INFLUENCE OF CURRENT AND FUTURE DEVELOPMENTS IN IR CMOS DETECTORS ON THE PERFORMANCES OF THEIR TESTING SYSTEMS

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ABSTRACT:

Some significant progresses have been made in performance on Infrared Detectors over the past years. Currently existing MCT (mercury cadmium telluride) and InSb Focal Plane Arrays commonly reach NETD (Noise Equivalent Temperature Difference) values lower than 20 mK. Type II Superlattice (T2SL) FPAs, supposed to be the next generation infrared detector technology are also now able to compete with the above described models. Even the processing of microbolometers is also continuously improving, leading to frequent NETD lower than 30 mK. It can be assumed this performance race will never stop and testing equipment of future detectors must be in accordance with these expected results. Infrared reference sources, i.e. blackbodies, are key elements of thermal imager test bench. Measured results are highly dependent on blackbodies characteristics, such as the temperature accuracy, the emissivity, the thermal uniformity and stability. The general rule of metrology considers the contribution of the reference instrument to the uncertainty of the tested device must be at most ¼ of this uncertainty. Most of the time a 1/10 factor is preferred in order to really consider the contribution of the reference instrument as negligible. Considering the case of the IR detectors, the above rule means the temporal stability of the blackbody must be now lower than 2 mK.

This paper first lists an overview of current performances and announced developments in IR detectors and the corresponding expected NETD and stability performances already existing or available in the near future. It demonstrates the existing testing sources available on the market have performances restricting the test of the new detectors. The second part of the paper describes the improvements brought to our next generation of IR reference sources in order to strongly reduce by 4 the temporal instability and shows this next generation of blackbodies is now compatible with the expected NETD values of the next generation of IR detectors.

1. STATE OF THE ART AND TENDENCIES ABOUT THE NOISE LEVEL OF IR DETECTORS

By the first half of the years 2000, most of the major manufacturers of blackbodies improved the stability of regulation of their low temperature blackbodies from approximately 10 mK to less than 2 mK. This modification was also linked to a decrease of the display resolution of the temperature from 0.01°C to 0.001°C. The actual need of such a high stability was not really obvious then. However, no one would consider today the qualification of a thermal imager for surveillance, tracking, human body detection or long-range identification using a 10 or 20 mK stability reference source.

The usual rule for calibrating and testing equipment requires at least a 4:1 ratio between the uncertainty of the calibrated system and the uncertainty contribution of the reference instruments. For a 20 mK NETD detector, it means the maximum expected contribution from the blackbody is 5 mK. This level of stability excludes a rather long list of blackbodies from the appropriate tools for testing cooled detectors.

The current developments on IR detectors shows that such NETD levels are quite usual. Among the references of cooled detectors with low level of NETD are 15 µm pitch Pelican-D InSb detector from SemiConductor Devices with 20 mK typical NETD or 15 µm pitch Scorpio MW HgCdTe from SOFRADIR with NETD lower than 16 mK at 293 K. With the new developments on T2SL FPAs, a 20 mK NETD is reached for instance by 15 µm pitch IR Nova's 640 MW detector, this value getting down to 12 mK for a 30 µm pitch model. These are examples of cooled detectors but some similar levels of NETD have been achieved on uncooled detectors or will be soon achieved. As an example to this assumption, L3 IRP recently announced their existing 17 µm microbolometer have been able to achieve an NETD of better than 26 mK.

The current tendencies show that the existing testing tools of IR detectors will soon become obsolete at least within less than a few years. Also considering the durability of these tools, time has come to switch to the next generation of blackbodies as the heart of the testing systems of IR FPAs.

2. IMPROVEMENTS ON BLACKBODY CONTROLLER

In order to be compliant with the future developments on IR FPAs, we improved the stability of our blackbodies through the development of a new controller of temperature regulation.

2.1. Considerations about the calculation of NETD

Before going further into the presentation of the improved stability of the blackbodies and in order to clearly understand the interest of this improvement, the calculation method of the NETD is reminded here.

