

Application Note (A2)

LED Measurements

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LED MEASUREMENTS

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LED MEASUREMENTS

1.0 INTRODUCTION

The instrumentation selected to measure the output of an LED must be equipped with the appropriate front end or input optics and the instrumentation must be calibrated using the appropriate standard. The type of instrumentation used along with the recommended input optics and calibration standard are dependant on the optical parameter to be measured. Accordingly, in order to select the proper measurement system, the optical parameter to be measured must be precisely specified.

The optical parameter of interest can be photometric, radiometric or spectroradiometric. This application note describes generally accepted methods of measuring the more commonly measured LED photometric, radiometric and spectroradiometric optical parameters. In addition, the appropriate standards and methods used to calibrate the measurement system are also described.

2.0 PHOTOMETRIC MEASUREMENTS

Although many common terms are used to define photometric light output, the basic unit of measurement of light is the lumen. All photometric quantities involve the lumen. The photometric quantities of particular interest associated with LED measurements are:

Luminous Flux (Φ_v) - The total luminous power emitted from a source (lumens). Flux emitted from an LED is in the forward direction and is, thus, the lumens per 2π steradians.

Luminous Intensity (I_v) - The luminous flux emitted from a source per unit solid angle in a specified direction (lumens per steradian or candelas).

2.1 Total Luminous Flux (lumens per 2π steradians)

Measuring the total luminous flux, Φ_v , of LEDs involves a two step procedure:

- 1) Calibration of the measurement system for total luminous flux response [A/lm].
- 2) Measurement of the total luminous flux [lm] of the test LED using the calibrated measurement system.

Instrumentation (total luminous flux) - The recommended instrumentation for measuring total luminous flux of an LED is listed below:

- 1) OL 730C Programmable Radiometer/Photometer
- 2) OL 730-5A or 730-5H UV-Enhanced Silicon Photodetector
- 3) OL 730-5-PF-LED Photopic Filter ($f < 1.5\%$)
- 4) OL IS-670 Integrating Sphere with LED Holder
- 5) OL ISA-7PH 7-Position LED Holder (optional)

The standards and associated accessories recommended for calibration of the measurement instrumentation consists of:

- 1) OL 245P, 220P, 200P or FEL-P Standard of Illuminance
- 2) OL 65A or 83A Programmable Current Source
- 3) OL 57, 57W, 56 or 61 and 62 Lamp Holder
- 4) OL 63 Adjustable Lamp Holder Mount (optional)

PHOTOMETRIC MEASUREMENTS

Calibration Procedure (total luminous flux response)

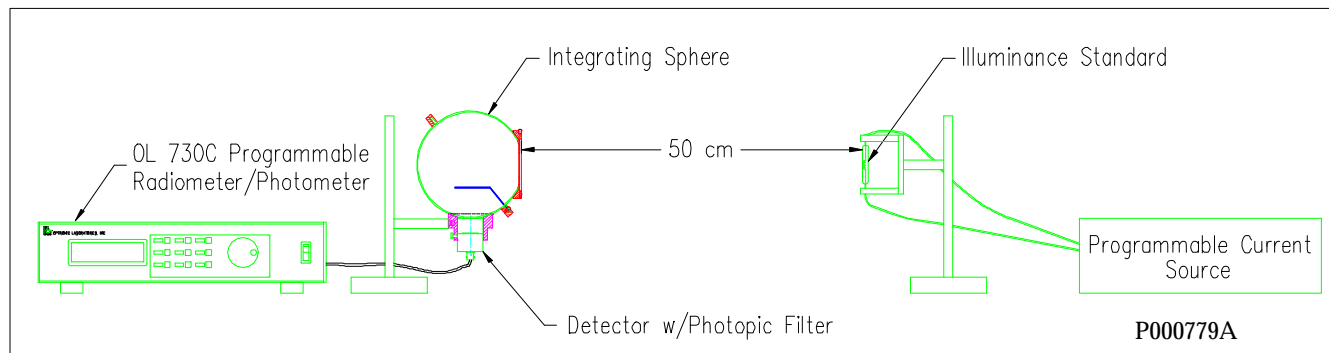


Figure 1- Total Luminous Flux - Setup for Calibration of Measurement System

Figure 1 shows the setup for calibrating the measurement system for total luminous flux response. The procedure is as follows:

- 1) Insert the OL 730-5 Detector / OL 730-5-PF-LED Photopic Filter combination into the detector port of the OL IS-670 Integrating Sphere.
- 2) Align the lamp standard of illuminance at a distance of 50 cm from the entrance port of the integrating sphere. Note: Follow alignment instructions supplied with the illuminance standard.
- 3) Record detector signal, S_k [A], as displayed on the OL 730C. Note: Allow the lamp standard to warm up according to the instructions supplied with the illuminance standard.
- 4) Compute the measurement system's calibration factor [A/lm] for total luminous flux response, K_{Φ_v} , using the relationship:

$$K_{\Phi_v} = S_k / E_v \cdot A_o$$

where, E_v = Illuminance of standard lamp [lm/cm²]
 A_o = Area of sphere entrance port [cm²] NOTE: Area of OL IS-670 entrance port is 7.92 cm².
 S_k = OL 730C signal [A]

- 5) The calibration factors can then be entered into the OL 730C Programmable Radiometer/Photometer using the procedure described in the DETECTOR SETUP LIBRARY section of the OL 730C Manual.

NOTE:

Follow instructions given in OL 730C Manual for inserting calibration factors. The OL 730C will then read directly in lumens when measuring the total luminous flux of an LED

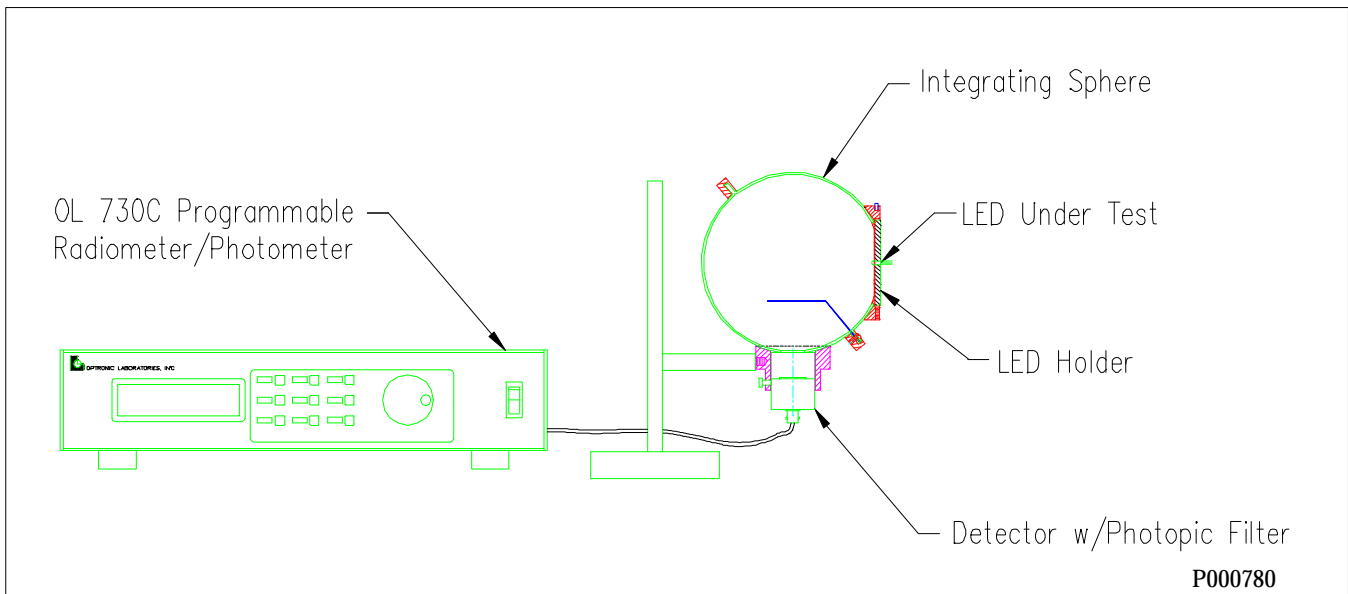
Measurement Procedure (total luminous flux)

