Metrics for Evaluating Flicker

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ENERGY STAR® Flicker Testing Tutorial
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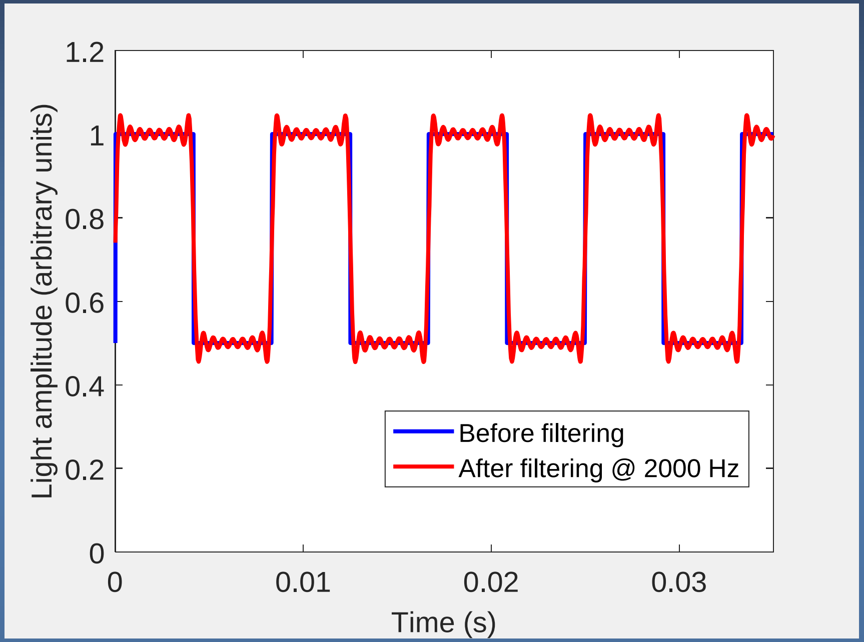
Percent Flicker

$$\text{Flicker Percent} = \frac{Max - Min}{Max + Min} 100$$

- Percent flicker sensitive to extreme points
- Careful when filtering
  - JA10 Standard
- Noise will add to percent flicker
- Applicable to any length waveform, periodic or not



