Quantifying Flicker: Fourier Filtering of Light

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Illuminating ENGINEERING SOCIETY

2016 Annual Conference

Agenda

Why is it important to measure flicker?

Flicker requirements in CA Title 24 and Title 20

What is physiological flicker?

What is IEEE PAR 1789?

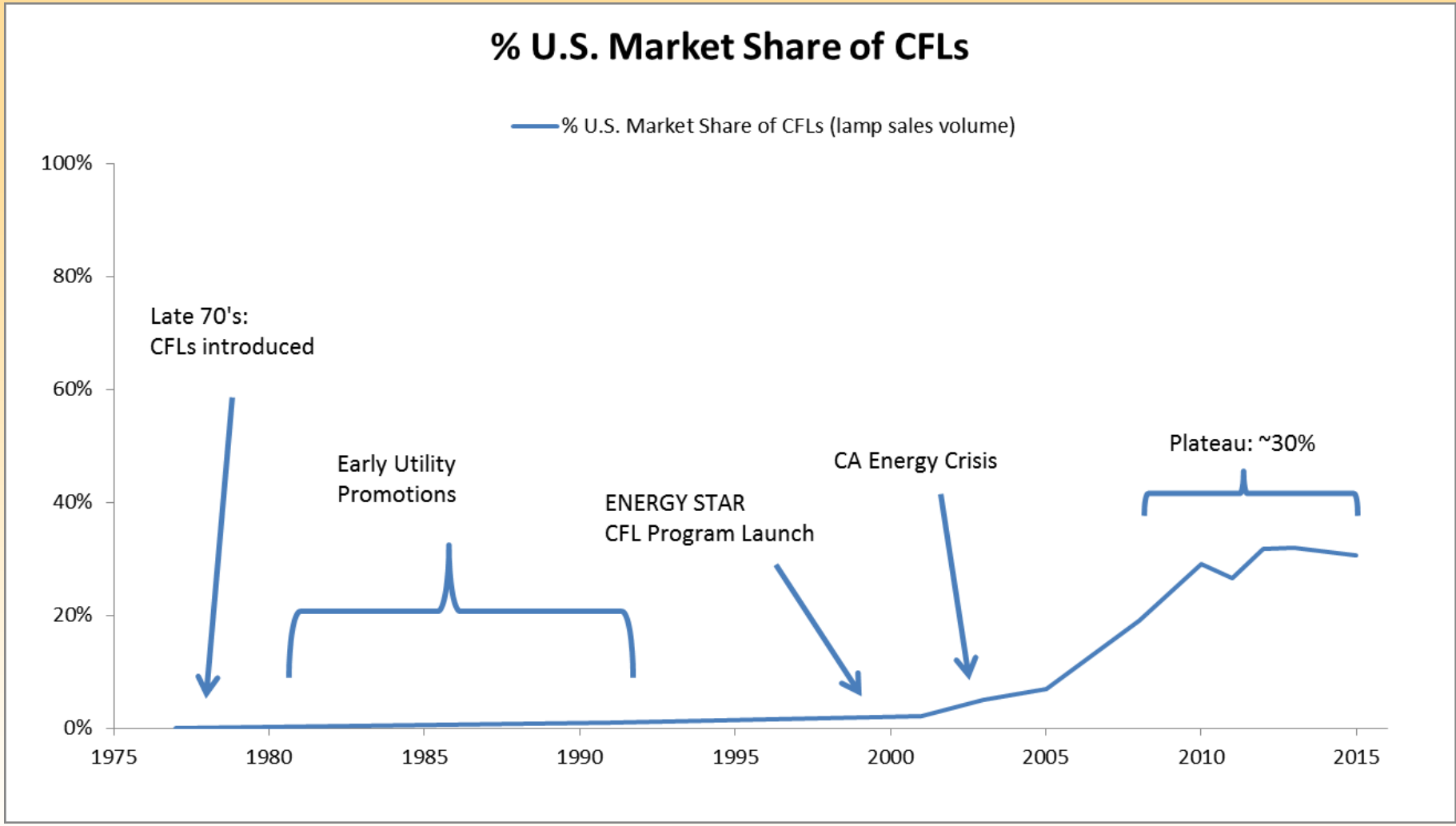
Flicker is a function of modulation and frequency

Using Fourier analysis to evaluate complex waveforms

Tested flicker performance of 53 LED lamps

Importance of publishing flicker information

CFL Market Share History



Sources: PNNL (for DOE), June 2006, "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market" ; D&R International (for DOE), Sept 2010, Energy Star CFL Market Profile; NEMA Lamps Sales Indices, & Presenter's market research; Cadmus (for CPUC), April 2010, "Compact Fluorescent Lamps Market Effects Final Report"

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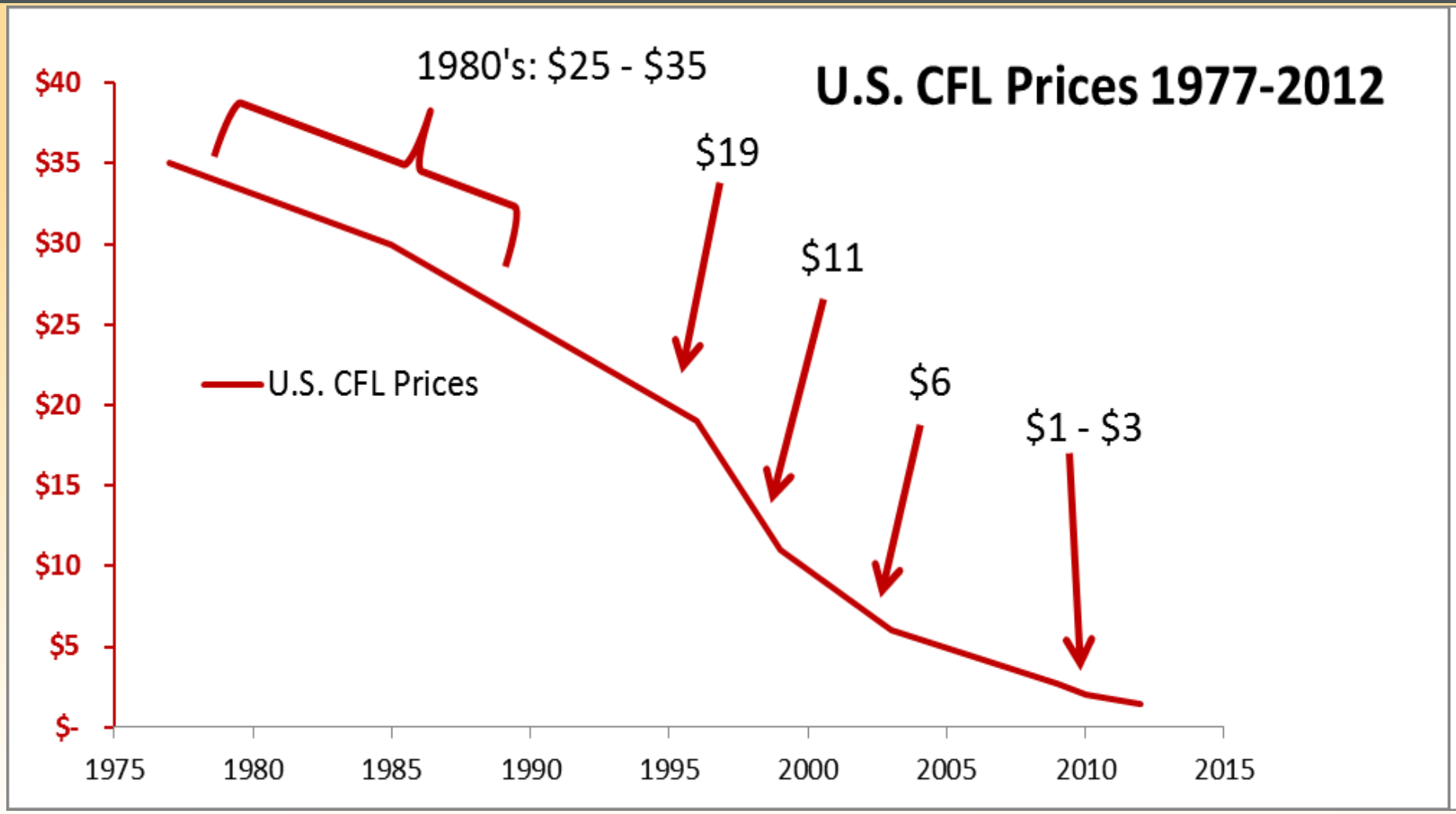

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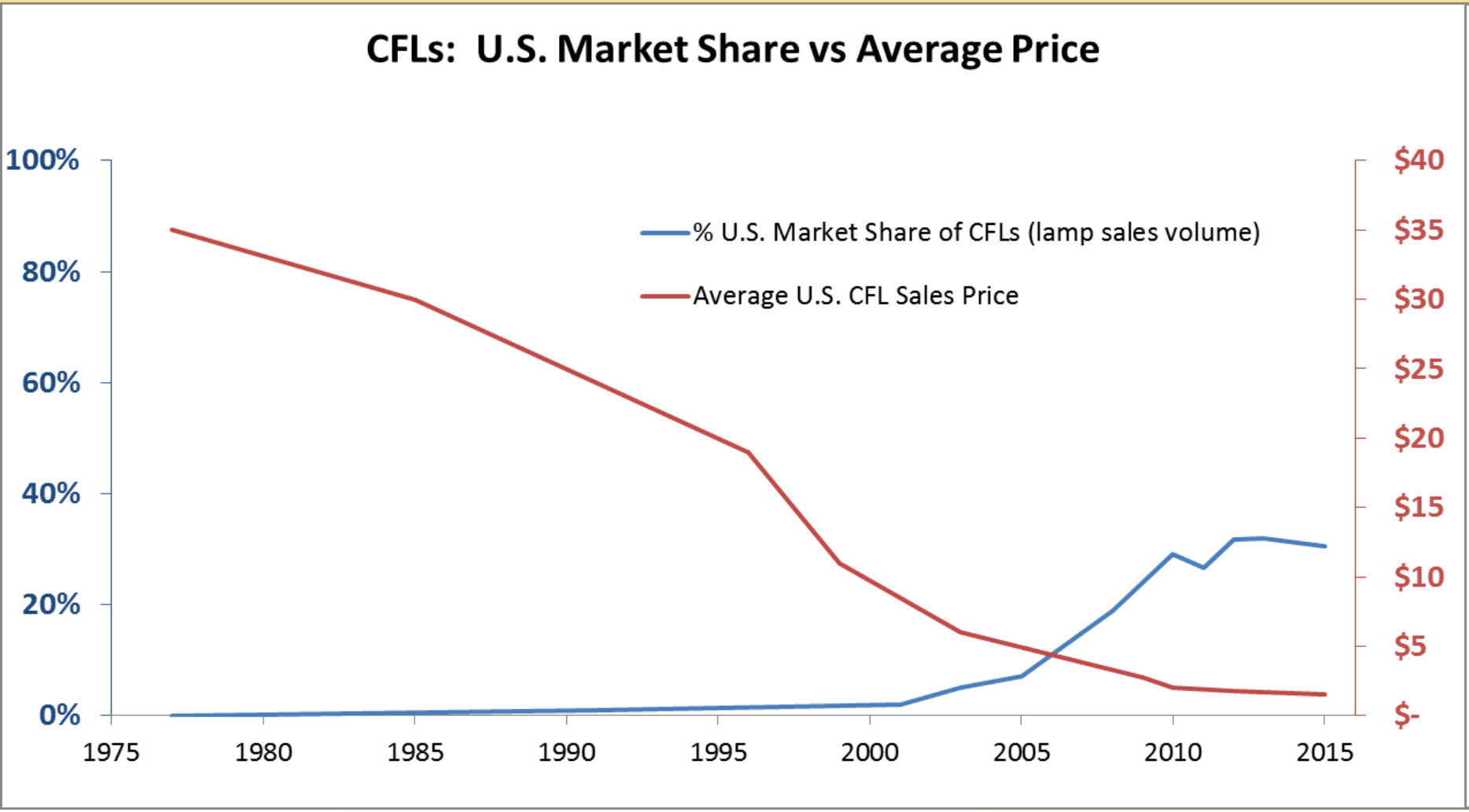

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Why did market share stall?

In by 2010 CFLs had:

- High availability
- High market awareness
- Low prices
- Significant rebate support and promotion

And yet market share stalled around 30%….

Why?

The Problem with CFLs

Theme	Specific Concerns
Compatibility	Don't fit in existing sockets, and not compatible with dimmers.
Light Quality	Poor light levels and harsh, cold, or "unfriendly" light. Inconsistent light color. Consumers experience headaches under fluorescent lighting.
Performance	Don't live up to their long life claims; early failure. CFLs buzz, hum, or flicker. Delayed start and a slow run up time (to full brightness).

In other words, people didn't like them!

1992 EPRI; Perceptions of Compact Fluorescent Lamps in the Residential Market; 1993 LRC; Quality vs Economy in Home Lighting: How Can we Find the Balance?; 1993 LRC; Residential Lighting Incentive Programs: What are the Alternatives to Compact Fluorescent Lamps
1997 (HMG for) CEC; Lighting Efficiency Technology Report, 1999: NEEA; LightWise; Market Progress Evaluation Report #1
2003: LRC; Increasing Market Acceptance of Compact Fluorescent Lamps; 2006: PNNL for DOE; Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market; 2010: Cadmus for CPUC; Compact Fluorescent Lamps Market Effects Final Report

CFL Quality Issues

Color – color temperature, and CRI

Color consistency –.

Flicker – visible flicker – distracting. Imperceptible flicker - headaches

Lifespan – especially in an enclosed fixture.

Start time – delay after turning on switch

Run-up time – time to “warm up” to full light output.

