WEPV026

MULTI-CHANNEL HEATERS DRIVER FOR SIRIUS BEAMLINE'S OPTICAL DEVICES

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Brazilian Synchrotron Light Laboratory

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HARDWARE DESIGN

Abstract

Thermal management of optomechanical devices, such as mirrors and monochromators, is one of the main bottlenecks in the overall performance of many X-Rays beamlines, particularly for Sirius: the new 4th generation Brazilian synchrotron light source. Due to high intensity photon beams some optical devices need to be cryogenically cooled and a closed-loop temperature control must be implemented to reduce mechanical distortions and instabilities. This work aims to describe the hardware design of a multi-channel power driver for vacuum-ready ohmic heaters used in critical optical elements.

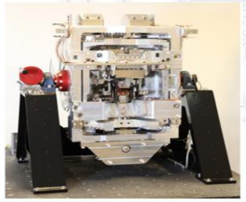

Figure 1: Sirius´ Double Crystal Monochromator (HD-DCM)

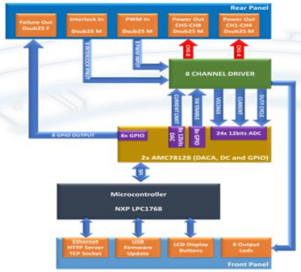

Figure 2: 8-Channel Heaters Driver Block Diagram.

The multichannel driver was designed to simultaneously deliver up to 1.5A at 12V to eight ohmic vacuum-compatible heaters. Each channel can be individually controlled by a TTL (Transistor-Transistor Logic) compatible PWM (Pulse-Width Modulation) signal. Optocoupled interlock inputs were implemented for safety purposes and failure outputs for open load and short-circuit signaling. A current limiter scheme has been included to protect both heater and driver from overload and short-circuits. Figure 2 shows the block diagram.

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The power driver is based on a simple buck DC-DC voltage regulator, which has its output voltage controlled by an input voltage (V_C) applied to a series resistor (R_C) at the feedback node.

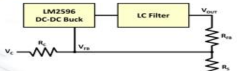

Figure 3:LM2596 Control Principle.

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Assuming a DC-DC stable control loop, the feedback node voltage (V_{FB}) is fixed at 1.3V. Considering the current drawn by the regulator feedback node (I_{FB} 10nA typical [8]) can be neglected, the output voltage is a linear function of control voltage (V_C) described by Eq. (1):

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- 15V up to 13.4A (200W) to power the output drivers.
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Figure 5: Mechanical Assembly.

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The front panel has an LCD display to show the channels status, a main switch, ethernet input and USB input for firmware updates.

At the rear panel, the AC line input and 2A fuse are connected to power supplies and the 25-pin Dsub connectors provide output power to heaters and I/O's to controller: Control Input, Failure Output, Interlock/Enable Input, Power Output (2x).

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The microcontroller LPC1768 is programmed using Mbed framework [10], running Mbed Os 2 as real-time operating system, arranging tasks in 4 separate threads:

- **Main thread**: running at normal priority, responsible for Ethernet reconnection in case of failure, device startup configuration and save persistent data into internal Flash.
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ELECTRONICS CHARACTERIZATION

Linearity

Due to hardware limitations, the output response is linear from 10% to 85% PWM duty cycle, obtained delivering power to 20Ω loads. PWM frequency has been adjusted to 1kHz.

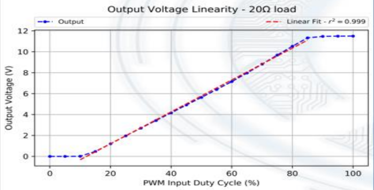

Figure 9: Output Linearity.

The null-input output noise presents 100kHz 60mVpp spikes. At this condition, 31.75mV DC voltage is applied to 20Ω loads. The signal is shown in Fig.10

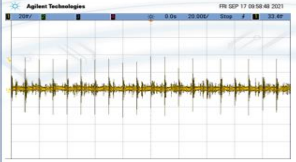

Figure 10:Output Voltage (Shorted-input and 20Ω load, AC coupling).

