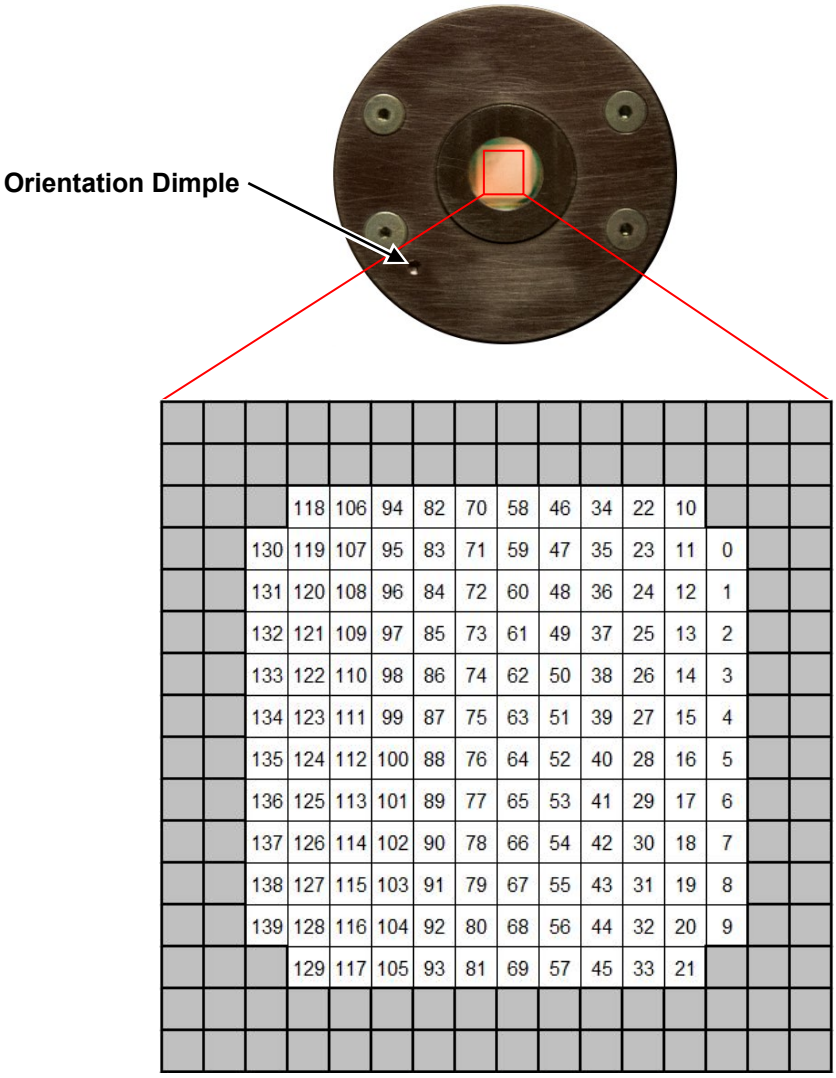


Figure 9 - DM Actuator Map

10.5 DM Apertures

In order to effectively use a deformable mirror, an understanding of the types of apertures, how they are calculated, and how they cover or are contained within the DM's reflective surface, is necessary.

Each type of aperture is different depending upon whether the DM is continuous or segmented.

A full explanation of the three types of apertures follows.



For clarity, the examples in this section depict a Multi-C DM.

The descriptions and formulas given apply to all other types of BostonMicromachines' DMs except for the Hex series.

This section contains the following topics:

Section 10.5.1 The Full Aperture

Section 10.5.2 The Active Aperture

Section 10.5.3 The Recommended Optical Aperture

10.5.1 The Full Aperture

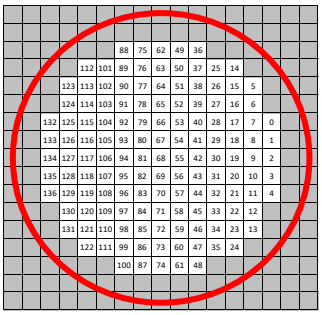
The Full Aperture (FA) is the largest circular region that fits within the DM's reflective surface. The Full Aperture is what you see when looking directly at the DM, and is also known as the Unpowered Surface Figure.

