

ReNormAction!

IBE-BIV seminar 10 November 2022

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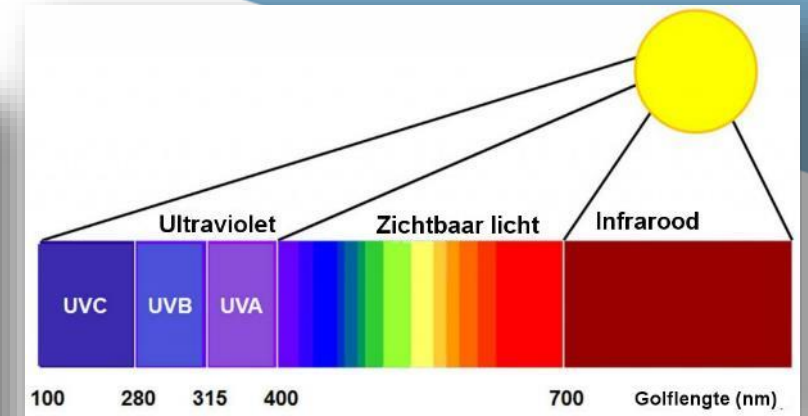
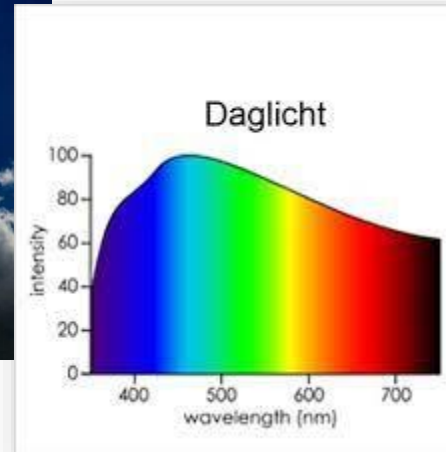
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Temporary Light Modulation

Wouter Wissink, Technology Advisor Volta VZW

IBE-BIV Seminar 10 November 2022

Artificial light versus natural light

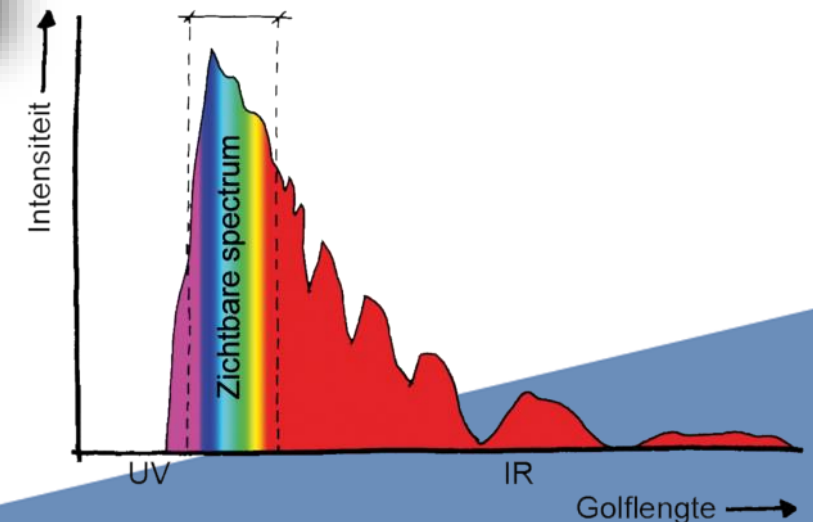


Natural light:

- Full-spectrum & dynamic
 - Light intensity and color temperature vary throughout the day
- UV & IR are blocked by the atmosphere and earth

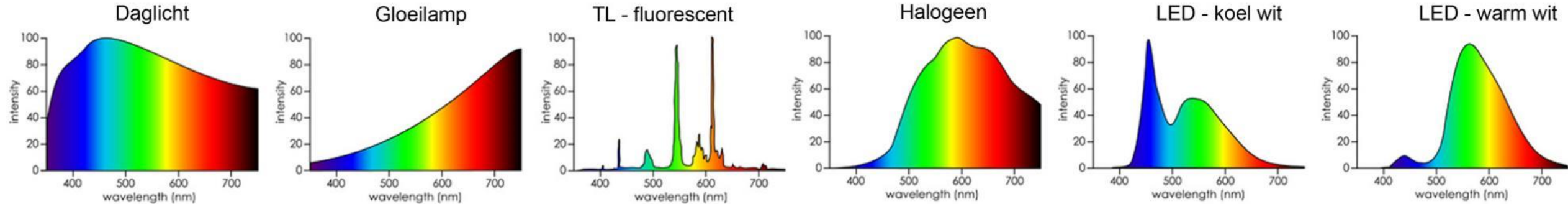
Light affects:

- Day-night rhythm
- Vitamin D balance
- Daylight inhibits melatonin production



Artificial light versus natural light

Emitted spectrum of different types of light sources



Artificial light:

- No source can fully replace daylight
 - Direct impact on complex systems in our bodies
 - Light during the night influences day and night rhythms
- LED is the new standard driven by **energy efficiency**
 - ⇒ Lumen output & spectrum can vary in nanoseconds

Desired: LiFi

- Data transfer by light modulation up to 10Gbps



Undesirable =

- Temporal Light Artefacts (TLA's)

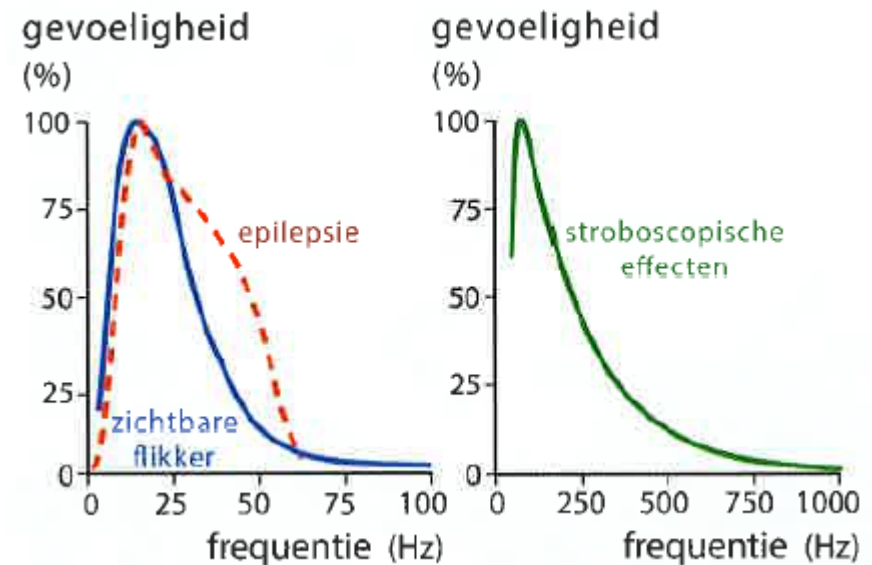
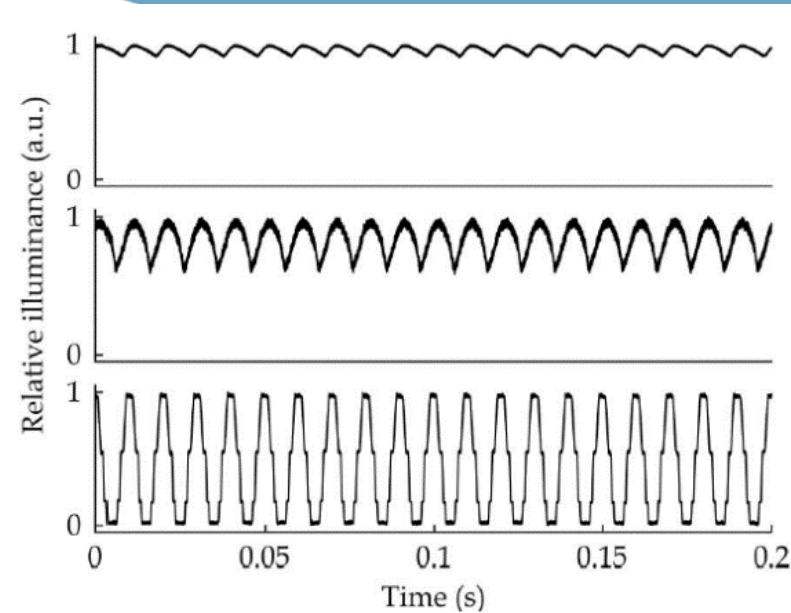
Causes of TLA's

Reason

- AC power 50/60Hz
- Mains voltage fluctuations
- Incompatible control electronics