Dimmability – non-dimmable might burn-up or fail if placed on a dimmer

Toxicity – CFLs contains mercury

California's Lighting Standards

2018 General Service Lamps – 45 lm/W

- 2020 Federal GS Std - 45 lm/W

LED General Service Lamps - 80 lm/W.

- Effective July 2019
- DOE may have higher standard in 2020

Small Diameter Directional Lamp - 70-80 lm/W

- Effective January 2018

12,885 GWh/yr savings in California alone!

- Comparable to 4+ power plants
- Will there be backlash against high efficacy lighting standards?

Is amenity of LED comparable to incandescents?

British Columbia's Lamp Standards Attempt

Province of British Colombia Ministry of Energy implemented lamp standards in ~2010/2011

- A few high cost halogens were available – but CFLs were the main product available to consumers
- Ministry received consumer outcry on a daily basis, steady phone calls: complaints that CFLs didn't meet expectations as replacements… comments about mercury, color, flicker, dimming, lifetime.
- The problem was not affordability, accessibility, or awareness…. The biggest problem was acceptability.

The law was eventually repealed!

2016 Title 24 Joint Appendix JA8

Res NC: All high efficacy sources

JA8 required for all: LED's, screw based lamps, downlights

Certified in CEC JA8 database and labelled:

- "JA8-2016" or
- "JA8-2016-E" (elevated temp)

Tested to **JA10 flicker** and AM ≤30% for frequencies ≤ 200 Hz

NEMA SSL 7A rating

Dimmable to ≤ 10%

Lum eff ≥ 45 lm/W

PF ≥ 0.9

Lamps CCT ≤ 3000K

Integral CCT ≤ 4000K

CRI ≥ 90

- **IES** & **CIE** Stds

Start time ≤ 0.5 sec

Lumen maint$_{6000}$ ≥ 86.7%

LM-80 LD70 ≥ 25,000 h

Survival ≥ 90%@6,000 h

Noise ≤ 24dBA@1 meter

- **ENERGYSTAR** Tests

What is Flicker?

Flicker is amplitude modulation of light at frequencies that have effects on human physiology

- Similar concept to sound and ultrasound
- At higher frequencies modulation perceived less

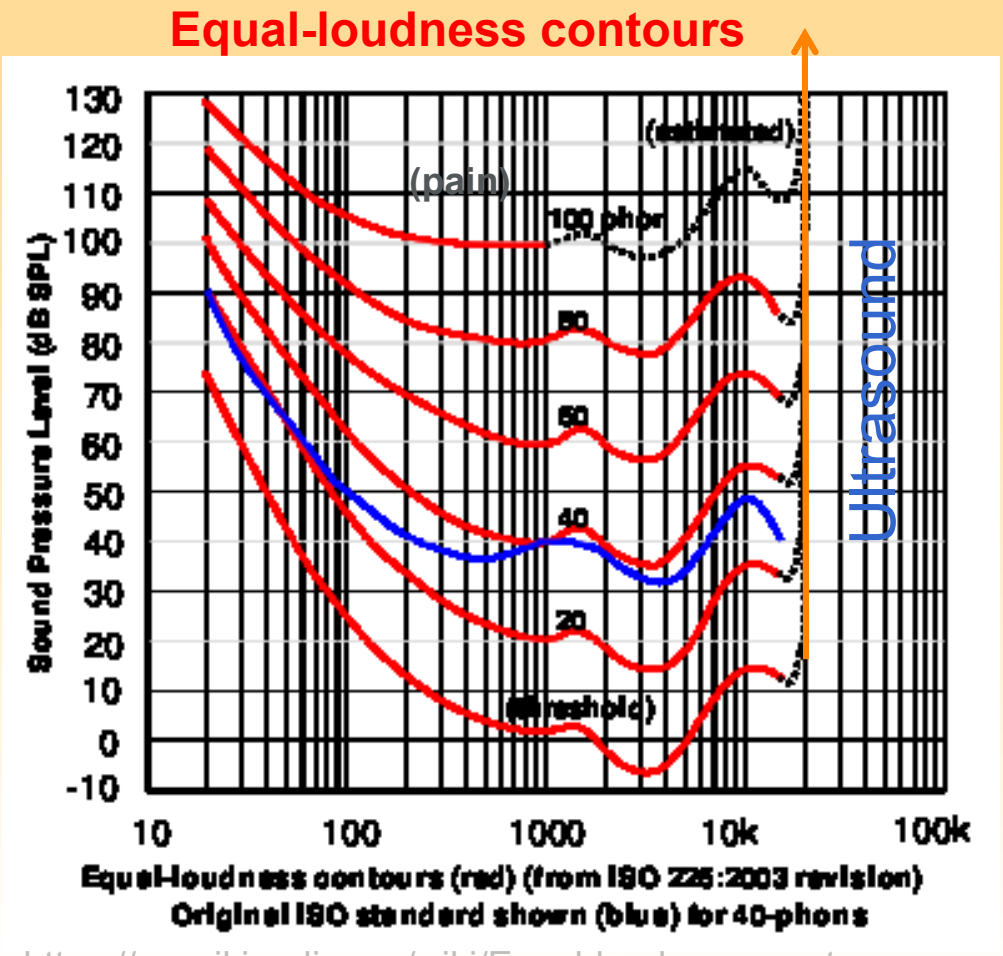
Perceptible flicker – can be noticed directly.

- 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

- Magnetic ballasted lighting studies: Veitch and McColl (1995), Veitch and Newsham (1998) and Wilkins et al. (1989)

Sound and Ultrasound



https://en.wikipedia.org/wiki/Equal-loudness_contour

Ultrasound used in industry for cleaning, welding, mixing etc.

- Worker complaints of nausea, hearing loss etc.

Ultrasound for sensing

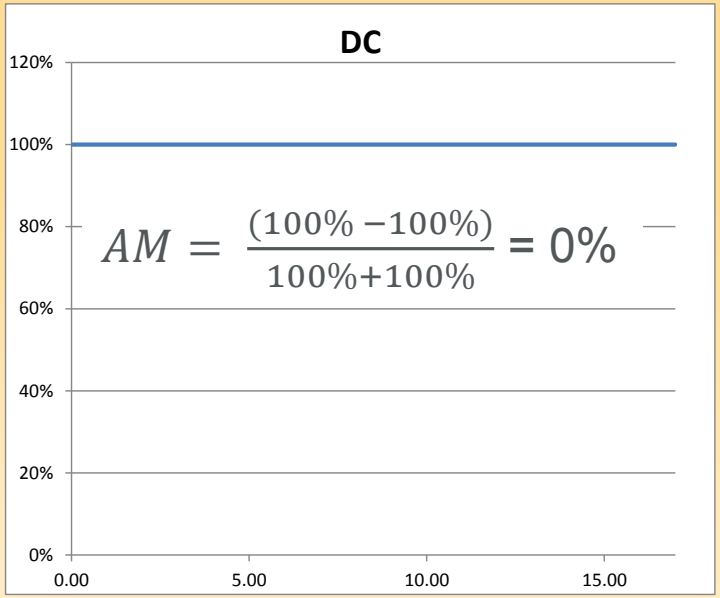
- General public complaints of headaches, nausea

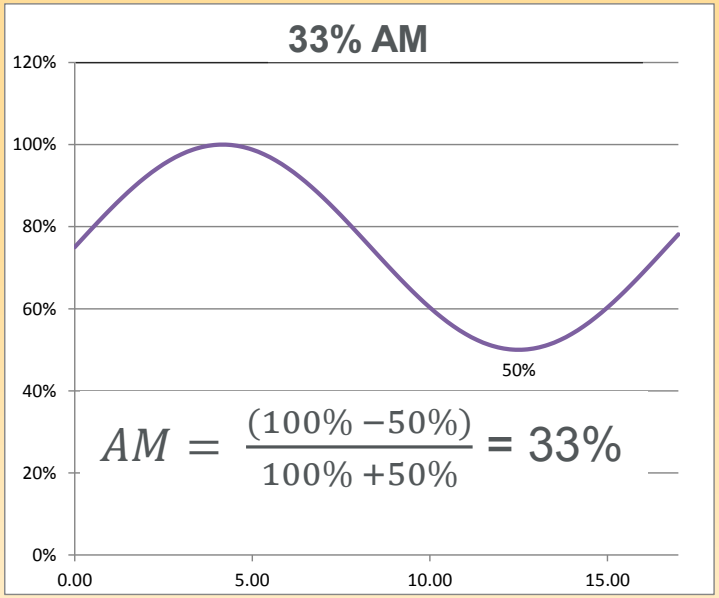
Limits set for 8 hour exposure

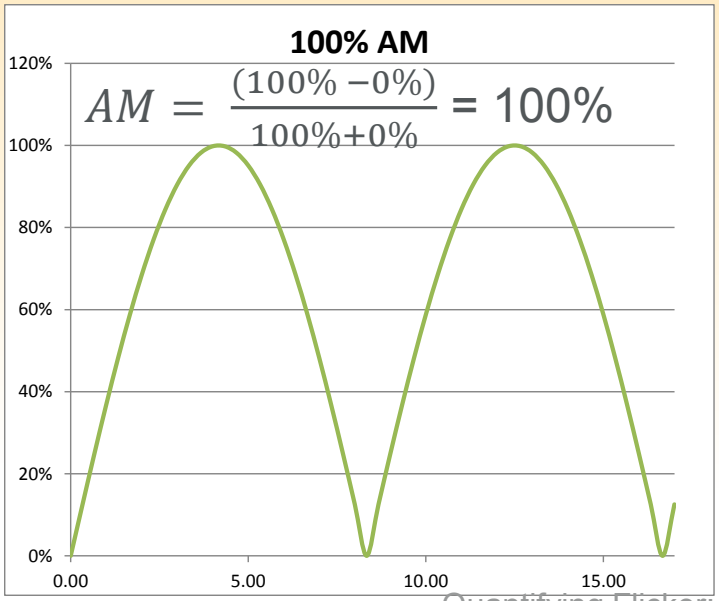
- 75 db for 20 kHz
- 115 db for ≥ 25 kHz

http://www.icnirp.org/cms/upload/publications/INIRCUltrasound.PDF

Amplitude Modulation (% Modulation)







$$AM = \frac{Max - Min}{Max + Min}$$

Why is Percent Flicker and Flicker Index a Misnomer?

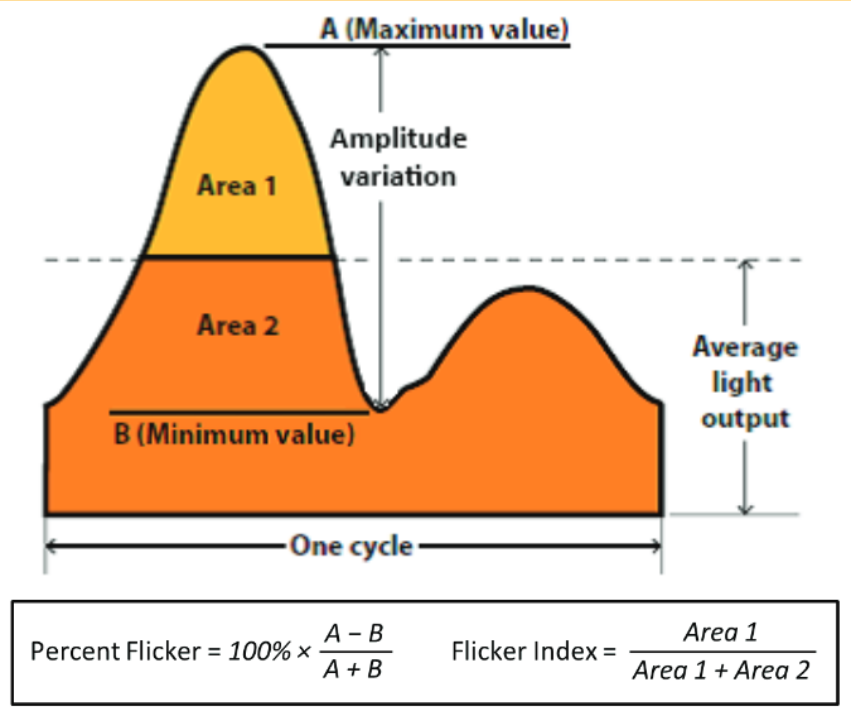
Percent Flicker

- Ratio of fluctuation to average (AKA modulation depth, % modulation, % AM)
- Most research based on this metric
- Easy to measure

Flicker Index

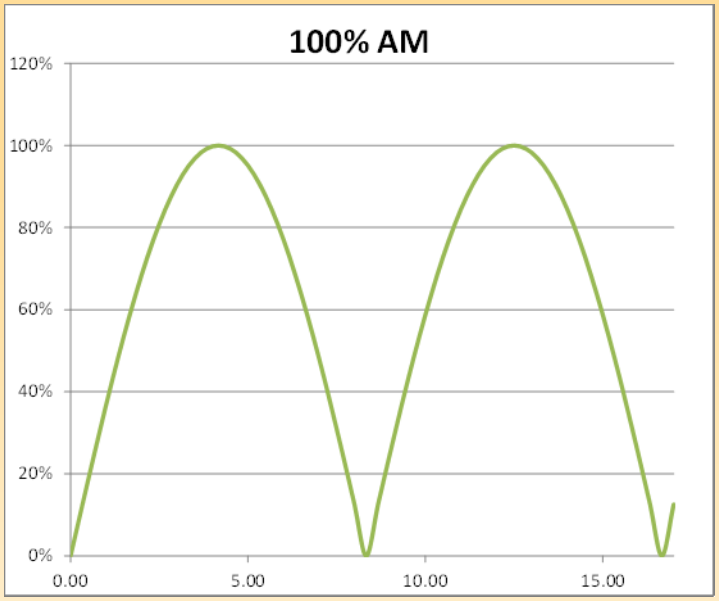
- Ratio of areas
- older research used this metric

