GAMMA SCIENTIFIC

The Guide to Radiometry

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Introduction

Radiometry is the measurement of radiation in the electromagnetic spectrum. This includes ultraviolet (UV), visible and infrared (IR) light.

Electromagnetic radiation is characterized by its frequency of oscillation. The frequency determines the "color" of the radiation (Figure 1). The speed of light is a constant, and frequency is related to wavelength by the relationship:

$$C = \lambda\gamma$$

C = speed of light

γ= wavelength

λ= frequency

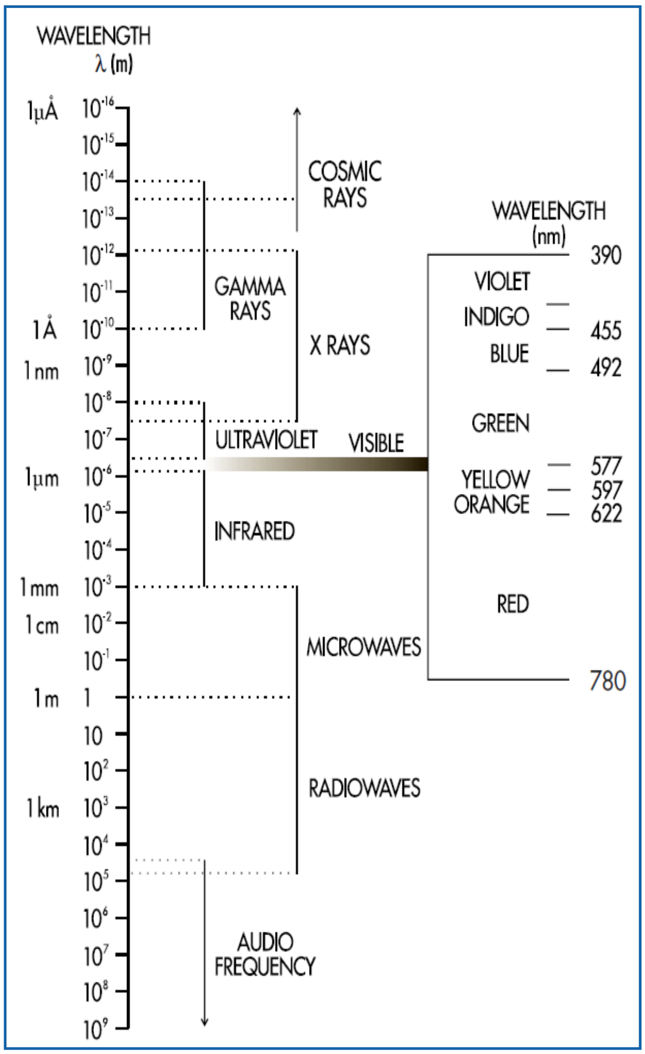


Figure 1

The preferred units of measure for wavelength are nanometers (nm) and micrometers (µm or "microns").

The visible region of the electromagnetic spectrum can divide into the basic colors of the rainbow: red, orange, yellow, green, blue, indigo and violet. Red light has the longest wavelength in the visible region (780 nm). Violet has the shortest (380 nm).

Ultraviolet light is shorter in wavelength than visible light. It extends approximately from 10 nm to 400 nm, and like other colors of the visible region,UV can be subdivided into multiple smaller regions: UVA, UVC, and VUV. The UVA region ranges from 315 nm to 400 nm and is the least harmful of UV radiation, UVB (280 - 315 nm), UVC (200-280 nm), and VUV, vacuum-ultraviolet (100-200 nm) are higher energy and have applications for medical and sterilization.

Infrared light extends from 700 nm to 100 microns. Its regions are know as near-IR, mid-IR and far-IR.

Measurements of optical radiation require specific methods to obtain accurate measurements. Gamma Scientific supplies calibrated detector/filter combinations that cover 200-2400 nm (0.3 to 2.4 µm). To obtain accurate measurements, one must understand the light source (laser, lamp, LED); the optical medium (air, water, optics); and the particular response characteristic of the detector.

