Phase C

EPS subsystem:

Electrical qualification tests

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RECORD OF REVISIONS

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1/0	December, the 17th 2007		Nicolas Steiner

DIPLOMA PROJECT OBJECTIVE

Distribution de l'énergie du picosatellite SwissCube

Proposé par : Space Center – EPFL

Résumé du problème :

Relation : diplôme 2006 : Gestion de l'énergie du picosatellite SwissCube

Le Space Center de l'EPFL (www.swisscube.epfl.ch) propose de collaborer à une grande aventure en participant à la conception d'un satellite de 1dm^3 / 1kg / 1W. Ce satellite est entièrement construit par des étudiants de l'EPFL et de la HES-SO. Le challenge est immense, d'autres écoles ont tenté l'expérience et ont réussi.

En 2006 un premier travail de diplôme a permis de réaliser l'électronique de gestion des panneaux solaires, des batteries et l'asservissement en tension du bus d'alimentation principal du satellite.

Il s'agit maintenant de réaliser la distribution de l'énergie vers les différentes unités du satellite. Cette distribution va dépendre d'une stratégie à définir entre les différents intervenants. Le coeur du système de distribution est un microcontrôleur connecté à un bus I2C. Une difficulté importante est le choix des composants en raison du niveau de radiation existant sur l'orbite choisie, de la plage de température de fonctionnement, des effets du vide (dégazage de certains composants, absence de convection, …) et du niveau de vibration.

Cahier des charges :

Objectif du travail de diplôme

Ce travail de diplôme consiste à développer les cartes électroniques contenant le système de gestion et de distribution de l'énergie, un système retardé d'enclenchement de la distribution des alimentations sur les cartes électroniques, un système d'acquisition et de surveillance des courants et des températures de chaque face sur lesquelles des cellules photovoltaïques sont fixées ainsi que de la température du PCB. Le design de l'électronique doit être compatible avec les contraintes d'environnement. Il doit être validé par des tests sous vide, en température, et des tests de vibration. L'ensemble de ces tests est défini par les responsables systèmes du Space Center.

Travail de semestre

Les délivrables du travail de semestre sont :

- un PCB non-monté de la carte EPS (Electrical Power System) dont le design a été réalisé par le candidat,
- une carte contenant un premier prototype fonctionnel de la gestion de l'énergie entre cellules photovoltaïques et batteries.

Cahier des charges pour le travail de diplôme

Les points suivants doivent être traités durant le travail de diplôme :

- montage et validation fonctionnelle de la carte EPS,
- test thermique sous vide partiel sur la plage d'utilisation, et vérification des performances.
- test vibration selon gabarit imposé par le Space Center,
- montage et validation de la carte de gestion de l'énergie,
- test des performances sous vide partiel sur la plage de température de fonctionnement,
- participation au meeting du Space Center, présentation du projet à la CDR (Critical Design Review)

Délivrables

- une carte EPS validée (EQM),
- une carte de gestion de l'énergie validée (EQM),
- un rapport conforme aux exigences fixées par le Space Center de l'EPFL.

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1 SUMMARY

The SwissCube project is an entire satellite design (1dm^3/1kg/1W) by universities and HES-SO students. This project is directed by the Space Center of the Swiss Federal Institute of Technology which is located at the EPFL in Lausanne.

The two main objectives of the SwissCube project are:

- A didactic and a pedagogic project which gives the opportunity to students to discover and work in a space environment.
- The SwissCube payload mission is to take pictures of the NightGlow phenomenon.

The diploma project objective is to mount and test the two EPS subsystem electronic boards under space conditions (partial vacuum, from -40ºC up to 60 ºC). The EPS subsystem (Electrical Power System) is in charged of the power management of the satellite by using solar cells, batteries, DC/DC converters and a µController. The EPS subsystem is also in charge of taking measures on board, such as voltage, current and temperature. By the end of the diploma project, two EPS boards have to be delivered to the Space Center of the EPFL for the first electrical integration tests.

The first board witch is in charge of the bus voltage regulation has been designed by Fabien Jordan during his diploma project. The second board which is in charge of the power management of the satellite has been designed by Nicolas Steiner during his semester project.

The present diploma report will describe which functions have been tested, how tests have been performed, the test results and which modifications have to be performed to improve the reliability of the EPS subsystem. This report will also detail component values calculation of critical functions.

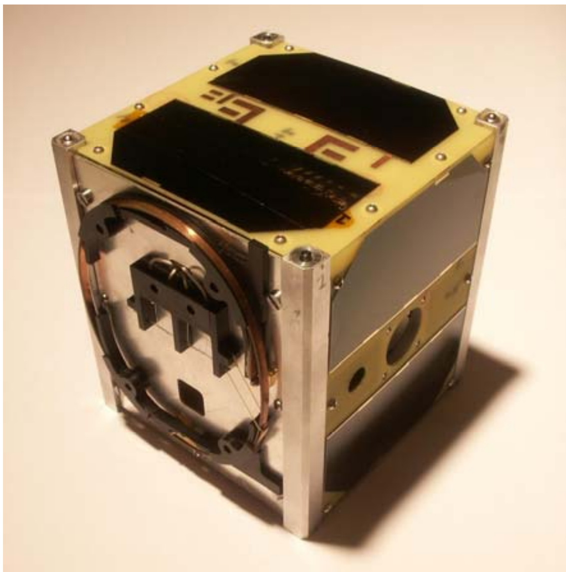
Most of the tests have been performed under partial vacuum at -40ºC and 60 ºC to simulate as closer as possible the space environment conditions.

Both boards passed the qualification tests with success. The design of both boards has been validated. Only minor modifications would have to be performed.

Further tests would have to be performed with other subsystems and finally with the entire satellite to validate the EPS subsystem.

2 INTRODUCTION

The SwissCube project is directed by the Space Center of the Swiss Federal Institute of Technology which is located at the EPFL in Lausanne. The aim of the project is an entire design of a CubeSat by EPFL and HES-SO students.



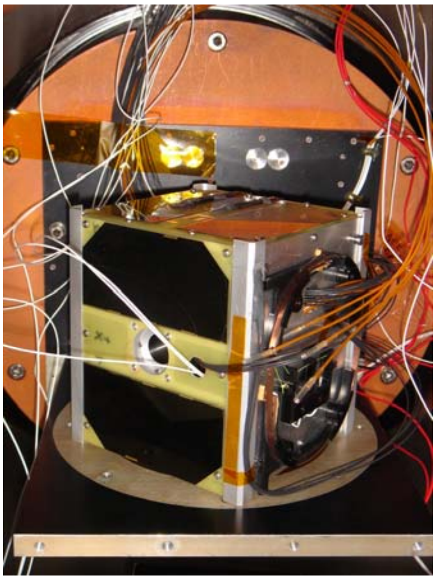


Figure 2-1 : Picture of the SwissCube prototype

2.1 CubeSat concept

The CubeSat concept has been developed in the US, especially at the California Polytechnic State University and the Stanford University at the end of the 1990th years.

The CubeSat concept is an international collaboration of over 60 universities and high schools for the design of picosatellites. It gives the opportunity to students and private companies to work in the space field, to put small payloads on orbit and to test microsystems reliabilities in the space environment. CubeSats are typically using commercial off-the-shelf electronic components.

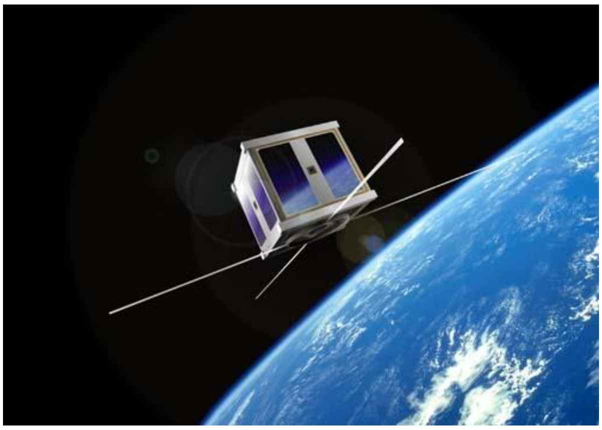


Figure 2-2 : Picture of the AAU CubeSat (Aalborg University in Danemark)

CubeSat size has been normalized in Stanford in 1999 so they can be grouped in such a way to be put on orbit. The normalized size is a 10 centimeters side cube and with a maximum weight of 1kg. This normalization allows picosatellites to be located in the P-Pod (Poly Picosatellite Orbiter Deployer).

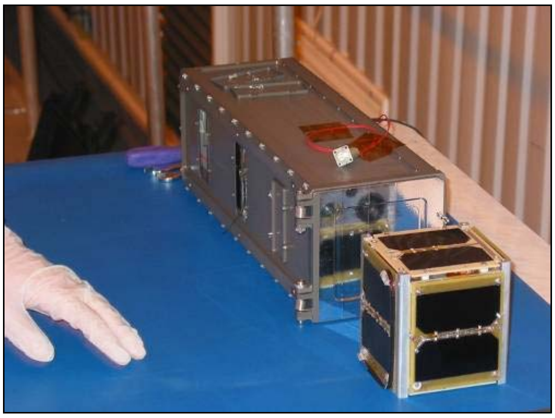


Figure 2-3 : P-Pod (Poly Picosatellite Orbiter Deployer)

2.2 SwissCube payload mission

The SwissCube mission is to take photos of the NightGlow phenomenon. This phenomenon is produced by a radiation of oxygen and hydrogen combination at an approximate height of 100km. This is the reason why the SwissCube will be placed on an orbit between 400 and 1000km. The launch vehicle's main payload is defining the height of the orbit.

If the SwissCube accomplishes its mission, pictures will be used to study the possibility of satellite orientation by using the NightGlow phenomenon.

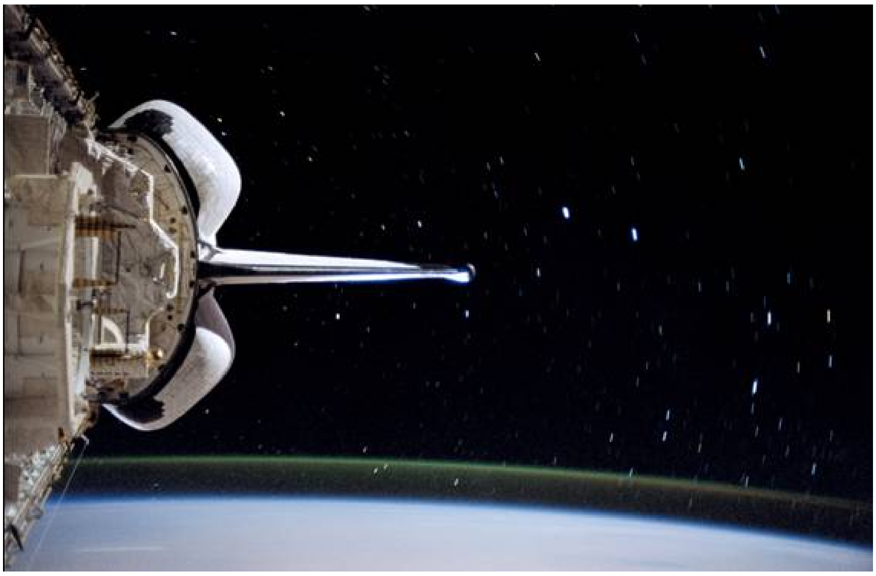


Figure 2-4 : Picture of the NightGlow phenomenon

2.3 SwissCube abbreviations

2.3.1 Subsystems abbreviations

EPS	Electrical Power System
ADCS	Attitude Determination and Control System
CDMS	Control and Data Management System
BEACON	Hardware Beacon Generator and Switch
PL	Payload
ADS	Antennas Deployment System

2.3.2 Other abbreviations

PMB	Power Management Board (part of the EPS subsystem)
MB	Mother Board (part of the EPS subsystem)
BB	Battery Board (used to connect negative terminals to the GND)
HBG	Hardware Beacon Generator (function of the PMB)
P-POD	Poly Picosatellite Orbiter Deployer
CL	Current Limitation (on the MB, used to supply subsystems)

2.4 EPS subsystem

The EPS subsystem (Electrical Power System) is in charge of the bus voltage control and the power management of the satellite. The EPS is composed of 2 PCBs. The Mother Board (MB) and the Power Management Board (PMB).

2.4.1 Mother Board

Its primary function is the 3.3 Volts bus regulation by using the photovoltaic cells, the batteries and DC/DC converters. The NightGlow phenomenon is only visible during eclipse. This is the reason why the SwissCube will be put on a helios-synchronous orbit. The satellite will be approximately 30% of the time in the dark (eclipse). During this night time, the subsystems will use the energy stored in the batteries. During the sun shining time, the energy coming from the cells, produced by the solar radiations and the earth reflected radiations will be used to power the subsystems and charge the batteries.

The main subsystem consumers are:

- Attitude Determination and Control System (induction coil)
- Control and Data Management System (RF transmitter)
- Antennas Deployment System (heater to melt nylon string)

2.4.2 Power Management Board

The main component of the PMB is a µController. This µController is in charge of turning ON and OFF subsystems, taking several measures and creating a software beacon signal. The beacon signal will be used to localize and communicate with the satellite when it passes over the ground station.

Measuring chains are used to filter and to adapt the voltage level of all measurements (voltage, current and temperature) before sending them to the A/D converter of the µController.

A Hardware Beacon Generator (HBG) is used as default beacon generator. If everything goes as expected, only the software beacon created by the µController will be used.

A hardware timer is used to create a delay of 15 minutes once the satellite gets out the P-Pod. This Cal Poly requirements has been written to make sure that all 3 satellites, getting out of the same P-Pod, are enough far away from each other before deploying there antennas and turning ON there HF amplifier.

3 REQUIREMENTS

Requirements have been written at different levels. Requirements of level 4 are specific to each subsystem.

The requirements of the EPS subsystems are given in the appendix.

After each tests the results will be compared to the requirements to verify if they are respected. If requirements are not respected, modifications will be suggested.

4 POWER MANAGEMENT BOARD

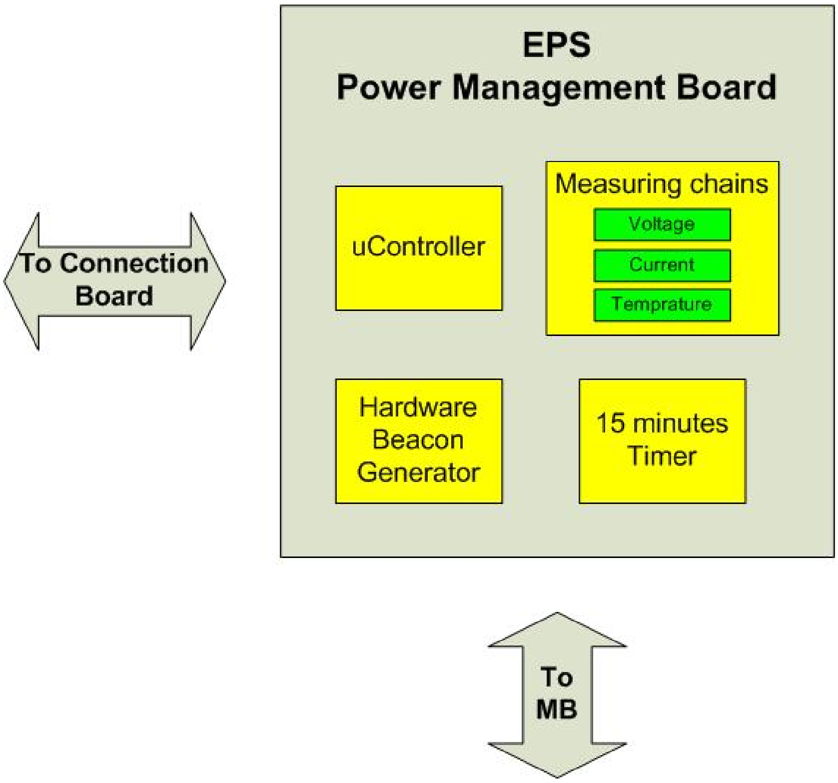


Figure 4-1 : PMB functional diagram

The semester project was dedicated to the schematic design of the Power Management Board of the EPS subsystem. During the semester project, all functions which are implemented on the PMB were defined. Then the electrical schematic has been realized by choosing commercial off-the-shelf electronic components knowing they have to consume very low power and would have to survive under space conditions.

For design explanations, refer to the semester report:

Phase-B_EPS_Power_Management_Board_Steiner.pdf

By the end of the semester project, a schematic of the PMB has been delivered to the layout department of the Heig-vd. During summer vacations, the layout of the PMB has been done and the PMB PCBs have been manufactured.

During the diploma project, the PMB has been mounted and tested under space conditions (partial vacuum, at low and high temperature).

4.1 Hardware Beacon Generator EPROM programming

The Hardware Beacon Generator uses an EPROM OTP memory to store the Morse signal. An oscillator and a binary counter are used to change addresses of the EPROM at a frequency of 10Hz. The LSB of each address is sent to the Beacon amplifier to create the Morse signal.

Before mounting the EPROM, it has to be programmed. To generate the binary file which will be loaded into the EPROM, a program has been developed by Jean Gubelmann during his semester project (for details, refer to S3_B_EPS_1_2_RBF_LUP_FMS_HBG.doc). This program generates a .hex file.

The message that will be sent is:

HB9EG/1

Message that will be loaded into the EPROM (after converting the upper message into Morse signal) is:

0	01	00	01	00	01	00	01	00	00	00	01	01	01	00	01	00
10	01	00	01	00	00	00	01	01	01	00	01	01	01	00	01	01
20	01	00	01	01	01	00	01	00	00	00	01	00	00	00	01	01
30	01	00	01	01	01	00	01	00	00	00	00					

Figure 4-2 : Message loaded into the EPROM

Remark: the left column gives the address (in hexadecimal) of the first pair of numbers of each line. Each pair of numbers represents the stored value (in hexadecimal, on 8 bits). When loading the .hex file, fill up the remaining addresses with zeros.

As the EPROM packaging is a TSOP28, an adapter DIL28/TSOP28 had to be bought (Dobbertin-Elektronik). A DIL28 EPROM has not the same pin out as a TSOP28 EPROM, this is the reason why a Veroboard adapter had to be realized.

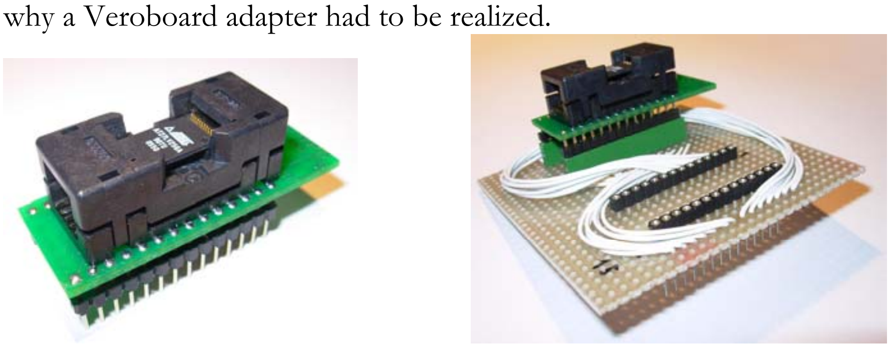


Figure 4-3 : EPROM programming adapter

Programming the EPROM needs the following material:

- The DIL28/TSOP28 adapter and its Veroboard adapter
- The program which generates the .hex files
- Any ERPOM programmer which supported AT27C256R family (Heig-vd class A09)

4.2 Hardware Beacon Generator and 15 minute timer oscillator

The HBG and the 15 minutes timer are using a timer (TS555) to control a binary counter. This timer uses resistances and capacities to generate an oscillation output by charging and discharging a capacity.

In this chapter, the values of the components are calculated. Then the oscillation fluctuation because of components tolerance and temperature drift are calculated.

4.2.1 Calculation of the component values for the oscillator

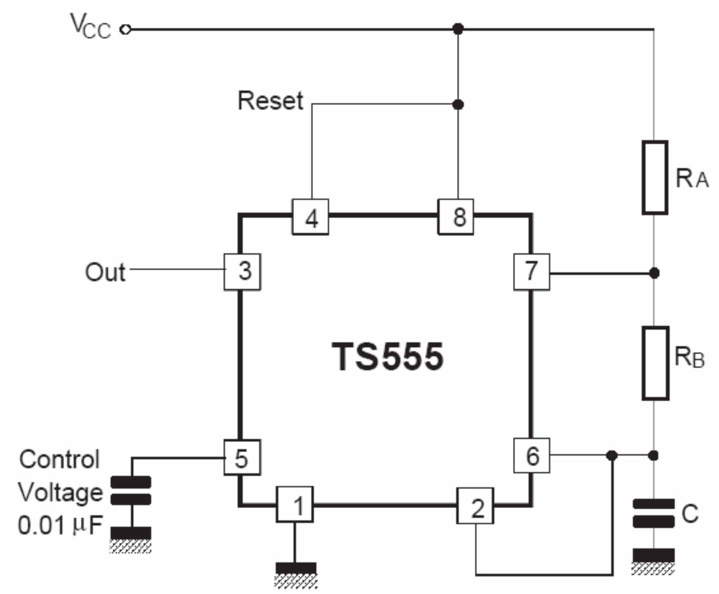


Figure 4-4 : Oscillator

The frequency of the output signal is given by the following relation:

$$f = \frac{1.44}{(R_A + 2 \cdot R_B) \cdot C} \qquad 4.1$$

As the HBG and the 15 minutes timer are critical function, redundancy is used on the timer TS555, 2 resistances in parallel for R_A and R_B and 2 capacities in parallel for C.

4.2.1.1 Hardware Beacon Generator components value

The HBG design requires an oscillation frequency of the timer of 320Hz to control the binary counter.

$$R_{A1} = R_{A2} = 10k\Omega \rightarrow R_A = 5k\Omega \tag{4.2}$$

$$C_1 = C_2 = 10nF \rightarrow C = 20nF \tag{4.3}$$

$$R_B = \frac{\frac{1.44}{C} - R_A \cdot f}{2 \cdot f} = 110k\Omega \tag{4.4}$$

$$R_B = 110k\Omega \rightarrow R_{B1} = R_{B2} = 220k\Omega \tag{4.5}$$

4.2.1.2 15 Minutes Timer components value

The 15 minutes timer is using a 14 stages binary counter (M54HC4020) to create the delay. The output of the timer is set at 3.3V when the 14th bit is set at 1, which means after $2^{13} = 8192$ clock impulses. A delay of 17 minutes instead of 15 (because of components tolerance) is used to calculate the components values.

$$f = \frac{1}{T} = \frac{1}{\frac{17 \cdot 60}{8192}} = 8.03Hz \tag{4.6}$$

$$R_{A1} = R_{A2} = 10k\Omega \rightarrow R_A = 5k\Omega \tag{4.7}$$

$$C_1 = C_2 = 100nF \rightarrow C = 200nF \tag{4.8}$$

$$R_B = \frac{\frac{1.44}{C} - R_A \cdot f}{2 \cdot f} = 446k\Omega \simeq 455k\Omega \tag{4.9}$$

$$R_B = 455k\Omega \rightarrow R_{B1} = R_{B2} = 910k\Omega \tag{4.10}$$

The real frequency is:

$$f = \frac{1.44}{(R_A + 2 \cdot R_B) \cdot C} = 7.87\,Hz \tag{4.11}$$

The real time delay is:

$$D_{elay} = \frac{8192}{7.87} = 17\min 21\sec \tag{4.12}$$

4.2.2 Oscillation frequency tolerance over temperature

The oscillation frequency is given by the following relation:

$$f = \frac{1.44}{(R_A + 2 \cdot R_B) \cdot C} \tag{4.13}$$

For redundancy reasons, 4 resistances and 2 capacities are used.

4.2.2.1 2 resistances in parallel tolerance

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2} \tag{4.14}$$

$$\Delta R = \frac{\partial R}{\partial R_1} \cdot \Delta R_1 + \frac{\partial R}{\partial R_2} \cdot \Delta R_2 \tag{4.15}$$

$$\Delta R = \left(\frac{R_2}{R_1 + R_2} + R_1 \cdot \frac{-R_2}{(R_1 + R_2)^2} \right) \cdot \Delta R_1 + \left(\frac{R_1}{R_1 + R_2} + R_2 \cdot \frac{-R_1}{(R_1 + R_2)^2} \right) \cdot \Delta R_2$$

$$\frac{\Delta R}{R} = \left(\frac{\frac{R_2}{R_1 + R_2}}{\frac{R_1 \cdot R_2}{R_1 + R_2}} + \frac{R_1 \cdot \frac{-R_2}{(R_1 + R_2)^2}}{\frac{R_1 \cdot R_2}{R_1 + R_2}} \right) \cdot \Delta R_1 + \left(\frac{\frac{R_1}{R_1 + R_2}}{\frac{R_1 \cdot R_2}{R_1 + R_2}} + \frac{R_2 \cdot \frac{-R_1}{(R_1 + R_2)^2}}{\frac{R_1 \cdot R_2}{R_1 + R_2}} \right) \cdot \Delta R_2 \tag{4.16}$$

$$\frac{\Delta R}{R} = \frac{\Delta R_1}{R_1} + \frac{-\Delta R_1}{R_1 + R_2} + \frac{\Delta R_2}{R_2} + \frac{-\Delta R_2}{R_1 + R_2}$$

Assuming that the resistors have a tolerance of ±1% and a temperature drift of +100ppm/°C, we can calculate the tolerance for the working temperature range of -40°C up to 60°C (temperature reference: 20°C).

Maximum positive drift:

$$D_{positive} = \frac{100}{10^6} \cdot (60 - 20) \cdot 100 = +0.4\% \tag{4.17}$$

Maximum negative drift:

$$D_{negative} = \frac{100}{10^6} \cdot (-40 - 20) \cdot 100 = -0.6\% \tag{4.18}$$

Resistance tolerance on the given working temperature range:

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2}{}^{+1.4\%}_{-1.6\%} \tag{4.19}$$

2 resistances in parallel tolerance

$$\frac{\Delta R}{R} = {}^{+1.4\%}_{-1.6\%} - {}^{+0.7\%}_{-0.8\%} + {}^{+1.4\%}_{-1.6\%} - {}^{+0.7\%}_{-0.8\%} \tag{4.20}$$

$$\frac{\Delta R}{R} = {}^{+1.4\%}_{-1.6\%} \simeq \pm 1.6\%$$

4.2.2.2 2 capacities in parallel tolerance

$$C = C_1 + C_2 \tag{4.21}$$

$$\Delta C = \frac{\partial C}{\partial C_1} \cdot \Delta C_1 + \frac{\partial C}{\partial C_2} \cdot \Delta C_2 \tag{4.22}$$

$$\Delta C = \Delta C_1 + \Delta C_2$$

$$\frac{\Delta C}{C} = \frac{\Delta C_1}{C_1 + C_2} + \frac{\Delta C_2}{C_1 + C_2} \tag{4.23}$$

Assuming that the capacities have a tolerance of ±10% we can calculate the tolerance of the equivalent capacities:

$$\frac{\Delta C}{C} = \pm 5\% + \pm 5\% \tag{4.24}$$

$$\frac{\Delta C}{C} = \pm 10\%$$

4.2.2.3 Frequency tolerance

$$\Delta f = \frac{\partial f}{\partial R_A} \cdot \Delta R_A + \frac{\partial f}{\partial R_B} \cdot \Delta R_B + \frac{\partial f}{\partial C} \cdot \Delta C \tag{4.25}$$

$$\Delta f = \frac{-1.44}{\left(R_A + 2 \cdot R_B\right)^2 \cdot C} \cdot \Delta R_A + \frac{-1.44 \cdot 2}{\left(R_A + 2 \cdot R_B\right)^2 \cdot C^2} \cdot \Delta R_B + \frac{-1.44}{\left(R_A + 2 \cdot R_B\right) \cdot C^2} \cdot \Delta C$$

$$\frac{\Delta f}{f} = \frac{\dfrac{-1.44}{\left(R_A + 2 \cdot R_B\right)^2 \cdot C}}{\dfrac{1.44}{\left(R_A + 2 \cdot R_B\right) \cdot C}} \cdot \Delta R_A + \frac{\dfrac{-1.44 \cdot 2}{\left(R_A + 2 \cdot R_B\right)^2 \cdot C}}{\dfrac{1.44}{\left(R_A + 2 \cdot R_B\right) \cdot C}} \cdot \Delta R_B + \frac{\dfrac{-1.44}{\left(R_A + 2 \cdot R_B\right) \cdot C^2}}{\dfrac{1.44}{\left(R_A + 2 \cdot R_B\right) \cdot C}} \cdot \Delta C \tag{4.26}$$

$$\frac{\Delta f}{f} = \frac{-\Delta R_A}{R_A + 2 \cdot R_B} + 2 \cdot \frac{-\Delta R_B}{R_A + 2 \cdot R_B} + \frac{-\Delta C}{C}$$

4.2.2.4 Hardware Beacon Generator oscillation frequency tolerance

$$\frac{\Delta f}{f} = -\frac{\pm 0.016 \cdot 5 \cdot 10^3}{5 \cdot 10^3 + 2 \cdot 110 \cdot 10^3} - 2 \cdot \frac{\pm 0.016 \cdot 110 \cdot 10^3}{5 \cdot 10^3 + 2 \cdot 110 \cdot 10^3} - \pm 10\%$$
$$\frac{\Delta f}{f} = - \pm 0.04\% - \pm 0.78\% - \pm 10\% = \pm 10.8\% \qquad 4.27$$

4.2.2.5 15 Minutes Timer oscillator frequency tolerance

$$\frac{\Delta f}{f} = -\frac{\pm 0.016 \cdot 5 \cdot 10^3}{5 \cdot 10^3 + 2 \cdot 455 \cdot 10^3} - 2 \cdot \frac{\pm 0.016 \cdot 455 \cdot 10^3}{5 \cdot 10^3 + 2 \cdot 455 \cdot 10^3} - \pm 10\%$$
$$\frac{\Delta f}{f} = - \pm 0.001\% - \pm 0.8\% - \pm 10\% = \pm 10.8\% \qquad 4.28$$

Minimum time delay:

$$D_{elay\_\min} = \frac{8192}{7.87 \cdot 1.108} = 15 \min 40 \sec \qquad 4.29$$

Maximum time delay:

$$D_{elay\_\max} = \frac{8192}{7.87 \cdot 0.892} = 19 \min 27 \sec \qquad 4.30$$

Requirement 4_EPS_61_02 is respected (the minimum time delay is over 15 minutes).

4.3 Error on measurements taken on board (U/I/T)

All measurements taken on the satellite and sent to the ground station have a certain error. Here is a description of all parameters which are intervening on the measurements error:

- Tolerance of the components (resistances, current sense, temperature sensor, etc…)
- µController resolution
- µController built-in voltage reference temperature drift
- Nonlinearity of the AD converter

In this chapter, the maximum error made on each measurement is calculated.

4.3.1 µController resolution and temperature drift

µController resolution and built-in voltage reference temperature drift are identical for all measurements.

Remark: The integral nonlinearity resolution of the µController MSP430f1611 is 2 Lsb. As measurements are sent to earth on 8 bits (not on 12 bits), the integral nonlinearity resolution won't be visible and must not be taken in account in the following calculation.

4.3.1.1 Resolution

The resolution is the smallest input variation that the AD converter is able to convert. The resolution corresponds to 1 LSB and is depending on the number of bits of the AD converter.

$$q = \frac{V_{ref}}{2^N} \qquad 4.31$$

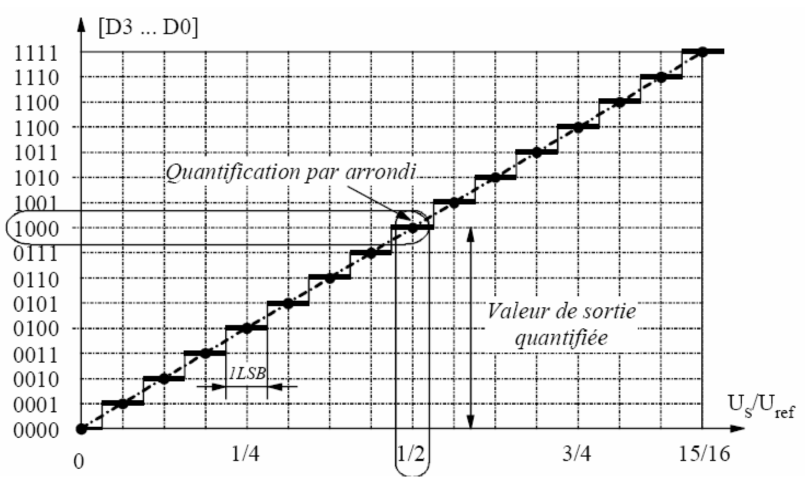


Figure 4-5 : Ideal AD converter

The µController MSP430f1611 is making AD conversion on 12 bits. On the PMB, the built-in reference voltage is used (2.5V).

Only the 8 MSB are used to send measurements to the ground station. This is why the resolution is calculated on 8 bits.

$$\mu C_{résolution} = \frac{2.5V}{2^8} = \frac{2.5V}{256} \simeq 10\left[mV\right] \tag{4.32}$$

4.3.1.2 Temperature drift

The temperature drift is the variation of the built-in voltage reference with the temperature. The temperature drift can be compared to a gain variation. The gain error is the difference between the nominal gain and the real gain as long as the offset is equal to zero. The gain error is given in %.

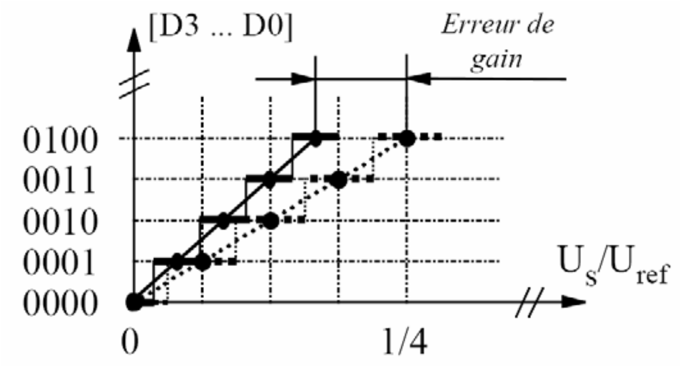


Figure 4-6 : Gain error

The built-in voltage reference of the µController MSP430f1611 has a temperature drift of ±100ppm/°C. Knowing that the working temperature range is -40°C up to 60°C, we can calculate the variation of the built-in voltage reference. 20°C is the reference temperature. The maximum temperature variation is 60°C (from -40°C to 20°C).

Built-in voltage reference incertitude on the full temperature range:

$$V_{ref} = 2.5\left[V\right] \pm 2.5\left[V\right] \cdot 100\left[ppm/{}^{o}C\right] \cdot 60\left[{}^{o}C\right] = 2.5 \pm 0.6\%\left[V\right] \tag{4.33}$$

$$E_{V_{ref}} = \pm 0.6\% \tag{4.34}$$

4.3.2 Voltage measurements

Voltage measuring chain (voltage on the analog input of the µController in function of the measured voltage):

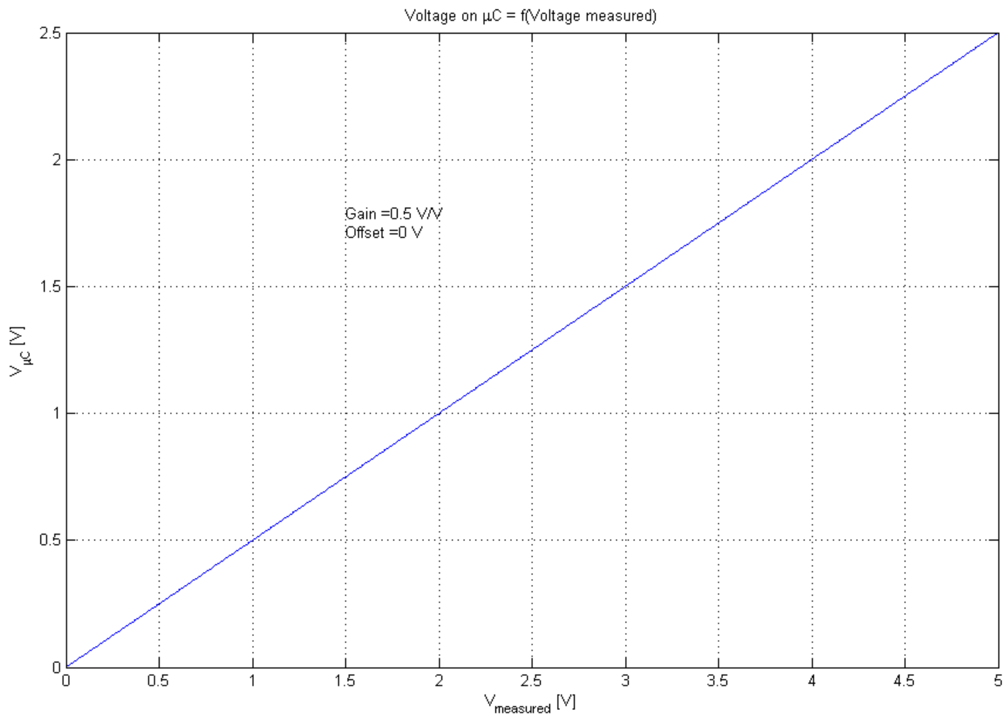


Figure 4-7 : Voltage measuring chain

$$G_{V\_meas\_chain} = 0.5\left[\frac{V}{V}\right] \tag{4.35}$$

$$O_{V\_meas\_chain} = 0\left[V\right] \tag{4.36}$$

4.3.2.1 Amplifier

Calculation of the differential amplifier gain:

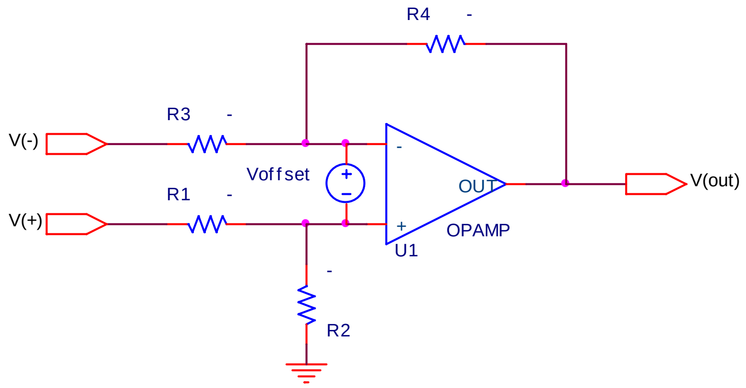


Figure 4-8 : Differential amplifier

$$V_{out} = \left(V_{-} - V_{offset}\right)\frac{-R_4}{R_3} + \left(V_{+} \cdot \frac{R_2}{R_1 + R_2} + V_{offset}\right) \cdot \frac{R_4 + R_3}{R_3} \quad 4.37$$

$$V_{out} = -V_{-} \cdot \frac{R_4}{R_3} + V_{offset} \cdot \frac{R_4}{R_3} + V_{+} \cdot \frac{R_2}{R_1 + R_2} \cdot \frac{R_4 + R_3}{R_3} + V_{offset} \cdot \frac{R_4 + R_3}{R_3}$$

Assuming that $R_3 = R_1$ and $R_4 = R_2$ we can write:

$$V_{out} = -V_{-} \cdot \frac{R_2}{R_1} + V_{offset} \cdot \frac{R_2}{R_1} + V_{+} \cdot \frac{R_2}{R_1} + V_{offset} \cdot \frac{R_2 + R_1}{R_1} \quad 4.38$$

$$V_{out} = \left(V_{+} - V_{-}\right) \cdot \frac{R_2}{R_1} + V_{offset} \cdot \left(\frac{R_2}{R_1} + \frac{R_2 + R_1}{R_1}\right)$$

$$G_{(V_{+} - V_{-})} = \frac{R_2}{R_1} \quad 4.39$$

$$G_{(V_{offset})} = 1 + 2 \cdot \frac{R_2}{R_1} \quad 4.40$$

Offset

The offset represents a horizontal displacement of the converting function. The offset error is given in [%FSR] (Full Scale Range) or in LSB.

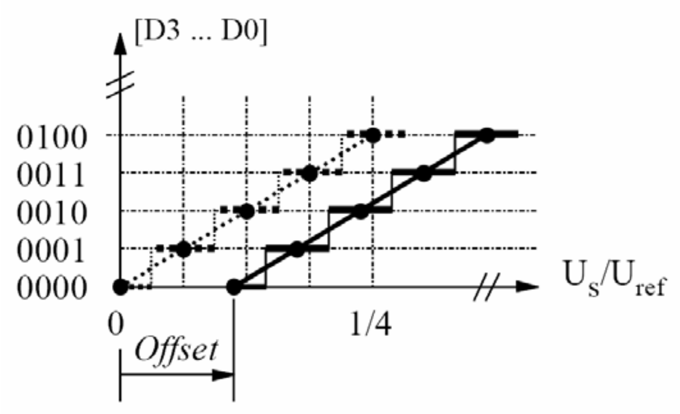


Figure 4-9 : Offset error

The maximum input offset for the amplifier OPA2333 is 10µV. Knowing that $G_{(V+-V-)}=0.5$, we can calculate the maximum output offset voltage:

$$V_{output\_offset\_max} = \left(1+2\cdot\frac{R_2}{R_1}\right)\cdot 10\mu V = 20\left[\mu V\right] \quad 4.41$$

$$E_{V_{output\_offset\_max}} = \frac{20\mu V}{10mV} = 0.002\left[LSB\right] \quad 4.42$$

This output offset voltage is very low and can be neglected.

Differential gain

The maximum gain variation of the differential amplifier can be calculated with the following equation:

$$\Delta G = \frac{\partial G}{\partial R_1} \cdot \Delta R_1 + \frac{\partial G}{\partial R_2} \cdot \Delta R_2 \qquad 4.43$$

$$\Delta G = \frac{R_2}{R_1^2} \cdot \Delta R_1 + \frac{1}{R_1} \cdot \Delta R_2$$

$$\frac{\Delta G}{G} = \frac{-\frac{R_2}{R_1} \cdot \frac{\Delta R_1}{R_1} + \frac{R_2}{R_1} \cdot \frac{\Delta R_2}{R_2}}{\frac{R_2}{R_1}} = -\frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2} \qquad 4.44$$

Assuming that all resistances have a tolerance of ±0.1% and a temperature drift of +25ppm/°C, we can determine the maximal gain variation of this amplifier. The temperature drift of the resistance must not be taken in account because resistances are placed next to each other so their temperature will always be the same and the resistances ratio (gain) won't change.

$$\frac{\Delta G}{G} = -\pm 0.1\% + \pm 0.1\% \qquad 4.45$$

$$\frac{\Delta G}{G} = \pm 0.2\%$$

4.3.2.2 µController

Error due to the resolution

The error on the measurement due to the µController resolution is ±0.5 LSB.

The gain of the voltage measuring chain is:

$$G_{V\_meas\_chain} = 0.5 \left[\frac{V}{V} \right] \qquad 4.46$$

We can now calculate the corresponding measured voltage of 0.5 LSB.

$$G_{V\_meas\_chain} = \frac{V_{out}}{V_{in}}\left[\frac{V}{V}\right] \tag{4.47}$$

$$\Delta V_{in} = \Delta V_{out} \cdot \frac{1}{G_{V\_meas\_chain}} = \frac{1}{2} \cdot LSB \cdot \frac{1}{G_{V\_meas\_chain}} = \frac{1}{2} \cdot 10mV \cdot 2 = 10[mV] \tag{4.48}$$

The error on the measurement due to the µController resolution is:

$$E_{resolution} = \pm 10[mV] \tag{4.49}$$

Error due to the temperature drift

The variation of the built-in voltage reference due to the temperature drift can be compared to a gain variation. This is why this variation will be added to the measuring chain gain variation.

4.3.2.3 Total error on the voltage measurement

Relation that gives the measured voltage and its error in function of the result after AD conversion (number that will be sent to the ground station.):

$$V_{measured} = \frac{V_{ref}}{2^8} \cdot n^{\#} \cdot \frac{1}{G_{V\_meas\_chain}} \pm \left(E_{G_{V\_meas\_chain}} + E_{V_{ref}}\right) \pm E_{resolution} \tag{4.50}$$

$$V_{measured} = \frac{2.5}{256} \cdot n^{\#} \cdot 2 \pm 0.8\% \pm 0.01[V] \tag{4.51}$$

$n^{\#}$ = result in decimal after AD conversion coded on 8 bits

4.3.3 Current measurements

Current measuring chain (voltage on the analog input of the µController in function of the measured current):

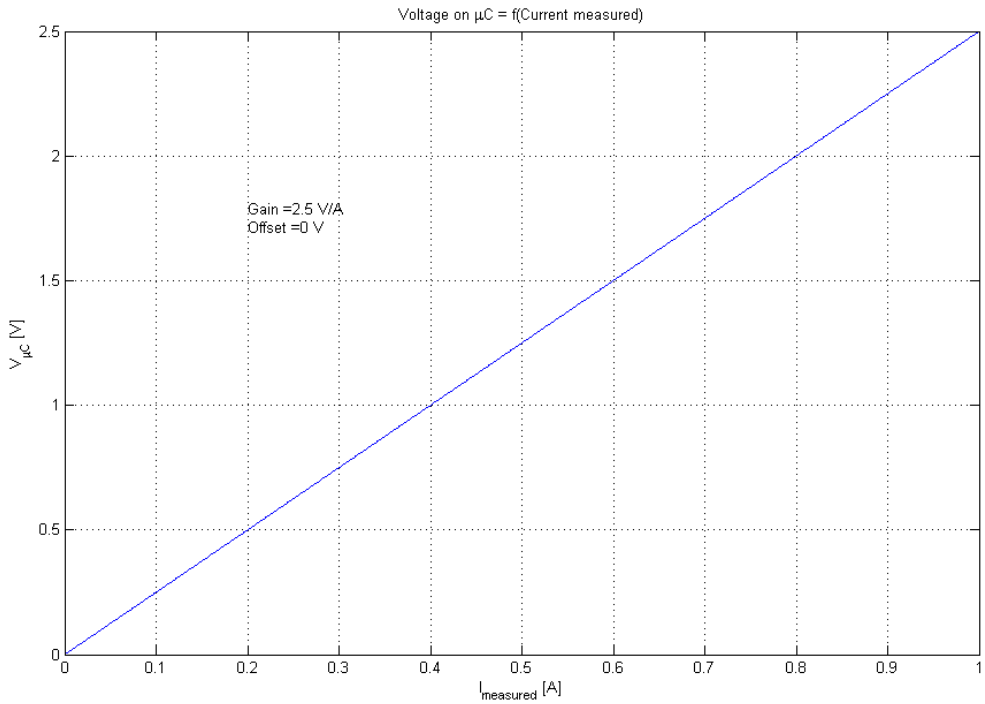


Figure 4-10 : Current measuring chain

$$G_{I\_meas\_chain} = 2.5\left[\frac{V}{A}\right] \quad (4.52)$$

$$O_{I\_meas\_chain} = 0\left[V\right] \quad (4.53)$$

4.3.3.1 Shunt

The chosen shunt (50mΩ) has a tolerance of ±1% and a temperature drift of +100ppm/°C. The error on the resistance value can be compared to a gain variation. Knowing that the shunt will work in a temperature range from -40°C up to 60°C, we can calculate the total resistance variation (temperature reference 20°C).

Maximum positive drift:

$$D_{positive} = \frac{100}{10^6} \cdot (60 - 20) \cdot 100 = +0.4\% \quad 4.54$$

Maximum negative drift:

$$D_{negative} = \frac{100}{10^6} \cdot (-40 - 20) \cdot 100 = -0.6\% \quad 4.55$$

Shunt tolerance:

$$R_{shunt} = 50^{+1.4\%}_{-1.6\%} \left[m\Omega \right] \quad 4.56$$

4.3.3.2 Current sense gain tolerance

The current sense gain has a tolerance over temperature of 5.5%.

$$G_{I\_sense} = 50 \pm 5.5\% \left[\frac{V}{V} \right] \quad 4.57$$

4.3.3.3 µController

Error due to the resolution

The error on the measurement due to the µController resolution is ±0.5 LSB.

The gain of the current measuring chain is:

$$G_{I\_meas\_chain} = 2.5 \left[\frac{V}{A} \right] \quad 4.58$$

We can now calculate the corresponding measured current of 0.5 LSB.

$$G_{I\_meas\_chain} = \frac{V_{out}}{I_{in}}\left[\frac{V}{A}\right] \tag{4.59}$$

$$\Delta I_{in} = \Delta V_{out} \cdot \frac{1}{G_{I\_meas\_chain}} = \frac{1}{2} \cdot LSB \cdot \frac{1}{G_{I\_meas\_chain}} = \frac{1}{2} \cdot 10mV \cdot 0.4 = 2\left[mA\right] \tag{4.60}$$

The error on the measurement due to the µController resolution is:

$$E_{resolution} = \pm 2\left[mA\right] \tag{4.61}$$

Error due to the temperature drift

The variation of the built-in voltage reference due to the temperature drift can be compared to a gain variation. This is why this variation will be added to the measuring chain gain variation.

4.3.3.4 Total error on the current measurement

Relation that gives the measured current and its error in function of the result after AD conversion (number that will be sent to the ground station.):

$$I_{measured} = \frac{V_{ref}}{2^8} \cdot n^{\#} \cdot \frac{1}{G_{I\_meas\_chain}} \pm \left(E_{G_{I\_meas\_chain}} + E_{V_{ref}}\right) \pm E_{resolution} \tag{4.62}$$

$$I_{measured} = \frac{2.5}{256} \cdot n^{\#} \cdot 0.4^{+7.5\%}_{-7.6\%} \pm 0.002\left[A\right] \tag{4.63}$$

$n^{\#}$ = result in decimal after AD conversion coded on 8 bits

4.3.4 Temperature measurements

Temperature measuring chain (voltage on the analog input of the µController in function of the measured temperature):

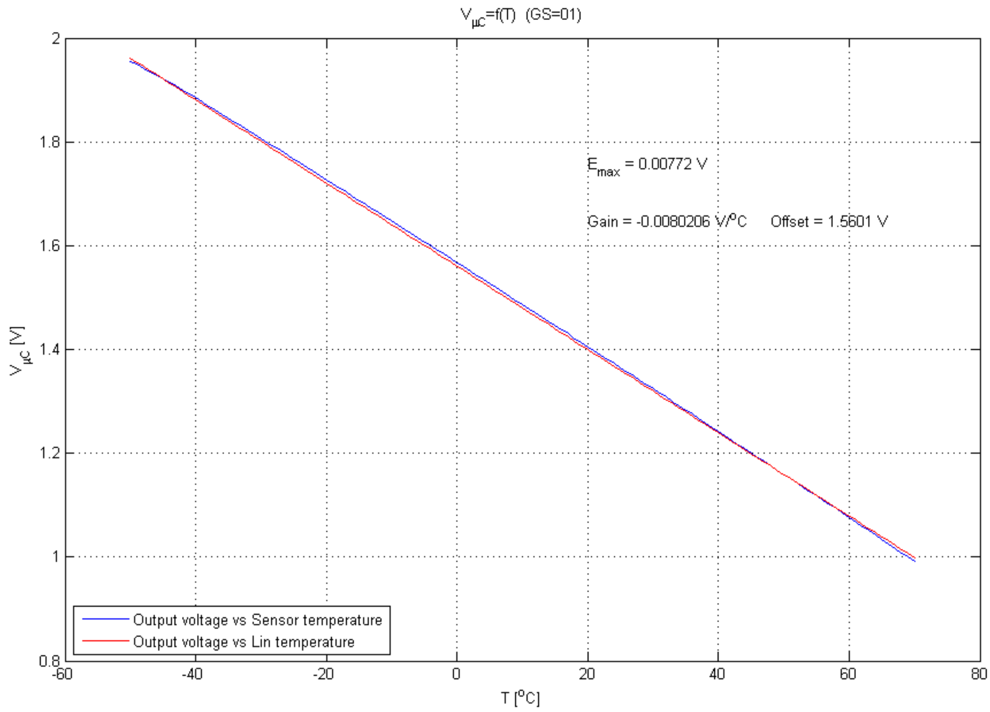


Figure 4-11 : Temperature measuring chain (real T and linearized T)

$$G_{T\_meas\_chain} = 8.02\left[\frac{mV}{^{o}C}\right] \quad 4.64$$

$$O_{T\_meas\_chain} = 1.56\left[V\right] \quad 4.65$$

4.3.4.1 Temperature sensor

Temperature sensors must be able to measure temperature from -50°C up to 70°C. For this working temperature range, the temperature sensor (LM94022) has the following tolerance:

$$\pm 1.8\left[^{o}C\right]$$

The temperature sensor (gain set as GS=01) is nonlinear. An array (given in the datasheet) gives the output voltage corresponding to every degree Celsius from -50ºC up to 150ºC. For software implementation facilities, the sensor is linearized on the working temperature range. To linearize the sensor we need 2 points. A Matlab code has been written to determine, by testing all possible combinations of two points available in the given array, the two best points which gives the minimal error on the entire working temperature range.