The output noise worst case occurs at 50% duty cycle input, 200mVpp spikes at 1kHz PWM frequency are shown in Fig. 11. In this condition, the driver delivers 5.89V to a 20Ω load. Temperature variations involved in thermal systems are usually long-term changes, thus tens of mV spikes at kHz frequencies does not affect overall performance.

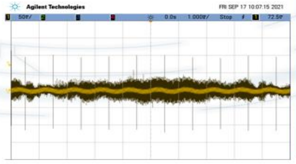

Figure 11: Output Voltage (1kHz 50% PWM Input) delivering 5.89V to 20Ω load, AC coupling).

Bandwidth

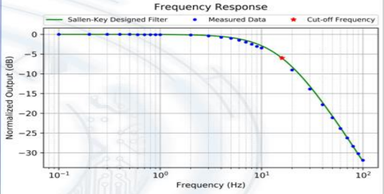

Figure 12: Single-channel Frequency Response.

The driver bandwidth is limited by the Sallen-Key filter, designed to cut-off over 16Hz. Figure 7 shows driver frequency response, that has been obtained using a sinusoidal modulated 1kHz PWM signal delivering power to 20Ω loads. The sinusoidal signal modulates from 20% to 80% duty cycle with 100mHz to 100Hz variation. The normalized output refers to peak-to-peak AC load voltage at a given frequency.

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Field Application Results

The heaters driver is employed in several optical devices at Sirius beamlines. The simplified block diagram of the Double Crystal Monochromator (HD-DCM) thermal management control system is presented in Fig. 13, using a NI CompactRIO as the main controller.

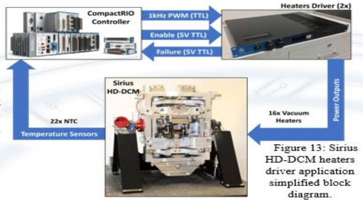
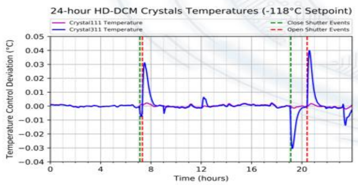


Figure 13: Sirius HD-DCM heaters driver application simplified block diagram.

A closed loop 24-hour long-term thermal stability is shown in Fig. 14, spotting DCM crystals temperature sensors during a regular user shift at EMA (Extreme condition Methods of Analysis) beamline.



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There is a strong correlation between variations and gamma shutter events, nevertheless crystals temperatures remain below 0.05°C deviation over 24 hours. The HD-DCM thermal system characterization and control loop tuning are not intended to be presented at this paper, however related works [4, 13] discuss this subject in-depth.

Conclusions

This work presented the hardware design concepts and results about a multi-channel heaters driver, intended to be used at beamlines optical devices, such as mirrors and monochromators. The driver is capable to deliver up to 18W per channel at 12V (36W per channel at 24V) simultaneously to eight ohmic heaters. The output power is controlled by 5V PWM signals that can be easily integrated to any digital controller.

In addition, 5V TTL failure outputs signalize malfunction heaters and enable inputs turn off power outputs 51ms afterwards a falling edge. An embedded webserver is implemented to allow fast diagnostics and a TCP socket is available for EPICS infrastructure integration.

Power outputs noise levels have not significant influence for thermal systems, typically characterized with long-term variations.

The first 20 units production set currently being used in first 6 Sirius` beamlines were manufactured in 2018. In 2021, 12 additional units have been produced for upcoming beamlines. Driver hardware failures have not been reported in the past years, supporting driver high reliability, usually an essential requirement for thermal management systems.

