# Fiber Optics

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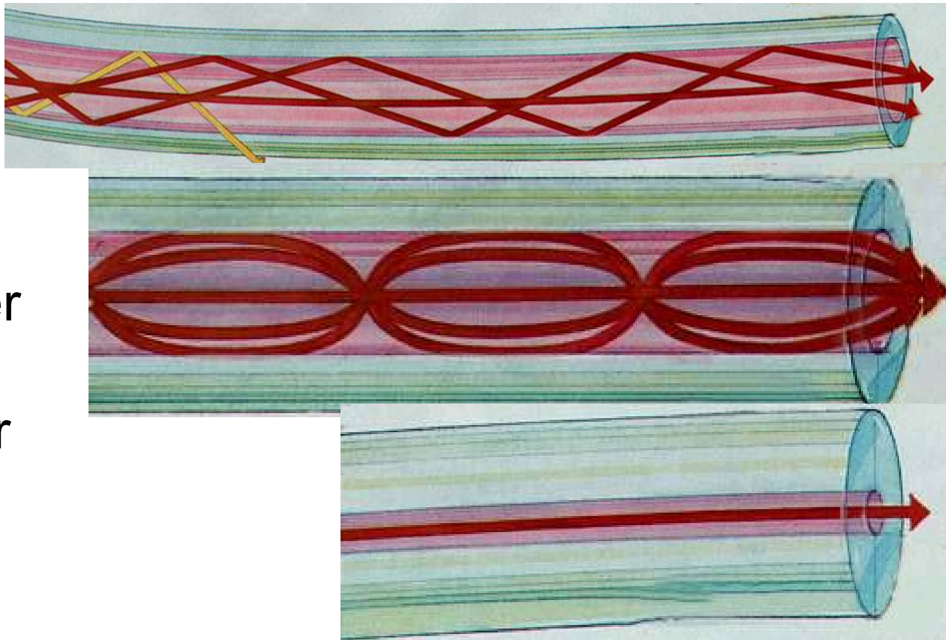
- Optical fibers work on the principal of total internal reflection.
- They can be used to transmit data signals in the form of light.
- They are used in endoscopes, which transmit an image using a bundle of optical fibers.
- Pros of optical fiber data networks
  - Speed – operate at high speeds
  - Bandwidth – large because many wavelengths can be sent down a single fiber
  - Distance – long transmission
  - Resistance – resists EM noise
  - Maintenance – cheap

- There are several types of optical fiber

  Step-Index Multimode Fiber

  Graded-Index Multimode Fiber

  Single-Mode Fiber



Pictures from: http://www.arcelect.com/fibercable.htm

## Dispersion of signal peaks within a step-index multimode fiber.

The difference in optical path length for a ray traveling down the center of a step-index multimode fiber vs. a ray traveling at the critical angle can be derived from concepts we learned in class.

$d = L / Cos(\theta_t)$

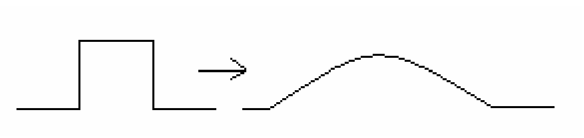
d = L n (n^2-Sin(θi))^(-1/2)

$\Theta = 0$, $d = L$

$\Theta = \theta_{critical}$, d = L n (n^2-Sin(θi))^(-1/2)

The dispersion of the signal peaks is related to the difference between the two distances.

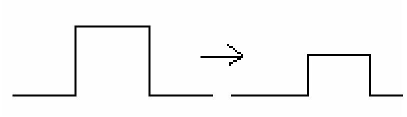
[L n (n^2-Sin(θi))^(-1/2)] – [L]



## Attenuation of signal peaks within a step-index multimode fiber.

The number of reflections within the fiber can be determined from geometry. This number is proportional to the to the signal loss within the fiber.

$N = d / ( Dia. / Sin(\theta_t) ) \pm 1$



Critical angle Eq. for optical fiber

θ = arcsin{[1 – (Ncl/Nco)^2]}^0.5

# Signal Attenuation

- Attenuation caused by absorption, scattering, and bending of fiber
- One of the major advantages of fiber optics is the ability to carry information much longer distance without being “refreshed” or strengthened.
- Better than say, copper wire.

In general, the index of refraction is a function of frequency or wavelength

Sensitivity: 0.5 – 1000 dB/km

$$D = -\frac{\lambda}{c}\left(\frac{d^2 n}{d\lambda^2}\right)$$

Po/Pi = 10^(-αL/10)

Av = 20 log10(Vs/Vd)

D proportional to wavelength – larger WL = more dispersion

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# Wave Plates and Beam Splitters

