# Optoelectronics

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# Overview of Optoelectronics

- **Light emission:**
  - Incandescent lamps
  - Light emitting diodes
  - Laser diodes
  - Vacuum fluorescent devices
  - Plasma devices
  - Gas lasers
  - Electroluminescent devices
- **Light detection:**
  - Photoconductors
  - Solar cells
  - Photodiodes
  - Phototransistors
  - Integrated photodetector chips

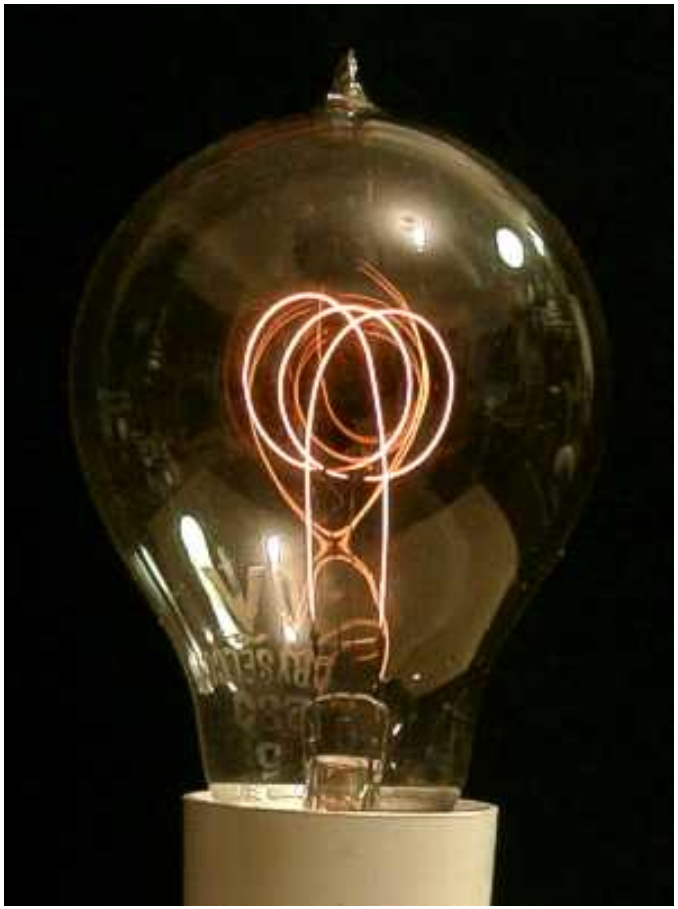
  

# Incandescent Lamps

- Incandescent lamps - the most common type used around the house - rely on heating up a thin wire (usually tungsten, but carbon before 1907) to white heat.
- The resistance of the wire increases with temperature (as do the resistances of most materials – “positive temperature coefficient of resistance”) so that it does not have “thermal runaway.”
- As seen in the original Hewlett-Packard Wein bridge oscillator, a light bulb can be used as a regulator for power or amplitude.

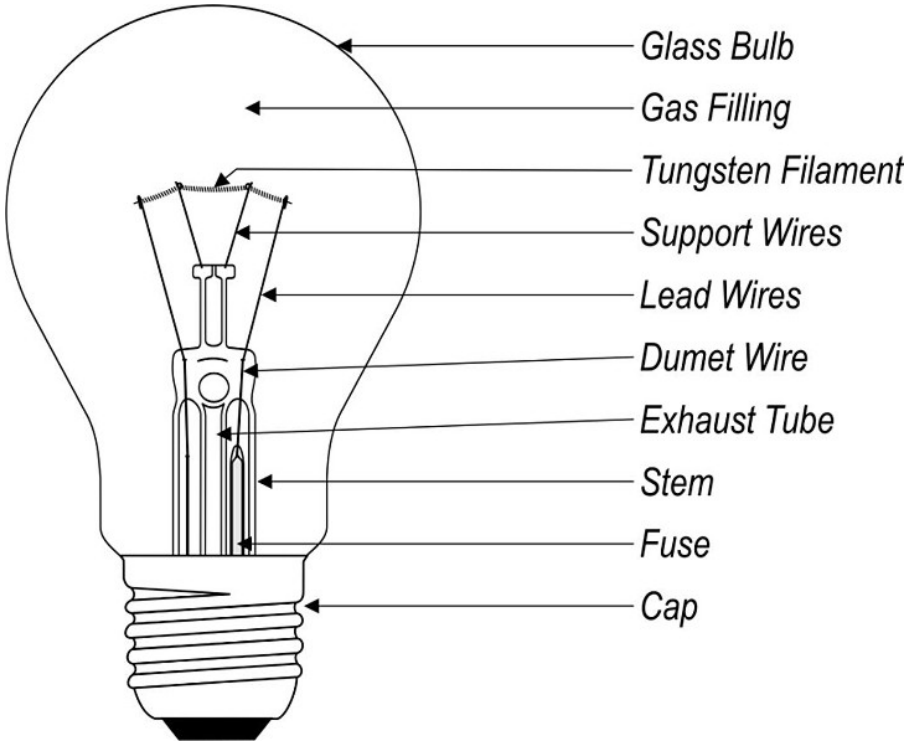
  

# Incandescent Lamps



**Carbon-filament lamp, Pre-1907.**

http://www.teralab.co.uk/Museum/Lamps/Museum_Lamps_Page1.htm




http://www.lamptech.co.uk/Documents/IN%20Introduction.htm

**Most developed nations have, or are in the process of implementing phase-out plans for incandescent lamps.**

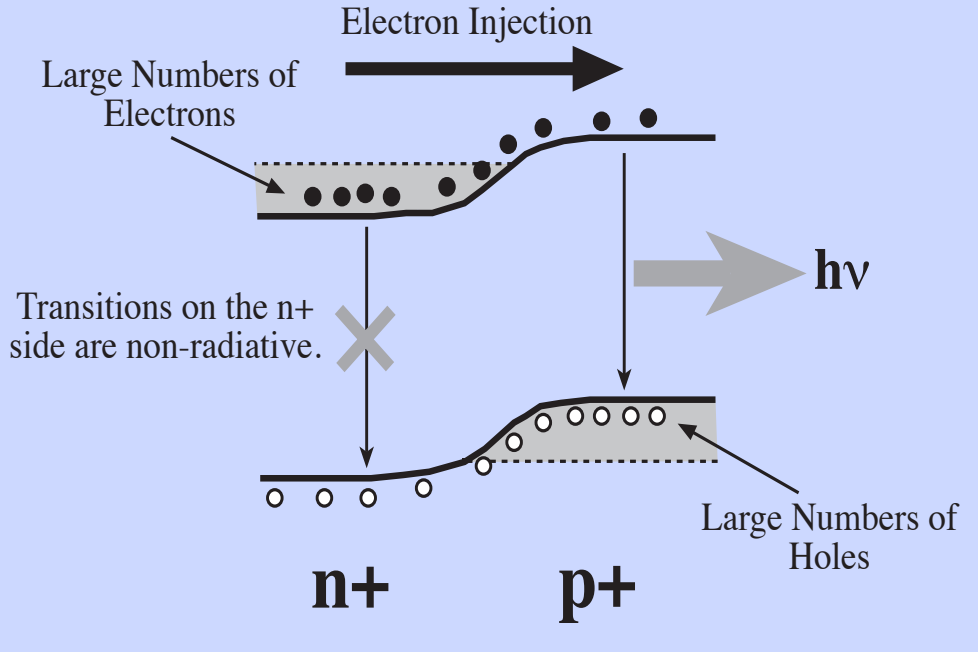
  

# LEDs - Overview

- Light emitting diodes, or LEDs, are inexpensive, solid-state light emitters.
- With improved new technologies, they are bright enough that they can be used for illumination (e.g., flashlights) with very low power consumption.
- They do no emit much heat, resist shocks, and last for tens of thousands of hours.
- They are increasingly being used for traffic signals, commercial and home lighting, LCD monitor and TV backlighting, etc.

# LED Mechanisms

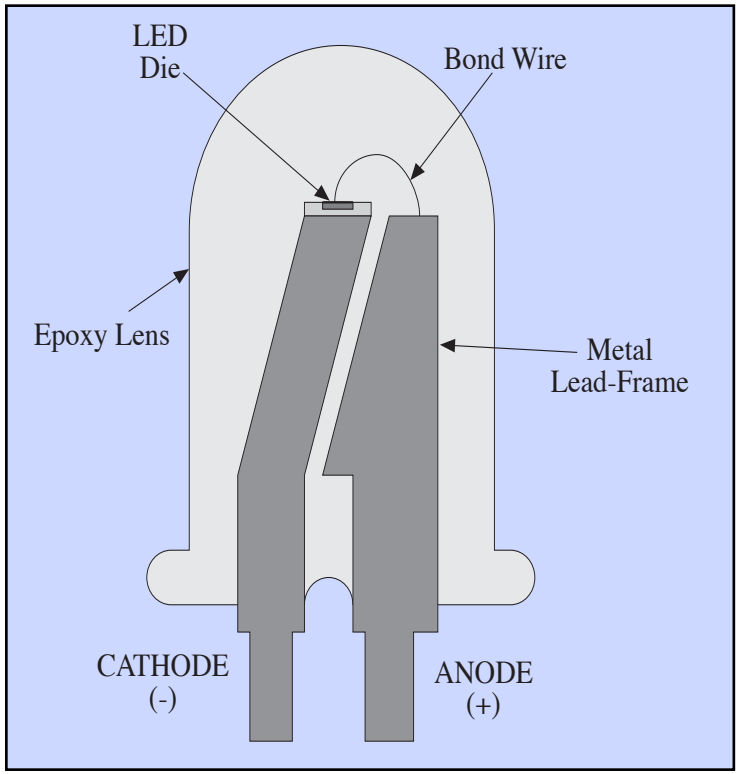


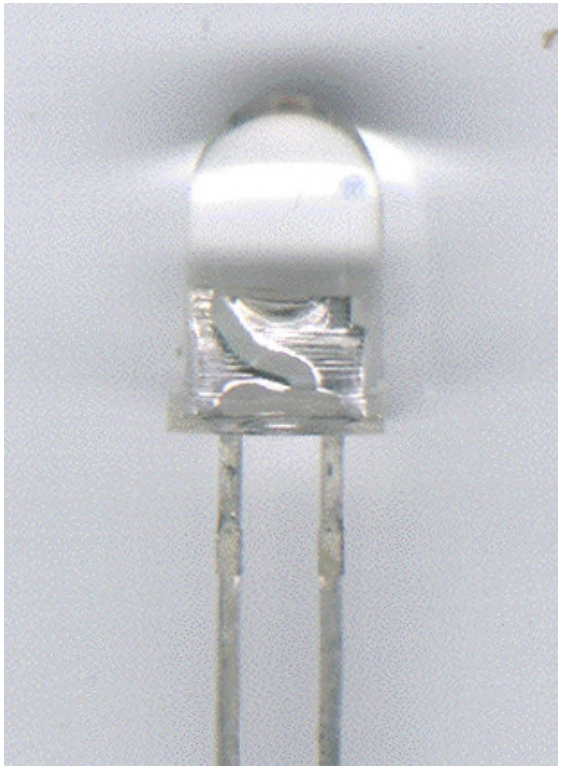

- When a forward bias is applied to an LED, electrons acquire enough energy to cross from the n+ through the depletion region to recombine in the p+ region (similar for holes leaving the valence band).
- Photons are emitted with no phase relationship to each other (incoherent).
- Very bright LEDs are now commonplace (>3 cd).
- Direct bandgap, large quantum efficiency (>80%).

**Typical materials: GaP, GaAs, GaAsP, SiC, etc.**

# Basic Low-Power LED

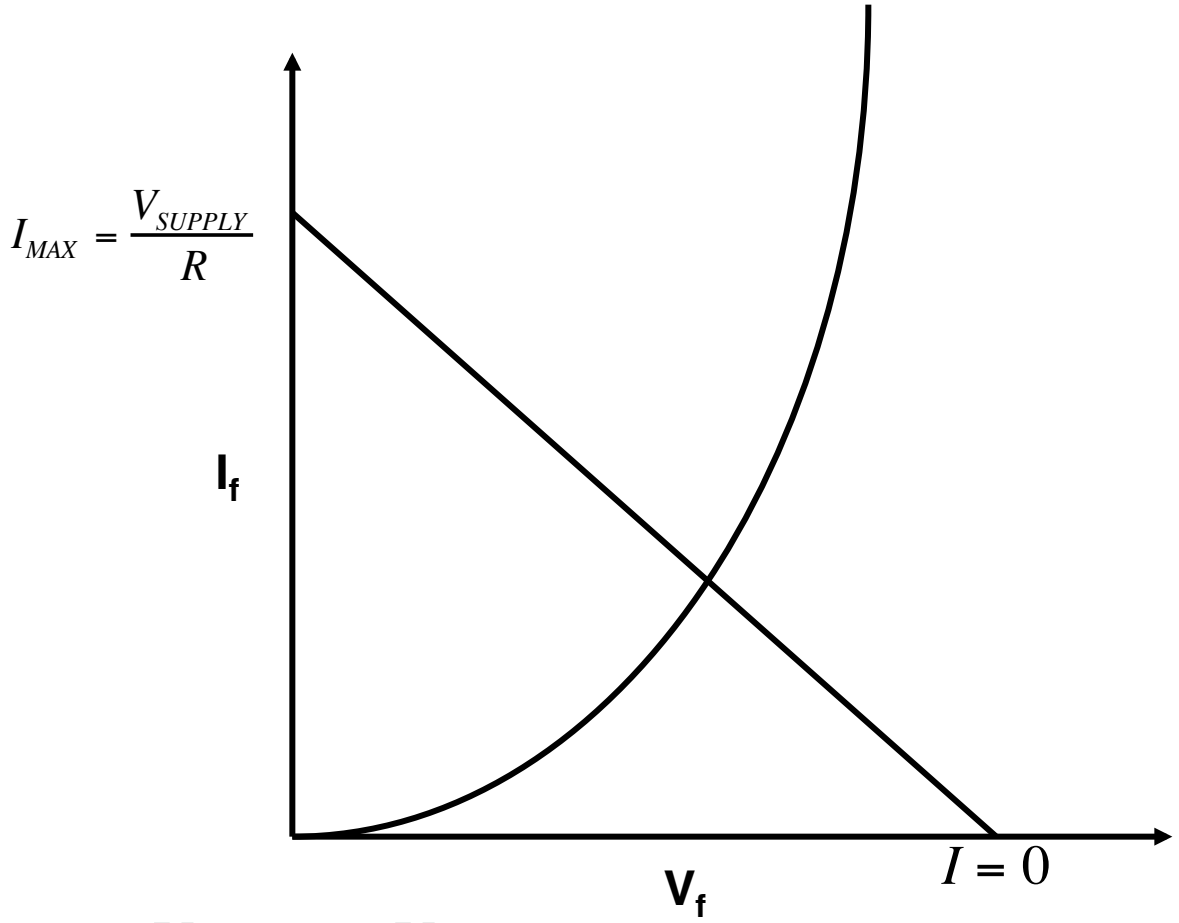


# Simple LED Drive with Resistor

- If driving from a voltage source, should limit current using a series resistor.
- Need to know the forward voltage of the LED to calculate the resistor's value.
- Determine the LED forward voltage, select the current you want (usually not more than 20 mA) and compute $R_{LED}$.

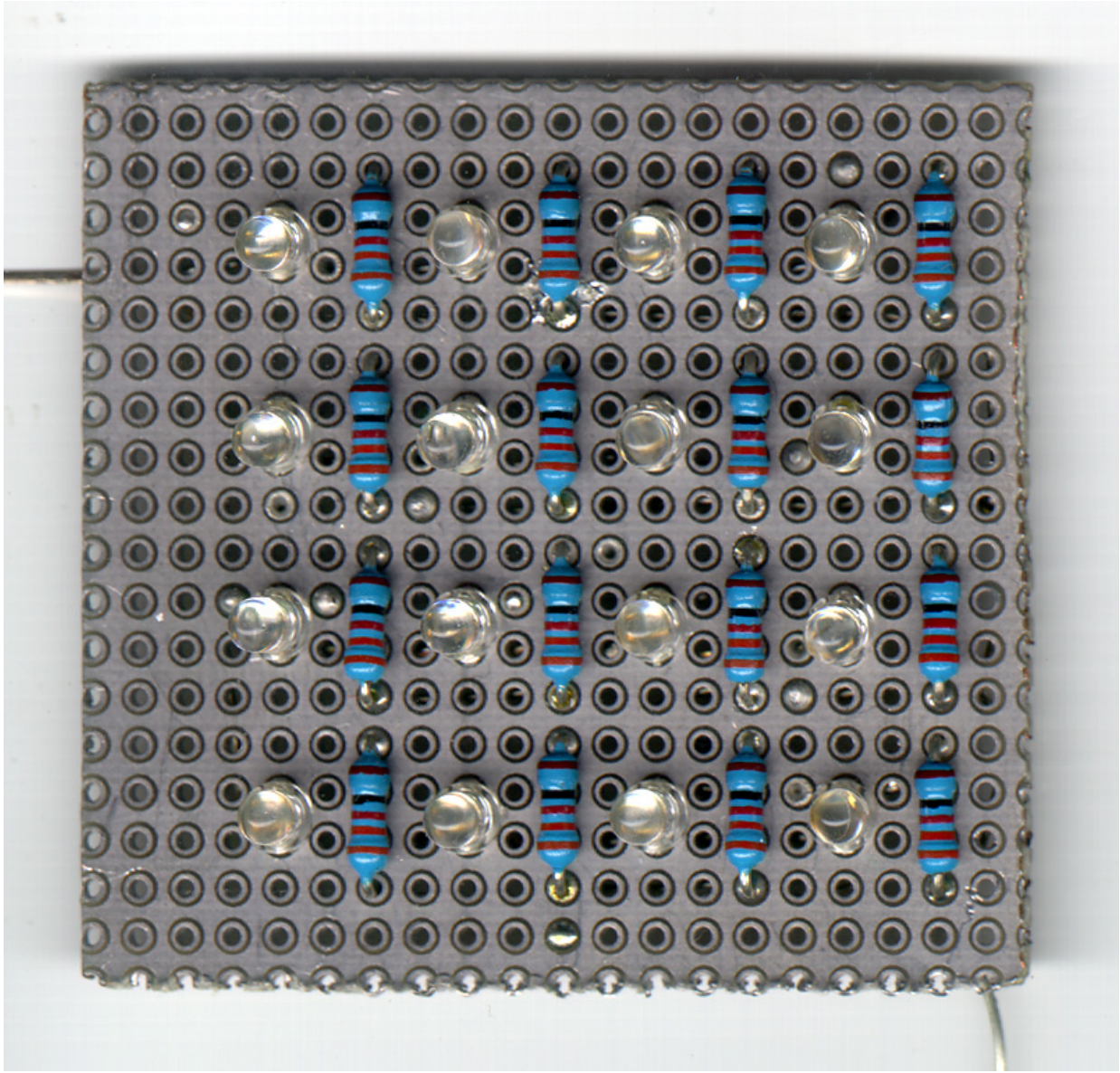



When all voltage is dropped across the diode

$$R_{LED} = \frac{V_{SUPPLY} - V_{fLED}}{I_{LED}}$$

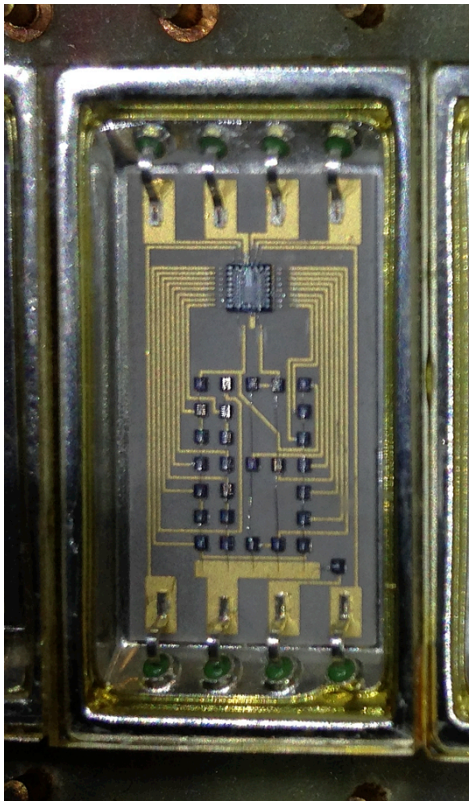
  

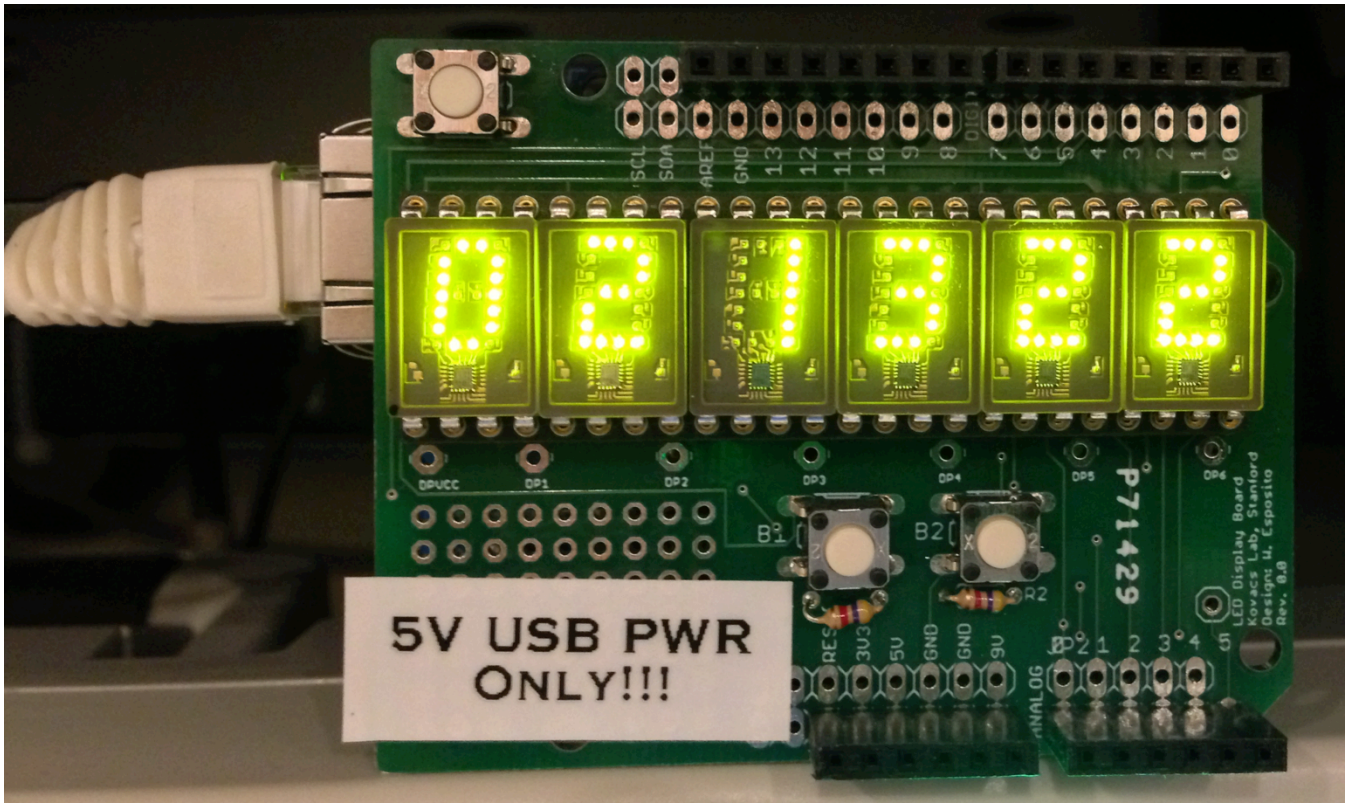
# Homemade LED Illuminator



# LED Matrix Display



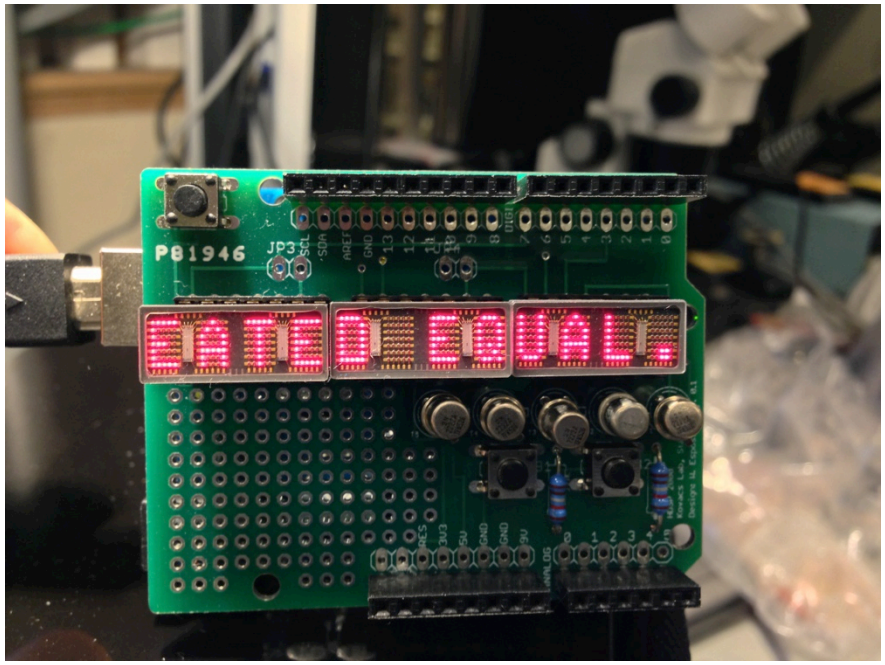




- Originated by Hewlett-Packard in 1969 (the 5082-7100 series), descendants of these displays remain among the most legible and beautiful (and most expensive).
- On-board decode logic translates 4-bit parallel data into the LED matrix pattern.

