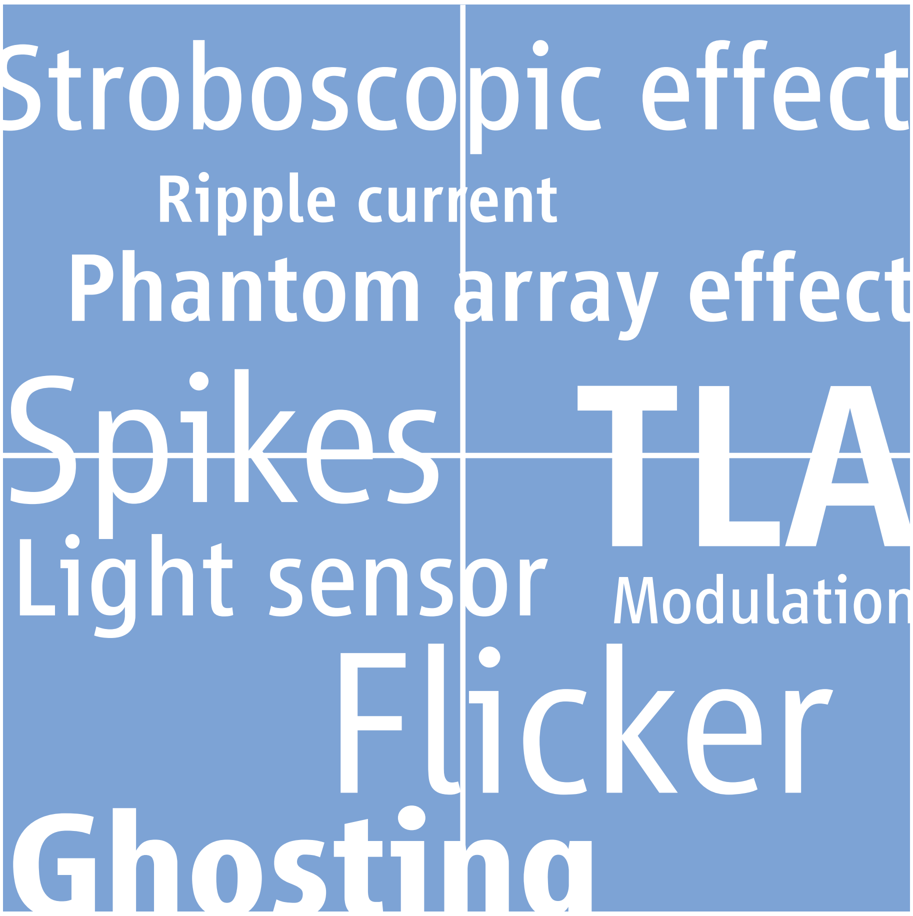
ZVEI:
Die Elektroindustrie

White Paper

Temporal Light Artefacts – TLA

Flicker and Stroboscopic Effect



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Temporal Light Artefacts – TLA

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Foreword

Good light has to satisfy the many (in some cases very) different requirements placed on lighting equipment. One quality requirement is determined by the intensity fluctuation of a light source over time.

The transition to "LED" electronic light sources with their almost immediate response time means that power supply influences have become perceptible. These include "ripple current", "pulse-width modulation", "spikes" or even just voltage fluctuations in the mains grid supply. The proper matching between drivers and LED modules plays a major role here.

Various terms such as flicker, flicker index, percent flicker, modulation depth, ripple current, PWM frequencies etc. are used to provide a basis for assessment.

However, on the basis of the information available or on the basis of their own measurements, at the moment it is very difficult even for lighting professionals to gain an accurate impression of the quality of lighting products with regard to the temporal intensity of a light source (in combination with its driver) used for a specific application.

Up to now there have been no clear and established definitions, appropriate standardized measuring methods, available instruments and relevant application-specific recommendations.

For this reason, the governing body of the European lighting industry has published a position paper entitled "LightingEurope Position Paper on Flicker and Stroboscopic Effect (Temporal Light Artefacts)" (see the references in the appendix).

A definition of temporal light artefacts (TLA) was recently provided in a CIE Technical Note:

"Change in visual perception, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a human observer in a specified environment"

TLAs are therefore all visual effects which are created by light sources, the intensity or spectral distribution of which change over time. Two well-known examples of such effects are flicker and stroboscopic effect.

