Texte zu den geplanten neuen EU-Regelungen zur umwelt-gerechten Produktgestaltung und zur Energieverbrauchs-kennzeichnung in der Beleuchtung – Zusammenstellung [*] des Umweltbundesamtes (UBA), Deutschland

Produkteigenschaften

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Lichtflimmern: Bestimmung und Bewertung

– Diskussionstext von Peter Erwin, Oktober 2017 –

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Functionality

Background information: Light flicker – Determination and Assessment

– Discussion Paper by Peter Erwin, October 2017 –

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Informations de fond: Scintillement – définition et évaluation

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* http://www.eup-network.de/de/eup-netzwerk-deutschland/offenes-forum-eu-regelungen-beleuchtung/dokumente/texte/

** http://www.eup-network.de/fileadmin/user_upload/Lichtquellen_Flimmern_Erwin_2017_10_DE.pdf

Es folgt ein unveränderter Originaltext.

EN: The following is an unmodified original text.

FR: Ce qui suit est un texte original.

"Light flicker:
Determination and Assessment.
Discussion Paper Oct 2017"

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Abstract:
In recent years, leading manufacturers in the lighting industry endorse a regulation of the light flicker property [14] (temporal irregularity of electrical light sources), because it was recognized that brightness fluctuations have a negative effect on the nervous system of humans (e. g. headache, dizziness) and other beings.
In the past, this has not been taken into account in the development of new technologies (such as compact fluorescent lamps, LEDs). But this behavior generates bad products and thus harms the acceptance of the technologies.

LED illuminants require control gears to convert the AC line voltage into a direct current necessary for the LED. However, these are often designed with minimal effort and due to physical reasons the LED generates the brightness fluctuations from the unconverted alternating component without delay.

In order to determine a measure for light flicker and application-dependent limits, different methods were developed worldwide by different bodies, which are widely unsuitable.

This paper shows the necessity of measuring, declaring and limitation of light flicker. Various measuring methods are compared, their disadvantages are brought up and the CFD method is shown for solving the problem.

Der Lichtpeter, November 14, 2017

Contents

1. Introduction

The ideal light source is sunlight. Artificial light sources exist to enable a life independent from the daily cycle. Their light, however, behaves differently than that of the sun and unfortunately in many ways incompatible with the perception and the effect to humans. In this paper the mainly treated aspect of temporal irregularity of light, nowadays communicated as (optical) light flicker or "TLA", "TLM", "light modulation", played an important role at the end of the 19th century setting the mains power supply frequency.

1.1. Artificial light sources

Light sources perceived by humans are considered ideal when they are designed without periodic fluctuations of the intensity (modulation).
However, there are also practical requirements which contradict this ideal approach: If the light source serves as a dynamic (information) source with the task to stimulate the brain in different ways. Examples include screens (cinema, TV, computer), special signal light (flashing blue light) or light effects in discotheques. In addition, LED lighting can also be used for optical data transmission as an alternative to WLAN.
This document in the further course deals with light sources for illuminating the environment (luminaires, illuminants), and light sources with static information (e. g. car rear lights, armatures).

1.2. Negative influence, causation

Regarding light sensitivity, the SCENIHR[*1] opinion of 2008 [17] states that modern compact fluorescent lamps are basically flicker-free due to their electronic ballasts. A renewed SCENIHR statement from 2012 [18] points to studies that concede residual flicker, even with incandescent lamps. The SCHEER[*2] opinion of 2017 [20] goes much further: Technically, there is no need for light flicker, because LEDs are in principle flicker-free. However, low-quality LED products generate a perceptible flicker, which is not due to the LED itself but to the (cheap) design of the control gear.

The human nervous system is affected by light flicker depending on duration, intensity and frequencies. There are risks of epilepsy seizures in the frequency range from 3 Hz to 70 Hz, in particular 15 to 20 Hz (e. g. multiple flashes of a photo apparatus [20] or the mass epilepsy triggered by the animated film Pokemon, episode 38, 1997 in Japan). Frequencies above the conscious perceptibility (flicker fusion frequency) lead to headaches due to the compensatory work of the cortex. This has been noticed in the exchange of light bulbs by fluorescent tubes of the production plants during the Golden Age of Capitalism and is evidenced by studies [10] [20]. People also experience dizziness when exposed to stroboscopic light. With chickens it is noticed that they do not lay eggs due to the stress caused by flickering light.
The perception of rotating and cyclical processes is deceived in the case of very flickering light (stroboscopic effect, wagon-wheel effect), which is why this is classified as dangerous at machine workplaces according to DIN EN 12464-1 [15] and is therefore to be prevented. Particularly people who are prone to rapid eye movements (e. g. nystagmus) due to low vision have even more sight problems with stroboscope light.

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*1 SCENIHR: European Commission: Scientific Committee on Emerging and Newly Identified Health Risks
*2 SCHEER: European Commission: Scientific Committee on Health, Environmental and Emerging Risks

The phantom array effect is also caused by stroboscopic light. The difference is the perspective of the observer: Watching a relatively small light source from a distance with fast eye movements or at different speed to the observer the light appears to be an array of light points. Examples of this are the daytime running lights and rear lights of motor vehicles which lead to irritation [19] [20].

Although there are no scientific findings on the influence of light flicker on disease patterns such as Irlen-Meares syndrome, myalgic encephalomyelitis, fibromyalgia, dyspraxia, autism and HIV, but light flickering strains the cortex, which, depending on intensity and duration, leads to overstraining [18] and can pose a danger due to the irritation caused by the phantom array effect [20].

1.3. Troubleshooting

The conversion of the mains alternating voltage into the direct current needed for the LED is associated with the costs of the electronics required for this purpose. At this point an optimum has to be found between the just-compatible modulation and the cost of the light source.

In any case, the current generated by the electronic ballast is responsible, which is directly followed with the light emission by the light-emitting element (recently LED). It contains the desired DC-component and the unwanted light flicker (see Figure 3), which is composed of the amplitudes of different frequencies [14]. The causes of this are the influence of the mains alternating voltage and its modification by dimmer and pulse width modulation (PWM) [20] or optical data transmission. PWM-controlled light sources require a PWM frequency far above the perceptibility [19].

It is important to set limits to protect people from negative influences [8]. For this purpose, a suitable measuring method is required, which can be universally applied to all electrical light sources in order to enable quantitative comparability.
Regulation and market surveillance ensure that cheap products that do not meet the requirements are not allowed on the market at all. Accordingly, the quality standard is raised, which is useful for the acceptance of the technology.

The suitability of a measuring method requires at least two properties:

- All frequencies influencing the nervous system must be detected.
- The quantification result must be a single, preferably simple, known measuring unit. Only then it can be declared in the technical data and on the packaging. It thus enables a categorization in quality grades (assessment) as well as the setting of limit values e. g. in standards.

The methods developed by different bodies worldwide have disadvantages in that they do not cover all frequencies or they provide the results of several sub-processes whose combination to achieve a single value is not defined.
Only the CFD (Compact Flicker Degree [12] [13]) fulfills this requirement. It was presented internationally in Bregenz on the LED Professional Symposium in September 2016 and has since been published worldwide in various articles.

2. Measurement + Calculation

A universal measurement method for the determination of the light flicker involves the following characteristics:

- AC amplitude relative to the direct component of the light (modulation),
- Fundamental frequency of the modulation,
- Waveform (all frequency components, harmonics),
- Frequency-dependent human perception threshold (consciously / unconsciously),
- Stroboscopic- and Phantom array effect.

In principle, the optical light signal is converted into an electrical voltage signal as loss-free as possible for all measuring methods. For this purpose, the hardware is preferably designed such that:

- Use of a V-lambda photodiode for suppressing the non-visible infrared light component, such as that of the incandescent lamp.

- Transimpedance amplifier with variable transimpedance for optimal use of the amplitude measuring range.

- Antialiasing low-pass-filter to maintain the sampling theorem, depending on the sampling frequency.

- Analog-to-digital converter with a sampling frequency between 2 kHz and 500 kHz for sufficient presentation and calculation.

