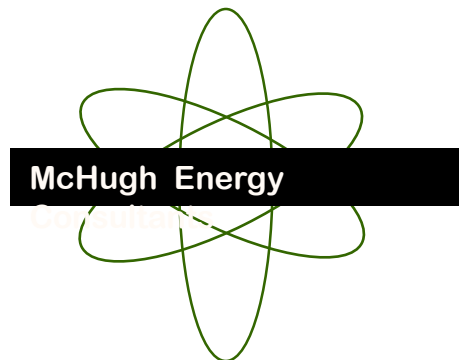


Measuring Flicker: California's JA10 Test Method and Its Uses

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EnergyStar Webinar June 30, 2016





What is Flicker?

- Flicker is amplitude modulation of light at frequencies that has effects on human physiology
 - Similar concept to sound and ultrasound.
- Perceptible flicker – can be noticed directly.
 - Impacted by intensity, frequency, moving objects
 - Some people more sensitive
 - Flicker can trigger seizures or migraines in some people
- Imperceptible flicker – impacts performance and health though not perceived

Non-perceptible flicker and human performance (1/2)



- Flicker can cause headaches and eyestrain even when the light source is not perceived to flicker (Wilkins et al. 1989).
- Wilkins compared the number of headaches reported by office workers under two types of fluorescent lamp—a 50Hz AC lamp with an amplitude modulation of around 50%, and a 32kHz lamp with a modulation of around 7%, neither of which gave perceptible flicker.
 - Subjects reported an average of 0.52 headaches per week with the 50 Hz system, **a value which halved after the installation of the high-frequency lighting.**
 - These results apply to frequencies above the perceptible range of flicker.
 - Prudent (precautionary principle) to reduce flicker at frequencies above the perceptible range to avoid the possibility of adverse non-visual effects.

Non-perceptible flicker and human performance (2/2)



- Visual performance of 48 undergraduate students was reduced under 60Hz AC lamps compared with 20-60kHz lamps, despite the absence of perceptible flicker (Veitch, 1995)
- Non-visual retinal responses to flicker above the critical fusion frequency (Berman et al, 1991)
 - Time-averaged human electroretinogram (ERG) responses to visual stimuli temporally modulated at rates exceeding the perceptual critical fusion frequency.
 - Synchronous response was found for a video display terminal (VDT) stimulus operating at **76 Hz**.
 - Directly viewed fluorescent luminaire elicited a synchronous response at rates up to **145 Hz**.
 - Modulating light from a slide projector produced responses up to **162 Hz**.

California Title 24 “reduced flicker operation” definition

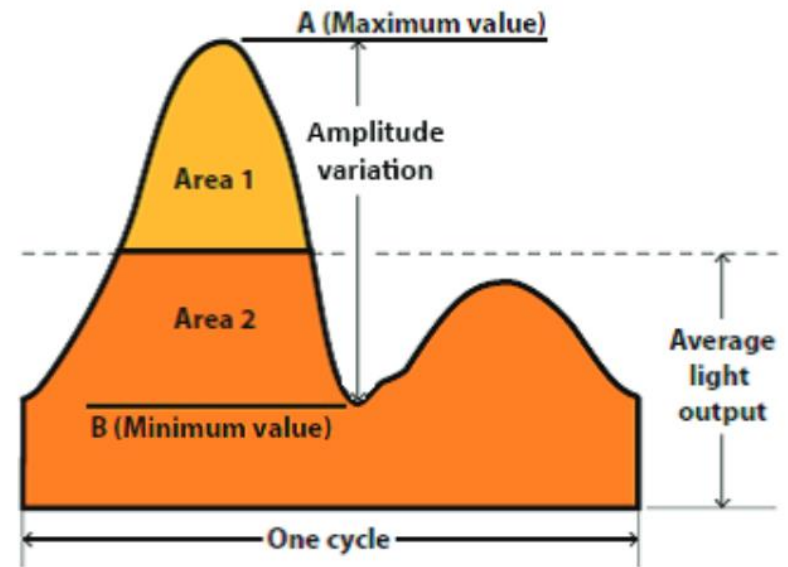


- JA8.4.6 Dimming, Reduced Flicker Operation and Audible Noise
 - (c) Light source in combination with specified control
 - shall provide “reduced flicker operation” when tested at 100 percent and 20 percent of full light output,
 - where reduced flicker operation is defined as having percent amplitude modulation (percent flicker) less than 30 percent at frequencies less than 200Hz,
 - tested according to the requirements in Joint Appendix JA-10.

What is amplitude modulation?



- Amplitude modulation or Percent Flicker
 - Most research based on this metric
 - Easy to measure
 - AKA Peak-to-Peak or Michelson Contrast
- Flicker Index – older research used this metric
 - More difficult to measure

