PRODEX EXPERIMENT ARRANGEMENT CHANGE NOTICE

PEA: 4000136662 **CN No:** 2
Institute: Institute of Thermomechanics (IT) of the Czech Academy of Sciences
Project: Development of FSUA for LISA mission – Phase B

Title of area affected: Funds and Term	**Article(s) of the Arrangement:** 2 & 3 **Initiator of change:** ESA

Description of change:

- The project will be prolonged until end of December 2023 to include all activities before the mission adoption.
- Design of Engineering Model included
- The cost plan is updated.

Reason for change:

- The activities in the current phase have been prolonged until the mission adoption expected to happen in November 2023. Design of Engineering model needed.

Funds *in addition to* those stipulated in Article 2.1 :

EURO: 143,319

Total amount LoL including present CN: 173,319 EURO

Effect on other Arrangement provisions: N/A	**Commencement of Term:** 1 Jan 2021 **End of Term:** 31 Dec 2023

Institute

Institute's representative(s):	Date
Miroslav Chomát doc. Ing. Miroslav Chomát, CSc. Digitally signed by doc. Ing. Miroslav Chomát, CSc. Date: 2023.05.16 09:56:35 +02'00'	

ESA

PRODEX Office representative(s):	Date
A. Deep Atul Deep Digitally signed by Atul Deep Date: 2023.05.11 09:16:02 +02'00' **V. Dowson** Veronique Dowson Digitally signed by Veronique Dowson Date: 2023.05.11 11:19:03 +02'00' **M. Lazerges**	Michel Lazerges Digitally signed by Michel Lazerges Date: 2023.05.15 14:23:51 +02'00'

1. WORK DESCRIPTION

In 2020, a PRODEX-funded project called “Development of FSUA for LISA mission – Phase B1” with the Institute of Physics (FZU), Astronomical Institute (ASU), Institute of Thermomechanics (IT) and Institute of Atmospheric Physics (IAP) started.

This change note refers to a natural continuation of the work started within this project as the project was prolonged and the budget enhanced to cover the mission adoption and start preparation of the engineering models. The technical work described covers 2023 and 2024. However, budget allocation has been made only for year 2023. A request for additional budget will be sent after LISA mission adoption review.

1.1. Proposed Developments

1.1.1. Hardware (software) description

There are several mechanisms onboard each of the spacecrafts directly connected to the scientific payload:

1 **PAAM** – Point-Ahead Angle Mechanism – The purpose of the PAAM is to compensate for the periodic variation in the out-of-plane point ahead angle – the difference in angle between the incoming and outgoing beams due to the relative velocity between the LISA spacecrafts. There is one PAAM mechanism per optical bench, two per spacecraft.

2 **FSU** – Fiber Switch Unit Actuator – there are two beams coming from each of the spacecrafts, each directed to one of the other two spacecrafts. Each of the optical benches which prepare these beams has two laser sources due to redundancy. Switching between the laser sources is performed using a λ\2 waveplate, which rotates the polarization of the incoming beam. By rotating this waveplate and with a combination of different polarizations of incoming beams and polarizing filters at the output, one can effectively select which of the beams is going to be used. In addition, the two optical benches on each Spacecraft are connected via an optical fiber to allow the phase of the light sent out on each arm to be compared. This so-called back-link fiber also needs a suitable level of redundancy and this will likely be implemented using the same FSU mechanism. There are four FSU mechanisms per spacecraft.

3 **BAM** – Beam Alignment Mechanism – replaced the former Active Aperture Mechanism – this mechanism is intended to shift the beam in two perpendicular directions. These shifts are the main contributors to Tilt-to-Length (TTL) coupling – this is the effect by which misalignments of the optical system introduce cross-coupling from rotations to path length. There are two BAM mechanisms per optical bench (Rx and Tx) and therefore 4 mechanisms per spacecraft.

The mechanism which is covered by this project is FSU, control boards located in the MCU and MCU box/housing. There is a list of requirements [AD-5], according to the current baseline and iterated during the Phase B1 of the project, which should be fulfilled by the **FSU** design:

- λ/2 waveplate with a diameter of 12 mm can be set arbitrary position with 1-degree tolerance within the 50-degree range is required.
- The mechanism actuation/detection has to be redundant.
- The expected lifetime is 12.5 years (in-flight), 2500 cycles (in-flight).
- The mechanism envelope should be 42x34x70 mm, with the beam axis approx. 20mm above the base. Control electronics are not part of this envelope.
- The mechanism has to be non-ferromagnetic and has to be UHV compatible (minimize outgassing).
- It has to hold its position during the launch or be able to find the correct position in orbit as needed.

All mechanisms are controlled from a common control electronics (**MCU** – Mechanism Control Unit), which is outside the optical bench. Our responsibility is to develop and manufacture (in the upcoming phases) the electronic board controlling the FSU and the MCU mechanics as well. Overall responsibility for MCU is on SRON, however. Control boards for other mechanisms are the responsibility of other partners as well. The requirements are then in [AD-6], [AD-7], and [AD-8].

1.1.2. Hardware (software) maturity

Table 1: TRL at the beginning and at the end of the project.

Item	Starting TRL	Target TRL
Mechanism	3	5
Encoder	3	5
Control electronics	2	3

The following tests/documents are expected to be provided in order to prove the TRL level:

- Analyses of the FSU mechanism
- Analyses of the MCU box/housing
- Production of the demo and engineering model of the mechanism
- Production of the demo model of the electronic boards
- Basic functional and environmental tests of the boards and the FSU EM
    - Functional tests in vacuum and air at operating temperature range (see [AD-5])
    - Vibration test, shock test (see [AD-5])
    - Stability tests
    - Preliminary lifetime tests
- Basic environmental tests of the MCU box/housing
- Test reports
- CAD models

1.1.3. Development approach

We have performed a lot of design iterations and tests of different building blocks within the Phase B1 of the project (as promised). The following building blocks were studied and tested:

1.1.3.1. Actuator

We have analyzed several different piezo-based designs. A number of simulations were performed, several test stands were created and tests were done. Internal reports and meeting notes are maintained within our Confluence system [RD-1].

Several test designs were prepared, manufactured and tested:

- Standard slip-stick design with one piezo and rotating part on the ball-bearing. Used mostly for surface analysis, control electronics preparation and coating studies.
- Three-finger design (several iterations) – we have demonstrated the redundancy (failure of one of three fingers does not affect the ability to rotate), developed control electronics and measurement, and surface analysis methods. High contact pressure was found. Used for principal verifications.
- Conical design (several iterations) – the design minimizes the contact pressure. Made of materials compatible with the final solution (Ti Gr5). Coatings applied. Currently being manufactured, tests are being prepared.

A number of simulations have been performed:

- Static simulations – for each of the designs we needed to define optimal dimensions to have well-defined piezo preloads. We have been testing the contact stresses as well. We have checked the deformation of the system itself because of the preload, distribution of the forces on the piezos, etc.
- Thermoelastic simulations – we have been successfully checking the stresses induced in the zerodur base plate if a three-point mount with flexible hinges is used. We have been trying to find the deformations and stresses induced on the rotating optic by operating temperature changes.
- Dynamic simulations – we have been checking the forces and stresses induced by the vibration during the launch. We tried to verify if the flexible hinges are usable for the design.

Based on this, the following design rules are the inputs for our work in B1+phases:

- Redundancy is crucial but based on the tests we have demonstrated that a stick-slip mechanism can be designed, where a failure of one of three piezos does not lead to failure of rotary movement.
- Piezo stacks are needed, as we can obtain them with insulating caps directly from the supplier.
- Tools for mounting the piezos were designed and tested.
- The rotating part clamps the vibrating part. The contact stress between those two parts has to be minimized. Otherwise, special coatings used to protect against cold welding and wear in general are damaged and not functional.
- A design with four piezos and trapezoidal double legs is the best current choice.
- Different coatings were studied, currently, a combination of TiN + CVD diamond is the promising one.
- Replacing the coatings with bulk material combination, which can prevent cold welding, is ongoing as well.

