A Brief Dialog About the Complexities of Light Flickering and Power Supply Designs.

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July 10, 2023

The biological effects of light flickering have been extensively researched by qualified scientists, and while this is a complex subject with numerous variables, we at LTF Technology primarily focus on Optoelectronic designs, development, and manufacturing of exceptional products rather than biology. In this white paper, we will provide a brief overview of flicker definitions and reference relevant studies, leaving the detailed discussion of the biological effects to the experts. Our goal is to highlight the significance of flicker-free LED lighting products and reaffirm LTF Technology's commitment to developing products with a deep awareness of the biological effects of artificial light on humans. Creating healthier light sources has always been at the core of our company's DNA, as evidenced by our introduction of best-in-class LED power supplies, COBs, Light Engines, and LED bulbs. We will also explore the role of LED driver designs and performance in the light flicker.

Let us begin by answering the question: **What is visible light?**

In simple terms, visible light is a form of energy that we can perceive with our eyes. Visible light refers to the particle-like energy that appears in the electromagnetic radiation spectrum between the range of 380-700 nm (nanometers) and is detected by the human eye. Light is essential for our well-being as it affects our sleep patterns, vitamin D levels, mood, and more.

Visible light spectrum. Credit: Spectrum graphic by By Gringer

What is Flicker?

Flicker can be defined as the irregular rapid changes in the amplitude or intensity of light over a short duration of time (frequency), which may or may not be perceived by our eyes. Flickers occurring at frequencies below 100 Hz are referred to as visible flicker, while higher frequency flickers are called invisible flicker. Opinions differ regarding the frequency at which flicker becomes invisible. For the purposes of this paper, we will mention that flickers above 100-120 Hz are not easily visible but can still be sensed depending on the background and individual perception.

Based on available studies and my personal experience working in the lighting industry for the past 20 years, both visible and invisible flickers have been associated with some health effects. Research [(1)] indicates that the flicker of fluorescent light causes high rates of workplace headaches and eyestrain, and there is a correlation between these symptoms. With LED lighting being the dominant technology in various applications, studying the flicker effects of LEDs has become even more important.

Earlier studies conducted by Arnold Wilkins [(2)] of the University of Essex found that working under fluorescent lighting could be a health hazard. The study revealed that office workers were half as likely, on average, to experience headaches under non-flickering lights. Since LED flickering is even more intense, with the light dimming by 100% instead of the approximately 35% of fluorescent lamps, there is a possibility that LEDs could be even more likely to cause headaches.

Some Common Symptoms of Lighting Flicker Include:

1. Disrupted Circadian Rhythms:
    - Flickering LED light, especially at certain frequencies, can disrupt circadian rhythms and sleep patterns.
2. Fatigue and Eye Strain:
    - Prolonged exposure to flickering LED light can contribute to fatigue and eye strain, negatively impacting productivity, and well-being.
    - Rapid changes in light intensity can overwork the visual system, leading to eye discomfort, dryness, and a decrease in visual performance.
3. Potential Health Concerns:
    - Individuals with photosensitive conditions such as epilepsy or migraines may experience adverse physiological reactions to flickering LED light.
    - Flicker can trigger seizures, migraines, or other symptoms in these cases, highlighting the importance of minimizing flicker for vulnerable populations.

The Role of LED Power Supplies in Flicker

The flicker performance of LED lighting is directly influenced by the design quality and performance of its power supply (LED driver), as well as dimmer control devices involved and the compatibility of these two essential components. The industry has witnessed numerous excellent LED driver designs and topologies. However, when it comes to designing and manufacturing LED drivers that are extremely reliable, high-performing, high power density, fully dimmable, compatible with a wide range of dimmers, flicker-free, compliant with industry standards, customizable, readily available, and cost-effective, we transcend basic design topologies. At LTF Technology, this task has become an art of design and engineering, resulting in fine-tuned, robust instruments that ensure a smooth flow of electrons and photons, which we refer to as LTF's LED drivers, Light engines, and Sunlight® bulbs.

