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a technological overview

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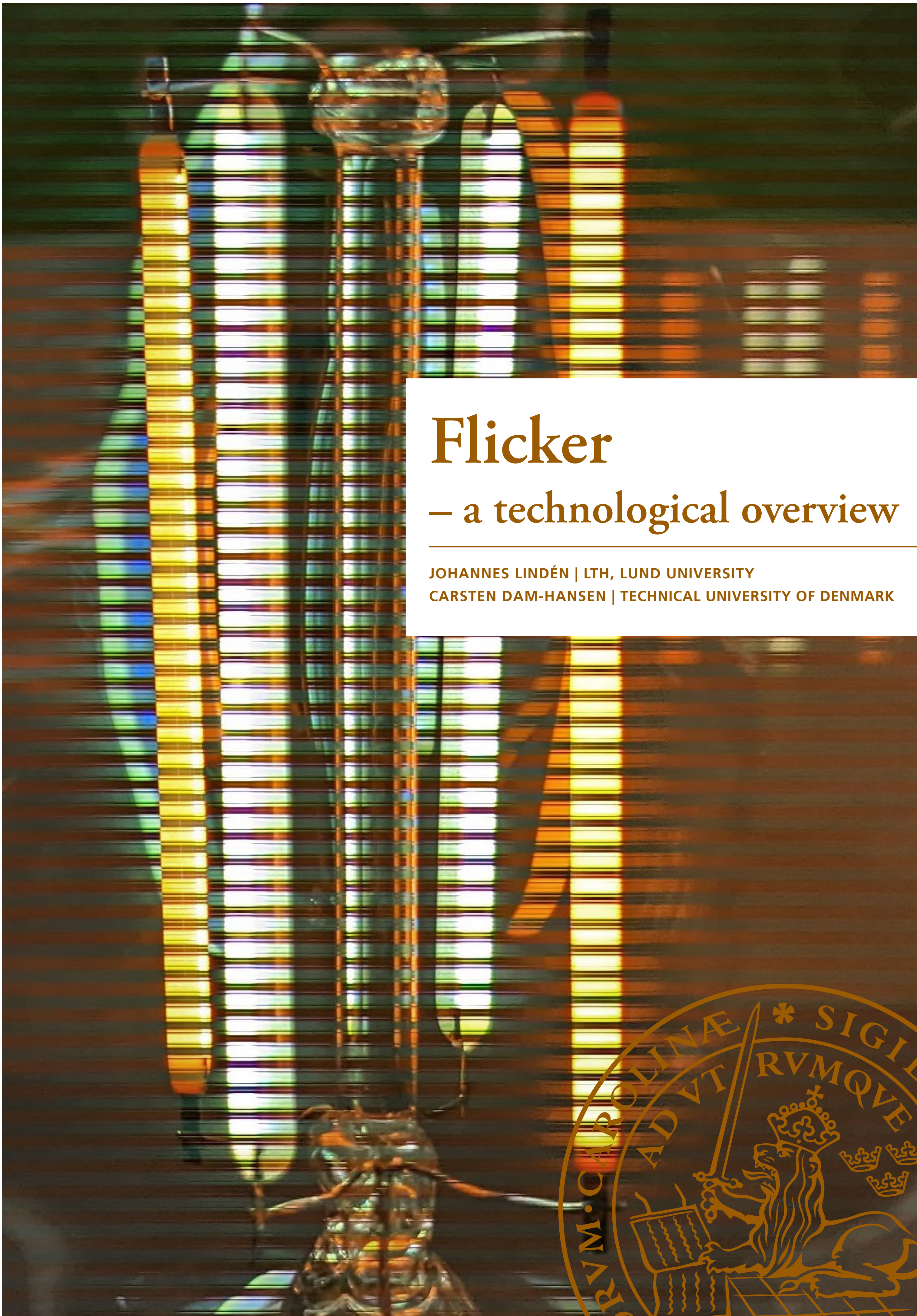

Flicker

– a technological overview

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Table of contents

Introduction

Flicker can be annoying, but above all it can have a negative effect on human health; causing irritation, headaches, eye strain and migraines. With the introduction of LED lamps, flicker has once again become a problem. In addition to the unnecessary suffering caused to individuals, the negative consequences create an obstacle to the wide and rapid adoption of new LED technology and thus 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 flicker, creating an urgent need to disseminate knowledge about flicker and how to measure it.

