Minor's Project in Space Technologies
Winter 2007

Phase B / C

SwissCube ADCS Hardware and Actuators

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Space Center

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1 RECORD OF REVISIONS

ISS/REV	Date	Modifications	Created/modified by
1/0	07/12/2007	First release	Laurent Hauser
1/1	19/12/2007	ADCS System Engineer Hervé Péter-Contesse	Laurent Hauser
1/2	02/01/2008	Advisor Muriel Noca	Laurent Hauser
1/3	10/01/2008	English corrections	Laurent Hauser Rachel Hauser

2 WORK PACKAGE

PROJECT: SwissCube Satellite PHASE: C	WP REF: 4610
WP Title: SwissCube ADCS Hardware and actuators **Responsible:** Space Center **Collaborator/assistant:** Muriel Noca, Hervé Péter-Contesse **Student:** Laurent Hauser **Start date:** 17-09-07 **End date:** 30-01-07 **WP Manager:** M. Noca, H. Péter-Contesse	**Sheet 1 of 3** **Issue Ref: 2** **Issue Date:** **01-10-07**

Introduction

This Work Package summarizes the work expected from the student during phase B/C (semester's project) of the SwissCube Project. The expected duration of the work is as stated above.

The objectives of this task will be four fold:

- Review the task description;
- Plan a schedule for your work, and review it with your project assistant;
- Perform the tasks and keep the project informed of the status;
- Provide the outputs and deliverables listed at the end of this document.

The student will report for all technical matters to the Lab assistant (when applicable) and project system engineer (assistant) assigned at the beginning of the semester.

The student will have to participate in the design meetings related to his topic (mechanical, electronics, data).

Deadlines are summarized here:

- Kick-off meeting (mandatory): September 21, 17h00 in ELD 010
- Mid-term review: October 31, time TBD ELD 010
- Draft report due: December 21 (for EPFL students)
- Final report due: January 7
- Final review/presentation: January 28-31

Deadlines related to the technical work will be given at the kick-off meeting.

Task Description:

During last semester project, the hardware (sensors, actuators and controller) for the SwissCube attitude determination and control system (ADCS) has been selected, and preliminary tests have been made. The goal of this project is to finalize and test the ADCS actuators, namely the magnetotorquers: test driver stage and the coils themselves, develop a 3D simulation model, build the test bench and implement the final design. Another part of the project will also be to finalize the ADCS board design and to perform tests with the magnetic field sensors (magnetometer).

This task includes :

- Review all documentation regarding the ADCS subsystem
- Finalize the ADCS magnetotorquer design: (first part of task)
  a. Design driver stage on a PCB that includes the microcontroller
  b. Fabricate 3 new magnetotorquers with improved epoxy and electrical connection
  c. Characterize operations of the magnetotorquers (thermal, magnetic field,…) via tests
  d. Develop a magnetotorquer simulation model.
- Update and finalize the ADCS Board: (second part of task)
  a. Implement design changes taking into account new sensor chosen by other students;
  b. Design interface between new hardware and micro-controller if needed;
  c. Test software and EMC with magnetometers.
- Provide recommendations and document all activities.

Inputs:

- "SwissCube Phase B-C Mission and System Overview" (S3-B-C-SET-1-2-Mission_System_Overview.pdf);
- "SwissCube ADCS Specifications Document" (S3-C-SE-2-0-Level_4_ADCS.pdf);
- S3_Phase_B-C-ADCS-1-3-ADCS_HW_and_System.pdf;
- SwissCube document templates;
- Reference: "Space Mission Analysis and Design", Larson & Wertz

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Outputs:

- Detailed magnetotorquer operation model;
- Magnetotorquer control software;

- Magnetometer performance characteristics and implementation.

All analyses should include documentation of the assumptions.

Deliverables:

- A final report including a short description of all outputs.
- A presentation at the final review at the end of the semester.
- A disk containing all analysis and documentation files for records.

3 INTRODUCTION

The present report describes the work accomplished during the project "SwissCube ADCS Hardware and Actuators". It was realized for the Minor's Project in Space Technologies (8 credits ETC).

SwissCube is the first entirely Swiss satellite program. It follows the CubeSat standard (1 kg with a 1 liter volume) developed by the Standford University and the California Polytechnic State University which provide an affordable access to space. The primary objective of the SwissCube project is "to provide a dynamic and realistic learning environment for undergraduates, graduates and staff in the development of small satellite technology" [R 1]. The secondary objective is to "house a science payload in order to take optical measurements and characterize the Nightglow phenomenon (Figure 1) over all latitudes and longitudes for a period of at least 3 months, with an extended duration of science mission up to 1 year" [R 2].

Figure 1: Nightglow phenomenon [R 1].

The ADCS (Attitude Determination and Control System) is the part of the Satellite where position, velocity and orientation are determined and controlled. The main tasks of this system are:

- To stabilize the satellite after launching by reducing and controlling the spinning rate
- To determine where the payload is pointing at in order to take pictures
- To orient the payload in order to take pictures (if it is technically possible)

Actually, the orientation of the payload is technically not possible. This task was then abandoned. Currently, the ADCS is composed of various sensors:

- 3x MagnetoMeters (MM)
- 3x Gyroscopes
- 6x Sun sensors
- 1x Temperature sensor

Finally, three MagnetoTorquers (MTs) are used as actuators. The MTs are just coils which produce a Magnetic Field (MF). The interaction between this MF and the Earth natural MF produces a resultant torque which is used to orient the satellite.

During the last semester project, the ADCS hardware was selected, and preliminary tests were performed. The goal of this project is to improve and test the ADCS actuators design by building a test board, testing the MTs and their driver stage, developing a 3D simulation model and then implementing the final design. Finally, if more time is still available, the ADCS board will be finalized and tests with the magnetometers will be performed.

This report will first present the different requirements relative to ADCS actuators. Then it will explain the chosen approach, the design and the test procedures. And finally, results will be exposed and several recommendations proposed.

4 DESIGN REQUIREMENTS

Here is a summary of the main requirements for ADCS concerning the MT in Table 1.

Magnetotorquer Requirements			
ADCS_MT_1	Main power supply	3.3±0.23	V
ADCS_MT_2	Power consumption (total)	<150	mW
ADCS_MT_3	Temperature range (Coil)	-45 to +70	°C
ADCS_MT_4	Temperature range (electronic)	-30 to +60	°C
ADCS_MT_5	Must be switched off when magnetometers are taking measures		
ADCS_MT_6	Dipole magnetic moment	≥28.5	mAm^2
ADCS_MT_7	Current regulation accuracy	<10	%
ADCS_MT_8	Current regulation resolution	<0.44	mA
ADCS_MT_9	Current regulation command rate	≤2	Hz
ADCS_MT_10	Outgassing TML	<1	%
ADCS_MT_11	CVCM	<0.1	%
ADCS_MT_12	External dimensions	70x80x5	mm

Table 1: Summary of ADCS requirements concerning magnetotorquers

5 DESIGN ASSUMPTIONS AND APPROACH

5.1 Approach

The first task was to review all documentation regarding the ADCS subsystem and particularly "SwissCube Phase B-C Project, Mission, Space and Ground System Overview" [R 3] and "SwissCube ADCS System and Hardware" [R 2].

