SMART LIGHTING

SMART LIGHTING ENGINEERING RESEARCH CENTER

Lighting Innovation for a Smarter Tomorrow

NSF

Smart Lighting
Lighting Innovation for a Smarter Tomorrow

Kenneth A. Connor

Education Director

Smart Lighting ERC

Rensselaer BOSTON UNIVERSITY UNM HOWARD UNIVERSITY ROSE-HULMAN INSTITUTE OF TECHNOLOGY MORGAN STATE UNIVERSITY

Goals

- Intro to Our Center
- Solid State Lighting
- Overall Vision
- Light
- Demos

The History of Lighting

THE CASE FOR A NATIONAL RESEARCH PROGRAM ON SEMICONDUCTOR LIGHTING

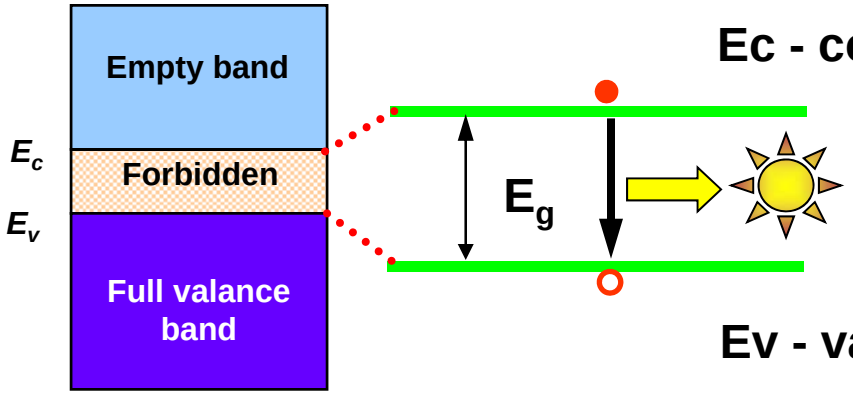
Roland Haitz and Fred Kish, Hewlett-Packard Company, Palo Alto, CA 94304

Jeff Tsao and Jeff Nelson, Sandia National Laboratories, Albuquerque, NM 87185-0601

Overview

- What's an LED
- Lighting Class LEDs?
- The Future of Solid State Lighting

Semiconductors for High Brightness LEDs

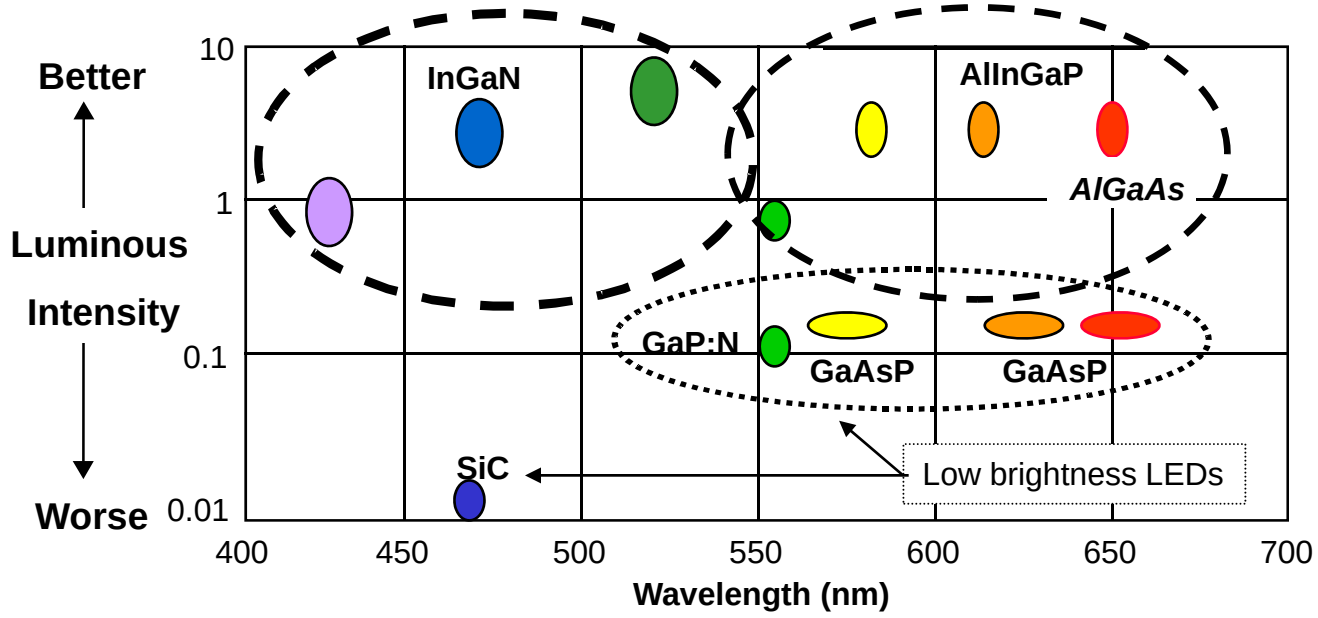


Ec - conduction band edge

Engineered, multilayered crystal structure to efficiently convert current to light. Materials used, layer design and crystal quality determine color and efficiency

Ev - valence band edge

What is an LED?



Very high brightness LEDs cover the entire visible spectrum using 2 different III-V compound semiconductor material systems

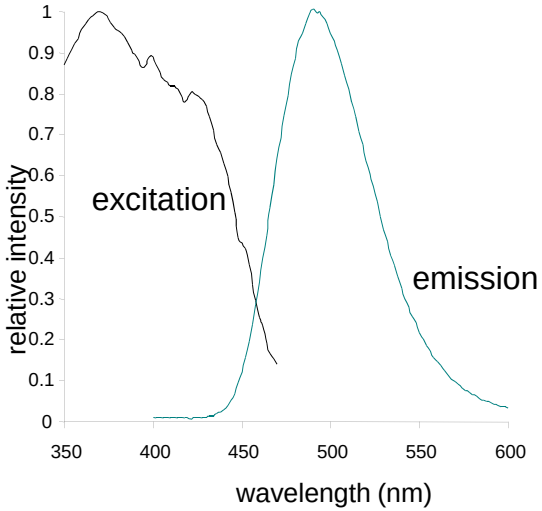
Ultra-violet | Blue | Green | Yellow | Orange | Red | Infra-Red

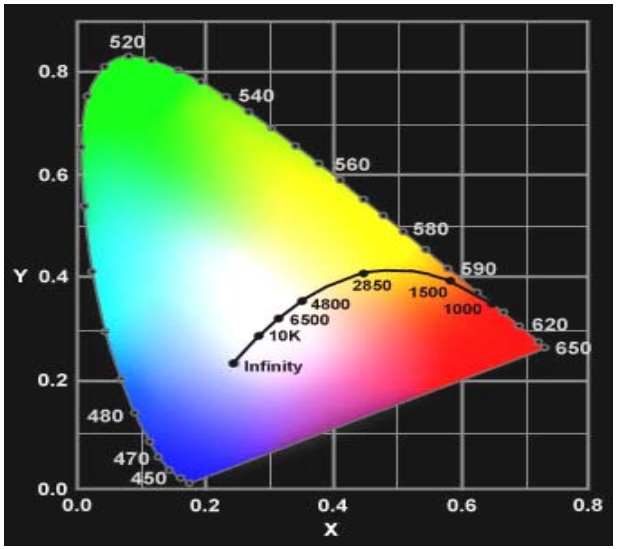
How to Make a White LED

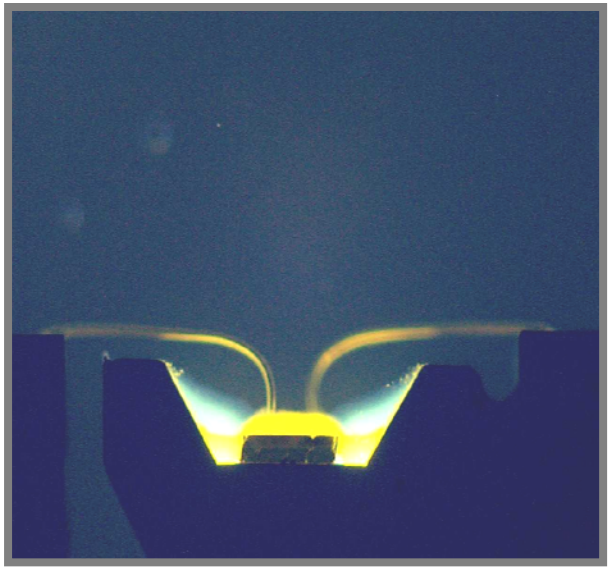
- **Mixing colors can make white LED**

  - **Red, Green, Blue LEDs used together**
  - **Blue LED plus Yellow Phosphor**
  - **UV LED plus various Phosphors**

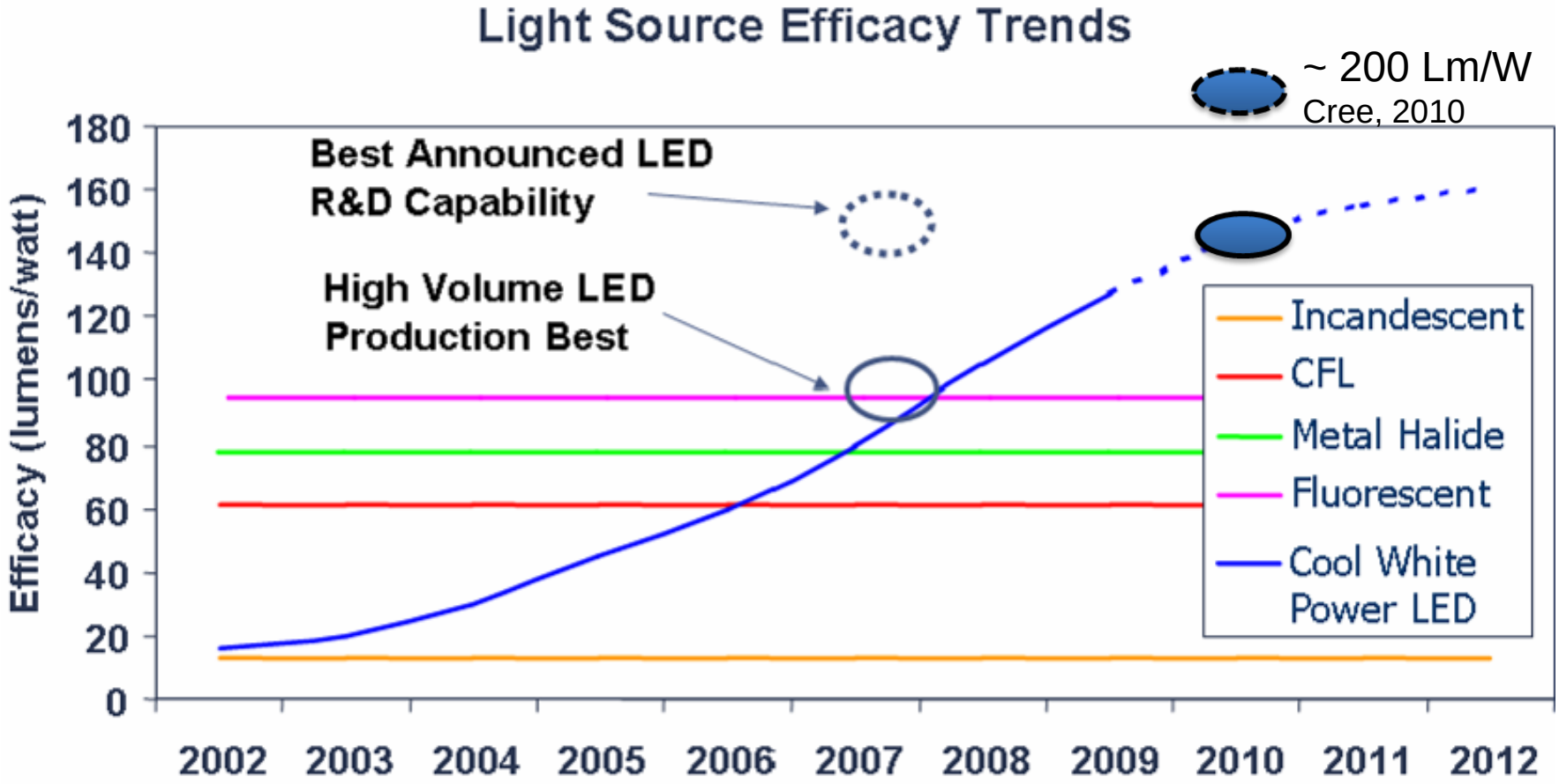
- **Phosphor - a material that absorbs light at one wavelength and emits it at another wavelength**