What is flicker?

In everyday language, the word flicker is most often used to describe something that a lamp, or the light from a lamp, *does*, namely that it flashes rapidly or fluctuates in intensity. Based on how the word flicker is defined scientifically, this usage is actually incorrect. Flicker is not something a lamp *does*. Flicker is something *you see*. What the *lamp* does, is it produces *temporal light modulation*, or TLM, i.e. light that varies/modulates over time.

TLM can give rise to several observable effects, of which flicker is one. Three effects are defined:

1. Flicker
If you see that the light intensity from a lamp varies – then you see *flicker*. However, this is only true as long as you don't move your eyes and the light source doesn't move either. As a consequence, flicker can only be seen as long as the modulation frequency is below about 90 Hz. Above 90 Hz, our eyes can no longer see variations in time.

2. Stroboscopic effects
But if there is motion involved, for example the light source moves or something moves in the light (such as a hand or a pencil) and a pattern emerges, then these are called *stroboscopic effects*, see figure 1.

Figure 1: Illustration of stroboscopic effects. Photo: J.Rydeman

3. Phantom array effects
And finally, there is a third effect, which appears during eye movements. If you see patterns during the brief moment you move your eyes, then you see *phantom arrays*, see Figure 2.

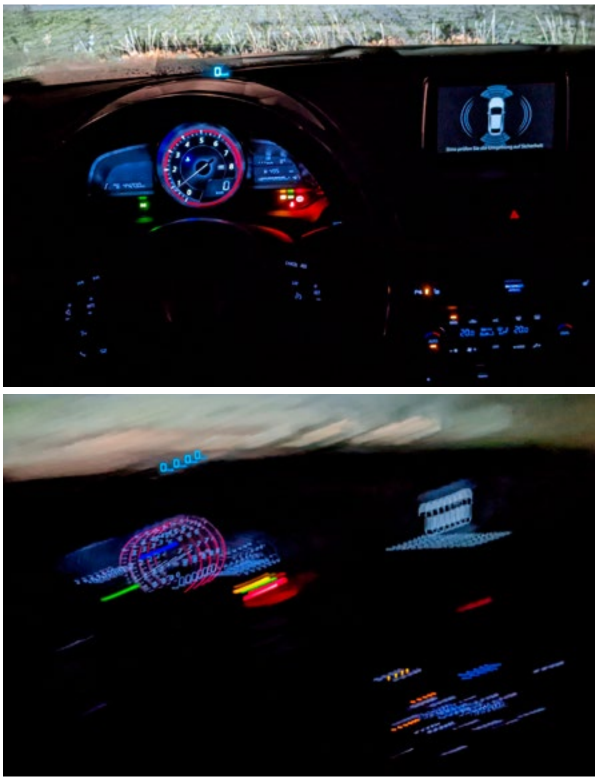

Figure 2: Illustration of phantom arrays. Photo: J.Ledig

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.

All these three effects – flicker, stroboscopic effects and phantom array effects – are examples of *Temporal Light Artefacts* or TLAs and are caused by TLM, see Figure 3.

