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# EURO-LABS

EUROpean Laboratories for Accelerator Based Science

HORIZON-INFRA-2021-SERV-01-07 Project EURO-LABS

## MILESTONE REPORT

# COOLING SYSTEM DEVELOPED

## MILESTONE: MS27

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**Abstract:**

This report presents the upgrades, implemented in the automatic characterization system for complex HEP detector systems, and their validation tests. Initially, it details the Graphic User Interface (GUI) designed to facilitate the system configuration and usage, providing explanations and validation results. Subsequently, the report covers the implementation of the new cooling system, including both the hardware and its integration with the GUI, and presents the corresponding validation outcomes.

For more information on EURO-LABS, its partners and contributors please see https://web.infn.it/EURO-LABS/

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## Delivery Slip

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Executive summary

*This report details the integration of several improvements and upgrades to the noise characterization system of complex HEP detector systems. The integration of automated software into a Graphical User Interface (GUI) to enhance and simplify electromagnetic noise characterization tests is described. This integration allows users to set up and run tests without an extensive knowledge of the Data AcQuisition (DAQ) and detector hardware, thereby improving detector performance and reliability.*

*The validation of the system, involved testing a serial chain of RD53A modules with planar sensors, confirmed the GUI's efficiency and reliability. Noise sensitivity tests revealed differences between chips, emphasizing the importance of Printed Circuit Board (PCB) layout and filtering capacitors. Additional tests, requested by CERN, assessed noise susceptibility in High Voltage (HV) lines, indicating that existing filtering marginally improves noise sensitivity.*

*A temperature control system has also been developed and integrated into the GUI. This system uses a chiller, isothermal enclosure, and cooling plate to maintain constant temperatures, reaching as low as -30°C, and is controlled remotely via the GUI using Python libraries. This advanced cooling system ensures accurate and reproducible results for testing detectors under realistic, stable conditions.*

## 1. INTRODUCTION

The integration of the automation software into a Graphical User Interface facilitates setting up and running electromagnetic noise characterization tests without an extensive knowledge of DAQ and detector hardware. This feature makes it quick and easy to characterize detectors and enable the possibility of running more complex and elaborate tests, thereby improving detector performance and reliability. Additionally, remote control of all devices ensures that once the measurement configuration is installed in EMCLab, it remains unchanged, minimizing variations in measurement conditions.

Developing an advanced cooling system capable of reaching low and stable temperatures allows for testing detectors under more realistic conditions, leading to more accurate and reproducible results. The ability to control temperature over a wide range enables its use as another variable that can be qualified. This can be useful for assessing detector performance across the entire operating temperature range and in failure or degradation scenarios where temperature is out of specifications. Furthermore, testing electronics inside an opaque and isothermal box reduces the base noise level, allowing for more accurate characterization of the detector.

## 2. GRAPHICAL USER INTERFACE

Once the automatic test system has been fully developed and validated, the next step is to upgrade it with a graphical user interface. The primary goal of this task is to reduce the time required to define and set all the variables necessary for performing tests, thereby making the communication between the user and the program more intuitive and efficient.

