PHOTOMETRIC FLICKER IN COMPUTER DISPLAYS BACKLIGHT AND A METHOD FOR REDUCTION OF ITS HUMAN HEALTH EFFECTS

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Abstract: Data analysis is presented, as well as measurements, from some CCFL and LED backlit computer displays, operated using dimming controls. A method for reducing the harmful effects of flicker is proposed based on computer software and IEEE STD 1789 flicker recommendations. Guidelines are presented to help guide practitioners in their evaluation of backlight displays concerning flicker. The paper shows how Pulse width modulation (PWM) works and why it is used in LCD LED backlit displays, as well as how to test a display to see its effects more clearly. The paper also looks at some methods some manufacturers are now adopting to address these concerns and provide flicker-free backlights instead.

Keywords: Photometric flicker, flicker index, flicker percent, PWM dimming, LED backlight LCD displays, human health effects

1. Introduction

Understanding why flicker matters is becoming increasingly essential for proper lighting design. All light sources modulate luminous flux and intensity to some degree, usually as a consequence of drawing power from AC mains – this effect is called photometric flicker. The periodic waveform that usually characterizes flicker can be principally described by four parameters: its amplitude modulation (i.e., the difference between its maximum and minimum levels over a periodic cycle), its average value over a periodic cycle (also called the DC component), its shape or duty cycle (the ratio between the pulse duration and the period of a rectangular waveform), and its periodic frequency (the number of recurring cycles per second). Flicker found in some solid state lighting (SSL) backlight systems can be a significant barrier to their adoption. Flicker is known to induce photosensitive epilepsy, migraines and headaches, and increased autistic behaviors in certain people. Reduced task performance, stroboscopic or phantom array motion effects, distraction, and annoyance are other possible consequences. Modulation depth, frequency, and waveform shape are known to affect flicker sensitivity, yet flicker is rarely reported in product literature.

2. Flicker and flicker metrics

With the introduction of LED lighting products to the marketplace, flicker has reemerged as a concern, partly because the time-modulation of LED light output can be greater than the modulation possible with fluorescent or HID sources. For LED sources, the amount of flicker present is generally determined by the LED driver or by the dimmer and driver pairing. Flicker is often detected indirectly, when a flickering light or an object lighted with flickering light is moving relative to the observer's gaze (***stroboscopic effect***), or when the observer's gaze is moving relative to the light or object (***phantom-array effect***). Both effects can be hazardous. It is important to note that when the optical and neurological systems sense the modulation of light output over time, that flicker may have a physiological effect on the human observer, whether the light modulation or its indirect effects are perceived or not. Populations that are more likely to be affected by flicker include autistic individuals; people who suffer from headaches or migraines and are sensitive to patterns and stripes; individuals with photosensitive epilepsy; and people performing reading tasks, since the presence of flicker can result in larger eye saccades, reducing comprehension. At this time, there is no standardized test procedure for measuring photometric flicker from light sources, and manufacturers rarely report flicker characteristics. The two most commonly used metrics for quantifying flicker are ***Percent Flicker*** and ***Flicker Index.*** **Percent Flicker** (with a limited range, from 0 to 100%) is easier to calculate, but **Flicker Index** (also with a limited range, from 0 to 1) has the advantage of being able to account for variation in waveform shape or duty cycle, for rectangular waveforms. Both metrics account for amplitude variation and DC offset, but since both only require analysis of a single waveform period, neither is able to account for variation in periodic frequency. Thus, both metrics are best used for comparing periodic light sources with the same frequency. Flicker sensitivity is generally accepted to be dependent on waveform frequency; the higher the frequency, the lower the sensitivity to most potential effects of flicker.

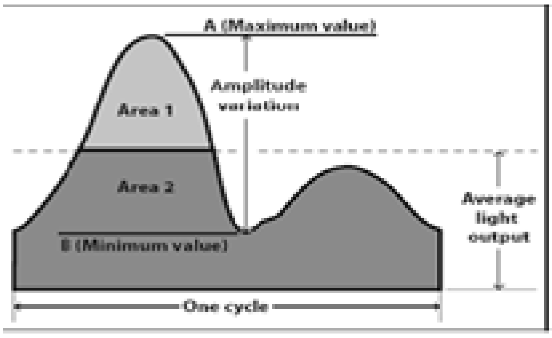

Fig.1 - Periodic waveform characteristics used in the calculation of flicker metrics [1]

Percent Flicker F%=(Max–Min)/(Max+Min) x100 (fig.1) shows the relative relation of light variation between minimum and maximum light output. The result of this formula is a percentage, which means the lower it is the better.