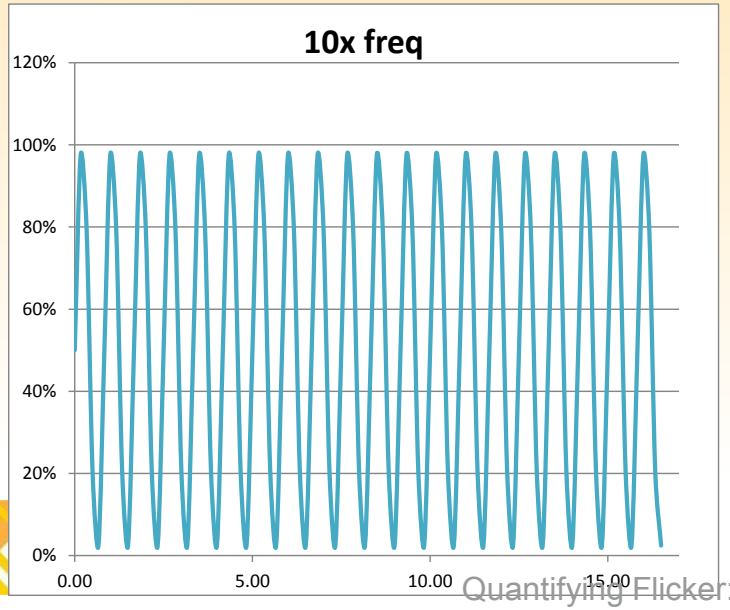
Neither account for frequency of waveform



Source: DOE Flicker Fact Sheet
Modified from IES Handbook

Frequency and Percent Flicker (%AM)





Both graphs 100% amplitude modulation

- Same min and max

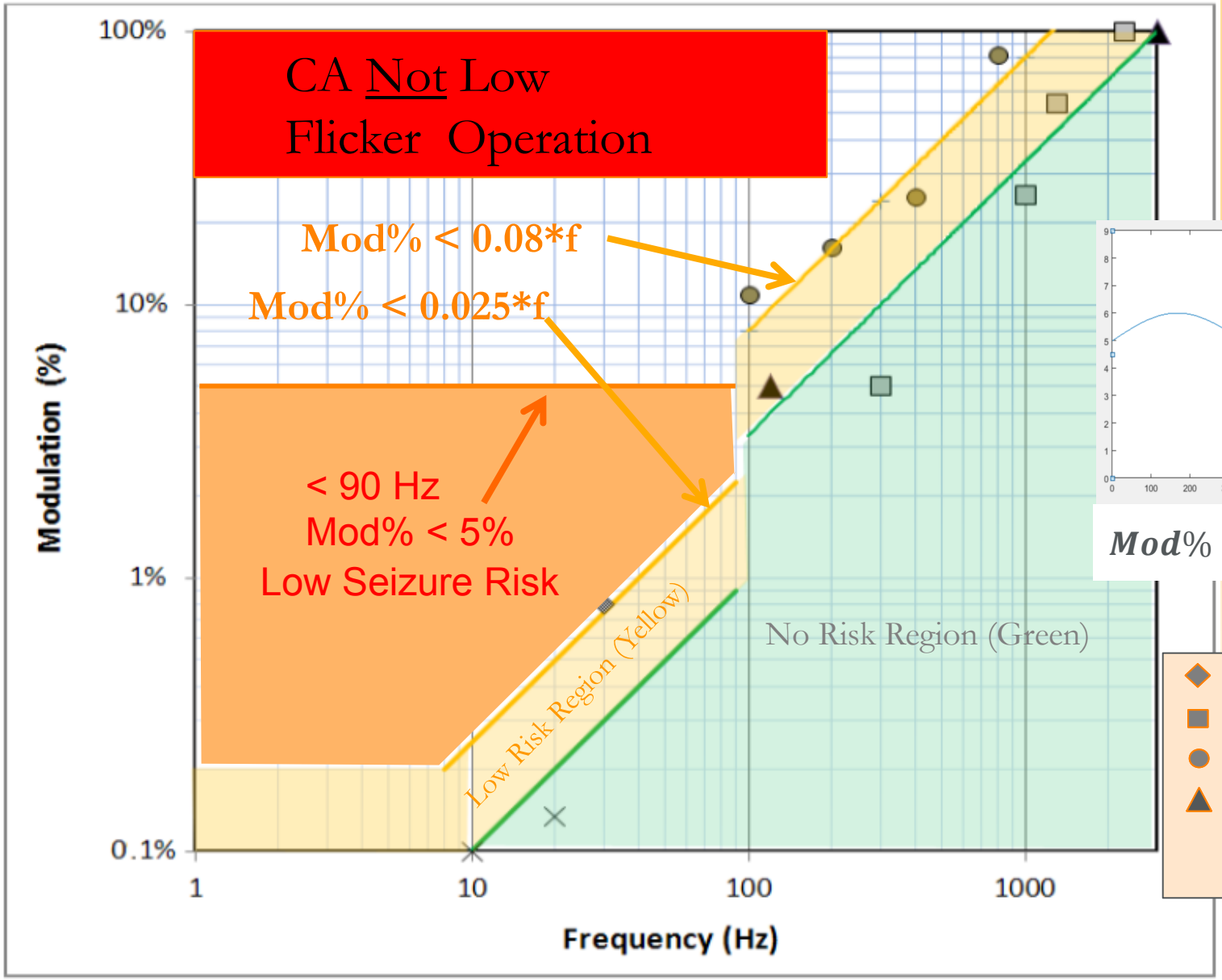
Percent flicker (and flicker index) a misnomer

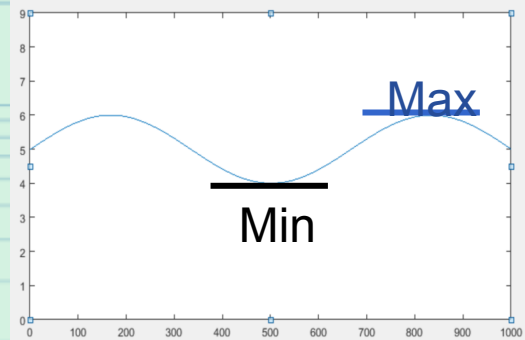
Flicker (perceived or imperceptible) a function of both:

- Modulation Depth
- **and Frequency**

Improved Definition of Flicker (IEEE PAR 1789)

Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers

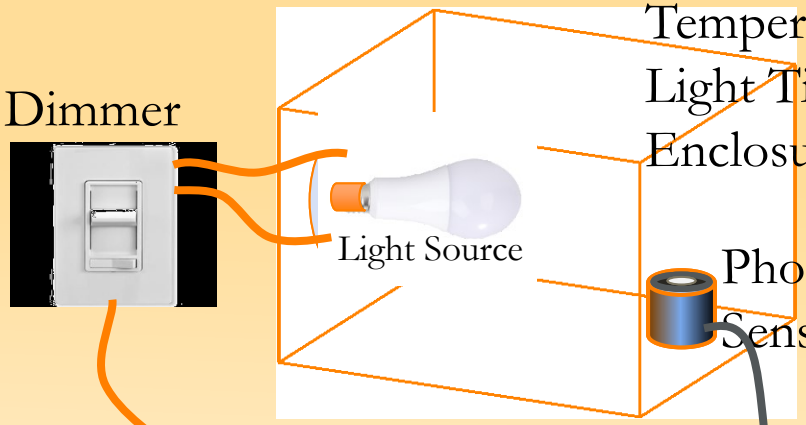




$$Mod\% = \frac{Max - Min}{Max + Min} \times 100$$

- Kelly 1964
- Bullough 2011
- Perz 2014
- Roberts & Wilkins 2012

Test Setup – JA10 Flicker Test



Temperature Controlled Light Tight Enclosure

Photometric Sensor

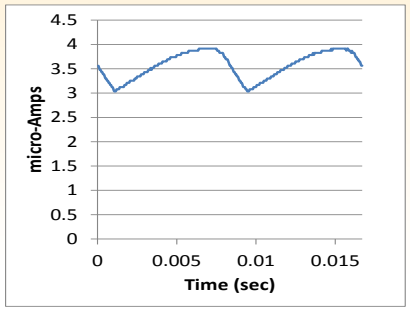
Regulated Power Supply

Transimpedance Amplifier

Digital Oscilloscope

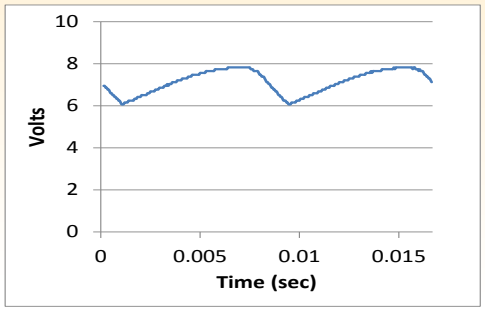
Digital Time Series Data

Sensor Output

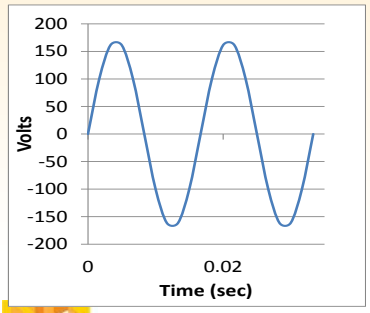


nanoAmps/lux

Amplified Sensor Output



Convert to Volts

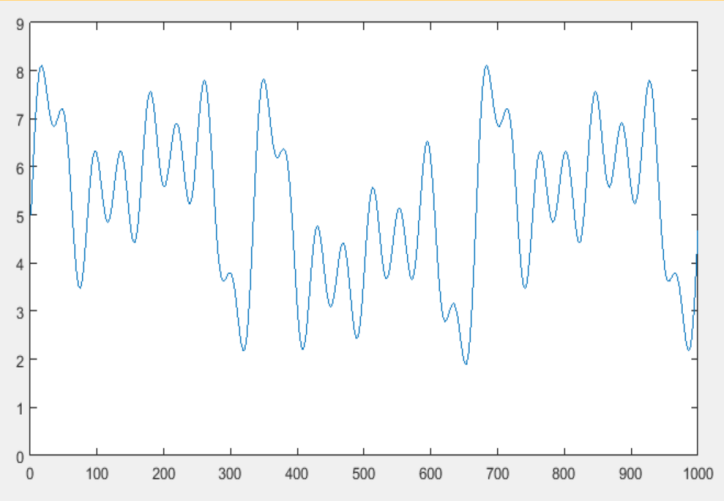


120 VAC, 60 Hz

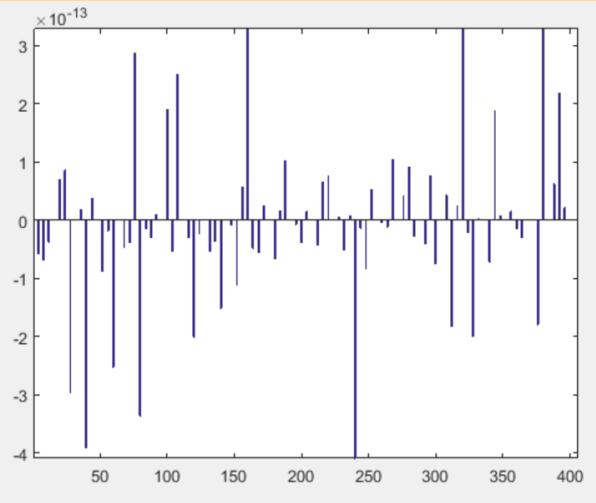
Time (sec)	Volts
0	7.125
1E-04	7.037
0.00015	6.949
0.0002	6.949
0.00025	6.861
0.0003	6.861
0.00035	6.773
0.0004	6.773
0.00045	6.686
0.0005	6.598

Fourier Filtering – Joint Appendix JA10

Time Series Data

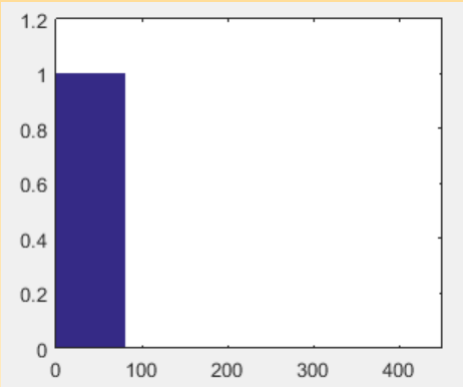


Fourier Transform To Frequency Domain

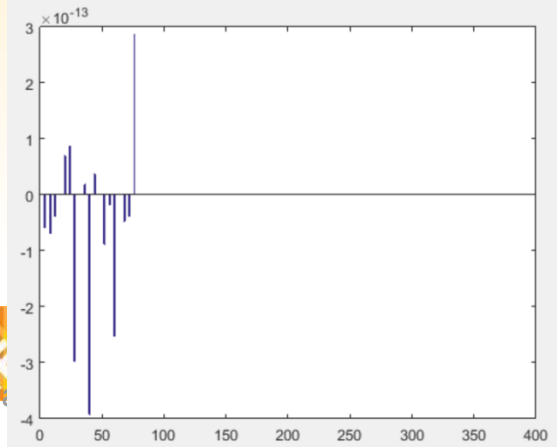


x

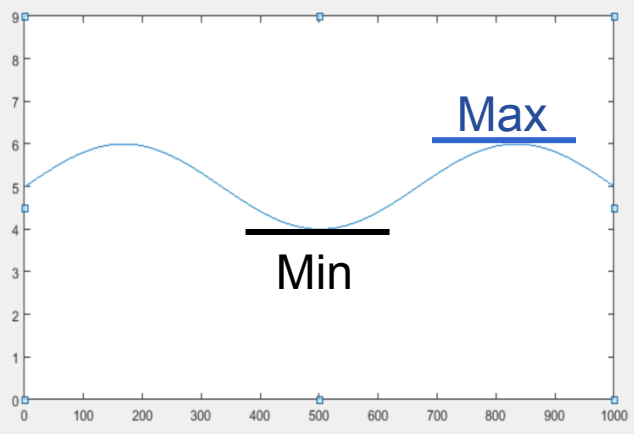
Cut-off Vector



Truncated Fourier Series



Inverse Fourier Transform Filtered Time Series



$$AM = \frac{Max - Min}{Max + Min}$$

Three Recommendations in IEEE 1789

Section 8.1.1 Simple recommended practices

1. If it is desired to limit the possible adverse biological effects of flicker, below 90 Hz, Modulation (%) is less than 0.025 ×frequency, between 90 Hz and 1,250 Hz, Modulation (%) is below 0.08 ×frequency and above 1,250 Hz, there is no restriction on Modulation (%).

