FINAL PUBLISHABLE SUMMARY REPORT

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Project acronym: CREAM
Project title: Compact and Reliable Electronic integrated in Actuators and Motors
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1.1. Executive summary

Compact and reliable Electronic integrated in Actuators and Motors

According to specific design procedures and performance analyses undertaken the concept architecture has been decided involving power electronic components of the MCPM inside the same package with control electronics package, the configuration of the overall EMA with particular analysis on thermal phenomena involved, the control algorithms to be implemented have been developed and the materials as well as manufacturing techniques have been determined. In particular, the design and modeling of the motor ensured the concept architecture trade-off analysis and provided the proposed construction and industrial files of the EMA including all materials implementation and manufacturing methodologies to be adopted. Following the final construction files determination the motor kit and mechanisms for prototypes have been finalized and the acceptance tests of the EMA, allowing validating the good manufacturing of the components as well as the complete mechanism tests validated the designed global EMA performance.

1.2. Project context and objectives

1.2.1. Context

The actual political, environmental and economical trends applied to air transport lead to move in the future to the All Electric Aircraft (AEA). The goal of this concept is to eliminate as many hydraulic power sources and complicated circuit of high-pressure hydraulic lines as possible. Moreover the engine which is currently required to produce thrusts, pneumatic power, hydraulic power and electrical power must be redesigned and optimised to produce thrust and predominantly electric power.

Today, it is clear that reliable electric actuators are one of the technical bottlenecks for realizing this ambitious technological vision of all electrical aircrafts. The goal of power by wire (PBW) is to significantly reduce or eliminate altogether the hydraulic connection and its associated risks by providing electrical power straight to the actuators. However the maturity of PBW technology is lagging behind. In fact the real challenge for the implementation of the power-by-wire aircraft is the development of compact, reliable, electrically powered actuators to replace the conventional hydraulic systems allowing the replacement of all electrical hydrostatic actuators by Electro-Mechanical Actuators - EMA (flight control actuators, braking system, landing gear actuators, propulsion inverters, various pumps, various auxiliary actuators).

1.2.2. Objectives

CREAM project objective was to reach new high performance and reliability capabilities of Electro-Mechanical Actuators (EMA) in harsh thermal environmental conditions ready to use in all-electric aircraft.

For this global objective, it was targeted to develop an advanced, smart, miniaturised and reliable electronic technological platform integrating new compact technologies, advanced components and assembly methods able to substantially improve the drive and control electronic modules and the EMA motors in order to:

- Provide high power density and compact characteristics of electronics modules integrated in actuators or motors (reduction by a factor 2 of the electronic volume and mass).
- Provide advanced new concept of thermal management of the electronic platform allowing higher performances and reliability.
- Provide high temperature and compact motor for actuators (reduction of 30% of the motor volume and mass).
- Integrate the new electronic and motor platform in actuator housing and a very severe thermal environment (above 200°C) providing performing thermal management.
- Provide validation of aeronautic reliability in high temperature at least at the same level than existing hydraulic systems (50.000 hours), and even better (100,000 hours) with health monitoring functionality.

1.2.3. Organisation

CREAM proposed an ambitious technological research program allowing to develop and validate a number of various emerging sub-components, packaging and motor technologies and to integrate them to a high performance smart electronic and motor technological platform destined to electric actuator preparation. The project was divided in 4 technical Work Package (WP).

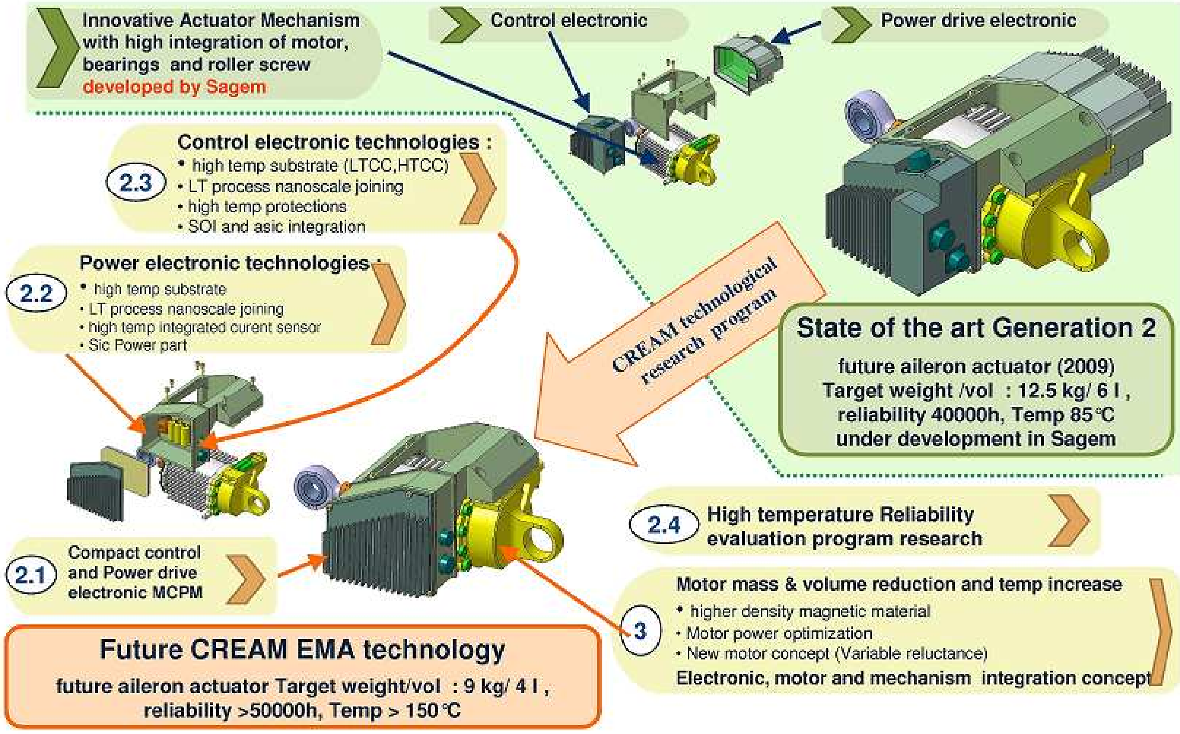


Figure 1 : CREAM technology applied to flight control actuator and developments in the different WP

- **WP1 (Specifications)** was oriented to the better understanding of the harsh environment and the complex validation plan to ensure the best implementation of the new actuator in aircrafts.
- **WP2 (Multi-Chip Power Module, MCPM Design)** was the core development of the CREAM project and led to the creation of the new electronic part of the actuator. This workpackage was divided in 4 sub-workpackages.
- WP2.1 refered to the technical coordination of this activity and all developments of the MCPM global packaging (electronic interface, global packaging and integrations between modules).
- WP2.2 refered to the development of a new power module for the actuator including power components interface with the control module and the compact high temperature power packaging.
- WP2.3 developed another electronic module dedicated to the control of the actuator for high temperature applications.
- WP2.4 dealt with the reliability of the electronic devices developed, including all assembling technologies and reliability of the modules integration.
- **WP3 (Actuator Global Integration)** was dedicated to the development of a new motor for this generation of actuator. New technologies, as new magnetic materials or new motor control method, were evaluated to improve the actuator.

- **WP4 (Technological platform validation)** aimed at validating the new actuator to perform the Technological Readiness Level expected.
- **WP0 and WP5** dealt with project management and dissemination, exploitation and standardisation aspects.

1.3. Main S&T results/foregrounds

The project is balanced between two main activities: technological research aiming at assessing and selecting technologies suited to CREAM constraints and development of a demonstrator embedding the selected technologies.

The first year of the project was dedicated to the identification of the end-user application for the CREAM technological platform (D1.2), a trade-off on the requirements applicable to this platform (D1.1), the definition of the technological plan for the project (D1.3), the definition of the validation plan of the technological platform (D1.4), the architecture of the demonstrator (D3.1) and the architecture of the MCPM (D2.1.1).
Planned deliverables within this first year have been delivered.

Based on these outputs, the second year was dedicated to the evaluation of technologies in each workpackage and to the detailed studies and breadboarding of all functions**.** Reliability bases have been increased, thanks to all technological test vehicles that were built and tested at extended temperature ranges. A major decision point (DMP2) was held and allowed to select the best candidate technologies for the demonstrator. Prototypes were designed, built and successfully tested for all critical functions of MCPM and the motor, thus securing all bases for detailed design activities.

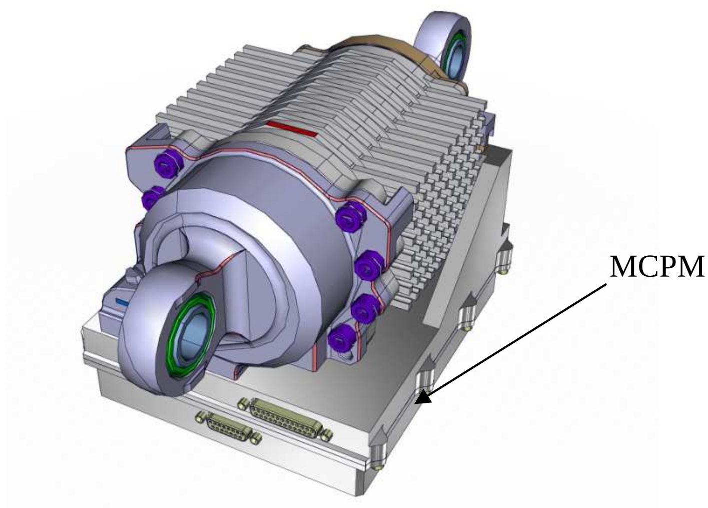


Figure 2 : CREAM EMA

The third year was dedicated to detailed design activities of the major components and boards, up to the elaboration of industrial files and the procurement of all parts for the final MCPM

demonstrators. Test bench architecture were also been refined and frozen, permitting the development activities of all test tools for final activities.
All necessary outputs were elaborated and delivered and detailed organization of partners for the manufacturing of final demonstrators was set up, taking into account the definition of hardware outputs and manufacturing requirements for all parts and subassemblies. Assessment of the difficulties associated to the new technologies and processes and solving the issues of the final mixing was a major activity.
All the subparts of the EMA were manufactured, tested and made available for integration in the final MCPM demonstrators. Most technologies selected during the design were specifically evaluated in complement of the technological planned activities.
All parts were integrated, glued, bonded and interconnected into the MCPM foreseen demonstration models (4 fully assembled MPCM have been manufactured and tested; an additional partial model was also manufactured).
The CREAM harsh environment dedicated test bench was developed, assembled, tested, integrated with MCPM so as to verify and tune all hardware and software items.
A test campaign allowing stressing all implemented technologies and high temperature specifically selected or developed parts was started and completed. Due to the tight schedule constraints, the campaign was restricted to major tests that were foreseen.

1.3.1. WP1 : Leader : UAC

The application selected for the technological platform is an **EMA for flight control application** (aileron) with additional environmental constraints to remain in line with the high temperature objective of this project. (D1.1 and D1.2).
The first tasks included an analysis of all high level requirements applicable to an actuator in harsh environment (D1.1) and elaboration of subassemblies target specifications (D1.2). These were the reference specifications for the EMA development tasks (WP2 and WP3).
The construction of the technological roadmap of the project (D1.3) was a major objective of the first project period. Technologies to be evaluated were selected accordingly with the requirements analysis on the EMA and its sub-assemblies.
Milestone DMP1(Decision Making Point #1) took place in April 2010: the technological plan of the project was set-up.
Milestone DMP2 took place in September 2011: the technologies selected in DMP1 to be investigated were evaluated in the Work packages 2 and 3 and the most appropriate of them were selected to be integrated into the CREAM final demonstrator.
From the system requirements on the demonstrator in D1.2, a validation plan of the technological platform was defined (D1.4).

