

AST4-CT-2004-516089
Contract n. 516089

MULFUN

MULTIFUNCTIONAL STRUCTURES

SPECIFIC TARGETED RESEARCH PROJECT (STREP)
Thematic Priority: 1.4 Aeronautics and Space

Final Activity Report

Partner		Country
INASMET	INAS	Spain
Thales Alenia Space Italia	ALE	Italy
CRISA ASTRIUM	CRISA	Spain
HTS GmbH	HTS	Germany
TTI Norte S.L.	TTI	Spain
EPSILON	EPS	France
RHe GmbH	RHE	Germany
PRINTCA	PRINTCA	Denmark
YUZHNOYE	YUZ	Ukraine

Reporting Period 01.01.05 – 29.02.08
Actual submission date: 07.04.08

Start date of project: 01.01.05

Duration: 3 years + 2 months

Issue	Revision	Date
1	0	

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1 SCOPE

This document gives an overview of the work performed in the Specific Targeted Research Project (STREP) entitled “**Multifunctional Structures**” (**MULFUN**), which corresponds to the Aeronautics and Space call of the Sixth Framework Programme.

2 PROJECT EXECUTION

The needs to reduce cost and provide added value by integration of functions is demanding for a weight and volume constrained design on aircraft and satellite. On the last years, lightweight composite materials have been increasingly used to reduce the structural weight and volume of equipment components. However, concentrating solely on structural mass reduction does not lead to further lowering of equipment mass because the structure typically represents as little as 10 to 15% of the total mass. The envisaged solution is to design structural elements that can integrate multiple functions, known as **multifunctional structures, MFS**.

In the conventional avionics equipment design, structural, thermal and electronic functions are generally designed and fabricated into separate elements:

- Load support based on shells and metallic frames structures
- Thermal management based on radiators or cold plates
- Electronics enclosures based on metallic black boxes and rigid PCB
- Electronic/power distribution based on Cables bundles / harness

This design results in significant mass penalties. The multifunctional technology aims to integrate all these functions, reducing weight and size up to the minimum.

The MFS design intends to integrate all these functions in **structural composite panels** and composite housings that have **electric properties** (patch within flexible integrated circuits mounted directly on the composite panel) and **thermal properties** (heat transfer elements embedded on the composite panel as thermal doublers and straps made of high conductive graphite fibres or alternatively active thermal integrated refrigeration circuits).

The project objective is the development of **lightweight –fully integrated advanced equipment for aircraft and spacecraft** (avionics electronic housings) based on these multifunctional structures. Within this project, four breadboards have been designed and manufactured. The first panels (BB1 and BB2) tested the different thermal concepts: passive (high thermal conductivity graphite fibres) and active (high thermal conductivity + mini-heat pipes) thermal dissipaters integrated to transfer the heat produced for an electronic circuit embedded on the panel.

A third BBM has corresponded to a **phase array antenna for aircraft** that has been used to demonstrate the scale up of composite panels with thermal dissipaters integrated. Finally, a **power electronic housing** breadboard (BBM4) has been designed and manufactured to test complex shape of composite panels, integration of both electronics and thermal concept on the composite panel.



Tasks have also been devoted to the study, analysis and testing of EMI-EMC and radiation shielding of the composite material.

The main innovations reside in:

- a multi-functions novel design approach
- integration of flexible electronics on composite structures
- studies of radiation and EMI-EMC shielding of composite materials
- the use of high thermal conductivity fibres (passive thermal control)
- use of commercial mini-heat pipes (technology transfer) as active thermal control system

The MFS technology provides a weight saving benefit of 40% in both aircraft and spacecraft equipments.

2.1 Objectives and Strategic Aspects

The main project objective is the development of highly integrated equipment using new multifunctional, high thermal conductive materials in aerospace applications.

The new concept provides a basis for integration of electrical, structural and thermal functions with simultaneous considerations of volume, mass savings as well as increase of reliability.

Scientific research objectives:

- To define the design techniques, tools and knowledge for MFS concept
- To study the processing and design concepts by using high thermal conductive fibers
- To define equipments, materials and design elements for integrated thermal elements as mini heat pipes
- To evaluate the materials and integration needs for flexible electronics

Technological research objectives:

- To assess the potentialities of MFS design concept for various applications
- To integrate functional elements: electrical, thermal and structural
- To use advanced modelling and simulation tools to design structures which include thermal and electrical functionalities
- To develop a methodology for cost and weight reduction by re-engineering current electronic housings
- Fabrication of critical samples as technology breadboard for various applications.

Quantified objectives

- To design, manufacture and validate a representative electronic panel based on MFS able to dissipate 20-40 W through its surface/volume, reduced in 30% vs aluminium panel.
- To redesign, manufacture and validate an optimized phase array antenna lay-up for transport applications by using MFS achieving a weight reduction of 30%, allowing its integration on the transport vehicle roof-structure.

- To redesign, manufacture and validate an electronic power housing by using MFS with a thermal dissipation of 48 W through its lateral panels, being 30% lighter than current aluminium housings.

2.2 Consortium

In the table below, the expertise and the role of the Partners involved in the MULFUN project is provided:

Organisation name	Country	Type	Relevant Expertise	Role in the project
INASMET (INA)	ES	RES	Development of advanced processes, materials and new manufacturing techniques.	Coordinator Thermo-mechanical design, manufacturing and testing of the antenna. Manufacturing of composite panels for the power electronic housing
Thales Alenia Space Italia (ALE)	I	IND	Telecommunications, remote sensing, orbital infrastructures and scientific satellites.	Thermo-mechanical design and testing of panels with passive and active thermal control.
CRISA ASTRIMUM (CRI)	ES	IND	Power electronics for space uses.	Power electronic housing specification and testing.
HTS GmbH (HTS)	DE	SME	Thermo-mechanical design, analysis and tests, handling of high-conductive carbon fibres, CFRP manufacturing	Manufacturing and testing of panels with passive and active thermal control.
TTI Norte S.L. (TTI)	ES	IND	System integration and production of advanced communication equipment for different sectors.	Telecom (antenna) application development .
EPSILON (EPS)	FR	SME	Design of thermal/fluidic and thermo-mechanical components of thermal systems	Thermo mechanical design and simulation of power electronic housing
RHe GmbH (RHE)	GE	SME	Manufacturing of customized hybrid circuits and electronic modules.	Electronics manufacturing and procurement for panels with passive and active thermal control
PRINTCA	DK	SME	Design and manufacturing of Rigid/Flex pcb and heat sinks to laminate outside.	Electronics manufacturing for the antenna
YUZHNOYE	Ukraine	ORG	Large heritage in space (development of spacecraft and launchers)	EMC-EMI and radiation shielding of composites

Table 1: MULFUN project consortium

2.3 Work Description

The project has been structured in three main phases, based on a building block approach; starting from basic research up to panel technology evaluation, scaling up the designs into a complex geometry and final validation. As the complexity increased



the lesson learnt from each partner, on electrical-materials-and thermal knowledge was progressively incorporated to the final multifunctional structures.

The first phase started with a general technology review of MFS concept and technology needs (WP1): CFRP structures, electrical circuit designs, thermal control systems (both passive and active concepts review), assembly aspects for metal-composite, electronic substrates-composite and closure aspects for housings constructions. Technology needs were also assessed and the two different approaches in thermal control (active and passive systems) defined. A CFRP structural panel based on a passive thermal control system (high dissipative graphite fibres, WP2), was developed. The second panel demonstrated the performance of active thermal control on the CFRP structures (mini-heat pipes, WP3). Both technological panels integrated onto its surface a dummy electronic circuit which was able to dissipate 150 Watts.

The second phase was focused on the development of two different applications which evaluated the technology developed in the first phase. The first prototype (BB3) was a scale up panel with thermal integrated system (WP4). The application chosen was a phase array antenna for aircraft communications. Two main aspects of MFS were verified on the antenna breadboard:

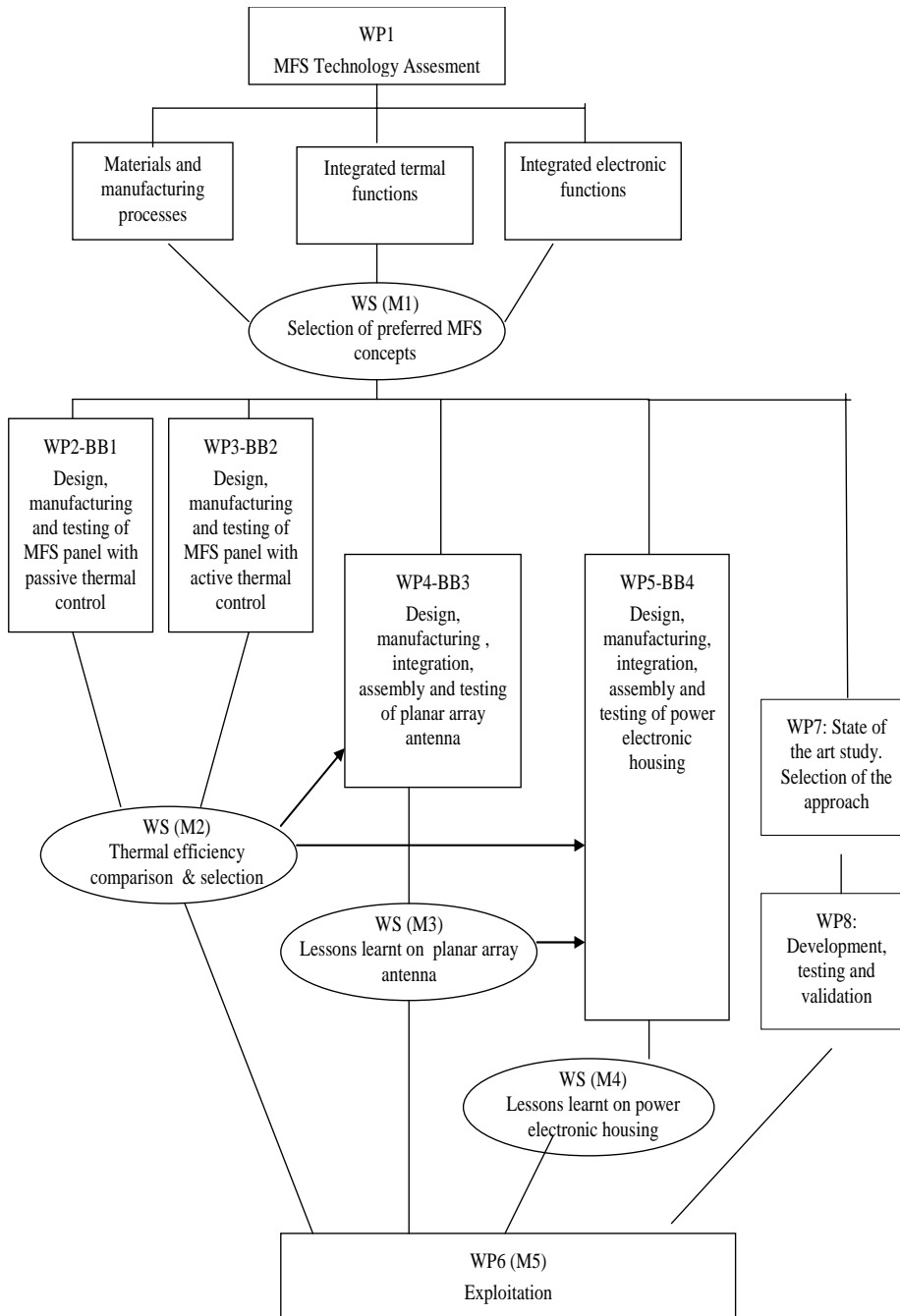
- the fully operational electrical design of an antenna integrated onto a CFRP structure
- the thermal system.

The second (BB4) prototype was a representative power electronic housing (WP5). The breadboard verified a MFS design on a complete close box, addressing the problems of assembly and integration of dummy electronics boards.

The third phase (WP6) covered exploitation aspects of the innovation produced (MFS advanced designs of antenna and power electronics housings). A market review of the identified potential applications was performed.

In parallel, studies related to the possibilities to shield the composite material against EMI – EMC and radiation have also been performed.

Below, the work logic is presented:



Within the project (38 months), the following results have been obtained:

WP1: MFS technology review

Traditionally, machined or cast aluminium boxes are the most common choices for aero and space electronics. Current satellite and aircraft packaging systems still utilize large “black boxes” (i.e., aluminium chassis), which contain multiple circuit boards and are connected to other black boxes with bulky cables. In the conventional aerospace electronic boxes, structural, thermal and electronic functions are generally designed and fabricated into separate elements:



- load support, based on shells and frame structures
- thermal management based on heat rejection, heat compensation and heat spreading
- electronic enclosures, based on black boxes
- electronic/power distribution, based on cable bundles / harness
- EMI/EMC, radiation shielding
- health monitoring

These functions are integrated under the MFS design. The multifunctional structure design concept places the majority of spacecraft electronics on the walls of the spacecraft that also include structural elements, thermal control and shielding.

The MFS design concept and main applied technologies are summarized in the scheme and paragraphs below. Nevertheless, an in deep study of the technologies, the previous experiences and the needs has been performed within the project

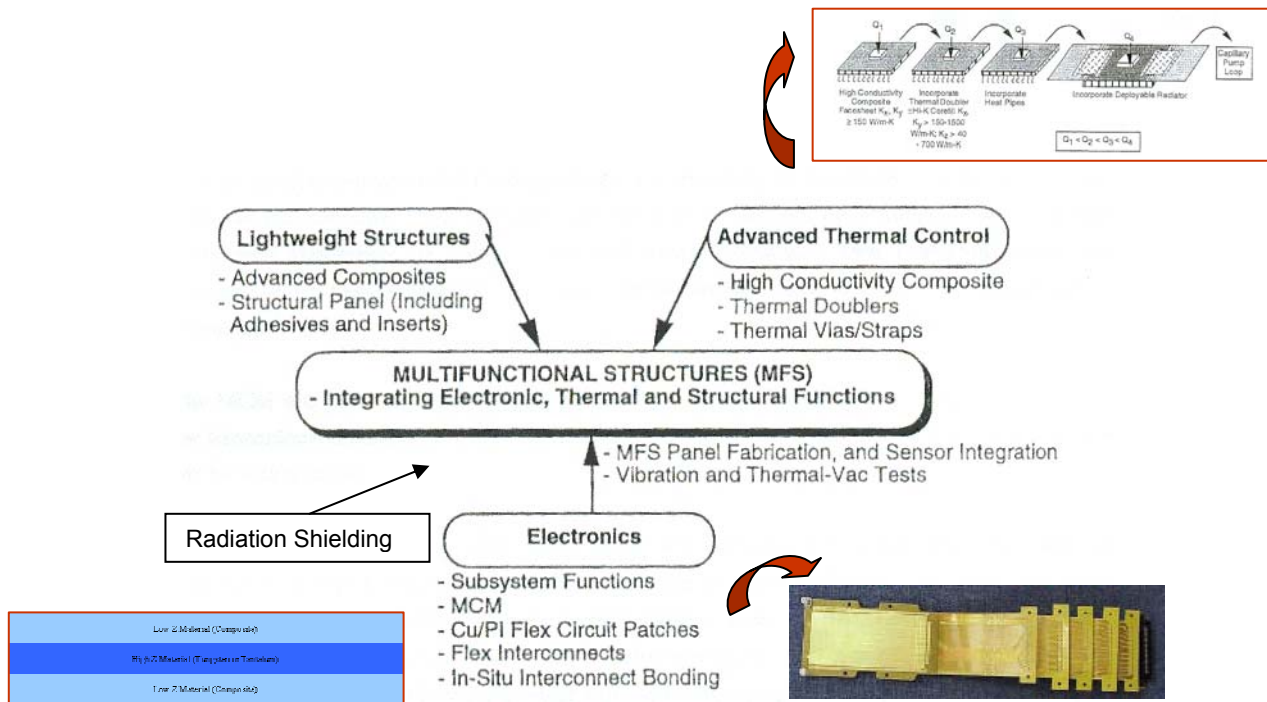


Figure 1: Multifunctional Technology Scheme.

The benefits of MFS against traditional design are:

- to eliminate chassis and cabling, reducing electronic enclosures and harness.
- to maximize functional elements volume ratio (maximum integration)
- weight and volume saving (>25% increase of mass fraction, > 50% increase on S/C volume availability)
- to reduce thermal paths from the electronic components to the spacecraft radiators, enhancing the heat radiation capability needed for the growing dissipation densities.
- to enhance robustness and reliability



Composite materials are central in aerospace applications due to the weight savings that could result from using low density polymer matrix composites made from high modulus, high strength fibres. The attributes of composites include high specific strength (strength per unit weight) and stiffness, corrosion and fatigue resistance, tailorable conductivities, controlled thermal expansion and the ability to be processed into complex shapes. As structural materials, composites offer numerous system level benefits over their predecessors. They are lightweight, which is critical for any aerospace platform since less structural weight allows for more fuel or payload. The physical, mechanical, electrical, and thermal properties of composites are highly tailorable, which can also afford them multifunctionality.

At the present time, the use of carbon composites is generally limited to applications characterized by certain requirements, often in terms of dimensional stability or specific mechanical properties (e.g. stiffness per unit mass). Unfortunately, mass specific thermal conductivity of traditional carbon composites is low, with penalty with respect to aluminium in global performance. The use of high-conductivity fibers could make such products attractive in the frame of several applications, despite the higher cost of the material and the related manufacturing issues (in particular, pitch fibers are brittle). Among the situations that could take advantage from the use of high conductivity CFRP on satellites, the following are worth being mentioned:

- to replace traditional CFRP when its use is driven by specific requirements, providing improved thermal performance and/or mass saving.
- to improve the capability of managing high power densities on radiator panels when the traditional thermal control approach (aluminium panel with heat pipes) is marginal even with optimized design.
- to improve the radiator efficiency in terms of power dissipation capability to mass ratio; the use of high conductivity CFRP skins can allow the increasing of the mass fraction, by limiting the need for dedicated thermal hardware (heat pipes, doublers, straps,...).
- the possibility to reduce the number of heat pipes (ideally, down to zero) enables the simplification and standardization of the layout of S/C panels; the aim is to reduce design/integration costs and schedule and to move towards standard panels.