Figure 2 - Total Luminous Flux - Instrumentation for Measuring LED

Figure 2 shows the setup for measuring the total luminous flux of an LED. The procedure is as follows:

- 1) Mount the LED Holder to the entrance port of the OL IS-670 Integrating Sphere and insert the LED under test.
- 2) The OL 730C will display the total luminous flux directly in units of lumens.

2.2 Luminous Intensity (millicandelas)

Measuring the luminous intensity I_v , of LEDs involves a two step procedure:

- 1) Calibrate the measurement system for illuminance response [$A/(lm/cm^2)$] & then calculate luminous intensity response [A/ cd].
- 2) Measurement of the luminous intensity [cd] of the test LED using the calibrated measurement system.

Instrumentation (luminous intensity) - The recommended instrumentation for measuring luminous intensity of LEDs is listed below.

- 1) OL 730C Programmable Radiometer/Photometer
- 2) OL 730-5A or 730-5H UV Enhanced Silicon Photodetector
- 3) OL 730-5-PF-LED Photopic Filter ($\tau < 1.5\%$)
- 4) OL 15 LED Receptor (includes single LED Holder)
- 5) OL 15-7PH 7-Position LED Holder (optional)

The standards and associated accessories recommended for calibration of the measurement instrumentation consists of:

- 1) OL 245P, 220P, 200P or FEL-P Standard of Illuminance
- 2) OL 65A or 83A Programmable Current Source
- 3) OL 57, 57W, 56 or 61 and 62 Lamp Holder
- 4) OL 63 Adjustable Lamp Holder Mount (optional)

Calibration Procedure (luminous intensity response)

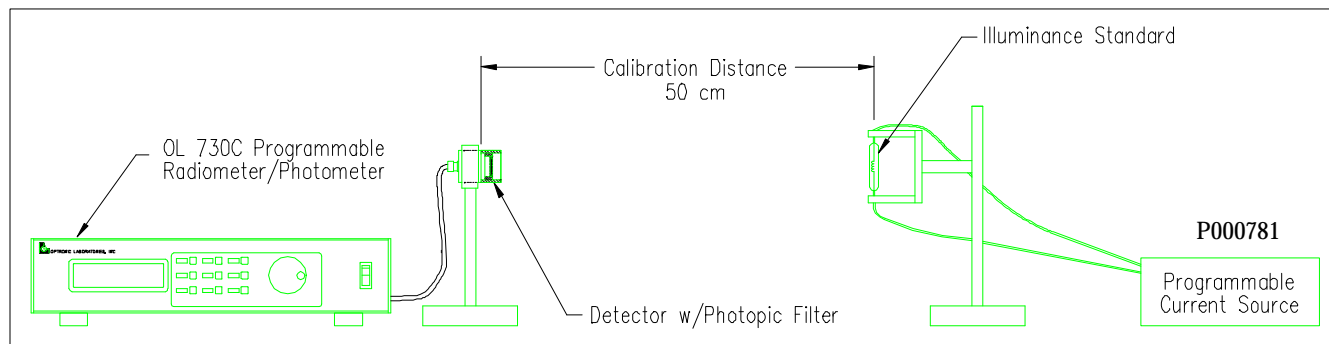


Figure 3 - Luminous Intensity - Setup for Calibration of Measurement System

Figure 3 shows the setup for calibrating the measurement system for illuminance response [A/fc or A/(lm/cm²)]. The procedure is as follows:

- 1) Align the lamp standard of illuminance at a distance of 50 cm from the measurement plane of the OL 730-5 Detector / OL 730-5-PF Photopic Filter combination. Note: Follow the alignment instructions supplied with the illuminance standard.
- 2) Record detector signal, S_k [A], as displayed on the OL 730C. Note: Allow the lamp standard to warm up according to the instructions supplied with the illuminance standard.
- 3) Compute the measurement system's calibration factor [A/(lm/cm²)] for illuminance response, E_v , using the relationship:

$$E_v = S_k / E_v$$

where, S_k = OL 730C signal [A]
 E_v = Illuminance of standard lamp [lm/cm²]

This calibration is performed without the OL 15 LED Receptor.

Note:

Since the area of the OL 730-5A Detector is 1 cm², it may be more convenient to convert the illuminance of the standard lamp to lm/cm². In this case, the illuminance response [A/(lm/cm²)] and the luminous flux response [A/lm] are identical.

- 4) The luminous flux response can now be multiplied by the field-of-view (FOV) of the OL 15 LED Receptor in steradians (either 0.010 or 0.001 sr - refer to the OL 15 LED Receptor Manual). This gives the luminous intensity calibration factors, K_{I_v} , [A/(lm/sr) or A/cd] for the OL 730-5A Detector / OL 730-5-PF-LED Photopic Filter / OL 15 LED Receptor combination. The calculation is performed as follows:

$$K_{I_v} = E_v \cdot \text{FOV}$$

where, E_v = Illuminance response [A/ fc or A/(lm/cm²)]
 FOV = Either 0.010 or 0.001 sr (Refer to the OL 15 LED Receptor Manual)

For direct reading in mcd, merely divide the luminous intensity calibration factors by 1000.

- 5) The calibration factors can then be entered into the OL 730C Programmable Radiometer/Photometer using the procedure described in the DETECTOR SETUP LIBRARY section of the OL 730C Manual.