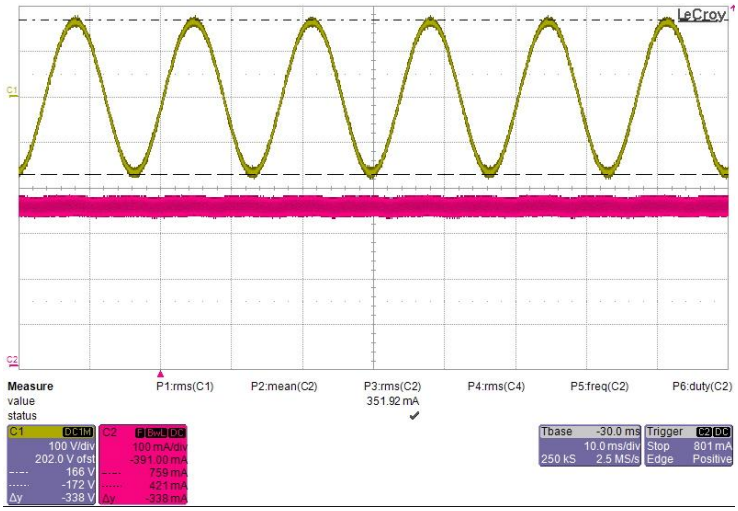
Designing an isolated LED driver equipped with a high-power-factor quasi-resonant flyback converter and applying constant-current sensing regulation methods will generate a sinusoidal current waveform at the input source and provide a stable DC output current on the primary side. By eliminating the need for an optocoupler or other means to cross the isolation barrier for feedback purposes, we not only reduce the driver's size but also enhance its safety and reliability. The process of fine-tuning the circuit addresses factors inherent in the control method that affect the shape of the electrical current.

LED loads require specific currents at the right voltage, which depends on the LED array configuration and power rating. LED arrays can be configured as constant voltage loads or constant current loads. Therefore, LTF has developed the DA series for 120VAC input, the DS series for 120VAC to 277VAC input LED drivers with power ratings ranging from 2W to 300W, accommodating different LED load conditions with constant current output and constant voltage models. We also offer the compact DL series for low voltage input drivers with 12VAC/DC and 24VAC/DC input, catering to COBs or low-power LED array loads, all with constant current output.

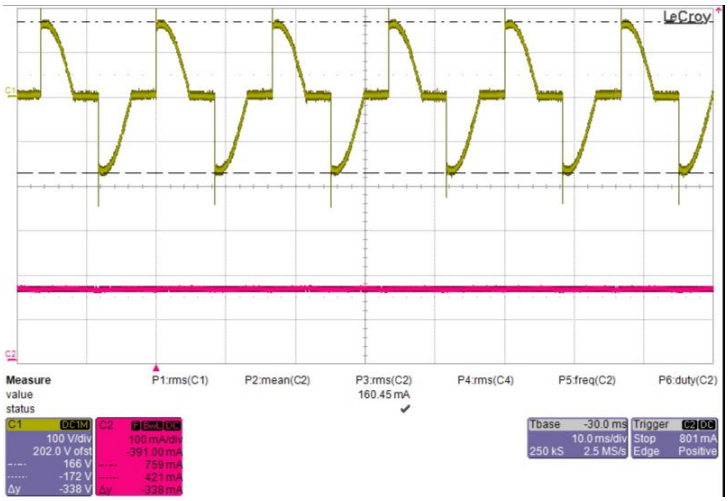
Advantages of LTF Products in Engineering Terms:

a. Wide range of options for constant current output drivers with ripple remover for low flickering. b. Multi-stage converters for DL series drivers to lower or remove output current ripples. c. Flexible dimming methods, including leading-edge, trailing-edge, 0-10V dimming, and wireless dimming. d. High efficiency, high power factor, low input current THD (total harmonic distortion). e. Low EMI (electromagnetic interference).

Scope graph images #1 illustrating the low flicker percentage <1% flicker of the LTF DA series LED driver both with and without a dimmer connected.