Important Terms

Radiometric Quantities and Units			
Quantity	**Symbol**	**Units**	**Abbrev.**
Radiant energy	Q	joule = watt-second	J=W·sr
Radiant energy density	U	joule/m^3	J/m^3
Radiant flux (Power)	Φ,P	watts = joules/second	W=J/s
Irradiance	E	watts/m^2	W/m^2
Radiant exitance	M	watts/m^2	W/m^2
Radiance	L	watts/m2·steradian	W/m^2·sr
Radiant intensity	I	watts/steradian	W/sr

In order to accurately describe an optical source, one must use the correct units and know how these units apply to detector-based radiometry. In practical light measurement applications, the receiver of optical radiation is a detection device that converts optical radiation to electrical current according to a known relationship.

The chart above is a short breakdown of radiometric terms and their corresponding units of measure.

Radiant Energy

Radiant energy refers to the amount of power reaching a given point accumulated over time. This is referred to as joules (watt-second).

Radiant Flux

Radiant flux is the fundamental unit in detector-based radiometry. It is defined as the total optical power of a light source, and is expressed in watts.

To measure radiant flux, the detector must collect all emitted light. Examples of typical flux measurements are shown in Figure 2. Focused lasers and fiber optic cables require only the proper sensor head because the source and detector can be configured so that all radiation is incident within the active area of the sensor. Diverging light sources, such as LEDs and lamps, may require an integrating sphere to capture light radiating in several directions.

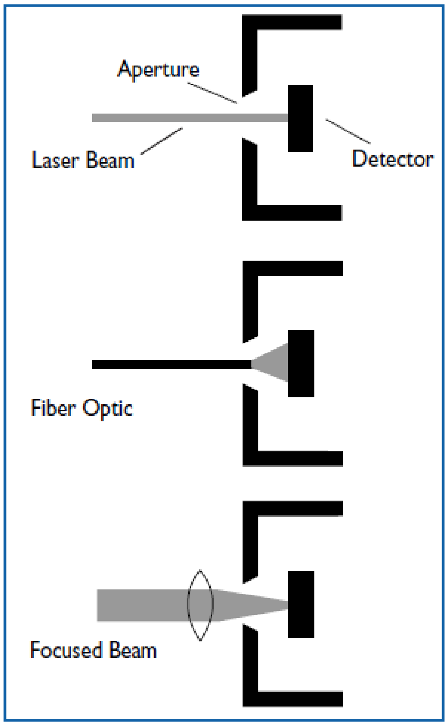


Figure 2

Irradiance

Irradiance is the amount of radiant flux incident on a known surface area. Its international unit of measurement is watt/m^2. However, because many sensor heads have a 1 cm^2 detector area, it is simpler to use watt/cm^2.

There are two ways to control the size of the detector area. The first is to use a sensor head with a known detector area. The second is to place an aperture with a known area between the source and the detector. When source radiation does not completely fill the detector, an aperture is the only reliable method of controlling detector area.