# Example LED Display Types



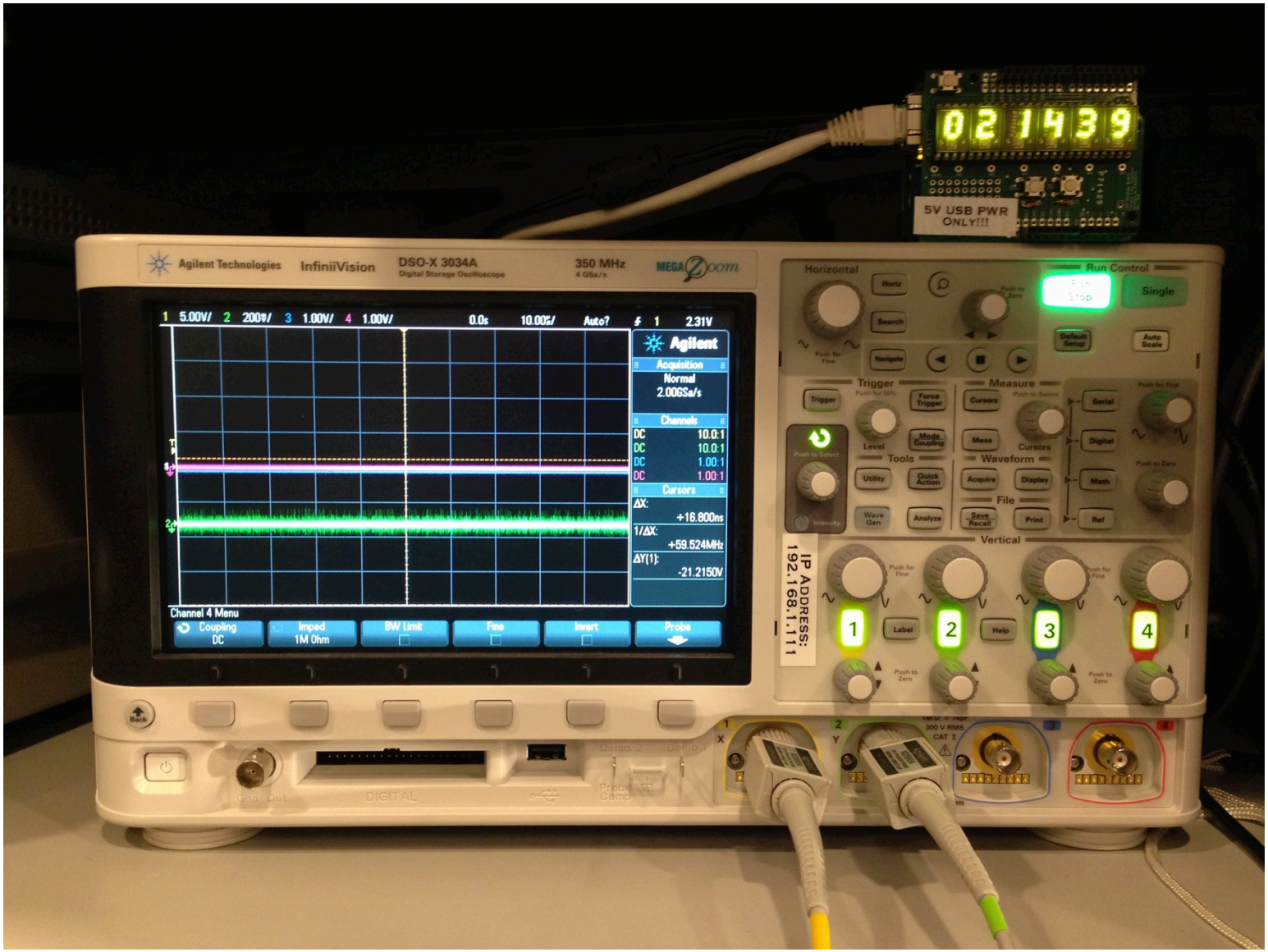

5X7 matrix alphanumeric.


Panel indicators.


7-Segment numeric.

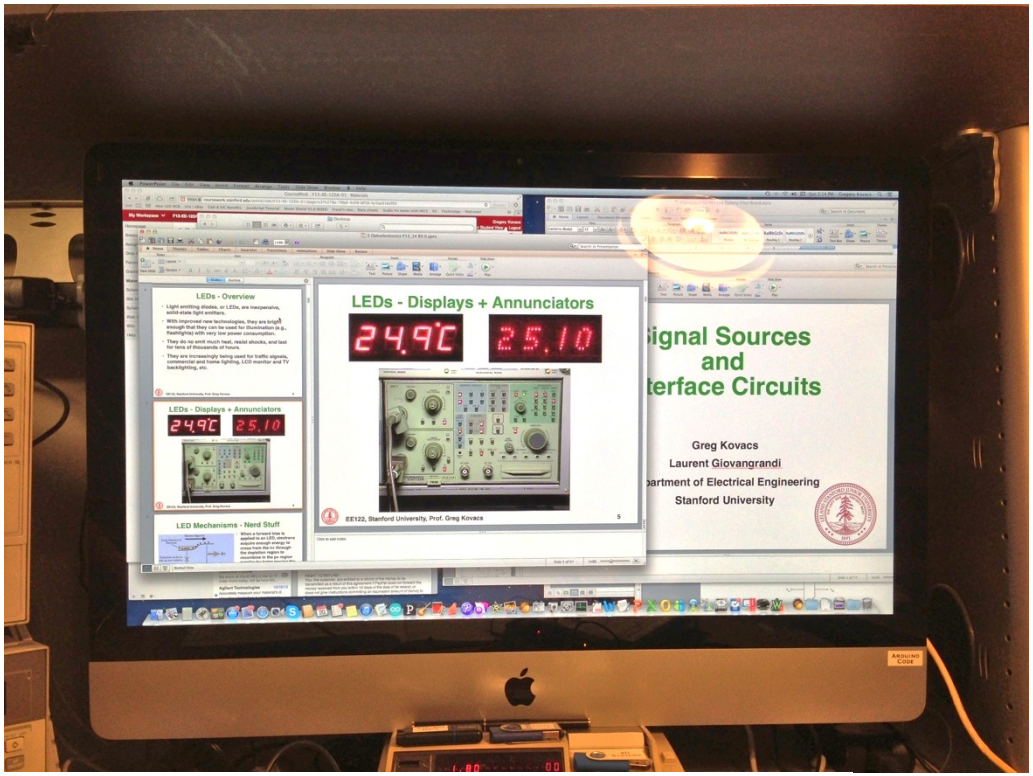
  

# Bench Tour: Examples

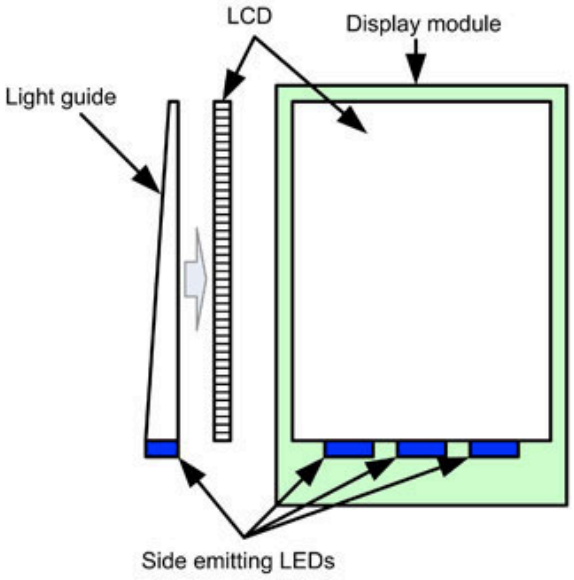


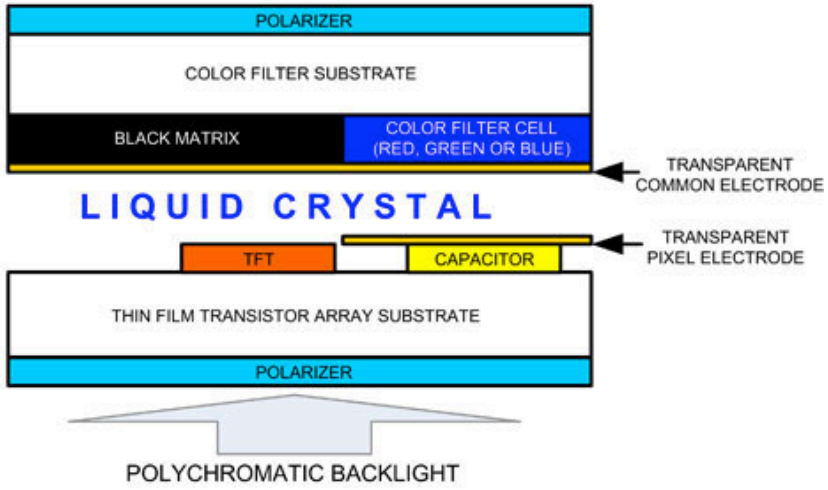

  

# Bench Tour: Examples




http://powerelectronics.com/site-files/powerelectronics.com/files/archive/powerelectronics.com/power_management/led_drivers/Fig-1-LCD-display-structure.jpg



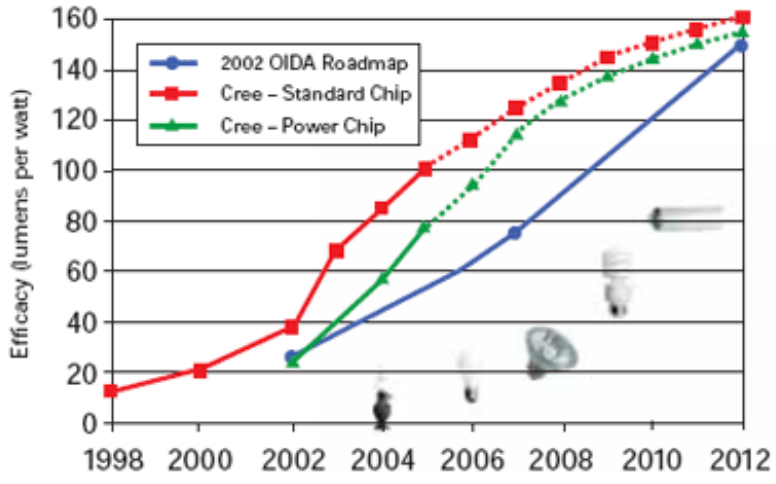

  

# Bench Tour: Examples

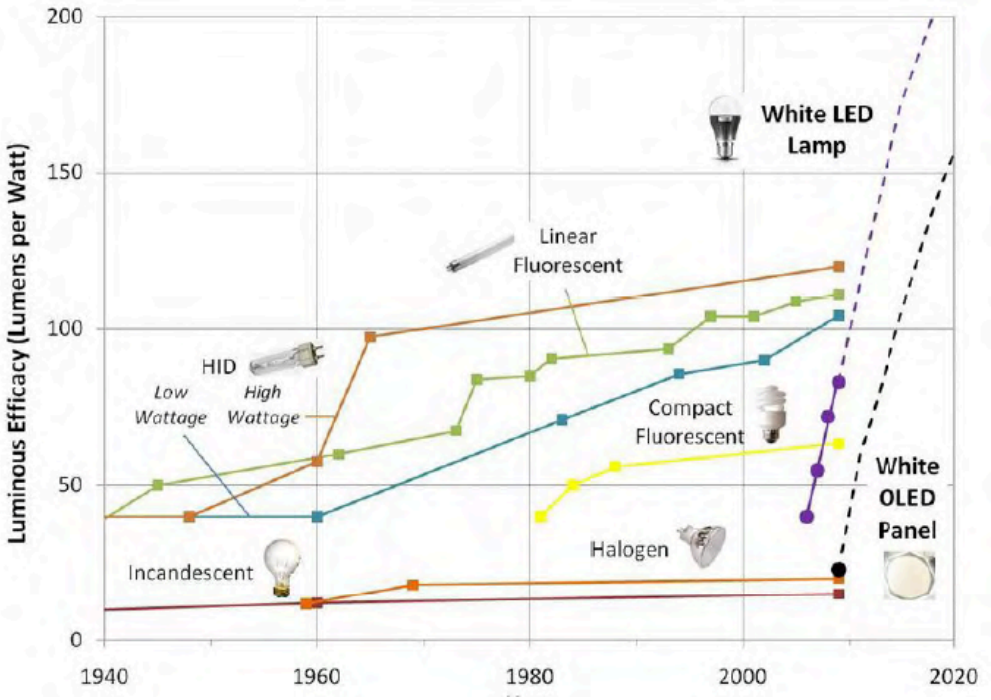
  

# Improvements In LED Lighting

- Primary goal is efficiency (lumens/watt).
- Striving for good color temperature (warm is what people are used to, not bluish).
- Reliability is key.
- Dollars per lumen is another interesting metric.




http://www.theledlight.com.cn/led-light-img/305-us-roadmap-big.gif



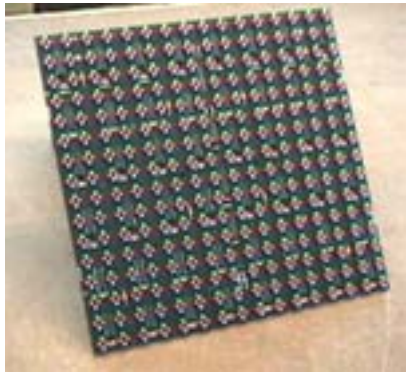

http://topbulb.wordpress.com/2010/11/19/lumens-per-watt-the-next-step-of-the-white-led-revolution/

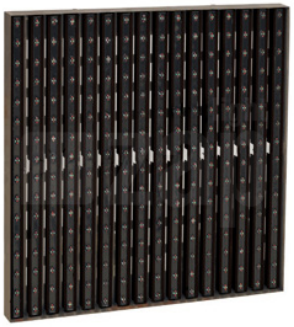
# Full-Color LED Displays

Fujitsu

http://ecem1.myblog.it/archives/2011/10/index-25.html



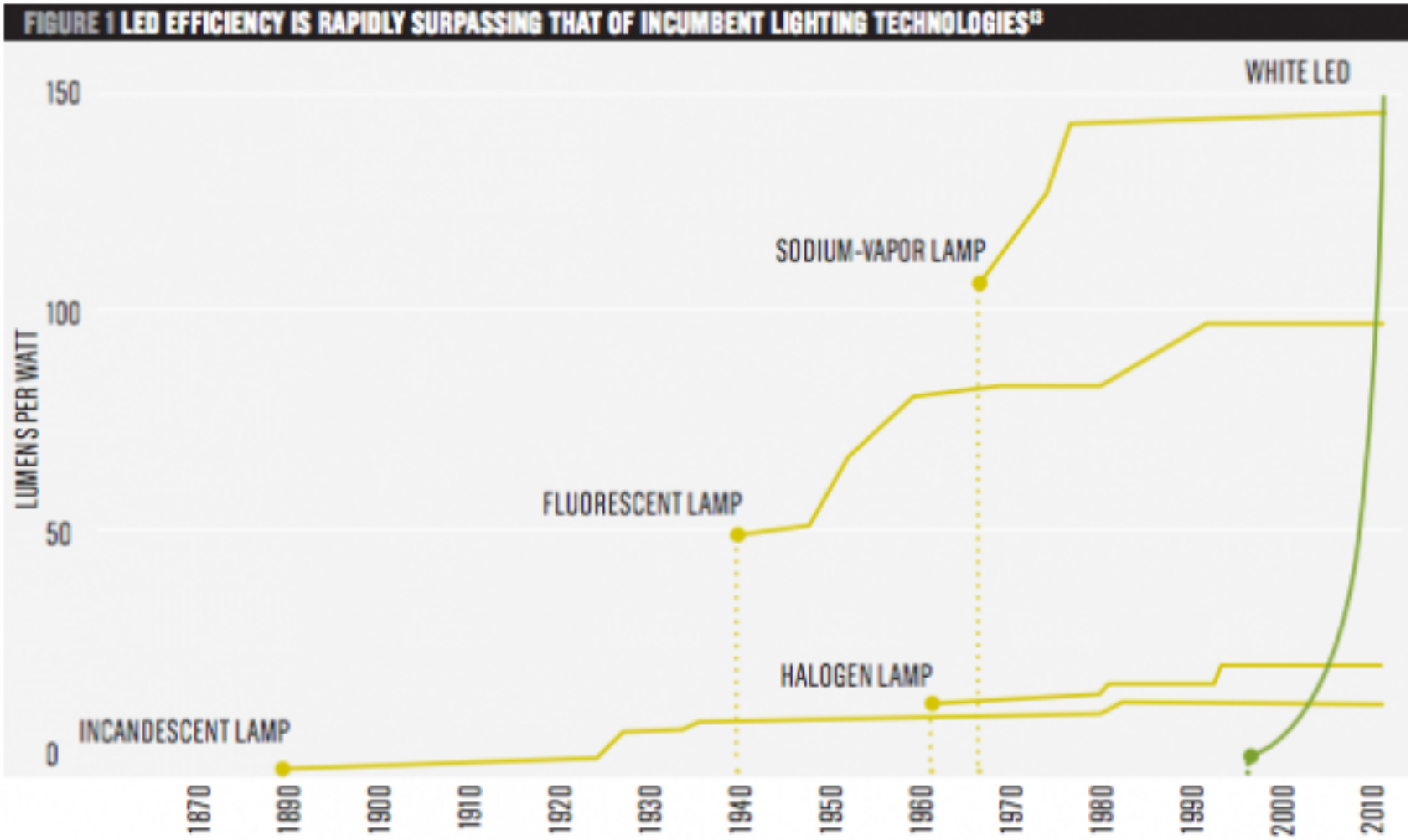
http://www.adartesc.com/LED_full_color.htm



http://led-screen.zapled.co.uk/outdoor-led-video-mesh-screen/

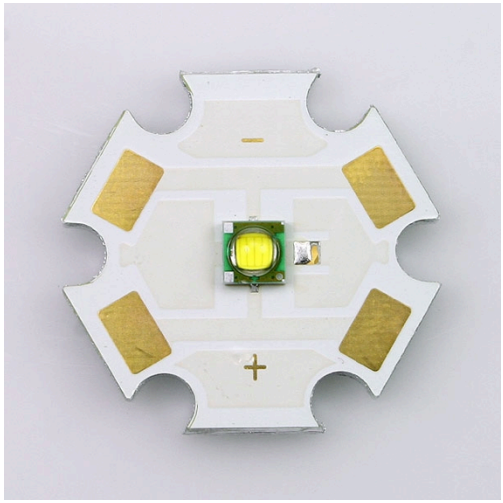
  

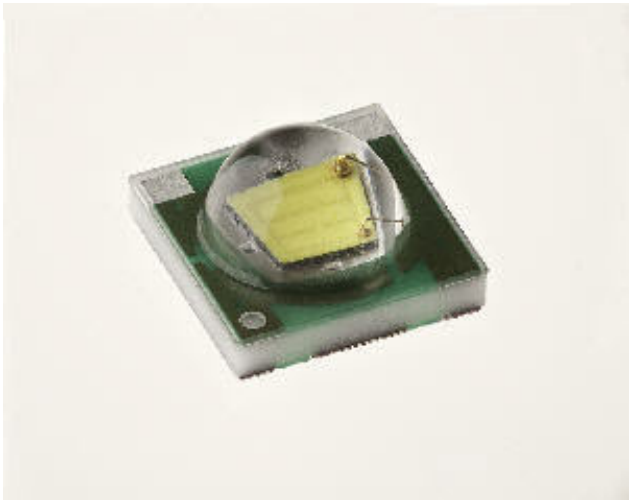
# Improvements In LED Lighting




http://www.energycircle.com/blog/2012/06/21/led-lighting-massive-opportunity-getting-better



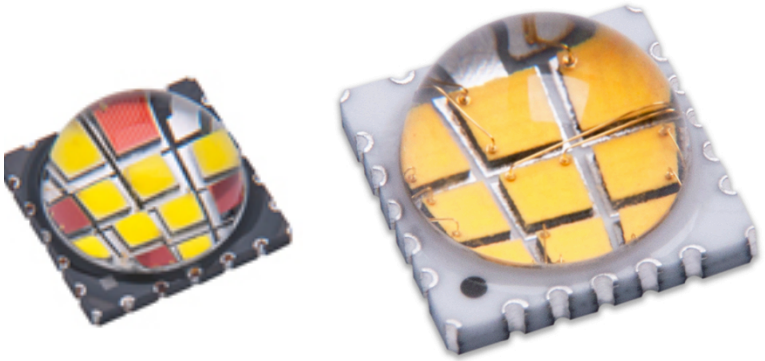


http://www.superbrightleds.com/moreinfo/component-leds/xpe-series-cree-led/325/

**One-chip LED - Cree XPE series, 1W.**


**http://www.ledssuperbright.com/images/100W_eylane.jpg**


http://www.cree.com/LED-Components-and-Modules/Products/XLamp/Arrays-NonDirectional/XLamp-CXA2540



**http://www.ledengin.com**

**Chip-On-Board (COB) array examples.**

# Commercial LED Lighting


**Philips 17W, 1055 lm lamp (indirect phosphor).**

http://www.lighting.philips.com

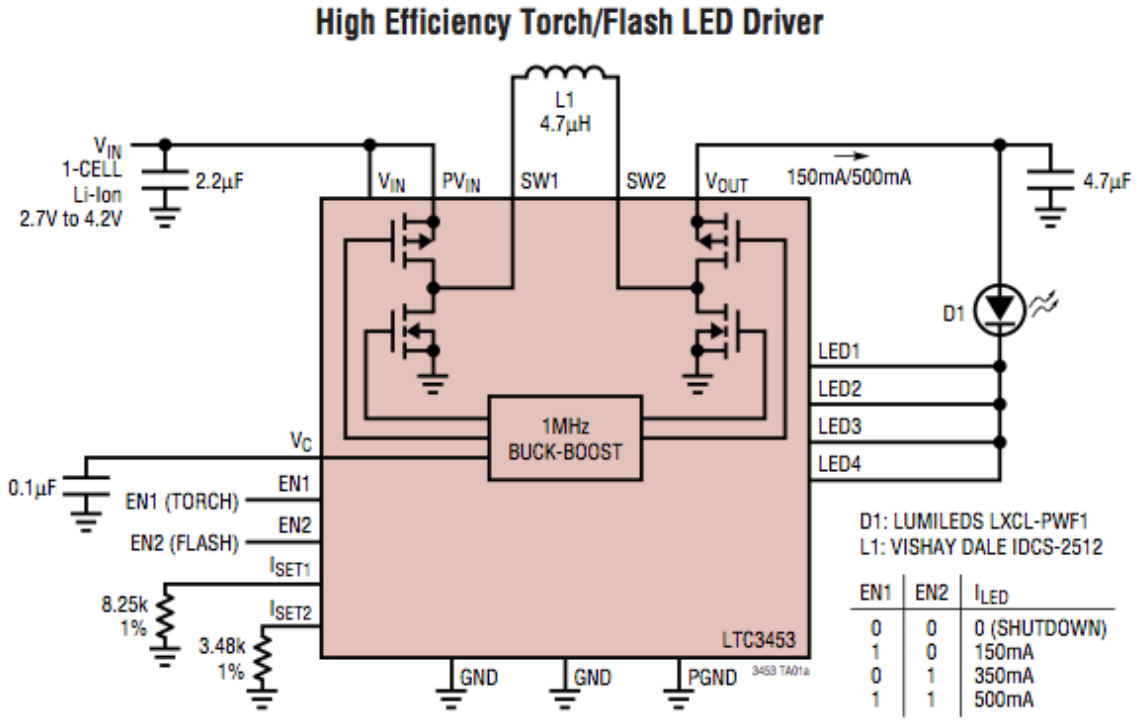
- **LED lighting is revolutionary and is taking off.**
- **Initial offerings were very poor. Cheaply built, poorly designed and expensive too!**
- **Newer designs may well realize the long-life potential of LED's 20 – 50,000 hrs.**