Main applied technologies:

Thermal control: From the thermal management point of view, integrating electronic component elements as MCMs, directly on structural panels has the clear advantage of reducing the heat paths and hence the temperature drops from the heat sources to the radiators on the external panels surface. On the other hand, the thermal control issues at PCB level and at unit level are passed-down to the components lay-out at panel level. Thus, eliminating the unit base plate, which spreads heat to all the footprint area, might cause hot spots in the lay-out.

Depending on the components power dissipation, a doubler would be required, punishing the mass saving claimed for the MFS concept. To keep the doubler-associated mass increase as low as possible, the use of high thermal conductivity CFRP is a suited solution. A reduction in the range 35%-55% of the doubler mass is obtained replacing aluminium by high thermal conductivity CFRP in isotropic configuration. Furthermore, the doubler can be replaced by including the high thermal

conductivity CFRP in the panel skin lay-up, in combination with mechanical resistance effective layers. Privileged heat conduction directions can also be selected through anisotropic configurations.

Incorporating high thermal conductivity fibres (used as thermal doublers or within the sandwich skins composite lay-up) to the structural panels allows enhancing the skin thermal conductivity either isotropically or in selected directions. This concept is suited for a wide range of applications, linked to the growing electronic components power density (higher average operating temperatures, localised hot spots and adverse thermal gradients, which reduce the equipment reliability and lifetime). For low and middle dissipation densities, it provides lighter configurations than aluminium doublers.

In the table below a comparison of the thermal conductivity of different materials is shown:

Reinforcement	Matrix	Thermal Conductivity W/mK	Modulus GPa
-	Silicon	125	
-	Aluminum	225	69
-	Copper	400	117
-	Epoxy	0.18	3
-	Air	0.025	131
Copper	Tungsten	167	248
Beryllium	Aluminum	210	179
Carbon Fibre (K1100)	Epoxy	300	186
Carbon fibre K1100	Cyanate Ester	460	
Carbon Fibre (K1100)	Aluminum	290	131
K1100		1000	225-265
K13C2U		620	
M60J		75	

Table 2: Thermal conductivity of different materials.

For high power dissipations (telecom satellites as well as scientific missions), it can be used in combination with active thermal control systems in satellite walls and it is an attractive solution, specially in the anisotropic configuration, for deployable panels used in combination with LHPs.

EMI-EMC shielding: An electronic system that is able to work correctly with other electronic systems and not produce or be susceptible to interference is said to be electromagnetically compatible with its environment. There are three criteria to determine if a system is electromagnetically compatible,

- It does not cause interference with other systems
- It is not susceptible to emissions from other systems
- It does not cause interference with itself



Currently, with the use of aluminium plates of certain thickness for the manufacturing of electronic boxes, there are no problems related to EMC, EMI and radiation shielding. However, in the MULFUN project, multifunctional structures that substitute the aluminium houses are being developed. The panels are constituted of high thermal conductivity fibres and may contain an aluminium honeycomb core. It is known that the EMC, EMI and radiation shielding behaviour of these composite materials is not good.

Shielding of Electromagnetic (EM) fields is accomplished through reflectance or absorption of the fields by a barrier. In most applications, the barrier is a metal, although coated and conductive plastics are being used more frequently in commercial applications. The shielding effectiveness of an enclosure is decreased by the introduction of discontinuities. These discontinuities are the holes, seals, joints, slots found in nearly all electrical and electronic equipment due to information transferring, connecting with other systems, etc. EMI shielding requirements are based on the level and quality of continuous electrical conductivity across all housing walls, fixed joints and seals.

Composite materials are not as electrically conductive as traditional metal structures. Therefore, extra steps must be taken to mitigate this deficiency. Conductivity may be provided by adding a conductive screen, plating or paint to the finished product. The technologies used to form conductive coatings include flame spray, arc spray, vacuum metallization, conductive paints, etc.

Other option consists in intercalating the fibres before fabricating the composites. Intercalation is the insertion of guest atoms or molecules (intercalates) in between the carbon layers of the fibres.

A new opportunity to modify the electrical conductivity of polymer matrix systems consists in the use of carbon nanotubes and nanofibers, recently discovered.

Flex-rigid electronic circuits: The cable is a flat matrix of polyimide film that lays out the various "wires" side-by-side. This flexible electrical insulation material has outstanding thermal, mechanical, and chemical properties. This configuration results in a very low mass structure that does not require the heavy bundling and tie-down hardware. The MFS cable has such low mass that can be tacked down with adhesive directly to the vehicle structure without complex brackets. The MFS cable is finished on each end with low-mass interconnects. A major benefit of the MFS technology is that these components can be cheaply mass-produced. Nearly all of the touch labour associated with manufacturing the cable is eliminated and at least 90% of the touch labour associated with installation of the cable is also eliminated. This reduction in manpower costs has obvious benefits and, in addition, the configuration facilitates test and verification capability.

Flexible circuitry is used in the MFS concept for a variety of reasons:

- Replaces both Printed Wire Boards (PWB) and cabling.
- Local electrical-bonding systems can eliminate all connectors.
- Lightweight/low volume.
- Standard product.

Space Radiation shielding: Natural space radiation in the form of electrons, protons and heavy ions can inflict damage on semiconductor devices used in space

electronics. This damage degrades the functionality of these devices and consequently shortens the lifespan of the mission.

Shielding against space radiation can be done at several levels: the electronic device level, the enclosure level and the spacecraft structure level. While the spacecraft structure provides some level of attenuation for incoming charged particles, it is usually not enough to provide the required level of shielding. As a result, radiation shielding is usually achieved by designing the walls (thickness) of the panel or enclosure to provide the required attenuation.

The amount of radiation shielding required for a given mission varies significantly depending on several variables that include mission parameters (orbit, altitude, inclination and duration), spacecraft design (spacecraft wall thickness and panel-enclosure location) and the type and sensitivity of semiconductors used. To achieve the optimum shielding with the minimum weight, all these variables have to be considered in the design.

Total ionizing dose can increase by three to six times using composite structures and composite electronic boxes as compared to using aluminium structure and aluminium electronic boxes as shown in Table 3. Dose to an MFS electronic panel can increase by an order of magnitude as compared to dose inside an aluminium structure and aluminium electronic box.

S/C Structure Electronics Box	Aluminum Aluminum	GrPc GrPc	GrPc MFS
Shielding, g/cm ² Equivalent, mil Al	0.68 100	0.34 50	0.21 30
Orbital Dose (10 yrs)			
600 km, 60° (LEO)	~4 krad	~10 krad	~24 krad
1600 km, 60°	~70 krad	~170 krad	~400 krad
3000 km, 60°	~270 krad	~770 krad	>2 Mrad
20,182 km, 55°	~400 krad	>2 Mrad	>5 Mrad
GEO (35,794 km)	~100 krad	~600 krad	>2 Mrad

Table 3: Total dose for various space structures (Slab Geometry)

In recent years, a multilayered - multimaterial approach for radiation shielding has been studied (COI, Inc Company), developing the concept of LowZ/ HighZ/ LowZ shielding. A schematic concept is shown below:

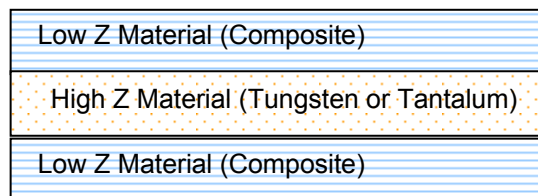


Figure 2: Multilayered-multimaterial concept.

It relies on optimising the shielding effectiveness by using two materials with large difference in atomic number, instead of a single shield material. From a radiation shielding standpoint, the composite can be any standard space material (PAN or pitch fibres with epoxy or cyanate ester); similarly, the High Z material can be tantalum, wolfram or any other material with high atomic number. A “heavy” material (high Z i.e.

high atomic number) is better absorber of electrons and bremsstrahlung than a low Z material even if the production of bremsstrahlung is higher in materials of high atomic number. However, a high Z material is less effective in stopping protons. Therefore structures where low Z and high Z layers are combined to get effective radiation shielding are in interest of this study.

WP2 & WP3 : Structural panels with passive and active thermal control

BB1 (WP2) and BB2 (WP3) were aimed at demonstrating the capability of implementing a fully integrated design concept based on a generic structural panel configuration, with particular focus on thermal control aspects.