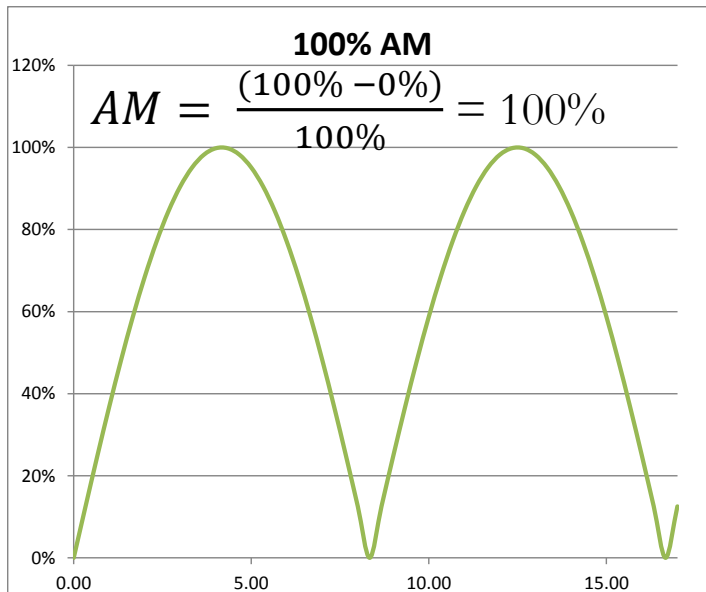
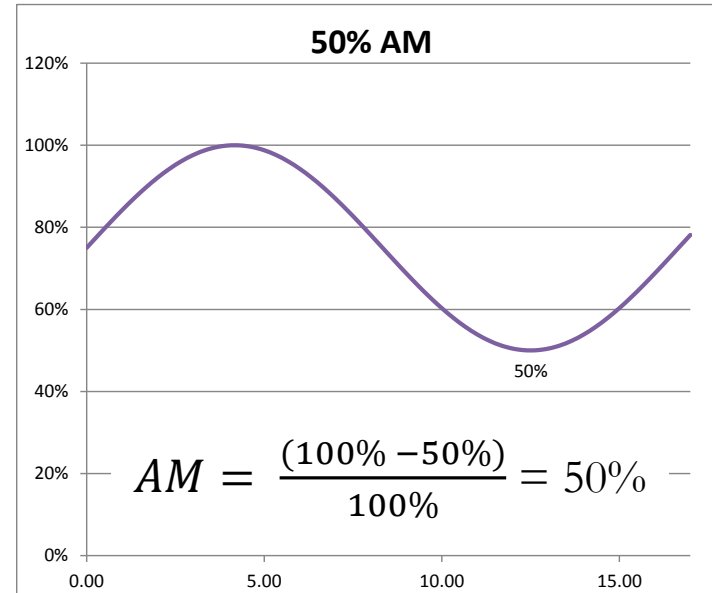
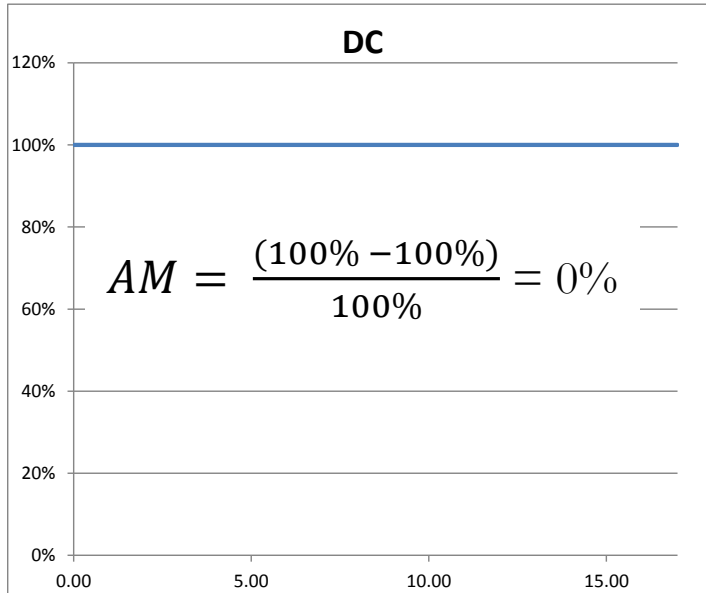


$$\text{Percent Flicker} = 100\% \times \frac{A - B}{A + B}$$

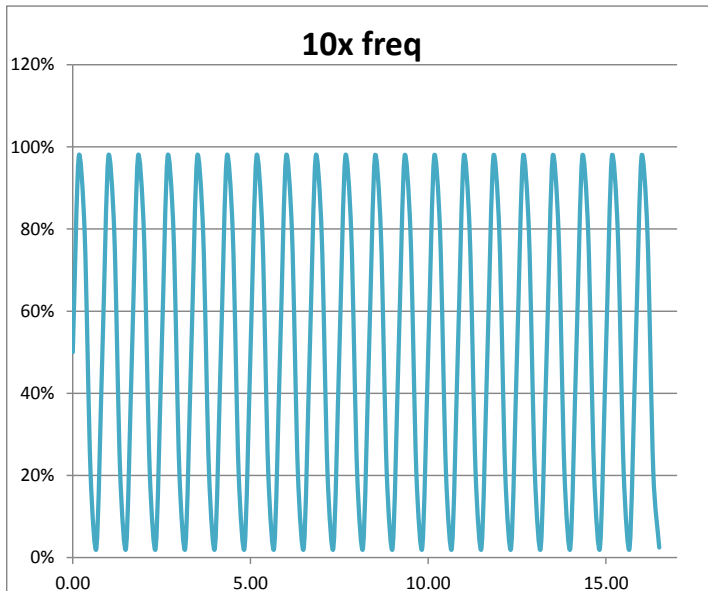
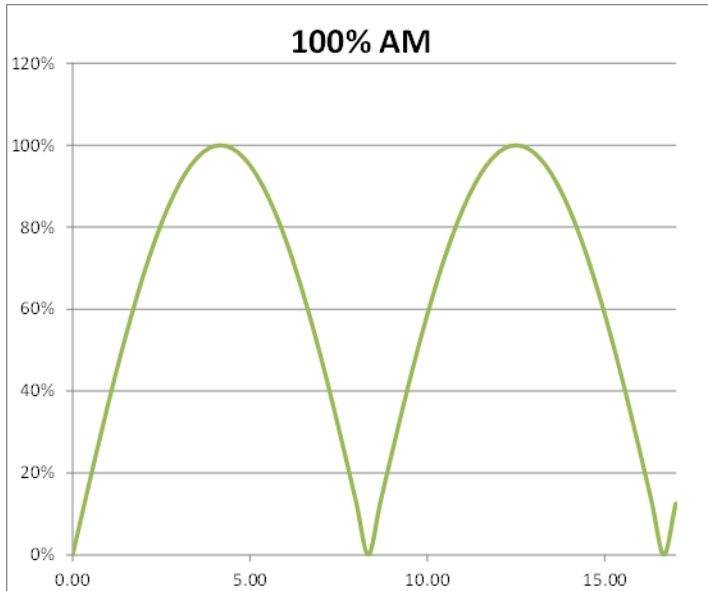
$$\text{Flicker Index} = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$$

