BY MIKE WOOD

Flicker, stroboscopic effect, and SVM

WE'VE LOOKED AT FLICKER and rolling shutter effects before in this column, back in 2011 and 2016, but the problems haven't gone away, and I think it's worth revisiting to see what's new and what's changed.

What triggered this thought was the recently ratified new version of the EU Ecodesign regulations, which will come into force in September of this year. I've been working with a small team of interested parties over the last year or so on lobbying for changes to these regulations as the proposed drafts would have had dramatic, and unintended, effects on entertainment lighting. In the past, entertainment lighting was largely exempted from these regulations as our usage was so different from the normal white light only use of industry and domestic users. However, the EU saw this as a loophole which other users could exploit by designating lamps as "for entertainment use" to avoid regulation, and thus wanted to remove our blanket exemptions. (This had happened before when banned 100 W lamps had been labeled as heaters and thus escaped regulation in as ironic a way as possible!) The loophole closing caused unforeseen problems. For example, at one point the draft regulations would have allowed the use of some incandescent theatrical lamps, such as the HPL, but would have banned RGB additive color mixing LEDs, even though they are much more efficient! This has taken a while to sort out, but, thanks to a small group of users, manufacturers, and trade associations led by PEARLE (Performing Arts Employers Associations League Europe) in Belgium, we now have a sensible and workable set of accommodations and exemptions for entertainment lighting and additive color mixing. (If you are a lighting manufacturer who exports to Europe and you weren't involved in this process, then you need to thank that group and do some catching up!)

What's this got to do with flicker you might ask? Well, although the Ecodesign regulations are primarily concerned with efficacy, they cover a wide range of topics and parameters including definitions of what is acceptable for flicker and other similar issues.

These issues all come under the heading of temporal light modulation, or TLM. This covers not only flicker but also other related phenomena, such as the stroboscopic effect and the phantom array effect. These are all related in that they are effects that arise from discontinuous lighting, but each presents different problems to the human eye and brain. Flicker covers the lowest frequencies from 3 to about 80 Hz and describes the visual unsteadiness you get from a stationary light when you are also stationary. A light bulb flickering at 60 Hz is the perfect example. For flicker below about 50 Hz, you will see the individual flashes, but once above that you won't necessarily be consciously aware of the flicker, but our eyes and brain still see it. These are the frequencies that can aggravate epilepsy, produce headaches or migraines and, even if you don't suffer from those overt symptoms, are likely reducing your performance and mentally distracting you. Flicker is what we've talked about before and it's long been known about and has established metrics such as the Percent Flicker and Flicker Index (see my article in the Summer 2016 issue of *Protocol* for more information).

> **"If you were trying to design the worst possible system for creating flicker and stroboscopic effects, then PWM might be it!"**

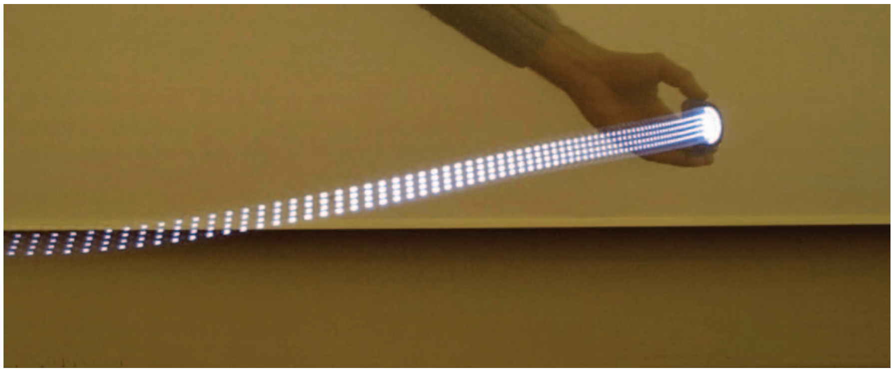
Once we get above 80 Hz things get a little trickier as we get into the dynamic as well as the static effects. The stroboscopic effect comes into play from about 80 Hz up to 2,000 Hz. It describes the phenomena from the viewpoint of a stationary observer viewing a non-stationary object. **Figure 1** shows the issue. As well as the obvious annoyance, there is a safety problem here if movement of rotating objects is misperceived because of poor lighting. These frequencies can also lead to headaches and the other health issues already mentioned.

The final TLM is the phantom array effect. This is closely related to the stroboscopic effect, but this time arises when the observer is moving and the environment is static. The phantom array is the line of lights you see from a brake light as you move your head from side to side while driving.