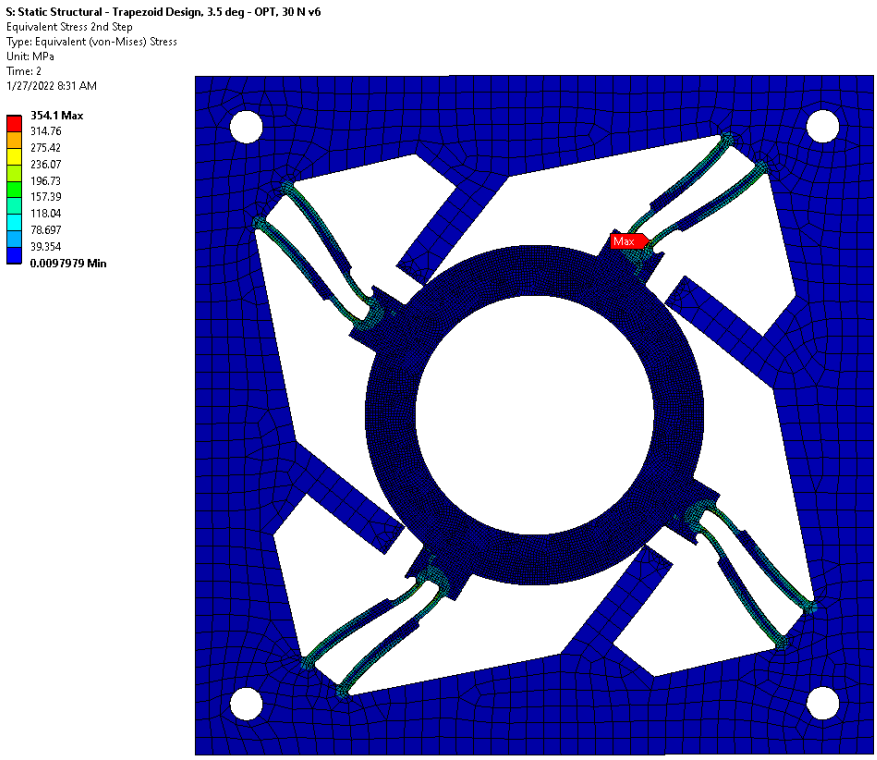

Figure 2: The most promising candidate of the actuator. Static simulation of stresses in the material.

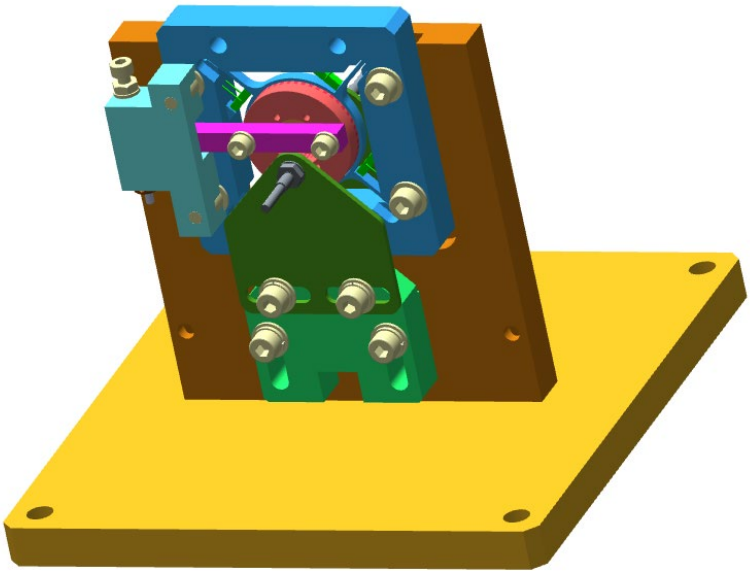

Figure 3: Test stand with the four piezo design (without the trapezoidal hinges). Being currently manufactured. Tests are to be performed during spring 2022. Tools for mounting the piezos are included, as this is a delicate operation. The tests were actually performed in 2022 and a new design has been prepared for manufacturing.

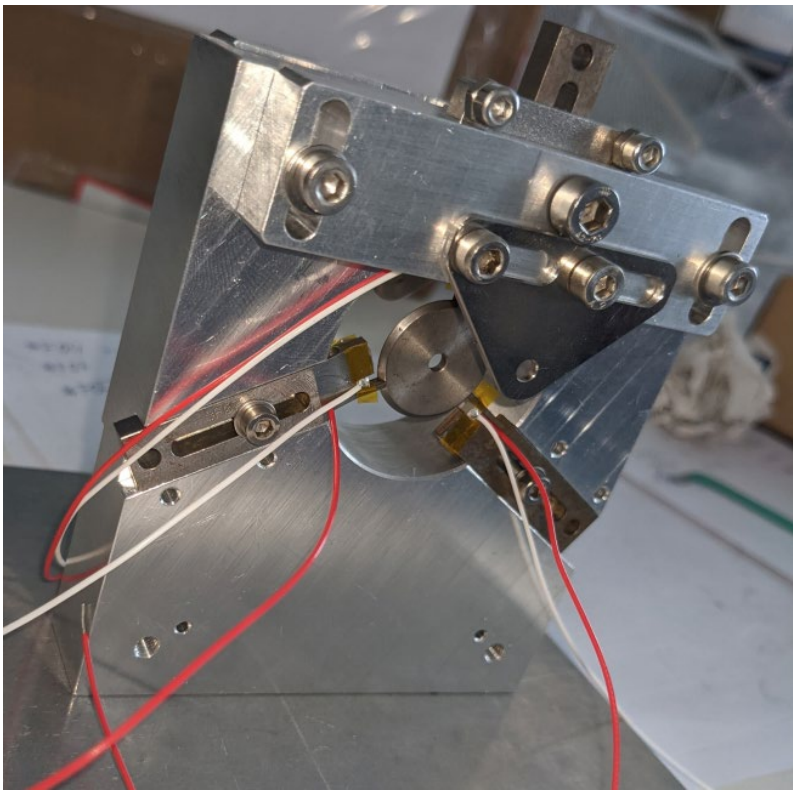

Figure 4: Three-finger test stand. Each finger used a single 2x2x2 mm piezo. Rotation speed was monitored. Several thousand rotations were a performer.

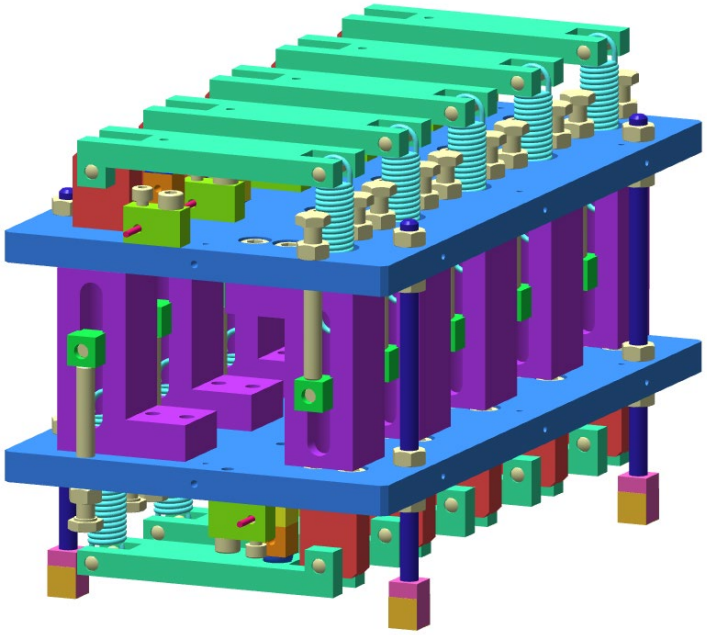

Figure 5: Cold welding test stand for accelerated tests of potential cold welding of a number (10x) samples with higher contact pressure. Currently being manufactured, tests are to be performed during spring 2022. Actual tests were finished successfully (no cold welding with newly selected coatings) by the end of 2022.

1.1.3.2. Encoder

We have analyzed several options for the absolute encoder, and we have selected the capacitive absolute encoder as the most promising one. The simulations were performed to check the possibility of achieving given resolution and accuracy within given space constraints. Cold redundancy was taken into account. Based on the simulations, several iterations of the demo encoder were produced and tested.

