

# Miniature Stirling Cryocoolers at Thales Cryogenics: Qualification Results and Integration Solutions

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## ABSTRACT

In 2015, Thales Cryogenics presented new miniature cryocoolers and cooler drive electronics for high operating temperatures (HOT). In this paper, an update is given regarding the qualification program performed on these new products. Integration aspects are discussed, including an examination of the influence of the dewar cold finger on the sizing and performance of the cryocooler.

The UP8197 and UP8497 and the corresponding cooler drive electronics will be placed in the reference frame of the Thales product range of high-reliability linear cryocoolers. Compatibility of the cryocoolers design with new and existing ¼" dewar designs is examined, and potential future developments are presented.

## INTRODUCTION

During the 2015 SPIE Defense, Security and Sensing exhibition, Thales Cryogenics presented an extension of their product range into the small form-factor domain [1], aimed towards detector cooling at high operating temperatures (HOT), typically 120 K to 150 K.

At that time, the cooler designs presented had not undergone qualification testing. Now, a year later, an update can be provided on these products and their qualification status.

Both the miniature linear coolers (UP8197 and UP8497) have completed their full tactical qualification programs. Following this successful qualification, both products are available on the market. In addition to the linear coolers, the rotary Size, Weight and Power (SWAP) cooler introduced at the same time has been redesigned for use with a new, generic, cold finger interface [1-3].

In this paper, the updated qualification results of the linear coolers and the matching cooler drive electronics will be presented, together with integration options for different available cold finger interfaces.

## POSITION IN PORTFOLIO

The different miniature coolers in the current Thales portfolio should be regarded in the context of detector operating regimes. Different competing medium wave infrared technologies have matured to a point where true HOT operation – with focal plane temperatures exceeding 140 K - becomes possible in an actual application next to laboratory demonstrators.

The availability of successful and cost effective HOT detectors and the adoption of these true HOT detectors by infrared camera manufacturers occurs slowly and guardedly, but surely.

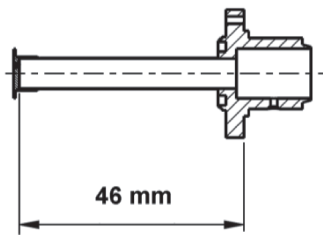


Figure 1. Thales CFA6 interface

Miniature coolers are required for many applications. For the foreseeable future, this means that both miniature coolers for the conventional temperature range around 77K are expected to be necessary in many applications. But in addition, new coolers for the true HOT operating domain will be required as well.

For the range of miniature coolers for detector temperatures around 77 K, a range of mature products is currently available. Many of these cryocoolers interface with the same cold finger sleeve, in order to provide maximum commonality for Integrated Detector/Cooler Assembly (IDCA) manufacturers. The standard ¼” cold finger sleeve (Thales CFA6 or C0012 definition) is seen in Figure 1.

The CFA6 cold finger is used in many cryocoolers, including larger coolers such as the RM4, designed for Long Wave Infrared (LWIR) detectors with operating temperatures around 60 K, or the LSF9597, designed for long-life operation for 24/7 surveillance cameras. Three miniature coolers are available within this range. These coolers are shown in Table 1.

For true HOT applications, smaller coolers should be used, with the selection depending on the SWAP constraints of the application, as well as the operating temperature. The UP8197 linear cooler (Figure 2) was designed for this purpose. Intended operating temperatures are 140 K and higher, but it has a potential application range down to 120 K.

This cooler is presented in the next section. First, the results of the qualification program are presented. Later, the available interfaces and the required future work are presented.

Table 1. Thales miniature coolers for low temperatures.