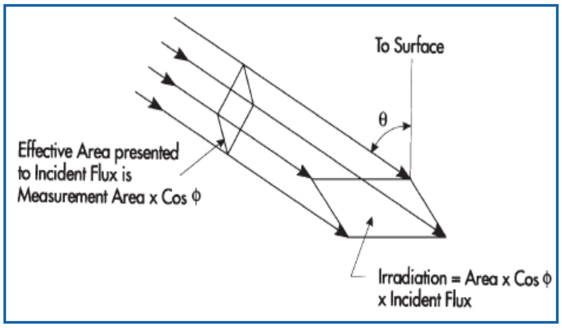


Figure 3

Important Terms

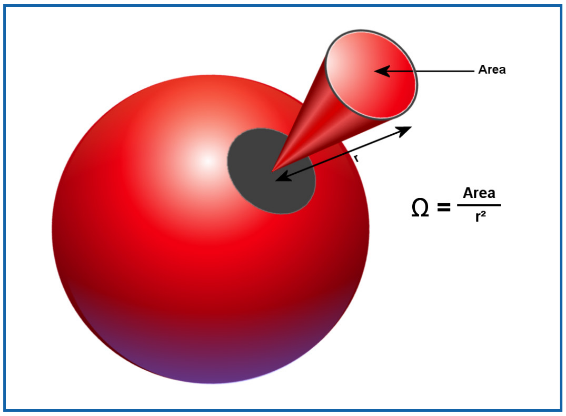


Figure 4

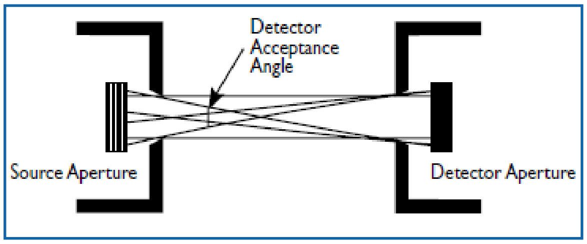


Figure 5

Radiant Exitance

Radiant exitance, a property of the light source, is the total radiant flux from the source divided by the surface area of the source. Its unit of measure is watt/m^2, simplified as watt/cm^2. This type of measurement only applies to extended light sources and is useful for making efficiency measurements of different light source materials.

Radiant Intensity

Radiant intensity is the amount of flux emitted through a known solid angle. It is measured in watts/steradian (watts/sr).

To measure radiant intensity, start with the angle subtended by the detector at a given distance from the source (Figure 4). Then divide the amount of flux by that solid angle.

Radiant intensity is a property of the light source and may not be relevant if the spatial distribution of radiation from the source is non-uniform. It is appropriate for point sources (and for close approximations, such as an LED intensity measurement), but not for collimated sources.

Radiance

Radiance is the radiant intensity emitted from a known unit area of a source. Units of radiance are used to describe extended light sources, such as flat panel display or an EL/O Panel unit for characterizing point sources.

To measure radiance, you need to define the area of the source to be measured, and also the solid angle received (Figure 5). This is usually simulated using an aperture and a positive lens in front of the detector. It is expressed as watts/cm^2 · sr

Calibration of Sensors

Radiometric sensors may be comprised of a detector (silicon, germanium, or indium-galium-arsenide, InGaAs) and a filter, or a combination of filters. Filters can be spectrally matched to detectors to create a desired response curve. This is accomplished by attenuating certain wavelengths.

The relationship between detectors and filters is delicate. A small variation in the thickness of the filter material is enough to cause a difference in the way two identical sensors perform. Therefore, sensors must be calibrated individually, to measure their unique responsivities (the relationship between detector output signal and incident flux).

One method of detector calibration is by "transfer of standards." Using this method, a detector is calibrated by comparing it with another detector of known response. Their responsivities are measured by alternately placing the two detectors in a radiant beam of known wavelength and intensity. Gamma Scientific calibrates each sensor head against a

Calibration by Transfer of Standards

$R_{\lambda t}$ = Responsivity of the test detector at wavelength (λ) .(A/W)

$R_{\lambda r}$ = Responsivity of the reference detector at wavelength (λ) .(A/W)

$I_{\lambda t}$ = Measurement of the test detector at wavelength (λ) . (A)

$I_{\lambda r}$ = Measurement of the reference detector at wavelength (λ) . (A)

$$R_{\lambda t}\left(\frac{A}{W}\right)=R_{\lambda r}\left(\frac{A}{W}\right)\left(\frac{I_{\lambda t}(A)}{I_{\lambda r}(A)}\right)$$

How to Specify a Radiometer System

Selecting a properly calibrated radiometric head and the right readout device are important in obtaining accurate results.

The sensor head converts electromagnetic radiation into an electrical signal. The readout device then receives this signal and interprets it. A properly calibrated measurement system will measure the light source and display the measurement in the appropriate optical units.