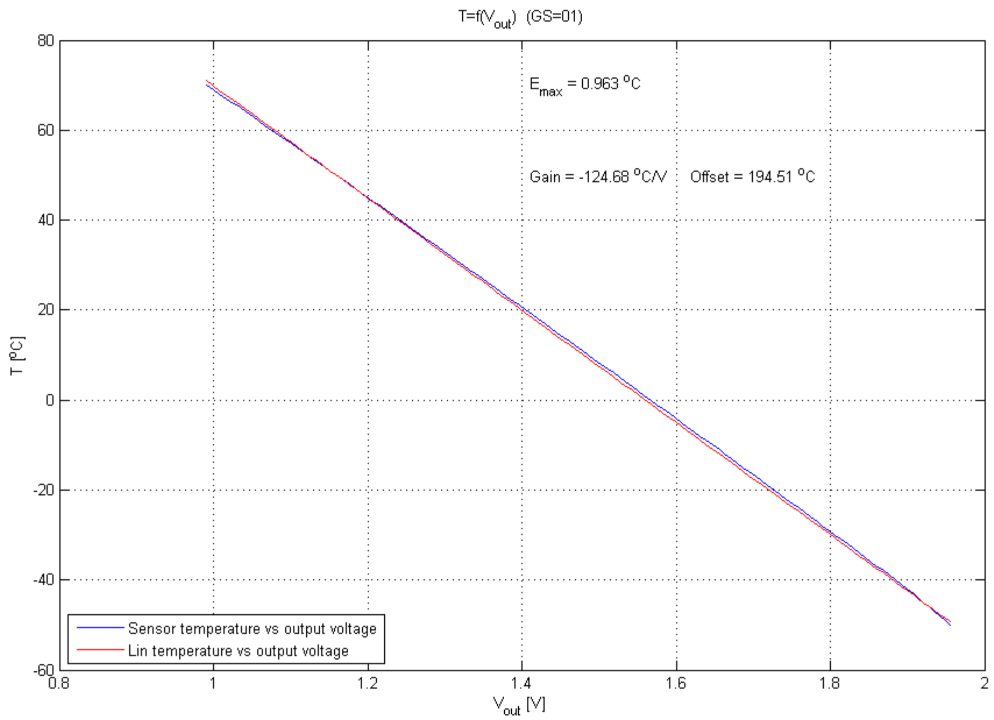


Figure 4-12 : Temperature sensor linearization

The linearization of the sensor in the working temperature range gives the following maximum error:

$$T_{sensor-lin} = T \pm 1\left[{}^{o}C\right] \tag{4.66}$$

Equation of the line:

$$T(U) = -124.68 \cdot U + 194.51\left[{}^{o}C\right] \quad 4.67$$

$$G_{\frac{1}{T\_meas\_chain}} = -124.68\left[\frac{{}^{o}C}{mV}\right] \quad 4.68$$

$$O_{\frac{1}{T\_meas\_chain}} = 194.51\left[{}^{o}C\right] \quad 4.69$$

µController

Error due to the resolution

The error on the measurement due to the µController resolution is ±0.5 LSB.

The gain of the temperature measuring chain is:

$$G_{T\_meas\_chain} = 8.02\left[\frac{mV}{{}^{o}C}\right] \quad 4.70$$

Calculation of the full measuring scale by using the linearized equation:

$$Measure_{Full\_scale} = T(U = 0V) - T(U = 2.5V) \quad 4.71$$

$$Measure_{Full\_scale} = (-124.68 \cdot 0 + 194.51) - (-124.68 \cdot 2.5 + 194.51) = 311.7\left[{}^{o}C\right]$$

We can now calculate the corresponding measured temperature of 0.5 LSB.

$$G_{T\_meas\_chain} = \frac{V_{out}}{T_{in}}\left[\frac{V}{{}^{o}C}\right] \quad 4.72$$

$$\Delta T_{in} = \Delta V_{out} \cdot \frac{1}{G_{T\_meas\_chain}} = \frac{1}{2} \cdot LSB \cdot \frac{1}{G_{T\_meas\_chain}} \quad 4.73$$

$$\Delta T_{in} = \frac{1}{2} \cdot 10mV \cdot (-124.68) = -0.6\left[{}^{o}C\right]$$

The error on the measurement due to the µController resolution is:

$$E_{resolution} = \pm 0.6\left[{}^{o}C\right] \quad 4.74$$

Error due to the temperature drift

The variation of the built-in voltage reference due to the temperature drift can be compared to a gain variation. This is why this variation will be added to the measuring chain gain variation.

4.3.4.2 Total error on the temperature measurement

Relation that gives the measured temperature and its error in function of the result after AD conversion (number that will be sent to the ground station.):

$$T_{measured} = \frac{V_{ref}}{2^8} \cdot n^{\#} \cdot G_{\frac{1}{T\_meas\_chain}} \pm \left(E_{G_{\frac{1}{T\_meas\_chain}}} + E_{V_{ref}} \right) + O_{\frac{1}{T\_meas\_chain}} \pm E_{resolution} \quad 4.75$$

$$T_{measured} = \frac{2.5}{256} \cdot n^{\#} \cdot -124.68 \pm 0.6\% + 194.51 \pm 3.4\left[{}^{o}C\right] \quad 4.76$$

$n^{\#}$ = result in decimal after AD conversion coded on 8 bits

4.4 Nonlinearity of measuring chains test

All measuring chains are using rail-to-rail operational amplifiers. These amplifiers have an output voltage swing from rail of maximum 50 mV (70mV over temperature). That implies that it is not possible to precisely measure very low currents and voltages.

4.4.1 Voltage measuring chains

For the voltage measuring chains, the OA voltage swing from rail has no consequence since the voltages that have to be measured will vary between about 3V and 4.5V. However, I decided to measure the full measuring scale (10mV to 5V) to verify if there is nonlinearity or not.

To have explicated graphs, the measured voltage has been converted (output of the differential filter or input of the µControllers) into the real voltage measured like if it was the result given by the µControllers after AD conversion.

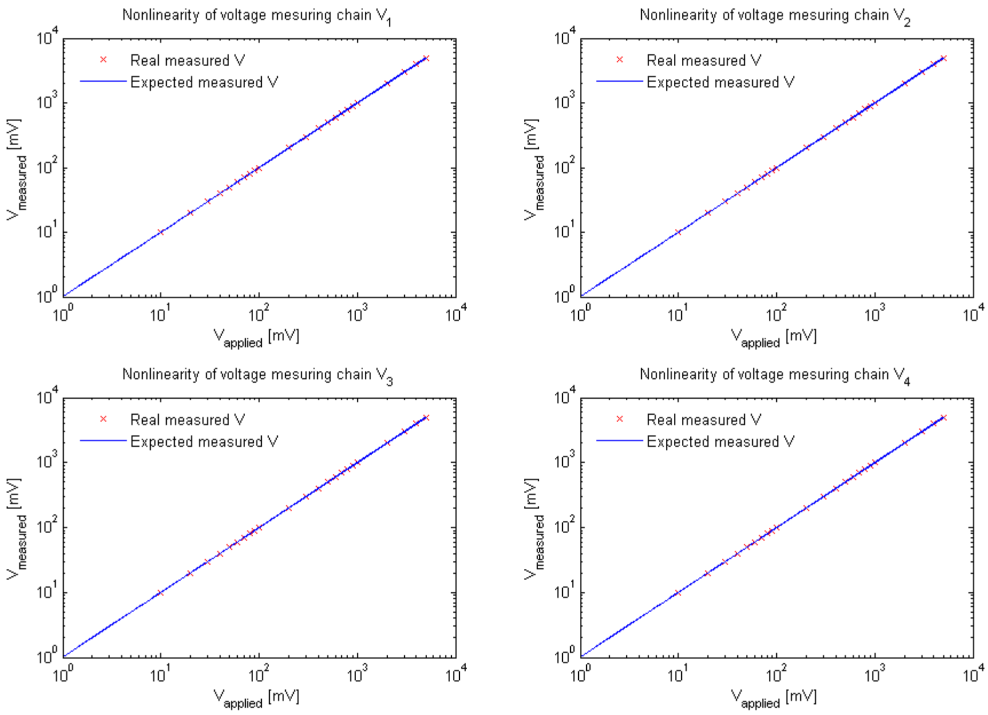


Figure 4-13 : Voltage measuring chains

Measuring chains V_5 and V_6 have not been verified because they are connected to the analog and digital power supply. It is not possible to modify their voltage.

As we can notice, on all measuring chains are linear.

4.4.2 Current measuring chains

For the current measuring chains, the operational amplifier voltage swing from rail has a consequence on low current measurements. When a face of the satellite is facing the dark, no current is produced. Because of the operational amplifier voltage swing from rail, the measured current (after AD conversion) will not be equal to zero. In addition to that, the current sensor has an output low voltage of 25mV (maximum 40mV).

To see how work the current measuring chains on the full measuring scale, I decided to apply a current (1mA to 1000mA) and measure the output of the current sensor and the follower.

To have explicated graphs, the measured voltage has been converted (output of the differential filter or input of the µControllers) into the real current measured like if it was the result given by the µControllers after AD conversion.

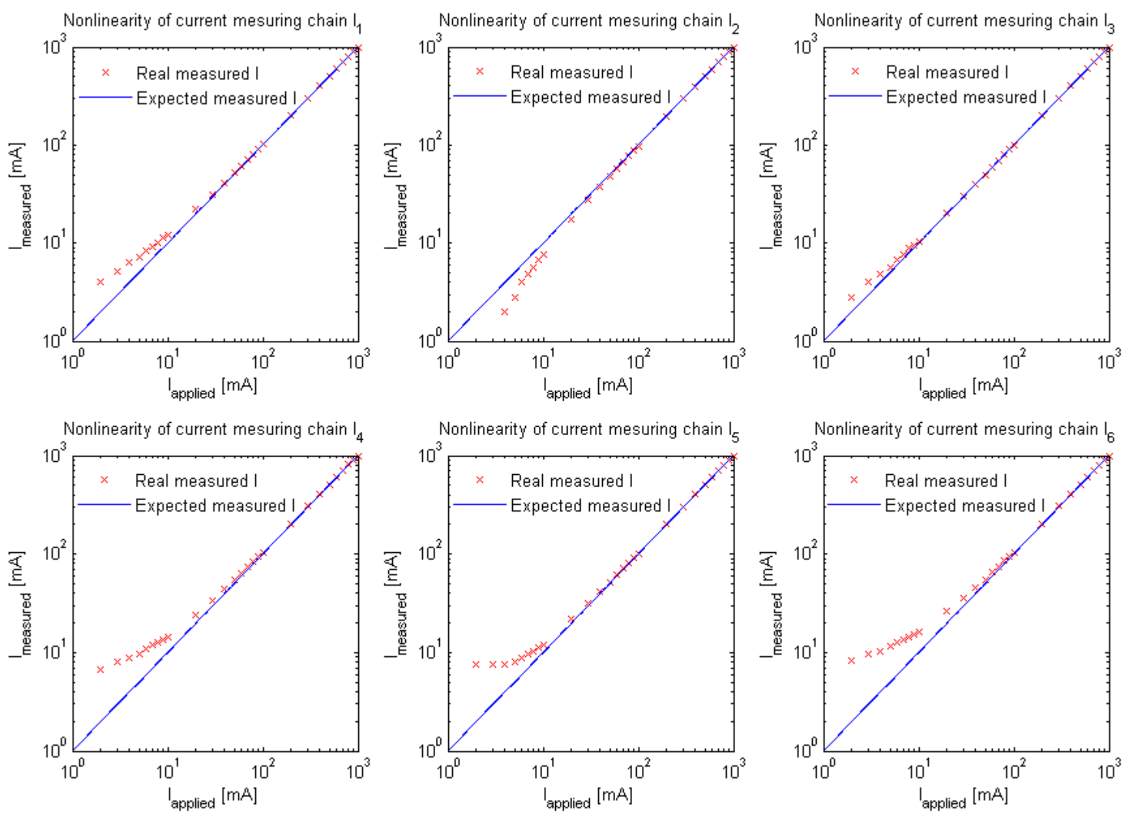


Figure 4-14 : Current measuring chains

Voltages measured on the output of the current sensors are exactly the same as the voltage measured on the output of the operational amplifier. As we can see on the graphs, there is a saturation on every current measuring chains, unless for measuring chain I_2.

Changing the design has been considered, but too many changes have to be performed to be able to measure low current. Current measurements are not used for regulation on board, but only as additional information.

The present design will be kept. Measurements under 15mA must not be taken in account.

4.4.3 Temperature measuring chains

For the temperature measuring chains, the operational amplifier voltage swing from rail has no consequence since the output voltage of the temperature sensor will vary between 991mV and 1955mV (respectively 70ºC and -50ºC). However, I decided to measure the full measuring scale (-50ºC to 70ºC) to verify if there is nonlinearity or not. I made measurement every 10ºC by applying the output voltage of the temperature chip (values of the voltage corresponding to the temperatures are available in the datasheet LM94022). On the axes of the following graph, voltage will be displayed instead of temperature.

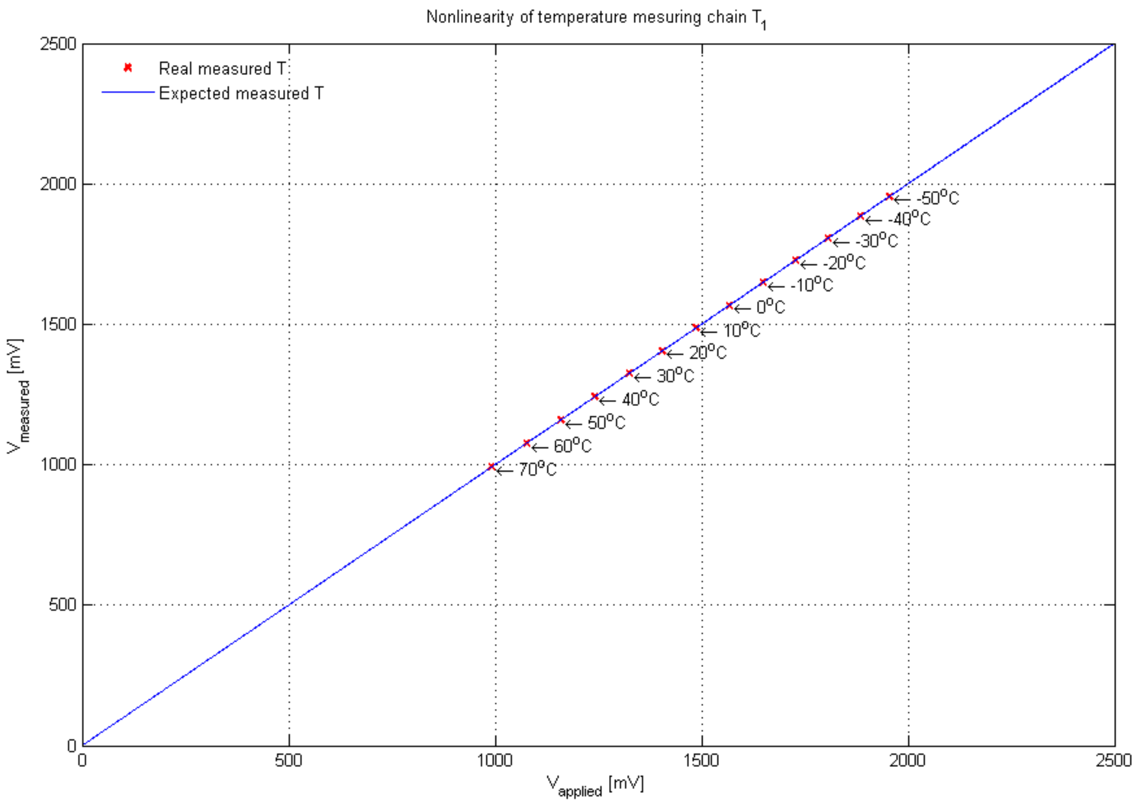


Figure 4-15 : Temperature measuring chains

On all measuring chains, the output voltages of the followers are exactly the same as the applied voltage (simulation of the temperature sensor). This is the reason why I only draw 1 graph. As we can notice, there is no nonlinearity.

Measuring chains are linear. Temperature sensors are nonlinear and have been linearizied in chapter 4.3.4.

4.5 Reset of the 15 minutes timer test

The reset of the 15 minutes timer is a critical function of the PMB. If the reset is not properly done, there is a risk of antennas deployment before the 15 minutes delay required.

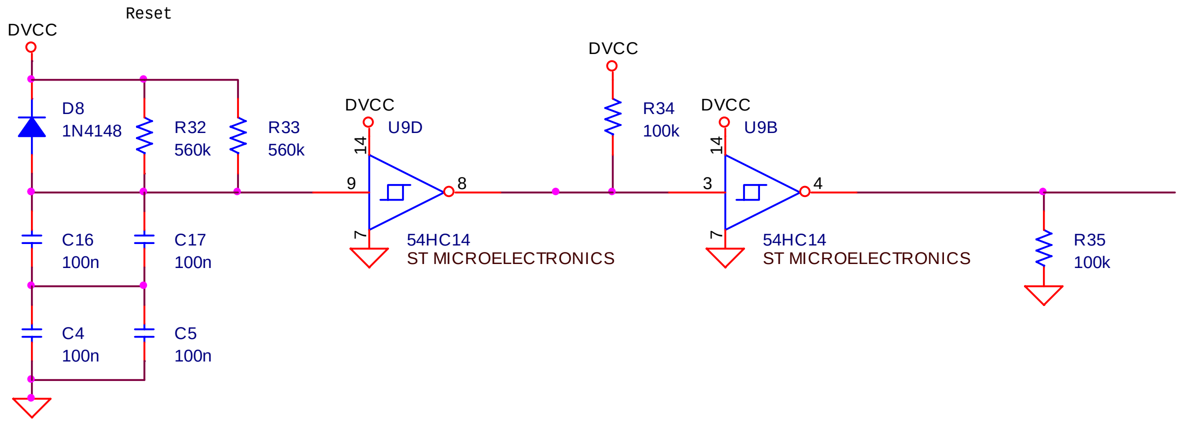


Figure 4-16 : 15 minutes timer reset circuit

First the voltages on the capacity, on the input and output of both trigger gates have been measured. Then the Beacon Current Limitation Enable signal and the antenna deployment signal have been measured to verify that the output stays at 0 during the reset.

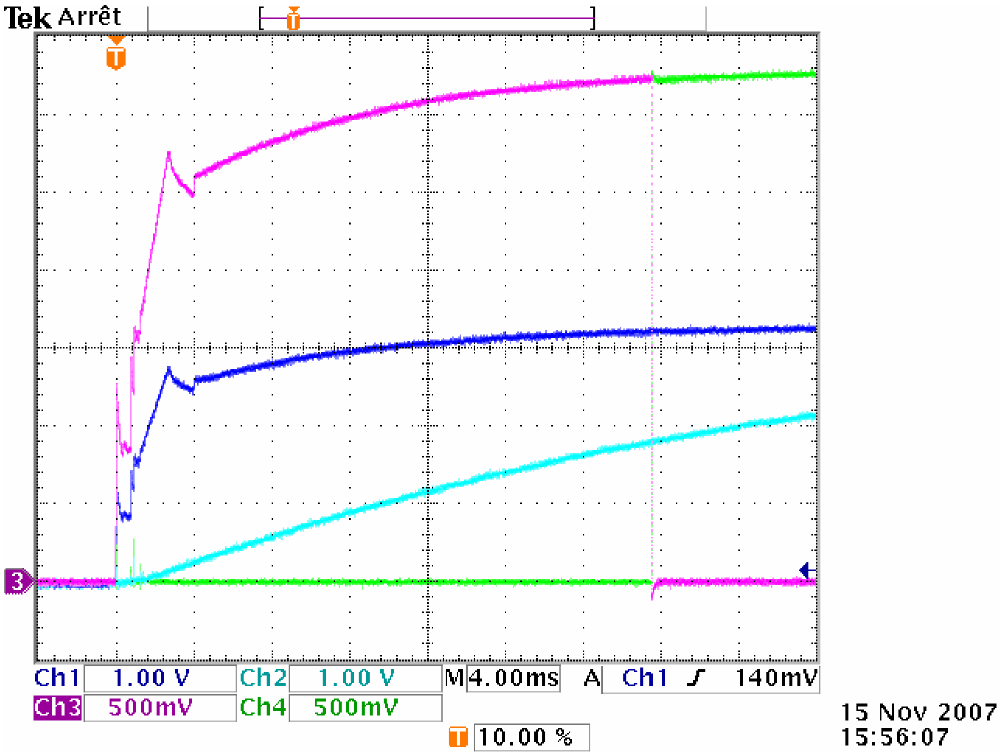


Figure 4-17 : 15 minutes timer reset

Ch1: power supply (measured on the chip)

Ch2: capacity charging (input of the first trigger)

Ch3: output of the first trigger / input of the second trigger

Ch4: output of the second trigger

Remark: To make the graph readable, Ch1 and Ch2 are 1V/div. Ch3 and Ch4 are 500mV/div.

As we can notify, the reset lasts about 28ms, until the capacity is charged at 1.85V (commutation voltage level of the trigger).

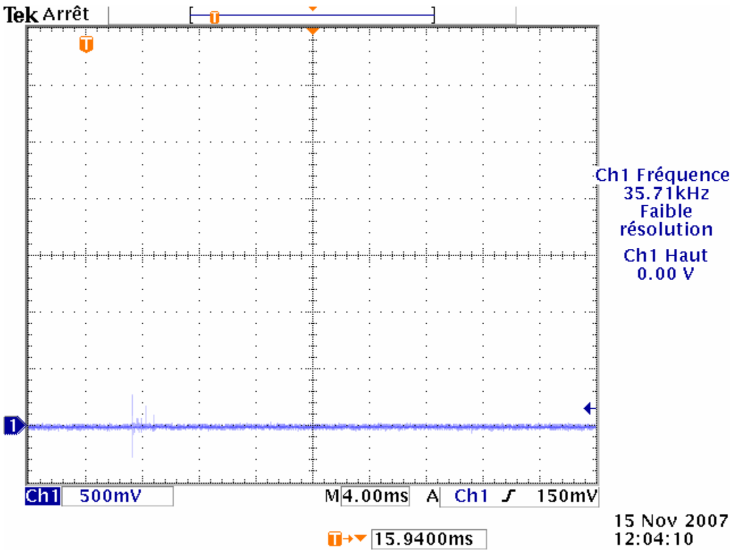


Figure 4-18 : Beacon Current Limitation Enable

The Beacon Current Limitation Enable stays perfectly at 0V during the circuit reset. There is no emission possible on the antennas before the deployment signal has been given.

The output of the 15 minutes which commands the antennas deployments (not shown on the graph) stays perfectly at 0 until the delay has been counted.

During integration tests, reset test would have to be performed one more time to verify its proper works with the power supply coming from the Mother Board.

This test has been performed with the following power supply:

HAMEG triple power supply HM8040-2 (inventory 24E-043)

4.6 Vibration and shock tests

During summer 2007, vibration tests (sine and random) and shock tests have been performed in Berlin on the satellite. I had the opportunity to prepare and participate to these tests. It was during summer 2007 and not during my Diploma project.

We received the PMB PCB from the manufacturer only 2 weeks before the vibration and shock tests. For missing time reasons, I decided to concentrate and mount only the components for the μController and the measuring chains. Components for the Hardware Beacon Generator and Switch and the 15 Minutes Timer have not been mounted for these tests.

4.6.1 Vibration

The purpose of the sinusoidal and random vibration testing is to demonstrate the ability of the satellite to withstand excitations of the launcher increased by a qualification factor.

Figure 4-19 : Vibration machine

Sinusoidal vibration:

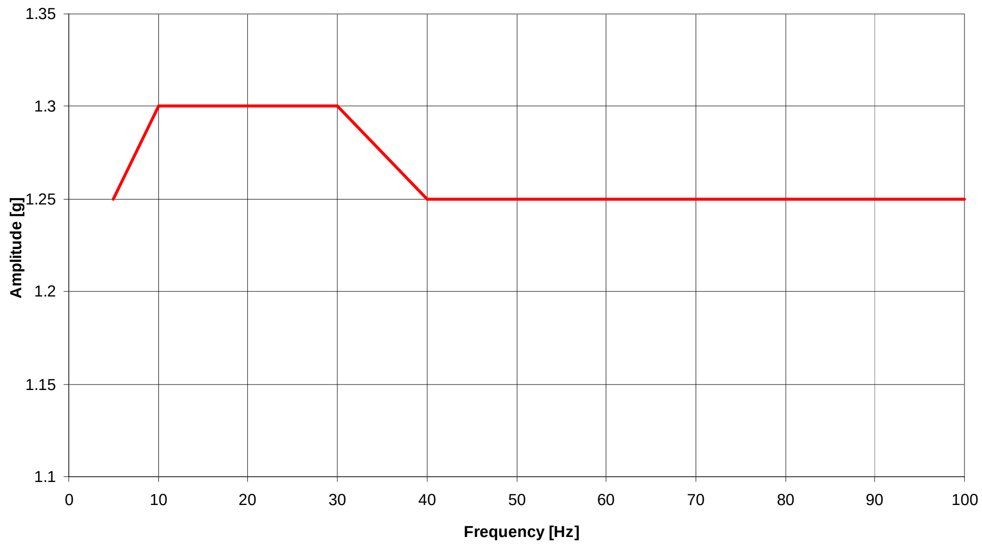


Figure 4-20 : Sinusoidal vibration profile

Random vibration:

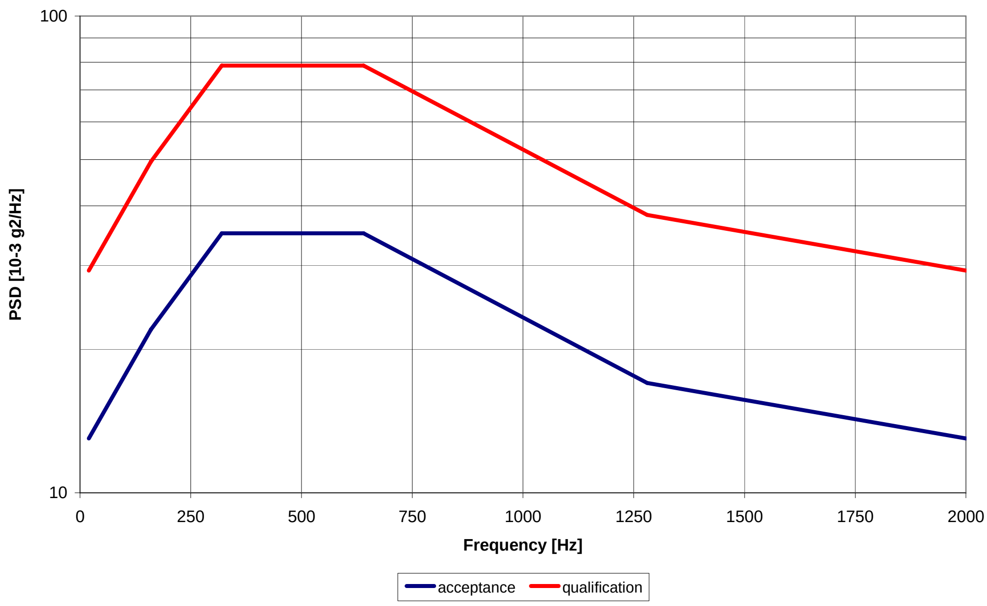


Figure 4-21 : Random vibration profile

4.6.2 Shock

The purpose of shock testing is to demonstrate the ability of the satellite to withstand the shocks induced by the separation of the payload from the launcher, or the booster burn out.

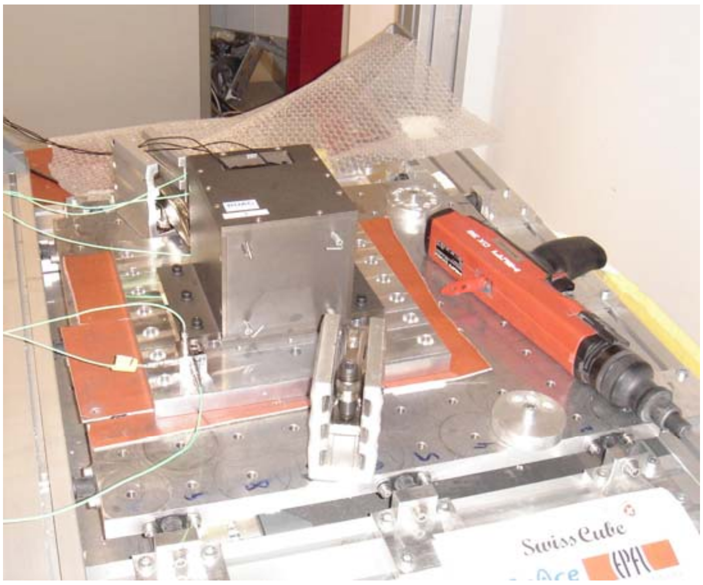


Figure 4-22 : Platform for shock tests

Shock

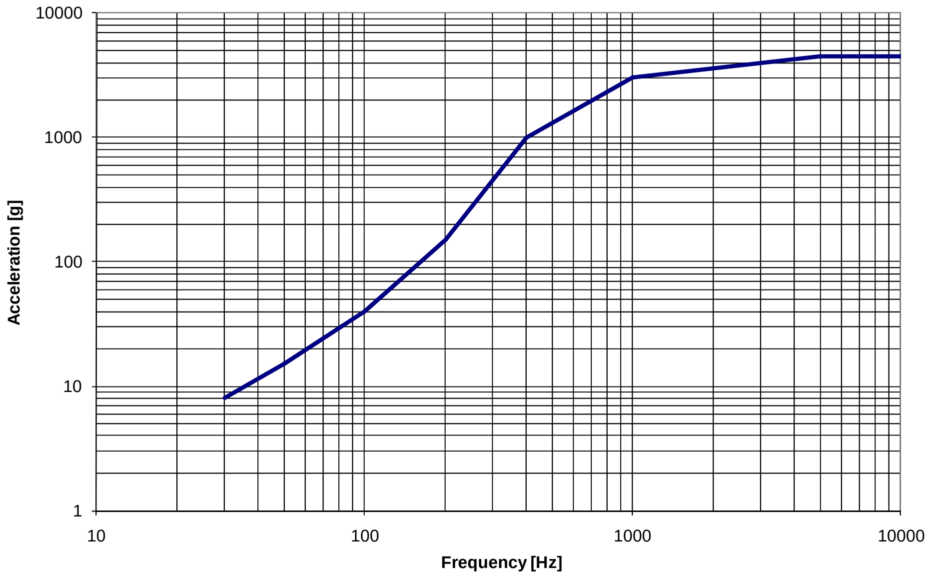


Figure 4-23 : Shock profile

4.6.3 What has to be verified

The soldering survives at vibration and shock tests had to be verified.

The proper working of the electrical functions of the board after vibration and shock tests has to be verified.

4.6.4 Issued to be solved before the tests

During the tests, electrical interfaces with other boards did not exist. That means no power supply and some measurements were available (cell temperature, battery voltage, etc.). To be able to verify the proper working of the mounted function (μController and measuring chains), a solution to simulate interfaces with other boards had to be found.

The solution was to design a testing board that could be quickly connected to the PMB before and after each test.

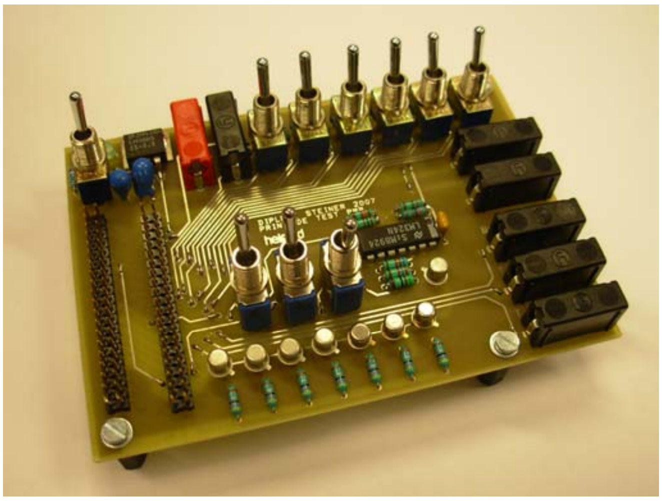


Figure 4-24 : PMB testing board

This board is supplied with 5VDC. It generates 3.3V to supply the PMB. It generates also other voltages that can be applied on the measuring chains inputs to simulate the output voltage of a temperature chips or the voltage of a batteries. It also has 6 current sources to simulate current delivered from the photovoltaic cells. 6 switches and 6 Leds are used to test the digital inputs and outputs of the µController. The testing board is connected to the PMB via flat wires and pins mounted on springs.

Figure 4-25 : PMB and testing board interconnection

4.6.5 How tests are performed

After each vibration or a shock test (test performed on each axis), the only thing that is verify is that the electrical functions of the board are working exactly the same as before the test. That means that the results of AD conversions of all measurements have to be the same before and after the tests. The result of the AD conversion (given in hexadecimal) is not compared to the real applied voltage or current to verify its corresponding. To compare AD conversion of the µController, debug session in the emulator and the JTAG USB Debug Interface is used.

Verification of the correct AD conversion (comparison with the reference voltage or current that is applied on the measuring chains) and verification that these conversions are within the given tolerance is performed thermal tests. For the thermal tests, all components are mounted and tested.

4.6.6 Tests setup and procedure

- Connect the testing board to the PMB.
- Connect the JTAG USB Debug Interface.
- Set the right voltage to apply on the voltage (3V) and temperature (2V) measuring chains.
- Turn on the current supplies.
- Go through the msp code by using step-by-step.
- After each series of conversion, note the result present in the ADC register.

4.6.7 Test results

All tests results are available in the following documents:

- S3-C-1-0-Sine_vib_STM_report.doc
- S3-C-1-0-Random_vib_STM_report.doc
- S3-C-1-0-shock_STM_report.doc

All results are within the tolerances (µController AD converter resolution).

Soldering did resist to all tests.

Requirements 4_EPS_52_01/2/3/4 are respected for the mounted electrical functions (µController and measuring chains) of the PMB.

4.7 Thermal qualification tests

Figure 4-26 : Thermal chamber

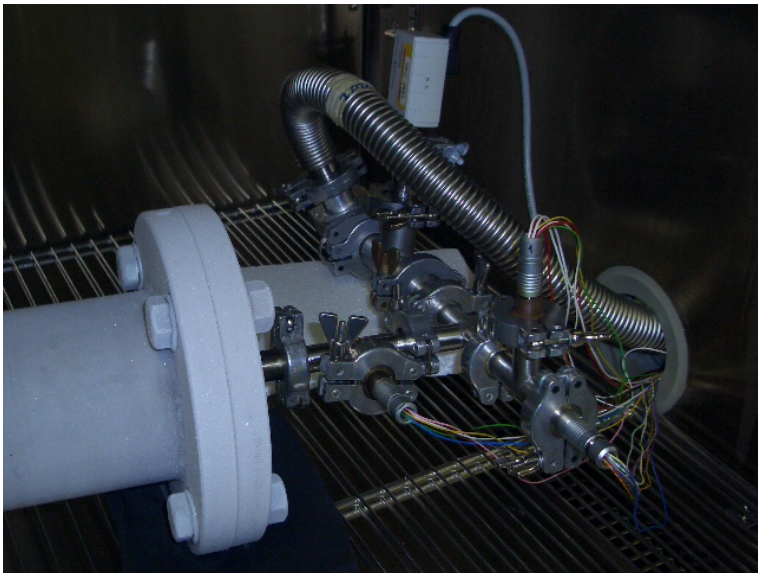


Figure 4-27 : Vacuum chamber (inside the thermal chamber)

4.7.1 What has to be verified

First of all, every testing steps described below hare tested at ambient temperature and pressure. Then the same tests hare performed under partial vacuum from -40°C up to 60 °C every 10 °C.

4.7.1.1 Measuring chains and µController AD conversion

Verify that all measurements given by the µController are within the calculated tolerance.

Verify that the noise amplitude on the analog inputs of the µController is lower than the calculated resolution.

4.7.1.2 µController digital inputs and outputs

Verify the proper operating of the I/O chain (chains that connects the I/O of the PMB to the I/O of the µController).

4.7.1.3 15 minutes timer

Verify that, once the power is turned ON, the 15 minutes timer waits at least 15 minutes before setting its output to 3.3V and then sets it back to 0V after at least 2 seconds.

4.7.1.4 Hardware Beacon generator

Verify that the HBG sends the expected message.

4.7.1.5 Electrical consumption of the PMB

Verify that the total electrical consumption of the PMB is in the range of the estimated consumption.

4.7.2 How tests are performed

4.7.2.1 Measuring chains and µController AD conversion

All measurements are saved in txt files using the UART communication port of the µController and a Matlab code.

A DC voltage laboratory supply is connected to all voltage measurement inputs of the PMB. A voltmeter is used to give the voltage reference.

6 DC current laboratory supplies are connected to all current measurement inputs of the PMB. 6 ampmeters are used to give the current reference.

A temperature sensor LM94022 is connected to all temperature measurement inputs of the PMB. A PT100 thermal resistance is placed close to the LM94022 to give the temperature reference.

To verify that the noise amplitude on the analog inputs of the µController is lower than the calculated resolution, measurements are sampled at a frequency of 100Hz during 1 second. Measurements are then loaded on Matlab. The average value is calculated and compared to the reference value. The maximum noise and the efficient value of the noise is calculated.

4.7.2.2 µController digital inputs and outputs

The µController is programmed to read digital inputs and to set digital outputs to the same state as the inputs.

4.7.2.3 15 minutes timer

The 15 minutes timer output is connected to an oscilloscope (single shoot). A stopwatch is used to measure the delay before the output is set at 3.3V and to measure the time that the output stays at 3.3V.

4.7.2.4 Hardware Beacon generator

The HBG output is connected to an oscilloscope. Once the 15 minutes timer set its output to 3.3V and then back to 0V, the HBG should start to send the message. The message and its frequency are verified.

4.7.3 Test results

After the PMB qualification tests (performed from -40ºC up to 60 ºC), we can notify that all average values are within the given accuracy unless V_6 (analog power supply) which is always a bit lower.

Remark: For these tests, the voltage measurement accuracy is $V_{Measured} \pm 2.6\% \pm 10mV$ because the resistances are 1% and not 0.1% like they will be on the flight model.

After trouble shooting on the voltage measuring chain V_6 (analog power supply) to figure out why results are always lower than the reference value, it has been turned out that the problem is coming from the inductances. Analog power supply is separated from the digital power supply with inductances for a less noisy supply. Inductances (which are in parallel for redundancy) have a maximum resistance of 4.7**Ω**. The current passing through these inductances is creating a voltage drop. The reference voltage for the voltage measuring chain V_6 is not 3.3V but 3.3V minus the voltage drop on the inductances. After measuring the new voltage reference (3.26V) we can notify that all average values on voltage measuring chain V_6 are within the given accuracy.

The noise amplitude is not the same on all measuring chains. The 1st measuring chain is always less noisy than the average and the 6th measuring chain is always more noisy than the average.

To find out if the noise is coming from the voltage or current supplies, form the temperature sensor or from something else, I started by setting all temperature inputs at a very stable value. A 1.8V voltage reference has been used for this test.

Temperature reference					
T_1	T_2	T_3	T_4	T_5	T_6
$V_{ref} = 1.791[V] \triangleq -28[^oC]$					

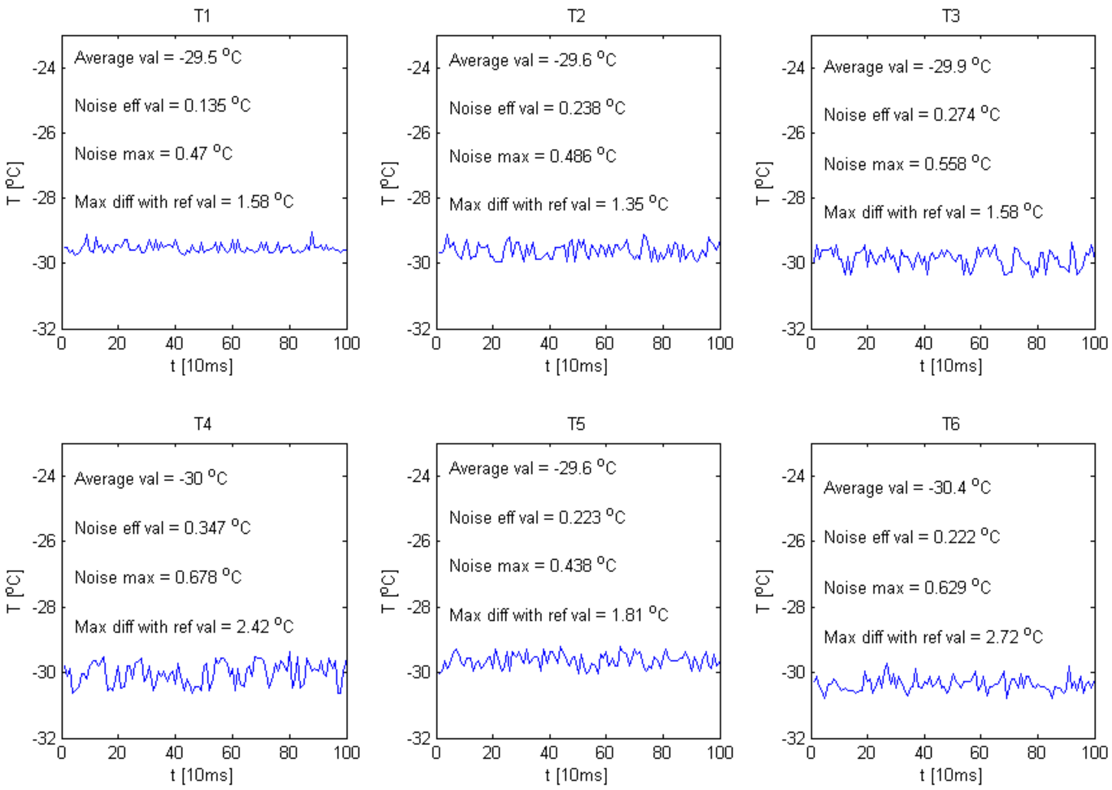


Figure 4-28 : Temperature measurements simulated by a voltage reference

As we can see on this test, the noise is not depending on the stability of the temperature sensor or on the voltage and current supply.

For the qualification tests, the first version of the PMB PCB has been used. On this first version, amplifiers and RC (100Ω, 1nF) which are before the analog inputs of the µController are physically far away from the µController which is not good. Just behind the current measuring chains, on the other side of the PCB, there is the quartz of the µController. On the next version of the PMB PCB, amplifiers and RC will be placed very close to the µController. At that time, new tests would have to be performed to determine whether the problem is coming from the physical location of the amplifiers and RC or not.

When looking at I_4 we can notify that for all negative temperature the result after AD conversion is always higher than the reference value but still in the given accuracy. After measuring the whole measuring scale at ambient temperature and pressure, I could notify that there is an offset varying between 5 and 10mA which is still in the given accuracy. For the moment, we can just notify that for low temperature, there is a quite big offset on I_4. New tests would have to be performed on the next version of the PMB once modifications have been performed.

4.8 PMB modifications

This chapter will detail all changes that have been applied on the PMB during the diploma project. These changes could either come from errors that have been discovered during the PMB mounting and testing, either from a functional change required from other subsystems or from the FMECA (Failure Mode Effect of Critical Analysis).

4.8.1 Changes on the schematic

4.8.1.1 Current limitations

Subsystem current limitation should be turned OFF as default status. The current limitations that have been chosen by Simon Kissling (during his 2 month working on the MB of the Swisscube last summer) are enabled at low level. The PMB schematic has been designed for current limitation enable at high level. This is the reason why pull down resistances have to be replaced by pull up resistances.

4.8.1.2 PMB temperature chip

Gain of the temperature chip (LM94022) has to be set at GS=01 which means pin GS0=1 and GS1=0. On the PMB schematic, signals have been inverted.

4.8.1.3 15 Minutes Timer

With the actual design, the 15 minutes timer stays at 3.3V for only 1 second. To make sure that the nylon of the antenna deployment system melts, the signal of the timer has to stay at 3.3V for at least 2 seconds. Modification: connect wire coming from U8C pin 9 on U6 pin 5 instead of pin 7.

On the first version of the PMB, the signal used to turn on the Beacon subsystem current limitation was the same signal as the one used for the ADS2 subsystem (output of the 15 minutes timer). This signal stays at 3,3V for only 2 seconds (time needed to melt the nylon string). The Beacon current limitation has to stay at 3.3V for the entire lifetime of the satellite. To enable the Beacon current limitation, use the same signal as the signal used to enable the HBG.

4.8.1.4 Unused functions

On the first version of the PMB schematic, the COM subsystem had the opportunity to do a hard reset on the PMB µController. This function will not by used anymore and has to be removed.

On the first version of the PMB schematic, a digital output of the µController (P4.6) was used to turn ON/OFF the HF amplifier. After reflection, it has been decided that it is more logical that the COM subsystem turns ON/OFF its own amplifier. This function will not by used anymore and has to be removed.

4.8.1.5 New functions

To save power, the Beacon Amplifier (on the Beacon subsystem) will only be turned on when there is a message to send. As there are 2 possibilities to send the Beacon signal (software and hardware), we need 2 possibilities to enable the Beacon Amplifier.

The first possibility is when the µController sends the Beacon. In this case, a port of the µController is used to enable the Beacon Amplifier.

The second possibility is when the HBG sends the Beacon. In this case, an output of the binary counter is used to enable the Beacon Amplifier. How to choose the binary output:

Referring to chapter 4.1 we know that 59 address locations are used to store the Beacon message (HB9EG/7). The Beacon Amplifier will be activated while the 7^{th} bit (A6) of the EPROM is at low level (see picture below). When the 7^{th} bit (A6) is at low level, the counter goes trough $2^7/2=64$ address locations which is more then the address location needed to store the message.

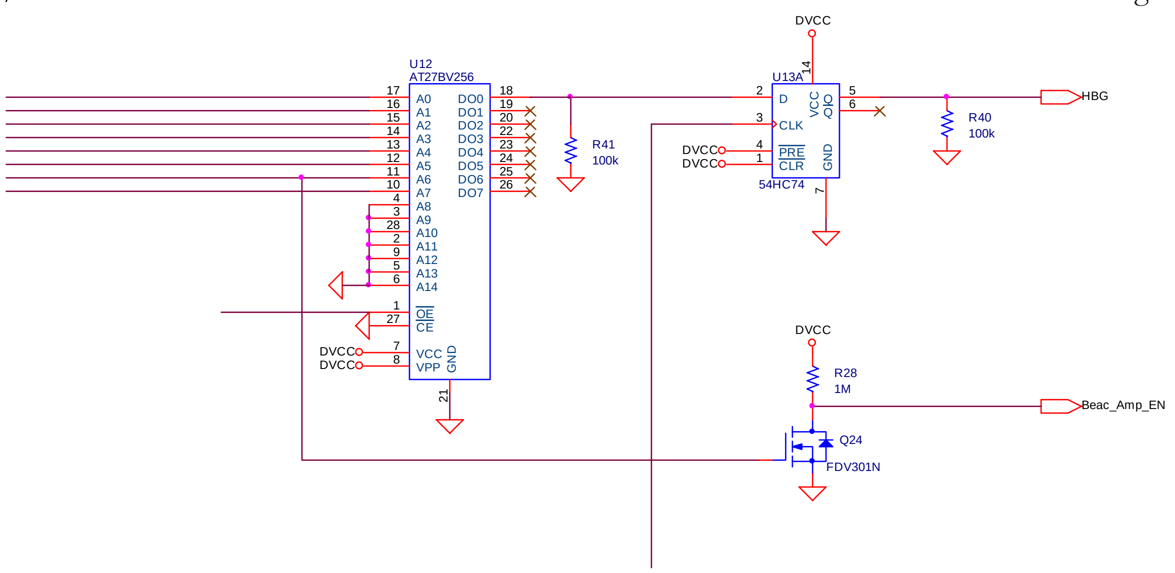


Figure 4-29 : Beacon Amplifier Enable (from the HBG)

As we can see on the schematic, the signal is inverted because we want the Beacon Amplifier to enable while A6 is at 0V.

4.8.2 Physical changes on the layout

4.8.2.1 μController analog inputs

On the analog inputs of the μController, a follower, a resistance and a capacity have to be placed. These components are used to charge the internal capacity of the μController before the conversion is performed. The resistance and the capacity have to be placed physically very close to the μController to avoid a too big resistance between C1 and the analog inputs and to avoid an inductance created by too long traces. For the next version of the PMB schematic, R1 and C1 have to be placed closer to the μController.

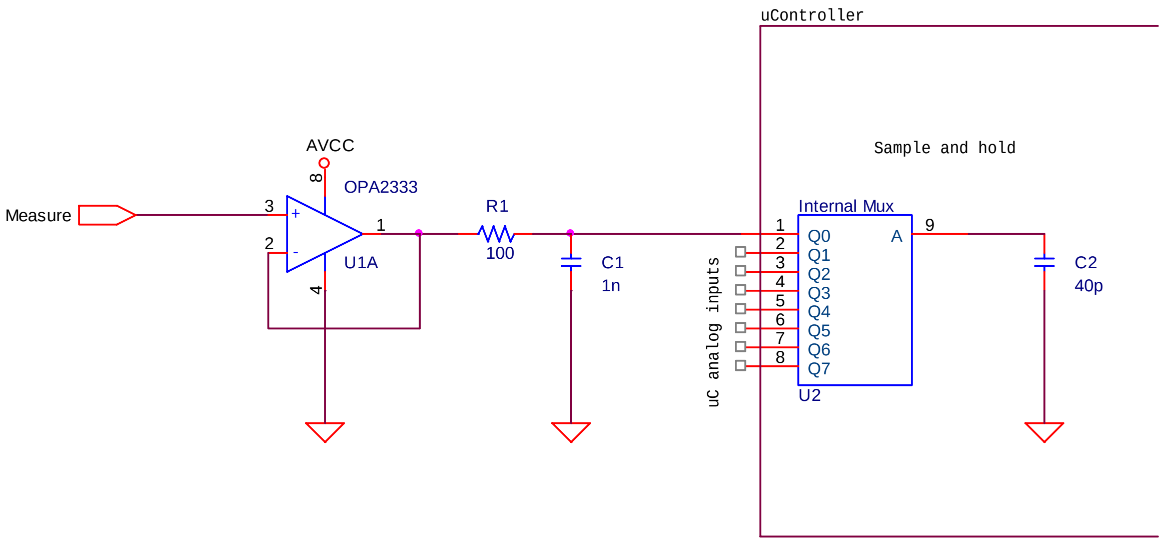


Figure 4-30 : RC filter on the μController analog inputs

4.8.2.2 μController quartz

Try to move the quartz far away from the current measuring chains which are for the moment just behind it, on the other side of the PCB.

First version of the PMB has been designed with an 8MHz quartz. On the next version, a 32768Hz (Farnell 1278039) quartz will be used. The footprint has to be changed.

4.8.2.3 Current measure (shunts)

On the first version of the PMB, 0805 footprint has been used for the 6 shunts. As the shunts have to be designed for 1A, 1206 footprint will be used for the shunts (50mΩ/0.5W).

The traces which are caring the power (traces that are coming from the cells and going through the shunts) have to be designed from 1A.

