EuroLaunch
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SED

Student Experiment Documentation

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Mission: REXUS 14

Team Name: Gekko

Experiment Title: Measurement of the variation in electric conductivity with altitude

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Payload Manager

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5	2013-08-04	3.1, 5.2, 7.2, 7.3, 7.4	Final report

Abstract: This document includes all relevant information about the Gekko experiment launched in 7 May 2013 on board the REXUS 14 sounding rocket. The scientific background and the objectives are described and the engineering considerations are also discussed. The document contains the detailed mechanical and electrical design of the payload, as well as the project management aspects and the outreach approach of the team. The flight results and the conclusion of the post-flight analysis are also included.

Keywords: REXUS, Gerdien condenser, polar region, sounding rocket, ion composition, precision current measurement, Space research

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ABSTRACT

Our scientific objective is to study the ionization of the atmosphere in different altitudes. We want to measure the variations of electric conductivity with altitude by recording the mobility spectrum of positive and negative ions. The measurements will be carried out by using Gerdien Condensers.

Such investigations are especially interesting at high latitudes, where galactic cosmic rays participate in greater degree in ionization processes. This means that not only particles of greater penetrating depth, considering the lower ionosphere, but also greater fluxes due to the decrease of magnetic rigidity should be considered. The polar cap, where measurements will be carried out, is also a special location from the point of view of ionization taking into account the direct connection partly to the tail of the magnetosphere, partly to the interplanetary space. Therefore, it is suitable to monitor from time to time the state of the atmosphere at greater altitudes and at high latitudes as well.

1 INTRODUCTION

1.1 Scientific/Technical Background

Our scientific objective is to study the composition of ionized molecules in different altitudes of the atmosphere. An applicable tool for this purpose is a Gerdien condenser [8], because it is designed to measure the ion mobility spectra of various molecules.

The composition and the variation of the composition of the atmosphere is a very important question since the concentration of harmful gases is increasing. For example the greenhouse gases are produced at the surface of the Earth, but they are transported to higher layers by diffusion and chemical reactions [9]. It is also interesting to compare our results with previous measurements and methods [10].

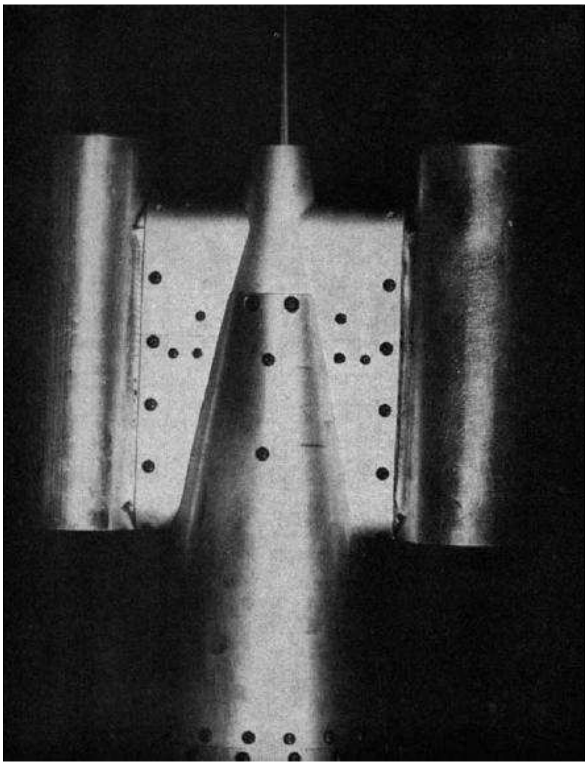


Figure 1. Nosecone mounted Gerdien condenser [8]

Investigations are especially interesting at high latitudes, where galactic cosmic rays participate in greater degree in ionization processes. This means that not only particles of greater penetrating depth – considering the lower ionosphere, – but also greater fluxes due to the decrease of magnetic rigidity should be considered. The polar cap, where measurements will be carried out, is also a special location from the point of view of ionization taking into account the direct connection partly to the tail of the magnetosphere, partly to the interplanetary space. Therefore, it is suitable to monitor from time to time the state of the atmosphere at greater altitudes and at high latitudes as well.

We are going to use Gerdien condensers to perform our measurements. The condensers are going to be placed on the outer side of the rocket, and as it moves, air flows inside the outer electrodes. The ion flow is directed toward the central electrode of the Gerdien condensers due to the electric field between the inner and outer electrodes. At a given speed the applied bias voltage determines the minimal mobility that an ion has to have in order to reach the central electrode. Since the critical mobility varies on the electric field of the condensers the group of the captured ions can be selected by changing the bias voltage.

During the flight several voltage sweep will be performed. The range of each bias voltage sweep is calculated taking into consideration the velocity of the rocket. The ion density is determined by measuring the current of the condensers [11].

To do correct measurements some crucial requirements shall be defined previously such as the applied bias voltage range in different altitudes or the saturation current. These requirements determine parameters of the electronics. On the next few pages we try to give a clear description what are these requirements and how we fulfil those.

The molecules which exist in the middle atmosphere consist mainly of oxygen, nitrogen, hydrogen and hydrates. Due to ionization effects (e.g. collisions, photoelectric effect, Lenard effect) electrons are released from molecules, thus positively charged ions will be produced. These electrons are attached to neutral molecules (e.g. oxygen, nitrogen,) creating negatively charged ions and combined with water molecules.

A few ions we used in our calculations are shown below :

- the photoionisation of direct and scattered Lyman radiation: NO^+
- the photoionisation by galactic cosmic rays: O^+, O_2^+, N^+, N_2^+
- the dissociative electron attachment to O_3 and three-body attachment to O_2: O^-, O_2^-

- the positive secondary ions and ion clusters: $O2^{+}\cdot X$, $NO^{+}\cdot X$, (X – halogen)
- the negative secondary ions: O_3^-, CO_3^-, NO_2^-, OH^-, NO_3^-, CO_4^-, O_4^-, HCO_3^-

In the middle atmosphere molecular weight does not separate molecules.

Before the presentation of the measuring method a few property of the ions shall be described. These are the mobility, mean free path and collisional cross section.

Mobility is the capability of movement of an ion in an electric field. So it shows how much the field can accelerate the particle. It is defined by equation 1.1.1 and its dimension is [m^2/Vs].

$$\mu = \frac{v}{E} \tag{1.1.1}$$

To determine the current which is measured during the flight, mobilities of the previously mentioned ion groups shall be determined. For this purpose the Einstein equation and the ideal gas equation are used as shown:

$$\frac{D}{\mu} = \frac{kT}{Q} \tag{1.1.2}$$

where D is the diffusion coefficient.

$$D = \frac{1}{2}\lambda\bar{v} \tag{1.1.3}$$

λ - free mean path

v – average diffusion speed

The mean free path is the path that an ion can do without collision with another particle. It is

$$\lambda = \frac{1}{n\sigma_s} \tag{1.1.4}$$

σ_s – collisional cross section

n – average ion density

The collisional cross section is the area which particles cannot pass without a collision with another particle. If we assume that ions are like spheres we get the following expression from the differential cross sections formula:

$$\sigma_s = (\frac{d}{2})^2\pi \tag{1.1.5}$$

d – diameter of the molecule

The density is expressed by the ideal gas equation (pV=NkT):

$$n = \frac{N}{V} = \frac{p}{kT} \tag{1.1.6}$$

Thus, for the mean free path we get the following expression:

$$\lambda = \frac{4kT}{pd^2\pi} \tag{1.1.7}$$

Equation 1.1.7 shows that if the pressure is small the mean free path will be large, and if the pressure is high the mean free path will be small and less energy can ionize molecules.

Requirement 1: The mean free path has to be less or equal than the distance between the inner and the outer electrode otherwise the air cannot be considered continuum.

Now the average ion drift speed shall be defined. To do this we use the Maxwellian speed distribution by means the speed distribution in different altitudes can be determined. The average speed is:

$$\bar{v} = \sqrt{\frac{8kT}{m\pi}} \tag{1.1.8}$$

Substituting the results obtained from Einteins equation:

$$\mu = \frac{2Q}{2pd^2\pi}\sqrt{\frac{8kT}{m\pi}} \tag{1.1.9}$$

Thus, the mobility of ions is inversely proportional to the square root of the mass of the ion, which means that it is more difficult to accelerate an ion of more mass with the same electric field.

Now we describe the measuring method we use.

The mobility spectrum of the ions is determined by measuring the condenser current and some knowledge of the atmosphere is also needed. These are the ion mobility in different altitudes, the speed of the rocket, the ion density, the temperature, pressure and so on.

The speed in different altitudes is given before the flight by EuroLaunch and the temperature, pressure and the neutral particle density (not ion density!) can be calculated by atmosphere models.

Figure 1 shows a sketch of the condenser:

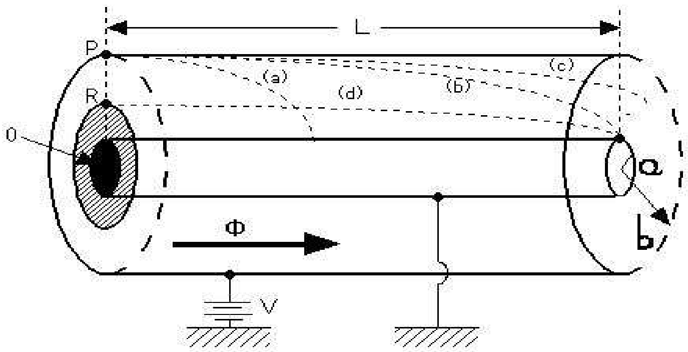


Figure 2. The Gerdien condenser method

It is obvious from figure 2 that there is a time limit for an io to move from the outer to the inner electrode. If the time that an ion needs to travel through the condenser without hiting the inner electrode is greater than the time that is needed to reach the end of the condenser, then no current can be measured.

An ion with mobility μ moves an incremental distance in the electric field E.

$$dr = vdt = \frac{v}{E}Edt = \mu Edt \tag{1.2.1}$$

Solving this differential equation we get the total time that an ion needs to move from the outer electrode to the inner electrode.

$$t = \frac{\ln\left(\frac{b}{a}\right)}{\mu V}\int_b^a rdr \tag{1.2.2}$$

If we assume that the rocket (air) is moving with a speed u, then the distance that an ion travels is u·t. If that length is less than the length of the condenser L (u·t < L), then all ions are collected and we get an inequality:

$$ut \leq L \Rightarrow u < \frac{2\mu VL}{(b^2 - a^2)\ln\left(\frac{b}{a}\right)} \tag{1.2.3}$$

Now the *critical mobility* can be defined:

$$\boxed{\mu_c = \frac{(b^2 - a^2)\ln\left(\frac{b}{a}\right)u}{2VL}} \tag{1.2.4}$$

Requirement 2: The critical mobility has to be less or equal than the average mobility of the previously mentioned ion groups.

Equation 1.2.4 shows that the critical mobility is inversely proportional to the bias voltage thus, the applied voltage can be expressed from this equation.

$$\boxed{V = \frac{(b^2 - a^2)\ln\left(\frac{b}{a}\right)u}{2\mu L}} \qquad (1.2.5)$$

In ideal case ions move along a parabolic path, but in reality they can enter into the condenser with different angles, and thus, few can be collected with mobilities slightly less than the critical mobility.

As the bias voltage is determined the current can be estimated.

From Gauss's law and the differential Ohm's law we get the following equations:

$$E = \frac{Q}{S_A \varepsilon_0} \qquad E = \frac{J}{\sigma} \qquad (1.2.6)$$

So, we get:

$$\frac{J}{\sigma} = \frac{Q}{S_A \varepsilon_0} \qquad I = \sigma \frac{Q}{\varepsilon_0} \qquad (1.2.7)$$

where J is the current density, I is the current, S_A is the surface of the inner electrode, Q is the charge of the ion and σ is the air conductance which equals $\sigma = nq\mu$ (q is the charge of the ion).

Because of Q=CV can can write:

$$I = \sigma \frac{CV}{\varepsilon_0} = q_i n_i \mu_i \frac{2\pi VL}{\ln\left(\frac{b}{a}\right)} \qquad (1.2.8)$$

Finally the minimal and the saturation current (the measurement range) can be determined. From the expression of the current (1.2.8) and the mobilities (1.1.9) we get requirement 3.

Requirement 3: The order of magnitude of the minimal current is 10^{-12}[A] and the maximal estimated current is about 10^{-8}[A].

<u>Ideal and real characteristics</u>

The ideal voltage-current characteristic of negatively charged ions is shown in figure 3.

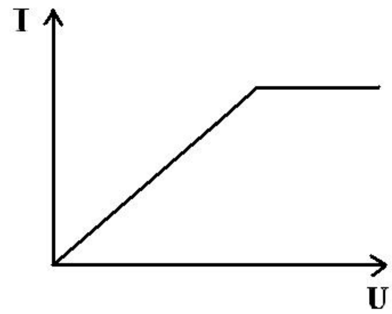


Figure 3. Ideal voltage – ampere curve

When the bias voltage is increased, more and more ions with mobility greater than the critical mobility are captured until the saturation current is reached:

$$I = G_i V = \frac{2\pi\sigma_i L}{\ln\left(\frac{b}{a}\right)} V = \frac{n_i q_i \mu_i C}{\varepsilon_0} V \qquad (1.3.1)$$

where G_i is the conductance of the condenser unit, σ_i is the conductance of the air, n_i is the number density and μ_i stands for the mobility of the ion.

The slope of the linear region is the conductance G_i. If the air consists of more ion groups the characteristic will looks like that in figure 4. It can be seen that there are breaks at different points, where the slope of the curve changes. These indicate the saturation current of the ion groups, so we get a full scale of ions with different mobilities.

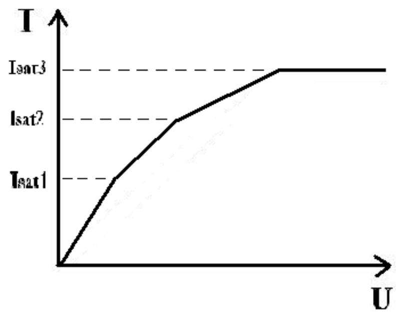


Figure 4. Characteristic curve in case of several ions presence

This is the method by means of which we can distinguish the different ion groups in the middle atmosphere.

The ion densities can be determined from the saturation currents and then the mobilities of the different ion groups can be found as it is shown below:

$$I_s = \sum_i n_i v_i A q_i = n_t \bar{v} A Q \qquad (1.3.2)$$

$$G = \sum_i G_i = \sum_i \frac{n_i q_i \mu_i C}{\varepsilon_0} \qquad (1.3.3)$$

$$\boxed{\mu_i = \frac{\varepsilon_0 G_i}{q_i C n_i}} \tag{1.3.4}$$

For the different saturation currents we have the expressions:

$$I_{1SAT} = V_1\left(\frac{I_1 - I_2}{V_1 - V_2}\right)$$

$$I_{2SAT} = V_2\left(\frac{I_2 - I_3}{V_2 - V_3} - G_1\right)$$

$$I_{3SAT} = V_2\left(\frac{I_3 - I_4}{V_3 - V_4} - G_1 - G_2\right) \tag{1.3.5}$$

$$\dots$$

$$I_{nSAT} = V_n\left(\left.\frac{dI}{dV}\right|_{Vn} - \left.\frac{dI}{dV}\right|_{Vn-1}\right)$$

A volt-ampere characteristic of a multicomponent ion gas is shown in figure 5. This curve is not linear so we have to use the last expression above.

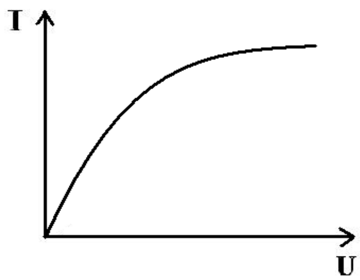


Figure 5. volt – ampere characteristic, multicomponent ion gas

1.2 Experiment Objectives

Obj.1	scientific	Recording ion mobility spectrum of positive and negative ions in the middle atmosphere.	primary
Obj.2	scientific	Determining the altitude dependence of the ion composition of the middle atmosphere up to 80 km (TBD).	secondary
Obj.3	scientific	Determining the bipolar air conductivity of the middle atmosphere up to maximum 80 km (TBD).	secondary
Obj.4	technical	Developing and testing a rocket-borne platform for Gerdien condenser measurements.	primary
Obj.5	technical	Developing and testing a universal data acquisition unit for in situ measurements in the atmosphere and in space.	primary

1.3 Experiment Overview

The Gekko experiment will perform bipolar air conductivity measurements with a use of Gerdien condensers.

The experiment consists of the following elements (see figure 2.):

- Two Gerdien condensers
- Electronics box (containing the analogue, the digital and the PSU boards)
- Ground Station

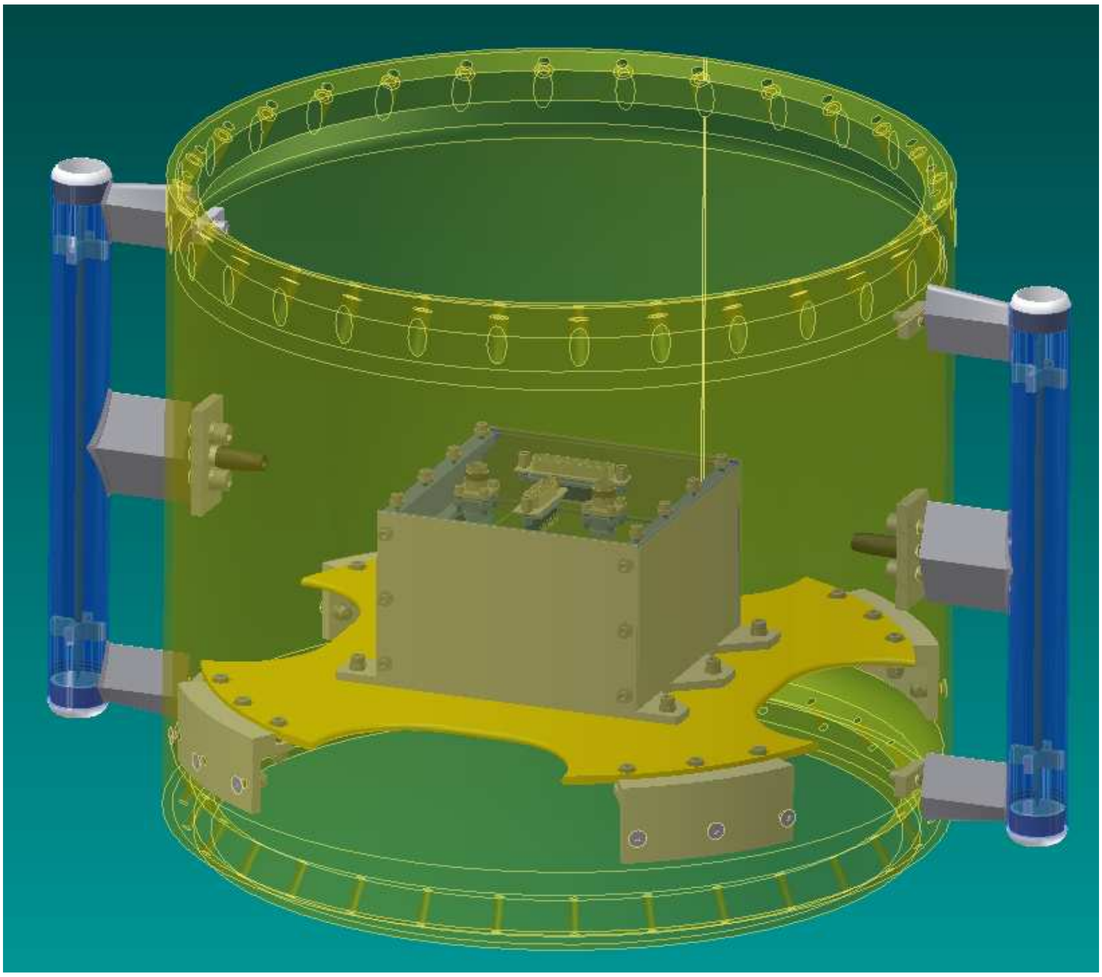


Figure 6. Experiment overview

The condensers are mounted on the outer structure of the rocket and connected to the electronic box with triaxial cables. The analogue interface card adjusts the bias voltage of the condensers and measures their currents.

The overall measurement control, the on-board data storage and the communication interface is implemented on the OBDH board.

The experiment is powered by the REXUS Service Module and the power supply is built up on the Power Supply Unit (PSU) board.

The ground station receives and displays the measured data.

1.4 Team Details

1.4.1 Contact Point

Institute: Budapest University of Technology and Economics
Space Research Group

Address: Goldmann Gy. ter 3.
Budapest
H1111 (postal code)
Hungary

E-mail: gekko@mht.bme.hu

phone: 0036-70-601-2471 (Zsolt Varadi)

1.4.2 Team Members

Gábor Balassa
Educational Background: Software Engineering and Physics, *BSc student*
Role in the project: Scientific background, GSE SW development and data evaluation
Expected workload: 14%

András Futó
Educational background: Electrical Engineering, *MSc student*
Role in the project: Electronic design
Object of thesis work for 10 academic credits
Expected workload: 14%

Ágnes Gubicza
Educational Background: Physics, *MSc student*
Role in the project: Scientific background, data evaluation
Expected workload: 14%

Adrián Gugyin
Educational Background: Electrical Engineering, *BSc student*
Role in the project: Electronic and software design
Expected workload: 14%

Bálint Kollek
Educational Background: Electrical Engineering, *MSc student*
Role in the project: Electronic design
Object of project laboratory for 10 academic credits
Expected workload: 14%

Ottó Botond Lőrinczi
Educational Background: Mechatronics Engineering, *PhD student*
Role in the project: Mechanical design
Expected workload: 15%

Dávid Szabó
Educational Background: Electrical Engineering, *MSc student*
Role in the project: Electronic and software design, Outreach
Expected workload: David Szabo is graduated in May 2012

Milan Trunk
Educational Background: Electrical Engineering, *MSc student*
Role in the project: Digital electronics and software design
Expected workload: Backup team member,
follows the Gekko team activity,
can be involved in the work if needed

Zsolt Váradi
Educational Background: Electrical Engineering, *PhD student*
Role in the project: Project management, Electronic design, Outreach
Expected workload: 15%

2 EXPERIMENT REQUIREMENTS

2.1 Functional Requirements

F.1.	The experiment shall measure the ion mobility during the flight of the rocket using two Gerdien condensers.
F.2.	The experiment shall adjust the bias voltage of the Gerdien condensers according to the velocity of the rocket.
F.3.	The experiment shall measure the current of the Gerdien condensers.
F.4.	The experiment shall use its own PSU to ensure continuous power supply for the electronics.
F.5.	The experiment shall measure the input current and input voltage of the PSU.
F.6.	The experiment shall store all measured data into an on-board non-volatile memory.
F.7.	The experiment shall send the data to the ground station through the RXSM during the whole flight of the rocket.

2.2 Performance requirements

P.1.	The ion mobility measurements shall be performed between 0,005 and 15 [$m^2/(Vs)$] for positive ions and from 0,01 to 20 [$m^2/(Vs)$] for negative ions.
P.2.	The ion mobility measurements shall be performed with an accuracy of 0,001 [$m^2/(Vs)$] for both positive and negative ions.
P.3.	The ion mobility measurements shall be performed at a rate of 128 measurements every second for both positive and negative ions.
~~P.4.~~	The bias voltage of the Gerdien condensers shall be adjusted in the range of -10 mV to -120 V for the positive ions and 10 mV to 120 V for negative ions.
P.4.	The bias voltage of the Gerdien condensers shall be adjusted in the range of -10 mV to -50 V for the positive ions and 10 mV to 50 V for negative ions.
P.5.	The bias voltage adjustment of the Gerdien condensers shall be performed with a minimum accuracy of 10mV.
P.6.	The current of the Gerdien condensers shall be measured in the range of 5pA to 2nA.
P.7.	The current measurements of the Gerdien condensers shall be performed with a minimum accuracy of 1pA.
P.8.	The PSU shall provide a +/-5V, +/-2,5V and a +3,3V output with 10% accuracy.
~~P.9.~~	The PSU shall provide two +/-15V outputs and a +/-120V output with 10% accuracy.
P.9.	The PSU shall provide two +/-15V outputs and a +/-60V output with 10% accuracy.
P.10.	The input current measurement shall be possible in the range of 20mA to 200mA.
P.11.	The input current measurement shall be performed with an accuracy of +/- 2mA resolution.
P.12.	The input voltage measurement shall be possible in the range of 20V to 40V.

P.13.	The input voltage measurement shall be performed with an accuracy of +/- 200mV resolution.

2.3 Design Requirements

D.1.	The experiment shall be designed to withstand the mechanical loads during the complete flight of the REXUS rocket.
D.2.	The experiment shall be designed to operate in the temperature profile of the pre-flight and flight phase of the REXUS.
D.3.	The experiment thermal dissipation must not heat up the outer structure more than 10°C over the ambient temperature
D.4.	The experiment thermal dissipation must not heat up the parts close to or in contact with the feed-through cable more than +70°C.
D.5.	The experiment thermal dissipation must not heat up parts facing other modules more than +50°C.
D.6.	The heat transport by convection must be limited in such a way that the air temperature at the module interfaces does not exceed the ambient temperature by more than 10°C
D.7.	The experiment shall be designed to operate under 1mbar air pressure (TBC).
D.8.	The experiment shall be connected to the RXSM experiment interface.
D.9.	The experiment interface connector shall be a D-SUB 15 male type.
D.10.	The experiment shall be able to communicate on the RS422 telemetry interface.
D.11.	The telemetry data rate shall be less than 30kbps.
D.12.	The experiment shall be powered over the RXSM power interface.

D.13.	The experiment shall be able to operate from the RXSM power line in the range of 24V to 36V supply voltage.
D.14.	The inrush current of the experiment shall not exceed 3A.
D.15.	The continuous input supply current of the experiment shall not exceed 1A.
D.16.	The voltage ripple fed back to RXSM over the power line shall be less than 500mV.
D.17.	The airflow of the Gerdien condensers shall be laminar.
D.18.	The Gerdien condensers shall be placed 40mm from the outer surface of the rocket.
D.19.	The experiment shall be equipped with enough non-volatile memory to store the entire data.
D.20.	The experiment shall not resonate during the flight. (the eigenfrequency of the experiment units shall highly exceed the frequency of rocket vibration during flight)
D.21.	The shift caused by the roll of the rocket shall not disturb the measurement

2.4 Operational Requirements

O.1.	The experiment shall be able to conduct measurements autonomously in case connection with the ground segment is lost.
O.2.	The bias voltage values shall be calculated according to the predicted flight profile before the flight.
O.3.	The calculated bias voltage values shall be uploaded into the onboard non-volatile memory before the flight.
O.4.	The start of the measurement shall be triggered by the LO control signal.
O.5.	The onboard memory pointer shall be set to its initial value after pre-flight tests by a ground command.
O.6.	The content of the onboard memory shall be downloaded to the ground station after payload recovery.
O.7.	The ground station shall store the received data onto a hard drive during the flight.

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

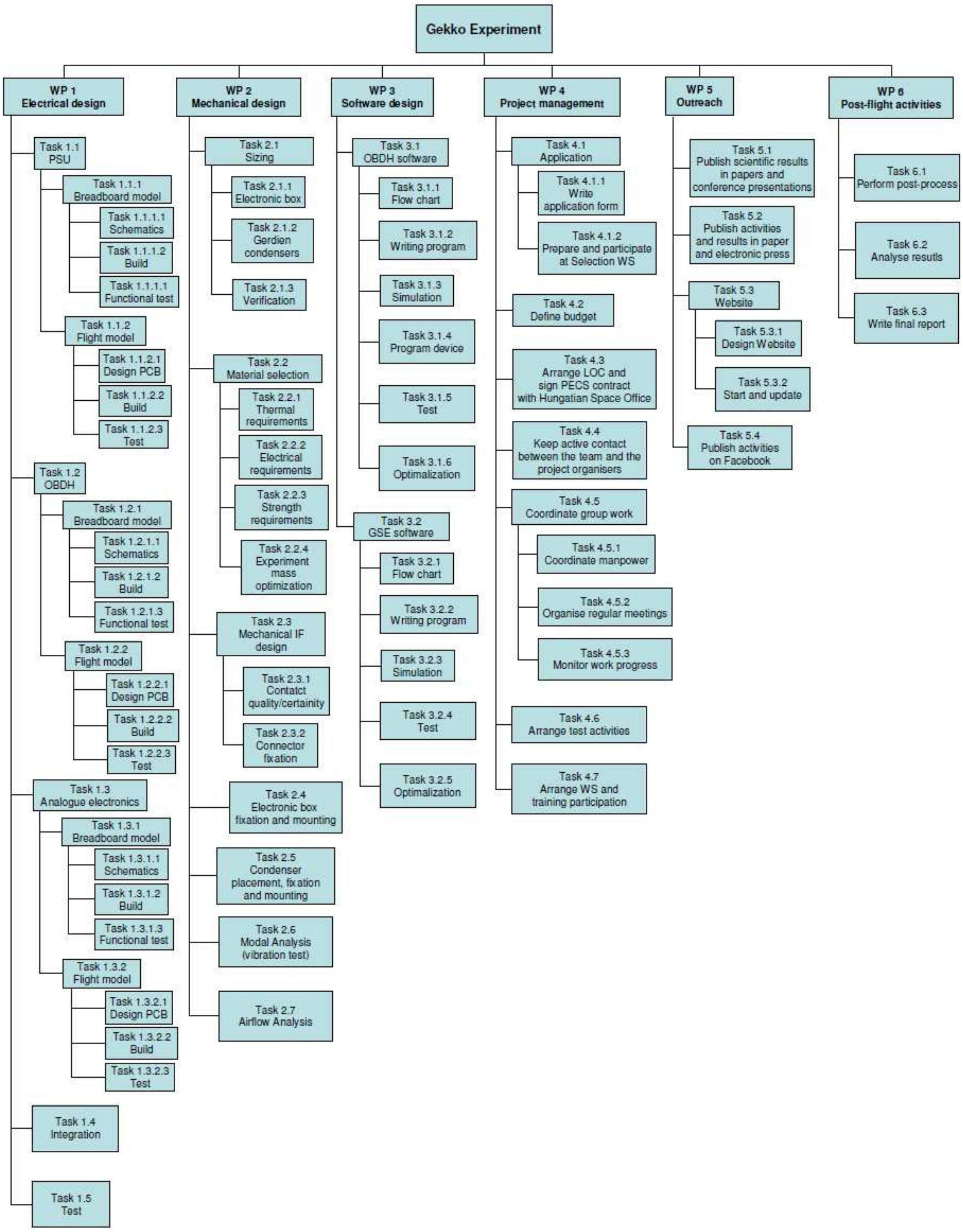


Figure 7. Gekko Team WBS

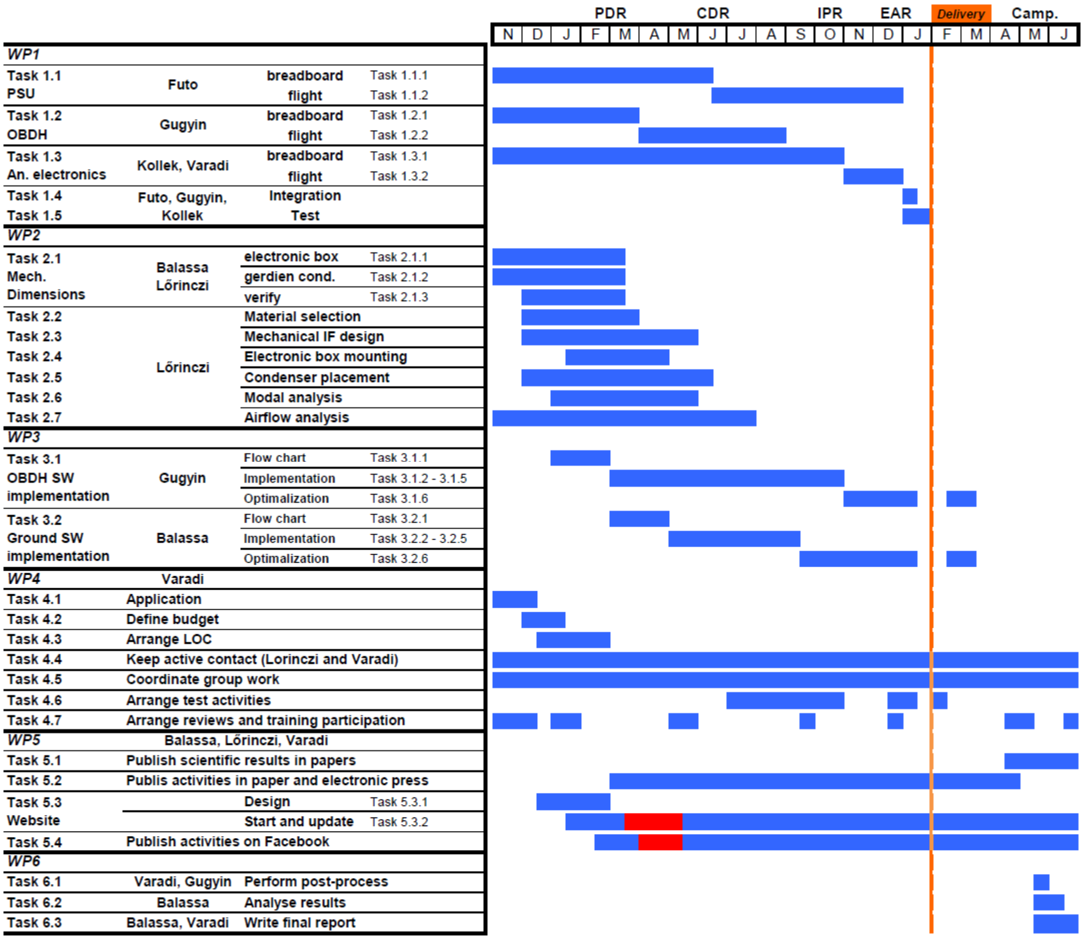


Figure 8. Schedule

(Legend: blue = completed,
red = to be completed - behind schedule
grey = to be completed
orange line = delivery deadline)

3.2 Resources

3.2.1 Manpower

Table 1 Manpower

	PDR	CDR	IPR	EAR	Delivery	Launch	Symposium
	2011/12-2012/02	2012/02-2012/06	2012/06-2012/09	2012/09-2012/12	2012/12-2013/01	2013/01-2013/05	2013/05-2013/06
Gábor Balassa	0	4h/w	4h/w	2h/w	4h/w	20h	40h
Ágnes Gubicza	20h	0	0	2h/w	0h	0h	
András Futó	12h	6h/w	35h/w	4h/w	0	0	
Adrián Gugyin	4h	2h/w	3h/w	2h/w	15h	20h	
Bálint Kollek	20h	6h/w	4h/w	2h/w	10h	0	
Ottó Lörinczi	30h	10h/w	10h/w	8h/w	30h	8h	
Dávid Szabó	8h	0	graduated				
Zsolt Váradi	50h	10h/w	10h/w	25h/w	25h/w	30h	40h
Milán Trunk	*backup*						

3.2.2 Budget

Experiment costs (contribution to launch costs not included):

Table 2 Budget

Travel	**19 280 EUR**
Equipment, tools, consumables:	**3 130 EUR**
Electronics:	
Components	490 EUR
PCB	840 EUR
Connectors, bolts	65 EUR
Mechancis:	
Material	1 290 EUR
Manufacturing	310 EUR
Connectors	105 EUR
Cables	30 EUR
TOTAL	**22 412 EUR**

Note: The budget does not include the costs of vibration test (it is available for free at EL-TECH Center Ltd.)

3.2.3 External Support

- Dr. Pál Bencze; Geodetic and Geophysical Institute, Sopron

  Support: definition of scientific objectives, description of the physical environment, processing measurement data

- Dr. József Szabó; Budapest University of Technology and Economics, Department of Broadband Infocommunications and Electromagnetic Theory, Space Research Group (BME-SRG)

  Support: electrical design and testing

- Dr. Antal Bánfalvi; BME-SRG

  Support: mechanical and thermal design

- Dr. László Csurgai-Horváth

  Suport: digital hardware and software development

- Hungarian Space Office

  Financial support

3.3 Outreach Approach

The progress of the development and the scientific results gained from the experiment will be published in Hungarian scientific magazines and space related news portals. The scientific results and engineering experiences will also be presented at national and international conferences and in scientific publications.

Our public relation strategy is based on the team website and the facebook page of the team. The website contains all relevant information about the background and the progress of the experiment, the team members and the supporting institutes. Up-to-date information will be regularly published both in the News thread of the website and on the facebook page.

Gekko site:
http://lab708.mht.bme.hu/gekko

Gekko on facebook:
http://www.facebook.com/GekkoTeam

Before the CDR, the following publications were made about the development of the Gekko experiment:

Papers:

- Ottó Botond Lőrinczi, Ágnes Gubicza, Zsolt Váradi:

  Mechanical design of a gerdien condenser for rocket experiment

  (Hungarian)

  20th International Conference on Mechanical Engineering, Kolozsvár, Romania, 2012.04.19-2012.04.22.

- András Futó:

  Power Supply Unit of a Gerdien Condenser based ion spectrometer

  (Hungarian)
  Scientific Student Conference, Budapest University of Technology, November 2012
  (András Futó awarded the 2nd prize in Hardware Section)
  http://tdk.bme.hu/VIK/DownloadPaper/Gerdien-kondenzatoros-ionspektrometer

Oral presentations:

- **Zsolt Váradi: The REXUS - Gekko experiment** *(Hungarian)*

  presentation in the 10th Hungarian Youth Forum (organised by the Hungarian Space Office and the Hungarian Astronautical Society)

- **Ágnes Gubicza: Study of the variation in air conductivity with altitude**

  presentation in a physics seminar at Budapest University of Technology and Economics (Hungarian)

- **Zsolt Váradi: The Gekko rocket-borne experiment** *(Hungarian)*

  presentation in the 28th Ionosphere- and Magnetosphere Physics Seminar, 7-9th March 2013. Kecskemét, Hungary

- **Zsolt Váradi: REXUS Gekko: Why to put a steel pipe on a rocket?**

  (Hungarian) presentation in the Europian Space Expo, 23rd March 2013. Budapest

Electronic publications:

Zsolt Váradi: Hungarian experiment in the ESA - REXUS rocket programme
Publication at the "Űrvilág" Hungarian space research related web portal (Hungarian)

Radio Interview:

We gave an interview to a Hungarian radio (Klubrádió) together with the BEXUS BioDos team. In the 30 minutes scientific/entertaining programme, we talked about the background *and the objectives of the Gekko experiment, gave the audience an introduction to the REXUS/BEXUS programme and also brought up topics like the importance of such projects, the benefits for the participating students and the fun parts of the mission.*

3.4 Risk Register

Table 3 Risk Register

ID	Risk (& consequence if not obvious)	P	S	P x S	Action
SF10	Due to improper aerodynamic design, the Gerdien condensers attached to the outer structure modify the planned flight profile of the rocket.	C	5	high	Active cooperation between the Gekko team, Eurolaunch and ESA in the mechanical design process.
SF11	(Residual of SF10)	A	5	low	Risk has been mitigated to acceptable level. No further action is required.
SF20	One or both of the condensers breaks off of the structure of the rocket thus modifying the flight trajectory.	B	5	medium	Risk has been mitigated after cooperation with DLR experts. Shake test is required to reduce the risk probability.
SF21	(Residual of SF20)	A	5	low	Vibration tests were performed to mitigate the risk to an acceptable level.
SF30	Health hazard caused by touching the HV parts of the system.	B	4	low	Use of protective covering on the edges of the condensers. Clear description of safe handling in chapter 6.
SF40	Condenser struts may act like wings	B	2	very low	Discussed with DLR experts, design considered safe from this aspect
SF50	Parachute lines entangle with the condensers	B	1	very low	Discussed with DLR experts, design considered safe from this aspect
MS10	Very low current levels not detectable due to internal or external noise sources.	C	2	low	Performance optimization of the analog circuits and proper noise reduction.
MS20	The timing of bias voltage generation corrupted due to loss of synchronization of the internal	B	2	very low	Redundant synchronization signal (LO+SOE)

	clock with the system clock.				reduces probability; increased sampling rate reduces severity.
MS30	LO trigger signal not received	A	3	very low	Acceptable risk: no action
MS40	Software failure during mission	A	3	low	Acceptable risk: no action
MS50	One or both of the condensers breaks off of the structure of the rocket.	B	4	low	Risk has been mitigated after cooperation with DLR experts. Shake test is required to reduce the risk probability.
MS51	(Residual of MS50)	A	4	very low	Vibration tests were performed to mitigate the risk to an acceptable level.
PE10	Loss of personnel	B	1	very low	No action required: backup persons are available (both physicist and engineer)
PE20	No backup person for mechanical design.	A	3	very low	Risk is on acceptable level. Searching for backup person is in progress.
TC10	Damage of component or material during development	B	3	low	Procurement of spare parts.
TC20	Late delivery of components or materials during development	B	3	low	Ordering components and materials with duly considered time reserve.
TC30	Late delivery of experiment hardware for integration	B	4	low	Dispatch of hardware with duly considered time reserve.

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The Gekko experiment consists of two Gerdien condensers and an electronic box. The condensers are mounted onto the outer structure of the rocket and the electronic box is placed inside the module.

The electronic box contains four PCBs: the PSU board, the OBDH board, the PCB for the analogue electronics and the motherboard. (See figure 9.) The interface connector to the RXSM, the technology connector and the TNC connectors to the condensers are placed on the electronic box. The condensers are connected to the electronic box by triaxial cables.

The signal and power connections between the 3 PCBs (analogue electronics, OBDH, PSU) and the external IF connectors are implemented on the motherboard.

The PSU board provides different power lines including HV outputs (+/-60V) for the OBDH and the analogue electronics as well. The electrical connections between the outputs of the PSU are shown in figure 10. The power supplies of the precision amplifiers (output A1 and A2) are not linked directly to the RXSM 28V, these outputs are connected to the 28V Ground on the analogue electronics board with 100kΩ resistors. The other ground points are combined in a star ground, which is implemented on the motherboard. The power supply voltages and the temperature is monitored and measured as HK data.

There are several analogue and digital signal lines between the analogue PCB and OBDH as shown in the figure. The current of the condensers and the bias voltages are measured by the AD converter on the OBDH board. Due to the large scale of the bias voltage the gain of the bias voltage amplifiers shall be switched by the microcontroller.

The experiment is interfaced with the RXSM and uses the RS422 communication interface, the power interface and the LO and SOE control signals.

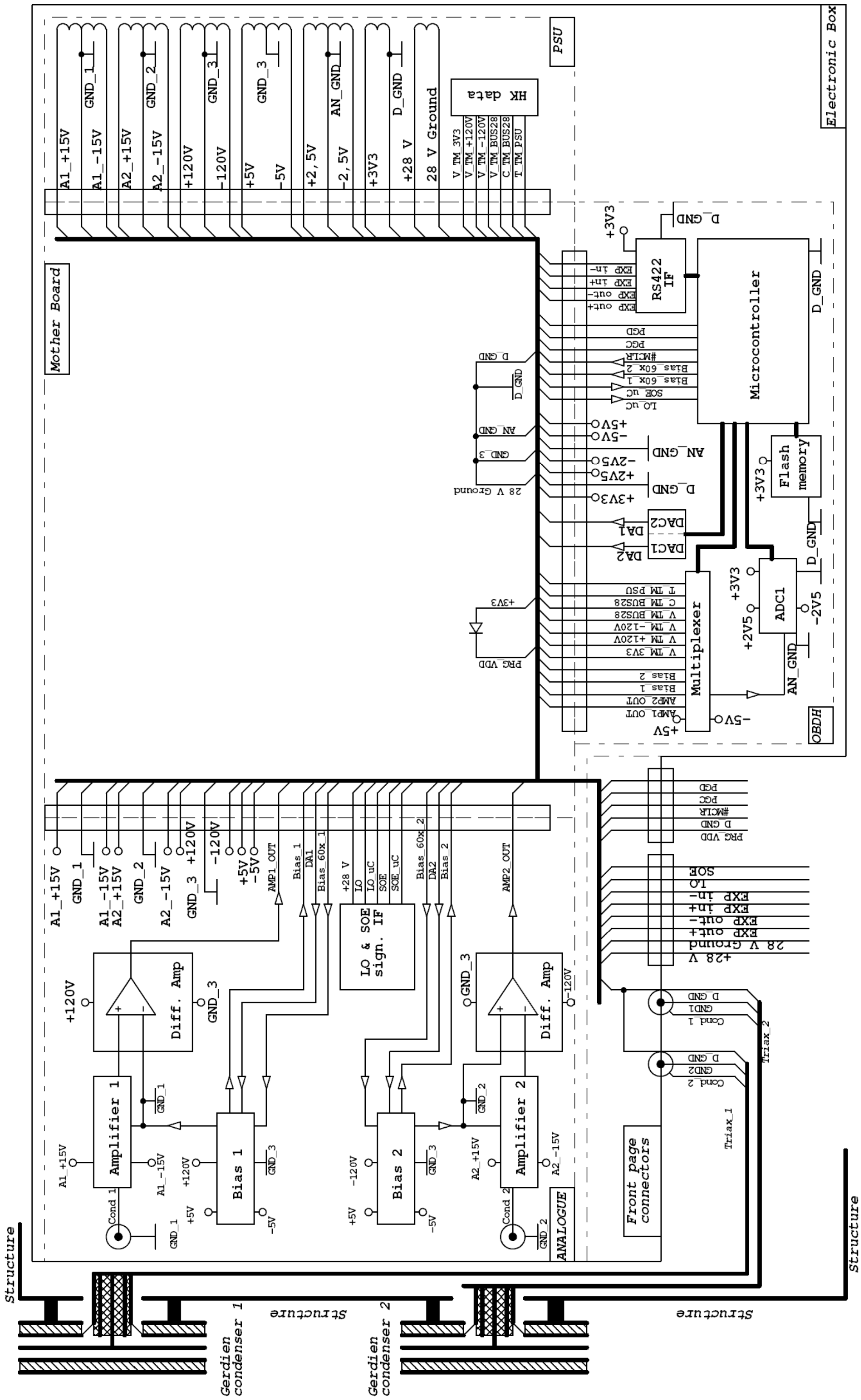


Figure 9. Experiment Setup

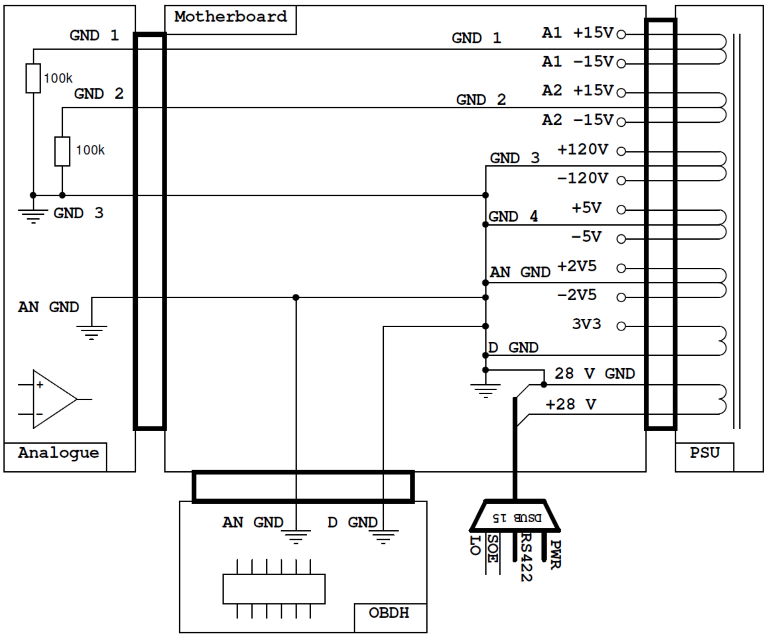


Figure 10 Grounding concept

4.2 Experiment Interfaces

4.2.1 Mechanical

Fixation and mounting of the Gerdien condensers

The Gerdien condensers will be mounted to the rocket wall by bolted connections with nord-lock washers and thread fixer (see Figure 11/b). We use stainless steel for most of the parts to meet the requirements in relation with high temperature and mechanical loads. At the extremities of the condensers, additional spacers prevent the parachute lines from entangling. The condensers are placed at the 90°and 270° positions (the 0°position is highlighted on Figure 6 by a vertical line on the module wall).

