Texte zu den geplanten neuen EU-Regelungen zur umweltgerechten Produktgestaltung und zur Energieverbrauchskennzeichnung in der Beleuchtung – Zusammenstellung [1] des Umweltbundesamtes (UBA), Deutschland

Diskussion über eine künftige Änderungsverordnung (Produktgestaltung)

Anhang II Nummer 2 – SVM-Höchstwert: **Stellungnahme des Herstellerverbandes LE [2] vom 29. März 2019**

Hinweis: Bitte beachten Sie, daß der angehängte Text nur in Englisch verfaßt ist.

EN: Information on the coming EU Lighting Regulations – Ecodesign and Energy Labelling – Compilation [1] of the Federal Environment Agency (UBA), Germany

Discussion of a future amending regulation (Product Design)

Annex II.2 – SVM limit value: Comments by the Industry Association LE [2] as of 29 March 2019

FR: Informations sur les futures réglementations de l'UE concernant l'éclairage – l'écoconception et l'étiquetage énergétique – Compilation [1] de l'Agence Fédérale de l'Environnement (UBA), Allemagne

Discussion d'un futur règlement modificatif (Conception des produit)

Annexe II, point 2 – Valeur maximale du SVM : Commentaires de l'association de producteurs LE [2] de 29 mars 2019

Indication : Veuillez noter que le présent texte n'est disponible qu'en anglais.

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[1] https://www.eup-network.de/de/eup-netzwerk-deutschland/offenes-forum-eu-regelungen-beleuchtung/dokumente/texte/

[2] LE = Lighting Europe; http://www.lightingeurope.org/

DE: ↓ **EN**: → page III **FR** : → page IV

Texte im Offenen Forum (**abc** = vorliegender Text)

- **Bestehende EG- und EU-Regelungen**
- **Studien der EU-Kommission**
- **Regelungsentwürfe**
  - Frühere Entwürfe
  - **Diskussion über eine künftige Änderungsverordnung**
    - **Vorab-Stellungnahmen und Hintergrundinformationen**
      - **Produktgestaltung Anhang II Nummer 2: SVM-Höchstwert**
        - **Stellungnahme von Lighting Europe (29. März 2019) [EN]**
        - Zu der Stellungnahme von Lighting Europe: Gegendarstellung von Peter Erwin (Juli 2019) [DE] [EN]
        - Meßwerte Lighting Europe (17. Dezember 2019) [EN]
        - Meßwerte von Energimyndigheten (4. Februar 2019) [EN]
        - Messungen im Umlaufverfahren im April 2020 – Bericht vom 30. April 2020 [DE|EN]
        - Stellungnahme von lichtfragen.info (4. Mai 2020) [DE|EN]
      - Andere Themen
    - Informelles Interessensgruppentreffen am 19. Februar 2020 *
- **Öffentliche Konsultationen auf EU-Ebene**
- **Diskussion im Offenen Forum**
- **Weitere Dokumente**

* Stand 20. März 2020: Diese Texte stehen noch nicht zur Verfügung.

Abkürzungen: ● EG = Europäische Gemeinschaft ● Energimyndigheten ist die staatliche Energieagentur Schwedens; https://www.energimyndigheten.se/en/ ● EU = Europäische Union ● SVM : Maß für die Sichtbarkeit des Stroboskopeffektes

EN

Documents in the Open Forum

(**abc** = text at hand)

- **Existing EC and EU Regulations**
- **Studies of the European Commission**
- **Draft regulations**
  - Earlier drafts
  - **Discussion of a future amending regulation**
    - **Comments in advance and background information**
      - **Product design Annex II.2: SVM limit value**
        - **Comments by Lighting Europe (29 March 2019) [EN]**
        - Reply to Lighting Europe's comments: Peter Erwin (July 2019) [DE] [EN]
        - Measured by Lighting Europe (17 December 2019) [EN]
        - Measured values by Energimyndigheten (4 Febraury 2019) [EN]
        - Round Robin Test April 2020 – Report as of 30 April 2020 [DE|EN]
        - Comments by lichtfragen.info (4 May 2020) [DE|EN]
      - Other issues
    - Informal stakeholder meeting on 19 February 2020 *
- **Public Consultations at EU level**
- **Discussion in the Open Forum**
- **Further documents**

* Status as of 20 March 2020: These texts are not yet available.

