MEMS Mirror Key Facts

- Mirrorcle Technologies’ MEMS mirrors are made entirely of monolithic single-crystal silicon, resulting in excellent repeatability and reliability. Mirror surfaces are coated with a thin film of metal with high broadband reflectance (standard coating materials are Au or Al).

- Smaller and medium mirror sizes are manufactured as integrated parts of the silicon MEMS chip, while larger mirrors are bonded onto MEMS actuators, allowing for custom mirror sizes.

- Positional precision of mechanical tilt in open loop driving of the mirror actuators is at least 14 bits (16384 positions) on each axis. For most devices, with mechanical tilt range of $-5^\circ$ to $+5^\circ$ on each axis, this tilt resolution is within 0.6 millidegrees or within 10 micro-radians.

- The mirrors deflect laser beams or images to optical scanning angles of up to 32° on each axis.
MEMS Mirror General Trade-Offs

- **SPEED:** Devices with larger-diameter mirrors are correspondingly slower due to increased inertia (for a given actuator). Inertia of a round mirror is proportional to the fourth power of the radius. Therefore, for a given actuator, speed reduces quadratically (square power) with an increase in mirror size. For example, to compare two integrated mirrors, a 0.8 mm with a 1.7 mm diameter, both having the same silicon die size and both having very similar mechanical tip/tilt angles. The 0.8 mm device's first resonant frequency is approx. 4 kHz, while the 1.7 mm device's is approx. 1.2 kHz.

- **COST:** One design parameter with a strong influence on key performance specifications is mirror size. To allow for fast speeds, larger mirrors require larger actuators which generally provide higher forces and torques; with increasing actuator die size more complex designs are often required. Additionally, larger die may require larger packages.

- **ROBUSTNESS:** Devices with smaller-diameter mirrors generally exhibit higher shock and vibration tolerance due to lower mass and angular inertia.
Integrated mirrors are monolithically fabricated as an integrated part of the gimbal-less actuator device structure. As the center of mirror inertia is approximately in the plane of the actuator’s rotating axis, they can be approximated with simple 2nd order models.
Its response can be approximated by a damped harmonic oscillator (specifically $2^{\text{nd}}$ order spring-mass system)


\[
\frac{d^2 \theta}{dt^2} + 2 \cdot \zeta \cdot \omega_n \cdot \frac{d\theta}{dt} + \omega_n^2 \cdot \theta = 0
\]
Approximate Model from Input to Output

\[ H_E(s) = 2 \cdot V_{bias} \cdot K_1 \]

\[ H_M(s) = K_2 \cdot \frac{\omega_n^2}{s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + \omega_n^2} \]

\[ K = 2 \cdot V_{bias} \cdot K_1 \cdot K_2 \]

\[ \zeta = \frac{1}{2 \cdot Q} \]

\[ \omega_n = 2 \cdot \pi \cdot f_n \]

\[ f_n = \frac{\omega_n}{2 \pi} \]

\[ H(s) = \frac{\omega_n^2}{s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + \omega_n^2} \]

Reduced to 3 Key Parameters, \( K, \zeta, \omega_n \)
Obtaining the 3 Key Parameters from Data

\[ K \] is the slope of the Static Response

\[ f_n \] and \( Q \) are shown here

\( Q \) is typically somewhat higher than shown and model should be adjusted to match graphs.

Users can obtain more accurate values from stored data in each device’s datasheet. Contact support@mirrorcletech.com for more information and provide your products’ serial numbers.
## Examples of Integrated Mirrors

<table>
<thead>
<tr>
<th>Device</th>
<th>Diameter [mm]</th>
<th>K [°/V]</th>
<th>$\zeta$ (Zeta)</th>
<th>$\omega n / 2\pi p$ [Hz]</th>
<th>Vbias [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3I8.2</td>
<td>0.8</td>
<td>0.0594</td>
<td>0.0067</td>
<td>3900</td>
<td>70</td>
</tr>
<tr>
<td>A7M10.2</td>
<td>1.0</td>
<td>0.0313</td>
<td>0.0067</td>
<td>4700</td>
<td>90</td>
</tr>
<tr>
<td>A3I12.2</td>
<td>1.2</td>
<td>0.0484</td>
<td>0.0067</td>
<td>1600</td>
<td>80</td>
</tr>
<tr>
<td>A7M20.2</td>
<td>2.0</td>
<td>0.0360</td>
<td>0.0067</td>
<td>1350</td>
<td>80</td>
</tr>
<tr>
<td>A5M24.2</td>
<td>2.4</td>
<td>0.0408</td>
<td>0.0067</td>
<td>880</td>
<td>80</td>
</tr>
</tbody>
</table>