The readout unit should be selected according to its features, and the detector head should be selected according to its power measurement range, wavelength calibration, and size. The two matched together will accurately measure the source in the correct optical units.

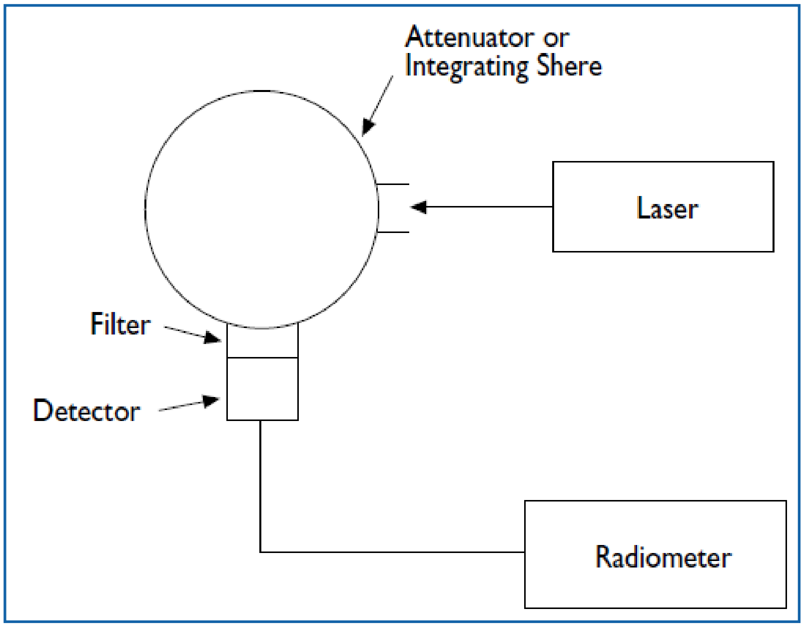


Figure 6

Consider The Source

As described previously in the "important terms" section, optical sources are characterized by certain units.

Collimated light sources, such as lasers, are typically characterized by radiant flux measurements (Figure 6). A beam that overfills a sensor head may be characterized by its power density (irradiance) in watts/cm^2. An integrating sphere can also be used in a radiant flux measurement in order to attenuate the laser power to be within the limits of the sensing device.

Point sources, such as LEDs, are characterized in units of radiant intensity, provided the spatial distribution is uniform. This type of measurement is easily achieved with an aperture and baffle tube to define the solid angle of detector acceptance. Measurements must always be made with a consistent solid angle. This constant solid angle may be defined by the detector's area and its distance from the point source. A point source may also be defined by units of radiant flux, provided all the radiation is captured in an integrating sphere.

Uniform extended sources such as lamps may be characterized by radiant flux or irradiance measurements.

Uniform extended sources such as flat-panel LCD displays, are best characterized by units of radiance.

Energy Measurements

Measurements of pulsed sources require special considerations. The standard unit of optical energy is the joule (watt-second). Integrating the signal over a known time period makes energy measurements. When making energy measurements of pulsed sources using silicon and germanium detectors, one must consider the effects of peak power on the detector. Saturation of the detector will cause the detector to behave non-linearly and will result in measurement error.

Wavelength and Optical Filters

Optical filters can be designed to allow certain wavelengths to pass through, while screening out others. A filter can be selected to modify a detector's response in order to limit the bandpass to match some desired response curve or to attenuate the input signal by a known amount. Many filter and detector combinations must be calibrated to ensure measurement accuracy.

A detector/filter combination that achieves a spectrally flat response is especailly useful for measuring broadband sources or sources where the peak wavelength is uncertain or may vary (Figure 7). Gamma Scientific uses flat filters that are accurate between 450 nm and 950 nm within ±5%.

