emitec since 1993 your partner for infrared temperature measurements

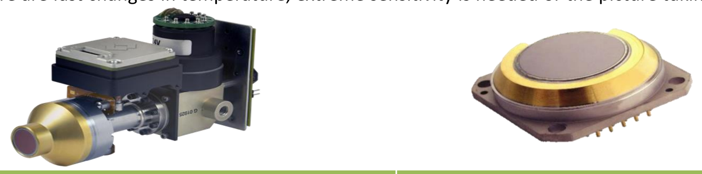
Trustfull testing leads to working products – working products lead to more recognition on the market – more recognition leads to more sales – more sales leads to more service demands – more service demands leads to more testing. Testing is the first and last thing we do, to ensure customer happiness.

Types of thermal cameras and their advantages

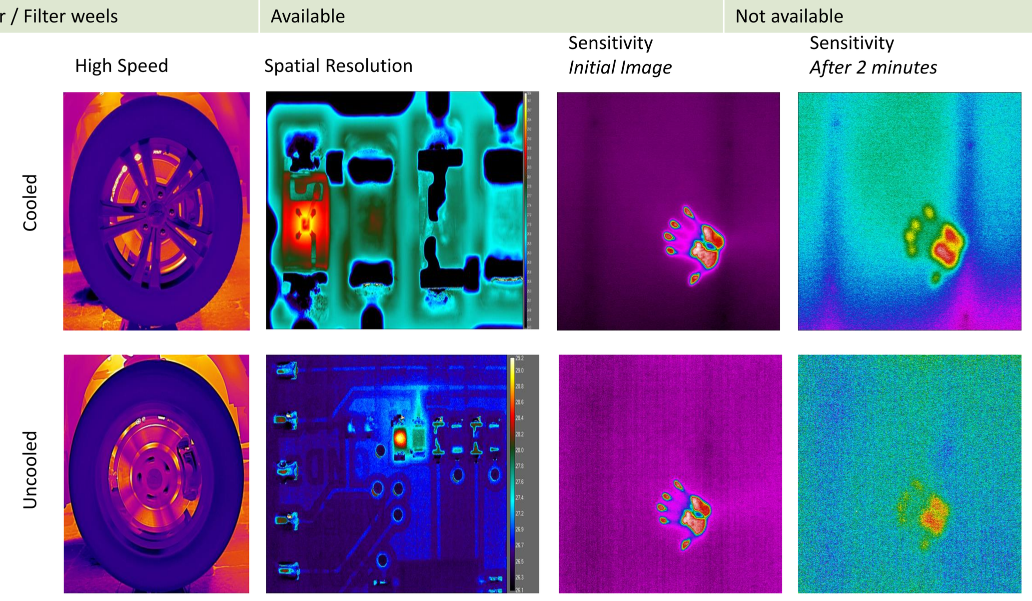
Cooled and uncooled camera sensors

On the market we can find two different types of thermal imaging cameras. On the one side we find the cooled quantum detector cores and on the other the uncooled so-called micro bolometer sensors. Both sensor types have specific characteristics and therefore able to perform better on different applications.

In general, the micro bolometer is a cheap, easy to use and flexible camera for all maintenance, building and some R&D applications. The quantum detector instead is used if there are fast changes in temperature, extreme sensitivity is needed or the picture taking must be timely well synchronized.



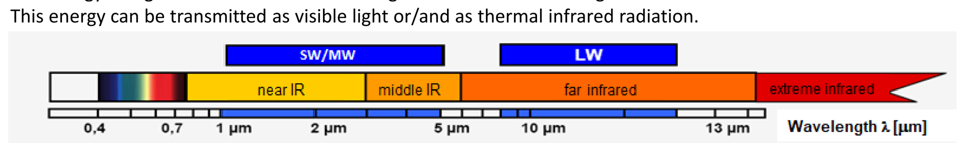
Camera type	Cooled quantum detector	Uncooled micro bolometer
Picture rate	50 Hz…~100 kHz	< 250 Hz
Integration time / response time	Nanoseconds (manual setting possible)	> 8 milliseconds (no manual setting)
Thermal Resolution (sensitivity) NETD	< 25 mK	25 mK – 200 mK
Trigger and Synchronisation Input	All the cameras	Rarely featured
Synchronised trigger	Available	Only next available picture (jitter of framerate)
Wavelength [µm]	NIR 0.9-1.7 µm, MWIR 1-5 µm, LWIR 7-12 µm	Only long wave 7-15 µm
Filter / Filter weels	Available	Not available



