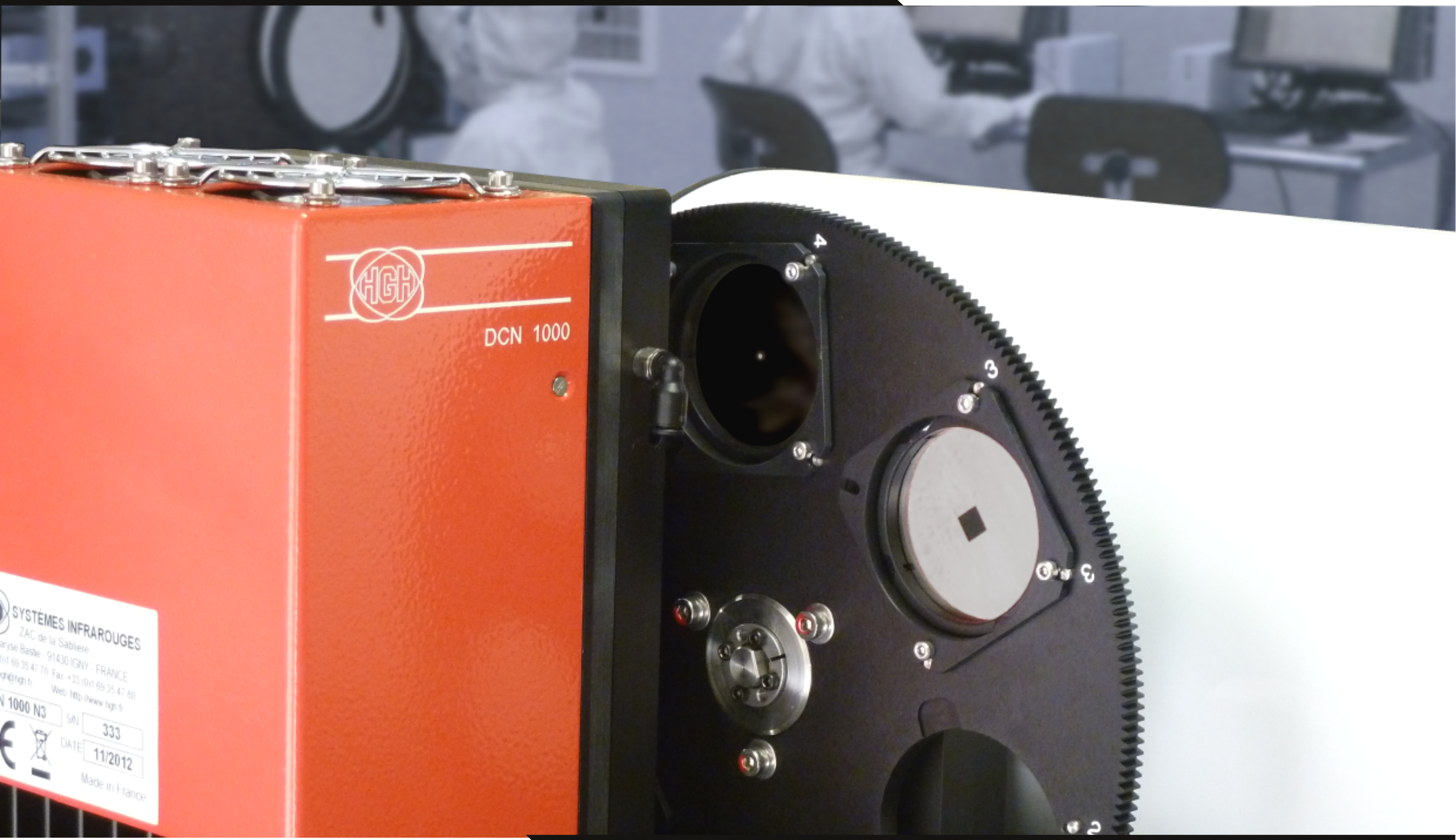
BLACKBODY White Paper



How to choose your blackbody?

As all infrared sensors require calibration, infrared calibrators are needed. And the blackbody is the most suitable of them.
A perfect blackbody is an ideal physical body that absorbs all incident radiation. At thermal equilibrium it emits electromagnetic radiation depending on, and only on, its temperature. It is an ideal emitter: it isotropically emits as much or more radiation at every wavelength than any other body at the same temperature.
Usual objects are not blackbodies. They do not absorb 100% of the incident energy and usually select the absorbed wavelengths. Consequently, they cannot re-emit all the incident energy. The ratio between the emitted energy and the incident energy is called emissivity. This ratio depends on wavelength.

