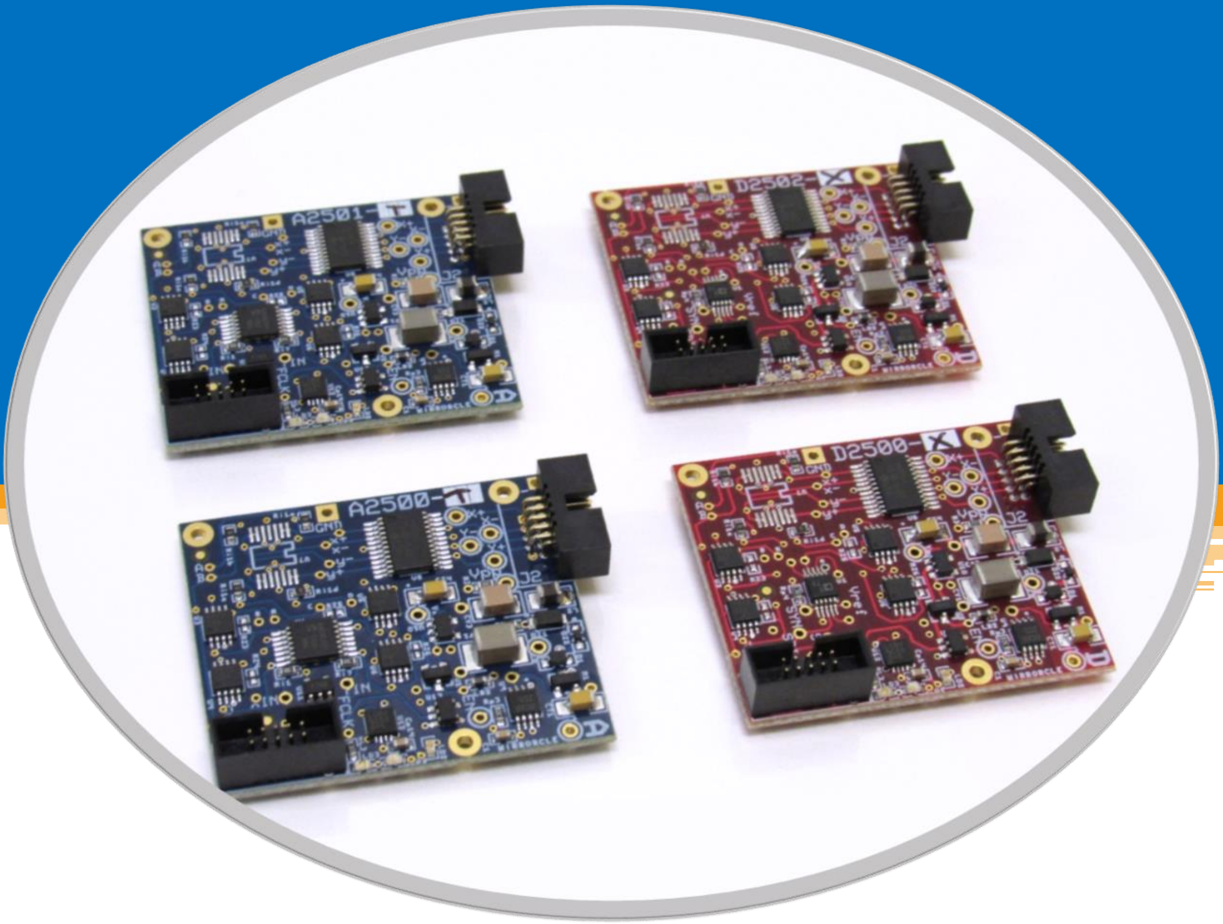
Mirrorcle MEMS Drivers 5.x
User Guide

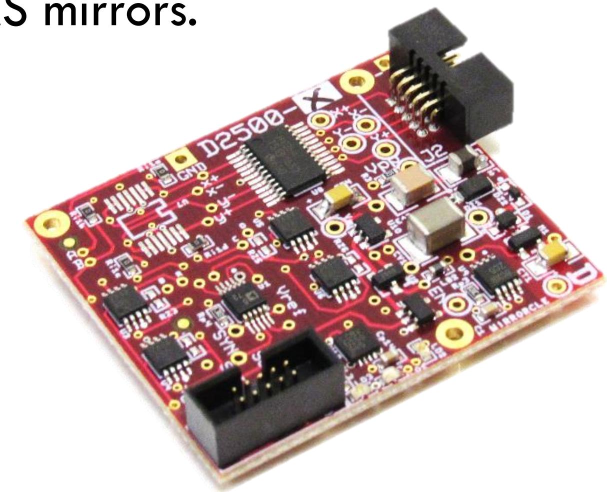


Mirrorcle Technologies, Inc.

Last Revised: Jul. 2021

Overview

There are two types of Mirrorcle MEMS Drivers: Digital input (with SPI inputs) and Analog Input (Bias Differential Quad-channel, with two analog inputs). Both drivers convert low-voltage user inputs into two differential pairs of high voltage analog outputs. These compact drivers include programmable 5th order low-pass filters (default) or 2nd order continuous time low-pass filters (option for larger quantities) for smoothing of the output voltages. These MEMS drivers are designed and optimized for the driving of Mirrorcle Technologies' quasistatic, resonant-quasistatic, and resonant MEMS mirrors.



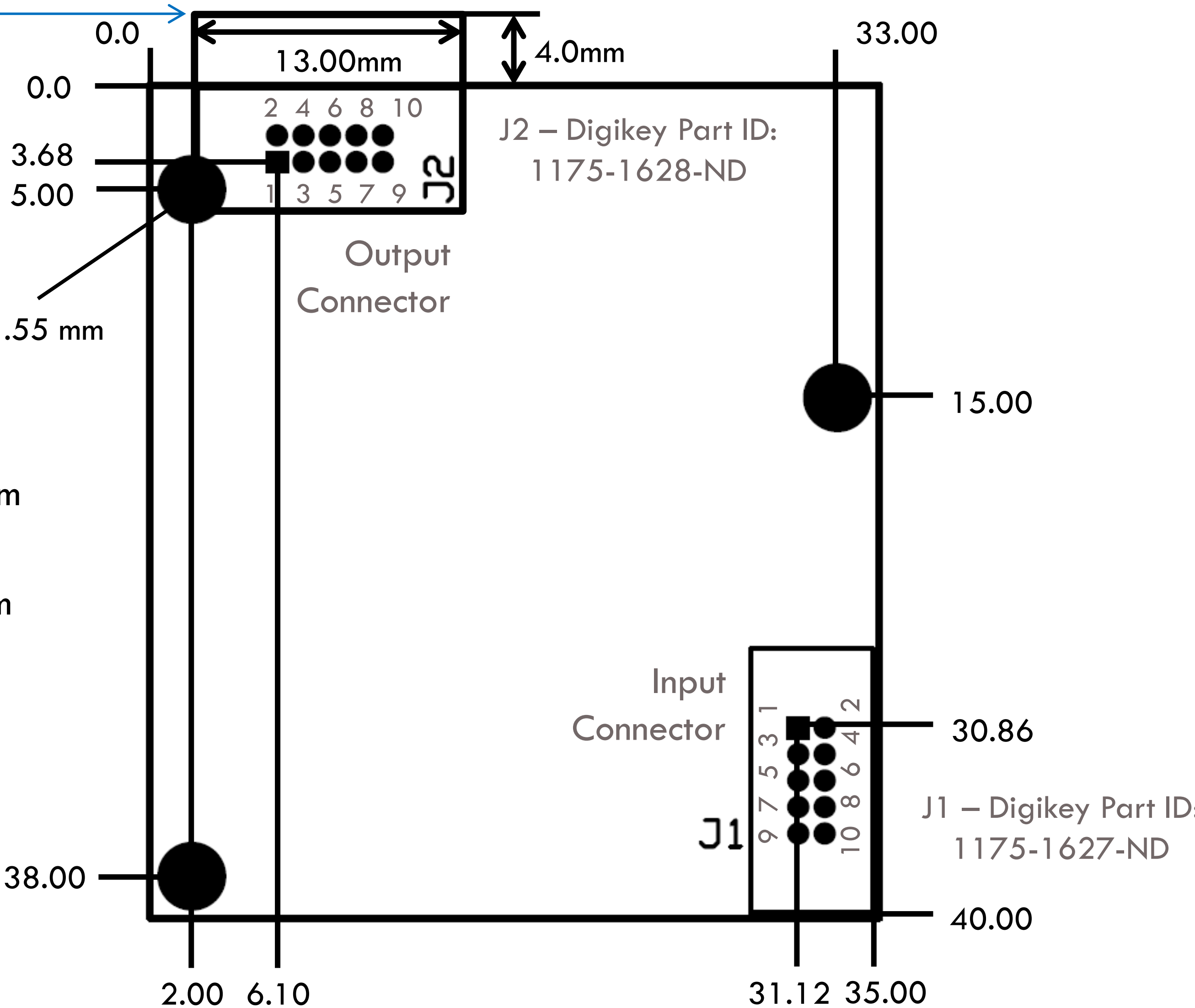
Dimensions approx.: 35mm x 40mm x 9.3mm

Features

- Low voltage supply and low power consumption (<100mW)
- Four high voltage output channels (two biased differential pairs) (~0V up to 200V)
- Embedded regulated DC/DC converter creates high voltage supply from the +5VDC supply (VDD)
- Four embedded Bessel low pass filters. User-provided clock sets cut-off frequency for all four LPFs with separate control for X and Y axis.
- (Optional for larger quantities) Four continuous time low pass filters.
- Small form factor, approximately ½ of a credit card size
- Power supply monitoring with auto-shutdown
- Bandwidth up to 25kHz (governed by the user-set LPFs)
- Analog Input – Two analog inputs for X and Y axis drive (+/- 10V)
- Digital Input – SPI digital inputs for X and Y axis drive (3VTTL)