Abbreviations: ● EC = European Communities ● Energimyndigheten is the national Energy Agency of Sweden (SEA); https://www.energimyndigheten.se/en/ ● EU = European Union ● SVM = Stroboscopic Visibility Measure

FR

Documents dans le forum ouvert (**abc** = présent document)

- **Règlements existants de la CE et de l'EU**
- **Études de la Commission européenne**
- **Projets de règlements**
  - Projets antérieurs
  - **Discussion d'un futur règlement modificatif**
    - **Commentaires en avance et informations de fond**
      - **Conception des produits, Annexe II, point 2 : Valeur maximale du SVM**
        - **Commentaires par Lighting Europe (29 mars 2019) [EN]**
        - Réponse aux commentaires de Lighting Europe : Peter Erwin (juillet 2019) [DE] [EN]
        - Valeurs mesurées par Lighting Europe (17 décembre 2019) [EN]
        - Valeurs mesurées par Energimyndigheten (4 février 2020) [EN]
        - Mesures dans le cadre de la procédure de circulation en avril 2020 – Rapport du 30 avril 2020 [DE|EN]
        - Commentaires de lichtfragen.info (4 mai 2020) [DE|EN]
      - Autres sujets
    - Réunion informelle des parties prenantes le 19 février 2020 *
- **Consultations publiques au niveau de l'UE**
- **Discussion dans le Forum Ouvert**
- **Autres documents**

* État au 20 mars 2020 : Ces textes ne sont pas encore disponibles.

Abréviations : ● CE = Communauté européenne ● Energimyndigheten et l'administration nationale suédoise de l'énergie ; https://www.energimyndigheten.se/en/ ● SVM : mesure de la visibilité stroboscopique ● UE = Union européenne

Es folgen vier Originaltexte, die vom Herausgeber in ein Dokument gebündelt und zur besseren Orientierung ergänzt wurden: durch eine durchgehende Bildernumerierung und am Anfang jedes einzelnen Abschnittes in der Kopfzeile durch eine Überschrift. Zur klaren Abgrenzung vom Originaltext sind diese Ergänzungen in dunkelroter Schrift und in {}-Klammern gesetzt.

Verbesserte Version dieser Aufbereitung vom 17. 5. 2019: Bei Ausdruck auf DIN-A-4-Papier sollten keine Seitenbereiche mehr verlorengehen.

EN: This is followed by four original texts, which have been bundled by the editor into one document and supplemented for better orientation: by a continuous image numbering and at the beginning of each individual section in the header by a heading. For a clear distinction from the original text these supplements are set in dark red letters and in {} brackets.

Improved version of this preparation dated 17 May 2019: No page areas should be lost when printing on DIN A4 paper.

FR: Viennent ensuite quatre textes originaux, que l'éditeur a regroupés dans un seul document et complétés pour une meilleure orientation : par une numérotation continue des images et, au début de chaque section individuelle dans l'en-tête, par un titre. Pour une distinction claire par rapport au texte original, ces ajouts sont indiqués en lettres rouge foncé et entre crochets {}.

Version améliorée de cette préparation datée du 17 mai 2019 : Aucune zone de page ne doit être perdue lors de l'impression sur papier DIN A4.

{A – SVM ≤ 0.4: Simple explanation}

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SVM ≤ 0.4:
Simple explanation

29 March 2019

{A – 1/22}

LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

SVM ≤ 0.4 impact on LED lighting

Summary:
Important objective of the EU Ecodesign revision for Lighting (“single lighting regulation”) is a further limitation of energy usage by more than 40 TWh annually by 2030.
The SVM ≤ 0.4 requirement for LED and OLED MLS is damaging this objective since it increases the energy consumption with 3% - 5% due to the additional required components and losses

The consumer will be dissatisfied:
Unintentional phasing out of light sources with small caps, and
The consumer is left behind with luminaires without light sources, thus with “empty sockets”

Recommendation:
The EU Ecodesign revision objectives can be achieved by increasing the SVM requirement from 0.4 to 1.6

{A – 2/22}

Product families at stake due to small size

LEDtube

LEDspot MV

Classic filament LED lamps

Industry & retail

office

residential

Hospitality: bars, restaurants, hotels,..

residential

Hospitality: bars, restaurants, hotels,..

