Application Note

SPD dependence of calibration factor for LMT near–infrared (NIR) radiometric systems

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Verteiler/Distribution	Users of IR 1600 or similar		

Requirements

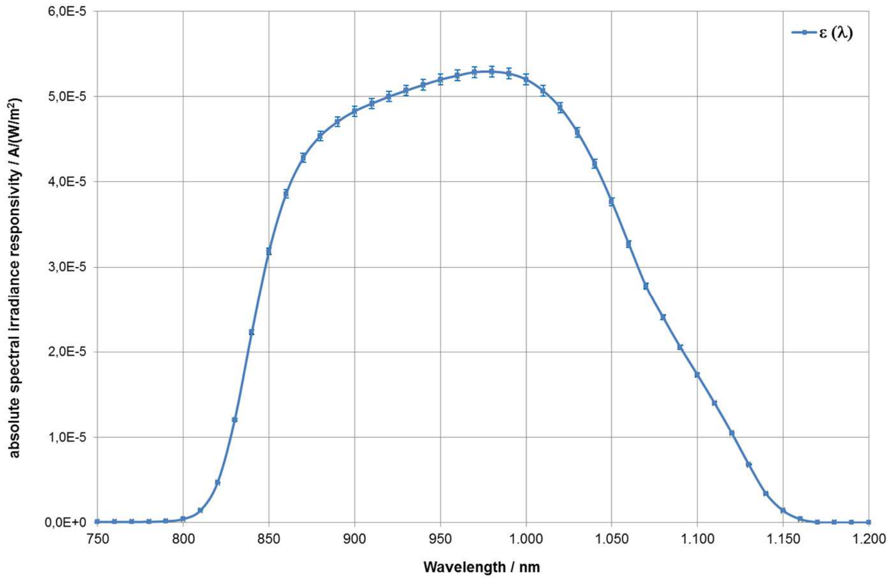
The spectral responsivity the IR radiometer must be available. Usually, LMT's NIR radiometer heads have been characterized with its sensitivity recorded in absolute units, i.e. $A/(W/m^2)$.

Alternatively, absolute sensitivity may be traced back from illuminance via the spectral power density (SPD) of a light source which covers both the visible as well as the NIR region. This may be for instance an Incandescent source like Wi41/G operating at Standard Illuminant A or any other Tungsten Halogen light source.

Irradiance responsivity

The figure below displays such a sensitivity curve in the range from 750 nm up to 1100 nm in steps of 10 nm. Uncertainty bars with a significance level of 95% are plotted at the measured wavelength nodes.

The near-infrared range is realized with a long band transmission filter at 800nm, while the upper edge is located at 1160 nm via the band gap of the silicon sensor. Since the area above 1100 nm is not easy accessible with standard measurement equipment, the responsivity in this area is extrapolated based on data sheets from Hamamatsu and/or from publications dealing with solar cells.



For the purpose of measuring near-infrared irradiance the radiometer head integrates signals from 780 nm – 1160 nm. As indicated above, the interval from 1100 nm to 1160 nm carries a higher measurement uncertainty.

Calculation of the "calibration factor"

Since the responsivity of the radiometer head is not flat but optimized for high sensitivity, the reading of the photo current is dependent on the individual spectrum $S_{LS}(\lambda)$ emitted by the light source under test.

In order to calculate the photo current generated by an irradiance of 1 W/m² in the near-infrared wavelength range, one needs to normalize the source's „relative“ spectral power distribution such that the irradiance from 780nm up to 1160 nm sums up to 1W/m², i.e.

$$\int_{780}^{1160} S_{LS}(\lambda)d\lambda = 1\ \frac{W}{m^2}$$

Corresponding SI units are $\left[\frac{W}{m^2 nm}\ nm\right] = \left[\frac{W}{m^2}\right]$

Once the spectrum is normalized, one can calculate the photo current I_{1W/m^2} per Watt NIR irradiance as

$$I_{1W/m^2} = \int_{780}^{1160} S_{LS}(\lambda) \cdot \varepsilon(\lambda)d\lambda$$

SI units $[A] = \left[\frac{W}{m^2 nm} \cdot \frac{A}{\frac{W}{m^2}} \cdot nm\right]$