The NETD is the acronym for Noise Equivalent Temperature Difference. It represents the temperature difference between an object and its environment needed to generate a variation of the signal equal to the standard deviation of the temporal noise. The usual method for measuring the NETD of a FPA or a camera is to entirely illuminate the field of view and the aperture of the sensor with the radiation of a blackbody stabilized at different temperatures. Some care has to be taken when the sensor is equipped with an AGC: it must be disabled.

For each temperature setpoints the following steps are repeated. First step is acquisition of N frames and calculation of the mean frame signal:

$$I_{mean}(i,j,T) = \frac{1}{N}\sum_{k=1}^{N} I_k(i,j,T) \qquad \text{Eq. 1}$$

Usual value for N is 100 and 2 temperatures around T0 = 293K are usually selected.

The slope of the signal is computed for each pixel $\frac{dI_{mean}}{dT0}(i,j)$.

Second step is the computation of the standard deviation of the signal for each pixel leading to the temporal noise value $TN(T0)(i,j)$.

The NETD of each pixel is thus obtained through Eq.2:

$$NETD(i,j) = \left|\frac{\varepsilon}{\frac{dI_{mean}}{dT0}(i,j)}\right| \times TN(T0)(i,j) \qquad \text{Eq. 2}$$

Where ε is emissivity of the blackbody used for the test.

The result from Eq. 2 is an “NETD map” of the sensor. The mean NETD and standard deviation NETD are thus calculated.

This reminder regarding the NETD calculation method shows the reference source must remain stable during the acquisition of the N frames at T0 which lasts a few seconds. If the reference source is unstable during this acquisition period, this instability will contribute to the temporal noise of the sensor.

In addition to this stability requirement, some other major performance evaluation functions such as the MRTD (Minimum Resolvable Temperature Difference) require a regular increase or decrease of the temperature at each step. The temperature of the object (i.e. the blackbody) must never overpass the setpoint even for very small steps otherwise this default may modify the judgement of the operator (target visible/ not visible) of this subjective test.

This requirement is an additional strong constraint on the regulation loop of the blackbody used for the tests.

2.2. Methods to improve the stability of regulation on an extended area low temperature blackbody

We improved the stability of regulation of our blackbodies along two axes of development.

First axis was to reduce the noise on the measurement of the temperature through the temperature sensor inserted into the emissive surface. The sensor used to measure and regulate temperature of a low temperature blackbody surface is a 4 wire Platinum resistive sensor.

Noise reduction consists both in the selection of a very low noise AD converter and in a careful filtering of main frequency. Figure 1 compares the noise level on the measurement of the temperature sensor on the previous generation electronics (red curve) and using a new generation AD converter and a better filtering circuit (blue curve) over a 5 seconds period. Data are converted into temperature units (mK) for better understanding. The usual stability of 2 mK rms of existing blackbodies is obvious on the red curve. The intrinsic noise level of the new generation electronics is much lower than 0.2 mK. This promising result is independent from the regulation loop parameters which also contributes to the instability of the temperature.