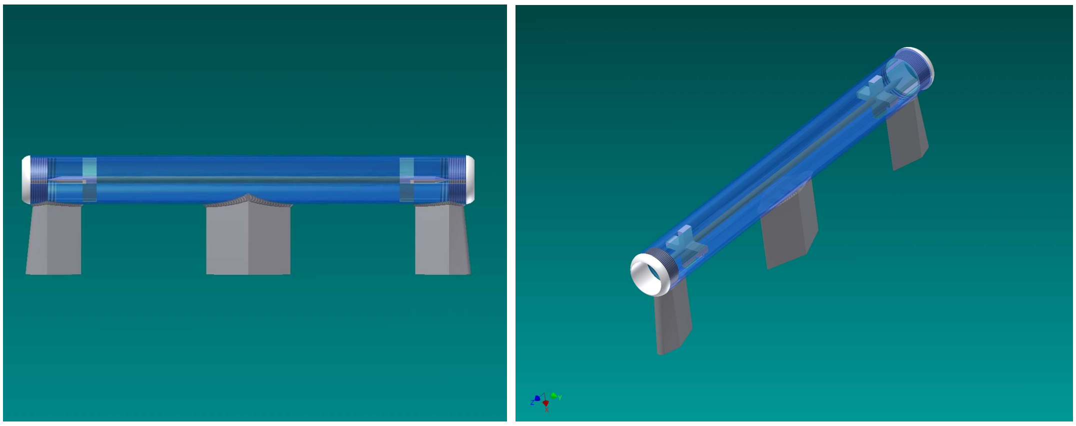


Figure 11/a. Fixing points of the condensers

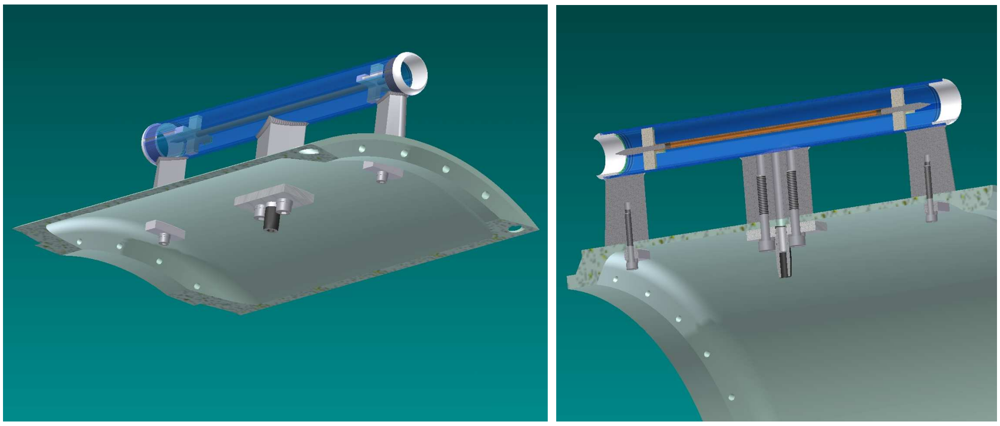


Figure 11/b. Mounting the condensers

Fixation and mounting of the electrical box

The electrical box will be fixed by bolted connections to the bulkhead of the experiment unit. Figure 12/a shows the structure of the electronics box, while figure 12/b shows the fixation of the electronics box to the bulkhead. The PCBs in the electrical box will be fixed by card lock retainers (see Figure 12/a).

We will use nord-lock washers for all bolted connections and thread fixer glue if needed. At the bottom of the electronics box, we need a flat surface that fits to the bulkhead, therefore we use countersunk head bolts; that is the only part where the nord-lock washers can't be used (see Figure 17/a).

Helicoils will be inserted into the wall-mounted bulkhead, thus we can mount or dismount the electronics box multiple times without damaging the threads.

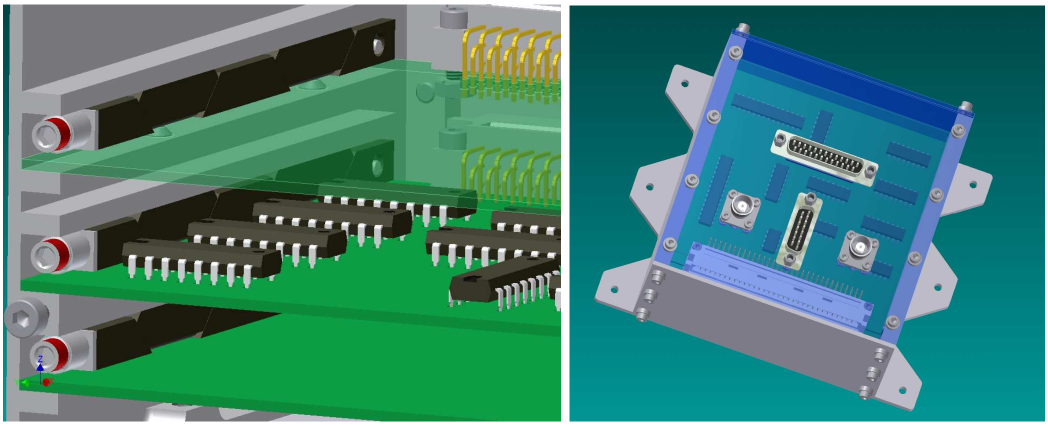


Figure 12/a. Mounting the electronics box

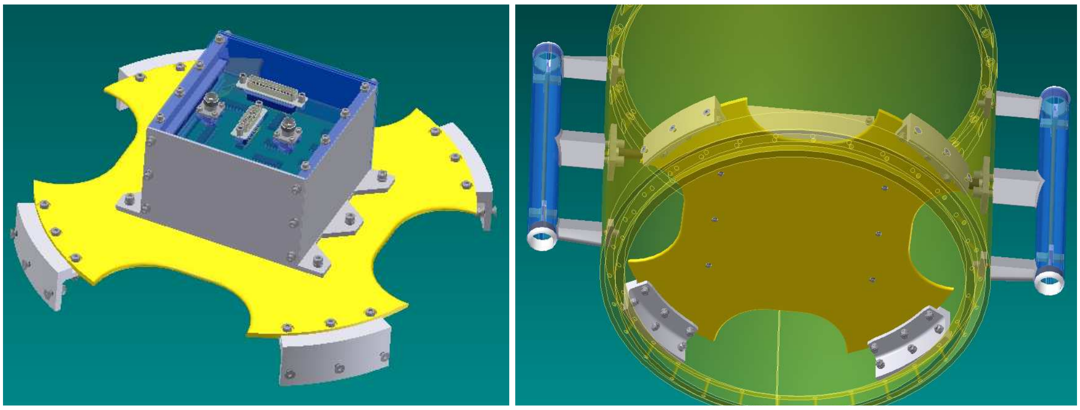


Figure 12/b. Mounting the electronics box

List of fasteners:

Gerdien condensers:

- 2 pieces of M6 bolts in each condenser
- 2 pieces of M6 nord-lock washers in each condenser
- 2 pieces of M4 bolts in each condenser
- 2 pieces of nord-lock washers in each condenser

Electrical box:

- 6 pieces of M4 bolts
- 6 pieces of M4 nord-lock washers
- 6 pieces of card lock retainers

Experiment centre of gravity can be adjusted to coincide with the geometrical centre of the rocket if necessary.

4.2.2 Electrical

The external electrical interfaces of the Gekko experiment are the following:

28V Power interface, RS422 data interface and the LO and SOE control signals (provided by the RXSM experiment interface connector). The interface circuits are presented on Figure 13.

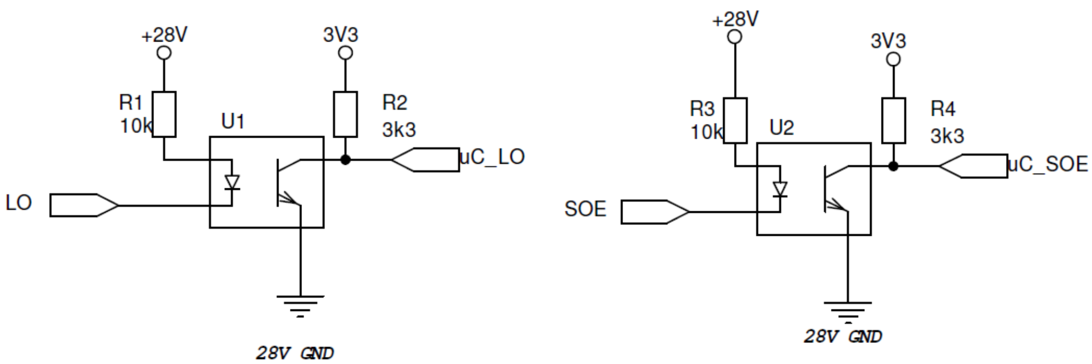


Figure 13. Control signal IF circuits

The data rate is 1200kbps on the downlink. The uplink channel is used for send TC and upload the bias voltage values into the onboard memory before flight.

A DSUB25 type connector (technology IF connector) is used for testing the experiment and programming the microcontroller. This connector is unavailable after the payload integration.

Figure 14 shows the connection method of the triaxial cables. The inner conductors and inner shields of the cables are connected to the electronic box by two TNC connectors. The outer shield is connected by cable lugs as shown on the picture,

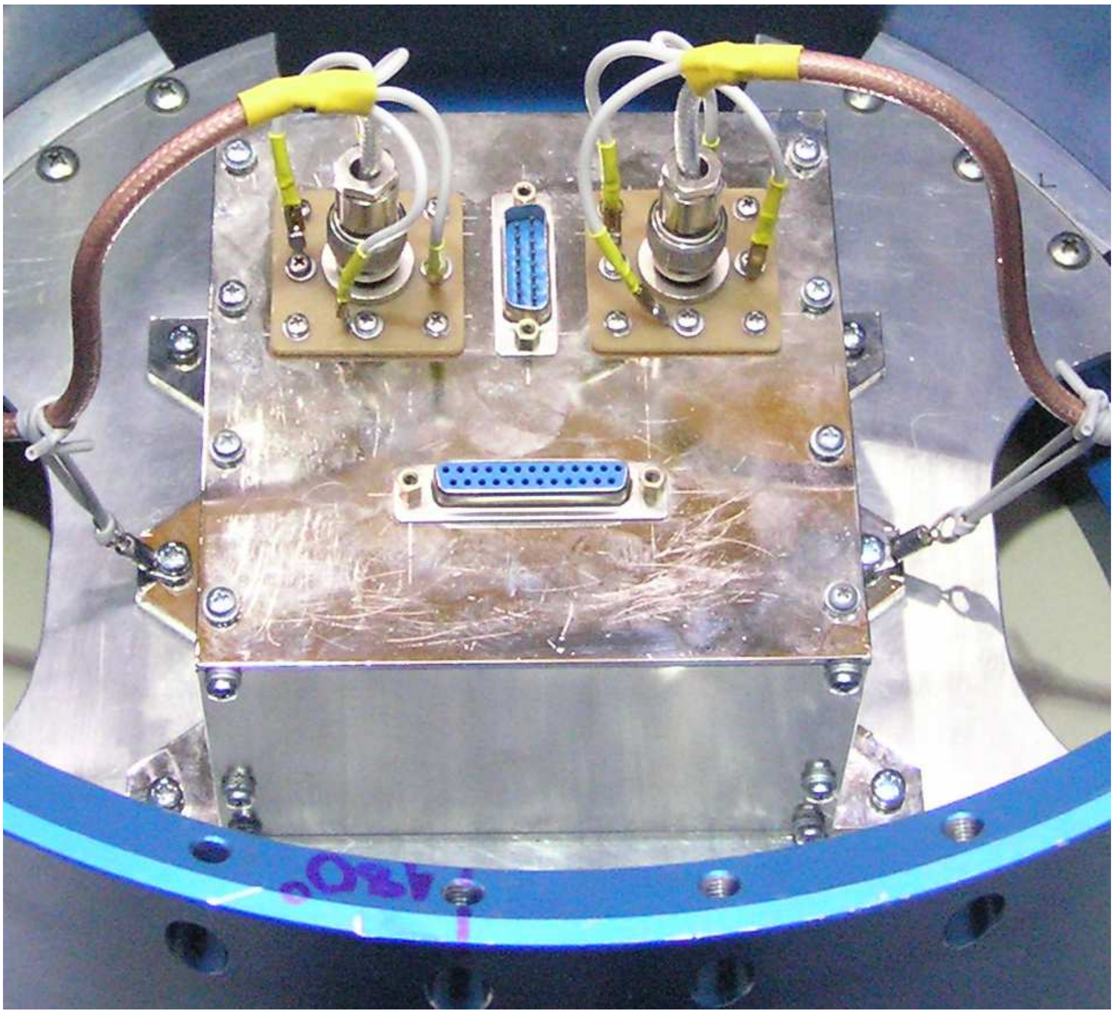


Figure 14. Connection of the triaxial cable

The connections at the condenser side are shown on the next pictures. The inner conductor of the cable is led inside the pipe and connected to the inner electrode. The role of the inner shield is to guard the inner conductor to reduce leakage current. This layer is galvanically isolated (not connected) at the condenser side. The outer shield is soldered to the outer electrode and the connection is covered by a heat-shrink tube.

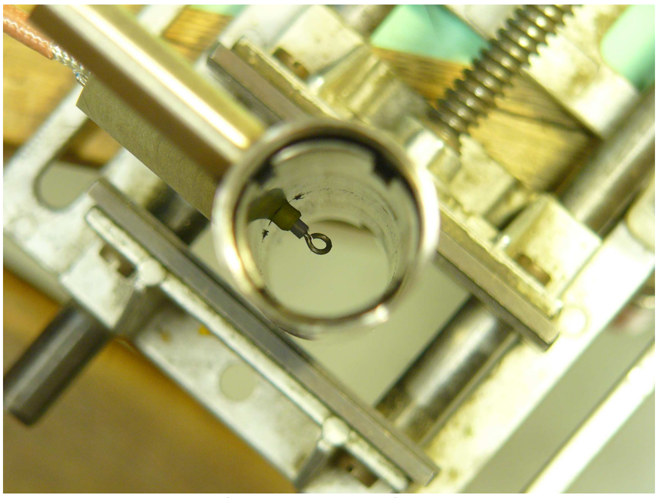


Figure 15/a Connection of the condenser

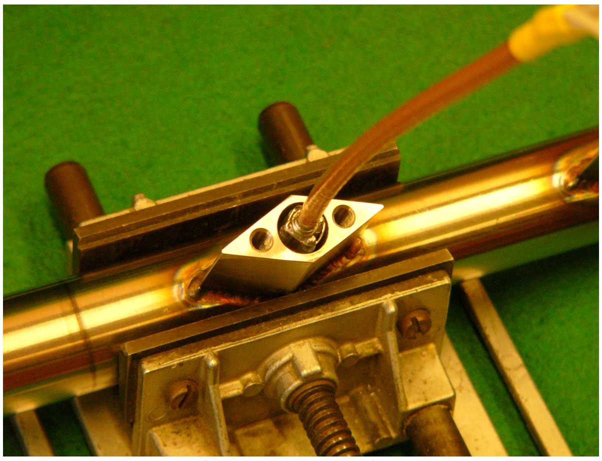


Figure 15/b Connection of the condenser

Figure 15/c connection of the condenser

Inside the electronics box the DSUB connectors are wired to the motherboard with PTFE Habia cables (see figure 16.). The TNC bulkhead connectors are assembled with RG316/U coaxial cables that end in SMA connectors as shown in figure. The SMA connectors are directly connected to the analogue electronics PCB. The bias voltages (outer shield of the triaxial cable) are also wired directly to the analogue PCB by using cable lugs and copper wires with PTFE insulation.

The datasheets of the cable assembly components (SMA-PCB → SMA angle plug → RG316/U coaxial → TNC bulkhead → TNC plug → triaxial) are included in APPENDIX C.

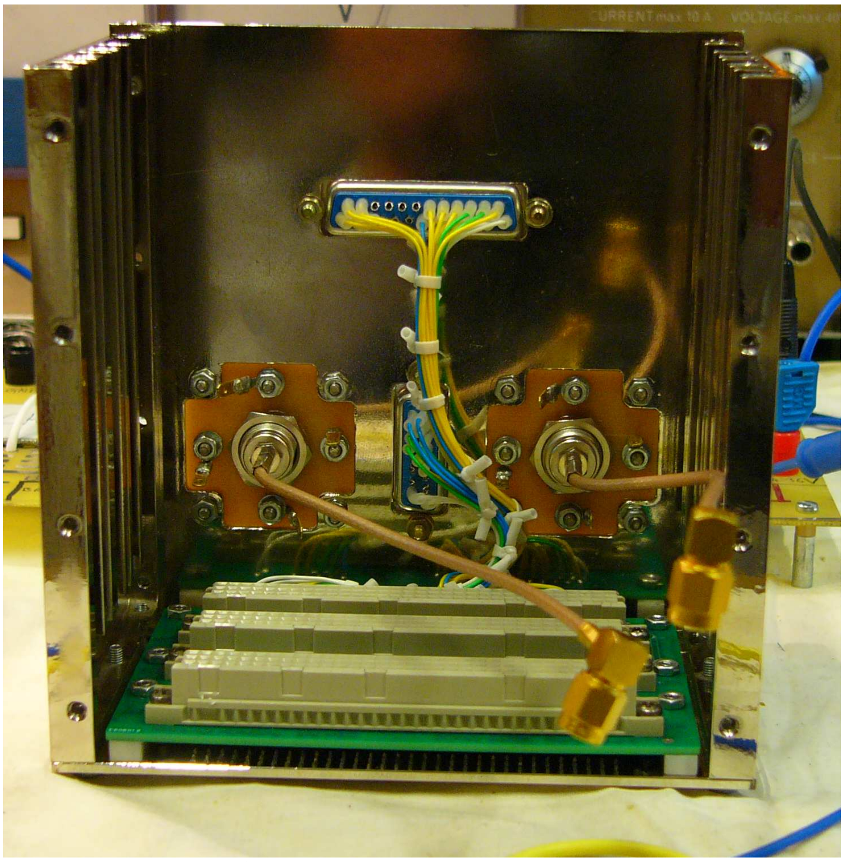


Figure 16. Cable connection in the electronics box

The internal connections between the PCBs are implemented on the motherboard. The PCBs are plugged into the motherboard with 96pin B2200-R960 type connectors.

4.3 Experiment Components

Table 4 Experiment component list

Component name	Qty	Note	Status
Electronic box	1	125 x 165 x 105, 826g	delivered
Gerdien condensers	2	65 x 25 x 280, 306,5g	delivered
M6 bolts/nuts/wahers	4		delivered
M4 bolts/washers	10		delivered
M3 bolts/nuts	28		delivered
B2200-R960	3+3	96pin connector	delivered
DB15 connector	1		delivered
DB25 connector	1		delivered
TNC connector	2+2	Telegärtner	delivered
SMA angle crimp	2	Telegärtner	delivered

SMA straight PCB	**2**	**Telegärtner**	**delivered**
PSU PCB	**1**		**delivered**
OBDH PCB	**1**		**delivered**
Motherboard PCB	**1**		**delivered**
Analogue PCB	**1**		**delivered**
ADS1147	**1**	**ADC**	**delivered**
PIC18F26K22	**1**	**uC**	**delivered**
SST25VF080b	**1**	**Flash memory**	**delivered**
SN74HC4051	**2**	**MUX**	**delivered**
max3070	**1**	**RS422**	**delivered**
MCP4822	**1**	**DAC**	**delivered**
OPA124	**2**	**precision opamp**	**delivered**
TL084	**1**	**opamp**	**delivered**
LM258	**2**	**opamp**	**delivered**
LM224	**2**	**opamp**	**delivered**
BS170	**2**	**n-ch mosfet**	**delivered**
BF259	**6**	**high voltage npn**	**delivered**
BF492	**6**	**high voltage pnp**	**delivered**
2N2222A	**2**	**npn tr**	**delivered**
INA169	**1**	**current tm**	**delivered**
LM193H	**1**	**comp**	**delivered**
LM113H	**1**	**v ref.**	**delivered**
LM258	**1**	**opamp**	**delivered**
SE555	**1**	**monostab**	**delivered**
2N2907A	**2**	**pnp tr**	**delivered**
2N2222A	**3**	**npn tr**	**delivered**
EFD25	**1**	**ferrit**	**delivered**

Table 5 Experiment summary table

Experiment mass (in kg):	1,634 (condensers; 0,817 kg each) 0,826 (electronic box) 2,460 (electronics box & condensers) 8,209 (total mass with module/bulkhead)
Experiment dimensions (in m):	0,065 x 0,025 x 0,28 (each condenser) 0,125 x 0,165 x 0,105 (electronic box)

Experiment footprint area (in m^2):	0,0189 (electronics box)
Experiment volume (in m^3):	4,55 x 10^{-4} (each condenser) 2 x 10^{-3} (electronic box)
Experiment expected COG (centre of gravity) position:	Experiment COG can be adjusted to coincide with the geometrical centre of the rocket.

4.4 Mechanical Design

The mechanical design of the experiment can be separated to two main parts; the condensers and the electronics box. In the following, each unit will be described in detail.

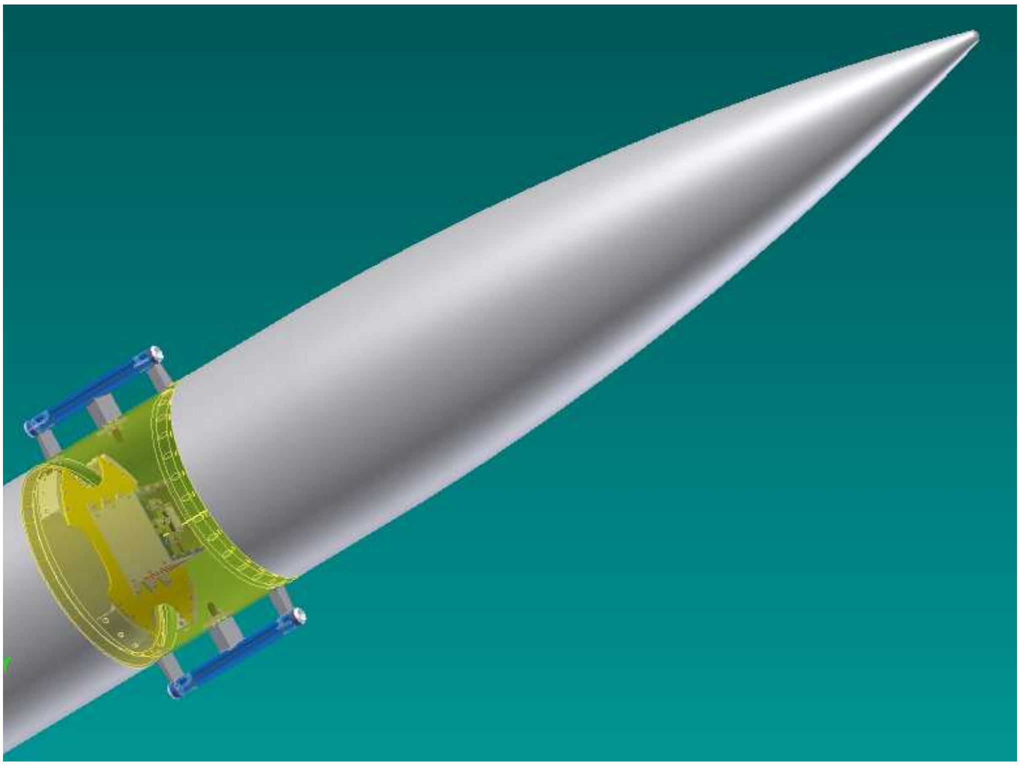


Figure 17. Placement of the condensers

The Gerdien condensers

The configuration of the condenser is shown in figure 18. The inner electrode is end in sleeve-nuts on both ends. The spacers of the centre electrode are fixed into these sleeve-nuts. The excursion is prevented by screw bond and fixation by shape. The spacers of the inner electrode are fitted in the notches of the outer electrode. The spacers of the inner electrode and the inlets are made of non-conductive material that can withstand the high temperature, practically ceramics (using plastics is preferable because of the easier manufacturing, we plan to use a plastic material that can be used for up to 500°C); the inner electrode will be made of bronze, all other parts are stainless steel.

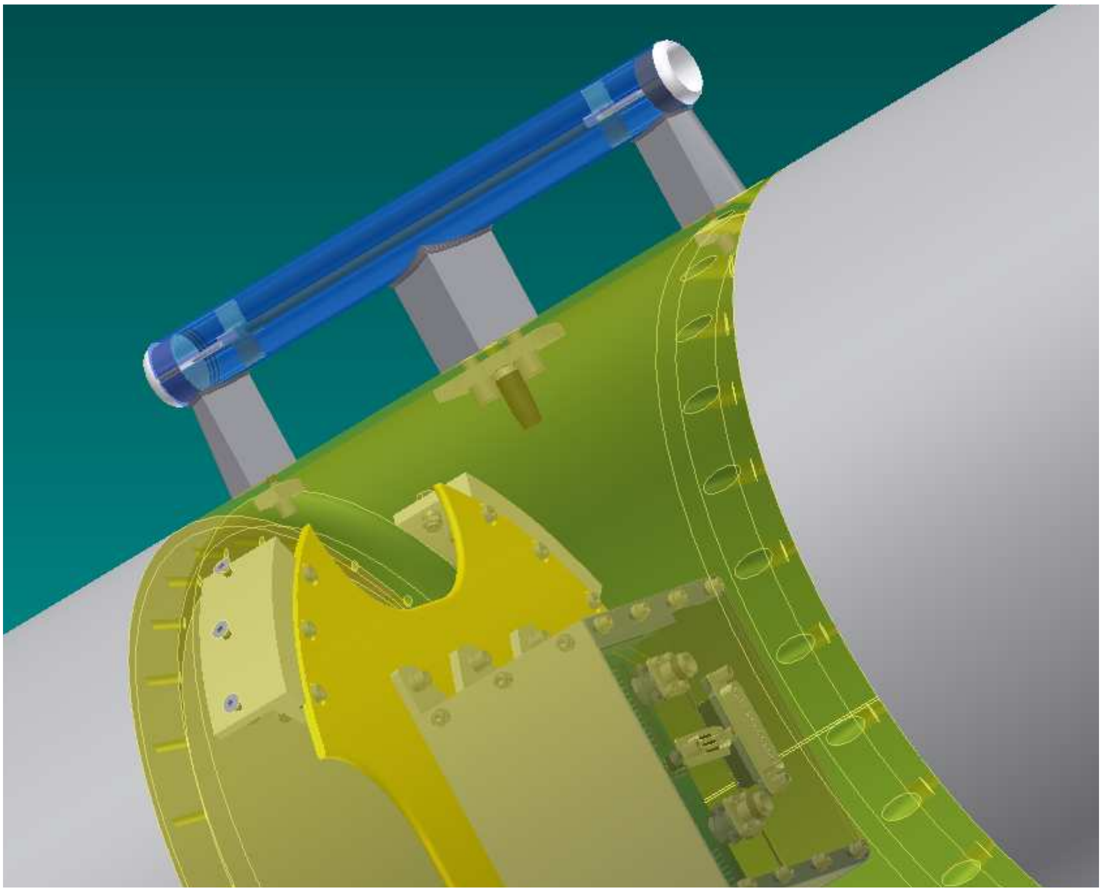


Figure 18. Condenser setup

The outer electrode is protected (mechanical protection and static shielding) by a coating and terminated by screw-caps for the fixation of all internal parts. Three spacers are used to mount the condenser and keep it far enough from the rocket. The spacers are welded to the condenser coating. The mechanical loads of the module wall are distributed by use of washers (see Figure 11/b). The condensers are mounted to the rocket by four M6 bolts (2 each) and four M4 bolts (2 each). Wires to the electrodes can be placed inside the spacers.

The aim of the additional struts (spacers at the extremities of the condensers is to prevent the parachute lines from entangling with the condensers. The design of the struts has been developed with the help of DLR experts; according to the latest feedback, regarding the new design, there is no risk of entanglement. The spacers at the extremities of the condensers are rounded in order not to damage the parachute lines, otherwise the cross section of the spacers is a double wedge shape, what is ideal for supersonic flights (Figure 19).

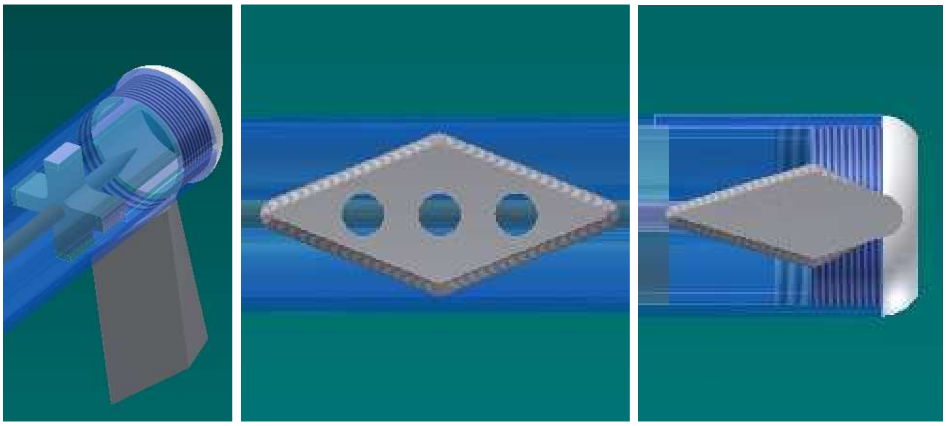


Figure 19. Condenser Inlet (left) and the cross-section of the main spacer (right)

For the results of finite element method analysis of the condensers (thermal and vibration), see chapter 5.3.

Laminar airflow in the condensers is another essential aspect for our experiment. In order to assure turbulence-free airflow, a defined distance has to be present between the rocket wall and the condensers as there is a turbulent boundary layer near the rocket. The thickness of the boundary layer is dependant of the distance measured from the tip of the rocket; therefore the necessary condenser distance varies in relation to the placement. In chapter 5.3 the needed distances are available in case of mounting the condensers at the top, or at the base of the payload.

The electronics box

The raw material of the electronics box is the STANAL 40 aluminium alloy. We use bolted connections in order to achieve easy mounting and proper fixation at the same time. All bolts fixing the box walls are the size of M3; for mounting the electronics box to the bulkhead, we use six pieces of M4 bolts. In the electronics box, there are four PCBs:

- Power supply PCB
- On-board data handling PCB
- Measurement/Signal amplifier analogue PCB
- Motherboard

At the sides of the electronics box grooves are designed to encase the PCBs equipped with the card lock retainers. At the inner end of the electronics box, there is room for the motherboard, at the top of the electronics box, the wires and cabling can be placed.

The connector interfaces are placed on the top of the electronics box; if there is not enough height for the connectors, these might be placed on the upper region of the front side.

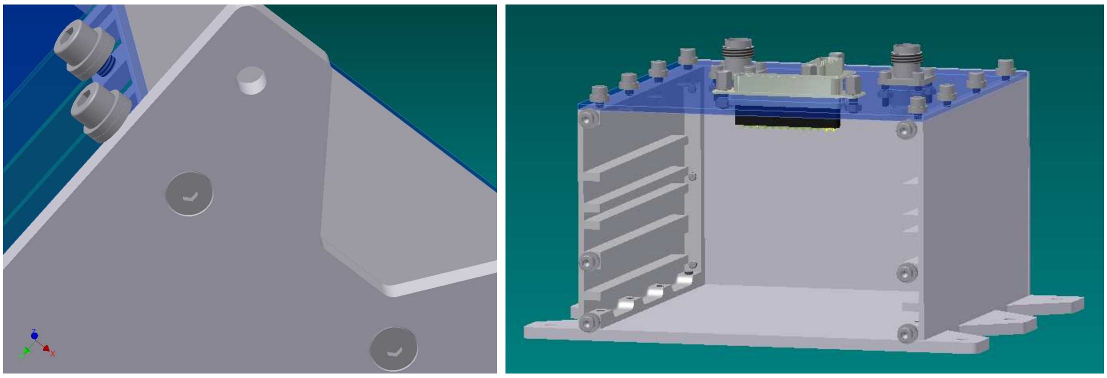


Figure 20/a. Structure of the electronics box

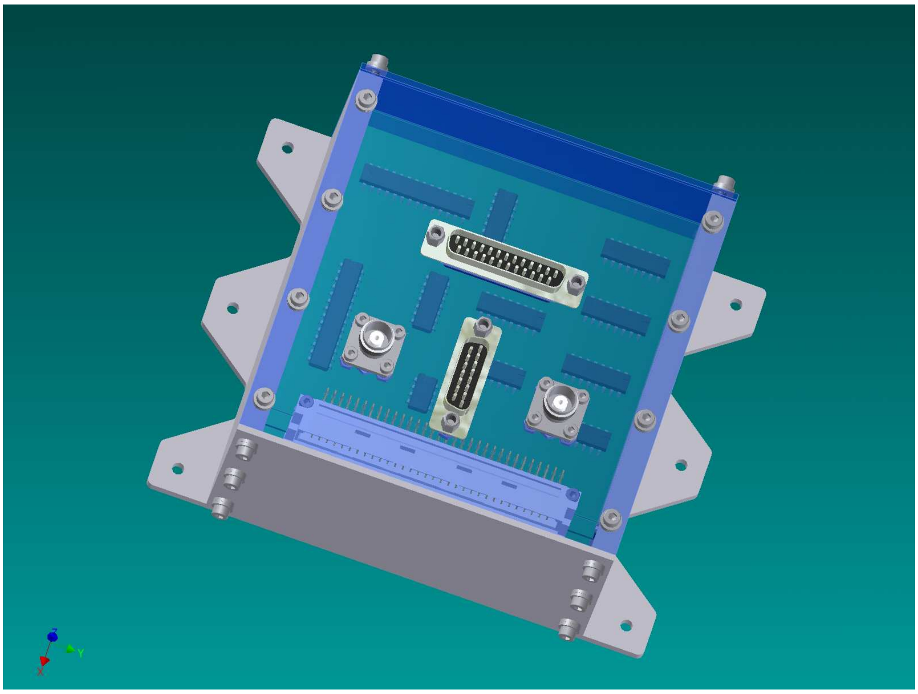


Figure 20/b. Electronics box assembly

Current mechanical drawings of the gerdien condensers are accessible in the appendix of the Student Experiment Documentation.

4.5 Electronics Design

4.5.1 Power Supply Unit

The power supply of the experiment will be located on a separate panel. It will be implemented as a flyback converter using magnetic feedback and current mode control with fixed switch-off time.

The control circuit uses discrete components, power MOSFET switches, and bipolar analogue integrated circuits including operational amplifiers, comparators, a voltage reference, and a 555 timer chip for the fixed off time. Each output will be filtered using common mode and differential mode filters.

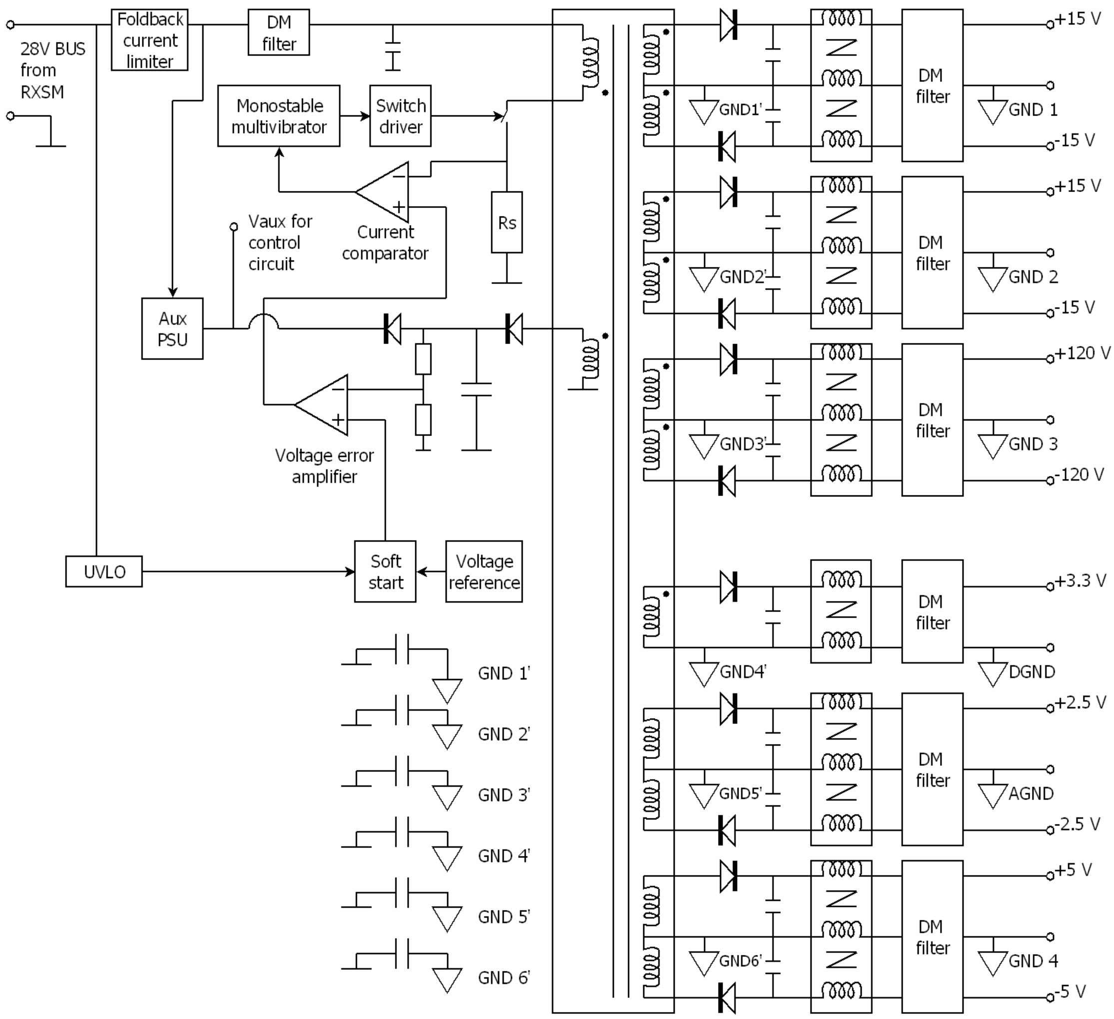


Figure 21. PSU block diagram
(Note that +/-60 outputs are used instead of +/- 120V)

The PSU provides stabilized supply voltages for the analogue and digital electronics, including a HV output (+/-60V) for the bias amplifiers. Table 6 shows the nominal voltages and currents for each output.

Description	Name	U_{nom} (V)	I_{nom} (mA)	P_{nom} (mW)
28 V bus from RXSM (maximal input current limited to 250 mA)	28V 28V Ground	28	110	3000
Analog supply for current sensor amplifier of gerdien condenser 1.	A1_+15V GND_1 A1_-15V	15 -15	3 3	45 45
Analog supply for current sensor amplifier of gerdien condenser 2.	A2_+15V GND_2 A2_-15V	15 -15	3 3	45 45
High voltage supply for bias generators	A3_+120V GND_3 A3_-120V	60 -60	1 1	60 60
Digital supply	D_+3V3 D_GND	3,3	60	198
Supply for telemetry A/D	A5_+2,5V AN_GND A5_-2,5V	2,5 -2,5	3 3	7,5 7,5
Supply for bias generator preamplifiers	A6_+5V GND_4 A6_-5V	5 -5	3 3	15 15

Table 6: Power supply voltages and planned nominal loads.

The A1 and A2 outputs are galvanically isolated from the others. GND_3, GND_4, AN_GND and D_GND are connected to the 28V Ground on the motherboard (see figure 10.). GND_1 and GND_2 is connected to the output of the bias amplifiers (see figure 16 in chapter 4.5.2).

The primary side of the power supply is designed to be capable of delivering at least 3 W of power for the transformer in all circumstances, even though the load on the secondaries will obviously not exceed 1 W.

The circuit diagram of the complete power supply unit can be found on the next page:

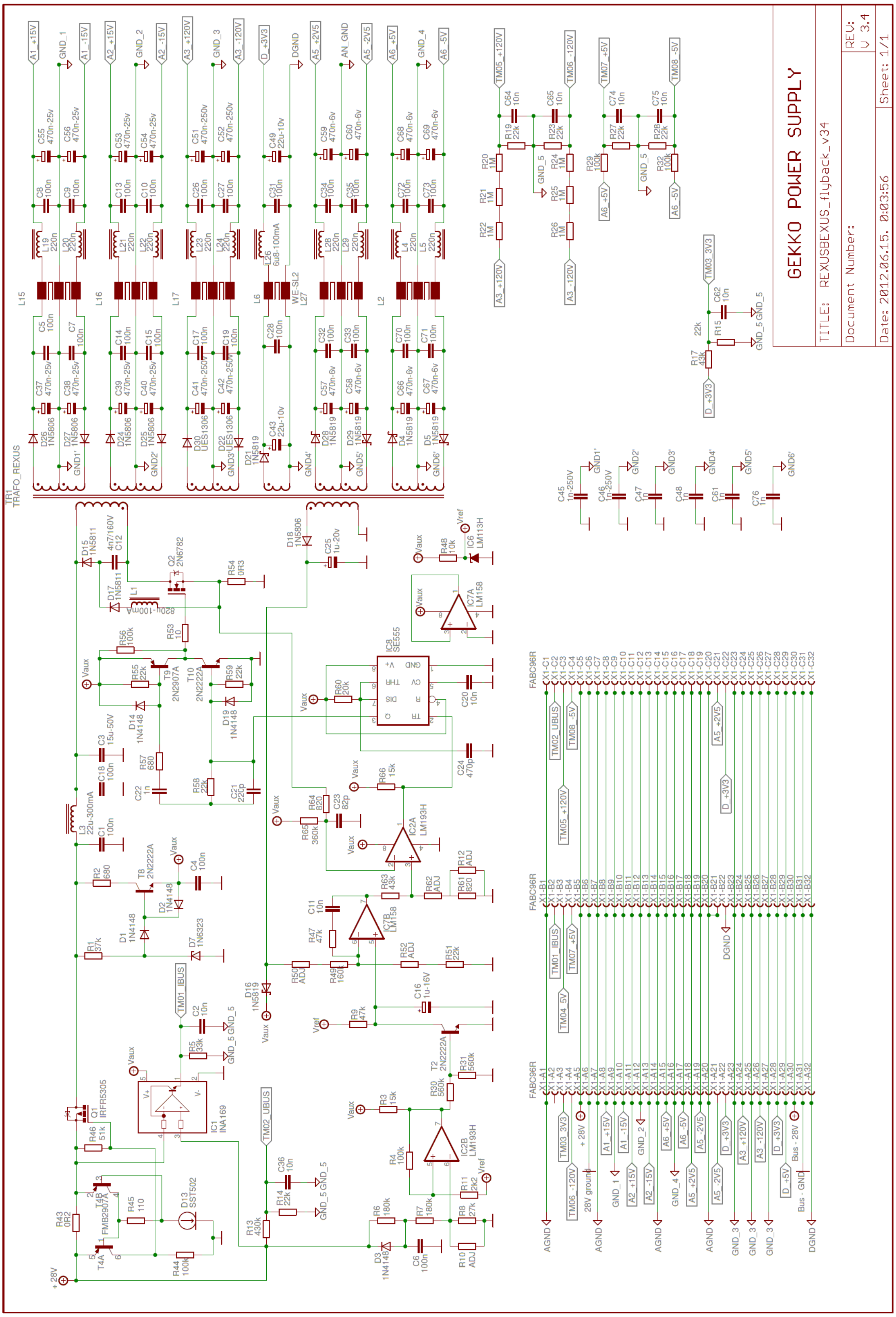


Figure 22. PSU circuit diagram

If an overload or a short circuit occurs on any output the other output voltages will decrease. As a consequence of the current mode control and the fixed switch off time the input current decreases when any of the outputs are shorted.

The switching power supply will have a nominal switching frequency of 50 kHz. The switch off time is fixed to 25 µsec. The L3 inductor ensures that the maximal voltage ripple fed back to the RXSM never exceeds the allowed 500 mVpp level. (The 28V power line series resistance is considered 1.3 Ω and the series inductance is 64 µH.)

The UVLO starts the power supply if the input voltage is above 23 V, and it disables the operation when the input voltage decreases below 20 V.

The complete control circuit of the power supply will consume a maximum of 20 mA. During start, when powered from the 28 V input, this translates to 560 mW. This decreases below 200 mW during normal operation.

The inrush current of the power supply is limited to maximal 250 mA by an FCL (foldback current limiter) circuit (this intervenes via MOSFET Q1).

The flyback transformer is coiled by us. The transformer has seven galvanically isolated secondaries, including a high efficiency auxiliary power supply for the control circuit.

4.5.2 Analogue electronic board

The analogue electronic board contains the required circuits for biasing the condensers and measuring their currents. This PCB is interfaced to the motherboard by a 96pin B2200-R960 type connector (see figure 9.)

Because of the expected ion density and the mechanical structure of the Gerdien condensers we have to deal with extremely low current flows. These low current flows (typically nanoampers) require a very precise measurement circuit which able to give correct results.

The conventional high side current monitoring is not good at this case, because of the low currents and the external noises. Therefore the chosen measurement method is the comparative current monitoring, which means that the measuring circuit always response with the same value of the incoming current, but the sign of the current is reverse. In the feedback path we can measure a voltage level which is proportional with the value of the current.

Theoretical block diagram of the precision low current measurement circuit:

Theory of the operation:

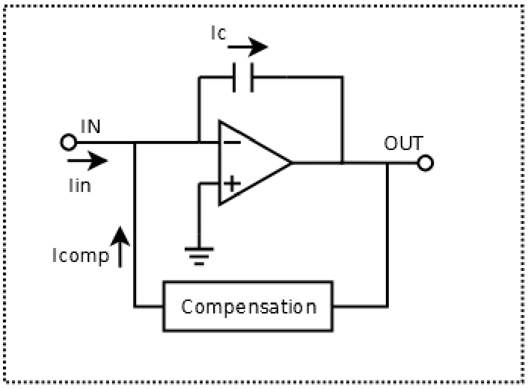


Figure 23. Low current measurement

Considering an ideal operation amplifier, the integrator's capacitor potential is unchanged if Ic is zero. In any other case the value of Ic is equal to Iin+ Icomp. Therefore in steady state the incoming current's absolute value is equal to Icomp.

In the real word if we want a precision circuit, and keep the measurement error below 10 percent we had to choose the exact components (semiconductors) very carefully. The key parameters for the operation amplifiers are: low offset voltage, low drift voltage, and the main is the very low input bias current.

Taking into account the above mentioned parameters the OPA124 is a suitable operation amplifier.

Even so the chosen operation amplifier has very good performance the input bias current is close to the current which has to be measured. So the compensation circuit has to deal with this current flow too. Fortunately the noise and the drift voltage of the amplifier are much lower than the output voltage, we do not have to care of them.

To perform the bias voltage adjustment two analogue signals are received (DA1, DA2) and amplified into the required range. Since the bias voltage shall be adjusted between 10mV and 50V the 12bit DA converter is unable to cover the required voltage range with a single stage amplifier. In order to extend the voltage range the bias voltage amplifiers are able to operate in 1x and 30x amplification mode.

The bias voltage adjustment and current measurement needs isolated power supply for the precision amplifiers (+/-15V). The (GND_1, GND_2) are connected to the inner electrode of the condensers.

