ABSTRACT:

The RM3 is the new development in RM series, thanks to its innovative onboard drive electronics it is now possible for users to extend easily their systems through new functionalities. During this presentation you will have an overview of advantages and benefits of this onboard digital driver electronics both for the Detectors’ Module makers and the End-users. Furthermore you will appreciate the specific performances of the RM3. Sofradir and SCD, both leading manufacturers of Detectors’ module, have contributed through their expertise to evaluate successfully the RM3, operated by the onboard driver electronics. The results of these new functionalities and cryogenic performances will be revealed throughout the presentation.

We plan to adapt this onboard drive electronics to the other products of the RM-series. The next generation of small sized camera’s requires increasingly reliable and yet compact Cryocoolers. The customers also need Easy to use & Easy to replace products. We will demonstrate how the RM3 can provide user-friendly solutions to meet these expectations.
THE DIGITAL ONBOARD DRIVE ELECTRONICS OPTIMIZES THE ROTARY CRYOCOOLER FUNCTIONALITIES FOR YOUR DEMANDING APPLICATIONS

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1. INTRODUCTION
The RM3 is a new one in RM series of the Thales Cryogenics rotary integral IDCA cooler range. The RM3 is a very compact cryogenic cooler that provides cryogenic temperature (~80k) for optronic applications like IR camera in military or civil application.

The RM3 is specified to run in a wide range of ambient temperatures and DC input voltages. It enables the system to remain functional from -46°C to +85°C and from 18Vdc to 28Vdc.

The RM3 cooler consists of 2 main sub assemblies: The cooler drive electronics and the cooler itself. The RM3 is the first rotary integral cooler with digital onboard electronics. The cooler drive electronics powers the three-phase brushless of the cooler motor and can deliver up to 30W in the cooler motor.

The RM3 drive electronics is based on a DSP (Digital Signal Processing). This allows to have on board the cryogenic cooler a lot of new functions which were not available or not available for user up to now: operational functions as well as diagnostic and maintenance functions. In addition, the cooler drive electronics can be easily adapted without hardware modifications in particular with regard to any specific customer need.
Two interface connectors are available. The main connector is a SUB-D 9 pins connector and ensures the input power interface with the system as well as the management of the interface signals with the system (stand-by signal, …). An additional connector is available on the cooler skin for the RS232 interface with the RM3 cooler drive electronics.

2. FUNCTIONS OF THE RM3 DRIVE ELECTRONICS

Main function
The main function of the RM3 onboard drive electronics is to power the cooler motor according to the position of the rotor given by the three Hall effect sensors and to stabilize the component (Infra Red detector) at the required cryogenic temperature thanks to the regulation loop.

Two regulation modes:
The RM3 drive electronics is able to drive the motor in two different regulation modes:
- Regulation loop on cryogenic temperature. In that case the cooler is driven so that cryogenic temperature is regulated according to the cold temperature set point.
- Regulation loop on motor rotation speed. In that case the cooler is driven so that motor rotation speed is regulated according to the motor speed set point.

The first mode (cold temperature regulation) is used in operational use. The regulation is ensured thanks to a Pulse Wide Modulation (PWM) signal. It has a frequency optimized with regard to the motor. This enables to optimize the motor efficiency. The cold temperature setpoint is programmable by the user in the range 300 mVdc to 1100 mVdc through the serial connection on the RS232 connector with very high resolution steps (45µV). It is in consequence very easy to set the precise cold temperature needed by the application.

The second mode (motor speed regulation) has several interests. On one hand, it can be used for development purposes to characterize detector dewar performances or image quality at a specific desired motor rotation speed. It can also be used to optimize integration with regard to induced vibrations. On the other hand, this motor speed regulation mode can be activated if the cold temperature sensor circuit is failed (short circuit or open circuit). In that case, the cooler could be driven by default at a constant rotation speed. This constant rotation speed is programmable according to the user instructions in the range 500 to 4500 rpm. For the user, this means that the system can remain functional in degraded mode even in case of failure on the cold temperature sensor circuit. The switch from mode 1 to mode 2 can be accessible through the serial connection on the RS232 connector.

Bias current:
The RM3 drive electronics delivers a bias current for the external cryogenic temperature sensor located in the cold tip of the detector dewar. In standard, the RM3 cooler drive electronics is able to manage Silicon junction type of cryogenic temperature sensors (example: 2N2222). The bias current function is available on the SUB-D 9 main connector. This allows dewar manufacturer to simplify their dewar electrical wiring.

The cold temperature information is always available for the user whatever the chosen regulation mode (temperature regulation or speed regulation) or if the cooler is used in Shut down mode. This information is available on the RS232 connector on demand.