- According to the calculation method, a detection of at least five periods of the modulation fundamental frequency for up to one second duration.

The correspondingly captured and digitized measuring signal is subjected to a calculation which can be classified on the two approaches "time-based" and "frequency-based".

2.1. Calculation methods in the time domain

These procedures include:

- The contrast methods (min-max, RMS) of Admesy B.V. [1] and Chroma Ate Inc [2].

- The common measurement method according to IES: RP 16 10 [3]. It provides the two values %Flicker (modulation depth) and Flicker Index (area ratios).

- Detection of stroboscopic light according to DIN EN 12464-1 [15], which is defined by the fact that periodic dark periods occur.

Time-based calculations are generally not suitable as a universal measuring method because the calculated value results mainly from amplitude ratios. The requirement for a frequency-dependent weighting can thus not be met.

2.2. Calculation methods in the frequency domain

For the calculation, the measurement signal is decomposed into its frequency components by Fourier transformation (FFT) and normalized to DC. Periodic signals can thus be described as a discrete spectrum of individual frequency components. All frequency components, and thus the waveform, are included in the calculation, even in non-sinusoidal shapes.

The key differences in these methods are the inclusion of all individual frequencies and their **frequency-dependent weighting** as a function of the effect on the nervous system.
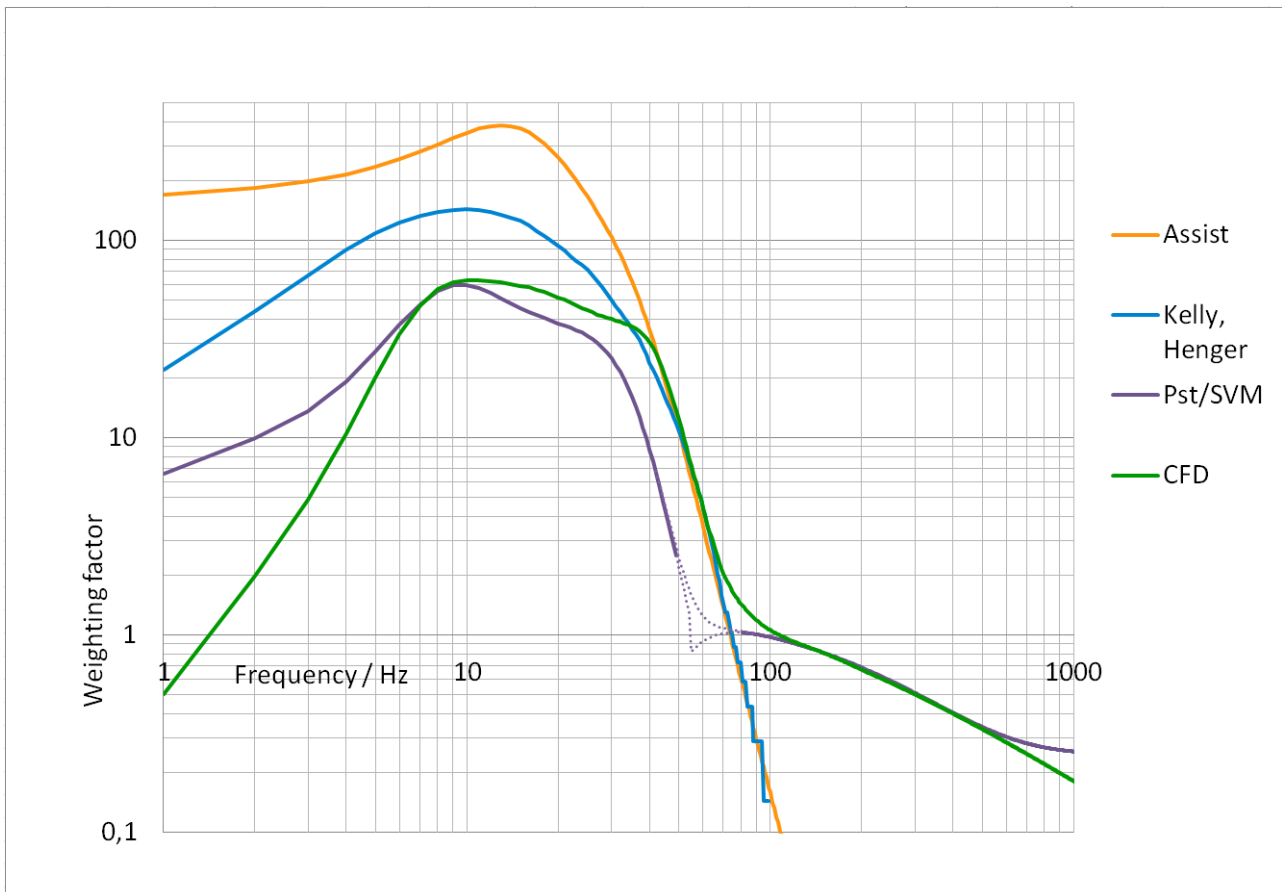
Figure 1: Characteristics of frequency-dependent weightings

- The **ASSIST** group [4] weights the frequencies of the signal (sampled at 2 kHz) according to a characteristic curve inspired by the flicker fusion threshold of 70 Hz. The calculation of the Pythagorean Sum on the single weighted frequencies leads to a metric value. This, in turn, is further evaluated to give the probability of flicker detection in percent.

- The weighting of the studies of **Kelly** (1961) and **Henger** (1986) [5] is based on the flicker fusion frequency at about 70 Hz.

- CIE: P_{st}**LM / SVM** [8] [9]
  P_{st}LM covers the frequency range for "flicker" up to approx. 65 Hz, SVM the range for "stroboscopic effects" from approx. 85 Hz to 2 kHz. To determine SVM, the vector p-norm (here called Minkowski norm) with p = 3.7 is applied on each weighted individual frequency.

- **CFD**: Compact Flicker Degree [12] [13]
  The CFD defines a single percentage as the final value by calculating the Pythagorean Sum on the single weighted frequencies.
  All frequencies for visible and invisible temporal non-uniformity of the light are included in the calculation. The range below 10 Hz is weighted lower to avoid the over-estimation of the FFT leakage effects occurring in practice.
  For dimmable light sources, the measurement is performed 1st with 100% brightness and 2nd with 25% brightness, the worse of both values is declared as the final value.

- The **JEITA** method (not in Fig. 1), applied by the companies Admesy B.V. [1] and Chroma Ate Inc [2], assigns a frequency-dependent characteristic to the individual frequencies which weights all frequencies ≥ 65 Hz by 0.

- According to **CEC Title 24** JA 10 [11] (see Figure 2), frequencies up to 200 Hz are taken into account by applying a reverse FFT to all frequencies ≤200 Hz after the FFT has been performed, and then calculating the modulation degree for the recovered time domain signal. This may not exceed 30%. This corresponds to a weighting factor of 1 for all frequencies ≤200 Hz and the factor 0 for all others.

- **IEEE 1789** [16] (see Figure 2, "Low Risk") suggests the Recommended Practice 1 (RP1) as the recommended range for the maximum modulation of a single frequency:
  - Below 8 Hz: fixed value of 0.2%.
  - Between 8 Hz and 90 Hz: 0.025% × frequency.
  - Between 90 Hz and 1250 Hz: 0.08% × frequency.
  - Above 1250 Hz: no limitation.
  Aside of the Recommended Practices RP1, RP2 or RP3, and at particular interest for sub-harmonics, the possibility of calculating the sum of all weighted individual frequencies is intended and its result must be <1.

3. Evaluation and Discussion

3.1. Frequency-dependent measuring methods and limit values

In principle, a distinction made between "visible flicker" and "non-directly visible stroboscopic effect" or "phantom array effect" (areas ◼1◼ and ◼2◼ in Figure 2) makes sense for explanatory purposes. However, there is no reason to set harsh thresholds for weighting and evaluating, since the transitional range is always smooth from the physiological point of view because it is always a mixture of subjective perception.