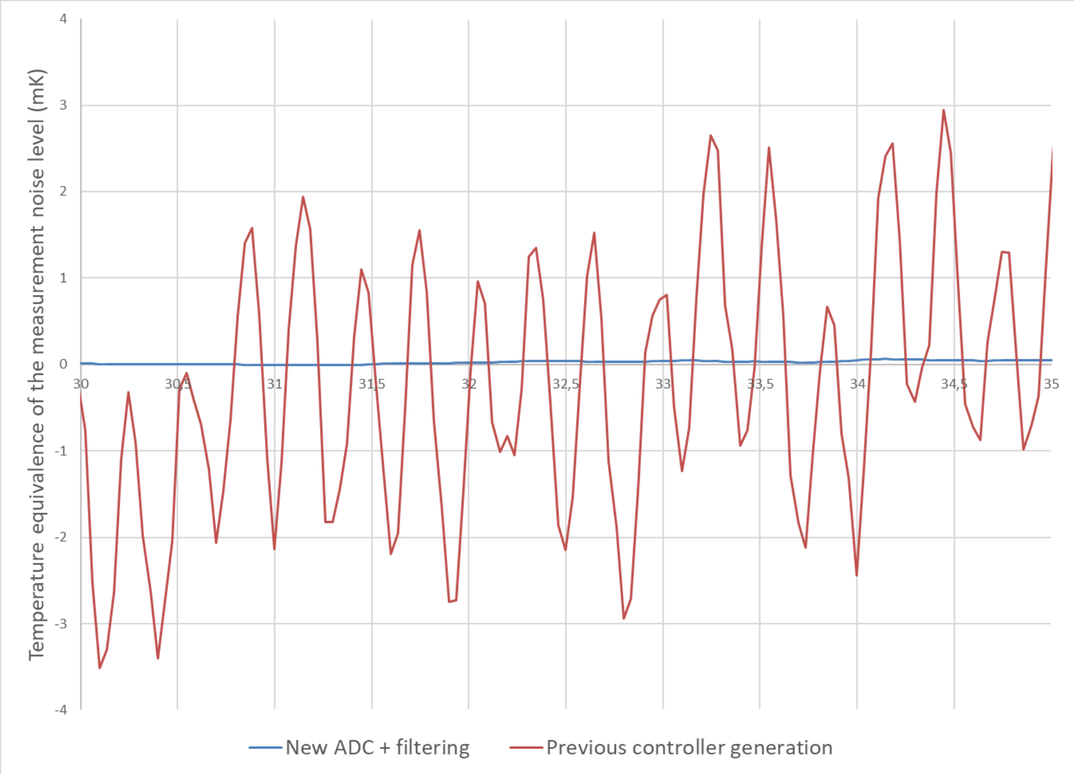

Figure 1. Noise level in mK before and after noise reduction

Second axis of improvement is on the optimized selection of the regulation parameters. A compromise must be found in order to optimize the stability, the heating and cooling time (slew rate) and to keep the temperature of the emissive surface from overpassing the setpoint.

When switching the emissive surface of a blackbody from temperature 1 to temperature 2, the curve showing the temperature of the surface vs. time can be divided in 3 phases. Figure 2 below shows these three phases.

