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TECHNICAL REPORT

colour inside

Equipment for general lighting purposes – Objective test method for stroboscopic effects of lighting equipment

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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EQUIPMENT FOR GENERAL LIGHTING PURPOSES – OBJECTIVE TEST METHOD FOR STROBOSCOPIC EFFECTS OF LIGHTING EQUIPMENT

FOREWORD

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IEC TR 63158, which is a Technical Report, has been prepared by IEC technical committee 34: Lamps and related equipment.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
34/436/DTR	34/496/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The fast rate at which solid state light (SSL) sources can change their intensity is one of the main drivers behind the revolution in the lighting world and applications of lighting. Linked to the fast rate of the intensity change is a direct transfer of the modulation of the driving current, both intended and unintended, to a modulation of the luminous flux. This light modulation can give rise to changes in the perception of the environment. While in some very specific entertainment, scientific or industrial applications a change of perception due to light modulation is desired, for most everyday applications and activities the change is detrimental and undesired. The general term used for these changes in the perception of the environment is “temporal light artefacts” (TLAs) and these can have a large influence on the judgment of the light quality. Moreover, the visible modulation of light can lead to a decrease in performance, increased fatigue as well as acute health problems like epileptic seizures and migraine episodes [1][3][1].

Different terms exist to describe the different types of TLAs that may be perceived by humans. The term ‘flicker’ refers to light variation that may be directly perceived by an observer. ‘Stroboscopic effect’ is an effect which may become visible for an observer when a moving or rotating object is illuminated (CIE TN 006:2016).

Possible causes for light modulation of lighting equipment that may give rise to flicker or stroboscopic effect are:

– AC supply combined with light source technology and its controlgear topology;
– dimming technology of externally applied dimmers or internal light level regulators;
– mains voltage fluctuations caused by electrical apparatus connected to the mains (conducted electromagnetic disturbances) or intentionally applied for mains-signalling purposes.

Lighting products that show unacceptable stroboscopic effect are considered as poor quality lighting.

Until recently, modulation depth (MD) – also called percent flicker – and flicker index (FI) were often used to quantify flicker or stroboscopic effect. It has been shown that both these metrics are not able to objectively score the level of flicker or stroboscopic effect as actually perceived by humans [1]. Therefore, instead of MD and FI, for ‘flicker’ the IEC-standardized ‘short-term flicker severity’ ($P_{\mathrm{st}}^{\mathrm{LM}}$) is used, which is derived from the widely applied and accepted IEC-standardized P_{st}-metric to assess the impact of voltage fluctuations on flicker [5]. For the objective assessment of stroboscopic effect, the stroboscopic effect visibility measure (SVM) is available [6].

In 2013, a clear need was identified for an objective test method for testing lighting equipment against flicker caused by voltage fluctuations induced by switching loads such as household appliances. Technical committee 34 developed and verified an objective test method for flicker using the flicker metric $P_{\mathrm{st}}^{\mathrm{LM}}$. This objective flicker test method is described in IEC TR 61547-1 [5].

In recent years the interest in objective testing of stroboscopic effect has also increased considerably. In the near future, CIE will start developing a basic standard on TLA metrology including objective test methods for flicker and stroboscopic effect.

This document provides practical considerations and application examples on how to objectively quantify the stroboscopic effect performance of lighting equipment in terms of SVM.

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1 Numbers in square brackets refer to the Bibliography.

EQUIPMENT FOR GENERAL LIGHTING PURPOSES – OBJECTIVE TEST METHOD FOR STROBOSCOPIC EFFECTS OF LIGHTING EQUIPMENT

1 Scope

This document describes an objective stroboscopic effect visibility (SVM) meter, which can be applied for performance testing of lighting equipment under different operational conditions.

The stroboscopic effects considered in this document are limited to the objective assessment by a human observer of visible stroboscopic effects of temporal light modulation of lighting equipment in general indoor applications, with typical indoor light levels (> 100 lx) and with moderate movements of an observer or nearby handled object (< 4 m/s). Details on restriction of the applicability of the stroboscopic effect visibility measure is given in Clause A.1.

For assessing unwanted stroboscopic effects in other applications, such as the misperception of rapidly rotating or moving machinery in an industrial environment for example, other metrics and methods can be required.

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. Temporal changes in the colour of the light (chromatic effects) are not considered in this test. This document describes the methodology for SVM and does not define any limits.

The objective method and procedure described in this document are based on CIE TN 006:2016 on temporal light artefacts (TLAs).

The method described in this document can be applied to objectively assess the stroboscopic effect of lighting equipment that is powered from any type of source, AC mains, DC mains, battery fed or fed through an external dimmer.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
auxiliary equipment
AuxEq
peripheral equipment that is part of the system under test

3.1.2
equipment-under-test
EUT
equipment subjected to stroboscopic visibility tests

3.1.3
temporal light artefact
TLA
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

Note 1 to entry: The change of visual perception is a result of comparing the visual perception of the environment lit by the modulated light to the visual perception of the same person in the same environment, when the environment is lit by non-modulated light.

[SOURCE: CIE TN 006:2016, 2.4.1]

3.1.4
flicker
perception of visual unsteadiness induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment

Note 1 to entry: The fluctuations of the light stimulus with time include periodic and non-periodic fluctuations and may be induced by the light source itself, the power source or other influencing factors.

Note 2 to entry: Flicker is a type of temporal light artefact.

[SOURCE: CIE TN 006:2016, 2.4.2, modified – Note 3 has been deleted.]

3.1.5
stroboscopic effect
change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment

EXAMPLE 1 For a square periodic luminance fluctuation, moving objects are perceived to move discretely rather than continuously.

EXAMPLE 2 If the frequency of a periodic luminance fluctuation coincides with the frequency of a rotating object, the rotating object is perceived as static.

Note 1 to entry: The stroboscopic effect is a type of temporal light artefact.

[SOURCE: CIE TN 006:2016, 2.4.3]

3.1.6
static observer
observer who does not move her/his eye(s)

Note 1 to entry: Only large eye movements (saccades) fall under this definition. An observer who only does involuntary micro-saccades is considered static.

[SOURCE: CIE TN 006:2016, 2.4.5]

3.1.7
static environment
environment that does not contain perceivable motion under non-modulated lighting conditions

[SOURCE: CIE TN 006:2016, 2.4.6]

3.1.8
average observer
observer representing the mean characteristics of a specified population of sighted individuals

Note 1 to entry: The population in question depends on the application a lighting system is designed for. It can also include specific groups of observers as for example migraine sufferers. A general average observer is based on data aggregated across gender and age but specific observers can be defined for subgroups.

[SOURCE: CIE TN 006:2016, 2.3.1]

3.1.9
visible artefact
perceptual effect of a light modulation detected by an average observer with a probability higher than 50 %

[SOURCE: CIE TN 006:2016, 2.3.2]

3.1.10
visibility threshold
level of light modulation, at which an average observer, when presented with and questioned about the visibility of an artefact, can detect the artefact with a probability of 50 %

[SOURCE: CIE TN 006:2016, 2.3.3]

3.1.11
stroboscopic effect visibility
measuremeasure of stroboscopic effect evaluated over a specified time interval of a relatively short duration

Note 1 to entry: The duration is typically 1 s, in accordance with CIE TN 006.

3.1.12
modulation depth
property of waveform calculated by taking the ratio of the difference between the maximum and minimum intensity to the sum of the maximum and minimum intensity

Note 1 to entry: Often, MD is calculated over one fundamental period of waveform modulation, however it can be calculated also over a much longer time over a multiple number of periods.

Note 2 to entry: MD is also often expressed as a percentage, by multiplying the ratio by 100 %.

3.2 Abbreviated terms

AC	alternating current
ADC	analog to digital converter
CIE	Commission Internationale de l'Éclairage
DC	direct current
DFT	discreet Fourier transform
EUT	equipment under test
FFT	fast Fourier transform
Hz	hertz
IEEE	Institute of Electrical and Electronics Engineers
kHz	kilohertz
LED	light emitting diode
MD	modulation depth
TLA	temporal light artefact

PoE power over Ethernet
RMS root mean square
TN technical note
SNR signal to noise ratio
SSL solid state lighting
SVM stroboscopic effect visibility measure
THD total harmonic distortion
TLD tapped linear driver

3.3 Symbols

C_A gain of the light amplifier
$C(f)$ spectrum of normalized signal
$E(t)$ illuminance
m_{ver} modulation depth of the modulation of the verification waveform
f_m modulation frequency
P_{st}^{LM} short-term flicker severity
SVM^E SVM-value of the standardized illuminance waveform $E(t)$
SVM^{EUT} SVM-value of the illuminance of an EUT measured with the SVM-meter
$SVM|_{noise}$ stroboscopic effect visibility measure noise level
T_{test} measuring period
$u(t)$ mains voltage signal
$u_E(t)$ output voltage of the light sensor amplifier

4 General

The generic schematic diagram of the stroboscopic effect measurement setup is depicted in Figure 1.

The light output of the system under test is measured. Subsequently SVM is calculated from the measured light waveform. Details on the test setup and equipment are given in Clause 5. The specification of the objective stroboscopic effect meter to calculate SVM is given in Clause 6.

