Light Emitting Diode

How to Measure the Electrical Characteristics of Luminaires Using LEDs

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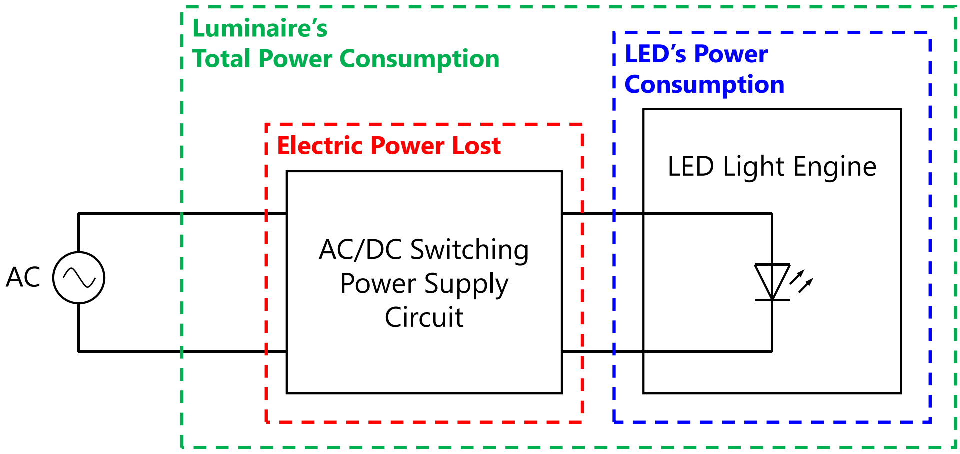
1. Overview

In recent years, LED luminaires have been replacing lighting devices using conventional technologies (e.g. incandescent/fluorescent [CFL] lighting). White LEDs for general applications now have improved luminous efficacies and it has led to an increased number of LED luminaires claiming to have high luminaire efficacies. As a result, when designing a luminaire it is very important for luminaire designers to learn how to determine the electric power consumption (i.e. luminaire efficacy). This application note provides information for this purpose with an emphasis on how to use an oscilloscope for electrical measurements.

2. Electric Energy Consumption/Luminaire Efficacy of the LED Luminaire

There are two different types of LED luminaires: those that contain internal power supplies and those that require external power supplies for operation. LED luminaires with an internal power supply include a module mounted with LEDs (i.e. LED light engine) and a power supply circuit to convert alternating-current (AC) power to power that is suitable to operate the LEDs (i.e. AC/DC transformer/LED driver). There are many different types of AC/DC switching power supplies: Typically, they convert AC current to DC current with a bridging diode and increase/decrease the DC voltage with both a switching circuit and capacitor at the same time; there are also other transformers that only perform switching from AC to DC. Regardless of the type of AC/DC switching power supply, when AC current is converted to DC current and/or AC voltage is changed from one voltage level to another, a power loss occurs in the power supply. The power consumption at the lighting system level is the sum of the power used in the LEDs on the module and the power lost in the power supply. In other words, if the power supply's loss increases it causes the luminaire's power consumption to escalate, causing the luminaire efficacy to decrease. As a result, when designing an LED luminaire, it is important to determine the power supply energy loss first and then choose the LED(s) and design the LED circuit.



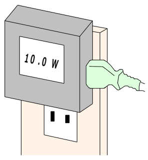
Luminaire's Power Consumption = Electric Power Loss in the Power Supply + LEDs' Power Consumption

Figure 1. Example of a LED Luminaire configuration

3. Typical Measuring Instruments

There are various approaches and instruments for measuring electrical characteristics (e.g. electric power). All of these approaches and measuring instruments have advantages and disadvantages. For examples of these instruments and a summary of their advantages and disadvantages, refer to Table 1 below.
In the following sections, two different approaches for measuring electric power are discussed: the first approach uses a digital oscilloscope and measures waveforms and calculates numerical values; the second approach uses a digital power meter and determines numerical values. The methods discussed here are intended to be performed with standard types of digital oscilloscopes/digital power meters. However, depending on the type of instrument used, it may cause damage to the instrument/equipment and/or danger to the user (e.g. electric shocks). Read the instructions/warnings for the instrument/equipment carefully and operate them correctly as instructed.

