Power Electronic Drivers' Influence on LED Light Flicker

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- *The views and opinions of this presentation do not represent views of the IEEE or IEEE PAR 1789 working group, but only reflect opinions of the presenter*

Presentation outline

- Introduction LED Lighting
- Flicker in Lighting
- LED drivers and flicker
- Conclusions

Introduction to LED Lighting

Incandescent	CFL	Philips LED	Cree LED
60 watts	13 watts	10.5 watts	9.5 watts
850 lumens	840 lumens	800 lumens	800 lumens
1000 hour life	12,000 hour life	20,000 hour life	25,000 hour life
$0.50/lamp	$4.47/lamp	$10.97/lamp	$12.97/lamp
25,000 hour life-cycle cost	25,000 hour life-cycle cost	25,000 hour life-cycle cost	25,000 hour life-cycle cost
$12.50 (cost of 25 lamps)	$9.31 (cost of 2.1 lamps)	$13.71 (cost of 1.25 lamps)	$12.97 (cost of 1 lamp)
$240.00 (energy cost)	$52.00 (energy cost)	$42.00 (energy cost)	$38.00 (energy cost)
$252.50	**$61.31**	**$55.71**	**$50.97**

Source: US Green Building Council, Massachusetts chapter (June 2013)
http://usgbcma.blogspot.com/2013/06/say-goodbye-to-incandescent-lamp-and.html

Applications of HB-LEDs

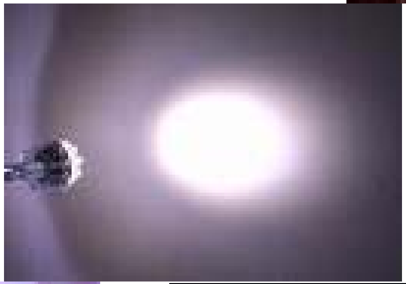
Illumination

-- Local Illumination

-- General Lighting

Ref : www.lumileds.com

www.colorkinetics.com



Motivation

People LOVE light quality from LEDs!

Brad Lehman lit by CFL

Brad lit by incandescent

Brad lit by LEDs

Why High Brightness LEDs?

- LEDs have an incredibly long life, lasting ~50,000 hours (depends on operating temperature). A fluorescent tube lasts 7,500 hours and a normal incandescent bulb lasts only 1,000 hours.

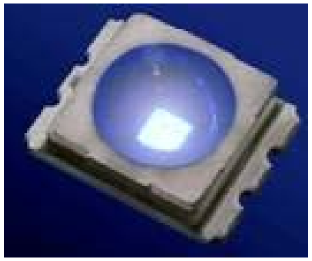
- LED bulbs are environmentally friendly and no mercury to dispose of as in some fluorescent lamps.

- Lower maintenance cost as LEDs have long lifetimes. For the same reason replacement costs are also reduced.

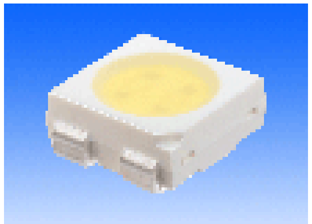
- High-levels of brightness and intensity as combinations of Red, Green and Blue produce various colors.

- Can be easily controlled and programmed.

Enlux



Cree



Nichia

Lumileds

Predictions

- According to statistics published by Optoelectronics Industry Development Association (OIDA), replacement of one 60 Watt bulb with an equivalent lumens LED white light bulb will
  - Save over **1800 pounds** of coal.
  - Reduce carbon dioxide emissions by **3000 pounds**
  - Reduce Sulphur dioxide emissions by **12 pounds**
  - Creates **no mercury** emissions

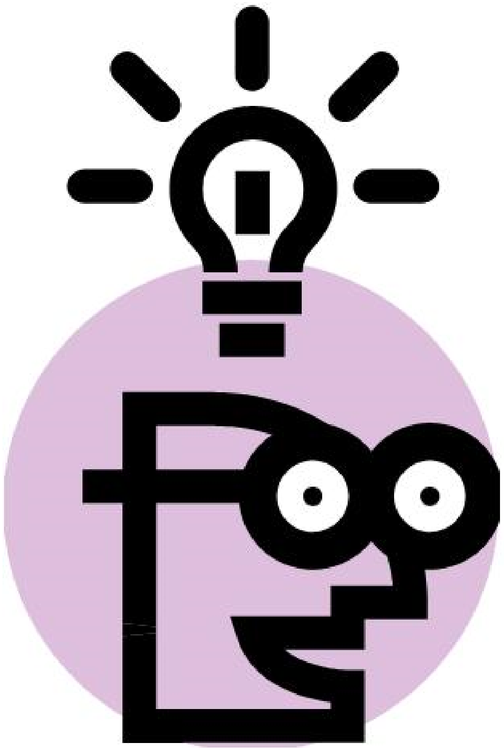
- DOE estimates that Solid State Lighting could potentially reduce the US electricity used for illumination up to **50% by 2025**.
  - Alleviate the need of more than **40** power stations of **1000MW.**

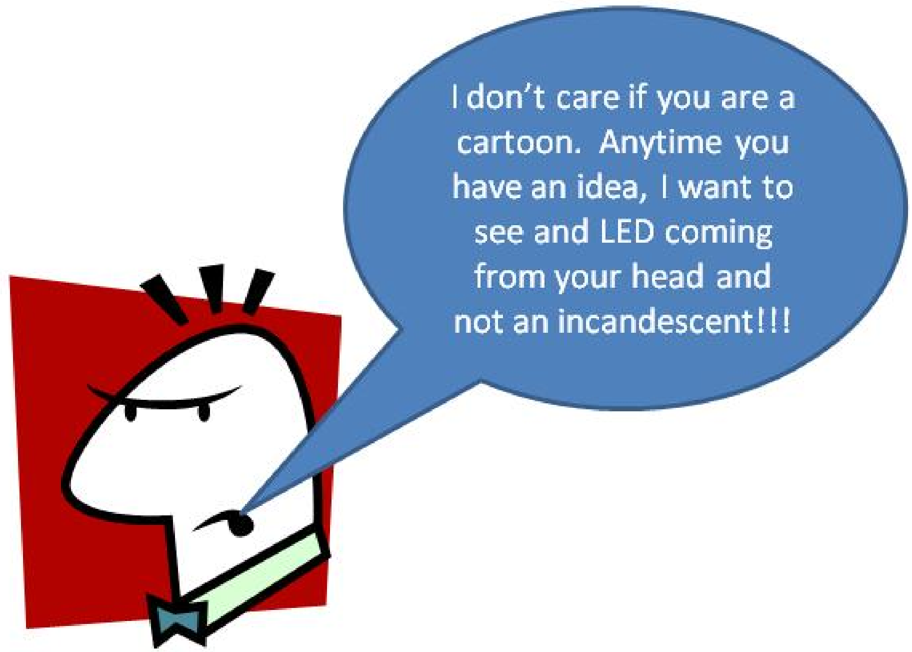
Power Conversion for "White" Light Sources

	Incandescent† (60W)	Fluorescent† (Typical linear CW)	Metal Halide‡	LED
Visible Light	8 %	21 %	27 %	15-25 %
Infrared	73 %	37 %	17 %	~ 0 %
Ultraviolet	0 %	0 %	19 %	0 %
Total Radiant Energy	81 %	58 %	63 %	15-25 %
Heat (Conduction + Convection)	19 %	42 %	37 %	75-85 %
Total	100 %	100 %	100 %	100 %

† IESNA Lighting Handbook – 9th Ed.

‡ Osram Sylvania





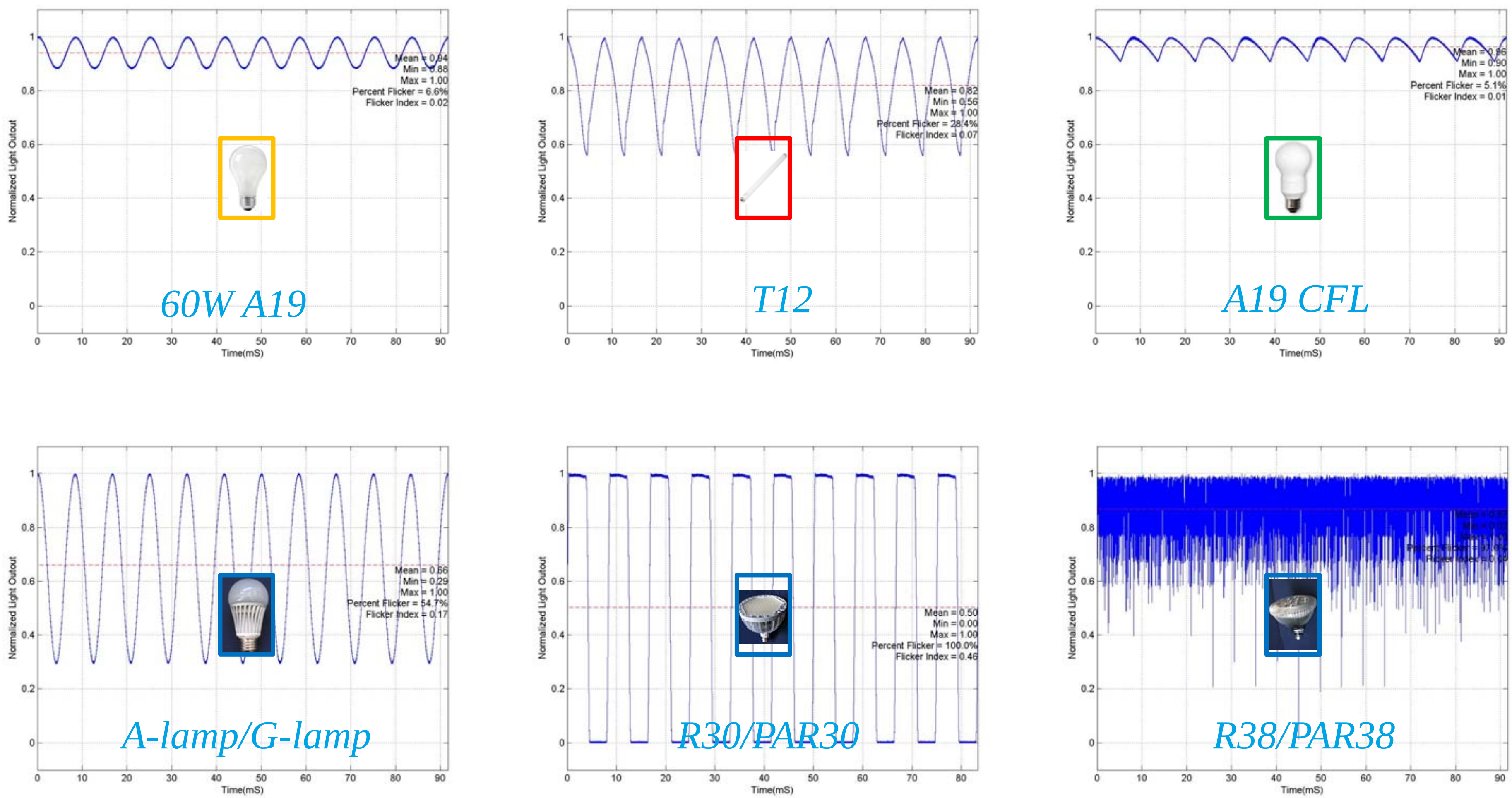
Comic strips go green.