Board Dimensions and Connector Locations

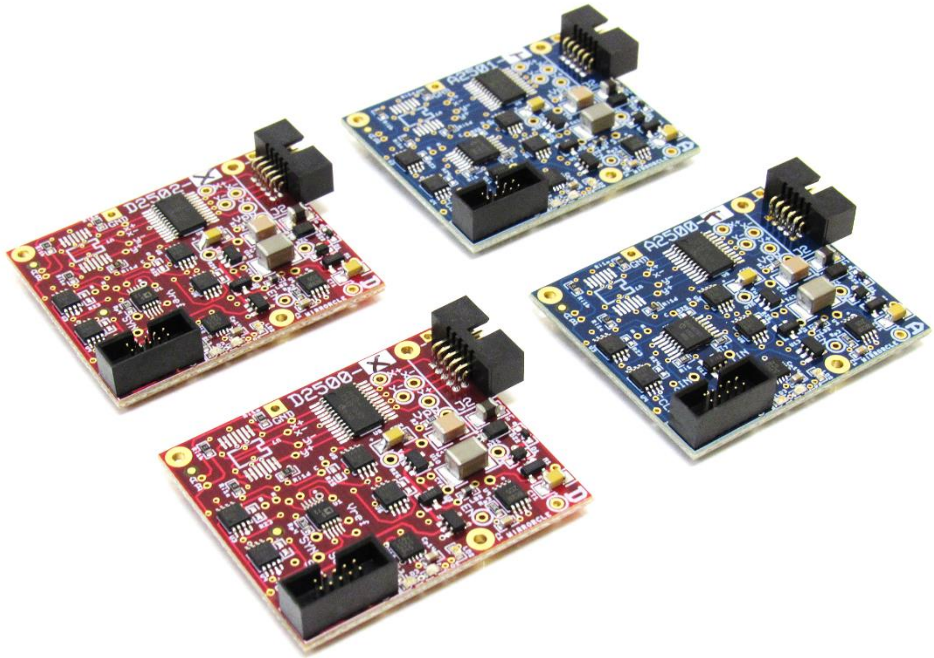
Connector stands out
4mm from edge of PCB



All dimensions are in mm

Dimensions approx.:
35mm x 40mm x 9.3mm

Driver Serial Number (S/N) Format



Driver S/N Format:

Analog Input: A#### - #

Digital Input: D#### - #

Letter A or D followed by at least 4-digit number.

Final letter designation for driver output range:

B: 160V, Vbias = 80V

T: 180V, Vbias = 90V

X: 200V, Vbias = 100V

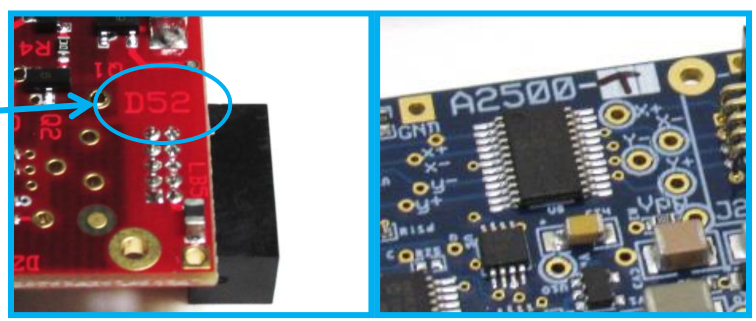
On backside of PCB

Design Version:

D## for Digital Input

A## for Analog Input

Example: D52



Example:

A2500 – T

MEMS Driver – Analog Input, with 180V driver output range (Vbias = 90V)

Driver Output Range Types

- Different MirrorcleTech MEMS Mirrors products may have different required or recommended driving voltage ranges to achieve best performance.
- The lowest-voltage driving range or category is “Boost 160” or B160 which has following specs:
  - Vbias = 80V, Vdifference = -160V to 160V
- The **typical driving range or category is “Turbo 180” or T180** with specs:
  - Vbias = 90V, Vdifference = -180V to 180V
- The next category is “eXtreme 200” or X200 with specs:
  - Vbias = 100V, Vdifference = -200V to 200V
- The Analog Input MEMS Driver has preset Range since the driver contains the Bias Differential Quad-channel circuit, where the bias cannot be adjusted
- The Digital Input MEMS Driver is typically X200 Range, providing the user to utilize the full voltage range since to set any Vbias and Vdifference since all 4 output channels are set via software.

Part Name, Numbering and Range

- To accommodate driving the different MirrorcleTech MEMS Mirrors products to achieve best performance, there are a few different options available:
  - **MEMS Driver – Analog Input** is a simpler interface, with three different voltage ranges, B160, T180 and X200 (**T180 being the most recommended**). These drivers require the user to provide a ±10V input for the X and Y axis, which corresponds to the Vdifference of the output range of the specific driver. For example, a T180 driver would correspond ±10V with a 0-180V Vdifference, about a Vbias of 90V. The maximum voltages should be checked with the specific device before operation, to prevent any damage to the device.
  - **MEMS Driver – Digital Input** are only recommended for advanced development kit users who have already used the Mirrorcle hardware, and understand the methodology of driving the device directly with all four channels. In this case, the user is required to generate the Biased-Differential-Quad channels correctly. The user is also responsible for setting the correct Vbias and Vdifference limitations, to not damage the device.

Driver Name	Board Version	Interface	Output Range	Part Number
MEMS Driver - Digital Input	5.4 RevB	Digital SPI	0-200V (X200)	DR-10-056-00
MEMS Driver - Analog Input	5.4 RevB	±10V Analog Inputs	0-160V (B160)	DR-11-054-00
MEMS Driver - Analog Input	5.4 RevB	±10V Analog Inputs	0-180V (T180)	DR-11-055-00
MEMS Driver - Analog Input	5.4 RevB	±10V Analog Inputs	0-200V (X200)	DR-11-056-00

J1: Input Connector Pinout and Functions

MEMS Driver - Analog Input

Input: 10 - Pin Header		
J1-Pin	**Name**	**Description**
1	XIN	Analog Input X (XIN)
2	YIN	Analog Input Y (YIN)
3	+5V	VDD (+ 5VDC)
4	GND	Ground
5	EN	MEMS Driver Output Enable
6	N/C	No Connection
7	N/C	No Connection
8	N/C	No Connection
9	FCLK_X	Filter Clock for X-Axis (60x filter cut-off)
10	FCLK_Y	Filter Clock for Y-Axis (60x filter cut-off)

Mating Cable for J1 Connector: – Digikey Part ID: SAM8218-ND

J1: Input Connector Pinout and Functions

MEMS Driver – Digital Input

Input: 10 - Pin Header		
J1-Pin	**Name**	**Description**
1	N/C	No Connection
2	N/C	No Connection
3	+5V	VDD (+ 5VDC)
4	GND	Ground
5	EN	MEMS Driver Output Enable
6	SDI	SPI Data for AD5664R (DIN)
7	SYN	SPI Sync for AD5664R (SYNC_)
8	SCK	SPI Clock for AD5664R (SCLK_)
9	FCLK_X	Filter Clock for X-Axis (60x filter cut-off)
10	FCLK_Y	Filter Clock for Y-Axis (60x filter cut-off)

Mating Cable for J1 Connector: – Digikey Part ID: SAM8218-ND

J2: Output Connector Pinout and Functions

Output: 10 - Pin Header		
J2-Pin	**Name**	**Description**
1	HV_A (X+)	MEMS Channel X+
2	GND	Ground
3	HV_B (X-)	MEMS Channel X-
4	GND	Ground
5	HV_C (Y-)	MEMS Channel Y-
6	GND	Ground
7	HV_D (Y+)	MEMS Channel Y+
8	GND	Ground
9	N/C	No Connection
10	N/C	No Connection

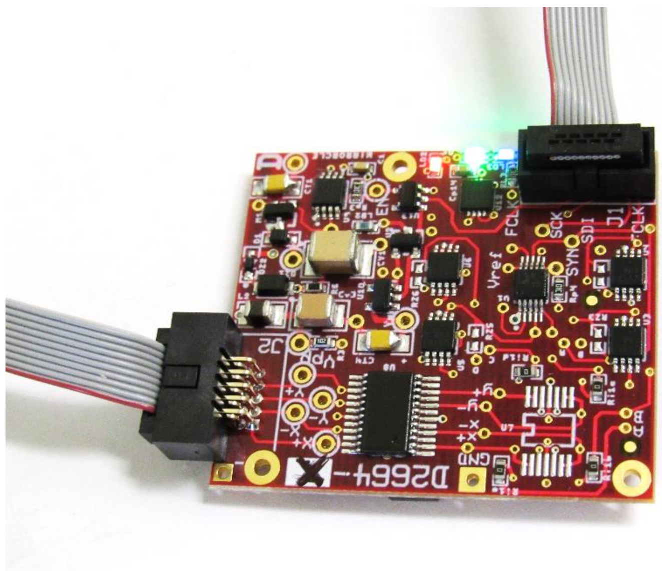
Mating Cable for J2 Connector: – Digikey Part ID: SAM8219-ND

Cables and Connections

- In prototyping quantities (generally <10 units per order), drivers ship with the input and output ribbon cable based on Mirrorcle recommendations:
  - Recommended cable for MEMS Driver input (J1): SAM8218-ND (6” length)
  - Recommended cable for MEMS Driver output (J2): SAM8219-ND (12” length)
- In larger and/or production orders with volume discounts, the cables are not included. Users can choose lengths/types according to their needs.