Compare the amplitude modulation results from JA10/JA8 database : at 40 Hz <1% amplitude modulation, for 90 Hz <2.25% AM, for 200 Hz <16% AM, for 400 Hz <32% AM, for 1,000 Hz <80% AM and for unfiltered data no limit on %AM.

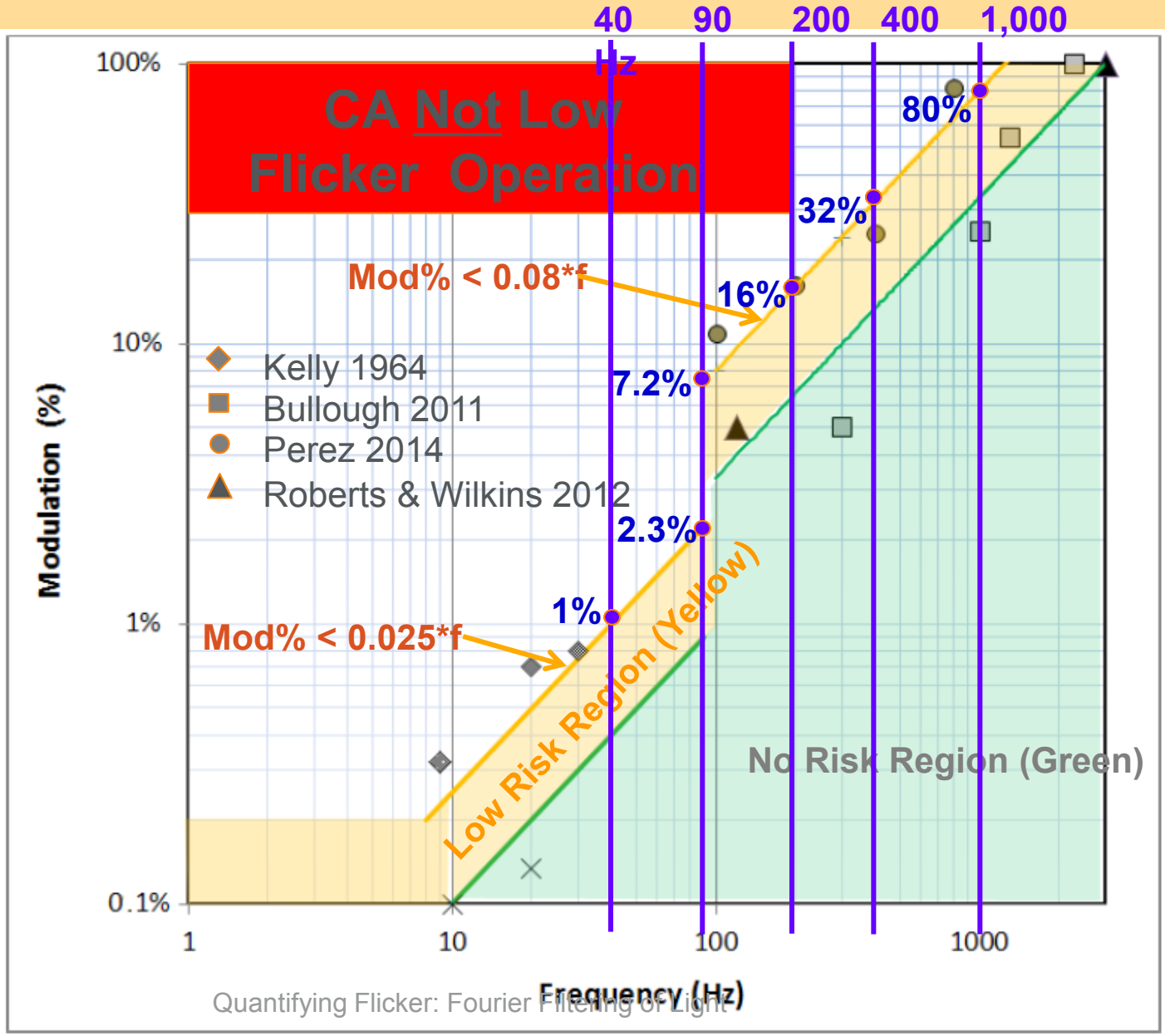
2. If it is desired to operate within the recommended NOEL (no observed effect level) *of flicker, below 90 Hz, Modulation (%) is less than 0.01 ×frequency, between 90 Hz and 3,000 Hz, Modulation (%) is below 0.0333 ×frequency and above 3,000 Hz, there is no restriction on Modulation (%).*

For 40 Hz this corresponds to no greater than 0.4% amplitude modulation, for 90 Hz <0.9% AM, for 200 Hz <6.7% AM, for 400 Hz <13.3% AM, for 1,000 Hz <33.3% AM.

3. (seizure prevention) For any lighting source, under all operating scenarios, below 90 Hz, Modulation (%) is less than 5%.

Compare the JA10 database amplitude modulation results filtered below 40 Hz and 90 Hz cut-off frequencies with the less than 5%AM recommendation.

JA10 for IEEE PAR 1789 Spec



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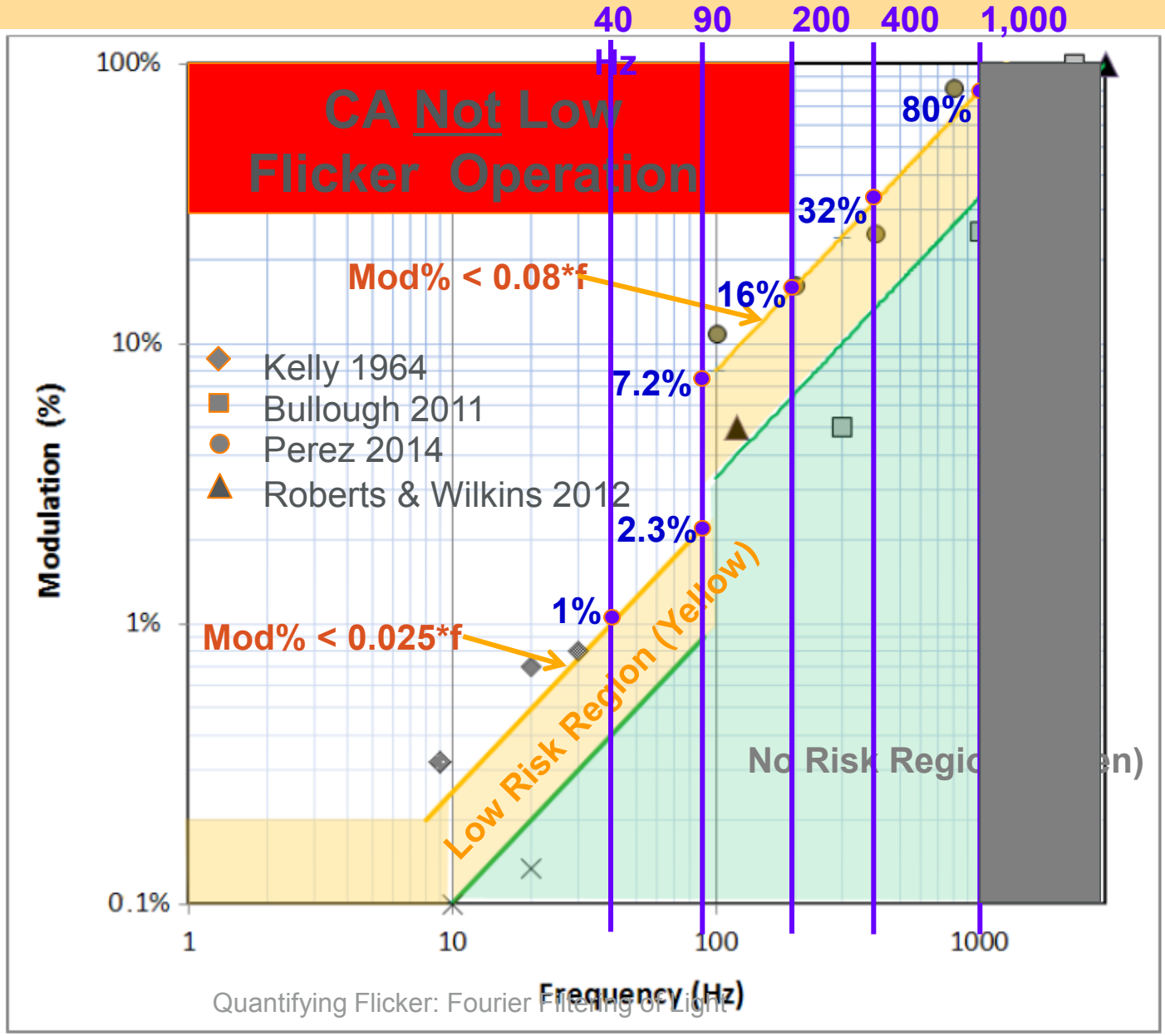

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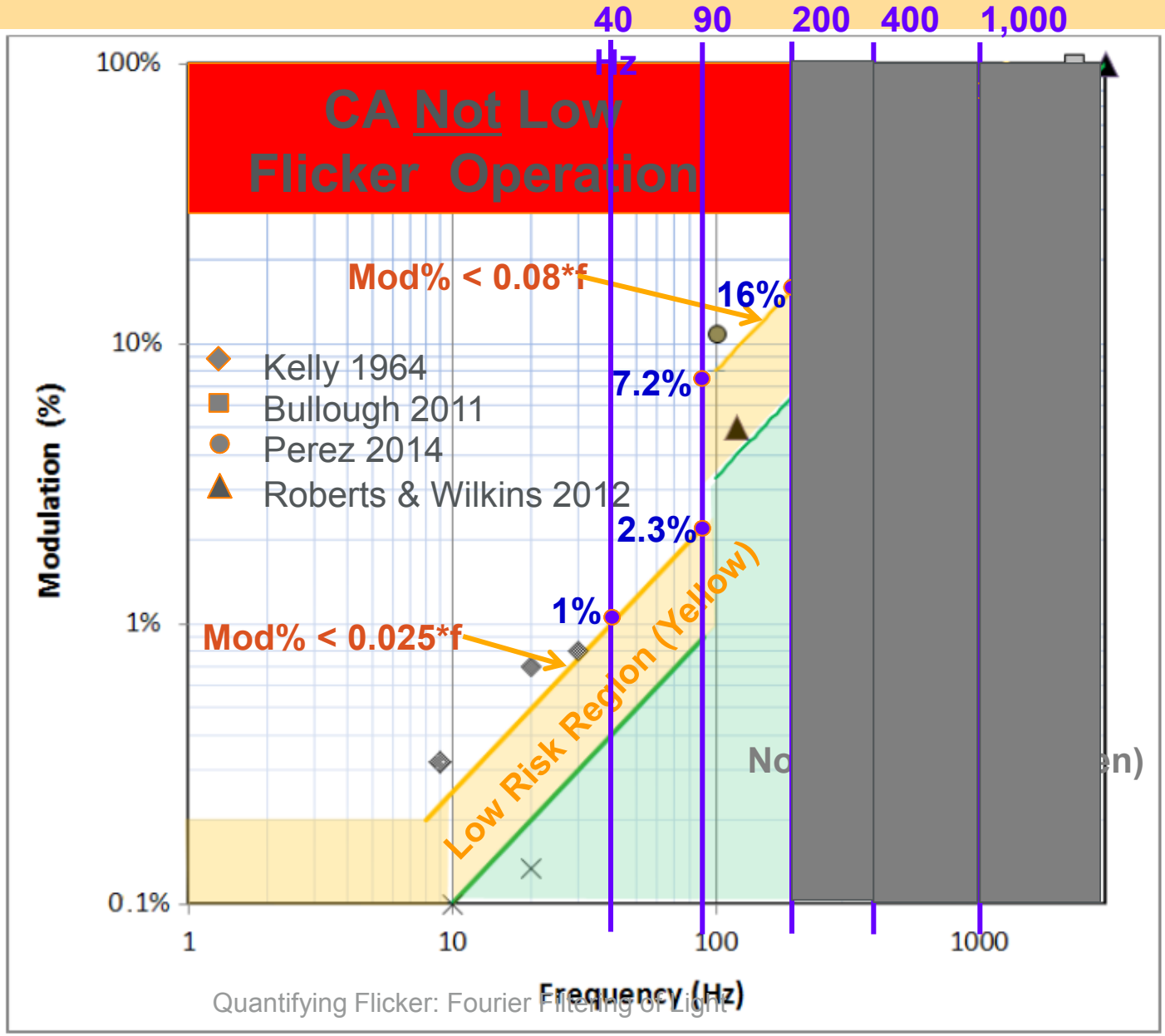

