TRANSFORMING POWER INTO SUCCESS

Final Review

New packaging techniques (NPT)
to increase power density
of power control and distribution units

ESA Contract No. 4000134603/21/NL/CRS

13th March 2024

Participants

ESA:

- Giulio Simonelli

Airbus:

- Julian Bozler

ASP:

- Martin Blaser (COO)
- Günter Weishaar (Project management)
- Marcos Arend (Engineering)
- Konstantin Lutz (Engineering)
- Stefano Falcini (Thermal Engineering
- Günther Neumann (Product Assurance)

Objective

Final Review

- **Date:** 13.03.2024
- **Time:** 09:00h – 12:00h
- **Location:** Telecon
- **Input:** Review Data Package definition in line with the list of deliverables
- **Description:** to assess the achievement and address further possible developments in the packaging technologies and/or propose further activities to increase the TRL of the selected technology/architecture.
- **Output:** final payment and contract closure

Agenda

- **Objective**
- **Work Logic**
- **Technical Summary**
- **Programmatic**
  - Status of deliverable documents
  - Problem areas, Status of action items, Progress: actual vs. schedule
  - Milestones and events accomplished
  - Milestone payment status
  - Schedule
- **Delivered Documents for Final Review**
- **Further Possible Developments**
- **Conclusion/MoM**

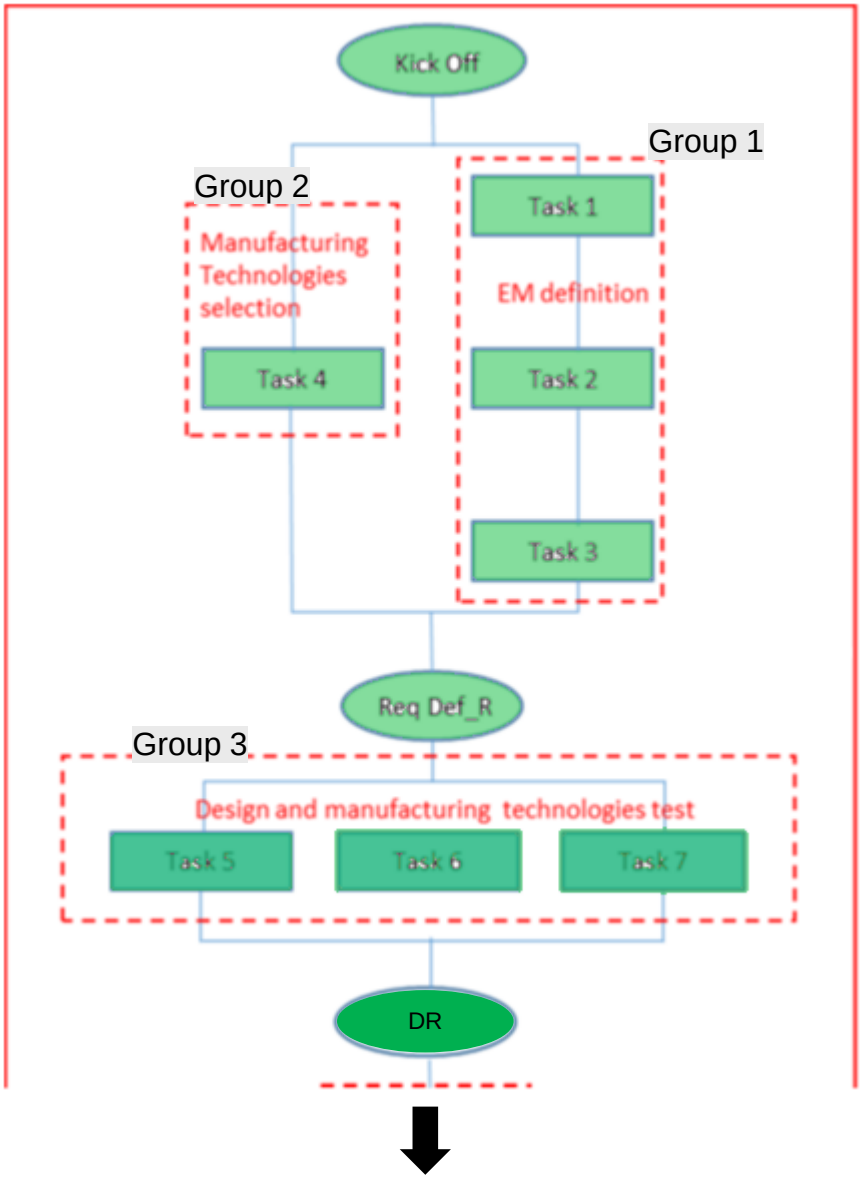
Work Logic

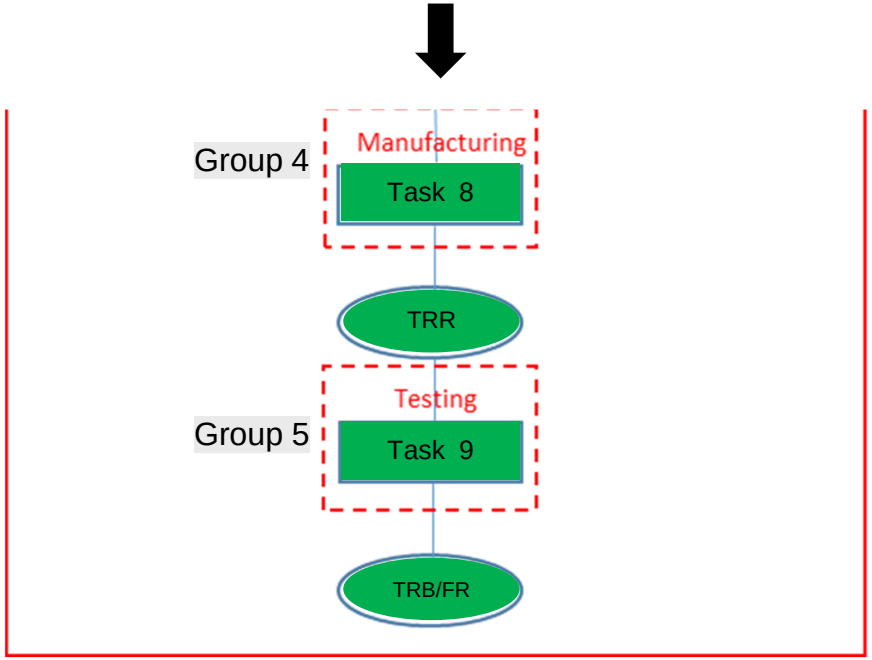
Work Logic

- **The work is organised in 9 tasks that are divided in the following 5 groups:**
  - **Group 1: Task 1, 2, 3:**
    - EM Definition
  - **Group 2: Task 4:**
    - Manufacturing technologies selection
  - **Group 3: Task 5, 6, 7:**
    - EM and GSE design and manufacturing feasibility tests
  - **Group 4: Task 8:**
    - EM and GSE manufacturing and test preparation
  - **Group 5: Task 9:**
    - EM Test and results evaluation

All nine tasks are successful completed.