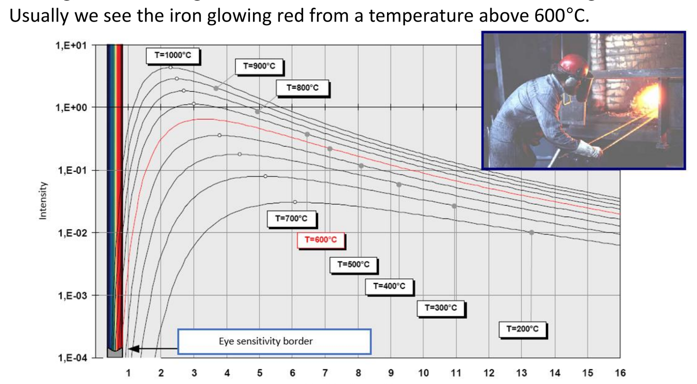
Emissivity factor

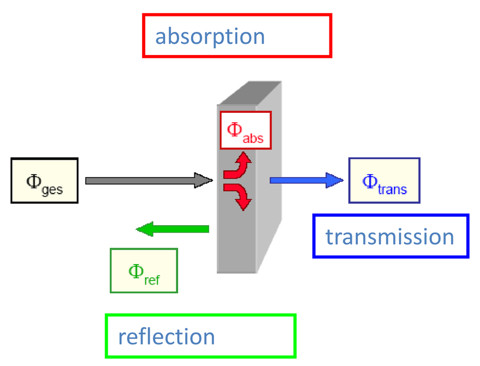
What is the emissivity of an object?

The emissivity of an object describes the effectiveness in emitting energy as thermal radiation.
The energy being transmitted is an electromagnetic radiation like sunlight is as well.
This energy can be transmitted as visible light or/and as thermal infrared radiation.



Depending on the heat of an object, it is sometimes possible to see the infrared radiation with our own eyes. In case of iron heating or melting, the iron changes its color from dark to white. This color change shows exactly the function of an infrared camera.
Usually we see the iron glowing red from a temperature above 600°C.





The emitting abilities of an object are the same as the absorption abilities of the object.

Absorption = Emission

Every Object has an absorption, a reflection and a transmission ability. Therefore, we also have factors for each of them to take care of. To measuring the temperature of an object, we need to know the % of reflection and the % of transmission within our wavelength or the emissivity factor.

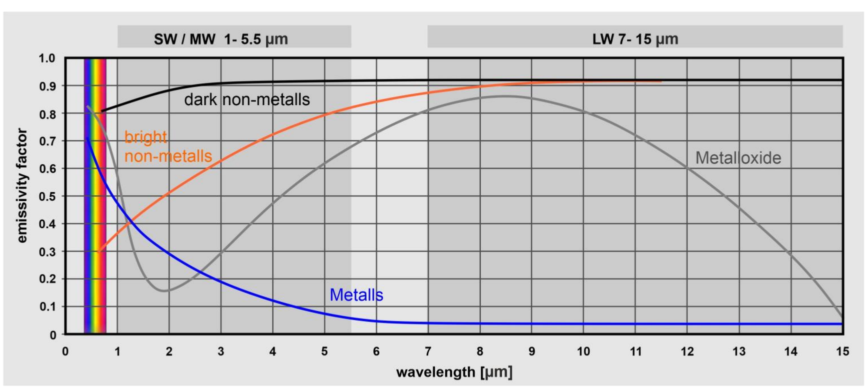
In the end it is always: 100% = 1.0 = radiation total = absorption + reflection + transmission and absorption = emission

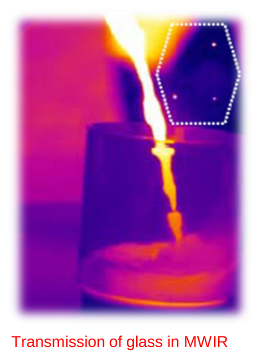
Emissivity for different materials and different camera systems

All factors can be different for each camera system therefore the factors have to be measured for each individual camera system.
The factors change because of wavelength of the camera system and filters used.