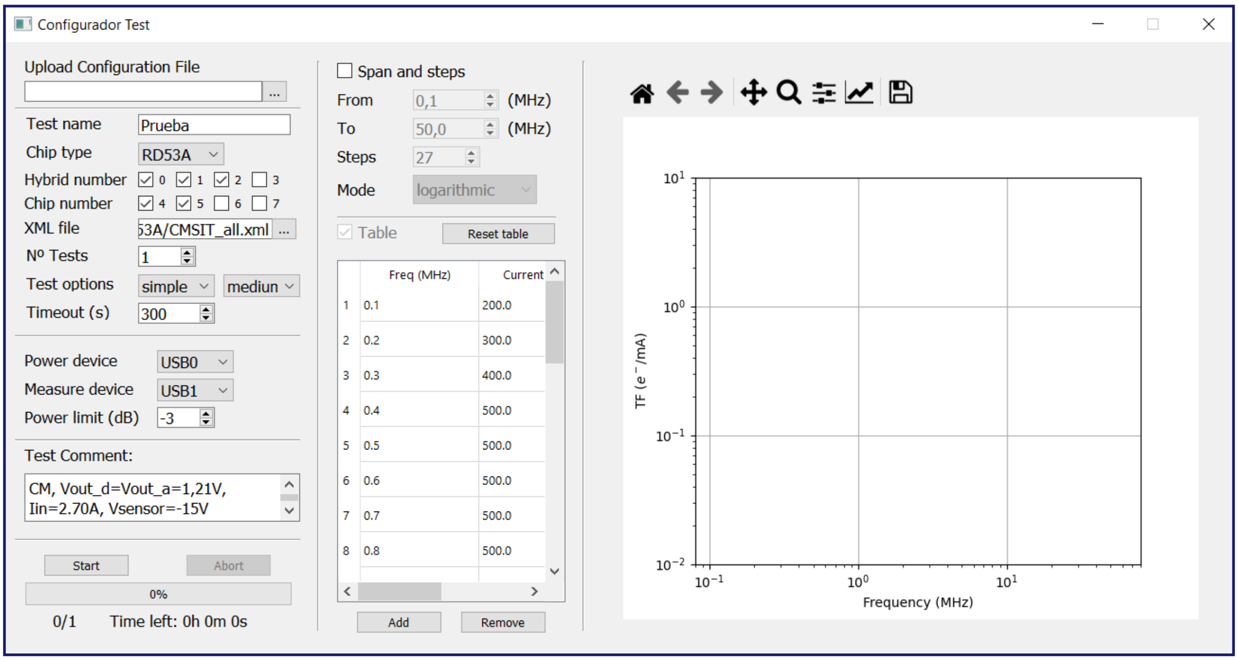


*Fig. 1 View of the graphical user interface.*

As we can see in Fig. 1, the GUI has two main areas: The left half displays the test parameter configuration, and the right half the result.

The core of the GUI lies in selecting the name of the run, the number of chips and type, the choice of the configuration file for the modules, the speed of the test and the ports to which the power and measurement devices are connected. It also simplifies the definition of the frequencies to be tested and the noise current amplitude to be injected at these frequencies. This can be done either automatically, by selecting the start and end frequency and number of steps, or manually, by inserting a custom list of frequencies and currents in the table.

Among all the utilities of the interface, the one that turns out the most helpful, is the possibility of uploading a previously created configuration file (located at the top left of the panel).

To launch the test, the lower left panel, which has two buttons is used: Start, to start the test; and Abort, which allows to stop the test in a controlled way and save the results obtained up to that point. Below these buttons we have a feedback area where the percentage of the test completed, the number of tests carried out with respect to the total and an estimation of the remaining time to complete the test is displayed.

The other main area, on the right-hand side, displays the results. This consists of a graph where the results obtained during the test are displayed.

The transfer function of all the Hybrids and Chips selected in the configuration section is represented. Using the toolbar we can modify the axes, zoom and move around the graph to better visualise the results and save the graph in the desired format. Once the test has been completed, the graph is automatically saved, including as well as individual graphs for each Hybrid and Chip tested to facilitate the visualisation of the results. All the test results and relevant info are also saved in “raw” format in a .csv file.

# 3. SYSTEM VALIDATION TEST

## 3.1. 2X2 HIGH DENSITY INTERCONNECT (HDI) WITH PLANAR SENSORS SYSTEM LEVEL TESTS

The efficiency and performance of the graphical user interface has been proven by testing a serial chain of two prototype of tracker barrel pixel modules with (2x2) RD53A readout chips (2x2 TBPX RD53A modules) with planar sensors, from a bigger set-up installed at CERN. Validation has focused on looking for issues when executing all available functions and checking for proper operation after long running times or several consecutive tests.

The system under test is formed by two modules connected in series. The module closest to the power supply is the module named (HQ10), and the one closest to ground (GND), F11 (See Figure 2).

As the noise floor is dependent on the temperature, maintaining a constant temperature allows us to get reliable results. So, the system is placed on an aluminium cooling plate, covered with a carbon fibre layer, and pressed with 3D printed clamps to ensure a good fixation.

