MAS836 – Sensor Technologies for Interactive Environments

Lecture 9 – Optical Sensing

Readings

- Fraden, Chapter 14 (3 Edition) or 13 (2 Edition)
- Assorted readings that will be posted...

Melles Griot Optics Guide

Melles Griot Fundamental Optics Tutorial

EG&G Optics Sensor Selection Advice

http://www.engr.udayton.edu/faculty/jloomis/ece445/topics/egginc/tp4.html

Photodetectors

http://www.engr.udayton.edu/faculty/jloomis/ece445/topics/egginc/tp4.html

Table 1 - Comparison of Light Sensor Characteristics

Electrical Characteristics	Photo-multiplier Tubes	Photo-diodes	Photo-transistors	CdS Photocells	Other Photo-conductors	Itegrated Circuits	Hybrids	Sensor Electronic Assembly
Available Wavelengths (µm)	0.2-0.9	0.2-2.0	0.4-1.1	0.4-0.7	2-15	0.2-1.1	0.2-15.0	0.2-15.0
Performance-to-cost ratio	Fair	Good	Excellent	Excellent	Fair	Fair	Fair	Good
Sensitivity	Excellent	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Linearity	Good	Excellent	Good	Good	Good	Good	Good	Good
Ambient Noise Performance	Fair	Very Good	Very Good	Very Good	Very Good	Excellent	Excellent	Excellent
Dynamic Range	Very Good	Excellent	Very Good	Good	Good	Very Good	Very Good	Very Good
Stability	Very Good	Very Good	Good	Poor	Fair	Very Good	Very Good	Very Good
Other Characteristics								
Reproducibility	Fair	Excellent	Fair	Poor	Fair	Very Good	Very Good	Very Good
Cost	High	Low	Very Low	Very Low	High	Medium	High	Medium
Ruggedness	Poor	Excellent	Excellent	Excellent	Good	Excellent	Very Good	Excellent
Physical Size	Large	Small	Small	Small	Small	Small	Medium	Medium
Ease of Customization	Poor	Easy	Fair	Fair	Poor	Poor	Poor	Fair
Cost of Customization	Very High	Low	Medium	Low	High	Very High	High	Medium
Lead time for Customization (weeks)	40	12	14	12	20	40	30	16
Speed	Ex	Vg/Ex	G	Poor	G/Pr	G	?	?

Photoelectric effect and band gaps

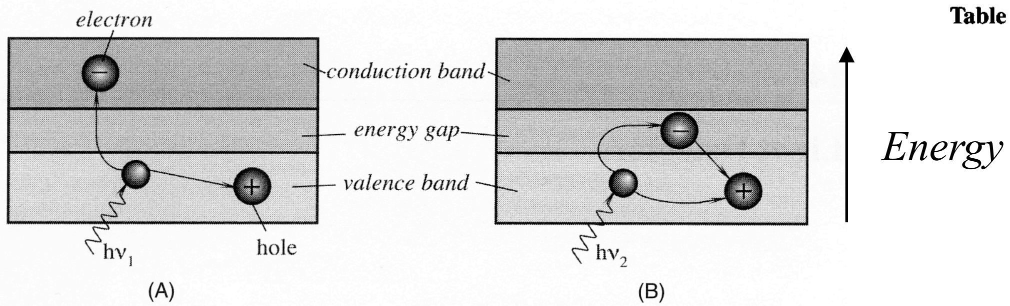


Fig. 14.1. Photoeffect in a semiconductor for high-energy (A) and low-energy (B) photons.

Table 14.1. Band Gaps and Longest Wavelengths for Various Semiconductors

Material	Band Gap (eV)	Longest Wavelength (μm)
ZnS	3.6	0.345
CdS	2.41	0.52
CdSe	1.8	0.69
CdTe	1.5	0.83
Si	1.12	1.10
Ge	0.67	1.85
PbS	0.37	3.35
InAs	0.35	3.54
Te	0.33	3.75
PbTe	0.3	4.13
PbSe	0.27	4.58
InSb	0.18	6.90

- Photoelectric effect
  - Photons knock electrons into conduction band
  - Band gap and work function
    - $E = h\nu$ (h is Planck's constant, ν is light frequency)
    - $K_{max} = h\nu - \phi = hc/\lambda - \phi$ (ϕ = Work Function, K_{max} is max kinetic energy of freed electron)

If light of a proper wavelength [sufficiently high energy of photons; see Eq. (14.1)] strikes a semiconductor crystal, the concentration of charge carriers (electrons and holes) in the crystal increases, which manifests in the increased conductivity of a crystal:

$$\sigma = e(\mu_e n + \mu_h p), \tag{14.3}$$

where e is the electron charge, μ_e is the electron mobility, μ_h is the hole mobility, and n and p are the respective concentrations of electrons and holes.

Photoresistors

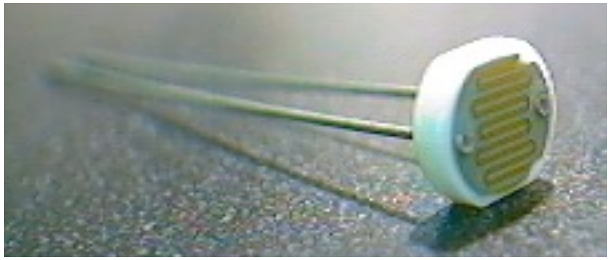
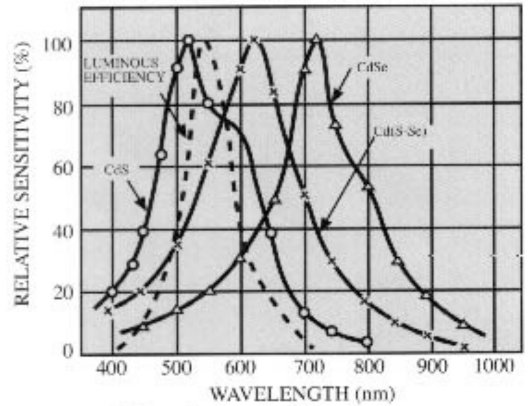
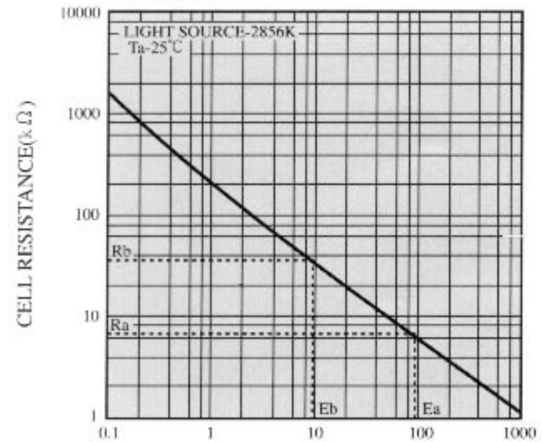


Figure 6:Spectral Response of CdS Cells and Spectral Luminous Efficiency(Human Eye Response)



CdS:cadmium sulfide
Cd(S.Se):cadmium sulfo-selenium
CdSe:cadmium selenide

Figure 8: CdS Resistance vs. Illuminance Characteristic Example



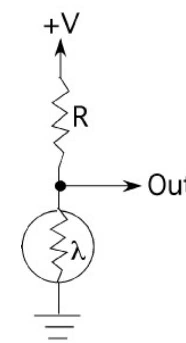
Goes from MΩ to Ohms

CdS tends to like Yellow...

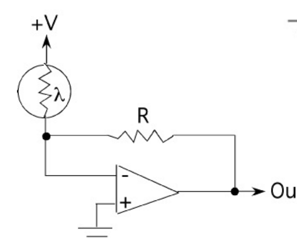
Photons knock electrons into conduction band
1 photon can release 900 electrons
Acceptor band keeps electron lifetime high
-> Lower Resistance with increasing light
Slow response...

- CdS (Cadmium Sulfide) and CdSe (Cadmium Selenide) cells are common

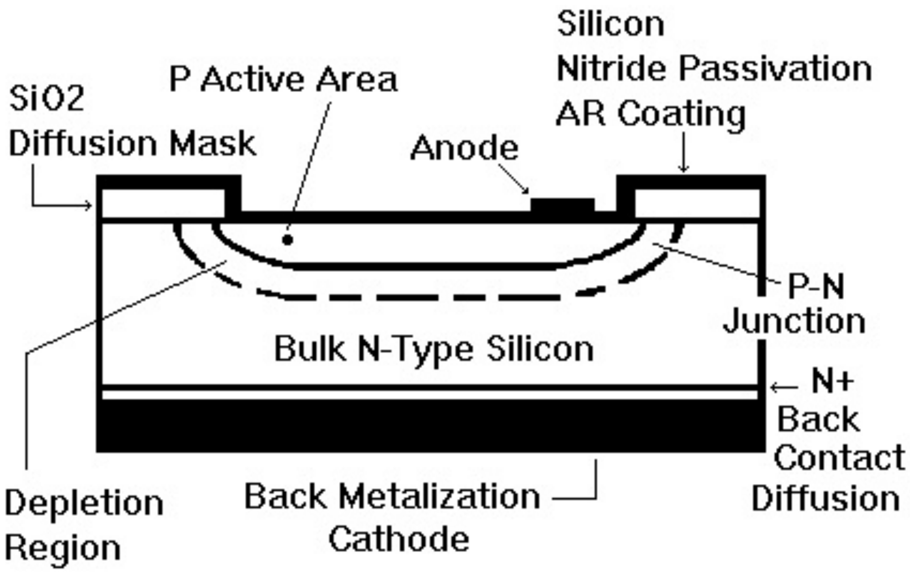
(I) Directly beneath the conduction band of the CdS crystal is a donor level and there is an acceptor level above the valence band. In darkness, the electrons and holes in each level are almost crammed in place in the crystal and the photoconductor is at high resistance.
(II) When light illuminates the CdS crystal and is absorbed by the crystal, the electrons in the valence band are excited into the conduction band. This creates pairs of free holes in the valence band and free electrons in the conduction band, increasing the conductance.
(III) Furthermore, near the valence band is a separate acceptor level that can capture free electrons only with difficulty, but captures free holes easily. This lowers the recombination probability of the electrons and holes and increases the number for electrons in the conduction band for N-type conductance

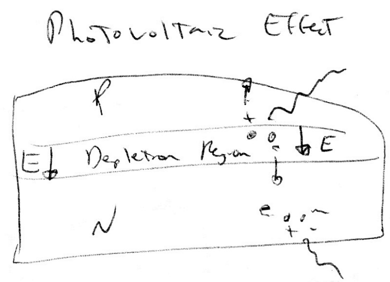


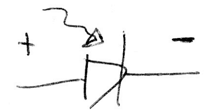
Condition like FSR’s (voltage divider, transimpedance amp, etc.)



Photodiodes





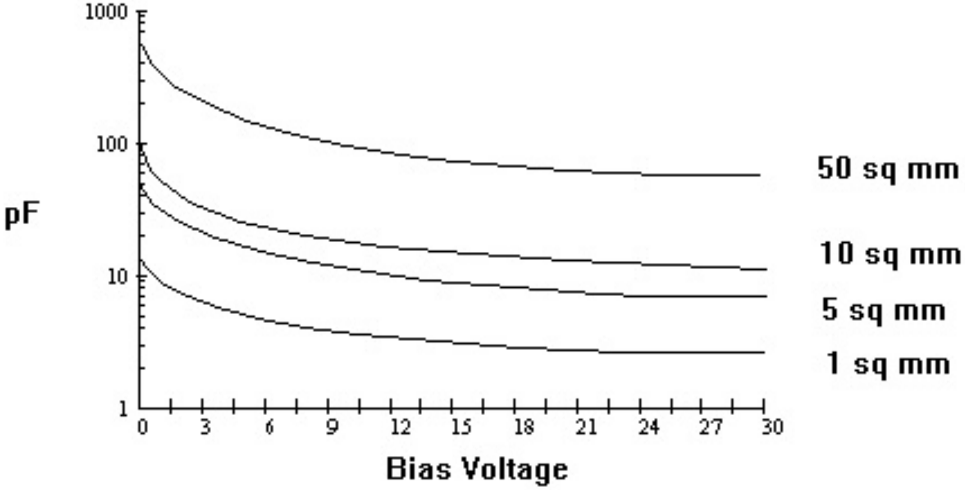


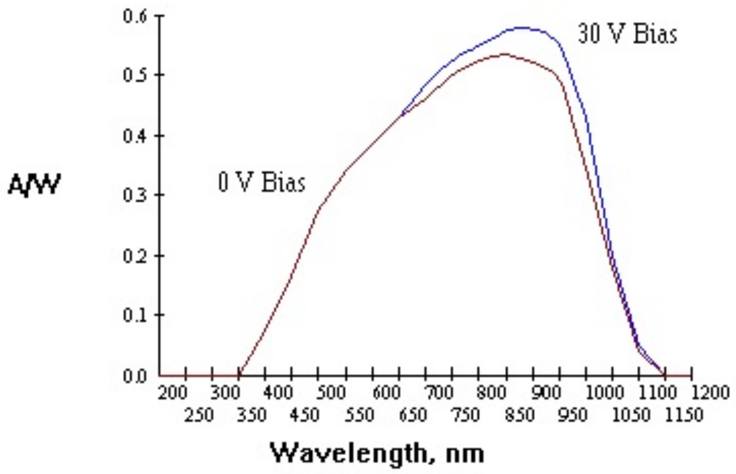
Solar Cells
- Big (optimized) versions

Photodiodes
- (Smaller)

- Photons interacting in the depletion region produce electron-hole pairs
  - Electrons diffuse through depletion region, driven by the E-field, to arrive at the N layer and electrode, producing current.
  - Make depletion region bigger (more reverse bias)
    - More efficient (higher probability of photon interaction)
    - Faster (charge doesn’t have to diffuse across longer lengths before it hits E-field, hence less charge stored, hence smaller capacitance)
    - PIN diodes increase the collection area - faster response

Capacitance and Response

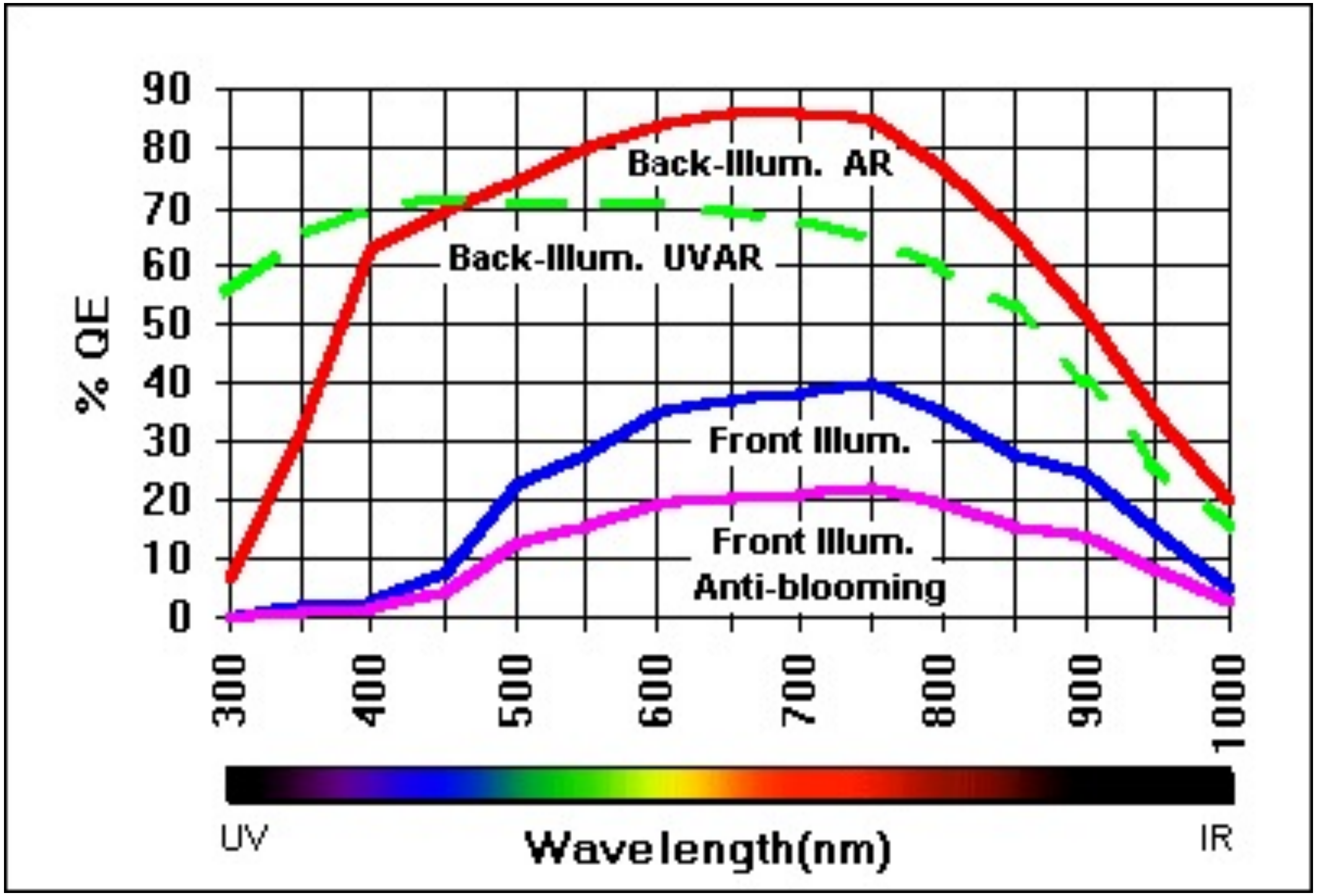




Silicon has more than 2x response in IR

Reverse bias lowers capacitance (makes device faster, extends sensitivity)

Quantum Efficiency



Thinned silicon

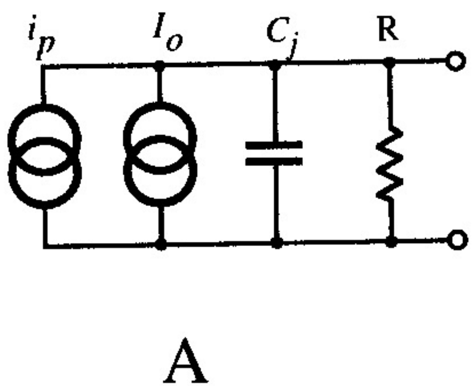
- More efficient, esp. at short λ

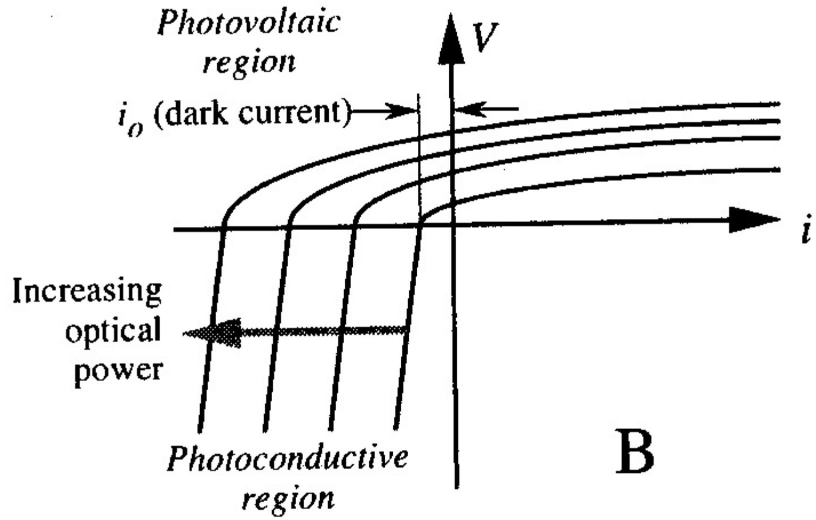
-Rear illumination better, as the pads/traces in front get in the way

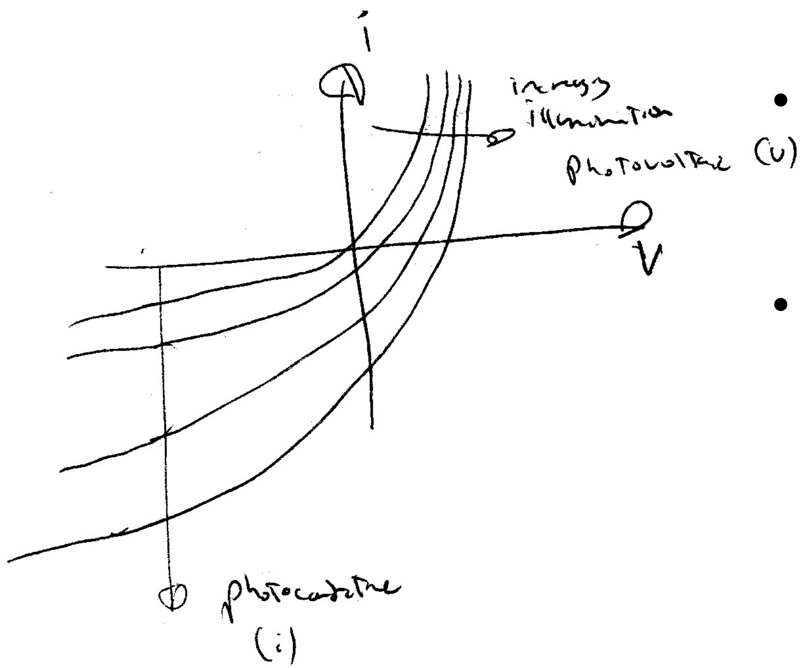
-AXAF/Chandra X-Ray imager

- Quantum efficiency (QE) is a figure given for a photosensitive device (charge-coupled device (CCD), for example) which is the percentage of photons hitting the photoreactive surface that will produce an electron-hole pair. It is an accurate measurement of the device's sensitivity.
  - Signal-to-noise ratio is also important!!

Photoconductive and photovoltaic operation



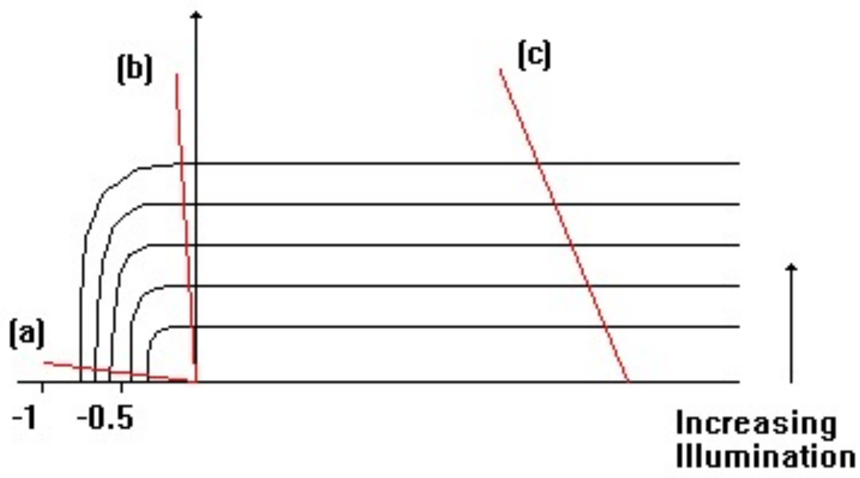




- Photovotaic - produces voltage with illumination
  - Typical photodiode (.2 mm^2) produces 30 μA in sunlight and 30 pA on a clear moonless night
- Photoconductive - increasing current with illumination
  - Reverse bias voltage applied
  - Much faster, more sensitive
  - **Dark current** threshold at zero illumination

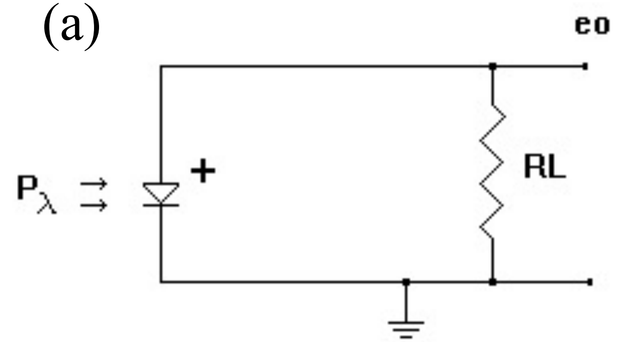
Photodiode modes (more)

Effect of Load Resistance



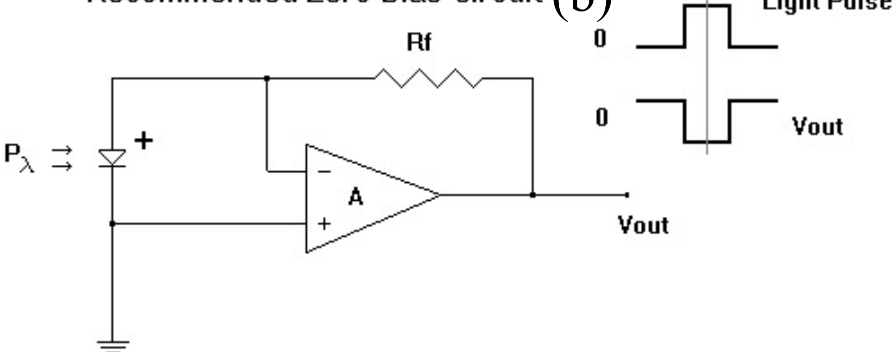
Basic Photovoltaic Circuit

(a)



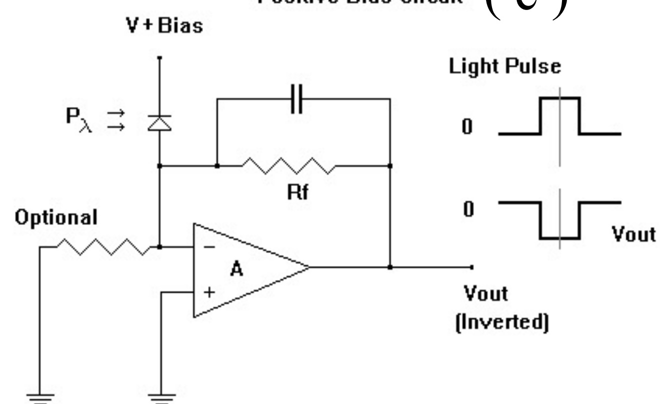
Logarithmic, Slow

Recommended Zero Bias Circuit (b)



Linear, low noise, slow

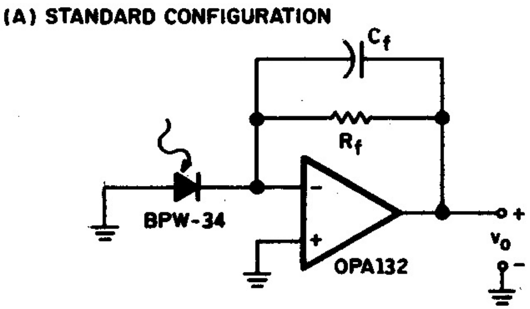
Positive Bias Circuit (c)

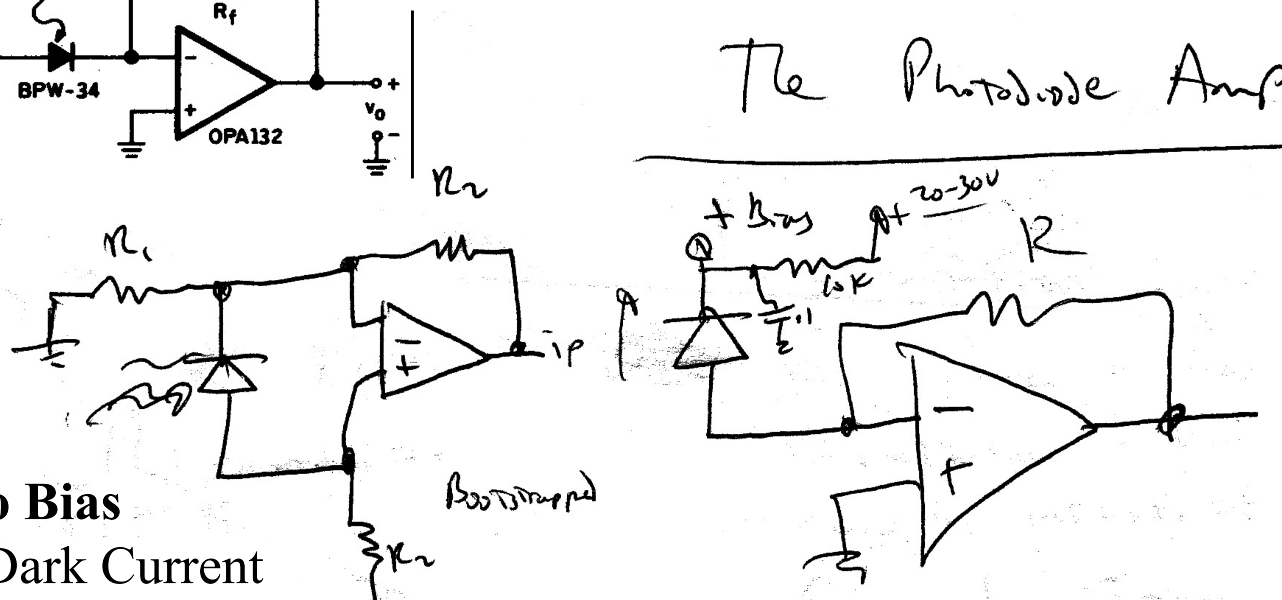


Linear, fast

http://www.centrovision.com/tech2.htm

Typical Circuits





Zero Bias
No Dark Current
Linear - Lower Noise
Slow, Precision Apps.