Most systems are either long wave LW (7-15 µm or 7-10 µm) or short/mid wave SW/MW (1-5.5 µm), but of course there are also near infrared cameras NIR (0.4 µm-1 µm).

Depending on used bandwidth of the system the result in measured radiation is an integration of a certain bandwidth. If we cut of a part of the bandwidth by using a filter to shorten the bandwidth, we get other behavior of the radiation and therefore other values.
May the filter help us to eliminate reflections within the monitored part, in this case the reflection goes to 0% and the absorption or emission will rise for reflection.
The emissivity in general is also bound on material, color and structure of the top layer. (see section how to measure emissivity)
This explains why for instance a MW camera might be better for measuring metallic materials but have other downsides.





Transmission of glass in MWIR

Measurement influences and how to avoid or compensate

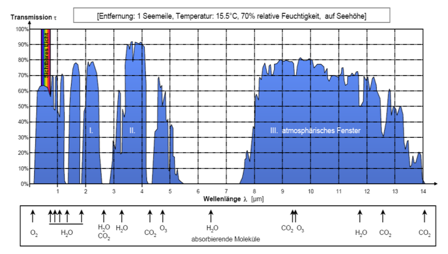
What can further influence your measurement?

Besides the wrong setting of emissivity factor, there are several other influences that could affect your measurement negatively.

- **External surrounding temperature $T_{atmosphere}$**
- **Distance to object [m]**
- **Humidity of the air [%]**
- **Reflected temperature $T_{reflected}$**
- Wrong measurement spot size (lenses – distance – object size)
- Wrong integration time (fast changes of temperature or moving objects)
- Changing of emissivity because of structural change of the object when heating or cooling

Atmospheric influence

The first four influences are directly connected to the temperature calculation. Besides the emissivity factor, the atmospheric temperature, the distance to the object and the humidity of the air will influence your measurement. These three information's do the calculation to take care of the real transmission of the air. Because the air has humidity has not 100 % transmission it is strongly dependent on distance and humidity, as more humid the air is, as more extreme is the attenuation.



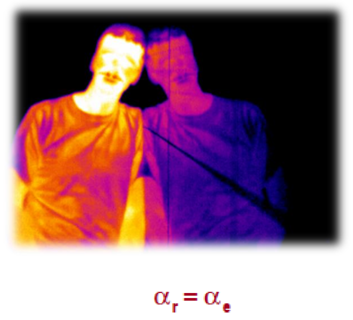
Reflected temperature influence

To correctly measure an absolute temperature, we must know the reflected temperature on our object. The reflected temperature is depending on your position and the direct reflection of other objects in the viewing field.

To take care of these reflections we must study the possible influence on our measurements.

1. **How good is our emissivity of the object we measure? (90 %, 60 %, 20 %?)**
2. **What radiation level does our reflected temperature have?**

If our object has an emissivity of 95 % the influence of the reflected temperature will be rather small, only 5 %. But the influence is of course bigger if the reflected temperature would be 2000 °C instead of 30 °C, in fact it will be warmed up because of surrounding and is possibly not the real temperature it will have later in use, not to forget that a good emissivity means the object is also a great absorber.
The effect is also happening if the reflected temperature is much cooler then the object.

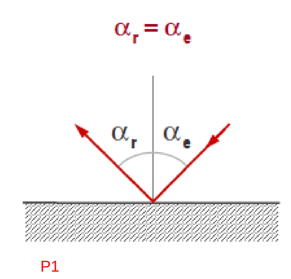


Imagine an emissivity of a metal with 40 %, so the reflected temperature takes care of 60 % of the measured value. Here the influence is massive. To not take care of the correct reflected temperature can destroy your work within seconds.