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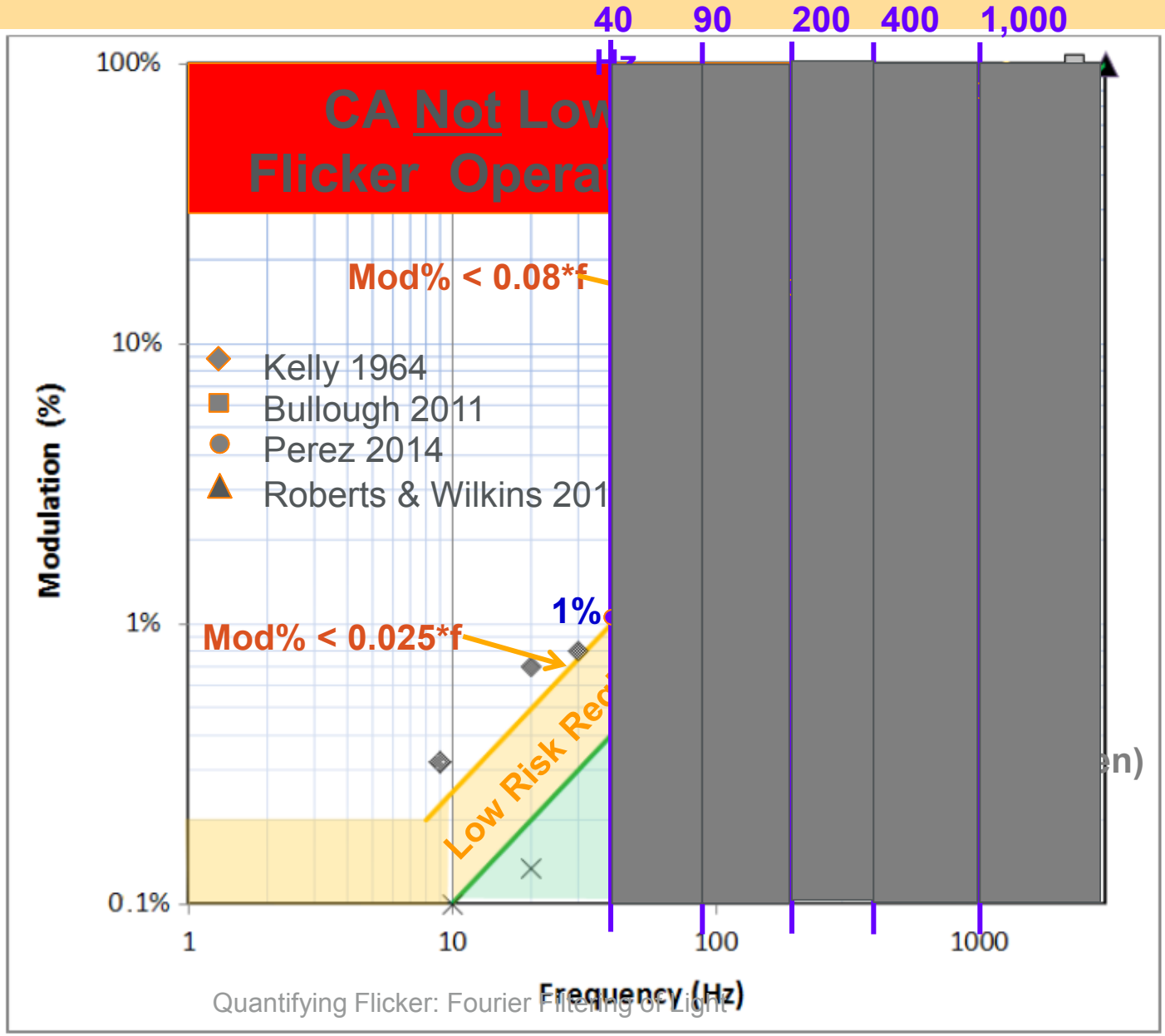


Flicker Tests of 25 LED A-lamps (2013)

Tests performed by California Lighting Technology Center

Interval between data points 8 μsec (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%.

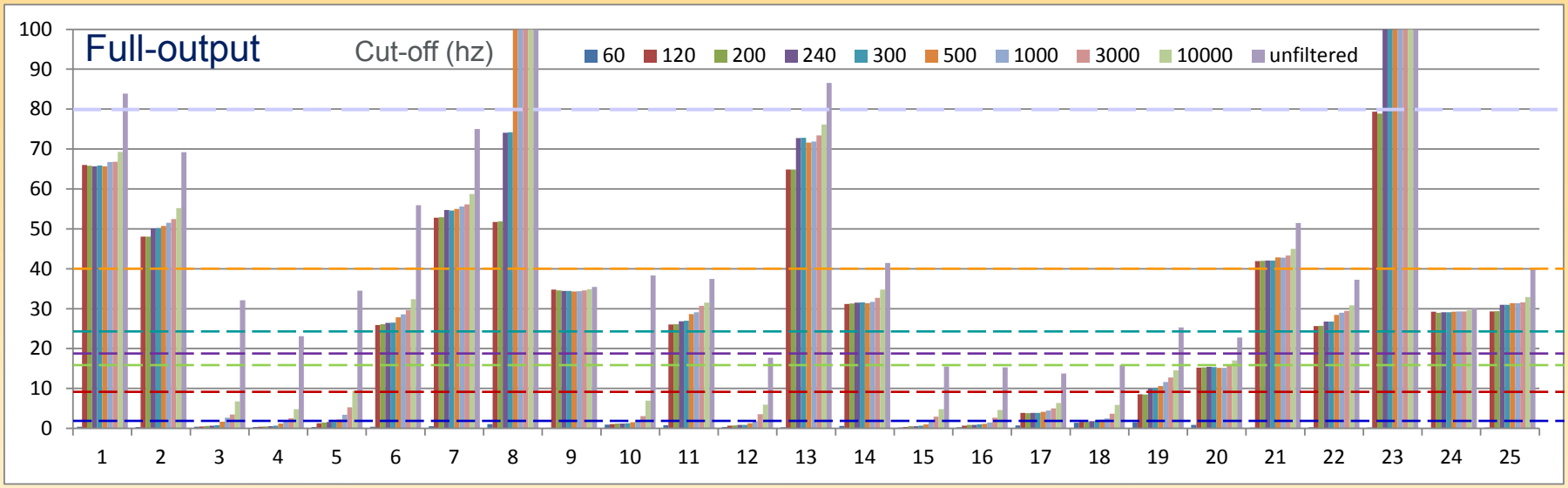
52% comply (48% fail) with T-24 flicker

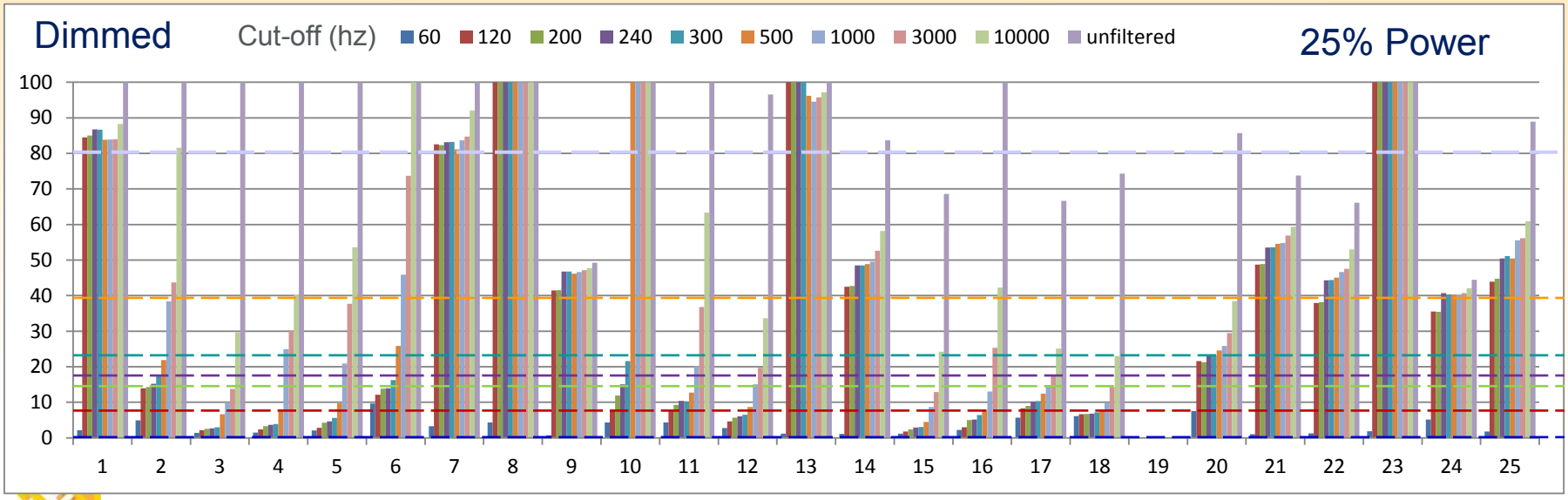
- 64% comply (<30% AM) at full light output
- 56% comply at 25% light output

36% comply with IEEE PAR 1789 standard

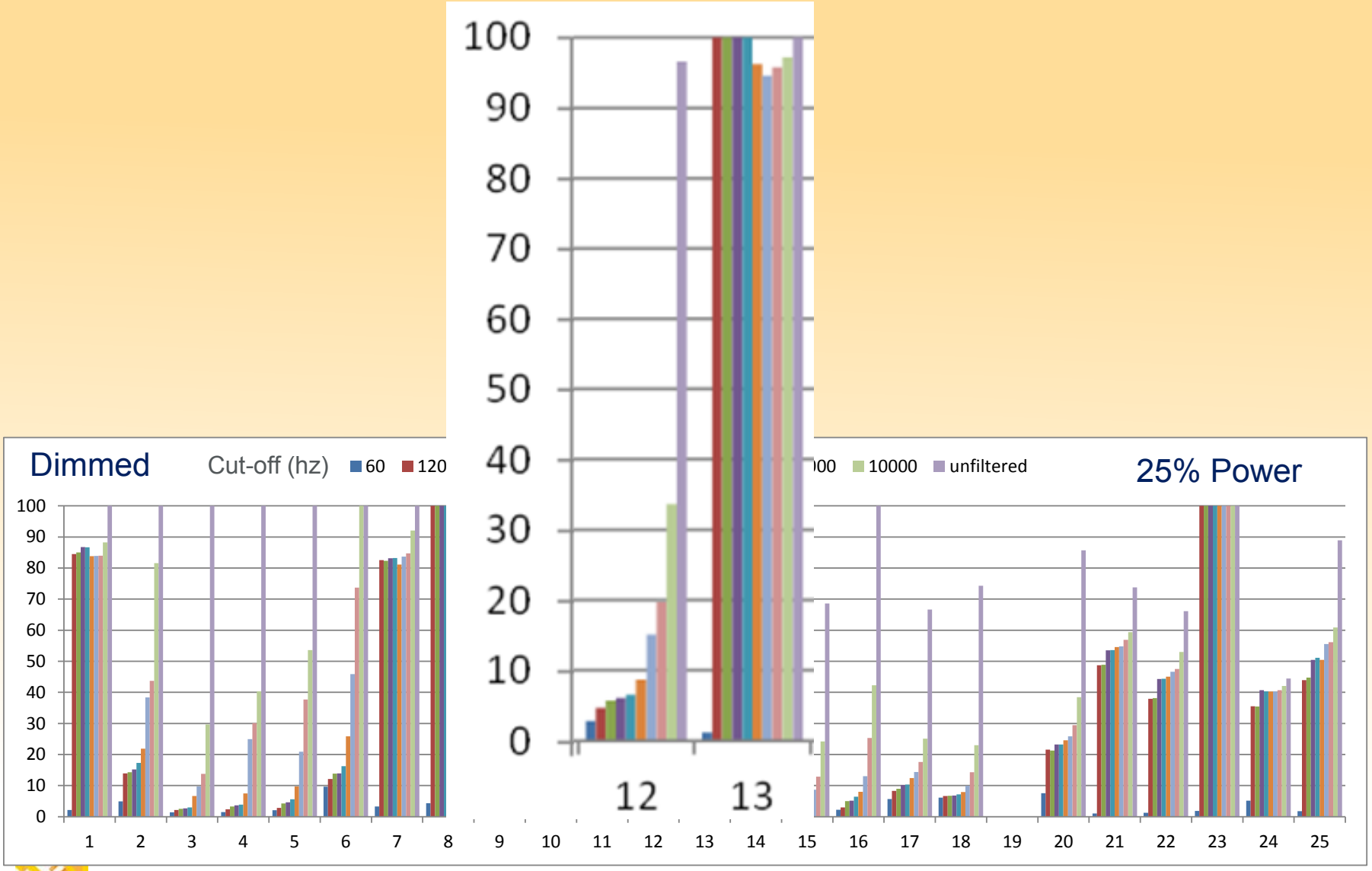
- Same products pass at 100% and 25% light output.
- At full light output, 4% failures at 60 Hz cut-off frequency
- At 20% light output, 64% failures at 60 Hz cut-off frequency