Source: DOE Flicker Fact Sheet
Modified from IES Handbook

Amplitude Modulation

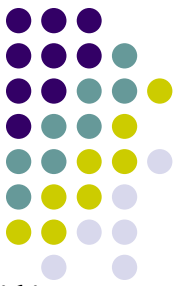


Frequency and Percent Flicker (%AM)

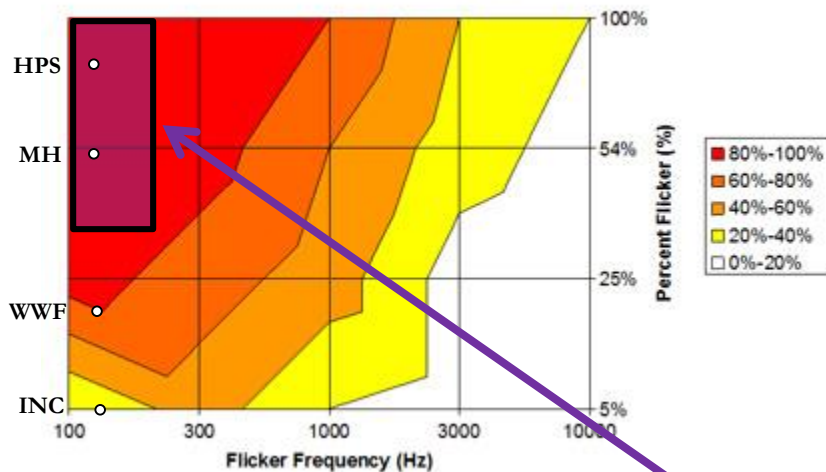


- Both graphs 100% amplitude modulation
 - Same min and max
- Percent flicker a misnomer
- Flicker (perceived or imperceptible) a function of both:
 - Percent amplitude modulation and
 - Frequency

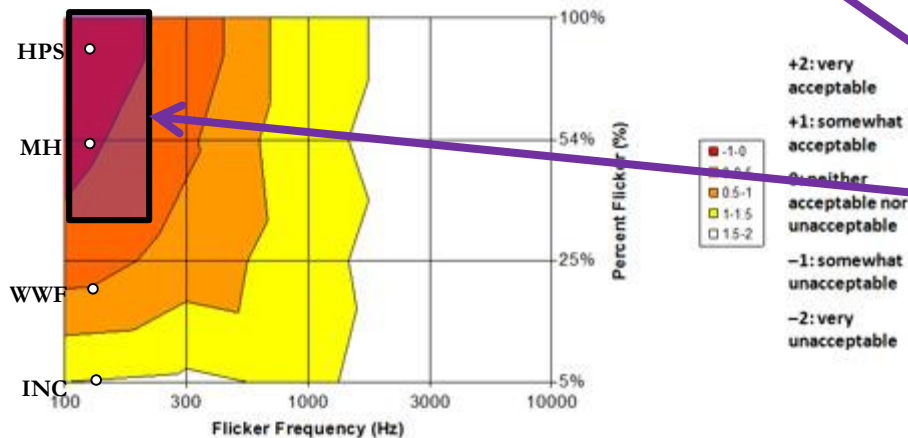
LRC 2012 Study on Perceptible Flicker



Detection of Stroboscopic Effects



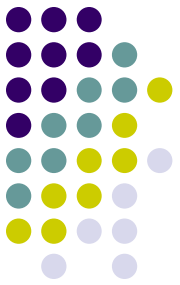
Acceptability of Stroboscopic Effects



- Detection and acceptability of flicker is a function of frequency and percent flicker (amplitude modulation)
- Red in top figure is most noticeable flicker
- Red in bottom figure is most unacceptable
- Rectangular boxes represents current T-20 definition of what is not an acceptable amount of flicker for control devices.