Direct reflection

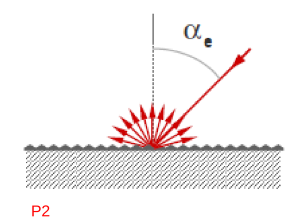
Depending on **the top structure** of your object the reflection can have two different impacts to your measurement. Either the top structure is bold and polished, therefore the reflection can be seen sharp and you can identify what exactly is reflected, we have a **direct reflection.**

In this case set the reflected temperature for each measurement point separately correlating to the temperature seen from the reflected object in the picture. (P1)

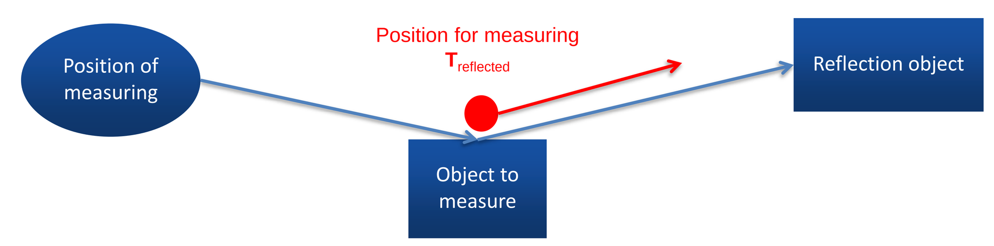


Diffuse reflection

If the **top structure** is rough instead or the reflection itself is totally homogeneous, we can use an average of the temperature coming from the reflection source and use it for each point on the measurement object as a global correction. (P2)



To determinate the $T_{reflected}$ by using your camera, you must measure the reflected object itself. To do this, you move to the position of your object to measure, set **emissivity factor E=1 =100 %. Now measure the radiated temperature coming from the reflected object according to above rules.**
In this case you measure the true radiation coming from the reflection source with no correction. The resulting temperature shown on the camera will then be the $T_{reflected}$ for your later measurement.



Measure the emissivity factor

What needs to be measured?

To determinate an emissivity factor there are several ways. One way is to have a part of known emissivity in the picture as a reference point. Example here: aluminum cube

The reference point can either be:

- Tape or colored part of the material with known emissivity
- A reference point by measuring it with a thermocouple (known temperature)
- A Hole in the material 5 times as deep as wide (cavern effect)

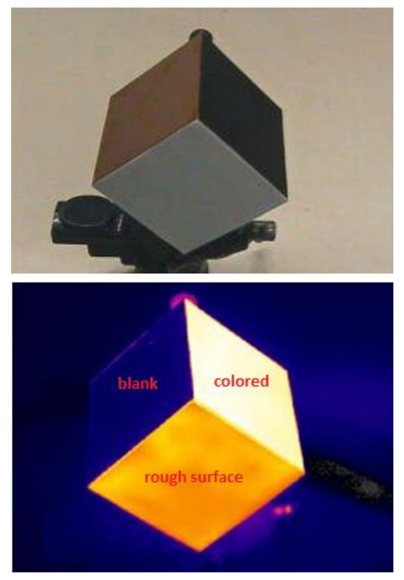
With all these methods we generally use in practical measurement, we do indeed not terminate the real emissivity over the full temperature band. We only know the emissivity factor of the observed material at the showed temperature.

The fact that the emissivity can change because of its own carried energy, makes the measurement more complicated in dynamic scenes.

In general the emissivity of material with a high emissivity factor does not change a lot, but materials with low emissivity factors can do easily.

To determinate the emissivity we must also know the reflected temperature. To measure the reflection, we measure the temperature of it like discussed in the above part of diffuse and/or direct reflection.

When we got the reference point, reference temperature or hole available, know the surface structure of our object and know the reflected temperature, we place this information into the camera and change the emissivity factor in the picture until we get the same temperature on the material as we had on the reference point (next to the reference point).



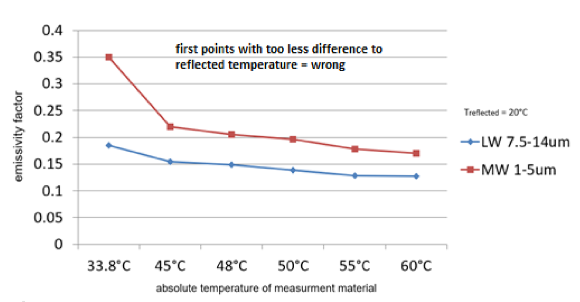
The resulting number is the emissivity factor for the certain material at the shown temperature.