The present ZVEI information booklet aims to provide an overview of the issue of temporal light artefacts, to explain the key definitions, to present suitable metrics and to provide a list of scientific and standardization publications. It is based in part on content from the LightingEurope position paper and supplemented by background information as well as application-specific observations.

TLA Evaluation Metrics

Existing evaluation and metrics are briefly summarized below, their vulnerabilities highlighted and more appropriate procedures identified.

Modulation depth (MD) and flicker index (FI)

Modulation depth (MD) and flicker index (FI) are frequently used to evaluate flicker and light modulation.

Figure 1 shows an example of the modulated luminous flux of a light source and the quantities used to calculate the modulation depth and flicker index.

Modulation depth (MD) is defined as follows:

$$MD = \frac{(L_{max} - L_{min})}{(L_{max} + L_{min})} \cdot 100\ \%$$

This formula corresponds to the classic formula for calculating modulation depth familiar from electrical engineering.

The formula for calculating flicker index (FI):

$$FI = \frac{A1}{A1 + A2}$$

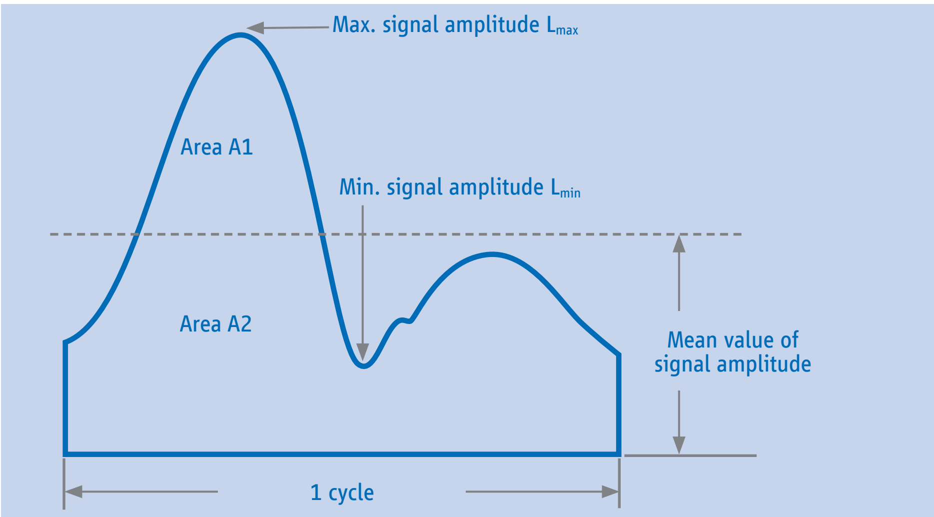
Here, the areas A1 and A2 which are enclosed by the curve shape to be measured (modulated light) are considered.

The ratio between the area A1 above the mean line and the total enclosed area (A2 + A1) is calculated.

However, the modulation depth (MD) and flicker index (FI) metrics for evaluating flicker and stroboscopic effect are only of limited use because they do not include the influences of mixed modulation frequencies, the individual shape of the curve and the duty cycle of the modulation on human perception to a sufficient extent. Another disadvantage is that MD and FI are of little significance without specification of the modulation frequency, and are restricted to short periods of assessment.

A further drawback is that readings that have been measured at different frequencies cannot be directly compared. Such a comparison would only be possible following frequency-based conversion.

Figure 1: Example of the modulation depth (MD) and flicker index (FI) metrics



Source: ZVEI

New, improved metrics

To overcome these drawbacks, CIE TC1-83 is currently working on developing and standardizing better TLA metrics.

The two metrics P_{st}^{LM} and SVM are currently being prepared for standardization:

P_{st}^{LM} metric

The purpose of this metric (P_{st}^{LM} of short-term light modulation) is to measure the visible flicker that is caused by light modulation in the 0.3 Hz to 80 Hz frequency range.

The details are described in IEC/TR 61547-1 and IEC 61000-4-15.

Figure 2 shows the block diagram of a flicker meter based on the P_{st}^{LM} metric. A reliable assessment of low-frequency flicker phenomena takes about 1 minute using this method.

Eye-brain model:

This block evaluates the signal with a so-called eye-brain model that reproduces the frequency-based flicker perception of an average person. The output signal of this block corresponds to the P_{st}^{LM} value.

