PROJECT FINAL REPORT

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4 Final report for the project

4.1 Final publishable summary report

EXECUTIVE SUMMARY.

The current project was devoted to the design and manufacture of a specific multi-components test bench dedicated to the future More Electrical Aircraft (MEA) power electronic converters. The aim was to deliver realistic functional and environmental conditions to test and age components and converters in use and in extreme environmental flight conditions.

This bench is dedicated to the improvement of the reliability of the on-board power electronics and allows leading tries of Verification and validation, investigation and qualification in a severe environment multi-constrained (electric, thermal, humidity, vibration). The prediction of the reliability, from the beginning of design phase, will allow to select as well the critical components as the architectures of the systems meeting the needs at best of customers and to introduce the new technologies in a mastered way.

The Power Test Bench (PTB) combine in one system a climatic chamber, a vibration test system and an electrical characterization bench test, including a Graphical User Interface to control, monitor and combine several parameters.

This test bench of combined constraints is designed to test electronic components as well as power converters of a certain dimension, having an available test surface of 850x850 mm2 and 600 mm height. It can also withstand a maximum mass of 75 kg.

PTB offers a multi-constraint test bench, in which temperature, humidity and vibration, as well as electrical parameters can be independently set according to different configurations defined by the Graphical User Interface (GUI).

In terms of environmental conditions, PTB can vary temperature from -65ºC to 180ºC, humidity from to 10 to 98% and can set vibration up to 85-100 g levels, 10 times higher than maximum accelerations defined at RTCA-DO-160.

Regarding electrical characterization, Power Test Bench is able to supply up to 1200Vdc, 400 Adc, or three-phase 312Vac, and can offer a maximum electrical power of 40KW. Characterization and acquisition of electrical and environmental parameters is implemented by a series of industrial sensors and modules and are registered and processed by our GUI, generating customizable reports.

By controlling the shaker, the climatic chamber and the AC and DC power sources from a full control system, the user is able to set the different test conditions to test the components and converters.

This PTB provides, among others expected impacts, a high efficiency in environmental testing of components due to shorter testing times derived from being able to test simultaneously, under several conditions of power, temperature and vibrations (sequentially) in multiple axes, without changing specimens' set-up.

SUMMARY DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES.

Endurance Tests and Reliability Prediction of avionics is a critical part of the development of on-board electronic equipment.

Today, reliability and life expectation of electronic converter are studied at components level by using military standards books like MIL-HDBK or estimate calculation based on background of components class used in similar application. These methods provide rough estimation and the results need to be compared to realistic endurance tests.

Consequently, among others activities, there are necessary accelerated testing to predict parts' reliability under a wide range of environments, to research fundamental failure mechanisms and to get to know the effect on reliability of the manufacturing processes. Traditionally this has been done by means of ATE systems for the functionality tests and with electrodynamic shaker systems and dynamic or thermal shock climatic chambers.

The interest and the need of this specific test bench is to give more confidence to the design in terms of reliability at components level and help the user to expertise and to validate the minimum life expectation of future aircraft power electronics converters. This test bench improves time efficiency and reliability of environmental testing of future More Electrical Aircraft (MEA) power electronic converters and components.

The Power Test Bench permits leading tries of verification and validation in a severe multi-constrained environment (electric, thermal, humidity, vibration), with the aim of predicting the reliability of the onboard power electronics from the beginning of the design phases, and introduce the new technologies in a mastered way.

The Power Test Bench has been structured in different blocks or products that are needed to build the final product, and they are linked in logical groups: Product Breakdown Structure figure (PBS).

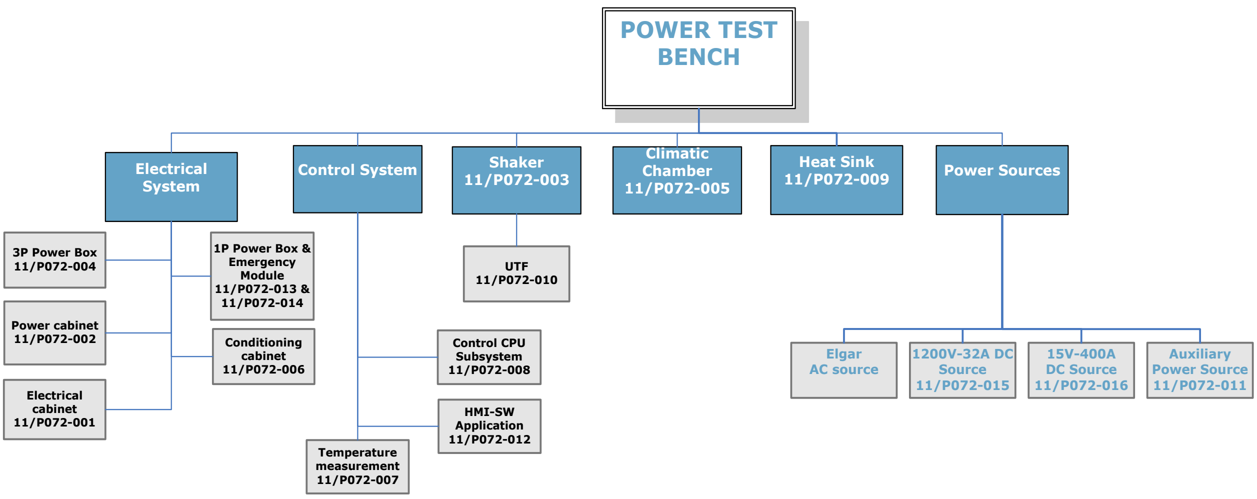


Figure 1. PTB Product Breakdown Structure

Each subsystem has been detailed and described to the most minimum element. Every part of the product is complemented by series of drawings done in CAD, in order to detail the design and help for the manufacture and the assembly activities.

The design includes also a Part List where all the components are detailed, with its identification number correlated to the drawing, the specific model, the provider, and other interesting data.

The Power Test Bench is composed of the following subsystems:

Temperature system: consist on a series of thermocouple sensors, located inside the chamber, which are connected to a Data Acquisition System in order to obtain and register the temperature.

Electrical system: The electrical system is in charge of supplying electrical power, providing the interconnections of required elements and outputs/inputs; that is, power sources and DAQ. The electrical system is physically divided into two racks:

- **Electrical Cabinet:** where cooper busbars and socket for passive components and interconnection for the test circuit to be implemented are available. The electrical cabinet consist on a Power Section sub-rack, where copper distribution bars are set and allow electrical high power supply to UUT. Also, this rack provides room on the lower side for placing additional passive components, sensor and sockets.

  Three main Power Sources are available and provides electrical supply to units under tests: Elgar SW5250 3-phase AC power source (optional), SkylifeHigh Voltage1200Vdc-32A Power Source and SkylifeHigh Current 15Vdc-400A Power Source.

- **Conditioning cabinet**: where power sources and boxes for interconnection with DAQ are available: 1P Power Box,Additional Auxiliary Power Source, Control Signal Box and Measurement box.

Control system: consists on a CPU, a HMI Workstation (keyboard, mouse and monitor) and a custom software application, developed under C programing language. Windows form (local) and web browser form (remote) is available. Control system consistd on the following modules located inside the Conditioning cabinet: Temperature DAQ, Voltage/current DAQ, Oscilloscope and a CPU.

