"Light: from simple optics to amazing applications"

Andrzej Kotlicki, Alex Rosemann
and Helge Seetzen

The Structure Surface Physics Laboratory

Faculty: Dr. Lorne Whitehead (In charge of the lab and the inventor)

Dr. Andrzej Kotlicki

RA: Dr. Michele Mossmann

Post Doctoral Fellows: Dr. Alexander Rosemann and Dr. Yasser Abdelaziez.

PhD student Helge Seetzen (also Chief Technology Officer of Brightside Technologies)

Graduate Students and Undergraduate researchers

UBC Structured Surface Physics

Outline

- Geometrical optics reminders: reflection, refraction, Snell's Law, Total Internal Reflection (TIR)
- Applications of TIR: fiber optics, retro-reflectors, guiding film
- Frustrated TIR – applications to "real" black and white reflective display. Electronic paper?
- New Developments in Solar Lighting Systems based on Prism Light Guides will be presented by Alex Rosemann
- New concept of electronic display – High Dynamic Range Display from our Spin-off company Brightside Technologies - will be presented by Helge Seetzen

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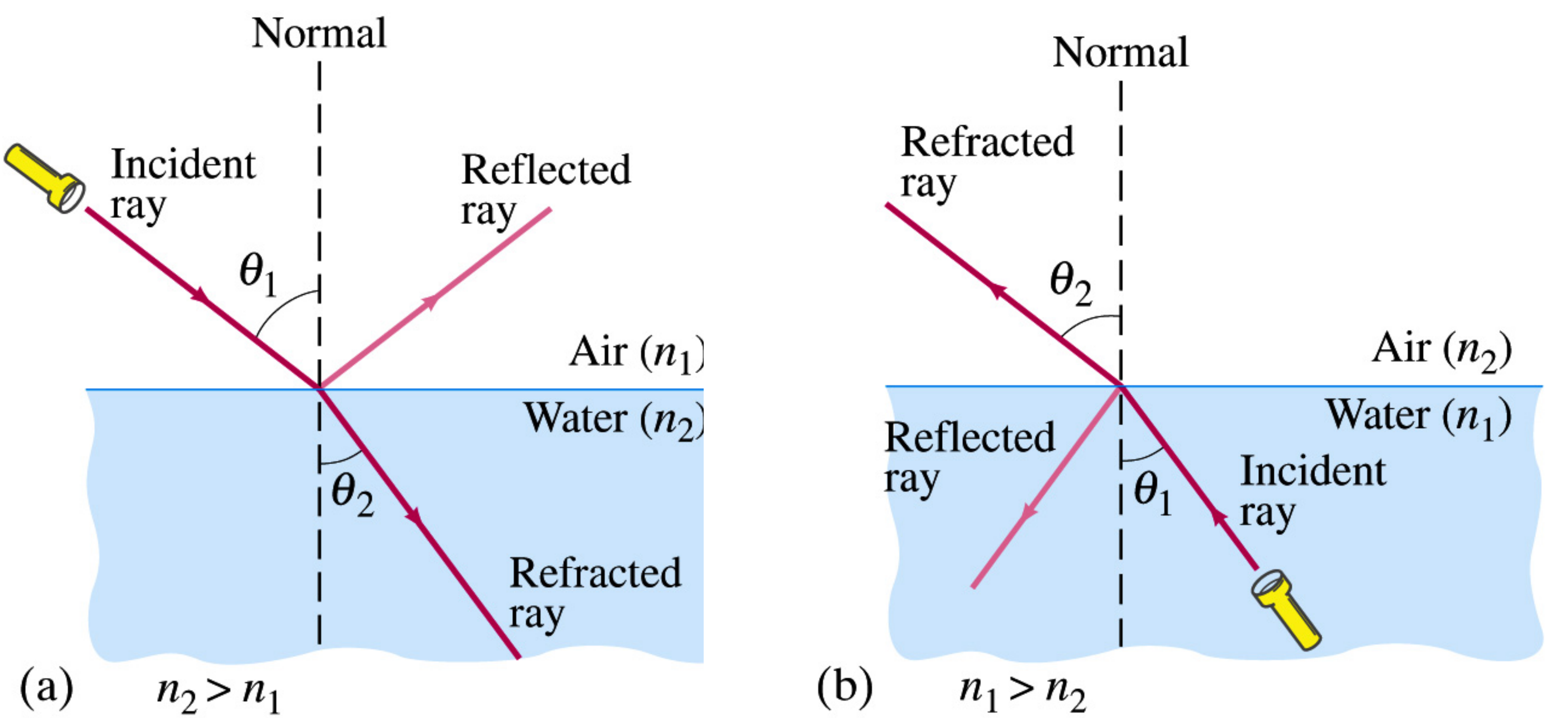
- Ray model of light.
- When we can use it?
- Wavelength of light 0.4 - 0.6μm

Snell's Law:

When light passes from the medium with refraction index n_1 into another with refraction index n_2:

$$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$



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Slide by Lorne Whitehead

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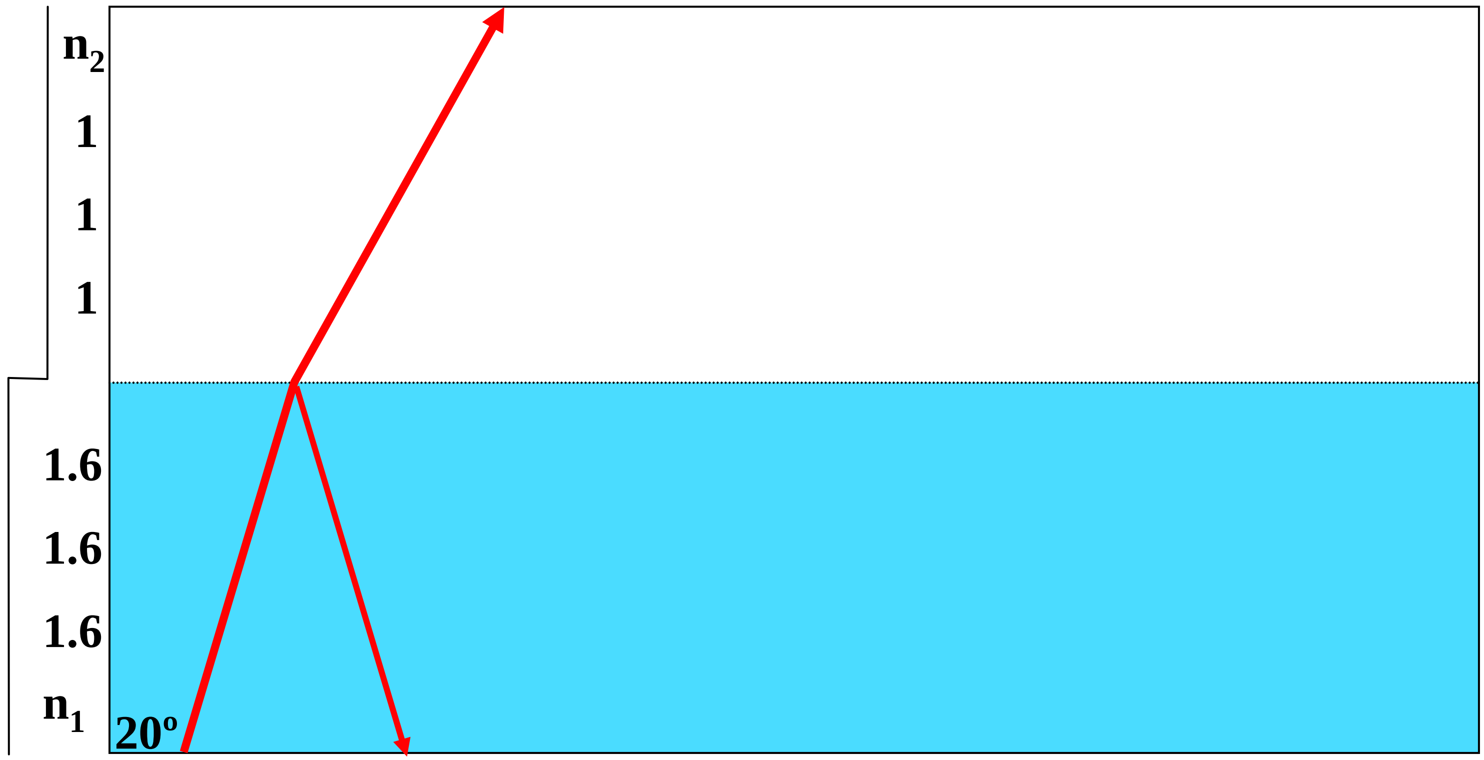

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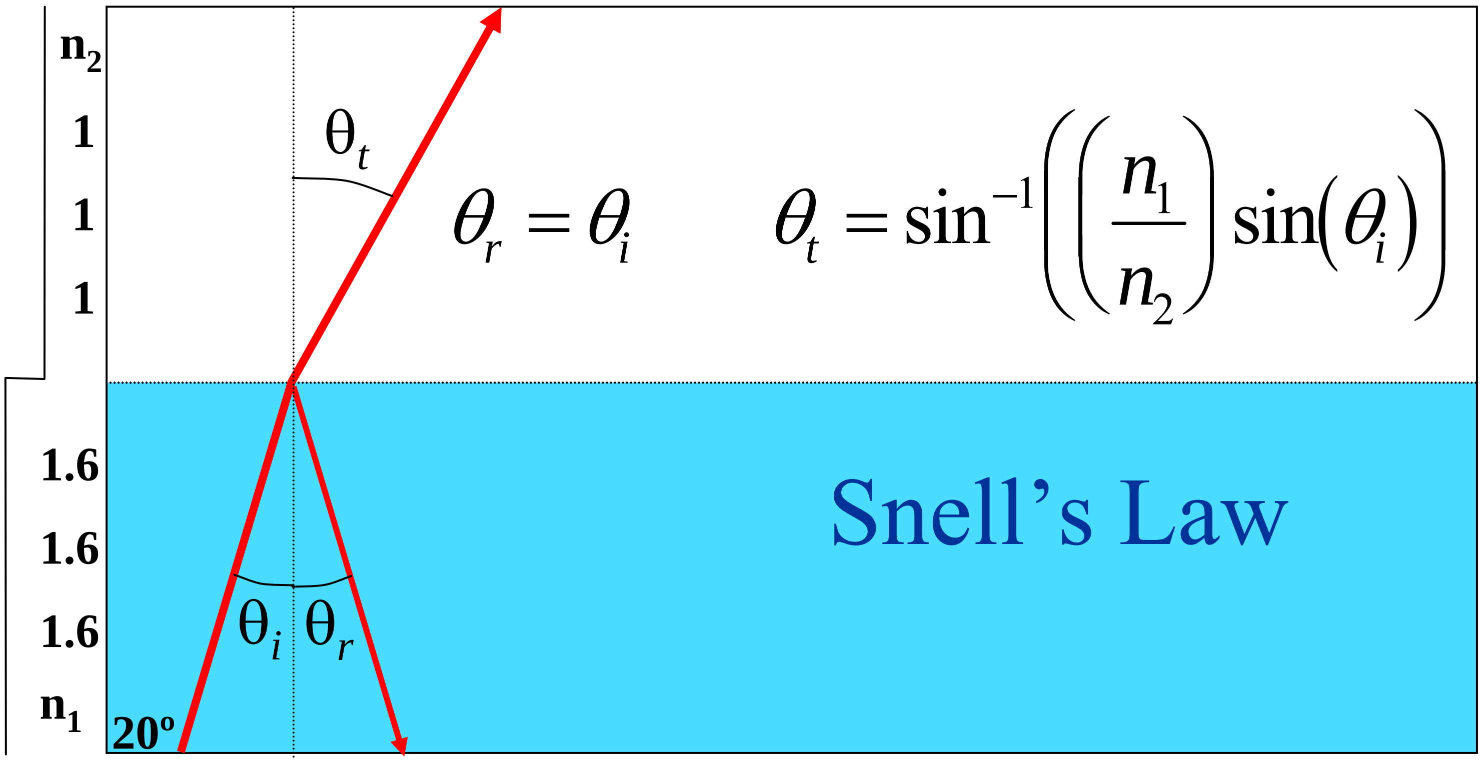

$$\theta_r = \theta_i \qquad \theta_t = \sin^{-1}\left(\left(\frac{n_1}{n_2}\right)\sin(\theta_i)\right)$$

Snell's Law

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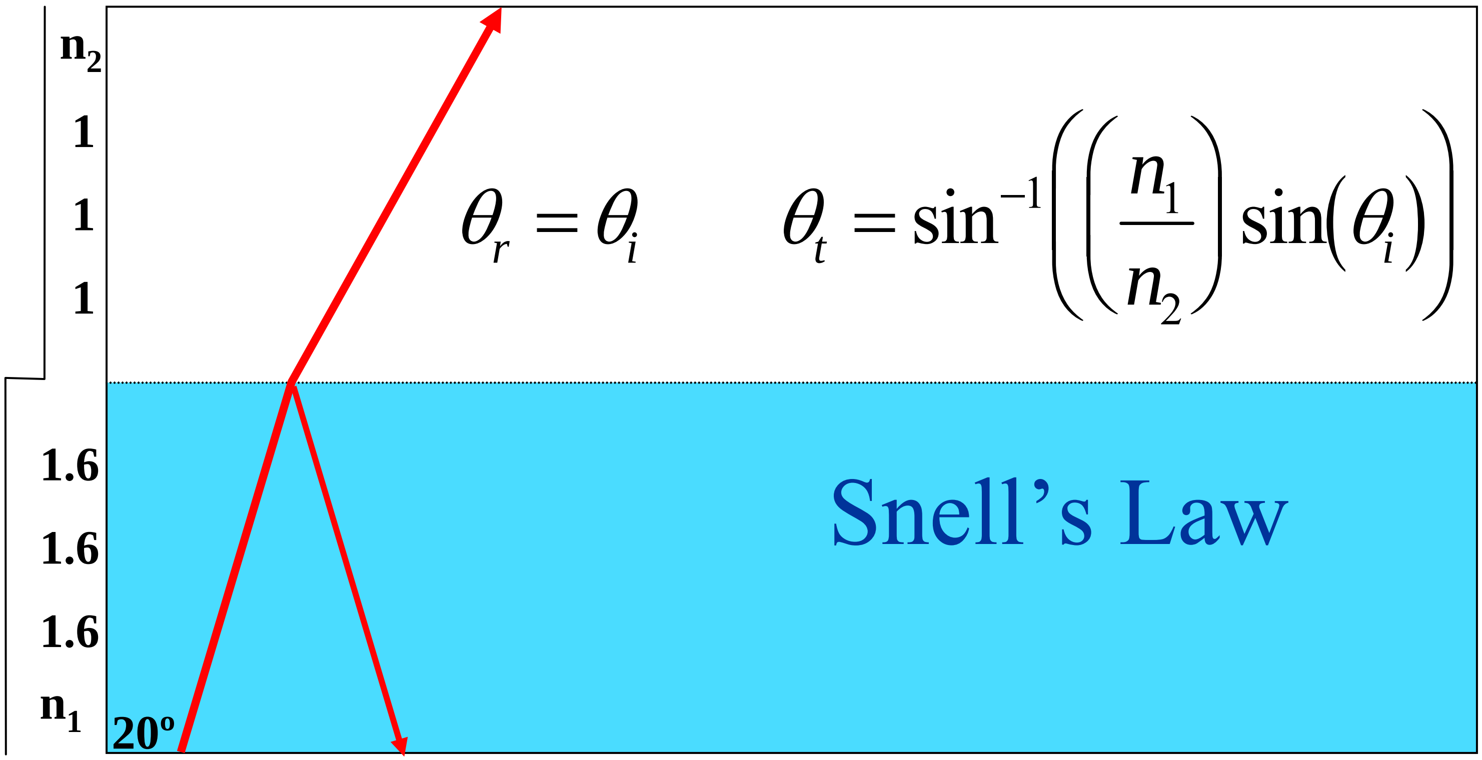

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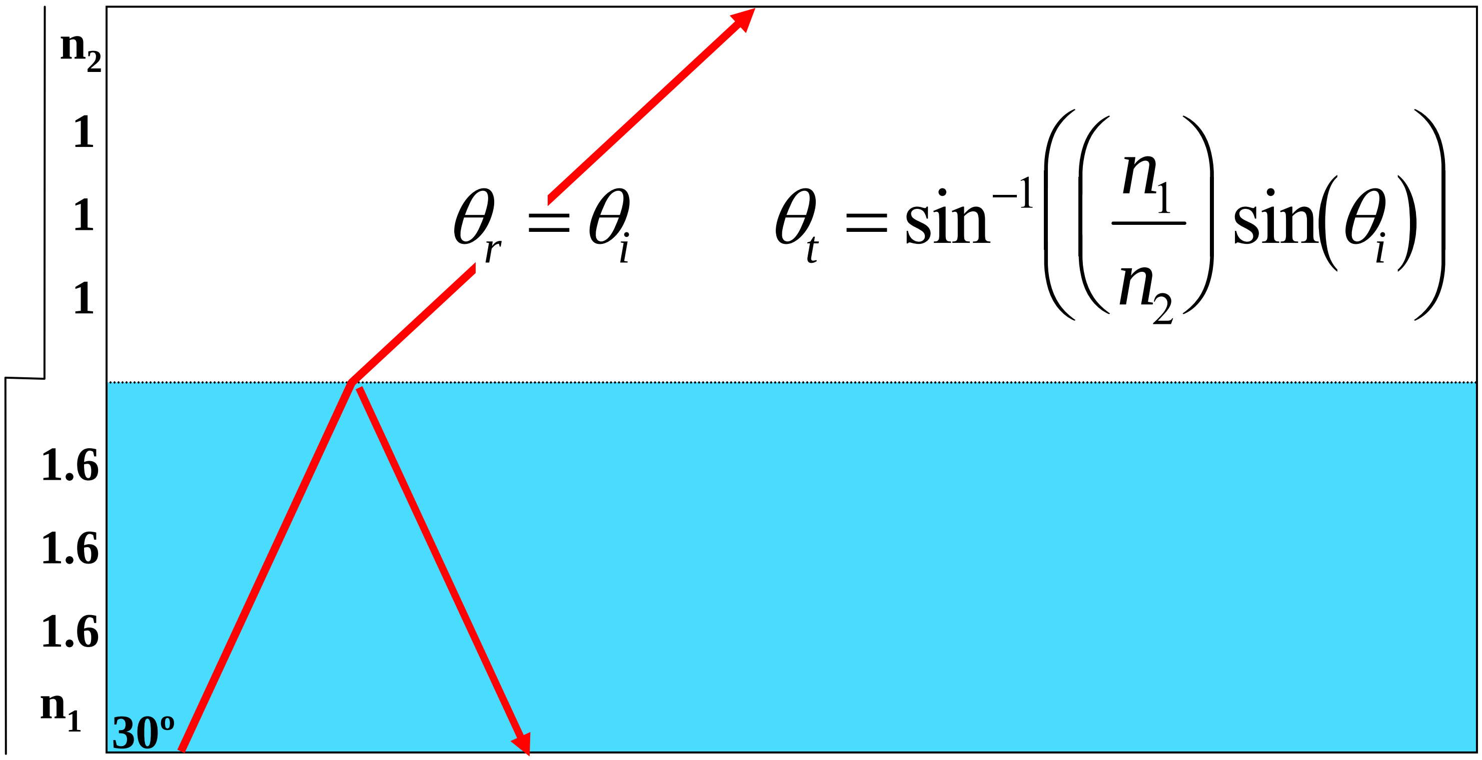