Driver Input (J1)

Driver Output (J2)



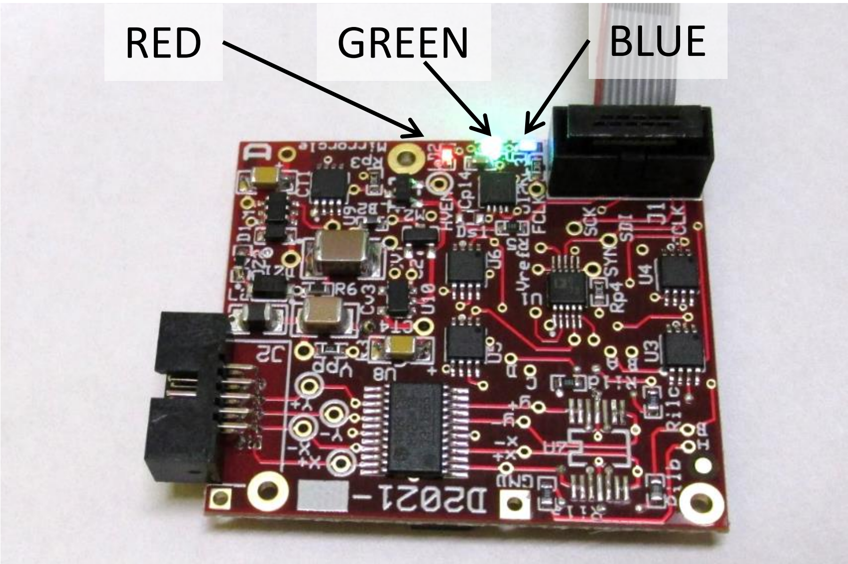
LED Definitions

In active operation of a MEMS driver, following 3 LEDs should all be ON:

LED Color	ON* Status	OFF Status
Green	+5VDC Power Supply	Power is OFF
Red	MEMS Driver Enabled: User set EN to HIGH and provided adequate VDD supply.	MEMS Driver disabled.
Blue	FCLK_Y** clock running (correct use) or HIGH	FCLK_Y is LOW

*Blue LED dims at Filter Clock (FCLK) frequencies > 100kHz

**Only one FCLK is verified by LED, but both must be provided in standard use.



Electrical Specifications - Inputs

Parameter	Sym.	Min.	Typ.	Max.	Units	Conditions
Power Supply						
Supply Voltage	VDD	4.85	5	5.2	V	
Supply Current	I_{DD}	6	7	8	mA	MEMS Driver Disabled
		20	25	30	mA	MEMS Driver Enabled **(100mA transient pulses at start up)***
Logic Inputs – Digital Pins						
Input Low Voltage	V_{INL}	-	0.2	0.4	V	
Input High Voltage	V_{INH}	2.7	3	-	V	See Max High voltage for digital pins below
MEMS Driver Enable	EN			5	V	
Digital SPI	SDI, SCK, SYN			3.3	V	Refer to **AD5664RBRMZ-3** datasheet and **Appendix A** for more information.
Filter Clock Voltage	FCLK_X, FLCK_Y			3.6	V	
Filter Clock						
Filter Clock Frequency	FCLK_X, FLCK_Y	3	-	3000	kHz	Filter Clock input frequency based on MEMS datasheet recommendation.
Analog Inputs						
X and Y analog inputs	XIN, YIN	-10	0	10	V	Refer to **Appendix B**
XIN and YIN input impedance	XIN, YIN		80.6		k Ohm	Effective, to opamp virtual ground

*Note: Power supply should be capable of at least 100mA current to avoid start-up failure. In OEM applications, a capacitor of at least 100uF is recommended at Vdd/GND supply before the MEMS Driver to accommodate

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Electrical Specifications - Outputs

Parameter	Sym.	Min.	Typ.	Max.	Units	Conditions
Driver Outputs						
MEMS Driver Output Range (B160)	HVA_A (X+), HVA_B (X-), HVA_C (Y-), HVA_D (Y+)	0.5	80	160	V	Refer to MEMS datasheet for maximum driving voltages of the MEMS device. (<50pF load)
MEMS Driver Output Range (T180)	HVA_A (X+), HVA_B (X-), HVA_C (Y-), HVA_D (Y+)	0.5	90	180	V	Refer to MEMS datasheet for maximum driving voltages of the MEMS device. (<50pF load)
MEMS Driver Output Range (X200)	HVA_A (X+), HVA_B (X-), HVA_C (Y-), HVA_D (Y+)	0.5	100	200	V	Refer to MEMS datasheet for maximum driving voltages of the MEMS device. (<50pF load)
MEMS Driver Bandwidth		50	-	25000	Hz	Bandwidth limited by Low-Pass Filters. If LPFs are bypassed, max. bandwidth is 25kHz

- MEMS driver output has a low current output capability, <0.05mA, intended to drive open-circuit electrostatic MEMS
- Not intended for larger capacitive loads (<50pF/channel) or long cables

Setting up FCLK_X and FCLK_Y inputs

- User must provide filter clocks for the 5th order Bessel LPFs of both axes (FCLK_X and FCLK_Y). **In standard uses, both are tied to the same clock.**
- **When either of those is not connected, or the clock is not running, output voltages do not update or follow the input.**
- The pins can be driven by ~3.3V CMOS33/TTL signal, 50% duty cycle
- Set clock frequency to the desired filter cut off frequency x 60
  - E.g.: Device datasheet (on the right) states "Recommended LPF cut off freq" of 500Hz, then FCLK Input = 30kHz
  - In cases where advanced users require to bypass the LPFs, 3MHz may be applied for minimal filtering and group delay.
- Filter part: MAX7413

Device Parameters Summary

Device ID : S31191

Actuator Type: A7M20.2

Actuator Mode : Gimbal-less Dual-Axis Quasistatic

Mirror Type and Size : Integrated mirror of 2000um diameter

Mirror Coating : Aluminum

Maximum Mech. Angle - X Axis [degrees] : 4.9996

Maximum Mech. Angle - Y Axis [degrees] : 5.1014

Maximum Vdifference - X Axis [V] : 160

Maximum Vdifference - Y Axis [V] : 159

Driver Bias Voltage (Vbias) [V] : 80

Maximum Mech. Angle - Coupled Axes [degrees] : 6.3902

Resonant Frequency - X Axis [Hz] : 1340

Resonant Frequency - Y Axis [Hz] : 1331

Quality Factor - X Axis : 77

Quality Factor - Y Axis : 76

Recommended LPF Cutoff Frequency (6th Order Bessel) [Hz] : 500

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Example device datasheet shown above.

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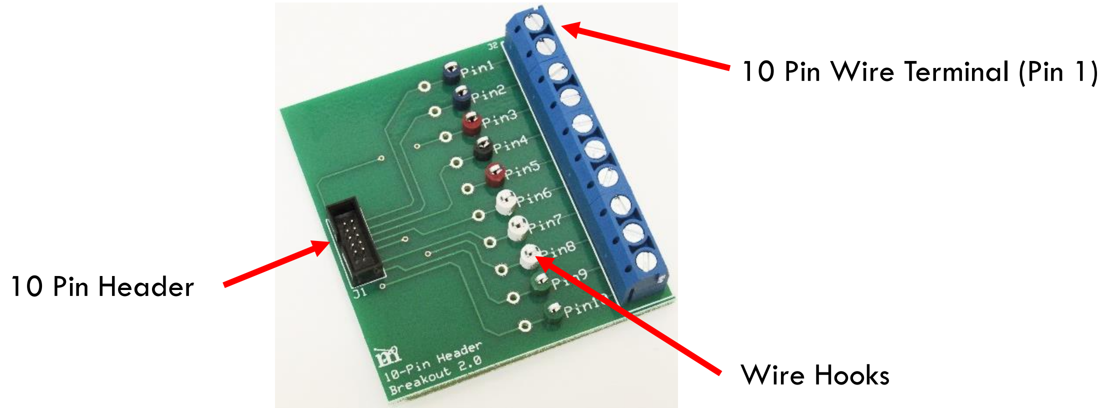
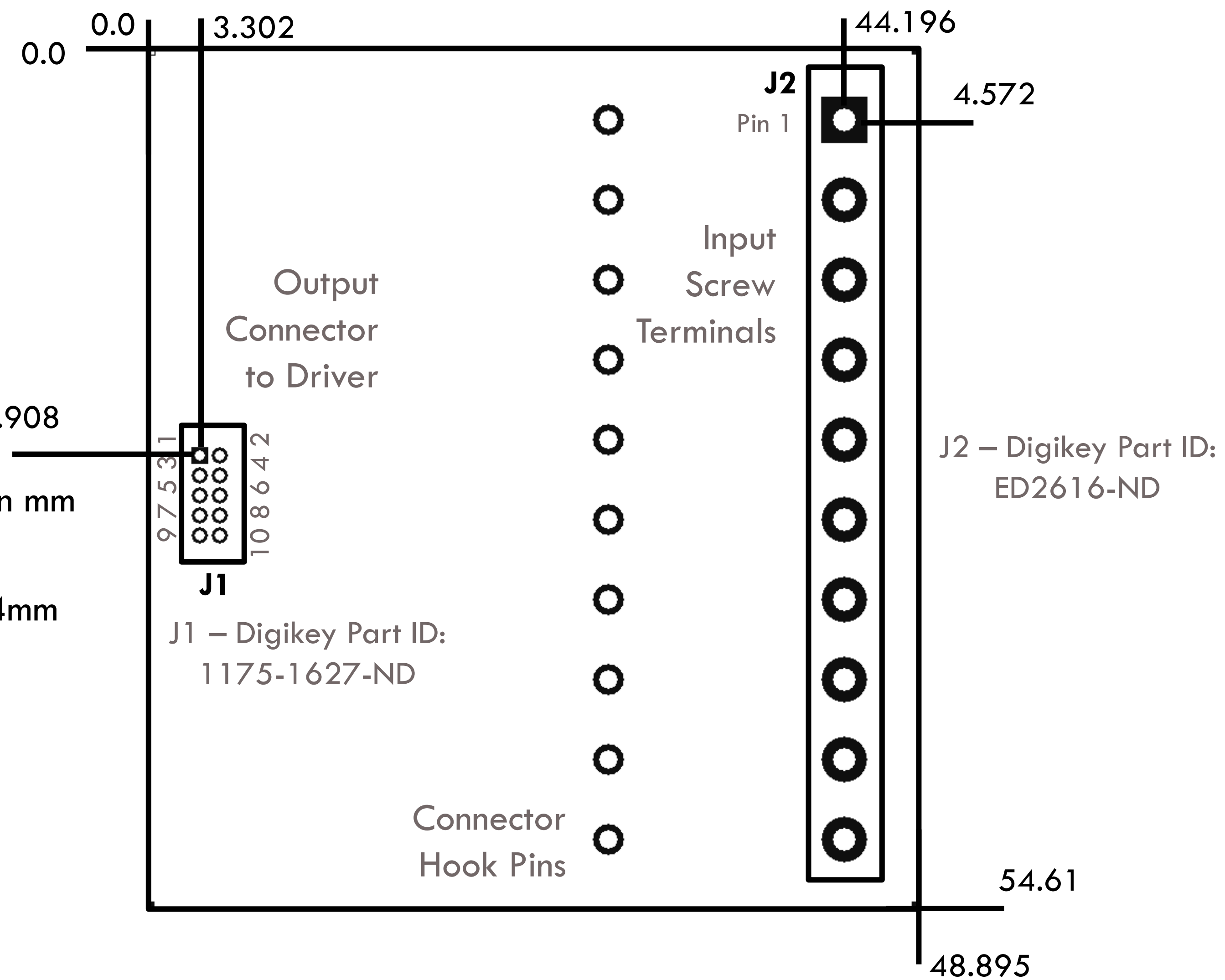
Driver Connections Breakout: BRK-DRIVER 5.x