In detail, BB1 and BB2 were conceived to demonstrate the capability of

- integrating surface mounted electronic devices and flexible circuitry
- using advanced materials assuring improved thermo-mechanical performance
- providing mass saving w.r.t. traditional design concepts
- embedding thermal control hardware into the structure (BB2 only).

Both demonstrators consist in rectangular (500mm × 800mm) sandwich constructions with Aluminum honeycomb and high-modulus Carbon Fiber Reinforced Plastic (CFRP) skins.

Flat (rigid/flex) motherboards, directly bonded to the skin, provided local interconnections (replacing both printed wire boards and cabling and eliminating connectors) and accommodated surface-mounted electronic devices, consisting in ceramic MCMs with bare dice and other components.

Six MCMs were distributed onto the panel, each one was able to dissipate up to 25 W (150 W power dissipation in total). MCMs were directly bonded to the skin.

The Thermal Control System (TCS) was in charge of collecting the power dissipated by electronics and spreading the collected heat through the panel to avoid hot spots. The panel radiated the heat from its outer face: good spreading capability was also a major contributor to the heat rejection efficiency.

The BB1 thermal control was required to be based on a purely passive approach, relying on proper selection and use of material properties. A dedicated trade-off was devoted to the selection of materials for the sandwich construction. High-conductivity CFRP was identified as potential skin material to fulfil the thermal conductivity and mass saving requirements.

Several commercial products were reviewed to select the optimum resin-fiber system. Finally, each face skin was made of 8 plies of K13D2U fiber in Bryte Ex-1515 cyanate ester resin, arranged in a quasi-isotropic layout. Carbon fiber K13D2U (Mitsubishi) showed an excellent compromise between performance and cost: thermal conductivity not far from the one of the well-known K1100 with significant cost saving. The cyanate resin Ex-1515 was chosen for its high thermal and moisture stability.



A traditional solution was adopted for the core: the bending stiffness of the panel was ensured by 20mm thick aluminum honeycomb. The selected type guarantees a good compromise between stiffness properties and mass density.

According to the project objectives, BB2 was similar to BB1 but its TCS was partially based on an “active” approach, consisting in the use of dedicated thermal hardware embedded into the structure. A more demanding layout of electronic units was implemented with respect to BB1 to test the TCS performance: in BB2 the six MCMs are concentrated in one row in the middle panel axis, parallel to the long side; in BB1 components were more uniformly distributed.

As for BB1, BB2 was a rectangular sandwich construction with aluminium honeycomb and high modulus CFRP skins. The main difference was that a set of heat pipes was embedded into the structure. High heat transport performance, capability to work against gravity, possibility to be manufactured in small diameters and to be easily bent, flexibility in shape and configuration make such heat pipes effective devices for the thermal control of electronic components. They are now widely used in a variety of terrestrial applications, such as CPU cooling in personal computers, constituting a consolidated off-the-shelf product.

Under a certain diameter these kinds of heat pipes are referred to as mini heat pipes. Flat Mini Heat Pipes and Heat Pipe Spreaders, in which the thickness of the device is one or two order of magnitude lower than the other dimensions, are currently receiving great attention.

In the present study, the aim was to obtain a standard “multifunctional skin” integrating small pipes (leaving a high percentage of the area free for inserts) equally spaced (regardless of the position of the units) and bonded to the inner face. The impact on the mechanical design was limited and the standardization of the panel could be pursued.

Considering the experimental nature of the project, commercial products were used to evaluate possible exploitation of consumer electronics thermal hardware.

In BB2 the panel skins are made of 8 plies of K13D2U fiber in Bryte Ex-1515 cyanate ester resin, arranged in a lamination that ensures a good matching between fine copper heat pipes and carbon fiber skins.

Below, pictures corresponding to BB1 and BB2 are shown:

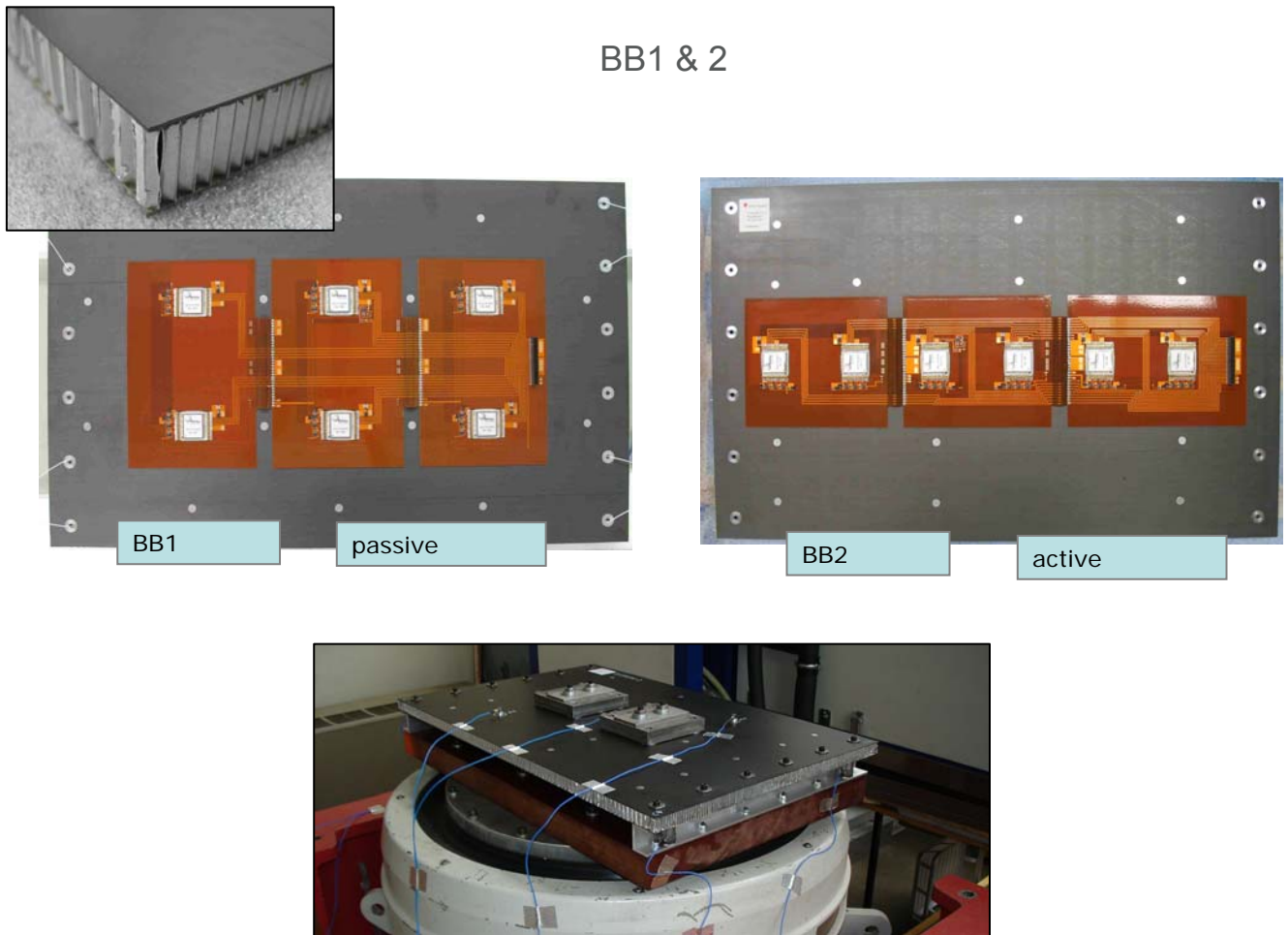


Figure 3: BB1 and BB2.

Dummy electronics have been designed and manufactured for the tests and evaluations of a passive (BB1) and an active (BB2) thermal controlled panel. The circuits simulate an electronic function with a defined power loss to determine the heat dissipation of the passive or active structural panel.

Special electronics packaging technologies have been developed to realize a concept that receipt in full of all project demands. PCB motherboards with cut-outs for integration of ceramic hybrids as well as flat and flexible connecting cables specify the main construction.

Multi Chip Modules (MCM) were used for the actual heat sources. Such a MCM consisting of a ceramic circuit board, SMD components, wire bonded bare dies and lead frames as well as hermetically sealed by a frame/lid technology is visible in Figure 4.

The innovation consists in the combination of materials and technologies as well as in flat interconnection between the single electronic circuits and the integration in the structural panel.

