AccurIC
Precision driven

AccurIC Ltd second submission to 14-BSTD-1 (Title 24, building code)

Dear California Energy Commission,

Since its last submission to the Title 24 building code docket (14-BSTD-1) in November, 2014, AccurIC Ltd has made a similar submission to the Title 20 appliance efficiency docket (14-AAER-1) in relation to the commission's proposed Voluntary Quality LED Lamp Specification. Several of the comments made in our Title 20 submission – particularly relating to photometric flicker – are equally relevant to Title 24. Therefore, in the interests of encouraging consistency across related codes and standards, we respectfully submit these comments for consideration in the context of Title 24.

Dave Bannister, CEO, AccurIC Ltd
6th February, 2015

California Energy Commission 2014 Appliance Efficiency pre-ruling Comments of AccurIC Ltd, via docket number 14-AAER-1 in relation to the proposed Voluntary California Quality LED Lamp Specification

Submitted by: Dave Bannister, CEO, AccurIC Ltd

On: 5th January, 2015

Address: 1, Conference Grove, Crowle, Worcester, WR7 4SF, United Kingdom

Email: daveb@accuric.com

Tel: +44 (0) 1905 570834

Mob: +44 (0) 07866 696686

Background:

AccurIC Ltd is an innovator in the area of LED lighting driver/ballast technology and the holder of patents and patent applications worldwide in the area of deeply-dimmable, flicker-suppressing circuit topologies. AccurIC Ltd both applauds the efforts of the California Energy Commission in driving the development of performance standards and welcomes the opportunity to comment on the ideas emerging therefrom. In particular, we welcome the opportunity to comment on the ideas emerging from the proposed Voluntary California Quality LED Lamp Specification, currently being drafted as part of the Commission's Title 20 process.

The purpose of the proposed voluntary specification, as expressed in Chapter 13 *Staff Proposal* of the Commission's Appliance Efficiency pre-ruling, is to provide a framework of quality performance specifications for general purpose LED lighting, covering performance items such as dimmability, flicker and incandescent equivalence. In view of the experiences and lessons arising out of the public's reaction to Compact Fluorescent Lamp (CFL) technology it is now widely accepted that issues around dimming, photometric flicker and luminous efficacy need to be addressed head-on, ahead of the anticipated mass roll-out of the next generation of general lighting technology – namely LED. LED technologies have the potential to make a significant contribution to efforts across both developed and developing countries, to reduce both energy-consumption and the release of CO_2, thereby helping to tackle issues around global warming, energy-dependency and energy-related costs of economic growth. However, in order to have its fullest possible impact, LED lighting must be developed in such a way as to meet the quality-related expectations of a public that is familiar with the dimmability and flicker-suppression quality of incandescent Tungsten. Evidence of the restraint on market-penetration arising out of the performance gap between LED and incandescent lighting is alluded to in Chapter 12 of the draft staff report, where, under the heading *Lessons Learned from the CFL Market* it is correctly stated that '*The relatively stable line between incandescent/halogen and LED/CFL market penetration implies that the large amount of momentum in the LED market is from the replacement of CFLs, not incandescent lamps'*. This market segmentation has persisted, even as the price of CFL lamps has reduced. It is therefore clear that such segmentation is at least in part a function of quality.

Several of our comments with respect to the proposed performance standards cite the work carried out by IEEE Working Group PAR1789, which in turn is based on peer-reviewed research in the area of biological effects of LED lighting flicker. However, AccurIC Ltd wishes to make clear that the comments offered herein reflect the views and opinions of the Company itself and do not purport to represent any official position of the IEEE. That said, the data and peer-reviewed research on which these comments are based are also the data and peer-reviewed research on which the draft recommendations of the IEEE PAR1789 Working Group are based and the recommended performance figures quoted in the main body of this submission are taken directly from the draft recommendations of the Working Group.

The recommendations arising out of this submission are summarised on Page 6.