Design of the actual current measure:

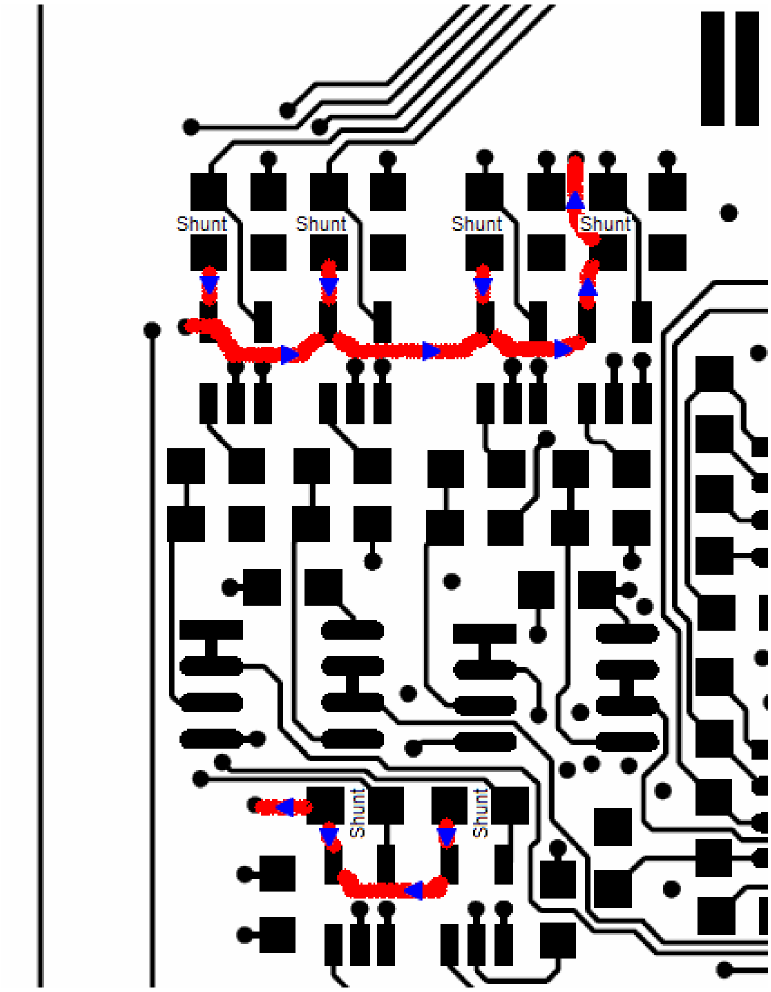


Figure 4-31 : Current traces

Red traces are the traces where the power passes.

Blue arrows show the direction of the current.

As we can see on the upper picture, there is some current passing through the traces that are connecting the shunt to the current sensor. This current creates a voltage drop on these traces. The voltage read on the sensor is not the same as the voltage on the shunt and the current measured is wrong.

For the next version of the PMB PCB, the layout has to be designed in such a way there is no current passing through the traces that are connecting the shunt to the current sensor.

4.8.2.4 Hardware Beacon Generator (HBG)

The footprint used for the EPROM is wrong.

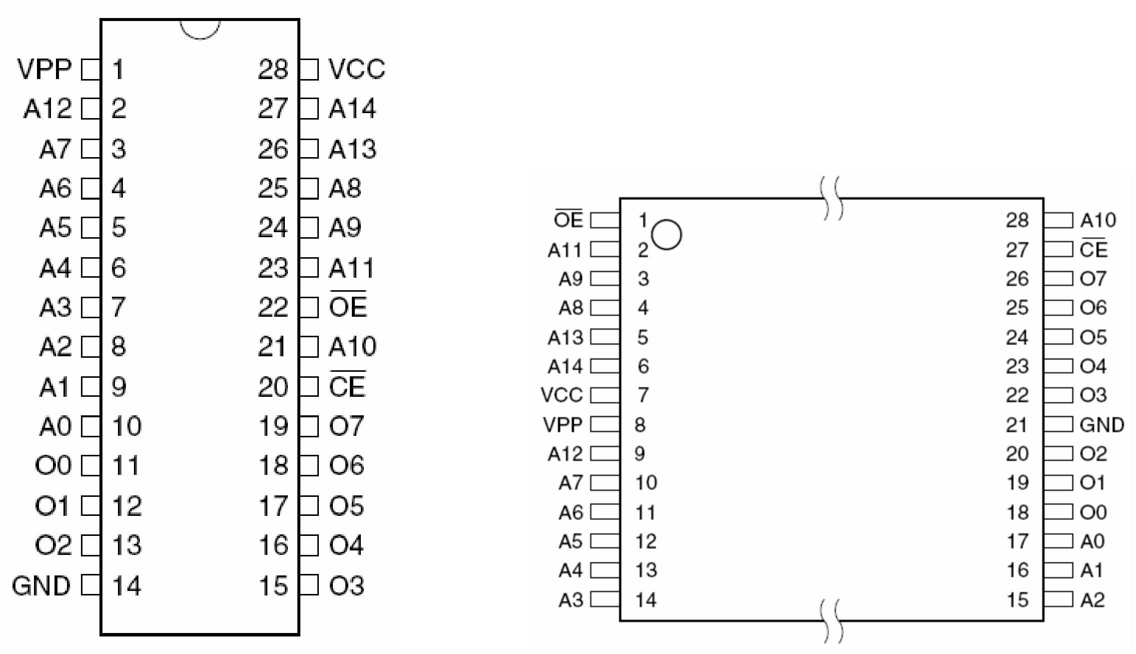


Figure 4-32 : Old footprint (left) new footprint (right)

On the new foot print, do not connect wire going from U11 pin 3 (Q14) to U12 pin 4 (A8)

Initially, the HBG could be unable by the µController when generating the software signal. This solution allowed the satellite to save a very few energy. In case of the µController failure we don't want the HBG to fail as well because enables are not at the expected level. This is why this option will be given up. The HBG will constantly generate the signal (enables will be connected to DVCC or GND).

4.8.2.5 Connector footprint

Footprint of J-MB and J-CB connectors has changed.

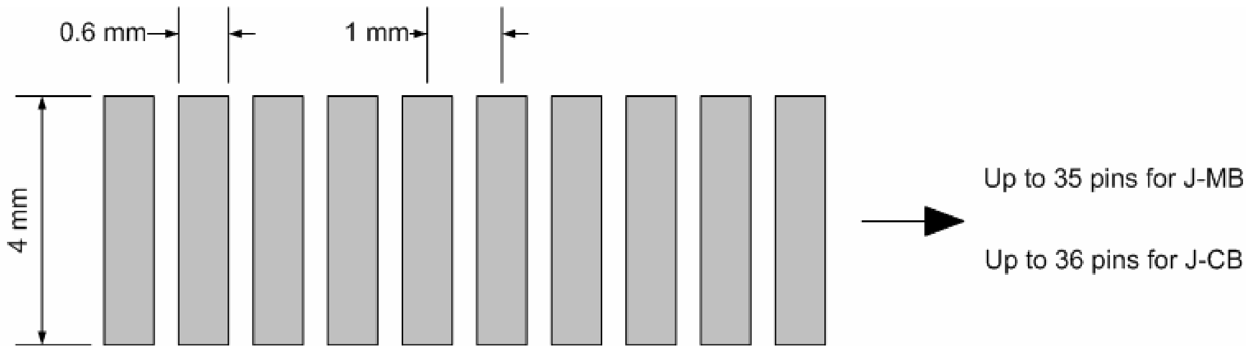


Figure 4-33 : New foot print for J-MB and J-CB

5 MOTHER BOARD

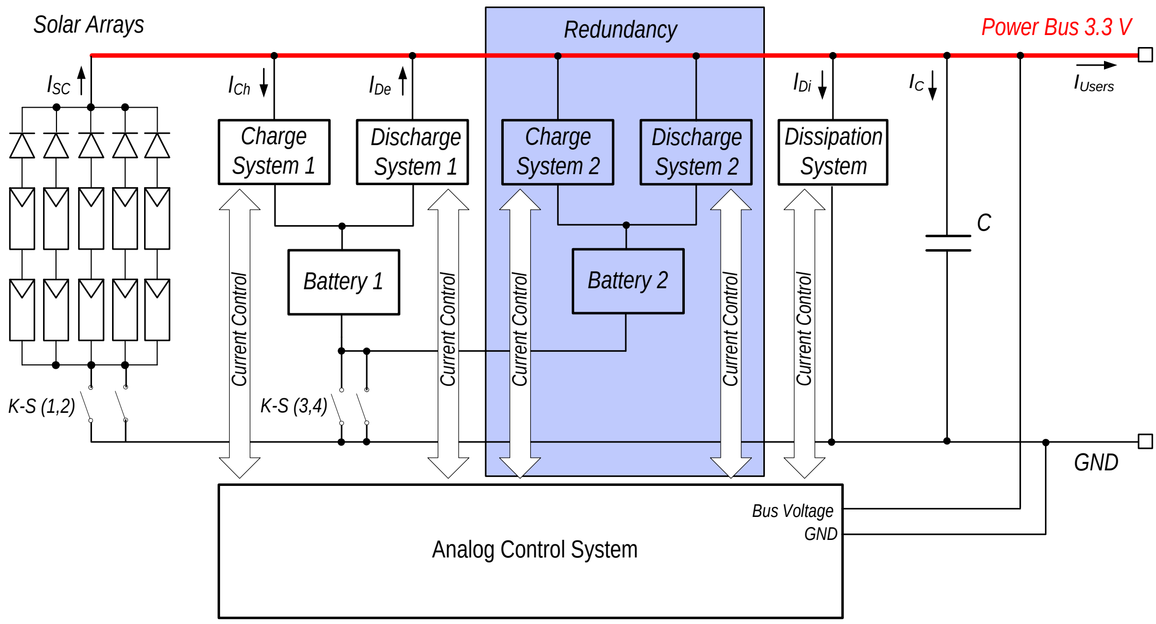


Figure 5-1 : MB bus voltage regulation design

The Mother Board is in charge of the bus voltage regulation by using the solar cells the batteries and DC/DC converters. The bus is then distributed to all subsystems via current limitations.

This board has been designed, mounted and partially tested by Fabien Jordan during his diploma project. The global design of the board has been validated but some problems were still remaining (sometimes the bus voltage stabilized at 0.6V instead of 3.3V when turning on the satellite, etc…).

To make sure that the board has the best reliability possible, the Mother Board design had to be improved. To achieve these modifications, Simon Kissling (student at the Heig-vd) was hired on the project for 6 weeks during summer vacations 2007. By the end of his 6 weeks working on the project, Simon Kissling delivered a brand new modified design.

As the electrical design and the mechanical dimensions have changed, a new layout had to be done.

The new version of the MB has been mounted and tested under space conditions (partial vacuum, at -40°C and 60 °C). After mounting each electrical block (regulation, step-up, step-down, dissipation, etc…) a basic electrical test was performed to validate the PCB layout.

In this chapter, before the test results presentation, the calculation of the protection voltage levels of the batteries is explained. When mounting the MB hysteresis circuit, components values on the schematic did not give the expected results.

5.1 Critical voltage level calculation

Varta Lithium polymer batteries used on the satellite have an operating range from 2.75V to 4.2V. They are delivered with a protection circuit (overcharge detection: 4.325±25mV, overdischarge detection: 2.5±80mV, overcurrent detection 3 - 5.5A). These protections circuits will be removed on the flight model. Overcharge and overdischarge voltage level protection have been designed on the Mother Board.

A step-up is used to charge the batteries and a step-down is used to discharge the batteries. The bus is regulated at 3.3V. Batteries voltage must always be higher then the bus voltage. This is the reason why the voltage levels protection of the batteries are 3.5V (overdischarge) and 4.2V (overcharge).

The maximum voltage of the batteries is protected via the step-up (the maximum output voltage of the step-up is 4.2V) and in case of failure, it is protected via a hysteresis comparator (4.26V).

The minimum voltage of the batteries is protected via a hysteresis comparator (3.48V).

5.1.1 Battery voltage level protection (hysteresis circuit)

When mounting and testing the hysteresis circuits on the mother board, the given value of the resistances on the schematic did not give the expected result. When looking at the datasheet (LTC1442), specific relations are given to calculate the resistance values.

5.1.1.1 Calculation of the resistance values

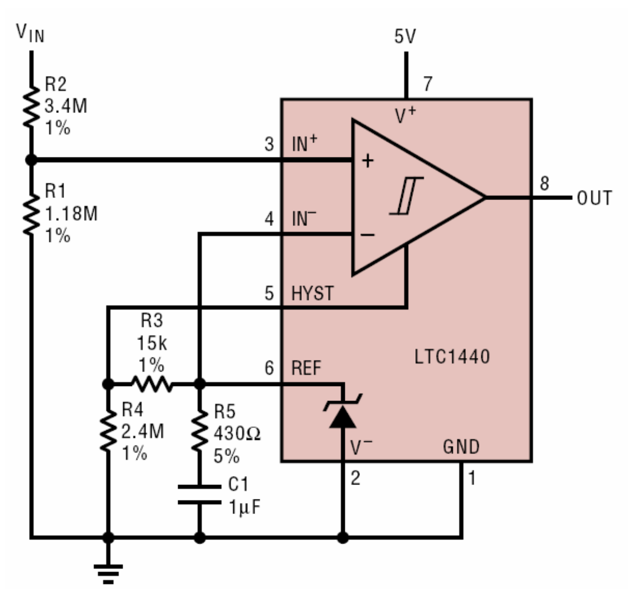


Figure 5-2 : Hysteresis comparator

Relations given in the datasheet to calculate the components value:

$$R_2 = R_1 \cdot \left(\frac{V_{in}}{V_{ref} + \frac{V_{HB}}{2}} - 1 \right) \tag{5.1}$$

$$V_{HB} = V_{HBin} \cdot \frac{V_{ref}}{V_{in}} \tag{5.2}$$

$$R_3 = V_{HB} \cdot 10^6 \tag{5.3}$$

V_{in}: voltage level when the output of the comparator passes from low level to high level.

V_{HBin}: hysteresis of the comparator

R_1 and R_2: set the switching voltage V_{in}

R_3: sets the hysteresis

High level protection

$V_{in} \simeq 4.25[V]$

$V_{HBin} = 0.3[V]$

$R_1 = 249[k\Omega]$

$$V_{HB} = 0.3 \cdot \frac{1.182}{4.25} = 83.4[mV] \tag{5.4}$$

$$R_3 = 83.4 \cdot 10^{-3} \cdot 10^{6} = 83.4[k\Omega] \rightarrow R_3 = 82.5[k\Omega] \tag{5.5}$$

$$R_2 = 249 \cdot 10^{3} \cdot \left(\frac{4.25}{1.182 + \frac{82.5 \cdot 10^{-3}}{2}} - 1 \right) = 616[k\Omega] \rightarrow R_2 = 619[k\Omega] \tag{5.6}$$

Results:

$R_1 = 249 \pm 0.1\% + 25 ppm/^{o}C[k\Omega]$

$R_2 = 619 \pm 0.1\% + 25 ppm/^{o}C[k\Omega]$

$R_3 = 82.5 \pm 1\%[k\Omega]$

$V_{in\_\max} = 4.27[V]$ (Tolerance and temperature drift are taken in account)

$V_{in\_\min} = 4.258[V]$ (Tolerance and temperature drift are taken in account)

$V_{HBin} = 298[mV]$

In case of failure of the step-up maximum output voltage, the battery will stop charging at 4.26V. It will restart charging when the battery voltage passes under 3.96V.

Low level protection

$V_{in} \simeq 3.75[V]$

$V_{HB} = 82.5[mV]$

$R_1 = 210[k\Omega]$

$$V_{HBin} = \frac{V_{HB} \cdot V_{in}}{V_{ref}} = \frac{82.5 \cdot 10^{-3} \cdot 3.75}{1.182} = 262[mV] \quad (5.7)$$

$$R_2 = 210 \cdot 10^3 \cdot \left(\frac{3.75}{1.182 + \frac{82.5 \cdot 10^{-3}}{2}} - 1 \right) = 445[k\Omega] \to R_2 = 432[k\Omega] \quad (5.8)$$

Results:

$R_1 = 210 \pm 0.1\% + 25 ppm/^o C[k\Omega]$

$R_2 = 432 \pm 0.1\% + 25 ppm/^o C[k\Omega]$

$R_3 = 82.5 \pm 1\%[k\Omega]$

$V_{in\_max} = 3.745[V]$ (Tolerance and temperature drift are taken in account)

$V_{in\_min} = 3.735[V]$ (Tolerance and temperature drift are taken in account)

$V_{HBin} = 261[mV]$

The battery will stop discharging at 3.48V. It will restart discharging when the battery voltage passes over 3.74V.

5.1.2 Battery voltage level protection (max output of the step-up)

To regulate its output voltage level, the step-up uses a feedback pin. The step-up keeps the feedback voltage level always at the same value (1.22V). By connecting a resistances divisor between the output of the step-up and the feedback pin, it is possible to set the output voltage level.

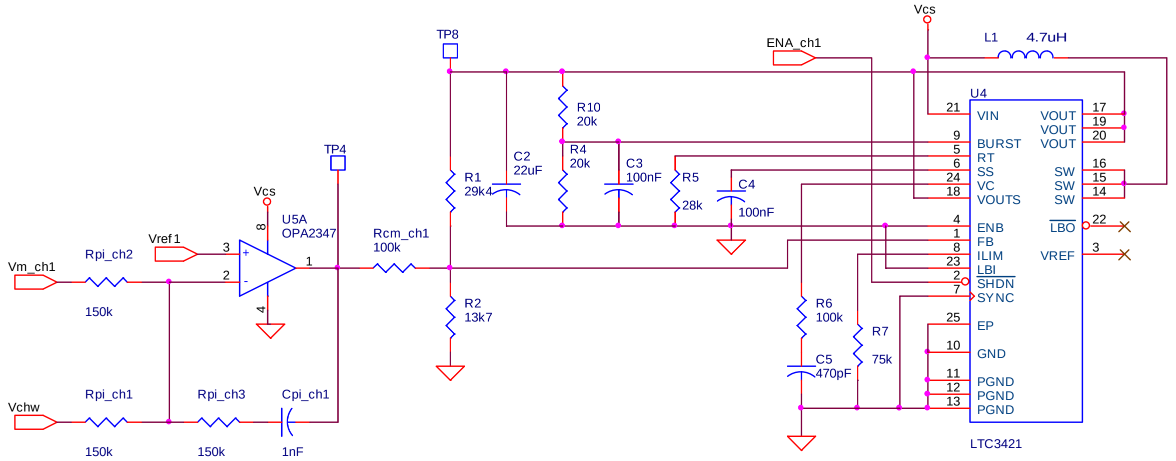


Figure 5-3 : Step-up

The resistances divisor between the output of the step-up and the feedback pin is made with R1, R2 and Rcm_ch1. The resistance divisor ratio can be changed by changing the voltage level on TP4 with the PI regulator.

Knowing the feedback voltage level, the maximum output of the step-up will be calculated.

The maximum output of the step-up is given by the following relation:

$$V_{out\_max} = \frac{V_{fb\_max}}{R_{cm\_ch1} // R_2} \cdot \left[R_1 + \left(R_{cm\_ch1} // R_2 \right) \right] \qquad 5.9$$

Resistances R1, R2 and Rcm_ch1 have a tolerance of ±0.1%+25ppm/ °C.

The temperature drift will not be taken in account in the next calculation because resistances are placed next to each other and their value fluctuation with the temperature won't have any influence on the resistance ratio.

The maximum output voltage is when TP4 is at 0V.

$$V_{out\_max} = \frac{1.22}{\frac{100k \cdot 13k7}{100k + 13k7}} \cdot \left[29k4 + \left(\frac{100k \cdot 13k7}{100k + 13k7} \right) \right] = 4.197[V] \tag{5.10}$$

When taking in account the components tolerance (0.1% for the resistances), the maximum high output voltage is when TP4 is at 0V, when Rcm_ch1//R2 have the smallest value (tolerance), when R1 has the biggest value (tolerance) and when the feedback voltage level is at its maximum value (tolerance available in datasheet).

$$V_{out\_max} = \frac{1.244}{\frac{(100k \cdot 0.999) \cdot (13k7 \cdot 0.999)}{(100k \cdot 0.999) + (13k7 \cdot 0.999)}} \cdot \left[(29k4 \cdot 1.001) + \left(\frac{(100k \cdot 0.999) \cdot (13k7 \cdot 0.999)}{(100k \cdot 0.999) + (13k7 \cdot 0.999)} \right) \right] \tag{5.11}$$

$$V_{out\_max} = 4.285[V]$$

When taking in account the components tolerance (0.1% for the resistances), the minimum high output voltage is when TP4 is at 0V, when Rcm_ch1//R2 have the biggest value (tolerance), when R1 has the smallest value (tolerance) and when the feedback voltage level is at its minimum value (tolerance available in datasheet).

$$V_{out\_max} = \frac{1.196}{\frac{(100k \cdot 1.001) \cdot (13k7 \cdot 1.001)}{(100k \cdot 1.001) + (13k7 \cdot 1.001)}} \cdot \left[(29k4 \cdot 0.999) + \left(\frac{(100k \cdot 1.001) \cdot (13k7 \cdot 1.001)}{(100k \cdot 1.001) + (13k7 \cdot 1.001)} \right) \right] \tag{5.12}$$

$$V_{out\_max} = 4.108[V]$$

5.1.3 Battery voltage protection analysis

5.1.3.1 Overdischarge protection

For the minimal battery voltage level protection, even if the components tolerances are taken in account, the battery voltage will never be lower than the bus voltage.

5.1.3.2 Overcharge protection

For the maximal battery voltage level protection, when the components tolerances are taken in account there is a risk of an overlap between the maximum output voltage of the step-up and the hysteresis circuit.

Ideally, the hysteresis circuit should never shut the step-up down. That means that the hysteresis switching level should be higher than the step-up maximum output voltage.

The only solution to avoid the overlap is to turn down the maximum output voltage of the step-up. Increasing the hysteresis switching level is not possible because the maximum battery voltage level would not be respected any more.

This is the reason why the actual design will be kept knowing that the histeresis circuit could turn the step-up OFF before it reaches its maximum output voltage level.

5.2 MB tests

The MB needs first to be tested under ambient temperature and pressure before being tested under space conditions.

5.2.1 What has to be verified

The functions of the bus voltage regulation board have to be verified. The following points are tested:

- The bus voltage must always be regulated at 3.3V±10% when applying a charging or a discharging current step of 1A.
- The step-up must shut down until the bus reaches 2.93V.
- The step-up must shut down when the battery reaches 4.26V.
- The step-down must shut down when the battery reaches 3.5V.
- The step-up must turn ON when more power is available than what is needed for the subsystems and when the battery voltage is under 3.9V.
- The step-down must turn ON when less power is available than what is needed for the subsystems and when the battery voltage is over 3.8V.
- Dissipation system must turn ON when more power is available than what is needed for the subsystems and to charge the batteries. The temperature of the components must be measured when dissipating the maximum power (~3W).
- When the power delivered from the solar cells is equal to the power consumed by the subsystems, batteries should not deliver or absorb any current. In this specific configuration, it will be verified that the step-up is not working at the same time as the step-down. We do not want one battery to be discharged and charge the other one.

5.2.2 How tests are performed

Most of these tests are performed under ambient temperature and pressure during the mounting of the board. Only critical functions like the dissipation, current steps, bus rise when releasing the kill switches, offset on the voltage references are measured under partial vacuum at -40ºC and 60 ºC.

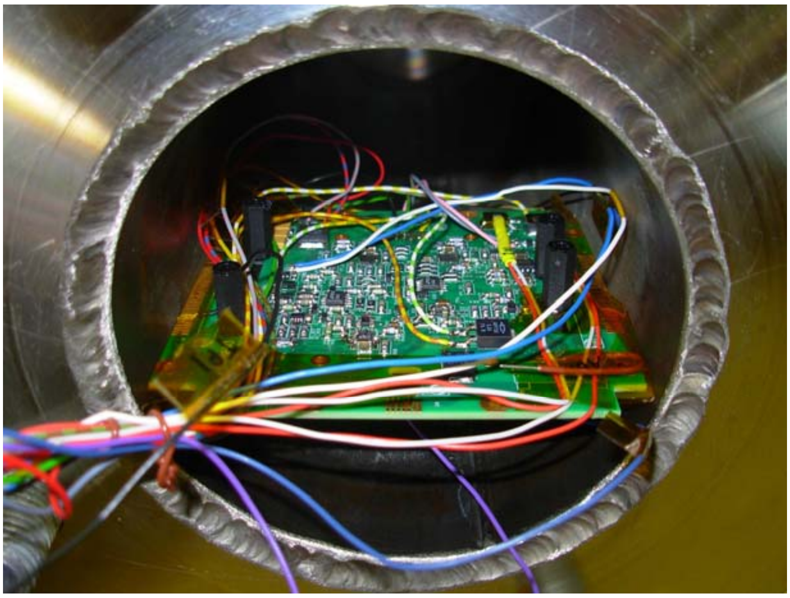


Figure 5-4 : MB in vacuum chamber

5.2.3 Overcharge and overdischarge detection tests

During this test, critical voltage protection levels have been measured.

Test conditions:

- This specific test has been performed under ambient pressure at 25±2ºC.
- A voltage supply was used to simulate the batteries voltage level.

Overcharge protection:

Maximum output voltage of the step-up	
Step-up 1	Step-up 2
4.176 [V]	4.175 [V]

Overcharge protection (hysteresis circuit)			
Turn OFF Step-up 1	Turn ON Step-up 1	Turn OFF Step-up 2	Turn ON Step-up 2
4.28 [V]	3.94 [V]	4.28 [V]	3.94 [V]

Overdischarge protection:

Overdischarge protection (hysteresis circuit)			
Turn OFF Step-down 1	Turn ON Step- down 1	Turn OFF Step- down 2	Turn ON Step- down 2
3.77 [V]	3.46 [V]	3.78 [V]	3.46 [V]

5.2.4 3.3V bus regulation

The following tests have been performed to verify different critical points of the bus voltage regulation:

- Bus voltage rise when releasing the kill switches.
- Discharging current step to simulate the antennas deployment.
- Charging current step to simulate when passing from the eclipse to the sun.
- Verify that the step-up and the step-down are not working together when the current delivered by the solar cells is equal to the current consumed by the subsystems.

When the satellite gets out of the P-Pod, the kill switches are released and turn the satellite ON. Kill switches will activate a circuit (on the Battery Board) with CMOS transistors to connect the negative terminals of the batteries to the GND of the satellite. When performing the following tests, the Battery Board was not available. This is the reason why a standard switch has been used to simulate the Battery Board.

Figure 5-5 : Switch used for the following tests

This switch has been used to perform the discharging and the charging current steps.

On the following oscilloscope prints, picks are visible on the signals (bus voltage or batteries current). These picks are coming from bounces into the switch shown on Figure 5-5.

5.2.4.1 Bus stabilization after kill switches release

This test has been performed to verify the rise of the bus when the kill switches are released.

Test at ambient temperature and pressure

Test conditions:

- This specific test has been performed under ambient pressure at 25±2ºC.
- A load consuming 18mA was connected to the bus to simulate the EPS PMB consumption.
- Batteries were charged at 4.2V±80mV.

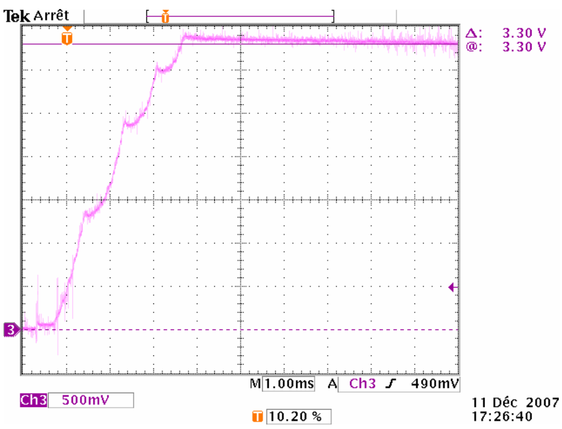


Figure 5-6 : 3.3V Bus rise when releasing the kill switches (Batteries 1 and 2 connected)

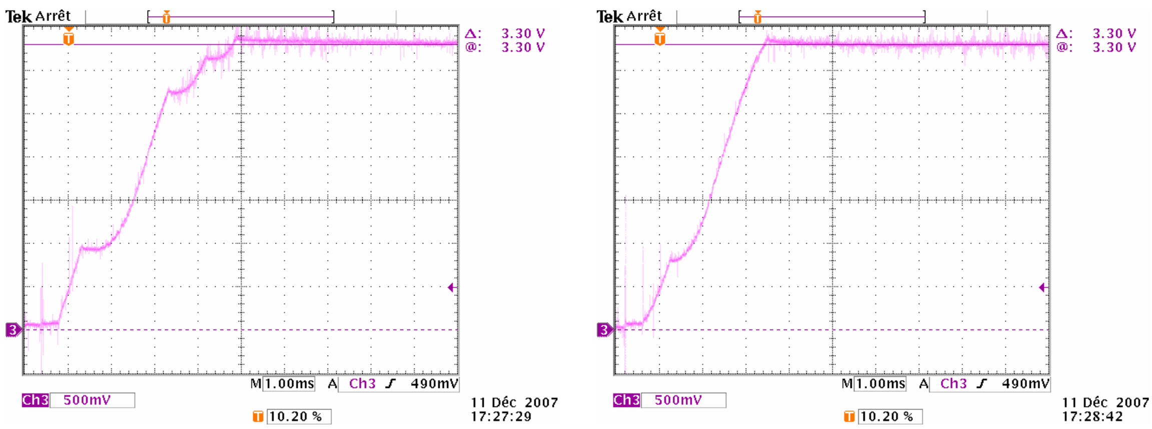


Figure 5-7 : 3.3V Bus rise when releasing the kill switches (left: Battery 1, right: Battery 2)

Ch3: bus voltage

Test at 60 ºC

Test conditions:

- This specific test has been performed at $1.5 \cdot 10^{-2}$mbar / 60±2ºC.
- A load consuming 18mA was connected to the bus to simulate the EPS PMB consumption.
- Batteries were charged at 4.2V±80mV.

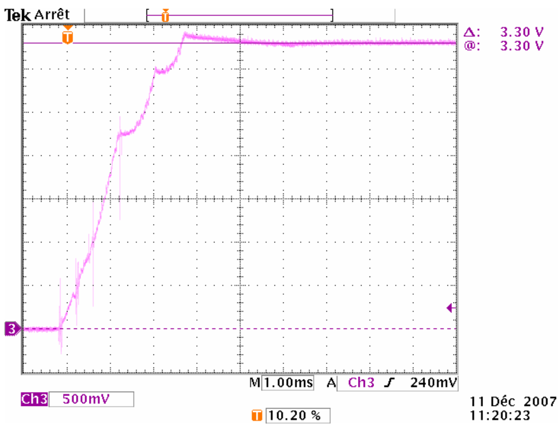


Figure 5-8 : 3.3V Bus rise when releasing the kill switches (Batteries 1 and 2 connected)

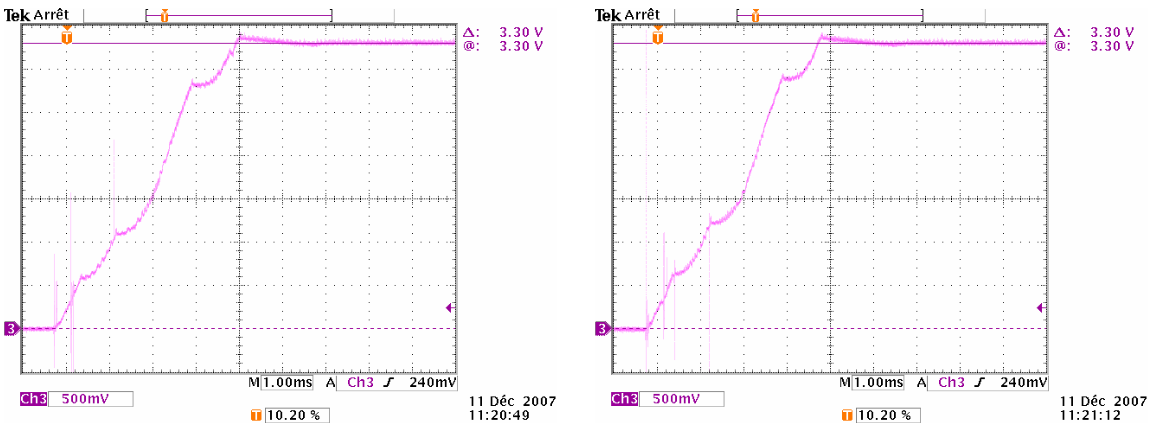


Figure 5-9 : 3.3V Bus rise when releasing the kill switches (left: Battery 1, right: Battery 2)

Ch3: bus voltage

Test at -40 °C

Test conditions:

- This specific test has been performed at $7.5 \cdot 10^{-1}$mbar / -40±2°C.
- A load consuming 18mA was connected to the bus to simulate the EPS PMB consumption.
- Batteries were charged at 4.2V±80mV.

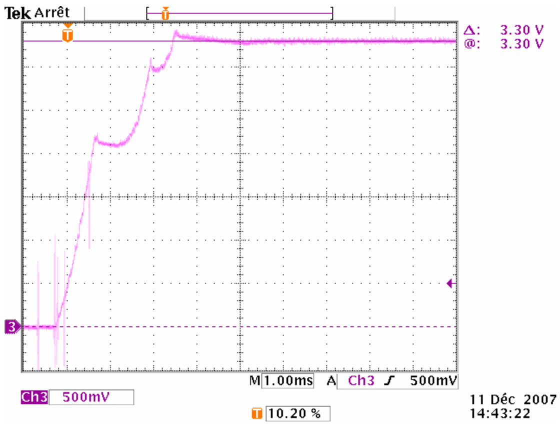


Figure 5-10 : 3.3V Bus rise when releasing the kill switches (Batteries 1 and 2 connected)

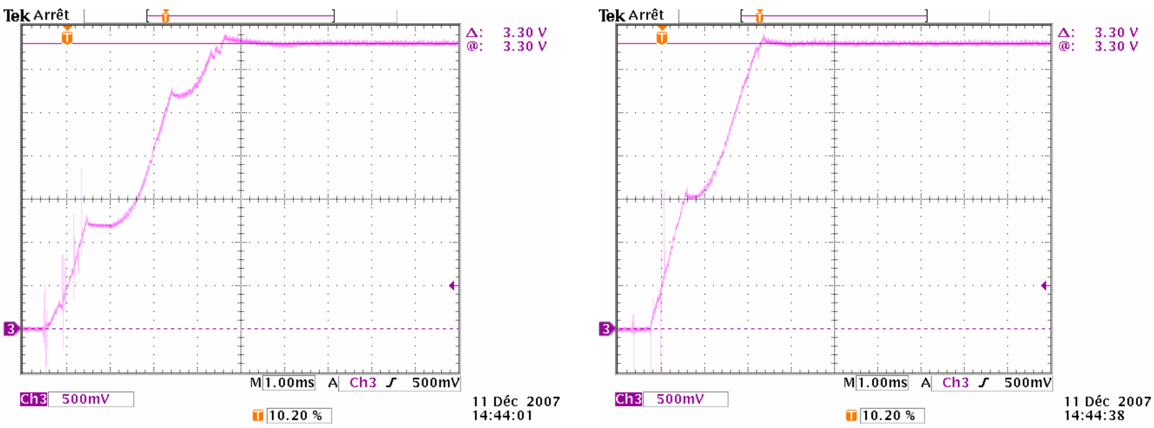


Figure 5-11 : 3.3V Bus rise when releasing the kill switches (left: Battery 1, right: Battery 2)

Ch3: bus voltage

Bus stabilization after kill switches release analysis

For all configurations (temperature and number of batteries) the bus is stabilized at 3.3V±10% in less than 4ms. Assuming that picks are coming from the switch bounces, when using the Battery Board (no more bounces) the bus will rise at 3.3±10% in less than 2ms. The over run is about 100mV which is very low (3%).

The 15 minutes timer reset of the PMB lasts 28ms. The rising time of the MB bus is enough fast to guaranty a perfect reset of the PMB 15 minutes timer.

5.2.4.2 Discharging current step (1A)

This test has been performed to verify the voltage drop of the bus when applying a discharging current step of 1A (antennas deployment simulation). A resistance of 3.3Ω plus wires has been used to perform the following tests and this is why the current is 870mA. A variable resistance has also been used to verify that discharging batteries with 1A is possible.

Test at ambient temperature and pressure

Test conditions:

- This specific test has been performed under ambient pressure at 25±2°C.
- A load consuming 870mA was connected to the bus.
- Batteries were charged at 4.2V±80mV.

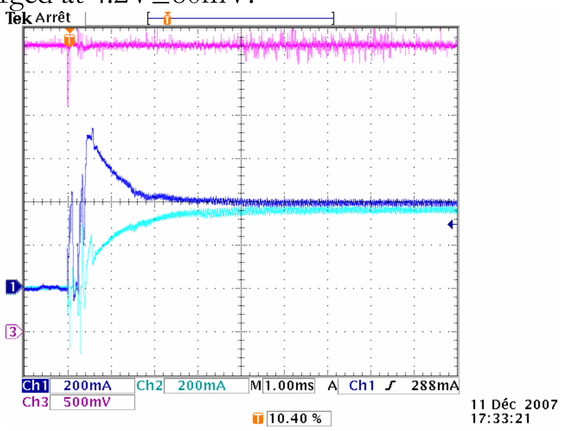


Figure 5-12 : Discharging current step (Batteries 1 and 2 connected)

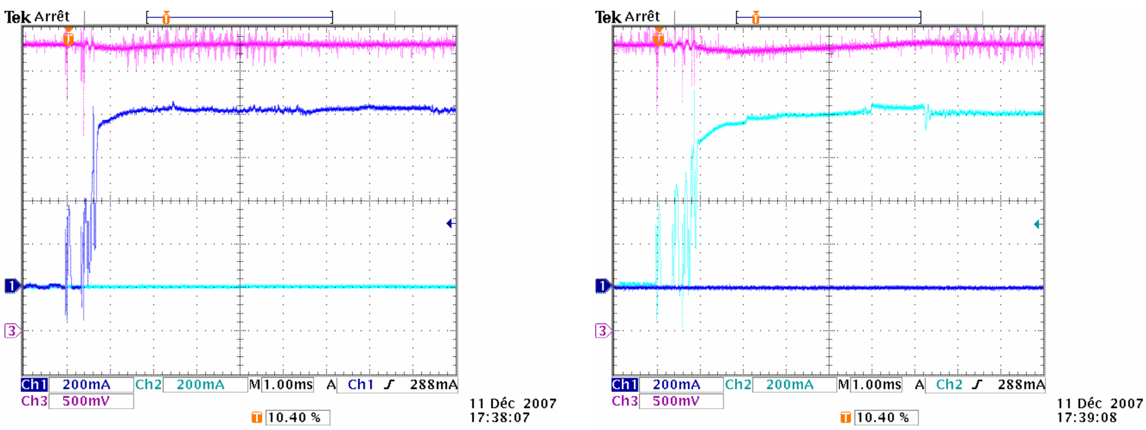


Figure 5-13 : Discharging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Test at 60 °C

Test conditions:

- This specific test has been performed at $1 \cdot 10^{-2}$mbar / 60±2°C.
- A load consuming 870mA was connected to the bus.
- Batteries were charged at 4.2V±80mV.

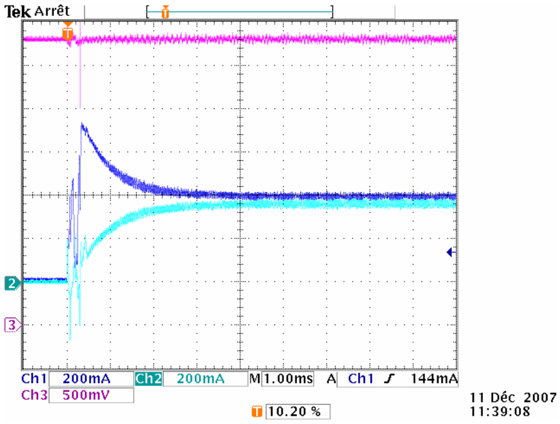


Figure 5-14 : Discharging current step (Batteries 1 and 2 connected)

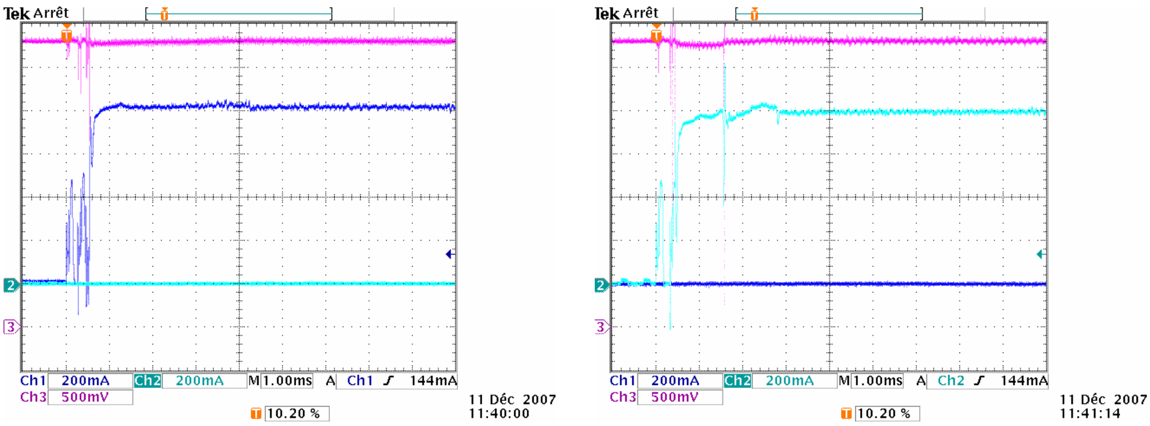


Figure 5-15 : Discharging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Test at -40 °C

Test conditions:

- This specific test has been performed at $7.5\cdot10^{-1}$mbar / -40±2°C.
- A load consuming 870mA was connected to the bus.
- Batteries were charged at 4.2V±80mV.

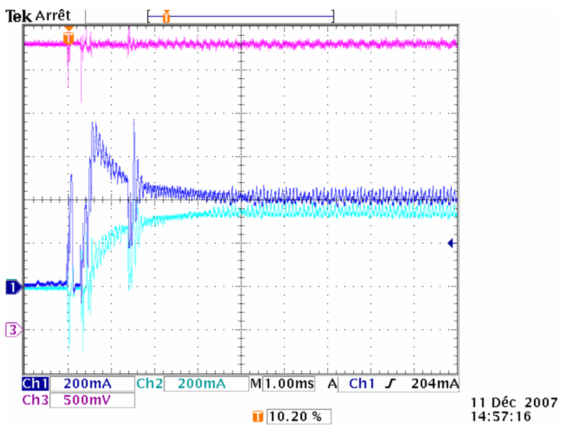


Figure 5-16 : Discharging current step (Batteries 1 and 2 connected)

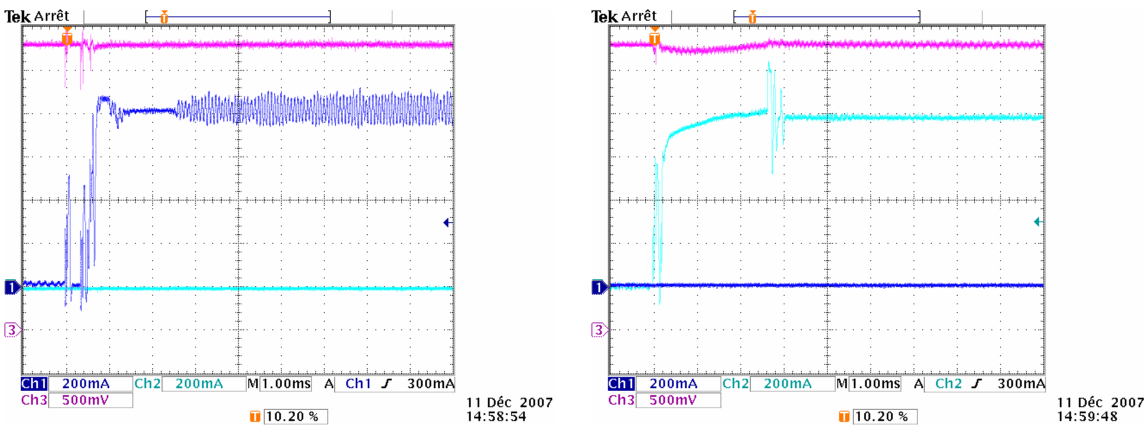


Figure 5-17 : Discharging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Discharging current step analysis

When the MB is turned ON and a current step of 870mA is applied, the bus is perfectly regulated when using fully charged batteries (4.2V).

During the test, when trying to apply a current step of 870mA with partial charged batteries (4.0V), the step-down was constantly trying a soft start and then it was turned OFF by the hysteresis circuit.

The problem was coming from the wires connecting the batteries to the MB and the battery voltage level. The wires connecting the batteries to the MB via the vacuum chamber connectors have a resistance of 0.6-0.7Ω. When trying to consume 870mA, the voltage drop is very important (the own voltage drop of the battery + voltage drop on the wires). The voltage of the battery visible by the hysteresis circuit on the MB passes under the critical voltage protection level of the battery when consuming a big current. The hysteresis circuits turn the step-down OFF. When no more current is consumed, the voltage passes over the critical voltage protection level and the step-down turn back ON. The phenomenon is visible on the following figure.

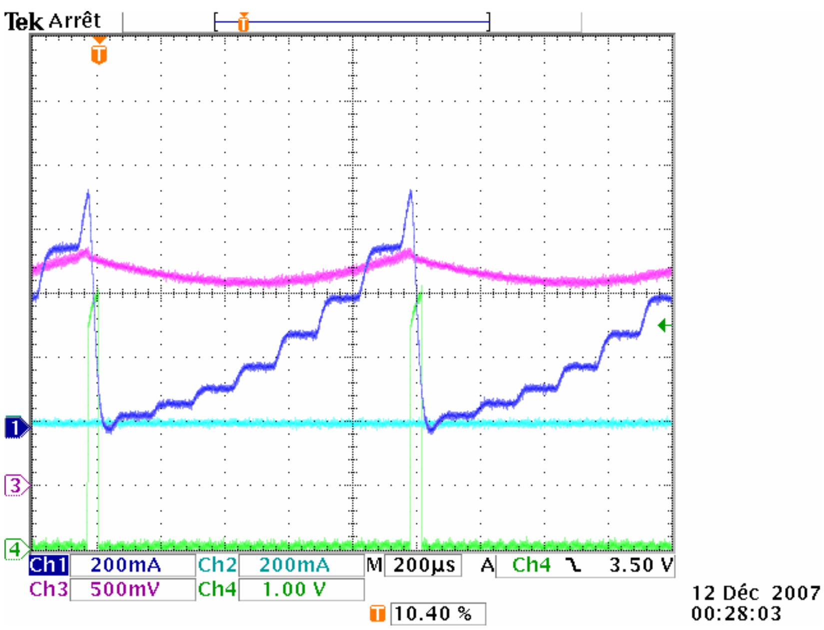


Figure 5-18 : Phenomenon when consuming to much current with a discharged battery

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Ch4: output of the hysteresis circuit (step-down OFF when Ch4=0V)

On the flight model, we have to be very careful to the entire resistance connecting the batteries to the step-down (wires and CMOS connecting the negative terminals via the Battery Board).

These tests respect 4_EPS_22_03 requirements

5.2.4.3 Charging current step (1A)

This test has been performed to verify the voltage over run of the bus when applying a charging current step of 1A.

Test at ambient temperature and pressure

Test conditions:

- This specific test has been performed under ambient pressure at 25±2°C.
- A current supply delivering 1010mA was connected to the bus.
- Batteries were charged at 3.8V±60mV.

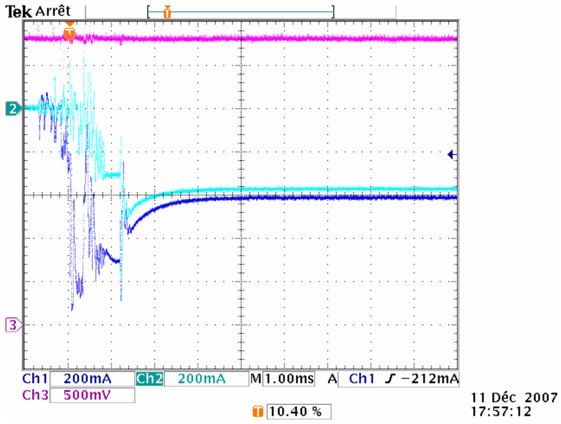


Figure 5-19 : Charging current step (Batteries 1 and 2 connected)

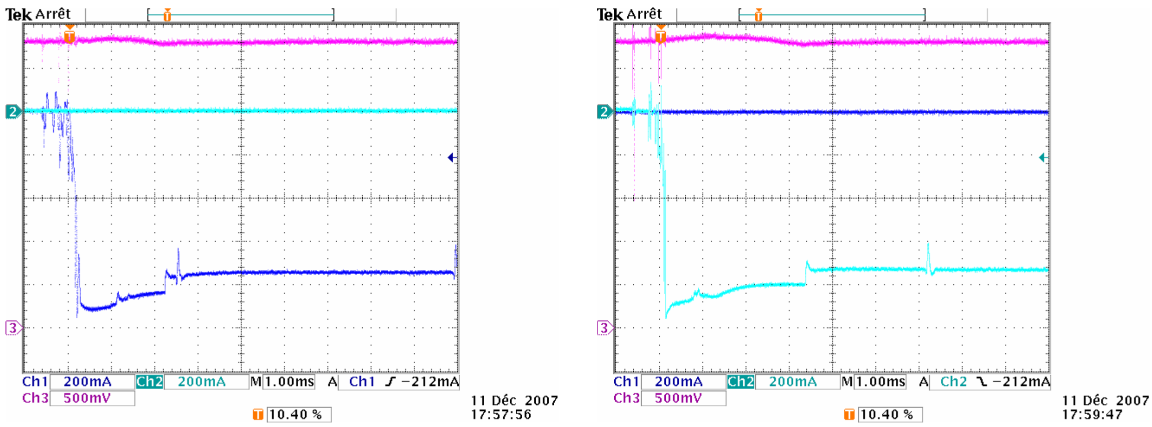


Figure 5-20 : Charging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Test at 60 °C

Test conditions:

- This specific test has been performed at $1.5 \cdot 10^{-2}$mbar / 60±2°C.
- A current supply delivering 1010mA was connected to the bus.
- Batteries were charged at 3.8V±60mV.

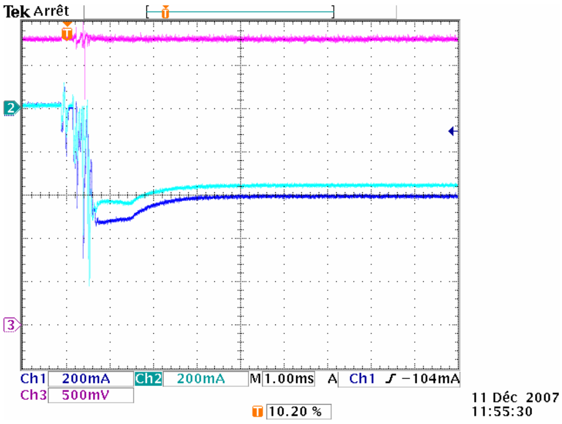
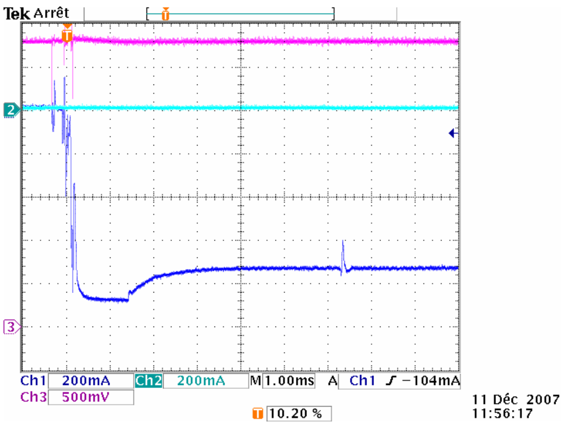


Figure 5-21 : Charging current step (Batteries 1 and 2 connected)



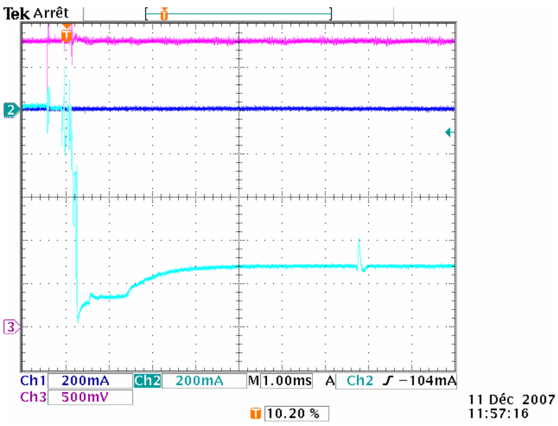


Figure 5-22 : Charging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Test at -40 °C

Test conditions:

- This specific test has been performed at $7.5 \cdot 10^{-1}$mbar / -40±2°C.
- A current supply delivering 1010mA was connected to the bus.
- Batteries were charged at 3.8V±60mV.