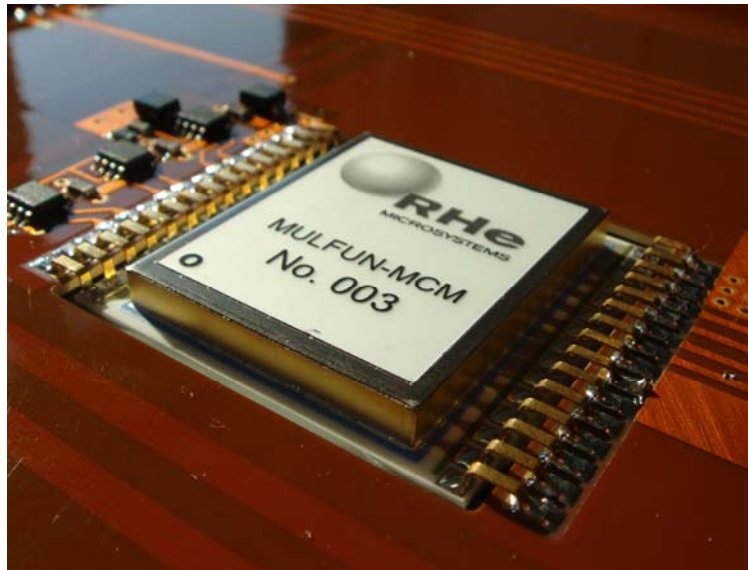


Figure 4: MCM contacted to the motherboard

Manufacturing of BB1 & BB2 involved several challenging tasks as the lamination of brittle and “dry” pitch fibers (avoiding any deterioration of the thermal properties), proper integration of heat pipes with a reliable and efficient process, optimization of the thermal interfaces (heat pipe/skin, MCM/skin).

The design and manufacturing phases were supported by several tests: measure of tensile characteristics, coefficient of thermal expansion, fibre volume fraction and thermal conductivity of the K13D2U/EX1515 CFRP; insert pull out (Al insert in sandwich); flatwise tension (sandwich); heat pipe pull out.

The manufactured breadboards passed successfully electrical, mechanical and thermal verification tests.

In order to assess and quantify the benefits of applying the MFS technology a trade off was performed considering different panel compositions. As can be seen in Figure 5, the mass required per unit area to keep a $T_{dye} = 78\text{ }^{\circ}\text{C}$ is much lower when high CFRP fibres is used.

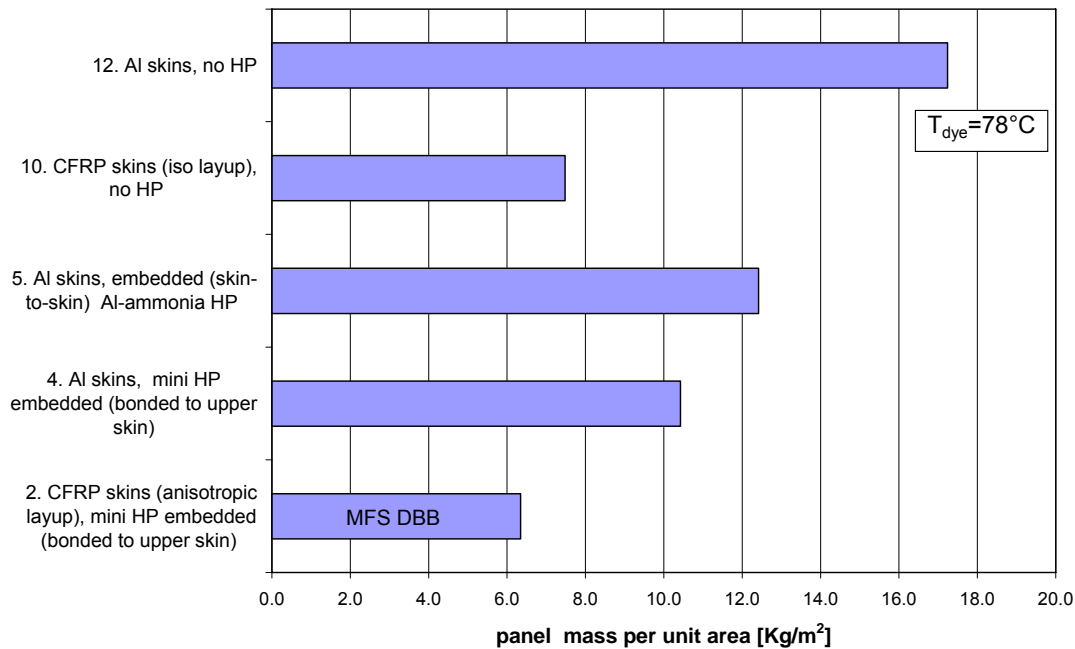


Figure 5: Mass per unit area to have a $T_{dye} = 78^\circ\text{C}$.

The principle behavior including thermal and mechanical properties of the passive and active panel construction was evaluated and successful tested within the BB1 and BB2 phase. The used dummy electronics based on the materials and packaging technologies mentioned above have worked without any failures before and after all tests. Hence it could be demonstrated that the new design using flat and flexible electronics is principally usable for real circuits integrated in MFS elements.

These prior investigations provide a base for further studies in the following work packages like the development of MFS housing elements for an antenna system.

The continuation of work after project close-out must focus on a further integration up to embedding of electronic systems in structural details. All following activities should aim at MFS tests under real conditions like at a flight or at an on orbit verification as an important stride towards the customer acceptance.

The new technologies open up new possibilities with regards to electronics packaging or housing concepts for industrial, aerospace or other applications wherever the reduction of mass in connection with an excellent heat dissipation is a important fact.

WP4: Integrated MFS breadboard: phase array antenna

In the framework of WP4, and in response to the technology needs of the aerospace industry, the Multifunctional Structure (MFS) concept has been applied to a phased-array antenna for avionics application. This breadboard has electronic scan capability in the elevation plane. Therefore, the installation of this kind of antenna on the top of the airplane can afford to users (pilots, travellers, etc.) to access to multimedia contents: TV, Internet, etc.



Phased-array antennas are emerging as a very feasible, interesting and necessary solution for mobile vehicles, substituting to traditional parabolic solutions. This is because in contrast to fix satellite services, which use conventional reflector antennas, mobile broadband applications demand novel smart antenna terminals. Due to the mobile nature of the application, the antenna has to track the satellite independently on the movement of the vehicle. This can be obtained by mechanical or electronics means. In avionics applications, the use of motors should be avoided in order not to introduce vibrations to the antenna system and also to have more reliable solutions. On the other hand, if a mechanical pointing system is used, this implies an increase in the total height of the terminal, which is contradictory with the strict aerodynamic requirement. The total height of the terminal should be minimised.

The antenna solution is based on a modular approach in such a way that the final antenna structure (number of modules) can be obtained by the repetition of the basic module. This number of modules will depend on the final service: coverage area, routes of the airplane, selected satellite, etc.

The concept of multifunctionality, which is the object of MULFUN project, has been applied to the antenna & RF front-end system. The multifunctionality has been applied in two ways: using multilayer technology at high frequency and using a composite base of aluminium foam and CFRP skins for holding the antenna. The first concept has allowed to reduce the number of connections and cabling and consequently the weight of the antenna. The second concept has allowed to provide good thermal dissipation and also reducing the weight of the system.

The initial objective of the MULFUN project was the design and development of a single module of antenna. However, all the aspects necessary for the implementation of the complete antenna have been taken into account:

- Complete mechanical integration
- Complete thermal dissipation

The BB3 breadboard will consist on 4 antenna modules: 1 real and 3 dummy antenna modules.

In addition, it has to be highlighted that the electrical design of one single antenna module has been a very challenging task. The number of necessary cables and connectors has been minimised at maximum level with respect to traditional designs by means of the use of multilayer technology, which at the frequency of operation we are working is also a very novel concept. In this way, it is obtained a robust, reliable and low weight prototype.

In detail, BB3 will permit to develop and demonstrate the capability of:

- ◆ Integrating surface mounted electronics devices
- ◆ Using advanced material with improved thermo-mechanical properties

From an electrical point of view, it can be said that there are three levels of boards and that each functional module is composed of the following PCBs:

- ◆ Patches layer → Highest level → **Patches PCB**
- ◆ Antenna modules → Intermediate level → **PCB_Up**: implements the antenna & RF front-end functionality. This printed circuit board includes the radiating elements, the first stage LNA, the down conversion chain and the IF amplification stage together with the combining network.

- ◆ Control & LO/IF distribution → Lowest level → PCB_Down will carry the control and power supply circuitry plus additional LO and IF distribution.

The relative position of the modules is a key aspect in the design of the complete antenna. An extensive work and simulation analysis was required in order to decide which the optimum configuration was. After some analysis, it was found that adjacent modules should be rotated 180° in order to improve the radiation performance of the antenna.

Next figure shows the top and bottom view of a real antenna based on 4 modules.