As it is not entirely controllable, the Full Aperture is typically not used, but is useful to know if the application calls for overfilling the useful area.

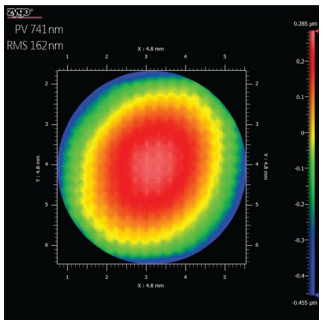
10.5.1.1 The Full Aperture for Continuous DMs

Continuous DMs have two or more rows of inactive actuators outside of the controllable actuators. The reflective area extends to the outermost inactive actuators.

The diameter of the Full Aperture is ([actuators across] + 3) x [pitch]



Full Aperture (red circle) overlaid on the actuator map

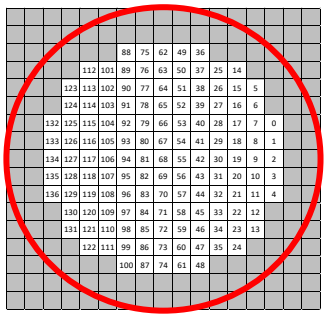


Surface scan of the Full Aperture

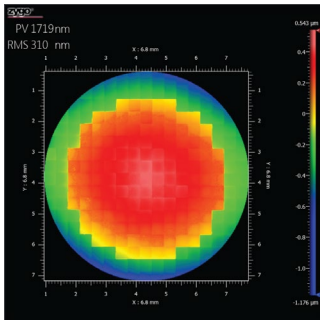
10.5.1.2 The Full Aperture for Segmented DMs

Segmented DMs have two or more rows of inactive actuators, outside of the controllable actuators. Each of these inactive actuators has a full size reflective segment. The reflective area extends to the outermost edge of the outermost reflective segment.

The diameter of the Full Aperture is ([actuators across] + 4) x [pitch]



Full Aperture (red circle) overlaid on the actuator map



Surface scan of the Full Aperture

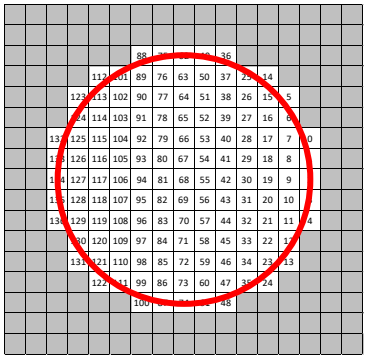
10.5.2 The Active Aperture

The Active Aperture (AA) is the largest circular region
that fits within the **displaceable controllable area** of the DM surface.

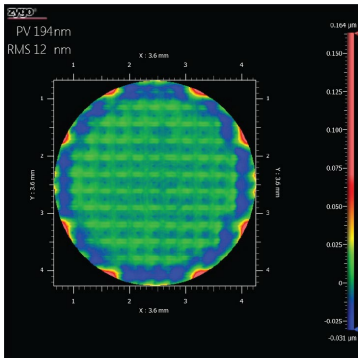
10.5.2.1 The Active Aperture for Continuous DMs

For continuous DMs, the Active Aperture is a circle inscribed within the outer controllable actuators. The area within the Active Aperture is displaceable **but not fully controllable at the edges** because the controllable outer actuators are coupled to actuators further out that cannot be controlled.

The diameter of the Active Aperture is ***([actuators across] -1) x [pitch]***



Active Aperture (red circle)
overlaid on the actuator map

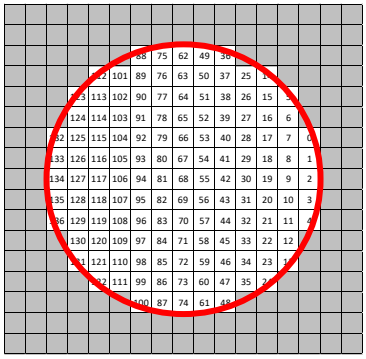


Surface scan of the
flattened Active Aperture

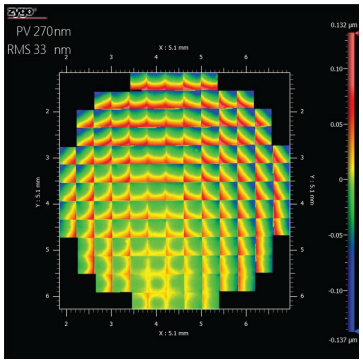
10.5.2.2 The Active Aperture for Segmented DMs

For segmented DMs, the Active Aperture is a circle inscribed within the outer controllable segments. The area within the Active Aperture **is fully controllable**.