	Percent flicker
Before filtering	33.3%
After filtering:	40.1%

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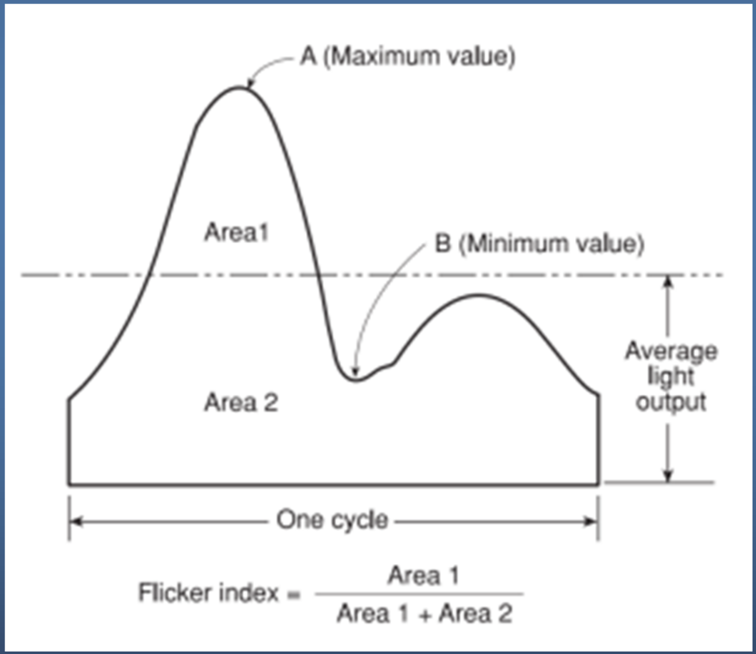
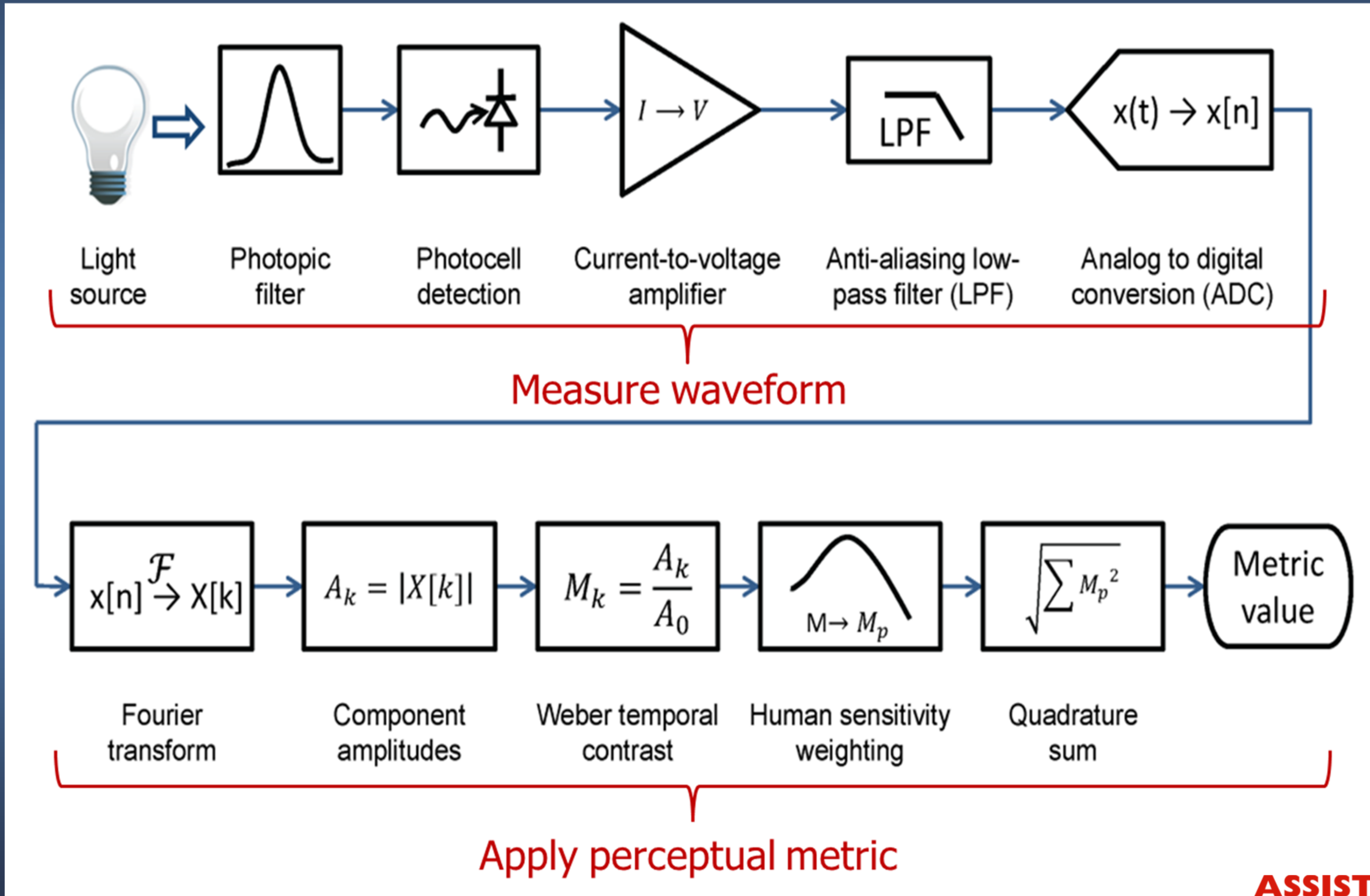
Flicker Index

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



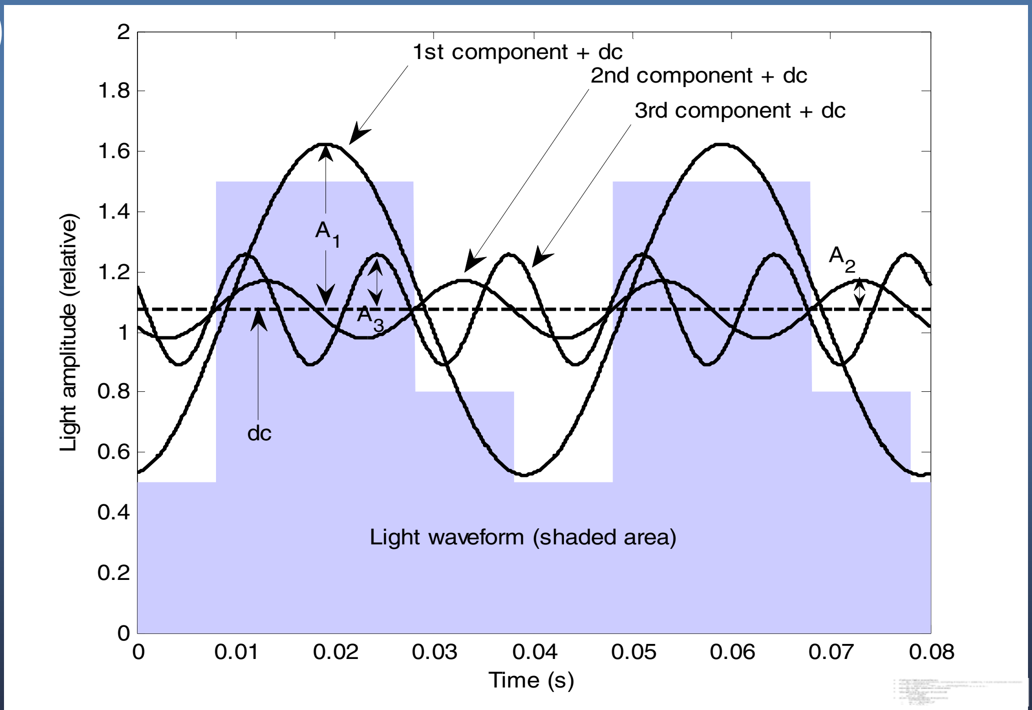
- Insensitive to noisy waveforms
- Developed for line frequency operated fluorescent lamps (50/60 Hz)
- Can be applied to any length waveform, periodic or not, but interpretation is dubious for fundamental frequencies other than 60 Hz
- If periodic waveform length should be integer number of periods

