Flicker explained

interpretation of the Technical Report IEC 61547

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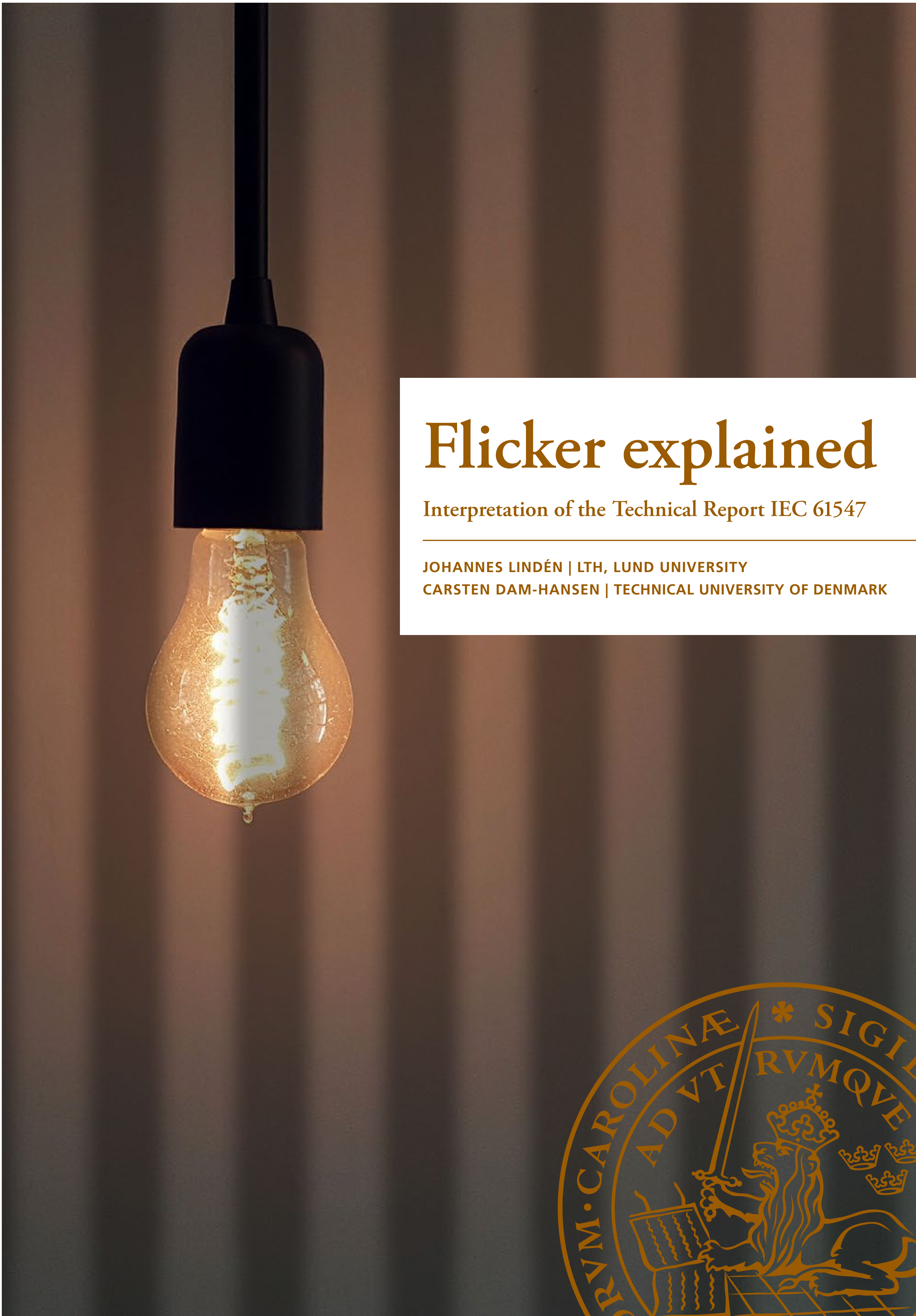

Flicker explained

Interpretation of the Technical Report IEC 61547

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Introduction

Flicker, or more precisely temporal light modulation (TLM), has re-emerged as a problem with the introduction of LED-based lighting technology. TLM, meaning variations in light intensity over time, may have negative effect on human health, causing annoyance, headaches, eyestrain and migraine. In addition to the unnecessary suffering TLM causes in individuals, the negative consequences of TLM create an obstacle to broad and rapid adaptation of the new LED-technology and consequently also an obstacle to potential energy savings.

The EU's new eco-design regulations entered into force in September 2021. These include, for the first time (in Europe) regulatory limits for TLM parameters for light sources and refers to new standards for measuring them. This creates an urgent need to spread awareness of TLM and information on how to measure it quickly, easily and correctly. However, the standards that describe the measures are technically complicated and are not aimed at industry professionals.

This document gives a thorough introduction to TLM, what it is, and how it is measured. Mainly, it gives an explanation and interpretation of the technical report TR IEC 61547:1-2020[1] (henceforth referred to as IEC 61547, unless otherwise stated), published by the International Electrotechnical Commission (IEC), which describes the equipment, method and measures required to assess a specific type of TLM effect – flicker. IEC 61547 is technically complicated and would be very difficult for non-technical readers to understand, because it is inconsistent in its use of terminology and might even appear to contradict itself.

This document also includes a guide and description on how to build a TLM-setup from scratch based on the standards, and what should be considered when doing so.

The purpose of this document is to increase knowledge about flicker in particular and TLM in general, taking the technical report IEC 61547 as a starting point. This work aims to bridge the gap between technical standards and reports on the one hand and the lighting industry on the other. This is with the aim of ensuring that the new EU eco-design regulations are followed which in turn will mitigate health issues caused by TLM and support a sustainable transition to LED technology.

Background

WHAT IS TLM?

Temporal light modulation means light intensity that varies (modulates) over time (temporally)*. TLM was a problem in fluorescent tubes for a period during the late 20th century when magnetic ballasts were used, however, this was solved at the time by the introduction of high frequency electronic ballasts. The reason that TLM has now re-emerged as a problem is because of the introduction of LED-based lighting technology. Regarding LEDs (light emitting diodes), it is important to point out that it's not the diode itself that is the source of the problem. The cause is always the electronic driver that feeds the diode with current. Therefore, the solution to the problem of TLM is often considered to be one of electronic engineering. Nowadays, however, there are plenty of cost effective driver solutions that do not cause TLM. A significant part of the solution is therefore to increase knowledge about TLM and how to prevent it, which is the purpose of this document.

> **Flicker is not something a lamp *does* – it is something you *see***

First a few comments about the word *flicker*. Colloquially we use it to describe what a lamp *does* – "the lamp is flickering". Strictly speaking, and based on how the word flicker is defined, this usage is incorrect. Flicker is not something a lamp *does* – it is something you *see*, something you *perceive*. What the lamp does is that it emits light which is *temporally modulated* and this can give rise to different effects, of which one is flicker.

Figure 1 gives an overview of different effects caused by TLM.