- PCBA which breaks out the input connection side of both digital and analog-input MEMS driver to easy to use terminals or test points / pins. Each pin of the 10-pin connector has its own screw terminal, hook, and hole connection and easy to read label. **Not necessary for OEM uses, but recommended and prepared for first-time users** of Mirrorcle's MEMS Drivers (Ver. 5.x). A new user should consider purchasing this item with the first purchase of a MEMS Driver 5.x, digital- or analog-input type.
- **INPUT**: Screw terminals, test points, connect pins - multiple options for easy connections.
- **OUTPUT**: 10-pin header connector (0.05", 2 rows, right angle) which can be directly connected to MEMS Drivers (Analog and Digital) of 5.x generations.
- This item is only offered with a purchase of a Mirrorcle MEMS Driver



Breakout Board Mechanical Dimensions



All dimensions are in mm

Dimensions approx.:
49mm x 55mm x 14mm

TROUBLESHOOTING

Troubleshooting Basics

- In any development, experimentation, troubleshooting of the MEMS driver, **no MEMS mirror should be connected** to the output of the driver.
  - Users should plug in MEMS Mirror only after they have verified signals follow the desired commands on **an oscilloscope**, and
  - observe that all four channels follow the "BDQ Principle" (see section in this guide) with bias and differences not exceeding maxima (per device datasheet), with smooth transitions (no steps/impulses/sharp edges), and with correct setting of the on-board LPFs (per device datasheet).
  - When users change code or settings of their FPGA/MCU Controller which is connected to the MEMS driver, we recommend testing outputs on an oscilloscope first, before connecting a MEMS Mirror.
  - In some cases when the digital signals (FCLK, SPI) have very high slew rates and high frequencies, there is a potential for crosstalk and simultaneous switching noise among the signals. Using digital signals with reduced slew rates where possible should be considered.
- To ensure proper signals are provided to the MEMS driver **we recommend troubleshooting with the Breakout PCB** for easy probing of inputs.

LEDs blinking or not all ON when driving

- **Green LED** indicates the 5V Supply status. If the LED is off, there is no 5V supply to the driver. Note that the LED may be on even before adequate voltage is provided.
- **Blue LED** is intended to help users verify that FCLK input clocks are provided. Note that it is only connected to FCLK_Y, but both clocks are needed for standard operation.
  - This LED is generally more dim due to pulsed nature of the voltage and more dim at higher frequencies. It is only for guidance/reminder to users to provide clocks to filters.
- **Red LED** indicates MEMS Driver is enabled and fully powered.
  - LED is OFF: +5VDC should be above 4.85V and stable, EN should be HIGH
  - LED is blinking: Same as line above - the driver is not able to bring up the Vpp supply due to inadequate current or voltage provided to VDD.
    - +5VDC power supply limit should be >100mA to allow for any transient pulses during MEMS driver enable. Alternatively, a capacitor of >100uF value should be at the Vdd / GND power supply input to the MEMS Driver.

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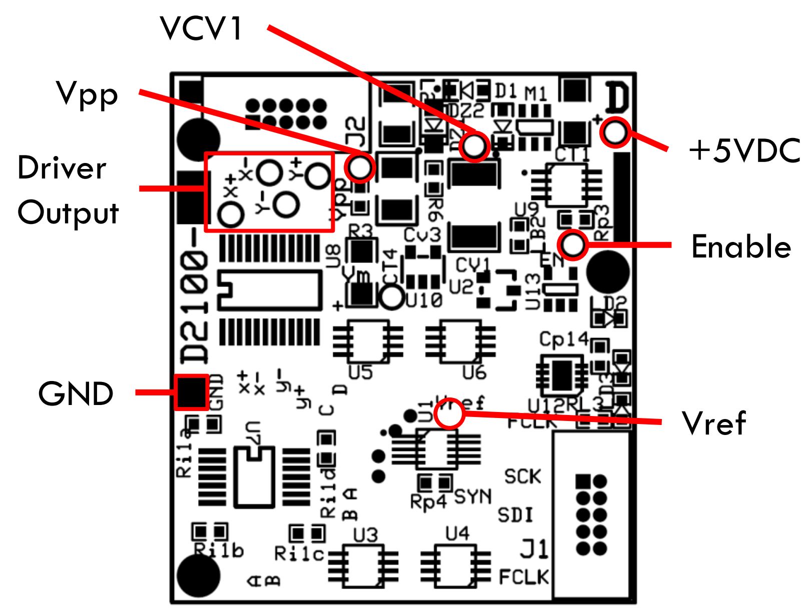
No Movement of MEMS Mirror

- Unplug MEMS Mirror and probe the +5VDC, Enable and Vpp (voltage should be >200V) test points to verify the correct voltages on the driver for proper operation
- Set driver inputs to be at Vbias, and measure the four driver output voltages to verify the driver operation
  - If driver output voltages are not correct, probe Vref (Vref = 1.25V) to ensure the DAC is enabled correctly
- If driver is working properly, connect the MEMS Mirror and repeat the measurements. If there is still no movement on MEMS Mirror, contact Mirrorcle Support: support@mirrorcletech.com



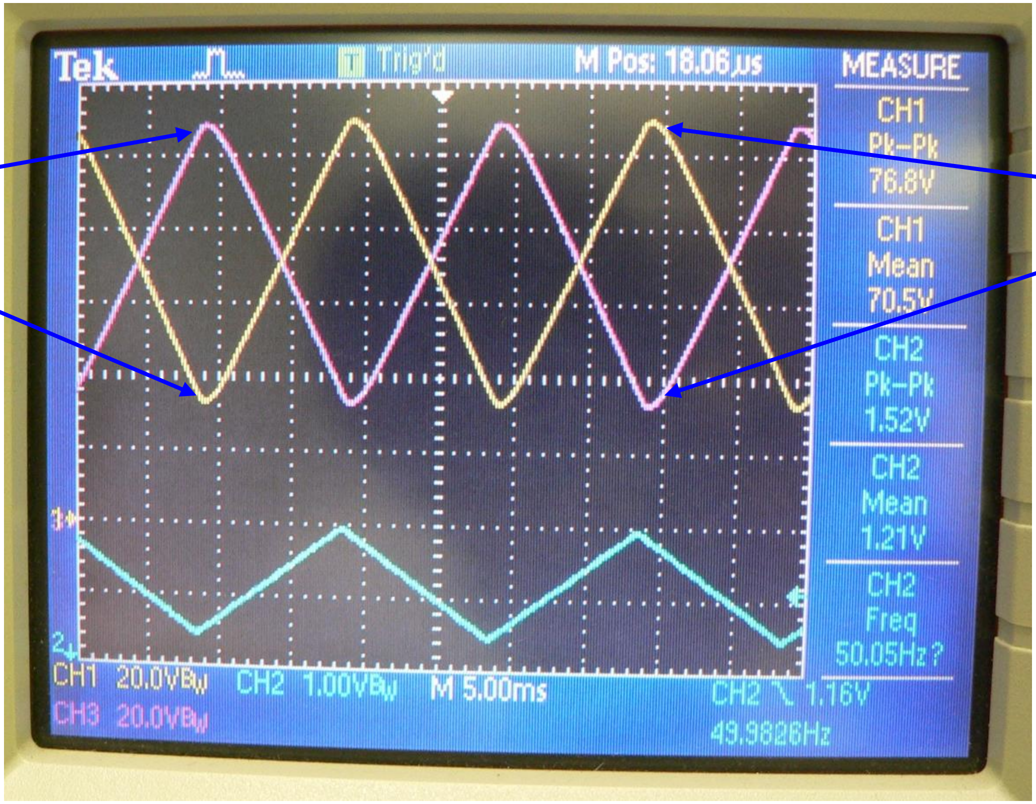
DRIVING THE MIRRORS - THE BDQ PRINCIPLE

The BDQ Principle - Overview

- Bias-Differential Quad-channel (BDQ) is the proper methodology for driving Mirrorcle MEMS Mirrors.
  - All four channels are biased to 80V (Vbias). This is MEMS mirror origin/rest position.
  - Pairs of channels apply (biased) differential voltages from ~0V to 160V. Mirror rotates approximately proportionally to the applied Vdifference for each axis.
  - Vdifference (X-axis) = HV_A (X+) – HV_B (X-)
  - Vdifference (Y-axis) = HV_C (Y-) – HV_D (Y+)
- All Mirrorcle control and driving hardware should be operated in this fashion and all Mirrorcle software supports this mode.
- In the **BDQ PicoAmp** <u>it is inherently implemented</u> by adding a bias to the four output channels and forcing them as differential pairs.