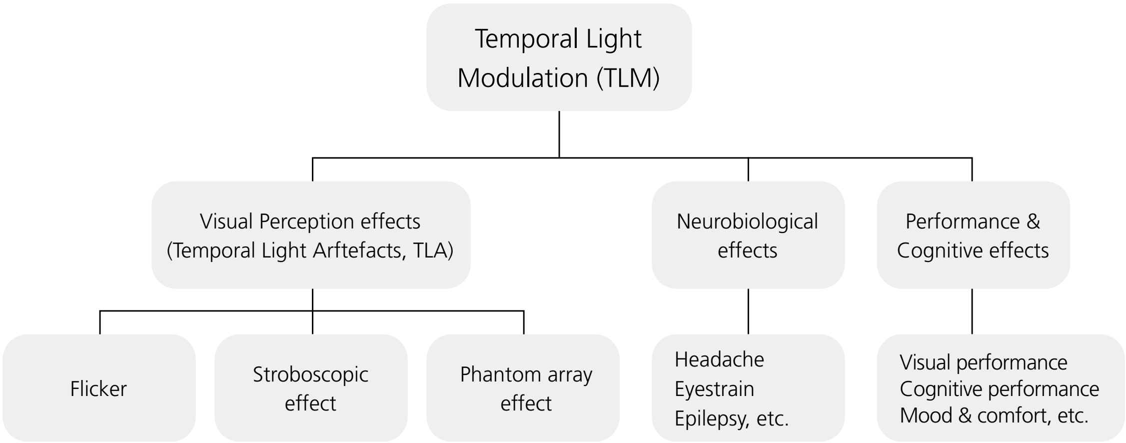

Figure 3: Overview of temporal light modulation (TLM) and its effects.

These three light artefacts are by definition visual effects. However, it has also been shown that TLM can cause non-visual effects, such as headaches, migraines and eyestrain. It can also affect cognitive performance and reading speed. In addition, children and highly sensitive people have been shown to be 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.

In addition to these effects on humans, TLM can also affect animals, such as chickens and it can also cause interference with imaging devices for photography and video. When using cameras on phones and computers, scrolling stripe patterns can appear on the screen, see Figure 4. These cameras can therefore be used to detect TLM.

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

Figure 4: Artefacts in video recording of light source with TLM

Why does TLM occur?

In the context of LED technology, it is important to point out that it is never the LED itself that causes the modulation. It is always the driving electronics that is the cause. Since we have 230 volts alternating current (AC) in the wall sockets (or 110 volts in north America), this has to be transformed to a lower voltage and into direct current (DC), and the modulation occurs due to poor electrical design. It may be a challenge to fit all the electronics into an E14 socket, but it is definitely possible. There are plenty of LED lamps on the market that do not modulate at all.

But for the manufacturer, it can sometimes be cheaper to exclude key components that would eliminate modulation and flicker.

In fact, even the old incandescent bulb also modulated to some degree. But the LED (which stands for Light Emitting Diode) is a diode, a rectifier. It only wants current in one direction, i.e. direct current. And a constant direct current gives totally modulation-free light.

How is TLM measured?

For some time now, it has been possible to characterise TLM using, for example, the measures Percent Flicker (also called Modulation Depth) and Flicker Index. These measures were developed when light sources modulated only at twice the mains voltage frequency, i.e. at 100 Hz (or 120 Hz in north America), and the light sources involved were mainly incandescent bulbs or fluorescent tubes. In other words, these measures do not account for frequency and are thus not suitable for light sources that modulate at other frequencies.

Since problems with flicker and light modulation can occur at all sorts of different frequencies when it comes to LED light sources, there has been some research on how to measure and quantify the effects of TLM in a more accurate way.

Currently there are two measurement standards: the short-term flicker indicator with the symbol P_{st}^{LM} for flicker (up to 90 Hz) and the Stroboscopic effect Visibility Measure (abbreviated SVM) with the symbol M_{VS} for stroboscopic effects (up to 2000 Hz).

Both measures are designed so that a measurement value of 1 means that the effects are visible 50% of the time, for a standard observer.

