Optics

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Journal Club

Oct. 18, 2022

Geometrical optics

Useful for $> 90\%$ of calculation.

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Exceptions

- Focus
- Long propagation
- Diffraction optical elements
  e.g. gratings.

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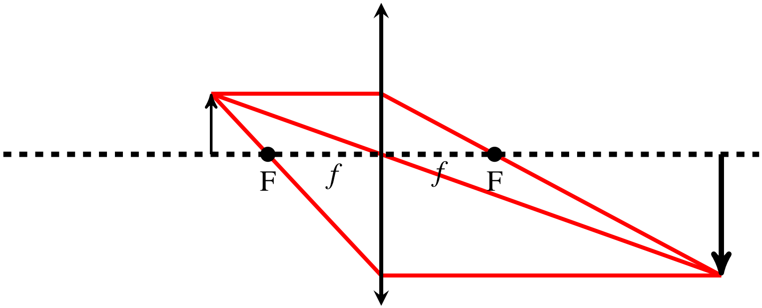
Ideal Lens



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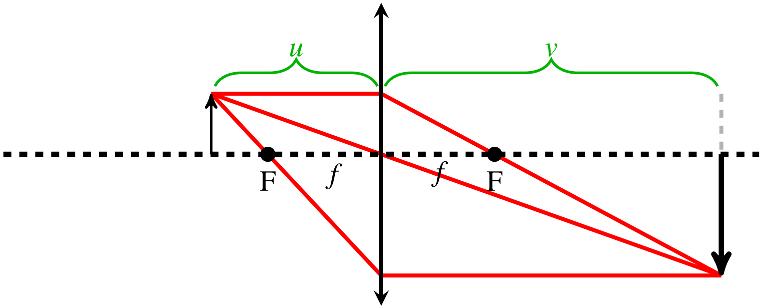

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

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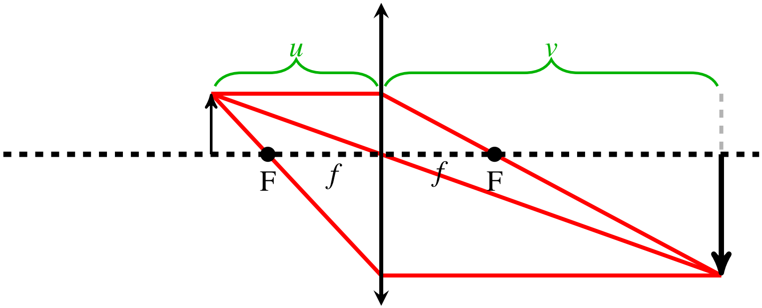

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$M = -\frac{v}{u}$$

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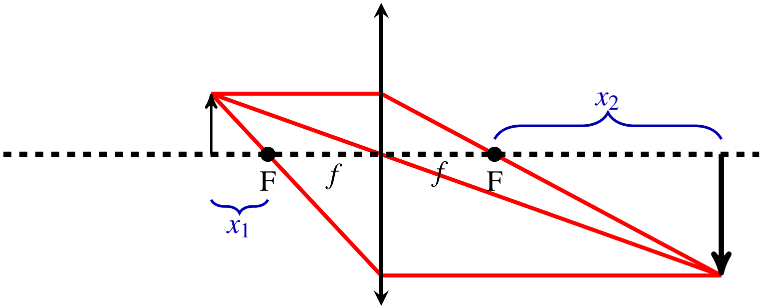
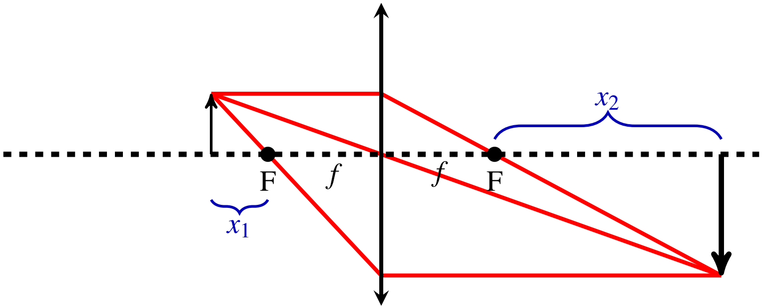