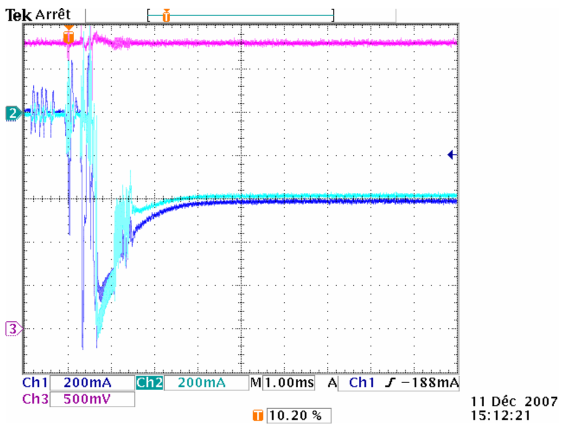


Figure 5-23 : Charging current step (Batteries 1 and 2 connected)

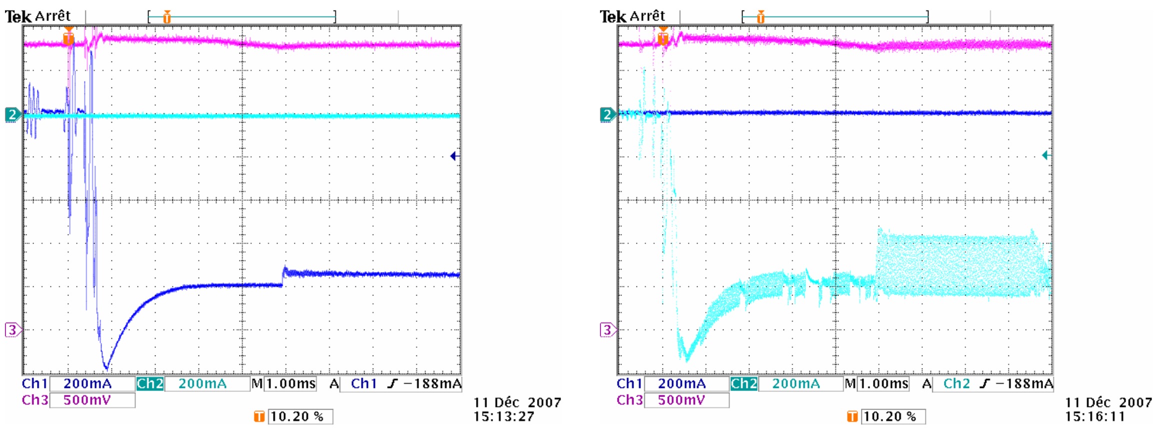


Figure 5-24 : Charging current step (left: Battery 1, right: Battery 2)

Ch1: current into battery 1

Ch2: current into battery 2

Ch3: bus voltage

Charging current step analysis

A charging current step of 1A is only possible when the batteries are enough discharged. In other terms, we can say the maximum charging current depends on the batteries voltage level (maximum step-up output voltage is 4.2V). The surplus current is dissipated in the dissipation circuits.

These tests respect 4_EPS_21_03 requirements.

5.2.4.4 Step-up / step-down working at the same time

When the power delivered from the solar cells is equal to the power consumed by the subsystems, batteries should not deliver or absorb any current.

This test has been performed to verify that the step-up and the step-down are not working together because of small offsets on the command signals.

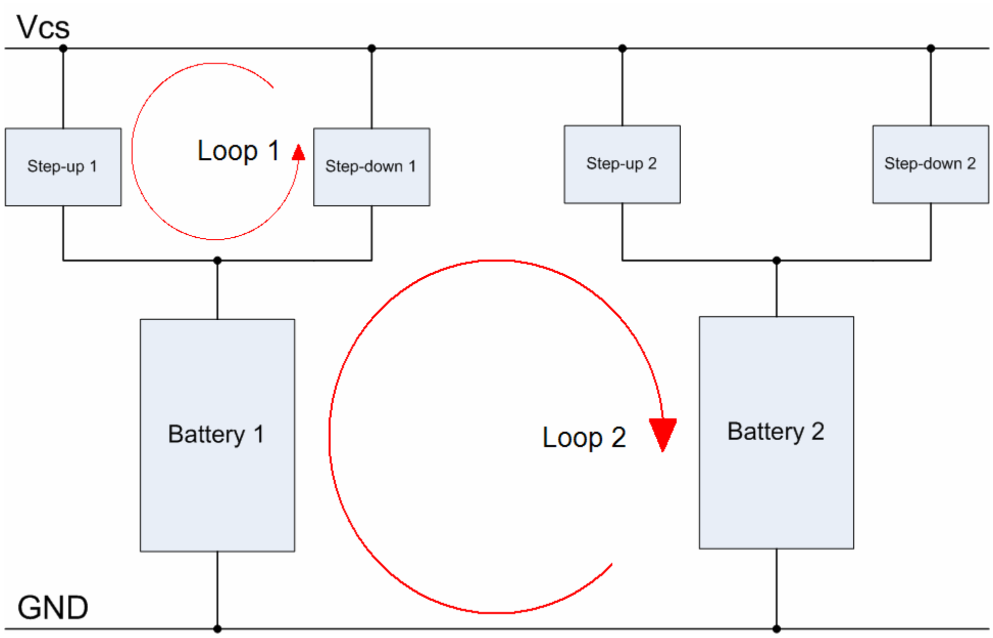


Figure 5-25 : 2 possible current loops between the step-up and the step-down

As we can see on the upper figure, 2 current loops are possible when the current delivered by the solar cells is equal to the current consumed by the subsystems. It is not possible to verify if there is a current loop 1 but it is possible to verify if there is a current loop 2 by measuring the batteries current.

During the test, only the loop 2 is verified.

Three different voltage references are used on the MB for the regulation. The output voltages of each voltage reference are measured to verify the temperature drift.

Test at ambient temperature and pressure

Test conditions:

- This specific test has been performed under ambient pressure at 25±2ºC.
- A load consuming 200mA / 400mA was used.

$Vref_{U2}$	$Vref_{U3}$	$Vref_{U7}$
$1.251[V]$	$1.252[V]$	$1.250[V]$

Test at 60 ºC

Test conditions:

- This specific test has been performed at $1.5 \cdot 10^{-2}$mbar / 60±2ºC.
- A load consuming 200mA / 400mA was used.

$Vref_{U2}$	$Vref_{U3}$	$Vref_{U7}$
$1.251[V]$	$1.249[V]$	$1.250[V]$

Test at -40 ºC

Test conditions:

- This specific test has been performed at $7.5 \cdot 10^{-1}$mbar / -40±2ºC.
- A load consuming 200mA / 400mA was used.

$Vref_{U2}$	$Vref_{U3}$	$Vref_{U7}$
$1.250[V]$	$1.253[V]$	$1.250[V]$

Step-up / step-down working at the same time analysis

For the tests, one load consuming 200mA and another consuming 400mA were connected to the bus separately. A current supply was also connected to the bus. The current limitation of the current supply was increased until the current delivered by the batteries was equal to 0A. At this point, I verified that both batteries were either delivering a few current or absorbing a few current.

In all configurations, batteries where always working together (charging or discharging at the same time).

The temperature drifts on the voltage references are very low and should not influence the bus voltage regulation.

5.2.5 Dissipation

During the day time of the satellite, all surplus current coming from the cells would have to be dissipated. The dissipation circuit is a critical function of the MB. When power is going to be dissipated, the satellite will be at its hottest temperature. If the thermal design is not appropriated, the components of the dissipation circuit will overheat and burn. The 3 dissipation circuits must be able to dissipate 4.6W, which means 1.53W per circuit (requirements 4_EPS_22_04).

This test has been performed to verify the maximum power that can be dissipated in each dissipation circuit (3 dissipation circuits at all) without saturating the dissipation circuit (saturation of the operational amplifier and the transistor).

First one dissipation circuit is tested at ambient temperature and pressure. Then all 3 dissipation circuits are tested under vacuum at 60ºC.

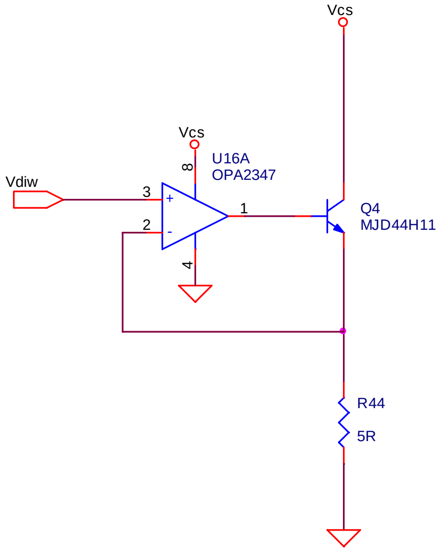


Figure 5-26 : Dissipation circuit

V_{diw} is the command coming from the proportional regulator (P=131 V/V). The collector-emitter saturation voltage of the transistor is 1V.

The theoretical maximum power that can be dissipated in one dissipation circuit (without increasing significantly the voltage of the bus) is when the transistor is saturated.

Calculation of the maximum power dissipated (assuming that the gain of the regulator P is infinite and that the voltage of the bus stays at 3.31V):

$$P_{\max\_calculated\_1\_circuit} = P_R + P_Q = \frac{U_R^2}{R} + U_{C-E\_sat} \cdot I \qquad 5.13$$

$$P_{\max\_calculated\_1\_circuit} = \frac{(3.31-1)^2}{5} + 1 \cdot \frac{(3.31-1)}{5} = 1.53[W]$$

This power represents the following current:

$$I_{P\_\max\_calculated\_1\_circuit} = \frac{U_R}{R} = \frac{(3.31-1)}{5} = 462[mA] \quad 5.14$$

5.2.5.1 Test at ambient temperature and pressure

Test conditions:

- This specific test has been performed under ambient pressure at 25±2°C.
- Both batteries have been disconnected to make sure all the current injected on the bus was dissipated in the dissipation circuit and not injected into the batteries.
- Only one dissipation circuit was mounted (R_{44} and Q_4).

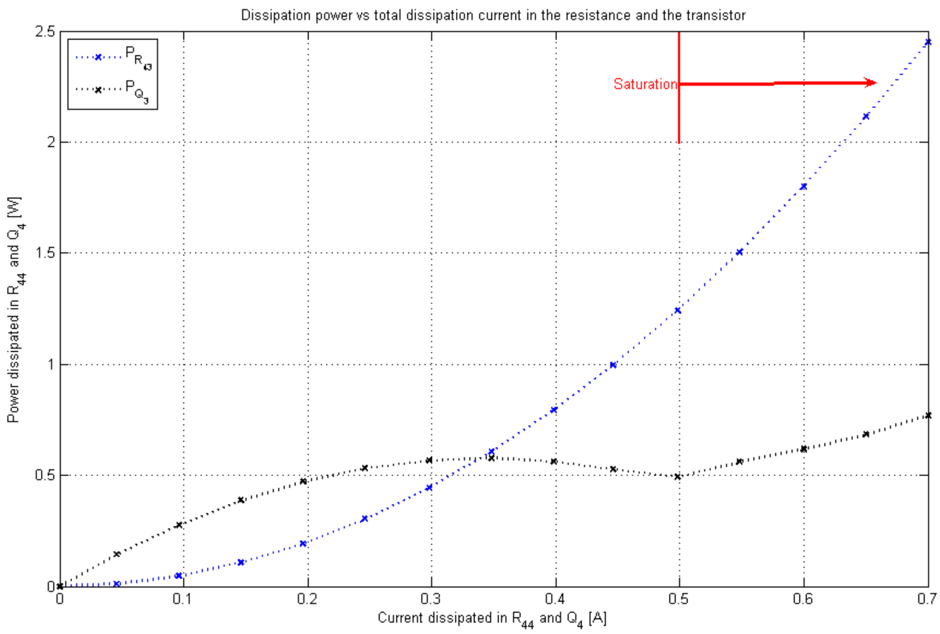


Figure 5-27 : Power dissipated in R and Q

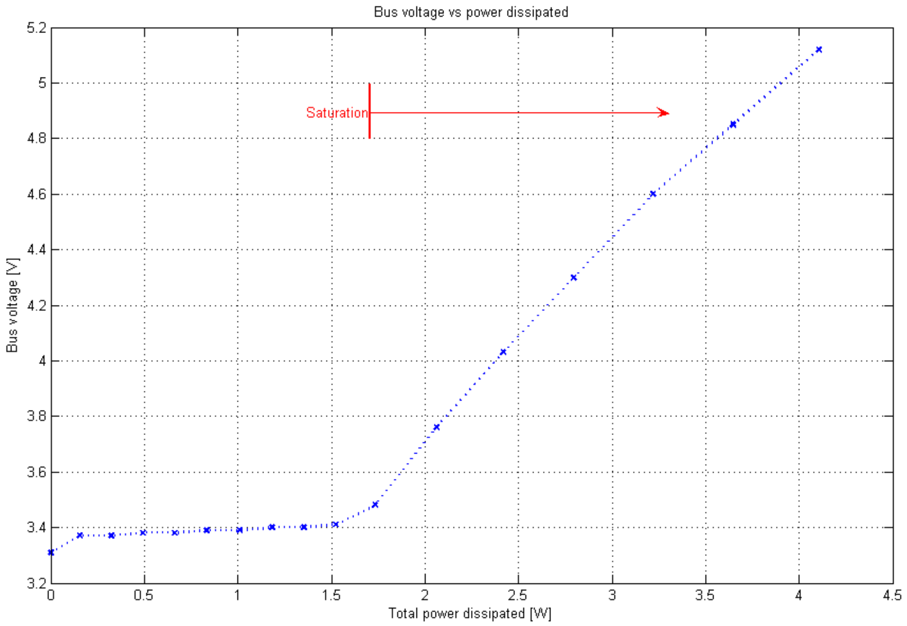


Figure 5-28 : Voltage of the bus

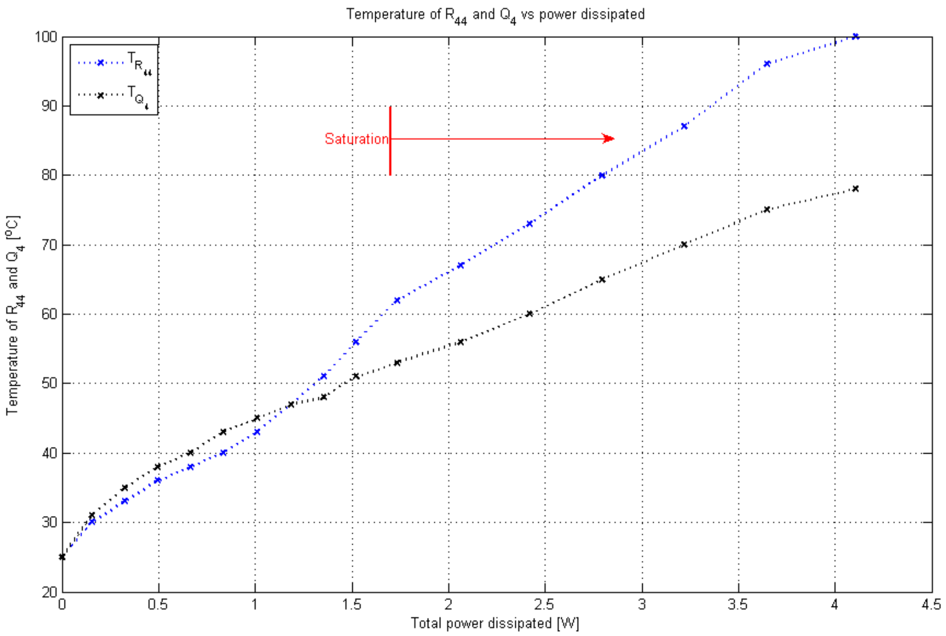


Figure 5-29 : Temperature of R and Q

Dissipation under ambient pressure and temperature analysis

On Figure 5-27 and Figure 5-28 we can see the saturation of the dissipation circuit. The maximal power dissipated before the saturation is 1.6W. When dissipating more power per dissipation circuit, the only solution is to increase the bus voltage level. This phenomenon is visible on Figure 5-28.

5.2.5.2 Test under vacuum at 60°C

Test conditions:

- This specific test has been performed at $1.5 \cdot 10^{-2}$mbar / 60±2°C.
- Both batteries have been disconnected to make sure all the current injected on the bus was dissipated in the dissipation circuit and not injected into the batteries.
- All three dissipation circuits were mounted.

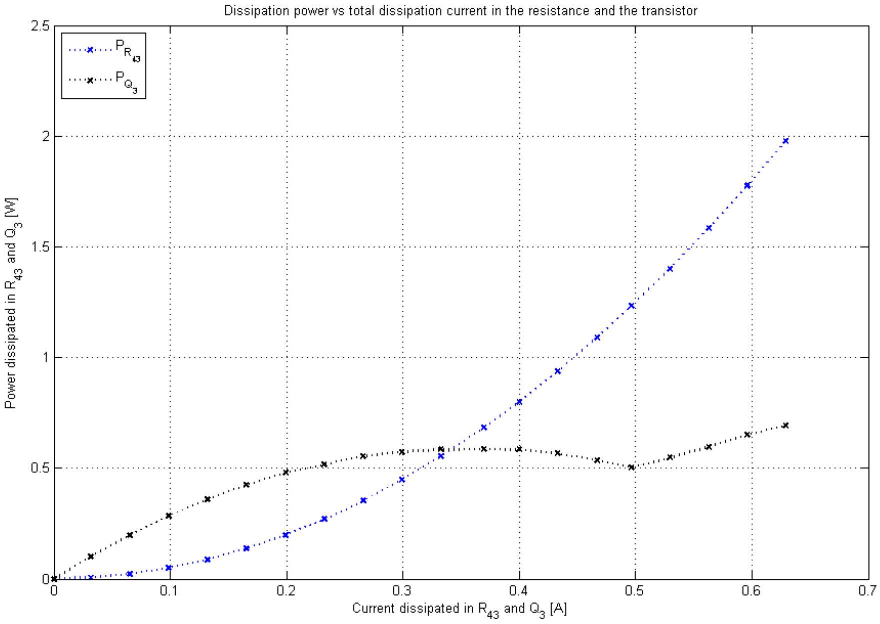


Figure 5-30 : Power dissipated in R_{43} and Q_3

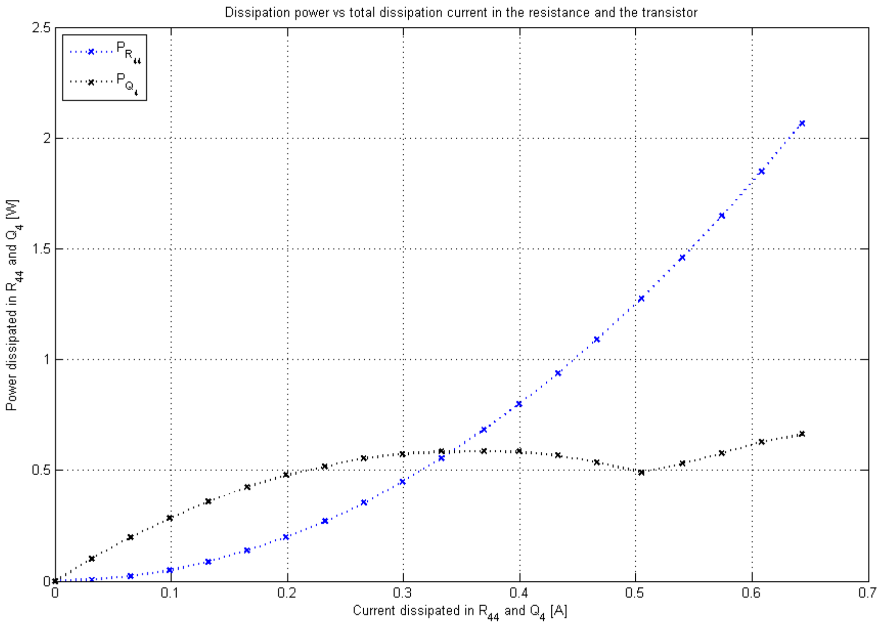


Figure 5-31 : Power dissipated in R_{44} and Q_4

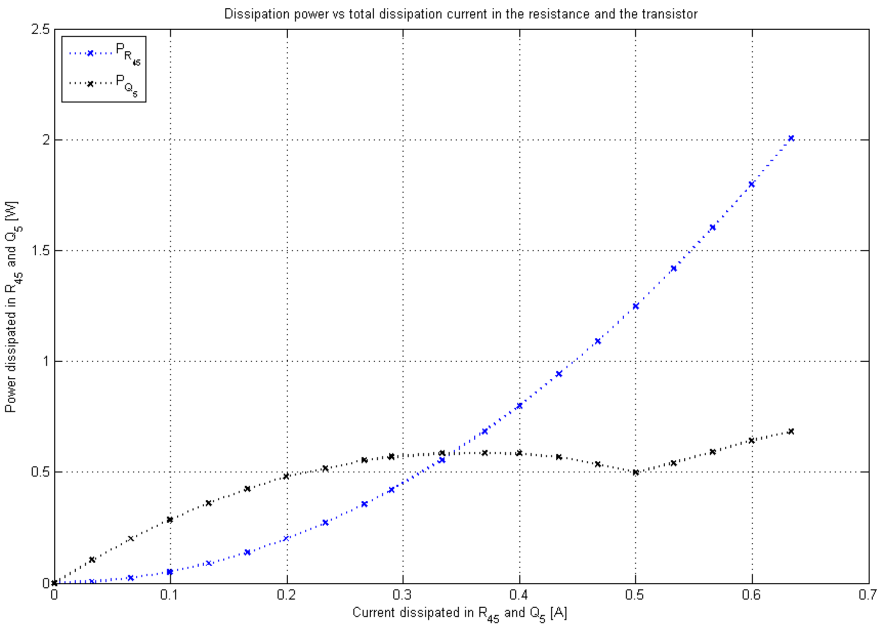


Figure 5-32 : Power dissipated in R_{45} and Q_5

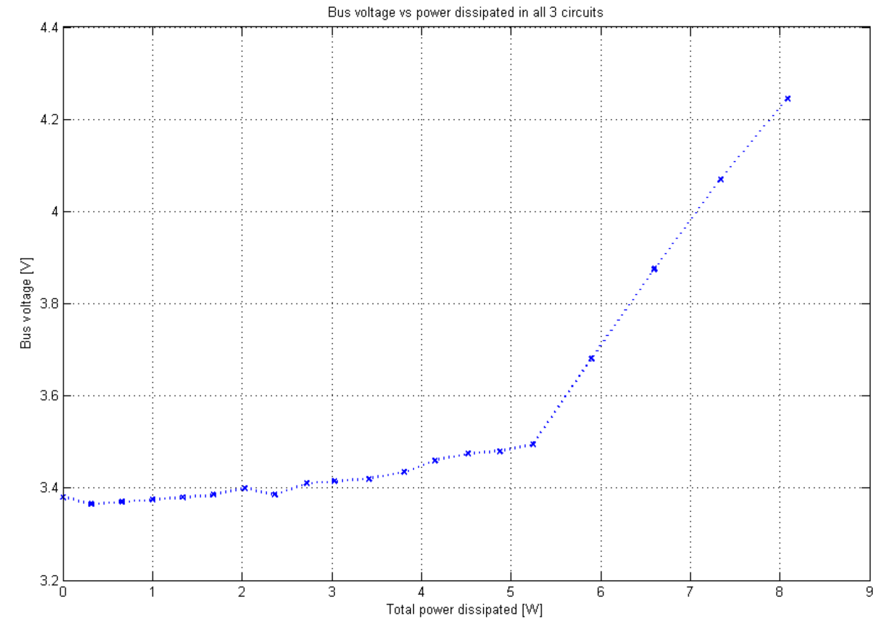


Figure 5-33 : Voltage of the bus

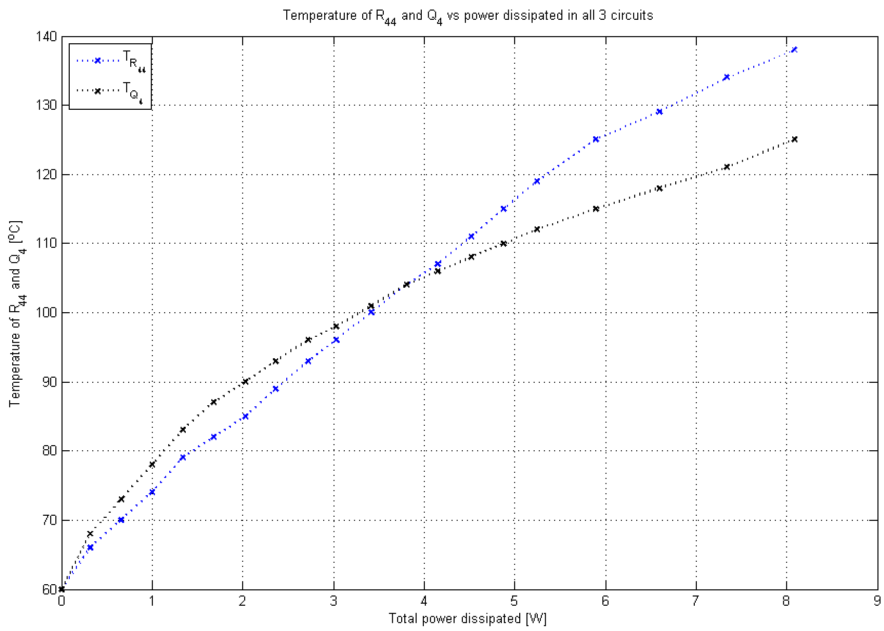


Figure 5-34 : Temperature of R_{44} and Q_4

The maximum power dissipated before the saturation is 5.2W. Knowing that the maximal expected power that is going to be dissipated is 4.6W, the dissipation circuit is so far well design.

Under space conditions (vacuum) there is no convection which helps the components to cool down. This is the reason why no cooler can by fixed on the components. For thermal dissipation, the resistance footprint is connected to the thermal layer and the transistor footprint is connected to the power supply layer.

When dissipating 4.6W the components package temperature rise to about 100ºC which is quite high. The transistor junction temperature might even be higher (not possible to measure).

When testing the dissipation circuit under vacuum at 60ºC, the MB was placed in unfavorable conditions. The PCB was isolated to the vacuum chamber by using Kapton tape (Figure 5-4). The heat could only be dissipated on the MB PCB. When the MB is going to be fixed on the structure, thermal conductivity via the thermal layer will help to dissipate the heat into the structure. A thermal drain could be added and connected on the component package and to the structure.

5.2.5.3 Dissipation conclusion

The dissipation circuit has to be tested in real conditions (under vacuum, at 60ºC, MB connected to the structure) to measure the temperature of the components when dissipating 4.6W.

If one circuit fails, the redundancy is not respected. When discussing with Fabien Jordan who is working on the project, he said that the maximum power that is going to be dissipated might be a bit lower. If requirements changes and 2 circuits are able to dissipate the power, redundancy will be respected if the component temperature, when using only 2 dissipation circuits to dissipate P_{max}, stays under 100ºC. The maximum junction temperature of the transistor is 125ºC and we want to have a certain reserve. If requirement doesn't change, a 4^{th} dissipation circuit needs to be added.

If the maximum power can be dissipated with all circuits minus one (for redundancy) but the components temperature gets to high, a thermal drain can be added on the components to connect them directly to the structure

Requirement 4_EPS_22_04 is so far respected but without redundancy.

5.2.6 Power efficiency of the MB

By performing the following tests, the power efficiency of the MB, the power efficiency of the batteries and the global power efficiency of the system will be quantify.

Requirements 4_EPS_23_03/4 are asking a power efficiency of 85% for the charge and the discharge (The chemical efficiency of the battery and the consumption of the MB are taken in account) witch means a global power efficiency (charge + discharge) of 72%.

5.2.6.1 Global power efficiency calculation

This test will give the global power efficiency of the MB (including the power efficiency of the batteries when charging and discharging).

The power efficiency is given by following relation:

$$\eta[\%] = \frac{E_{discharge}}{E_{charge}} \cdot 100 \qquad 5.15$$

To perform this test, batteries are discharged until both hysteresis protections circuit turned both step-down OFF. Batteries are then charged to a certain voltage level. Current injected on the bus, voltage of the bus and the discharging time are noted to be able to calculate the energy injected. Batteries are then discharged until both hysteresis protections circuits turn both step-down OFF. Current consumed by the load, voltage of the bus and the time are noted to be able to calculate the energy restituted.

The power efficiency of the MB changes with the charging and the discharging current. Biggest the current is, biggest the power lost on the internal resistance of the batteries and on the current measuring shunt is important.

High current is used to perform this test so the result will be close to the worse case.

Dissipation circuits are disconnected to make sure no current is dissipated instead of being injected into the batteries.

To calculate the energy injected into the batteries, the following relation is used:

$$E_{Charge} = \int_0^t U_{bus} \cdot I_{bus}\, dt \qquad 5.16$$

To calculate the energy restored by the batteries, the following relation is used:

$$E_{discharge} = \int_0^t U_{bus} \cdot I_{bus}\, dt \qquad 5.17$$

Batteries charge

	V_{CS} [V]	I_{VCS} [mA]	P [W]	t [sec]	E [J]
1	3.313	903	2.992	240	2694
2	3.313	803	2.66	2520	1352
3	3.313	752	2.491	2280	152
4	3.312	701	2.322	1800	51
E_{Charge}=17282 [J]					

Batteries discharge

	V_{CS} [V]	I_{VCS} [mA]	P [W]	t [sec]	E [J]
1	3.308	718	2.375	5160	12256
E_{Charge}=12256 [J]					

Power efficiency

$$\eta_{MB+Batteries}[\%] = \frac{E_{discharge}}{E_{charge}} \cdot 100 = \frac{12256}{17282} = 71\% \qquad 5.18$$

5.2.6.2 Batteries power efficiency calculation

This test will give the power efficiency of the battery when charging and discharging.

Same relations than the one in chapter 5.2.6.1 are used to calculate the power efficiency of the battery.

To perform this test, the battery is discharge on a load. Just before disconnecting the battery the voltage level of the battery is noted.

The battery is then charged with a constant current. The starting and the final voltage on the battery (while charging) are noted. For the stored energy calculation we assume that the voltage on the battery increases linearly while charging on the working range (3.5V to 4V). The average value is calculated and multiplied by the charging current and time of the charge to determine the stored energy.

The battery is then discharged on the same load than before until its voltage reaches the voltage notify at the beginning of the test. The starting and the final voltage on the battery and current in the load (while discharging) are noted. For the restored energy calculation we assume that the voltage on the battery decreases linearly while discharging on the working range (4V to 3.5V). If the voltage decreases linearly, the current in the load decreases linearly. The average values (voltage and current) are calculated and multiplied together and then multiplied with the discharging time to determine the restored energy.

Batteries charge

V_{Bat_start}[V]	V_{Bat_end} [V]	I_{Bat} [mA]	P [W]	t [sec]	E [J]
3.98	4.358	750	3.127	3600	11256

Batteries discharge

V_{Bat_start}[V]	V_{Bat_end} [V]	I_{load_start} [mA]	I_{load_end} [mA]	P [W]	t [sec]	E [J]
4.005	3.57	895	800	3.21	2640	8474

Power efficiency

$$\eta_{Battery}[\%] = \frac{E_{discharge}}{E_{charge}} \cdot 100 = \frac{8474}{11256} = 75\% \qquad 5.19$$

5.2.6.3 Power efficiency of the MB calculation

The power efficiency of the MB multiplied by the power efficiency of the batteries gives the global power efficiency. Calculation of the MB power efficiency:

$$\eta_{MB+Battery} = \eta_{MB} \cdot \eta_{Battery} \tag{5.20}$$

$$\eta_{MB} = \frac{\eta_{MB+Battery}}{\eta_{Battery}} = \frac{0.71}{0.75} = 95\% \tag{5.21}$$

5.2.6.4 Power efficiency conclusion

Requirements 4_EPS_23_03/4 are not respected (for only 1 %). As we can notify, the MB has very high power efficiency. The problem is coming from the batteries. This test has been performed with batteries which were 1 year old. If this test is performed with brand new batteries, the global power efficiency might be higher. Anyway, the MB design can be validated because it is almost impossible to increase the power efficiency of the electronic which is already very high.

6 CONCLUSION

This final chapter will resume the test results, the problems encountered during the diploma project, the further work and the critical functions which have to be carefully taken in account during the integration tests.

The last subchapter is dedicated to my personal impressions after working on the SwissCube project.

6.1 Power Management Board

During the PMB thermal tests, no major problem was encountered. Some modifications need to be performed on the next version. Nevertheless, the first version of the PMB, which has been delivered to the Space Center, can be used for the first integration tests.

6.1.1 Points we need to be aware for the integration tests

6.1.1.1 Hardware Beacon Generator (HBG) message

The EPROM mounted on the PMB which will be used for the electrical integration tests has been programmed to transmit the message «swisscube» in Morse instead of «HB9EG/1».

6.1.1.2 Beacon amplifier enable

The µController and the HBG should be able to enable the beacon amplifier. On the PMB which will be used for the electrical integration tests, this function doesn't exist. The corresponding pin on the MB connector must not be connected. The pull up resistance on the Beacon subsystem will activate the Beacon amplifier.

6.1.1.3 Measuring chains

RC filters on the analog inputs of the µController are physically far away from the µController. The measurements could be a little bit noisy.

6.2 Mother Board

The MB passed with success the thermal qualification tests. However, there are some details we have to be careful about for the further electrical and mechanical integration tests.

6.2.1 Functions which need to be tested or validated

Two critical functions need to be validated during the electrical integration tests:

- Discharging the batteries with a high current.
- Dissipating 4.6W without overheating the components and check redundancy.

One function needs to be tested during the electrical integration tests:

- Subsystems current limitations need to be tested with all subsystems.

6.2.1.1 Discharging batteries with a high current

When discharging a battery with a high current (1A), the own voltage drop of the battery is quite important. In additional to the battery voltage drop, there is a voltage drop on the wires connecting the battery to the MB and a voltage drop on the CMOS transistor on the Battery Board.

Depending on the battery voltage level and on the current consumed, the voltage on the hysteresis circuit can pass under the critical low voltage level. The step-down will shut-down and when no more current is consumed, there is no more voltage drop and the step-down turns back ON. The system enters in oscillation.

It is very important to test this point on the final model, especially when the batteries are cold.

6.2.1.2 Dissipation system

When dissipating 4.6W, the temperature of the dissipation resistance and transistor gets quite high, almost 100ºC.

If the maximum dissipated power stays at 4.6W, a redundancy circuit has to be added.

The dissipation system needs to be tested at 60ºC when one dissipation circuits is disconnected (failure simulation), but also when the MB is connected to the structure and is able to dissipate the heat into the structure. The temperature of the dissipation resistance and transistor should be under 100ºC.

6.2.1.3 Subsystems current limitations

The subsystems current limitations have to be tested when they are enabled by the EPS, when they are supplying subsystems and when they are in short circuit.

6.3 Further work

The next step is to perform the electrical integration tests starting with the EPS subsystem (MB + PMB+ batteries+ solar cells) and then connecting every subsystems, one after the other.

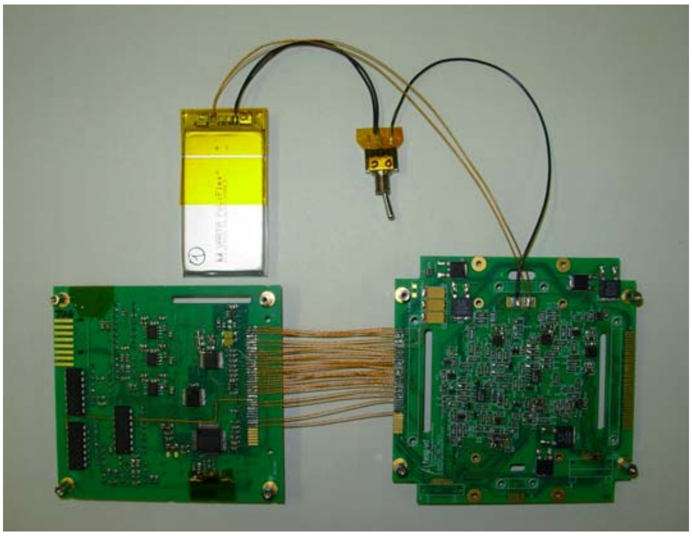


Figure 6-1 : Boards delivered to the Space Center

6.4 Personal impressions having worked on the SwissCube project

This project has given me the opportunity to discover a fascinating technical area which is the space environment. In this specific environment, every single part of the satellite has to be designed in such a way to present the highest reliability, to avoid any failure and this is what makes every design steps even more interesting.

As I studied in the Energetic Systems department which is related to high power systems, this project gave me the opportunity to learn a lot in microelectronics and low power system designs.

I am definitively satisfied of this diploma project, especially because I had the chance to learn so many things in three months, in an environment which was still unknown when starting the project.

Yverdon-les-Bains, December the 17th 2007

Nicolas Steiner

7 ACKNOWLEDGEMENTS

I would like to thank Mr. Correvon and the assistants of the IAI institute for all the support they gave me during my semester and diploma project and without whom all the work I have done wouldn't have been possible.

I would like to thank also the SwissCube team, especially Muriel Noca for providing me such an interesting semester and diploma project.

8 REFERENCES

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[R2] Electrical block Diag (v19).vsd

[R3] Report of the Hardware Beacon Generator and Switch and 15 Minutes Timer design S3_B_EPS_1_2_RBF_LUP_FMS_HBG.doc

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10 APPENDIX

10.1 EPS requirements (level 4)

10.1.1 Functional

4_EPS_10_01 **Start**

The EPS shall be able to switch on the satellite 15 minutes after ejection from the P_POD.

To fulfill mission critical functions

3_SSR_61_09

4_EPS_10_02 **Supply**

The EPS shall supply all the satellite subsystems.

To fulfill mission critical functions.

3_SSR_10_01

4_EPS_10_03 **Power Generation**

The EPS shall generate as much power as possible from the solar cells to the power bus.

To fulfill critical mission functions

3_SSR_10_01

4_EPS_10_04 **Power Storage**

The EPS shall store a part of the power generated by solar cells in order to return it during eclipse.

To fulfill critical mission functions.

3_SSR_10_01

4_EPS_10_05 **Power Conditioning**

The EPS shall condition the power on a controlled power bus.

To fulfill non-critical mission functions.

3_SSR_10_02

4_EPS_10_06 **Power Distribution**

The EPS shall distribute the power from the power bus to the users.

To fulfill non-critical mission functions

3_SSR_10_01

4_EPS_10_07 **Power Protection**

The EPS shall protect the power bus against short-circuits.

To fulfill critical mission functions

3_SSR_10_01

4_EPS_10_08 **Reference time**

The EPS shall give reference time aboard the satellite.

To time tag TM and data and to allow aboard scheduling performance

3_SSR_24_12

4_EPS_10_09 **Generation of beacon message**

The EPS shall ensure generation of beacon signal and shall switch between Hardware and Software generation.

To fulfill mission critical function

3_SSR_10_01

4_EPS_10_10 **Switch between LPTM and HTPM mode**

The EPS shall have the capability to switch between HTPM and LPTM mode.

To ensure transmission of main RF data (advanced housekeeping and science data)

3_SSR_21_03

4_EPS_10_11 **Measurements**

The EPS shall ensure measurements of voltage, current and temperature.

To monitor health of the Space System

3_SSR_10_06

10.1.2 Mission and Performance

10.1.2.1 Unit modes

4_EPS_21_01 **Subsystem modes**

The EPS shall have the following modes: "OFF", "CHARGE", DISCHARGE" and DISSIPATION" modes.

To fulfill its functions

4_EPS_10_02

4_EPS_21_02 **OFF mode**

In this mode the whole subsystem shall be turned off. This mode shall occur only before launch

OFF mode definition

4_EPS_21_01

4_EPS_21_03 **CHARGE mode**

In this mode some power shall go from the power bus to the batteries. This mode shall occur during daytime.

CHARGE mode definition

4_EPS_21_01

4_EPS_21_04 **DISCHARGE mode**

In this mode some power shall go from the batteries to the power bus. This mode shall occur during eclipse.

DISCHARGE mode definition

4_EPS_21_01

4_EPS_21_05 **DISSIPATION mode**

In this mode some power shall be dissipated with the dissipation system. This mode shall occur during daytime when the batteries are fully charged.

DISSIPATION mode definition

4_EPS_21_01

10.1.2.2 Unit states

4_EPS_22_01 **OFF mode**

In mode OFF EPS shall be fully deactivated. All power sources (batteries and solar cells) shall be disconnected.

state definition

4_EPS_21_02

4_EPS_22_02 **CHARGE mode**

In mode CHARGE the batteries can be charged with a current of [0 to 1] Ampere.

state definition

4_EPS_21_03

4_EPS_22_03 **DISCHARGE mode**

In mode DISCHARGE the batteries can be discharged with a current of [0 to 1] Ampere.

state definition

4_EPS_21_04

4_EPS_22_04 **DISSIPATION mode**

In mode DISSIPATION the dissipation system can dissipate a power of [0 to 4.6 W].

state definition

4_EPS_21_05

10.1.2.3 Unit state H/W

4_EPS_23_02 **Consumption in OFF mode**

The EPS shall not consume any power in OFF mode.

SSR power budget

4_EPS_21_02

4_EPS_23_03 **Charge efficiency**

The charge efficiency shall be more than [85%]. The chemical efficiency of the battery and the consumption of all analog components are taken in account in this value.

SSR power budget

3_SSR_31_17

4_EPS_23_04 **Discharge efficiency**

The discharge efficiency shall be more than [85%]. The chemical efficiency of the battery and the consumption of all analog components are taken in account in this value.

SSR power budget

3_SSR_31_17

10.1.2.4 Reliability and redundancy

4_EPS_25_01 **Latch-up protection**

The EPS shall be designed with a latch-up protection circuit in order to protect the microcontroller.

To mitigate SEL

3_SSR_25_03

4_EPS_25_02 **Single Event Units**

The EPS H/W and S/W design for critical functions shall mitigate possible SEUs.

Protection

3_SSR_25_01

4_EPS_25_03 **Redundancy**

The EPS critical functions shall be redundant.

to ensure performance of mission critical functions

3_SSR_25_03

4_EPS_25_04 **Tests**

Reliability of the electrical system shall be demonstrated by tests.

Tests requirements

3_SSR_25_02

10.1.3 Design

10.1.3.1 Constraints

4_EPS_31_01 **Outgassing**

The EPS material shall satisfy 3_SSR_31_15.

Arianespace user's manual

3_SSR_31_15

4_EPS_31_02 **Launch date**

The EPS shall be ready for integration in the Engineering Qualification Model for December 2007.

Launch date deadline

3_SSR_31_09

4_EPS_31_03 **Contamination**

Nasa approved materials shall be use whenever possible to prevent contamination of other spacecraft during integration, testing and launch.

CalPoly spec.

3_SSR_31_13

10.1.3.2 Thermal

4_EPS_32_01 **Temperature**

The EPS shall be capable of measuring the temperature of its PCB and the batteries.

Thermal analysis- To monitor health of the Space System

3_SSR_10_06

4_EPS_32_02 **Thermal design of the boards**

The thermal design of the boards shall ensure that all components are maintained within their qualification range throughout the lifetime of the subsystem

Thermal analysis

3_SSR_32_02

4_EPS_32_03 **Thermal design of the batteries**

The thermal design of the batteries shall ensure that they are maintained within their qualification range throughout the lifetime of the subsystem.

Thermal analysis

3_SSR_32_02

10.1.3.3 Maintainability

4_EPS_33_01 **Electrostatic sensibility**

The EPS shall be handled with precaution against electrostatic discharges.

Manufacturer recommendations

3_SSR_33_01

4_EPS_33_02 **Maintenance during storage and ground life**

The EPS shall be designed to require no maintenance during storage and ground life. If ground maintenance during storage or ground operation cannot be avoided, the maintenance requirements shall be documented.

To survive storage and ground life

3_SSR_33_01

10.1.4 Interfaces

10.1.4.1 Thermal

4_EPS_42_01 **Thermal model**

A thermal model of the EPS shall be created and thermal interfaces optimized considering the whole satellite thermal design.

Thermal Analysis. Thermal management report

3_SSR_32_02

4_EPS_42_02 **Thermal dissipation**

The EPS shall use a thermal dissipation circuit with a dissipation capability of [4.6W].

Thermal control

4_EPS_21_05

10.1.4.2 Electrical

4_EPS_43_01 **Power link**

The EPS shall provide one power link composed of GND and [3.3]V [+/-7%] signals.

Space system alimentation-

3_SSR_31_16

4_EPS_43_02 **Power supply conditioning for the beacon**

The EPS shall be able to condition one power link composed of GND and [6.4V] [+/-7%] signals.

RF requirements

3_SSR_31_16

10.1.4.3 Data interfaces

4_EPS_44_01 **Communication bus**

The EPS shall be connected to the internal communication bus.

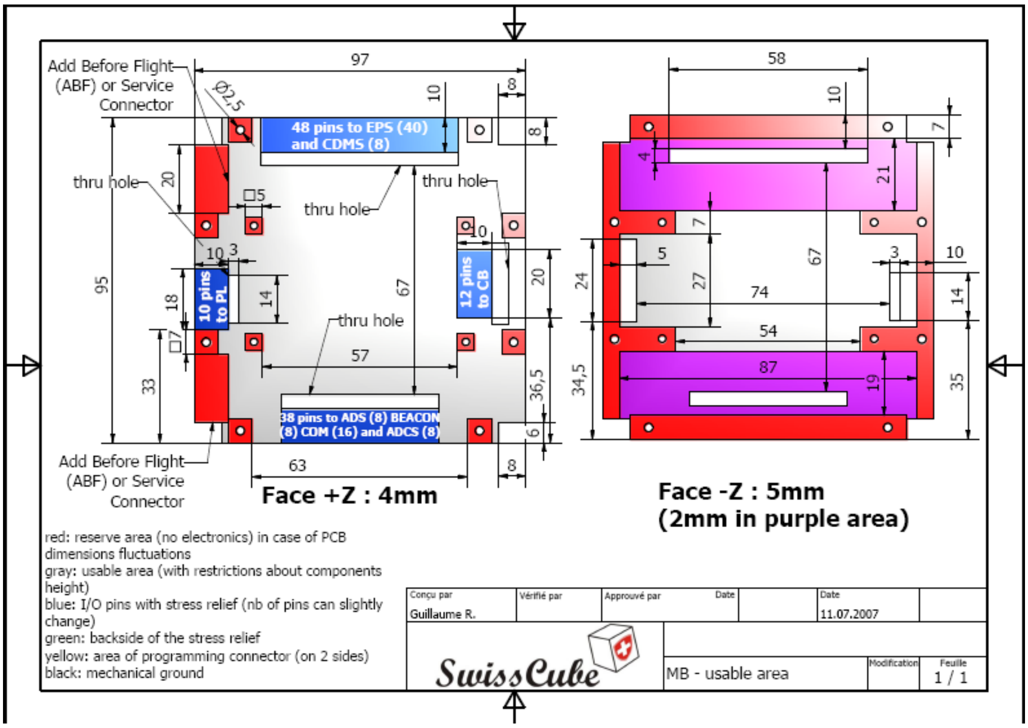
To ensure communication with other subsystems

4_COM_44_01

10.1.4.4 Physical properties

4_EPS_45_01 **EPS motherboard dimensions**

The EPS motherboard shall fulfill the layout described below.



Space System configuration.

The height of the PCB shall not exceed [15]mm and this value should not be reached on the whole surface. Detail should be discussed with mechanical engineer.

4_SC_10_04

4_EPS_45_02 **EPS weight**

The EPS shall weight at maximum [188]g.

Space System mass budget.

3_SSR_45_01

10.1.4.5 Other interfaces

4_EPS_46_01 **Test**

The EPS shall be accessible by specific interfaces for test purpose.

Test requirements

3_SSR_25_02

10.1.5 Environmental

4_EPS_50_01 **Environment**

The EPS shall survive under the environment constraints described in the SwissCube Environment Requirements document.

S-3B-STRU-1-3-Launch Environment G. Röthlisberger

Space Environment at earth distances between [400 and 1000km]

3_SSR_50_01

10.1.5.1 Thermal

4_EPS_51_01 **Non-operational temperature range**

The EPS shall survive the qualification temperature range from [-30] to [60]°C in "OFF" mode.

Thermal Analysis

3_SSR_32_02

4_EPS_51_02 **Charge temperature range**

The EPS shall survive the qualification temperature range from [-30]°C to [60]°C in "CHARGE" mode.

Thermal Analysis

3_SSR_32_02

4_EPS_51_03 **Discharge temperature range**

The EPS shall survive the qualification temperature range from [-30] to [60]°C in "DISCHARGE" mode.

Thermal Analysis

3_SSR_32_02

4_EPS_51_04 **Dissipation temperature range**

The EPS shall survive the qualification temperature range from [-30]°C to [60]°C in "DISSIPATION" mode.

Thermal Analysis

3_SSR_32_02

10.1.5.2 Static and dynamic loads

4_EPS_52_01 **Acceleration**

The EPS shall survive an acceleration of [10.4]g including margins.

Launch requirements

3_SSR_52_02

4_EPS_52_02 **Random vibration**

The EPS shall be able to sustain the random vibration qualification and acceptance tests as described in 3_SSR_52_04.

Launch environment

3_SSR_52_04

4_EPS_52_03 **Sine vibration**

The EPS shall sustain sine vibration as described in 3_SSR_52_03.

Launch environment

3_SSR_52_03

4_EPS_52_04 **Shock**

The EPS shall sustain shock as described in 3_SSR_52_06.

Launch environment.

3_SSR_52_06

10.1.5.3 Vacuum

4_EPS_53_01 **Vacuum**

The EPS shall operate under vacuum conditions.

Space environment requirement

3_SSR_53_01

10.1.5.4 Radiation

4_EPS_54_01 **Total dose**

The EPS shall survive to a TID of maximum [20]kRad.

Analysis using ESA Spenvis Tool

This is the value for 1 year in orbit

3_SSR_54_02

10.1.6 Operational

10.1.6.1 Autonomy

4_EPS_61_01 **Life time**

The EPS shall have an operational life time of [1] year on earth and [3] months in orbit.

Mission duration

3_SSR_61_01

4_EPS_61_02 **Activation of LPTM**

The EPS shall activate LPTM mode no earlier than 15 minutes after ejection from the P_POD.

Calpoly launch specs.

3_SSR_21_02

10.1.6.2 Failure management

4_EPS_63_01 Failure propagation

Failure of one part or element of the EPS shall not result in consequential damage to the equipments or other satellite components.

To minimize failure propagation

3_SSR_63_01

4_EPS_63_02 Recovery plans

For the nominal phase, possible failure scenarios and recovery plans shall be elaborated.