The next step was to improve the MT fabrication process and to solve problems of epoxy and electric connections.

Then, the electronics linked to MTs were redesigned and implemented. A model of the electronics was also programmed with MatLab Simulink in order to simulate the circuit behavior.

When the test board was built, various tests were performed to define and validate the final design of actuator electronics.

Finally, the present report was written including a list of future tasks and a few recommendations.

5.2 Assumptions

The following assumptions were taken into account according to the "ADCS System and Hardware" report [R 2]:

1. The ADCS board has a supply voltage of 3.3 V. Thus its components must comply with the latter...
2. The ADCS is not a critical system, therefore no redundancy is needed. But to ensure reliability, current limitations must be implemented for each wire going to a sensor or an actuator. This will prevent the shutdown of the whole ADCS board if a short occurs.
3. The MTs are glued on a PCB (Printed Circuit Board) inside the faces of the satellite. They should then resist to temperatures ranging from -45° C to 70° C, according to the values found in "SwissCube Thermal Management" [R 4] plus a margin of 10° C.
4. The temperature range for the ADCS board is from -30° C to 60° C when a 20° C margin is taken into account.
5. The maximal current range in the MT is comprised between -30 and 30 mA.
6. The PWM frequency set by the MSP is fixed at 32.5 kHz.

6 TECHNICAL DESCRIPTION

6.1 Magnetotorquers Fabrication

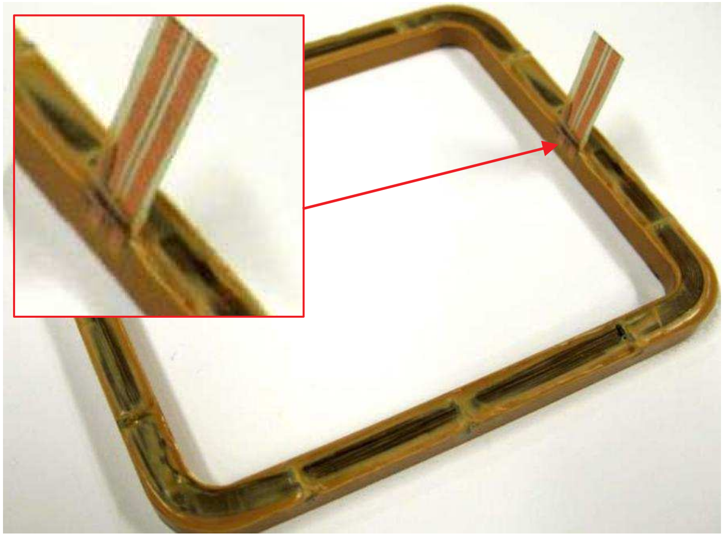


Figure 2 : Coils with a detailed view of the connection wire [R 2].

6.1.1 Relevant Problems

The fabrication process of MTs is described in the "SwissCube ADCS System and hardware" report [R 2]. Some problems appeared in coils, namely:

- The connection wire coming from inside the coil could generate little cracks in the resin around the wire (Figure 2).
- There are remaining bubbles in the resin (Figure 1 and Figure 3).
- The thickness is limited to 5 mm.

Since they could alter the OutGassing (OG) properties of the coils, these problems with the actual EPO-TEK 920 (Appendix A.1, page 37) must be eradicated.

Figure 3 : Detailed view of the consequence of a bubble.

6.1.2 Resin

With a more fluid resin, the number and size of bubbles could be decreased. The new resin needs the following important characteristics:

- Low viscosity
- Low density
- Operating temperature range from -40° C to 70° C. (cf. Requirement ADCS_MT_3, page 10)
- Low TML (Total Mass Loss) (cf. Requirement ADCS_MT_10, page 10).
- Low CVCM (Collected Volatile Condensable Mass) (cf. Requirement ADCS_MT_11, page 10).
- CTE (Coefficient of Thermal Expansion) shall be around the PCB's CTE.

After a first preliminary research, six epoxy resins were retained. Their characteristics are summarized in Table 9 (Appendix A.2, page 38).

It was finally decided to keep the EPO-TEK 920 because resins with a lower viscosity have a CTE too high. They could detach the MT from the PCB when the temperature increases because their CTE was too different. Moreover, the coils with the actual fabrication process passed the OG tests with great success.

6.1.3 Connection Wires

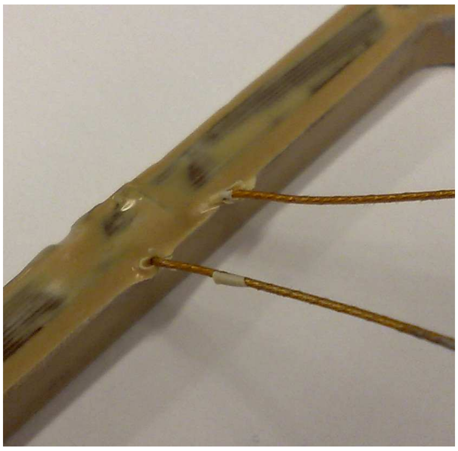


Figure 4 : Detailed view of a new coil connection.

The solution that was retained was to connect space qualified wires to the coil inside the coils (Figure 4). The first advantage of this method is that even if some cracks appear, the OG properties are not changed. The second advantage is that the two wire bonds (positive and negative voltage wires of the MT) are located on each side of the coils to avoid short circuits. Connections are made before the molding step and are then recovered by the resin during the rest of the fabrication process. Figure 5 shows one of the tree new coils.

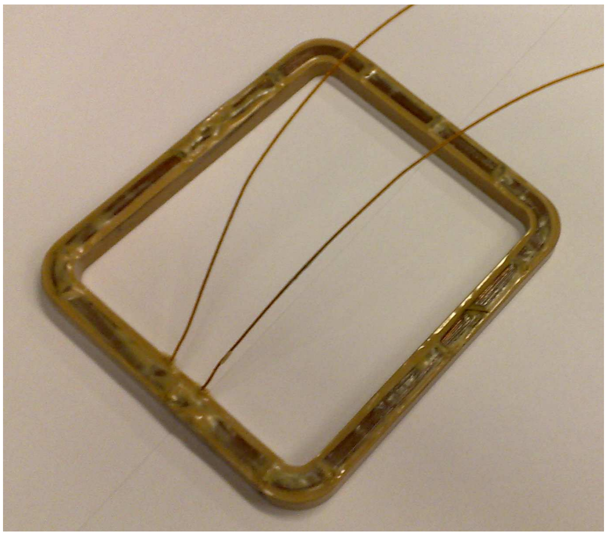


Figure 5 : View of a new coil.