Modulation Index F_m=(Max–Min)/Average (fig.1) shows how much the light current signal modulates around the average signal. The larger the value for the modulation depth, the larger is the deviation from the average value. Small values indicate a small modulation which shows a good quality of the luminaries.

Flicker Index F_i=Area1/(Area1+Area2) (fig.1). At this method the total emitted light current of the light source will be used for the calculation and not only the minimum and maximum values.

Flicker index puts the light current which is over the average into relation with the total light current. But one has to consider that the flicker index system does not include the periodical light change into the calculation. This means, if two luminaries have the same flicker index value the luminaries with the higher light change basic frequency is the better one. For the human observer, flicker can be broken into categories, based on detection (sensation) and perception:

1.Sensation - The eye/brain/neurological system detects the modulation of light output over time in the external conditions, and neurons respond.

2.Visible flicker - The luminous modulation is sensed and consciously perceived.

3.Invisible flicker - The luminous modulation is sensed, but not consciously perceived (unless it is appreciated in terms of effects on spatial perception, such as the phantom array or the stroboscopic effect).

For most people, flicker that occurs with a frequency of less than 60 Hz is visible. The frequency at which a flickering light source fuses into an apparently constant source varies for individuals and depends on the modulation amplitude, adaptation luminance, and visual field size of the source. However, this ***Critical flicker fusion frequency (CFF)*** occurs generally in the range of 60Hz to 100Hz. Invisible flicker, occurring at a rate greater than the CFF, may nonetheless have physiological effects even though the individual normally cannot report the conscious perception of flicker. With the introduction of SSL, flicker has re-emerged as a consideration, partly because the modulation of LED light output has been frequently observed to be greater than the modulation seen with fluorescent or HID sources. The key observation is that flicker index accounts for differences in waveform shape, while percent flicker does not. Furthermore, simple periodic waveforms which transition faster from their low levels to their high levels have higher flicker index values, as in the progression from triangle to sinusoidal to square waveform. Simply put, among otherwise similar simple periodic waveforms, square waveforms will always have the highest flicker index. LED systems should always be visually evaluated, ideally with flicker-sensitive observers. Waving a finger or pencil rapidly under the LED source, or spinning a flicker wheel, can expose the presence of flicker through the stroboscopic effect, even for those who are not naturally sensitive (fig.2):

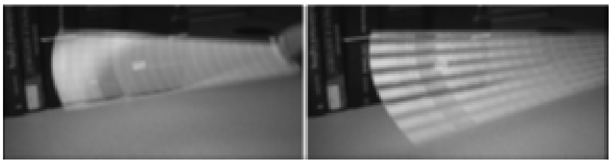

Fig.2 – (left) Smooth blur from flicker free light (right) Stroboscopic effect from flickering lamp

3. PWM in LCD backlit displays

It is well known that PWM is often used to dim LEDs by pulsing the current through them intentionally. The luminous intensity of the LED can be adjusted by varying the length of time that the LED current is high or low. Thus, PWM dimming circuits may be designed to operate at any frequency, whether the input is dc or ac. It should be mentioned that there are technologies that drive the LEDs with PWM signals even when not dimmed. That is, the simple PWM square wave current is sent through the LED at all times and at full intensity. The frequency being utilized is often programmed into the driving controller. Therefore, it is often only a matter of software design to alter the PWM dimming frequency. This concept is used in the following experimental research. Keeping the same maximum value and increasing duty ratio would have the effect of increasing the average current and causing the LED to become proportionally brighter. On the other hand, dimming with the analog method would directly adjust the continuous value of the LED current and maintain 0% flicker while changing the dimming level of the circuit. PWM has been known to operate at low frequencies of 180 - 240Hz for example which are likely to be more problematic than higher frequencies ranging up in to the Kilohertz range (e.g. 18,000Hz). The modulation of the cycling has an impact on the perceived brightness. In some examples the backlight is literally being turned on/off rapidly across the full brightness adjustment range. In those examples the luminance output is controlled really by the duty cycle only. In other examples the backlight is not always being completely turned off but rather the voltage applied to the backlight is being rapidly alternated, resulting in less extreme differences between the on and off states. Often this modulation will be narrow in the high brightness range of the display, but as you reduce further, the modulation becomes wider until it reaches a point where the backlight is being switched completely off. From there, the change in the duty cycle controls the further changes in the luminance output. [2]