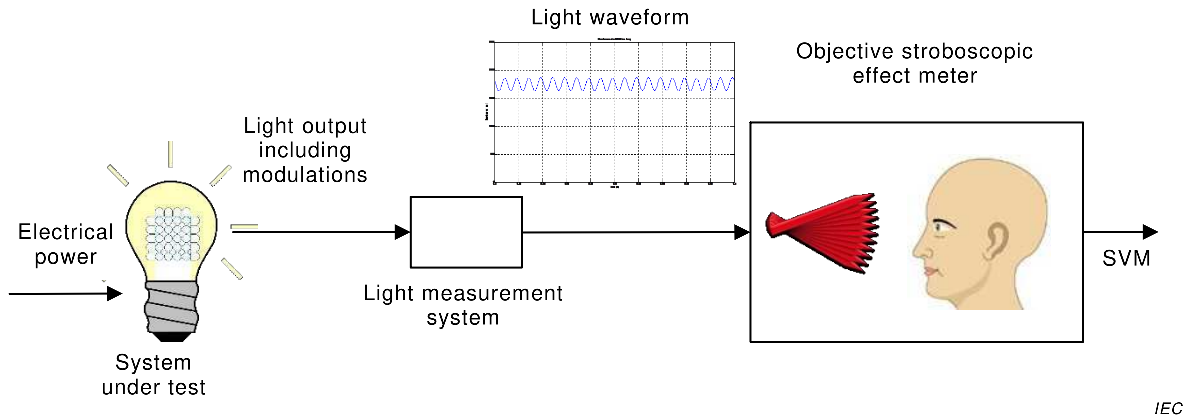


Figure 1 – Schematic of the stroboscopic effect measurement method

The type of equipment under test (EUT) may depend on the purpose of the test. For instance the following different application tests may be considered (see Figure 2):

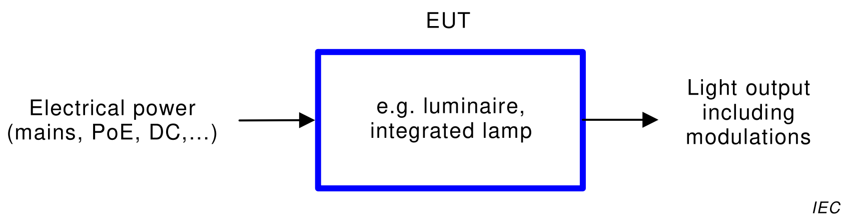
– testing the intrinsic performance of lighting equipment such as luminaires, controlgear or integrated lamps;
– testing the performance of lighting equipment under dimming conditions.

Note that in each of these different test applications, there is a difference between the EUT and the auxiliary equipment, which is peripheral equipment that is part of the system under test (to enable testing), but not part of the test. Application-specific setup and equipment requirements are given in Clause 9.

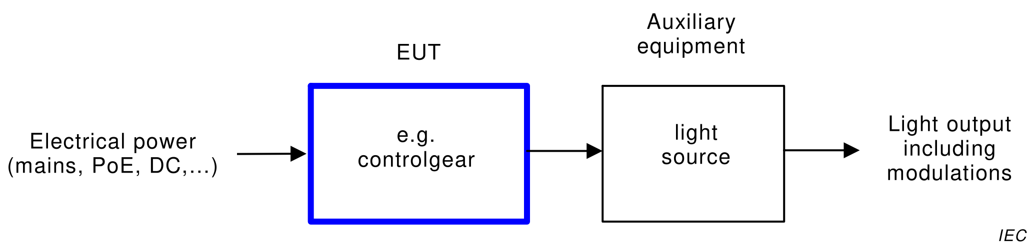
5 Laboratory and equipment requirements

5.1 Schematic of the measurement setup

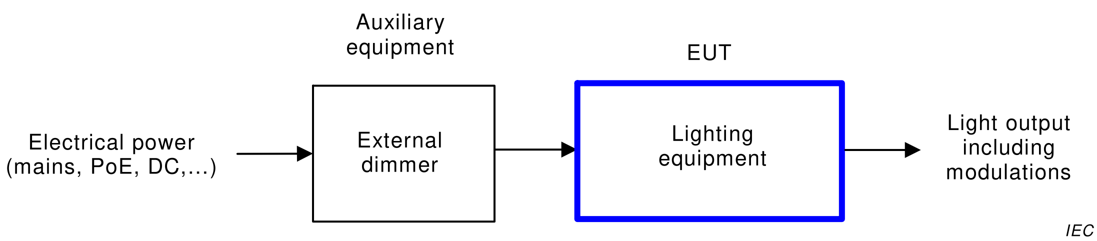
The general schematic diagram of the SVM measurement setup is depicted in Figure 3. General requirements for the equipment and laboratory are given in the subsequent subclauses. Application-specific (auxiliary) equipment is specified in Clause 9.



a) Light source as EUT



b) Control gear as EUT



c) Setup with external dimmer

Figure 2 – Different possible applications for an SVM test

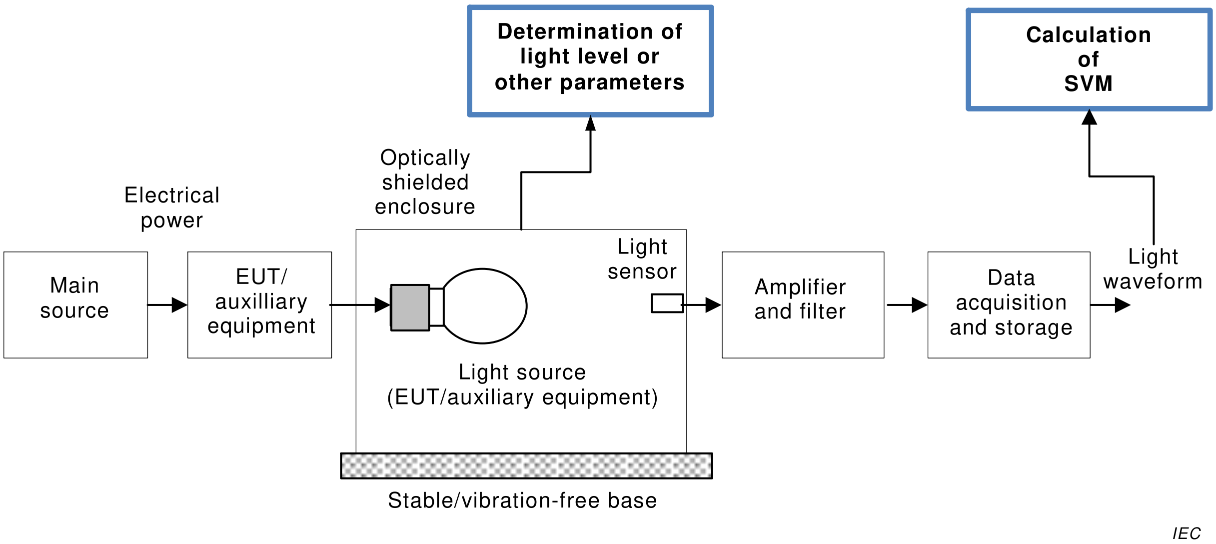


Figure 3 – Schematic of the TLA measurement method

5.2 Laboratory and environmental conditions

It is recommended to execute the measurements in a room or setup where environmental effects such as electromagnetic disturbances, ambient light and vibrations have negligible impact (see also 5.4).

It is recommended to apply ambient temperatures that lie within the specified operating temperature of the EUT and measurement equipment.

5.3 Electrical power source

The electrical power source connected to the EUT and to auxiliary equipment, if applicable, shall be a stable source at the specified nominal frequency, voltage (or current) level, and capable of providing the required power level.

The nominal value of the rated supply voltage of the EUT, or rated supply current of the EUT shall be measured at the supply terminals of the EUT.

It is recommended that the nominal value of the test voltages, or supply current, and frequency (if applicable), are within the tolerance interval of ± 0,5 % (RMS-level in the case of alternating current).

For SVM measurements, the level of voltage fluctuations and harmonics on the mains power source shall be sufficiently low.

Low-frequency voltage fluctuations (below 50 Hz) are less important for SVM measurements. The harmonic distortion of the mains source in the frequency range up to 2 kHz should be limited. A maximum total harmonic distortion of the voltage (THDv) of 4 % is recommended.

5.4 Optical test environment

The illuminance of the light source of the EUT is to be measured for processing by the SVM meter. There is no need for measuring the absolute value. Only the relative illuminance is to be determined.

The light source of the EUT and the light sensor are to be located in an optically shielded environment to avoid disturbances from light sources other than the EUT.

The test environment should also be mechanically robust to avoid vibrations of the EUT and light sensor as that may give rise to unwanted variations in the illuminance.

Most lighting equipment have a non-uniform distribution of light and therefore it is recommended to measure indirectly via a reflecting surface. An integrating sphere, such as an Ulbricht sphere, may be applied. This may be convenient because then the orientation and alignment of the EUT with respect to the light sensor is less critical.

5.5 Light sensor and amplifier

A photodiode with a filter and an appropriate amplifier is to be applied for measuring the illuminance (or more specifically: the relative illuminance) of the EUT.