Work Logic Flow

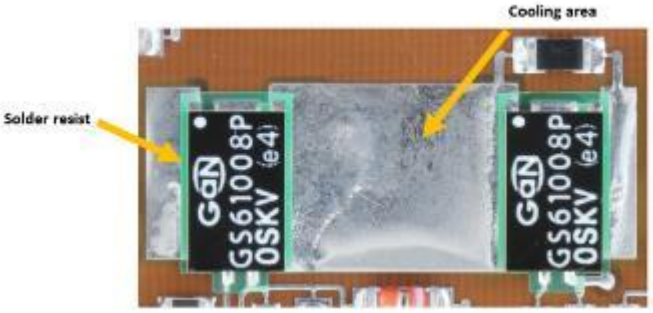


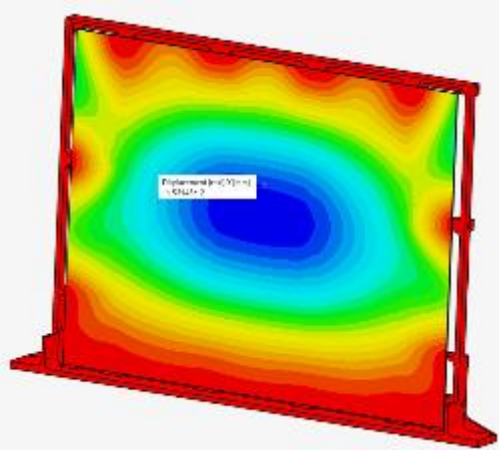


Technical Summary

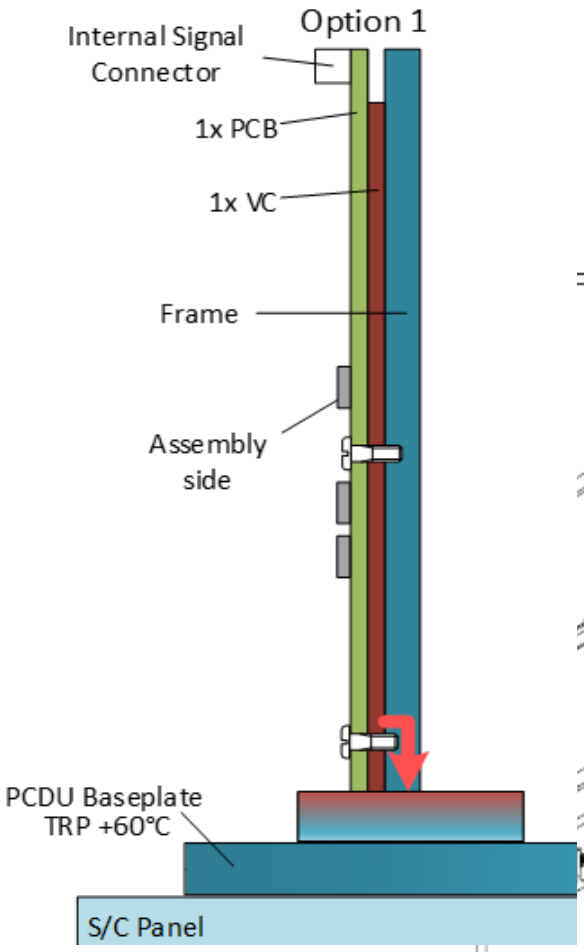
The Challenges

- Extensive use of SMD Power Dissipative Devices
  - PCB Area Effective Use
  - „ Punctual “ Hot Spots
  - Mechanical (Steinberg) and Thermo-Mechanical Fatigue
- Vertical Modularity
- Double Insulation
- PCB Substrate: Thermal Conductance x Cost
- The SARM Extensive Thermal Cycling
- The Vapor Chamber Applicability and the Verification

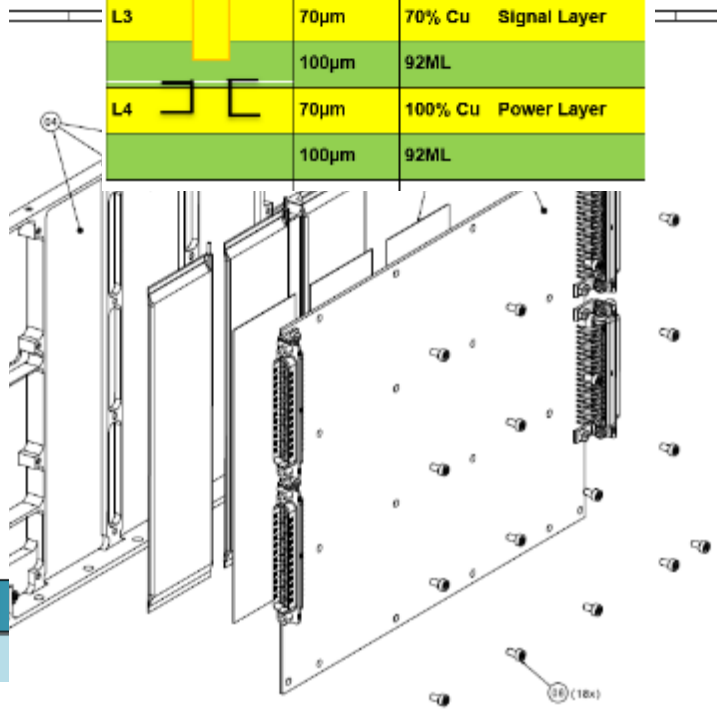


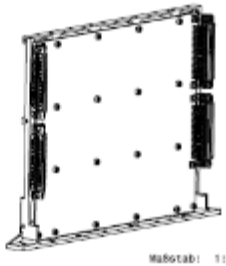


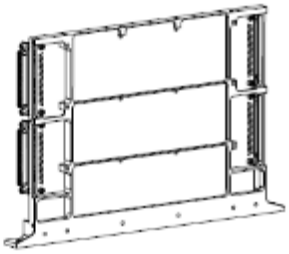
The Design



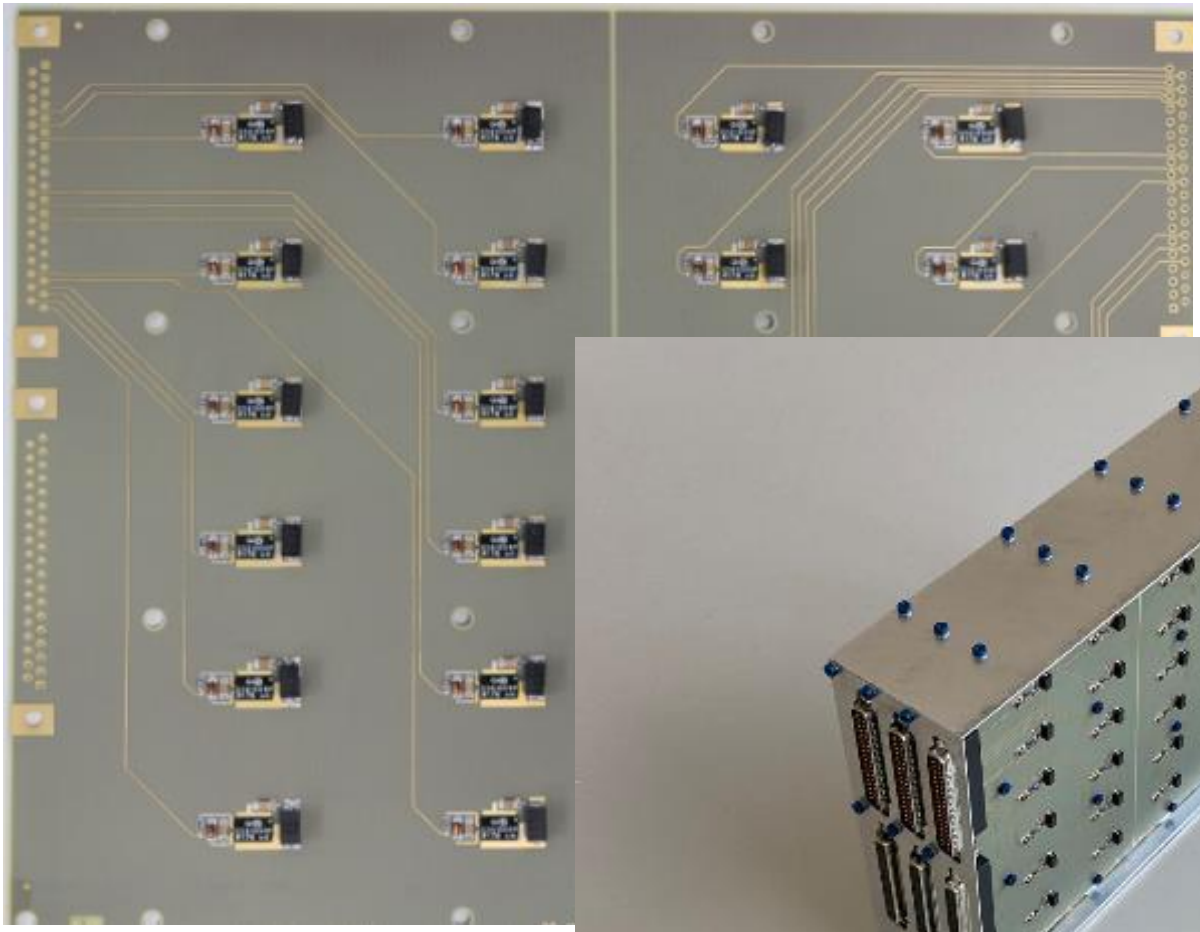
L1	70µm	70% Cu	Power Layer
	100µm	92ML	
L2	70µm	70% Cu	Signal Layer
VIAS	420µm	92ML	
L3	70µm	70% Cu	Signal Layer
	100µm	92ML	
L4	70µm	100% Cu	Power Layer
	100µm	92ML	

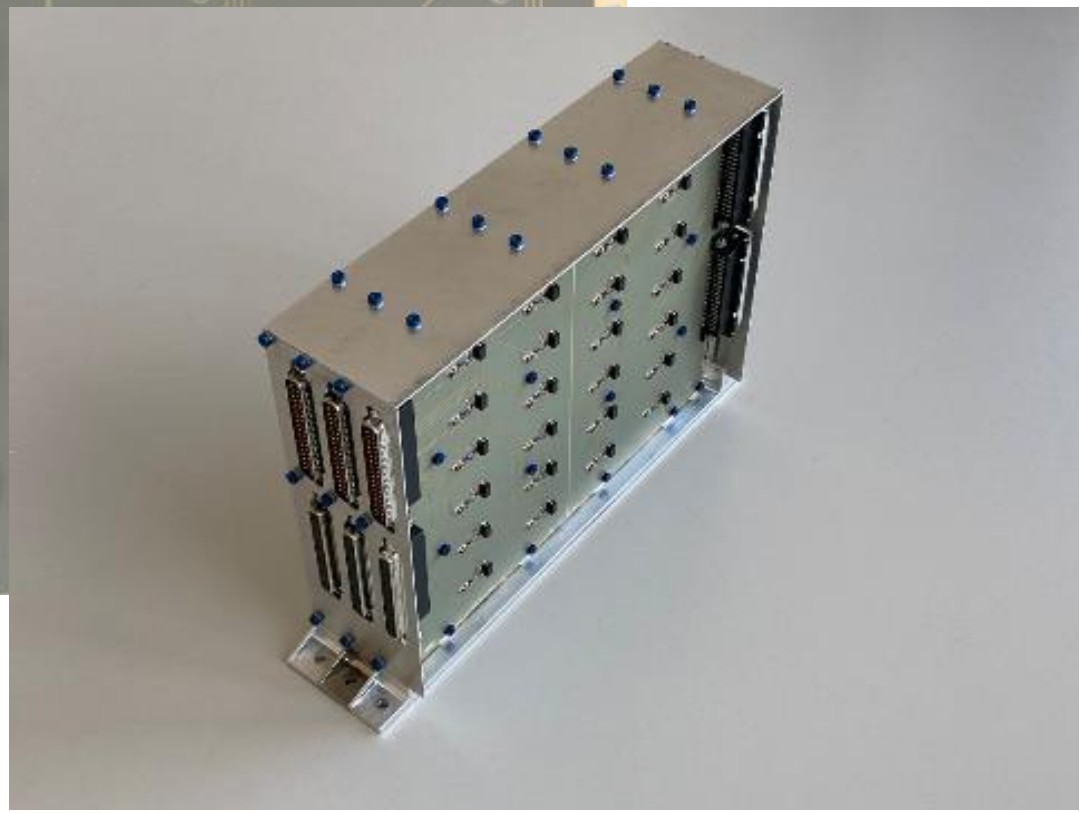






The Product





The Tests


Vapor Chamber Tests
Mechanical Inspection
Thermal Conductivity
Cold Start
Mechanical Inspection
Low Pressure Resistance
Mechanical Inspection
Thermal Vacuum Cycling
Thermal Conductivity
Mechanical Inspection
Microsection
Module Tests I
Mechanical Inspection
Thermal Control Performance
Thermal Vacuum Cycling
Mechanical Inspection
Thermal Control Performance
Microsection
Module Tests II
Mechanical Inspection
Thermal Control Performance
Hot Spot HALT
Mechanical Inspection
Assembled Modules Equipment Simulation
Mechanical Inspection
Thermal Control Performance
Vibration Tests
Mechanical Inspection
Thermal Control Performance
Microsection

Vapor Chamber Test Summary

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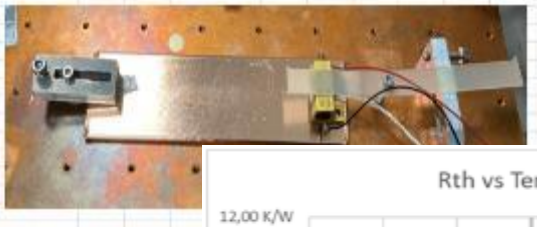
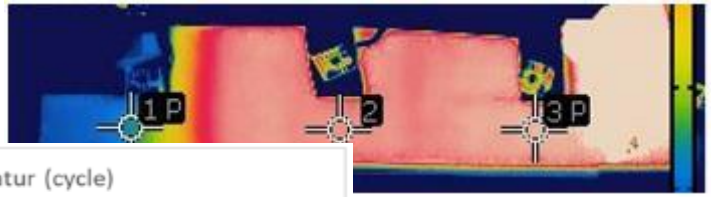
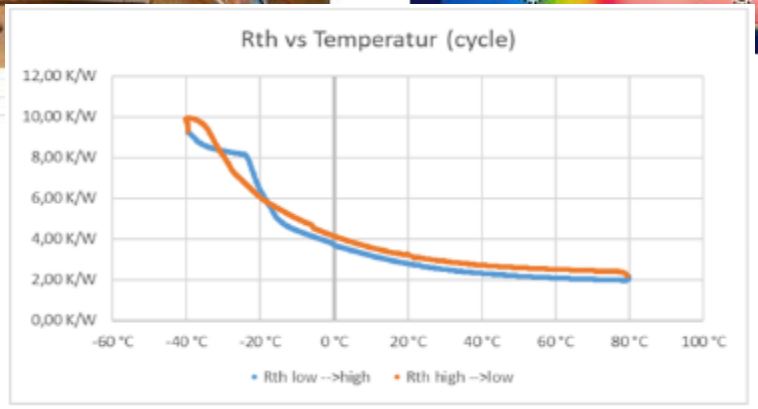
Thermal Conductivity

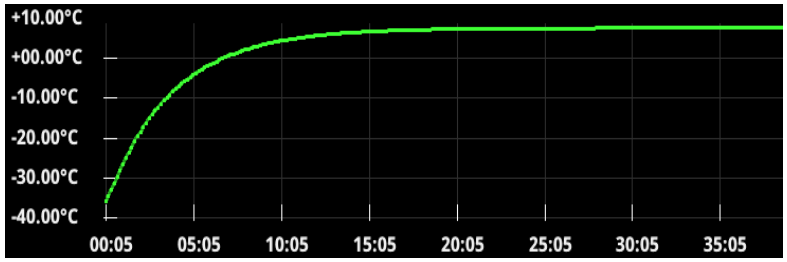
		PT100	Rth
20,00 °C	5,04 W	41,84 °C	2,33 K/W
1Bar			
20,00 °C	5,04 W	45,34 °C	3,04 K/W
VAC			
20,00 °C	10,03 W	75,67 °C	3,31 K/W
VAC			
-20,00 °C	5,04 W	10,98 °C	8,15 K/W
VAC			
-40,00 °C	5,04 W	7,49 °C	8,42 K/W
VAC			







Cold Start



Low-pressure Resistance

Vapor Chamber Test Summary

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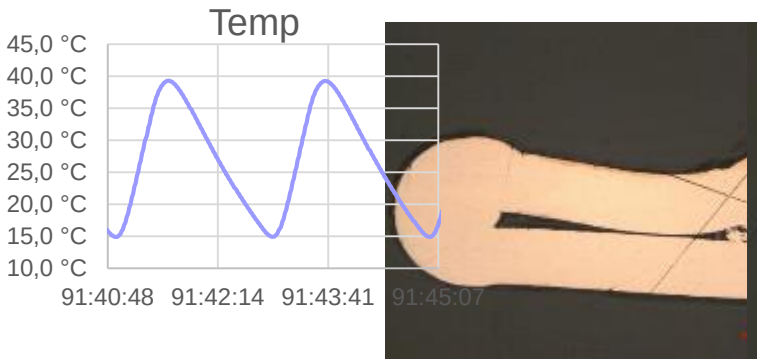
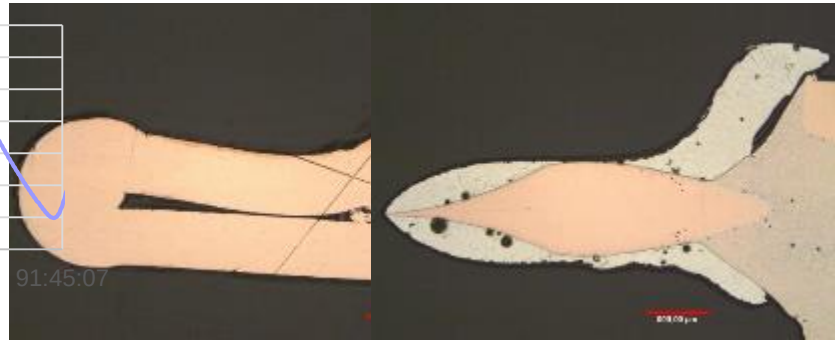
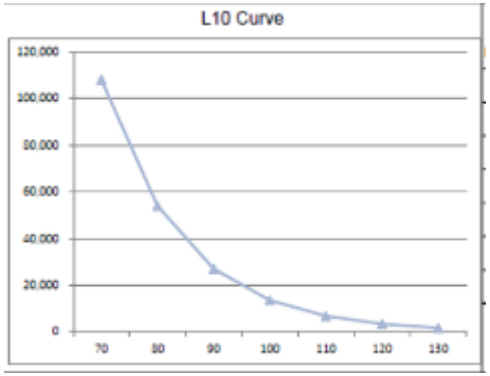
Thermal Vacuum Cycling

55 thousand cycles





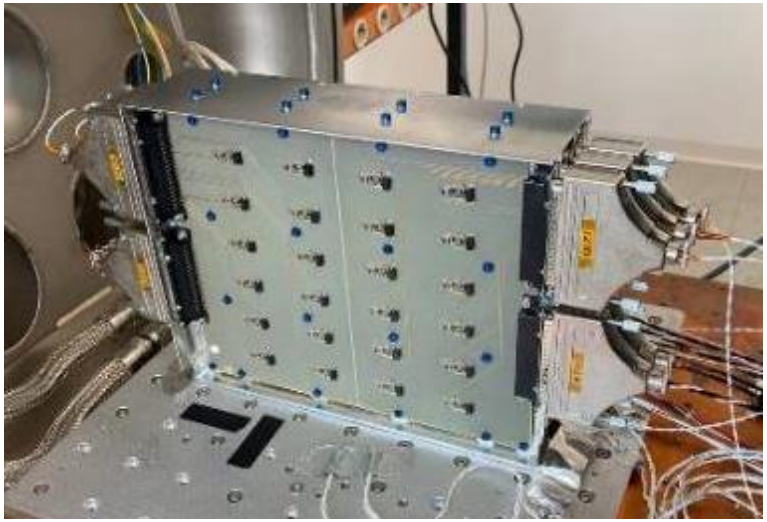
Life Experiment Report



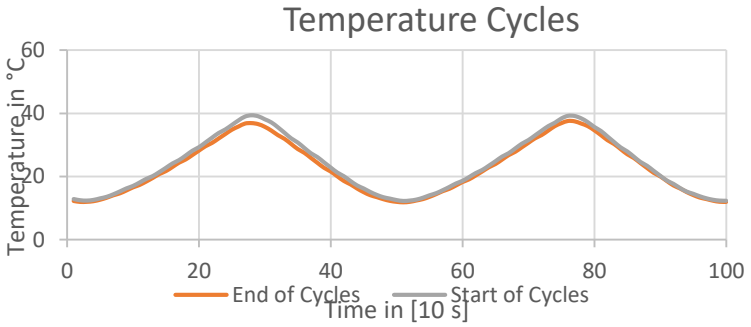
Stress/Elevated Temperature Ts (°C)	Unstress Temperature Tu (°C)	Acceleration Factor AF	Qutntity of Test Devices n (pcs)	Poisson Distribution Factor $B_{r,n}$	Requlred test time with 1 failure t (hours)	Actual test time with 1 failure t (hours)	Verified MTTF (hours)	Verified L10 (hours)
130	80	32	50	2.3026	723.6	744.0	378,274	54,039

Expected an average temperature over the Vapor Chambers less than 70° C. Applying the L10 curve we will get a life bigger than 100K hours

Module Test Summary – Thermal Cycling



5 000 cycles 25 K delta



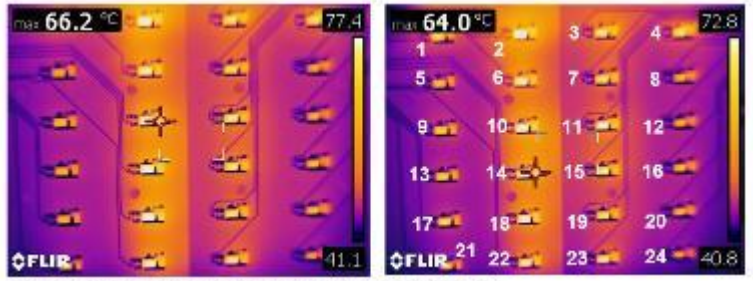
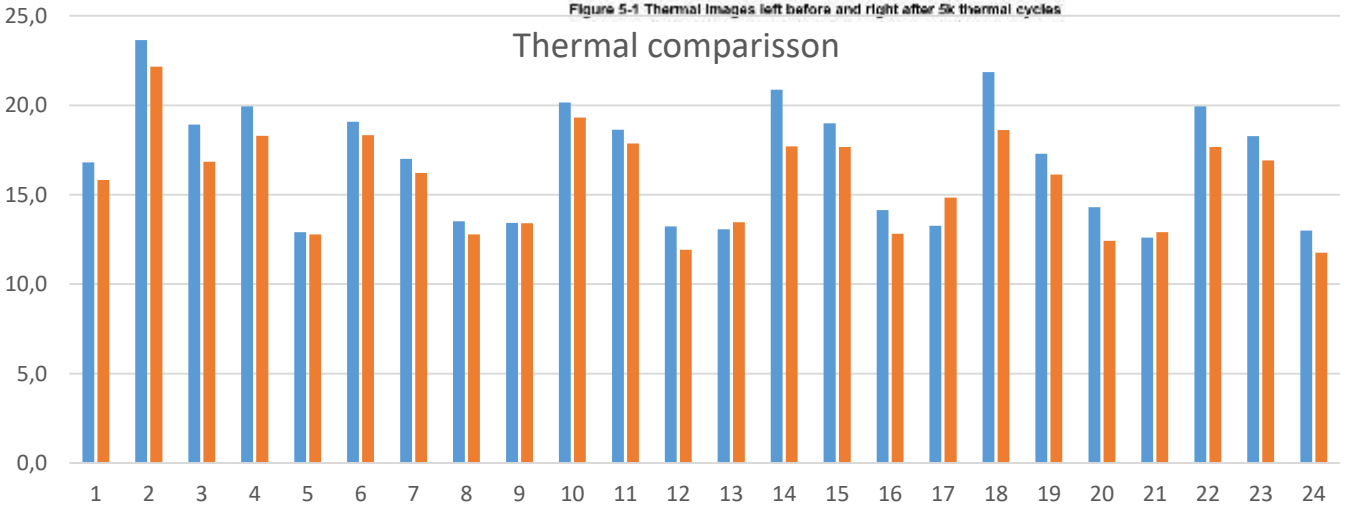


Figure 5-1 Thermal images left before and right after 5k thermal cycles



Vibration Test Summary

Sine: 6 g Random: 12 g_{rms}

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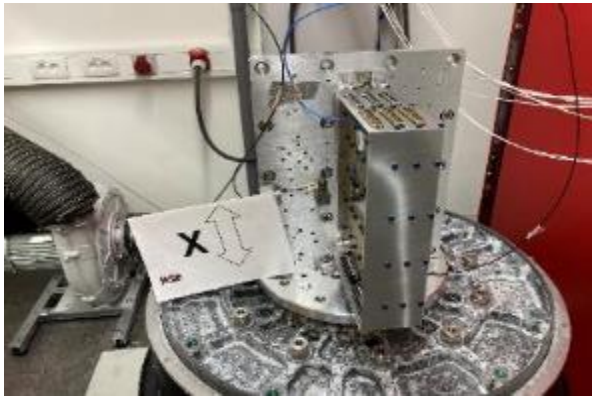

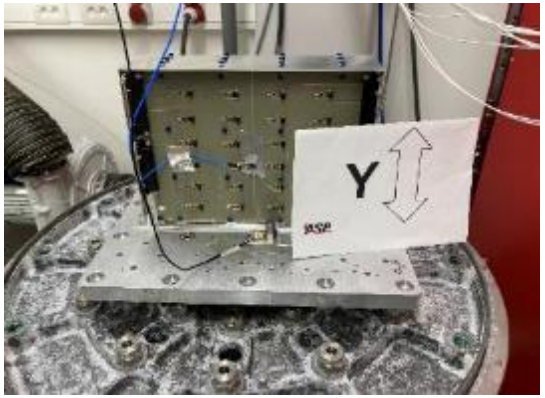

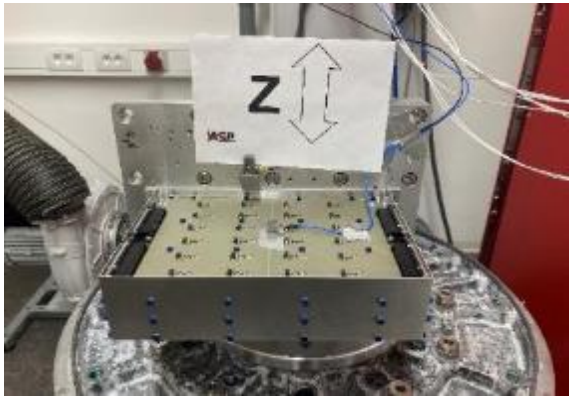

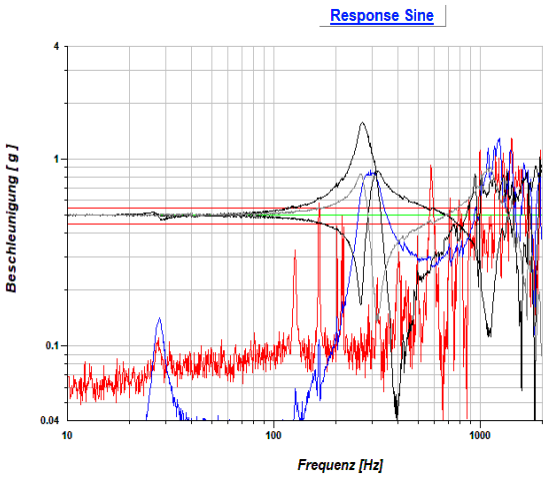

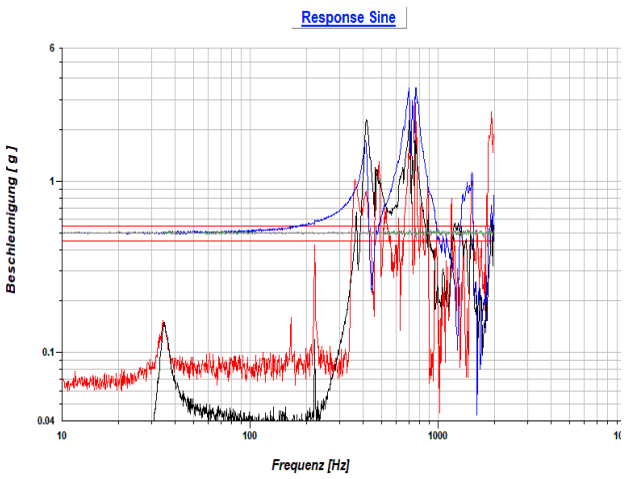

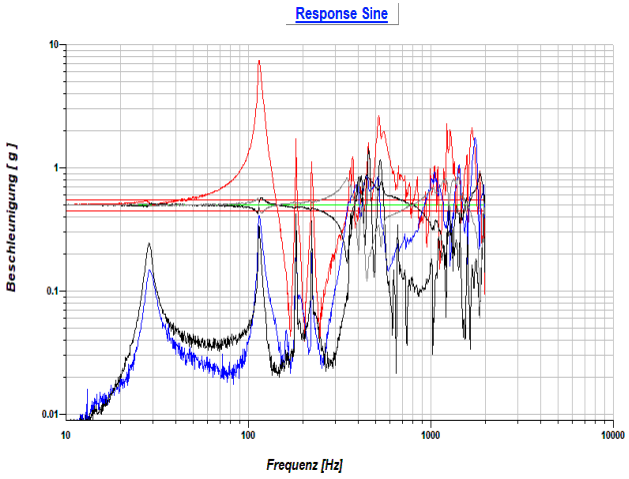

Vibration Test Summary

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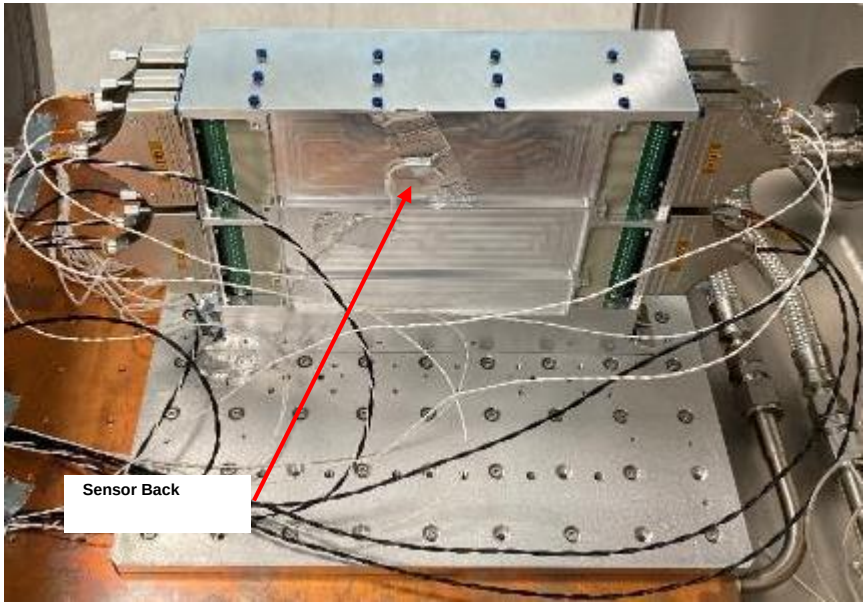
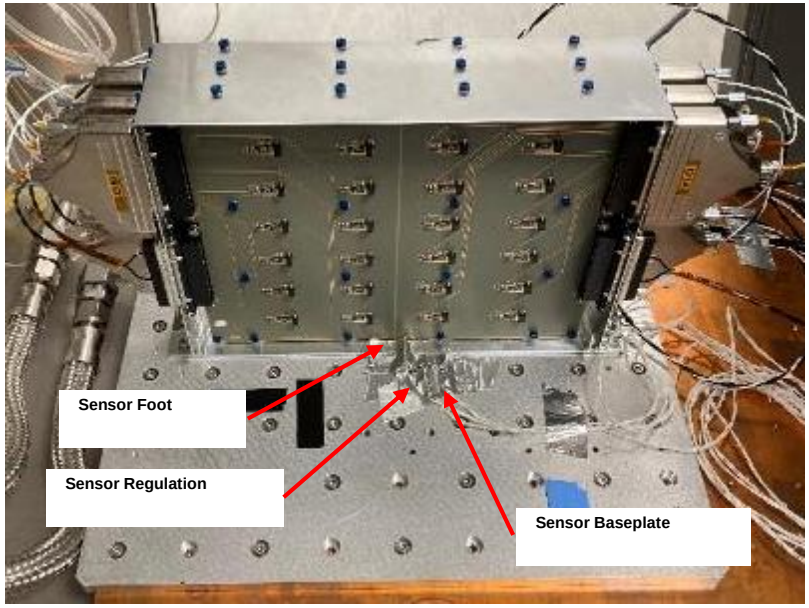
ASP