6.2 Test Board Design

6.2.1 Actual Board Description

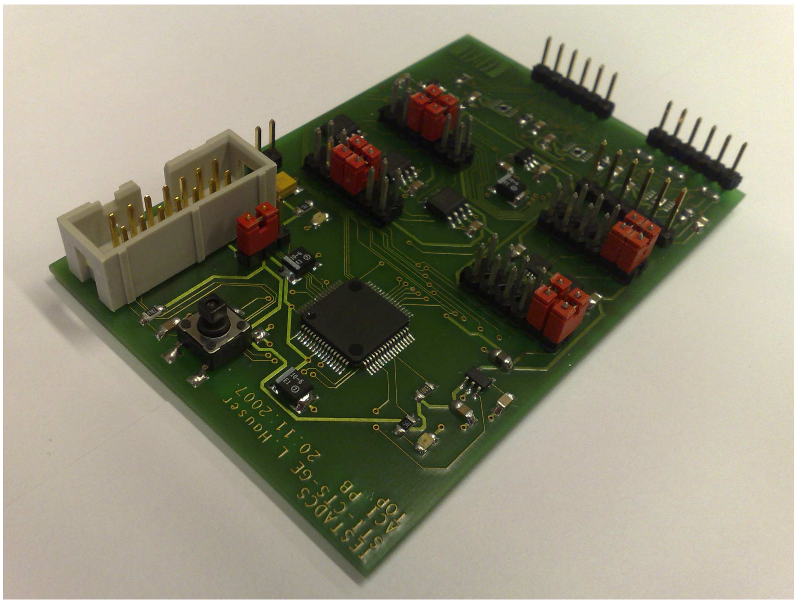


Figure 6 : Picture of the new test board.

This board is designed in order to perform tests and make choices regarding SwissCube ADCS actuators. A picture of this new test board is shown in Figure 6. The last ADCS Board was designed by Hervé Péter-Contesse [R 1]. Some parts of the circuit concerning actuators were copied and some other parts were changed.

The principle of the actuator circuit is quite simple. The ADCS MSP (Mixed Signal Processor) generates three PWM (Pulse With Modulation) signals to create a current in the three MTs (a current in a coil produces a magnetic field). However, the MSP can provide neither a high current, nor a negative voltage. An HB (H-Bridge) per MT is then necessary to provide positive or negative current.

Since the signal has to be transported from the ADCS board to the MTs in the satellite, a filter is added between the HBs and the outputs. The filters permit to smooth the high variations of current due to the PWM. The advantage of using these is to avoid interferences in the rest of the satellite.

The main problem in the electronics design is the HBs. No component respecting all requirements was found. It was then decided to mount the two best HBs on a new board and to make a final choice by testing them.

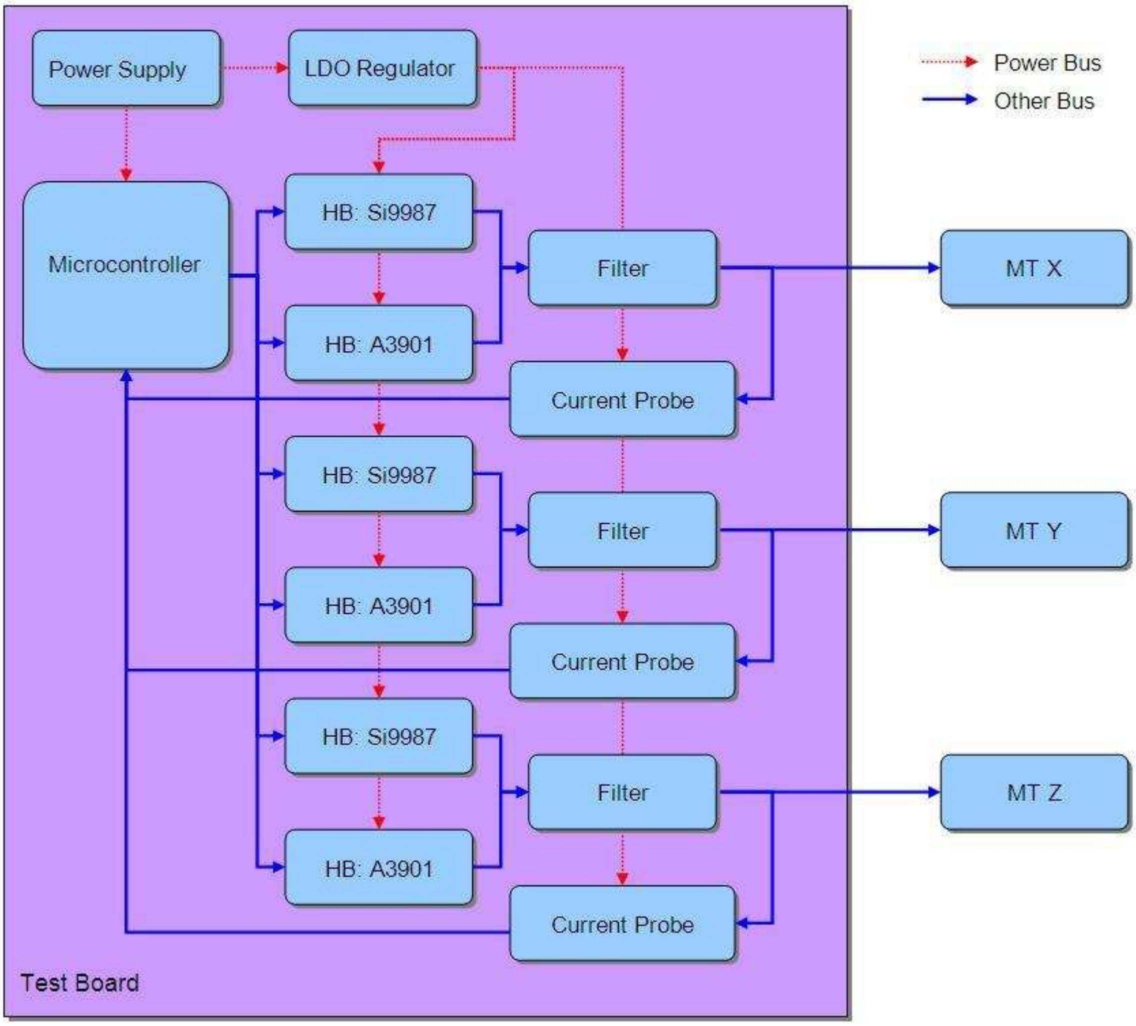


Figure 7 : Principle of the test board.

The principle of the test board is described in Figure 7 and the complete circuit is shown in Appendix D.2.1 (page 69). Note that a LDO is used because this component will be present in the final board.

Another task accomplished in this project is the design of a Current Probe (CP). In the previous version, calculations and tests showed that the coils' resistance changes a lot with temperature. This change implies a big variation of current and of the MF then. The CP allows the implementation of a current regulator in the MSP software by connecting it to an ADC (Analogic to Digital Converter) Input of the MSP.