It consists of:

- The rotor–rotor is a disk with carefully designed conductive patterns. It is connected to the rotating part of the FSU. The rotor is the passive part.
- The stator – is a static disk coaxial and parallel to the rotor. There are sensing electrodes on the stator. From the signals from the stators and the known geometry of the stator (or calibration using the external encoder), we derive the actual rotation.

Based on this, the following design rules are the inputs for our work in the B1+ phases:

- Resolution is well achievable; accuracy is an issue and is much more dependent on the production and design quality.
- Within given space constraints, cold redundancy is probably not achievable using a single disk rotor. Two well-separated rotors are needed to reduce cross-talks.
- Need to calibrate for rotor/stator distance and actively measure it as well.

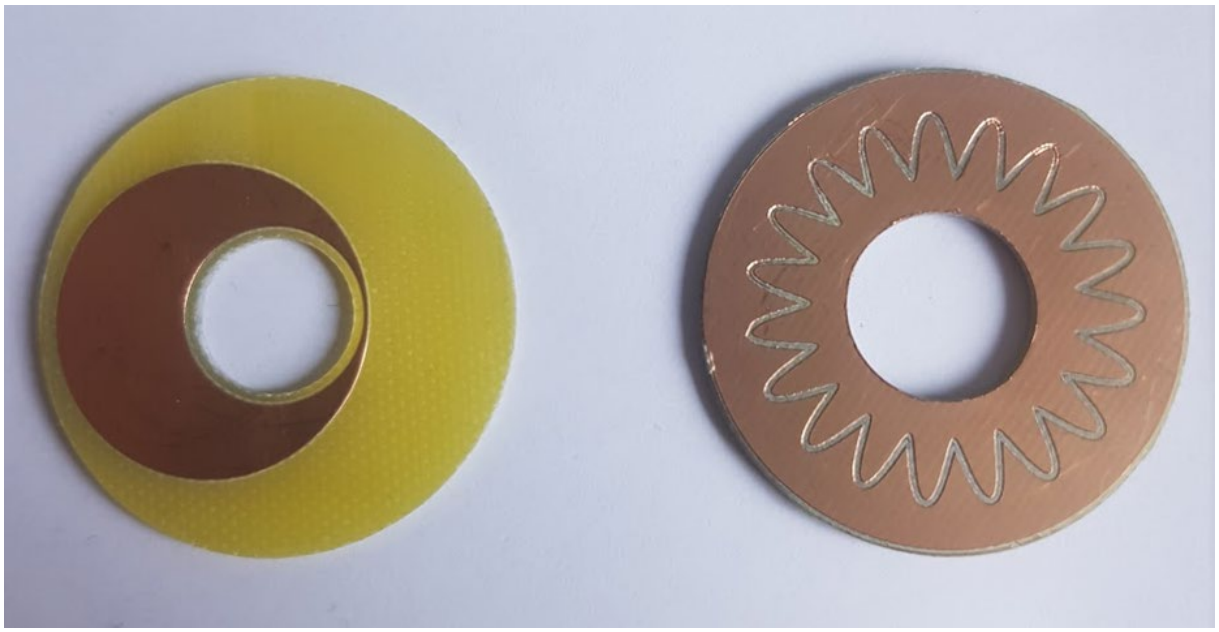

Figure 6: Example of two rotors. The low-resolution component (on the left) is connected with the high-resolution (right). Normally they can be on two sides of the single disk, but we need to prevent cross-talks.

2. APPLICABLE (AD) AND REFERENCE (RD) DOCUMENTS

2.1. Applicable Documents

The following documents are applicable to the Contract.

[AD-1]	ECSS-E-ST-10C Rev.1
[AD-2]	LISA-UKOB-INST-TN-009 – OB Mechanism Architecture Trade
[AD-3]	ESA-L3-EST-DD-001 – LISA Payload Definition Document
[AD-4]	LISA-FZU-FSU-PL-001 Engineering Plan
[AD-5]	FSU_RD_WiP_Snapshot_230116 – Functional and performance requirements
[AD-6]	AD18_IDS_ESA-LISA-EST-PL-RS-004_i0r3 – LISA IDS System and Interface Requirements Document
[AD-7]	ESA-L3-EST-MIS-SP-001, ESA-TEC-SP-006666, Iss2Rev0 – LISA Environment Specification
[AD-8]	SRON-LISA-MCU-SP-0001 – LISA OB MCU housing requirements

2.2. Reference Documents

The following documents can be used as a reference to the Contract.

[RD-1]	https://space-cas-cz.atlassian.net/wiki/spaces/LISA/overview
[RD-2]	LISA-FZU-MCU-RP-001_1.0_MCU-Housing_Design_Description.docx
[RD-3]	LISA-FZU-FSU-RP-001_1.0_FSU-Design_Description.docx
[RD-4]	LISA-FZU-MCU-RP-002_1.0_FSU-FEE_Design_Description_and_Analysis.docx
[RD-5]	LISA-FZU-MCU-AN-001_1.0_MCU-Housing_Analysis.docx
[RD-6]	LISA-FZU-FSU-AN-001_1.0_FSU-Mechanism_Analysis.docx
[RD-7]	LISA-FZU-FSU-ML-001_1.0_FSU-Mechanism_CAD_Model.stp
[RD-8]	LISA-FZU-MCU-ML-001_1.0_MCU-Housing_CAD_Model.stp