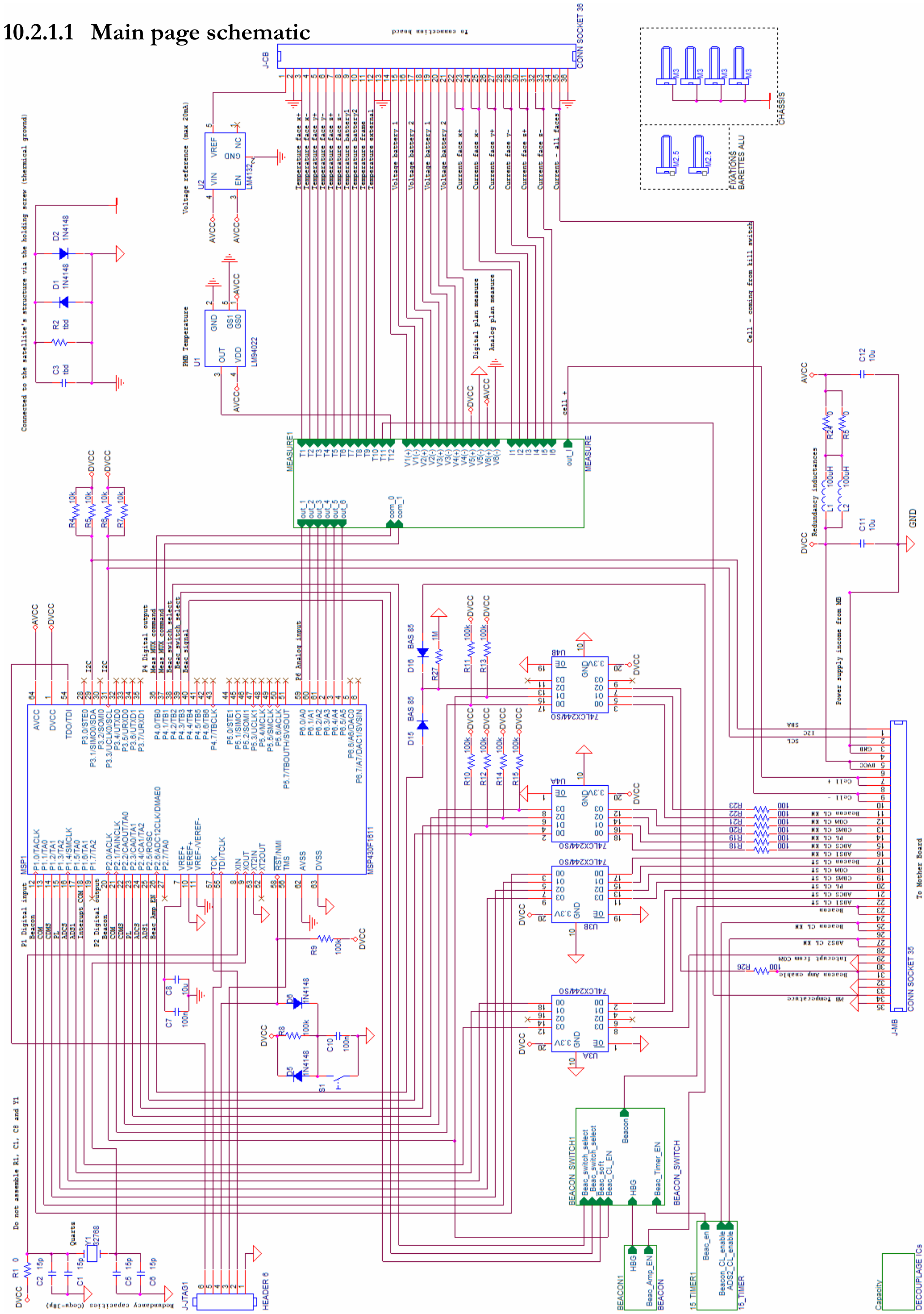
To ensure mission duration objectives

3_SSR_63_03

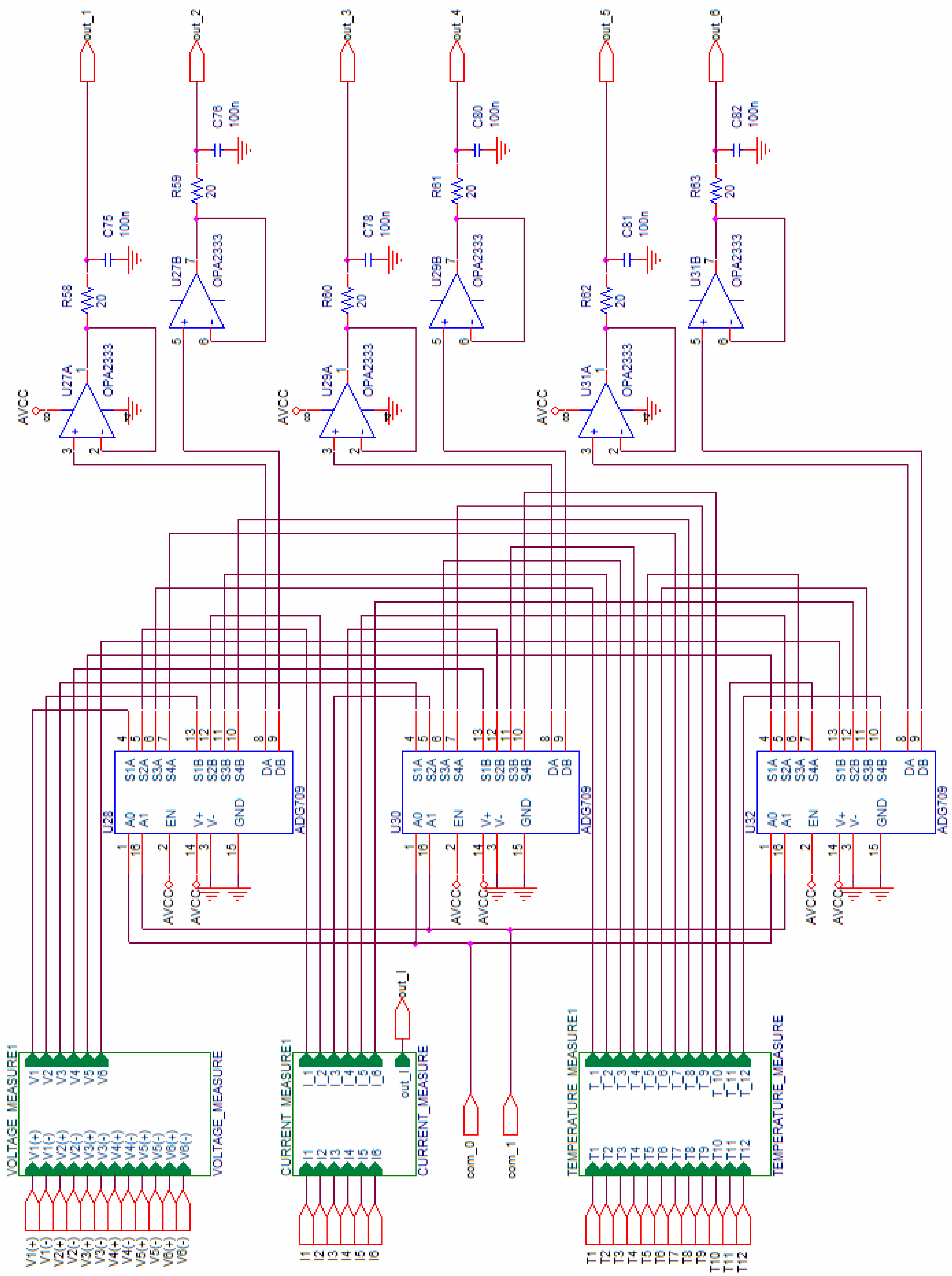
10.2 PMB

10.2.1 PMB schematic

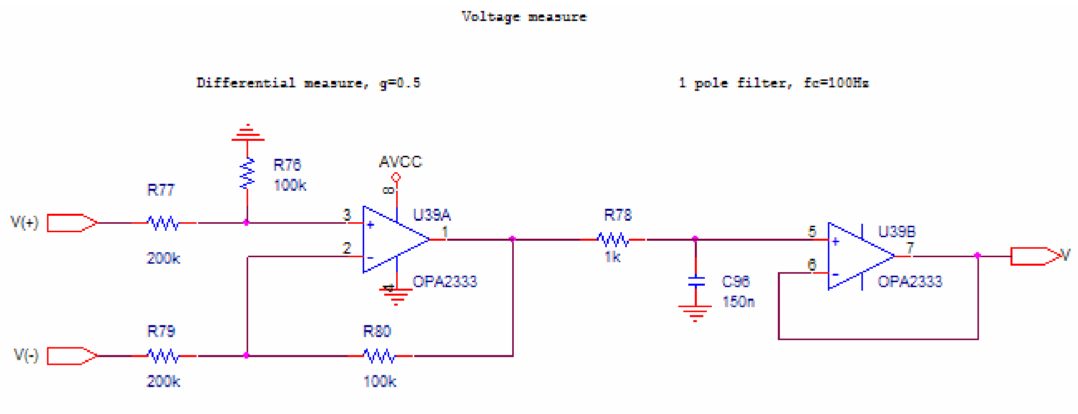
10.2.1.1 Main page schematic



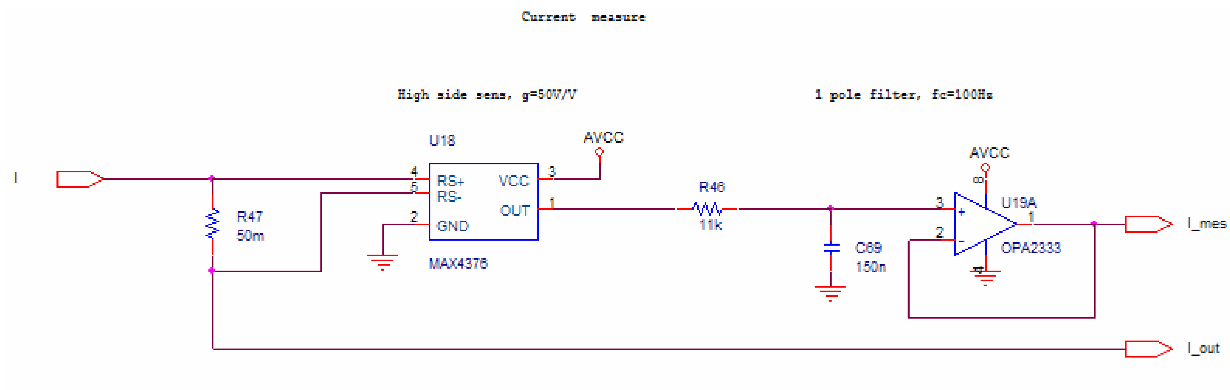
10.2.1.2 Measurements



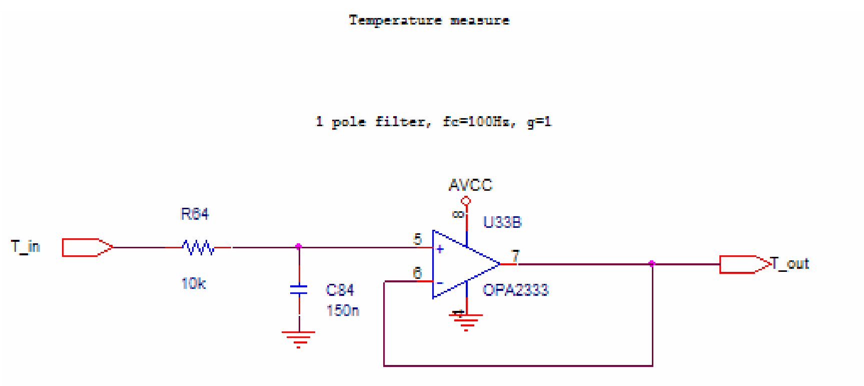
10.2.1.3 Voltage measuring chain



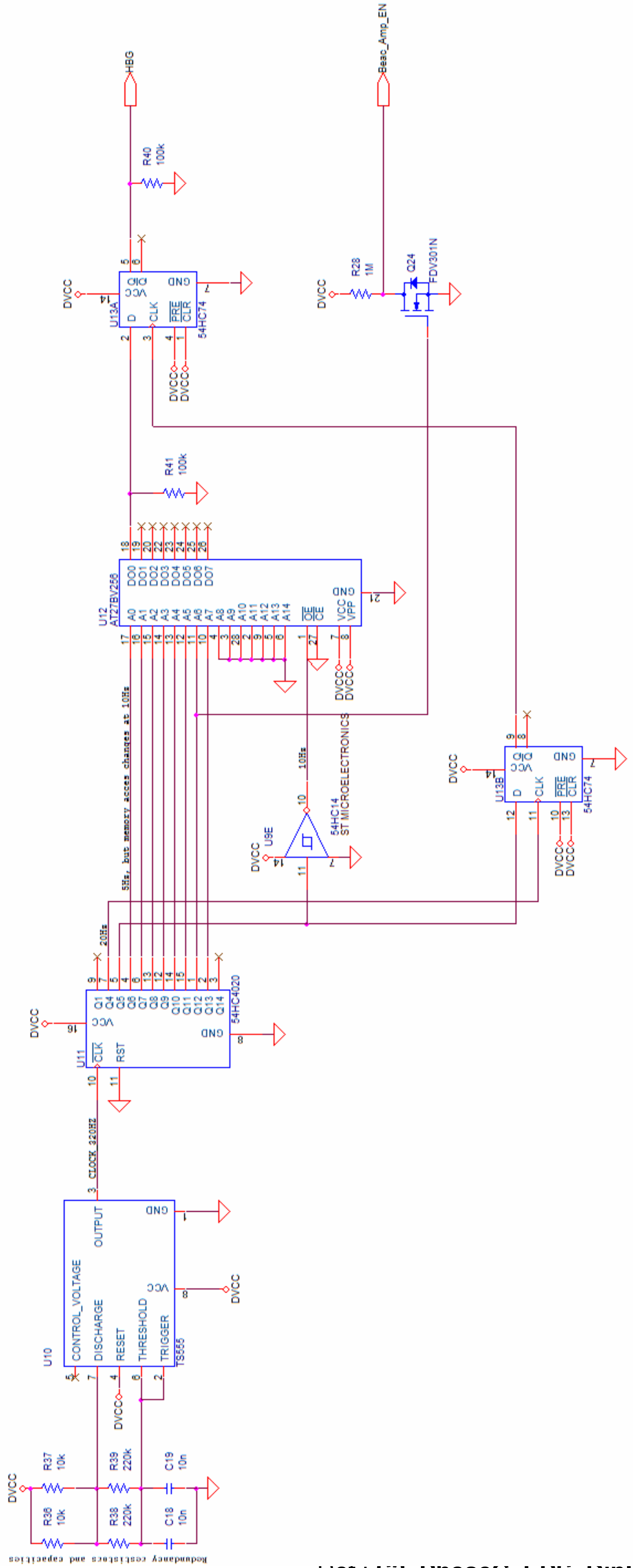
10.2.1.4 Current measuring chain



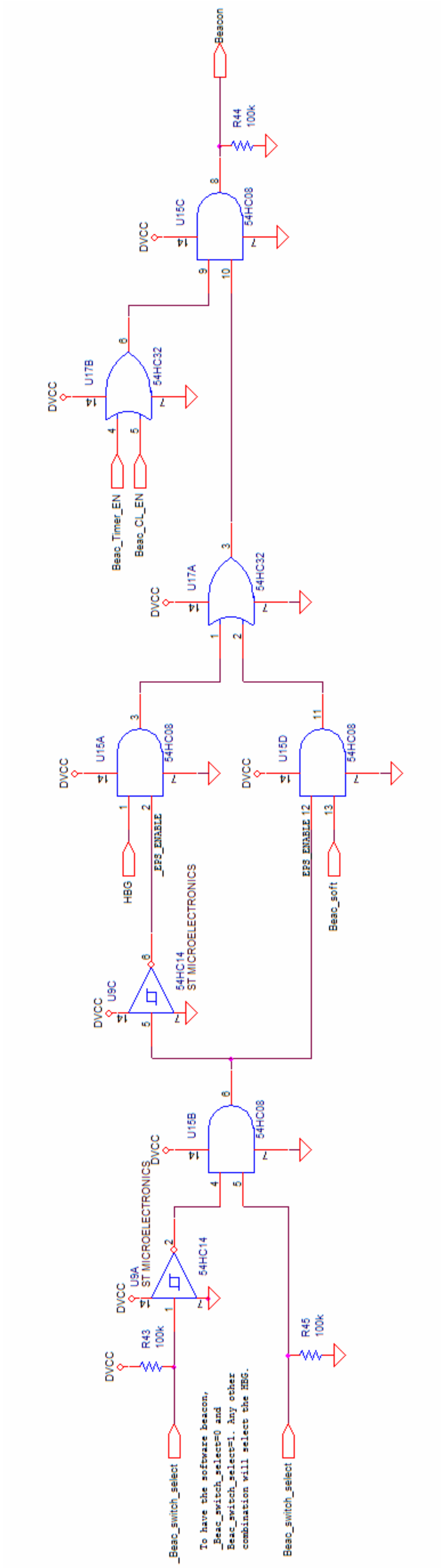
10.2.1.5 Temperature measuring chain



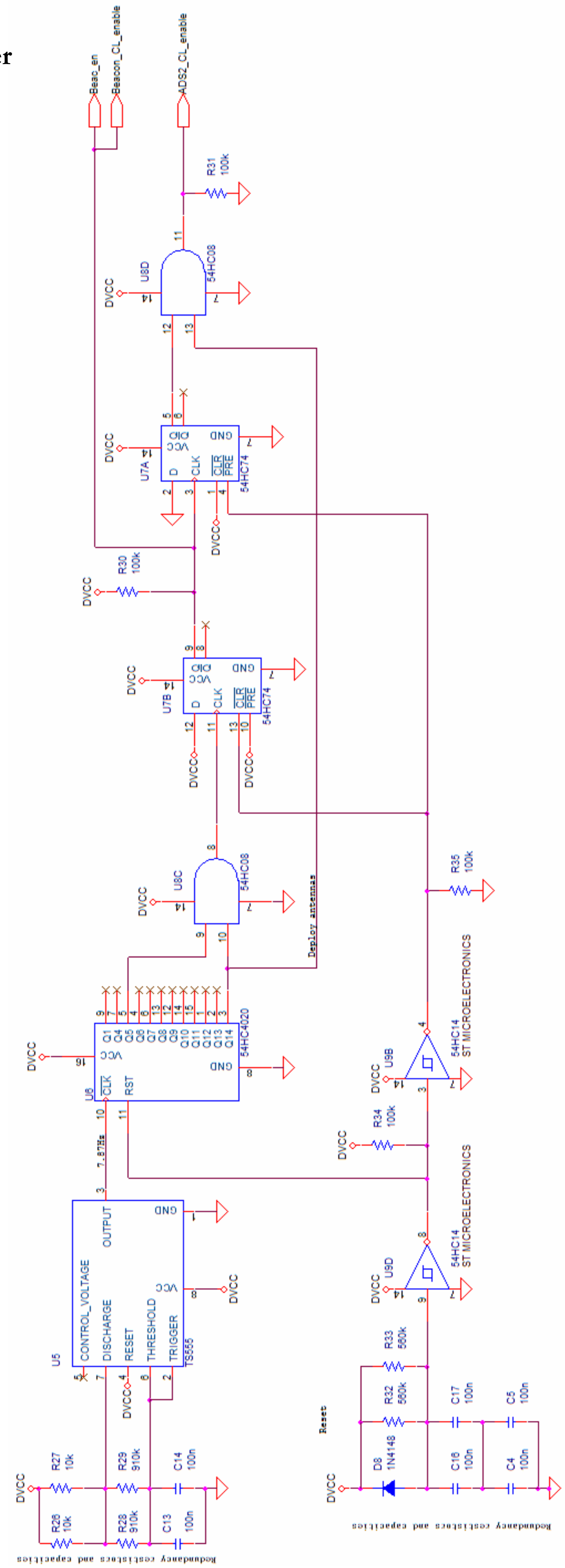
10.2.1.6 Hardware Beacon Generator



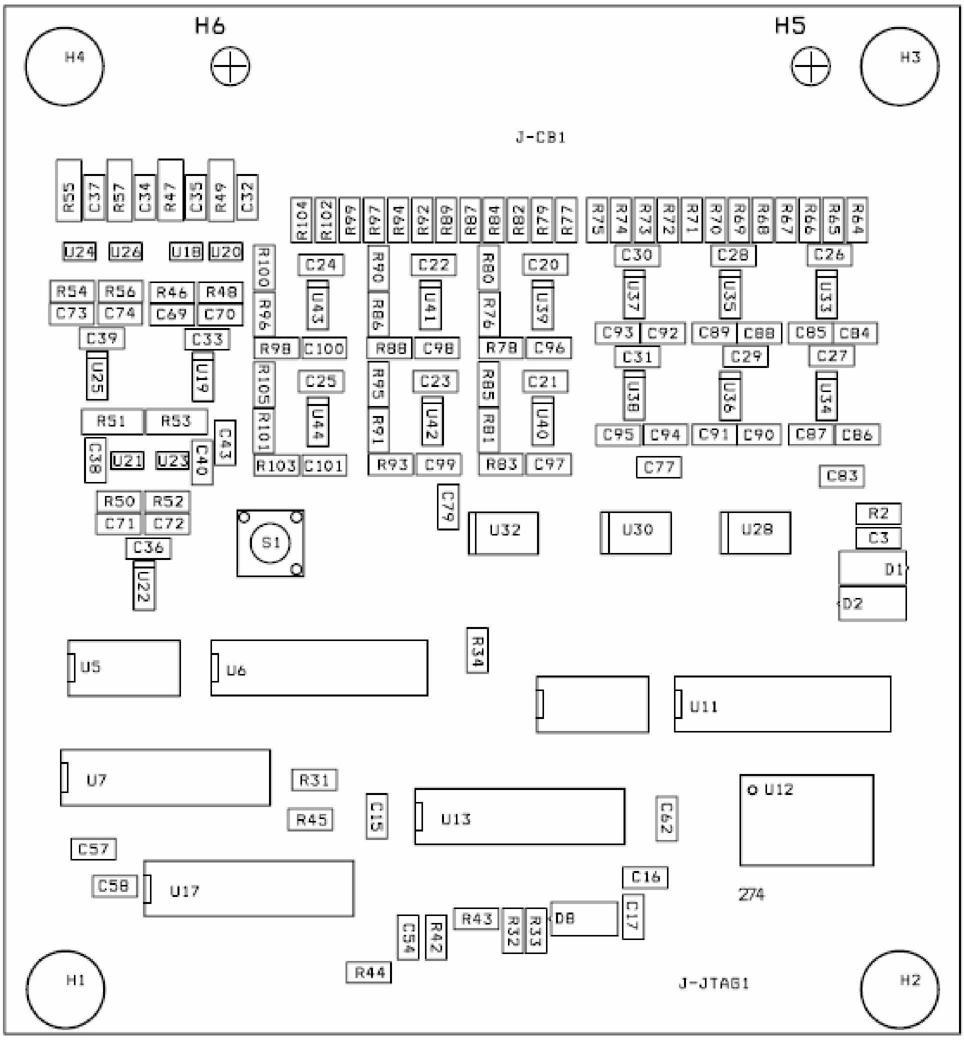
10.2.1.7 Beacon Switch

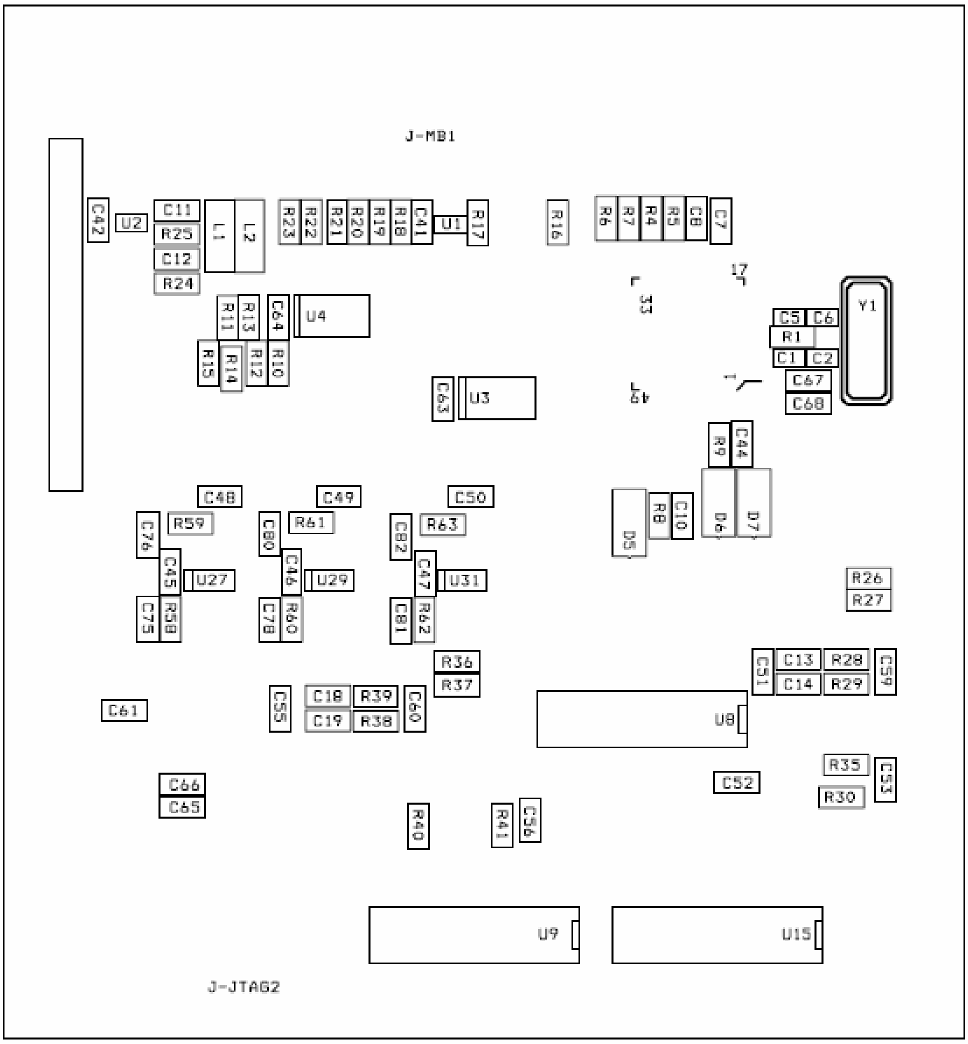


10.2.1.8 15 minutes timer



10.2.2 PMB layout




J-MB1
C42
U2
C11
R25
C12
R24
L1
L2
R23
R22
R21
R20
R19
R18
C41
U1
R17
R16
R6
R7
R4
R5
C8
C7
Y1
C5
C6
R1
C1
C2
C67
C68
R11
R13
C64
U4
R15
R14
R12
R10
C63
U3
R9
C44
C48
C49
C50
R8
C10
D5
D6
D7
C76
R59
C80
R61
C82
R63
C45
U27
C46
U29
C47
U31
C75
R58
C78
R60
C81
R62
R26
R27
R36
R37
C51
C13
R28
C14
R29
C59
C61
C55
C18
R39
C19
R38
C60
U8
C52
R35
R30
C53
C66
C65
R40
R41
C56
U9
U15
J-JTAG2

10.2.3 PMB components list

Quantity	Part	Manufacture	Manufacture Ref.	Distributor	Distributor Ref.
4	15p	AVX	1206GA150JAT2A	Farnell	1301842
1	tbd				
56	100n	AVX	12065C104K4Z2A	Farnell	1301719
11	10u	Kemet	C1206C106K8RAC	Farnell	1288264
2	100n				
2	10n				
1	4.7n	AVX	12065C472KAT2A	Farnell	499341
24	150n	PHYCOMP	2238 911 15652	Farnell	644330
5	1N4148				
2	BAS 85	PHILIPS	BAS85	FARNELL	1097282
1	HEADER 6				
2	100uH	Epcos	B82432-A1104-K	Distrelec	351910
1	MSP430F1611	TI	MSP430F1611		
1	FDV301N	FAIRCHILD SEMICONDUCTOR	FDV301N		
3	0				
1	tbd				
20	10k				
29	100k				
7	100				
2	1M				
2	910k				
2	560k				
2	220k				
6	11k				
6	50m			Farnell	1099913
6	20				
12	200k				
6	1k				
1	SW PUSHBUTTON			Distrelec	200310
1	LM94022	National Semiconducter	LM94022BIMG	Farnell	1312600
1	LM4132	National Semiconductor	LM4132EMF-2.5	Farnell	1312763
2	74LCX244/SO	TI	74LVC244ADBRG4	Farnell	1236352
2	TS555	STM	TS555MP		
2	54HC4020	STM	M54HC4020		
2	54HC74	STM	M54HC74		
2	54HC08	STM	M54HC08		
1	54HC14	STM	M54HC14		
1	AT27BV256				
1	54HC32	STM	M54HC32		
6	MAX4376	Maxim	MAX4376FAUK+	Maxim	MAX4376FAUK+
18	OPA2333	Burr-Brown from TI	OPA2333AIDG4	Farnell	1230455
3	ADG709	Analog Devices	ADG709BRUZ	Farnell	9604359
1	32768	EPSON TOYOCOM	MC-146 32.768KHZ ±20PPM,7.0PF	Farnell	1278039

10.2.4 PMB Matlab code

10.2.4.1 Linearization of temperature chip LM94022

```
%Erreur max sur capteur de température LM94022 si on le linéarise sur la
%plage de fonctionnement
clear all; close all; clc;

%Chargement du fichier (tableau disponible dans la datasheet)
file = load('TvsV.txt');       %chargement du fichier
T = file(1:121,1);   %première colone: température (-50 à 70 degré)
V_GS01 = file(1:121,3).*10^-3;   %troisième colone: tension pour gain GS01

%Erreur max
e_min = 10000;

%Double boucle qui teste toutes les combinaisons de points possibles
%par lequels passe la droite de linéarisation
for i = 1:121
    for j = 1:121
        if i ~= j
            %Ecriture du système d'équation: g*V_GS01(i) + o =T(i) and
            %g*V_GS01(j) + o = T(j) sous forme matricielle
            A = [V_GS01(i) 1;
                 V_GS01(j) 1];
            B = [T(i);
                 T(j)];
            X = A\B;      %avec X(1)=gain et X(2)=offset
            T_lin_GS01 = V_GS01.*X(1) + X(2); %calcul de T avec la lin
            e_GS01 = T-T_lin_GS01;   %erreur entre le capteur et la lin
            e_max_GS01 = max(abs(e_GS01));   %erreur max
            if e_max_GS01 < e_min
                e_min = e_max_GS01;
                Gain = X(1);
                Offset = X(2);
                T1 = T(i);
                T2 = T(j);
                T_lin_GS01_best = T_lin_GS01;
            end
        end
    end
end

%Graph du capteur réel et de la linéarisation
figure(1)
plot(V_GS01,T,'b','LineWidth',1); hold on; grid on;
plot(V_GS01,T_lin_GS01_best,'r','LineWidth',1); hold on; grid on;
xlabel('V_o_u_t [V]');
ylabel('T [^oC]');
title('T=f(V_o_u_t)  (GS=01)');
legend('Sensor temperature vs output voltage','Lin temperature vs output voltage','Location',
'SouthWest');
texte = ['E_m_a_x = ',num2str(e_min,3),' ^oC'];
text(1.41,70,texte);
texte = ['Gain = ',num2str(Gain,5),' ^oC/V     ','Offset = ',num2str(Offset,5),' ^oC'];
text(1.41,50,texte);
```

10.2.4.2 Voltage measuring chains nonlinearity verification

```
%Calibration des chaines de mesure de tension
clear all; close all; clc;

%Tension
V = [10 20 30 40 50 60 70 80 90 100 200 300 400,...
     500 600 700 800 900 1000 2000 3000 4000 5000];

%Tension de sortie des capteurs de courant ainsi que des amplis suiveurs
Vout_V1 = [5 10 15 20 25 30 35 40 45 50 100 150 200 250 300 349 399,...
           449 499 998 1497 1996 2495];
Vout_V2 = [5 10 15 20 25 30 35 40 45 50 100 150 200 250 300 350 400,...
           450 500 1000 1500 2000 2500];
Vout_V3 = [5 10 15 20 25 30 35 40 45 50 100 150 200 250 300 350 400,...
           450 500 999 1498 1998 2497];
Vout_V4 = [5 10 15 20 25 30 35 40 45 50 100 150 200 249 299 349 399,...
           449 499 997 1495 1994 2493];
%Création d'une matrice des tensions
Vout_V = [Vout_V1; Vout_V2; Vout_V3; Vout_V4];

%Tension après conversion AD idéale des tensions mesurées en sortie des
%capteurs et amplis
V_meas = Vout_V.*2;

%Création d'un vecteur de 5000 points
vecteur = [1:5000,1];

%Graph des tensions mesurés en fonction des tensions appliquées
for i =  1:4
    figure(1)
    subplot(2,2,i);
    loglog(V,V_meas(i,:),'rx'); hold on;
    loglog(vecteur,vecteur); hold on;
    xlabel('V_a_p_p_l_i_e_d [mV]');
    ylabel('V_m_e_a_s_u_r_e_d [mV]');
    axis([1 10000 1 10000]);
    title(strcat('Nonlinearity of voltage mesuring chain V_',num2str(i)));
    legend ('Real measured V','Expected measured V','Location','NorthWest');
    legend('boxoff');
end
```

10.2.4.3 Current measuring chains nonlinearity verification

```
%Calibration des chaines de mesure de courant
clear all; close all; clc;

%Courant appliqué
I = [2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300 400,...
     500 600 700 800 900 1000];

%Tension de sortie des capteurs de courant ainsi que des amplis suiveurs
Vout_I1 = [10 13 16 18 21 23 25 28 30 55 79 104 129 153 178 203 228 253,...
           503 753 1003 1253 1503 1754 2004 2254 2487];
Vout_I2 = [1 2 5 7 10 12 14 17 19 43 68 93 118 142 167 192 217 242,...
           494 746 997 1248 1450 1751 2003 2254 2493];
Vout_I3 = [7 10 12 14 17 19 22 24 26 50 75 100 125 149 174 199 224 248,...
           501 753 1004 1255 1506 1758 2009 2260 2485];
Vout_I4 = [17 20 22 24 27 30 32 34 36 61 85 111 135 160 185 210 235 260,...
           512 764 1016 1268 1520 1772 2023 2275 2490];
Vout_I5 = [19 19 19 20 22 24 26 28 30 55 79 104 129 154 179 204 229 254,...
           507 758 1011 1262 1514 1767 2018 2270 2484];
Vout_I6 = [21 24 26 29 32 34 36 38 40 65 89 114 138 164 188 213 237 262,...
           513 764 1013 1262 1512 1762 2012 2261 2488];
%Création d'une matrice des tensions
Vout_I = [Vout_I1; Vout_I2; Vout_I3; Vout_I4; Vout_I5; Vout_I6];

%Courant après conversion AD idéal des tensions mesurées en sortie des
%capteurs et amplis
I_meas = Vout_I./(50*50*10^-3);

%Création d'un vecteur de 1000 points
vecteur = [1:1000,1];

%Graph des courants mesurés en fonction des courants appliqués
for i =  1:6
    figure(1)
    subplot(2,3,i);
    loglog(I,I_meas(i,:),'rx'); hold on;
    loglog(vecteur,vecteur); hold on;
    xlabel('I_a_p_p_l_i_e_d [mA]');
    ylabel('I_m_e_a_s_u_r_e_d [mA]');
    axis([1 1000 1 1000]);
    title(strcat('Nonlinearity of current mesuring chain I_',num2str(i)));
    legend ('Real measured I','Expected measured I','Location','NorthWest');
    legend('boxoff');
end
```

10.2.4.4 Temperature measuring chains nonlinearity verification

```
%Calibration des chaines de mesure de température
clear all; close all; clc;

%Tension appliquée
V_T = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];

%Tension de sortie des capteurs de courant ainsi que des l'amplis suiveurs
Vout_T1 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T2 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T3 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T4 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T5 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T6 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T7 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T8 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T9 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T10 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T11 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];
Vout_T12 = [1955 1885 1806 1727 1648 1567 1486 1405 1324 1242 1242 1159,...
           1076 991];

%Création d'une matrice des tensions
Vout_T = [Vout_T1; Vout_T2; Vout_T3; Vout_T4; Vout_T5; Vout_T6; Vout_T7;...
          Vout_T8; Vout_T9; Vout_T10; Vout_T11; Vout_T12];

%Création d'un vecteur de 2500 points
vecteur = [1:2500,1];

%Graph des tensions mesurés en fonction des tensions appliquées
for i =  1:1
    figure(1)
    plot(V_T,Vout_T(i,:),'rx','LineWidth',2); grid on; hold on;
    plot(vecteur,vecteur); hold on;
    xlabel('V_a_p_p_l_i_e_d [mV]');
    ylabel('V_m_e_a_s_u_r_e_d [mV]');
    axis([0 2500 0 2500]);
    title(strcat('Nonlinearity of temperature mesuring chain T_',num2str(i)));
    legend ('Real measured T','Expected measured T','Location','NorthWest');
    legend('boxoff');
    text(1955,1955,' \leftarrow -50^oC','FontSize',10);
    text(1885,1885,' \leftarrow -40^oC','FontSize',10);
    text(1806,1806,' \leftarrow -30^oC','FontSize',10);
    text(1727,1727,' \leftarrow -20^oC','FontSize',10);
    text(1648,1648,' \leftarrow -10^oC','FontSize',10);
    text(1567,1567,' \leftarrow 0^oC','FontSize',10);
```

```
    text(1486,1486,' \leftarrow 10^oC','FontSize',10);
    text(1405,1405,' \leftarrow 20^oC','FontSize',10);
    text(1324,1324,' \leftarrow 30^oC','FontSize',10);
    text(1242,1242,' \leftarrow 40^oC','FontSize',10);
    text(1159,1159,' \leftarrow 50^oC','FontSize',10);
    text(1076,1076,' \leftarrow 60^oC','FontSize',10);
    text(991,991,' \leftarrow 70^oC','FontSize',10);
end
```

10.2.4.5 Qualification tests graph under vacuum and temperature

```
%Détermination du bruit sur les mesures ainsi que de la valeur moyenne
%mesurée qui sera comparée à la valeur appliquée
clear all; close all; clc;

%Remplir le nom du fichier à charger et à traiter
file = dlmread('-40.txt','\t',3,2);
%Remplir les bornes min et max pour les graphs des tensions (en V)
V_min = 3;
V_max = 4.5;
%Remplir les bornes min et max pour les graphs des courants (en mA)
I_min = 140;
I_max = 190;
%Remplir les bornes min et max pour les graphs des températures (en oC)
T_min = -55;
T_max = -35;
%Remplir la valeur de référence de chacune des valeurs mesurées
%(6 tensions, 6 courants et 12 températures)
ref = [4.1 4.1 4.1 4.1 3.3 3.3 171 172 171 172 171 170 -38.2 -38.2,...
       -38.2 -38.2 -38.2 -38.2 -38.2 -38.2 -38.2 -38.2 -38.2 -38.2];

%Boucle qui parcourt les 24 mesures
for i = 1:24
    somme = 0;
    noise_max = 0;
    max_diff = 0;
    for j = 1:length(file)
        somme = somme + file(j,i);
    end
    average_val = somme/length(file);
    noise = average_val - file(:,i);
    noise_max = max(abs(noise));
    eff_noise = sqrt(sum(noise.^2)/length(file));
    max_diff = max(abs(ref(i)-file(j,i)));
    switch i
        %Graphs des tensions
        case {1,2,3,4,5,6}
            figure(1)
            subplot(2,3,i); plot(file(:,i)); hold on;
            xlabel('t [10ms]');
            ylabel('V [V]');
            axis([0 100 V_min V_max]);
            title(strcat('V',num2str(i)));
            switch i
                %Graphs des tensions des batteries
                case {1,2,3,4}
                    texte = strvcat(strcat('Average val = ',num2str(average_val,3),'V'),...
                                    strcat('Noise eff val = ',num2str(eff_noise,3),' V'),...
                                    strcat('Noise max = ',num2str(noise_max,3),' V'),...
                                    strcat('Max diff with ref val = ',num2str(max_diff,3),'
V'));
                    text(5,0.9*average_val,texte);
                %Graphs des tensions des alimentations
                otherwise
                    texte = strvcat(strcat('Average val = ',num2str(average_val,3),'V'),...
                                    strcat('Noise eff val = ',num2str(eff_noise,3),' V'),...
                                    strcat('Noise max = ',num2str(noise_max,3),' V'),...
                                    strcat('Max diff with ref val = ',num2str(max_diff,3),'
```

```
V'));
                    text(5,1.2*average_val,texte);
                end
            %Graphs des courants
            case {7,8,9,10,11,12}
                figure(2)
                subplot(2,3,i-6); plot(file(:,i)); hold on;
                xlabel('t [10ms]');
                ylabel('I [A]');
                axis([0 100 I_min I_max]);
                title(strcat('I',num2str(i-6)));
                texte = strvcat(strcat('Average val = ',num2str(average_val,3),' mA'),...
                                strcat('Noise eff val = ',num2str(eff_noise,3),' mA'),...
                                strcat('Noise max = ',num2str(noise_max,3),' mA'),...
                                strcat('Max diff with ref val = ',num2str(max_diff,3),' mA'));
                text(5,0.9*average_val,texte);
            %Graph des températures
            otherwise
                figure(3)
                subplot(3,4,i-12); plot(file(:,i)); hold on;
                xlabel('t [10ms]');
                ylabel('T [^oC]');
                axis([0 100 T_min T_max]);
                title(strcat('T',num2str(i-12)));
                texte = strvcat(strcat('Average val = ',num2str(average_val,3),' ^oC'),...
                                strcat('Noise eff val = ',num2str(eff_noise,3),' ^oC'),...
                                strcat('Noise max = ',num2str(noise_max,3),' ^oC'),...
                                strcat('Max diff ref val = ',num2str(max_diff,3),' ^oC'));
                text(5,-49,texte);
        end
    end
```

10.2.5 PMB new pin out

J-MB				
Pin assignation	Name	Detail	Type	
			Analogue	Digital
1	I2C_SDA	I2C (SDA)	-	Input/Output
2	I2C_SCL	I2C (SCL)	-	Input/Output
3	GND	PMB 0V power supply	Input	-
4	GND	PMB 0V power supply	Input	-
5	Vcc	PMB 3.3V power supply	Input	-
6	Vcc	PMB 3.3V power supply	Input	-
7	cell(+)	cell +	Output	-
8	cell(+)	cell +	Output	-
9	cell(-)	cell -	Output	-
10	cell(-)	cell -	Output	-
11	Beacon_EN	Beacon current limitation Enable	-	Output
12	COM_EN	COM current limitation Enable	-	Output
13	CDMS_EN	CDMS current limitation Enable	-	Output
14	PL_EN	Payload current limitation Enable	-	Output
15	ADCS_EN	ADCS current limitation Enable	-	Output
16	ADS1_EN	ADS1 current limitation Enable	-	Output
17	Beacon_ST	Beacon current limitation State	-	Input
18	COM_ST	COM current limitation State	-	Input
19	CDMS_ST	CDMS current limitation State	-	Input
20	PL_ST	Payload current limitation State	-	Input
21	ADCS_ST	ADCS current limitation State	-	Input
22	ADS1_ST	ADS1 current limitation State	-	Input
23	BEAC_SIG	Beacon signal	-	Output
24	BEAC_SIG	Beacon signal	-	Output
25	BEAC_EN_inv	Beacon current limitation Enable (from Timer)	-	Output
26	BEAC_EN_inv	Beacon current limitation Enable (from Timer)	-	Output
27	ADS2_EN_inv	ADS2 current limitation Enable (from Timer)	-	Output
28	ADS2_EN_inv	ADS2 current limitation Enable (from Timer)	-	Output
29	COM_EXT_INT	External interrupt from COM	-	Input
30	GND	PMB 0V power supply	Input	-
31	BEAC_amp_EN	Beacon amplifier enable from uC	-	Output
32	BEAC_amp_EN	Beacon amplifier enable from uC	-	Output
33	GND	PMB 0V power supply	Input	-
34	MB_TP	MB temperature	Input	-
35	GND	PMB 0V power supply	Input	-

J-CB				
Pin assignation	**Pin Name**	**Detail**	**Type**	
			Analogue	**Digital**
1	2.5_Vcc	Connection board 2.5V power supply	Output	-
2	GND	Connection board 0V power supply	Output	-
3	T1	Temperature cell face x+	Input	-
4	T2	Temperature cell face x-	Input	-
5	T3	Temperature cell face y+	Input	-
6	T4	Temperature cell face y-	Input	-
7	T5	Temperature cell face z+	Input	-
8	T6	Temperature cell face z-	Input	-
9	T7	Temperature battery 1	Input	-
10	T8	Temperature battery 2	Input	-
11	T9	Temperature frame	Input	-
12	T10	Temperature external	Input	-
13	GND	Connection board 0V power supply	Output	-
14	V1(+)	Voltage Battery 1 +	Input	-
15	V1(-)	Voltage Battery 1-	Input	-
16	V2(+)	Voltage Battery 2 +	Input	-
17	V2(-)	Voltage Battery 2 -	Input	-
18	V1(+)	Voltage Battery 1 +	Input	-
19	V1(-)	Voltage Battery 1-	Input	-
20	V2(+)	Voltage Battery 2 +	Input	-
21	V2(-)	Voltage Battery 2 -	Input	-
22	I1	Current cell face x+	Input	-
23	I1	Current cell face x+	Input	-
24	I2	Current cell face x-	Input	-
25	I2	Current cell face x-	Input	-
26	I3	Current cell face y+	Input	-
27	I3	Current cell face y+	Input	-
28	I4	Current cell face y-	Input	-
29	I4	Current cell face y-	Input	-
30	I5	Current cell face z+	Input	-
31	I5	Current cell face z+	Input	-
32	I6	Current cell face z-	Input	-
33	I6	Current cell face z-	Input	-
34	Cell(-)	Voltage cell – coming from kill switch	Input	-
35	Cell(-)	Voltage cell – coming from kill switch	Input	-
36	GND	Connection board 0V power supply	Output	-

10.2.6 PMB thermal qualification tests results

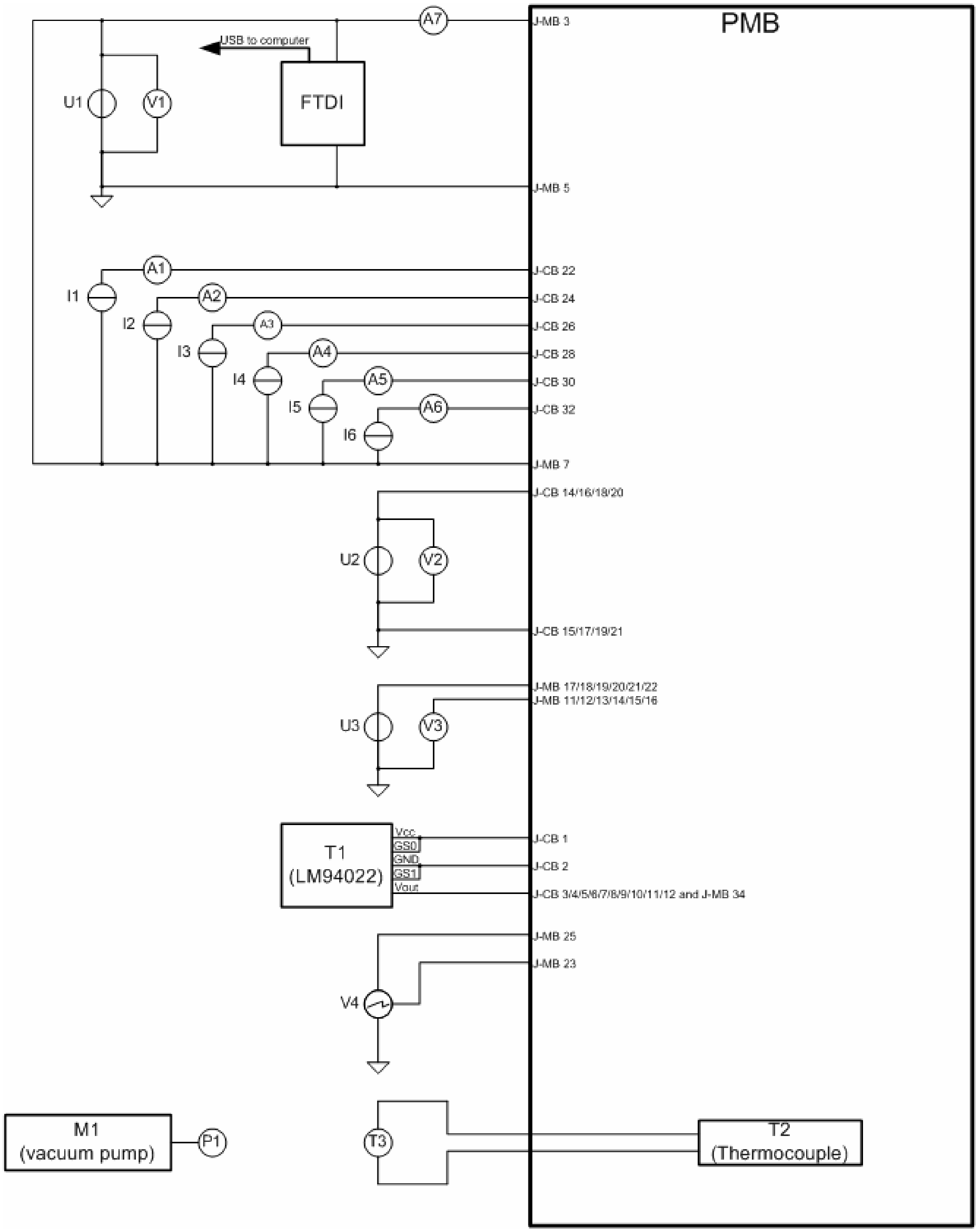
Meaning of the abbreviations present on the measuring chains graphics:

- **Average val** is the average value of the 100 points taken in 1 sec.
- **Noise eff val** is the efficient value of the noise present on the 100 measured points.
- **Noise max** is the maximum value of the noise (maximum difference between every measured points and the average value).
- **Max diff** with ref val is the maximum difference between every measured points and the reference value given by the multimeter or by the PT100.

10.2.6.1 PMB thermal tests setup

- Program the µController so it makes AD conversion of every measurements and sends them via the UART at a frequency of 100Hz. Program the µController so it sets the digital outputs at the same level than the digital inputs (P2=P1).
- Connect a laboratory supply to the 3.3V auxiliary supply of the PMB (power OFF).
- Connect the UART to the computer.
- Connect all voltage measurement. Solder a bridge on J-CB 14/16/18/20 ($V_{1+}/V_{2+}/V_{3+}/V_{4+}$) and connect it to a DC voltage power supply (power OFF). Solder a bridge on J-CB 15/17/19/21 ($V_{1-}/V_{2-}/V_{3-}/V_{4-}$) and connect this bridge to the GND of the PMB. Connect a voltmeter to the supply to have the voltage reference.
- Connect all 6 current measurement inputs of the PMB (J-CB 22/24/26/28/30/32) to 6 DC current power supply (power OFF). Connect all negative terminals of the 6 DC current power supply together and with J-MB 7 and with the 3.3V of the PMB (current sense are high-side current sense, this is why we have to set the voltage level of all 6 shunts at the high level). Connect an ampmeter on all 6 current measuring chains to have the current reference.
- Connect an LM94022 temperature sensor to all temperature measurement inputs of the PMB (J-CB 3/4/5/6/7/8/9/10/11/12 and J-MB 34). Supply the temperature sensor by using the 2.5V regulator (J-CB 1). Place a thermocouple next to the LM94022 to have the temperature reference.
- Connect all digital inputs and outputs of the µController. Solder a bridge on J-CB 17/18/19/20/21/22 and connect it to a DC voltage supply (power OFF). Connect the negative bound of the DC voltage supply to the GND of the PMB. Connect all digital outputs (J-CB 11/12/13/14/15/16) to voltmeters (the µController sets the digital inputs level on the digital outputs which allows verification of the good function of the digital inputs/outputs chains of the PMB).
- Connect the 15 minutes timer and the HBG on an oscilloscope.
- Set the voltage and current levels.
- Start the tests.