Flicker

Flicker in Lighting

- Flicker, flutter, shimmer
  - Repetitive change in magnitude over time, or modulation, of the luminous flux or luminance of a light source
  - Light output modulation
- Visible vs. invisible, sensation vs. perception
  - Visible flicker = Light output modulation is sensed and perceived **(<60Hz~90Hz)**
  - Invisible flicker = Light output modulation is sensed, but not perceived **(>90Hz)**
  - Sensation: external conditions are detected and neurons respond
  - Perception: the brain detects AND the mouth can report it sees

Light source modulation



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Even battery powered flashlights can be programmed to flicker

1. High brightness

   145Hz (long duty cycle)

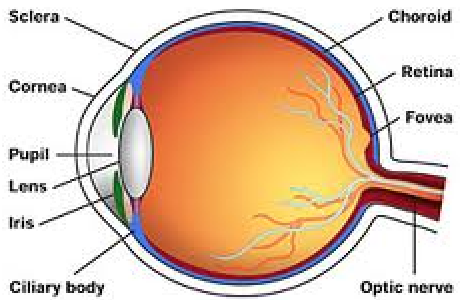
2. Low brightness

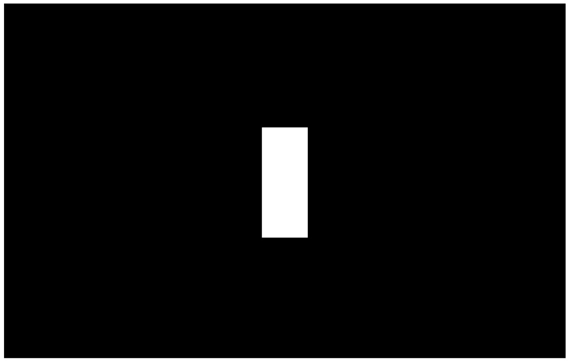
   57Hz (double pulse)

3. Flickering

   10Hz

Eye Saccade



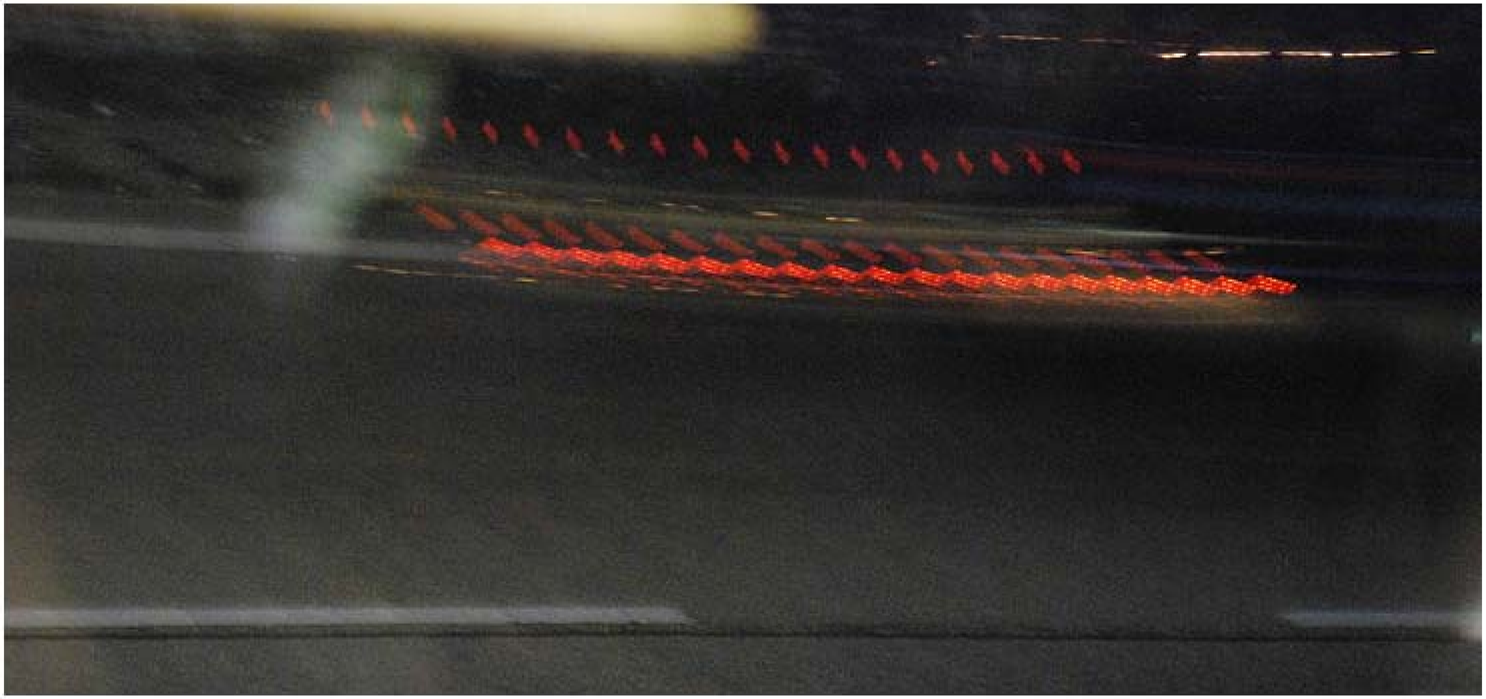


- Eye in motion from (e.g. left to right) more sensitive to flicker
- Experiment: CRT with flickering bar (vs.) constant illuminating bar
  - Above what frequency is image same?
  - Implication to LED tail-lights (worst case scenario here)
  - Experiment designed by Jane Roberts and A. Wilkins, Univ. Essex, gives worst case upper bound of perceptible flicker

Driving at night

Do any of you find this annoying?

Strobing LED car tail lights



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The “phantom array”

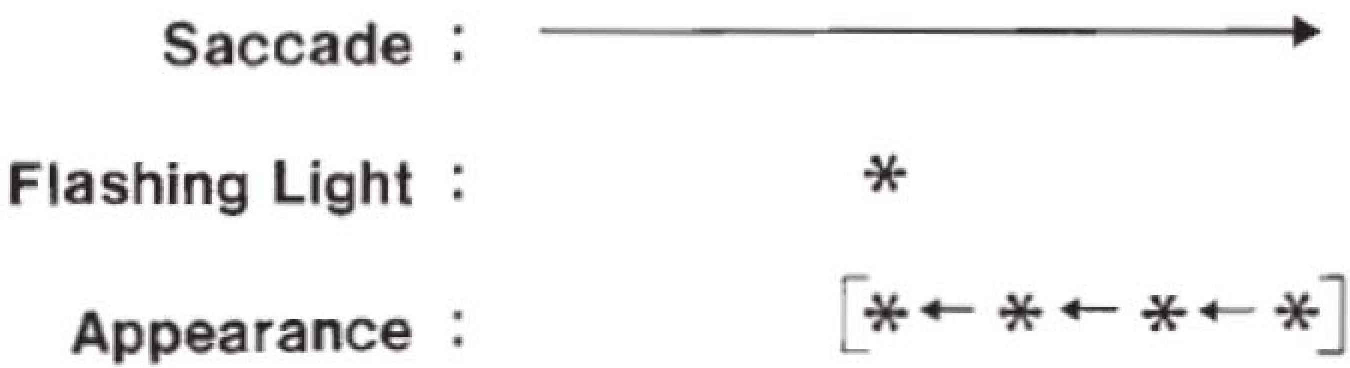
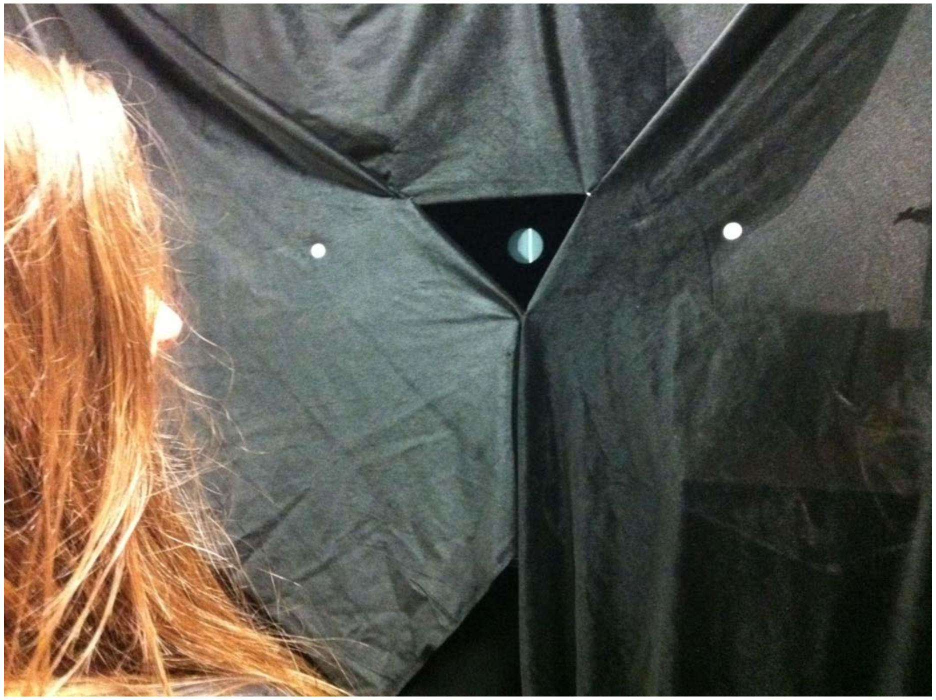


