APPLICATION NOTE

NOVEMBER 22

SUPERCONTINUUM SOURCES FOR HYPERSPECTRAL IMAGING

For more than a decade, supercontinuum sources have replaced lasers in applications requiring many colors or broad-band illumination. The price, form factor, and reliability of supercontinuum sources have now reached a level where applications like hyperspectral imaging may benefit from the bright and very directed light produced by supercontinuum sources. Supercontinuum sources offer several benefits:

- High brightness – the output from a supercontinuum can be focused down to the fundamental diffraction limit resulting in high brightness.
- Long standoff distances – compared to LEDs and halogen lamps, it is possible to transmit supercontinuum beams over long distances with limited losses as the beam remains well confined spatially. This is due to the low divergence of the supercontinuum light.
- Contrast in illumination - Due to the high level of light confinement, large contrast between areas that are to be illuminated and areas that are not can be achieved. This is useful for indirect illumination, for example, trans-interactance measurements.

Irradiance calculation

Before diving into the data for any light source and especially when comparing different illumination technologies, we recommend paying close attention to the specifications and your specific illumination geometry.

In a supercontinuum source, the light is emitted from a single-mode fiber aperture. Once the light has left the fiber, analysis can be made simpler and quite accurate by assuming the so-called Gaussian beam propagation. This is done by using well-established closed-form expressions and even matrix formalisms for the analysis of multi-element systems. This formalism is well-known for users and designers of lasers and laser systems. It is also possible to perform paraxial beam propagation analysis by only knowing the initial beam parameters (confocal parameter and distance to beam waist). Irradiance at a given position can be calculated by also knowing the power carried in the beam.

In the world of illumination, manufacturers of halogen and LED light sources often specify power per unit area per unit wavelengths. The unit used is typically mW*mm^{-2}*nm^{-1}. The manufacturers of laser pumped plasma sources, on the other hand, also take the angular extend of the source into consideration, and the unit used is mW*mm^{-2}*sr^{-1}*nm^{-1}.

Direct comparison of these terminologies can be challenging for users – as there is no simple conversion from one set of units to another – and any conversion depends on the geometry of the measurement setup. Therefore, we recommend caution while making any such comparisons. Ultimately, it is a good idea to confirm the performance of specific configurations experimentally.

Do not hesitate to contact NKT Photonics with any questions related to expected power irradiance levels.

How to estimate the irradiance in a specific geometry?

Let us assume we want to illuminate a line under a hyperspectral imaging camera in a push broom configuration.

The parameters are:

Fan line length (FLL) = 100 mm (usually depends on the width of the conveyor belt or sample channel that is to be illuminated).

Fan line width (z) = 500 um (width of the illuminated line).

Area of illumination

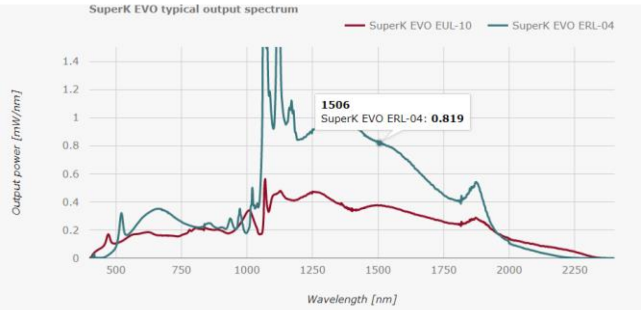
At first, we assume that the area is uniformly illuminated (this is not the case, and we shall return to this later).

The illuminated area = 100 mm x 500 um = 50 mm^2

Power density for the source

The power density of NKT Photonics Supercontinuum sources can be found on our website.

In this example, we will assume the source is a SuperK EVO ERL-04 laser, and we are interested in the irradiance at 1500 nm. The power density is 0.819 mW/nm.



Irradiance

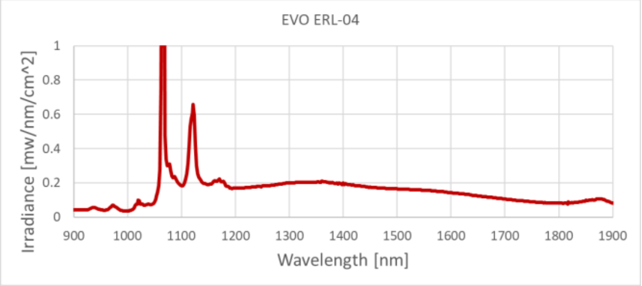
The irradiance can be calculated as,

Irradiance = Power density/Illumination Area

=0.819 mW/nm / 50 mm^2 = 16.38 uw/mm^2

= 1.64 mW/nm/cm^2.