Measurement Procedure (luminous intensity)

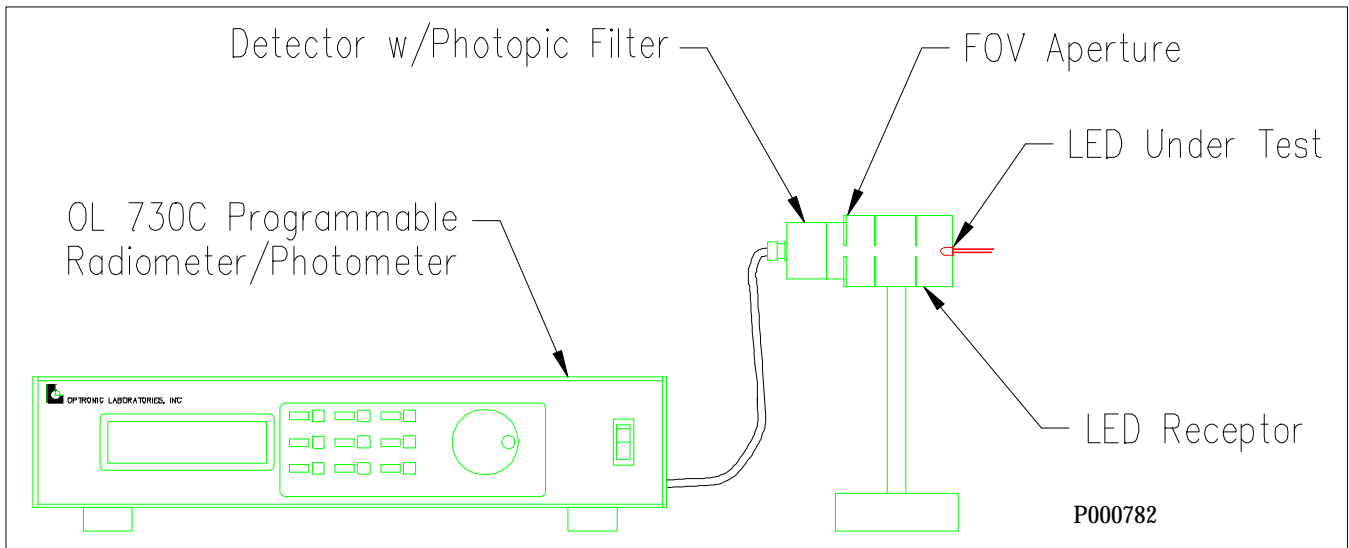


Figure 4 - Luminous Intensity - Instrument for Measuring LED

Figure 4 shows the setup for measuring the luminous intensity of an LED. The procedure is as follows:

- 1) Insert the desired FOV aperture into the OL 730-5 Detector / OL 730-5-PF-LED Photopic Filter combination.
- 2) Insert the OL 730-5 Detector / OL 730-5-PF-LED Photopic Filter combination into the detector end of the OL 15 LED Receptor.
- 3) Insert the test LED into the source end of OL 15 LED Receptor.
- 4) Select the appropriate OL 730C Detector Setup and readout the luminous intensity directly in units of candelas and/or millicandelas.

3.0 RADIOMETRIC MEASUREMENTS

The basic unit of measurement for radiometric quantities is the watt. The radiometric quantities of particular interest with LED measurements are:

Radiant Flux or Power (Φ_R) - The time rate of flow of radiant energy (watt). Flux emitted from an LED is in the forward direction and is, thus, watts per 2π steradians.

Radiant Intensity (I_R) - The radiant flux emitted from a source per unit solid angle in a specified direction (watts per steradian).

3.1 Total Radiant Flux or Power (watts per 2π steradians)

Instrumentation (total radiant flux or total power) - The recommended instrumentation for measuring the power output of an LED is listed below.

- 1) OL 730C Programmable Radiometer/Photometer
- 2) OL 730-5A or 730-5H UV-Enhanced Silicon Photodetector
- 3) OL 730-5-RF Radiometric Filter
- 4) OL IS-670 Integrating Sphere with LED Holder
- 5) OL ISA-7PH 7-Position LED Holder (optional)

Calibration Procedure (total radiant flux response or total power response)

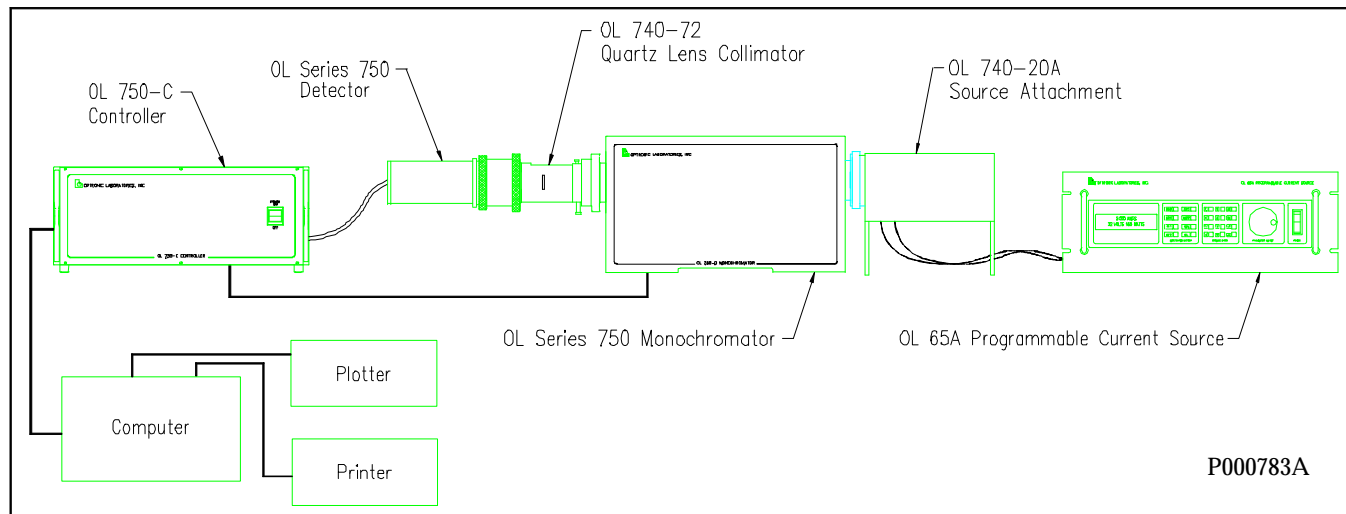


Figure 5 - Total Radiant Flux Setup for Spectroradiometric Measurement of Monochromatic Flux

The instrumentation and standards required for determining the radiant power response calibration factor (K_{Φ_R}) for the measurement system consists of an OL Series 750 Automated Spectroradiometric Measurement System configured for measuring the spectral response of photodetectors as shown in Figure 5. The calibration involves the following procedure:

- 1) Measure the monochromatic flux [Watt] in the collimated beam at the wavelength of interest (for highest accuracy, choose a wavelength relatively close to the peak wavelength of the LED). This is accomplished by positioning an OL 750 Calibrated Detector in the collimated, monochromatic beam such that the collimated beam **underfills** the 1 x 1 cm detector. The calibrated detector is the NIST traceable standard used to measure the monochromatic flux.

The monochromatic flux, Φ_R [W], at the specified wavelength is determined from the relationship:

$$\Phi_R = S_{std} / R_{std}$$

where, S_{std} = Standard detector signal [A]
 R_{std} = Spectral response of standard detector at specified wavelength [A/W]

2) With the OL IS-670 positioned such that the entrance port is centered in the collimated beam and the OL 730-5A or OL 730-5H Detector with OL 730-5-RF Radiometric Filter inserted in the sphere exit port, record the detector signal, S_k [A]. This configuration is illustrated in Figure 6.

