Introduction to Acousto-optic Modulators

by Olen Rambow

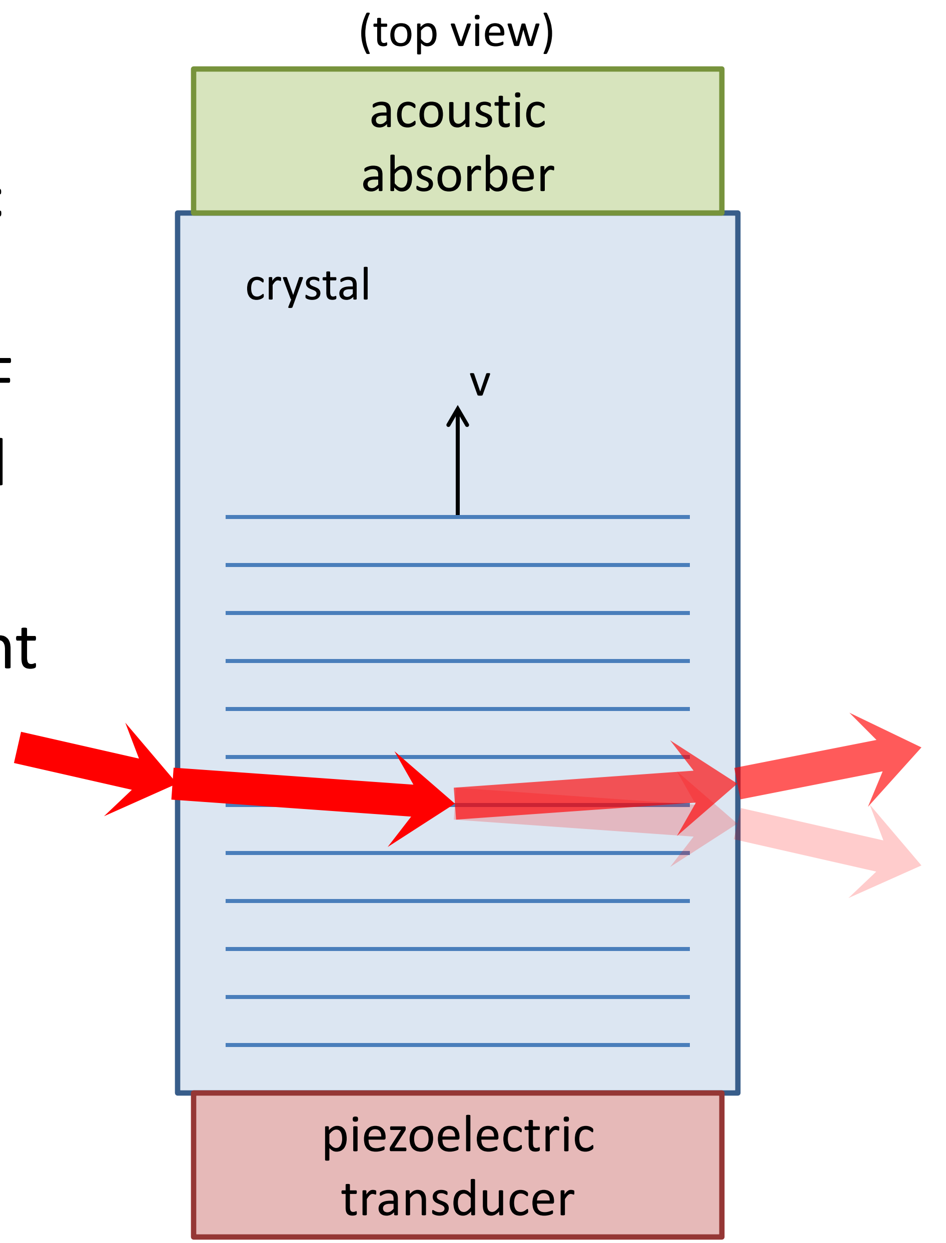
September 2013

www.olenrambow.com

Contents

1. How an AOM Works

- An AOM is a crystal connected to a piezoelectric transducer.
- The transducer generates RF acoustic waves in the crystal at some fixed frequency.
- These waves will diffract light under certain conditions.
- An acoustic absorber prevents reflection of the waves back through the crystal.



An AOM changes a laser's . . .

- Direction
- Intensity
- Frequency
- Phase
- Polarization

An AOM changes a laser's . . .

- Direction
- Intensity
- Frequency
- Phase
- Polarization

$$\sin\theta = \frac{n\lambda}{2\Lambda}$$

where:

- θ is the deflection angle of the diffracted beam
- λ is the laser's wavelength
- Λ is the acoustic wavelength
- n is ± 1 if the signal driving the transducer is a sine wave

An AOM changes a laser's . . .

- Direction
- Intensity
- Frequency
- Phase
- Polarization

- Up to about 85% of the beam power is diffracted.
- Diffraction efficiency depends on beam size and is higher for a *larger* beam.

An AOM changes a laser's . . .

- Direction
- Intensity
- Frequency
- Phase
- Polarization

- The frequency of the *diffracted* beam is shifted up or down by the acoustic frequency, depending on the input beam angle.
- If the laser is angled (slightly) in the *opposite* direction of the acoustic wave, its frequency *increases*.
- If the laser is angled in *same* direction as the acoustic wave, its frequency *decreases*.

An AOM changes a laser’s . . .

- Direction
- Intensity
- Frequency
- Phase
- Polarization

- The phase of the *diffracted* beam is shifted by the phase of the acoustic wave.

An AOM changes a laser’s . . .

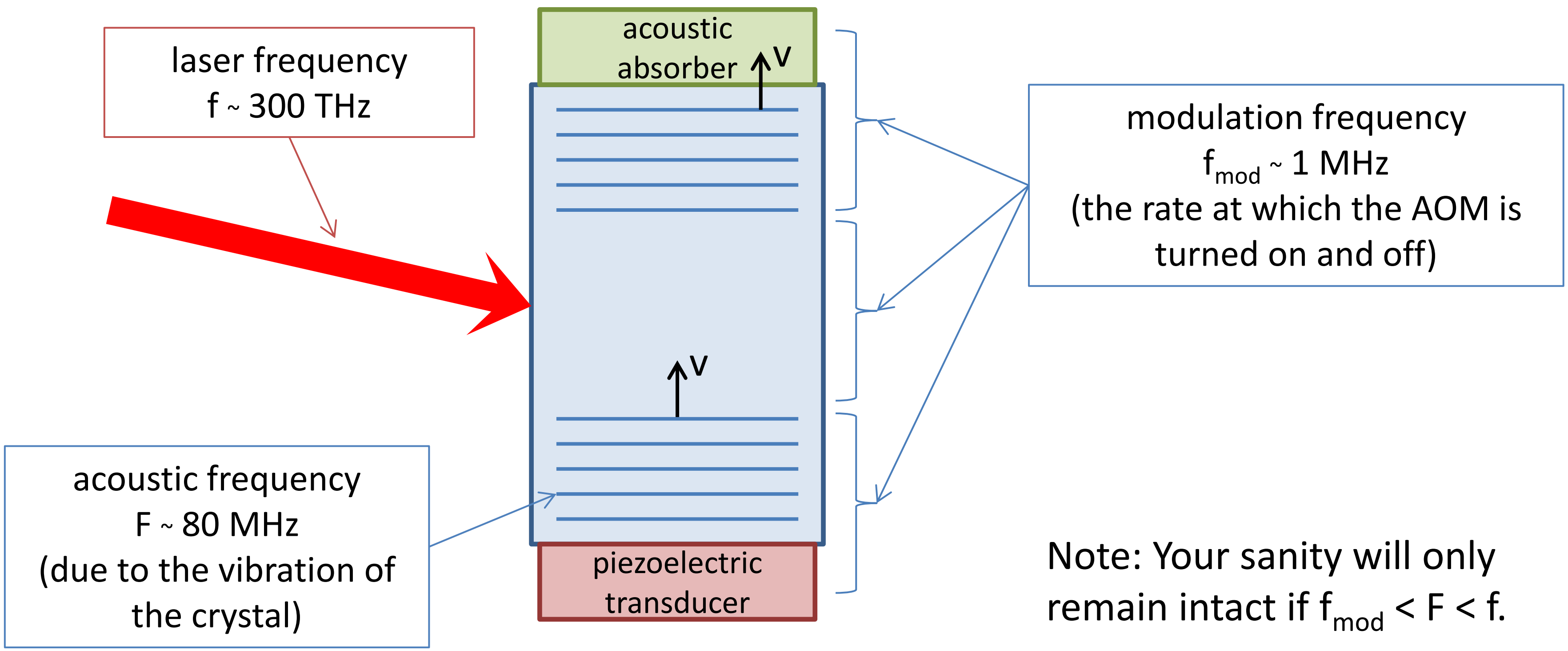
- Direction
- Intensity
- Frequency
- Phase
- Polarization

- The acoustic wave induces a birefringent phase shift.

