Lecture 9/28/22

Sensing Methods: Optical Sensing

Make use of some property of light that is = f(measurand).

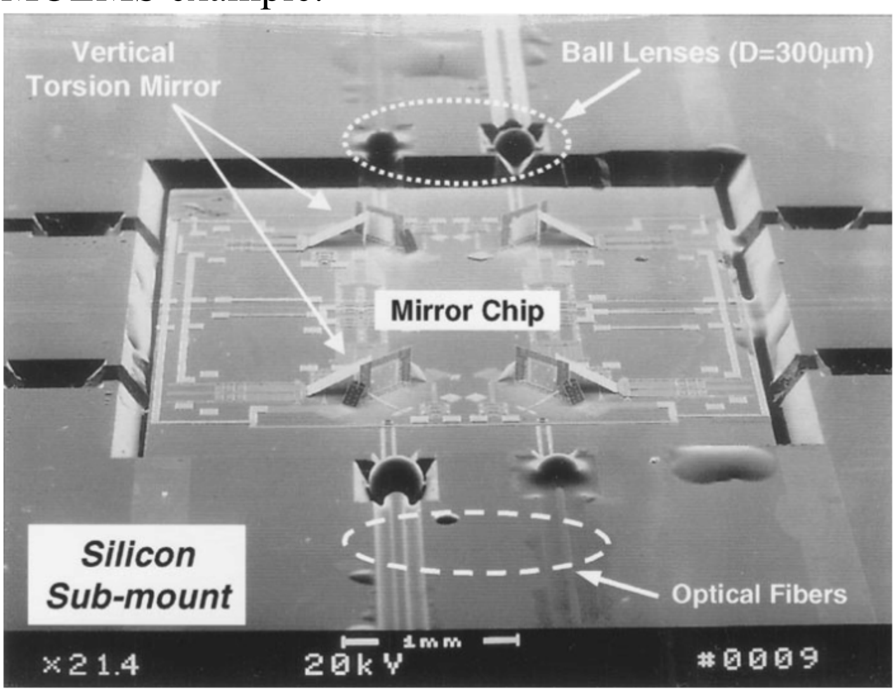
Properties of light that can *possibly* be manipulated for sensing purposes:

1) Intensity
2) Phase
3) Wavelength (Spectral Content)
4) Spatial Position
5) Frequency
6) Polarization

Optical components (detectors, sources, mirrors, lenses, gratings, waveguides, etc.) can be fabricated on or in a MEMS chip.

MOEMS: Micro-Opto-Electro-Mechanical Systems, which combine MEMS and micro-optics.

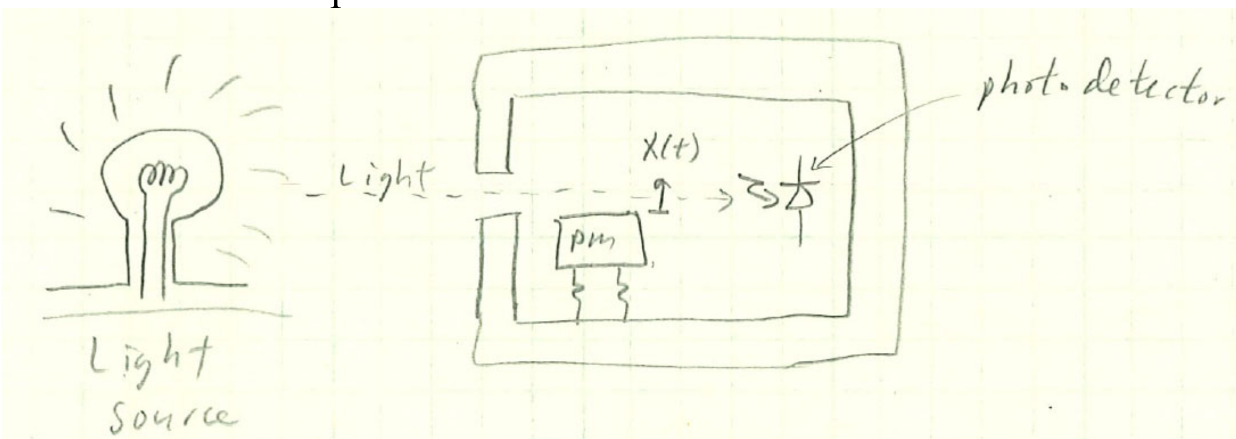
MOEMS example:



Curtesy: https://www.researchgate.net/figure/Scanning-electron-micrograph-SEM-of-the-2-2-2-fiber-optic-switch_fig9_3239903