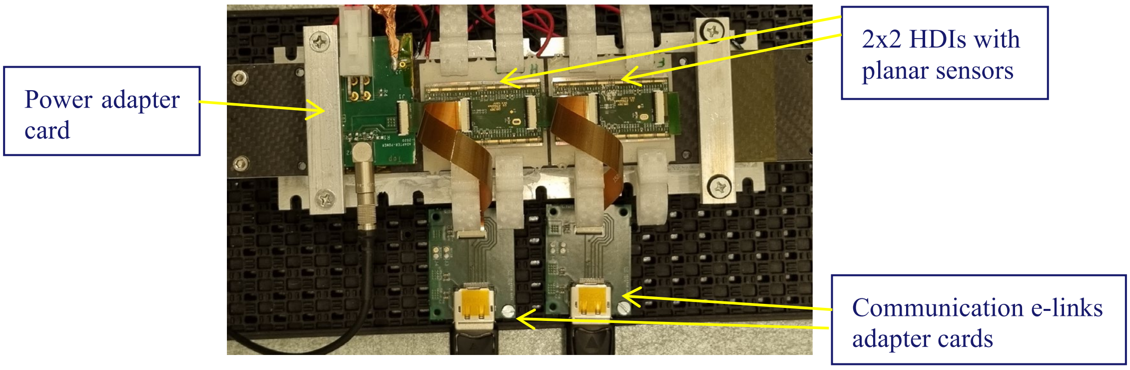


*Fig. 2 System formed by two modules in series.*

The first test, carried out to verify the proper functioning of the configuration parameters and a good graphical representation of the results, consisted in measuring the noise sensitivity variation between the chips in the modules. Figure 3 shows big differences of the transfer function between chips in the same module. Both PCB layout and position of filtering capacitors can explain the differences.

As can be seen, there are no measurements of readout chips of HQ10 module (ROC0 and ROC1) because these chips were not working properly and provoking communication errors all the time, hence they were disabled.

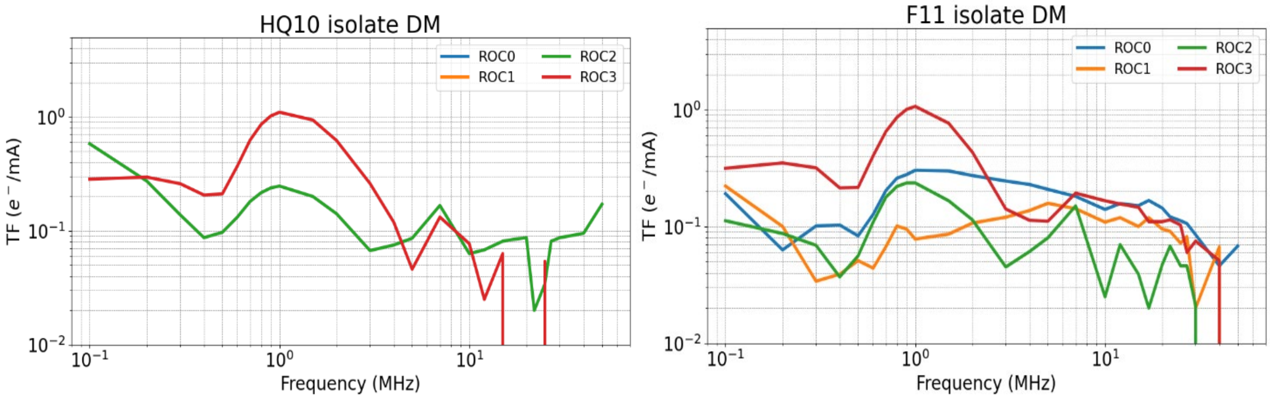


*Fig. 3 Transfer Function (TF) measured in module HQ10 (left) and F11 (right).*

## 3.2. 2X2 HIGH DENSITY INTERCONNECT (HDI) WITH PLANAR SENSORS HV LINES PERTURBATION

The second validation test was to characterize a serial chain of 2x2 RD53A modules, with the focus on analysing noise entering through the HV lines (sensor bias). The goal of these tests is to quantify the susceptibility to noise in power lines of the chips in a full serial chain with hybrid powering (serial and parallel power), trying to differentiate the contribution of the Low Voltage (LV) (chip, serial) and HV (sensor bias, parallel) powering. The final purpose of this study is to get insight into the need of capacitive filtering in the sensor bias lines. This is important to close the HDI and adapter designs optimizing as much as possible the material budget of the detector.