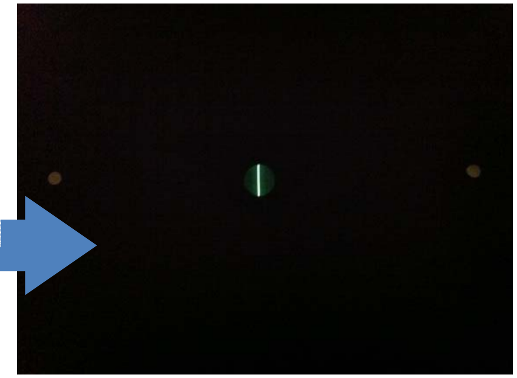
Figure 1. If you shift your gaze saccadically from the left to the right of a point light source in a darkened room, blinking on and off at 120 Hz, you will see phi movement to the left within a phantom array that is displaced to the right. From “Saccadic Eye Movements and the Perception of Visual Direction,” by W. [A.] Hershberger, 1987, *Perception & Psychophysics, 41*, p. 39. Copyright 1987 by Psychonomic Society, Inc. Reprinted with permission.

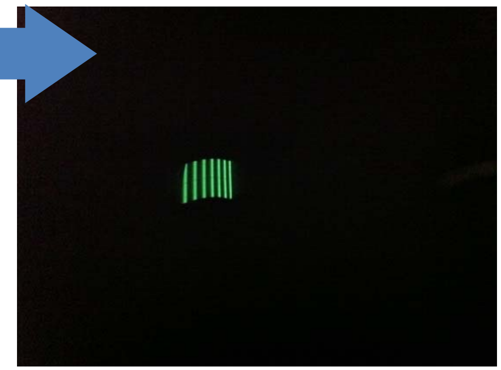
Experimental Setup



Participants view flickering line in the dark and make eye saccade

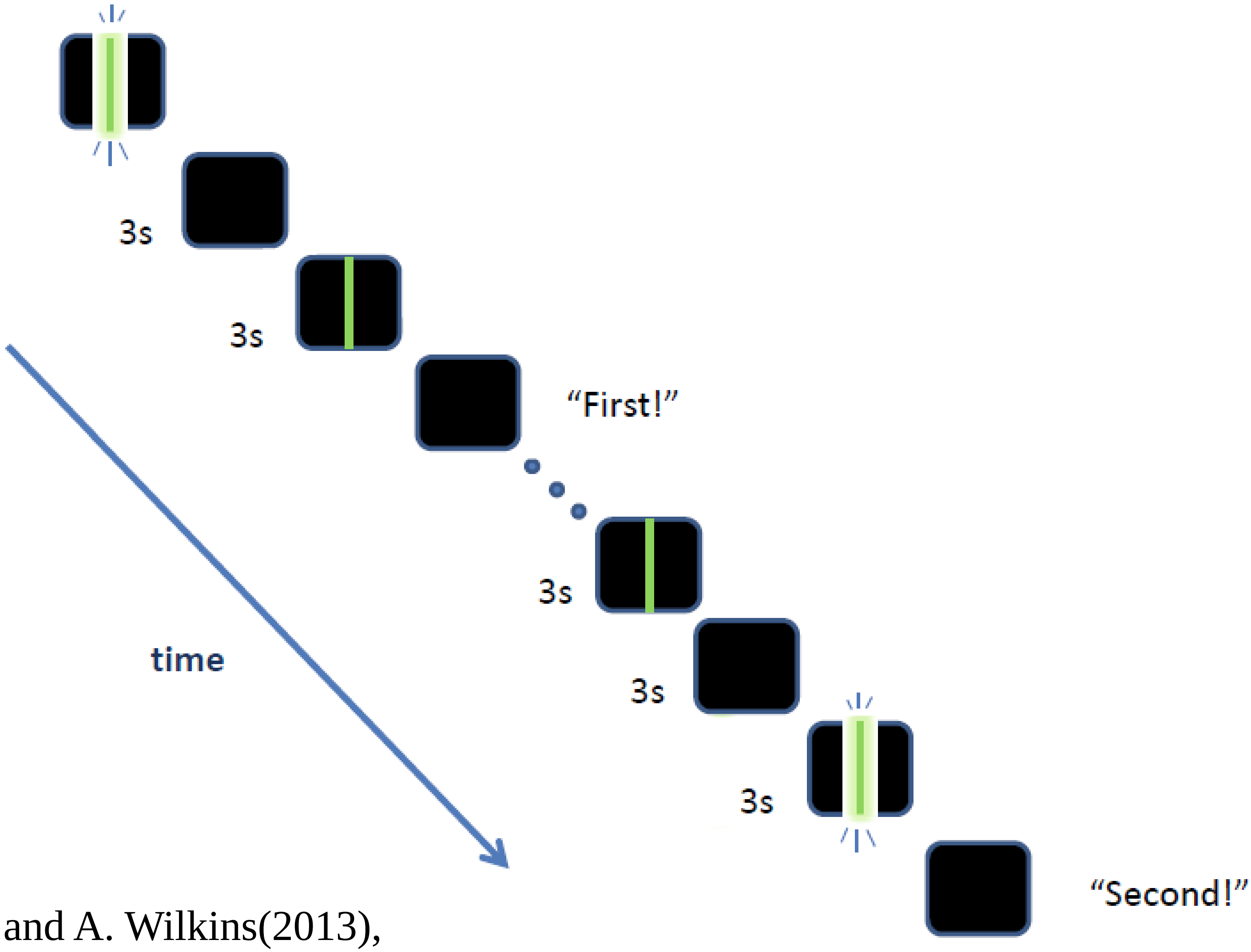
Which do you see?



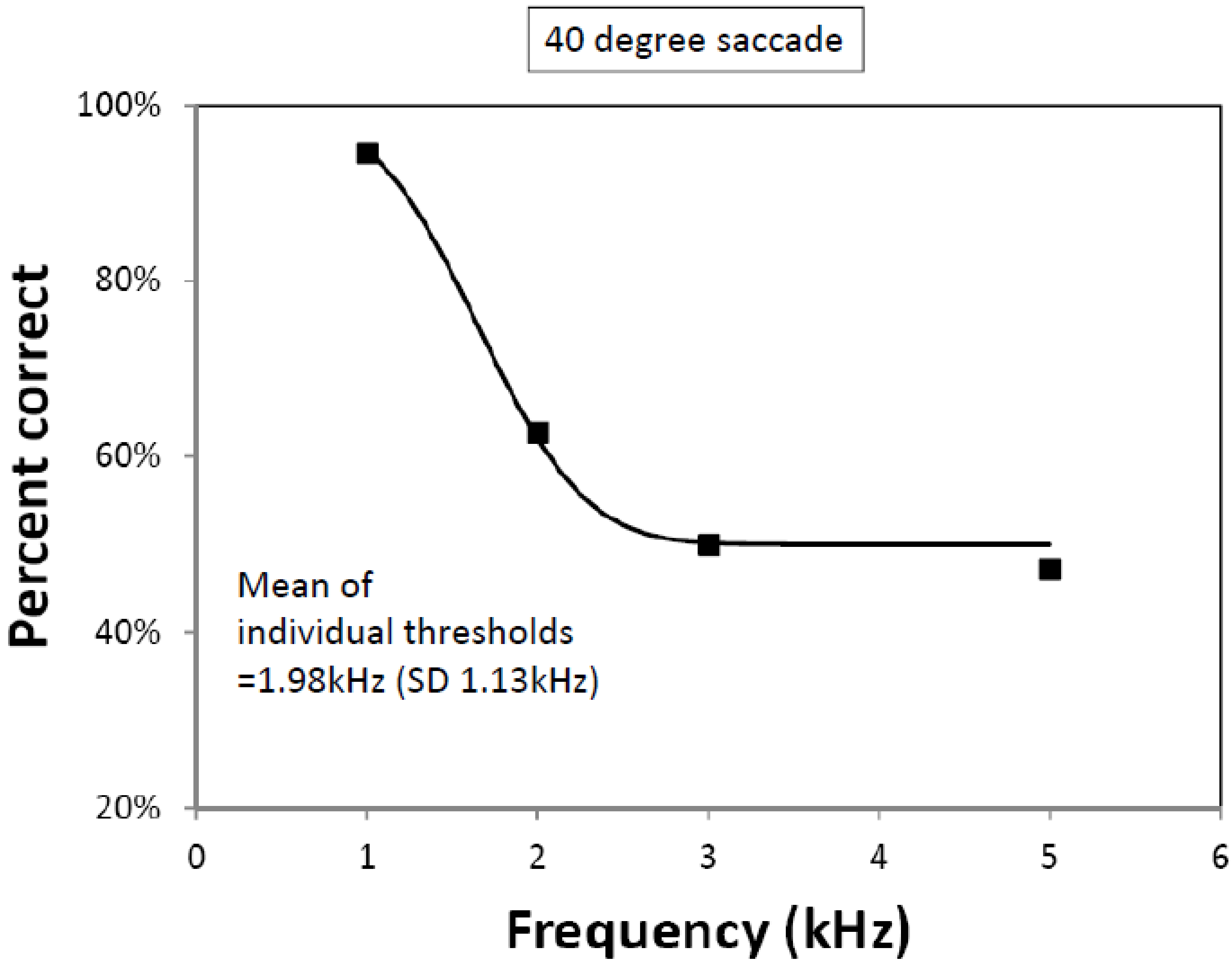


Roberts and A. Wilkins(2013), Lehman et al (2011)

Two-interval force choice



Roberts and A. Wilkins(2013),



Roberts and A. Wilkins(2013),

Stroboscopic Effect:

Flickering light on a moving object

Lighting Research Center (ASSIST) at RPI
(Bullough, Sweater Hickcox, Klein, Lok, Narendran)

- What is max value of flicker that a viewer can detect stroboscopic effects?