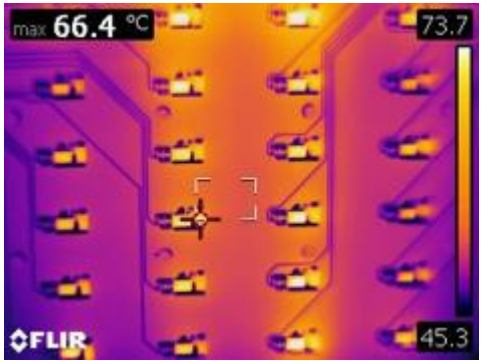


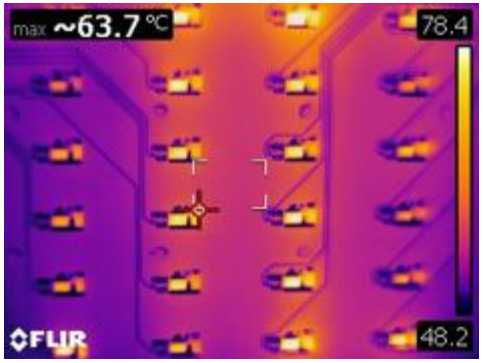


30,0 °C	before	after
Back	50,4 °C	54,6 °C
Foot	44,7 °C	47,7 °C
Baseplate	30,0 °C	30,0 °C
Power	162,7 W	175,2 W

70,0 °C	before	after
Back	86,3 °C	86,5 °C
Foot	78,2 °C	77,9 °C
Baseplate	70,0 °C	70,0 °C
Power	168,8 W	168,8 W

-30,0 °C	before	after
Back	8,3 °C	8,9 °C
Foot	-10,0 °C	-8,7 °C
Baseplate	-30,0 °C	-30,0 °C
Power	170,9 W	173,7 W





Thermal Control Performance

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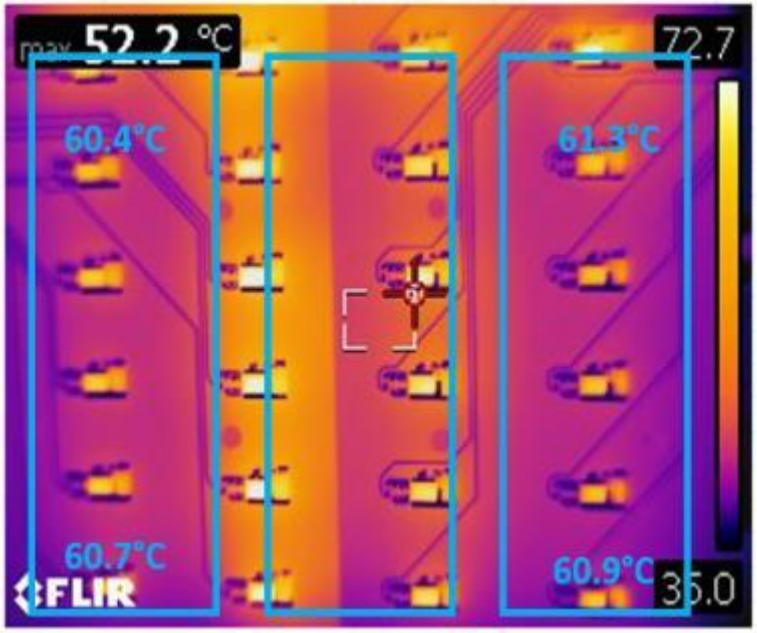
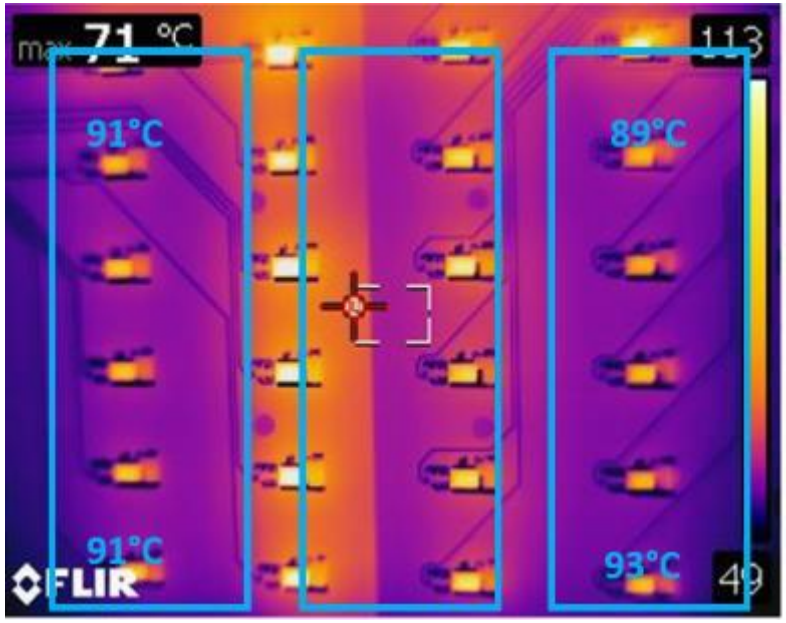
60W



120W



Thermal Control Performance

Mass Saving Impact

By simulations and analysis was evaluated the necessary frame mass addition for achieving a similar vapor chamber thermal control. Was necessary to add around 2.1kg of aluminum mass (a block) for the 120W dissipation case and around 1kg for the 60W case. **Considering a PCDU with 6 dissipative modules (60W) the total mass save would be around 6kg.** A more realistic evaluation shall consider a total redesign for the module without vapor chambers. **An average 4kg total saving mass can be considered a better evaluation, resulting in around 10% - 20% of the total mass saving for the whole equipment (standard PCDU mission design).**

Removing the Vapor Chambers (Experimental 120W)

Position	with VCs	with Dummies	Delta
1	104.5 °C	166.8 °C	62.3 °C
2	95.3 °C	152.5 °C	57.3 °C
3	89.3 °C	143.5 °C	54.3 °C
4	84.0 °C	132.5 °C	48.5 °C
5	80.0 °C	123.8 °C	43.8 °C
6	72.0 °C	110.0 °C	38.0 °C