M_p for Direct Flicker



M_P for Direct Flicker

- Collect light waveform
  - Xn = sampled waveform, Sampling frequency > 1000 Hz, > 0.2% amplitude resolution
- Fourier transform
  - $X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{i2\pi kn}{N}}$, $A_k = \frac{\sqrt{Re(X_k)^2+Im(X_k)^2}}{N}$, $k = 1, 2, 3, \ldots$
- Divide by dc (Weber contrast)
  - $M_k = \frac{A_k}{A_0}$
- Weight by human threshold sensitivity
  - $M_{P_k} = \frac{M_k}{M_{DTH_k}}$
- Sum independent frequency components
  - $M_P = \sqrt{\sum_k \left(M_{P_k}\right)^2}$
  - $k = 1, 2, 3, \ldots$



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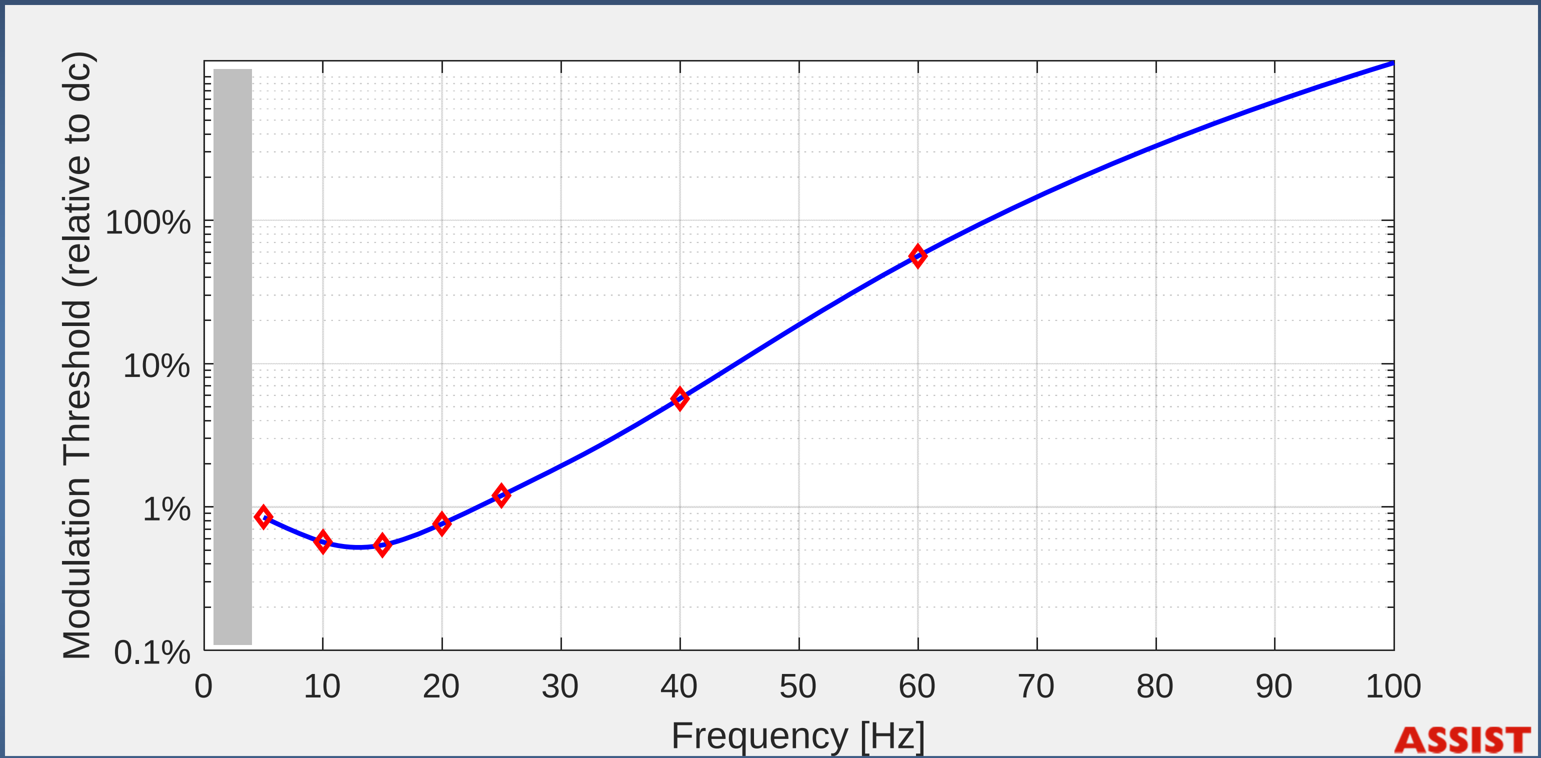
M_P Spectral Weighting Factors