The fraction of each cycle for which the backlight is in an "on" state is called the duty cycle. By altering this duty cycle the total light output of the backlight can be changed. As you reduce the brightness to reach a lower luminance, the duty cycle becomes progressively shorter, and the time for which the backlight is on becomes shorter, while the time for which it is off is longer. This technique works visually since cycling the backlight on and off sufficiently fast means the user cannot see this flickering, because it lies above their flicker-fusion threshold. The main reasons for the use of PWM is that it is simple to implement, requiring only that the backlight can be switched on and off rapidly and also gives a large range of possible luminance.

The luminance of LED backlights can be adjusted greatly by altering the current passing through them, though this has the effect of altering the color temperature slightly. This analogue approach to LED luminance is also undesirable since the accompanying circuits must take into account the heat generated by the LED's. LED's heat up when on, which reduces their resistance and further increases the current flowing through them. Using PWM the current can be forced to hold a constant value during the duty cycle, meaning the color temperature is always the same and current overloads are not a problem.

4. Side Effects of PWM

PWM can introduce distracting visual effects if not used carefully. In order to understand what is being seen we need to look at the flicker in real displays. Shown on figure 3, is a plot of a CCFL backlight showing the luminance of RGB components over a single cycle.

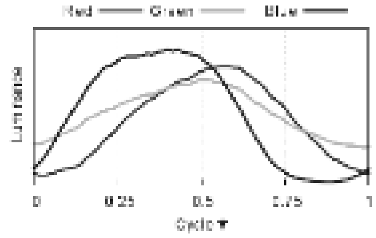

Fig.3 – PWM in CCFL backlight

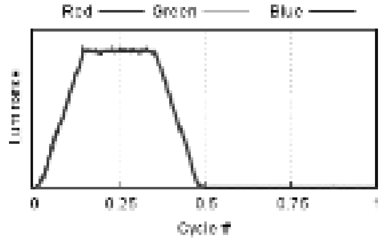

Fig.4 - PWM in W-LED backlight

Interestingly, the color of the CCFL backlight also varies significantly during the course of each cycle as well. This is due to phosphors in the CCFL that have different response times. The use of phosphors also means the backlight will continue to emit light for a few milliseconds after the backlight power is switched off at the end of a duty cycle. The averaged color over time remains neutral.

Flicker from LED backlights is typically much more visible than for CCFL backlights at the same duty cycle because the LED's are able to switch on and off much faster, and do not continue to "glow" after the power is cut off. This means that where the CCFL backlight showed rather smooth luminance variation, the LED version shows sharper transitions between on and off states. As seen on figure 4, there is no significant change in backlight color during cycling. Where the effect of flicker can really come into play is any time the user's eyes are moving [3]. Under constant illumination with no flickering (e.g. sunlight) the image is smoothly blurred and is how we normally perceive motion. However, when combined with a light source using PWM several discrete afterimages of the screen may be perceived simultaneously and reduce readability and the ability of the eyes to lock onto objects. In fact, while the eyes are moving (such as when reading) it is possible to see the effects of flicker at several hundred hertz. The ability to observe flicker is greater with peripheral vision, as it is more sensitive. It is also important to distinguish the difference between flicker in CRT displays and CCFL and LED backlit TFT displays. While a CRT may flicker as low as 60Hz, only a small strip is illuminated at any time as the electron gun scans from top to bottom. With CCFL and LED backlit TFT displays the entire screen surface illuminates at once, meaning much more light is emitted over a short time. This can be more distracting than in CRTs in some cases, especially if short duty cycles are used.