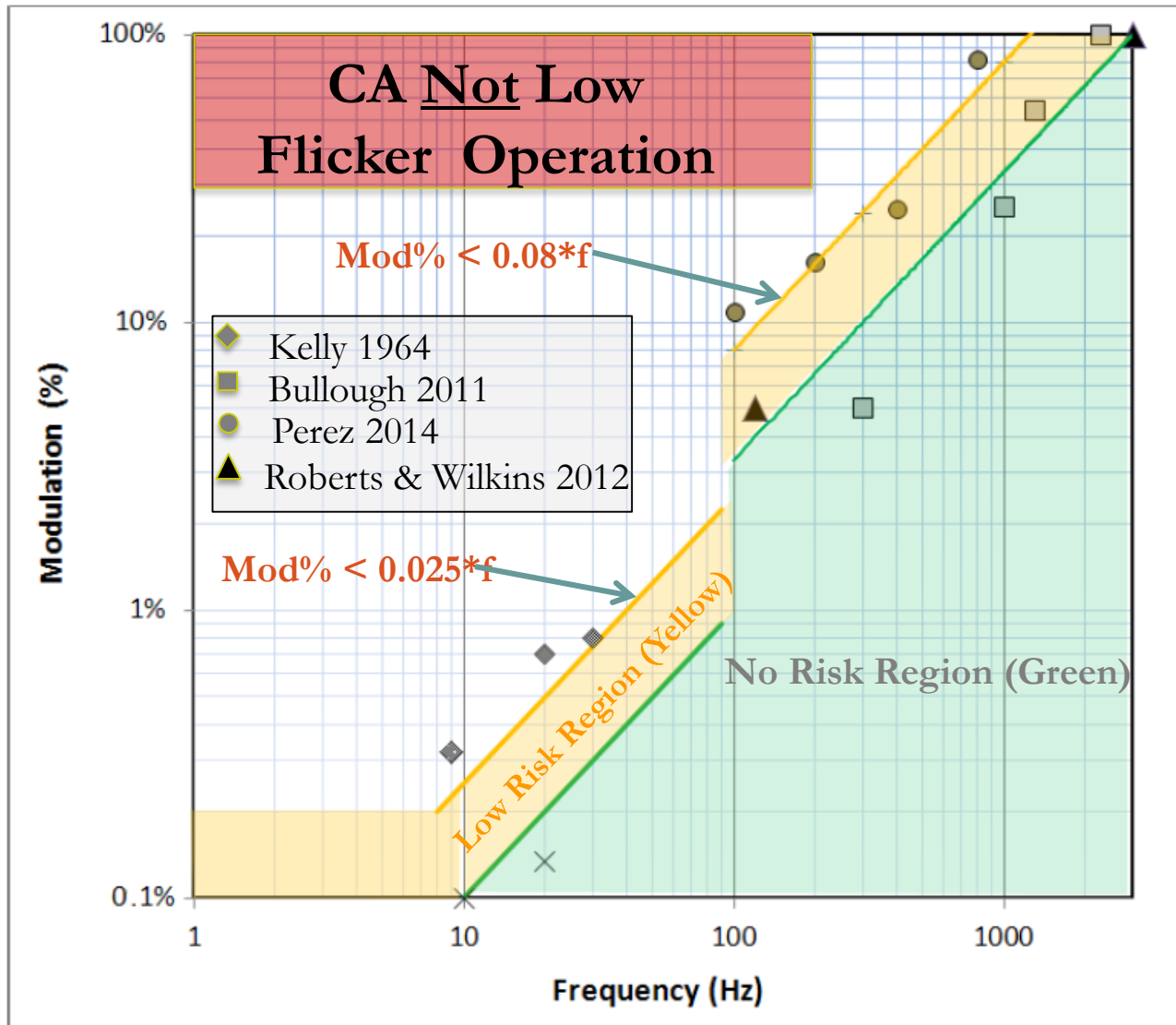
“Amplitude Modulation”

Nomenclature

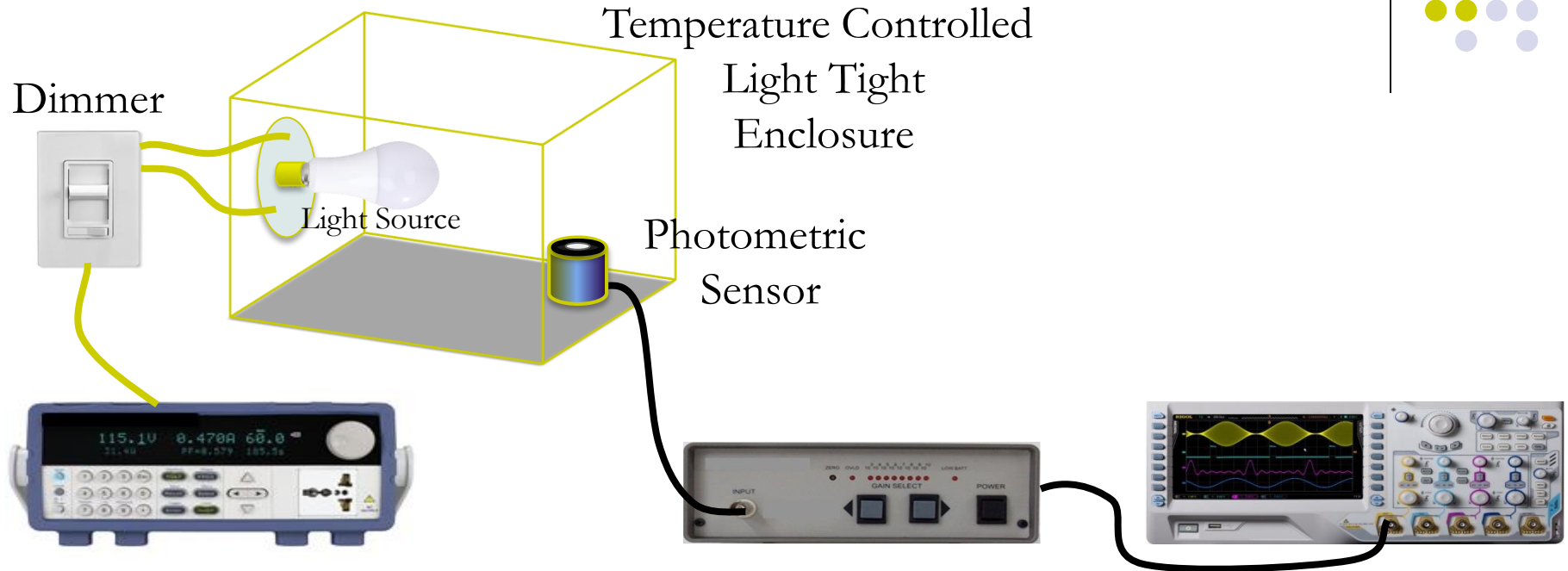


- “Flicker” is a physiological response to modulation of light under different conditions (intensity, frequency, source size, movement, individual differences etc.)
- Amplitude modulation has impacts even when flicker is not perceived
- Confused by two terms “flicker index” and “percent flicker”
- Percent Amplitude Modulation has a single unambiguous technical meaning
- Current T-24 definition for “reduced flicker operation” a combination of percent amplitude modulation ($<30\%$) and cut-off frequency (for frequencies less than 200 Hz)