By:
Chris Bowyer
Megan Frantz
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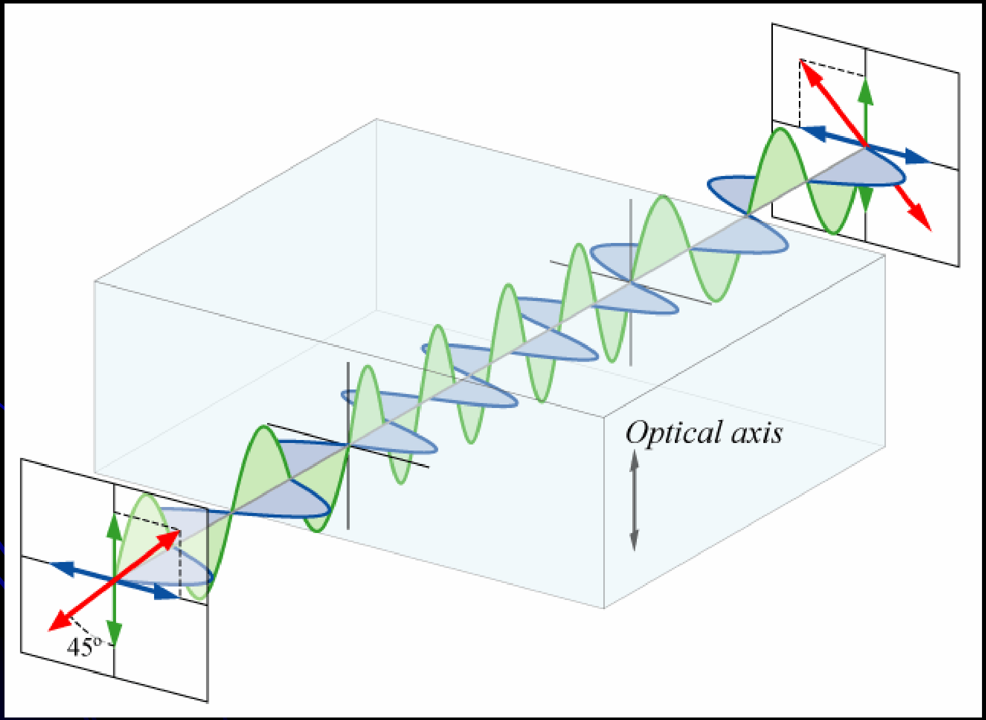
# Wave Plate

## Definition

- A wave plate consists of a carefully adjusted thickness of a birefringent material such that the light associated with the larger index of refraction is retarded by a specific amount. Often times 90° in phase, making a quarter wave plate or 180°, half wave plate.



# Wave Plate

Three kinds of waveplates: Low-order, zero-order, and true-order waveplates

Many flavors:

- Octadic Waveplate
- Quarter Waveplate
- Half Waveplate
- Full Waveplate

Materials used to construct waveplate tend to be a calcite or crystal quartz lattice where extraordinary (perpendicular) index of refraction differs from ordinary (parallel) refractive index.

Waveplate adds phase shift delta to orthogonal components

$\delta = \pi$ radians if half-waveplate

Flips the polarization of linearly polarized incident light, rotates the plane of polarization by $\pi/2$, also transforms left-circularly polarized light into right-circularly polarized light

$\delta = \pi/2$ radians if quarter-waveplate

Transforms linearly polarized light into circularly polarized light, commonly used in Q-switches and isolators.

# Wave Plate

## Theory

Coherent plane wave propagating in **z** direction:

$$\vec{E} = A\cos\left(\vec{k}\cdot\vec{r}-\omega t\right) = A\cos\left(kx-\omega t\right)\hat{i} + A\cos\left(ky-\omega t\right)\hat{j}$$

The two components of the plane wave are in phase

$$\vec{E} = A\cos\left(kx-\omega t\right)\hat{i} + A\cos\left(ky-\omega t+\delta\right)\hat{j}$$

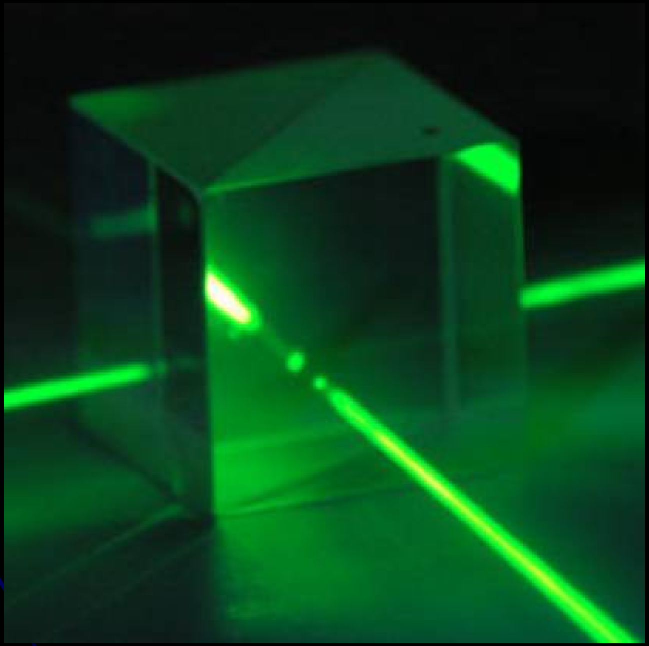
$$\delta = \frac{2\pi d\left(n_e-n_o\right)}{\lambda_i}$$

is the phase shift given by a waveplate where *d* is the thickness of the birefringent material, $n_e$ is the refractive index encountered by the extraordinary ray while $n_o$ is the refractive index encountered by the ordinary ray, and $\lambda_i$ is the incident wavelength.

# Beam Splitter

## Definition

- A Beam Splitter is an optical device that splits a beam of light.