The diameter of the Active Aperture is ***[actuators across] x [pitch]***



Active Aperture (red circle)
overlaid on the actuator map



Surface scan of the
flattened Active Aperture

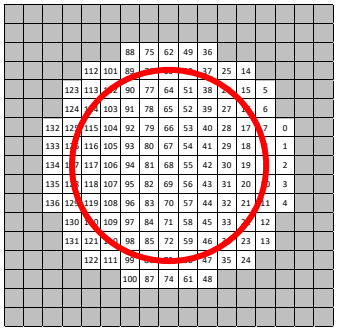
10.5.3 The Recommended Optical Aperture

The Recommended Optical Aperture (OA) is the largest circular region that fits within the **displaceable FULLY controllable area** of the DM surface.

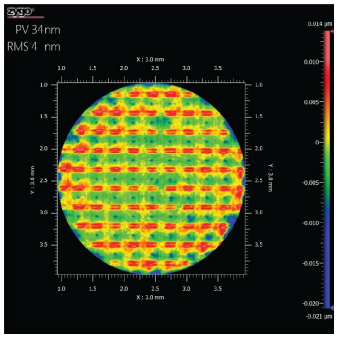
10.5.3.1 Recommended Optical Aperture for Continuous DMs

For continuous DMs, the Recommended Optical Aperture is a circle inscribed within the next actuator in from the outer controllable actuators. Like the Active Aperture, the area within the Recommended Optical Aperture is displaceable but is also **fully controllable at the edges** because the controllable outer actuators are coupled to actuators further out that can also be controlled.

The diameter of the Recommended Optical Aperture is ***([actuators across] -3) x [pitch]***



Recommended Optical Aperture (red circle) overlaid on the actuator map

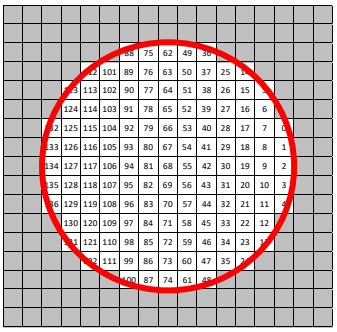


Surface scan of the flattened Recommended Optical Aperture

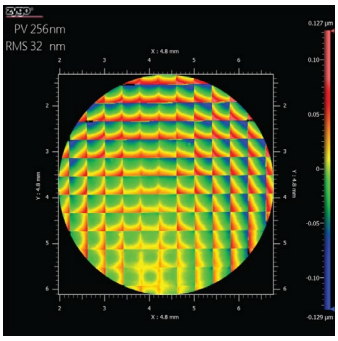
10.5.3.2 The Recommended Optical Aperture for Segmented DMs

For segmented DMs, the Recommended Optical Aperture is a circle inscribed within the outer controllable segments. The Recommended Optical Aperture is the same size as the Active Aperture as no interactuator coupling exists.

The diameter of the Recommended Optical Aperture is ***[actuators across] x [pitch]***