A distinction between the "stroboscopic effect" and the "phantom array effect" is also useful for explanatory purposes. However, for the evaluation of a light source, the assessment and for limit values, there must be no difference for the following reason:
Imagine the position of an observer standing under a streetlamp. The street lamp emits its light with 100 Hz rectangle. The observer experiences stroboscope light. Now he moves away from this lamp (about 300 yards), so that the light of the street lamp appears to the observer as a small light source. If the observer now quickly moves his eyes (saccades), then he experiences the phantom array effect of this lamp. During the walk away from the lamp, depending on the distance of the observer from the lamp, each intermediate state between stroboscope light and phantom array effect is possible and thus defined.
Since the observer does not modify the street lamp, but only his own position, the technical property of the lamp, namely the emitted stroboscope light, remains, independent of the effect on the human being. Consequently, only one common weighting curve for "stroboscopic effect" and "phantom array effect" or, respectively, for each frequency, only one limit value can be attributed to the measuring method. In turn it follows that the street lamp can only have a single measured value.

3.2. Suitability for evaluation

The basis of frequency-dependent weightings for Kelly / Henger [5], ASSIST [4], JEITA [1] [2] and $P_{st}LM$ are studies in which the subjects are in resting position (no body movements and no eye movements). In these methods, the uppermost frequency included is based on the flicker fusion frequency. This may serve as a point of reference, but it is unrealistic and is useless for practice, because either man or at least his eyes are always in motion. Thus, the limit value is set too low at about 70 Hz.

Regarding the effect on humans the stroboscopic and phantom array effect take over the primary role [7] at frequencies from approx. 90 Hz to 2 kHz. Stroboscopes with double mains frequency are perceptible even in small movements and cause discomfort, sometimes even vertigo or irritation. It is also known that frequencies up to 250 Hz pass from the retina to the brain and are finally processed there [6], which can lead to strains that are associated with fatigue and headache [10]. These effects are taken into account:

- – with CEC Title 24 JA 10 up to 200 Hz,
- – with IEEE 1789 RP1 1 up to 1250 Hz,
- – with SVM 75 up to 2 kHz,
- – with CFD 1 up to 20 kHz.
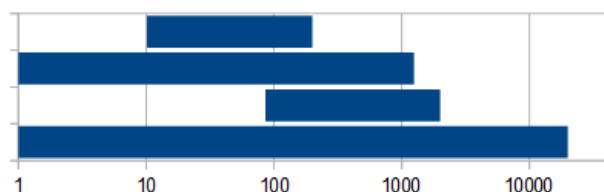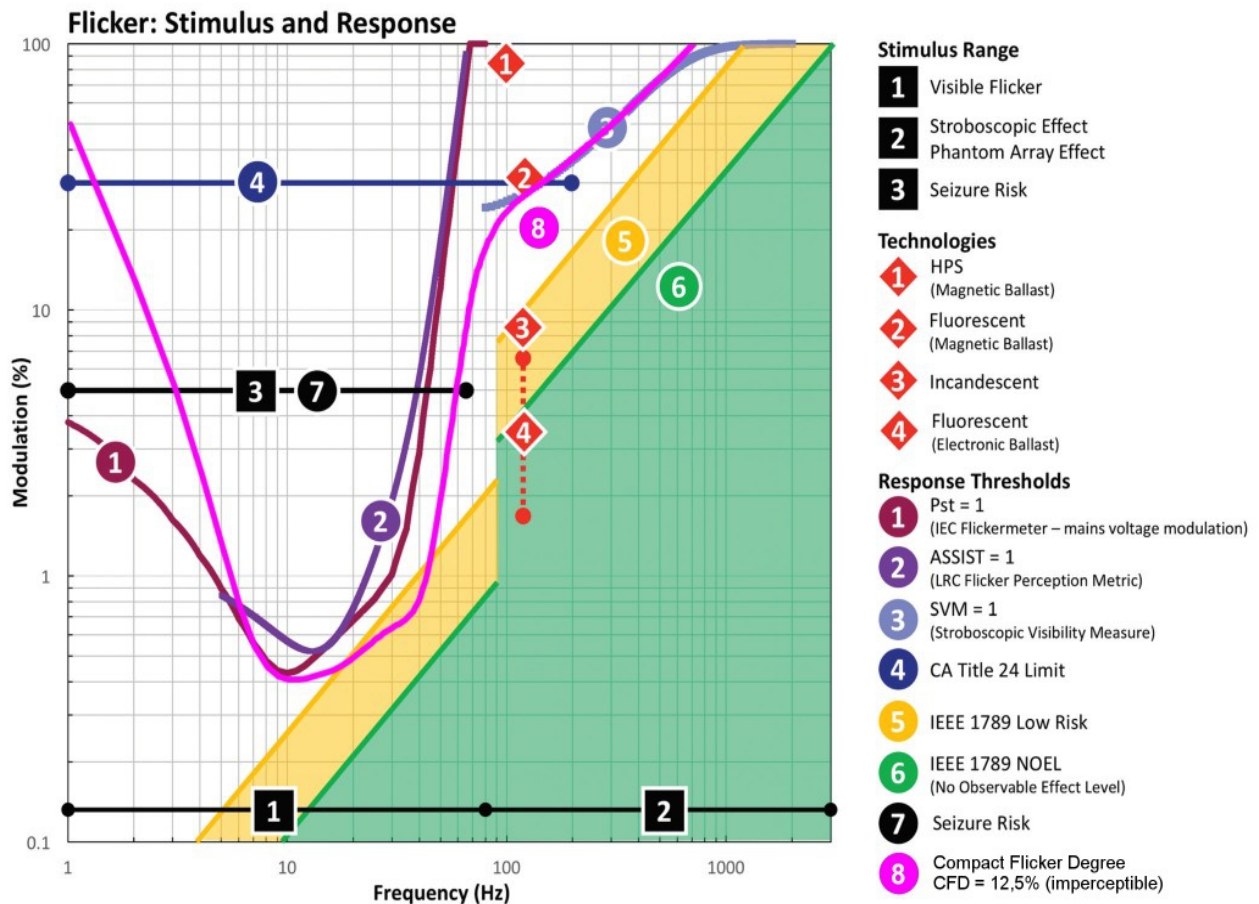
3.3. Other methods, comparison

Figure 2: Characteristics of frequency-dependent thresholds

Figure 2 is created from a U.S. Department of Energy document [9], the CFD data has been added to it. The graph shows the following evaluation limits of modulation over frequency:

- $P_{st}LM$ (1): 50% probability of average perception.
- ASSIST (2): 50% probability of average perception.
- SVM (3): Same as $P_{st}LM$, Limit value has not yet been definitively fixed.
- CEC Title 24 JA 10 (4): Frequencies ≤200 Hz and a modulation >30%: "High flicker"
- IEEE 1789: (5): RP1:"Low Risk", (6): RP2: "No Observable Effect Level"
- Compact Flicker Degree (8): CFD<12.5%: "Low-flicker" (imperceptible)

3.4. DIN EN 12464-1

According to DIN EN 12464-1 [15] (not in the graphic), stroboscopic light induced by mains power supply, must be avoided at workstations in indoor areas in order to prevent accidents. Light sources that do not meet the corresponding paragraph of this standard would already have to indicate a limitation of usability: "Not suitable for working".

The EU Commission has so far neglected the product labelling. The number of stroboscopic flickering illuminants already on the consumer market is high. Thus, it is only a matter of time, when, for example, the first workshop accident happens because neither the worker nor the operator of the workshop is aware of the stroboscope light of the lighting system.

3.5. IES: RP1610

Apart from ignoring the frequency components (see section 2.1.), this primitive, widespread method (not in the graph) provides the two values of %flicker and flicker index, which is difficult to convey. Additionally it is not defined how they could lead to an assessment together.

3.6. CIE: $P_{st}LM$ / SVM

Here, two measured values are obtained, for the in principle one measuring of modulation degrees of different frequencies, which is difficult to convey.