Programmatic

Document Status Overview

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Ref.	Documentation	Definition Review	Design Review	Test Readiness Review	Test Review Board	Final Review	Due Date	Doc.: No.	
Task1: D-01	Thermal Mechanical Constraints and Overall System Assumptions Technical Note	Issue 1					06.09.2021	GSTP-PACK-DOC-001	
Task2: D-02	PCDUs Packaging Options, Thermal Mechanical Architectures and PCBA Technology Options Technical Note	Issue 1					12.10.2021	GSTP-PACK-DOC-002	
Task3: D-03	EM Development Plan		Issue 1				01.08.2022	TN-K066-10000ASP003	
Task3: D-04	Evaluation matrix and Trade Off TN	Issue 1					10.11.2021	TN-K066-10000ASP004	
Task3: D-05	Architecture Justification of the Selected Packaging concept, Thermo-Mechanical Architecture and PCBA Technology TN	Issue 1					10.11.2021	TN-K066-10000ASP005	
Task4: D-06	Manufacturing Technologies Survey	Issue 1					10.11.2021	TN-K066-10000ASP06	
Task4: D-07	EM Manufacturing Feasibility Assessment Plan		Issue 1				04.04.2022	TN-K066-10000ASP007	
Task4: D-08	PCBA and power component description TN	Issue 1					10.11.2021	TN-K066-10000ASP008	
Task7: D-09	Manufacturing Technologies Feasibility Report		Issue 1				12.12.2022	incl. in D06/D07/D16	i
Task3: D-10	EM PCDU requirements Definition		Issue 2				28.06.2022	SPE-K066-10000ASP001-i2	
Task5: D-11	Interface Control Document (Mech, Therm, Connectors)		Issue 1				01.08.2022	TN-K066-10000ASP011	
Task3: D-12	Test Plan and GSE Requirement definition		Issue 1				10.05.2022	TN-K066-10000ASP012	
Task5: D-13	EM Design Justification Document		Issue 1				26.08.2022	TN-K066-10000ASP013	
Task5: D-14	Thermal ~~and Mechanical~~ (for Mechanical see D-23) Analyses		Issue 1				08.06.2022	TN-K066-10000ASP014	
Task5: D-15	Tests Specifications		Issue 1				20.06.2022	SPE-K066-10000ASP015	
Task5: D-16	Manufacturing Files (including electrical schematics, mechanical drawings, part lists etc)		Issue 1				10.06.2022	TN-K066-10000ASP016	
Task5: D-17	EM User Manual			Issue 1			12.12.2022	incl. in D15/D13. Doc.	i
Task6: D-18	GSE Description			Issue 1			12.12.2022	no specific GSE.	r
~~Task6: D-19~~	~~Test Specification~~	-		~~Issue 1~~	-	-		see D-15 (double)	s
Task6: D-20	Test Procedures							Headline	h
Task6: D-201	Thermal Vacuum Test Procedure (Unit Level)			Issue 2			15.12.2022	TP-K066-10000ASP01	
Task6: D-202	Vibration Test Procedure (Unit Level)			Issue 2			15.12.2022	TP-K066-10000ASP02	
Task8: D-21	Photographic Documentation			Issue 1			12.12.2022	Incl. in the documents	I
Task3: D-22	Test Reports							Headline	h
Task3: D-221	VC Thermal Cycling Test Report			Issue 1			27.10.2022	TR-K066-10000ASP01	
Task3: D-221	Frame Design and Process			Issue 1			20.03.2023	TR-K066-10000ASP03	
Task3: D-222	VC Microsection Test Report			Issue 1			27.10.2022	TR-K066-10000ASP02	
Task3: D-223	Thermal Vacuum Test Report (Unit Level)				Issue 1		25.07.2023	TR-K066-10000ASP04	
Task3: D-224	Vibration Test Report (Unit Level)				Issue 1		25.07.2023	TR-K066-10000ASP05	
Task3: D-23	Final Report					Issue 1	19.02.2024	TR-K066-10000ASP06	
Task3: D-24	Technical Data Package					Issue 1		see D-01 to D-32	D
Task3: D-25	Summary Report					Issue 1	27.02.2024	RP-K066-10000ASP01	
Task3: D-26	Executive Summary Report					Issue 1	29.02.2024	RP-K066-10000ASP02	
Task3: D-27	Abstract					Issue 1	11.03.2024	AB-K066-10000ASP01	
Task3: D-28	Contract Closure Documentation					Issue 1	04.03.2024	CC-K066-10000ASP01	
Task5: D-29	Mechanical Harmonic Analysis		Issue 1				27.06.2022	TN-K066-10000ASP029	
Task5: D-30	Broschure					Issue 1		BR-K066-10000ASP01	
Task5: D-31	Final Review (Power Point presentation)					Issue 1	13.03.2024	FR-K066-10000ASP01	
Task5: D-32	Final Presentation (Power Point presentation)					Issue 1		FP-K066-10000ASP01	
Task5: D-33	Technical Achievement Template					Issue 1	13.03.2024		

Problem areas, if any, and corrective actions planned and/or taken

- None

Status of action items

- No open Action Items

Description of progress: actual vs. schedule

Schedule:

- WP1000/Task 1 to WP9000/Task 9 are completed

Actual:

- All documents acc. SoW are delivered

Milestones and events accomplished

• Contract signed ESA/ASP	25.05.2021
• Subcontract signed Airbus/ASP	11.06.2021
• Kick-off meeting successful held	01.06.2021
• 1st progress report/meeting	02.07.2021
• 2nd progress report	30.07.2021
• 3rd progress report/meeting	16.09.2021
• 4th progress report/meeting	21.10.2021
• Definition Review successful completed	26.11.2021
• 5th progress report/meeting	28.01.2022
• 6th progress report/meeting	11.03.2022
• 7th progress report/meeting	08.04.2022
• 8th progress report/meeting	12.05.2022
• Technical Meeting Airbus/ASP	23.05.2022
• Design Review successful completed	30.06.2022
• 9th progress report/meeting	31.08.2022
• 10th progress report/meeting	28.10.2022
• Test Readiness Review successful completed	25.11.2022
• 11th progress report/meeting	27.01.2023
• 12th progress report/meeting	10.02.2023
• 13th progress report/meeting	03.05.2023
• 14th progress report/meeting	16.06.2023
• Test Review Board successful completed	28.07.2023

Milestone payment status

- Advanced Payment,
  - ESA->ASP complete
  - ASP->Airbus complete
- MS1: Successful completion of tasks 1,2,3,4 and successful Definition Review
  - ESA->ASP complete
  - ASP->Airbus complete
- MS2: Successful completion of tasks 5,6,7 and successful Design Review
  - ESA->ASP complete
  - ASP->Airbus complete
- MS3: Successful completion of task 8 and successful Test Readiness Review
  - ESA->ASP complete
  - ASP->Airbus complete
- MS4: Upon the Agency's acceptance of all deliverable items due under the Contract and the Contractor's fulfilment of all other contractual obligations including submission of the Contract Closure Documentation.