A-lamp results

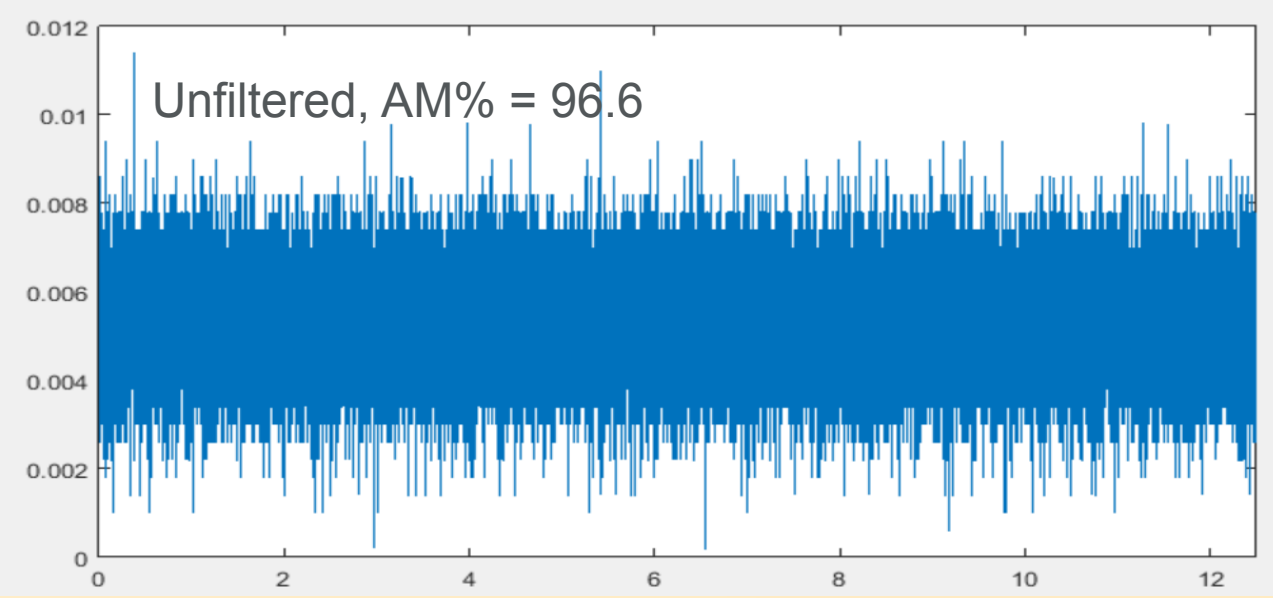


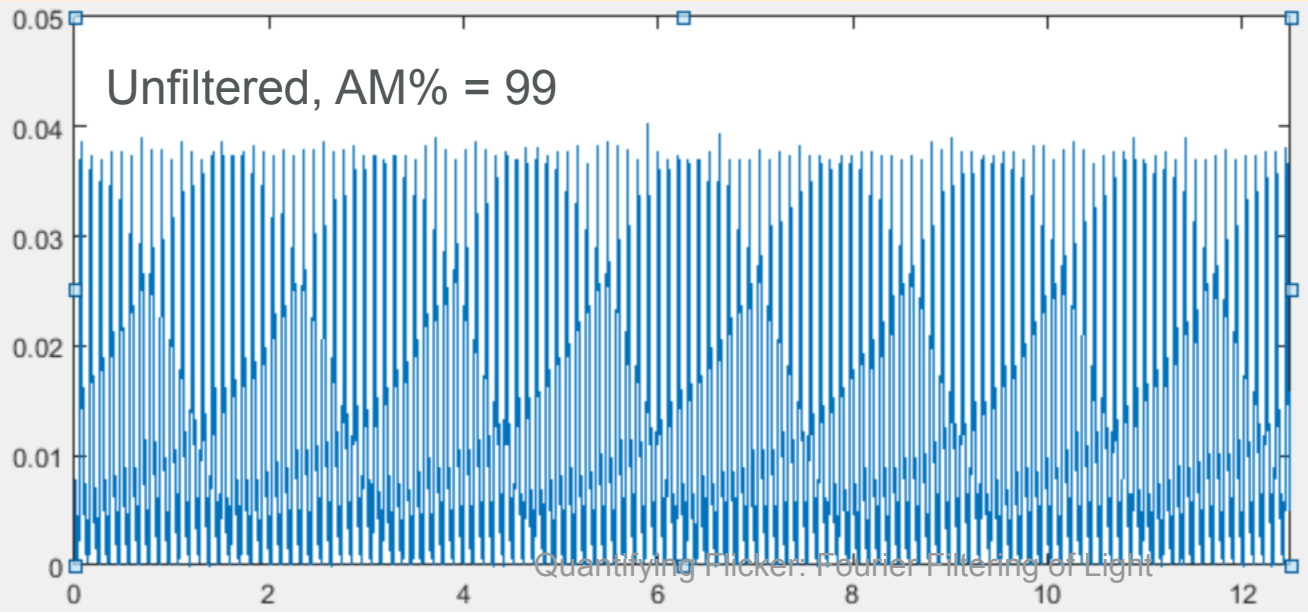


Comparing similar unfiltered Mod%



Example of filtered waveform





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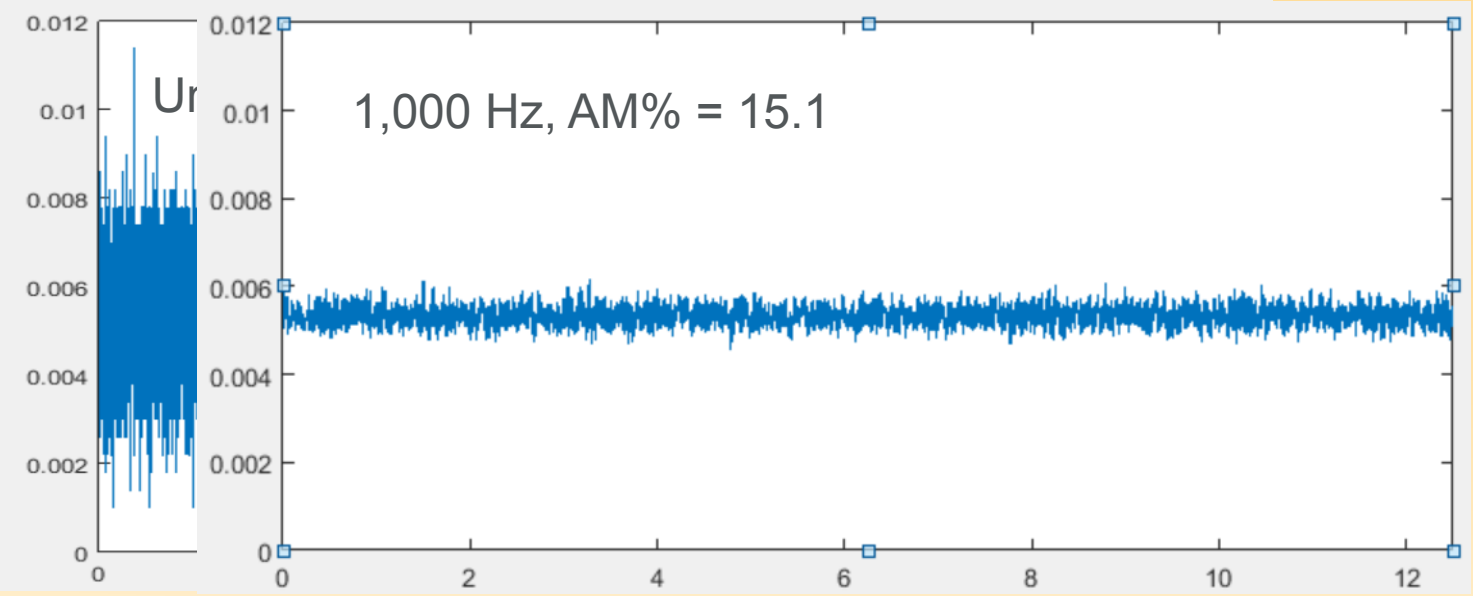

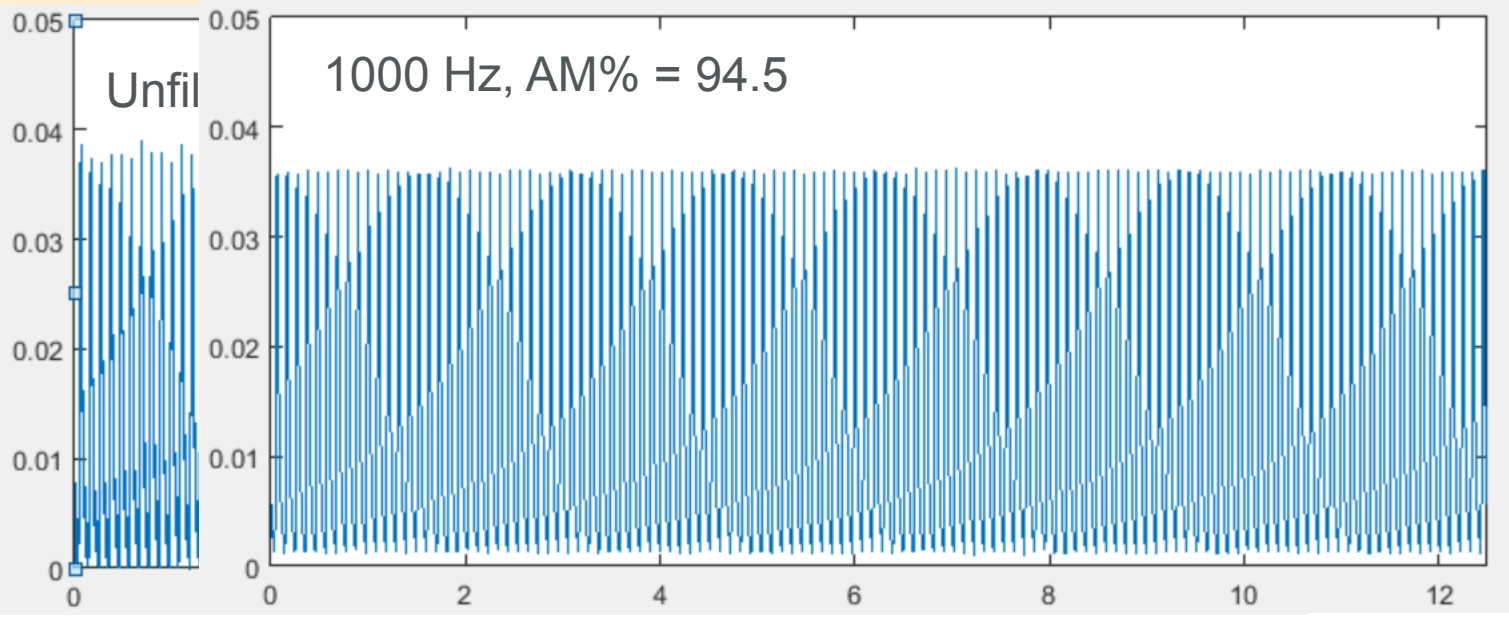

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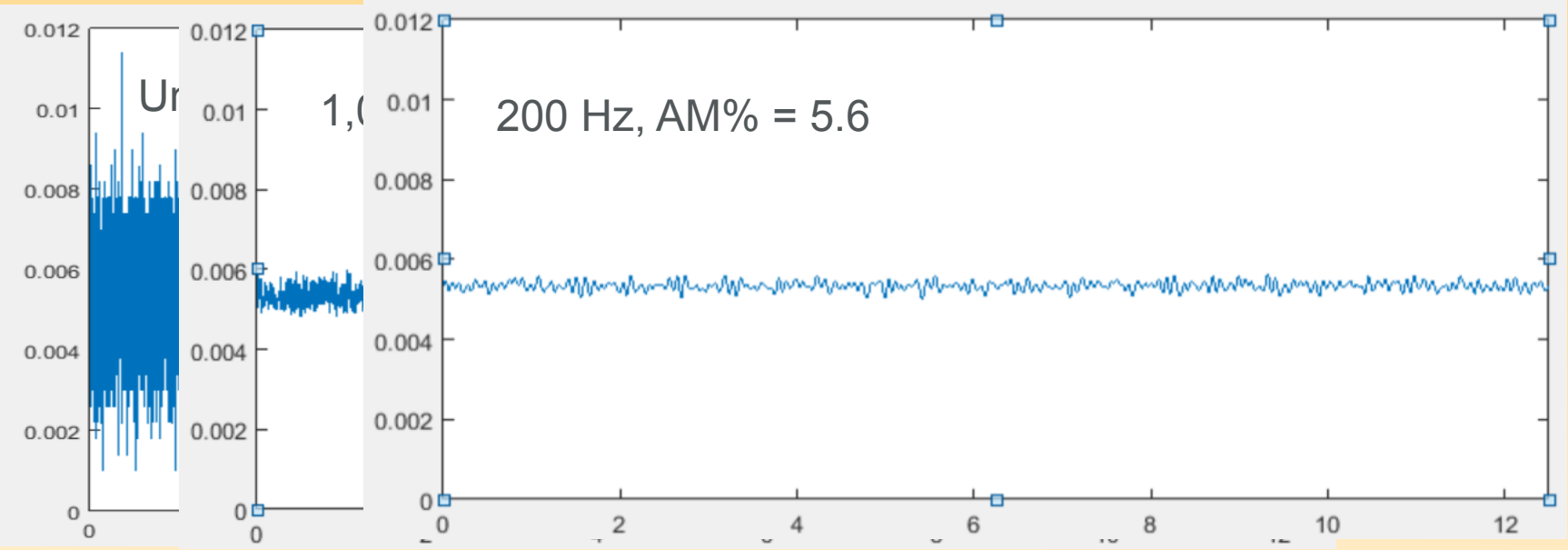