Unfortunately, there is no metric for Phantom array effects yet. Worse yet, there are no measures for the most adverse effects either – neurological and cognitive effects. These are the effects that should be the basis for determining the limits for modulation for general illumination. In this area, more research is needed.

Why is this important?

Fortunately, the EU has agreed on limits for flicker and stroboscopic effects in the updated eco-design directives, with the result that from September 2021 P_{st}^{LM} must not exceed a value of 1, and stroboscopic effect visibility measure (SVM) must not exceed 0,9 – narrowing to 0,4 in 2024. These limits apply to full load of the light source, that is, undimmed. Please note that these limits apply to lighting products sold on the EU market, but that different limits may be appropriate for different applications. For example, lower limit values could be considered for schools and hospitals, compared to warehouses.

The introduction of these new limit values creates an urgent need to disseminate knowledge about TLM and how to measure it.

The effects that occur in a mobile camera (see Figure 4) can be used to give an indication of whether a light source is flickering. It is important to keep the camera as close to the light source as possible. If no stripe patterns appear on the screen, it is fairly certain that the lamp is not flickering. However, this is not a reliable way to "measure" flicker. Stipe patterns can occur even if the lamp does not cause flicker. But there is another way to use the mobile camera when buying LED lamps. In connection with the updated eco-design directives, the European Union has introduced a new energy label and this label includes a QR code, see Figure 5. Scanning this code with the mobile camera leads to the EPREL (European Registry for Energy Labelling) database, where additional information about the product is available, such as the values for the "Flicker metric" and the "Stroboscopic effect metric" – P_{st}^{LM} and SVM respectively. It should be noted, however, that the information in the EPREL database is as of today's date not totally reliable. Many light sources state the value of 0, or the value of 1 for P_{st}^{LM} and 0,4 for SVM, i.e. exactly on the legislation limit. It's highly unlikely that these are actually the measurement results.

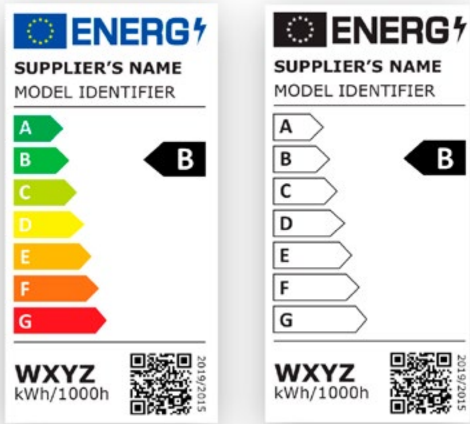

Figure 5: Example of the new EU energy label for lighting products

A major reason for the increased focus on flicker and TLM is the non-visual effects mentioned above, such as headaches, migraines, eyestrain, and effects on cognitive performance and reading speed, for example. The fact that TLM causes both visual and non-visual effects is well established. The big unanswered question is how important the non-visual effects are compared to the visual ones. Testing the visual effects is relatively easy, but the non-visual ones are more difficult. However, from the research that has been done, it appears that the importance of TLM for these effects is large for a subset of individuals in the population, who are more sensitive than others to visual stress. What are the effects of TLM on this subgroup? What are the effects of different TLM conditions on the physiological, behavioural and health domains? What role do other parameters besides flicker frequency play in the effects? These questions should form the basis for future research on TLM and human well-being. In the meantime, it would be wise to apply the precautionary principle.

Some clarifications

As mentioned above, the updated eco-design directives sets requirements for the first time for light sources sold on the EU market: SVM must not be higher than 0,9 (0,4 from 2024) and P_{st}^{LM} must not be higher than 1. Compliance with these requirements is the responsibility of producers and can be required by the public authorities. As always in these contexts, standards, clear definitions and consistent terminology are needed to ensure that everyone is clear about what is being discussed.

In the cases of SVM and P_{st}^{LM} there are the two documents IEC TR 63158 and IEC TR 61547, respectively, issued by the International Electrotechnical Commission (IEC). Especially in the case of the report dealing with flicker and P_{st}^{LM}, IEC TR 61547, there are some details that are worth clarifying.