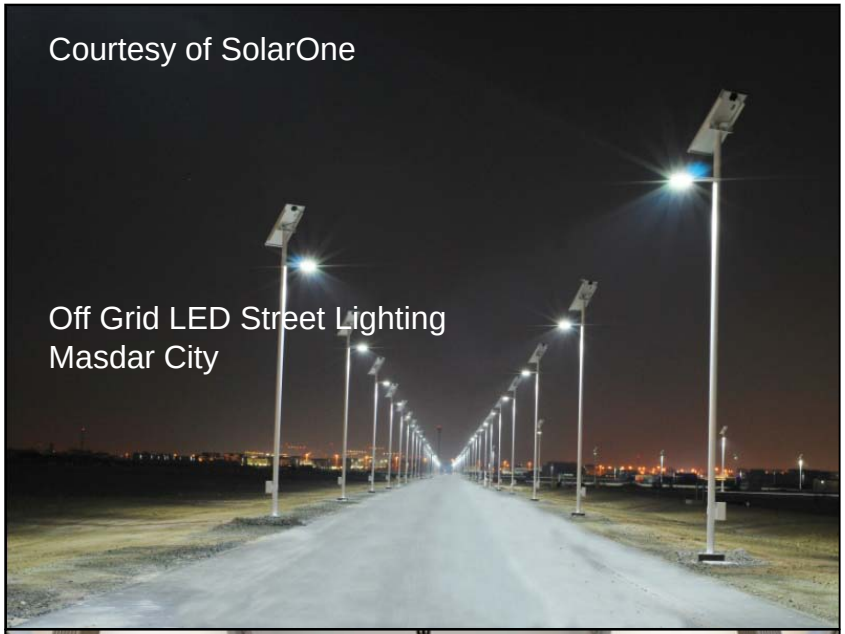


White LED Efficiency Increasing Rapidly



Early LED Use
Architainment (Architecture and Entertainment)

Solid State Lighting – Coming fast



- Many street lighting programs
- 100% SSL buildings are starting to appear (mostly in Asia)
- Many hundreds of start-up companies in Solid State Lighting
- Generally still not ready for prime time
  - Lack of good standards
  - Very high prices
  - Lots of “junk LED bulbs”

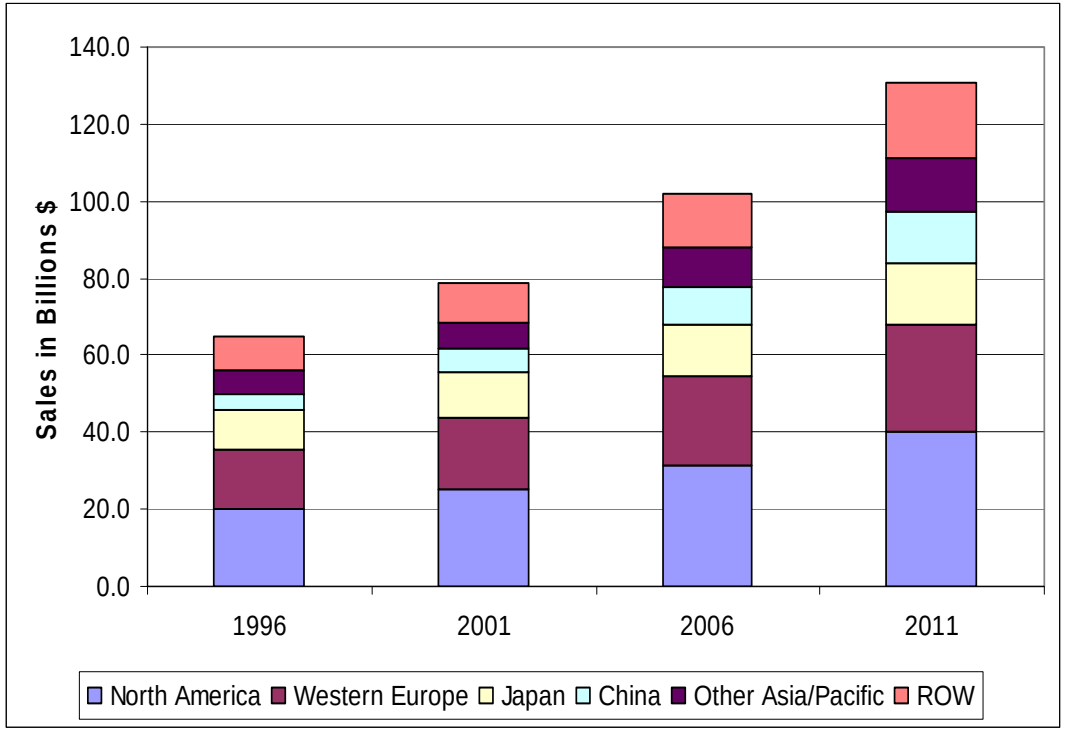
The Total Lighting Market is Huge

Global Lighting Market Size

(in billions)	2006	2011
Lamps (Front-end)	$20.9	$25.4
Fixtures (Back-end)	$81.1	$106.6
Total	$102	$132

North America approximately 29% of the worldwide market

Total Lighting Equipment Market



Source: Fredonia Group, Inc.

So there is a tremendous revenue opportunity for LEDs

SMART LIGHTING

This is where research is published, not peer reviewed literature


US007196354B1

(12) **United States Patent**
Erchak et al.

(10) **Patent No.: US 7,196,354 B1**
(45) **Date of Patent: Mar. 27, 2007**

(54) **WAVELENGTH-CONVERTING LIGHT-EMITTING DEVICES**

(75) Inventors: **Alexei A. Erchak**, Cambridge, MA (US); **Michael Lim**, Cambridge, MA (US); **Elefterios Lidorikis**, Newton, MA (US); **Jo A. Venezia**, Boston, MA (US); **Michael G. Brown**, Tyngsboro, MA (US); **Robert F. Karlicek, Jr.**, Chelmsford, MA (US)

(73) Assignee: **Luminus Devices, Inc.**, Woburn, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 25 days.

(21) Appl. No.: **11/238,667**

(22) Filed: **Sep. 29, 2005**

6,452,217	B1	9/2002	Wojnarowski
6,475,819	B2	11/2002	Franz
6,476,549	B2	11/2002	Yu
6,480,389	B1	11/2002	Shie
6,481,874	B2	11/2002	Petroski
6,501,103	B1	12/2002	Jory
6,504,180	B1	1/2003	Heremans
6,504,181	B2	1/2003	Furukawa
6,518,600	B1	2/2003	Shaddock
6,608,332	B2	8/2003	Shimizu
6,624,491	B2	9/2003	Waitl
6,627,521	B2	9/2003	Furukawa
6,642,618	B2	11/2003	Yagi
6,690,268	B2	2/2004	Schofield
6,759,723	B2	7/2004	Silverbrook
6,791,259	B1	9/2004	Stokes

(Continued)

OTHER PUBLICATIONS

"NeoPac sets new standard with 500 lumen LED lighting", LEDs Magazine, http://www.ledsmagazine.com/press/9495, Date announced Jul. 5, 2005, Date of website printout Jan. 23, 2006.

Some Examples of MR-16 LED Products

DOE Testing – Many product claims are misleading

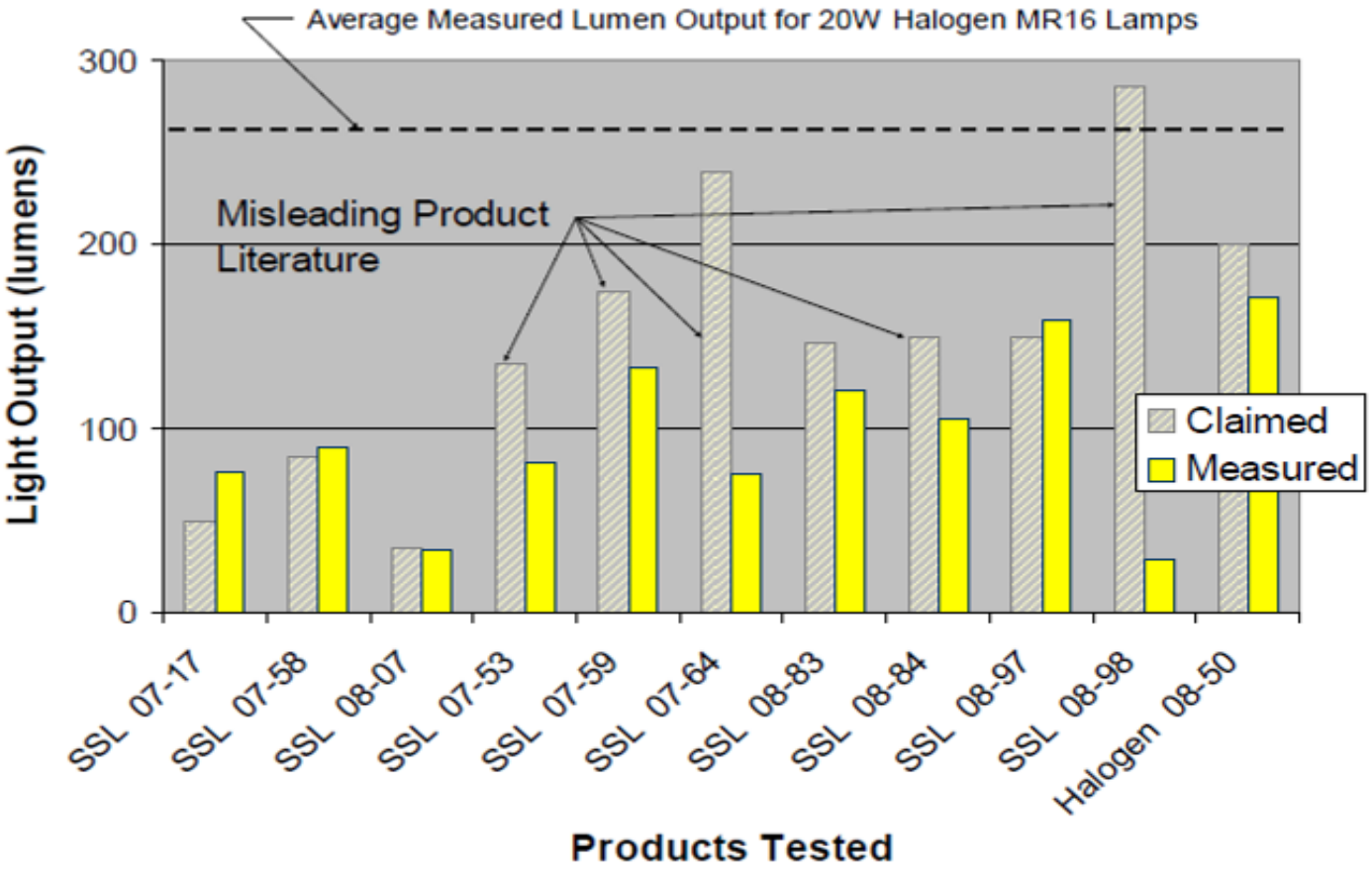


Figure 5. Measured Light Output of Halogen MR16 Lamps and LED Replacements Compared to Manufacturers' Reported Values

Smart Lighting ERC

A Top Down Vision

Comfort

The Right Light
where you want it

Health

Therapeutic
Lighting

Energy Efficient Lighting Systems

Lighting Systems interfaced to external grid & building systems

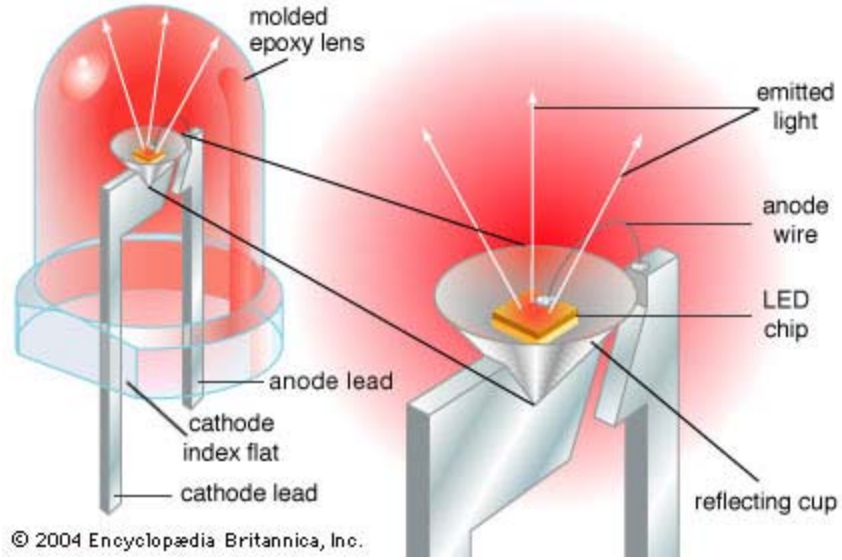
Adaptive
Lighting Systems

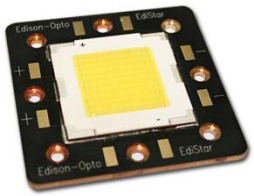
Lighting and Data
at the same time

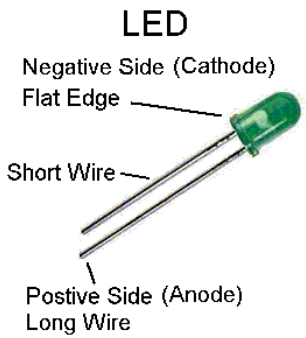
Productivity

Information

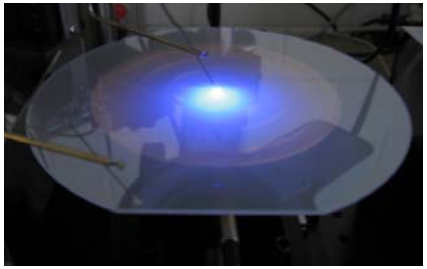
Solid State Lighting



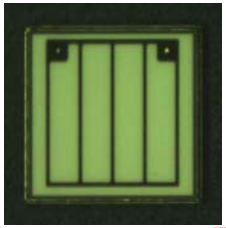




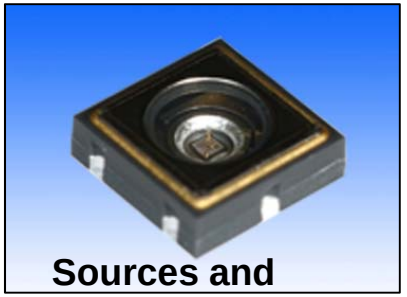
Smart Lighting ERC View of LED Supply Chain