Please be aware that this case is only applicable if there is 0 % of transmission. This state is not given with some PVC, Plastics or semiconductor materials. It can be easily tested by holding your hand in the back of it. If you can not see it on the camera, it has no transmission.

How to determinate a real emissivity factor over a wider range of temperatures?

To be able to have a real emissivity factor determination we must do the measurement the same way as described above, but make sure that the temperature of our measurement object have a temperature difference of at least 30 Kelvin.

This difference is needed to separate the radiation from the reflected temperature and the target object clearly. In a laboratory we can use a controllable heater plate and heat a piece of our material on it to different temperature levels.
Do the measurement above for more then one temperature.



Example: ambient temperature 20°C and stable reflected temperature → measure emissivity at
➢ 55°C, 100°C and 150°C of the object

Now you know the emissivity factor on three different Temperatures. Maybe you must average them as the camera on its own can only handle one factor at the same time. There are ways though to handle changing factors via a self calibration on the software.

Calculation of the measurement field

Calculation of the measurement field

The calculation of the measurement field or the size of pixels at the target can be done by two different approaches. Either by using the optics mrad-value which is an arch measurement showed in most microbolometer units and multiply by distance:

Measurment field (ideal):

$$x_{ideal}\,[mm] = d\,[m] \cdot \varphi_{IFOV}\,[mrad]$$

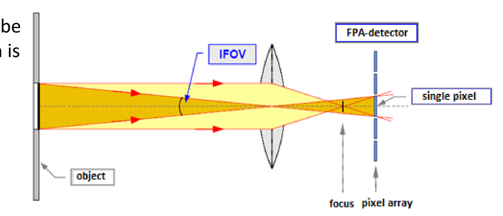
Measurment field (real)

$$x_{real}\,[mm] = d\,[m] \cdot \varphi_{IFOV}\,[mrad] \cdot 3$$

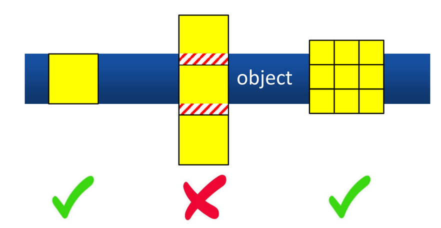
The other approach is to calculate it by using the focal length of the optic and the pixel size of the camera detector (detector pitch) to calculate the mrad-value and then use the above formula.

$$\varphi IFOV[mrad] = \tan^{-1}\left(\frac{Pitch\ detector\ [um]}{focal\ length\ [mm]*1000}\right) * 1000$$

The ideal measurement spot size must be multiplied with 3 to know the minimum spot size to measure in real conditions. It is unlikely to be precise enough to corelate a single pixel exactly on the target. Not impossible but very tricky.



Pixel size on object

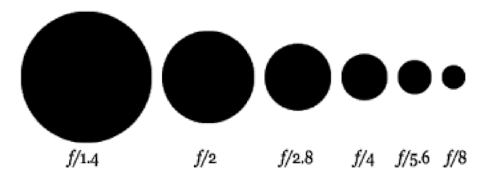


Optics and the F-Number

Optics/Lenses

Each camera system provides different optics and lenses to reach the spatial resolution for the needed application. Available are different lenses from super wide angle to wide angle down to tele lens and macroscopic lenses.

Available are lenses with automatic focus or with manual focus.
Not all lenses work with all cameras.
The basic rule says the camera gets more sensitive with wider lenses.



F-Number

The f-number of a camera system tells more about the size of the camera aperture. Usually there are two sizes of f-numbers available.

	f/2.5	f/4
Pro	Because of big aperture the f/2.5 is most suitable for very fast changes and highspeed recording, due to the fact that the radiation level is much higher.	f/4 is most suitable for macroscopic thermography, if the aperture is smaller, we get a much greater depth of focus.
Contra	Because of optical and physics issues the depth of focus is less good in case you would use a macroscopic lense on the f/2.5 aperture compared to a bigger f-number.	Due to the fact less radiation goes through the aperture, it is less good for fast changing behavior where smallest integration times are requested.