To begin with, it may be worth repeating that flicker is defined as something perceptual, i.e. something subjective, and that this is therefore not consistent with how the word flicker is used in everyday life. However, having said that, it may be worth pointing out that the measure P_{st}^{LM} as described in IEC TR 61547 is intended to measure flicker *objectively*. How can you objectively measure something subjective? Without getting into a semantic or philosophical discussion, let's just note that this situation is not much different from how we treat the measurement of light in general. Light can also be defined as something subjective, something that makes an impression. Nevertheless, it is still possible to measure light objectively with, for example, a photometer. Just as the measurement of electromagnetic radiation can be examined with respect to the sensitivity of the human eye, light intensity fluctuations can be examined with a flicker meter that provides a result value.

The next detail that needs to be clarified is that the measure presented in IEC 61547 is called P_{st}, not P_{st}^{LM}.

To clarify this, we need to look at the background to IEC 61547 and the measure of flicker.

The light flicker meter described in IEC 61547 (henceforth referred to as **IEC Light Flickermeter**) was developed as a consequence of the introduction of the LED lamp, and was based on an earlier flicker meter (which we henceforth refer to as **IEC Flickermeter**). The IEC Flickermeter was invented at a time when the incandescent lamp was the most common light source, and the purpose of this meter was to ensure that the fluctuations in the mains voltage were of sufficient quality so that the incandescent lamps did not cause flicker. The IEC Flickermeter registers the mains voltage (not the light fluctuations), and from this *simulates* how visible the flicker from a 60 W incandescent lamp would have been if it had been connected to the registered mains voltage. The measure given by the IEC Flickermeter was the short-term flicker indicator, P_{st}. The IEC Flickermeter and P_{st} are thus based on the incandescent lamp. This was reasonable at the time, as the incandescent lamp was the most common light source, and therefore there was an almost direct connection between fluctuations in the mains voltage and fluctuations in the light. With this in mind, one could say that P_{st} is a measure of mains voltage quality expressed in the flicker of a 60 W incandescent lamp.

The fact that the IEC Flickermeter records the mains voltage but provides a measure of light flicker has led to differences of opinion about what P_{st} actually measures: voltage or light? In the electrical context, P_{st} is often seen as a measure of mains voltage fluctuations, while in the light context it is seen as a measure of light flicker. The answer is that P_{st} is a measure of light flicker, nothing else. But to get a value for light flicker, the voltage fluctuations must be registered.

With this follows an interesting observation: what you ”measure” or register (in this case the voltage), is not necessarily what you get a ”measure” of (the light flicker). But this is actually the case in many other situations when something is measured, such as temperature. Temperature can be measured in several ways, e.g. with a alcohol thermometer or with an electrical sensor (so-called thermocouple). In one case it registers volume change, and in the other voltage. The methods of measurement differ, but in both cases the final measure is temperature.

Then, when the LED lamp was introduced, there was no longer a direct link between voltage fluctuations and light fluctuations. Thus, a flicker meter was developed that registered the light fluctuations directly, regardless of the light source or mains voltage fluctuations - the IEC Light Flickermeter.

To clarify the type of meter used in the measurement procedure, another symbol for short-term flicker indicator was introduced in IEC 61547: P_{st}^{LM}, where LM stands for "Light Measurement".

Thus, the IEC flicker meter registers line voltage and the resulting measure is denoted P_{st}, while the IEC light flicker meter registers light intensity variations and the resulting measure is denoted P_{st}^{LM}. See illustration in Figure 6.

In an attempt to "avoid confusion", an additional symbol was introduced in IEC 61547: P_{st}^{V}, where V indicates that voltage is being registered, i.e. that the IEC flicker meter is being used. In other words P_{st}^{V} is exactly the same as P_{st}.