The photodiode, optical filter and amplifier combination should satisfy the following characteristics.

a) The optical filter should match the photodiode to the eye sensitivity curve of CIE 1931 which is the CIE 1931 standard observer function specified in ISO 11664-1:2007.
b) The cut-off frequency of the amplifier should enable measurement of all SVM-relevant frequencies (up to 2 kHz). A 3 dB cut-off frequency of 3 kHz is recommended (see 5.8.1).
c) The output voltage of the amplifier should vary linearly with the illuminance and no offset-voltage should be present.

5.6 Signals to be measured

The output voltage $u_{\mathrm{E}}(t)$ of the light sensor amplifier is measured as a function of time over a period T_{test}. The output voltage $u_{\mathrm{E}}(t)$ varies linearly with the illuminance $E(t)$:

$$u_{\mathrm{E}}(t) = C_{\mathrm{A}} \cdot E(t) \text{ is measured between } 0 < t < T_{\mathrm{test}} \quad (1)$$

where C_{A} is the constant including the gain of the amplifier and which links the output voltage of the light sensor amplifier to the illuminance.

In certain applications, additional parameters might be measured during the test. For example, in the case of dimming or light regulation the light level of the light source may be of interest. See Clause 9 for application specific requirements.

The signal can be measured with an oscilloscope. It is recommended to apply an appropriate low-pass filter in the oscilloscope to limit the noise.

The measured signal is to be recorded for further processing (see 5.8).

5.7 Duration of the measurement

The duration of the test (duration of the data acquisition after the stabilization period) shall be a minimum of 1 s.

5.8 Signal processing

5.8.1 Anti-aliasing filter

The light output of some types of lamps may contain spectral components at frequencies well above 2 kHz (kHz-range) that are not producing visible stroboscopic effect. Depending on the sampling frequency (see 5.8.2) these higher frequency components may be undersampled and this may lead to aliasing which gives artefacts in the light sensor signal. It is recommended to avoid such aliasing effects by applying a low-pass filter between the amplifier output of the light sensor and the measurement system. A cut-off frequency of at least 3 kHz is recommended. However, the cut-off frequency should also be limited to avoid the need for high sampling frequencies.

EXAMPLE A 1st order low-pass filter with a 3 dB cut-off frequency of 3 kHz will have an attenuationof 10 dB at 9 kHz and -1,6 dB at 2 kHz. For adequate acquisition of the signal up to 9 kHz, a sampling frequency of at least 18 kS/s applies. A higher order Butterworth filter increases the accuracy.

5.8.2 Sampling frequency

For processing of the signals, in accordance with the Nyquist criterion, the sampling frequency shall be at least twice the bandwidth of the signal, which is approximately twice the highest frequency within the signal to be measured.

For incandescent lighting technology, the illuminance signal has a spectrum of interest that is at least twice the spectrum of the mains signal for incandescent lamps. For non-incandescent types of lighting equipment much higher frequencies in the kHz region may be present, depending on the controlgear technology applied. The frequency range above 2 kHz is not of interest for stroboscopic effect and therefore these should be filtered before sampling (see 5.8.1).

For the MATLAB®[2] implementation of the SVM meter given in [16] a sampling rate of at least 20 kS/s is recommended.

5.8.3 Signal resolution

In 5.10 it is recommended to have a noise level of $SVM < 0,05$. Various influence quantities may contribute to this noise level. The quantization noise from the analog-to-digital convertor (ADC) is one contributing factor. It is recommended that the quantization noise contribution from the ADC is 0,2 times the overall noise level, which gives $SVM < 0,01$. The consequence for the minimum number of bits N for the ADC is as follows.

For a light waveform with 100 Hz sinusoidal modulation, a level of $SVM = 1$ is generated with approximately 25 % modulation depth (see Figure A.2). In order to enable measurement of an SVM level of 0,01, the spectral component which contributes to $SVM = 0,01$ is -52 dB down the average light level; see Formula (A.4). An accurate measurement of such a spectral component can be achieved if the signal to noise ratio (SNR) due to quantization is at least 10 dB lower, i.e an SNR level of -62 dB.

The signal-to-noise ratio of the spectrum calculated for an N-bit ADC, expressed in dB, is

$$SNR(N) = 6,02N + 1,76 \tag{2}$$

In practice this means that at least a 12-bit ADC is required.

5.9 SVM calculation

The SVM calculation and verification method is detailed in Clause 6.

5.10 Verification noise-level of the setup

In theory, if the illuminance from the EUT's light source were constant, then $SVM = 0$. In a practical setup however, if an EUT with constant light level is measured, the SVM result may be not equal to zero, due to modulations arising from the light sensor and its amplifier and due to numerical artefacts. This may give a non-zero result and is called the stroboscopic effect visibility measure noise level of the setup: $SVM|_{\text{noise}}$.

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2 MATLAB is the trademark of a product supplied by The MathWorks, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named.

The noise level $SVM|_{\text{noise}}$ can be verified as follows.

Install a suitable DC-fed reference light source, either an incandescent or halogen lamp. Feed the lamp with a constant voltage. Verify that the voltage of this reference light source has a tolerance interval of less than ± 0,5 % during the recording of the reference waveform.

Measure the illuminance and determine the actual SVM-level using the stroboscopic effect visibility measure meter and verify whether the actual level satisfies the following:

$$SVM|_{\text{noise}} < 0{,}05 \quad (3)$$

6 Stroboscopic effect visibility meter

6.1 General

For an objective assessment of the stroboscopic effect, the SVM-meter specified in Annex A is used.

6.2 Verification

Verification of the stroboscopic effect visibility meter may be performed using the procedure and reference waveforms given in Clause A.5.

It is recommended that the outcome of the verification test satisfies the following for the reference waveforms given in Clause A.5:

$$\left| SVM^{\text{E}} - SVM \right| \;/\; SVM^{\text{E}} \times 100\ \% < 5\ \% \quad (4)$$

where SVM^{E} is the reference SVM value of the verification illuminance waveform $E(t)$ applied; see Formulae (A.7) and (A.8), and SVM is the SVM-value measured at the output of the SVM meter for the frequencies, amplitudes and reference waveforms listed in Table A.1.

6.3 Evaluation of results

For actual light waveforms, the SVM level that is measured by the SVM meter may range between 0 and near 9: $SVM = 0$ is obtained for a waveform without any modulation, while $SVM \approx 9$ is obtained for a 100 % rectangular pulse-modulated waveform with an infinitely small duty cycle.

SVM is an objective measure derived from laboratory and perception studies with persons. SVM results can be interpreted as follows (CIE TN 006:2016). If the value of the visibility measure equals one, the modulated light waveform produces stroboscopic effect that is just visible, i.e. at visibility threshold. This means that an average observer will be able to detect the artefact with a probability of 50 %. If the value of the visibility measure is above unity, the effect has a probability of detection of more than 50 %. If the value of the visibility measure is smaller than unity, the probability of detection is less than 50 %. These visibility thresholds show average detection of an average human observer in a population under laboratory conditions, i.e. the observer is aware that he/she is trying to observe stroboscopic effect. Visibility, however, is not the same as acceptability in actual applications. The acceptability level of an artefact might be well above the visibility threshold. Acceptability depends on the duration of exposure, the type of activities (criticality) and typical speed of movement involved in these activities. Examples of measured SVM levels of conventional lighting equipment are given in Clause C.1.

7 Test setup and operating conditions

7.1 General

The EUT should be tested within its intended operating and climatic conditions.

7.2 Ageing

Ageing of the EUT should be according to the applicable product performance standard.

7.3 Mounting

See 5.4.

7.4 Stabilization before measurement

An appropriate stabilization time should be applied for the EUT before execution of the test. The specification of the EUT or the type of technology may indicate the typical stabilization time required. Product standards can be used as a guidance for determining the appropriate stabilization time. For LED technologies see CIE S 025:2015 for guidance on stabilization.

7.5 Operation

The EUT should be operated as follows.

- The test should be applied while the EUT is operated as intended under normal operating conditions as laid down in the relevant product standard at stabilized luminous flux and at normal laboratory conditions.
- Testing is recommended at one combination of supply voltage and frequency, as specified by the manufacturer (see also 5.2).
- An EUT including a light-regulating control should be tested at a light output level of 50 % ±10 % from the maximum light output. If a light output level of 50 % is not available for the EUT including a light regulation function, the test shall be done at the level which is closest to 50 %. If two steps equally distant to 50 % are available, the lower level (< 50 % shall be used for the test (see IEC 61547:2009/ISH1:2013[8][9]).
- Luminaires and controlgear should be tested with light sources or loads for which they are intended. Where such equipment can operate with light sources of different wattages, a light source of minimum wattage is recommended. See specific recommendations for testing controlgear in 9.3.
- If light sources can operate at different colours, select the colour that gives the maximum light output (modulation off).

8 General test procedure

The following general procedure for execution of a test is recommended:

a) mount the light source of the EUT in the optically shielded enclosure;

b) switch on the EUT and any auxiliary equipment and apply sufficient stabilization time (7.4);

c) apply the general operational conditions outlined in 7.5;

d) apply the recommended settings for the data acquisition (test duration, sample rate, filtering) given in Clause 5;

e) measure the light waveform and calculate the SVM level.

Examples of test results of a number of EUTs are given in Annex C.

9 Application-specific equipment, procedures and conditions

9.1 General

Application-specific recommendations for setup, equipment, procedures and conditions are given in 9.2 to 9.4.