Firstly, it is performed the acquisition of voltage, current, and temperature of the different UUT's. Secondly, it is provide a series of digital and analog I/O to enhance testing capabilities and performance. Thirdly, it controls the different power sources and thermal chamber in order to provide the desired operating test conditions. Lastly, the HMI provides the Power Test Bench users with an interface, allowing the interaction with all the different modules.

Shaker system: is a machine which generates vibrations over the tray where elements (DUT) are placed.

The electrodynamic shaker is the component dedicated to provide to the DUT the desired vibrations: 5-10 times more than level of constrains applied during product qualification (RTCA D0-160) of converter using these devices, i.e. it can provide accelerations with amplitude up to 85 – 100 g.

The electrodynamic shaker is supported by an isolated support structure which performs the aptitude to tilt from 0º (horizontal position) to 90º (vertical position) and vertical regulation in order to provide vertical and lateral vibration.

Although the shaker has the possibility of changing the direction of vibration, the initial proposal was to maintain the electrodynamic shaker in horizontal position and allow the vibration in both axes, vertical and horizontal, by means of the use of a mechanism to change vibration axis direction without changes in specimen fixings. This mechanism was initially identified as “Lever arm” and many research efforts were carried out to get a technical solution that was able to comply with the full vibration range required in the DO-160 standard.

However, the progress in the development and research of a solution to the “Lever arm” did not give the expected results and this mechanism had to be removed. The way of changing the vibration axe in the Power Test Bench is currently by a positioning system either of the climatic chamber or the shaker, and the vibration axis can be switched without changing the DUT’s set up, which was one of the main goals of the project.

Climatic Chamber system: is a box or enclosure covering the tray where the DUTs are located, where the specified environmental conditions (extreme temperature, thermal cycling or extreme humidity) are controllable.

It is a monoblock type with high thermal gradient, ready to be integrated with a vibration test system and has regulation and control through microprocessor. The electrodynamic shaker remains under the climatic chamber and the upper part of the mounting plate enters the climatic chamber through an aperture in its bottom, being thus leveled with floor of the chamber.

Climatic chamber has a temperature conditioning system and it provide rapid temperature changing rates in the range of -65 °C to +180 °C. From the HMI it can be set the temperature and humidity of the chamber air with high accuracy. High circulating air rates even ensure distribution of temperature and humidity in the test space. Climatic chamber has entry ports, so devices under test can be connected to outer measurement systems through these ports.

Heat Sink system: ensures a low temperature at the tray where devices are placed in order to avoid devices failures. The heat sink is a passive component that cools the test specimen by dissipating heat into the surrounding air. So the heat sink is a heat exchanger designed to increase the surface area in contact with the cooling medium surrounding it, such as the air.

The heat sink is made of aluminum alloy (AW5083) with high thermal conductivity; the values depend on the temper of the alloy. Thermal adhesive or thermal grease fills the air gap between the heat sink and device to improve its thermal performance.

The heat sink is bolted to the UTF fix plate and the test specimen is fixed at the top of the heat sink.

Regarding the manufacturing related to vibration transmission, several prototypes, corresponding to the mechanism to change vibration axis direction without changes in specimen fixings, have been developed and tested to reach the solution shown.

Additionally, some other components have been developed under many hours of software and stress tests, having also been involved other elements not shown in this collection. These are for instance, either the electronic components to get the power supplies loaded and/or the special cables to read the signals other receive, that is the measurement box where to connect the temperature probe and get the values.

And it has been developed an Human-Machine-Interface that makes every part work synchronized and monitored at the time the tests are running. Throughout one screen can be controlled and set in barely few minutes the whole bench at a time and every devices independent from each other.

Within the Power Test Bench the user will be able to take the systems to extreme conditions such as:

- a temperature of -65°C to +180°C,
- an adjustable humidity of 15% to 95% H.R.,
- a sine shaker force of 35,6 kN,
- a shock vibration of 84,3 kN ,
- a sine peak acceleration of 110g,
- a random (rms) acceleration of 75g,
- a low DC voltage power source of 6 kW (15V, 400A)
- a high DC voltage power source of 32 kW (1200V, 32A)
- a 3-phase AC power source

DESCRIPTION OF THE MAIN S&T RESULTS/FOREGROUNDS

1 ELECTRICAL SYSTEM:

The electrical system is in charge of supplying electrical power, providing the interconnections of required elements and outputs/inputs; that is, power sources and DAQ. The electrical system is physically divided into two racks:

- **Electrical Cabinet:** where cooper busbars and socket for passive components and interconnection for the test circuit to be implemented are available. The electrical cabinet consist on a Power Section sub-rack, where copper distribution bars are set and allow electrical high power supply to UUT. Also, this rack provides room on the lower side for placing additional passive components, sensor and sockets.

  Three main Power Sources are available and provides electrical supply to units under tests. These sources can be software programmed and are able to operate under high voltage and current conditions, in terms of voltage, current, and power. The available power sources are the following:

  - Elgar SW5250 3-phase AC power source (optional)
  - SkylifeHigh Voltage1200Vdc-32A Power Source (P/N :11/P072-015)
  - SkylifeHigh Current 15Vdc-400A Power Source (P/N :11/P072-016)

- **Conditioning cabinet**: where power sources and boxes for interconnection with DAQ are available. This cabinet comprises the following sub-racks:
  - 1P Power Box distributes one-phase power supply to equipment. The Emergency Stop Module is associated to this module and provides emergency stop functionality.
  - Additional Auxiliary Power Source is available for low performance requirements such as the gate switch of IGBTs; an Agilent, E3631A Power Source is able to provide up to+/-25V and 80W
  - Control Signal Box: provides an interface of digital and discrete I/O provided by the DAQ modules, by means of connectors which can be used to add new testing capabilities.
  - V & I measurement box: conditions voltage and current outputs to signals scaled to DAQ voltage and current ranges, which can be used to read values from transducers and components

These components have been developed under many hours of software and stress tests, such as the electronic components to get the power supplies loaded and/or the special cables to read the signals other receive, that is the measurement box where to connect the temperature probe and get the values.

The electrical system is compliant with UNE electrical regulations.

Main characteristics of the Electrical system design:

- Commercial components for cabinets and rack: We have designed the solution for commercial, standard components, in order to allow ease of replacement and modification. This solution is also more cost-friendly. That applies to wirings and connector, rack structure, and transducer conditioning. The electrical cabinet, for example, is entirely designed with Schneider Electric components and bus bars. The conditioning cabinet, on the other hand, uses standard electronic rack-based structure.

- Flexibility for different schematic connection: We have studied the different UUT and estimated their power consumption, operating conditions and electrical characteristics. With these considerations, our hardware design allows a wide range of circuit connections and topologies. For this sole purpose, the electrical cabinet allows socket for including a wide range of passive components, fuses and, if needed, current/voltage transducers. Also, the power sources terminals are connected to bus bars, ensuring different routing configurations with the two main power sources.

- Expandable structure. Our standard, rack based design permits an immediate increase in its capabilities by adding additional rack-based modules to the already existing ones, which allow increasing the number of UUT and the associated electronics. If more space were needed for testing purposes, or to locate more modules, expansions can be easily implemented.