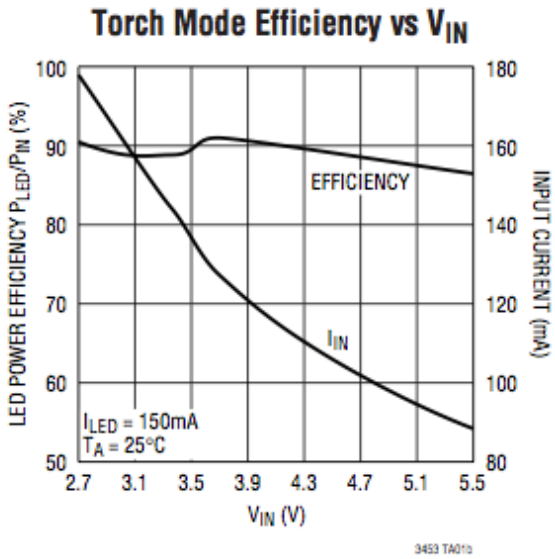

**Ecosmart 17W, 950 lm lamp.**

http://www.homedepot.com

# Flashlight Driver IC: LTC3453

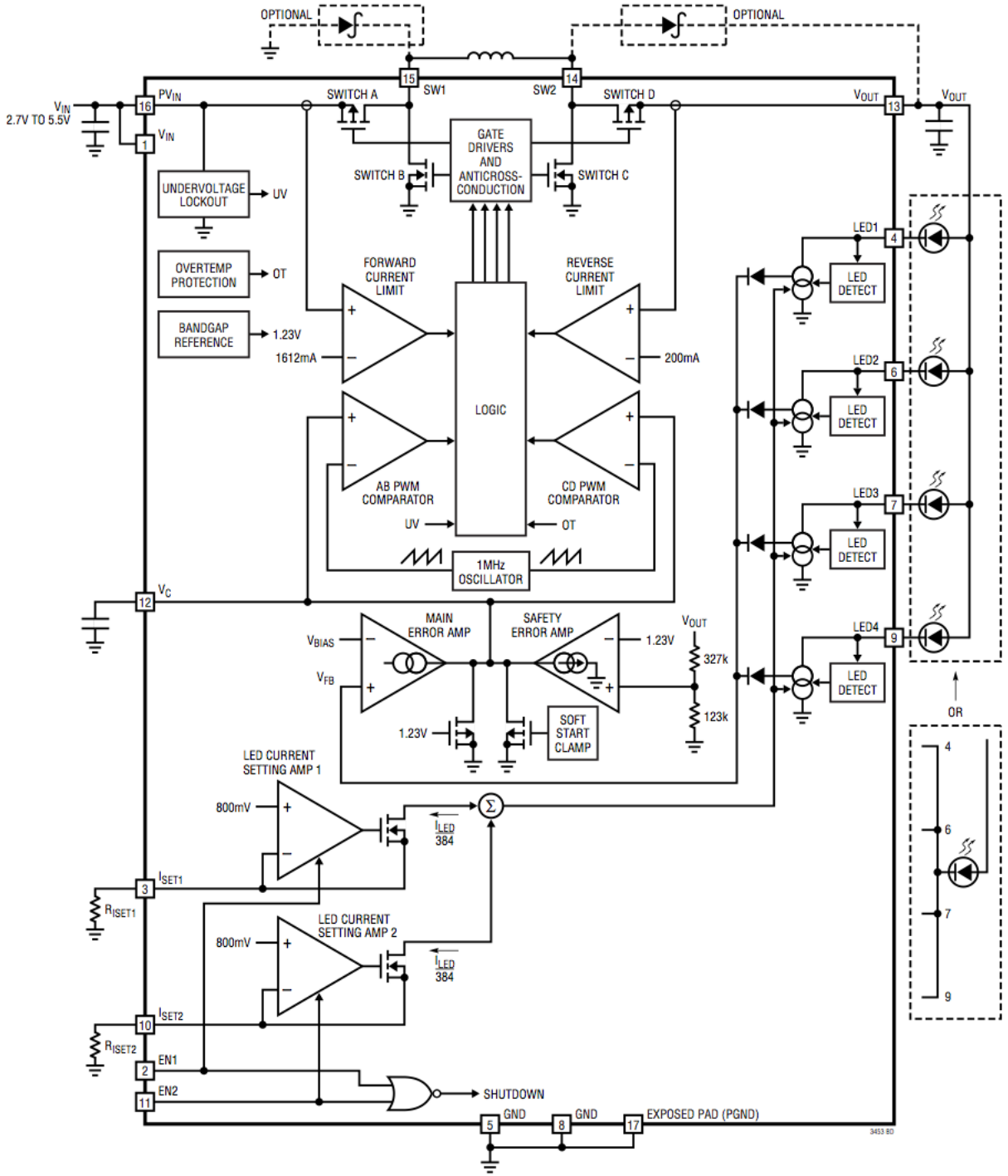



http://cds.linear.com/docs/en/datasheet/3453fa.pdf

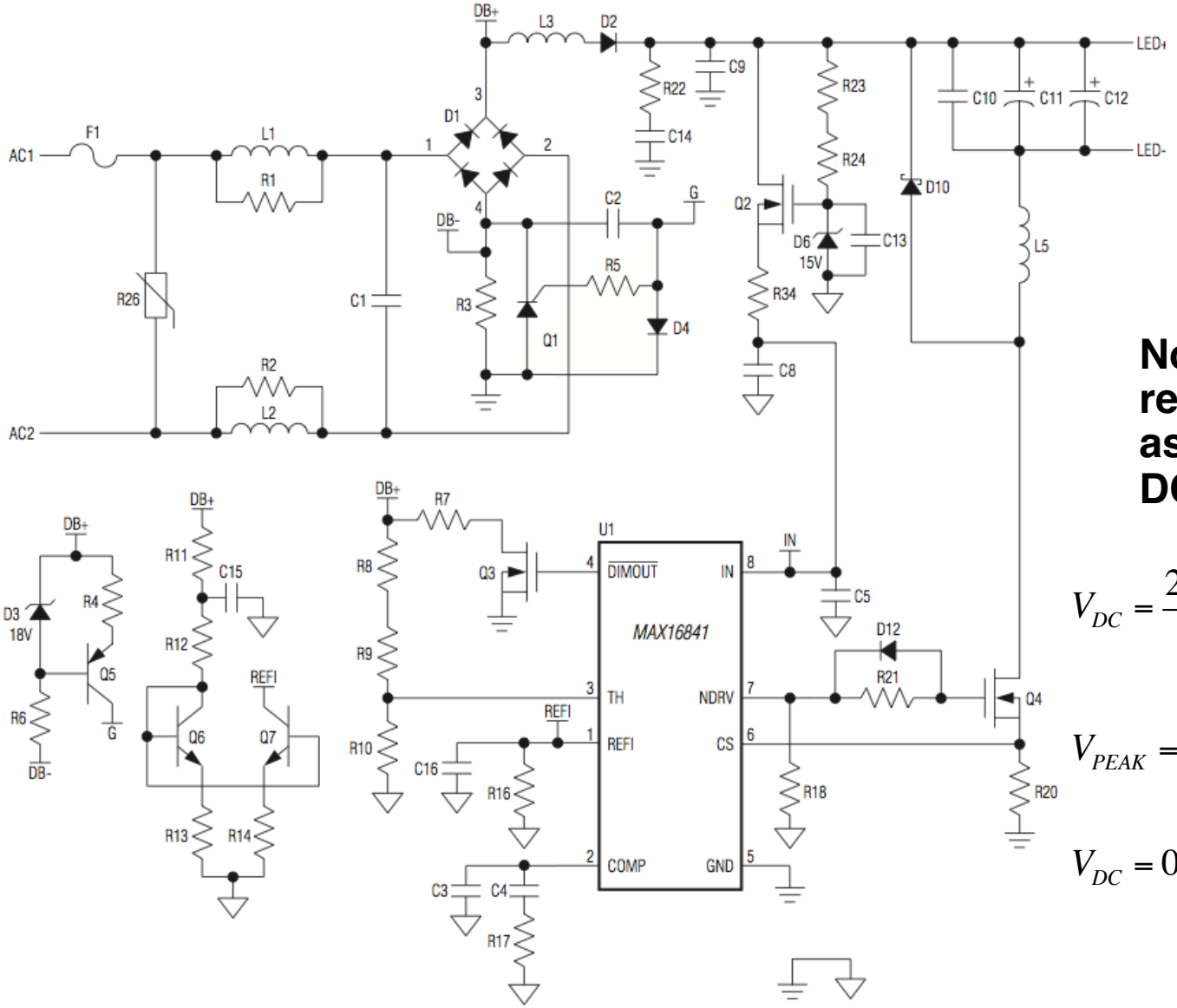
  

# LTC3453




http://cds.linear.com/docs/en/datasheet/3453fa.pdf

# Off-Line LED Driver IC: MAX16841




**Note: 115 VRMS rectified full-wave as shown yields a DC voltage given by:**

$$V_{DC} = \frac{2V_{PEAK}}{\pi} = 0.637V_{PEAK} = 0.9V_{RMS}$$

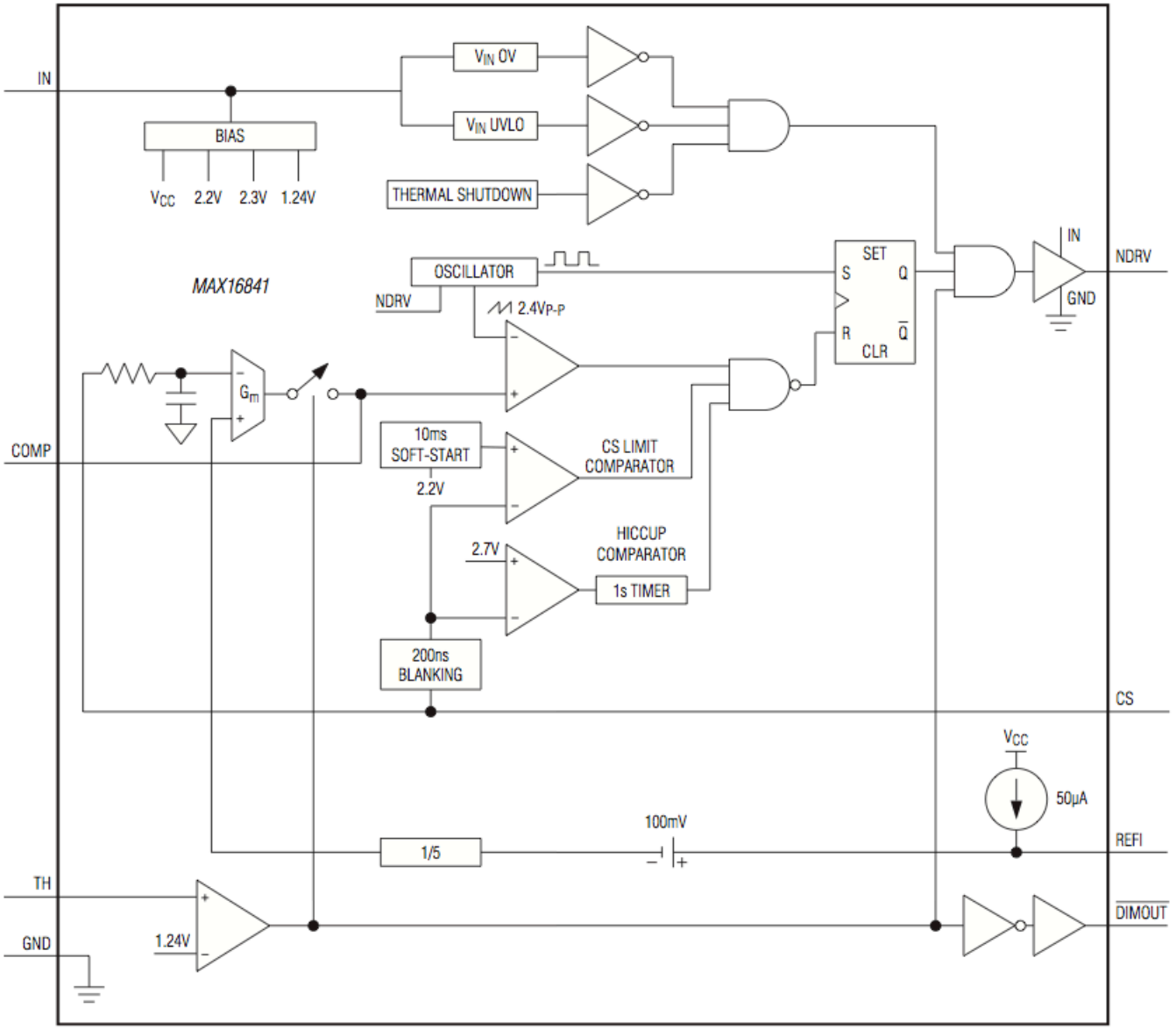
$$V_{PEAK} = \sqrt{2}V_{RMS}$$

$$V_{DC} = 0.9(115) = 104V$$

http://datasheets.maximintegrated.com/en/ds/MAX16841.pdf

# Off-Line LED Driver IC: MAX16841



http://datasheets.maximintegrated.com/en/ds/MAX16841.pdf

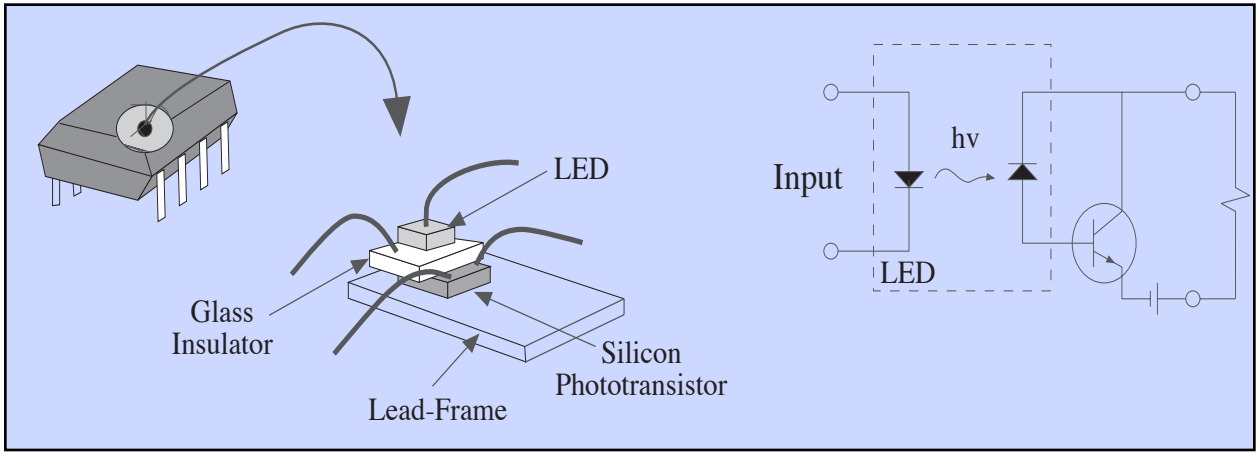
# Visualizing Infrared Emitters

- **Infrared-emitting LEDs can be visualized using a CCD camera (such as a camcorder) because silicon detectors are sensitive to short-wavelength infrared light.**
- **You can also use special infrared phototransistors (in smoky gray packages).**
- **A simple visualizer is an IR phototransistor in series with a visible LED.**
- **Phosphor cards are also available (Thorlabs, Edmund Scientific, Kodak) that "translate" IR into visible light.**



# Optoisolators




- Optoisolators are assemblages of electrically isolated emitters and detectors that use light to send information across a transparent insulator (glass, air, etc.)
- The circuits on either side of the insulating gap can be thousands of volts different, and this is useful in industrial, medical (patient isolation) and automotive applications.
- Most modern optoisolators use LED's and phototransistors and have switching speeds in the MHz range. Special, feedback-linearized optoisolators exist for analog signal transmission and are covered in EE122B.

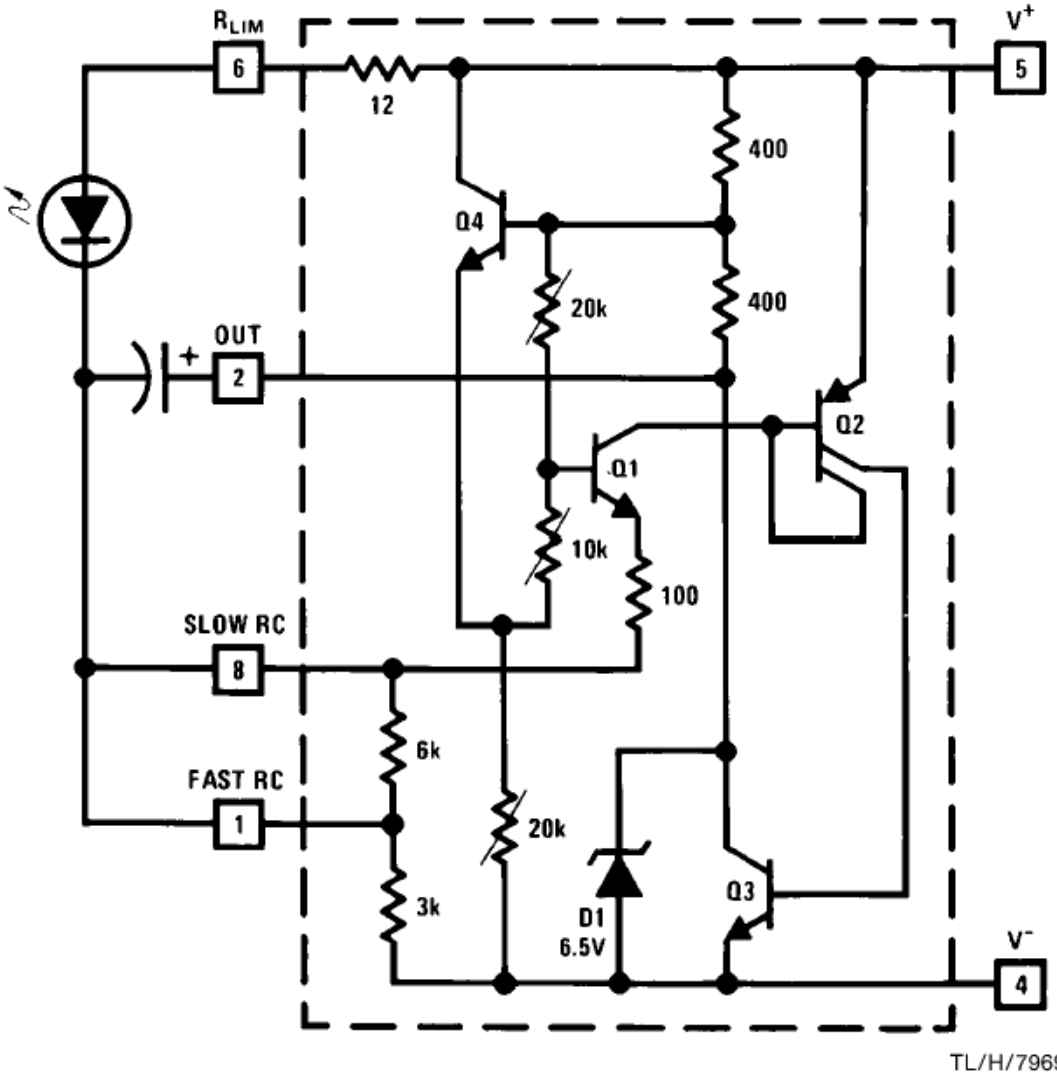
# Modulation of LEDs

- LEDs can be modulated very fast, using current sources or simple voltage switches.
- MHz data rates are possible, and this is a common way to transmit signals optically (e.g., some consumer audio equipment).
- Interestingly, your retina can resolve light pulses in the few nanoseconds, but the perceived length is as much as eight orders of magnitude longer - this is the impulse response of your visual system.

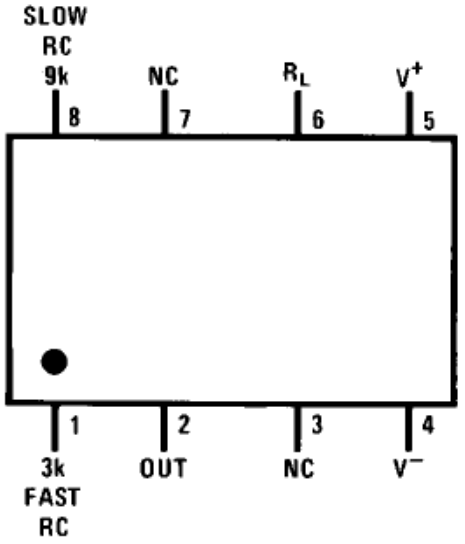
# Example Blinker - LM3909

Typical 1.5V Flasher




TL/H/7969–1

Dual-In-Line Package




TL/H/7969–2

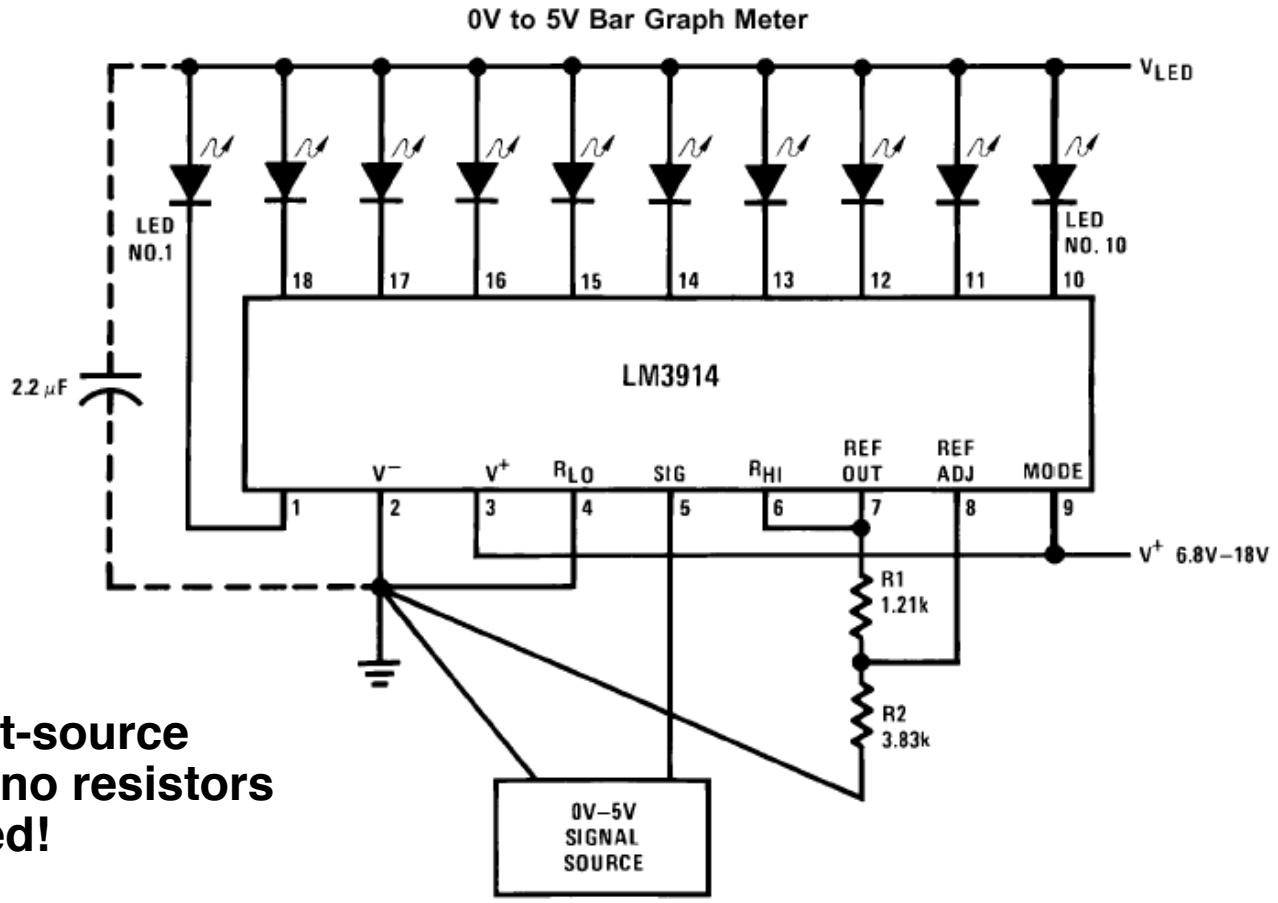
Top View

Order Number LM3909N
See NS Package Number N08E

**Source: National Semiconductor LM3909 Datasheet.**

# LED Bar Graph Driver - LM391X Series




**Current-source drive - no resistors required!**

$$\text{Ref Out V} = 1.25\left(1 + \frac{R2}{R1}\right)$$

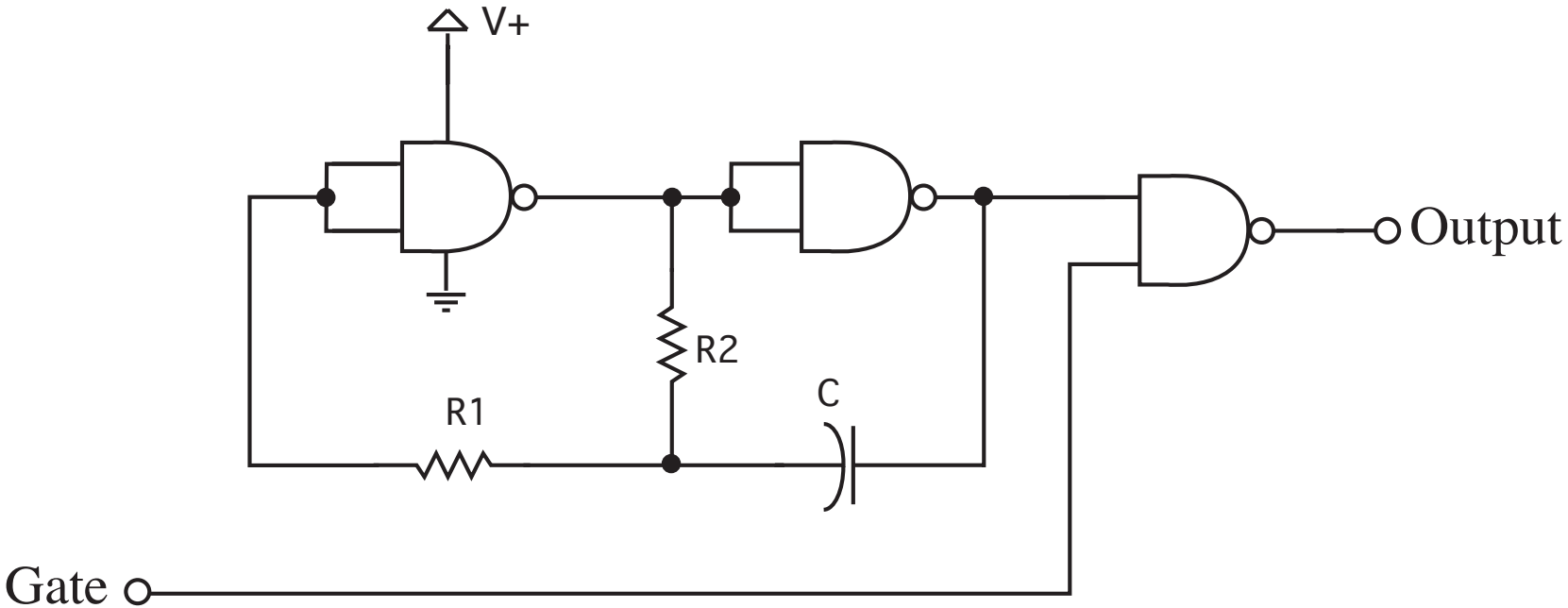
$$I_{LED} \cong \frac{12.5}{R1}$$

**Note:** Grounding method is typical of *all* uses. The 2.2 µF tantalum or 10 µF aluminum electrolytic capacitor is needed if leads to the LED supply are 6" or longer.

**Source: National Semiconductor LM3914 Datasheet.**

# Simple Gated Pulser

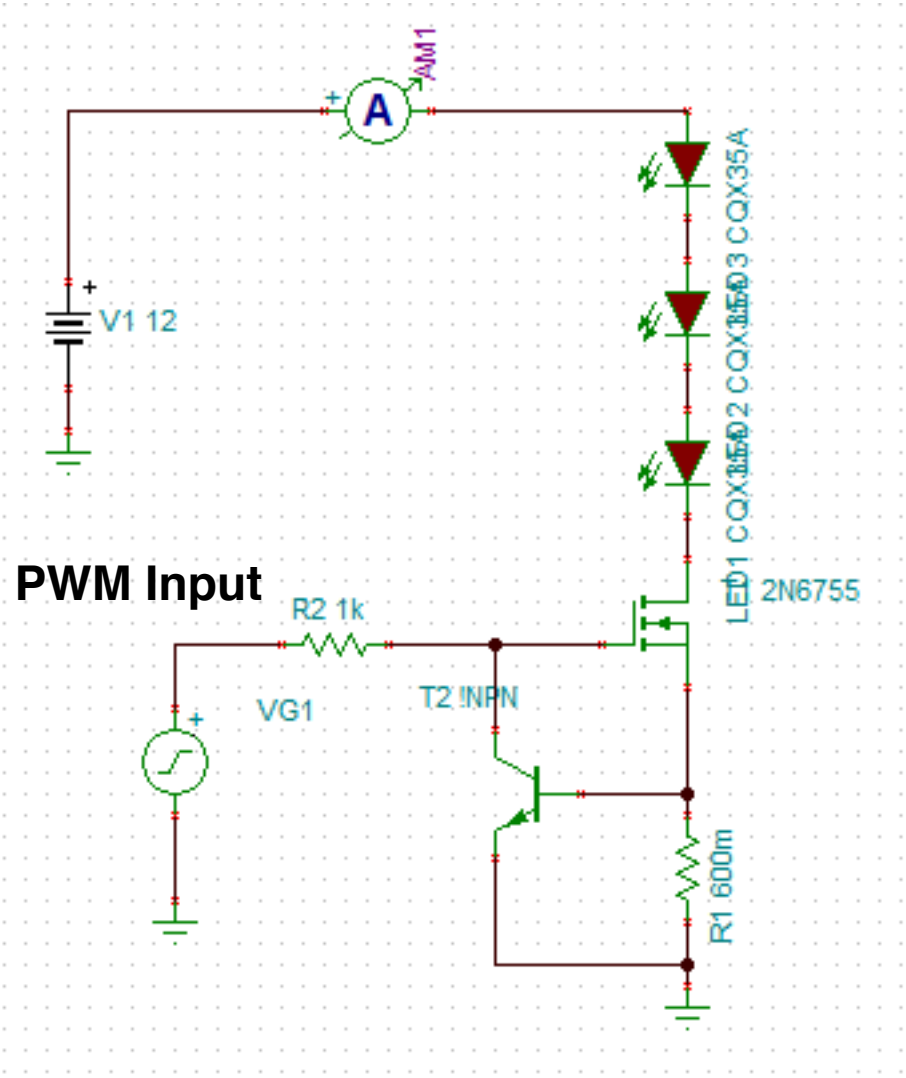


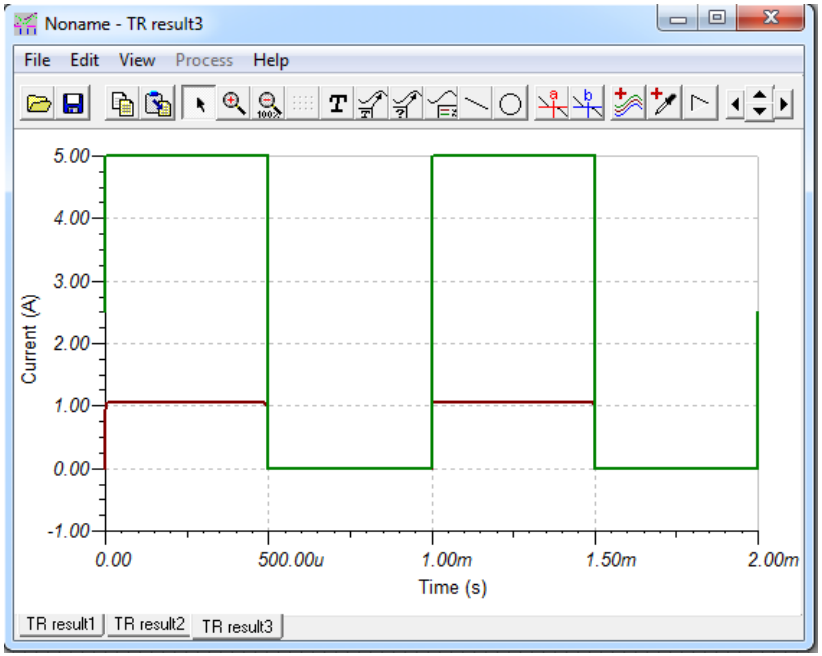

$$R_1 \approx 10 R_2 \qquad f_o \approx \frac{1}{R_1 C}$$

**Can use 74HC, 74HCT, or 4000-series CMOS (4000-series can operate over wider supply voltage ranges).**

# Simple Current Driver with PWM




$$R_1 \approx \frac{0.6}{I_{LED}}$$

# Hacked Infrared Blinker

- Easy to modify an inexpensive safety blinker light to use infrared LEDs instead of visible.
- Can also hack the flash frequency.

