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## Simpler alternative to NEMA 77 to implement IEEE 1789-2015 closely

*Additional submitted attachment is included below.*

We are writing on behalf of Public Health England ("PHE"), to follow up our previous submission.

We are now concerned about the representations that have been made in support of NEMA 77, and so we wish to provide more detail about why this would be completely insufficient to protect against adverse health effects arising from exposure to modulating light.

We are now also in a position to give a much simpler practical proposal, one which makes the purported advantages of NEMA 77 redundant.

**Basis of our concerns**

The frequency of the alternating current that drives the vast majority of California's lighting is 60 Hz. Regardless of regulations, this frequency is typically excluded from the modulation in the light produced by LEDs and other lighting products, because it is both annoying and a public health hazard. However, the most common solutions produce flicker at twice this frequency, i.e. 120 Hz. The main effect on light modulation of the regulations being discussed will be to determine the acceptable levels of flicker at these two frequencies. Indeed, a recent survey of flicker in LED lighting solutions in the UK showed that all of these lamps had modulation with a base frequency of 100 Hz (where the frequency of the alternating current is 50 Hz), and only for a small minority was the percent modulation (for avoidance of doubt "percent modulation" and "x% modulation" in this response refer to Michelson contrast) lower than levels expected to be capable of producing adverse health effects (CIBSE/SLL/PHE, 2016).

We strongly recommend that the stringency of the regulations at 120 Hz be made a priority in decisions concerning the regime to be adopted, whilst not weakening current requirements at 60 Hz. In this way, this section of the regulations will have maximum influence on the quality of lighting products.

Naomi Miller (Docket Number: 17-BSTD-02, TN# 222567) makes the valid point that a standard based on visibility will not ensure against adverse effects on neurobiological responses. The research she cites was also cited in the IEEE 1789-2015 expert review light modulation of LEDs and health, and demonstrates clearly that adverse neurobiological responses occur when modulation is not normally visible to the human eye (except under certain conditions that support perception of the phantom array; e.g. small luminous targets on a dark background). In addition, neurobiological responses should be taken to include retinal responses (without which neurobiological responses would not be possible). There is an additional possibility that the health of the eye and retina are adversely affected by invisible flicker (Price, 2017).

However, we do not agree with her response that setting the SVM threshold to 1 would be sufficient. (Docket Number: 17-BSTD-02, TN# 222548) provides a reproduction of the IEEE figure for categorizing flicker by percent modulation and frequency (copied as Figure 1). This is a log-log chart, and points that appear as comparable in magnitude are in fact only comparable in order of magnitude:

- At 60 Hz, 0.6% modulation or greater may produce an effect, whereas NEMA 77 proposes a threshold of over 30%. These are clearly not comparable levels, and the NEMA 77 proposal is inadequate.

- At 120 Hz, 4% modulation or greater may produce an effect, whereas SVM thresholds or 1 and 1.6 relate to 28% and 45% modulation respectively (approximately). Again, there is no comparison, and both these SVM levels are clearly inadequate.

Some of the advocates of NEMA 77 are claiming it has an advantage in being able to implement IEEE 1789-2015 diagram more closely than previous standards, and allowing for the shape of the waveform. These would be important advantages if true, but as we have just set out the NEMA 77 option is not comparable to the IEEE 1789-2015 thresholds, and certainly not close to it at either 60 Hz or 120 Hz. Moreover, there is a simpler way to implement the IEEE 1789-2015 diagram closely; the PPF metric (Physiological Percent Flicker; Price, 2017) was developed from first principles to prevent light modulation producing any retinal response and closely reproduces the thresholds of IEEE. For all frequencies from 100 Hz and above, a PPF threshold of 1% will correspond closely with the IEEE 1789-2015 no observable effect threshold (3% will correspond closely with the IEEE 1789-2015 low risk threshold at these frequencies). See Figure 2 in the Annex containing our proposal.