The schematic of the circuit is shown on figure 24:

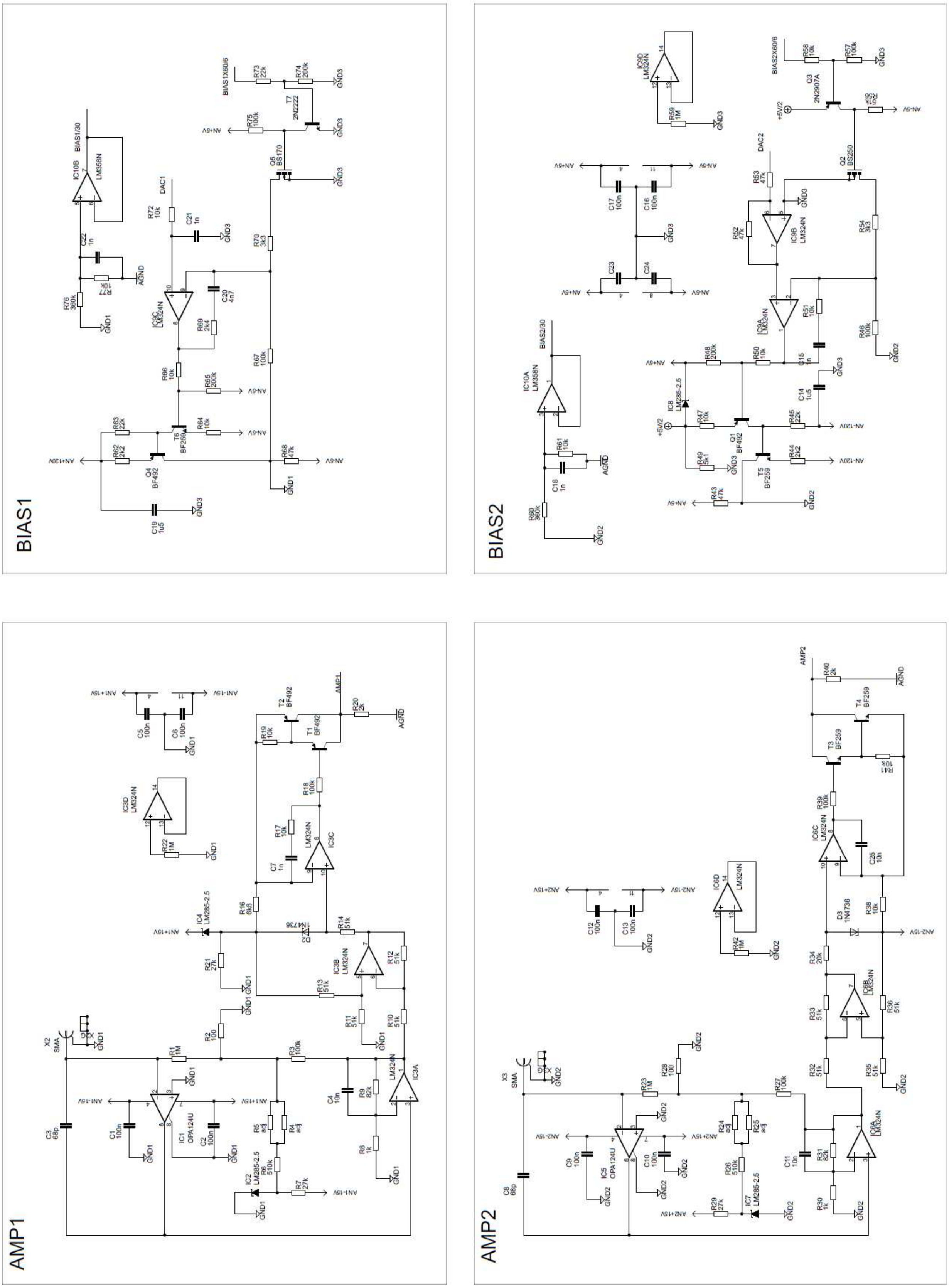


Figure 24. Amplifier schematic

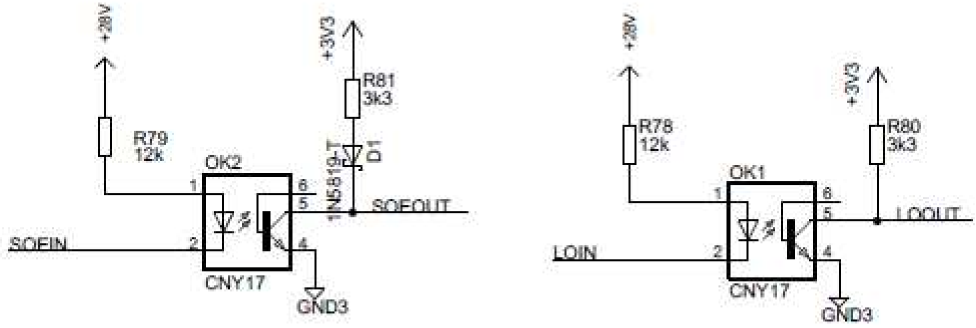


Figure 25. Control IF circuits

4.5.3 Digital electronics

The digital electronics of the Gekko experiment are located on the OBDH board. The OBDH board is consists of a PIC18F microcontroller, a flash memory chip, the RS422 I/F IC, an AD and a DA converter (see figure 26). The OBDH board is connected to the motherboard by a 96pin B2200-R960 type connector.

The 16 analogue channels – including the outputs of the amplifiers, the applied bias voltages and the TM lines – are connected to the ADC by two multiplexers. The ADC is a 16bit, precision $\Delta\Sigma$ converter with a built in voltage reference. The communication between the ADC and the microcontroller is performed on the SPI bus. A symmetrical +/- 2.5V analogue supply voltage is applied to extend the analogue input voltage range to -2.048V to 2.048V. In that case the ADC runs on 15 bits resolution which means 0.0625mV LSB. During a sweep the condenser current and bias voltages also need to be measured in every single point. To record a 64 point mobility spectrum in a second (P.3.) 256 AD conversion is needed for each condenser so the sample rate of the ADS is set to 1000/s.

The DAC has two independent analogue output so the Gerdien condensers can be biased individually. The bias amplifiers are built up on the analogue electronic board and described in section 4.5.2. The bias voltage range can be extended by the Bias_60x_1 and Bias_60x_2 control signals (see figure 26).

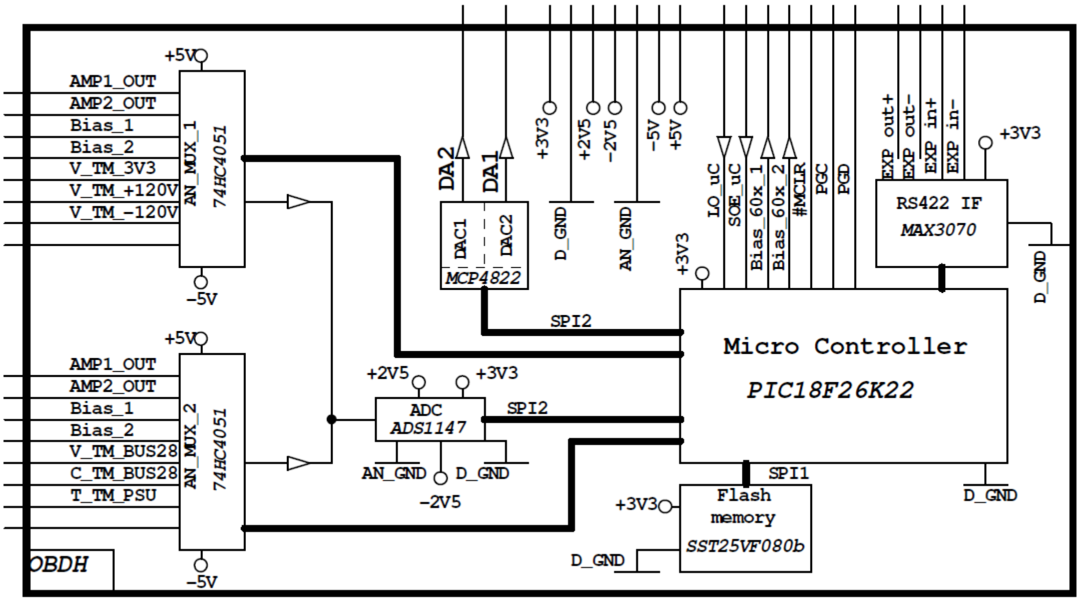


Figure 26. Gekko digital electronics

All of the measured data and bias voltage values as well shall be stored in a non-volatile memory. Considering a 600s flight time a 16 Mbit flash memory is suitable. While the AD and DA converters communicate on the same SPI bus, the Flash memory uses a different SPI bus.

In order to increase resistance against the vibration the internal calibrated RC oscillator is used as clock source instead of external quartz crystal.

The LO and SOE control signal is used for triggering the measurement. These interface circuits are realized on the analogue electronics board.

The schematic of the OBDH board is shown on the next figures:

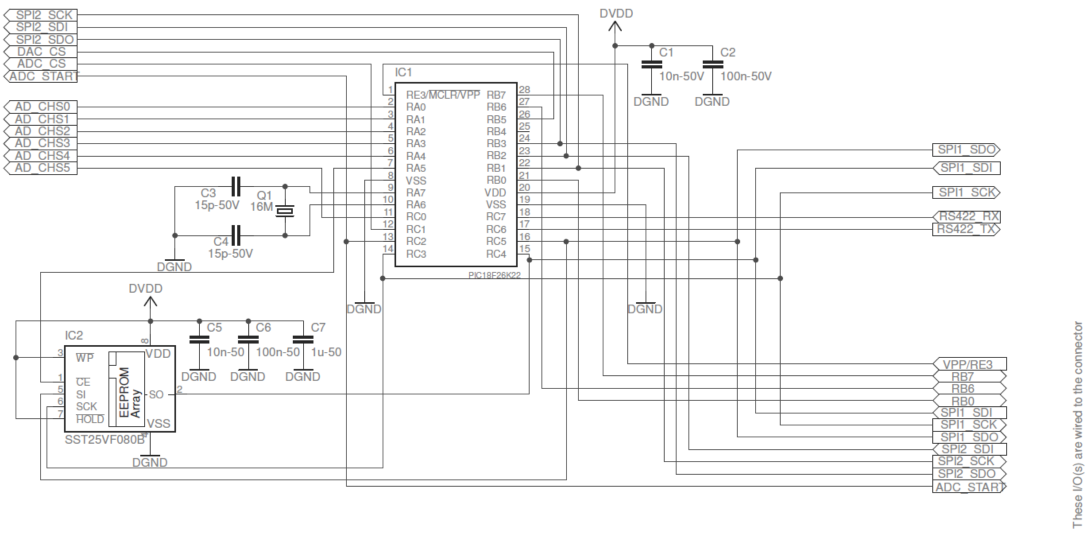


Figure 27. Microcontroller and memory

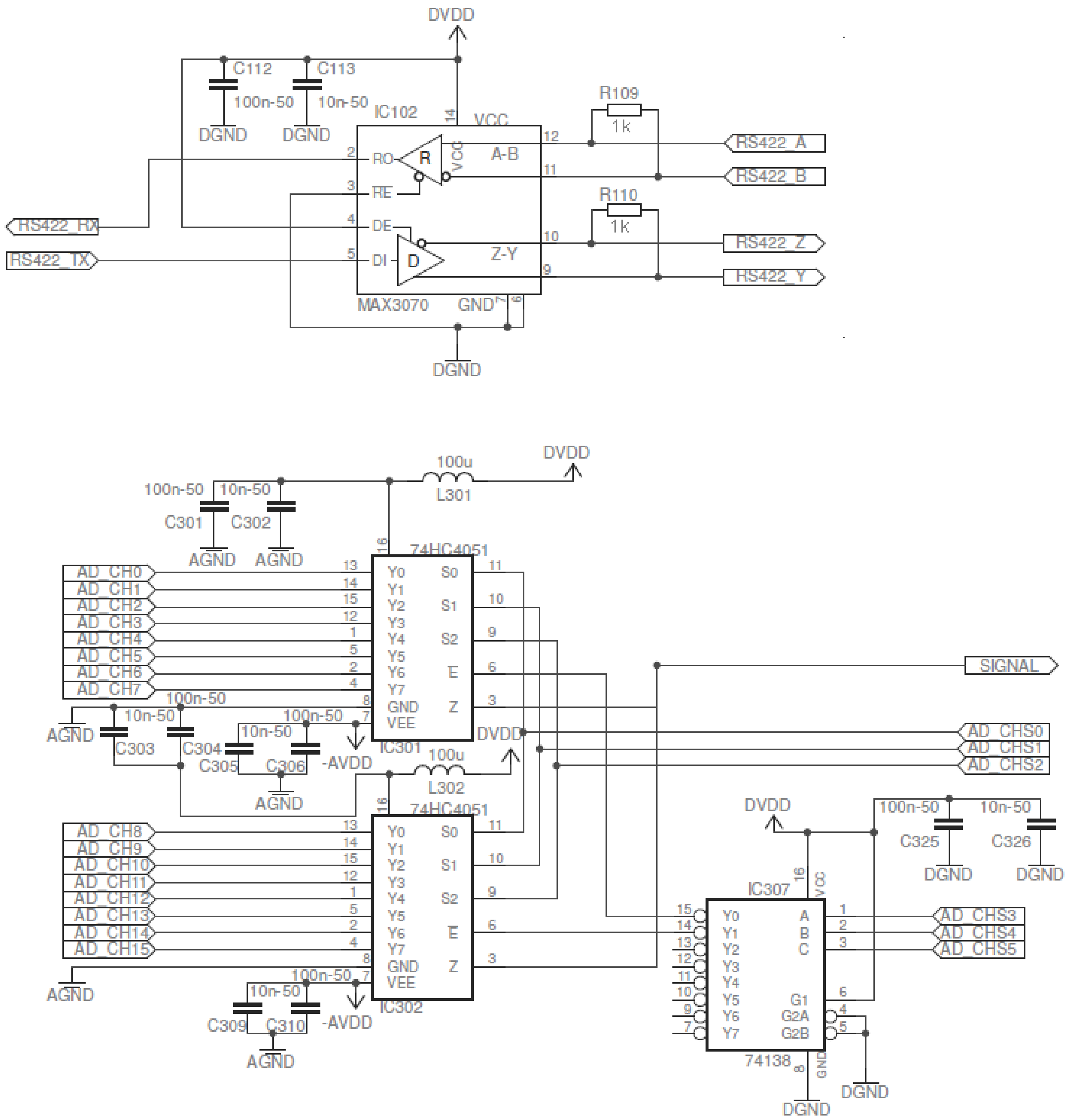


Figure 28. Multiplexers and RS422 IF

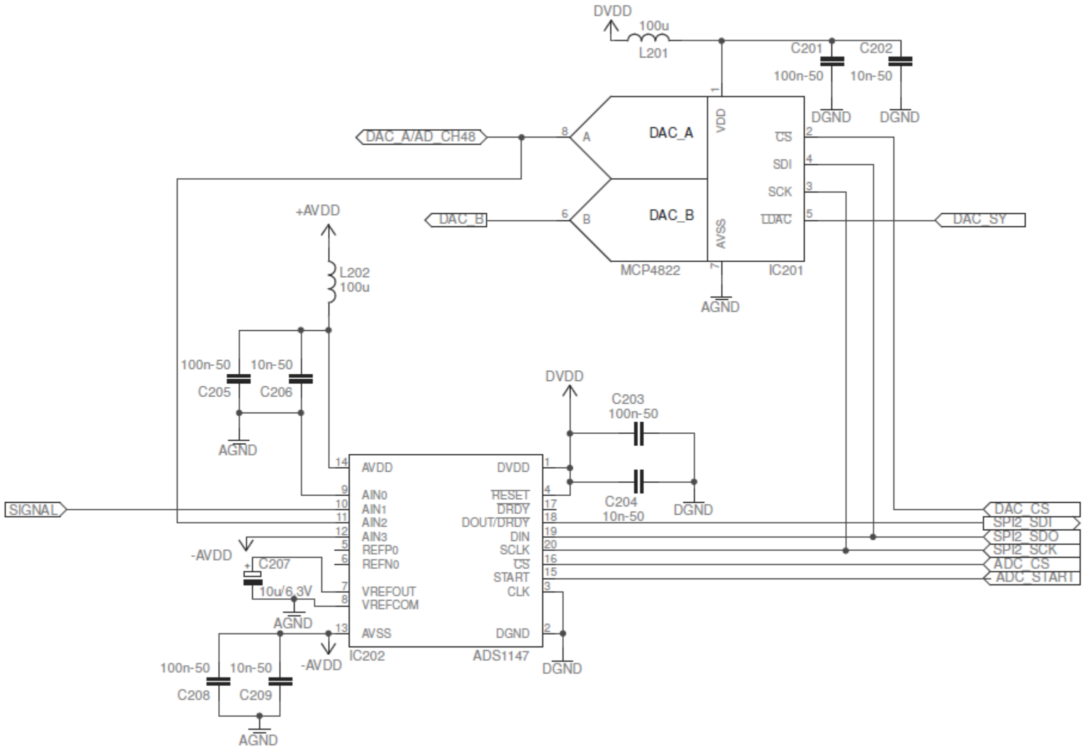


Figure 29. AD and DA converters

4.6 Thermal Design

Thermal Design of the condensers

Due to the heat generated by the friction, the proper selection of structural and soldering materials is fundamental. From the REXUS manual, we could get an approximate temperature value “over 200 °C” for the rocket coverage. As a result of discussions with DLR experts, the temperature is highly dependent on the angle of surface and the airflow. There is a reasonable probability of temperatures up to even 500°C.

Checking the thermal conditions for the condensers, we got roughly similar results. The method determining the coverage temperature (empirical formula):

$$T_{cover} = T_0 \cdot (1 + 0{,}174 \cdot M^2)$$

Where:

- T_{cover} is the temperature of the coverage [K]
- T_0 is the air temperature [K]
- M is the Mach number (current velocity of rocket)

The air temperature is more important in the lower altitudes, where the density is higher. In addition, the maximum velocity of the rocket is at the altitude of 24 km. This point is approximately at the top of the tropopause, where the temperature is ≈ -56 °C ≈ 217 K.

Thus, the data is as follows:

$$T_0 \approx 217 \text{ K}$$

$$M \approx 3$$

The coverage temperature:

$$T_{cover} = 217 \cdot (1 + 0{,}174 \cdot 3^2) = 557 \text{ K} = 283 \text{ °C}$$

This formula does not take the heat transfer processes into account, so it can be considered as an estimate regarding the condenser walls. For the inlets, the boundary conditions are much more complicated, and higher temperatures can be expected. Considering the low melting point temperature of soft solders and structural polymers, great care must be taken choosing the materials during the development; final verification can be carried out based on material data, simulation and thermal test. The results of finite element thermal analysis can be found in chapter 5.3.

4.7 Power System

The Gekko experiment will be powered on the 28V power line from the REXUS service module. No additional batteries will be used. The experiment power will be switched on and off by the service module (see chapter 6.1.3) and the operational time is 10min. The power consumption doesn't changes significantly while the experiment is powered.

Table 8 Detailed power budget:

Unit	Maximum power consumption	Power consumption with 20% margin	Energy consumption
PSU board	300mW	360mW	60mAh
Analogue board	350mW	420mW	70mAh
OBDH board	150mW	180mW	30mAh
Total	800mW	960mW	**160mAh**

4.8 Software Design

After the experiment is powered on the system initialization is executed and the system steps into standby mode. In this mode the HK data collection is performed in every 5 seconds. The HK data frames are stored in the onboard flash memory and transmitted to the GSE as well. At this stage the software accepts telecommands such as “download flash memory content”, “erase memory” or “test run”.

The system changes into prepare mode and sends “LO detected” string to the ground station when the LO signal is pulled down. In this mode no current measurement is performed.

The nominal operation mode is triggered by the SOE control signal. The bias voltage sweeps and measurements starts after SOE trigger event and synchronized to the internal timer. All of the measured data is stored into the flash memory and transmitted to the ground station as well. The measurements can be triggered by TC during tests.

After all of the measurements are done the software steps into post operational phase. At this time the HK data collection is still running but the condensers are not biased, there is no electrical field in the pipes.

During the countdown the experiment goes through the processes without any intervention. The operational modes of the OBDH software are shown on Figure 30.

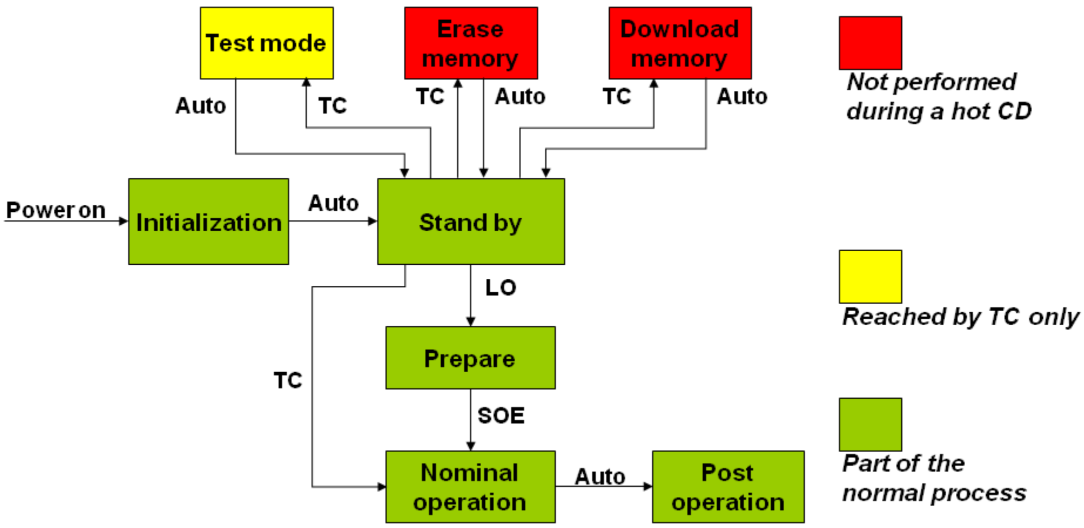


Figure 30. On-board software state diagram

When nominal operation is performed the program adjusts the bias voltage in a predefined voltage range and measures the condenser current and the bias voltage as well. After 4 current and 4 bias voltage measurements were done with both condensers a data frame is formed, transmitted to the ground station and stored into the onboard memory. Every frame contains 16 measurement data including 2x4 current and 2x4 bias voltage measurements as shown below.

Experiment data frame:

Frame Byte #	1-2	3-4	5-36	37-39	total
content	SYNC WORD	FRAME CNT	PAYLOAD DATA	TIME STAMP + PARITY + PL/TM	
Size [Bytes]	2	2	32	3	39
Size [bits]	16	16	256	22+1+1	312

where “PAYLOAD DATA”:

Data byte #	1-2	3-4	5-6	7-8	…	29-30	31-32
Content	V_GC1 bias #1	C_GC1 #1	V_GC2 bias #1	C_GC2 #1		V_GC2 bias #4	C_GC2 #4

In nominal mode, the measurement and the serial communication performed in parallel. The transmission of a single data frame starts with the sync word and frame counter and proceeds with the data bytes. The transmission of the data frame terminates with the time stamp. One characteristic curve is recorded in every second and consists of 128 consecutive measurements (64 current and 64 bias voltage values).

The HK data frame format is similar to the measurement data frames:

Frame Byte #	1-2	3-4	5-24	25-27	total
content	TM SYNC WORD	FRAME COUNT #	HK DATA	TIME STAMP + PL/TM + PARITY	
Size [Bytes]	2	2	16	3	23
Size [bits]	16	16	128	22+1+1	184

where "HK DATA":

HK Data byte #	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16
Content	V_3V3	V_+120V	V_-120V	V_BUS28	C_BUS28	T_PSU	V_+5V	v_-5V

- One data frame is 39 bytes long
- One telemetry frame is 23 bytes long
- All frames contain a unique counter value that can be used as a serial number and also a 22-bit timestamp for further identification.
- The timestamp started at power on.
- The resolution of the timestamp is 15 ms
- The remaining 2 bits are the HK data indicator and a parity bit for basic error-detection.

As one data frame contains 4 points of the characteristics of both condensers, the total 64 points of the voltage – ampere curve are transmitted in 16 frames. HK data is sent in every 5 seconds. The download data rate is calculated as follows:

$$data\ rate = \left(\frac{1}{5} * 23byte * 10bit\right) + (16 * 39byte * 10bit) = 6240bps$$

The main program flow diagram of the OBDH SW is shown on *Fig. 31*.

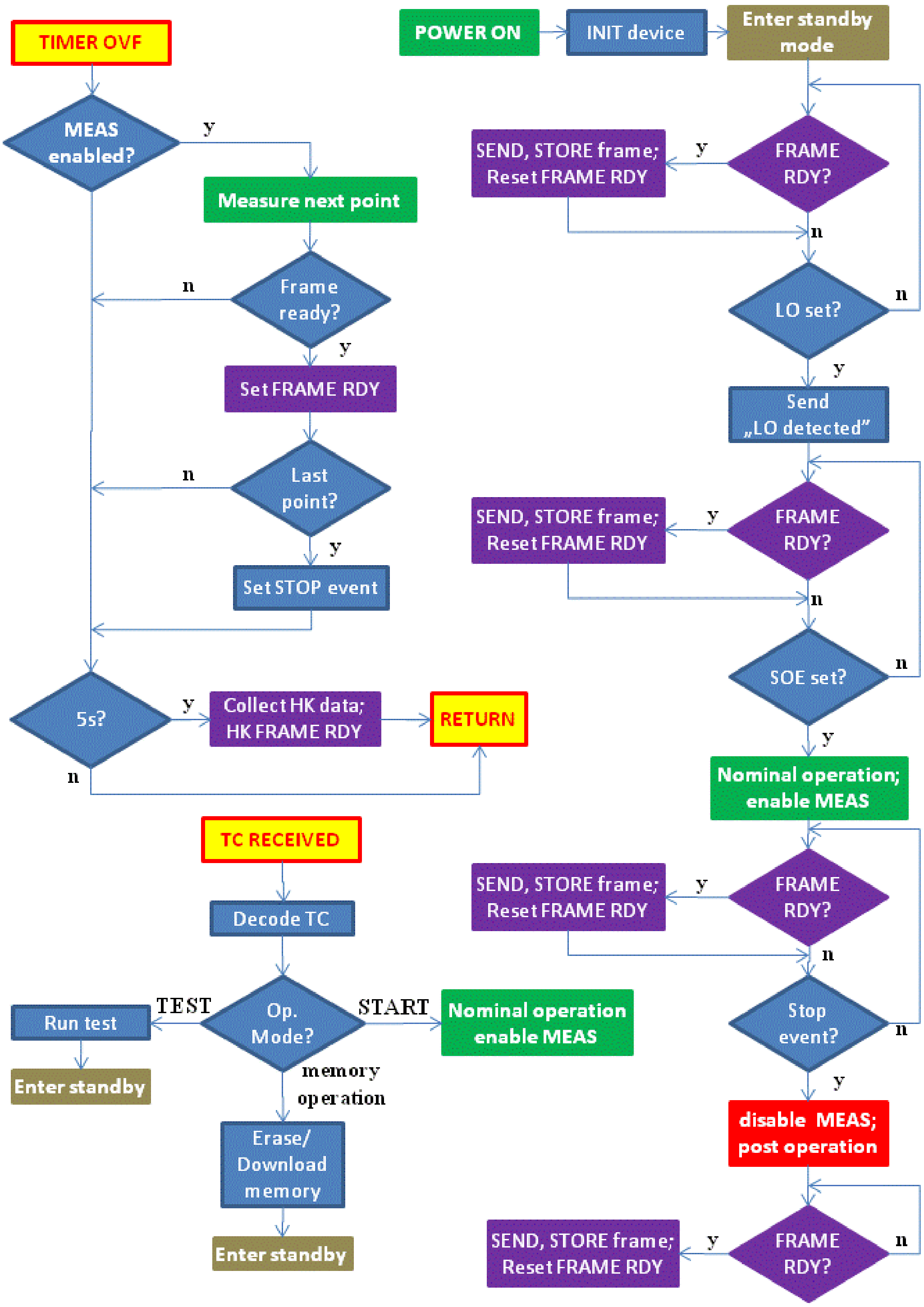


Figure 31. On-board software flowchart

In nominal mode the experiment shall take the measurements in predefined bias voltage ranges. The bias voltage steps (ΔU_{bias}) are the same within one characteristic so each sweep can be defined by the start value ($U_{bias,0}(i)$) and step ($\Delta U_{bias}(i)$). These data are stored in the EEPROM of the PIC.

When a timer interrupt occurs in nominal mode the OBDH shall take four AD conversion and two DA conversion to collect one-one point (+ , -) of the actual characteristic. The transient time of the precision amplifier is in the order of the AD conversion time so the voltage adjustment cannot be followed by the current reading on the same condenser. The order of these steps is the following:

1. SET DA1 (bias +)
2. START ADC_CH3 (Bias -), WAIT to AD_read, READ AD_CH3 (Bias -)
3. START ADC_CH4 (Current -), WAIT to AD_ready,READ AD_CH4 (Current -)

4. SET DA2 (bias -)
5. START ADC_CH1 (Bias +), WAIT to AD_ready, READ AD_CH1 (Bias +)
6. START ADC_CH2 (Current +), WAIT to AD_ready, READ AD_CH2 (Current +)

The converted data bytes are stored in the internal SRAM until a whole frame is ready. The transmission to the ground station is initiated when the frame is ready.

The HK data frame is generated in every five seconds. Each data packet is equipped with a time stamp which is extracted from the ‘clock’ counter during frame assembly.

A table of periodic processes during the mission is shown below:

Task name	*period*	*op. mode*	*remark*
Status monitor	7.5 ms	stand by, prepare	
Nominal HK	5 s	continuous	
Nominal measurement	1 s	nominal	15ms / point
Timestamp count	15 ms	continuous	
Access to RS422	60 ms	nominal	access time: 10ms/transmission

4.9 Ground Support Equipment

The GSE shall be able to support the pre-flight tests (including troubleshooting and hardware tests), simulate the service module, upgrade the on-board SW and support the operator to inspect and control the experiment.

Thus the Gekko GSE consists of:

- a REXUS service module simulator and a break-out box (built up on a common panel, see figure 32.)
- an experiment IF cable assembled with DSUB 15 male/female connectors
- a Ground Station IF cable assembled with DSUB 9 male/female connectors
- an RS232 → USB converter
- a technology IF cable assembled with DSUB 25 male/female connectors
- two power cables (with banana plugs)
- a laptop with the installed ground station SW
- installed MPLAB (to re-compile the on-board SW if necessary)
- USB A to mini USB converter (connect PICkit3)
- PICkit3 programmer and debugger

During the pre-flight tests the experiment is connected to a laptop. Commands are sent to the experiment and the HK and measurement data are received and processed with the GSE software written in C# language.

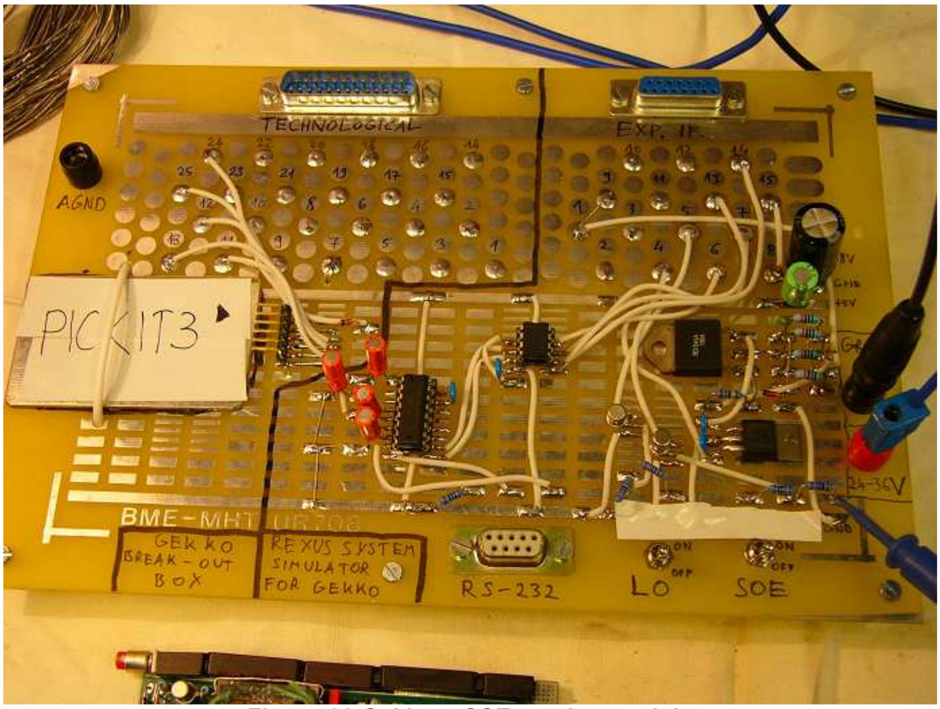


Figure 32 Gekko – GSE service module

All measurement and telemetry data will be stored and monitored during the flight. A picture of the program is shown in Figure 32.

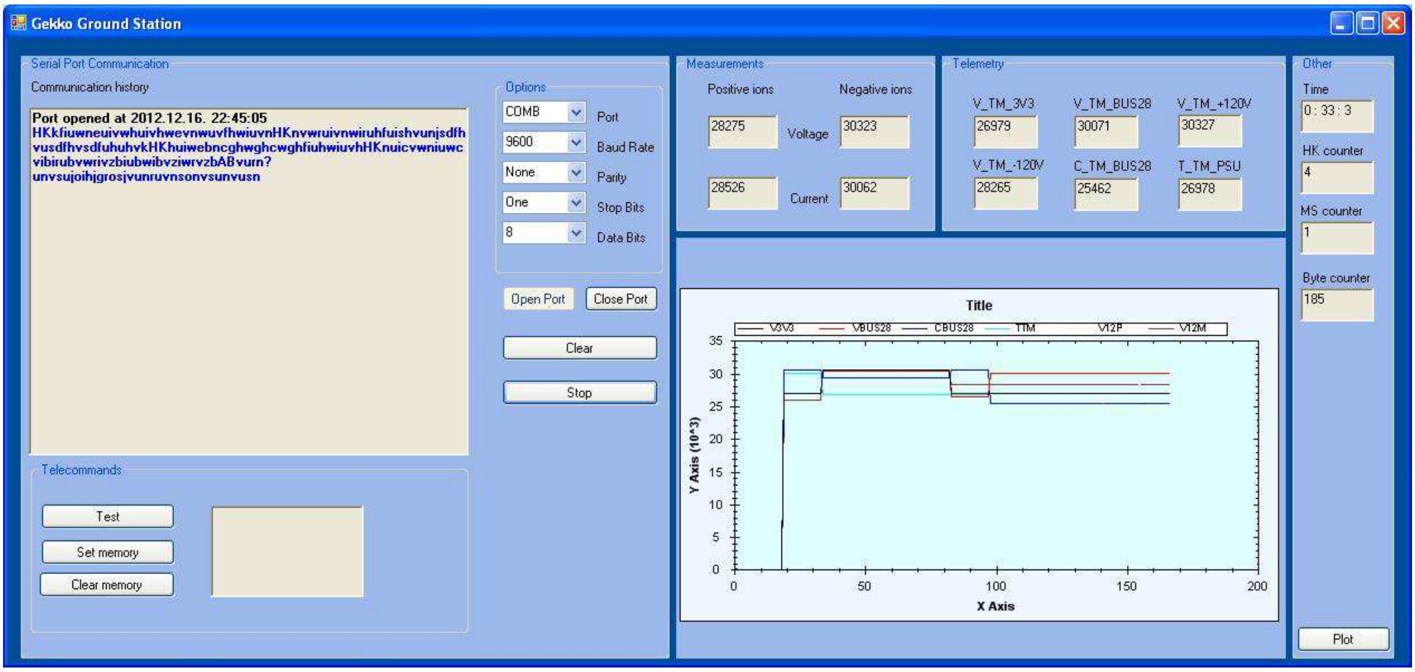


Figure 32. Ground Software user interface

The main sections of the ground station SW are the serial port communication, telemetry, telecommands and measurements. There is also another section which shows the elapsed time, speed, temperature and the height. The plot buttons are to draw diagrams of the related measurements.

In the communication history window we will see the main steps of the measurement for example communication is ready, port is opened, error occurred and so on.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

Table 9 Verification table

ID	Requirement text	Verification	Status
F.1.	The experiment shall measure the ion mobility during the flight of the rocket using two Gerdien condensers.	A	Done
F.2.	The experiment shall adjust the bias voltage of the Gerdien condensers according to the velocity of the rocket.	R, T	Done
F.3.	The experiment shall measure the current of the Gerdien condensers.	R, T	Done
F.4.	The experiment shall use its own PSU to ensure continuous power supply for the electronics.	R	Done
F.5.	The experiment shall measure the input current and input voltage of the PSU.	R, T	Done
F.6.	The experiment shall store all measured data into an on-board non-volatile memory.	R, T	Done
F.7.	The experiment shall send the data to the ground station through the RXSM during the whole flight of the rocket.	R, T	Done
P.1.	The ion mobility measurements shall be performed between 0,005 and 15 [$m^2/(Vs)$] for positive ions and from 0,01 to 20 [$m^2/(Vs)$] for negative ions.	A	Done
P.2.	The ion mobility measurements shall be performed with an accuracy of 0,001 [$m^2/(Vs)$] for both positive and negative ions.	A	Done
P.3.	The ion mobility measurements shall be performed at a rate of 128 measurements every second for both positive and negative ions.	R	Done
~~P.4.~~	The bias voltage of the Gerdien condensers shall be adjusted in the range of -10mV to -120V for the positive ions and 10mV to 120V for negative ions.	R	Done
P.4.	The bias voltage of the Gerdien condensers shall be adjusted in the range of -10mV to -	R	Done

	50V for the positive ions and 10mV to 50V for negative ions.		
P.5.	The bias voltage adjustment of the Gerdien condensers shall be performed with a minimum accuracy of 10mV.	R, T	Done
P.6.	The current of the Gerdien condensers shall be measured in the range of 5pA to 2 nA.	R, T	Done
P.7.	The current measurements of the Gerdien condensers shall be performed with a maximum accuracy of 1pA.	A, R, T	Done
P.8.	The PSU shall provide a +/-5V, +/-2,5V and a +3,3V output with 10% accuracy.	R, T	Done
~~P.9.~~	The PSU shall provide two +/-15V outputs and a +/-120V output with 10% accuracy.	R, T	Done
P.9.	The PSU shall provide two +/-15V outputs and a +/-60V output with 10% accuracy.	R, T	Done
P.10.	The input current measurement shall be possible in the range of 20mA to 200mA.	R, T	Done
P.11.	The input current measurement shall be performed with an accuracy of +/- 2mA resolution.	R, T	Done
P.12.	The input voltage measurement shall be possible in the range of 20V to 40V.	R, T	Done
P.13.	The input voltage measurement shall be performed with an accuracy of +/- 200mV resolution.	R, T	Done
D.1.	The experiment shall be designed to withstand the mechanical loads during the complete flight of the REXUS rocket.	A, T	Done
D.2.	The experiment shall be designed to operate in the temperature profile of the pre-flight and flight phase of the REXUS.	A, T	Done
D.3.	The experiment thermal dissipation must not heat up the outer structure more than 10°C over the ambient temperature	A	Done
D.4.	The experiment thermal dissipation must not heat up the parts close to or in contact with the feed-through cable more than +70°C.	A	Done
D.5.	The experiment thermal dissipation must not heat up parts facing other modules more than +50°C.	A	Done
D.6.	The heat transport by convection must be limited in such a way that the air temperature at the module interfaces does not exceed the ambient temperature by more than 10°C	A	Done

D.7.	The experiment shall be designed to operate under 1mbar air pressure.	R, T	Done
D.8.	The experiment shall be connected to the RXSM experiment interface.	I	Done
D.9.	The experiment interface connector shall be a D-SUB 15 male type.	I, R	Done
D.10.	The experiment shall be able to communicate on the RS422 telemetry interface.	R, T	Done
D.11.	The telemetry data rate shall be less than 30kbps.	A, T	Done
D.12.	The experiment shall be powered over the RXSM power interface.	R, T	Done
D.13.	The experiment shall be able to operate from the RXSM power line in the range of 24V to 36V supply voltage.	R, T	Done
D.14.	The inrush current of the experiment shall not exceed 3A.	A, T	Done
D.15.	The continuous input supply current of the experiment shall not exceed 1A.	A, T	Done
D.16.	The voltage ripple fed back to RXSM over the power line shall be less than 500mV.	T	Done
D.17.	The airflow of the Gerdien condensers shall be laminar.	A	Done
D.18.	The Gerdien condensers shall be placed 40mm from the outer surface of the rocket.	R, I	Done
D.19.	The experiment shall be equipped with enough non-volatile memory to store the entire data.	A	Done
D.20.	The experiment shall not resonate during the flight. (the eigenfrequency of the experiment units shall highly exceed the frequency of rocket vibration during flight)	A	Done
D.21.	The shift caused by the roll of the rocket shall not disturb the measurement	A	Done
O.1.	The experiment shall be able to conduct measurements autonomously in case connection with the ground segment is lost.	R, T	Done
O.2.	The bias voltage values shall be calculated according to the predicted flight profile before the flight.	A	Done
O.3.	The calculated bias voltage values shall be uploaded into the onboard non-volatile memory before the flight.	T	Done
O.4.	The start of the measurement shall be triggered by the LO control signal.	T	Done

O.5.	The onboard memory pointer shall be set to its initial value after pre-flight tests by a ground command.	T	Done
O.6.	The content of the onboard memory shall be downloaded to the ground station after payload recovery.	T	Note Done
O.7.	The ground station shall store the received data onto a hard drive during the flight.	T	Done

5.2 Test Plan

Table 10 Electrical test

Test number	1
Test type	Electrical Performance Test
Test facility	Student laboratory of the University Space Research Group
Tested item	Breadboard circuit, precision amplifier
Test level/procedure and duration	Unit level, Performance test
Test campaign duration	2 days
Verified Requirements	P6, P7
The test objectives	The test aims to determine the maximum sensitivity of the percision amplifier. This test is to verify the calculations by using the reference test generator.

Table 11 Thermal test - PSU

Test number	2
Test type	Thermal
Test facility	Thermal chamber at BUTE
Tested item	PSU breadboard
Test level/procedure and duration	Board level, Acceptance test, 4hrs
Test campaign duration	1day
Verified Requirements	P8-P13, D2, D14, D15
The test objectives	After the breadboard production the dc and ac parameters

	are measured. The test aims to make the final adjustments on the PSU and verify the related performance and design requirements. Both, static and dynamic measurements are performed at 3 different temperature level: -40, +25 and +70 degrees. Under the static measurements values of the voltages and the currents are recorded. Under the dynamic measurements the switch on current- and voltage signals are recorded.

Table 12 Thermal test – Analogue electronics

Test number	3
Test type	Thermal
Test facility	Thermal chamber at BUTE
Tested item	Analogue electronics breadboard
Test level/procedure and duration	Board level, Acceptance test, 4hrs
Test campaign duration	2days
Verified Requirements	P5-P7, D2
The test objectives	After the breadboard production the dc and ac parameters are measured. The test aims to make the final adjustments on the analogue electronics, verify the related performance and design requirements and to produce the scale factors according to the temperature. Both, static and dynamic measurements are performed at 3 different temperature level: -40, +25 and +70 degrees. In case of the amplifiers the offset and offset drift are measured.

Table 13 Thermal test - OBDH

Test number	4
Test type	Thermal
Test facility	Thermal chamber at BUTE
Tested item	OBDH breadboard
Test level/procedure and duration	Board level, Acceptance test, 4hrs
Test campaign duration	2days

Verified Requirements	D2, D10, D11
The test objectives	This test is to verify that the OBDH electronics are able to operate in the REXUS thermal environment. Both, static and dynamic measurements are performed at 3 different temperature level: -40, +25 and +70 degrees.

Table 14 Software test – OBDH, GSE

Test number	5
Test type	Electrical Test
Test facility	Student laboratory of the University Space Research Group
Tested item	OBDH breadboard
Test level/procedure and duration	Board level, Acceptance test, 4hrs
Test campaign duration	2days
Verified Requirements	F6, F7, O1, O5
The test objectives	This test is to verify that the software of the EGSE and the software of the OBDH are working properly.

Table 15 Thermal test

Test number	6
Test type	Thermal
Test facility	Thermal chamber at BUTE
Tested item	Breadboard model
Test level/procedure and duration	System level, Acceptance test, 4hrs
Test campaign duration	3 days
Verified Requirement	F2, F3, F5-F7, D2, D10, D12, O1, O4-O7
The test objectives	This test is to verify that the experiment is working properly. Both, static and dynamic measurements are performed at 3 different temperature level: -40, +25 and +70 degrees.

Table 16 Thermal test

Test number	7
Test type	Thermal
Test facility	Thermal chamber at BUTE
Tested item	Flight model
Test level/procedure and duration	System level, Acceptance test, 4hrs
Test campaign duration	3 days
Verified Requirement	F2, F3, F5-F7, D2, D10, D12, O1, O4-O7
The test objectives	This test is to verify that the experiment is working properly. Both, static and dynamic measurements are performed at 3 different temperature level: -40, +25 and +70 degrees.

Table 17 Vibration test – Electronics box

Test number	8
Test type	Vibration (transient and sinusoidal)
Test facility	EL-TECH Center, Budapest
Tested item	Electronic box, flight model
Test level/procedure and duration	System level, Qualification test, 4hrs
Test campaign duration	1 day
Verified Requirement	D1
The test objectives	This test is to demonstrate that the mechanical calculations are correct. The box can withstand without damage under the vibration test is carried out in accordance with the requirements of the rocket.

Table 18 Vibration test – Gerdien condensers

Test number	9
Test type	Vibration (transient and sinusoidal)
Test facility	EL-TECH Center, Budapest
Tested item	Gerdien condensers

Test level/procedure and duration	System level, Qualification test, 4hrs
Test campaign duration	1 day
Verified Requirement	D1
The test objectives	This test is to demonstrate that the mechanical calculations are correct. The condensers and their mountings can withstand without damage under the vibration test is carried out in accordance with the requirements of the rocket.

Table 19 Vacuum test – Electronics box

Test number	10
Test type	Vacuum test
Test facility	Vacuum chamber at BUTE
Tested item	Electronic box
Test level/procedure and duration	System level, 15mins
Test campaign duration	1 day
Verified Requirement	D7
The test objectives	This test is to verify that the experiment withstands the REXUS pressure environment. The primary goal of this test is to recognize possible coronal effects inside the electronic box. During this test the experiment operates in normal operational mode under 1mbar pressure.

Table 20 Vacuum test – Gerdien condensers

Test number	11
Test type	Vacuum test
Test facility	Vacuum chamber at BUTE
Tested item	Gerdien condensers
Test level/procedure and duration	Unit level, 2mins
Test campaign duration	1 day

Verified Requirement	D7
The test objectives	This test is to verify that the high voltage doesn't cause coronal effects on the Gerdien condensers. The test is performed under 1mbar air pressure.

Table 21 RF Test

Test number	12
Test type	RF Test
Test facility	RF anechoic chamber at BUTE
Tested item	Whole experiment
Test level/procedure and duration	System level
Test campaign duration	2 days
Verified Requirement	
The test objectives	This test is performed to measure the effects of the RXSM S-band transmitter on the experiment. The test is made in an RF anechoic chamber with an S-band transmitter operating with TBD dBm power. To see the direction dependence a rotator platform is used.

Table 22 Wind tunnel test

Test number	13
Test type	Aerodynamic
Test facility	TBC
Tested item	Gerdien condensers
Test level/procedure and duration	Unit level, Acceptance test
Test campaign duration	1 day
Verified Requirement	D1, D17
The test objectives	This test is to verify the design performance of Gerdien condenser by the measurement of the physical parameters.

Component tests are performed after the procurement, before the board population. Test facilities are the multimeters and characterispcope.

5.3 Test Results

5.3.1 Mechanical stress and vibration analysis and test
(Verification of Req D.1 and D.20.)

The experiment will be designed to withstand all loads due to acceleration and vibrations. Verification can be carried out by finite element method analysis regarding the material selection results. Vibration simulation and test is also feasible in the lab.