Taking advantage of this study, it has been used to verify the proper functioning of the interface during long time tests.

During this study, HV lines have been shown to be quite insensitive to noise, so it is not easy to measure their transfer function as we are very close to the noise floor level of the system. Averaging several measurements has demonstrated in some cases, such as ROC1 and ROC3 readout chips, to be useful to increase the signal to noise ratio of the test, getting more precise, sensitive and repetitive results as shown in Figure 4. These plots show the average value in coloured lines, with each measurement in grey in the background. It should be noted that the higher number of measurements the more reliable and less noisy the results are.

The results conclude that the R-C filtering already included in the HDI (High Density Interconnect) seems to improve a little the noise sensitivity of the system. The filtering included in the stage before the module, the power adapter card, has no effect and can be removed without affecting the detector performance.

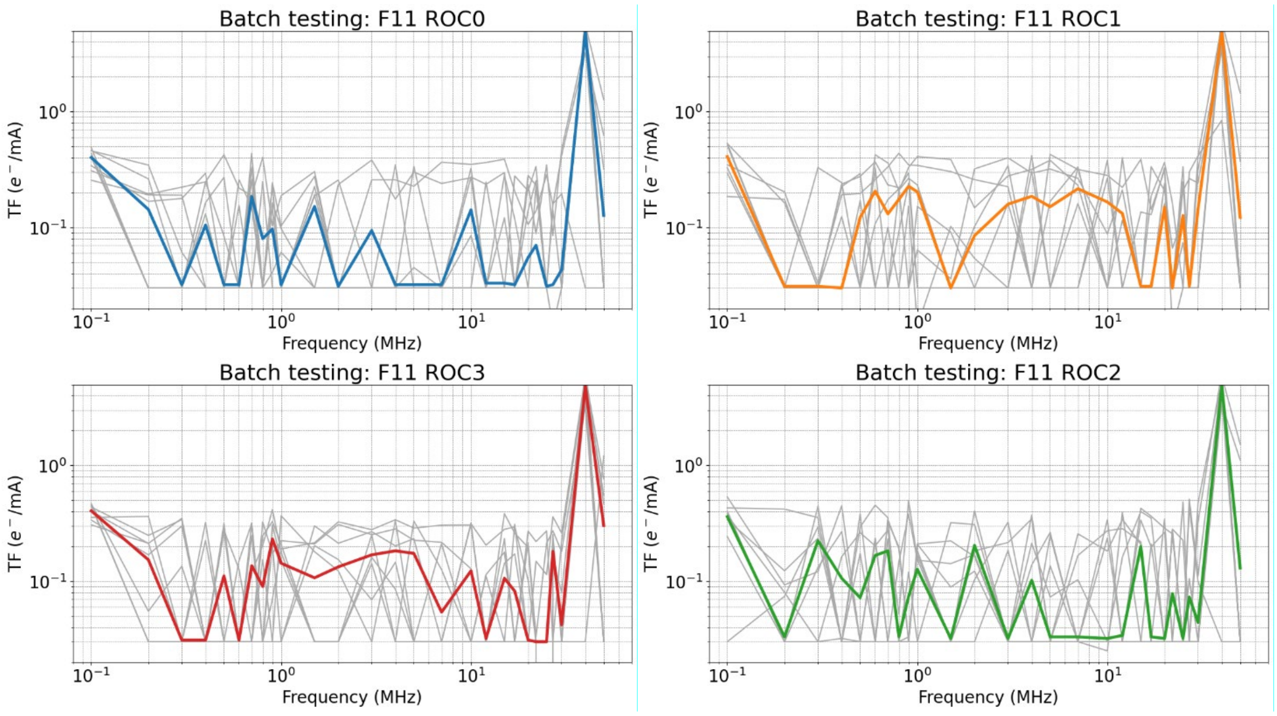


*Fig. 4 Average Transfer Function (TF) of ROC0 (top left), ROC1 (top right), ROC3 (bottom left) and ROC2 (bottom right) of the module F11.*

The layout of the plots in Figure 4 follows the distribution of the chips inside the module, with ROC0 and ROC3 being the closest to the power supply placed on the left and ROC1 and ROC2 the closest to the global GND.