This has a similar range as the stroboscopic effect but stretches higher up

REFERENCE: GOSIA PERZ, EINDHOVEN UNIVERSITY OF TECHNOLOGY

Figure 1 – Stroboscopic effect



REFERENCE: M. NISA KAHN

Figure 2 – Phantom array effect

in frequency, perhaps to 2.5 or 3 kHz.

In the not so distant past, neither the stroboscopic effect nor the phantom array effect had good metrics. (Arguably neither does flicker, although the metrics of Flicker Index and Flicker Percent exist they are purely mechanical standards that take no account of human perception.) In reality, it's not just the frequency that affects how significant these effects are, but also the shape of the varying waveform, the depth of the modulation, and how the human eye/brain combination tries to make sense of this rapidly changing data. There are better metrics available now, and one in particular, Stroboscopic Visibility Measure (SVM), has gained a strong following. Originally developed in 2015 by Gosia Perz at the Eindhoven University of Technology and since continued and confirmed by others, SVM is now adopted and published by the CIE as *TN 006:2016*. SVM is based on threshold visibility and was developed using real subjects so more realistically reflects what a person sees and perceives. Its disadvantage is that it's not a simple metric. It requires measuring the light waveform and then performing a Fourier analysis on it to break it down into component sine waves and then summing the effects of each frequency. (Fourier analysis is a mathematical method for approximating any required waveform shape by the sum of simple sine waves.)

Why does all this matter to us in entertainment lighting? Well, we like to dim our lighting. When we dim LED lighting, we tend to do it by turning the LED on and off very quickly and varying the ratio of the on time to the off time to give the eye the impression of dimming. The technique is called pulse width modulation (PWM) and is used in just about every entertainment lighting luminaire. The frequencies we use for PWM are well above the 80 Hz limit for flicker but often fall right into the range for stroboscopic and phantom array effects. PWM frequencies from 300 Hz to 1 kHz are common in our industry. The new Ecodesign requirements for SVM are that it should be less than or equal to 0.9 from September 2021, dropping to 0.4 in September 2023. However, those figures of 0.4 and 0.9 for SVM are meaningless unless you can relate them to PWM frequencies.

> **"Entertainment lighting products with PWM rates of 1 kHz or lower are likely not to be acceptable . . ."**

Fortunately, we can, by assuming the worst case. In the worst case a pure PWM LED dimming signal is a square wave, and it modulates the signal all the way from 0% to 100%. (I call this the worst case, but real PWM isn't far away. If you were trying to design the worst possible system for creating flicker and stroboscopic effects, then PWM might be it!) With those assumptions, we can remember our high school math, use the standard Fourier expansion for a square wave, and plot out the results. **Figure 3** shows exactly that, a plot of SVM against PWM frequency. (It uses a custom Visual Basic function for Excel, which calculates SVM using the first seven terms of the Fourier expansion.)

Now we can see that an SVM of 0.9 (the requirement from September 2021) equates to a minimum PWM frequency of about 900 Hz and the 2023 standard of 0.4 will increase that to around 1500 Hz. *Caveat: These are worst-case approximations*