Table 1. Instruments for Measuring Electrical Characteristics

Measuring Instruments[1]	Advantages	Disadvantages
Simple Electric Power Meter 	・Easy connection ・Inexpensive ・Excellent portability	・Limited to electric power measurement (Current/voltage measurement is not supported) ・Low accuracy (trade-off for the inexpensive price)
Digital Multimeter 	・Easy operation ・Compact models available; excellent portability ・Some can measure electrical characteristics (e.g. voltage, current, resistance)	・Unable to determine the real power in AC circuits (i.e. effective voltage/current; however, power factor measurement is not supported) ・The circuit must be disconnected when measuring the current.
Digital Oscilloscope 	・Monitors the waveform ・Calculates electric power/power factor by using the obtained waveform data.	・Expensive ・Poor portability
Digital Power Meter 	・Electrical characteristics (e.g. voltage, current, electric power, power factor, etc.) are displayed in numeric values. ・Electric power consumption data (e.g. accumulated electric power consumption, electric power consumption vs. time, etc.) are displayed in a graph.	・Complicated wiring ・Expensive ・Poor portability

Note:
[1] The images are only for reference purposes.

4. How to Measure Electrical Characteristics with a Digital Oscilloscope

4.1. Digital Oscilloscope

The oscilloscope observes the change of an electrical signal (e.g. voltage, current, etc.) over time and presents the waveform on the display in a graph. Analog oscilloscopes (i.e. cathode-ray oscilloscopes [CRO]) were previously widely used, though now have been almost entirely replaced with digital storage oscilloscopes (DSO). DSOs are equipped with liquid-crystal display (LCD) panels and analog-to-digital converters (ADC), and store data in digital format. With these features, DSOs convert captured voltage signals (i.e. voltage waveforms) to digital data via the converter to store in the memory and present these waveforms in numeric data. This allows DSOs to calculate effective values and average values; if the voltage and current are measured at the same time via two different channels, it will allow the oscilloscope to calculate the electric power consumption and power factor.

4.2. How to Select an Oscilloscope and Probe

4.2.1. DSO

Refer to Table 2 below for important items to consider when selecting a digital oscilloscope.

Table 2. Typical DSO Specifications

Items	Descriptions/Required Specifications
Number of Channels	The number of channels that the device is capable of using for a measurement is an important feature when selecting an oscilloscope. To determine electric power consumption, the oscilloscope is required to measure the voltage waveform and current waveform simultaneously. For this reason, the minimum number of channels is two.
Bandwidth	It refers to the range between the upper and lower frequencies that an oscilloscope can capture, typically measured in hertz. To capture/measure radio frequency signals or signals with fast rise times, the bandwidth is an important factor to consider when selecting an oscilloscope. As a general rule, the samples per second should be at least 5 times higher than the bandwidth being measured for accurate measurements; however, most of the oscilloscopes available in the market at reasonable prices these days have bandwidths over a few dozen MHz. As a result, there will be no issues when using a general-purpose AC electric power supply (i.e. typically operated on 50~60 Hz) for measurements.
Sampling rate	It refers to the frequency of the sampling input signals, measured in the number of samples per second. Typically, the samples per second rate should be at least 5 higher than the maximum bandwidth being measured; however, there will be no issues when using a general-purpose AC electric power supply (i.e. typically operated on 50~ 60 Hz) for measurements.
Insulation Type	Typical oscilloscopes do not provide isolation from the ground (i.e. chassis ground) nor isolation between channels; the chassis and channels are electrically connected. When measuring a signal with this type of oscilloscope, if the reference point to measure the waveform is a point other than ground or the potentials between the

	channels are different, it may damage the instrument and/or cause injury (e.g. electrical shock). This can be avoided by either using a special type of oscilloscope with channel-to-channel isolation and channel-to-ground isolation, or by using a high differential probe. For more details on high differential probes, see 2) High Voltage Differential Probes below.