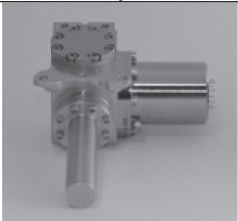
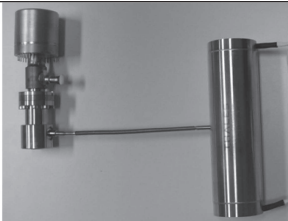
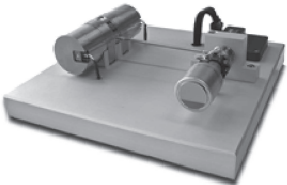
RM2 Rotary Monobloc	UP8497	LSF9997
		
Compressor 82x51.5x46 mm	Compressor 119 x 35mm	Compressor 119 x 44 mm
High power density Suitable for 77 K operation Balanced design for low vibrations and acoustic noise Produced in large series	High power density Designed for 110 K Suitable for 77 K operation Redesign (2015) qualified [1, 5], undergoing industrialization.	Smallest flexure-bearing compressor [5] Designed for 110 K Suitable for 77 K operation Moving-magnet design Designed for reliability In series production



Figure 2. Photograph of the UP8197 cooler.

UP8197 QUALIFICATION RESULTS

Performance qualification results

Based on the initial characterization of the cooler [1], the nominal parameters of the cooler were changed slightly compared to the original specification, in order to increase the available heat lift (allowable AC input power to the cooler) at +23 C and +71 C. Updated performance measurements are shown in Figure 3.

These performances were measured with a laboratory test dewar not optimized for heat load—the estimated parasitic heat load of the dewar itself was 250 mW at 150 K, 23 C. The characterization of this heat load at 150 K was done with the warm-up method [9], as measurements with the boil-off method are not practical at these tip temperatures. The result of the multi-slope warm-up is shown in Figure 4.

Compared to the previously reported performance numbers [1], the maximum input power to the cooler has increased by 33% from 15 W to 20 W. The advantage of the increased input power is that both the absolute available cooling power has increased, and the cool down time will decrease.

Cool down time has been tested in the same laboratory test dewar. The thermal characteristics of this lab dewar are different from a typical tactical dewar. Therefore, the test results are not fully relevant for cool down times in common tactical dewars. The expected cool down time in tactical dewars is scaled from the measured CDT in the lab dewar. Results are shown in Figure 5. It can be concluded that typical cool down times in tactical dewars are between 120 and 130 seconds

- The cooler is fully characterized in the lab dewar. The characterization consists of the cool down time, and the performance mapping for relevant operating conditions (input power, ambient temperature, and tip temperature).

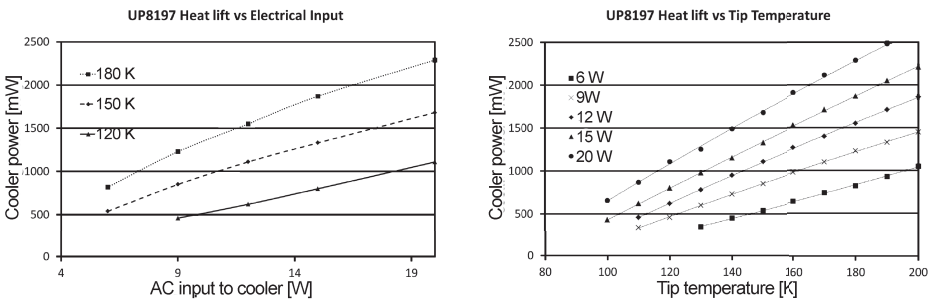
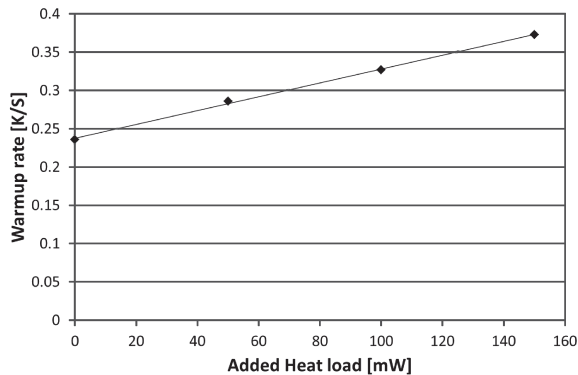


Figure 3. Typical performance of the UP8197 cooler. Left graphs show the cooling power versus input power at different tip temperatures. The right graph shows cooling power versus tip temperature at different input powers.