Recommended Optical Aperture (red circle) overlaid on the actuator map



Surface scan of the flattened Recommended Optical Aperture

10.6 Multi Driver DRV00120-03 Mechanical Drawing

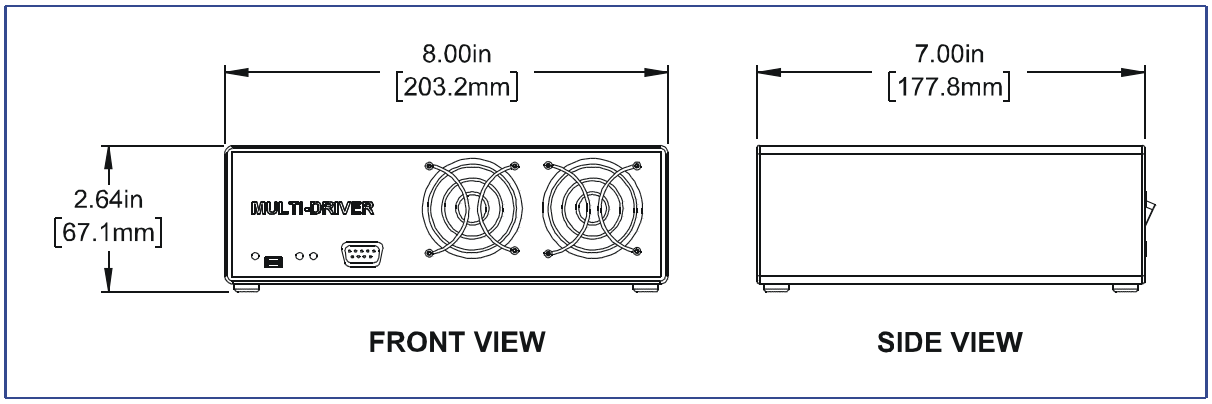


Figure 10 - Multi Driver DRV00120-03 Mechanical Drawing

10.7 Multi Driver Auxiliary Output DE-9 Details

The 9-pin female connector on the Multi Driver's front-panel (see Figure 4 - Front Panel of Multi Driver) provides synchronization and temperature alarm outputs, and four customizable low-voltage analog outputs.

Timing information is provided by the Frame-Sync Output on Pin 2.

When a transfer from the USB FIFO to the DACs is active (about 32µs per cycle) the Frame-Sync Output is set high (3.3V) and when not active, i.e. between frames, the output is set low. The minimum low time is 1µs.

The Multi Driver enclosure temperature information is provided by the Over-Temperature Error Output on Pin 6.

When the temperature in the Multi Driver enclosure has exceeded 50° C, the Over-Temperature Error Output is set high (3.3V) and when under that temperature the output is set low.

Monitoring up to four actuators or program control of external devices is effected through the four Low-Voltage Outputs on Pins 3, 4, 8, and 9.

The output on these pins can be scaled between 0 and 5V in the same way that actuator outputs on the 37 pin J1-J4 connectors are scaled between 0 and 300V. Each pin is addressed programmatically in the same manner as an actuator. Pin to actuator mapping is as indicated in the table below. Utilizing these outputs requires a modified DM profile.



To obtain this modified DM profile please contact Boston Micromachines.

The pins are numbered as shown in Figure 11 - Multi Driver Front-Panel DE-9 Connector.

The connector pinout. is provided in Table 6 - Multi Driver Front-Panel DE-9 Outputs.

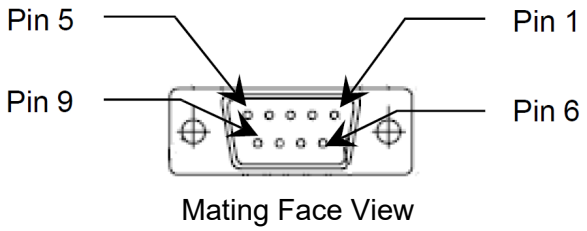


Figure 11 - Multi Driver Front-Panel DE-9 Connector

Table 6 - Multi Driver Front-Panel DE-9 Outputs

Pin	Description
1	General-Purpose Host Output
2	Frame Sync Out
3	Low-Voltage Out A157
4	Low-Voltage Out A159
5	Ground
6	Over-Temperature Error Out
7	Ground
8	Low-Voltage Out A158
9	Low-Voltage Out A160

10.8 Multi Driver Dataflow and Error Detection

To control the high voltage power supplies, the Multi Driver contains five (5) digital-to-analog converters (DACs), each with 32 channels, for a total of 160 channels. Of these,

- 140 channels are output to the high voltage power supplies to drive the DM.
- 4 channels are reserved for use as low voltage outputs on the Driver Auxiliary Output DE-9 connector.
- 16 channels are un-used.