9.2 Phase cut dimmer compatibility test of lighting equipment

For the application of external dimming, usage of the standardized NEMA SSL-7A dimmer is recommended. The dimmer is operated in the 'max-min or repetitive peak current or voltage'-mode (see NEMA SSL-7A:2015, 4.6 to 4.8). A recommended prerequisite for the test is that the EUT complies with the dimmer compatibility test given in IEC TR 63037:2016. Instead of the NEMA SSL-7A dimmer, a phase-cut dimmer can also be applied which complies with the test requirements given in IEC TR 63036:2016. Testing is done at 50 % light output level as described in 7.5.

The block diagram of the testing setup is given in Figure 4.

Examples of SVM measurements under dimming conditions are given in Clause C.2.

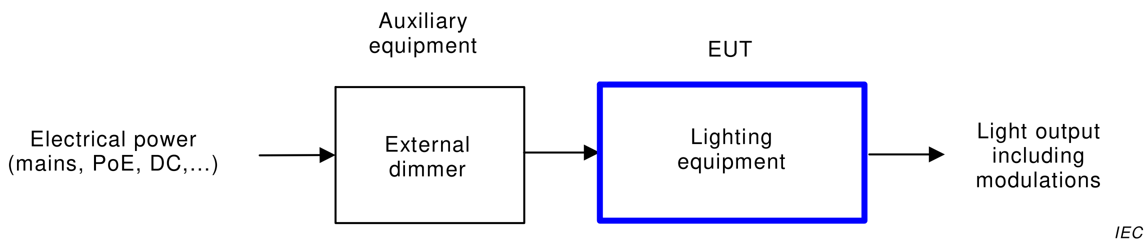


Figure 4 – Dimmer compatibility testing

9.3 Controlgear testing

For measuring the SVM of a controlgear, care should be taken in the choice of the light source, which is crucial, since its electrical properties (e.g. capacitance) will have an effect on magnitude and shape of the measured light waveform. Furthermore it is recommended to select a number of points within the specified operating V/I window of the driver. Refer to available controlgear performance standards for an appropriate choice of the light source (load).

The block diagram of the setup is given in Figure 5.

NOTE In the case of LED sources the current has a linear relation to the light output. Hence a reference source can be applied in this case and the output current can be used for assessment.

Examples of SVM measurements for lighting equipment with different controlgear are given in Clause C.1.

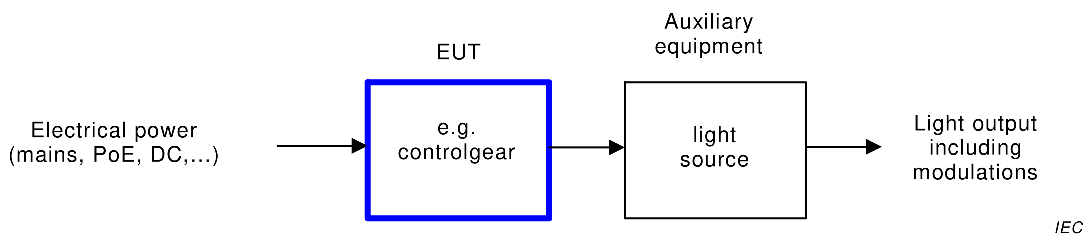


Figure 5 – Controlgear testing

9.4 In-situ testing

In principle, SVM tests can be applied to an individual product as well as to test the SVM performance of installations in actual applications (in-situ). However, the latter in-situ testing is much more prone to measurement uncertainties due to various influence quantities such as ambient light and light modulations from other light sources or daylight or moving subjects.

Therefore, SVM measurements should normally be done at product level. The TLA performance of an actual application environment of multiple light sources is generally better than the TLA performance of a single light source due to the averaging out of the light modulation from the different light sources.

10 Test report

The test report should contain all the information necessary to reproduce the test. In particular, it is advised to record the following information:

a) identification of the EUT, e.g. brand name, product type, serial number;

b) any associated equipment, e.g. external dimmer, light source for controlgear;

c) the relevant operating conditions of the EUT, e.g. light output level in the case of dimming;

d) the types of interconnecting cables, including their length, and the interface port of the EUT to which they were connected;

e) any specific conditions for use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are essential for stroboscopic effect performance;

f) the warming-up/stabilization time of the EUT if applicable;

g) identification of the test equipment, e.g. brand name, product type, serial number;

h) any specific conditions necessary to enable the test to be performed;

i) the nominal mains test frequency and voltage applied;

j) the applied settings of auxiliary equipment or signals (dimming levels, modulation frequencies, relative modulation levels);

k) the duration of the test for each disturbance signal;

l) the SVM acceptance criteria that have been applied.

11 Measurement uncertainties

11.1 General

The stroboscopic effect test is subject to uncertainties. Annex B gives an overview of the main influence quantities for the measurement uncertainty of the test results.

11.2 Verification tests

11.2.1 General

To limit the uncertainty of the test, it is recommended to perform the following verification tests at regular intervals.

11.2.2 Stroboscopic effect visibility meter

See 6.2 and Clause A.5.

11.2.3 Electrical power source parameters

See 5.3. Verify that the nominal value of the test voltages, or supply current, and frequency (if applicable), are within the tolerance interval of ± 0,5 % (RMS-level in the case of alternating current). Verify that the total harmonic distortion of the voltage (THDv) of the mains source in the frequency range up to 2 kHz is less than 4 %.

11.2.4 Electromagnetic compatibility and test environment

See 5.2 and 5.4.

Verify the absence of electromagnetic interference effects and the optical shielding performance of the enclosure in which the light source of the EUT and the light sensor are located. This can be done as follows.

Install the light sensor in the test environment where no EUT is present or in operation. Close the optical test environment and put all (other than the EUT) test equipment into operation. Switch on the lighting of the room in which the test equipment is located. Verify the absence of electromagnetic disturbances and/or unwanted light ingress in the optical test environment by checking the voltage signal at the output of the amplifier.

Verify that vibrations of the test environment do not give rise to unwanted variations in the measured illuminance. This verification test is part of the noise-level verification test described in 5.10.

11.2.5 Light sensor and amplifier

Verify that the light sensor fulfils the recommendations given in 5.5.

Verify the absence of an offset voltage at the output of the amplifier by covering the light sensor such that no light can enter the photodiode. Verify that voltage at the output of the amplifier is less than 0,1 % of the maximum voltage level of the amplifier (within its operating range).

Verify the linearity of the sensor by positioning the photodiode at different distances from a stable small light source in an optical chamber. The voltage should vary linearly with $1/r^2$.

Verify the clipping level of the voltage output of the amplifier, and make sure that tests are executed below this level.

11.2.6 Overall noise-level of the setup

Verify the overall noise level of the test setup using the method recommended in 5.10.

11.2.7 Repeatability

Repeatability of the test method can be verified using repeatability conditions [17] and a very stable light source with a waveform that gives an SVM-level well above the noise floor. For instance, a 100 Hz pulse-modulated LED light source with 50 % duty cycle may be applied for that purpose.

It is recommended to repeat the test with this light source at least five times during five consecutive days. The standard deviation of the individual SVM test results shall be within 2 % of the average SVM value.

11.3 Quality assurance

For quality assurance of the test setup it is recommended to execute the following verification tests prior to every actual test:

1) noise-level of the setup (see 5.10);
2) test of a reference light source which is a very stable light source with a specific waveform that produces a specific known value of SVM.

Annex A
(normative)

Specification of the stroboscopic effect visibility meter

A.1 Background

For quantification of the temporal light artefact performance of a lighting product or system, two different effects should be distinguished, i.e. flicker and stroboscopic effect. The stroboscopic effect visibility measure (*SVM*) is recommended for the quantification of the stroboscopic effect, while for flicker, the existing IEC short-term flicker metric $P_{\mathrm{st}}^{\mathrm{LM}}$ is recommended. More background on the two TLA-metrics *SVM* and $P_{\mathrm{st}}^{\mathrm{LM}}$ can be found in CIE TN 006:2016. Specific details on the IEC flicker metric $P_{\mathrm{st}}^{\mathrm{LM}}$ can be found in [5].

Annex A provides the specification for calculating the stroboscopic effect visibility measure (*SVM*) of a light waveform. More specific details on the development and validation of the *SVM* metric are given in [6].

For both the flicker and the stroboscopic effect, studies have shown that in modulations consisting of multiple frequencies close to their respective visibility thresholds, all these frequencies contribute to the visibility of the overall modulation. Reports from literature also show that the frequency summation can be different for different artefacts. The generic method for the visibility quantification of TLAs is given in CIE TN 006:2016. The specific summation formula for the stroboscopic effect visibility measure introduced by Perz et al. [6] is as follows:

$$SVM = \sqrt[3{,}7]{\sum_{i=1}^{\infty}\left(\frac{C_i}{T_i}\right)^{3{,}7}} \qquad \text{(A.1)}$$

where

$C_i = S_i / S_1$ is the relative amplitude of the *i*-th Fourier component S_i of the relative illuminance I_i (relative to the DC-level);

T_i is the visibility threshold for the stroboscopic effect for a sine wave at the frequency of the *i*-th Fourier component.