4.2.2. Current Probes

If an AC probe is used to measure AC current/voltage (e.g. main electric power), it may cause the measurement to be inaccurate. In this case, AC/DC current probes should be used. Ensure that a probe with sufficient capacity is selected to measure the target signals (e.g. the maximum currents, peak currents, etc.). Additionally, when measuring a low current, it is important to consider the oscilloscope's sensitivity (resolution).

Figure 2.
Example of a Current Probe

4.2.3. High-Voltage Differential Probes

If the oscilloscope is a non-isolated input oscilloscope, depending on how the instrument is used, it may cause damage to the instrument and/or electrical shock. For this case, using a differential (isolated) probe enables the oscilloscope and/or the other channels to be isolated to ensure safe measurement.

Figure 3.
Example of a High-Voltage Differential Probe

4.3. How to Use a Digital Oscilloscope

This section provides only basic instructions on how to use a digital oscilloscope. When using an oscilloscope refer to the manuals provided by the manufacturer for instructions on how to operate it properly.

4.3.1. Calibration of the Oscilloscope

The oscilloscope and probes must be calibrated in order to ensure that the measurement is accurate and it should be done on a regular basis by an accredited laboratory.

4.3.2. Adjusting the Probe Settings

Passive probes are normally attached to oscilloscopes when purchased and the most common type of probes used with oscilloscopes typically have a 10:1 attenuation factor. For cases where other types of probes are used (e.g. current probes used when measuring current), the probe may have different attenuation factors. In this case, it is important to use the proper attenuation factor for the measurement and to ensure that the corresponding channel of the oscilloscope is correctly adjusted to match the attenuation factor. If the attenuation factors do not match between the probe and the corresponding channel, it may cause measurement errors; ensure that the same attenuation factor that is appropriate for the measurement is set on both the probe and oscilloscope sides.
Additionally, if a current probe is used continuously, the probe's magnetic core will become magnetized and it will prevent accurate measurements; ensure that the residual magnetisms are reduced/eliminated

on a regular basis. Depending on the probe that is used, this can be done by pressing the button to degauss when current is not applied to the measured item.

4.3.3. Adjusting the Horizontal and Vertical Settings

The range of the vertical axis (i.e. voltage) should be adjusted to enlarge the waveform to the maximum level while ensuring that the high and low points of the waveform do not exceed the vertical range of the field. If the range of the vertical axis is larger than it should be, it may cause the waveform to be difficult for the oscilloscope to read (see Figure 5); if it is too small, the waveform may be cut off at the top and bottom (see Figure 6). In either case, the oscilloscope may not be capable of displaying numeric values for the waveform due to these incorrect settings.
When setting the range of the horizontal axis (i.e. time), ensure that a sufficient number of wave cycles is displayed per measurement. If the range chosen is not sufficient, a correct waveform will not be formed and it will cause the oscilloscope to fail to display numerical values (see Figure 7).

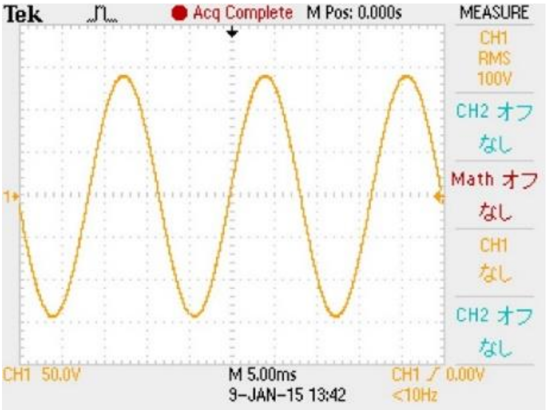


Figure 4.
Normal waveform is displayed (AC100V/60Hz)