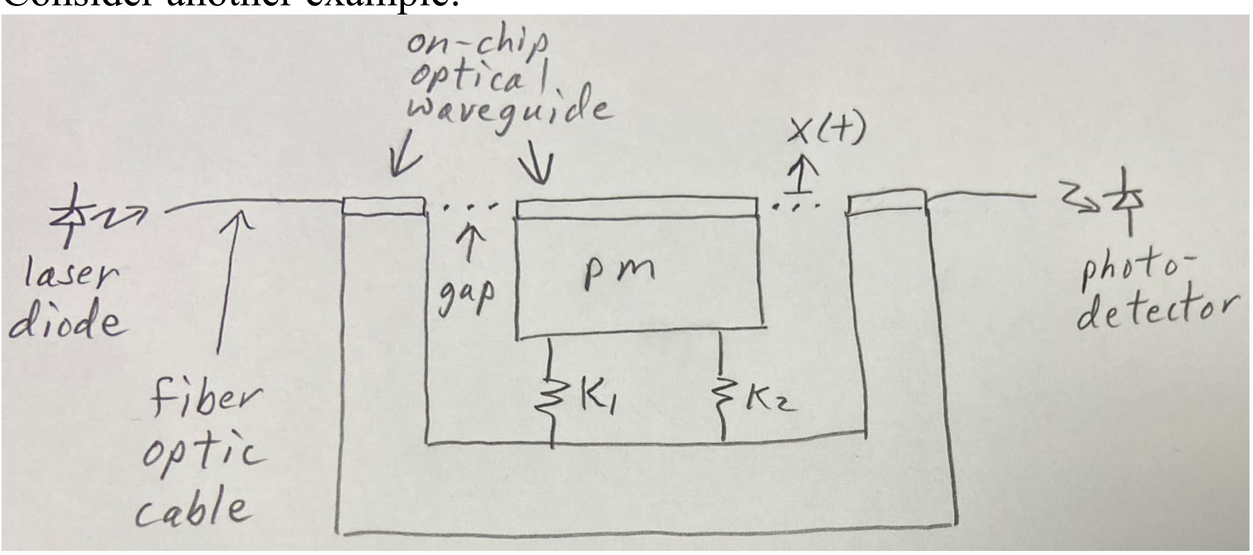
1. <u>Intensity</u> → optical power level

Consider this example:



Some measurand will move the proof mass (PM) by x(t) and partially or fully block the opening that light enters the box through. This modulates the light level (i.e. light intensity) of the light reaching the photodetector.

Consider another example:



At PM rest (i.e. x(t) = 0), the on-chip waveguides (could be fiber optic cable pieces) are aligned and maximum optical power reaches the photodetector. When the PM moves a small amount, the on-chip waveguides misalign and optical power to the photodetector drops.

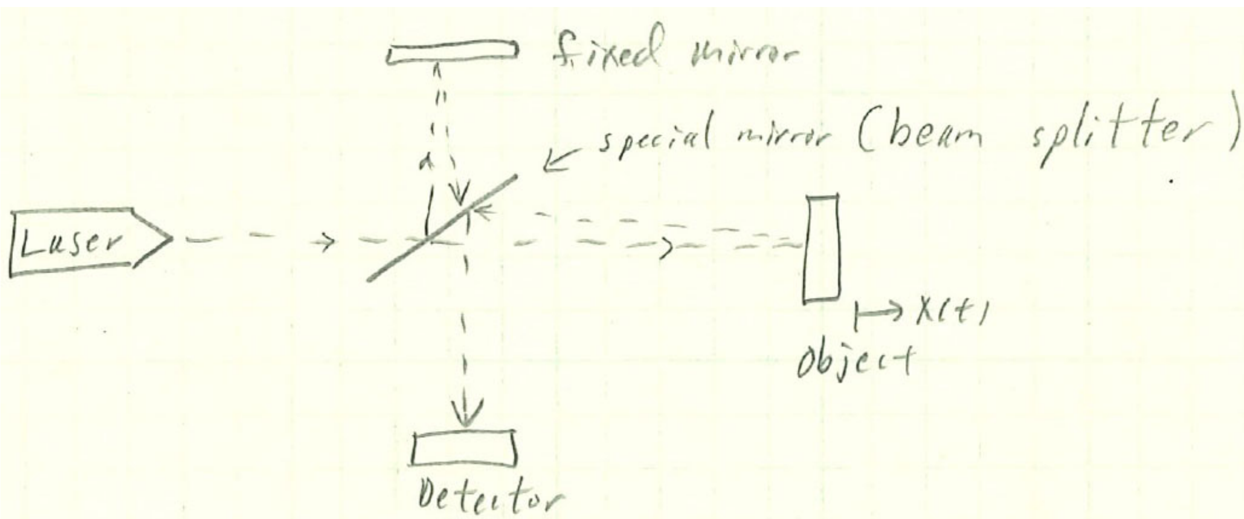
Note, there are two performance issues with this approach:

1) The diameter (or width) of the optical waveguide determines the possible range of x(t) measurement.