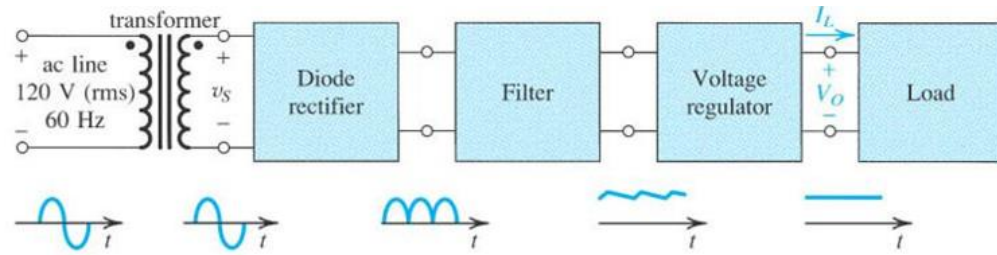
Impact

- Irritation, headache
- Epilepsy

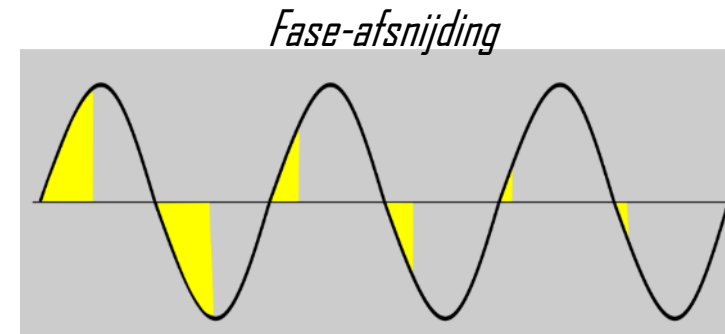
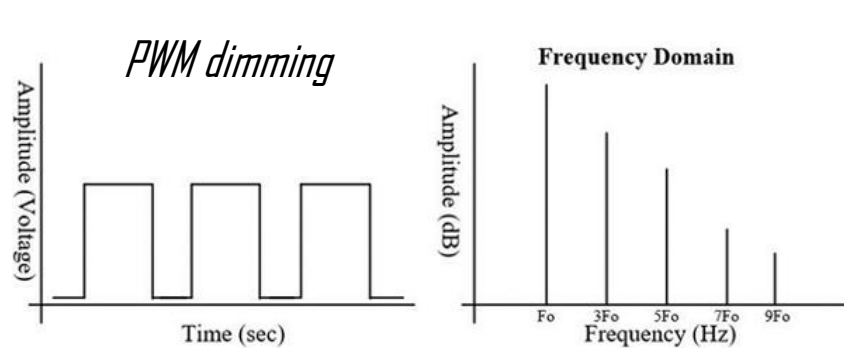


Causes TLA's

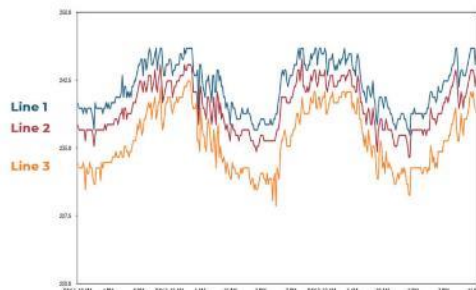
1. 100Hz – mains voltage



2. $\gg 100\text{Hz}$ – switching frequency, vb: Pulse Width Modulation (PWM) of phase-cut dimmers



3. Spikes or fluctuation of main voltage



Very difficult to detect and disprove

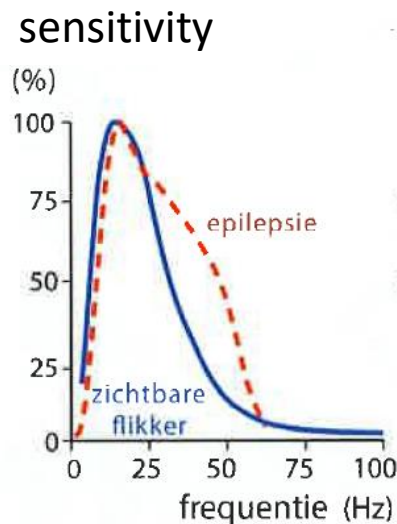
The 3 types of TLAs

Flickering: 0,3 – 80Hz

perception of visual instability, caused by a light stimulus whose luminance or spectral distribution fluctuates with time, for a **static observer in a static environment**

- Immediately visible to the eye
- Can be both periodic and non-periodic
- Gives rise to headache, irritation
- Light flicker has greatest effect on **epileptic attacks**

Does not move his eyes



Note: flicker amplitude also plays a big role

Tool: Spinning wheel makes flicker frequencies visible



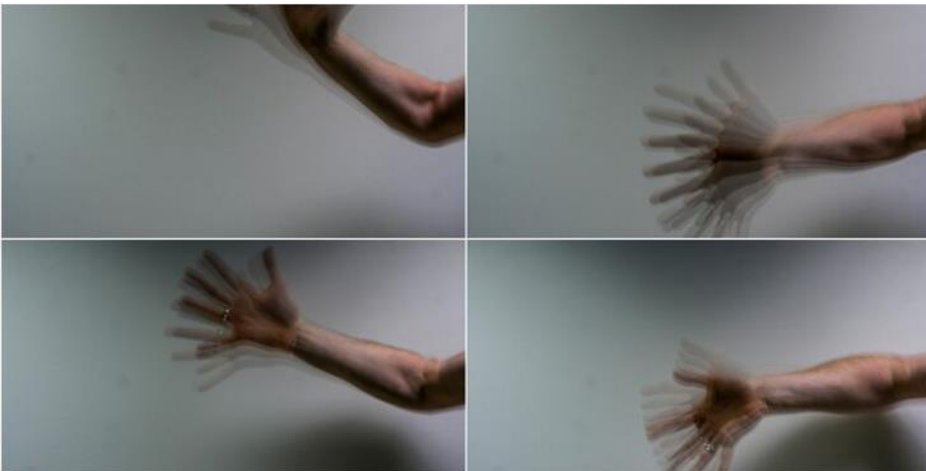
The 3 types of TLAs

Stroboscopic effect: >80 - 2000Hz

change in motion perception caused by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a non-static environment.



- Very common with retro-fit lamps and poor driver designs
- Not directly or difficult to see with the eye
- Experienced as chopped-up movement
- Effect is easy to observe with mobile camera



The 3 types of TLAs

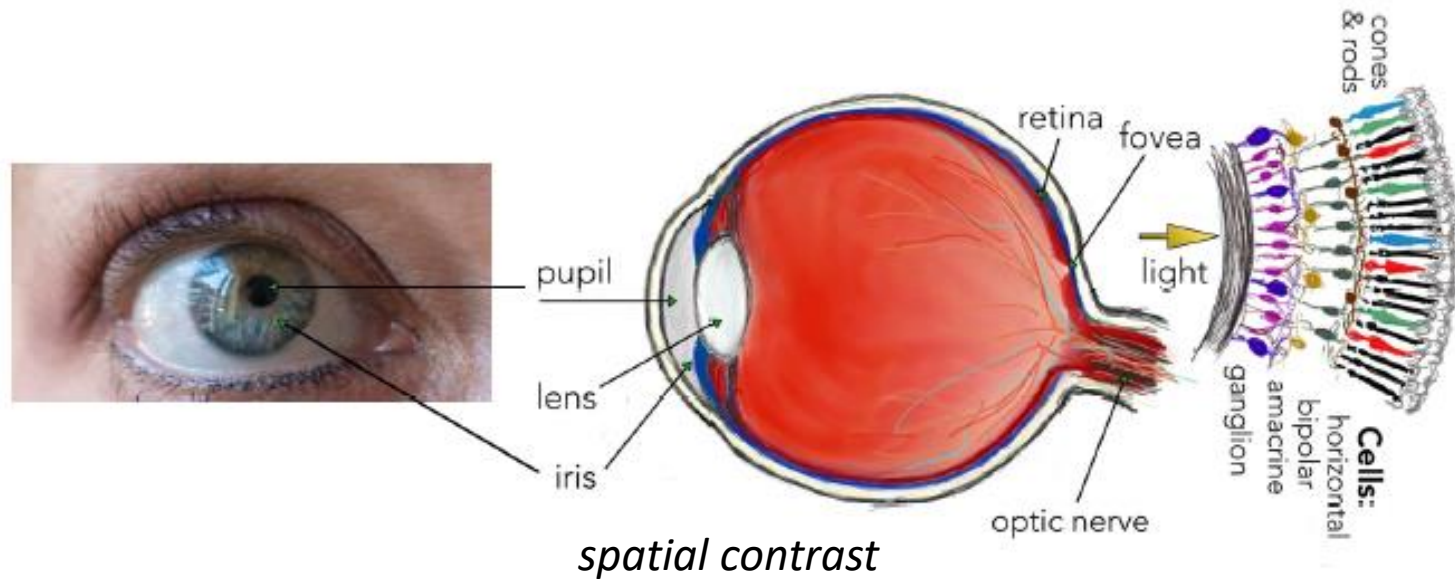
Phantom effect (ghosting)

change in the perceived shape or spatial positions of objects caused by a light stimulus, whose luminance or spectral distribution fluctuates over time, for a non-static observer in a static environment



- Often observed in a high-contrast environment between a small light source (e.g. taillight) with a modulated light source against its background (night)
- Results in the perception of a series of spatially extended copies of the light source