Sensitivity / wavelength / thermal resolution

Wavelength for what applications?

Different cameras are manufactured to reach out for different wavelength sensitivity and different applications. To properly handle the requests for sensitivity, different sensor materials and filters are needed. Depending on the observed materials (measurement object), one or the other wavelength observation offers better results and opportunities.

Wavelength	General fields of use	
NIR Near Infrared (0.9 µm -1.7 µm)	➢ Good for fast acquisition and high temperature metal measurements > 300 °C ➢ No temperature measurements below 300 °C possible ➢ Cheaper in price then MWIR or LWIR ➢ Good for small microscopy < 3 µm/pixel ➢ luminescence measurements	
MWIR Middle wave infrared (1 µm-5 µm)	➢ Great for broadband applications from -20 °C to 3000 °C ➢ Perfect for gas detection and spectral radiometry ➢ Good for far distance view ➢ Good for microscopy applications down to 3 µm/Pixel ➢ Good for fast acquisition and fast temperature changes ➢ Better emissivity on metals then LWIR cameras	
LWIR Long wave infrared (7 µm-15 µm)	Cooled: ➢ Highest price ➢ Great for high speed acquisitions ➢ Perfect for high dynamic scenes and fast temperature change ➢ Best for low temperature measurements < 30 °C ➢ Great for applications from -40 °C to 3000 °C ➢ Microscopy down to 6 µm/pixel	Uncooled: ➢ Low price and easy use ➢ Good for high dynamic measurements ➢ Bad for moving objects or fast temperature changes ➢ Microscopy down to 25 µm/pixel ➢ Good for low temperature measurements <30°C

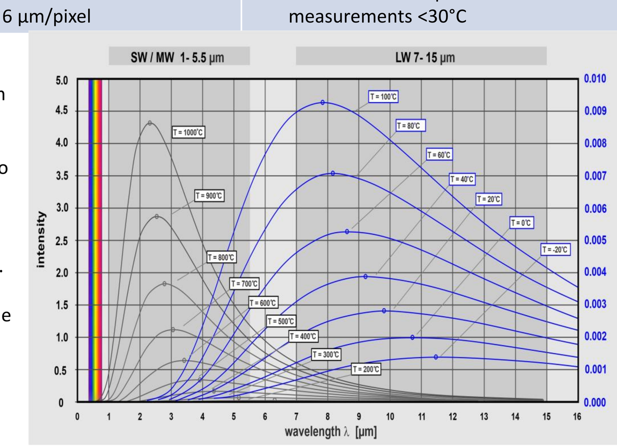
NETD = Noise Equivalent Temperature Difference

The NETD value prescribed in the datasheet does give information about the smallest temperature value shown from the camera, corresponding to its noise level.

A camera having a value of 30 mK can show differences down to 30 mK. This value though can be negatively influenced by the choice of lens, measurement range and surrounding Temperature. Depending on what lens you use, it can be that Your camera with 30 mK specified will only deliver 60 mK NETD.

From a measurement point of view in absolute temperature, the NETD does not correspond the to the smallest temperature Difference measurable, it only can be shown, measurable absolute values of difference are approximately 6 to 10 times the NETD.

Absolute measurable difference = 6 * NETD (30 mK) = 180 mK
This figure is just to illustrate; additional negative influences can be caused by the stability of the camera system and its temperature drift compensation.

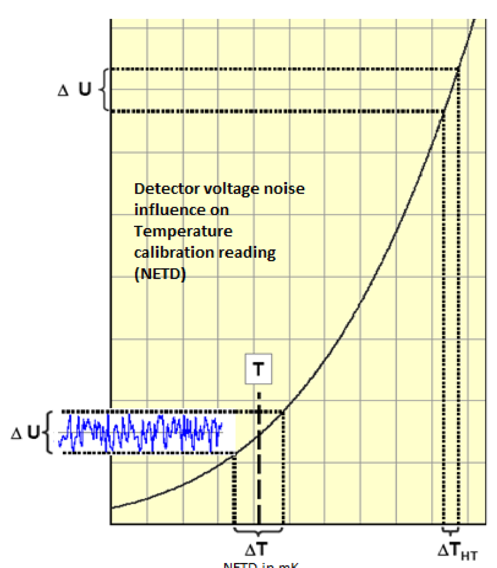


Radiation intensity level depending on absolute temperature of object

Resolution settings and windowing functions

A variety of different resolutions are available, starting from low pixel amount up to HD values of 1200x800 pixels.
The question about what is needed and what is nice to have is all over present. In most cases a camera with 640x512 pixels is enough for 95 % of all applications.
More interesting is the available pixel pitch which does directly lead to the geometrical resolution together with a certain lens or in general the variety of lenses available.