Communication:
The RM3 drive electronics has an ergonomic serial connection allowing it to communicate with a laptop or a personal computer. The communication function is available on the RS232 connector at all time when the drive electronics is powered. Communication is allowed when the cooler is running in an operational mode. A software application enables this communication with an user-friendly interface Fig.1. The communication allows the programming in the non volatile memory (ROM memory) of the various programmable parameters (cold temperature set point, …) and also the reading from the drive electronics of the information and measurements recorded by the drive electronics.

![Software interface](image.png)

Figure 1. Software
**PID parameters:**
PID (Proportional Integral Derivative) parameters can be adapted depending on the transfer function of the total regulation loop (Cooler drive electronics, cooler, dewar). This enables optimization of temperature stability for all types of applications (high or small thermal masses, thermal resistance between the cooler and the detector, ...). These PID parameters can be tuned through the serial connection on the RS232 connector.

**Stand by mode:**
The STAND-BY function is accessible by short-circuiting STAND BY and CONTROL pins on the main interface connector. When this function is activated, the cooler is regulated to the STAND-BY temperature which can be different from the normal cold temperature set point. The STAND BY temperature set point is programmable by the user through the serial connection on the RS232 connector. The STAND-BY temperature set point can be tuned in a wide range, the same range as the cold temperature set point (300 mVdc to 1100 mVdc). For the user, this allows to have a stand-by running mode of the system with energy savings. It also enables to reach the cold tip temperature in a short cooldown time when starting from the stand-by temperature.

**Shut down:**
The SHUT DOWN function is accessible by short-circuiting the SHUT DOWN and CONTROL pins on the main interface connector. This function allows to stop the power to the cooler motor while maintaining the drive electronics turned-on. For example, this function can be used to record the rise of the cold tip temperature when the cooler is stopped. This can enable the user to have an easy characterization of the dewar thermal losses whenever he wants and to have a follow up of this dewar performance, very useful for cooler replacement management and maintenance purpose: the user can decide to replace or not the cooler depending the dewar thermal losses.

**Cool down indicator:**
Cool down indicator is an open collector output available on the main interface connector and named "COOL DOWN INDICATOR". The cooldown indicator is activated when the cold temperature voltage is within a defined range around the cold temperature set point. The range can be programmed (by the user) on request within a range of +/- 1Vdc from the cold temperature set point through the serial connection on the RS232 connector.

The logic of the output level (high level and low level) can be programmed. For example, high level of the output can be programmed as being "cold temperature set point not reached" or on the contrary as being "cold temperature set point reached".

The cooldown indicator can for example be used by the customer to switch on the detector at a desired temperature that can be different from the cold temperature set point. It can also be used as alarm in both directions: in case the cold temperature warms up too much or in case the cold temperature goes abnormally too low.

**Start-up:**
The RM3 drive electronics is designed to manage a smooth start of the cooler motor. The start of the motor is made in a progressive way to limit the peak of current at start. For the customer, this enables an easier and optimized design of the system power supply.

**Protections:**
The RM3 drive electronics is protected against handling errors of the operators. It includes a protection against reverse polarity on the input power supply lines, an overvoltage protection on the power input lines, an over current protection on the power input lines and a protection in case the rotation of the motor rotation is blocked whatever is the reason.

A security stops the cooler if the current exceeds a critical threshold.

**Hour counter:**
The electronic has an integrated hour indicator. It measures the cooler running time with a resolution and an accuracy of one second. As a consequence, when the RM3 drive electronics is powered but the cooler stopped (for example in shut down mode), the hour counter stops incrementing. The cumulative operating time (expressed in hours, minutes and seconds) made by the cooler since its first start is available to the user for reading only on the serial connection on the RS232 connector. This function gives a lot of interesting possibilities both for the user and the cooler manufacturer. The benefits can for example be seen for maintenance follow up and also for more accurate estimation of the field reliability of the RM3 depending on the customer real application. The hour counter is also accessible in writing at manufacturer level to reset its value between 0 and 100000 if necessary for maintenance purposes.

**Data recording:**
The electronic ensures data acquisition in real time or in
batch mode. The following parameters are recorded: motor rotation speed, cooldown time, cooler input power and cryogenic temperature. The last 10 performances of the cooler are stored and can be on demand accessible via the RS232 connector to the manufacturer for diagnostic and maintenance purposes.

**Traceability:**
The serial number of the cooler driven by the drive electronics is stored in the drive electronics memory for easy traceability in service.

3. **PERFORMANCES OF THE RM3 DRIVE ELECTRONICS**

**Efficiency:**
The RM3 drive electronics has a high efficiency (ratio between output power from the drive electronics to the motor and DC input power to the drive electronics). The **efficiency is better than 73% in steady state mode and 90% in cool down mode** for 17W input power to the RM3 drive electronics. The no load input power for the RM3 drive electronics is in the range of 50mA.