# 4. TEMPERATURE CONTROL SYSTEM

## 4.1. SET-UP

As mentioned above, maintaining a constant temperature during the test is essential to get reliable results. Therefore, a cooling system, consisting of a chiller, an isothermal enclosure, and a cooling plate has been developed (See Figure 5). This development will allow to achieve temperatures down to -30ºC, which is a typical operating temperature for detector chip/sensor in the LHC trackers. Thus, the results will be more realistic and also exhibit a lower thermal noise.

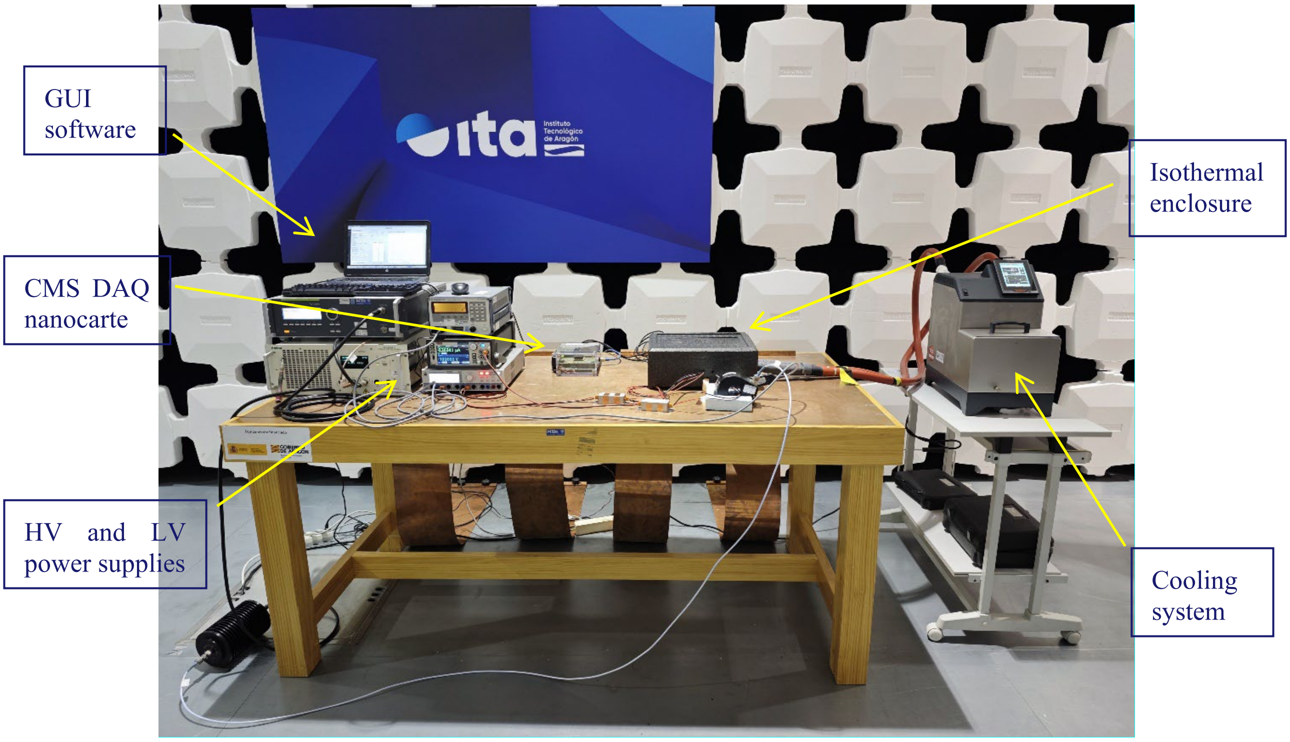


*Fig. 5 Temperature control system set-up.*

As can be seen in Figure 6, all the electronics of the detector are located inside the isothermal box. Thanks to this enclosure, the base noise floor is lowered both by its opacity, which blocks light, and also by keeping the temperature of the electronics low.