An additional goal of the vibration test is to prove that the experiment will not resonate during the flight. To ensure this, the eigenfrequency of the experiment units should highly exceed the frequency of rocket vibration during flight. Based on an ANSYS modal analysis, this requirement is fulfilled, the first results can be seen below:

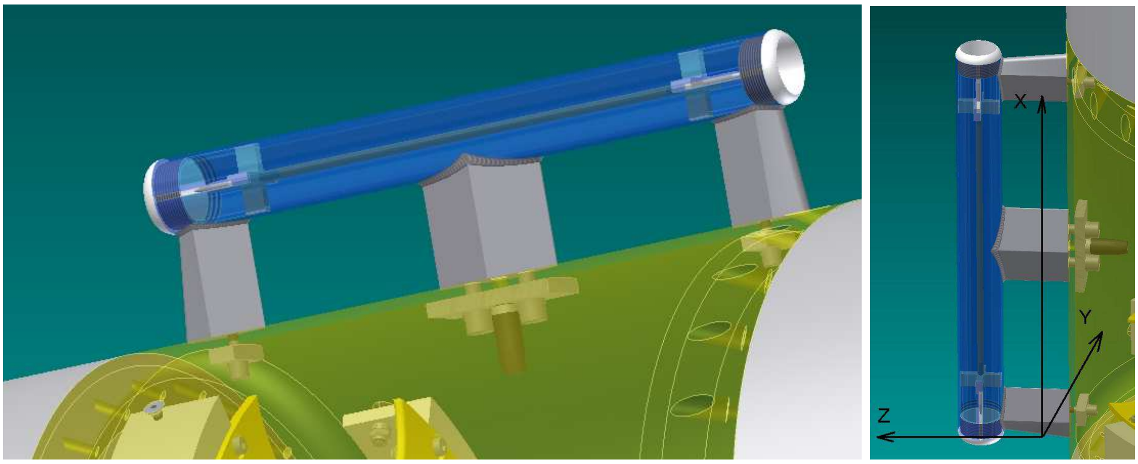


Figure 33. ANSYS model geometry

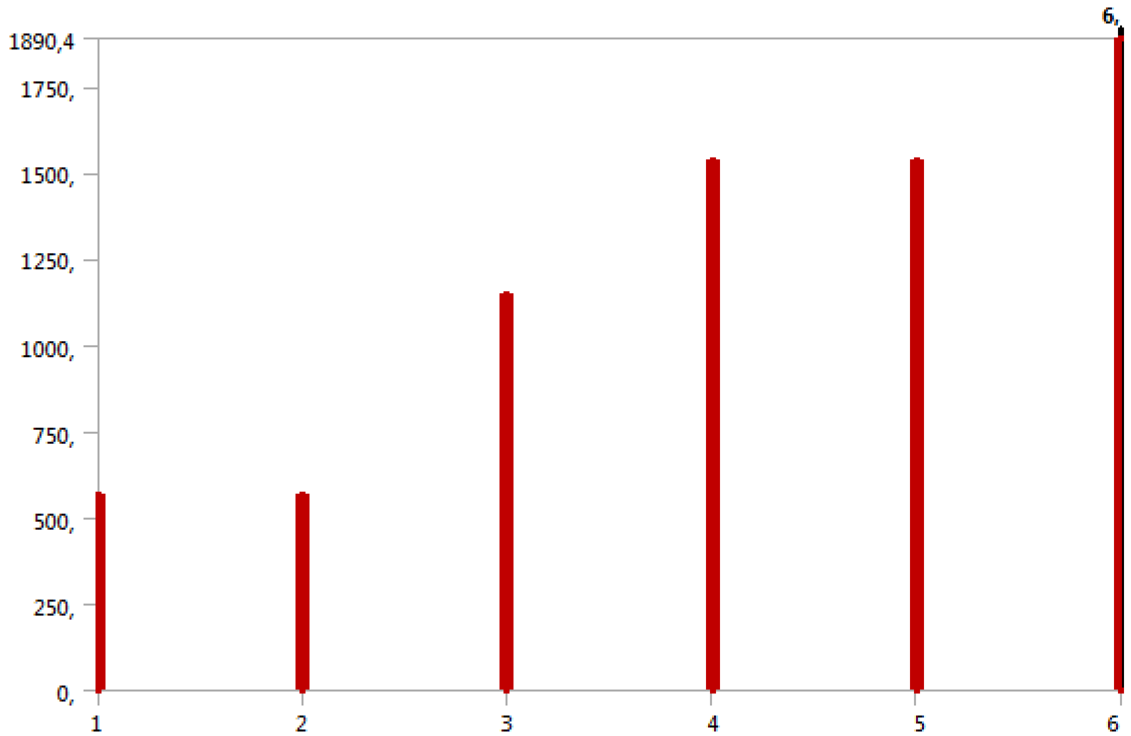


Figure 34. Natural frequencies of the condensers (x: order, y: frequency)

As seen on figure 34. the 6th mode is the highest frequency below 2000 Hz, thus there is no need to analyze higher modes. The eigenfrequencies are as follows:

Table 23 Eigenfrequencies

mode	1	2	3	4	5	6
Frequency [Hz]	568,24	569,42	1145,9	1534,4	1535,4	1890,4

To ensure that the calculated eigenfrequencies are correct, the frequency response diagrams (bode) have to be determined for the condensers. The results can be seen below:

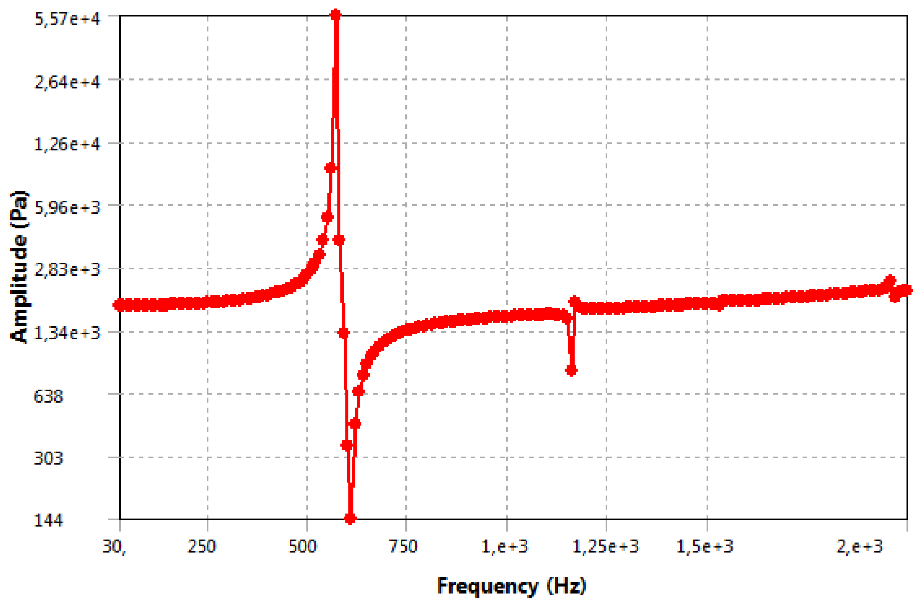


Figure 35. Frequency response, z axis

The local maximum on the diagram is at 570 Hz

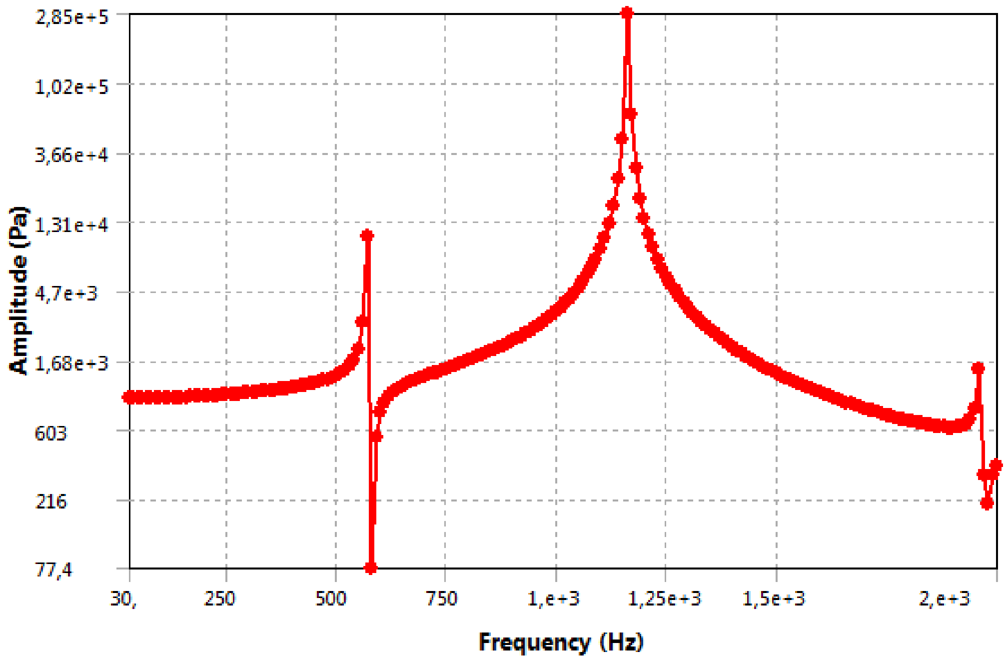


Figure 36. Frequency response, y axis

The local maxima on the diagram are at 570 Hz and 1150 Hz.

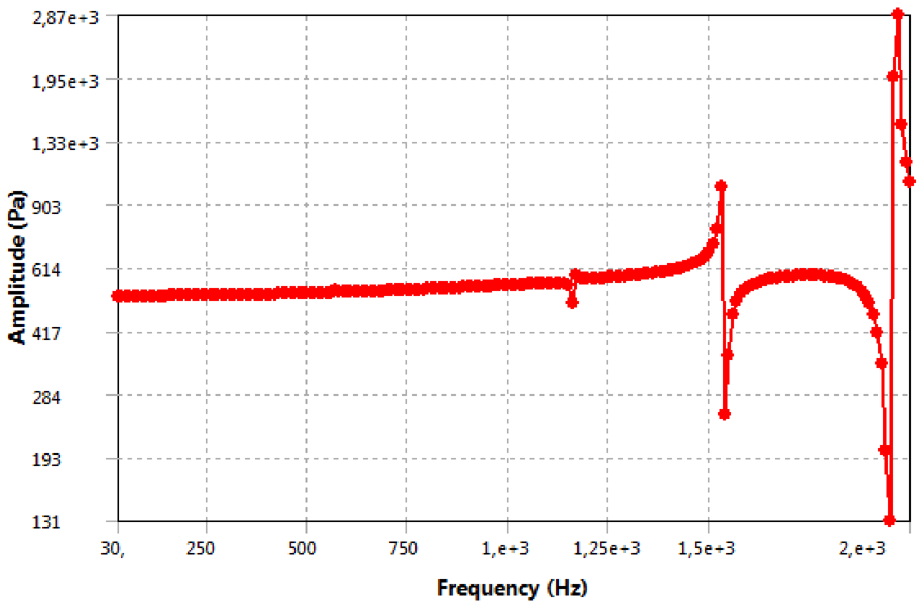


Figure 37. Frequency response, x axis

The local maxima on the diagram are at 1535 Hz and 1890 Hz.

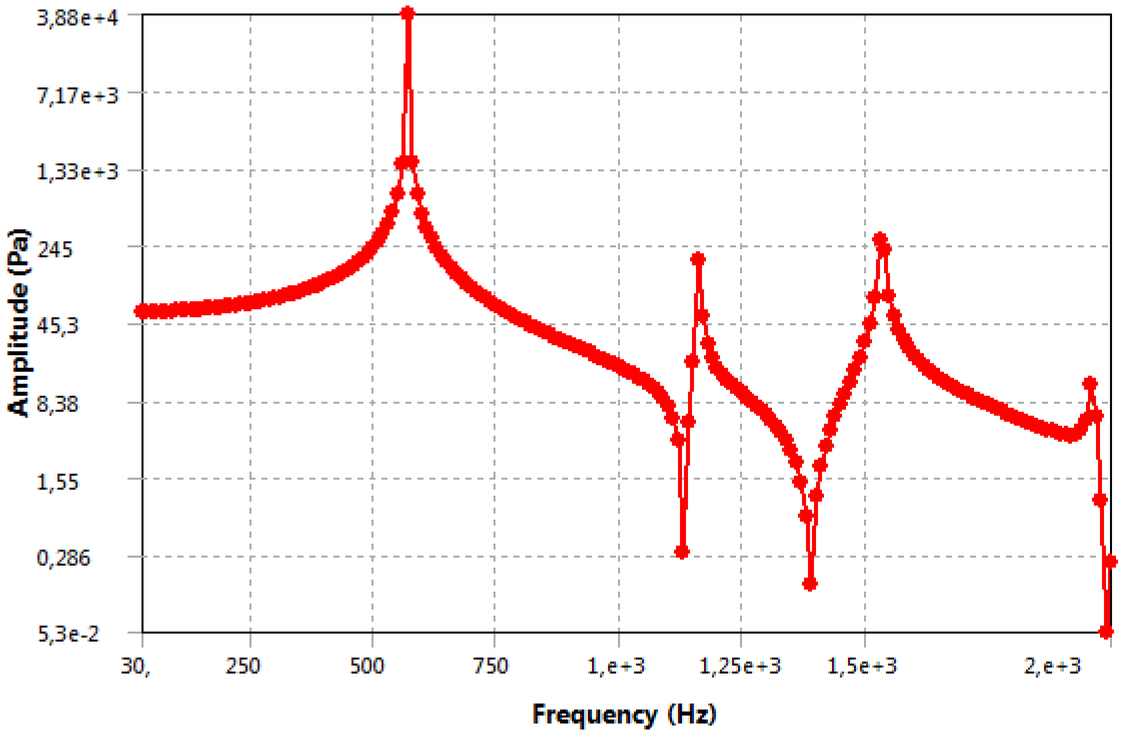


Figure 38. Frequency response, inner electrode, z axis

The local maxima on the diagram are at 560 Hz, 1150 Hz and 1535 Hz.

The results of the modal analysis and the frequency response analysis are similar, however the 1535 Hz mode turned out to be irrelevant (analysis results confirmed the statement above). As the next step, the deformation, strain and stress have to be checked at the critical frequencies.

Due to the long time and high amount of needed computation capacity for the FEM analysis, the number of tests have to be minimized:

Table 24 Analysis frequencies

mode	1	2	3	4	5	6
Frequency [Hz]	568,24	569,42	1145,9	1534,4	1535,4	1890,4
Analysis frequency [Hz]	570		1150	1535		1980
Axes	z, inner electrode z		y	x		x,y

Boundary conditions of the vibration analyses:

The boundary conditions of the vibration analyses were as follows:

The outer surface of the 300 mm RX module was a fixed support, and the inertial load (acceleration) was applied for one axis at a time. For the x axis, 240 m/s^2, for y and z axes, 130 m/s^2.

Compared to our plans with just one spacer (before the CDR), the effects of the modifications were as expected. Due to the additional struts, the stiffness of the structure increased, as well as the natural frequencies (except for the inner spacer where no modifications were made). The stress decreased, however the applied material (stainless steel 440) is much stronger than the previously applied aluminium alloy.

The test results for the x axis, peak acceleration is 240 m/s^2:

Table 25 Analysis results, x axis

Frequency [Hz]	1535	1980
Max. Deform.	$4{,}7\cdot10^{-6}$	$4{,}2\cdot10^{-6}$
Max. Strain	$3{,}95\cdot10^{-4}$	$3{,}08\cdot10^{-4}$
Max. Stress	6,63 MPa	17,07 MPa

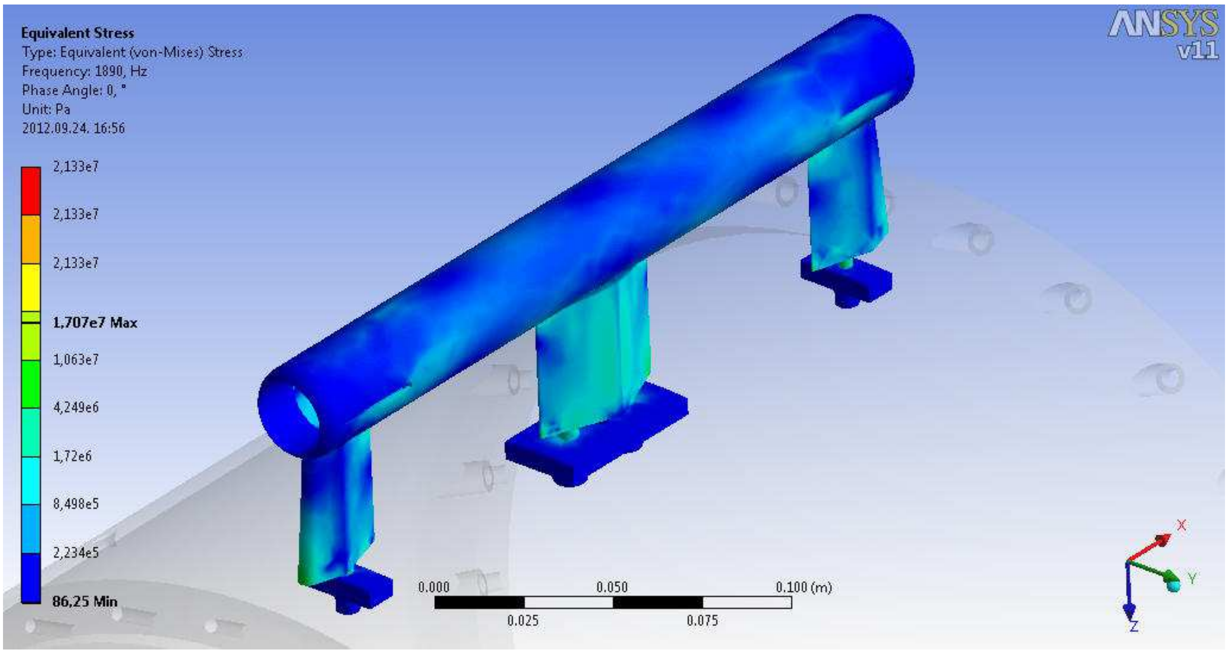


Figure 39. Maximal stress response, x axis

The maximal stress occurs in the welds of the struts, however, the value of 17,07 Mpa is lower than the yield point of the used material nearly by two orders of magnitude; the stress in the bolts are also negligible.

The test results for the y axis, peak acceleration is 130 m/s^2:

Table 26 Analysis results, y axis

Frequency [Hz]	570	1150	1890
Max. Deform.	$3{,}63 \cdot 10^{-5}$	$7{,}37 \cdot 10^{-6}$	$1{,}72 \cdot 10^{-6}$
Max. Strain	$4{,}58 \cdot 10^{-4}$	$1{,}06 \cdot 10^{-4}$	$4{,}73 \cdot 10^{-5}$
Max. Stress	41,2 MPa	18,55 MPa	5,08 MPa

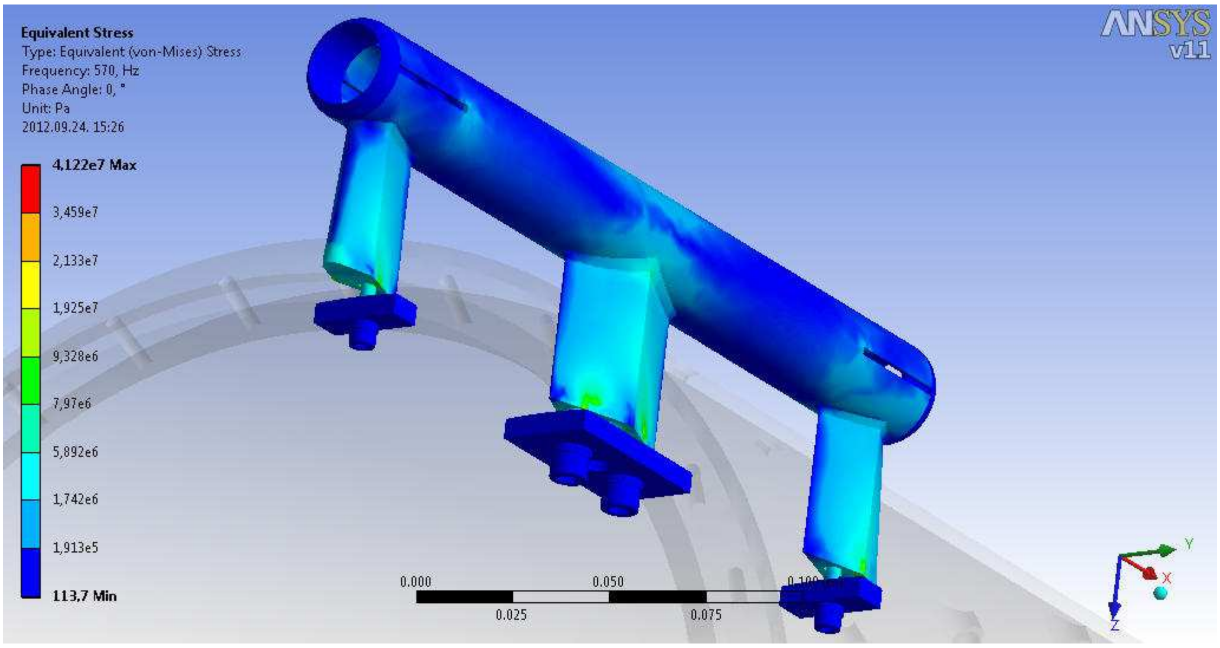


Figure 40. Maximal stress response, y axis

In this case, the maximal stress occurs in the weld of the main spacer. The value of 41,2 MPa is less than the 10% of the acceptable stress for the used material; it poses no risk.

The test results for the z axis, peak acceleration is 130 m/s^2:

Table 28 Analysis results, z axis

Frequency [Hz]	570
Max. Deform.	$2{,}15 \cdot 10^{-5}$
Max. Strain	$2{,}3 \cdot 10^{-4}$
Max. Stress	4,36 MPa

The maximal stress of 4,36 MPa – occurring at the base of the additional struts – is negligible considering that the yield point of the stainless steels is above the aforementioned value by two orders of magnitude.

Table 29 Analysis results, inner electrode x axis

Frequency [Hz]	570
Max. Deform.	$4{,}76 \cdot 10^{-5}$
Max. Strain	$4{,}41 \cdot 10^{-4}$
Max. Stress	38,4 MPa

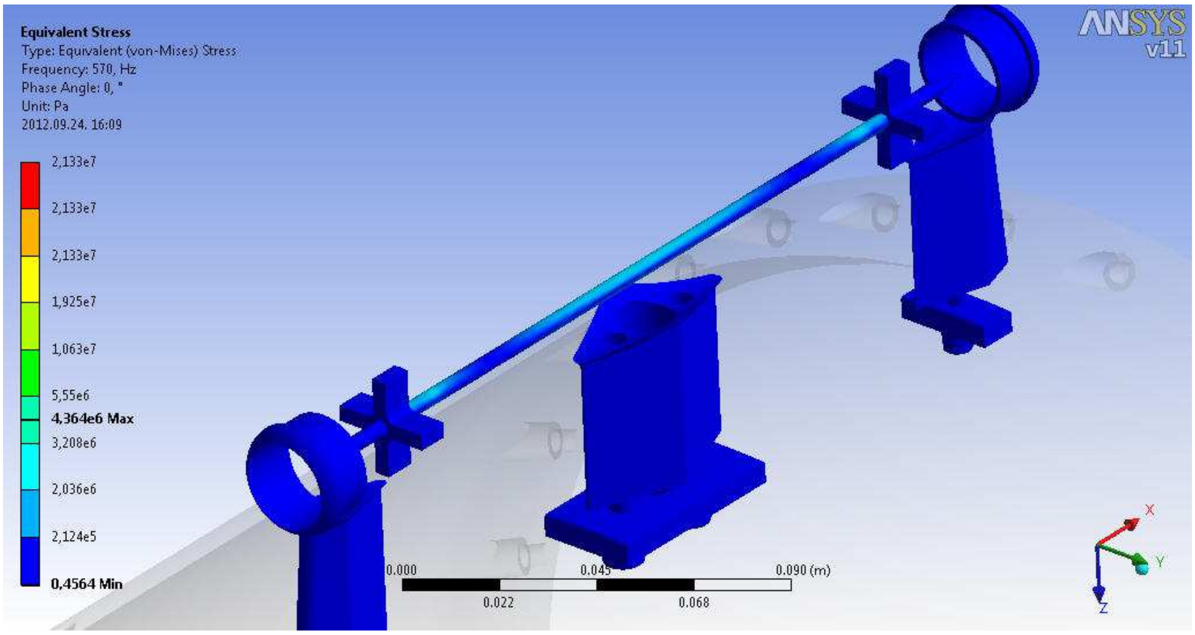


Figure 41. Maximal stress response, inner electrode, z axis

The maximal stress of 38,4 MPa must be taken into account, however the yield point of the inner electrode is over 100 MPa.

In conclusion, the welds are the critical parts of the construction, but the stress is rather low, a safety factor of 2 can be applied for all parts (for the struts, even a value of 10).

It is important to emphasize, that the inspection of the weld quality is essential; defects and bubbles can weaken the weldment. The maximal deformation is below 0,3 mm, the effect of deformation on the measurement is not significant.

The final verification of the condensers will be carried out by vibration test. The vibration analysis of the electrical box and parts will be feasible after the finalization of the PCBs.

After the CDR, some modifications have been carried out on the mechanical design of the condensers, in close cooperation with DLR MoRaBa. Additional struts have been attached to the condensers, thus the natural frequencies increased, and the stress decreased. It can be said, that the current – and final – model have the strongest structure compared to all previous ones.

The shaker tests (**test 8 and test 9**) were performed in two stages: x and y axis in Budapest at EL-TECH Center (figure 42.) and z axis in Bremen at DLR (figure 43). Both shaker tests were successful.

Figure 42. Shaker test (x and y axis)

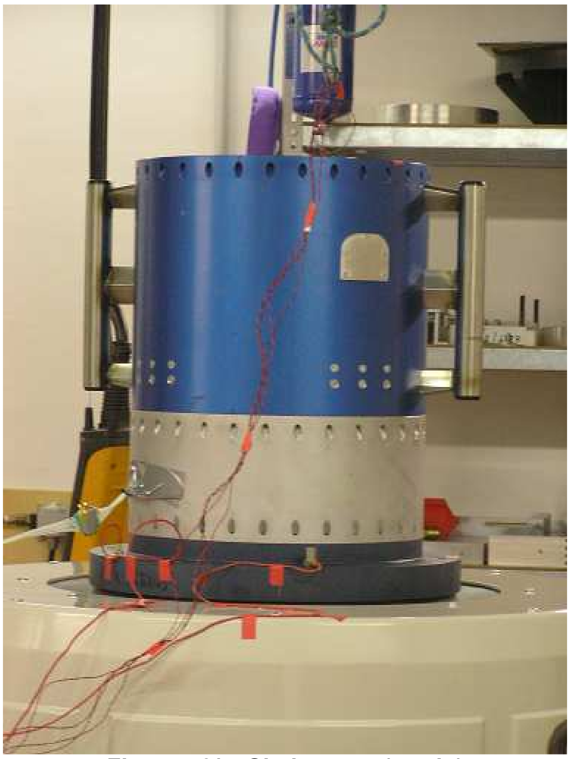


Figure 43/a. Shaker test (z axis)

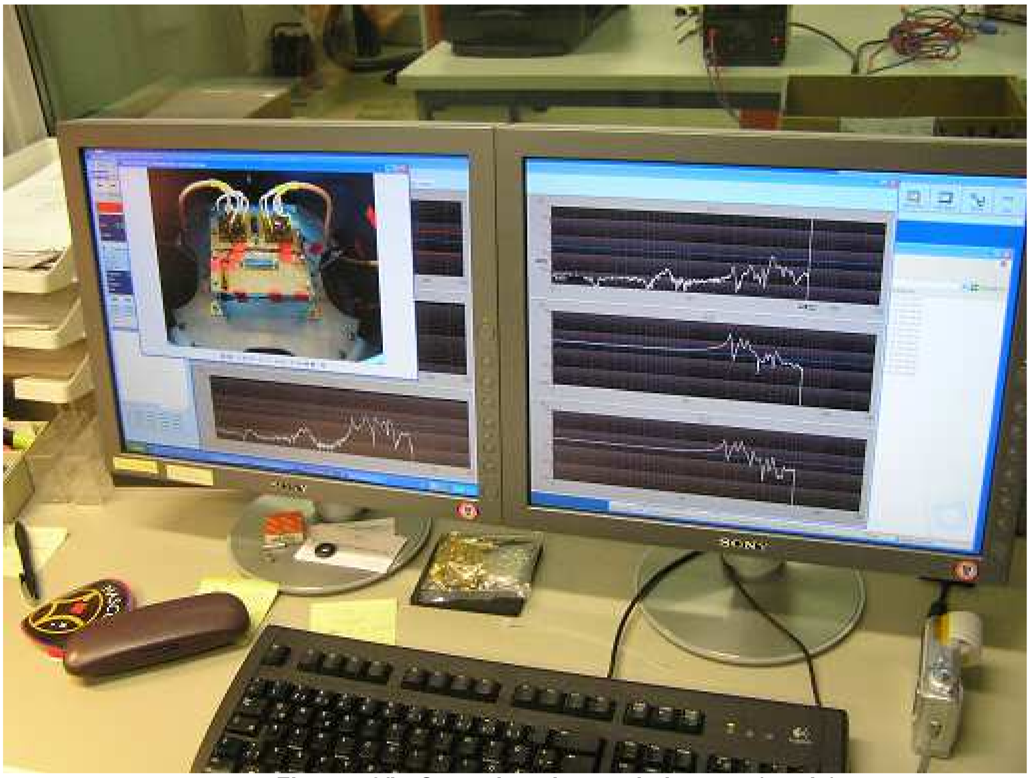


Figure 43/b. Control station at shaker test (z axis)

5.3.2 Thermal simulation of the condensers

The goal of thermal simulation was to determine the cooling ability of the condenser spacers. Since the condensers take high amount of friction heat, the spacers have a key role in the cooling process. The boundary conditions were as follows: The heat flux on the condenser is 7000 W/m^2, and the temperature of the rocket wall is 100°C (according REXUS manual). The results show that the spacer can cool down the condenser effectively.

Assuming only 100°C on the condenser surface, there is no need of modifying the plans, however our possibilities in the choice of soldering material broaden, we can focus on electrical properties of soldering materials instead of the melting point temperature.

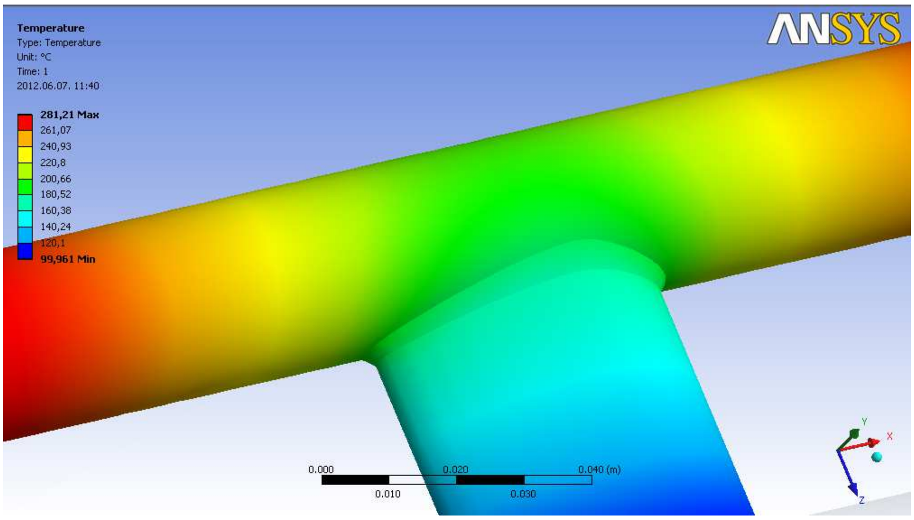


Figure 44. Temepratur distribution of the condenser

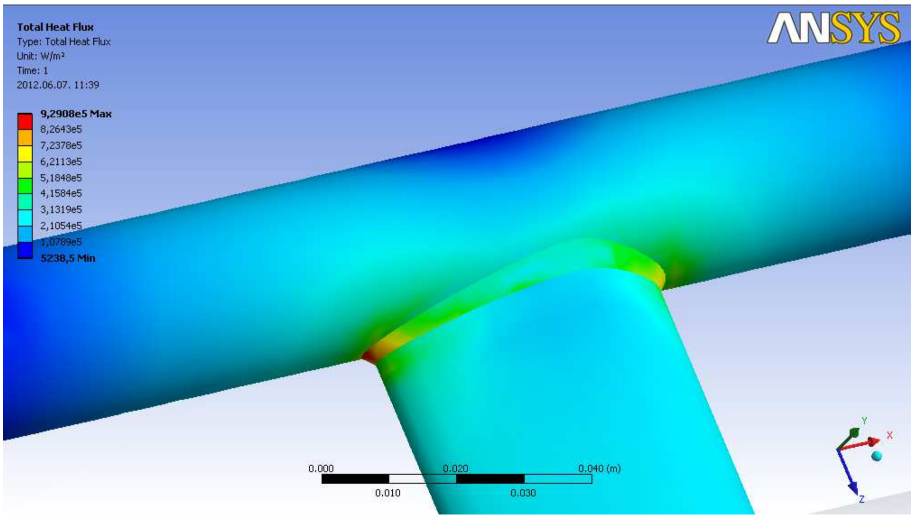


Figure 45. Heat flux distribution of the condenser

The exact boundary conditions are to be determined based on related literature or further discussion with endorsing professors or experts from the organiser space agencies.

5.3.3 FEM analysis of airflow
(verification of D.17)

During the finalization of the mechanical design, we discussed with the experts from DLR MoRaBa; one of the main issues was the effect of the condensers on the rocket trajectory. The discussion concluded in the result that the condensers have no relevant influence on the rocket trajectory: „It is indeed true that the wedge shaped struts create more lift than ones of circular cross section, but the struts are not big enough to mesmerize the mission.”
That’s why we focused on the airflow characteristics inside the condensers. Depending on the airflow velocity, we can adjust the bias voltage of the condensers. If the velocity is lower, we can decrease the voltage and the experiment becomes safer.

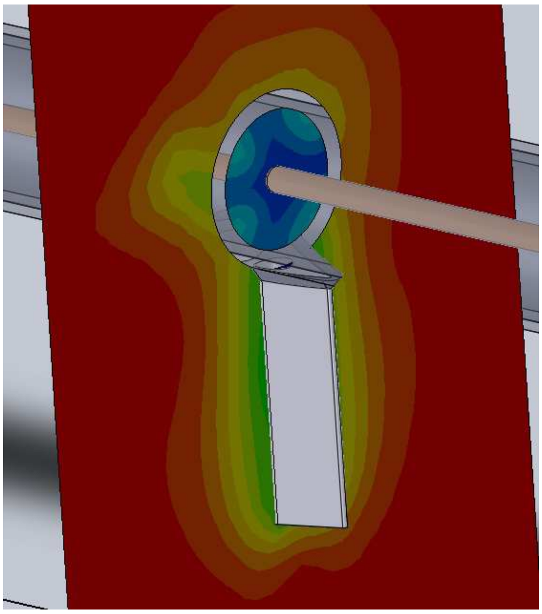


Figure 46. Airflow velocity in a cross-section of the condenser

As the results show, the airflow velocity inside the condenser is much slower than the undisturbed flow. The value changes between 0.8-1.2 Mach; that is similar to the estimation given by the experts from DLR.

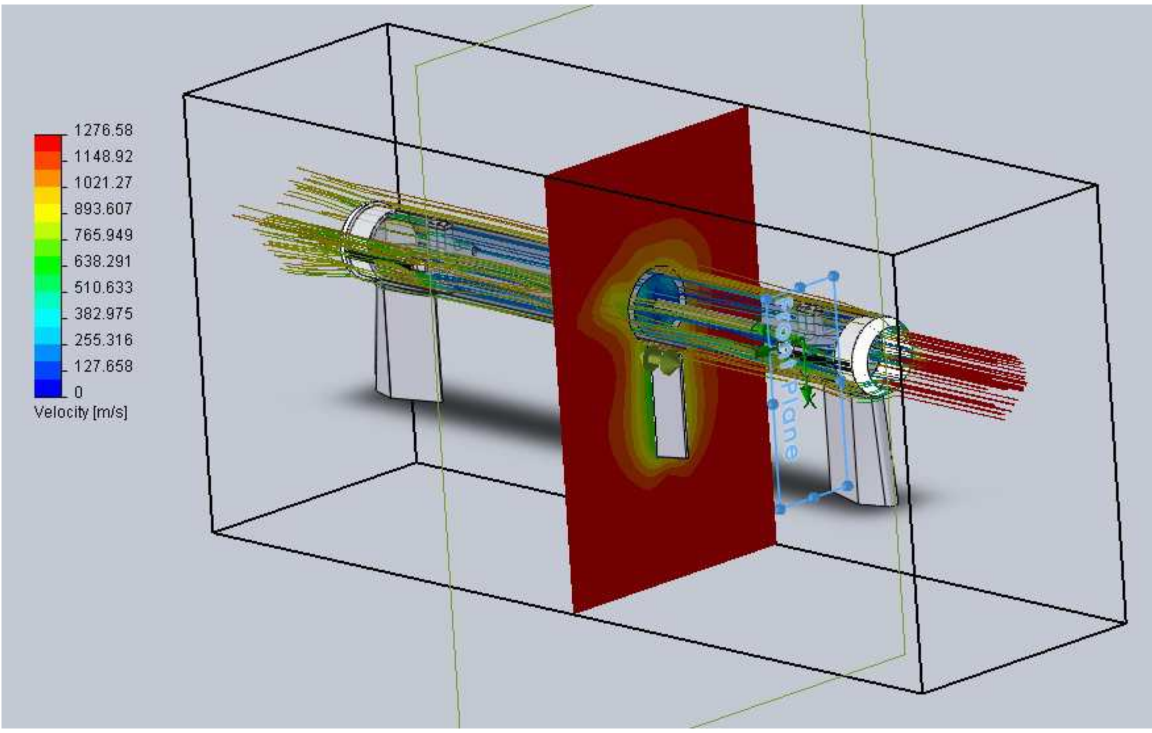


Figure 47. Airflow velocity and trajectories

It is important to emphasize that in this case, the boundary conditions represents the properties of the atmosphere near to the surface. Assuming higher altitudes, the atmosphere, and the airflow characteristics might show great differences.

Boundary layer:

The calculation of the accurate flow profile is possible by solving a Navier - Stokes equation, but this is not necessary, as our goal is to determine the thickness of the boundary layer.

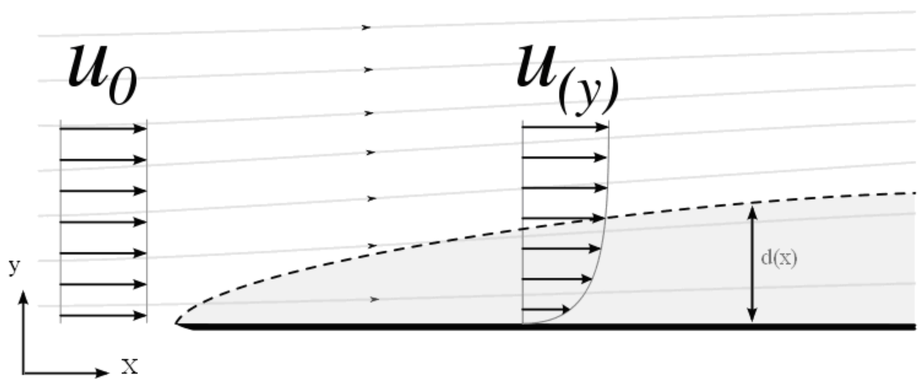


Figure 48. Heat flux distribution of the condenser

Determining the thickness of the boundary layer:

The thickness of the boundary layer is a distance – measured from the wall – where the velocity of the flow reaches 99% of the undisturbed flow velocity.

$$u_y = 0{,}99 \cdot u_0 \qquad \textbf{(1)}$$

The thickness depends on the type of the flow; assuming laminar flow, the boundary layer is thinner than in turbulent flow. The flow type (laminar or turbulent) is highly dependent on the density/compression properties of the air and on the flow velocity.

Due to the high flow velocity, it is recommended to assume turbulent flow in the boundary layer (this of course does not mean that the flow is also turbulent outside the boundary layer). Based on the properties of the air valid near the surface, a „worst case” value can be obtained; if the results of the worst case calculations are appropriate, so they will be for all other case. An additional safety factor of n = 2 can be used to determine the condenser distance with absolute certainty.

1, Assuming laminar flow

$$d(x) \approx 4{,}91 \cdot \sqrt{\frac{\nu \cdot x}{u_0}} \approx \frac{4{,}91 \cdot x}{\sqrt{\mathrm{Re}}} \tag{2}$$

2, Assuming turbulent flow

$$d(x) = \frac{0{,}382 \cdot x}{\sqrt[5]{\mathrm{Re}}} \tag{3}$$

where:

- x : the distance from the entry-edge in x direction [m]
- X : specific length [m]
- y : the distance from the wall in y direction [m]
- d : thickness of boundary layer [m]
- Re : Reynolds-number [-]
- u_0 : velocity of undisturbed flow [m/s] (≈ 1250 m/s)
- u(y): flow velocity [m/s]
- μ : dynamic viscosity [Pa · s]
- ν : kinematic viscosity [m^2 /s]
- ρ : density [kg/m^3]

Reynolds-number:

$$\mathrm{Re} = \frac{\rho \cdot u \cdot X}{\mu} = \frac{u \cdot X}{\nu} \tag{4}$$

The „specific length” used in equation (4) is, for example the profile length of an airplane wing, therefore it is recommended to use the full length of the condenser or the height of the module. From the foregoing, X ≈ 0,3 m.

$$Re = 2{,}8355 \cdot 10^{7}$$

If the value of the Reynolds-number is such high (well above the value of Re = 2320), then the resulting flow is certainly turbulent. This supports the initial hypothesis, that it is recommended to assume turbulent flow in the boundary layer.

Dynamic viscosity:

The dynamic viscosity of the air is 10^{-5} Pa · s magnitude, and it increases with the rising of the temperature. During the calculations, using the dynamical viscosity of the air at the temperature of 0°C is appropriate, its value is:

$$\mu = 1{,}71 \times 10^{-5}\ \text{Pa} \cdot \text{s}$$

Kinematic viscosity:

The kinematic viscosity can be converted from the dynamic viscosity by the following formula:

$$v = \mu / \rho \qquad (5)$$

The density of air at the temperature of 0°C : 1,293 kg/m^3

Thus, the dynamical viscosity of air is: $v = 1{,}71 \cdot 10^{-5} / 1{,}293 = 1{,}3225 \cdot 10^{-5}$ m^2 /s

The thickness of the boundary layer from the data obtained formerly:

$$d(x) = \frac{0{,}382 \cdot x}{\sqrt[5]{\mathrm{Re}}}$$

x = 1,4 .. 1,7 m (distance from the tip of the rocket)

d_{min} = 0,01728 m = 17,28 mm

d_{max} = 0,020989 m = 20,989 mm

Considering the safety factor, the final result is:

$d_{max} \cdot n = 0{,}020989 \cdot 2 = 0{,}041978$ m ≈ 42 mm

In conclusion, it can be said, if the condenser is placed from 40-50 mm of the rocket wall, its inlet will be reached by an undisturbed, laminar air flow.

These caltulations considered that the entry edge is perpendicular to the airflow. While the nosecone is on, the rocket tip has much better aerodynamic properties as the above mentioned case. When the nosecone will be detached, the aerodynamics will deteriorate, but the distance between the entry edge and the condenser inlet will decrease, just as the thickness of the boundary layer near the condensers. Based on these assumptions, detachment of the nose cone does not affect the experiment, except a temporary disturbance at the moment of detachment. The risk of the nosecone breaking the condensers down might be considered.

By this time the condenser placement is fixed. The Gekko experiment is placed into the first module under the nosecone. The calculations above (regarding the boundary layer) are valid.

Note that the wind tunnel test was not done. The verification of D17 is based on FEM analysis.

The study below that was made before CDR closure deals with the relation of the boundary layer and condenser placement.

It has become clear, the placement of the condensers affect the flight stability of the rocket. In order to gain stability, the condensers may have to be placed at the base of the payload. On Figure 49, the distance between the condensers and the rocket wall is determined in order to avoid the turbulent boundary layer.

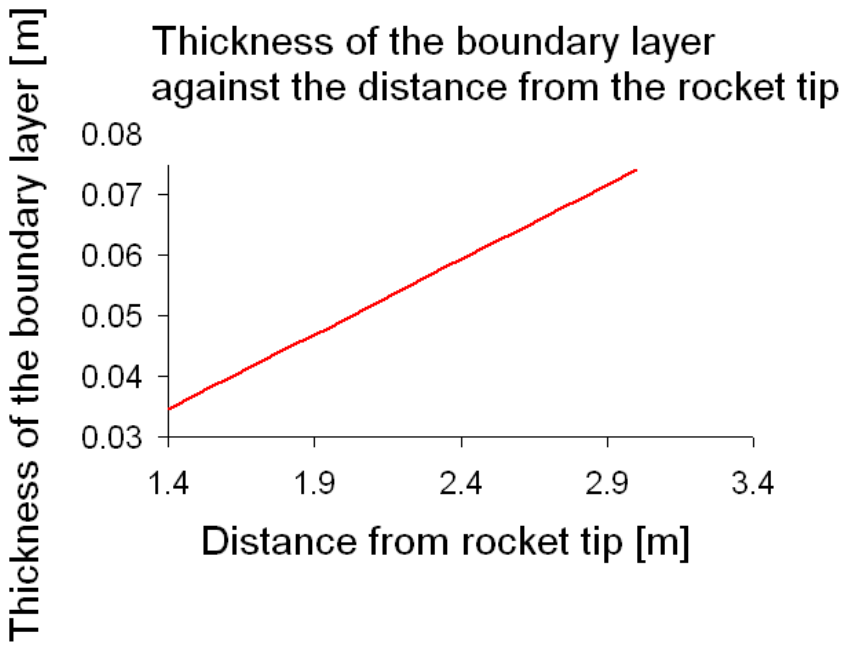


Figure 49. Thickness of the boundary layer against the distance from the rocket tip

Calculating the needed distance, a safety factor of 2 has been used, thus the distances on the figure are twice the values of the strictly needed distances. Based on these results, at the base of the payload, a distance of 60 mm would be preferable, but theoretically the previous distance of 40 mm is still adequate. Increasing the distance would lower the resonance frequencies of the condensers, and possible hazardous stress may occur in the structure.

For the 40 mm distance, the strength of the structure is appropriate. If a decision is made on increasing the distance to 60 mm, new finite element analysis will be required for verification.

An additional aspect for aerodynamics is that the struts (that shall prevent parachute lines from entangling with the condensers) at the extremities of the condensers may act like wings, so the rocket will behave as a glider during the descending phase causing unwanted stability.

The design of our struts has been devepoled in cooperation with experts from DLR; in conclusion, the overall opinion was that the aforementioned risk is very low - the lift created by the struts cannot endanger the mission.

5.3.4 Calculations on the effect of roll during flight
(Verification of D.21.)

The effect of the 4 Hz roll should be taken into consideration in the range relevant for the measurement, more precisely, in the lowest speed point of the above mentioned range. If the velocity conditions are appropriate in the critical point, there is no need of further investigation, but when the results predict possible occurrence of problems, the range suitable for the measurement should be determined.

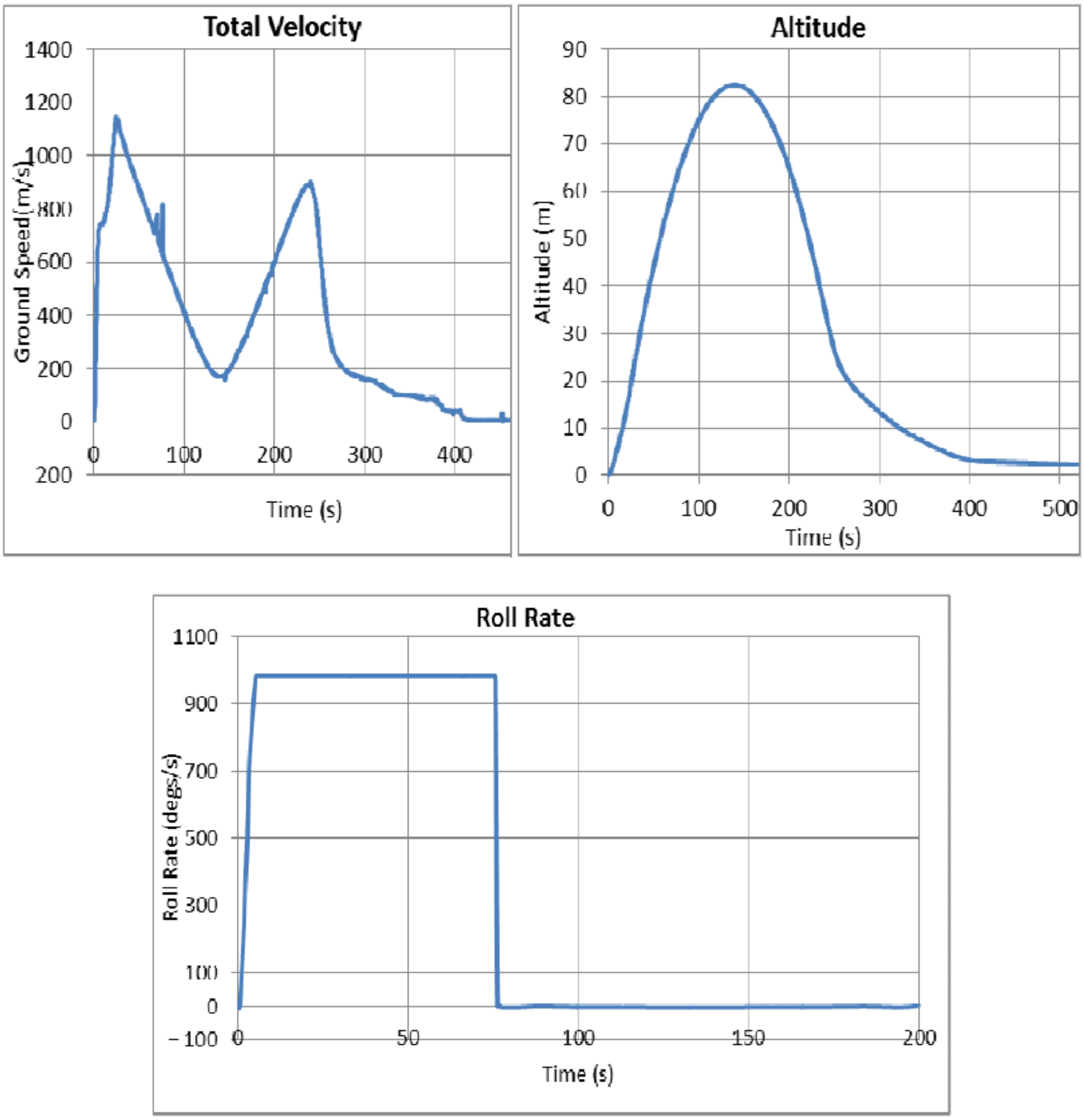


Figure 50. Velocity, Altitude and Roll characteristics of the rocket [12]

The measurement will be carried out in the 25 – 90 km altitude range, the velocity in this range is between 250 – 1250 m/s, the roll frequency varies between 0 – 4 Hz. That is, the following data is valid in the planned range of the measurement:

Roll frequency: 4 Hz

Minimum velocity: 250 m/s

The larger inner diameter of the condenser is 22 mm, the symmetry axis of the condenser is approximately 200 mm from the center line of the rocket (the axis of the roll), the maximum condenser length is 300 mm. Considering the minimum velocity of 250 m/s, therefore the particles pass through the condenser in 1,2 ms time.