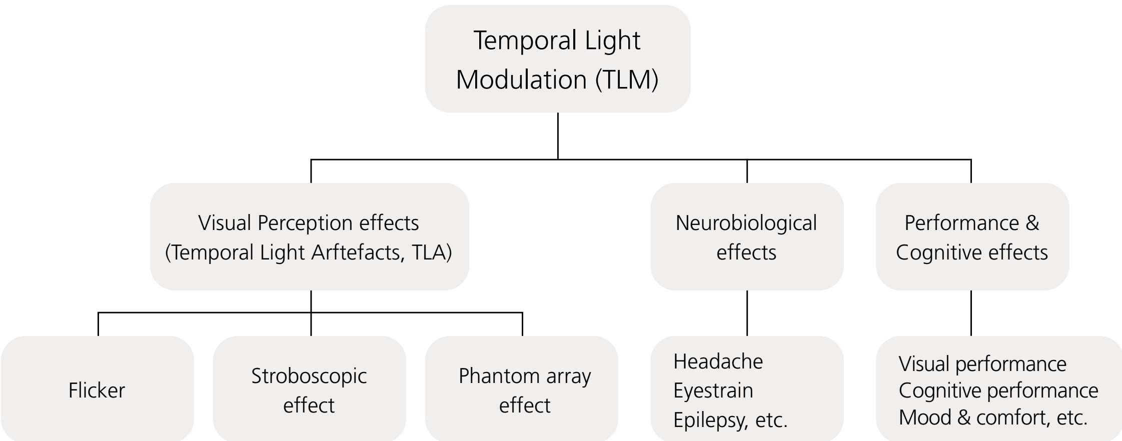

Figure 1: Overview of temporal light modulation (TLM) and its effects.

* In a medical context, the word *temporal* can also refer to the side-area of the brain/skull, near the *temples*. However, in this context *temporal* refers to something that has to do with *time*.

If exposed to TLM there are three different visual effects that can be perceived:

1. Flicker
If you look at a lamp and see that the light intensity is varying, then you are perceiving flicker. However, this is only valid as long as you don't move your eyes, and if the light source is not moving. In technical terms, flicker is defined as "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". As a consequence, flicker is only perceptible as long as the modulation frequency is below about 90 Hz. At higher frequencies our eyes cannot resolve the temporal variations. And as can be seen from the definition, flicker is a subjective rather than objective phenomenon.

2. Stroboscopic effect
If movement is involved, e.g., the light source is moving or some object is moving in the light (such as a hand or a pencil) and a pattern emerges, the observed effects are called *Stroboscopic effects* (see Figure 2).

Figure 2: Illustration of stroboscopic effect. Photo: J.Rydeman

3. Phantom array effect
Finally, there is a third effect, which appears during saccades (simultaneous rapid movements of the eyes). If you see a pattern during the very short period of time you move your eyes, then you are seeing phantom arrays (see Figure 3).

Both stroboscopic effects and phantom array effects are visible at much higher frequencies than 90 Hz. Stroboscopic effects are visible at frequencies up to 2000 Hz and phantom array effects at frequencies as high as 11 000 Hz[2].

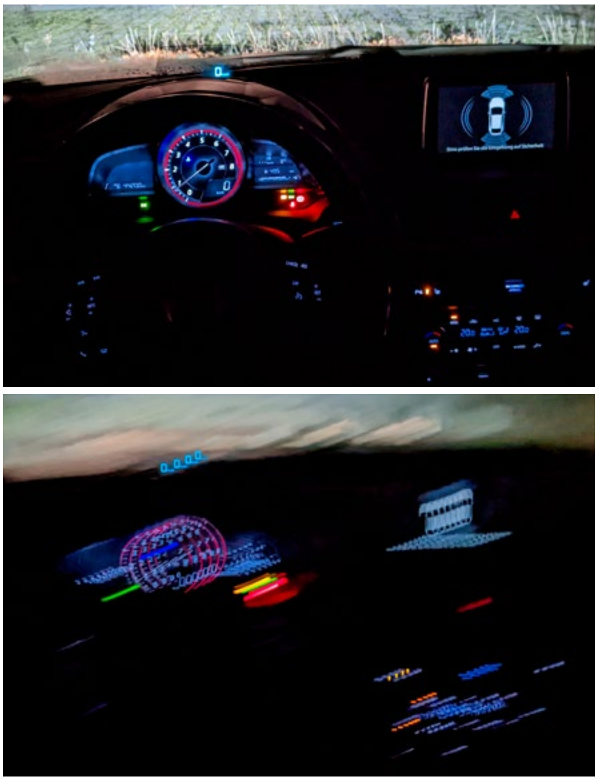

Figure 3: Illustration of phantom array effect. Photo: J.Ledig

All three effects mentioned above – flicker, stroboscopic effect and phantom array effect – are examples of *Temporal Light Artefacts* or TLAs* and they are, as stated, caused by TLM. These three light artefacts are by definition visual. However, it has also been demonstrated that TLM can cause non-visual effects, such as headache, migraine and eyestrain[4,5]. It has also been shown that TLM can affect cognitive performance and reading speed[6,7]. Furthermore, it has been observed that children and highly sensitive people are more affected than others.

These neurological and cognitive effects are probably more severe than the visual effects, since those that suffer from them are not necessarily aware that it is a light source that is the cause of their problems.

Beyond the effects TLM can have on humans, it has also been shown to have negative effects on animals such as hens[8], and it can also cause interference with imaging devices for photography and video. However, these effects are not considered in this work.

* There is recently a discussion initiated about the appropriateness of the term *artefact*[3] since the word "artefact" in North America is used for "trivial side-effects" and outside North America for man-made objects.

HOW IS TLM MEASURED?

For many decades it has been possible to quantify TLM using measures such as Percent Flicker (also known as Modulation Depth) and Flicker Index. However, these measures were developed at a time when light sources, if modulated at all, were modulated at a frequency of 100 Hz (or 120 Hz in north America), and the light sources involved were mainly incandescent bulbs or fluorescent tubes. The reason for the fixed frequencies is that for these light sources, the TLM frequency is twice the mains voltage frequency, which is 50 Hz in Europe and 60 Hz in North America. In other words, these measures do not take account of frequency and are thus not suitable for light sources that modulate at other frequencies.

Currently, there are two methods that have become standards for measuring TLM: short-term flicker indicator P_{st}^{LM} for flicker (up to 90 Hz), and the Stroboscopic effect Visibility Measure M_{VS} for stroboscopic effects (up to 2000 Hz). Note that the symbol M_{VS} for Stroboscopic effect Visibility Measure is often confused with the abbreviation of the same: SVM. Both P_{st}^{LM} and M_{VS} are designed so that if the measurement result equals 1, it means that the probability of observation of the effect for a standard observer is 50%. A higher measurement result means a higher probability. Currently there are no measures for phantom array effect, but possibly more seriously, there also no metrics suitable for quantifying the neurological or cognitive effects. More research is needed in this field[9].

In September 2021, the European Union updated its eco-design directives, including, for the first time, regulations and limits for TLM in lighting products. They state that P_{st}^{LM} cannot exceed 1 and M_{VS} cannot exceed 0.9 (which will be lowered to 0.4 by 2024). These limits apply to full load of the light source, that is, undimmed.