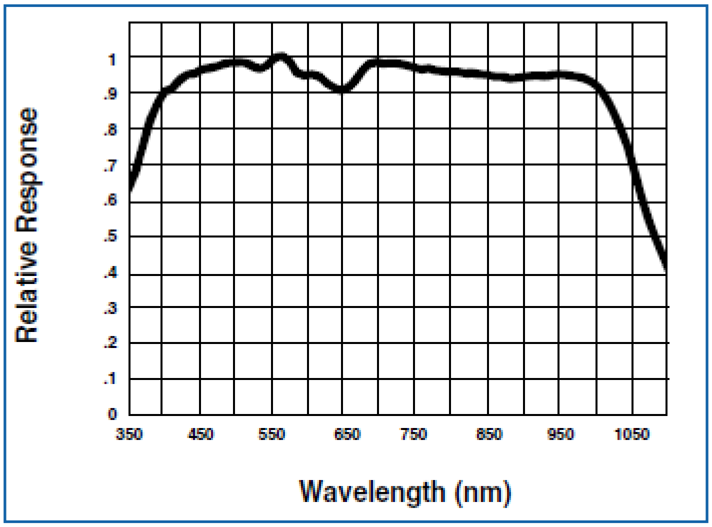


Figure 7

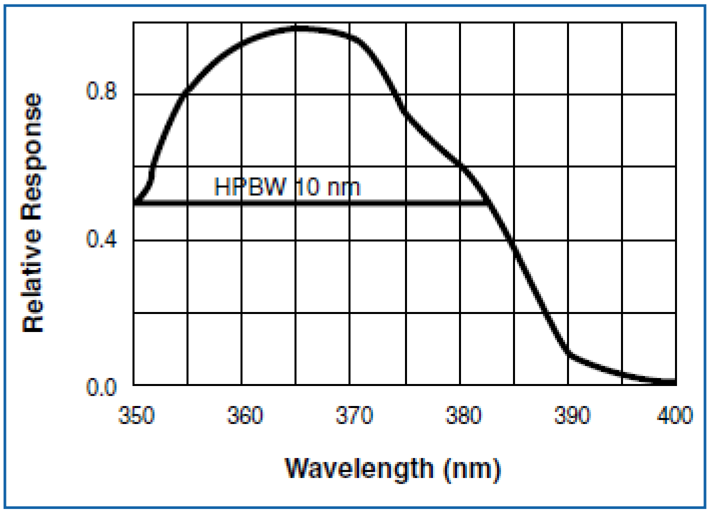


Figure 8

Detector/filter combinations that allow a specific broadband transmission are well suited for measuring arc lamp distribution peaks, visible light or UV spectral content (Figure 8).

Narrow bandpass filters are usually utilized for laser power measurements. This type of detector/filter combination assures that only the monochromatic radiation from the laser reaches the detector's active surface.

An important consideration to make before specifying a sensor head is how much power will be measured. In addition to having a well-defined wavelength range, they should also have a well-defined power handling capacity.

How to Specify a Radiometer System

Silicon, InGaAs and Germanium as Light Measurement Materials

Silicon, InGaAs and germanium are especially well-suited to measure light. These materials are specially processed to convert incident radiation to an electrical signal by the photoelectric effect. The conversion ratio or detector responsivity is linear over the sensor's input range. For a silicon sensor, this range spans 12 decades. For a germanium sensor it spans 9 decades. The sensor's response is also uniform over the active surface, making it ideally suited for both pwoer and power density measurements.

The InGaAs sensors are used in the telecommunications/fiber industries when high sensitivity, low dark current and high dynamic impedance are needed.

Once the applications and characteristics of the source and receiver have been fully defined, a radiometer system can be selected.

Gamma Scientific offers radiometer systems ranging from an extremely portable handheld meter that is durable enough for field use to a sophisticated benchtop model that interfaces with a computerized data acquisition system.