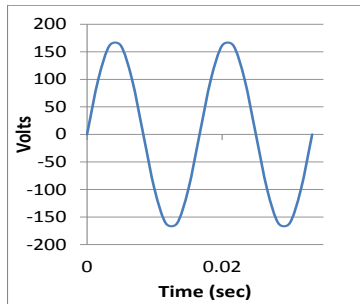
Improved Definition of Flicker (IEEE PAR 1789)



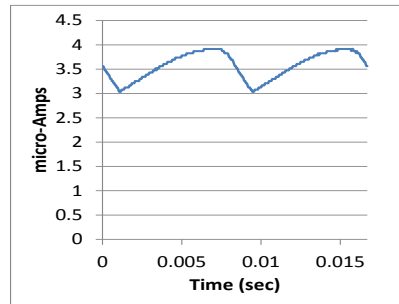
Test Setup – Flicker Test



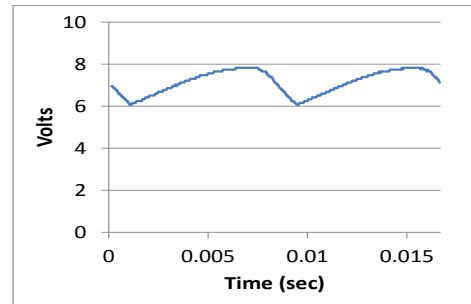
Regulated
Power Supply



Sensor Output



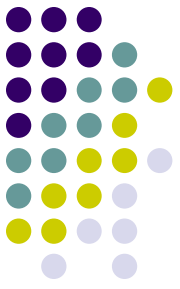
Transimpedance
Amplifier



Digital Oscilloscope

| Time (sec) | Volts |
|------------|-------|
| 0 | 7.125 |
| 1E-04 | 7.037 |
| 0.00015 | 6.949 |
| 0.0002 | 6.949 |
| 0.00025 | 6.861 |
| 0.0003 | 6.861 |
| 0.00035 | 6.773 |
| 0.0004 | 6.773 |
| 0.00045 | 6.686 |
| 0.0005 | 6.598 |

Filtering amplitude modulation for cut-off (low pass) frequencies



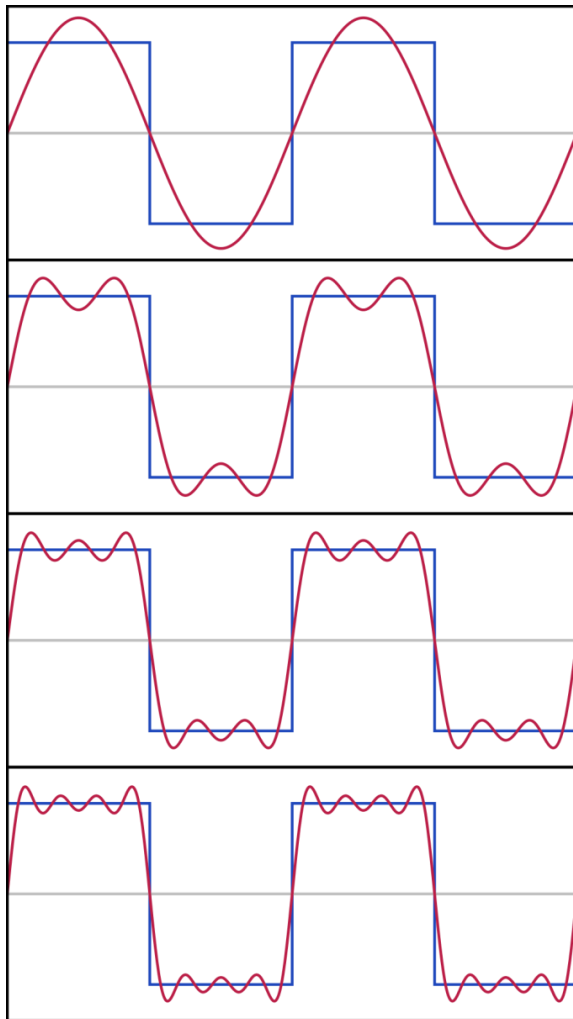
- Measure light output with a fast response photometric sensor
- Digitize signal (digital oscilloscope)
- Use **Fourier analysis** to characterize waveform as Fourier series $I(t)$ of light intensity I with respect to time t

$$I(t) = C_0 + \sum_{n=1}^{\infty} (a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t))$$

- C_0 = DC component of signal
- ω_0 = fundamental frequency (lowest frequency component)
- Create a virtual low-pass filter by setting coefficients a_n and b_n to zero for frequencies ($n\omega_0$) above cut-off frequency
- Put data back into time domain (inverse transform)
- Calculate amplitude modulation for modified (filtered) signal

$$\text{Amplitude Modulation} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}$$