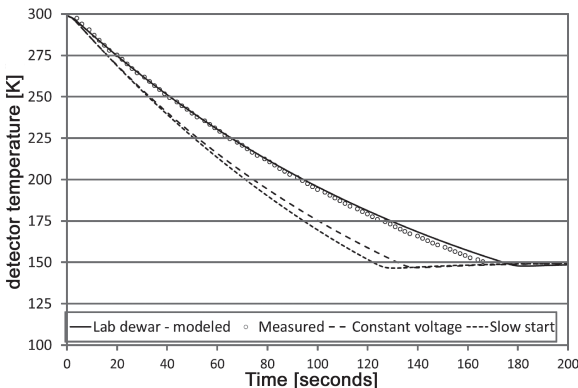
**Figure 4.** Determination of dewar heat load at 150 K using the warm-up method [9]. The resulting heat load is 250 mW.

- A transient thermal model of the cooler with the test dewar is built in the ThermXL thermal modelling software [6]. This model contains the full integration of the cooler in the application, including the impact of thermal resistances, heat sinking, etc.
- The transient model will predict tip temperature as a function of time. This prediction is compared to the measured cool down curve on the cooler to validate the model.
- The model is then used to calculate the transient behavior of the cooler in a dewar of typical characteristics. In this case, a detector is used with a dewar heat load of 220 mW between 23°C and 150 K, and a thermal mass of 180 J between 23°C and 150K.

The results are shown in Figure 5. It can be seen that the model results on the lab dewar are close to the measurement results. This validates the accuracy of the model. The other two results show typical values for two scenarios. The different scenarios use the effect that the maximum drive voltage for linear coolers at startup is lower than when the cooler is cold. In the first scenario, the safe ‘warm’ startup voltage is used for the entire cool-down. In the second scenario, the voltage ramps up from the low value at startup to the value at the cold tip temperature. This reduces the cool down time of the detector. This feature, called ‘slow start’, is a standard feature in all Thales linear cooler drive electronics .

**Exported vibrations**

One important advantage of a dual opposed-piston linear cryocooler is that the vibrational forces exported by the cooler are already at a very low level, without the need for a tuned balancer



**Figure 5.** Cool down curves for the UP8197. Markers show the measured value in the lab dewar. Solid line is the simulated performance in the lab dewar. The two dashed lines are the simulated cool down curves in a representative tactical dewar.

or flexible mounting. This also has the advantage of resulting in low acoustic noise exported by the camera.

Two qualification models of the UP8197 were tested for exported vibrations. This was done using a three-axis accelerometers with either the compressor or the cold finger free-standing. No test dewar was mounted during exported vibrations testing. A measured vibration spectrum of the cold finger can be seen in Figure 6. This spectrum is measured at full input power. In regulation, the induced vibrations will scale with input power. As expected, the largest vibration exported by the cold finger occurs at the drive frequency, in the direction of motion of the displacer.

As the UP8197 is equipped with separate connections for each linear drive motor, it is possible to apply Thales AVR to the cooler [7, 8], enabling even lower vibration levels. In case an accelerometer with sufficient sensitivity is used, a similar reduction can be expected as with prior tests – which is at least a factor 50 reduction along the displacer axis.

Environmental conditions

The UP8197 has undergone a full environmental qualification program. The tests conducted are shown in Table 2. All environmental qualification tests were performed successfully. An example test can be seen in Figure 7.

UP8197 COLD FINGER INTERFACES

Cold finger interface definitions

An aspect of miniaturization is the reduction of the overall system length along the optical axis. The total length from the rear of the cooler to the front of the dewar window becomes an important parameter. HOT operation enables shorter overall lengths without much impact on performance. Therefore, interfaces for the UP8197 in HOT applications are no longer based on standard CFA6 interface as shown in Figure 2.

The 2015 product definition of the UP8197 [1] is based on a Thales proprietary short cold finger definition. Based on market feedback since then, two more variants of the UP8197 cold