Photovoltaic

Generic transimpedance amp

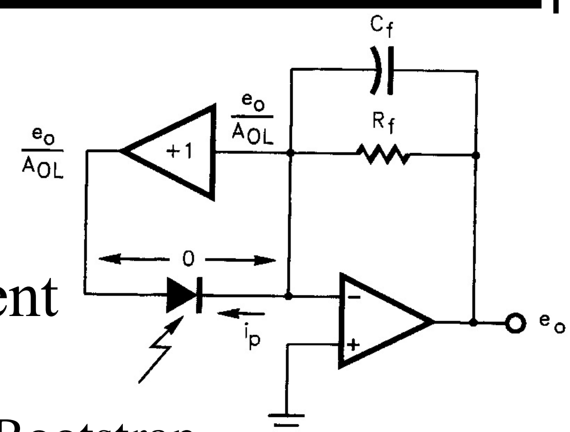
Biased

$V = -i_p R$

Need a PS

Higher noise, but faster

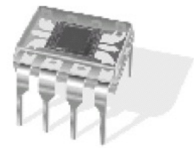
- Transimpedance amplifier traditionally used
- Johnson, shot, and amplifier noise dominant
- Bootstrapping removes junction capacitance for photovoltaic device - faster, linear, no dark current
  - Can put photodiode in amplifier feed



2-amp Bootstrap

Photodiode IC’s

BURR - BROWN®



OPT211

MONOLITHIC PHOTODIODE AND AMPLIFIER

FEATURES

- WIDE BANDWIDTH, HIGH RESPONSIVITY:

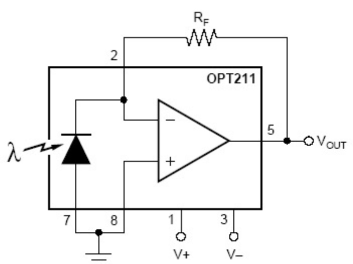
R_F	BANDWIDTH	
1MΩ	50kHz	*150kHz
100MΩ	5kHz	*13kHz

*with bootstrap buffer

- PHOTODIODE SIZE: 0.090 x 0.090 inch (2.29 x 2.29mm)
- HIGH RESPONSIVITY: 0.45A/W (650nm)
- LOW DARK ERRORS: 2mV max
- EXCELLENT SPECTRAL RESPONSE
- LOW QUIESCENT CURRENT: 400μA
- TRANSPARENT 8-PIN DIP

APPLICATIONS

- MEDICAL INSTRUMENTATION
- LABORATORY INSTRUMENTATION
- POSITION AND PROXIMITY SENSORS
- PHOTOGRAPHIC ANALYZERS
- BARCODE SCANNERS
- SMOKE DETECTORS



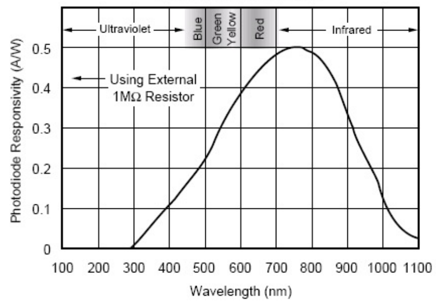
DESCRIPTION

The OPT211 is a monolithic photodiode with on-chip FET-input transpedance amplifier, that provides wide bandwidth at very high gains. Uncommitted input and feedback nodes allow a variety of feedback options for maximum versatility. Trade-offs in responsivity (gain), bandwidth and SNR can easily be made.

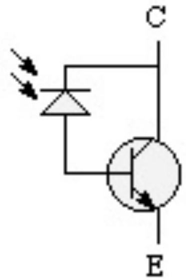
The monolithic combination of photodiode and transimpedance amplifier on a single chip eliminates the problems commonly encountered in discrete designs such as leakage current errors, noise pickup and gain peaking due to stray capacitance. The 0.09 x 0.09 inch photodiode is operated at zero bias for excellent linearity and low dark current. Direct access to the detector’s anode allows photodiode bootstrapping, which increases speed performance.

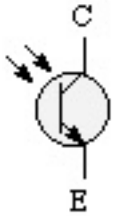
The OPT211 operates over a wide supply range (±2.25V to ±18V) and supply current is only 400μA. It is packaged in a transparent plastic 8-pin DIP specified for the 0°C to 70°C temperature range.

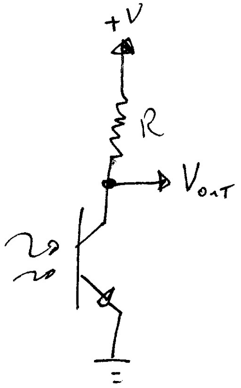
SPECTRAL RESPONSIVITY



The Phototransistor







- Like diodes, all transistors are light-sensitive. Phototransistors are designed specifically to take advantage of this fact. The most-common variant is an NPN bipolar transistor with an exposed base region. Here, light striking the base replaces what would ordinarily be voltage applied to the base -- so, a phototransistor amplifies variations in the light striking it. Note that phototransistors may or may not have a base lead (if they do, the base lead allows you to bias the phototransistor's light response).
- Phototransistors run in the photoconductive mode
- They're pretty slow, on average (e.g., Khz response)
- …But give a fair amount of gain and are very easy to use.
  - Generally ground emitter and provide a collector resistor to set gain
- Photodarlingtons give more gain, but can be slower…

http://encyclobeamia.solarbotics.net/articles/phototransistor.html

Using an LED as a photosensor

Very Low-Cost Sensing and Communication
Using Bidirectional LEDs

Paul Dietz, William Yerazunis, and Darren Leigh

Mitsubishi Electric Research Laboratories
201 Broadway
Cambridge, Massachusetts 02139 USA

In Ubicomp 2003

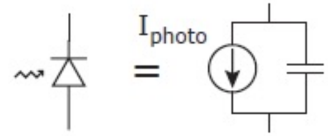


Fig. 2. Reverse-biasing an LED for photosensing

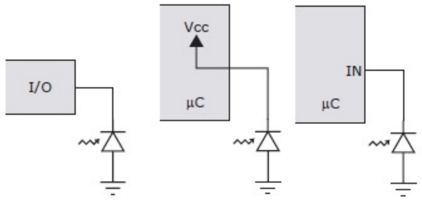
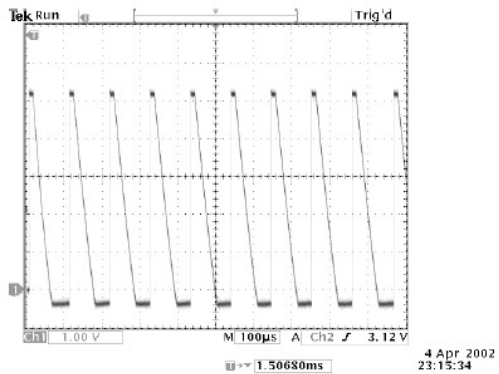


Fig. 3. LED used as a photosensor



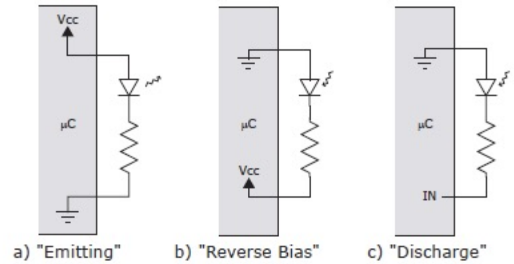


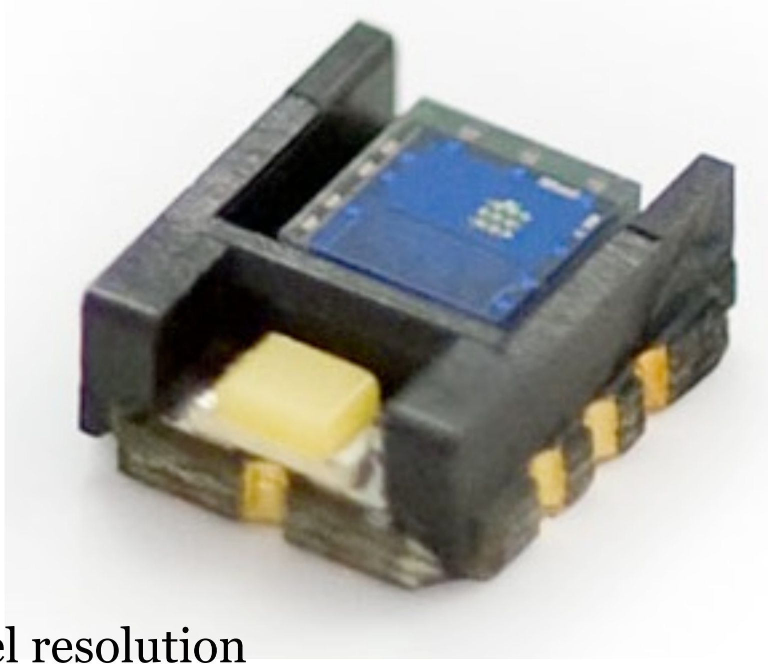
Fig. 5. Emitting and sensing light with an LED

- Use a Microprocessor pin – put a back bias on the LED, change the pin to input, and count down until the pin switches threshold.
- Can use the LED as both emitter and detector.
- Dates back to MID-80's Forrest Mims articles…

Color Sensors

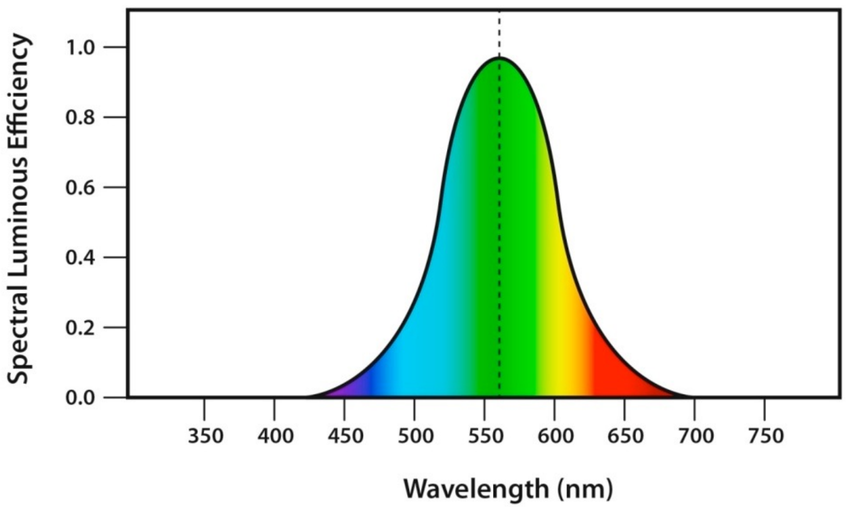
Color Light Sensor - Avago ADJD-S371-Q999

http://www.sparkfun.com/commerce/product_info.php?products_id=8618

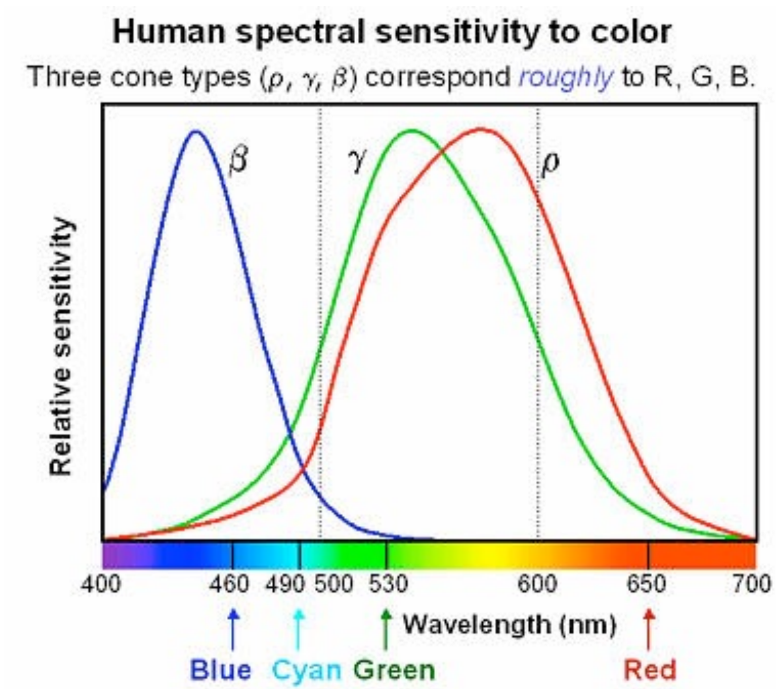


Features:
- 10 bit per channel resolution
- Independent gain selection for each channel
- Wide sensitivity: 0.1k - 100k lux
- Two wire serial communication
- Built in oscillator/selectable external clock
- Low power mode (sleep mode)
- Integrated solution with sensor, LED and separator in module for ease of design

Response of the Human Eye



http://www.npt.co.uk

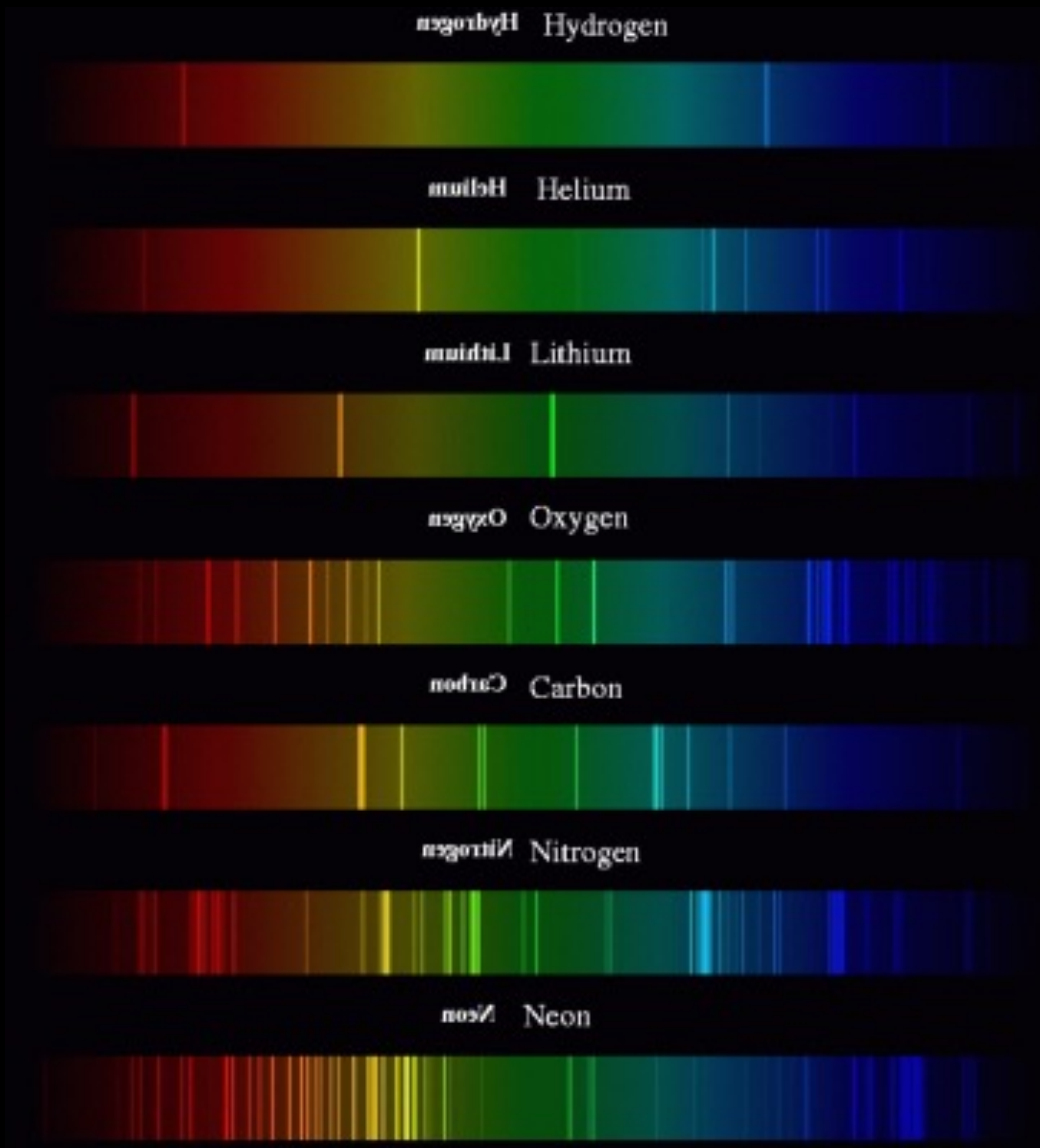


http://astro.swarthmore.edu/ir/ir_basics.html

We see only a limited EM spectral band

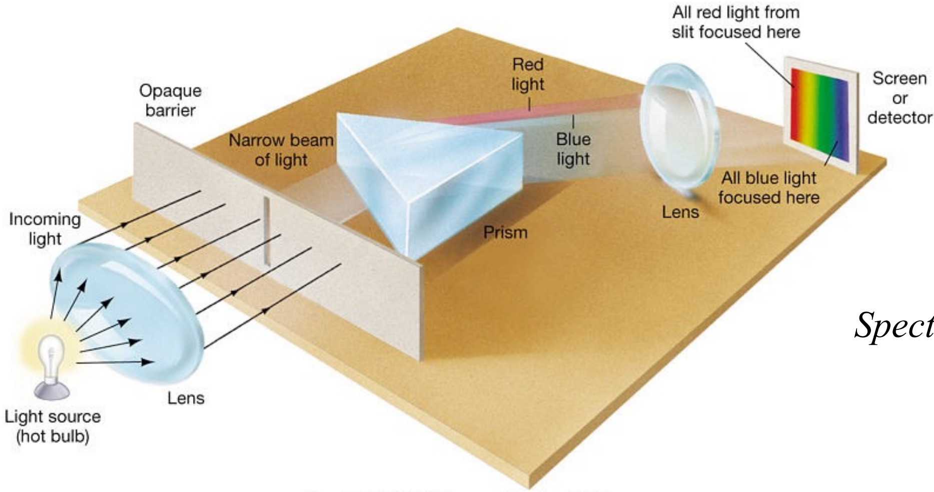
Our perception of color is based on only 3 sampling distributions

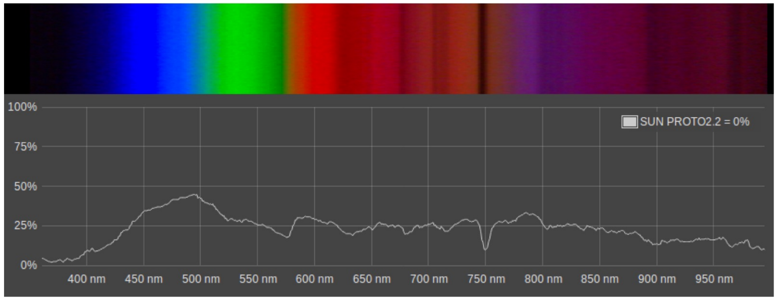
But the light also has ‘fingerprints’ of what kind of stuff it came from!!



Spectral Lines

Spectrometers





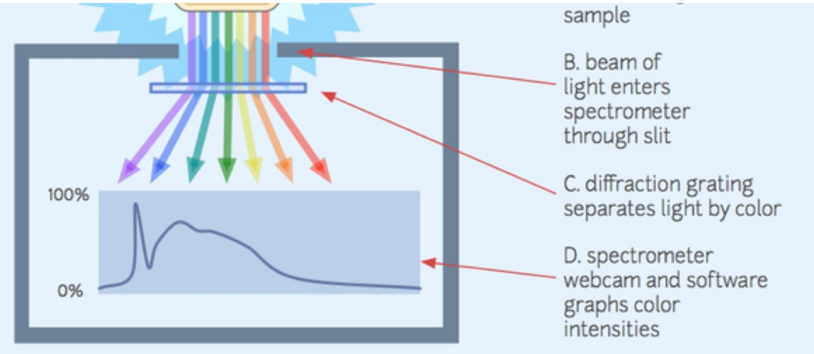
Spectral lines correspond to emission or absorption of molecules

Emission, Florescence, Absorption Spectroscopy

Must know/calibrate light source spectra & detector spectral response

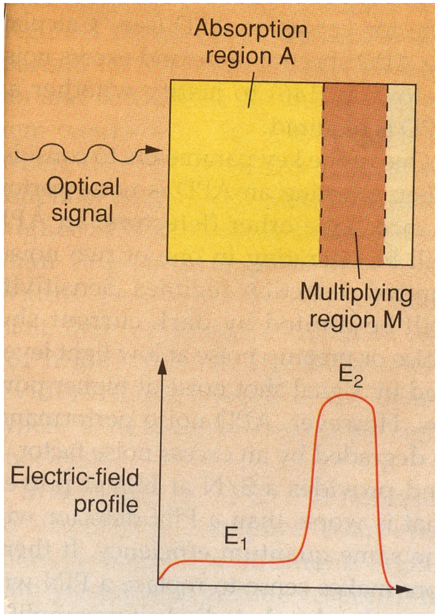
http://pages.uoregon.edu/jimbrau/astr122-2007/Notes/Chapter4.html

http://publiclab.org/



Public Lab's grating spectrometer (can also reflect off CD)

Avalanche Photodiode (APD)



Photoelectrons generated in E1 and doping in region E2 generates avalanche gain from collisions

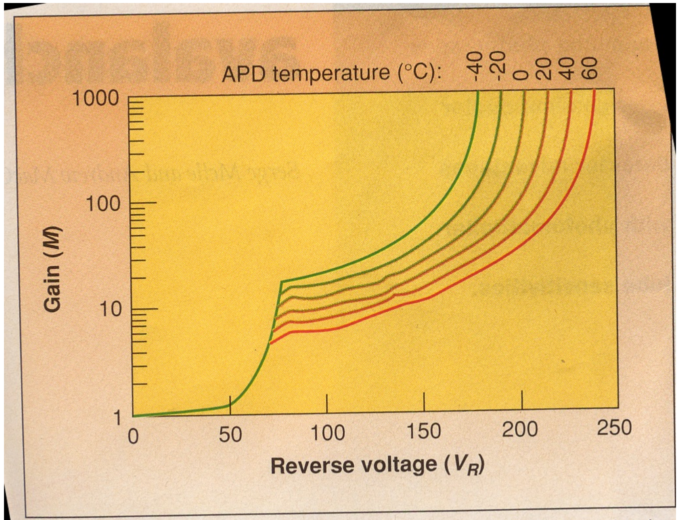


FIGURE 1. In operation at various temperatures, the gain of an avalanche photodiode depends on the reverse voltage, V_R.

- High voltage across detector produces avalanche gain (e.g., factor 300)
- Very Sensitive and Fast response (e.g., ns)
  - Voltage tends to be large to get enough output
    - 100-400 volts are standard
    - Recent devices run at about 30 volts or so...