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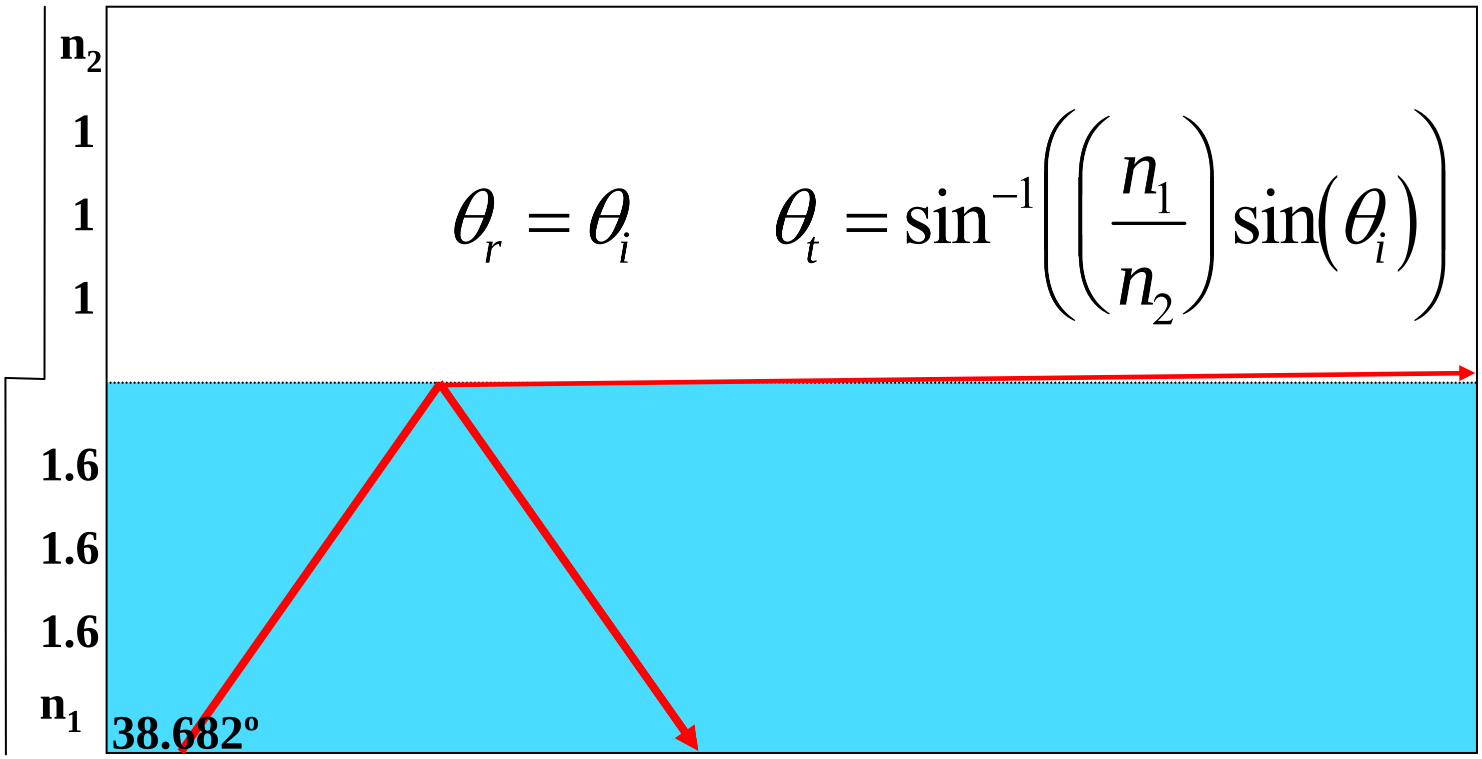
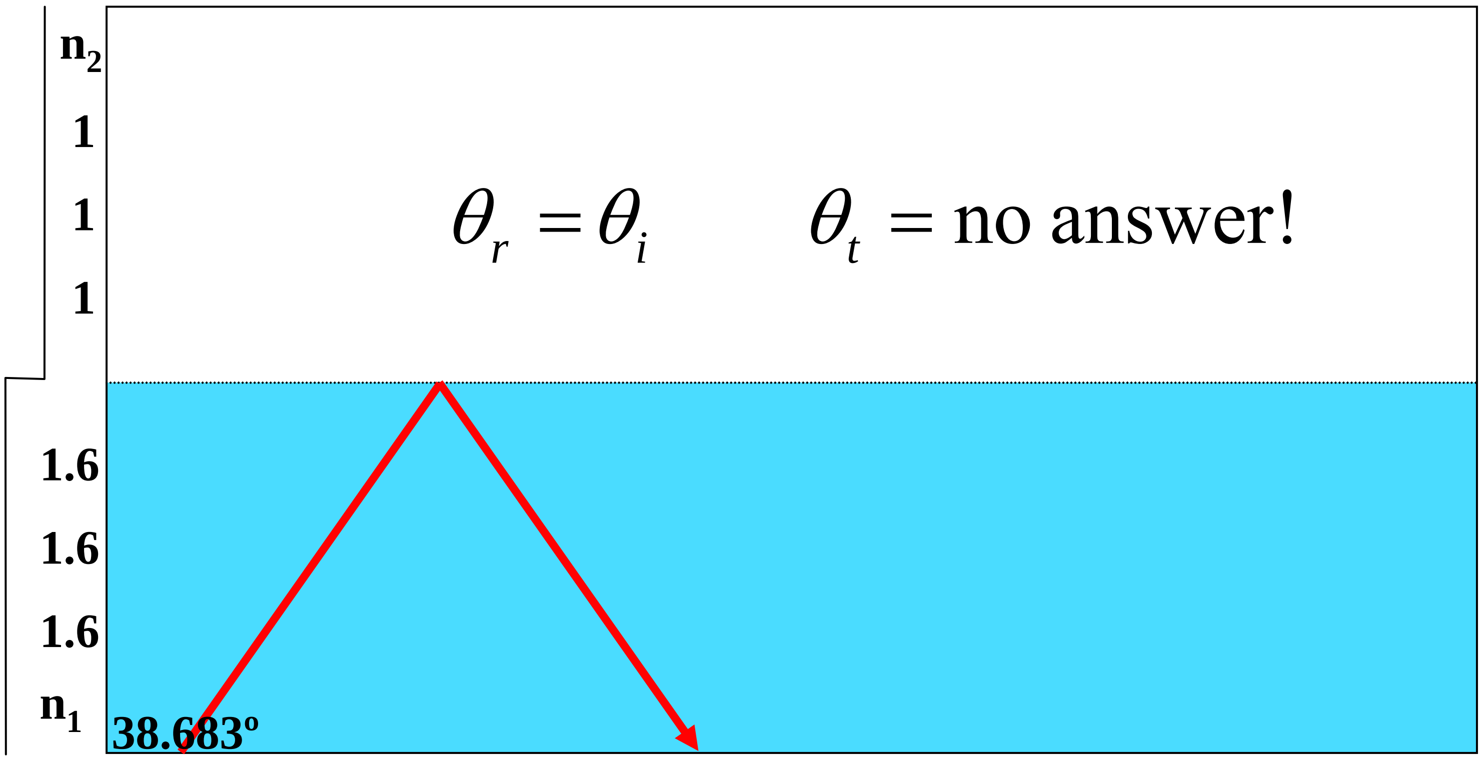


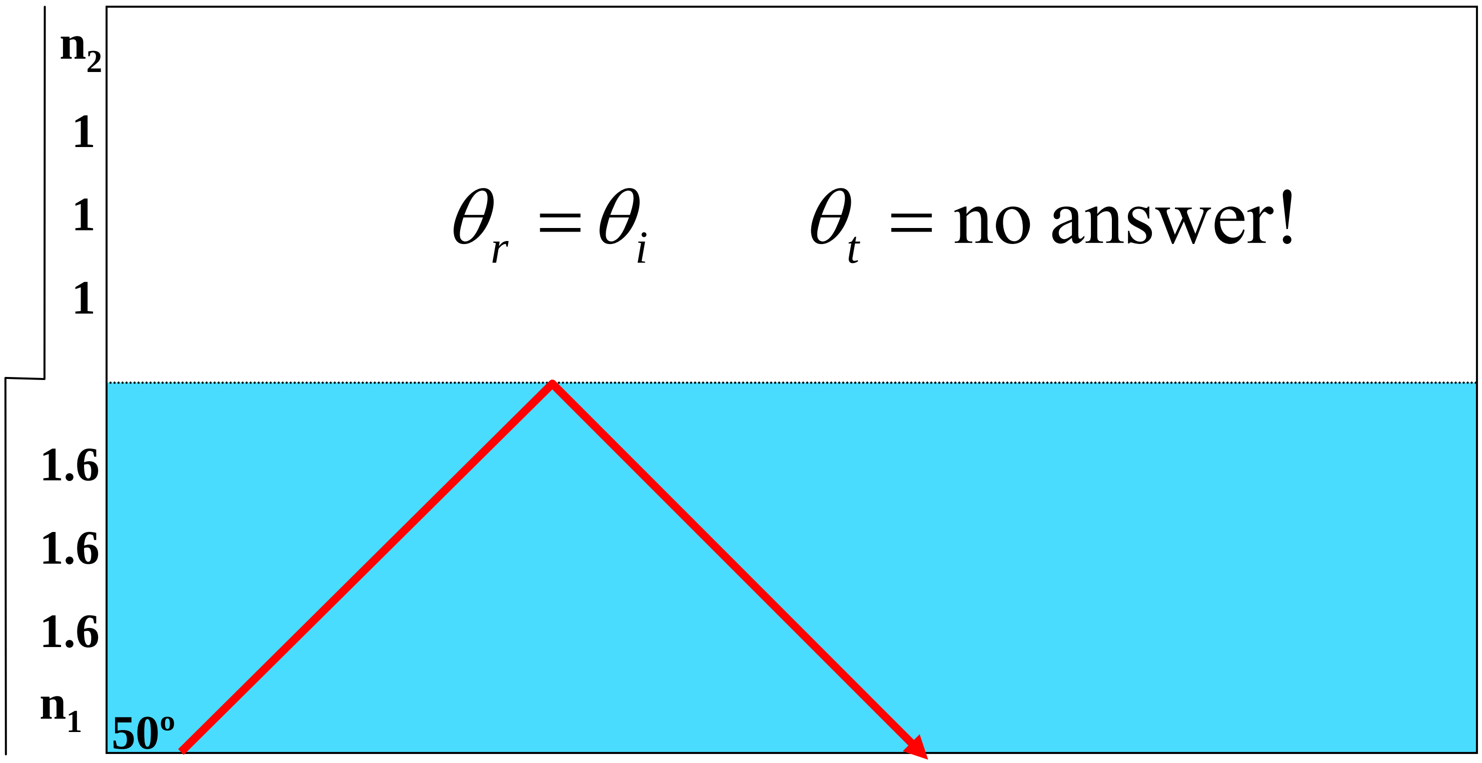
$$\theta_r = \theta_i \qquad \theta_t = \sin^{-1}\left(\left(\frac{n_1}{n_2}\right)\sin(\theta_i)\right)$$

Slide by Lorne Whitehead



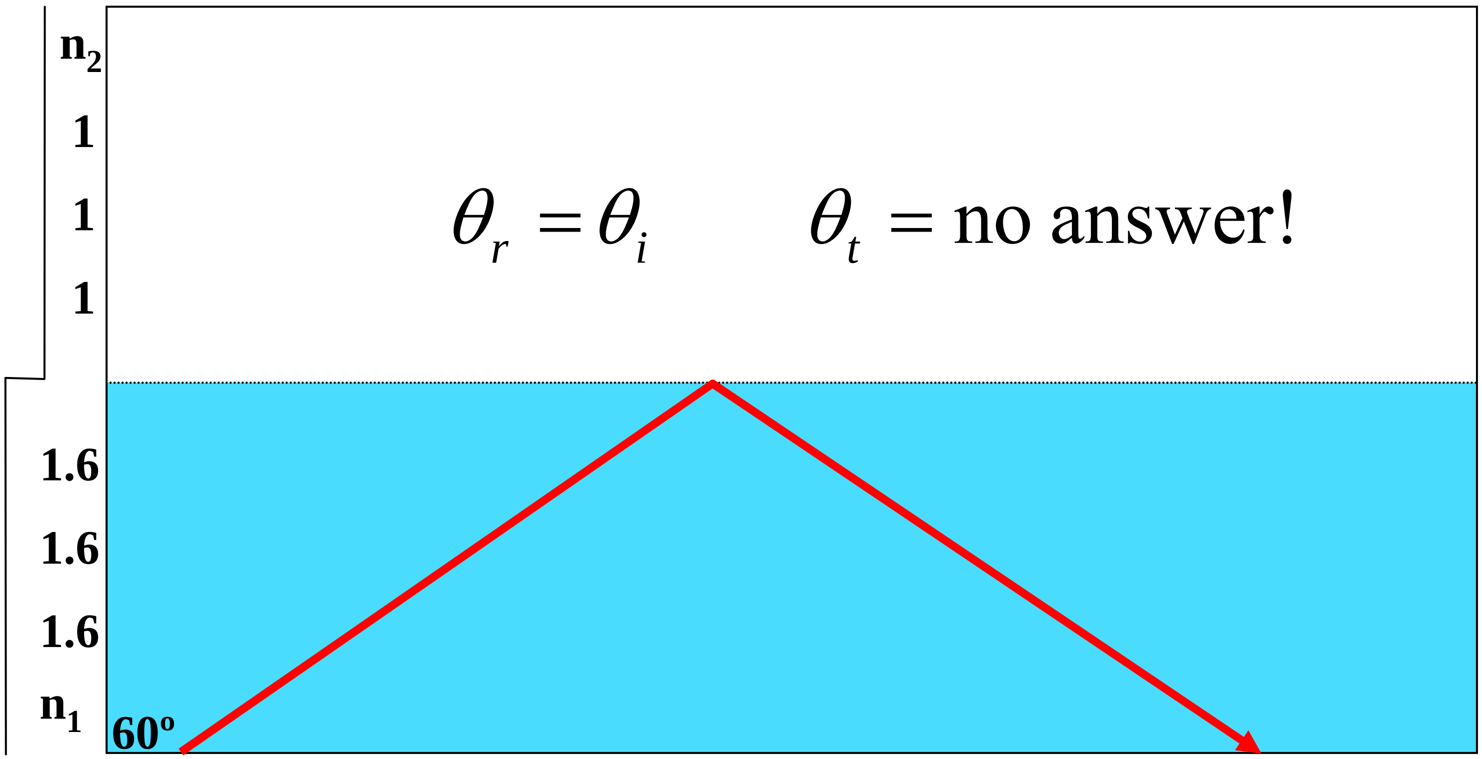
Total Internal Reflection !

Slide by Lorne Whitehead



Total Internal Reflection !

Slide by Lorne Whitehead



$$\theta_r = \theta_i \qquad \theta_t = \text{no answer!}$$

Total Internal Reflection !

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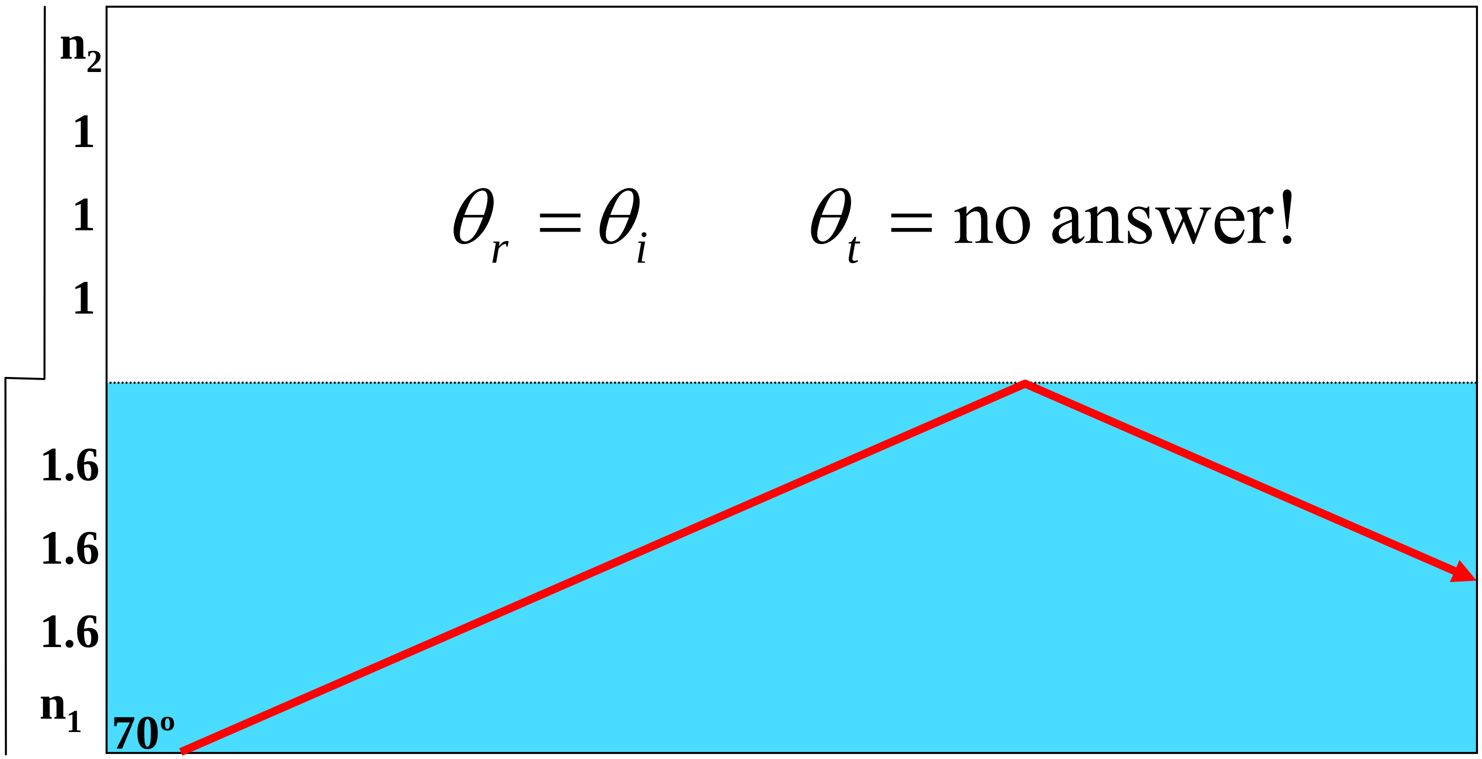

Total Internal Reflection !

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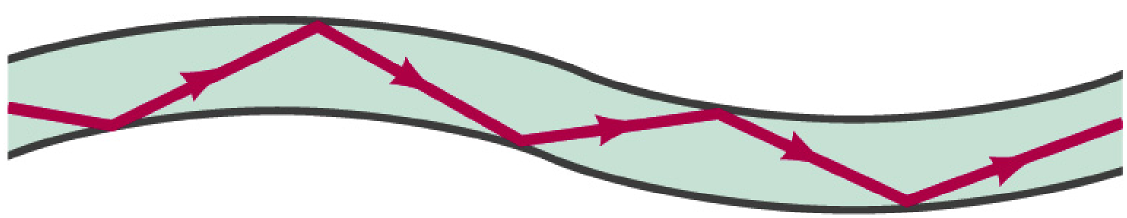
Critical angle

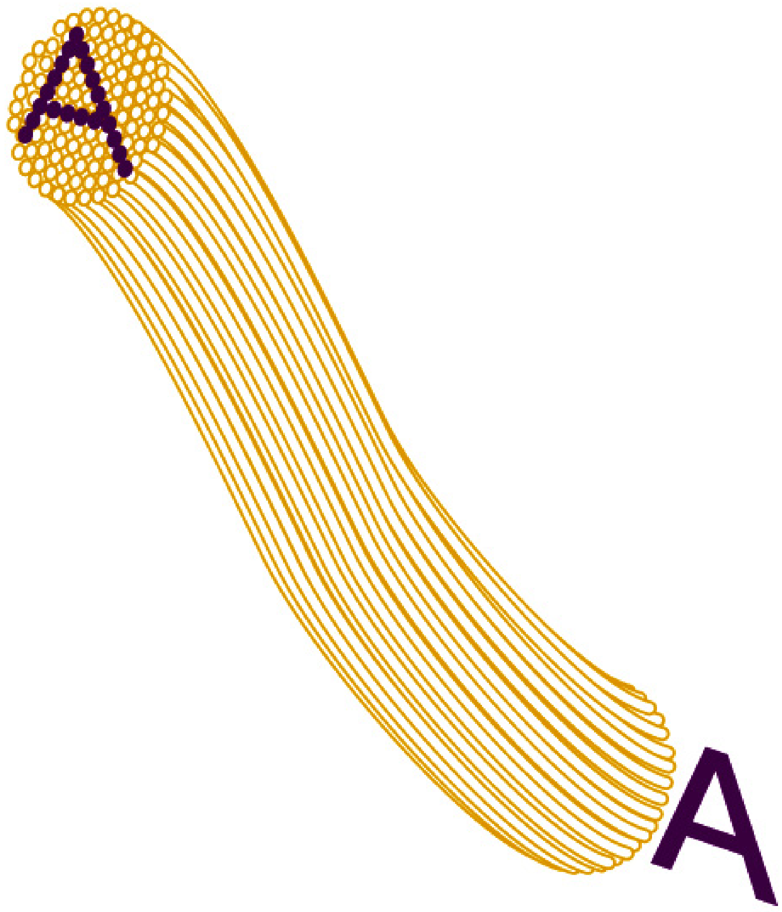
- $n_1\sin(\theta_1) = n_2\sin(\theta_2)$
- $\theta_2 = 90^o$
- $\theta_1 = \sin^{-1}(n_2 / n_1)$
- For water $\theta_1 = 49^o$
- For glass $\theta_1 = 42^o$

Fiber Optics

- Fiber optics for communication

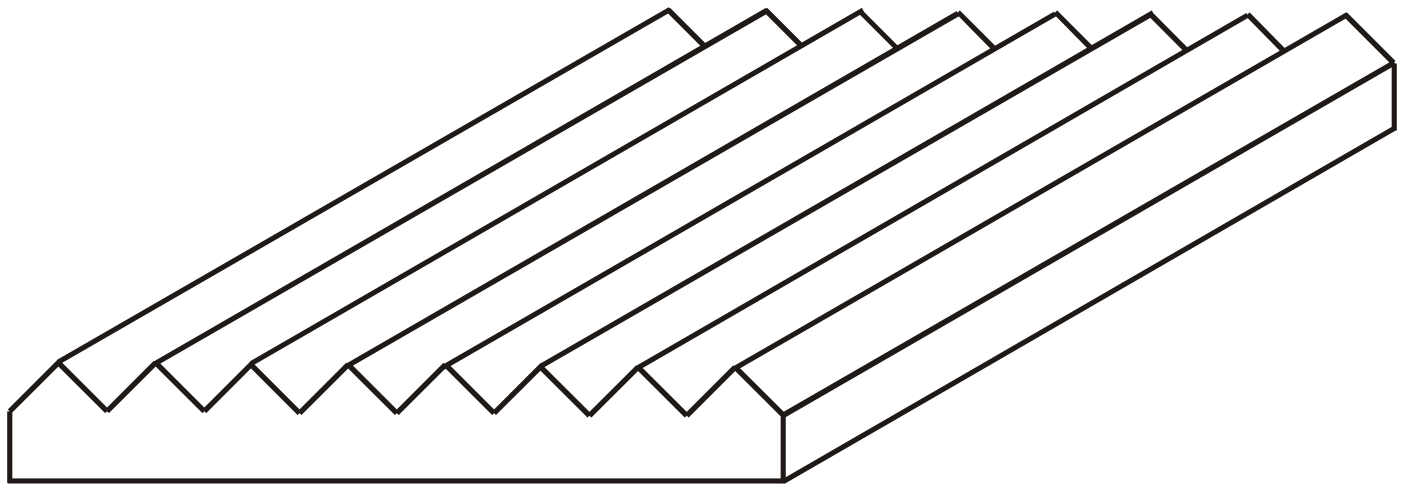


Fiber Optics
Endoscopes



(a)

Guiding film
3M Optical Lighting Film (OLF)



Micro-replicated light guiding film uses linear 90 degree prisms

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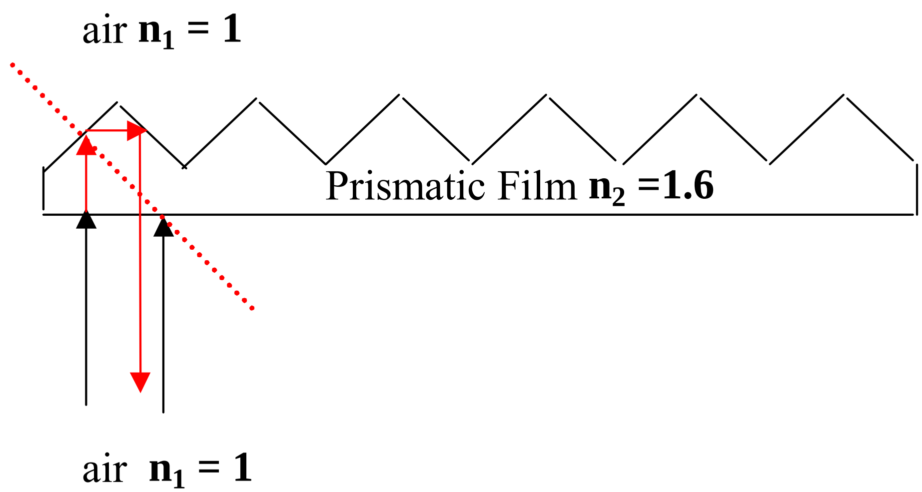
Samples

Rainbow

Reflective side

Transparent side

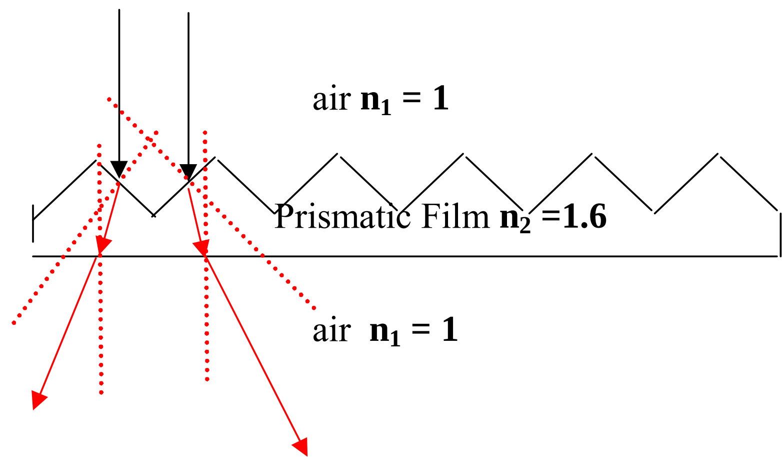
Image deformations



The critical angle for total internal reflection is

$$\alpha_c = \sin^{-1}(n_1/n_2) = 38.7°.$$

The angle of incidence, 45°, is larger than critical, therefore a total internal reflection occurs and the light is reflected at the angle 45°. The same happens on the second face, so the light is send back and leaves the film at 180° to the original direction.



The light comes from the medium with a smaller so there is no total internal reflection. The refracted angle is

$\alpha_r = \sin^{-1}(\sin(45°)n_1/n_2) = 26.2°$.

The incidence angle on the bottom surface is

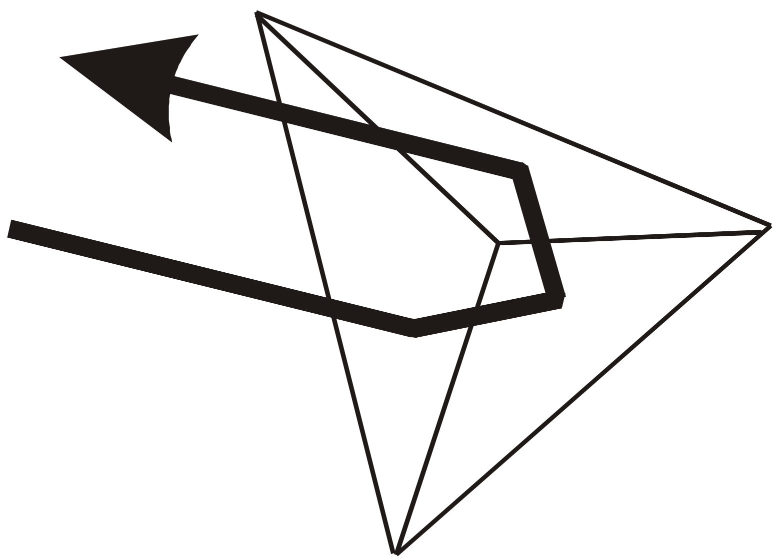
$45 - 26.2 = 18.8$

which is less than critical angle so there in no total internal reflection and we have an other refraction:

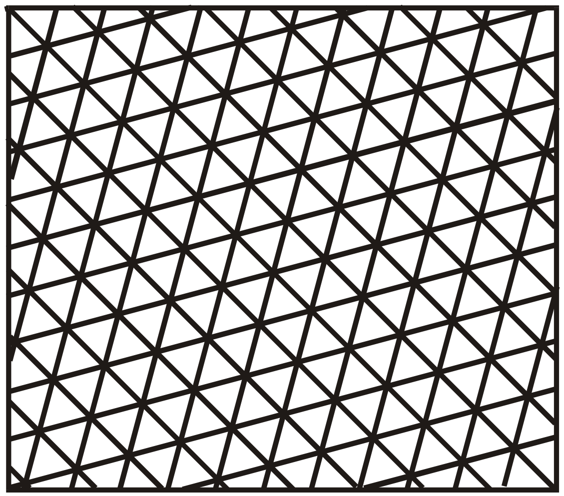
$\alpha_{r2} = \sin^{-1}(\sin(18.8°)n_2/n_1) = 31°$.

Retro-Reflection

Light undergoing 1- 3 reflections from a corner cube with the inner reflecting surfaces returns at 180 degree to the incident light - “retro-reflection”.

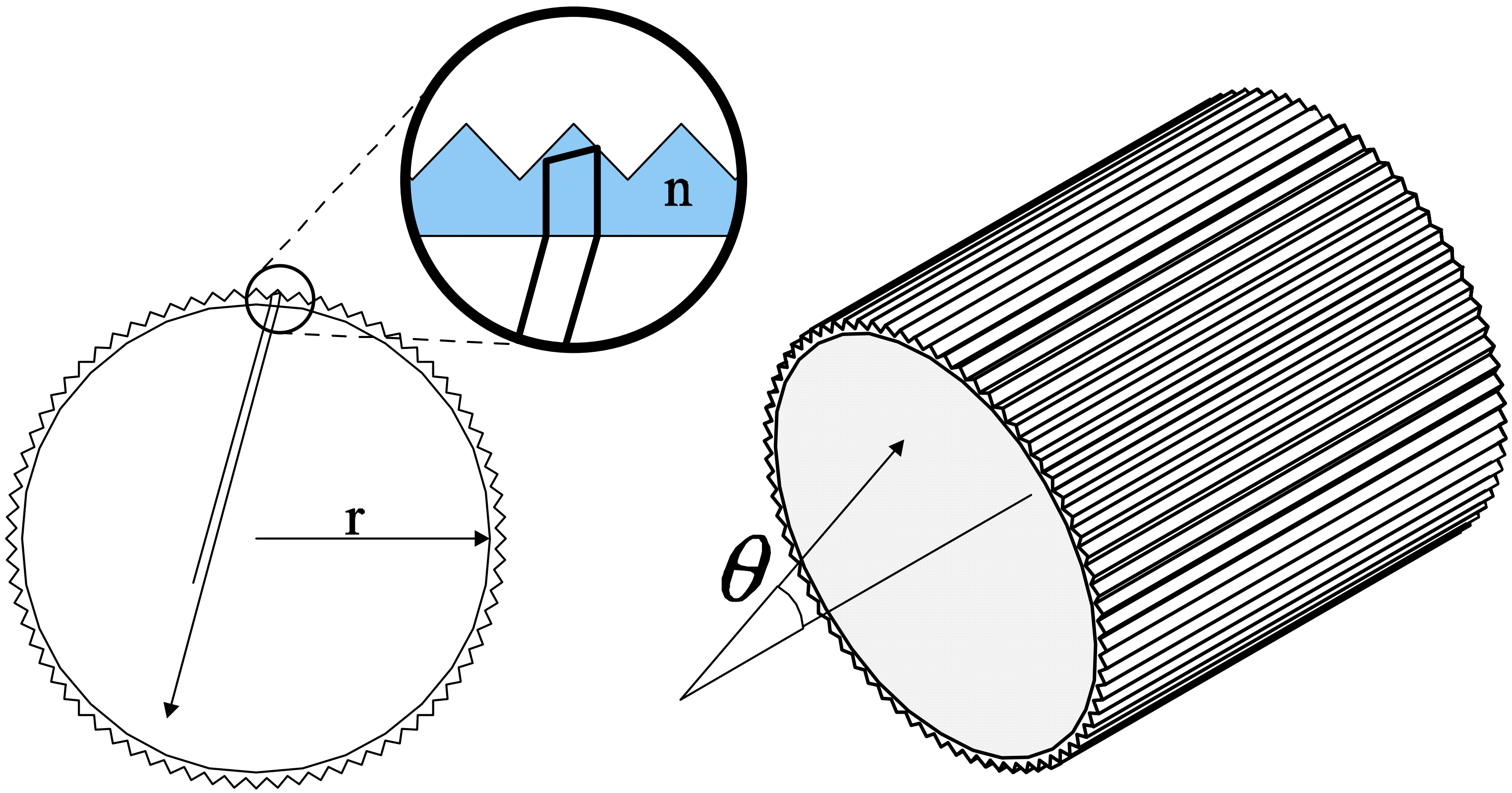


3M Diamond Grade^{TM} Reflective Sheeting



An array of corner cubes forms retro-reflective sheet material

The prism light guide



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McDonald's Roof Beam Light Guide System

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Vertical Light Guides 3M Bldg. 275 St. Paul, MN

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Light Guide Illumination of Boston’s Callahan Tunnel

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Highly directional down lighting from new Light Guides and Sulfur Lamps in Smithsonian Air and Space Museum

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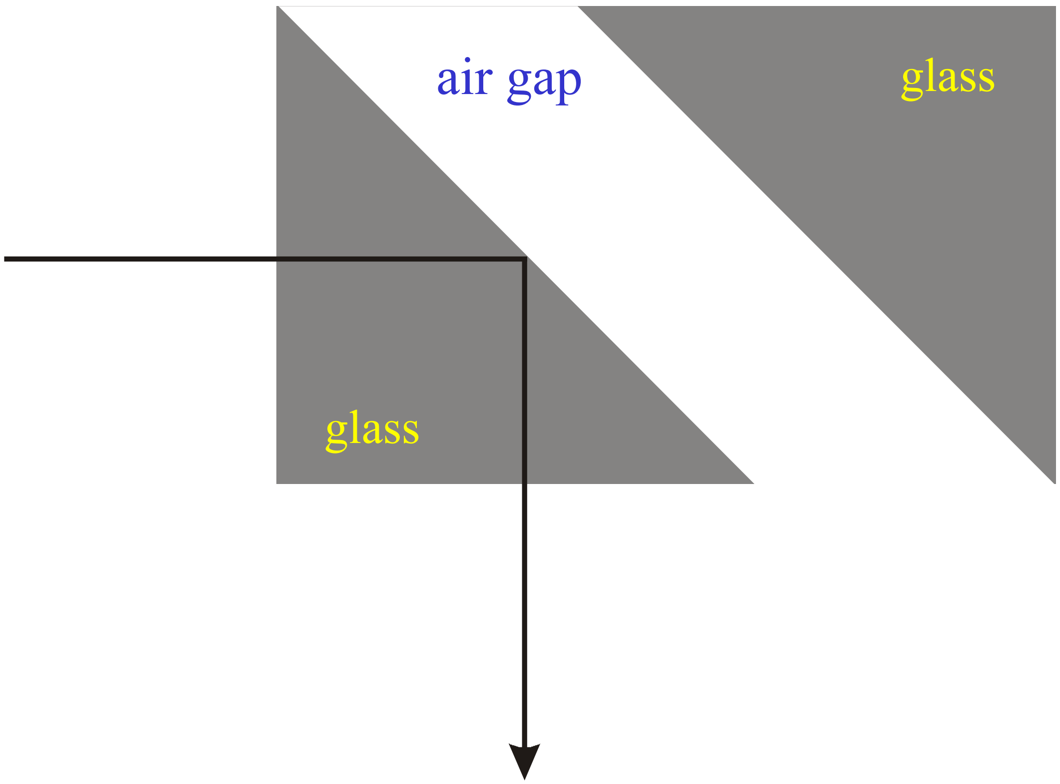
Solar Lighting Systems based on Prism Light Guides

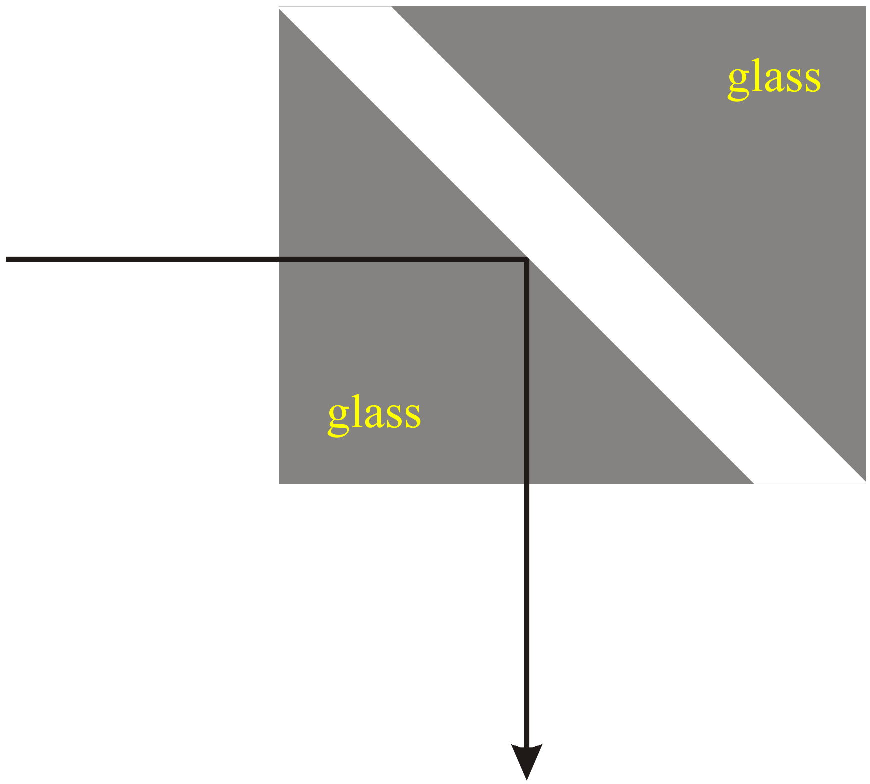
- Long History
- New Developments will be presented by Alex

Frustrated TIR – applications to “real” black and white reflective display.
Electronic paper?

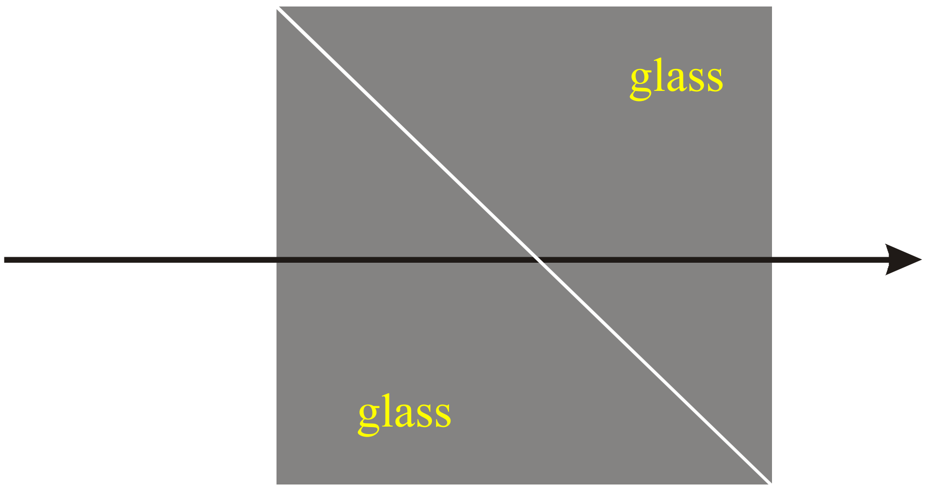
TIR...



TIR...



Frustrated TIR



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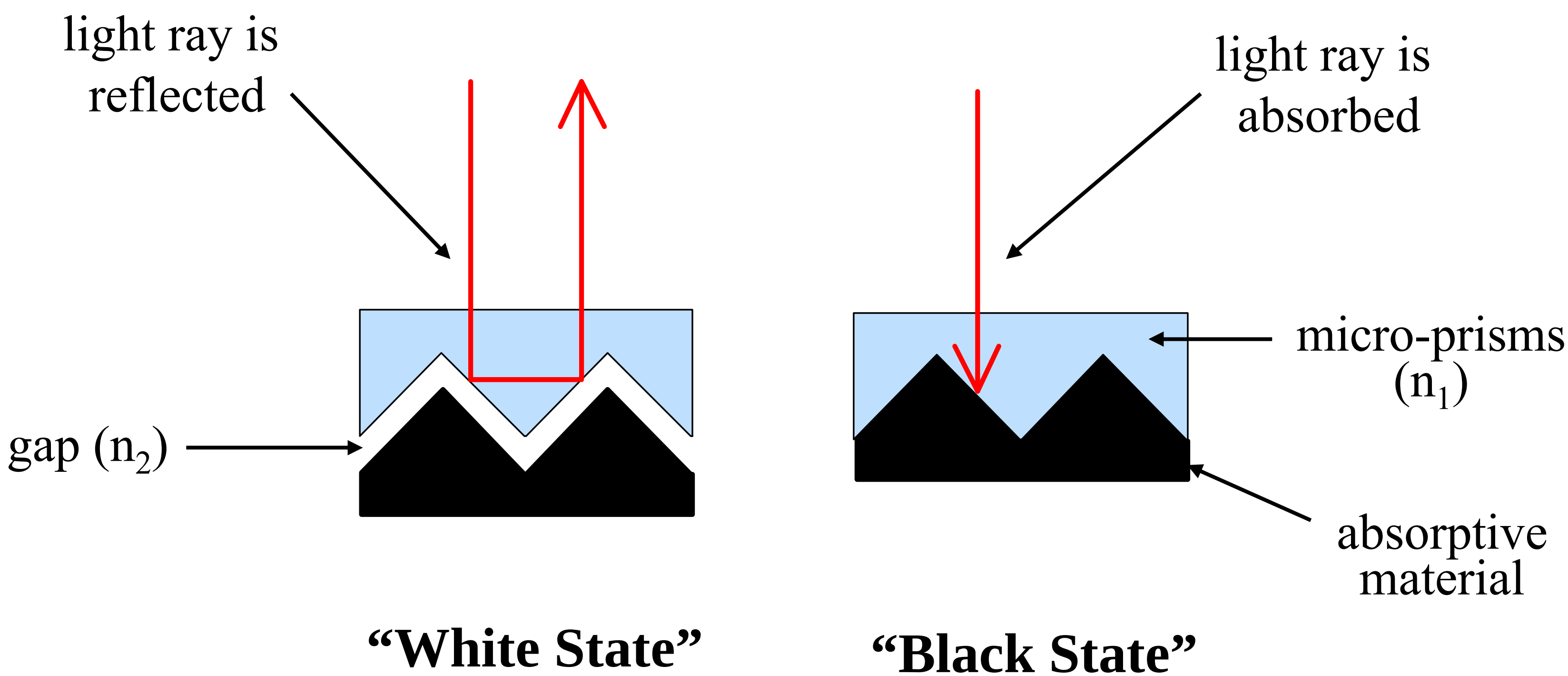
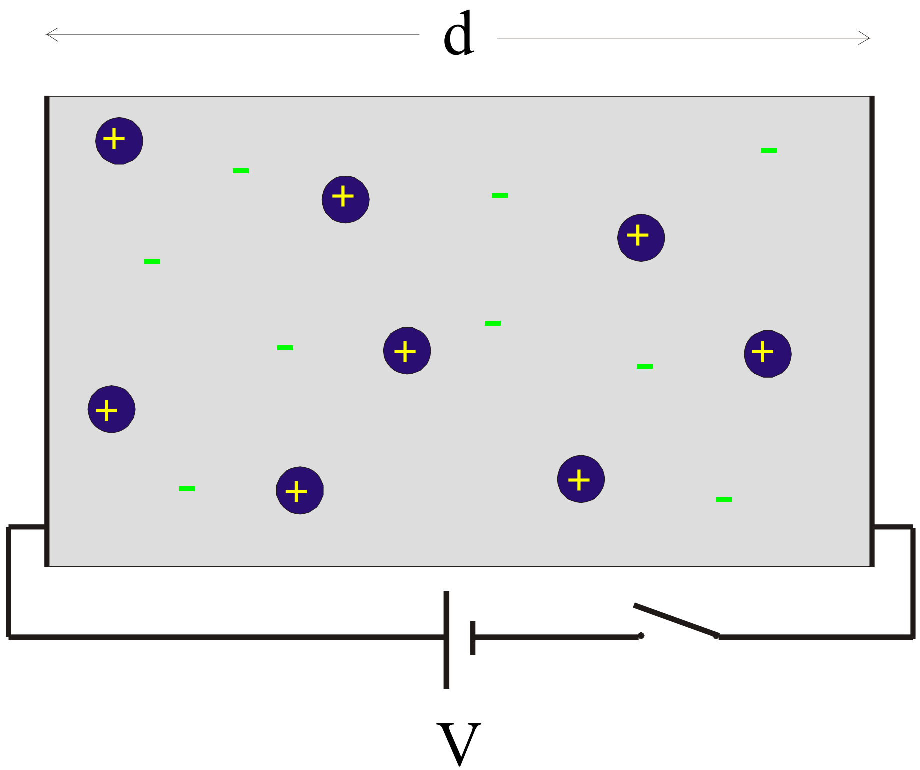
Principle of a TIR-based Reflective Display



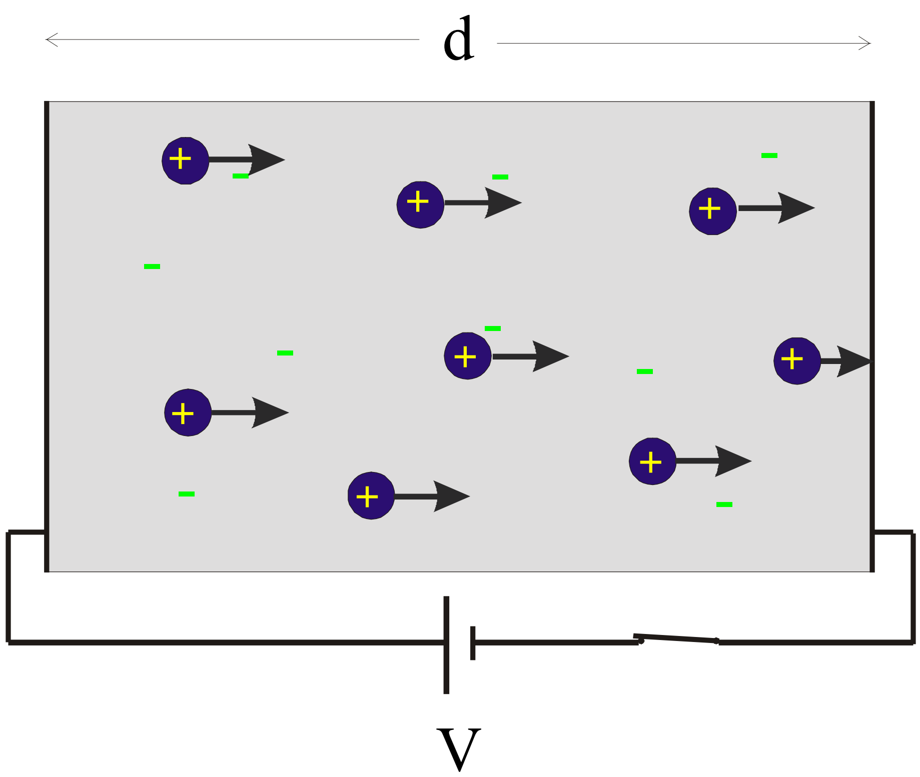
Electrophoresis

- Controlled motion of charged particles in a medium in response to an applied electric field



electrophoretic mobility: μ

Slide by Michele Mossman



Particle velocity: $v = \frac{\mu V}{d}$

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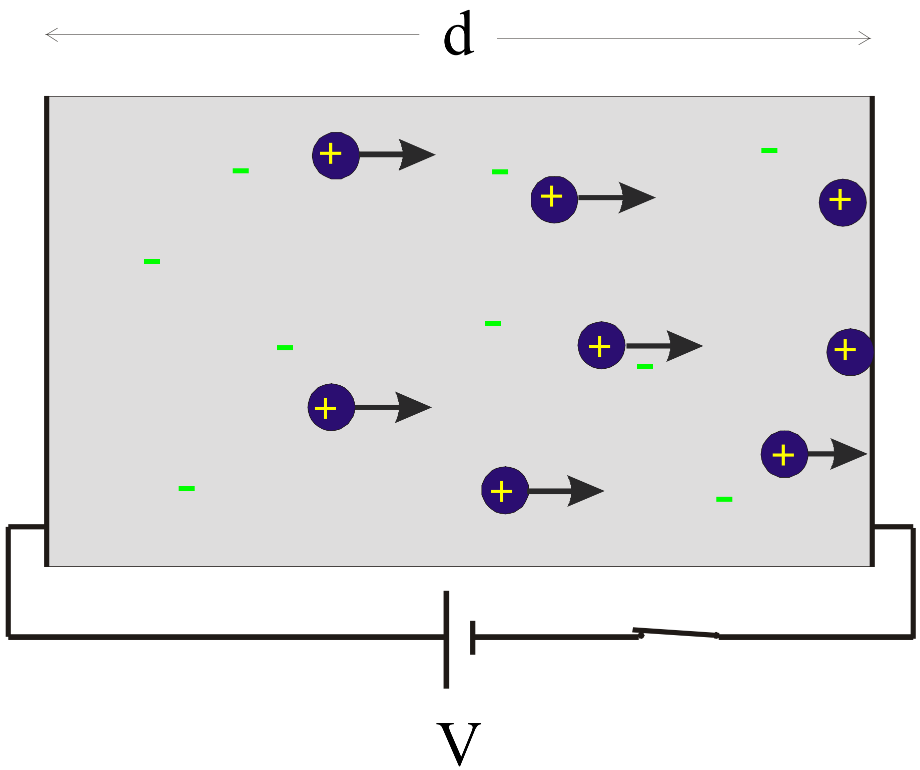

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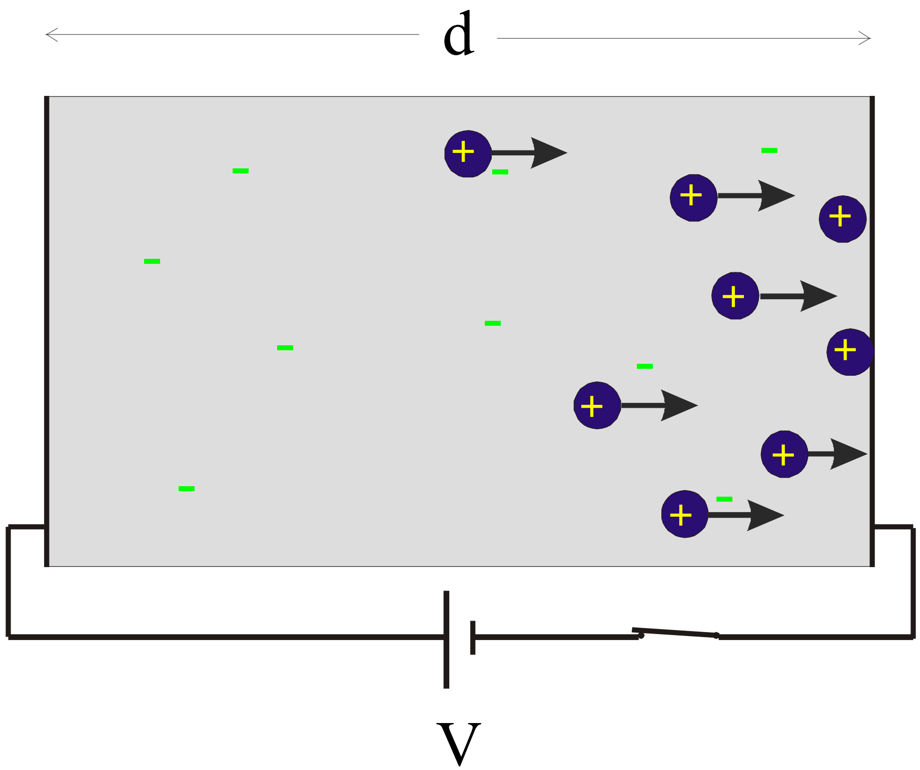

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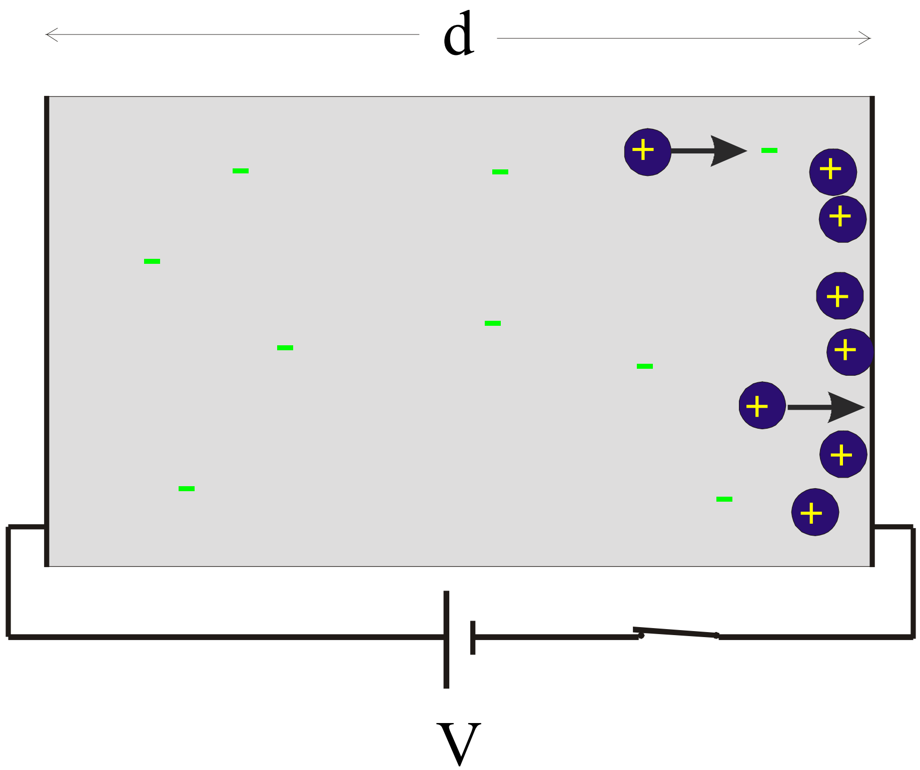

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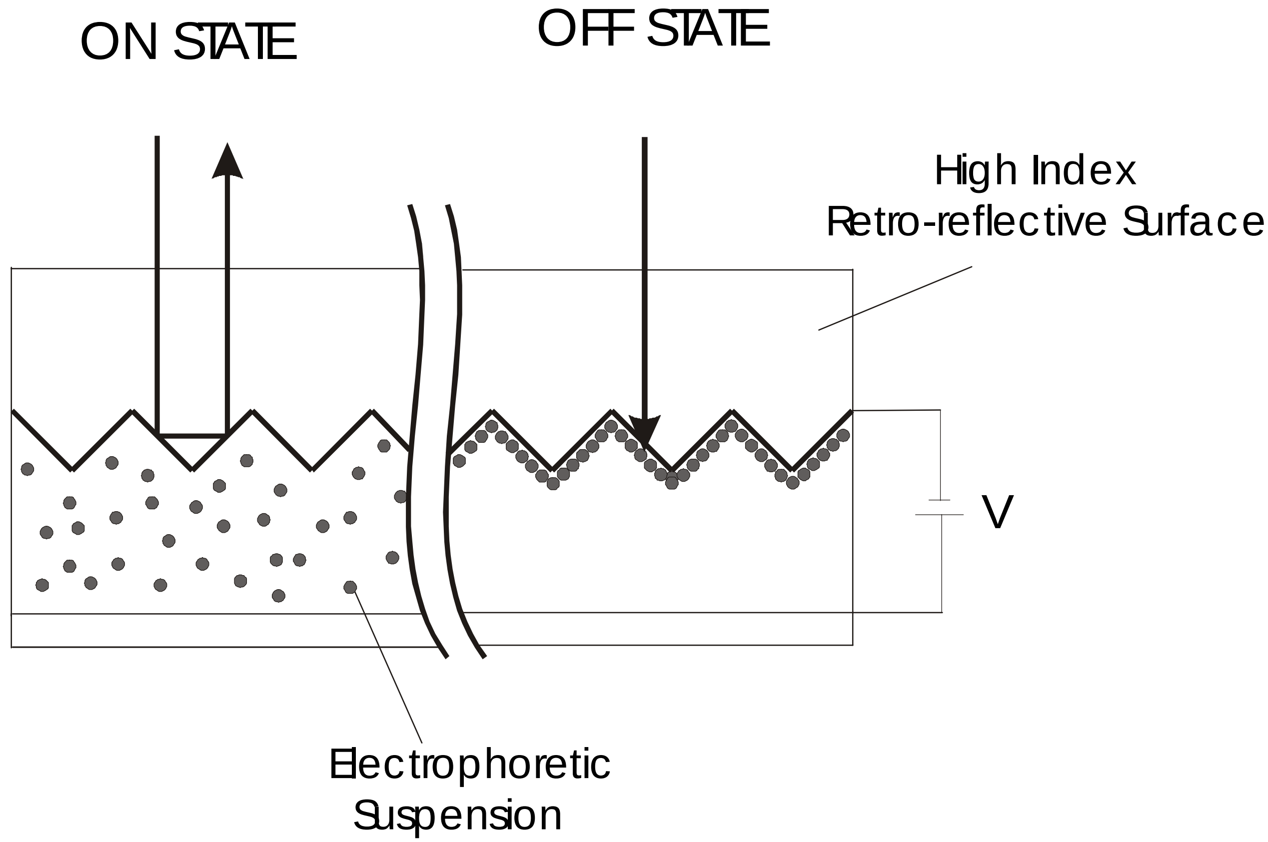
Electrophoretic TIR Display



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CLEAR Electronic Paper

Conventional LCD Display

Non-switching Demonstration Of TIR-based reflective display

The TIR-based reflective display has an image quality very similar to printed white paper.

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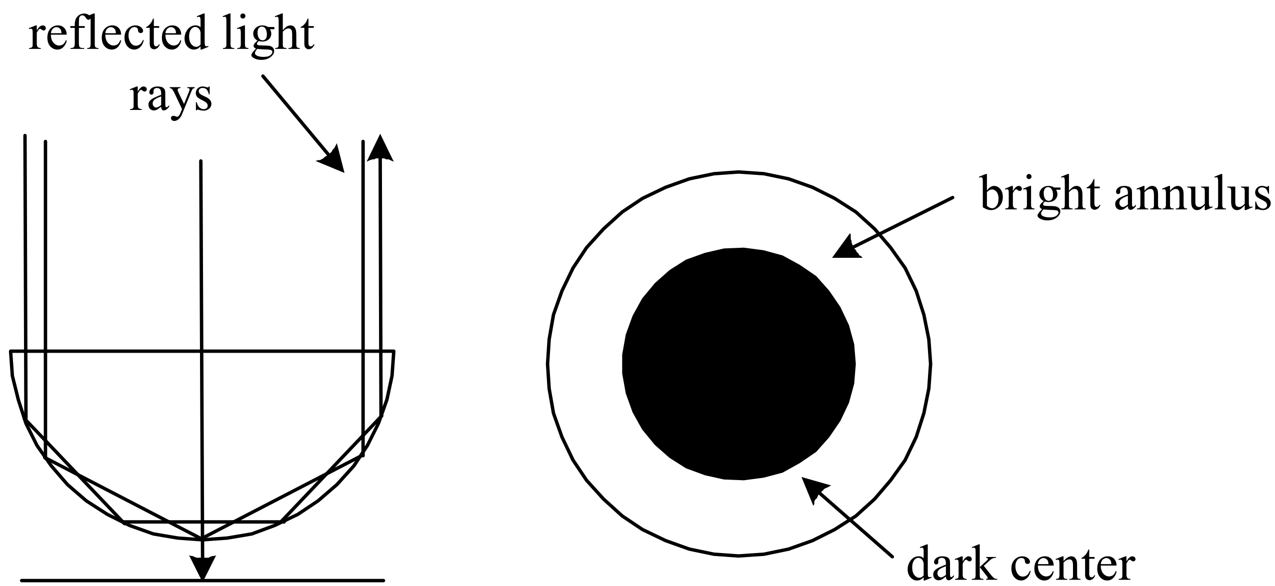
Hemispherical Microstructures



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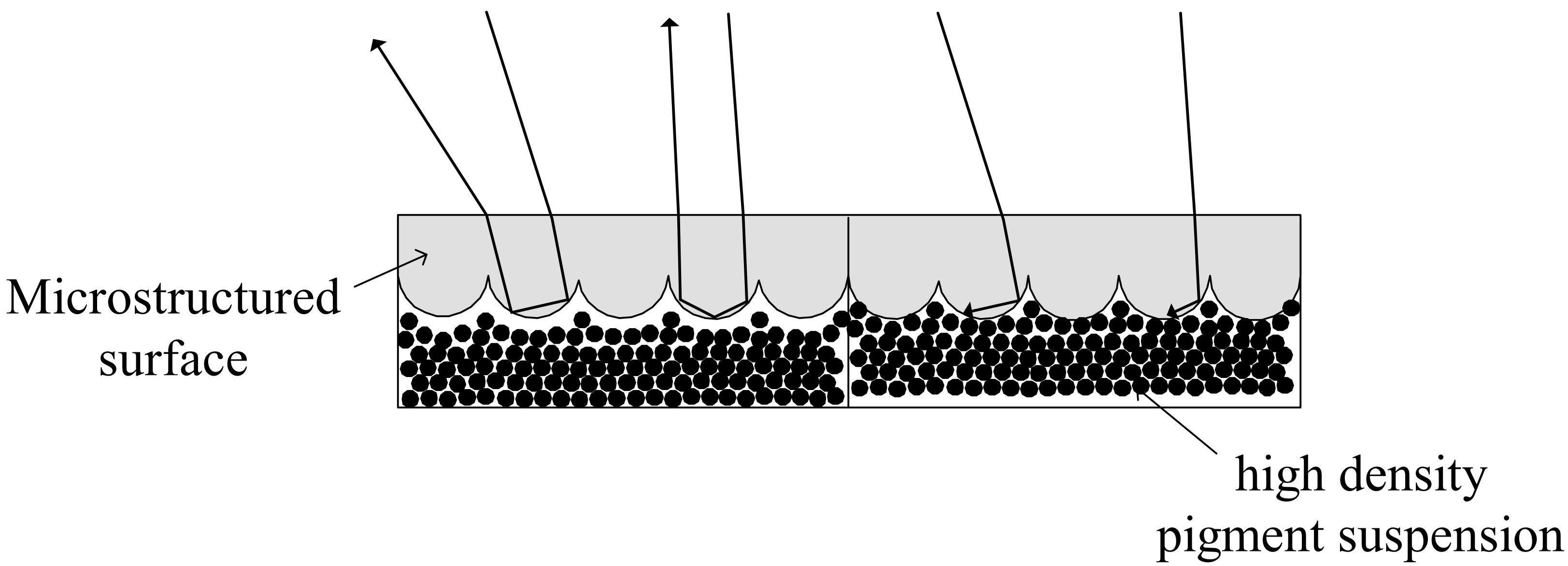
Hemispherical Microstructures



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New concept of electronic display – High Dynamic Range Display from our Spin-off company

Brightside Technologies - Helge

Light: from simple optics to amazing applications

The Solar Lighting Project at UBC

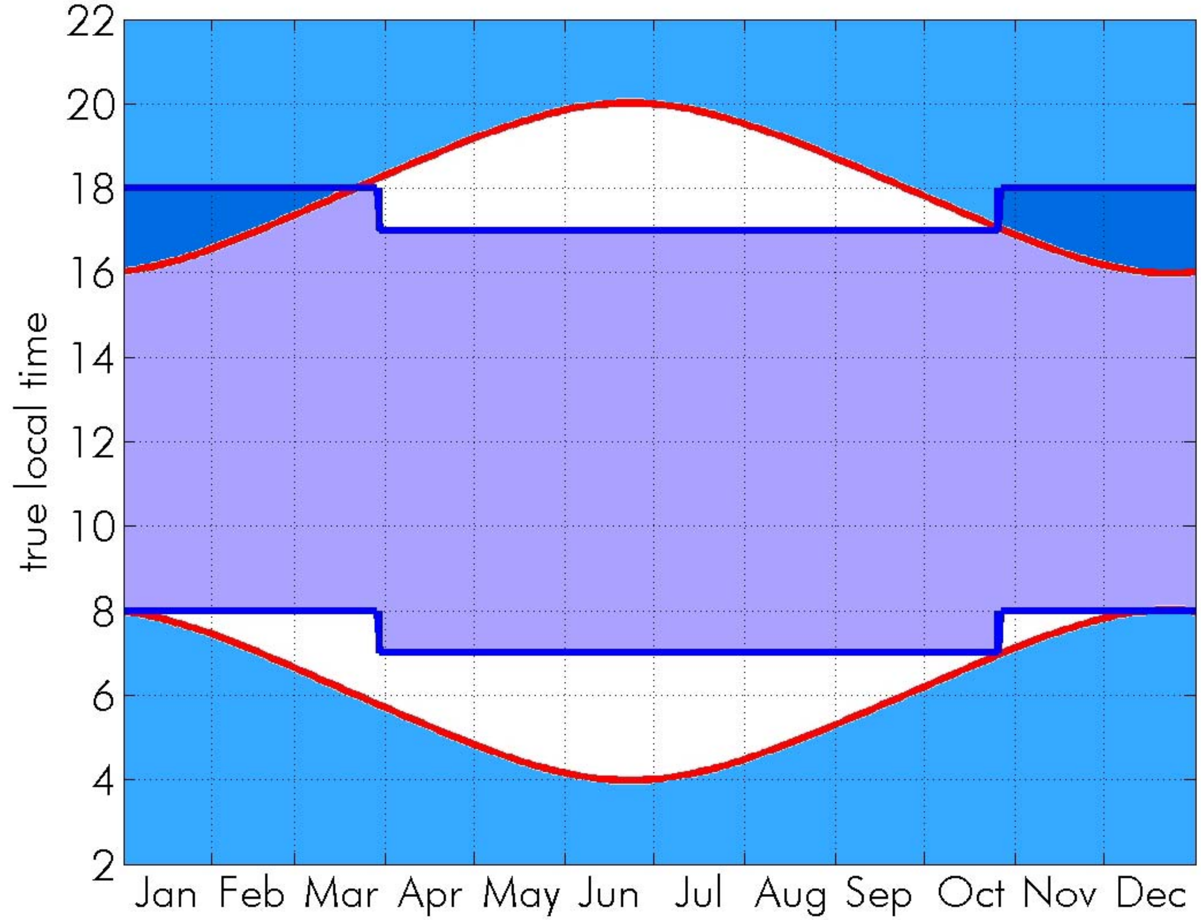
Alexander Rosemann

February 18, 2006

Solar Lighting Project – Project Partners

- Korea Institute of Energy Research, Taejon, Korea
- Natural Resources Canada, Ottawa, ON
- University of British Columbia Vancouver, BC

Motivation for daylight utilisation



In Vancouver, daylight is available during 94 % of the working hours

Project Aim

- Daylight Utilisation in Deeper Building zones
- Use of materials that are potentially low-cost in mass production
- Demonstration of the system in a portable test environment
- Demonstration of the system in a real building
- …

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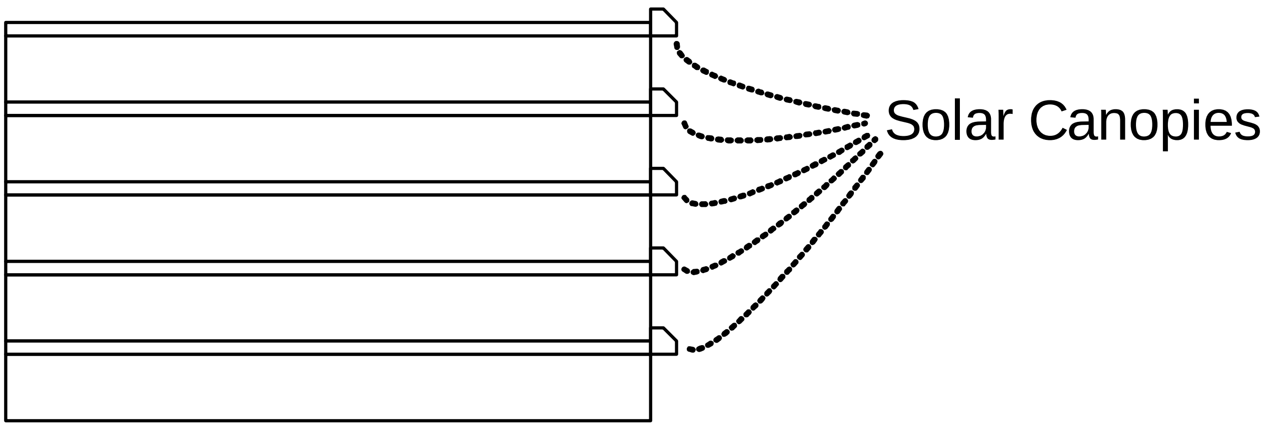
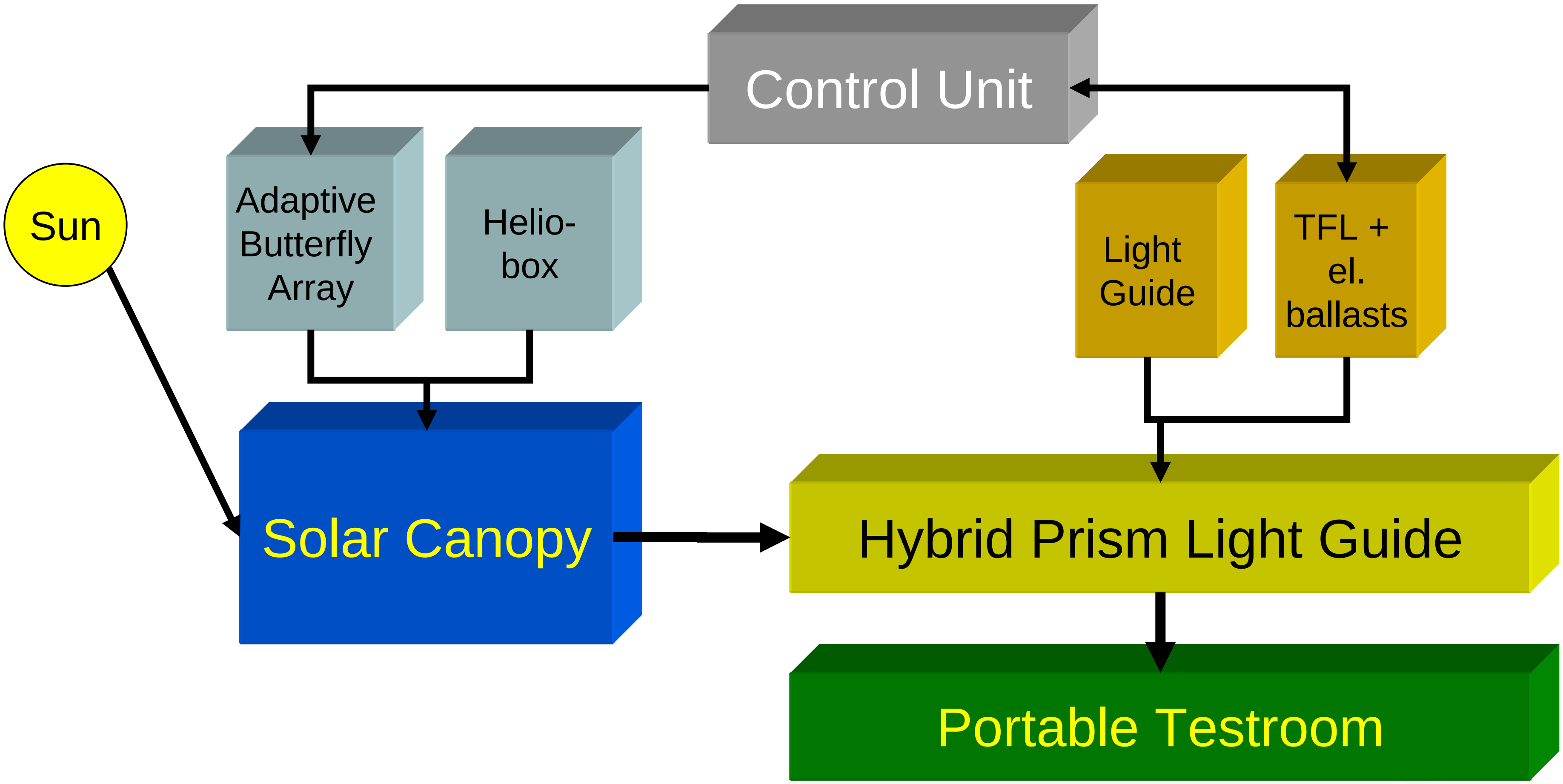
Basic Idea



Example building cross section with solar canopies on south-facing wall feeding prism light guides

UBC Solar Lighting Project



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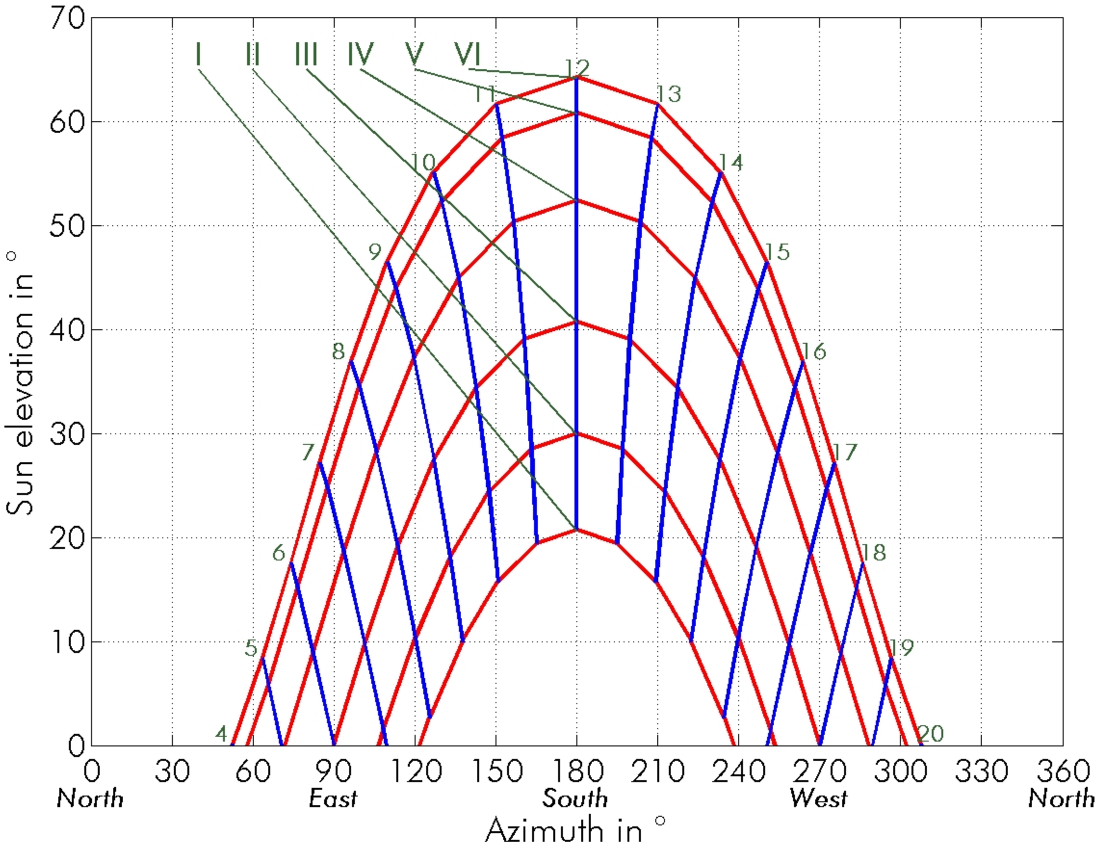
Heliostat design



Sun positions in Vancouver

Adaptive Butterfly Array

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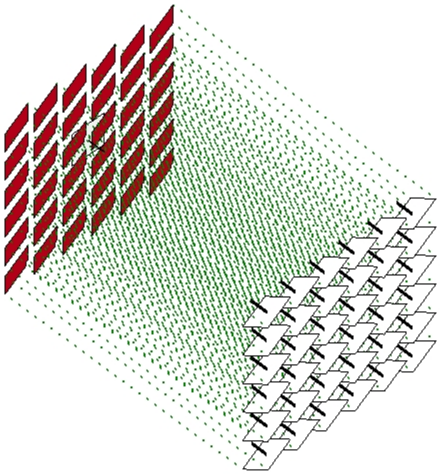
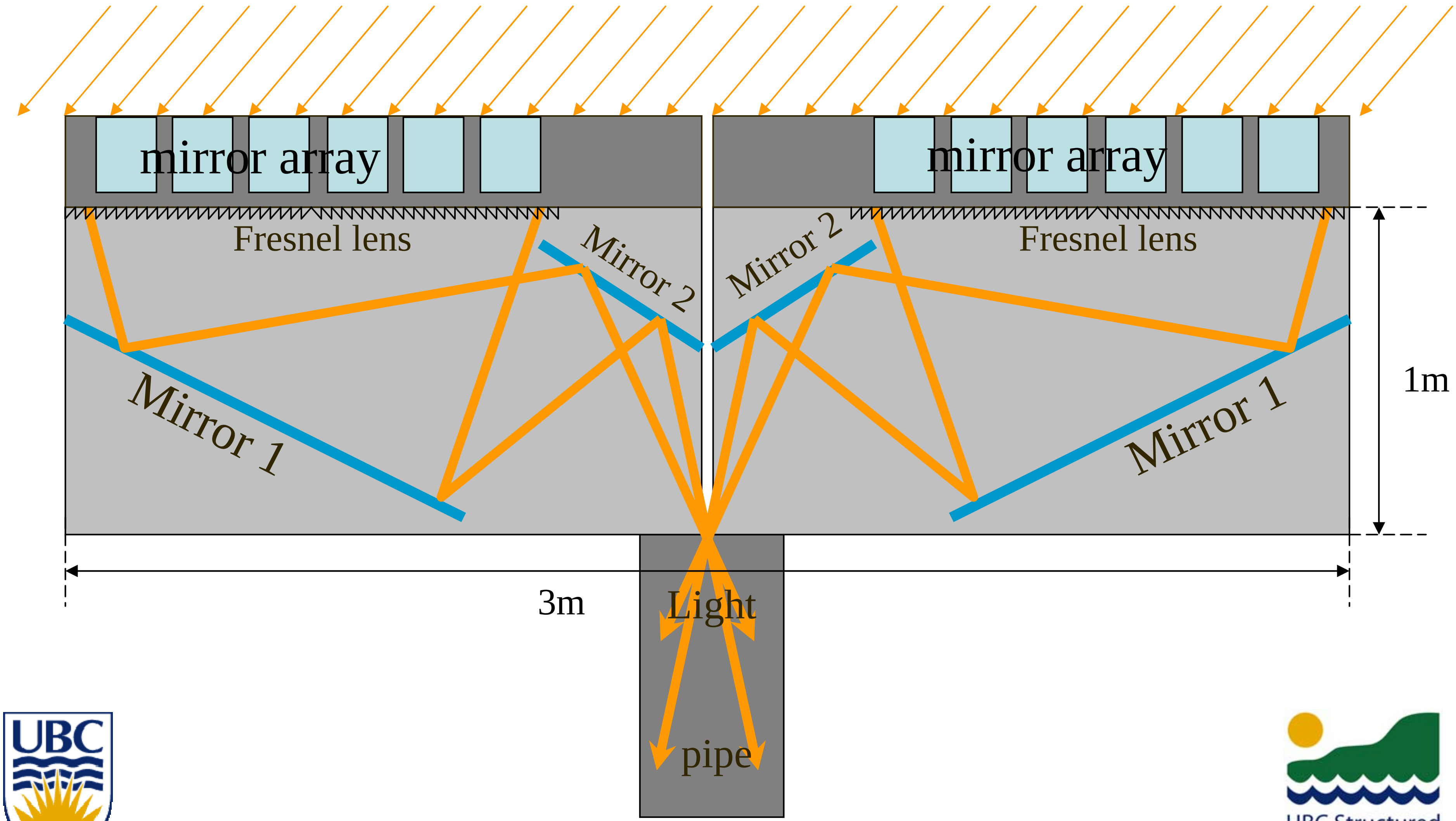
Adaptive Butterfly Array – April 21st

2 pm



Canopy System



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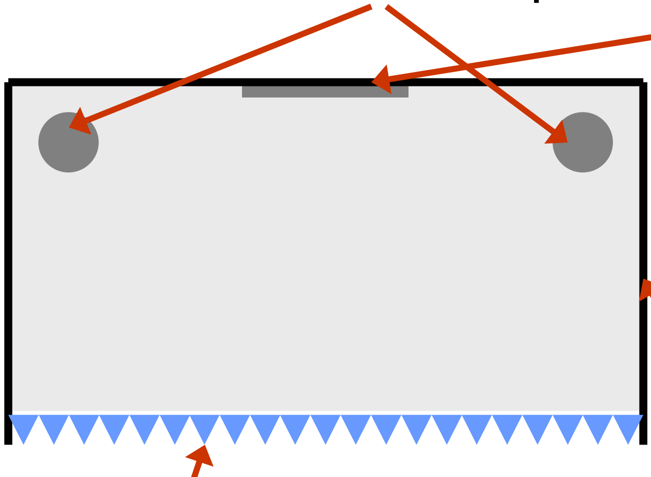
Prism Light Guide



Portable testroom

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South Wall

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Redirecting the direct sunlight with the Adaptive Butterfly Array

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Measurement Overview

- Artificial Lighting
- Daylighting
  - Daylight entering through the South window
  - Daylight entering through the solar canopy system

What did we measure?

Illuminance (Luminous Flux / Area), measured in lx

Measuring height: 0.8 m

What are the target values?

Recommendation in office buildings: 500 lx on the task area and 300 lx in surrounding areas

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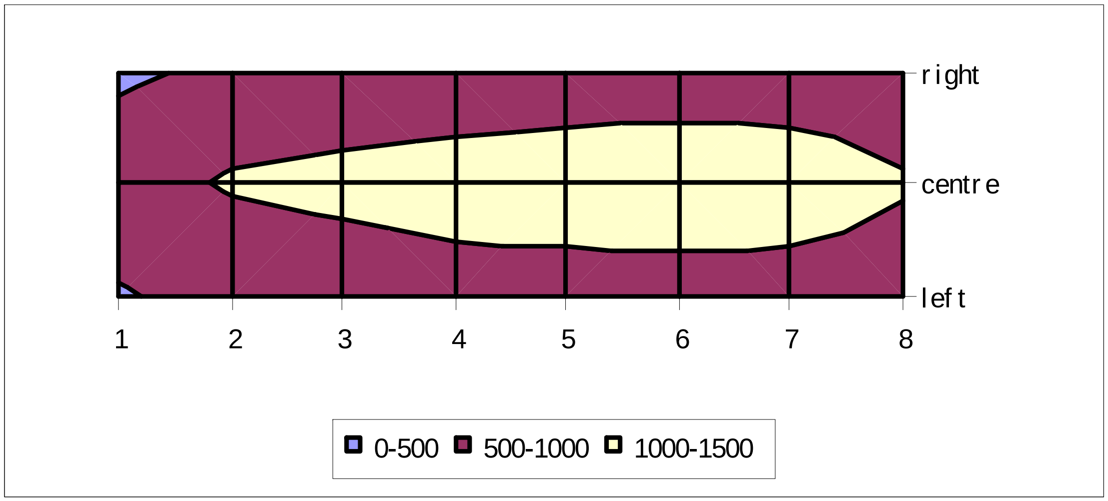
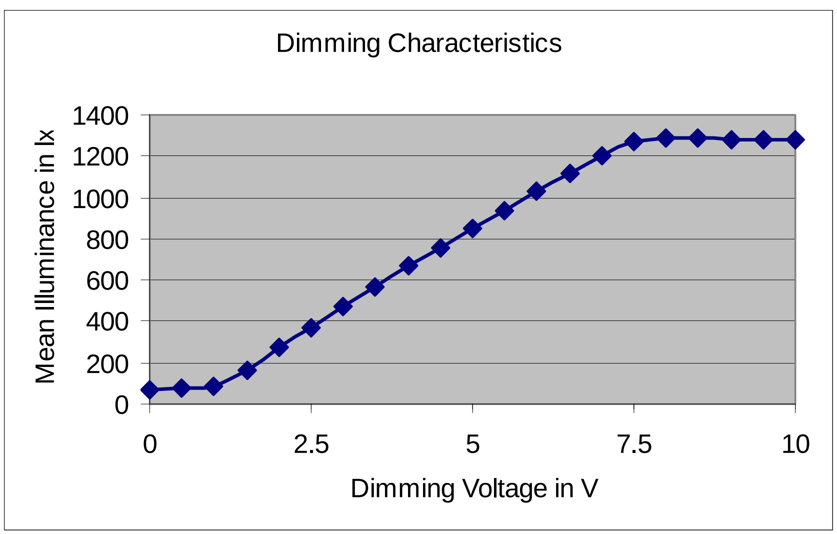
Artificial lighting dimming characteristics



Illuminance distribution for a dimming voltage of 10 V
The relative illuminacne distribution does not change with dimming.

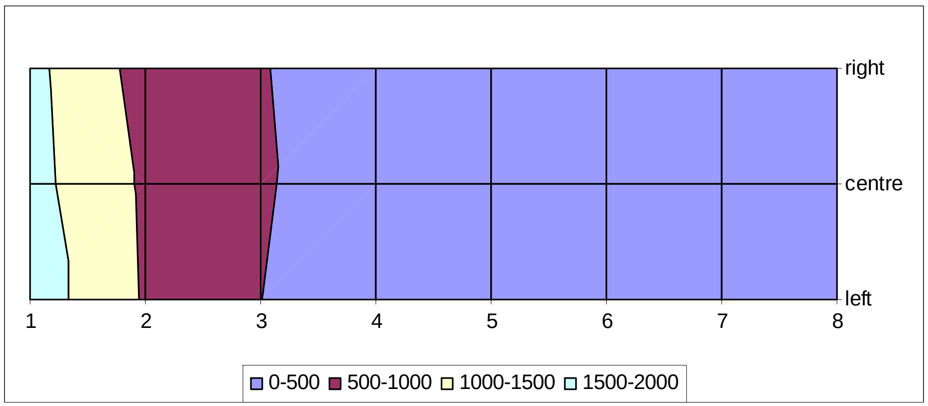


The mean illuminance varies with the dimming voltage as shown in the figure.
This data is useful for the control algorithm

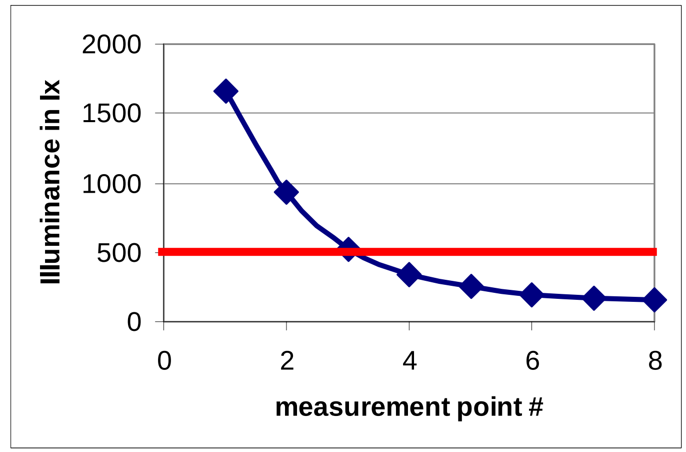
Daylighting measurements 1

Setup: SOUTH WALL uncovered
Hybrid light guide blocked

$\overline{E} = 527\ lx$



Illuminance distribution



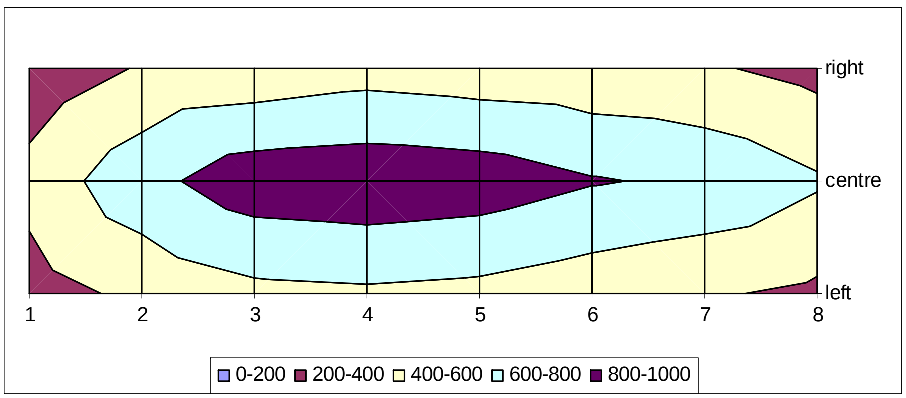
Illuminance along the centre line

The illuminance is very non-uniform. Although the mean illuminance is above 500 lx, the values drop below 500 lx in the second half of the room. For this scenario artificial lighting is required all the time.

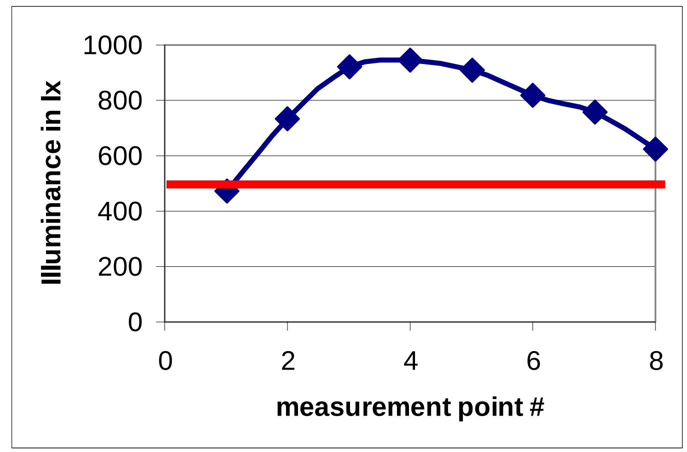
Daylighting measurements 2

Setup: SOUTH WALL covered
Hybrid light guide open
11:08 am TLT

$$\overline{E} = 550\ lx$$



Illuminance distribution



Illuminance along the centre line

The mean illuminance is above 500 lx, the values are well above 500 lx in the centre line, even in the second half of the room. For this scenario artificial lighting is <u>not</u> required.

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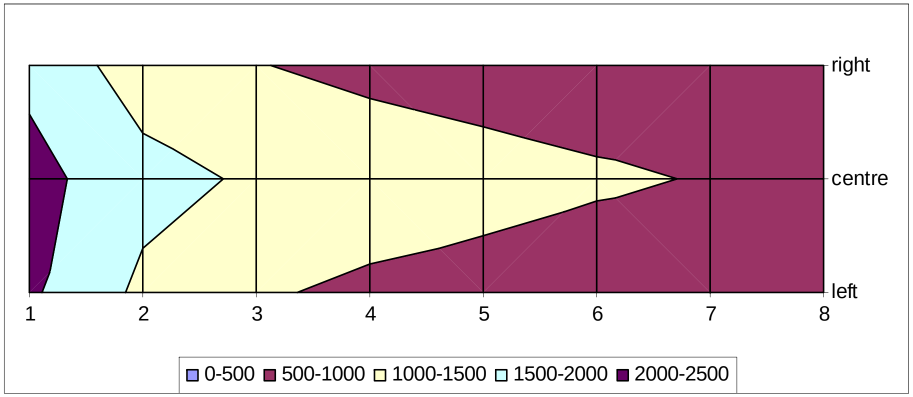
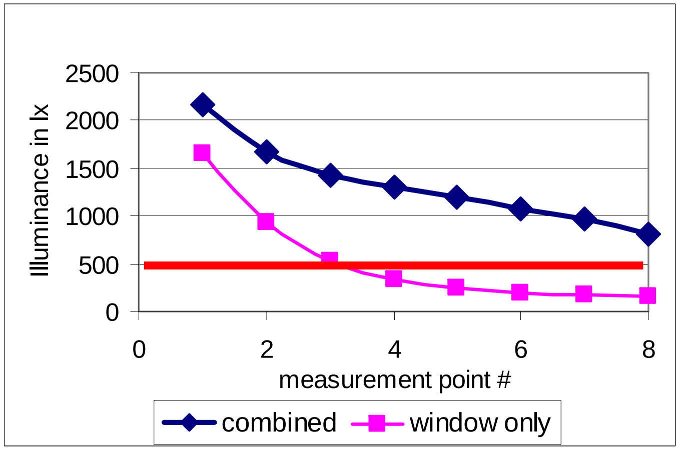
Combined Daylighting Results

Setup: SOUTH WALL open
Hybrid light guide open
Simulated results

$\overline{E} = 1094\ lx$



Illuminance distribution



Illuminance along the centre line

The mean illuminance is above 500 lx, the values are well above 500 lx in the centre line, even in the second half of the room. For this scenario artificial lighting is <u>not</u> required.

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Illumination in deeper building zones

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Thank you for your attention

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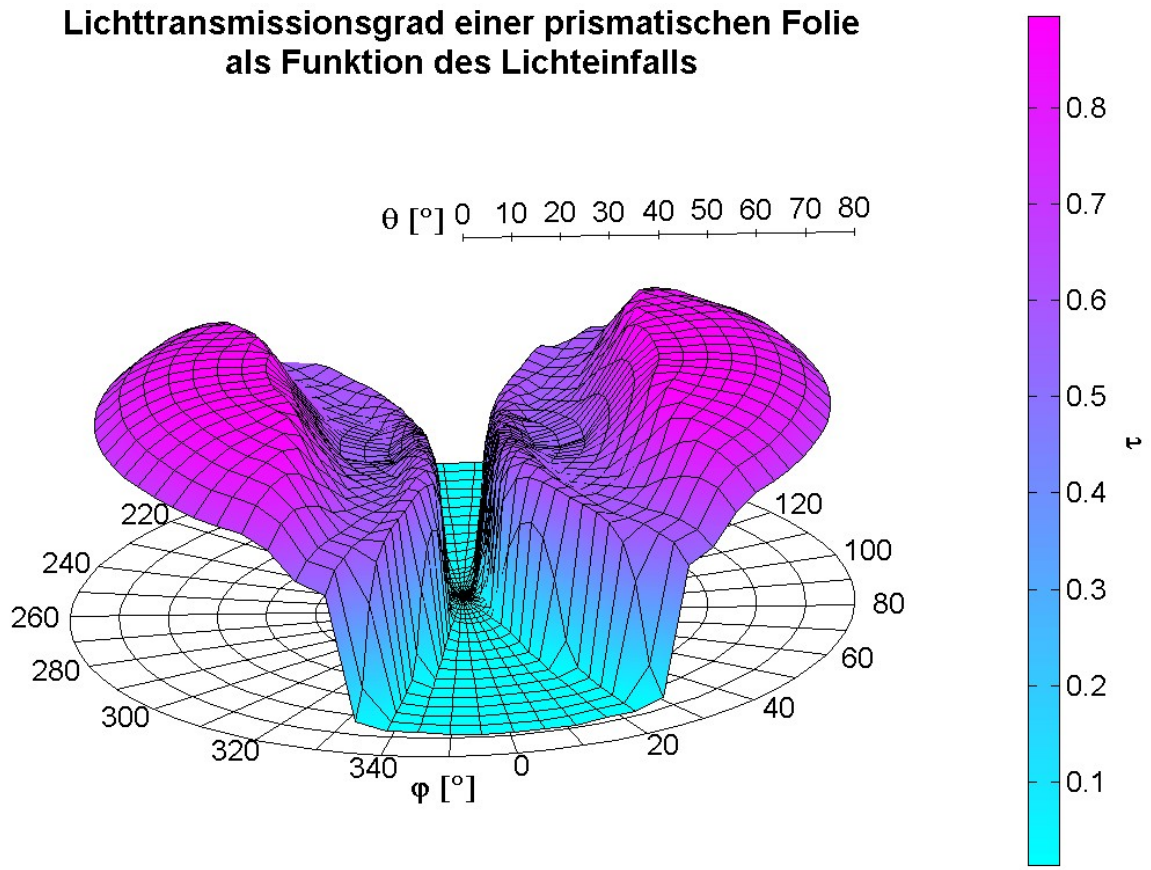
Luminous Transmittance of the optical lighting film



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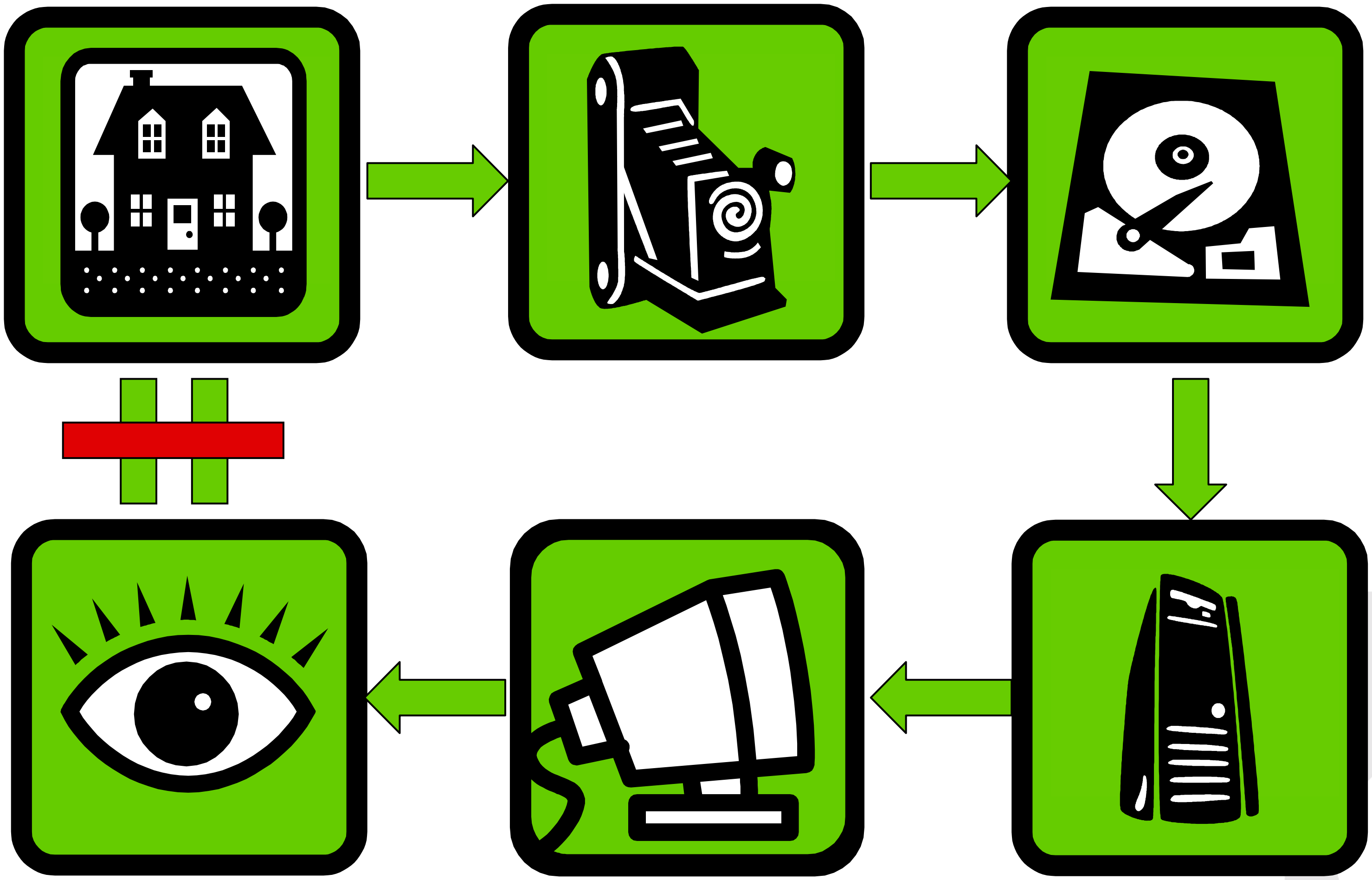
High Dynamic Range Imaging Pipeline

Helge Seetzen

February, 2006

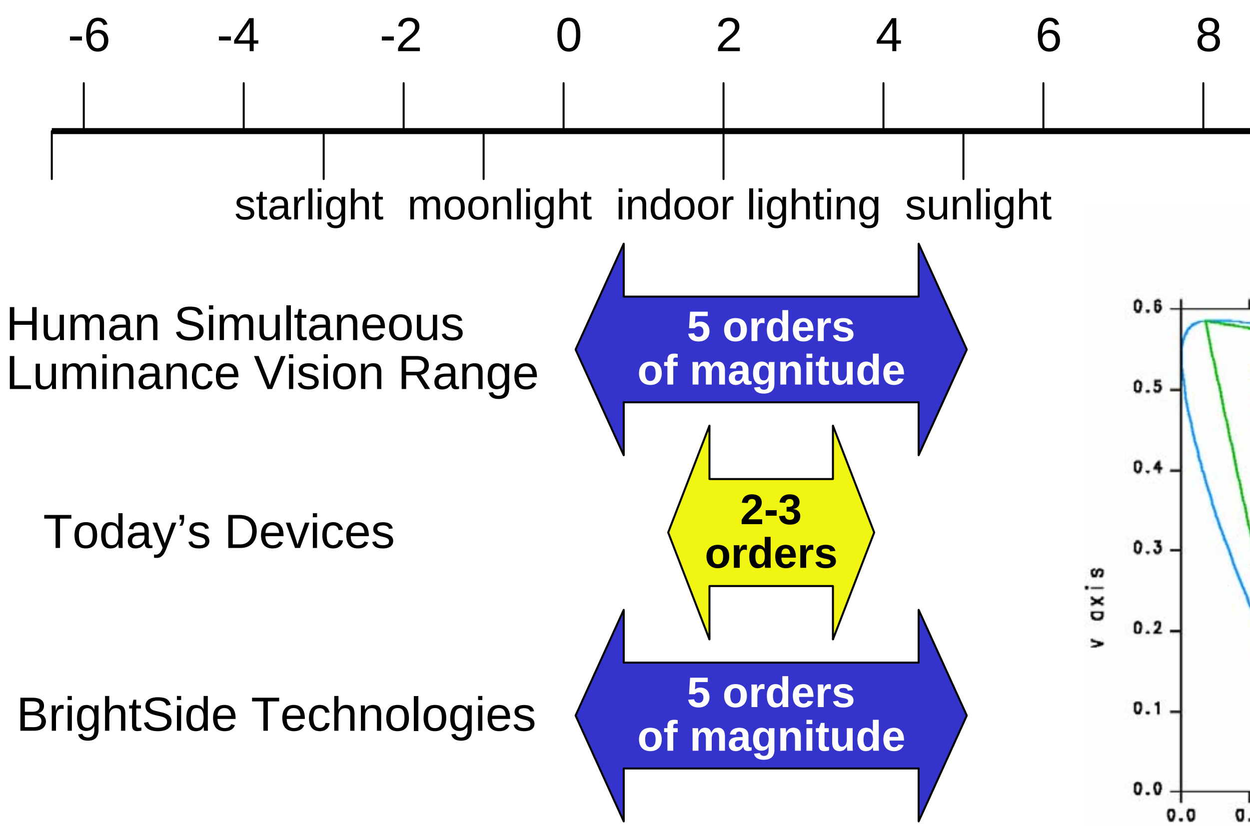
Imaging Pipeline – 8-bit rules!