The gap in the transition from $P_{st}LM$ to SVM is also problematic. If one were to close it, the slopes of both curves at the intercept point do not match (lower dotted line in Fig. 1). This can be circumvented by using the p-norm with p = 1.5 on the $P_{st}LM$ and SVM results of each single frequency before applying the Minkowski summation. The effect is clearly visible in figure 6 of table 2.

The application of the vector p-norm with p = 3.7 results in the waveform taking less consideration, as in the case of IEEE 1789; Harmonic components lose importance. This becomes clear when one contemplates the results, e. g. sine-wave with 100% modulation in table 2, fig. 15, compared to a stroboscope light with a 1.2% DC portion in table 2, fig. 16. The SVM value differs too little.

3.7. CEC Title 24 JA10

The simple definition for "low flicker" with a modulation of ≤30% for frequencies ≤200 Hz results in a strong underestimation (at least factor 50) for frequency components between 5 Hz and 35 Hz, whereby a clearly visible flicker is wrongly certified with the label "low flicker".
A large discrepancy (factor 60) also occurs versus IEEE 1789 RP1, which sets the modulation limit of 0.5% at 20 Hz.

3.8. IEEE 1789

According to IEEE 1789 [16] RP1, the modulation of the single frequency, which exceeds the range "Low Risk" most, is evaluated. The same applies to RP2 ("No Observable Effect Level"). If frequency mixtures are present (which is the normal case), the calculation basis is missing. According to IEEE 1789, the waveform does not matter when the energy content of the fundamental frequency of two waveforms is the same (e. g. sine with 100% degree of modulation in table 2 fig. 15 versus fig. 16 with a tiny DC portion of 1.2%).

According to IEEE 1789, the light of a European incandescent lamp is already considered to be risky, although 100 years of experience show that there is no risk. The modulation shown in Figure 2 relates to a US-American incandescent lamp which, however, has a factor-2 lower modulation because of the higher thermal inertia due to the much stronger filament (120V operation) and the higher mains frequency of 60 Hz. This has obviously not been taken into account when setting the limit values for compatibility, which is why the IEEE 1789 meets acceptance problems in Europe.

An explanation for plausibility is missing for the quality step from less than 90 Hz to beyond 90 Hz by a factor of 3.125. From a physiological point of view this cannot be real; the transition would have to be smooth. Slightly different frequencies in this range lead to very different results.

3.9. CFD

The transition from the non-linear frequency range up to about 70 Hz, which is perceptible when situated rested, into the range which is rather perceptible under motion, the CFD performs this as smooth (physiologically plausible).

The CFD value range covers 0% to beyond 150%, depending on the number of significant individual frequencies depending on the shape of the light emission curve. For example, in contrast to a sinusoidal curve as in fig. 15, needle pulses as in fig. 11 have many frequency components with maximum amplitude.

The single CFD percentage as a comprehensive measurand for modulated light is suitable for declaration and permits categorization according to a traffic light system:

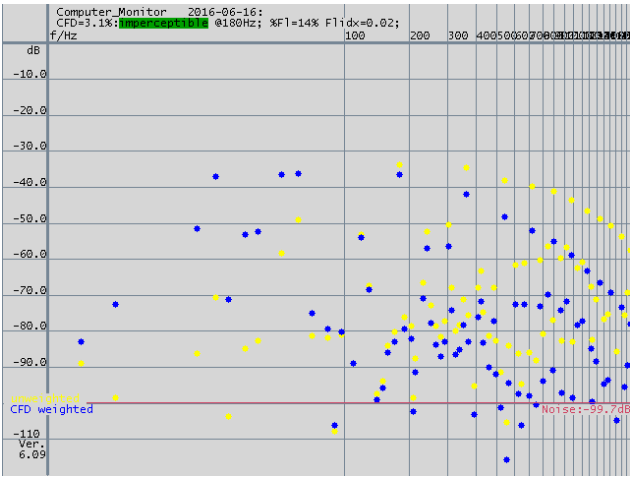|		
	0 < CFD < 1% Flicker free Color: Dark green	Practically no modulation.
	1% < CFD < 12.5% Low flicker Color: Dark green	Modulation imperceptible.
	12.5% < CFD < 25% Acceptable Color: Yellow-green	Modulation possibly perceptible but acceptable, 20% not suitable for work in the office.
	25% < CFD < 50% Moderate Color: Yellow	Modulation perceptible and impairment of well-being upon prolonged exposure, increased eye strain in the workplace.
	50% < CFD < 75% Strongly affected Color: Orange	Stroboscopic effects induced by mains power supply, certainly perceptible by more than 50% of the population, impairment of the well-being upon long exposure, hardly suitable for working.
	CFD > 75% Extremely affected. Color: Red	Stroboscopic effects, certainly perceptible by more than 75% of the population, prolonged exposure leads to physical impairment (headache, malaise), unsuitable for the correct perception of movement. Dangerous for jobs with cycling or rotating parts.
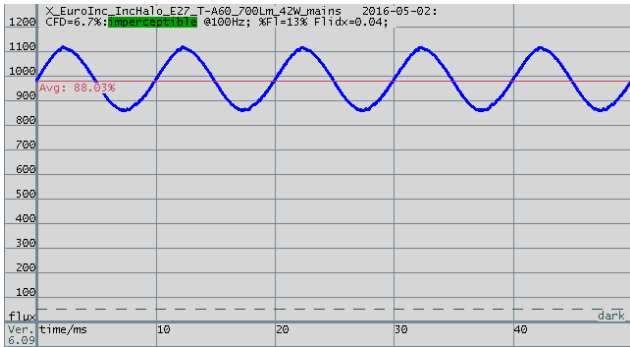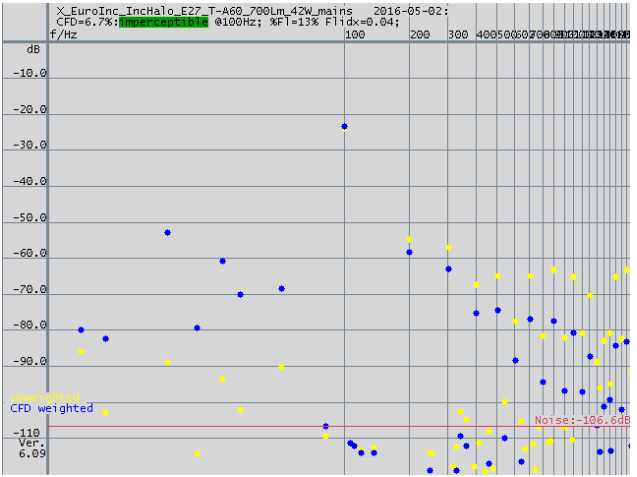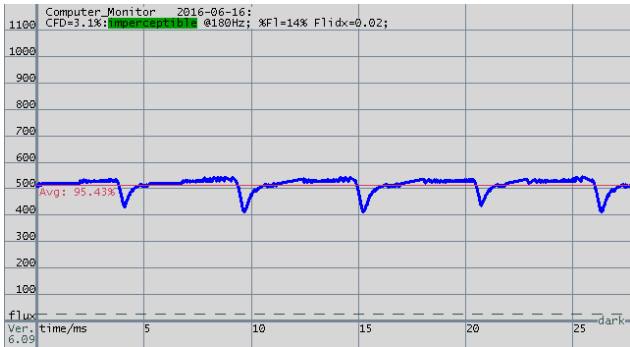
Table 1: CFD categorization according to a traffic light system

In practice, approximately 1000 commercially available light sources as well as over 100 technically generated test light signals have been measured with the CFD. The results of the measurements of extraordinary light emissions have been visually checked for plausibility.

4. Examples with measurement results

The most frequently occurring case of light modulation is the flickering of light at double the mains frequency. Many of the illuminants on the market (about 25% of the cheap LED filaments) have massive stroboscopic effects: the modulation of the fundamental frequency is >= 100%. The light emission curve has large amplitude and is usually not sinusoidal, especially in the case of dimmed control.