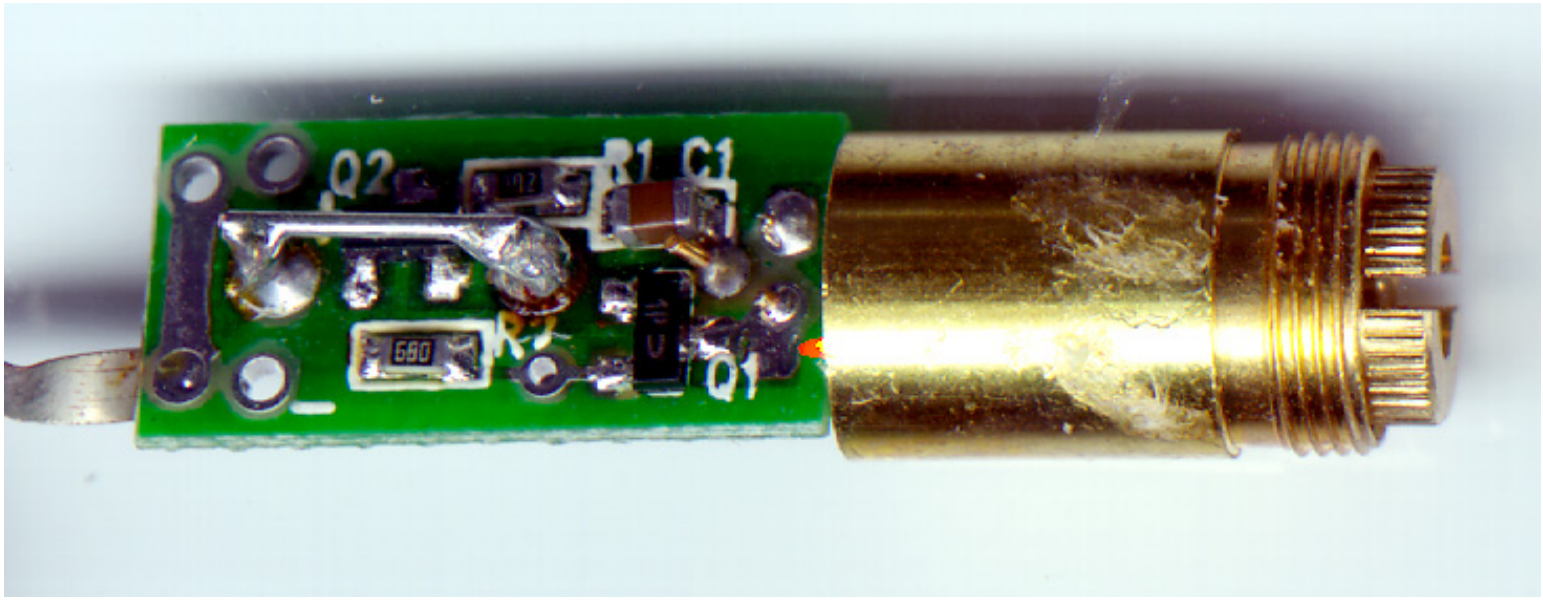

  

# Solid-State Lasers

- **Single Heterojunction - pulsed - needs very small pulses of very large currents to lase.**
- **Double Heterojunction - CW - what is in laser pointers, laser printers, etc.**

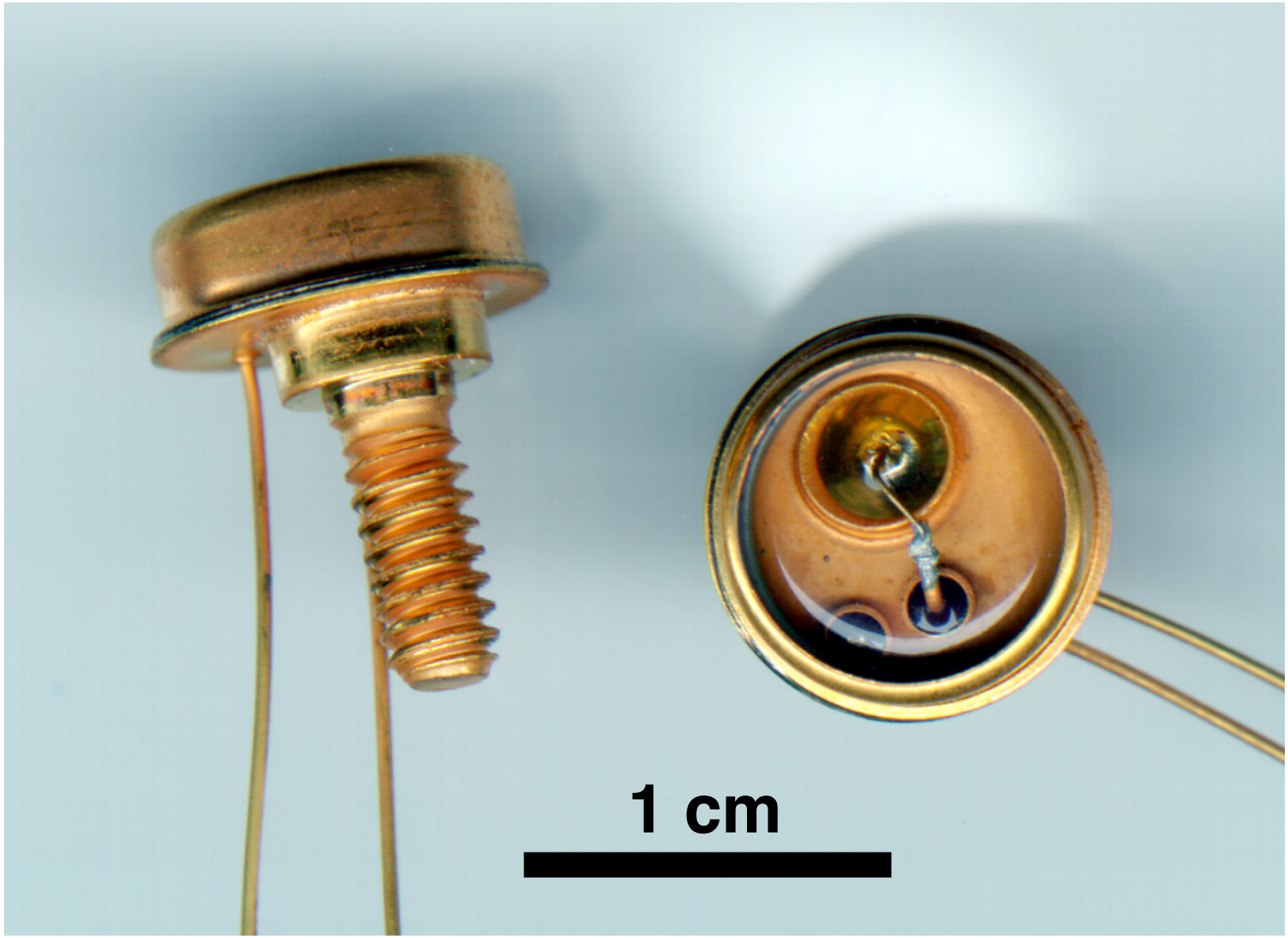
  

# Hacking the Laser Pointer



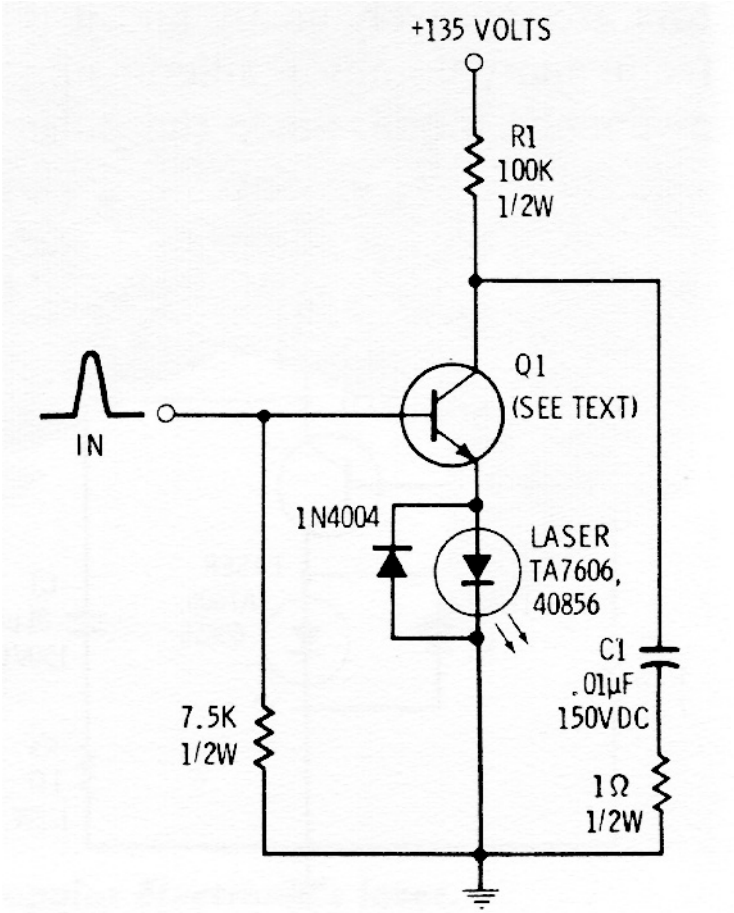
# High-Power Laser Diodes



# Avalanche Transistor Pulser

- By triggering avalanche breakdown in transistors, very high energy, short current pulses can be obtained.
- The energy stored in a capacitor is rapidly discharged through the laser.

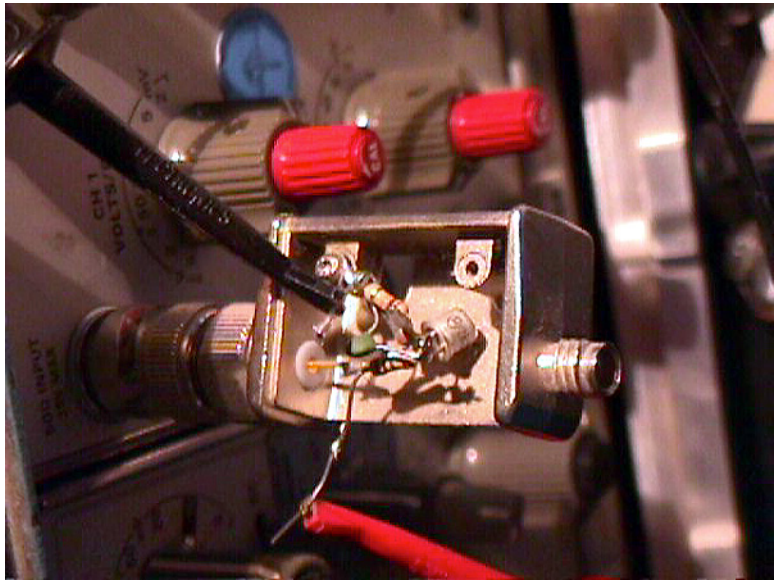


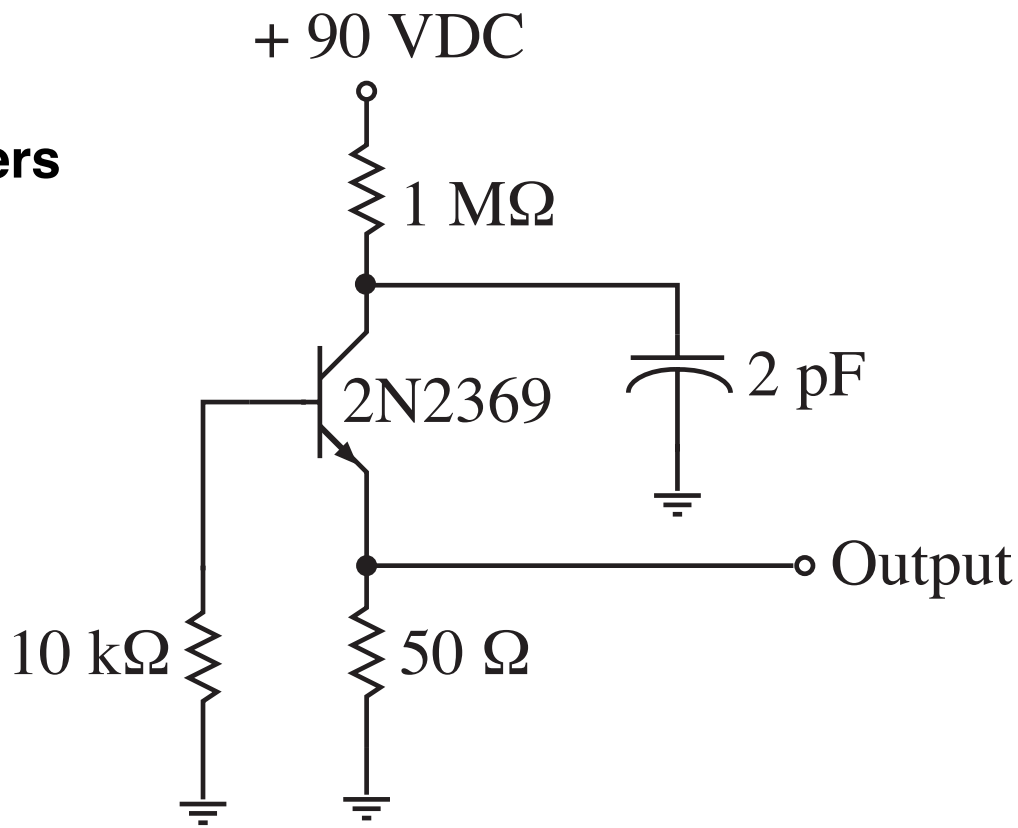

Source: "Semiconductor Diode Lasers," R. W. Campbell and F. M. Mims, H. W. Sams & Co., 1972.

# Williams' Avalanche Pulser

- **Excellent way to generate ultrashort pulses.**
- **Can be modified to drive lasers or LEDs.**
- **See LTC AN-47 for details on choosing the transistor, etc.**

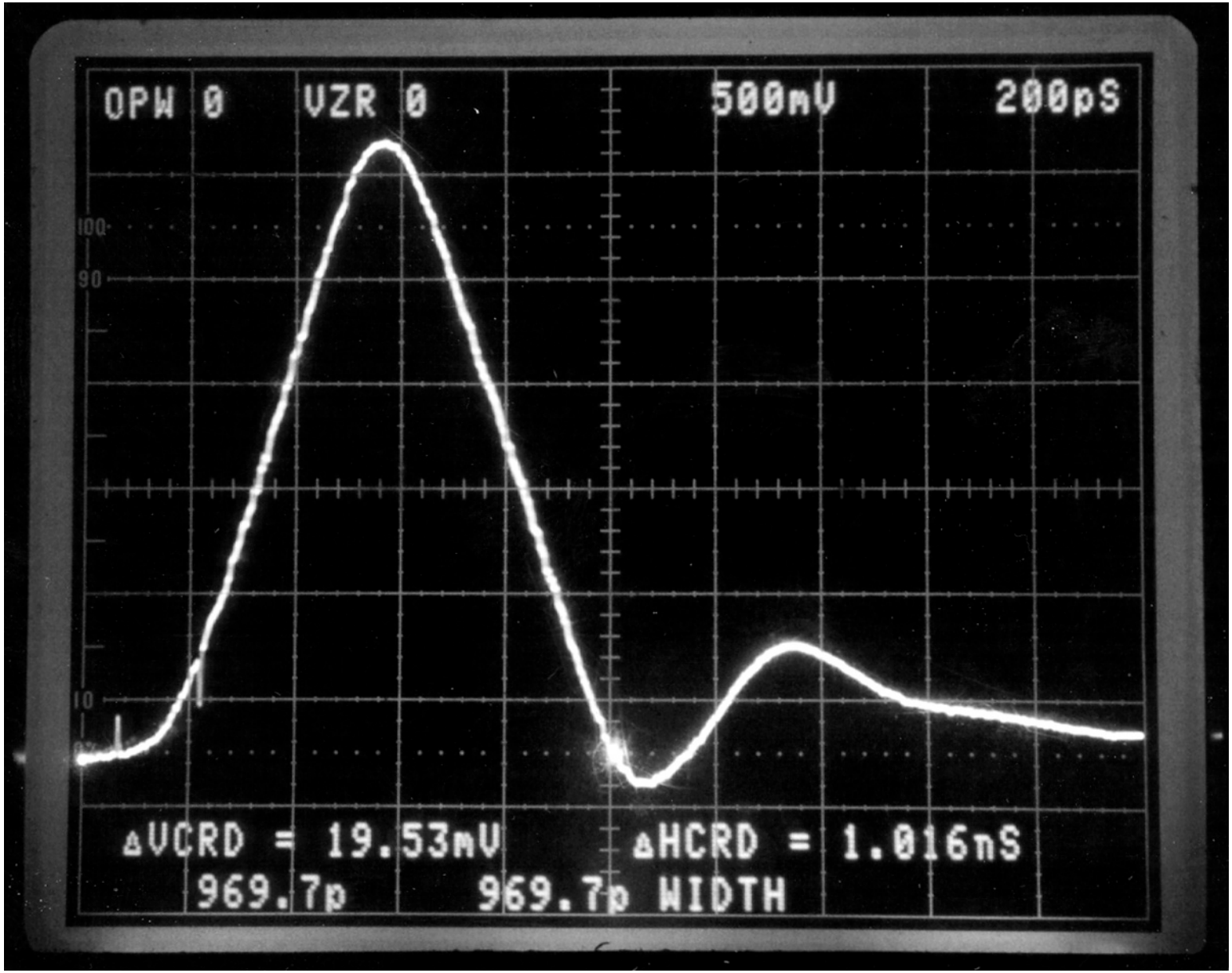





**Source: Linear Technology, AN-47 "High Speed Amplifier Techniques," 1991.**

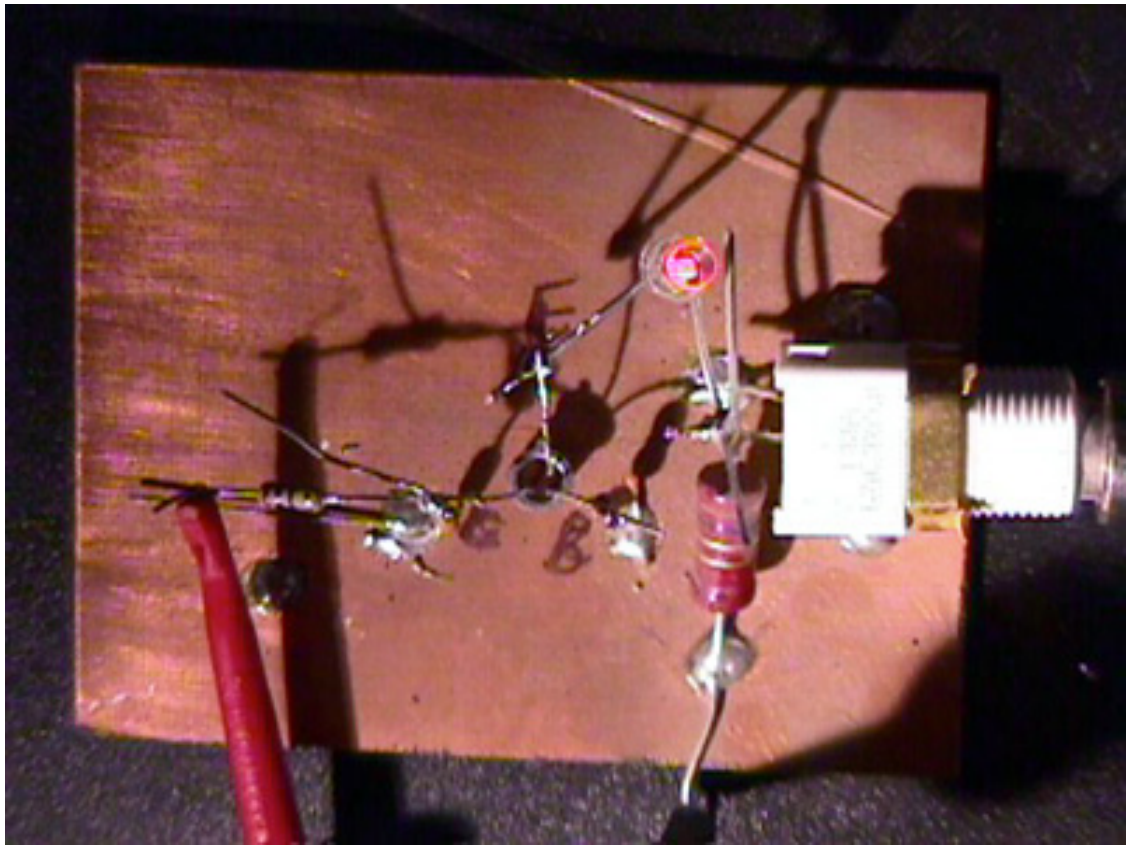
  

# Williams' Avalancher on 1 GHz Scope



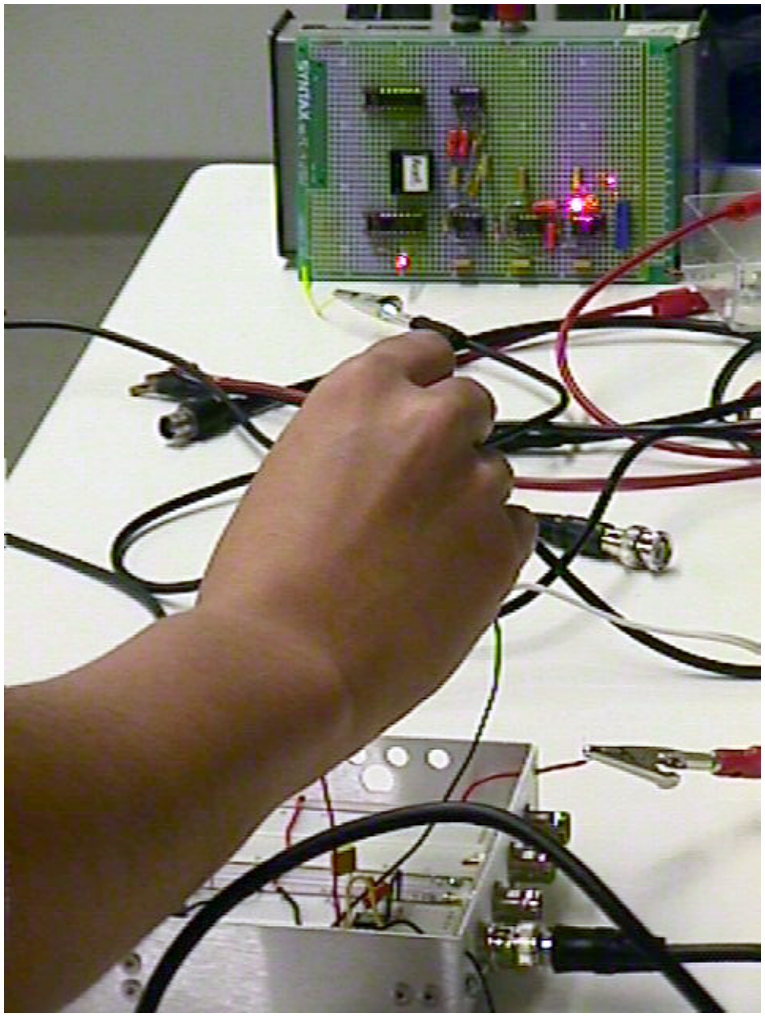

  