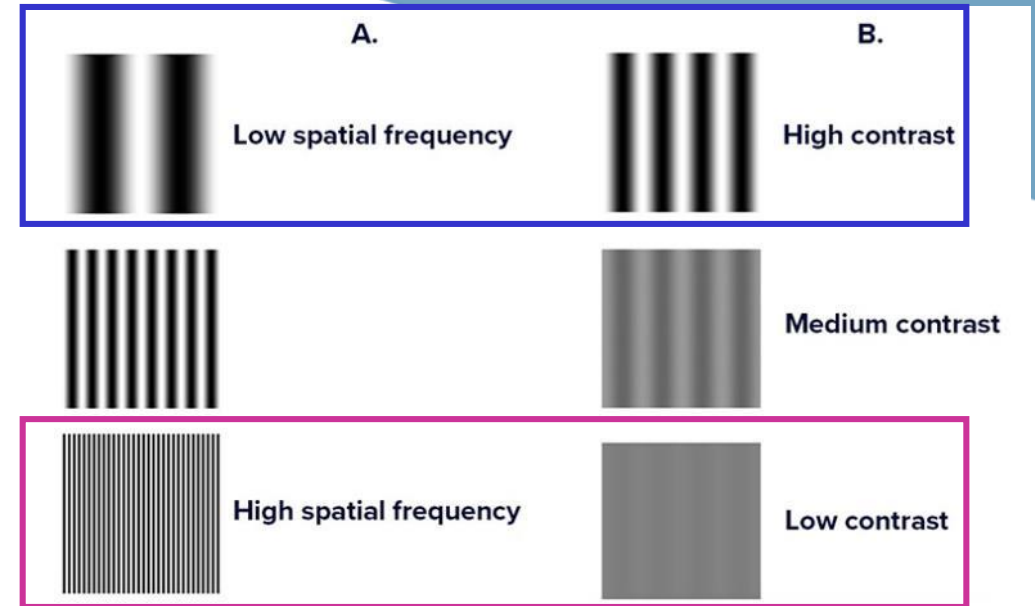
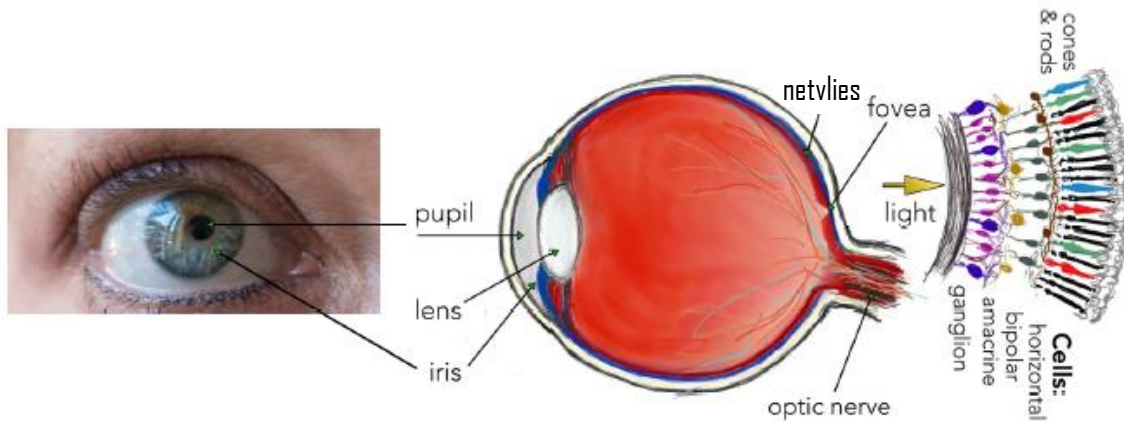
Functioning of cells in the eye



- **rod** highly sensitive to light (night) = scotopic vision, position is in the periphery of our retina
- **Cone** sensitive to color (day) = photopic vision, position is in the center, the fovea

- Eyes must adapt to light-dark changes between cones and rods in speed and amount of light = challenge
- The signal from cone and rods must be further processed by horizontal, bipolar, amacrine and finally the ganglion cells
- the electrical signal is integrated and converted into nerve spikes

Ganglion cells of the eye



3 types of ganglion cells :

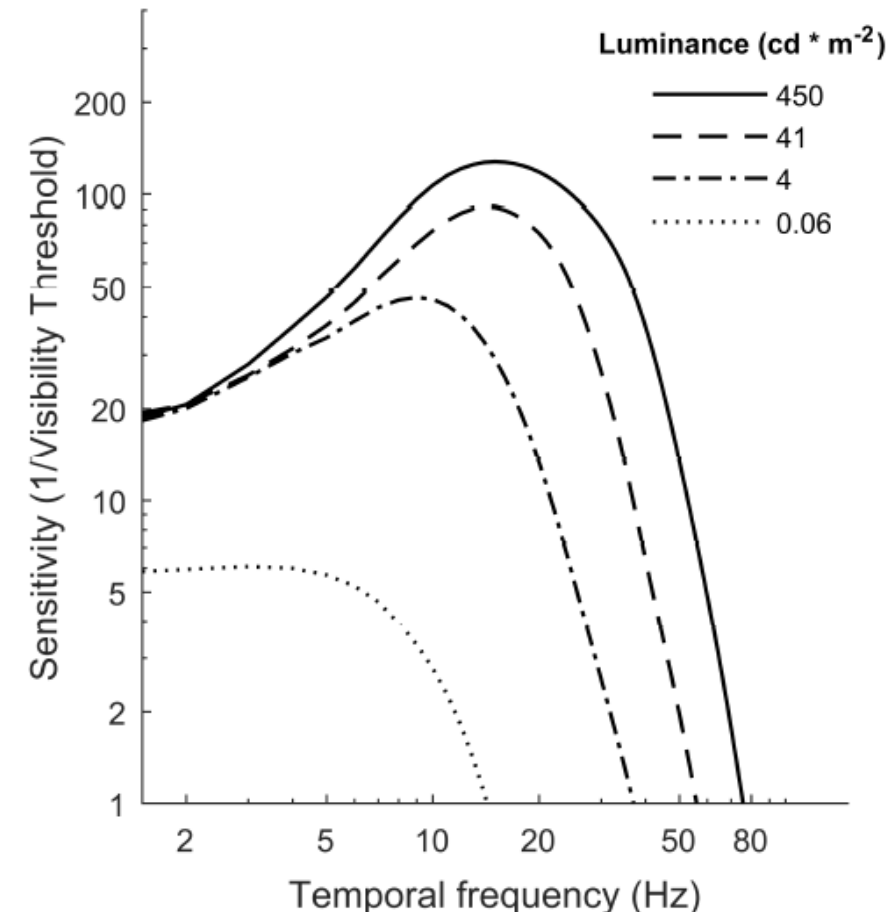
- **Midget:** around fovea \Rightarrow slow and sustained \Rightarrow low contrast detection \Rightarrow sensitive to high spatial frequencies
- **Parasol:** in periphery \Rightarrow fast and transient \Rightarrow sensitive to high contrast detection \Rightarrow low spatial frequencies
- **Bistratified:** unimportant in this story

Visibility and sensitivity

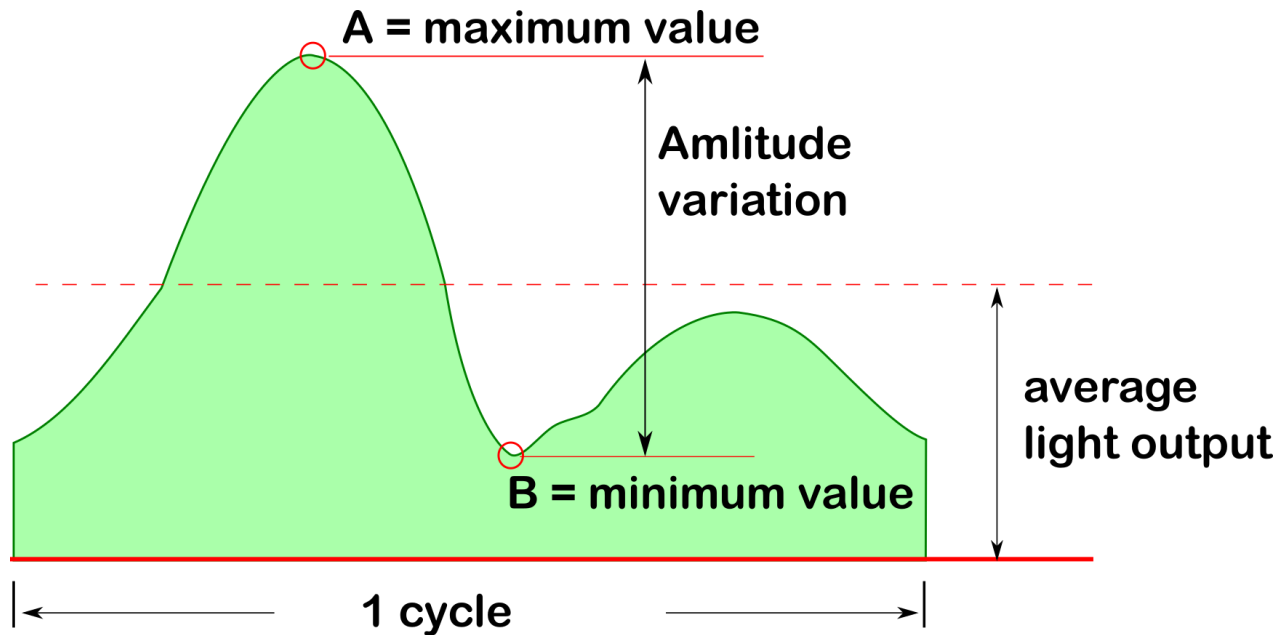
- **Visibility threshold**: smallest amount of intensity of a stimulus needed to produce a perception

$$MD = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad \text{MD: modulation depth}$$