Bi-directional Driving with Unipolar Outputs

HV_B is high
HV_A is low
Vdifference(X) is
negative so mirror
rotates in X- direction



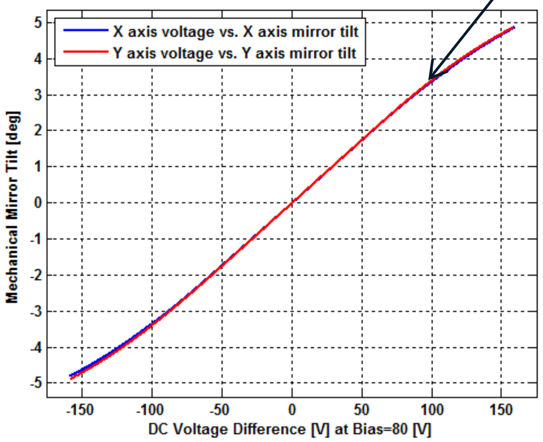
HV_A is high
HV_B is low
Vdifference(X) is
positive so mirror
rotates in X+ direction

Resulting X
movement

Bi-directional driving with unipolar voltages. Direction depends on which portion of the rotator (X+ or X-) is driven with the higher voltage. As a result each axis can move from negative angle to positive angle from rest/normal position.

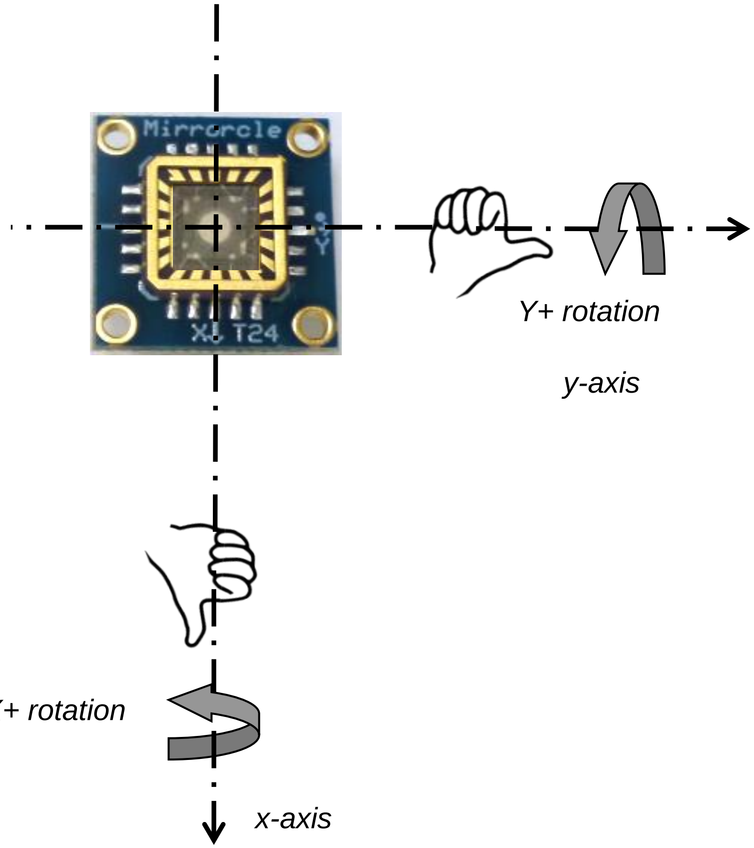
The BDQ Principle – Vbias and Vdifference

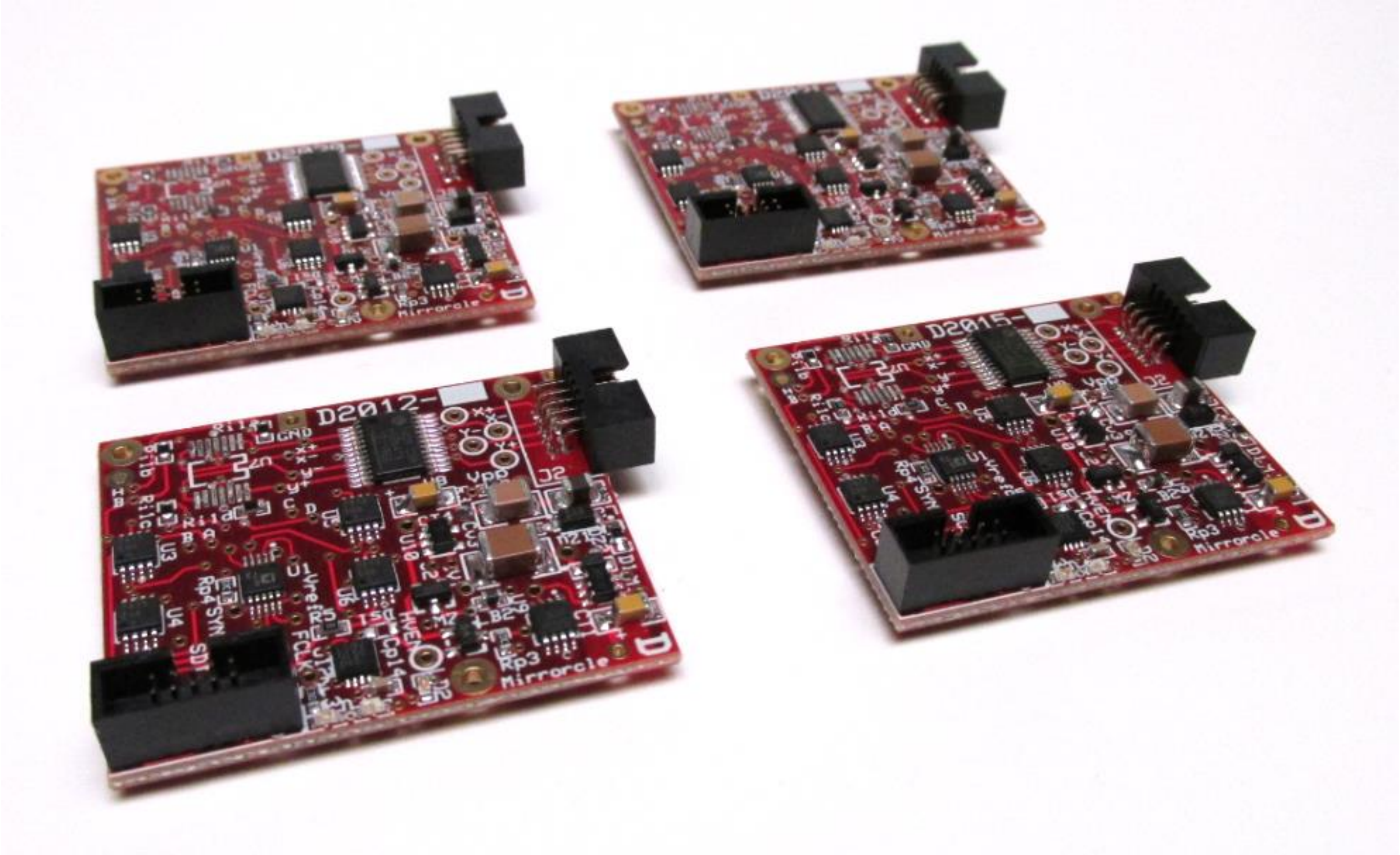
- Opposing actuator channels are given differential inputs operating at that bias. E.g. X+ channel 110V and X- channel 50V means X axis is driven by Vdifference of 60V at Vbias of 80V.
- Each command for each axis of the MEMS mirror is therefore comprised of Vbias and Vdifference setting where Vbias is constant (80V) and Vdifference is such that a desired angle is obtained. In the example below Vdifference of +100V can be applied to obtain +3.3° of rotation about the X axis.



Axes Orientation and Sign of Vdifference

- X+ and Y+ mirror rotation is defined by the rule of (right-hand) thumb, based on the x and y axes as shown.
- **X Axis:**
  - Vdifference(X) >0 results in X+ rotation about the x-axis
  - Vdifference(X) <0 results in X- rotation about the x-axis
- **Y Axis:**
  - Vdifference(Y) >0 results in Y- rotation about the y-axis
  - Vdifference(Y) <0 results in Y+ rotation about the y-axis
- Typically, MirrorcleTech MEMS mirrors are mounted so that X-axis driving provides laser beam sweep in the horizontal plane.





APPENDIX A: SPECIFIC INSTRUCTIONS FOR MEMS DRIVER – DIGITAL INPUT

Initialization of DAC (AD5664R)

1. Set up DAC. Following the AD5664R DAC datasheet*, we recommend the following initialization sequence which must be run by the master controller which communicates commands to the PicoAmp on every power up of the PicoAmp. The sequence is to reset the DAC, turn on its internal reference, enable all 4 channels, and set up for software loading.

   2621441 Decimal or 0x280001 to command FULL RESET

   3670017 Decimal or 0x380001 to command ENABLE INTERNAL REFERENCE

   2097167 Decimal or 0x20000F to command ENABLE ALL DAC CHANNELS

   3145728 Decimal or 0x300000 to command ENABLE SOFTWARE LDAC

2. After the above sequence, user can check whether the DAC is ready and the commands were successfully loaded into registers if the internal reference comes up to 1.25V. This is pin 10 of the DAC, labeled Vref. It is good to check this voltage at this point when debugging.
3. Now user can start streaming voltages commands to each channel. All development / debug should be performed without a MEMS device connected. Channels are assigned as follows:

   Digital input DAC_A_{in} outputs DAC voltage DAC_A which is amplified and goes to HV_A (X+)

   Digital input DAC_B_{in} outputs DAC voltage DAC_B which is amplified and goes to HV_B (X-)

   Digital input DAC_C_{in} outputs DAC voltage DAC_C which is amplified and goes to HV_C (Y-)

   Digital input DAC_D_{in} outputs DAC voltage DAC_D which is amplified and goes to HV_D (Y+)

4. User should verify that correct voltages are streaming at desired sample rate. There are four holes in the board before each of the LPFs where it is convenient to check DAC outputs. Minimum output is 0V for 16'h0000 (0x0000) and maximum output is 2.5V for 16'hFFFF (0xFFFF) input.