6.2.2 H-Bridges

The first HB is a Si9987 (Appendix D.3.1, page 81). It satisfies the temperature range of -40 to 70 °C but the supply voltage range advised by the manufacturer is from 3.8 V to 13.2 V. The requirements concerning alimentation of the ADCS board specify a voltage of 3.3 V (cf. Requirement ADCS_MT_1, page 10). Some preliminary simple tests were performed at ambient temperature and they showed the device is working at a 3.3 V supply voltage.

The second selected HB is an A3901 (Appendix D.3.2, page 83). It satisfies the supply voltage, but not the temperature requirements. Actually, the range guaranteed by the manufacturer is from -20° C to 85° C. The main characteristics of HBs are compared in Table 2.

Description	Unit	Si9987	A3901
Power Supply	[V]	**3.8 to 13.2**	2.5 to 5.5
Temperature Range	[° C]	- 40 to 85	**- 20 to 85**
Peak Output Current	[A]	1.5	0.4
Maximum PWM Frequency	[kHz]	500	250

Table 2 : Comparison of the two H-Bridges.

It was decided to perform tests before making the final choice. Both HBs were mounted on the test board and are separately connectable using jumpers.

6.2.3 Filter

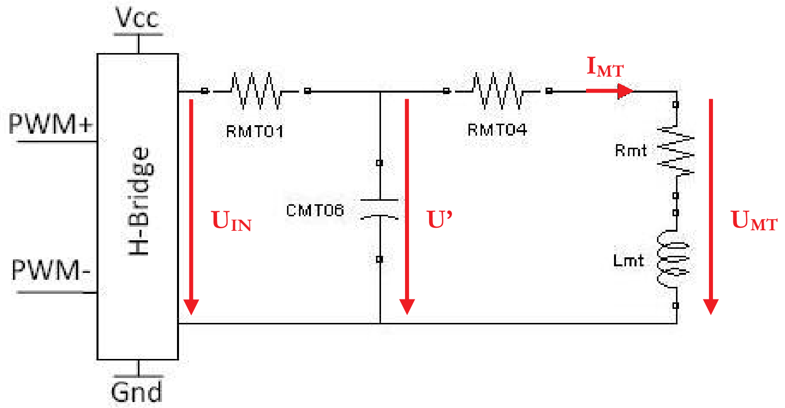


Figure 8 : Magnetotorquers electronic scheme.

The filter was redesigned in order to obtain a better current efficiency in the MTs. It is composed by a resistor and a capacitor that form a simple low-pass filter. The following points must be taken into consideration when choosing the resistor and capacitor:

- The value of the resistor should be small to have the highest current in the MT.
- The cutoff frequency must be low enough to smooth the PWM signal.
- The time constant of the circuit should be small to provide or stop the current as quickly as possible.

The scheme of the electronic circuit is shown in Figure 8. MATLAB has been used to choose the value for the resistor R_{MT01} and C_{MT06}. A function was first created to calculate and plot the transfer function of this circuit (Appendix C.1, page 61). Then a simulation of the electronic circuit was implemented using Simulink (Appendix C.2, page 64). Finally, a function compares the old and the new circuit.

Description	Unit	Old Filter	New Filter
R_{MT01}	[Ω]	82	10
C_{MT06}	[µF]	0.1	1
R_{MT04}	[Ω]	0	1
Cutoff Frequency	[kHz]	19.41	15.91
Filter Time Constant	[µs]	8.2	10
Voltage Gain U_{MT} / U_{IN} (*)	[dB]	-5.75	-7.13
Current I_{MT} (**)	[mA]	16.4	26.1
* : calculated with a sinus signal at the frequency of 32.5 kHz ** : calculated with a PWM of 95 % cycle ratio			

Table 3 : Comparison of the old and the new circuit (with RMT = 109.2 Ω and LMT = 29.4 mH [R 2]).

MATLAB permits to easily observe what the effects of changing component values are. The characteristics of the previous and the new filters are compared in Table 3. The complete result of this comparison is available in Appendix C.1 and C.2.

The main advantage of the new filter is that the current in the coil is really bigger and that other characteristics are not much degraded.

6.2.4 Current Probe

There are two difficulties for the design of the CP (Current Probe). The first one is that the current can be positive or negative (between -25 mA and 25 mA for peak current). And secondly, the differential resistor (every solution uses one) shall be as small as possible. Finally, the input range of the MSP's ADC is from 0 V to 2.5 V and the current regulation accuracy is <10 % (cf. Requirement ADCS_MT_7, page 10). The main solutions that were studied in this project are presented in the following sections.

6.2.4.1 First Solution

The first solution proposed by Hervé Péter-Contesse in his report is to use three differential amplifiers with offsets. The circuit is shown in Figure 9.

"With R_1=R_3, R_2=R_4 and C_2=C_4 we obtain the following equation for the output voltage:

$$\underline{v_{out}} = \frac{\underline{Z_2}}{R_1}\left(\underline{v_2} - \underline{v_1}\right) + V_{ref\,2} = \frac{R_2}{R_1}\frac{1}{1 + j\omega R_2 C_2}\left(\underline{v_2} - \underline{v_1}\right) + V_{ref\,2}$$

Thus with V_{ref1}=2.5V, the reference voltage for the ADC, and V_{ref2}=V_{ref1}/2=1.25V, negative and positive currents can be measured. C_2 and C_4 create a first order optional filter and C_6 stabilizes V_{ref2}.

The ratio R_2/R_1 sets the gain and must be chosen according to the RMT value to ensure an output range of 2.5V. Caution must be enforced when choosing the resistors values to ensure small leakage currents and measurement errors: we must have $i_{coil} >> i_{R1,3}$ and $i_{R5} >> i_{R4}$. These currents must be small to have a small current consumption; we have to be careful with the input impedance of the operational amplifier if the resistors value is high!" [R 2]

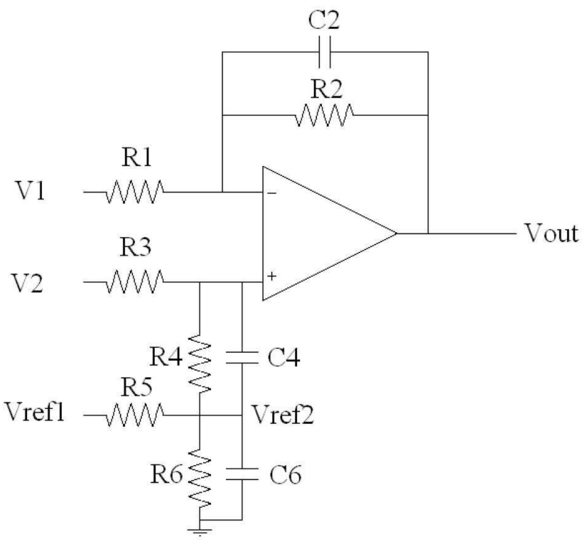


Figure 9 : Current probe with a differential amplifier and an offset [R 2].