3) Compute the total radiant flux calibration factor, K_{Φ_R} [A/W], from the relationship:

$$K_{\Phi_R} = S_k / \Phi_R$$

where, S_k = OL 730C signal [A]
 Φ_R = Monochromatic flux at the specified wavelength [W]

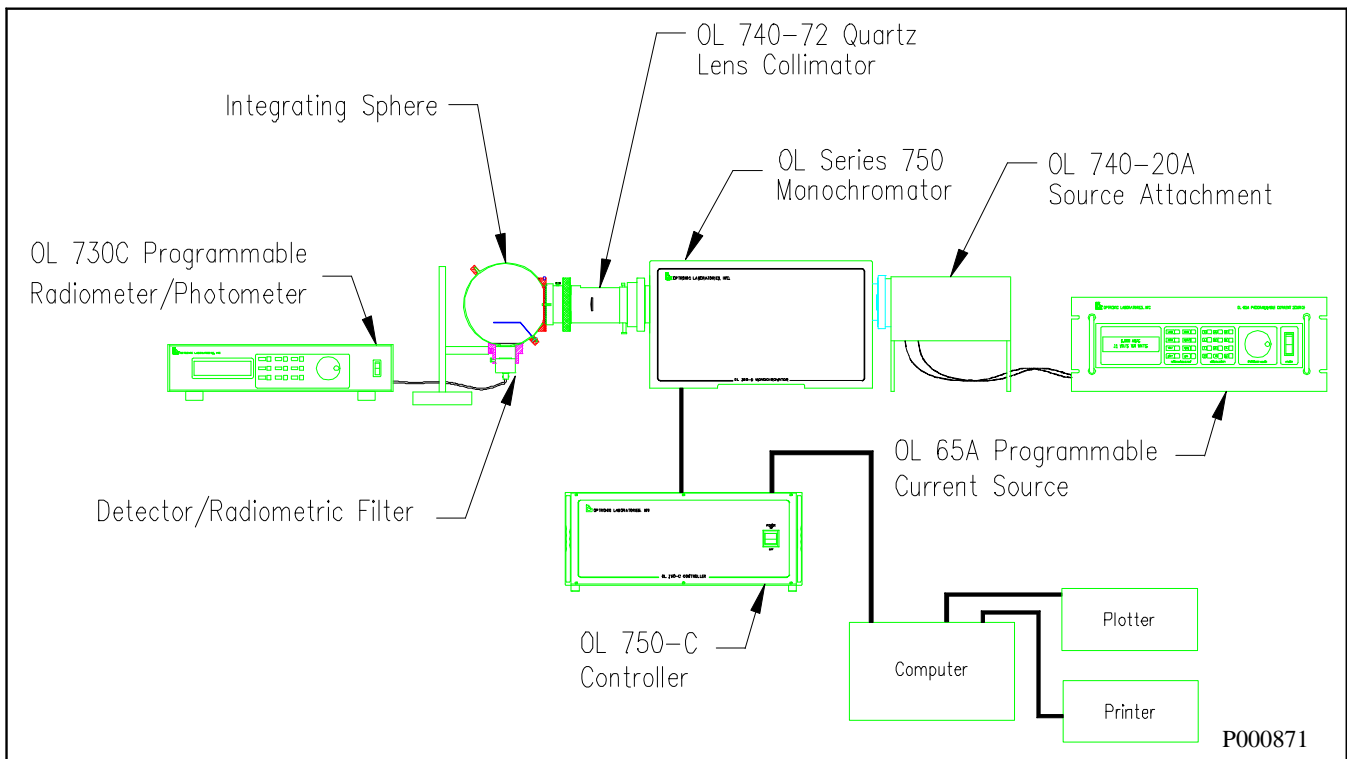


Figure 6 - Setup for Determining Total Radiant Flux Response Calibration Factor

4) Enter calibration factor into the OL 730C using the procedure described in the DETECTOR SETUP LIBRARY section of the OL 730C Manual.

Measurement Procedure (total radiant flux or total power)

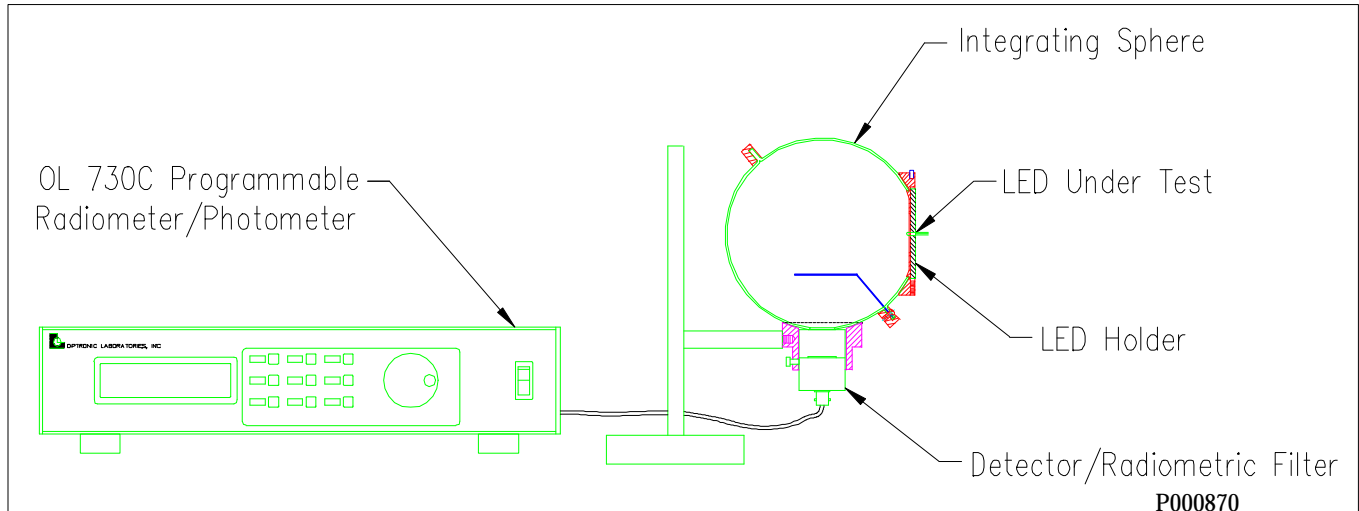


Figure 7 - Total Radiant Flux - Instrumentation for Measuring LED

Once the calibration factor has been entered into the OL 730C, the LED to be tested should be positioned at the entrance port of the OL IS-670 Integrating Sphere such that all of the radiant flux emitted by the LED is collected by the sphere. The OL 730C will display the radiant power directly in units of watts

3.2 Radiant Intensity (watts per steradian)

Instrumentation (radiant intensity) - The instrumentation recommended for measuring the radiant intensity of LEDs is listed below.