*Very often new users of the AD5664R DAC miss the details in its user guide, most notably that it is programmed by "negedge" clock (data is loaded on high to low transitions of the clock)

Vbias Settings

- Refer to page 1 of the device datasheet for the Bias Voltage (Vbias) values. The MEMS driver has a range from 0V-200V, corresponding to the DAC values of 0-65535. Those DAC values are a combination of Vbias and Vdifference digital values. Vbias digital value is computed as follows:
  - Vbias digital value = (Vbias/200)*65535

Example, if a device datasheet states Vbias of 80V:

- The Vbias digital value would be (80/200)*65535 = 26214

*MEMS Driver circuit Gain tolerance of +/- 1.5%

VdifferenceMax Settings

- The MEMS driver has a range from ~0V-200V, corresponding to the DAC values of 0-65535. VdifferenceMax sets the maximum Vdifference that will be applied to the MEMS mirror for any user input. The Max Vdifference and Vbias voltages refer to the device datasheet. It should be calculated as follows.
  - VdifferenceMax digital value = (VdifferenceMax/200)*65565, where VdifferenceMax(Vdiff) is the maximum Vdifference allowed for the mirror per device datasheet.
  - Vdifference range would be from (Vbias – Vdiff/2) to (Vbias + Vdiff/2)

Example, with Maximum Vdifference of 140V, and Vbias of 80V:

- VdifferenceMax digital value = (140/200)*65535 = 45874
- The example device voltage range would be from: 3277 (26214 – 45874/2) to 49151 (26214 + 45874/2)

*MEMS Driver circuit Gain tolerance of +/- 1.5%

Bringing Up the Driver

Note: This sequence should be performed and verified the correct voltages are being output before connecting to an actual MEMS Device.

1. Power the Driver board by providing VDD (Pin 3) and GND (Pins 4) to J1.
2. Send the register setting sequence via SPI bus to Setup the DAC (See DAC initialization page). This will enable DAC's internal reference and outputs.
3. After DAC is enabled, send the Vbias digital input (See Vbias settings page) values to all four channels of the DAC to set the MEMS device outputs to Vbias.
4. Set the FCLK frequency to control the filter cut-off (See FCLK settings page) per recommended settings for the MEMS mirror connected to the PicoAmp.
5. Enable the MEMS Driver outputs by sending a TTL High (3V to 5V) through Pin 5 on J1.

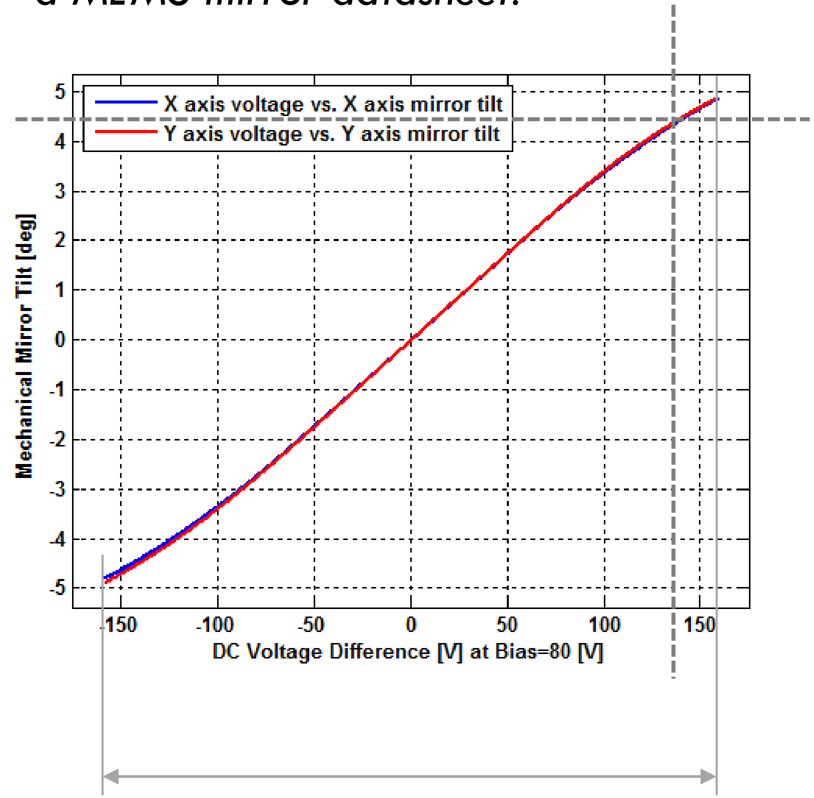
   WARNING: BEFORE ENABLING THE MEMS DRIVER OUTPUTS, ENSURE THAT THE VOLTAGE OUTPUT ON ANY CHANNEL WILL NOT EXCEED MAX VOLTAGE OF MEMS DEVICE PER THE DEVICE DATASHEET.

6. Now all MEMS Driver outputs HVA_A (X+) through HV_D (Y+) should be at Vbias (which should match the MEMS Mirror datasheet recommendation). MEMS mirror may move slightly to a new, 'biased origin.' This is the MEMS mirror's zero position or origin.
7. PicoAmp is now ready to drive the MEMS mirror to new positions. Although signals are filtered, user should avoid discontinuous waveforms with large, abrupt steps or impulses.
8. When ready to plug in the MEMS device: MEMS mirrors should not be connected or disconnected when MEMS Driver Outputs are enabled. Therefore, disable the MEMS Driver (Pin 5 to GND), connect the MEMS device, and re-enable the MEMS Driver.

Applying Desired MEMS Drive Values

- Each MEMS mirror includes a characterization report (datasheet) in pdf and raw data form.
- Static Response characterization provides a reference for dependence of mech. angle on Vdifference for each axis. From these Vdifference values, all four channels' digital input values should be calculated:
  - E.g. angle of the mirror needs to be +4.5° on both axes. From the graph we determine Vdifferences of ~135V.
  - $DAC\_A_{in} = 26214 + (\mathbf{135V}/200V)*32767$
  - $DAC\_B_{in} = 26214 - (\mathbf{135V}/200V)*32767$
  - $DAC\_C_{in} = 26214 + (\mathbf{135V}/200V)*32767$
  - $DAC\_D_{in} = 26214 - (\mathbf{135V}/200V)*32767$

Example of Static Response graph from a MEMS mirror datasheet:



Safe range of Vdifference for this example MEMS mirror. Exceeding these limits may damage the MEMS mirror.

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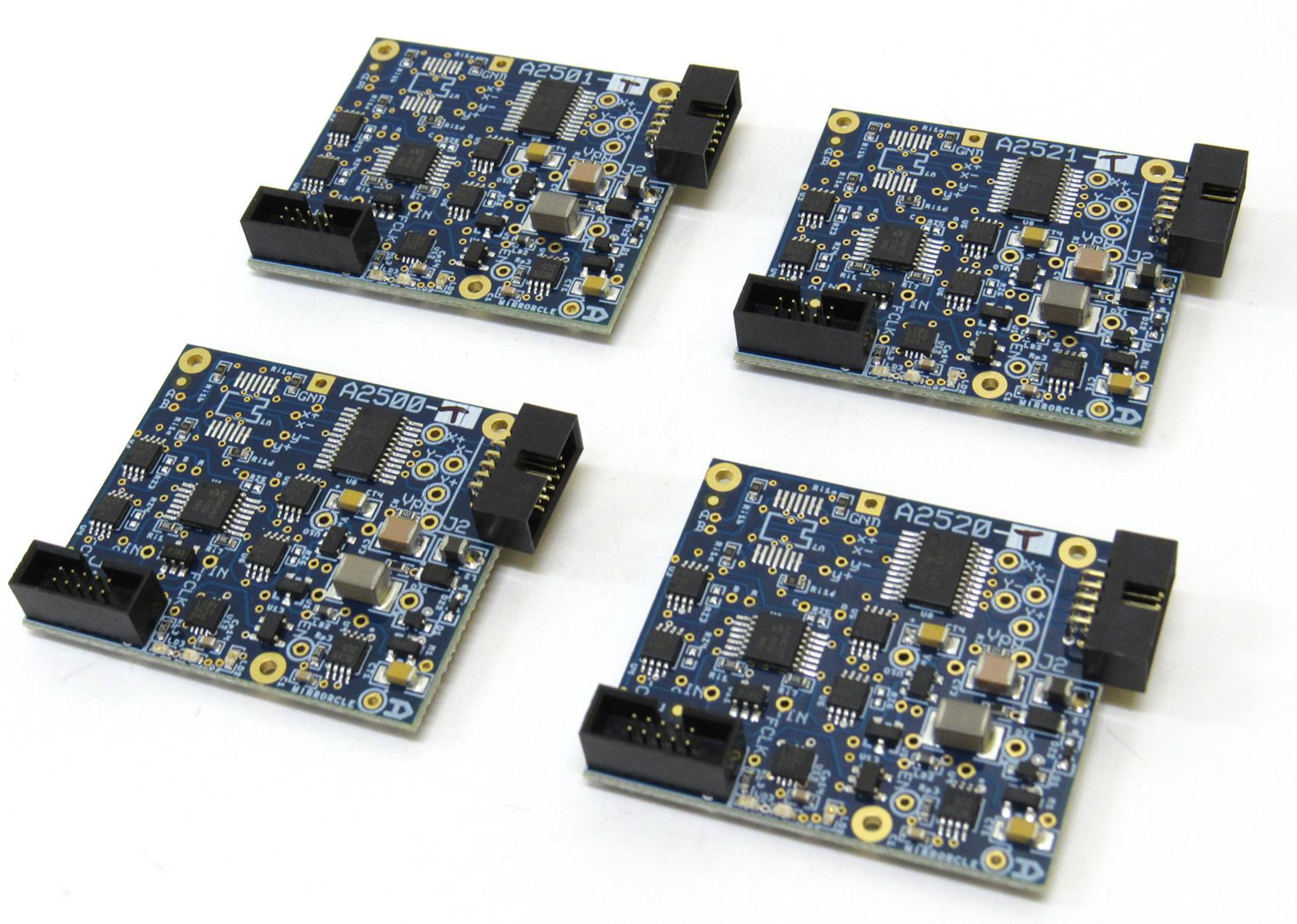
Shutting Down the Driver

1. Send only Vbias digital input to all four channels to return the mirror to origin. (zero the Xnorm and Ynorm terms)
2. Disable the MEMS Driver by sending a Digital Low to Pin 5 on J1.