A blackbody has an emissivity of 1.0 at all temperatures and wavelengths while any other object has an emissivity <1.
Manufacturing a blackbody consists of regulating the temperature of an object and making its emissivity tends towards 1 over a spectral band as wide as possible. Such a device is then used for multiple applications such as detectors, cameras and non-contact thermometers calibration and characterization.

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BLACKBODY INFRARED RADIATION

The infrared radiation is the electromagnetic radiation where wavelengths are between 700 nanometers and 1 millimeter. Thus, it is located between the red limit of visible spectrum and the shortest microwaves. All bodies with a temperature above the absolute zero emit infrared radiation.
However, at any given temperature and wavelength, there is a maximum amount of radiation that any surface can emit. If a surface emits this maximum amount of radiation, it is known as a blackbody.

A blackbody is compared to an idealized radiator that absorbs all incident energy upon its surface, regardless of direction and wavelength. It re-emits this electromagnetic radiation with 100 % efficiency according to Planck's law. The emission curves only depend on the temperature of the blackbody.

$$\frac{dR(\lambda,T)}{d\lambda} = \frac{2\pi hc^2\lambda^{-5}}{\exp(\frac{hc}{\lambda KT}) - 1}$$

The Wien law gives the wavelength (in microns) corresponding to the maximum spectral radiance of a blackbody at given temperature T (in Kelvin):

$$\lambda_{peak} = \frac{2898}{\mathrm{T}}$$

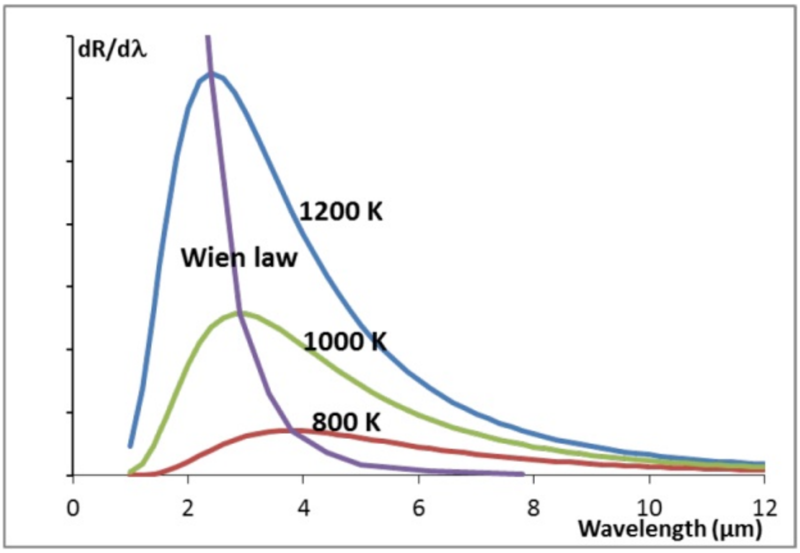

Figure 1 - Wien Law.

The wavelength of maximal infrared radiation decreases if the blackbody temperature increases.

The total amount of emitted radiation (in Watt) of a blackbody is given by the Stefan-Boltzman law. It also only depends on the blackbody temperature T (in Kelvin):

$$R = \sigma T^4 \quad \text{where } \sigma = 5.67 \times 10^{-8} W \cdot m^{-2} \cdot K^{-4}$$

An infrared reference source is designed to have the highest emissivity possible (>0.9), whatever the wavelength. This source is usually called blackbody.

All infrared sensors for thermography (pyrometers, thermal cameras…) convert thermal radiation received into an electrical signal to give a temperature measurement. These sensors need to be calibrated with a blackbody infrared reference source in order to ensure the temperature measurement accuracy.

BLACKBODY'S MAIN CHARACTERISTICS

EMISSIVITY

As mentioned before, emissivity is defined by the ratio of the energy radiated by an object to the one radiated by a perfect blackbody. The objective of every manufactured blackbody is to reach an emissivity as close as possible to 1 at any wavelength.

High emissivity is one of HGH blackbodies' strengths, with an emissivity of 0.98 for all extended area blackbodies and >0.99 for the cavity blackbodies. For the extended area blackbodies, the high emissivity is obtained thanks to a specific paint characterized by the LNE (French equivalent of the NIST). HGH applies a radiometric calibration to their blackbodies to reach an apparent emissivity of 1.00 over the entire infrared band, from 1 to 14µm. To understand the importance of this radiometric calibration one can perform a simple test: measure the temperature (with an infrared thermometer) of a blackbody (emissivity of 0.98) at 100°C with and without the radiometric calibration. Without the radiometric calibration the apparent temperature of the blackbody is 98°C, where it is 100°C with the radiometric calibration.