Data flows from the PC to the DM as follows:

1. Data for all of the actuators consists of 160 16-bit (2 bytes) output levels, which translates into 320 bytes of data. In the PC, this is bundled with a checksum and sent across the USB interface to the Multi Driver.

2. In the Multi Driver, the built in USB protocol verifies the checksum, and, if validated, loads the data into a FIFO buffer. If the checksum is not validated the data send is retried.

3. The DACs are loaded in parallel, one channel at a time. First, data from the FIFO is pulled out in groups of 5 16-bit words, one for each of the 5 DACs. This data is formatted properly for the DACs, and then loaded into the same channel in each DAC. This process takes 1µs.

4. The cycle repeats with 5 new words for the next DAC channel until all 32 channels of the DAC are loaded. This takes in total 32µs.

   Note that if the FIFO does not go empty exactly on a 320 byte boundary, an error condition, handled as described below, is generated.

5. Once fully loaded, the data in the DACs is immediately used to control the high voltage power supply outputs to the DM actuators.

6. After the last DAC channel is loaded, and a short 1µs pause, the hardware is ready for the next packet if and when one is sent.

Table 7 - ERROR LED Codes

ERROR LED State	Meaning
Off	Neither of the errors described below are present.
Illuminated Solid	The USB FIFO has gone empty before all 32 DAC channel groups have been received. This most likely indicates an error due to the host software sending a packet that is less than 320 bytes in size. This is usually caused and cleared by the host software. This error immediately sets all actuator values to 0. This error condition will be cleared if the FIFO subsequently goes empty exactly on a 320-byte boundary.
Illuminated Blinking	The temperature in the Multi Driver enclosure has exceeded 50° C. When this occurs: • An over-temperature condition is reported on the DE-9 connector. See Section 10.7, Multi Driver Auxiliary Output DE-9 Details • An over-temperature condition is reported over the USB connection to the host PC. • The high-voltage supply is disabled until the power is removed from the Multi Driver and the internal enclosure temperature drops below 50° C.

10.9 System Performance

System performance, also referred to as system latency, is a measure of the time:

- **Starting** when the host PC first starts sending DM data to the Driver
- **Ending** when the DM mirror reaches its desired shape.

The total system latency is comprised of the time it takes to complete three sequential stages of the DM control process.

Stage	Performance Factor
Data is sent from the host PC to the Driver and processed	Data Latency Time Determined by the data transmission speed and the driver processor and DAC speed.
Amplifiers are changed to their desired value	Amplifier Slew Time Determined by the amplifier slew rate and the magnitude of the change in voltage level.
DM actuators change to their desired value	Mechanical Response Time Determined by the physical characteristics, primarily the mirror architecture, of the DM.

These stages, along with some necessary terms and concepts, are now described in greater detail.

Frame Size

The amount of data required to define all actuators on a DM is known as the DM Frame Size. The Frame Size scales with actuator count. For example:

- Multi-DMs have Frames comprised of 160 16-bit (2 bytes) output levels, which translates into 320 bytes of data.
- A Kilo DM, with just over a thousand actuators, each defined by 16-bit (2 bytes) output levels, has a Frame sizes of 2kB of data.

Data Latency

The first component of total system performance is the time it takes to transmit a Frame of data from the PC to the driver, process (decode) that data, and load it into the digital-analog converters (DACs). This time period is known as the Data Latency time.

The Data Latency time is dependent upon the length of two overlapping operations:

- **The time it takes the PC to transmit a single Frame of data to the Driver.**

  The start of this part of the process is the start of the Data Latency time period. The length of the transmission time is dependent upon the size of the Frame and the speed of the PC to Driver connection.

  Note that although for some drivers the host PC can send data for individual or multiple actuators, Data Latency is measured using a full Frame of data.

- **The time it takes the Driver processor to decode and write that data to the DACs.**

  This part of the process begins almost immediately (typically within a few µseconds) after the Driver starts receiving data, and it typically extends past when the data transmission ends. The length of the processing and loading operation is dependent upon the speed of the on-board microprocessor (typically a CPLD or an FPGA) and the speed of the DACs.