Vacuum Photodiodes

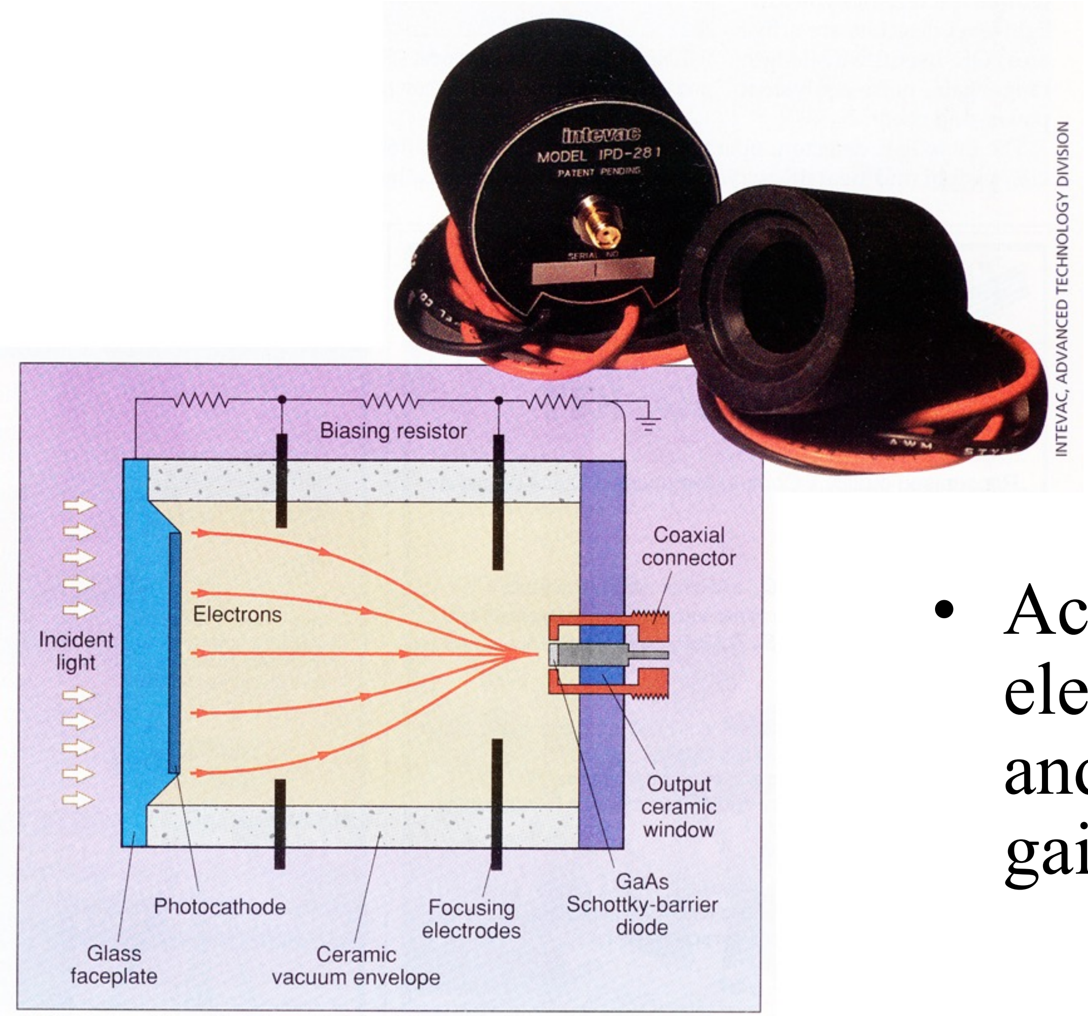


FIGURE 1. In an intensified photodiode (IPD), incoming light strikes a photosensitive cathode and generates photoelectrons, which are accelerated and focused onto a gallium arsenide photodiode. Use of special photocathode materials provides high quantum efficiency, and current multiplication gives an IPD gain. Photo shows packaged devices.

- Accelerating, focused electric field acts as lens and provides avalanche gain at diode

Photomultiplier Tubes

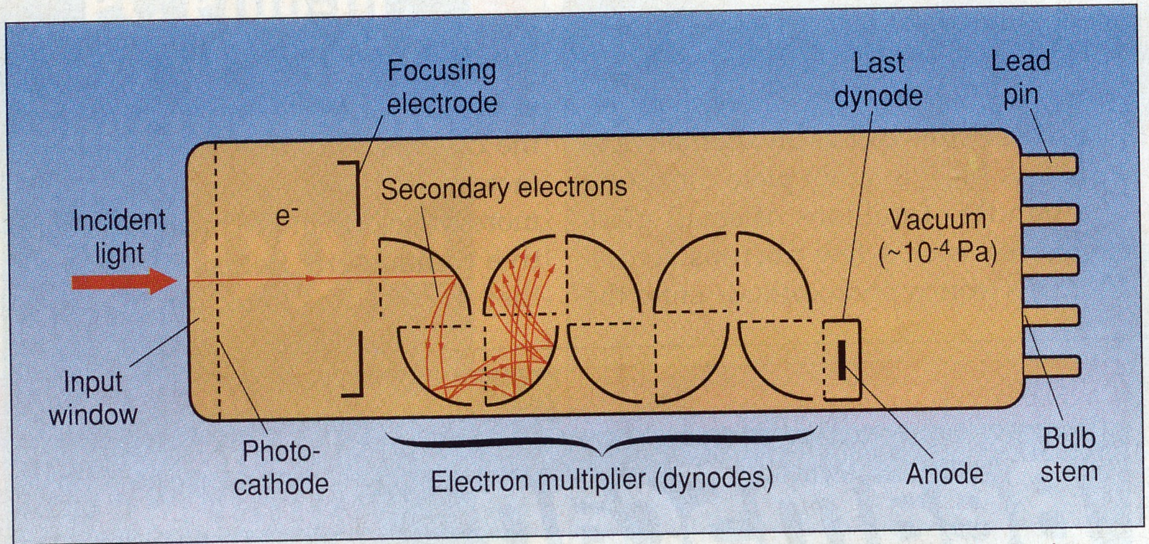
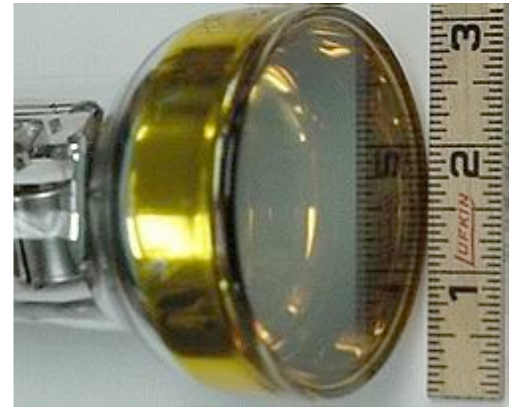
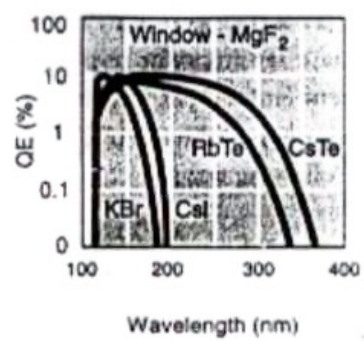
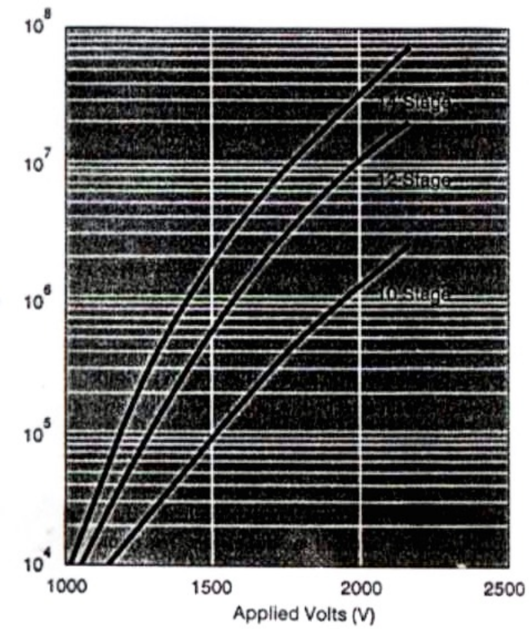


FIGURE 3. Photomultiplier tubes have a glass, metal, or ceramic envelope, a photocathode that emits electrons when exposed to light, secondary emitting electrodes that multiply the electrons, and a collection electrode or anode.

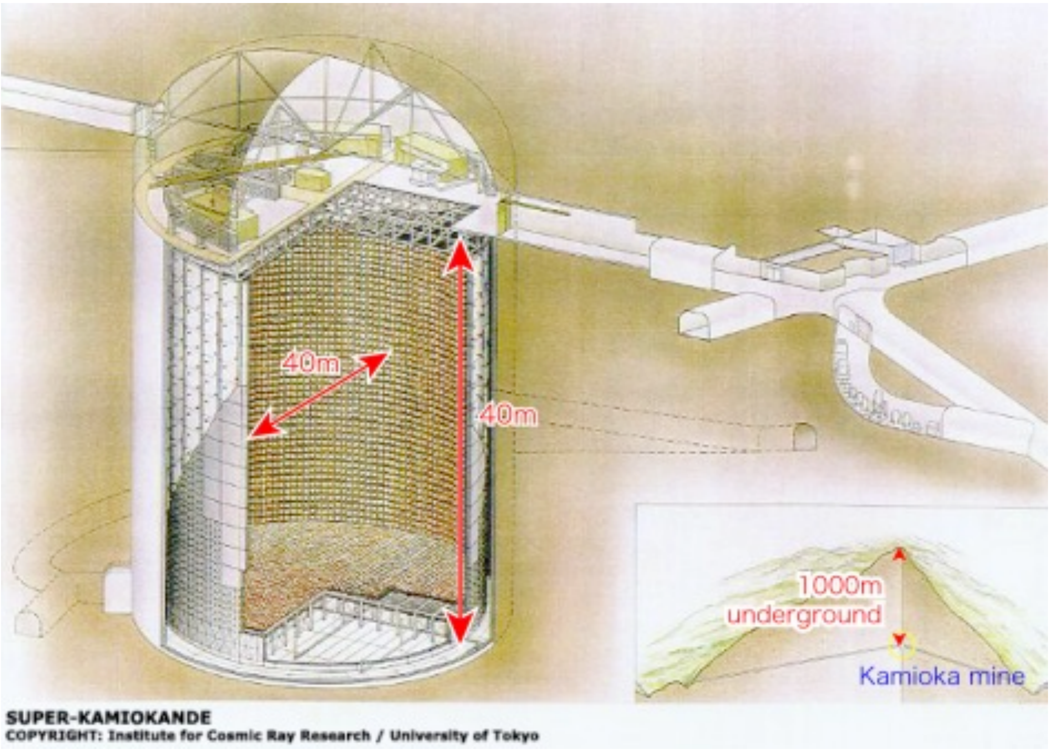






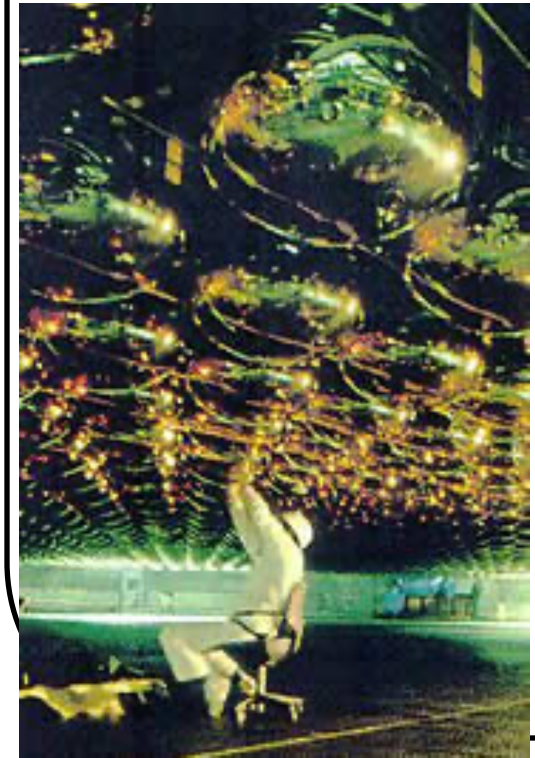
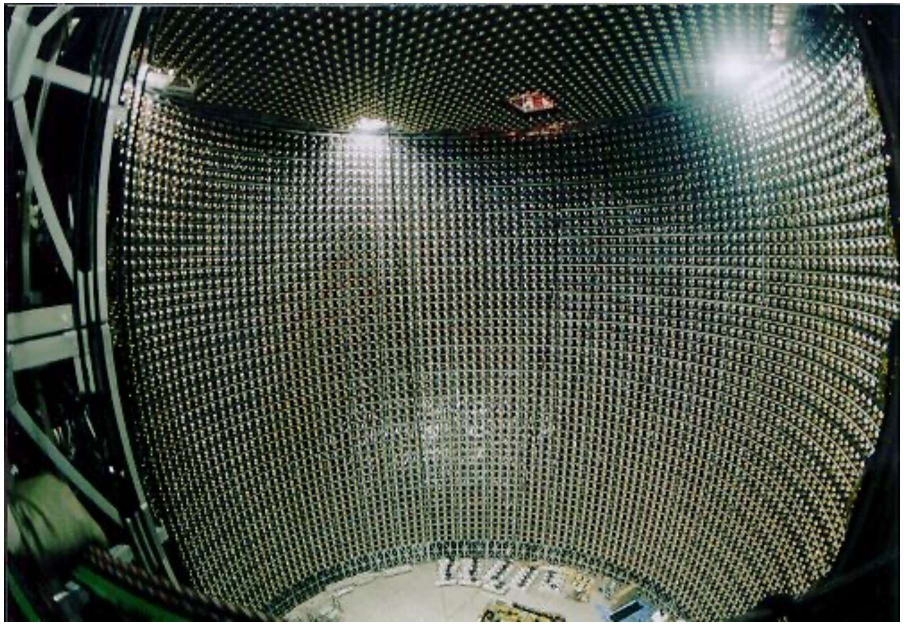
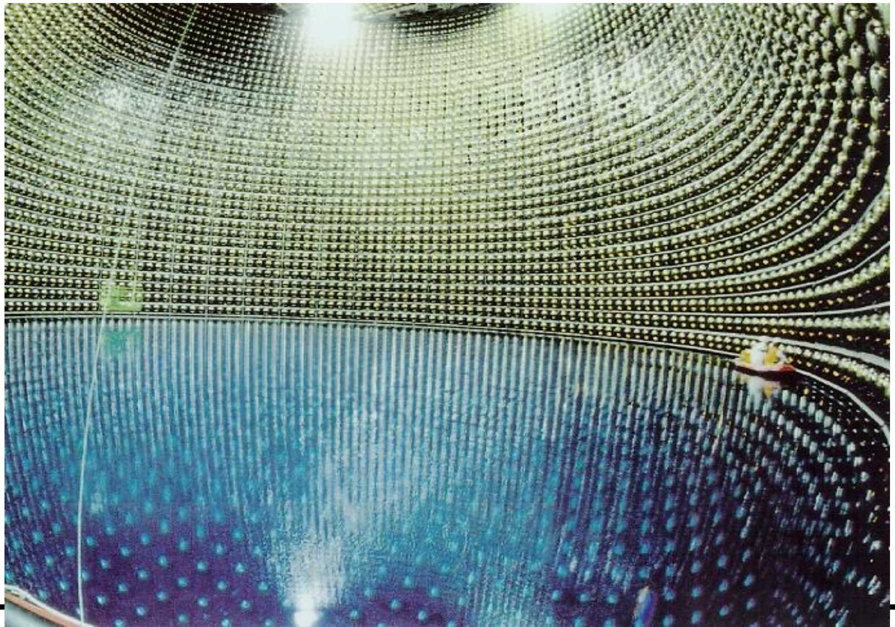
- Most sensitive photodetector

Super Kamiokande

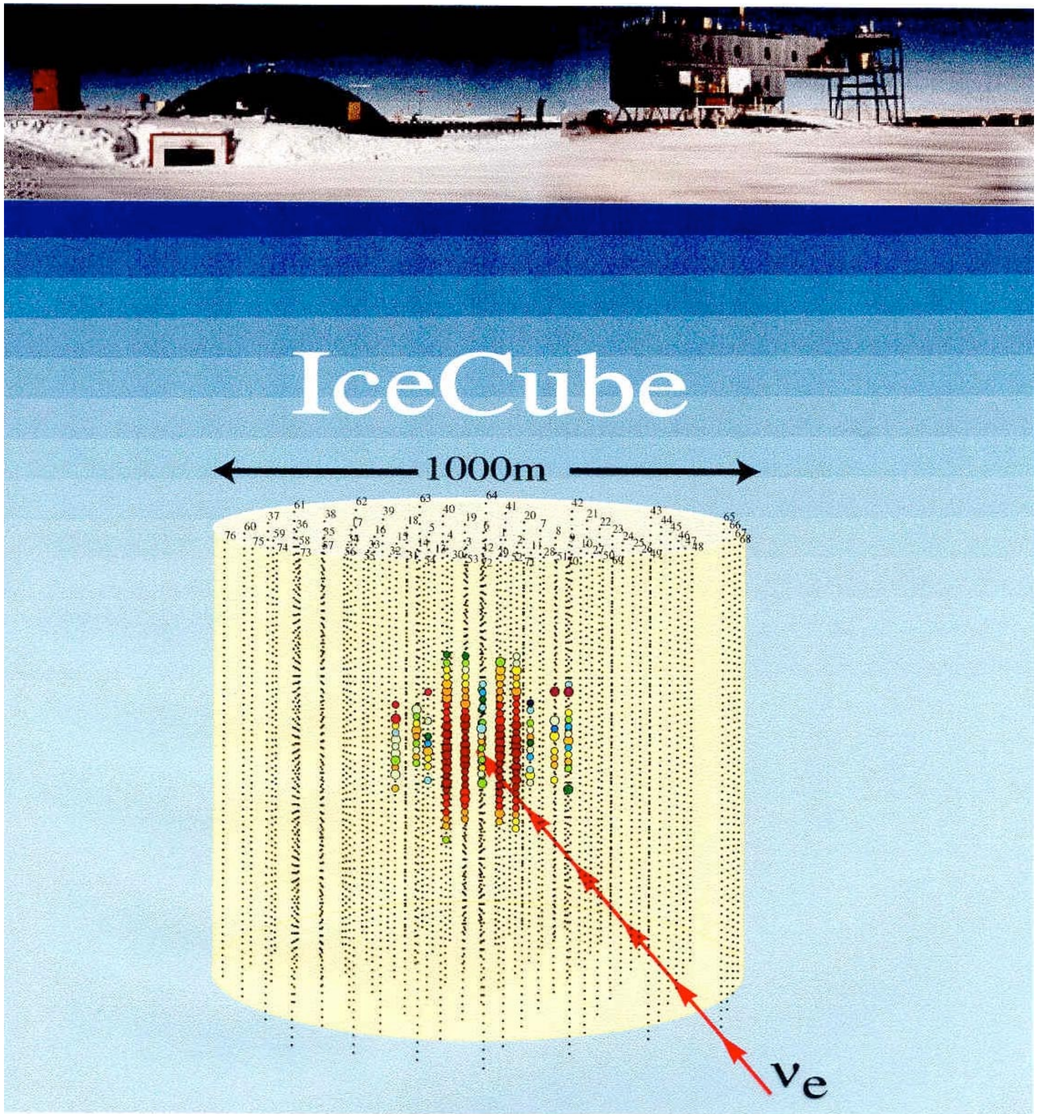


- The Super-Kamiokande Detector, University of Tokyo. The detector consists of an inner volume and an outer volume which contain 32,000 and 18,000 tons of pure water, respectively. The outer volume shields the inner volume in which neutrino interactions are studied. The inner volume is surrounded by 11,000 photomultiplier tubes that detect pale blue Cherenkov light emitted when electrons are struck by neutrinos.

Kamiokande Photos

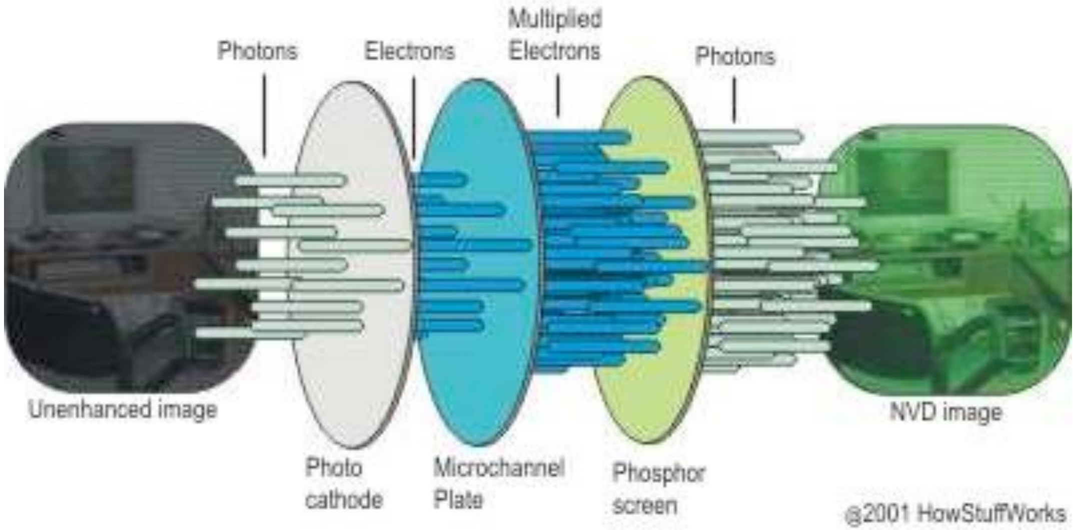





Ice Cube Neutrino Observatory



3600 phototube detectors in strings under Antartic ice up to 1.5 miles deep

IMAGE INTENSIFIER



- Photocathode converts photons to electrons
- These photoelectrons are accelerated quickly through a microchannel plate with circa 1kV across it.
- A phosphor plate converts the photoelectrons back into light
- Cascaded geometries, autogated beam optics, etc. have been implemented

Use a Lens to increase sensitivity

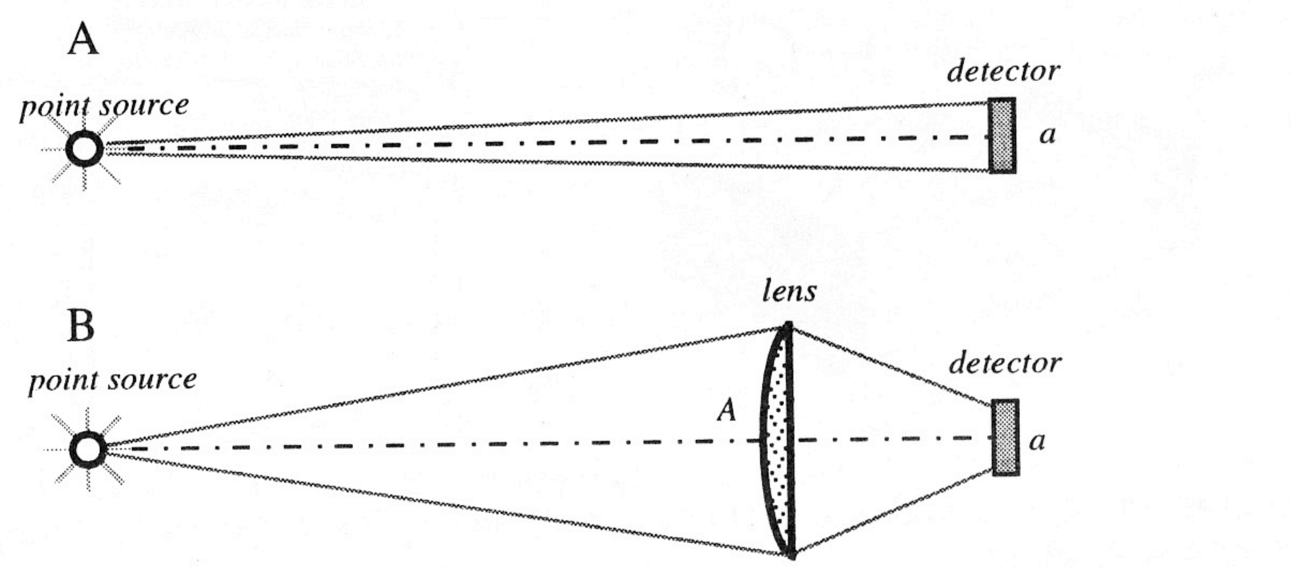
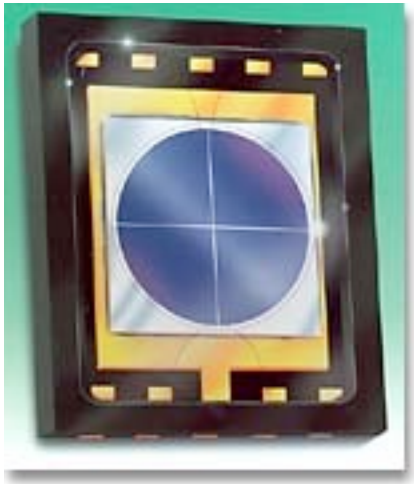
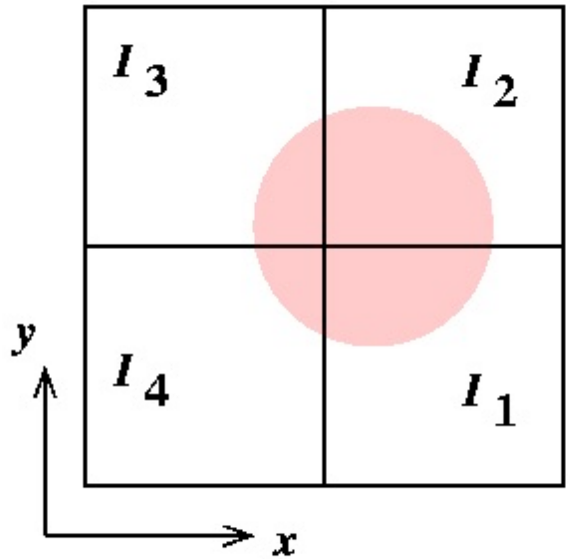


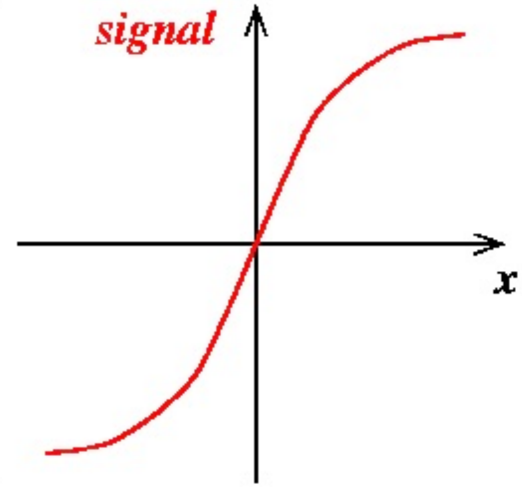
FIGURE 13.13. Efficiency of a detector depends on its surface area *a* (A) or the area of the focusing system (B).