# Beam Splitter

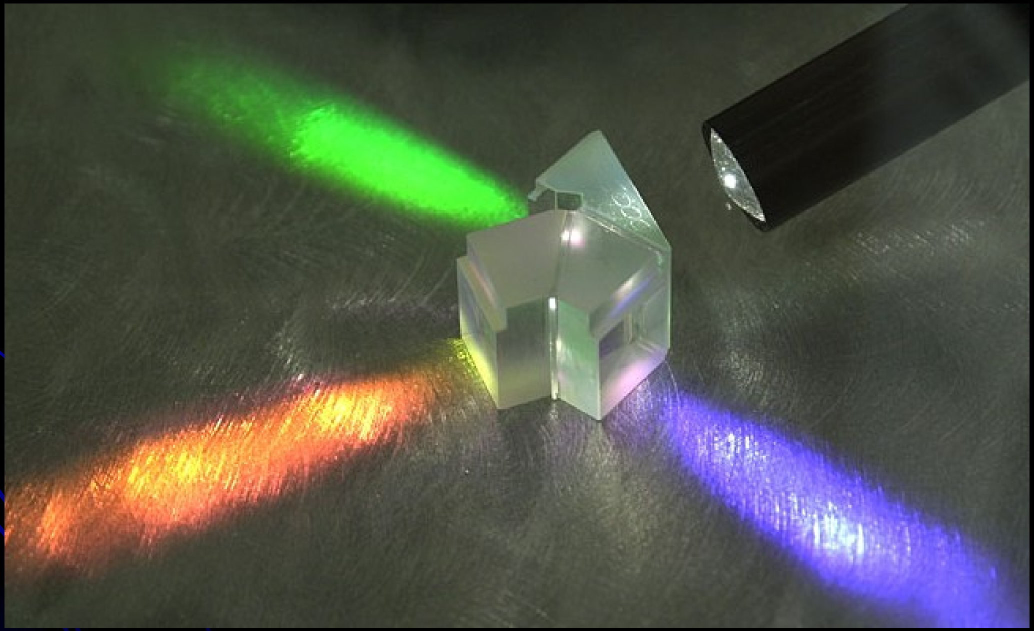
## Uses and Theory

- The most common form is a cube, made from two triangular glass prisms which are glued together.
- Another design is the use of a half-silvered mirror.
- A third version of the beam splitter is a dichroic mirrored prism assembly which uses dichroic optical coatings to split the incoming light into three beams, one each of red, green, and blue.

# Beam Splitter

## Example

- Michelson Interferometers
- Multi-tube colour television cameras



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- http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html
- http://en.wikipedia.org/wiki/Beam_splitter
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- http://scienceworld.wolfram.com/physics/WavePlate.html
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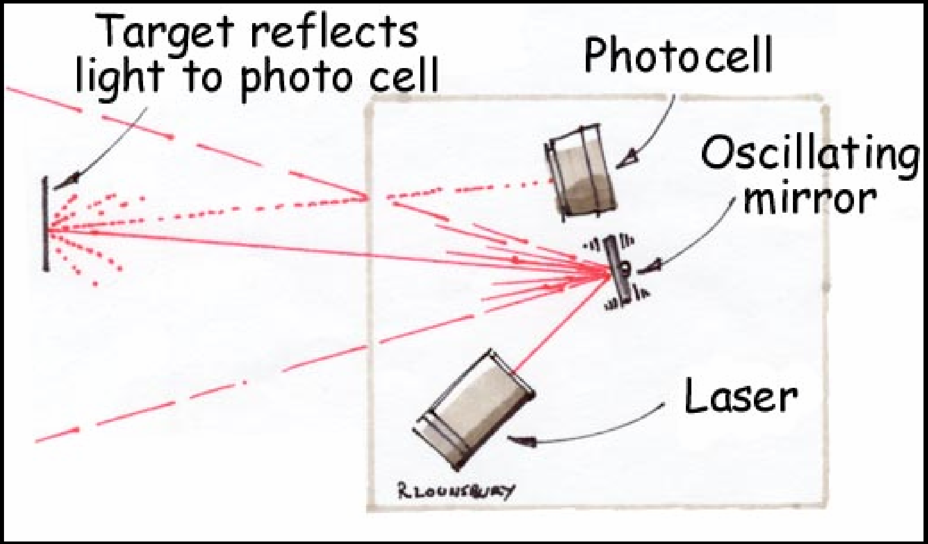
# Laser Barcode Scanner

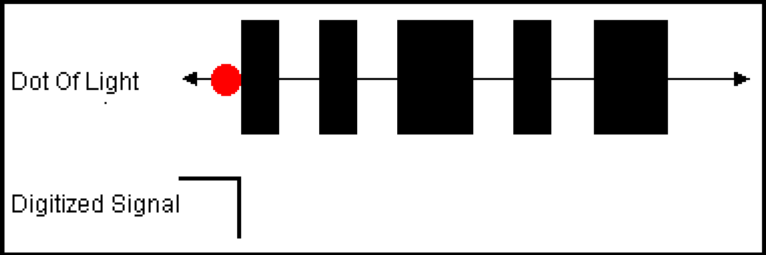
These devices are used everyday all across the world to facilitate data entry into a computer.  Originating in the 1970's, these scanners use several optical concepts to accomplish this task.  So how does this little box organize all this data from a bunch of little lines?