6.2.4.2 Second Solution

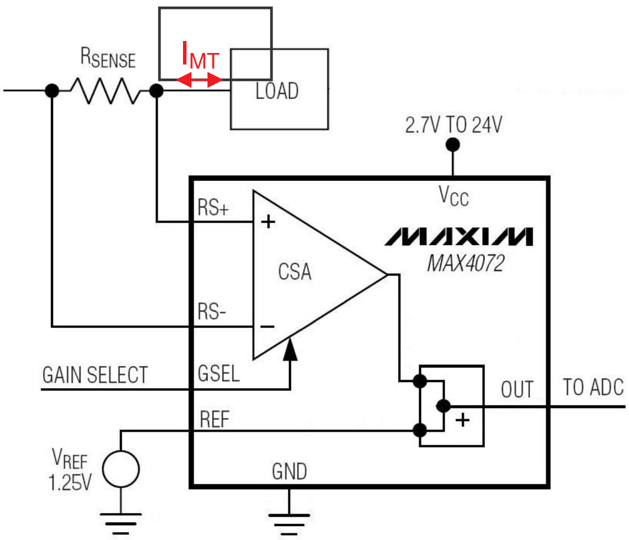


Figure 10 : Current probe with a MAX4072.

The second solution is to use a MAX4072 (Appendix D.3.3, page 87). This component amplifies a differential voltage, adds an offset (V_{ref}) and provides a voltage output (Figure 10).

Note that the gain (GAIN SELECT) of the MAX4072 can be set to 50 or 100. A complete design of this circuit is laid out in Appendix 0 (page 67).

The main advantage of this solution is that it is possible to use a very low shunt resistor (R_{sense}) with a gain of 50. However, the nominal input voltage advised by datasheets is 0.075 V and with this circuit it is 0.025 V when the current is 25 mA which is not perfect.

6.2.4.3 Third Solution

Finally, the last solution is to use an INA170 (Appendix D.3.4, page 92). This component amplifies a differential voltage, adds an offset (V_{ref}) and provides a current in the output (Figure 11).

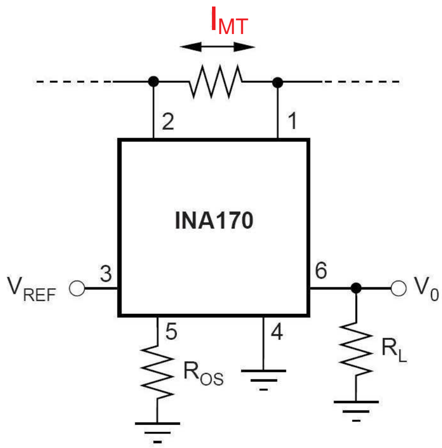


Figure 11 : Current probe with an INA170.

A complete design of this circuit is laid out in Appendix D.1.1 (page 66). The output voltage V_o is given by the following formula (R_s is the shunt resistor):

$$V_{OUT} = \left(\frac{V_{REF} \bullet R_L}{R_{OS}}\right) \pm \left(\frac{I_S \bullet R_S \bullet R_L}{1k\Omega}\right)$$

The main problem with this circuit is that the gain changes with the output resistor. Moreover, the ADC input resistor of the MSP has to be taken into account or an operational amplifier is needed. Finally, the input voltage advised by datasheets is about 0.125 V in normal mode. And with this circuit, the differential input voltage is 0.25 V when the current is 25 mA which is quite critical.

Because of the aforementioned issues, this solution was given up.

6.2.4.4 Selected Solution

The differential amplifier is complicated and needs a lot of components. Moreover, the stability, precision and temperature drift of the circuit have to be studied. The solution of the MAX4072 is simpler and its specifications are well known. This solution was then chosen.

The outputs of the three MAX4072 are directly connected to the ADC inputs of the MSP (Appendix D.2.1, page 69). Figure 12 shows the theoretical output voltage of the CP when a reference of 1.25 V and a 1 ohm shunt resistor are used. This is also the ADC input voltage of the MSP.

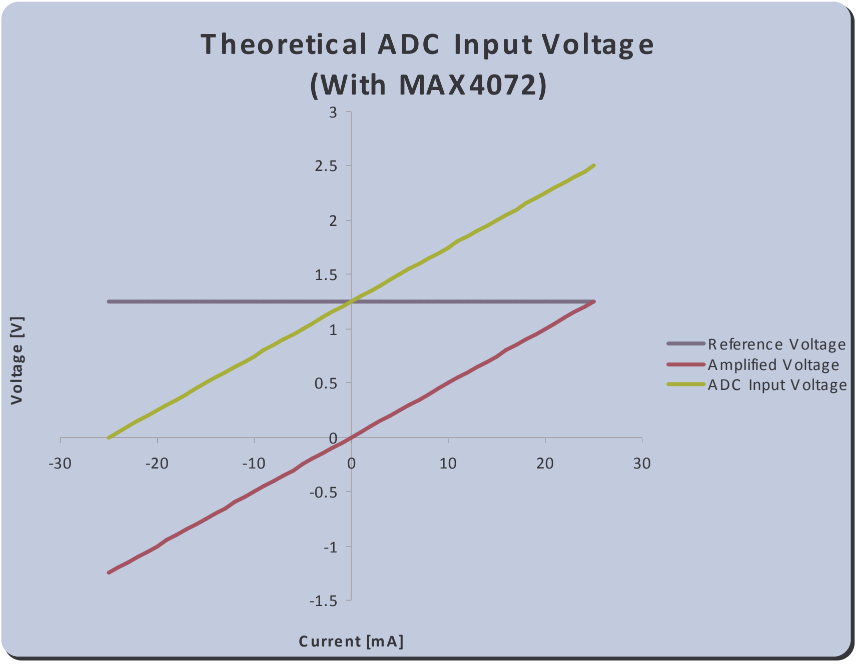


Figure 12 : Theoretical output voltage of the current probe.

6.2.5 Shunt Resistor

The selected shunt resistor is a SR73 (SR732ATBK1R00F, Appendix D.3.5, page 95) with a value of 1 Ohm. The advantages of this component are the fabrication precision of 1 % and the low temperature drift of 100 ppm/°K. It will be possible to respect the current regulation accuracy of 10 % (cf. Requirement ADCS_MT_7, page 10).

The flicker noise created by the resistor was calculated using the following formula [R 6] (Appendix 0, page 67):

$$\overline{V^2} = 4 \cdot k_b \cdot T \cdot R \cdot \Delta f = 2 \cdot 10^{-05} mV$$

- $\overline{V^2}$: Voltage variation average
- k_b : Boltzmann constant
- R : Resistance
- Δf : Bandwidth
- T : Temperature

The result is very small (> 2 * 10^{-6} V) and its influence in the current measurements can be neglected.

6.2.6 Reference Voltage

The MAX4072 needs a voltage reference of 1.25 V. This voltage is provided by the REF3225 (Appendix D.3.6, page 96) used for the MSP ADC input. This component provides a voltage of 2.5 V and a voltage divisor divides it by two (Figure 13). The current in the divisor has to be small to use a small energy. But it has to be much bigger than the current used by the MAX4072 to guaranty the divisor precision. This current is calculated by the following formula:

$$I = \frac{V_{ref\,2.5}}{R_{MT07} + R_{MT08}} = \frac{2.5}{100k + 100k} = 12.5\ \mu\text{A}$$

The reference bias current input of the one MAX4072 is 20 µA and the maximum current is 60 µA. The current of 12.5 µA in the voltage divisor is too small to guarantee a voltage a 1.25 V and an operational amplifier was added (Figure 13). It is a simple OPA333 (Appendix D.3.7, page 100). The complete calculation is detailed in Appendix D.1.3 (page 68).

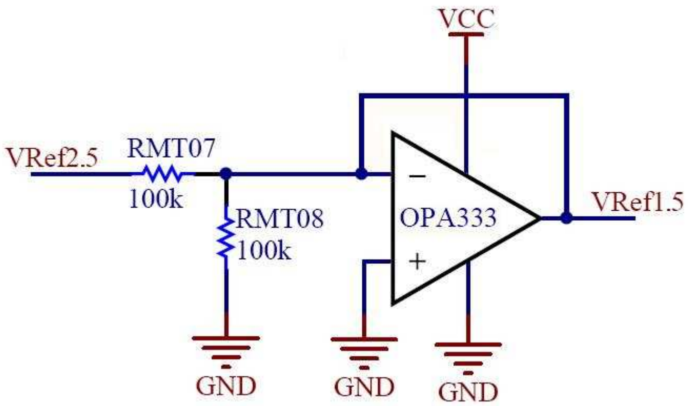


Figure 13 : Voltage reference of 1.25 V with a REF3225 output.

6.2.7 Low Dropout Voltage Regulator

A low dropout (LDO), ultralow-noise and low-power voltage regulator was added (Appendix D.3.8, page 104). This component is powered by the main ADCS power supply and the LDO powers all components used for actuators, namely: the three HBs (Actually six for the test board: three Si9987 and three A3901), the three current probes (MAX4072), the voltage reference (REF3225) and the operational amplifier (OPA333). Note that the voltage reference (REF3225) should not be powered by the LDO in the final version.

The advantages of adding this component are:

- A current limitation of 200 mA in case of shorts for example.
- The possibility of cutting the power of all actuators components in low consumption mode using only one output of the MSP.

6.3 Current Regulator

A current regulator will be implemented as soon as the integrated current probes (MAX4072) will be received. The MSP software will first measure three currents (one per MT) with ADC inputs, then calculate the difference with the orders given by the main board, and finally set a new PWM rate computed by a PID regulator.

7 TESTS

7.1 Magnetotorquer Impedance Characteristics

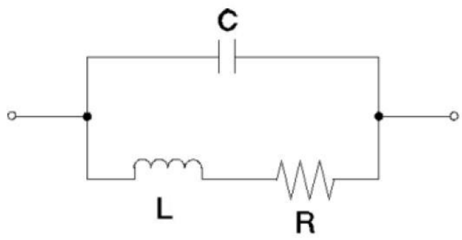


Figure 14 : Magnetotorquers equivalent circuit.

The impedance of the three MTs was measured with a spectral analyzer (Agilent 4294A) at ambient temperature. These measurements give us the equivalent circuit and the frequency response of the coil. When a frequency range between 1 kHz and 50 kHz is considered, the equivalent circuit is composed by a resistor and an inductor in parallel with a capacitor (Figure 14). The capacitor is so small that it can be neglected.

	Unit	MT 01	MT 02	MT 03
Resistance	[Ω]	110.5	111.5	110.8
Inductance	[mH]	29.2	29.4	29.4
Capacitance	[pF]	83.4	69.3	84.3

Table 4 : Magnetotorquers measured characteristics at ambient temperature.

Table 4 shows the measured values for the three MTs considering the equivalent circuit of Figure 14. The frequency response of the first MT is shown in Figure 15 and is almost the same for others MTs (Appendix B.1, page 39). Table 5 also shows that MTs have the same impedance at 32.5 kHz which is going to be the PWM frequency.

It is then possible to consider that there is no difference between MTs which could be important in the design of the current regulator.

	Unit	MT 01	MT 02	MT 03
Impedance norm |Z|	[kΩ]	6.64	6.56	6.70
Impedance angle	[°]	88.58	88.64	88.65

Table 5 : Magnetotorquers measured characteristics at 32.5 kHz and ambient temperature.

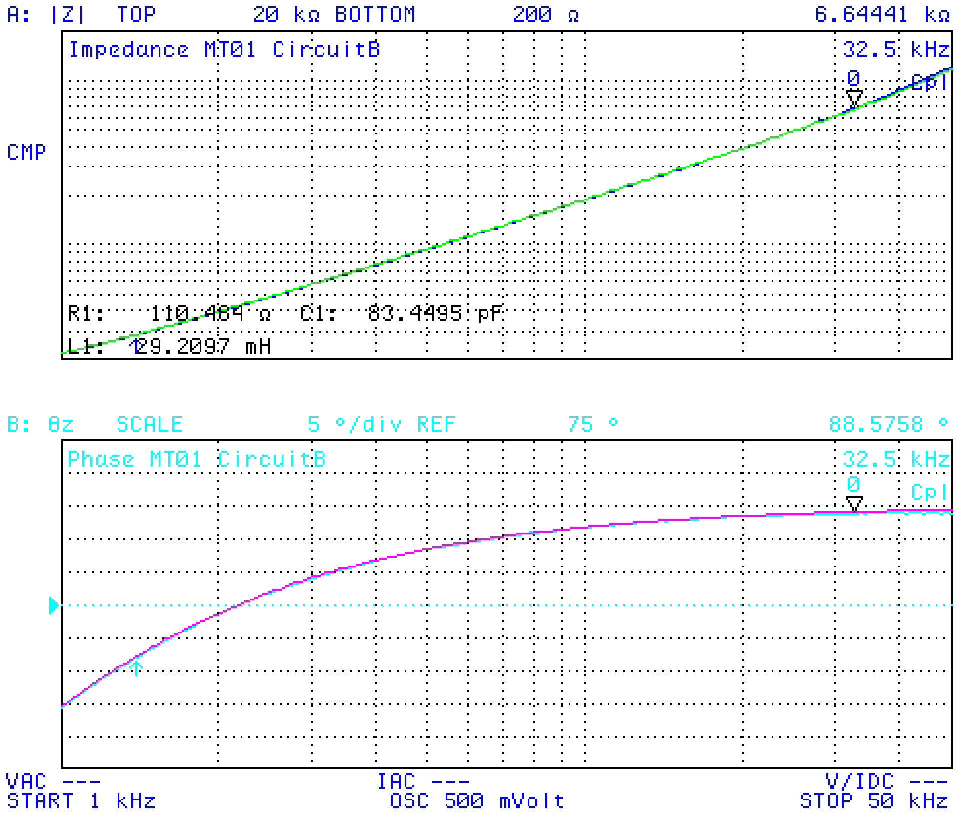


Figure 15 : Frequency response of the magnetotorquer 01.