% flicker < 0.16*(flicker_freq) – 5.6

Example: flicker_freq=120Hz

% flicker < (0.16)*120-5.6 = 13.6%

Where % flicker = (Max – Min)/(Max+Min)

Alliance for Solid-State Illumination Systems and Technologies (ASSIST). 2012. *ASSIST recommends… Flicker Parameters for Reducing Stroboscopic Effects from Solid-state Lighting Systems*. Vol. 11, Iss. 1, Troy, NY: LRC www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp

Flicker: Potential Health Effects

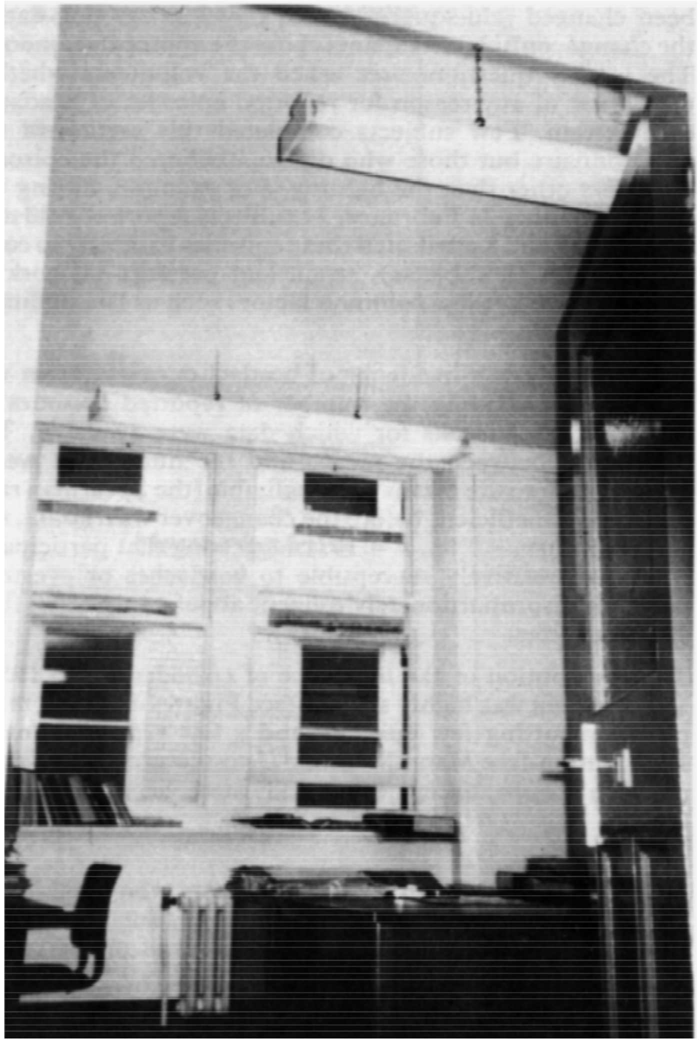
- Photosensitive epilepsy
  - Short exposure to 3 – 70 Hz flicker (i.e., visible modulation) may cause seizures in sensitive people
  - 1 in ~20,000 people
- Malaise: headache and eyestrain
  - Slower onset to frequencies in range of 100-120Hz have been published
  - Exact population frequency is not known (not everyone affected)

Source: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/veitch_flicker_philly2010.pdf

A double-masked study of headache and eye-strain

Compared conventional ("flickering") lighting (100Hz) with high-frequency ("non-flickering") lighting (>20kHz)

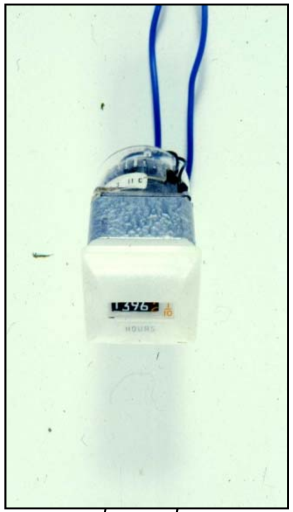
Seminal study by A. Wilkins (1989)



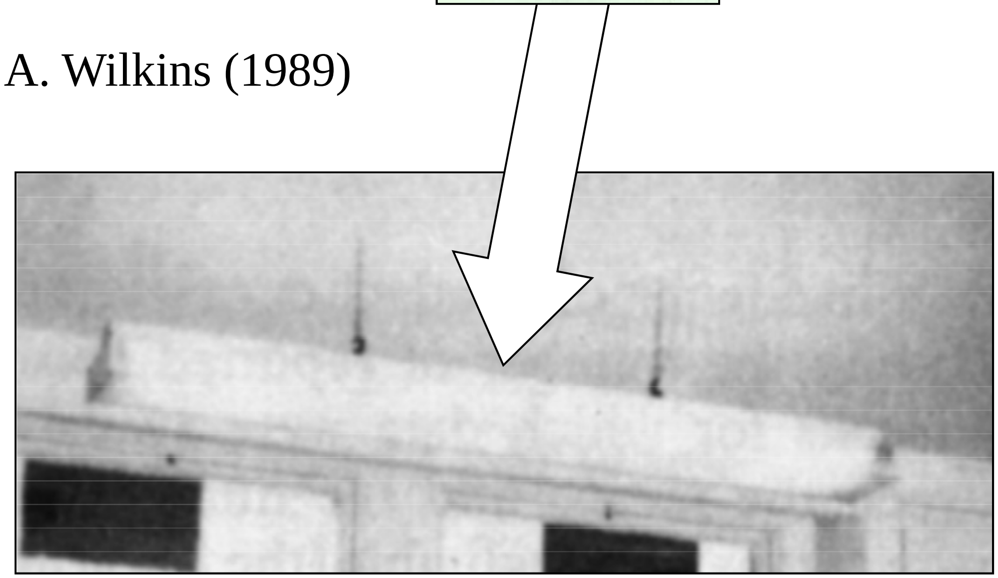
Timers measured hours lamp was turned on

Hidden in casing

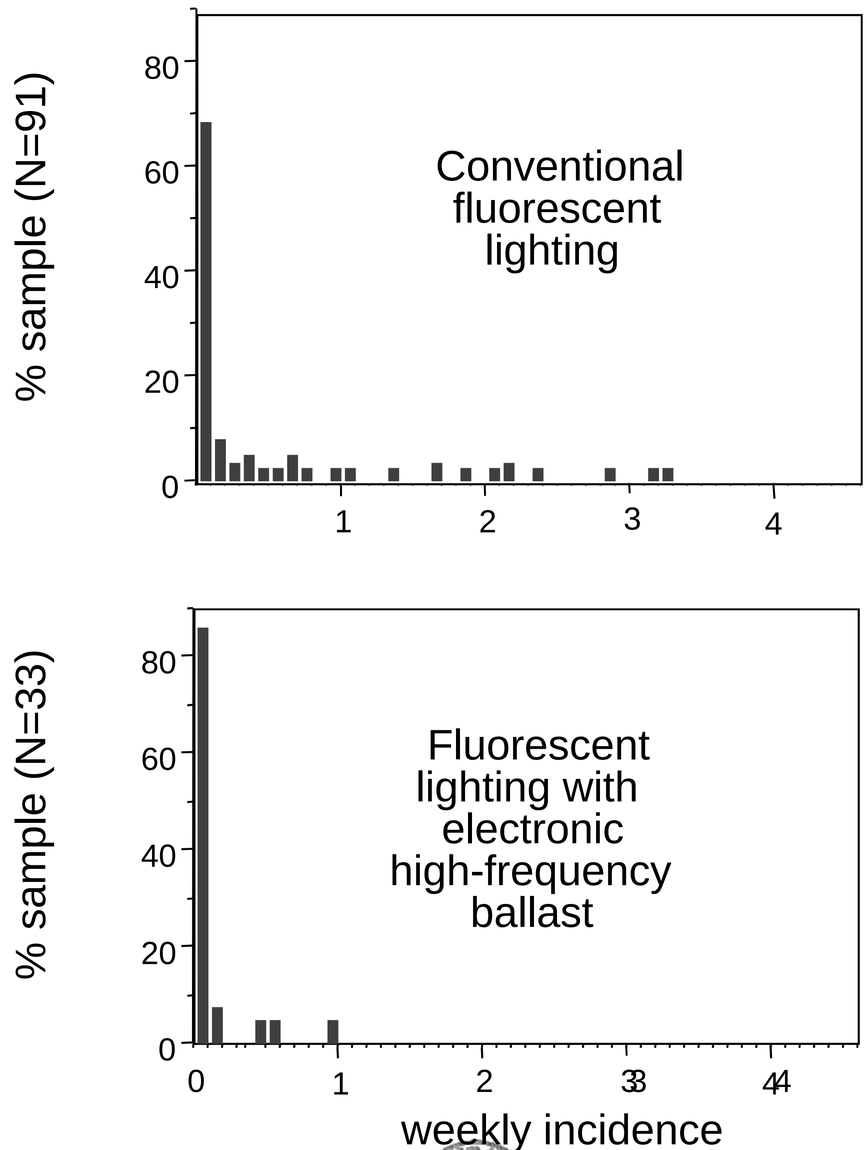
Showed HF lights left on for longer



A. Wilkins (1989)



Headaches and lighting: over twice the occurance of headaches when magnetic ballasts with 120Hz