- Lens collects light over increased area
- Effective gain at optical wavelengths is roughly k = 0.92 (A/a)
  - A is area of lens, a is area of detector

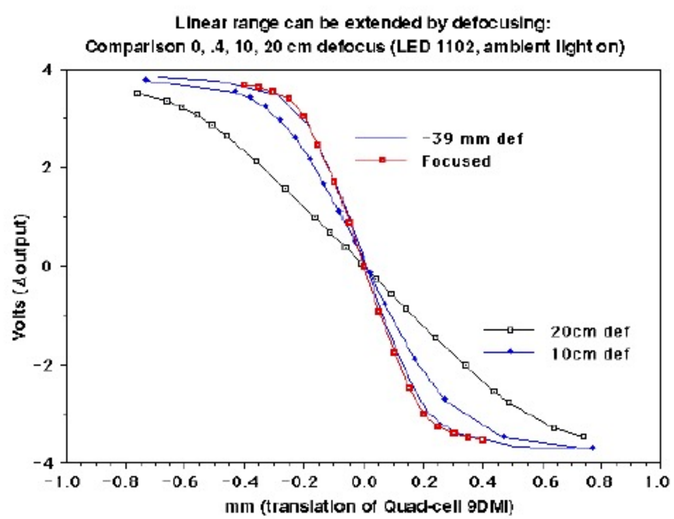
Dual and Quad Cell Arrays







- Difference over sum gives position
- Limited dynamic range
  - Need to see signal on all of the cells
- Defocus can increase range by making spot bigger
  - With less resolution…



Lateral Effect Photodiodes

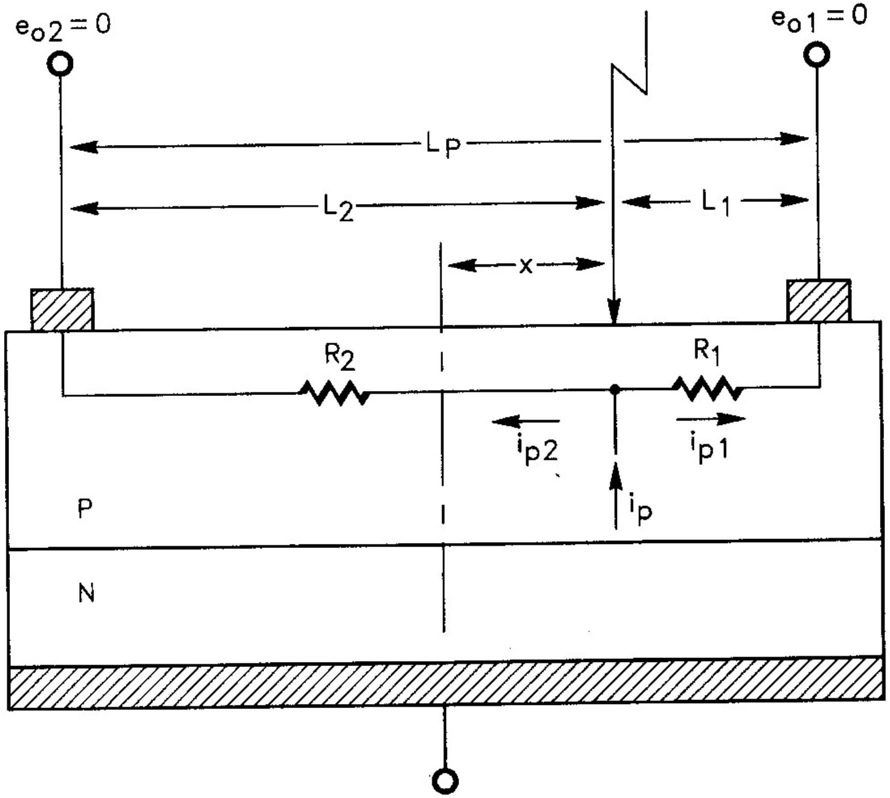


Figure 1.8 With the lateral photodiode, internal resistance forms a current divider that separates i_p into two components whose magnitudes reflect the position of an incident light beam.

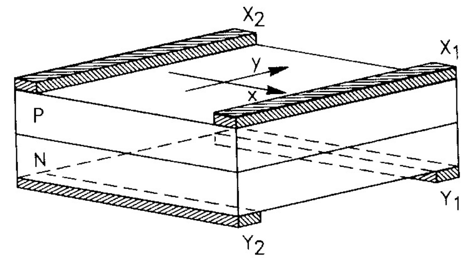


Figure 1.10 A duo-lateral photodiode makes both diode surfaces perform lateral current division with two electrode pairs placed for X and Y position indications.

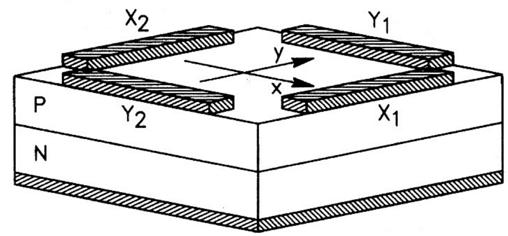
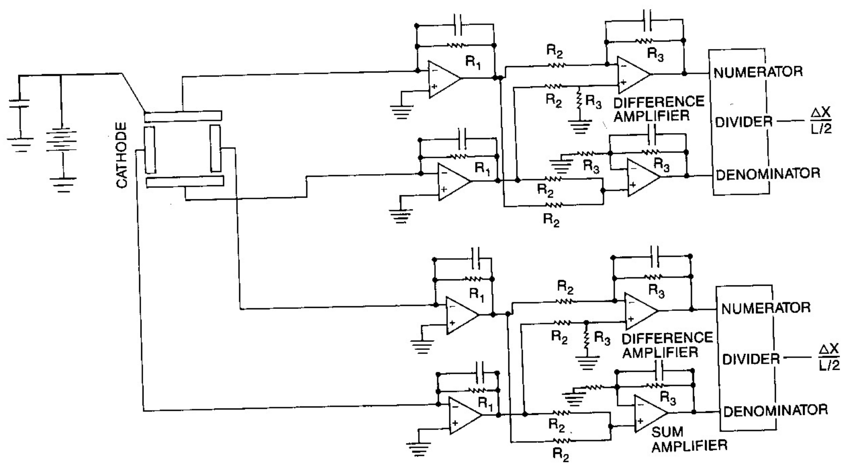


Figure 1.12 A tetra-lateral photodiode places two electrode pairs on the top surface for two-dimensional position sensing without the need for segmented bottom contacts.

CIRCUIT FOR SC SERIES POSITION SENSORS



Also called "photopots" - photoelectrons create current that divides in proportion to position

- Made by UDT, Hammamatsu, etc.
- Somewhat expensive...

CMOS and CCD Imagers

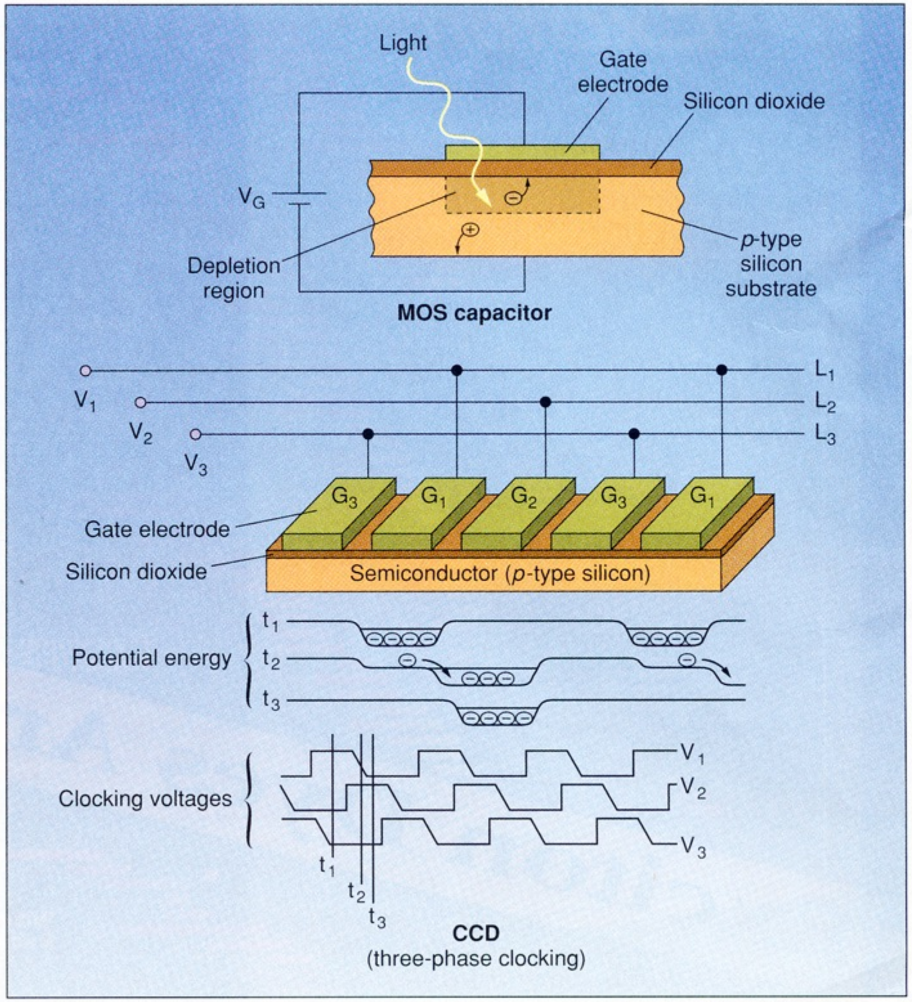
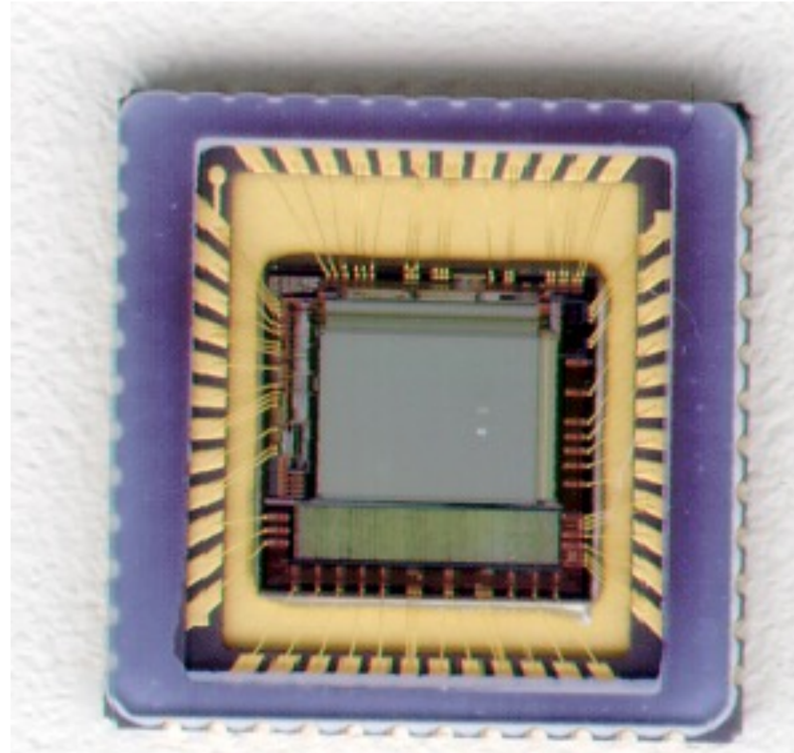


FIGURE 4. Light absorbed by the substrate of a *p*-type metal-oxide-silicon (MOS) capacitor (top) creates mobile electrons that become trapped in the depletion region under the gate. Three-phase CCDs (bottom) use a carefully timed sequence of three gate voltages to move accumulated electrons across an array of MOS capacitors. Note the potential energies and voltages at times t_1, t_2, and t_3. Gates G_1, G_2, and G_3 define a single point.



VVL (Edinburg pioneers in CMOS cameras)

Photocurrent integrated, then put into transfer register

CMOS Imager - Image charge transferred to transport bucket-brigade register

CCD Imager - Charge moved across continuous substrate

CID array - wire on each photodiode attached to big multiplexer

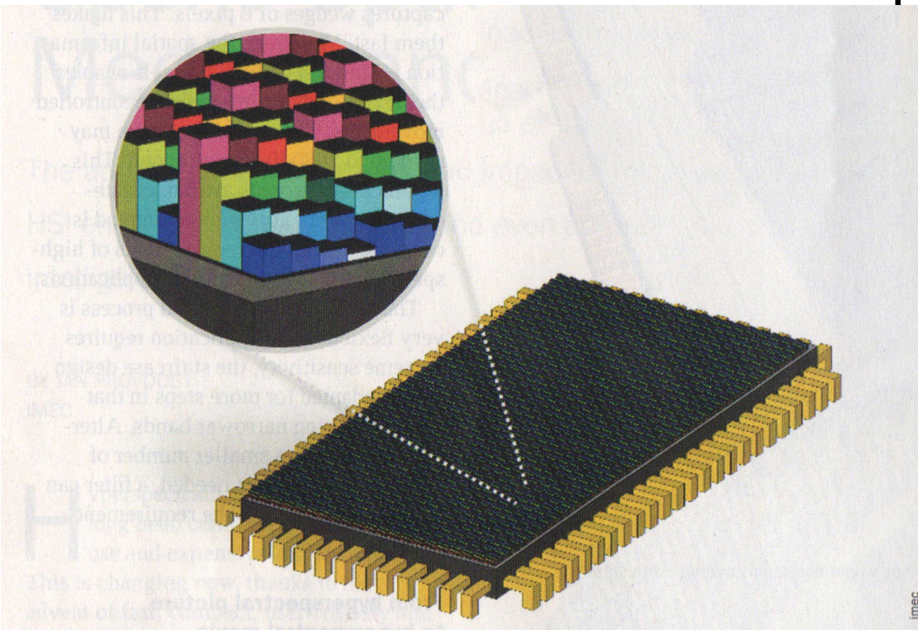
Cameras on a Chip

Tend to be used with digital image processing chip
- See Mat Laibowitz's work with TI digital image processor

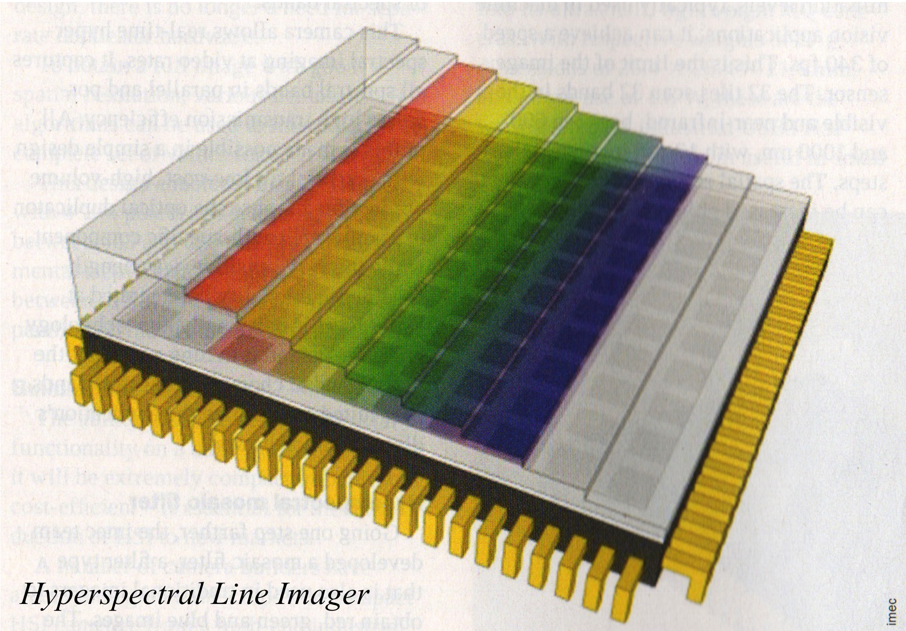
- In tiny packages with embedded lenses (and even zoom), typical HDresolution for cellphone cameras
  - Many makers (ALPS, ST, etc.)
- Different kinds of imagers
  - CID's, CCD's, photodiode arrays
    - Line arrays, matrices, etc.
  - Embedded ADC
    - Analog storage, not digital!
    - Beware of dark signal in late pixels for slow readout.

Hyperspectral Imagers

From left to right: an HSI chip with 32 filter tiles, an optical duplicator and an HSI camera with integrated tile-chip and duplicator.



An HSI chip with per-pixel filters forming a 4 × 4 pixel mosaic.



Hyperspectral Line Imager

A postprocessed Fabry-Perot staircase (not to scale) enables whole-spectrum coverage with small adjacent bands.

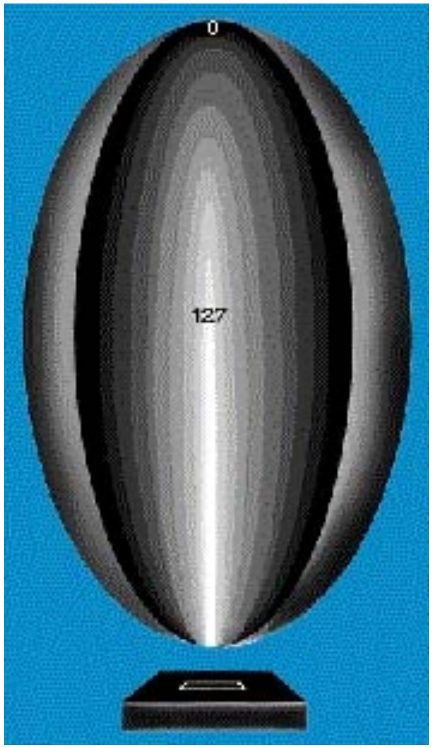
This ultracompact HSI camera from Ximea is designed for industrial uses including UAVs and drones.

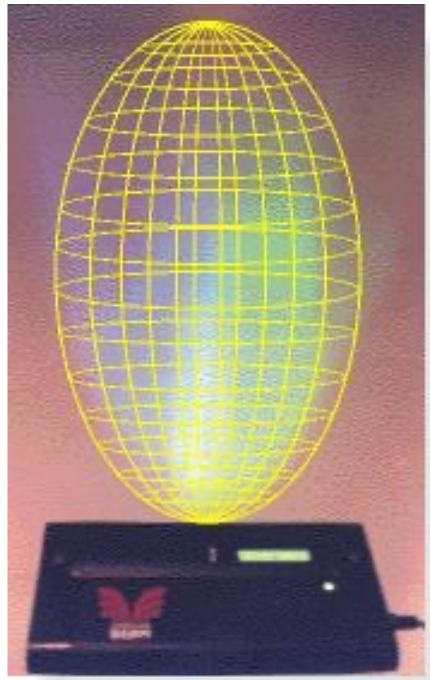
Photonics Spectra Magazine, April 2015
(by Jan Provoost, IMEC)

Applications

- Focal Plane Apps
  - Computer Vision, Range by Defocus, etc.
- Occultation - Interruptor (light curtain)
- Range by intensity of reflection (Dimension Beam)
  - Easily fooled by albedo variation
- Range by triangulation
- Range by phase slip of CW modulated beam
- Range by TOF pulse
- Range by Interferometry

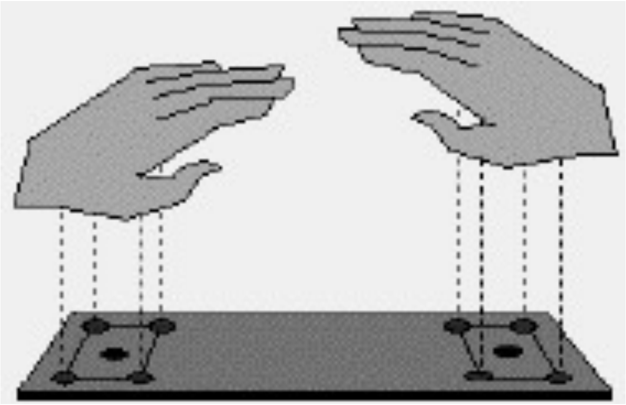
Optical Theremins – the Dimension Beam





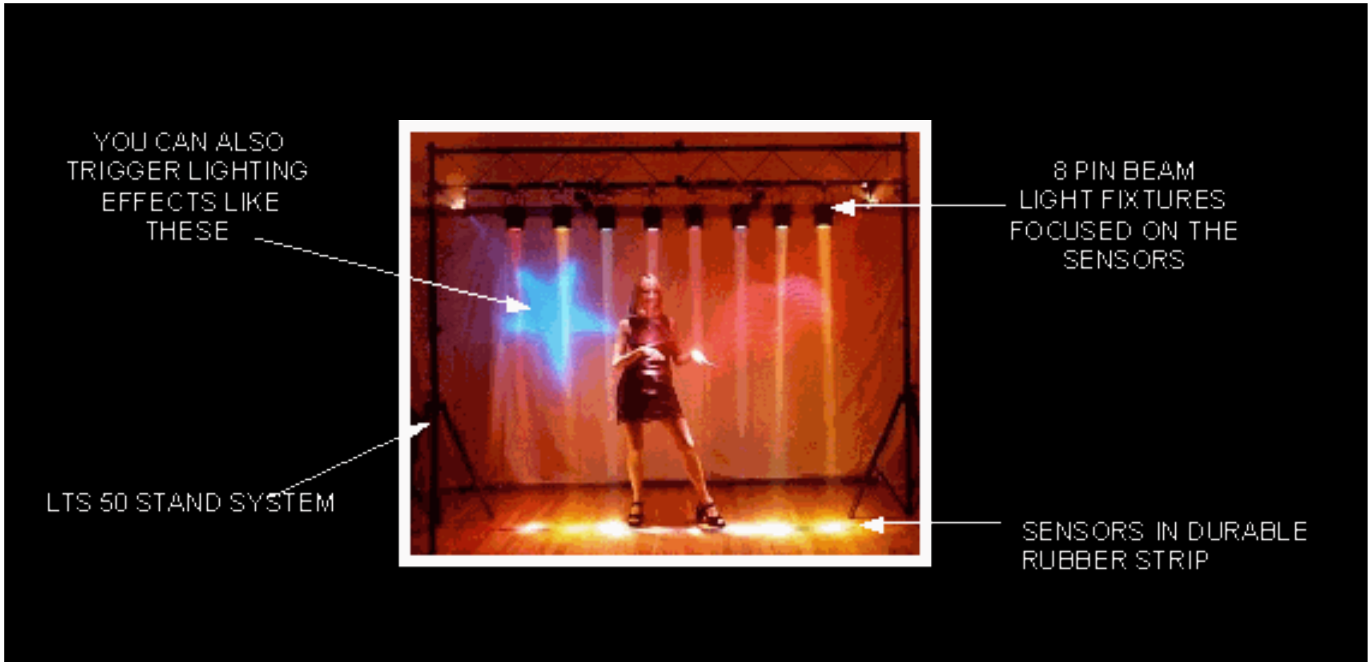
- Infers distance from intensity of simple IR reflection
- One dimensional
- Intrinsically more directional than capacitive methods

IR Theremins – Taraballa's Palm Driver



- Leonello Taraballa (runs CNUCE @ Pisa)
- 1 IR source below each hand
- 4 IR receivers there
  - Get idea of distance and 2D inclination

Optical Interrupters

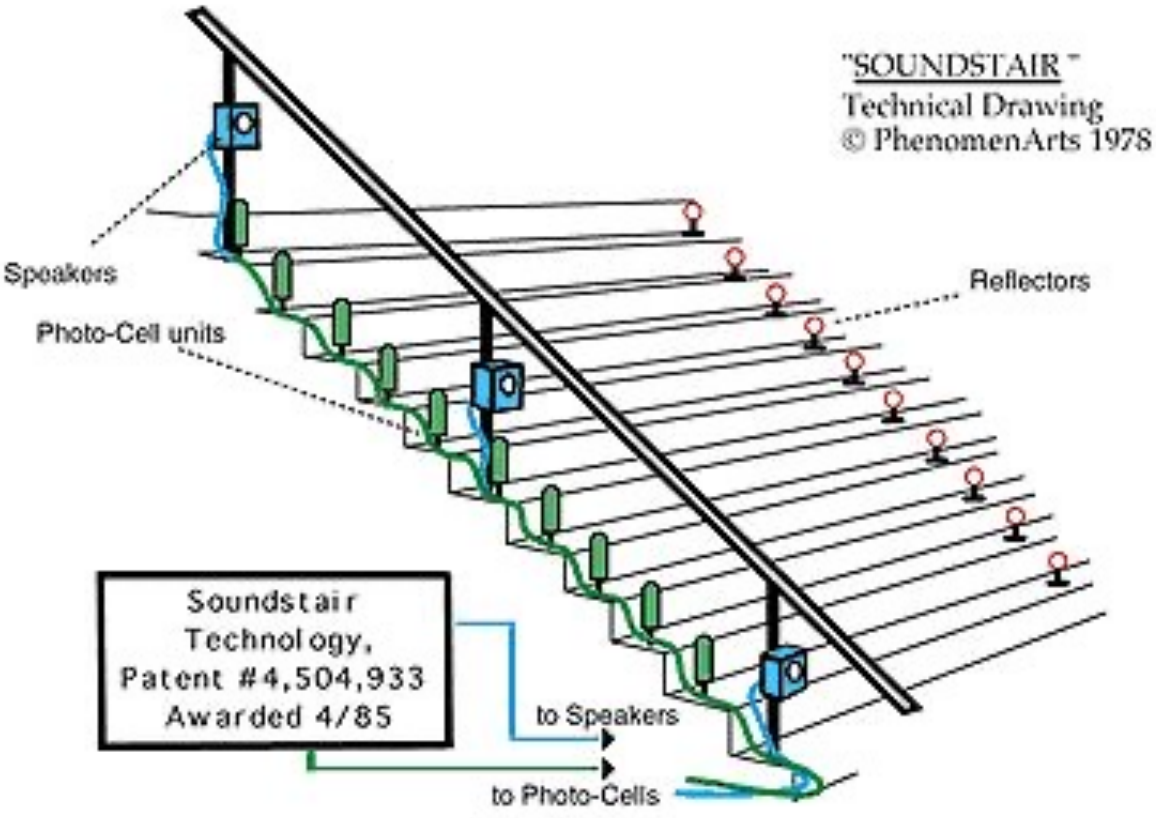


Synthabeams

- Interrupt beam of light to photosensor
- Simple trigger…

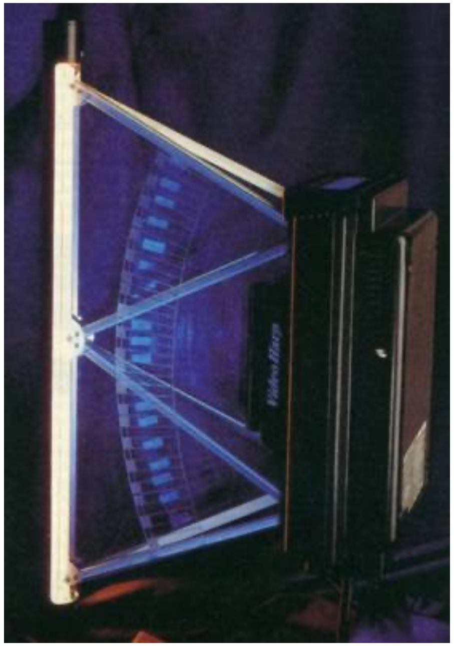
OptiMusic

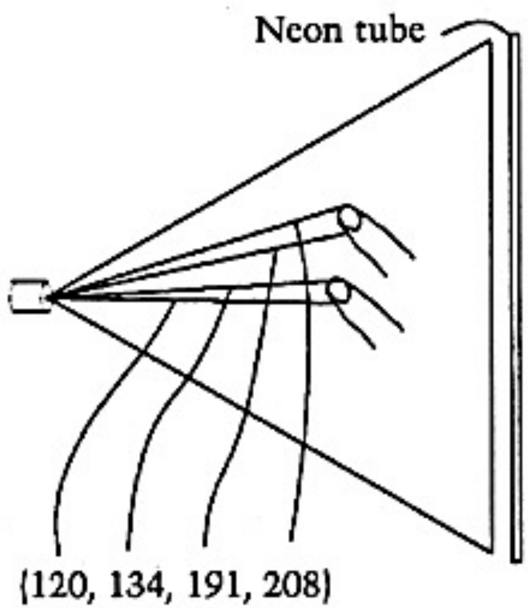
Chris Janney's Soundstair, 1977

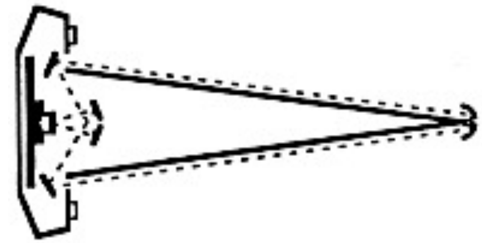


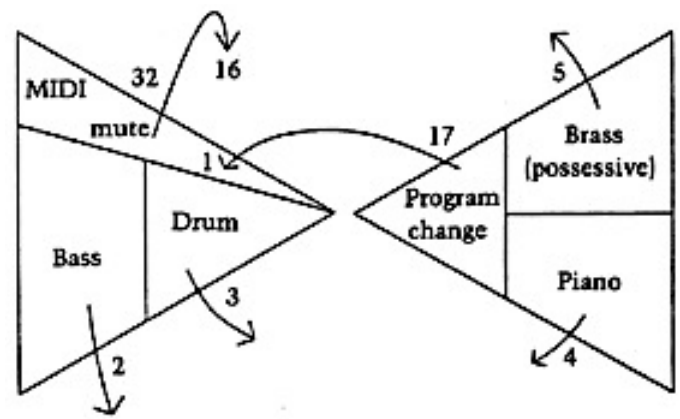
- Interruptor with optical path folded

Rubine and McAvinney (CMU) 1990



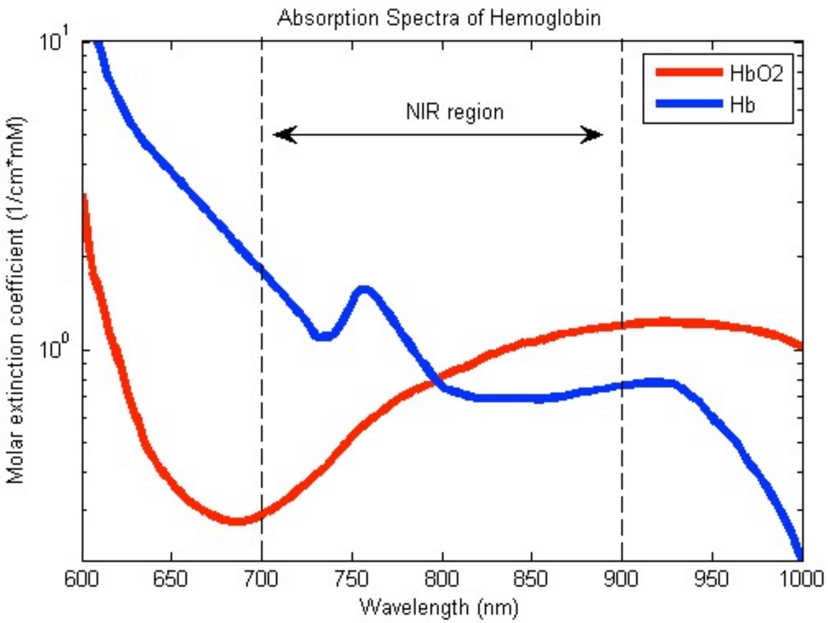






- The VideoHarp
- Handheld
- Images shadows of both fingers
- Made by the “Sensor Frame Corp.”, 1991

Pulse Oximetry (reflective sensing through the skin)



From Wikipedia

Sense at 660 and 940 nm

Description

The AFE4490 is a fully-integrated analog front-end (AFE) that is ideally suited for pulse-oximeter applications. The device consists of a low-noise receiver channel with a 22-bit analog-to-digital converter (ADC), an LED transmit section, and diagnostics for sensor and LED fault detection. The device is a very configurable timing controller. This flexibility enables the user to have complete control of the device timing

TI Home > Semiconductors > Data Converters > Analog Front End (AFE) > Medical Analog Front End >

AFE4490 (ACTIVE) 2 reviews

Integrated Analog Front End for Pulse Oximeters

AFE4490 Integrated Analog Front-End for Pulse Oximeters (Rev. H)

Triangulation

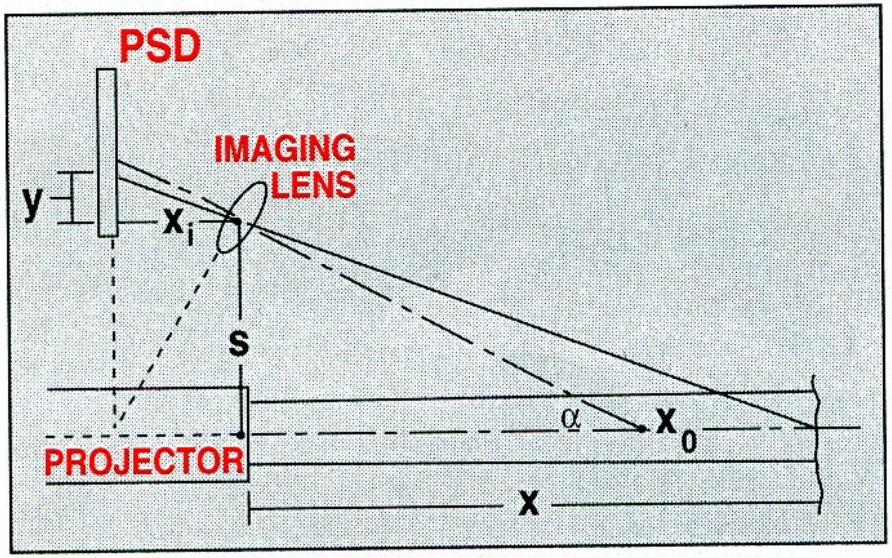


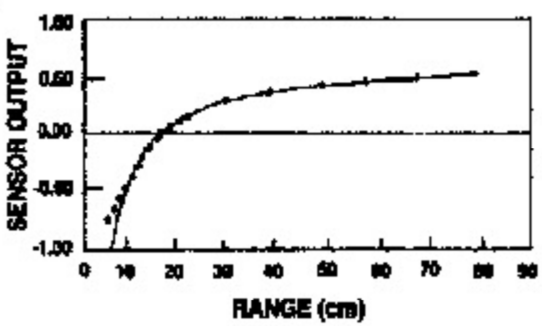
Figure 1. *An active triangulation sensor measures the distance to a reflecting surface along a projected IR beam by imaging the illuminated area on a position-sensing detector (PSD). The dimension labeled y indicates the position of the focused spot and is inversely proportional to the object distance, x.*

$$y = \frac{s x_i}{x}$$

where:

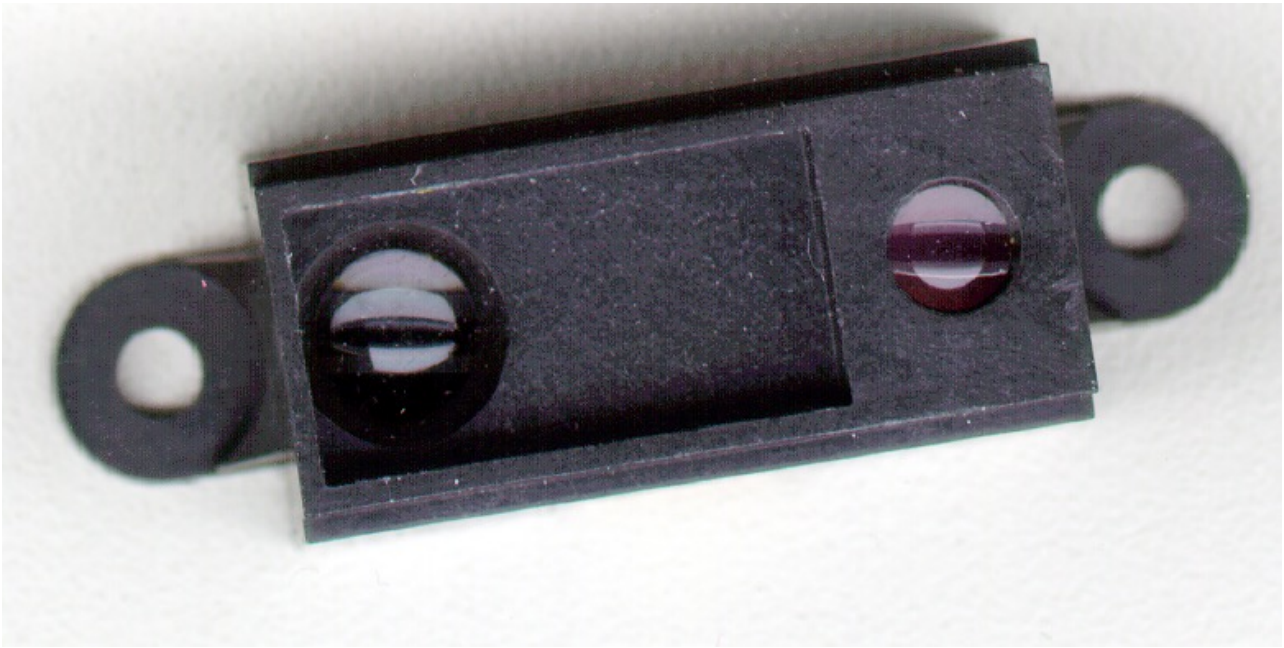
- x = the distance to the object
- s = the triangle base
- x_i = the image distance behind the principal point

- $y = s\, x_i/x = f \sin(\alpha)/x$
  - y is imager coordinate (e.g., readout displacement)
  - f is focal length of the lens
  - x is range of the object
- Asymptotic - tuned for short ranges



- Use synchronous demodulation, lateral effect photodiode

Commercial Devices

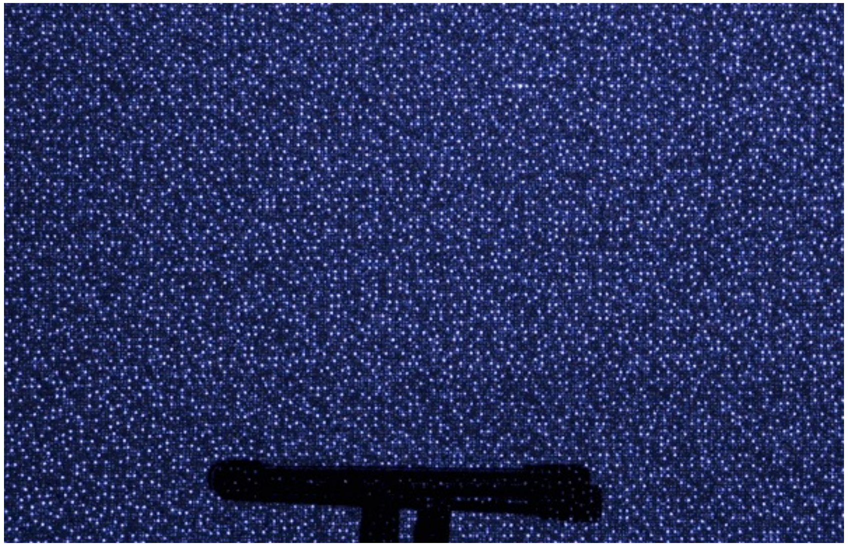


- Sharp rangefinder modules - used for toilet flushers, etc.
- Direct digital output of range
- Models optimized to different ranges
  - (e.g., Sharp GP2D12 – 0-80 cm, GP2Y0A2YK – 20-150 cm)

Canesta Virtual Keyboard

- Laser-projected keyboard, and triangulation ranging to fingers

Microsoft Kinect Cameras



http://www.futurepicture.org/?p=116

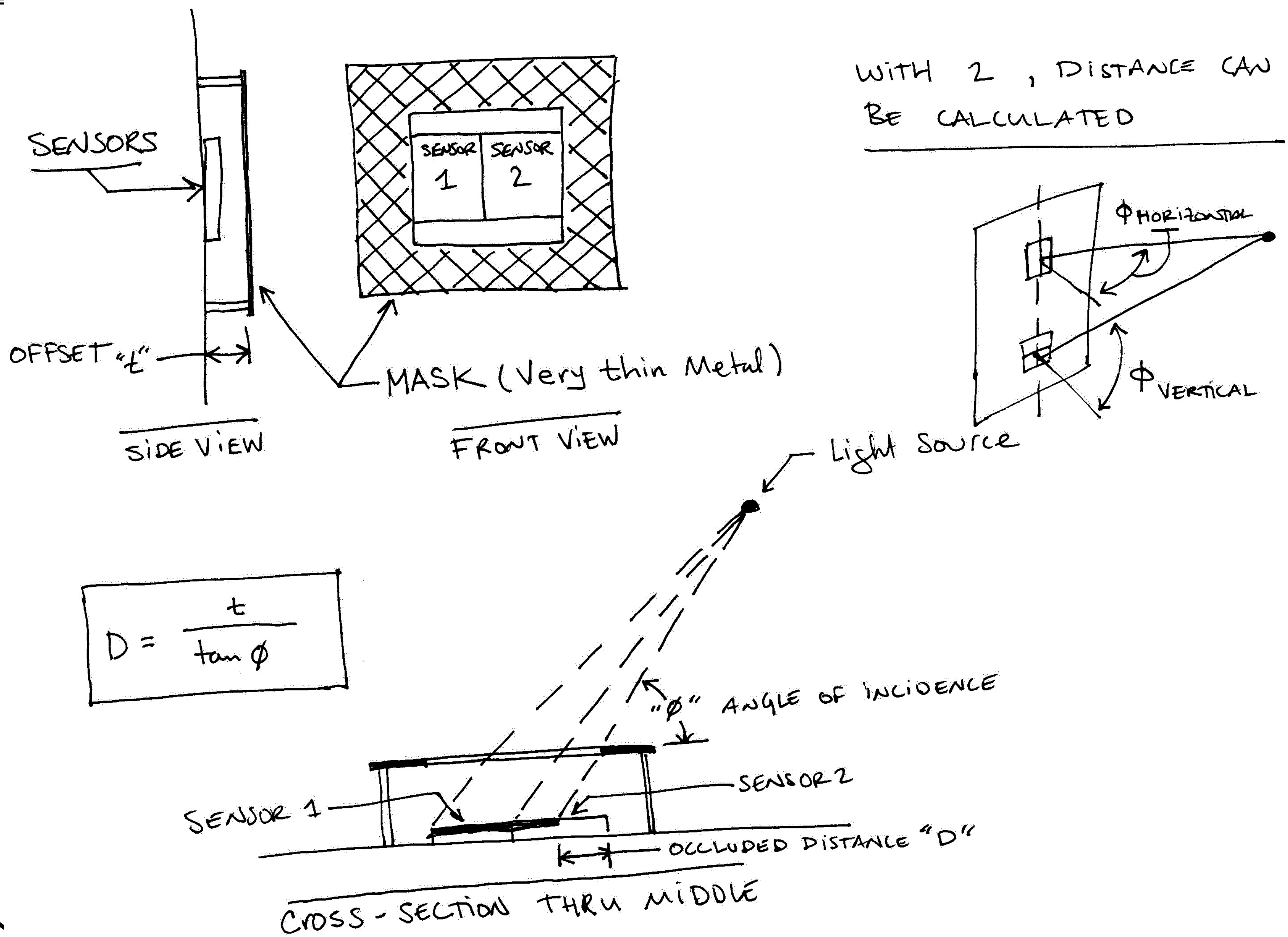
- 3D image from dot pattern structured light
- Holographic projector generates unique dot pattern
- Embedded processor looks for deviations of dots from predicted location

Stereo Cameras

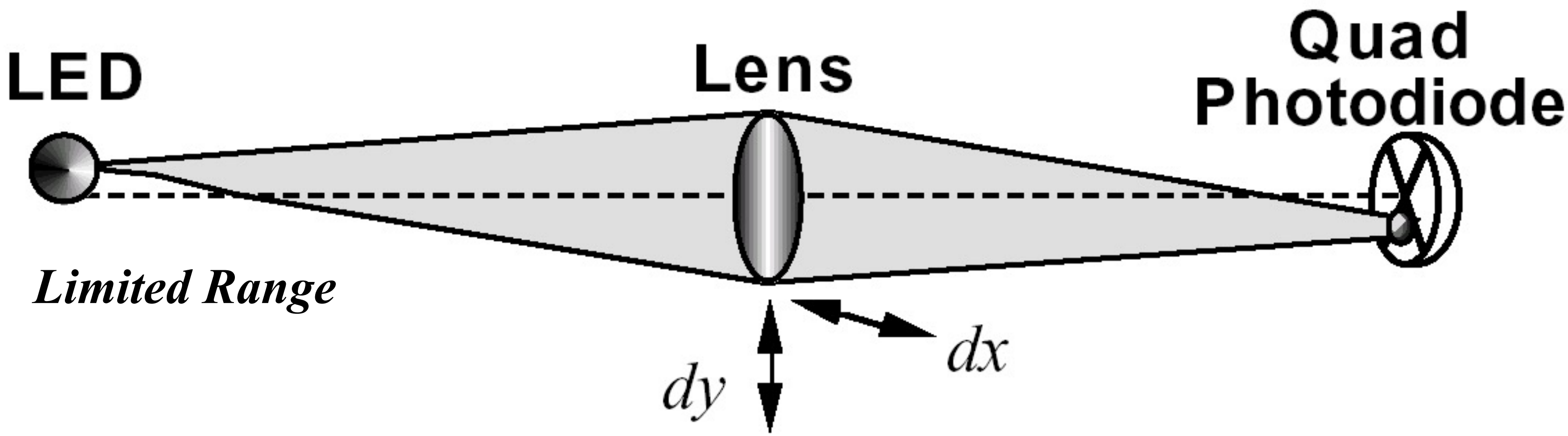
For example, the Leap Motion Controller

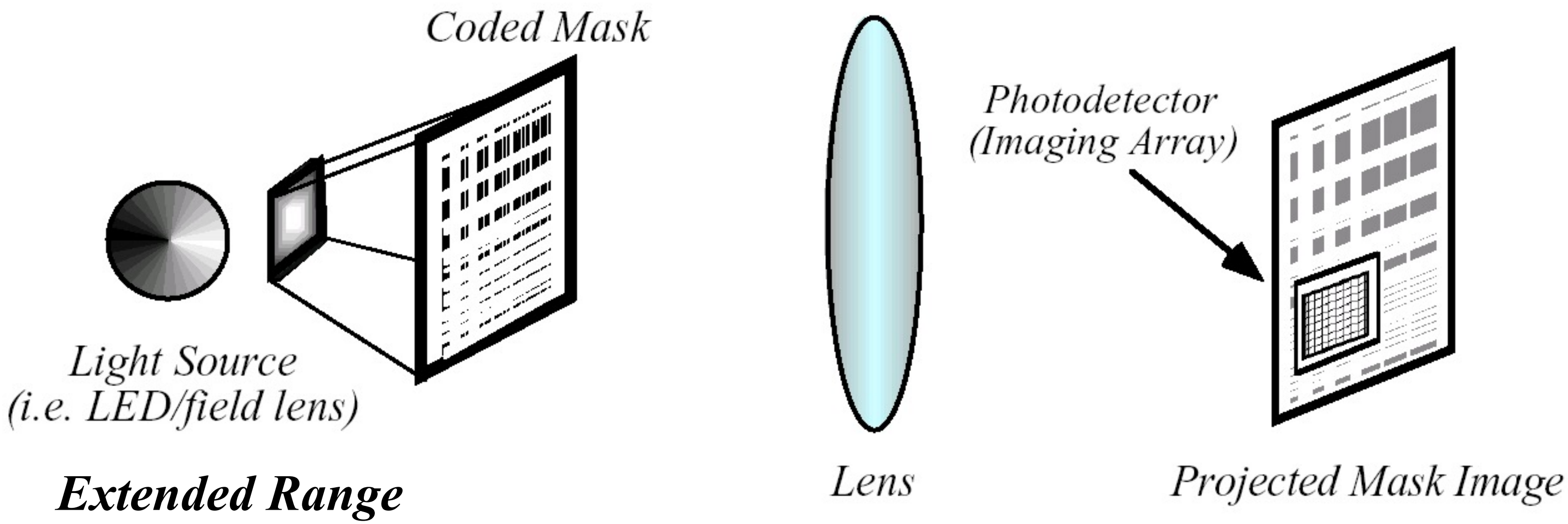
- Depth Perception by correlated images
  - Like evolution provided for us

Range by Occlusion

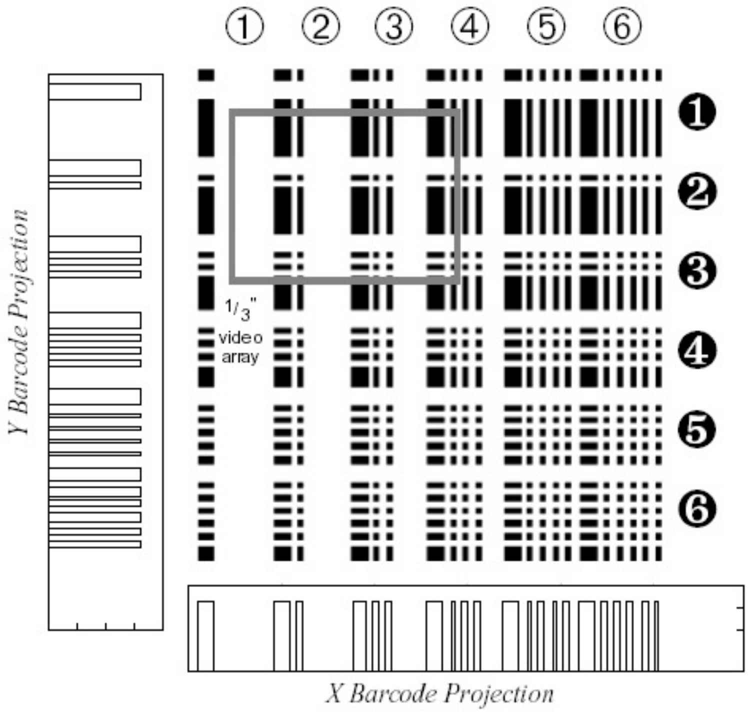


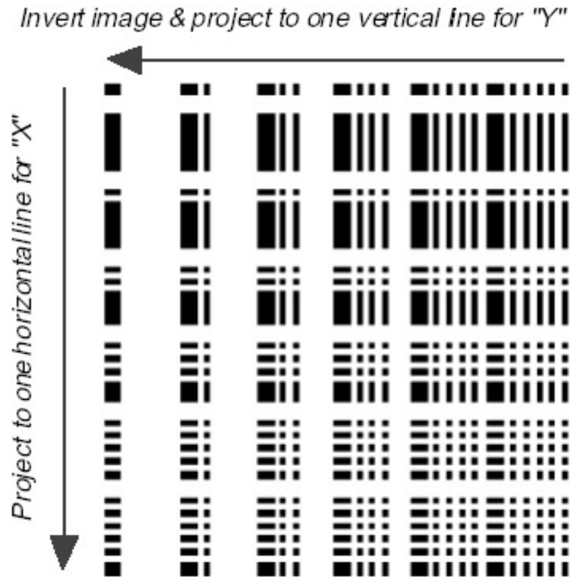
Straightness Monitors





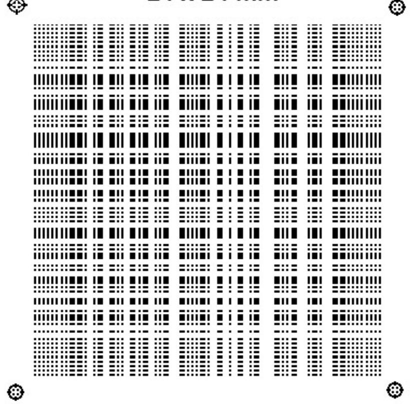
2D Coincident Barcode

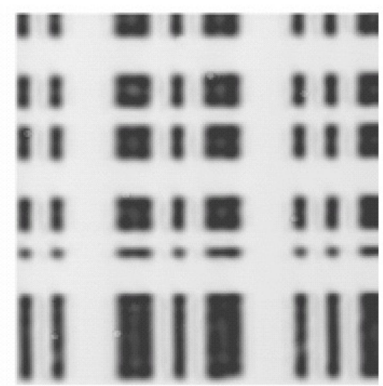




12 x 12 mm

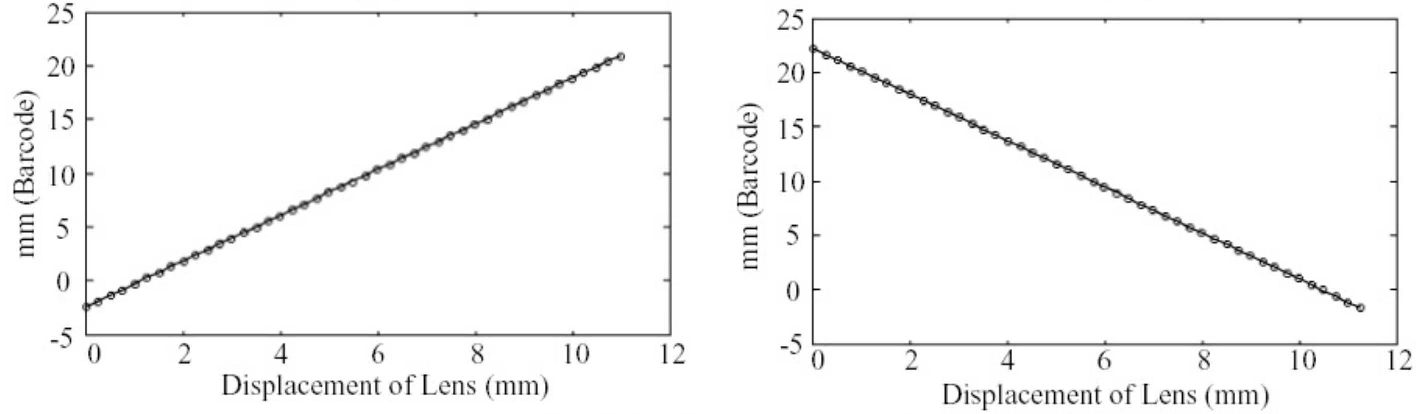
24 x 24 mm



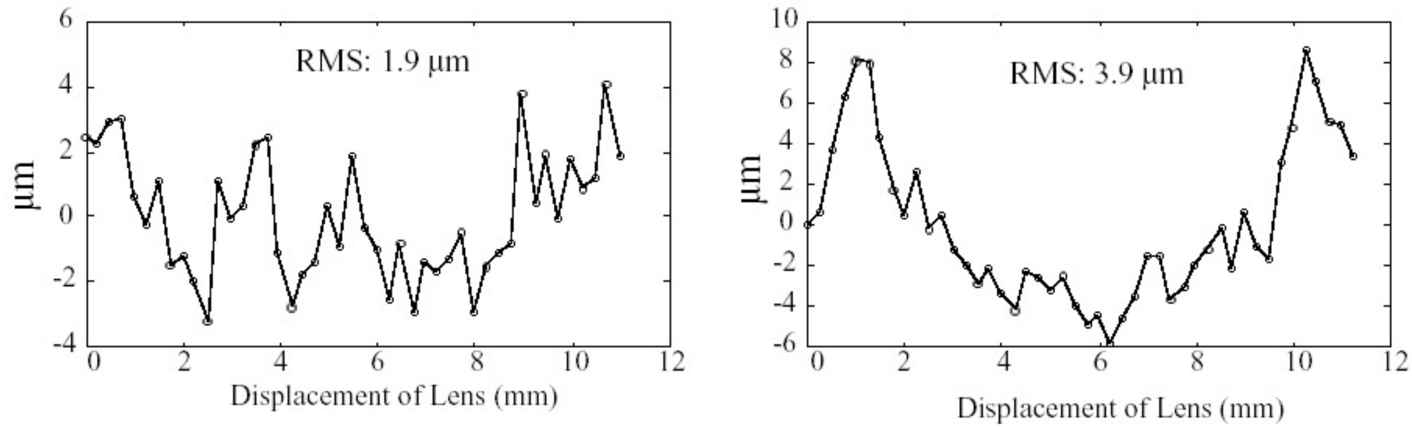


Micron-Level Resoultion Across Meters

Vertical (Y) Scan | **Horizontal (X) Scan**



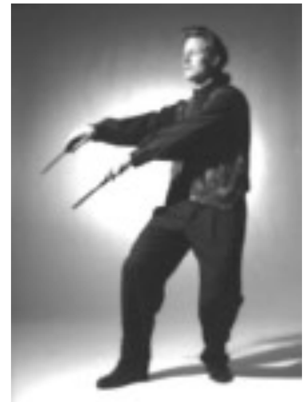
Position Measurements



Straight-Line Residual

9-meter optical path

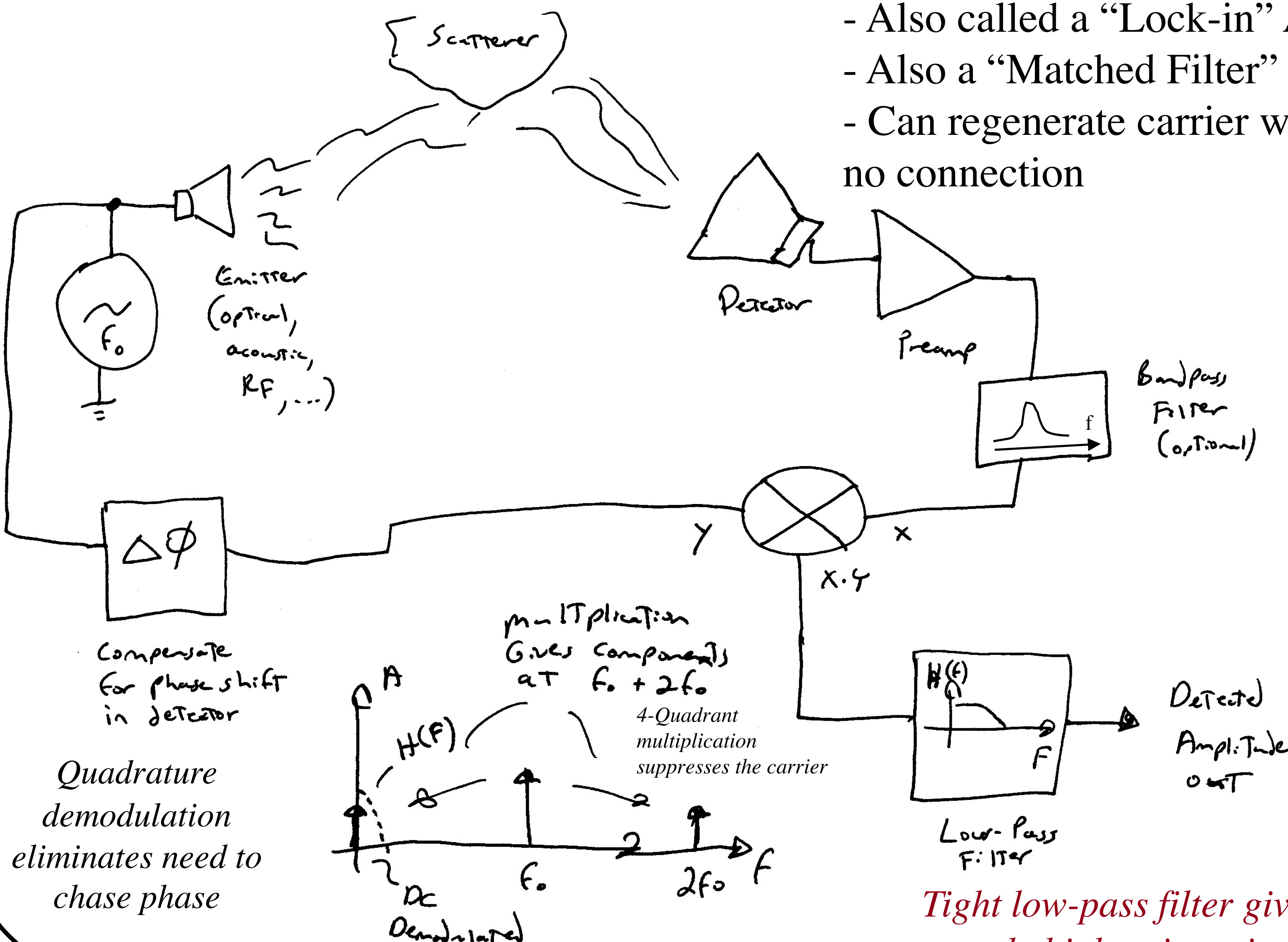
The Buchla Lightning



- Most ubiquitous baton controller
  - Designed by Don Buchla, 1991 (I) and 1996 (II)
  - $2K each
- A pushbutton on each wand, continuously tracked in x,y across range of several meters
- 1 AA battery lasts about 60 hours
- IR tracking
  - Photodiode array receives signal
- Intrinsic mappings in electronics unit

Synchronous Detection

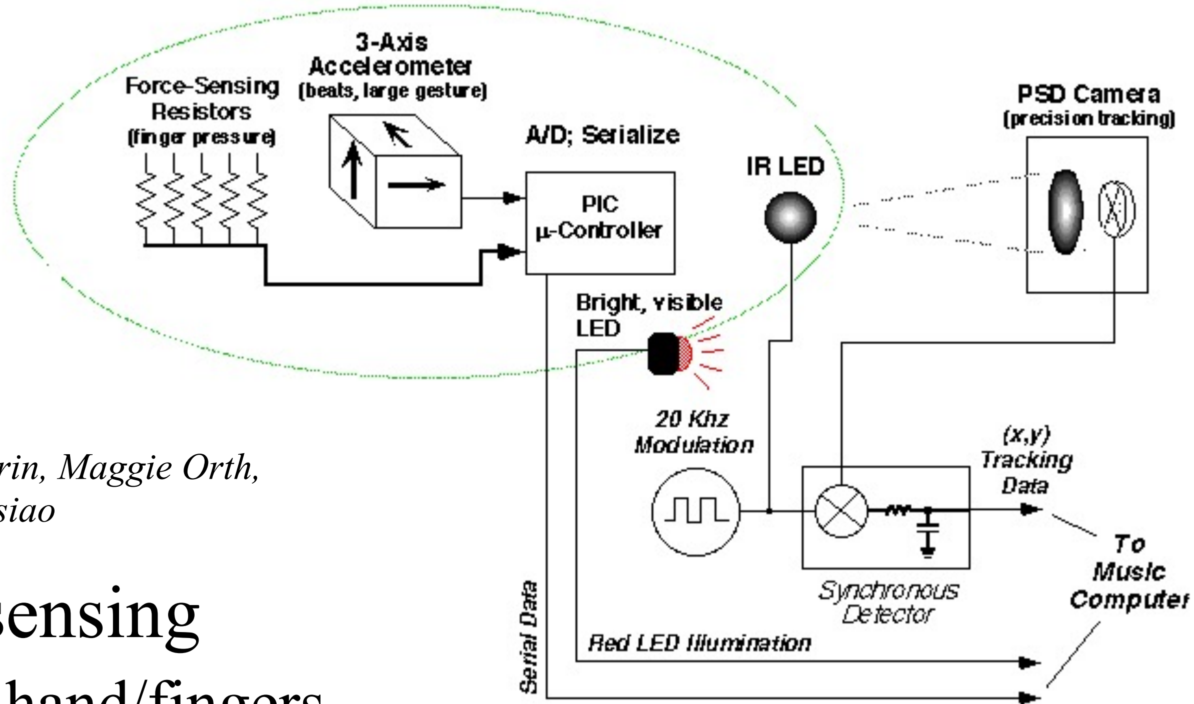
- Also called a "Lock-in" Amplifier
- Also a "Matched Filter" of sorts
- Can regenerate carrier with PLL if no connection



Quadrature demodulation eliminates need to chase phase

Tight low-pass filter gives extremely high noise rejection!

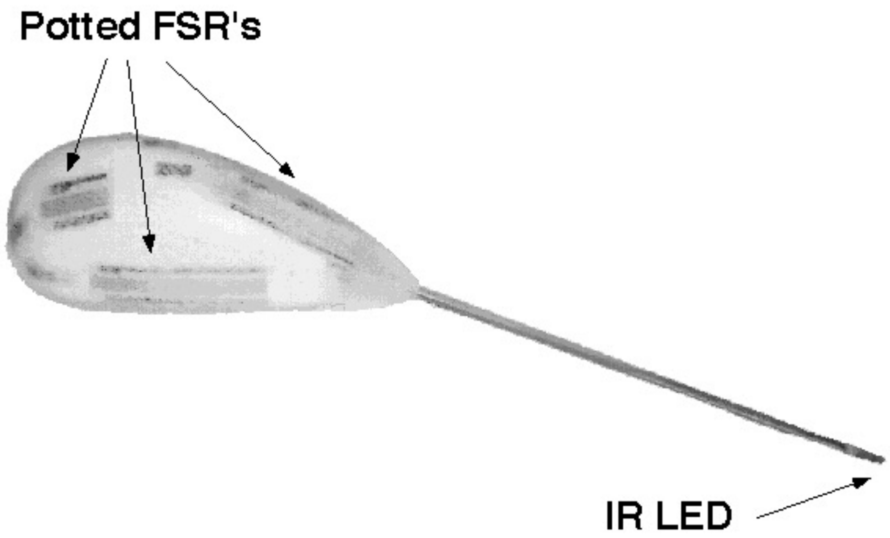
The "Digital Baton" System



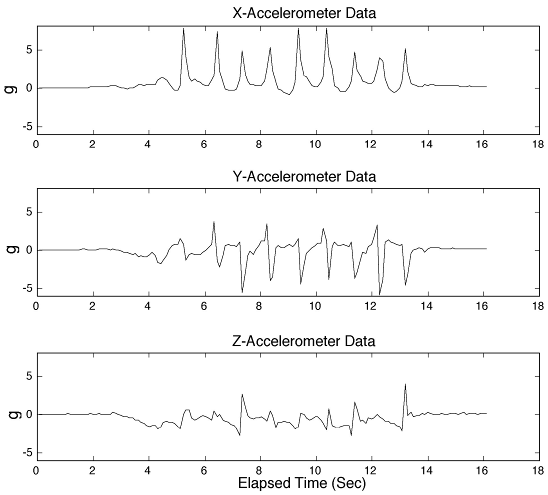
Joe Paradiso, Theresa Marrin, Maggie Orth,
Chris Verplatse, Kai-Yuh Hsiao

- Multimodal sensing
  - 5 FSR's for hand/fingers
    - Thumb, index finger, middle finger, last 2 fingers, palm
  - 3-axis accelerometers (ADXL05) for beats, large gesture
  - 2-axis Optical tracking of baton tip position
    - Synchronous PSD camera sees only tip LED
      - Fast tracking, insensitive to any background light

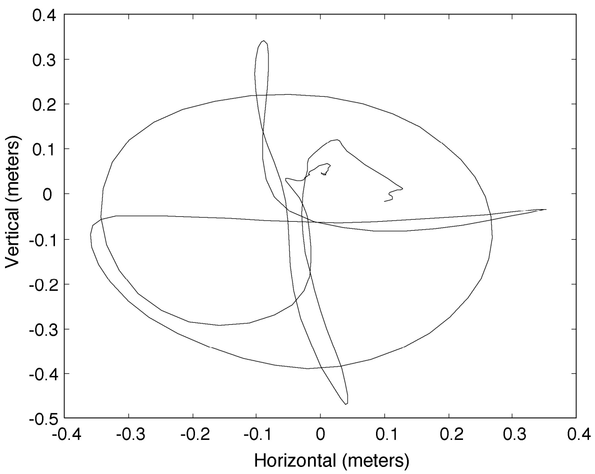
The Physical Baton



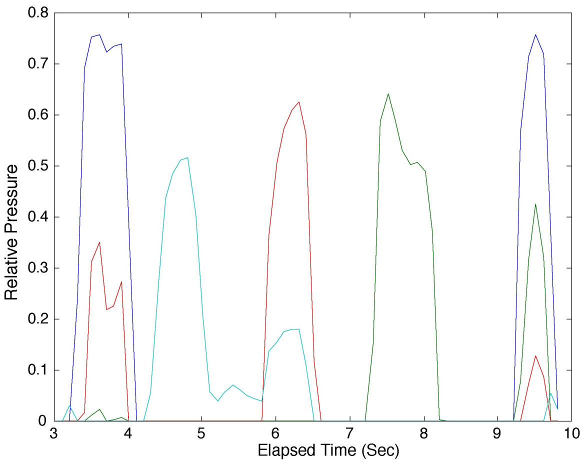
Accelerometers



IR Tracker



Finger Pressure



The Baton in Performance

Hundreds of baton performances worldwide in the *Brain Opera*

New York	Austria	Copenhagen	Tokyo	Florida	Lisbon
Lincoln Center	*Ars Electronica*	*Electronic Cafe*	*Yebisu Gardens*	*Kravis Center*	*Festival Acarte*

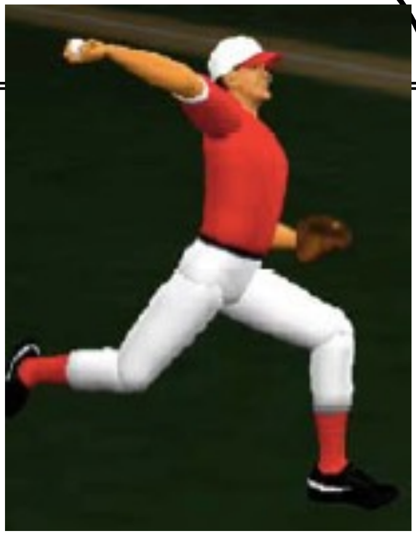
http://brainop.media.mit.edu

Nintendo Wii Batons

Wii & Nunchuck

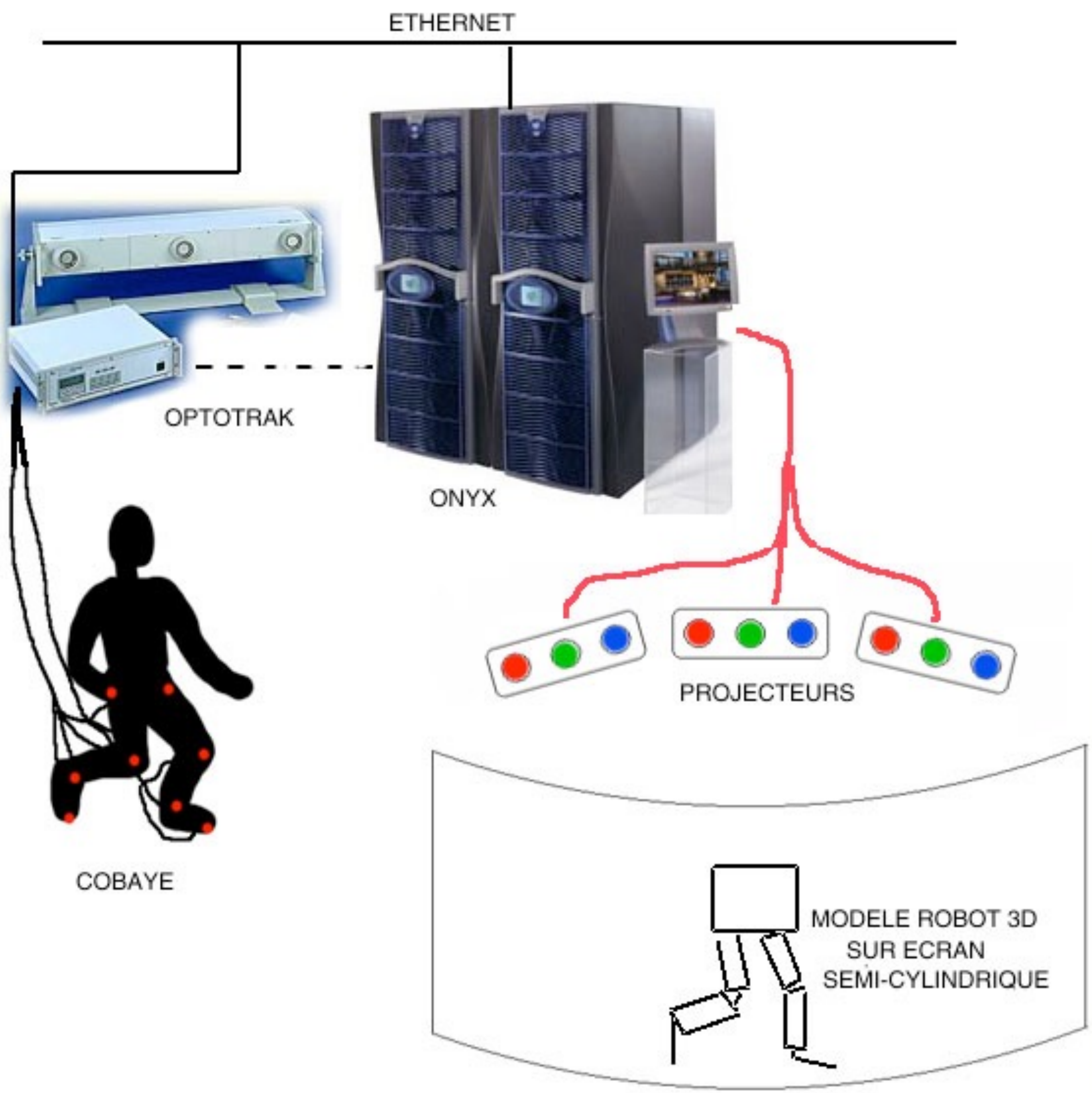
- 3-Axis accelerometer, IR pointer, buttons, expansion
  - Like our baton, but optical part is reversed (camera on Wii)
  - An explosion of musical apps
    - http://www.nintendogal.com/video-28-New-Ultimate-Band-Trailer.html
    - Kyma interface (and many many others)
  - See also famous Johnny Lee Wii "hacking" videos
    - http://www.cs.cmu.edu/~johnny/projects/wii/
    - IEEE Pervasive Computing Summer 2008 article
    - Not musical, but informative

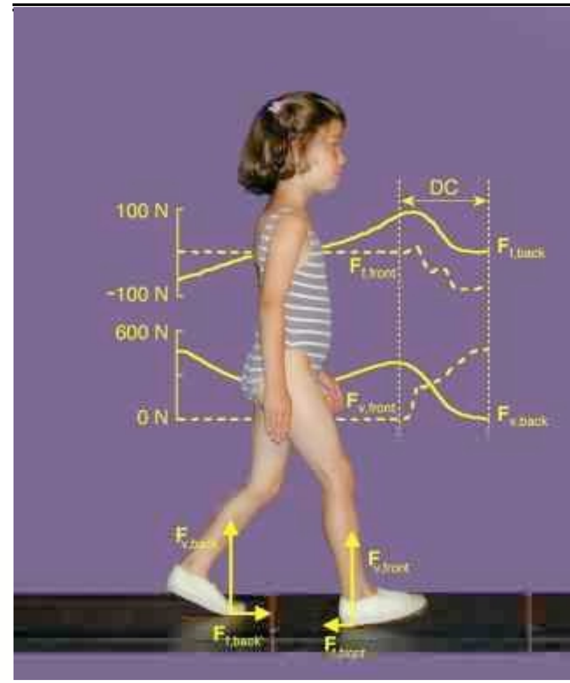
IR Optical Motion Trackers



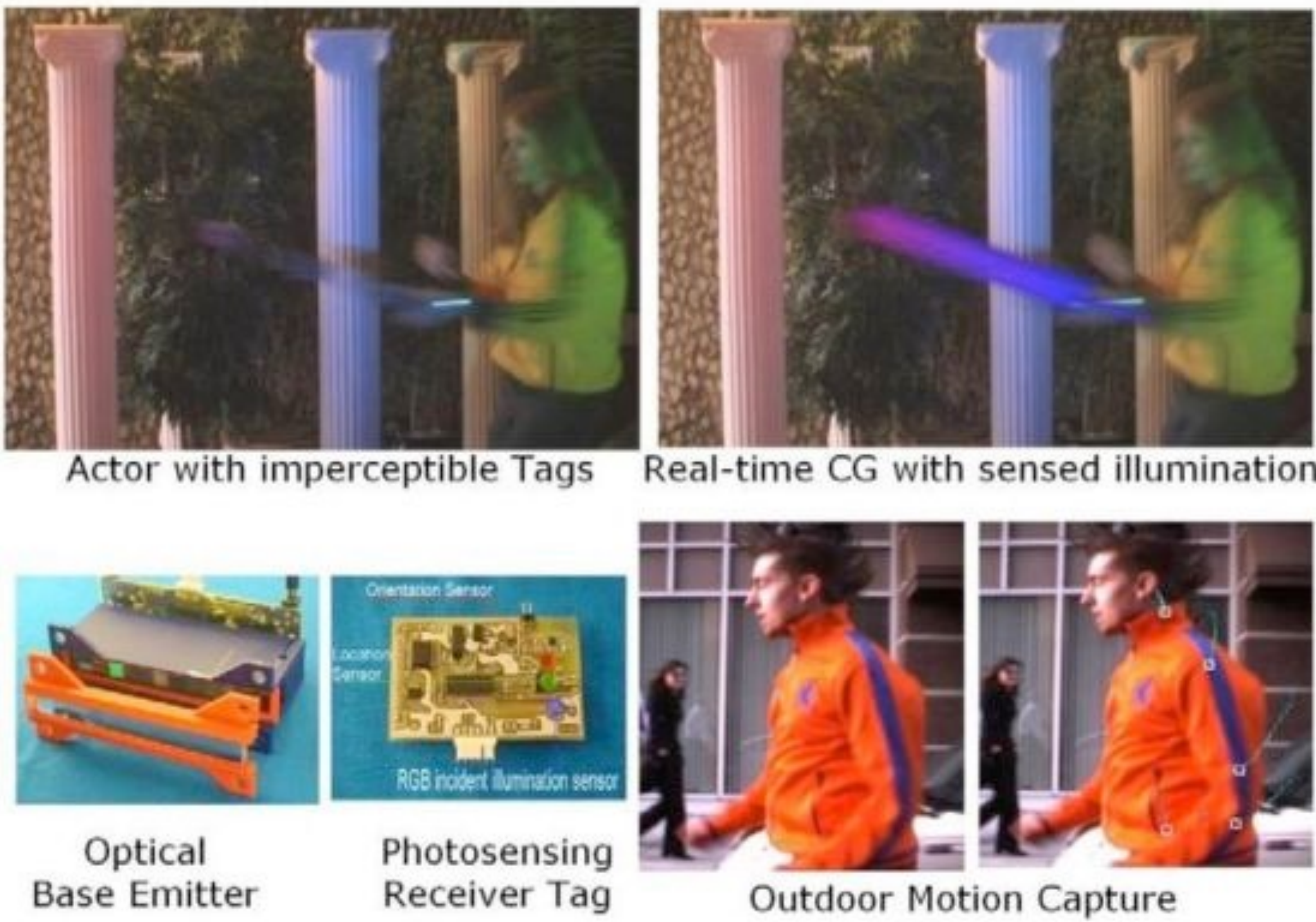
XOS, Vicon, etc. optical trackers

Selspot active optical motion tracker



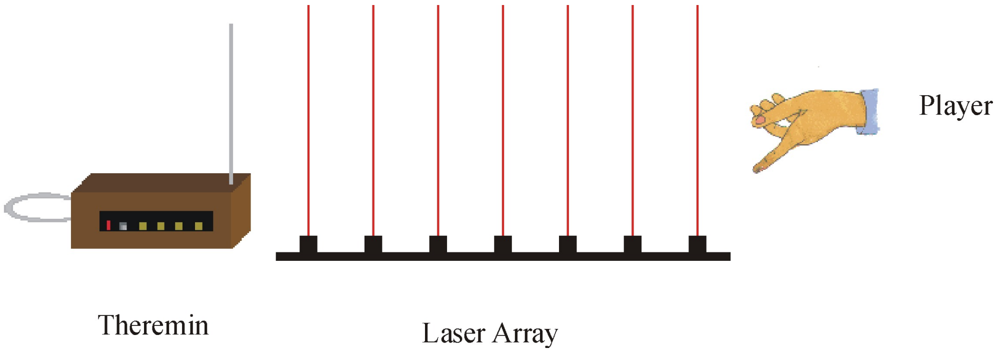


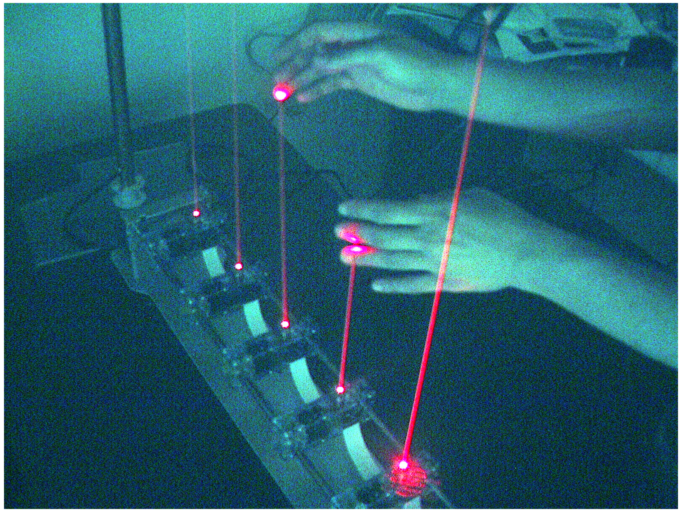
Camera Culture's Second Skin



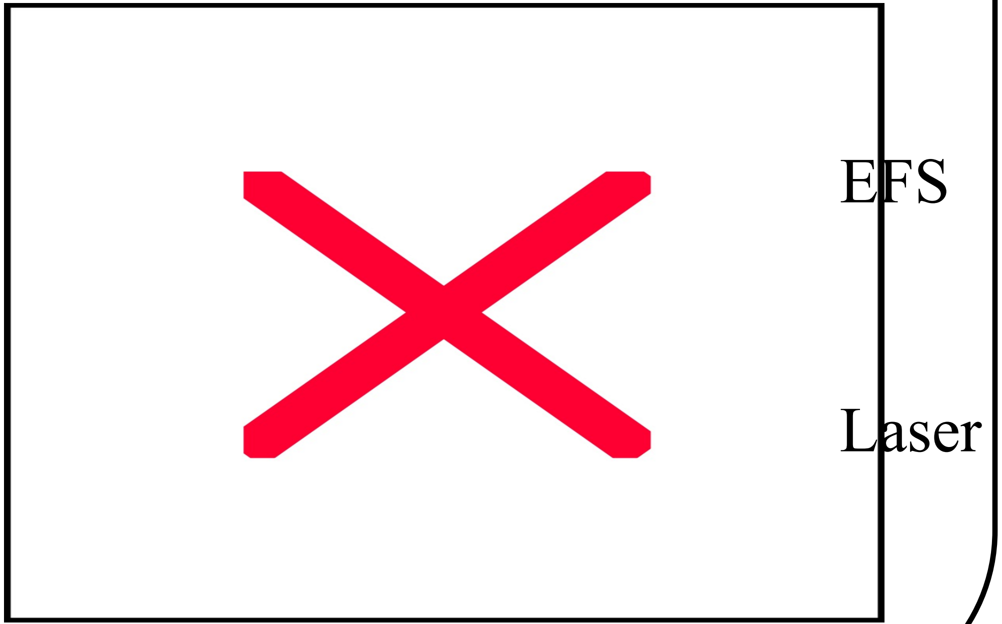
- Sequential structured light sent from different orientations
- Photodiode node emits RF pulse/broadcast when emitted light is detected.

The Terminova



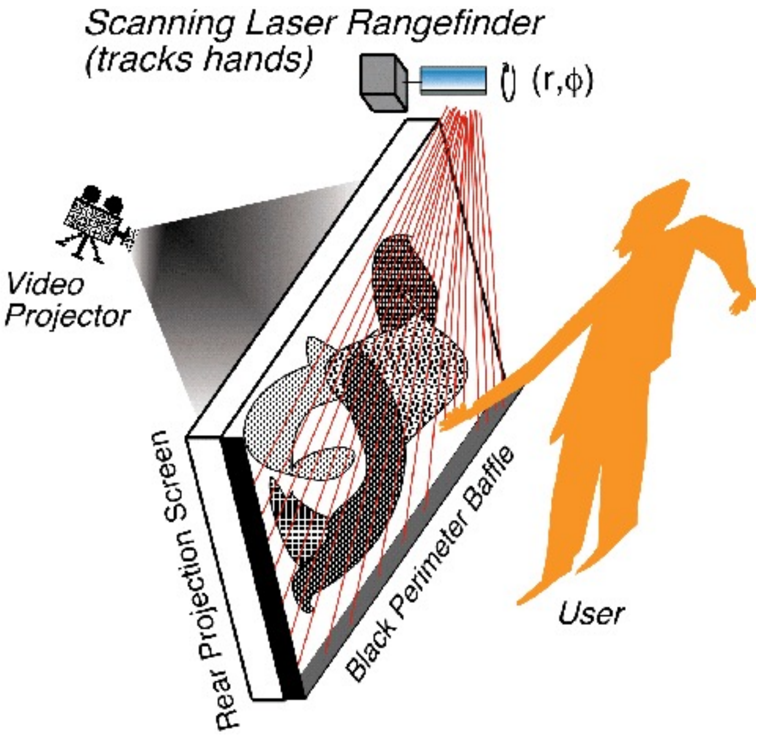


- Hybrid of continuous Theremin controller and 1D laser intensity ranges
- Motor-controlled Laser “frets” - give visual feedback to the player
- Auto-calibration - changes the placement of the laser “frets” for the current user since capacitances vary
- Auto tuning - move hands across calibration beacons
- Selective quantization - can “lock” to notes without sacrificing the ability to play in-between & modulate
- Laser frets can be different kind (e.g. timbre) of control



Demo by Leila Hasan and Nicholas Yu

Application of laser rangefinder

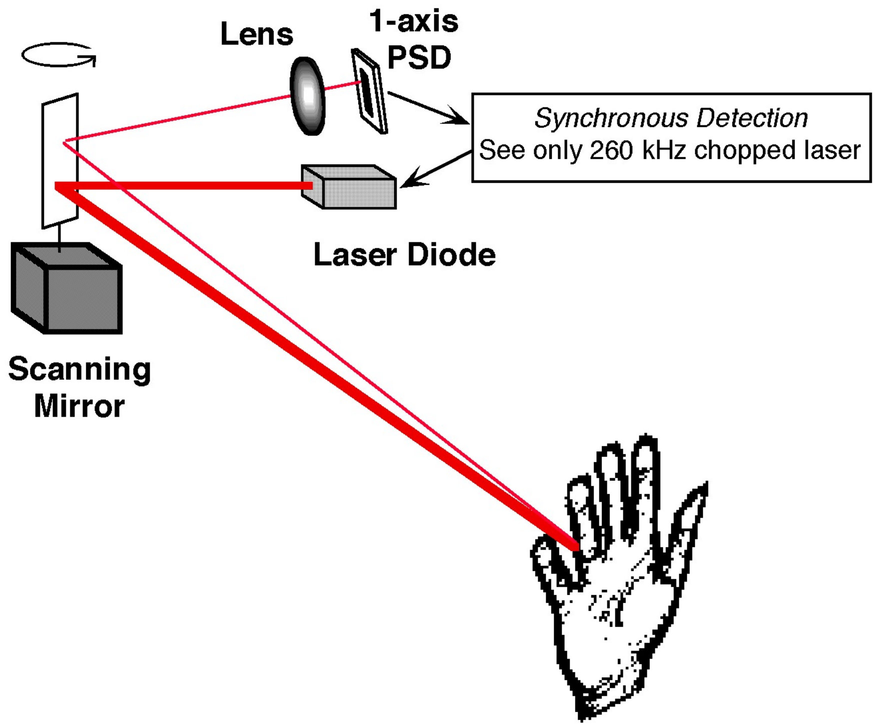


2D scanning laser rangefinder tracks bare hands (r,θ) in front of screen

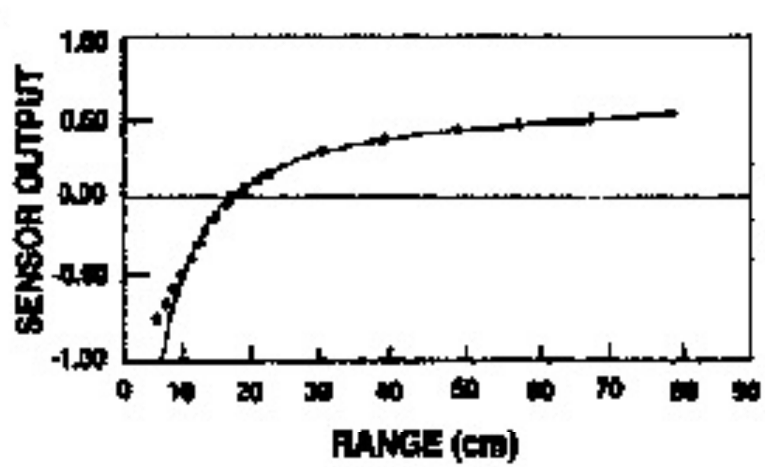
- **Defines very explicit sensitive plane**
- **Insensitive to background light**
- **Can track multiple (non-occluding) hands from one location**
- **Accurate, fast, repeatable, can control graphics!**

True rangefinding used - not intensity of reflection (e.g., D-beam)

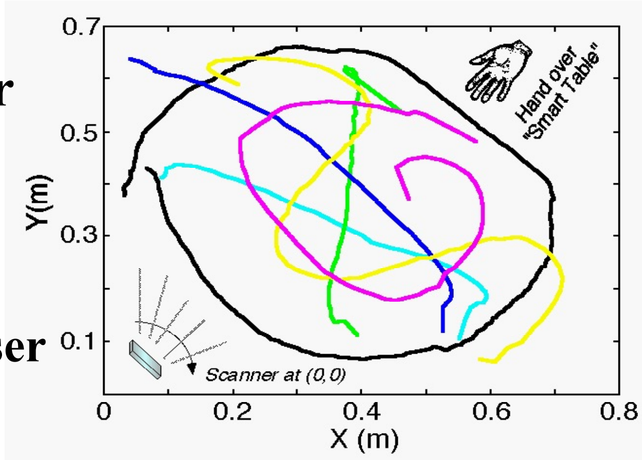
Original Triangulation Rangefinder



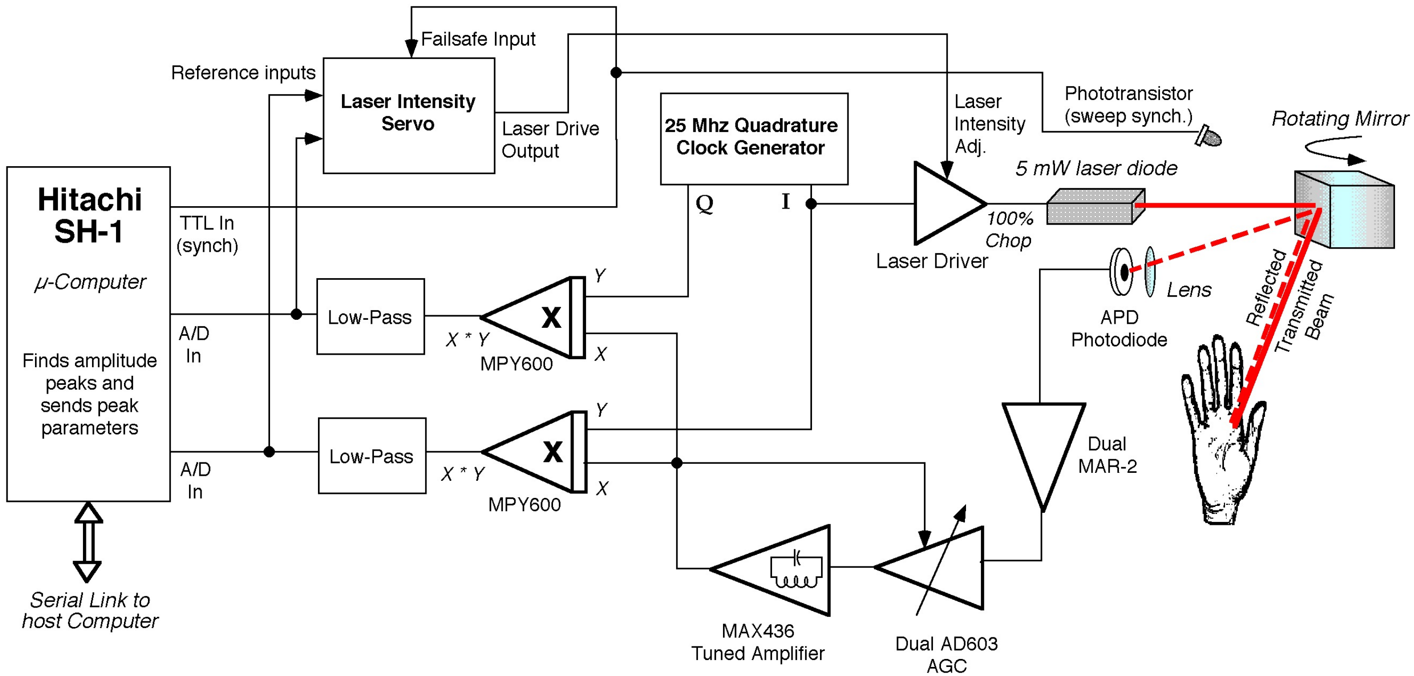
Asymptotic Response



- Have built inexpensive scanning laser rangefinder
- Current unit uses triangulation
  - Tracks 1-2 meters of range @ 20-30 Hz; 90˚ scan
- No CCD or vision processing; use PSD camera
  - Quick, insensitive to ambient lighting; sees only laser spot
- Soon use quadrature phase demodulation
  - Much more range and range accuracy!



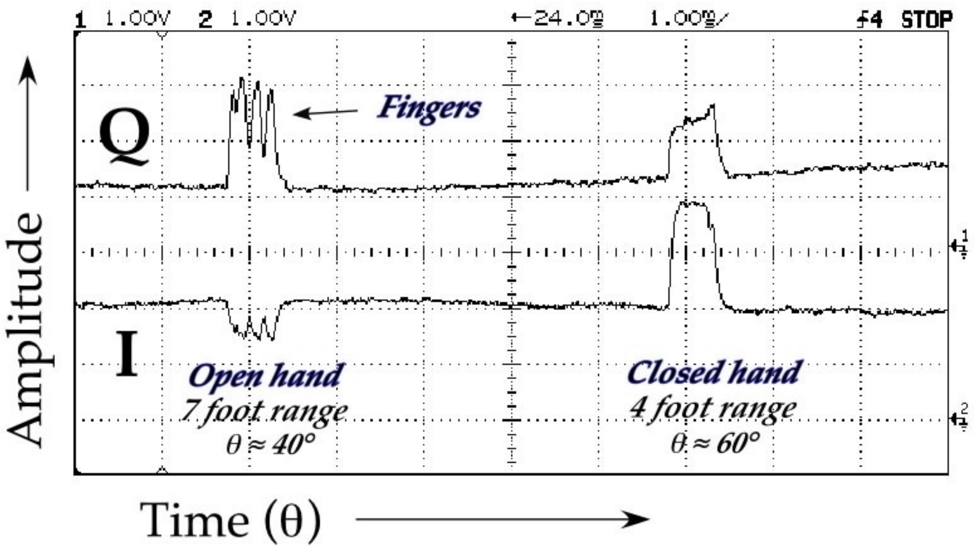
Simple Phase-Detection Rangefinder

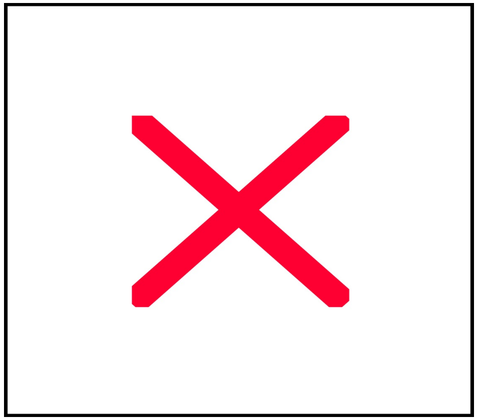


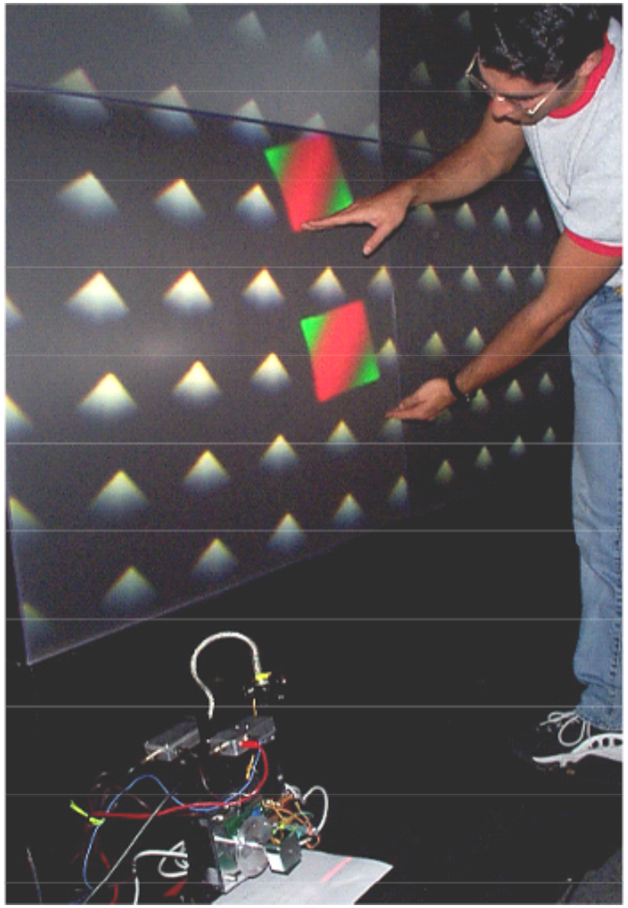
Measure time light takes to go to/from hand

- **σ = 1.5 cm resolution constant over 4 meter, 90 deg range**
  - **Mirror wobble; 4-point FIR filter wipes this out**
- **Detect bare hands, complexion insensitive**
- **Scans up to 30 Hz**
- **Unaffected by any background or projected light**
- **Eyesafe**
- **Inexpensive (<$500. parts), simple**

Hand Detection against Smart Wall

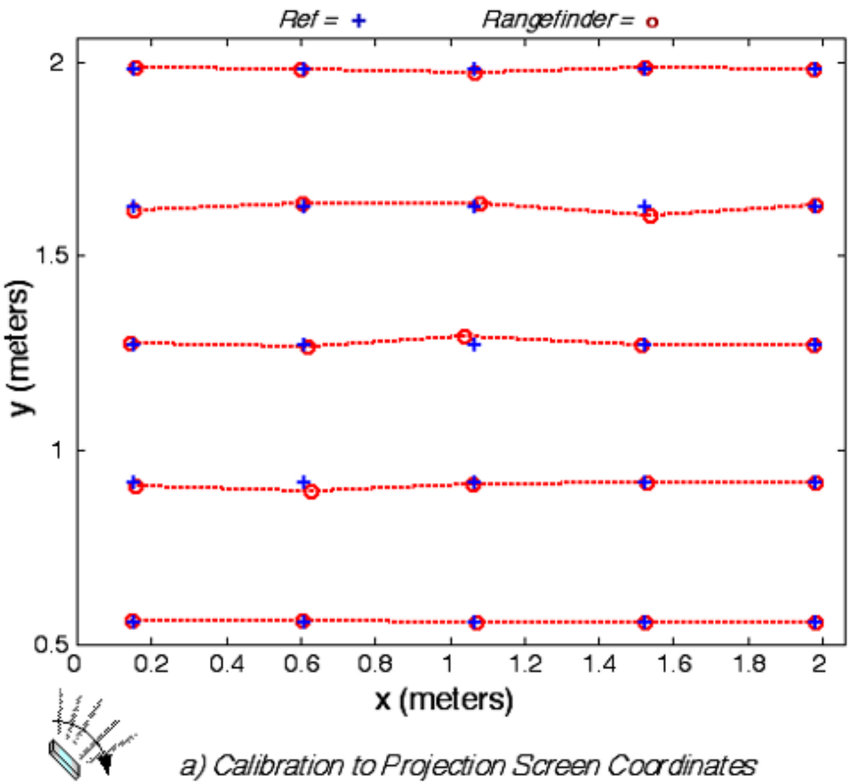




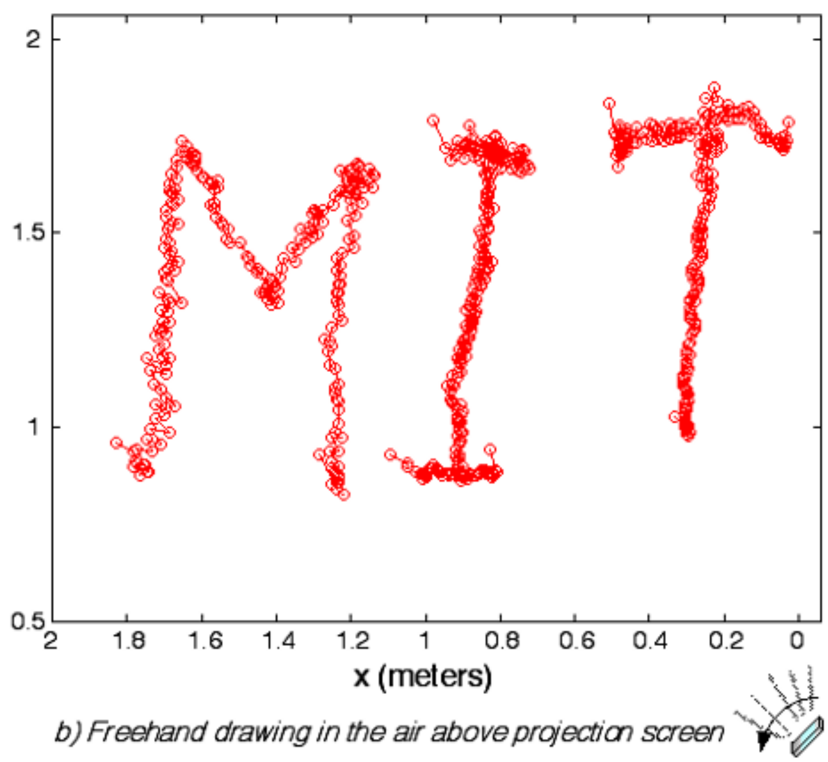


- **Laser scans against black, nonreflective frame**
  - **Hands stand out nicely**
  - **Little signal processing needed; PIC finds all peaks**

Calibration



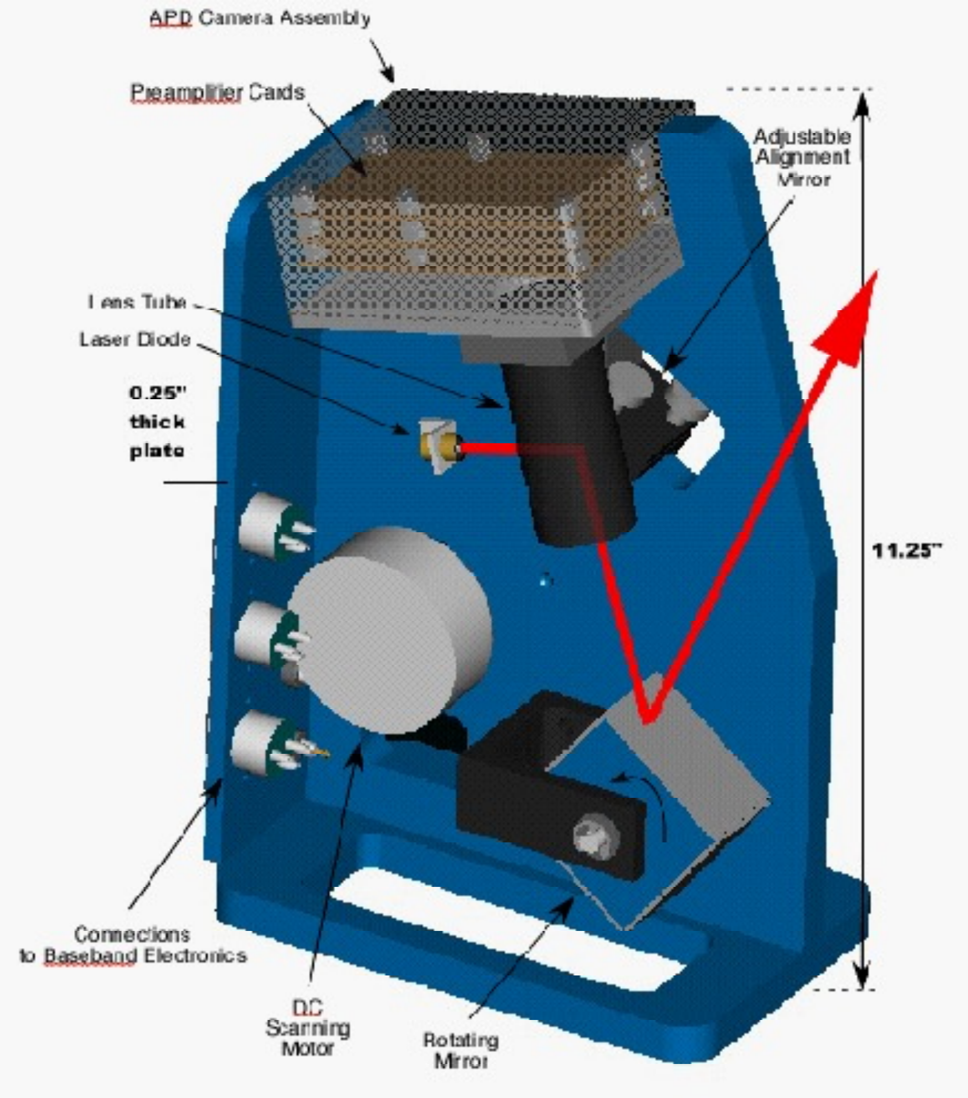
a) Calibration to Projection Screen Coordinates

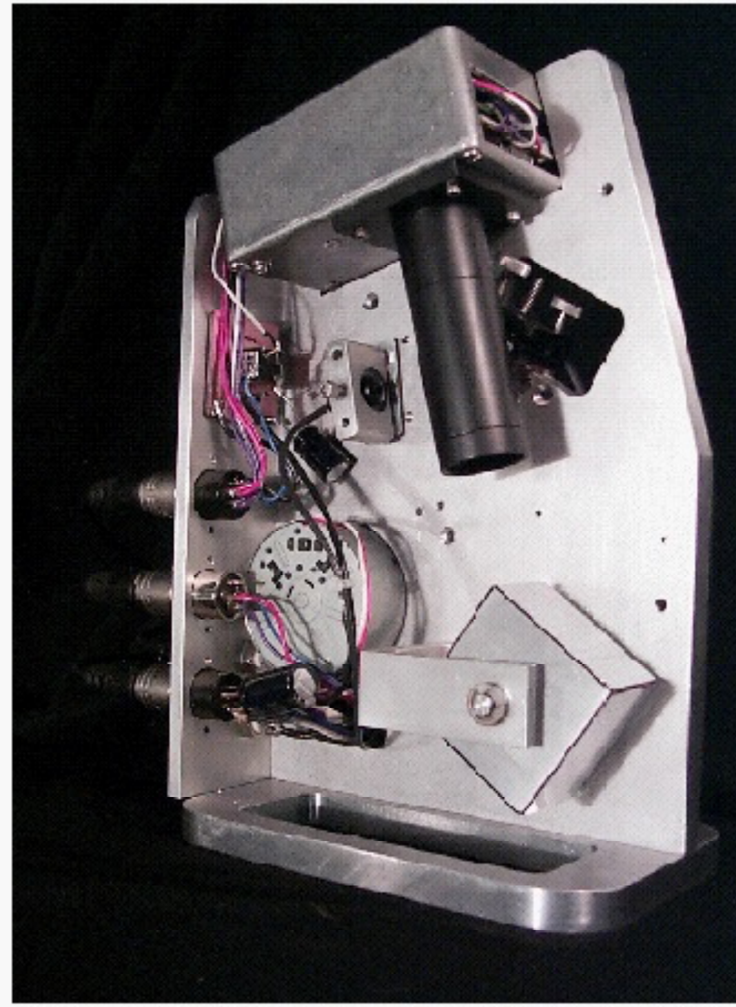


b) Freehand drawing in the air above projection screen

- Place hand at 25 points on screen at setup
  - 3'rd order fit to rangefinder raw data
  - Global accuracy within 2" across 6' x 8' screen

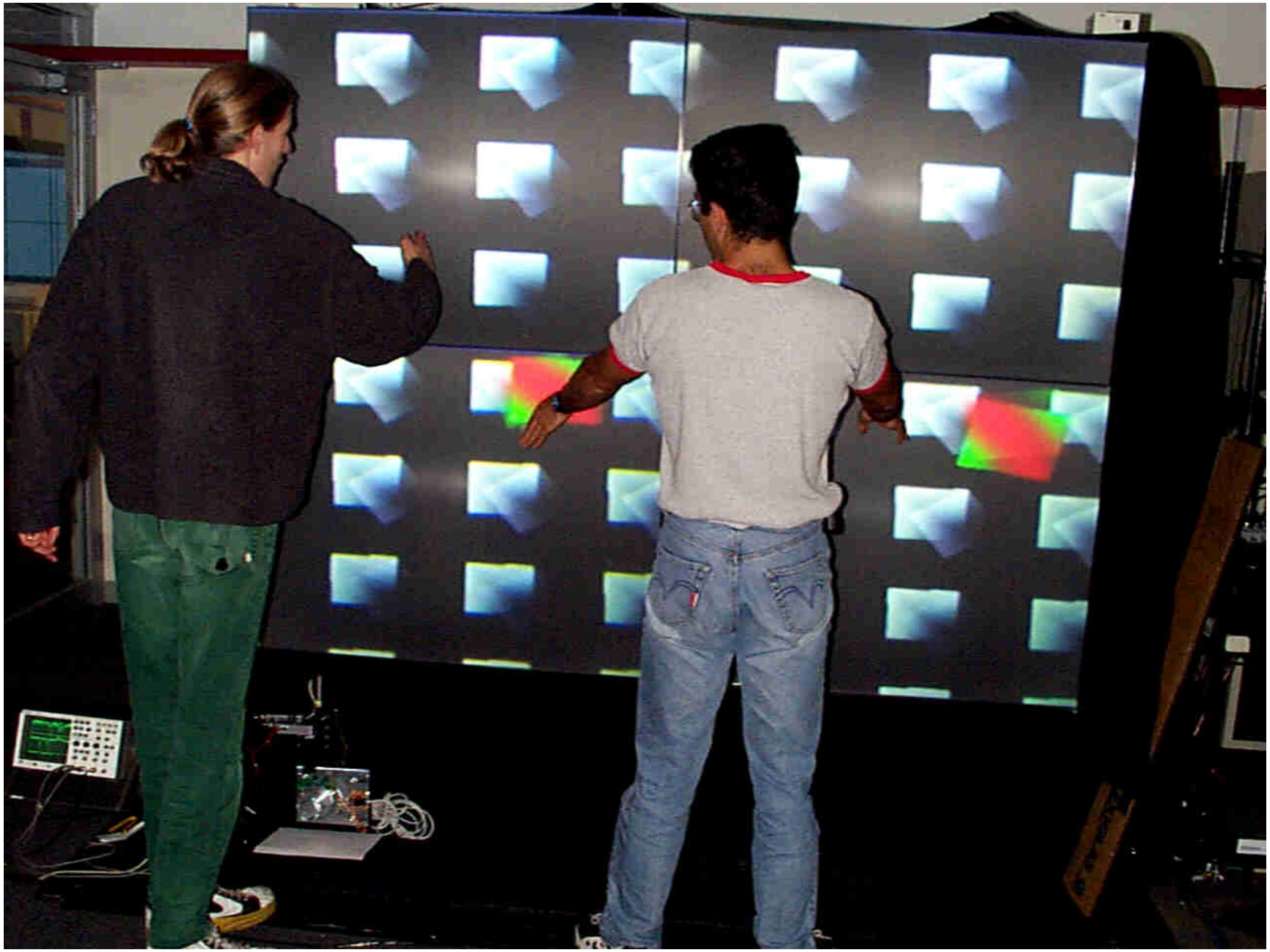
Latest Design





Gigged at SIGGRAPH 2K - Emerging Technologies

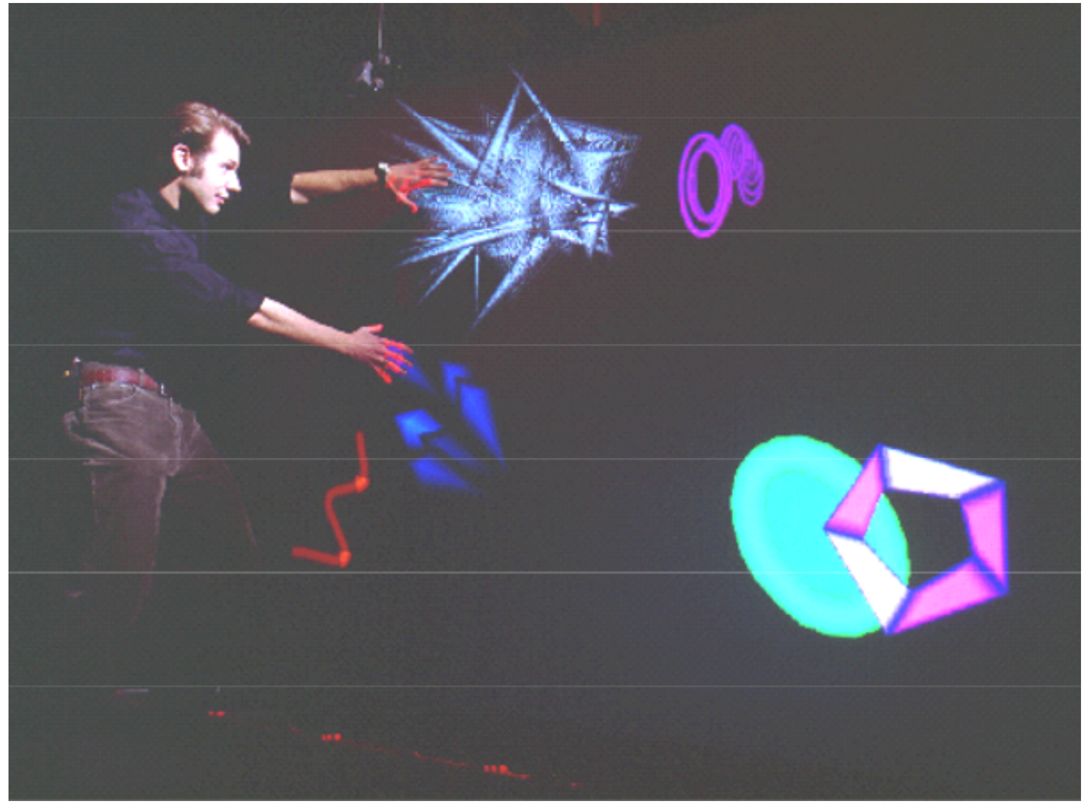
Rotating Cubes - 1997 first demo



Very simple percussion-based mapping on Raveolution box

LaserStretch

25
SIGGRAPH 98
celebrating 25 years of discovery

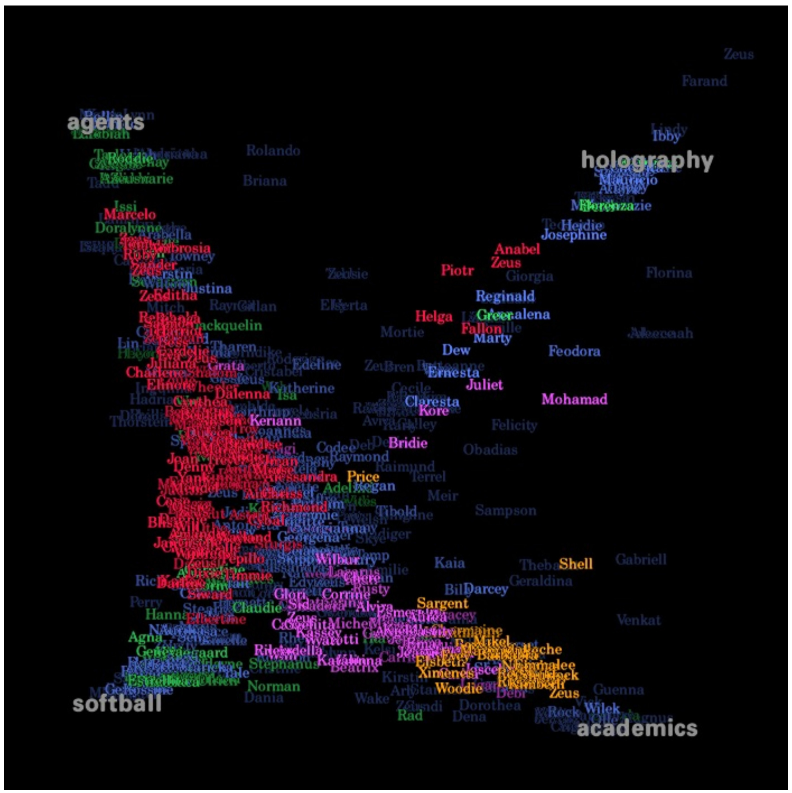


Augmented port of mouse-driven music app.

- Applications
  - Demo with Pete Rice’s Stretchable Music
  - At SIGGRAPH ‘98 (Orlando, FL, July 1998)

LaserWho

New collaboration between Sociable Media and Responsive Environments Groups



Interactive Music by Kai-Yuh Hsiao

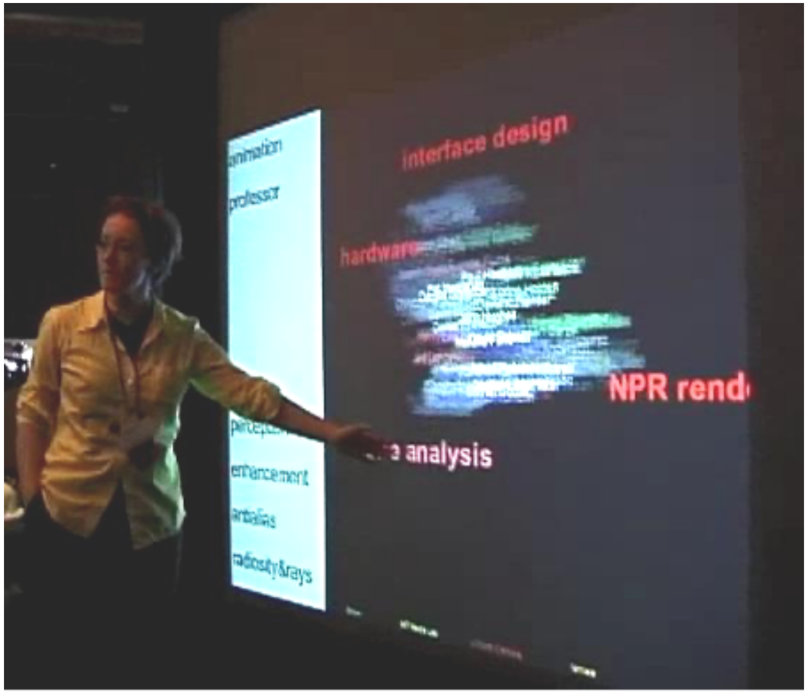
- 11 Themes
  - One for each anchor
  - One for blank state
- Sounds vary with:
  - Hand Presence
  - Hand position
  - Hand velocity
  - Number/type of anchors
  - Energy of system...

2(or more)-Handed Interactions...

Judith Donath, Joe Paradiso, Dana Spiegel, Kai-Yuh Hsiao, Danah Beard, Ari Adler

LaserWho Gigs 1999/2000

SIGGRAPH 2000, New Orleans



Opera Totale 5
Mestre, Italy

Commercial Rangefinders

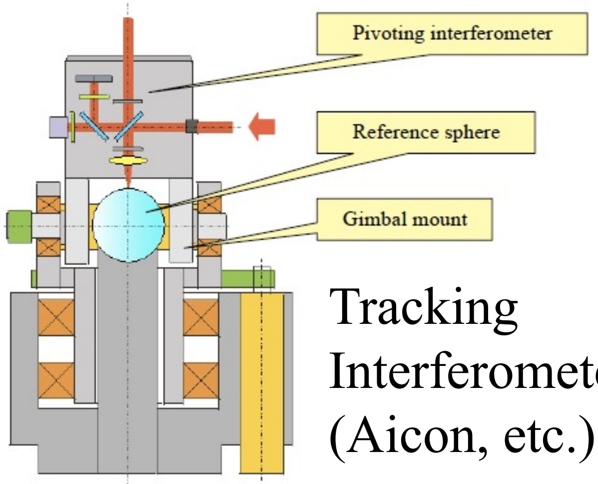
Leica DISTO™ - the innovative hand-held laser meter for fast and easy distance measurements of length, squares and volumes with the press of a button. Save time and money and emphasise your competence with modern measuring methods.

Leica TPS1200+

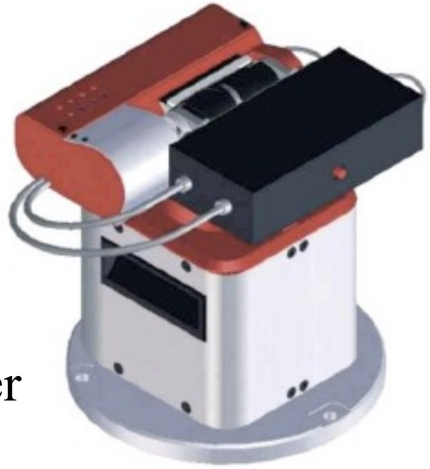
The Total Station with the Plus

The new Leica TPS1200+ is our most competitive total station ever. It provides the market's most accurate reflectorless EDM with the smallest laser dot and measures distances over 1000 meters. Thanks to the new telescope fitted to all Leica TPS1200+ models, the user also benefits from the most accurate measurements to reflectors.

- Reflectorless range 1000 m
- PinPoint accuracy 2 mm
- Laser dot size 2 cm/50 m



Tracking Interferometer (Aicon, etc.)



S100 Standard

- Easy to integrate due to small dimensions and low weight
- Large 270° scanning angle
- Two switching fields, also available as S100 Professional variant with 16 switching fields
- Switching field range 4.5 m (10 % remission), max. 10 m (at 45 % remission)
- Adjustable object resolution
- CANopen interface
- Configuration memory in the system plug
- Operating temperature range from –10 °C to +50 °C

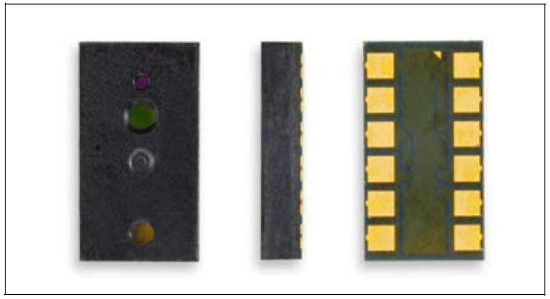
Single Pixel TOF Ranging Chip

life.augmented

VL6180X

Proximity and ambient light sensing (ALS) module

Datasheet - production data



Features

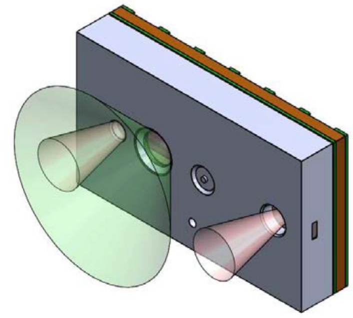
- Three-in-one smart optical module
  - Proximity sensor
  - Ambient Light Sensor
  - VCSEL light source
- Fast, accurate distance ranging
  - Measures absolute range from 0 to above 10 cm
  - Independent of object reflectance
  - Ambient rejection
  - Crosstalk compensation for cover glass
  - Ranging beyond 100mm is possible with certain target reflectances and ambient conditions but not guaranteed
- Two programmable GPIO
  - Window and thresholding functions for both ranging and ALS

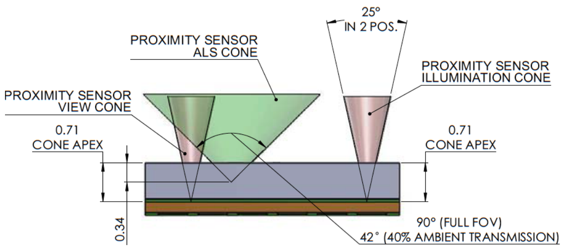
Description

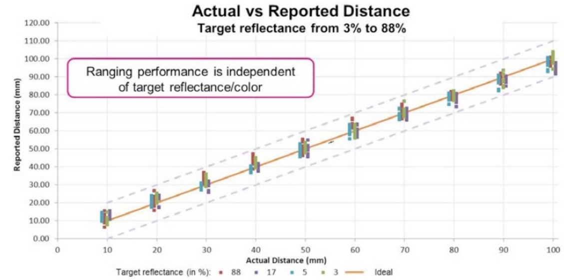
The VL6180X is the latest product based on ST's patented **Flight**Sense™ technology. This is a ground-breaking technology allowing absolute distance to be measured independent of target reflectance. Instead of estimating the distance by measuring the amount of light reflected back from the object (which is significantly influenced by color and surface), the VL6180X precisely measures the time the light takes to travel to the nearest object and reflect back to the sensor (Time-of-Flight).

Combining an IR emitter, a range sensor and an ambient light sensor in a three-in-one ready-to-use reflowable package, the VL6180X is easy to integrate and saves the end-product maker long and costly optical and mechanical design optimizations.

The module is designed for ultra low power operation. Ranging and ALS measurements can be automatically performed at user defined







From EE Times

Uses SAPD sensor

http://www.eetimes.com/document.asp?doc_id=1280829

Rangefinding Imagers – ~~the future ??~~

(12) **United States Patent**
Bamji

(10) **Patent No.: US 6,323,942 B1**
(45) **Date of Patent: Nov. 27, 2001**

(54) **CMOS-COMPATIBLE THREE-DIMENSIONAL IMAGE SENSOR IC**

(75) Inventor: **Cyrus Bamji**, Fremont, CA (US)

(73) Assignee: **Canesta, Inc.**, Palo Alto, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/401,059**

(22) Filed: **Sep. 22, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/132,064, filed on Apr. 30, 1999.

(51) **Int. Cl.**[7] **G01C 3/08**
(52) **U.S. Cl.** **356/5.01**; 356/5.08; 356/5.04
(58) **Field of Search** 356/5.01–5.08, 356/141.1

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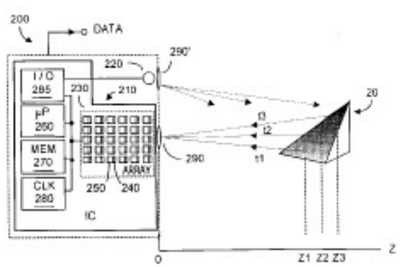
* cited by examiner

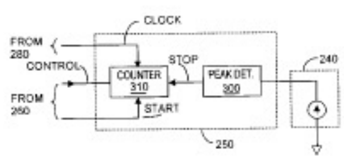
Primary Examiner—Stephen C. Buczinski

(57) **ABSTRACT**

A three-dimensional imaging system includes a two-dimensional array of pixel light sensing detectors and dedicated electronics and associated processing circuitry fabricated on a common IC using CMOS fabrication techniques. In one embodiment, each detector has an associated high speed counter that accumulates clock pulses in number directly proportional to time of flight (TOF) for a system-emitted pulse to reflect from an object point and be detected by a pixel detector focused upon that point. The TOF data provides a direct digital measure of distance from the particular pixel to a point on the object reflecting the emitted light pulse. In a second embodiment, the counters and high speed clock circuits are eliminated, and instead each pixel detector is provided with a charge accumulator and an electronic shutter. The shutters are opened when a light pulse is emitted and closed thereafter such that each pixel detector accumulates charge as a function of return photon energy falling upon the associated pixel detector. The amount of accumulated charge provides a direct measure of round-trip TOF. In either embodiment, the collection of TOF data permits reconstruction of the three-dimensional topography of the light-reflecting surface of the object being imaged. The CMOS nature of the array permits random-order read-out of TOF data if desired. Using a light source of a known wavelength and filtering out incoming light of other wavelengths permits use of the system with or without ambient light.

25 Claims, 7 Drawing Sheets





The Present!!

- Canesta rangefinding imager
- 3DV Systems (Microsoft)
- Mesa Imaging (Swiss)
- Lincoln Lab APD timing array

Kinnect Impacts These…