2) This technique actually measures |x(t)|.

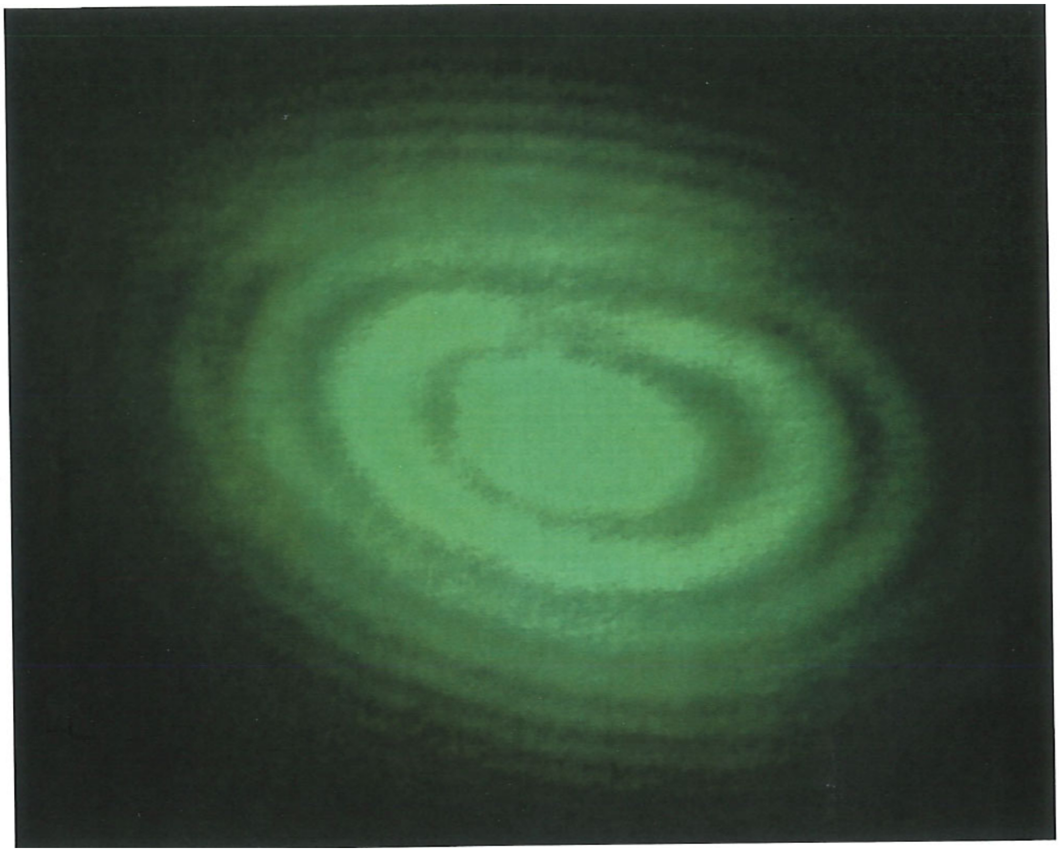
2. <u>Phase</u>

With a coherent light source (i.e. a laser), all the photons possess a definite phase relationship to each other. Therefore, consider an <u>interferometer</u>:



The light from the fixed mirror and the object (x(t) motion) add constructively (optical power maxima) and destructively (optical power minima), producing an "interference pattern" of the optical wavelength.