For simplicity of notation, the summation in Formula (A.1) is done over all normalized amplitudes. Outside of the frequency range in which the visibility threshold curve is defined, the normalized amplitudes should be set to zero.

If the value of *SVM* equals one, the input modulation of the light waveform produces a stroboscopic effect that is just visible, i.e. at visibility threshold. This means that an average observer will be able to detect the artefact with a probability of 50 %. If the value of the visibility measure is above unity, the effect has a probability of detection of more than 50 %. If the value of the visibility measure is smaller than unity, the probability of detection is less than 50 %. These visibility thresholds show the average detection of an average human observer in a population. This does not, however, guarantee acceptability. For some less critical applications, the acceptability level of an artefact might be well above the visibility threshold. For other applications and artefacts that are more critical such as flicker, the acceptable levels might be below the visibility threshold.

Furthermore it should be noted that SVM is an objective measure for the level of indirect changes in perception caused by light modulations that may be undesired. Reduced performance, visual fatigue and annoyance were adverse effects that were part of the perception experiments done by Perz et al [6]. SVM is not linked to health effects. Nor is SVM a measure for assessing unwanted stroboscopic effects in industrial applications, for example the misinterpretation of rapidly rotating machinery in a workshop, if the frequency of a periodic luminance fluctuation coincides with the rotation frequency (or its multiples). For the safety aspect of the potential misperception of fast rotating or moving objects, other metrics and methods are required.

The sensitivity curve is based on work by Perz et al [6] and Wang et al [7]. It was designed for an application in an office environment, but it can be applied in a broader context. The sensitivity curve in the example was measured in a room with no other light sources except the modulated light source. This results in the most critical situation that can be expected given the context. The sensitivity curve is based on data from more than 160 participants and the data comes from two laboratories. The specific application restrictions for SVM given in CIE TN 006:2016 are:

– average light level > 100 lx, fully adapted;
– fastest movements being moderate speed hand movements ≤ 4 m/s, movements in the modulated light.

The above restrictions generally apply for general purpose indoor lighting equipment.

A.2 Detailed specifications of the stroboscopic effect meter

A.2.1 Schematic of the SVM meter

The various blocks of the SVM meter are depicted in Figure A.1. More details on the functions of the blocks a to d are given in Clause A.2.

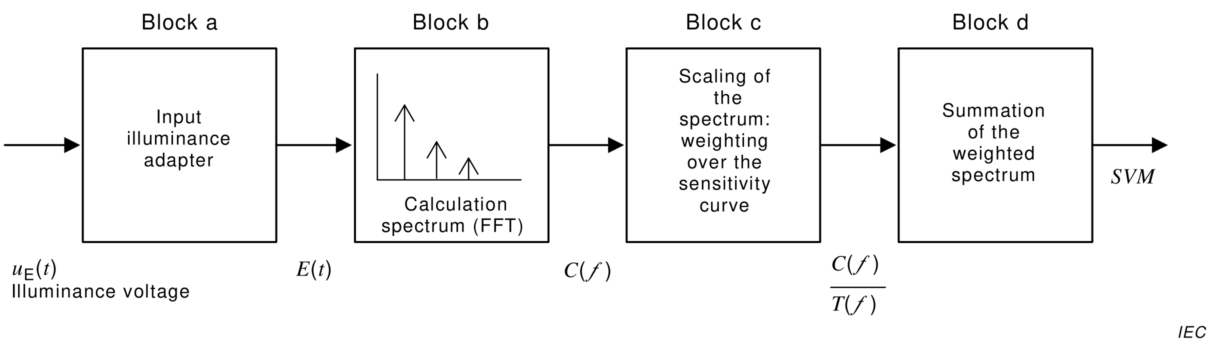


Figure A.1 – Structure of the stroboscopic effect visibility meter

A.2.2 Block a: illuminance adapter

This block contains an illuminance adapting circuit that scales the measured voltage $u_E(t)$ of the light waveform:

$$E(t) = \frac{u_E(t)}{\text{mean}(u_E(t))} \tag{A.2}$$

Applying the signal normalization makes the stroboscopic effect visibility measure independent of the illuminance level. Note that the amplifier and the filter are present before block a, see Figure 3.

A.2.3 Block b: calculation of spectrum

The spectrum $C(f)$ of the normalized signal is calculated as a second step.

$$C(f) = F\{E(t)\} \tag{A.3}$$

In practice this spectrum is calculated using a fast Fourier transform (FFT). See Clause A.3 for the numerical implementation.

A.2.4 Block c: weighting with the stroboscopic effect sensitivity curve

The frequency dependent sensitivity curve $T(f)$ for the calculation of SVM is given in Figure A.2. The threshold curve gives the relative amplitude for a sinusoidal modulation in addition to a constant illuminance level that is just visible with a probability of 50 % for an average observer. Details are given in CIE TN 006:2016.

The following Formula (A.4) applies for the visibility threshold:

$$T(f) = \frac{1}{1 + e^{-a(f-b)}} + 20 \cdot e^{-f/10} \tag{A.4}$$

where

f is the frequency in Hz;

a = 0,005 18;

b = 306,6.

The sensitivity curve is defined up to 2 000 Hz. Above 1 000 Hz the sensitivity threshold equals approximately one. This means that the light waveform may have a 100 % modulated sinusoidal modulation giving a relative spectral component of one.

The maximum sensitivity for perception of stroboscopic effect is near 80 Hz. Below 80 Hz, the stroboscopic effect sensitivity threshold increases again, which means that the stroboscopic effect becomes less visible. Below 30 Hz the stroboscopic effect will be negligible, even with a sinusoidal modulation of 100 %. Moreover, in the frequency range below 80 Hz, the directly visible flicker effect becomes much more dominant than the stroboscopic effect. Although the stroboscopic effect will also be visible, flicker will be perceived as much more annoying.

A.2.5 Block d: summation of the weighted spectrum

Finally, Formula (A.5) gives the weighted spectrum summed up for all frequency components up to 2 kHz (see Formula (A.1)):

$$SVM = \sqrt[3{,}7]{\sum_{i=1}^{N(\leq 2\text{ kHz})} \left(\frac{C_i}{T_i}\right)^{3{,}7}} \tag{A.5}$$

where

$C_i = 2 \cdot S_i / S_1$ is the relative amplitude of the i-th Fourier component S_i, see Formula (A.6), of the relative illuminance I_i (relative to the DC-level);

T_i is the visibility threshold for the stroboscopic effect for a sine wave at the frequency of the i-th Fourier component.

Beyond 2 kHz, no stroboscopic visibility threshold curve is defined. Therefore, the normalized amplitudes of the spectral components are only summed up to 2 kHz.

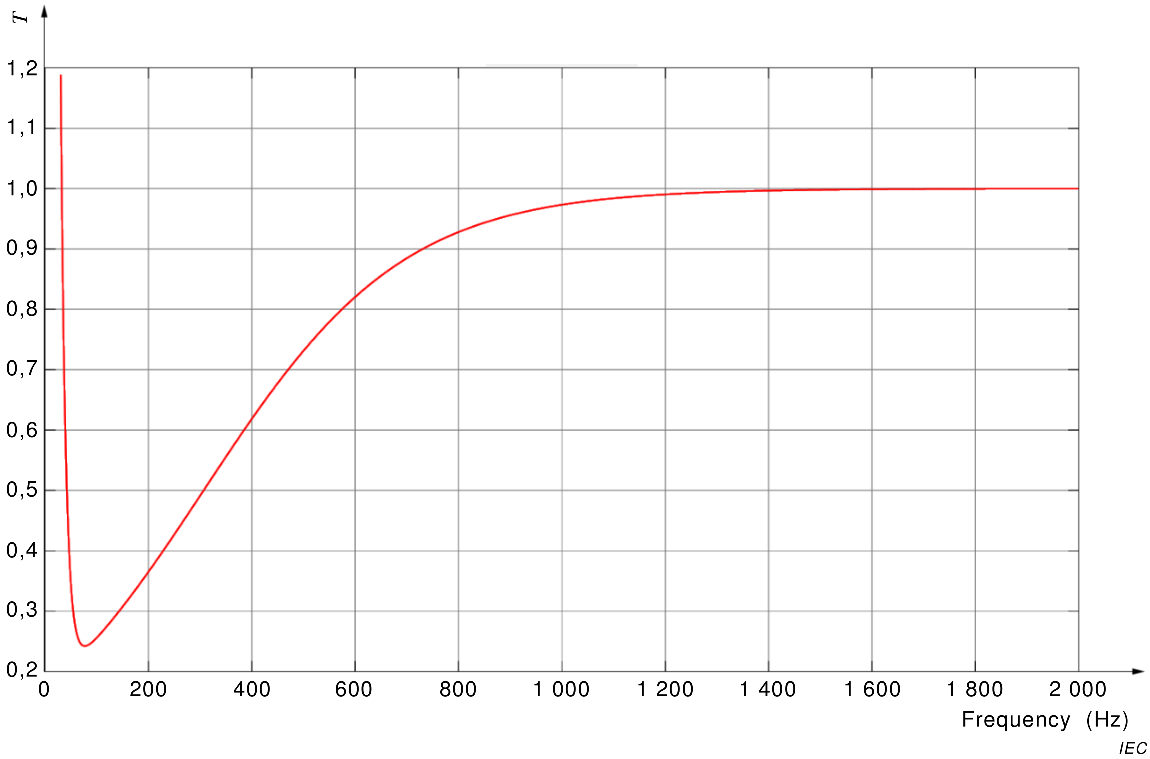


Figure A.2 – SVM sensitivity threshold T

A.3 Numerical implementation of SVM

SVM is calculated using a signal (generally a voltage) that is proportional to the luminous flux of the lighting equipment under test (EUT). Suppose this signal is represented by the following waveform that is acquired with a sample rate of F_{S} for the duration of T second:

$$\text{Illuminance signal} = I_i \text{ for } 1 < i < N = F_{\text{S}} + 1 \tag{A.6}$$

where $N = F_{\text{S}} \cdot T$ is the total number of samples, and the step size of the signal is $\Delta t = 1/F_{\text{S}}$.