- 1) OL 730C Programmable Radiometer/Photometer
- 2) OL 730-5A or 730-5H UV-Enhanced Silicon Photodetector
- 3) OL 730-5-RF Radiometric Filter
- 4) OL 15 LED Receptor (includes single LED Holder)
- 5) OL 15-7PH 7-Position LED Holder (optional)

Calibration Procedure (radiant intensity response)

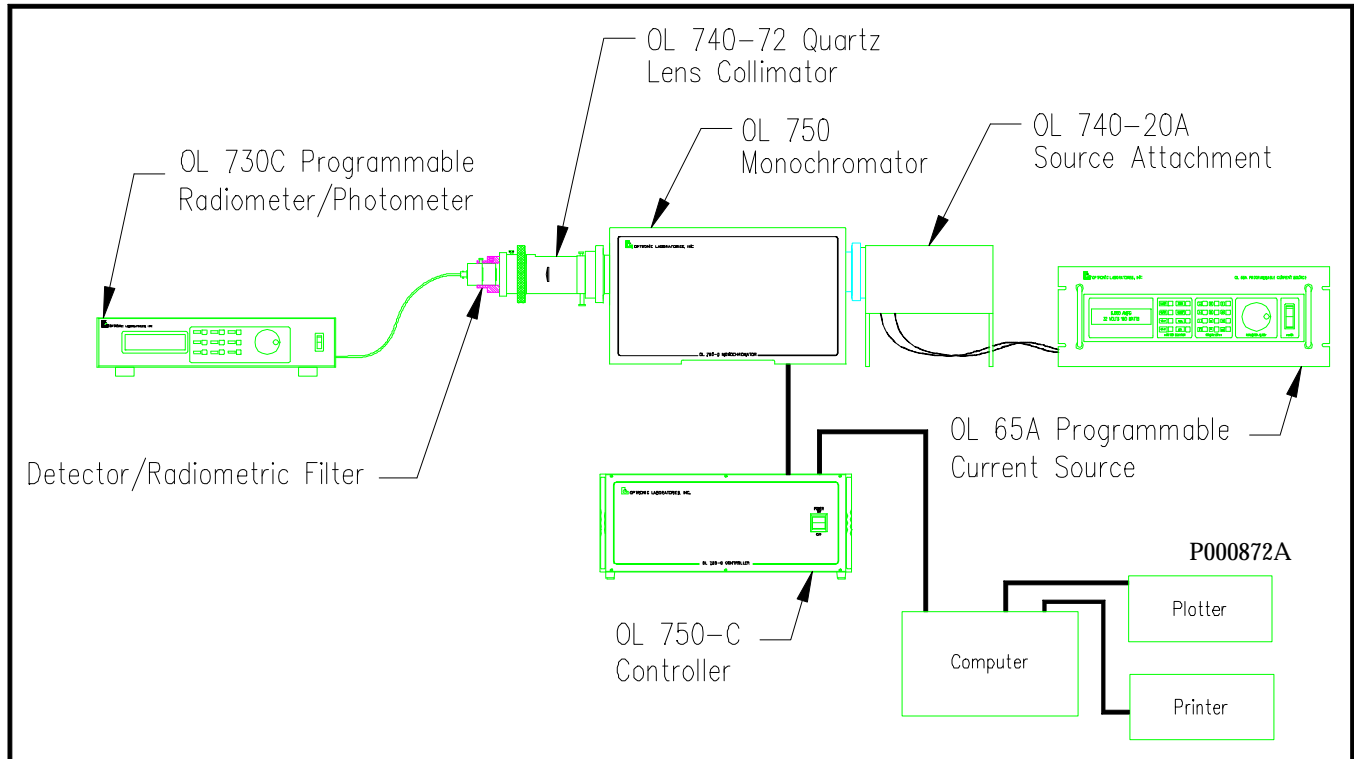


Figure 8 - Radiant Intensity - Spectroradiometric Measurement of Monochromatic Irradiance

The instrumentation and standards required for determining the radiant intensity response calibration factor, K_{R} [A/(W/sr)], for the measurement system consists of an OL Series 750 Automated Spectroradiometric Measurement System configured for measuring the spectral response of photodetectors as shown in Figure 5. The calibration involves the following procedure:

- 1) Measure the monochromatic irradiance [W/cm²] in the collimated beam at the wavelength of interest (for highest accuracy, select a wavelength relatively close to the peak wavelength of the LED). This is accomplished by positioning an OL 750 Calibrated Detector in the collimated beam such that the beam **overfills** the 1 x 1 cm detector. The monochromatic irradiance, E_R [W/cm²] at the specified wavelength is determined from the relationship:

$$E_R = S_{std} / R_{std}$$

where, S_{std} = Standard detector signal [A]

R_{std} = Spectral response of standard detector at specified wavelength [A/(W/cm²)]

- 2) Position the OL 730-5A or 730-5H Detector / OL 730-5-RF Radiometric Filter combination in the collimated, monochromatic beam such that the beam overfills the 1 x 1 cm detector and record the detector signal at the specified wavelength.
- 3) Compute the irradiance calibration factor, E_R [A/(W/cm²)], from the relationship:

$$E_R = S_K / E_R$$

where, S_K = OL 730C signal [A]

E_R = Monochromatic irradiance at the specified wavelength [W/cm²]

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- 4) The irradiance response calibration factor, K_{I_R} [A/(W/sr)], can now be multiplied by the FOV of the OL 15 LED Receptor (either 0.010 or 0.001 steradians - refer to the OL 15 LED Receptor Manual). The radiant intensity calibration factors K_{I_R} [A/(W/sr)] is calculated as follows:

$$K_{I_R} = E_R \cdot \text{FOV}$$

where E_R = Irradiance calibration factor at the specified wavelength [A/(W/cm²)]

FOV = Either 0.010 or 0.001 sr (Refer to the OL 15 LED Receptor Manual)

For direct reading in milliwatt per steradian, merely divide the radiant intensity calibration factors by 1000.

- 5) Enter the calibration factors into the OL 730C using the procedure described in the DETECTOR SETUP LIBRARY Section of the OL 730C Manual.

Measurement Procedure (radiant intensity)

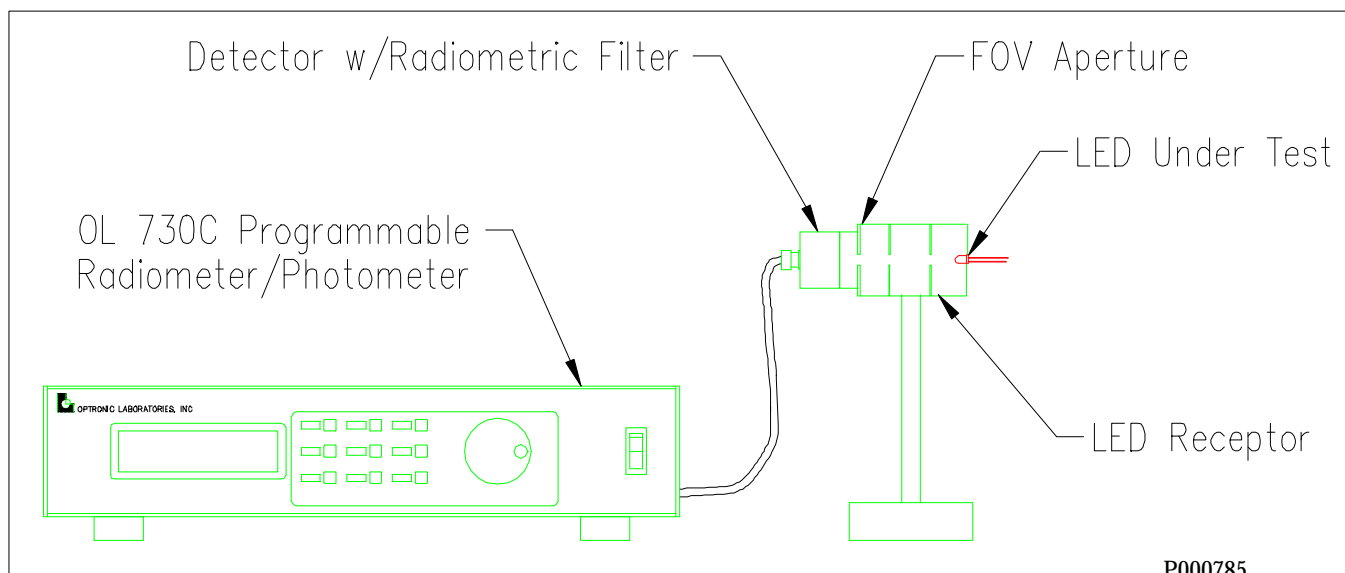


Figure 9 - Radiant Intensity - Instrumentation for Measuring LED

Figure 9 shows the setup for measuring the radiant intensity of an LED. The procedure is as follows:

- 1) Insert the desired FOV aperture into the OL 730-5 Detector / OL 730-5-RF Radiometric Filter combination.
- 2) Insert the OL 730-5 Detector / OL 730-5-RF Radiometric Filter combination into the detector end of the OL 15 LED Receptor.
- 3) Insert the test LED into the source end of the OL 15 LED Receptor.
- 4) Select the appropriate OL 730C Detector Setup and read out radiant intensity directly in units of watts/steradian.

4.0 SPECTRORADIOMETRIC MEASUREMENTS

When quantities are considered for monochromatic radiant energy, they become functions of wavelength. Therefore, their designations must be preceded by the adjective “spectral,” as in “spectral irradiance.” The symbol itself, for each quantity, is followed by the symbol for wavelength (λ). For example, spectral irradiance has the symbol $E(\lambda)$.

If spectral concentration of a quantity X is considered, it may also be preceded by “spectral” but the symbol is now subscripted. For example, $X_\lambda = dX/d\lambda$. If the spectral distribution of the source is known, in the visible wavelength range (i.e. 380 - 780 nm), the following relationship between the lumen and the watt can be used to convert from one to the other:

$$\Phi_v = 683 \int P_\lambda \cdot V_\lambda \cdot d\lambda$$

where, P_λ = Spectral power distribution of the light source from 380 to 780nm [W/nm]
 V_λ = Photopic luminous efficiency function [lm/W]
 λ = Wavelength (usually expressed in nanometers).

When a photometric or radiometric measurement of a light source is made, it is *not* possible to convert from photometric to radiometric units or vice versa, *unless* the spectral distribution of the source is precisely known. In the special case of a monochromatic light source - such as a laser - the equation simplifies as shown below. For example, in the case of a laser whose output is one watt at the peak of the Photopic Function (555 nm), the output is 683 lumens:

$$\text{Lumens} = P \cdot V = 1 \text{ watt} \cdot 683 \text{ lm/W} = 683 \text{ lm.}$$

The spectroradiometric quantities of particular interest with LED measurements are:

Spectral Radiant Flux or Spectral Power (Φ_λ) -The time rate flow of radiant energy over a specified wavelength interval (W/ nm).

Spectral Radiant Intensity (I_λ) - The total radiant flux emitted by a source per unit solid angle over a specified wavelength interval (W/ (sr nm)).

Peak Wavelength -The wavelength at which the LED has the maximum radiant output (nm).

4.1 Spectral Radiant Flux or Power (watts per nm)

Instrumentation (spectral radiant flux or power) - The recommended instrumentation for measuring the spectral power output of an LED is listed below:

- 1) OL Series 750 Automated Spectroradiometric Measurement System configured for measuring the spectral output of light sources.
- 2) OL IS-670 Integrating Sphere with LED Holder
- 3) OL 750-HSD-301 High Sensitivity Silicon Photodetector
- 4) OL IS-7PH 7-Position LED Holder (optional)

The standards and associated accessories recommended for calibration of the measurement instrumentation consists of:

- 1) OL 245M, 220M, 200M or FEL-M Standard of Spectral Irradiance
- 2) OL 65A or 83A Programmable Current Source
- 3) OL 57, 57W, 56 or 61 and 62 Lamp Holder
- 4) OL 63 Adjustable Lamp Holder Mount (optional)

Calibration Procedure (spectral radiant flux response or power response)

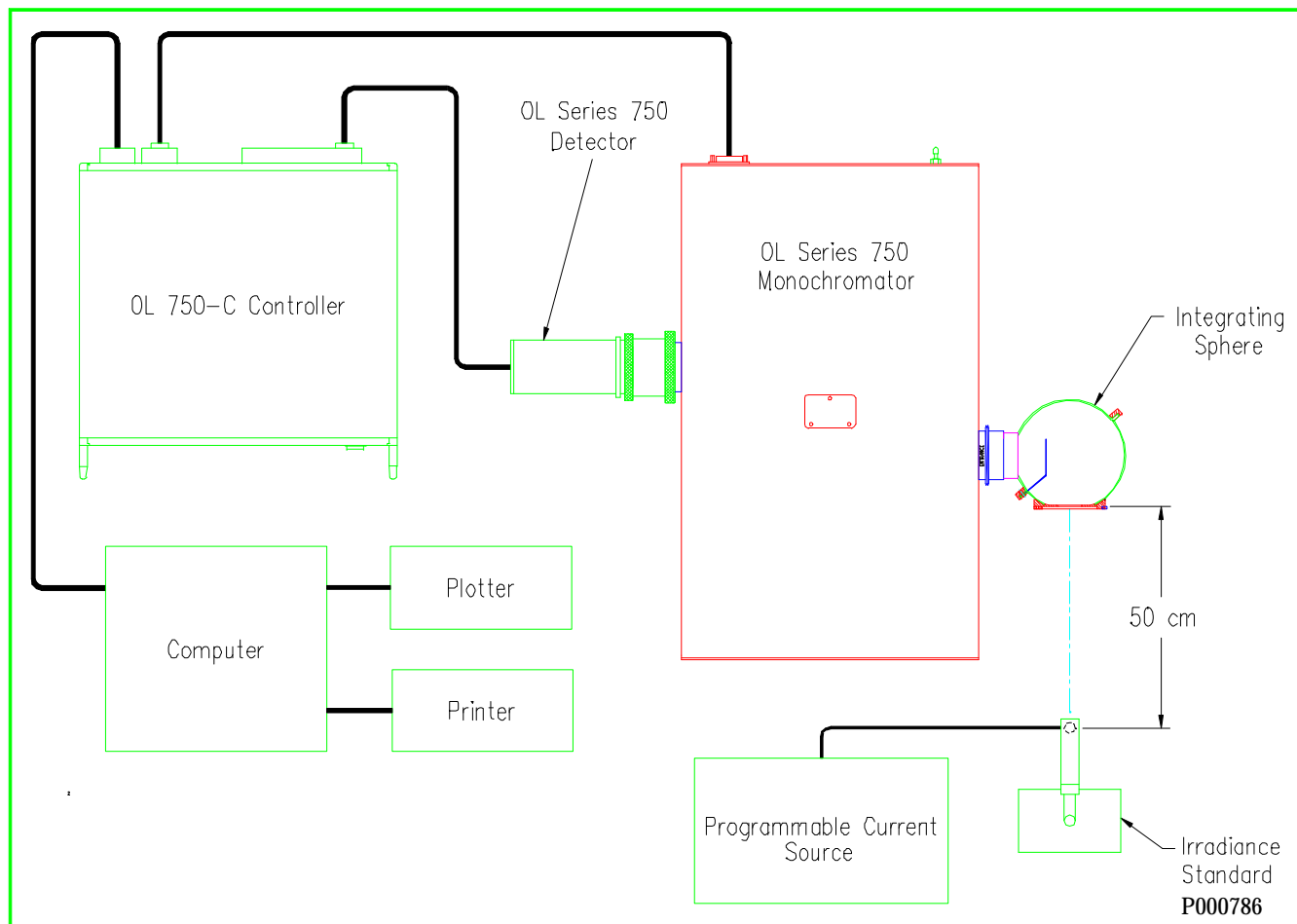


Figure 10 - Spectral Radiant Power Setup for Calibration of Spectral Measurement System

