UDT INSTRUMENTS

MAKING LIGHT WORK OF LIGHT MEASUREMENT

The Guide To

RADIOMETRY

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Additional References from UDT Instruments:

Photomety & Radiometry:

Guide to Photometer & Radiometer System Configuration
(PDF; including a catalog of UDTi components)

Application Pages (on the UDTi website):

LED Test & Measurement
Laser Test
Fiber-Optic Test
General Radiometry

About UDT Instruments

HISTORY

The early beginnings of UDT Instruments can be traced to 1967 when a small group of inventors at United Detector Technology (UDT) began manufacturing the first commercially available transimpedance amplifiers for planar-diffused and Schottky barrier silicon photosensors. Over the next several years, this same group of people went on to pioneer leading-edge technological innovations for photometers, radiometers, fiber-optic power meters and optical position-sensing instruments. By the early 1980's, this highly skilled and successful group grew into an autonomous entity known as UDT Instruments.

Drawing on the momentum generated by UDT's precision photometric instruments,the company developed an inventive handheld colorimeter for the growing television and computer peripherals markets. The development of UDT's SLS9400 colorimeter promises to strengthen our company's position as a leader in precision electro-optics instrumentation, while meeting the stringent demands of a multitude of CRT calibration requirements. UDT is poised and ready to excel to greater technological excellence with only one goal in mind: to meet and exceed the ever-changing needs of its customers worldwide.

SERVICE

We at UDT Instruments stand behind our products and the companies who use them. For this reason, we continue to service those same light-measuring instruments that we built twenty years ago. By offering these services to our customers, both new and established, we stay involved with our products and extend a personal touch to our business relationships. We know of no other company in our industry that hires more qualified sales engineers, people who really understand light measurement principles and practices. By hiring such knowledgeable engineers, we ensure you that you will get the best electro-optic instruments to fit your application and budget.

QUALITY

The instrument you receive is certain to be reliable and accurate. We maintain a Quality program that affects every indicator module, sensor head, and optical accessory we sell. And when it comes time for re-calibration, upgrades, or repairs, you'll discover that our service and metrology departments reflect this same commitment to quality and personalized service.

About UDT Instruments

TECHNOLOGY

UDT Instruments has always been and continues to be at the forefront of light measurement technology. We hold U.S. and worldwide patents on our QED products, which are absolute radiometric reference standards in the visible and near IR spectrum. Our QED-200 product won a prestigious IR-100 award as one of the 100 most significant U.S. inventions in 1986. These products were developed in conjunction with the National Institute of Standards & Technology (NIST) and the National Physical Laboratory (NPL). UDT Instruments continues to work with the NIST under Cooperative Research And Development Agreements (CRADA) in order to develop even more state-of-the-art products into the 21st Century.

PUBLICATIONS

In addition to our comprehensive "Guide To" tutorial series, UDT regularly publishes articles in trade journals and other scientific literature which we've made available as application notes to explain subtle details and applications of our technology.

PROFESSIONAL SOCIETIES

UDT is committed to supporting the industry through its professional society affiliates. We are proud to be sustaining members of:

- Society of Photo Optical Instrumentation Engineers (SPIE)
- Optical Society of America (OSA)
- National Association of Broadcasters (NAB)
- Laser Institute of America (LIA)
- Illuminating Engineering Society of America (IES)
- Society For Information Display (SID)

UDT also actively participates in the Council for Optical Radiation Measurement (CORM) and the Commission Internationale l'Eclairage (CIE).

WARRANTY

UDT Instruments warrants that its products are free from defects in material and workmanship under normal use and service for a period of one year from the date of shipment from our factory. UDT Instruments's obligation under this warranty is limited to the replacement or repair of any product determined to be defective during the warranty period, provided the product is returned to the factory prepaid. This warranty does not apply to any equipment that has been repaired or altered, except by UDT Instruments, or which has been subject to misuse, negligence, or accidents. It is expressly agreed that this warranty will be in lieu of all warranty of merchantability. No other warranty is expressed or implied. UDT Instruments is not liable for consequential damages.