$$M_{DTH} = 1.254 \times 10^{-2} - 7.571 \times 10^{-4} f - 4.007 \times 10^{-5} f^2 + 6.757 \times 10^{-6} f^3 - 2.3306 \times 10^{-7} f^4 + 2.958 \times 10^{-9} f^5$$

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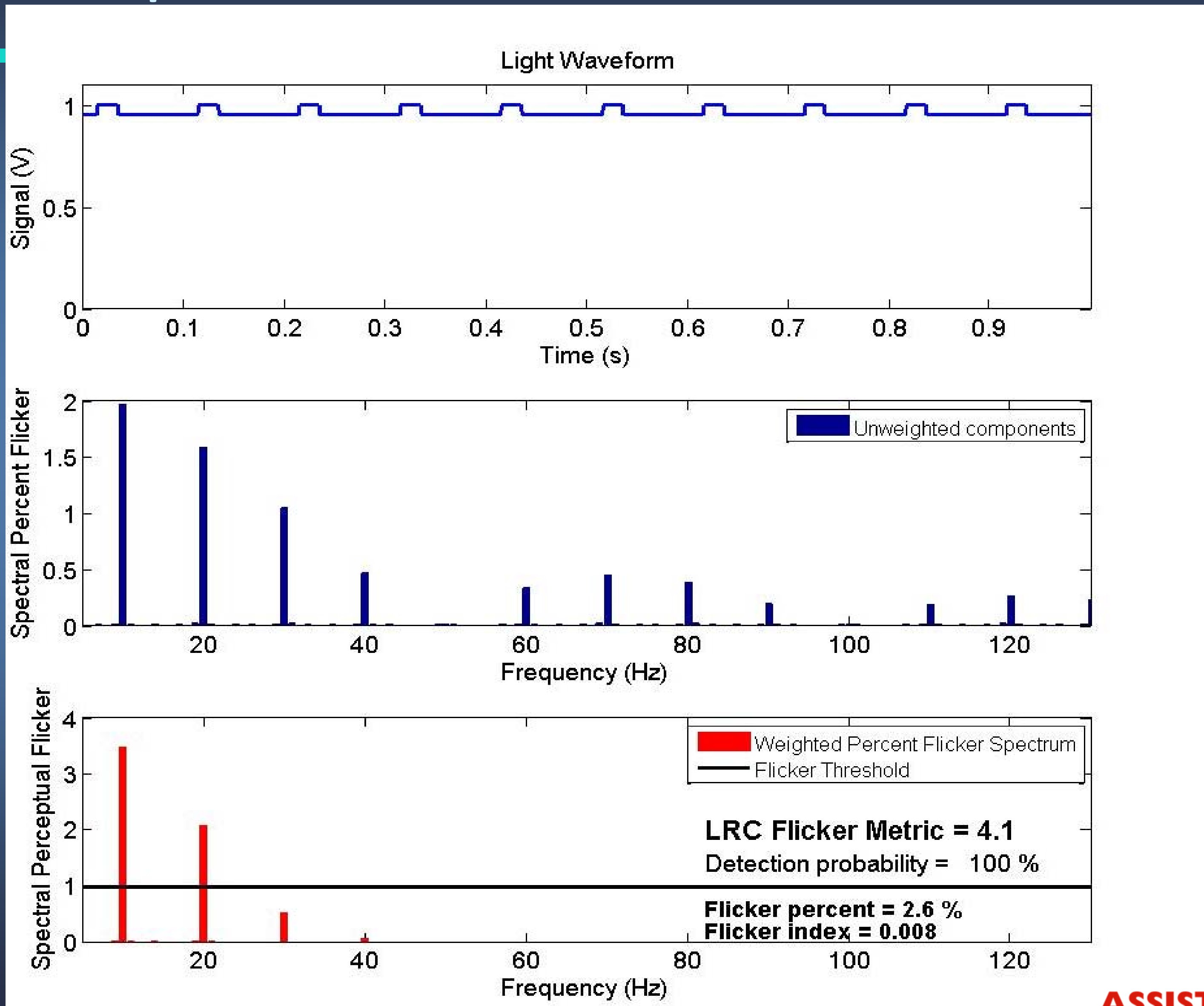
M_P Example