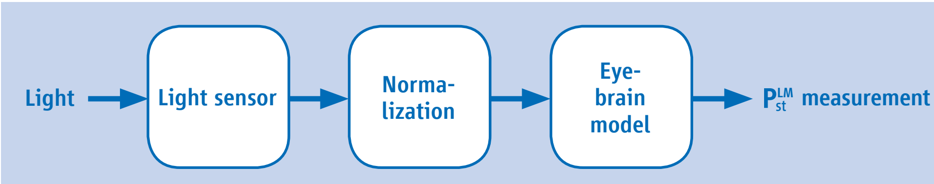
Threshold for P_{st}^{LM}:

The recommended threshold is P_{st}^{LM}= 1. The threshold was determined on the basis of a representative test group and represents the average perception threshold for visible flicker (criterion of IEC/EN 61000-3-3).

SVM metric

The stroboscopic visibility measure (SVM) metric aims to assess the stroboscopic effect which can occur in conjunction with moving objects and light modulation in the frequency range 80 Hz to 2,000 Hz.

Figure 2: Block diagram P_{st}^{LM} metric



Source: ZVEI

Light sensor:

The first block contains the light sensor. This converts the measured light signal into a proportional electrical signal.

Normalization:

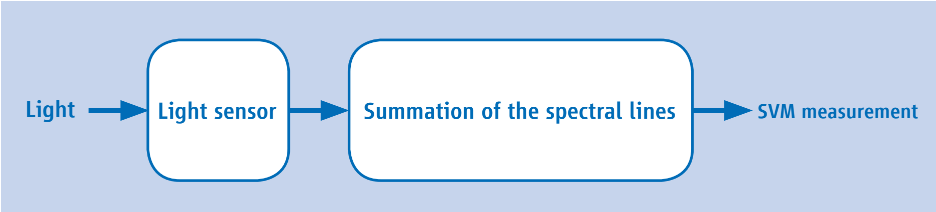
This block scales the input signal in such a way that the amplitude of the output signal is independent of the absolute light level (e.g. illuminance). To do this, the input signal is normalized to the average value (DC portion) of the input signal.

The block diagram of a flicker meter based on the SVM measurement method is shown in Figure 3. A signal of at least 1 second is required to calculate the SVM value.

Light sensor:

The first block contains the light sensor. This converts the measured light signal into a proportional electrical signal.

Figure 3: Block diagram SVM metric



Source: ZVEI

Summation of the spectral lines:
The SVM value is calculated in this block. This is achieved through summation of the frequency components of the input signal based on the following formula:

$$SVM = \sqrt[3,7]{\sum_{i=1}^{N(\leq 2kHz)} \left(\frac{C_i}{T_i}\right)^{3,7}}$$

The individual normalized frequency components C_i of the signal are weighted based on human perception and added up using T_i for each frequency.

T_i in the formula represents the perception threshold of the stroboscopic effect for a sinusoidal signal with the frequency of the frequency component i.

The frequency-dependent sensitivity curve T(f) is shown in Fig. 4

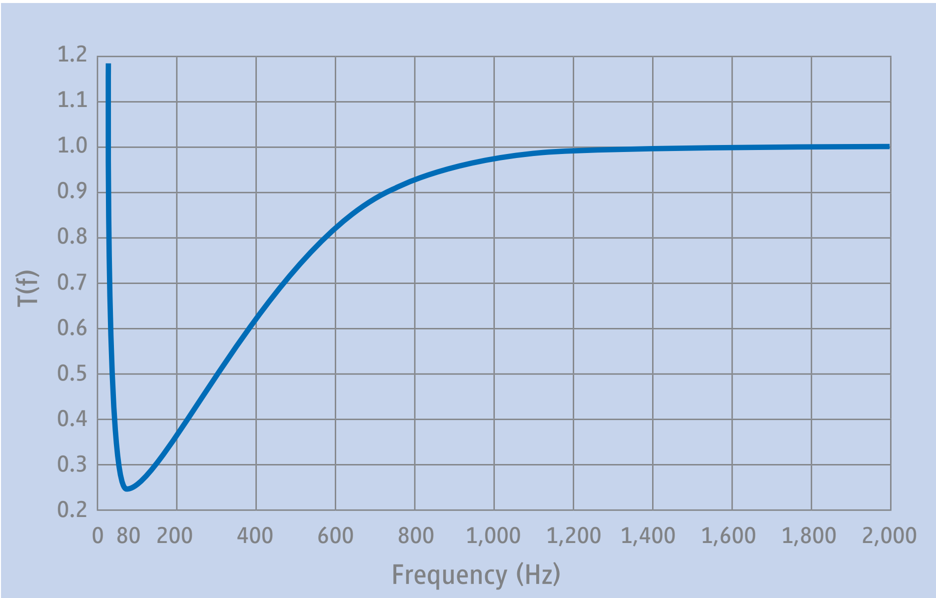
The output signal of this block corresponds to the SVM value.