$$x_1 x_2 = f^2$$

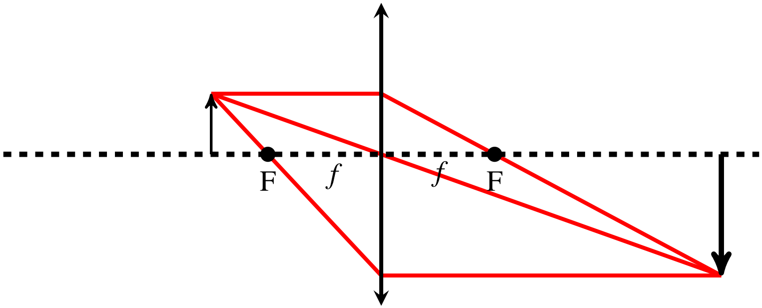
Ideal Lens



$$x_1 x_2 = f^2$$

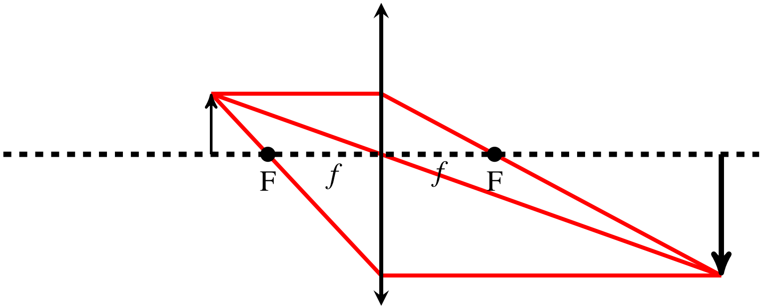
$$M = -\frac{f}{x_1} = -\frac{x_2}{f} = -\sqrt{\frac{x_2}{x_1}}$$

Ideal Lens



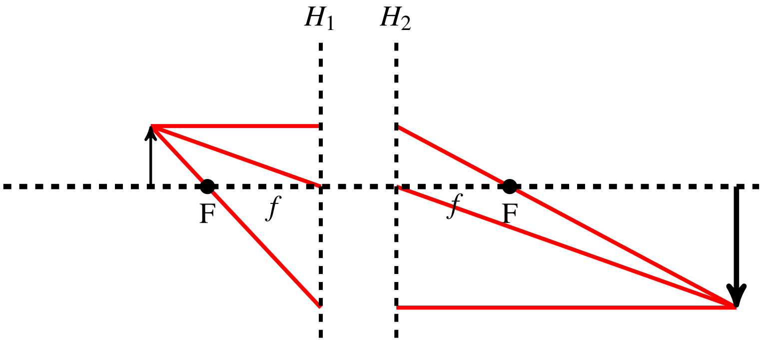
Conjugate plane: Perfect image under ray optics

Ideal Lens

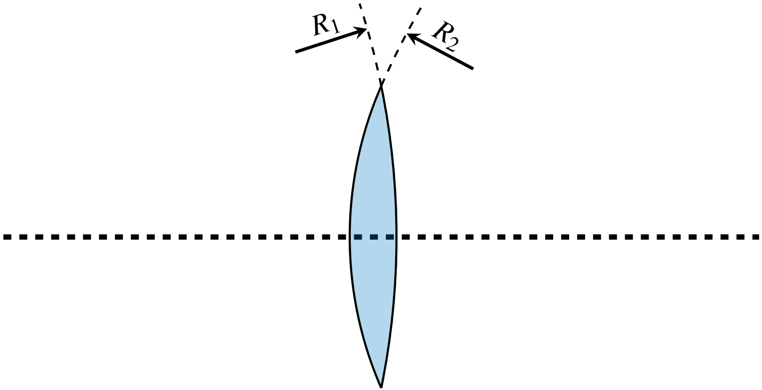


Conjugate plane: Perfect image under ray optics
Principal planes: Conjugate plane where $M = 1$

