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Submission Title: Health impact of light flicker: implications for visible-light communications
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Re: N/A

Abstract: We discuss the health impacts of light flicker and outline restrictions in the PHY and MAC in order to enable a 'healthy' IEEE VLC standard.

Purpose: Helping the 802.15 VLC SG to shape the scope of a VLC standard

Health impact of light flicker: implications for visible-light communications

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Main conclusions up front (2-cent version)

- Bad news:
  - Visible-light communications (VLC) causes flicker
  - Flicker can incur health impacts
- 'Healthy' VLC avoids flicker
- Good news: Puts no major restrictions on VLC

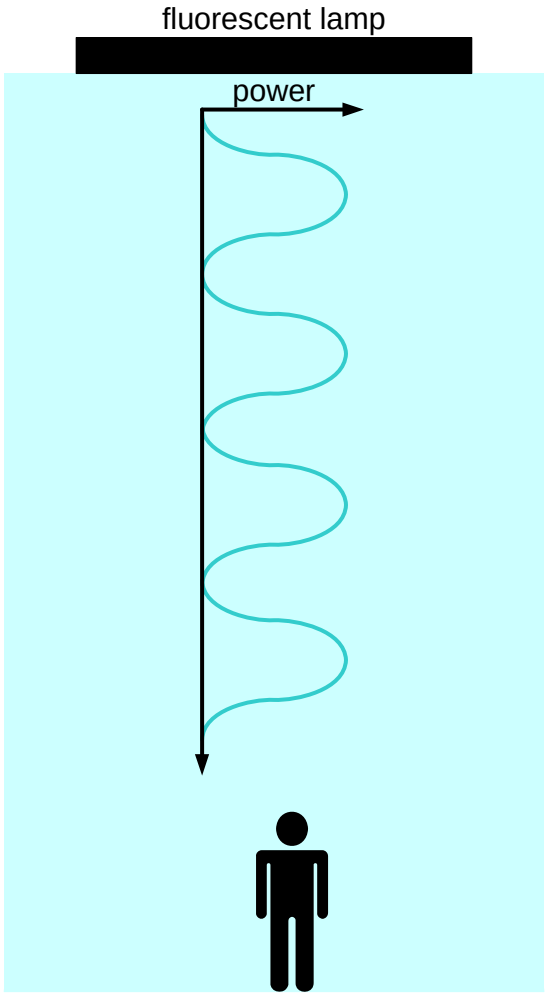
Outline

- What is light flicker?
- Relevance for VLC?
- Health impact of light flicker
- Rough frequency estimates for flicker-free light
- Critical fusion frequency: Right figure of merit?
- Implications for VLC
- Regulation of light flicker in standards
- Implications for VLC
- Open questions
- Conclusions

What is light flicker?

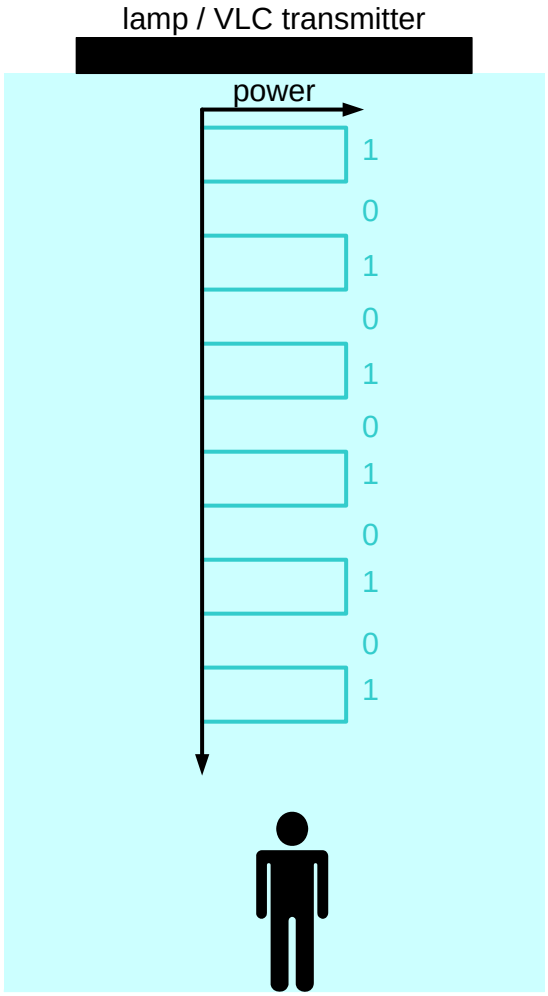
- Variation of optical power as sensed by (human) eye
- Sensing not necessarily conscious
- Critical fusion frequency (CFF, a.k.a. flicker fusion threshold): “frequency at which an intermittent light stimulus appears to be completely steady to the observer“ (Wikipedia). Conscious appearance!

Typical example for light flicker?



Large body of research on impact of flicker from fluorescent lighting (magnetic ballasts)

Relevance for VLC?



- VLC relies on intensity modulation
- VLC thus always leads to flicker!