A. Wilkins (1989)

Risk Assessment

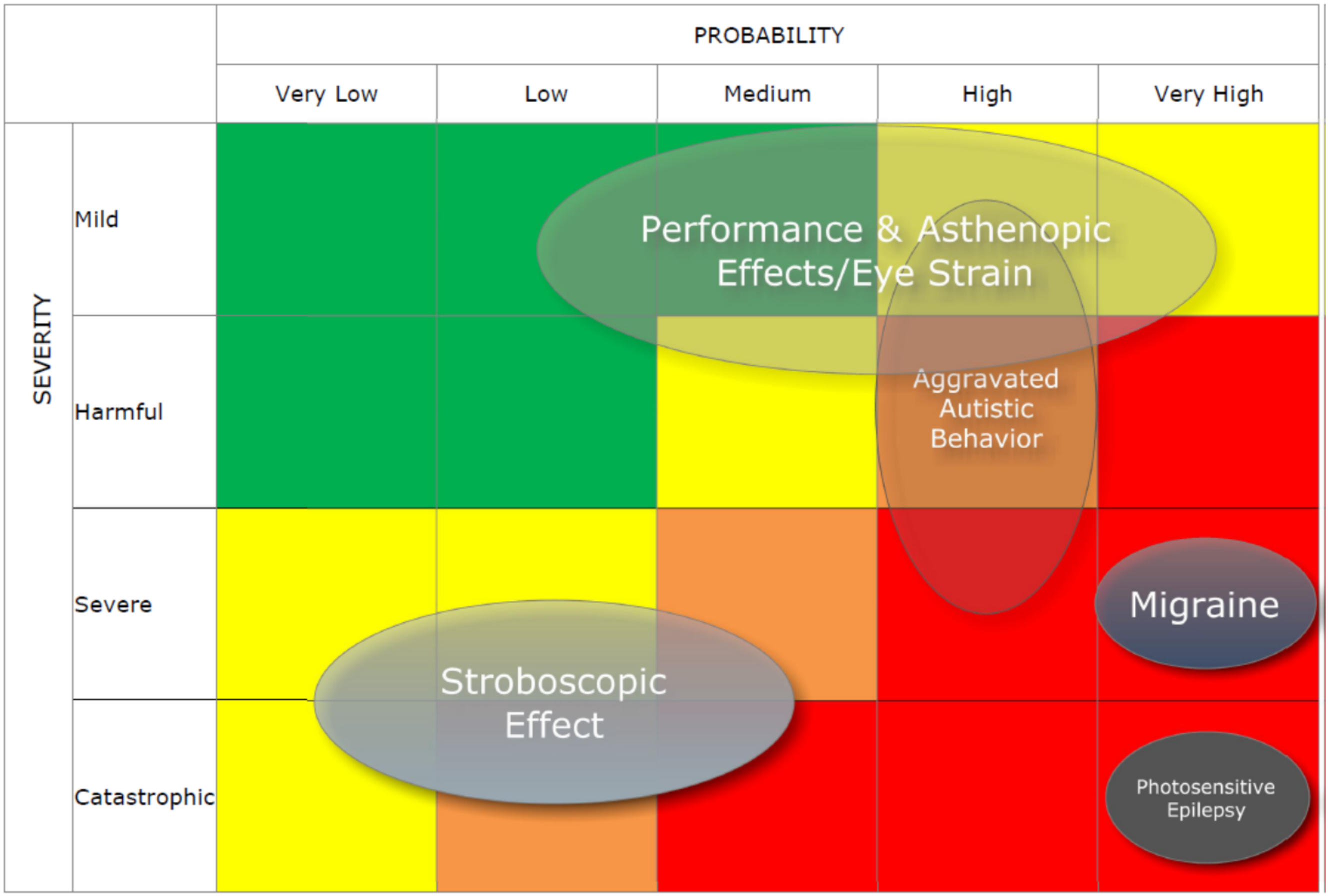


Table 2 Risk Levels

Risk Level	Color code
Low	
Medium	
Serious	
High	

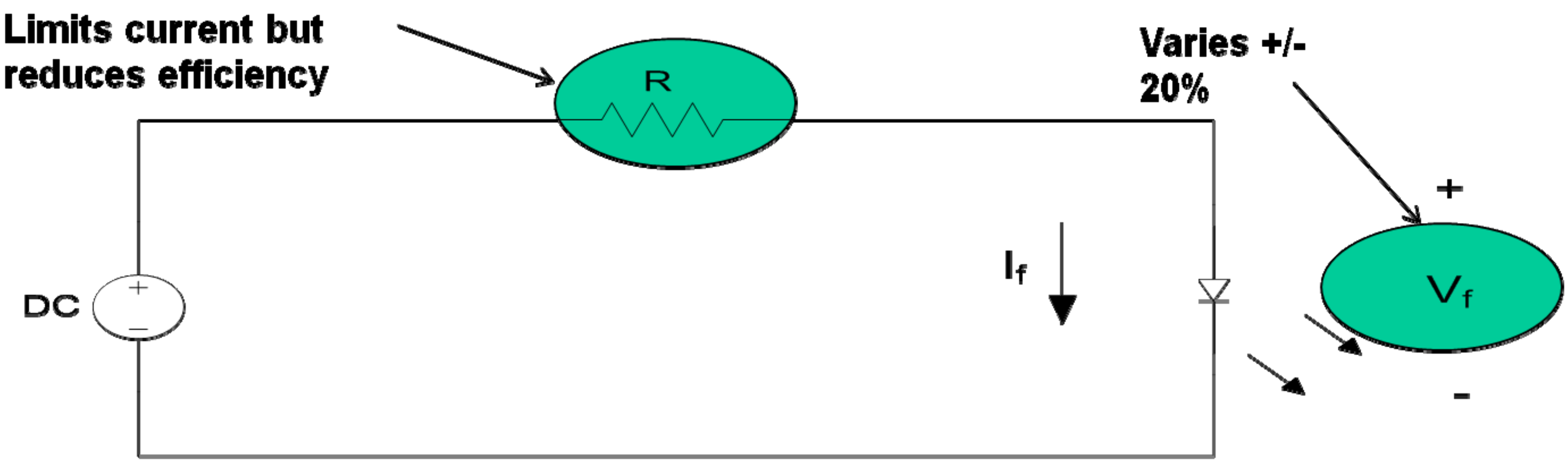
Figure 1 Risk Matrix by Hazard. Greater opacity corresponds to greater certainty

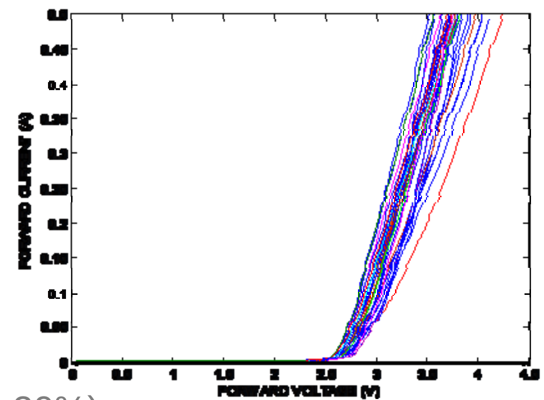
G, Ryder, R. Altkorn, X. Chen, JA Veitch, M. Poplawski, Safety 2012, the 11th World Conference on Injury Prevention and Safety Promotion

LED Drivers and Flicker

What makes LEDs different? Why the concern about flicker?

Methods of Driving LEDs – Basic Circuit

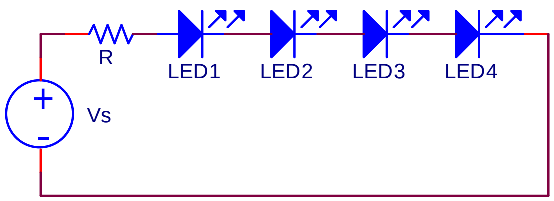


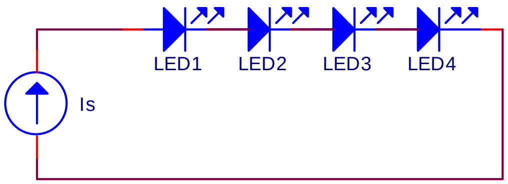


- Basic Circuit Advantages
  - Simple and low cost

- Basic Circuit Disadvantages
  - Lower efficiency due to resistor R
  - Uneven light intensity due to Vf variations from temperature (+/- 20%)
  - Reliability impacted by Vf variations due to temperature – higher temperature causes increase in current causing higher junction temperature of LED

1 Strings of LEDs with 1 Source





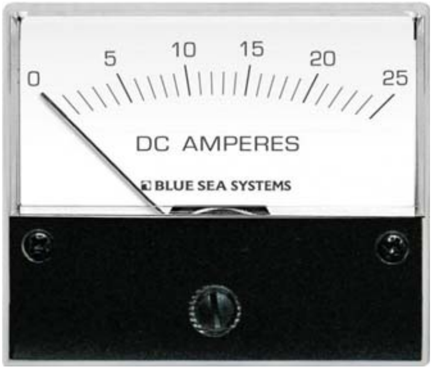
Series combination of LEDs with a voltage source (left), with a current source (right)

- Operate the source as a current source instead of voltage source and regulate string current
- Regulating current = regulating luminous intensity (if temperature is constant)