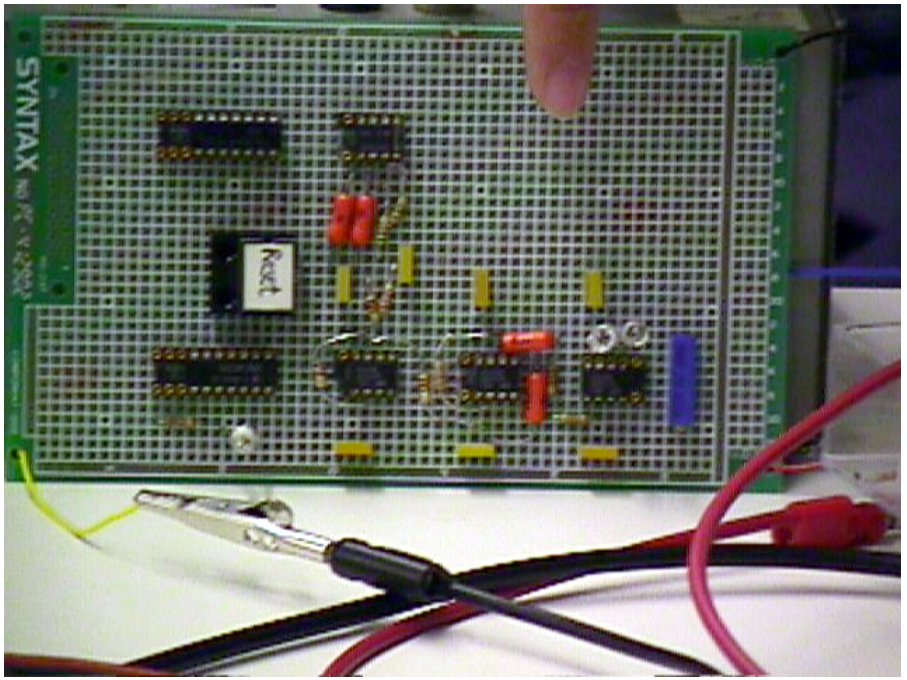
# Avalanche LED Driver

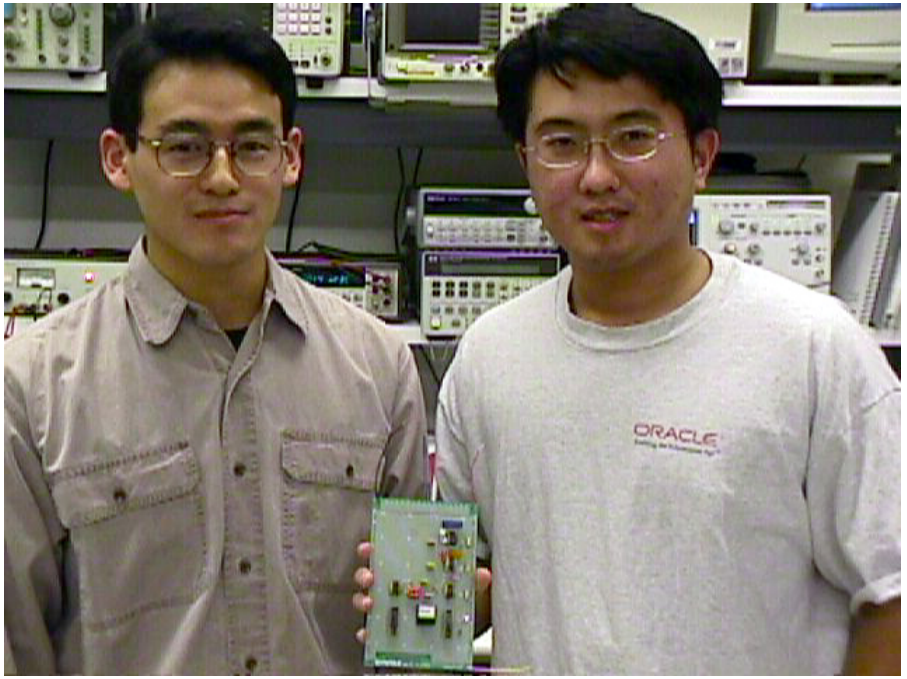


# Laser Tag





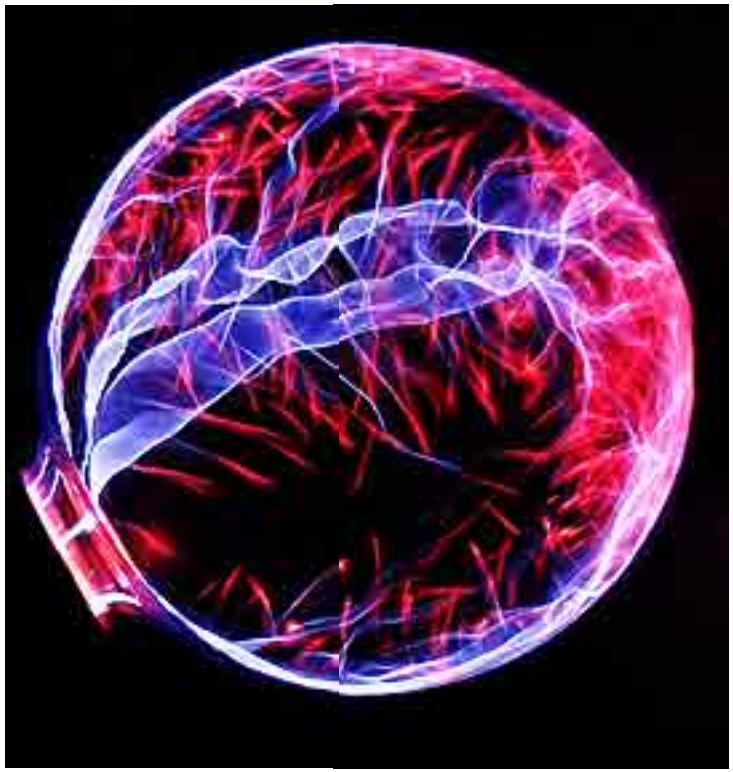
# Gas Discharge Lamps

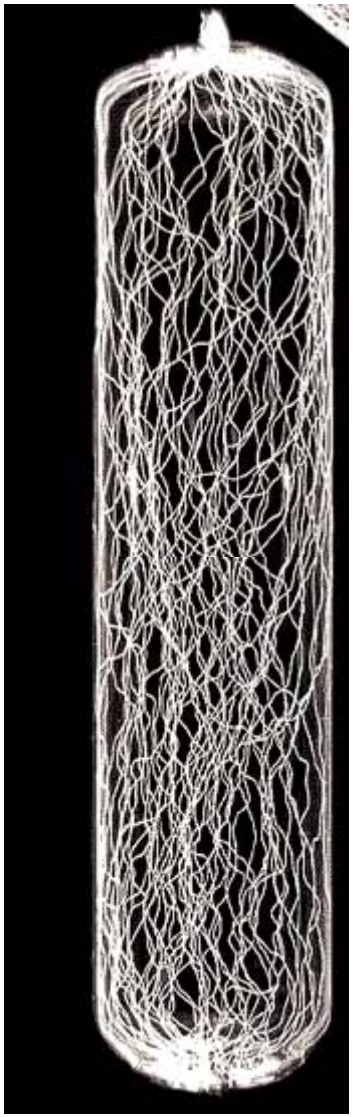
- A variety of cool displays can be achieved using gas discharge lamps.
- Simple NE-2 (neon) lamps break down around 65 - 90V and can be used for blinkers and power indicators.
- More complex devices are also possible.


**See:** http://www.neonshop.com/

# Plasma Art

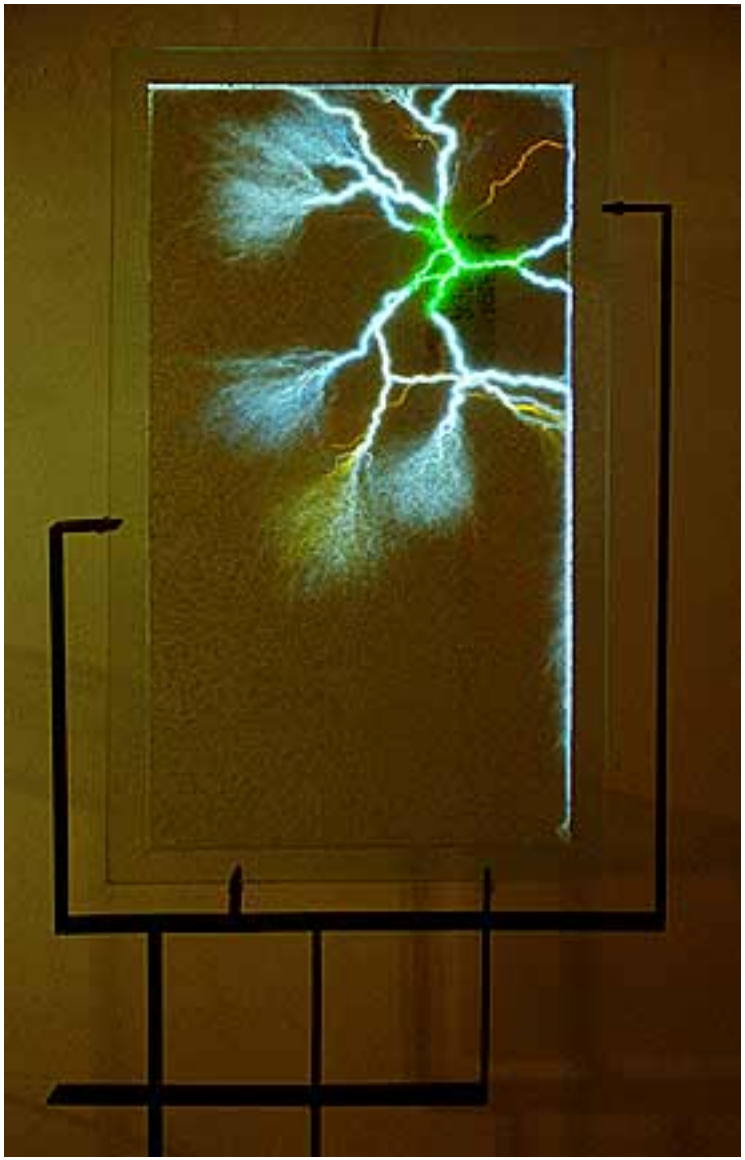




http://strattman.com/products/

# Check out: http://strattman.com/



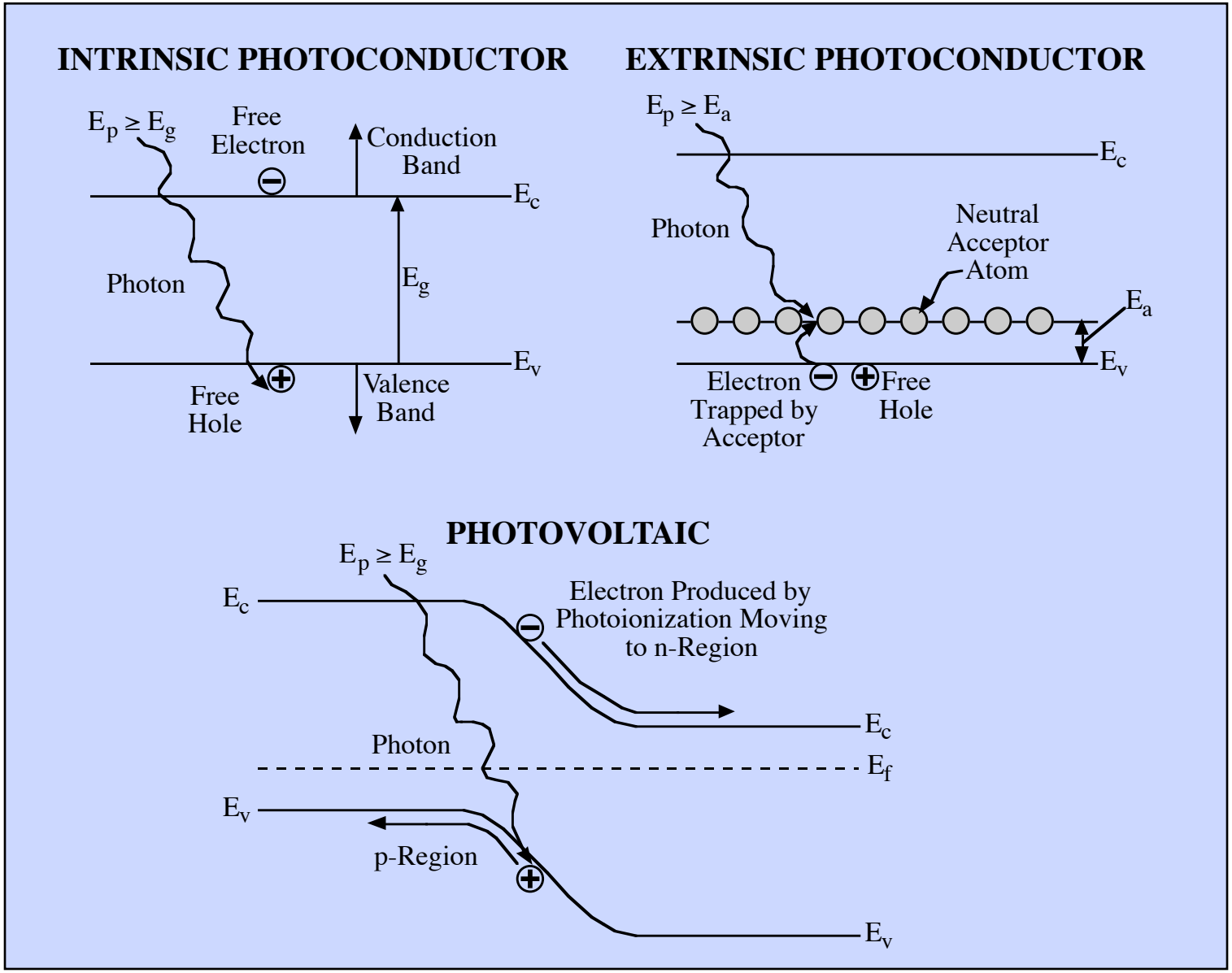
  

# Detecting Light

- Light sensors are essential for a large variety of devices.
- Examples: optical data links, camera exposure meters, automatic night lights, clock display dimmers, etc.
- There are basically two types to be considered in EE122: junction type and photoconductors.

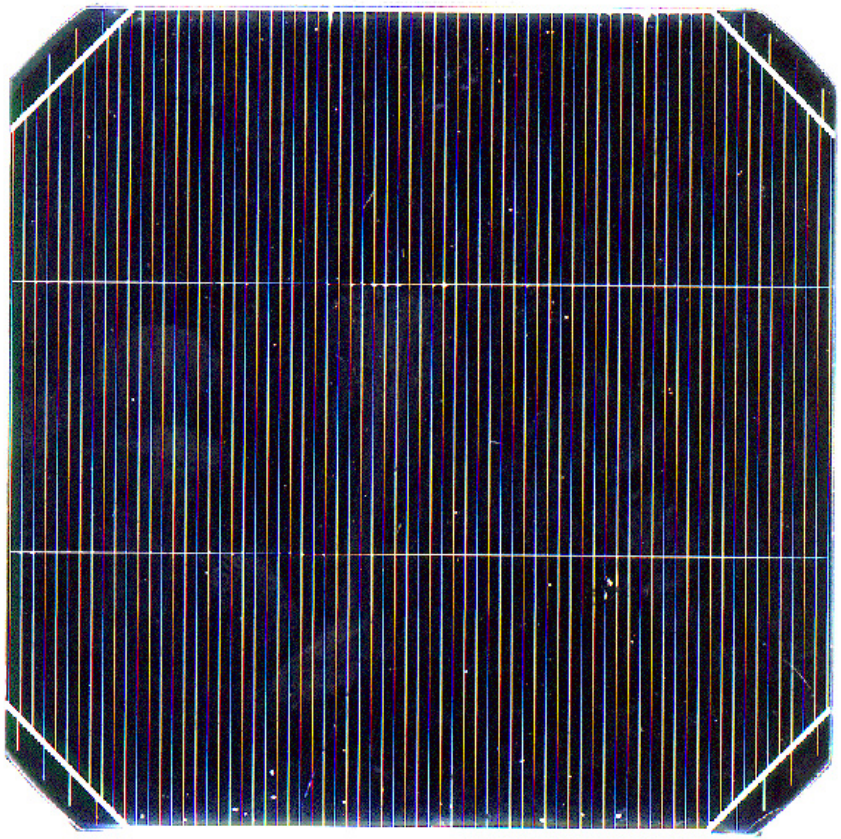
# Mechanisms of Light Detection



# Solar Cells

- Solar cells are photojunctions that are designed to produce useable electrical power (theory about 100 mW/cm$^2$ at 100% efficiency on Earth).
- Many surplus sources have good deals on them, and you can easily design simple circuits that are entirely light powered.



**In space, you can choose solar or nuclear (for now).**

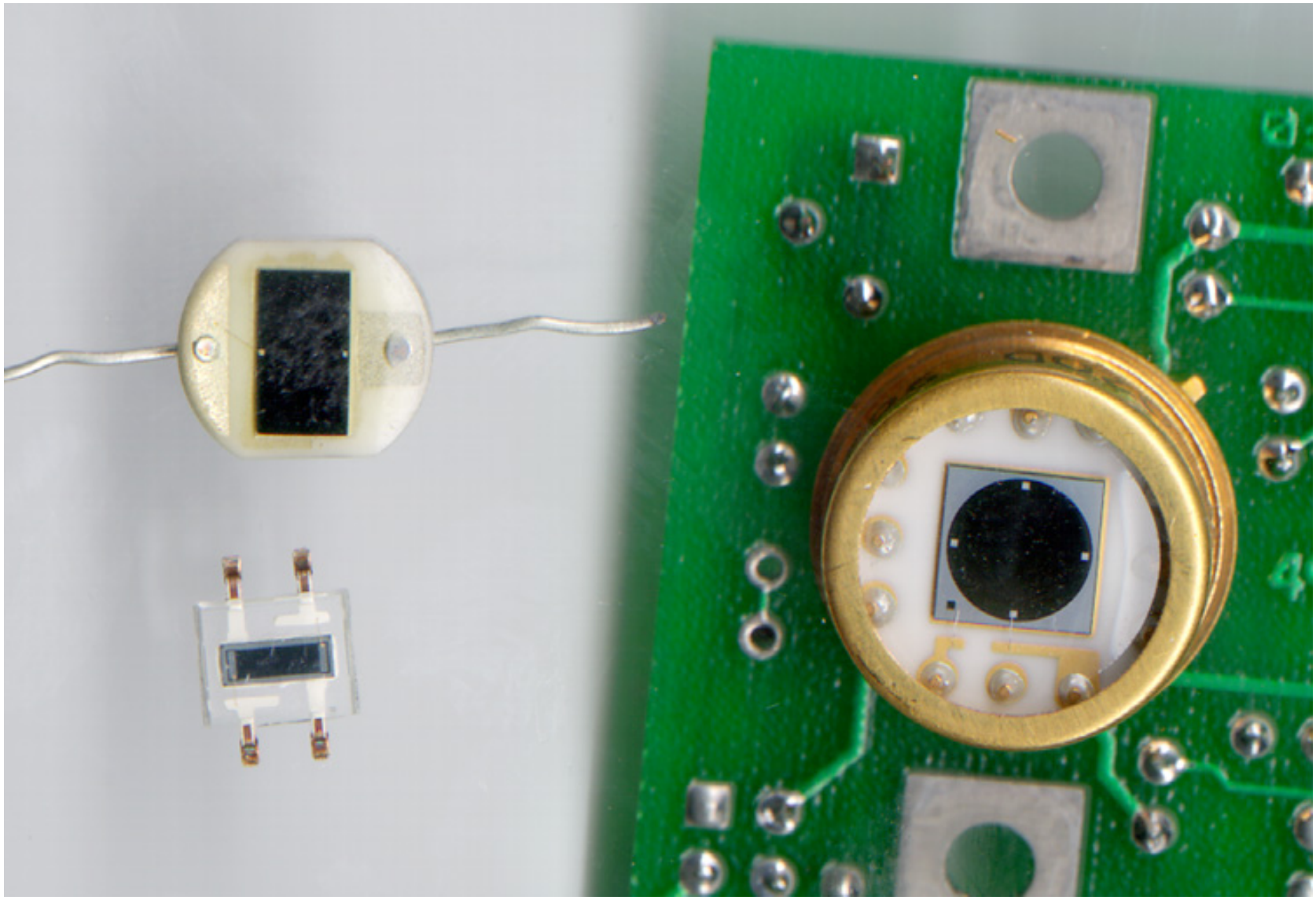
  

# Photodiodes/Phototransistors

- Photodiodes and phototransistors (usually the base lead is not used, so they can be treated as similar parts) are common detectors for light.
- They are capable of detecting fast light pulses (up to GHz rates in some cases) if they are appropriately designed and have fast circuitry to work with.
- They are inexpensive, and are available for visible light and for IR (some have built-in smoky gray filters).