The linear velocity based on the data above is 5,02 m/s. In 1,2 ms, the condenser clears 6,024 mm distance perpendicular to the travelling direction of the rocket. This means, the condenser clears 27,38 % of its diameter laterally while a particle passes through. In my opinion, that strongly influences the measurement, therefore at the top of the trajectory, the measurement results will not be confident.

In the following, I narrow the measurement range, on one hand, due to the above mentioned effect, on the other hand, because the average free-path length of the particles at the altitude of 100 km is in the same order of magnitude with the sizes of the condenser; that could lead to further difficulties. Finally, as the rocket approaches the summit of its trajectory, its orientation becomes more and more indeterminate, thus the airflow may not be parallel to the longitudinal axis of the condenser.

Narrowing the measurement range to altitudes 25 – 80 km, the free-path and orientation problems are eliminated, the velocity varies between 600-1200 m/s, the value of the roll frequency is approximately 3,7 Hz. Calculation results obtained using the new data: the pass-through time is 0,5 ms, the linear velocity is 4,65 m/s. Therefore, the condenser clears 2,325 mm distance perpendicular to the travelling direction of the rocket.

Based on the 2,325 mm shift present in the 25-80 km altitude range, it can be said that the shift is approximately 10% of the condenser diameter. (At higher velocities, shift reduces to 0,6 mm, namely ≈ 2,72 % of the condenser diameter). Accordingly, the roll of the rocket does not effect the measurement in the altitude range of 25-80 km. At the lower velocity ranges reducing the effect of roll, a possibly used correction factor could increase the reliability of the measurement results.

5.3.5 Electronics – Board level tests

PSU

The breadboard model of the PSU was built up and tested on room temperature. Table 30 shows the outputs at different input voltages.

Temperature	25	°C							
Uin [V, set]	24			28			36		
LOAD	min	nom	max	min	nom	max	min	nom	max
Uin [V, measured]	23.920	23.920	23.910	27.930	27.920	27.910	35.940	35.930	35.920
Uaux [V]	9.444	9.442	9.439	9.444	9.442	9.438	9.445	9.442	9.438
Iin [mV = mA]		50.600	61.400		43.600	54.800	33.000	37.300	46.400
U +2,5 [V]		2.400	2.363		2.395	2.357		2.393	2.350
I +2,5 [mA]		0.237	0.915		0.235	0.914		0.236	0.910
U -2,5 [V]		-2.489	-2.456		-2.490	-2.458		-2.491	-2.466
I -2,5 [mA]		-0.362	-0.960		-0.362	-0.962		-0.362	-0.965
U +3,3 [V]	3.383	3.309	3.290	3.381	3.306	3.284	3.382	3.307	3.284
I +3,3 [mA]		33.300	59.300						
U +5 [V]		5.154	5.124		5.158	5.135		5.157	5.148
I +5 [mA]		2.255	3.236		2.248	3.245		2.248	3.255
U -5 [V]		-4.994	-4.941		-4.950	-4.936		-4.941	-4.917
I -5 [mA]		-2.127	-3.079		-2.130	-3.076		-2.127	-3.067
U +15_1 [V]		16.734	16.700		16.694	16.688		16.670	16.609
I +15_1 [mA]		5.175	5.720		5.160	5.715		5.155	5.690
U -15_1 [V]		-17.435	-17.370		-17.444	-17.409		-17.433	-17.444
I -15_1 [mA]		-5.500	-6.080		-5.500	-6.090		-5.500	-6.105
U +15_2 [V]		16.718	16.700		16.680	16.675		16.656	16.597
I +15_2 [mA]		5.125	5.685		5.115	5.680		5.110	5.655
U -15_2 [V]		-17.324	-17.270		-17.340	-17.301		-17.334	-17.341
I -15_2 [mA]		-5.350	-5.925		-5.355	-5.940		-5.350	-5.950
U +120 [V]		135.260	135.000		134.800	134.800		134.550	133.800
I +120 [mA]		1.346	1.693		1.342	1.690		1.339	1.679
U -120 [V]		-141.230	-140.700		-141.200	-140.960		-141.080	-141.100
I -120 [mA]		-1.418	-1.761		-1.417	-1.764		-1.416	-1.766

Table 30. PSU bread-board model, static tests

Note that the PSU breadboard model test was done with the old, +/- 120V output transformer.

The next figures show the results of the PSU flight model board level test that was performed on room temperature.

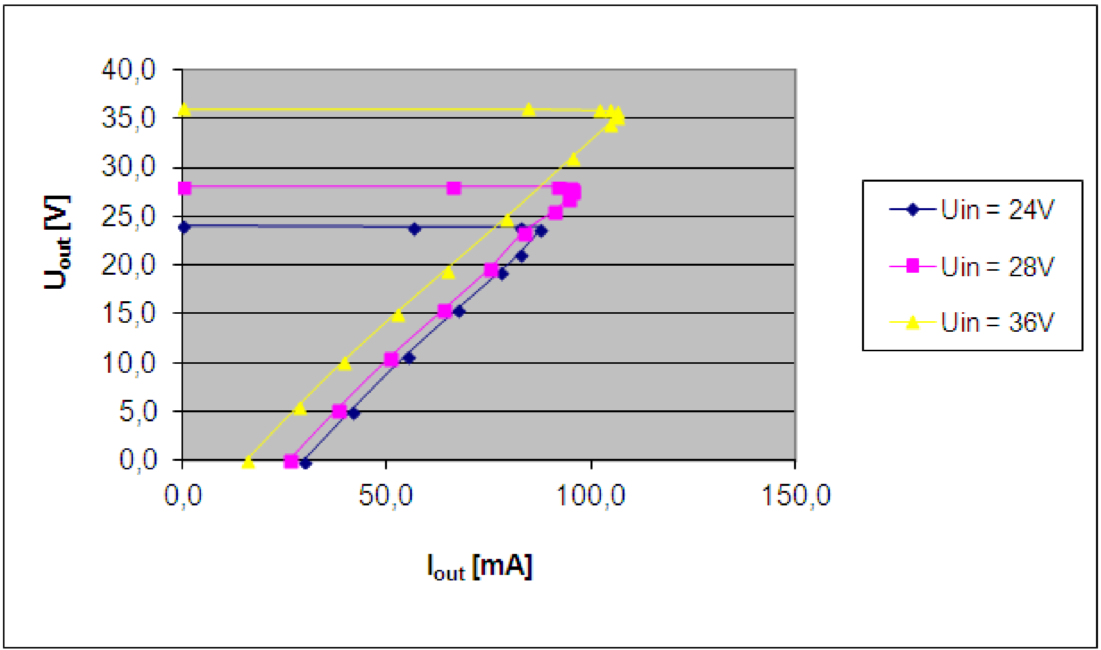


Figure 51. Input current limiter of the PSU

BUS-28V	24	28	36
V-BUS-28	1,172	1,367	1,754
Scale factor	20,478	20,483	20,525

I_{in}	27,6	37,5	54,1	19,1	27,9	46,4	15,7	22,2	36,3
C-PS-IN	1,088	1,494	2,15	0,752	1,099	1,844	0,617	0,881	1,435
Scale factor	25,368	25,1	25,163	25,399	25,387	25,163	25,446	25,199	25,296

AN+60V	74,4	70,5	
V-AN+60	1,751	1,652	
Scale factor	42,49	42,676	

AN-60V	-75	-71,5	
V-AN-60	-1,766	-1,678	
Scale factor	42,469	42,61	

AN+5V	5,258	5,154	5,136	5,262	5,154	5,139	5,262	5,157	5,128
V-AN+5	1,767	1,731	1,725	1,768	1,731	1,726	1,768	1,732	1,724
Scale factor	2,9757	2,9775	2,9774	2,9762	2,9775	2,9774	2,9762	2,9775	2,9745

AN-5V	-5,264	-5,157	-5,142	-5,264	-5,158	-5,144	-5,264	-5,16	-5,149
V-AN-5	-1,764	-1,729	-1,724	-1,765	-1,729	-1,725	-1,765	-1,73	-1,729
Scale factor	2,9841	2,9826	2,9826	2,9824	2,9832	2,982	2,9824	2,9827	2,978

I+3.3V	0	14,5	117,8	0	14,5	117,7	0	14,5	117,8
C-DIG+3.3	0	25,7	243	0	25,6	243	0	25,5	238
Scale factor		564,2	484,77		566,41	484,36		568,63	494,96

Figure 52. Define the scale factors for HK data processing

Amplifier board

Several functional tests were performed on the breadboard model of the analogue electronics before we started the PCB design.

The next figures show the results of the performance tests that were made with the flight model PCB.

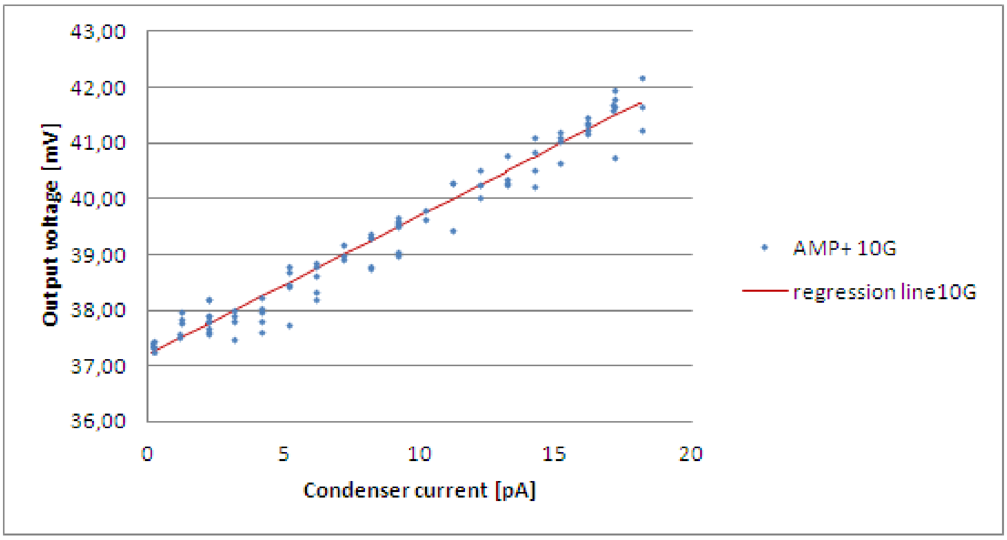


Figure 53. Characteristic of the precision amplifier, 0-20pA (+)

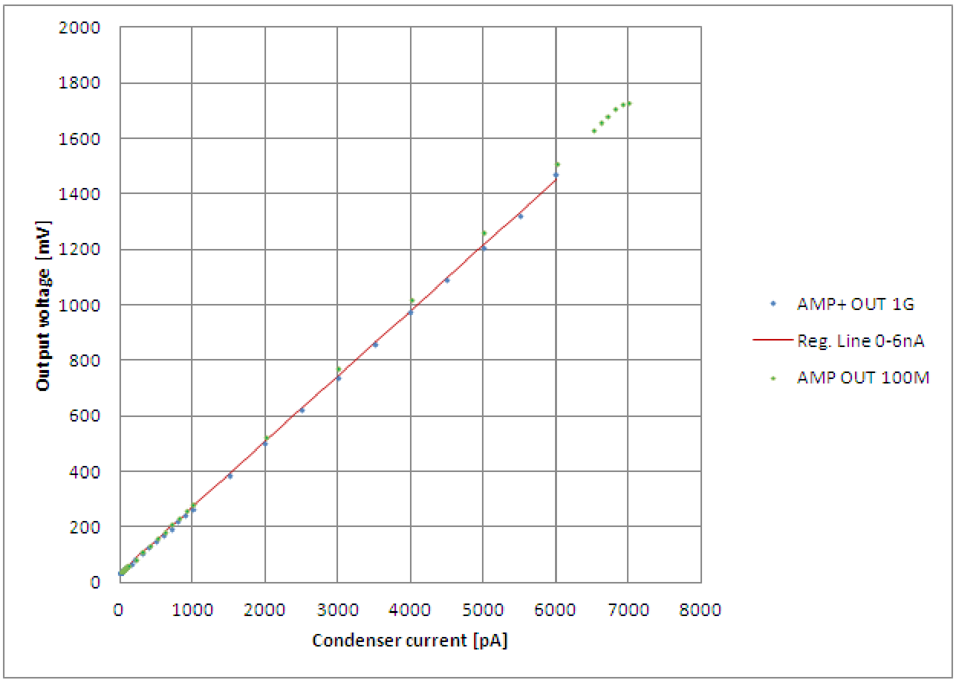


Figure 54. Characteristic of the precision amplifier, 0-6nA (+)

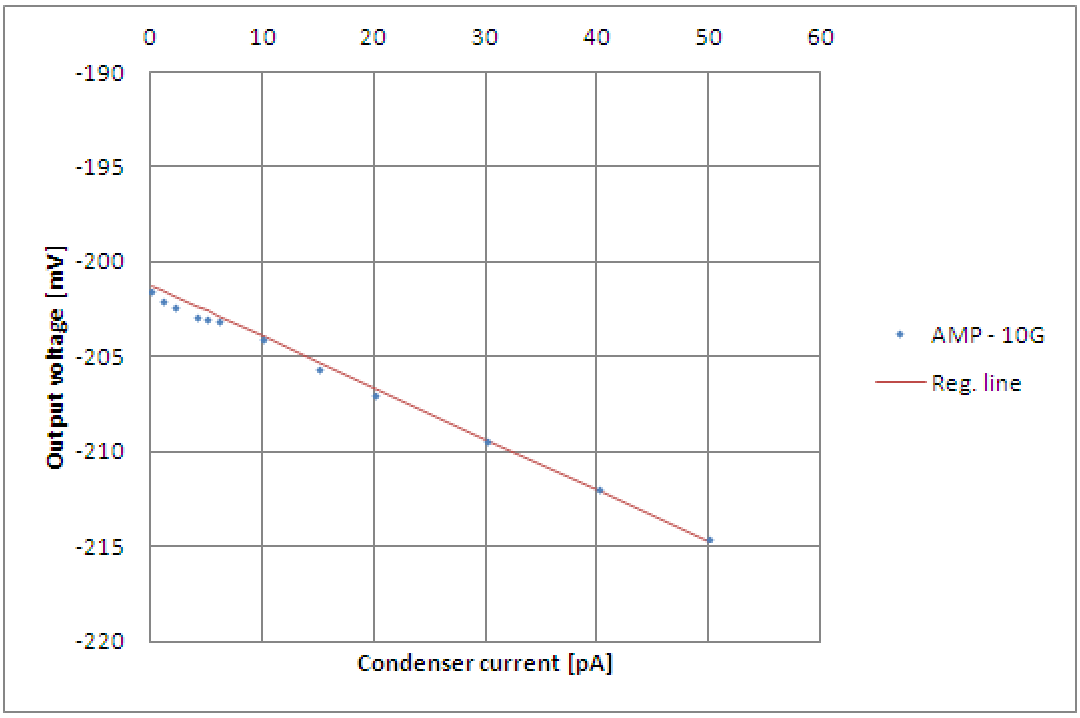


Figure 55. Characteristic of the precision amplifier, 0–50pA (-)

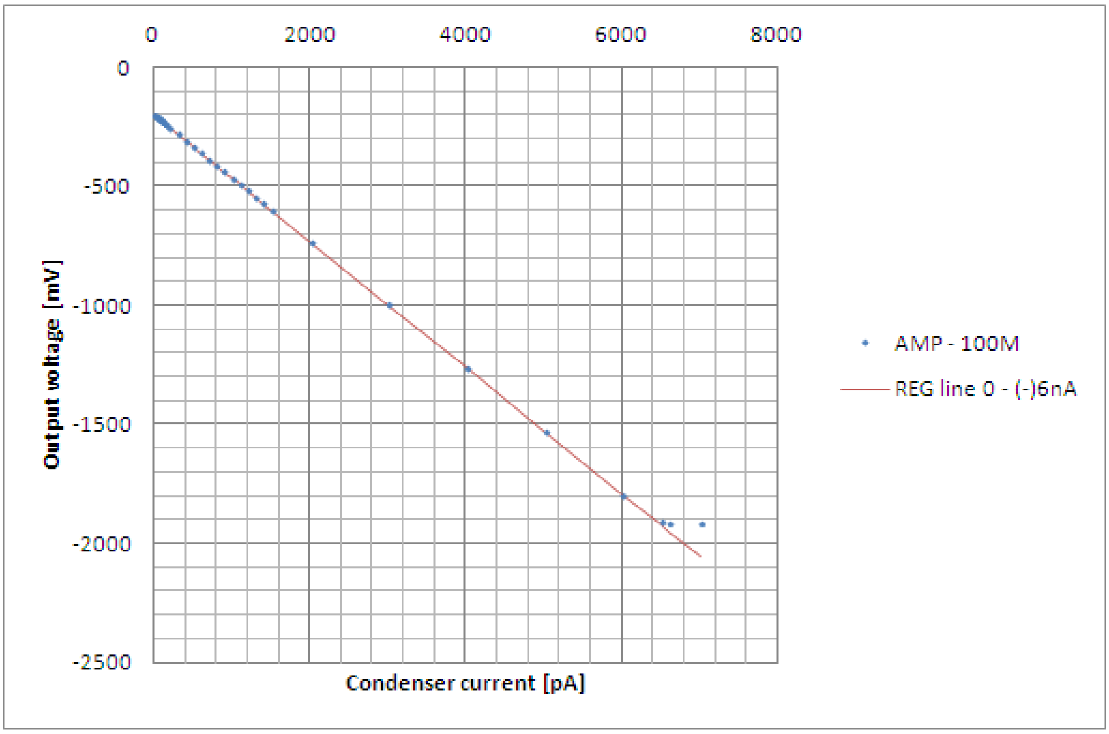


Figure 56. Characteristic of the precision amplifier, 0-6nA (-)

After the tests we fitted a regression line to the points of the characteristics. The estimation of the measured current of the condensers is based on these lines. The parameters of the regression in the full range (0-6nA and 0-(-6) nA) on room temperature are the following:

	slope [mV / pA]	offset [mV] (T=20°C)
positive	**0,235**	**36**
negative	**-0.265**	**-201**

(Test 3)

Since the input offset voltage of the precision amplifiers are depending on the temperature (tipical +/-2µV / °C, max +/-4µV / °C, see datasheet in Appendix C) the voltage drift shall be measured. The results presented on figure 57 and 58.

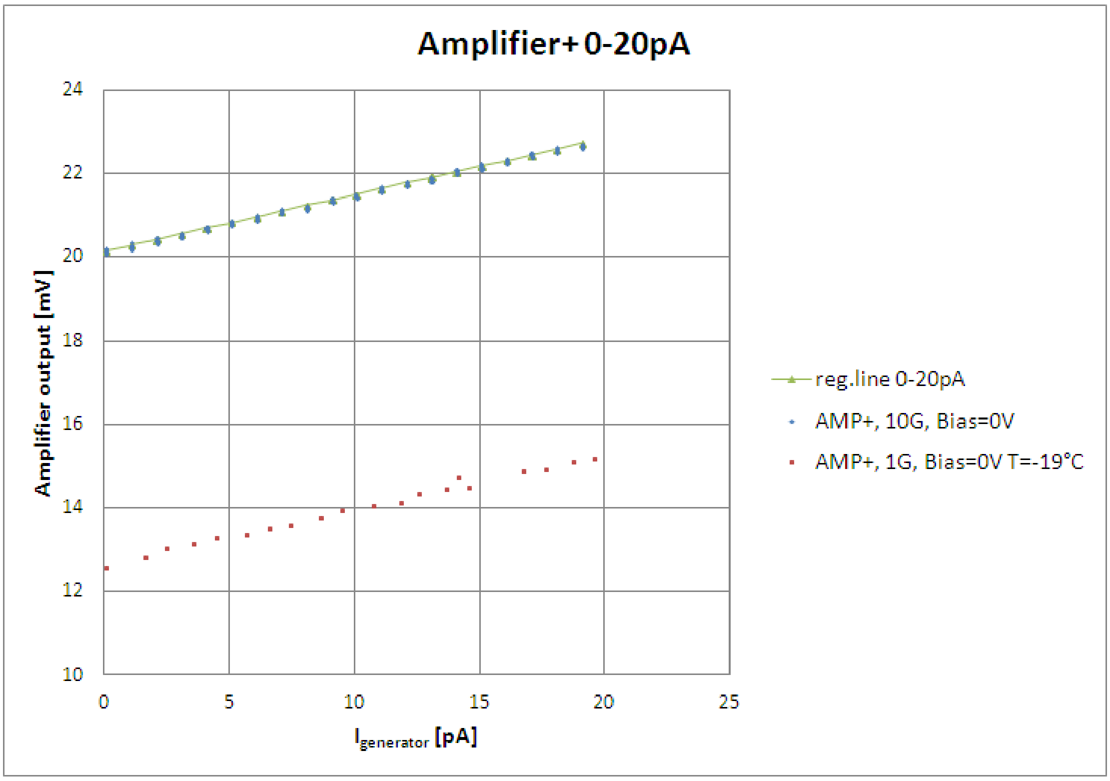


Figure 57. precision amplifier, thermal test

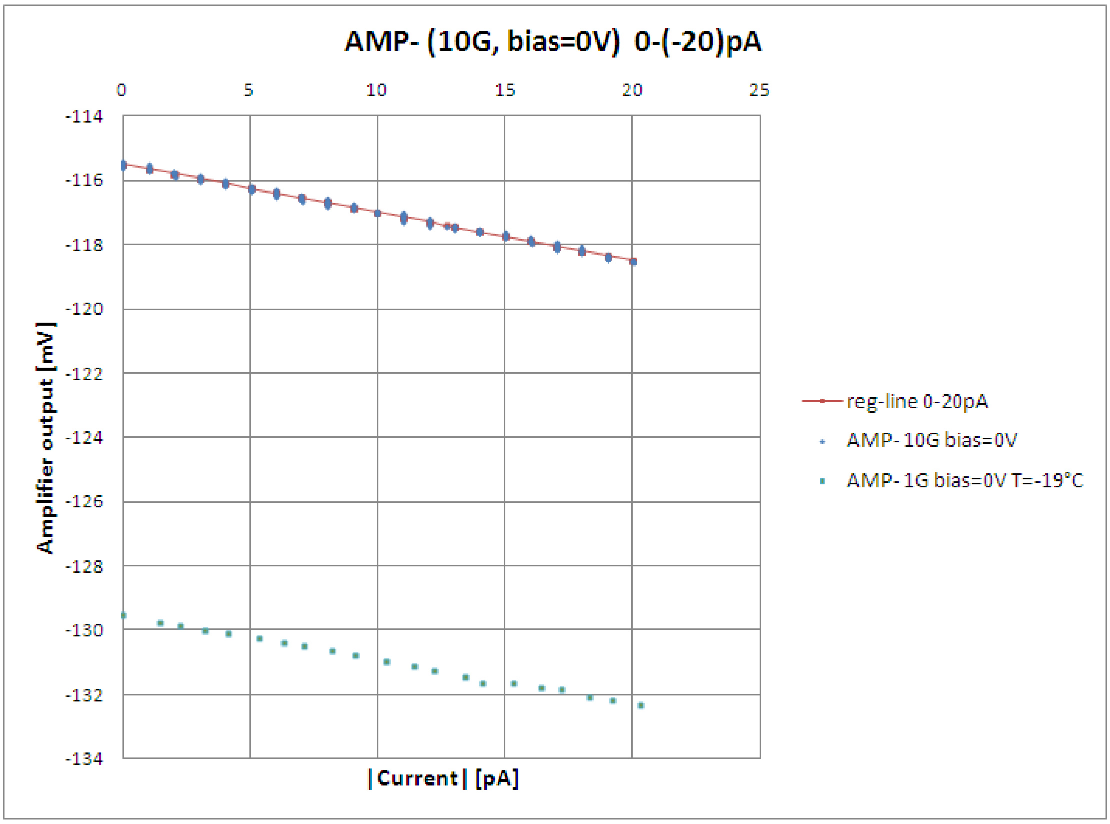


Figure 58. precision amplifier, thermal test

(Note that the flight model PCB was modified after the thermal test so these figures can be used to calculate the voltage drift but the absolute values are not correct.)

The temperature decreased by 45°C during the thermal test and the offset of the precision amplifiers changed:

ΔT = -45°C	voltage drift @ ADC	error in measured current	input offset voltage drift @ opa124
positive amplifier	-7.4 mV	-55 pA	55 µV
negative amplifier	-14,7 mV	-92 pA	92 µV

The measured input offset voltage drift is in the limit (1,22µV/°C and 2,04µV/°C). The temperature is monitored in the Gekko experiment so the temperature effect can be considered in the data evaluation.

The bias voltage amplifiers were tested on room temperature and on -20°C. The results are shown on the next figure.

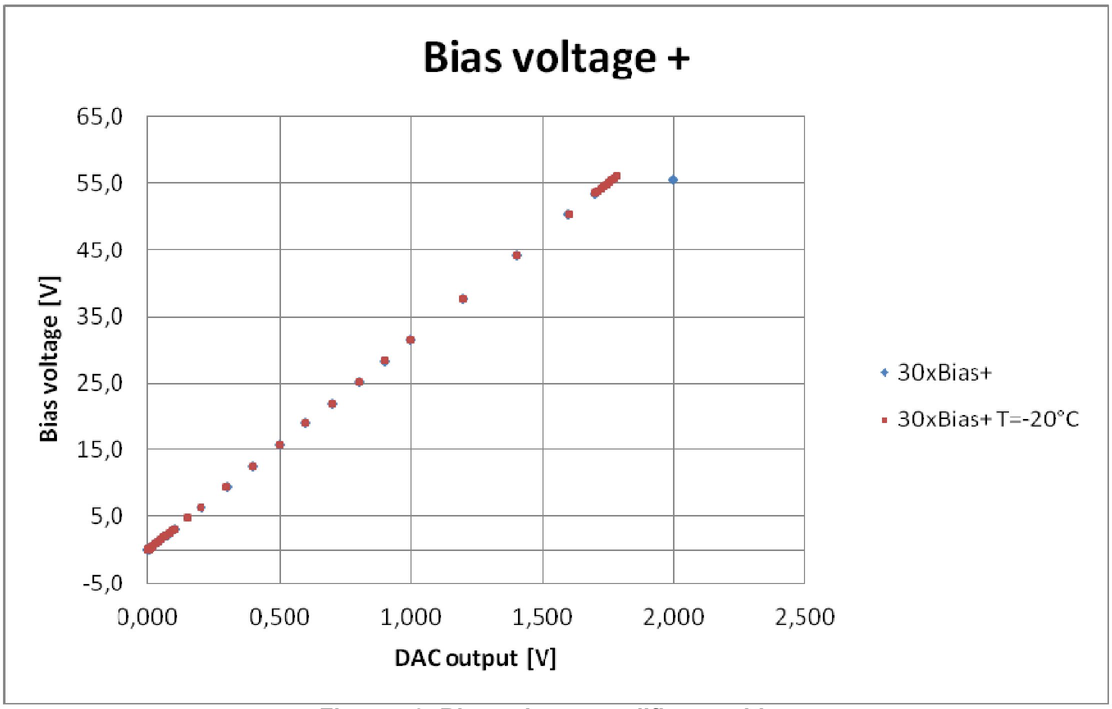


Figure 59. Bias voltage amplifier, positive

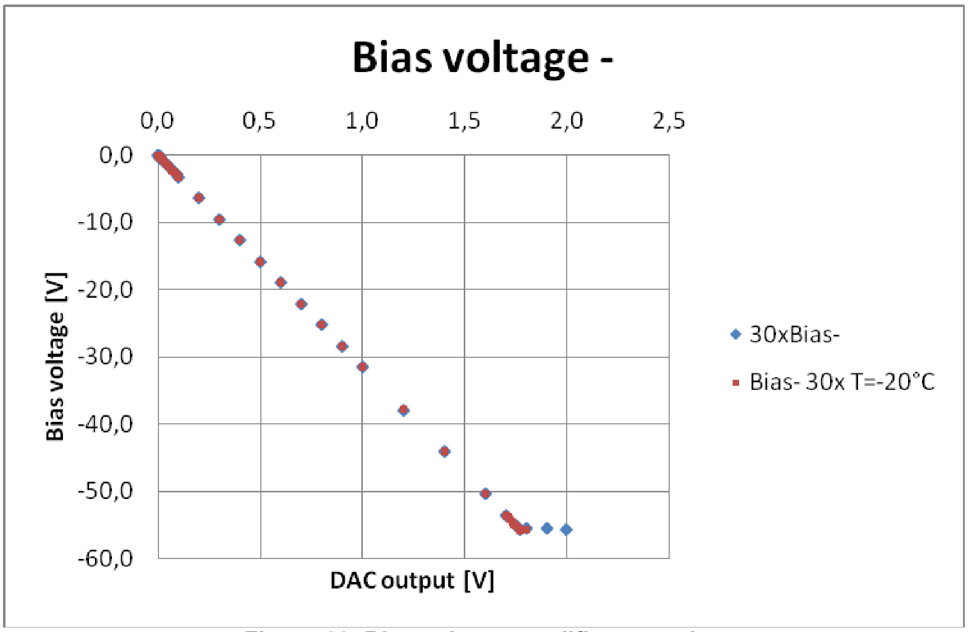


Figure 60. Bias voltage amplifier, negative

The test shows that the temperature has no notable effects on the bias voltage amplifiers. At 30x mode the (bias/DAC) rate in case of the positive amplifier is 31,4 and -31.6 for the negative bias amplifiers.

The LO and SOE control circuits were also tested on room temperature and -20°C as well.

OBDH board

We have built a qualification model of the Gekko OBDH that was tested in thermal chamber (**Test 4**). This model was also used for software development and testing. The design of the flight model was initiated after the final board level tests of the qualification model.

5.3.6 System level tests

We made several tests with the whole experiment to verify the following requirements: F.2, F.3, F.5-F.7, D.10, D.12, O.1, O.4-O.7. The next picture was taken on the integration week:

Figure 61. Performing a system level test, integration week, DLR Bremen

The experiment was connected to the Gekko GSE which supplied power to the experiment and provided communication IF. The following table shows a set of HK data after a test run.

C_3V3 [mA]	V_+60 [V]	V_-60 [V]	V_BUS [V]	C_PS_IN [mA]	Temp [°C]	V_+5V [V]	V_-5V [V]
39,41	71,71	-72,63	28,06	24,86	21,61	5,16	-5,18
39,28	71,71	-72,63	28,06	24,86	21,61	5,16	-5,18
39,38	71,71	-72,63	28,06	24,87	21,61	5,16	-5,18
39,38	71,71	-72,63	28,06	24,98	21,61	5,16	-5,18
40,38	71,71	-72,52	28,02	27,81	21,58	5,17	-5,19
38,74	71,71	-72,75	28,01	27,94	21,59	5,16	-5,17
34,62	70,33	-71,26	28,01	36,31	21,59	5,14	-5,18
35,53	70,71	-71,59	28,02	26,19	21,59	5,16	-5,18
35,11	70,48	-71,33	28,02	32,76	21,60	5,15	-5,16
34,13	70,25	-71,23	28,02	26,01	21,59	5,17	-5,19
35,78	70,80	-71,54	28,01	29,46	21,60	5,16	-5,17
34,74	70,32	-71,26	28,01	36,32	21,58	5,14	-5,19
35,81	71,11	-71,79	28,02	26,20	21,59	5,16	-5,18
35,17	70,47	-71,33	28,02	28,86	21,58	5,16	-5,16
34,07	70,25	-71,24	28,02	25,06	21,59	5,16	-5,19
35,69	70,80	-71,54	28,02	29,45	21,59	5,16	-5,17
34,65	70,33	-71,26	28,01	36,31	21,59	5,14	-5,18
37,58	71,61	-72,56	28,02	26,20	21,60	5,16	-5,18
35,14	70,47	-71,33	28,01	32,76	21,59	5,15	-5,16
34,04	70,25	-71,24	28,01	24,93	21,60	5,16	-5,19
35,72	71,11	-71,83	28,02	26,57	21,61	5,17	-5,18
35,47	70,71	-71,51	28,02	28,47	21,59	5,16	-5,18
35,04	70,50	-71,37	28,02	30,65	21,59	5,16	-5,17
34,77	70,38	-71,30	28,01	32,89	21,60	5,15	-5,16
34,43	70,30	-71,27	28,01	35,22	21,61	5,15	-5,16
34,16	70,26	-71,25	28,01	37,63	21,60	5,14	-5,18
37,55	71,65	-72,64	28,01	26,18	21,59	5,16	-5,18
35,17	70,47	-71,33	28,01	32,77	21,61	5,15	-5,16
34,07	70,25	-71,24	28,02	24,89	21,61	5,16	-5,19
37,27	71,80	-71,31	28,02	29,44	21,59	5,16	-5,17
34,50	70,33	-71,27	28,01	36,29	21,60	5,14	-5,18
37,52	71,71	-72,70	28,02	24,89	21,61	5,16	-5,18
39,13	71,71	-72,63	28,06	24,86	21,61	5,16	-5,18
39,19	71,71	-72,62	28,06	24,86	21,61	5,16	-5,18
39,16	71,70	-72,63	28,06	24,86	21,62	5,16	-5,18

5.3.7 Vacuum test

The aim of the vacuum test (**Test 10, 11**) is to looking for corona effect caused by the high voltage system. The electronics box was tested in a vacuum chamber at the university. This test was performed without the condensers.

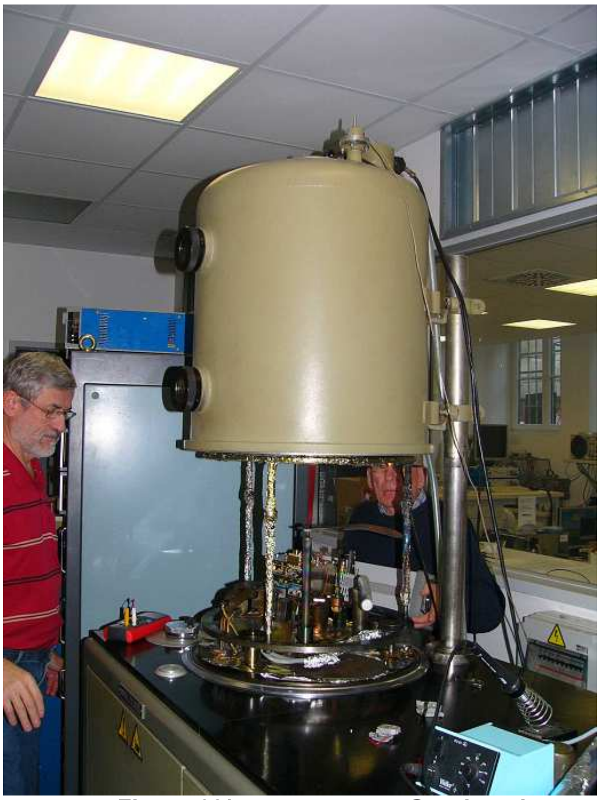


Figure 62/a. vacuum test @ university

Figure 62/b. vacuum test @ university

During the tests the experiment was running and the high voltage outputs were monitored by a multimeter. The air pressure was decreased to 10mbar and released several times to increase the possibilities of a corona effect. The test was repeated at lower pressure (1mbar). After the test we analysed the recorded HK data and we didn't find the sign of any corona effect.

The vacuum test was repeated on the integration week at the DLR with the whole module including the Gerdien condensers as well. The experiment was operating during the whole test while the pressure was reduced to 0.3 mbar. We monitored th HK data and we also made visual inspection to recognize a possible corona effect. This test was performed successful too.

Figure 63. preparing the vacuum test, DLR, Oberpfaffenhofen

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and mass

Table 31 Experiment mass and volume

Experiment mass (in kg):	1,634 (condensers; 0,817 kg each) 0,826 (electronic box) 2,460 (electronics box & condensers) 8,209 (total mass with module/bulkhead)
Experiment dimensions (in m):	0,065 x 0,025 x 0,028 (each condenser) 125 x 165 x 105 (electronic box)
Experiment footprint area (in m^2):	0,018900 (electronics box)
Experiment volume (in m^3):	4,55 x 10^{-4} (each condenser) 2 x 10^{-3} (electronic box)
Experiment expected COG (centre of gravity) position:	Experiment COG can be adjusted to coincide with the geometrical centre of the rocket.

The current mass estimation does not include some parts on the PCBs and the cables needed for the experiment, final weigh will slightly increase.

6.1.2 Safety risks

- Due to improper aerodynamic design, the Gerdien condensers attached to the outer structure of the rocket modify the planned flight profile of the rocket.

  This risk has been mitigated to acceptable level by active cooperation between the Gekko team, Eurolaunch and ESA in the mechanical design

- One or both of the tube shaped condensers breaks off of the outer structure of the rocket thus modifying the flight trajectory.

  This risk has been mitigated by cooperation with DLR experts. The risk probability was reduced by performing the shaker tests (see 6.2.1 for proper handling of the condensers).

- Health hazard caused by touching the HV parts of the system.

  In order to reduce the probability of health hazard, protective covering is applied on the edges of the condensers (see 6.2.2 for safe handling of the HV parts).

6.1.3 Electrical interfaces

Table 32 Electrical interfaces applicable to REXUS

REXUS Electrical Interfaces		
Service module interface required? Yes/No (usually yes)		
	Number of service module interfaces:	1
	TV channel required? If yes, when is it required:	no
Up-/Downlink (RS-422) required? Yes		
	Data rate - downlink:	6.5 Kbit/s
	Data rate – uplink	0.1 Kbit/s
Power system: Service module power required? Yes		
	Peak power consumption:	1.2 W
	Average power consumption:	1 W
	Total power consumption after lift-off (until T+600s)	0,16Wh
	Power ON	600s before lift-off
	Power OFF	600s after lift-off
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO:	Yes
	SOE:	26s after lift-off
	SODS:	No

6.1.4 Launch Site Requirements

The required equipments, tools and infrastructural stuffs from the launch site are listed below.

- a 230V/50Hz power outlet
- 1 desk (size: 120 x 75 x 60 (width x height x depth))
- 3 chairs
- internet connection
- DC Power Supply with 28V/100mA (adjustable) output
- screwdriver set
- soldering station

6.2 Preparation and Test Activities at Esrange

Experiment preparation

After the module is integrated the Gekko experiment is ready for operation. To prepare the experiment for the hot countdown only the RXSM interface is used. Replacement of any part of the hardware is not considered.

(The condensers and the electronic box will be already attached to the rocket when the payload is shipped to Esrange.)

Table 33 Experiment preparation activities

Day 1	Task	Responsible required time	Task	Responsible required time
Stage 1	Check the attachment of the Gerdien condensers (visual checking)	O. Lőrinczi ***10 mins***	Set up Ground Station	G. Balassa ***20 mins***
	Place the protective covering onto the edges of the condensers	O. Lőrinczi ***5 mins***	Prepare Gekko GSE	G. Balassa ***20 mins***
	Remind other experimenters to pay attention of the HV system	Zs. Váradi ***10 mins***		
	Check the mounting of the Electronic box to the module (visual checking)	O. Lőrinczi ***10 mins***		
	Connect the electronic box to the Gerdien condensers	Zs. Váradi ***10 mins***		
Stage 2	Connect the Gekko GSE to the electronic box through the technological connector.	Zs. Váradi ***10 mins***		
	Perform functional tests on the experiment and ground station	Zs. Váradi G. Balassa ***1 hour***		
	Upload on board memory content (bias voltage value) if necessary (optional)	Zs. Váradi G. Balassa ***1 hour***		
	Upload the OBDH software update if necessary (optional)	G. Balassa ***1 hour***		
	Remove technological connector.	Zs. Váradi ***10 mins***		
	Connect the experiment interface connector to the electronic box	Zs. Váradi ***10 mins***		

Table 34 Flight Simulation Test activities

	Task	Responsible required time
FST - 30mins	Set up Ground Station, Start Ground Software	G. Balassa ***15 mins***
FST	Monitor telemetry data on the ground station	Zs. Váradi G. Balassa
	Set the experiment operational mode manually by sending TC (e.g. from “Stand by” to “Prepare” in case of absence of LO signal)	G. Balassa
After FST *(Power required on the experiment interface connector)*	Set the operational mode into “Stand by” and reset the mass memory pointer to its initial value at the end of the test before power off	G. Balassa
After FST	Remove the protective covers from the condensers	O. Lőrinczi ***10 mins***

6.2.1 Handling of the module

While working on the module, it can sit on a bench as the length of the condensers is shorter than the height of the module. After mounting the condensers, the bulkhead brackets can be inserted. After mounting the electronics box to the bulkhead, it can be inserted into the module from the bottom due to big cable cut outs in the bulkhead (that was a request from experts in order to make room for another experiment and optimise the arrangement of the payload).

The safe handling/holding points of the module: When carrying the module, it would be preferred not to pick it up by the condensers, however its mechanical strength is sufficient in case of emergency (or in a situation when the module can only be picked up by the main spacers of the condensers). The safe handling points are the bottom and top edges of the module.

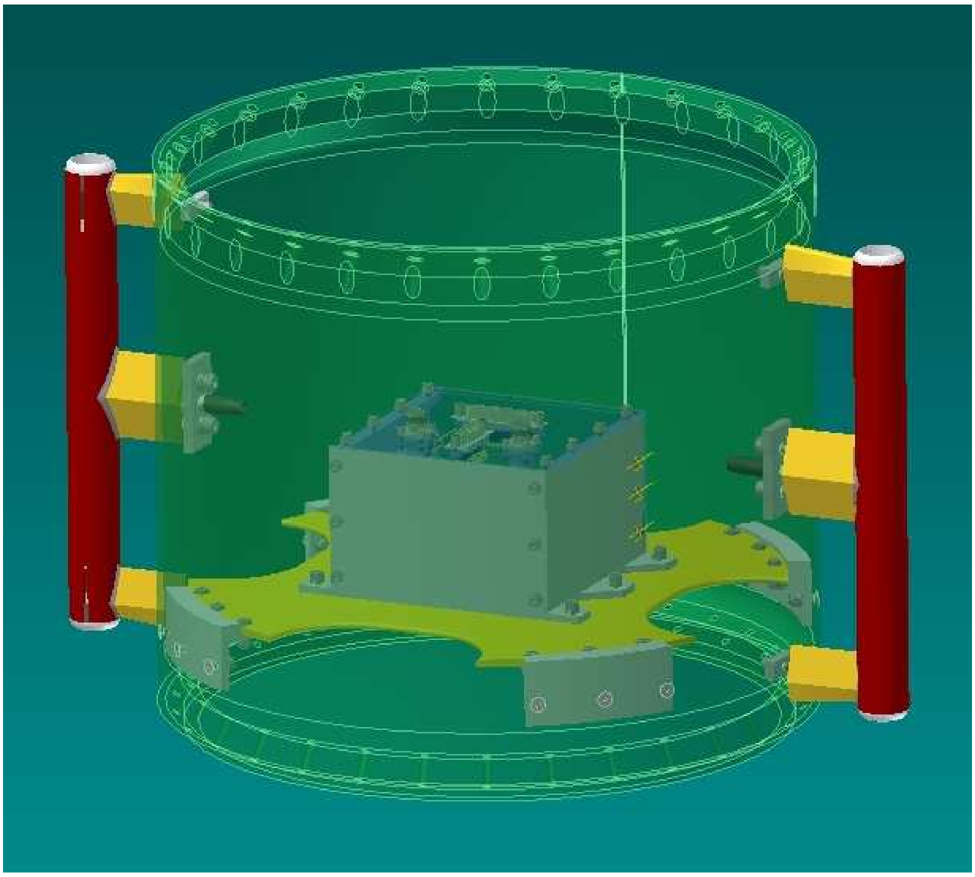


Figure 45. Safe handling points of the Gekko module

6.2.2 HV system description, safe handling

The HV is generated on the PSU board and always presented inside the electronic box while the experiment is powered on. This means +/-60V with respect to the RXSM 28V ground. The surface of the electronic box is equipotential to the RXSM structure. The high voltage is led to the inner electrode of the condensers when a test is performed or during the flight.

- Since the condensers are connected to the electronic box by coaxial cables **the only reachable HV parts are the inner electrodes of the condensers**.

- Note that the HV is not automatically applied when the experiment is powered on, it requires a telecommand or (LO+SOE) to start the operation.

- The maximum voltage between one of the inner electrodes and the rocket structure (outer electrode, electronic box) is 60V and the voltage between the two inner electrodes can be 120V in worst case.

- **Protective covering shall be used** on the edges of the condensers to avoid touching the inner electrodes. (These covering shall be removed after the final test.)

- **The experiment shall be powered off when the top cover of the electronic box is open.**

- After powering off the experiment the condensers discharges in less than 1s and the module is safe to handle.

6.3 Timeline for countdown and flight

The flight will be followed through the Ground Station by Gábor Balassa and Zsolt Váradi. (Other team members may join TBC.)

- **T-30min** Turn on the Ground Station computers (main and redundant)
- Run the ground software
- **T-600s** experiment is powered, connection with the main Ground Station shall established
- **T-590s** HK data collection and monitoring the LO signal starts
- **T-300s** run a test to check the offset voltages of the amplifiers
- **T-0** detection of the LO signal is reported to the Ground Station
- **T+26s** data acquisition starts after receiving the SOE signal
- **T+81s** System steps into post operational mode. Bias voltage is set to 0V and measurement is stopped. HK data acquisition remains while external power is available

6.4 Post Flight Activities

- Equipment recovery (done by SSC)
  Note: After the experiment is powered off the power supply stops and the high voltage discharges in less than 1s.
- Remove the condensers and the electronic box from the module (Ottó Lőrinczi)
- Loading the content of the on board memory to the Ground station (Gábor Balassa)
- Pack up the electronic box and the condensers and transport them back to BUTE (Gekko team members)
- Analysis and evaluation of scientific and HK data (Gábor Balassa)
- Publishing results

EuroLaunch
A DLR and SSC cooperation

7 DATA ANALYSIS PLAN

7.1 Data Analysis Plan

The Gekko experiment will carry out air conductivity measurements in the altitude range of 22km and 75km. While the measurement is running one mobility spectrum is being recorded in every second. This means that a bias voltage is applied to the Gerdien condensers in a predefined voltage range and the current of the inner electrode is measured. The physical background of the measurement method is detailed in chapter 1.1.

The applied bias voltage range for each characteristic curve is defined taking into consideration the velocity and the altitude of the rocket, the physical dimensions of the condensers and the estimated ion density and its distribution in the middle atmosphere above ESRANGE.

The actual velocity and altitude are not available real time therefore the measurements are scheduled according to the elapsed time. Using this method the recorded mobility spectrums have time dependence instead of altitude dependence. The approximated flight profile (including the v(t-T0) and h(t-T0) functions) are provided before the launch campaign by the EuroLaunch. The estimation of the ion composition is based on former studies of the atmosphere [8], [13], [14]. Table 35 shows the calculated bias voltage sweeps with 5 km resolution.

Table 35. Bias voltage ranges

height [km]	bias voltage range [V]			
	positive ions		negative ions	
	V_{min}	V_{max}	V_{min}	V_{max}
22,4	9,99E+01	1,12E+02	7,77E+01	1,03E+02
27,4	4,38E+01	4,92E+01	3,39E+01	4,50E+01
32,4	1,96E+01	2,19E+01	1,52E+01	2,04E+01
37,4	8,69E+00	9,73E+00	6,75E+00	8,99E+00
42,4	4,03E+00	4,54E+00	3,13E+00	4,15E+00
47,4	1,95E+00	2,18E+00	1,51E+00	2,01E+00
52,4	1,00E+00	1,12E+00	7,78E-01	1,04E+00
65	5,38E-01			5,60E-01
70	7,65E-02	8,57E-02	5,94E-02	7,90E-02
75	3,42E-02	3,83E-02	3,54E-02	3,54E-02
80	2,00E-02			
85	5,96E-03	6,53E-03	4,63E-03	6,16E-03
90	3,21E-03			
95	4,63E-04	5,20E-04	3,60E-04	4,79E-04

Since the bias voltage calculations are based on estimations for the control of the results an extra sweep is also performed after each calculated sweep to cover the full bias voltage range thus extending the mobility spectrum.

All of the measured data including the condenser currents and the bias voltages will be available after the flight. The first step is to order the current values to the corresponding bias voltage values thus creating the current-voltage characteristic curves, $I_{cond}(U_{bias},t)$. In order to determine the altitude dependence and increase the precision of the measurement the real flight profile shall be obtained from EuroLaunch. The measurement error caused by the offset voltage of the precision amplifier is also corrected. The results are several mobility spectrums with altitude parameters ($I_{cond}(U_{bias},h)$).