- The modulation depth at the threshold is called **visibility threshold**
- Sensitivity/sensitivity is the inverse of modulation and is called *Contrast Sensitivity Function CSF*



Percentage flicker: peak to peak contrast

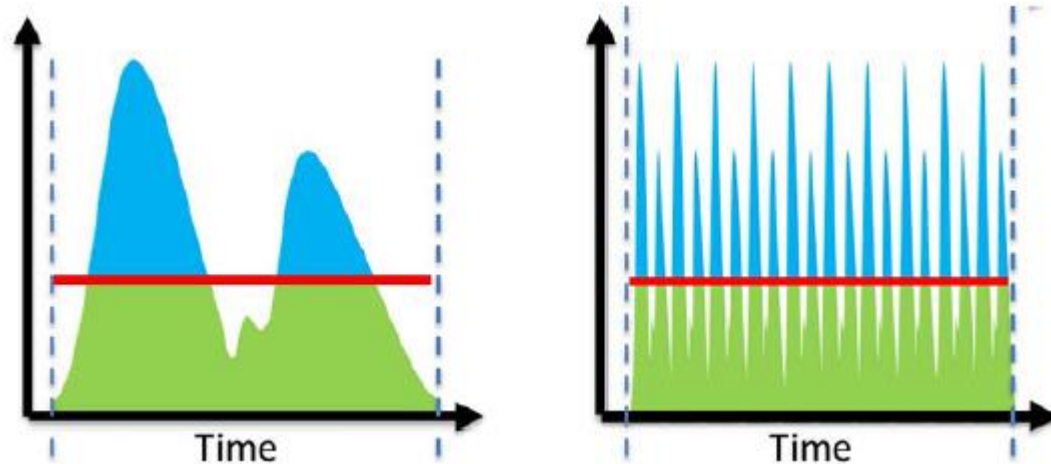
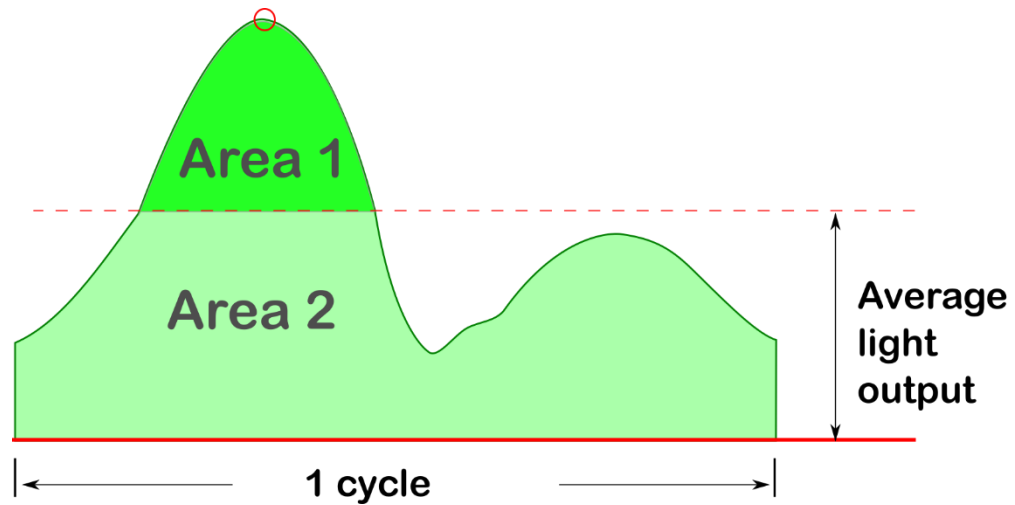


$$\text{Flicker percentage} = \frac{A - B}{A + B} \times 100\%$$

- Based on amplitude
- Easy to calculate
- Independent of the shape of the wave
- Condition: periodic wave

➔ **Disadvantage:** this is a measure of the modulation depth of a stimulus and not the visibility of flickering; only dependent on spikes & no distinction between waveforms

Flickerindex FI



$$\text{Flicker index (FI)} = \frac{\text{Area1}}{\text{Area1} + \text{Area2}}$$

- Based on waveform
- Amount of flicker from the cyclic variation in the power of a light source
- Qualitative light FI < 0.1
- Used to quantify flicker of different light sources

Disadvantage: both percentage flicker and Flicker Index are based on 1 cycle so effect of frequency is not included!

De Minkowski exponent – Fourier analyse

$$FVM = \sqrt[n]{\sum_{m=1}^{\infty} \left(\frac{Cm}{Tm}\right)^n}$$

<1 not visible

=1 just visible

>1 visible

Cm: amplitude of the m-th Fourier component divided by DC value = dimensionless energy

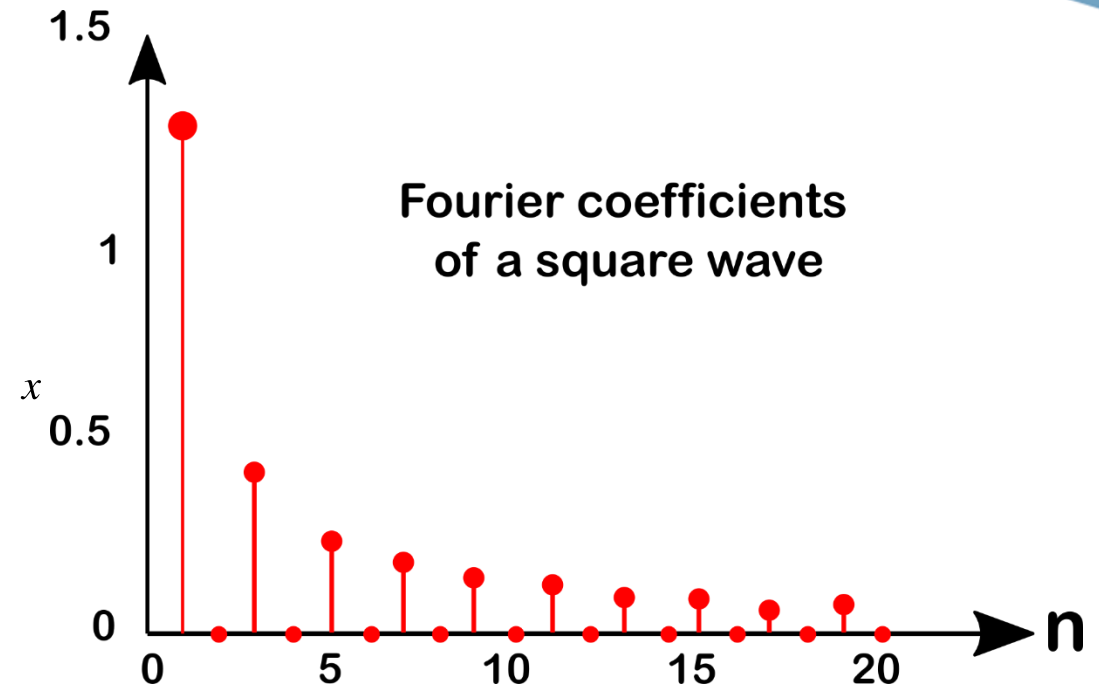
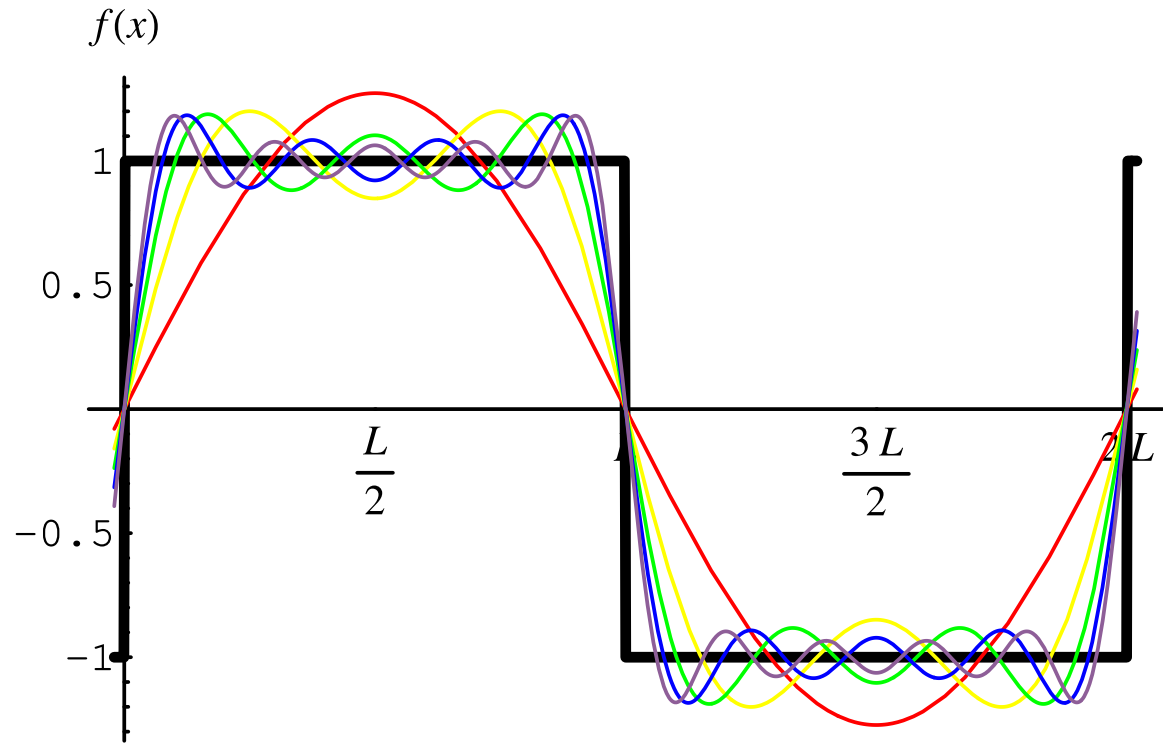
Tm: visibility threshold of a sine wave at the corresponding frequency