Important Note on Frequency

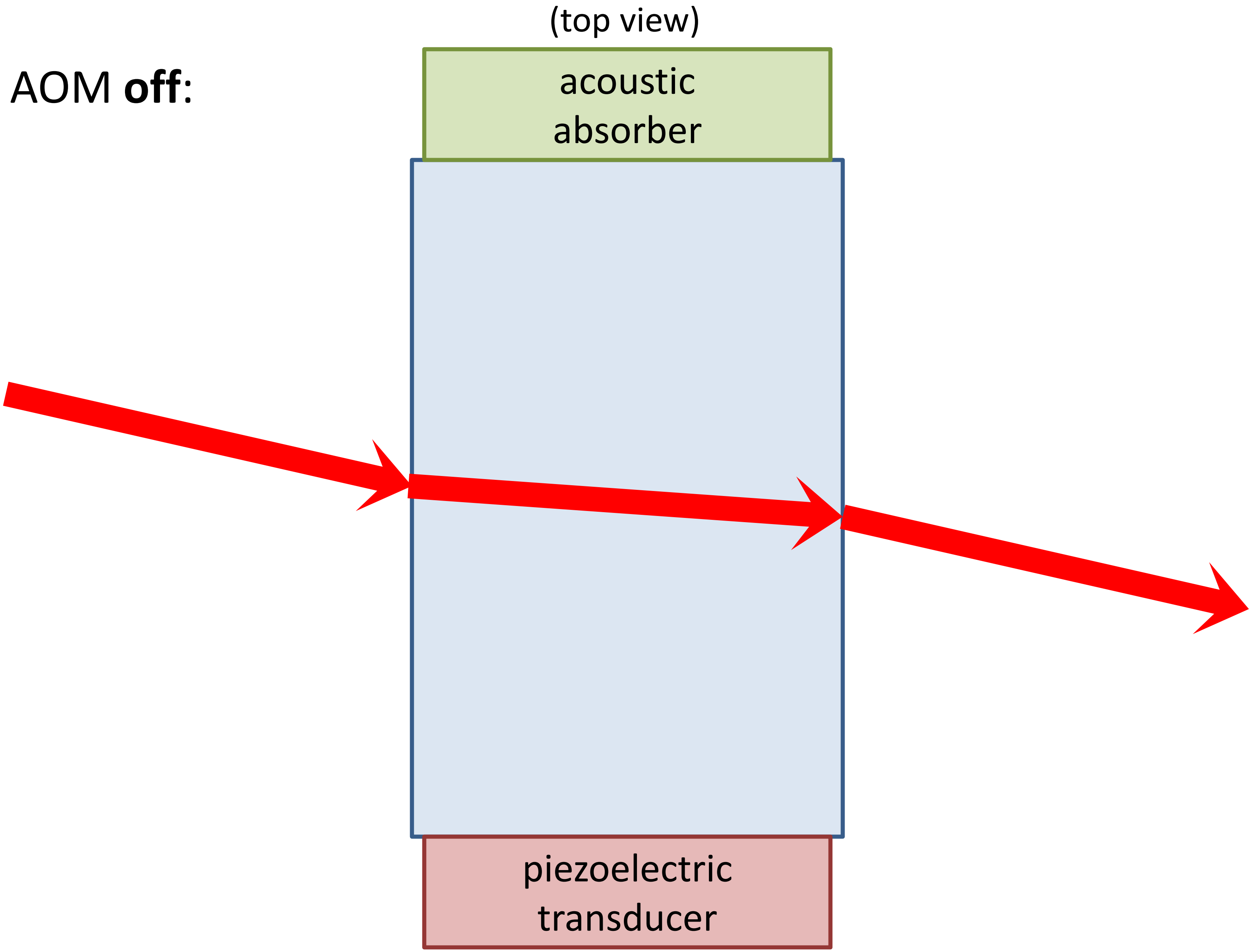
When using an AOM, there are three frequencies of interest, and you must not get them mixed up:

- the laser frequency, f
- the acoustic frequency, F
- the modulation frequency, f_{mod}



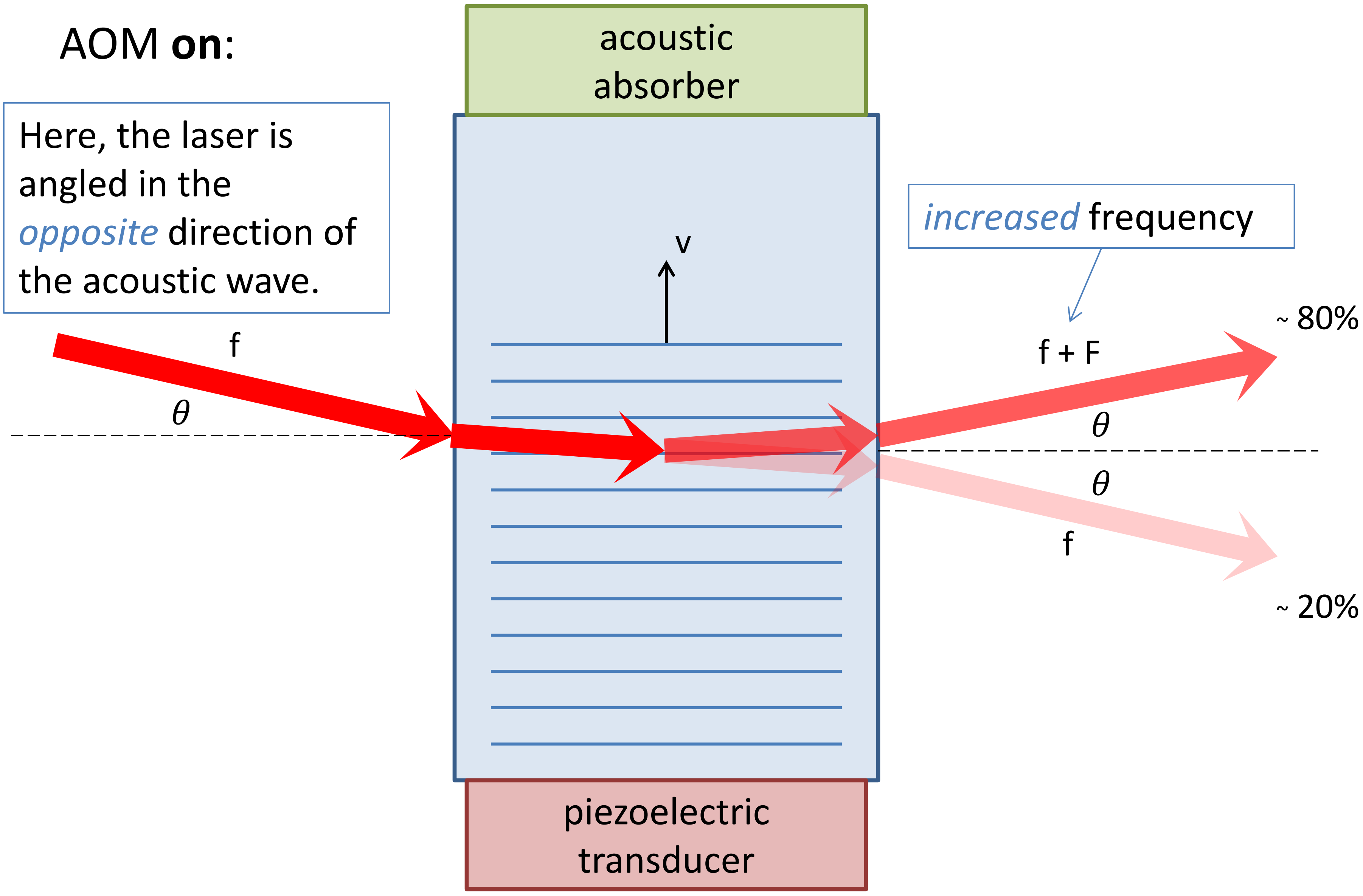
Note: Your sanity will only remain intact if $f_{mod} < F < f$.

AOM **off**:

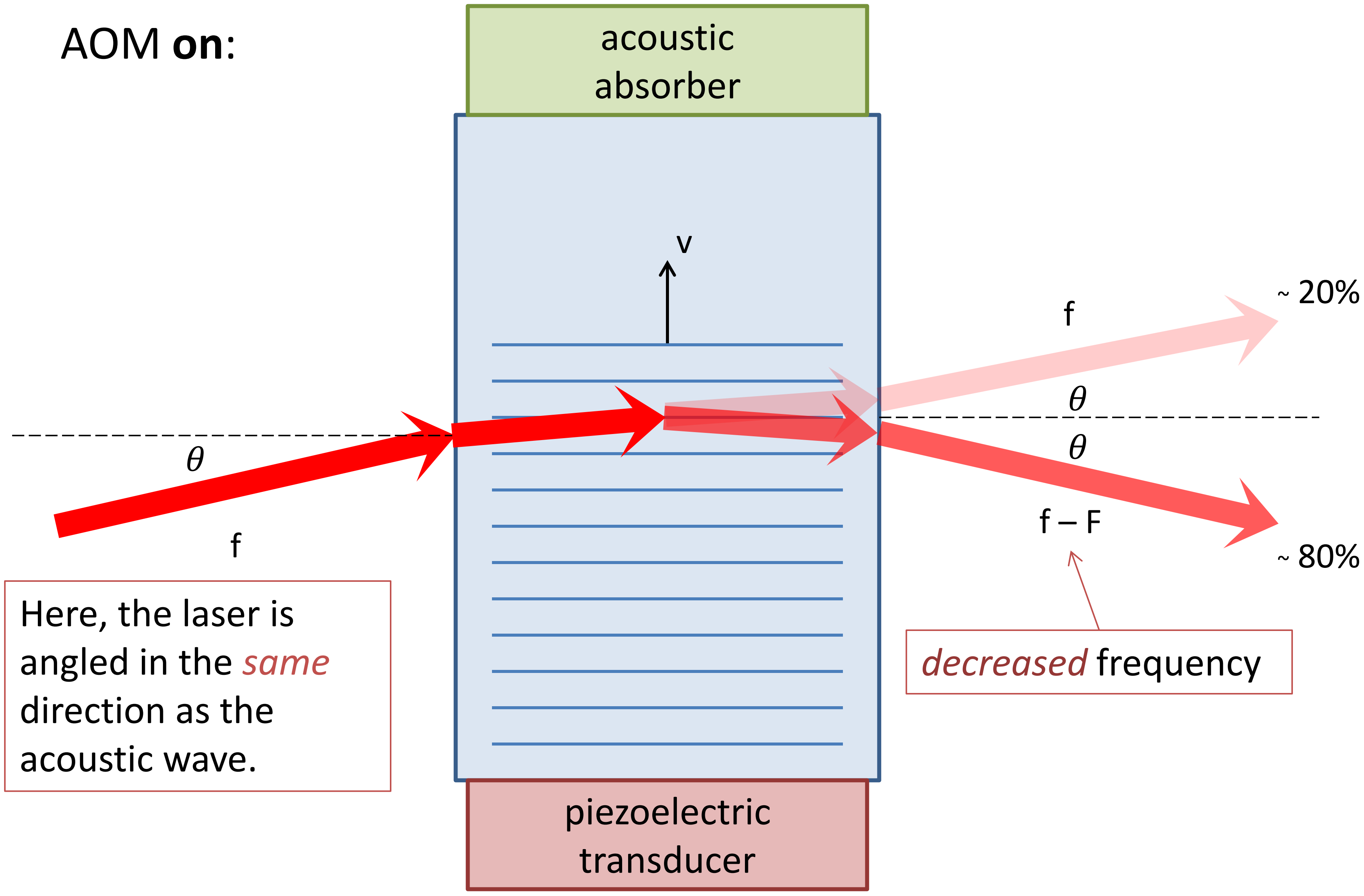


AOM **on**:

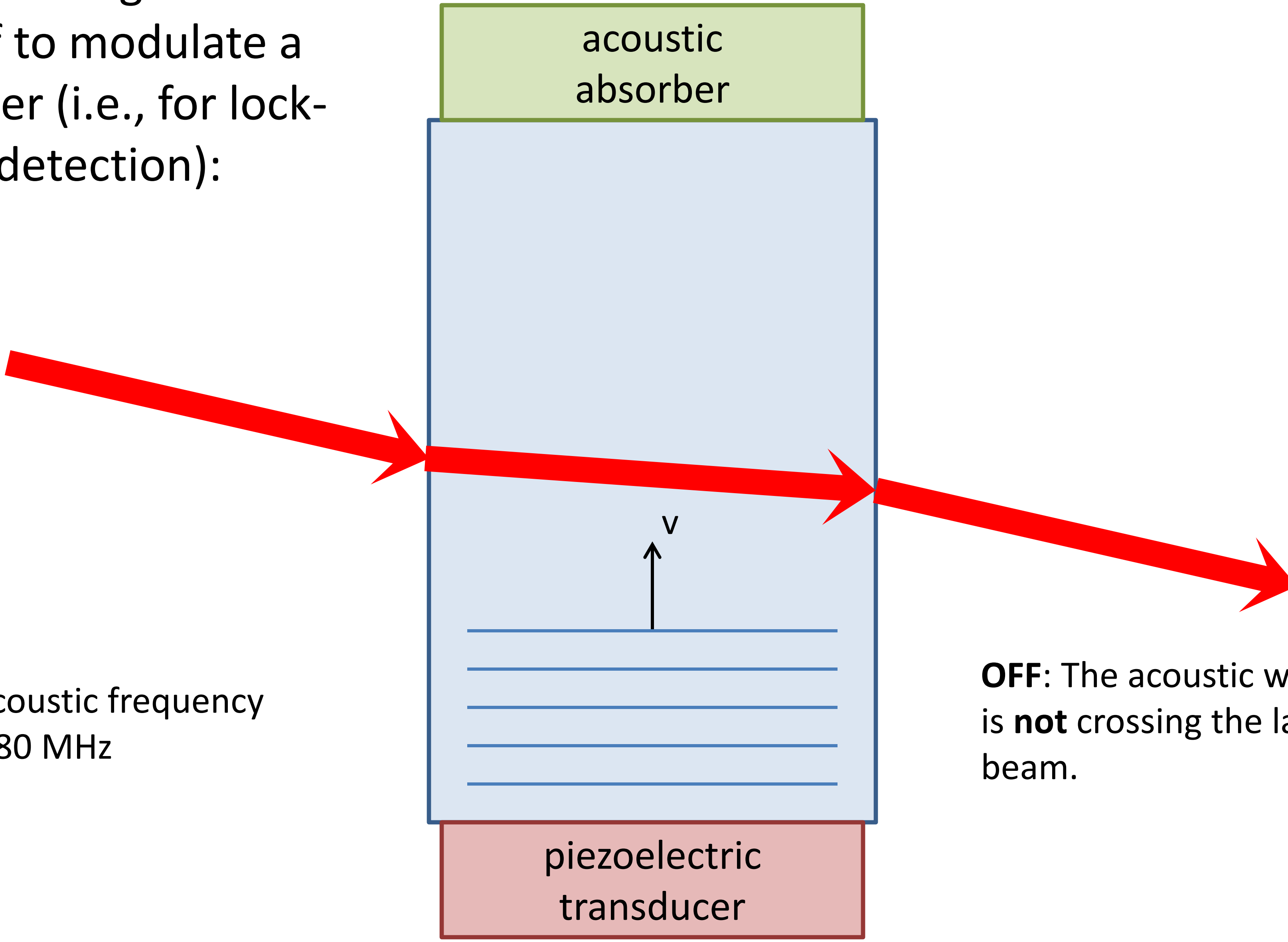
Here, the laser is angled in the *opposite* direction of the acoustic wave.



AOM **on**:


acoustic
absorber
v
f
~ 20%
θ
θ
θ
f
f – F
~ 80%
Here, the laser is angled in the *same* direction as the acoustic wave.
decreased frequency
piezoelectric
transducer

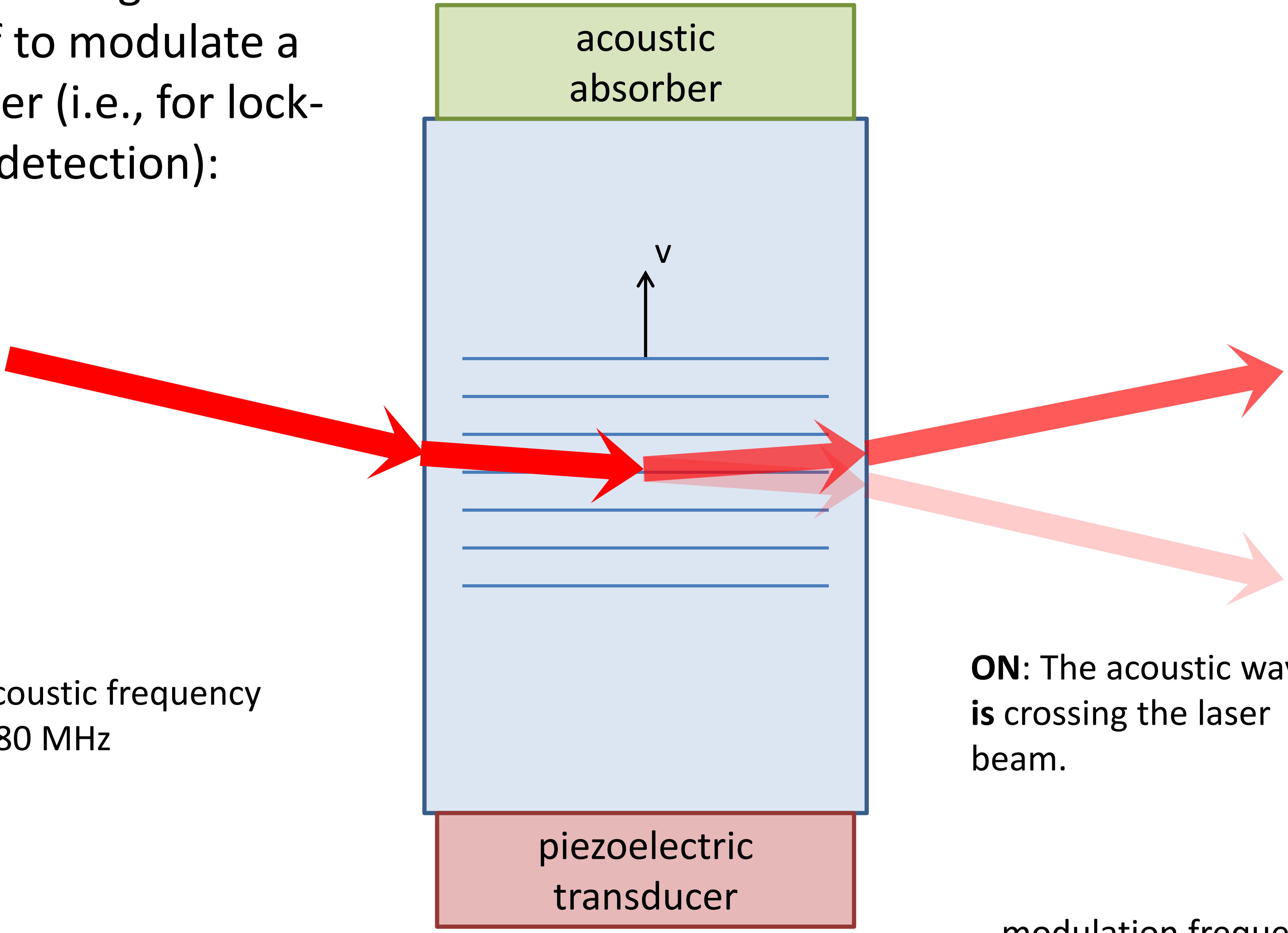
Switching on and off to modulate a laser (i.e., for lock-in detection):



acoustic frequency ~ 80 MHz

OFF: The acoustic wave is **not** crossing the laser beam.