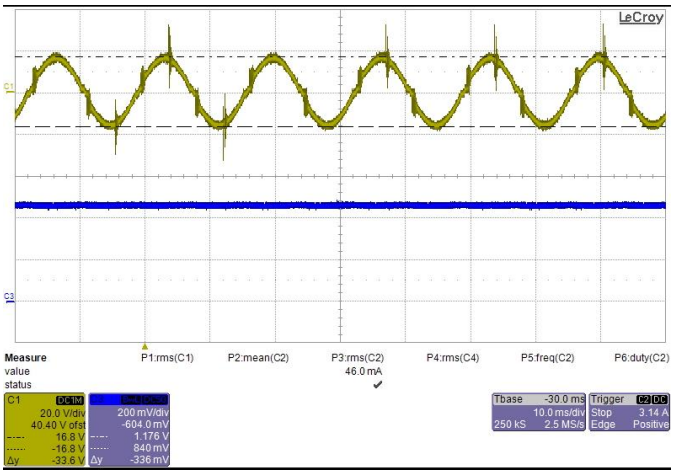


#1 Demonstration of input voltage and output current

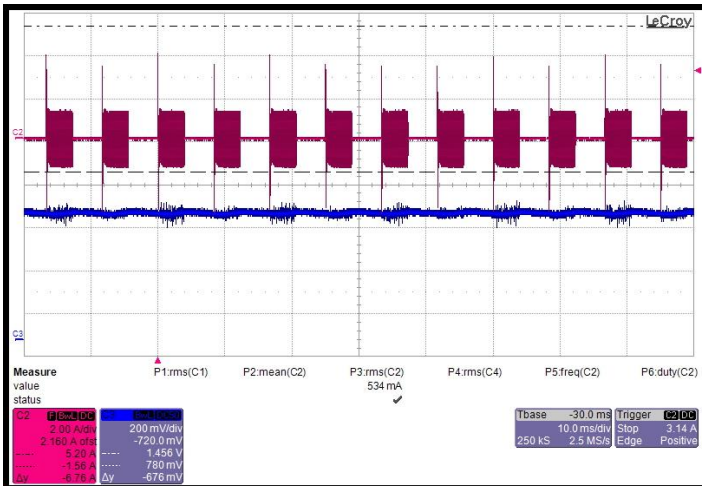


#2 Demonstration of input voltage and output current with a forward phase Triac dimmer.

For MR16 Sunlight2®, we demonstrate image #3 & 4 the input flicker at 100% and the nearly flicker-free output of the LED driver with less than 1% flicker in Sunlight2® MR16 bulbs, showcasing the significant reduction in flicker with or without a dimmer.



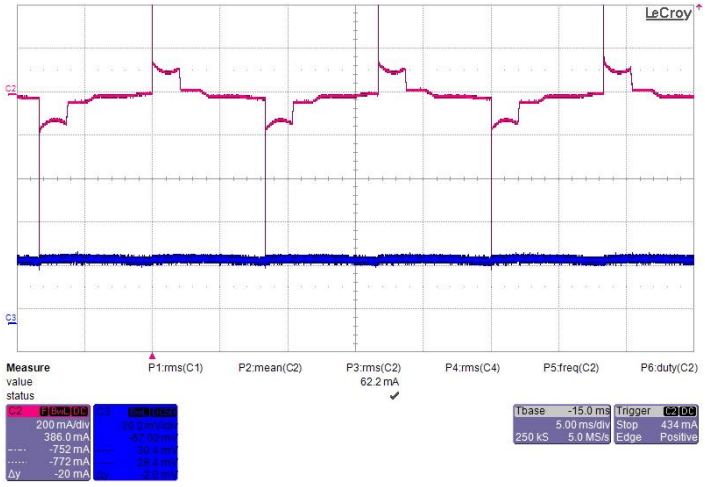
#3 Demonstration of high frequency 100% flicker input Voltage and flicker free output of LED driver in Sunlight2® MR16 bulbs.