Example:
In microscopy applications, so very small targets should be measured, the microbolometer ends at a geometrical resolution of 25 µm/pixel.
The cooled cameras can reach there down to 3 µm/pixel in case of a 12 µm pitch camera detector. So a maximum of 4x gain or a ¼ of the pixel pitch can be reached.



Temperature drift and NUC

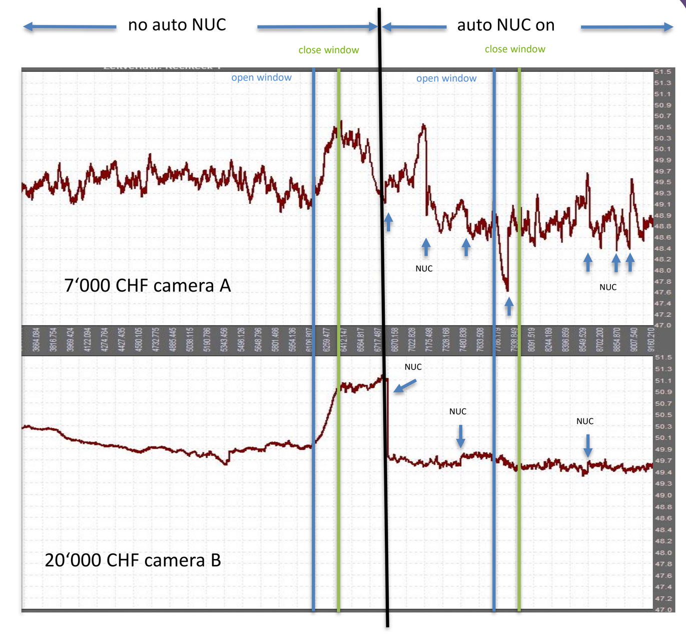
Like all measurement devices in this world, also thermal cameras, must fight against unstable external influences. Since the detector is thermally unstable it will react also to internal and external temperature changes. The change can be forced by internal heating, external ambient temperature changes or direct exposures to heat sources.

To avoid high influences and stabilize measurement, the thermal cameras do always measure internal temperature on different locations and in the attached optics.

The camera itself gets to know its own thermal behavior via tests in a thermal chamber while it is reading a static black body temperature.

Whereas the temperature drift option corrects for changing internal and external temperature, the NUC or non-uniformity correction option does correct the drifting of each pixel to the other pixels to optimize signal to noise ratio.

Depending on quality of the camera which is directly coupled to the pricing and size of the camera you get different behavior of these features.



To visualize, see the graph on the right with a lower priced camera and a higher priced microbolometer camera looking onto an infrared calibrator having 50 °C ± 0.1 °C.

The units have both been powered for 2 hours before logging.
The first 120 minutes it works without NUC ON, then the Auto NUC is enabled for the other 40 Minutes.

During both operations, the window is opened to create an environmental change of -5 Kelvin to the room temperature.

The temperature drift behavior is a bigger contribution then the small NETD value, as both cameras offer < 30 mK here.
Also be aware that the figure of accuracy in the specification does not reflect the quality of the temperature drift behavior directly.

For most accurate readings:
Cooled cameras are much less affected by this behavior as the detector itself is stabilized to a specific temperature of -77 Kelvin.
External changes can only heavily have influence against the controlled cooler, which is always working.
The temperature drift is here always corrected, not only at a NUC situation.

Filters and Windows

Type of Filters

To enhance the working skill for different measurements the camera can be equipped with additional filters.
In filters we differ in:

- Warm filters (between lens and detector)
- Cold filters (directly on the detector)

The difference for these two kind of filters is that the transmission for radiation is much higher in a cold filter, as the performance on a cooled down filter does not have a such high level of self-radiation to the detector like a warm filter located in the lense has.