Cm/Tm: normalized energy

$$FVM = \sqrt[3.7]{\sum_{m=1}^{\infty} \left(\frac{Cm}{Tm}\right)^{3.7}}$$

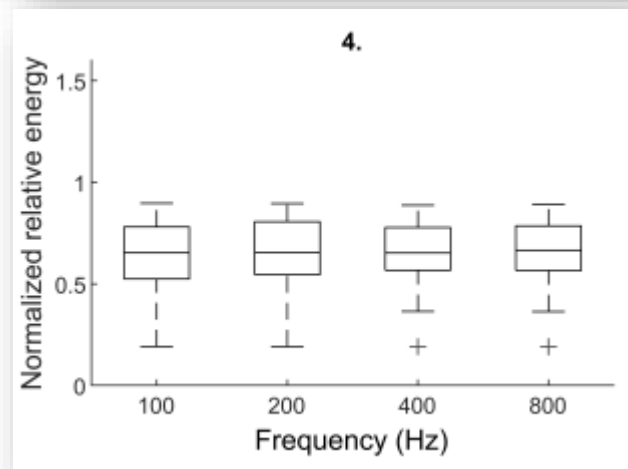
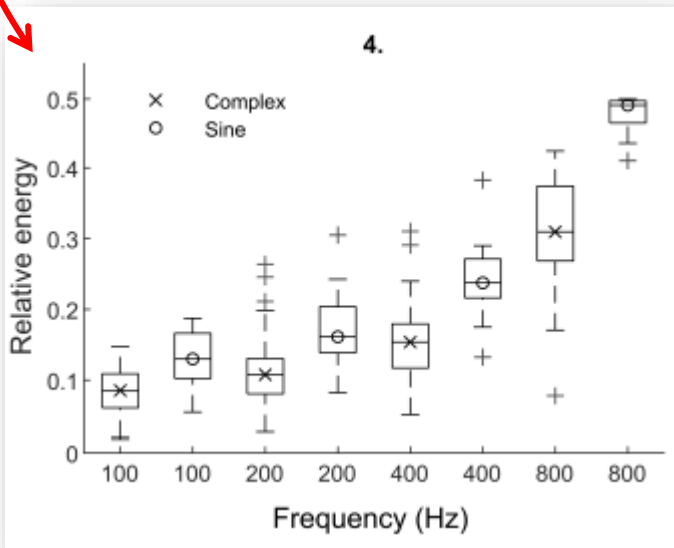
Note: factor 3.7 = experimenteel vastgesteld

Fourier analysis

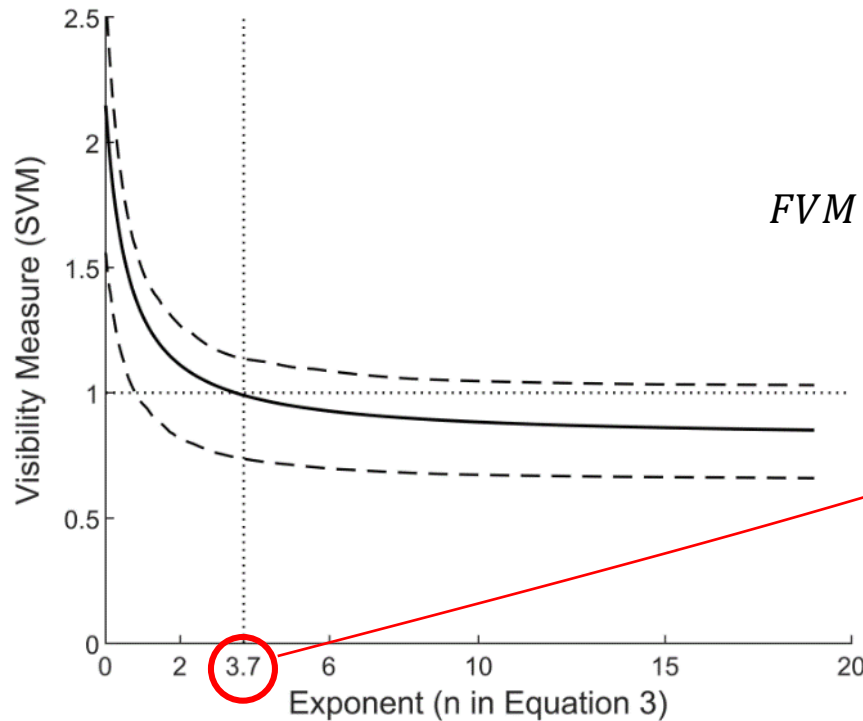


No.	Frequency components			
1	100 Hz	200 Hz		
2		200 Hz	400 Hz	
3	100 Hz	200 Hz	400 Hz	
4	100 Hz	200 Hz	400 Hz	800 Hz

1. Complex waveform created consisting of multiple sinus (table) with same VT
2. Relative energy measured
3. Normalized energy using VT of individual sine waves



n: if we add up all the normalized energy values \Rightarrow
FVM must be = 1

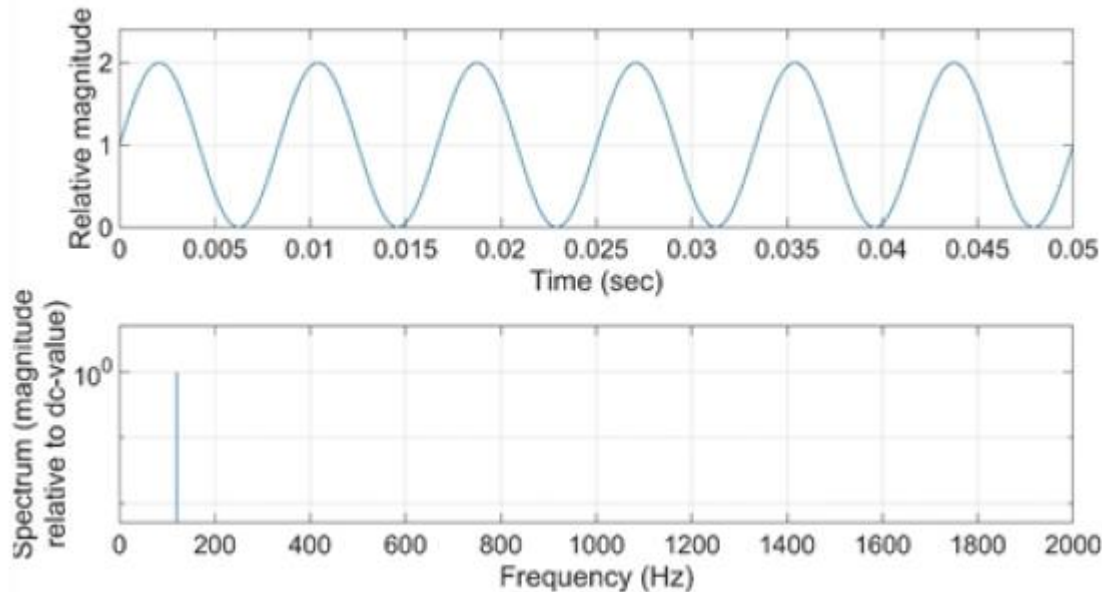


$$FVM = \sqrt[3.7]{\sum_{m=1}^{\infty} \left(\frac{C_m}{T_m} \right)^{3.7}}$$

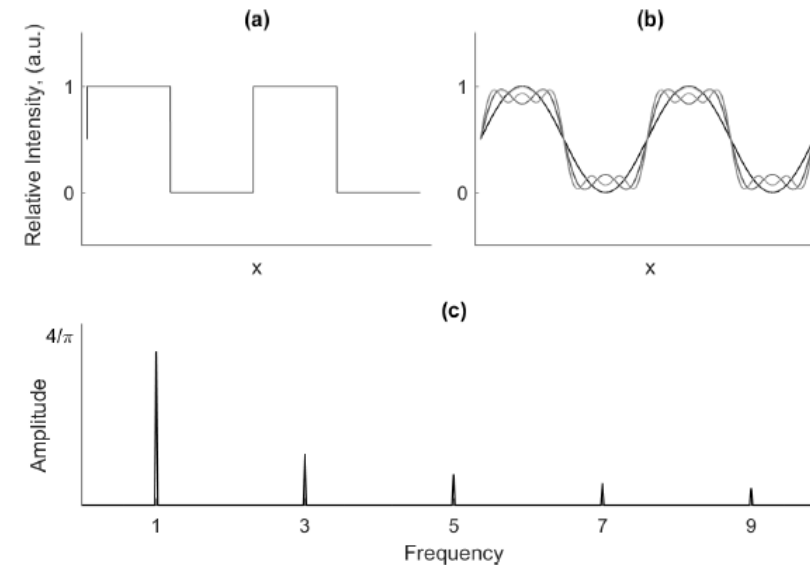
SVM

- Based on both frequency and luminance level
 - Luminance: office 500lx and streetlighting 10-20lux
 - Frequencies: only on sine is not sufficient due to max. fourier < 1