***Let's find out!***

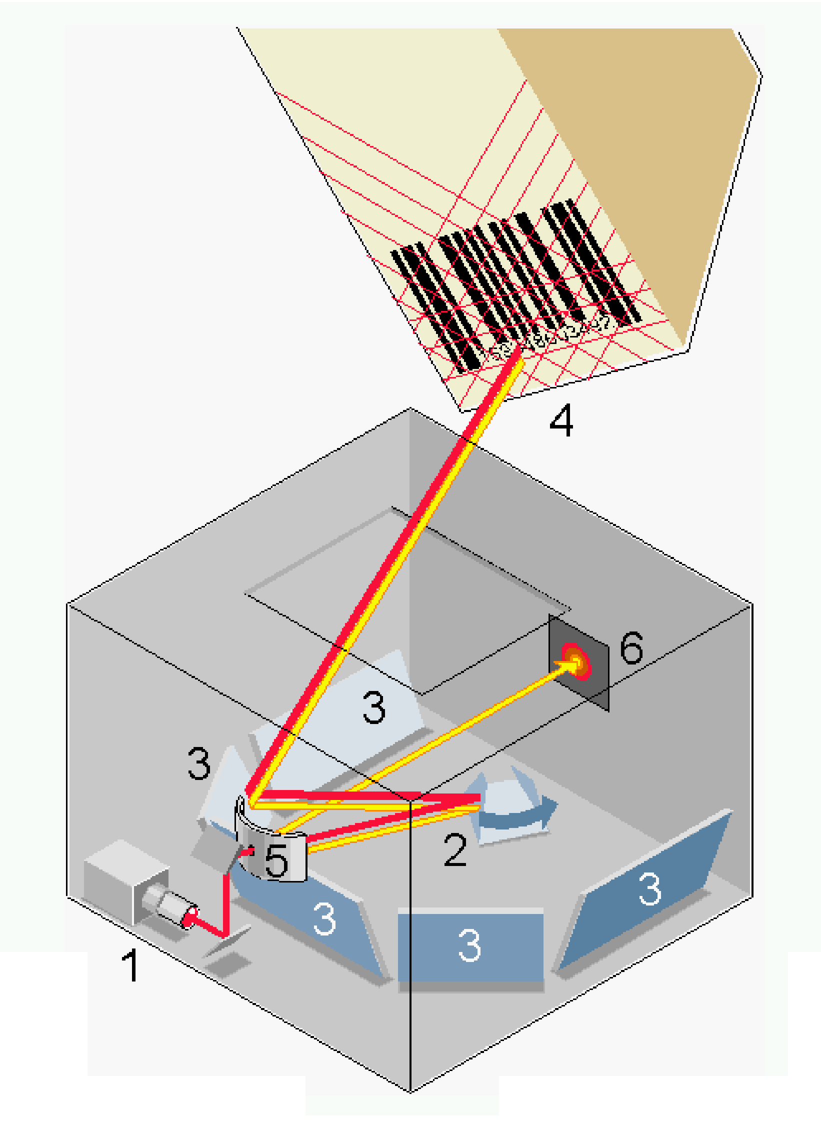
**By: Dominic Held, Corey Miller, and Joel Schultz**



Laser scanners use a moving pinpoint of light to illuminate the barcode, and a single photocell receives the reflected light. Most laser scanners sweep the laser beam horizontally using an electronically controlled mirror.



The dark lines in the barcode reflect less light. This enables the photocell to sense differences in the width of the bars.



From Computer Desktop Encyclopedia
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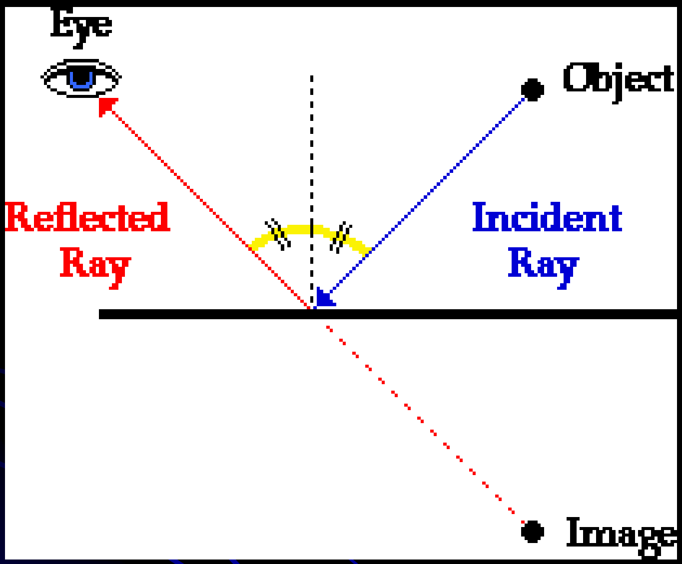
1. Using mirrors, a HeNe laser is aimed at a rotating mirror.
2. The rotating mirror reflects this beam to one of 5 angled mirrors within the device.
3. The fixed mirrors reflect the laser beam toward the awaiting barcode.
4. The barcode reflects back a portion of this beam, based on the white and dark lines.
5. The beam returns to the fixed mirror, which reflects the beam back to the rotating mirror, which sends it back to the two way spherical mirror.
6. The beam is reflected off the spherical mirror and completes its journey at the sensor

# Main Optical Principles

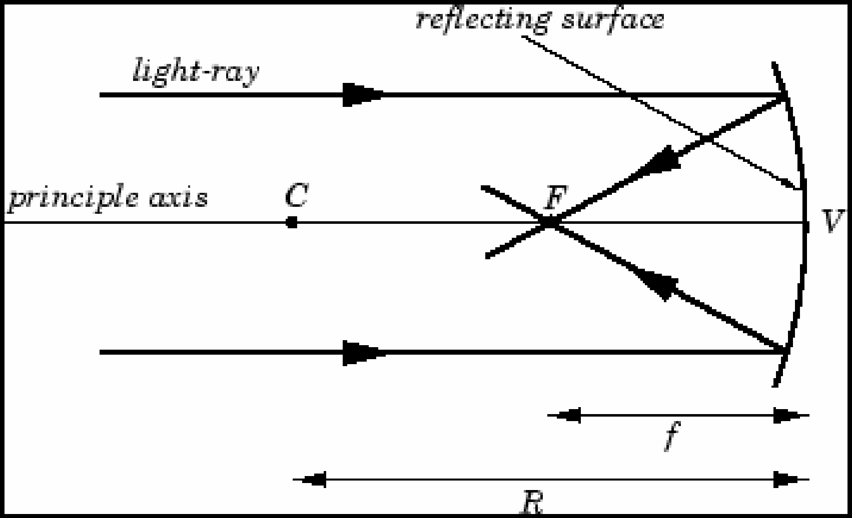
## Flat Mirror



The Law of Reflection states that the angle of incidence equals the angle of reflection.

$$\theta_i = \theta_r$$

## Spherical Mirror



The light rays approaching the mirror from the focal point are reflected parallel to the principle axis.