The conventional light sources of these product families are phased out due to energy requirements. The LED replacement light sources of these product families are unintentionally phased out due to too strict SVM requirements. The electronics for *'very strict SVM'* do not fit in the cap.

3

{A – 3/22}

Product families at stake due to small size (continuation)

LEDcapsule G9

LEDspot R7s

LEDspot PAR

Residential, hospitality

Residential, hospitality

Public buildings, retail

The conventional light sources of these product families are phased out due to energy requirements. The LED replacement light sources of these product families are unintentionally phased out due to too strict SVM requirements. The electronics for *'very strict SVM'* do not fit in the cap.

{A – 4/22}

Luminaire product families at stake

TL luminaires

Halogen MV luminaire

Incandescent deco luminaires

The conventional light sources for these luminaires are phased out due to energy requirements. The LED replacement light sources for these luminaires are unintentionally phased out due to too strict SVM requirements. The customer is left behind with NO light source for the luminaire.

{A – 5/22}

Luminaire product families at stake (continued)

Halogen G9 luminaires

Halogen R7s luminaires

PAR luminaires

The conventional light sources for these luminaires are phased out due to energy requirements. The LED replacement light sources for these luminaires are unintentionally phased out due to too strict SVM requirements. The customer is left behind with NO light source for the luminaire.

{A – 6/22}

{B – SVM ≤ 0.4: Impact on LED & OLED Mains-Connected Light Sources (MLS)}

SVM ≤ 0.4 Impact on LED & OLED Mains-connected Light Sources (MLS)

29 March 2019

LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

SVM ≤ 0.4 impact on LED lighting

Summary:

- Important objective of the EU Ecodesign revision for Lighting (“single lighting regulation”) is a further limitation of energy usage by more than 40 TWh annually by 2030.
- The SVM ≤ 0.4 requirement for LED and OLED MLS is damaging this objective since it:
  - Increases the energy consumption with 3% - 5% due to the additional required components and losses
  - Impedes small (P ≤ 25W) dimmable retrofit LED bulbs (A60, GU10, Candles, T5) due to their size limitations
  - Impedes IoT solutions with RF Connected retrofit LED bulbs due to their size limitations
  - Increases the cost due to additional components

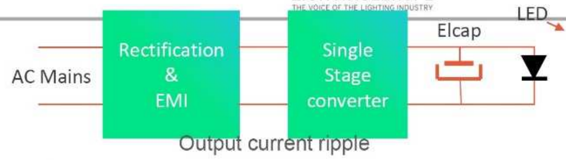
Recommendation:

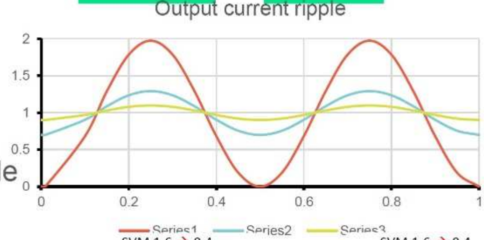
The EU Ecodesign revision objectives can be achieved by increasing the SVM requirement from 0.4 to 1.6

SVM ≤ 0.4 impact om LED MLS driver design

- Future lighting products have to comply with EMCD 2014/30/EU with input current harmonic requirements as defined in the harmonized EN 61000-3-2 standard and the upcoming Ecodesign revision (SLR) with a SVM requirement on the light output (stroboscopic effect)
- The input current harmonic requirements for P ≤ 25W and P> 25W are managed by the control gear via a:
  1. Simple single-stage topology with an output capacitor *or*
  2. Single-stage topology with output capacitor + ripple reduction circuit *or*
  3. Sophisticated and larger dual-stage topology with an internal capacitor *or*
  4. Simple single-stage topology with an input capacitor (only applicable for P ≤ 25W)
- The SVM requirement of ≤ 0,4 requires a further modification of the above control gear topology
- The characteristics, the required modifications and the consequences & limitations of the above topologies are summarized in the following slides.