7.2 Temperature Range Test for H-Bridges

7.2.1 Objectives

The first one, a Si9987 satisfies the temperature range (-40 to 70 °C) but not the supply voltage (only 3.8 to 13.2 V) requirements. Some preliminary simple tests were performed at ambient temperature and they show that the device is working at a 3.3 V supply voltage. The second HB, an A3901 satisfies the supply voltage but not the temperature range requirements.

It was then decided to mount the two HBs on a test board and to test which one is best. A temperature range test was performed in order to make the final choice.

Thus the test objective is to verify the two following requirements for the two HBs:

- ADCS_MT_1 Main power supply: 3.3 ± 0.23 V
- ADCS_MT_4 Temperature range (electronic): - 30 to + 60° C

The more specific purposes of the test are:

- To verify if the Si9987 still works normally at a 3.3 V supply and in the temperature range from -30° to 60° C.
- To verify if the A3901 works normally in a temperature range from -30° to 60° C.

7.2.2 Procedure

Figure 16 : Picture of the test setup.

The configuration for this test setup is shown in Figure 16 and its principle is illustrated by a bloc scheme in Figure 17. The test board was situated in the chamber and the other instruments (power supply, current meter and oscilloscope) and the MTs outside. The whole procedure of the test is described in Appendix B.2 (page 40).

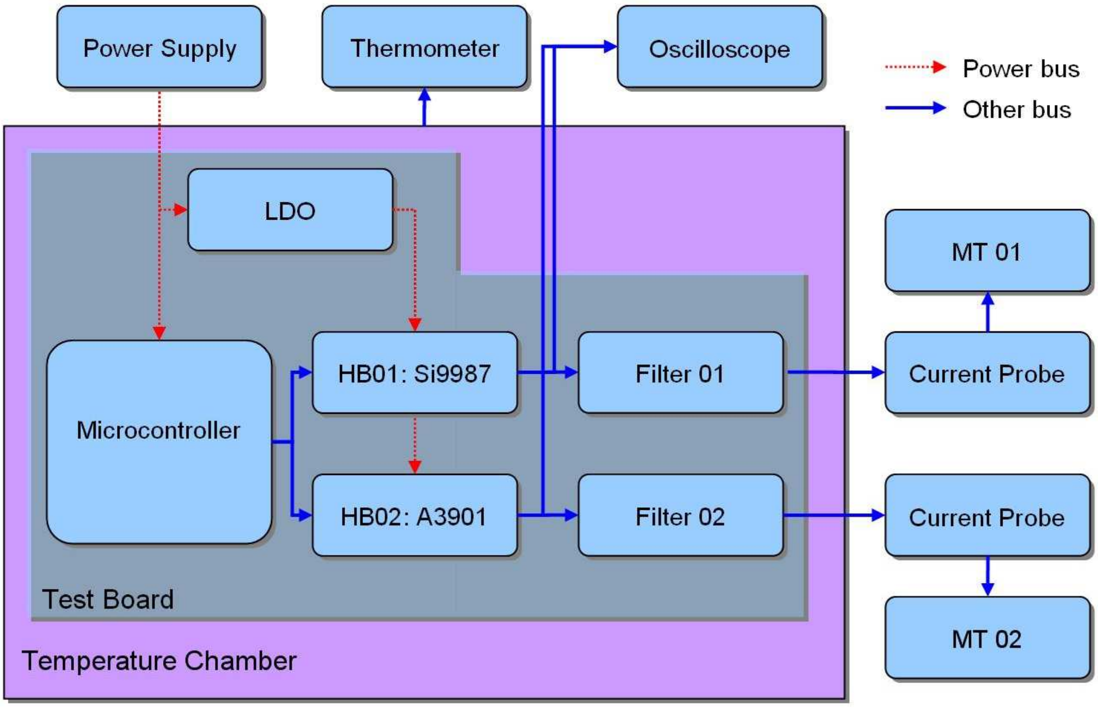


Figure 17 : Principle of the temperature range test for magnetotorquer H-Bridges.

7.2.3 Results

7.2.3.1 Measurement

During the test, the temperature was changed from -40 °C to 70 °C with steps of approximately 10 °C. For each step, the temperature and both currents of MT 01 and MT 02 were measured and the PWM curves were also observed on the oscilloscope.

The observations focused on the general shape of the curve (oscillations) and on the time needed to increase the voltage from 0 V (Gnd) to nominal voltage. A picture of the oscilloscope was taken in order to permit a visual comparison after the test.

The process was not automatic. For each step an operator changed the temperature, wrote the measurements (I_{01}, I_{02}, T), picture numbers and comments about PWM in Table 6.

Step [°C]	Temp. [°C]	I_{MT01} [mA] Si9987	I_{MT02} [mA] A3901	Picture number (CD) (Temperature °C)	Comments about PWM
-40	-40	22.10	23.21	27, 28 (-40.2°)	No particular observation
-30	-30	22.09	23.21	25, 26 (-32.5, -33.3°)	No particular observation
-20	-20	22.08	23.22	23, 24 (22, -22.7°)	No particular observation
-10	-10	22.08	23.22	20, 29 (-11.5, -9.8°)	No particular observation
0	0	22.08	23.22	31, 32 (0.9, 3.4°)	No particular observation
10	10	22.08	23.22	33, 34 (10, 11.9°)	No particular observation
20	20	22.07	23.20	35, 36 (20.4, 21.2°)	No particular observation
30	30	22.06	23.19	37, 38 (32.1, 33.1°)	No particular observation
40	40	22.04	23.17	39, 40 (41.8, 42.4°)	No particular observation
50	50	21.98	23.11	41, 42 (49.3, 50°)	No particular observation
60	60	22.00	23.12	43, 44 (59.7, 61°)	No particular observation
70	70.5	21.98	23.10	45, 46 (70°)	No particular observation

Table 6 : Temperature Range Tests Measurements.

7.2.3.2 Current

The current I_{MT01} and I_{MT02} provided by the HBs are represented in Figure 18.