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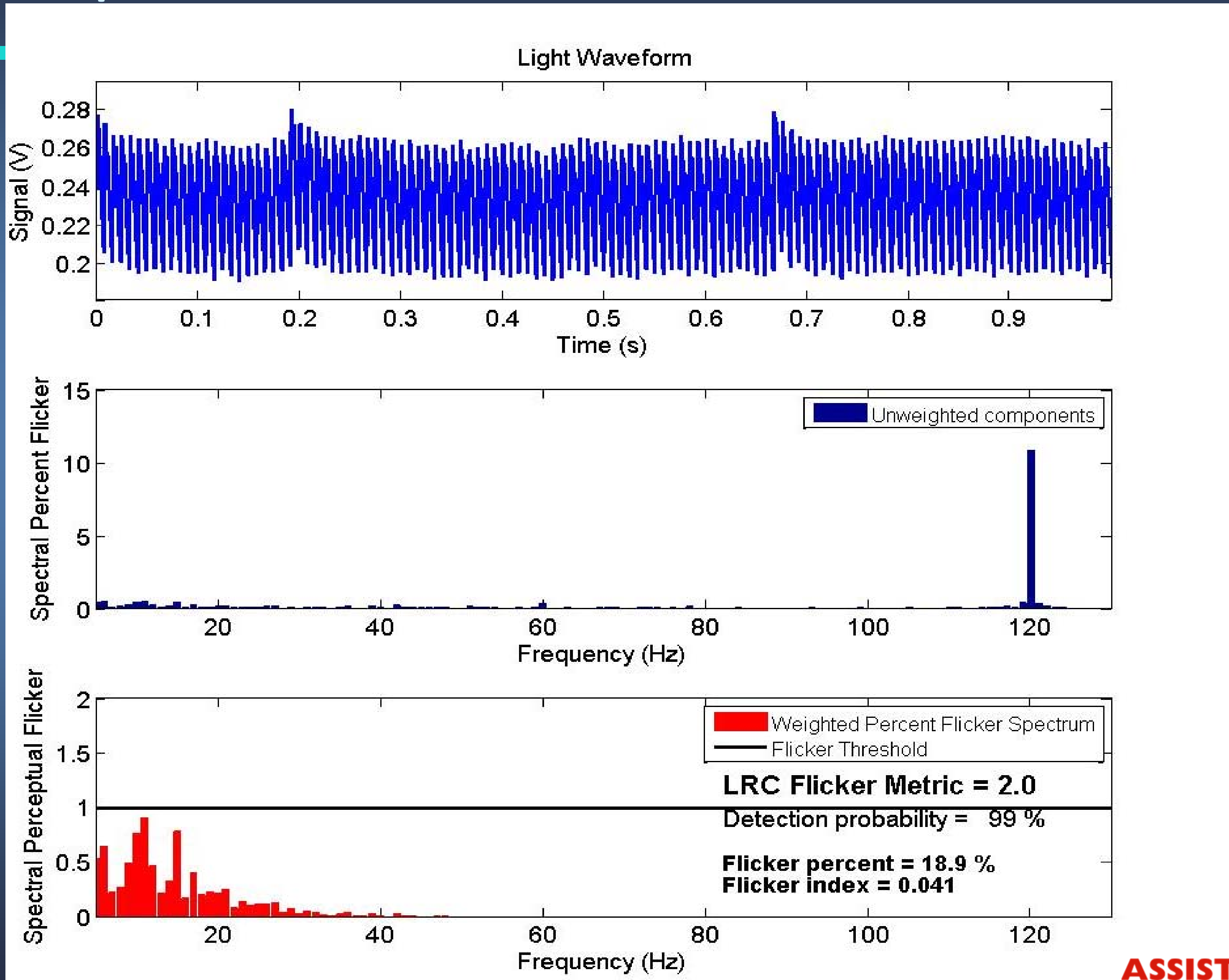
M_P Example



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M_P Waveform requirements

- Waveform length: 2 seconds
  - Lowest frequency is 5 Hz → 1/5 seconds x 10 = 2 s
  - Extra length allows for “window” to minimize finite sampling errors.
- Waveform amplitude precision better than 0.5% (threshold for flicker perception)
- Multiple waveforms (10) are captured to catch transient events
  - Maximum MP for the sample of waveforms is reported
- Waveforms longer than 2 s reduce sensitivity to transients
  - Long waveforms can be split-up into multiple 2-second intervals for processing