In connection with the updated eco-design directives, the European Union has introduced a new energy label for electrical products. This label includes a QR-code, which when scanned directs to the EPREL database (European Registry for Energy Labelling), where additional information about the product is found (see Figure 4). For light sources, this information include values for "Flicker metric" and "Stroboscopic effect metric" – short-term flicker indicator and stroboscopic effect visibility measure, respectively. It should be noted, however, that the information in the EPREL database is todays date not totally reliable. Many light sources states the value of 0, or the value of 1.0 for P_{st}^{LM} and 0.4 for M_{VS}, i.e. exactly on the legislation limit. It's highly unlikely that these are actually measurement results.

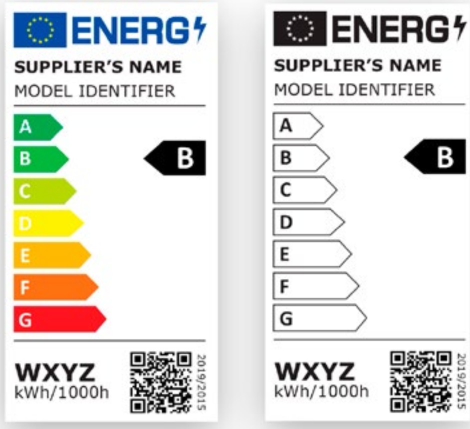

Figure 4: Example of the new energy label from EU

TECHNICAL REPORT IEC 61547-1:2020

The technical report TR IEC 61547-1:2020 was published as a consequence of the introduction of LED lamp technology. The first edition was issued in 2015, followed by a second in 2019, and a third in 2020, which was applicable during this work. The report is an unofficial document which must be purchased from standardisation bodies, which is the reason for it not being reproduced in detail in this document. Note that the IEC 61547 is a report (TR stands for Technical Report), and not a standard. In practice, however, it is used as a standard.

The full title of IEC 61547 is "*Equipment for general lighting purposes – EMC immunity requirements – Part 1: Objective light flickermeter and voltage fluctuation immunity test method*". As the title indicates, the report describes an objective flickermeter, and also how to test the immunity of a light source to voltage fluctuations.

Note here that the report claims to describe an "objective" meter of "flicker". Since it was pointed out above that *flicker* is defined as something *subjective*, and, in contrast to how the word is used colloquially, not something *objective*, it might be appropriate to elaborate briefly on this. Thus, flicker is defined as something subjective – which strictly means that if you cannot see it, it doesn't exist. Yet the flickermeter is an "objective flickermeter". How do you objectively measure something subjective? Without getting into semantics or a philosophical discussion, let's just note that this situation is not very different from how we treat the measurement of light. Light can also be defined as something subjective, something that gives an impression. Nevertheless, it is still possible to measure it objectively using, for example, a photometer. Just as electromagnetic radiation can be investigated using the V(λ) function*, a recorded waveform of light intensity fluctuations can be investigated by a function (the flickermeter) resulting in a value.

The *light flickermeter* described in IEC 61547 is a further development of the IEC *flickermeter* described in the standard IEC 61000-4-15[10], with associated limits and recommendations as per the standard IEC 61000-3-3[11], which was published in 1994. Henceforth the instrument described in IEC 61000-4-15 will be referred to as the *IEC Flickermeter* and the instrument described in IEC 61547 as the *IEC Light Flickermeter*.

THE SHORT-TERM FLICKER INDICATOR P_{ST}

The short-term flicker indicator, symbol P_{st}, which is one output of the IEC Flickermeter and is described in IEC 61000-4-15, was developed at the time when incandescent light bulbs were the most common light source in residential homes. The purpose of the development of the IEC Flickermeter and P_{st} was to achieve a tool for assessing voltage fluctuations in the power supply in order to avoid visible flicker from lamps and complaints from electric power customers, as at that time complaints mainly concerned unsteadiness of light levels from lamps. P_{st} is therefore based on the 60 W incandescent light bulb. P_{st} is a measure of flicker and is designed so that a resulting value higher than 1 means that the flicker causes annoyance in 50% of the cases for a standard observer. However, P_{st} is not the only output from the IEC Flickermeter, the primary output being the *instantaneous flicker sensation* P_{inst}, which is a time resolved measure indicating the flicker sensation at every moment in time. Also, in addition to the short-term flicker indicator P_{st}, there is also the long-term flicker indicator P_{lt}. Both P_{st} and P_{lt} are the result of statistical analysis of P_{inst}, giving an indication of the flicker perception in both the short-term (10 min) and long-term (2 hours).

According to the original standard IEC 61000-4-15 and the IEC Flickermeter described therein, the voltage fluctuations need to be logged for 10 minutes to obtain a value for the short-term flicker indicator P_{st}. Note here that the fact that it is necessary to monitor the voltage to assess the light flicker has led to some confusion and differences of opinion: is P_{st} a measure of voltage or light? In the electrical community P_{st} is sometimes viewed as a measure of supply voltage fluctuations, and in the lighting community as a measure of flicker. P_{st} is a measure of flicker. However, in order to obtain a value you need to monitor the voltage using the IEC Flickermeter. By doing so, the IEC Flickermeter *models* the light fluctuations as they would have appeared from a 60 W incandescent lamp connected to that voltage. This was reasonable at the time because there was more or less a direct link between the fluctuations of the voltage supply and the light fluctuations. Therefore, measuring the voltage was regarded as being equivalent to measuring the light.

With this in mind, you might say that "P_{st} is a measure of the supply voltage quality expressed in terms of the light flicker from a 60 W incandescent lamp", or that the IEC Flickermeter is only a measure of flicker from such a lamp.

It is worth noting here that P_{st} is in fact used as a characteristic of power supply voltage quality and that the parameter is used as a requirement level for other electrical appliances.

It follows that in the case of the IEC Flickermeter and P_{st}: what you "measure", or monitor (in this case the voltage), is not what you get a "measure of" (the light flicker). This is actually the case in many situations where any quantity is measured, for example when measuring temperature, which can be done either using an alcohol thermometer or a thermocouple, or some other kind of device. However, it is worth pointing out in this case to avoid confusion**. From the time it was introduced, the IEC Flickermeter was incorporated into voltage measurement devices which were connected to a voltage power line (either directly or by the use of current clamps) and then a simulation was performed of the behaviour of an incandescent 60 W light bulb to obtain a value for the short-term flicker indictor P_{st}.

Since P_{st} was developed at the time when incandescent lamps were the most commonly used light source, this modelling of light fluctuations based on voltages fluctuations made sense because there was more or less a direct link between the fluctuations in the voltage supply and the light fluctuations.

* V(λ) (pronounced V-lambda) – the function that describes the sensitivity of the human eye to electromagnetic radiation.

** It all boils down to the definition of the word *measurement*, which according to the International vocabulary of metrology[12] presupposes a description of the measurement procedure.

Around the beginning of 21st century, however, with the introduction of LED lighting technology, there was no longer a (simple) connection between the voltage and light fluctuations. Suddenly there were LED lamps introduced to the market showing very low sensitivity to voltage fluctuations, but also LED lamps that inherently generated significant level of flicker, regardless of the quality of the supply voltage. With this came a need to assess the light intensity variations emitted from any light source, regardless of the power supply voltage.