Switching on and off to modulate a laser (i.e., for lock-in detection):

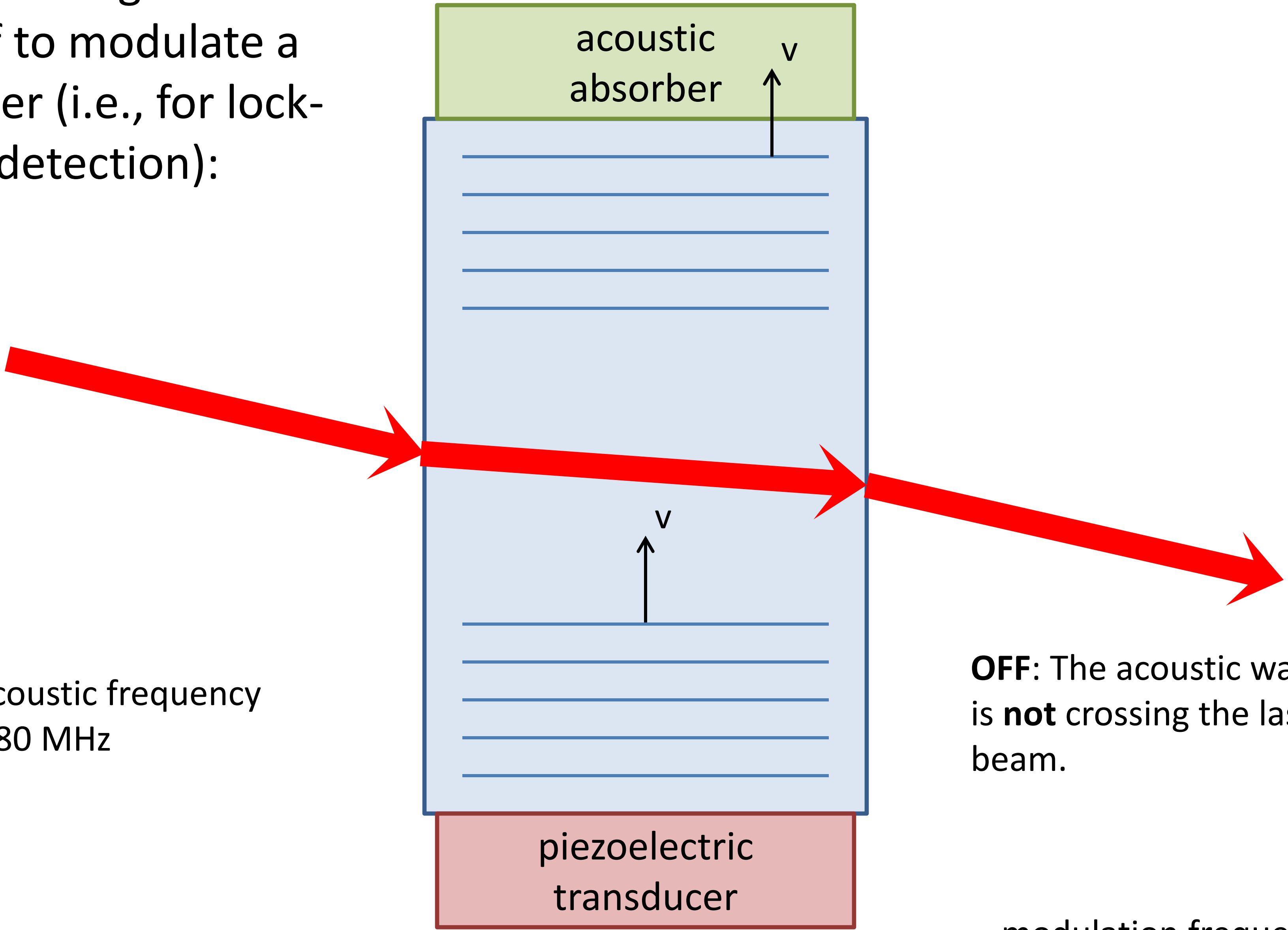


acoustic frequency
~ 80 MHz

ON: The acoustic wave **is** crossing the laser beam.

modulation frequency
~ 1 MHz

Switching on and off to modulate a laser (i.e., for lock-in detection):

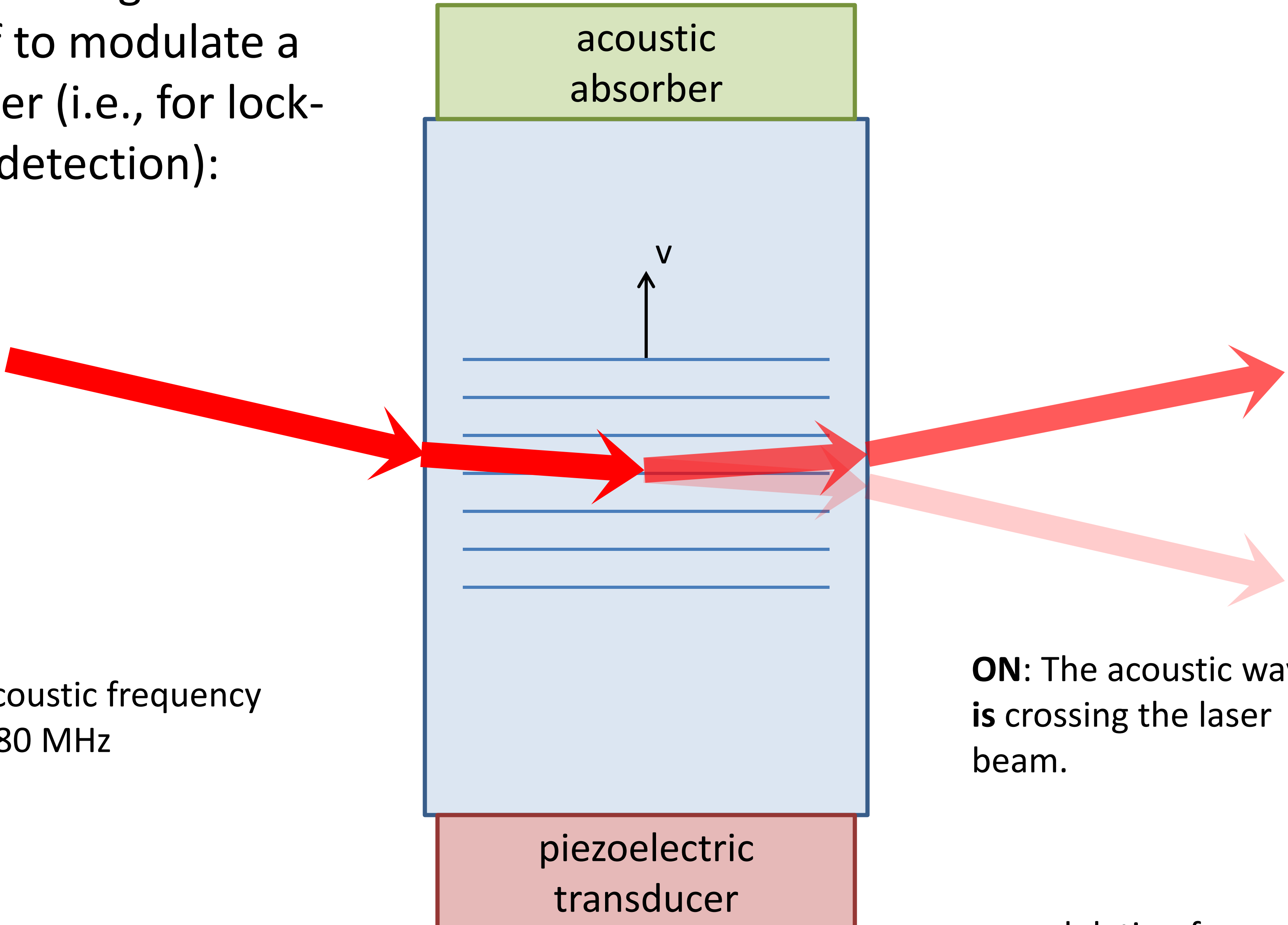


acoustic frequency ~ 80 MHz

OFF: The acoustic wave is **not** crossing the laser beam.

modulation frequency ~ 1 MHz

Switching on and off to modulate a laser (i.e., for lock-in detection):



acoustic frequency
~ 80 MHz

ON: The acoustic wave **is** crossing the laser beam.