These two components of Data Latency are shown in **Figure 12**. Note that writing to the DACs begins right after the data receive starts and continues after the data receive ends.

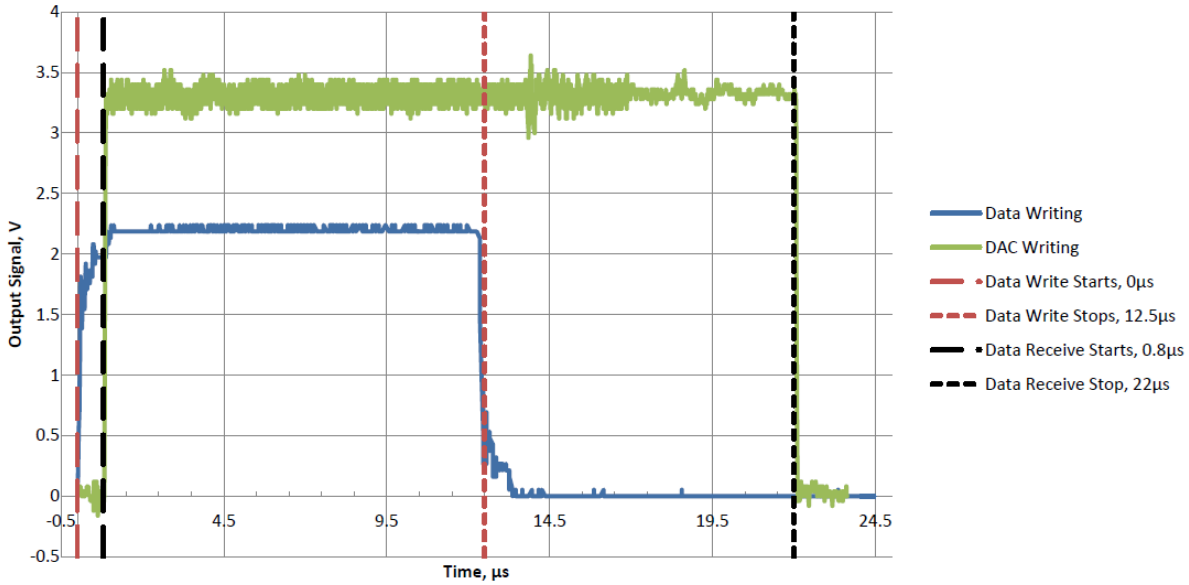


Figure 12 - Kilo-DM Data Latency

This graph is for a Kilo-DM using a Kilo-class Driver. Other DM sizes are similar. Boston Micromachines measures and publishes the Data Latency for each DM and Driver combination.

Frame Rate

It is often useful to look the Data Latency component of system performance in terms of a frequency instead of a time period.

When expressed in that manner, the number of Frames of data that can be sent in a given time interval, in this case one second, is known as the **Frame Rate**. The Frame Rate of Boston Micromachines' DM and Driver combinations is typically in the kHz range.

The Frame Rate is inversely proportional to the Data Latency time.

Driver Comparison

The Data Latency period \ Frame Rate frequency can be optimized by using a faster Driver and data connection combination. All Boston Micromachines DM models have both a standard and high speed driver available.

Amplifier Slew Rate

Another necessary term is Amplifier Slew Rate.

The high voltage amplifiers in the Driver must change their output voltages to move the mirror from one shape to another. The rate of change (or "slew") in the output voltage per unit time is known as the **Amplifier Slew Rate**.

The amplifiers in Multi- and Kilo-class Drivers slew at 2V/µs.
The amplifiers in X-class and S-class Drivers slew at 20V/µs.

Amplifier Slew Time

As soon as the entire Frame of digital data is fully loaded into the DACs, the analog values for all of the actuators are sent to the high-voltage amplifiers. Each amplifier then changes (or "slews") its output voltage from its current value to its new value. The time this takes is known as the **Amplifier Slew Time**.