3. WORK BREAKDOWN STRUCTURE (WBS)

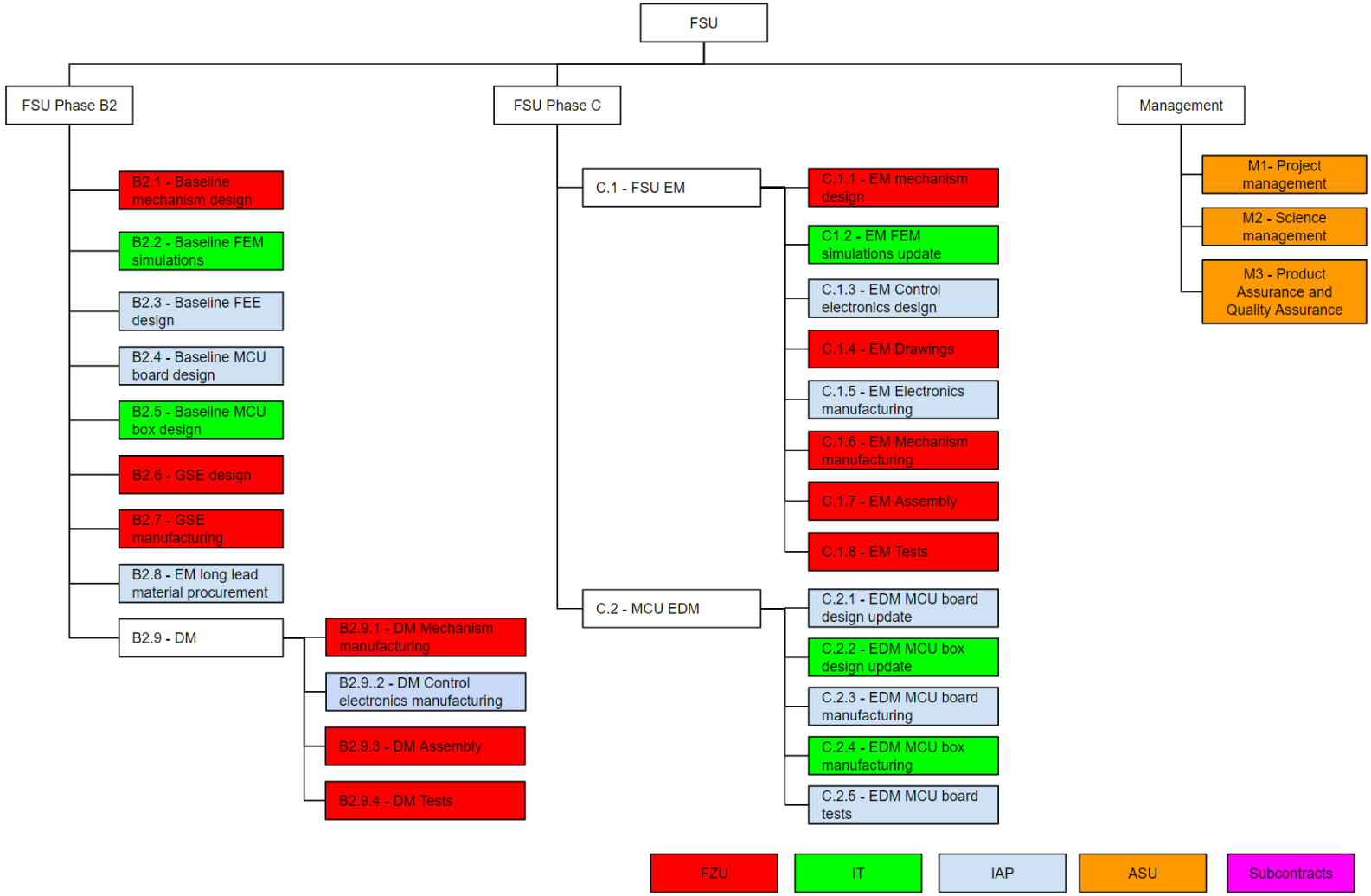

Figure 7: Proposed work breakdown structure of the project with responsibilities of different institutes color coded.

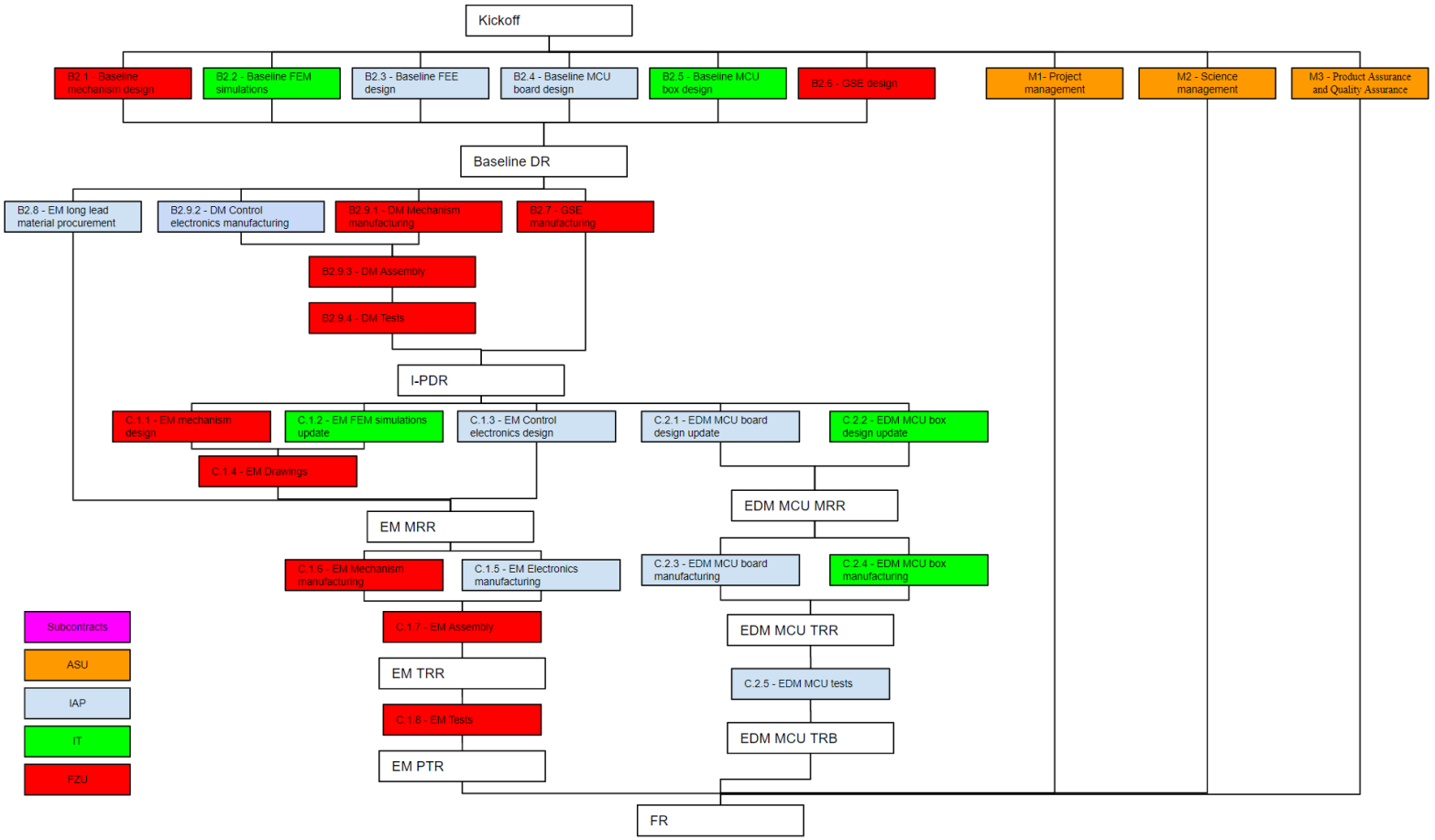

Figure 8: Proposed work logic. FSU EM is tested in our consortium and delivered to the OB team for assembly onto the OB and further tests with any required EGSE. The functionality of the MCU control boards is tested internally with the FSU EM but then sent to SRON together with the MCU box/housing for further assembly and tests of the MCU box/housing are tested internally only environmentally.

4. WORK PACKAGES

Work Package number:	WP B2.1
Work Package Title:	Baseline mechanism design
Responsible entity:	FZU
Local Managers:	Niels Lund
Project phases:	B2
Work Package Start and End dates:	2022-11-01 – 2023-02-28
Objectives: Prepare the baseline design of the FSU mechanism.	

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team

Description of work:

- Prepare baseline design of the mechanism (actuator, rotor, mechanical connection of encoder rotors, base mount to the zerodur, redundancy included)
- Prepare mechanism design report
- Prepare the initial version of EM CAD models
- Prepare DCL, DML, DPL
- Prepare the first version of the mechanism test plan

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism design report
- DOC-2: Mechanism test plan, first issue
- DOC-8: FSU DPL, first issue
- DOC-9: FSU DCL, first issue
- DOC-10: FSU DML, first issue
- SW-1: EM CAD model

Non-deliverables:

- N/A

Work Package number:	WP B2.2
Work Package Title:	Baseline FEM simulations
Responsible entity:	IT
Local Managers:	Igor Zolotarev
Project phases:	B2
Work Package Start and End dates:	2022-11-01 – 2023-02-28

Objectives: Prepare the baseline design FEM simulations of the FSU mechanism.

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team

Description of work:

- In collaboration with WP B2.1 prepare FEM simulations
  - Thermoelastic
  - Static
  - Dynamic

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism design report
- DOC-12: Mechanism analysis report
- SW-10: FSU Structural and thermal FEM models

Non-deliverables:

- N/A

Work Package number:	WP B2.3
Work Package Title:	Baseline FEE design
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	B2
Work Package Start and End dates:	2022-11-01 – 2023-02-28

Objectives: Prepare the baseline design of the FSU mechanism encoder and FEE electronics.

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team

Description of work:

- Prepare the baseline design of the encoder and FEE electronics, including the connector
- Prepare FEM simulations in Ansys Maxwell
- Build a prototype of the encoder and FEE
- Design and build an encoder test stand (upgrade the existing one)
- Update the design report
- Update the mechanism test plan
- Update DCL, DML, DPL

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism design report
- DOC-2: Mechanism test plan
- DOC-5: FSU FEE design & analysis report
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- DOC-16: MCU FSU control boards DPL
- DOC-17: MCU FSU control boards DCL
- DOC-18: MCU FSU control boards DML
- SW-1: EM electro schematics, first issue

Non-deliverables:

- Encoder and FEE prototypes for internal tests

Work Package number:	WP B2.4
Work Package Title:	Baseline MCU FSU control boards design
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	B2
Work Package Start and End dates:	2022-11-01 – 2023-04-30

Objectives: Prepare the baseline design of the FSU control boards to be placed into the MCU box/housing.