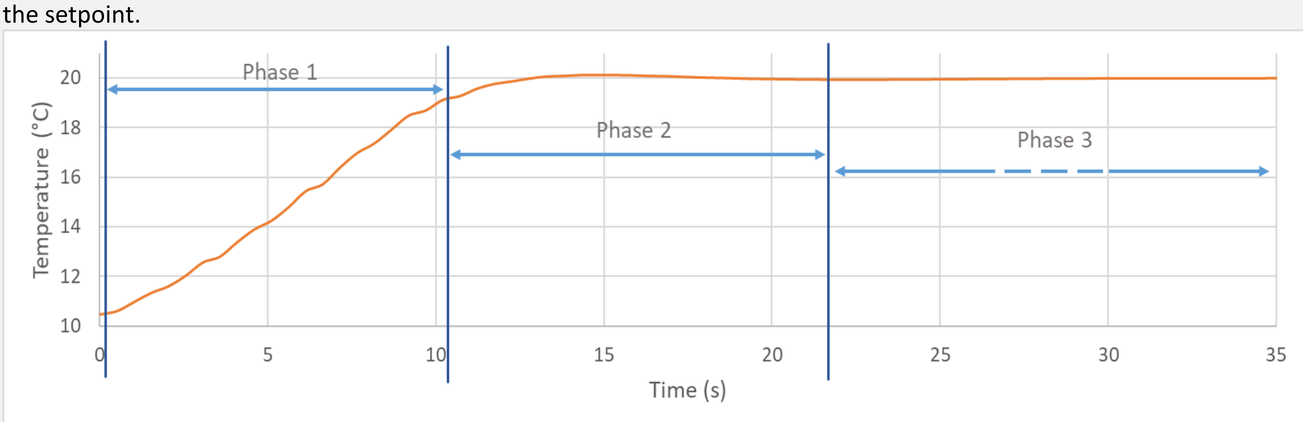

Figure 2. The three phases of the temperature regulation

Phase 1 is the warm up time. It represents the time required for the blackbody to switch from the previously stabilized departure point (Temperature 1) to a temperature closed to the arrival point (Temperature 2). The slope of this portion of curve is given as the slew rate (in °C/s). During this phase the temperature of the blackbody is not stabilized neither temporally nor spatially. This transitory mode cannot be used for the test of any sensor and a high slew rate must be considered. Phase 2 is the stabilization time. It represents the time required by the temperature surface to enter and remain within a stabilization criterion about the arrival temperature. Once this phase is complete, tests on a sensor can be performed during Phase 3, i.e. the stabilized phase. During this phase the stability of the temperature of the blackbody is optimized for the test of sensor.

The regulation parameters modify the duration of each phase as follow. Phase 1 duration is directly proportional to the power supply of heating or cooling elements of emissive surface. However, increasing the power supply leads to temperature overpasses the setpoint during

Phase 2. Multiple overpasses may occur which requires fast reaction from the regulation loop in order to keep the temperature within the stabilization criterion and reduce Phase 2 duration. On the contrary Phase 3 requires slow regulation parameters in order to be less sensitive to external influence (air flow for instance) and avoid the temperature to escape from the stabilization criterion. Obviously, defining the regulation loop parameters is a question of compromise and we developed a procedure allowing the blackbody temperature to quickly reach Phase 3 and remain stabilized at the temperature setpoint with a high stabilization criterion of 0.5 mK rms for the usual test conditions of thermal detectors. The following data shows the results of this procedure applied to a 100 x 100 mm² emissive surface low temperature blackbody. A 10°C temperature change is applied from 40°C initial temperature. Figure 3 shows the curve of blackbody surface temperature vs. time. The three previously described phases are easily identifiable on Figure 3. The slew rate is calculated from the data of Phase 1 : > 0.6°C/s. This value is a rather high figure compared to slew rate of usual blackbodies.

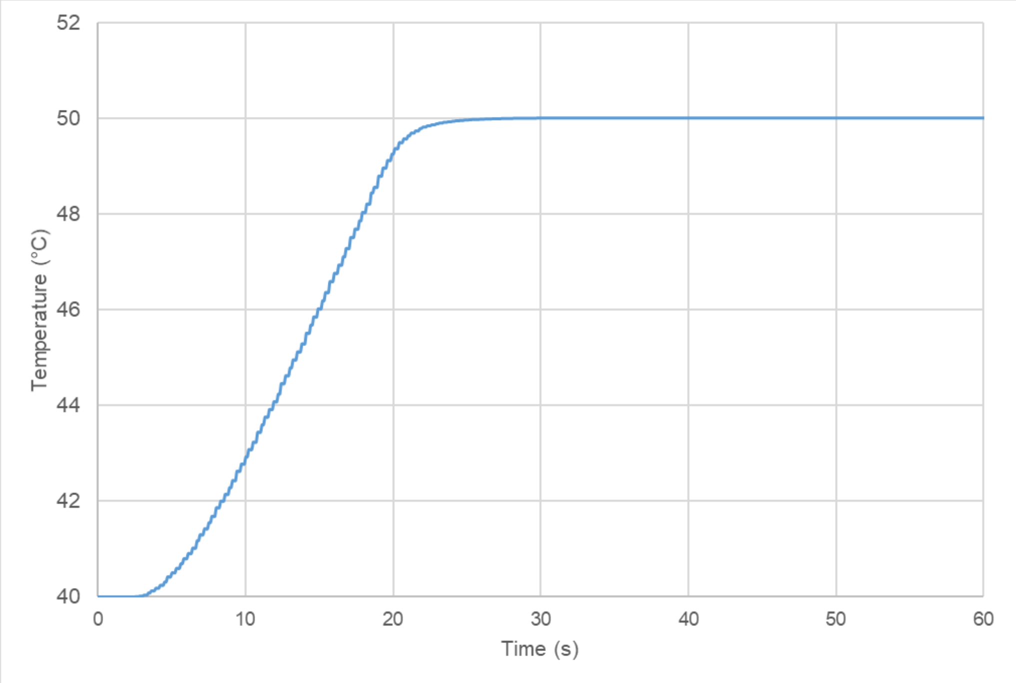

Figure 3. Regulation curve of a high stable blackbody

A zoom of the Phase 2 is shown on Figure 4: despite the above calculated high slew rate, the temperature never overpasses the temperature setpoint. This shape of signal is particularly suitable for an efficient MRTD test scenario. Total duration of transitory phases 1 + 2 is consequently less than 30 seconds whereas typical duration of this transitory phase on the existing blackbodies is about 50 seconds.