The following pictures show excerpts of light emission curves of different light sources and the corresponding frequency spectrum. In addition, the modulation values of different measuring methods are given:

- Light emission curve - Results of various calculation methods	- Corresponding FFT-Analysis, shown up to 1 kHz: - yellow: unweighted, blue: CFD-weighted. - Comment
 Fig. 3: European incandescent at 50 Hz mains power: CFD = 7% IES: Percent flicker = 13.2% ; Flicker index = 0.040 IEEE 1789: risky with 12.7% @100Hz (x 1.6) CEC Title 24 JA10: Percent flicker = 12.6% (pass) LRC Flicker Metric = 0.02; Detection prob. = 0.40% $P_{st}LM = 0.017$; SVM = 0.494; $P_{st}LM\&SVM = 0.495$	 Agreement on slight flicker, except for IEEE 1789: this incandescent is regarded as „risky"
 Fig. 4: Computer monitor: CFD = 3% IES: Percent flicker = 13.7% ; Flicker index = 0.018 IEEE 1789: recmd with 0.7% @60Hz (x 1.2) CEC Title 24 JA10: Percent flicker = 5.0% (pass) LRC Flicker Metric = 0.06; Detection prob. = 0.51% $P_{st}LM = 0.084$; SVM = 0.125; $P_{st}LM\&SVM = 0.132$	 Agreement on very low flicker.
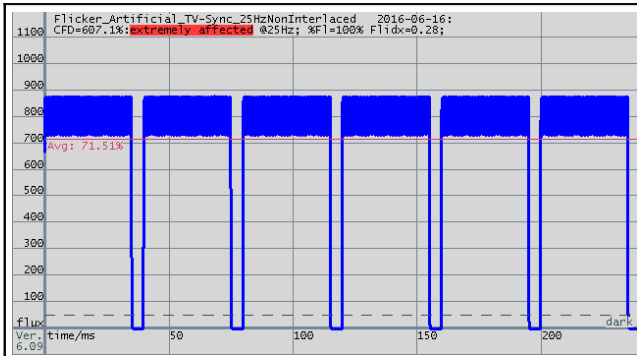
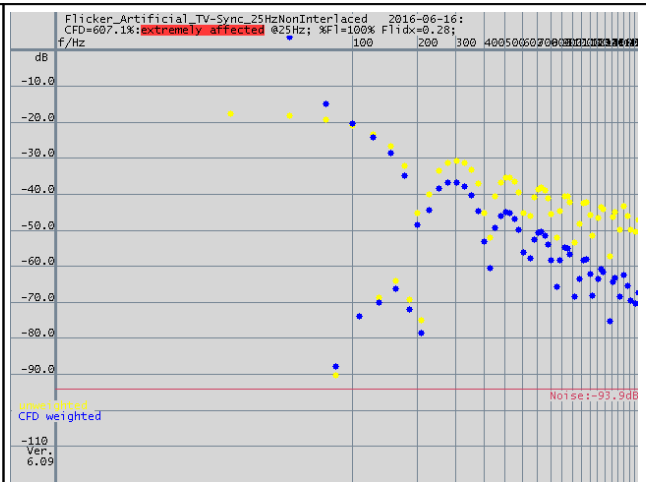Fig. 5: TV screen, non-interlaced:
CFD = >150%
IES: Percent flicker = 100.0% ; Flicker index = 0.285
IEEE 1789: severe with 26.6% @25Hz (x 5.3)
CEC Title 24 JA10: Percent flicker = 100.0% (fail)
LRC Flicker Metric = 22.18; Detection prob. = 100.00%
$P_{st}LM$ = 34.956; SVM = 1.078; $P_{st}LM\&SVM$ = 34.962
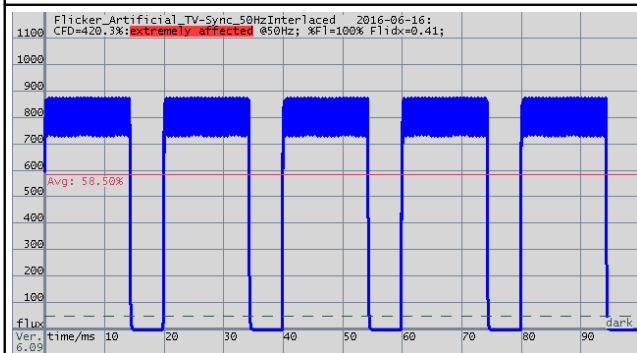
Agreement on extreme flicker.
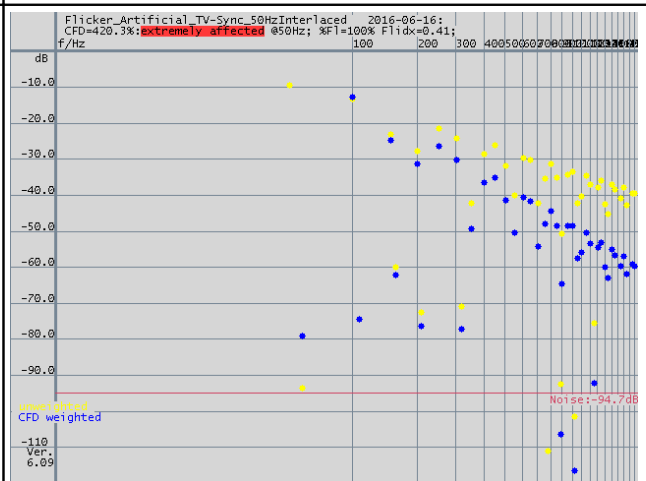

Fig. 6: TV screen interlaced:
CFD = >150%
IES: Percent flicker = 100.0% ; Flicker index = 0.415
IEEE 1789: severe with 68.1% @50Hz (x 13.6)
CEC Title 24 JA10: Percent flicker = 100% (fail)
LRC Flicker Metric = 3.65; Detection prob. = 100.00%
$P_{st}LM$ = 5.994; SVM = 2.235; $P_{st}LM\&SVM$ = 6.741

Agreement on extreme flicker.
For $P_{st}LM\&SVM$: application of the p-norm with p=1.5.
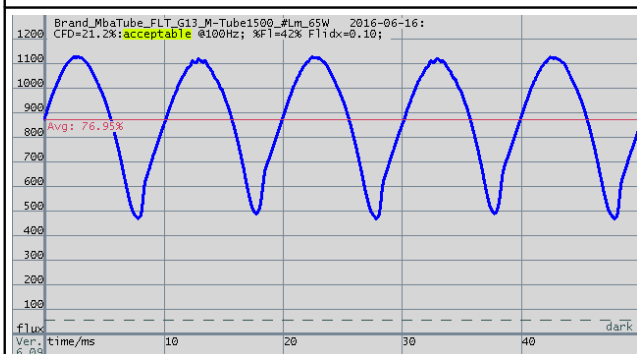
Fig. 7: Fluorescent tube with magnetic ballast:
CFD = 21%
IES: Percent flicker = 41.9% ; Flicker index = 0.101
IEEE 1789: risky with 32.1% @100Hz (x 4.0)
CEC Title 24 JA10: Percent flicker = 35.6% (fail)
LRC Flicker Metric = 0.11; Detection prob. = 0.66%
$P_{st}LM$ = 0.177; SVM = 1.252; $P_{st}LM\&SVM$ = 1.254
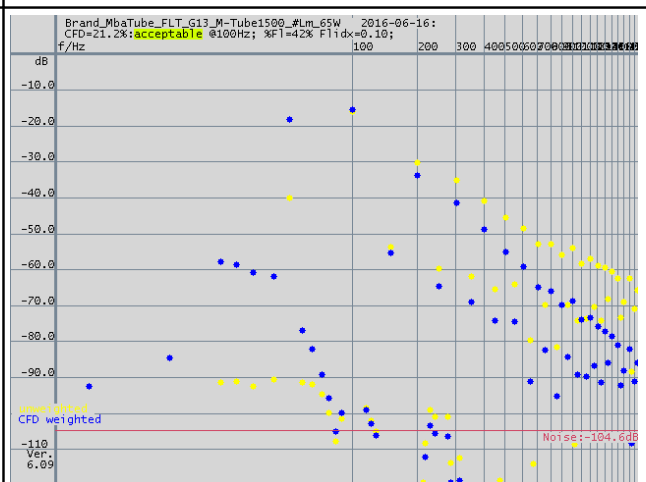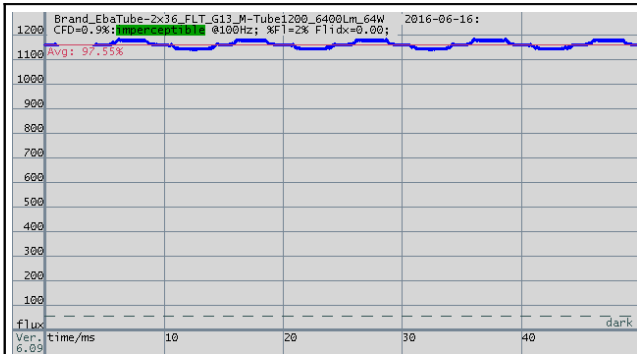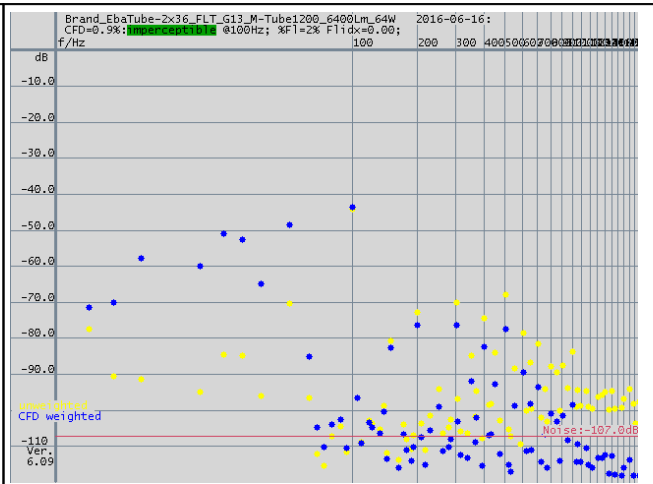
According to ASSIST no flicker is perceptible.

