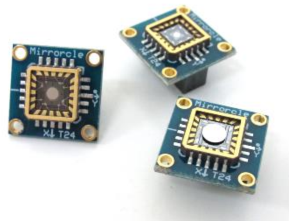
mirrorcle
TECHNOLOGIES, INC.



Mirrorcle Technologies MEMS Mirror *Preliminary* Datasheet

A8L2.2-4600AU-TINY48.4

OVERVIEW

Mirrorcle Technologies Gimbal-Less Dual-Axis MEMS Mirrors are based on proprietary fabrication technology. They provide fast optical beam steering across two axes, while requiring ultra-low power. The mirrors deflect laser beams or images to optical scanning angles of up to 20° on each axis. Compared to large-scale galvanometer-based optical scanners, these devices require several orders of magnitude less driving power: continuous operation of the electro-static actuators that drive the mirror tip-tilt rotation dissipates less than 1mW of power.

Mirrorcle Technologies MEMS Mirrors are made entirely of monolithic Single-Crystal Silicon (SCS), resulting in excellent repeatability and reliability. Flat, smooth mirror surfaces are coated with a thin film of metal with high broadband reflectance.

FEATURES

- ☐ Two-axis Gimbal-less MEMS Mirror
- ☐ **4.6mm diameter** round mirror
- ☐ Flat, Aluminum-coated mirror
- ☐ ±5° Mechanical Tip-Tilt Rotation
- ☐ Electro-static Actuation
- ☐ Ultra-low power consumption
- ☐ Highest Point-to-Point Precision
- ☐ High robustness and reliability
- ☐ Wide operating temperature range
- ☐ Window options for visible and IR wavelengths

Applications

- ☐ LiDAR / 3D Sensing
- ☐ Biomedical Microscopy and Imaging
- ☐ Free-space communication
- ☐ Metrology
- ☐ 3D Scanning and Imaging
- ☐ Laser Marking
- ☐ Dynamic Solid-State Lighting (Laser-phosphor)

MODULAR DESIGN

Mirrorcle actuators lend themselves inherently to a modular design approach. Each actuator can utilize electrostatic rotators of arbitrary length, arbitrarily stiff linkages, and arbitrarily positioned mechanical rotation transformers. In addition, the device can have an arbitrarily large mirror diameter. This modularity easily allows the devices to be customized for any application requirement.

Due to this design flexibility and a wide variety of applications that require beam steering, with widely different specifications, we provide many types of gimbal-less two-axis actuator designs. With over 20 major design and manufacturing generations, multiple sub-generations of design tuning for a specific customer or set of specifications, the complete list of working designs has over 100 device types. Several of the most successful designs are in series production.

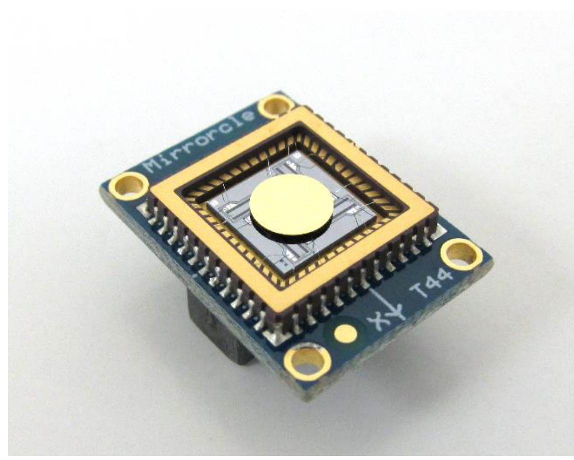


Figure 1. Image of the A8L2.2-4600AU-TINY48.4 device. The connectorized package "TINY48.4" is 15mm x 20mm x 9mm

MULTIPLE SCANNING MODES

Mirrorcle devices can operate from DC response to dynamic, resonant modes. When operated near the resonant frequency, devices give significantly more angle at lower operating voltages and sinusoidal motion. Namely, the MEMS actuators utilize single-crystal silicon springs to support the MEMS mirror and to provide restoring force during actuation. It is possible to define these modes of operation in three distinct categories shown below and in Fig. 2:

a) In **point-to-point mode** or **quasi-static mode**, both axes are utilizing the wide bandwidth of operation of the device from DC to some frequency, and not allowing for resonance and ringing. Therefore, mirror can hold a DC position, move in a uniform velocity, perform vector graphics, linear raster patterns, etc.