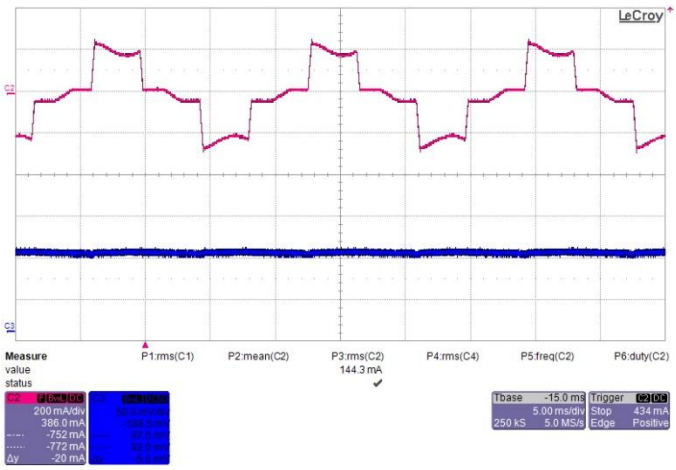
#4 Demonstration of high frequency 100% flicker input voltage at 50% dim position and flicker free output of LED driver in Sunlight2® MR16 bulbs.

LTF Quantum Lux ™ light engines can directly be driven by input line voltage and dimmed by Triac or ELV dimmer, easily integrated into lighting system without external LED driver. They have higher PF, low THD and EMI, and providing the lowest flicker rate compared to other products in the market.

LTF Quantum Lux ™ AC DOB light engines, such as QLUXDOBAL30516W28LED930K has lower flickering percentage,



New Quantum Lux™ AC DOB Input Current and Light Output Sensor Voltage Waveform at dimmed Level showing less than 2% flicker



New Quantum Lux™ AC DOB Input Current and Light Output Sensor Voltage Waveforms without Dimmer showing less than 2% flicker

Overview of Dimming Range and low flicker options: Achieving a wide dimming range without introducing flicker poses a challenge. As the duty cycle approaches 0% or 100%, the flicker amplitude tends to increase. In most cases there are several approaches that a design engineer can take advantage of depending on product application and other requirements.

1. High Frequency PWM:
    - Increasing the PWM frequency helps reduce flicker perception by shifting it outside the range of human visual sensitivity.
    - A higher frequency, typically above 1 kHz, minimizes the perception of flicker and improves visual comfort.
2. Hybrid Dimming:
    - Combining PWM dimming with other methods, such as analog or digital control, can mitigate flicker issues.
    - Transitioning to another dimming method at lower light levels effectively reduces or eliminates flicker.

3. Flicker-Free Algorithm:
    - Implementing intelligent algorithms in LED drivers can dynamically adjust the PWM duty cycle to minimize flicker.
    - These algorithms monitor the human eye response and optimize the dimming profile for flicker-free operation.
4. Adaptive Control:
    - Adaptive control techniques adjust the PWM parameters based on real-time feedback.
    - By continuously monitoring the flicker level and user preferences, the system can dynamically optimize the dimming parameters for flicker reduction.
5. Synchronization:
    - Synchronizing the PWM dimming frequency with the AC line frequency helps reduce perceptible flicker.
    - This synchronization minimizes interference between the LED driver and the power grid, resulting in smoother dimming operation.
6. Calibration and Testing:
    - Rigorous calibration and testing processes are crucial to ensure flicker-free operation.
    - Measurement and analysis of flicker metrics, such as flicker index and modulation depth, help validate the performance of flicker reduction techniques.

By addressing these challenges and implementing appropriate solutions, LED driver designers can achieve flicker-free dimming, enhancing visual comfort and ensuring a superior lighting experience. Continued research and development in this field will lead to further advancements in flicker reduction techniques, resulting in even better performance and user satisfaction.

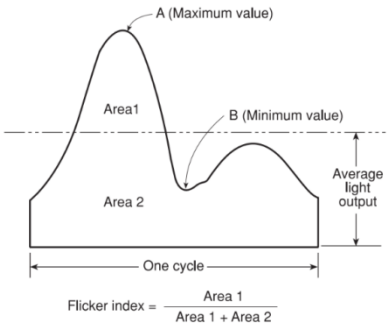
Flicker Measurement:

Modulation Depth (MD) is a metric used to quantify the degree of variation in light output during pulse width modulation (PWM) dimming of LEDs. It measures the difference in brightness between the on and off states of the LED. Modulation Depth is typically expressed as a percentage and is calculated by dividing the difference between the maximum and minimum light intensities by the maximum intensity.