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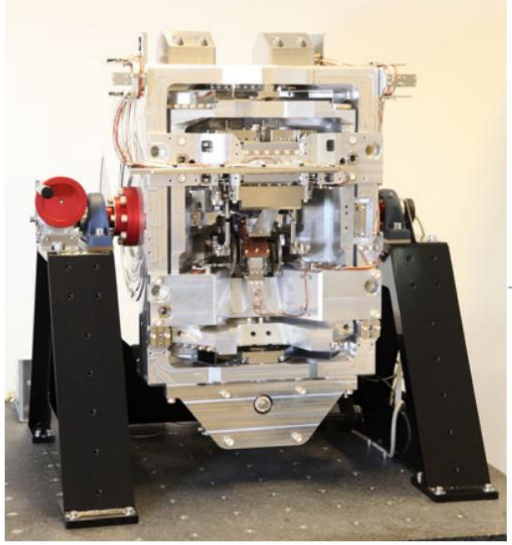

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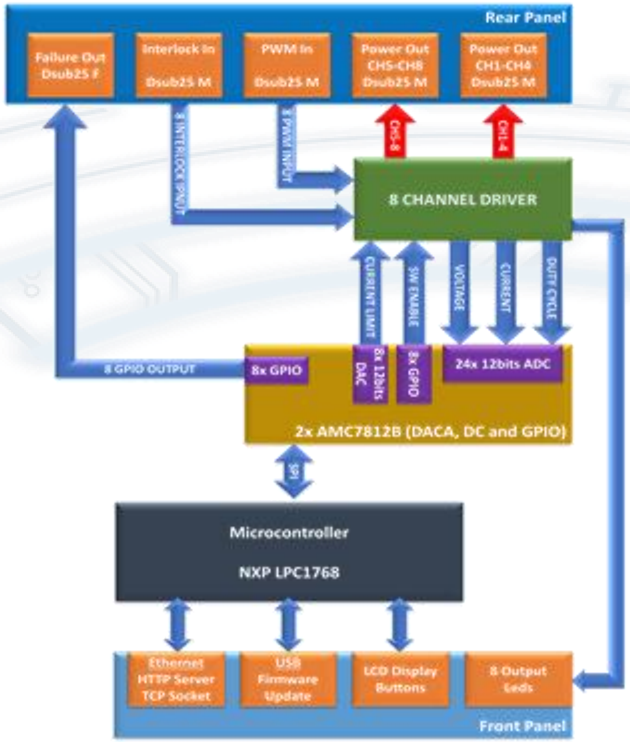

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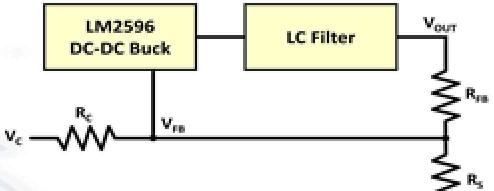

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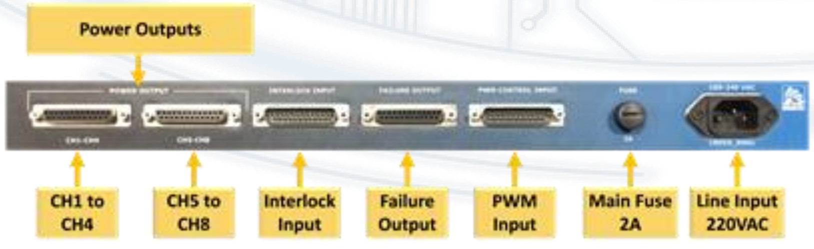

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HEATERS DRIVER

GIE - Electronics Intrumentation Group

CNB-SAP-24V

Channel	Voltage (V)	Current (A)	Power (W)	Resistance (ohm)	Duty Cycle PWM (%)	Current Limit (A)	Failure	Overload	Open Load	Enable
1	21.93	1.13	24.78	19.41	96	2.00	No	No	No	Yes
2	22.07	1.13	24.94	19.53	96	2.00	No	No	No	Yes
3	22.07	1.08	23.84	20.44	96	2.00	No	No	No	Yes
4	22.08	1.11	24.51	19.89	96	2.00	No	No	No	Yes
5	22.12	1.15	25.44	19.23	96	2.00	No	No	No	Yes
6	21.98	1.17	25.72	18.79	96	2.00	No	No	No	Yes
7	22.16	1.13	25.04	19.61	96	2.00	No	No	No	Yes
8	21.88	1.17	25.60	18.70	96	2.00	No	No	No	Yes