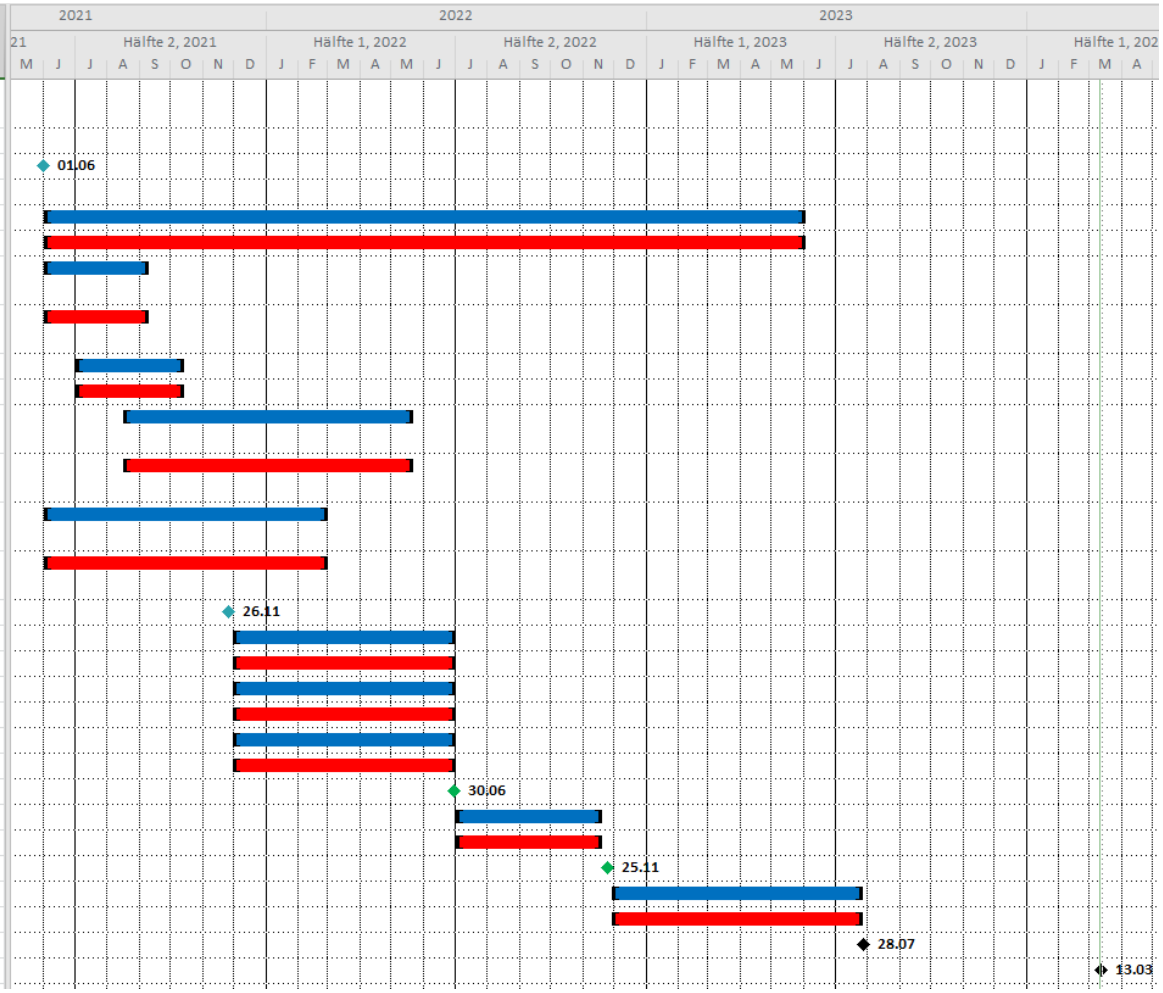
Schedule 03/2024

AIRBUS
DEFENCE AND SPACE

ASP

GANTT-DIAGRAMM

	Vorgangsname	Anfang	Ende
1	**New packaging techniques to increase power density of power control and distribution units**		
2			
3	**Kick off (T0)**	Die 01.06.21	Die 01.06.21
4			
5	WP0000, Task 0: Project Management	Die 01.06.21	Don 01.06.23
6	WP0100, Task 0: Project Management	Die 01.06.21	Don 01.06.23
7	WP1000, Task 1: Mission needs / Thermal Mechanical Constraints	Die 01.06.21	Don 09.09.21
8	WP1100, Task 1: Mission needs / Thermal Mechanical Constraints	Die 01.06.21	Don 09.09.21
9	WP2000, Task 2: Alternative Packaging Solutions	Don 01.07.21	Die 12.10.21
10	WP2100, Task 2: Alternative Packaging Solutions	Don 01.07.21	Die 12.10.21
11	WP3000, Task 3: Selection of Thermal Mechanical Architecture	Mon 16.08.21	Fre 20.05.22
12	WP3100, Task 3: Selection of Thermal Mechanical Architecture	Mon 16.08.21	Fre 20.05.22
13	WP4000, Task 4: Review and Selection of manufacturing technology	Die 01.06.21	Mon 28.02.22
14	WP4100, Task 4: Review and Selection of manufacturing technology	Die 01.06.21	Mon 28.02.22
15	**Definition Review (T0+4m)**	Fre 26.11.21	Fre 26.11.21
16	WP5000, Task 5: EM design	Mon 29.11.21	Don 30.06.22
17	WP5100, Task 5: EM design	Mon 29.11.21	Don 30.06.22
18	WP6000, Task 6: EGSE/MGSE design	Mon 29.11.21	Don 30.06.22
19	WP6100, Task 6: EGSE/MGSE design	Mon 29.11.21	Don 30.06.22
20	WP7000, Task 7: Feasibility Samples/Coupons	Mon 29.11.21	Don 30.06.22
21	WP7100, Task 7: Feasibility Samples/Coupons	Mon 29.11.21	Don 30.06.22
22	**Design Review (T0+10m)**	Don 30.06.22	Don 30.06.22
23	WP8000, Task 8: Manufacturing of EM and GSE	Fre 01.07.22	Fre 18.11.22
24	WP8100, Task 8: Manufacturing of EM and GSE	Fre 01.07.22	Fre 18.11.22
25	**Test Readiness Review (T0+18m)**	Fre 25.11.22	Fre 25.11.22
26	WP9000, Task 9: Test execution	Mon 28.11.22	Mit 26.07.23
27	WP9100, Task 9: Test execution	Mon 28.11.22	Mit 26.07.23
28	**Test Review Board (T0+25m)**	Fre 28.07.23	Fre 28.07.23
29	**Final Review**	Mit 13.03.24	Mit 13.03.24



Delivered Documents for Final Review

- D-23: Final Report.
  - The Final Report shall provide a complete description of all the work done during the activity and shall be self-standing, not requiring to be read in conjunction with reports previously issued. It shall cover the whole scope of the activity, i.e. a comprehensive introduction of the context, a description of the programme of work and report on the activities performed and the main results achieved.

- D-24: Technical Data Package – technical documents are delivered
  - Each (design and development) Contract shall be completed with a Technical Data Package. For a Contract with Phases, the Technical Data Package shall be provided at the end of a Phase in the case that the Agency decides not to proceed with the next Phase. The Technical Data Package consists of the final versions of all approved technical documents, delivered during the execution of the activity.

- D-25: Summary Report.
  - For each (design and development) Contract, one Summary Report shall be produced. It shall summarise the findings of the Contract concisely and, informatively. The Summary Report shall be approximately twenty (20) pages or six thousand (6000) words.

  NOTE: The Agency may request the Contractor to produce the Summary Report in the form of a paper suitable for publishing in a technical journal.

- D-26: Executive Summary Report.
  - The Executive Summary Report shall concisely summarise the findings of the Contract. It shall be suitable for non-experts in the field and should also be appropriate for publication. For this reason, it shall not exceed five (5) pages of text and ten (10) pages in total (one thousand five hundred (1500) to three thousand (3000) words).

Delivered Documents for Final Review

- D-27: Abstract.
  - Each (study) Contract shall also be completed with an Abstract, summarising the work performed. It shall be suitable for application at symposiums or technical journals, normally not exceeding three (3) to four (4) pages of text with colored illustrations or photographs where appropriate.
- Brochure
  - A Brochure is intended for marketing purposes. It shall be concise and it shall include a short description of the work performed and applications of the development, a photograph or functional drawing if applicable, technical fact sheet, estimate of availability (delivery time) and a contact point for marketing purposes. It shall contain one (1) or two (2) pages of text (i.e. up to about seven hundred (700) words).
  - A Brochure using the Website Article Template
  - https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Download_Area
- Photographic Documentation – included in the technical documents/presentations
  - Photographic documentation comprises photographs of hardware under manufacture, showing major progress, as well as of tests and test set-ups. Videos presenting the functioning of hardware/test set-up and relating test activities may also be included in this category.
- D-28: Contract Closure Documentation.
  - The Contract Closure Documentation is a mandatory deliverable, due at the end of the Contract (or at the end of a Phase in case the Agency decides not to proceed with the following Phase). For the avoidance of doubt, “end of the Contract” shall mean the finalisation of a series of tasks as defined in the Statement of Work attached to this Contract. Therefore, work performed under Riders or Contract Change Notices adding new tasks with respect to the original Contract shall require separate Contract Closure Documentation. The contents of the Contract Closure Documentation shall conform to the layout provided in Annex A hereto.
  - Template available

Delivered Documents for Final Review

- NPT Technology Achievement Template

- Final Review by Telecon
  - Location: Telecon
  - Input: Review Data Package definition in line with the list of deliverables
  - Description: to assess the achievement and address further possible developments in the packaging technologies and/or propose further activities to increase the TRL of the selected technology/architecture.
  - Output: final payment and contract closure

- Hardware will stay at ASP. Loan agreement.

Conclusions and the Next Steps

- Were covered R&D, designs, analysis, manufacturability, qualification, and test efforts for achieving a disruptive new thermal control proposition for space avionics
- The Vapor Chamber (VC) technology presented the potential for a considerable product volume/mass reduction for the challenging application of high dissipative SMD elements assembled over a simple PCB board.
- Another advantage of the developed technology is the capability to implement a feasible thermal control for high dissipative hot spots caused by electrical failure.
- The developed technology presented potential for other space avionics products, such as high-power solid-state RF amplifiers (transponders) and high-power processing boards with multiple cores.
- The next steps:
  - Planned performance improvements (as VP base edge double covered)
  - Generating a higher fidelity vapor chamber model based on fluid flow and multi-phase operation,
  - Design validation in a true space mission (getting heritage, increasing the TRL).

Thank you very much

for your cooperation and support in this exciting and challenging project!