- Modular architecture and removable components. Our rack-based design allows an easy replacement and substitution of individual modules. All the component and modules are integrated into standard sub-racks, allowing immediate mounting and dismounting when repairs or modifications are needed.

- Durability. It has been taken into account the average test period and the frequency of tests, in order to correctly scale them. This is particularly relevant when designing power sources and copper distribution bars, as they are the components more subject to stress. Rack structure and copper bars have been selected over scaled, in order to withstand higher mechanical and electrical requirements.

- Cost. It has been tried to simplify the components needed to perform the testing, in terms of associated wiring, passive components and sensors. Regarding sensors, for example, the electrical design for each of the test avoids the use of cost-expensive and high lead time voltage transducers. Also, the total number of associated passive components have been limited to just a resistor per each UUT, simplifying thus the circuits and sparing costs. Only one transducer for UUT is needed to perform all the characterization, sparing costs and complexity.

- Power Sources design. We have chosen to design from scratch the High Power Source. The reason is that available power sources which can accomplish requirements were far too expensive, so the best option was to design a specific power source able to work under voltage and current requirements. For this reason, and in order to avoid overcost, the DC power source is internally split into two sources, one High Voltage and one High Current power source.

- Wiring. Safe practice wiring have been implemented, separating power cables from signal ones. In order to keep distance from power cables, for example, a sub rack has been created, named V& I Measurement Box, which serves as the only available external interface between conditioned signal outputs from the chamber and the Control System inside the Conditioning Cabinet where DAQ modules are located. This module is safely separated from the electrical cabinet and power modules, where high power and high EMI are present.

1.1 Electrical Cabinet

Electrical cabinet provides connection between the Primary Power Source and the multicomponent test bench located inside the thermal chamber, by using copper, high current distribution bars.

This rack also contains all the electrical equipment and wiring which permits to connect UUTs from the chamber towards the power sources, including sensors and transducers needed to acquire and perform the test.

Electrical cabinet contains the power sources which provide voltage and current supply to the multicomponent power tests.

On the superior cabinet there are placed the distribution copper bars, the electrical equipment is placed on the middle, and on the inferior part, free space is available for routing cables to other racks (such as wiring from the Secondary Power Supply). The following figure helps us to understand it.

Figure 2. PTB Electrical Cabinet

The equipment that emits more electromagnetic noise is installed at the same rack, in order to reduce constructively the electromagnetic noise into the conditioning cabinet.

1.1.1 Power Sources Section

Power sources provide voltage and current supply under different specifics conditions demanded by the different tests, as well as a fixed, stable power supply for all the conditioning transducers. There are 4 main power sources which are detailed below:

- **High Power, AC Source:** This power source supplies three-phase alternate current, up to 5250VA and 260Vrms, and is provided by Thales. There are 3 copper bus bar connected to each of the phases, as well a fourth copper bar connected to ground.
- **High Current DC Power Source:** This Power Source is able to operate up to 400A at 15V. There is an independent pair of copper bars associated to this source. Also this power source has the following characteristics which must be explained:
  - It has a low switching load dynamics, no more than 10-20 Hz, when working at high current modes. This affects tests related to switching components or power converters.
  - Also, if required, this power supply can include a feature which allows to programmatically change the time response of the source under different loads, meanly an over-damped of under-damped response. This functionality is limited since certain time response will not be reached. When testing capacitor, for example, it is interesting to allow a sub-damped response, in order to avoid high voltage transient pikes, which can degrade the component. On the other hand, when testing the equipment, it is very important to allow a fast transient response, so an over-damped response may be programmed.
  - The default remote control is the output voltage to be generated. If required, a current reference could be established and the voltage will vary according to load requirement.
  - The instantaneous current and voltage at the output is available at the remote control, but additionally the average voltage and current each 10sec (sample time of control system) is monitored.
  - Load and line regulation can be switched from voltage to current regulation by software. We propose a software-based regulation switching, which is available only before the HMI start performing the test, which prevent on-load switching and associated risk.
- **High Voltage DC Power Source:** This Power Source can operate up to 1200V at 32A. Due to being extremely difficult to provide such high voltages with a single source, two 600Vdc @32A High Voltage Power Sources are used and serially connected to provide 1200Vdc. This set operates as a single source, so only one is need to control one of the sources to operate as a single, 1200Vdc @ 32A power source. There will an independent pair of copper bars associated to this source.

Figure 3. PTB DC Power Sources

1.1.2 Power Section

Power Section consists on a sub-rack in which copper distribution bars are placed.

In order to maximize safety, a division has been made in which the group of alternate current copper bars is placed over a single structure support, and the remaining pair of continuous bars is set onto another.

Distribution bars are placed into horizontal rack bars, to allow cable routing below.

Two copper bars are devoted for the 1200W power source. Its flexibility permits as maximum 750A in the case it is used for other objectives.

4 copper bars are devoted for the three-phase electric power.

In order to feed the current power source, it is used a bipolar current copper bar.

There are 4 copper distribution bars connected to 3-Phase + GND power supply, 2 distribution bars connected to High Voltage power supply and other two bars which are connected to the High Current power supply. All the distributions bars can be easily bored in order to place different wire terminals and for different tests.

1.2 Conditioning Cabinet

Conditioning cabinet is the interface between DAQ modules and the signals from these tests, using conditioning modules and connectors to convert and ensure safe and easy connectivity. This module works also as a power distribution and breaking unit, supplying energy to the rest of the modules and providing electrical protection.

In the same rack, several equipment (oscilloscope and USB modules) that emit noise are going to be inserted into an EMC box or sub-rack, to be protected from electromagnetic interferences proceeding from the electrical cabinet.

Figure 4. PTB Conditioning Cabinet

The Conditioning cabinet comprises the following sub-racks:

- 1P Power Box distributes one-phase power supply to equipment. The Emergency Stop Module is associated to this module and provides emergency stop functionality.
- Additional Auxiliary Power Sourceis available for low performance requirements such as the gate switch of IGBTs; an Agilent, E3631A Power Source is able to provide up to+/-25V and 80W
- Control Signal Box: provides an interface of digital and discrete I/O provided by the DAQ modules, by means of connectors which can be used to add new testing capabilities.
- Measurement box : conditions voltage and current outputs to signals scaled to DAQ voltage and current ranges, which can be used to read values from transducers and components

1.2.1 1P Power Box

It consists on a subrack which is in charge of distributing one-phase AC power supply to the different modules located in the cabinet as well as proving safe-breaking power supply. A series of 16A circuit breakers over a Schuko rail provides individual splitting capabilities for all the power lines, and a general ON/OFF breaker is able to completely shut down all the power.

On the rear panel there are standard electrical schuko connectors for 230Vac equipment: auxiliary function generators, V & I sub-rack, CPU control module, etc…

In the rear panel there is also a connector for the emergency stop buttons or other devices. There is a 24V power supply in charge of feeding a global contactor through the emergency buttons, which is automatically shut down and all the Power Box are turned-off if some emergency stop button is pressed. The contactor is normally open for avoid problem if inside 24V power source is damaged.

The front panel contains the individual breakers for the connections located in the rear panel as well as the general ON/OFF breaker.

It has a three status LEDs, one per phase, which lights ON when power supply is working. A residual current device (RCD) is also installed for protect devices which do not have this function inside them.