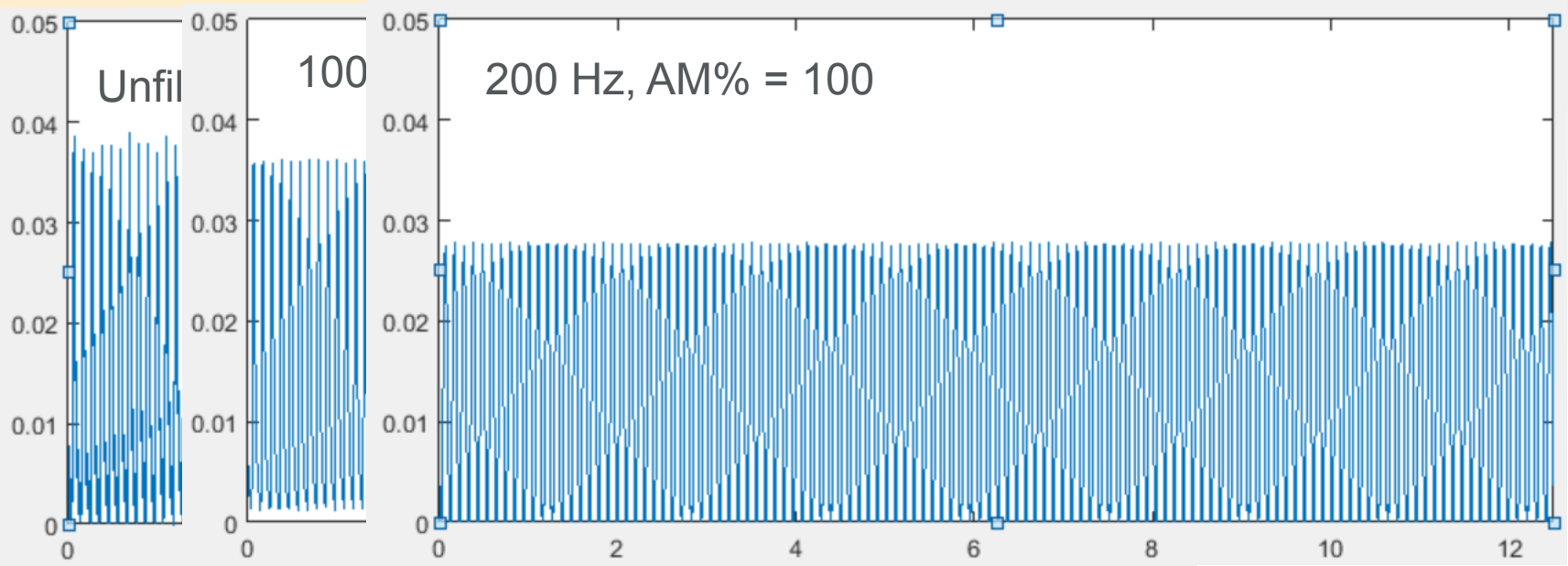

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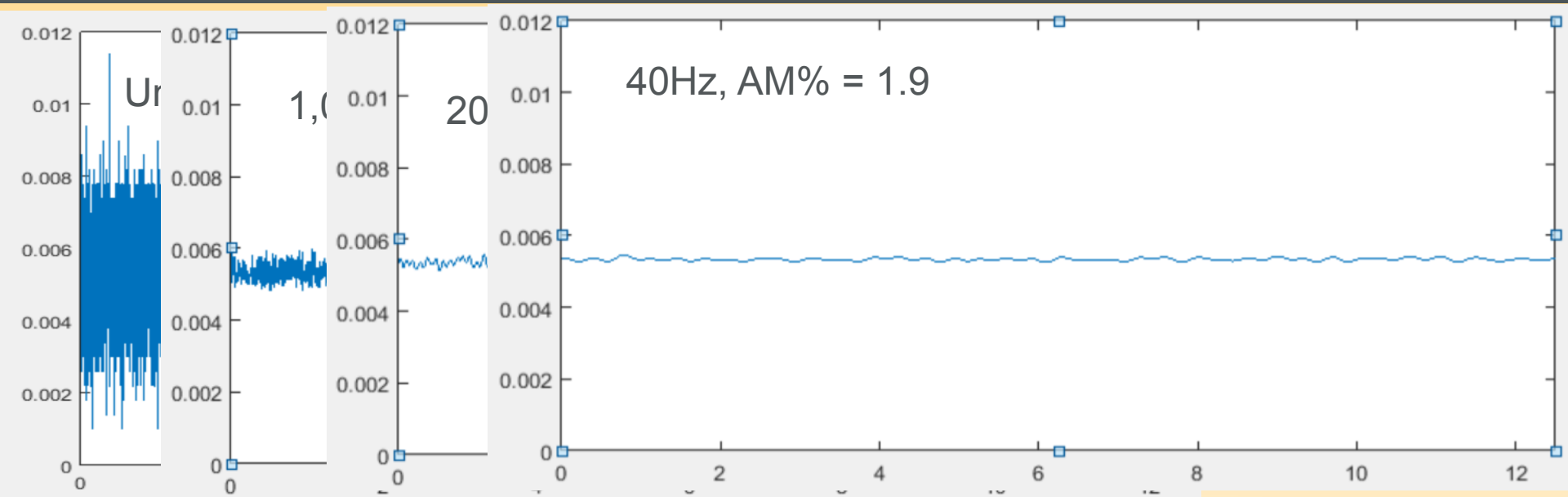
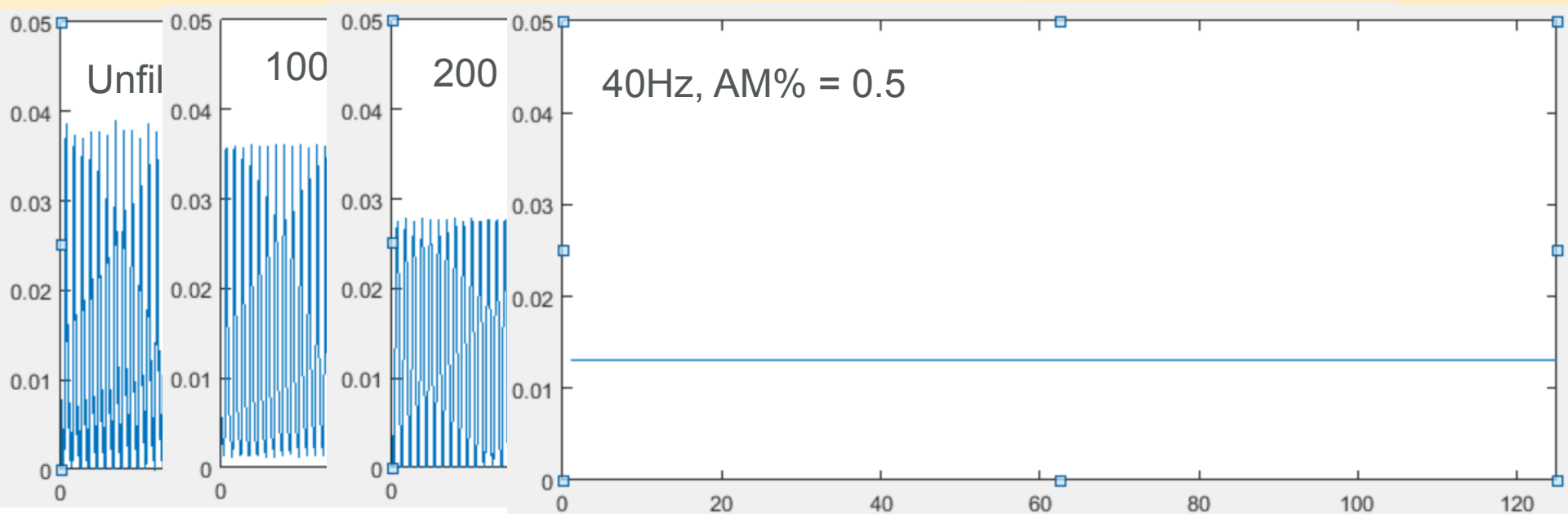


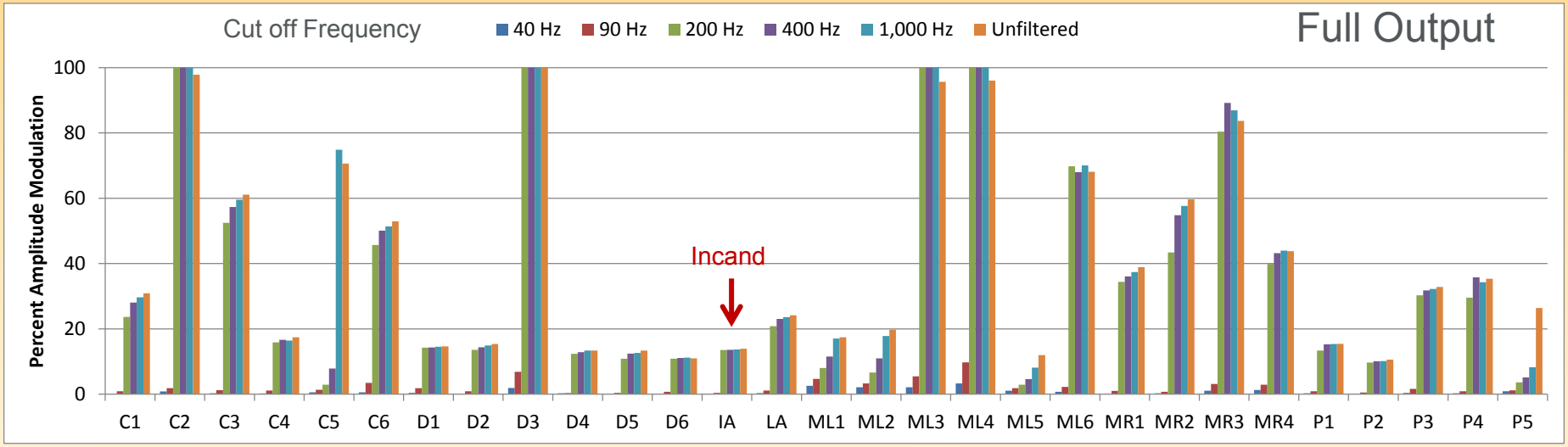


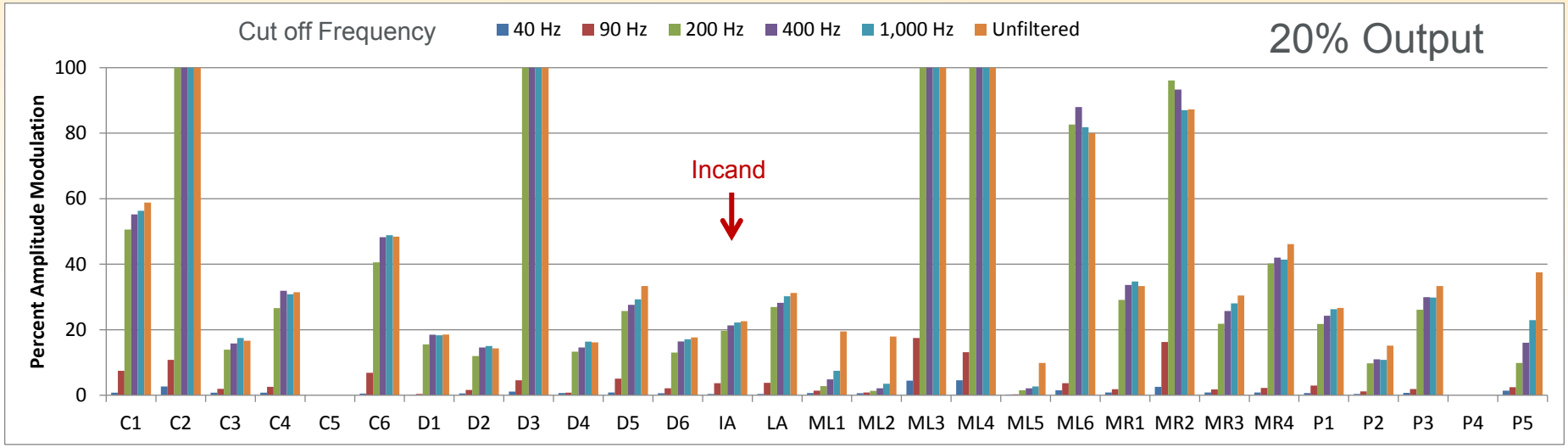
A lamp tests Tabular Results

Lamp	60	120	200	240	300	500	1000	3000	10000	un-filtered	Pass IEEE	Pass IEEE and @25%	Pass T-24	Pass T-24 and @25%
omni1	0.4	66.0	65.8	65.7	65.8	65.6	66.7	66.8	69.3	83.9	0	0	0	0
omni2	0.3	48.0	48.1	50.1	50.2	50.7	51.6	52.5	55.2	69.2	0	0	0	0
omni3	0.4	0.5	0.6	0.7	0.8	1.7	2.7	3.5	6.7	32.1	1	1	1	1
omni4	0.3	0.4	0.5	0.5	0.6	1.2	1.8	2.6	4.8	23.1	1	1	1	1
omni5	0.3	1.3	1.5	1.6	1.6	2.2	3.4	5.3	9.4	34.5	1	0	1	1
omni6	0.4	25.9	26.1	26.4	26.5	27.8	28.6	29.6	32.4	55.9	0	0	1	1
omni7	0.6	52.8	52.9	54.7	54.6	55.0	55.6	56.1	58.7	75.0	0	0	0	0
omni8	1.1	51.8	51.8	74.1	74.2	100.0	100.0	100.0	100.0	100.0	0	0	0	0
omni9	0.1	34.8	34.6	34.5	34.4	34.3	34.4	34.6	34.8	35.5	0	0	0	0
omni10	1.0	1.1	1.2	1.2	1.3	1.5	1.9	3.1	7.0	38.3	1	0	1	1
omni11	0.8	26.0	26.1	26.8	27.0	28.6	29.1	30.7	31.5	37.4	0	0	1	1
omni12	0.3	0.7	0.8	0.9	0.9	1.3	1.8	3.6	5.9	17.7	1	0	1	1
omni13	0.3	64.9	64.9	72.8	72.8	71.6	71.9	73.4	76.2	86.5	0	0	0	0
omni14	0.6	31.2	31.3	31.5	31.6	31.4	31.7	32.7	34.7	41.4	0	0	0	0
omni15	0.2	0.4	0.6	0.6	0.7	1.0	1.7	2.9	4.8	15.5	1	1	1	1
omni16	0.3	0.7	0.9	0.9	1.0	1.2	1.5	2.7	4.6	15.3	1	0	1	1
omni17	0.8	3.9	3.8	3.9	3.9	4.2	4.5	5.1	6.3	13.8	1	0	1	1
omni18	1.4	1.6	1.6	1.8	1.9	2.1	2.5	3.7	5.9	15.9	1	0	1	1
omni19	1.5	8.6	8.5	9.9	10.1	10.6	11.6	12.7	14.6	25.3	0	0	1	0
omni20	0.9	15.2	15.3	15.4	15.3	15.1	15.2	15.6	17.0	22.7	0	0	1	1
omni21	0.2	41.9	42.0	42.1	42.1	42.9	42.8	43.3	45.0	51.4	0	0	0	0
omni22	0.3	25.6	25.7	26.7	26.8	28.4	29.0	29.4	30.8	37.3	0	0	1	0
omni23	0.2	79.3	78.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0	0	0	0
omni24	0.1	29.2	29.0	29.1	29.1	29.2	29.3	29.3	29.6	30.1	0	0	1	0
omni25	0.2	29.3	29.3	31.0	30.9	31.4	31.4	31.6	32.9	40.1	0	0	1	0
										Totals	36%	13%	64%	50%