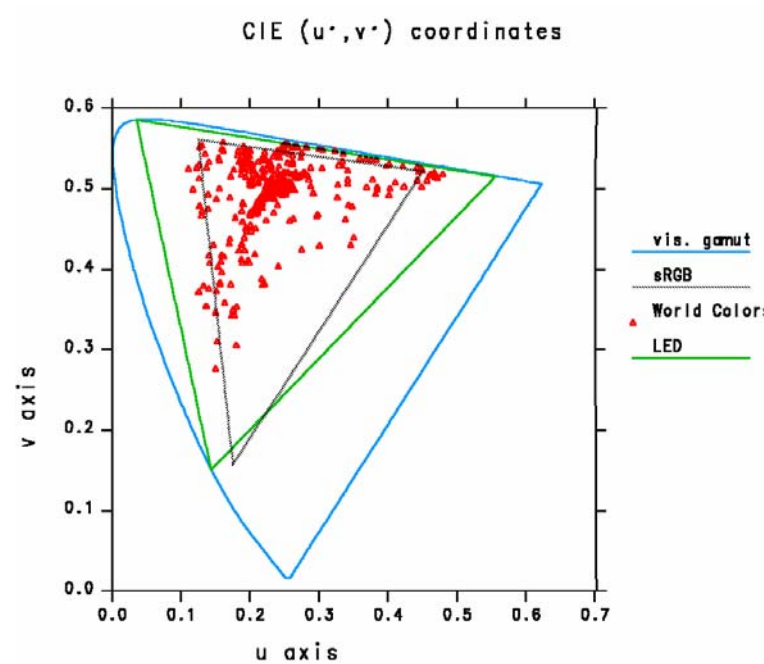


BRIGHTSIDE™

Image Quality – What are we missing?

Human Overall Luminance Vision Range
(14 orders of magnitude, scale in log cd/m2)



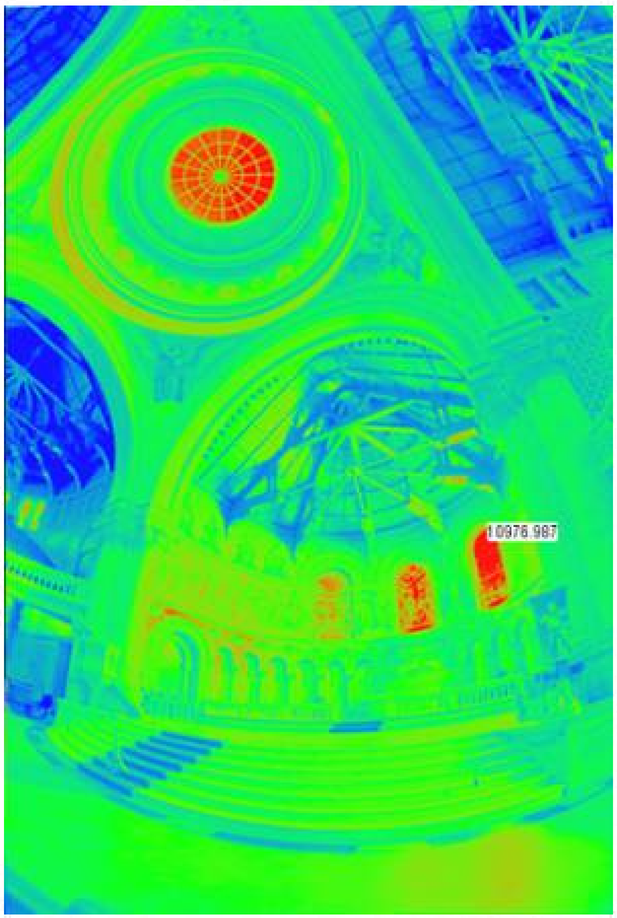


Overcoming the 8-bit Barrier

Requirements:

1. High Dynamic Range
2. Compatibility
   - New devices need to function in 8-bit environment and still deliver significant benefit
   - New devices need to be usable in stand-alone mode
3. Cost
   - Ideally no extra cost compared to 8-bit devices
   - If extra cost is necessary then in line with benefit

The Scene



Stanford Memorial Church
Courtesy Paul Debevec

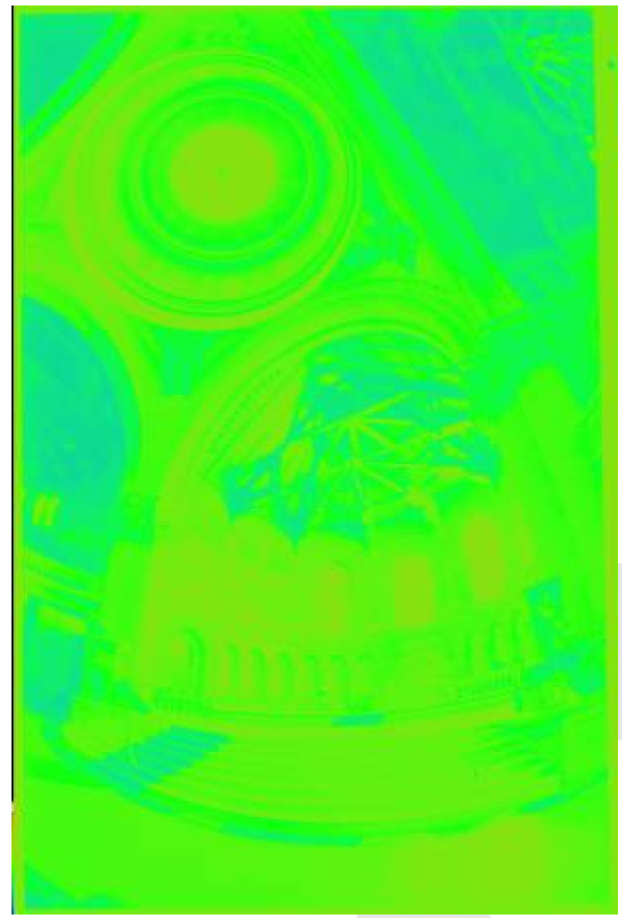


Image Capture – Multiple Exposures

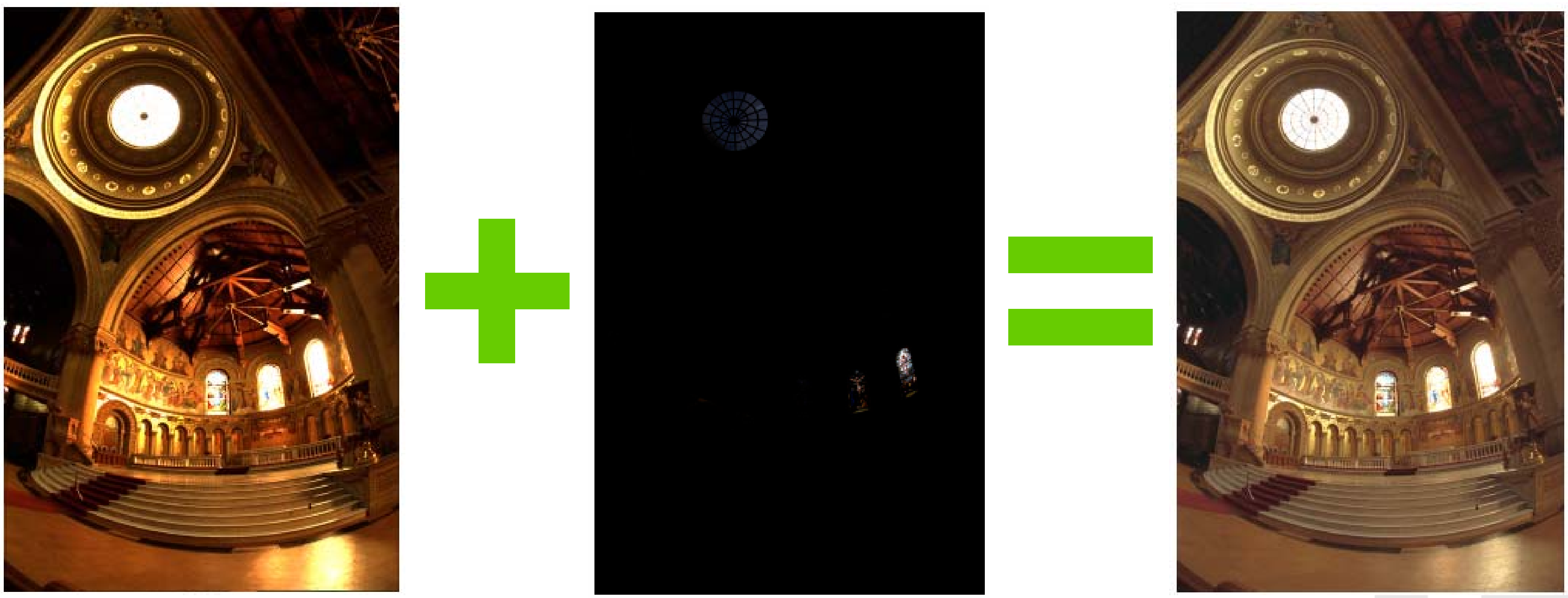
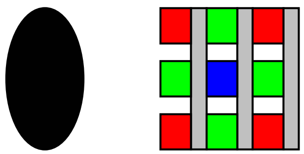
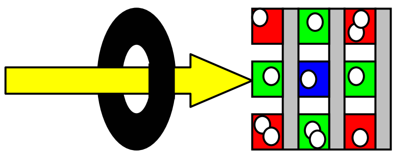


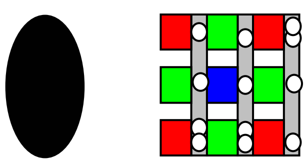
Image Capture – 8-bit to 16-bit CCDs



Shutter is closed



Shutter opens and light hits the CCD.



Shutter closes (transfer to register and readout)

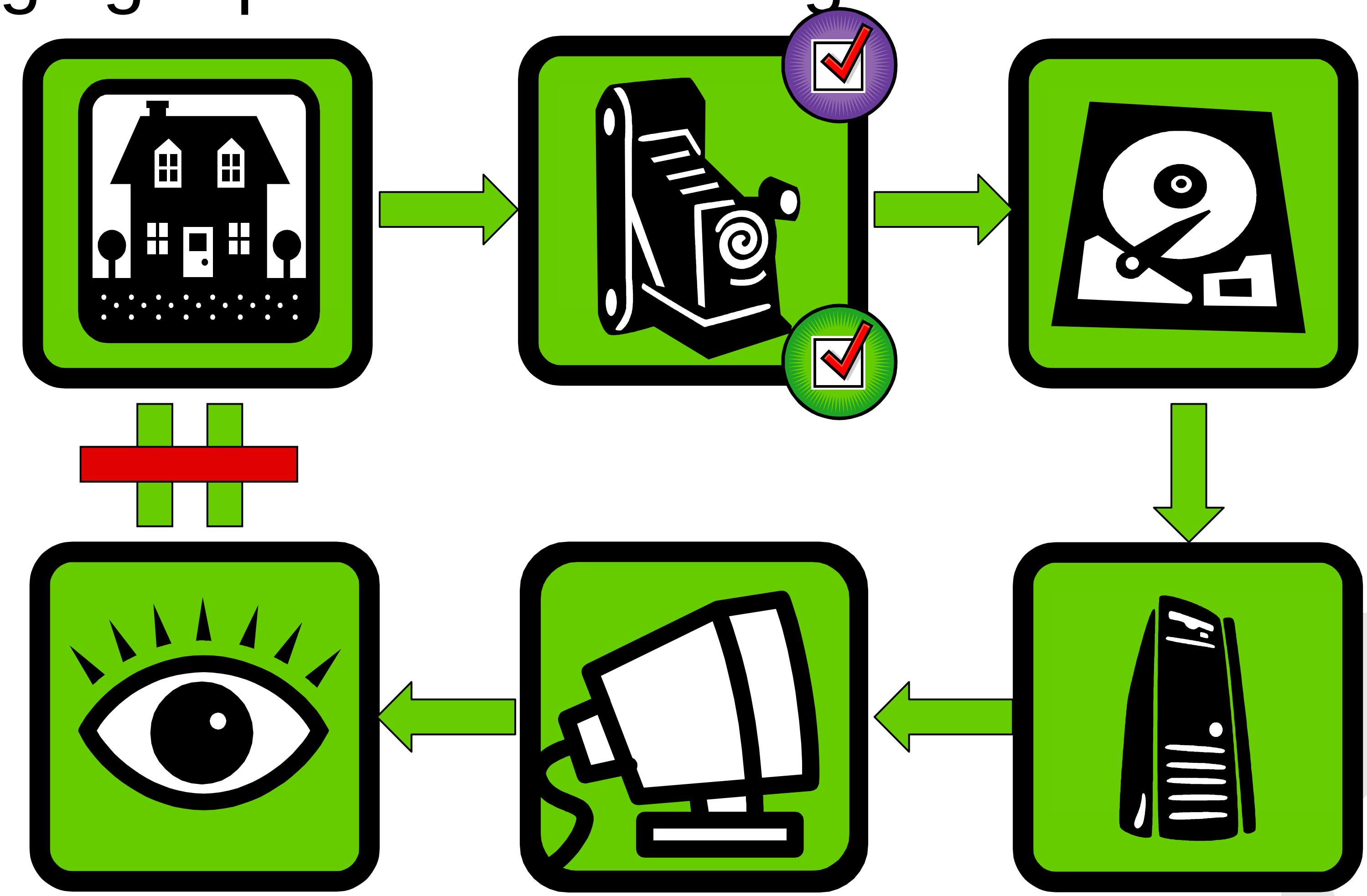
Compatibility

- existing CCD
- can output 8-bit image (ignore second exposure)

Cost

- firmware change only
- zero incremental cost

Imaging Pipeline – Our Progress



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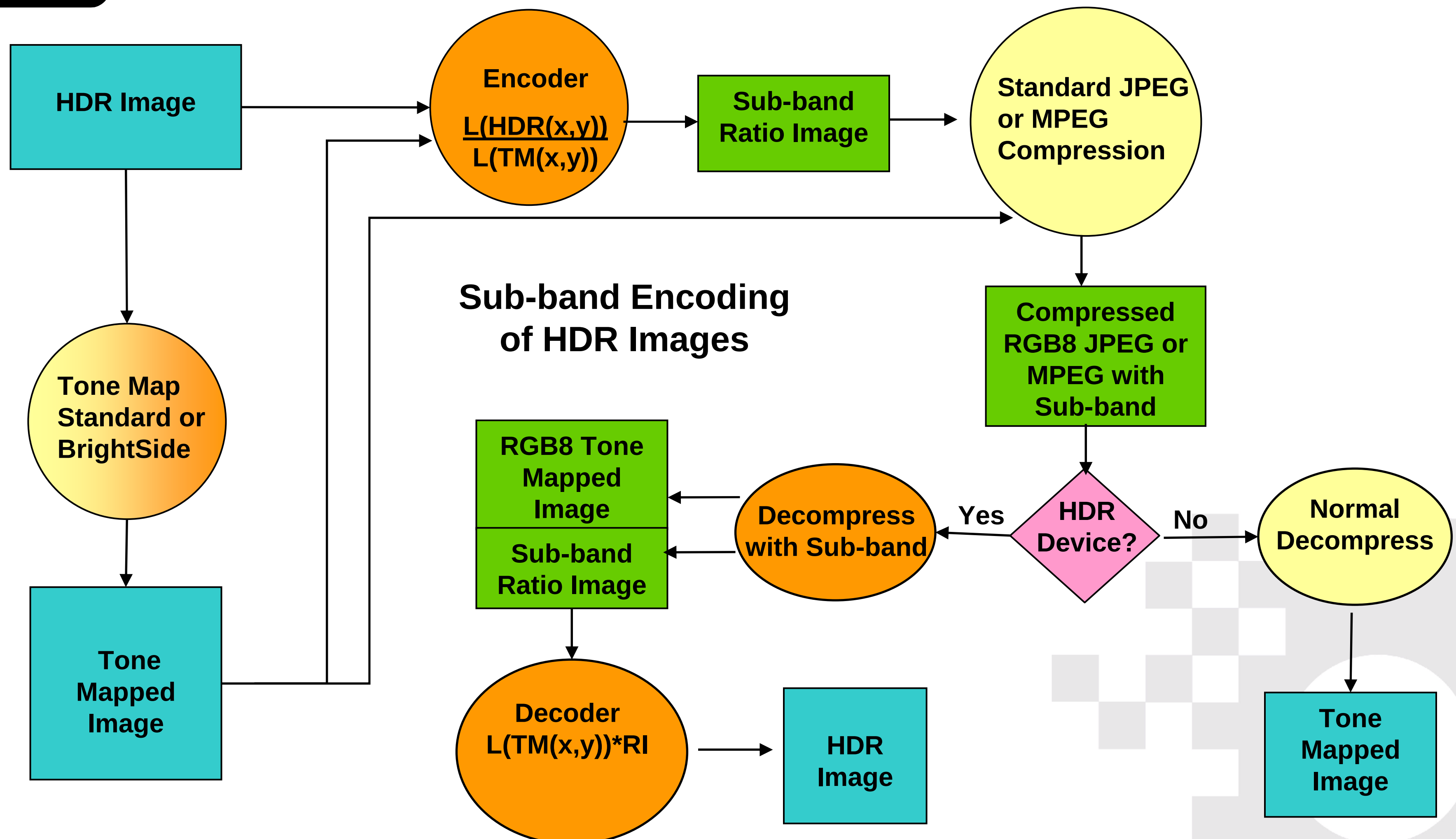
Data Storage – Size is a Problem!

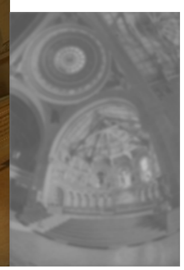
▪ RAW Image Data	->	4.5Mb	(100%)
▪ Radiance XYZE	->	1.3Mb	(29%)
▪ 8-bit BMP	->	1.2Mb	(27%)
▪ 8-bit JPEG	->	65kb	(1.4%)
▪ JPEG HDR™	->	70kb	(1.5%)

Data Storage – JPEG / MPEG HDR

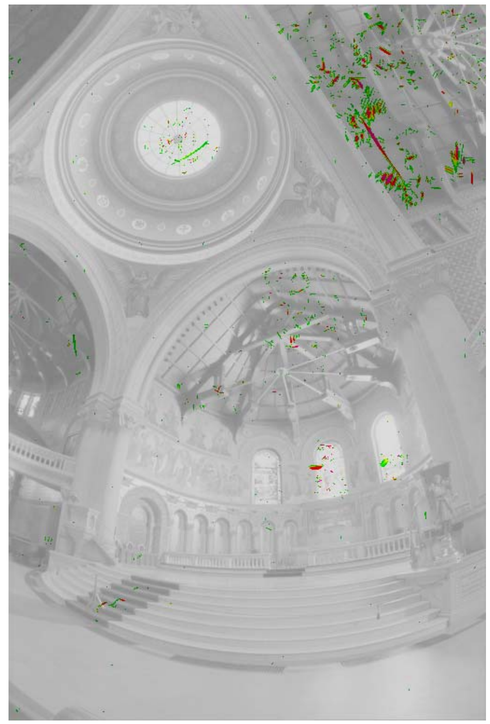


Data Storage – Image Quality

Tone-Mapped RGB8



Subband Image



Visual Difference Predictor

Compatibility

- indistinguishable from RGB8 JPEG
- tone mapped image can be customized
- compatible with most formats