As a first step in the frequency analysis, the time domain digital signal is transferred to a frequency representation using the discrete Fourier transform (DFT), usually implemented using the fast Fourier transform (FFT) algorithm.

The spectrum S_i is calculated using the discrete Fourier transform (DFT), usually implemented using the fast Fourier transform (FFT) algorithm. Hence, the spectral components are given by:

$$S_i = FFT(I_i) \text{ for } 1 < i < N \tag{A.7}$$

This transformation gives a two-sided spectrum where the step size in the frequency domain is:

$$\Delta f = 1/T \text{ Hz} \tag{A.8}$$

The maximum frequency F_{max} range that can be calculated is given by:

$$F_{\text{max}} = \frac{N-1}{2} \cdot f = \frac{N-1}{2} \cdot \frac{F_{\text{s}}}{N} \approx \frac{F_{\text{s}}}{2} \qquad \text{(A.9)}$$

As the frequency range of interest is up to 2 000 Hz, a minimum sampling frequency of F_{s} = 4 000 Hz is required (for the purpose of calculating the spectrum; due to the extension of the spectrum beyond 2 kHz and the avoidance of aliasing effect, a higher sample rate is required; see 5.8.1).

For more reliable amplitude estimation of the spectrum, it is recommended to apply common spectral techniques such as ‘nulling’ and ‘windowing’. Nulling is applied to increase the resolution in the frequency domain. Windowing is applied to decrease the uncertainty of the calculation of the level of the spectral components in case the modulation frequency that is to be captured does not coincide with one of the frequency samples (or in other words: if the total duration of the waveform does not fit with an integer number of periods of the modulation of interest in the waveform). Therefore, windowing (by e.g. a Hanning window) can be applied before the FFT is executed.

The FFT delivers a two-sided spectrum (half of the spectrum is imaged at negative frequencies). Therefore a factor of 2 is applied when calculating C_i; see Formula (A.5).

Apart from the wanted frequency components, adjacent frequencies also become available. To avoid inclusion of these adjacent frequency components, the frequency components of interest can be captured by a peak-finding algorithm.

Clause A.6 gives an example of the numerical implementation and application of the SVM calculation in MATLAB®.

A.4 Example

Figure A.3 gives an example of an illuminance signal that consists of a constant level plus a 100 % pulse modulation at 100 Hz. The bottom part of the figure shows the corresponding relative C_i spectrum and the sensitivity threshold given in Formula (A.4).

The SVM value calculated for this waveform is approximately SVM = 4,97. The spectral component at 100 Hz is the main contributing component to the value of SVM.

A.5 Verification waveform of the stroboscopic effect meter

For the verification of the proper implementation of the calculation of SVM, the following verification waveforms can be used:

$$E_{\text{sqr}}(t) = 1 + m_{\text{ver}} \cdot \text{sign}(\sin(2\pi f_{\text{ver}} t)) \qquad \text{(A.10)}$$

$$E_{\text{sin}}(t) = 1 + m_{\text{ver}} \cdot \sin(2\pi f_{\text{ver}} t) \qquad \text{(A.11)}$$

where

$E_{\text{sqr}}(t)$ and $E_{\text{sin}}(t)$ are square pulse and sinusoidal modulated illuminance waveforms respectively;

f_{ver}	is the modulation frequency of the illuminance ripple added to the DC-value;
m_{ver}	is the modulation depth of the illuminance ripple;
$0 \le t \le T$,	where T = 1 s;
$\mathrm{sign}(\sin(2\pi f_{\mathrm{ver}} t))$	is the square function with frequency f_{ver}.

When applying the theoretical spectral components (Fourier transform) of the waveforms of Formulae (A.10) and (A.11) with the parameters specified in Table A.1, and using the Formulae (A.4) and (A.5), the resulting analytically calculated values of SVM should be as indicated in the last column of Table A.1.

The verification waveforms specified by Formulae (A.10) and (A.11) can be expressed as a Fourier series using the following general Fourier representation

$$x(t) = a_0 + \sum_{n=1}^{\infty} a_n.\cos(2\pi n f_0 t) + b_n.\sin(2\pi n f_0 t) \qquad \text{(A.12)}$$

where

a_0	represents the average level of the signal;
a_n and b_n	are the Fourier coefficients;
$f_0 = 1/T$	is the frequency of the period T of the waveform.

For the square pulse waveform of Formula (A.10), the Fourier coefficients are:

$$a_0 = 1,$$

a_n =0, for all values n (because the pulse waveform is an odd function)

$$b_n = m_{\mathrm{ver}} \cdot \frac{4}{n\pi} \quad \text{for odd values of } n, \qquad \text{(A.13)}$$

$$b_n = 0 \quad \text{for even values of } n.$$

When substituting the Fourier coefficients of Formula (A.13) into Formula (A.5) for SVM, using $C_n = b_n / a_0 = b_n$, the following value of the amplitude m_{ver} of the square pulse waveform for a given value of SVM^{E} is obtained:

$$m_{\mathrm{ver}}(f_{\mathrm{ver}}) = \frac{SVM^{\mathrm{E}}(f_{\mathrm{ver}})}{\sqrt[3,7]{\sum_{n=1,3,\ldots}^{N(n \cdot f_{\mathrm{ver}} \le 2\mathrm{kHz})} \left\{ \left(\frac{4}{n\pi}\right) \Big/ T(n \cdot f_{\mathrm{ver}}) \right\}^{3,7}}}, \qquad \text{(A.14)}$$

with the condition that $m_{\mathrm{ver}} \le 1$.

Formula (A.14), together with Formula (A.4), is used to calculate the analytical exact reference values of SVM^{E} for the square pulse waveforms given in Table A.1 (waveforms VW-sq1 up to VW-sq4).

For the sinusoidal reference waveform of Formula (A.11) the Fourier coefficients are simply as follows:

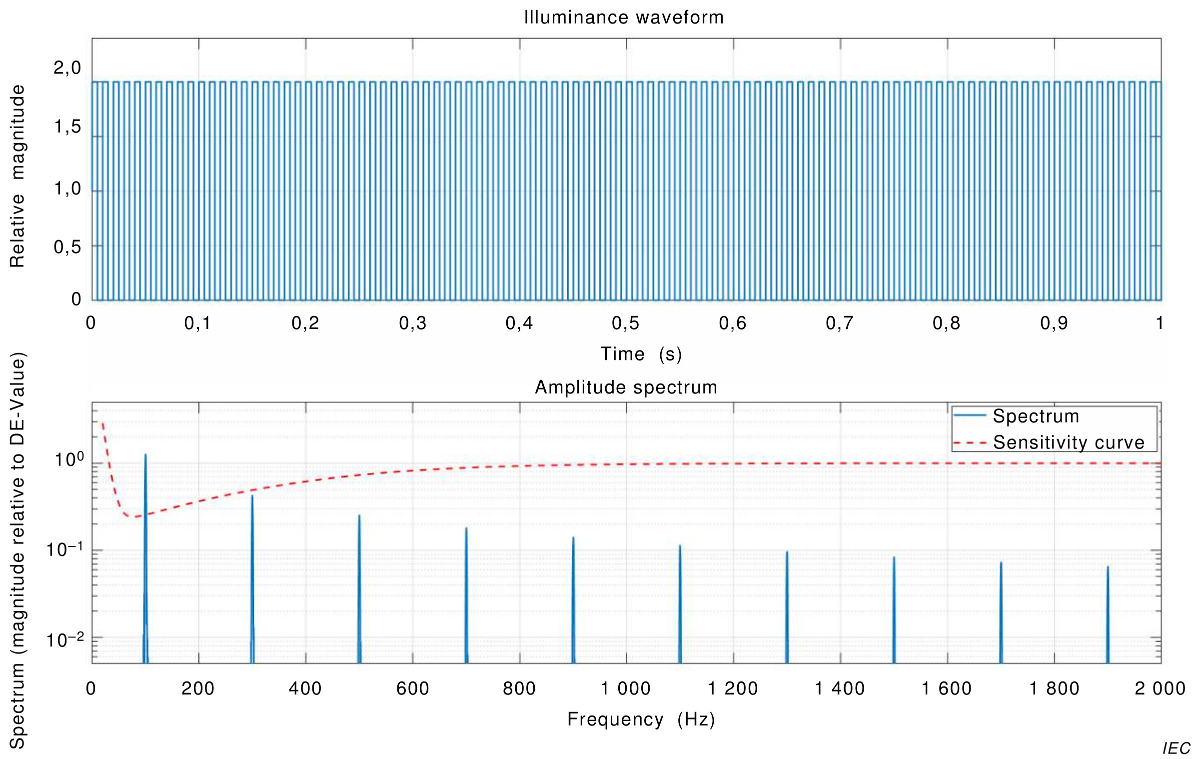
$$a_0 = 1, \; a_1 = m_{\mathrm{ver}} \tag{A.15}$$

Substituting this in Formula (A.5), the following value of the amplitude m_{ver} of the sinusoidal reference waveform for a given value of SVM^{E} is obtained:

$$m_{\mathrm{ver}}(f_{\mathrm{ver}}) = SVM^{E}(f_{\mathrm{ver}}) \cdot T(f_{\mathrm{ver}}), \tag{A.16}$$

with the condition that $m_{\mathrm{ver}} \leq 1$.