modulation frequency
~ 1 MHz

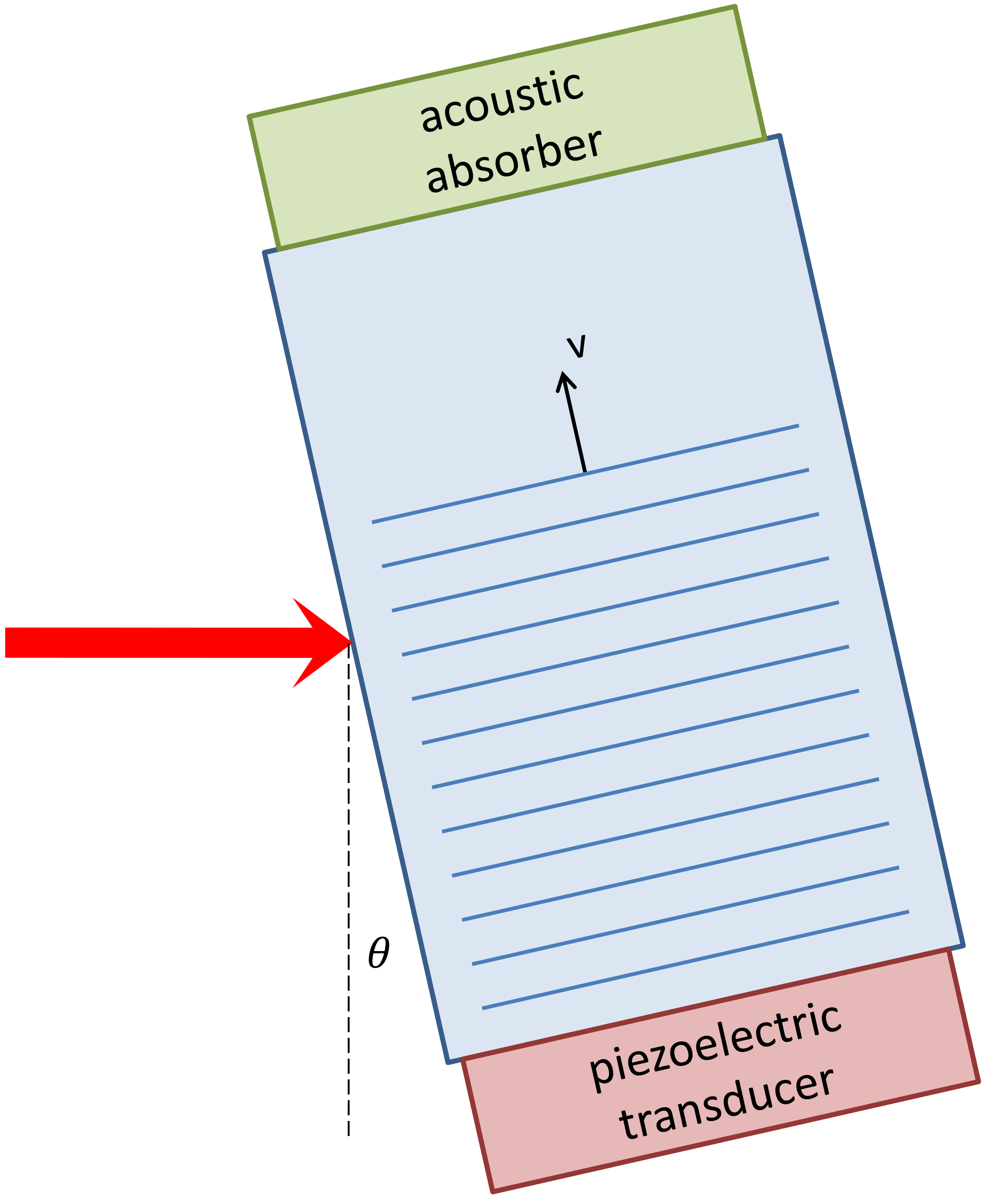
2. Considerations for Using an AOM

To optimize an AOM's performance, you must pay attention to . . .

- laser input angle
- vertical positioning of the AOM
- polarization of the laser
- rise time (switching speed)
- beam size

Laser Input Angle:

- The AOM should be mounted so that its angle with respect to the laser beam can be finely controlled.
- For a typical AOM, the desired angle is about 0.5°.

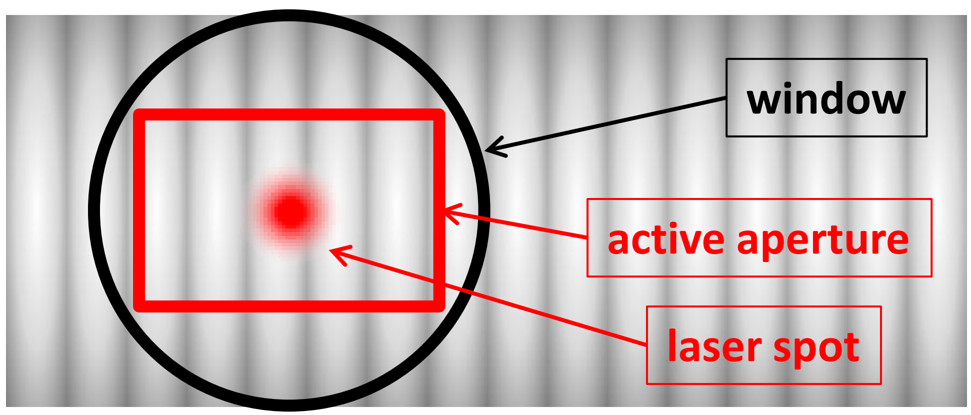


(top view)

Vertical Positioning:

- Since the acoustic wave is weaker and distorted near the surfaces of the crystal, the vertical position of the AOM should be adjusted so that the laser passes through the center of the crystal.
- The laser beam must be smaller than the “active aperture,” and the vertical position adjusted to maximize diffraction efficiency.
- A typical active aperture may be 2.5 mm wide and 1.0 mm high.

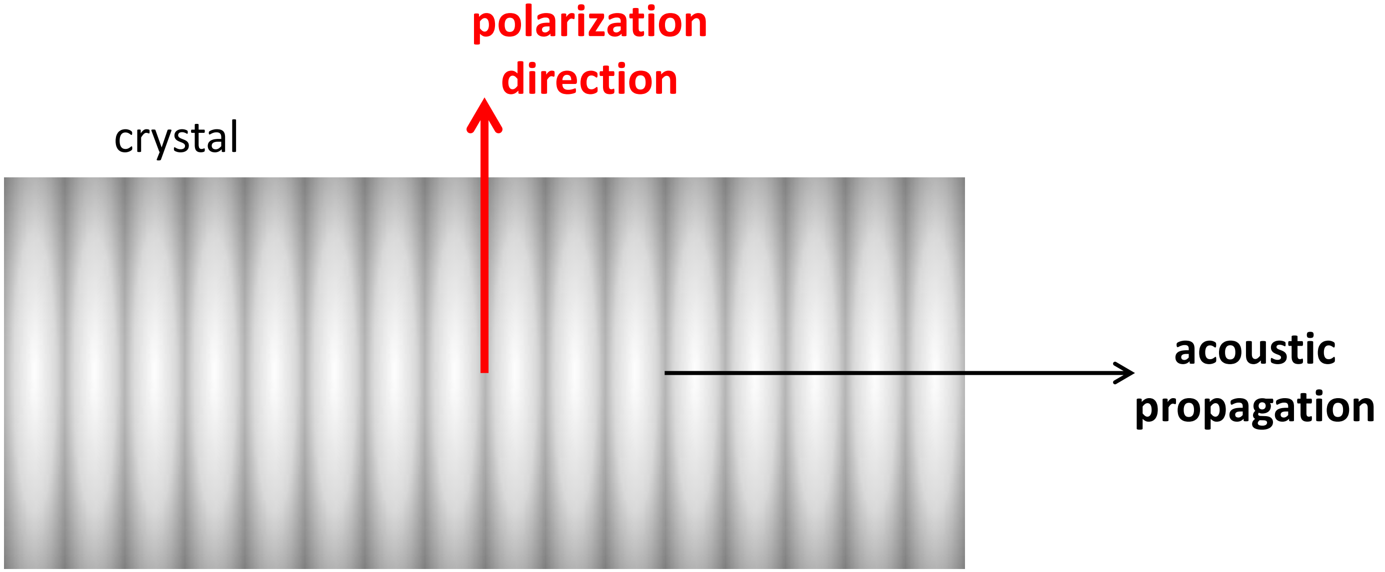
crystal



(side view)

Polarization:

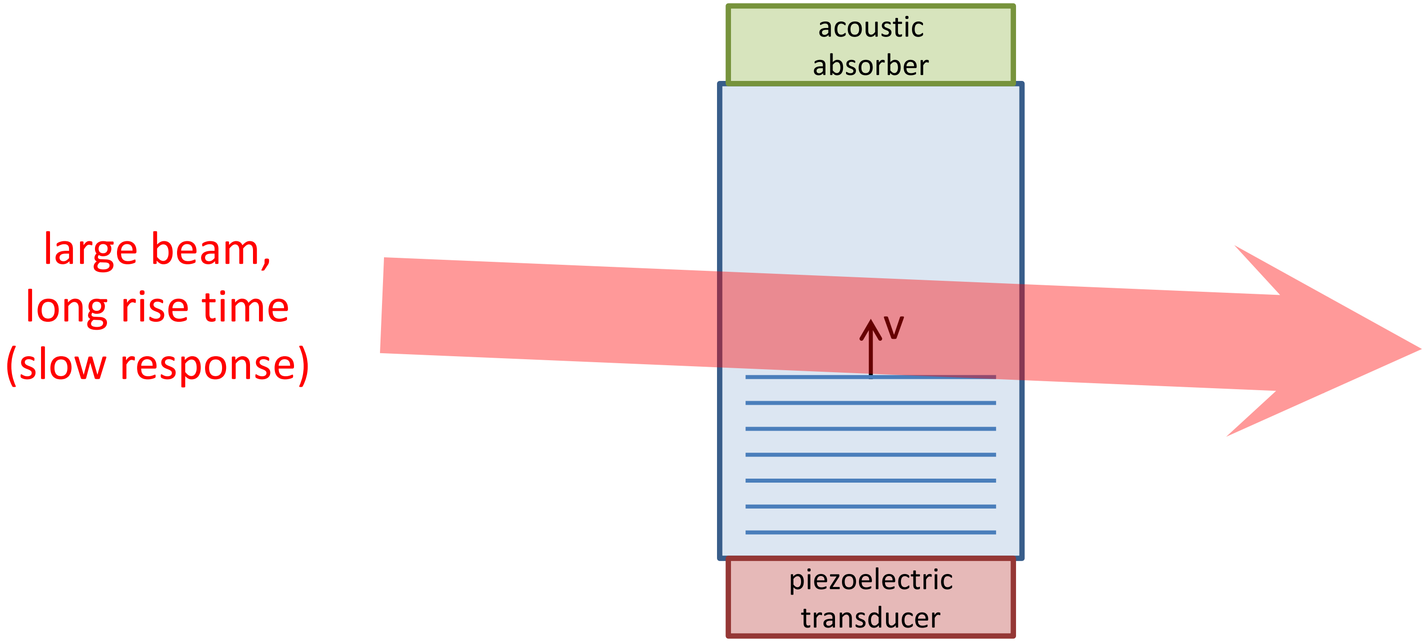
- The highest diffraction efficiency is achieved with linear polarization oriented perpendicular to the acoustic wave propagation direction.