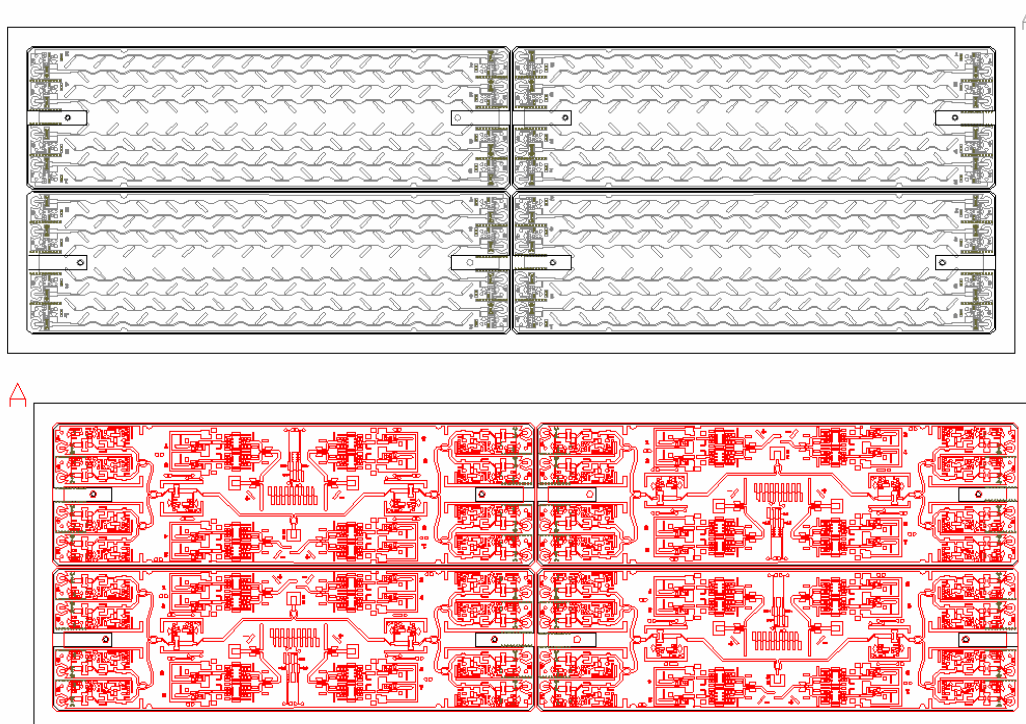


Figure 6: a) Antenna Layer (in front of the patches PCB). b) RF Layer (in front of the PCB_Down)

The PCB Up is a rigid board based on the employment of multi-layer technology. The necessity of bonding different layers together with the operational frequency band and the experience of the Partners has driven the selection of RO4003C substrate.

RO4003 Rogers High Frequency Circuit Materials are glass reinforced hydrocarbon/ceramic laminates. The adhesive to be used to bond the different substrates does not alter significantly the electrical loss of the bonded construction, while still providing ease of fabrication. RO4450B prepreg adhesive system is selected according to Rogers recommendations. Each ply of RO4450B prepreg will bond to a nominal 0.1mm thickness when recommended bonding parameters are used.

From the mechanical point of view, the antenna is composed of a sandwich base plate and some metallic components to assemble the PCB-s. As for the previous breadboards, the skins of the sandwich panel are made of the high thermal conductivity fibre K13D2U and the Ex1515 resin.



It should be highlighted that the thermal requirements of the antenna are quite restrictive. The maximum environmental temperature and the maximum operating temperature of the electronic circuit are very close. Therefore, the thermal control of the antenna is aid by a fan. In order to facilitate the air flow through the core of the panel, an aluminium foam has been used (instead of the honeycomb core used in BB1 and BB2).

The major disadvantage found in WP1 & WP2 was related with the impossibility of repair when the electrical circuits are directly bonded onto the panel. With BB3, the antenna, different ways to integrate the electronics were considered. Finally, blind rivet nuts were used to place the PCB-Down over the base plate.

Several manufacturing trials were performed in order to facilitate the manufacturing of the antenna and avoid problems. In the following picture, the final phase array antenna is shown:



Figure 7: BB3: Phase array antenna.

In the framework of WP4 a demonstrator of phased-array antenna for avionics application has been developed. The electrical design of the antenna has been implemented in multilayer rigid PCBs which integrate different RF, control and DC functionalities in different layers.

The PCBs are mounted on a “composite” frame, which allows reducing weight with respect to traditional designs based on aluminium (**35 % mass saving**). The BB3 has successfully passed the mechanical, thermal and electrical tests.

WP5: Power electronic housing

The objective of this prototype is the demonstration of the technical feasibility of a CFRP electronic housing featuring multifunctional properties in terms of thermal, structural and electrical aspects.

In order to focus on the multifunctional aspects of the prototype, a real component designed by CRISA is selected. It is the Sequential Electronic box for Ariane V. The current design is based on several vertical PCBs mounted on classical aluminium housing. The objective is to use spare electronic components available in Crisa facilities and to design and manufacture a new CFRP housing adapted to the available electronics. Summarising, the selected prototype consists of the following components:

- An aluminium external frame providing mounting features to the satellite panel.

- An aluminium inner frame for holding and positioning the mother board.
- A CFRP sandwich component which is the base for mounting the rest of the components. Both metallic frames are adhesively bonded to this sandwich component. The sandwich skins are high K carbon fibre and cyanate ester resin and the core is graphite foam. High thermal conductivity of this component in all directions (including through the thickness) provides heat dissipation from the electronics.
- The housing vertical walls, manufactured in one part in the same material explained before for the skins.
- The lid of the box in the same CFRP material.
- Wedge Locks (guides) for holding the PCBs. A different kind of guide from that used on the aluminium design has been selected because it is more suited for the CFRP configuration (no additional ribs are needed in the walls)
- Mother board, same than the aluminium design (spare component from CRISA).
- PCBs and aluminium stiffeners, also spare components coming from the aluminium design (spare component from CRISA).

The following figure is an exploded view of the box, where the main components can be shown:

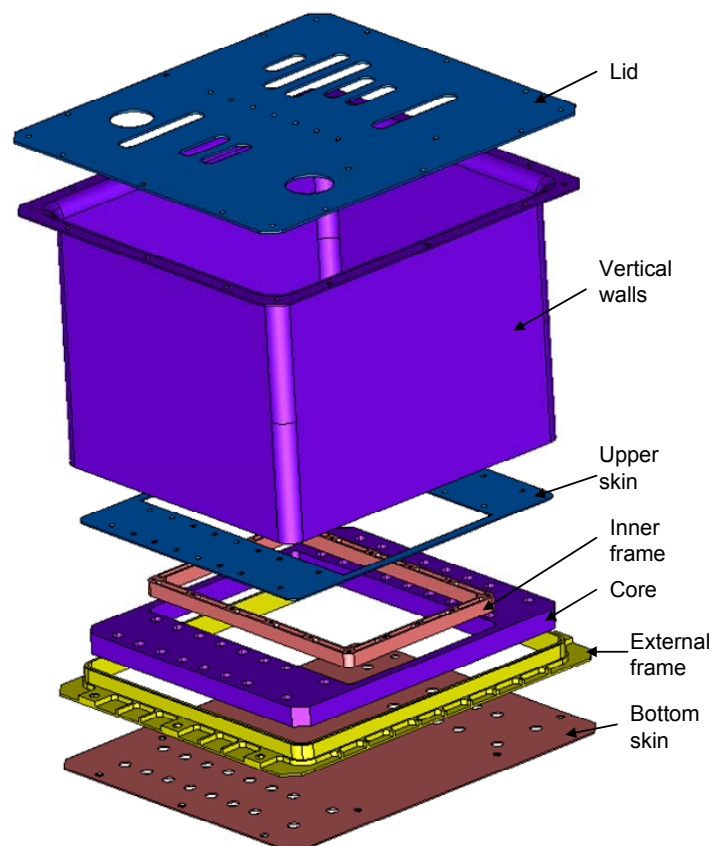


Figure 8: Exploded view of the box

A CFRP detailed design and complete thermal and mechanical analyses (vibration study) have been performed in order to validate the chosen geometry. The main results obtained in the analyses are summarized below:

		Comments on advantages of CFRP design	Savings
Mass	Housing (*)	Aluminium: 2.8kg CFRP: 1 kg	++
	Boards & Stiffeners	Identical than aluminium design: 5.4 kg	0
Thermal analysis	Average Temperature	Boards: +2.7°C Box skins: +4.2°C for top cover +2.4°C for lateral panels	~ 0
	Flux	74% exchanged by conduction (instead of 79% with aluminium design)	~ 0
Mechanical analysis	Natural frequencies	Boards: Identical than aluminium design	0
		Box skins: More uncoupling of housing modes with boards ones	++
	Stress	Boards: Identical than aluminium design	0
		Box skins: CFRP panels more resistant than aluminium design	++
	Maintaining parts: - riveting solution insures a good clamping - sticking solution: to be validated during manufacturing	+	

From the analytical point of view, the initial objective of this study was currently reached. Indeed, a good compromise between weight reduction, thermal and mechanical performances has been found.

Regarding the manufacturing, both skins, together with the graphite core and the two aluminium frames form the sub-assembly called Base Plate, which is the basis for mounting the rest of the box elements, including electronics. The graphite core is obtained by milling and drilling from a commercial sheet (15 x 210 x 240 mm). This specific graphite foam has been selected due to its outstanding through the thickness thermal conductivity. In contrast, mechanical properties are very poor, which complicates the machining process.