SVM threshold values:

The threshold values have not yet been defined. Meaningful application-specific values are currently being discussed.

SVM = 1 represents the visibility threshold of test persons concentrating on evaluating the stroboscopic effect under laboratory conditions. Depending on the application conditions, the actual acceptance threshold may be much higher.

Figure 4: SVM sensitivity curve T(f)



Source: ZVEI

Other Uses of the Term Flicker

The European standard EN 61000-3-3 "Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems for equipment ..." is often referred to informally as the "flicker standard". It relates primarily to electrical loads with periodically changing current consumption in public low-voltage supply grids. Changing the current consumption and the actual impedance of the supply network creates a temporary modulation of the supply voltage, which in turn can lead to annoying light modulation of lighting devices - flicker.

EN 61000-3-3 thus limits the temporally modulated current e.g. of home appliances. To assess a device under test, the time-dependent voltage fluctuations caused by the modulated current consumption are measured at a defined network impedance and evaluated based on a signal evaluation process similar to one of the P_{st}^{LM} methods described above.

ZVEI Recommendations for TLA Metrics

The ZVEI group of authors supports the preferred metrics and acceptance criteria contained in the "LightingEurope Position Paper on Flicker and Stroboscopic Effect (Temporal Light Artefacts)", the core statements of which are summarized below.

Preferred metrics

As already described in the "TLA evaluation metrics" section, the modulation depth (MD) and flicker index (FI) metrics are not suitable for objectively predicting the visibility of flicker and the stroboscopic effect for humans, as they do not adequately take into account the frequency, waveform, and the duty cycle of the light modulation.

Instead, the Lighting Division of the ZVEI recommends the "perception of short term light modulation" (P_{st}^{LM}) metric standardized within IEC (see IEC TR 61547-1) to evaluate flicker and the "Stroboscopic Visibility Measure" (SVM) for objective assessment of the stroboscopic effect.

Both the TLA phenomena and the P_{st}^{LM} and SVM metrics are described in a CIE Technical Note which was published in August 2016. In addition, standardization work has been started in IEC TC34. It is striving to achieve alignment between the IEC and CIE.

Availability of Measuring Instruments

Since some of the metrics described in this paper are relatively new, the selection of commercially available instruments is still small. A web search using parameters such as flicker meters, SVM and Pst can be useful here.

Evaluation of System Components

Often, it is only possible to assess the individual components in combination with other system components. The interaction between LED modules and drivers requires special attention. The resulting TLAs are generally not an independent characteristic of the driver, they also depend on module parameters in many device types. The TLAs can depend on the workpoint, i.e. the module current and voltage, but also on the differential resistance of the module. For example, low differential resistance in certain system combinations can lead to higher TLAs than higher differential resistance.

The most obvious expression of this interaction is the modulation depth of LED current and light at double mains frequency (e.g. 100 Hz) and is reflected accordingly by the SVM value.

For these reasons, it is recommended to use matched systems or to carry out appropriate system tests.

TLA-Acceptance Criteria

The acceptance criteria for the TLA metrics depend both on the visibility and on the relevance and risk in the respective application. For example, in a workshop it is essential to avoid stroboscopic effects for the safe operation of rotating machines, whereas they rarely play a role in walkways or storage spaces.

The specification of metrics and their acceptance criteria thus depends on the specific application.

The visibility threshold $P_{st}^{LM} \leq 1.0$ can be a good reference value for general applications (such as spaces in homes, offices). With regard to the SVM metric, further experience needs to be gained in the next few years in the lighting industry.

Some international and regional light application and industry standardization bodies are also working on defining limits for flicker and stroboscopic effects.

Light Modulating Interactions with Technical Devices and Machinery

In addition to the visible effects, temporal modulations of light can also cause adverse interference with technical equipment. Known examples include striped image interference in digital cameras in cases where the object being shot is illuminated with PWM-dimmed LED systems.

Further problems can occur e.g. in film cameras, security/surveillance cameras, webcams, sports cameras, high-speed cameras, visual inspection systems, barcode readers, pulse oximeters, sensors, optical measurement laboratories, light barriers etc.