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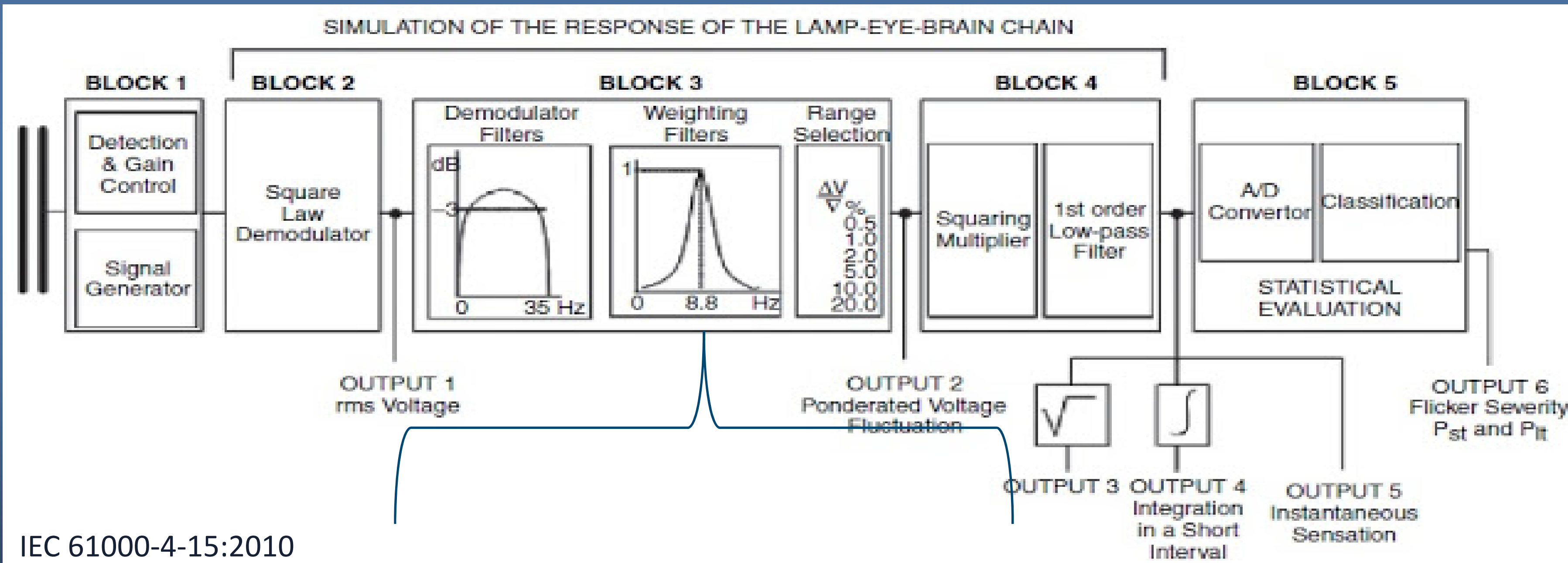
P_{st} for Direct Flicker

- IEC Flicker Meter
  - Flicker from incandescent lamps due to powerline disturbances
  - Omit blocks 1 and 2 when measuring light output directly



IEC 61000-4-15:2010

$$F(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \times \frac{1 + s/\omega_2}{\left(1 + s/\omega_3\right)\left(1 + s/\omega_4\right)}$$

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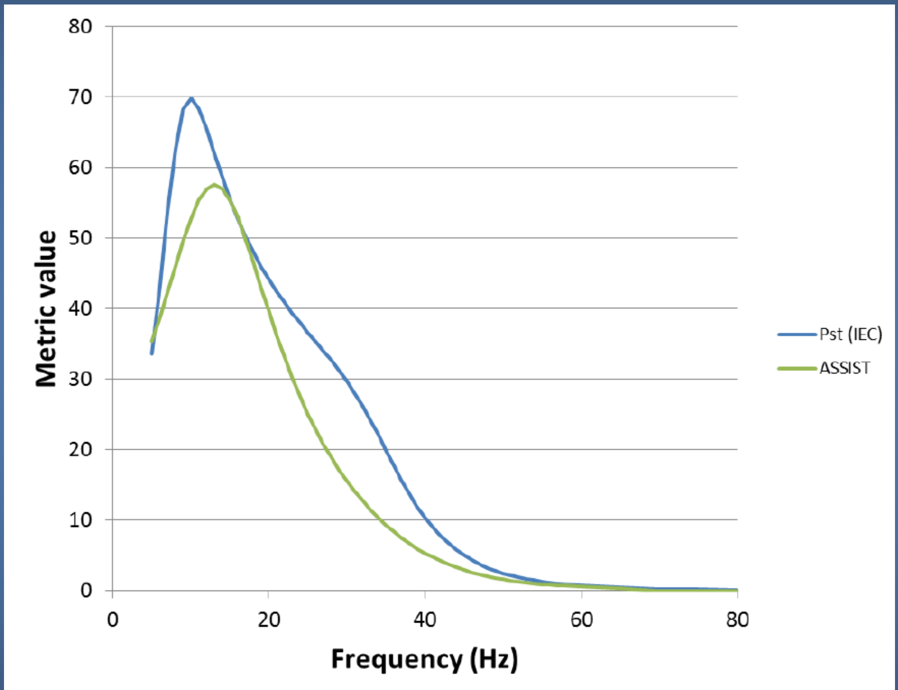
P_{st} (as adopted by NEMA 77 Standard)