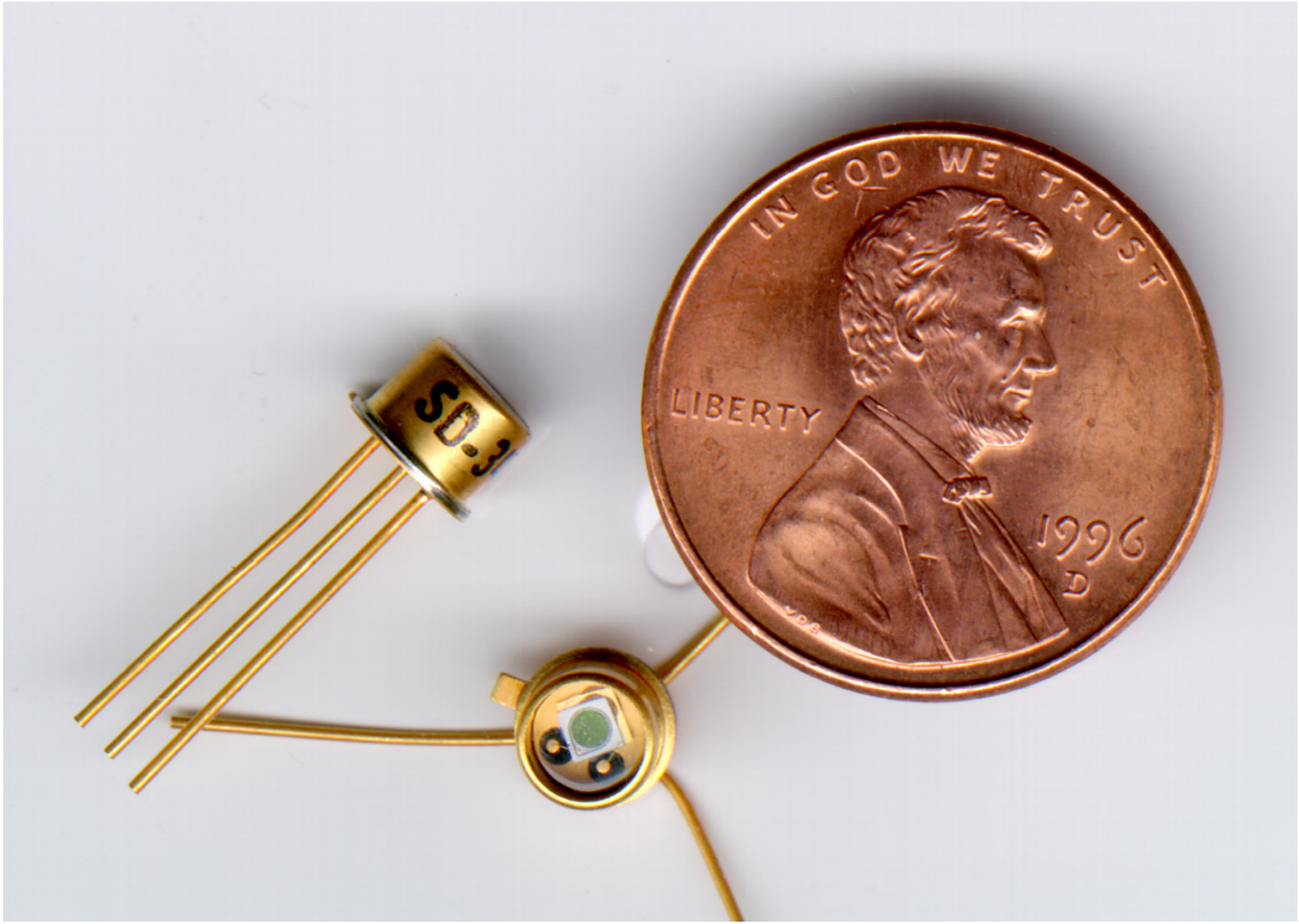
  

# Typical Photodiodes



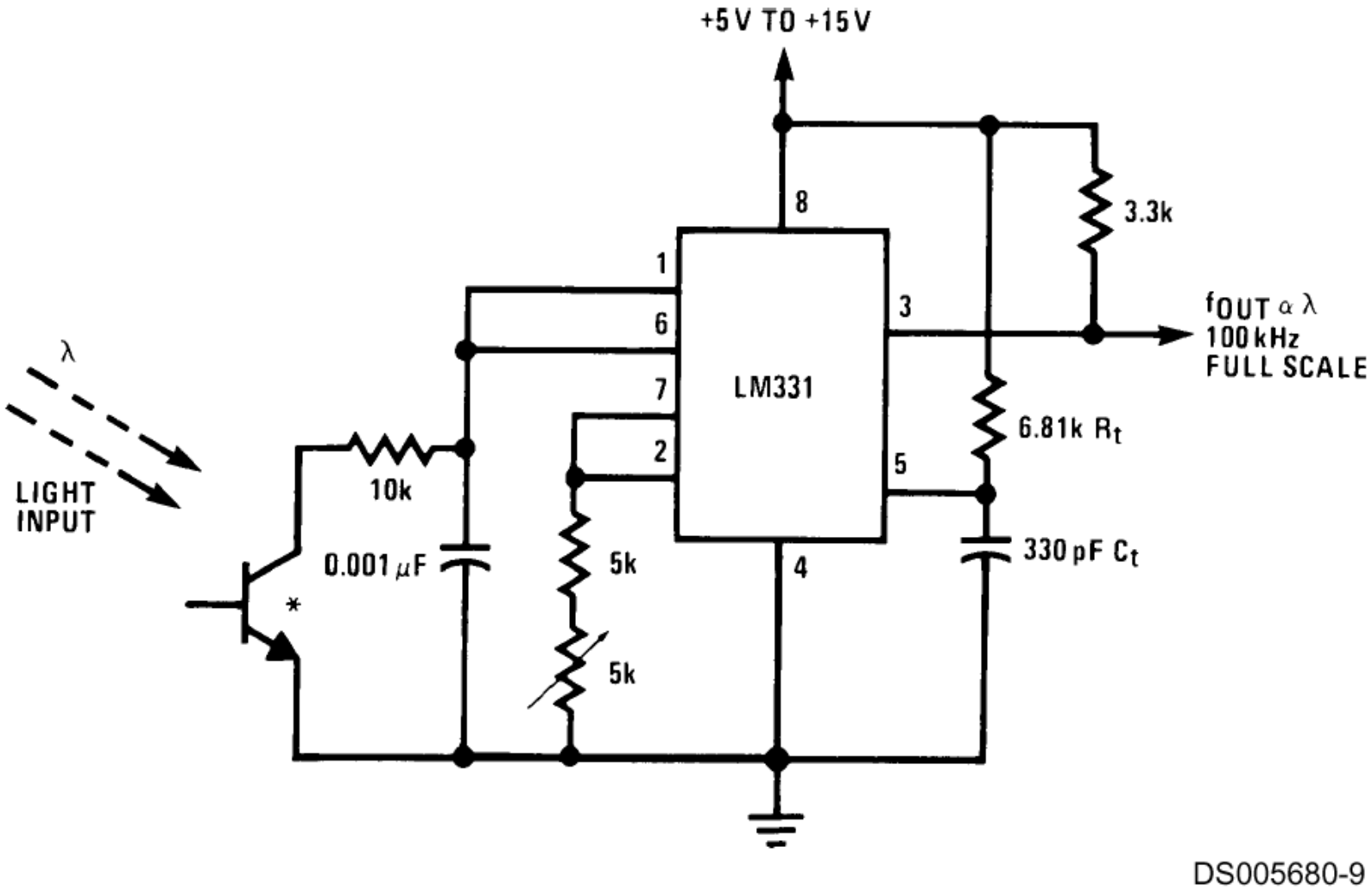
  

# Typical Phototransistors



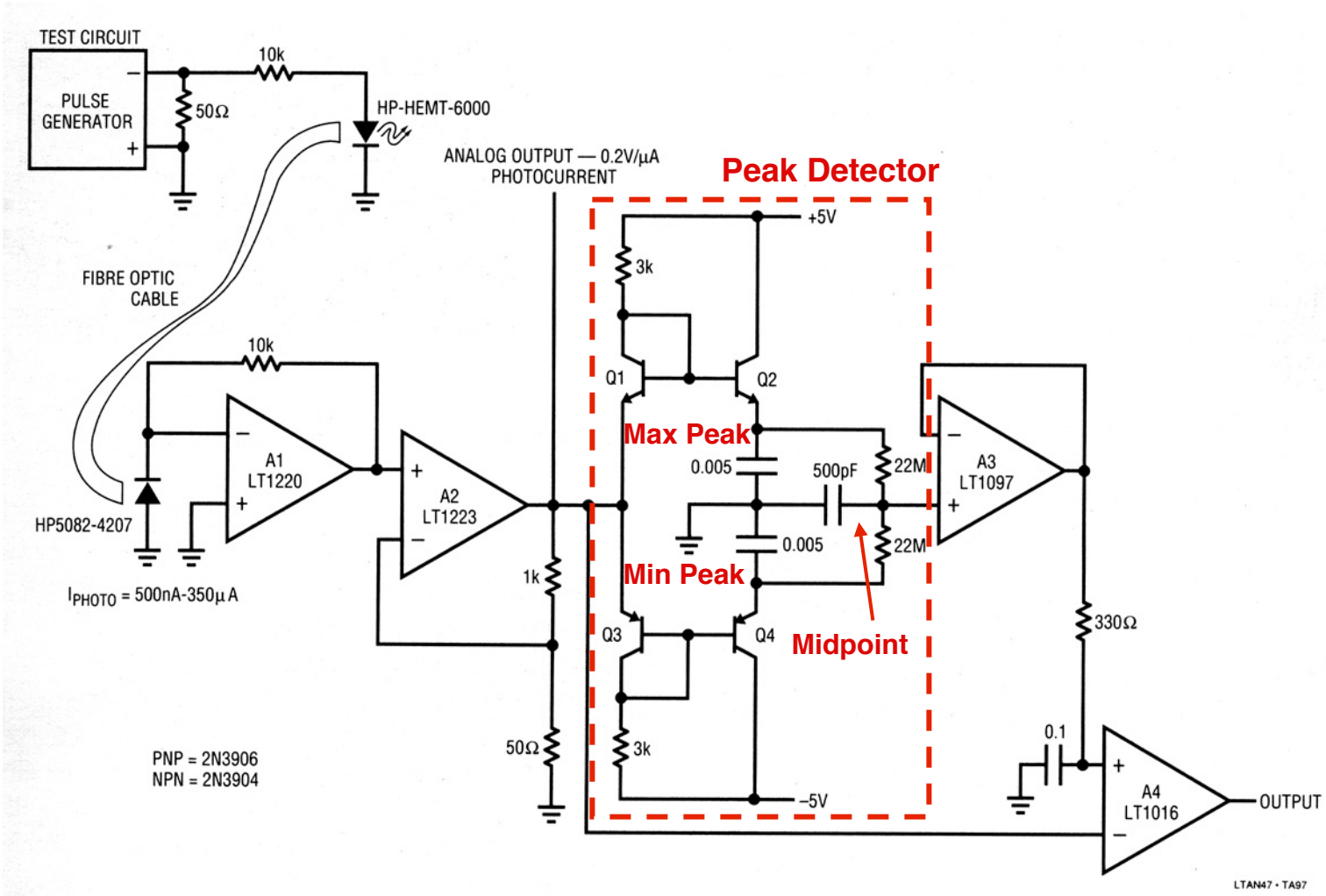
# Light-To-Frequency Converter




Source: National Semiconductor LM331 Datasheet.

# Fast Optical Data Receiver




**Source: Linear Technology, AN-47 "High Speed Amplifier Techniques," 1991.**

# Shannon's Theorem

$$C = B\log_2\left(\frac{S}{N}+1\right)$$

**C = channel capacity in bits/second**

**B = bandwidth in Hz**

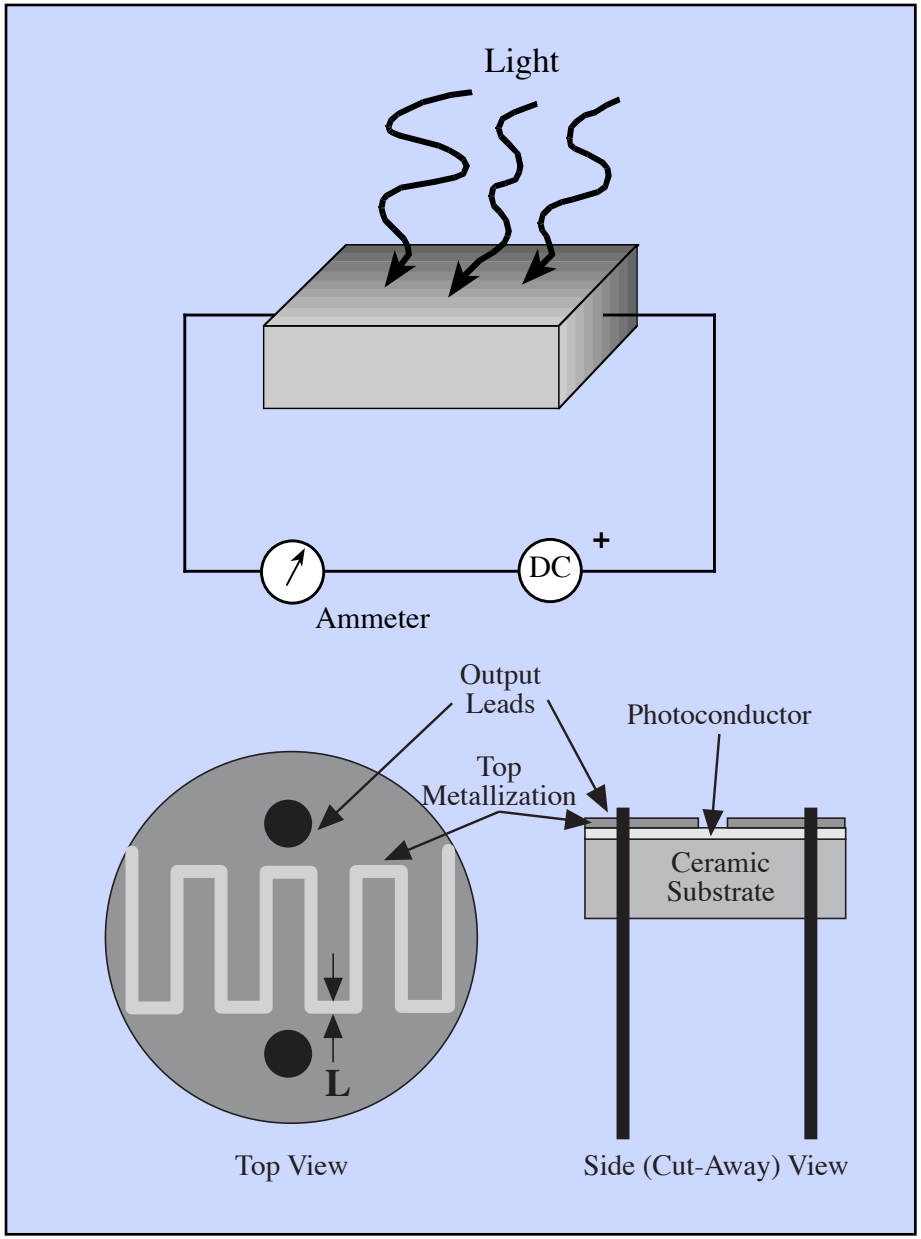
**S = signal level**

**N = noise level**

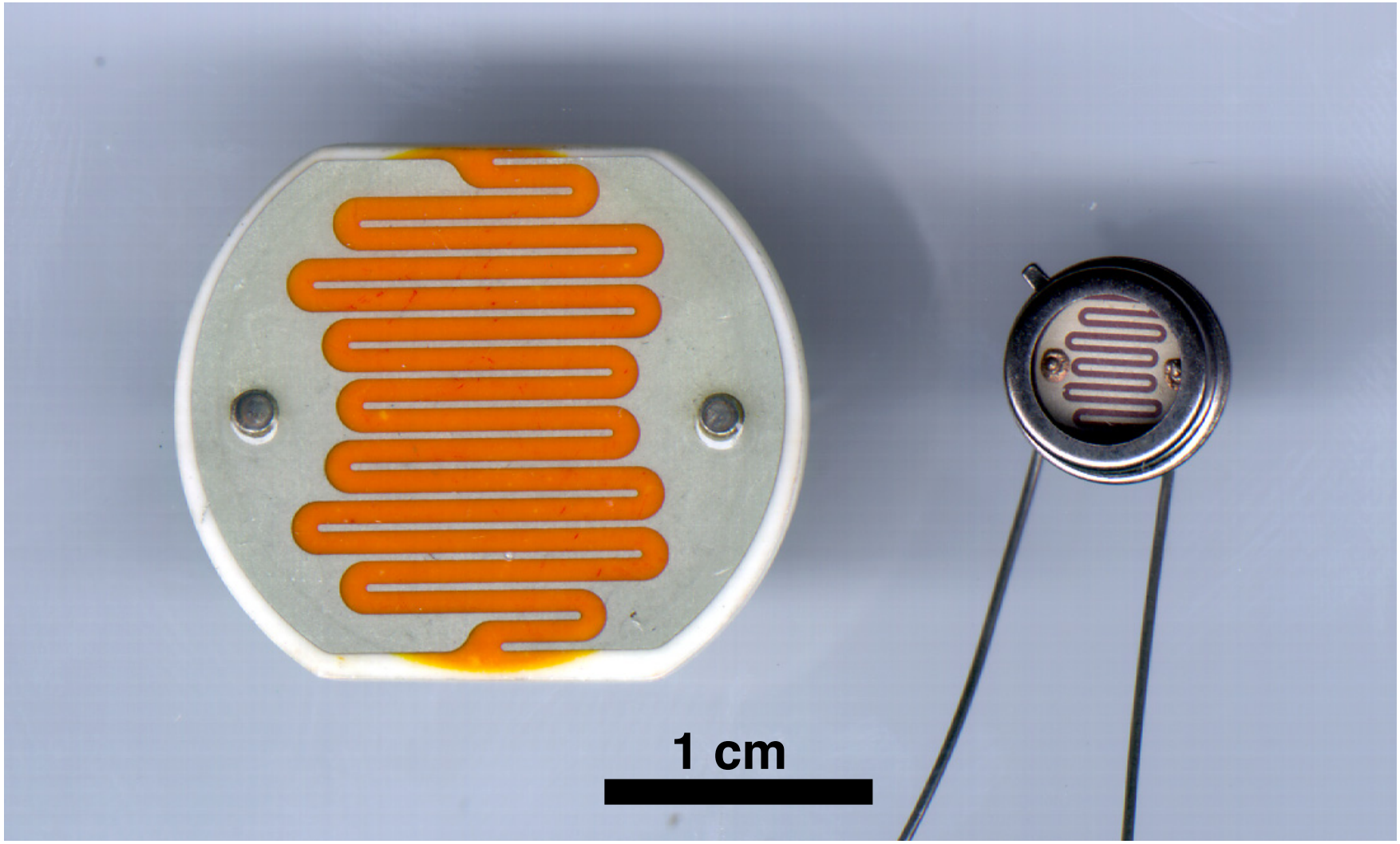
# Photoconductors - The CdS Cell

- Incoming photons of sufficient energy promote carriers into the conduction band.
- If they have sufficiently long lifetimes, the resistance of the photoconductor decreases.
- Thus, they act like light-controlled resistors and can be substituted for ordinary resistors in circuits.
- Key - they are much slower to respond than photojunctions!



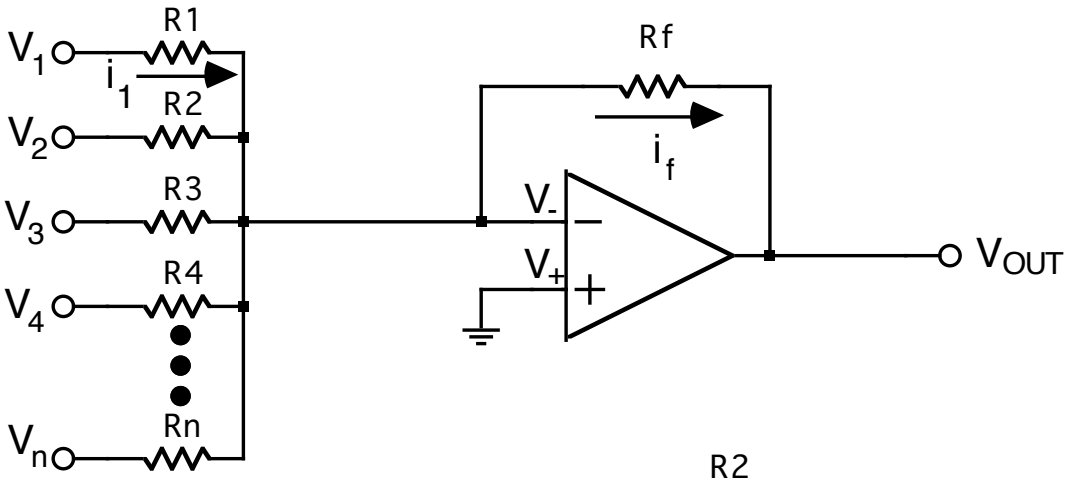
# Typical CdS Cells



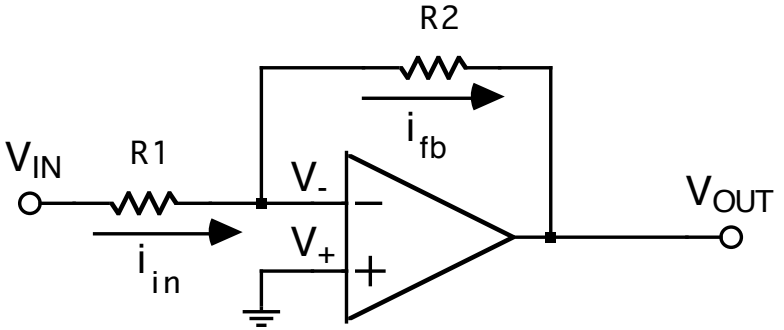

  

# Example - Light-Controlled Amplifiers

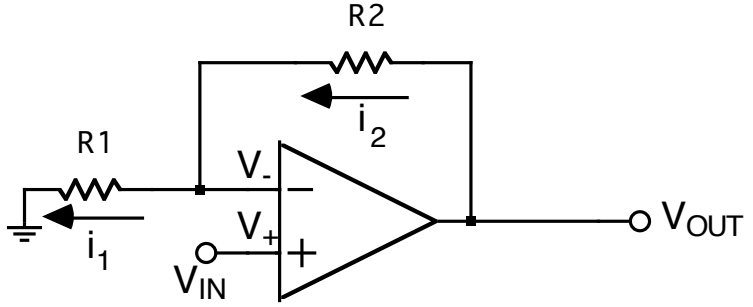
- All of the common op-amp configurations can be made light sensitive by substituting a CdS cell for one or more resistors.
- Could make an amp that turned down the volume on a stereo when the lights were dimmed, or could use this to make a radio that got louder when the sun came up.




$$A_V = -\frac{R2}{R1}$$



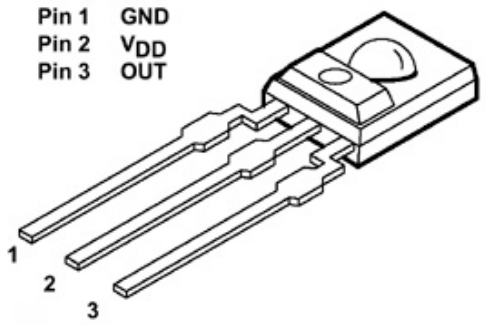

$$A_V = \left(1 + \frac{R2}{R1}\right)$$



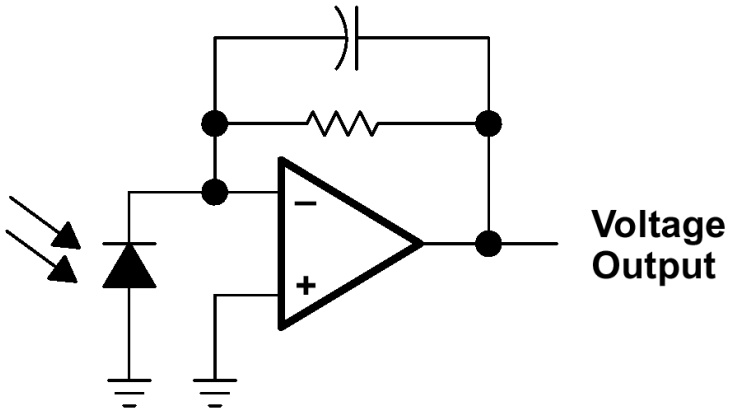

  

# Integrated Photosensors

- There are several integrated photodetectors on the market, incorporating amplifiers and even current-to-frequency converters on the same chip as the photosensor.
- Taos: www.taosinc.com
- Hammamatsu: www.hamamatsu.com