Fig. 8: Fluorescent tube with electronic ballast:
CFD = <1%
IES: Percent flicker = 2.4% ; Flicker index = 0.005
IEEE 1789: noel
CEC Title 24 JA10: 1.4% (pass)
LRC Flicker Metric = 0.03; Detection prob. = 0.43%
$P_{st}LM$ = 0.020; SVM = 0.049; $P_{st}LM$&SVM = 0.050
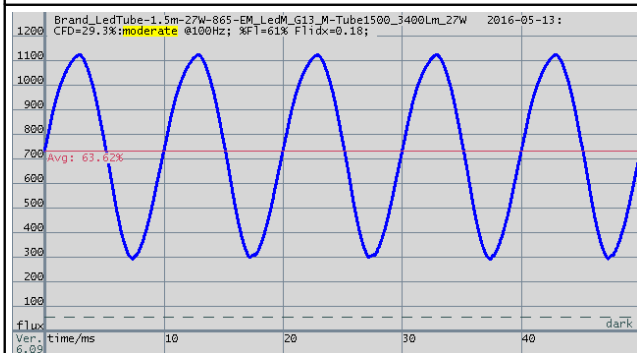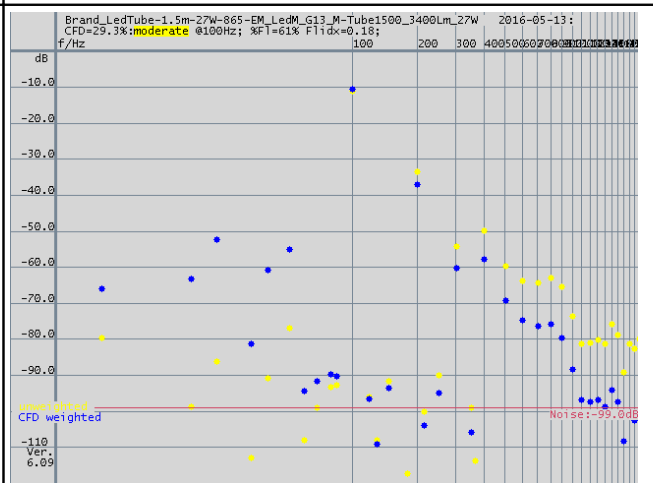

Agreement on no flicker.

Fig. 9: LED illuminant with moderate ballast:
CFD = 29%
IES: Percent flicker = 61.0% ; Flicker index = 0.176
IEEE 1789: risky with 55.3% @100Hz (x 6.9)
CEC Title 24 JA10: Percent flicker = 57.5% (fail)
LRC Flicker Metric = 0.05; Detection prob. = 0.47%
$P_{st}LM$ = 0.044; SVM = 2.158; $P_{st}LM$&SVM = 2.162

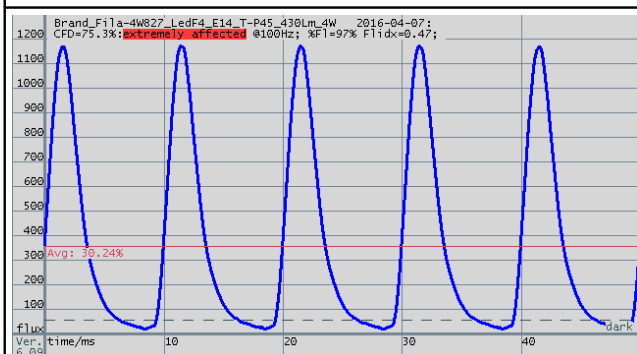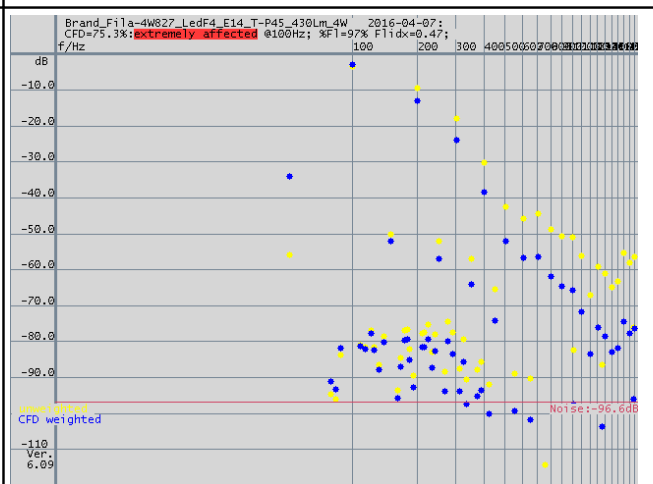Agreement on clear flicker except ASSIST.

Fig. 10: LED illuminant with insufficient ballast:
CFD = 75%
IES: Percent flicker = 96.9% ; Flicker index = 0.466
IEEE 1789: risky with 100.0% @100Hz (x 16.9)
CEC Title 24 JA10: Percent flicker = 100.0% (fail)
LRC Flicker Metric = 0.11; Detection prob. = 0.65%
$P_{st}LM$ = 0.107; SVM = 5.301; $P_{st}LM$&SVM = 5.310

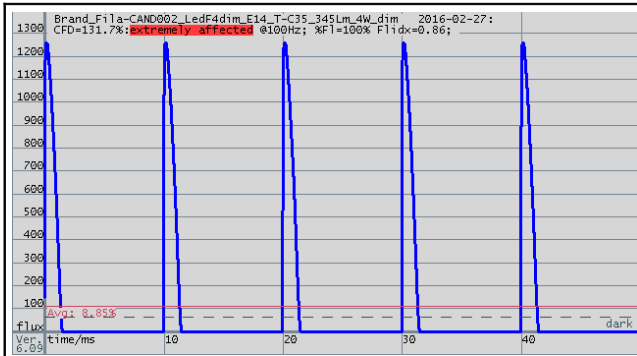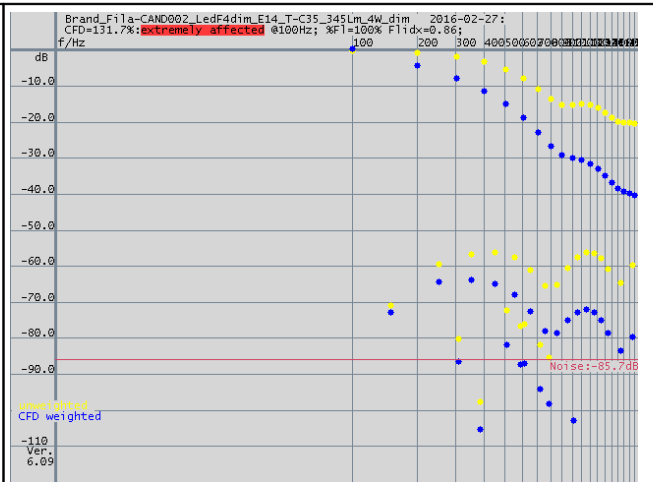Agreement on strong flicker except ASSIST.