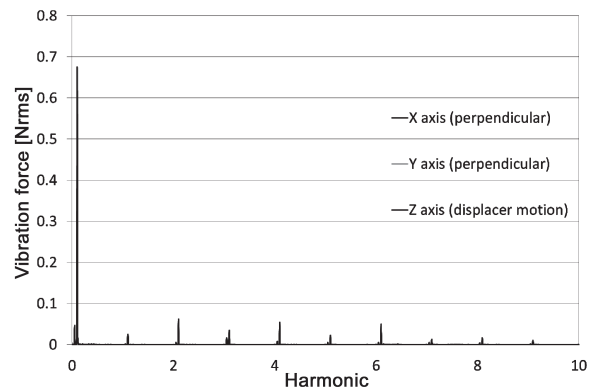
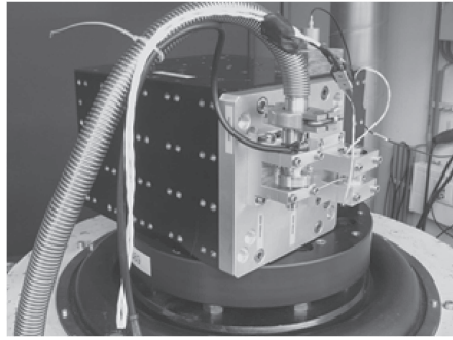


Figure 6. Induced vibration levels of the cold finger in three axes, measured with an accelerometer.

Table 2. Environmental tests

Test type	Test
Thermal	Dry heat, operating and storage
	Cold, operating and storage
	Change of temperature
Mechanical	Repetitive shock (bump)
	Shock, operating
	Random vibration, operating
	Sine vibration
	Acceleration, operating



**Figure 7.** UP8197 mounted on the shaker table undergoing operating random vibration testing.

finger have been proposed to meet various requirements. One variant that has been under discussion since 2015 is a harmonized cold finger sleeve, designed to interface with small coolers from several manufacturers.

The final configuration of this interface has been discussed with several manufacturers. A copy of this drawing is available on request. The other variant interfaces with the existing CFA6 cold finger. The advantage is that the cooler can be combined with existing detectors already available. The three variants are summarized in Table 3.

Both alternative versions are still under development. For the version with the common interface, all dimensions critical to the coolers performance remain unchanged, so no impact on cooler performance is expected. Only limited delta qualification is expected to be necessary once test equipment with this interface becomes available.

The other foreseen modification is a cold finger with the standard 1/4" CFA6 interface (Figure 2). This variant is also currently under development. This variant is expected to have a different performance than the other two variants.

Because the cold finger is longer, a longer regenerator is possible. This will lead to higher efficiency because of reduced regenerator losses. On the other hand, because of the larger overall gas volume in the system the maximum input power will decrease. The same absolute cooling power is available but at a lower input power.

An indication of the expected efficiency difference (regenerator influence only) can be seen in Figure 8. This estimation does not yet take into account the lower losses due to the increased conduction length of the cold finger, which can be another benefit of a longer cold finger.

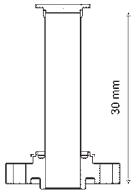
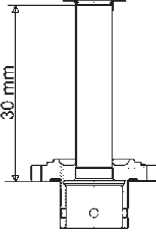
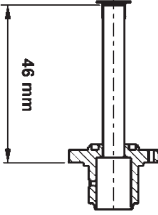
## COOLER DRIVE ELECTRONICS FOR MINIATURE LINEAR COOLERS

The LPCDE1220 cooler drive electronics is designed for low power coolers. In particular, the UP8197 and UP8497 coolers can both be driven by it (see Figure 9). The LPCDE has undergone a full qualification program similar to that performed for the UP8197. A full feature set is available [1]. Typical performance characteristics are the programming capability over the serial port combined with dedicated I/O lines for specific functions such as 'Cooler Ready' and 'Remote On/Off'. Furthermore, the electronics allows the voltage ramp up feature during cool down and dual set points for a Standby function.

Typical performance characteristics of the cooler drive electronics are high efficiency and regulation stability. In Figure 10 the temperature drift measurements are shown. In the left graph, the temperature drift with varying ambient temperature is shown. This is measured with a dual diode test dewar. One diode is used as the input device for the cooler drive electronics. The other is used as an independent temperature measurement. Over the temperature range of -50 °C to 90 °C the error in diode voltage due to temperature drift is less than 0.2 mV, corresponding to 0.1 K.

The right graph of Figure 10 shows the regulation stability over a 15 minute interval. Within this interval, the diode voltage remains constant within a 0.05 mV bandwidth, corresponding roughly to 30 mK.