Total Power: 199.86W

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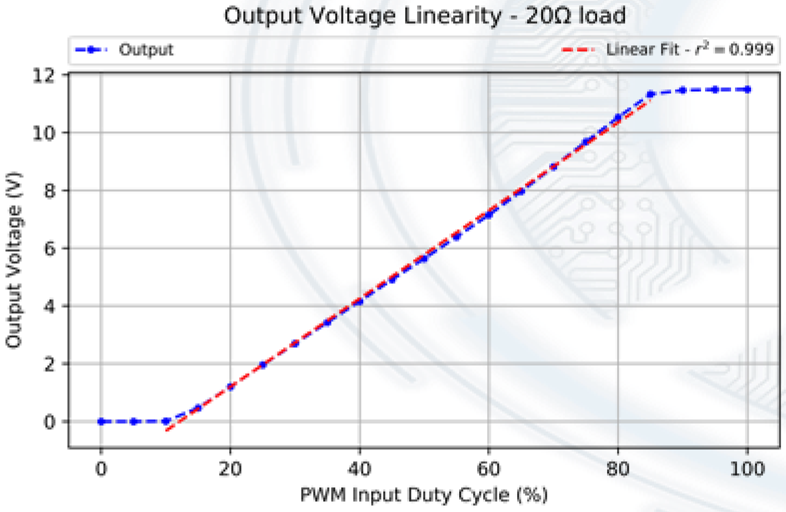

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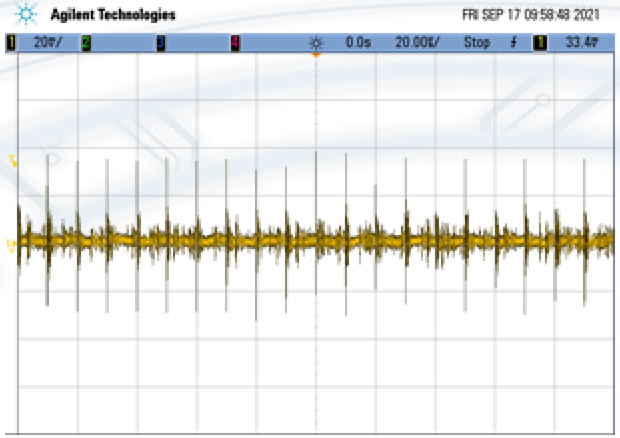

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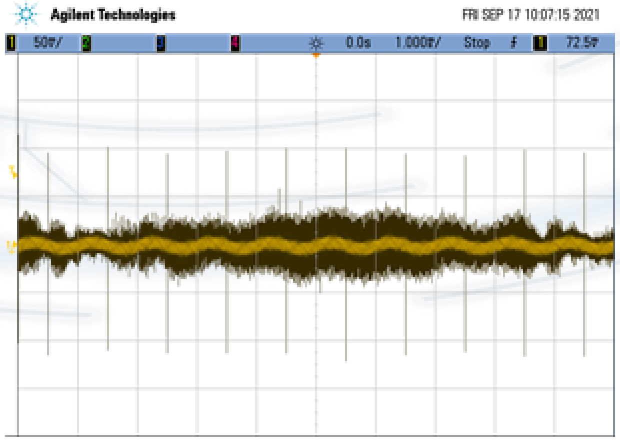