Health impact of light flicker

- Visual discomfort [Stone, 1990]
- Eyestrain [Lindner, 1993]
- Headache [Wilkins, 1989]
- Increase in speed and decrease in performance of mental tasks (reading comprehension …) [Küller, 1998]
- Repetitive behaviour of autistic children [Colman, 1976]
- Photosensitive epilepsy (2% of all epilepsy cases) [Harding, 1995]

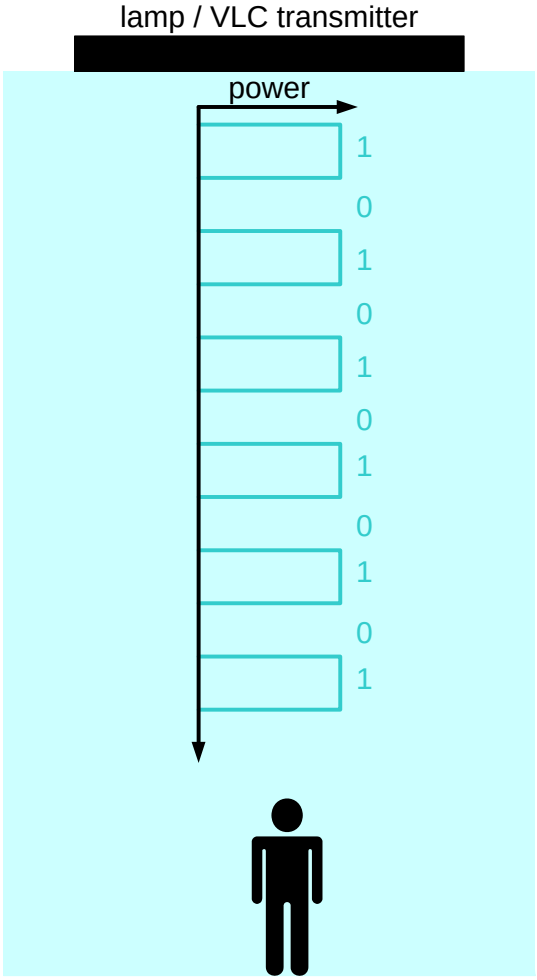
Rough frequency estimates for flicker-free light

- CFF proportional to modulation index
- Cinema picture frequency: 2 x 24 Hz
- Television picture frequency: 50-60 Hz
- Computer monitor: > 50 Hz

CFF: Right figure of merit?

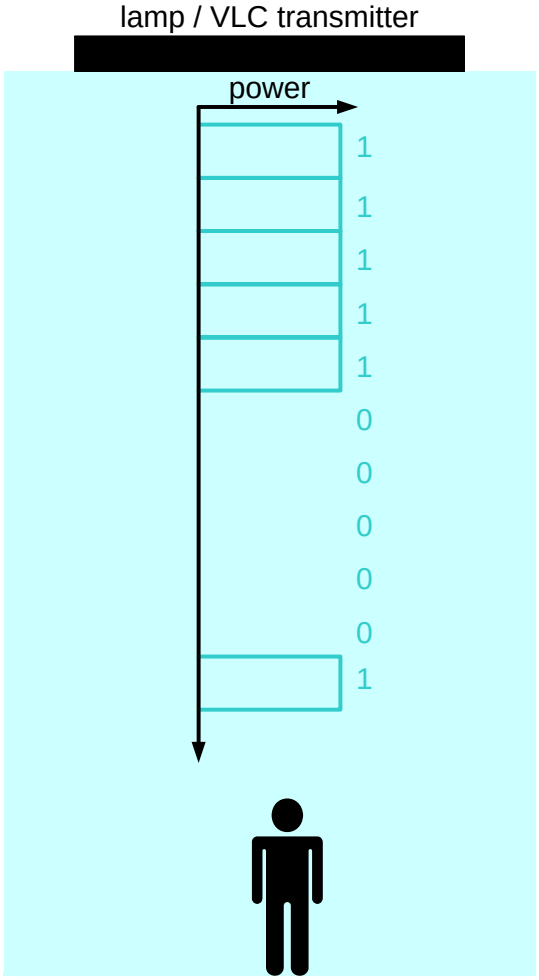
- No agreement in literature on cut-off frequency (CF) for discernible health impact
- In-phase distortion of human ERG at ~ 150 Hz: even flicker beyond CFF impacts the nervous system [Berman, 1991]
- Open question: CF > CFF?
- I suggest: yes
- CF might be even higher than 150 Hz!
- Suggestion: CF of at least 1 kHz (precautionary principal)
- Notice: even for low-bit-rate transmission!

Implications for VLC: modulation frequency



- Modulation frequency >> CF
- Neglect potential dependence of CF on modulation index
- Good news: CF << f_3dB of LEDs, lasers
- Thus: can meet health requirements without major restrictions on bit rate
- But …

Implications for VLC: ‘symbol bunching’



- Bunching of ‘high’ and ‘low’ can result in flicker < CF
- Thus: avoid symbol bunching
- Potential means:
  - PHY
    - modulation: pulse-position modulation, phase-shift keying, …
    - coding: 8-10 line coding, …
  - MAC (?)

Regulation of light flicker in standards

- EN61000-3-3 regulates light flicker caused by imperfect sine-wave driving voltage
- Constraints for fundamental and harmonics

Implications for VLC

- VLC needs to comply with EN 610003-3 in order to gain CE certification! [Wright, 2001]

Open questions

- Impact of light flicker for animals (pets, barn cattle, …)?
  - Different CF?
  - Different health impacts?
  - Any regulations in national laws or standards?

Conclusions

- Light flicker has health impact on humans/animals
- VLC (due to intensity modulation) results in flicker
- Need to keep flicker frequency well above 150 Hz
- Low modulation frequency may arise from bunching of symbols
- Avoiding health risks from flicker without major sacrifice of bit rate possible
- Closer look needed at
  - Cut-off frequency
  - Impact on animals
  - Implications of EN 610003-3 for VLC

(My) Vision

Let’s create a save VLC technology!

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