1.2.2 Emergency stop subrack

This sub-rack is connected to the Power Box already explained in the former chapter, and provides safe power break for all AC/DC power supplies by mean of an emergency stop button. This emergency button does not directly shut down power, but is able to break the 24V electrical circuit which feeds the general contactor.

On its rear panel two connectors are located, for entering and exiting the 24V supply. On its front panel, an emergency stop button can split the circuit and also two status led are provided. One of the led shows the emergency button status (pressed state powers on the led), and the other indicates if there is 24Volts power supply (if there is supply, led blinks).

This module is installed inside the conditioning cabinet, and the devices for emergency stops, such as door switch for cabinets and racks are also installed.

1.2.3 V&I measurement box

Subrack in charge of distributing specific power supply for the transducers, and also convert and condition their electrical outputs into values able to be read by DAQ equipment.

It entails low power supplies which provide energy to feed current/voltage transducers, from an external power supply connected to the 1P Power Box. A single 24Vdc 1A power supply and a single 0-5V 1A power supply are enough to feed all the required sensors. Low current harnesses can be connected from front connectors at this box in order to feed the transducers; allowing them to connect either those located inside climatic chamber or the ones used for measurement outside it.

There are also included conditioning modules (voltage/sensor transducers) that provide a voltage (typically 0-5V, ±10V) or a current (4-20mA) output, regardless of the original signal type under conditioning. In other terms, voltage/current transducers have a voltage or current output.

Moreover, since this box includes inputs signal from DAQ, additional resources have been included. So there are connectors available for TTL and Isolated discrete signals.

Regarding its physical architecture, the box consists on a heavy rack with frontal and rear panels which can be flipped by hinges, allowing easy replacement and manipulation of the elements located inside. The front panel is entirely occupied by the 48 socket connectors. By replacing the frontal panel, we can have direct to the shunt resistors, which allow us easy replacements and substitutions. The rear panel has connectors to be used to connect DAQ modules with the box.

1.2.4 Temperature Measurement Box:

There are series of thermocouple sensors, located inside the chamber, which is connected to this box that entails a Data Acquisition System in order to obtain and register the temperature. The Temperature Measurement Box serves as an interface between sensors and extensor cables, providing thus ease of interconnection and replacement a variable number of temperature sensors.

Extensor wire are used for connecting this box with the DAQ, and routed as long as desired.

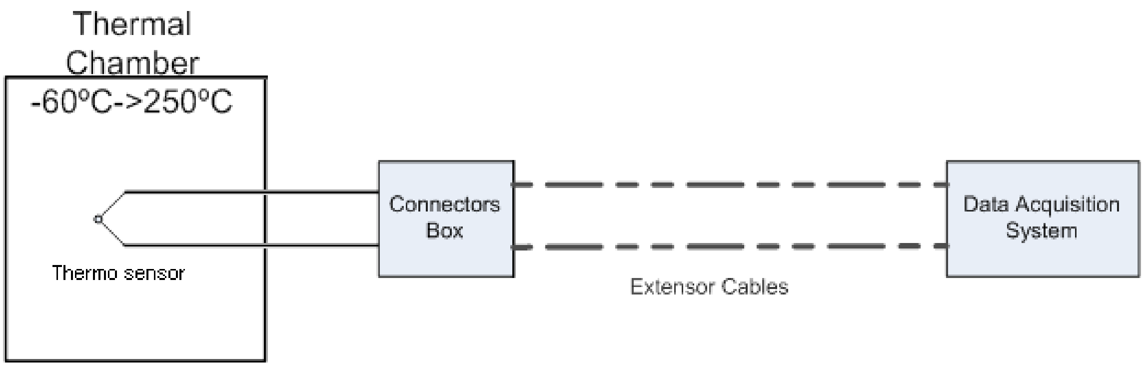


Figure 5. Temperature system logical diagram

Thermocouples have been selected as the core of our solution because they can afford a wider temperature range, allows more accurate measures and behave better under aggressive atmospheres and vibrations. They can also be used in long distances without appreciate loss of accuracy and have a linear response, opposed to thermistor outputs. Its low price, standardization and interchange ability (standard plugins/sockets, materials and type of cables) make them the best option for this solution.

This solution has with the following advantages:

- Modular design: it is easy to replace deteriorated segments without replacing the entire cable. This is especially important with the thermocouple junctions, which apart from being far more expensive are prone to deterioration due to the extreme environmental conditions inside the chamber.
- Long safe distance between the thermal chamber and the measurement equipment: we can put a distance up to 20m between the chamber and the DAQ instruments without appreciate loss of accuracy nor response time, reducing risks for the users and electromagnetic pollution.
- Costs: thermocouple extensor is cheaper than thermocouple sensor cable, resulting in reduced costs.

1.2.5 Control Signal Box

The Control Signal Box provides interconnection between digital and analog DAQ as well as analog, power signal from the Auxiliary Power Source. It consists on a rack, with frontal and rear panels with hinges to allow easy access to its interior. On the rear panel, interconnection between DAQ and power supply are provided, while the front panel serves as an interface of power and signal outputs.

The control signal box serves for two different purposes:

- Interface between DAQ Outputs and components subject to testing.
- Auxiliary power signals.
- Available connections for fixed power sources (same ones as V&I measurement box).

- **Digital/ Analogy Outputs interface:** This box serves as an interface between DAQ analogy and discrete outputs and components to be tested inside the chamber. Then, control signal for IGBT/MOSFET selective switching during testing is available in this box. There are three main groups of interface outputs on the front panel:
    - Analogy outputs: 6 analogy outputs connector and one common ground per each two signals.
    - TTL outputs: 24 digital/TTL outputs and 1 common ground per each 8 signals..
    - Isolated outputs: there are 3 groups of isolated, variable digital outputs. Each of them has a common voltage reference (COM), ground (GND) and 8 digital outputs.
- **Auxiliary power source signals:** A wide range of active, electronic integrated, such as MOSFET and IGBT’s, need a control voltage signal (usually called Vge) to allow switching between on/off states. This signal has a typical range of ±5 to ±20V and must be independent for every UUT. In order to provide up to 24 independent signal, 24 isolated digital outputs serves as remote-controlled switches. To accomplish this operating mode, all three COM terminals are directly connected to the secondary positive terminal, while the 3 grounds are connected to the negative one from the source. Switching modes are enabled by means of software, actuating independently over every individual isolated digital output, thus allowing multiple operative modes.

2 CONTROL SYSTEM:

The control system consists on a CPU, a HMI Workstation (keyboard, mouse and monitor) and a custom software application, developed under C programing language. Windows form (local) and web browser form (remote) are available. Control system consists on the following modules located inside the Conditioning cabinet: Temperature DAQ, Voltage/current DAQ, Oscilloscope and a CPU.