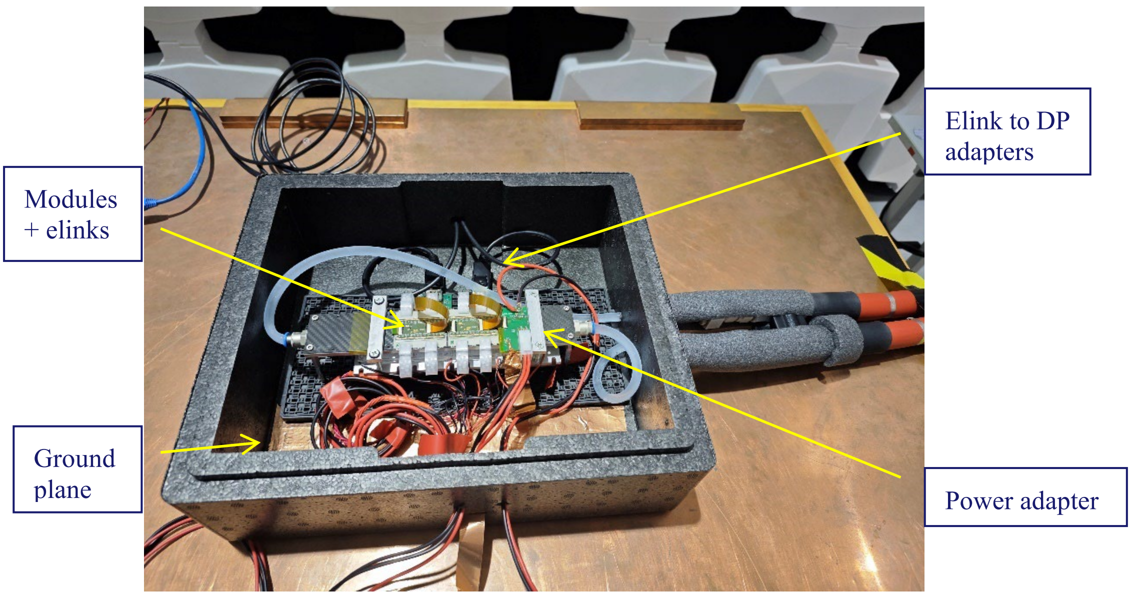


*Fig. 6 Electronics inside the isothermal enclosure.*

To achieve the low temperatures, a liquid bath cooling system is used (**Huber MINISTAT 240**), with the temperature range down to -45º and flow and pressure adjustment of the pump. This device can be manually controlled through an integrated display, that also shows the set values and a graph of the temperature evolution, as displayed in figure 7. It can also be completely controlled remotely through serial port (USB) or Ethernet. Using the Python API provided by the manufacturer it can be interfaced to the previously developed GUI.


*Fig.7 Cooling system device along with the control interface.*

## 4.2. GUI IMPLEMENTATION OF TEMPERATURE CONTROL

To implement the temperature control within the GUI, slight modifications have been made (See Figure 8). A new control field has been added where you can select the port where the chiller is connected and the temperature at which you want to perform the test. This area can be disabled if another cooling system is operated. The launch and feedback area has been reorganised and a new label with the current working temperature has been implemented.

Taking advantage of the need to change the GUI, certain definitions have been simplified, such as the number of modules and chips that can be characterized. A grid has also been added to the graphical representation to improve the visualisation of the data.