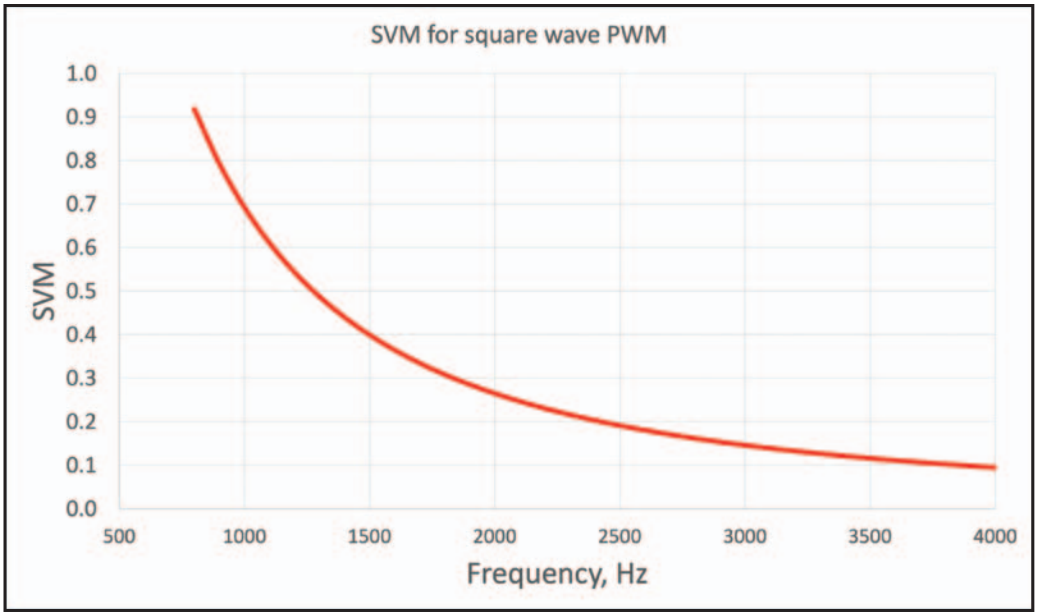


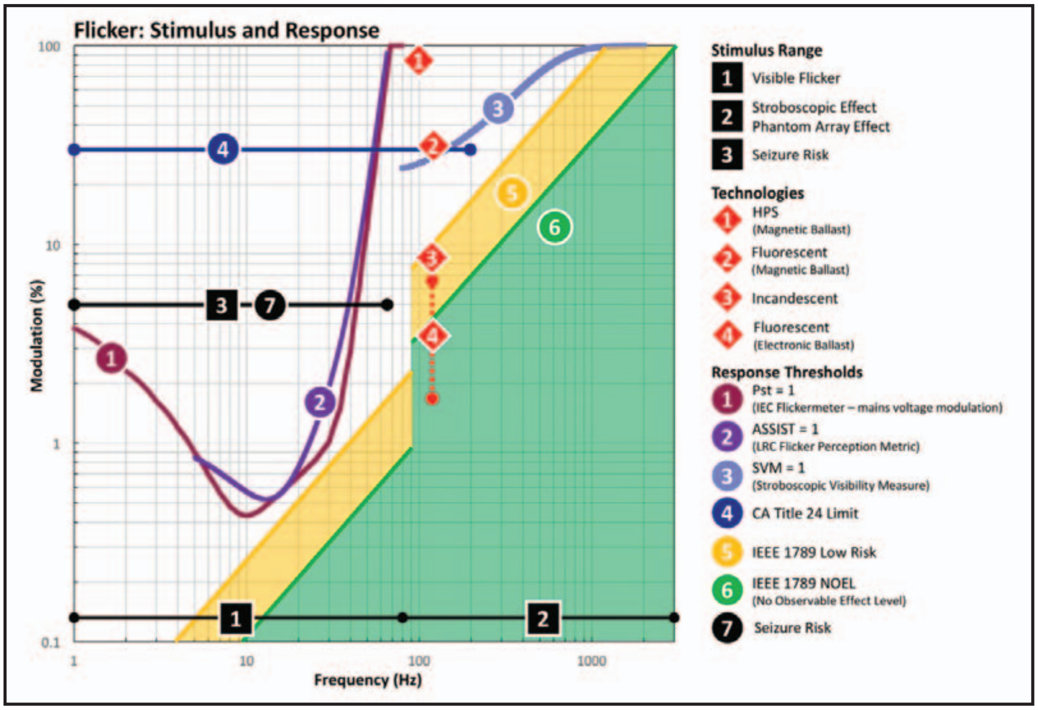
Figure 3 – SVM for square wave PWM

assuming a square wave and 100% modulation. A real product may differ, but I suspect not by much.

The EU Ecodesign regulations aren't the only requirements for PWM frequency, *IEEE 1789* lays down other metrics as does draft legislation elsewhere. **Figure 4** shows the current situation as seen by the US Department of Energy with all the various metrics and requirements overlaid on a single chart.

The y axis of this chart is percentage modulation. As discussed earlier, PWM is close to 100%, so for LED dimming effects we should ignore everything except the very top line of this chart. At 1200 – 1500 Hz we hit the 0.4 SVM and the *IEEE 1789* limit for "Low Risk." However, we don't get fully into the "No Observable Effect Level" until we reach 3 kHz. I've also had recent conversations with the DoE labs where they suggest that the phantom array and stroboscopic effects may still be a problem all the way up to 5 kHz.

None of these higher levels above those called for by the EU Ecodesign requirements are legislated for yet, but we as an industry should take notice of the way the wind is blowing. Entertainment lighting products with PWM rates of 1 kHz or lower are likely not to be acceptable, and we should be looking at 3 kHz or above in the not too distant future. Yes, I know there are many products around that are capable of these frequencies, but it's by no means the norm, and requires some engineering work to maintain smooth dimming. What the EU Ecodesign regulations should show us is that we are unlikely in the future to get many concessions for entertainment lighting. This is not the days when we used lamps that nobody else did, now we use the same LEDs as everybody else, and will have to follow the same rules. ■



REFERENCE: US DEPARTMENT OF ENERGY

Figure 4 – Temporal light modulation

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.