Comments on proposed performance standards:

The draft staff report proposes, in Chapter 13, to place specification limits on dimmability, flicker and incandescent equivalence for future LED-based general lighting in the state of California.

In terms of dimmability, it is proposed that an LED lamp/fixture claiming to be dimmable, must be capable of being dimmed down to a level of 10% or below. This is directly in line with the corresponding specification proposed by the Commission in its CASE document entitled *Residential Lighting* issued as part of its consultation on the proposed 2016 Building Standards Update (Title 24). This correspondence makes the valid case that what is good for new build is equally good for new technology installed in existing buildings. Our response to this proposed performance criterion is therefore identical to the response we gave in the context of the Title 24 consultation (ref 1):

We wish to point out that, due to the response of the eye, 10% dimmed (light output being 90% down on full brightness) corresponds to a perceived brightness level of 32% (light output is perceived as being down by only 68%). We therefore suggest that in order for the minimally-acceptable dimming performance to correspond to a perceived dimming level of 10%, the minimally-acceptable dimming depth for a high-efficacy light source should be 1%. In our submission, in an era which will see lighting controls and daylight harvesting methods increasingly used in residential and commercial buildings, such a minimally acceptable deep dimming capability will be seen as a "must have" rather than simply as a desirable feature.

In terms of incandescent equivalence, two further performance criteria are proposed in Chapter 13 of the draft staff report. Namely, maximum colour temperature (3000 K) and minimum lumen output – or more accurately, a series of minimum lumen outputs, dependent upon the input power of the incandescent bulb to which equivalence is being claimed. The proposed set of lumen output minima, when taken together with the proposed mandatory Tier 1 and Tier 2 standards in respect of CRI and Efficacy, form a good set of performance criteria aimed at encouraging the improvement in quality required from LED lighting. It is interesting to note, however, that the minimum Efficacies proposed in Chapter 13 are higher than that proposed by the Commission in Appendix JA-8 of the CASE report (Ref 5) relating to new-build residential lighting – namely, 45 lm/W. We therefore suggest that in order to establish consistency, the proposed minimum efficacy for high efficacy lighting in new-build should be increased in line with at least the corresponding proposed Tier 1 standard given in Chapter 13 of the 2014 Appliance Efficiency Pre-Rulemaking document – namely 55 lm/W.

We now turn to the issue of photometric flicker. Despite stating that lamps should, if claiming to be dimmable, pass a 'flicker test' as well as (and by implication, whilst) providing dimming down to 10% or below, the draft staff report does not currently propose either maximum levels of photometric flicker versus frequency, or a specific test method. Furthermore, by proposing that a flicker test be applied to dimmable lamps only, the report implies that all photometric flicker is related to dimming. Whilst it is important to establish both performance criteria and related test methods to ensure compatibility between LED lamps and dimmers, it has been established by peer-reviewed research that photometric flicker can and indeed does arise from mechanisms that are only party-related, or even unrelated to the action of a dimmer-switch. Furthermore, due to its mode of operation, whereby a DC current is used to produce photon emission via electron-hole pair combination across a semiconductor junction, the optical output of an LED is particularly sensitive to any mechanism that can cause fluctuations in the DC current flowing through it. Research publications cited in the references section of this submission (Refs, 2, 3 & 4) also show that a significant proportion of people are sensitive, either through stroboscopic detection or saccades, to photometric flicker at frequencies up to a few thousand Hertz.

By way of illustration, the following is a non-exhaustive list of the various mechanisms that can give rise to variations in DC current through and therefore flicker in the optical output of an LED lamp:

1. Dimming the lamp below a point where the input current taken from the dimmer switch falls below the holding current of the switch
2. The presence of a signal at the second harmonic of the mains frequency, arising from full wave mains rectification at the input of the driver
3. The presence of a Pulse-Width Modulation (PWM) signal used to actuate dimming in response to the state of a dimmer switch

In view of both the multiplicity of mechanisms by which flicker can be generated and the sensitivity of a significant proportion of the population to flicker frequencies up to a few kilo-Hertz, it is necessary to establish and define maximum levels of flicker versus frequency in a manner similar to that used in defining EMC/EMI limits in electrical and electronic appliances. Namely, by constructing a 'mask' which defines these maximum levels and by defining a practicable filter-based test method by which the light output of an LED lamp can be tested against the mask. Defining such a mask has been the central focus of the work carried out by the IEEE PAR1789 Working Group on LED flicker. Figure 1 shows the general construction of the mask that defines the proposed upper-limit of flicker percentage, versus flicker frequency, for LED lamps that limit, through their performance, the biological effects of flicker. Figure 2 shows the equivalent proposed maximum flicker level versus flicker frequency for LED lamps that produce no flicker effect.

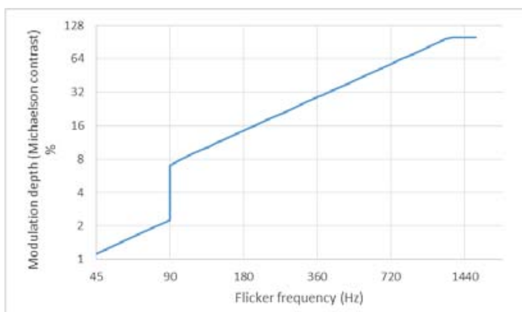

Figure 1: Proposed maximum LED flicker mask, for limiting biological effects (currently under consideration by IEEE Working Group PAR1789)

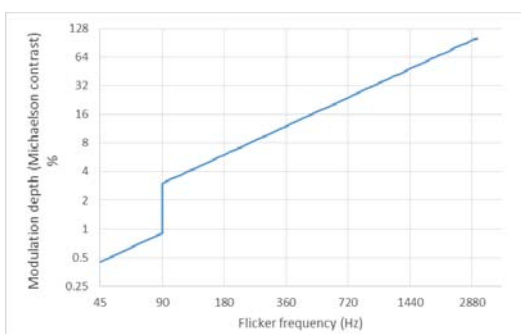

Figure 2: Proposed maximum LED flicker mask, for avoiding biological effects (currently under consideration by IEEE Working Group PAR1789)

We strongly suggest, in order for a flicker performance related standard for LED lighting in the state of California to be aligned with emerging recommendations, based on peer-reviewed research, that the maximum flicker mask shown in Figure 1 should be used as the basis for such a standard.

In proposing such a mask, however, it is also necessary to propose a test method that would be suitable in testing LED lamps for adherence to the proposed flicker standard. The basis of such a test method is already outlined in the Commission's CASE document entitled *Residential Lighting* issued as part of its consultation on the proposed 2016 Building Standards Update (Title 24) – Appendix JA10. Such a test method can be briefly outlined as follows:

1. Measure light output in the time domain, using equipment having a recording interval no greater than 50 microseconds and using a recording period of at least 2 seconds
2. The resulting data should be stored at a series of dimming levels (one data file for each dimming level)
3. Using the data in each data file:
    a. Conduct a Fourier Transform – thereby placing the data into the frequency domain
    b. Filter the resulting frequency domain data, into Low Pass filter bands, with cut-off frequencies increasing in Octaves
    c. Transform the filtered frequency domain data within each filter band back in to the time domain
    d. Calculate the modulation depth within each filter band

By choosing the cut-off frequencies of the low pass filters used in step 3(b) to be 90, 180, 360, 720 and 1440 Hz and defining appropriate maximum levels of modulation depth for each filter band, a stepwise approximation to the mask shown in figure 1 can be constructed. Figure 3 shows the low pass filter bands (shown as dotted lines) and the stepwise approximation to the mask (shown in red). The resulting flicker performance criteria, all of which need to be met in order to provide a sufficiently low flicker performance across all flicker frequencies, are summarised in Table 1.

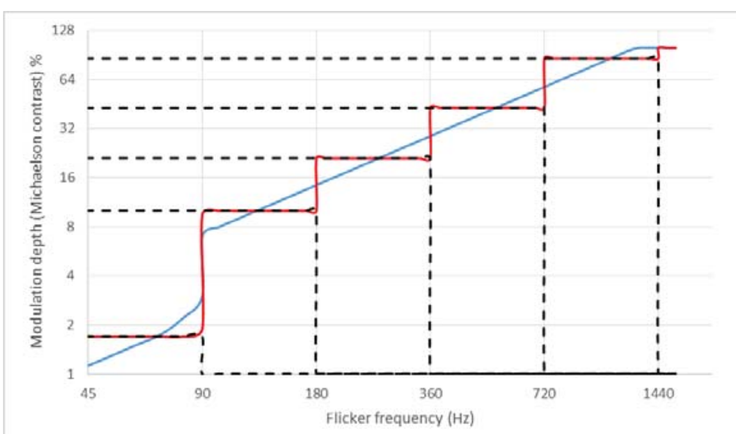

Figure 3: The construction of Low Pass Filter bands which, when used additively (see Table 1) provide a stepwise approximation (red line) to the draft IEEE PAR1789 maximum flicker mask

Low Pass Filter cut-off frequency, f_u, Hz	Maximum Modulation depth (Michaelson contrast) %
90	1.7
180	10
360	21
720	43
1440	86

Table 1: Maximum modulation depth for each low pass filter band – required, in order to ensure compliance with the stepwise flicker mask shown in figure 3.

Note: In order to ensure alignment with the proposed dimmability specification, the maximum flicker (modulation depth) criteria given in Table 1 should be met at the following dimming levels: 100% (undimmed) 50%, 20% and 10%

Summary:

The following summarises AccurIC Ltd's submission to Docket Number 14-AAER-1 in relation to the proposed voluntary California quality LED lamp specification.

1. The various references to 200 Hz, which currently imply that photometric flicker above this frequency is of little or no importance, should be removed
2. Maximum acceptable levels of flicker, expressed in terms of modulation depth, should be defined at frequencies up to at least 1,440 Hz, with this frequency chosen by reference to the following recommendation
3. Maximum acceptable levels of flicker should be defined for low pass frequency bands, with cut-off frequencies of 90 Hz, 180 Hz, 360 Hz, 720 Hz, 1,440 Hz, in accordance with the figures shown in Table 1 of this submission
4. The flicker limits should apply to dimming levels down to the minimally acceptable lower limit of dimming for an LED lamp, according to the quality specification – currently 10%
5. Consideration should be given to reducing the minimally acceptable lower limit of dimming, from 10% to 1%.

References:

(1) 2016 Building Standards Update. Comments submitted by AccurIC Ltd, via Docket number 14-BSTD-01. October, 2014. Dave Bannister. http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-11-03_workshop/comments/AccurLC_Comments_10-29-14_TN-73917.pdf

(2) J. D. Bullough, Sweater Hickcox , K., Klein, T. R., and N. Narendran, "Effects of flicker characteristics from solid-state lighting on detection, acceptability and comfort," Light. Res. Technol., vol. 32 43, pp. 337-348, Jul. 2011.

(3) B. Lehman, and A.J. Wilkins. (2014, September) Designing to mitigate the effects of flicker in LED lighting. IEEE Power Electronics Magazine.

(4) J. E. Roberts, and A. J. Wilkins, "Flicker can be perceived during saccades at frequencies in excess of 1 kHz," Lighting Research and Technology, 2012.
(5) Codes and Standards Enhancement initiative (CASE). Residential Lighting. Measure Number: 2016-RES-LTG1-F. California Utilities Statewide Codes and Standards Team. David Douglass-Jaimes, Michael McGaraghan, John McHugh. October, 2014. http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-06-24_workshop/final_case_reports/2016_T24_CASE_Report-Res_Lighting_Oct2014-V5.pdf

Dave Bannister, MSc, MIEEE

CEO, AccurIC Ltd