Basic Concept for LEDs

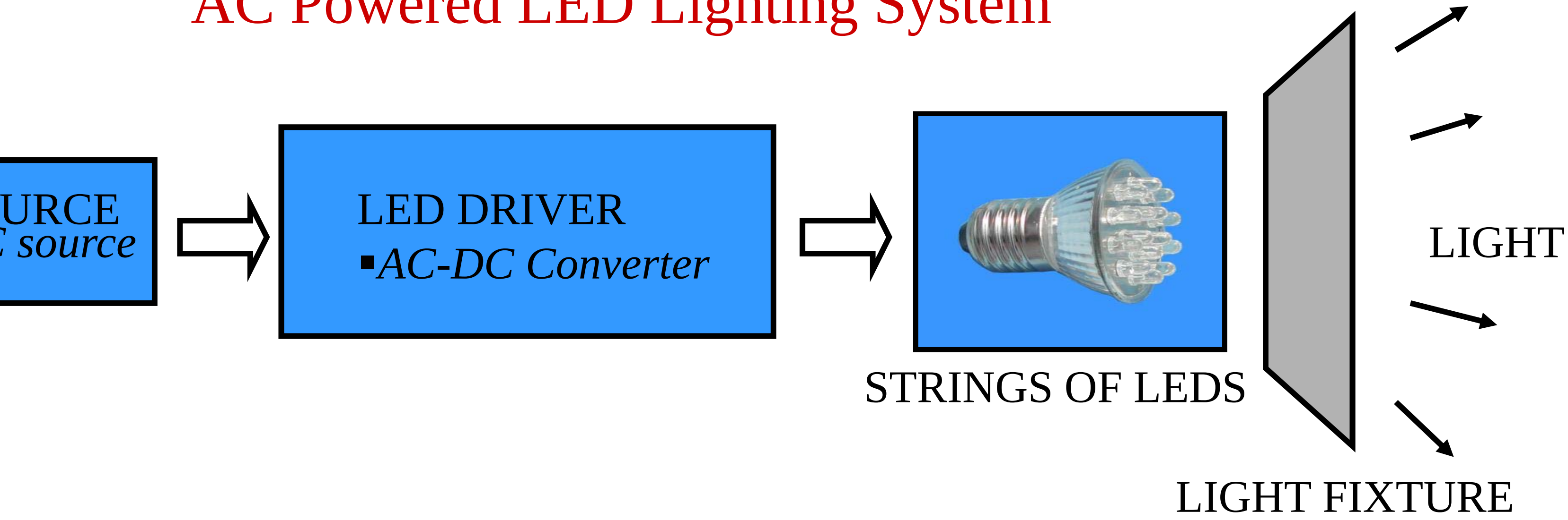
Light Output (luminance) is roughly proportional to the LED current.

$\propto$



ED Drivers and Flicker: The Concern?

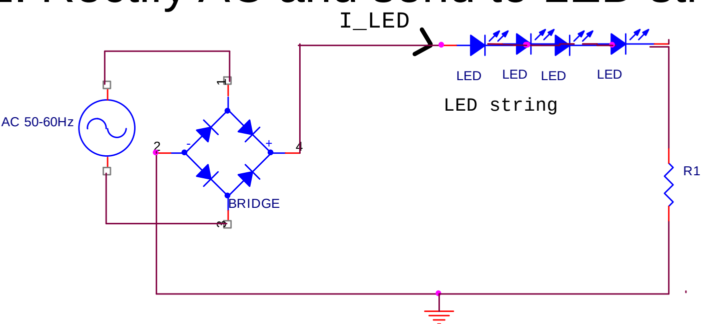
AC Powered LED Lighting System



AC-DC converters often have 120Hz harmonics (flicker) in their current. How much is acceptable? (120Hz = twice the line frequency, which would be 100Hz in Europe.)
AC LEDs: It is possible to eliminate AC-DC converter using a few special techniques: Reduce costs, eliminate capacitors, smaller size, increased lifetime. But this gives 100Hz/120Hz flicker.

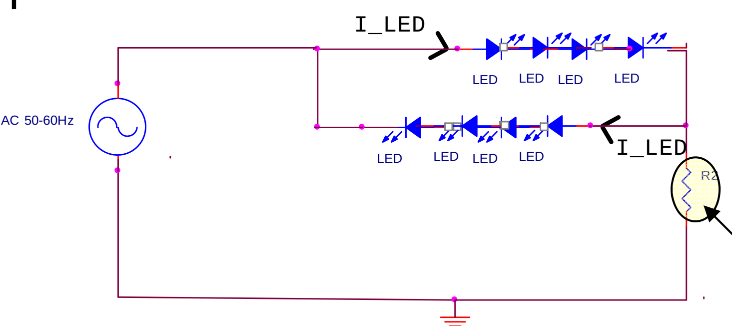
AC LEDs

l. Rectify AC and send to LED string

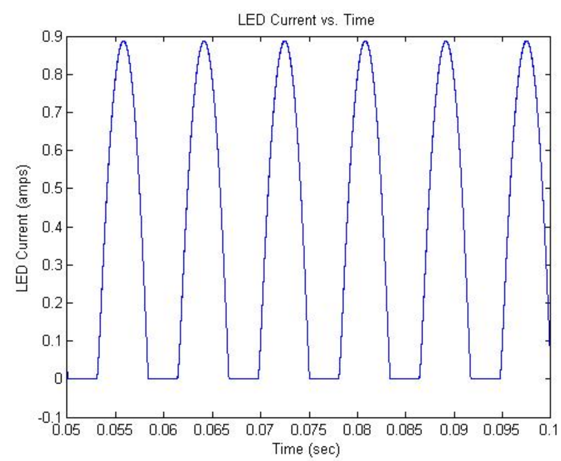


Luminous Flux

Directly power two LED strings with
pposite Anode/Cathode connections



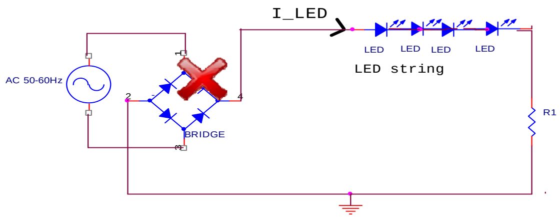
Or a capacitor



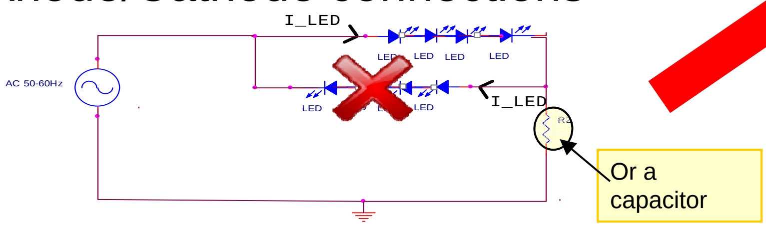
Luminous Flux
(periodic every 1/120 sec)
is proportional to LED current

Failures may cause 60 Hz flicker: Open circuit in rectifier or in LED string

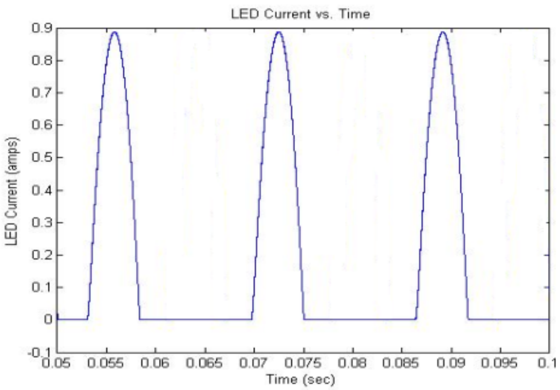
) Rectify AC and send to LED string



) Directly power two LED strings with
posite Anode/Cathode connections



Luminous Flux



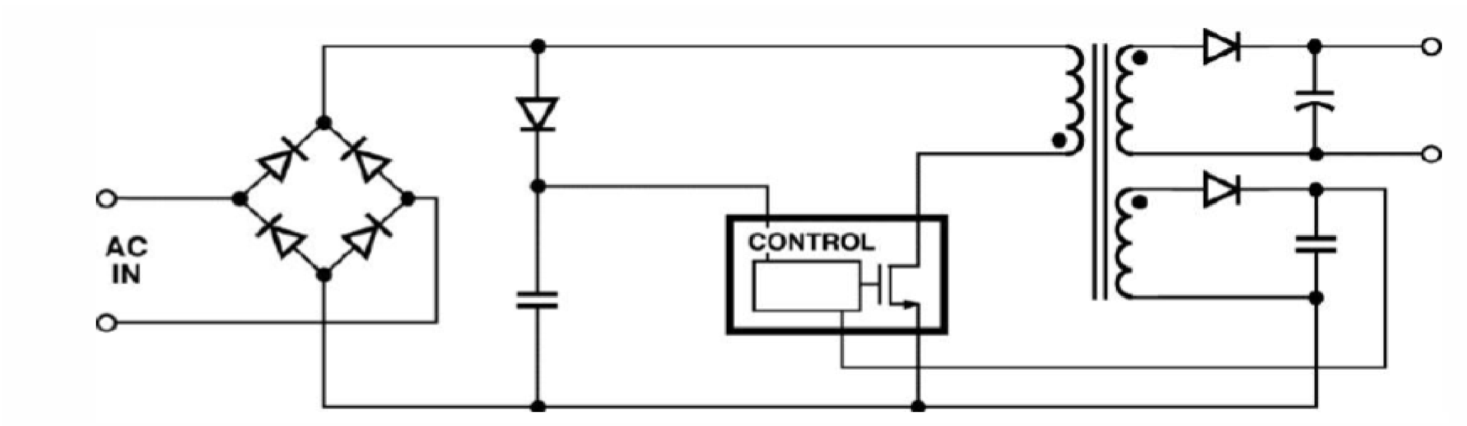
(c) Simulation of current through HB LEDs. Luminance is proportional to current, causing lamp to flicker at the AC mains line frequency *(shown periodic every 1/60 sec)*

What About Power Electronic Drivers?