Ideal Lens



Spherical lens



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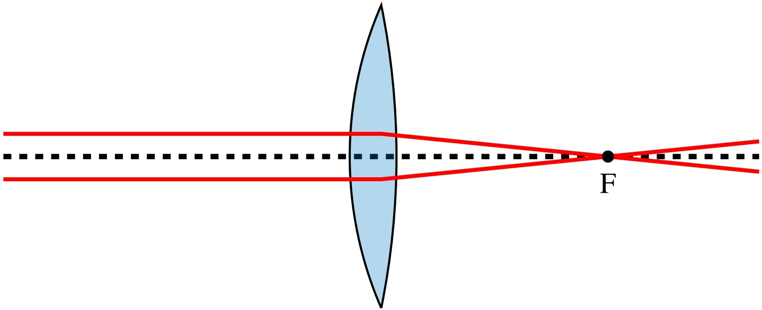

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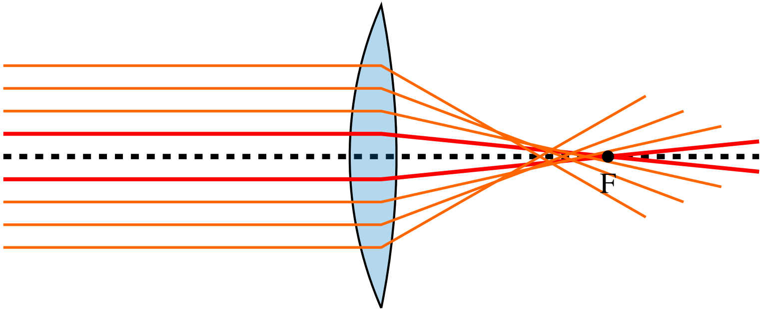

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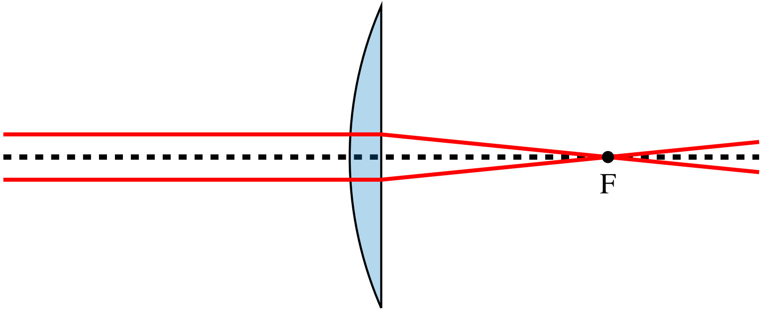
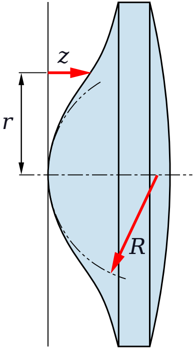
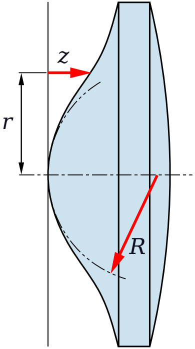


Aspherical lens



Aspherical lens



Use cases

- Collimation
- Fiber coupling

Other lens types

Reflective

- No chromatic shift
- Can be aspherical
- More difficult beam path layout

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Reflective

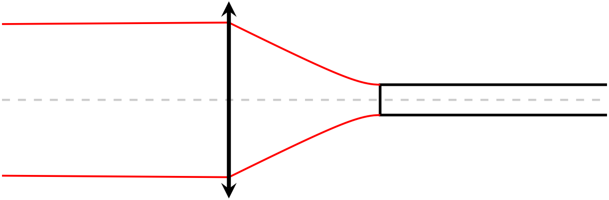
- No chromatic shift
- Can be aspherical
- More difficult beam path layout