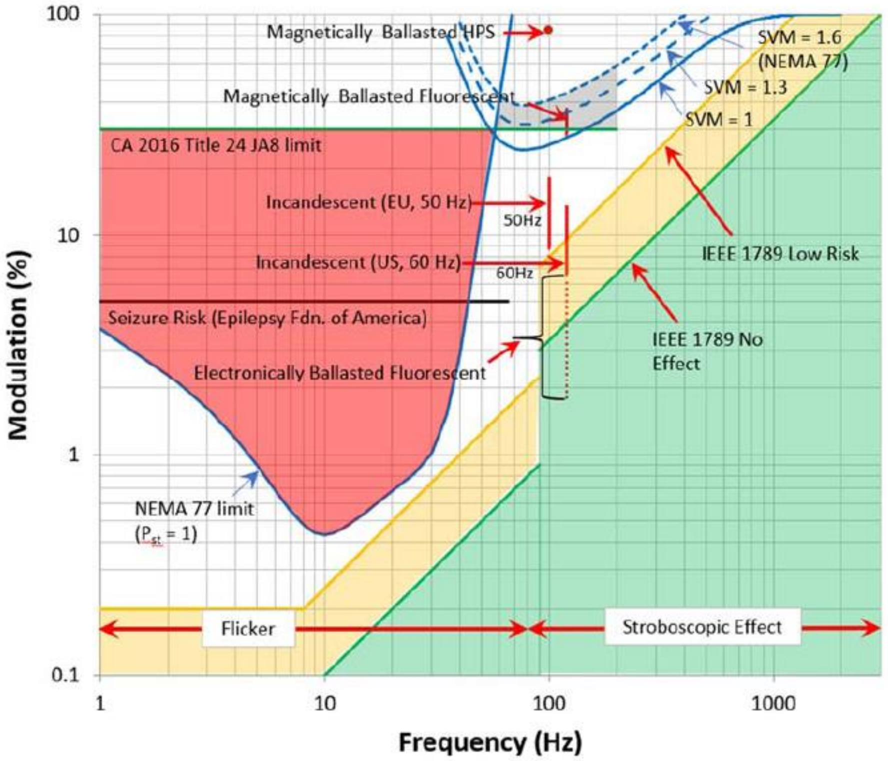


*Figure 1: Comparison of TLA measures and conventional light sources.*

Below these frequencies, we are not aware of any technical or any sufficient commercial need to permit modulation, and certainly no case for ignoring the effect limits at 60 Hz as effectively proposed by NEMA 77. In our experience consumers would be keen to return products with 60 Hz modulation in any case.

(Docket Number: 17-BSTD-02, TN# 222548) states that CIE are considering NEMA 77 metrics seriously for global standards. Luke Price, as CIE Secretary for Division 6 on Photobiology and Photochemistry, attended its most recent workshop on light modulation in Jeju, South Korea (together with John O'Hagan, CIE Director for Division 6 on Photobiology and Photochemistry), where he also presented the PPF metric. It is important to note that CIE are considering many viewpoints and metrics equally seriously, and are now including the PPF metric in those considerations as well as further viewpoints that would oppose the adoption of NEMA 77.

We have concentrated on 60 Hz and 120 Hz above. However, note that if LEDs flickered at other relevant frequencies as shown within the IEEE 1789-2015 diagram, these would equally be important.

The use of some control gear (for dimming or daylight management) may introduce flicker or modulation at other frequencies, as well.

Yours sincerely

Luke Price

Professor John O'Hagan

**NOTE: Annex attached below**

**Annex – Details of proposed flicker regime**

IEEE 1789-2015 (the Flicker Report) sets out the regime for the effects of periodic sinusoidal modulation, including modulation visible as flicker, schematically reproduced in Figure 2 panel 1 (please always refer to the original set out in the Flicker Report for exact numbers and descriptions, full reference details are given below).

In panels 2 and 3 of Figure 2, the blue lines have been added as part of the schema, and represent thresholds below which the Physiological Percent Flicker (PPF: Price, 2017) is lower than the percentage figures indicated. Please note these are not perfectly straight lines, and should not be extrapolated to lower frequencies.