The Amplifier Slew Time is determined by two factors:

- The Driver's Amplifier Slew Rate.
  The faster the slew rate, the shorter the Amplifier Slew Time.
- The magnitude of the change in the amplifier output voltage.
  The greater the difference between the current output state and the desired output state, the longer the Amplifier Slew Time.

Table 8 - Driver Specifications

DM Type	Driver Type	Data Connection	Data Latency	Frame Rate	Amplifier Slew Rate
Multi-, Multi-ESF, Hex-111	Multi-	USB 2.0	fixed 125µs	8 kHz	2V/µs
Multi-, Multi-ESF Hex-111	X-class	Camera Link	under 5µs	up to 100 kHz	20V/µs
492, 648, Kilo, 2K, 3K, 4K, Hex-255, Hex-507, Hex-1011	Kilo-class	SFP+ Fiber Link	under 22µs	up to 45 kHz	2V/µs
492, 648, Kilo, 2K, Hex-255, Hex-507, Hex-1011	Kilo-class Low Latency	SFP+ Fiber Link	under 17µs	up to 60 kHz	2V/µs
492-S, Kilo-S, Hex-507-S, Hex-1011-S	S-class	SFP+ Fiber Link	under 20µs	up to 50 kHz	20V/µs

Mechanical Response Time

The final component of total system performance is the time it takes an actuator to move the desired distance after the application of a voltage change. This is known as the Mechanical Response Time.

The Mechanical Response Time is determined primarily by the mirror architecture of the DM. Actuator pitch and stroke length are the major factors that affect mechanical response time. DMs with larger pitches and longer strokes have larger, more flexible actuators, and more flexible actuators take longer to respond. The surface type of the DM (continuous or segmented) also contributes to mechanical response time to a lesser but measurable degree.

The Mechanical Response Time is quantified as the time it takes an actuator to go from 10% to 90% deflection when making a small (100-150nm) step. BMC DMs have mechanical response times that range from under 20 microseconds to approximately 100 microseconds, depending on the DM model.

Mechanical response time can be a relatively small part of the total system performance if strokes or step sizes are small or a relatively large part of the total system performance if strokes or step sizes are larger.

Application Examples and System Performance Considerations

The nature of the DM application will determine which components of the total system performance metric are most important.

- Some applications are more concerned with sending commands as quickly as possible. In these cases the Data Latency and/or the Amplifier Slew Rate are most important.
- Other applications need to detect a settled wavefront for analysis in the control loop. In these cases the Mechanical Response Time is most important.

If you require assistance in analyzing your application, please contact Boston Micromachines.

10.10 Deflection and Inter-Actuator Coupling

For segmented DMs, the actual displacement is determined only by the magnitude of the command sent to the actuator.
By their nature, segmented DMs have no inter-actuator coupling.

For continuous DMs, the actual displacement is determined by:

- The magnitude of the command sent to the actuator.
- An offset caused by inter-actuator coupling.

The magnitude of this offset is related to the stroke, the actuator spacing, and the relative displacement of adjacent actuators.

As the mirror surface that is directly controlled by an individual actuator is attached to the mirror surfaces over adjacent actuators, the position of those adjacent surfaces negates the full effect of the actuator.

The closer the surrounding surfaces are to the actuator's driven position the greater the coupling.

While quantifying inter-actuator coupling becomes complicated when the adjacent mirror surfaces are at differing positions, it is relatively straightforward when the adjacent surfaces are un-powered.

The DM- and Driver-specific System Data Sheet supplied with the system contains Deflection vs. Command curves for the following scenarios:

- **A single actuator with the adjacent surfaces un-deflected.**

  This is a common occurrence at the edges of the active actuator array that is bordered by 2 actuator-sized rows of mirror surface that do not have actuators. Inter-actuator coupling is at its maximum in this scenario, to the point that in larger stroke models full deflection is not possible.

- **A contiguous 4 x 4 actuator array with the adjacent surfaces un-deflected.**

  This is a more common occurrence within the active actuator array. Due to the fact that in this case 16 actuators are pulling on the adjacent un-powered actuators, inter-actuator coupling at the center of this array is significantly reduced from the single actuator scenario described above.



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