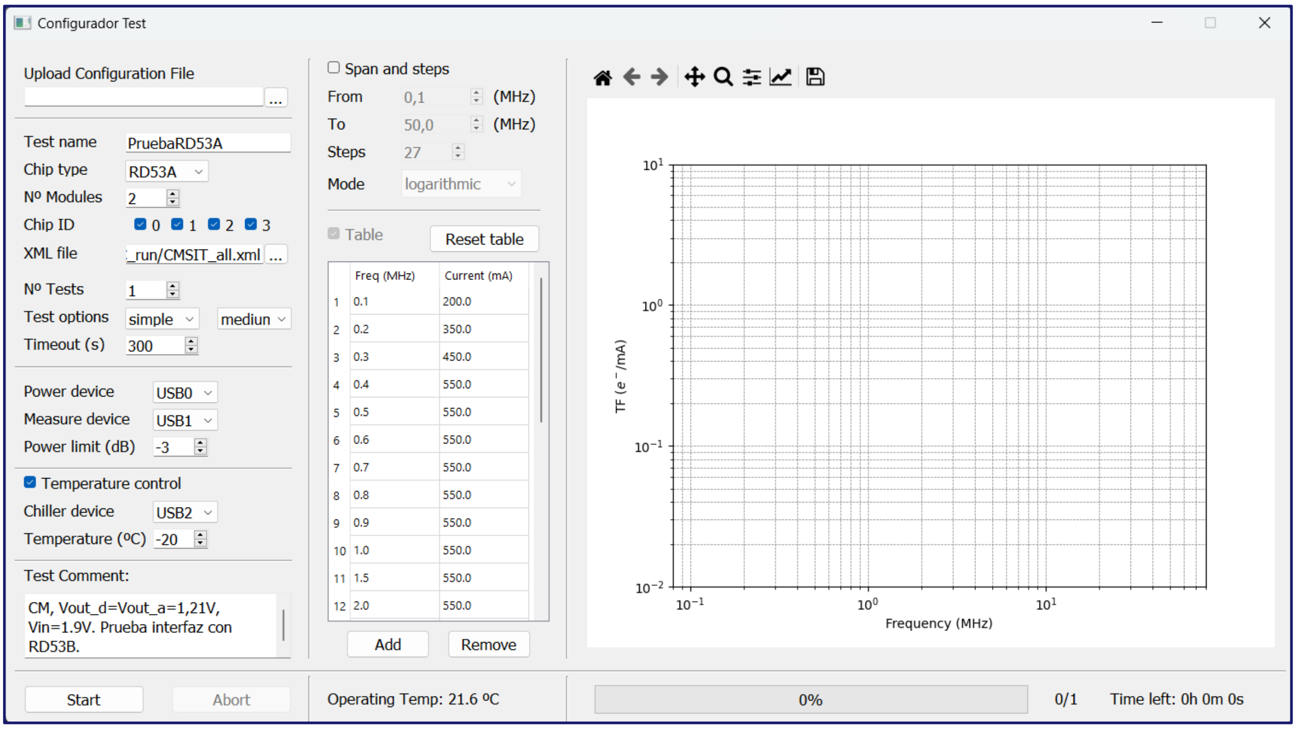


*Fig.8 GUI with the temperature control implemented.*

## 5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The GUI has been fully developed and validated through laboratory tests using a serial chain of 2x2 RD53A HDI modules with planar sensors. Improvements in data processing have been introduced to enhance the reliability of the results. Additionally, a temperature control system, encompassing both hardware and software, has been developed, integrated into the GUI, and validated with the same RD53A 2x2 HDI modules.

The implementation of temperature control necessitated slight modifications to the interface. In the future, new functionalities can be integrated to facilitate, improve, or extend the capabilities of the measurement process.

# ANNEX: GLOSSARY

| Acronym | Definition |
|---|---|
| GUI | Graphical User Interface |
| DAQ | Data Acquisition |
| EMCLab, | Electromagnetic Compatibility Laboratory |
| HDI | High-Density Interconnect |
| TBPX | Tracker Barrel PiXel |
| RD53A | Pixel readout chip designed by the RD53 collaboration – First Prototype (A) |
| ROC | Recovery-Oriented Computing |
| HV | High voltage |
| LV | Low Voltage |