b) The second mode is a mixed mode in which one axis is used in **quasi-static mode,** and the other axis is used in **resonant mode**. A typical use case is to run one axis very fast (e.g. few kHz,) to create horizontal lines, and to run the other axis with a sawtooth-like waveform to create a raster pattern that covers a rectangular display or imaging area. The axis operating at resonance should have its parameters carefully obtained, initially at low voltages and angles, to avoid exceeding maximum mechanical angles.

c) Third mode is **resonant mode**. In this case both axes are utilizing the narrow, high gain resonance to obtain large angles of deflection and relatively low voltages and high speeds. Motion is limited to very narrowband, sinusoidal trajectories with a phase lag to the applied voltage. Resulting 2D motion describes circles, ellipses, and various higher order Lissajous patterns and can be modulated at some rate. When devices that are designed for point-to-point mode are driven near or at resonance, they may exceed safe operating angles. Thus, near or at resonance operation is done with significantly lower voltages and with additional care.

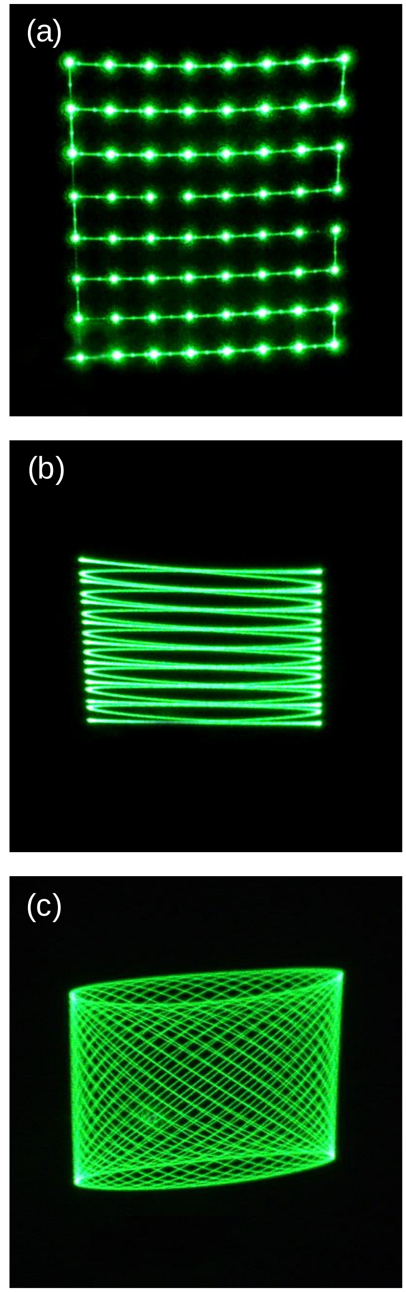


*Figure 2. Photographs of examples of using Mirrorcle MEMS Mirror in **(a)** point-to-point scanning mode (quasi-static) on both axes with the laser beam stopping at each angle, then stepping to the next angle, **(b)** resonant scanning mode on the x-axis (sinusoidal beam motion) and quasi-static on the y-axis (triangle wave motion in this example), and **(c)** resonant scanning mode on both axes, showing a 2D resonant Lissajous pattern. All images were taken with a CW laser using the same Mirrorcle MEMS mirror.*

MEMS Mirror Device Specifications

RECOMMENDED OPERATING CONDITIONS

Parameter	Test Conditions	Min.	Typ.	Max.	Units
Mechanical Tilt	Vbias = 90V, VdifferenceMax = 175V	±4.7	±5	±5.25	Deg
VdifferenceMax	Vbias = 90V			180	V
First Resonant Frequency	X-Axis	300		375	Hz
First Resonant Frequency	Y-Axis	300		375	Hz
First Resonance Quality Factor	Same for X-Axis and Y-Axis	25		40	
Recommended Low Pass Filter (LPF)	Same for X-Axis and Y-Axis	100		130	Hz
Second Resonant Frequency	Same for X-Axis and Y-Axis	1400		1700	Hz
Second Resonance Quality Factor	Same for X-Axis and Y-Axis	0.5		3	
X-Axis Step Response	0° to 2° Step Input with Recommended LPF		5		ms
Y-Axis Step Response	0° to 2° Step Input with Recommended LPF		5		ms
Point-to-Point Precision			1.0		mDeg.

MIRROR SPECIFICATIONS

Parameter	Test Conditions	Min.	Typ.	Max.	Units
Mirror Diameter			4.6		mm
Mirror Radius of Curvature		5			m
Mirror Surface Roughness		10			nm
Mirror Coating		Gold			
Mirror Reflectivity	At 905nm, s-polarized, 22.5° AOI	95			%
Mirror Coating Thickness	Metallization layer	50	60	70	nm
Total Die Width	Square Die	7.22	7.25	7.27	mm
Total Die Thickness		0.4952	0.5012	0.5072	mm

ENVIRONMENTAL AND MECHANICAL CONDITIONS

Parameter	Test Conditions	Min.	Typ.	Max.	Units
Operating Temperature Range		-40		105	°C
Operating Humidity Range	No Condensation, Relative Humidity			90	%
Storage Temperature Range		-40		105	°C
Storage Humidity Range	No Condensation, Relative Humidity			90	%
Mechanical Shock	5 Times/axis, 3 axes		100		g
Vibration	20g, 4 min/cycle, 4 cycles/ axis	20		2000	Hz

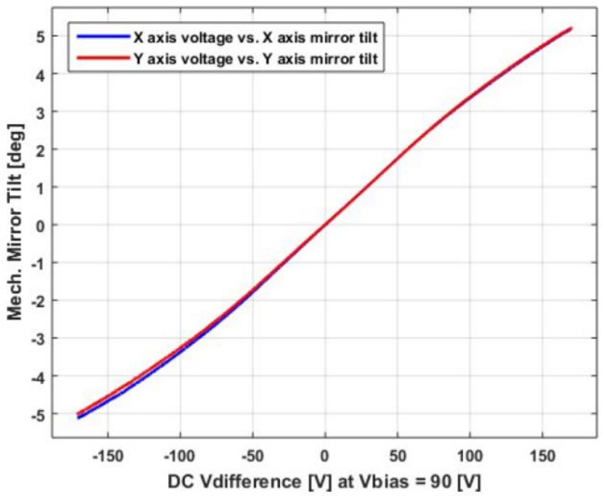
WARNING

Proper ESD protection and a clean environment is needed when handling Mirrorcle MEMS mirrors to prevent any damage from electro-static discharge, or any dust particles landing on the MEMS mirror.

MEMS Mirror Device Typical Characteristics

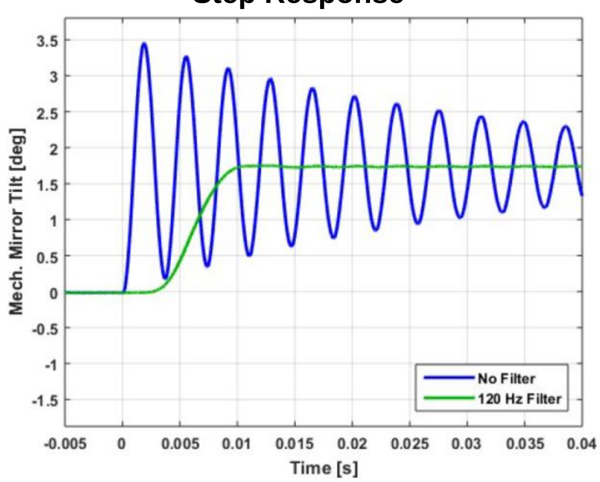
Note: These curves shown below are typical responses that are characteristic for this type of device. Individual device responses may vary by ±5%

DC Static Response



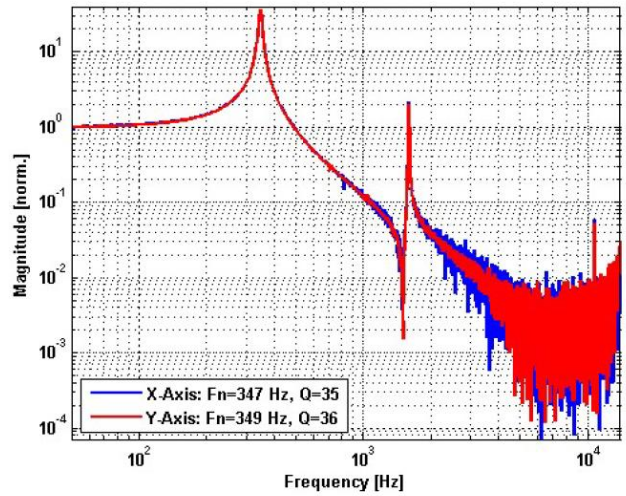
During the datasheet process, the MEMS device is driven from origin to the maximum voltages about the Vbias voltage, and the corresponding angles are recorded. This test ensures the device can reach the maximum specified mechanical tilt angle.

Step Response

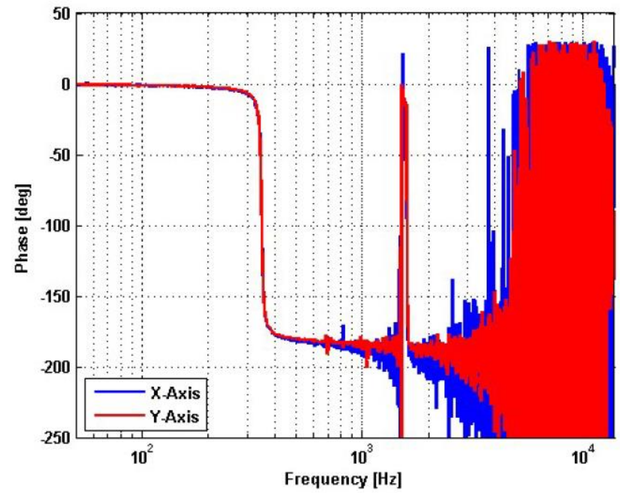


The MEMS device is driven with a step waveform with the recommended low-pass filter, and without any filtering to show the response time of the device. The low-pass filtered waveform's step response is governed by the filter bandwidth and has no ringing. The unfiltered waveform has a large ring, and takes >50ms to fully settle.

Small Signal Frequency Response - Magnitude



Small Signal Frequency Response - Phase



A wide band (0-20kHz) and very small amplitude noise waveform is applied to the MEMS driver and the mirror's response is measured by the 2D PSD for each axis. From the input (waveform) and output (device angle), a complex frequency response (amplitude and phase) is obtained and plotted for each axis.

MEMS Mirror Driving Recommendations

LINEARIZED DRIVING OF FOUR-QUADRANT (4Q) DEVICES

Mirrorcle Development Kits and OEM MEMS drivers utilize a device-specific method of driving the 4Q MEMS actuators with a Bias-Differential Quad-channel (BDQ) scheme. This scheme linearizes actuators' voltage-angle relationship and improves smooth transitions from one actuator to another within the device. In this mode both the positive rotation portion and the negative rotation portion of each rotator are always (differentially) engaged, and therefore the voltages and torques are always continuous. All Mirrorcle MEMS drivers are designed to operate in this mode and therefore have four channels with biased output (two differential pairs). Inputs are either digital or analog and only two channels are required to command x-axis and y-axis position.

MEMS MIRROR MODULE

MEMS Mirror Modules (MMM) combine a MEMS Mirror with a MEMS Driver, allowing users to conveniently and safely control MEMS mirrors from their own hardware platforms (e.g. NIDAQ, MCU or FPGA module).

The recommended MEMS Mirror Module for this product includes the Analog-Input MEMS Driver with T180 driving scheme, also termed "BDQ PicoAmp T180". As mentioned, use of the Analog MEMS Driver requires bench-top lab equipment such as function generators or a data acquisition (DAQ) card. Its -10V to +10V input range is particularly well suited for use with National Instruments NIDAQ cards.

For convenient experimentation with the driver, a breakout PCBA is added in the bundle which breaks out the MEMS Driver input connector into convenient terminals and test points.

DRIVING RECOMMENDATIONS

Mirrorcle strongly recommends all first time users of the MEMS mirrors to start with the Mirrorcle Development Kit. The Development Kit comes with a USB MEMS Controller, three different MEMS mirrors, red laser and optical breadboarding with mounts for the MEMS mirror and laser. The Development Kit also includes an extensive Software Suite with SDKs in C++, Matlab and LabView, with options to upgrade to Python, Android for Java, and C++ for Linux (Raspberry Pi). In addition to the SDKs, the Software Suite also includes Windows based Applications like MirrorcleDraw, MTIDevice-Demo, Mirrorcle Linear Raster, etc. The development kit allows users to quickly setup the MEMS mirror to perform an incoming inspection and evaluate the device for their specific application. MirrorcleDraw is a powerful software that enables the user to generate or import content, quickly change the size, rotation, filter settings, refresh rate and many other settings.

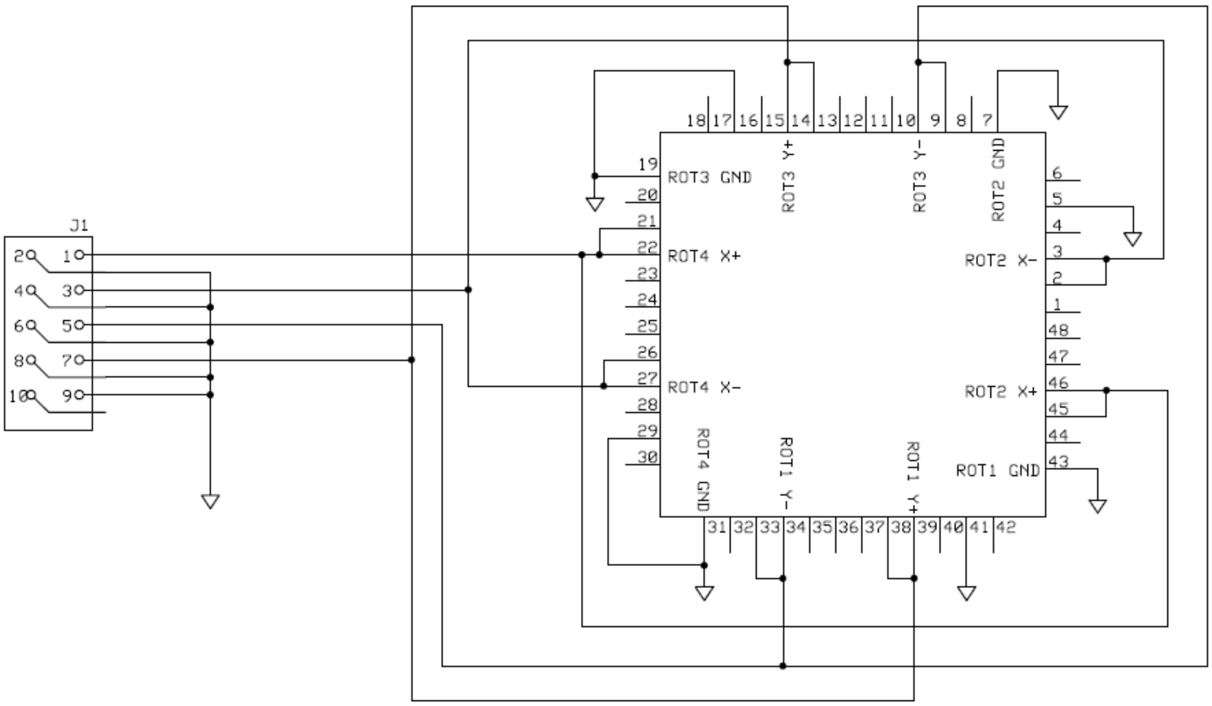
For users ready to integrate the MEMS mirror into their applications, various layers of integration are available, starting at the lowest level with a digital or analog input MEMS driver. The MEMS drivers require the user to generate the MEMS mirror position signals on their own processor / platform. For users that require a higher level of integration, the OCCIE MEMS Controllers are recommended. The OCCIE MEMS controllers have a similar firmware to the Development Kit MEMS controller and are able to receive all the same API commands in the various software languages provided in the SDK.

Recommended MEMS Mirror Module Part Number:
(Example for B-type window, Wedge and Tape attachment): **MMM-111-B/W/TP-SP**

Recommended MEMS Driver Part Number:
T180 Analog MEMS Driver 5.x: **DR-11-055-00**

MEMS Mirror Electrical Connections

TINYPCB CIRCUIT AND CONNECTIONS



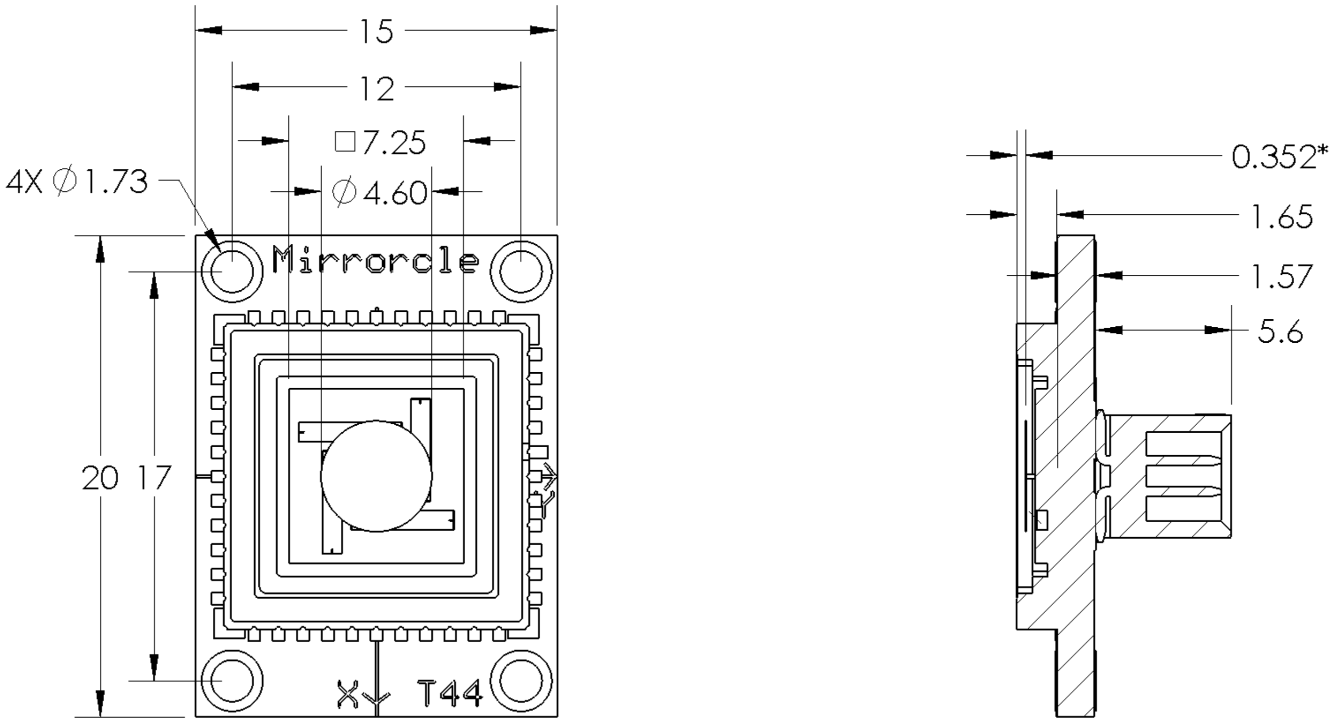
10 - Pin Header – J1		
Pin	**Name**	**Description**
1	HV_A (X+)	MEMS Channel X+
2	GND	Ground
3	HV_B (X-)	MEMS Channel X-
4	GND	Ground
5	HV_C (Y-)	MEMS Channel Y-
6	GND	Ground
7	HV_D (Y+)	MEMS Channel Y+
8	GND	Ground
9	N/C	No Connection
10	N/C	No Connection

Connector Part No.	Pins	Recommended Mating Cable
Digikey ID: 1175-1629-ND	10	Cable: SAM8219-ND

HIGH VOLTAGE WARNING

Mirrorcle MEMS Drivers are High Voltage Amplifiers that can produce hazardous voltages and currents which may be harmful. Use caution and exercise preventative safety measures to prevent contact between the high voltages and any personnel or equipment.