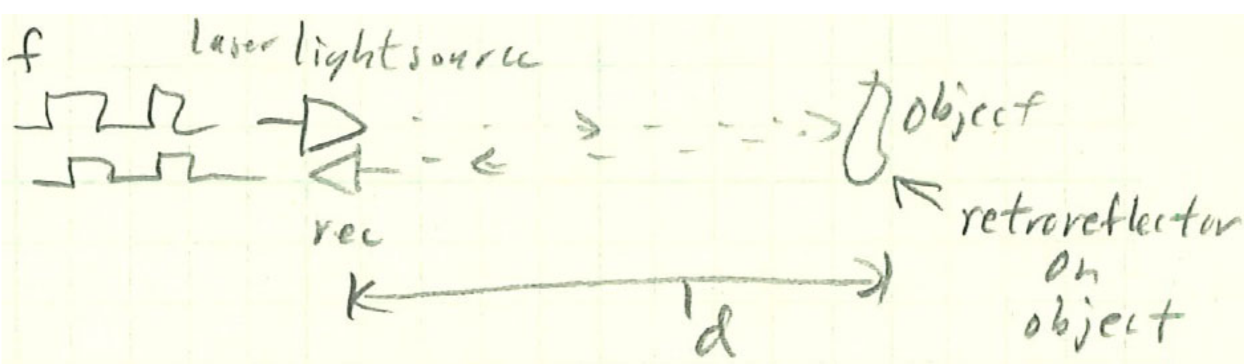
Example interference pattern:



Since x(t) changes the interference pattern, an interferometer can be used to measure very small displacements (fractions of a wavelength):

Green laser: $\lambda = 532$ nm
HeNe (red) laser: $\lambda = 632.8$ nm

Interferometers are useful for measuring the transmissibility, as we already discussed. They are also useful for range finding:



Let τ_d be the time delay for the pulses to reach the target and return, where:

$\tau_d = \frac{2d}{c}$. The speed of light is c: 3×10^8 m/s.

Example: if d = 100 m and f = 1 MHz, then:

$$\tau_d = \frac{2(100)}{3 \times 10^8} = 6.67 \times 10^{-7} s.$$

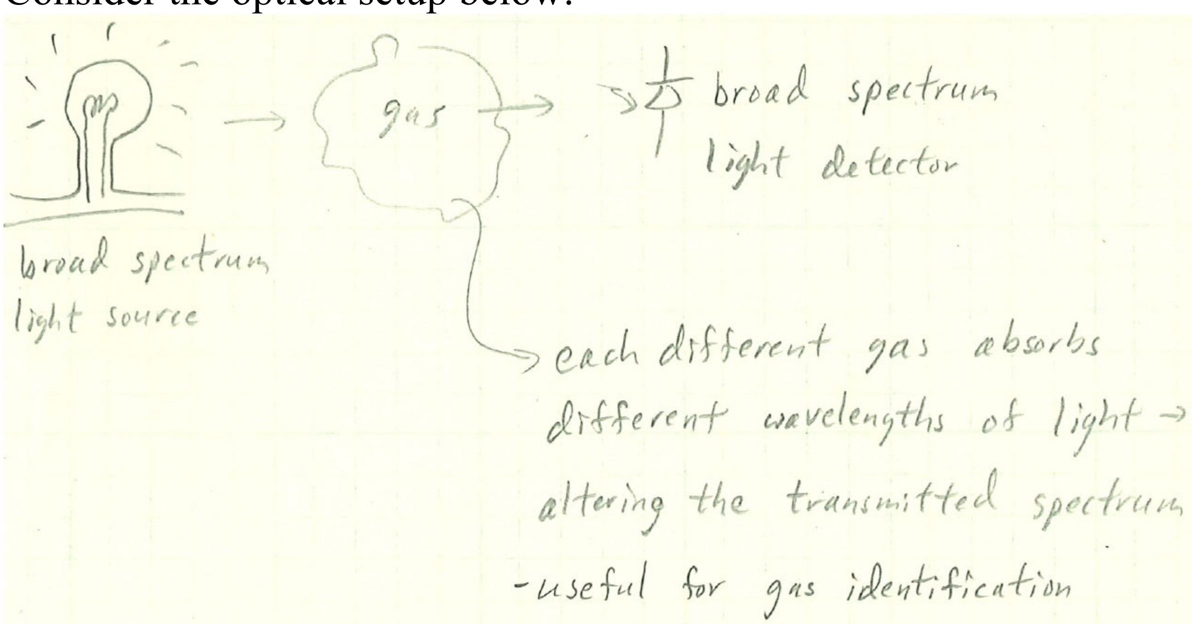
The resulting pulse train phase delay is PD, where:

$$PD = 360^o \left(\frac{\tau_d}{T}\right) = 360^o \left(\frac{6.67 \times 10^{-7}}{1 \times 10^{-6}}\right) = 240^o.$$

Note: a 240° phase shift of a 1 MHz pulse train is very detectable! Note, if PD > 360°, a range ambiguity exists.