Materials and Devices



Materials and Subsystems



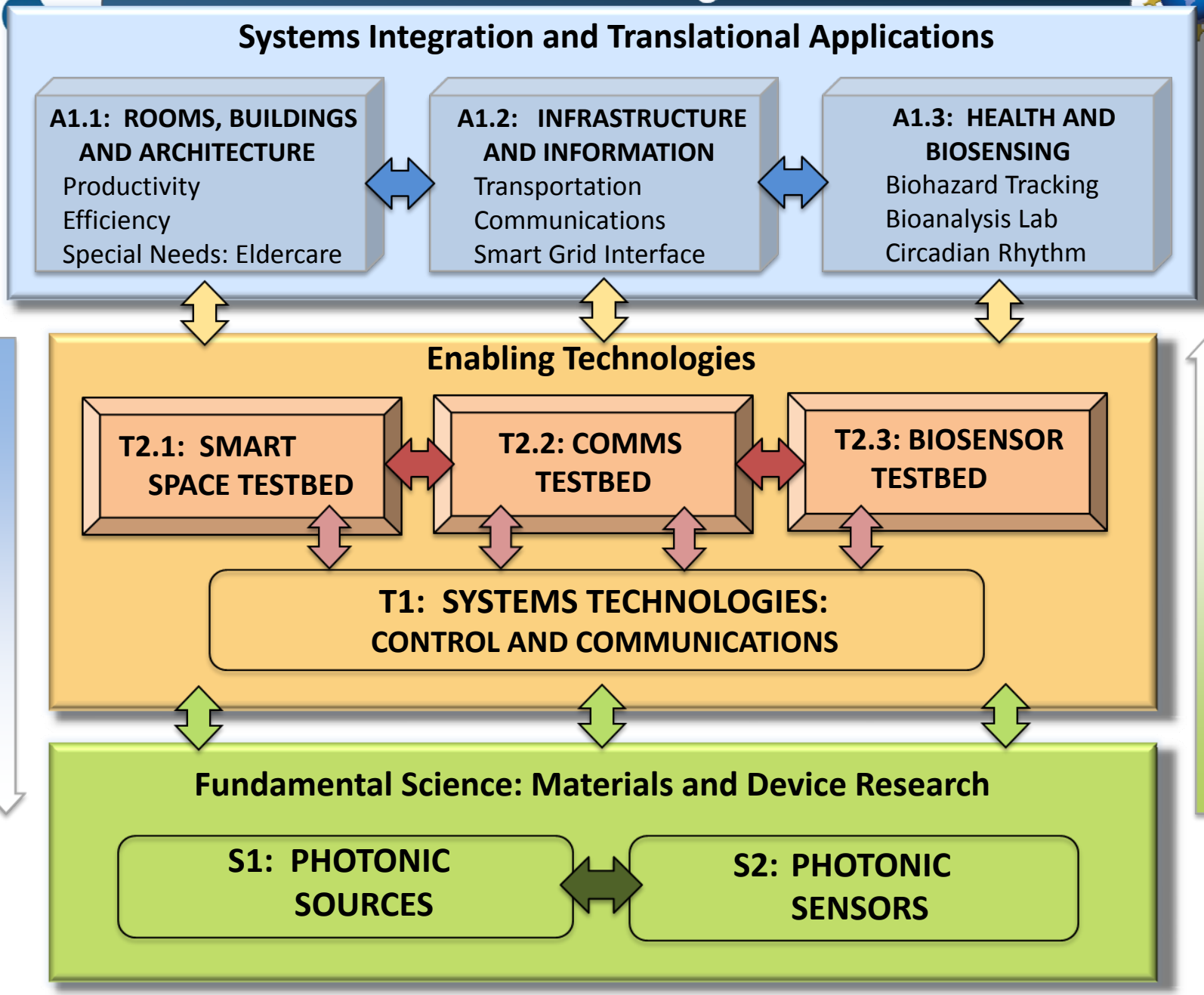
Sources and Sensors

Materials and Subsystem Integration

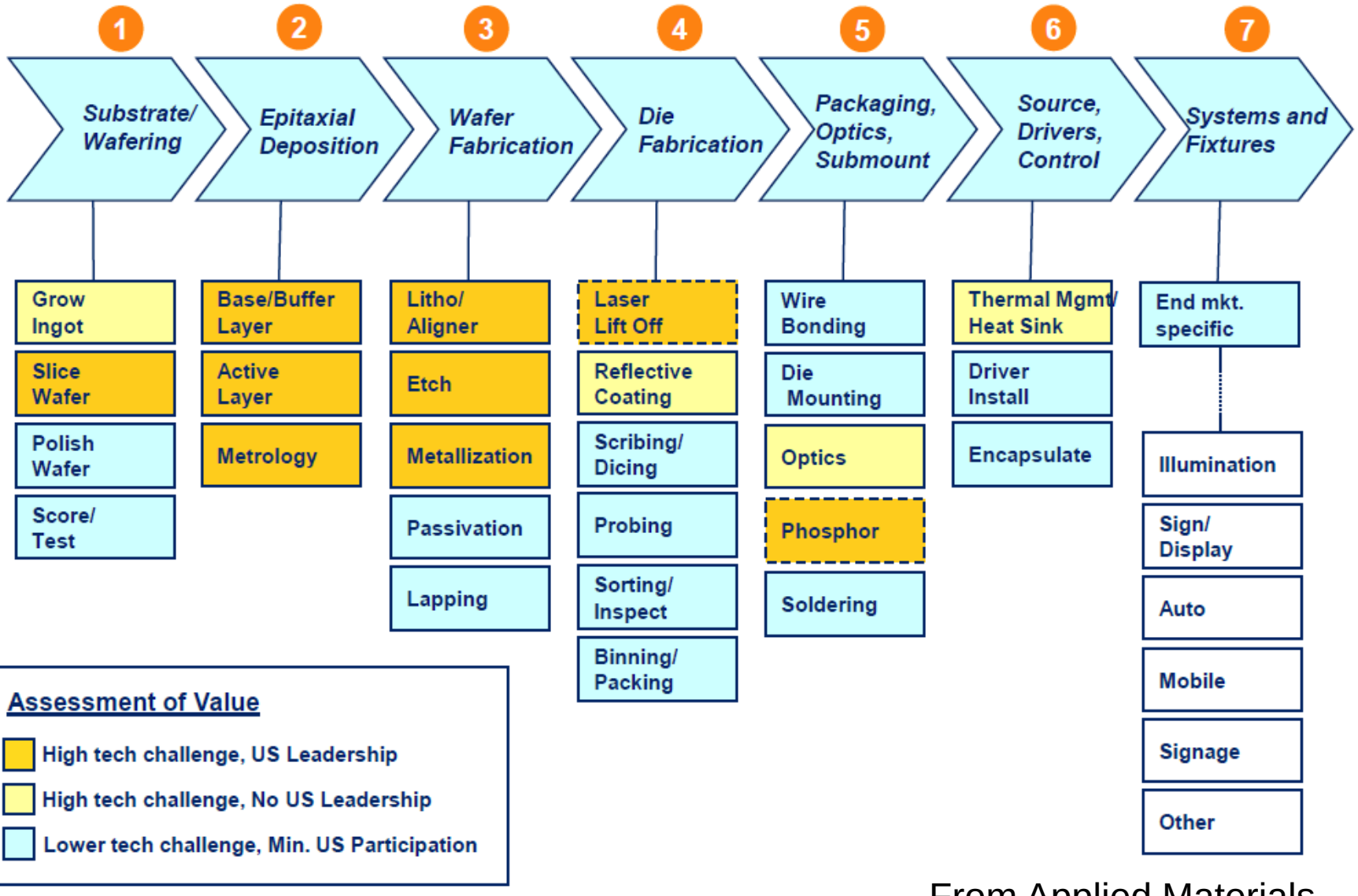
Full System Integration

Smart Spaces

3 Level Diagram



Industrial View of LED Supply Chain



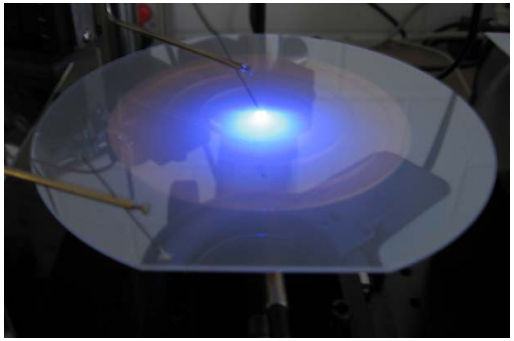
From Applied Materials

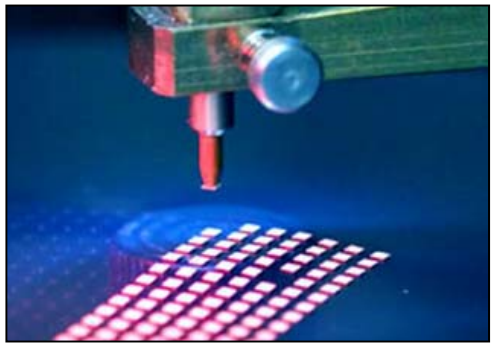
Novel Uses of SSL

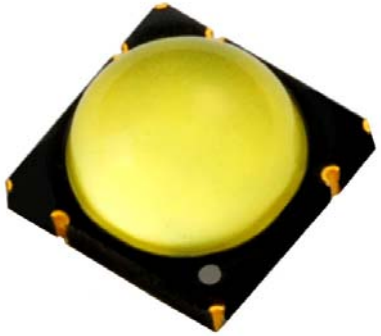
- LEDs and Lighting
- Key System Level Aspects
  - Chips and Packaging
  - Electronics and Optics
  - Bulbs and Sockets
- Other LED Applications
- Smart Lighting

Square Source in a Round Lighting Hole?

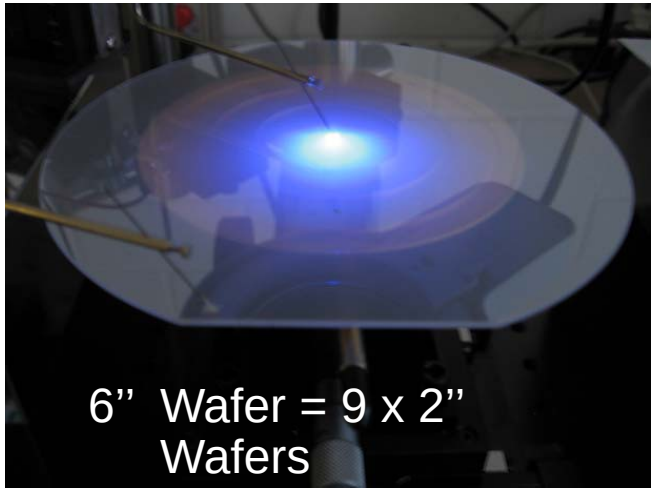
- DC device in an AC Powered World
- Cool light source with thermal management challenges
- Great LED Efficacy – High Lm/W
  ….But low Lumens per part
- Cost still way too high ($100 per 1000 Lm)
  Can Semiconductor “Thinking” do the job?