Comparison of M_P and P_{st} Spectral weighting

- Calculation are done in the time-domain
  - No Fourier transform
  - Filtered waveform = $P_{st}(t)$
  - Pst = statistical evaluation of $P_{st}(t)$
- Need at least **180 seconds** of waveform data
- First 20 seconds of waveform are removed from final reporting (startup transient)
- Frequency range:
  - ~0.1 Hz to 80 Hz
  - Sampling rate, fs > ~ 200 Hz

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Stroboscopic Visibility Measure (SVM)
(as adopted by NEMA 77 standard)

$$SVM = \sqrt[3.7]{\sum_{m=1}^{\infty}\left(\frac{C_m}{T_m}\right)^{3.7}} \begin{cases} <1 \; not\ visibile \\ =1 \; just\ visibile \\ >1 \; visible \end{cases}$$

M Perz et al. Lighting Res. Technol. 2015; Vol. 47: 281–300
L Wang et al. SID Digest 2015; Issue 50.2: 754 – 757

Cm is the m-th Fourier component of the light output waveform, and *Tm* (Figure 5) is the visibility threshold at the m-th frequency, which weights the Fourier components.

- Calculated from 80 to 2000 Hz
- Waveform amplitude precision > ~5%
  - 8-bit Oscilloscopes are adequate
  - Sampling rate, fs > ~ 5000 Hz

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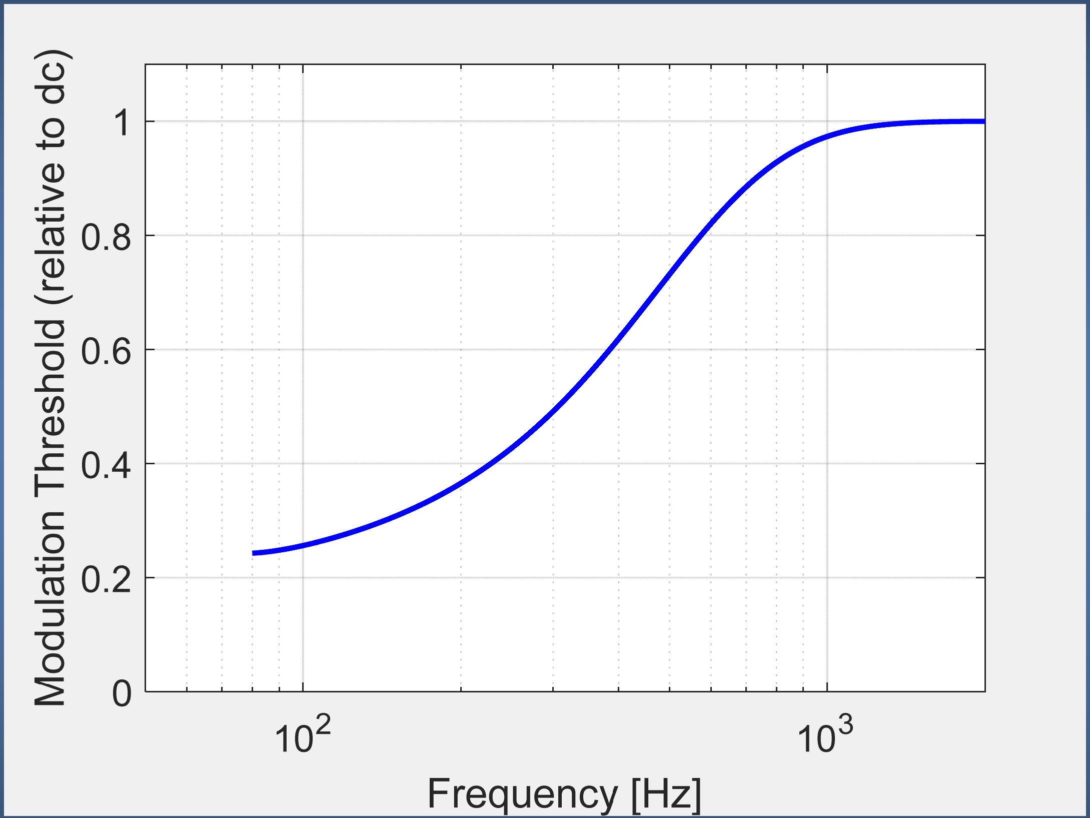
SVM