Fig. 11: LED illuminant with insufficient ballast dimmed to 25%:
CFD = 132%
IES: Percent flicker = 100.0% ; Flicker index = 0.860
IEEE 1789: risky with 100.0% @100Hz (x 24.4)
CEC Title 24 JA10: 100.0% (fail)
LRC Flicker Metric = 0.15; Detection prob. = 0.83%
$P_{st}LM$ = 0.154; SVM = 8.111; $P_{st}LM\&SVM$ = 8.123

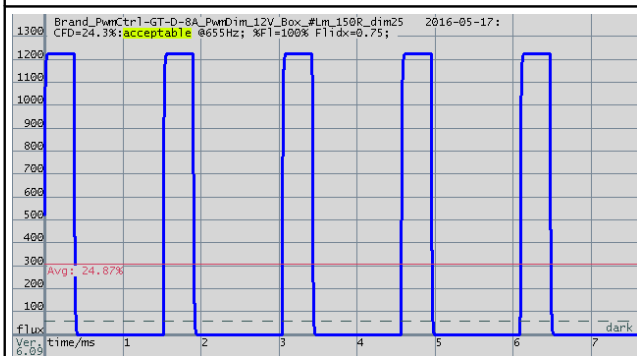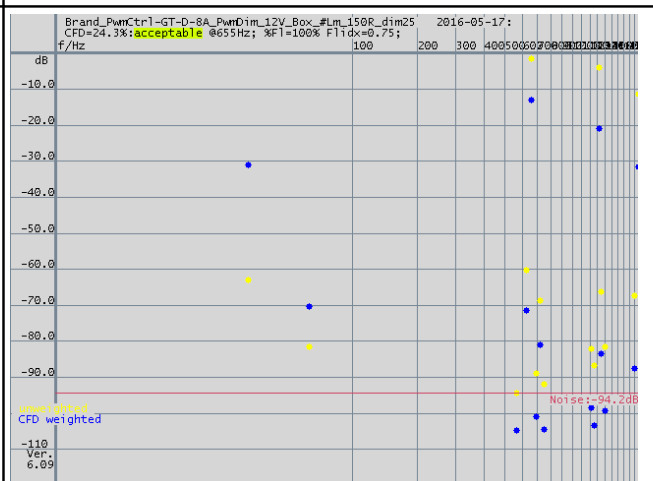Agreement on extreme flicker except ASSIST.

Fig. 12: LED without ballast on a PWM dimmer with 655 Hz switching frequency:
CFD = 24%
IES: Percent flicker = 100.0% ; Flicker index = 0.746
IEEE 1789: risky with 100.0% @655Hz (x 3.2)
CEC Title 24 JA10: Percent flicker = 0.1% (pass)
LRC Flicker Metric = 0.07; Detection prob. = 0.52%
$P_{st}LM$ = 0.133; SVM = 2.060; $P_{st}LM\&SVM$ = 2.060

Agreement on moderate flicker. But to IES extreme values, because the frequency is not taken into account.
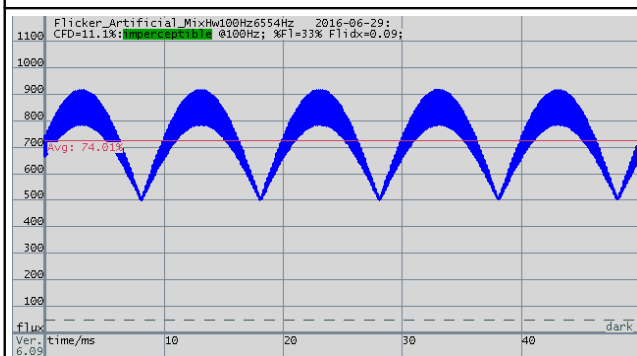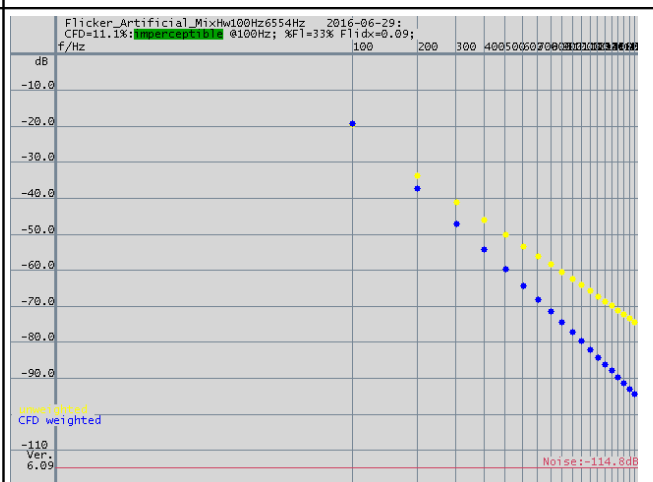

Fig. 13: 6554 Hz modulated with 100 Hz-half-wave:
CFD = 11%
IES: Percent flicker = 32.5% ; Flicker index = 0.087
IEEE 1789: risky with 20.8% @100Hz (x 2.6)
CEC Title 24 JA10: Percent flicker = 21.7% (pass)
LRC Flicker Metric = 0.02; Detection prob. = 0.40%
$P_{st}LM$ = 0.016; SVM = 0.811; $P_{st}LM\&SVM$ = 0.812
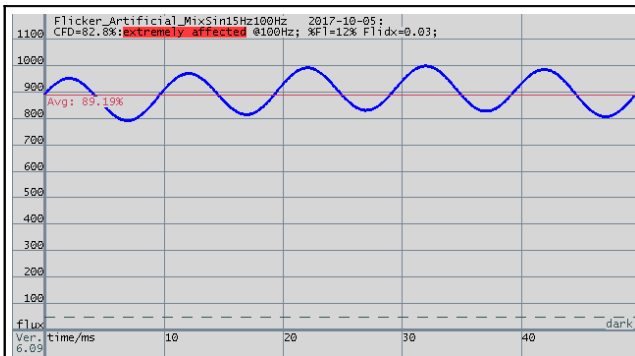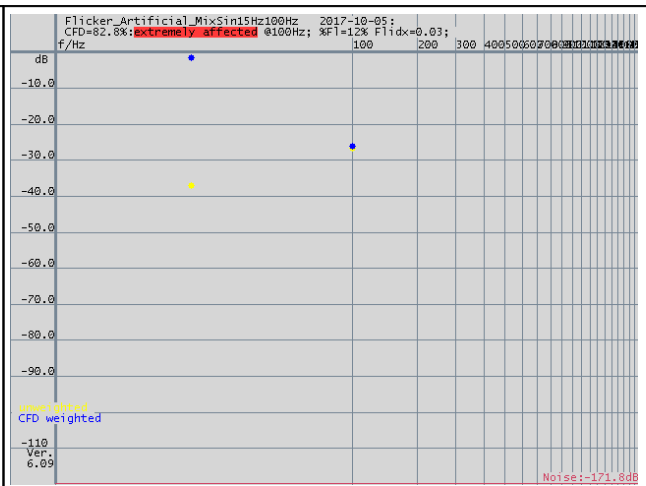

Agreement on imperceptible flicker, except IEEE 1789.