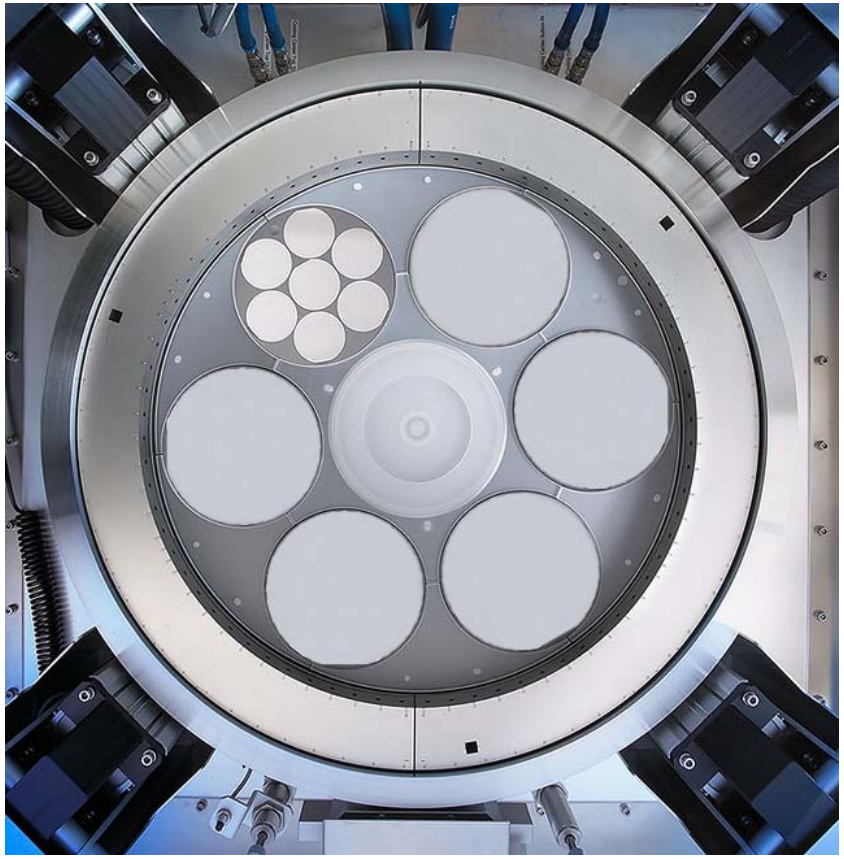






LEDs – the Chips will be Free (almost)



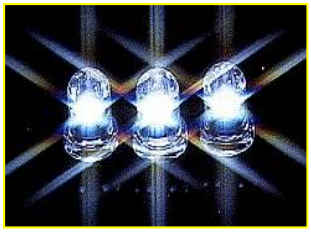


Aixtron 42x2 or 6x6 Production Tool

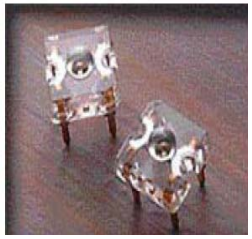
- Low cost, large diameter substrates
- New LED Growth Platforms (faster, lower cost)
- Automated Production
- Are radically different approaches to LED chip manufacturing required?

Packaging: Thousands of Styles

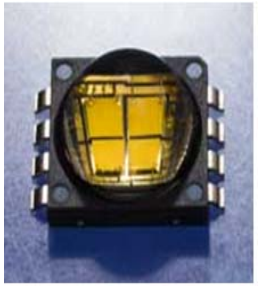
Standard Types
(< 1/8 W) – low cost, low light

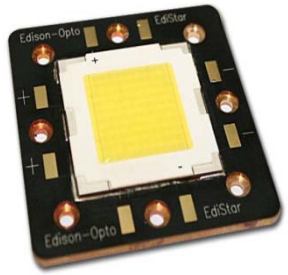


Medium Power Types
(< 1/2 W)



High Power Types
(1 to 100 W)

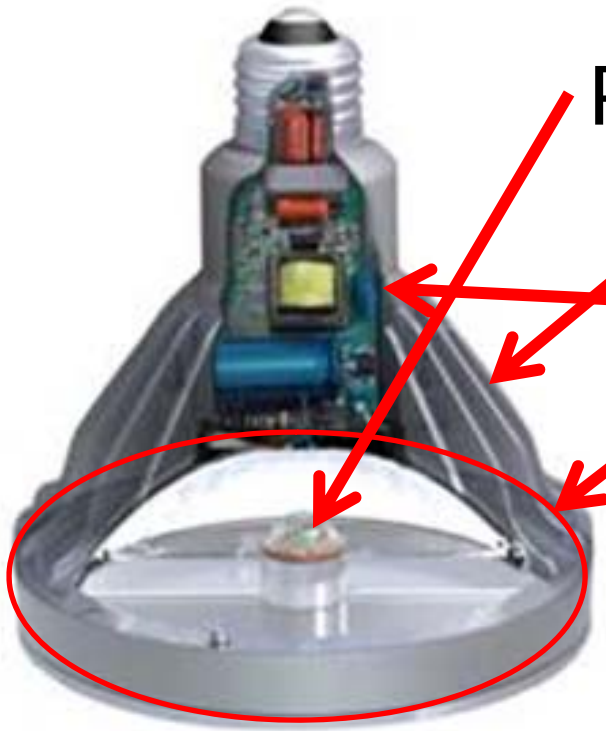




- No Standard Package – though some more popular than others

- Lighting Trends: (1) Lots of small LEDs spread out (diffuse)
  (2) Biggest Chip in Smallest Package (spot)

System – Putting it all together



Packaged

The mal P

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FUTURE
???????

INSIDE

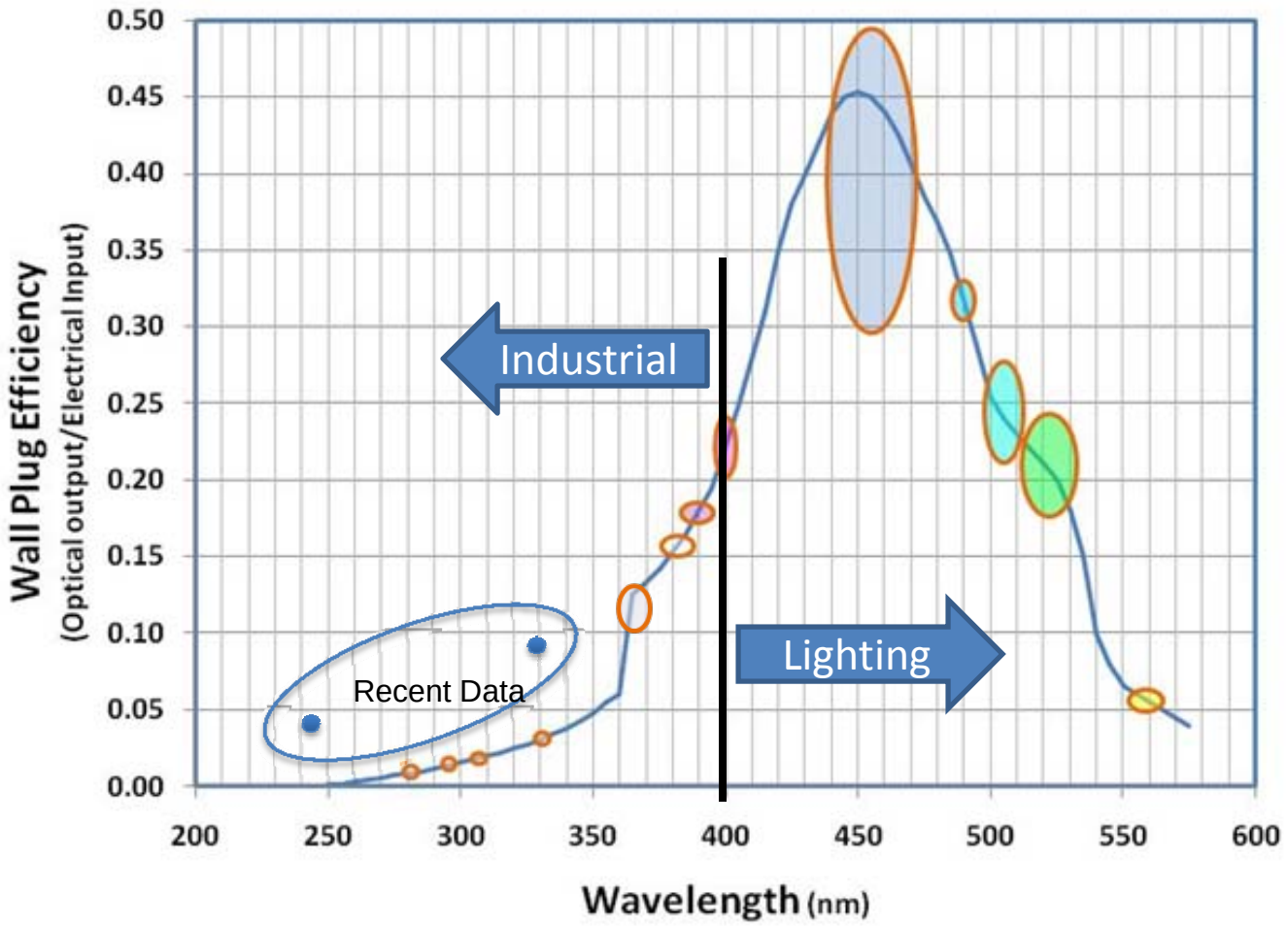
AC LED at 200 Lm/W
Thermal Glass Heat Sink
Remote Phosphor
Non-Yellow Phosphor
Internal Smart
Grid Interface
Etc.

Cree LRP-38™ @ 55 Lm/W

(Efficiency of system parts are approximate)

Will we still need a socket?

Efficiency versus Wavelength



Nitride Based LEDs

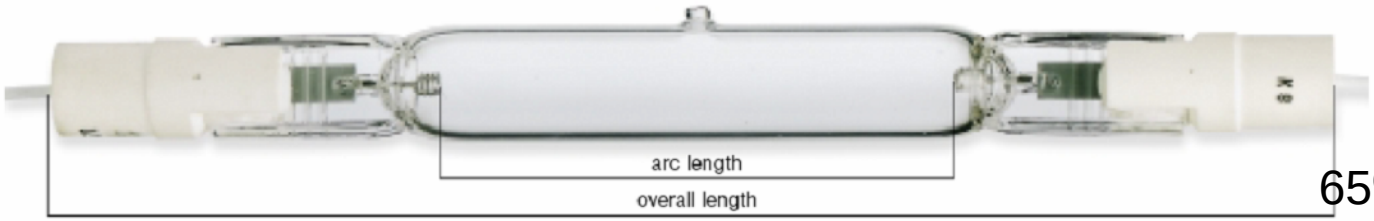
What About Other Energy Efficiency Applications

UV Curing

- Cuts drying energy consumption by ~70%
- No solvent emission – “dries” by polymerization

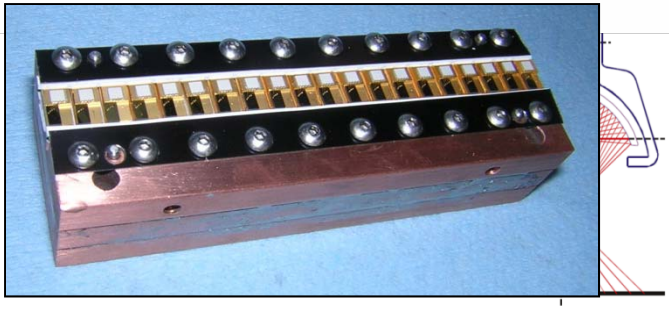
Only ~20% of manufacturing processes that could be UV cured are using UV curing today

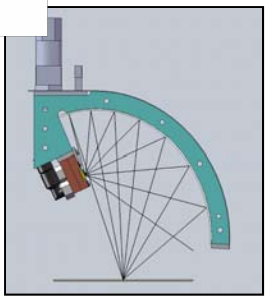
Replace Hg Bulbs with UV LEDs



Hg Arc Lamp
(300 W/in)
65% of energy in IR

UV LED Array
(150 W/in)
No IR





Water or solvent based coating using 1.2MBTUH gas fired forced air oven	UV Arc Lamps 2 300W/in, 60" wide bulb	Projected High Power UVLED system
2,880,000 lbs/yr	1,080,000 lbs/yr	540,000 lbs/yr

Hg Lamps – about $700M/year in Replacement Lamps

Green House Gas Emissions Reductions for a single product
(3 production lines @ 24x5)

Today's Lighting

- Do we really need sockets?
  (when LEDs outlast buildings)
- Semiconductor paradigm the right model?
  (Can we get the costs we need?)
- Lighting Design – What we want or a cover up for poor light sources

Look Up

Right Above the Smart Lighting ERC Door

NEXXUS™ LIGHTING

Lamp Facts	
Chip Supplier	Nichia
Packager	Citizen
LED Count	108
Watts	7.8
Lumens	550
CCT	3000K
Cost	$90

Compared to a 75W PAR 30 Incandescent Lamp:

- Electrical savings offsets higher cost in one to two years, depending on usage (on-time) – for 24 hr. operation at $0.12/kWhr, payback is < 1 year
- Lifetime of over 50,000 hours, or about 20x better than an incandescent bulb

The Smart Lighting ERC would like to thank Nexxus for providing the lamp

Summer Undergrad Students

- Irene Benny- RPI
- Rachel Romines – Rose-Hulman
- Dennis Deensie – Morgan State
- Daniele Manikeu – Morgan State
- Adrianna Anderson – St. Rose
- Tiffany Knapp – St. Rose

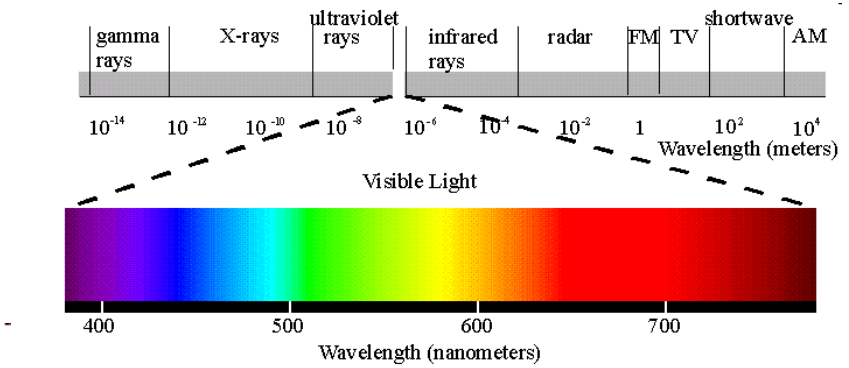
LIGHT

LIGHT – How Do We Use It?