This need is the origin of the IEC 61547 and the IEC *Light* Flickermeter. It describes a flickermeter which uses the *light variations* as a direct input, in contrast to the original IEC Flickermeter, which takes the *voltage* as an input, and *models* the light from a 60 W incandescent lamp.

Thus, the IEC Light Flickermeter consists of the same components and algorithms (or blocks) as the IEC Flickermeter, except it does not include those components and algorithms that simulate the incandescent lamp. One conclusion from this is that for the IEC Flickermeter, the 60 W incandescent lamp is *part* of the instrument, while for the IEC *Light* Flickermeter, it is a light source, like any other, which can be assessed.

This means that if you measure a 60 W incandescent light bulb using the IEC Light Flickermeter, you will get the same resulting value of P_{st} as if you measure the voltage using an IEC Flickermeter (provided the 60 W incandescent lamps is as similar as possible to the ideal one).

In order to clarify which instrument is being used in the measurement procedure, a second symbol for the short-term flicker indicator was introduced in IEC 61547, P_{st}^{LM}, where LM stands for "Light Measurement". Therefore, the IEC Flickermeter takes the voltage as input and the output short-term flicker indicator is denoted as P_{st}, while the IEC *Light* Flicker meter takes the light intensity as input, and the output short-term flicker indicator is written P_{st}^{LM}.

Note that P_{st} and P_{st}^{LM} are still measures of the same thing: flicker, only obtained using slightly different instruments (just as you can measure temperature or any other quantity by using different instruments).

In order to "avoid confusion", or to "be extra clear about which instrument has been used", yet a third symbol is introduced in IEC 61547: P_{st}^{V}, where V indicates it is the voltage that has been used as input, hence it's the IEC Flickermeter that has been used. In other words: P_{st}^{V} is exactly the same thing as P_{st}.

Unfortunately, this has not always ensured the avoidance of confusion. In some literature it is stated that there are two types of short-term flicker, and that what distinguishes them is whether it is the power supply voltage or the light source itself that is the cause of the flicker.

Just as P_{st} is implemented in several voltage measurement devices, P_{st}^{LM} is now more frequently implemented in light measurement devices. As mentioned above, the duration for logging the voltage using the IEC Flickermeter to obtain P_{st} is 10 min. For P_{st}^{LM}, using the IEC Light Flickermeter however, the recommended duration of the logging of light intensity variations is 3 minutes.

It's worth noting that Matlab functions for both P_{st} and P_{st}^{LM} are freely available for download (see Jourdan[13] for P_{st} and Banerjee[14] for P_{st}^{LM}), provided you are able to monitor voltage or light waveforms, and have a licence for Matlab.

As mentioned, in P_{st}^{LM}, LM stands for "Light Measurement". And st stands for "short-term". However, it is not obvious what the P stands for. During the course of this work, no obvious answer became apparent, but the most probable answer is "Perceptibility". However, there have also been several other candidates: Planning levels, Pegel (German for level), Papillotement (French for flicker) and even Paracetamol.

Despite the best intentions of trying to avoid confusion, the introduction of different symbols might give the impression of inconsistency, especially as various publications and websites tend to mix the use of both symbols and terms. One reason for the room for improvement might be the fact that the report is created at the intersection of disciplines – the electrical and lighting communities.

The risk of difficulties in communication is increased by the inconsistent use of terminology in IEC 61547. In addition to being referred to as "short-term flicker *severity*" in IEC 61000-4-15 and IEC 61000-3-3, many different names are used for the short-term flicker indicator throughout the report: *short-term flicker value*, *intrinsic flicker*, *intrinsic flicker performance of lighting*, *intrinsic flicker performance of a light source*, *flicker severity value*, *flicker performance*, *flicker metric*, and *short-term flicker metric*.

The table below summarises, with some notes, the important information about the two TLM measures mentioned in this work, short-term flicker indicator P_{st} and stroboscopic effect visibility measure M_{VS}.

Quantity / Phenomenon	Name of measure	Symbol
Flicker	Short-term flicker indicator*	P_{st}**
Stroboscopic effect	Stroboscopic effect visibility measure (SVM)	M_{VS}***

* In IEC 61000-4-15 and IEC 61000-3-3 the alternative term “short-term flicker severity” is used.

** For clarity, the symbol P_{st}^{LM} can be used to indicate that the IEC Light Flickermeter was used (i.e., the light was detected), or the symbol P_{st}^{V}, to indicate that the IEC Flickermeter was used (i.e. the voltage was detected).

*** SVM is used as an abbreviation for Stroboscopic effect Visibility Measure, but also, incorrectly, sometimes as its symbol.

Interpretation of the Technical Report

The following section will consider some specific content of the TR IEC 61547-1:2020 report, and hence refer to specific pages and sections. As mentioned, the report is not freely available, but must be purchased. Therefore, longer parts of the text cannot be reproduced in this work. The review of the report is restricted to the definitions, symbols and figures. The rest of the report is regarded as having been dealt with by the text in the earlier sections of this work.

AMENDMENTS TO THE DEFINITIONS AND SYMBOLS

Section 3.1.1 – the definition of flicker

Here flicker is defined as something subjective – the *perception of visual unsteadiness* […]. This has also been pointed out earlier in this work and because this is unlike the colloquial use of the word flicker, it is suggested that this at least should be pointed out in a note to the definition. Especially as the title of the report includes the word "objective" referring to a flickermeter.

Three flickermeters

No fewer than three flickermeters are included among the definitions – the flickermeter, the voltage flickermeter and the light flickermeter. Following directly after the definition of *flicker* where it is stated that this is something to do with perception of light, a presentation of three flickermeters, one of which is called a *voltage* flickermeter only increases the confusion. Let's look at them one at a time.

Section 3.1.2 – the flickermeter

The definition of the flickermeter is simply an *instrument designed to measure any quantity representative of flicker*. This means that the input to the meter could be basically anything – light flux, voltage, current, or even sound. It is assumed that the main reason for including this definition is that it is the only flickermeter defined in the International Electrotechnical Vocabulary[15] and electropedia[16] (IEC term 161-08-14).

Section 3.1.3 – the voltage flickermeter

The definition of the voltage flickermeter is as follows:

instrument which is designed to measure any quantity representative of flicker resulting from mains voltage fluctuations

The phrase "*resulting from mains voltage fluctuations*" gives the impression that it is the *cause* of the flicker that determines what the instrument should be called, which of course cannot be the case. More correctly, it should be stated that the voltage flickermeter is using the *voltage* as input, and this to evaluate the flicker as it would have been perceived in respect of a 60 W incandescent bulb. The correct way to phrase it would be "*instrument which is designed to measure any quantity representative of flicker using voltage as input*". It would also be appropriate to note that one of the outputs of the voltage flickermeter is P_{st}, which could also be denoted P_{st}^{V} when clarification of which procedure being used is needed.

Section 3.1.5 – the light flickermeter

The definition of the light flickermeter goes as follows:

instrument designed to measure flicker resulting from temporal changes in the intensity of the light in an objective way

In a note to the definition it says that "the light flickermeter is based on the IEC 61000-4-15 specifications", that is the voltage flickermeter. A better clarification though would be to say that the light flickermeter is a *modification* of the voltage flickermeter. This is, by the way, the word used in Annex A of the report, where the modifications are described. More details about this are given below.