Single Stage: Has Power Factor Correction (PFC) but produces high (up to 100%) flicker at twice line frequency

Two Stages: Has PFC and the ability to reduce the 120 Hz flicker

Typical Single-Stage LED driver

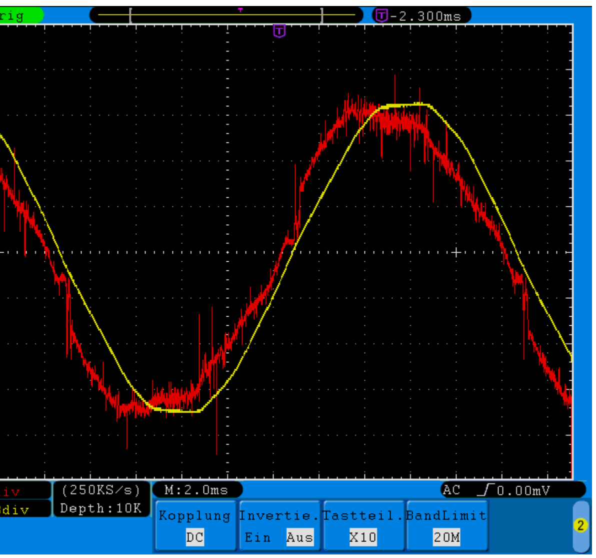


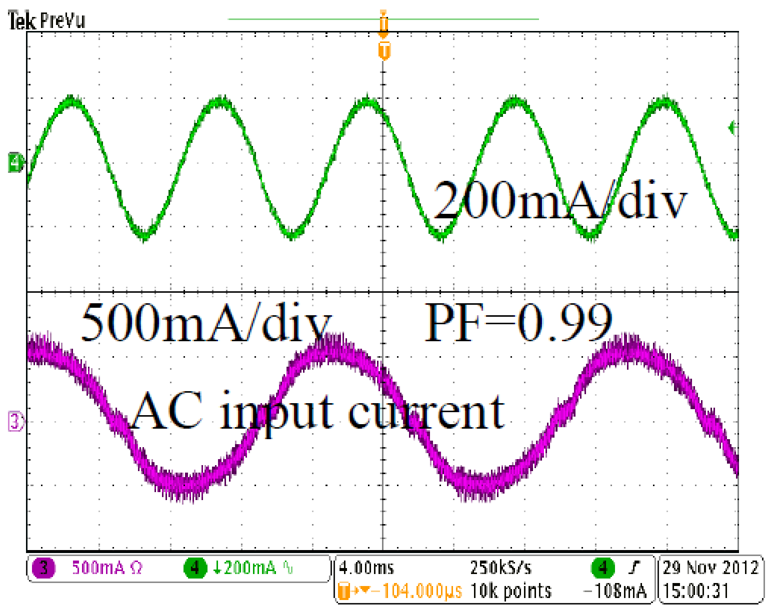
Source: EE Web.com (March 27, 2013 article)

Flyback converter is able to keep input current in phase with AC voltage for PFC

Output LED current has substantial flicker at 120 Hz (unless peripheral circuits added for cancellation- Fang(2013), Hu(2012))

Typical Single-Stage LED driver



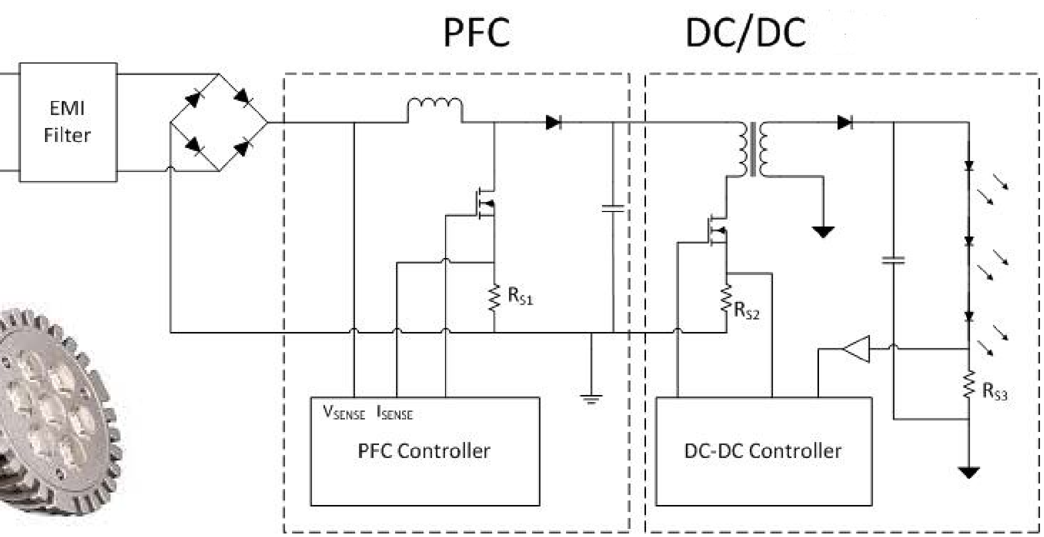


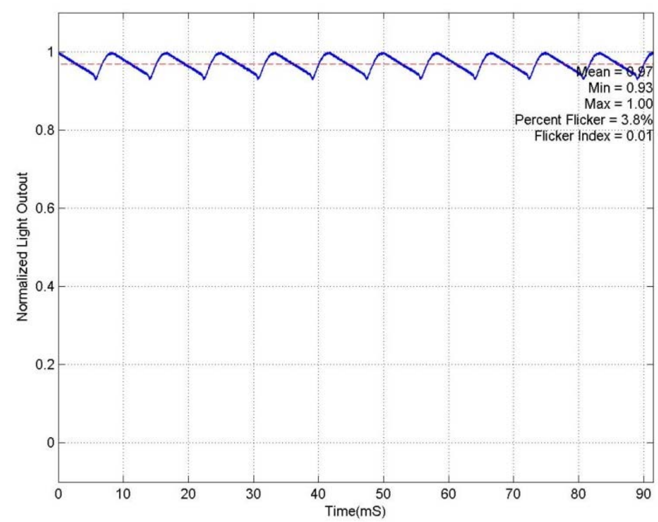
Fang(2013), IEEE TPEL

C source input
urrent in phase with
ne voltage

Output LED current has
large flicker at 120 Hz

Typical Dual-Stage LED driver





It is possible to eliminate flicker completely

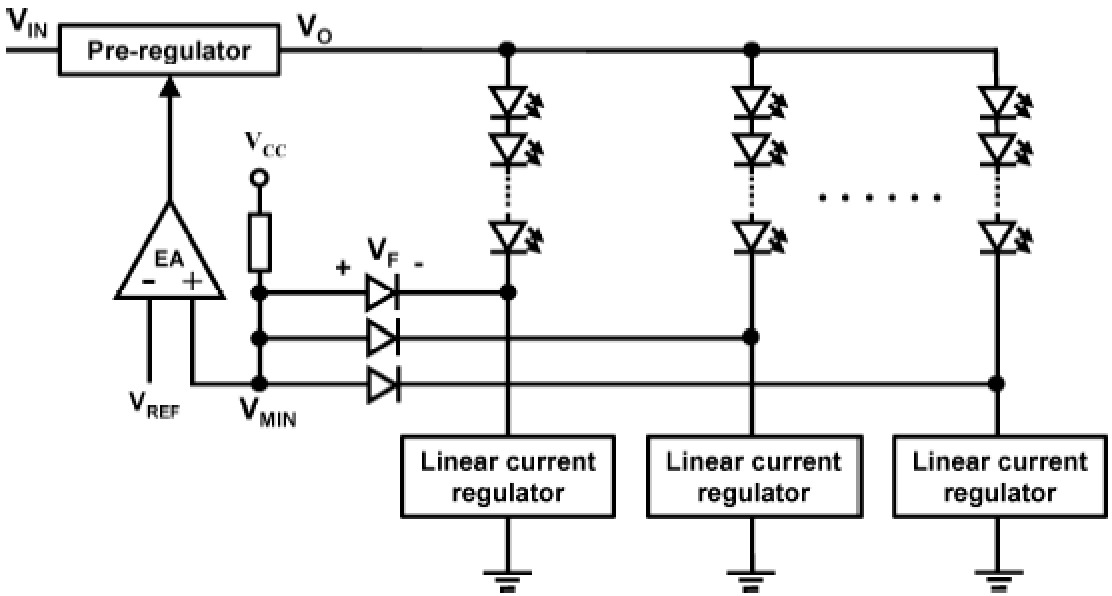


Fig. 3. LED driver with a switching voltage preregulator and detection circuit for minimum voltage drop of linear regulators.

e From: IEEE TRANSACTIONS ON POWER ELECTRONICS, NOVEMBER 2008
Driver With Self-Adaptive Drive Voltage", Yuequan Hu and Milan M. Jovanovi´c,

- DC/DC or AC/DC converter acts as pre-regulator to create Vo above the required highest string voltage (voltage imbalance among strings!)
- Linear regulators can keep current constant and the same in each string
- PWM dimming (series) can be added to the Linear current regulator
- Adjust Vo according to Vmin so Vo adapts to which strings are on/off

Power Factor Correction (PFC) Architecture Trade-Off

Dual-stage PFC

- Near perfect PFC possible
- With proper control and component design, flicker can also be kept minimal
- BUT: Boost stage adds components and cost

Single-Stage with PFC

- Modulating the input impedance improves PF
- BUT: Higher %Flicker at twice line frequency usually remains
- (Some have proposed combining passive pfc with single stage power converter… to impact both pf and flicker.)

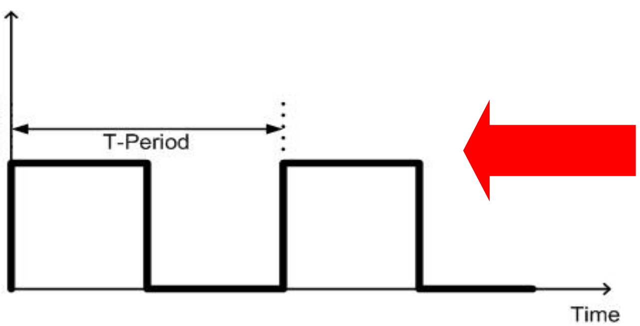
It Comes Down to Flicker vs. cost vs. Performance

Triac Phase Modulate Dimmers

PWM Dimming

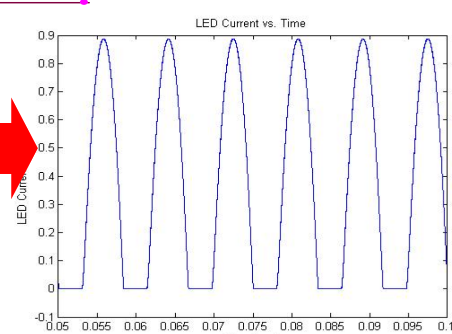
Used with either AC Mains or DC power as source

Can increase or induce flicker



Common LED Currents

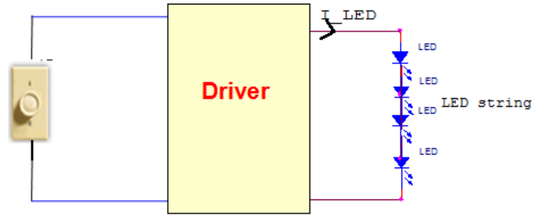
(1/T=f=100~120Hz)



few LED lamps will visually flicker on AC wall dimmers (3Hz~25Hz) because they fail to work properly.