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team

Description of work:

- Prepare the baseline electronic and mechanical design of the MCU FSU control board
- Prepare the FSU FEE design & analysis report
- Prepare the initial version of the MCU FSU control boards test plan
- Prepare the initial version of MCU FSU control boards schematics

Excluded tasks:

- N/A

Deliverables:

- DOC-5: FSU FEE design & analysis report, first issue
- DOC-7: MCU FSU control boards test plan, first issue
- DOC-16: MCU FSU control boards DPL, first issue
- DOC-17: MCU FSU control boards DCL, first issue
- DOC-18: MCU FSU control boards DML, first issue
- SW-9: MCU FSU control boards schematics, first issue

Non-deliverables:

- N/A

Work Package number:	WP B2.5
Work Package Title:	Baseline MCU box/housing design
Responsible entity:	IT
Local Managers:	Radek Kolman
Project phases:	C
Work Package Start and End dates:	2022-11-01 – 2023-04-30

Objectives: Create baseline MCU box/housing design.

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team

Description of work:

- Prepare baseline design of the MCU box/housing
- Perform static and dynamic simulations
- Perform thermal and thermoelastic simulations
- Prepare MCU box/housing design report
- Prepare MCU box/housing test plan

Excluded tasks:

- N/A

Deliverables:

- DOC-4: MCU box/housing design report
- DOC-6: MCU box/housing test plan, first issue
- DOC-13: MCU box/ housing DPL, first issue
- DOC-14: MCU box/ housing DCL, first issue
- DOC-15: MCU box/ housing DML, first issue
- SW-8: MCU box/housing CAD model

Non-deliverables:

- N/A

Work Package number:	WP B2.6
Work Package Title:	GSE design
Responsible entity:	FZU
Local Managers:	Libor Švéda
Project phases:	B2
Work Package Start and End dates:	2022-11-01 – 2023-06-30

Objectives: Design the GSE needed for production and tests of the DM and EM of the FSU.

Inputs:

- Phase B1 results:
  - Design report
  - Requirements
  - Engineering Plan
- MoM from IDS and MCU team
- Mechanism baseline CAD model
- FEE+encoder baseline electro schematics
- DOC-1: Mechanism design report
- DOC-2: Mechanism test plan

Description of work:

- Design test stands needed for performing the tests described in the test plan
- Update the test plan accordingly
- GSE design description is going to be part of the mechanism test plan

Excluded tasks:

- N/A

Deliverables:

- SW-3: GSE CAD model, first issue
- SW-5: GSE electro schematics, first issue
- DOC-2: Mechanism test plan

Non-deliverables:

- N/A

Work Package number:	WP B2.7
Work Package Title:	GSE manufacturing
Responsible entity:	FZU
Local Managers:	David Hlaváček
Project phases:	B2
Work Package Start and End dates:	2023-07-01 – 2023-12-31

Objectives: Manufacture the GSE designed in WP B2.5

Inputs:

- DOC-2: Mechanism test plan
- SW-3: GSE CAD model
- SW-5: GSE electro schematics

Description of work:

- Prepare manufacturing documentation for the GSE
- Purchase all needed components for the GSE
- Manufacture the parts
- Assemble
- Prepare the first version of the control software
- Update the GSE CAD model if needed
- Update GSE electro schematics if needed
- Update the mechanism test plan if needed
- GSE hardware is not deliverable in the sense that it is supplied to ESA, it is used for internal purposes only

Excluded tasks:

- N/A

Deliverables:

- DOC-2: Mechanism test plan
- SW-3: GSE CAD model
- SW-4: GSE control software, first issue
- SW-5: GSE electro schematics

Non-deliverables:

- N/A

Work Package number:	WP B2.8
Work Package Title:	Long lead EEE part procurement
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	B2
Work Package Start and End dates:	2023-09-01 – 2024-03-20
Objectives: Procure long lead components for EM electronics production.	

Inputs:

- DOC-9: FSU DCL
- DOC-17: MCU FSU control boards DCL

Description of work:

- Prepare Long Lead Items list
- Procure the long lead items for manufacturing of EM electronics.

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- Long lead material for EM

Work Package number:	WP B2.9.1
Work Package Title:	DM Mechanism manufacturing
Responsible entity:	FZU
Local Managers:	David Hlaváček
Project phases:	B2
Work Package Start and End dates:	2023-03-01 – 2023-06-16

Objectives: Manufacture the DM intended for internal tests of the mechanism principle.

Inputs:

- DOC-1: Mechanism design report
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- SW-1: EM CAD model

Description of work:

- Adapt the EM CAD model if needed for the DM mechanism
- Prepare manufacturing documentation for the DM mechanism
- Acquire materials and parts needed for the DM production mechanism
- Produce parts of the DM mechanism

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- DM mechanism parts

Work Package number:	WP B2.9.2
Work Package Title:	DM Control electronics manufacturing
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	B2
Work Package Start and End dates:	2023-03-01 – 2023-06-16

Objectives: Manufacture the control electronics for the DM.

Inputs:

- DOC-1: Mechanism design report
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- SW-1: EM CAD model
- SW-2: EM electro schematics

Description of work:

- Prepare manufacturing documentation for DM encoder and readout electronics
- Acquire materials and parts needed for DM encoder and readout electronics
- Manufacture and test the DM encoder and readout electronics (FEE)

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- DM encoder parts
- DM FEE & MCU FSU control board

Work Package number:	WP B2.9.3
Work Package Title:	DM assembly
Responsible entity:	FZU
Local Managers:	Asen Christov
Project phases:	B2
Work Package Start and End dates:	2023-06-17 – 2023-07-15

Objectives: Assemble the DM

Inputs:

- DOC-1: Design report
- DM cad model
- DM electro schematics
- Manufactured DM mechanism parts
- Manufactured DM encoder parts
- Manufactured DM FEE parts

Description of work:

- Assemble the mechanism mechanics, encoder and FEE
- Initial power on
- Update design report based on the experience
- Update the test plan according to the experience

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism Design report
- DOC-2: Mechanism Test plan

Non-deliverables:

- Assembled DM

Work Package number:	WP B2.9.4
Work Package Title:	DM tests
Responsible entity:	FZU
Local Managers:	Michael Prouza
Project phases:	B2
Work Package Start and End dates:	2023-07-15 – 2023-08-15

Objectives: Perform tests of the DM

Inputs:

- Assembled DM
- DOC-1: Mechanism Design report
- DOC-5: Mechanism Test plan

Description of work:

- Perform the tests with the DM
- Update the Mechanism test plan
- Update the Mechanism test report

Excluded tasks:

- N/A

Deliverables:

- DOC-2: Mechanism test plan
- DOC-3: Mechanism Test report, first issue

Non-deliverables:

- N/A

Work Package number:	WP C.1.1
Work Package Title:	EM mechanism design
Responsible entity:	FZU
Local Managers:	Niels Lund
Project phases:	C
Work Package Start and End dates:	2023-09-01 – 2023-10-15

Objectives: Design the EM mechanism based on the baseline design and DM tests.

Inputs:

- DOC-1: Design report
- DOC-2: Mechanism test plan
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- SW-1: EM CAD model
- SW-2: EM Electro schematics

Description of work:

- Based on the experience with DM design and baseline mechanism design prepare the design of the EM
- Update DPL, DML, DCL, mechanism design report and test plan if needed

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism Design report
- DOC-2: Mechanism Test plan
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- SW-1: EM CAD model

Non-deliverables:

- N/A

Work Package number:	WP C.1.2
Work Package Title:	EM FEM simulations update
Responsible entity:	IT
Local Managers:	Igor Zolotarev
Project phases:	C
Work Package Start and End dates:	2023-09-01 – 2023-10-15

Objectives: Prepare the baseline design FEM simulations of the FSU mechanism.