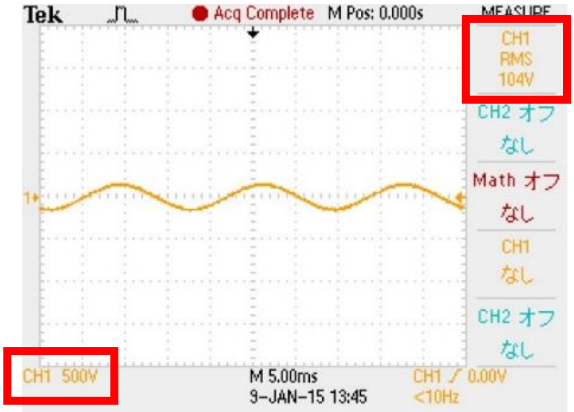


Figure 5.
Range of the vertical axis is too large

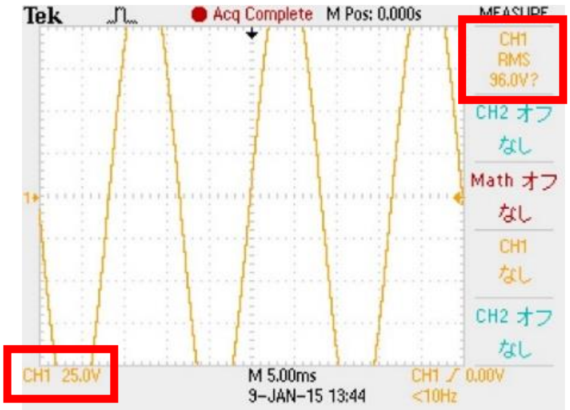


Figure 6.
Range of the vertical axis is too large

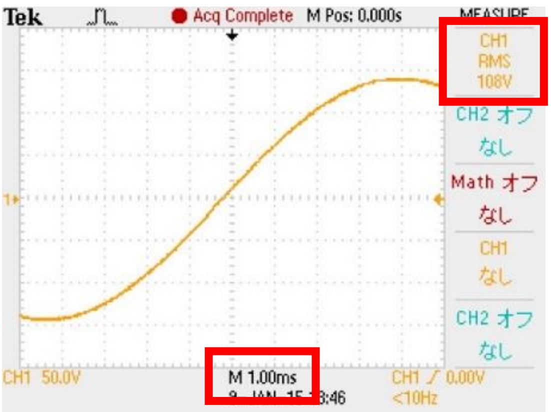


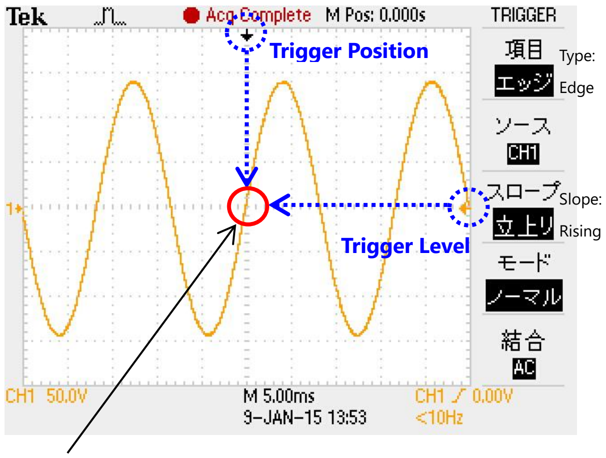
Figure 7.
Range of the horizontal axis is too small

4.3.4 Adjusting the Trigger Settings

A digital oscilloscope stores digital data in its memory after capturing voltage signals and converting them into digital data via the AC-DC transformer. Once the memory has reached full capacity, it will overwrite the oldest recording on a first-in, first-out basis. This can cause the waveform displayed on the oscilloscope to be unstable (e.g. the waveform appears to jitter back and forth horizontally on the oscilloscope display). To control the recording of signals in the memory and acquire a static image of the signals, the trigger function should be used and adjusted correctly.
The trigger settings can be adjusted by using trigger setting items, examples are listed in Table 3. If a trigger event does not occur, adjust the trigger level and/or change the trigger type (e.g. Edge, Video, Pulse, and Logic). If these settings are appropriate, then a valid trigger event occurs when a signal crosses the trigger point defined by the trigger position and trigger level according to the other settings (e.g. trigger type and slope).