3. Wavelength (Spectral Content)

Consider the optical setup below:



This instrument is called a <u>spectrometer</u>. Example spectrometer results:

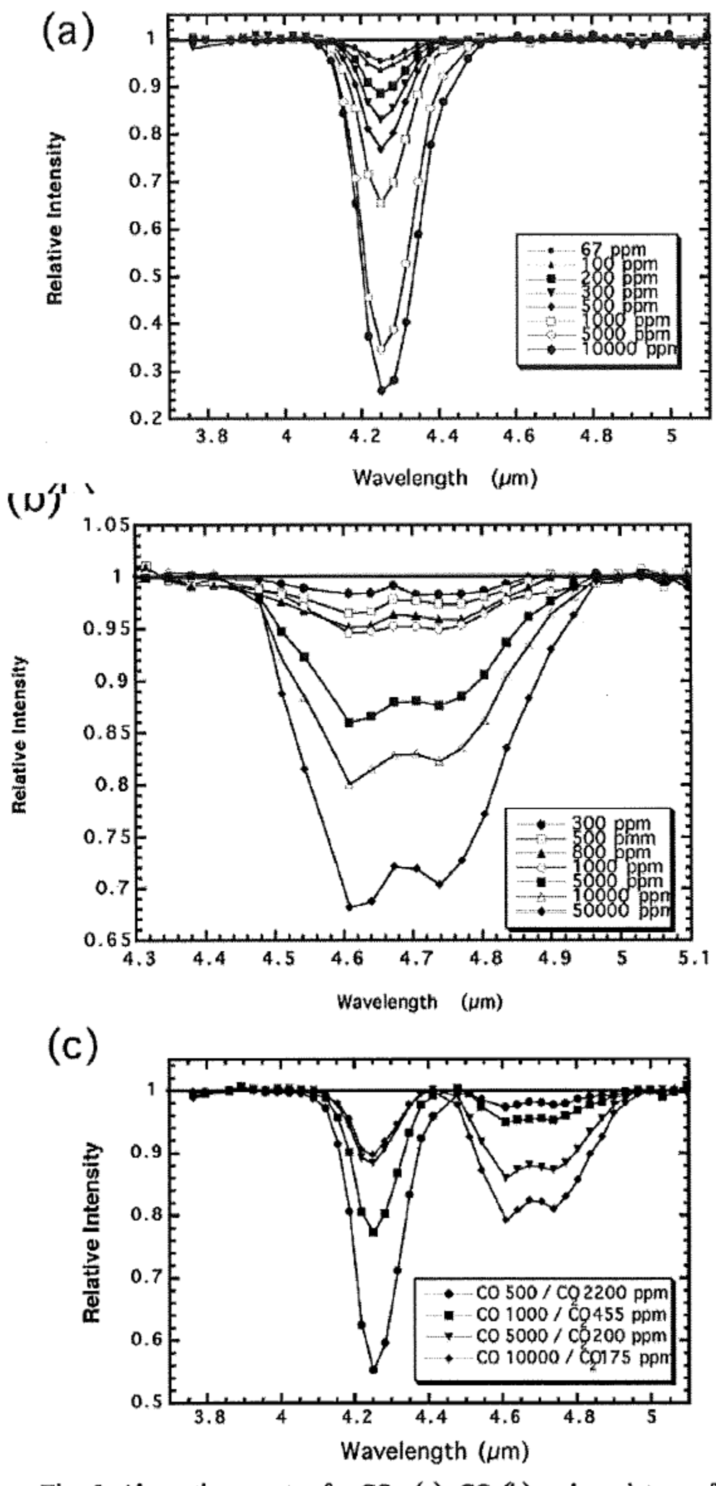


Fig. 5. Absorption spectra for CO_2 (a), CO (b) and a mixture of CO_2 and CO (c) for various gas concentrations.