Unlike the regime illustrated in the Flicker Report in panel 1 of Figure 2, the PPF calculation can be applied to non-sinusoidal waveforms, to predict the magnitude of response of the eye to general periodic flicker. The PPF metric achieves this by modelling the fastest photoreceptor responses in the eye as a simple exponential low pass filter, which mimics their delayed and smoothed response. Panels 2 and 3 show that their prediction in this frequency region are remarkably consistent with the consensus review of published data on the effects of flicker in Flicker Report.

- We recommend that adopting a PPF threshold of 1% will ensure all sources are categorised as having "No Observable Effect" according to the regime in the Flicker Report. This is our main proposal.

- However, we also note that Arnold Wilkins considers that the NOEL limit Temporal Light Artefacts may not be stringent enough to preclude perceivable effects or health effects. A cautious approach to preclude any likely events below this limit is to use a 0.2% PPF threshold test to all frequencies, which would also simplify the process above by eliminating the need for the test in step 4. (although the base frequency still needs to be determined, in order to identify one period of the data).

- A 3% PPF threshold would be sufficient to ensure that all sources are categorised as Low Risk, according to the regime in the Flicker Report. Whilst (Price, 2017) reports that this may eliminate the risk of health effects for a fixated observer in a static environment, it is important to recognize that the health effects associated with free observers in end-users environment where rapid eye movements known as saccades may be extremely important to predict the effects of periodic flicker and modulation on health. We believe that adopting a 3% PPF threshold would leave a significant risk of compliant products causing adverse health effects as well as other undesirable effects including Temporal Light Artefacts.

**Technical requirements**

Equipment capable of reproducing the waveform of periodic flicker will support calculation of the PPF metric. The main technical requirement is a sampling frequency at least ten times faster than the highest frequency producing an effect (e.g. 3 kHz, implying sampling rates of at least 30 kHz) and a sample containing several periods of the lowest frequency of interest. Although the PPF is only being recommended to implement the flicker report's own recommendations, it is useful to detect the presence of flicker down to the lowest frequency producing an effect (e.g. 3 Hz, implying a sampling duration of at least 1 second).