5. A method for reducing the effects of PWM and flicker free backlights

If possible, the best method would be to purchase a laptop or a display not relying on PWM for dimming, or at least one which uses a much higher cycling frequency. Few manufacturers seem to have implemented PWM at frequencies that would limit visible artifacts (well above 500Hz for CCFL and above 2000 Hz for LED). Several LED-based displays are currently available which do not use PWM. Some manufacturers promote "flicker free" monitors in their range (BenQ, Acer) who are designed to not use PWM at all and instead use a Direct Current (DC) method of backlight dimming.

Another method, which will be used in the current research, is to use software called IntelPWMControl. This utility is designed to work with on-board Intel graphic cards, seen on many contemporary laptops and desktops. The frequency being utilized is often programmed into the driving controller. Therefore, it is often only a matter of software design to alter the PWM dimming frequency. The utility addresses the backlight driver of the display and programs the frequency of the utilized PWM control signals, thus allowing the researcher to change it and measure the resulting luminance of the display.

6. Reducing the potential health effects caused by flicker according to IEEE 1789

When discussing the potential human impacts of flicker, it is important to understand the difference between sensation and perception. Sensation is the physiological detection of external conditions that can lead to a nervous system response, while perception is the process by which the brain interprets sensory information. Some sensory information is not perceived, and some perceptions do not accurately reflect the external conditions. As a result, some people who suffer from flicker sensitivity may not be aware that flicker is the reason they are suffering, or even that the light source responsible for their suffering is flickering. [4], [5]. For **Invisible flicker**, electroretinograms have indicated that modulation of light in the frequency range of 100Hz to 160Hz and even up to 200Hz is resolved by the human retina although the flicker is too rapid to be seen. 100Hz and 120Hz modulation of light has been shown to cause blockages in the lateral geniculate nucleus (LGN) of the thalamus, a body that controls eye movements. Several studies show that the characteristics of human eye movements across text and the visual performance in tasks involving visual search are affected by modulation from CCFL and LED backlit LCD displays. Sensitivity effects due to flicker at frequencies above perception have also been observed in normal people with good vision and health.

It is well established that flicker above the CFF can be detected in EEGs and electroretinograms. A number of studies have indicated that invisible flicker can interfere with eye movements. The effect of flickering lighting from video displays on the extent of saccadic eye movement during reading generally increases by approximately the width of one letter. In addition, individuals with high critical flicker fusion frequency (CFF) respond with a pronounced attenuation of EEG α waves and an increase in speed and decrease in accuracy of performance in low flicker lighting.

Fig.5 summarizes the recommended operating area of CCFL and LED backlights as a function of frequency and Modulation (%): Mod%=100× $(L_{max}–L_{min})/(L_{max}+L_{min})$, where Lmax and Lmin correspond to the maximum and minimum luminance, respectively. Operating in the shaded area minimizes visual discomfort or annoyance and also gives low risk for headaches and photosensitive epileptic seizures.

7. Photometric measurements and results

Flicker measurements of two different backlit LCD computer displays with CCFL and LED technology have been made using a test setup consisting primarily of light-impermeable box, an analogue photo sensor with matching trans-impedance amplifier TAOS TSL 12S and digital acquisition device National Instruments USB-6009, together with digital signal processing software NI LabView Signal express.

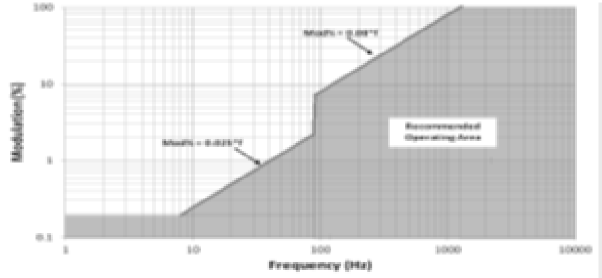

Fig.5 - Recommended operating area of CCFL and LED backlights

This allowed the capture of even very high frequency luminous flux modulation. The tested computer systems consisted of: business class older IBM ThinkPad T42 with CCFL backlit IPS LCD display and a newer consumer class Lenovo B590 with W-LED backlit TFT LCD display.