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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 (see Figure 1). The speed of light is a constant, and frequency is related to wavelength by the relationship:

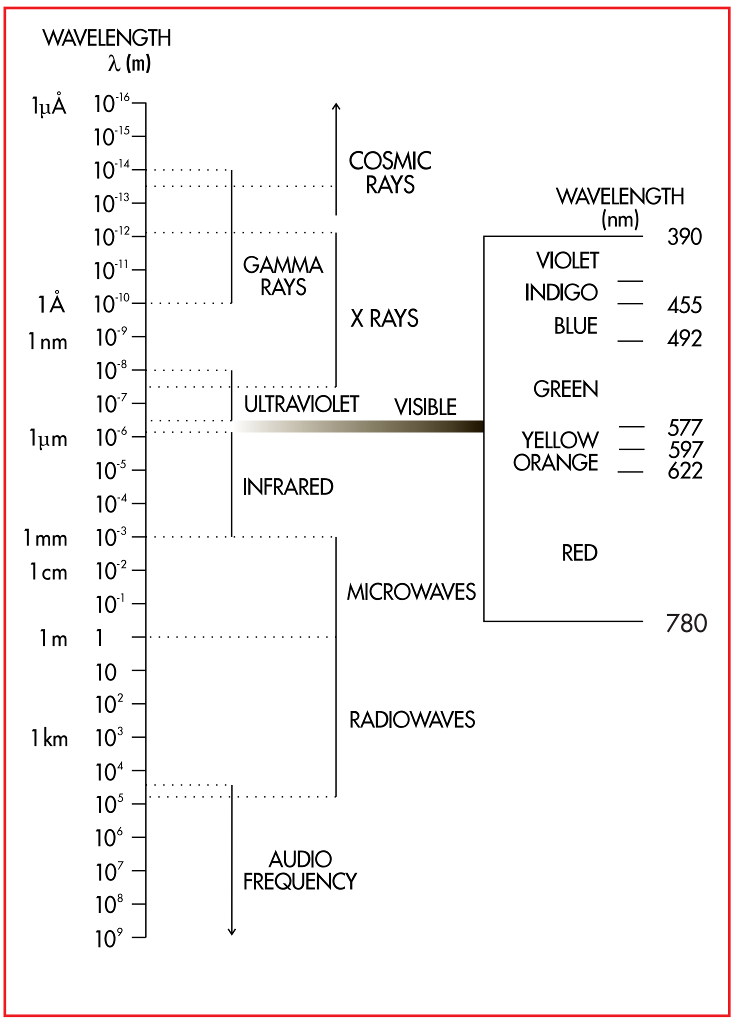

Figure 1

$C = \lambda\gamma$

C = speed of light

γ = wavelength

λ = frequency

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 3 smaller regions: UVA, VUV and UVC. The UVA region ranges from 400 nm down to 320 nm and is the least harmful of UV radiation. The vacuum-ultraviolet (VUV) and UVC regions are shorter and important to the study of cancer.

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

Measurements of optical radiation require specific methods to obtain accurate measurements. UDT Instruments supplies calibrated detector/filter combinations that cover from 200-1800 nm (0.2 to 1.8µm). To obtain accurate measurements, one must understand the light source (i.e. laser, lamp, LED); the optical medium (i.e. air, water, optics); and the particular response characteristics of the detector.

IMPORTANT TERMS

Radiometric Quantities and Units

Quantity	Symbol	Units	Abbrev.
Radiant energy	Q	joule=watt-second	J=W•s
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/m^2•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 displayed on the left is a short breakdown of radiometric terms and their corresponding units of measure.

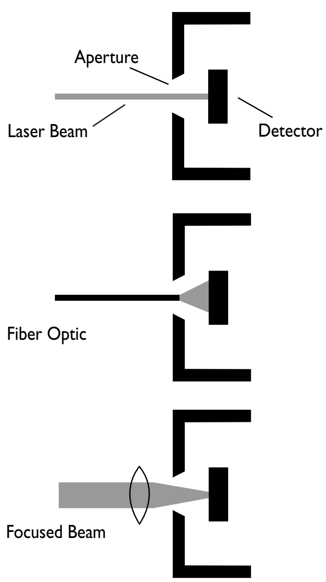

Figure 2

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.

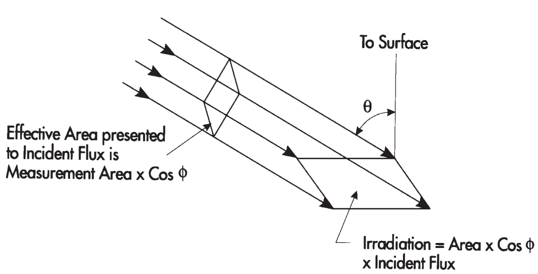

Figure 3

Irradiance

Irradiance is the amount of radiant flux incident on a known surface area. Its international unit of measure 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.