10.2.6.2 PMB thermal tests connection schematic



10.2.6.3 List of material (PMB thermal tests)

Name on schematic	Device	Inventory
U1	HAMEG Triple power supply HM8040-2	24E-043
U2	HAMEG Triple power supply HM8040-2	24E-043
U3	DELTA Elektronika power supply	01E-241
I1	DELTA Elektronika power supply	ALS-3
I2	DELTA Elektronika power supply	01E-923
I3	DELTA Elektronika power supply	165
I4	DELTA Elektronika power supply	-
I5	DELTA Elektronika power supply	01E-200
I6	DELTA Elektronika power supply	01E-888
T1	LM94022	-
T2	PT100	-
M1	PFEIFFER vacuum pump	-
V1	HAMEG Digital multimeter HM8011-2	24E-043
V2	FLUKE 179	-
V3	FLUKE 179	-
V4	HP Oscilloscope 52600A	01E165
A1	HP Multimeter 34401A	-
A2	HP Multimeter 34401A	24E-161
A3	HP Multimeter 34401A	24E-163
A4	HP Multimeter 34401A	01E-1034
A5	HP Multimeter 34401A	01E-1025
A6	HP Multimeter 34401A	01E1031
A7	HP Multimeter 34401A	24E-371
T3	ALIGENT Data acquisition 34970A	-
P1	PFEIFFER vacuum single gauge	16M-040

10.2.6.4 Test under vacuum at 60°C

Test conditions	
PMB temperature during the test	Pressure during the test
$60 \pm 1 \left[{}^{o}C \right]$	$9.5 \cdot 10^{-3} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$15.1 \left[mA \right]$	$3.3 \left[V \right]$	$16.9 \left[mA \right]$	$3.3 \left[V \right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 2sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10 \left[Hz \right]$	8sec	17sec

Digital Inputs/Outputs

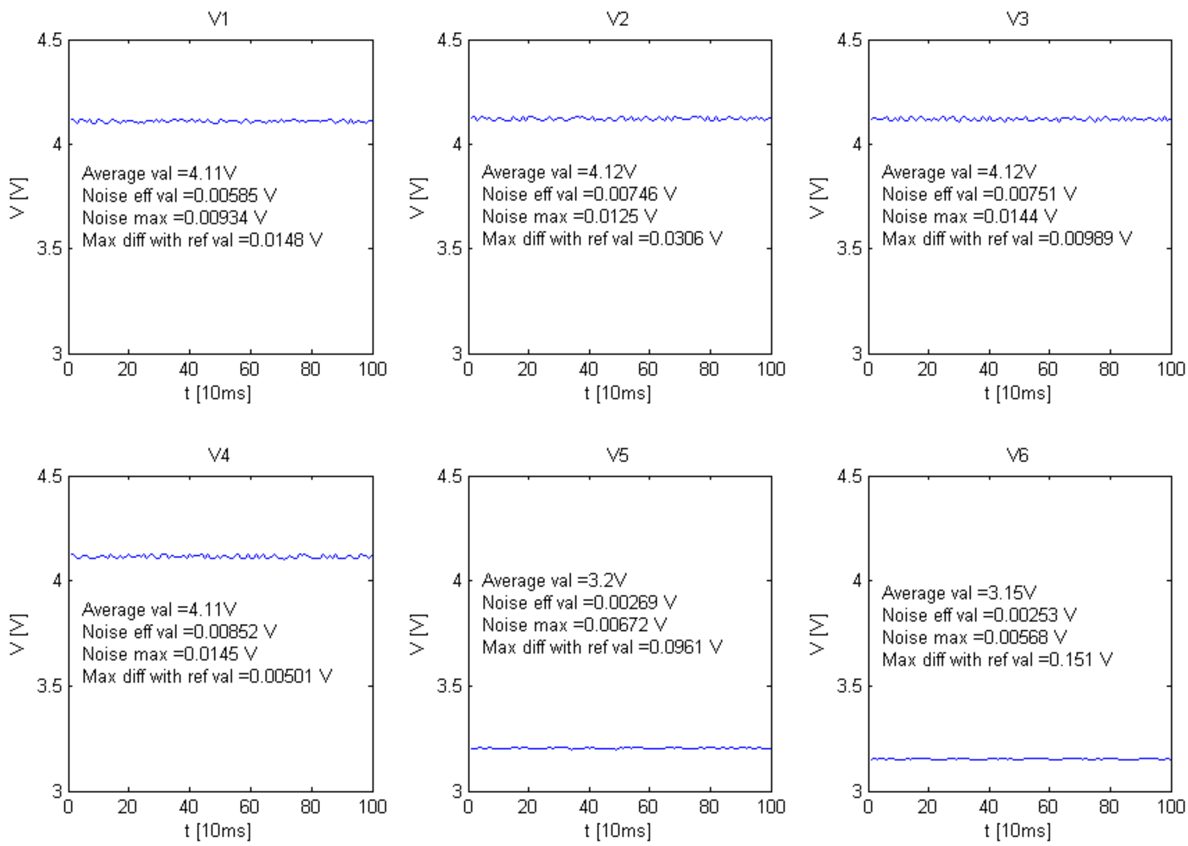
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

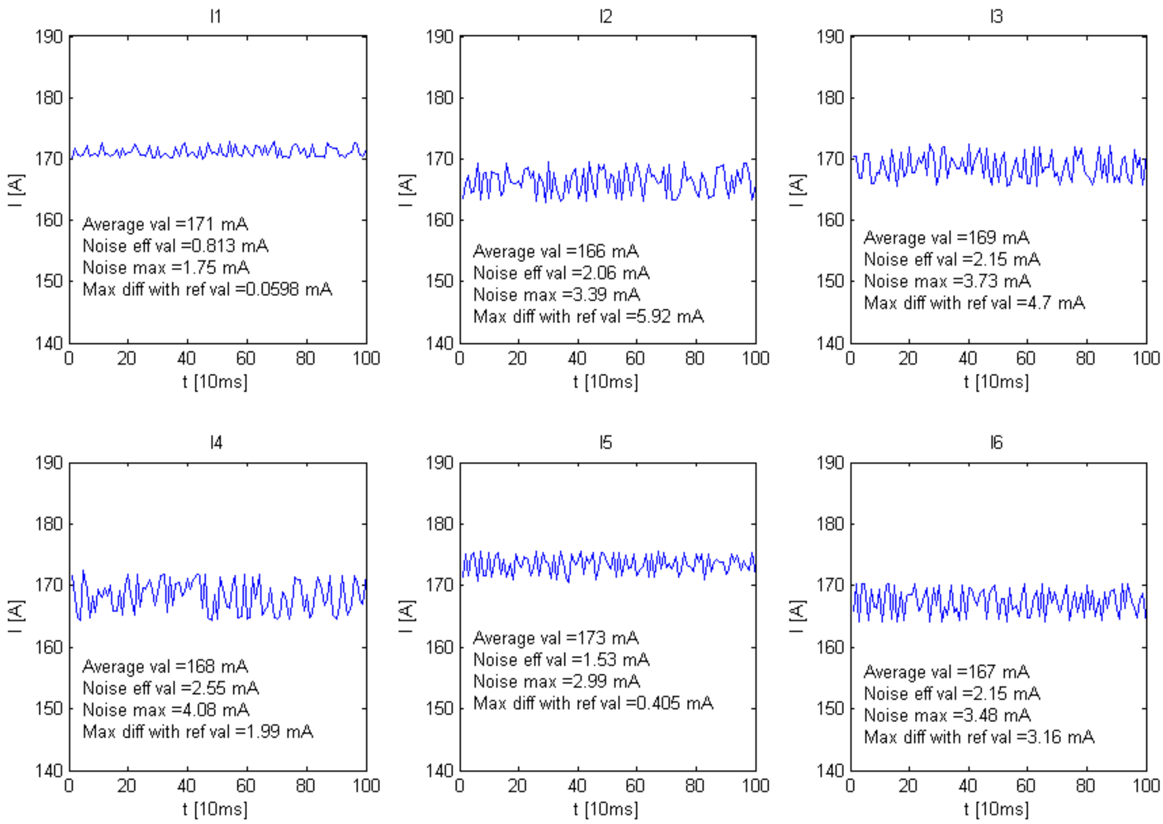
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$171[mA]$	$170[mA]$	$172[mA]$	$168[mA]$

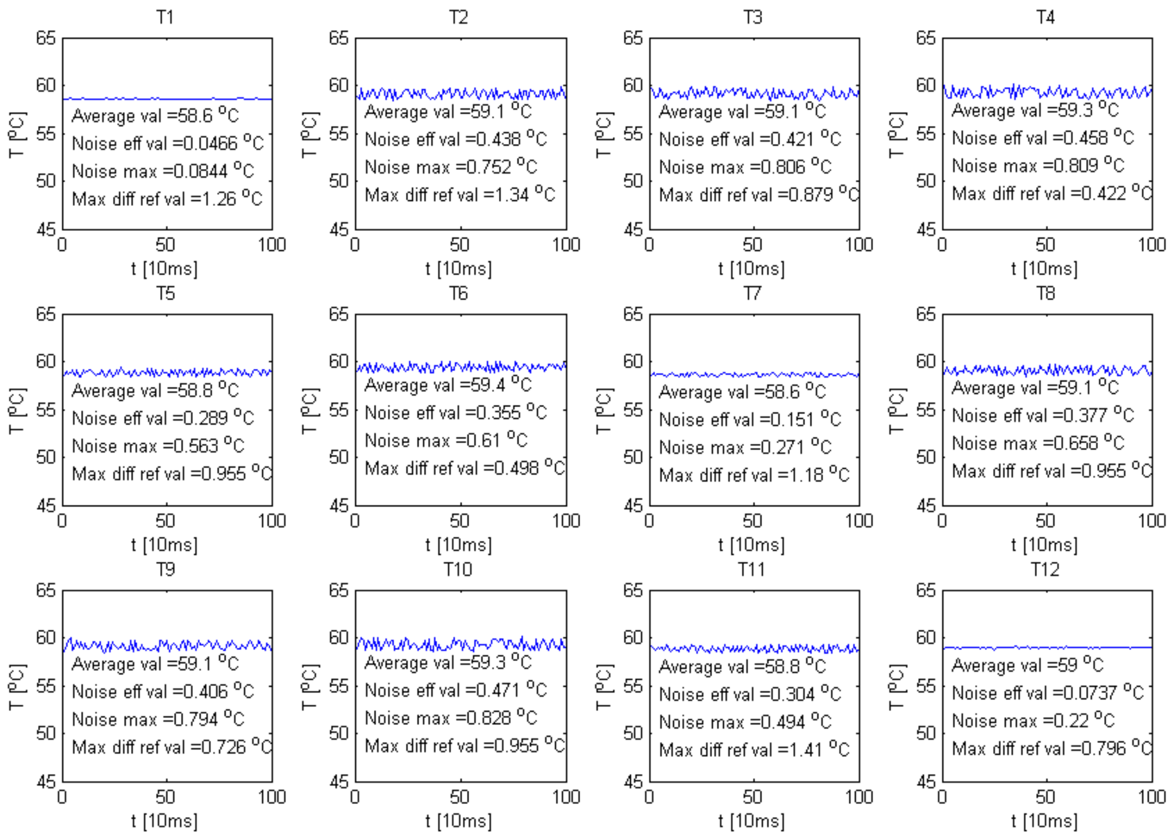
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$59.9\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.5 Test under vacuum at 50°C

Test conditions	
PMB temperature during the test	Pressure during the test
$50 \pm 1 \left[{}^{o}C \right]$	$9 \cdot 10^{-3} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$14.8 \left[mA \right]$	$3.3 \left[V \right]$	$16.4 \left[mA \right]$	$3.3 \left[V \right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 25sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10 \left[Hz \right]$	8sec	17sec

Digital Inputs/Outputs

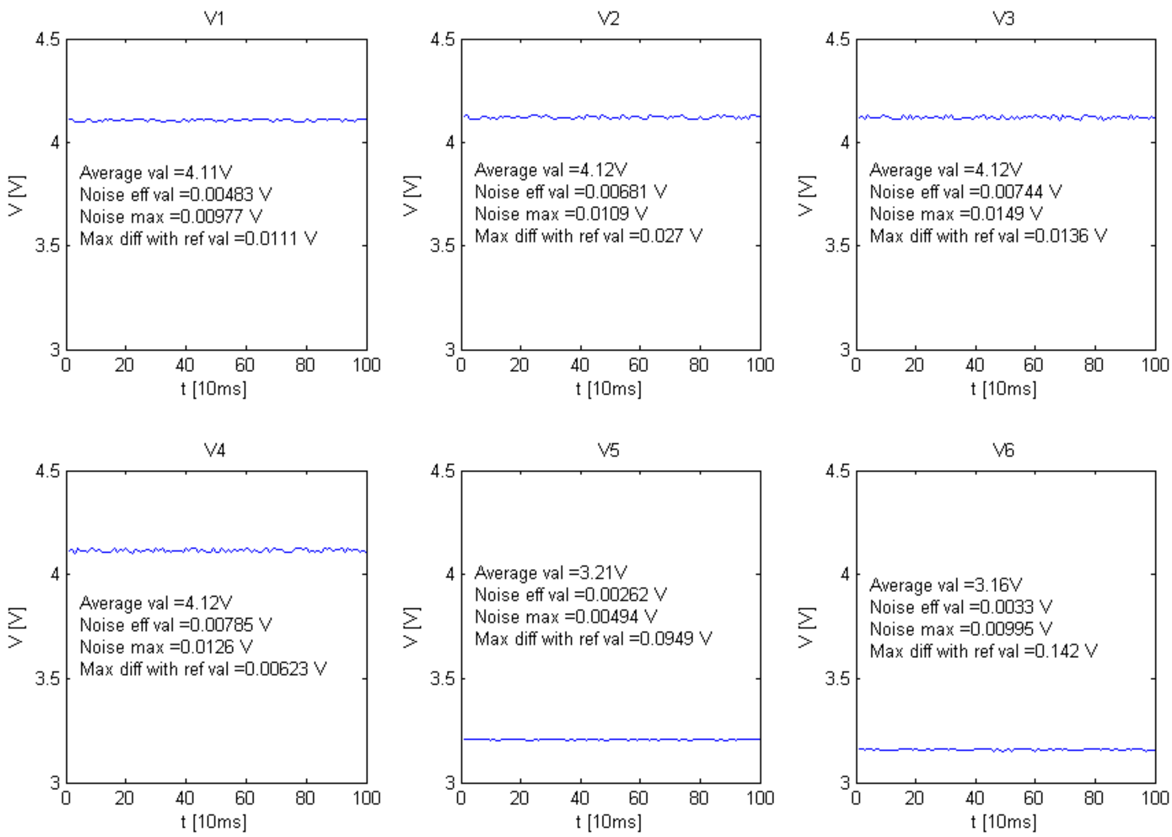
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

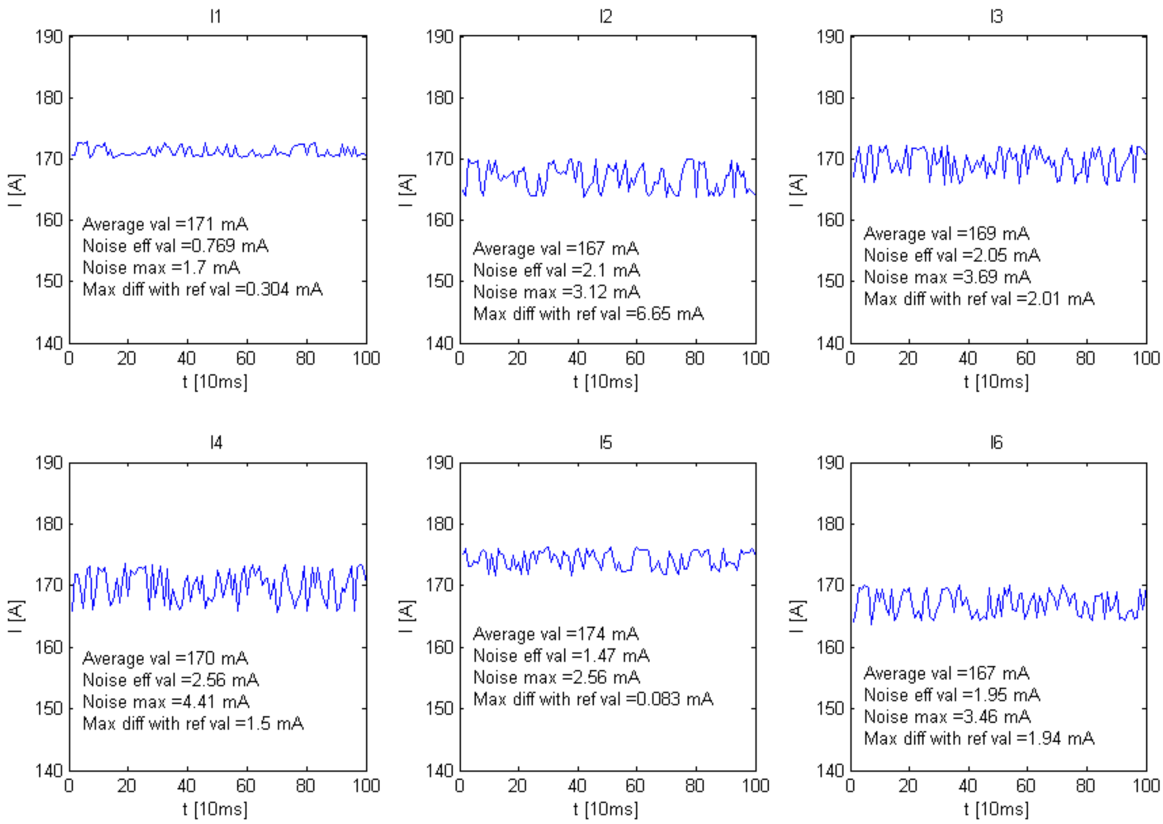
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$171[mA]$	$170[mA]$	$172[mA]$	$168[mA]$

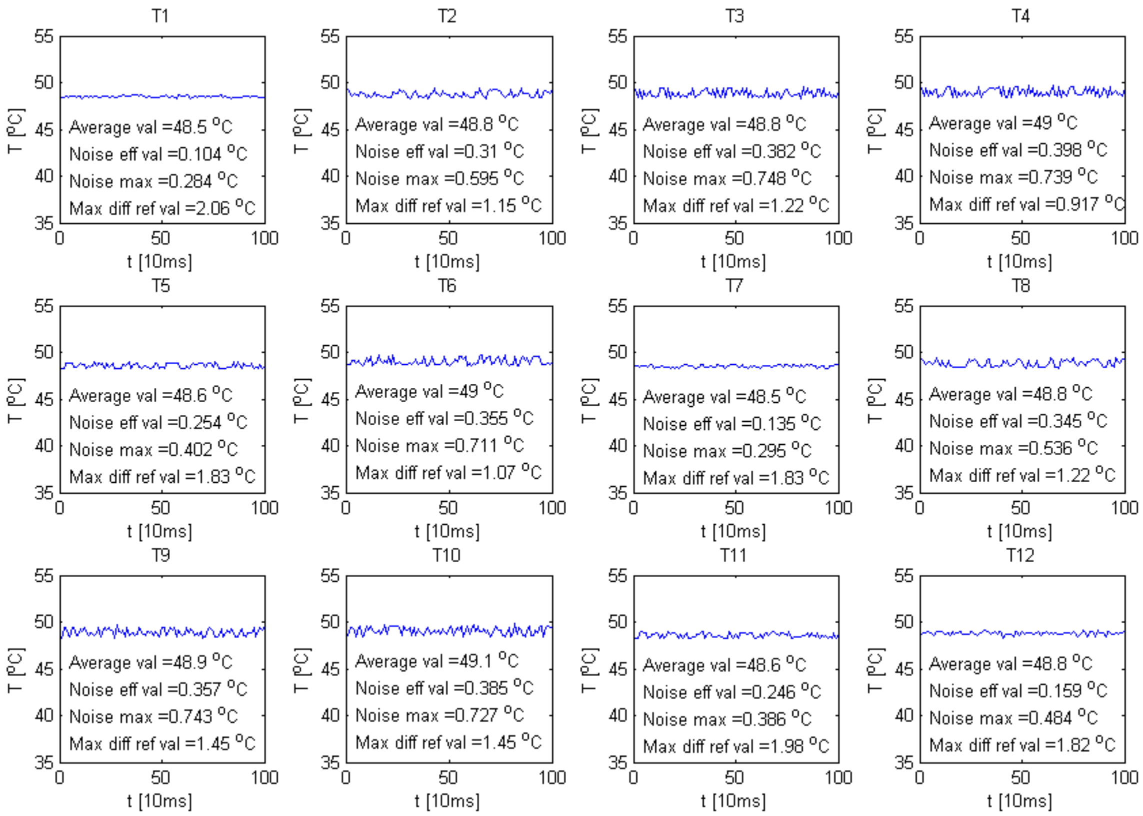
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$50.5\left[{}^oC\right]$											

Results after AD conversion



10.2.6.6 Test under vacuum at 40°C

Test conditions	
PMB temperature during the test	Pressure during the test
$40 \pm 1 \left[{}^{o}C \right]$	$1.5 \cdot 10^{-2} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$14.5[mA]$	$3.3[V]$	$16.3[mA]$	$3.3[V]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 33sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10[Hz]$	8sec	17sec

Digital Inputs/Outputs

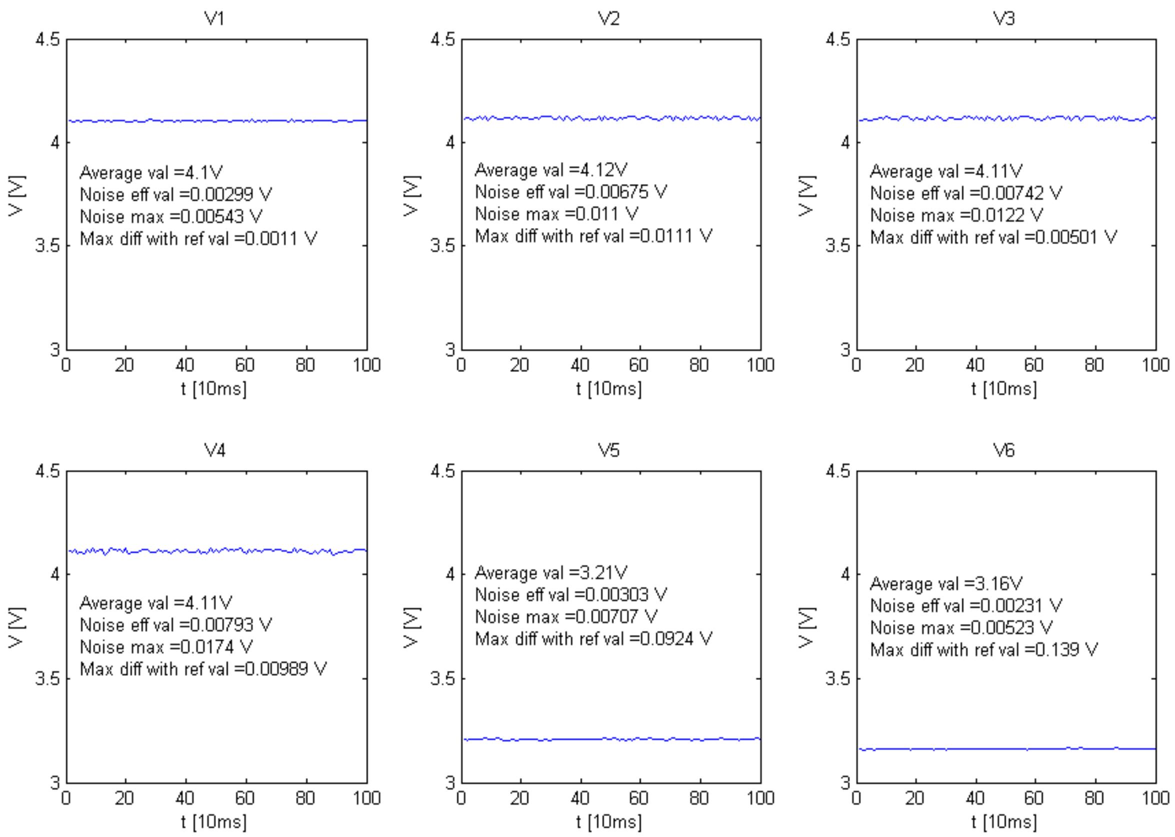
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

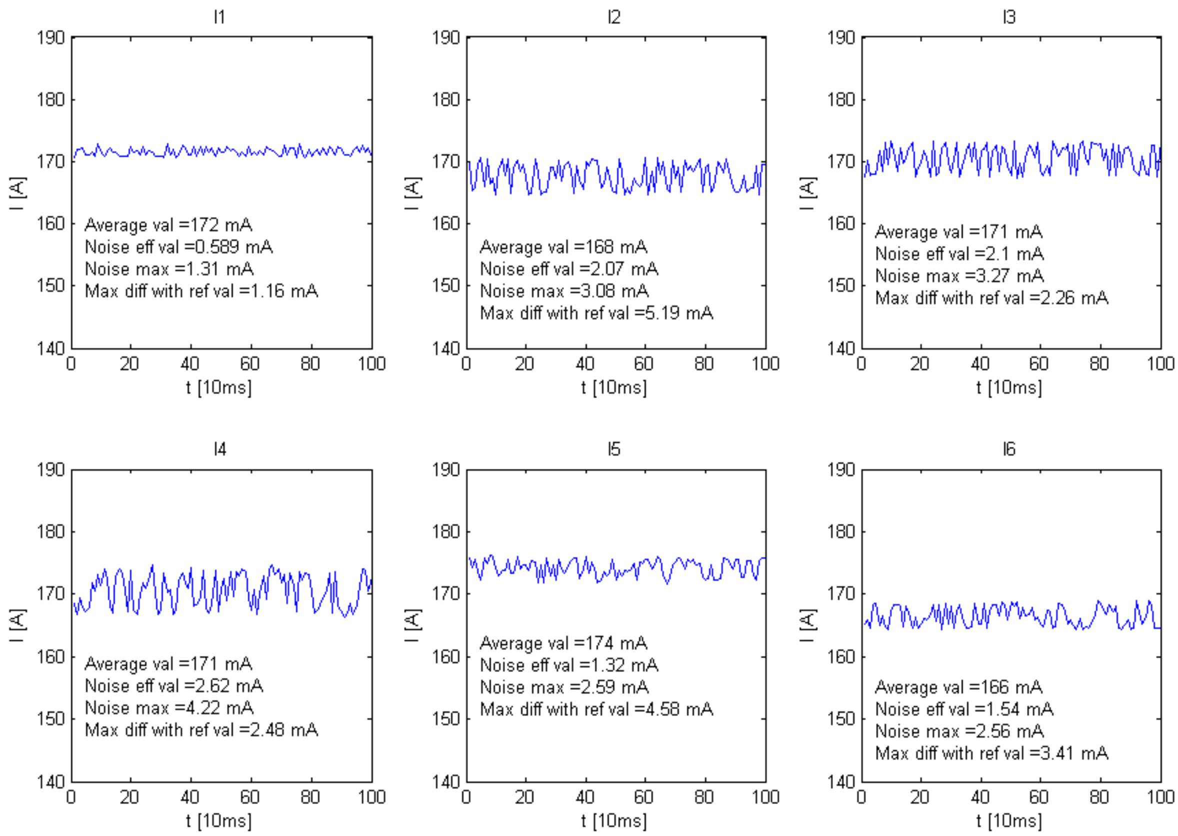
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$171[mA]$	$170[mA]$	$171[mA]$	$168[mA]$

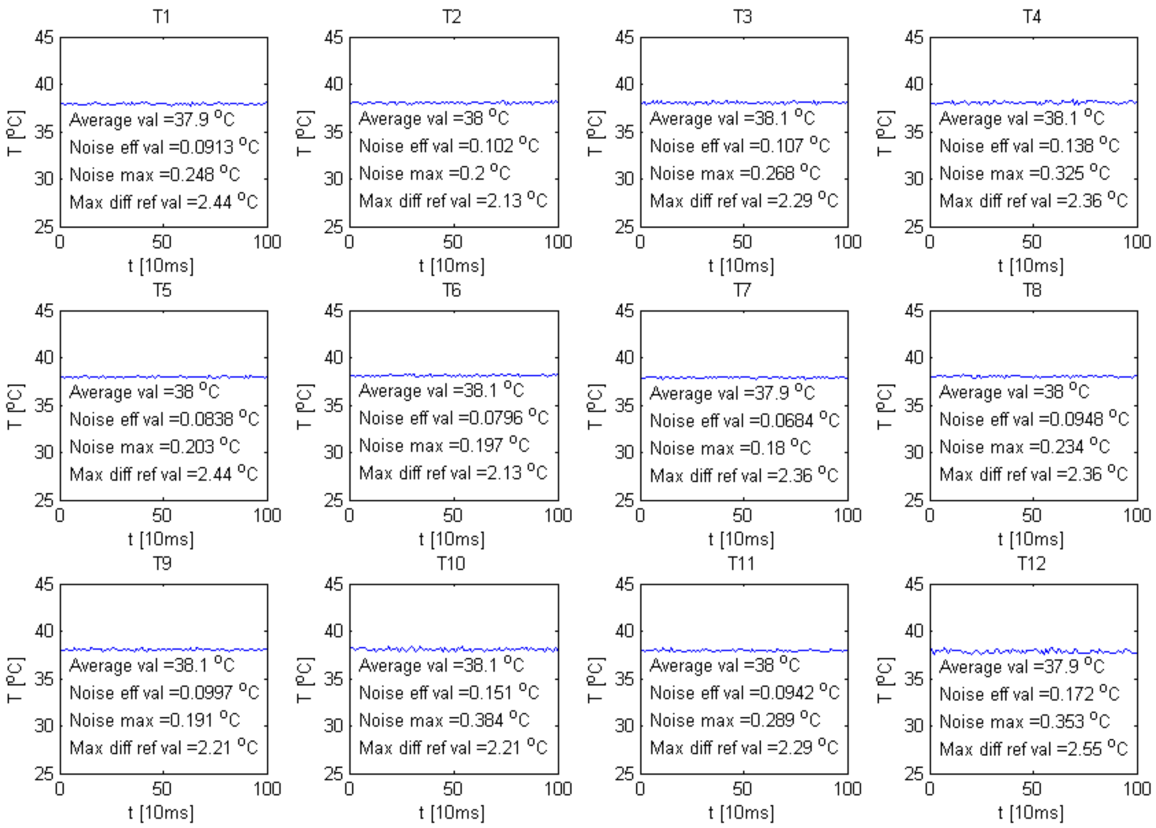
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$40.3\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.7 Test under vacuum at 30°C

Test conditions	
PMB temperature during the test	Pressure during the test
$30 \pm 1.5 \left[{}^{o}C \right]$	$2 \cdot 10^{-2} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$14.3[mA]$	$3.3[V]$	$16.1[mA]$	$3.3[V]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 34sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10[Hz]$	8sec	17sec

Digital Inputs/Outputs

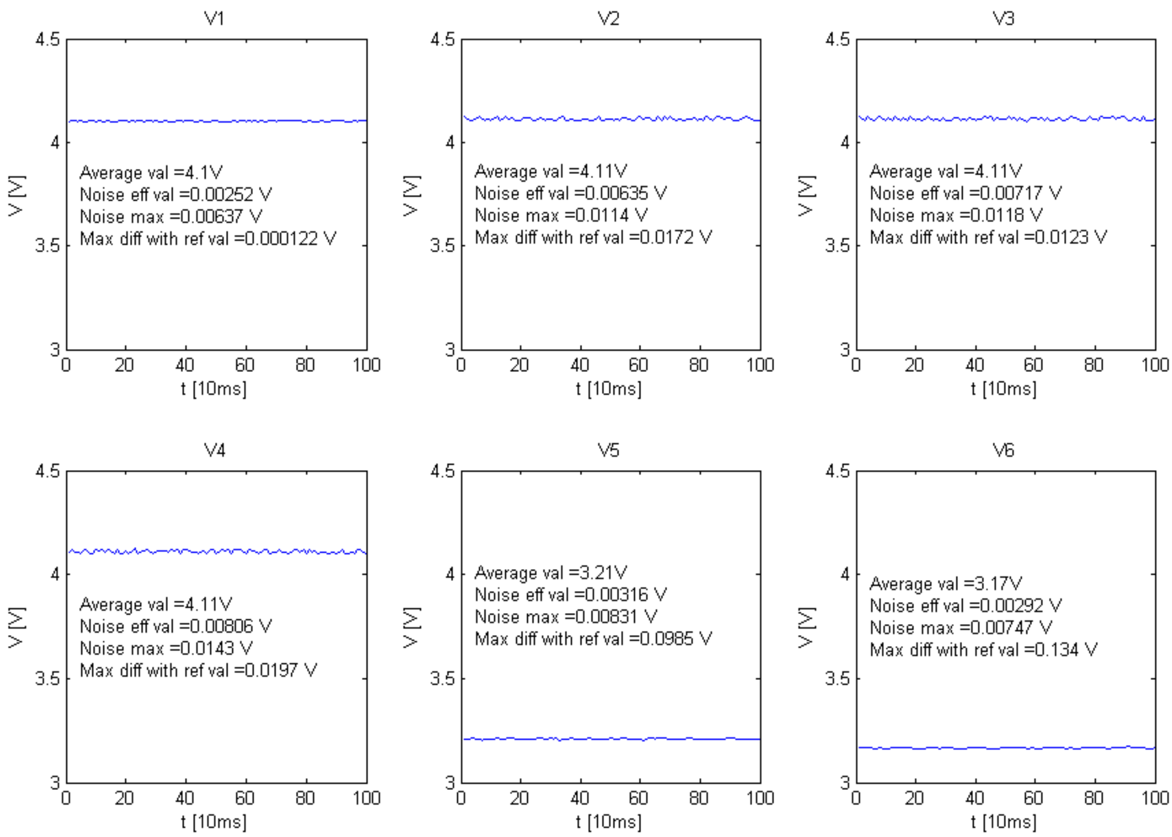
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

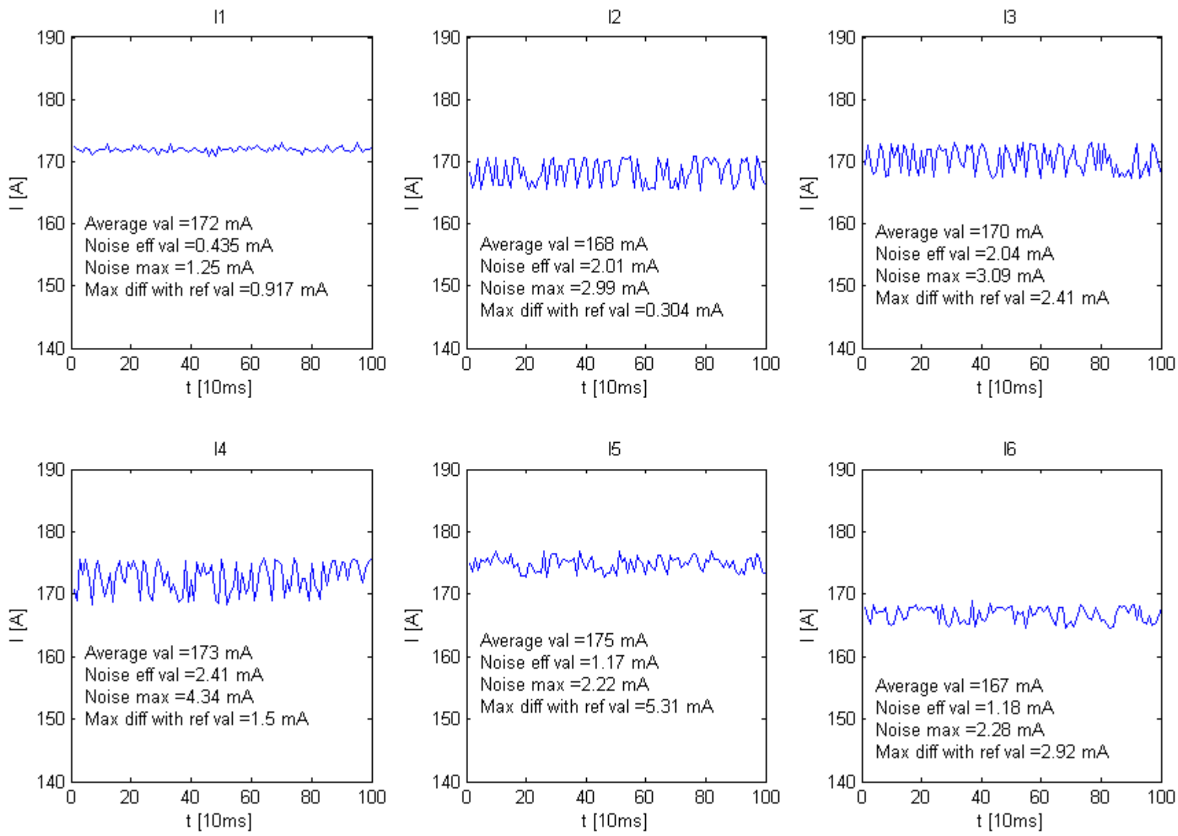
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$170[mA]$	$170[mA]$	$171[mA]$	$168[mA]$

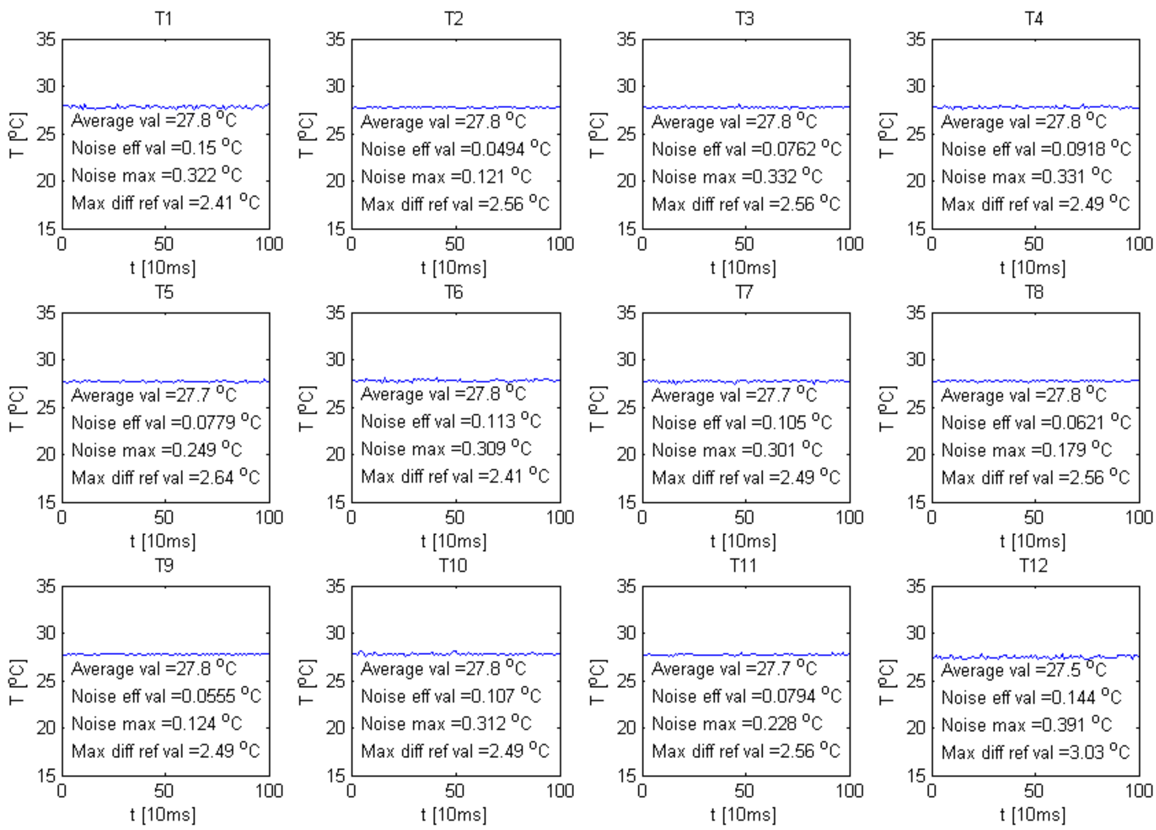
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$30.3\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.8 Test under vacuum at 20°C

Test conditions	
PMB temperature during the test	Pressure during the test
$22 \pm 1 \left[^{o}C \right]$	$8.5 \cdot 10^{-3} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$14.6 \left[mA \right]$	$3.3 \left[V \right]$	$15.6 \left[mA \right]$	$3.3 \left[V \right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 36sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10 \left[Hz \right]$	8sec	17sec

Digital Inputs/Outputs

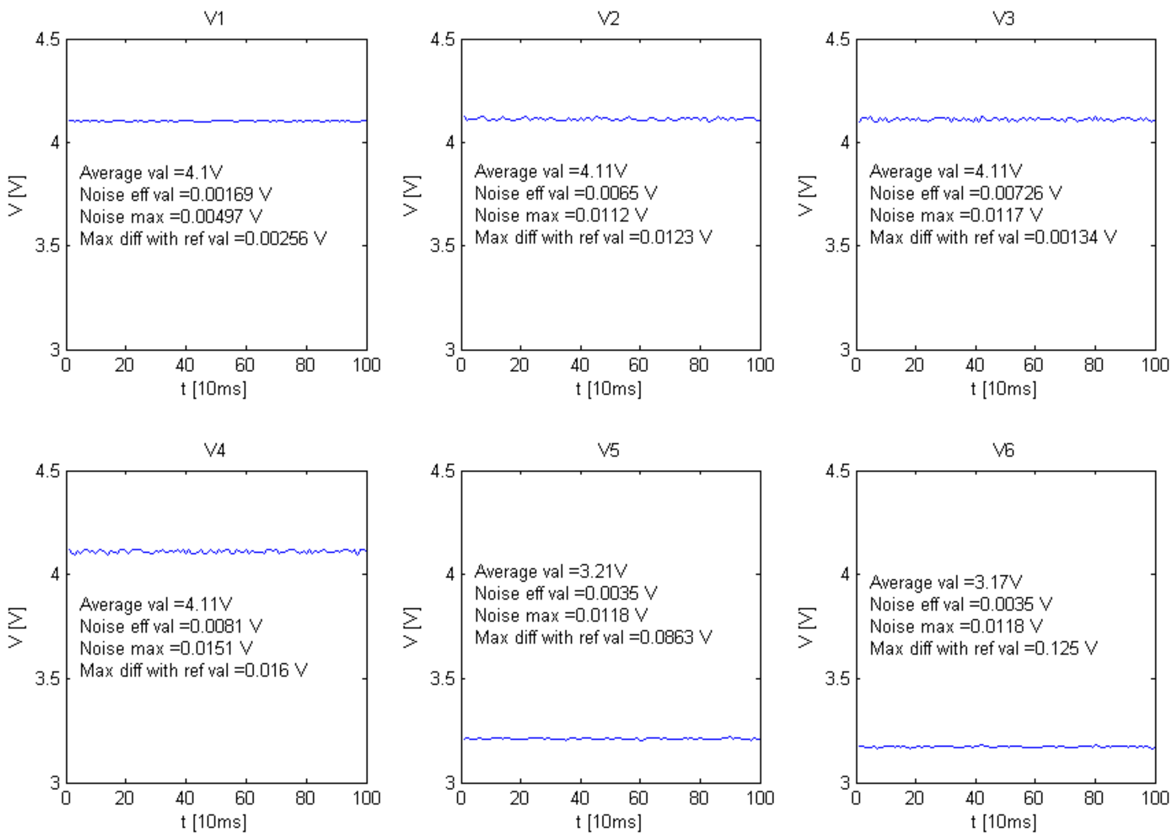
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

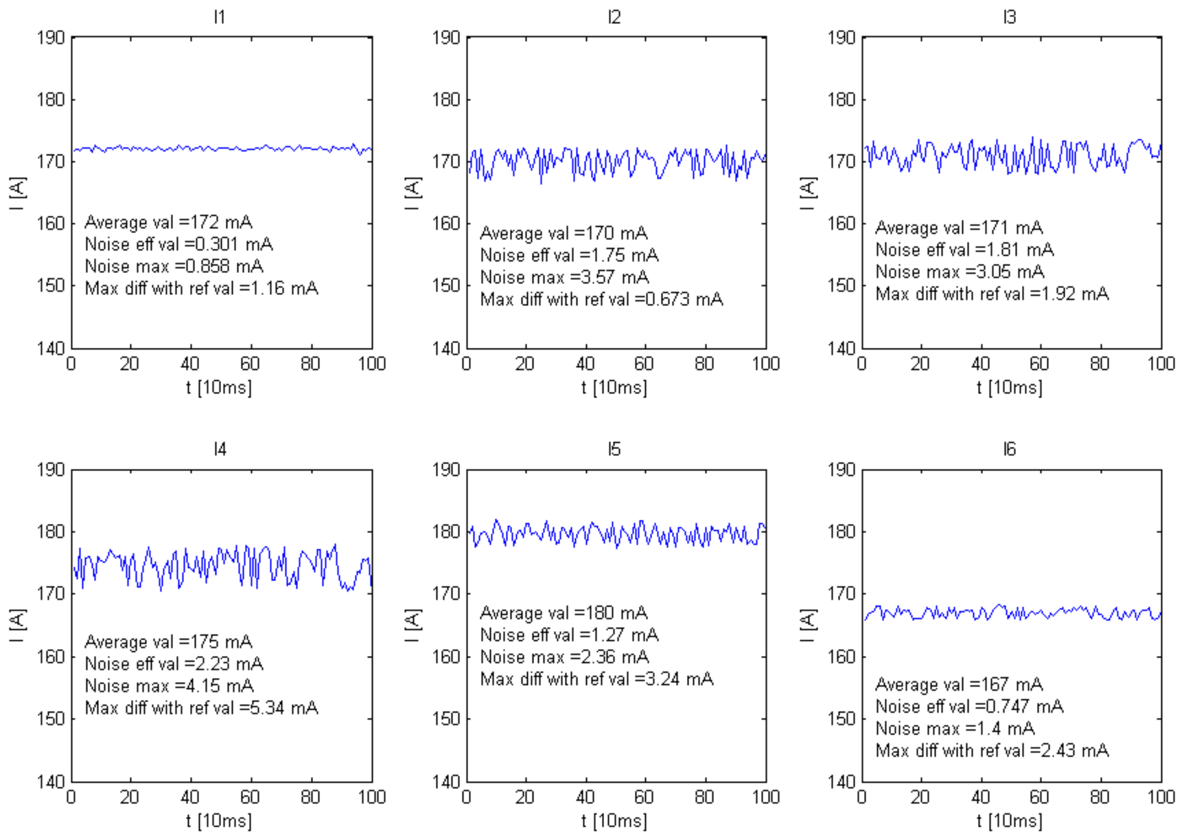
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$170[mA]$	$170[mA]$	$176[mA]$	$168[mA]$

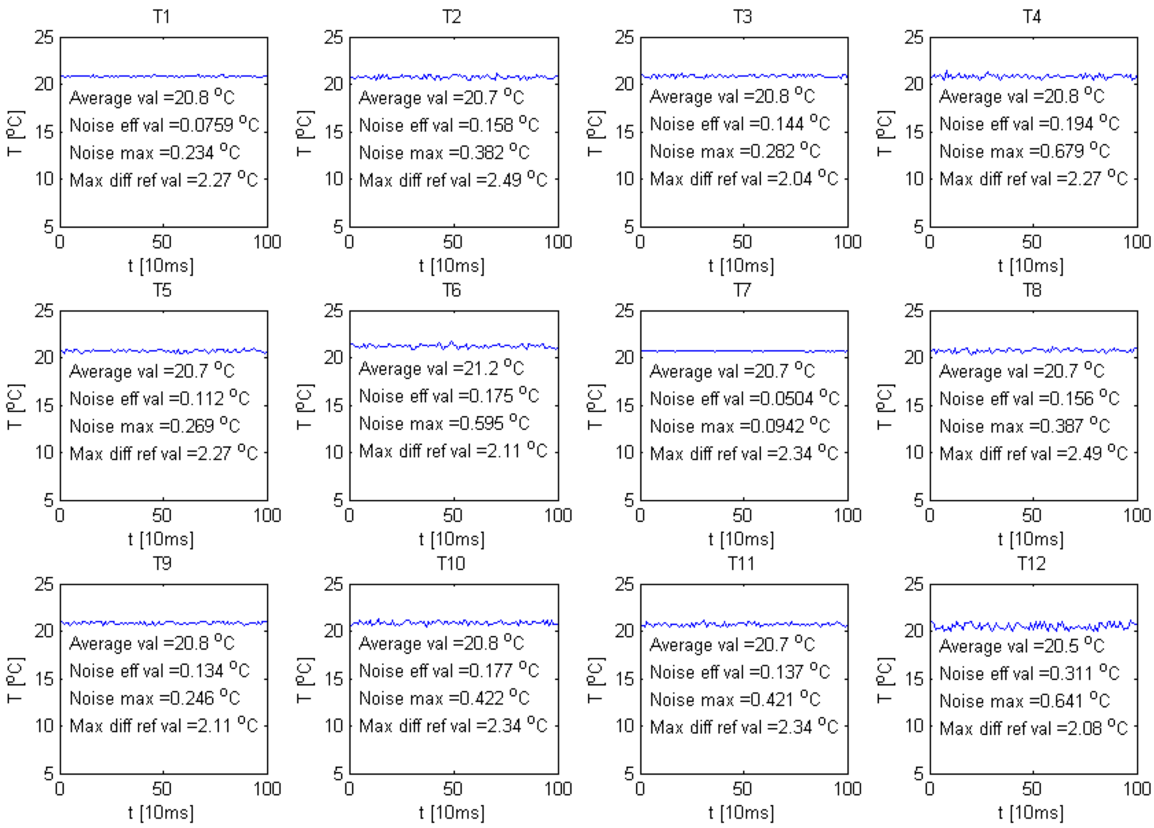
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$23\left[{}^oC\right]$											

Results after AD conversion



10.2.6.9 Test under vacuum at 10°C

Test conditions	
PMB temperature during the test	Pressure during the test
$10 \pm 1 \left[{}^{o}C \right]$	$4.5 \cdot 10^{-3} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13.9 \left[mA \right]$	$3.3 \left[V \right]$	$15.3 \left[mA \right]$	$3.3 \left[V \right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
17min 34sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10 \left[Hz \right]$	8sec	17sec

Digital Inputs/Outputs

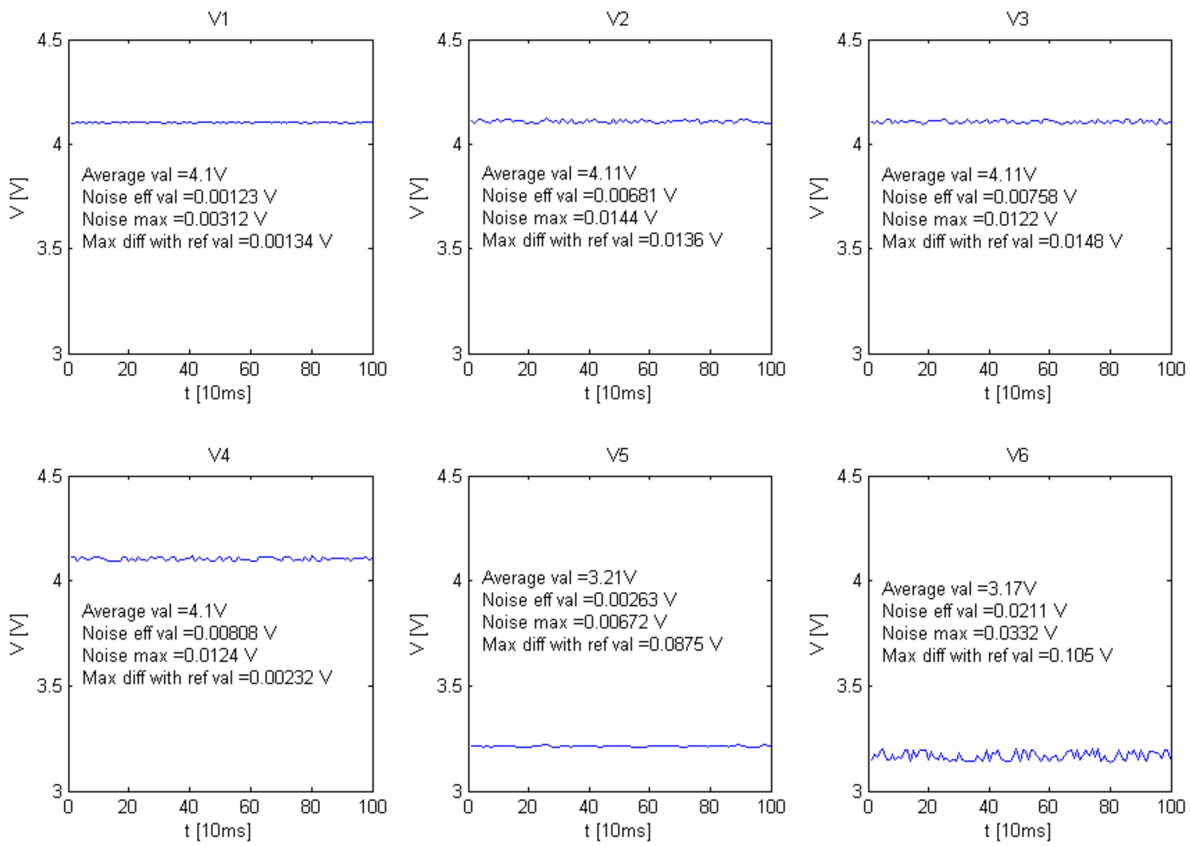
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