Control system logical architecture can be described in the following block diagram;

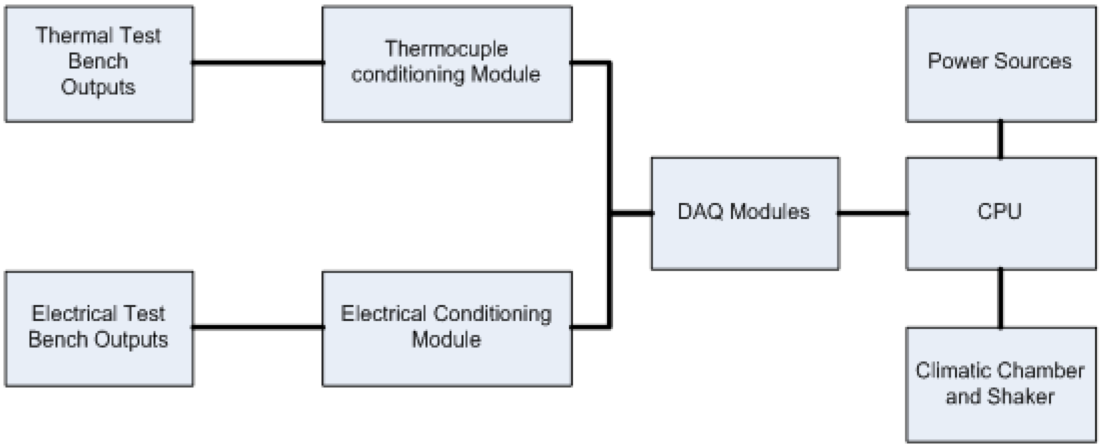


Figure 6. Control system logical diagram

The Control System:

- Performs acquisition of voltage, current, and temperature of the different UUT's.
- Provides a series of digital and analog I/O to enhance testing capabilities and performance
- Controls the different power sources and thermal chamber in order to provide the desired operating test conditions.
- Allows the interaction of the Power Test Bench users with all the different modules.

The Power Test Bench involves a PC-based CPU unit, which allows using PCI and PCI express cards for DAQ modules as well as external, RS232 or USB modules. It also provides a modular and upgradeable architecture and offers a good balance between costs and robustness.

In regards of the DAQ modules, external modules have been used, instead of PCI or PCI express ones, as they offer better performance and are most cost-friendly. These modules are connected via RS232/GPIB/USB or similar standard interfaces so interchangeability, upgradeability and modular design is easily achieved and limited only by the maximum bandwidth and simultaneous connections each protocol can provide.

Additionally, the Control System doesn't consume high bandwidth nor requires fast polling acquiring or control, so using external modules is not a problem regarding communication control and bandwidth rate. Safely USB, RS232, LAN or GPIB protocols are used to control and acquire all the electrical and thermal parameters and to command power sources and signal generators implying also a great spare in terms of complexity and costs.

The system is designed to test up to 24 UUT simultaneously, if the required wiring, connectors and DAQ equipment are connected.

Throughout one screen of the Human-Interface-Machine it can be controlled and set in barely few minutes the whole bench at a time and every devices independent from each other. The entire PTB can be synchronized and monitored at the time the tests are running is the application, from the following protocols:

- Advantech modules (Communication through USB)
- Skylife Power Source (Communication through RS232)
- Agilent source (Communication through RS232)
- Agilent source (Communication through GPIB)
- Shaker (Communication through Ethernet)
- Climatic Chamber (Communication through MODBUS)
- Heat Sink (Communication through MODBUS)
- Oscilloscope (Communication through USB)

Following are some details of how to define a test or represent it while the test is running:

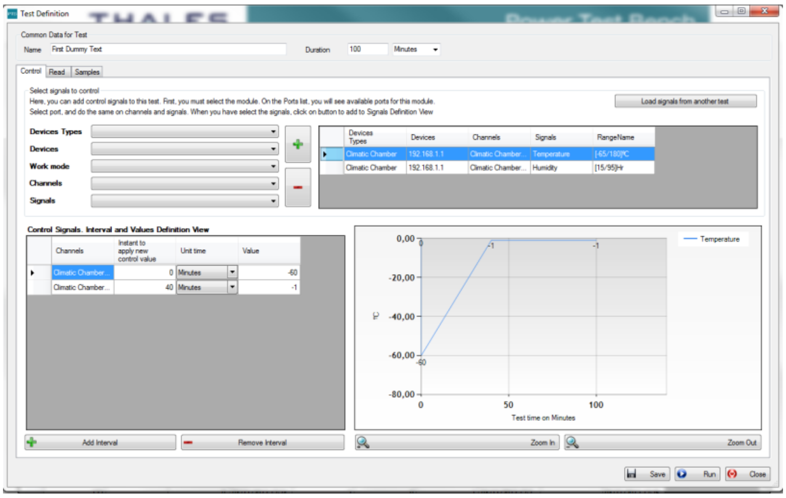


Figure 7 Test Definition

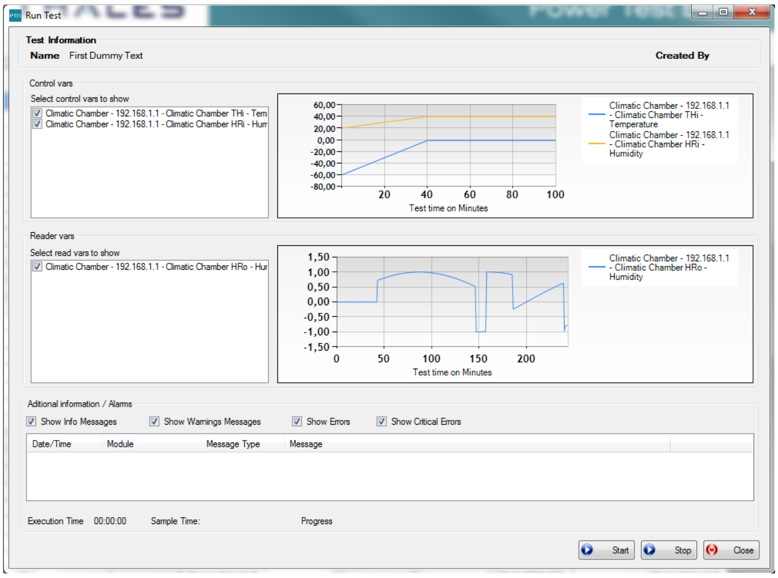
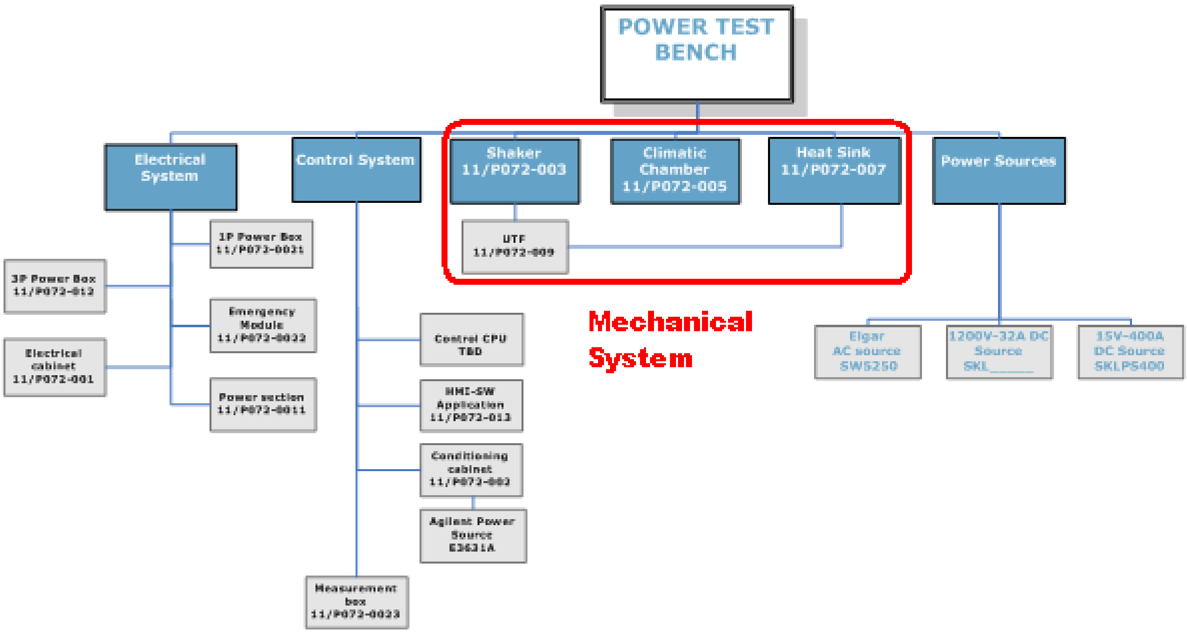