(side view)

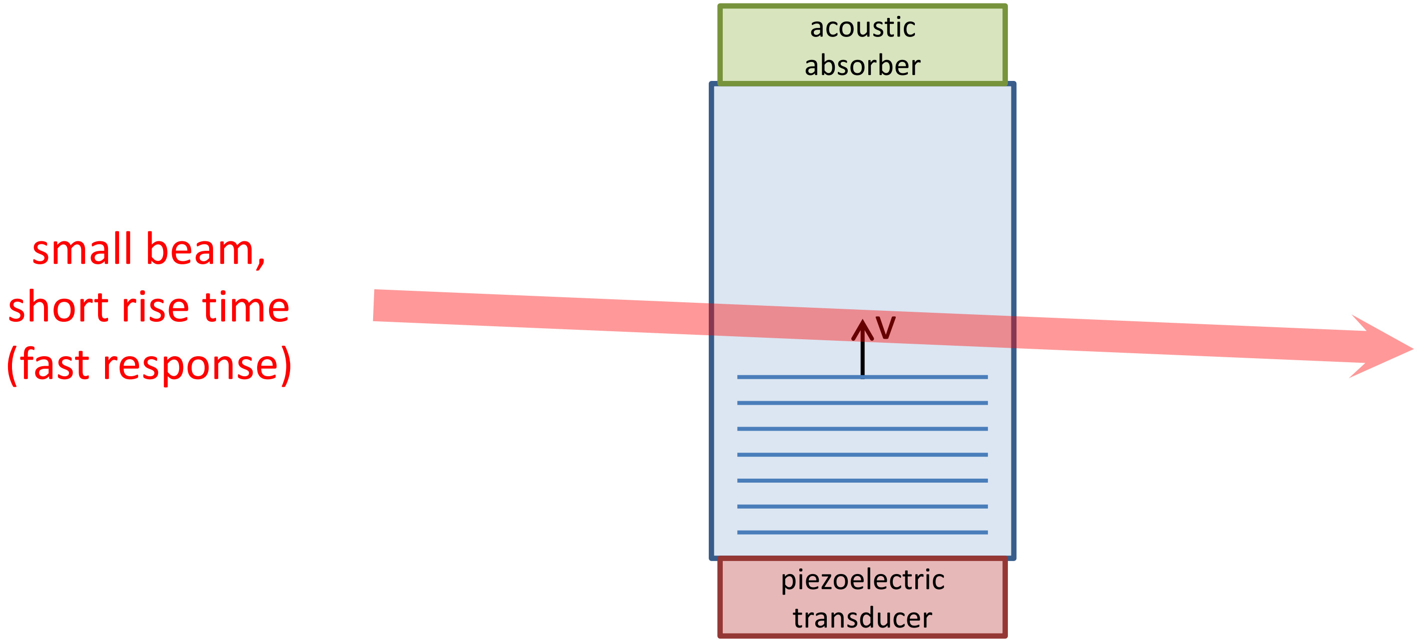
Rise Time:

- The rise time is the amount of time it takes for the beam to be diffracted when the acoustic wave crosses it.
- Rise time depends on beam size because a larger beam requires more time for the acoustic wave to cross it.
- Example: For 10 MHz modulation, the rise time must be less than 25 ns. If the acoustic wave speed is 4200 m/s, this corresponds to a beam diameter of 0.1 mm.



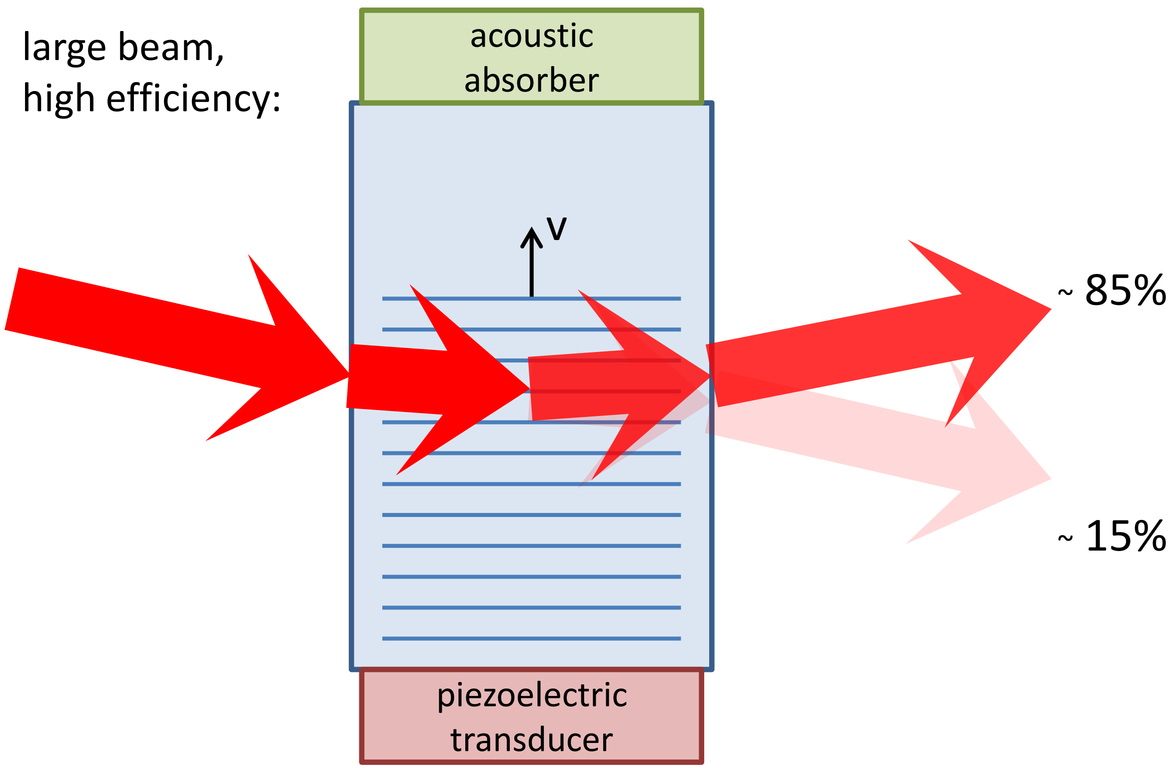
Rise Time:

- The rise time is the amount of time it takes for the beam to be diffracted when the acoustic wave crosses it.
- Rise time depends on beam size because a larger beam requires more time for the acoustic wave to cross it.
- Example: For 10 MHz modulation, the rise time must be less than 25 ns. If the acoustic wave speed is 4200 m/s, this corresponds to a beam diameter of 0.1 mm.



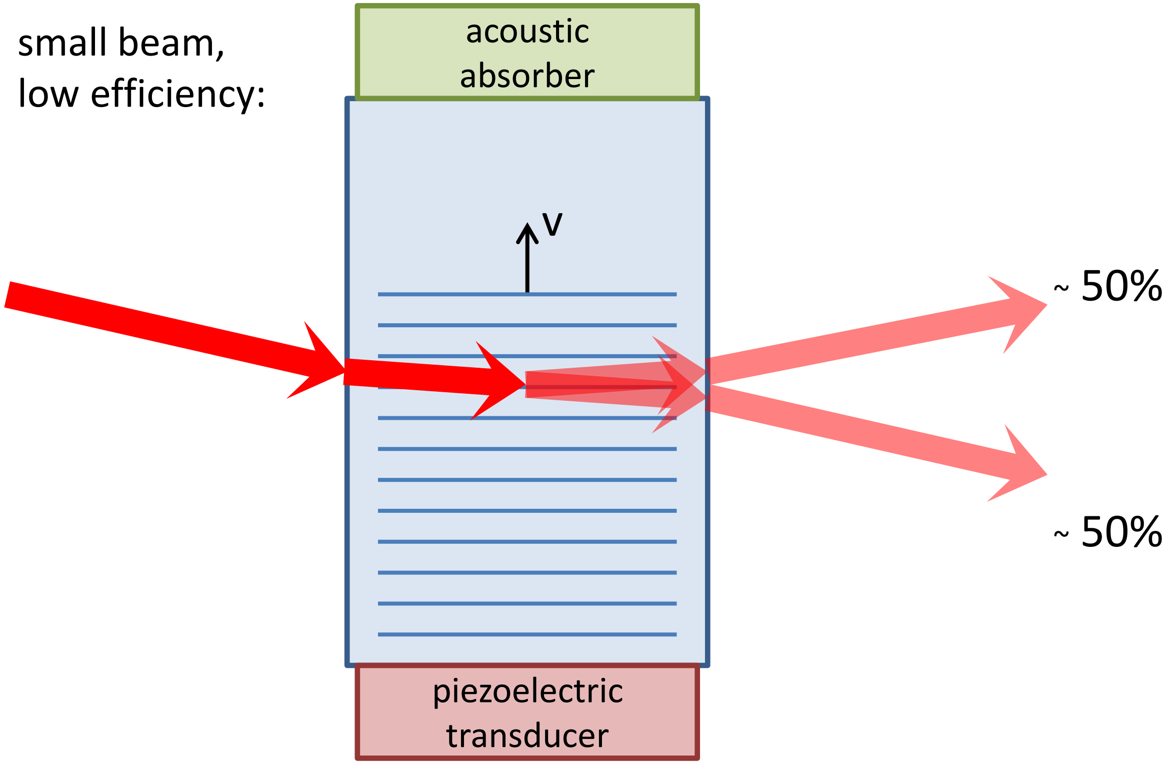
Beam Size:

- Diffraction efficiency also depends on beam size.
- A larger beam results in higher efficiency.
- Still, the beam must be smaller than the active aperture.
- A tradeoff always occurs between rise time and diffraction efficiency. You must make the beam smaller to get a shorter rise time, but the diffraction efficiency will decrease.



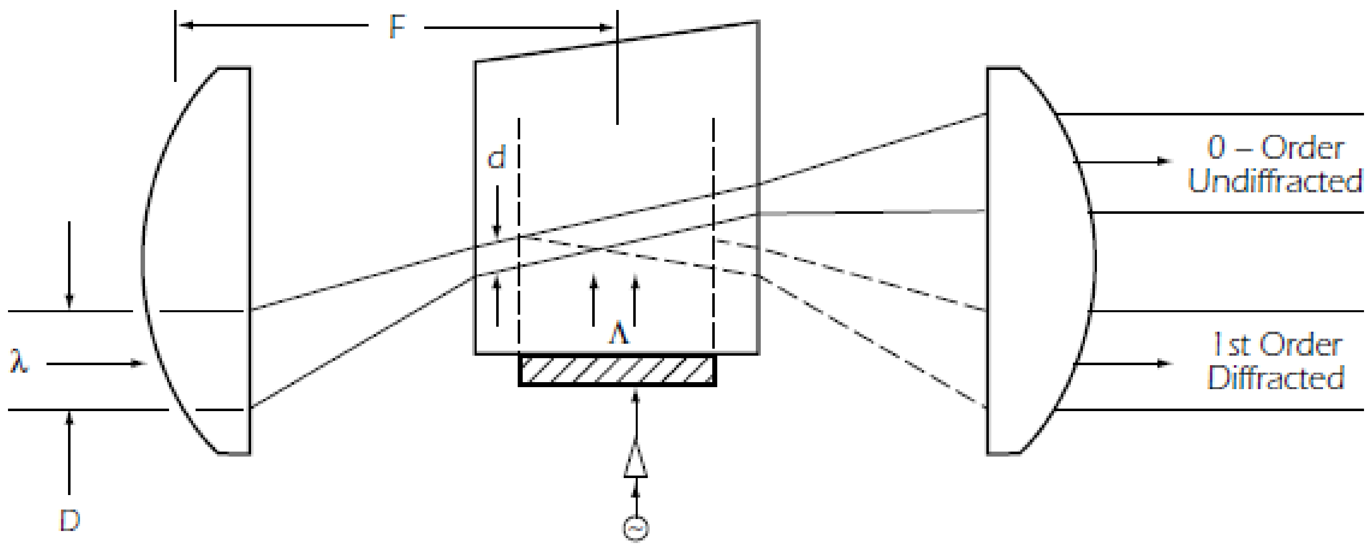
Beam Size:

- Diffraction efficiency also depends on beam size.
- A larger beam results in higher efficiency.
- Still, the beam must be smaller than the active aperture.
- A tradeoff always occurs between rise time and diffraction efficiency. You must make the beam smaller to get a shorter rise time, but the diffraction efficiency will decrease.



Beam Size:

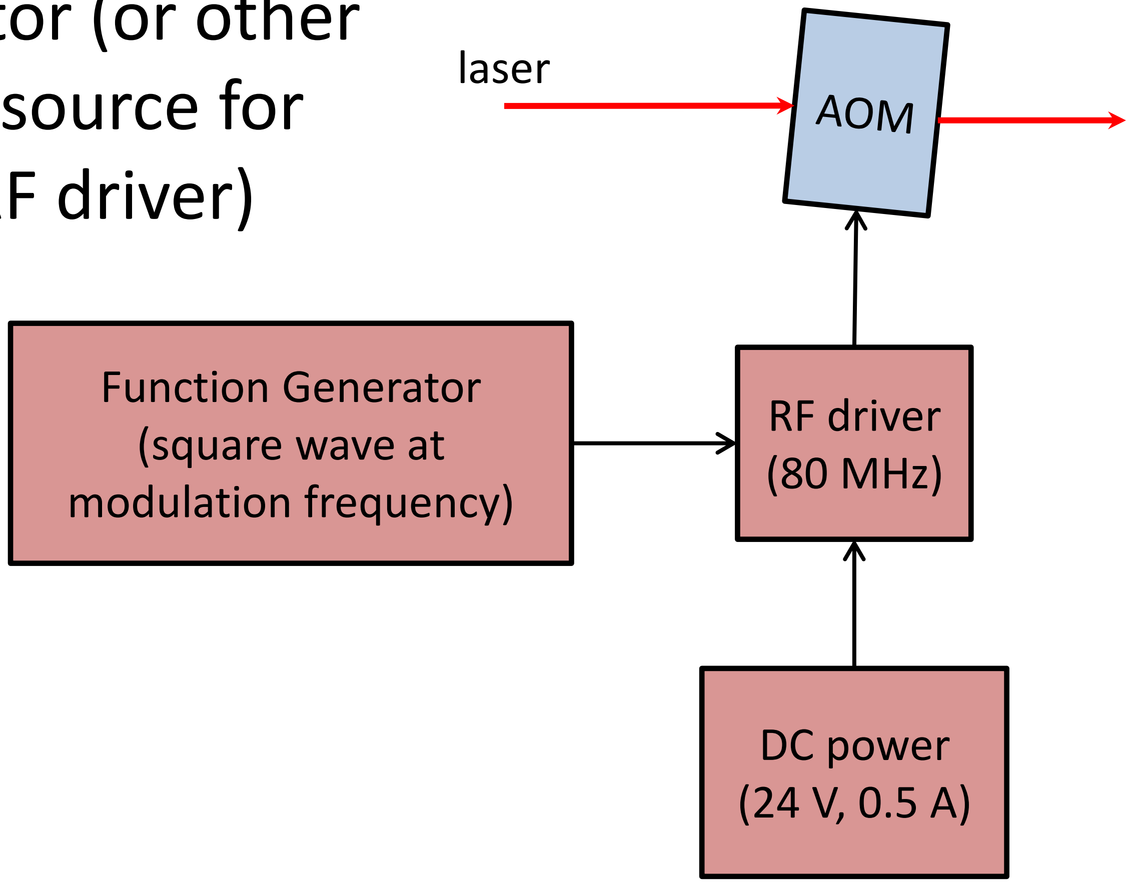
- It is common practice to place convex lenses before and after the AOM with the focal point located at the center of the crystal, as in the following figure from Gooch & Housego:



3. Accessories and Operation

An AOM requires certain accessories:

- RF driver
- power supply (for the RF driver)
- function generator (or other variable voltage source for controlling the RF driver)

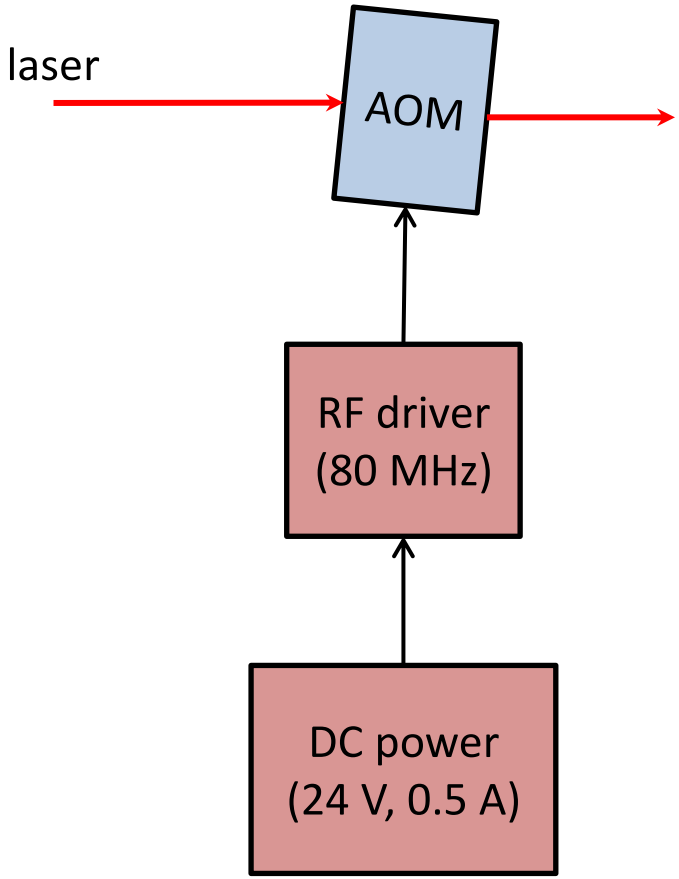


RF Driver:

- Each AOM model has an RF driver made specifically for it. When you order the AOM, you should also order the corresponding RF driver from the manufacturer.
- The RF driver puts out a sinusoidal voltage signal that drives the piezoelectric transducer on the AOM at the acoustic frequency that is appropriate for the crystal. Generally, you do not control this frequency.
- The AOM is controlled by modulating the power output of the RF driver. An output power of zero corresponds to the "off" state of the AOM, and nonzero power corresponds to "on" (note that you may need to determine what power level yields optimal diffraction efficiency).
- The output power of the RF driver is controlled by applying a voltage between zero (off) and one (maximum power) to the "analog input" terminal on the RF driver.

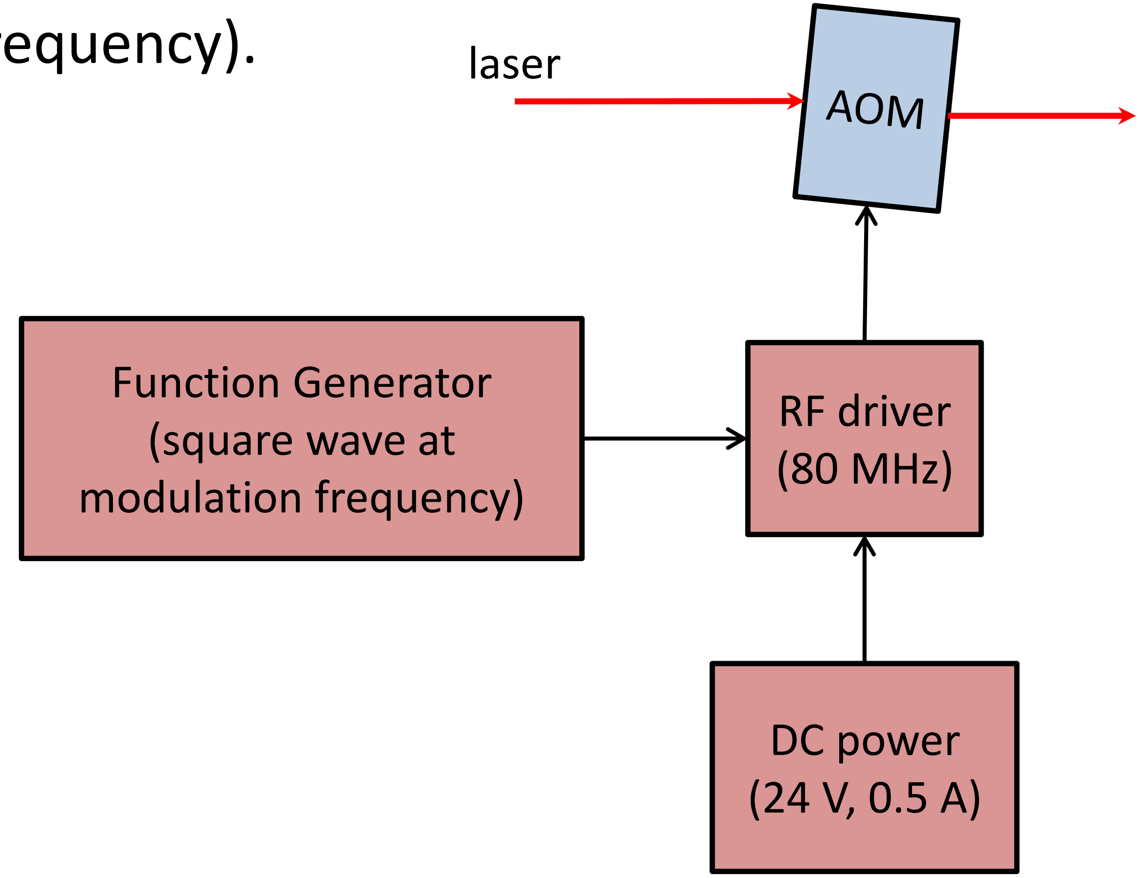
Power Supply:

- The RF driver may not come with a power supply.
- Check the specifications to determine what kind of power supply is needed, and order your own. Typically, a DC power supply of 24 V that can supply a current of about 0.5 A is needed.



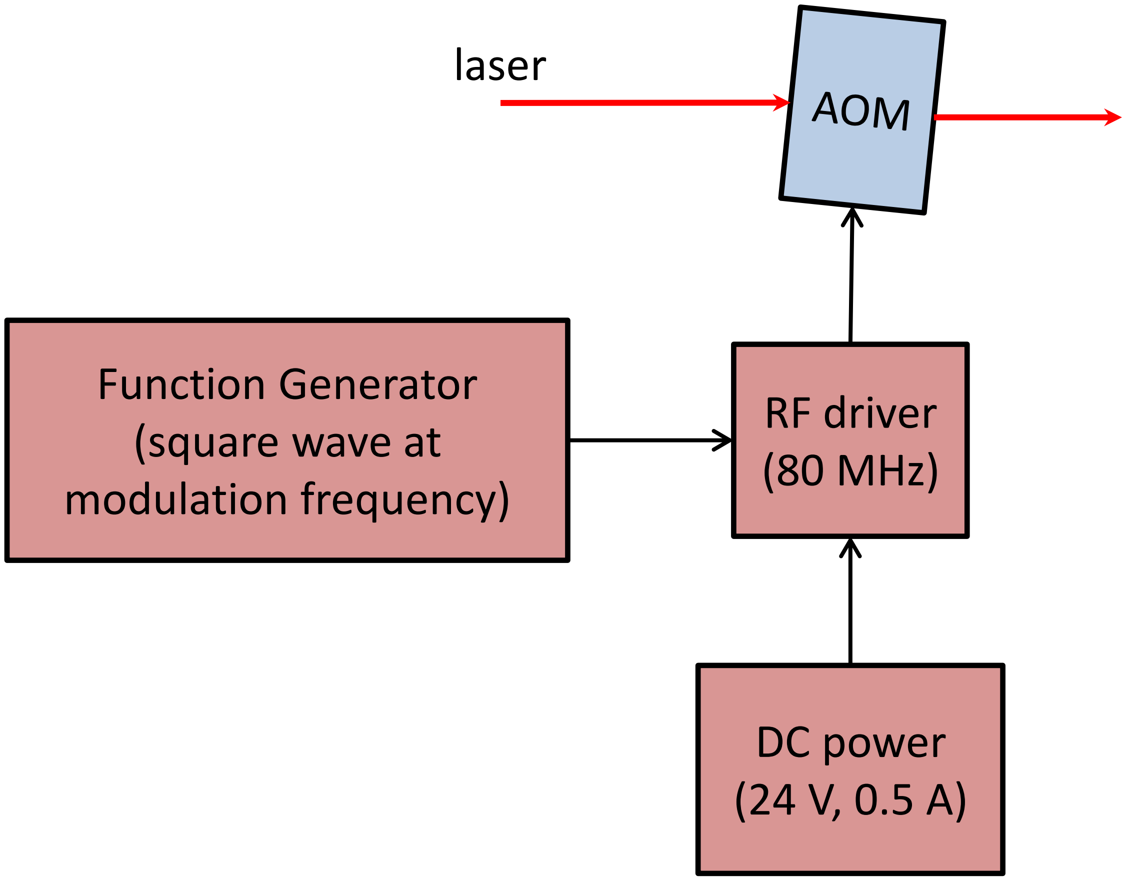
Function Generator:

- A function generator is typically employed to apply the analog input voltage to the RF driver.
- An offset square wave oscillating between zero volts and one volt can be used to turn the AOM off and on at the desired frequency (the modulation frequency, which is different from the acoustic wave frequency).



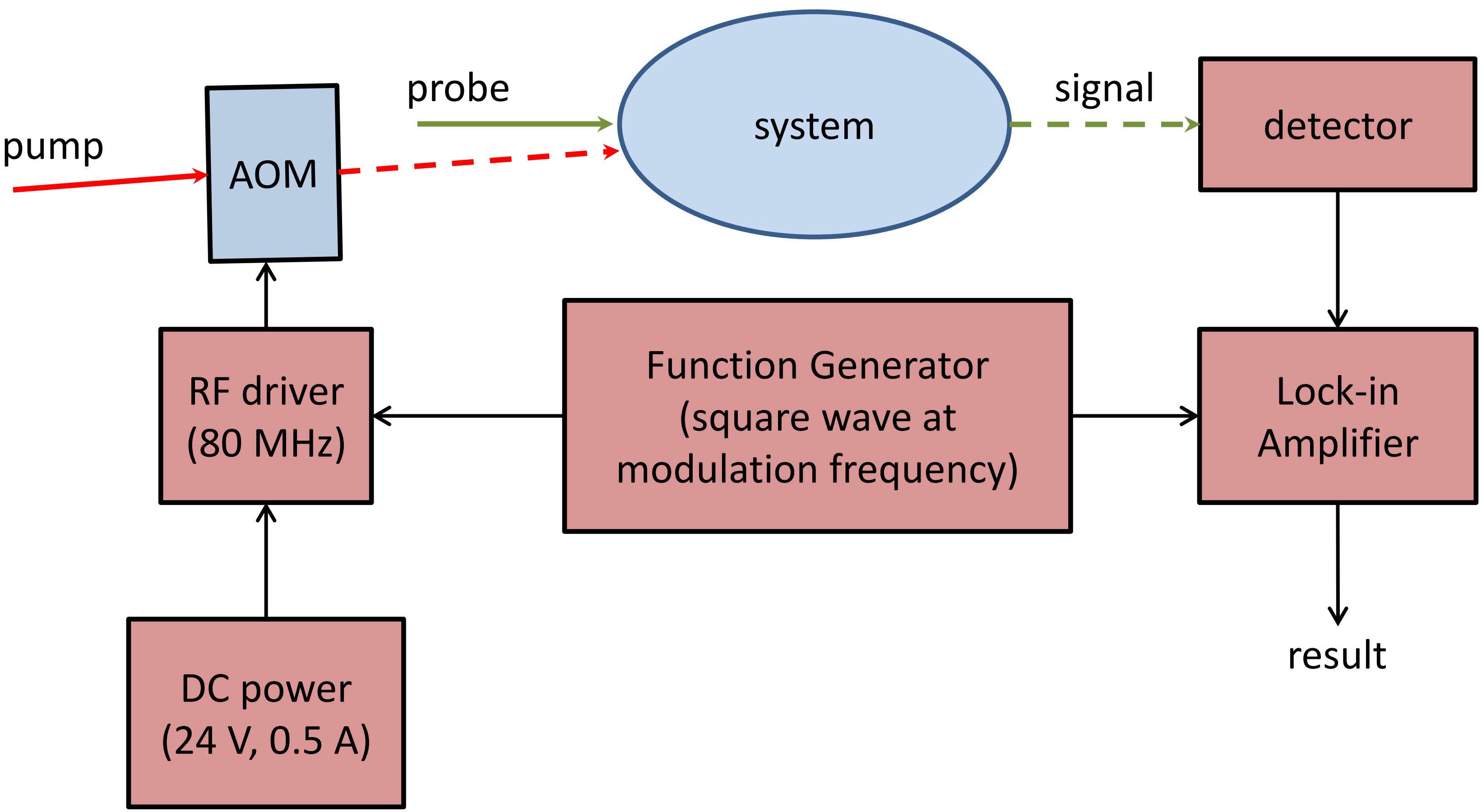
Operation:

- First connect the AOM to the RF driver.
- Then apply power to the RF driver.
- Finally, apply the analog input signal to the RF driver.
- To disconnect the AOM, apply these steps in reverse order.



Typical Experimental Setup:

- An AOM is used to modulate a laser (pump) at a known frequency.
- The modulated laser is incident on some system along with another laser (probe), which is not modulated.
- The system response is detected and sent to a lock-in amplifier, which calculates the changes in the signal at the modulation frequency.



The End

www.olenrambow.com