1.3.2. WP2: Electronics

The architecture of the MCPM was set (D2.1.1). Several problems impacting the feasibility of the MCPM as defined in the DOW were identified and solved one by one. The design of the subassemblies of the MCPM was done as well. The design of the power electronics (D2.2.1) and of the control electronics (D2.3.1) has been completed. Breadboards were developed, manufactured and successfully tested for critical functions.
Technological research activities improved the consistency and completeness of reliability data bases. They delivered useful inputs for technological choices (DMP2).

The design of the critical parts of these modules has then been frozen in order to secure the global schedule of the project. The CPU was designed, simulated and developed. Test vehicles were manufactured with initially selected technology. Due to cost issues and unavailability of critical compiling tools, another high temperature compliant technology was finally selected for the CPU development and wafers were manufactured. Successive test boards were developed for CPU testing. CPU test campaign at ambient temperature ended successfully with the validation of all CPU functionalities.

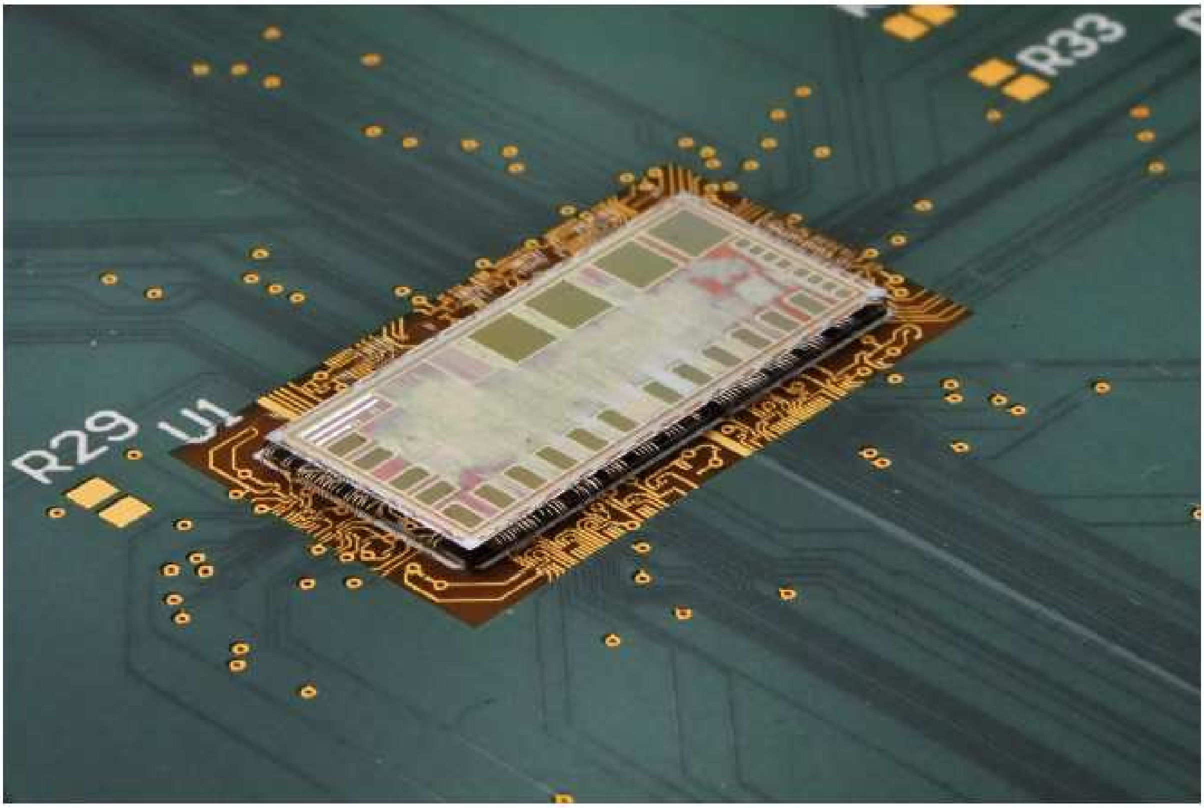


Figure 3 : High Temperature compliant CPU

All detailed studies were completed for all functions, development activities for all MCPM parts, subassemblies, mechanical parts and frames have been completed also and industrial manufacturing files including layouts for all assemblies and modules have been finalized. MCPM architecture was broken down into all necessary physical parts. List of materials were consolidated and part procurement done (electronics parts, baseplate and other items). An important issue was associated to the careful checking of the compatibility for all technologies foreseen to be finally integrated and mixed in the final demonstrator and to the finalization of associated mounting processes, from the individual parts up to the demonstrator with its mechanical frame.

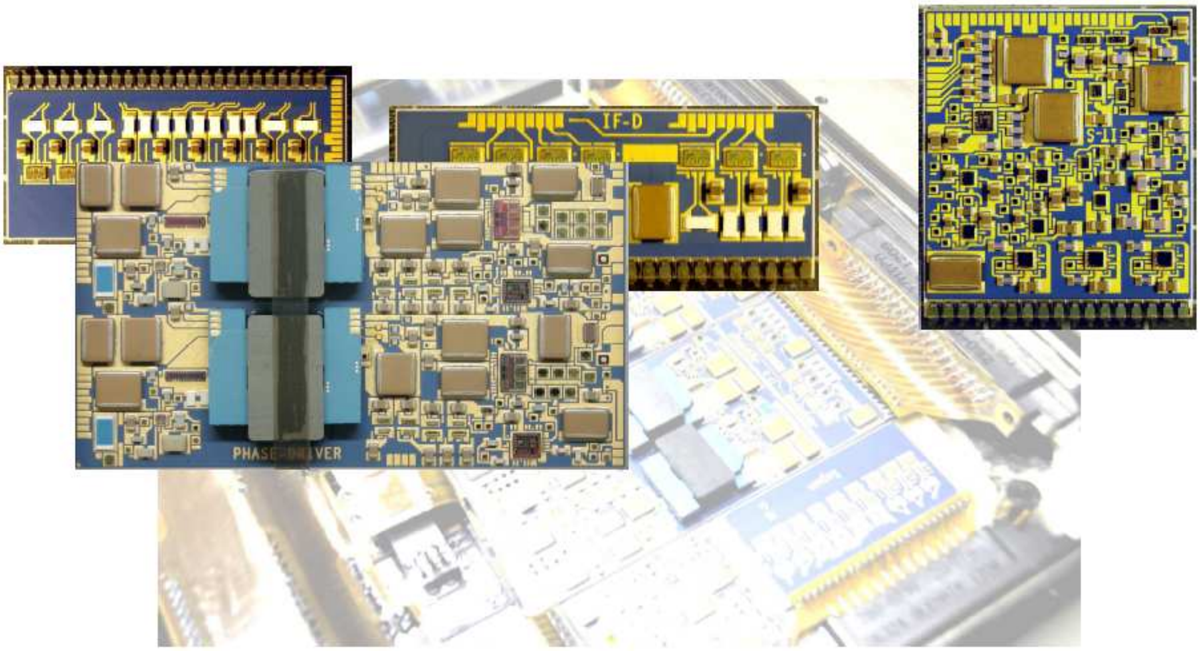


Figure 4 : MCPM subassemblies

A dedicated organization was set between partners so as to enable a smooth integration of the MCPM. The integration of the main subparts of the MCPM has been successfully carried out. **Thanks to high manufacturing yields that were obtained, 4 full MCPM units have been manufactured**. One additional partial MCPM was also manufactured with available parts, dedicated to testing.

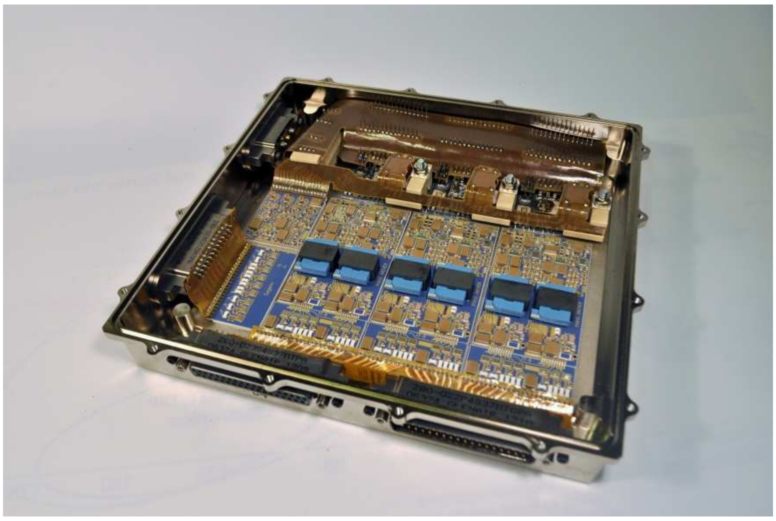


Figure 5 : MCPM (demonstrator)

1.3.3. WP2.1 : MCPM Global conception and coordination Leader HISPANO-SUIZA

Based on the (D1.2) EMA requirements, a functional declination to MCPM level was made to build the MCPM architecture (D2.1.1). This architecture choice was made in accordance with partner technological program and planned contributions and their abilities to provide it with a reasonable confidence level.

Then, volume allocation, area shape, interconnections and assembly process were defined according to several constraints;

- the MCPM architecture (D2.1) that describes signals exchanges between all subassembly and MCPM environment,
- the technological and research program and recommendation guide (D2.1.2) that allowed to select the best technologies candidates according to EMA target (D1.2) and research program (D1.3),
- The design of the power electronics (D2.2.1) with both its flux-gate current sensor (D2.2.3) and its copper diamond metal substrate (D2.2.4) and the power module interface with electronic (T2.2.2).
- the electrical architecture and design of the control function (D2.3.1) that is also based on the research activities on the core processor, the SOI driver, .
- and some evolutions that comes during the geometrical integration to come to a MCPM design (T2.13).

Then, the MCPM architecture was broken down into all necessary physical parts. During this integration process, several problems impacting the feasibility of the MCPM as defined in the DOW were revealed and solved one by one. Nevertheless, delay on the MCPM manufacturing D2.1.3 proved that this task was more difficult than expected and required additional process investigations on dedicated vehicle tests to success.

The main issues were;

- The ability for the EPLF-LPM to produce the whole control function. Then, SAGEM took in charge the production of the MCM and the EPFL-LPM reduced its contribution to power supply part and test tools to solve some test means issues on the high temperature core research activities leaded by EPFL-LSM and AS.
- Due to critical control device procurement unavailability, the control function firstly electrically designed in the (D2.3.1) was reworked and an external control module has been designed and the high temperature communications links was developed and finalized. Then the architecture defined in the (D2.1.1) changed; the MCM control to driver and control to MCPM was changed as well.

The CPU was designed, simulated and developed. Due to cost issues and unavailability of critical compiling tools, another high temperature compliant technology was finally selected for the CPU development and wafers were manufactured.

Technological research activities improved the consistency and completeness of reliability data bases. They delivered useful inputs for technological choices. After a budgetary checking and an evaluation of the potential risk to fail to procure any material, a technology selection has been made that fits technological recommendations issued from DMP2.