Lens set

- Could fix chromatic shift
- Could fix monochromatic aberration
- Better surface quality
- May not be UV compatible

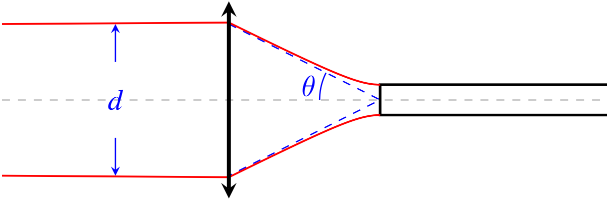
Fiber coupling

Collimation



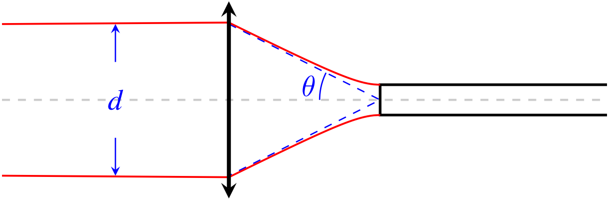
Fiber coupling

Collimation



Fiber coupling

Collimation

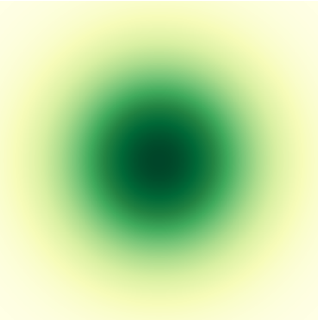


$$d \approx 2f \tan\theta$$

Alignment

Fiber coupling

Alignment



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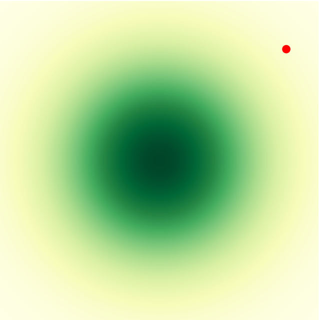

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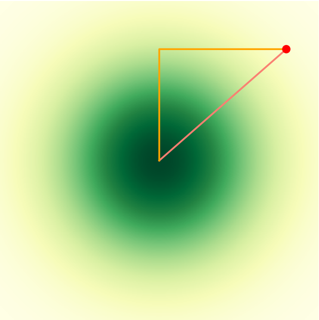

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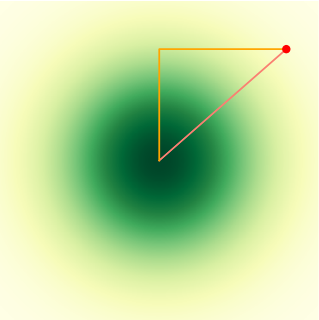

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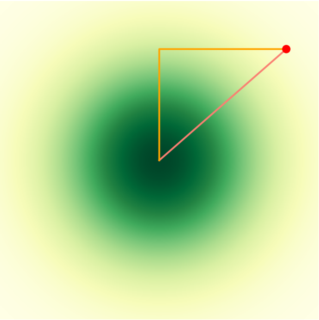

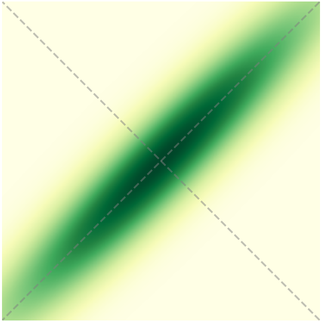

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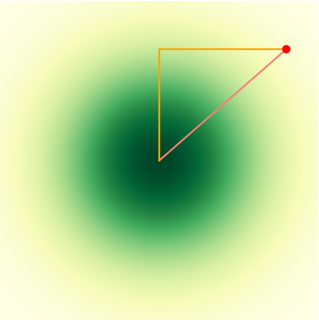

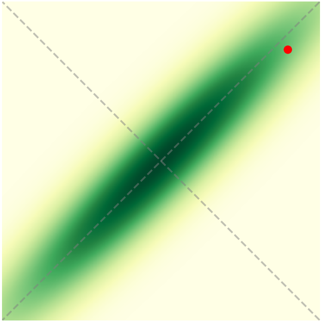

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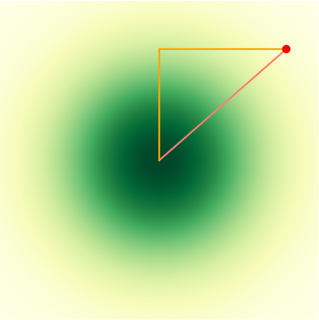

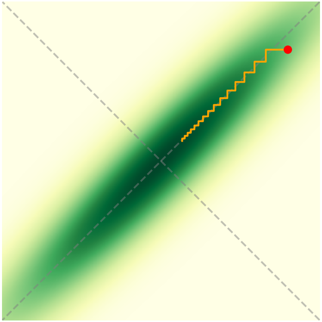

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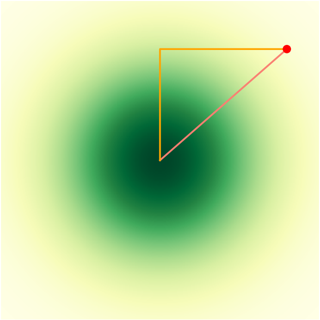

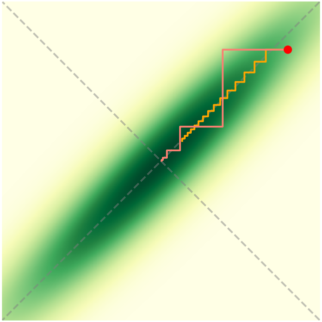

Polarization

Polarization: Polarizers

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PBS Cubes

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- Based on coating
- Easy to use for both polarizations
- OK loss (few %)
- low-mid extinction
- Wavelength dependent

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- Based on birefringence
- Non 90 reflection angle
- Low loss
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- Etaloning
- Broadband

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Thin film

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Polarization: Waveplates

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Other WP type: Achromatic, "Magic"

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Normal incident

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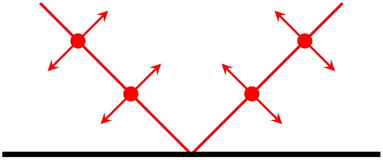

$\updownarrow$ *p*-polarization

● *s*-polarization

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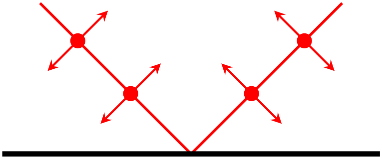
Simple surface

- (metal or dielectric)
- π phase shift
- Change relative amplitude



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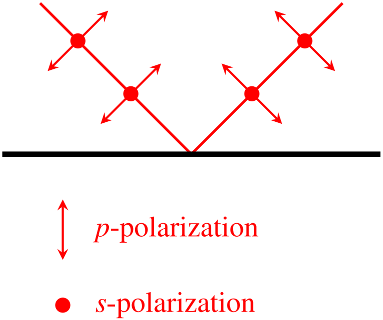

Coating

- "Arbitrary" phase shift
- Change relative amplitude
- (dielectric mirror, dichroics)

Electro-optic modulator (EOM)

Electro-optic modulator (EOM) i.e. electrically variable waveplate

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DC EOM: adjustable waveplate

- Rotate polarization
- (with polarizer) Turn beam on/off
- Temperature drift compensation

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AC EOM: phase/polarization modulation

- Polarization modulation
- Power modulation
- Phase modulation/sideband
- Asymmetric sideband