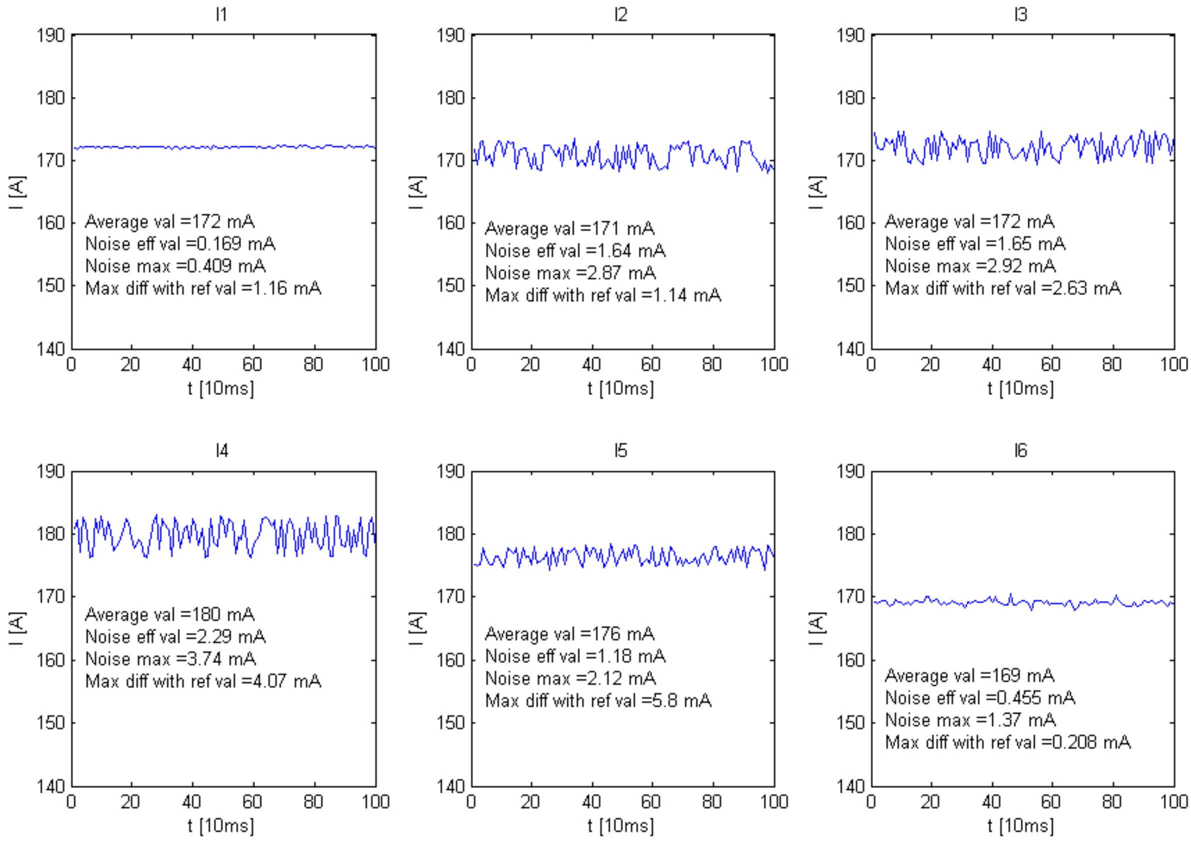
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$172[mA]$	$171[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

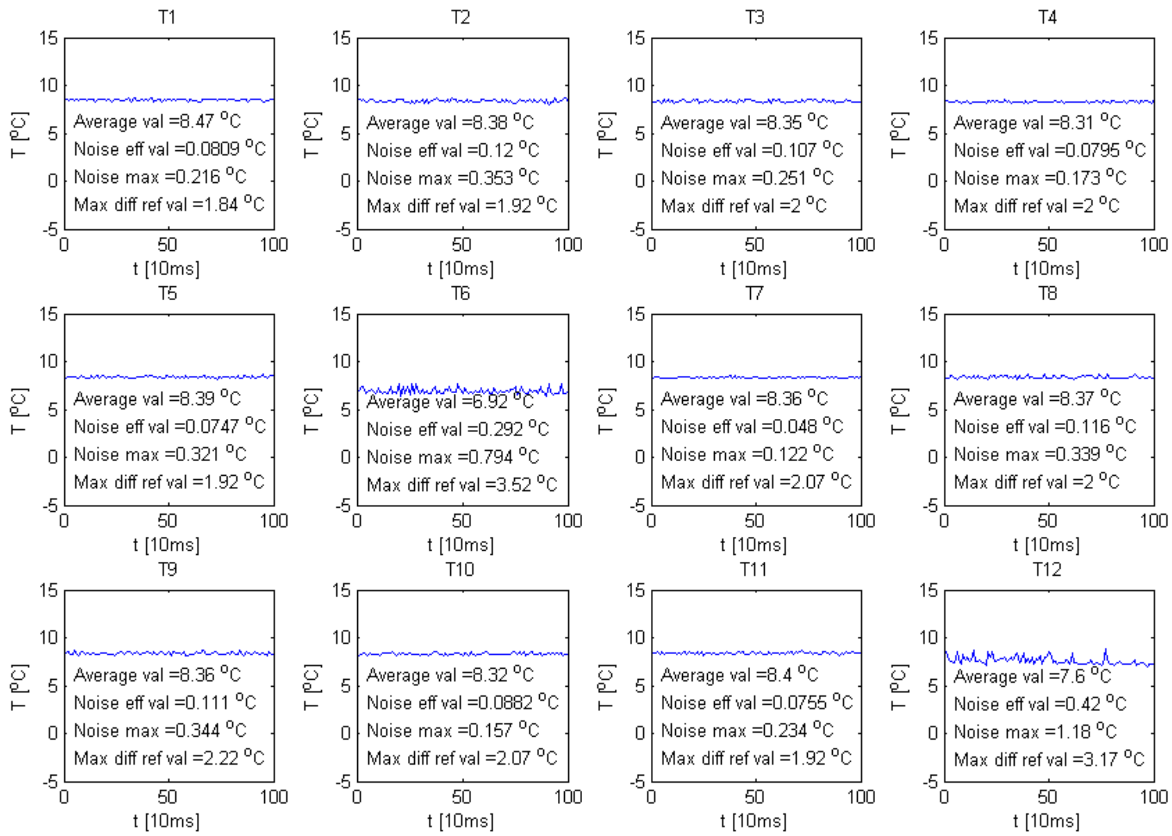
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$10.4\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.10 Test under vacuum at 0°C

Test conditions	
PMB temperature during the test	Pressure during the test
$0 \pm 1 \left[{}^{o}C \right]$	$3.5 \cdot 10^{-3} \left[mbar \right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13.7 \left[mA \right]$	$3.3 \left[V \right]$	$15.2 \left[mA \right]$	$3.3 \left[V \right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
16min 55sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10 \left[Hz \right]$	8sec	17sec

Digital Inputs/Outputs

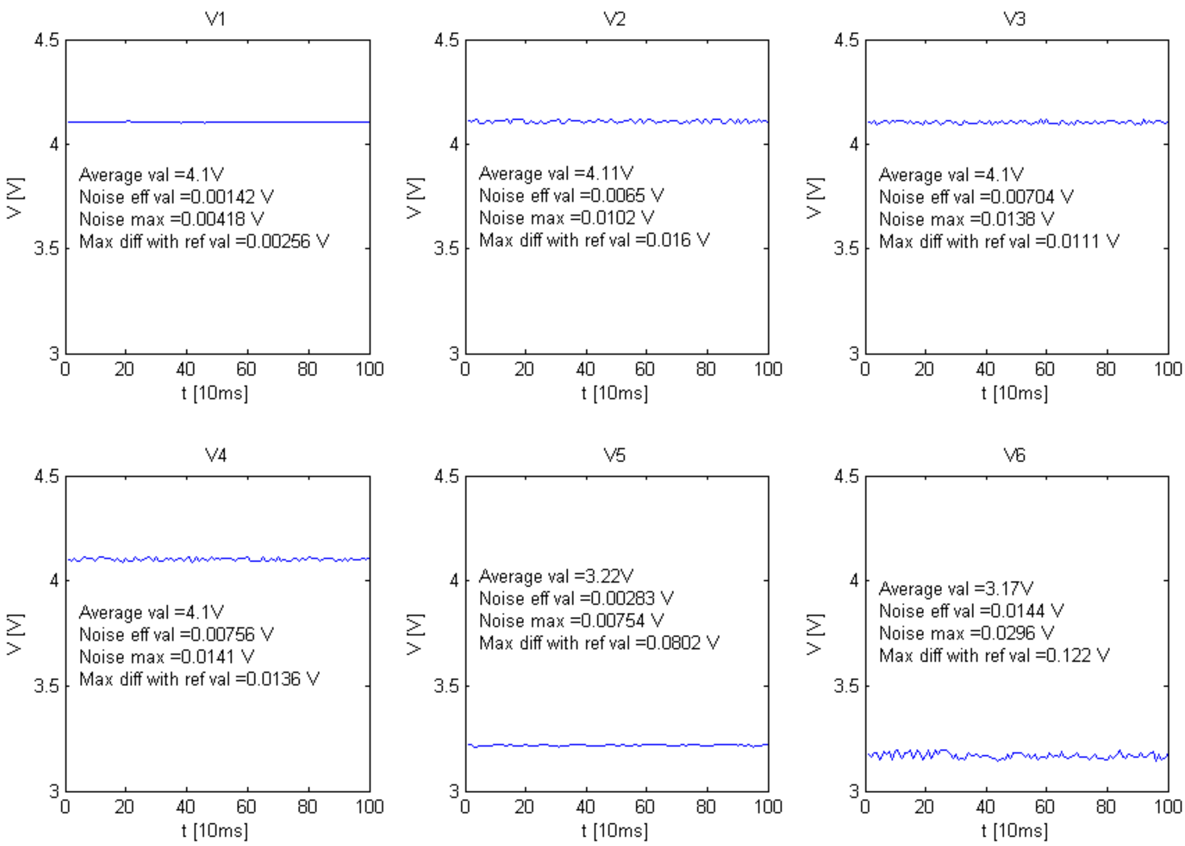
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

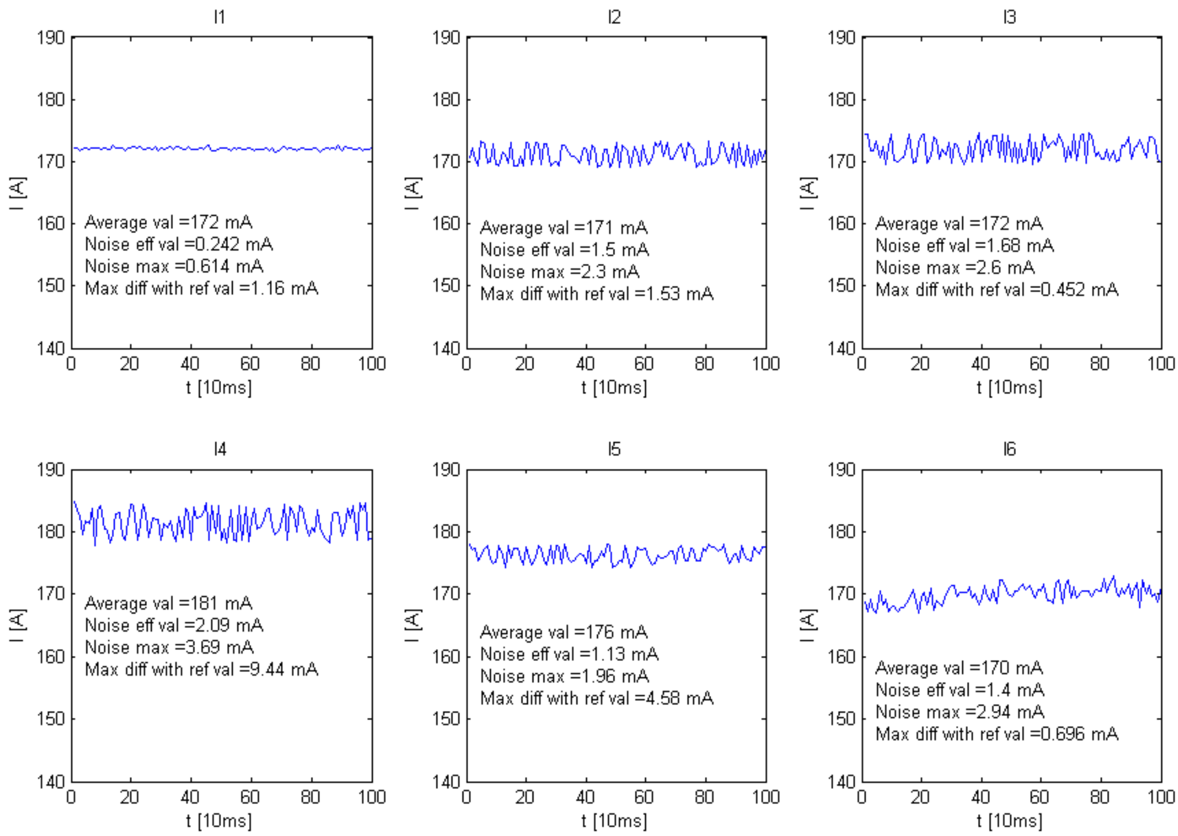
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$170[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

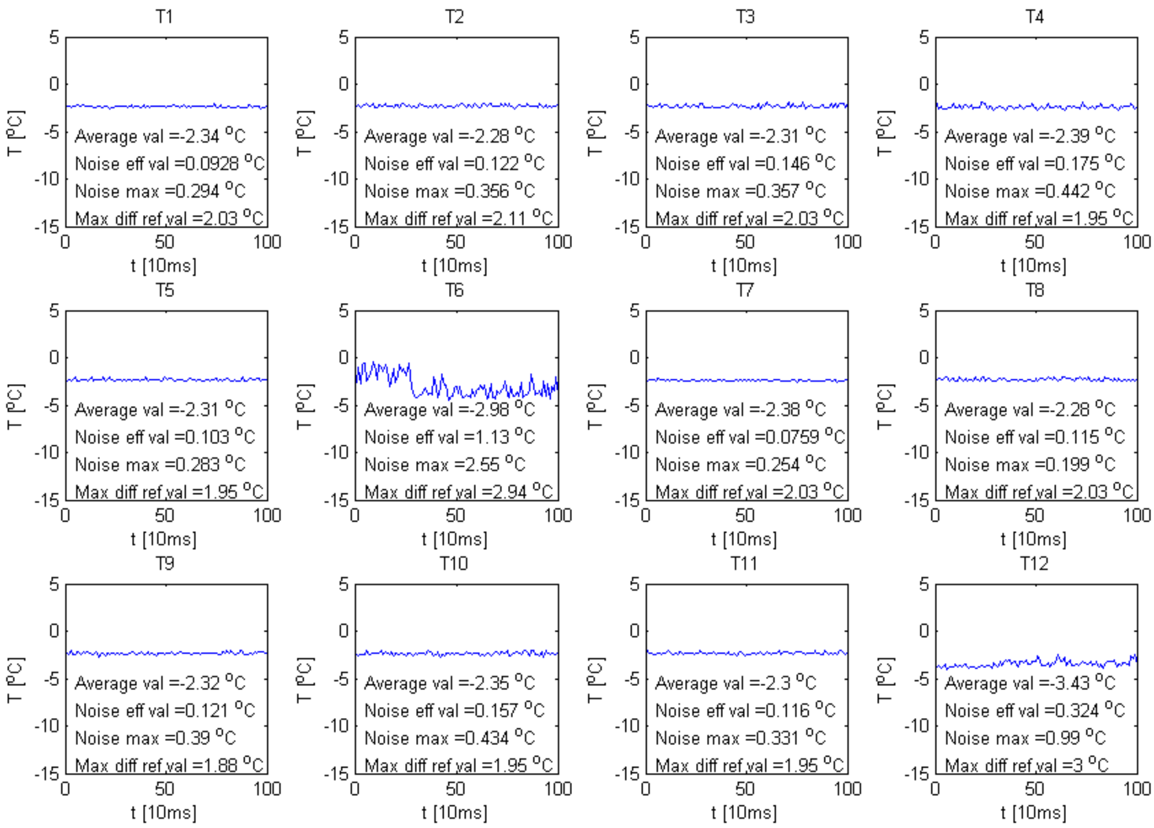
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$-0.3\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.11 Test under vacuum at -10ºC

Test conditions	
PMB temperature during the test	Pressure during the test
$-10\pm1\left[{}^{o}C\right]$	$3.2\cdot10^{-3}\left[mbar\right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13.5\left[mA\right]$	$3.3\left[V\right]$	$15.9\left[mA\right]$	$3.3\left[V\right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
16min 38sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10\left[Hz\right]$	8sec	17sec

Digital Inputs/Outputs

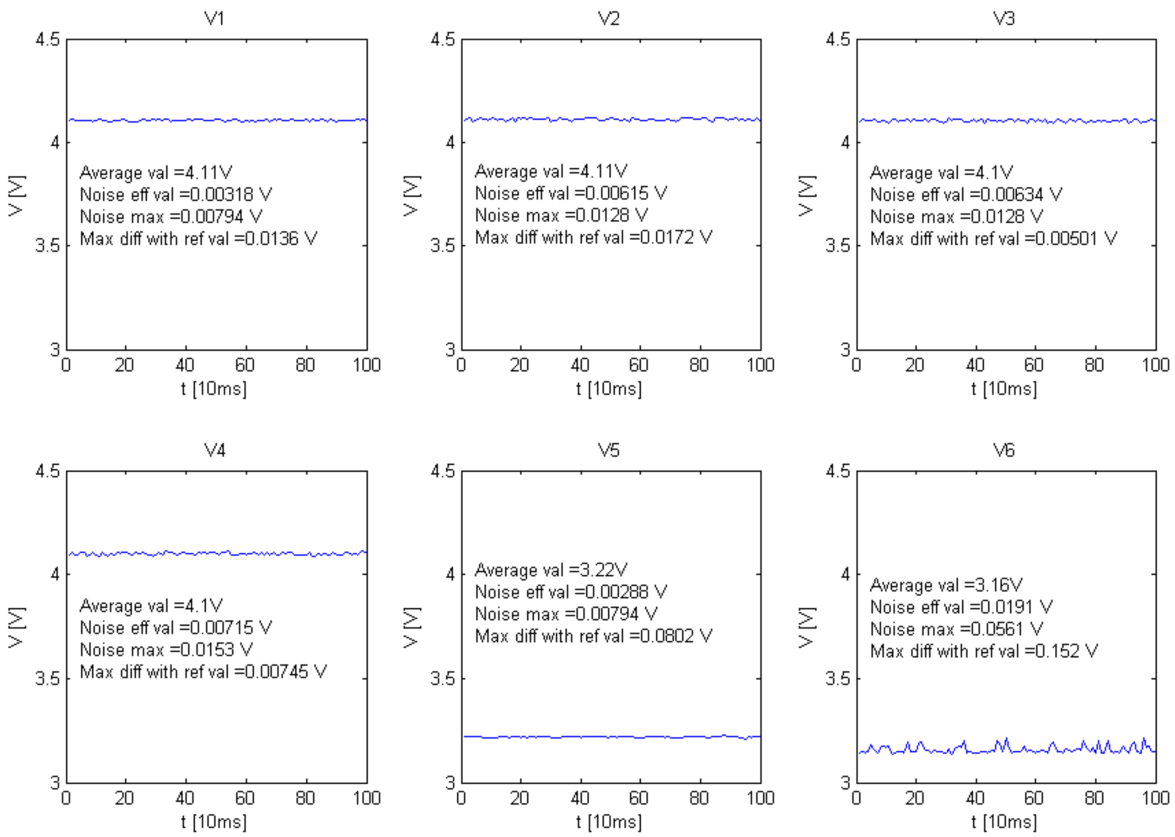
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

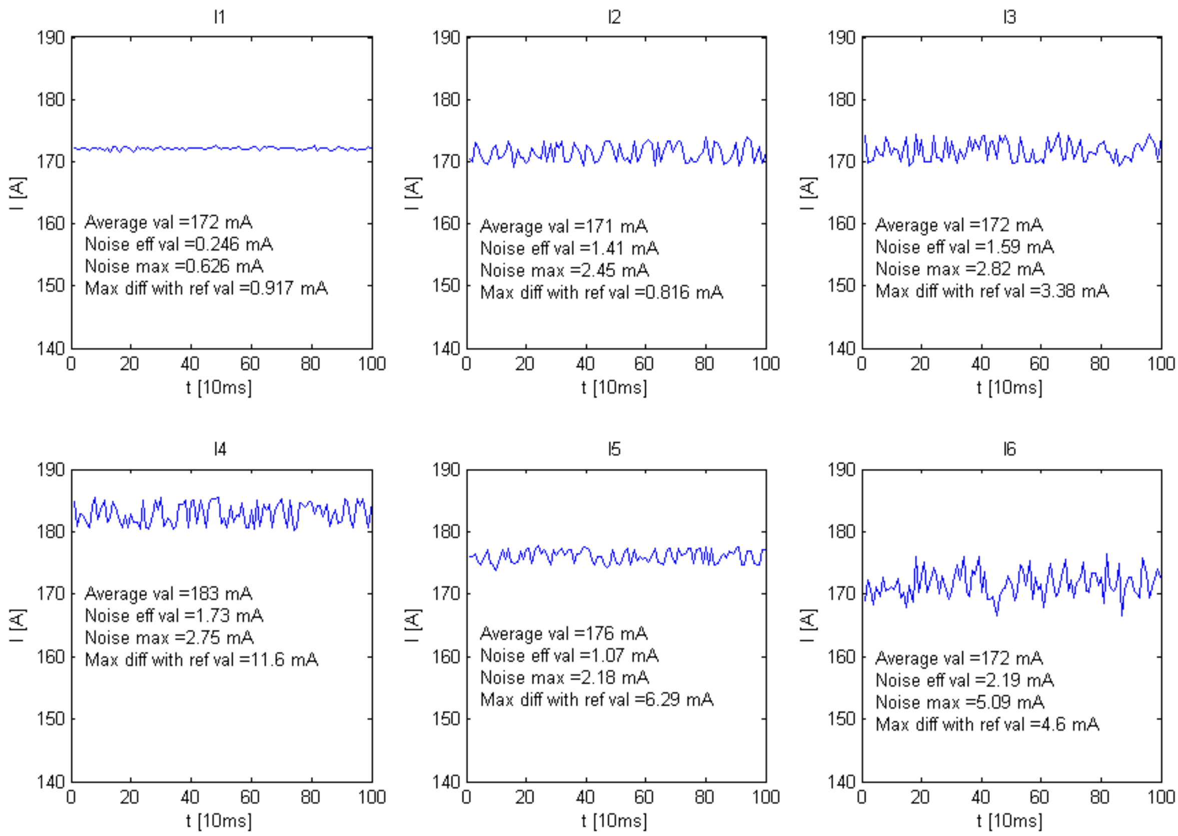
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$172[mA]$	$170[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

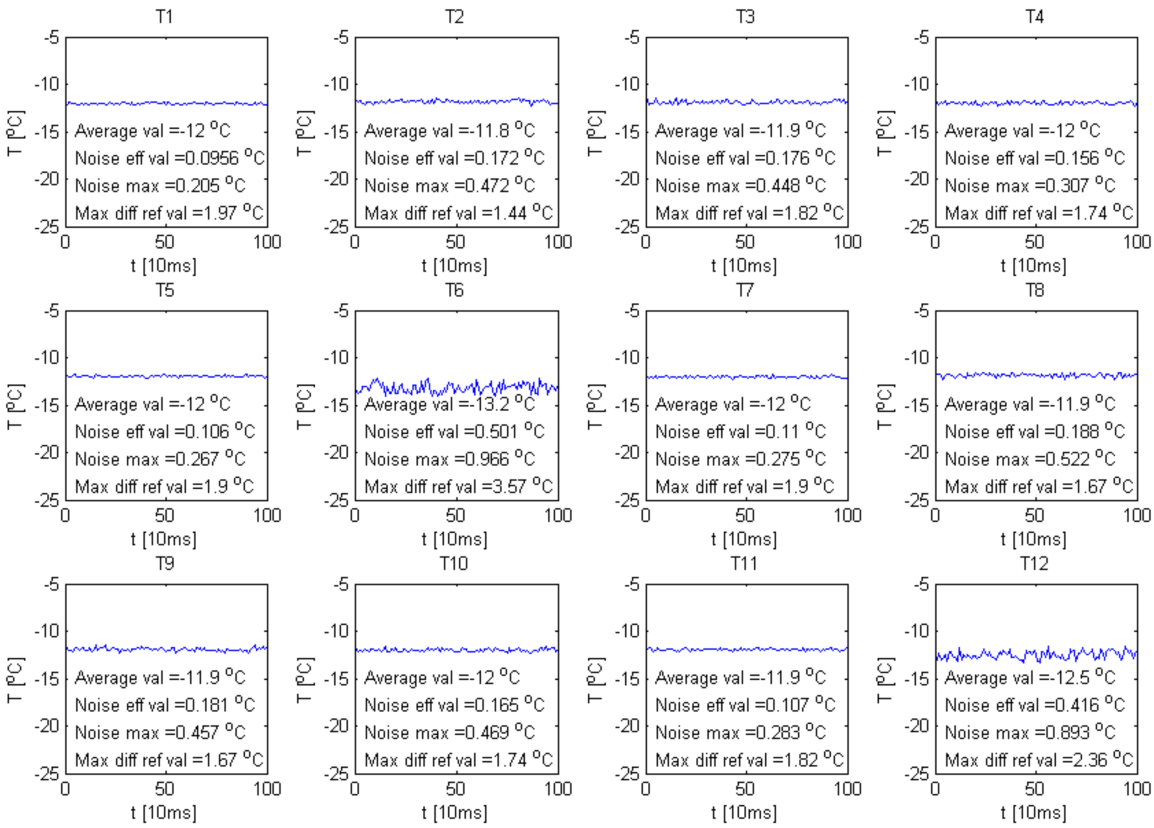
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$-10.1\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.12 Test under vacuum at -20ºC

Test conditions	
PMB temperature during the test	Pressure during the test
$-20\pm1\left[{}^{o}C\right]$	$5\cdot10^{-3}\left[mbar\right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13.3\left[mA\right]$	$3.3\left[V\right]$	$14.4\left[mA\right]$	$3.3\left[V\right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
16min 16sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10\left[Hz\right]$	8sec	17sec

Digital Inputs/Outputs

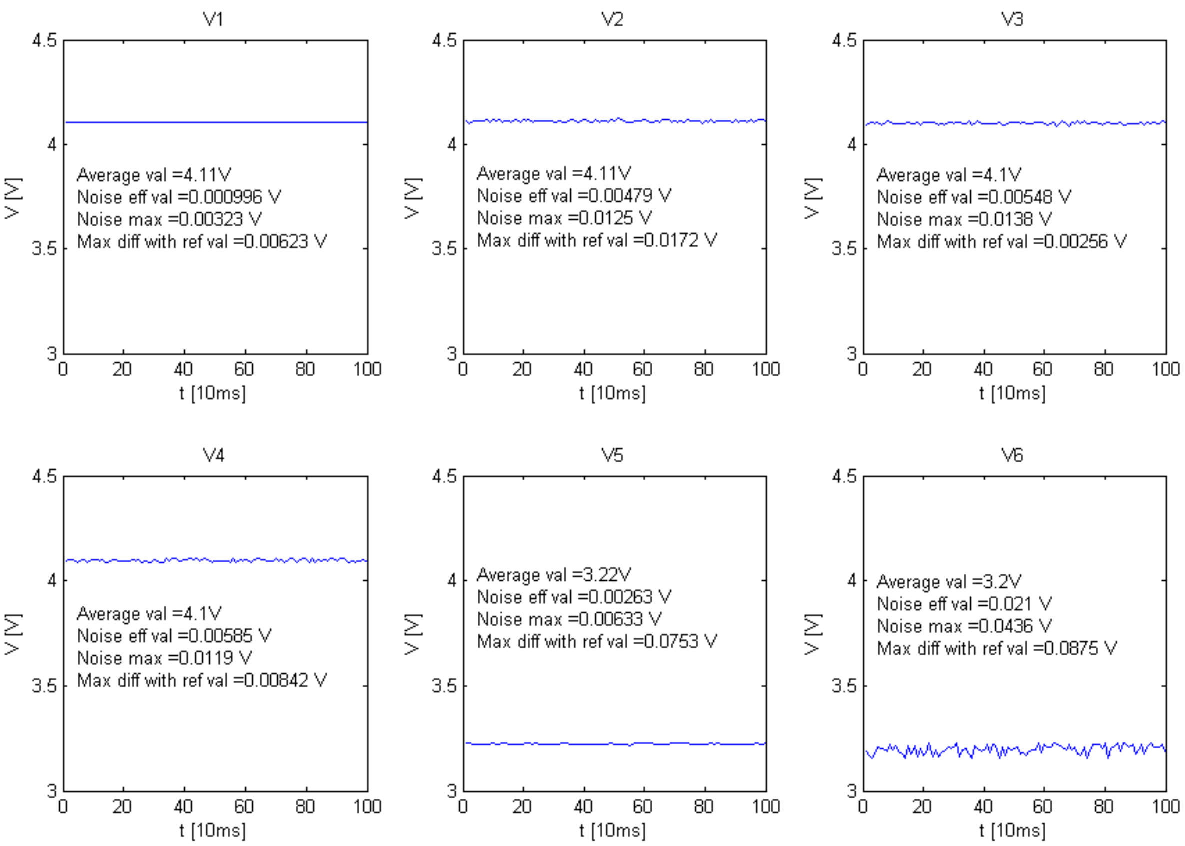
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

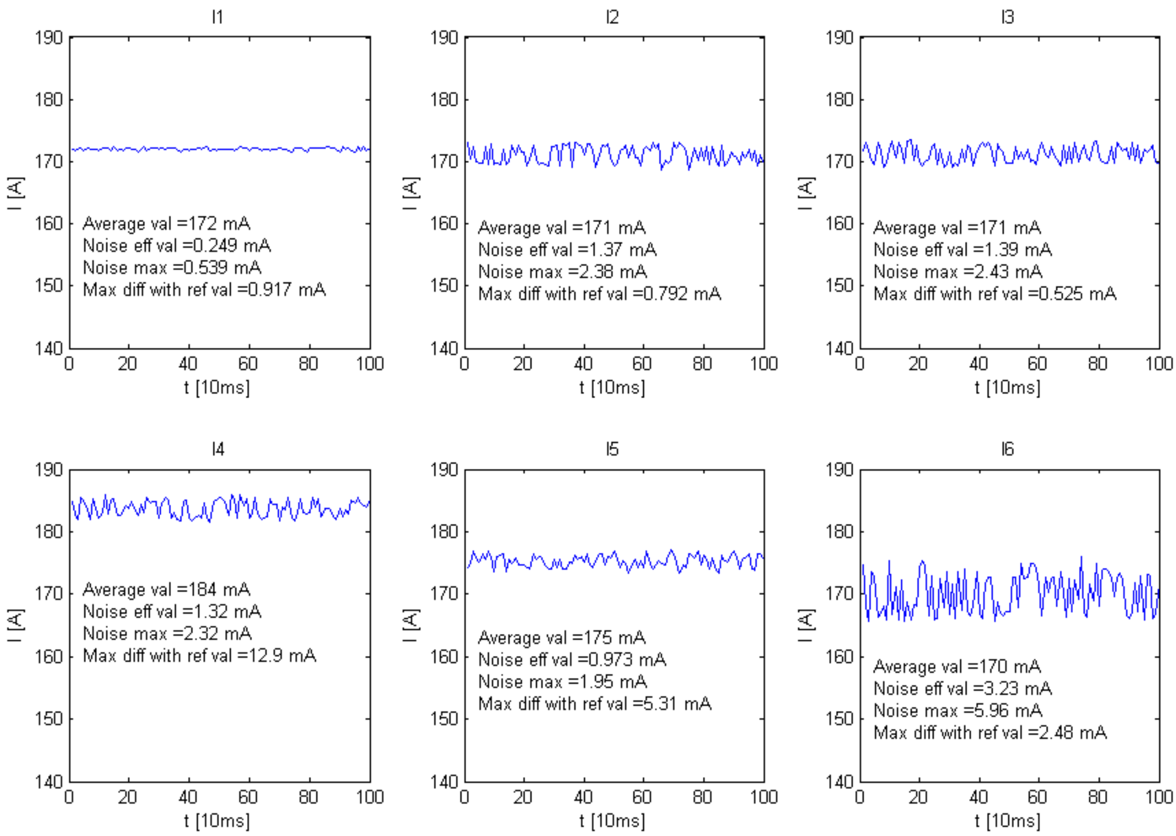
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$170[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

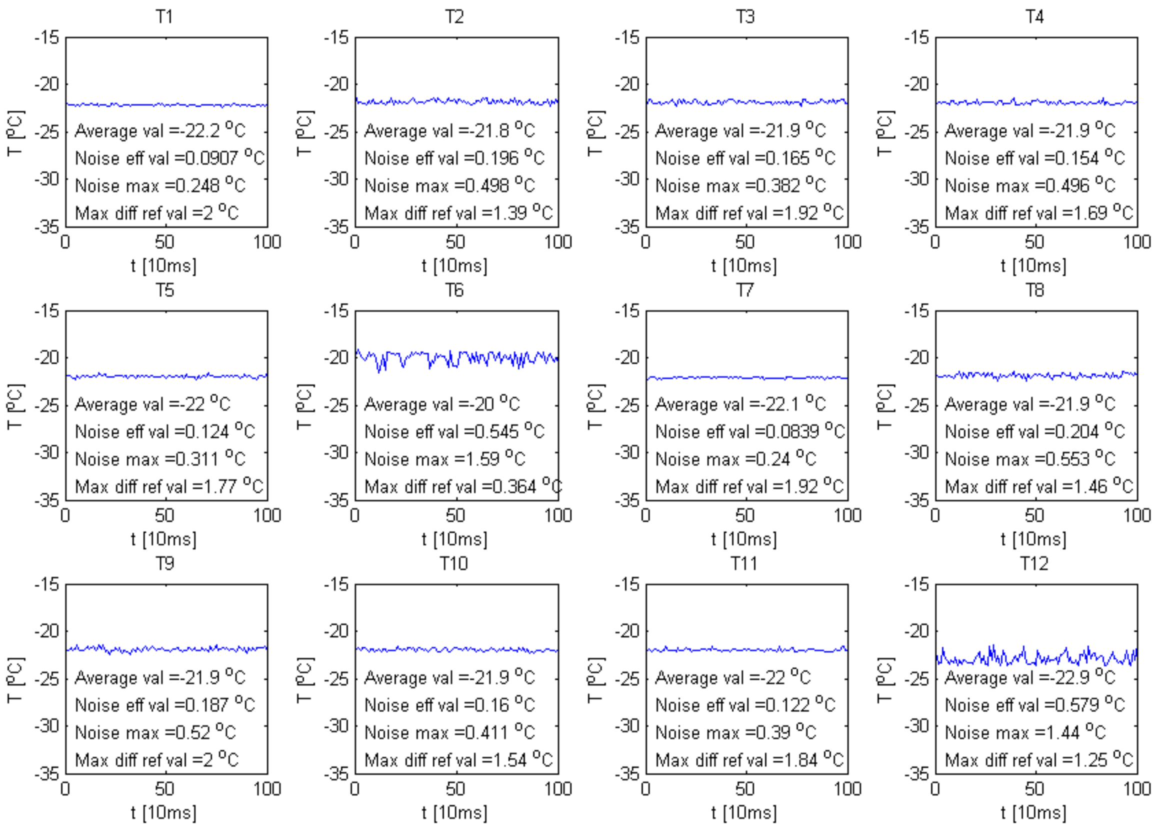
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$-20.2\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.13 Test under vacuum at -30ºC

Test conditions	
PMB temperature during the test	Pressure during the test
$-30 \pm 1 \left[{}^{o}C\right]$	$1 \cdot 10^{-2}\left[mbar\right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13.1\left[mA\right]$	$3.3\left[V\right]$	$14.3\left[mA\right]$	$3.3\left[V\right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
15min 55sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10\left[Hz\right]$	8sec	17sec

Digital Inputs/Outputs

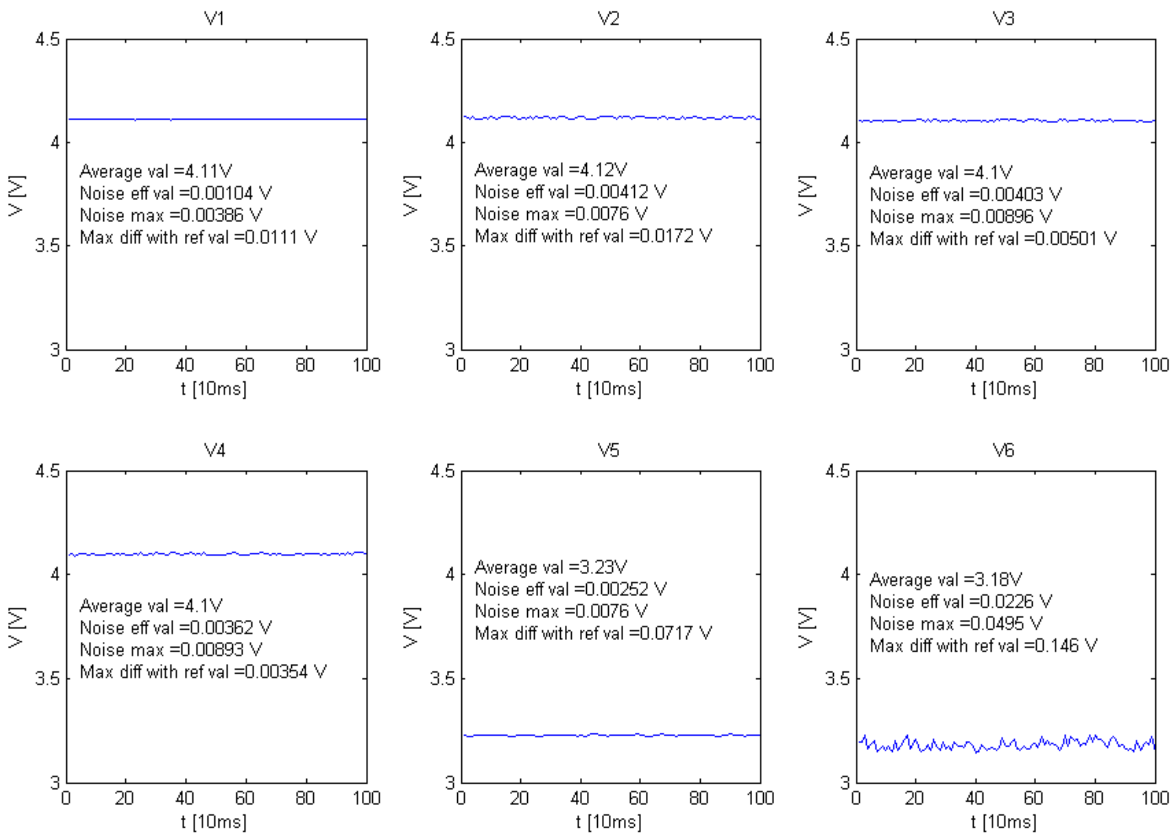
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

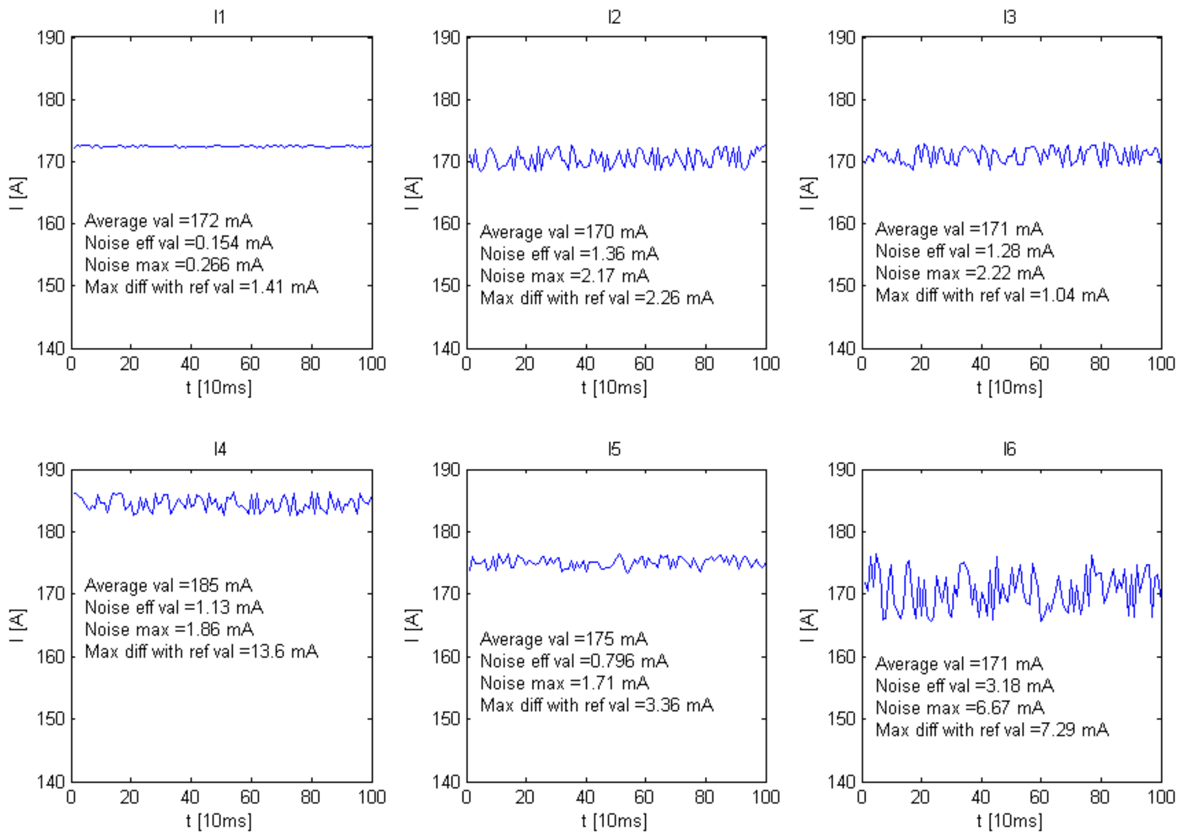
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$171[mA]$	$171[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

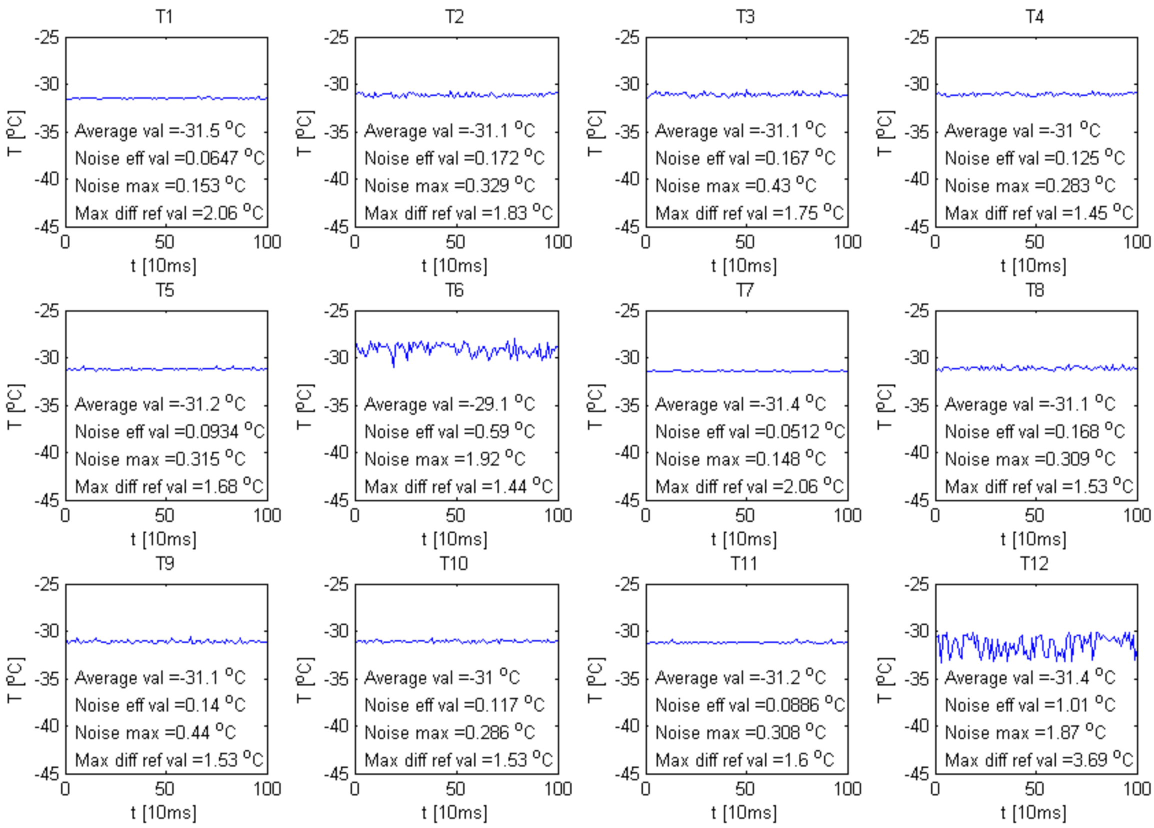
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$-29.5\left[{}^{o}C\right]$											

Results after AD conversion



10.2.6.14 Test under vacuum at -40ºC

Test conditions	
PMB temperature during the test	Pressure during the test
$-40 \pm 2\left[{}^{o}C\right]$	$9 \cdot 10^{-1}\left[mbar\right]$

Consumption of the board

Consumption before the test (without current in measuring chains)		Consumption after the test (with current in measuring chains)	
Current	Voltage	Current	Voltage
$13\left[mA\right]$	$3.3\left[V\right]$	$13.9\left[mA\right]$	$3.3\left[V\right]$

15 minutes timer

Time before setting the output at 3.3V	Time that the output stays at 3.3V
15min 36sec	2sec

HBG

Morse message sent	Frequency	Message emission time	Time between 2 emissions
swisscube	$10\left[Hz\right]$	8sec	17sec

Digital Inputs/Outputs

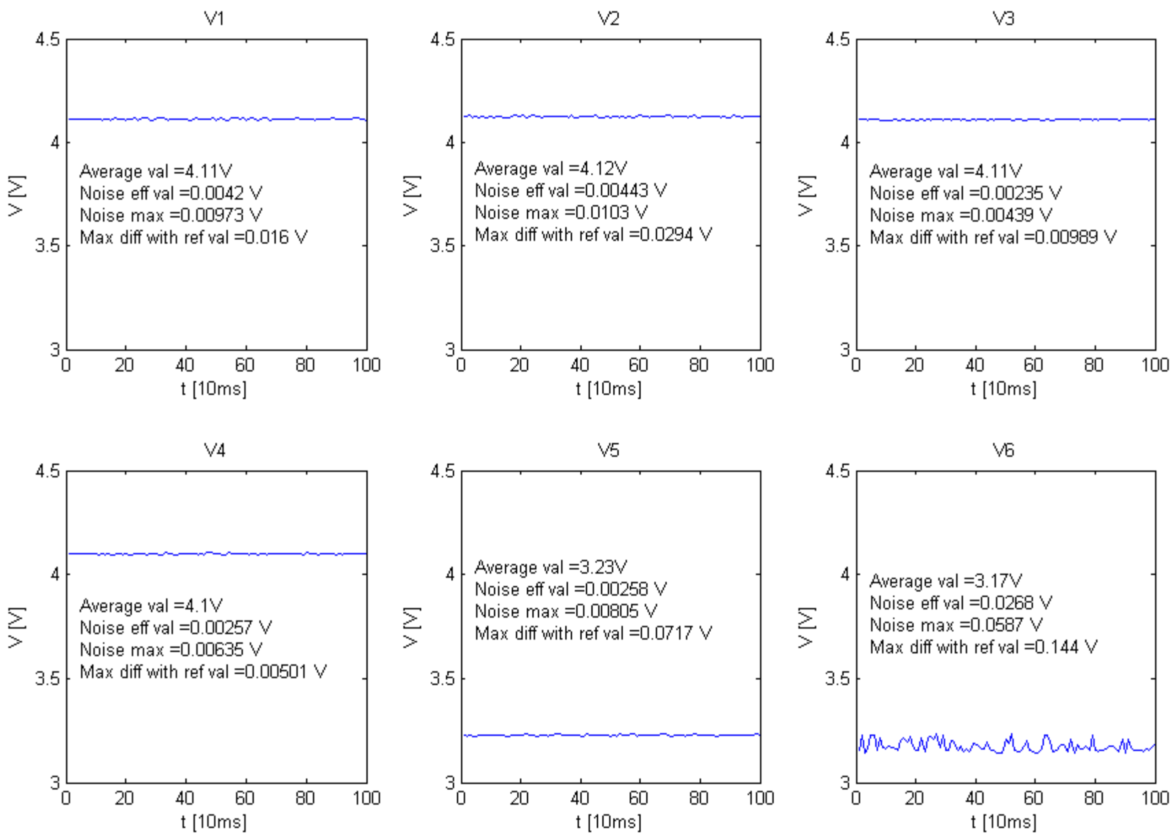
Input chains	Output chains
Ok	Ok

Measuring chains

Voltage measuring chains

Applied voltage					
V_1	V_2	V_3	V_4	V_5	V_6
$4.1[V]$	$4.1[V]$	$4.1[V]$	$4.1[V]$	$3.3[V]$	$3.3[V]$

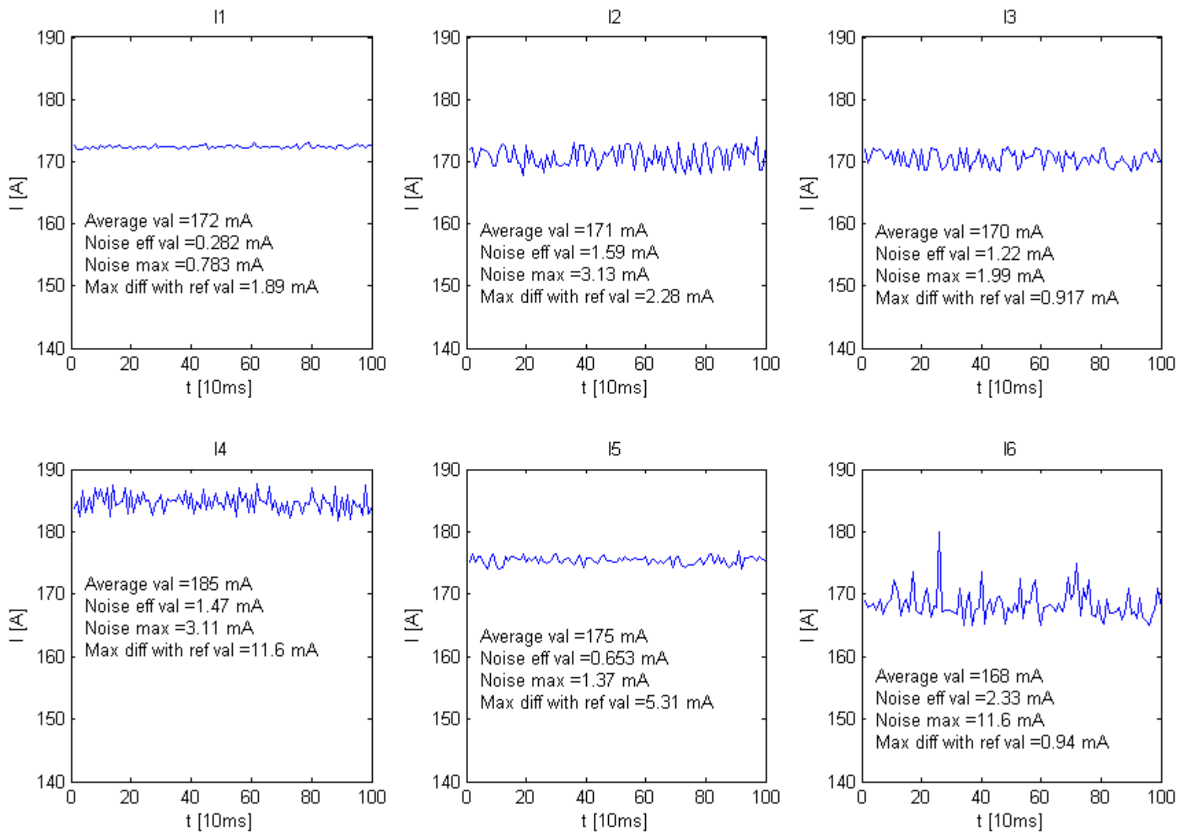
Results after AD conversion



Current measuring chains

Applied current					
I_1	I_2	I_3	I_4	I_5	I_6
$171[mA]$	$172[mA]$	$171[mA]$	$172[mA]$	$171[mA]$	$170[mA]$