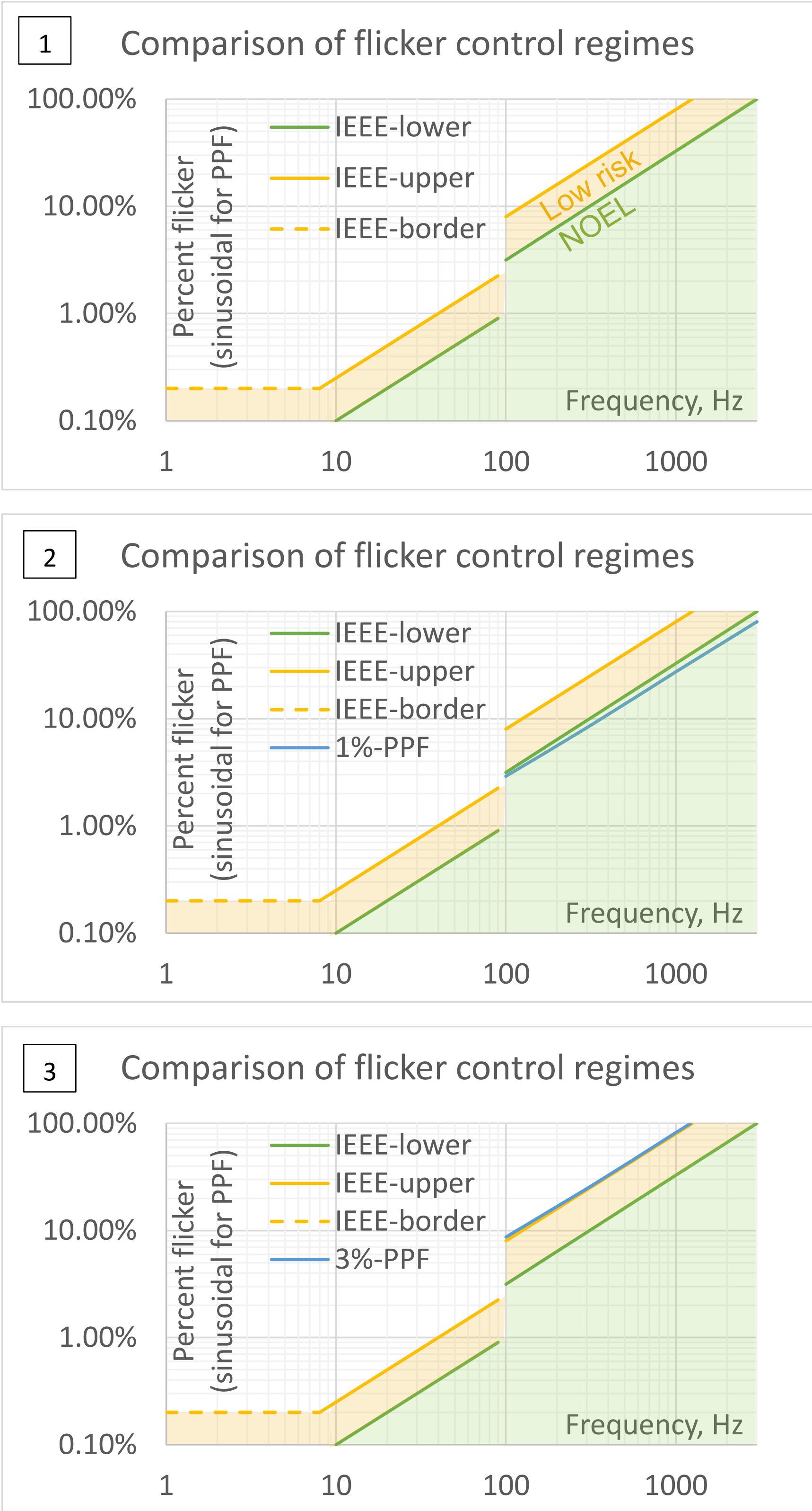


*Figure 2. Panel 1 shows the IEEE 1789-2015 regime showing the No Observation Effect Limit and area (NOEL, green line and shaded area, respectively) and the low risk limit and area (yellow line and area, respectively). In panels 2 and 3, the blue curved lines shows the 1% and 3% PPF threshold, below which PPF values are less than 1% or 3% respectively for any given frequency from 100 Hz to 3000 Hz. In this frequency region, the 1% threshold is only slightly more and 3% only slightly less conservative than the IEEE 1789-2015 regime NOEL and Low risk limits (green and yellow lines) respectively.*

**Process for implementing the PPF-based flicker test (all frequencies of periodic flicker):**

1. Take a measurement of the source, and a measurement of the background. (The following are not usually a problem in a suitable testing environment: any flicker or variation in the background; noise in the background is greater than 0.5% of the variation in the signal. In either case the measurements should be repeated in improved conditions).
2. Take the difference between the source and the average background, to give the signal due to the source being tested, u(t).
3. Apply exponentially smoothing with a half life of 3 ms to u(t), to give the smoothed signal, s(t).
4. Determine the base frequency of the resulting smoothed signal, using a Fourier decomposition algorithm. If this is less than 100 Hz, then the source does not comply (i.e. if any component below 100 Hz has a magnitude of greater than 0.2%), and if not then continue to the next step.
5. Calculate the percent modulation (Michelson contrast) of the smoothed signal, to give the value of the PPF metric. If this is greater than the PPF threshold being tested, then the source does not comply, and if not, then the source complies with both tests and it is not considered to flicker above the threshold being tested. To avoid the effect of boundary conditions, this calculation is carried out using a single period of the smoothed signal after at least 30 ms from the starting point, i.e. using one period of data from u(t>30ms).

**References**

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