It would also be appropriate to clarify that the light flickermeter takes the light fluctuations as direct input, and not the voltage fluctuations as the voltage flickermeter does. Also, it should be stated that one of the outputs of the light flickermeter is the same short-term flicker indicator P_{st} as from the voltage flickermeter, but that, if needed, it can be denoted P_{st}^{LM} to clarify which procedure was used.

Why the phrase "in an objective way" is included in the definition is puzzling, especially since the phrase is not included in the definitions of the other flickermeters. The author of this work suggests that the phrase is deleted in upcoming editions.

Section 3.1.7 – the short-term flicker indicator P_{st}
There is nothing to add to the definition here. However, it could be appropriate, either here or in the symbols section, to note that the short-term flicker indicator can be denoted P_{st}^{V} or P_{st}^{LM}, to indicate whether the voltage flickermeter or light flickermeter was used to obtain the result.

Furthermore, either here, in the abbreviation section or symbols section, it should be stated what P and st stands for. As mentioned above, it is most likely that P stands for *Perceptibility*. st stands for short-term.

Section 3.3 Symbols
The description of the symbol P_{st}^{LM} is as follows:

flicker metric of the illuminance of an EUT without the application of voltage fluctuations and measured with a light flickermeter*

Here it should be clearly stated that P_{st}^{LM} is the short-term flicker indicator P_{st}, but that the addition of LM indicates measurements performed using a light flickermeter, i.e., where the light has been used as a direct input. The phrase "without the application of voltage fluctuations" implies that the symbol is not the one used when immunity tests are being performed (for this the symbol $P_{st}^{LM}(I)$ is used, which is the next symbol described in the report). This, however, doesn't exclude the possibility of voltage fluctuations being present when P_{st}^{LM} is measured. Therefore, is it suggested that the phrase is removed. The suggested description of the symbol therefore becomes:

P_{st}^{LM} – short-term flicker indicator, P_{st}, where LM indicates measurements are performed using a light flickermeter, which uses the luminous variation as input

Among the following symbols described in the report are $P_{st}^{LM}(I)$, $P_{st}^{LM}(C)$, P_{st}^{V} and $P_{st}^{V}(N)$. All the descriptions of these symbols start with "flicker metric". It is suggested that for the first two this text is replaced simply with "P_{st}^{LM}", and then information added about what the I and the C stand for.

It is stated later in the report that I stands for Immunity, but the meaning of C is never explained. It appears, however, to stand for Combination.

The suggested description of the two symbols therefore becomes:

$P_{st}^{LM}(I)$ – P_{st}^{LM} of the illuminance of an EUT with the application of voltage fluctuations, measured with a light flickermeter and as a result of an immunity test. I stands for Immunity.

$P_{st}^{LM}(C)$ – P_{st}^{LM} of the illuminance of the combination of a light source and a dimmer measured with a light flickermeter. C stands for Combination.

The description of next symbol, P_{st}^{V}, is as follows:

Flicker metric of the supply voltage measured with a voltage flickermeter

Since flicker has earlier been defined as a perception of light, it becomes very confusing to describe something as a "flicker metric of the supply voltage". Given the background of P_{st} – that it is a measure of flicker, but with the motivation being to indicate the quality of the supply voltage – the description makes more sense, but this should then be explained in additional text. The important thing with P_{st}^{V} is that the V indicates that a flickermeter was used, i.e., voltage was used as input. Therefore, it is suggested that the description should read:

P_{st}^{V} – short-term flicker indicator, P_{st}, where V indicates measurements are performed using a voltage flickermeter, which uses voltage as the input

The description of the last symbol is suggested to be

$P_{st}^{V}(N)$ – P_{st} of the noise level from an unmodulated supply voltage measured using a voltage flickermeter

* Authors note: EUT stands for Equipment Under Test. This is included in the abbreviations in the report.

AMENDMENTS TO FIGURES

There are two figures in the technical report IEC 61547 that require changing: Figure 1 on page 12 and Figure A.1 on page 29. The suggested changes are described below.

Figure 1, page 12

Some information is missing in Figure 1a, the figure that describes the voltage fluctuation emission test of an apparatus, or equipment under test (EUT).

- First, it is not obvious that the empty rectangle at the beginning of the flow chart indicates the reference impedance. Usually, an impedance is denoted by the letter Z. Adding the letter Z inside the box, and to the text referring to the reference impedance would avoid any confusion.
- The objective of the procedure described in Figure 1a is to test the voltage fluctuations emitted by the EUT. It is important to remember that the EUT can be any electrical device. It is therefore suggested that the words "of an electric apparatus, EUT" is added to the caption of the text, so that it reads "Voltage fluctuation emission test *of an electric apparatus, EUT*, as specified in IEC 61000-3-3, using the IEC voltage flickermeter specified in IEC 61000-4-15".
- It is not obvious that the arrow pointing downwards from the EUT box represents a connection to earth. Either, use of an alternative symbol is suggested, or this should be made clear in the text.
- The text "(60 W incandescent lamp)" to the far right is somewhat confusing. It is probably there to indicate that the voltage flickermeter is based on this type of lamp. As this is, however, pointed out earlier, the text should be omitted.

Figure 1b describes the voltage fluctuation immunity test. Here too, some information can be clarified or additional information added:

- The text "of lighting device" should be added to the caption and "= lighting equipment" removed from the figure
- As in a), the downwards pointing arrow should be replaced with a proper earth symbol
- The text "(60 W inc. lamp)" to the far left of the figure should be removed

The completed revision of Figures 1a and 1b are shown below, including the bullets suggested above and some additional details for clarification.

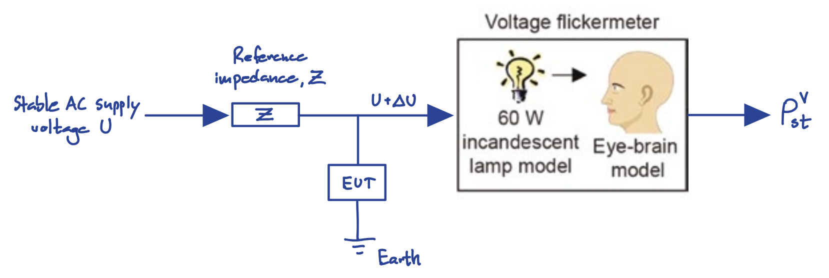

Figure 1a) Voltage fluctuation emission test of an electrical apparatus, or equipment under test (EUT), as specified in IEC 61000-3-3, using a voltage flickemeter specified in IEC 61000-4-15

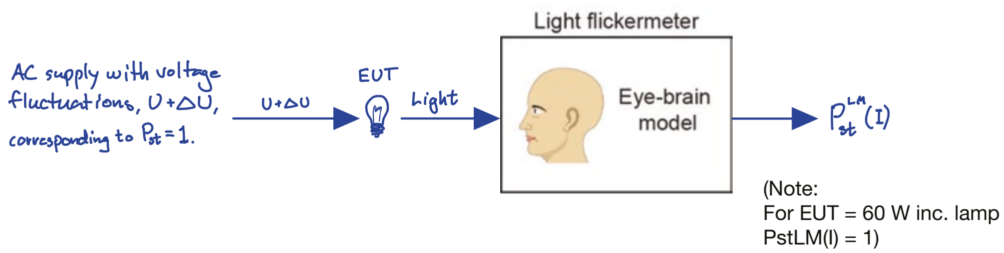

Figure 1b) Voltage fluctuation immunity test of a lighting device, or equipment under test (EUT), as specified in this document

Figure A.1, page 29

The second figure requiring changes is Figure A.1 in Annex A, page 29. It describes the modifications made to the IEC Flickermeter in order to achieve the IEC Light Flickermeter. The figure is adapted from figure 2.8, page 26 in a doctoral thesis by R. Cai, *Flicker interaction studies and flickermeter improvement*[17].