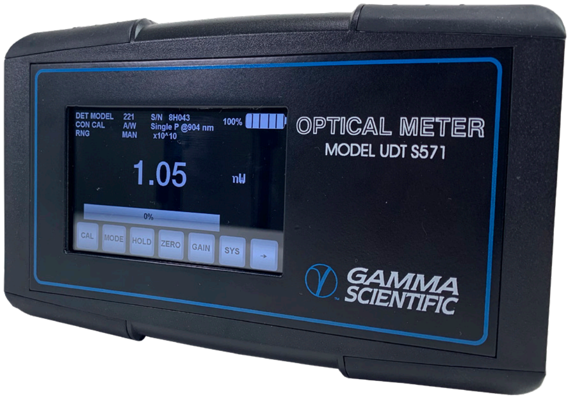
(Above) flexOPM S400 Benchtop Optical Meter with 268UVC detector

(Left) S571 Handheld Optical Meter with 247 radiometric detector

Detector Specifications

Model	Active Area	Spectral Range	Minimum Power	Maximum Power	Part Number
221 Silicon Sensor Head	1.0 cm^2	350 - 1100 nm	0.05 nW	2.4 mW	U23-01-102
222 UV Sensor Head	1.0 cm^2	200 - 400 nm	0.1 nW	7.2 mW	U23-01-103
247 Flat Response Sensor Head	1.0 cm^2	350 - 1100 nm	0.13 nW	6.4 mW	U23-01-168
260 Silicon Sensor Head - Mini	0.34 cm^2	350 - 1100 nm	0.05 nW	1.5 mW	U23-01-177
261 Germanium Sensor Head	0.50 cm^2	800 - 1750 nm	0.5 nW	6.0 mW	U23-01-178
262 Flat Response Sensor Head - Mini	0.34 cm^2	350 - 1100 nm	0.13 nW	4.0 mW	U23-01-179
264 Laser Sensor Head	0.34 cm^2	350 - 1100 nm	35 nW	40 mW	U23-01-181
280 InGaAs Sensor Head	0.03 cm^2	800 - 1750 nm	140 µW	2.2 mW	U23-01-258
268LP Laser Sensor Head - Low Profile	1.0 cm^2	350 - 1100 nm	0.7 nW	60 mW	U23-01-203
268R Flat Response Sensor Head - Low Profile	1.0 cm^2	350 - 1100 nm	0.13 nW	6.0 mW	U23-01-189
268UVA Optimized Sensor Head	1.0 cm^2	365 nm	0.5 nW/cm^2	100 mW/cm^2	U23-01-208
268UVC Optimized Sensor Head	1.0 cm^2	254 nm	50 nW/cm^2	500 mW/cm^2	U23-01-210
268BLUE UV/Blue Optimized Sensor Head	1.0 cm^2	450 nm	0.5 nW/cm^2	50 mW/cm^2	U23-01-211
S2575 Silicon Sensor/ Minisphere	N/A	450 - 1100 nm	30 nW	950 mW	U21-00-042
S2575GE Germanium Sensor/Minisphere	N/A	800 - 1750 nm	3 nW	1600 mW	U21-00-054
S2575R Flat Response Sensor/Minisphere	N/A	350 - 1100 nm	60 nW	1800 mW	U21-00-053

Optical Meters



S571 High Performance Handheld Optical Meter

The model S571 High Performance Handheld Optical Meter is ideal for photometric, radiometric, laser power, and fiber optic measurements. Designed to be used in a laboratory setting or field environment, the microprocessor controlled architecture features a color touch panel display, micro USB computer interface, and analog voltage output.

flexOPM S400 Benchtop Optical Meter

The S400 Series Optical Meters are ideal for photometric, radiometric, laser power, and fiber optic measurements. Models incorporating up to 4 individually calibrated sensor heads are available. The device has power and energy measurement capabilities and temperature stabilized detector options available. This system features a microprocessor controlled architecture with USB, RS-232, RS-485 and IEEE-488.2 interfaces.

Our wide range of optical meters, photometric and radiometric sensors is complemented by ISO/IEC 17025 accreditation by NVLAP (NVLAP lab code 200823-0), resulting in unmatched performance and custom configuration as required.

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