The type of ions can be determined on the basis of the breakpoints in the volt – ampere characteristic therefore the collected ionized molecules are identified by calculating the gradient of the curves. At a breakpoint the bias voltage determines the critical mobility of a specific ion. The relation between the critical mobility and the bias voltage is defined as follows:

$$\mu_c = \frac{(b^2 - a^2)\ln\left(\frac{b}{a}\right)u}{2VL}$$

- μ_c is the critical mobility
- a is the radius of the inner electrode
- b is the radius of the outer electrode
- L is the length of the condenser
- u is the air speed
- V is the bias voltage

Replacing V with a bias voltage at a breakpoint we get a mobility value which corresponds to a certain molecular weight. The last step is the identification of the molecule by its molecular weight.

After the launch campaign we will perform a scientific analysis involving scientific data obtained by Scandinavian observatories. The results will also be compared to results of former sounding rocket measurements [13], [14].

7.2 Launch Campaign

The launch campaign took place on CW 18-19, 2013. Three students participated from the Gekko team on the launch campaign:

Gábor Balassa (science, tests, ground station operation)

Ottó Botond Lőrinczi (mechanics, tests, failure analysis)

Zsolt Váradi (electronics, tests, ground station operation, failure analysis)

The REXUS 14 was launched on the 7th of May, 2013 at 8:00 am. Due to a failure the Gekko experiment was not able to take measurements and therefore the scientific objectives of the experiment were not fulfilled.

7.2.1 Flight preparation activities:

After setting up the GSE we performed mechanical checkout of the experiment. We haven't found any damage or loose screw. The electronics box, as well as the condensers were clean.

The experiment was powered and functional test was performed with the GSE. During the functional test normal HK data frames were received. After updating the on-board software the experiment was ready to perform the individual test with the REXUS service module. (Due to the new calculations of the predicted flight trajectory, the on-board software update and the individual test were repeated.)

The bench test with the other experiments (Space Sailors, Caesar and PoleCats) was successfully carried out. After the final checkout of the experiment modules (done by the ESA and EuroLaunch experts), the integration of the payload was started. The protective covering of the condensers were marked as Remove Before Flight objects.

On the 4th of May at the Flight Readiness Review the experimenters and payload managers reached the conclusion that the REXUS 13 and 14 rockets are ready for flight.

7.2.2 Failure analysis

Table 36. Event timeline:

Event	Time	Consequence / action
Experiment power on	T-600	*Nominal operation confirmed*
Calibration test initiated	T-300	

Calibration test done	T-240	*Successful*
Lift-off	T-0	*Short circuit on power line*
Input current exceeds 20A	T+1,5	*The REXUS power protection unit switched off the Gekko experiment*

No data frame was received after lift-off. According to the flight telemetry of the DLR TM station, the input current of the Gekko experiment suddenly increased after lift-off. The power line protection unit switched off the experiment after a 10msec overload, during which the input current reached approximately 20 Amps (note: the nominal input current of the Gekko is ~30mA).

After payload recovery the following pictures were taken.

Figure 46. The REXUS14 payload after the recovery

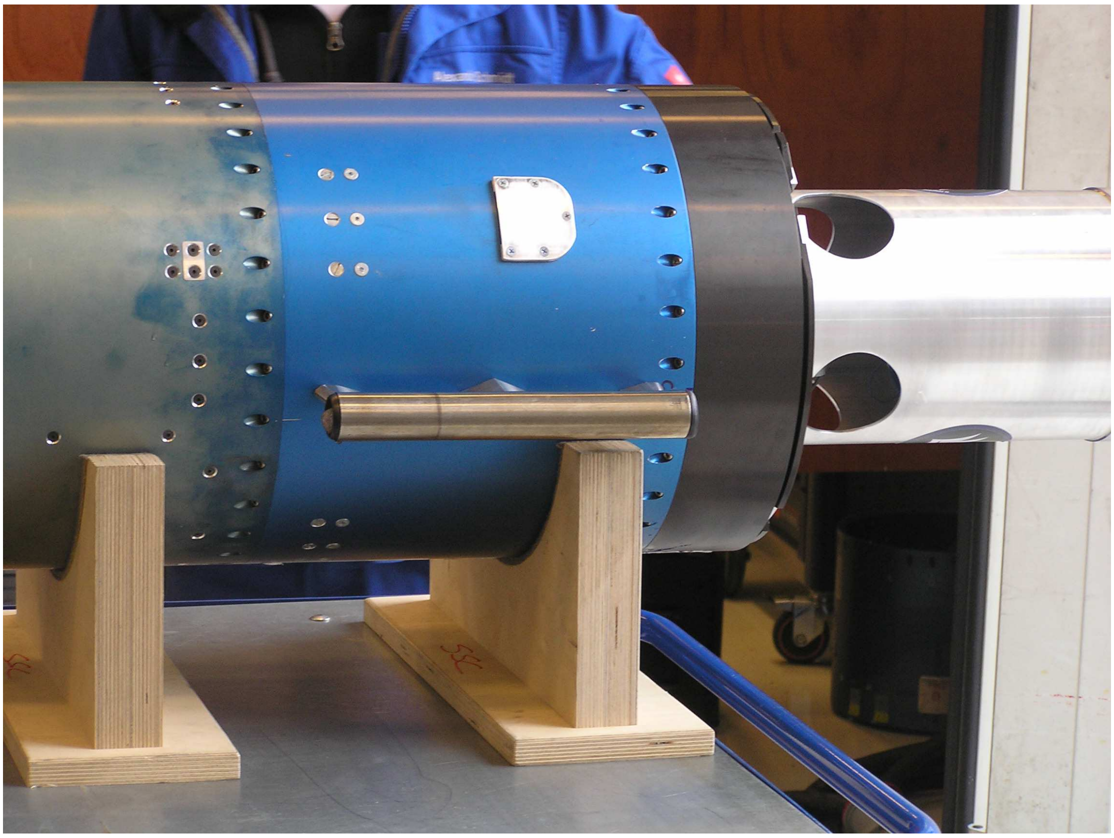


Figure 47. After payload recovery

The first inspection revealed that the sensors were filled with snow, the tip insulation rings were deformed (melted) and some burning smell leaked from the experiment modules. After the experts disassembled the payload they found a lot of soldering tin inside the Gekko module and some tin inside the Caesar module.

The following pictures were taken when we started the inspection and analysis after the recovery of the Gekko module.

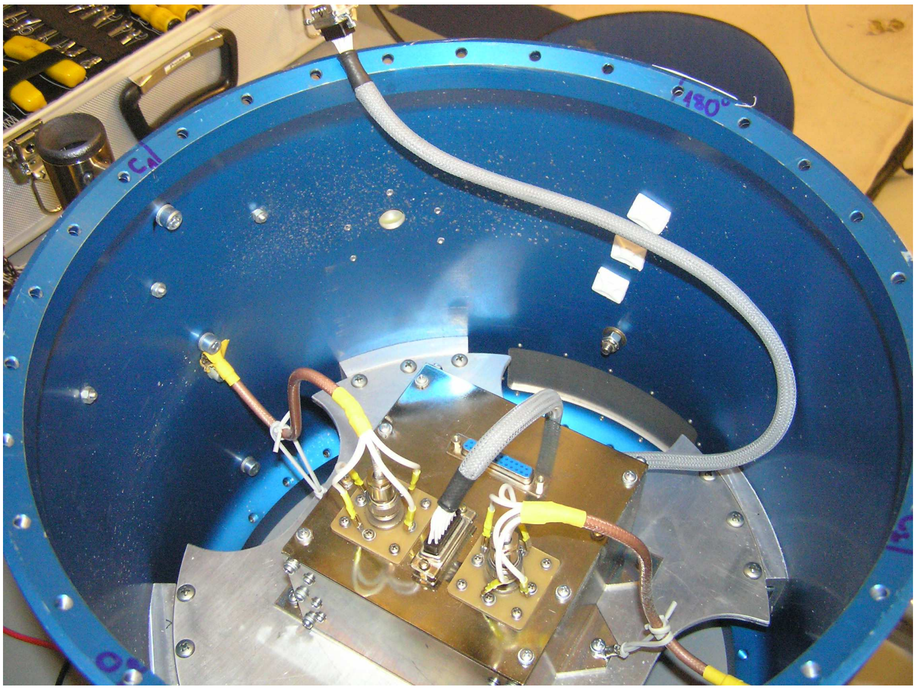


Figure 48. The module wall is covered by soldering tin

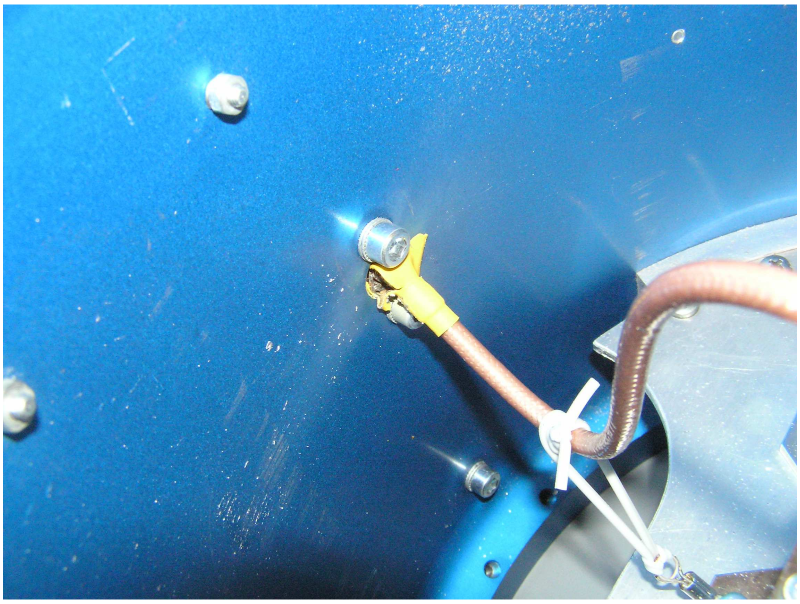


Figure 49. The attachment of the triaxial cables are damaged

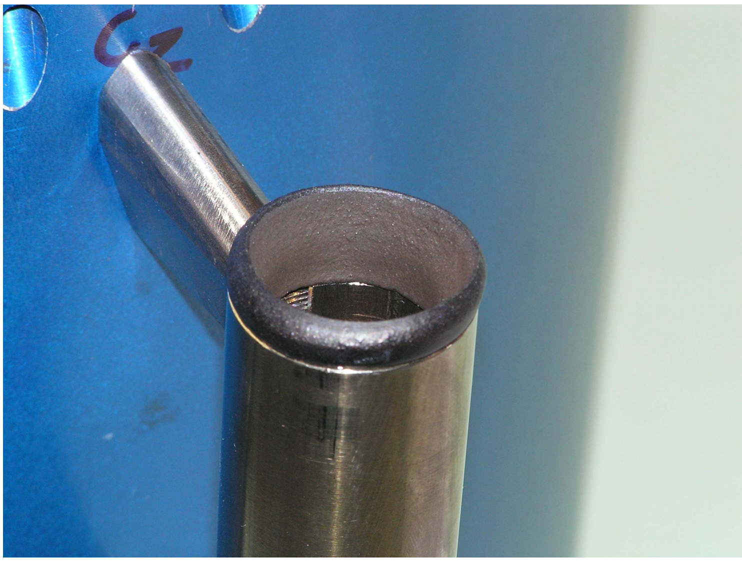


Figure 50. Insulation ring melted during the flight

We recognized that the cable attachments were damaged, the two shielding layer of the triaxial cable were shorted and the soldering tin of the triaxial cable was melted and sprayed into the module. Most of the tin was deposited on those sides of the electronics box that were facing to the sensor attachment and on the wall of the experiment module (Figure 48.).

The impedance of the experiment power line was checked through the experiment IF cable by a multimeter. There was no short circuit on the power line.

According to the study and calculations of our physicist, the unexpected high temperature was probably the consequence of shockwaves in the tubes [15]. Since the air pressure was higher in the pipes than in the module the hot air was able to flow in, melt the soldering tin and spread it into the module. The plastic insulation on the cables (figure 49. yellow material) was damaged by the hot airflow which also damaged the PTFE insulation between the shielding layers of the triaxial cables.

The disassembly of the electronics box was done step by step in order to identify the location of the short circuit. Each stage of the disassembly was documented by photos.

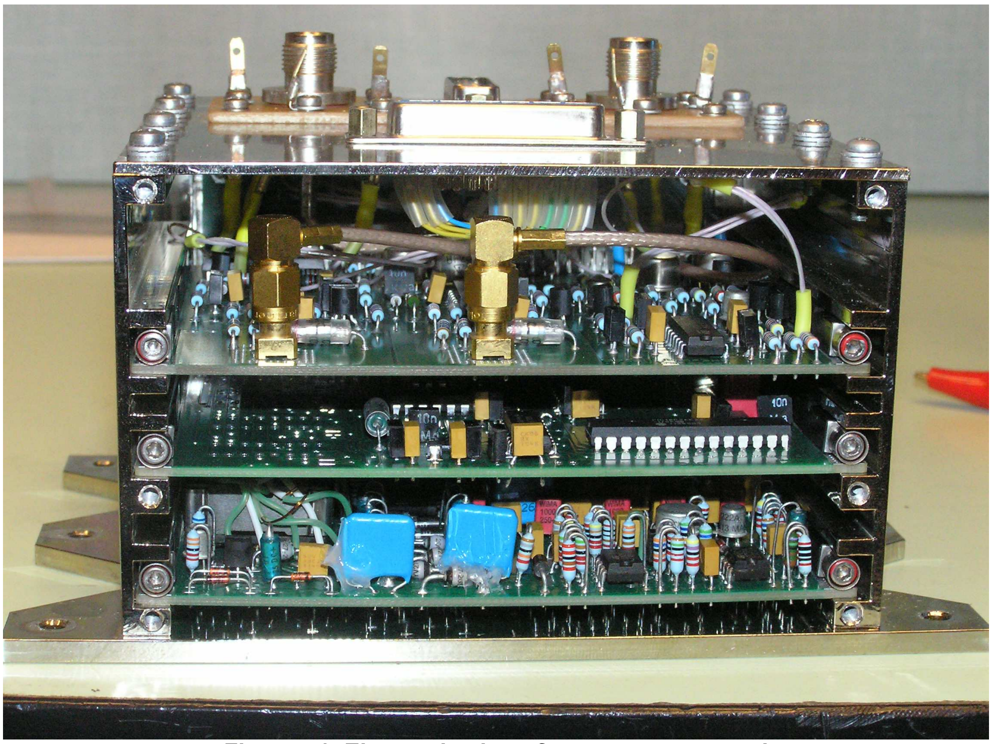


Figure 51. Electronics box, front cover removed

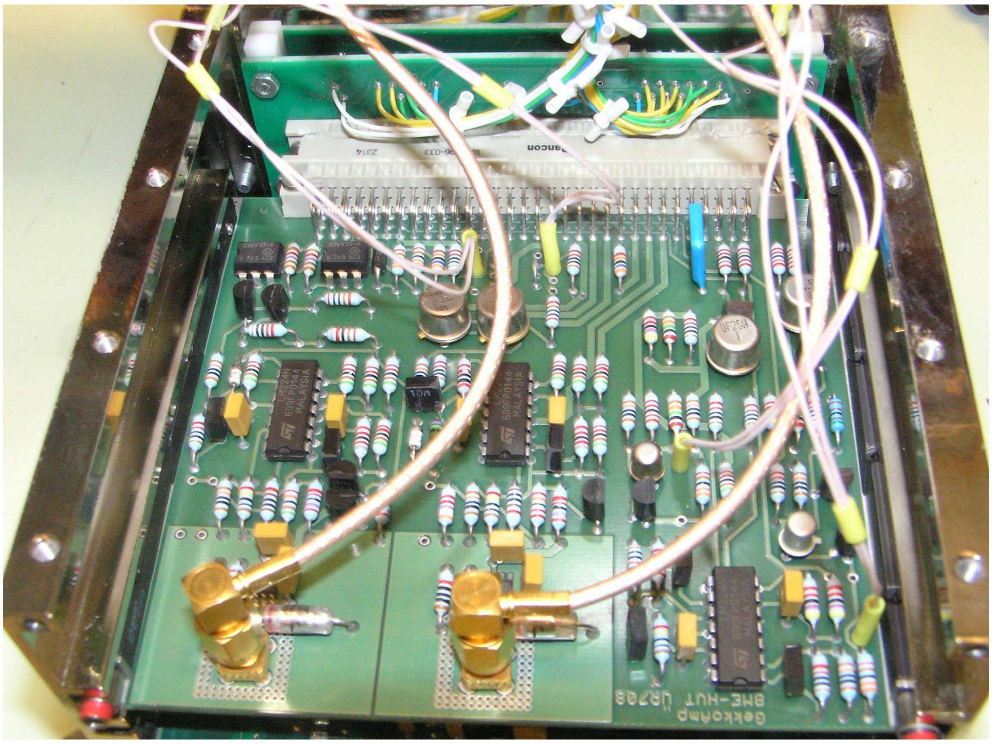


Figure 52. Amplifier board and cable assembly undamaged (top cover opened)

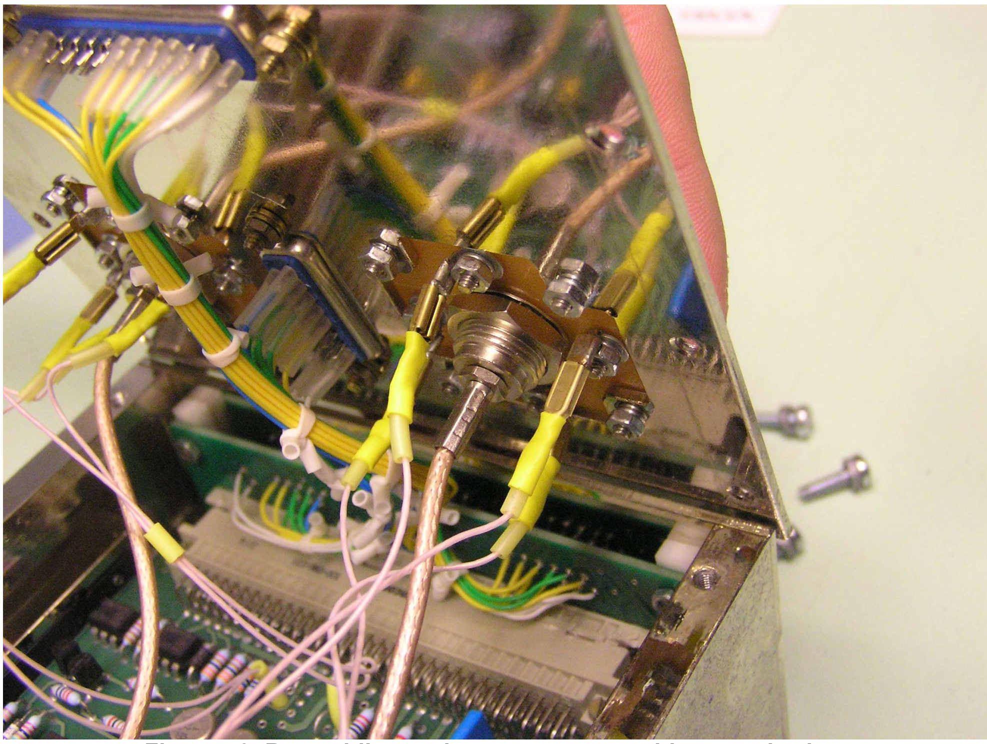


Figure 53. Box cabling and connector assembly are unbroken

There was no (extra) soldering tin inside the electronics box, the cabling was undamaged and the components were on their places. The only place on the top panel where the *+28V* is directly connected to the module is located close to the optocouplers which lay under the cable lugs (*28V GND*) (Figure 53.). The insulation of the cable lugs (figure 53. yellow plastic) was undamaged.

The next two panels – the OBDH PCB and the PSU PCB – were inspected in the next step. We haven't found any irregularity at the first time. (Figure 54, 55.)

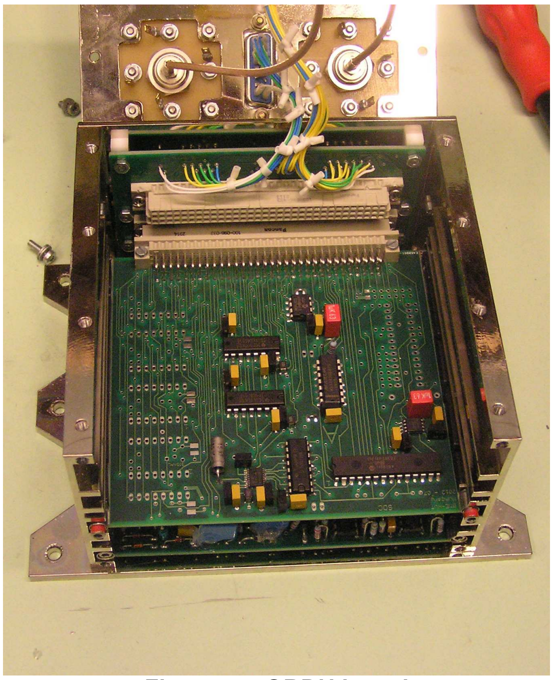


Figure 54. OBDH board

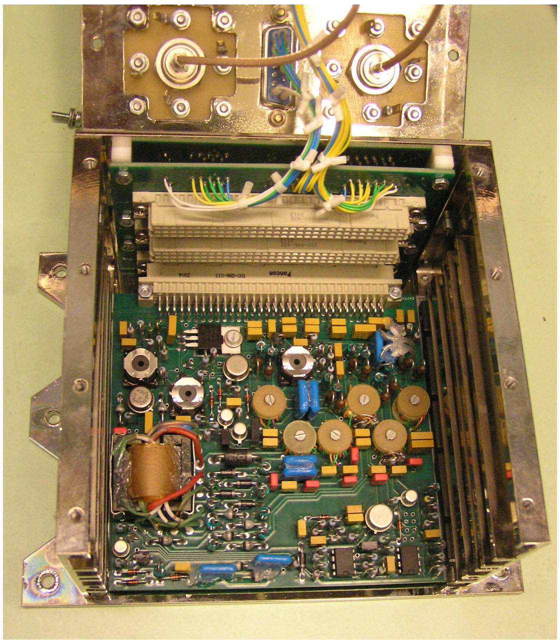


Figure 55. PSU board

After the first inspection we haven't found the reason of the short circuit. The electronics box was reassembled, connected to the GSE and powered with a current limited benchtop power supply. The power consumption was below the nominal (25mA input current) and the communication couldn't be established.

After the next disassembly we have found a burning point on the inner wall of the electronics box under the PSU board (Figure 56.). This point was under a resistor pin – one of the few pins that the *+28V* is directly connected to. Figure 57 shows the schematic of the UVLO circuit with the highlight of the corresponding pin.

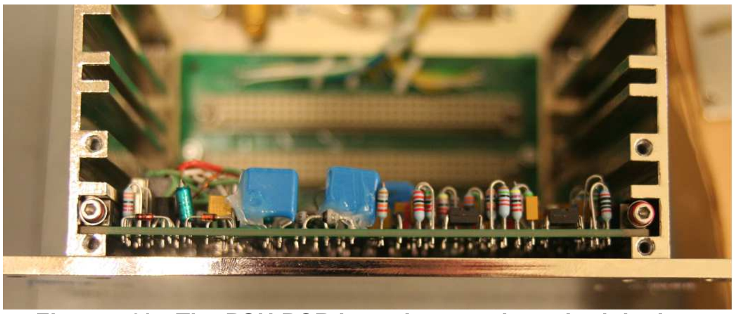


Figure 56/a. The PSU PCB bent down and touched the box

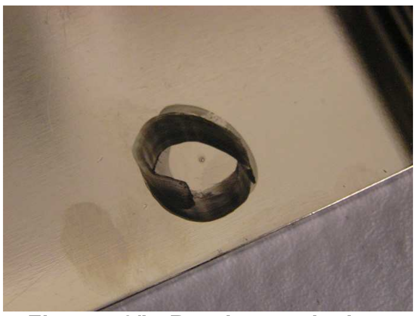


Figure 56/b. Burning on the box

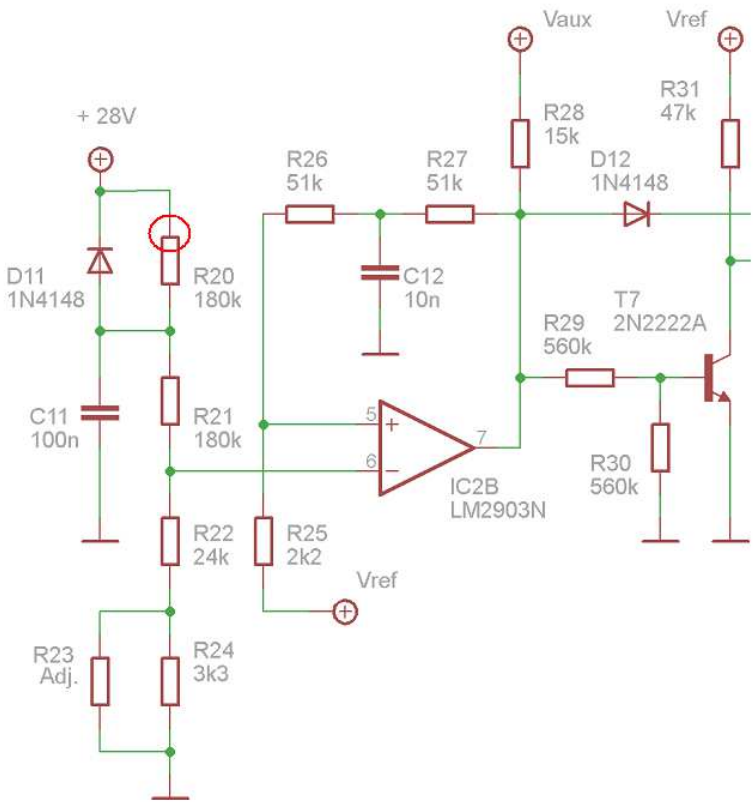


Figure 57. The UVLO circuit. The pin of R20 touched the structure

The PSU was further investigated to find the cause of the failure. We realized that the voltage reference IC (LM285-1.2) was damaged, and the reference voltage was much lower than in normal case. Due to the failure of the reference voltage the control circuit blocked the operation of the PSU.

By this point the Launch campaign came to its end. We have presented our preliminary results on the Post Flight Meeting. The reason of the short circuit and the very high input current was found. When we left ESRANGE we still didn't know the reason of the damage of the voltage reference IC.

The investigation continued at the university. By studying the PSU board with microscope, we have found that not only one pin but 6 other pins touched the structure. The next figure shows the components which shorted to the electronics box.

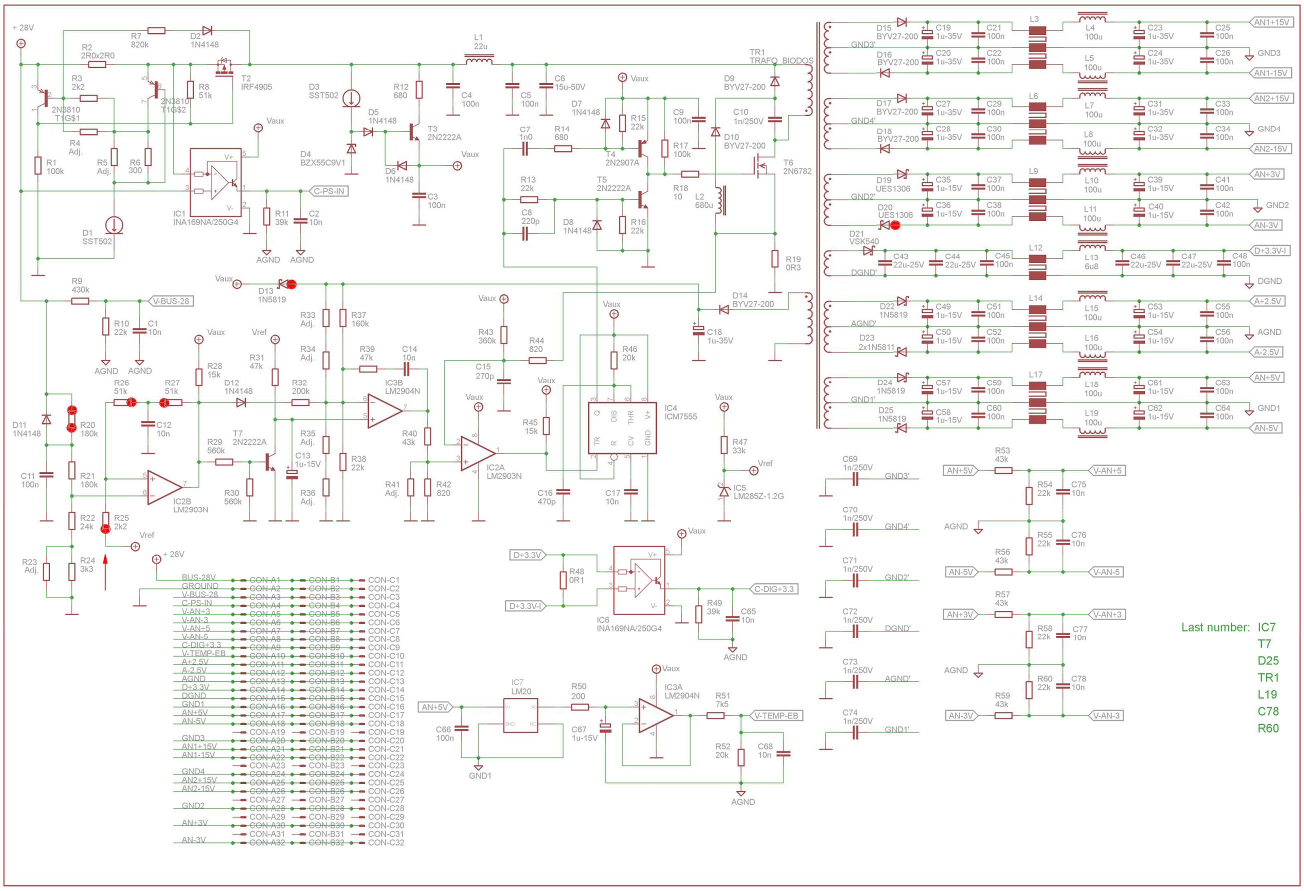


Figure 58. Pins that are shorted to the structure

The pins of the components on the PSU board were cut after soldering therefore the cutting edges are clearly visible under the microscope. In case of those pins that hit the electronics box, the edges lost their sharpness. The next picture (figure 59) was taken in oblique light. It is clearly visible that the pin of R20, where the high current gone through, is bent.

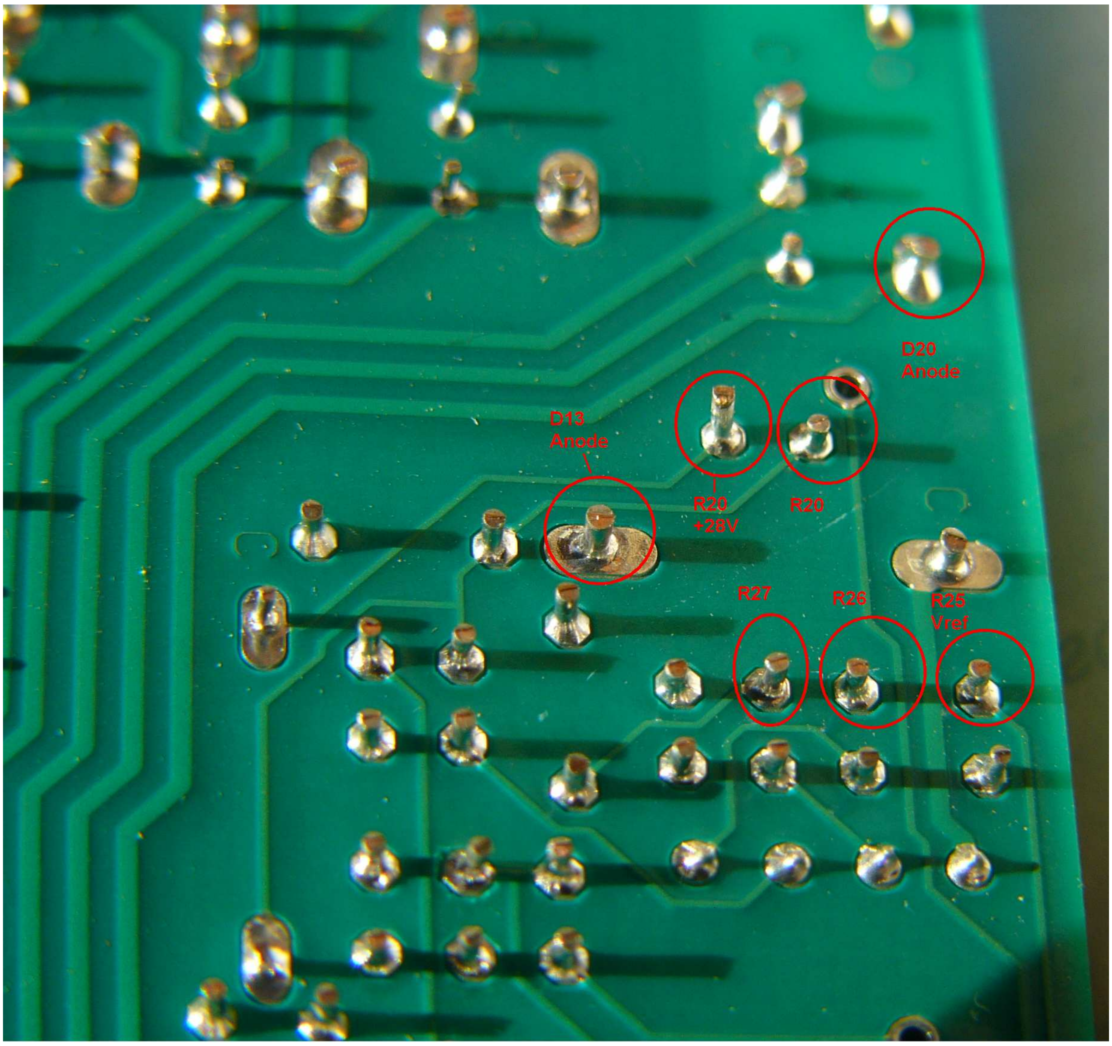


Figure 59. The highlighted pins touched the module

After this inspection, we were able to find the most probable cause of failure of the voltage reference. Figure 60 shows a model to understand where did the high current flow and how did the potential of the structure shift.

The high current – induced by the short circuit of the +28V line – flowed through the structure causing a “dU” voltage drop on its impedance. Since the +28GND line was not shorted, its potential remained 0V. As shown on figure 60, the “dU” potential appeared on the voltage reference IC increasing its current and damaging the IC.

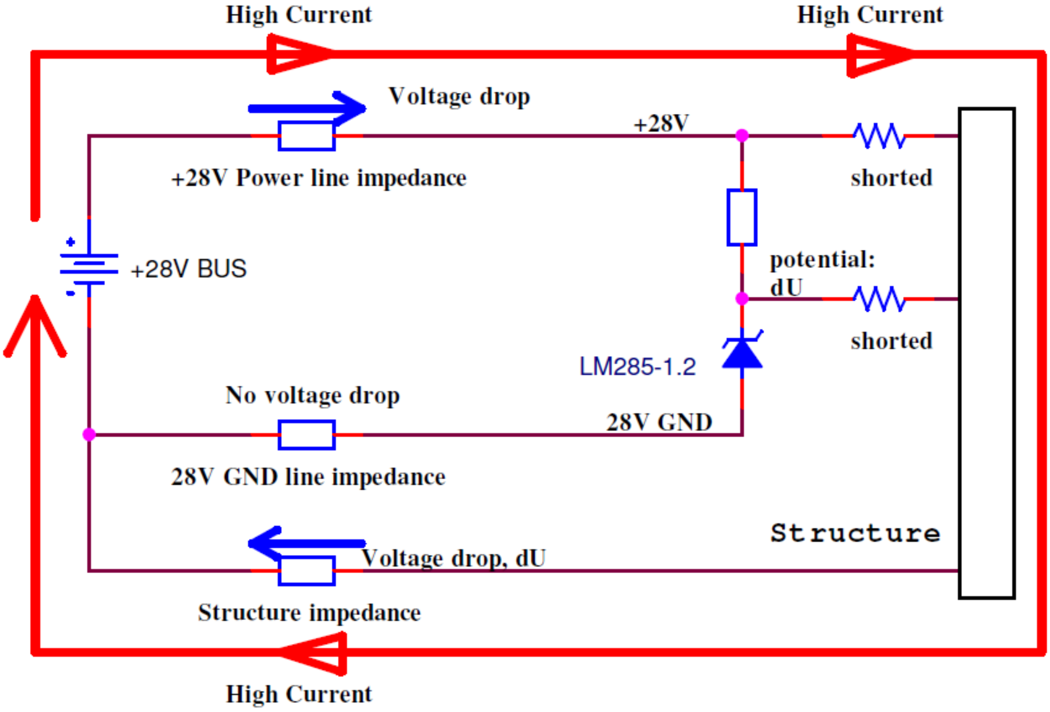


Figure 60. Modelling the effect of the short circuit

The failure analysis regarding the electronics came to a conclusion. The short circuit was the consequence of the bend of the PSU board due to the high acceleration after lift-off. On the PSU board 7 pins were found that probably touched the structure. Since the short circuit current was high enough to induce a voltage shift on the structure resistance, as a secondary effect, the voltage reference circuit was damaged.

7.3 Results

7.3.1 Technical and scientific results

The short circuit on the power line occurred after lift-off ant therefore the Gekko experiment was unable to perform measurements. The scientific objectives (Obj. 1 - 3.) were not met.

The technical objectives, objective 4 and 5 are fulfilled. We successfully developed an experiment to conduct Gerdien condenser measurements and, even if the first flight was not successful, we gained a lot of experience.

7.3.2 Outlook, improvements and recommendations

At this time we are working on the improvement of the experiment in order to come up a proper solution to prevent the failures that we experienced during the REXUS14 launch. Three different parts are targets of improvement: the insulation ring on the tip of the sensors, the attachment of the triaxial cables and the condensers and the electronics box construction and placement.

The insulation ring was made from a special thermo plastic material (Appendix C) of which the maximum short term (a few hours) operating temperature is 500°C. The deformation of this ring was not a critical failure but still a problem that shall be corrected. A possible solution for this problem is to use a commercial ceramic ring. In that case the mechanical parameters shall be adjusted to the available dimension of the ceramic ring.

The most critical point of the improvements is the cable assembly of the Gerdien condenser. In order to connect the central electrode – which is attached to the cable by screw connection – a mounting hole shall be left on the outer electrode. The increased air pressure in the pipe can cause airflow through this mounting hole thus damaging the insulation of the triaxial cable (that actually happened to the Gekko experiment). In order to prevent the hot air flowing into the module, the hole shall be sealed with a proper material. And lastly, the soldering connection of the outer electrode shall be replaced by screw connection.

The short circuit can be prevented without rebuilding the electronics box by placing a capton tape under the PSU board. However, it is more preferable to change the orientation of the electronics box. In this case the static acceleration has much less effect on the panels.

The failure of the experiment also revealed a possible are of improvement of the REXUS Service Module. The REXUS power protection and distribution unit did not limit the input current (or the limitation not started before the Gekko experiment was switched off) when the short circuit occurred and the experiment remained in off state without trying to power it on again. With a small improvement of the service module – configurable current limiting switches and a “retry” algorithm – a temporary failure (such as the short circuit experienced in the case of Gekko during lift-off) would not mean the total loss of an experiment.

7.4 Lessons Learned

The Gekko project provided us a lot of experience even if the scientific objectives were not fulfilled. The most important lessons that we learned are as follows:

- Proper project management is essential to a well done experiment and it takes a lot of time. A good and updated Gantt-chart can help a lot.
- For those students who did not receive academic credit for their work, it was very hard to take the time to work on the development. On the other hand, the students who worked for credits – as part of their thesis or project laboratory – put a lot of effort in accomplishing their tasks.
- For BSc and MSc students, the exam term shall be highlighted with “red” on the Gantt-chart as they clearly won’t be able to dedicate enough time for the development during these weeks. This affects not only the development of the experiment, but the workshop/training participation as well.
- It is very important to perform tests and simulation as early as possible. We could have saved our time and money if we carried out one of our simulations earlier. In any case, it’s better late than never.
- Sometimes we had to repeat a test because every result was documented but the test conditions were not.
- Breadboards are important: With the use of breadboard models we didn’t have to re-design any PCB thus saving us time and money.
- It’s better to order the components (or at least check the availability at the distributor) before initiating the PCB production. Different manufacturers can use different footprints for the components.
- Using a common software environment within the team: we have lost some time and made some mistakes with converting or re-drawing the schematics that were made with different software by different team members.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

This section contains a list of all abbreviations used in the document.
Add abbreviations to the list below, as appropriate.
In version 5 of the SED (final version), delete unused abbreviations.

AIT	Assembly, Integration and Test
asap	as soon as possible
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CDR	Critical Design Review
COG	Centre of gravity
CRP	Campaign Requirement Plan
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
FCL	Foldback Current Limiter
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HK	House Keeping
HV	High Voltage
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IPR	Interim Progress Review
LO	Lift Off
LT	Local Time
LOS	Line of sight

Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
OBDH	On Board Data Handling
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
PSU	Power Supply Unit
SED	Student Experiment Documentation
SNSB	Swedish National Space Board
SODS	Start Of Data Storage
SOE	Start Of Experiment
SSC	Swedish Space Corporation (EuroLaunch)
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or -
TBC	To be confirmed
TBD	To be determined
UVLO	Under Voltage Lockout
WBS	Work Breakdown Structure

8.2 References

(Books, Paper, Proceedings)

[1] EuroLaunch: **BEXUS User Manual** (2010), **REXUS User Manual** (2010)

[2] European Cooperation for Space Standardization ECSS: Space Project Management, **Project Planning and Implementation**, ECSS-M-ST-10C Rev.1, 6 March 2009

[3] SSC Esrange: **Esrange Safety Manual**, EU A00-E538 , 20 March 2006

[4] European Cooperation for Space Standardization ECSS: Space Engineering, **Technical Requirements Specification**, ECSS-E-ST-10-06C, 6 March 2009

[5] European Cooperation for Space Standardization ECSS, Space Project Management, **Risk Management**, ECSS-M-ST-80C, 31 July 2008

[6] European Cooperation for Space Standardization ECSS: Space Engineering, **Verification**, ECSS-E-ST-10-02C, 6 March 2009

[7] Project Management Institute, **Practice Standard for Work Breakdown Structures – second Edition**, Project Management Institute, Pennsylvania, USA, 2006

[8] David A. Burt - The development of a Gerdien condenser for sounding rockets – Scientific report no 8., University of Utah, 1967

[9] Murray J. McEwan and Leon F. Phillips – Chemistry of the atmosphere Wiley, New York, 1975

[10] V.V. Smirnov, V.F. Radionov, A.V. Savchenko, A. A. Pronin, V.V Kuusk – Variability in aerosol and air ion composition in the Arctic spring atmosphere, Atmospheric Research, Volume 49, Isuue 2, 1998

[11] Bragin J.A., Tulinov V.F., Smirnih L.L., Jakovlev S.G., – Simultaneous measurement of the ion concentration and intensity of cosmic ray in the height range 10-70 km,(in Russian). Kosmicheskie Issledovanija, XI.488-489,1973.

[12] REXUS User Manual, Document ID: RX_REF_RX_user_manual v7-7_06Sep12

[13] Beig G. – Global change induced trends in ion composition of the troposhere to the lower thermosphere. Ann. Geophysicae, 26, 1181-1187, 2008.

[14] Farrock H., – Design of a simple Gerdien condenser for ionospheric D region charged particle density and mobility measurements. Penn. State University, Sci.Rep.No.433,1975.

[15] Zsolt Váradi, Ottó Botond Lőrinczi, Gábor Balassa, Pál Bencze - Rocket-borne experiment for the measurement of the variation in electric conductivity with altitude, ESA-PAC Symposium, 2013

APPENDIX A – EXPERIMENT REVIEWS

REXUS / BEXUS

Experiment Preliminary Design Review

Flight:	REXUS 14
Payload Manager:	Mikael Inga
Experiment:	Gekko
Location:	Esrange, Kiruna, Sweden
Date:	Tue 28 Feb, 2012

1. Review Board members

Mark Uitendaal	SSC Esrange
Olle Persson	SSC Esrange
Hans Henriksson	SSC Esrange
Mikael Inga	SSC Solna
Mark Fittock	DLR Bremen
Martin Siegl	DLR Bremen
Markus Pinzer	DLR MORABA
Nils Hoeger	DLR MORABA
Peter Turner	DLR MORABA
Alexander Schmidt	DLR MORABA
Koen de Beule	ESA Technical Directorate (Chair)
Natacha Callens	ESA Education Office
Paul Stevens	ESA Education Office (Minutes)

2. Experiment Team members

Zsolt Váradi
Bálint Kollek
Ottó Larinczi
Dávid Szabó

3. General Comments

- SED
    - The document was generally good, however it was noted that the SED was light on mechanical detail, suggesting a lack of expertise in this field. Please elaborate this section prior to submission of SED v2-0.
    - The electronic content in the SED was very good, as was the Requirements, Verification and Testing sections.
    - The SED preface is included in the template for your reference only. For future versions of the SED you should either delete this section or write a preface that is relevant to your experiment.

- Presentation
    - The presentation was generally well delivered, with good timing. It was clear, concise, and provided some clarification on the mechanical design. The team engaged well with their audience.
    - It was noted that there were some discrepancies in the mass estimates provided in the SED and the presentation. Please try to be consistent in the information you provide to us

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
    - The Requirements and Constraints section of the SED was very good. The panel commend you for this.
    - Please be careful with the use of should and shall when describing your requirements. Make sure these are correctly classified.

- Mechanics (SED chapter 4.2.1 & 4.4)
    - **The aerodynamic effects of the Gerdien condensers on REXUS 14's flight profile are a major concern. If the experiment is mounted too far forward in the payload, it will almost certainly create instabilities. To mitigate this effect your experiment will have to be mounted toward the base of the payload. You should seek further advice from EuroLaunch regarding module placement and associated air-flow characteristics.**
    - In the event that the Gerdien condensers are mounted at the base of the payload; please inform us at which distance from the external module skin will they have to be mounted, to avoid the turbulent flow region?
    - Please be aware that the nosecone will detach from the payload at T+60s. This will seriously affect the air-flow characteristics of the

payload, so it is recommended that you take this account.

- **Please ensure that the Gerdien condenser mountings are as aerodynamic as possible, so as to reduce instabilities. It is recommended that you manufacture the mountings from solid aluminium, and that they take on the form of a wing leading edge. You will most likely be assigned a small experiment module, so please ensure that you have adequate room for your mountings.**
- When conducting your thermal analysis, please note that the re-entry temperature of 200°C quoted in the RX User Manual is an upper case value. In reality it is closer to 100°C. This is worth keeping in mind when selecting your external component materials.
- The capacitors to be used for your Gerdien condensers will produce significant heat. Please be aware that this may have an impact on your measurements.
- The Gerdien condenser mountings should also act as a heat sink to avoid over-heating the sensors.
- **Chapter 4 will require elaboration prior to submission of SED v2-0. Please include as much information as possible, especially with regard to experiment dimensions, mass and footprint. The internal layout of the electronics box should also be presented in detail, along with FE and Modal analyses.**

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)
  - **Please be aware that you will be situated <1m away from S-band RF transmitters, when integrated into the RX14 payload. This will almost certainly produce interference, greater than the pA current flows you aim to measure. It is strongly recommended that you conduct interference tests, and use filtering on your input stage.**
  - **Please take care when designing your PCB. Ensure that you have adequate shielding and that filters are put into place. It is recommended that you test your electronics systems for RF interference also.**
  - The panel acknowledged that you will not require SOE and SODS commands during flight. TC will only be required before lift-off.
  - The downlink requirements you have quoted (38.2 kHz with a 3 ms gap) for data transfer are a little unrealistic. Please reconsider and re-define your requirements.
  - It is recommended that you re- consider using uplink during flight, in case you need to manually adjust your bias voltage in-flight. Please be aware that uplink capability is available to you.

  - Otherwise the electronics design is very good so far. Keep up the good work.

- Thermal (SED chapter 4.2.4 & 4.6)
  - Your approach to thermal analysis has been very good to date. However it is recommended that you look into the thermal properties of the electronics box, and compare them against the REXUS temperature profiles to ensure your experiment will operate at its optimum temperature.
  - It is recommended that you perform thermal simulations using Ansys or a similar system, to assess the thermal characteristics of the Gerdien condensers and their mountings.
  - It is recommended that you provide a table outlining the thermal ranges of individual components.