Considering that, one might think that the emissivity is not as important as the apparent emissivity. However, the radiometric calibration is calculated in a lab environment, at a temperature around 22-23°C, over a certain band of the spectrum and is valid only in the band and conditions it was calculated. The main challenge is then to control the environment. The higher the emissivity, the less sensitive to its environment the blackbody radiation will be.

Moreover, the radiometric calibration is performed to match the total signal of a perfect blackbody over the band of calibration, but not to match the signal at each wavelength. This means that the spectral radiation is not the same as a perfect blackbody, but the higher the emissivity, the closer the spectral radiation is from a perfect blackbody.

Finally, for applications where the ambient temperature is far from the temperature to which the radiometric calibration was performed, it is better to use the real emissivity of the blackbody and not the apparent one and apply correction on the measurements afterword. HGH blackbodies have the capability of using the blackbody without any radiometric calibration.

STABILITY

The stability is the ability for a blackbody to be regulated and emit the same temperature over time. A high stability is necessary to guarantee that the blackbody remains at the same temperature during the tests performed. HGH's blackbodies benefit from a high and constant stability over the whole range of temperatures.

High stability will be useful when performing NETD and noise measurements of high-end infrared sensors and cameras. Indeed high-end sensors and cameras have low noise and small NETD which require a high stability to comply with the 4:1 test accuracy ratio (https://en.wikipedia.org/wiki/Calibration) between the device being tested and the calibration device. For example, the DCN1000 from HGH has a 0.002K stability which allows it to perform NETD testing of all cooled infrared detectors (typical NETD for those types of sensors is between 30mK and 10mK).

TEMPERATURE ACCURACY

When dealing with the temperature accuracy of a blackbody, 4 elements must be taken into account:

- The temperature sensor (usually Pt sensor)
- The electronic measurement unit
- The quality of the contact between the temperature sensor and the emissive area
- The emissivity of that area

If only one of those parameters is not controlled, the temperature accuracy cannot be guaranteed. The problem is the quality of the contact between the temperature sensor and the emissive area is not measurable. That is why when specifying the temperature accuracy, vendors only specify the accuracy of their temperature sensor combined with their measurement card but not the actual accuracy of the blackbody temperature. In conclusion, the temperature accuracy given by vendors might be a good indication but it is a parameter to consider with a lot of caution.
HGH pays attention to the emissivity of their blackbodies and the contact between temperature sensors and the emissive area to insure that the blackbody temperature accuracy is as close as possible from the accuracy of the temperature sensor.

HGH’s blackbody calibrations have a long durability. The durability of calibration is the period of time during which the blackbody is still considered as calibrated. Most blackbodies are to be calibrated every year. HGH's DCN1000 series has a validity period of two years. This is the result of the reliability of every component involved in the radiometric calibration: temperature sensor, electronic components, emissive area and emissive paint.

HEATING TIME, COOLING TIME

Heating and cooling time are also important characteristics of blackbodies, not because they will change the performance of the test but because they will increase productivity. Waiting 5 minutes for a 1°C temperature change is not acceptable, especially when constantly switching the blackbody temperature.
With HGH's DCN1000 blackbodies the stabilization time is shorter than 60 seconds for a temperature change of less than 10°C, regardless the blackbodies are heating or cooling.
HGH’s blackbodies can be set at any temperature at any time, there is no need to follow a step by step procedure when cooling down to a low temperature (<0°C).
For example, when cooling a blackbody from 100°C to 25°C, the time with a low cost blackbody is around 15 minutes. For high end blackbodies a typical cooling slew rate is -0.2°C/s, so they require just more than 6 minutes to cool down from 100°C to 25°C, and with HGH's DCN1000 this time is as low as 3 minutes.

Also, for dual temperature applications (NETD for example) HGH developed a dual emissive area blackbody: the TwiN1000. The TwiN1000 has two independent emissive areas with a 0-150°C temperature range. Better than having a short cooling and heating time, the TwiN1000 allows you to work at two temperatures simultaneously.

FLEXIBILITY OF USE

HGH's Blackbodies can be used and controlled by different means:

- With the touchscreen on the electronic units.
- On a computer connected to the blackbody (HGH's blackbodies are by default connected to a network) with HGH's blackbody software or with HGH's test and measurement software.
- Directly on your phone through HGH e-Blackbody App.
- On Labview with HGH exclusive drivers for Labview.

All of these four ways to control your blackbody are easy to use. The e-Blackbody and Labview driver are exclusive features by HGH.

CONCLUSION

When manufacturing their blackbodies, HGH makes no compromises since every characteristic is important. From emissivity to stability, flexibility of use to reliability, HGH has provided the market with high-end blackbodies for over 30 years and is still committed to insure the best product for their customers.