2nd Round Results (many lamp types)

C = Candle lamp, D = Downlight, IA = Incandescent A lamp, LA = LED A-lamp,
ML = Low Voltage Multi-reflector (MR-16) lamp,
MR = Line Voltage Multi-Reflector (MR-16) lamp, P = PAR lamp





2nd round testing tabular results

Lamp	100% Output 40 Hz	100% Output 90 Hz	100% Output 200 Hz	100% Output 400 Hz	100% Output Hz	100% Output Unfiltered	20% Output 40 Hz	20% Output 90 Hz	20% Output 200 Hz	20% Output 400 Hz	20% Output 1,000 Hz	20% Output Unfiltered	100% Output IEEE	20% Output IEEE	100% + 20% IEEE	100% Output T-24	20% Output T-24	100% & 20% T-24
C1	0.18	0.88	23.65	28.08	29.67	30.88	0.78	7.48	50.56	55.22	56.30	58.82	0	0	0	1	0	0
C2	0.87	1.83	99.99	100.00	100.00	97.80	2.68	10.78	99.99	99.99	100.00	100	0	0	0	0	0	0
C3	0.29	1.22	52.48	57.31	59.53	61.11	0.78	1.94	13.95	15.82	17.51	16.67	0	1	0	0	1	0
C4	0.21	1.14	15.89	16.63	16.44	17.42	0.77	2.55	26.59	31.89	30.86	31.43	1	0	0	1	1	1
C5	0.57	1.35	2.89	7.88	74.85	70.64	N/A	N/A	N/A	N/A	N/A	N/A	1	0	0	1	0	0
C6	0.59	3.48	45.71	50.10	51.36	52.94	0.49	6.86	40.60	48.24	48.88	48.39	0	0	0	0	0	0
D1	0.41	1.87	14.25	14.31	14.56	14.65	0.18	0.42	15.51	18.48	18.30	18.52	1	1	1	1	1	1
D2	0.14	0.92	13.58	14.36	14.92	15.38	0.56	1.65	11.96	14.58	15.01	14.29	1	1	1	1	1	1
D3	1.93	6.84	100.00	99.99	100.00	100.00	1.10	4.60	99.99	99.99	100.00	100	0	0	0	0	0	0
D4	0.27	0.37	12.35	12.84	13.35	13.38	0.69	0.79	13.33	14.58	16.39	16.13	1	1	1	1	1	1
D5	0.18	0.41	10.86	12.40	12.64	13.38	0.85	5.10	25.69	27.63	29.28	33.33	1	0	0	1	1	1
D6	0.12	0.71	10.86	11.07	11.22	10.98	0.63	2.14	13.03	16.43	17.10	17.65	1	1	1	1	1	1
IA	0.10	0.40	13.52	13.60	13.68	13.92	0.41	3.67	19.72	21.32	22.20	22.58	1	0	0	1	1	1
LA	0.37	1.11	20.82	23.02	23.61	24.14	0.41	3.77	26.95	28.23	30.23	31.25	0	0	0	1	1	1
ML1	2.60	4.68	8.04	11.52	17.06	17.42	0.66	1.38	2.80	4.83	7.46	19.48	0	1	0	1	1	1
ML2	2.10	3.29	6.62	11.00	17.79	19.74	0.62	0.83	1.33	2.14	3.53	17.95	0	1	0	1	1	1
ML3	2.10	5.44	99.99	99.99	99.99	95.65	4.48	17.46	99.98	99.99	100.00	100	0	0	0	0	0	0
ML4	3.31	9.74	99.99	99.97	99.99	96.04	4.59	13.15	99.97	99.99	99.99	100	0	0	0	0	0	0
ML5	1.06	1.87	2.89	4.62	8.16	11.95	0.23	0.31	1.51	2.13	2.66	9.88	0	1	0	1	1	1
ML6	0.72	2.24	69.79	68.01	70.05	68.14	1.50	3.67	82.66	87.95	81.78	80	0	0	0	0	0	0
MR1	0.18	1.00	34.38	36.09	37.40	38.93	0.85	1.86	29.09	33.69	34.74	33.33	0	0	0	0	1	0
MR2	0.30	0.76	43.42	54.84	57.63	59.65	2.59	16.28	96.12	93.33	87.05	87.23	0	0	0	0	0	0
MR3	1.09	3.14	80.39	89.22	86.93	83.67	0.82	1.78	21.82	25.71	28.08	30.43	0	0	0	0	1	0
MR4	1.27	2.89	39.91	43.21	43.98	43.80	0.86	2.26	40.24	42.02	41.40	46.15	0	0	0	0	0	0
P1	0.28	0.91	13.37	15.23	15.36	15.44	0.67	2.97	21.75	24.26	26.26	26.67	1	0	0	1	1	1
P2	0.17	0.53	9.71	10.10	10.16	10.56	0.40	1.17	9.76	10.98	10.83	15.15	1	1	1	1	1	1
P3	0.43	1.64	30.28	31.77	32.23	32.85	0.73	1.93	26.08	29.97	29.86	33.33	0	0	0	0	1	0
P4	0.28	0.92	29.53	35.77	34.27	35.34	N/A	N/A	N/A	N/A	N/A	N/A	0	0	0	1	0	0
P5	0.88	1.19	3.64	5.14	8.26	26.39	1.41	2.45	9.86	16.03	22.91	37.5	1	0	0	1	1	1
												Totals	38%	33%	19%	59%	67%	52%

Data Summary

California Standard (< 30% AM < 200 Hz)

- At full power 60% (32/53) of LED lamps pass
- At 20% of light output 62% (31/50) pass.
- CREE (2014) found that 73% (75/103) of their tested products would pass
  - Flicker problem even for non-dimming lamps
  - CA standard relatively easy to pass

IEEE PAR 1789 Recommended Practice

- At full light output 36% (19/53) passed
- At 20% light output 16% (8/50) passed
  - Possible to pass IEEE standard
  - More likely if lamps rated for flicker

Modernized Appliance Efficiency Database System (MAEDBS)

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Data Certification Forms and Instructions for Manufacturers Lighting Products

Name	last modified Color dates added today	Size
2013 JA8 High Efficacy LEDs.zip	Oct 13, 2016	2.1 mb
	Oct 20, 2016	2 mb
Ballasts (BLST).zip	Aug 17, 2015	2 mb

Old database

New database

Spreadsheet Data Format for Upload

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ
1	Action	Manufacturer	Brand	ModelNumber	LightTech	ProductType	ConnectionType	LightSourceDimmingType	Efficacy	CCT	DUV	CRI	CRIg	StartTime	PowerFactor	TempTest	RatedLife	LumenMaint	SurvivalRate	ProjectedL70	DimmingLevel	NoiseFull	NoiseDimmed	FlickerFullUnfiltered	FlickerFull1000Hz	FlickerFull400Hz	FlickerFull200Hz	FlickerFull90Hz	FlickerFull40Hz	FlickerDimmedUnfiltered	FlickerDimmed1000Hz	FlickerDimmed400Hz	FlickerDimmed200Hz	FlickerDimmed90Hz	FlickerDimmed40Hz	FlickerMinUnfiltered	FlickerMin1000Hz	FlickerMin400Hz	FlickerMin200Hz	FlickerMin90Hz	FlickerMin40Hz	Marking	RegulatoryStatus
2																																											
3																																											

Full Output

20% Output

Min Output

Specifiers: MAEDBS Advanced Search for JA8 Lights

MAEDBS Advanced Search | PublicSearchHelp.pdf

https://cacertappliances.energy.ca.gov/Pages/Search/AdvancedSearch.aspx

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- ☑ Manufacturer
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- ☑ Model Number
- ☑ Light Source Technology
- ☑ Product Type
- ☑ Connection Type
- ☑ Light Source Dimming Type
- ☑ Light Source Initial Efficacy (lumens/watt)
- ☑ Rated Correlated Color Temperature (CCT)
- ☑ DUV
- ☑ Color Rendering Index
- ☑ Color Rendering R9
- ☑ Start Time (milliseconds)
- ☑ Power Factor
- ☑ Ambient or Elevated Temperature Test
- ☑ Rated life (hours)
- ☑ Lumen Maintenance After 6,000 Hour Test (percent)
- ☑ Survival Rate After 6,000 Hour Test (percent)
- ☑ IES LM-80 and TM-21 Projected L70 (inseparable SSL luminaires only) (hours)
- ☑ Minimum Dimming Level (percent)
- ☑ Audible Noise at 100% Light Output (dbA)
- ☑ Audible Noise at 20% Light Output (dbA)
- ☑ Flicker - Percent Amplitude at 100% Light Output (percent)
- ☑ Flicker - Percent Amplitude at 100% Light Output and 1000Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 100% Light Output and 400Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 100% Light Output and 200Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 100% Light Output and 90Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 100% Light Output and 40Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 20% Light Output (percent)
- ☑ Flicker - Percent Amplitude at 20% Light Output and 1000Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 20% Light Output and 400Hz Cutoff Frequency (percent)
- ☑ Flicker - Percent Amplitude at 20% Light Output and 200Hz Cutoff Frequency (percent)

Specifiers: Download and Review Flicker Data

https://cacertappliances.energy.ca.gov/Pages/Search/AdvancedSearch.aspx

Search

Search Clear

Search Results 37 record(s) found

Export To: Excel CSV

	Manufacturer	Brand	Model Number	Light Source Technology	Product Type	Connection Type	Light Source Dimming Type	Light Source Initial Efficacy (lumens/watt)	Rated Correlated Color Temperature (CCT)	DUV	Color Rendering Index	Color Rendering R9

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	S	T	U	V	W	X	Y	Z
1	Manufacturer	Brand	Model Number	Light Source Technology	Product Type	Connection Type	Light Source Dimming Type	Light Source Initial Efficacy (lumens /watt)	Rated Correlated Color Temperature (CCT)	DUV	Color Rendering Index	Color Rendering R9	Start Time (milliseconds)	Power Factor	Ambient or Elevated Temperature Test	Rated life (hours)	Lumen Maintenance After 6,000 Hour Test (percent)	IES LM-80 and TM-21 Projected L70 (inseparable SSL luminaires only) (hours)	Minimum Dimming Level (percent)	Audible Noise at 100% Light Output (dbA)	Audible Noise at 20% Light Output (dbA)	Flicker - Percent Amplitude at 100% Light Output (percent)	Flicker - Percent Amplitude at 100% Light Output and 1000Hz Cutoff Frequency	Flicker - Percent Amplitude at 100% Light Output and 400Hz Cutoff Frequency	Flicker - Percent Amplitude at 100% Light Output and 200Hz Cutoff Frequency
2	Fountain	Fountain	LED6871-**	Diode	le	Direct Wired	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.01	0.01	0.01	0.01
3	Fountain	Fountain	LED6892-***	Diode	le	Direct Wired	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.14	0.12	0.12	0.12
4	Fountain	Fountain	LED6894-***	Diode	le	Direct Wired	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.01	0.01	0.01	0.01
5	Fountain	Fountain	LED6872-**	Diode	le	Direct Wired	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.01	0.01	0.01	0.01
6	Fountain	Fountain	LED6893-***	Diode	le	Direct Wired	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.03	0.01	0.01	0.01
7	Cordelia Lighting	Electric	7	Diode	le	Connect	Cut Controls	60	2700	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.1	0.07	0.07	0.07
8	Cordelia Lighting	Electric	0	Diode	le	Connect	Cut Controls	60	4000	0.0033	90	50	300	0.9	Ambient	50000		50000	0.1	24	24	0.1	0.07	0.07	0.07

W	X	Y	Z	AA	AB
Flicker - Percent Amplitude at 100% Light Output (percent)	Flicker - Percent Amplitude at 100% Light Output and 1000Hz Cutoff Frequency (percent)	Flicker - Percent Amplitude at 100% Light Output and 400Hz Cutoff Frequency (percent)	Flicker - Percent Amplitude at 100% Light Output and 200Hz Cutoff Frequency (percent)	Flicker - Percent Amplitude at 100% Light Output and 90Hz Cutoff Frequency (percent)	Flicker - Percent Amplitude at 100% Light Output and 40Hz Cutoff Frequency (percent)
0.01	0.01	0.01	0.01	0.01	0.01
0.14	0.12	0.12	0.12	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01
0.02	0.01	0.01	0.01	0.01	0.01

+ data at 20% dimming and minimum dimming

Summary

Physiological flicker broader scope than TLA

- Perceptible flicker (TLA) and …
- Imperceptible flicker with impact on health and performance
- IEEE PAR 1789 captures both effects of flicker

Flicker is an important metric of lighting quality

- A function of modulation depth **and frequency**

Fourier analysis can provide repeatable decomposition of signal into different frequencies that can be weighted or filtered to better reflect physiological response.

Flicker and Lighting Market

Some really good LED products

- Less flicker than incandescent!

Some really high flicker LED products

- 100% AM at 120 Hz!

- Poorly performing products could poison the market for LEDs and make for unhappy clients

Market transformation tools:

- Minimum flicker standards (i.e. T-24 and T-20)
- Recommended practice: i.e. IEEE PAR 1789
- Information: JA8 database,
- More information: ENERGYSTAR, DLC, CEE – test and list requirement.

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