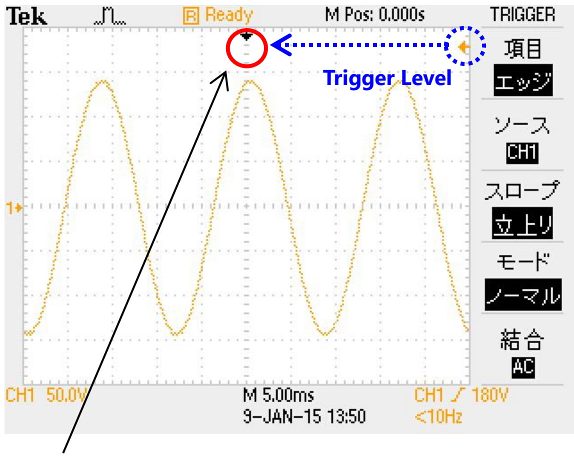
Table 3. Trigger Setting Items

Items	Notes
Trigger Type	Select the shape of a waveform from several options (typically, “edge”, “pulse”, “video” and “logic”). When any waveform that matches a selected type is detected, a trigger event occurs. Edge triggering is the basic and most common type. To measure a typical AC waveform (see Figure 8), select the “edge” type.
Source	Select sources (e.g. channels, external sources, etc.) used to trigger signals
Slope	For edge triggering, it is required to select an option from “rising slope” or “falling slope” for the oscilloscope to trigger when a signal meets selected conditions (e.g. If “rise” has been selected and a signal meets the selected conditions for the trigger level at the rising slope, then a trigger event occurs).
Trigger Position	Set the horizontal position (i.e. time/horizontal axis) to trigger signals. To see the portion of a waveform captured before the point where triggering occurs, adjust the trigger position horizontally for the captured waveform.
Trigger Level	Set a voltage level (i.e. voltage/vertical axis) to trigger signals. When a signal meets set conditions (e.g. slope, trigger position, trigger level, etc.), then a trigger event occurs.



Since the signal reached the point on the rising slope where both the trigger position and trigger level cross on the display, a valid trigger event has occurred (this makes the unstable waveform appear static).

Figure 8.
When a Valid Trigger Event has Occurred



Since the signal does not reach the point where the trigger position and level cross, a trigger event has not occurred (the waveform will continue to move horizontally).

Figure 9.
When a Trigger Event Fails to Occur or is not Applied

4.4. How to Measure Electric Parameters with a Digital Oscilloscope

This section provides details on how to measure electrical parameters for AC power supplies using a digital oscilloscope.

4.4.1. How to Connect to a Digital Oscilloscope with Peripheral Equipment

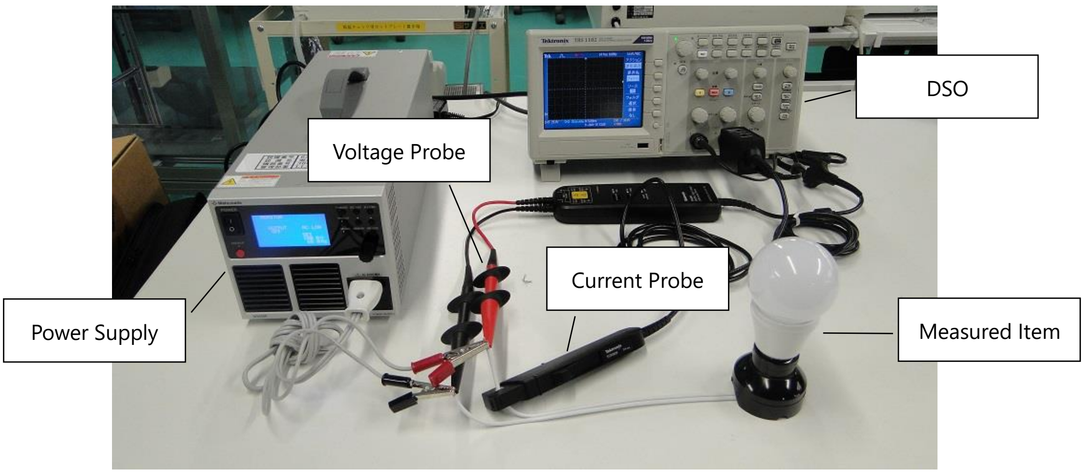


Figure 10. How to Connect to a Digital Oscilloscope (Example)