Fig. 14: Frequency mixture: Sine-waves:
      2.8% Mod. @15 Hz + 9.4% Mod. @100 Hz:
CFD = 83%
IES: Percent flicker = 12.1% ; Flicker index = 0.030
IEEE 1789: risky with 2.8% @15Hz (x 7.5)
CEC Title 24 JA10: Percent flicker = 12.1% (pass)
LRC Flicker Metric = 5.18; Detection prob. = 100.00%
$P_{st}LM$ = 5.101; SVM = 0.365; $P_{st}LM$&SVM = 5.102

Agreement on extreme flicker except IES und CEC.
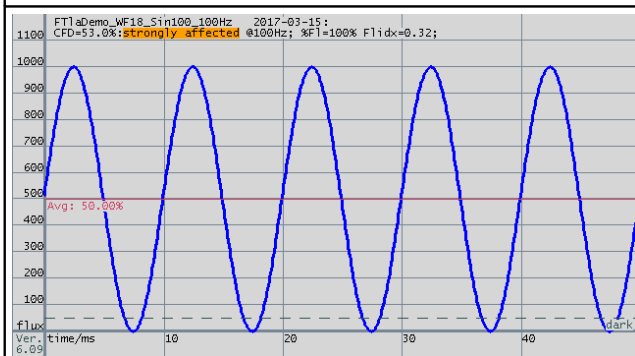
Fig. 15: Sine-wave 100% Mod. @100 Hz:
CFD = 53%
IES: Percent flicker = 100.0% ; Flicker index = 0.318
IEEE 1789: risky with 100.0% @100Hz (x 12.5)
CEC Title 24 JA10: Percent flicker = 100.0% (fail)
LRC Flicker Metric = 0.08; Detection prob. = 0.56%
$P_{st}LM$ = 0.079; SVM = 3.902; $P_{st}LM$&SVM = 3.909
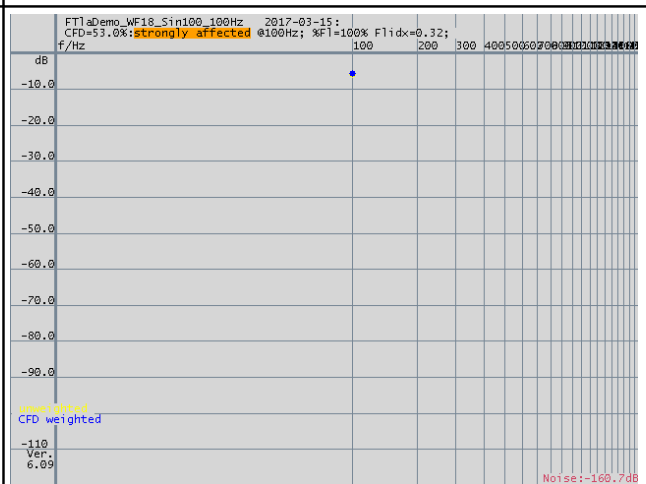
Agreement on strong flicker except ASSIST.

Fig. 16: Strobe: Rectangular 97.6% Mod. @100 Hz
      Duty cycle 1/90:
CFD = 80%
IES: Percent flicker = 97.6% ; Flicker index = 0.496
IEEE 1789: risky with 100.0% @100Hz (x 12.5)
CEC Title 24 JA10: Percent flicker = 100.0% (fail)
LRC Flicker Metric = 0.08; Detection prob. = 0.56%
$P_{st}LM$ = 0.079; SVM = 4.357; $P_{st}LM$&SVM = 4.363
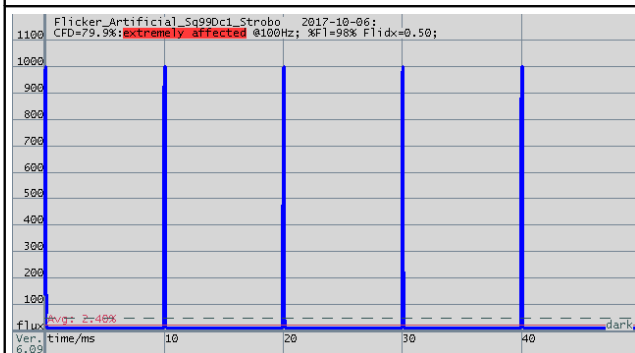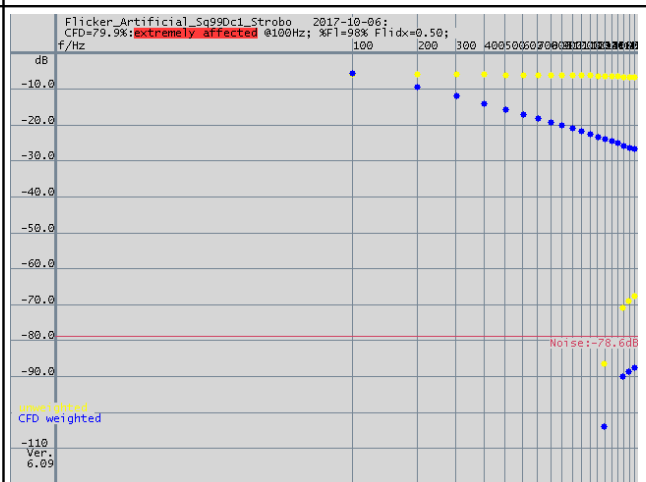
Agreement on extreme flicker except ASSIST.
To IEEE 1789 the exceedance of limit value identical with figure 15.
SVM: Discrimination from figure 15 significantly below the actual effect.

Table 2: Pictures of light emission curves

5. Summary

It is necessary to measure and assess light for illumination or static information purposes with respect to all modulations affecting humans and other beings. For this all frequency components should be considered at least up to 2 kHz, better up to 20 kHz. Consequently, the calculation is possible only in the frequency domain, whereby at best each individual frequency is weighted according to the influence on the human being. According to human perception, the weighting curve does not contain any definition gaps or discontinuities.

For the declaration in the technical data or on the packaging, a single measurement is best suited. Several measurements for the same annoyance - the effect of light modulation on humans - are poorly communicable. In addition, the use of a single measure also makes it clearly easier to define normative application-dependent limit values, as shown in Table 1.

In this paper, the following measuring methods were analyzed for suitability:

- DIN EN 12464-1 [15]:
  The section for evaluating light flicker only considers the state of the mains power frequency-dependent strobe light "present" or "not" → unsuitable.

- Contrast methods according to Admesy B.V. [1] and Chroma Ate Inc [2]:
  The value calculated from the amplitude ratios does not correspond to the requirement for a frequency-dependent weighting → unsuitable.

- IES: RP-16-10 [3]:
  The two values calculated from amplitude ratios do not contain any frequency-dependent weighting and are poorly communicable → not suitable.

- Jeita to Admesy B.V. [1] and Chroma Ate Inc [2]:
  The upper limit of 65 Hz excludes mains power frequency-dependent strobe light.
  → unsuitable.

- CEC Title 24 JA10 [11]:
  The lack of weighting of individual frequencies inhibits the detection of flicker in the photosensitive frequency range from 5 Hz to 35 Hz → unsuitable.

- IEEE 1789 RP1 [16]:
  The jump discontinuity at 90 Hz in the weight curve lacks any physiology. The sole evaluation of the fundamental frequency excludes different kinds of light emission curves → hardly suitable.

- CIE: $P_{st}LM$ / SVM [8] [9]:
  The two measured values for the areas "Flicker" and "Stroboscopic light" contain a definition gap in the transition area. They complicate conveyance and the setting of normative limits. This gap could be closed computationally and the two values combined into one → conditionally suitable.

- CFD [12] [13]:
  For measuring the entire frequency range without definition gaps or discontinuities with frequency-dependent weighting one single percent unit is provided → suitable.

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