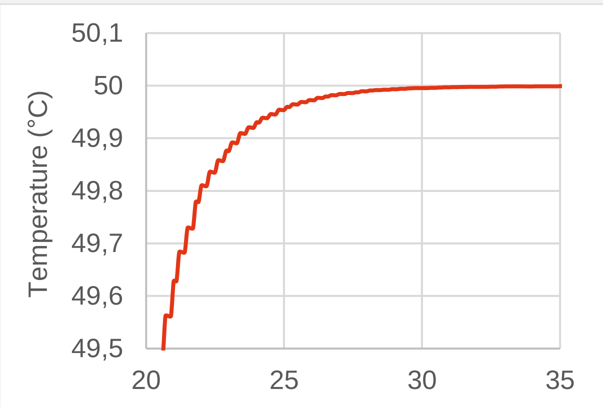

Figure 4. Temperature never overpasses setpoint

Now let's consider the regulation stability of the stabilized blackbodies, i.e. the standard deviation of the temperature over Phase 3. A zoom of this phase is shown on Figure 5.

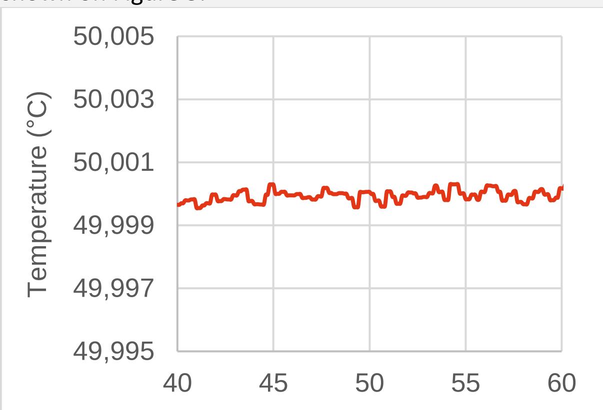

Figure 5. Long term regulation phase

A calculation of the standard deviation of the temperature is computed over at least 5 minutes: the stability of this extended area blackbody is less than 0.2 mK, better than the expected 0.5 mK criterion defined above. This result allows a negligible contribution on the calculation of the NETD of a high sensitive thermal sensor.

The next example shows a typical temperature scenario applicable to an MRTD test. The blackbody is operating in differential mode i.e. the temperature of the surface is regulated in differential vs. the temperature of a target, usually at room temperature. This mode leads to a stronger constraint on the regulation loop and stability as it requires two simultaneous measurements of temperature. Starting point is ΔT = 1°C, regular steps of -0.1°C are then applied down to ΔT = 0.4°C then temperature switches down to ΔT = -0.1°C and regular steps of -0.1°C down to ΔT = -0.5°C are applied. The cooling down option is also an additional constraint since cooling always requires more power than heating. Figure 6 shows the result of this scenario.