4.4.2. Measuring Effective Voltage/Current

Effective voltage and current can be represented by the following Equation 1 and Equation 2 respectively. Digital oscilloscopes measure electricity according to a set sampling rate and store instantaneous values recorded at set intervals in the memory and it allows the oscilloscope to display effective values that have been calculated by the oscilloscope itself immediately after measurements. If it is possible to retrieve numerical data from the oscilloscope, then it will be possible to process the data on a computer by using spreadsheet software.

When triggering a signal, if the captured waveform appears cut off on the top/bottom or the number of the periods on the display is not sufficient, it may prevent the oscilloscope from storing correct instantaneous data; this may lead to incorrect numerical values being displayed on the screen. Adjust the horizontal/vertical scales (i.e. time and voltage scales) to ensure that appropriate shape of waveform/number of the periods are displayed on the screen (The numbers of periods displayed on the screen should be integral numbers).

$$Effective\ Voltage(V) = \sqrt{\frac{1}{T}\int_0^T v(t)^2 dt} \qquad \text{Equation 1}$$

where
v(t): Instantaneous voltage value, T: Number of periods (the number of sample captured)

$$Effective\ Current(A) = \sqrt{\frac{1}{T}\int_0^T i(t)^2 dt} \qquad \text{Equation 2}$$

where
i(t): Instantaneous current value, T: Number of periods (the number of sample captured)

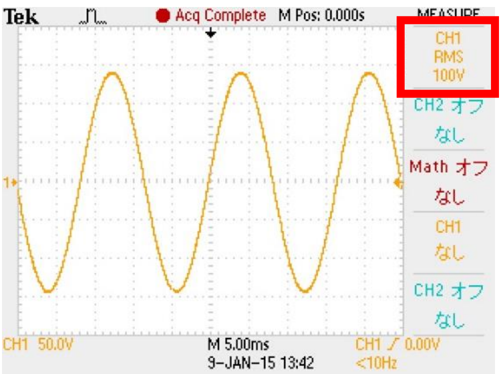


Figure 11. How an Oscilloscope displays effective values on the screen (Example)

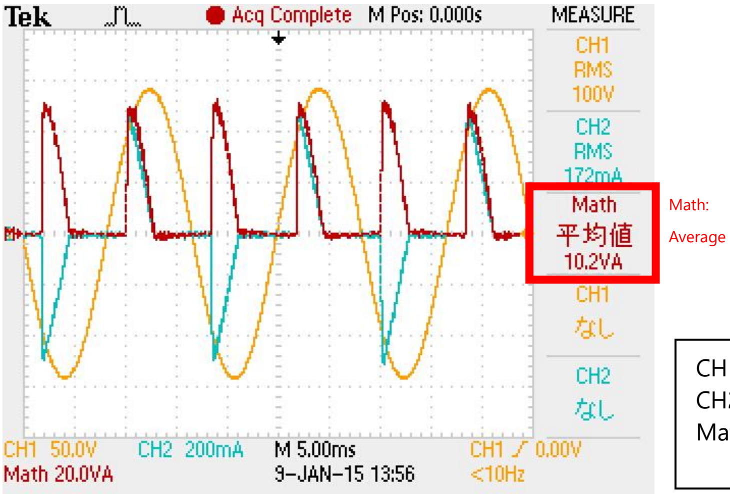
4.4.3. How to Measure Effective Power (i.e. Power Consumption)

Effective power (i.e. power consumption) can be determined by Equation 3 below. If voltage and current signals are captured simultaneously, oscilloscopes can determine the effective power (i.e. power consumption) by using the measurement results.

$$Effective\ Power(W) = \frac{1}{T}\int_0^T v(t)i(t) dt \qquad \text{Equation 3}$$

where
v(t)i(t): Instantaneous electric power value, T: Number of periods (the number of sample captured)

1) The oscilloscope has used the math functions to multiply the instantaneous samplings of current and voltage and displayed the results as instantaneous samplings of electric power in waveforms (i.e. the Math waveform in red).
2) Additionally, it has used the calculated power waveform and displays the average value (i.e. “10.2VA” on the right side shown in the red box). This value is the effective power (power consumption).