Thin film pyroelectric array as a detector for an infrared gas spectrometer

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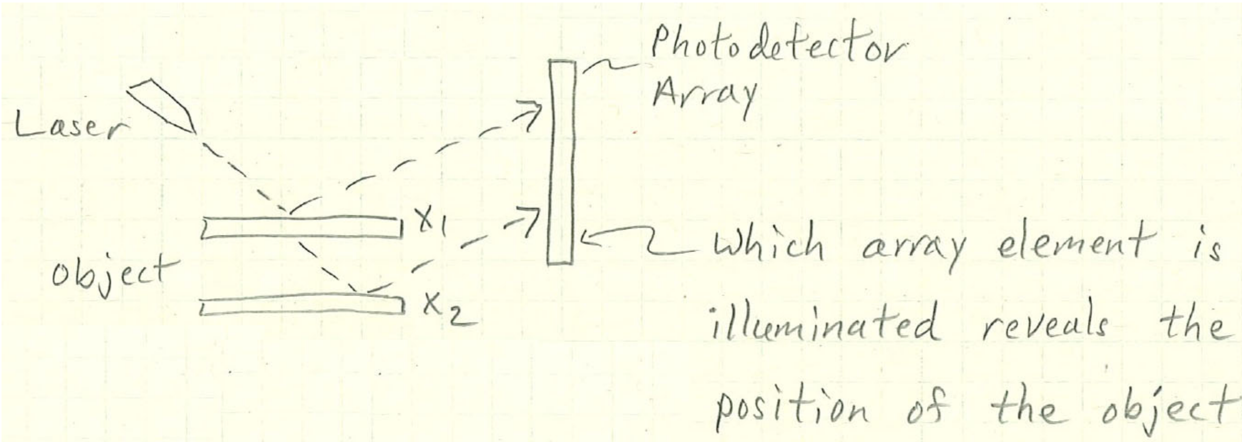
4. Spatial Position

Consider:



This system can be used to measure translational <u>or</u> angular movement. The photodetector array could also be a 2-D array, such as a CMOS or CCD camera chip, which could be used to measure 2-D motion.

5. Frequency

Change-of-frequency based detection makes use of the Doppler shift. The general equation for the Doppler shift is:

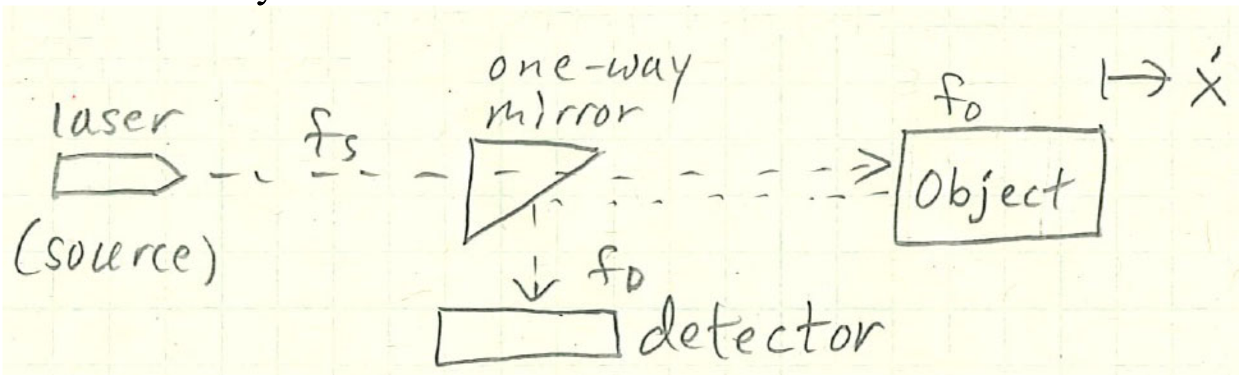
$$f = \frac{c \pm \dot{x}_r}{c \pm \dot{x}_s}$$

Where c is the wave speed (could be the speed of light, but also could be the speed of sound).

Also, $\dot{x}_r$ is the receiver velocity: $+\dot{x}_r$ if the receiver is moving toward the source, and $-\dot{x}_r$ otherwise.

Similarly, $\dot{x}_s$ is the source velocity: $+\dot{x}_s$ if the receiver is moving away from the source, and $-\dot{x}_s$ otherwise.

Consider this system:



So what is f_D?

$$f_O = f_s\left(\frac{c-\dot{x}}{c}\right) = f_s\left(1-\frac{\dot{x}}{c}\right)$$

$$f_D = f_O\left(\frac{c}{c+\dot{x}}\right) = f_O\left(\frac{1}{1+\dot{x}/c}\right) = f_s\left(\frac{c-\dot{x}}{c+\dot{x}}\right)$$

With light: c = 3x10^8 m/s → $\Delta f = |f_s - f_d|$ is very small.

However, with sound: c = 331 m/s (20^{o}C, dry air, 1atm)*

*some texts list other values for the speed of sound…

With sound as the wave, Δf is much larger and therefore easier to work with for "slow" moving objects.

6. Polarization

Light is an EM wave, and surface properties of an object reflecting light can alter the EM vector representation. Some optical systems make use of this for applications such as machine vision.