IMPORTANT TERMS

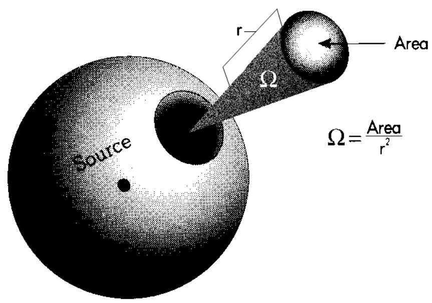

Figure 4

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.

To make radiant existence measurements, one must know the surface area of the source and then measure the total radiant flux leaving the source.

Radiant Intensity

Radiant Intensity is the amount of flux emitted through a known solid angle. It is measured in **watts/steradian**.

To measure radiant intensity, start with the angle subtended by the detector at a given distance from the source (see 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 measurements), but not for collimated sources.

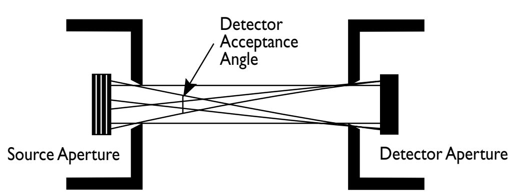

Figure 5

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 a CRT 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 (see 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·ster**.

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CALIBRATION OF SENSORS

Radiometric Sensors may be comprised of a detector (i.e. silicon or germanium) 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 (refer to explanation in left insert).

UDT Instruments calibrates each sensor head against a NIST-traceable detector. The calibration data is then matched to a readout device.

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)

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

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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.

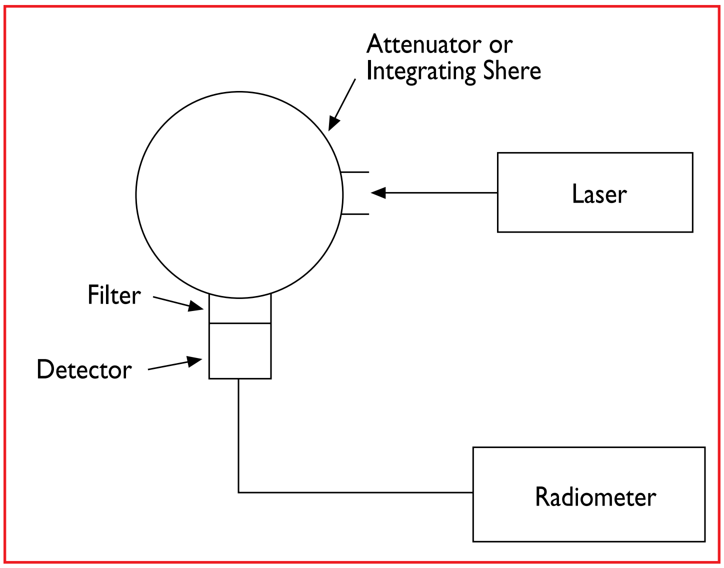

Figure 6

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 baffled 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.

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HOW TO SPECIFY A RADIOMETER SYSTEM

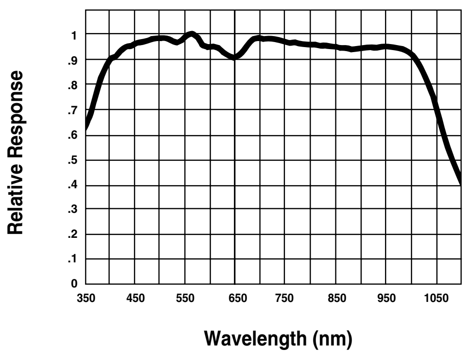

Figure 7

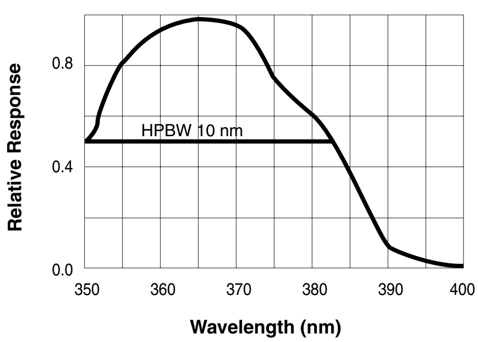

Figure 8

SEE ALSO:

The *Guide to Photometer & Radiometer System Configuration*, available as a free PDF download at:

www.udtinstruments.com

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 (Figure 7) is especially useful for measuring broadband sources or sources where the peak wavelength is uncertain or may vary. UDT Instruments' newest flat filters are accurate between 450 and 950 nm to within ±5%.

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.

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 power 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.

UDT Instruments 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.