CH1—: Voltage measured at channel 1
CH2—: Current measured at channel 2
Math—: Calculated value (instantaneous power) as a result of CH1 x CH2

Figure 8. A Digital Oscilloscope Calculating/Displaying Effective Power (Power Consumption)

4.4.4. Apparent Power/Power Factor

In the case of typical AC/DC power supplies, a phase difference occurs between voltage and current due to the reactive components of circuit elements used (e.g. capacitors, inductors, etc.). This phase difference generates reactive power that does not contribute to energy consumption in a luminaire. The sum of reactive power and effective power (i.e. actual electric power consumed in a luminaire) is referred to as apparent power (see Equation 4).
Apparent power can also be calculated by Equation 5; with this equation it is possible to determine apparent power by using effective values measured in section 2.4.2. Power factor refers to a value representing the ratio of effective power to apparent power (see Equation 6). The larger this value is and the closer it is to 1 (100%), the more desirable the power factor is for a power supply.
At an individual level, since only effective power is consumed by luminaires, even if the power factor is poor and the reactive power is large, it will not cause the luminaire power consumption to increase. At a facility level, however, a poor power factor may be an issue: the rated capacity of a facility (e.g. power plant, etc.) is measured in apparent power; if a power supply with poor power factor is used, it will cause the load on the facility to increase. To improve the power factor, there are cases where power factor correction (PFC) circuits are used.

$$Apparent\ Power(VA) = Effective\ Power(W) + Reactive\ Power(var)$$ Equation 4

$$Apparent\ Power(VA) = Effective\ Voltage(V) \times Effective\ Current(A)$$ Equation 5

$$Power\ Factor = Effective\ Power(W)\ /\ Reactive\ Power(var)$$ Equation 6

4.5. How to Determine Power Supply Efficiency and Luminous Efficacy

To determine power supply conversion efficiency and power loss, measure the power consumption on both the input and output sides (see Equations 7 and 8). To determine the luminaire efficacy, attach the optics (e.g. secondary lens, covers, etc.) to the LED module and measure the system-level luminous flux and input power (i.e. luminaire power consumption). To determine the LED luminous efficacy, remove the optics from the LED module and measure the luminous flux and the output power of the LED module (see Equations 9 and 10).

Accordingly, when evaluating the LEDs for the chosen application, measure the LED module without any optics attached. If a part that can cause power loss is used on the same PCB, take this into consideration.

$$Power\ Supply\ Power\ Loss(W) = Input\ Power(W) - Output\ Power(W)$$ Equation 7

$$Power\ Supply\ Conversion\ Effeciency(VA)$$

$$= (Output\ Power(W)\ /\ Input\ Power(W)) \times 100$$ Equation 8

$$Luminaire\ Efficacy(lm/W)$$

$$= Luminaire\ Luminous\ Flux(lm)\ /\ Output\ Power(W)$$ Equation 9

$$LED\ Luminous\ Efficacy(lm/W)$$

$$= LED\ Module\ Luminous\ Flux(lm)\ /\ Output\ Power(W)$$ Equation 10

5. How to Evaluate with a Digital Power Meter

5.1. Digital Power Meters

There are various types of instruments to measure electric power, ranging from ones that are inexpensive and simple to use but limited in capabilities to ones that are expensive, multifunctional and excellent in accuracy. Among these various types of watt meters, this section focuses on digital power meters (see Section 3) and provides information on how to measure with a digital power meter. In addition to basic features (e.g. instantaneous measurement/display of effective voltage/currents, power consumptions, power factors, etc.), some digital power meters are capable of providing advanced measurements (e.g. peak value, crest factor, total harmonic distortion [THD], etc.). It is possible to select a digital power meter that has the functions and degree of accuracy needed for the chosen application.