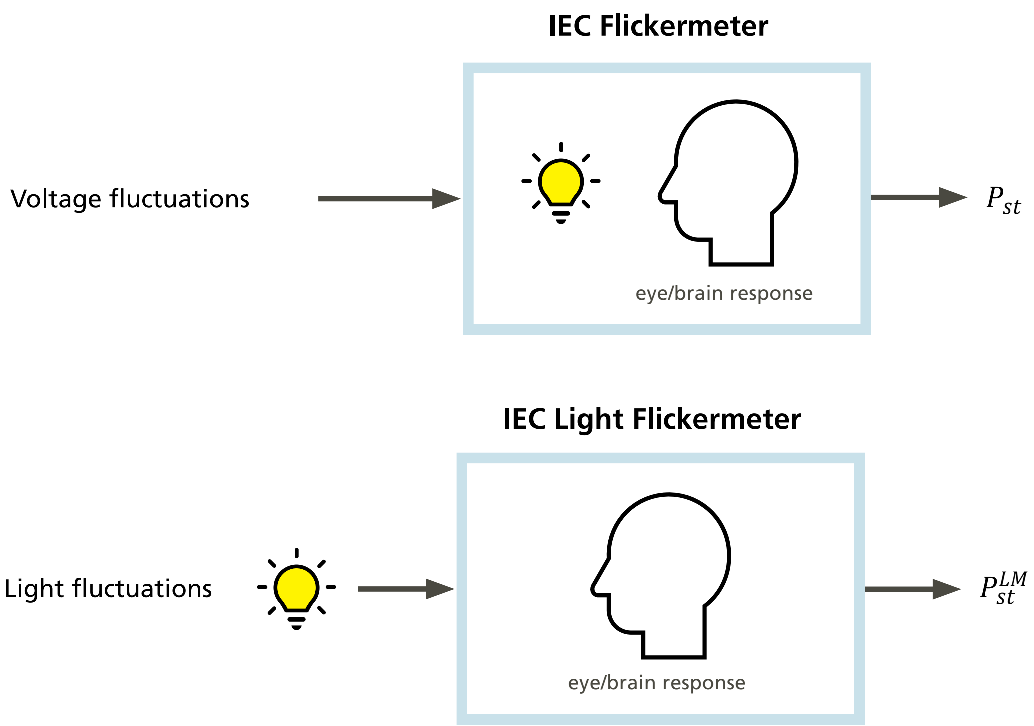

Figure 6: Two versions of flickermeters, with different input, but with the same resulting measure.

One explanation for the confusion may be that the report was written at the intersection of two disciplines – the electrical and lighting community.

The situation is not helped by the inconsistent terminology used in the reports on the subject. In IEC 61547 alone, P_{st}, short-term flicker indicator, has a variety of names: 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 report states that LM stands for Light Measurement, and that st stands for short-term. But it is a bit curious that it is not clear what P stands for. In the course of this work, however, it seems most plausible that P would stand for "Perceptibility", but several suggestions have also emerged: Planning levels, Pegel (level in German), Papillotement (flicker in French) or even Paracetamol (because the more flicker, the more headache).

The table below summarises, with some notes, the main information on TLM measures mentioned in this text.

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.

Final words

This text is the result of the project Flicker Explained, a collaboration between Lund University and the Technical University of Denmark (DTU), supported by the Swedish Energy Agency, through the EELYS project "Flicker Explained", project no. P2021-00030.

The project has also produced two other publications:

- Flicker explained: interpretation of the Technical Report IEC 61547, which is a detailed review of the Technical Report IEC 61547, including explanations and suggestions for changes.
- Flicker Explained - Guide to IEC 61547 for the lighting Industry, which is a concise version of the first and intended to serve as a guide for interested parties in the lighting industry. Available in English, Swedish and Danish.

All publications produced within the Flicker Explained project can be found via www.design.lth.se/lightinglab.

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