Inputs:

- DOC-1: Design report
- DOC-2: Mechanism test plan
- DOC-8: FSU DPL
- DOC-9: FSU DCL
- DOC-10: FSU DML
- SW-1: EM CAD model
- SW-2: EM Electro schematics
- SW-10: FSU Structural and thermal FEM models

Description of work:

- Update the FEM simulations of the mechanism with modifications included in the WP C.1.1:
  - Thermoelastic
  - Static
  - Dynamic

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism design report
- SW-10: FSU Structural and thermal FEM models

Non-deliverables:

- N/A

Work Package number:	WP C.1.3
Work Package Title:	EM Control electronics design
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	C
Work Package Start and End dates:	2023-09-01 – 2023-10-15

Objectives: Design the control electronics needed to run the EM mechanism and encoder.

Inputs:

- DOC-1: Mechanism Design report
- DOC-2: Mechanism Test plan
- DOC-5: FSU FEE design & analysis report
- SW-1: CAD model
- SW-2: Electro project
- SW-9: MCU FSU control boards schematics

Description of work:

- Based on the experience with DM design update concept of FEE
- Based on the experience with DM update the MCU FSU control boards design
- Prepare the design of the control electronics to be delivered as EGSE with EM
- Update DPL, DML and DCL mechanism design report and test plan if needed

Excluded tasks:

- N/A

Deliverables:

- DOC-5: FSU FEE design & analysis report
- DOC-7: MCU FSU control boards test plan
- DOC-16: MCU FSU control boards DPL
- DOC-17: MCU FSU control boards DCL
- DOC-18: MCU FSU control boards DML
- SW-1: EM CAD model
- SW-2: EM Electro Schematics
- SW-7: EM EGSE electro schematics
- SW-9: MCU FSU control boards schematics

Non-deliverables:

- N/A

Work Package number:	WP C.1.4
Work Package Title:	EM Drawings
Responsible entity:	FZU
Local Managers:	Libor Švéda
Project phases:	C
Work Package Start and End dates:	2023-10-15 – 2023-11-12

Objectives: Prepare the production documentation for the EM mechanism.

Inputs:

- DOC-1: Mechanism Design report
- DOC-2: Mechanism Test plan
- SW-1: EM CAD model
- SW-2: EM electro schematics

Description of work:

- Prepare manufacturing documentation for the EM mechanism

Excluded tasks:

- N/A

Deliverables:

- DOC-1: Mechanism Design report
- SW-1: Mechanism CAD model

Non-deliverables:

- EM manufacturing documentation

Work Package number:	WP C.1.5
Work Package Title:	EM Electronics manufacturing
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	C
Work Package Start and End dates:	2023-11-13 – 2024-03-20

Objectives: Manufacture the control electronics needed for EM.

Inputs:

- DOC-1: Mechanism Design report
- SW-2: EM Electro schematics
- SW-7: EM EGSE electro schematics
- EM manufacturing documentation

Description of work:

- Manufacture the EM encoder
- Manufacture the EM FEE
- Manufacture the EGSE needed to control the EM
- Perform standalone (unit-level) testing of the electronics
- Prepare software for controlling the EGSE

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- SW-6: EM EGSE control software
- HW-2: EM harness
- HW-3: EGSE for controlling the EM
- EM encoder
- EM FEE

Work Package number:	WP C.1.6
Work Package Title:	EM Mechanism manufacturing
Responsible entity:	FZU
Local Managers:	David Hlaváček
Project phases:	C
Work Package Start and End dates:	2023-11-13 – 2024-03-20

Objectives: Manufacture the mechanism parts based on the manufacturing documentation.

Inputs:

- DOC-1: Mechanism Design report
- SW-1: EM CAD model
- EM manufacturing documentation

Description of work:

- Procure parts and materials for the EM mechanism
- Manufacture the parts, and apply coatings, if needed

Excluded tasks:

- Procuring long lead items for EM

Deliverables:

- SW-1: EM CAD model

Non-deliverables:

- EM manufacturing documentation

Work Package number:	WP C.1.7
Work Package Title:	EM assembly
Responsible entity:	FZU
Local Managers:	Asen Christov
Project phases:	C
Work Package Start and End dates:	2024-03-21 – 2024-04-03

Objectives: Assemble the EM mechanism

Inputs:

- DOC-1: Mechanism design report
- SW-1: EM CAD model
- SW-2: EM Electro schematics
- SW-6: EM EGSE control software
- SW-7: EM EGSE electro schematics
- EM manufacturing documentation
- EM mechanism parts
- EM encoder
- EM FEE
- HW-2: EM harness
- HW-3: EGSE for controlling the EM

Description of work:

- Assemble the mechanism, together with the encoder and EGSE control electronics
- Perform initial power on
- Update EM harness if necessary
- Update EGSE if necessary

Excluded tasks:

- N/A

Deliverables:

- HW-1: EM mechanism
- HW-2: EM harness
- SW-6: EM EGSE control software
- SW-7: EM EGSE electro schematics

Non-deliverables:

- N/A

Work Package number:	WP C.1.8
Work Package Title:	EM tests
Responsible entity:	FZU
Local Managers:	Michael Prouza
Project phases:	C
Work Package Start and End dates:	2024-04-18 – 2024-06-06

Objectives: Test the EM mechanism

Inputs:

- HW-1: EM mechanism
- HW-2: EM harness
- HW-3: EGSE for controlling the EM
- SW-6: EM EGSE control software
- DOC-2: Mechanism test plan

Description of work:

- Perform tests with the EM according to the test plan

Excluded tasks:

- N/A

Deliverables:

- HW-1: EM mechanism
- HW-2: EM harness
- HW-3: EGSE for controlling the EM
- DOC-2: Mechanism Test plan
- DOC-3: Mechanism Test report

Non-deliverables:

- N/A

Work Package number:	WP C.2.1
Work Package Title:	EDM MCU FSU control boards design update
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	C
Work Package Start and End dates:	2023-10-15 – 2024-01-16

Objectives: Update the MCU FSU control boards' design based on the experience with the DM.

Inputs:

- DOC-1: Mechanism design report
- DOC-2: Mechanism test plan
- DOC-5: FSU FEE design & analysis report
- DOC-7: MCU FSU control boards test plan
- SW-9: MCU FSU control boards schematics
- MoM

Description of work:

- Update the design of the MCU based on the experience with the DM and according to the EM design and specification updates
- Update the FSU FEE design & analysis report, schematics, DPL, DML, DCL and test plan if needed

Excluded tasks:

- N/A

Deliverables:

- DOC-5: FSU FEE design & analysis report
- DOC-7: MCU FSU control boards test plan
- DOC-16: MCU FSU control boards DPL
- DOC-17: MCU FSU control boards DCL
- DOC-18: MCU FSU control boards DML
- SW-9: MCU FSU control boards schematics

Non-deliverables:

- N/A

Work Package number:	WP C.2.2
Work Package Title:	EDM MCU box/housing design update
Responsible entity:	IT
Local Managers:	Radek Kolman
Project phases:	C
Work Package Start and End dates:	2023-10-04 – 2024-01-16

Objectives: Update the MCU box/housing design based on the experience with the DM.

Inputs:

- DOC-4: MCU box/housing design report
- DOC-5: FSU FEE design & analysis report
- MoM

Description of work:

- Update the design of the MCU box/housing based on the experience with the DM and according to the EM design and specification updates and discussions with the MCU team
- Update the MCU box/housing design report, CAD, DPL, DML, and DCL plan if needed
- Update the thermal, thermoelastic, static and dynamic simulations

Excluded tasks:

- N/A

Deliverables:

- DOC-4: MCU box/housing design report
- DOC-6: MCU box/housing test plan
- DOC-13: MCU box/housing DPL
- DOC-14: MCU box/housing DCL
- DOC-15: MCU box/housing DML
- SW-8: MCU box/housing CAD model
- MCU box/housing drawings

Non-deliverables:

- N/A

Work Package number:	WP C.2.3
Work Package Title:	EDM MCU FSU control boards' manufacturing
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	C
Work Package Start and End dates:	2024-01-30 – 2024-06-01

Objectives: Manufacture the EDM MCU FSU control boards.