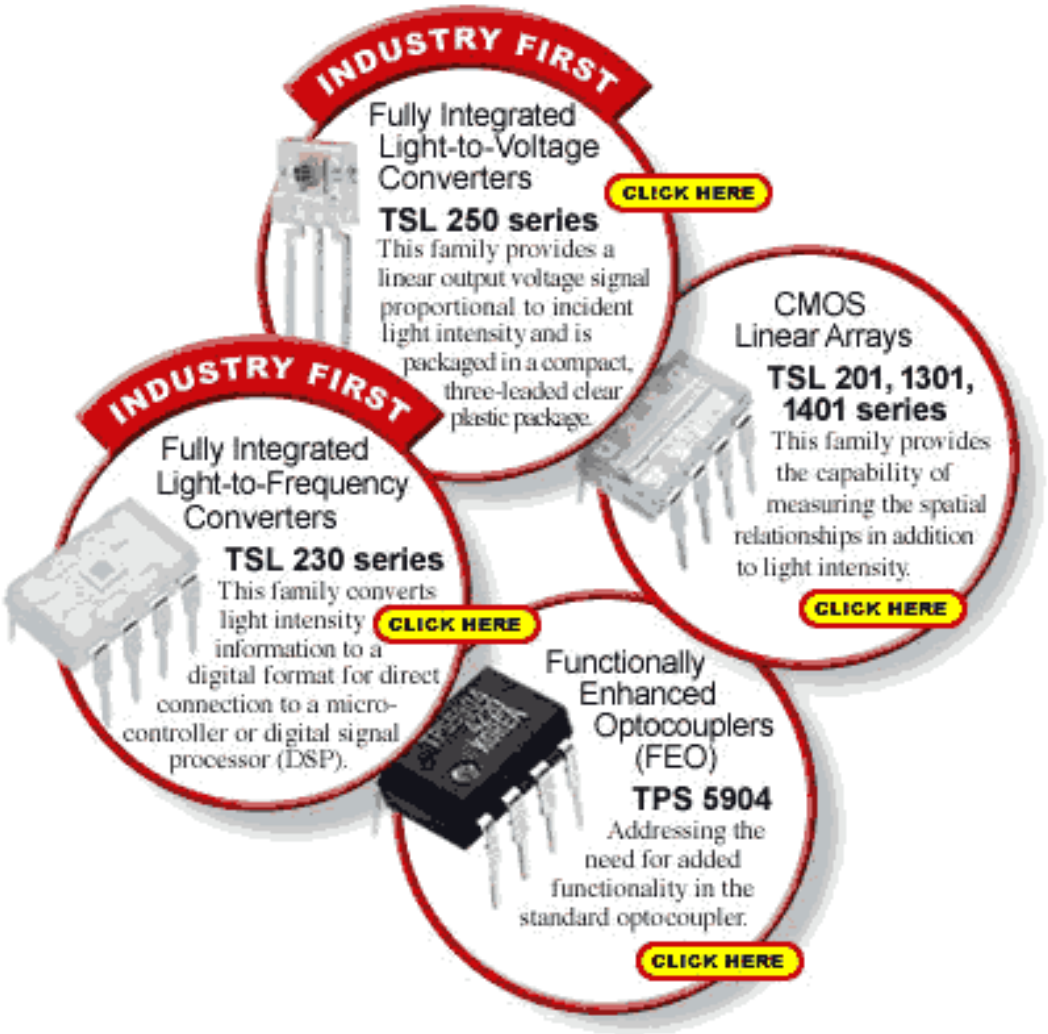



Source: Texas Instruments Datasheet

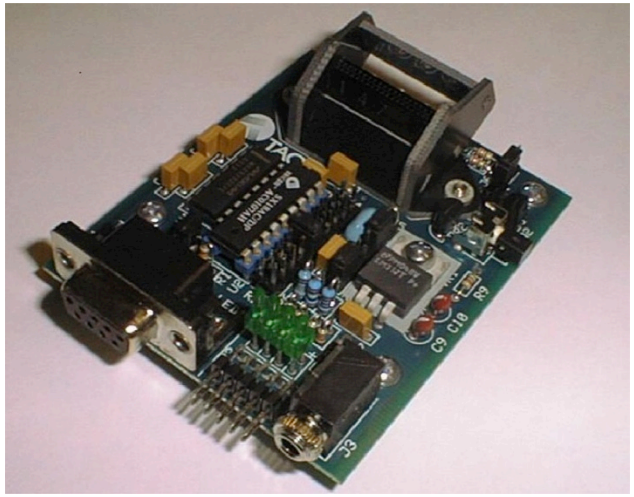


# www.taosinc.com

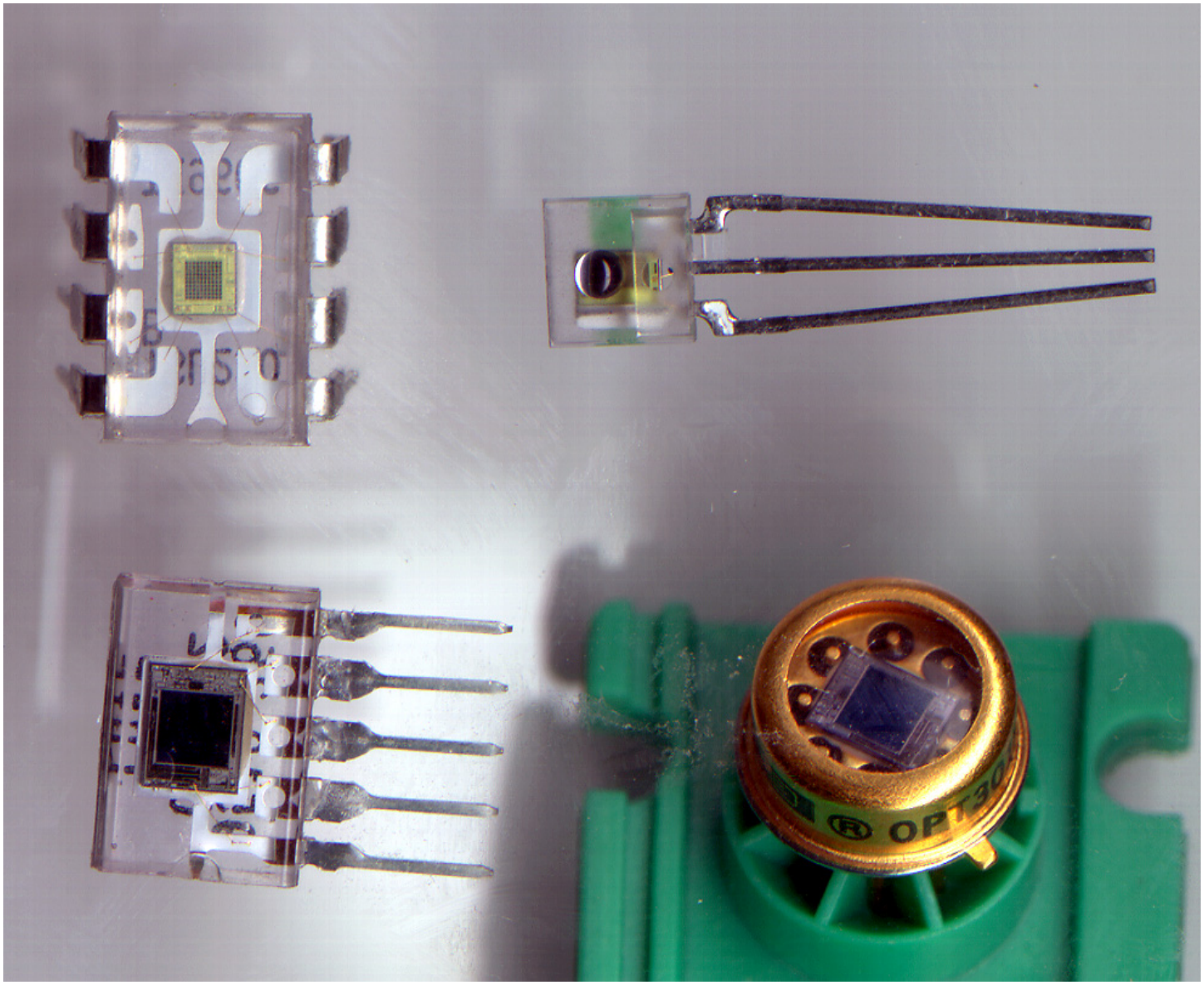






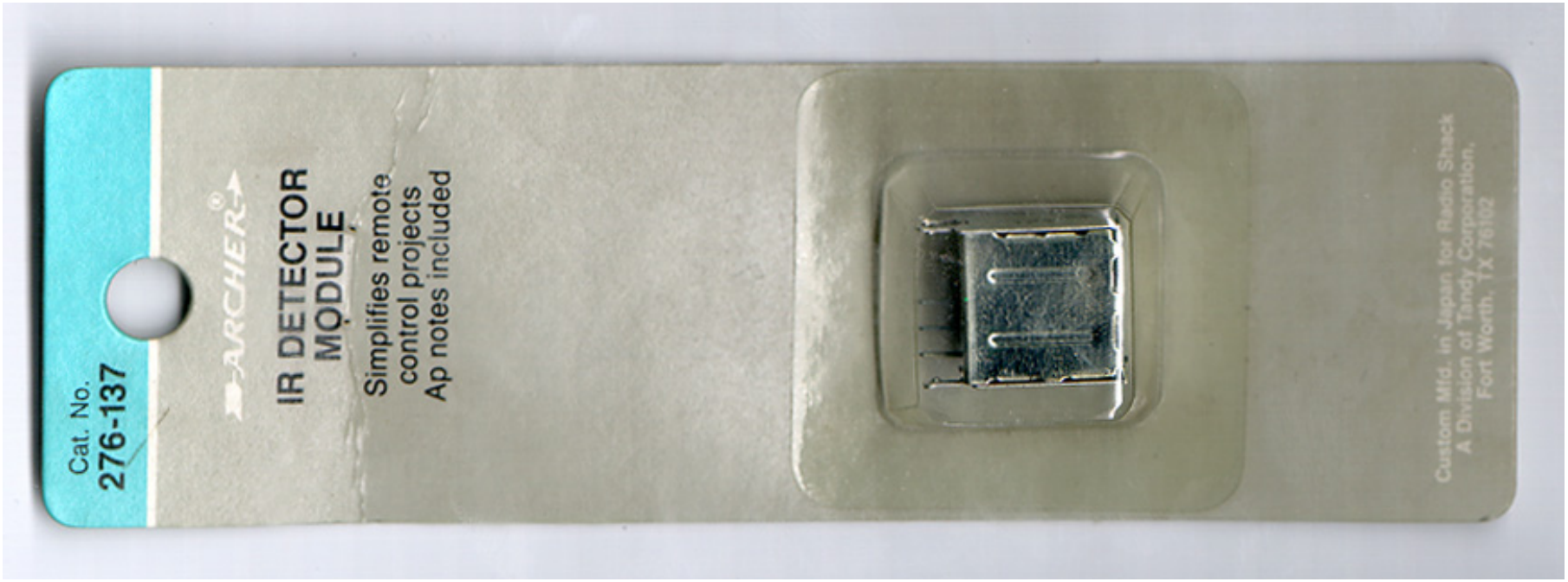
  

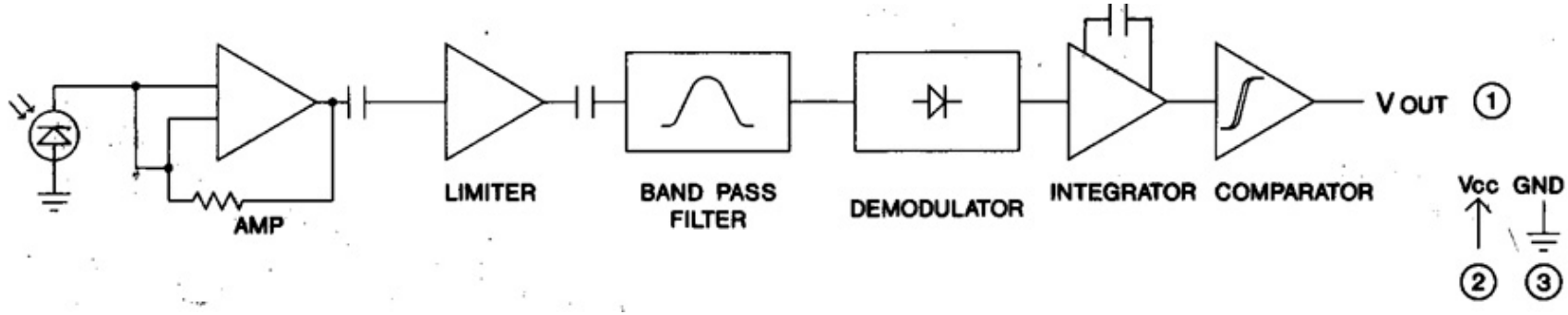
# Integrated Light Detectors



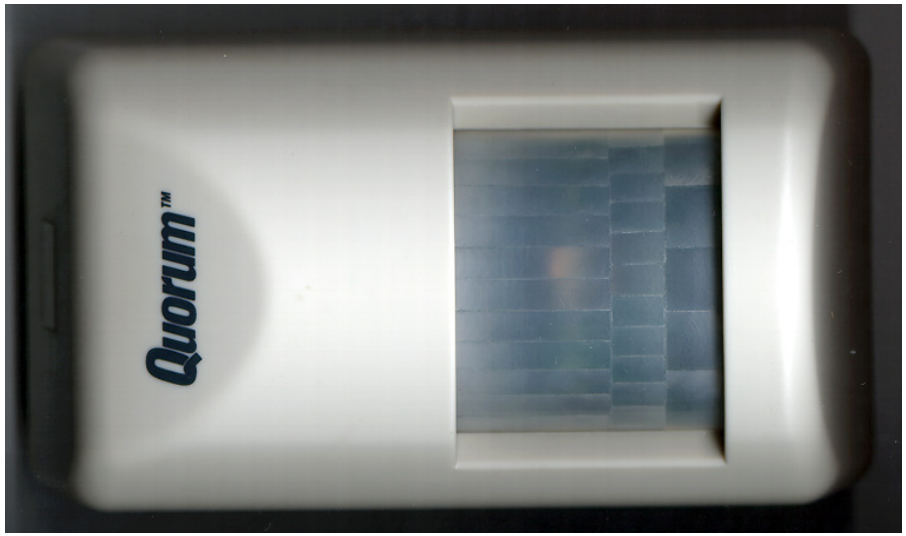
# Integrated IR Detector for Remote Controls

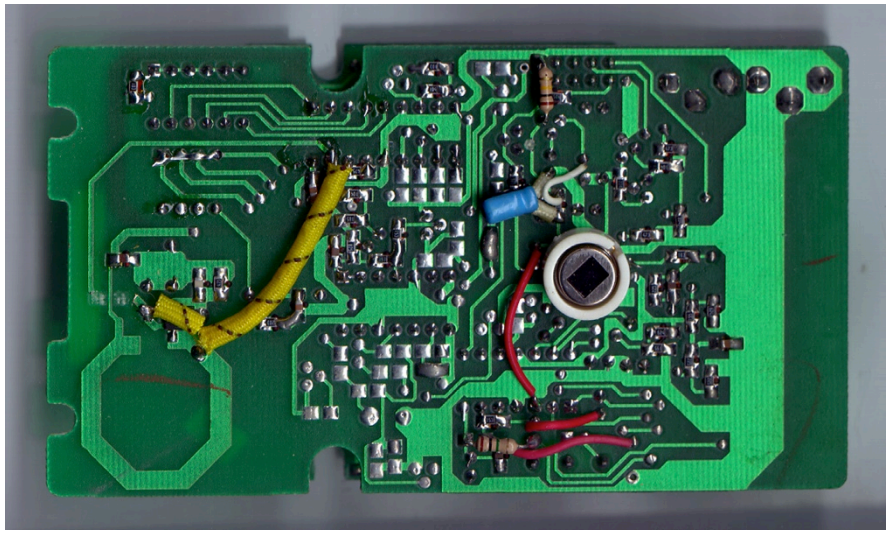


# Infrared Intrusion Alarms

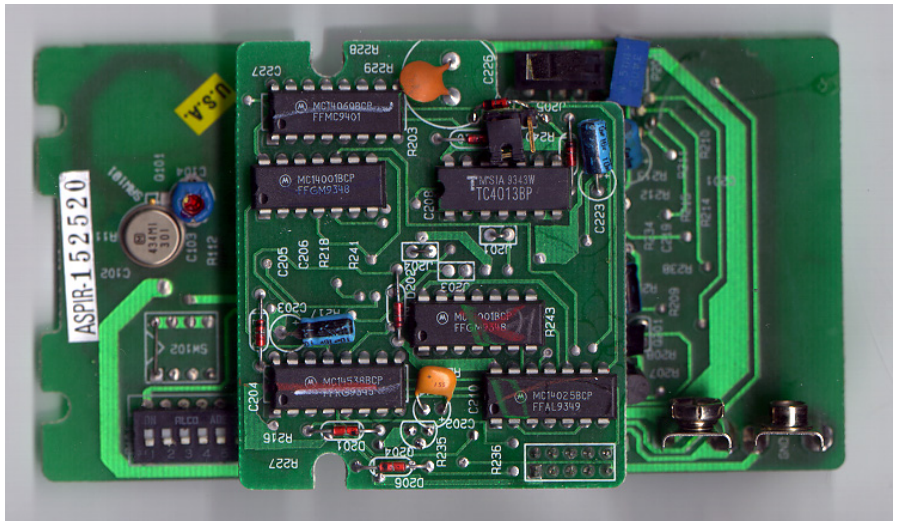


**Passive IR (PIR) sensor has no DC response.**

**Must "chop" light.**

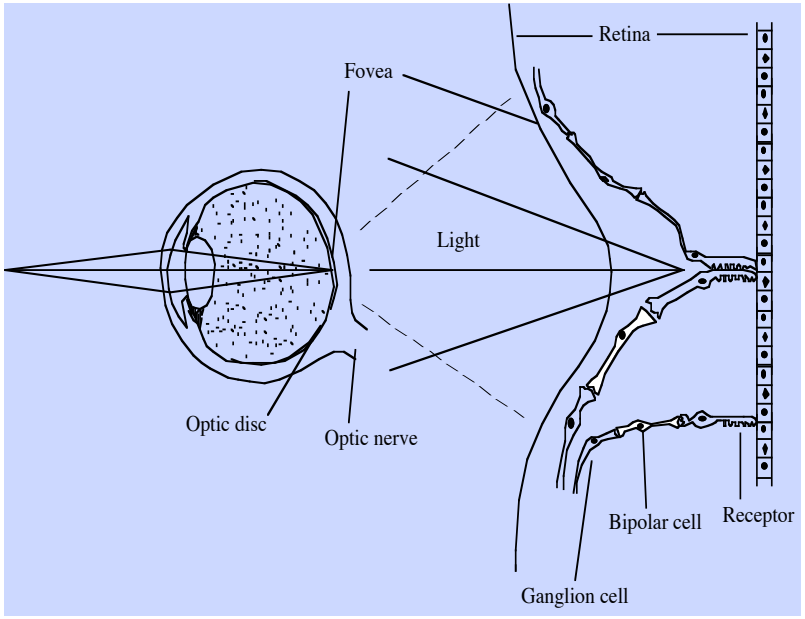
**Multiple lenses chop IR from moving warm body (intruder) since each covers unique sector.**

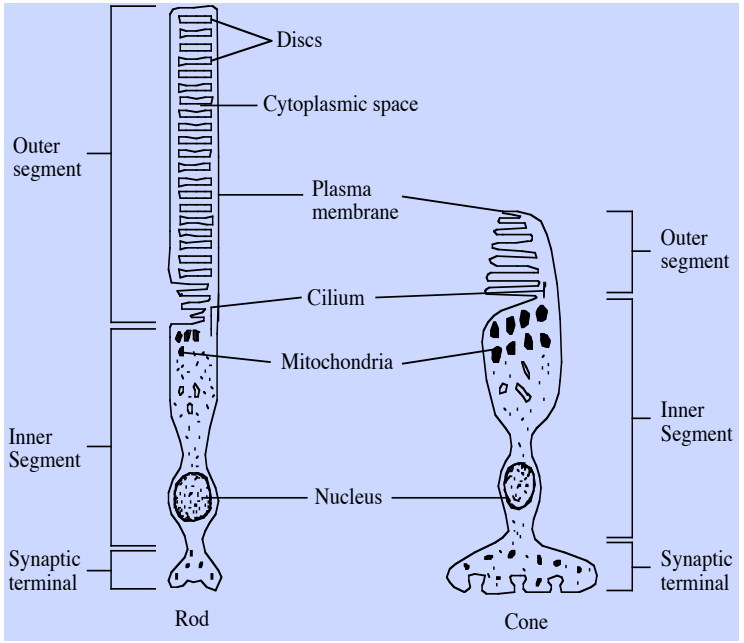


# ASIDE: BIOLOGICAL PHOTOSENSORS

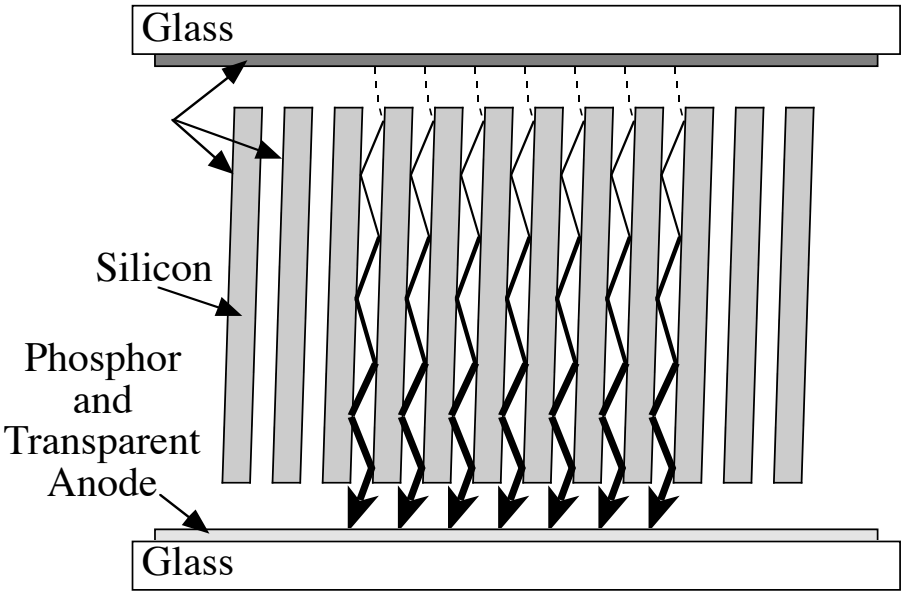
| Rods | Cones |
|---|---|
| More photopigment | Less photopigment |
| Slow response: long integration time (can detect flickering light up to 12 Hz) | Fast response: short integration time (can detect flickering light up to 55 Hz) |
| High amplification: single quantum detection | Probably less amplification |
| Saturating response | Nonsaturating response |
| Not directionally sensitive | Directionally sensitive |
| Highly convergent retinal pathways | Less convergent retinal pathways |
| High sensitivity | Low sensitivity |
| Low acuity | High acuity |
| Achromatic: one type of pigment | Polychromatic: three types of pigment |

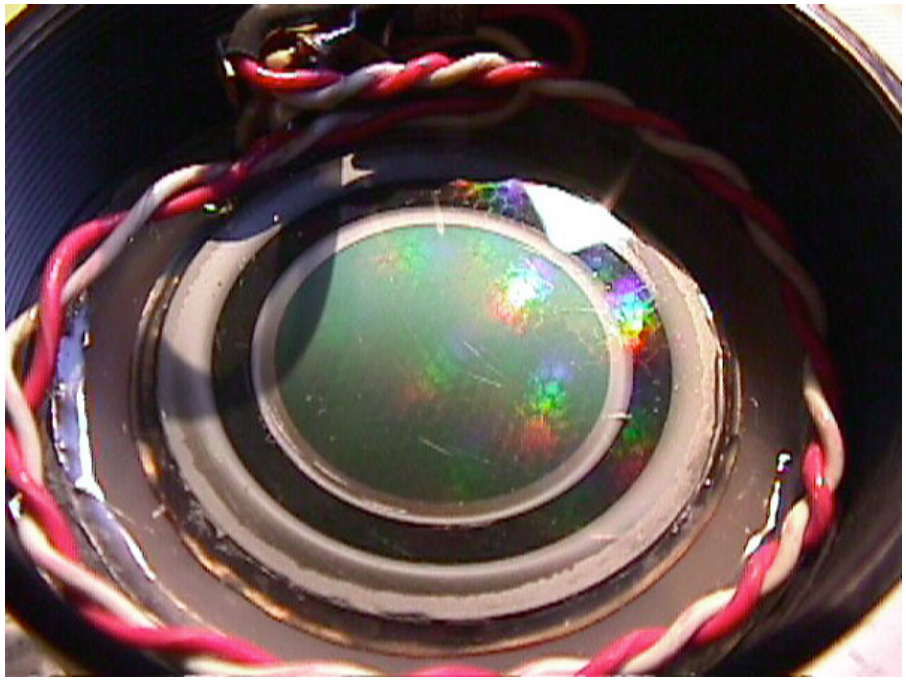


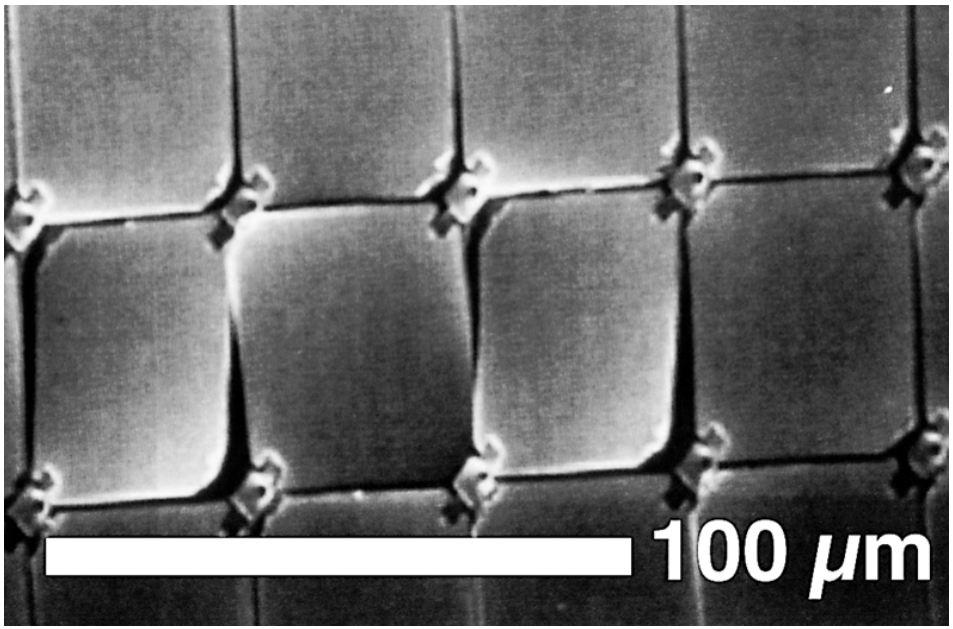
# Photomultipliers/Night Vision



# Digital Light Valves




**Images courtesy Texas Instruments, Inc.**
**Used with permission.**

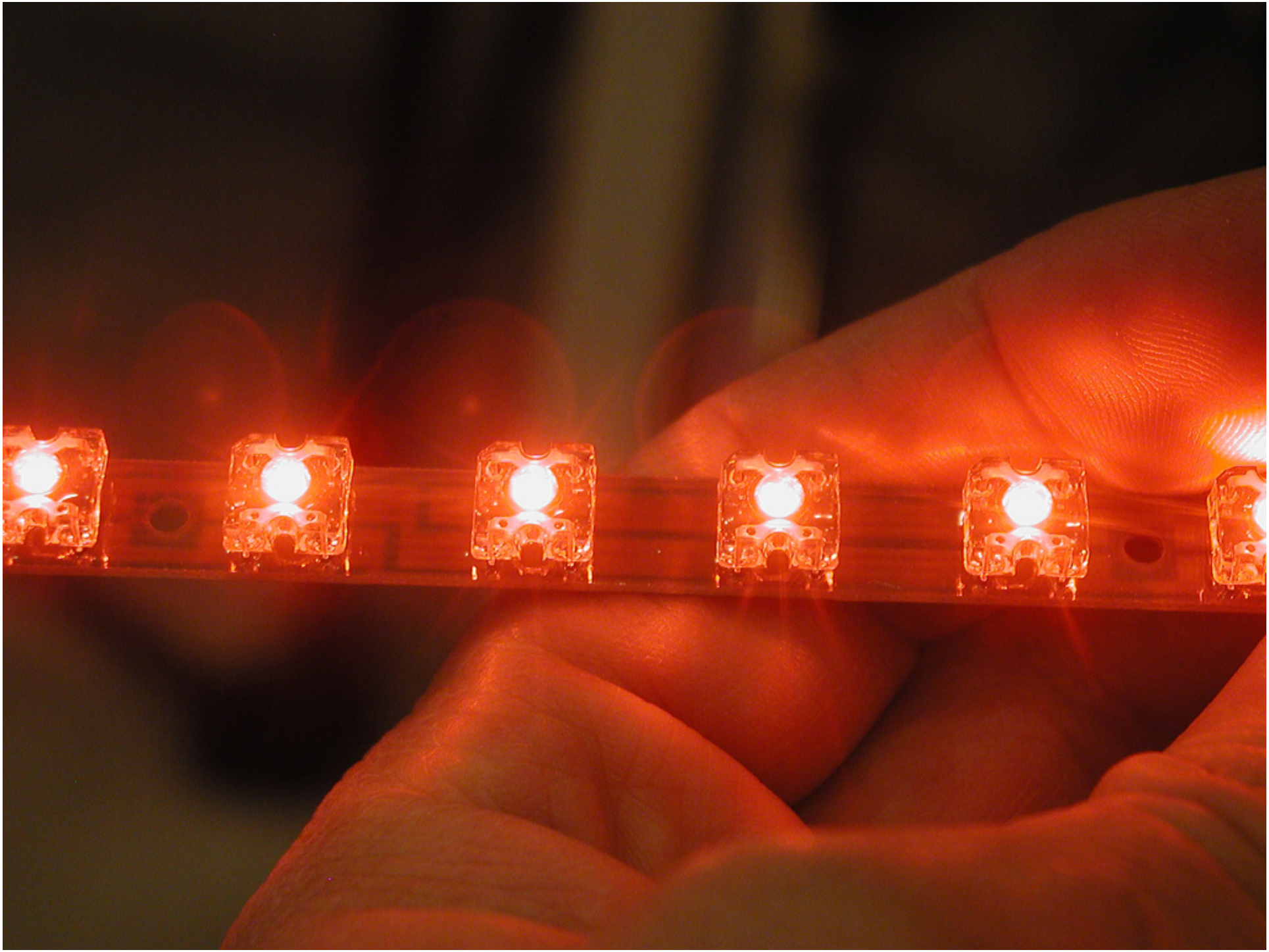
# Appendix 1: Brakelight LED Bars

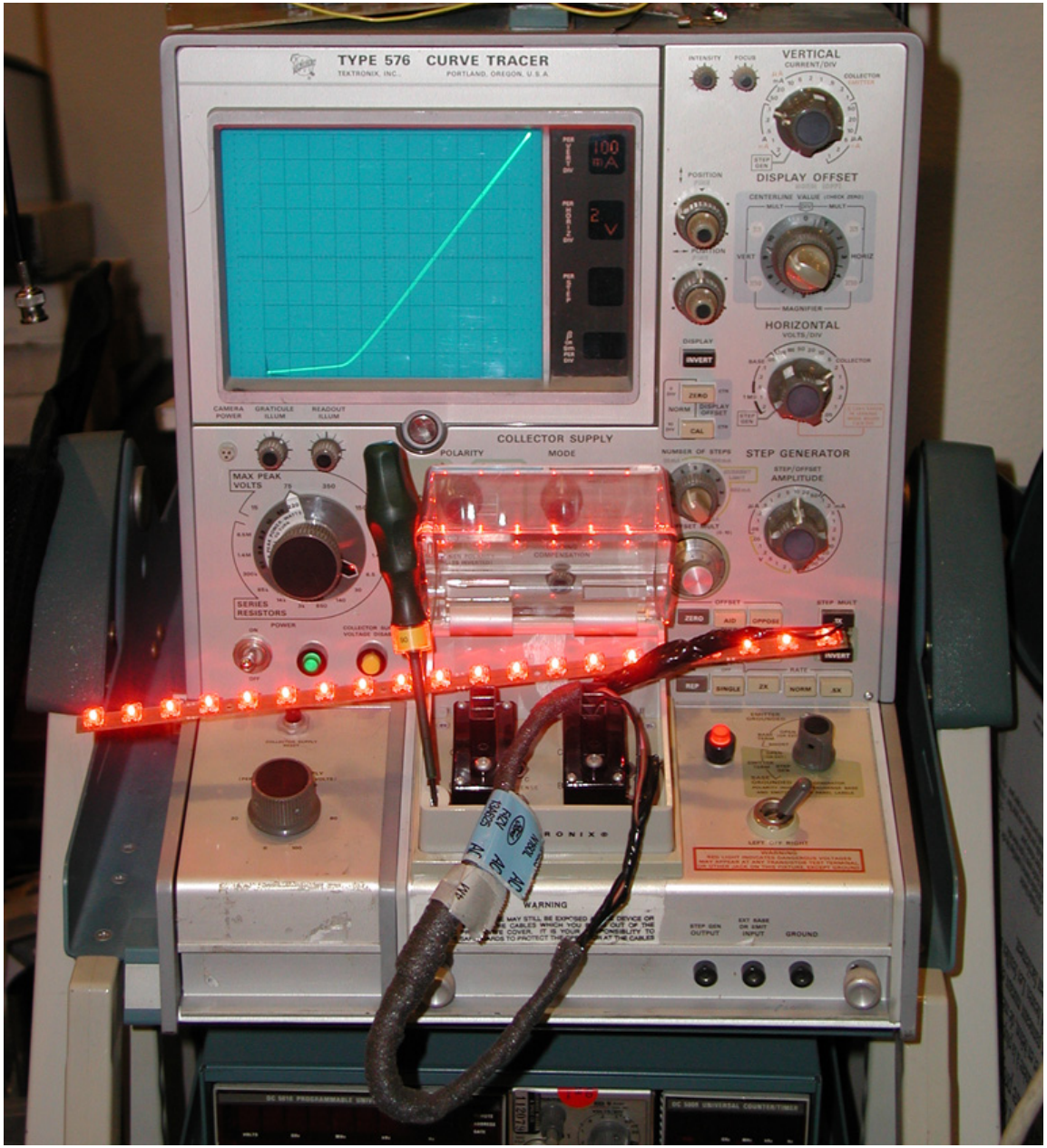
# LED Brakelight Bars

- HP part number QPWR-C397, Ford part number F4ZV-13B506-AB
- 20 super-bright red LED's arranged as four groups of five LED's in series.
- Series resistor to limit LED current.
- Parallel resistor for sensing - after series resistor in circuit.
- Want to characterize:
  - Circuit diagram with both resistors measured.
  - Pulse response - drive with IRLZ-34 MOSFET and measure resulting current on oscilloscope by using the built-in series resistor (tap in at red lead and at point where red lead connects to circuit board, then use Ohm's law to convert the voltage signal you get on the scope to current.