Figure 8 Test Execution

3 MECHANICAL SYSTEM:

As mentioned before the PTB combines in one system a climatic chamber, a vibration test system and an electrical characterization bench test.

The mechanical system components are in charge of supplying temperature, humidity and vibrations to the specimen to be tested. The mechanical system components are summarized in the next figure. In terms of environmental conditions, PTB can vary temperature from -65ºC to 180ºC, humidity from 10 to 98% and can set vibration up to 85-100g, 10 times higher than maximum accelerations defined RTA-DO-160.



In the following pages details of breakdown structure of the mechanical systems (Shaker, Climatic Chamber and Heat Sink) are shown.

Traditional electrodynamic-shaker systems are usually mounted underneath the climatic chamber and the shaker rod directly moves an expansion head that serves as a mounting plate for components. This expansion head has to have a very high rigidity and a careful design in order to leave its natural resonance frequencies outside of the test spectrum. This normally leads to complex design, expensive and heavy magnesium expansion heads-mounting plates. The shaker remains outside the climatic chamber and the upper part of the mounting plate enters the climatic chamber through an aperture in its bottom, being thus leveled with floor of the chamber.

In this disposition, the useful payload of the shaker is penalized by the high mass of the expansion head-mounting plate. Furthermore, this disposition only has 1 axis or DOF movement, the mounting plate is coaxial to the shaker's rod and moves up and down producing displacement, acceleration and velocity in one axis. If a component has to be shacked in more than one axis, then it has to be fixed to the mounting plate in sequential orthogonal positions. This implies different fixtures or interfaces for each component, manipulating the component in a hot or cold environment or multiplying by the number of axis to be tested the environmental conditioning times.

The proposal submitted presented a very innovative technical solution that included a mechanism to change vibration axis direction without changing in specimen fixings that it's considered a technological challenge. A high rigidity UTF (Universal Test Fixture) substitutes the expansion head and the base plate.

All the steps of the procedure to change vibration axis, without changing shaker orientation, would have a significant impact in testing times. This is the challenge and the most important innovation aspect of the initial proposal if it would work at the maximum values of vibration (2000 Hz and above). The mechanical parts, described below, are in charge of supplying vibrations to the components (DUT=Device Under Test) and systems to be tested.

3.1 Shaker

During the execution of the project have been proposed two possible subsystems for the vibration axis switch:

- "Lever arm" (INITIAL OPTION)
- Back up option (2nd design-OPTION B)

The main components of the shaker system for the two options are:

MAIN COMPONENTS "Lever arm" (INITIAL OPTION)	MAIN COMPONENTS Back up option (2nd design-OPTION B)
• Electrodynamic shaker • "Lever arm" • Guided plate	• Electrodynamic shaker • Positioning system (2nd design-OPTION B) • Guided plate

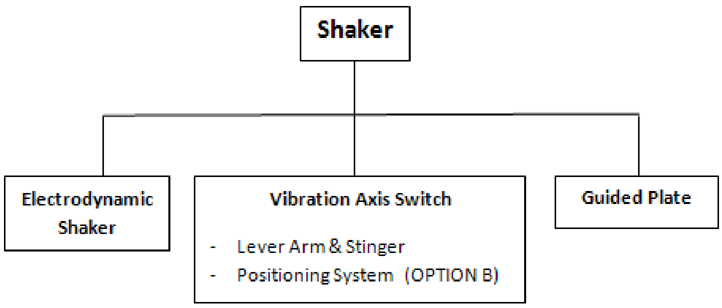


Figure 9. Shaker Configuration Options

The electrodynamic shaker is supported by an isolated support structure which performs the aptitude to tilt from 0º (horizontal position) to 90º (vertical position) and vertical regulation. Although the shaker has the possibility of changing the vibration's direction, the initial proposal was to maintain the electrodynamic shaker in horizontal position and allow getting both directions of vibration (vertical and horizontal) by means of adequate components or parts.

In that sense the proposal submitted presented a very innovative technical solution that included a mechanism to change vibration axis direction without changes in specimen fixings. This mechanism was initially identified as "Lever arm" and all efforts of the research were carried out to get a technical solution that was able to comply with the full vibration range required in the scope of the CfP.

3.1.1 INITIAL OPTION - "Lever arm"

The main function of the "Lever arm" is to change the direction of vibration axis, allowing the electrodynamic shaker to be in the same position and have the possibility of vibration of a DUT fixed over the Guided Plate in both directions without changes in specimen fixings.

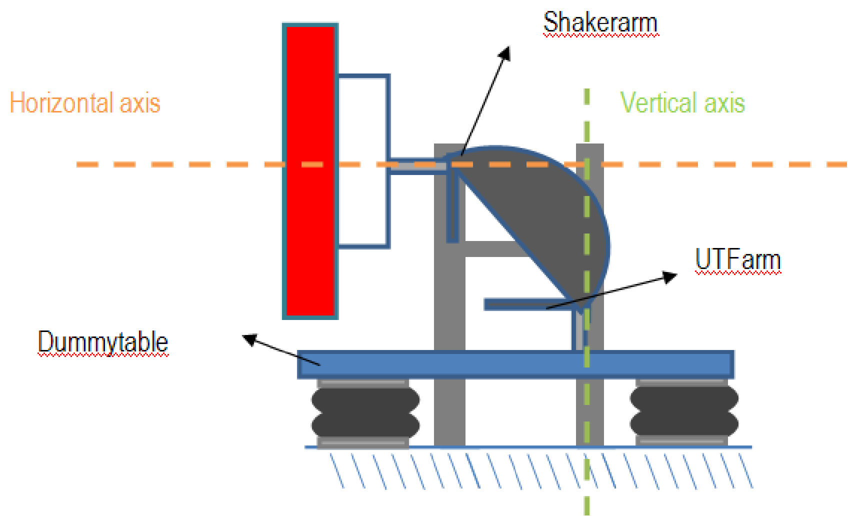


Figure 10. Lever Arm Drawing

This ability to vibrate in both directions must be carried out by the correct use of the "Lever arm" and the disposition of some guiding components attached to the Guided Plate which allows the vibration in the required direction.