The following changes are suggested for this figure, and some text referring to it:

- First, the caption says "Structure of the IEC 61000-4-15 flickermeter that uses voltage as input". However, it should be pointed out that the figure actually describes a *modified* version of the IEC Flickermeter from IEC 61000-4-15, that is the IEC *Light* Flickermeter. In the text above the figure it even says: "an adapted flickermeter which uses illuminance as input instead of the voltage (see Figure A.1)."
- A text in the figure reads "Red blocks indicate the incandescent-lamp specific blocks". This is actually only true for the box that reads "Lamp response filter (Depends on the lamp type)". The rest of the red blocks are the input "*Voltage signal*", "*Voltage adapter*" (Block 1) and "*Demodulator with squatting multiplier*" (Block 2). These have nothing to do with the incandescent lamp, but are only removed for the modification to the IEC Light Flickermeter.

So, a suggestion for a new caption reads "Structure of the IEC 61000-4-15 flickermeter (that uses voltage as input), with modifications to the IEC light flickermeter (which uses illuminance as input) shown in red".

- The first rectangles (the input "*Voltage signal*", "*Voltage adapter*" (Block 1) and "*Demodulator with squatting multiplier*" (Block 2)) are the parts omitted from the IEC Flickermeter in order to change it to an IEC Light Flickermeter. Hence, there should be a clarification that light, or illuminance, should be used as input, rather than the voltage.
- One output from Block 4 is shown in the figure, marked as "Output 5". It is not obvious what this is, but it is suggested later in the Annex, section A.2.4 on page 31, that this is the *instantaneous flicker sensation* P_{inst}. It is suggested that this is either described in the text or removed from the figure. Also it is not clear why the arrow indicating Output 5 is red. This is adapted from the original figure in R. Cai[17], but even in the original, there is no explanation as to why this arrow is red.

A complete revision of Figure A.1 can be seen below, including the bullet point items suggested above and some additional details for clarification.

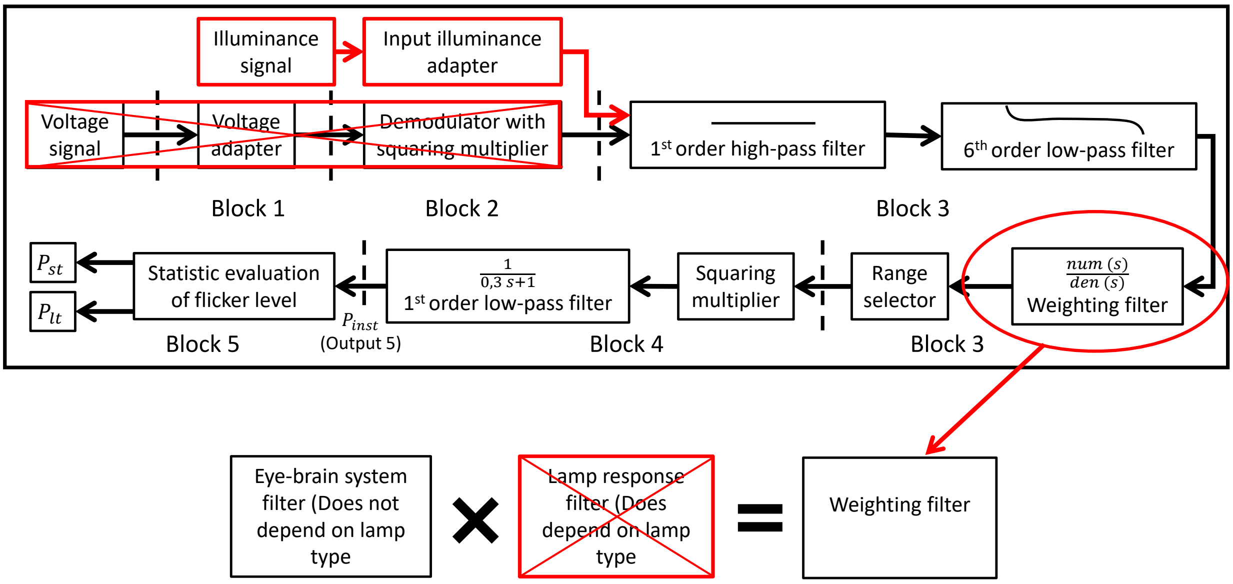

Figure A.1 – Structure of the IEC 61000-4-15 flickermeter (that uses voltage as input), with modifications to the IEC light flickermeter (which uses illuminance as input) shown in red

Instructions to build setup

GENERAL

When it comes to building a TLM measurement setup, there are some general aspects that need to be considered, such as the degree of accuracy, need for flexibility and cost.

There are several TLM detectors available off the shelf that directly output the resulting TLM value (Light Flicker Analyzer from Everfine, BTS256-EF from Gigahertz Optic, LabFlicker from Viso System, etc.). However, there are a larger number of handheld devices that output the measures Percent Flicker and Flicker Index (which are obsolete, as mentioned before) but do not give the recommended measures of P_{st}^{LM} and SVM.

The international commission on illumination, CIE, released a technical note in 2021 entitled *Guidance on the Measurement of Temporal Light Modulation of Light Sources and Lighting Systems* CIE TN 012 2021[18]. The document gives good general recommendations in respect of TLM measurements*. Note that the document is a "Technical Note", TN. The technical committee TC 2-89 responsible for the publication is currently working on a Technical Report on the same subject, which will contain more details on measurements of TLM. In the meantime, during the creation of a TLM measurement setup, consultation of the technical note as a complement to IEC 61547, is recommended.

It should be noted that issues regarding the calculation of both SVM and P_{st}^{LM} in respect of uncertainty and reproducibility have recently been observed[19–21]. These issues impact on inter-laboratory comparisons and verification of the compliance to EU legislations. These issues are subjects for further investigations and will be considered in future updates. An inter-laboratory comparison (IC 2022) is in the planning stage of the Solid State Lighting (SSL) Annex under the International Energy Agency (IEA)**. IC 2022 will be on TLM measurements and compare measurements of P_{st}^{LM} and M_{VS} for five artefacts. It will also compare measured waveforms, and also investigate the issues mentioned above.

The remainder of this section gives an overview of parameters and equipment important to consider in the process of establishing a TLM measurement setup, followed by a guide on measurement procedure. Finally, examples of three different types of measurement setups are described, including a field-measurement setup, a low-cost and a high-cost lab setup.

Considering field measurements, it is important to acknowledge the different conditions and parameters that distinguish these measurements from laboratory measurements. These are parameters such as power supply characteristics, obstructive background illumination and ambient temperature. All these parameters influence the uncertainty of the measurement, and need to be controlled as far as possible. The conditions should also be described in the measurement report.

Moreover, the meaning of "field measurement" is not entirely clear. Does it involve assessment of 1) the individual source, 2) the view from the location of a specific observer, or 3) the scene as a whole? No consensus or guidelines about this exist. In the meantime, the recommendation for these kinds of measurements is therefore to report too much rather than too little information.

The rest of this section will consider laboratory measurements, unless otherwise stated.

PARAMETERS TO CONSIDER

Sampling rate

For P_{st}^{LM} the recommended sampling rate is 10 kS/s, and for SVM 20 kS/s. In the documentation there are recommendations for cut-off filters of the amplifiers at 2kHz for P_{st}^{LM} and 3 kHz for SVM. However, experience has shown that if the sampling rate recommendations are followed, there is no need for cut-off filters.

* In the document the short-term flicker indicator P_{st}^{LM} is referred to using the name "short-term flicker *index*"

** www.iea-4e.org/ssl/our-work/testing-standards/

Sampling duration
The sampling duration for P_{st}^{LM} is 180 seconds and for SVM 1 second.

Signal-to-noise ratio
There are several parameters influencing the signal-to-noise ratio (SNR), such as detector responsivity, level of background light and resolution of the digitiser. It is desirable to keep the SNR as high as possible.

Detector linearity
If the light intensity at a detector increases by a given factor and the signal from the detector increases by the same factor, the detector is linear. The linearity of the detector needs to be ensured. If the system can measure absolute values of the light source intensity this is fairly straight forward. Otherwise, the easiest way is to record the signal intensity at different distances and verify the inverse square law relation between the distance and the light intensity. When doing so, use of a small size, omnidirectional high-intensity light source is recommended, so that the light source can be considered a point source. A rule of thumb is that the distance between detector and light source should be at least 10 times the size of the light source. The measurements must be performed within the linear range of the detector.

EQUIPMENT TO CONSIDER

This section discusses some more complex issues and contains general tips concerning the equipment in a measurement setup.

A general TLM setup consists of the following components:

- Power supply for light source
- Test chamber
- Detector
- Digitiser
- Data processing tool

Power supply
When performing controlled TLM measurements it is important that the light source under investigation is powered by a stable and reliable power source. For this, use of an off-the-shelf power supply is recommended. Although usually quite expensive, it is necessary to perform reliable and reproducible measurements.

Test chamber
It is important to enclose the light source under test in an optically shielded chamber in order to block out possible obstructive light, e.g. ambient light from daylight or other light sources. An integrating sphere would be ideal, but is associated with a high cost. Often, a well optically shielded box is sufficient.

Detector
Since TLM measurements are relative, no absolute calibration of the detector is needed. A photodiode is a simple and cheap component with high temporal response. It needs a transimpedance amplifier to convert the photocurrent into a voltage signal. Many detectors with a wide range of different prices are available off the shelf, with or without built-in amplifiers.

It is possible to build your own detector for TLM measurements at a very low cost. Detailed instructions are given in the document *Design Tips How to measure light flicker in LED lamps* from the Richtek Technology corporation[22]. The detector described in this document is based on the integrated circuit TSL257, which includes a photodiode and a transimpedance amplifier. The resulting detector has a bandwidth of approximately 350 kHz, depending on the combination of resistor and capacitor used. Note, however, that this detector is sensitive to electrical noise if not sufficiently shielded.

Several documents recommend that the detector is V(λ)-corrected, meaning that the spectral responsivity should match that of the human eye. A V(λ)-corrected detector means that both the spectral transmittance of the filter in front of the detector *and* the spectral sensitivity of the detector are taken into consideration. It makes sense to apply such a filter if it is suspected that the light source to be investigated exhibits chromatic modulation, that is, its spectral distribution changes over time, not just the absolute intensity of the light source. This only occurs rarely. A more important reason for using a photometric filter is to remove unwanted infrared radiation, which can be present in very bright light sources or light sources with insufficient heat disposal. However, to overcome this problem, an optical short-pass filter that removes longer wavelengths could also be utilised. Considering that photometric filters may be difficult to get hold of and that they attenuate the signal, a short-pass filter could be a good compromise. Depending on cost and the accuracy required, the photometric filter may even be omitted entirely.

Digitiser

The voltage signal from the amplifier needs to be converted to a digital signal using an oscilloscope, digital multimeter or a dedicated analogue-to-digital converter (ADC). Here it's important to consider the resolution of the captured signal, that is, the resolution of the digitised voltage. This is often specified in bits, and a minimum resolution of 10 bits is recommended. An example of an ADC is a data acquisition unit from National Instruments, a so-called NI-DAQ, to be controlled using Labview software. However, this is very expensive, not least because it also requires a Labview licence. There are low-cost alternatives though, e.g. a voltage-measurement DAQ MCC 118 which can be combined with a Raspberry Pi single board computer, a system that offers 12-bit resolution and 100 kS/s sampling rate[*].

Data processing tool

The captured signal needs to be processed and the TLM measures calculated. The process of calculating both P_{st}^{LM} and SVM is described in the reference documents (IEC 61547 & IEC 63158), but the process is not easily implemented (especially not for P_{st}^{LM}). There are toolboxes available in Matlab that are free to download. The function for P_{st}^{LM} is called light_flickermeter_metric_PstLM[14] and the function for SVM is called stroboVisibilityMeasure[23].
Matlab itself, however, is not free, but needs a licence. However, open source alternatives to Matlab are available[24].

MEASUREMENT PROCEDURE

While performing a measurement, the following procedure and consideration is recommended:

a) Put the lamp to be tested in an optically shielded enclosure. Ambient light should be prevented as far as possible.
b) Switch on the lamp. Before the measurement is performed, the lamp needs to be turned on for a sufficient time to stabilise. This is usually around 15 minutes, but could take longer depending on the lamp or luminaire. For details, consult the standard published by CIE[25]. This is important especially if P_{st}^{LM} is being measured because of the long sampling duration. The stabilisation is largely for temperature reasons because the light output is generally temperature dependent. As the temperature of the light source increases, its light output decreases.
c) Perform the measurement. If the device used for the measurement does not automatically output the measurement values, some post-processing of the acquired data is required.
d) Calculate the measurement results. This involves loading the temporal waveform data and performing the calculation, e.g. using Matlab, and then running the appropriate functions to achieve the desired resulting measurement values.

* www.mccdaq.com/DAQ-HAT/MCC-118.aspx

THREE SETUP EXAMPLES

1. Field-measurement setup
Figure 5 illustrates a field-measurement setup for assessing an individual ceiling luminaire. A tripod is used to get the detector as close to the light source as possible without the detector being saturated. All ambient light such as daylight or light form surrounding luminaires should be blocked as far as possible.

In the example in Figure 5 an off-the-shelf detector is used. For the majority of the time, such detectors need to be connected to a computer in order to output the result, especially if P_{st}^{LM} is being derived, since this requires 180 seconds of data acquisition. It is necessary to mount the detector, e.g. on a tripod, to keep it steady during the measurement. If the detector is held by hand, vibrations will influence the measurement result.