**Cold temperature stability:**
Thanks to the digital programming of the RM3 drive electronics, the cold temperature set point is fully independent from any drift due to external environment. This enables to have a **very accurate regulation of the cold temperature**.

Cold temperature stability in stable environment Fig 2 and Fig 3:
In constant voltage supply and constant ambient temperature conditions, the amplitude of a possible drift or instability of the cold temperature does not exceed +/-0.075 mV (approximately 0.05K depending on the temperature sensor characteristics) with regard to the programmed cold temperature set point.

Long term and short term cold temperature stability:
Over the whole range of ambient temperatures and power supply voltages, the cold temperature stability is better than +/-0.75 mV (approximately +/-0.5K depending on the temperature sensor characteristics) with regard to the programmed cold temperature set point.
Within this 1.5 mV range, the long term variation speed of the cold tip temperature is smaller than 1 mV/min measured over a 24 hours time.
Within this 1.5 mV window, the short term variation speed of the cold tip temperature is smaller than 0.075 mV/s measured over a 1 minute time.

**Bias current:**
The stability of the generated bias current is better than 0.5µA over the complete specified range of ambient temperatures and input voltages.

**EMC aspects:**
The RM3 drive electronics ensures the filtering of conducted disturbances on input and output leads and of parasitic radiations by means of adapted filtering. It allows on one hand to remain operational in perturbed electromagnetic environments and on the other hand not to pollute the environment in which it is used.

These EMC performances have been tested according to

![Figure 2. COLD TEMPERATURE STABILITY FROM -40°C TO +85°C](image)
MILSTD461F in conductivity (see graph 4) and in radiation (see graph 5) according to tests CE101, RE101, RE102, CS101, RS101 with very satisfying results according to our customer: this EMC very good behavior allows to remove additional filtering usually used with other similar cooler to remove electronic noise on the image.

The grounding of the RM3 drive electronics is connected to the mechanical grounding of the cooler skin. This grounding is available for shielding purposes on one pin of the SUB-D 9 pins main connector.

Figure 3. COLD TEMPERATURE STABILITY @ -46°C at 24 VDC during 16 hours.
4. QUALIFICATION STATUS

Extensive validation testing has been made on the RM3 drive electronics as well as on the RM3 cooler and combination of both. This validation testing has covered all the ambient temperature range, all the specified mechanical environments and also life time testing. During these validation tests, all the characteristics and performances have been verified. The next step is to pass the formal qualification for the complete RM3 cooler (cooler + drive electronics). This formal qualification includes a full test plan on a batch of 6 coolers. These coolers are submitted to a full qualification in thermal and mechanical environment which are followed by a life time test according to a climatic profile. Thanks to the extensive validation testing already undertaken, the success of the qualification is guaranteed. This qualification is planned to be finished by the end of the first semester 2010 as endurance tests are still going on to confirm estimated MTTF of 10 000 hours. At that time, 7000 hours of running time has already been reached.

5. TEST DONE BY DEWAR MANUFACTURER

5.1 Test performed by SCD

SCD has performed all cryogenic tests on 2 RM3 coolers. SCD and its customer appreciated temperature stability performance, EMC performances and user friendly communication connection with laptop.

Regarding cryogenic performances, cool down time performances – to reach 77 K - at different temperatures from – 40°C to 70 °C - have been measured by SCD. Performances of both coolers were better than requested (see graph 6).

Regarding input power, measurements have been performed by SCD without load (graph 7) or with load (graph 8).

Input power performances measured were better than requested with more than 3 watt saving which is more than 30% (at ambient temperature) to 45% (at –40°C).

Graph 6 – Input power in regulation without load
5.2 – Test performed by Sofradir

Sofradir has performed tests with our RM3 cooler in their MARS MW detector. Cool down time to 90 K measurements are illustrated in graph 9 at different temperature from –40°C to + 85°C. Input power measurements at different temperatures from –40°C to + 85°C are given in graph 10.
6. CONCLUSION

The RM3 cooler including its RM3 onboard digital drive electronics is now available and gives full satisfaction regarding stability and cryogenic performances tested by dewar manufacturer. Thanks to the DSP technology used for its drive electronics, the RM3 is able to provide a lot of new functions and benefits for the user. It is perfectly suited for new application as well as for replacement or upgrade of existing systems.

It is now planned to adapt the RM3 drive electronics for the other products in our RM rotary integral IDCA range.

Graph 9 – Cool down time to 90 K with RM3 in MARS MW Sofradir detector

Graph 10 – Input power in regulation with load with RM3 in MARS MW Sofradir detector