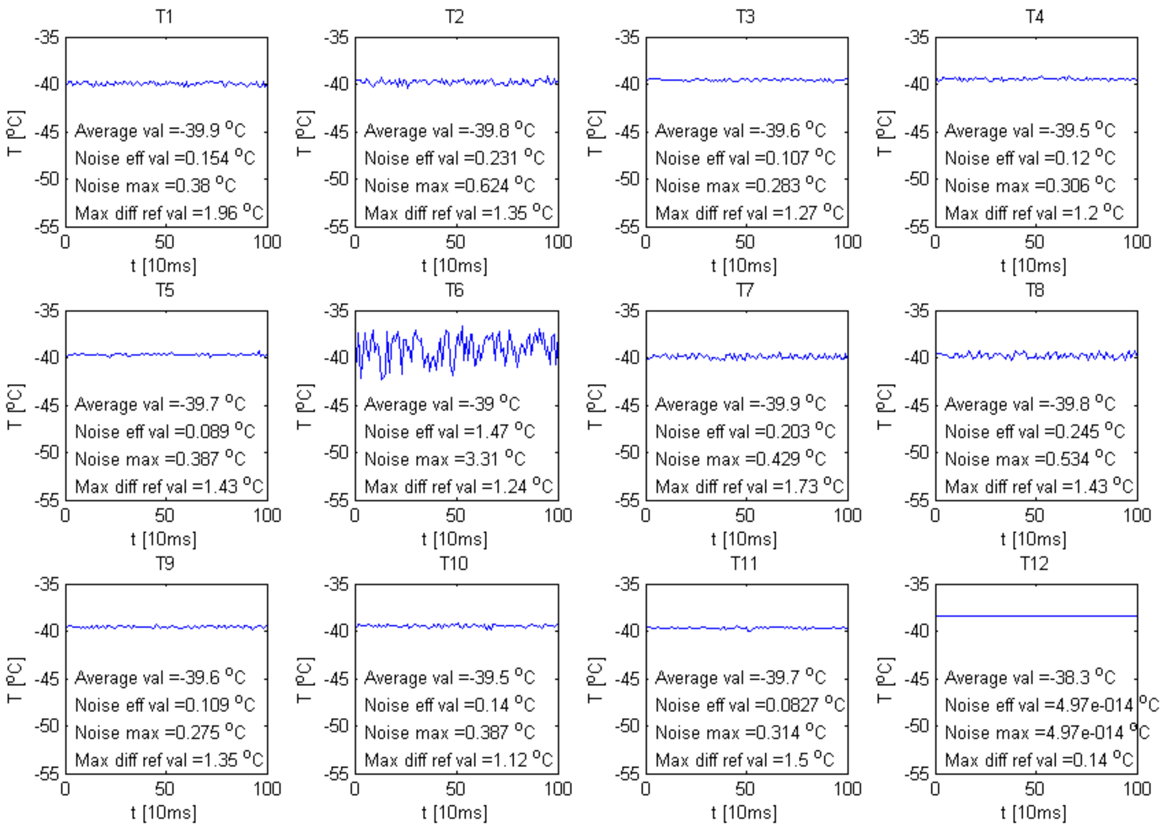
Results after AD conversion



Temperature measuring chains

Temperature											
T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
$-38.2\left[{}^{o}C\right]$											

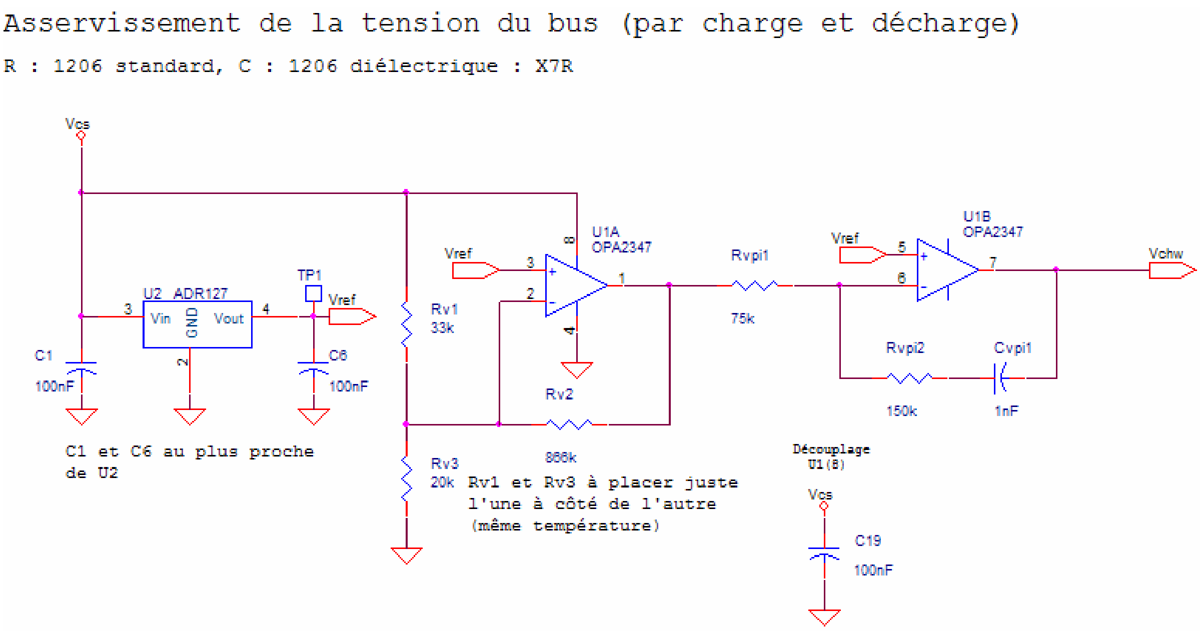
Results after AD conversion



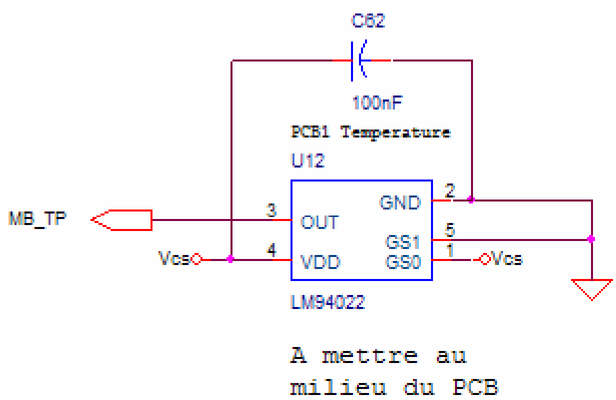
10.3 MB

10.3.1 MB schematic

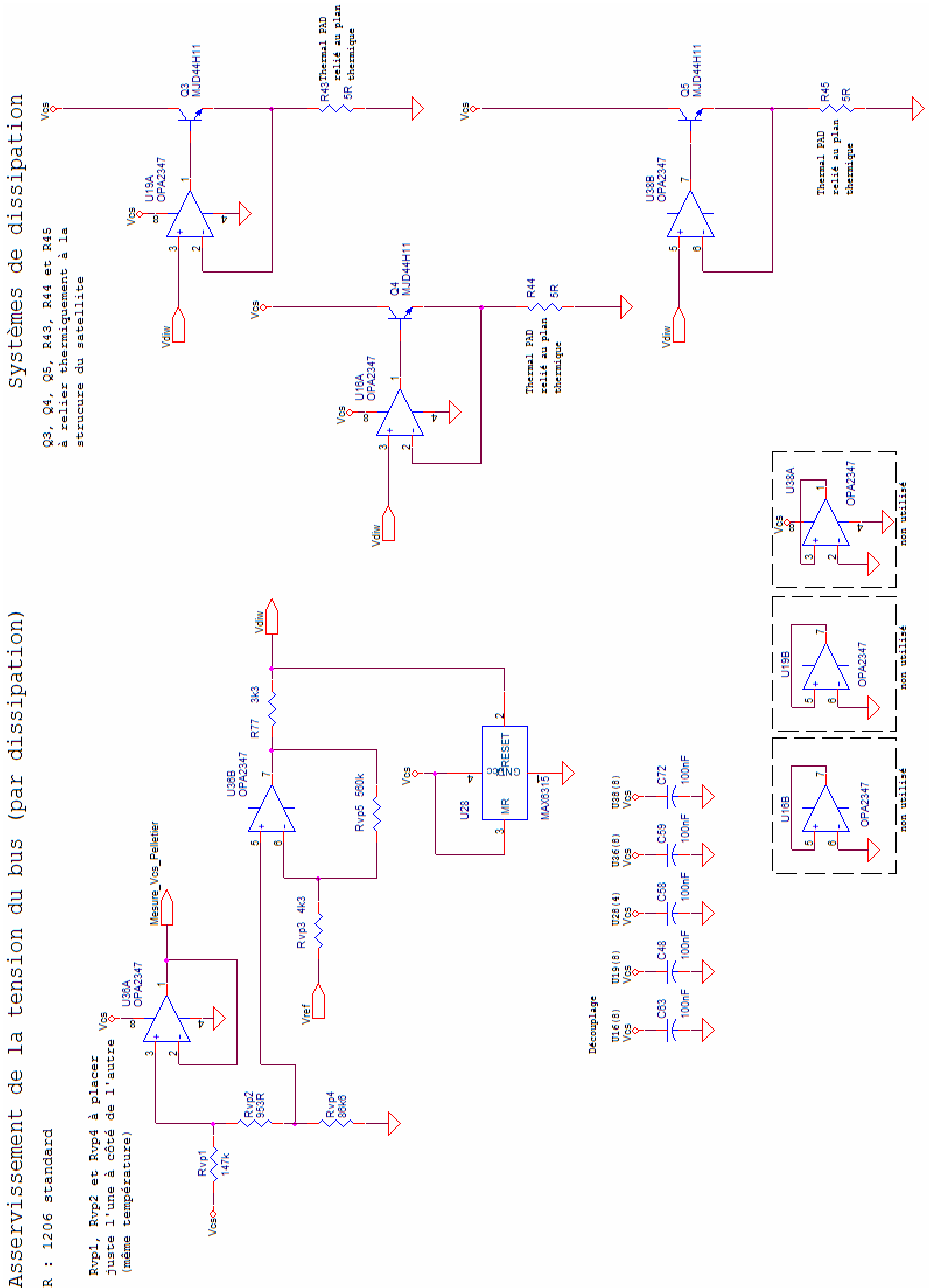
10.3.1.1 Bus voltage level regulation (by charging and discharging)



10.3.1.2 MB temperature

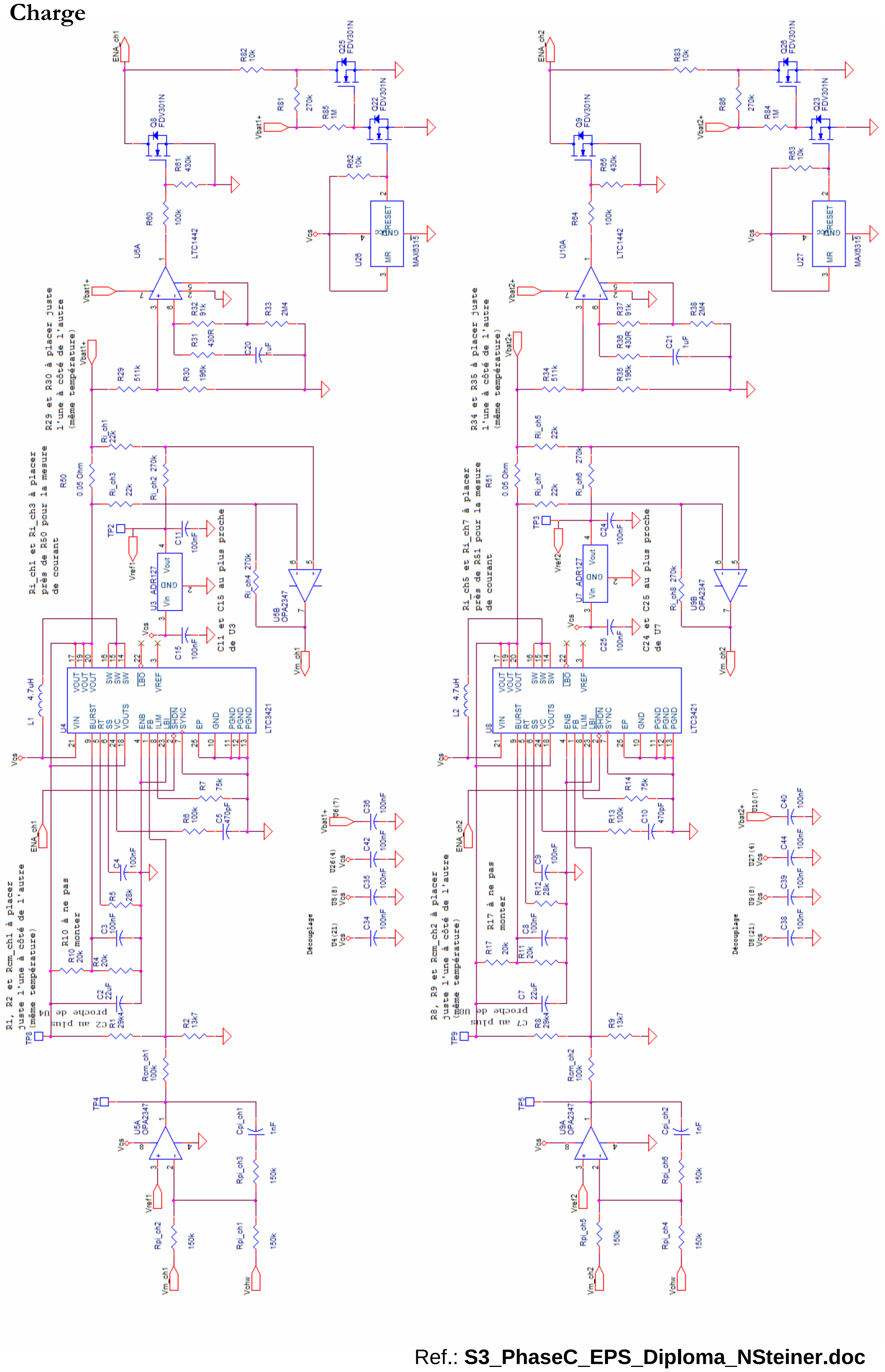


10.3.1.3 Bus voltage level regulation (by dissipating)

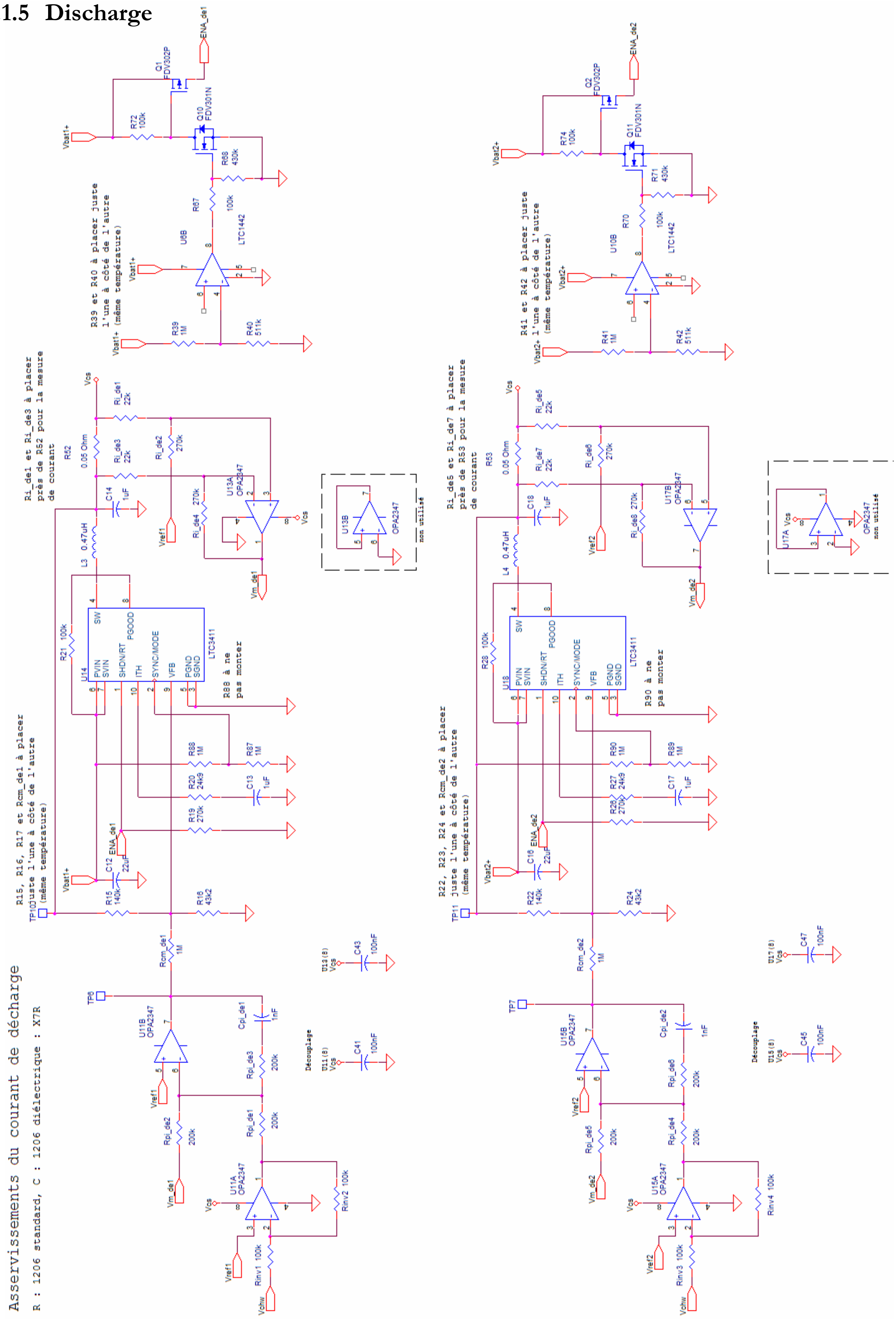


10.3.1.4 Charge

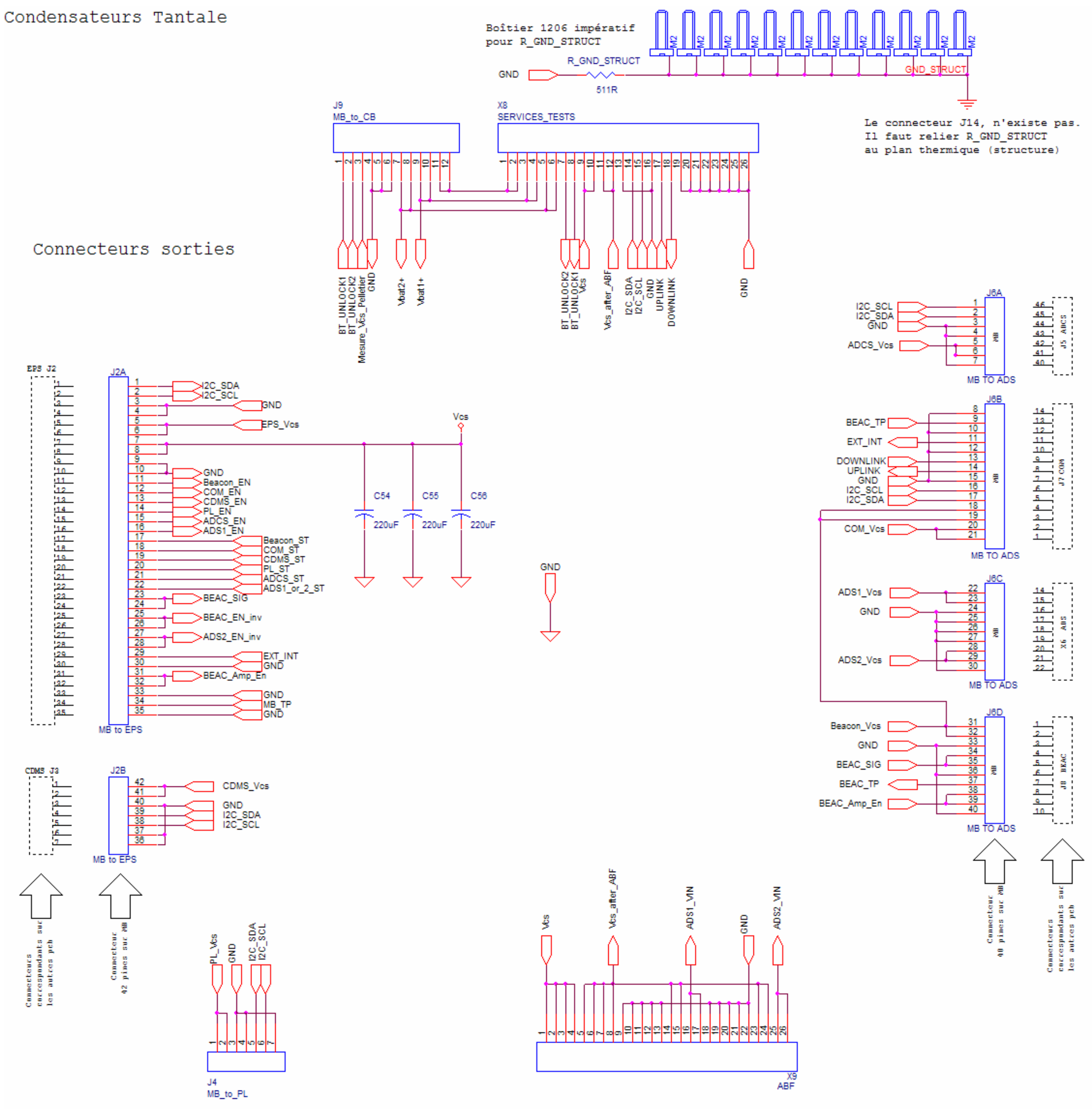
Asservissements du courant de charge
R : 1206 standard, C : 1206 X7R



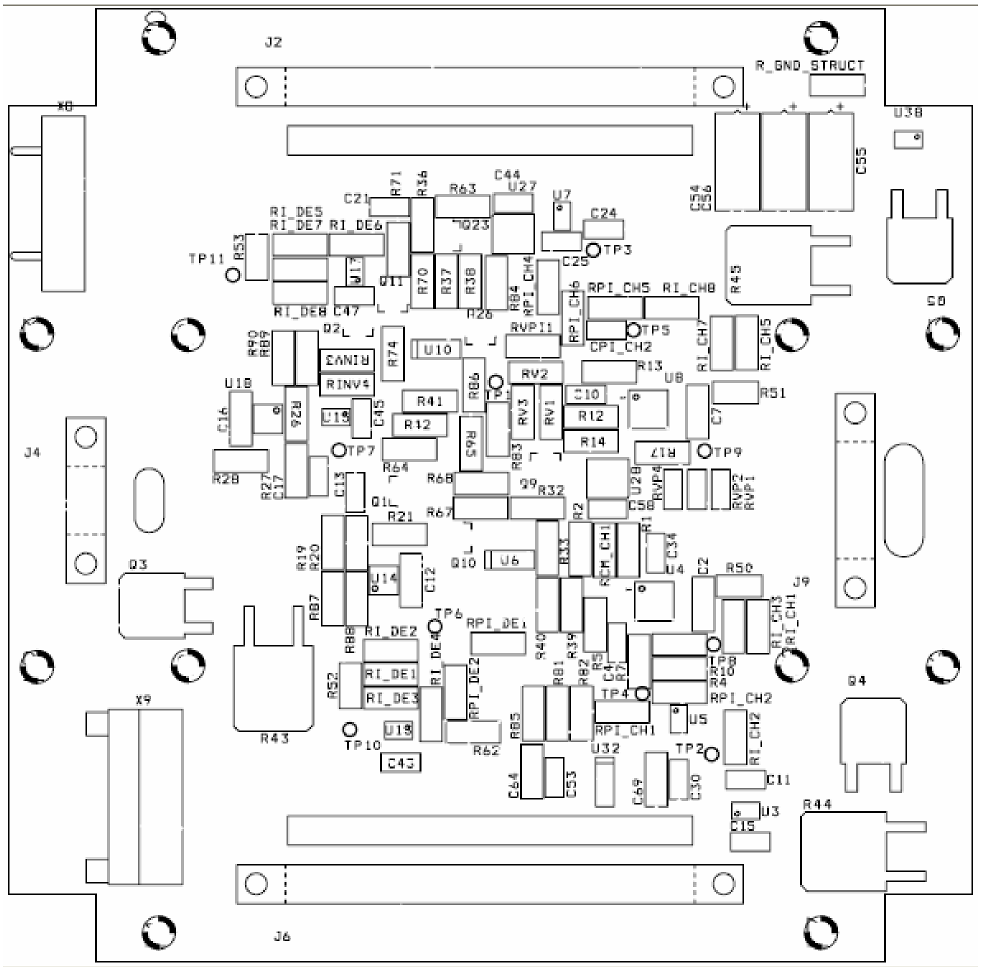
10.3.1.5 Discharge

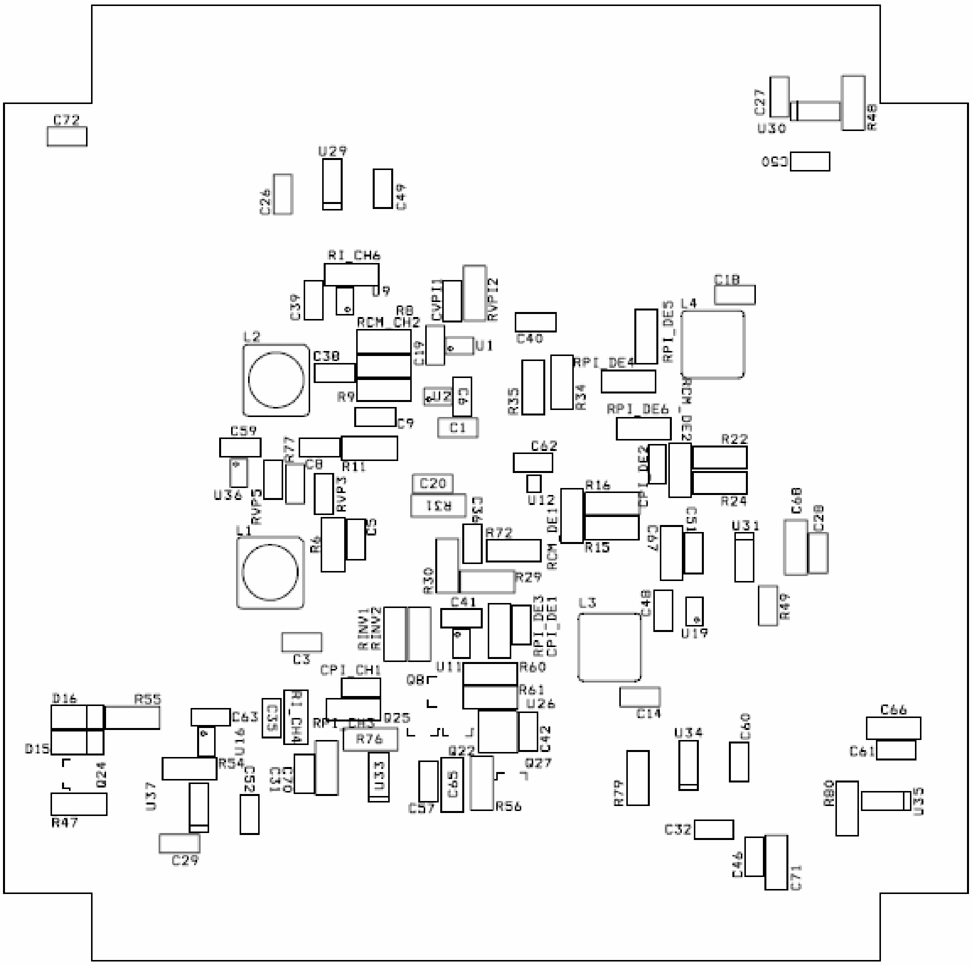


10.3.1.6 Connections



10.3.2 MB layout




C72
U29
C26
C49
C27
U30
R48
C50
RI_CH6
C39
U9
R8
RCM_CH2
CVPI1
RVPI2
C40
C18
L4
RPI_DE5
L2
C38
C19
U1
R9
U2
C6
R35
R34
RPI_DE4
RCM_DE2
C9
C1
RPI_DE6
C59
R77
C8
R11
C62
CPI_DE2
R22
R24
U36
RVP5
RVP3
C20
R31
C34
U12
R16
C51
C68
C28
L1
R6
C5
R72
RCM_DE1
R15
C67
U31
R30
R29
C41
RINV1
RINV2
RPI_DE3
CPI_DE1
L3
C48
U19
R49
C3
CPI_CH1
U11
R60
Q8
R61
U26
C14
D16
R55
C63
C35
RI_CH4
RPI_CH3
Q25
R76
C42
C66
D15
U16
R54
C52
C31
C70
U33
Q22
Q27
U34
C60
C61
Q24
U37
C57
C65
R56
R79
R80
U35
R47
C29
C32
C46
C71

10.3.3 MB components list

Quantity	Part	Part mounted on MB	Tolerance	Manufacture	Manufacture Ref.	Distributor	Distributor Ref.
5	1nF						
37	100nF						
12	22uF					Farnell	8031538
2	470pF						
6	1uF						
8	10nF						
3	220uF						
2	BAS 85			FARNELL	1097282	PHILIPS	BAS86
2	4.7uH		20%	DIGI-KEY	445-2964-1-ND	TDK Corporation	RLF7030T-4R7M3R5
2	0.47uH		20%	FARNELL	3903473	VISHAY DALE	IHLP-2525CZ-01-0.47UH-20%
2	FDV302P			FARNELL	9846115	FAIRCHILD SEMICONDUCTOR	FDV302P
3	MJD44H11			FARNELL	9557806	ON SEMICONDUCTOR	MJD44H11G
10	FDV301N					FAIRCHILD SEMICONDUCTOR	FDV301N
1	511R		1%				
2	100k		0.10%	FARNELL	1141019	TYCO ELECTRONICS	RN73C2A100KBTG
4	1M		0.10%	FARNELL	1160303	WELWYN	PCF0805R 1M0BI.T2
8	22k	22k1	1%				
12	270k		1%				
14	100k		1%				
7	150k	162k	1%				
6	200k		1%				
3	75k		1%				
1	147k		0.10%	FARNELL	1140368	TYCO ELECTRONICS	RN73C2A147KBTG
1	953R		0.10%	FARNELL	1140803	TYCO ELECTRONICS	RN73C2A953RBTG
1	4k3	4k02	1%				
1	86k6		0.10%	FARNELL	1141012	TYCO ELECTRONICS	RN73C2A86K6BTG
1	560k		1%				
1	33k		0.10%	FARNELL	1108904	WELWYN	PCF0805-13-33K-B-T2
1	866k	1M	1%				
1	20k		0.10%	FARNELL	1108899	WELWYN	PCF0805-13-20K-B-T2
2	29k4		0.10%	FARNELL	1140962	TYCO ELECTRONICS	RN73C2A29K4BTG
2	13k7		0.10%	FARNELL	1140926	TYCO ELECTRONICS	RN73C2A13K7BTG
4	20k	19k6	1%				
2	28k	27k4	1%				
2	43k2		0.10%	FARNELL	1160245	WELWYN	PCF0805R 43K2BI.T2
2	24k9		1%				
2	140k		0.10%	FARNELL	1160268	WELWYN	PCF0805R 140KBI.T2
4	511k		0.10%	FARNELL	1160294	WELWYN	PCF0805R 511KBI.T2
2	196k		0.10%	FARNELL	1353227	WELWYN	PCF0805R-196KBT2
2	430R		1%				
2	91k	90k9	1%				
2	2M4		1%				
3	5R		1%	FARNELL	9764232	CADDOCK	MP725-5.00-1%

9	1M		1%				
10	10k		1%				
4	0.05 Ohm		1%	FARNELL	1099913	WELWYN	LR1206-R05FI
4	430k	475k	1%				
1	3k3	3k32	1%				
11	OPA2347			FARNELL	1207096	TEXAS INSTRUMENTS	OPA2347EA/250G5
3	ADR127			Digi-Key	ADR127AUJZ-REEL7CT-ND	Analog Devices	
2	LTC3421					LINEAR TECHNOLOGY	LTC3421EUF
2	LTC1442			Digi-Key	LTC1442CS8#PBF-ND	Linear Technology	LTC1442CS8#PBF
1	LM94022			FARNELL	1312600	NATIONAL SEMICONDUCTOR	LM94022BIMG
2	LTC3411			FARNELL	1273928	LINEAR TECHNOLOGY	LTC3411EMS#PBF
3	MAX6315			Digi-Key	MAX6315US29D2-TCT-ND	Maxim Integrated Products	MAX6315US29D2-T
5	TPS2020			FARNELL	8456690	TEXAS INSTRUMENTS	TPS2020D
2	TPS2023			Digi-Key	296-2563-5-ND	Texas Instruments	TPS2023D
1	TPS2022			FARNELL	8456704	TEXAS INSTRUMENTS	TPS2022D

10.3.4 MB Matlab code

10.3.4.1 Dissipation at ambient temperature and pressure

```
%Dissipation à température et pression ambiante (1 circuit)
clear all; close all; clc
format compact; format short g;

R = 5;
Ur = [0 0.23 0.48 0.73 0.98 1.23 1.49 1.74 1.99 2.23 2.49 2.74 3,...
      3.25 3.5 3.76 4.01];
Vcs = [3.31 3.37 3.37 3.38 3.38 3.39 3.39 3.4 3.4 3.41 3.48 3.76,...
       4.03 4.3 4.6 4.85 5.12];
Ivcs = [0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800];
Tr = [25 30 33 36 38 40 43 47 51 56 62 67 73 80 87 96 100];
Tq = [25 31 35 38 40 43 45 47 48 51 53 56 60 65 70 75 78];

Uq = Vcs-Ur;
I = Ur/R;
Pr = Ur.*I;
Pq = Uq.*I;
P = Pr+Pq;

figure(1);
plot(I, Pr,'x:',I, Pq,'xk:','Linewidth',2); hold on; grid on;
xlabel('Current dissipated in R_{44} and Q_4 [A]');
ylabel('Power dissipated in R_{44} and Q_4 [W]');
title('Dissipation power vs total dissipation current in the R and Q');
legend('P_{R_{43}}','P_{Q_3}','Location','NorthWest');
axis([0 0.7 0 2.5]);

figure(2);
plot(P, Vcs,'x:','Linewidth',2); hold on; grid on;
xlabel('Total power dissipated [W]');
ylabel('Bus voltage [V]');
title('Bus voltage vs power dissipated');

figure(3);
plot(P, Tr,'x:',P, Tq,'xk:','Linewidth',2); hold on; grid on;
xlabel('Total power dissipated [W]');
ylabel('Temperature of R_{44} and Q_{4} [^oC]');
title('Temperature of R_{44} and Q_4 vs power dissipated');
legend('T_{R_{44}}','T_{Q_4}','Location','NorthWest');
```

10.3.4.2 Dissipation under vacuum at 60°C

```
%Dissipation à 60 degré
clear all; close all; clc
format compact; format short g;

R = 5;
Rwire = 0.55;
Ur43 = [0 0.158 0.326 0.493 0.660 0.827 0.995 1.162 1.329 1.496 1.664,...
        1.848 1.999 2.166 2.334 2.483 2.646 2.814 2.980 3.144];
Ur44 = [0 0.157 0.325 0.492 0.659 0.826 0.993 1.161 1.328 1.495 1.662,...
        1.846 1.997 2.165 2.333 2.523 2.700 2.870 3.040 3.214];
Ur45 = [0 0.161 0.328 0.496 0.663 0.830 0.997 1.165 1.332 1.450 1.667,...
        1.851 2.000 2.169 2.336 2.499 2.662 2.830 2.998 3.166];
V = [3.38 3.42 3.48 3.54 3.6 3.66 3.73 3.77 3.85 3.91 3.97 4.04 4.12,...
     4.19 4.25 4.32 4.56 4.81 5.06 5.29];
Ivcs = [0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5,...
        1.6 1.7 1.8 1.9];
Tr44 = [60 66 70 74 79 82 85 89 93 96 100 104 107 111 115 119 125,...
        129 134 138];
Tq4 = [60 68 73 78 83 87 90 93 96 98 101 104 106 108 110 112 115,...
       118 121 125];

Vcs = V-Rwire*Ivcs;
Uq3 = Vcs-Ur43;
Uq4 = Vcs-Ur44;
Uq5 = Vcs-Ur45;
Ir43 = Ur43/R;
Ir44 = Ur44/R;
Ir45 = Ur45/R;
Pr43 = Ur43.*Ir43;
Pr44 = Ur44.*Ir44;
Pr45 = Ur45.*Ir45;
Pq3 = Uq3.*Ir43;
Pq4 = Uq4.*Ir44;
Pq5 = Uq5.*Ir45;
P = Pr43+Pq3+Pr44+Pq4+Pr45+Pq5;

figure(1);
plot(Ir43, Pr43,'x:',Ir43, Pq3,'xk:','Linewidth',2); hold on; grid on;
xlabel('Current dissipated in R_{43} and Q_3 [A]');
ylabel('Power dissipated in R_{43} and Q_3 [W]');
title('Dissipation power vs total dissipation current in R and Q');
legend('P_{R_{43}}','P_{Q_3}','Location','NorthWest');
axis([0 0.7 0 2.5]);

figure(2);
plot(Ir44, Pr44,'x:',Ir44, Pq4,'xk:','Linewidth',2); hold on; grid on;
xlabel('Current dissipated in R_{44} and Q_4 [A]');
ylabel('Power dissipated in R_{44} and Q_4 [W]');
title('Dissipation power vs total dissipation current in R and Q');
legend('P_{R_{44}}','P_{Q_4}','Location','NorthWest');
axis([0 0.7 0 2.5]);

figure(3);
plot(Ir45, Pr45,'x:',Ir45, Pq5,'xk:','Linewidth',2); hold on; grid on;
xlabel('Current dissipated in R_{45} and Q_5 [A]');
ylabel('Power dissipated in R_{45} and Q_5 [W]');
title('Dissipation power vs total dissipation current in R and Q');
```

```
legend('P_{R_{45}}','P_{Q_5}','Location','NorthWest');
axis([0 0.7 0 2.5]);

figure(4);
plot(P, Vcs,'x:','Linewidth',2); hold on; grid on;
xlabel('Total power dissipated [W]');
ylabel('Bus voltage [V]');
title('Bus voltage vs power dissipated in all 3 circuits');

figure(5);
plot(P, Tr44,'x:',P, Tq4,'xk:','Linewidth',2); hold on; grid on;
xlabel('Total power dissipated [W]');
ylabel('Temperature of R_{44} and Q_{4} [^oC]');
title('Temp of R_{44} and Q_4 vs power dissipated in all 3 circuits');
legend('T_{R_{44}}','T_{Q_4}','Location','NorthWest');
```

10.4 Work paper

10.4.1 Week from September 17th to 21st

Monday

- Lundi du Jeune Fédéral

Tuesday

- Thermal test on the batteries at Ruag in Nyon.

Wednesday

- Writing the test procedure for the PMB.
- Searching and ordering a converter DIL28/TSOP28 to program the EPROM of the HBG.

Thursday

- Modification of the Matlab code and the µController code to be able to take thermal and voltage measure during thermal cycling test during next week at Ruag in Nyon.
- Meeting with Fabien Jordan and Claude Guinchard for the MB layout.

Friday

- Trouble shooting the Matlab code and the FTDI for the thermal cycling acquisition (FTDI was dead).
- Preparing thermal sensor for the thermal cycling tests.

10.4.2 Week from September 24th to 28th

Monday

- Preparation of the thermal cycling tests at Ruag (installing the PMB acquisition system, gluing all the temperature sensors).

Tuesday

- Calculation of all measures accuracy (voltage, current, temperature).
- Created a Matlab code to calculate the optimal linearization of the temperature sensor.

Wednesday

- Written the PMB test procedure
- Called Dopplin-Electrinik to find out when I will receive the DIL28/TSOP28 adapter.

Thursday

- Sent an e-mail to TI to know the built-in voltage reference accuracy.
- Developing the Matlab codes and the msp code for the PMB qualification tests.

Friday

- Calculated the components for the oscillation frequency (HBG and the 15 minutes timer).
- Added the built-in voltage reference temperature drift in the accuracy calculations.
- Created the material list for the PMB qualification tests.

10.4.3 Week from October 1st to 5th

Monday

- Preparation of the vacuum chamber and testing if heating the board at 60°C was possible.

Tuesday

- Modification on the MB schematic (add beacon CL enable coming from PMB and going to Beacon, add power supply coming from Beacon current limitation and going to COM).
- Preparation document for MR. Maillard so he can mount 2 more PMB.
- Tried to program the EPROM for the Hardware Beacon Generator (did not work because the converter DIL/TSOP had not the right pin out).
- Created a Vero board for the DIL/TSOP adapter.

Wednesday

- Programmed the EPROM
- Tried the Beacon. Did not work because the footprint on the PMB was wrong (the size is correct but the pin out is wrong, there is a gap of 7 on the pins but the rank of the pins are the same).
- Prepared modification documents to mount the EPROM on the PMB.

Thursday

- Tested the Beacon (the EPROM worked like expected). Could read swisscube on the oscilloscope.
- Cabled the vacuum chamber (soldered wires on Lemo connectors and on the PMB).

Friday

- Finished cabling the vacuum chamber.
- Controlled connections on the vacuum chamber.
- Tested all functions of the board before starting the qualification tests. Still have to solve the problem with the current measures. By using 1 current supply, it is difficult to set the willing current in each measuring chains because the shunts resistances are very low. The cable resistances have a quite big influence on the current division between each chain. Maybe use 6 current supplies instead of 1.

10.4.4 Week from October 8th to 12th

Monday

- Tried to load all measures on the computer via UART and Matlab. Did work like expected for the voltage and temperature measures. Did not work like expected for the current measures (it works well if only 1 measuring chain is loaded with a current, but if 2 or more measuring chains are loaded with a current, the current sensors don't give the right output voltage).

Tuesday

- Trouble shoot on the current measuring chains problem found on Monday. The voltage given by the current sense was coherent when loading only 1 current measuring chain. When loading 2 or more current measuring chains, the output voltage of the current senses were dropping down more or less depending on which sense were tested. The problem was that the traces going from the current sense to the shunt to make the measure were also used to transmit the current coming from the photovoltaic cells. The transmitted current created a voltage drop on the trace. The voltage read on the current senses was not the same as the real voltage on the shunt. To by able to do the qualification tests of the PMB, I cut some traces and soldered wires so the current did not take the traces connecting the current sense to the shunt.
- Started the qualification tests (did the test at ambient temperature and pressure and under vacuum at 30°C and 40°C).

Wednesday

- Performed PMB qualification tests under vacuum at 20°C, 50°C and 60°C.
- Modified the Matlab code that will be used to calculate the average measured value and the noise on the µController analog inputs.
- Prepared a new FTDI for Fabien Jordan so he can perform other tests on the satellite.

Thursday

- Meeting with Fabien Jordan to talk about modifications on the MB and the PMB and to make sure that the MB schematic is ready for Claude Guinchard. A digital output had to be added on the PMB to turn ON and OFF the beacon amplifier (to save energy when no message is sent). On the PMB and the MB, the same signal was used to enable the Beacon and the ADS2 current limitation. These 2 current limitations are not working at the same time, this is why signals had to be modified. We specified to Claude Guinchard which traces needed to by thicker to transmit the power.
- Discussion with Mr. Correvon to know how to treat the PMB qualification test results.
- Soldered a wire on the PMB so the 15 minutes timer stays at 3.3V for 2 seconds instead of 1 second.

Friday

- Connected a voltage reference (1.8V) on the temperature inputs to have a very stable voltage and to be able to determine the noise.
- Filed up the material list of the PMB thermal qualification tests.
- Draw the connection schematic of the PMB thermal qualification tests.

10.4.5 Week from October 15th to 19th

Monday

- Preparation of the material and the thermal chamber for the qualification tests (10°C and under).
- Performed tests at 10°C, 0°C, -10°C, -20°C and -30°C.

Tuesday

- Performed PMB qualification tests at -40°C.
- Draw measures with Matlab.
- Modify 1 PMB for St-Imier (current measure, EPROM and 15 min timer).

Wednesday

- Explained into details the modifications that have to be made on the PMB.
- Started to describe the vibration and shock tests that have been performed in Berlin.

Thursday

- Tidy up all the material that has been used form the thermal qualification test.
- Started to prepare the PMB to test the full range of the measuring chains (voltage and current). Did not find a good solution yet to apply a triangle current signal on the current measuring chains.

Friday

- Measured the nonlinearity of current measuring chains. Decided not to apply a triangle current signal but to measure the output voltage of the current sense and the follower amplifier while setting a current manually (from 1mA to 1000mA). Realized measures and plot them on Matlab.

10.4.6 Week from October 22nd to 26th

Monday

- Measured if there were nonlinearity on the voltage and the temperature measuring chains. Verified full measuring scale and treaded the results on Matlab.
- Tested the PMB that will be given to St-Imier for programming.

Tuesday

- Trouble shoot on voltage measuring chain V_6 to figure out why results after AD conversion are always lower then 3.3V. Problem: the inductances between DVCC and AVCC are creating a voltage drop because of there resistances. So the result after AD conversion is correct.
- Think about other solutions to be able to measure low current under 10mA. It is possible but the design changes are too important.
- Meeting in St-Imier to deliver the PMB to the students who will design the software.

Wednesday

- Measured the whole current measuring chain I_4 to verify why results after AD conversion (for negative temperature) were always higher then the reference value. Found the presence of a low offset but still in the given accuracy. Need to do some more tests with the next version.
- Modify the schematic of the PMB for the next version.

Thursday

- Preparation of the mid-term review presentation.
- Modification on the measuring chains accuracy.

Friday

- Mid-term review at the EPFL
- Correction on the measure error (voltage, current and temperature measures).

10.4.7 Week from October 29th to November 2nd

Monday

- Study the MB electrical design.
- Started the MB test procedure.

Tuesday

- Wrote the MB test procedure (what has to be verified, how tests will be performed).

Wednesday

- Wrote the MB test procedure.
- Worked on the report.

Thursday

- Test on the PMB, make sure the commutation between hardware and software beacon is possible.
- Respond to questions on the PMB (for St-Imier).
- Worked on the report.

Friday

- Worked on the report.
- Discussion with Mr. Correvon about the MB components mounting and the thermal tests. The mounting procedure should describe every step and every test to perform after every step. The thermal tests under vacuum should be performed at the extreme temperature of the temperature working range (-40ºC and 60 ºC).
- Respond to MR. Guinchard questions on the MB layout.

10.4.8 Week from November 5th to 9th

Monday

- Failure analysis on the EPS PMB and MB at the Epfl with Renato Krpoun and Ted Choueiri.
- Modification of the PMB schematic. Removed msp enable for the HBG. Put an OR gate on the Beacon switch so the Beacon signal is sent to the MB when the Timer or the msp put a high state. Placed full redundancy on the capacities of the Timer reset. For more reliability, the Beacon signal is not going through the driver any more.

Tuesday

- Worked on the MB mounting and testing procedure.
- Layout review with Claude Guinchard and Marc Correvon. Checked the power traces dimensions. Decided to order the 3 PCBs in 1.55mm thickness and 17.5µm traces thickness.

Wednesday

- Forum HES-SO 2007 in Martiny

Thursday

- Worked on the MB test procedure.
- Searched for a voltage regulator with current fold back protection to supply the MSP on the PMB. In case a short circuit (after a radiation) we don't wan the all PMB, especially the HBG to be out of usage.
- Ordered Maxim samples of the voltage regulator (Max882).
- Checked all the material needed to mount the MB.

Friday

- Ordering missing components for the Mother Board.
- Calculation of some resistances value to be able to use the mini-Melf resistances space qualified which are available at the IAI institute.

10.4.9 Week from November 12th to 14th

Monday

- Applied modifications on the PMB which will be delivered to the space center for the integration tests.
- Prepared the vacuum chamber cabling for the MB tests.

Tuesday

- Tested the reset of the 15 minutes timer on the PMB.
- Meeting at the EPFL with Fabien and David to talk about the integration tests.

Wednesday

- Preparing documents for the MB mounting.
- Modified the schematic to be able to enable the Beacon Amplifier easer with the µController or with the HBG.
- Worked on the report.

Thursday

- Continued testing the 15 minutes timer reset. Made oscilloscope capture and wrote explanation in the report.
- Prepared the Matlab code for the power efficiency of the MB calculation.

Friday

- Reflection on the antennas deployment system with Fabien Jordan.
- Worked on the report.

10.4.10 Week from November 19th to 23rd

Monday

- Worked on the report.

Tuesday

- Received the MB PCB.
- Mounted and tested the bus voltage regulation of the bus.

Wednesday

- Mounted and tested the reset, the hysteresis and the first step-up.
- Had to recalculate the resistance for the hysteresis circuit for the step-up and the step-down.

Thursday

- Mounted and tested the 2 step-up.

Friday

- Mounted and tested the 2 step-down.
- Tested the bus voltage regulation with the 2 step-up and the 2 step-down.

10.4.11 Week from November 26th to 30th

Monday

- Mounted and tested the subsystems current limitations.
- Mounted the dissipation circuit.
- Tried to charge the batteries. Had a problem with the wiring and had to change the 2 step-down after they burned.

Tuesday

- Performed test on the MB. Applied current step (charging and discharging) to verify the response of the current and the voltage fluctuation of the bus.
- Encountered problem when discharging batteries at 1A. The step-down turned into a weird mode. The problem was coming from the batteries which were too much discharge. The voltage was falling close to the critical low level. Could not explain exactly what was creating this problem.

Wednesday

- Tested the dissipation system at ambient temperature and pressure from 0A to 900mA.
- Started the power efficiency calculation of the MB (charge discharge). Performed the discharge of the battery.

Thursday

- Finished the power efficiency calculation.
- Tested if the step-up and step-down were working at the same time.

Friday

- Performed new tests for the dissipation and the power efficiency of the MB, the battery and the global power efficiency.
- Worked on the report. Explained the tests results.

10.4.12 Week from December 3rd to 7th

Monday

- Cabled the vacuum chamber to perform the tests under vacuum at high and low temperature.

Tuesday

- Performed thermal tests under vacuum.
- Tested the dissipation circuit at high and low temperature.
- Measured the voltage level of the voltage references at -40ºC and 60 ºC.
- Tested the bus stabilization when releasing the kill switches at -40ºC and 60 ºC.

Wednesday

- Performed test on the MB.
- Analyzed the thermal tests (dissipation).

Thursday

- Trouble shooting on the MB. Tried to find out why the step-down 1 did not work like the step-down 2 and why the step-up 1 did not work like the step-up 2.
- I started by turning OFF both step-up. Both step-down were working like expected which means that the problem was coming from on of the step-up.
- Then I turned both step-down OFF. Step-up 2 was working like expected but not step-up 1.
- I compared the components values of both circuits. I tried the internal regulation of both step-up. The step-up 1 had an output voltage fluctuation way bigger then the step-up 2.
- The output capacitor of step-up 1 was dead.
- After changing the capacitor, the bus was regulated like expected. Further tests are going to be performed to validate the board.

Friday

- Trouble shooting on the step-down 1. When working without any load, the battery current was oscillating when using the step-down 1 but not with the step-down 2. When consuming 18mA (about the consumption of the PMB) the battery current did not oscillate any more.
- Decided not to change the design and to perform the thermal tests.

10.4.13 Week from December 10^{th} to 14^{th}

Monday

- Prepared the vacuum chamber for the thermal tests (charge/discharged tests under partial vacuum at 60ºC and -40 ºC).
- Worked on the report (appendix).

Tuesday

- Performed thermal tests on the MB under vacuum at -40ºC and 60 ºC.
- Tested the bus rise, a discharging current step of 1A, charging current step of 1A and verifying that the step-up and the step-down are not working at the same time.
- Worked on the report.

Wednesday

- Treated the results of the thermal tests.
- Worked on the report.

Thursday

- Connected the MB to the PMB.
- Worked on the report.

Friday

- Worked on the report.
- Meeting at the EPFL to present the work that has been done during the diploma project to the sponsors.

10.4.14 Week from December 17^{th} to 21^{st}

Monday

- Return three copy of the diploma report to MR. Correvon.