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$$\begin{aligned}\phi =&\phi_0 + \beta\sin(\omega t)\\ \tilde{A} =&A_0\exp(\mathrm{i}\phi)\\ =&\tilde{A_0}\exp(\mathrm{i}\beta\sin(\omega t))\\ =&\tilde{A_0}\sum_{n=-\infty}^{\infty}J_n(\beta)\exp(\mathrm{i}n\omega t)\end{aligned}$$

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AC EOM: phase/polarization modulation

- Polarization modulation
- Power modulation
- Phase modulation/sideband
- Asymmetric sideband: sawtooth drive

$$\phi = mod(\phi_0 + \omega t, 2\pi)$$

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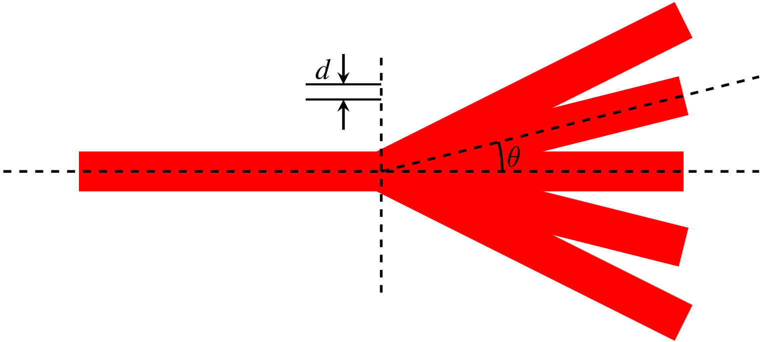
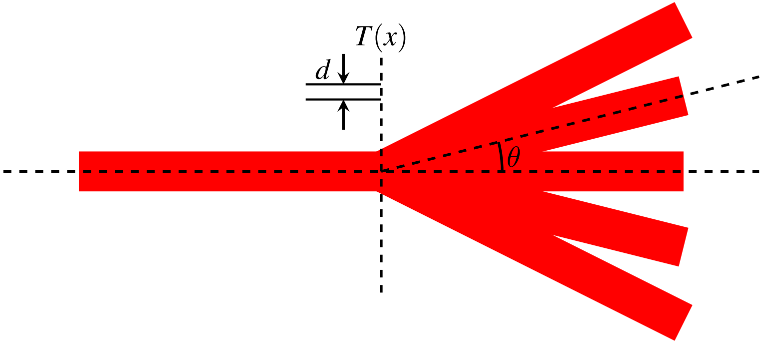


$$d \sin \theta_n = n\lambda$$

Acousto-optic modulator (AOM) i.e. dynamic/moving grating



$$d \sin \theta_n = n\lambda$$

$$T(x) = \sum_n a_n \exp\left(\mathrm{i}\frac{2n\pi x}{d}\right)$$

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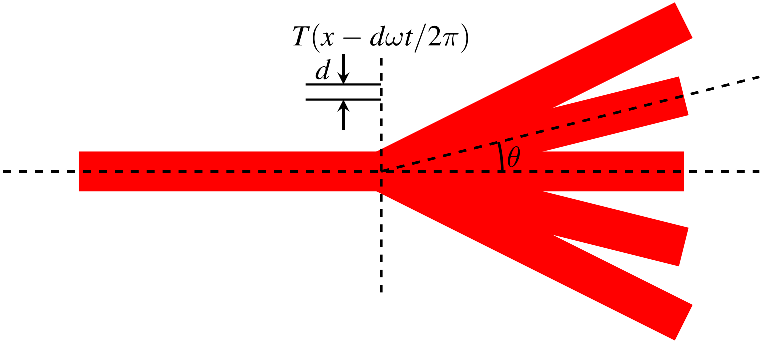

$$d \sin\theta_n = n\lambda$$

$$T(x) = \sum_n a_n \exp\left(\mathrm{i}\frac{2n\pi(x - d\omega t/2\pi)}{d}\right)$$
$$= \sum_n a_n \exp\left(\mathrm{i}\frac{2n\pi x}{d} - \mathrm{i}n\omega t\right)$$