Fourier Series Approximation

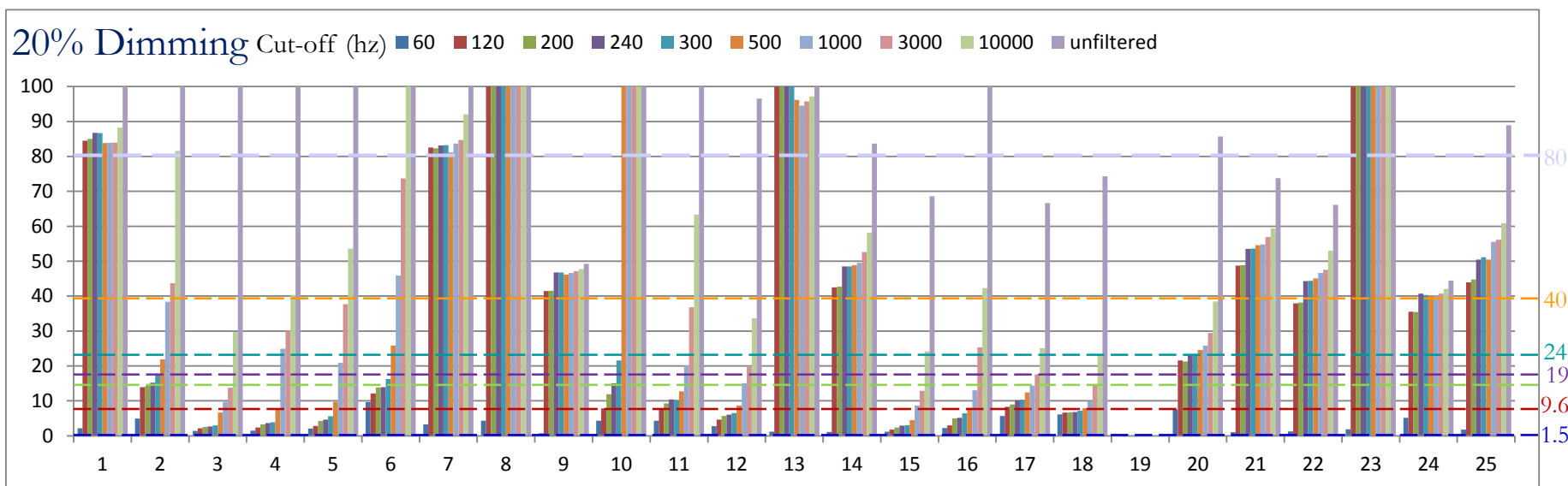
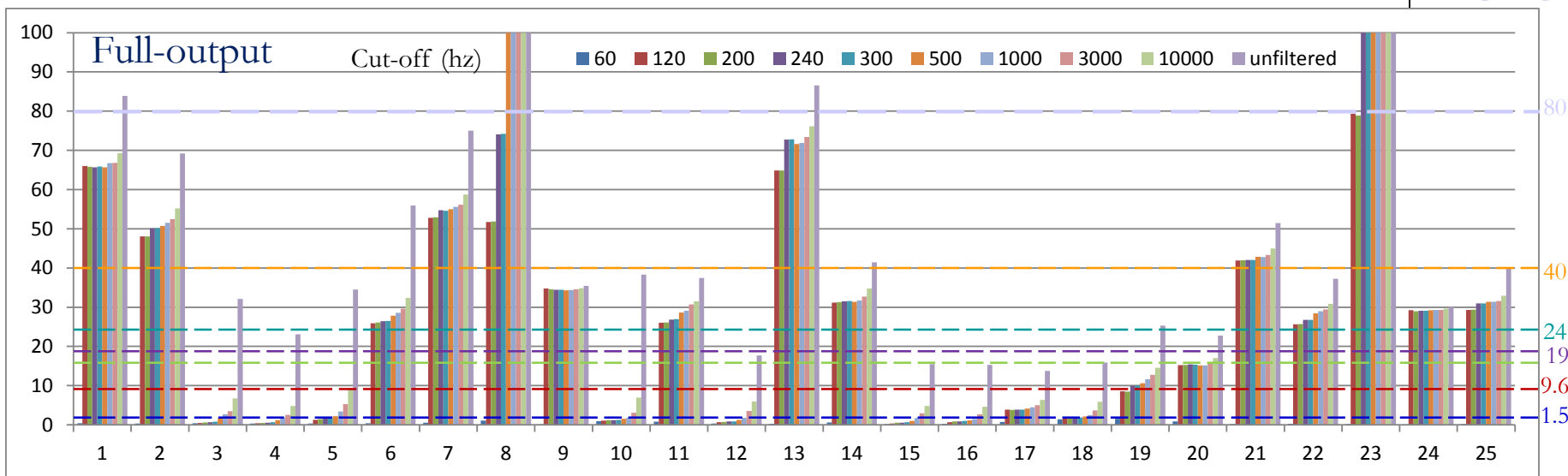


- First four partial sums of a Fourier series approximating a square wave.
- Square wave hard to approximate due to sharp transition
 - Sharp transition is a high frequency

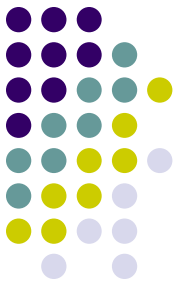
Flicker Tests of 25 LED A-lamps (2013)



- Tests performed by California Lighting Technology Center
- Interval between data points 8 μ sec (125,000 data points per sec), data collection duration 1 sec.
- Ratio of 200 hz cut-off %AM to unfiltered %AM ranged from 2% to 100%.
- **52% comply (48% fail) with T-24 flicker**
 - 64% comply (<30% AM) at full light output
 - 56% comply at 25% light output
- **36% comply with IEEE PAR 1789 standard**
 - Same products pass at 100% and 25% light output.
 - At full light output, 4% failures at 60 Hz cut-off frequency
 - At 20% light output, 64% failures at 60 Hz cut-off frequency