- In case of vertical vibration of the DUT installed over the Guided Plate, when the shaker is in horizontal, it requires the use of the "Lever arm" and a pair of "stingers" (one on each end) to make the correct installation with the electrodynamic shaker and with the Guided Plate.

- In case of horizontal vibration of the DUT installed on the Guided Plate, when the shaker is in horizontal, the “Lever arm” is not used and needs to be removed. In this configuration only one “stinger” is needed to transmit the vibration.
- In case of shaker in vertical position it would be analogous to what is expressed before, but this configuration would require two stingers for horizontal vibration and only one stinger for vertical vibration.

In the event of a change of direction of vibration (vertical to horizontal), it is necessary to:

- uncoupling the “stingers”;
- remove and disassemble the “Lever arm”;
- change the position of the guidance elements of the Guided Plate;
- attach the “stinger” to the electrodynamic shaker.

The initial concept of "Lever arm" was based on the change of direction of vibration by rotation. The rotation was achieved by bending the flexures. In document D3.8 “R&D Activities - Switch Vibration Axis Development Summary and current situation” it is detailed that the course of research of a solution for the “Lever arm” concept has resulted in the evolution of some parts of the initial conceptual design.

The movement and forces are transmitted from the electrodynamic shaker and to the Guided Plate using “stingers”. The stinger is basically used to dynamically decouple the shaker from the structure that is going to vibrate. The stinger is also a mechanical fuse and it has a determined life number of cycles.

The next table summarizes all possible configurations for a specific required vibration:

Type of vibration of the Guided Plate	Shaker position	Lever arm	Stinger
Horizontal vibration	Horizontal	Not required	One
Vertical vibration	Horizontal	Required	Two

Note. The configuration showed is not the only possible with this concept since the electrodynamic shaker could be positioned in vertical and the conversion mechanism of the vibration direction would have the same features.

3.1.2 BACK UP OPTION (2nd design-OPTION B)

In the initial configuration the shaker was placed around the UTF with horizontal orientation and transmitted the force/acceleration/movement directly in horizontal vibration tests (X direction) or by means of a lever arm in vertical vibration test (Z direction). In both vibration tests the join element is a stinger. The shaker has always the same position and orientation.

However, due to that different “Lever arm” prototype R&D activities did not show the expected results, a set of new mechanical configurations were proposed, they are part of the 2nd Design (option B).

This task was devoted to find a 2nd Design (OPTION B) with the same level of test bench integration (vibration test, climatic chamber, electrical characterization and graphical user interface) and the vibration axis switch without changing set up of the DUT that were the main goals of the project, accepted in the CDR.

Document D3.7 “Mitigation Plan-Option B (Analysis)” describes and collects information of three possible configurations, which takes into account the actual constraints and the identified requirements and is proposed to Thales as solutions to the installation and use of the PTB.

For each of the configurations shown, it is provided detailed information on components description (functional, structural performances, reliability and life cycle ...), theoretical calculations, and experimental test, safety instructions, installation, operation and maintenance requirements.

The next table summarized the three possible combinations:

MECHANICAL CONFIGURATION OPTIONS	
B1	The shaker has horizontal movement and vertical/horizontal orientation. The climatic chamber and UTF have vertical movement.
B2	The shaker has vertical/horizontal movement and vertical/horizontal orientation. The climatic chamber and the UTF have always the same position.
B3	The shaker has always in the same position and vertical/horizontal orientation. The climatic chamber and the UTF have vertical/horizontal movement.

COMPARATIVE TABLE.

The comparative table is structured in:

- Parameter: variable to be evaluated for each configuration. The evaluation scale is:
  - Good (+).
  - Regular (O).
  - Bad (-).
- Configuration option: B1, B2 and B3.

At the end of the comparative table there is a justification table for each parameter.

ID	PARAMETER	B1	B2	B3
1	Structure complexity and functional requirements	O	+	-
2	Resistance to service conditions	O	+	O
3	Reliability	O	+	O
4	Installation requirements	-	O	-
5	Operation requirements	O	O	O
6	Safety requirements	+	+	+
7	Maintance requirements	O	+	O
8	Test room space and equipment distribution	O	O	-
9	Structural compatibility with the solution A for future technical developments	O	+	-
10	Risk probability	-	O	-

At the end of document D3.7 “Mitigation Plan-Option B (Analysis)” it is included a summary of advantages and disadvantages of each solution. The final configuration wasn’t agreed with Thales.

The main characteristics of the electrodynamic shaker are:

- Lightweight yet robust interchangeable armatures give the highest performance with reduced capital cost.
- Advanced switching power amplifiers offer high reliability, reduced space requirements, and simple installation and operation.
- State-of-the-art vibration control system enables remote monitoring and control.
- Air cooled.
- Trunnion mounted with Lin-E-Air isolation and body rotation gearbox for vertical or horizontal operation.

The electrodynamic shaker has the following main performances:

a) Armature diameter • 440 mm

b) Mass of moving element • 31,6 kg

c) Sine force (peak) • 35,6 kN

d) Random force (rms)[2] • 35,6 kN

[2]Random and shock forces ratings assume a payload approximately twice the mass of the armature; shock pulse 2 ms.

e) Maximum 1/2-sine shock force	• 84,3 kN
f) Usable frequency range	• D.C. to 3 kHz
g) Armature resonance	• 2,6 kHz
h) Velocity (sine peak) full-field	• 1,8 m/s
i) Acceleration (sine peak)	• 110g
j) Acceleration (random rms)	• 75g
k) Displacement (pk-pk) continuous	• 50,8 mm

The amplifier has the following main performances:

a) Power range	• 8 - 40 kVA in 8 kVA increments
b) Total armonic distortion	• 0,5 to 0,8% at rated output into resistive load
c) Input impedance	• 10 kΩ nominal
d) Input sensitivity	• 1,0 V for 100 V rms output
e) Signal to noise ratio	• > 68 dB, with respect to 100 V rms output, 10 kΩ input termination and rated resistive load connected
f) Power efficiency	• > 90% (not including Field Power Supply)

3.2 Climatic Chamber System

The climatic chamber has among other the following main characteristics:

- Component specifically designed for the current project.
- Lower base/wall:
  - Base removable/detachable.
  - Square window min. dimensions (mm): 930 x 930 (W x D)
  - Uniform contact pressure seals suitable for the temperature range and able to withstand horizontal and vertical movements of 25 mm.
  - Free of supports or obstacles and able to install a specific interface plate/seals and an UTF (Universal Test Fixture).

  - Provisions to install a specific interface plate/seals and an UTF (Universal Test Fixture).
- Upper wall with a removable lid to install appropriate components. Ddimensions (mm): 500 x 500 (W x B).
- Lateral walls (both)
  - 2 access ports (port holes) of 100 mm diameter (min.) on both sides of the chamber (right-left).
  - Centered on the surface and manufactured in stainless steel, each with removable silicone plug closed and a slotted for electrical cables pass into the camera.

