ANNEXE 1

Mission dimensioning and EMC studies for CIRCUS

Prepared by	Function	Signature	Date
M. DEKKALI	Project manager		
Verified by	**Function**	**Signature**	**Date**
Approved by	**Function**	**Signature**	**Date**
M. DEKKALI	Project manager		
For application	**Function**	**Signature**	**Date**
K. ISSAUTIER	Principal investigator		

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l'Observatoire de Paris | LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

CNRS – Observatoire de PARIS
Section de MEUDON – LESIA
5, place Jules Janssen
92195 Meudon Cedex – France

CHANGE RECORD

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00	00	31/08/2020	M.DEKKALI	Creation of the document
00	01	02/09/2020	M.DEKKALI	Final release for distribution

LIST OF ACRONYMS

Acronym	Definition
ADC	Analog-to-Digital Converter
ADCS	Attitude Determination Control System
CIRCUS	Characterizing the Ionosphere with a Radio receiver on a CUbeSat
DAC	Digital-to-Analog Converter
DSP	Digital Signal Processing
EMC/EMI	Electro-Magnetic Compatibility / Electro-Magnetic Interference
EPS	Electrical Power System
FPGA	Field Programmable Gate Array
GPS	Global Positioning System
HW	Hardware
I/F	Interface
OBC	On-Board Computer
P/F	Platform
P/L	Payload
QTN	Quasi-Thermal Noise
SIM	Sonde à Impédance Mutuelle
SW	Software

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1 Introduction

1.1 Scope of the document

This document constitutes the so called “Special Technical Conditions of Contract” for the studies of the CIRCUS mission and EMC tests of the associated CubeSat platform. The expected work relates to the following points, which correspond to the three workpackages detailed in chapter 3. Namely:

- To study of mission scenarios and sizing of the platform accordantly
- To carry out the EMC testing for characterization of the platform
- To provide an EMC simulation model of this same platform

This document details the scope of the activities to be carried out by the Contractor in accordance with the project requirements. The Contractor must comply with the specific clauses defined here, as well as the general purchasing conditions of the Observatoire de Paris.

1.2 Selection criteria

The Contractor will be selected following according to the criteria listed below:

ID	Selection criteria	Contribution
1	Suitability of the proposal with respect to the tasks defined in this contract	30%
2	Experience and/or technical expertise of the candidate in the fields of activity described in this contract	25%
3	Global cost	25%
4	Compatibility of the schedule with the constraints of the project	20%

2 Presentation of the CIRCUS mission

2.1 Context

CIRCUS is a nanosatellite mission to explore the E/F layers of the Earth's ionosphere. The project is led by LESIA in cooperation with LPC2E, ONERA, and Sorbonne University.

Its scientific objective is to measure in-situ the local parameters of the ionospheric plasma (density and temperature of electrons) with a high temporal and frequency rate, with challenges in space weather. These measurements will be performed in the range from 20kHz to 20MHz using two complementary measurement methods:

- Quasi-thermal plasma noise spectroscopy (QTN, developed at LESIA)
- The mutual impedance probe (SIM, developed at LPC2E)

Radio measurements constituting the heart of the mission, CIRCUS is therefore coupled with important technical objectives: the mission will indeed experiment innovative instrumentation; and demonstrate the feasibility of a radio experiment on a CubeSat platform.

Scientific drivers

- To access the macroscopic parameters (density, temperature) of the ionospheric plasma, by probing regions where the ionosphere is poorly known (first radio measurements in these regions)
- To perform measurements at high spatial-temporal and frequency resolution for the study of ionospheric turbulence
- To combine the QTN and SIM measurement methods in a single experiment to optimize scientific feedback according to ambient plasma conditions and inter-calibrate the measurements

Technological drivers

- To experiment with a new instrumental combination associating a radio spectrometer and a mutual impedance probe
- To deploy in space a miniaturized and very demanding in performance payload, but with limited resources
- To demonstrate the feasibility of a radio experiment on a nanosatellite platform

The CIRCUS experiment is considered on a 3U CubeSat for a lifetime of approximately 2 years. The nanosat will be placed in a polar orbit at an altitude of about 500 km. This will allow it to scan the entire surface of our globe and thus to make measurements throughout its trajectory and its descent, down to about 100 km.