1. Single-stage topology with output capacitor





Characteristics:

- Fulfils strict mains current harmonic requirements
- Highest conversion efficiencies
- Compatible with phase-cut (wall) dimmers

Modifications for SVM requirement:

- Increasing the electrolytic capacitor (elcap) at the output side

Consequences / limitations:

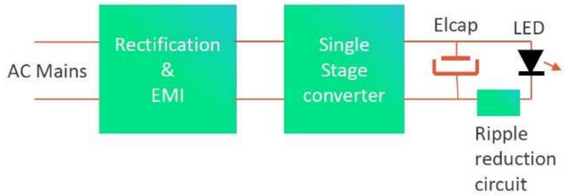
- Capacitor volume scales inversely with SVM requirement (e.g. 8x10 → 10x18 mm or 6x14 → 10x20 mm)
- Capacitor technology is mature, no breakthroughs expected
- This impedes the following products due to size restrictions:
  - Compact integrated products (GU10, Bulbs, T5 replacements)
  - High power integrated products (up to 150W HID replacements)
  - IoT solutions with RF connected products

  Note: These size restrictions do not appear at SVM ≥ 1.6

SVM 1.6 → 0.4
Elcap size 8x10 → 10x18 mm

SVM 1.6 → 0.4
Elcap 6x14 → 10x20 mm

2. Single-stage topology with output capacitor + ripple reduction circuit



Characteristics:

- Fulfils strict mains current harmonic requirements
- Compatible with phase-cut (wall) dimmers

Modifications for SVM requirement:

- Physics of ripple reduction is increasing the RC time constant of the output filter
- RC time constant is formed by electrolytic capacitor (elcap) at the output and dynamic resistance of LED load

Consequences / limitations:

- Additional electronic circuits/components can increase the resistance of the LED load at the cost of efficiency.
- Typical efficiency losses for the additional ripple reduction circuits: 3%-5% or even more.

3. Dual-stage topology with an internal capacitor

Characteristics:

- Fulfils strict mains current harmonic requirements
- Compatible with phase-cut (wall) dimmers
- Requires considerable more size (& cost) than single stage converters and are therefore mainly used in LED control gear and not in retrofit lamps
- No direct SVM issues at 100% power level, however, dimming or load adaptation (window drivers) can cause output current ripple

Modifications for SVM requirement at dimming:

- Amplitude dimming: non
  - PWM dimming: SVM includes frequencies up to 2 kHz, typical PWM frequencies of 1 kHz have a high impact on SVM
- **Consequences / limitations:**
  - Higher PWM frequencies are undesired, as the audible sensitivity increases, switching losses increase and color accuracy deteriorates (e.g. Connected Lighting products)
  - Typical efficiency loss for extra conversion: 3%-5% or even more

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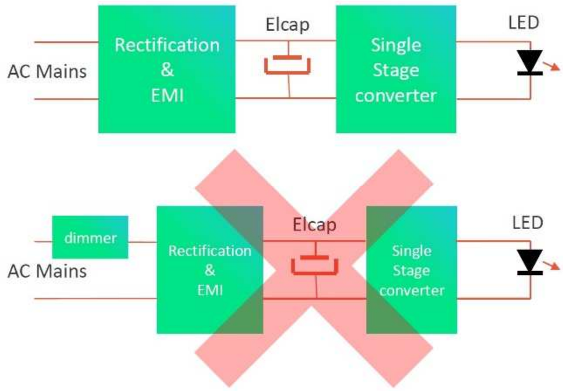
4. Simple single-stage topology with an input capacitor

Characteristics:

- Fulfils less strict mains current harmonic requirements
- Only applicable for P ≤ 25W
- Fulfils SVM ≤ 0.4 requirement
- Highest conversion efficiencies
- Not compatible with phase-cut (wall) dimmers since repetitive inrush current peaks (induced by the dimmer operation) will lead to excessive heat g eneration and almost instant failure of products



Modifications for SVM requirement:

- None

Consequences / limitations:

- Not dimmable!