The metrics P_{st}^{LM} and SVM cannot be used to make a general assessment of the compatibility of light sources with technical equipment.

In workplaces with rotating machines, the lighting must be considered in a risk analysis for each type of workplace. No universal threshold values can be specified.

Rough Classification of Applications

As mentioned in the "TLA-Acceptance Criteria" section, the TLA-relevant requirements for lighting equipment can depend to a large extent on the specific application environment.

Although it is still too early to make a list of specific recommendations and limits, the following classification is intended to stimulate a discussion among experts:

- Residential (including hotel rooms, home care)
- Offices, other permanent workspaces
- Lobby areas (e.g. concierge)
- Schools, educational facilities
- Retail (spotlights, track lighting)
- Industrial/commercial/trades with rotating machines
- Heavy industry
- Circulation areas such as walkways and stairwells
- Underground car parks, multi-storey car parks
- Street lighting
- Car parks, public spaces
- Tunnels
- Hospital, ancillary rooms
- Hospital, patient rooms
- Hospital, operating theatres
- Storage spaces, warehouses
- Sport facilities
- Architectural lighting
- Illuminated signs/displays
- Public areas (such as museums, libraries, cinemas)
- Recreation rooms
- Control rooms
- Airports
- Railways
- Lighting for skilled trades (such as pottery, hairdressing, baking)
- Camera-monitored areas
- Television broadcasts

Comparison with Traditional Lighting Technologies

Lighting system	P_{st}^{LM}	SVM
60 W incandescent lamp with ideal mains supply	<0.1	approx. 0.2–0.6
60 W incandescent lamp with defined mains voltage modulation according to IEC 61547	1	approx. 0.2–0.6
Fluorescent lamp with conventional ballast and ideal network (P_{st}^{LM} can - depending on the age of the lamp - be significantly higher)	<0.1	approx. 1.0–1.5
Fluorescent lamp with conventional ballast and defined mains voltage modulation according to IEC 61547	<1	approx. 1.0–1.5
Fluorescent lamp with Electronic Ballast (FL and CFL) with ideal network and undimmed (P_{st}^{LM} may be significantly higher in dimmed operation)	approx. 0.1	approx. 0.1–1.0

Source: ZVEI

Outlook

Some of the main scientific works on Temporal Light Artefacts (TLAs) date back to the mid-20th century, although the term TLA was not familiar at the time.

The current discussion surrounding TLAs was stimulated above all by the technological change from traditional light sources to LED-based lighting systems, because the light emission of LEDs reacts very quickly to time-dependent operating conditions.

The P_{st}^{LM} and SVM evaluation metrics described in this ZVEI information therefore help to achieve an improved quantitative description of light quality and are gaining in importance in the lighting industry.

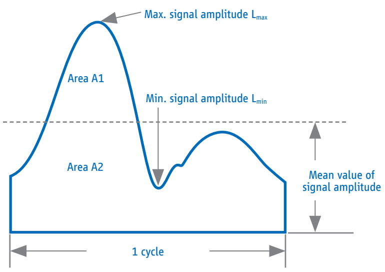
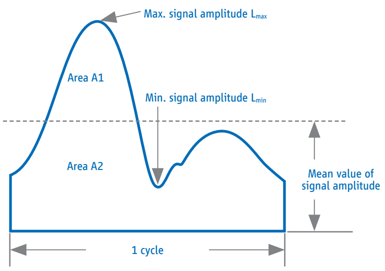
It is expected that valuable experience will be gained in the next few years in the professional use of the measurements methods described and, possibly also, further refinements of these, and that the variety of commercially available instruments will increase significantly.

In addition, further important insights are expected from the ongoing research into TLA phenomena.

Appendix 1: Definitions

The following definitions and explanations of terms used in this publication, as well as of terms which are not used directly but are related to aspects of TLAs, are intended to ensure a uniform approach and terminology.