Triac Dimmer

**ficulties caused by phase
dulated dimmers**



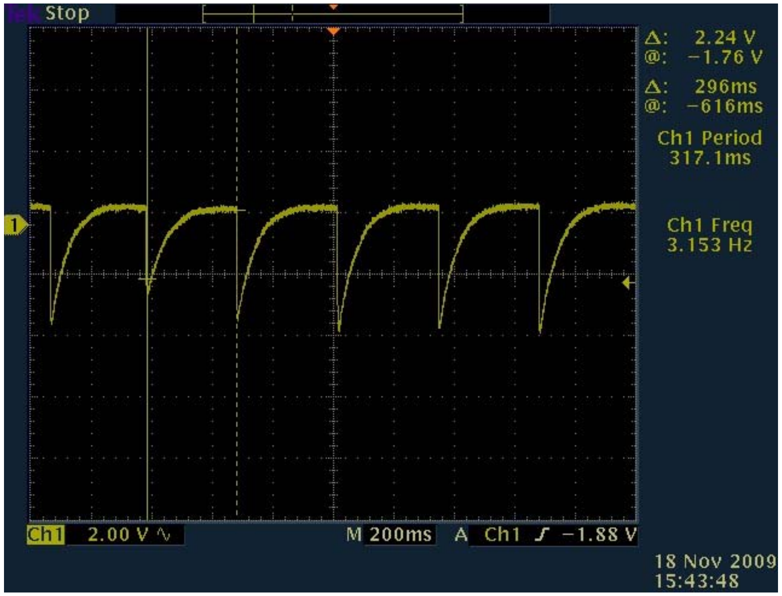
Dimmer malfunctions during light load with current less than nimum latching and holding currents, as is often the case with gle LED lamps (Rand et al, PESC 2007).

- ➢ **Solution: Add resistor or active load to the LED lamp: When dimming on triac, there is a forced power sink wasting energy to keep the triac on. (not great…)**

equire a large hold-up capacitor to keep current in LEDs during off-time of the dimmer (not realistic in size, cost, lifespan, etc.)

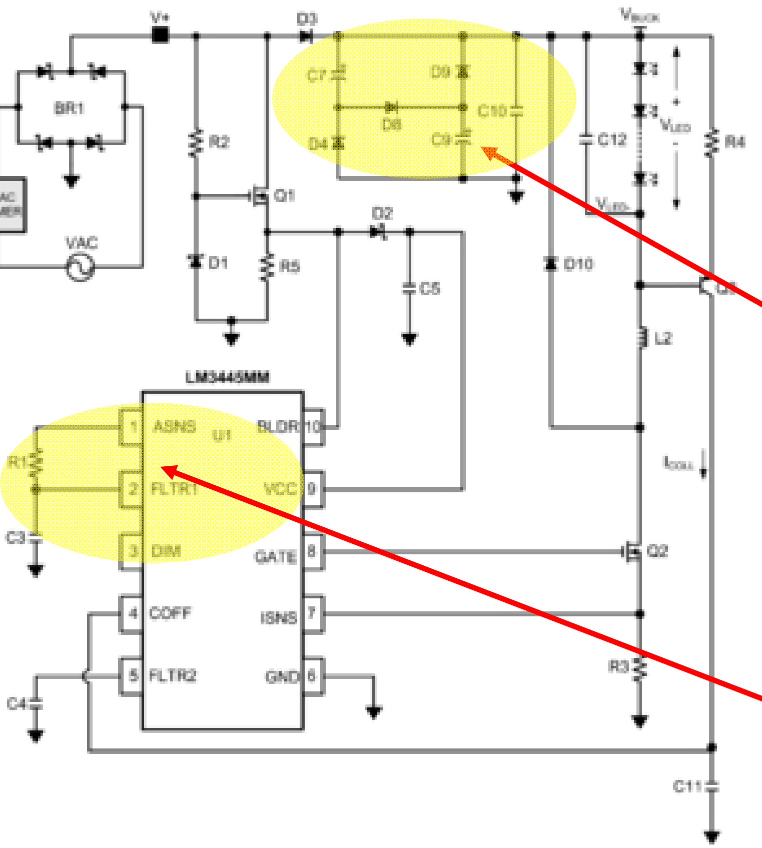
The Concern?

A few LED lamps will visually flicker on AC wall dimmers (3Hz~25Hz) because they fail to work properly.



Commercial LED lamp flickers at 3.15Hz when connected to typical residential dimmer switch.

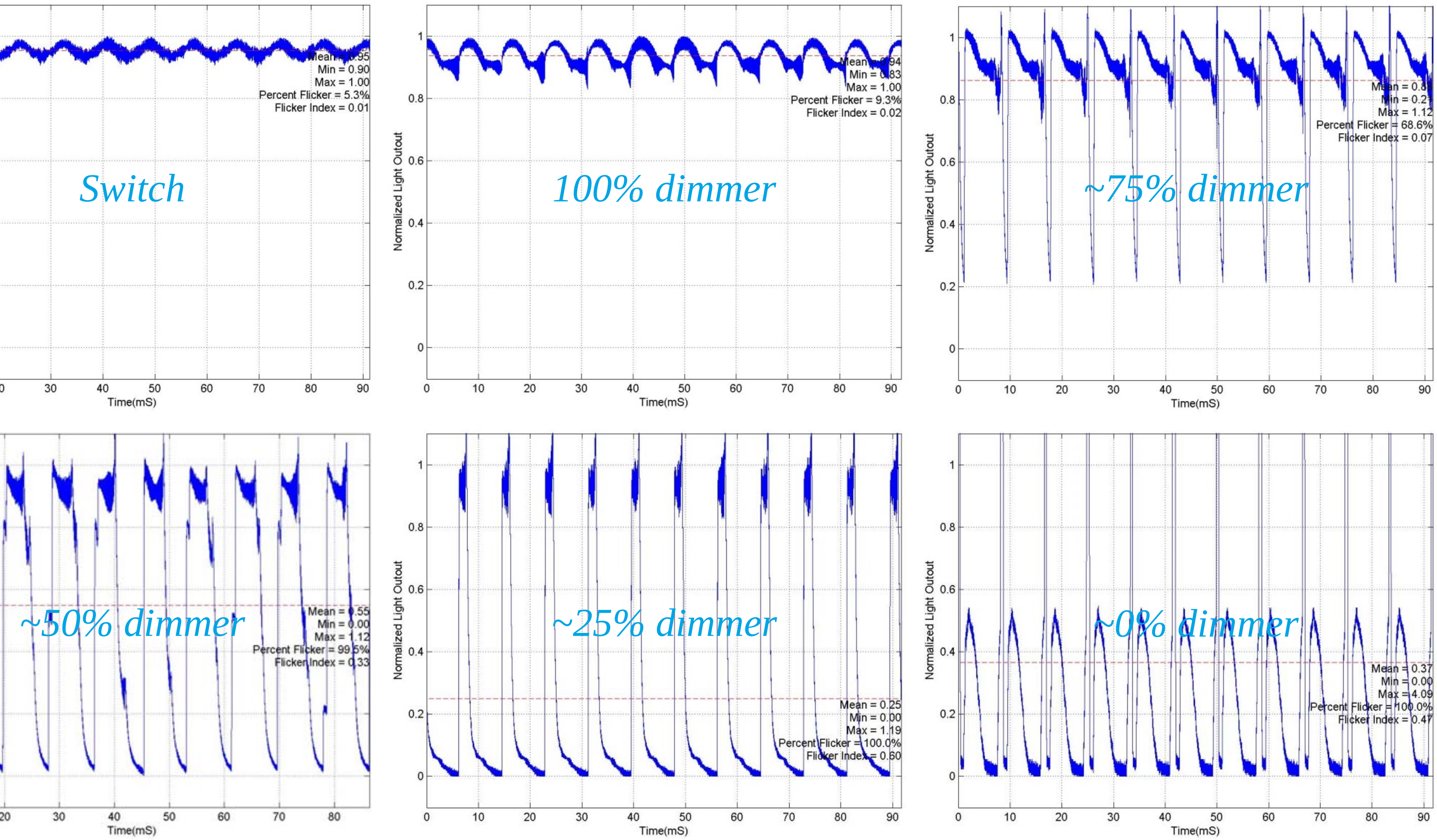
Solution: holdup capacitor – LM3445



- Vcc receives power at all times
- Triac off– the <u>capacitive valley fill circuit</u> still powers the buck converter's input voltage
- Dimming level corresponds to the on-time of the Triac
- Add Passive PFC

Many LED driver manufacturers now keep DC voltage across LEDs at all times, even during triac off-time

LED PWM Dimming Example



Conclusions

- *Various level of 120 Hz flicker appear in all lighting*
- *The driving method for LED lamps influences the amount and shape of the flicker*
- *IEEE PAR1789 Standard Committee intends to provide a recommended practice for how to apply this information*

http://grouper.ieee.org/groups/1789/

IEEE PAR 1789 - PURPOSE

Vision: *Bring together a community of lighting environmental psychologists, medical researchers, lamp designers, LED driver designers, and LED lamp users to openly discuss concerns for LED lighting.*

- There is a need to create a community where experts among the above different fields can communicate.
- Suggest a recommended practice, not a standard. Representation on IEEE P1789 from ENERGY STAR, CIE and NEMA may later incorporate findings into standards if deemed necessary.
- IEEE Standards Association has a unique open process that MUST involve all interest groups including academics, national labs, industry, customers… (current membership is ~50 with around 25% academics, 25% government labs, 50% industry/consulting)
- International participation from members and from standards groups

IEEE PAR 1789 - PURPOSE

- Describe some possible health risks, such as headaches, eye strain and epileptic seizure, associated with low frequency modulation of High Brightness LEDs in different applications
- Provide recommended practices to aid design of LED driving systems to modulate at safe frequencies for their particular applications in order to protect against the described health risks.

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