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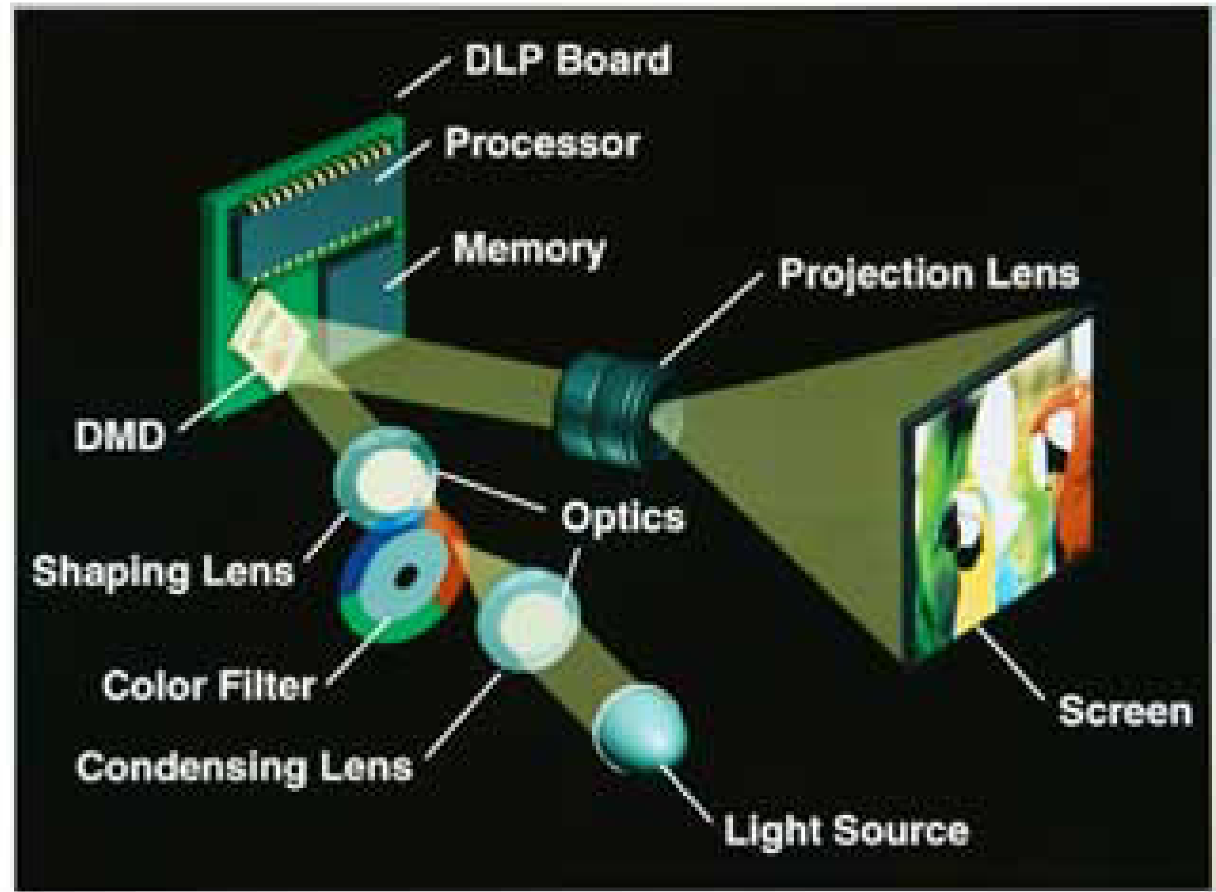
# DLP TV

DLP is a cutting-edge optical device used in television and projectors.  A system of lenses, a color filter and millions of mirrors creates a sharp image.

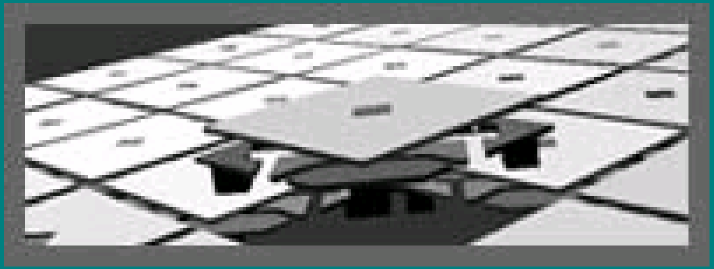
Rafferty Kelly
Jeremy Bond
Chad Hodgkins

# What is DLP?

- *Digital Light Processing* in TV’s and projection systems
- Light source → Converging Lens → Color Filter → Converging Lens → Mirrors → Lens