2.2 Building blocks

2.2.1 Product tree

The tree structure below identifies the main components of the CIRCUS project:

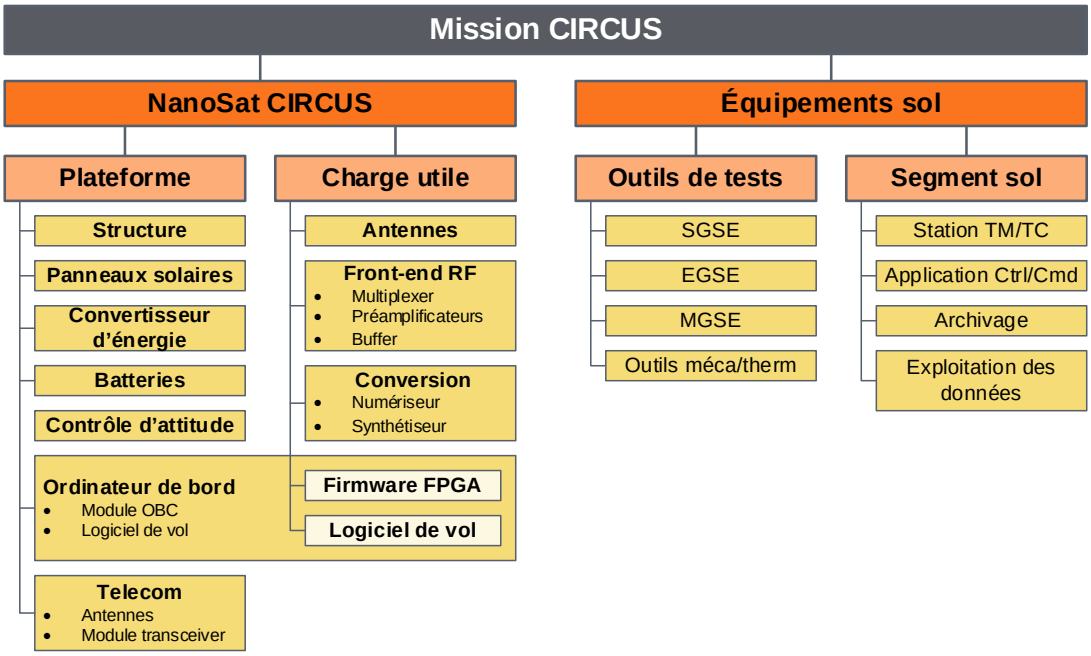

Figure 1. CIRCUS product tree

2.2.2 The platform (P/F)

According to our preliminary predictions, the P/F would consist of the following modules:

- Mechanical (and thermal) structure
- Solar panels
- Power supply (EPS)
  - DC-DC converter
  - Voltages distribution
- Batteries
- Attitude Determination and Control System (ADCS)
  - Magnetometer/Magnetorquers
  - Reaction wheels
  - Solar sensors
  - GPS
- On-Board Computer (OBC)
  - OBC module
  - FPGA firmware
  - P/F flight SW
  - P/L flight SW
- Telecom
  - S-band transceiver
  - Patch antennas

2.2.3 The payload (P/L)

The P/L corresponds to the QTN/SIM instrument of the CIRCUS experiment. It is made up of three fundamental elements.

1. **The measurement antennas**

   The measurement antennas are made up of four deployable wired-monopoles. Each monopole has a length of 1m and should be as thin as possible (typically 1mm diameter). The monopoles are combined 2 by 2 to form dipoles appropriate to QTN and SIM measurements:

   - 2x orthogonally crossed dipoles for QTN measurements
   - 2x V-shaped dipoles for SIM measurements

   To do this, the antennas are switched sequentially from one mode to another; and QTN / SIM measurements are time-shared.

2. **The QTN receiver / spectrometer**

   It consists of two reception channels operating in parallel or separately.

   The radio signal from antennas is injected in the reception channels via the input multiplexer (Mux). The preamplifiers adapt the input signal to adjust it to the ADC dynamic range. After anti-aliasing filtering (AAF), the signal is digitized at a rate of 60 MS/s with a 16-bit resolution.

   In order to access the details of the radio signal in the observation range (20kHz- 20MHz), the spectrometer calculates and supplies the wavelet and/or Fourier components with the requested resolution, as well as the correlations of the two pathways.

3. **The SIM transmitter / receiver**

   In the SIM configuration, the ionospheric medium is excited by the emitter using one of the two dipoles. This transmitter consists of a D/A converter generating the desired waveform. This signal is used to scan the entire observation range step by step. Wave / Plasma interactions are detected on the other dipole, then digitized and analyzed for each frequency step into one of the two receiving channels.

2.2.4 The ground segment

The ground segment is a part of the CIRCUS mission. It derives in two main products:

- The test equipment accompanying the development and validation phases
- The ground segment intended for the commissioning and in-flight operations

2.3 System partitioning

A possible partitioning of the CubeSat equipped with its P/L is illustrated below:

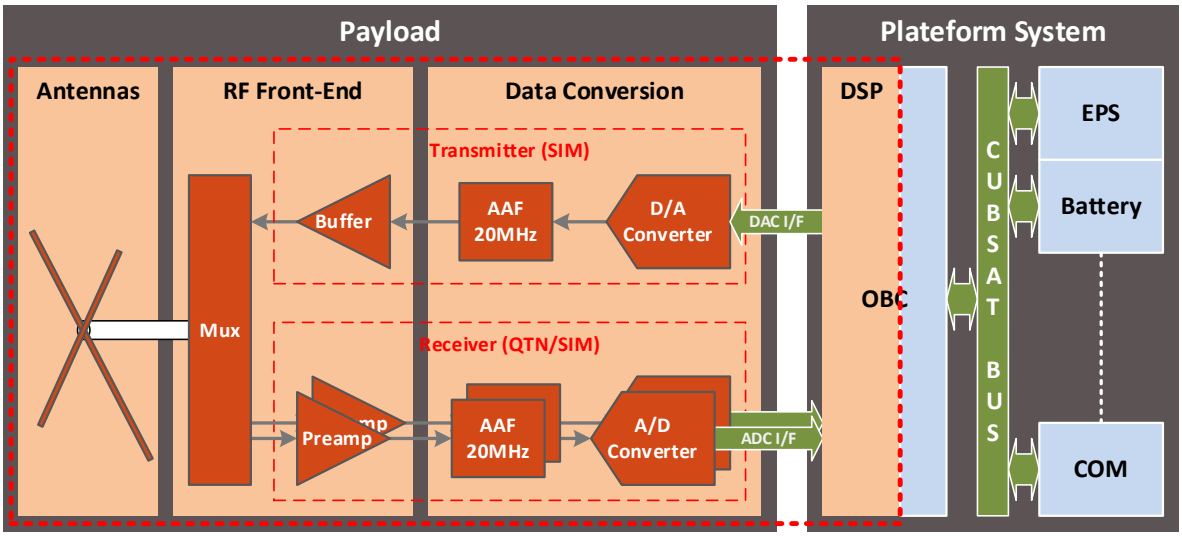

Figure 2. CIRCUS system partitioning

The payload section is specific to the QTN and SIM P/L. It consists of the measurement antennas connected to an RF front-end, which is itself interfaced to the data conversion board.

The digital functionalities of the P/L are implemented in the FPGA of the OBC component of the P/F. To do this, the latter must have the necessary resources to manage both, the in-flight operations of the satellite and the scientific modes of the instrument: acquisition of time series from ADC, generation of waveforms to the DAC, execution of on-board DSP algorithms.

The FPGA firmware and the P/L embedded SW ensure all processing and flight operations related to scientific experience. The P/F SW focuses on the management of TM/TC/HK and the operations of the CIRCUS mission.

This architectural assumption supposes, that the OBC integrates the FPGA resources and that it has adequate links to interface with the ADCs and the DAC.

2.4 Instrument datasheet

Item	Configuration	Format	Consumption	Mass	Interfaces to the P/F
Measurements antennas	4 monopoles arranged orthogonally to each other and on the same plane, which is perpendicular to the prograde direction	1m / monopole (2m tip-to-tip when deployed)	2 à 4 W during 30s upon deployment	< 500gr	- Volume of ½U for the 4 monopoles - Cmd/Ctrl for the deployment
Electronics	- RF front-end - Data conversion board	2 PC104 standard cards	< 1 W distributed over the 2 cards	< 300gr	- Volume of ½U for 2 boards - Pwr: 3V3, +5V - I/F ADC/DAC: SREDES links (5 LVDS pairs @ 2 Gb/s)
On-board processing	- FPGA Firmware - Flight SW	CPU and FPGA from the OBC	< 4 W into the OBC	cf. OBC	SW partition dedicated to the P/L

3 Scope of activities

The activities will be organized around the three workpackages described below. The Contractor will provide a technical and financial proposal detailing:

- The activities program and related schedule
- Deliverables and their deadline
- The details of costs

3.1 Workpackage 1: Preliminary study of the mission

The purpose of this workpackage is to identify a representative architecture of the CIRCUS CubeSat based on realistic mission scenarios.

3.1.1 Tasks

After analyzing the need, the Contractor must proceed to the study of mission scenarios adapted to the scientific objectives. Then, it will propose an avionics architecture of the CubeSat, that satisfy the requirements of the mission (orbit, pointing, in-flight operations, I/F with the P/L, etc.) At the end of this study, all the components of the P/F will have been identified and their accommodation and I/F defined.

This workpackage covers at least the following points:

- The study of the mission in its orbital aspects
- The definition of the avionics architecture of the P/F, by specifying its I/F with the P/L
- The architecture of the flight SW and the HW/SW partitioning
- The ground segment concepts
- A 3D model, including the technical budget assessment
- The technical risk analysis
- The proposal of a development plan and schedule for a complete mission
- The cost estimated of the mission (excluding P/L) from prototyping to launch, including the ground segment and operations center

3.1.2 Deliverables

At the end of this study, the Contractor will provide the following deliverables:

- The mission scenario study report
- The P/F study report and justifications of the technical choices, including:
  - The list of components and their accommodation into the CubeSat
  - The P/F internal interfaces and towards the P/L
  - The architecture of the P/F software
  - The technical budget assessment (mass, power, data rate, etc.)
  - The description of the ground segment
  - The assessment of technical risks

- The development plan and the associated schedule
- The project management and organizational plan, as visualized by the Contractor
- The cost estimate for the full mission

3.2 Workpackage 2: EMC measurement campaign

This workpackage concerns the EMC tests, that aim to characterize the P/F and its components from the electromagnetic cleanliness point of view.

3.2.1 Tasks

The EMC measurement activities aim to characterize the conducted and radiated emissions of the P/F components taken individually, then of the P/F system assembled. These tests are declined as follows:

- Conducted emissions at the electrical I/F of the components of the P/F
- Radiated emissions of each individual component
- Conducted emissions at the electrical I/F between the solar panels and the rest of the P/F
- Conducted emissions at the electrical I/F between the P/F and the P/L
- Radiated emissions of the assembled satellite (final configuration with the solar panels deployed)

The P/F configuration is a priori the one considered in section 2.2, that will be refined at the end of the mission study of the workpackage 1. To be in representative conditions, the components must be activated in an appropriated operating mode, which will be specified before the beginning of testing.

Although the band covered by the P/L is 20KHz - 20MHz, the tests will be extended over a wider range of at least 10kHz - 100MHz. Particular attention will be paid to conducted and radiated emissions from solar panels.

Some components of P/F may have numerous I/F that are not necessarily relevant in terms of EMC/EMI. To limit the test steps, the Contractor will select the I/F to be characterized in agreement with the LESIA.

3.2.2 Deliverables

At the end of this workpackage, the Contractor will provide:

- The EMC test report(s), where the results will be recorded, as well as the configuration of each test and the conditions under which it was conducted
- The data resulting from the measurements (format remains to be defined)

3.3 Workpackage 3: EMC modeling and simulation

The objective of this workpackage is to build an accurate and reliable EMC model of the P/F in order to predict the electromagnetic noise from the P/F that can interfere with the P/L.

3.3.1 Tasks

The activities will focus on the modeling of the conducted and radiated emissions; first from the P/F subsystems taken separately, then from the assembled P/F as a whole. In longer terms, the model parameters will be adjusted taking into account the results obtained during measurement campaign of the workpackage 2.

The conducted emissions model:

> The Contractor will produce a model at the relevant I/F of each P/F subsystem. In this purpose, he will identify and list the sources of interferences for each module. In addition, when applicable, the models must take into account interferences that propagate from one subsystem to another passing through a third one.

The radiated emissions model:

> The Contractor will also produce a model of the radiated field of all the subsystems, in particular for the solar panels. Combined with the noise from the DC-DC converters of the EPS, these are probably the most important source of interferences due to their proximity with the measurement antennas of the P/L. Particular attention will therefore be paid to this topic.

In both cases (conducted and radiated emissions), analyses by simulation will be performed at the subsystems level, then at the P/F system level.

3.3.2 Deliverables

At the end of this workpackage, the Contractor will provide a report describing the modeling strategies, the simulations / measurements comparisons and predictions of the conducted and radiated emissions seen at the interfaces of the CIRCUS P/L. This relates to:

- A descriptive note of the model
- The report recording the simulation results and predictions
- The EMC models of the P/F and its components

4 Process of activities

4.1 Organization

The activity described in this contract is in the full responsibility of the Contractor. It is therefore committed to implement the manpower and the technical resources needed to carry out the tasks.

Activities will take place on the premises of the Contractor or its partners. It will define an organization, where the project manager will be explicitly identified. The project manager will be the main interlocutor to the LESIA project manager; namely:

Moustapha Dekkali – CIRCUS project manager
Observatoire de Paris-Meudon / LESIA
11, avenue Marcelin Berthelot – 92195 Meudon Cedex
Email: moustapha.dekkali@obspm.fr
Tel.: +33 (0) 1.45.07.76.86

Alternatively:

Karine Issautier – Principal investigator of the CIRCUS mission
Observatoire de Paris-Meudon / LESIA
11, avenue Marcelin Berthelot – 92195 Meudon Cedex
Email: karine.issautier@obspm.fr
Tel.: +33 (0) 1.45.07.76.67

4.2 Planning and payment schedule

The work for all tasks should be done over a period of 2 to 3 months from the kick-off meeting. At this meeting, the Contractor and LESIA will agree on the schedule proposed in the response to the call for tenders.

Payments will be subject to the deliverables of each workpackage defined in Chapter 3. They will therefore be spread out in three payments of 1/3 of the total amount.

If necessary, the Contractor may have a cash advance which will be deducted in proportion to the intermediate payments. This advance shall not exceed 1/3 of the total cost.

4.3 Meetings

4.3.1 Kick-off meeting

A kick-off meeting will be held before the start of activities to clarify their contour, when necessary. This will be:

- To point out the activities related to the contract
- To adjust working methods on both sides
- To agree on deliverables and deadlines
- …

This meeting will be held before End-October 2020.

4.3.2 Periodic meetings

Meetings to monitor activities will be set up at regular time intervals (a priori weekly). They aim to take stock of:

- The tasks done and to come
- The problems encountered if any, their impact and the corrective solutions provided
- The planning
- …

Meetings may, if desired, be initiated by the Contractor.

4.3.3 Key points

Key points will be implemented before each workpackage and their end.

Regarding the key points upstream of the workpackage 2 and 3, they aim to endorse the testing and modeling / simulation program in order to authorize its execution. This will be:

- To validate the test or modeling / simulation configuration
- To check the conditions under which the activity will be conducted
- To examine the consistency of procedures to make sure that they cover the use cases

At the end of each workpackage, a closing key point will decide on the compliance of the activity done. This will be:

- To ensure the completeness of deliverables
- To check the compliance of tests and simulation models
- To verify the results obtained

This key point will be held at the latest within 15 days of the deliveries. If the key point reveals contractual deficiencies, a corrective action plan will be proposed and implemented by the contractor. Payment can only be initiated after this step.

The deliveries for these key points remain within the scope of the deliverables defined in chapter 3.

5 Special clauses

5.1 Versioning

In order to monitor changes in the content of deliverables, the contractor will implement versions management that it will maintain throughout the contract.

5.2 Derogations

Any modification of activity having an impact on this contract must be approved by LESIA. The Contractor undertakes to formally report these changes.

5.3 Intellectual properties

The deliverables are the property of LESIA. As such, LESIA will have all rights regarding their use. At a minimum, the Contractor must inform LESIA if he wishes to use them outside the CIRCUS context.