{B – 13/22}

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Summary of consequences if product has to fulfil PQ and SVM ≤ 0.4

Application	Topology	Efficiency penalty	Size	Dimmer Compatibility
Integrated LED MLS with P > 25W	Dual-stage	3-5%	Not OK	Yes
	Single-stage + C at output	--	Not OK	Yes
	Single-stage + ripple reduction	3-5%	Not OK (thermal)	Yes
Integrated LED MLS with P ≤ 25W	Single-stage + C at input	--	Not OK	No
	Single-stage + C at output	--	Not OK	Yes
	Single-stage + ripple reduction	3-5%	Not OK (thermal)	Yes

{B – 14/22}

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Summary of consequences if product has to fulfil PQ and SVM ≤ 1.6

Application	Topology	Efficiency penalty	Size	Dimmer Compatibility
Integrated LED MLS with P > 25W	Dual-stage	3-5%	Not OK	Yes
	Single-stage + C at output	--	OK	Yes
	Single-stage + ripple reduction	3-5%	Not OK (thermal)	Yes
Integrated LED MLS with P ≤ 25W	Single-stage + C at input	--	OK	No
	Single-stage + C at output	--	OK	Yes
	Single-stage + ripple reduction	3-5%	Not OK (thermal)	Yes

Brussels, 29 March 2019

Stroboscopic effect

Visibility, Acceptability and Health concerns

Stroboscopic effect is visible as a series of still images when fluctuating light illuminates a moving object. In its extreme form this effect is often used in discotheques. Stroboscopic Visibility Measure (SVM) is a new measure recently defined to quantify the visibility of stroboscopic effect. SVM is intended to predict **human perception** of this phenomenon. SVM is developed for applications where human movements (up to 4 m/s) are present.

SVM is **not** developed for industrial applications (e.g. rotating machines) or to predict interference with devices with an optical input (e.g. cameras, barcode scanners).

When stroboscopic effect is observed, an object that would appear as a distorted streak in non-strobing light appears as an array of objects. The effect on the retina is the same as observations of periodic structures that are common in everyday life (e.g., fences, brick walls, rows of trees, striped clothing, and spoked wheels) – an array of images is formed on the retina. Observation of an array of objects is not intrinsically unacceptable.

The recent draft Ecodesign Regulation proposal for strict limits on SVM (SVM ≤ 0.4) is based on a fundamental underlying **assumption** that visibility of stroboscopic effect is identical to acceptability of stroboscopic effect, and moreover that it is also identical to "health risk".

Visibility

Perz/Sekulovski did the original work to derive SVM (Stroboscopic *Visibility* Measure), determining the human sensitivity curve from testing with over 200 participants. The recent Veitch/Martinsons study used a smaller number of participants (36) and a similar setup, and the results agree well. The visibility threshold is defined at SVM 1.0. The Perz/Sekulovski measurements actually indicate a slightly higher sensitivity to stroboscopic effect than the Veitch/Martinsons results. Why, then, is there such a discrepancy in the SVM recommendations reached by interpretation of the results of the two scientific studies?

A complication in determining visibility is that a certain percentage of people think that they see stroboscopic effect when there is none present. This effect appeared in both studies, where about 10 % of people 'detected' stroboscopic effect when the light source was driven with Direct Current resulting in an SVM = 0 and no stroboscopic effect.

Acceptability

Several studies have shown that people do find a certain amount of stroboscopic effect *acceptable*. In fact, the Veitch/Martinson study showed that there was no significant difference in acceptability from SVM = 0 to SVM = 3. The ASSIST studies showed that

acceptability of stroboscopic effect was generally high but depended on the contrast and speed of motion. Work by Perz/Sekulovski found acceptable values of SVM for various applications ranging from SVM = 1.0 to 2.3, all above the visibility threshold of SVM 1.0.

Stroboscopic effect is **only** visible when there is enough object motion with sufficient contrast and sufficient light levels, and without other light sources reducing the effect. This can be tested in laboratory circumstances but does not happen often in real-life situations. In real-life situations there are usually multiple light sources (including daylight) and very limited motion. Thus, in practice stroboscopic effect will only be visible during a small percentage of the time. Presumably these factors all play a role to yield the results above that some visibility of stroboscopic effect is acceptable.