In a field measurement such as this it has to be borne in mind that the luminaire is connected to a uncontrolled power source, i.e. the public mains electrical supply, if this is so.

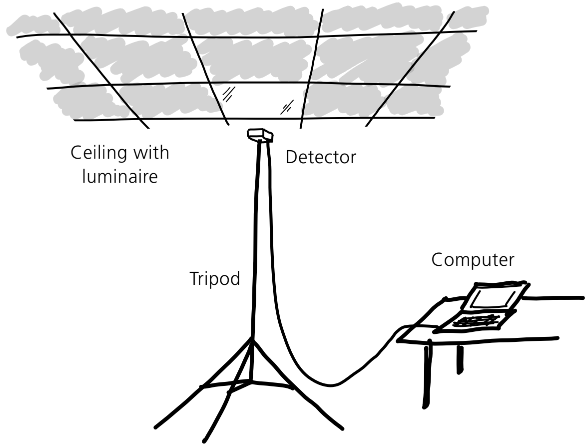

Figure 5: Illustration of a field-measurement setup

2. Low-cost lab setup
Figure 6 illustrates a low-cost laboratory setup. This excludes for example a controlled power supply because the light source is directly plugged into a mains power outlet. This must be stated in the measurement report, if such a report is to be produced.

This low-cost example includes an analogue-to-digital converter, or DAQ, of the open source kind, e.g. the DAQ MCC 118 for Raspberry Pi. Furthermore, if open source programming software such as Octave or Python is used, there is no extra cost for the Matlab licence. In this case, however, corresponding functions for calculating P_{st}^{LM} and SVM need to be achieved.

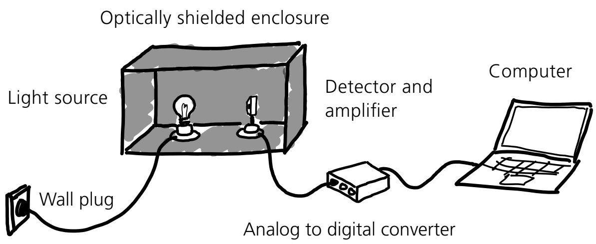

Figure 6: Illustration of a low-cost lab setup

3. High-cost lab setup
Figure 7 illustrates a by-the-book example of a TLM measurement setup, including a power supply to the light source to be measured, an integrating sphere, and an off-the-shelf detector. Note however, that by using an off-the-shelf detector you have no control over the sampling rate, duration time or calculations of the TLM measures. For this, a self-built detector system is needed, and the possibility of implementing the functions for calculating the measures. This is possible using a DAQ device (NI-DAQ or DAQ MCC 118 or equivalent) and software for programming (open source such as Octave or Python, or licence-based such as Matlab).

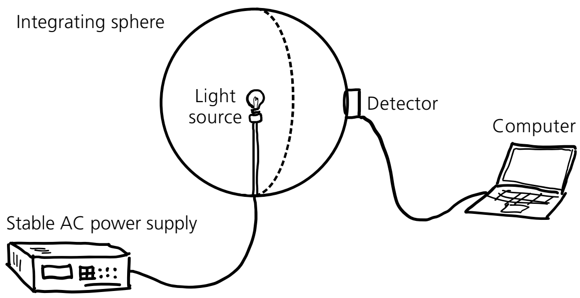

Figure 7: Illustration of a high-cost lab setup

Conclusions

Temporal light modulation (TLM), colloquially known as "flicker", creates an obstacle to potential energy savings and constitutes a threat to human health and wellbeing. The EU's new eco-design directives aim to regulate the degree of TLM in light sources on the EU market, however, the standards and reports describing the background are technically complicated.

This document is a product of the project Flicker Explained, with the objective of bridging the gap between the technical documents and the lighting industry. Furthermore, the project is motivated by the new eco-design directives and the limits on the measures of stroboscopic effect visibility measure (M_{VS} < 0.9) and short-term flicker indicator (P_{st}^{LM} < 1). Note that by September 2024 the limit on stroboscopic effect visibility measure will be even stricter (M_{VS} < 0.4).

Colloquially the word "flicker" is used to describe something a lamp *does*, as in "the lamp is flickering". Strictly speaking, this usage is incorrect based on how the word flicker is defined. Flicker is not something a lamp *does* – it is something you *see*. What the lamp does is emit light which is *temporally modulated* and that can give rise to different effects, of which one is flicker.

Part of the reason for the confusion is the origin of the flicker measure, short-term flicker indicator P_{st}. This was developed with the purpose of being a tool to assess voltage fluctuations in the power supply in order to avoid visible flicker from incandescent light bulbs, which was the most common light source at the time. In a sense you can say that in the case of the IEC Flickermeter and P_{st}, what you "measure", or monitor (the voltage), is not what you get a "measure of" (the light flicker).

Below is a list of some possible "pit falls" that it is good to be aware of when working with TLM, flicker and the measures P_{st} and SVM.

- Flicker is defined as something subjective, but is assessed in an objective way
- The word *temporal* can in a medical context refer to the side-area of the brain/skull that is near the *temples*. However, in TLM *temporal* refers to something that has to do with *time*.
- P_{st}, P_{st}^{LM} and P_{st}^{V} are symbols for the same measure: short-term flicker indicator, which is a measure of flicker. The different symbols are used to indicate which measurement procedure was used: P_{st}^{LM} indicates that the IEC Light Flickermeter was used (i.e., the light was detected), and P_{st}^{V}, indicates that the IEC Flickermeter was used (i.e. the voltage was detected).
- P stands for "Perceptibility".
- st stands for "short-term".
- LM stands for "Light Measurements".
- The correct term for P_{st} is "short-term flicker indicator". However, it has many names in the literature, including *short-term flicker severity*, *short-term flicker value*, *intrinsic flicker*, *intrinsic flicker performance of lighting*, *intrinsic flicker performance of a light source*, *flicker severity value*, *flicker performance*, *flicker metric*, and *short-term flicker metric*
- The symbol M_{VS} of Stroboscopic effect Visibility Measure is often confused with the abbreviation of the same: SVM.

It is worthy of mention that the research area of TLM is a very active one. For example issues regarding the calculation of both M_{VS} and P_{st}^{LM} considering uncertainty and reproducibility, have recently been observed. These issues are currently being researched and will be considered in future updates. Also, it needs to be emphasised that SVM and P_{st}^{LM} are measures of visual effects, only. At the moment there are no measures for non-visual effects, such as headache, migraine and eyestrain or the effect on cognitive performance and reading speed. These neurological and cognitive effects are probably more severe than the visual effects because those that suffer from them are not necessarily aware that a light source could be contributing to their problems. More research is needed in this field.

Suggestions on improvements and amendments of both text and figures in IEC 61547 are presented in this document, together with an instruction on how to build a TLM measurement setup.

This document, together with IEC 61547 and the technical note CIE TN 012:2021 constitute a thorough instruction on the task of measuring TLM and of building a measurement setup. Updates of both IEC 61547 and CIE TN 012:2021 are expected within a few years.

The Flicker Explained project has also produced a document "Flicker Explained - Guide to IEC 61547 for the lighting Industry", which gives an introduction to TLM, what it is and how it is measured. This guide is available online* in English, Swedish and Danish.

* www.design.lth.se/lightinglab

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