- Illumination – Lighting in our homes and work, for our cars, etc.
- Imaging – Microscopes, telescopes, photography, etc
- Displays – Television and Computer Monitors (CRT, Plasma, LCD, etc.)
- Signaling – Traffic lights (cars, trucks, trains, boats, etc.), laser pointer, etc.
- Information – Optical fibers, read-write for storage (CD, DVD, Blu-Ray, etc), barcode, etc.
- Cutting, etching, etc.

Characteristics of Light

- Spectrum (Color)

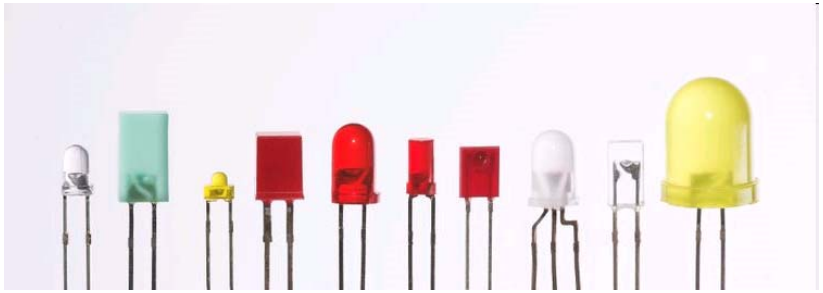


- Polarization

- Time Variation (Blinking)

- Direction

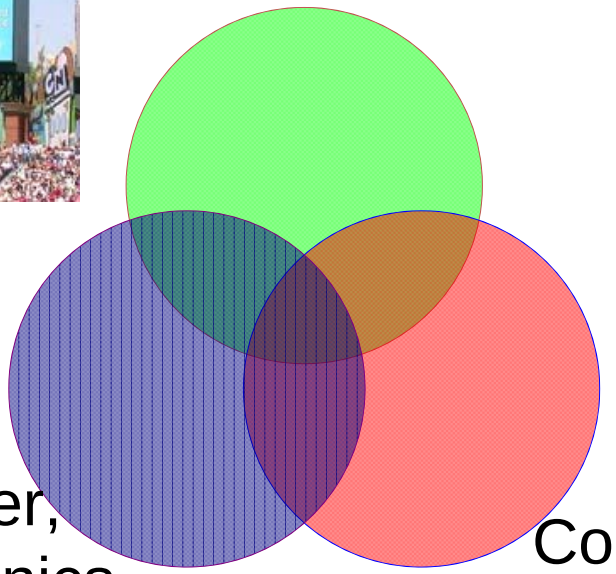
Making Light Smart



- Light Source
  - LED
- Power for Light Source
  - Battery (DC Voltage)
- Control
  - Computer (Processor)

Smart Lighting

Light Source

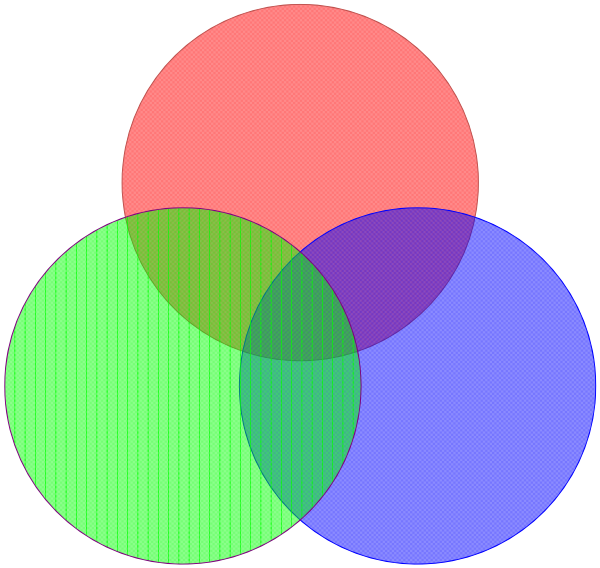


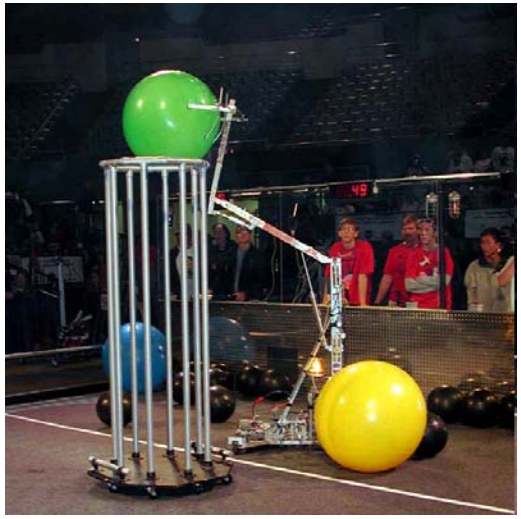
Electrical Power, Sensors, Electronics

Computer Control

Smart Lighting System

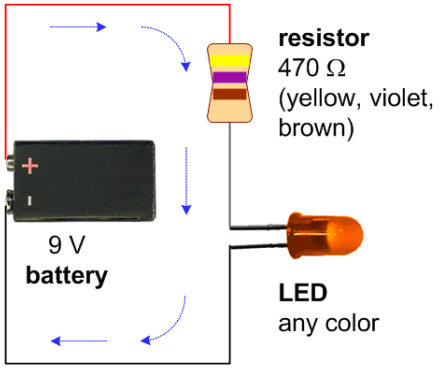
Similar to Robotics





Making Light Through Electronics

- LED (Light emitting diode)
- Resistor
- Wires
- Battery



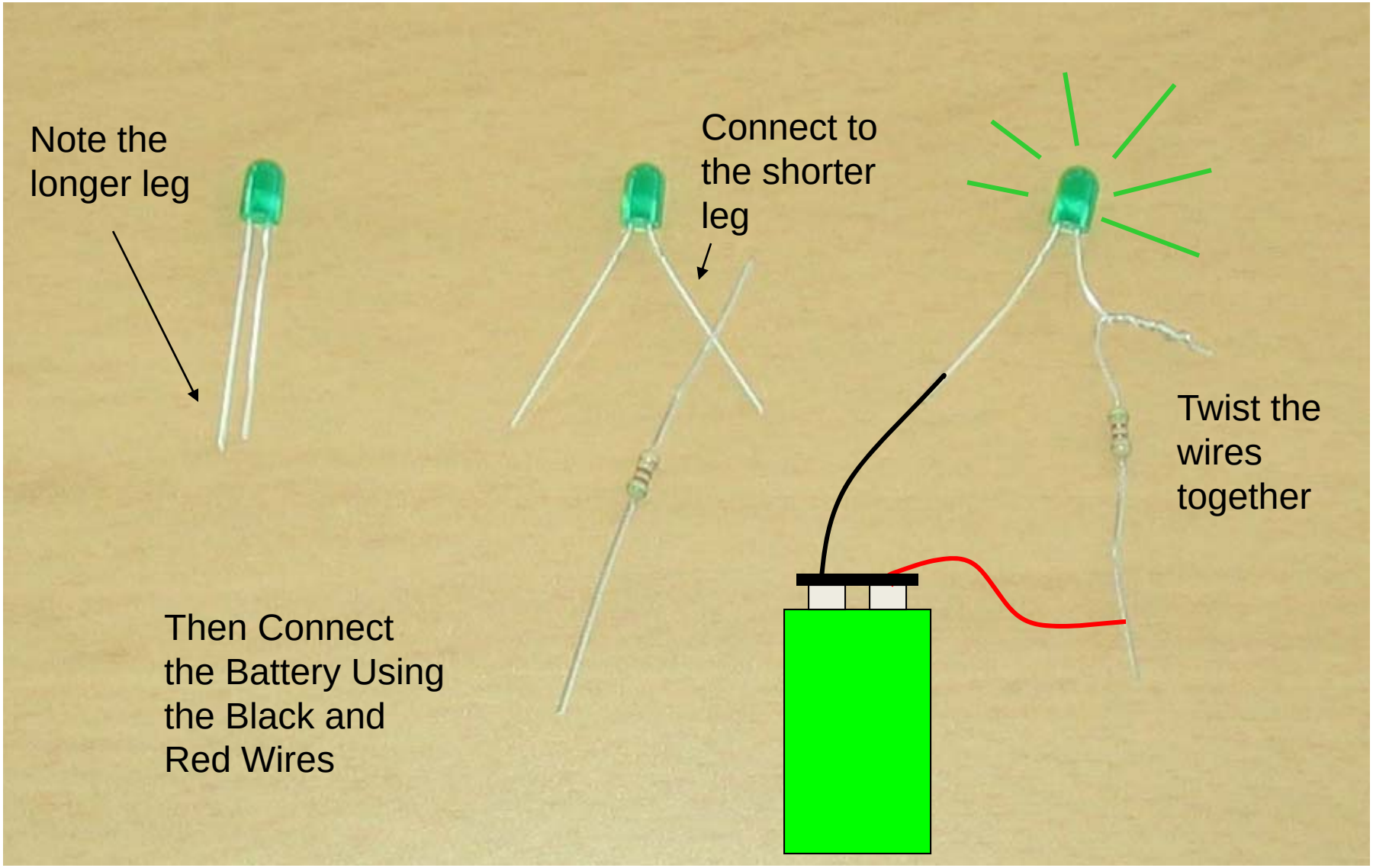
We have made a solid state light

Such a light could be used to send flashing signals

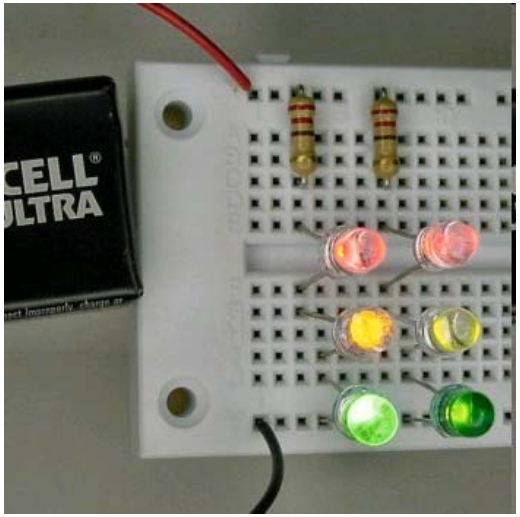
This is what the stop and go lights (red, yellow, green) are made from these days

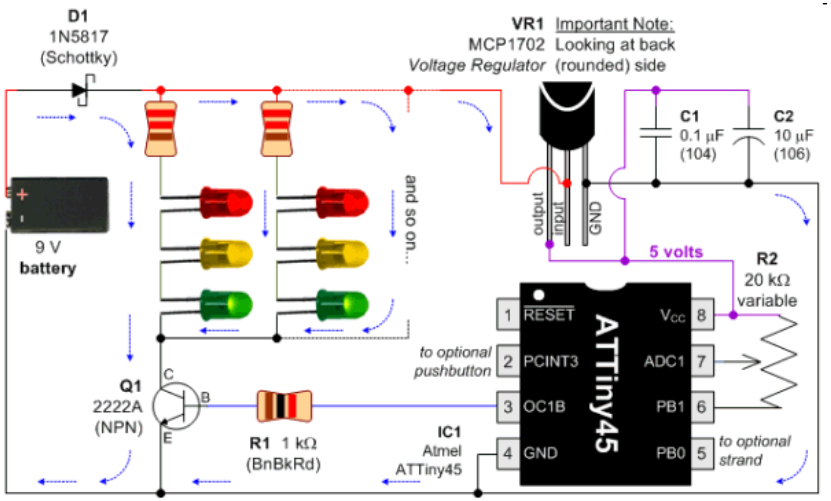
http://www.robotroom.com

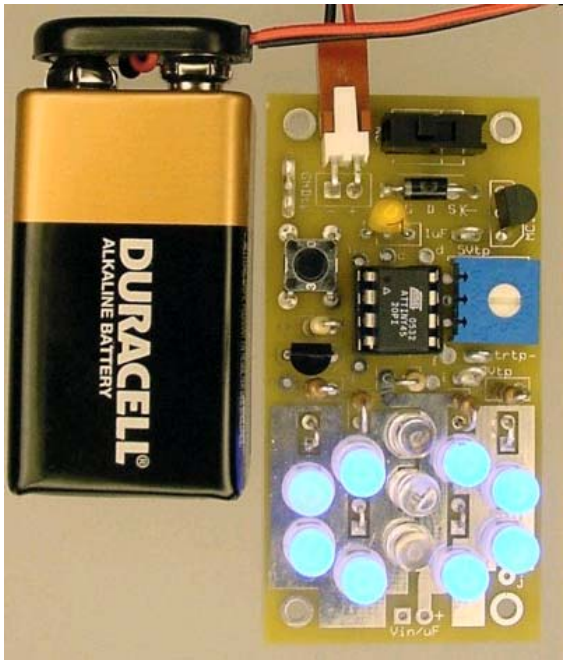
At Home Without the Protoboard



Many Other Projects are Possible







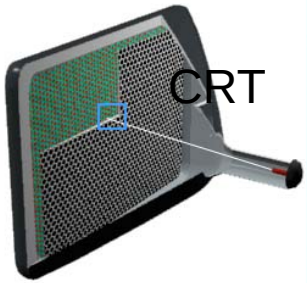
http://www.robotroom.com

Flashing Lights Sending Information

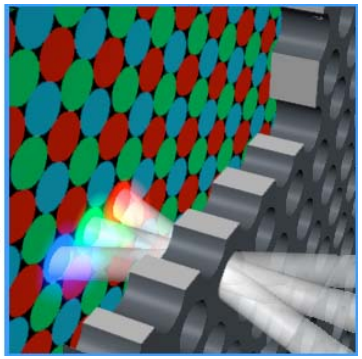
- Remote Control – See it on a camera
- Music Traveling on Light
- Hearing a Remote
- Sound Activated Switch
- Polarization & Displays