5.2. How to Use a Digital Power Meter

5.2.1. Circuit Connection Examples

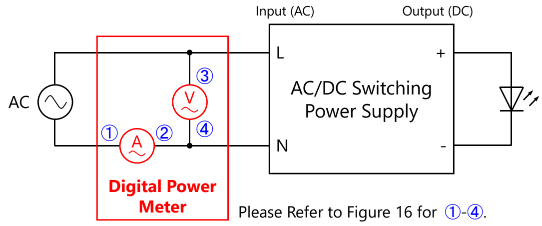


Figure 13.
Measuring Luminaire Power Consumption (Connecting to the power supply on the input side)

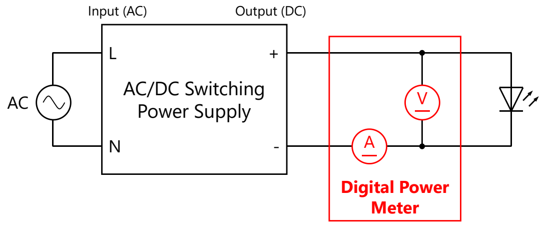


Figure 14.
Measuring Luminaire Power Consumption (Connecting to the power supply on the output side)

5.2.2. How to Connect a Digital Power Meter to Measure Luminaire Power Consumption

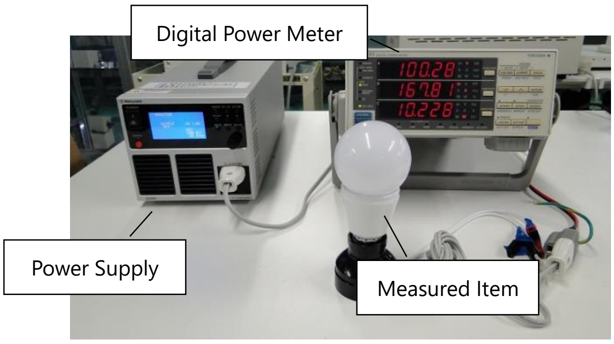


Figure 15.
Digital Power Meter Connection Example

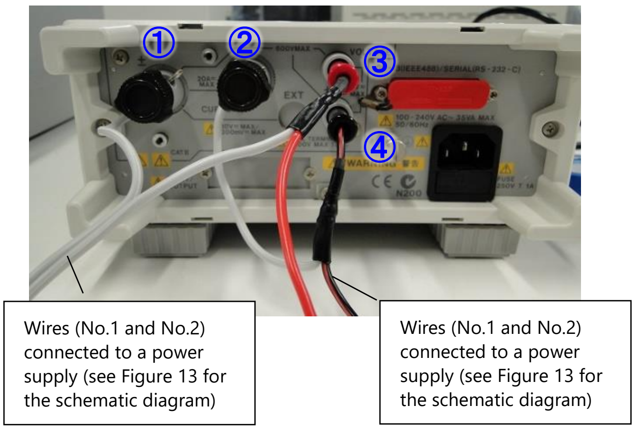


Figure 16.
Electrical connections on the back of a digital power meter

5.2.3. How a Digital Power Meter Displays Measurement Results

Figure 17. Display of Measurement Results (Example)

Digital power meters display measurement result in numbers (see Figure 17). In the above example, the digital power meter is displaying effective voltage (Display A), effective current (Display B) and effective power (i.e. power consumption [Display C]); it can show other measurement results (e.g. apparent power [VA], power factor [PF], etc.) on these displays.

6. Summary

This application note only provides information of how to measure electrical power with an oscilloscope and digital power meter (i.e. watt meter). There are many other types of instruments available for power measurement. Consider the purposes/requirements and select the appropriate instruments for the chosen application.

Light Emitting Diode

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