$MD = (I_{max} – I_{min}) / I_{max}$

Where:

- I_{max} is the maximum light intensity during the on state of the PWM signal.
- I_{min} is the minimum light intensity during the off state of the PWM signal.



Modulation Depth directly affects the perceptibility of flicker. Higher values of Modulation Depth indicate a larger difference in light intensity between on and off states, resulting in more noticeable flicker. Conversely, lower values of Modulation Depth indicate a smaller difference and reduced flicker.

In flicker-free LED dimming, it is desirable to minimize the Modulation Depth to ensure a smooth and continuous dimming experience without perceptible flicker. This can be achieved by optimizing the PWM duty cycle, frequency, and control algorithms to create a gradual transition between brightness levels.

Accurate measurement and control of Modulation Depth are crucial for evaluating the quality of dimming performance in LED lighting systems. It helps assess the effectiveness of flicker reduction techniques and ensures that the LED driver operates within acceptable visual comfort limits.

By considering Modulation Depth as part of the design and testing process, LED manufacturers and lighting designers can deliver flicker-free dimming solutions that provide a high-quality and visually comfortable lighting experience for users.

In conclusion, flicker-free LED lighting products play a crucial role in promoting healthier lighting environments. LTF Technology, with its extensive expertise in LED driver design and engineering, offers a range of reliable, high-performance products that address the challenges of light flickering. By continuously innovating and refining our designs, we strive to deliver flicker-free LED drivers, Light Engines, and Sunlight® bulbs that enhance visual comfort, ensure user satisfaction, and contribute to overall well-being.

Link to LTF products:

- Line Voltage LED Drivers
- Low Voltage LED drivers
- AC LED boards
- LED COBs
- Architectural LED bulbs

About LTF:

LTF® Technology: Powering Creativity and Innovation in LED Lighting.

LTF® Technology is fueled by an unwavering passion for new product development, driven by creativity and innovation. Since 2007, we have emerged as a prominent engineering company and manufacturer of OEM LED lighting components, serving the Architectural, Commercial, and Residential lighting industries across the globe. Our dedicated team at LTF is committed to pushing the boundaries of advanced engineering, pioneering design, and cutting-edge technologies to create the highest quality, most reliable, and versatile lighting components available in the market. With our commitment to excellence, LTF Technology has established itself as a leader in the industry. We understand the evolving needs of our customers and strive to stay at the forefront of LED lighting innovation. By combining our extensive expertise with a relentless pursuit of excellence, we have developed a comprehensive range of products that meet the diverse requirements of our clients.

At LTF, we believe that engineering is an art form. Our team of skilled professionals approaches each project with a creative mindset, embracing challenges and seeking unique solutions. We thrive on transforming ideas into reality and pride ourselves on delivering products that exceed expectations.

Innovation is the driving force behind our success. We constantly explore emerging technologies and industry trends to ensure our lighting components are at the forefront of innovation. By staying ahead of the curve, we empower our customers with cutting-edge solutions that enhance their lighting designs and elevate their projects.

Reliability is at the core of everything we do. We understand that our lighting components are critical to the success of our clients' projects, and we take that responsibility seriously. Through rigorous testing, meticulous quality control measures, and robust manufacturing processes, we ensure that our products consistently meet the highest standards of performance and reliability.

With a global presence and commitment to OEM customer satisfaction, LTF Technology is dedicated to delivering lighting components that go beyond illumination. We aim to inspire, transform, and enhance the spaces where our products are installed.

Join us on this journey of creativity, innovation, and excellence as we continue to illuminate the world with cutting-edge LED lighting solutions. Experience the LTF difference and discover why we are trusted by industry professionals worldwide.

References:

1. Dr. G.W. Brundrett (1974), Human sensitivity to flicker.
2. Dr. Arnold Wilkins, 2017, The scientific reason you don't like LED bulbs.
3. https://www.ies.org/definitions/flicker-index/
4. https://www.ies.org/lda-magazine/lda-hot-topics/flicker-frustration-measuring-what-you-cant-see/