Health

Epileptic seizure is a concern only below 65 Hz and is of greatest concern from 5 to 30 Hz (source: Epilepsy Foundation of America). Similarly, migraines have only been demonstrated to be caused by frequencies up to 60 Hz and have not been documented at 75 Hz or above. Seizures and migraines are therefore not associated with stroboscopic effect but with flicker. Flicker is already addressed by the measure P_{st}^{LM} in the Ecodesign Regulation. The limit $P_{st}^{LM} \leq 1.0$ is much stricter than the limit prescribed by the Epilepsy Foundation of America, so this concern is already covered in the Ecodesign regulation. Stroboscopic effect is only suspected to be associated with headache and eyestrain and depends on the amount of modulation and the frequency. Wilkins' study of fluorescent light showed that the incidence of headaches was 'more than halved' when 'conventional' (100 Hz magnetically-ballasted fluorescent) lighting was replaced by 'new' (electronically-ballasted fluorescent) lighting but did not differ significantly when 'new' lighting was replaced by 'conventional'. His work has not been reproduced. Unpublished work performed with employees in an office space lit by LED luminaires with the ability to change SVM from 0.5 to 1.3 shows **no increase in headaches or eyestrain** with the two different values of SVM, even with long term exposure (13 weeks). This implies that the *acceptability* threshold in a real-life situation for office application will be above SVM = 1.3.

Long-term evidence of the acceptability and the lack of health effects of a certain amount of stroboscopic effect is provided by conventional lighting, some forms of which have been in use for over 100 years. Incandescent lamps have SVM as high as 0.8. HID lamps have SVM as high as 3 or more. While it may not be advisable to use lighting with very high SVM in applications such as office lighting, it is completely acceptable in other applications.

Conclusion

Stroboscopic effect is **not** associated with health effects and should not be confused with flicker, which is already covered in the revised Ecodesign requirements for light sources. Visibility is not the same as acceptability and visibility is not the same as a health risk. Scientific studies show that a certain amount of stroboscopic effect is acceptable. All acceptable values found (SVM 1.0 - 2.3) are higher than the visibility threshold (SVM 1.0).

Therefore, strict limits on SVM intended to eliminate visibility or to eliminate health effects are unnecessary.

Moreover, strict limits on SVM damage the objective of the Ecodesign regulation. To comply with strict SVM limits the energy consumption will increase 3-5% due to additional components and losses and several small LED light sources will

unintentionally be banned from the EU market. Simultaneously the equivalent conventional light sources will be phased out.

The EU Ecodesign revision objectives can be achieved while increasing the SVM requirement from 0.4 to 1.6 (at full load, for indoor applications only).

LightingEurope therefore proposes to change the legislative requirement as follows:

Stroboscopic effect for LED and OLED MLS	SVM ≤ ~~0.4~~ **1.6** at full load (except for ~~HID with Φ_{use} > 4 klm and for~~ light sources intended for use in outdoor ~~applications,~~ **or** industrial applications ~~or other applications where lighting standards allow a CRI < 80~~)

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Brussels, 18 March 2019

Stroboscopic effect: List of references

Below are several references relevant to Stroboscopic Effect. Included are scientific papers, as well as standardization documents. It should be noted that this document is not intended to set any limits on Stroboscopic Visibility Measure (SVM) but serves as a compilation of all known sources on this topic.

CIE: International Commission on Illumination / Commission Internationale de l'Eclairage

“Visual aspects of time-modulated lighting systems–definitions and measurement models,” CIE TN 006:2016 (2016).
Summary: Technical note describing Temporal Light Artefacts, providing definitions and technical background. “In the first part of the Technical Note (TN), new **definitions** for the perceptual effects modulated light can produce are given. In the second part, an overview of the relevant literature is given as well as an overview of the parameters that influence the visibility of the different TLAs.”
http://files.cie.co.at/883_CIE_TN_006-2016.pdf

IEC: International Electrotechnical Commission (IEC)

Equipment for general lighting purposes - Objective test method for stroboscopic effects of lighting equipment. IEC Technical Report (TR) 63158:2018 Geneva, Switzerland: IEC, 2018.
Summary: IEC technical report describing stroboscopic effect. “The object of this document is to establish a common and objective reference for evaluating the performance of lighting equipment in terms of stroboscopic effect.” This document describes the **methodology** for SVM and **does not define any limits**.
https://webstore.iec.ch/publication/61455

NEMA: National Electrical Manufacturers Association (NEMA)

Temporal light artifacts: Test methods and guidance for acceptance criteria. NEMA 77-2017 Rosslyn, VA: NEMA, 2017.
Summary: The standard describes the measurement methods for P_{st} (flicker) and SVM (stroboscopic effect) and gives guidelines for indoor and outdoor levels. “The purpose of the standard is: to recommend a method of quantifying the visibility of temporal light artifacts (TLA), and to recommend initial, broad application-dependent limits on TLA.” The standard also compares several Temporal Light Artefacts (TLA) requirements with conventional (non-LED) light sources. The **guideline for acceptance criteria** for SVM is stated as follows: SVM ≤ 1.6 for light sources for indoor application area and no limit for light sources for outdoor application area. This is the only global standard giving SVM acceptance criteria.
https://www.techstreet.com/standards/nema-77-2017?product_id=1949775

