Light Emitting Diode

LED Flicker in Lamps or Luminaires

Table of contents

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode

1. Overview

Depending on the situation, some people may detect flicker in fluorescent lamps and some other types of lamps/luminaires operating at the frequency of general-purpose alternating current (i.e. 50/60 Hz depending on the country/region) or even double frequency (i.e. 100/120 Hz). Flicker, however, is not the only issue for these lamps/luminaires. For LED lamps/luminaires, if a poorly designed power supply is used to drive the LEDs (e.g. LED drivers incapable of sufficiently smoothing the current, etc.), the lamp/luminaire may have a visible flicker and it may have a negative impact on human health (e.g. headache, dizziness, fatigue, nausea, eye strain, etc.). To minimize safety/health hazards from lamps/luminaires, the manufacturers may be required to meet applicable statutory/regulatory requirements to be able to sell the lamps/luminaires.

For those reasons, when designing an LED lamp/luminaire flicker is an issue that must be dealt with and sufficient verification should be performed to ensure that the lamp/luminaire has no flicker. Since flicker in LED lamps/luminaires relates to the waveform pattern (i.e. frequency, amplitude and their combination), Nichia performed an evaluation to determine the waveform patterns that may create visible flicker. In addition to measurements of flicker metrics, the evaluation results include data collected using a sensory analysis since flicker is subjective and can vary from person to person.

Note that the evaluation results/data do not represent the performance of the LEDs. An important point to understand when designing a flicker-free lamp/luminaire is that the chosen LED driver will have a great impact on the light output of the LED. Additionally, the conclusions and recommendations discussed in this application note are merely Nichia's opinions based on the results and findings of the evaluation; simply following them does not guarantee that the chosen application will be free from flicker issues. Sufficient verification should be performed using the chosen lamp/luminaire (i.e. assembled as completely as possible in its intended use environments) to ensure that there are no issues.

2. Primary Cause of LED Flicker

Flicker in LED lamps/luminaires are usually due to the LED driver. LEDs are devices that respond very quickly to current variations (i.e. fast response time). As shown in Figure 1 below, the light output waveform of LEDs is almost proportional to the waveform of the current passing through the LED. As the difference in the brightness (i.e. the amplitude between the peak and fall) and the intervals between the waves increase (i.e. low frequency), so does the likelihood of visible flicker in the light output. This may not be the case when LEDs are used with an LED driver with proper current control (e.g. pulse-width modulation [PWM] dimming control, etc.); if only the amplitude is large and the frequency is sufficiently high, flicker will not be detected by the human eye.

However, if a low performance LED driver is used, as shown in Figure 2 (i.e. incapable of smoothing) the output current waveform is more likely to have a large amplitude; if this output current waveform has a low frequency[1], it may increase the likelihood of causing flicker in the LED light output. Another concern of using an LED driver incapable of sufficiently smoothing is that the current flowing through the LED may exceed the absolute maximum rating current.

Note:

[1] Inexpensive, low-quality LED drivers are prone to have a frequency of 100/120 Hz (i.e. double frequency of the general-purpose AC).

These frequencies are too low and may cause the LED to flicker.

Light Emitting Diode

This may occur due to the fluctuating output current waveform of these LED drivers; even if the average output current value is below the absolute maximum rating current, the current may easily exceed the absolute maximum rating current at the peak of the waves. Nichia recommends using an LED driver capable of smoothing the output current as shown in Figure 3. To design a flicker-free LED lamp/luminaire, it is very important to select/design a proper LED driver.
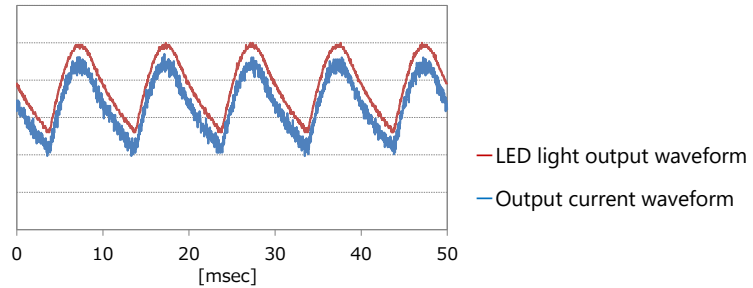

— LED light output waveform

— Output current waveform

Figure 1. Output current vs LED light output
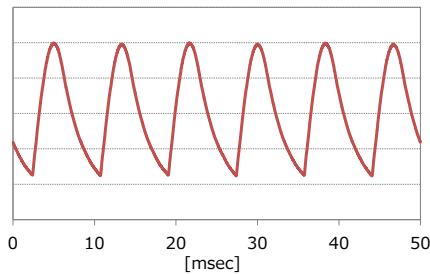
Figure 2. Example of an output current with large variations
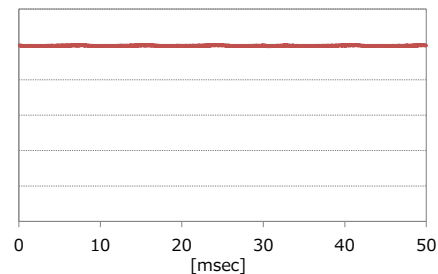
Figure 3. Example of an evenly smoothed output current

3. Standards for Flicker in LED Lamps/Luminaires

3.1. Japan Electrical Appliances and Materials Safety Act

The Act on Product Safety of Electrical Appliances and Materials (known as the "PSE Act") and orders from the Ministry of Economy, Trade and Industry (METI) include LED lamps and luminaires for general lighting applications and stipulate that the lamp/luminaire must not create a sensation that the light output is flickering (i.e. technical requirement). In its official correspondences (i.e. Dear Colleague letters), METI has clarified this requirement; LED lamps/luminaires must meet either of the following standards:

1)   There are no gaps in the light output (i.e. ≤ 5% of the peak light output) and the periodic frequency is ≥ 100 Hz.

2)   The pulse repetition frequency (PRF) is ≥ 500 Hz.

For example, the waveform shown in Figure 4 below meets the first standard above with the PRF = 100 Hz and the minimum light output = 80% of the peak. However, the waveform shown in Figure 5 below does not meet either set of the standards above since there are gaps in the light output and the PRF < 500 Hz. If an LED luminaire has the same light output characteristics shown in Figure 5, it will be considered unacceptable to the requirements of the PSE Act.

This document contains tentative information, Nichia may change the contents without notice.

3/17
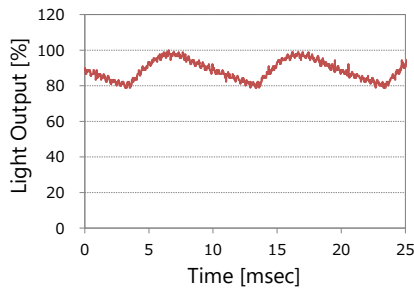
SP-QR-C2-210927-1
Sep. 10, 2021

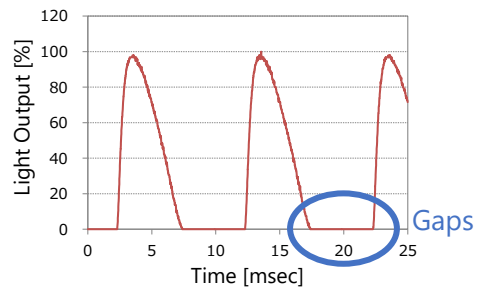Figure 4. Example of a PSE-compliant light output waveform

Figure 5. Example of a PSE non-compliant light output waveform

3.2. Flicker Metrics: Percent Flicker and Flicker Index

There are several metrics/tools to quantify flicker (e.g. percent flicker, flicker index, etc.), and laboratory testing and reporting may be required for product certification (e.g. Energy Star program).

Percent flicker:

It is "a relative measure of the cyclic variation in output of a light source (percent modulation)"[2], represented by equation 1 below. The value can vary from 0 to 100%. The lower the percentage is, the smaller the variation and when it is 0% the waveform becomes completely flat; the higher the percentage is, the larger the variation and when it is 100% the waveform indicates the lamp/luminaire is cycling between on and off.

Flicker index:

It is "a measure of the cyclic variation in output of a light source taking into account the waveform of the light output"[2] and "the ratio of the area under the light output curve that is above the average light output level to the total area under the light output curve for a single cycle"[2]. The value can be calculated by equation 2 below and can vary from 0 to 1; like percent flicker, the smaller the value is the smaller the variation.

Note that both metrics do not take into consideration the frequency factor; a high percent flicker/flicker index value does not necessarily lead to flicker. For example, a lamp/luminaire that has light output gaps with 100 percent flicker will not cause visible flicker when the periodic frequency is sufficiently high (i.e. ≥ several kHz)
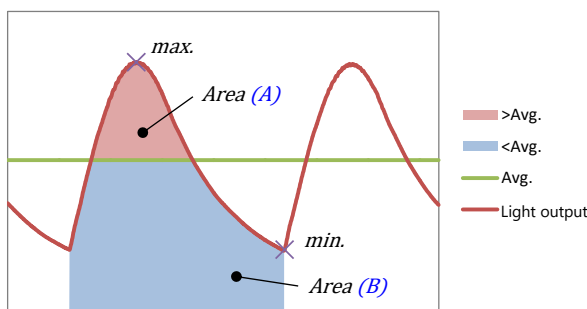

Figure 6. Percent flicker and flicker index

Equation 1:

$$Percent\ flicker = 100 \times \frac{max - min}{max + min}$$

Equation 2:

$$Flicker\ index = \frac{Area\ (A)}{Area\ (A) + Area\ (B)}$$

Note:
Area (A):   Area under the light output curve that is above the average light output level.
Area (B):   Area under the light output curve that is below the average light output level.

Note:

[2] ANSI/IES RP-16-10

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4. Evaluation of LED Flicker

Nichia performed an evaluation to determine the change in flicker when the frequency and amplitude of the output current from an LED driver are varied.

4.1. Requirements for Measuring Equipment: Photodetectors and Oscilloscopes

For the evaluation, proper measuring instruments are required to capture the light signals (i.e. LED light output) and convert them into a graphical representation (i.e. waveform). For example, if a photometer is used to measure the light output in lux (i.e. illuminometer), choose one that is capable of:

- continuously measuring the light output
- responding quickly enough to the frequency of the light output waveform
- converting the sampled digital data to an analog voltage waveform (when an oscilloscope is used with this illuminometer to graphically display the light signals)

There is another type of photodetector using a photodetector device and an amplifier to increase the power of a signal (i.e. photodetector circuit shown in Figure 7 below). This system also requires an oscilloscope to display the waveform.
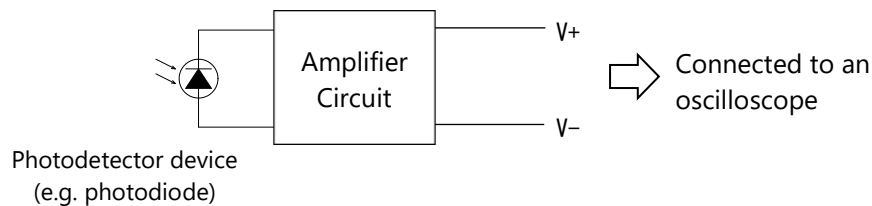
Figure 7. Example of a photodetector circuit

4.2. Evaluation Objectives/Method

This evaluation was performed to determine:

- the relationship between the output current frequency of the LED driver (i.e. 50 to 500 Hz) [3] and LED flicker
- the relationship between the waveform amplitude[4] and LED flicker

In the evaluation, the minimum light output[5], percent flicker, and flicker index were calculated for each waveform condition to quantify the level of flicker. Additionally, the level of perceived flicker was evaluated both when the observer viewed the emitting area of the LEDs and when the observer made quick movements (e.g. writing, hand waving, etc.) while illuminated by the LEDs.

Note:

[3] The periodic frequency of the output current waveform after rectified by the internal diode bridge (i.e. 100 Hz, 150 Hz, 300 Hz, 500 Hz, and 1 kHz) was twice the original frequency.

[4] Smoothing capacitors with different capacitances were used for the LED driver to generate waveforms with different amplitudes.

[5] The minimum light output values were determined and expressed in a percentage as a fraction of the maximum light output value of the waveform.

For the equipment configuration used to evaluate the light output waveforms, refer to Figure 8 below and for the method to evaluate the perceived flicker level, refer to Figure 9 below.
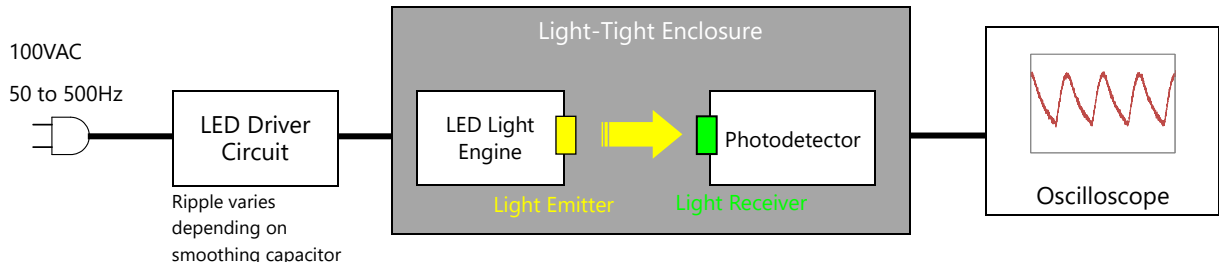

Figure 8. Equipment configuration used to measure the light output waveforms
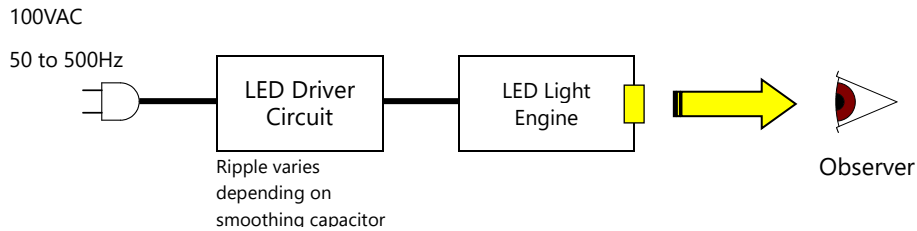

Figure 9. Equipment configuration used to perform the sensory evaluation

5. Evaluation Results

Section 5.1 below only presents measurement and observation data. Interpretation and discussion of this data is presented in later sections: 5.2 (i.e. Summary of findings) and 5.3 (i.e. Conclusion and recommendations).

5.1. Waveform Measurement
5.1.1. Repetition Frequency: 100 Hz
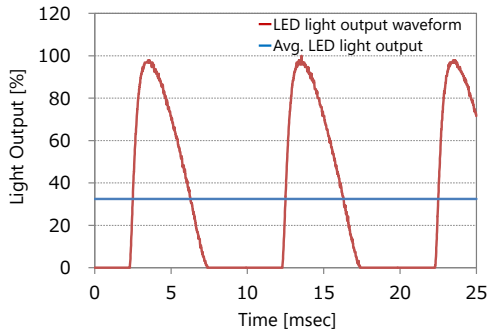
Figure 10. 100Hz-1

Min. light output:	0 [%]
Percent flicker:	100 [%]
Flicker index:	0.55
Observation result:	Flicker was perceived.
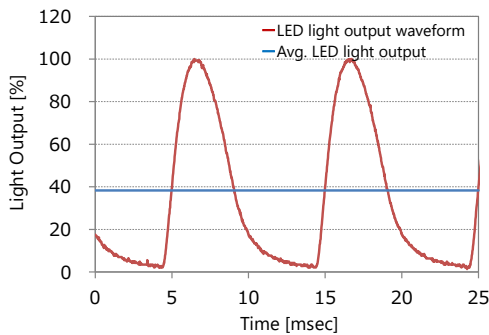
Figure 11. 100Hz-2

Min. light output:	1 [%]
Percent flicker:	97 [%]
Flicker index:	0.42
Observation result:	Flicker was perceived.
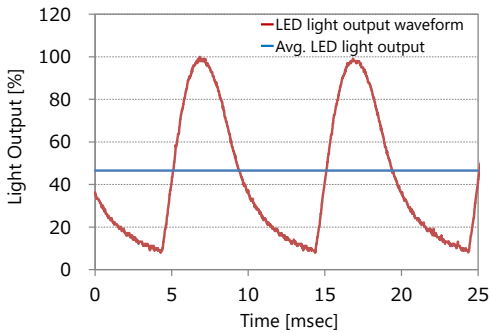
Figure 12. 100Hz-3

Min. light output:	8 [%]
Percent flicker:	85 [%]
Flicker index:	0.30
Observation result:	Flicker was perceived.
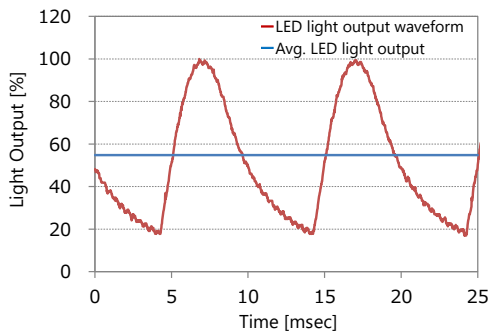
Figure 13. 100Hz-4

Min. light output:	17 [%]
Percent flicker:	71 [%]
Flicker index:	0.22
Observation result:	Flicker was perceived.

Light Emitting Diode

Light Emitting Diode
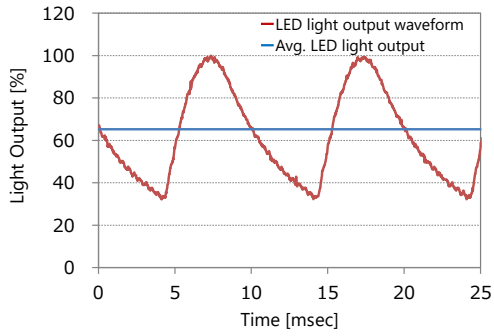
Figure 14. 100Hz-5

Min. light output：	32 [%]
Percent flicker：	51 [%]
Flicker index：	0.15
Observation result:	No flicker was perceived.
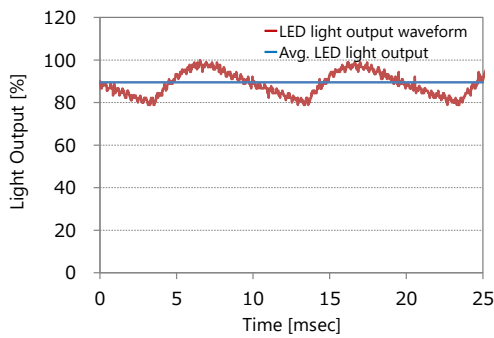
Figure 15. 100Hz-6

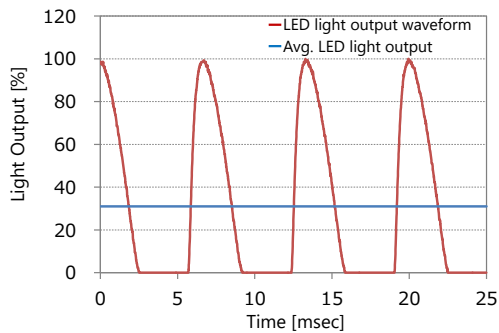|	
Min. light output：	78 [%]
Percent flicker：	13 [%]
Flicker index：	0.03
Observation result:	No flicker was perceived.

5.1.2. Repetition Frequency: 150 Hz

Figure 16. 150Hz-1

Min. light output：	0 [%]
Percent flicker：	100 [%]
Flicker index：	0.55
Observation result:	Flicker was perceived.
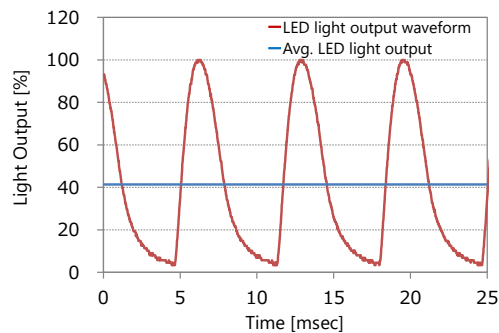
Figure 17. 150Hz-2

Min. light output：	3 [%]
Percent flicker：	93 [%]
Flicker index：	0.38
Observation result:	Flicker was perceived.

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode
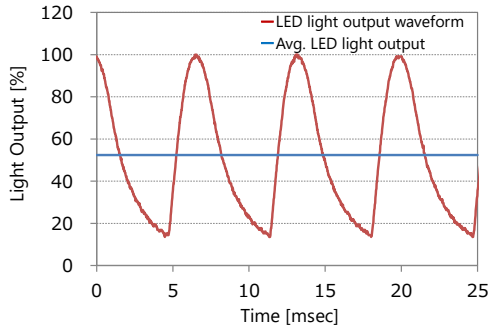
Figure 18. 150Hz-3

Min. light output	:	14 [%]
Percent flicker	:	76 [%]
Flicker index	:	0.25
Observation result:		Flicker was perceived.
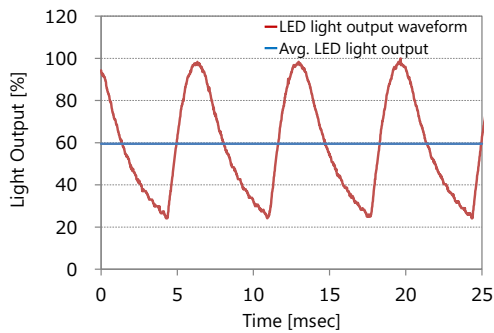
Figure 19. 150Hz-4

Min. light output	:	24 [%]
Percent flicker	:	61 [%]
Flicker index	:	0.18
Observation result:		Flicker was perceived when the object was moving fast.
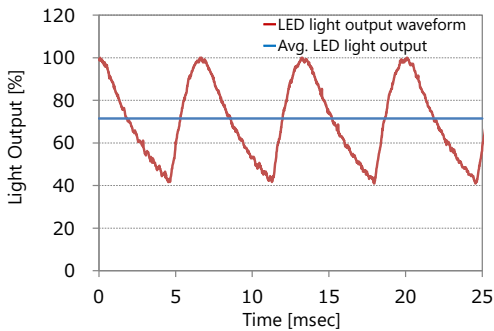
Figure 20. 150Hz-5

Min. light output	:	41 [%]
Percent flicker	:	42 [%]
Flicker index	:	0.11
Observation result:		No flicker was perceived.

Figure 21. 150Hz-6

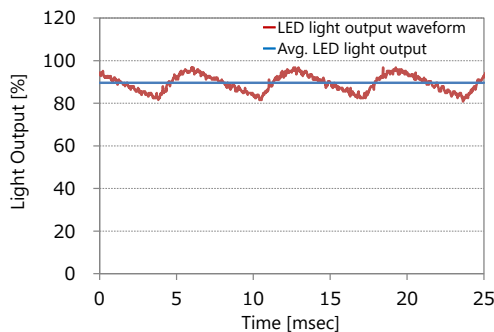| Min. light output | : | 81 [%] |
Percent flicker	:	11 [%]
Flicker index	:	0.02
Observation result:		No flicker was perceived.

5.1.3. Repetition Frequency: 300 Hz
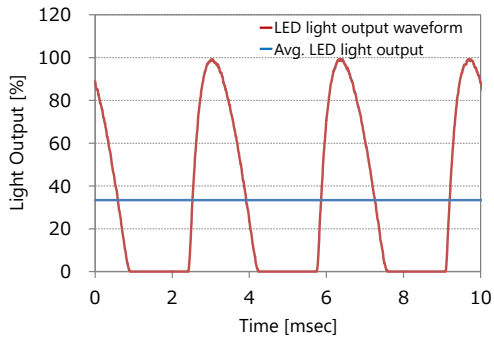
Light Emitting Diode

Figure 22. 300Hz-1

Min. light output : 0 [%]
Percent flicker : 100 [%]
Flicker index : 0.53
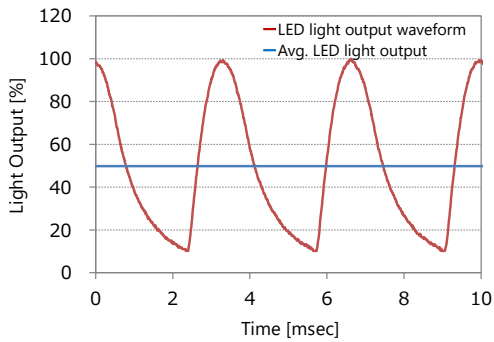Observation result: Flicker was perceived.

Figure 23. 300Hz-2

Min. light output : 10 [%]
Percent flicker : 81 [%]
Flicker index : 0.28
Observation result: Flicker was perceived when
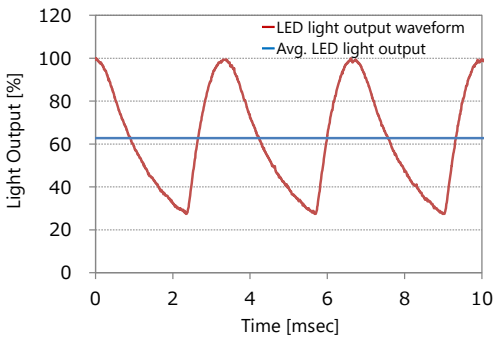the object was moving fast.

Figure 24. 300Hz-3

Min. light output : 26 [%]
Percent flicker : 59 [%]
Flicker index : 0.17
Observation result: Flicker was perceived when
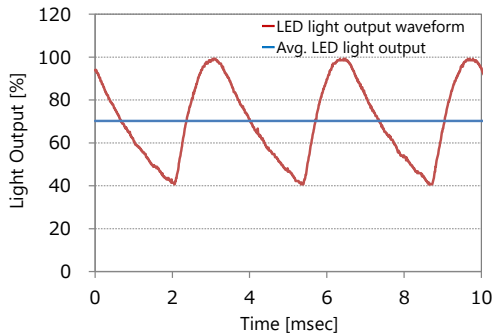the object was moving fast.

Figure 25. 300Hz-4

Min. light output : 40 [%]
Percent flicker : 43 [%]
Flicker index : 0.12
Observation result: No flicker was perceived.

SP-QR-C2-210927-1
Sep. 10, 2021
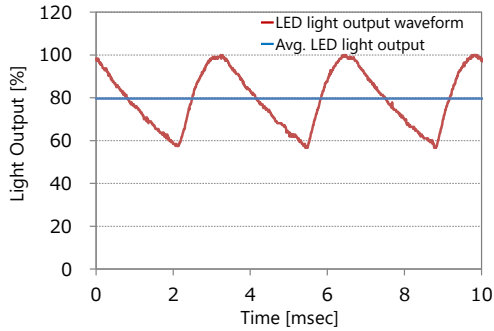
Light Emitting Diode

Figure 26. 300Hz-5

Min. light output： 57 [%]
Percent flicker： 28 [%]
Flicker index： 0.07
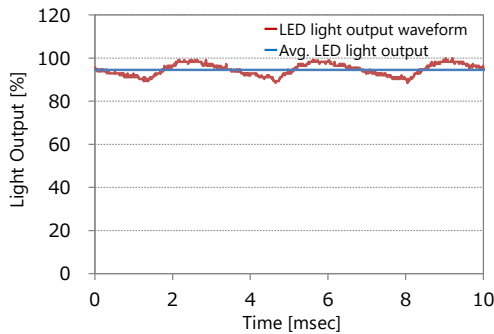Observation result: No flicker was perceived.

Figure 27. 300Hz-6

Min. light output： 89 [%]
Percent flicker： 6 [%]
Flicker index： 0.01
Observation result: No flicker was perceived.
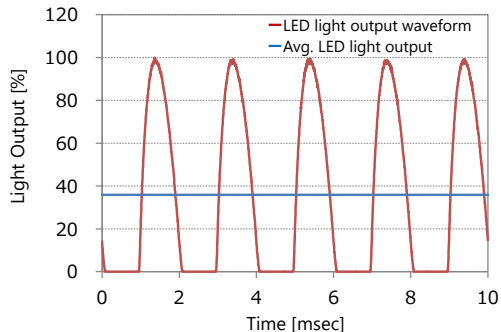
5.1.4. Repetition Frequency: 500 Hz

Figure 28. 500Hz-1

Min. light output： 0 [%]
Percent flicker： 100 [%]
Flicker index： 0.51
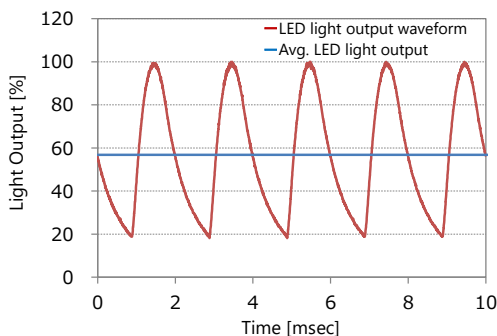Observation result: Flicker was perceived when the object was moving fast.

Figure 29. 500Hz-2

Min. light output： 18 [%]
Percent flicker： 69 [%]
Flicker index： 0.22
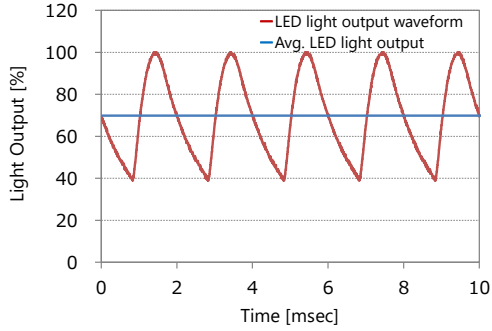Observation result: No flicker was perceived.

Light Emitting Diode

Figure 30. 500Hz-3

Min. light output：	39 [%]
Percent flicker：	44 [%]
Flicker index：	0.13
Observation result:	No flicker was perceived.
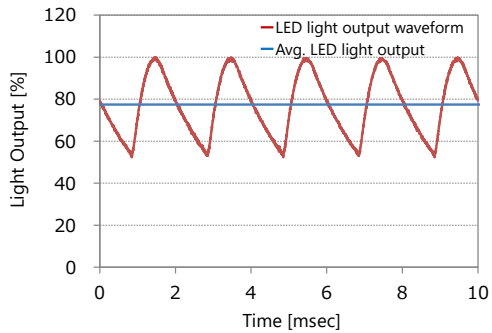
Figure 31. 500Hz-4

Min. light output：	52 [%]
Percent flicker：	31 [%]
Flicker index：	0.08
Observation result:	No flicker was perceived.

Figure 32. 500Hz-5

Min. light output：	67 [%]
Percent flicker：	20 [%]
Flicker index：	0.05
Observation result:	No flicker was perceived.

Figure 33. 500Hz-6

Min. light output：	91 [%]
Percent flicker：	5 [%]
Flicker index：	0.01
Observation result:	No flicker was perceived.

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode

5.1.5. Repetition Frequency: 1 kHz

Figure 34. 1kHz-1

Min. light output:	0 [%]
Percent flicker:	100 [%]
Flicker index:	0.48
Observation result:	No flicker was perceived.

Figure 35. 1kHz-2

Min. light output:	35 [%]
Percent flicker:	49 [%]
Flicker index:	0.14
Observation result:	No flicker was perceived.

Figure 36. 1kHz-3

Min. light output:	56 [%]
Percent flicker:	28 [%]
Flicker index:	0.08
Observation result:	No flicker was perceived.

Figure 37. 1kHz-4

Min. light output:	67 [%]
Percent flicker:	20 [%]
Flicker index:	0.05
Observation result:	No flicker was perceived.

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode

Min. light output : 78 [%]
Percent flicker : 12 [%]
Flicker index : 0.03
Observation result: No flicker was perceived.

Figure 38. 1kHz-5

Min. light output : 95 [%]
Percent flicker : 3 [%]
Flicker index : 0.01
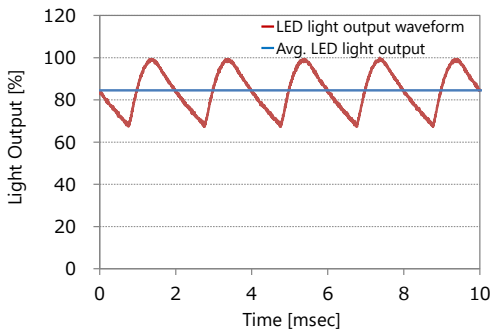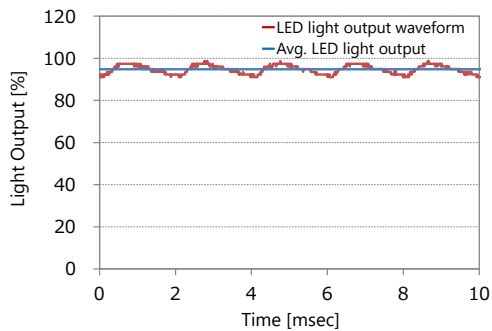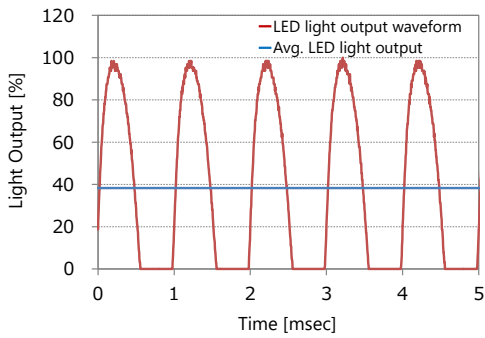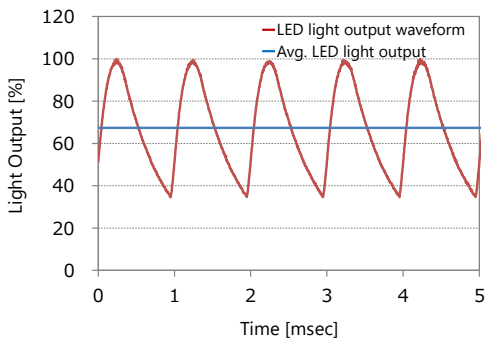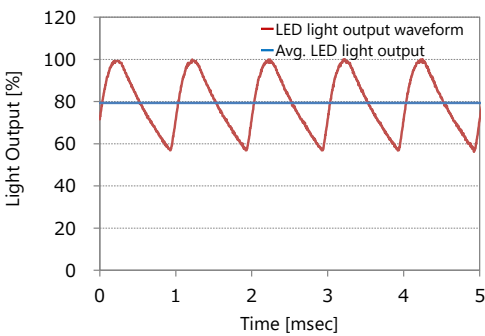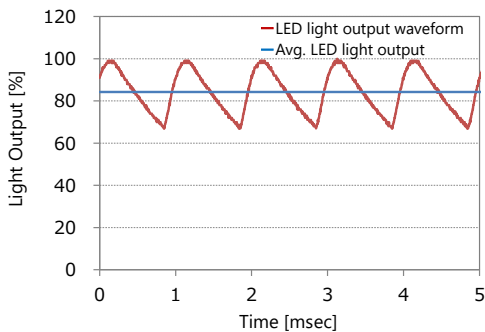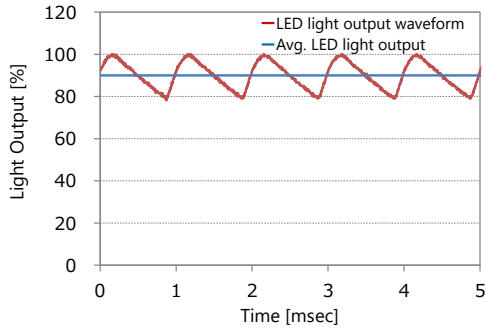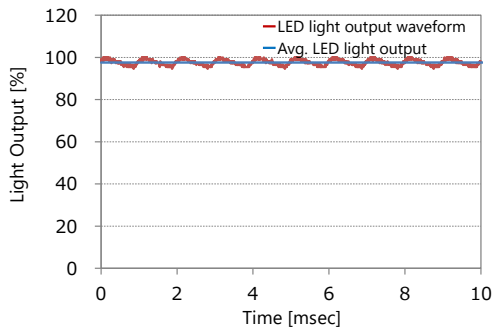Observation result: No flicker was perceived.

Figure 39. 1kHz-6

5.2. Summary of Findings

The measurement and observation results shown in 5.1 can be interpreted as follows:

- When the percent flicker was ≤ 40%, the observer had no sensation of flicker in the light output under any of the evaluated repetition frequency conditions (see Figure 40 below).

- When the flicker index was ≤ 0.1%, the observer had no sensation of flicker in the light output under any of the evaluated frequency conditions (see Figure 41 below).

- The higher the frequency was, the less likely it was to create a sensation that the light output was flickering; at 1 kHz frequency, the observer had no sensation of flicker in the light output regardless of the percent flicker and flicker index value (see Figures 40 and 41 below).

- When the minimum light output was ≥ 40%, the observer had no sensation of flicker in the light output under any of the evaluated repetition frequency conditions (see Figure 42 below).

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode

Figure 40. Perceived flicker vs. percent flicker [%]

Figure 41. Perceived flicker vs. flicker index

Figure 42. Perceived flicker vs. minimum light output [%]

SP-QR-C2-210927-1
Sep. 10, 2021

Light Emitting Diode

5.3. Conclusion and Recommendations

As mentioned earlier in this application note, the PSE Act and METI orders require that LED lamps/luminaires create no sensation of flicker in the light output at a repetition frequency ≥ 100 Hz and the minimum light output ≥ 5%. However, the evaluation results revealed that light output waveforms meeting this requirement may still create a sensation of flicker.

For the percent flicker and the minimum light output level, there is a relationship between the two variables shown in Figure 43 since only the maximum and minimum light output values are required to calculate percent flicker.
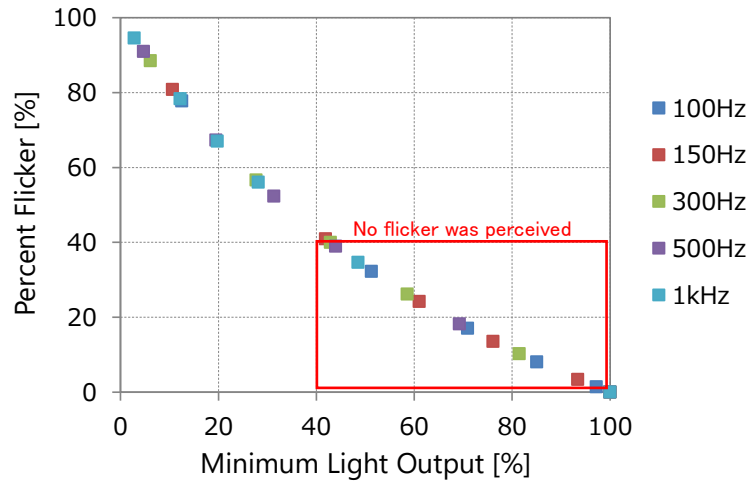

Figure 43. Minimum light output level [%] vs. percent flicker [%]

6. Summary

This application note has demonstrated the relationship between the frequency/amplitude of the light output waveform and flicker in LED lamps/luminaires. Nichia hopes that this information is helpful when selecting/designing an LED driver for the chosen application. However, it includes results based on a sensory evaluation using the human eye under Nichia's evaluation conditions/environments (e.g. observer, ambient conditions, light output with special waveforms such as Square, Triangular, etc.) and results may not be the same under different conditions/environments. Verification of the chosen application must be performed assembled with the LEDs and LED driver properly in place to ensure there is no flicker in the light output.

This document contains tentative information, Nichia may change the contents without notice.

16/17

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Light Emitting Diode

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