Table 3. Interface options for the UP8197

Thales Short Sleeveless CFA6/S	Common Cold Finger	Thales Standard ¼" CFA6
		
Novel sleeveless design	Sleeved design with heritage	Sleeved design with heritage
Potential for further miniaturization	Single Cold Finger design for multiple cryocooler manufacturers	Compatible with large range of existing coolers.
Lower performance spread expected	Flexibility for customers; cryocooler choice can be made per application without changing dewar design	Flexibility for customers as existing dewars can be used.
Cost advantage		46mm inner length
30mm inner length	30mm inner length	
Fully qualified	Delta qualification required	Under development

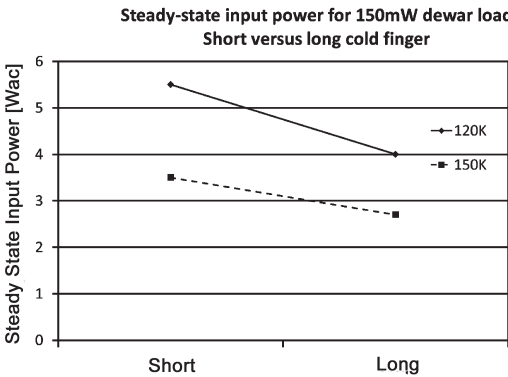


Figure 8. Estimated influence of regenerator length on cooler efficiency. Shown is the necessary input power for a dewar load of 150 mW. The longer regenerator has a higher efficiency and a lower required input power.

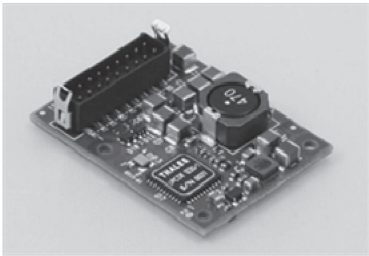
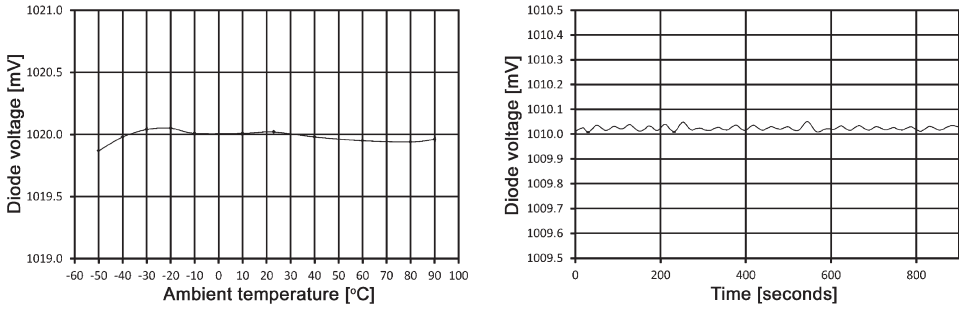


Figure 9. Photograph of the LPCDE1220 Cooler drive electronics.



**Figure 10.** Temperature stability measurements with the LPCDE. The left graph shows the temperature stability (drift) with different ambient temperatures. The right graph shows the regulation stability over a 15 minute period.

The efficiency of the drive electronics is measured when driving the UP8197. The measured efficiency depends on the output power and the DC voltage. For an output power larger than 4 W, the efficiency is better than 90 %.

CONCLUSIONS

While HOT technologies are maturing, and system integrators consider how to benefit from this new technology, more accurate requirements are expressed for the necessary coolers. Thales Cryogenics works with thermal imager manufacturers to provide a full range of products suitable for the entire gamma of current HOT SWaP requirements.

Two new products, the UP8197 and UP8497 linear cryocoolers are now available to complement the Thales product portfolio for these miniature applications. The UP8197 for true HOT application of 120 K and higher, and the UP8497 for the gap between this and conventional 77 K applications. Both coolers and the matching cooler drive electronics LPCDE1220 are presently qualified and available.

New variants of the UP8197 with different cold finger options, such as a common interface for interchangeability with other manufacturer’s coolers and existing ¼” interfaces for higher efficiency and interchangeability with a large range of existing dewar detector combinations, are foreseen for the near future.

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