Use of Filters

The use of filters enables us different possibilities in the field.

- Look through flames or through glass
- Optimize measurement of flames
- Detect certain gases (CO_2, methane, butane, CO, SF_6, R404, and many others)
- Optimize measurement capabilities on glass or CFK and plastics
- Use polarization filters to get rid of reflections
- Enlarge measurement range capabilities with additional Filters

Windows for protection or to look inside chambers

The windows are used to enable to look through a material that is not transmissive for the camera.
If a window is used, the camera must be told the special parameters for the look through window.
Important here is:

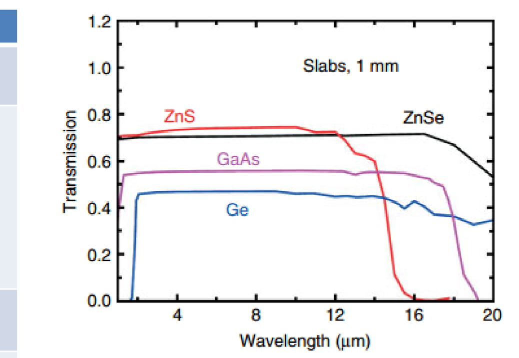
- Transmission factor of the window
- Temperature of the window

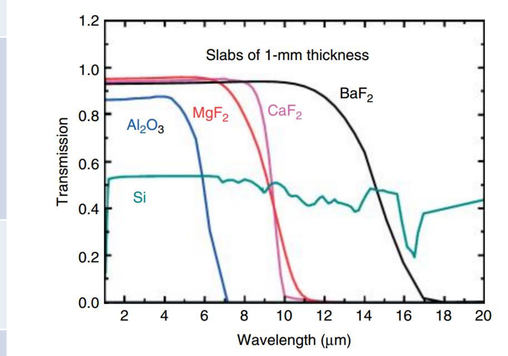
In many cases the windows are used because the measurement object is inside of a structure, which cannot be opened during test. This applies for instance in vacuum chambers, temperature chambers or also for instance in exhausts.
Or to protect the camera from the surrounding with a housing (Dust, high temperature, extreme humidity, else)

As seen above the own temperature of the window is an important parameter. On one side it is to determinate the self radiation coming from the window, but on the other hand these materials have a maximum temperature where they remain transmissive.

There are different materials to use depending on Application (only the most common ones showing):

Name	Info	Wavelength
BaF2 Barium Chloride	Low Price/ good withstand	Visible to 16 µm
Ge Germanium	High Knoop Hardness, Excellent MWIR to FIR Transmission Transmission for 7-14 µm lost at 90 °C of window temperature	1.6 µm to 20 µm
Al2O3 Sapphire Glass	Very Durable/ Good Transmission in IR	Visible to 6 µm
Si Silicon	Low Cost/ Lightweight	0.4µm to 20 µm
ZnSe Zinc Selenide (toxic, handle with care)	Low Absorption, High Resistance to Thermal Shock Transmission for 7-14 µm lost at 300 °C of window temperature	Visible to 20 µm
ZnS Zinc Sulfide	Excellent Transmission in Both Visible and IR, Harder and More Chemically Resistant than ZnSe	Visible to 14 µm
Possible contact: www.thorlabs.com or www.edmundoptics.de		

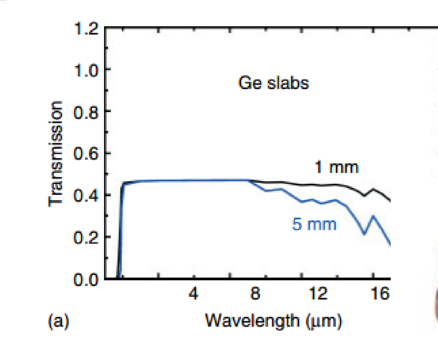




Besides of the material, other parameters will increase the inaccuracy of the measurement and lowest sensitivity of the system.

Thickness of the window does change behavior of transmission / wavelength and the total transmission factor like seen in picture (a).

Also, all the above materials can be additionally coated, so they get other behavior which leads for instance to better transmittance or different temperature behavior.



(a)

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