   WARNING: DO NOT DISABLE DIGITAL INPUTS PRIOR TO THIS STEP TO AVOID ERRONEOUS SPI DATA TO THE PICOAMP WHILE MEMS Driver IS ENABLED.
3. Remove power as needed, unplug cables or disable inputs, etc.



APPENDIX B: SPECIFIC INSTRUCTIONS FOR MEMS DRIVER – ANALOG INPUT

Bringing Up the Driver

Note: This sequence should be performed and verified the correct voltages are being output before connecting to an actual MEMS Device.

1. Power the Driver board by providing VDD (Pin 3) and GND (Pins 4) to J1.
2. Set the FCLK frequency to control the filter cut-off (Page 10) per recommended settings for the MEMS mirror connected to the PicoAmp.
3. Prior to enabling the MEMS driver, send mirror origin voltage to analog inputs X and Y.
4. Enable the MEMS Driver outputs by sending a TTL High (3V to 5V) through Pin 5 on J1.

   WARNING: BEFORE ENABLING THE MEMS DRIVER, ENSURE THAT THE VOLTAGE OUTPUT ON ANY CHANNEL WILL NOT EXCEED MAX VOLTAGE OF MEMS DEVICE PER THE DEVICE DATASHEET.

5. Now all MEMS Driver outputs HVA_A (X+) through HV_D (Y+) should be at Vbias specified for the driver (which should match the MEMS Mirror datasheet recommendation). MEMS mirror may move slightly to a new, 'biased origin.' This is the MEMS mirror's zero position or origin.
6. BDQ PicoAmp is now ready to drive the MEMS mirror to new positions. Although signals are filtered, user should avoid discontinuous waveforms with large, abrupt steps or impulses.
7. When ready to plug in the MEMS device: MEMS mirrors should not be connected or disconnected when MEMS Driver Outputs are enabled. Therefore, disable the MEMS Driver (Pin 5 to GND), connect the MEMS device, and re-enable the MEMS Driver.

WARNING: SEE FOLLOWING SLIDES FOR SAFE RANGE OF INPUT VOLTAGES WHEN USING MIRRORCLE MEMS MIRRORS

Analog Input Definitions

- BDQ PicoAmp: XIN
  - Input range: -10V to +10V
    - Two X-axis outputs have Vbias and Vdifference(X) between them
  - Origin voltage (no tip/tilt requested): 0V
    - Two X-axis outputs of the driver remain at Vbias
- BDQ PicoAmp: YIN
  - Input range: -10V to +10V
    - Two Y-axis outputs have Vbias and Vdifference(Y) between them
  - Origin voltage (no tip/tilt requested): 0V
    - Two Y-axis outputs of the driver remain at Vbias

Analog Output Range Types

- Different MirrorcleTech MEMS Mirrors products may have different required or recommended driving voltage ranges to achieve best performance.
- The most typical driving range or methodology is “Boost 160” or B160 which has following specs:
  - Vbias = 80V, Vdifference = -160V to 160V
- The next category is “Turbo 180” or T180 with specs:
  - Vbias = 90V, Vdifference = -180V to 180V
- The next category is “eXtreme 200” or X200 with specs:
  - Vbias = 100V, Vdifference = -200V to 200V

Output Definition

Name	$V_{maxMEMSDriver}$	Vbias	Vdifference (Min, Max)	*HVGain
B160	160V	80V	-160V, 160V	64
T180	180V	90V	-180V, 180V	72
X200	200V	100V	-200V, 200V	80

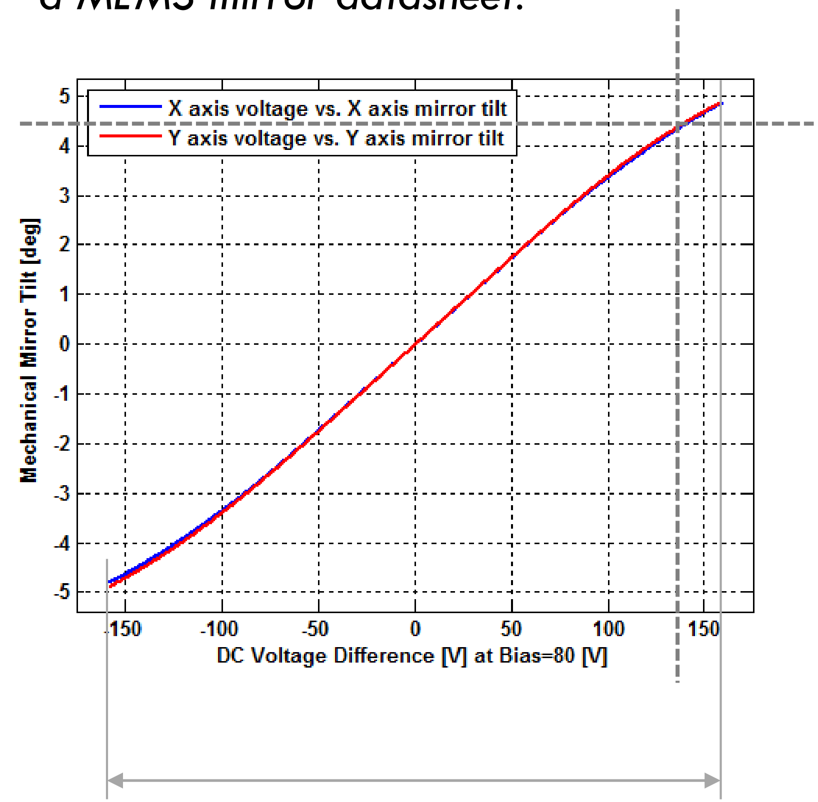
- HV_A (X+) = Vbias + (XIN/8)*HVGain
- HV_B (X-) = Vbias - (XIN/8)*HVGain
- HV_C (Y-) = Vbias + (YIN/8)*HVGain
- HV_D (Y+) = Vbias - (YIN/8)*HVGain
- Therefore:
  - Vdifference(X) = HV_A – HV_B = (XIN/4) * HVGain
  - Vdifference(Y) = HV_C – HV_D = (YIN/4) * HVGain

*MEMS Driver circuit Gain tolerance of +/- 1.5%

Applying Desired Input Voltages

- Each MEMS mirror includes a characterization report (datasheet) in pdf and raw data form.
- Static Response characterization provides a reference for dependence of mech. angle on Vdifference for each axis. From these Vdifference values, XIN and YIN are simply calculated:
  - E.g. angle of the mirror needs to be +4.5° on both axes. From the graph we determine Vdifferences of ~135V.
  - XIN = Vdifference(X) * 4/HVGain
  - YIN = Vdifference(Y) * 4/HVGain

Example of Static Response graph from a MEMS mirror datasheet:

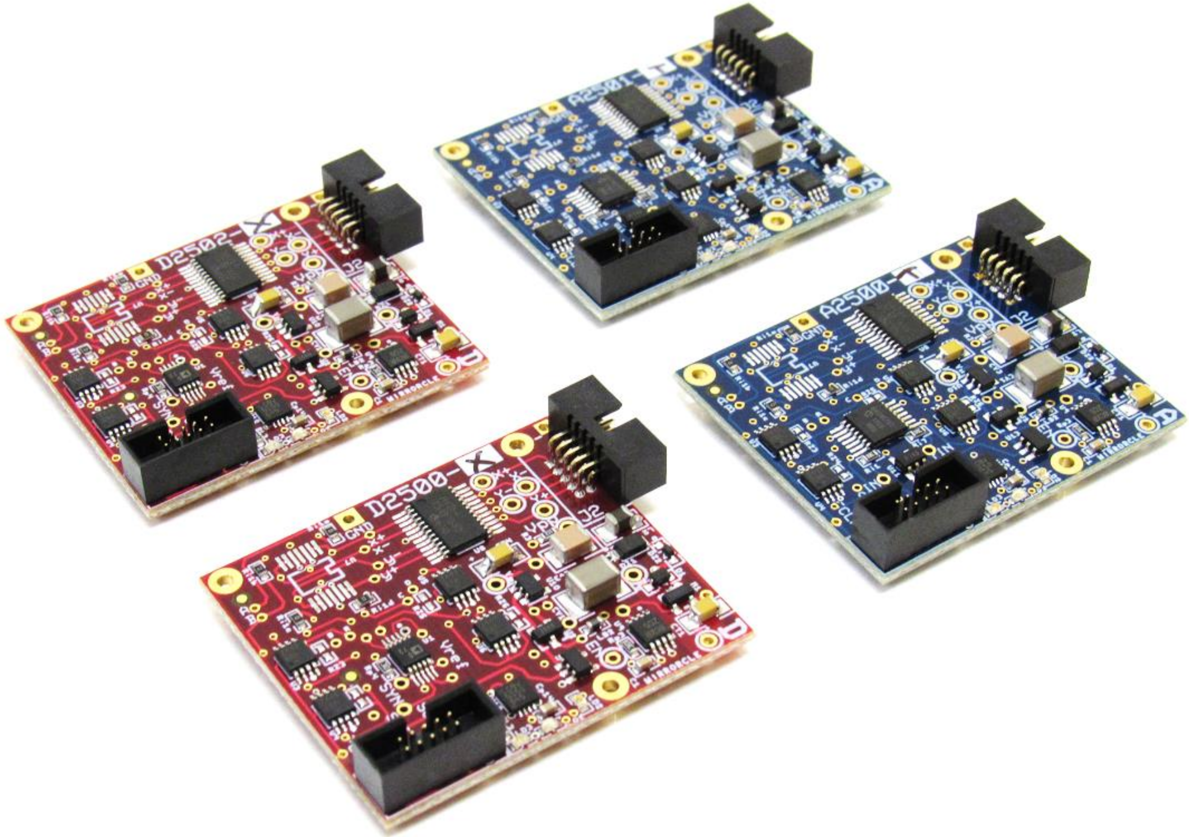


Safe range of Vdifference for this example MEMS mirror. Exceeding these limits may damage the MEMS mirror.