This Formula (A.16), together with Formula (A.4), is used to calculate the analytical exact reference values of SVM^{E} for the sinusoidal waveforms given in of Table A.1 (waveforms VW-sn1 up to VW-sn4).



The top figure shows an illuminance signal with a ripple consisting of 100 % square pulse modulated signal with a frequency of 100 Hz.

The bottom figure shows the corresponding relative spectrum; the red dashed line is the sensitivity threshold $T(f)$ (see Formula (A.3); calculated value of SVM = 4,97)

Figure A.3 – Example of an illuminance signal with a ripple

Table A.1 – Specification of the parameters of the verification waveforms

Verification waveform No.	**Type of modulation**	**Modulation frequency** f_m Hz	**Modulation depth** m_{ver}	**Reference value of the stroboscopic effect visibility measure** SVM^E
VW-sq1	Square pulse – Formula (A.10)	99	0,200 5	1,000
VW-sq2		100	0,201 2	1,000
VW-sq3		100	0,020 1	0,100
VW-sq4		100	0,804 8	4,000
VW-sq5		101	0,201 9	1,000
VW-sn1	Sinusoidal – Formula (A.11)	32	1,000 0	0,991
VW-sn2		100	0,256 3	1,000
VW-sn3		500	0,731 4	1,000
VW-sn4		1 900	0,999 7	1,000

It is recommended to apply the parameters and waveforms given in Table A.1. The reference values for the outcome of the SVM can be used to verify proper numerical implementation of the SVM. For the square pulse-modulated waveform, a low frequency of 100 Hz is chosen to avoid the uncertainty effect of aliasing that is present in numerical tools such as MATLAB® when emulating a square waveform. In MATLAB®, band-limiting of the waveform is not possible prior to sampling due to the fact that the MATLAB® square-pulse waveform is sampled intrinsically (and always under sampled because the spectrum of a square-pulse periodic waveform extends to infinity). For the 100 Hz pulse-modulated waveform, linearity is also checked (SVM = 0,100 and 4,000) and the proper peak-finding is verified by applying a small frequency shift of 1 Hz.

A.6 Example of SVM implementation in MATLAB®

An example of SVM implementation is given on MATLAB Central [16].

When using this implementation with MATLAB version R2016b, this will give numerically calculated SVM values within approximately 1 % of the analytical reference values SVM^E given in Table A.1.

Annex B
(informative)

Uncertainty considerations

B.1 General

Annex B provides information related to the measurement uncertainty of the value of the *SVM* metric.

General information on uncertainty evaluations of measurement data can be found in the Guide to the expression of uncertainty in measurement (GUM), JCGM 100:2008 [17].

B.2 General symbols

X_i	influence quantity (also called input quantity in the GUM [17])
x_i	estimate of influence quantity X_i
δX_i	correction for influence quantity
$u(x_i)$	standard uncertainty of x_i
c_i	sensitivity coefficient
y	result of a measurement (the estimate of the measurand), corrected for all recognized significant systematic effects
$u_\mathrm{c}(y)$	combined standard uncertainty of y
$U(y) = k \cdot u_\mathrm{c}(y)$	expanded uncertainty of y
k	coverage factor = 2

B.3 Measurand

The measurand associated with the light fluctuation test is *SVM*, the stroboscopic effect visibility measure.

B.4 Influence quantities

The measurand *SVM* depends on a number of influence parameters, which can be categorized in different groups as depicted in Figure B.1.

Table B.1 gives the list of influence quantities that may be considered to derive the overall uncertainty of the value of the *SVM*. This table gives mainly a qualitative assessment of the relevance of the influence quantities with regard to its contribution to the overall uncertainty of the measurand *SVM*.

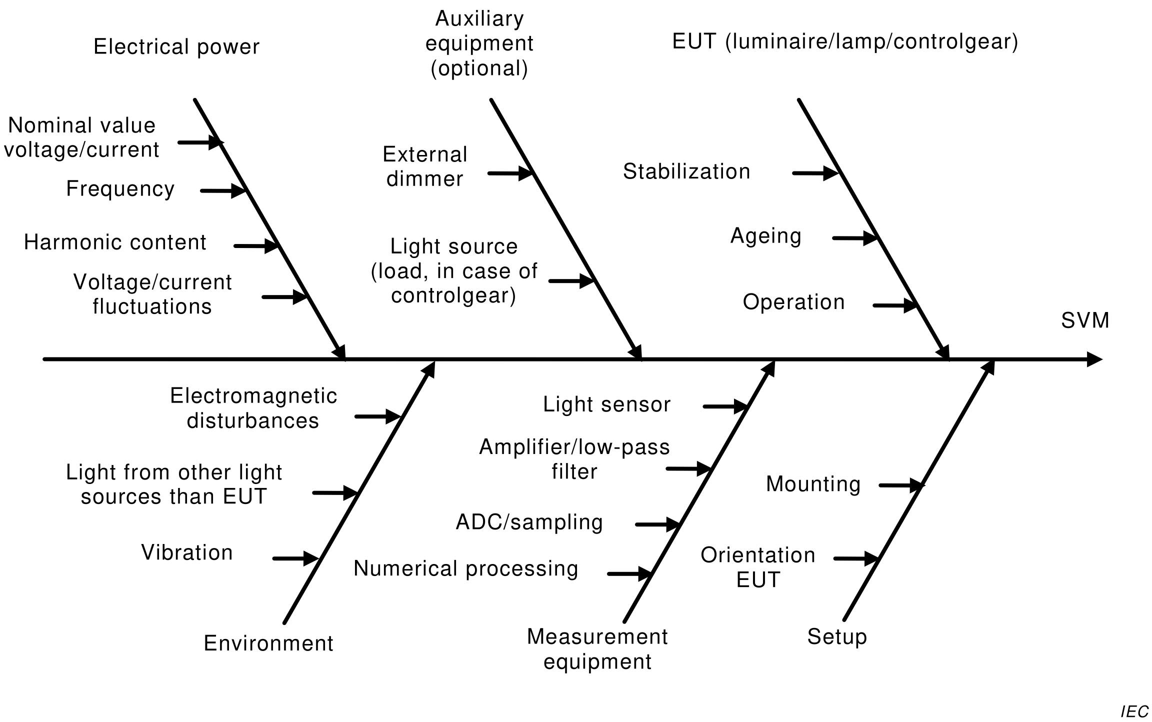


Figure B.1 – Fishbone diagram representing the categories of influence quantities contributing to the uncertainty of the SVM measurement

Table B.1 – Influence quantities and their recommended tolerances

Main category	Sub category	Importance	Nominal value	Recommended tolerance/value/ reference
Electrical power supply	Nominal voltage or current	Minor	230 V, 120 V	± 0,5 %
	Frequency	Minor	50 Hz, 60 Hz	± 0,5 %
Electrical power supply disturbances	Harmonics	Minor	n.a.	THD < 4 %
	Voltage fluctuation	Minor, as the level of the fluctuations is small and the frequencies are below the frequency range of interest for stroboscopic effect.		
Auxiliary equipment (optional)	External dimmer	Relatively important to achieve reproducibility, because of the variety of external dimmers.	Average light-levels to be used to specify dimming levels; see 7.5 and 9.2	Apply standard dimmers; see 9.2
	Light source (load, in case of controlgear)	Relatively important to achieve reproducibility.		See 9.3
EUT	Stabilization	A stable average light level is essential. Effect of warming-up can be made negligible once a stable light level is achieved. Stabilization procedure might be necessary after switch-on and after switching to different operational modes (light regulation).	Technology dependent	See 7.4
	Ageing	Important for some specific technologies.	Technology dependent	n.a.
	Operation	Relatively important to achieve reproducibility.	Technology dependent	See 7.5
Measurement equipment: light sensor, filter and amplifier	Sensitivity	Minor if nominal levels are well above noise level.		See 5.5
	Linearity/offset	Generally minor.		See 5.5
	Optical filter	Minor if compliant with CIE sensitivity curve.	CIE 1931	See 5.5
	Low-pass filter	Minor if cut-off frequency > recommended value.	3 kHz	See 5.8.1
Measurement equipment: SVM meter	ADC/sampling	Can be made negligible provided sample rate is adequately chosen in conjunction with low-pass filter cut-off frequency.		See 5.8
	Numerical processing of data (implementation of SVM calculation)	To be determined by verification test.	< 5 %	See 6.2 and Clause A.5
Test environment	Optical noise	Can be made negligible.		See 11.2.4
	EM disturbances	Can be made negligible.		See 11.2.4
	Vibration	Can be made negligible		See 11.2.4
Setup	Mounting and orientation	Minor		See 7.3

Annex C
(informative)

Examples of test results

C.1 SVM measurement results of conventional lighting equipment

SVM measurement results of a number of conventional lighting equipment are given in Table C.1. No voltage modulation is present on the mains i.e. measurements have been performed with a stable source. The light output ripple (normalized to the average) of each source is depicted in Figure C.1.