Cost

- very low (~5% extra size)
- real time decoding possible

Imaging Pipeline – Our Progress

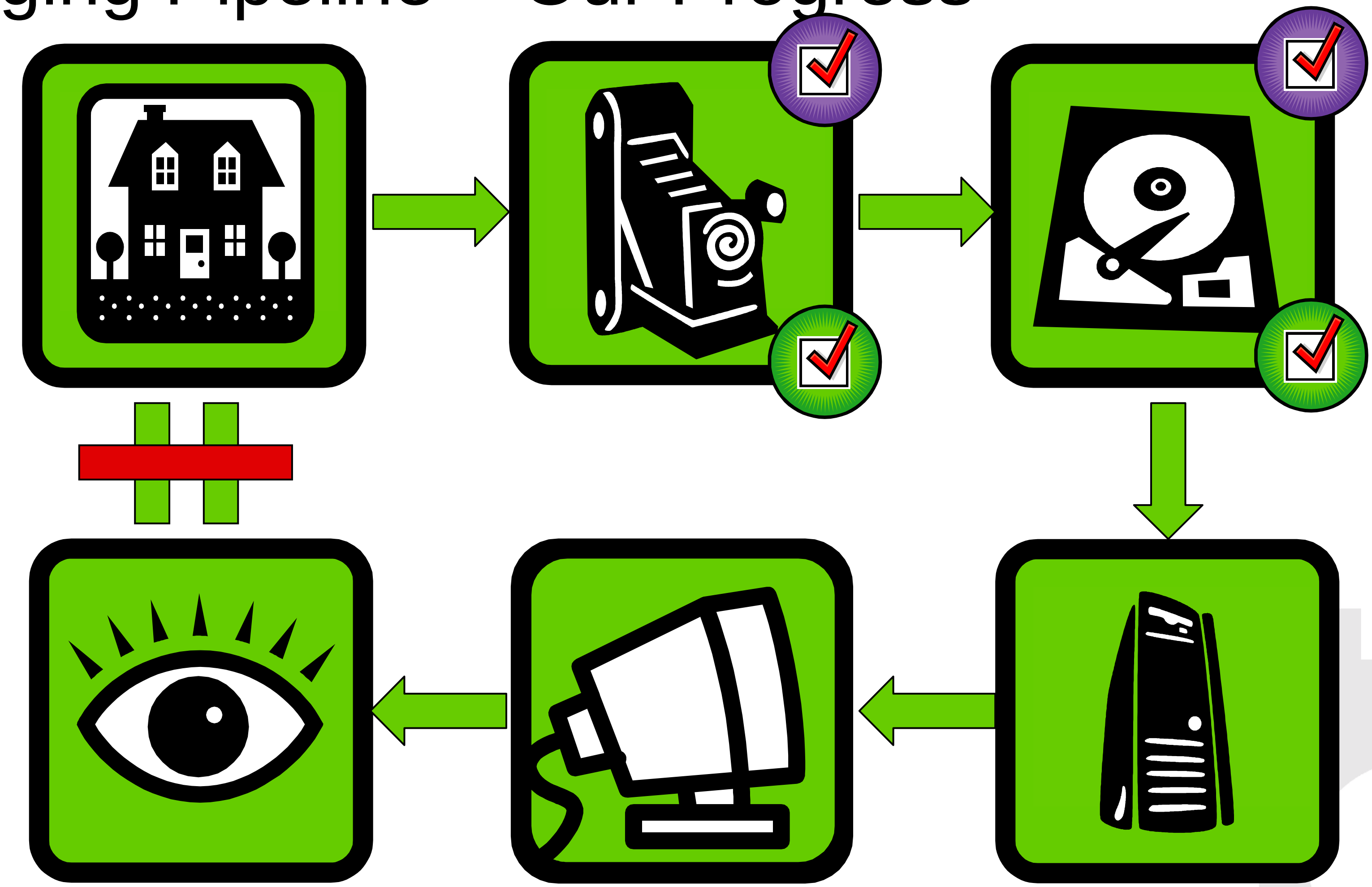


Image Processing

- Floating point GPUs are becoming standard
- Most CG and Games done in HDR today
- TV remains low dynamic range and is unlikely to change soon
- Reverse Tone Mapping and Saturation Extension provide quality gain even for legacy content

Image Processing - Extension

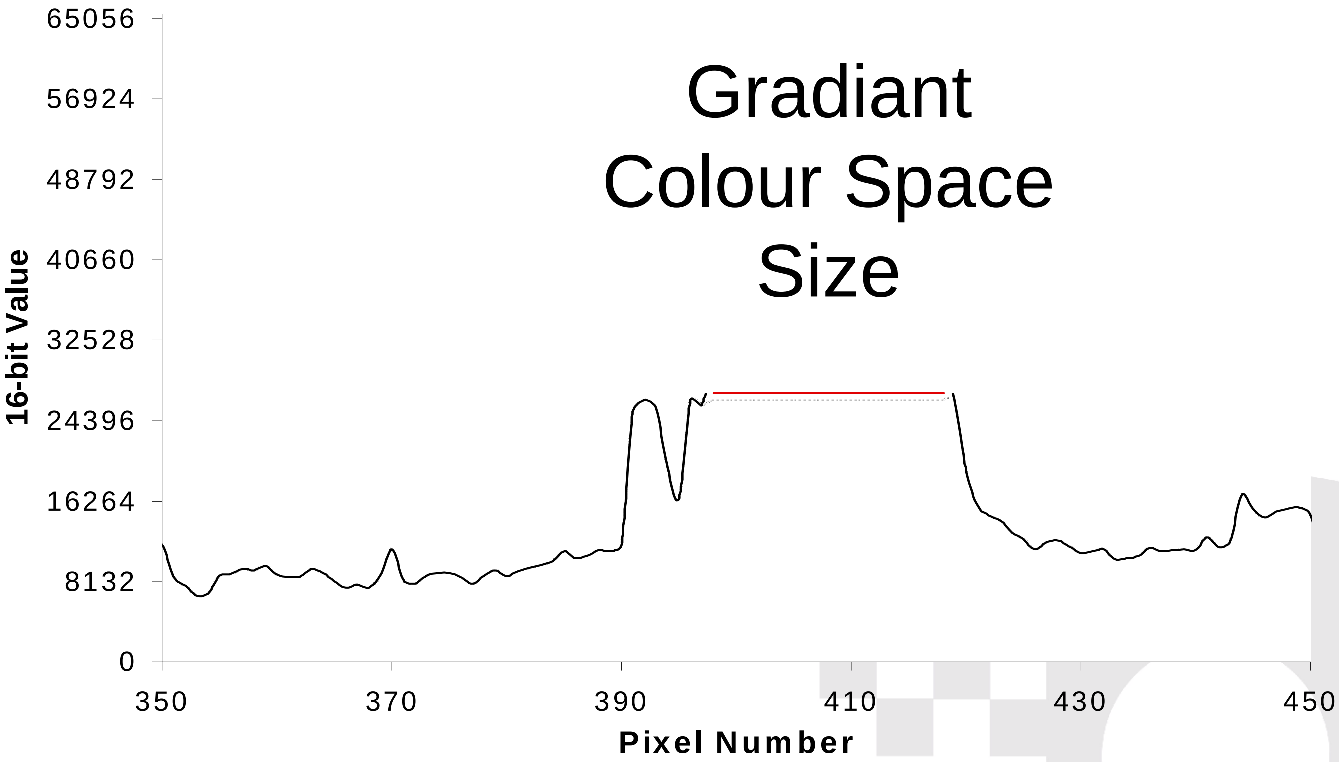


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Image Processing - Extension

Compatibility

- only needed for legacy content
- calculation supported in 8-bit processor

Cost

- very fast (1-2 operations per pixel)

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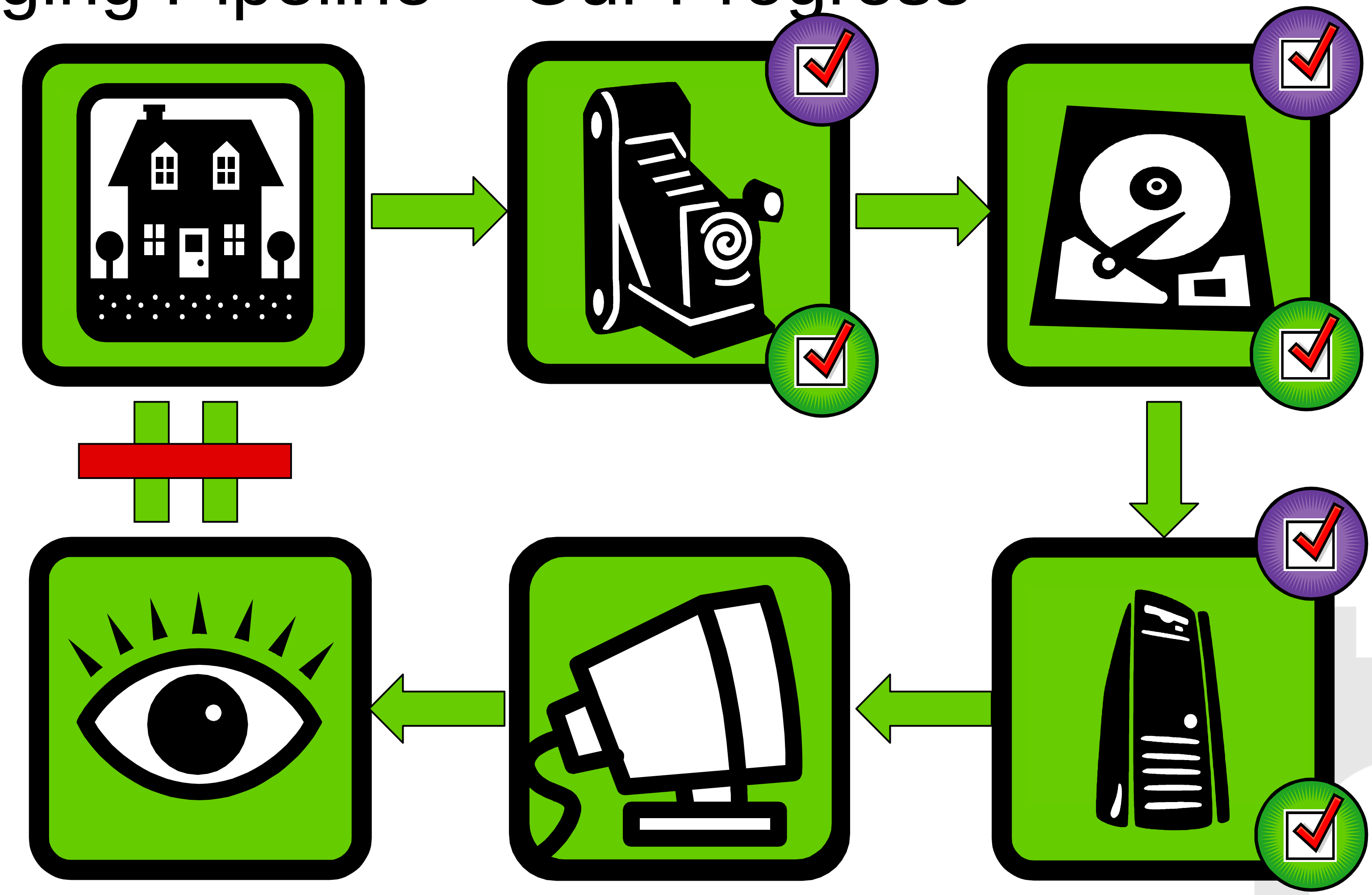
Imaging Pipeline – Our Progress



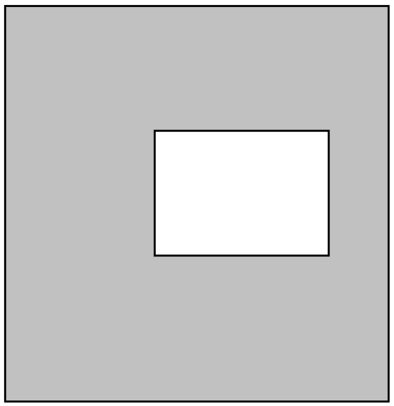
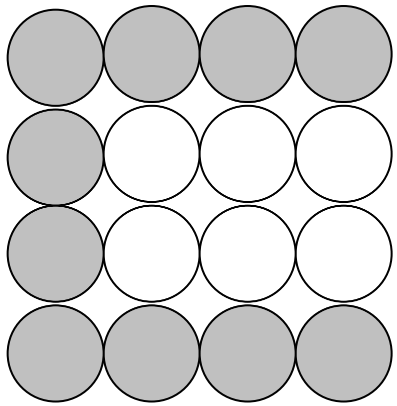
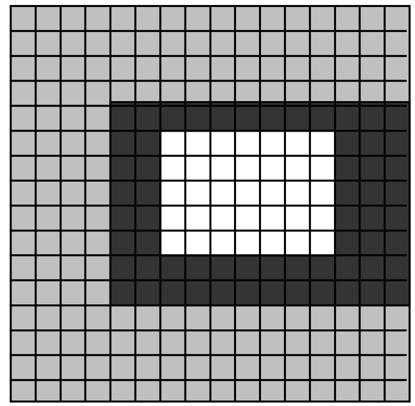
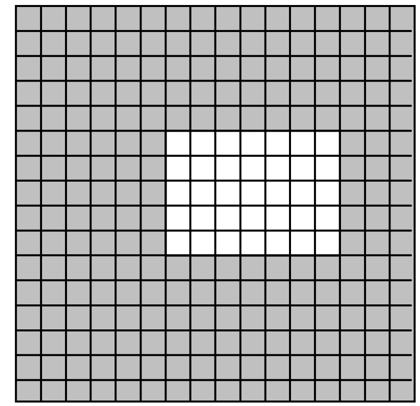
Display Technology – Concept

High resolution colour LCD

High Dynamic Range Display

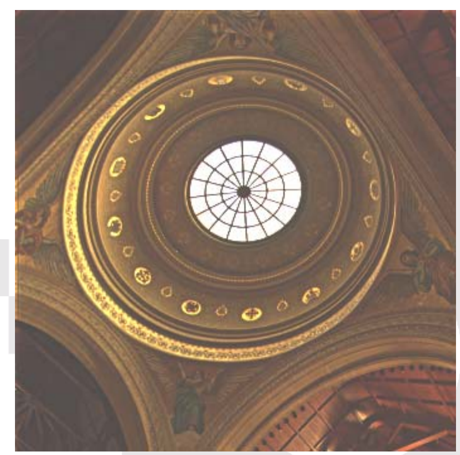
Low resolution Individually Modulated LED array

Display Technology – Image Processing

HDR Image | **LED array** | **LCD with correction** | **Output image**



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Display Technology – Review

- Compatibility
  - Legacy support through Reverse Tone Mapping and Saturation Extension
  - Small number of LEDs allows encoding of LED data in conventional video signal
- Cost
  - LED cost money (less every day)
  - Significant power reduction (~25% of comparable constant backlight LCD on average)

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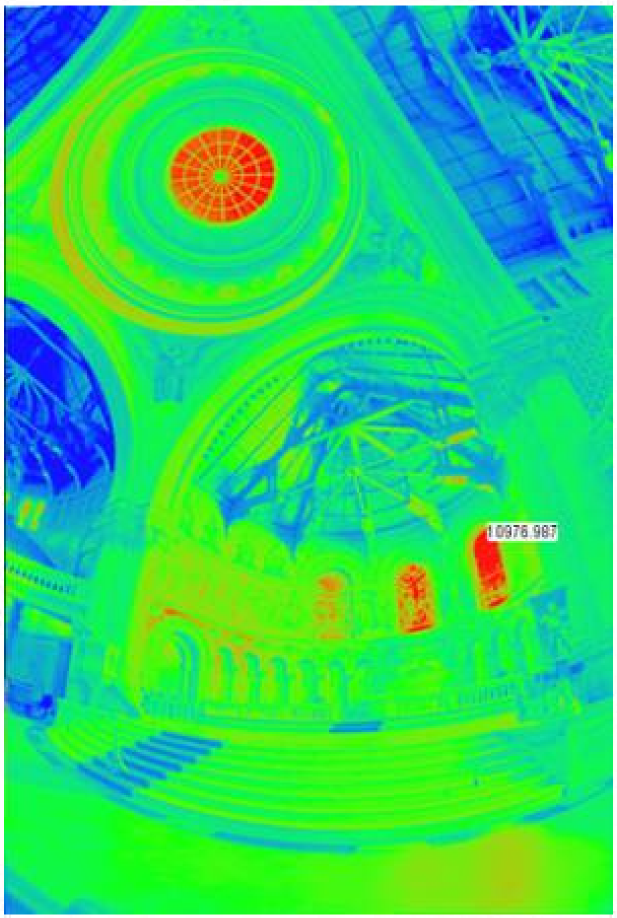
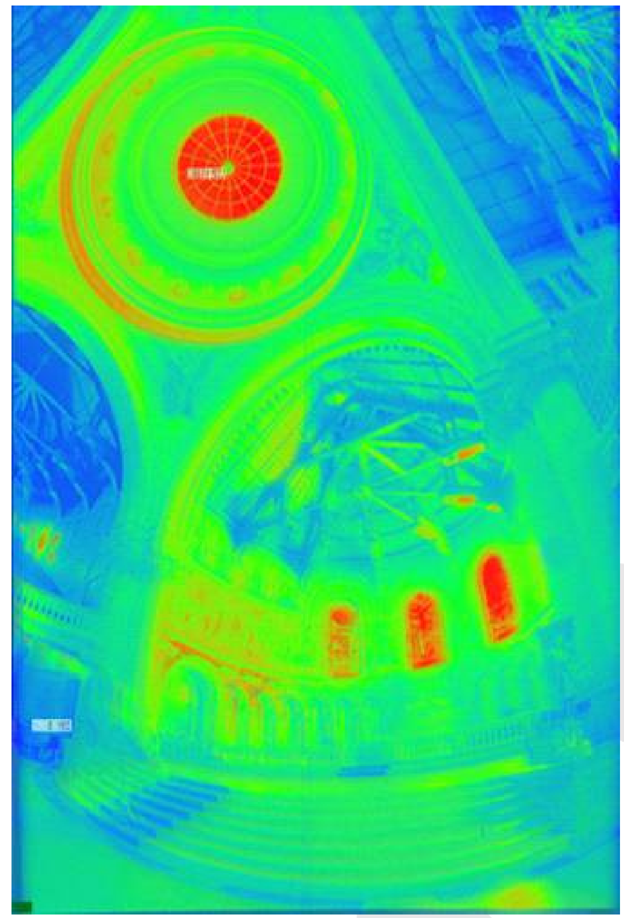
Display Technology – Results



Stanford Memorial Church
Courtesy Paul Debevec



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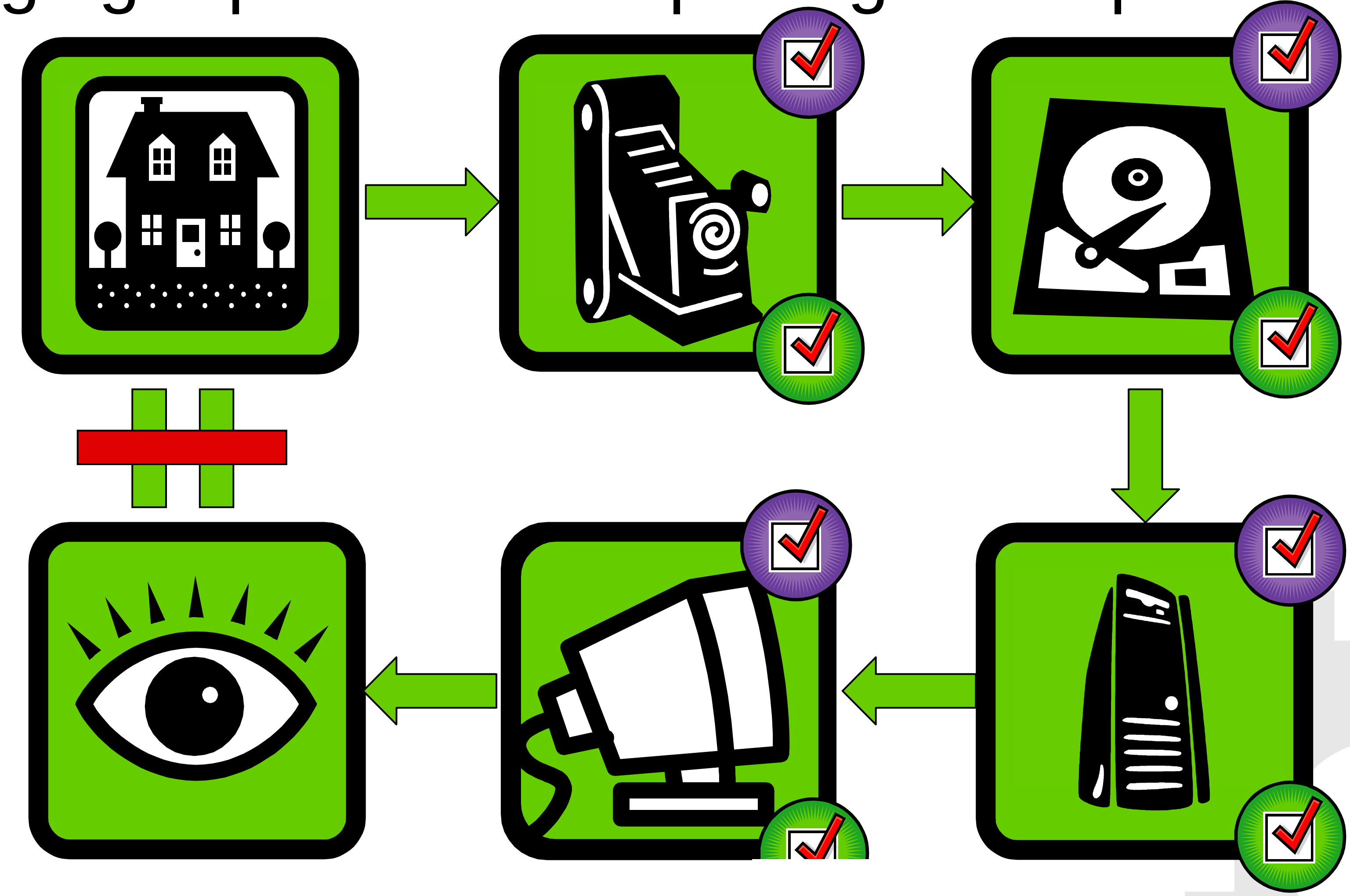
Imaging Pipeline – Completing the Equation



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DR37-P

"This product really is so different that your brain has trouble remembering that it actually is an LCD display"

Bit Tech Magazine

"When these displays become more affordable in the next year or two, I don't know how we'll ever go back to the old way."

David Kirk, NVIDIA

"The item with the biggest "WOW" factor at SIGGRAPH"

Game Developers Magazine

"The Future of Gaming"

Hollywood Reporter Magazine

"… creating the unnerving sensation that you are somehow seeing beyond the display screen"

VFXWorld Magazine