Figure 10 shows the setup for calibrating the measurement system for spectral radiant power response. The procedure is as follows:

- 1) Align the lamp standard of spectral irradiance at a distance of 50 cm from the entrance port of the integrating sphere. Note: Follow alignment instructions supplied with the irradiance standard.
- 2) Multiply the spectral irradiance values E_{std} , [W/(cm² · nm)] of the standard lamp by the area of entrance port of the OL IS-670 Integrating Sphere, A_o , (7.92 cm²) and store these spectral “power” values, Φ_{std} , [W/nm] in the computer. Note: This is easily accomplished using the “File Arithmetic” routine provided with the OL Series 750 General Operating Software (GOS).
- 3) Perform a spectral power scan of the standard lamp over the wavelength range of interest and store the spectral power response calibration factors, K_{Φ} , [(W/nm)/A]. Note: The OL Series 750 GOS performs the calculations automatically using the following equation:

$$K_{\Phi} = \Phi_{\text{std}} / S_k$$

where, Φ_{std} = Spectral power values
 S_k = OL Series 750 detector signal

Measurement Procedure (spectral radiant flux or power)

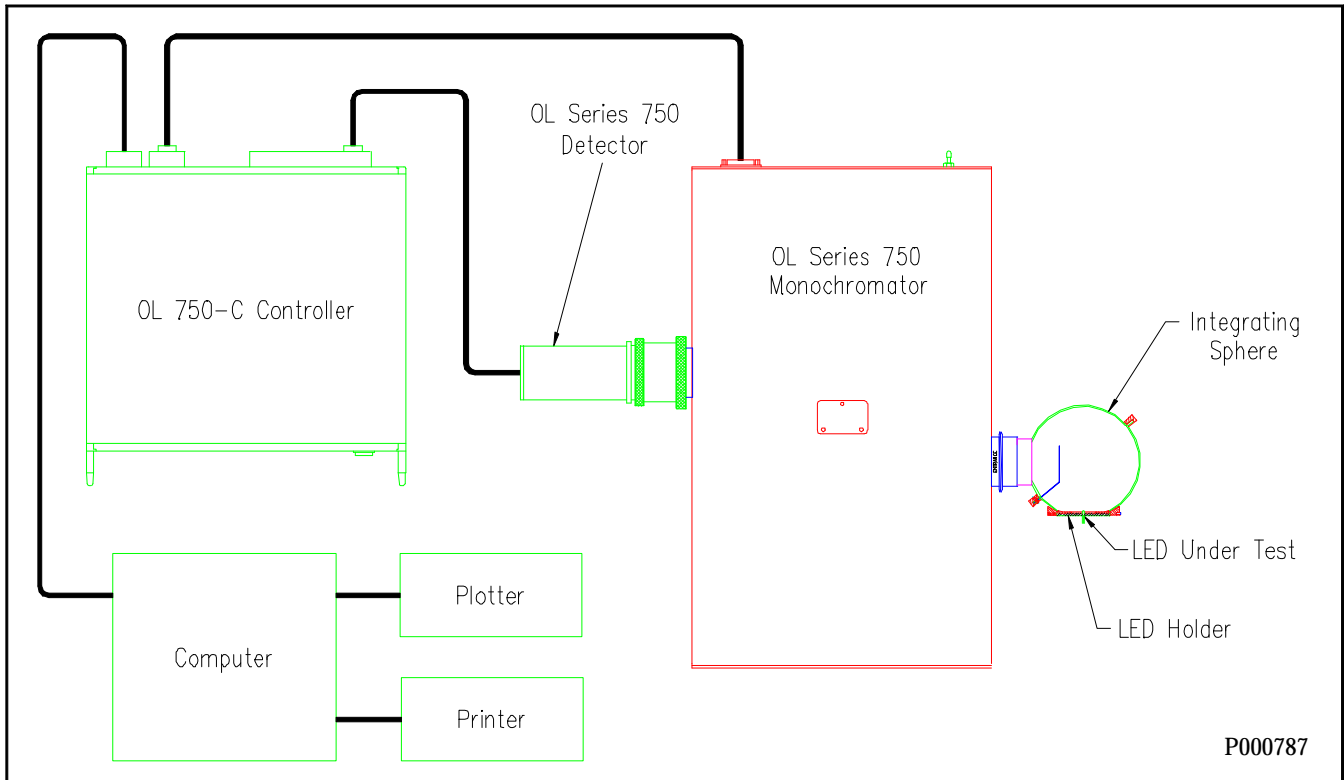


Figure 11 - Spectral Radiant Power - Instrumentation for Measuring LED

Figure 11 shows the setup for measuring the spectral power output of an LED. The procedure is as follows:

- 1) Insert the test LED at entrance port of the OL IS-670 Integrating Sphere such that all of the radiated flux is collected by the sphere.
- 2) Using the measurement routine and the appropriate spectral power response calibration factors, K_{Φ} , measure the spectral power output of the test LEDs, Φ [W/nm]. The OL 750 GOS performs this calculation automatically as follows:

$$\Phi = K_{\Phi} \cdot S_k$$

where, K_{Φ} = Spectral power response calibration factors [(W/nm)/A]

S_k = OL Series 750 detector signal [A]

4.2 Spectral Radiant Intensity (watts per steradian nm) _____

Instrumentation (spectral radiant intensity) - The recommended instrumentation for measuring the spectral radiant intensity of an LED is listed below.