*In some package configurations with a “/H” designation in the product name, this device is shipped with an increased damping factor of approximately 0.036. Contact support@mirrorcletech.com for more information.*
Bonded mirrors are fabricated separately from the MEMS actuator structure and are subsequently assembled on top of actuators. As the center of mirror inertia is above the plane of the actuator’s rotating axis, they typically exhibit two distinct resonances and are approximated with 4th order models.
Bonded MEMS Mirrors Overview

- Its response can be approximated by a damped harmonic oscillator (specifically 4\textsuperscript{th} order spring-mass system)
Approximate Model from Input to Output

\[ \zeta = \frac{1}{2 \cdot Q} \]\[
\omega_n = 2 \cdot \pi \cdot f_n \]

Control Voltage \rightarrow \text{Mechanical spring-mass system response} \rightarrow \text{Mirror angle}

\[ H(s) = K \cdot \frac{\omega_{n1}^2 \cdot \omega_{n2}^2 \cdot (s + z_1)(s + z_2)}{(s + p_1)(s + p_2)(s + p_3)(s + p_4) \cdot \omega_z^2} \]

7 Parameters, \( K, \zeta_1, \zeta_2, \zeta_z, \omega_{n1}, \omega_{n2}, \omega_z \)

\[ p_1 = -\omega_{n1} \zeta_1 - i \omega_{n1} \sqrt{1 - \zeta_1^2} \]
\[ p_2 = -\omega_{n1} \zeta_1 + i \omega_{n1} \sqrt{1 - \zeta_1^2} \]
\[ p_3 = -\omega_{n2} \zeta_2 - i \omega_{n2} \sqrt{1 - \zeta_2^2} \]
\[ p_4 = -\omega_{n2} \zeta_2 + i \omega_{n2} \sqrt{1 - \zeta_2^2} \]
\[ z_1 = -\omega_z \zeta_z - i \omega_z \sqrt{1 - \zeta_z^2} \]
\[ z_2 = -\omega_z \zeta_z + i \omega_z \sqrt{1 - \zeta_z^2} \]
Obtaining the 7 Key Parameters from Data

K is the slope of the Static Response

[p1, p2], [p3, p4], [z1, z2] and Q1 are shown here (Q is typically somewhat higher than shown and model should be adjusted to match graphs)

Users can obtain more accurate values from stored data in each device’s datasheet. Contact support@mirrorcletech.com for more information and provide your products’ serial numbers.
### Examples of Bonded Mirrors

\[ \zeta_1 = 0.01 \quad \zeta_2 = 0.0033 \quad \zeta_z = 0.00125 \]

<table>
<thead>
<tr>
<th>Device</th>
<th>Diameter [mm]</th>
<th>( K ) [°/V]</th>
<th>( \omega_{n1} / 2\pi ) [Hz]</th>
<th>( \omega_{n2} / 2\pi ) [Hz]</th>
<th>( \omega_z / 2\pi ) [Hz]</th>
<th>Vbias [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A8L2.2</td>
<td>5.0</td>
<td>0.0356</td>
<td>280</td>
<td>1360</td>
<td>1290</td>
<td>90</td>
</tr>
<tr>
<td>A7B2.1</td>
<td>3.6</td>
<td>0.0437</td>
<td>410</td>
<td>1020</td>
<td>930</td>
<td>80</td>
</tr>
</tbody>
</table>
Closing Comments

- The models are approximate and assume linear response which is not true in reality at all angles etc.
- Damping is also approximated as it is ultimately a function of angle.
- Note that for different Vbias setting, the gain factor $K_{\text{new\_bias}}$ can be estimated from a known $K_{\text{known\_bias}}$ as follows: $K_{\text{new\_bias}} = K_{\text{known\_bias}} \times \frac{V_{\text{bias\_new}}}{V_{\text{bias\_known}}}$
Disclaimer for MEMS Mirror Models

- This disclaimer is issued in regard to the approximate models provided in this Application Note including any accompanying software, data, media, and on-line or printed documentation.

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- The models are an ongoing research project and hence they may undergo revision from time to time.
Thank You for Choosing

Additional Resources:

- Mirrorcle MEMS Mirrors – Technical Overview
- Mirrorcle Documentation Portal
- Mirrorcle Web Page – Support
- Mirrorcle Web Page – Application Notes
- Mirrorcle Web Page – Publications

If you have any further questions or suggestions please email us:

support@mirrorcletech.com