The test method, applied to both systems consisted of measurements of the luminous flux from the displays using three settings of the brightness control: 100%, 50% and 0%. Initially the displays were measured with their native PWM frequency. Next the B590 display was programmed, using IntelPWMControl utility, to use 1050Hz frequency for the PWM control of the brightness. T42 uses dedicated ATI video card and it was not possible to program it with the utility, which works only on Intel cards. The B590 display was measured again using the three brightness levels. Finally the percent modulation from all measurements was calculated. The summarized results are presented in table 1. Only some of the actual display measurements in graphical form from ThinkPad T42 and B590 are shown on fig.6, due to lack of space.

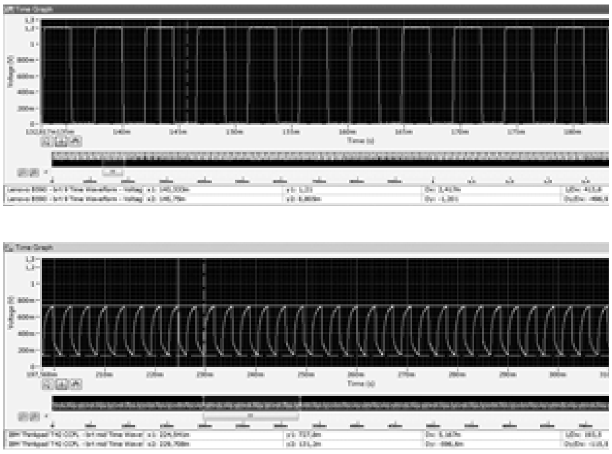

Fig.6 – Luminous flux measurements - B590 (top – brightness 50%; PWM 220Hz) and IBM ThinkPad T42 (bottom – brightness 50%; PWM 280Hz)

Table1 – Summarized measurements results

LCD	Native PWM Frequency	
	Brightness %	
	50%	0%
T42	280Hz;Mod=69	280Hz; Mod=90
B590	220Hz;Mod=100	220Hz; Mod 100
LCD	IntelPWMControl Frequency	
	Brightness %	
	50%	0%
T42	-	-
B590	1050Hz; Mod 100	1050Hz; Mod 100

8. Analysis and conclusion

At 100% brightness both displays show a constant luminance output. Looking at these displays in this mode, although not affected by flicker would be nevertheless uncomfortable, because they will be too bright and will need dimming. At 50% PWM controls the backlight. The modulation is always 100% for B590 system and varies from 50 to 90% for T42 system, but the luminance reduction is controlled by the duty cycle which becomes progressively shorter. There are much shorter "on" peaks in the 0% brightness graphs. The measured native frequencies were 220Hz and 280Hz respectively, which is fairly typical. The signal graphs from

B590 system allow us to examine the behavior of the luminance output. B590 has W-LED backlight dimmable to 0% by using PWM. The changes between on and off are very steep and sudden, as the LED backlight is able to turn on and off very rapidly. This can lead to potentially more noticeable flicker and associated issues as the changes are more pronounced. The signal graphs from T42 system are typical for CCFL backlit display using PWM all the way down to 0% brightness. The transitions from on to off are less sudden as the phosphors don't go dark as quickly as with LED backlight units. As a result, the use of PWM may be less problematic to users.

The analysis so far shows that both systems have objectionable flicker from human observer point of view for all brightness levels, except for full brightness, but it would also be uncomfortable. The evaluation criteria for possible human health effects are the border line from fig.5 and the equation: %Mod ≤ 0.08PWM frequency. For B590 system %Mod should be ≤ 17.6%; the actual is 100%. For T42 system %Mod should be ≤ 22.4%; the actual is 69%. It is obvious that both systems are designed wrongly and are not suitable for sensitive users and prolonged use.

The final step is to analyze the B590 system after reprogramming the PWM frequency to the maximum hardware possible frequency of 1050Hz. Here %Mod should be ≤ 84%; the actual is 100%. This is still not perfect but way better than before. This proves that using PWM frequency reprograming makes otherwise poorly designed displays suitable for sensitive users and allows for prolonged use.

For those who do suffer from side effects including headaches and eye strain there is a possible suggested solution in this research.

9. References

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