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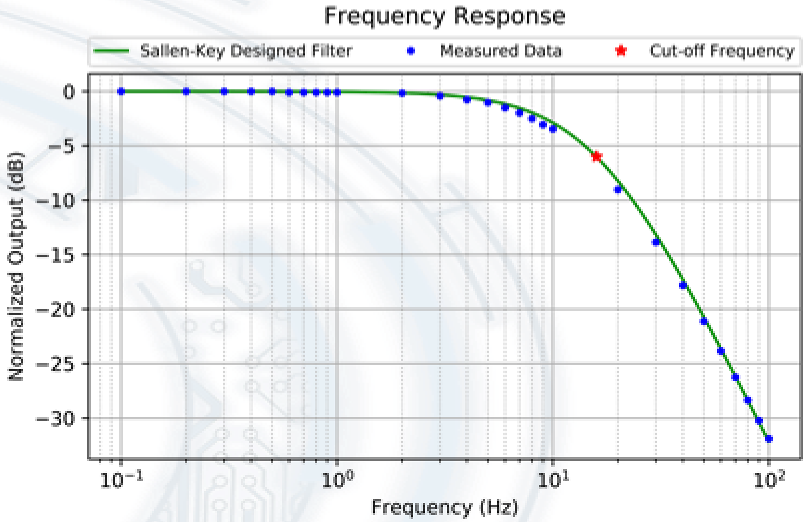

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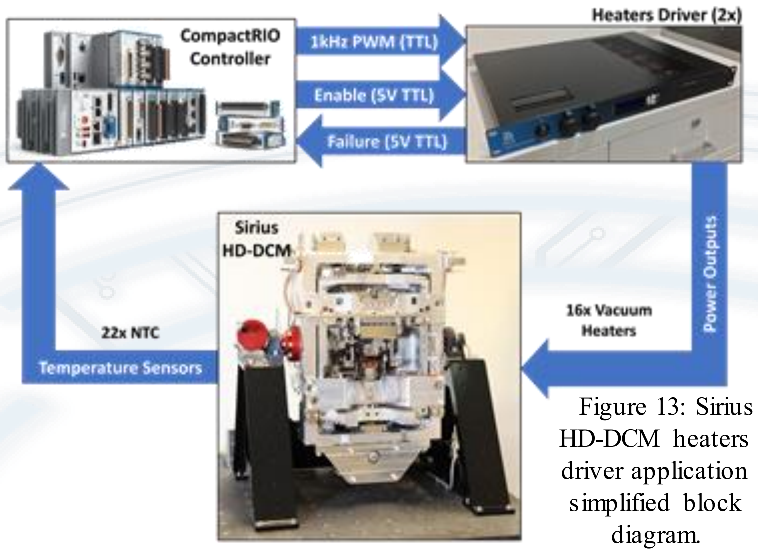

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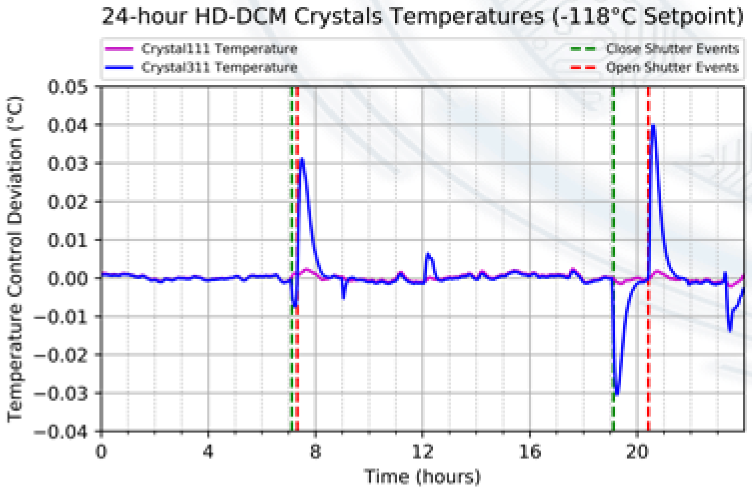

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