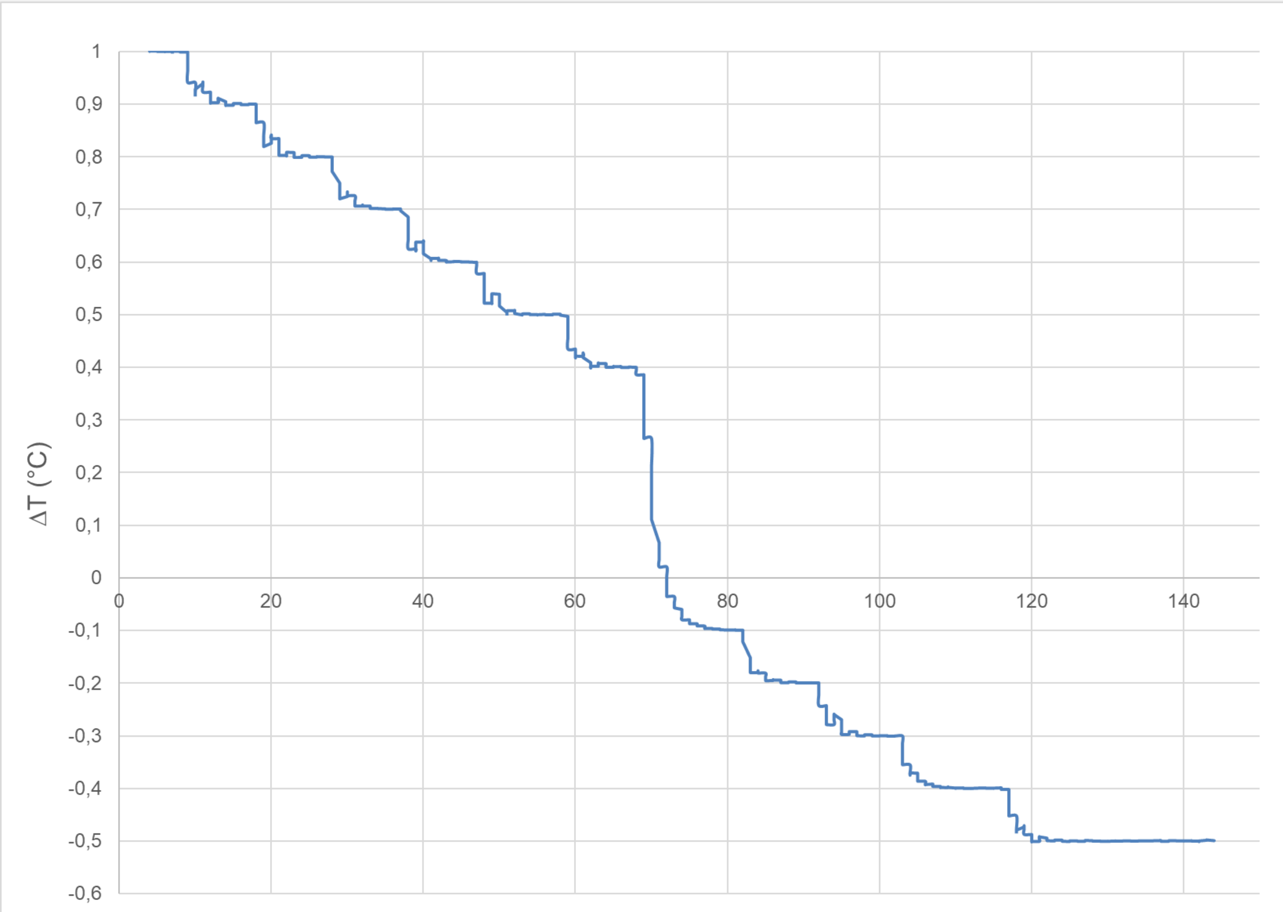

Figure 6. MRTD scenario

The above scenario corresponds to the decreasing phase analysis of an MRTD test. Again, whatever the temperature setpoint, the temperature never overpasses the setpoint: there is no risk of confusion for the observer of the target pattern. A similar and even faster curve is obtained for the increasing phase. Consequently, the total duration of the MRTD test (decreasing + increasing phases) for a given pattern frequency using the above blackbody is less than 4 minutes compared to 7 minutes at least on existing blackbodies.

3. CONCLUSION

Blackbodies are the essential elements of the testing benches of IR FPAs and IR sensors. As reference sources, their specifications must be in accordance with the more and more demanding requirements from IR sensor manufacturers. Their contribution to the uncertainty of measurement of IR sensors must be negligible. HGH recently developed new electronics for blackbodies with residual instability lower than 0.2 mK and regulation curve suitable to the measurement of NETD and MRTD of the existing most outstanding thermal sensors and the next generations.

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