Shutting Down the Driver

1. Return mirror back to origin by setting the appropriate origin voltages to analog inputs X and Y.
2. Disable the MEMS Driver by sending a Digital Low to Pin 5 on J1.

   WARNING: DO NOT UNPLUG OR DISABLE ANALOG INPUTS PRIOR TO THIS STEP TO AVOID APPLYING ERRONEOUS VOLTAGES TO ACTIVE MEMS DRIVER ANALOG INPUTS.
3. Remove power as needed, unplug cables or disable inputs, etc.

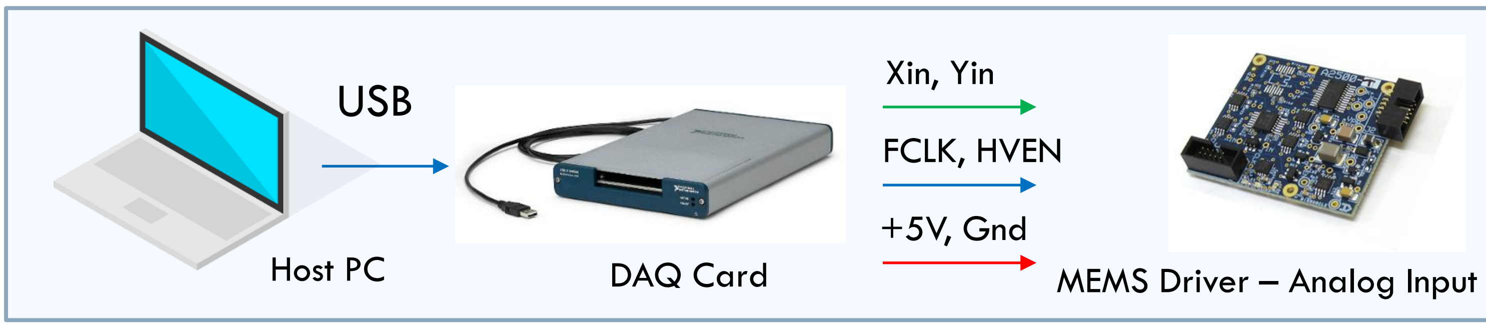


APPENDIX C: DRIVING THE MEMS DRIVER FROM CONTROLLERS

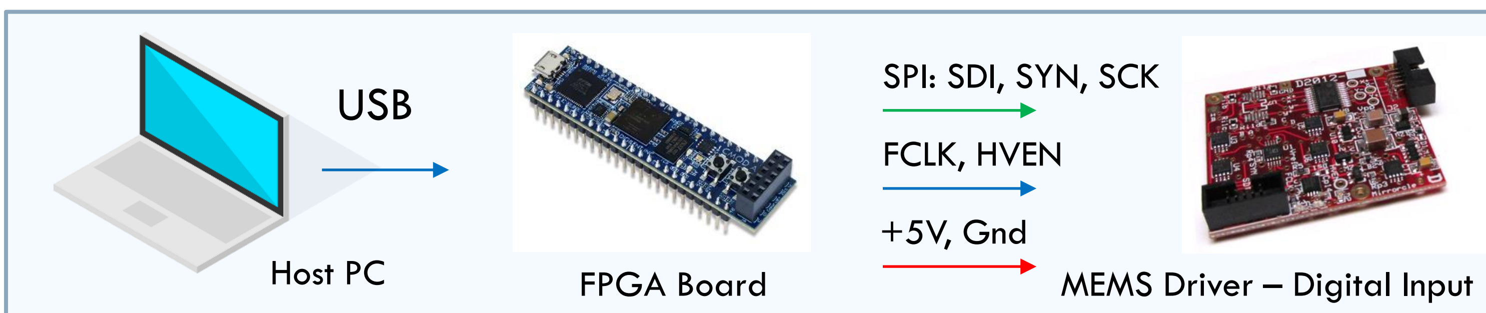
Overview

- The MEMS drivers can be setup and controlled using external sources such as Data Acquisition (DAQ) controllers, or Mixed-Signal controller development boards.
- These controllers typically have applications that can be ran from a HOST PC for users to control and adjust various settings, and send content to the drivers to move the MEMS mirrors

Recommended options:
USB-NI 6341



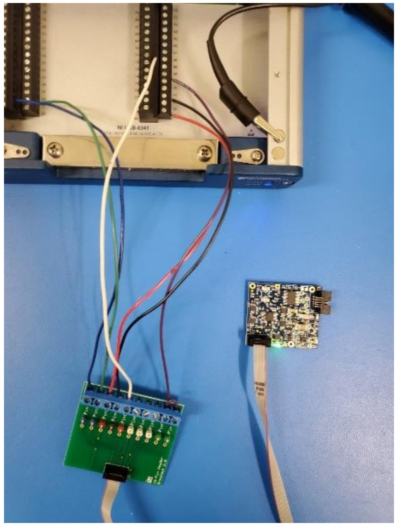
Recommended options:
CMOD A7, PYNQ-Z1, Arty A7, Basys-7



MEMS Driver – Analog Input: Example

- Option 1: Connect the DAQ card to the MEMS Driver breakout board according to the scheme specified in the MEMS Driver Breakout Board pinout and your respective DAQ pinout. An example connection guide is show below for National Instruments' USB NI 6341
- Option 2, shown in example below: Connect the DAQ terminals directly to the ribbon cable and input of the MEMS Driver, at connector J1. This setup will not utilize MEMS Driver Breakout Board.

MEMS Driver – Analog Input			USB-NI 6341	
J1-Pin	**Name**	**Function**	**Screw Terminal Pin**	**Function**
1	XIN	X-Axis Analog Input	15	AO0
2	YIN	Y-Axis Analog Input	31	AO1
3	VDD	+5V Supply	96	+5VDC
4	GND	Ground	94	DGND
5	EN	MEMS Driver Output Enable	73	P1.0
9	FCLK_X	Filter Clock for X-Axis	91	PFI13 / P2.5
10	FCLK_Y	Filter Clock for Y-Axis	91	PFI13 / P2.5



Note: FCLK_X and FCLK_Y can be driven from the same clock for a simplified solution

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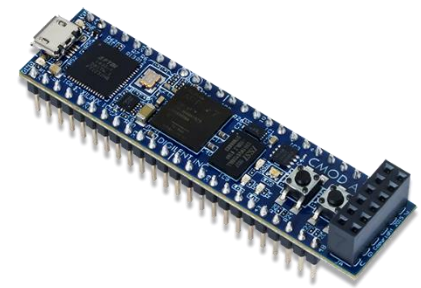
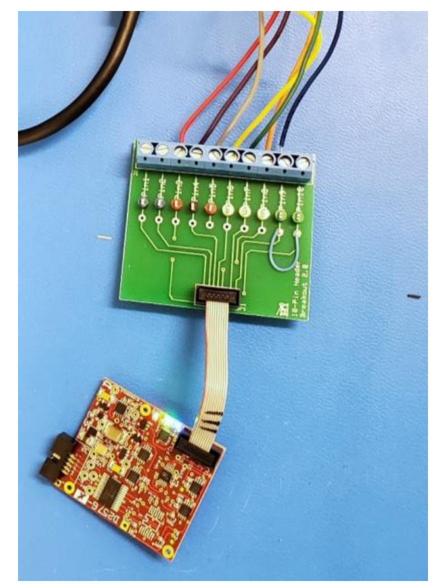
MEMS Driver – Digital Input: Example

- Connect the FPGA board to the MEMS Driver breakout board according to the scheme specified in the MEMS Driver Breakout Board pinout and your respective DAQ pinout. An example connection guide is show below for Digilent CMOD-A7 development board



MEMS Driver – Digital Input			CMOD-A7	
J1-Pin	**Name**	**Function**	**Board Pin**	**Function**
3	VDD	+5V Supply	24	VU (+5V)
4	GND	Ground	25	Ground
5	EN	MEMS Driver Output Enable	1-14, 26-30	GPIO
6	SDI	SPI Data for AD5664R	1-14, 26-30	SPI MOSI
7	SYN	SPI Sync for AD5664R	1-14, 26-30	SPI CS_
8	SCK	SPI Clock for AD5664R	1-14, 26-30	SPI Clock_
9	FCLK_X	Filter Clock for X-Axis	1-14, 26-30	Timer output
10	FCLK_Y	Filter Clock for Y-Axis	1-14, 26-30	Timer output



Note: FCLK_X and FCLK_Y can be driven
from the same clock for a simplified solution

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Controller Recommendations

- MEMS Driver - Analog Input Controller Requirements:
  - At least 2 analog output channels at rates of >50ksps
  - analog output range of ±10V
  - 3-5 Digital outputs with timer and clock output capability
- MEMS Driver - Analog Input Controller examples:
  - National Instruments USB-NI 6341 (X-series)
  - Measurement Computing DT9812 Series

- MEMS Driver - Digital Input Controller Requirements:
  - FPGA or MCU based controller with at least 5 GPIO pins available
  - Controller capable of providing commands over SPI
  - Controller capable of timer and clock output
- MEMS Driver - Digital Input Controller examples:
  - Digilent CMOD A7, PYNQ-Z1, Arty A7, Basys-7
  - Mikroelectronika MINI-M4 series, MINI-32 series