EU SCHEER (Scientific Committee on Health, Environmental and Emerging Risks) Opinion

Following a request from the European Commission, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) reviewed recent evidence to assess potential risks to human health posed by Light Emitting Diodes (LEDs) emissions. In June 2018, SCHEER published its "Final Opinion on potential risks to human health of Light Emitting Diodes (LEDs)" concluding that "there is **no evidence of direct adverse health effects** from LEDs emission in normal use (lighting and displays) by the general healthy population." "Some people report that they are sensitive to temporal light modulation from LEDs."
https://ec.europa.eu/health/scientific_committees/consultations/public_consultations/scheer_consultation_05_en (2018).

IEEE: Institute of Electrical and Electronics Engineers

IEEE Power Electronics Society. *IEEE recommended practices for modulating current in high-brightness LEDs for mitigating health risks to viewers*. S1789-2015 New York, NY: Institute for Electrical and Electronics Engineers, Inc. (IEEE). 2015. The paper predates current terminology on flicker and stroboscopic effect.
Summary: This is a literature study of health effects related to flicker and stroboscopic effect. Three levels of limits are suggested, with the intention of avoiding any imaginable potential health effect. The terminology in this document is not aligned with the CIE definitions (CIE TN 006:2016). Moreover, the publication of this report has created intense debate, as many organizations do not accept the findings therein.
https://standards.ieee.org/standard/1789-2015.html

ASSIST (Lighting Research Center, Troy, NY, USA)

J. D. Bullough, K. S. Hickcox, T. R. Klein, and N. Narendran, "Effects of flicker characteristics from solid-state lighting on detection, acceptability and comfort," Light. Res. Technol.43, 337–348 (2011).
J. D. Bullough, K. S. Hickcox, T. R. Klein, A. Lok, and N. Narendran, "Detection and acceptability of stroboscopic effects from flicker," Light. Res. Technol. 44, 477–483 (2012).
J. D. Bullough and D. Marcus, "Influence of flicker characteristics on stroboscopic effects," Light. Res. Technol.48, 857–870 (2016).
JD Bullough, KS Hickcox, TR Klein, A Lok, and N Narendran. Assist recommends: Flicker parameters for reducing stroboscopic effect from solid-state lighting systems. 2011.
Assist Recommends...Application Considerations Related to Stroboscopic Effects from Light Source Flicker (Lighting Research Center, 2015)
Summary: Studies were done with human observers to determine visibility and acceptability of stroboscopic effect. **No health effects were investigated. Participants found that some visibility is acceptable.**
https://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp

Wilkins paper

A Wilkins, I Nimmo-Smith, A Slater and L Bedocs, "Fluorescent lighting, headaches and eyestrain" Lighting Res. Technol. Vol 28, No. 1, pp 11-18 (1989). The paper predates current terminology on flicker and stroboscopic effect.
Summary: Scientific article describing headache and eyestrain experiments done with fluorescent lighting (both magnetically- and electronically-ballasted). "The difference in headache incidence was significant for the group which experienced the conventional

lighting first, but not for the group which experienced the reverse order. When the two groups were combined the aggregate difference was marginally significant." The paper concludes that ***flicker* can cause headaches.** (Thus, the headaches are not caused by stroboscopic effect!)
https://www1.essex.ac.uk/psychology/overlays/1989-82.pdf

Articles

M Perz, D Sekulovski, I Vogels, I Heynerickx, J Opt Soc America A, Stroboscopic effect: contrast threshold function and dependence on illumination level, Vol 35, No. 2, p 309-319 (2018). https://www.osapublishing.org/josaa/abstract.cfm?uri=josaa-35-2-309

M. Perz, D Sekulovski, P Beeckman "Acceptability Criteria for the Stroboscopic Visibility Measure", CIE 2017 Midterm Meetings and Conference on Smarter Lighting for Better Life (2017).
https://www.techstreet.com/standards/acceptability-criteria-for-the-stroboscopic-effect-visibility-measure-wp05-453-459?product_id=2011382