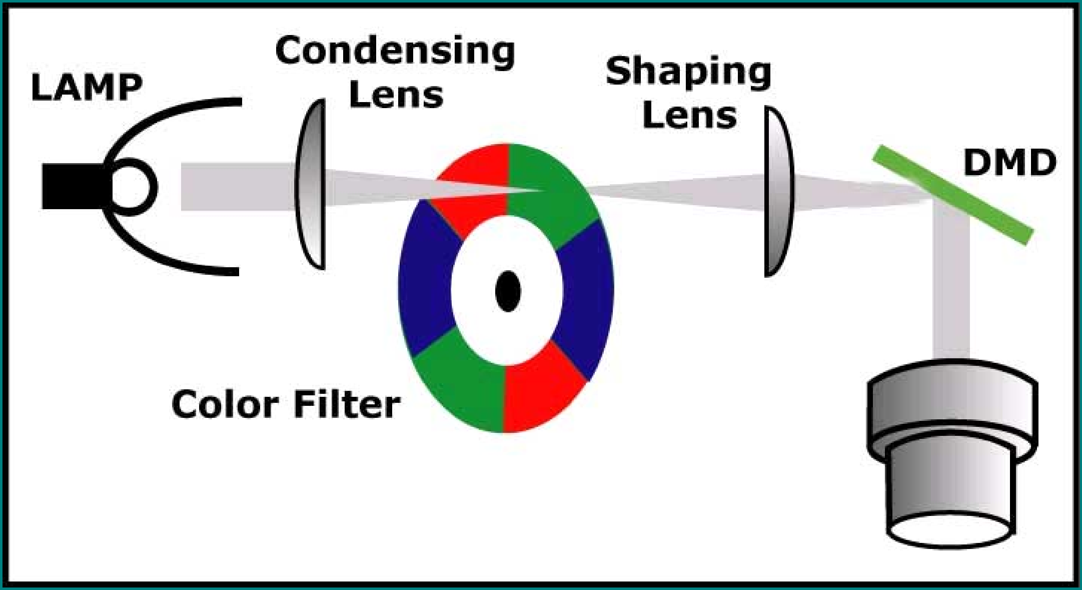
# The Digital Micromirror Device



- Each of the microscopic mirrors represents one pixel and can rotate ± 10°
- Area= 16 µm² (~ 1/5 of human hair)
- Each mirror has a Switched Blazed Grating. This behaves like a diffraction grating. This controls the intensity of the light.
- The angle of the mirror will change which fringe (intensity) is shown.

# Color Wheel and Lenses

- Color Filter
  - Contains RGB colors (allows 16.7 million total colors)
  - Spins at 9000 rpm’s
- Lenses
  - First lens placed 1f from the color wheel.
  - Second Lens placed close to 1f from the color wheel to focus light onto the DMD.



# Useful Lens Equations

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

Used to determine the placement of the color wheel.

$$\frac{1}{f} = \left(\frac{n}{n_m} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right].$$

Used to determine the specifications of the lenses.

$$M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$$

Determines the distance between the shaping lens and the DMD. Also, determines the distance from the projector lens to the screen.

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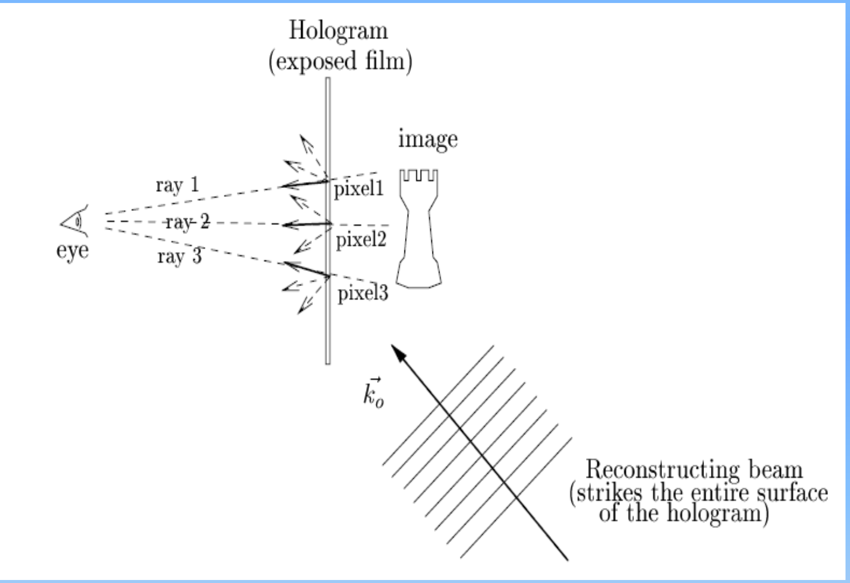
# Holograting

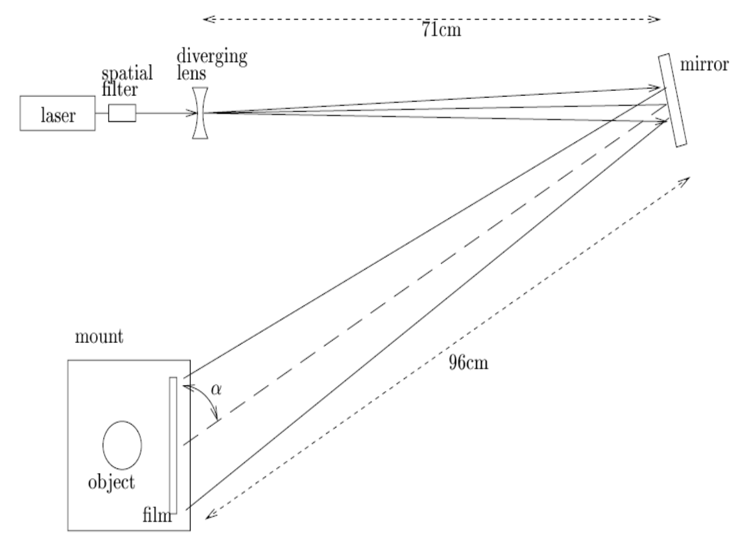
Sarah Mason
Josh Herzog
Stephen Bryant

A hologram is the recording of the interference pattern between a laser beam, and its reflection from an object. These patterns are captured on film. When this film is illuminated with a beam of light, the bright and dark spots on the film act as a diffraction grating producing an image.

# How to view



# How to make



The E-field when it strikes the film will be the superposition of the N+1 plane waves

$$E(\vec{r}) \quad = \quad A_o e^{i\vec{k_o}\cdot\vec{r}} + A_1 e^{i\vec{k_1}\cdot\vec{r}} + \cdots + A_N e^{i\vec{k_N}\cdot\vec{r}}$$

The translucency of the film is proportional to the intensity of the light striking it

$$\begin{aligned} t(\vec{r}) \quad & \alpha \quad |E(\vec{r})|^2 \\ & = \quad E^*(\vec{r})E(\vec{r}) \end{aligned}$$

Substituting in we get

$$= \left| \sum_{n=0}^{N} A_n e^{i\vec{k_n}\cdot\vec{r}} \right|^2$$

$$= |A_o|^2 + \left| \sum_{i=1}^{N} A_i e^{i\vec{k_i}\cdot\vec{r}} \right|^2 + A_o^* \sum_{i=1}^{N} A_i e^{i(\vec{k_i}-\vec{k_o})\cdot\vec{r}} + \sum_{i=1}^{N} A_i^* A_o e^{i(\vec{k_o}-\vec{k_i})\cdot\vec{r}}$$

This function represents the opaqueness of the film across the surface.
The third term is responsible for the holography.