Repeatability of A-lamp flicker tests



- Tested flicker results between two test laboratories
 - California Lighting Technology Center (CLTC)
 - Pacific Northwest National Lab (PNNL)
- Same products and same dimmers over range of flicker
 - 2 products high, 1 product moderate, 1 product low
- Close agreement for all products

Round robin test results

| | CLTC | PNNL | Diff |
|-----------|--------|--------|--------|
| Product 1 | 100.00 | 99.80 | 0.20% |
| Product 2 | 29.79 | 30.10 | -1.05% |
| Product 3 | 11.22 | 11.00 | 1.96% |
| Product 4 | 100.00 | 100.00 | 0.00% |

Amplitude modulation results are unfiltered

Flicker – Ornamental & Reflector



Results for best performing dimmer

| Type | N | Pass IEEE | % Pass IEEE | Pass T-24 | %Pass T-24 |
|-------------------|----|--------------|----------------|--------------|---------------|
| Candle | 7 | 0 | 0% | 2 | 29% |
| Down | 6 | 4 | 67% | 5 | 83% |
| MR Line | 4 | 0 | 0% | 0 | 0% |
| MR Low Voltage | 6 | 0 | 0% | 3 | 50% |
| PAR | 11 | 4 | 36% | 7 | 64% |
| Totals | 34 | 8 | 24% | 17 | 50% |

Compliance likely increases after rating method broadly used

Type of dimmer – impact small on T-24 but large on IEEE compliance

CA Residential Lighting Standards – Effective in 2017



- Requires all high efficacy luminaires
- Relaxes High Efficacy Definition
 - Screw base sockets high efficacy, if JA-8 source
 - All hardwired or GU-24 options in Table 150.0-A remain
- Recessed Downlights must have “JA8-2016-E” labeled source and no screw base
- Recessed or enclosed luminaires must pass life span and depreciation testing at elevated temps
- Maintain Existing Control Requirements

High Efficacy Light Sources (2016 T-24 Table 150.0-A)



| Legacy High Efficacy Light Sources | JA8 Compliant <u>and Labelled</u> Light Sources |
|--|--|
| <ol style="list-style-type: none"> 1. Pin-based linear or compact fluorescent light sources using electronic ballasts. 2. Pulse-start metal halide. 3. High pressure sodium. 4. GU-24 sockets containing light sources other than LEDs. a,b 5. Luminaires with hardwired high frequency generator and induction lamp. 6. Inseparable SSL luminaires that are installed outdoors. 7. Inseparable SSL luminaires with colored light sources that are installed for decorative lighting. | <ol style="list-style-type: none"> 8. All light sources in ceiling recessed downlight luminaires. Note that ceiling recessed downlight luminaires shall not have screw bases regardless of lamp type as described in Section 150.0(k)1C. 9. GU-24 sockets containing LED light sources. 10. Any light source not otherwise listed in this table and certified to the Commission as complying with Joint Appendix 8. |
| <p>Notes: a. GU-24 sockets containing light sources such as compact fluorescent lamps and induction lamps. b. California Title 20 Section 1605(k)3 does not allow incandescent sources to have a GU-24 base.</p> | |

Appendix JA8-2016



- Joint Appendix JA8 - requirements for lamps qualifying as high efficacy, high quality light sources,
 - but significantly changed
- 2016 - tech neutral – more than LEDs
- Includes replacement lamps, regardless of base type, and integral luminaires
 - Including screw base lamps
- Includes robust quality/amenity requirements



Requirements in JA8

- New requirements for Residential Construction – Effective 1/1/2017
 - CRI: ≥ 90 , R9 value (red) ≥ 50
 - CCT: Lamps $\leq 3000\text{K}$, luminaires $\leq 4000\text{K}$
 - Duv: ± 0.0033 (approximately 4 MacAdam steps)
 - Must be dimmable to 10%
 - **“Reduced flicker operation” at 100% and 20% light output**
 - **< 30% percent flicker at frequencies less than 200 Hz**
 - **Registered in JA10 database**
 - Noise: $\leq 24\text{dBA}$, Power Factor: ≥ 0.90 ,
 - Efficacy: $\geq 45\text{ lpw}$

Requirements in JA8 (continued)



- Life Related Requirements
 - Early Failure: 90% of lamps operational at 6,000 hr
 - Minimum Rated Lifetime: 15,000 hrs
 - Lumen Maintenance: At least 86.7% at 6,000 hrs
 - Elevated temperature test for products in recessed/enclosed fixtures
- Compatibility (LED only):
 - LED sources complying with JA8 must meet NEMA SSL7A as Type 1 or Type 2 products.
- Certification and Labeling:
 - Products must be marked with “JA8-2016”
 - In recessed / enclosed fixtures, must be marked with “JA8-2016-E” (passed elevated temperature)
 - Products must be certified in CA appliance efficiency database

Appendix JA10 – Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements



- Results specific to a light source and its dimmer
 - JA 8 only requires you show compliance with one dimmer type for each dimmer type (forward phase cut, reverse phase cut, 0-10 V etc) the light source is compatible.
- Test Equipment
 - Light tight enclosure (does not have to be an integrating sphere)
 - Photodetector with rise time < 10 microsec
 - Transimpedance amplifier
 - A-D conversion (digital oscilloscope, data acquisition card etc)

JA10 – Flicker Test Method: Test Conditions



- Test conditions similar to test methods for other luminous measurements.
 - Fluorescent – wired according to 10 CFR 430.23(q).
 - Fluorescent lamp pre-conditioning ≥ 100 hr
 - Power supply frequency & voltage $\pm 0.5\%$
 - Temperature $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$
- Dimming levels 100%, 20% and min
- Lamp stabilization per industry standards
 - Additional measurements stable when measurements at one min intervals deviate by no more than 0.5%
- Data recording interval ≤ 50 microseconds (equipment measurement rate ≥ 20 kHz)
- Data capture duration ≥ 1 second