- 1) OL Series 750 Automated Spectroradiometric Measurement System configured for measuring the spectral irradiance of sources
- 2) OL 15 LED Receptor (includes single LED Holder)
- 3) OL 750-HSD-301 High Sensitivity Silicon Photodetector
- 4) OL ISA-7PH 7-Position LED Holder (optional)

The standards and associated accessories recommended for calibration of the measurement instrumentation consists of:

- 1) OL 245M, 220M, 200M or FEL-M Standard of Spectral Irradiance
- 2) OL 65A or 83A Programmable Current Source
- 3) OL 57, 57W, 56 or 61 and 62 Lamp Holder
- 4) OL 63 Adjustable Lamp Holder Mount (optional)

Calibration Procedure (spectral radiant intensity response)

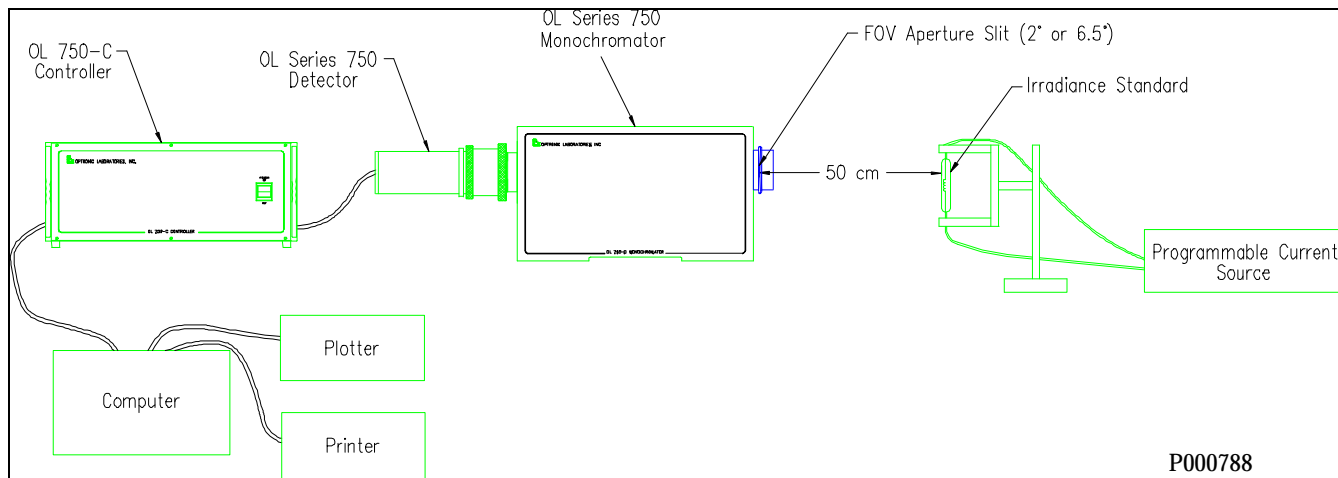


Figure 12 - Spectral Radiant Intensity - Setup for Calibration of Measurement System

Figure 12 shows the setup for calibrating the measurement system for spectral radiant intensity response $[(W/(sr \cdot nm))/A]$. The procedure is as follows

- 1) Insert either the 2° or 6.5° FOV aperture slit at the entrance port of the OL 750 Monochromator and the desired rectangular slit at the exit port.
- 2) Align the lamp standard of spectral irradiance at a distance of 50 cm from the entrance slit (aperture).
- 3) Multiply the spectral irradiance values of the standard lamp, E_{std} , by $(1000 \text{ sr}^{-1} \cdot \text{cm}^2)$ if using the 2° FOV aperture and by $(100 \text{ sr}^{-1} \cdot \text{cm}^2)$ if using the 6.5° FOV aperture and store these spectral radiant intensity values, I_{std} , $[W/(sr \cdot nm)]$ in the computer. Note: This is easily accomplished using the "File Arithmetic" routine provided with the OL Series 750 GOS.
- 4) Perform the spectral radiant intensity calibration scan over the wavelength range of interest and store the calibration factors, K_I , $[(W/(sr \cdot nm))/A]$. Note: the OL 750 GOS performs the calculation automatically using the following equation:

$$K_I = I_{std} / S_K$$

where, I_{std} = Spectral radiant intensity values $[W/(sr \cdot nm)]$
 S_K = OL Series 750 detector signal [A]

Measurement Procedure (spectral radiant intensity)

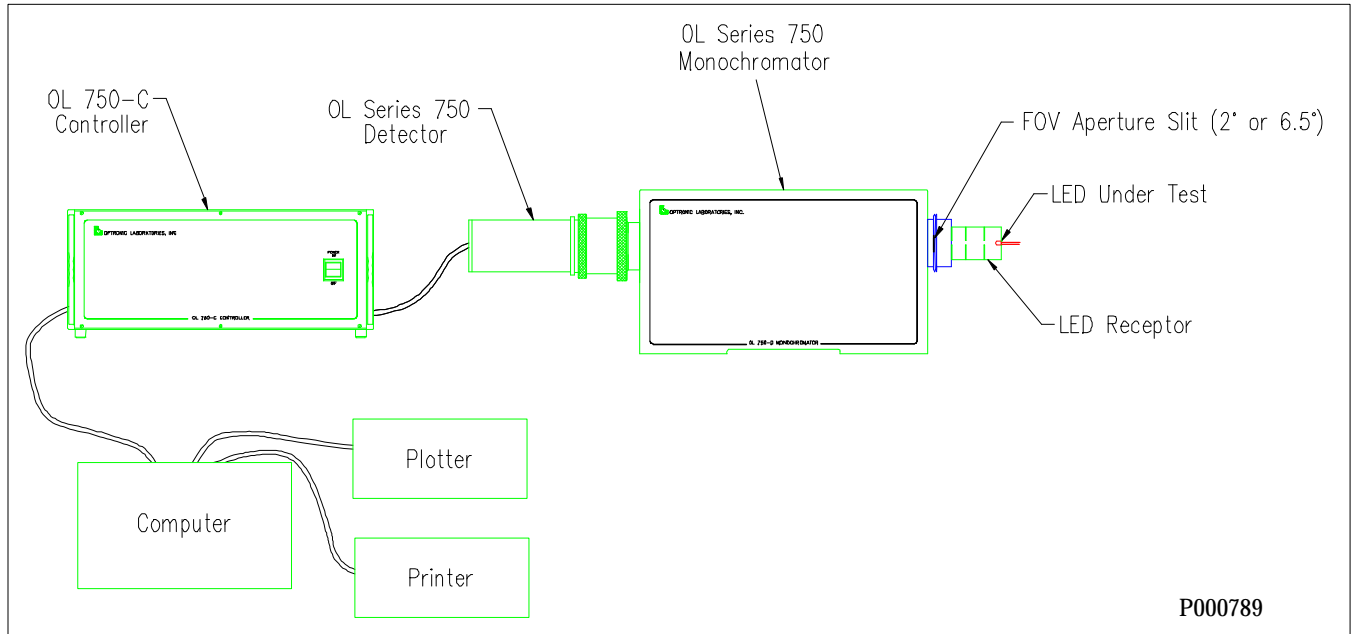


Figure 13 - Spectral Radiant Intensity - Instrumentation for Measuring LED

Figure 13 shows the setup for measuring the spectral radiant intensity of an LED. The procedure is as follows:

- 1) Mount the OL 15 LED Receptor to the entrance port of the monochromator.
- 2) Insert the test LED into the source port of the OL 15.
- 3) Using the measurement routine and the appropriate spectral radiant intensity calibration factors, K_I , measure the spectral radiant intensity of test LEDs, I [$W/(sr \cdot nm)$]. The OL 750 GOS performs the calculation automatically as follows:

$$I = K_I \cdot S_k$$

where, K_I = Spectral intensity response calibration factor [$(W/(sr \cdot nm))/A$]

S_k = OL Series 750 detector signal [A]

4.3 Peak Wavelength and 50% Power Points

The procedure for measuring the peak wavelength of an LED is similar to the calibration and measurements described in Sections 4.1 and 4.2. Once either the spectral radiant power or the spectral radiant intensity of the LED has been determined and the data saved, both the peak wavelength and 50% power points can be easily determined using the "Utilities Routine" provided with the OL Series 750 General Operating Software.