The irradiance across the spectral range 900-1900 nm is shown in the graph below.



How does this compare to other light sources?

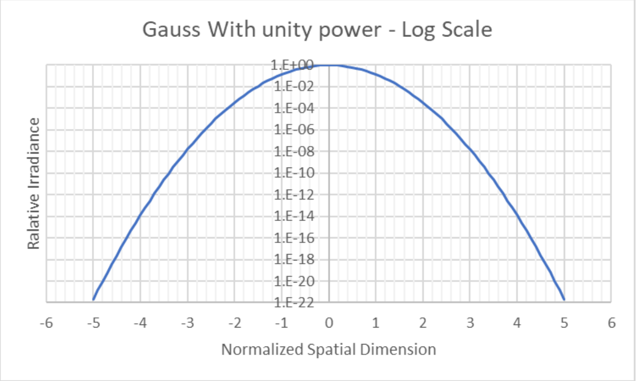
It is worth mentioning that most commercially available LED bars typically deliver an irradiance that is an order of magnitude lower compared to this. It highlights one of the advantages of using a supercontinuum source.

LEDs can deliver a lot of power, but not in well-defined areas – and any optical power that is reaching the sample outside the region of interest of your camera is lost energy that results in heating of the sample.

Another important fact to be noted is that, while using LED light sources, the width of the illumination line increases, and the effective line intensity reduces with increasing working distances. However, using a supercontinuum light source, due to the spatially coherent nature of the beam, the increase in linewidth is minimal and can often be mitigated using optics. The appropriate illumination line length can also be achieved by choosing the optics with the right fan angle.

High spatial suppression

Compared to non-laser sources, supercontinuum sources have a high spatial contrast between the most intense section of the illuminated area and the surroundings. Please refer to the plot below showing the theoretical cross-section of a normalized Gaussian beam.

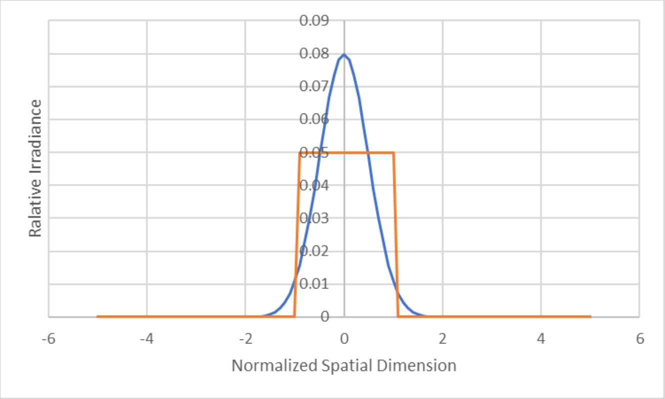


In this normalized case, 86% of the power is contained within the transverse range [-1:1]. At twice the distance, i.e., outside the range [-3:3], the irradiance is already reduced by 8 orders of magnitude!

Gaussian vs. Flat-top assumption

In the above example, we assumed the line is uniformly illuminated. That is not the case – the beam or line has a Gaussian intensity distribution along the width. Along the length of the line, special optics make the intensity almost uniform.

This assumption underestimates the irradiance in the center of the beam and overestimates the power at the edges. The figure below illustrates this by showing the relative irradiance for a Gaussian function and a top hat function (the two functions have equal integrated power under the curve).



The impact of the assumption is, if a camera field of view covers the range [-1,1], by assuming uniform intensity distribution, we are underestimating the irradiance in our calculations above. On the other hand, if the camera covers the range [-2:2], our calculations are about right.

Note: if the camera field of view covers [-1:1], the relative alignment of the camera and the illumination source becomes very important, as little stray or "lost" light can compensate for the misalignment.

The system designer can best evaluate the actual impact of this assumption – if the camera/light source combination is good (and the setup's ability to maintain that alignment over time), there is a significant upside. On the other hand, if alignment cannot be maintained, there will be a significant penalty.