MD sinus ≤ 1



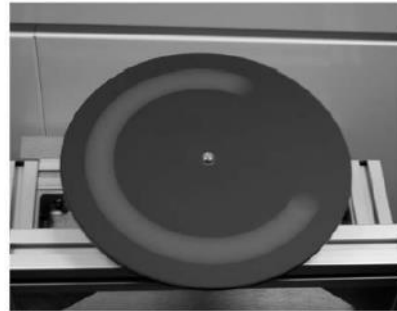
MD blok golf = $4/\pi$



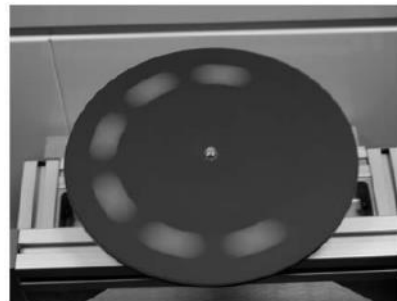
Measuring TLA's



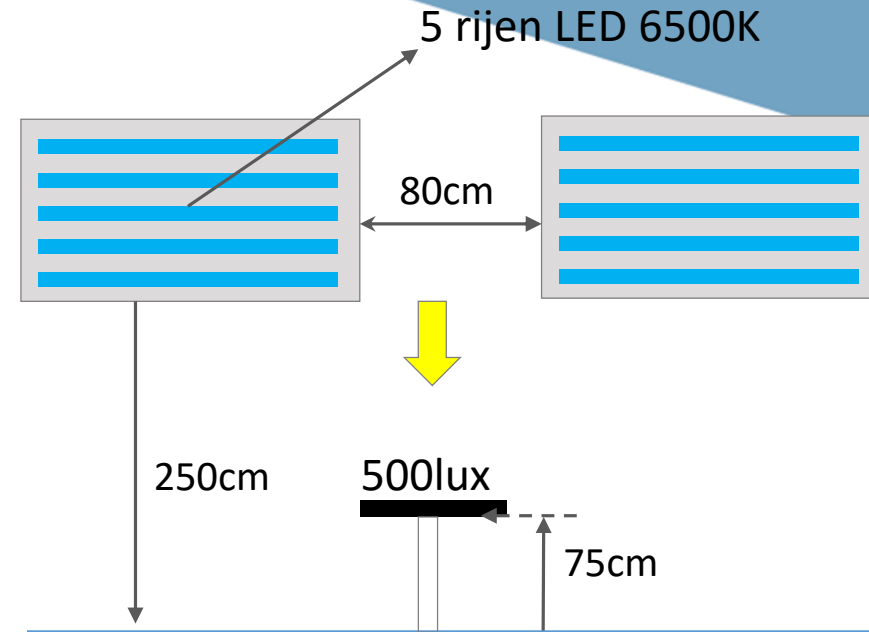
(a)



(b)



(c)



- Disc of 27 cm diameter
- Black surface with reflection of 7%
- White dots with reflection of 81% (diameter 2.6cm)
- Rotation 4m/s (max. movement in an office)

Experiment trials : frequencies

Test	F1 [Hz]	F2 [Hz]	F3 [Hz]	F4 [Hz]	F5 [Hz]	F6 [Hz]	F7 [Hz]	F8 [Hz]	F9 [Hz]	golfvorm
1	50	100	200	400						Sinus
2	50	100	200	400						Sinus + (square wave) blok golf
3	50	100	200	400	800					Sinus repeat test 1 + 800Hz
4	100	150	200	250	300	400	500	750	800	Sinus

Trial 1,2 and 3 in Western Europe with about 20 people, different ages

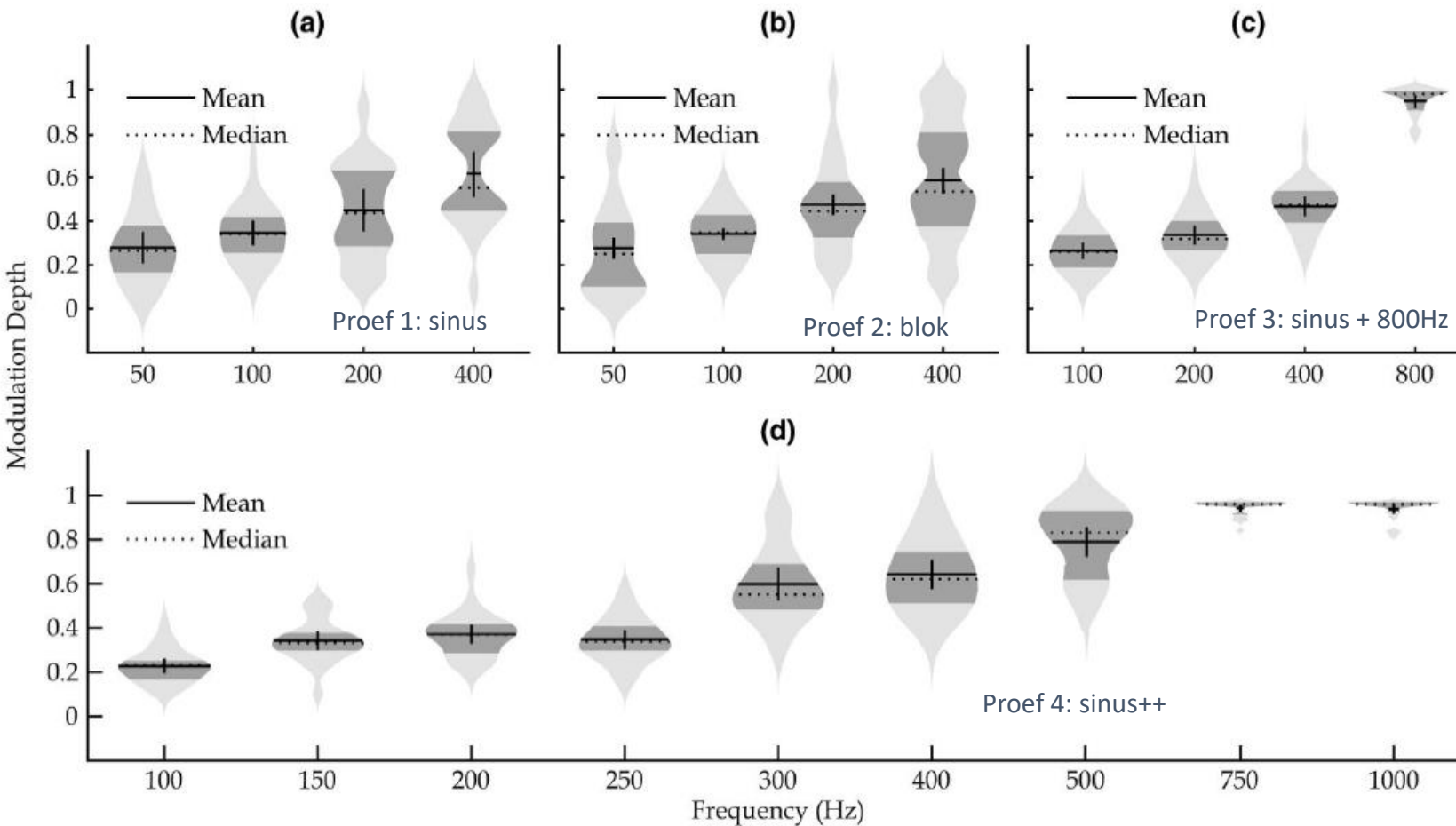
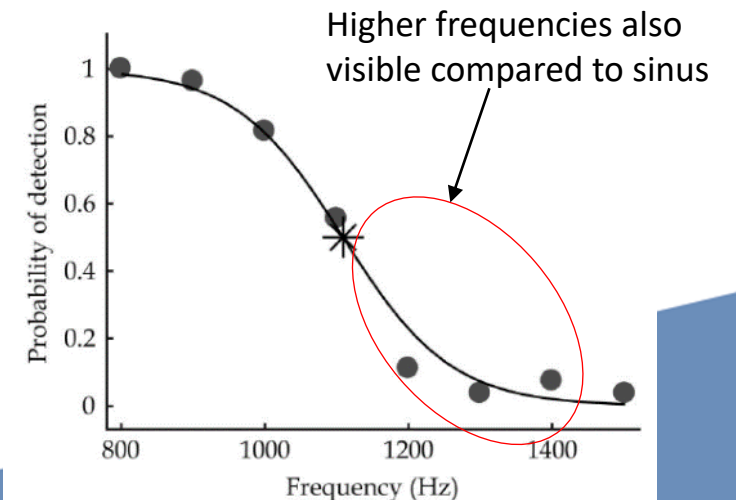
Trial 4 in Asia 21 people aged 21 to 47

Experiments results : frequenties

Conclusions:

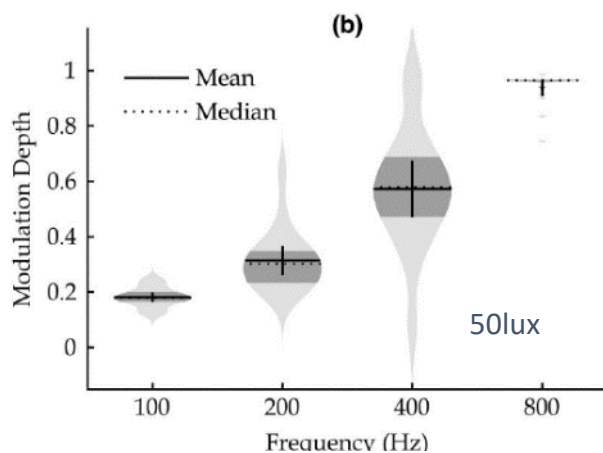
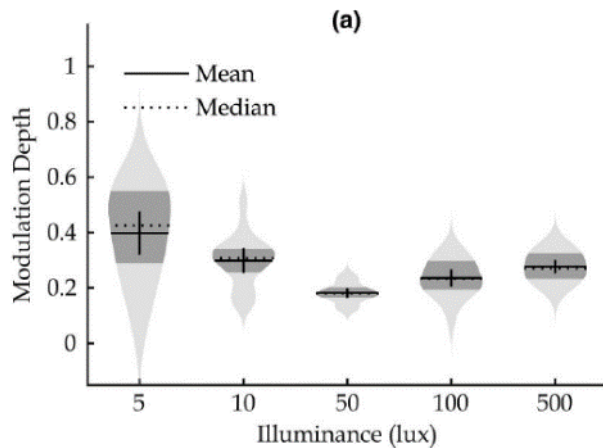
- If you divide the amplitude of the block by /4 you obtain the sine wave
- At high frequencies in trial 3&4:
 - Max modulation of sine = 1 is almost invisible to anyone >750Hz

Puur blokgolf:



Experimental tests: different illuminances

- Previous tests were with 500lux = office, street lighting is much lower, so extended tests needed:
- 5 different levels: 5 lux, 10 lux, 50 lux, 100 lux and 500 lux
- At 50 lux also different frequencies: 100/200/400Hz and 800Hz



Results:

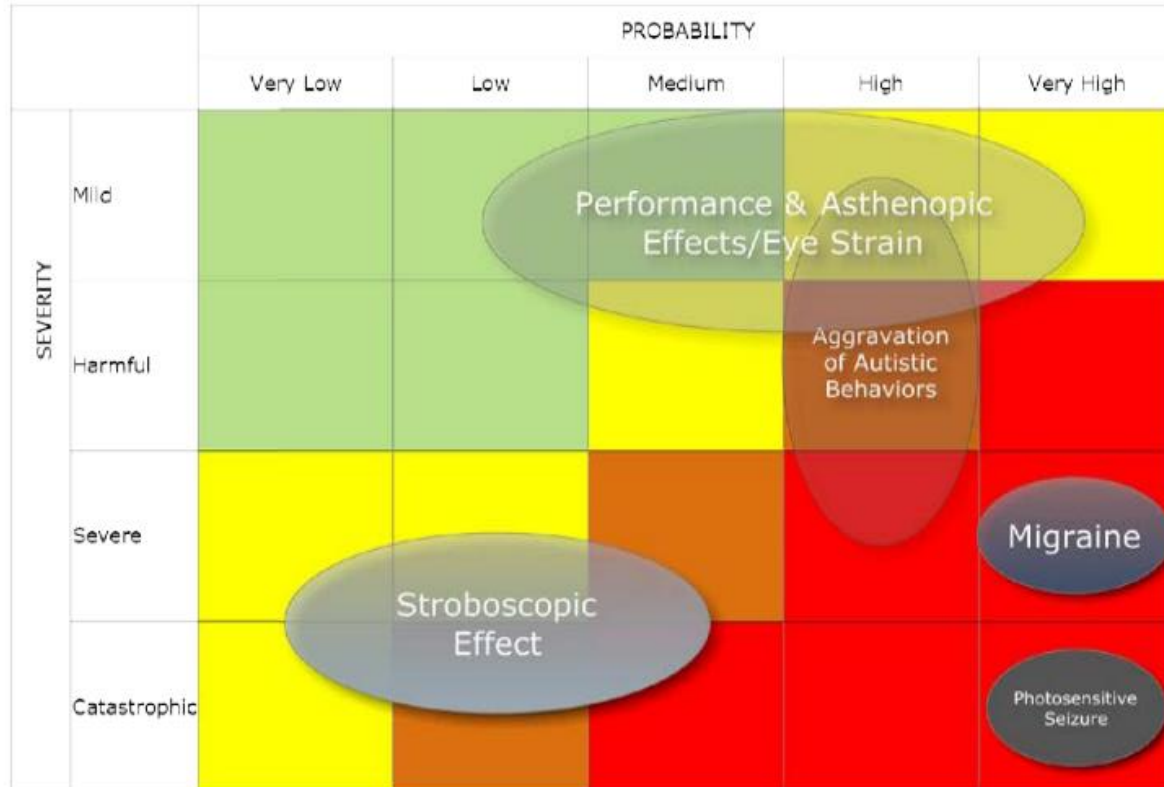
- Huge deviation at 5lux
- Lowest threshold at 50 lux MD
- At $f = 100\text{Hz}$ lowest threshold frequency (50lux)
- High sensitivity at 50lux

Conclusions:

- Results of 100Hz and 50lux can be compared with the results of 500lux in previous measurements
- For low illuminance levels the results differ scotopic vision plays a role

IEEE 1789-2015

- IEEE recommended practices for Modulating Current in High-Brightness LEDs for mitigating Health Risks to Viewers



NOTE—Greater saturation corresponds to greater certainty.

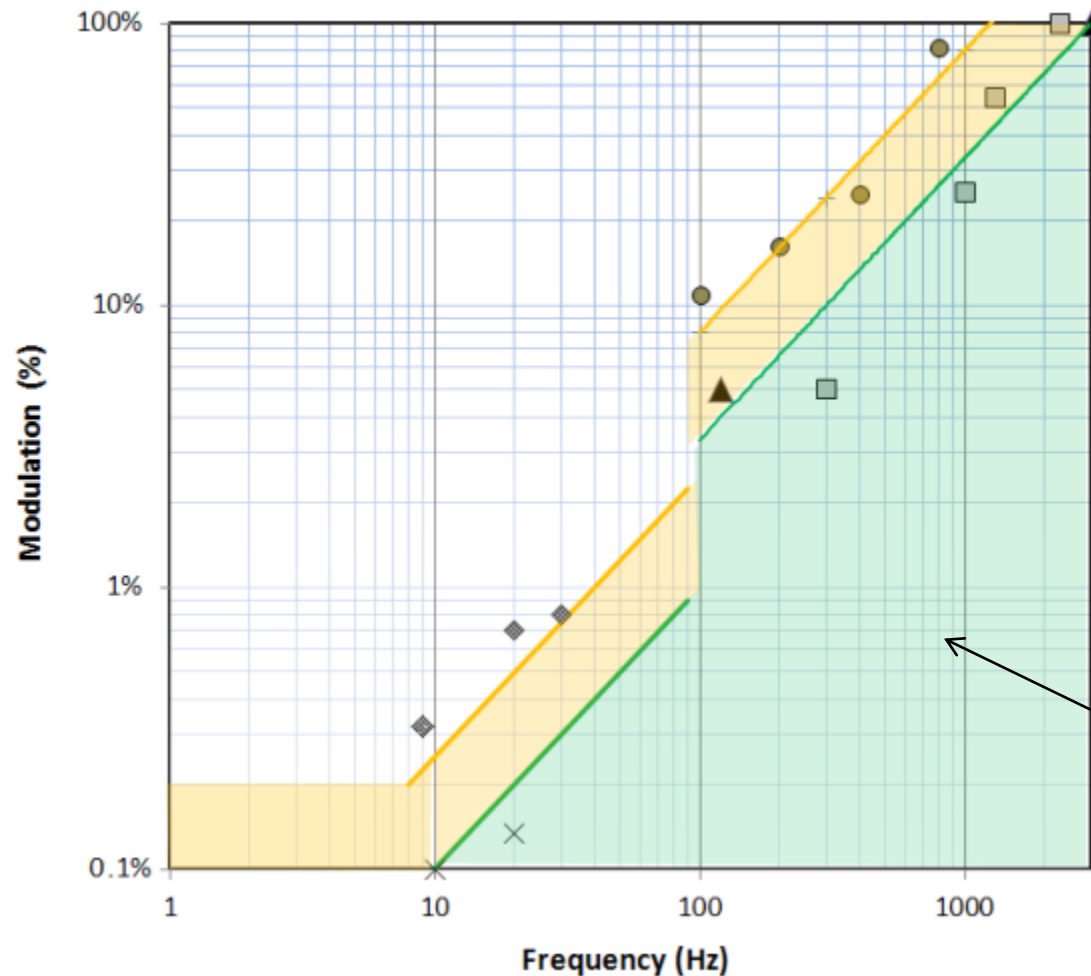
Figure 16—Risk matrix by hazard

Table 2—Risk matrix

Severity	Probability				
	Very low	Low	Medium	High	Very high
Mild	Light Green	Light Green	Light Green	Yellow	Yellow
Harmful	Light Green	Light Green	Yellow	Orange	Red
Severe	Yellow	Yellow	Orange	Red	Red
Catastrophic	Yellow	Orange	Red	Red	Red