# Other useful equations

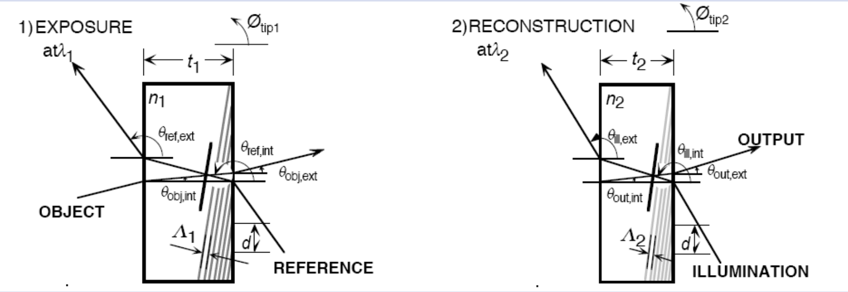
## Angle equation

$$\sin\theta_{out} = m\frac{\lambda_{ill}}{\lambda_{\exp}}(\sin\theta_{obj} - \sin\theta_{ref}) + \sin\theta_{ill}$$

## Variables

$$diff_1 = (\theta_{ref,int} - \theta_{obj,int})/2$$

$$diff_2 = (\theta_{ill,int} - \theta_{out,int})/2$$



## Fringe separation during exposure

$$(1/\Lambda_2) = (2/\lambda_{2int}) \cdot \cos(90° + diff_2)$$

## Fringe separation during reconstruction

$$(1/\Lambda_1) = (2/\lambda_{1int}) \cdot \cos(90° + diff_1)$$

## Diffraction

$$\sin\theta_{out} = \sin\theta_{in} + m\lambda f$$

## Interference

$$f = \frac{\sin\theta_2 - \sin\theta_1}{\lambda}$$

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# Hush

Or the plagues of a thousand angry curmudgeons will curse you and your children and your childrens’ children.

# Spectrometer

Visualize color, one wavelength at a time

Brian Doozan
Josh Kenealy
Katie McAlpine

# General

- A spectroscope is an optical device that splits light into separate wavelengths
  - They are able to make very accurate angle measurements.
- There are several devices that can diverge a beam of light
  - Diffraction gratings
    - Passing light through slits or reflecting off ridges
  - Prisms
    - Passing light through a prism of glass

# General

- When a wave passes through a diffraction grating, light will be diffracted at an angle proportional to the wavelength.
- This is useful to separate white light into colors.
- It is used by astronomers to detect which elements in a star or gas cloud exist.
  - Elements each emit a “fingerprint” spectra, which can be detected with spectroscopy.

# Mathematical

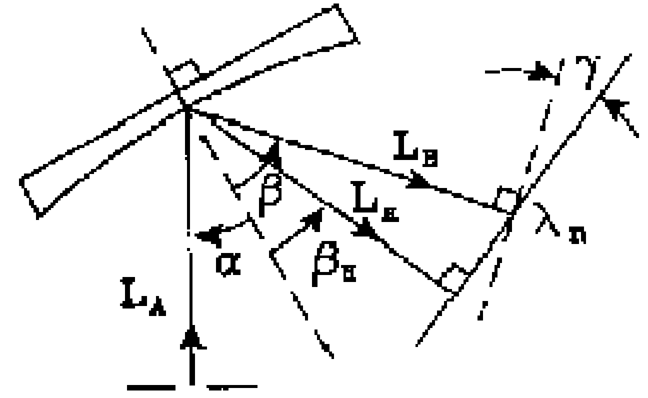


Figure 2 - Spectrograph Configuration

1. Grating Equation

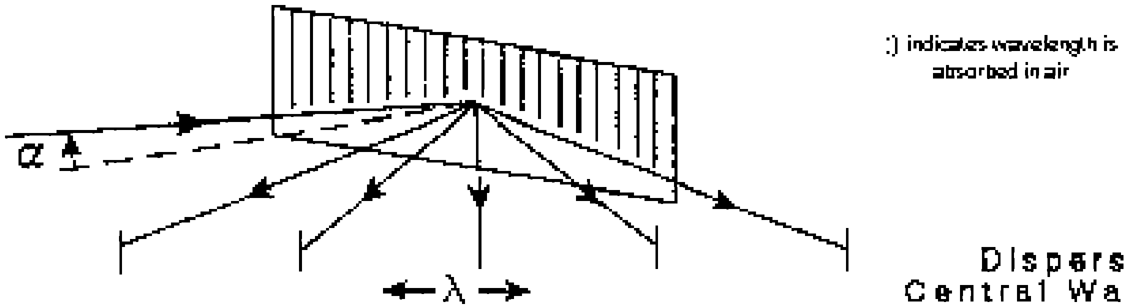
$$\sin(\alpha)+\sin(\beta)=10^{-6}mN\lambda$$

$$2\sin\left(\frac{\beta+\alpha}{2}\right)\cos\left(\frac{\beta-\alpha}{2}\right)=10^{-6}mN\lambda$$