Inputs:

- DOC-5: FSU FEE design & analysis report
- SW-9: MCU FSU control boards schematics

Description of work:

- Manufacture the MCU circuit boards according to the board schematics
- Initial MCU circuit board tests (power on tests, inspections)

Excluded tasks:

- N/A

Deliverables:

- HW-4: EDM MCU FSU control boards/boards

Non-deliverables:

- Spare EDM MCU FSU control boards/boards

Work Package number:	WP C.2.4
Work Package Title:	EDM MCU box/housing manufacturing
Responsible entity:	IT
Local Managers:	Igor Zolotarev
Project phases:	C
Work Package Start and End dates:	2024-01-30 – 2024-06-01
Number of Full-Time Equivalent (FTE) for the Work Package:	0.58

Objectives: Manufacture the EDM MCU box/housing.

Inputs:

- DOC-4: MCU box/housing design report
- SW-8: MCU box/housing CAD model
- MCU box/housing drawings

Description of work:

- Manufacture the box/housing according to the board schematics

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- EDM MCU box/housing

Work Package number:	WP C.2.5
Work Package Title:	EDM MCU electronics tests
Responsible entity:	IAP
Local Managers:	Jan Souček
Project phases:	C
Work Package Start and End dates:	2024-06-15 – 2024-09-16

Objectives: Integration and testing of MCU FSU control boards

Inputs:

- DOC-7: MCU FSU control boards test plan
- HW-3: EGSE for controlling the EM
- HW-5: EDM MCU FSU control boards
- SW-6: EM EGSE control software
- SW-7: EM EGSE electro schematics

Description of work:

- Perform board-level functional tests of the MCU EDM boards
- Perform interface tests with the EM encoder
- Perform environmental tests (EMC – local facility at IAP, Thermal + TVAC – Thermal Vacuum Chamber at FZU)

Excluded tasks:

- N/A

Deliverables:

- DOC-8: EDM MCU test report

Non-deliverables:

- N/A

Work Package number:	WP M1
Work Package Title:	Project management
Responsible entity:	ASU
Local Managers:	Jiří Svoboda
Project phases:	B2, C
Work Package Start and End dates:	2023-01-01 – 2024-10-15

Objectives: Maintain communication within the team, with the international consortium (IDS, LISA) and ESA.

Inputs:

- N/A

Description of work:

- maintain the management and communication tools (Confluence, Jira, tools for teleconferences)
- organize periodic meetings (management, technical)
- reporting to ESA
- communication to LISA Consortium and LISA IDS
- active participation in the LISA National Project Manager Board (NPMB)

Excluded tasks:

- N/A

Deliverables:

- regular progress reports

Non-deliverables:

- reports to LISA IDS
- reports to LISA NPMB
- minutes of meetings

Work Package number:	WP M2
Work Package Title:	Science management
Responsible entity:	ASU
Local Managers:	Georgios Loukes Gerakopoulos
Project phases:	B2, C
Work Package Start and End dates:	2023-01-01 – 2024-10-15

Objectives: The main goal is to manage the Czech scientific contribution to the LISA Consortium and coordinate activities between the scientific and technical team.

Inputs:

- N/A

Description of work:

- Organization of the activities of the Czech scientific team in the LISA Consortium.
- Development of gravitational waveform templates needed for the detection of gravitational waves from an Extreme Mass Ratio Inspiral by LISA.

Excluded tasks:

- N/A

Deliverables:

- N/A

Non-deliverables:

- Organization of meetings between the scientific and engineering teams within this project
- Codes producing Gravitational Waveforms for Extreme Mass Ratio Inspirals
- Gravitational Waveform templates for Extreme Mass Ratio Inspirals.

Work Package number:	WP M3
Work Package Title:	Product Assurance and Quality Assurance
Responsible entity:	ASU
Local Managers:	Jan Vaverka
Project phases:	B2, C
Work Package Start and End dates:	2023-01-01 – 2024-10-15

Objectives: Project coordination and maintenance management tools.

Inputs:

- N/A

Description of work:

- Hire the PA manager
- Prepare PA plan
- Support the rest of the team with PA tasks
- Radiation tests of selected components, if needed

Excluded tasks:

- N/A

Deliverables:

- DOC-11: PA plan, first issue

Non-deliverables:

- N/A

5. DELIVERABLES

5.1.Documentation

Table 2: Deliverable Documentation. X means to be supplied initially or a modified version. F means the final version.

	Milestone (delivery event/date)									Note
	Kick-off	I-PDR	EM MRR	MCU EDM MRR	EM TRR	EM TRB	MCU EDM TRR	MCU EDM TRB	FR	
Management Documentation										
Progress report		X	X	X	X	X	X	X	X	
Schedule	X	X	X	X	X	X	X	X	X	
Action Items List	X	X	X	X	X	X	X	X	X	
Deliverable Items List		X	X	X	X	X	X	X	F	
Summary report									F	
Technical Documentation										
DOC-1: Mechanism design report [RD-3]		X	X			X			F	Mechanism design description
DOC-12: Mechanism analysis report [RD-6]		X	X			X			F	Mechanism analysis
DOC-2: Mechanism test plan		X	X			X			F	Test for both mechanism and encoder
DOC-3: Mechanism test report		X	X			X			F	Test results for both mechanism and encoder
DOC-4: MCU Housing Design Description [RD-2]		X	X	X			X	X	F	MCU box/housing design
DOC-13: MCU Housing Analysis [RD-5]		X	X	X			X	X	F	MCU box/housing analysis
DOC-5: FSU FEE Design Description and Analysis [RD-4]		X	X	X			X	X	F	MCU FSU control boards design, encoder design and analysis
DOC-6: MCU Housing test plan		X					X	X	F	Test plan for the MCU box/housing
DOC-7: MCU FSU control boards test plan		X					X	X	F	Test plan for the MCU FSU control boards
DOC-8: EDM MCU test report								X	F	Test reports for the MCU FSU control boards
PA Documentation (to be tailored to the Phase of the activity)										
DOC-8: FSU DPL		X	X	X	X	X	X	X	F	
DOC-9: FSU DCL		X	X	X	X	X	X	X	F	
DOC-10: FSU DML		X	X	X	X	X	X	X	F	

	Milestone (delivery event/date)									Note
	Kick-off	I-PDR	EM MRR	MCU EDM MRR	EM TRR	EM TRB	MCU EDM TRR	MCU EDM TRB	FR	
DOC-13: MCU box/housing DPL		X	X	X	X	X	X	X	F	
DOC-14: MCU box/housing DCL		X	X	X	X	X	X	X	F	
DOC-15: MCU box/housing DML		X	X	X	X	X	X	X	F	
DOC-16: MCU FSU control boards DPL		X	X	X	X	X	X	X	F	
DOC-17: MCU FSU control boards DCL		X	X	X	X	X	X	X	F	
DOC-18: MCU FSU control boards DML		X	X	X	X	X	X	X	F	
DOC-11: PA plan		X	X	X	X	X	X	X	F	

5.2. Hardware

- HW-1: FSU Engineering model mechanism (2x)
- HW-2: FSU Engineering model harness (2x)
- HW-3: FSU EGSE model including harness (for controlling the EM)
- HW-4: EM MCU Housing (1x)
- HW-5: EM FSUA-FEE (Front end electronics)

5.3. Software

- SW-1: FSU EM CAD model ([RD-7])
- SW-2: FSU EM Electro Schematics
- SW-3: GSE CAD model(s) (test stands, calibration stands, jigs)
- SW-4: GSE control software (scripts, test stands, calibration stands)
- SW-5: GSE electro schematics (test stands, calibration stands)
- SW-6: FSU EM EGSE control software (provide a way to run the mechanism without the MCU)
- SW-7: FSU EM EGSE electro schematics
- SW-8: MCU housing CAD model ([RD-8])
- SW-9: FSU-FEE schematics
- SW-10: FSU Structural and thermal FEM models
- SW-11: MCU Structural and thermal FEM models