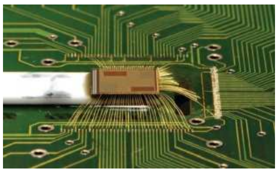


Figure 6 : CPU test chip

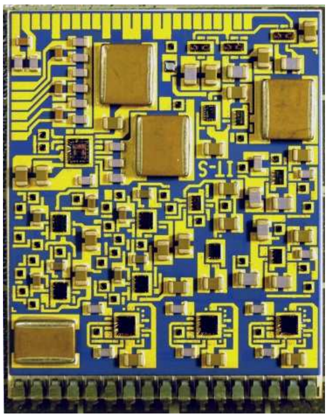


Figure 7 : Driver board

All detailed studies were completed for all functions, development activities for all MCPM parts, subassemblies, mechanical parts and frames were completed also and industrial manufacturing files including layouts for all assemblies and modules were finalized. List of materials was consolidated and part procurement done (electronics parts, baseplate and other items). An important issue was associated to the careful checking of the compatibility for all technologies foreseen to be finally integrated and mixed in the final demonstrator and to the finalization of associated mounting processes, from the individual parts up to the demonstrator with its mechanical frame.

The integration of the main subparts of the MCPM was completed. A thermal simulation model and analysis was performed and delivered (D2.1.4). Assembly of the MCPM prototypes was also completed. The manufactured MCPM was visually and electrically inspected and validated and the MCPM prototype caracterisation and test results were delivered (D2.1.5).

Figure 8 : Top and bottom views of one the functionnal MCPM manufactured in WP2.1 and delivered to technological validation test campaign (WP4)

1.3.4. WP2.2 : Leader FRAUNHOFER IISB

In this work package the main focus was set to the power part of the MCPM. The goal was to design and realize all parts necessary for the power transmission to the EMA. Several general thermal and electrical conditions like ambient temperature and maximum temperatures or transmitted current in the area of the power parts were given by the overall requirements of the MCPM. This work package was strongly interrelated with the work packages WP2.1 and WP2.3. The overall design matching was an important point of several iterations which were needed to optimize the whole MCPM.
Based on the WP2.1 MCPM architecture and design specification (D2.1.1) that describes electrical interfaces and preliminary assembly principles and geometrical constraints, a power module specification was emitted (D2.2.1) to develop a power module based on wide bandgap devices. From the PM specification (D2.2.1) and the results of the technological investigations (D2.4.1), a collaborative works with all partners directly involved in the MCPM design allowed to refine the PM design constraints.

The first step in the task list of this work package was to define an electrical layout of the power module. The layout was permanently improved and had to undergo several iterations until it was finalized. This part of the work was performed by the two partners Semelab and HISP.

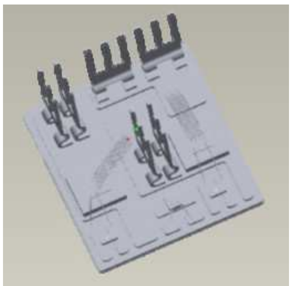


Figure 9 power module

The second task, which was started parallel to the first one, was investigations on various materials for the realization of the MCPM.
For the design of the power module, test vehicles were manufactured with initially selected technology. Research works on metal diamond substrate (D2.2.4) led to the development of dedicated samples to be integrated into the power module design. Technological research on attachments (D2.2.2) allowed to select appropriate assembly technological choice to reach a reliable PM assembly. Technological research on the flux-gate current sensor (D2.2.3) led to the design and the integration of a miniturized sensor. The main issue was then to procure unusual parts size, finishing and to develop new process to manufacture the PM in the remaining time and budget according to the DMP2 choices.
Materials for isolated substrates like Copper, Aluminium, Aluminium oxide or silicon-nitride were under investigation. Also special materials for baseplates like AlSiC were also checked for usefulness in this project. On the other side several materials for attaching the components and for the component subassembly were tested for their usability in the high temperature application. This includes silicone based glues and encapsulation materials. The test methods were for example active power cycling, passive temperature swings, sheer tests and hot storage tests according to general standards. The materials were tested and compared to each

other under a wide temperature range (-55 to 300°C). This was made so as to be able to choose the best combination of materials in order to meet the requirements of high temperature electronics. Common and new die attach technologies were also a huge part of the investigations on lifetime and reliability, therefore this work was mainly performed in work package 2.4.

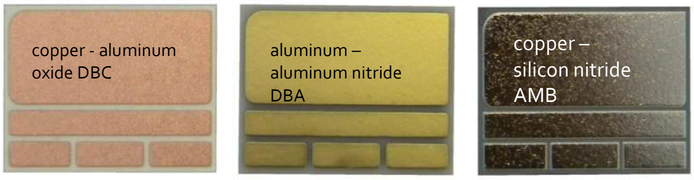


Figure 10 substrates with differnt ceramic and metalisation

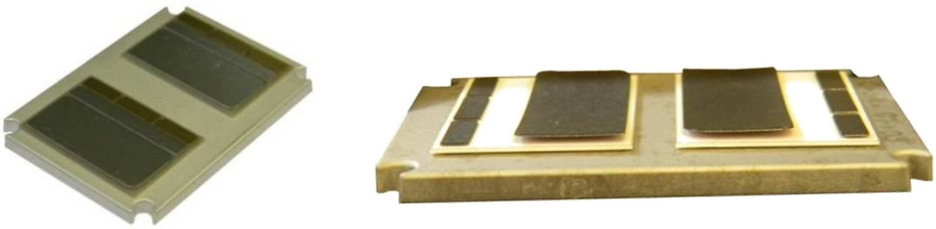


Figure 11 AlSiC baseplate before and after passive temperature swings

From the beginning of the project a special part was dedicated to the idea of using an optimized and customized heat spreader made out of a copper diamond matrix. This heat spreader was used to improve the heat dissipation of the silicon dies when they are heated up by the load current. This technology was provided by the company RHP. They also manufactured the required amount of parts.

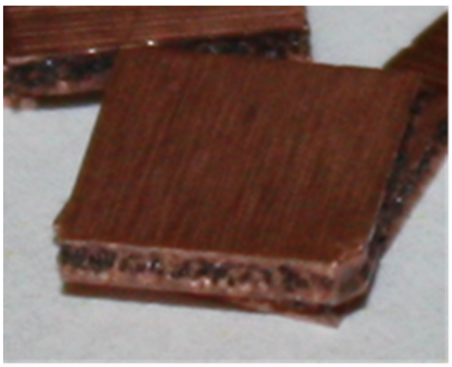


Figure 12 copper diamod heat spreader

An important part of the design and of the power part was to be able to measure the current with is controlled by the power part. Because of the focus on high temperature application, a customized current sensor had to be developed by the company LEM. They also took care in the work package for the design and procurement of the Flex pcbs which were needed to for transmitting the energy. Because of the high energy density and the high temperatures standard solution available on the market were not suitable for this application.

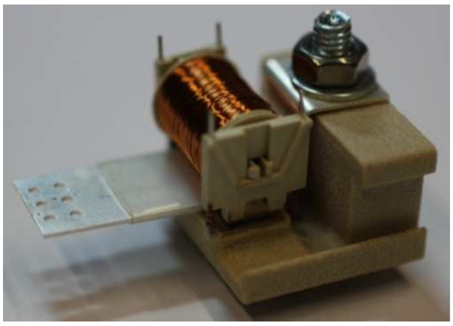


Figure 13 current sensor for high temperature application

Integration of the PM with MCM and filtering sub-assemblies to fit the MCPM integration targets (T2.1.3) required a dedicated organization between all involved partners so as to solve all new issues at the various integration steps.

The final subassembly of the power part was performed by the Fraunhofer IISB. In the first step, the power modules were soldered to the baseplate for the MCPM by Semelab, which was also responsible for the manufacturing of the power modules. In a second step, further components for the power part were glued to the baseplate. The third step was the connection of the power parts the drivers of the power modules. The last step in the power part sub assembly was the connection of the flex pcb to all relevant components of the power part.

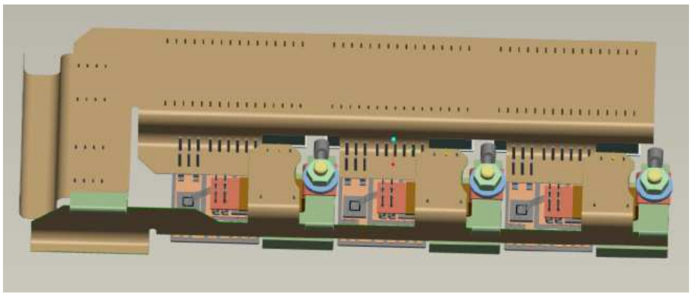


Figure 14 power part subassembly

The power part was successfully integrated into the MCPM. This work was also performed by the Fraunhofer IISB.

1.3.5. WP2.3 : Leader EPFL

Task 2.3.1

In WP2.3, the high temperature technological research on the driver and core processing were initiated through coordination meetings to ensure consistency between WP2.3 research work and the WP2.1 MCPM development targets.
For the high temperature core (D2.3.2), a detailed specification was drawn up according to partner knowledge on EMA control and to adjust the requirements to the necessary need for a high temperature demonstrator.
For the high temperature driver, a collaborative work was set to merge the SOI design knowledge and wide bandgap drivers experience to specify the requirements of the dies for development.

Then, design of the critical parts of these modules was frozen in order to secure the global schedule of the project. It was possible to establish the D2.3.1 MCM specification and to begin the design in accordance with the D2.1 MCPM specification and WP2.3 research works. A first MCM design was emitted (D2.3.1).

To secure the design, several breadboards were produced and tested on critical functions like the driver and its power supplies; they were developed, manufactured and successfully tested. It allowed some necessary modifications that were implemented on MCM to be identified.

An issue came from cost and complexity of the initial design that exceeded EPFL-LPM budget and manufacturing abilities. Then a rework on schematics was done using newly available components and recent knowledge on wide bandgap semiconductor behaviour. Despite this work that have delayed the MCM conception, the design still exceeded the EPFL-LPM abilities and this activity was transferred to SAGEM.

A second issue was the cost and the minimum of quantity of the component procurement that exceeded expectations. To limit this overcost, the number of MCPM component procurement was reduced from 10 to 5 and an assembly process was investigated to increase manufacturing yield. Those actions also contributed to the MCPM end of manufacturing delay.

Task 2.3.2

The AS3222 SoC is used for control systems applications, such as motor control in high-temperature environment (225°C). It is a 32-bit core processor based on the AMBA system that includes peripherals such as On Chip Memories (SRAM, ROM and Cache), Serial Interfaces (UART and SPI), Watchdog Timer, Reset and Clock Managers:

- Designed for 100 MHz operation @ 225°C:
  - Alternative frequency/temperature operation: 25 MHz @ 225°C.
  - Alternative frequency/temperature operation: 100 MHz @ 25°C.
- 32-bit PowerPC Core (e200z6 Architecture).
- Bus Interface Unit (AMBA 2.0 v6).
- Embedded Memory (RAM and ROM):
  - 64KB RAM
  - 64KB ROM
- External Memory Interface – Parallel Bus Port.
- Memory Management Unit.
- 32 KB Cache Memory:
  - Parity bit detection security feature
- Four SPI Interfaces.
- Two RS232 SCI Interfaces.
- Sixteen bits GPIO for test purpose:
  - 8bits Input
  - 8bits Output
- Reset Manager.
- Clock Manager including configurable clock divider.
- Two External Interrupt Sources for PWM and VIT
- JTAG Debug Interface (Nexus 3):
  - PowerTRACE II programmer/debugger compliant.

  - Mictor connector compliant.
- Voltage levels LVTTL compliant (3.3V)
- Output clock drive compliant to the Actel APA1000 clock specifications.
- No SEU correction support

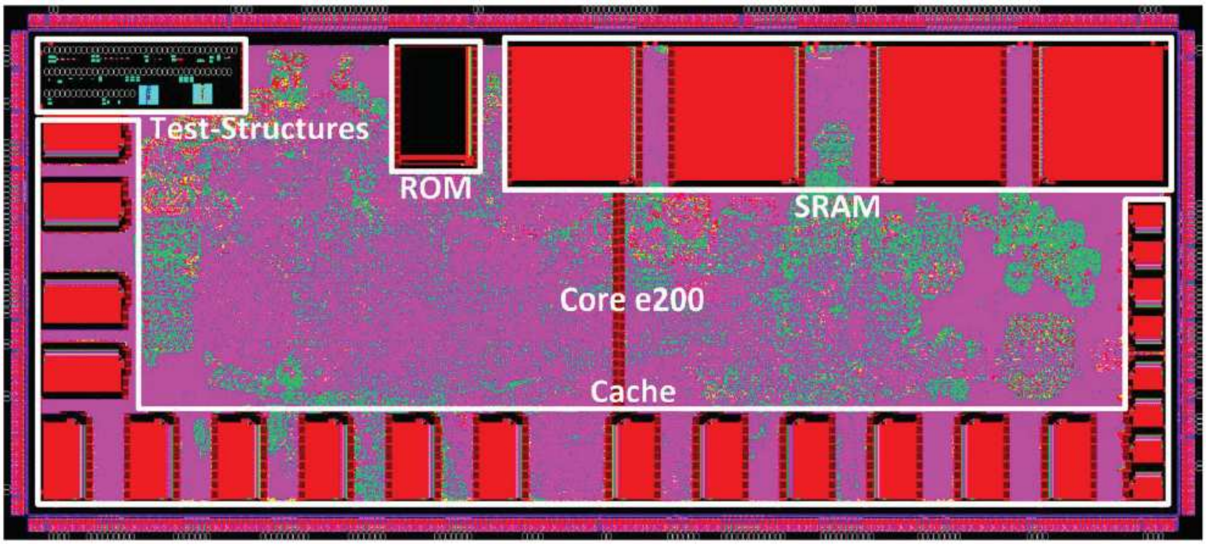


Figure 15 : H.T. CPU Layout

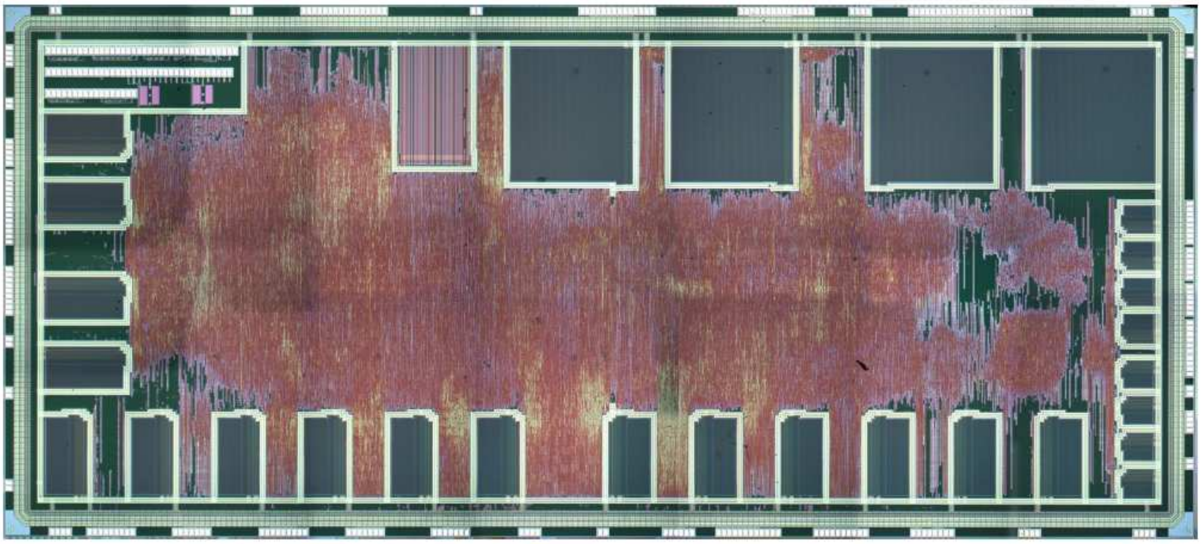


Figure 16: H.T. CPU Micrograph

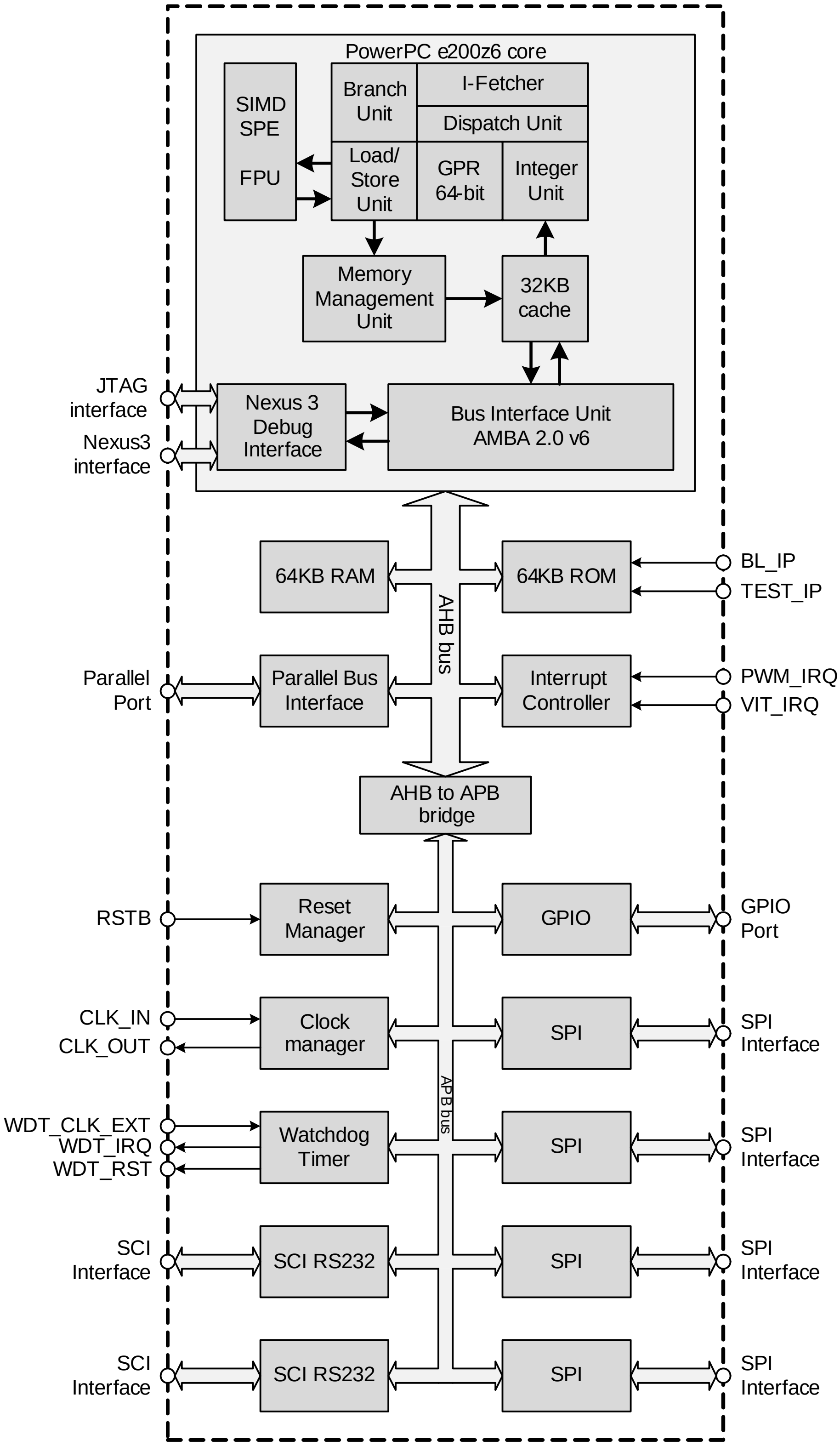


Figure 17 : CPU functional diagram

The AS3222 SoC was fabricated in Bulk process and the CPU was able to operate easily at 200°C. The AS3222 was designed to operate at 38MHz clock at 175°C. It was capable to operate at 43MHz clock at room temperature and, by the furthest test point, at 33MHz at 200°C.

Task 2.3.3

The goal of T2.3.3 was to select, develop and characterise the technologies needed for the fabrication of the logic and driver functions of the CREAM electromechanical actuator (EMA). Below is a schematic of control loop of the CREAM EMA showing the various modules. The logic module can be considered the “brain” of the EMA processing the data from the resolver and calculating the required inputs for the motor and as such it consists of many complex digital logic devices with their own peculiar packaging requirements.

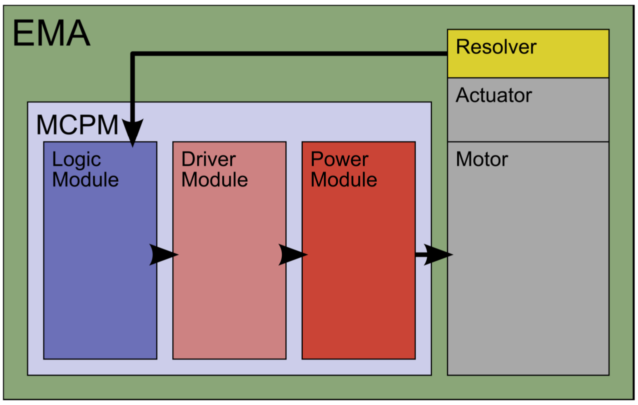


Figure 18 : Overall EMA architecture (functional schematic of the control loop)

As the operating temperatures for the CREAM EMA exceeded the limits of every day printed circuit boards and electronic components alternative technologies were evaluated, including ceramic substrates for the circuits, high temperature epoxies and silicones for attaching components, high temperature solders and wirebonding technologies for interconnects.

Of the substrate technologies available, Low-Temperature Co-fired Ceramic (LTCC) was selected for study. This technology can be used for making compact multilayer circuits and is commonly used in mobile phones. Its other advantages are that it remains stable at temperatures up to and above 200°C and that passive components can be integrated directly into the substrate to make the final assembly more compact. Various forms of LTCC were tested to see which type was better suited to the requirements of the CREAM EMA and also integrated resistors were evaluated to determine if this technology could be used. It was found that a particular form of LTCC was suited to the large circuits required by the logic module as it remained stable during processing. Also, it was found that the integrated passive components did not have the required precision for use in the electronics for the EMA.

As high electrical conductivity was a requirement for the assembly of the discrete components high temperature solders were tested as apposed to conductive adhesives. The solders tested both performed equally well after high temperature storage and temperature cycling. However the high lead solder appeared to cause less stress on the component and as such would make a better solution than the lead free solder.

Epoxy was used successfully as a die attach technology for decades and is widely used in aerospace applications. Its chemical stability, flexibility and excellent bond strength ensure a reliable bond in harsh conditions over a long period of time as shown with the two epoxies evaluated in this report. Both a electrically conductive and non-conductive solder were tested and were able to withstand temperature cycling with no measurable degradation and could survive at 210°C for a long period of time.

The high temperature dies have wire bond pads that are composed of mainly aluminium which eliminates the used of gold wires due to the incompatibility of gold and aluminium at high temperatures. Alumium wires were tested as this ensured the maximum compatibility with the die bond pad. Of the pad metallisations tested both the silver, silver-palladium and the gold platinum-palladium performed well. However as silver presents a risk at high temperatures as it oxidizes, a silver free pad metallisation was recommended.

Although it was not possible to manufacture the logic module of the CREAM EMA due to technical and budgetary constraints described above. The research in T2.3.3 provided enough data to select suitable packaging technology for the logic module. In addition to this, some the technology research was used to design and manufacture the compact and high temperature capable transformers used in the CREAM EMA driver modules (shown below).

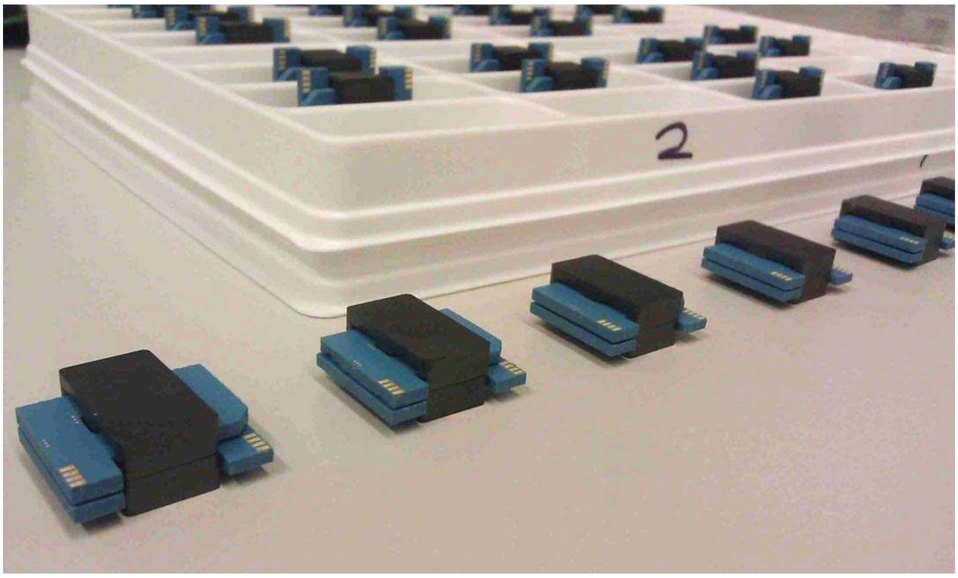


Figure 19 : Transformers (for MCPM control functions)

1.3.6. WP 2.4 : Leader FRAUNHOFER IISB

In this work package, the focus was set to evaluate die attach materials. Active Power Cycling tests were performed to evaluate different empirical and physical lifetime models for power electronic assemblies and to generate a reliability database.
At Power Cycling the Divices Under Test (DUTs) are thermo-mechanical loaded with temperature swings achived by current feeding and cooling. With enough current the top temperature $T_{DUT,top}$ is reach, which simulates the real stress of the devices in it’s application. By mounting the devices on a cooling board, the bottom temperature limit $T_{DUT,bot}$ is specified. The top limit is reached by a constant current load. A complete cycle consists of a heating phase and a cooling phase.

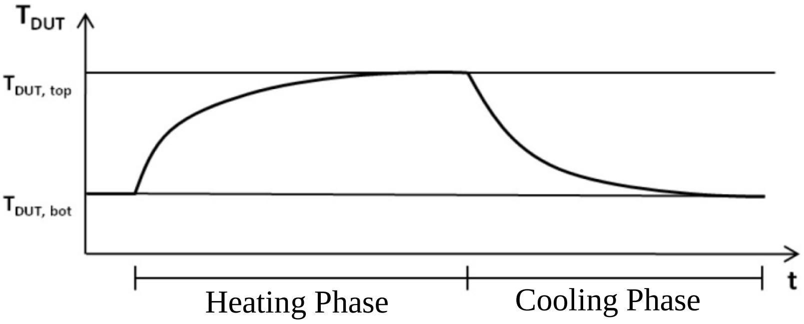


Figure 20 : Cycling profiles

Figure 21: Temperature course of the devices

In its latest version 3.0, the Power Cycling Test (PCT3) setup at Fraunhofer IISB consists of an energy input with "machinery off", a power supply, a computer and a measurement data capture, a chamber for the devices under test (DUTs) for upto 20 DUTs and a tempering unit.

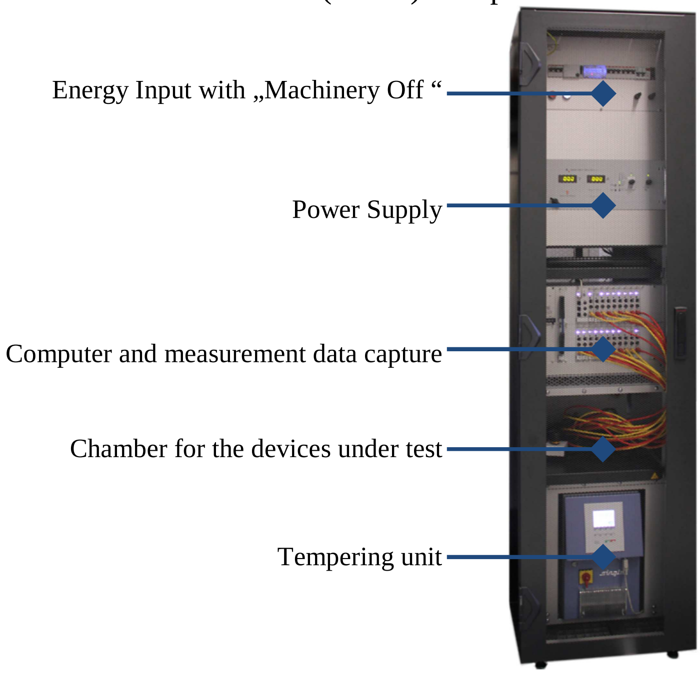


Figure 22: Power Cycling Test System (PCT) 3

The following table shows the experimental powercycling runs in addiction to the bondings and test conditions.

Table 1: Tested packagings and conditions for power cycling

ΔT	**T_{min}**	**Bonding Die-Bottom**	**Bonding Die-Top**	**Substrate**
130	40	Silver-Sinter	Wire-Bonds	Al2O3
130	40	Silver-Sinter	Wire-Bonds	AlN
150	40	Silver-Sinter	Wire-Bonds	Al2O3
130	40	Silver-Sinter	Sintered Silver-Ribbon	AlN (DAB)
130	40	Solder (Au88Ge12)	Wire-Bonds	Al2O3
130	40	Solder (Pb95Sn5)	Wire-Bonds	Al2O3
150	40	Silver-Sinter	Wire-Bonds	Al2O3
150	40	Silver-Sinter	Wire-Bonds	AlN
130	80	Silver-Sinter	Wire-Bonds	Al2O3

ΔT	T_{min}	Bonding Die-Bottom	Bonding Die-Top	Substrate
130	80	Silver-Sinter	Wire-Bonds	AlN

For a temperature swing of 130 K, the packaging results of the Power Cycling Test are compared in the following figure.

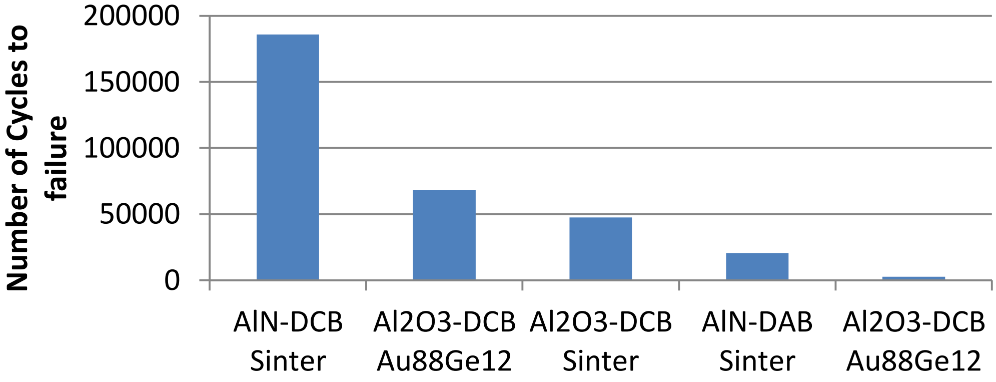


Figure 23: Power Cycling Results for sintered and soldered DUTs which were power cycled at ΔT = 130 K and T_{min} = 40 °C

The Aluminium-Nitride-Ceramic with DCB showed the best results. At an temperature swing of 150 K, the behavoiur is the same, like depicted in the following figure.

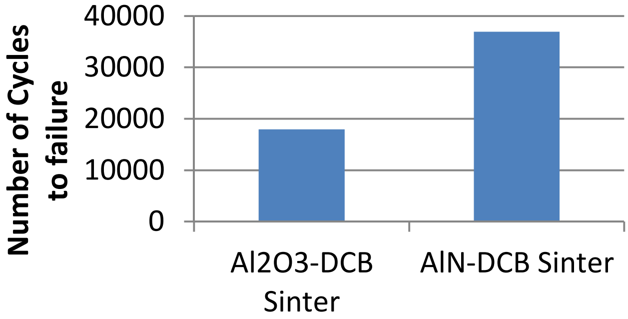


Figure 24: Power Cycling Results for sintered and soldered DUTs which were power cycled at ΔT = 130 K and T_{min} = 40 °C

Empirical models (LESIT and the CIPS2008) describe the dependence of lifetime (number of cycles in powercycling test) on the mission profile parameters (e.g. junction temperature, dwell time, frequence of temperature swing, etc).
Physical models (Shir Knörr and Suhir Energy) describe the dependence of lifetime on the failure and deformation mechanisms.
A comparision of all tested lifetime models for Al_2O_3- and AlN-DCBs and sintered dies can be seen in the following figures.

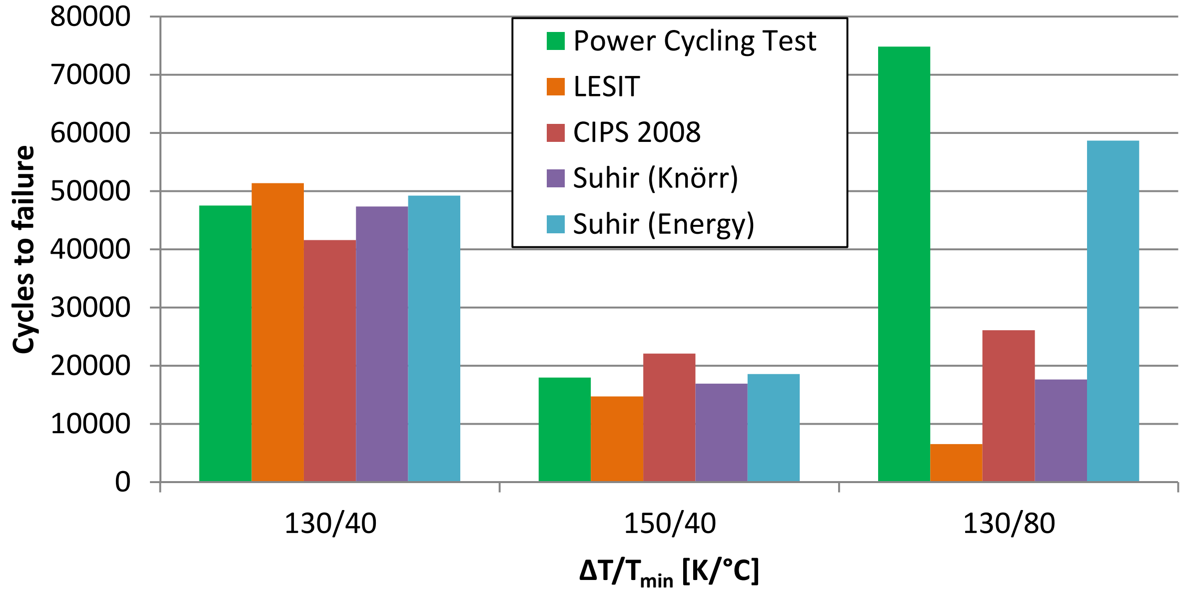


Figure 25: Comparison ot the all tested lifetime models for Al_2O_3

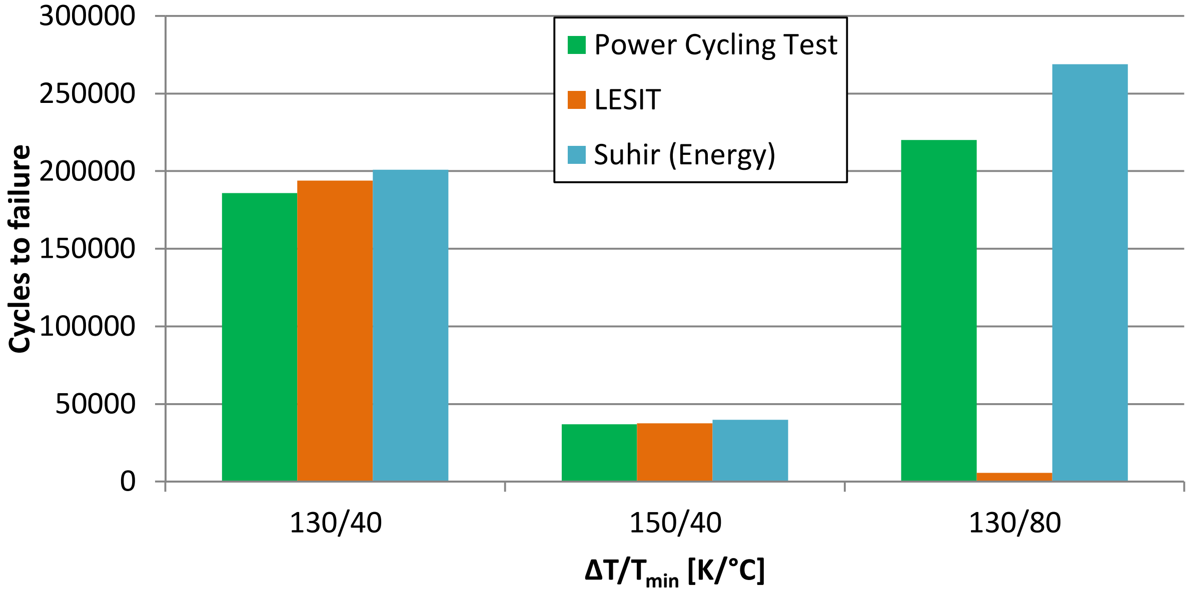


Figure 26: Comparison ot the all tested lifetime models for AlN

The empirical approch has a very limited application for the power cycling lifetime at various cooling temperature, while one of the physical models can predict the correct range of number of cycles to failure. But especially the higher lifetime at higher cooling temperatures can not explained by the models, which makes further research neccassary. In addition to that the different power cycling tests consisted only of one run each, which have to approved by retests.

1.3.7. WP3: Motor : Leader TEIP

Independently from paper analysis and simulations under finalisation on an optimised global architecture according to several criteria (D3.1), it was agreed that the demonstrator will be an assembly of two blocks integrated together: a mechanical block containing the actuator (linear roller screw), the motor, some sensors and other mechanical interfacing mechanical components and a physical block (optimized in volume, weight, reliability etc.) containing the MCPM.

Figure 27 CREAM Motor

Figure 28 MCPM Housing

A first prototype of the motor was built and delivered promising results. Thermal analyses and simulations were carried out. A second prototype with improved insulation and thermal performances was developed and successfully tested. A third prototype was also manufactured and acceptance tested. (D3.4).
Studies for optimization of control algorithms were carried out.
The mechanical parts of interface between the MCPM (electronics) and the actuator were designed and manufactured and finally delivered for MCPM manufacturing.

Based on the existing technological roadmaps available, an analysis of alternative materials to be implemented (permanent magnet, soft ferromagnetic, conducting, insulating materials) as well as topologies on Permanent Magnet (PM) machine technologies applicable to the CREAM technological platform was performed.

Technical specifications, concerning both topological and spatial limitations, were taken into consideration. The main available motor topologies satisfying these requirements were examined. Each configuration was investigated and its advantages and drawbacks were studied. The main focus was oriented to special performance, efficiency and reliability issues of the CREAM technological platform.

As the adopted technological platform asks for high power density-high efficiency actuator designs under heavy thermal environment, thermal robustness and efficiency of the motor had to be secured by introducing state of the art magnetic materials.

The final selection of the proposed stator lamination is a trade of between efficiency, mechanical behaviour and commercial availability. Additional thermal stresses were taken into consideration in order to select the best compromise presenting good efficiency levels (including switching frequency losses components) and allowing for a stable enough stator tooth manufacturing.

In addition the selection of the proposed permanent magnet material was the object of a trade of between efficiency, thermal stability and mechanical behaviour. To that respect high grade

NdFeB alloys reached a maximum working temperature of 240°C. NdFeB thermal performance seemed to grow more rapidly than that of SmCo. Following a detailed analysis by 3D FEM modelling and experimental validation in a particular magnetic circuit tested in a chamber with controllable temperature SmCo permanent magnet alloy was adopted for the motor due to its better safety margins to over-temperature technological platform requirements.

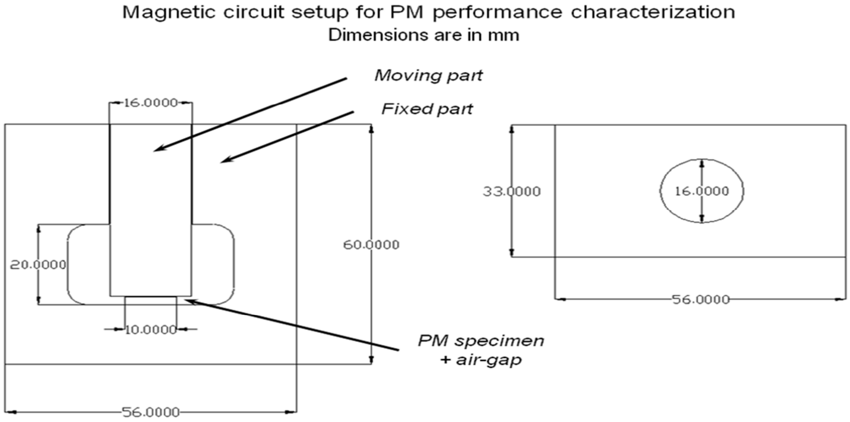


Figure 29 : Magnetic circuit with variable air-gap that was used for PM material characteristics variation measurement with temperature (dimensions in mm)

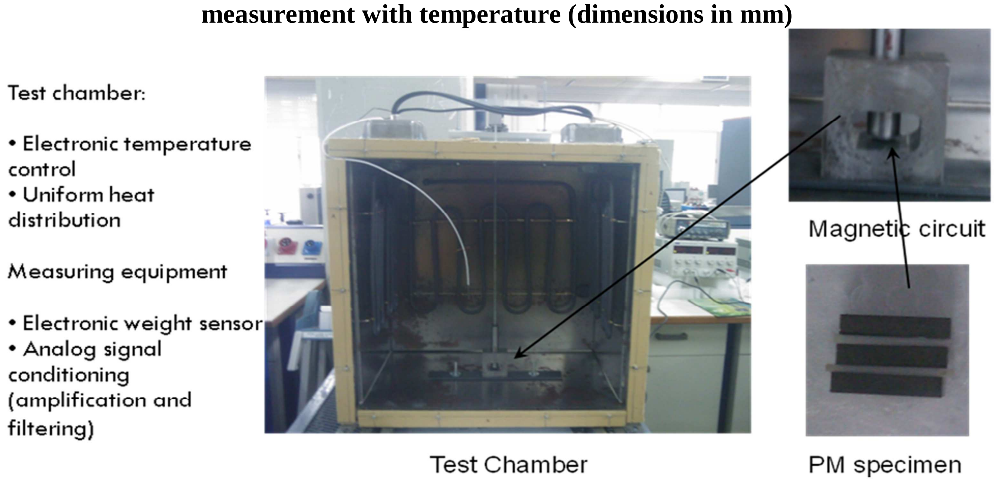


Figure 30 : Test chamber with controllable temperature including the magnetic circuit, the permanent magnet specimen as well as the testing - measuring equipment.

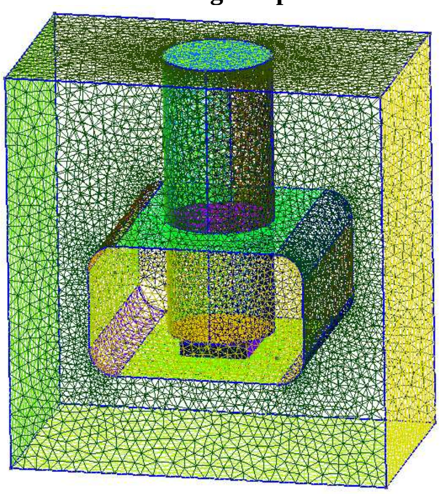


Figure 31 : Geometry and 3D finite element mesh of the modeled magnetic circuit.

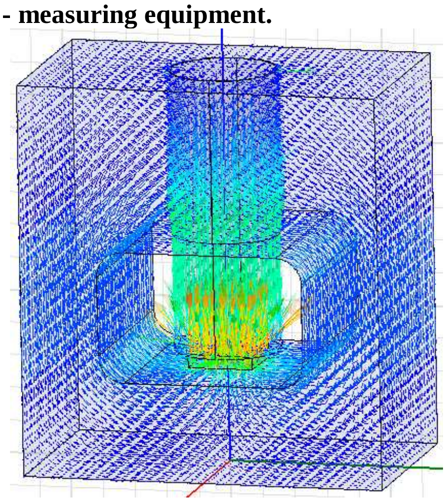


Figure 32 : Magnetic field distribution calculated by the 3D finite element model

The final selection of the proposed stator lamination is a trade of between efficiency, mechanical behaviour and commercial availability. Additional thermal stresses were taken into consideration. Particular iron laminations selected enable achieving the best compromise as its design delivers good efficiency levels (including switching frequency losses components) and allows for a stable enough stator tooth manufacturing.

The research conducted regarding the insulating materials of the actuator illustrated that the materials that were examined to withstand up to 300 ^{o}C are mainly mica based components. The final selection of the proposed insulation material constitutes a trade-off between thermal behaviour, commercial availability and space restrictions in the machine slots.

For construction of the windings specially enamelled with aromatic Polyimide round copper wires have been selected.

Concerning the motor winding arrangements particular configurations of Fractional Slot Concentrated Windings were examined due to the advantages of low cogging torque, short end turns, high slot fill factor, as well as fault tolerance and flux-weakening capabilities.

The preliminary design of the motor structure has been achieved by considering classical machine design techniques. Although such analytical approaches do not enable detailed design optimisation, due to the approximate electromagnetic field representation, they deliver a sub-optimum set of design variables, within a region of the global optimum. Such an approach enables, in a next step, the use of fast and robust local optimisers linked with a detailed finite element model.

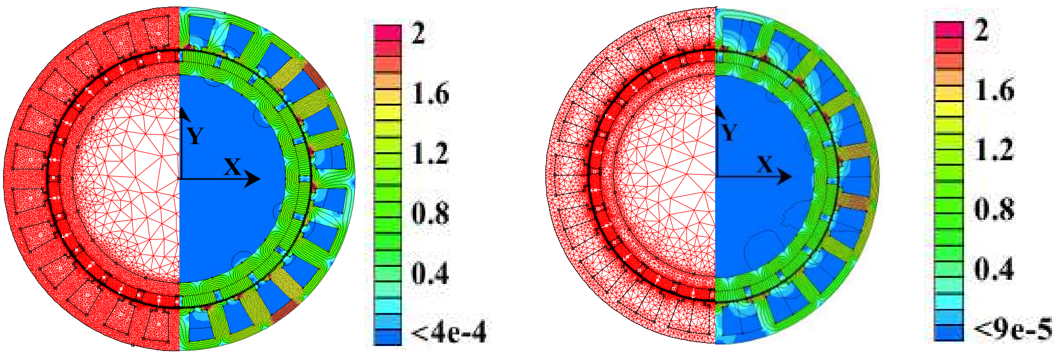


Figure 33 : Comparison of the finite element analysis and magnetic field distributions of the non-overlapping alternate teeth wound and the non-overlapping all teeth wound winding configurations, respectively, of the permanent magnet motor.

Critical actuator design is based on finite element methodologies combined with a particular optimisation algorithm, developed in order to facilitate the comparative approach on the stator geometry optimisation of surface permanent magnet machines involving non-overlapping alternate teeth wound and the non-overlapping all teeth wound winding configurations. More specifically, a Rosenbrock based optimisation algorithm is introduced in order to minimize an application-specific penalty function through a Sequential Unconstrained Minimization Technique. The proposed formula of the penalty function includes efficiency-performance related terms, as well as technical terms, related to the manufacturing cost of each stator configuration. Proper terms ensuring non violation of the optimisation constraints have been also introduced. The algorithm offered stable convergence characteristics in all design cases considered.

Advanced three dimensional finite element analysis was equally performed or the thermal phenomena leading to discretizations involving several millions of elements.

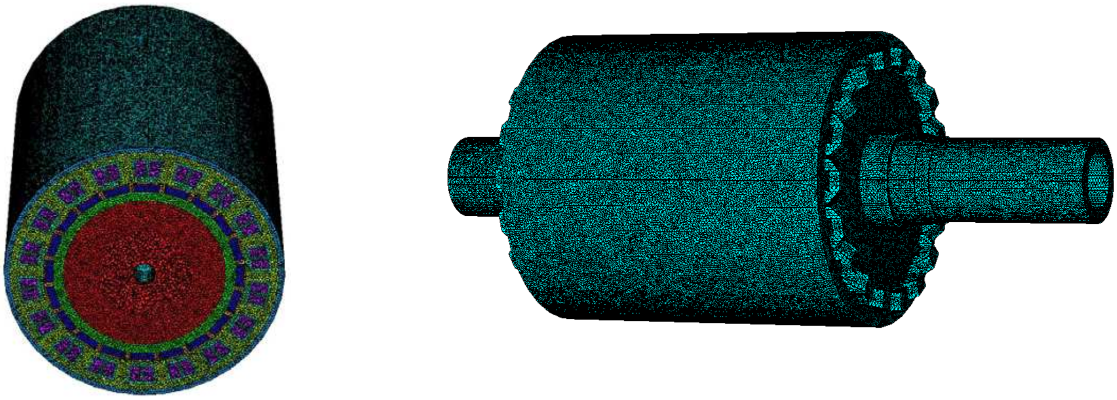


Figure 34 : Discretization implemented in the 3D thermal finite element model of the permanent magnet motor

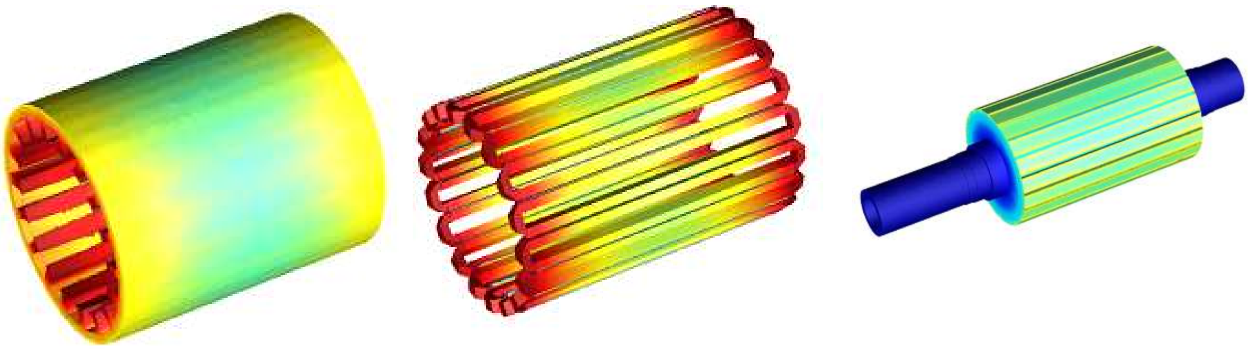
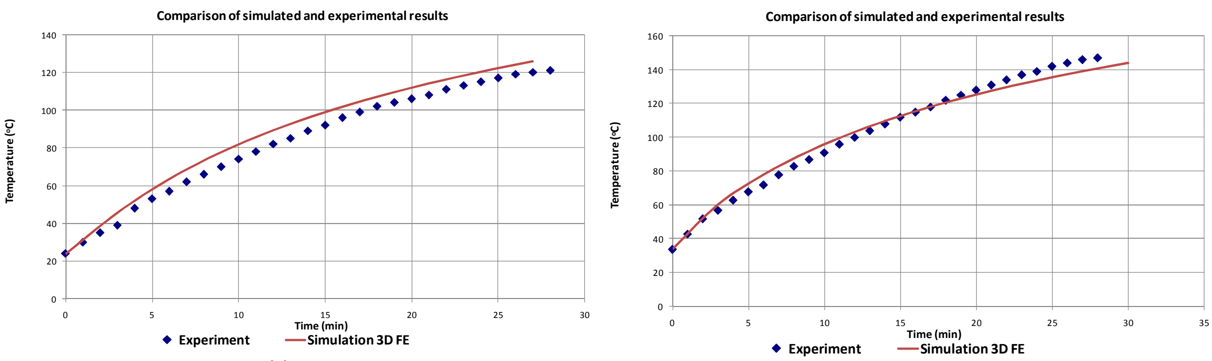


Figure 35 : Calculated temperature distributions in the motor (stator core, windings and rotor parts)



(a) (b)

Figure 36 : Comparison of the simulated and measured temperature time variations in the motor (a) housing and (b) windings

Appropriate lumped parameter thermal models were equally developed, enabling fast thermal analysis, the parameters of which were determined by the finite element approaches and validated by temperature measurements.

The thermal investigation shown that at nominal operating conditions (15 N·m) with the presence of carter the winding end zone part is the hottest motor point with an overheat of approximately 100 ^{o}C with respect to the temperature of the environment at steady state and a thermal constant of 15 minutes. In addition under extreme motor loading (30 N·m) 100 ^{o}C overheat is attained within 2.5 minutes, indicating the maximum time period admissible for this regime.

In order to minimize overall losses of the motor, a control technique featured by the capacity of the real time estimation of the power losses due to the injected switching frequency components by the PWM excitation was proposed. The identification of this part of power losses enables the controller to regulate properly the PWM voltage switching frequency attaining increased efficiency for the total motor performance. The investigation concerning the impact of the switching frequency selection in accordance with the results obtained led to optimisation of motor's operational characteristics under different load conditions by selecting appropriate switching frequencies.

Independently from paper analysis and simulations under finalisation on an optimised global architecture according to several criteria, it was decided that the demonstrator will be an assembly of two blocks integrated together: a mechanical block containing the actuator (linear roller screw), the motor, some sensors and other mechanical interfacing mechanical components and a physical block (optimized in volume, weight, reliability etc.) containing the MCPM.

Figure 37 : CREAM motor rotor and stator parts

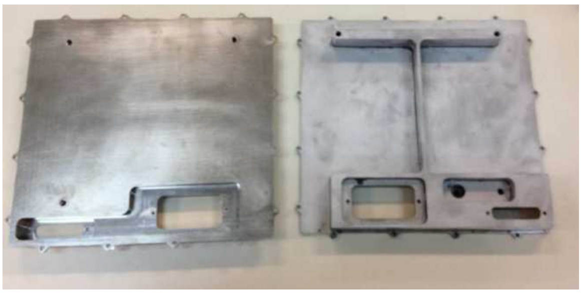


Figure 38 : MCPM Housing parts

The motor simulated results were validated by several motor prototypes construction and testing enabling to attain the performance requirements and improve thermal behaviour. The motor kit and mechanisms for prototype were finalized. The acceptance tests of the motors prototypes were performed. The global packaging strategy adopted for global EMA prototype actuator mechanism was followed and the respective parts have been constructed and provided in order to validate the specified global EMA performance.

1.3.8. WP4: Validation : Leader SAGEM

Validation strategy was put in place. Due to Consortium reorganization, Sagem took the lead of WP4 and was now the major contributor for all WP4 activities.
Based on previous analyses and on Sagem knowhow and available tools, the architecture of the test bench was studied, detailed and frozen, with the aim of permitting final validation of the demonstrator, mainly through thermal stress cycling.
All hardware and software parts were developped, assembled and integrated into the benches and test softwares. The test benches were connected to MCPM units so as to tune and verify all parts and test sequences.
A dedicated MCPM unit for test bench integration has been manufactured, allowing determination of all test parameters and activation scenari. It also allowed the careful verification of the temperatures of the most critical items during activation.
Once all items ready for final validation campaign, tests were carried out on dedicated MCPM units so as to stress all parts and technologies. Due to schedule constraints, the testing sequences focused on major configurations that were foreseen in harsh environment. Results are documented in D4.3 and D4.4.

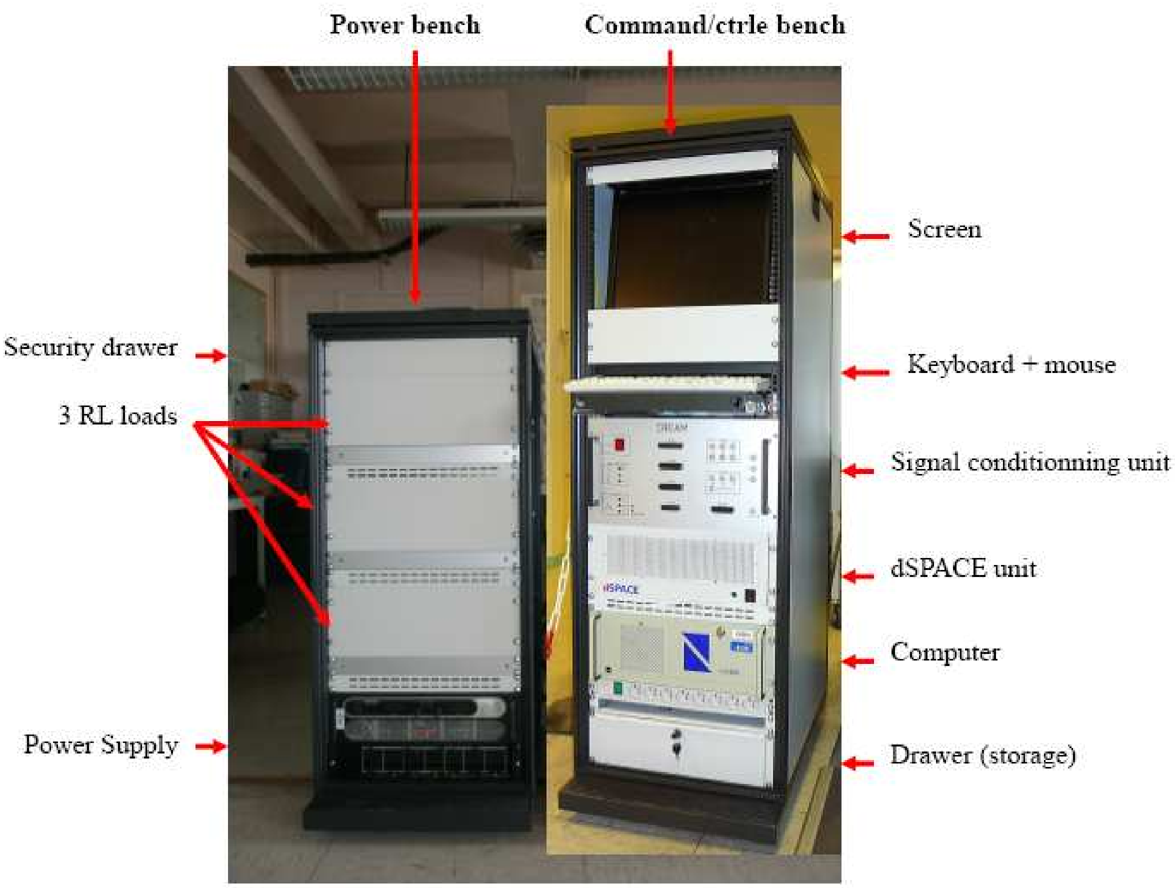


Figure 39 : CREAM Test Bench

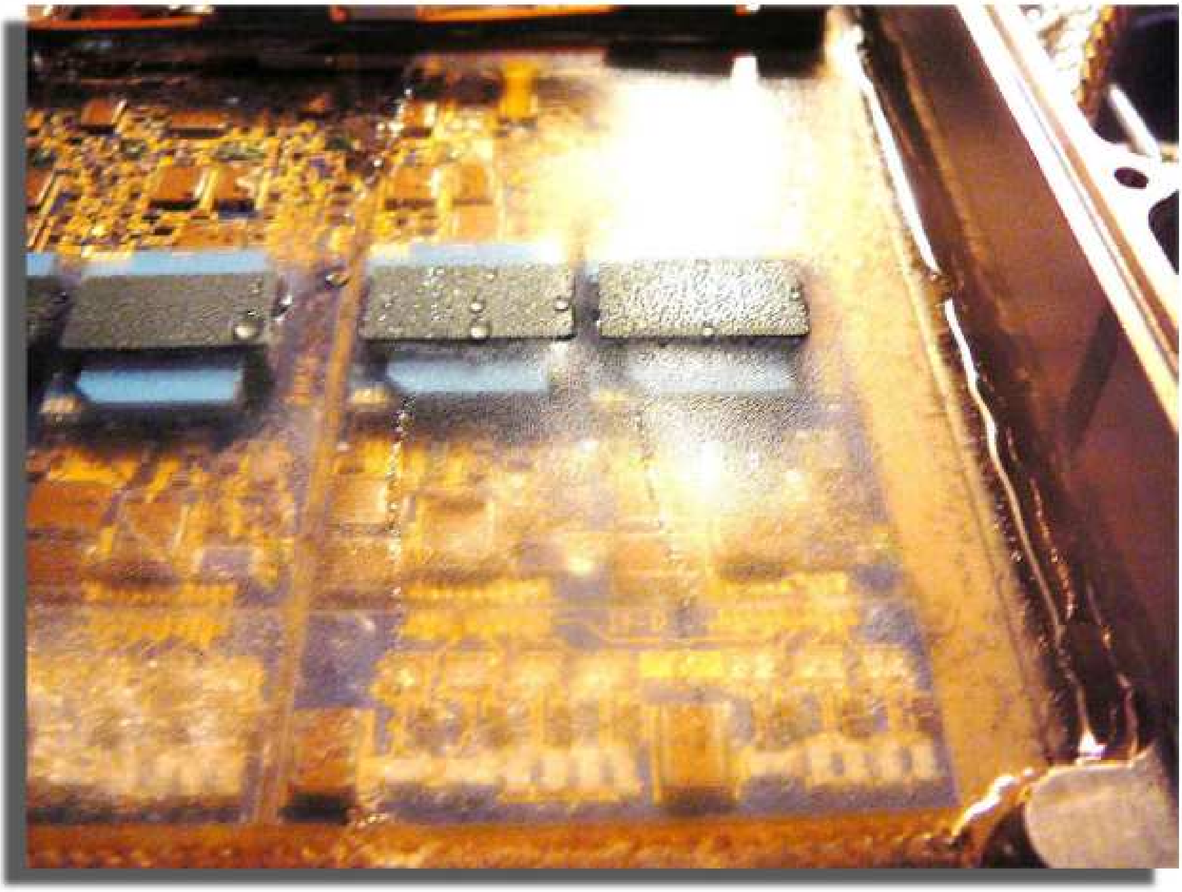


Figure 40 : CREAM Final testing

1.3.9. WP5: Dissemination/Exploitation: Leader ALMA

This work package conducted to continuously monitor and provide means for the CREAM partners to share their knowledge within the consortium as well as to disseminate and exploit the results to the aeronautic community at large.

It was split into different deliverables which conducted to the following actions:

First of all the **Dissemination strategy definition**, which conducted the different deliverables such as different issue of the Plan for Use and Dissemination of Foreground, as well as a report of external dissemination.

Then the task linked to **Communication and dissemination to general public** conducted to different actions and Deliverables: a project identity set and a project website. The project identity set contains different items:
- the logo,
- the brochure,
- the set of slides for power point presentation.

These were used in every single communication aspects concerning the dissemination of the CREAM project.

The logo :

The Brochure:
It is an A4 format containing four pages presenting the project context and objectives as well as the consortium. The final version is presented below.

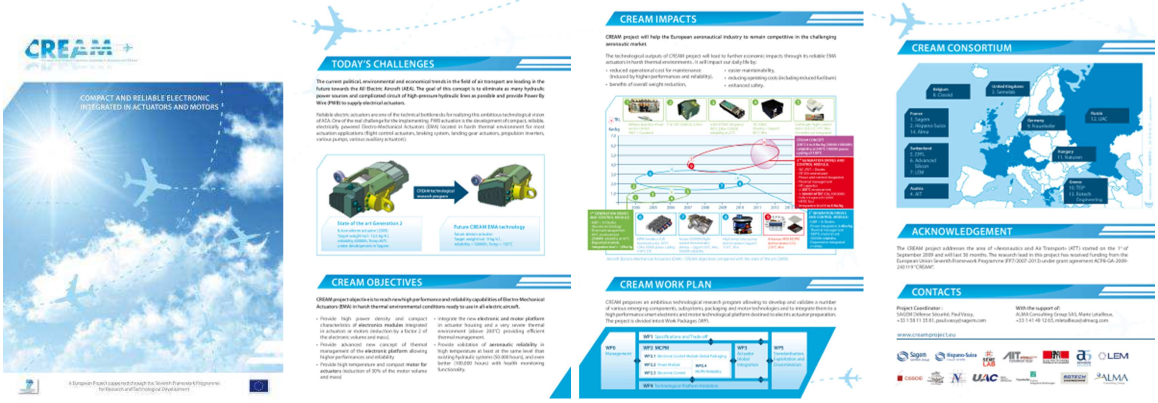


Figure 41 : CREAM Brochure

The graphic charter:
The graphic charter for all project PowerPoint presentations was also created.

Figure 42 : Graphic charter for PowerPoint presentations

The site is functional for access by the public and contains useful and interesting information about the CREAM project. The project website is available on www.creamproject.eu; It is composed of different folders as displayed on the following screenshot:

- Home,
- Project Description,
- Partners,
- News & Events,
- Download Areas.

This way it contains the main information on the CREAM project, including public information on the project, the Kick-Off Meeting and the Steering Committees, and was updated regularly.

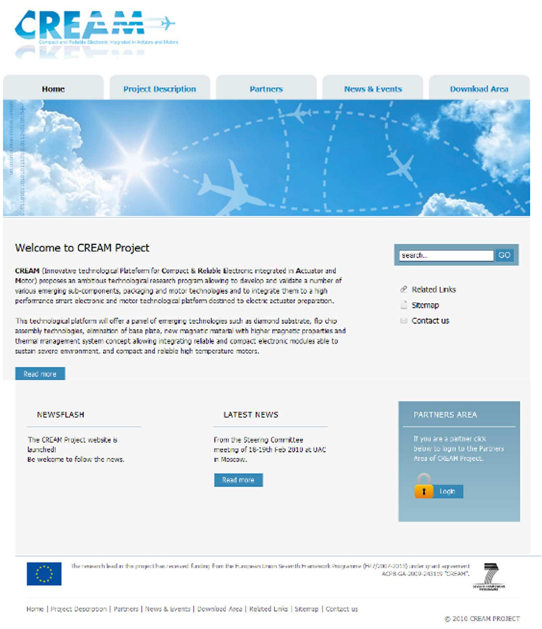


Figure 43 : CREAM Website Home page

Another task was linked to the **External dissemination to scientific and industrial community**. Several actions of dissemination were made, through publications and dedicated conferences. All the conclusion of this task is listed in the paragraph hereafter linked to dissemination, table A1 and A2. Another action, linked to the **Management of knowledge, IPR and exploitation roadmap** conducted to the deliverable Exploitation roadmap, which is also available hereafter in the table B1. In term of Contribution to standardization process, the finalisation of this task is available through a deliverable report: Report on standardisation activities.

1.4. Potential impact and main dissemination activities and exploitation of results

1.4.1. Potential impact

The following technological outputs of CREAM project will lead to further economic impacts:

- Reliable "application-ready" high-temperature electronic modules: Establishment of European know-how in the field of high-temperature electronics,
- Successful development of high thermal conductive materials with high thermal stability: Such materials are of interest in many areas where reliable cooling is a topic,
- A new technology & design for measuring current in harsh environment, reusable in various sectors,
- High temperature & compact motor controller: foreseen applications in valves and pumps,
- Reliable EMA actuators in hard thermal environment: reduced operational cost for maintenance.

Immediate benefits derived from the wider application of electrical power and electronics in actuation include higher performances and reliability, benefits of overall weight reduction, easier maintainability, reducing operating costs (including reduced fuel burn) and enhanced safety.

Europe needs to answer rapidly to USA investigations in order to remain competitive in the challenging aeronautic market. CREAM project results will support the European aeronautical industry in the strong competition between Europe and USA. CREAM results are able to establish the credibility of electric actuation as a primary reliable method for aircraft actuators including flight critical control surfaces, by integrating innovative concepts and sub-systems and reliability testing methods.

1.4.2. Dissemination and exploitation of results

The exploitation and dissemination in the CREAM project conducted to different actions :

- publications and patent
- workshops and conferences
- thesis
- press release

The plan of dissemination and exploitation gathered a summary of all these actions.

The publications submitted by Fraunhofer , TEIP and EPFL are:

- Evolution of shear strength and microstructure of die bonding technologies for high temperature applications during thermal aging (FhG)
- Reliability of insulating substrates - high temperature power electronics for more electric aircraft (FhG)
- Geometry Optimization of PMSMs Comparing Full and Fractional Pitch Winding Configurations for Aerospace Actuation Applications (TEIP)
- Thermal Investigation of Permanent Magnet Synchronous Motor for Aerospace Applications (TEIP)

- High Temperature Permanent Magnet Machine Actuators for Aerospace Applications (TEIP)
- Test vehicle for studying thermal conductivity of die attach adhesives for high temperature electronics (EPFL)
- Long-term mechanical reliability of ceramic thick-film circuits and mechanical sensors under static load (EPFL)

Moreover, TEIP presented its results in five related international Conferences while two more presentations in international Conferences are scheduled in 2013. In addition one Ph.D thesis (by E. Tsampouris) was finalized linked with the motor design developments of the project while a second Ph. D thesis related to high temperature materials for motors and associated control techniques is expected to be concluded in 2013.

The consortium co-organised together with SAGEM and EPFL-LSM a workshop on "Aerodays 2011, LTCC: A packaging technology suitable for high density integration and high temperature applications" on the 30/03-01/04/2011 in Madrid that gathered actors in European projects and gave a presentation of our project. For more information, see website. A cross-fertilization meeting with Actuation 2015 representatives has been conducted.

1.5. Relevant contact details.

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http://www.creamproject.eu

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11	Naturen Industrial, Informatics and			Hungary

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