Displays

Mirasol
MEMS



CRT



Plasma

TI LED DLP MEMS

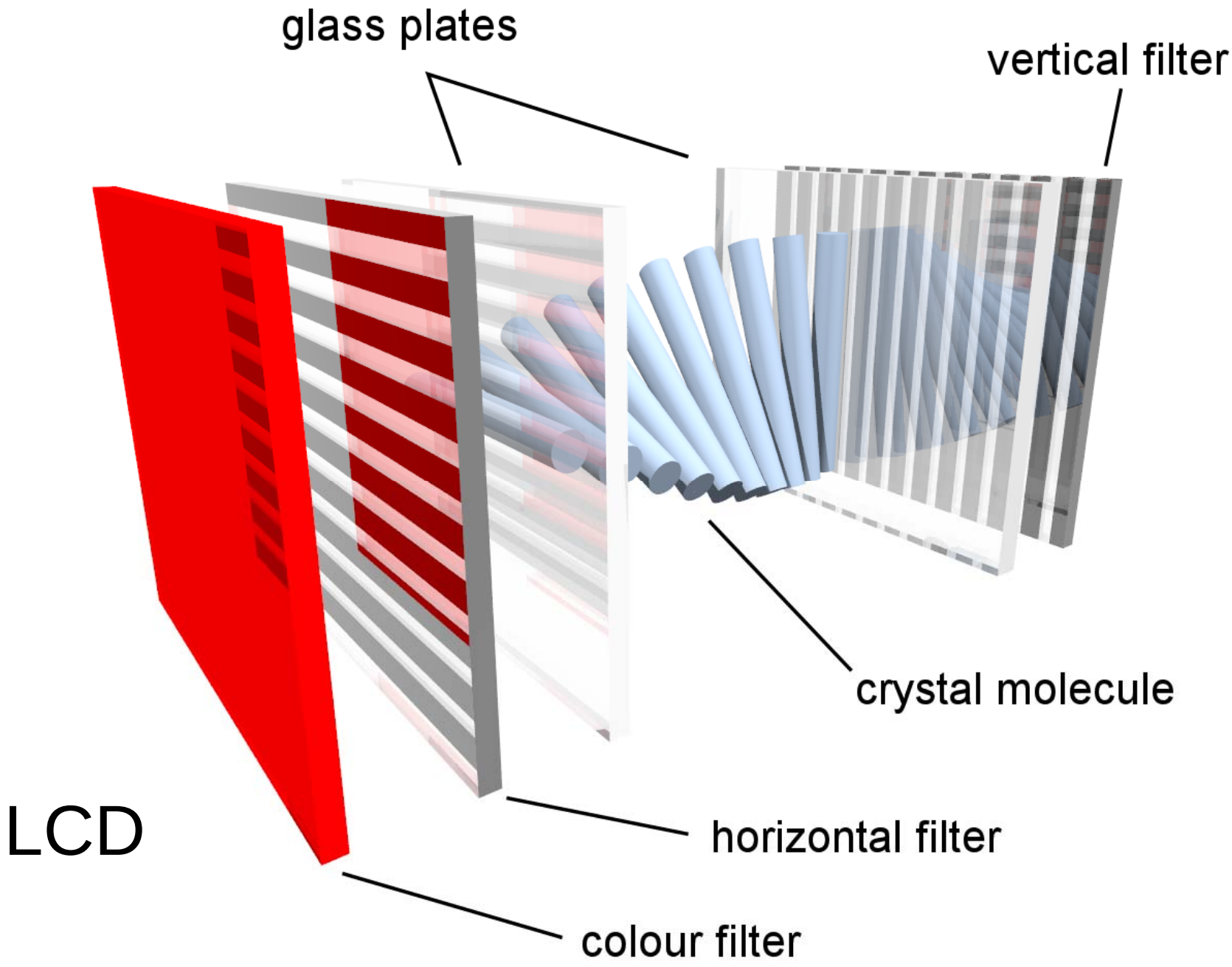
http://www.dlp.com/tech/what.aspx

LCD

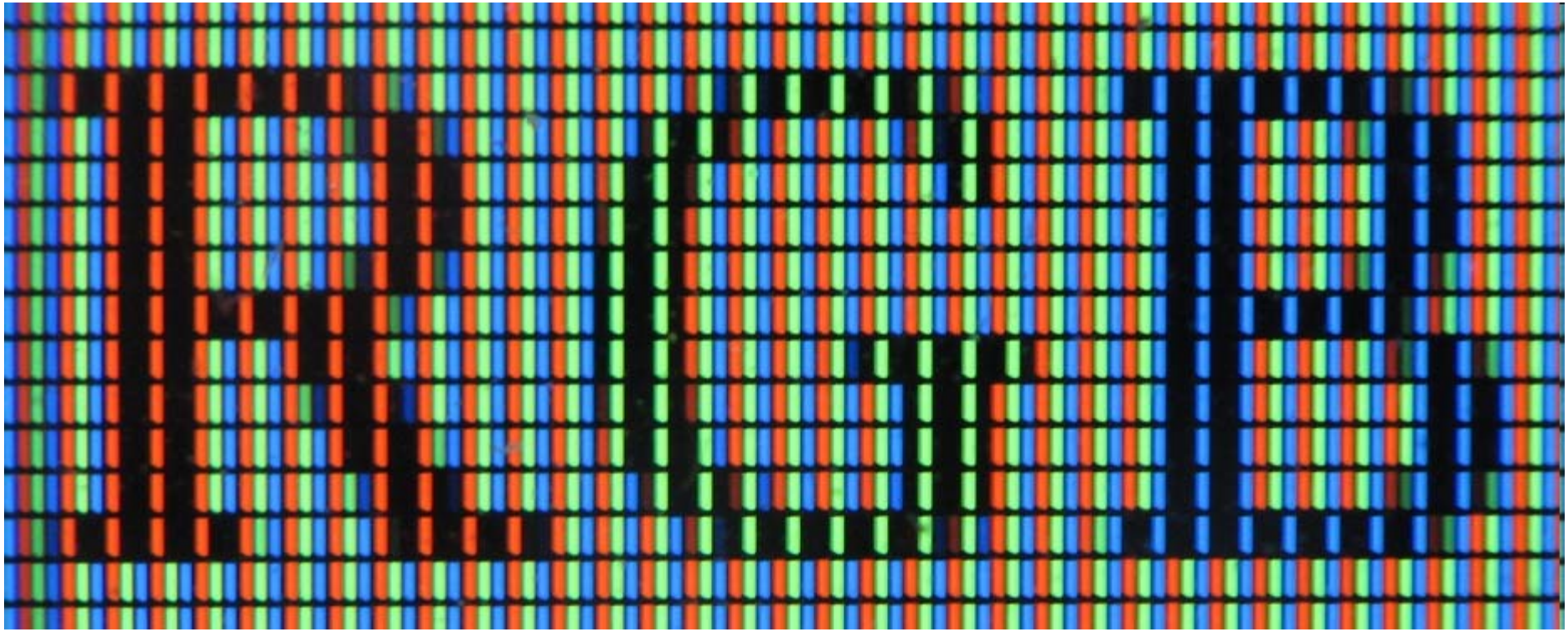
We Can Also Control Light Electrically

Crystal

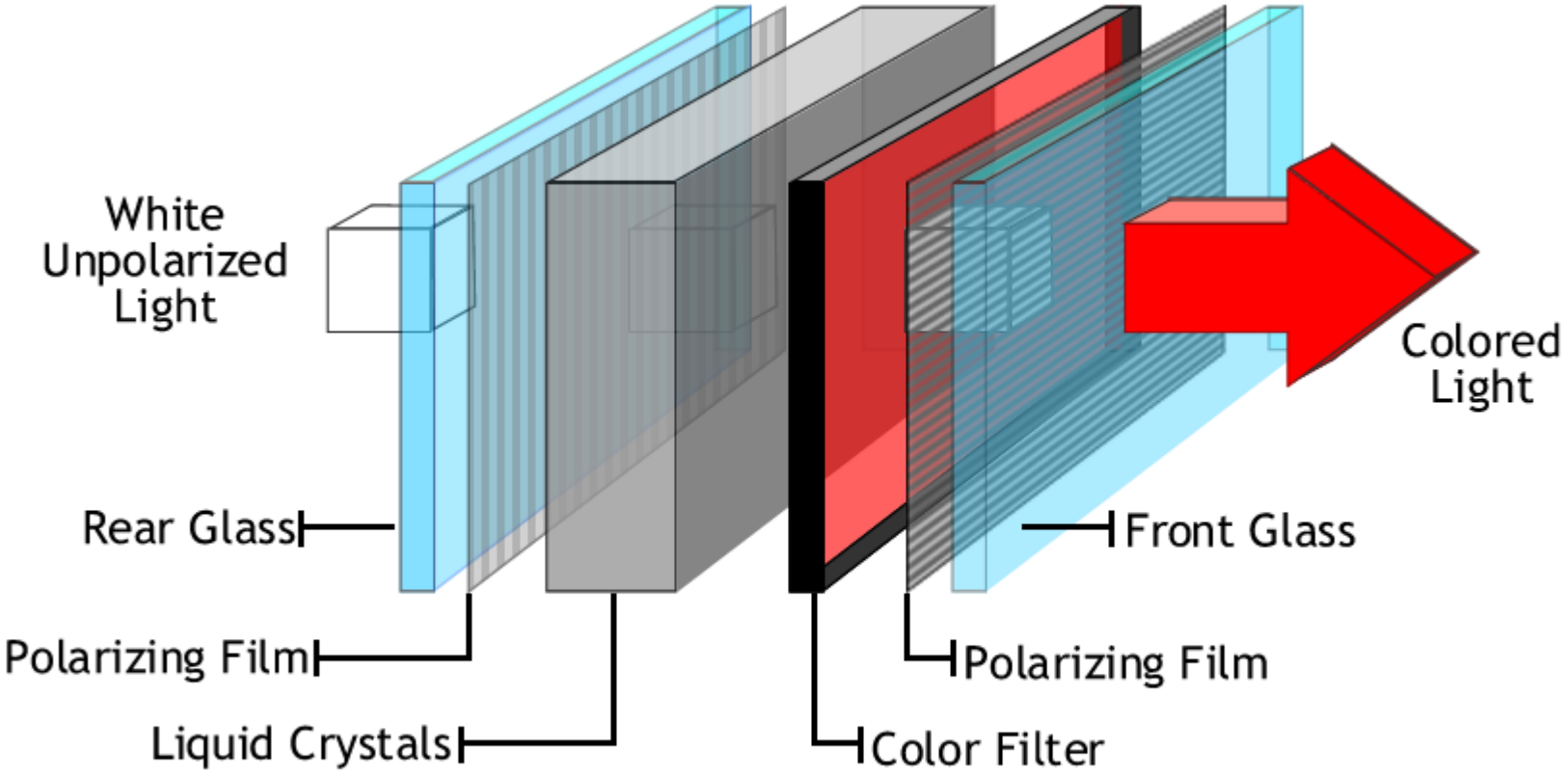
Liquid Crystal


glass plates
vertical filter
crystal molecule
horizontal filter
colour filter
LCD