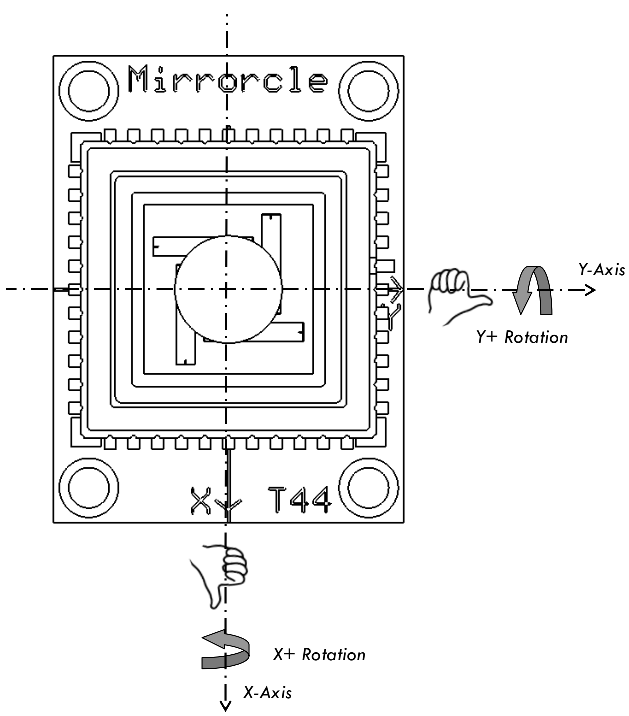
A8L2.2-4600AU-TINY48.4 DIMENSIONS



*0.352mm is distance from surface of MEMS mirror to top of LCC Cavity

MEMS Mirror and LCC Cavity Tolerances: ±50µm
PCB Parts, Holes and Dimensions Tolerances: ±100µm

All units in mm



MEMS Mirror Part Name and Cover Attach Specifications

MEMS Mirror Part Name Format:

AAAA.A-BBBBCC-DDDD-EE/**F**/GG

- A: MEMS actuator Design ID (e.g.: A8L2.2)
- B: Mirror diameter in microns (e.g.: 4600)
- C: Mirror coating (AL, AU, or SI for uncoated silicon)
- D: MEMS carrier package ID (e.g.: TINY48.4)
- E: Cover window selection (e.g.: B)
- **F: Wedge option: '/W' for Wedge, or blank for no wedge**
- G: Cover attachment method (e.g.: EP)

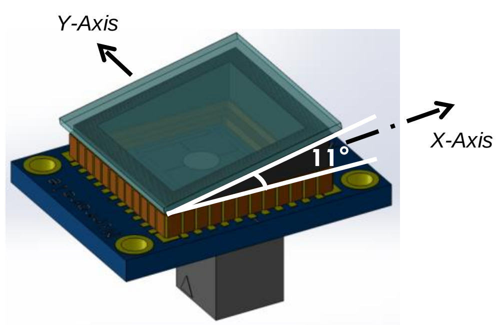
Window Coating Options

Window Coating	Coating Range [Min]	Coating Range [Max]	AOI [°]	Transmittance [%]	Part Number
Type A	400 nm	675 nm	22.5°	99.5%	A
Type B	675 nm	1040 nm	22.5°	99.5%	B
Type C	1040 nm	1600 nm	22.5°	99.5%	C

- All three window types transmittance are specified for ±10° from AOI (Angle of Incidence) of 22.5°

Wedge for Tilted Window

- The AR-coated window can be mounted on an anodized aluminum wedge with a tilt to avoid reflections from the window to appear within (near the center of) the MEMS field-of-regard.
- The standard wedge is designed with a -11° tilt about the MEMS Y-axis (negative rotation about the Y-axis, sending the residual reflection UP)



Package Cover Attachment Options

- There are 3 methods of attaching the cover to the package:
- The cover is permanently attached to the package using adhesive. Part: /**EP**
- The cover is attached to the MEMS package using double-sided tape on all 4 edges. Part: /**TP**
- A cover with temporary window (uncoated) is lightly attached for easy removal using double-sided tape on only 2 edges. Part: /**TW**

Example with Wedge and A-Type Window with Epoxy: A8L2.2-4600AU-TINY48.4-A/W/EP

Example without Wedge and B-Type Window with Tape: A8L2.2-4600AU-TINY48.4-B/TP

DISCLAIMERS

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