Table C.1 – Numerical results of SVM calculations of conventional lighting equipment

No.	Lighting equipment	SVM
1.	Incandescent bulb [60 W]	0,567
2.	Fluorescent tube with magnetic controlgear [18 W]	0,700
3.	Fluorescent tube with magnetic controlgear [58 W]	1,302
4.	High intensity discharge lamp with magnetic driver HID SON [100 W]	2,924
5.	High intensity discharge lamp with electronic driver HID CPO [60 W]	0,008

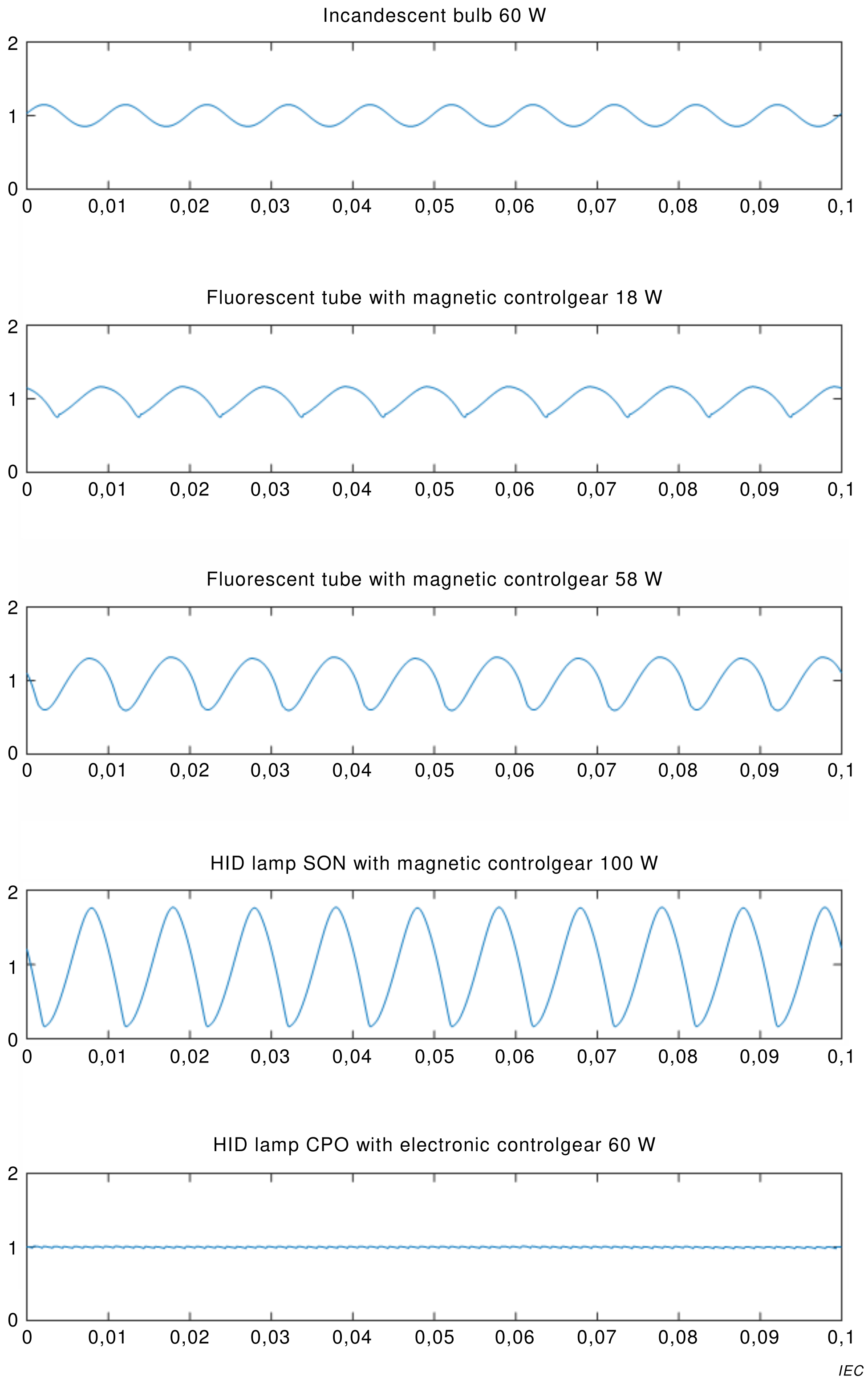


Figure C.1 – Normalized light ripple of conventional lighting equipment

C.2 SVM test under dimming conditions

SVM measurement results of four samples of lighting equipment under dimming conditions using an external dimmer are given in Table C.2. Dimming level 1 indicates minimum dimming and thus maximum light output, whereas dimming level 6 indicates maximum dimming and thus minimum light output.

Table C.2 – Numerical results of SVM calculations of four samples of lighting equipment under dimming conditions

Dimming level	Light output	SVM			
		60 W incandescent lamp	8 W integrated LED lamp	20 W integrated LED lamp	13 W integrated CFL lamp
1	100 %	0,374	1,148	0,010	0,042
2	75 %	0,448	1,593	0,009	0,018
3	50 %	0,476	1,619	0,005	0,042
4	40 %	0,479	1,337	0,004	0,047
5	30 %	0,474	1,006	0,009	0,045
6	20 %	0,459	0,527	0,003	0,039

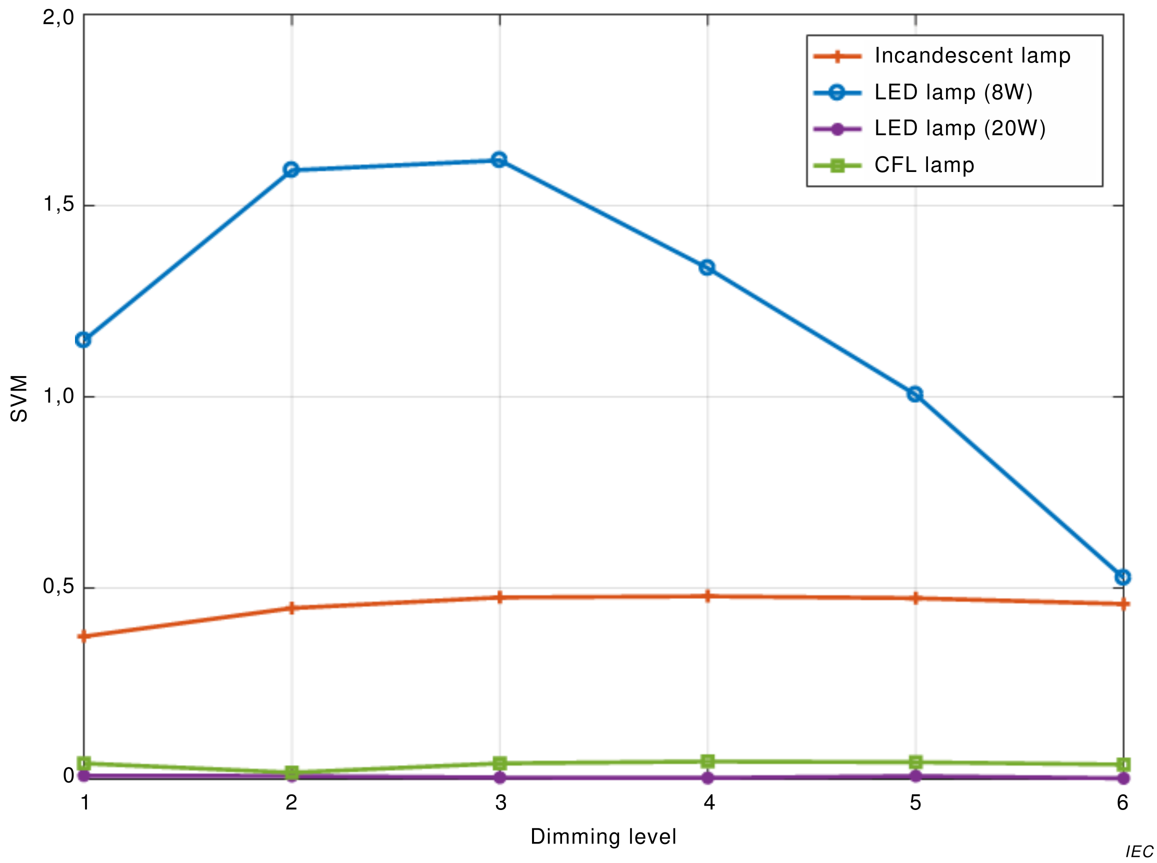


Figure C.2 – Graphical SVM results of four samples of lighting equipment under dimming conditions

Note that the tests have been performed under stable mains voltage conditions i.e. there are no voltage fluctuations present on the mains.

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch