Acousto optic modulators

Additional details relevant for servos
AOM = acousto optic modulator

- AOM = acousto optic modulator (or deflector)
- RF signal converted to sound waves in crystal
  - Use fast piezo-electric transducer like Li NbO$_3$
- Sound waves are collimated to form grating
- Bragg scatter from grating gives deflected beam
  - can separate from original
- Problem with AOM -- weak link
- Sound takes time to travel from transducer to laser beam
  - Time delay: $t_D = l / v$ -- acts like multi-pole rolloff
  - (phase shift increases with frequency)

![Diagram of AOM](image)

- Input laser beam
- Sound transducer ex: LiNbO$_3$
- RF signal ~ 1 Watt 40 MHz
- Sound absorber (suppress reflections)
- Aperture
- Refractive index variations due to sound waves
- Undeflected beam
- Deflected beam
Thick gratings

- Many layers
- Reflectivity per layer small

Examples:
- Holograms -- refractive index variations
- X-ray diffraction -- crystal planes
- **Acousto-optic shifters -- sound waves**
  - grating spacing given by sound speed, RF freq.

\[
\delta L = 2d \sin \theta_B = n\lambda
\]
\[d = \frac{v_{\text{sound}}}{f_{\text{microwave}}}\]

Bragg angle:

![Diagram showing input, output, integer wavelengths, and grating planes.](image)
Typical AOM materials

Glass AOM
• sound speed 6 km/sec
• time delay 160 nsec / mm distance from transducer
• 40 MHz drive --> 150 μm fringe spacing
• for 0.6 micron light, Bragg angle = 2 mrad = 0.1 degree

Table 2. Acousto-Optic Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Chemical formula</th>
<th>Spectral range (μm)</th>
<th>Figure of merit $M_2$ (10$^{-15} m^2/W$)</th>
<th>Bandwidth (MHz)</th>
<th>Typical drive power (W)</th>
<th>Index of Refraction</th>
<th>Acoustic Velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused silica/quartz</td>
<td>SiO$_2$</td>
<td>0.3 - 1.5</td>
<td>1.6</td>
<td>to 20</td>
<td>6</td>
<td>1.46 (6343 nm)</td>
<td>5900</td>
</tr>
<tr>
<td>Gallium arsenide</td>
<td>GaAs</td>
<td>1.0 - 11</td>
<td>104</td>
<td>to 350</td>
<td>1</td>
<td>3.37 (1.15 μm)</td>
<td>5340</td>
</tr>
<tr>
<td>Gallium phosphide</td>
<td>GaP</td>
<td>0.59 - 1.0</td>
<td>45</td>
<td>to 1000</td>
<td>50</td>
<td>3.31 (1.15 μm)</td>
<td>6320</td>
</tr>
<tr>
<td>Germanium</td>
<td>Ge</td>
<td>2.5 - 15</td>
<td>840</td>
<td>to 5</td>
<td>50</td>
<td>4.0 (10.6 μm)</td>
<td>5500</td>
</tr>
<tr>
<td>Lead molybdate</td>
<td>PbMoO$_4$</td>
<td>0.4 - 1.2</td>
<td>50</td>
<td>to 50</td>
<td>1 - 2</td>
<td>2.26 (633 nm)</td>
<td>3630</td>
</tr>
<tr>
<td>Tellurium dioxide</td>
<td>TeO$_2$</td>
<td>0.4 - 5</td>
<td>35</td>
<td>to 300</td>
<td>1 - 2</td>
<td>2.26 (633 nm)</td>
<td>4200</td>
</tr>
<tr>
<td>Lithium niobate</td>
<td>L$_6$NbO$_3$</td>
<td>0.5-2</td>
<td>7</td>
<td>&gt; 300</td>
<td>50-100</td>
<td>2.20 (633nm)</td>
<td>6570</td>
</tr>
</tbody>
</table>
AOM driver

• Fixed frequency: 40 MHz
• Can change amplitude (power) with input voltage
  – does not change Bragg angle
  – need voltage controlled oscillator (VCO) to change angle
• RF power determines
  – sound wave amplitude,
  – density change,
  – refractive index modulation depth,
  – diffracted light power

Saturation effects
• Bragg diffraction saturates
  – deflected beam power diffracted back into undeflected beam
• Acoustic wave saturates
  – Index modulation depth no longer linear in microwave power
  – higher order diffracted beams
Low pass filter

- Above knee phase shift is constant -- amplitude rolls off

\[
V_{in} = V_0 \cos(2 \pi f t)
\]

Response on oscilloscope
Time delay

- Amplitude is constant
- When $1/f$ approaches delay time
  - Phase increases rapidly
  - Phase shift linear in $f$
- Grows exponentially on semi-log plot
- Cannot compensate with lead

\[ \text{Phase response} \]

\[ \log(f) \]

\[ f = \frac{1}{2 \pi t_D} \]

\[ \text{phase} \]

\[ 0 \text{ degrees} \]
\[ -90 \text{ degrees} \]
\[ -180 \text{ degrees} \]
\[ -270 \text{ degrees} \]

**Response on oscilloscope**

- Refractive index variations due to sound waves
- Input laser beam
  - Deflected beam
  - Undeflected beam
- RF signal
  - ~ 1 Watt
  - 40 MHz

\[ t_d = \frac{l}{v} \]

\[ \text{time} \]

\[ \text{voltage} \]