RGB

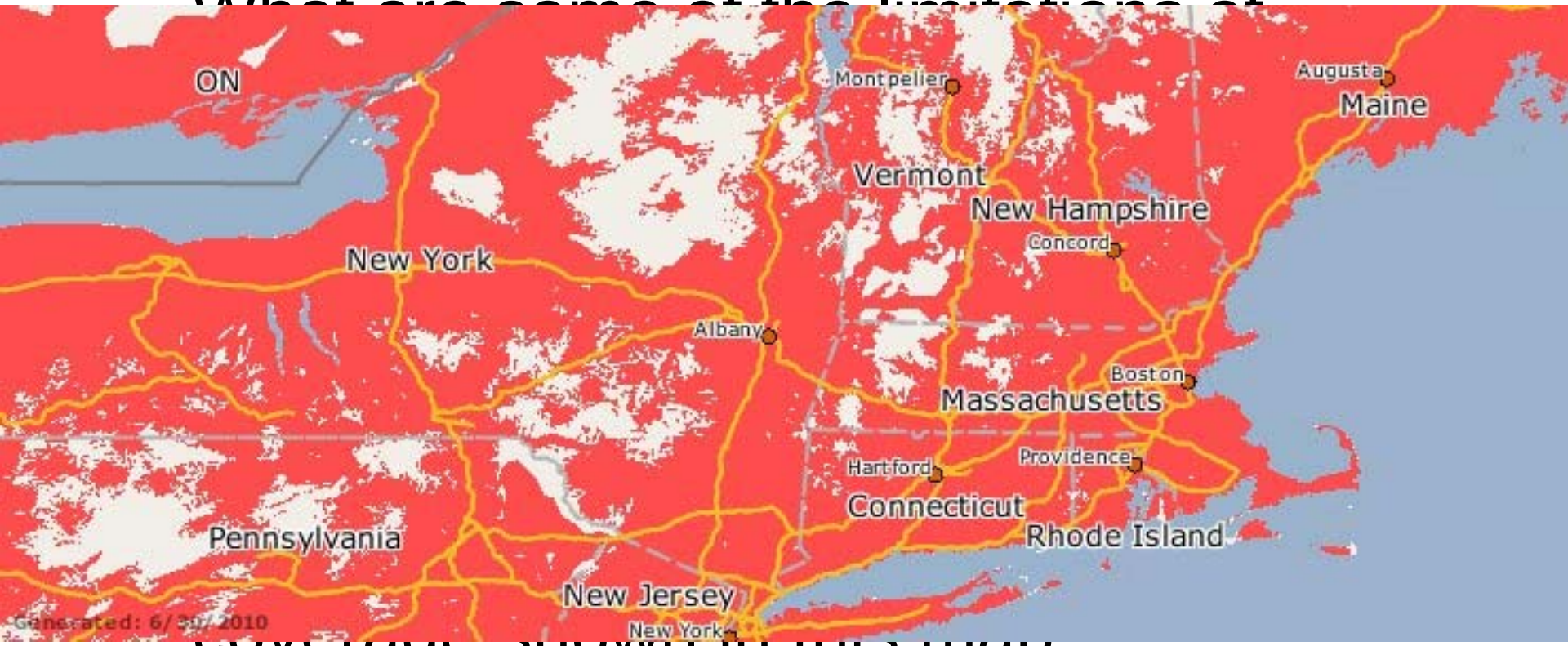


LCD


White
Unpolarized
Light
Colored
Light
Rear Glass
Front Glass
Polarizing Film
Polarizing Film
Liquid Crystals
Color Filter
© Lon Koenig

The Future?
Iridium – An Entertaining Failure or Now on the Road to Success?

What are some of the limitations of coverage shown in this map?

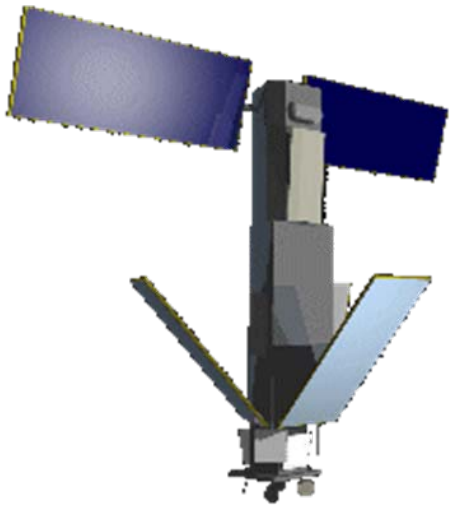


Iridium

- 1987: Two Motorola engineers envision a constellation of low orbiting satellites.
- 1990: The Iridium System is announced.
- 1995: FCC License granted
- 1998: Constellation of 66 satellites successfully launched.
- 1999: Chapter 11
- 2002: Licenses, etc. assigned to New Iridium

Note: Financing was several billion dollars

Iridium Flares – Fun With Satellites

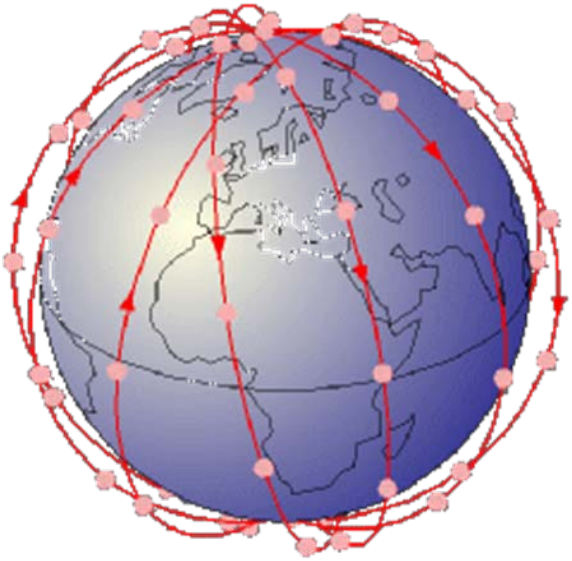


- The Iridium satellites are relatively small telecommunications satellites in a low Earth orbit.
- Each satellite has three main mission antennas (MMAs), which are flat, highly reflective surfaces, that can reflect the Sun's rays to an observer on the ground when the geometry is correct.

Iridium Flares – Fun With Satellites

- The satellite's attitude is controlled so that the long axis remains vertical, with one MMA always pointing forwards. Given this knowledge of the attitude, together with the orbital position of the satellite and the Sun and observer's location, it is possible to calculate the angle between the direction to the observer from the satellite and the line of a perfect reflection of the Sun. This is the so-called "mirror angle" and determines the magnitude of the flare.

Iridium Flares



- Heavens Above is an extensive website with information on tracking objects in space, notably including Iridium Satellites.

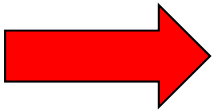
Iridium Flares

- In the main Heavens Above webpage, select your location either exactly by longitude and latitude or from their extensive database.
- Choose United States, then Sycaway (where I live) Latitude: 42.742, Longitude:73.653, Elevation: 121 m
- Select Iridium Flares for the Next 7 Days.

Iridium Flares

Clicking on the time of the flare will load another page with more details, including a map showing the track of the flare along the ground, and the location of the nearest point of maximum intensity.

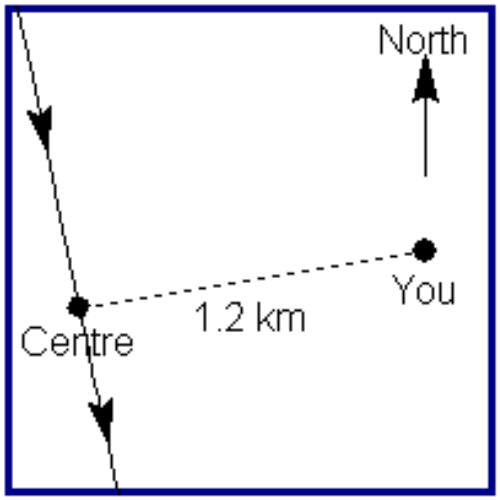
Search Period Start: 21:24, Sunday, 10 November, 2002
Search Period End: 22:24, Sunday, 17 November, 2002
Observer's Location: Sycaway (42.7420°N, 73.6530°W)
Local Time: Eastern Standard Time (GMT - 5:00)



Date	Local Time	Intensity (Mag)	Alt.	Azimuth	Distance to flare centre	Intensity at flare centre (Mag.)	Satellite
13 Nov	05:31:13	-2	26°	162° (SSE)	27.0 km (W)	-7	Iridium 11
14 Nov	05:25:17	-2	25°	162° (SSE)	21.5 km (E)	-7	Iridium 3
15 Nov	06:42:50	-1	29°	76° (ENE)	39.7 km (E)	-7	Iridium 28
16 Nov	06:36:44	-7	28°	74° (ENE)	1.2 km (W)	-7	Iridium 30
17 Nov	05:16:14	-1	26°	170° (S)	35.0 km (W)	-7	Iridium 26
17 Nov	06:30:35	-1	28°	73° (ENE)	45.9 km (W)	-6	Iridium 57
17 Nov	17:34:52	-1	60°	34° (NE)	30.1 km (W)	-8	Iridium 46

Iridium Flares

Iridium Flare Details



Map showing path of flare centre over Earth's surface

Date: Saturday, 16 November, 2002
Your Location: Sycaway (42.742°N, 73.653°W)
Time Zone: Eastern Standard Time (GMT - 5:00)
Satellite: Iridium 30
Antenna (MMA): Front
Flare centre is at: 42.740°N, 73.668°W
Distance to centre: 1.2 km (0.8 miles)

	At your location	At flare centre
Time:	06:36:44	06:36:44
Magnitude:	-7	-7
Altitude:	28°	28°
Azimuth:	74° (ENE)	74° (ENE)
Mirror angle:	0.0°	0.0°

Iridium Flares

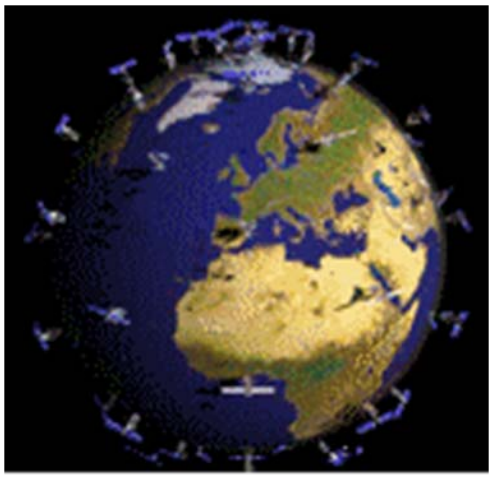
magnitude

This is a measure of the brightness of a celestial object. The lower the value, the brighter the object, so magnitude -4 is brighter than magnitude 0, which is in turn brighter than magnitude +4. The scale is logarithmic, and a difference of 5 magnitudes means a brightness difference of exactly 100 times. A difference of one magnitude corresponds to a brightness difference of around 2.51 (the fifth root of 100).

The system was started by the ancient Greeks, who divided the stars into one of six magnitude groups with stars of the first magnitude being the first ones to be visible after sunset. In modern times, the scale has been extended in both directions and more strictly defined.

Examples of magnitude values for well-known objects are;

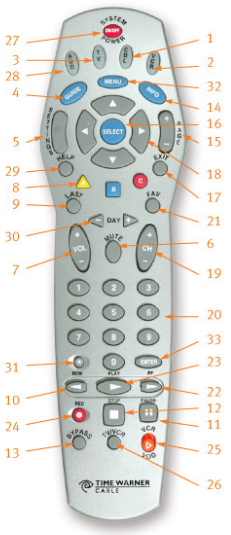
Sun	-26.7 (about 400 000 times brighter than full Moon!)
Full Moon	-12.7
Brightest Iridium flares	-8
Venus (at brightest)	-4.4
International Space Station	-2
Sirius (brightest star)	-1.44
Limit of human eye	+6 to +7
Limit of 10x50 binoculars	+9
Pluto	+14
Limit of Hubble Space Telescope	+30



Iridium Flares

- What will you see?
- Look at http://homepage.mac.com/kevision/video/iMovieTheater25.html and http://www.youtube.com/watch?v=1PFUP5LPyuA