2. Angular Dispersion

$$\frac{d\beta}{d\lambda}=\frac{10^{-6}mN}{\cos(\beta)}$$

# Resolving Power



() indicates wavelength is absorbed in air

| Order | | | | | | Dispersion at Central Wavelength |
|---|---|---|---|---|---|---|
| 1st | 200 | 400 | 600 | 800 | 1000 | 10 nm/mm |
| 2nd | (100) | 200 | 300 | 400 | 500 | 5 |
| 3rd | (66.6) | (133.3) | 200 | 266.6 | 333.3 | 3.3 |
| 4th | (50) | (100) | (150) | 200 | 250 | 2.5 |

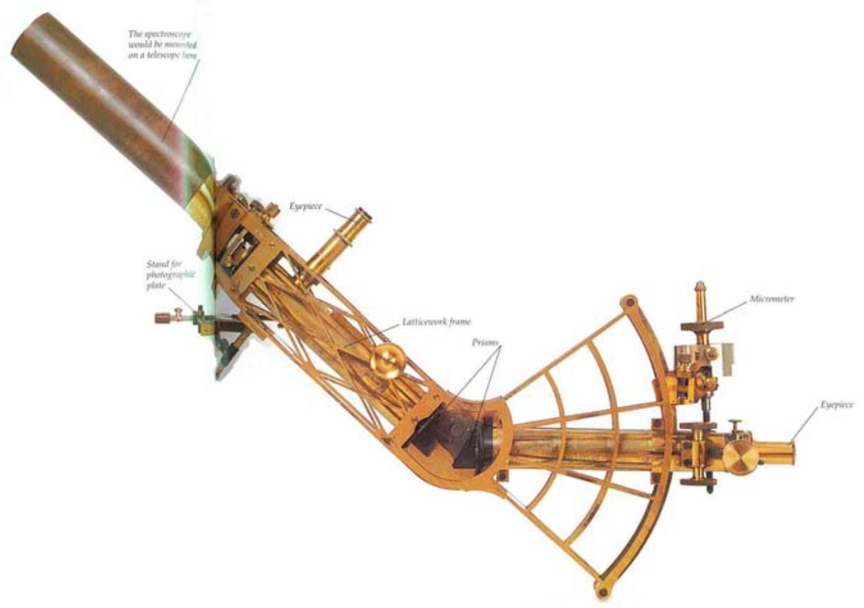
Figure 3 - Dispersion and Order

## Resolving Power

$$R = \frac{\lambda}{(\Delta\lambda)_{\min}} = mN = \frac{Na(\sin(\beta) - \sin(\alpha))}{\lambda}$$

# Precision

- First Spectroscopes contained prism or grating in which the sample was placed and the observer saw the visible lines.
- Pro’s: Can find visible lines in the visible spectrum. Can precisely measure the length of the visible spectrum leading to what we have today. Able to discover characteristic wavelengths of elements.
- Con’s: Only good for the visible spectrum.

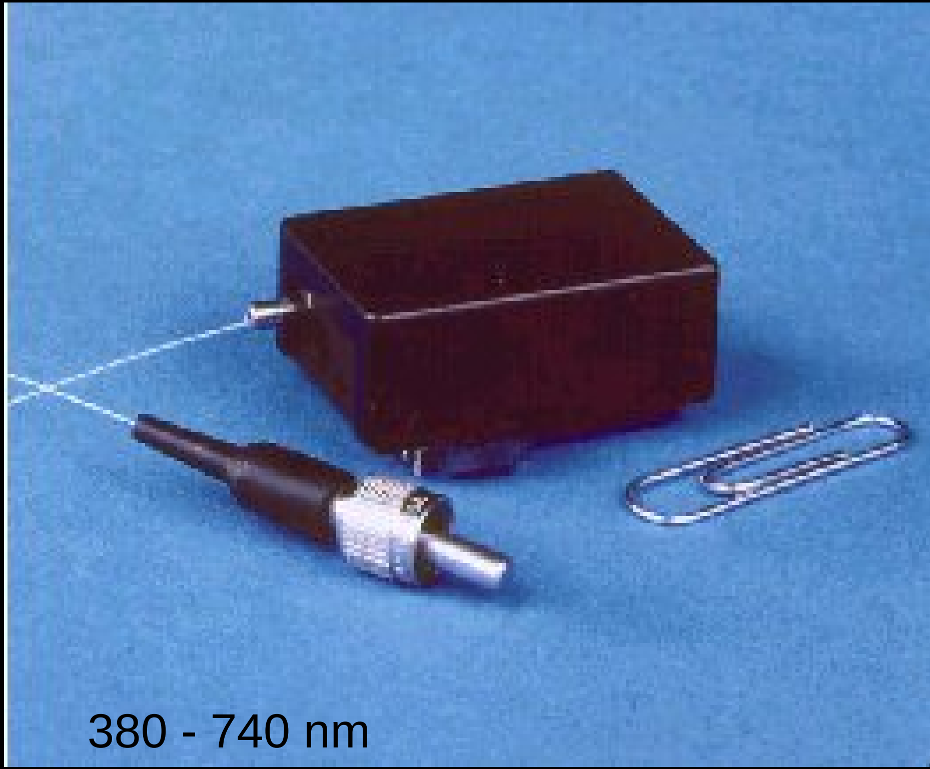


# Precision

- Next step was the Spectrograph that used photographic film. User simply placed an exposed camera at the eye piece of the instrument.
- The longer the exposure of the film the more information that was collected from the test sample.
- Able to use this for other spectrums( microwave, radio, and audio frequencies) using a diffraction grating.
- Pro’s: more accurate in details for the characteristic line spectrum for elements.

# Precision

- Spectrometers today use electronics (i.e. photodetector's). Coupled with a computer we can get a more accurate spectrograph of the test sample.
- This improved the accuracy of the spectrometer greatly.
- Eye piece is replaced by CCD's (charged-couple devices) improving the spectrographic analysis.
- Pro's: Spectrometers are scaled down in size while still being accurate.



380 - 740 nm

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