- Software (SED chapter 4.8)
  - It is not necessary to use mutex, if you do not require real-time control or telemetry.
  - **Please ensure that data stored on your flash memory cannot be overwritten or corrupted, in the event of glitches, power cycling or hard cuts during flight.**

    It was noted that you have expressed an estimated flight time of 5 minutes. Please be aware that the nominal flight time for REXUS experiments is 600 seconds. We can power down your experiment when required, but the exact timeline will have to be calculated and defined well in advance.

  - The software flow diagrams presented in the SED were good, but it was noted that there were no "*I'm alive*" signals incorporated into your software. It is recommended that you include this.

- Verification and testing (SED chapter 5)
  - Your approach to verification and testing was generally well thought out. However, please pay close attention to your verification methods. Follow the guidelines outlined in the verification presentation.
  - Your Test Plan will require further elaboration, specifying all tests (functional, performance, mechanical etc.), and which facilities you will need. You should also begin considering any special requirements and consumables which may be required for certain tests.

- Safety and risk analysis
  - The technical risks outlined in the SED were very well considered.

However it is recommended that you also incorporate project planning risks into your risk register; including loss of personnel through illness, injury or withdrawal. Manufacturing and integration risks should also be included, such as damage to critical components, late delivery of materials etc. Please give as much thought as possible to all risks.

- Launch and operations (SED chapter 6)
  - The physical properties of the experiment were completed to a high standard, but the rest of Chapter 6 will require elaboration prior to submission of SED v2-0.
  - Chapter 7 will also require further elaboration. At this stage you should have a good idea of how you will analyse your data after recovery; this should be presented accordingly.

- Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)
  - The WBS was well thought out and well defined, as was the Project Schedule. The panel commends you for this.
  - **It is strongly recommended that you recruit more mechanical engineers into your team, to support you in the mechanical design and manufacture of the experiment.**
  - **It is recommended that you recruit a dedicated software student into your team, and ensure that he is present at all key events and reviews. Most problems stem from under developed software, so don't underestimate the amount of time and effort required for development and de-bugging.**
  - Please re-consider your budget. At present it seems insufficient to cover the costs of materials, equipment, testing etc. Please provide a detailed break-down of the budget, including all major costs.

- Others
  - EuroLaunch can provide predicted trajectory data in advance, to aid your bias voltage calculations. This can be used either in parallel to, or instead of real-time data.
  - Please be aware that a separate umbilical, for late uploads/updates cannot be provided.

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - The main concern for the panel, is your mechanical and thermal design. The mechanical set-up needs to be further defined, and analysed, taking into consideration all of the points mentioned in the Mechanical section above.
  - The aerodynamic design of your experiment requires further consideration.
  - The allocation of manpower also needs to be addressed. More support is required for the mechanical and software design.
  - Review and address all discrepancy items and inconsistencies listed within this report, prior to submission of SED v2-0.

- PDR Result: pass / conditional pass / not passed
  - **Pass**

- Next SED version due
  - SED v2-0

Experiment Critical Design Review

Flight:	**REXUS 14**
Payload Manager:	Mikael Inga
Experiment:	GEKKO
Location:	DLR,Oberpfaffenhofen, Germany **Date:** 04/07/2012

1. Review Board members

Mark Fittock	DLR Bremen
Martin Siegl	DLR Bremen
Andreas Stamminger	DLR MORABA
Tobias Ruhe	DLR MORABA
Nils Hoeger	DLR MORABA
Frank Hassenplug	DLR MORABA
Markus Pinzer	DLR MORABA
Frank Scheuerpflug	DLR MORABA
Alexander Kallenbach	DLR MORABA
Wolfgang Jung	DLR MORABA
Natacha Callens	Esa Education
Alex Kinnaird	Esa Education – minutes
Koen DeBeule	ESA Technical Directorate
Mikael Inga	SSC Solna - chair
Jianning Li	SSC Solna

2. Experiment Team members

Gábor Balassa (BUTE)

Ottó Lörinczi (BUTE)

Zsolt Váradi (BUTE)

Bálint Kollek (BUTE)

3. General Comments

- Presentation
  - The presentation was good. Speakers were confident and engaged the audience.
- SED
  - There is a marked improvement in the document from PDR – well done
  - However there are still minor points which need improvement:
    - Chapter 7 needs expanding and clarifying.

- There seems to have been a reduction in information available in software, please re-include this information.
- Update the 'issued by' on the cover page.
- Update the references section.
- Pg.1 uses the old EuroLaunch logo, please update this.
- Pg.2 uses a standard text from the SED guidelines please replace it by a short description of your team and project.Pg. 5 (in the abstract), you refer to a launch at the polar cap, please change this to the polar circle or similar.
- Pg. 18 the legend for the Gantt chart is missing, please include this.
- Pg. 71 Please do not use centimetres but millimetres.
- Pg. 73 when using figures from the manual please reference them.
- Pg. 82 some incorrect abbreviations (not your fault) these will be updated in the SED guidelines.

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
  - Use minimum accuracy not maximum accuracy.

- Mechanics (SED chapter 4.2.1 & 4.4)
  - Please include a mechanical sketch of the whole module (top + side view etc.) with basic dimensions including overall height, dimensions of condensers and 'spacers'.
  - If your outer structure is bespoke this should be included and detailed in your mechanical section .
  - Please use 'nord-lock' washers.
  - In general the analysis is not complete enough, at a minimum the two M6 screws should be included.
  - The FEA boundary conditions are not clear, be careful when using figures from the user manual, you still need to implement your own Safety factor on top of these.
  - You include results from the thermal analysis without real figures, please include the numbers here along with comparison of the (material and design) limits and the safety factor.
  - **Please include the cable feedthrough and the D-SUB bracket.**
  - **You need to update your mechanical design following the comments from the panel about your spacers – you should follow the advice from DLR MORABA. Specifically you should include:**
    - **Additional struts at the extremities of your condensers with a smooth transition surface.**
    - **Increase the length of your module to 300mm.**
    - **Do not use the upper part of your module as this will contain balance weights.**
    - **Keep in touch with the experts whilst performing this new design, follow their advice.**
  - You should also consider
    - The additional struts should be welded to the condensers (take care of the precise alignment with the rocket longitudinal axis).
    - The struts should also be connected to the module by a screw from the inner side of the module in a similar fashion to your central spacer.
    - Your strut thickness should be >8mm if you use a circular cross section.
    - Consider the use of nord-lock washers (it saves on Loctite).
    - **You must now use a wall-mounted bulkhead with a 300mm module**

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)
  - Include the interface to the REXUS module, make this more detailed with a schematic.
  - Please include filtering in the power supply, as mentioned in previous lectures, check the team site.
  - What happens if the HV short circuits? Be careful with overload protection.

- It is not clear how the rocket is insulated from the 240V. Please include this.
- Use filtering to filter S-Band, this should also be included in your development test.
- On the input to the RX you need 1k not 120ohm, check the user manual for more details.
- Remove the crystal oscillator from the schematic.
- Include some calculations about drift based on assume initial velocity.
- Co-axial cable connections should be clear, especially if they can and should be removed during testing/integration.
- A lot of GNDs - come up with a clear grounding concept.
- Pg. 40 two inputs from the condensers, one back tracks on the positive, but the one on the bottom is disconnected – check this.
- Be careful with the PCB design specifically filtering and grounding.

- Thermal (SED chapter 4.2.4 & 4.6)
  - You should repeat the thermal analysis on the condensers (following the redesign) with correct boundary conditions. It seems you were incorrectly informed on the temperature for this, please ask for advice if you need it.
  - Consider the use of thermal ablation material.
  - Consider the effects of aerodynamic heating (see thermal), you may need to include coatings in this section.
  - With regards to aerodynamic heating please be careful with your current material choice, it is likely it's insufficient, you should review this and consider another material (perhaps steel).
  -

- Software (SED chapter 4.8)
  - You should clarify who in your team is responsible for software, and possible get some help if you need it.
  - Consider carefully your choice of microprocessor.
  - Consider sending all raw data rather than using compression, it won't 'cost' that much more and may be more reliable.
  - Include the logging of your received data in your SED.

- Verification and testing (SED chapter 5)
  - In general you need expand your test plan.
  - You should include an RF test.
  - For your aerodynamic test ensure you have all the boundary conditions, put these in the SED.
  - A coronal test should be included as you use +100V in a reduced pressure environment.
  - Your vibration levels should be at qualification not acceptance.
  - It is recommended you perform a shaker test at qualification level for the Gerdien condensors.

- Safety and risk analysis (SED chapter 3.4)

  - You should include the risk of one (or both) of the condensers breaking off – both to the experiment and the rocket.
  - Update risk register to include all failure mechanisms (for example the above comment – consider risks to the rocket from your experiment).
  - For personnel risks consider that you have no back up for your team member responsible for mechanical .
  - It doesn't seem like FS10 and MS10 have been mitigated, make sure they are.
  - Because of your design it is suggested you include a diagram/description of safe handling and holding points (can we pick the module up by the condensers for example). Also include this in chapter 6.
  - Consider how we can work on the module, does it sit on a bench like the other modules, or do we use a mount? Also include this in chapter 6.
  - There is a risk during re-entry that your condensers act like wings and cause some gliding to the rocket – research and include this risk.
  - Consider the risk of parachute entanglement with condensers.
  - Be sure to include the risks associated with the HV system.

- Launch and operations (SED chapter 6)
  - See above for safe handling and working points.
  - Please include a full plan of operations (including preparation activities) , with people responsible etc. See the SED guidelines for more on this.
  - Include a safe handing procedure when HV is powered on.
  - Be aware that people will view the HV system as a risk, be sure to include safety measures in general in this section.
  - Think about how long after power off until the module is safe to handle, think about the recovery and include this in this chapter.
  - Table 22 needs to include total mass including bulkhead and module.
  - Be aware the flight simulation is planned for ESRANGE, change your SED to reflect this.
  - Don't reference other sections in chapter 6 – this should be a standalone chapter. If you have to repeat other sections here that is OK.
  - In your timeline (and design) power on should be at T-600s not T-1200.

- Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)
  - With your resource (manpower) allocation, it is not clear how the percentages work, use man hours if you can or make it clear what the percentages mean.
  - Make the role of the 'backups' clear.
  - Include a more detailed budget in the SED.
  - Add URL for your Facebook page and website on the outreach chapter.
  - Post more on Facebook page, try drum up more likes.
  - Update your website, your latest news at the moment is the PDR.
  - Update the latest milestones on the website.
  - Add all new team members on the team member list (be sure to include them on join-space too)
  - Add pictures to the gallery on the website.
  - Include all the sponsors logos on the website.

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Correct all the comments in this report, specially consider the points in safety and chapter 6.
  - **Provide an updated SED with the required mechanical changes in full.**

- CDR Result: conditional pass.

- Next SED version due
  - Provide an updated mechanical section in **version 2-2** ASAP for review by the panel, the deadline for this is **4pm on Thursday 19th of July.** The experts will then decide whether the new design is suitable and whether you can fully pass the CDR. For this update concentrate on the required mechanical changes.
  - Following the above submission a further submission of **version 2-3** covering all the points in this report (specifically safety and chapter 6) is strongly recommend for submission by the 5th of August.
  - **Version 3-0** will be due in around the **27th of August** TBC.

OBDH

Components

-

REXUS

Experiment Integration Progress Review

REVIEW

Flight: RX-14

Payload Manager: Mikael Inga

Experiment: GEKKO

Review location: Budapest, Hungary

Date: 04Oct2012

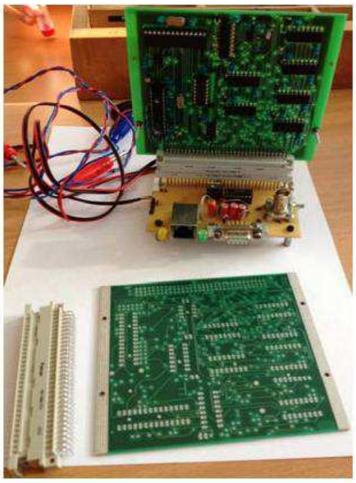
Review Panel

Mikael Inga – SSC

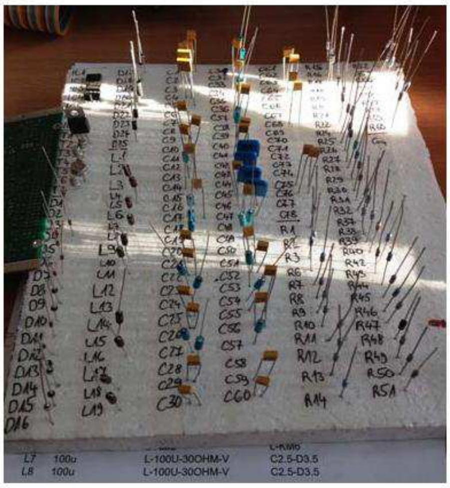
Experiment Team members

Ottó Botond Lőrinczi	Vilmos Gorócz (Cooperating visitor)
András Futó	Veronika Grósz (Cooperating visitor)
Bálint Kollek	József Szabó (Endorsing professor)
Adrián Gugyin	Antal Bánfalvi (Endorsing professor)
Zsolt Váradi	Gábor Kocsis (Endorsing professor)

PICTURES



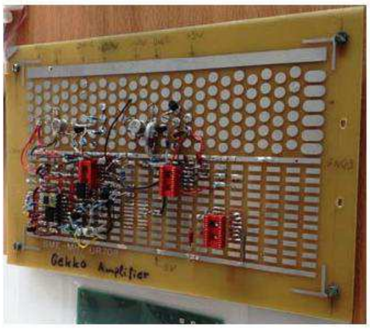
OBDH



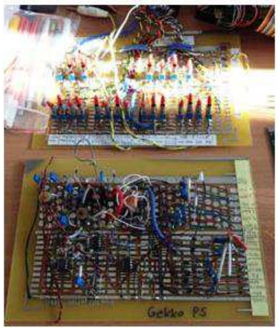
Components

REXUS

Experiment Integration Progress Review



Amplifier board



Power supply board

GENERAL COMMENTS

- The major concerns are about the condensers design (outside the module).

PANEL COMMENTS AND RECOMMENDATIONS

Science

- Measurements from LO up to approx. 75km altitude, maybe delay nose cone ejection to avoid disturbing measurements.
- How to test/calibrate condensers?
- Wind tunnel might be needed to calibrate condensers, bias voltage set to wide range

Requirements and constraints (SED chapter 2)

- No comments.

Mechanics (SED chapter 4.2.1 & 4.4)

- Design is frozen after discussion with DLR, MORABA.
- 6 weeks to manufactory, get go-ahead from EuroLaunch.
- 2-3 weeks to manufactory the OBDH box.
- Condensers and module to be vibration tested at 12g qualification levels.
- Electronics to be vibration tested at 6g acceptance levels.
- Manufactory by team or get a bulkhead?
- Delivery of module from EuroLaunch?

Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- Reuse of design from Biodos.
- Power supply High-Voltage switching problems, probably already solved.

REXUS

Experiment Integration Progress Review

- Amplifier board is new but design is almost finished (tested on breadboard).
- Already breadboard testing of all subsystems.
- All components in-house.

Thermal (SED chapter 4.2.4 & 4.6)

- Condenser measurements not sensitive to melting material.

Software (SED chapter 4.8)

- LO and SOE signals can be tested.
- Only one parity bit is used for downlink checksum.

Verification and testing (SED chapter 5)

- Thermal and Vacuum tests on system level (some breadboards already tested) still to be done.
- Vibrating test, outer parts qualification levels level, electronics acceptance levels
- RF-tests to determine if transmitters will disturb condenser measurements.
- Aerodynamic testing???

Safety and risk analysis (SED chapter 3.4)

- SF-11 replaces SF-10. (SF10 – High not acceptable).

Launch and operations (SED chapter 6)

- No TC during flight.
- Power off at end (after 400s).

Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- EAR in end of November, beginning of December.
- Webpages and etc. to be updated

SED

- What's needed for 3.2? (Alex Kinnard, ESA)

End-to-end Test

- Not performed.

Others

- No Comments.

FINAL REMARKS

REXUS

Experiment Integration Progress Review

Page 4

Summary of major actions for the experiment team

- Finalize and go into testing phase.

IPR Result: pass / conditional pass / fail

- Conditional pass, updated SED to be submitted.

Next SED version due

- TBD (Alex Kinnard, ESA)

Summary of actions for EuroLaunch

- Send module to team.
- Send bulkhead to team if we have one ASAP.
- EAR, PL Integration, Bench test time and Place??

REXUS

Experiment Acceptance Review

REVIEW

Flight: RX-14

Experiment: Gekko

Review location: Budapest

Date: 06Dec2012

Review Panel

Dr. Alexander Schmidt – DLR/MORABA

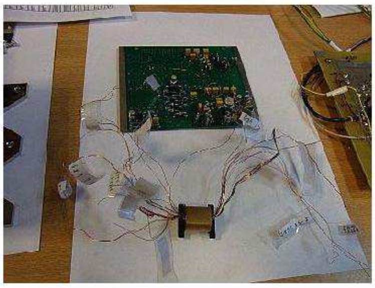
Experiment Team members

Zsolt Varadi Otto Lorinczi Gabor Balassa Adrain Gugyin Andras Futo Supporting professors: Jozsef Szabo Antal Banfalvi Laszlo Csurgai-Horvath Gabor Kocsis Visiting guest from BioDos: Vilmos Gorocz Veronika Grosz Borbala Marosvari (Daemon)	

PICTURES

REXUS

Experiment Acceptance Review



GENERAL COMMENTS

- Experiment not ready, Condensers will be mounted within the next two weeks,
- Venting hole will be manufactured as well as new covers by the team
- Team has to move in another building but work will not be affected to much
- No test with service System Simulator possible, boards not ready , no optocoupler available
- Team is still big many people to work on it

PANEL COMMENTS AND RECOMMENDATIONS

Science

- Science achievements will be fulfilled

Requirements and constraints (SED chapter 2)

- No comments

Mechanics (SED chapter 4.2.1 & 4.4)

- Team will make a second venting hole on the opposite of the old one as recommended in the user manual
- Team will manufacture new cover plates which fit to the bore holes
- Gerdien Condensers are under manufacturing, will be ready after SEW
- Greater holes will be manufactured into the bulkhead for assembly of the experiment
- Team implemented all requests from CDR

Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- 2 PCB are ready (mother board; OBDH)
- 2 PCB under population/production: PSU + Amplifier
- P.4 changed +-10mV to+-50V
- P.9 changed PSU shall provide +/- 15 V and +/- 60V

REXUS

Experiment Acceptance Review

- Engineering model OBDH tested in thermal chamber
- Flight model PCB OBDH successfully performed functional tests
- PSU breadboard functional tests successful
- Components same as BIoDoS therefore tested

Thermal (SED chapter 4.2.4 & 4.6)

- OBDH board tested, see above
- PSU and amplifier not tested due to failure of test chamber
- Alternative test chambers are available

Software (SED chapter 4.8)

- Software ready in parts: data acquisition, structure in memory needs to be otpimized
- Only working on a lower Baud rate

Verification and testing (SED chapter 5)

- vacuum test will be done after integration at the university 1… 20 mbar
- vibration test after integration at EL-TECH facility
- wind tunnel test skipped due to lack of wind tunnel – airflow simulation made instead

Safety and risk analysis (SED chapter 3.4)

- no comments

Launch and operations (SED chapter 6)

- Section 6.4 will be updated until end of January 2013

Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- Deadlines will be modified

SED

- New submission date 16th Dec. or later depending on the tests
- Section 6.4 will be improved

End-to-end Test

- Test with the Simulator was partly possible, boards are not all ready, the tests possible to do worked well

Others

- Hardware will be ready at the end of 2012

- Test finished mid of January maybe + 1 week
- Delivery should be possible end of January

FINAL REMARKS

Summary of major actions for the experiment team

- Finishing the mechanical mounting
- Finishing the electronics hardware end of 2012
- Fulfilling tests: thermal: PSU flight model, amplifier flight model, full system thermal test first week of january
- Shaker test at university : to be done before delivery

EAR Result: pass / conditional pass / fail

- Conditional pass

Next SED version due

- 16th Dec but not the whole test results, or later with test results

Summary of actions for EuroLaunch

- Precise trajectory after flight required
- Nothing special for preflight and recovery

APPENDIX B – OUTREACH AND MEDIA COVERAGE

Gekko Team web site: http://lab708.mht.bme.hu/gekko

Gekko on Facebook: http://www.facebook.com/GekkoTeam

Publications and presentations:

- Ágnes Gubicza – Study of the variation in air conductivity with altitude

presentation in a physic seminar at BUTE
(http://www.phy.bme.hu/~jakovac/Eloadasok/Gubicza_Agi/gubicza_diak.pdf)

- Zsolt Váradi – Hungarian experiment in the ESA - REXUS rocket programme

Publication at the "Űrvilág" Hungarian web portal

(http://www.urvilag.hu/hazai_kutatohelyek_es_uripar/20120406_magyar_kiserlet_az_esa_rexus_raketaprogramjaban)

- Lőrinczi Ottó Botond, Gubicza Ágnes, Váradi Zsolt - Mechanical design of a gerdien condenser for rocket experiment

20th International Conference on Mechanical Engineering. Kolozsvár, Romania, 2012.04.19-2012.04.22.

APPENDIX C – ADDITIONAL TECHNICAL INFORMATION

Mechanical drawings

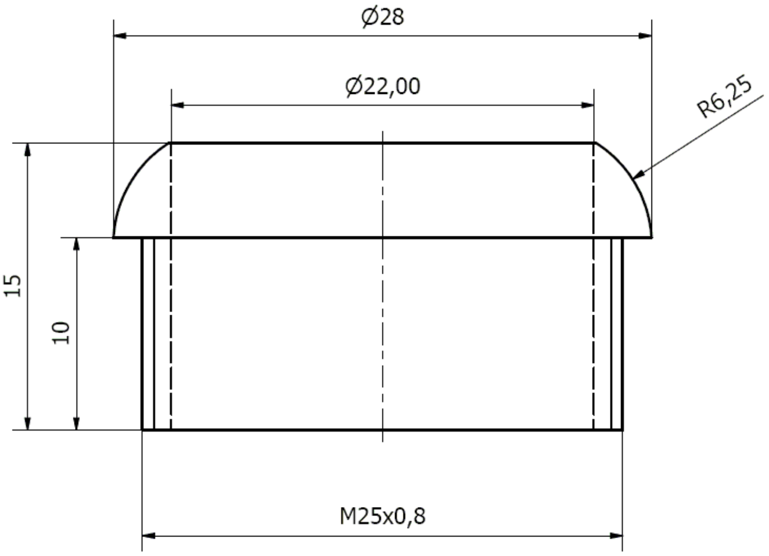


Figure C1. Screw cap

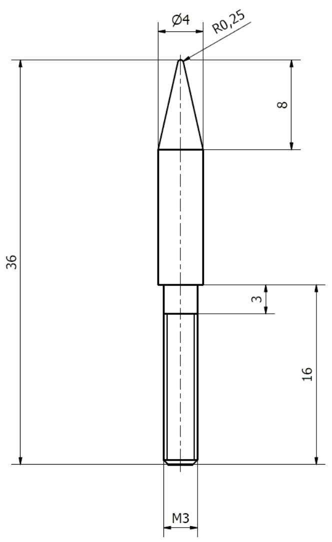


Figure C2. inner electrode

EuroLaunch
A DLR and SSC cooperation

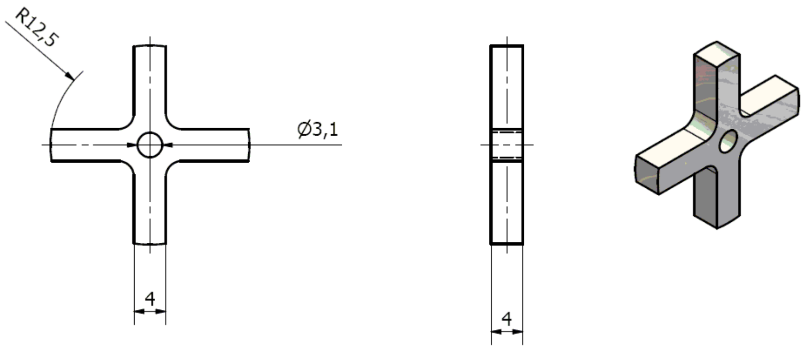


Figure C3. Inner/outer electrode spacer

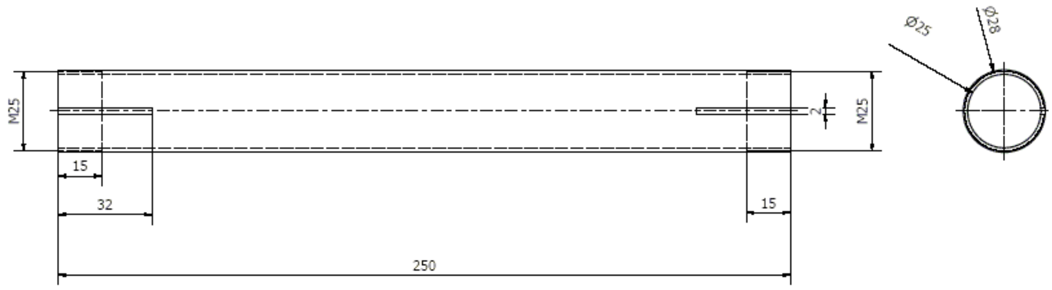


Figure C4. Coating

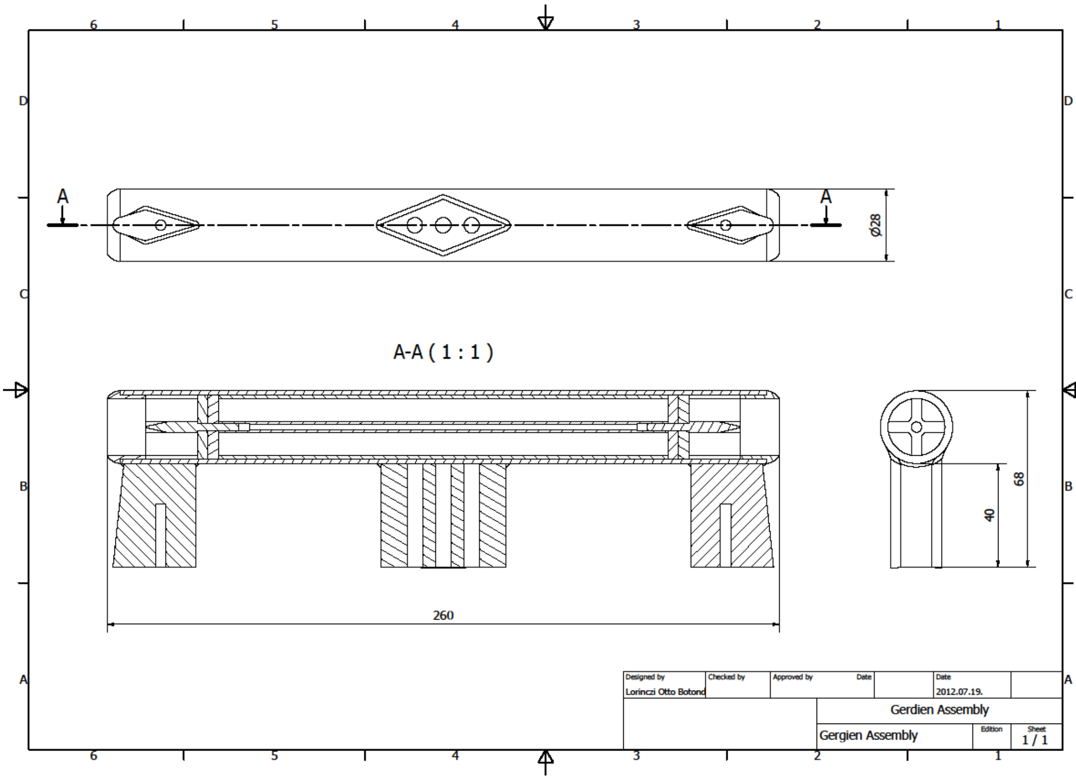


Figure C5. Gerdien Condenser Assembly

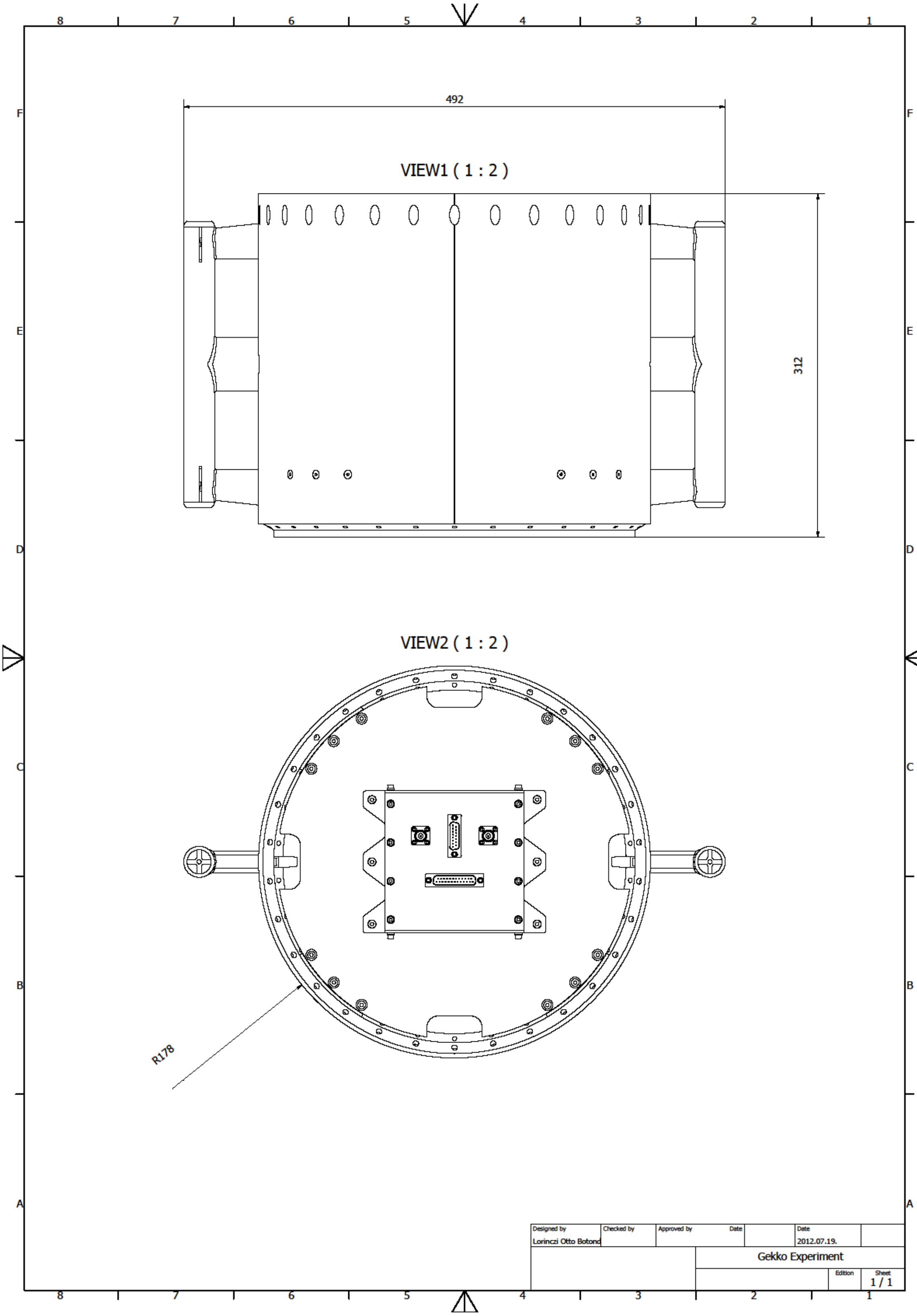


Figure C6. Gekko Experiment

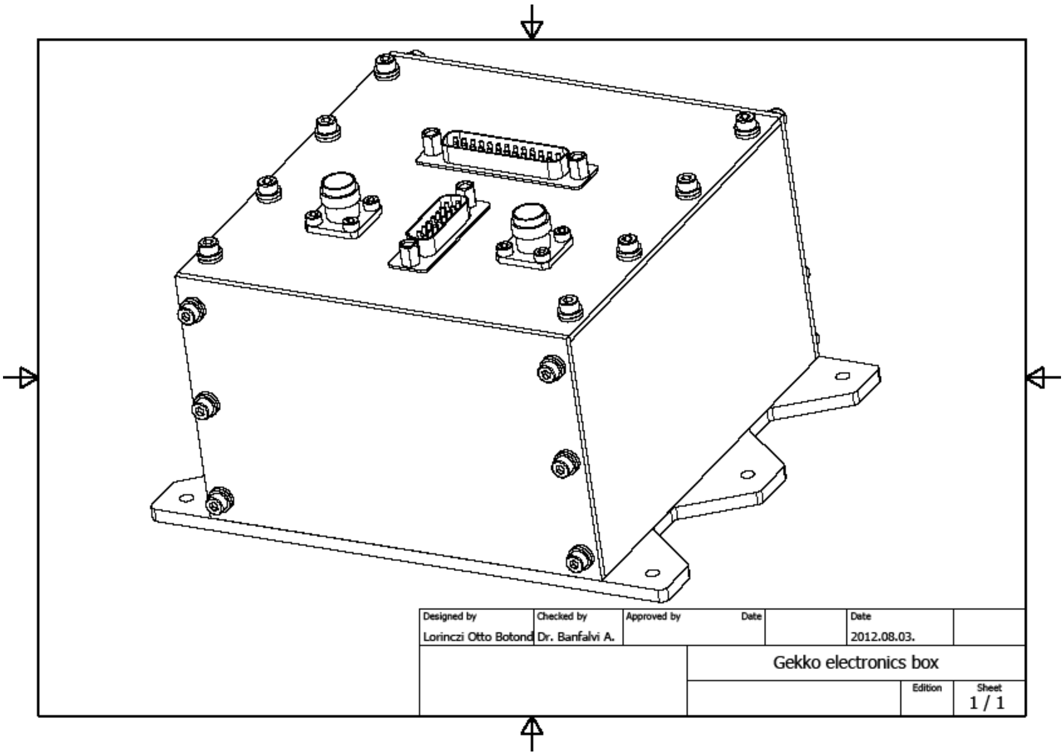


Figure C7. Electronics box assembly

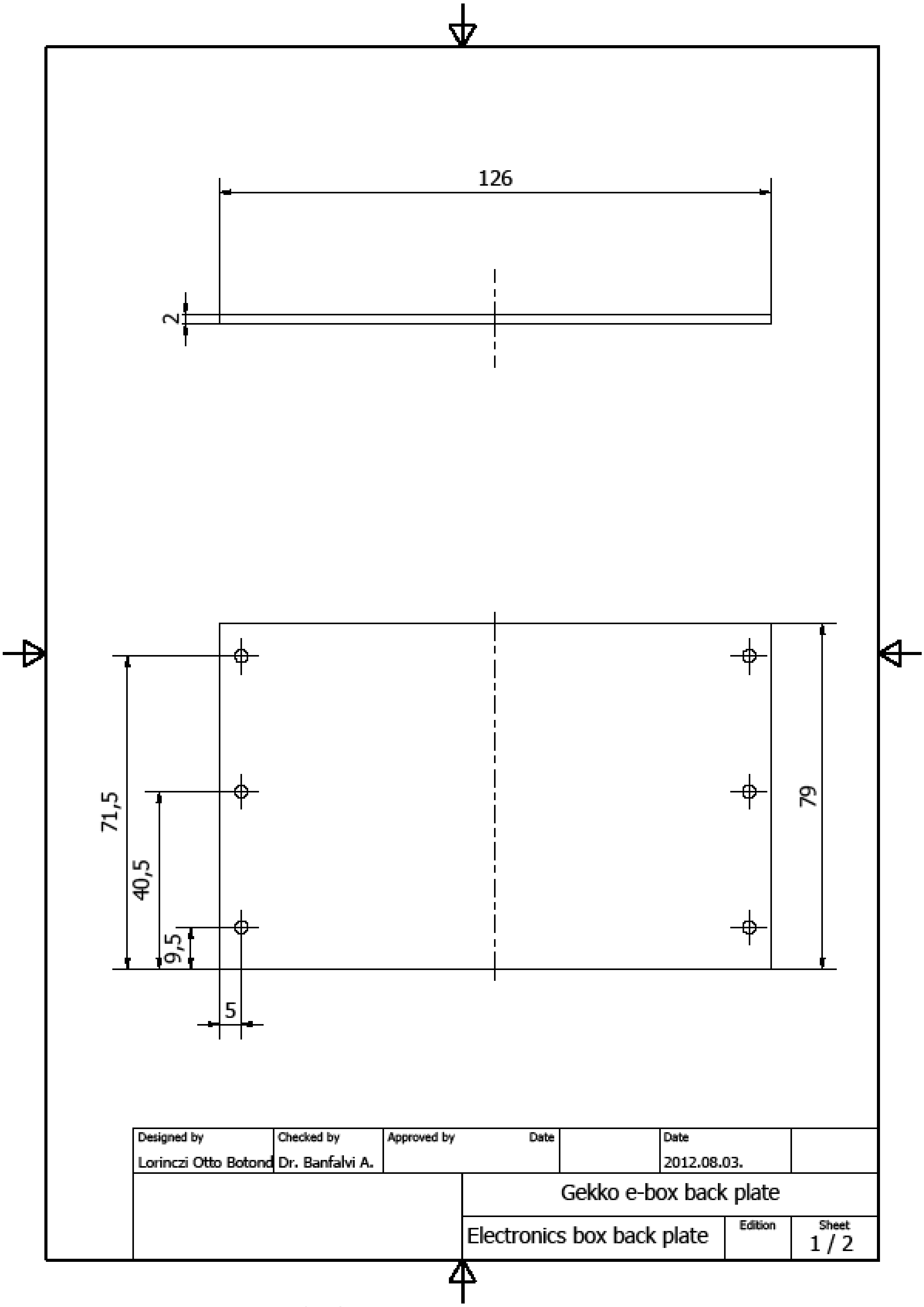


Figure C8. Gekko Electronics box back plate

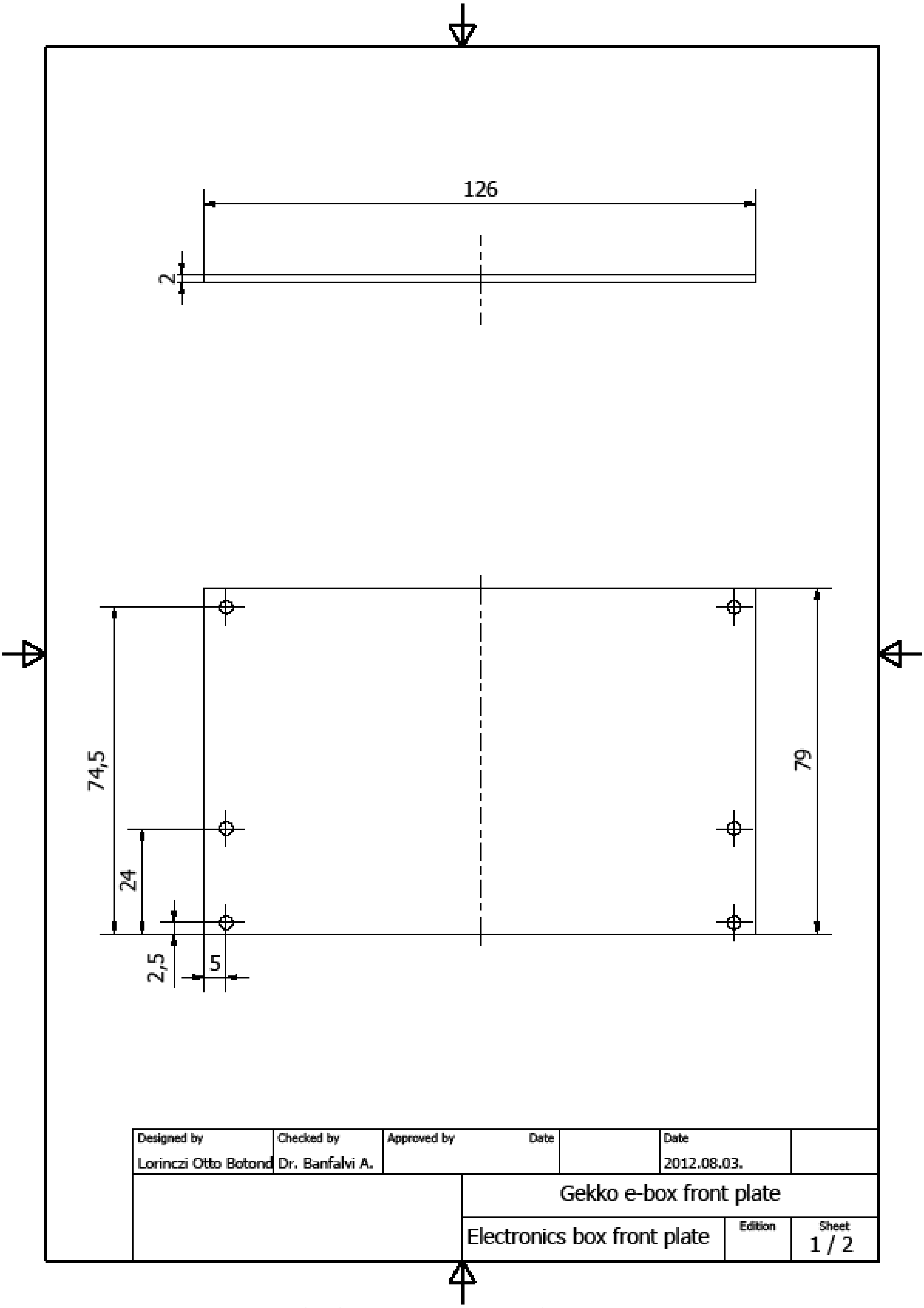


Figure C9. Gekko Electronics box front plate

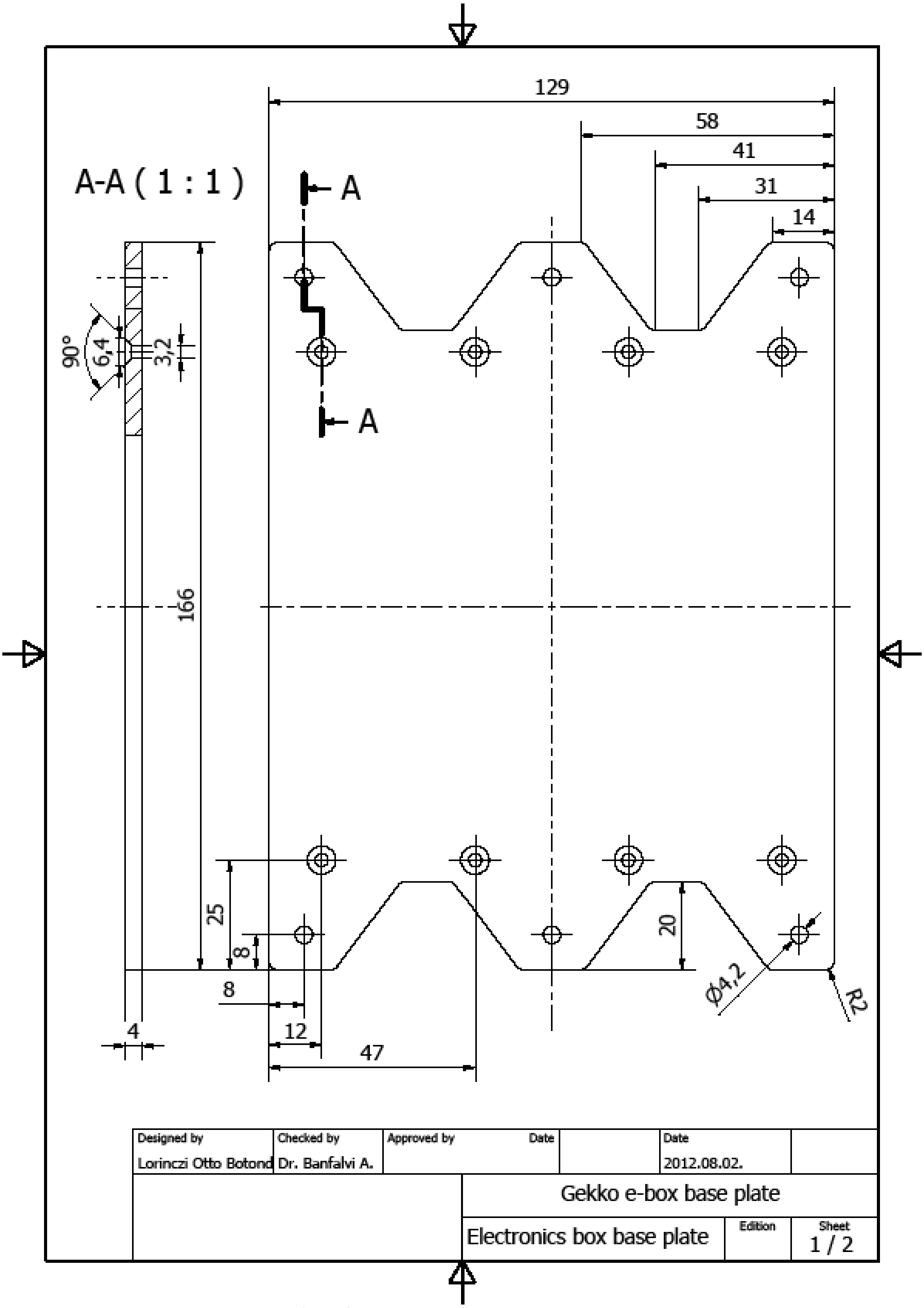
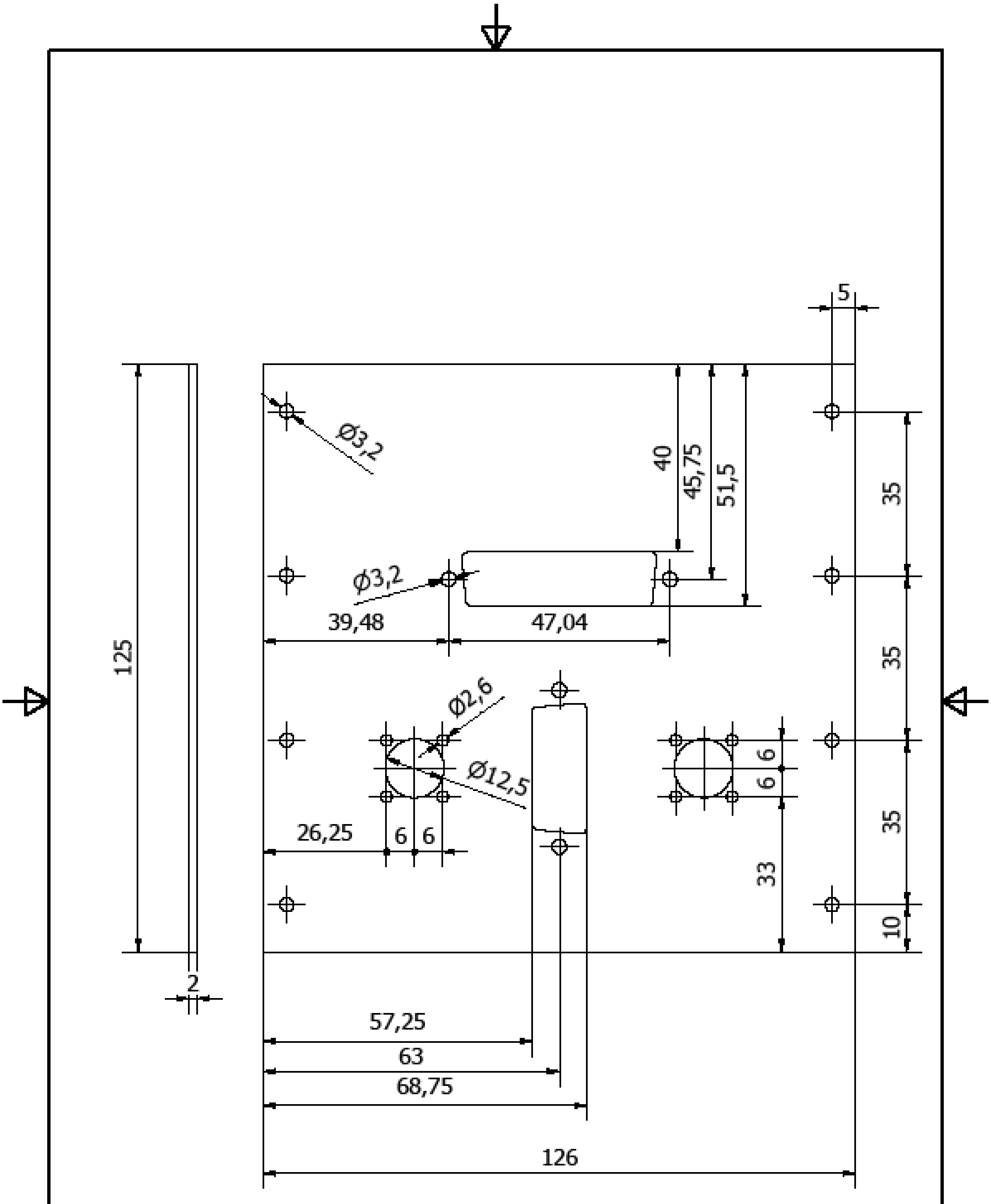
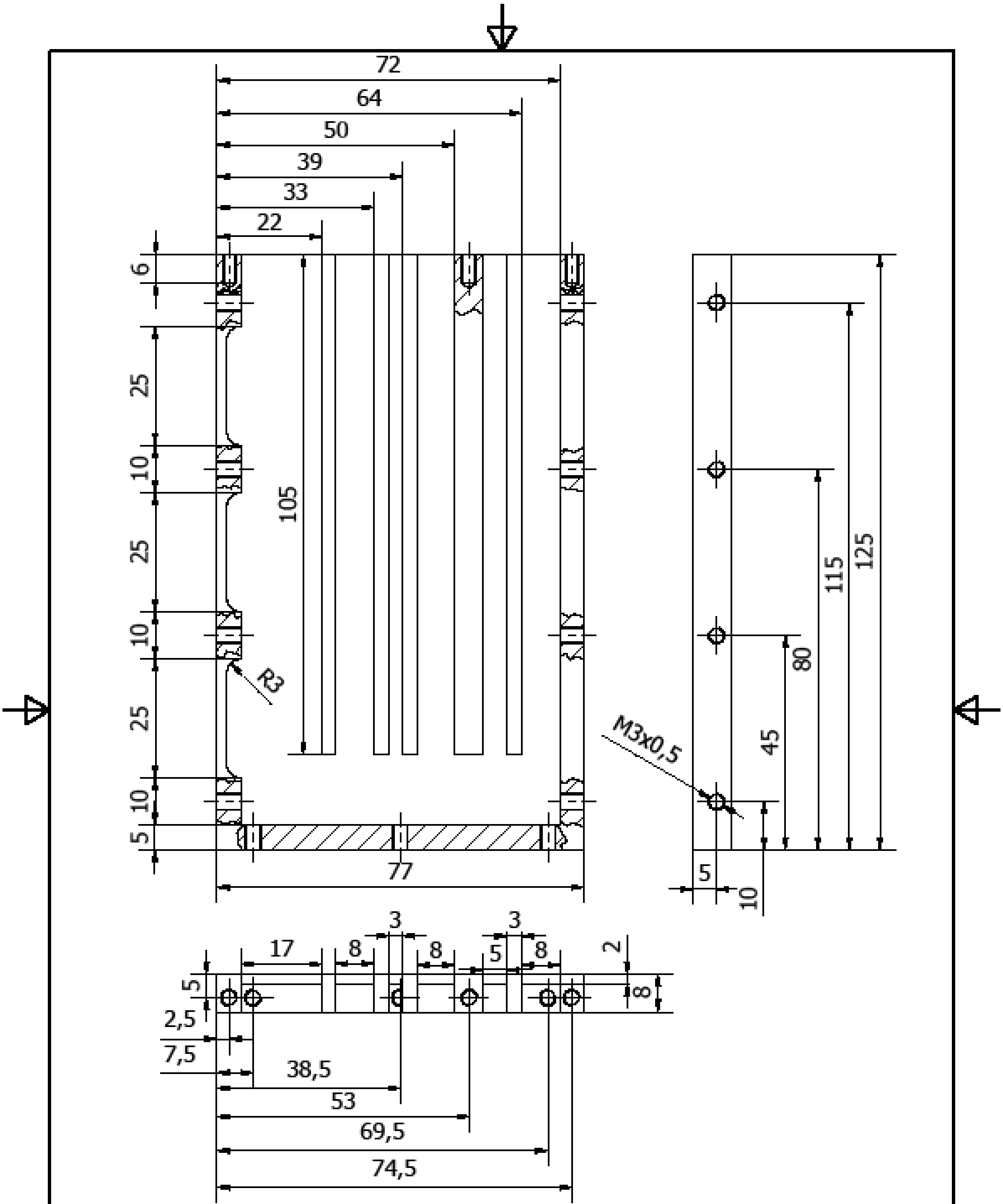