The climatic chamber and its associated cabinet have the following main performance:

PERFORMANCE (Temperature test – Climatic test)

a) Temperature range	• Adjustable: -65 °C to +180 °C.
b) Temperature deviation in space	• ± 1 º C to ± 2 º C
c) Temperature gradient	• 5ºC/min. (average value): +180ºC to 0ºC. • 4ºC/min. (average value): 0ºC to -20ºC. • 2ºC/min. (average value): -20ºC to -40ºC. • 1ºC/min. (average value): -40ºC to -50ºC. • 0.5ºC/min. (average value): -50ºC to -65ºC.
d) Heating rate	• 5ºC/min. (average value): -65ºC to +180ºC.
e) Internal heat dissipation	• 5 kW (range: -20ºC to +100ºC).
f) Temp. deviation in time	• ± 0.5 º C to ± 1 º C.
g) Humidity range	• Adjustable: 15% to 95% H.R.
h) Humidity deviation in time	• ± 1% to ± 3% R.H.
i) Dew point range	• +5ºC to +89.5ºC.

3.3 Heat Sink System

The heat sink system ensures a low temperature at the tray where devices are placed in order to avoid devices failures. The heat sink is a passive component that cools the test specimen by dissipating heat into the surrounding air. So the heat sink is a heat exchanger designed to increase the surface area in contact with the cooling medium surrounding it, such as the air

The heat sink system comprises the following components:

- Heat sink main plate
- Insulation elements
- Flexible connectors
- External dissipating unit
- Control system
    - Control Tª sensor centered in plate to give mid Tª of plate
    - Control unit, as to set mid Tª of plate
    - Fluid loss detection system (alarm to Control System)
- External heat exchanger and heat transfer unit. This element must be placed ideally outside the test cell.

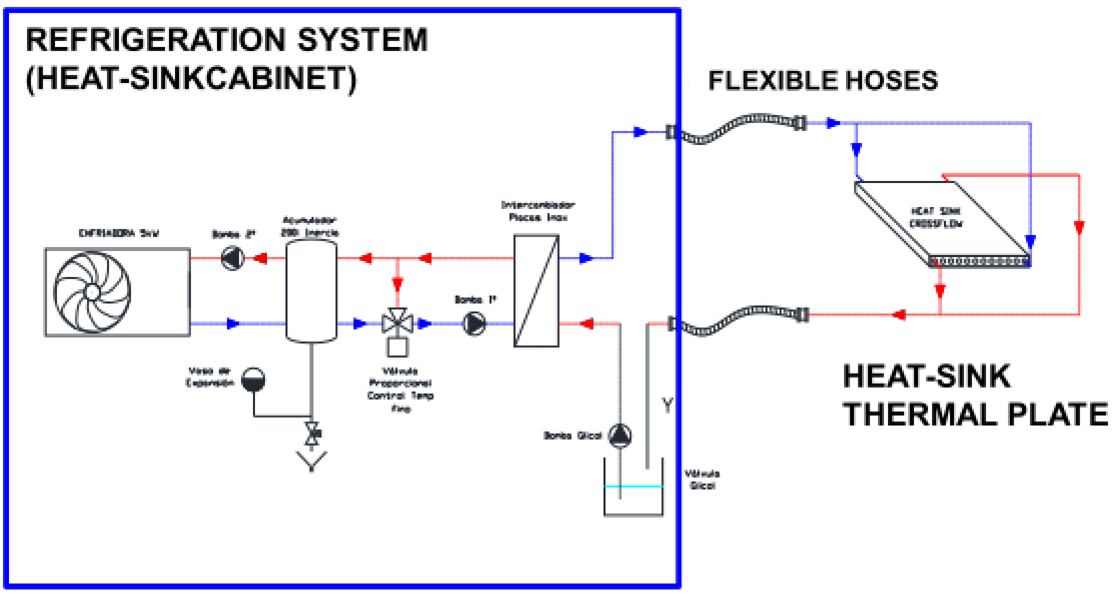


Figure 11. Heat Sink Drawing

THE POTENTIAL IMPACT

Endurance Tests and Reliability Prediction of avionics is a critical part of the development of on-board electronic equipment.

Today, reliability and life expectation of electronic converter are studied at components level by using military standards books like MIL-HDBK or estimate calculation based on background of components class used in similar application. These methods provide rough estimation and the results need to be compared to realistic endurance tests.

Consequently, among others activities, there are necessary accelerated testingto predict parts' reliability under a wide range of environments, to research fundamental failure mechanisms and to get to know the effect on reliability of the manufacturing processes. Traditionally this has been done by means of ATE systems for the functionality tests and with electrodynamic shaker systems and dynamic or thermal shock climatic chambers.

The interest and the need of this specific test bench is to give more confidence to the design in terms of reliability at components level and help the user to expertise and to validate the minimum life expectation of future aircraft power electronics converters. This test bench improves time efficiency and reliability of environmental testing of future More Electrical Aircraft (MEA) power electronic converters and components.

The Power Test Bench permits leading tries of verification and validation in a severe multi-constrained environment (electric, thermal, humidity, vibration), with the aim of predicting the reliability of the onboard power electronics from the beginning of the design phases, and introduce the new technologies in a mastered way.

The power components and equipment will be tested and aged by being subjected to extreme conditions the system is able to reach such as:

- a temperature of -65°C to +180°C,
- an adjustable humidity of 15% to 95% H.R.,
- a sine shaker force of 35,6 kN,
- a shock vibration of 84,3 kN ,
- a sine peak acceleration of 110g,
- a random (rms) acceleration of 75g,
- a low DC voltage power source of 6 kW (15V, 400A)
- a high DC voltage power source of 32 kW (1200V, 32A)
- a 3-phase AC power source

From a full control system, the user is able to control the shaker, the climatic chamber and the AC and DC power sources and set several test conditions simultaneously to perform complex and necessary tests without moving the specimens to different machines. The users are able to automatize the tests and optimize the time employed to perform all the verification procedures.

The reduction in the testing times are also derived from the Power Test Bench capability of performing the tests in sequential multiple axes without changing the disposition of the tested specimens inside the test chamber and without reconditioning it, thus eliminating the problems that this arises.

In order to change the position of the shaker around the UTF to shake sequentially in all 3 axes, initially there was going to be a lever arm that was going to transmit the movement from the electro-dynamic shaker to the UTF for vertical vibration when the shaker is in horizontal position. It was going to make possible stand the shaker in horizontal position even in vertical excitation. The progress in the Lever arm development and research did not give the expected results in the time available and to get the axis change it was proposed to replace the transmission system based on "Lever arm", by a positioning system (either for the climatic chamber or the shaker).

Moreover, with the PTB there is also a lower energy consumption of the test bench, by the use of insulation techniques in the climatic chamber and the implementation of an adequate heat sink that cools the test specimen by dissipating heat into the surrounding air.

In addition, this test rig, with its big size and proper wires and connections, is able to test and monitor several components at the same time, up to 25 components can be controlled simultaneously.

Furthermore, the test bench is able to run two different types of test: Steady (automatic and manual) and Transient tests:

- In the **steady state mode**, the user defines the test to be executed and the system captures data every ten seconds for all devices connected inside the chamber. Note the number of DUTs to be tested is limited by the maximum data acquisition capacity. This type of test can be executed automatically, the normal mode, where automated signals profiles are available or predefined. The test bench has also a manual modethat executes steady state tests where the procedures aren't predefined and consequently manual modification of the control signals has to be done.
- The **transient mode** is a troubleshooting mode that allows to manual capture data every micro second of a reduced set of devices limited by the maximum data acquisition capacity.