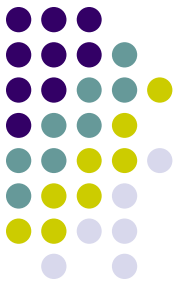


Processing of Data

- Conduct a Fourier analysis to transform data for each dimming level into the frequency domain.
- Filter frequency data for cut-off frequencies
 - Vector multiplication with cut-off vector
 - Cut-off vector: 1's below cut-off frequency and 0's for higher frequencies
- Perform inverse Fourier transform to place data back in time domain.
- Calculate percent amplitude modulation on resulting time domain data for each filtered dataset over the full sampling duration.

$$\text{Percent AM} = \frac{(Max - Min) \times 100}{(Max + Min)}$$

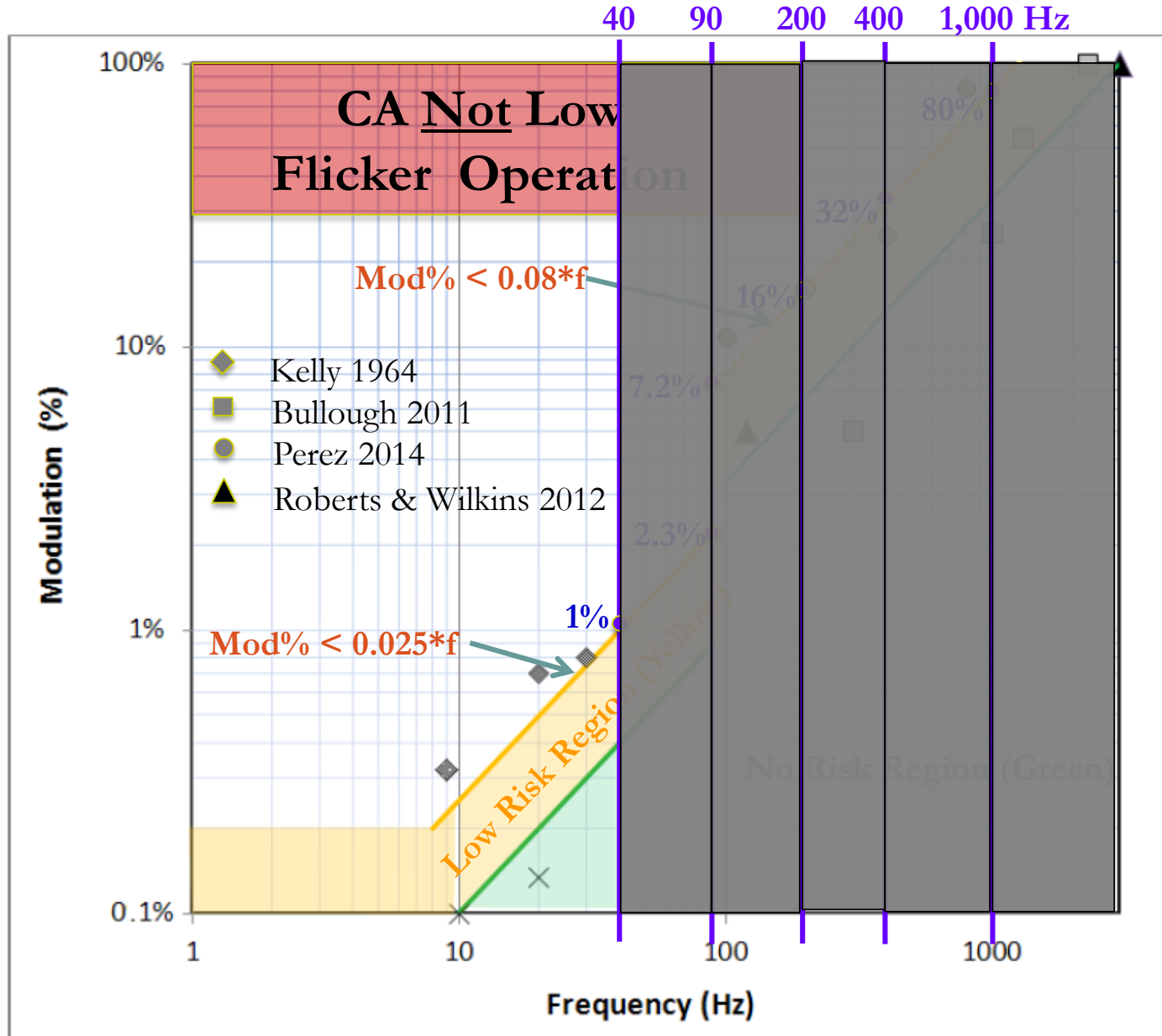
Data Processing and Reporting



| Cut-off Frequency | 100% Output | 20% Output | Minimum Output |
|-------------------------|-------------|------------|----------------|
| Unfiltered (∞) | %AM | %AM | %AM |
| 1,000 Hz | %AM | %AM | %AM |
| 400 Hz | %AM | %AM | %AM |
| 200 Hz | %AM | %AM | %AM |
| 90 Hz | %AM | %AM | %AM |
| 40 Hz | %AM | %AM | %AM |

- Three physical test conditions
- Post processing of 5 cut-off frequencies
- Percent Amplitude Modulation calculated

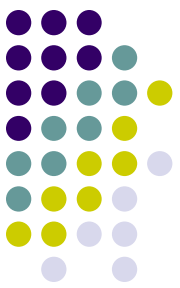
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