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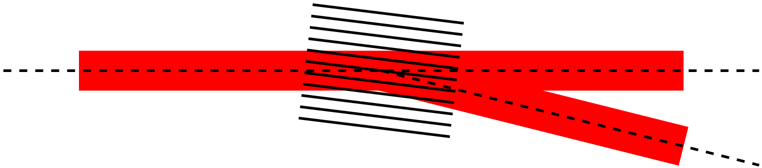
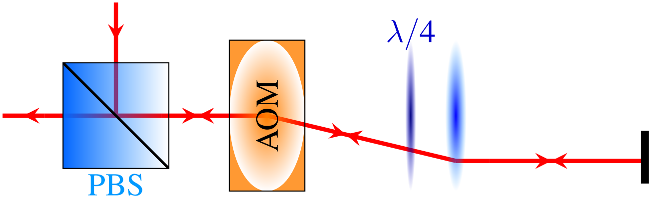


Acousto-optic modulator (AOM) i.e. dynamic/moving grating

Double Pass



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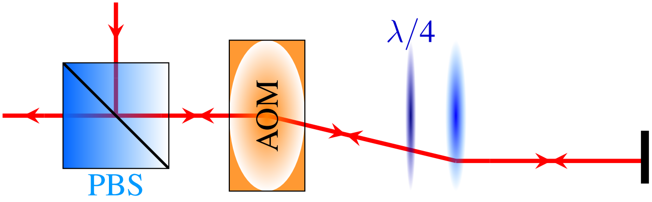
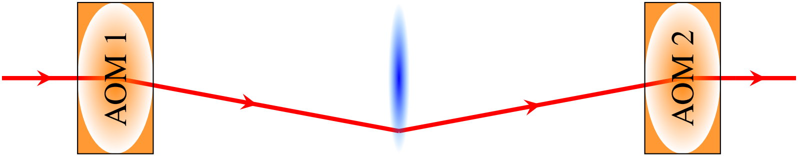


Tandem



AOM vs EOM

AOM	EOM

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AOM	EOM
40 – 2000MHz	DC – 40GHz

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Tunable (AOBD vs AOM)	Tunable (if not resonant)

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Good suppression of wrong order	Bad suppression of wrong order

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40 – 2000MHz	DC – 40GHz
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No/little polarization modulation	Support polarization modulation

AOM vs EOM

AOM	EOM
40 – 2000MHz	DC – 40GHz
Tunable (AOBD vs AOM)	Tunable (if not resonant)
Good suppression of wrong order	Bad suppression of wrong order
No/little polarization modulation	Support polarization modulation
Multiple frequencies in single beam (Requires multiple AOMs)	Multiple frequencies in single beam

AOM vs EOM

AOM	**EOM**
40 – 2000MHz	DC – 40GHz
Tunable (AOBD vs AOM)	Tunable (if not resonant)
Good suppression of wrong order	Bad suppression of wrong order
No/little polarization modulation	Support polarization modulation
Multiple frequencies in single beam (Requires multiple AOMs)	Multiple frequencies in single beam
Steer beam with frequency	Cannot steer beam

AOM vs EOM

AOM	EOM
40 – 2000MHz	DC – 40GHz
Tunable (AOBD vs AOM)	Tunable (if not resonant)
Good suppression of wrong order	Bad suppression of wrong order
No/little polarization modulation	Support polarization modulation
Multiple frequencies in single beam (Requires multiple AOMs)	Multiple frequencies in single beam
Steer beam with frequency	Cannot steer beam
Switching implies frequency shift (Can shift back with another AOM)	Switching without frequency shift (DC)

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40 – 2000MHz	DC – 40GHz
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Steer beam with frequency	Cannot steer beam
Switching implies frequency shift (Can shift back with another AOM)	Switching without frequency shift (DC)
Slow (μs)	Fast (ns)