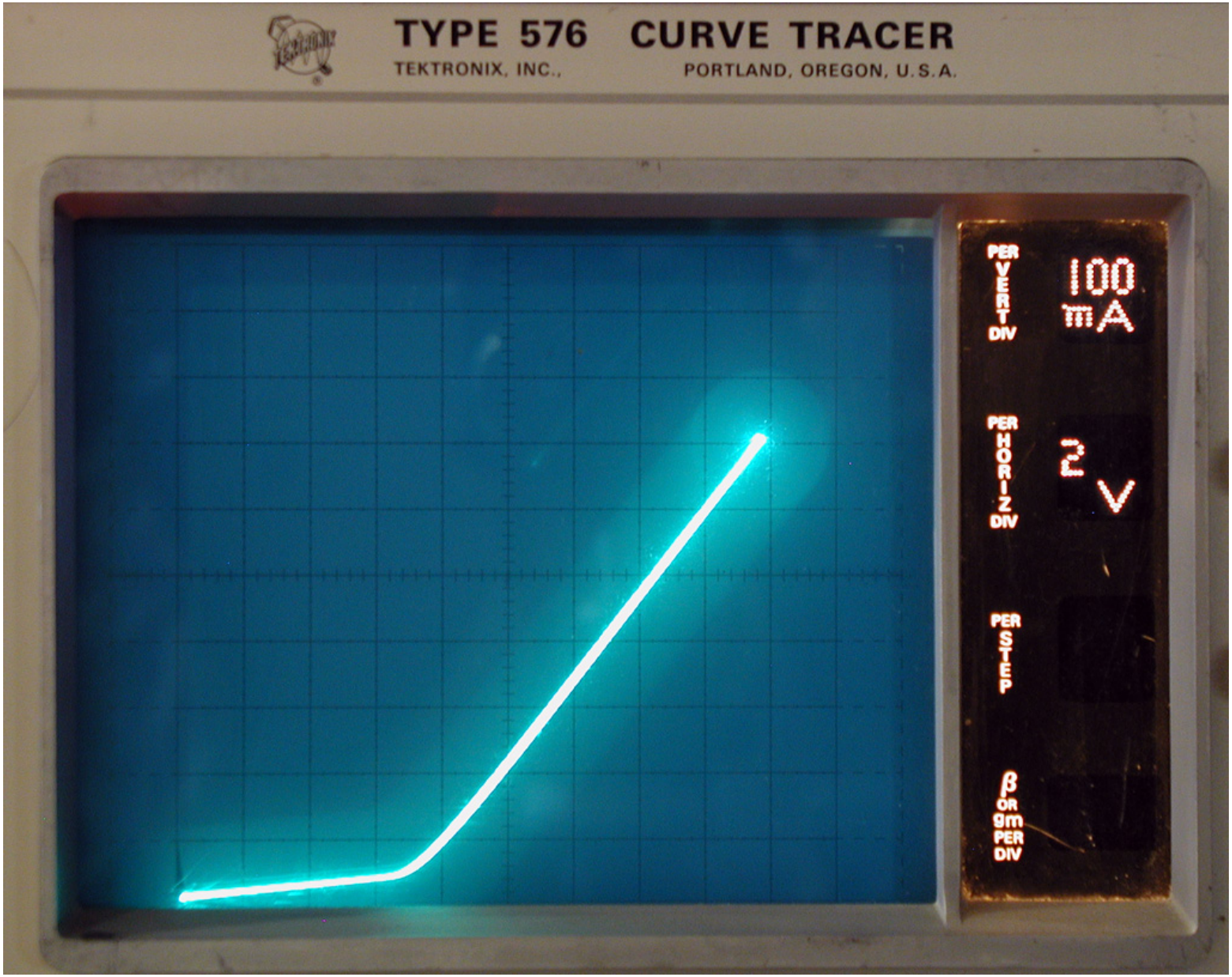


# Curve Tracer



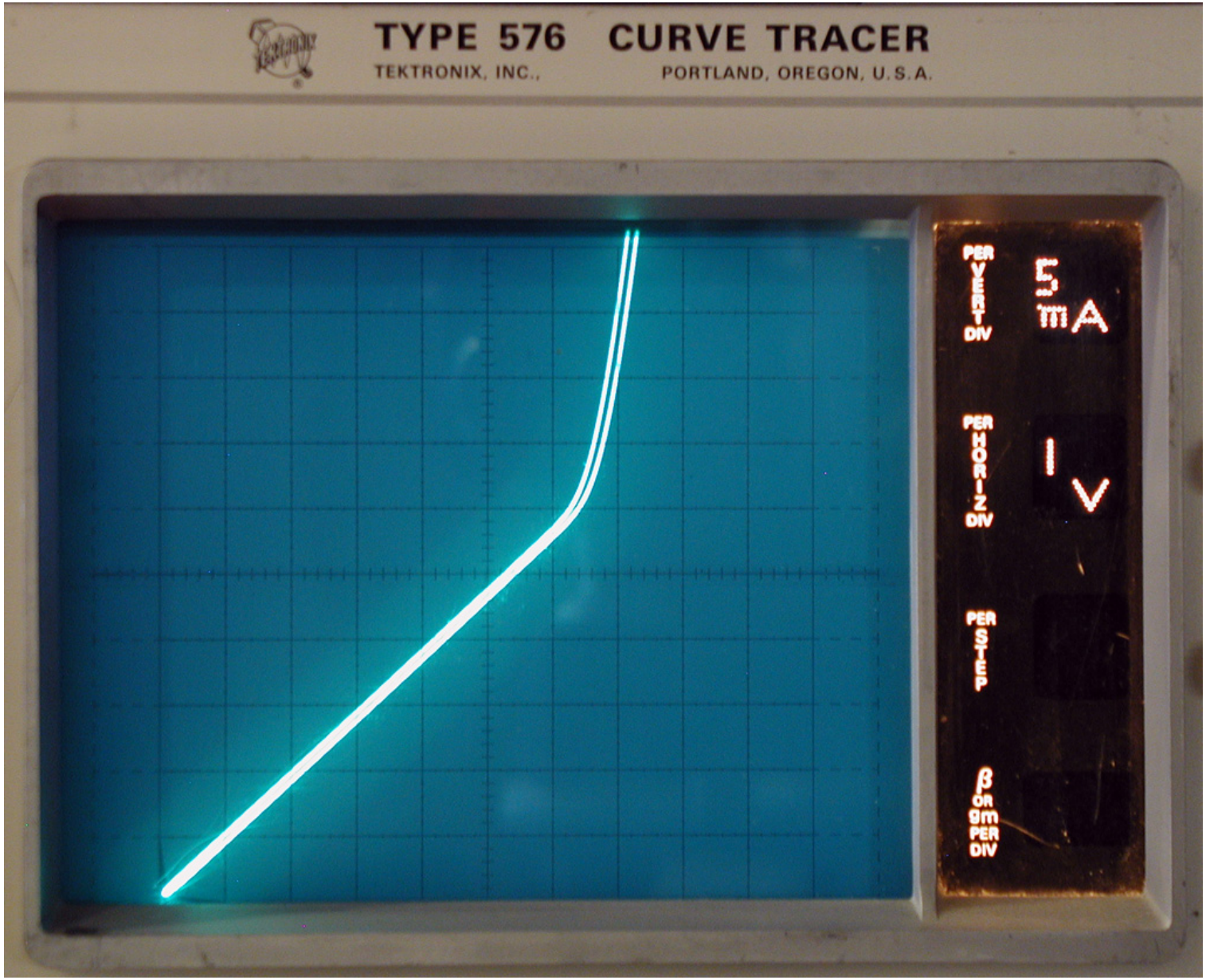

  

# Full Range



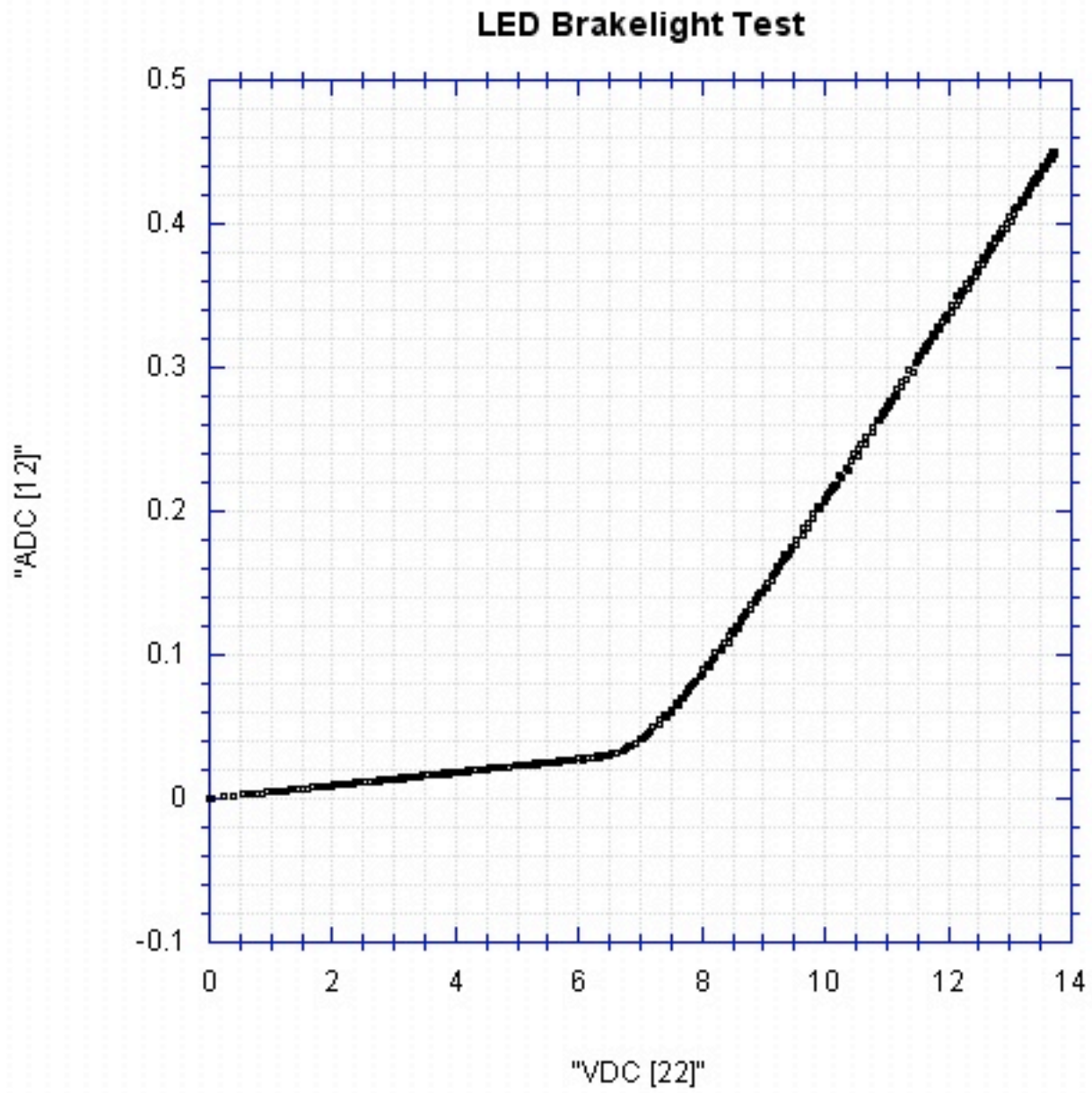

  

# Lower Voltages



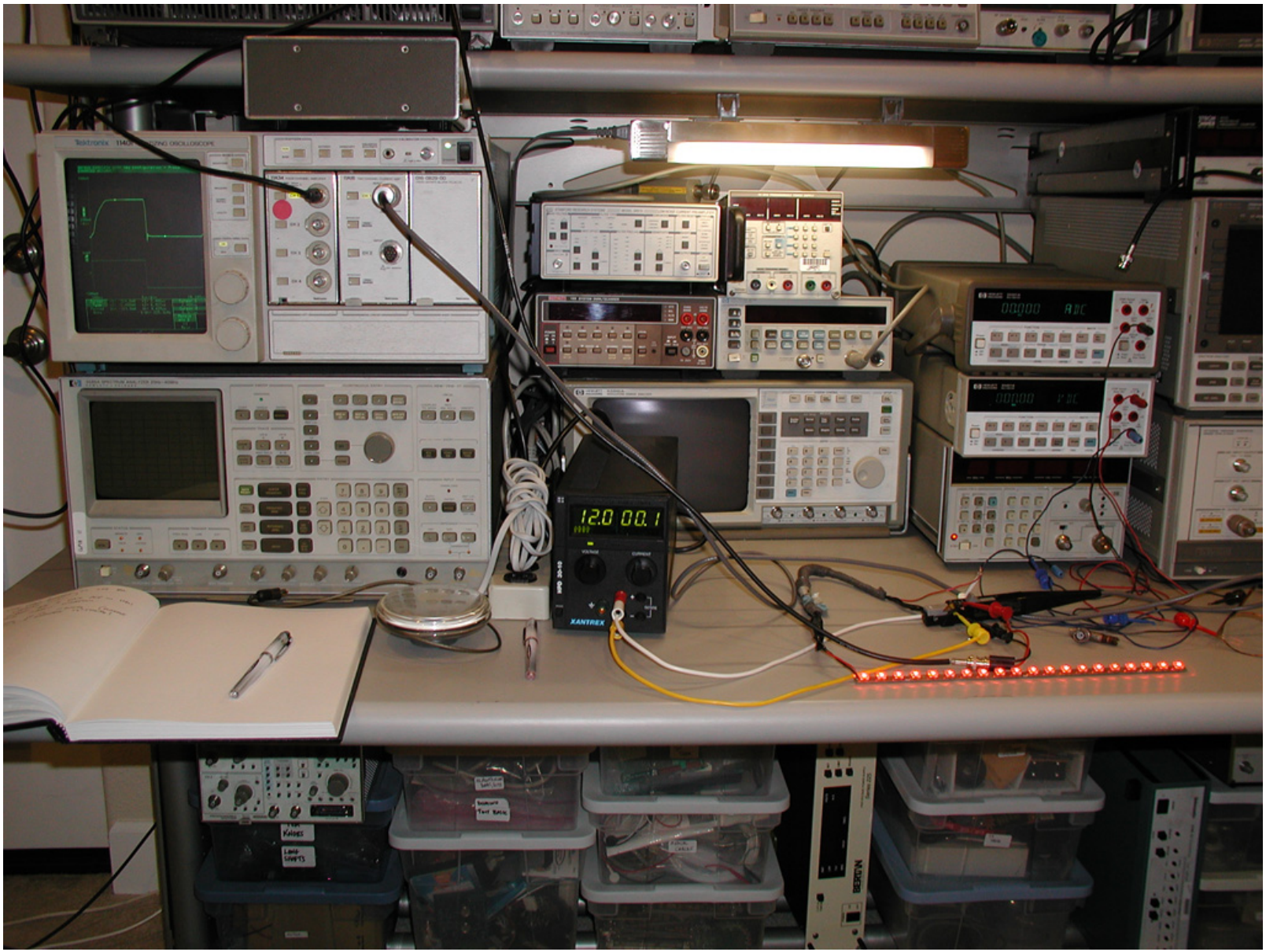

  

# Precision I-V Curve



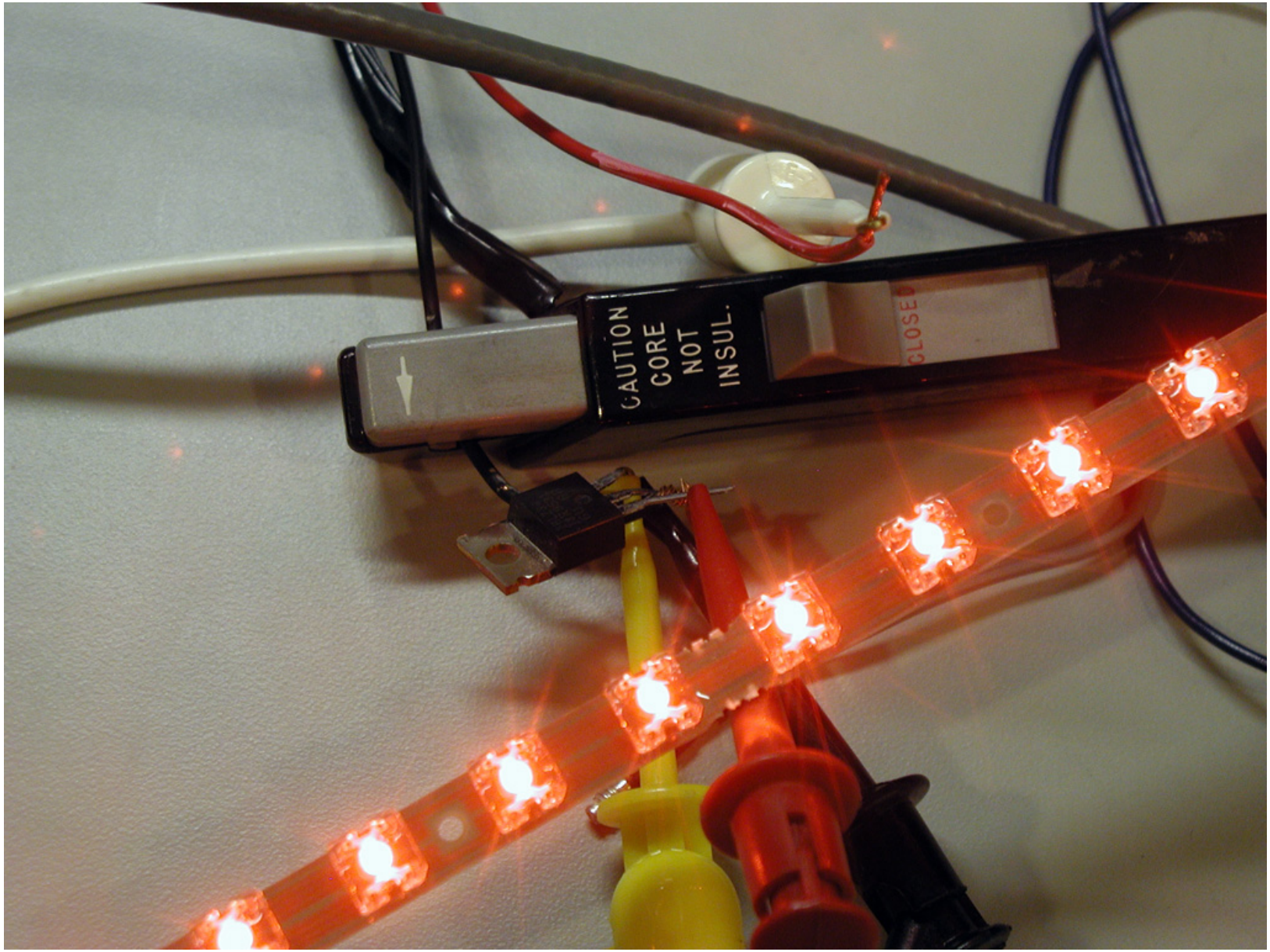

  

# Pulse Testing



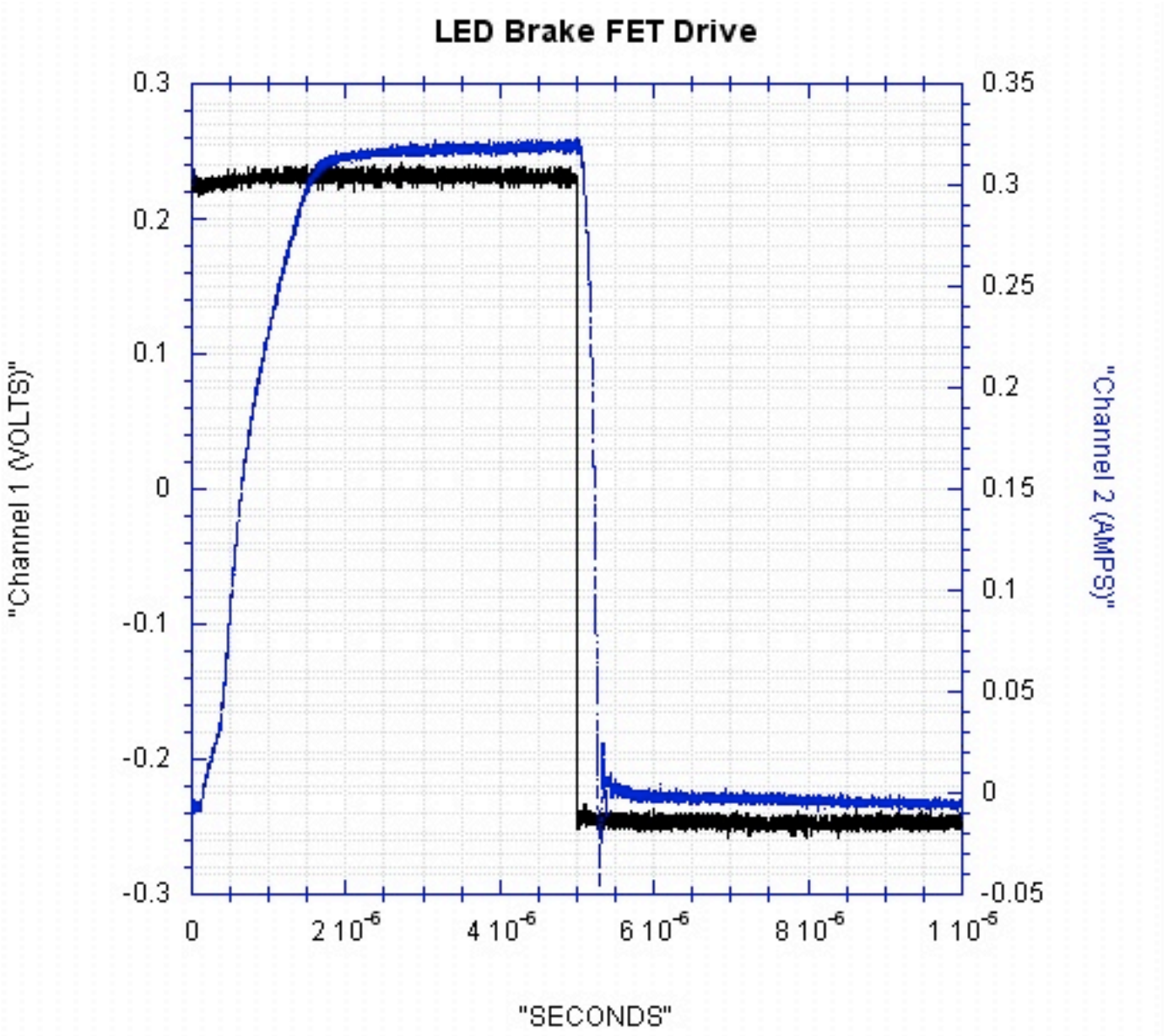

  

# Pulse Testing IRLZ34 Close-Up



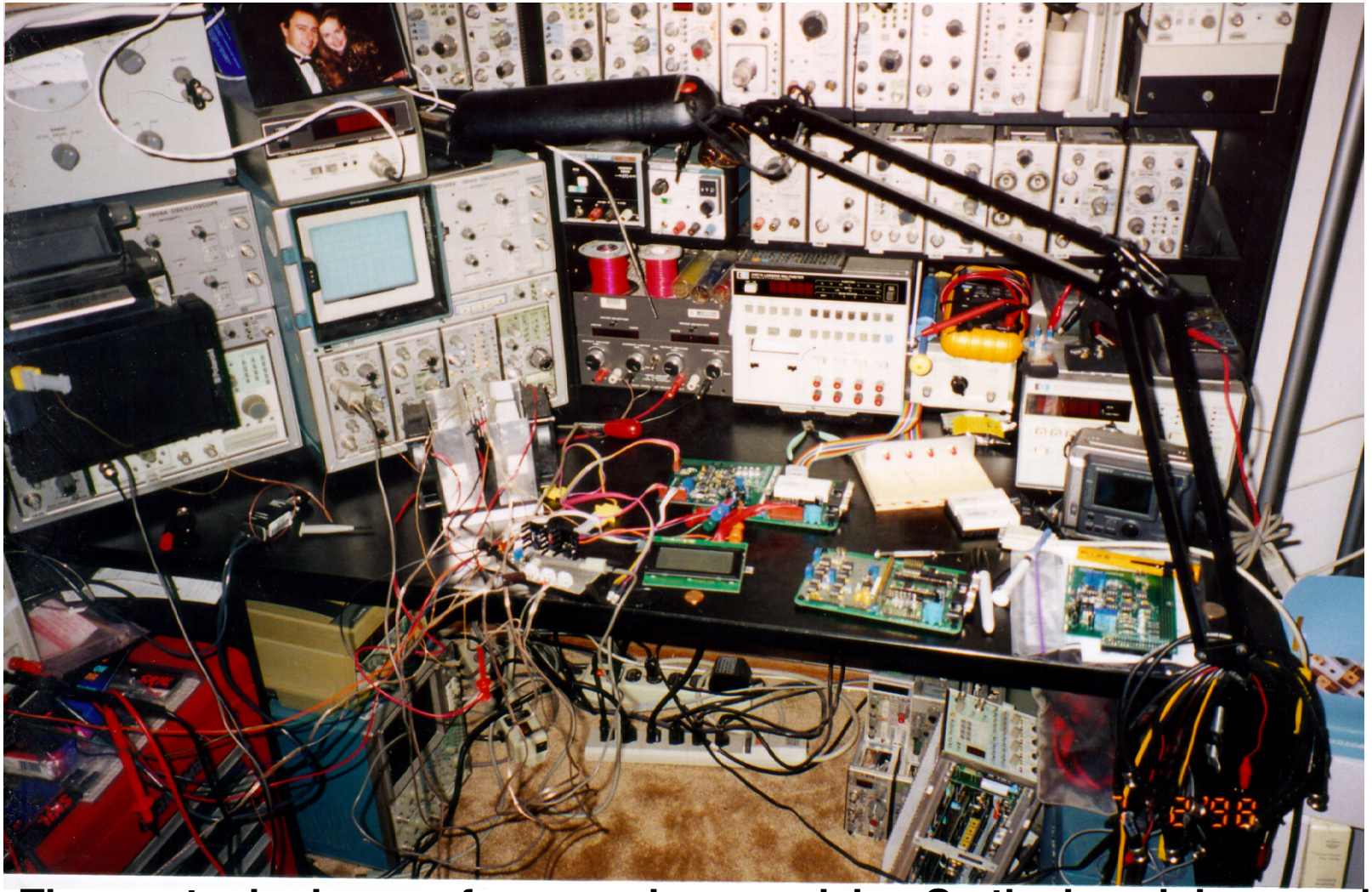

  

# Pulse Drive Response



# ANALOG HACKER (GREG'S) BENCH 1990s



**The master bedroom of our condo was a lab… On the bench is an early prototype for the company Cepheid, which a few of us co-founded.**