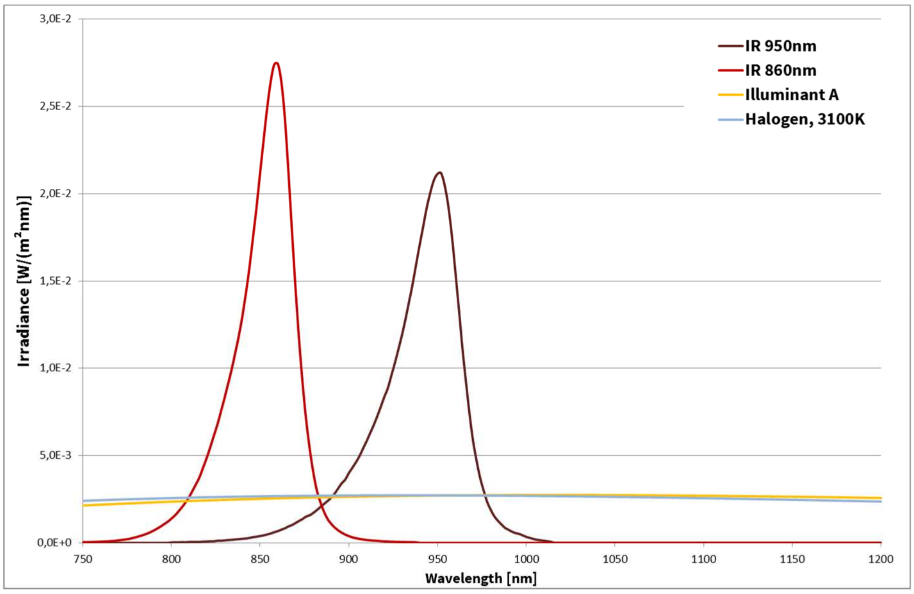
The calibration factor to determine the NIR irradiance from the photo current is given by the inverse number, i.e. the photo current needs to be divided by I_{1W/m^2}:

$$E_{IR}[780{,}1160] = \frac{I}{I_{1\frac{W}{m^2}}} \cdot 1000 \qquad \left[\frac{mW/m^2}{A}\right]$$

The integration yields into a sum of the contributions from all measured data points. Usually, $\varepsilon(\lambda)$ is available in discrete steps of $d\lambda$ = 10nm. Since in most cases mW/m² or mW/sr is used (as for instance in LMT's goniophotometer software LIMES 2000), the calibration factor is multiplied by 1000.

In order to generate the conversion to mW/sr, the calibration factor must be multiplied with the squared distance of the radiometer head.

The calculation generates very reliable numbers for light sources, which do not have a strong contribution at the edges of the responsivity curve, for example for infrared-diodes.



On request an excel file doing this calculation is provided by LMT. Several examples are shown in the figure above. For instance, the SPD of a 950nm-IR-Diode yields into a value of $4.851*10^{-05}$ A/(W/m²). Hence, the corresponding calibration factor is $2.061*10^{7}$ (mW/m²)/A and in case the distance is 25m, the calibration factor becomes $1.288*10^{10}$ (mW/sr)/A.

The algorithm is similar to calculating tristimulus values, i.e. it has to conserve the energy below the curve while extrapolating the SPD at the wavelength nodes where $\varepsilon(\lambda)$ is known.

Sources of IR spectra

Spectra of NIR sources should be either measured, which is the straight forward way, or downloaded from the light source manufacturer's data base. A useful tool is for instance the Color-Calculator by OSRAM Sylvania, which delivers on request the (ir-)radiance of the source already with a value of 1W/m² when calculating the SPD.

Spectra of Incandescent or Tungsten-Halogen sources may be calculated using the specific form of the Planckian formula given in CIE 015, which uses the colour temperature as the only input parameter. Successively, one has to normalize the radiation within the wavelength band of interest, i.e. 780 nm to 1160 nm, to 1 W/m².

IR radiometer head with photometer unit

Instead of using a dedicated radiometer unit, LMT offers as well employment of NIR radiometer heads in combination with the standard photometer unit. This requires more preparatory work since the IR radiometer head needs to be exchanged with the photometer head but has been proven a viable and economic solution under the assumption, that the sensor is easily accessible.

In this case one needs to calculate the "calibration factor" in the unit $\frac{mW/m^2}{lx}$.

The photometer unit will still display lux; however, the software will transfer this into the corresponding radiometric unit, i.e. mW/m² or mW/sr.

The calculation is straight forward but relies on the fact that the IR radiometer head always simulates a photometer with a sensitivity of 20nA/lx. If this is given, the formerly calculated factor E_{IR}, i.e. the current per 1W/m² must be divided by 20 nA/lx, respectively multiplied by $5{\cdot}10^{7}$ lx/A:

$$E_{IR}\left[\frac{lx}{W/m^2}\right] = 5 \cdot 10^7 \cdot E_{IR}\left[\frac{A}{W/m^2}\right]$$

Software implementation

When using the software LIMES 2000, the operator should have in mind that the illuminance is given in a certain distance, i.e. on a screen or on a spherical surface. This distance is usually called screen distance. In contrast to the software setting, the display of the unit always shows the actual illuminance at the sensor which may be different from what the software is displaying, especially if the sensor distance deviates from 25m or the actual observation angle differs from (0/0).

Therefore, if the user wants to have the software show the same values than the ones displayed by the unit, screen distance should be set to the actual distance of the sensor and the geometry should be set to "Sphere".

This must be kept in mind, if the sensor is often exchanged and the unit is used as well with standard photometers for headlamp measurement, because for the latter case the screen geometry is usually used with a distance of 25m. Especially, test reports using illuminance values on a screen will differ, when the geometry or distances are changed.