6. SCHEDULE

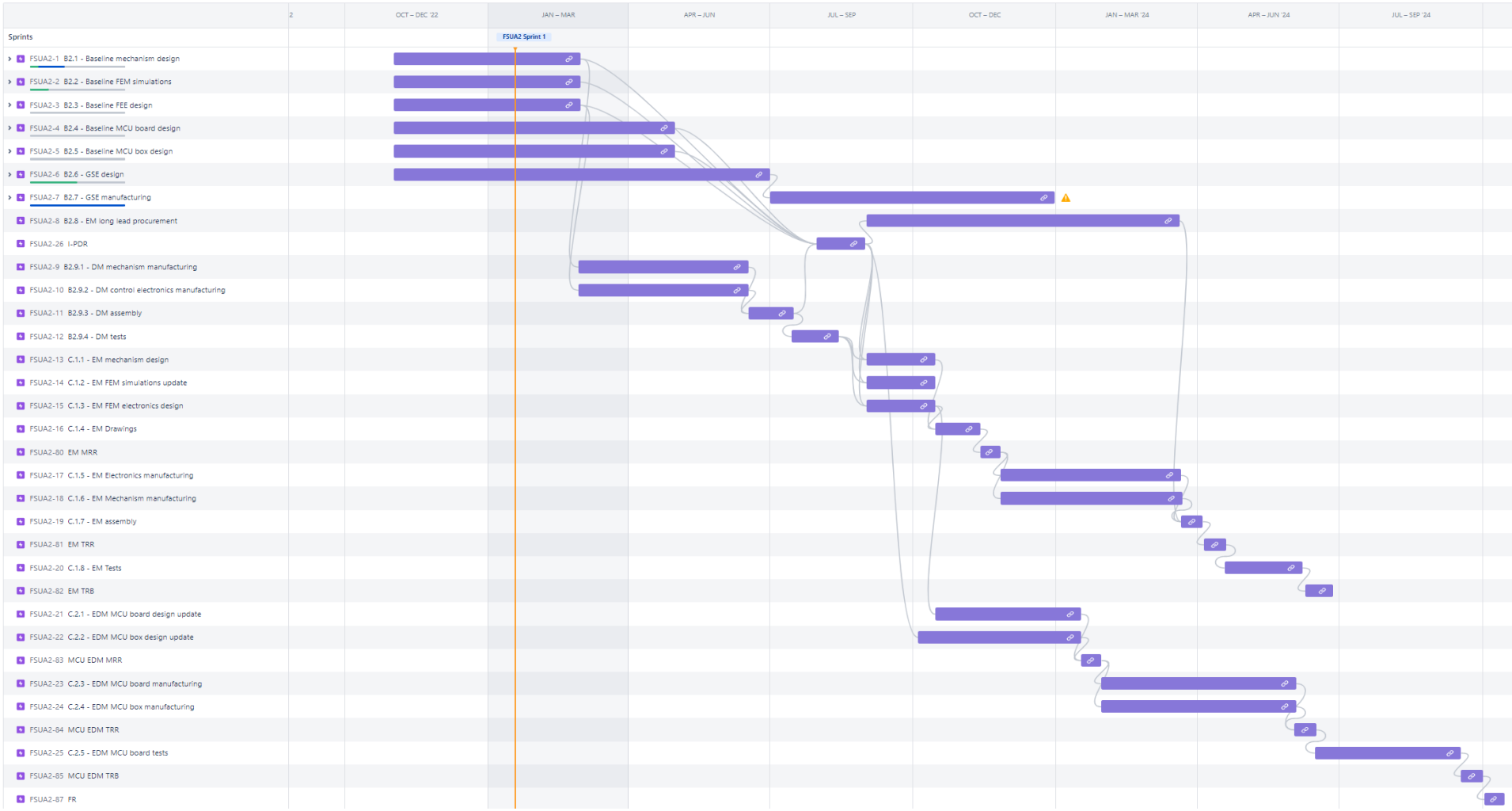

Figure 9: Updated Gantt chart of the project

7. INVOICING

The process of invoicing remains the same as during the Phase B1

8. PROJECT CHECKPOINTS

Project progress and deliverables will be checked according to Table 3.

Table 3: Checkpoints for deliverables readiness.

Check-Point number	**Planned date**	**Description**
Kickoff	01/2023	PRODEX project kick-off
I-PDR	08/2023	IDS and OB teams invited, MCU team invited
EM MRR	11/2023	IDS and OB teams invited
MCU EDM MRR	1/2024	IDS and MCU teams invited
EM TRR	4/2024	IDS and OB teams invited
EM TRB	6/2024	IDS and OB teams invited
MCU EDM TRR	6/2024	IDS and MCU teams invited
MCU EDM TRB	9/2024	IDS and MCU teams invited
FR	10/2024	PRODEX project final review

FINANCIAL PLAN

Project Name: Development of FSUA for LISA mission – Phase B

Institute: Czech Academy of Sciences, Institute of Thermomechanics

PI: Miroslav Chomát

Starting date: 01/01/2021 Ending date: 31/12/2023

Table 4: PRODEX experiment arrangement – IT costs

INSTITUTE COSTS	2021		2022		2023		TOTAL
	FTE[(1)]	Costs	FTE	Costs	FTE	Costs	(Costs)
Miroslav Chomát	0,1	3550	0,25	856	0,25	11475	**15 881**
Igor Zolotarev	0,1	3550	0,3	1065	0,25	11475	**16 090**
Radek Kolman	0,1	3550	0,2	710	0,3	13770	**18 030**
Jiří Šonský	0,1	3550	0,2	710	0,3	13770	**18 030**
Michal Mračko	0	0	0	0	0,5	21480	**21 480**
Ladislav Musil	0	0	0	0	0,2	8040	**8 040**
Luděk Pešek	0,1	3550	0,2	710	0,2	9180	**13 440**
Dušan Gabriel	0,1	3550	0,2	710	0,2	9180	**13 440**
Jan Masák	0	0	0	0	0,2	8040	**8 040**
Vítězslav Bula	0	0	0	0	0,5	21480	**21 480**
							-
Total Manpower	**0,60**	**21 300**	**1**	**4 761**	**2,39**	**127 890**	**153 951**
Travel cost (* Exhibit A to Table 1)		-		-		2 400	**2 400**
Cost of items purchased by Institute, funded from PEA (** Exhibit B to Table 1)		-					-
Miscellaneous costs (*** Exhibit C to Table 1)		-		1 259			**1 259**
Overheads (state % and costs they apply to):	Rate:	Overhads	Rate:	Overhads	Rate:	Overhads	
	10%	2 130	9%	550	10%	13 029	**15 709**
Items purchased by ESA on behalf of Institute (see Table 2)		-		-		-	-
Grand Total		**23 430**		**6 570**		**143 319**	**173 319**

Table 5: Exhibit A to Table 4 - IT Travel plan.

Year	*Destination and purpose*	*Number of trips*	*Number of persons per trip*	*Number of days per trip*	*Travel costs per person/trip*	*Total cost for all travelers per trip (EURO)*	*Total cost for all trips (EURO)*
2021						-	-
						-	-
						-	-
						-	-
Total 2021						-	-
2022						-	-
						-	-
						-	-
						-	-
Total 2022						-	-
2023	OB meeting	1	2	3	1 200	**2 400**	**2 400**
						-	-
						-	-
						-	-
Total 2023						**2 400**	**2 400**
Grand Total							**2 400**

Table 6: Exhibit B to Table 4 - Items purchased by the IT.

Year	*Item, supplier, proposed country of purchase (*)*	*Unit price*	*Number of units*	*Total Price (EURO)*
2021				-
				-
				-
				-
Total 2021	N/A	N/A	N/A	-
2022				-
				-
				-
				-
Total 2022	N/A	N/A	N/A	-
2023				-
				-
				-
				-
Total 2023	N/A	N/A	N/A	-
Grand Total				-

Table 7: Exhibit C to Table 4 – Miscellaneous costs at IT.

Year	*Miscellaneous cost, designation*	*Total Price (EURO)*
2021		
Total 2021		**-**
2022	Small equipment and components < 5000 EUR	1 259
Total 2022		**1 259**
2023		
Total 2023		**-**
Grand Total		**1 259**

Table 8: Items to be purchased via ESA on behalf of the IT (above 5 000 Euro)

Year	***Item (*), supplier and proposed country of purchase (**), planned month/year of procurement (***)***	***Total Price (EURO)***
Total		**-**
Total		**-**
Total		**-**
Grand Total		**-**