Figure C10. Gekko Elecronics box base plate



Designed by	Checked by	Approved by	Date		Date	
Lorinczi Otto Botond	Dr. Banfalvi A.				2012.08.02.	
	Gekko e-box top plate					
	Electronics box top plate				Edition	Sheet 1 / 2

Figure C11. Gekko Electronics box top plate



Designed by	Checked by	Approved by	Date	Date
Lorinczi Otto Botond	Dr. Banfalvi A.			2012.08.03.
	Gekko e-box PCB holder plate			
	Electronics box PCB h 1	Edition	Sheet 1 / 2	

Figure C12. Gekko Electonics box PCB holder plate - left

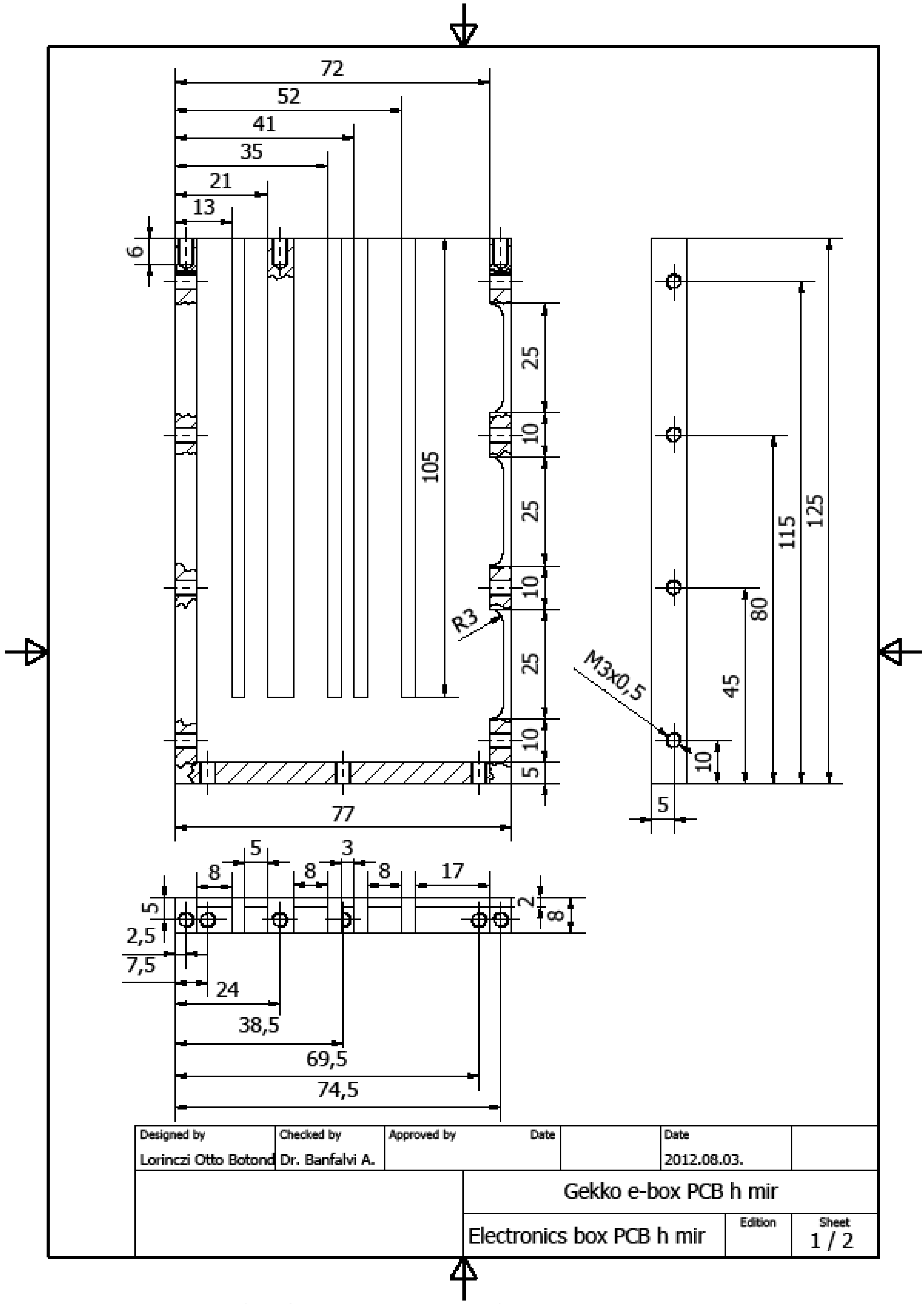
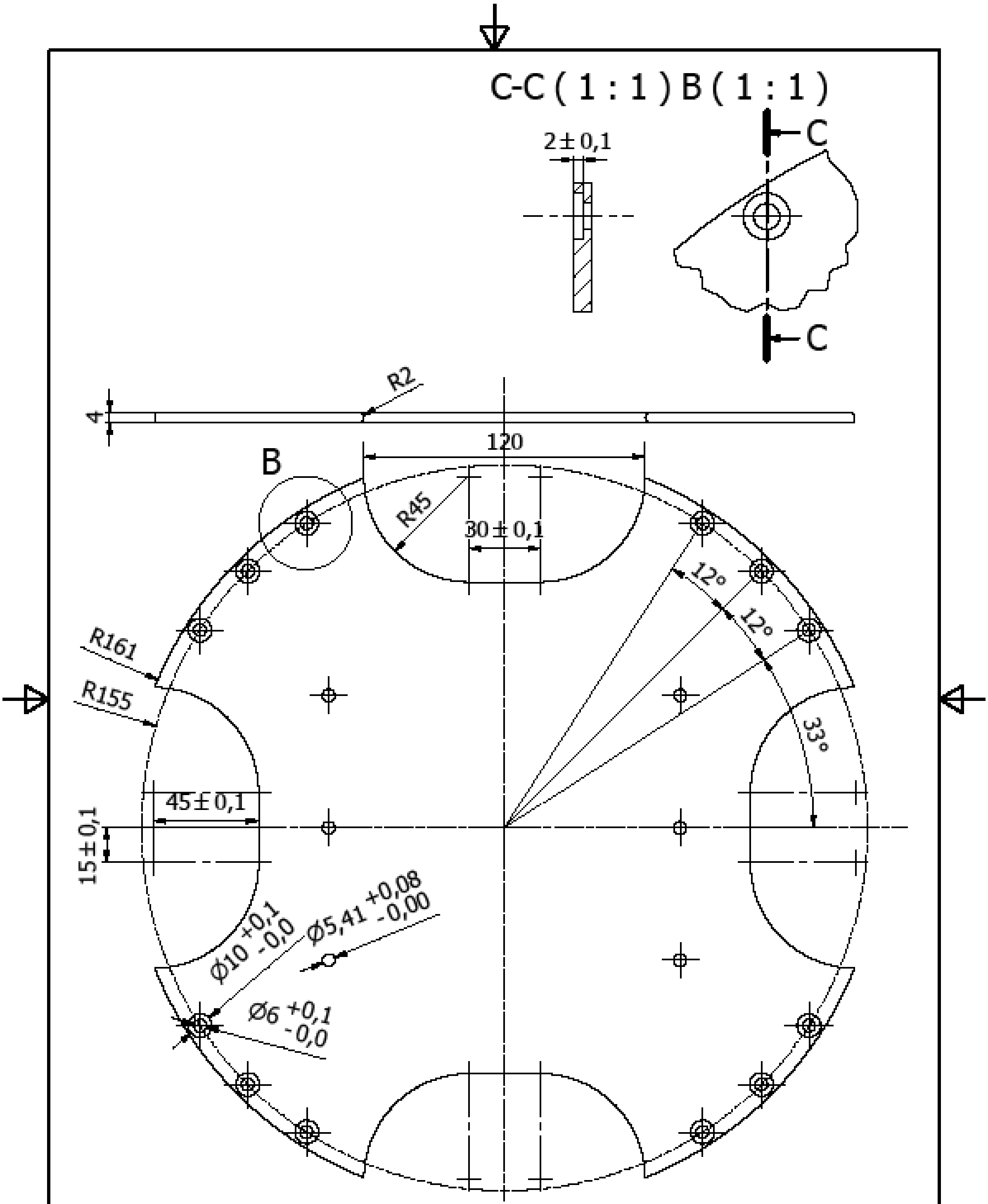


Figure C13. Gekko Electonics box PCB holder plate – right



Designed by	Checked by	Approved by	Date	Date
Lorinczi Otto Botond	Dr. Banfalvi A.			2012.08.03.

	Gekko Bulkhead		
	Bulkhead	Edition	Sheet 1 / 1

Figure C14. Gekko bulkhead manufacturing drawing

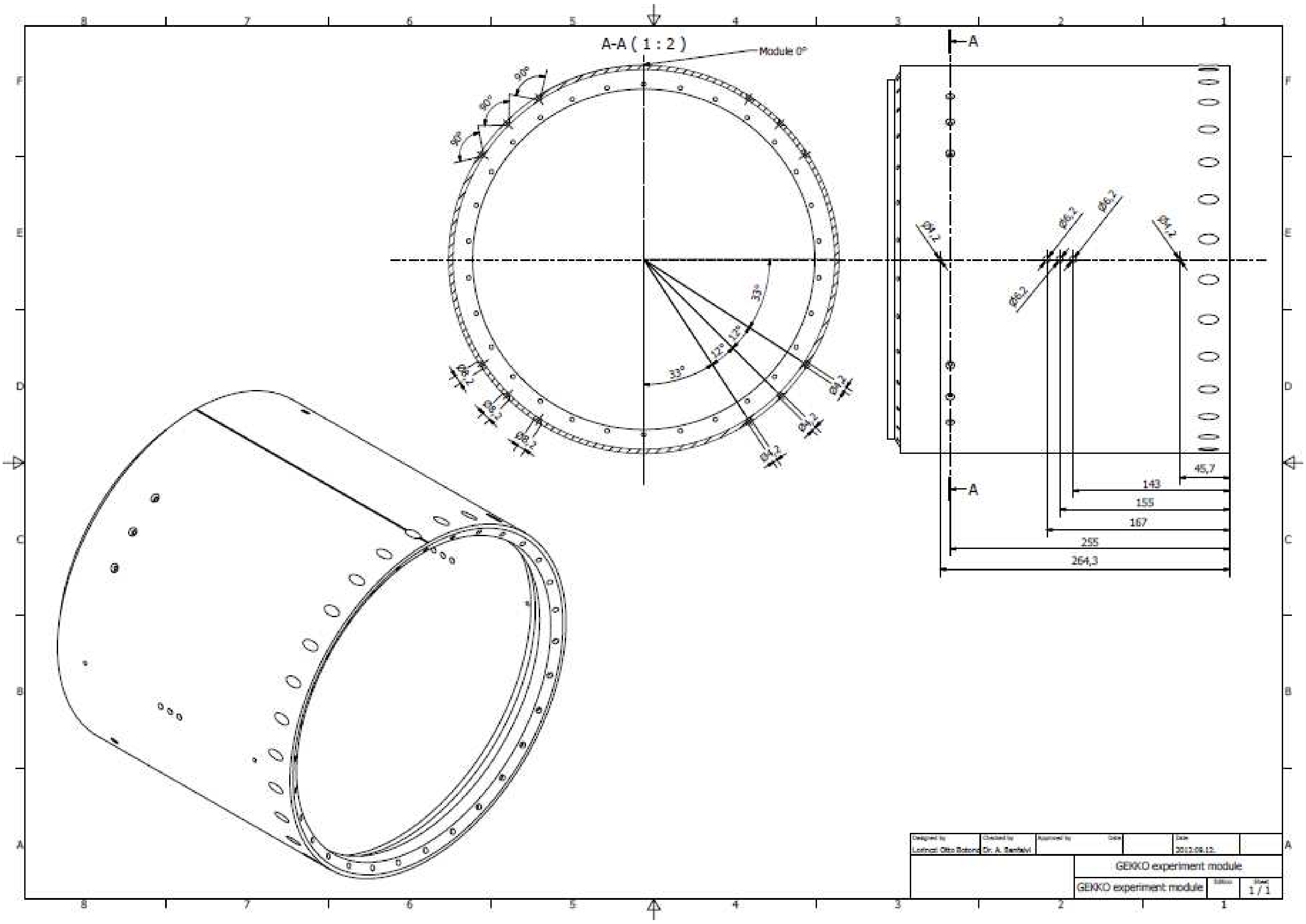


Figure C15. Gekko bulkhead manufacturing drawing

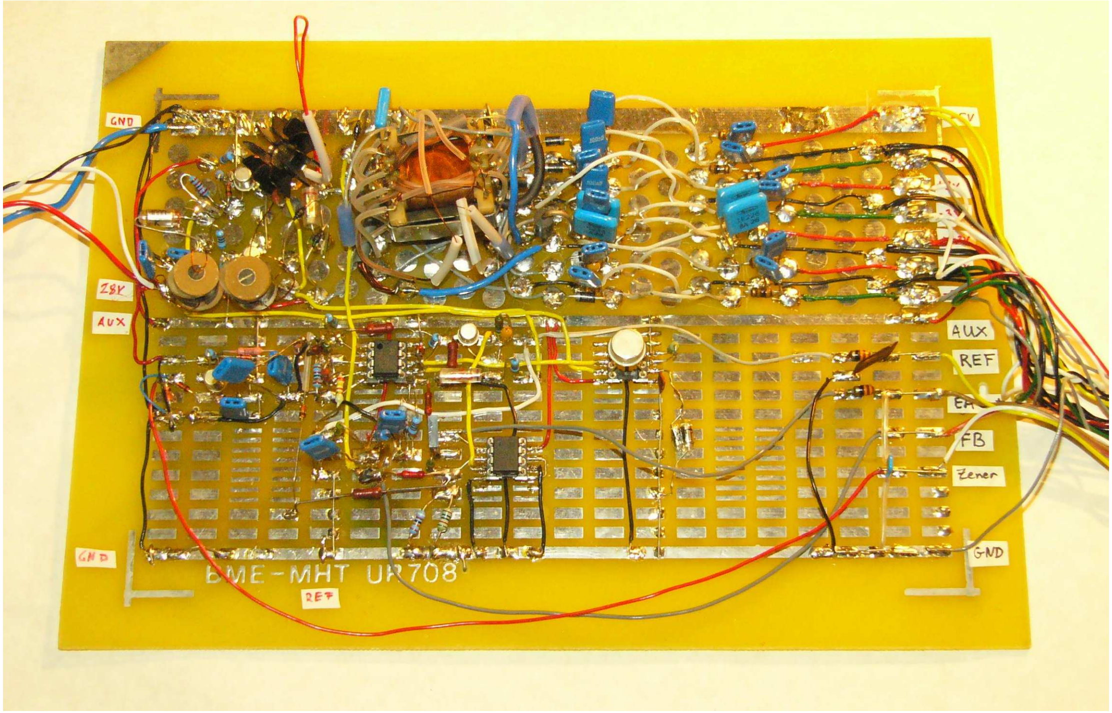


Figure C16. Breadboard model of the PSU

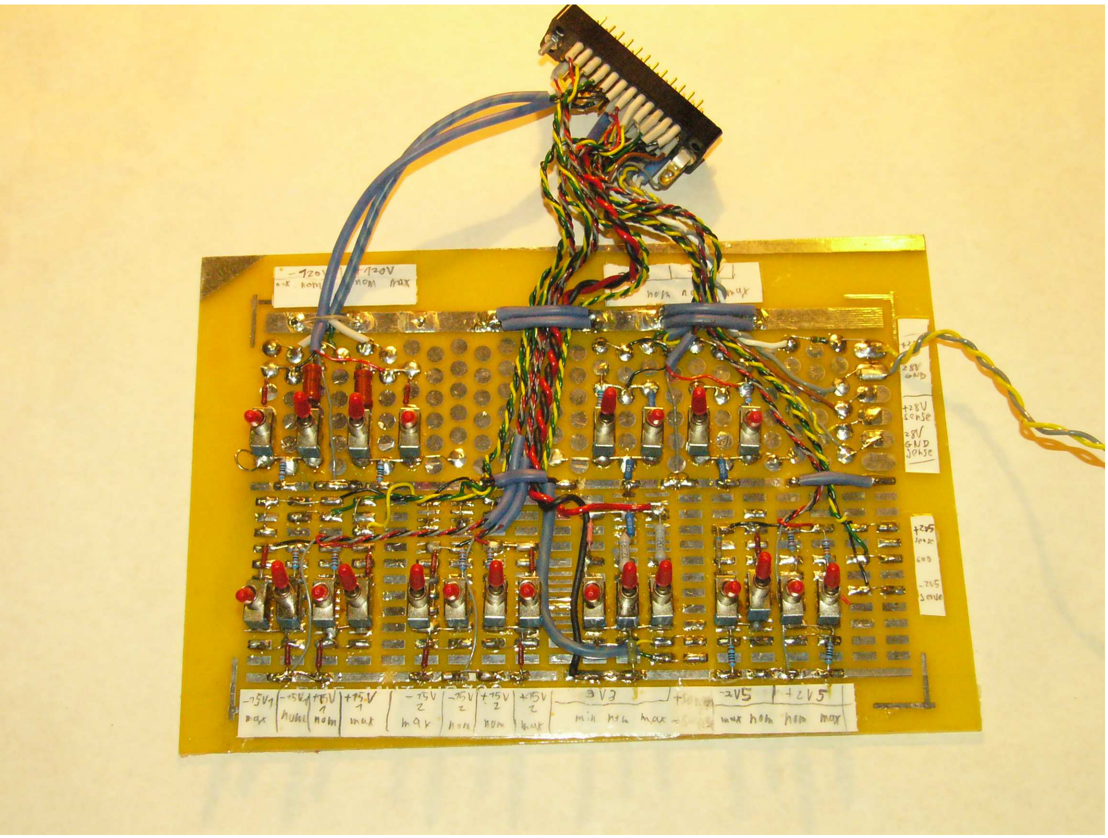


Figure C17. Test setup of the PSU

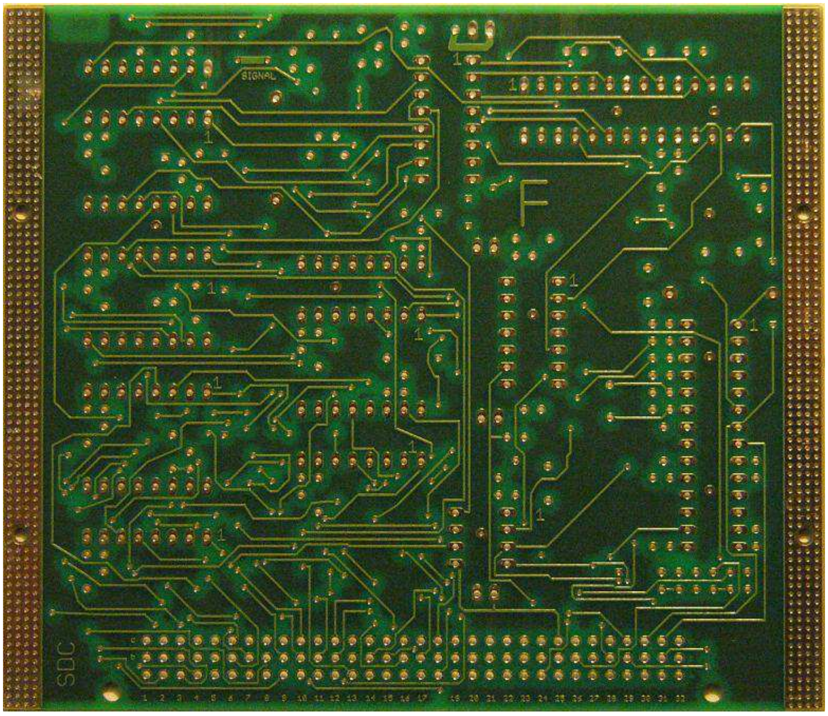


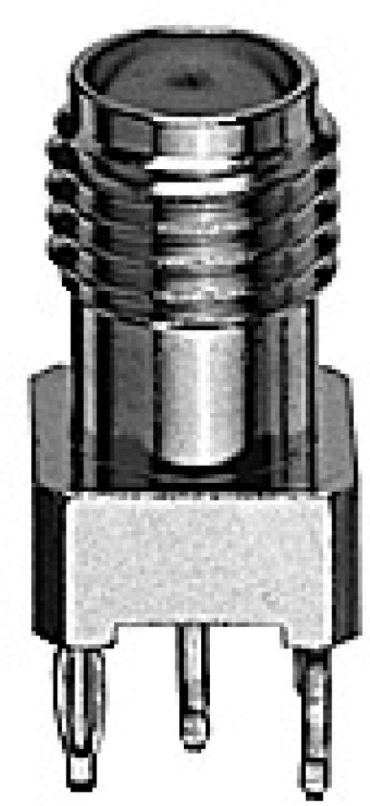
Figure C18. OBDH PCB, flight model

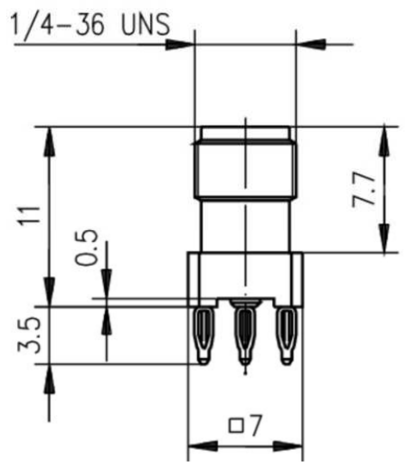
Data sheets of the coaxial/triaxial cable assemblies:

Telegärtner
KARL GÄRTNER GMBH

order number: J01151A0331

SMA Receptacle, female, for Printed Circuits in Press-In Technology





Technical Attributes	
Finish	Gold
Remarks	Further technical information on request
Mount. dim.	Z78

Product description

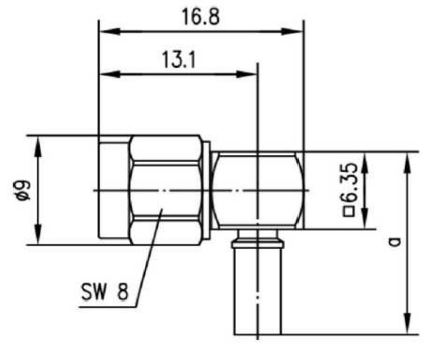
Lerchenstr. 35, D-71144 Steinenbronn, Tel. +49 (0) 7157 125 100, Fax +49 (0) 7157 125 120, E-Mail: info@telegaertner.com

EUROLAUNCH
A DLR and SSC cooperation

Telegärtner
KARL GÄRTNER GMBH

order number: J01150A0061

SMA Angle Plug Crimp G7 (RG-316/U)



Technical Attributes	
Cable group; cable	G7 (RG-316/U)
Finish	Gold
Remarks	>29 dB/1 GHz; >24.5 dB/2 GHz; >21 dB/4 GHz
Dimensions	a=14.9
Assembly	C0403
Crimp die	N01003A0009

Product description

The SMA series is a very popular coax connector with threaded coupling, and can be used up to frequencies of over 18 GHz (depending on type). The impedance is controlled at 50 Ω. Connector styles are available for flexible, conformable and semi-rigid cable types. Versions of the SMA connector are available for mounting to printed circuit boards using both through-hole soldered and through-hole press-fit techniques, as well as surface mount types (SMD). Solder, crimp and clamp techniques are used to terminate this series to cables. SMA applications include communications, satellite and test equipment.

Lerchenstr. 35, D-71144 Steinenbronn, Tel. +49 (0) 7157 125 100, Fax +49 (0) 7157 125 120, E-Mail: info@telegaertner.com

Habia Cable

RG 316/U

50 Ohm Coaxial Cable

Construction:

Alternatives:

Acc. to M17/138-00001
PFA jacket
Specified SRL limits

Acc. to M17/113-RG 316
FEP jacket (Transparent)
Specified SRL limits

Speedflex 316
Low Smoke Zero Halogen

Alternative jacket colours
also available

Construction: Ø (mm)

Conductor..........Silver plated copper covered steel (7x0,17) 0,51
Dielectric..........Solid PTFE 1,52
Braid..........Silver plated copper (0,10) 2,05
Jacket..........FEP, White 2,50

Weight..........15 kg/km

Technical Data / Attenuation & Power:

Impedance..........50 ± 2 Ohms
Capacitance..........94 pF/m
Velocity of signal propagation..........70%
Signal delay..........4.7 ns/m
Working voltage, AC r.m.s..........1000 max
Working voltage, DC..........2000 max
Attenuation, typical values..........see table
(Nominal values at an ambient air temperature of +20°C)
Power, typical values..........see table
(Ambient temperature of +20°C at sea level and VSWR 1.0)
Suitable for frequencies..........up to 2,5 GHz
Minimum bend radius (MBR)..........single bend: 15mm
Minimum bend radius (MBR)..........multiple bends: 30mm
Operating temperature..........-55 / +200
Flame resistance..........passes IEC 60332-3 Cat A
Flammability..........passes UL 94 V-0
Connectors..........compatible with all standard types

Frequency (MHz)	Attenuation (dB/100m)
100	26,7
200	37,9
300	46,6
400	54,0
500	60,5
600	66,4
700	71,8
800	76,9
900	81,7
1000	86,3
1100	90,6
1200	94,8
1300	98,8
1400	102,7
1500	106,4
1600	110,0
1700	113,6
1800	117,0
1900	120,3
2000	123,6
2100	126,8
2200	129,9
2300	132,9
2400	135,9
2500	138,9

Frequency (MHz)	Power (W)
100	340
200	240
300	196
400	170
500	152
600	139
700	129
800	120
900	113
1000	108
1100	103
1200	98
1300	94
1400	91
1500	88
1600	85
1700	82
1800	80
1900	78
2000	76
2100	74
2200	72
2300	71
2400	69
2500	68

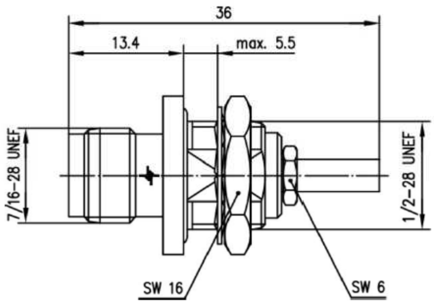
Data provided indicates nominal values unless stated otherwise and is only valid for reference purposes at the time of publication and is subject to change without prior notice.
These products are manufactured generally in accordance with the Mil Spec in terms of design parameters and performance.
Habia are not qualified to release product to the appropriate QPL.

www.habia.com World Class Solutions

Ref: CC-eRG316-01
Date: 2005-02-24

order number: J01011A0058

TNC Bulkhead Jack Crimp G7 (RG-316/U) solder/crimp with seal ring + barrier sealing



Technical Attributes	
Z	50 Ω
Cable group; cable	G7 (RG-316/U)
Remarks	solder/crimp with panel and barrier sealing
Mount. dim.	Z04
Crimp die	N01003A0009
Assembly	A4016

Product description

The TNC series is a commonly used coax connector. The same size as BNC connectors, but with a threaded coupling mechanism, this connector can be used up to 11 GHz. Both 50 Ω and 75 Ω impedances are available. Connector styles are available for flexible, conformable and semi-rigid cable types. Versions of the TNC connector are available for mounting to printed circuit boards using both through-hole soldered and through-hole press-fit techniques. Both crimp and clamp cable termination processes are used for this series. Applications for these connectors range from signal and data to video transmission where vibration resistance is required. TNC's are a low-cost high-frequency solution for coax connections.

Mating face sealing for TNC connectors between plug and jack (mated) according to IP 68. The classifications are general statements for the relevant series. Individual connectors may deviate from the values shown. If in doubt, please consult our engineers.

Note

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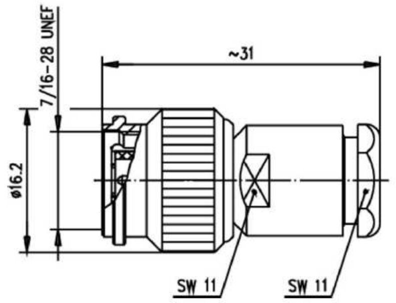
1 / 1

order number: J01010A2608

TNC Straight Plug G1 (RG-58C/U); G5 (RG-223/U); RG-141A/U; RG-142B/U
MIL-clamp IP 67



Technical Attributes	
Z	50 Ω
Cable group; cable	G1 (RG-58C/U); G5 (RG-223/U); RG-141A/U; RG-142B/U; 1.0/2.95 AF
Remarks	MIL-clamp IP 67
Assembly	A02

Product description

The TNC series is a commonly used coax connector. The same size as BNC connectors, but with a threaded coupling mechanism, this connector can be used up to 11 GHz. Both 50 Ω and 75 Ω impedances are available. Connector styles are available for flexible, conformable and semi-rigid cable types. Versions of the TNC connector are available for mounting to printed circuit boards using both through-hole soldered and through-hole press-fit techniques. Both crimp and clamp cable termination processes are used for this series. Applications for these connectors range from signal and data to video transmission where vibration resistance is required. TNC's are a low-cost high-frequency solution for coax connections.

Mating face sealing for TNC connectors between plug and jack (mated) according to IP 68. The classifications are general statements for the relevant series. Individual connectors may deviate from the values shown. If in doubt, please consult our engineers.

Note

Combination connectors and cable clamps can be utilised to create a further number of TNC connector variations.

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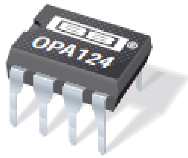
Precision amplifier

BURR - BROWN®



OPA124

Low Noise Precision *Difet*® OPERATIONAL AMPLIFIER

FEATURES

- LOW NOISE: 6nV/√Hz (10kHz)
- LOW BIAS CURRENT: 1pA max
- LOW OFFSET: 250µV max
- LOW DRIFT: 2µV/°C max
- HIGH OPEN-LOOP GAIN: 120dB min
- HIGH COMMON-MODE REJECTION: 100dB min
- AVAILABLE IN 8-PIN PLASTIC DIP AND 8-PIN SOIC PACKAGES

APPLICATIONS

- PRECISION PHOTODIODE PREAMP
- MEDICAL EQUIPMENT
- OPTOELECTRONICS
- DATA ACQUISITION
- TEST EQUIPMENT

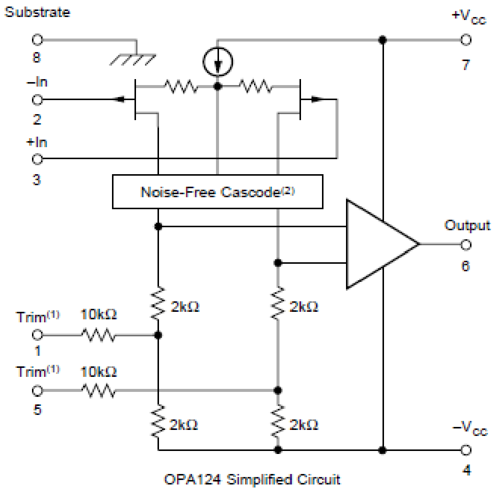
DESCRIPTION

The OPA124 is a precision monolithic FET operational amplifier using a ***Difet*** (dielectrical isolation) manufacturing process. Outstanding DC and AC performance characteristics allow its use in the most critical instrumentation applications.

Bias current, noise, voltage offset, drift, open-loop gain, common-mode rejection and power supply rejection are superior to BIFET and CMOS amplifiers. ***Difet*** fabrication achieves extremely low input bias currents without compromising input voltage noise performance. Low input bias current is maintained over a wide input common-mode voltage range with unique cascode circuitry. This cascode design also allows high precision input specifications and reduced susceptibility to flicker noise. Laser trimming of thin-film resistors gives very low offset and drift.

Compared to the popular OPA111, the OPA124 gives comparable performance and is available in an 8-pin PDIP and 8-pin SOIC package.

BIFET® National Semiconductor Corp.,
Difet® Burr-Brown Corp.



OPA124 Simplified Circuit

NOTES: (1) Omitted on SOIC. (2) Patented.

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Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

SPECIFICATIONS

ELECTRICAL

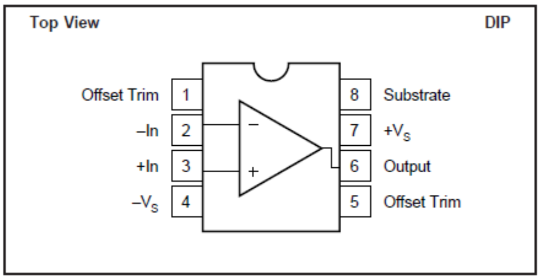
At V_{CC} = ±15VDC and T_A = +25°C, unless otherwise noted.

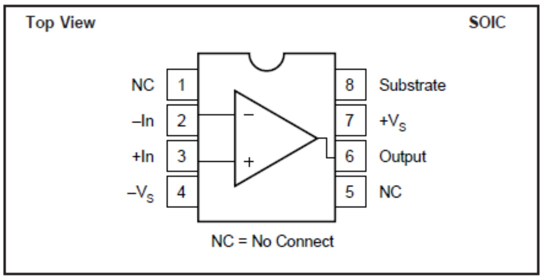
PARAMETER	CONDITION	OPA124U, P MIN	OPA124U, P TYP	OPA124U, P MAX	OPA124UA, PA MIN	OPA124UA, PA TYP	OPA124UA, PA MAX	OPA124PB MIN	OPA124PB TYP	OPA124PB MAX	UNITS
INPUT NOISE											
Voltage, f_O = 10Hz(4)			40	80		*	*		*	*	nV/√Hz
f_O = 100Hz(4)			15	40		*	*		*	*	nV/√Hz
f_O = 1kHz(4)			8	15		*	*		*	*	nV/√Hz
f_O = 10kHz(5)			6	8		*	*		*	*	nV/√Hz
f_B = 10Hz to 10kHz(5)			0.7	1.2		*	*		*	*	µVrms
f_B = 0.1Hz to 10Hz			1.6	3.3		*	*		*	*	µVp-p
Current, f_B = 0.1Hz to 10Hz			9.5	15		*	*		*	*	fAp-p
f_O = 0.1Hz thru 20kHz			0.5	0.8		*	*		*	*	fA/√Hz
OFFSET VOLTAGE(1)											
Input Offset Voltage	V_{CM} = 0VDC		±200	±800		±150	±500		±100	±250	µV
vs Temperature	T_A = T_{MIN} to T_{MAX}		±4	±7.5		±2	±4		±1	±2	µV/°C
Supply Rejection	V_{CC} = ±10V to ±18V	88	110		90	*		100	*		dB
vs Temperature	T_A = T_{MIN} to T_{MAX}	84	100		86	*		90	*		dB
BIAS CURRENT(1)											
Input Bias Current	V_{CM} = 0VDC		±1	±5		±0.5	±2		±0.35	±1	pA
OFFSET CURRENT(1)											
Input Offset Current	V_{CM} = 0VDC		±1	±5		±0.5	±1		±0.25	±0.5	pA
IMPEDANCE											
Differential			10^{13} || 1			*			*		Ω || pF
Common-Mode			10^{14} || 3			*			*		Ω || pF
VOLTAGE RANGE											
Common-Mode Input Range		±10	±11		*	*		*	*		V
Common-Mode Rejection	V_{IN} = ±10VDC	92	110		94	*		100	*		dB
vs Temperature	T_A = T_{MIN} to T_{MAX}	86	100		*	*		90	*		dB
OPEN-LOOP GAIN, DC											
Open-Loop Voltage Gain	R_L ≥ 2kΩ	106	125		*	*		120	*		dB
FREQUENCY RESPONSE											
Unity Gain, Small Signal			1.5			*			*		MHz
Full Power Response	20Vp-p, R_L = 2kΩ	16	32		*	*		*	*		kHz
Slew Rate	V_O = ±10V, R_L = 2kΩ	1	1.6		*	*		*	*		V/µs
THD			0.0003			*			*		%
Settling Time, 0.1%	Gain = –1, R_L = 2kΩ		6			*			*		µs
0.01%	10V Step		10			*			*		µs
Overload Recovery, 50% Overdrive(2)	Gain = –1		5			*			*		µs
RATED OUTPUT											
Voltage Output	R_L = 2kΩ	±11	±12		*	*		*	*		V
Current Output	V_O = ±10VDC	±5.5	±10		*	*		*	*		mA
Output Resistance	DC, Open Loop		100			*			*		Ω
Load Capacitance Stability	Gain = +1		1000			*			*		pF
Short Circuit Current		10	40		*	*		*	*		mA
POWER SUPPLY											
Rated Voltage			±15			*			*		VDC
Voltage Range, Derated		±5		±18	*		*	*		*	VDC
Current, Quiescent	I_O = 0mADC		2.5	3.5		*	*		*	*	mA
TEMPERATURE RANGE											
Specification	T_{MIN} and T_{MAX}	–25		+85	*		*	*		*	°C
Storage		–65		+125	*		*	*		*	°C
θ Junction-Ambient: PDIP			90			*			*		°C/W
SOIC			100			*			*		°C/W

* Specification same as OPA124U, P

NOTES: (1) Offset voltage, offset current, and bias current are measured with the units fully warmed up. For performance at other temperatures see Typical Performance Curves. (2) Overload recovery is defined as the time required for the output to return from saturation to linear operation following the removal of a 50% input overdrive. (3) For performance at other temperatures see Typical Performance Curves. (4) Sample tested, 98% confidence. (5) Guaranteed by design.

CONNECTION DIAGRAMS





PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER[1]	TEMPERATURE RANGE	BIAS CURRENT pA, max	OFFSET DRIFT µV/°C, max
OPA124U	8-Lead SOIC	182	–25°C to +85°C	5	7.5
OPA124P	8-Pin Plastic DIP	006	–25°C to +85°C	5	7.5
OPA124UA	8-Lead SOIC	182	–25°C to +85°C	2	4
OPA124PA	8-Pin Plastic DIP	006	–25°C to +85°C	2	4
OPA124PB	8-Pin Plastic DIP	006	–25°C to +85°C	1	2

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

ABSOLUTE MAXIMUM RATINGS[1]

Supply	±18VDC
Internal Power Dissipation[2]	750mW
Differential Input Voltage[3]	±36VDC
Input Voltage Range[3]	±18VDC
Storage Temperature Range	–65°C to +150°C
Operating Temperature Range	–40°C to +125°C
Lead Temperature (soldering, 10s)	+300°C
Output Short Circuit Duration[4]	Continuous
Junction Temperature	+175°C

NOTES: (1) Stresses above these ratings may cause permanent damage. (2) Packages must be derated based on θ_{JA} = 90°C/W for PDIP and 100°C/W for SOIC. (3) For supply voltages less than ±18VDC, the absolute maximum input voltage is equal to +18V > V_{IN} > $-V_{CC}$ – 6V. See Figure 2. (4) Short circuit may be to power supply common only. Rating applies to +25°C ambient. Observe dissipation limit and T_J.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PRODUCT DATA SHEET

>> POLYBENZIMIDAZOLE (PBI)

Duratron® CU60 PBI

QUADRANT
ENGINEERING PLASTIC PRODUCTS

Duratron CU60 PBI offers the highest temperature resistance and best mechanical property retention over 200 °C of all unfilled thermoplastics. Duratron CU60 PBI is very "clean" in terms of ionic impurity and does not outgas (except water). These characteristics make this material extremely attractive to high-tech industries such as semiconductor and aerospace industries. Usually Duratron CU60 PBI is used in critical components to decrease maintenance costs and to gain valuable production "uptime". It is used to replace metals and ceramics in pump components, valve seats (high tech valves), bearings, rollers, high temperature insulators.

Physical properties (indicative values *)

PROPERTIES	Test methods	Units	VALUES
Colour	-	-	black
Density	ISO 1183-1	g/cm³	1.30
Water absorption:			
- after 24/96 h immersion in water of 23 °C (1)	ISO 62	mg	60 / 112
	ISO 62	%	0.74 / 1.37
- at saturation in air of 23 °C / 50 % RH	-	%	7.5
- at saturation in water of 23 °C	-	%	14
Thermal Properties (2)			
Melting temperature (DSC, 10 °C/min)	ISO 11357-1/-3	°C	NA
Glass transition temperature (DSC, 20 °C/min) - (3)	ISO 11357-1/-2	°C	415
Thermal conductivity at 23 °C	-	W/(K.m)	0.40
Coefficient of linear thermal expansion:			
- average value between 23 and 100 °C	-	m/(m.K)	25×10^{6}
- average value between 23 and 150 °C	-	m/(m.K)	25×10^{6}
- average value above 150 °C	-	m/(m.K)	35×10^{6}
Temperature of deflection under load:			
- method A: 1.8 MPa	ISO 75-1/-2	°C	425
Max. allowable service temperature in air:			
- for short periods (4)	-	°C	500
- continuously : for min. 20,000 h (5)	-	°C	310
Min. service temperature (6)	-	°C	-50
Flammability (7):			
- "Oxygen index"	ISO 4589-1/-2	%	58
- according to UL 94 (1.5 / 3 mm thickness)	-	-	V-0 / V-0
Mechanical Properties at 23 °C (8)			
Tension test (9):			
- tensile stress at yield / tensile stress at break (10)	ISO 527-1/-2	MPa	NYP / 130
- tensile strength (10)	ISO 527-1/-2	MPa	130
- tensile strain at yield (10)	ISO 527-1/-2	%	NYP
- tensile strain at break (10)	ISO 527-1/-2	%	3
- tensile modulus of elasticity (11)	ISO 527-1/-2	MPa	6000
Compression test (12):			
- compressive stress at 1 / 2 / 5 % nominal strain (11)	ISO 604	MPa	58 / 118 / 280
Charpy impact strength - unnotched (13)	ISO 179-1/1eU	kJ/m²	20
Charpy impact strength - notched	ISO 179-1/1eA	kJ/m²	2.5
Ball indentation hardness (14)	ISO 2039-1	N/mm²	375
Rockwell hardness (14)	ISO 2039-2	-	E 120
Electrical Properties at 23 °C			
Electric strength (15)	IEC 60243-1	kV/mm	28
Volume resistivity	IEC 60093	Ohm.cm	$> 10^{14}$
Surface resistivity	ANSI/ESD STM 11.11	Ohm/sq.	$> 10^{13}$
Relative permittivity ε_r : - at 100 Hz	IEC 60250	-	3.3
- at 1 MHz	IEC 60250	-	3.2
Dielectric dissipation factor tan δ : - at 100 Hz	IEC 60250	-	0.001
- at 1 MHz	IEC 60250	-	-
Comparative tracking index (CTI)	IEC 60112	-	-

Note: 1 g/cm³ = 1,000 kg/m³ ; 1 MPa = 1 N/mm² ; 1 kV/mm = 1 MV/m.

NA: not applicable

NYP: there is no yield point

Legend:

(1) According to method 1 of ISO 62 and done on discs Ø 50 mm x 3 mm.

(2) The figures given for these properties are for the most part derived from raw material supplier data and other publications.

(3) Values for this property are only given here for amorphous materials and for materials that do not show a melting temperature (PBI & PI).

(4) Only for short time exposure (a few hours) in applications where no or only a very low load is applied to the material.

(5) Temperature resistance over a period of min. 20,000 hours. After this period of time, there is a decrease in tensile strength – measured at 23 °C – of about 50 % as compared with the original value.
The temperature value given here is thus based on the thermal-oxidative degradation which takes place and causes a reduction in properties. Note, however, that the maximum allowable service temperature depends in many cases essentially on the duration and the magnitude of the mechanical stresses to which the material is subjected.

(6) Impact strength decreasing with decreasing temperature, the minimum allowable service temperature is practically mainly determined by the extent to which the material is subjected to impact. The value given here is based on unfavourable impact conditions and may consequently not be considered as being the absolute practical limit.

(7) These estimated ratings, derived from raw material supplier data and other publications, are not intended to reflect hazards presented by the material under actual fire conditions. There is no 'UL File Number' available for Duratron CU60 PBI stock shapes.

(8) Most of the figures given for the mechanical properties are average values of tests run on dry test specimens machined out of 16 mm thick compression moulded plate.

(9) Test specimens: Type 1 B

(10) Test speed: 5 mm/min [chosen acc. to ISO 10350-1 as a function of the ductile behaviour of the material (tough or brittle)]

(11) Test speed: 1 mm/min.

(12) Test specimens: cylinders Ø 8 mm x 16 mm

(13) Pendulum used: 4 J.

(14) Measured on 10 mm thick test specimens.

(15) Electrode configuration: Ø 25 / Ø 75 mm coaxial cylinders ; in transformer oil according to IEC 60296 ; 1 mm thick test specimens.

* This table, mainly to be used for comparison purposes, is a valuable help in the choice of a material. The data listed here fall within the normal range of product properties of dry material. However, they are not guaranteed and they should not be used to establish material specification limits nor used alone as the basis of design.

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