Małgorzata Perz, Dragan Sekulovski, Ingrid Vogels & Ingrid Heynderickx (2017): Quantifying the Visibility of Periodic Flicker, LEUKOS, DOI:10.1080/15502724.2016.126960
https://www.tandfonline.com/doi/full/10.1080/15502724.2016.1269607

M Perz, IMLC Vogels, D Sekulovski, L Wang, Y Tu, IEJ Heynderickx, Modeling the visibility of the stroboscopic effect occurring in temporally modulated light systems. Lighting Res. Technol, Vol. 47, No. 3, pp. 281-300 (2014). https://journals.sagepub.com/doi/abs/10.1177/1477153514534945?journalCode=lrtd

M Perz, I Vogels, and D Sekulovski. "Evaluating the visibility of temporal light artefacts". In: Lux Europa 2013: 12th European Lighting Conference. 2013.

Summary: The scientific articles above provide the basis for the Stroboscopic Visibility Measure and are based on experiments done with over 200 participants. The second article (CIE 2017) includes **recommended levels** of SVM for different applications. All levels are between 1.0 and 2.0.

D Sekulovski, S Poort, P Deurenberg, M Perz, L Waumans. "On the effects of long-term exposure to moderate level modulated light." (2019)

Summary: Study deliberately investigating health effects from stroboscopic effect of LED lighting, and showing that no health effects (eyestrain/headaches) for light sources were caused by changing SVM from 0.5 to 1.3 in an office environment. 46 participants filled out 2813 surveys over the course of 13 weeks, and "…there was no interaction effect between the individual level of complaints and the amount of light modulation". The paper has been submitted to Lighting Research and Technology. A copy of the draft is available upon request.

Basis for SVM limit in draft Single Lighting Regulation

JA Veitch, C Martinsons, Interim Report: Visual Perception under Energy-Efficient Light Sources - Detection of the Stroboscopic Effect Under Low Levels of SVM, (2018).

Summary: Preliminary report of measurements of **visibility** of stroboscopic effect. Results are consistent with work from Perz et al on SVM (listed above). **No health effects were investigated**. **No limits were suggested**.
https://www.eceee.org/static/media/uploads/site-2/news/iea_4e_ssl_annex_svm_report.interim_results3.pdf

Thesis on SVM

G. Perz, Modelling visibility of temporal light artefacts, Thesis, Tue, 2019-02-05.

Summary: Includes the detailed underlying research for the SVM metric for the **visibility** of stroboscopic effect.
https://pure.tue.nl/ws/files/114194362/20190205_Perz.pdf

Other papers

D Polin, S Klir, M Wagner, TQ Khanh, Reducing the stroboscopic effects of LED luminaires with pulse width modulation control, Lighting Res. Technol. Vol. 0, pp. 1-11 (2016). https://journals.sagepub.com/doi/abs/10.1177/1477153515615934

AA Eastman and JH Campbell. “Stroboscopic and flicker effects from fluorescent lamps”. In: Illuminating Engineering 47.1 (1952), pp. 27–35.

JP Frier and AJ Henderson. “Stroboscopic effect of high intensity discharge lamps”. In: Journal of the Illuminating Engineering Society 3.1 (1973), pp. 83–86. https://ies.tandfonline.com/doi/abs/10.1080/00994480.1973.10732230?journalCode=uzie20#.XF3ptVxKiUk

Tu, L Wang, J Zhang, et al. “Cross-cultural similarities in the visibility of the stroboscopic effect”. In: Solid State Lighting (ChinaSSL), 2013 10th China International Forum on. IEEE. 2013, pp. 170–173.
https://psycnet.apa.org/record/2016-44092-001

L Wang, Y Tu, J Zhang, et al. “Influence of illumination level on the visibility of the stroboscopic effect”. In: Proceedings of 7th Lighting Conference of China, Japan and Korea. CJK. 2014.

Andrew Bierman, “A Model for Predicting Stroboscopic Flicker”, Lighting Research Center, Rensselaer Polytechnic Institute, paper presented @ IES Conference Portland, 12 August 2017.
https://www.lrc.rpi.edu/programs/solidstate/pdf/Bierman-IES-2017.pdf