Note: higher saturation color is more certain result

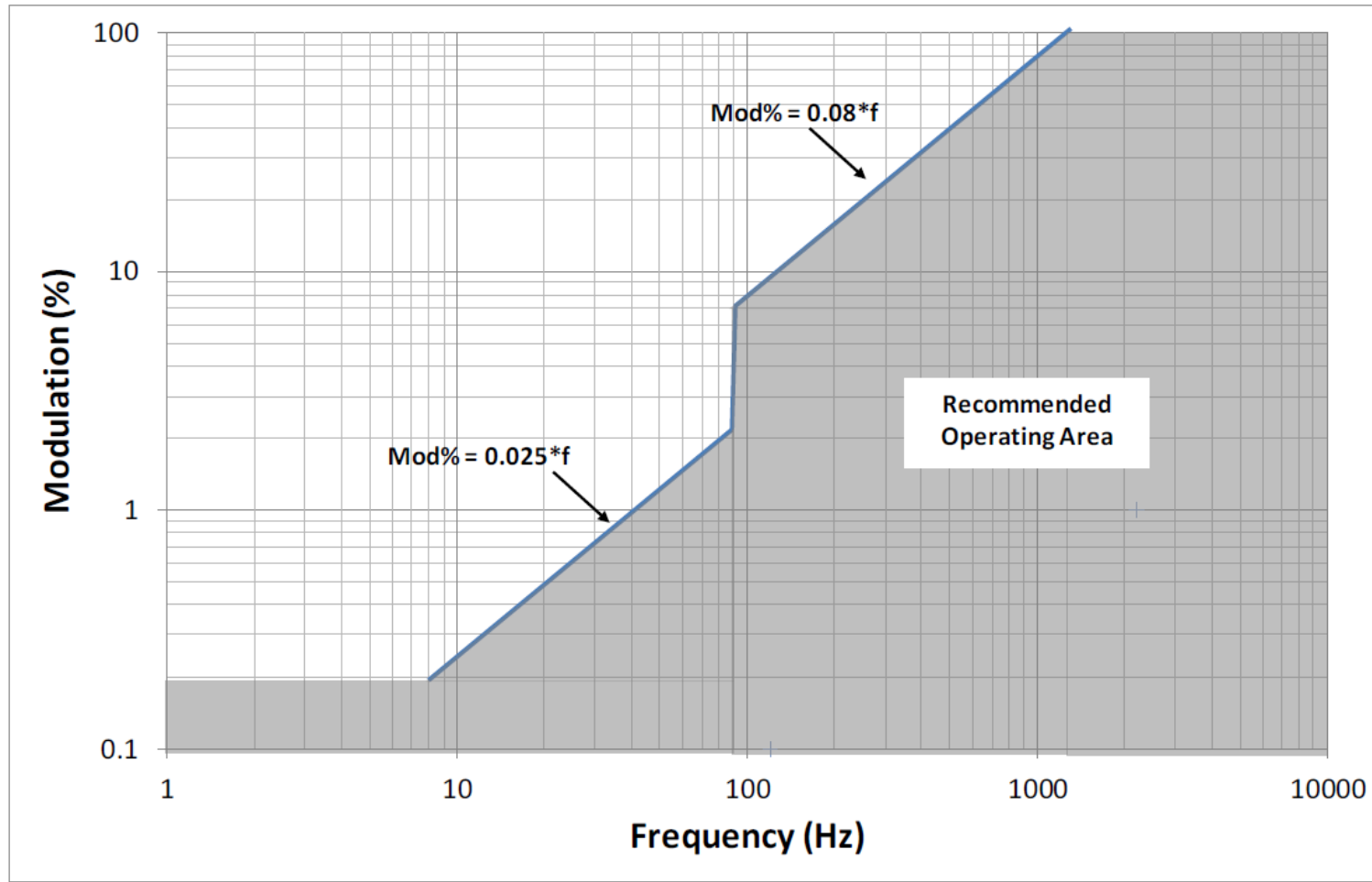
IEEE 1789-2015



- low frequency with high modulation = visible flicker = immediate effects
- flicker with a low modulation and a high frequency become noticeable only after several minutes (e.g. headache).

Green: no effect
Orange: low risk

recommendations

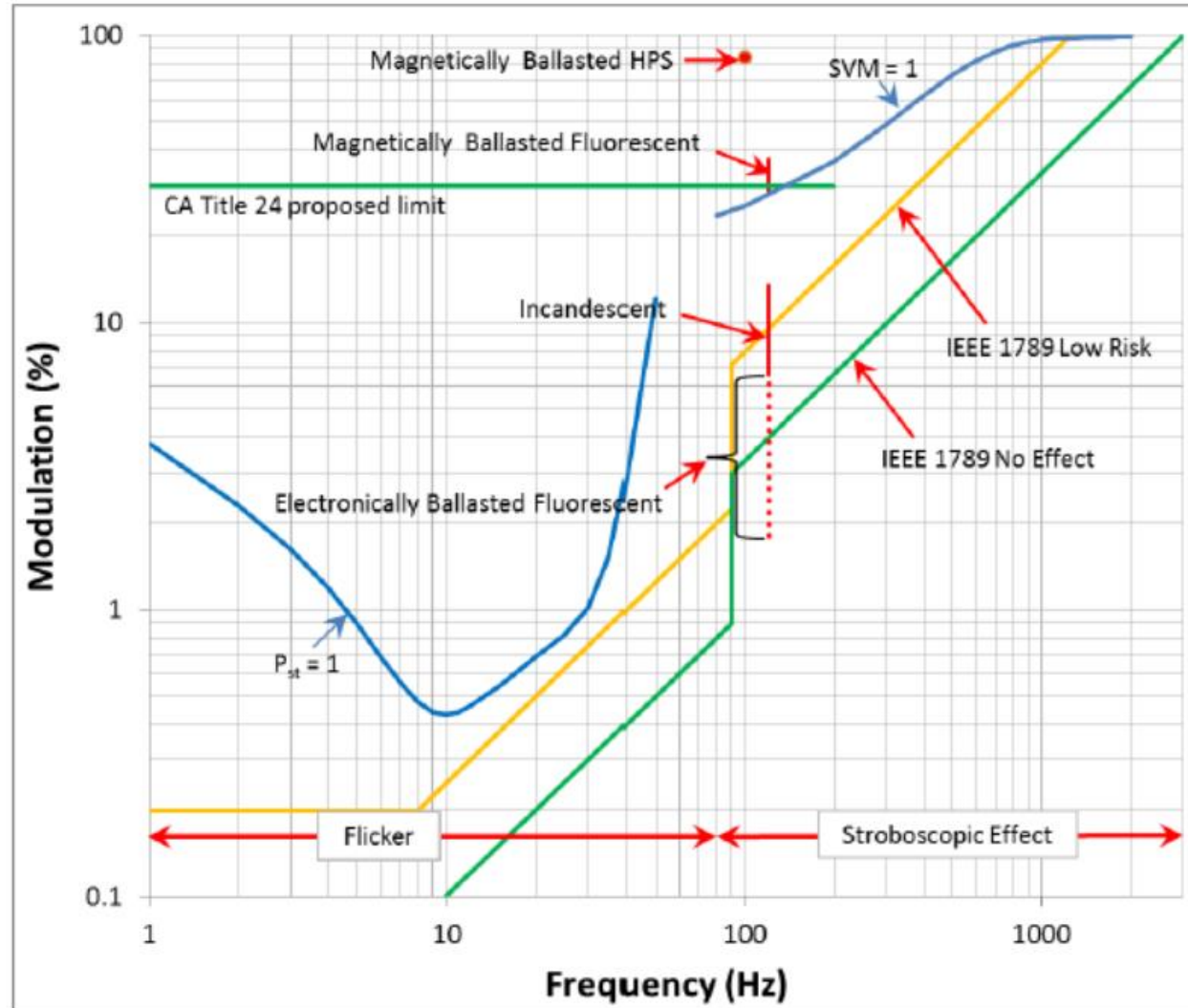


$$MD = 100 \times \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

Above 1250Hz, no restrictions anymore!

IEEE 1789-2015

- IEEE recommended practices for Modulating Current in High-Brightness LEDs for mitigating Health Risks to Viewers



New ecodesign regulation

TLA: Temporal Light Artefacts: Flicker en stroboscopic effect.

- **Flicker** (Pst value) **PstLM** ≤ 1 (PstLM = Short Term Perceptibility for light modulation)
- **Stroboscopisch effect SVM** ≤ 0,9 and
 - ⇒ per 1-9-2024 obligation SVM ≤ 0,4: except outdoor, industrial and other applications with CRI ≤ 80

Ref:

Modelling visibility of temporal light artefacts

Citation for published version (APA):

Perz, M. (2019). *Modelling visibility of temporal light artefacts*. [Phd Thesis 2 (Research NOT TU/e / Graduation TU/e), Industrial Engineering and Innovation Sciences]. Technische Universiteit Eindhoven.

Thank you

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