Name	Definition	Publication or standard	Remarks
Illuminance (lm/m2)	Quotient of luminous flux dΦ hitting a surface element containing the point, and the area dA of this element. $E = \frac{d\Phi}{dA}$ The unit of illuminance E is lux, unit symbol lx = lm/m2.	IEC 60050-845: 1987/CIE 17.4: 1987; 845-01-38	
Dimming level			Whenever 'dimming level' is referred to, a basic distinction is made between A) the luminous flux of a light source based on the 100% value, and B) the electrical power consumed (as a basis for the luminous flux output of the light source), based on the 100% value
Flicker (light flicker)	Impression of fluctuation in visual sensations caused by light stimuli with temporal variation of luminance or spectral distribution.	IEC 60050-845:1987, 845-02-49	The official translation of 'flicker' in German is 'Flimmern'. Although there are slight differences between the definitions of flicker (as defined in the English literature) and Flimmern, it makes little sense to create a fundamental objective distinction between the two.

Name	Definition	Publication or standard	Remarks
Critical flicker frequency (Hz)	The critical flicker frequency (CFF) is the "threshold frequency of a sequence of light stimulants above which flicker is imperceptible". It is between 22 Hz and 90 Hz. Flicker occurs when there is incomplete fusion. A minimum amount of time is required for the excitation caused by the chemical processes triggered in the retina of the eye by light stimulation. If the time interval between two stimuli is shorter than this minimum time, the stimuli cannot be perceived as individual events.	IEC 60050-845: 1987/CIE 17.4: 1987; 845-02-50	This assessment applies for an average observer.
Short-term flicker severity P_{st}	Assessment quantity for changes in luminance perceived by an average (or normal) observer. Assessment quantity P^{V}_{st} for changes in luminance caused by fluctuations in the supply voltage. Assessment quantity P^{LM}_{st} for changes in luminance caused by the ballast/light source combination with standardized (constant) supply voltage.	IEC/TR 61547-1: 2015 und IEC 60050-161:1990, 161-08-18	Change in the lighting level that is directly perceived by an average (or normal) observer. The frequency range from 0 Hz to 80 Hz is considered. The visibility threshold was determined in series of tests carried out on volunteers. In short-term flicker, a distinction is made between flicker caused by the power supply voltage (P^{V}_{st} – and flicker caused by the light source in connection with the ballast (P^{LM}_{st}).)
Flicker index (FI)	$FI = \frac{A1}{A1 + A2}$ The flicker index describes the ratio of the A1 areas above the luminous flux average of emitted light to the total emitted luminous flux (area A1 + A2) in an observation interval.		
Modulation (%)	See Modulation Depth or Percent Flicker (MD).		
Modulation depth or Percent Flicker (MD)	$MD = \frac{(L_{max} - L_{min})}{(L_{max} + L_{min})} \cdot 100\ \%$ The modulation depth is the relationship between the difference and the sum of the maximum and minimum light signal amplitudes.		
PWM dimming	PWM stands for pulse width modulation. The light source is powered by pulses of current. The power supply pulsates at a rate that is faster than can be perceived by the human eye. The dimming effect arises from the ratio of the active period to the cycle time (duty cycle).		Typical pulse frequencies are in the range of 200 Hz to 600 Hz; the full frequency range is 100 Hz to 2,000 Hz.
Ripple current	RMS value of AC component, e.g. an LED module power supply.		In some cases the AC component is specified relative to the DC voltage component as a percentage.

Name	Definition	Publication or standard	Remarks
Stroboscopic effect (wagon-wheel effect)	Change in perception of motion of a static observer in a non-static environment caused by a light stimulus, the brightness or spectral distribution of which fluctuates over time.	SVM metric in accordance with CIE TN 006:2016	Effect which can become visible to an average observer when a moving or rotating object is illuminated. The frequency range from approx. 50 Hz to approx. 2 kHz is considered.
SVM Stroboscopic Visibility Measure	$SVM = \sqrt[3,7]{\sum_{i=1}^{N(\leq 2kHz)} \left(\frac{C_i}{T_i}\right)^{3,7}}$		New metric for evaluating the stroboscopic effect.
Duty cycle	Ratio of the active period to the cycle time during PWM dimming.		
Temporal Light Artefacts (TLAs)	A change in the visual perception of a human observer in a particular environment caused by a light stimulus, the luminance or spectral distribution of which fluctuates over time.	In accordance with CIE TN 006:2016	
Phantom Array Effect	Change in perceived shape or spatial position of objects, induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a non-static observer in a static environment	In accordance with CIE TN 006:2016	Example: In a saccade (rapid movement of the eyes between fixed points) over a small light source, the light source is perceived as a series of spatially extended light spots
			In the metrological evaluation, the frequency range of approx. 50 Hz to approx. 2 kHz is considered.

Source: ZVEI

Appendix 2: References

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