Remote Controls

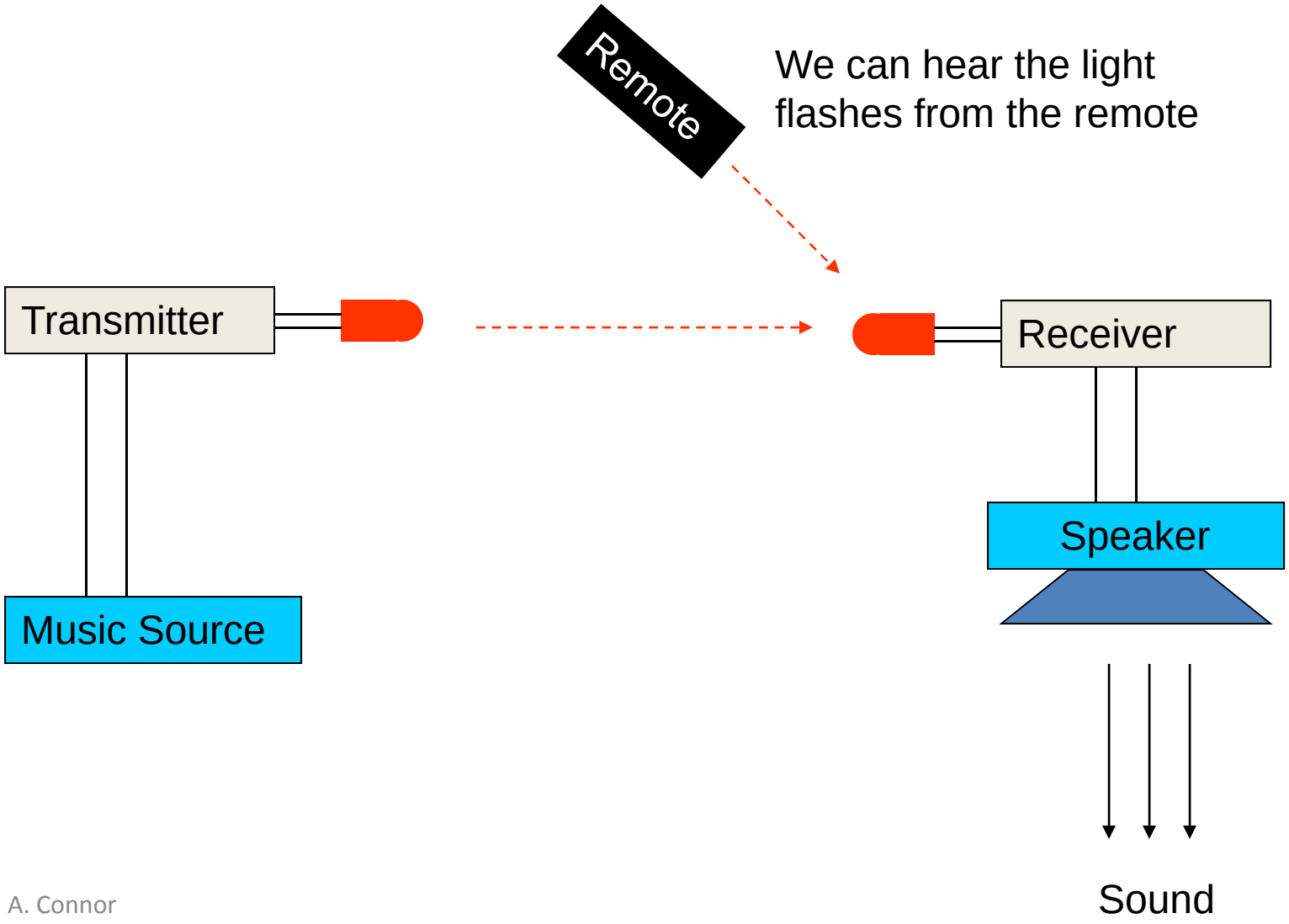


DTV Remote Functions

1 **CBL** Turns cable box ON/OFF
2 **VCR Power** VCR/DVD ON/OFF
3 **TV Power** ON/OFF
4 **GUIDE** Displays Picture-in-Picture Program Guide
5 **SETTINGS** Displays Settings menu
6 **MUTE** Turns sound ON/OFF
7 **VOL** Volume control
8 **A, B, C** Used for on-screen options. On-screen display indicates which button to use for various functions.
9 **LAST** Return to last channel viewed
10 **REWIND** VCR/DVD/DVR/On Demand
11 **PAUSE** VCR/DVD/DVR/On Demand
12 **STOP** VCR/DVD/DVR/On Demand
13 **BYPASS** (Future use)
14 **INFO** Displays program information
15 **PAGE** Displays next or previous page in Program Guide and Info screens
16 **SELECT** Selects highlighted on-screen options and channels
17 **EXIT** Exits interactive screens
18 **ARROWS** Scroll through interactive screen options
19 **CH** Channel up/down
20 **NUMBER PAD** Enter channel or PIN #
21 **FAV** Selects favorite channels
22 **FAST-FORWARD** VCR/DVD/DVR/On Demand
23 **PLAY** VCR/DVD/DVR/On Demand
24 **RECORD** with VCR/DVR
25 **VCR/VOD** To operate your VCR/DVD, switch must be set to VCR. Set to down position for On Demand programming.
26 **TV/VCR** Switch control between TV and VCR/DVD
27 **SYSTEM POWER** Turns cable box, TV, VCR/DVD and audio ON/OFF
28 **AUD POWER** ON/OFF
29 **HELP** Provides more info
30 **DAY +/-** Skip forward or backward a whole day in the Program Guide
31 **(•)** Future use
32 **MENU** Displays Program Guide
33 **ENTER** Immediately tune to the channel number you've just entered

- Infrared Light
- Cannot be seen by humans
- Can be seen by digital camera
- Remote control sends light flashes to TV or any other device it is to control

Music Traveling on Light Flashes



Butterfly and Bee Vision

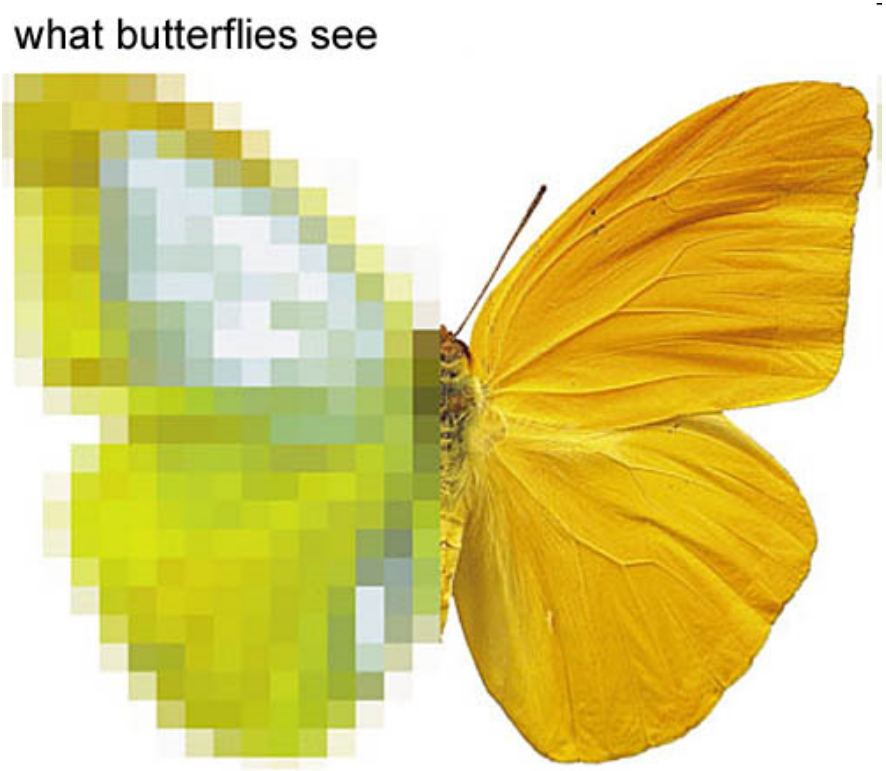


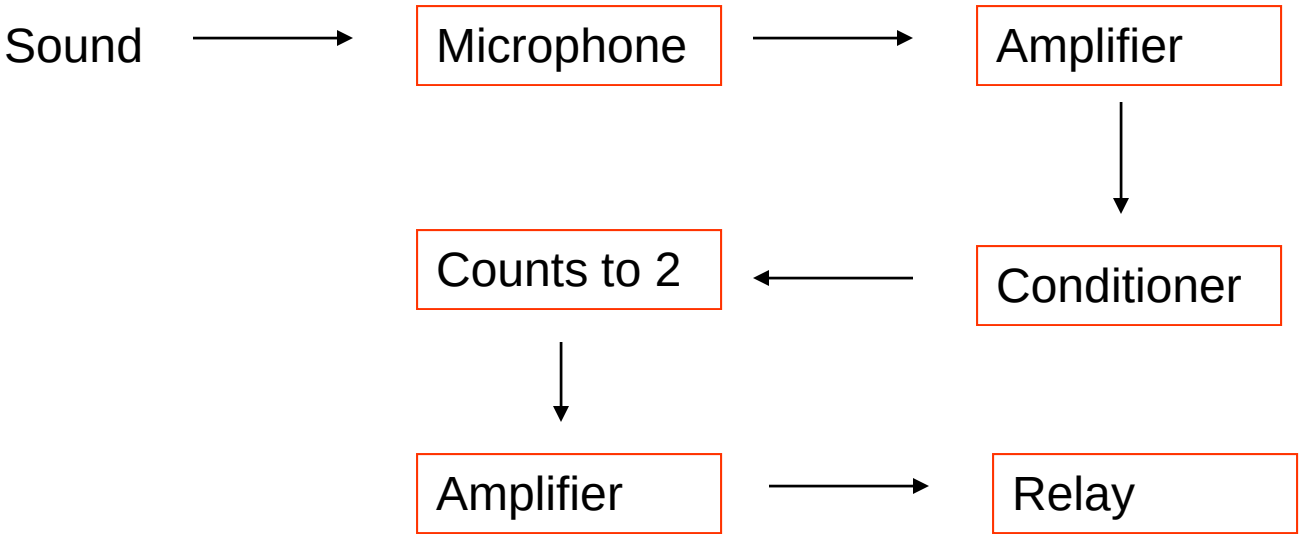
Image made with light visible to humans

Image made with only UV light

The Clapper

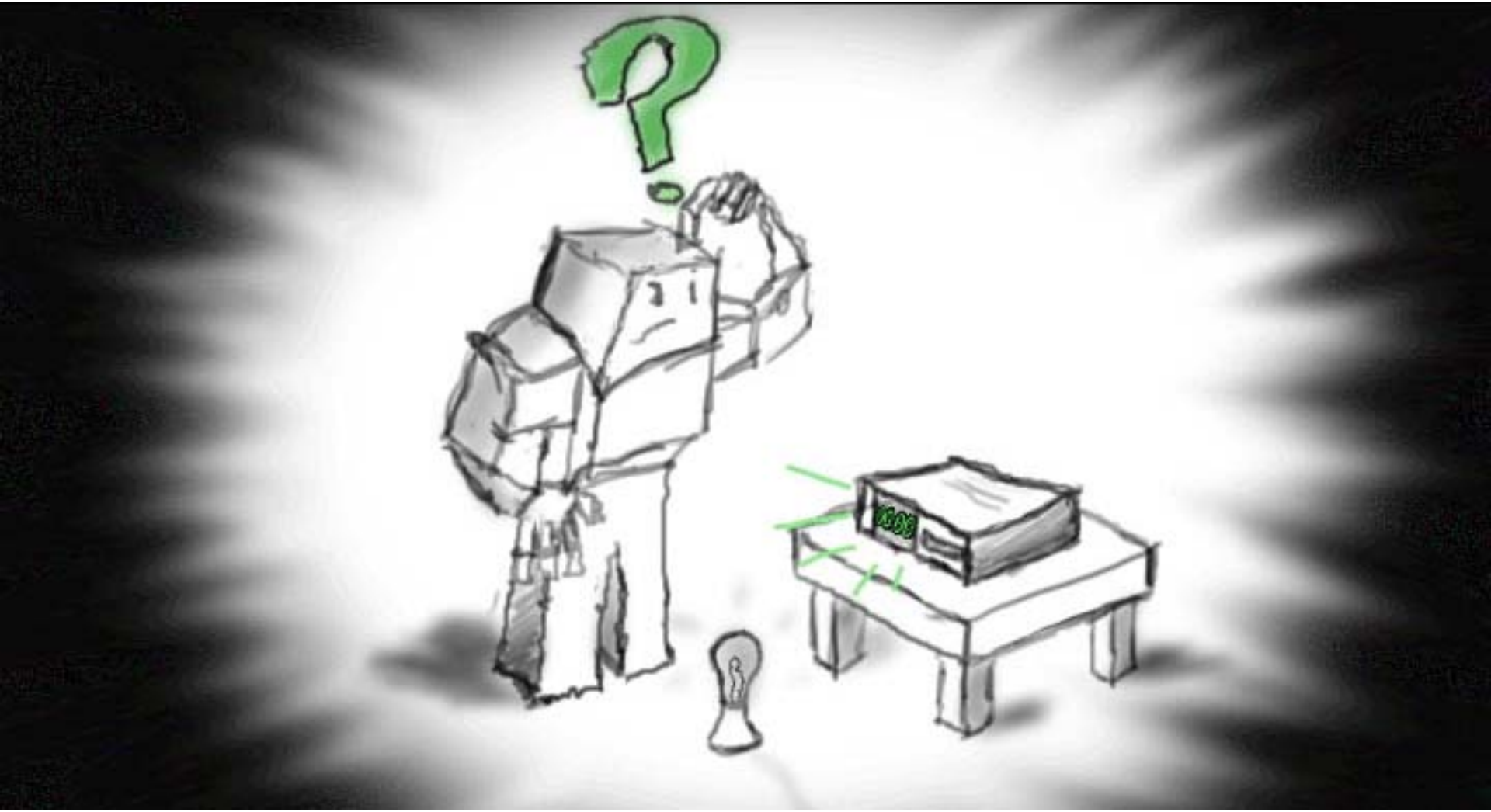

THE CLAPPER
CLAP ON! CLAP OFF!
The Sound Activated On/Off Switch
NOW WITH CLAP DETECTION LIGHTS

The Clapper



This is a good example of a system that makes a decision based on some kind of input

Questions?



More to Come