The following table includes the stacking sequence of each of the laminates:

Part	Number of layers	Thickness (mm)	Lay-up
Lower skin	12	1	[0/45/90/-45/0/90] _s
Upper skin	12	1	[0/45/90/-45/0/90] _s
Vertical walls	16	1.33	[(0/45/90/-45) ₂] _s
Lid	18	1.5	[(0/45/90/-45) ₂ /0] _s

The vertical walls have been manufactured in a single component, although some concern existed at the design stage about the ability of the brittle carbon fibres to conform to the fillet radii of the part. It is particularly complicated the lamination of the four corners in which three different edges converge. For assessing the technical feasibility of the proposed single part approach, several manufacturing trials on a scaled mould have been performed.

In the following figure, the developed electronic box is shown:

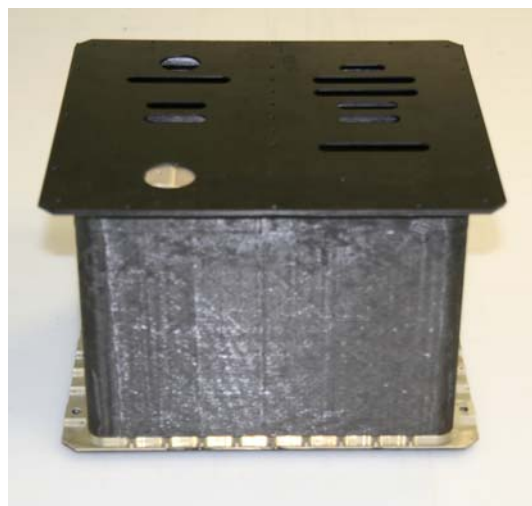


Figure 9: Developed electronic box

The manufactured box has been submitted to the following test campaign:

1. Initial Functional and Electrical Tests
2. Dry Thermal Tests
3. Mechanical Acceptance Tests:
4. Final Functional and Electrical Tests
5. Inspection and physical properties
6. Mass measurement.

It is concluded from the analysis of the obtained results that the MULFUN_ES has passed successfully the Validation Tests. A **mass reduction of 65 %** was achieved.

WP6: Exploitation and dissemination

Within this WP the technologies used in the development of the project have been analysed. The summary of the developed technologies is provided in the table below:

Technology	Demonstrator	Objective
Composite support panel with high-conductivity CFRP skins	BB1/BB2/BB3	Mass minimisation and simplification of the design w.r.t. standard support panels for electronics, based on use of high-k pitch fibers (integrated structural and thermal functions).
Integration of advanced distributed electronics in the facesheets	BB1/BB2	Reduction of cabling and connections, simplification of thermal paths by integration of flat (flexible) motherboards providing local interconnects and supporting surface-mounted components (MCM technology) Hermetic hybrids using frame technology, motherboards with flat electronics interconnections
Integration of embedded mini heat pipes	BB2	Mass/envelope minimisation and simplification of the design w.r.t. standard support panels for electronics, based on the integration of the thermal hardware into the structure (integrated structural and thermal functions).
Multilayer construction at high frequency. Implement different electrical functionalities in a single board (different layers)	BB3	Reduce cabling and connections → reduce weight and volume Reduce thermal paths from the electronic components
Manufacturing of a box composed of high conductivity fibres. Use of carbon foam (sandwich structure) for the base.	BB4	Reduce weight and volume

Main conclusions after the development & testing of these breadboards are:

- The results obtained show that the MFS concept provides advantages vs current radiator panel for space component.
- The possibility to have a high conductivity core increases the thermal dissipation even without the use of heat pipes.
- Mitsubishi K13D2U skins in Ex-1515 cyanate ester resin resulted in a good compromise in terms of performance/availability to cost/ratio.
- The CRS Cu-water mini heat-pipe is a commercial product resulting in cost savings and good performance.
- The criticality of using heat pipes is CFRP coupling (CTE mismatch). It is necessary to use a proper adhesive able to accommodate the differential expansion.



- Locating components directly over the skins has as main disadvantage that in case of a failure, the removal of the component is not easy. However, this solution is the best one from the power dissipation point of view.

- The use of multilayer PCBs at high frequency is feasible and really interesting to reduce weight and size.

A SWOT analysis of the Multifunctional Technology has been performed. Potential applications of the applied technologies as well as of the developed prototypes have been identified.

The following papers have been submitted:

- The paper *Development of light-weight multifunctional structures* was presented at the ICES 2007, the major international conference on thermal and environmental control of space systems.
- *Ku-band only-receive phased-array antenna for multimedia communication* paper accepted at the European Microwave Conference (EuMC). Active Array Antennas & Components (October 2008, Amsterdam)

WP7: EMC-EMI and radiation shielding: State of the art and selection of the approach to be followed

Within this WP, the study of materials and coatings to provide protection against electromagnetic and x-rays radiations has been performed. Analysis of the experience possessed by Yuzhnoye shows that most widespread and reliable means to provide shielding properties against electromagnetic radiation to composite materials are the followings:

- Fabric glassed (by the type of TSON, KVANT), containing in the fibre composition the rare-earth elements;
- Fabric (coal or Capron) with reflective covering, which is coated by the electrochemical way;
- Metallization film (polyethylene-terephthalate and polyimide);
- Foil.

To provide protection against penetrating radiation Yuzhnoye possesses an experience to create the following materials:

- Materials of the winding type containing of the rubber/silica compositions filled with hard-weight elements;
- Materials on the fabric base impregnated with epoxide bonding agents containing hard-weight elements;
- Silicone-organic rubbers with filler of hard-weight elements;
- Materials of the raising type on the base of the epoxide bonding agents and oxide/ hard-weight elements fluorine compositions;
- Protective coverings on the latex base with the hollow metallization spherical filler.

Yuzhnoye participates in the works generating lightened self-stuck materials on the base of super thin high-strength fabrics doubled with one-side metallization films.

With reference to the set task and on the base of theoretical evaluation founded on the experience possessed it is offered to consider the following variants of combined protection:



1. Coating on internal part, as an additional layer, the following
 - Tungsten foil layer of 0.1 mm thickness.
 - Self-stuck material on the base of the lower-thick polymer containing in its composition the layer with hard-weight elements;
 - Combined fabric-filmed self-stuck material containing hard-weight elements;
 - Protective covering, containing the hollow metallization spherical filler and hard-weight elements.
 - Metallic covering onto ready castings by the electrical-chemical way.
 - Hard –weight metal by the raising way or the precipitating way.
2. Introduce, as an additional filler, into bonding agent of casting the following:
 - Fillers containing hard-weight elements
 - Hollow metallization spherical filler and rare-earth elements

From the study performed, it can be summarized that:

1. Efficiency of shielding against electromagnetic radiation is a function of the following:
 - MFS structures;
 - Type of MFS element MFS material;
 - Magnetic permeability of material;
 - Specific conductivity of material;
 - Structure and parameters of the electromagnetic wave (the wave type, the field intensity, frequency, polarization, directions of extending, and etc.);
 - Mutual positioning of a radio noise source/receptor;
 - Quantity and parameters of the holes and apertures in MFS;
 - Quality of electric contact between MFS elements,
- 2 To increase the efficiency of shielding against electromagnetic radiation in composite structures, it is necessary raise their conductivity by the additional electro conductive layers inserting way.
- 3 Under space environment conditions the ionization dose is cumulated in consequence of the electron and proton radiations. Physical aspects of shielding for electron and proton radiations differ essentially.
 - Electron radiation of the space environment is shielded more effectively with materials possessing high core charge. Incidentally, negative factor is an increasing the intensity of generating the braking radiation, which contribute its share into ionization dose behind protection.
 - Proton radiation of the space environment is shielded more effectively with light materials, from which hydrogen is best.
 - Most well-known decision concerned to protection against the space environment electron radiation is to generate structures by the “sandwich” form with alternating layers of materials possessing low and high core charge.
For MFS, the role of materials with low core charge executes carbon-plastic casings, were carbon is dominant element. If to allocate a layer of hard-weight metal between them, it may be obtained, obviously, integrated solution allowing to improve simultaneously both protective performance concerned to space radiation and those concerned to EMC.
Most perspective decision is presented to allocate the tungsten layer between carbon-plastic casings.
- 4 Modern technique of radiation designing based on the developed construction 3-D models usage allows determining a view and geometry, and allocation area, and the protection value in the hard accordance with requirements for stability

against space radiations in the orbit referenced. Developer obtains a possibility to concentrate protection in those places, where it is effective in maximum rate, and take away it from areas, in which no protection is required. In so doing, at the smaller mass expenditures the protection higher level is provided for equipment, which is sensitive to the space radiation effects.

WP8: EMC-EMI and radiation shielding: manufacturing, testing and validation

The results obtained in this work package are summarized hereafter:

1. Experimental research of shielding efficiency of MFS samples in a frequency range of 1-12 GHz were carried out by channel measurements and measurements in free space (in anechoic room). Results of the carried out research lead to the following basic conclusions:

- 1.1. The attenuation of electromagnetic radiation by examined sandwich samples №1 and №2 in frequency range of 1-12 GHz is equal to 11-60 dB. The minimal value of attenuation is at the lower frequencies of the examined bandwidth.
- 1.2. The results of channel and free space (anechoic room) measurements for a sample given by INASMET - Technalia, Spain, are in close agreement.
- 1.3. The estimation of measurements error indicates that the total error of measurements does not exceed ± 3 dB.
- 1.4. Large SE values are associated with small size of honeycomb cells. SE values can be changed in certain limits by varying of size of honeycomb cells.
- 1.5. The results for case mock up are better in comparison with described in chapter 3 results for MFS samples. Obtained SE values of 30...60 dB in frequency range of 1-12 GHz meets the requirements for shielded facilities of the II-III classes [7]. Thus, the MFS similar to examined one can be used in device structures without additional shielding.

2. The calculation made showed that incorporation of tungsten into composite structure having thickness 50 μ m was the optimal decision to enhance the shielding properties.

3. The results of simulation of electrons transport through MFS materials, conducted by means of three-dimensional GEANT-4 code, completely confirm the validity of developed concept of improvement of space radiation shielding characteristics of MFS. For all energies in the range, typical for real space electron radiation, the accumulated dose behind the shielding, formed by modified sandwich panels with tungsten insertions, is up to 6-22 % lower, than behind an aluminum plate of 2 mm thickness.

4. The results of experimental research of MFS efficiency for electron radiation shielding qualitatively are in close agreement with the results obtained by means of three-dimensional simulation of electron transport through materials of the examined samples. These results confirm validity of decision on modification of MFS structures to improve their characteristics on space radiation shielding.

5. An estimation of protective properties of modified sandwich panels was conducted by means of three-dimensional Monte-Carlo simulation for the following orbits:

- a. a geostationary orbit with altitude of 35794 km and inclination of 0 degrees,



-
- b. a circular orbit with altitude of 1600 km and inclination of 60 degrees.
The results of calculations indicate that the required level of space radiation shielding is achieved with the developed concept of MFS modification.
6. It is necessary to continue research on improvement of space radiation shielding properties of MFS to integrate the methods of radiation designing into the process of MFS development.
7. Tungsten powder insertion into the CFRP sheets does not impair strength of MFS on detachment because the interlaminar strength of the sheets exceeds the adhesive joint strength of honeycomb filler with the sheets in 3-4 times, and the adhesive joint strength determines destruction of the structure.
8. Tests on radiation ageing indicate that for irradiation level up to $1.4 \cdot 10^3$ MRad the failure stress at even detachment of the sheets from honeycomb filler it is not affected by electron radiation, i.e. at these doses the radiation ageing of MFS materials is absent.



2.4 Results

As described in the previous chapter, during the project, four breadboards have been developed.

The technologies required for the MFS design have been developed and successfully applied in the four prototypes.

In all the cases, good mechanical, thermal and electrical performances have been obtained. EMC-EMI and radiation shielding aspects have also been considered. Different approaches in order to obtain a shielding behaviour comparable to a 2 mm thick aluminium plate have been evaluated.

Mass savings of around 35 % in the phase array antenna and around 65 % in the electronic box have been obtained. Therefore, the tasks and objectives of the MULFUN project have been successfully fulfilled.

The MULFUN project represents a first step in the development of the multifunctional structures. However, several aspects for future work have been identified:

- Thermal
 - Thermal transfer between the electronics and the panel
 - Temperature monitoring in order to evaluate the distribution in the panel
 - Alternative cooling by using fuel-air on avionics
 - Assess delamination and CTE for integration of active cooling devices into CFRP
- Manufacturability
 - Tools for series production (thermoplastics, RTM), complex shapes (curved panels- CFRP sandwich for fuselage) stiffeners
 - Assembly process: obtain higher conductivity through the thickness (bonding)
- Materials
 - Adhesives with less thermal resistance
 - Nanomaterials for EMI/Radiation on monolithic laminate
- Materials
 - Adhesives with less thermal resistance
 - Nanomaterials for EMI /Radiation on monolithic laminate
- Maintenance
 - Possibility of repairing the electronic circuits (removal of the electronics from the plate)
 - Methods of inspection
- Electronics
 - Introduction of heat sinks in intermediate layers to increase the thermal dissipation on high power devices.



3 DISSEMINATION AND USE

This section provides a publishable summary of each exploitable result the project has generated.

Multi-functional structural elements based on high-k carbon materials

Description: The developed technology consists of lightweight structural elements with high thermo-mechanical performance, based on the use of advanced composite materials with high-thermal conductivity high-performance graphite fibers and other high-conductivity carbon products, and on integrated design and manufacturing approaches.

Thermo-structural integration provides the capability of managing increased power density applications and permits mass saving and simplification of the layout, additionally supporting standardization. The need for dedicated thermal hardware is minimised and the necessary hardware, in turn, is embedded into the structure as much as possible.

The acquired knowledge is potentially applicable and advantageous for structural support panels and equipment envelopes within a wide range of aero-space applications.

Market application: The technology is usable for the markets/applications as follows:

- Space (radiators, solar arrays, active antennas, avionics, supports for dissipating payloads and optics)
- Aeronautics (avionics, antennas)
- Telecommunication

The technology is potentially applicable at different levels: application at preliminary stage to improve space products already started; full application under definition for future missions (from 2010).

Stage of development: The current state could be described with the TRL 5. Demonstrators exist on bread boards which were tested under relevant environmental conditions.

Property rights: Neither intellectual property rights exist nor a protection of rights is planned at the moment.

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Frame-lid technology:

Description: The frame-lid package is a special housing technology of electronic circuits. This technology confines itself to the protection of circuit parts where it is necessary e. g. in case of mounted bare dies or printed resistor. The electronics circuit board is used as the package bottom. The frame and lid complete the housing. The result is a hermetically sealed package with a reduce weight.

Market application: The packaging technology is usable for the markets/applications as follows:

- Space
- Avionic
- Telecommunication
- Industrial applications

The frame-lid packaging technology act as a circuit protection in all applications mentioned above.

The technology launch is planned for mid – end of 2008.

Stage of development: The current state could be described with the TRL 5 according to NASA or TRL 4 according to ESA space technology. Demonstrators exist on bread boards which were tested under relevant environmental conditions.

Property rights: Neither intellectual property rights exist nor a protection of rights is planned at the moment.

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Flat rigid/flexible motherboards and interconnections directly bonded on structural details/MFS:

Description (poss. products, functions, main advantages, innovations): The flat and flexible electronics is a technology which could be used for an assembly or integration of circuit boards and components on structural details like MFS. The designs consists of flat and rigid/flex motherboards and active elements in MCM technology. The main advantage is the flat form and the flexible interconnections which allow a direct bonding of the electronics on CFRP surfaces of the MFS element. An optimum heat dissipation could be guaranteed because of the close connection of the heat sources and the structural element as heat sinks. Thus, the excellent thermal properties of the CFRP surface / MFS panel is exploited. Moreover, the heavy housing and connecting cables could be removed and consequently the weight reduced in every case where the new technology is applicable.

Market applications: The flat flexible electronics technology is usable for the markets/applications as follows:ç

- Space
- Avionic

The technology could be used for integrated electronics which should replace bulky electronics boxes and heavy harnesses.

The technology launch is planned for 2010.

Stage of development (prototype, demonstrator, ind. product): Although, the current state could be also described with the TRL 5 according to NASA or TRL 4 according to ESA space technology it must follow further investigations regarding the optimisation of bonding technology and bonding material. Demonstrators also exist on bread boards which were tested under relevant environmental conditions.

Property rights: Neither intellectual property rights exist nor a protection of rights is planned at the moment.

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Multilayer design and manufacturing at high frequency

Result description: Implementation of a phased-array antenna combining two technologies developed within MULFUN project: high frequency multilayer PCB based on rigid substrate and composite base for structural and thermal improvement.

Possible market applications: telecommunications

Applications and further research: Before working in MULFUN project, all the electronics systems developed by TTI were supported by heavy aluminium structures.



On one side, working with multilayer PCBs has allowed us to integrate different electrical functionalities that previously were implemented in different boards.

Regarding the composite structures, TTI considers them applicable to other systems like the indicated in the following paragraphs:

- Currently TTI works on the development of telecontrol boards for space applications. They are Rx and Tx boards. In the case of the transmitting boards it is important to use this type of structures for dissipation of heat of the power amplifiers without an increase in the total weight.
- HPAs for ground applications
- Phased-array antennas. The concept developed within MULFUN was for a receiving phased-array. A step further should be done in the case of a transmitting antenna. In the case of high frequency phased-arrays it is necessary to combine several solid state devices. There exist several technologies to carry out the signal combining: coplanar, waveguide, etc. Main problem to deal with is the dissipation of the heat generated by these HPAs. TTI considers that in the future the concepts developed within BB2 could be applied. In any case, it is necessary to analyse the feasibility of its application in each concrete case. It is not allowable to sacrifice the electrical performance of the system in order to incorporate these concepts to the different designs.

Stage of development: Laboratory prototype

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