$$T_m(f) = \left(\frac{1}{1 + e^{-a(f-b)}} + 20e^{-f/10Hz}\right)$$

Where: f is frequency
a = 0.00518 s
b = 306.6 Hz

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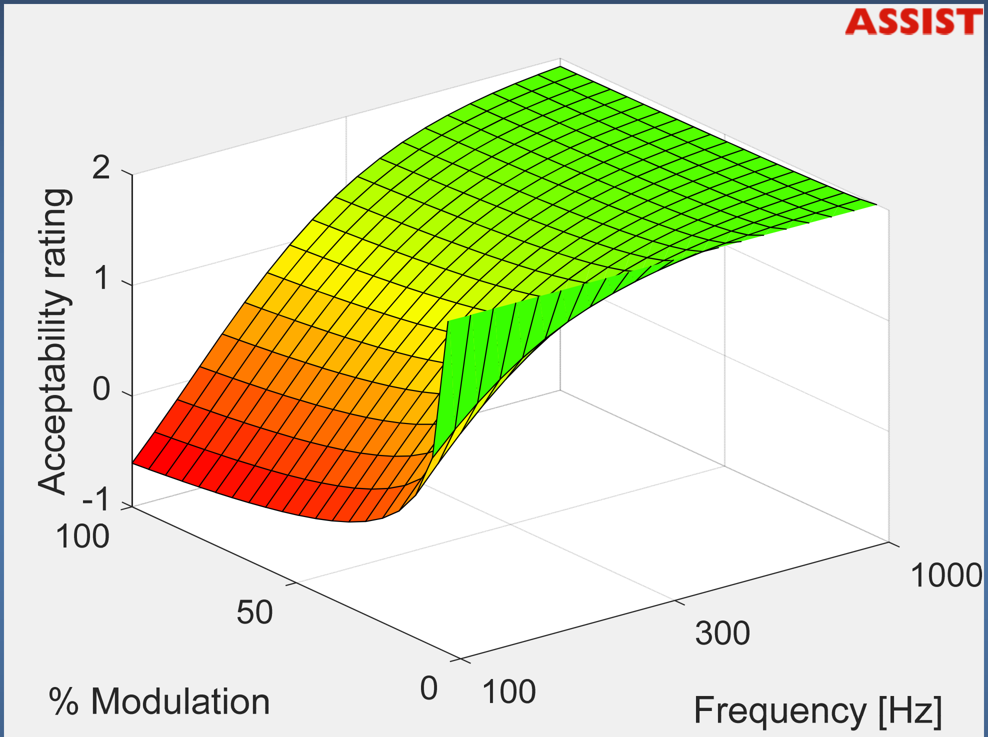
Stroboscopic Acceptability Metric (SAM)

+2 very acceptable
+1 somewhat acceptable
0 neither acceptable nor unacceptable
-1 somewhat unacceptable
-2 very unacceptable

$$a = 2 - \frac{4}{1 + \frac{f}{130 log_{10}(p_P) - 73}}$$

$$p_P = p \underbrace{\frac{C_P(DUT)}{C_P(squarewave, f_{DUT}, p_{DUT})}}_{C_P \text{ ratio}}$$



$$C_P ratio = \frac{\sum_n \Phi_{DUT,n} \exp(i2\pi f_{max} n / f_s)}{\sum_n \Phi_{Square,n} \exp(i2\pi f_{max} n / f_s)}$$

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Ratio of single component discrete Fourier Transforms

Wave shape	C_P ratio (DUT/square)
	% Flicker*: Threshold, 10%, 50%
Square	1.00
Sine	0.78
Rectified sine	0.66, 0.65, 0.59
Ramp	0.64
Rectangular 20% duty cycle	0.59, 0.63, 0.84
Rectangular 80% duty cycle	0.59, 0.55, 0.45
Sawtooth	0.50
Rectangular 10% duty cycle	0.31, 0.34, 0.51

Same waveform measurements requirement as SVM

* For non-symmetrical waveforms the ratio dc(DUT)/dc(square) changes with % flicker

Thank you!

- Acknowledgments
  - ASSIST program sponsors
  - US Environmental Protection Agency
  - LRC faculty, staff and students

Questions?

http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp

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