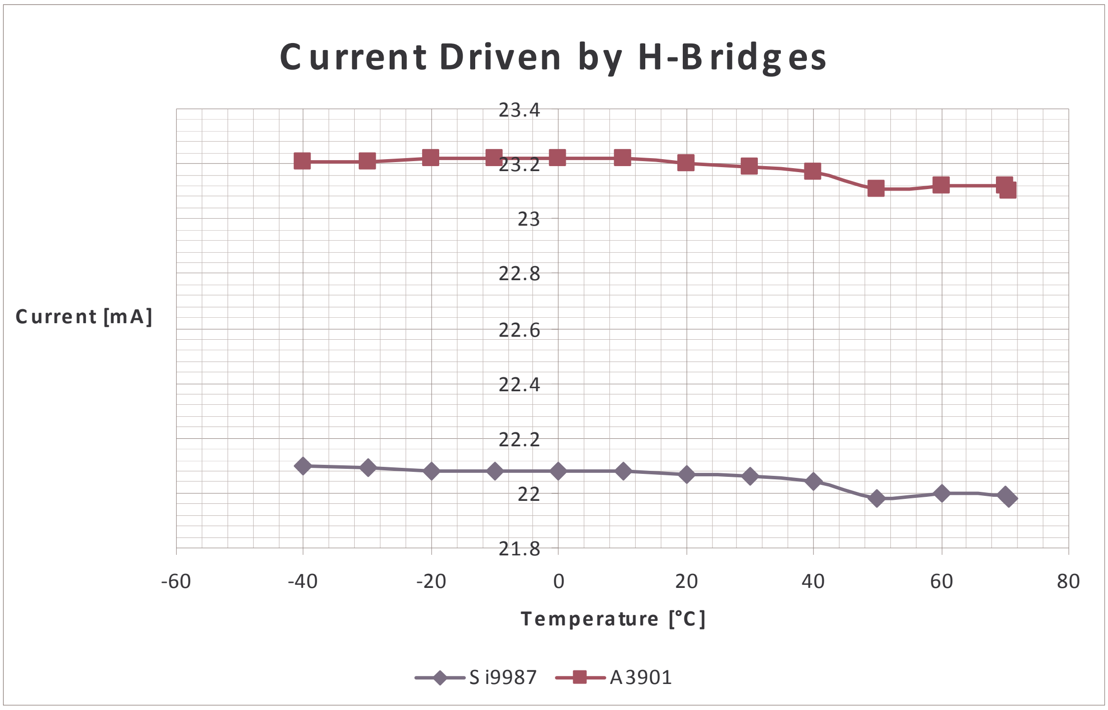


Figure 18 : Graph of the current driven by the H-Bridges.

Firstly, the current is much lower than what was expected with theoretical simulations. It is explained by the neglected effects, the imprecision of components and the resistance of wires (which are in this test much longer than in the final version).

The second element to underline is that the current provided by the A3901 is always higher than by the Si9987. This is due to the internal HB rising time.

Finally, both currents do not change a lot in the temperature range from – 40° C to 70° C. The difference between maximum and minimum current is 0.12 mA for the two HBs. This value also corresponds to maximum and minimum temperatures. Therefore the current depends on the temperature, but its variations are very low. The test was successful for the Si9987 and for the A3901.

Table 7 summarizes the measurements from a statistical and thermal point of view.

	Current [mA]			Current [mA]		
	Min I	Average I	Max I	- 40° C	20° C	70° C
Si9987	21.98	22.05	22.10	22.10	22.07	21.98
A3901	23.10	23.18	23.22	23.21	23.20	23.10

Table 7 : Statistical Comparison of the Current Provided by H-Bridges.

7.2.3.3 PWM

All pictures taken during the test are available in Appendix B.2 (page 40). Table 8 shows some of them for minimum, ambient and maximum temperatures (about – 40° C, 20° C and 70° C). The temperature indicated was measured exactly when the picture was taken.

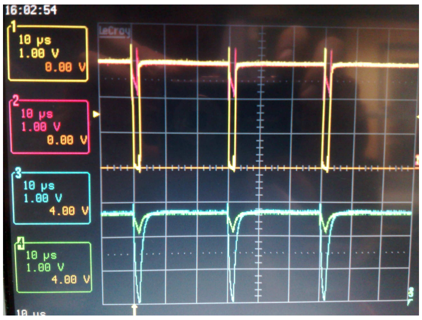
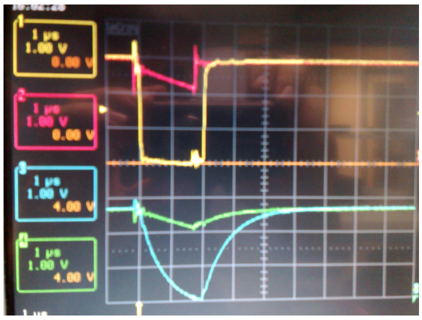
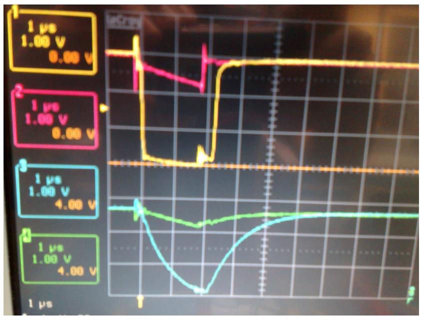
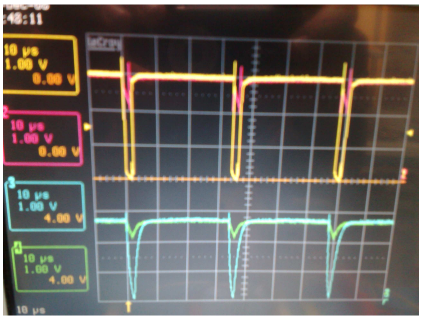
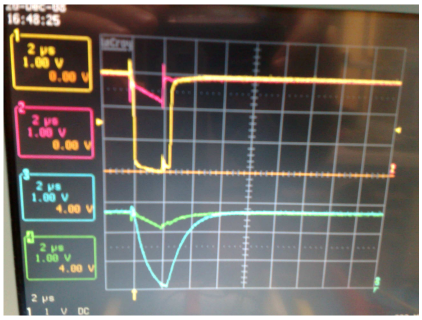
Temp. [° C]	Picture	Temp. [° C]	Picture
-40.2°	 1 V / div & 10 µs / div	-40.2°	 1 V / div & 1 µs / div
21.2°	 1 V / div & 10 µs / div	20.4°	 1 V / div & 1 µs / div
70°	 1 V / div & 10 µs / div	70°	 1 V / div & 2 µs / div
Legend	Yellow : Si9987 output voltage Red : A3901 output voltage Blue : Magnetotorquer voltage MT01 (powered by Si9987) Green : Magnetotorquer voltage MT02 (powered by A3901)		

Table 8 : Picture of the PWM Curve Measured During the Temperature Range Test.

These pictures show that there is no relevant change in the PWM curve in this range of temperatures.

Note that the PWM curves are very different for the Si9987 and the A3901's one. The Si9987 provides a nice PWM and its voltage passes through zero on every cycle. The A3901 provides a smoother signal and its voltage is never equal to zero. It is probably due to the kind of HB transistors and it is also the reason why the current average is always higher. A disadvantage of the A3901 is that the electric time constant is longer but it is still short (less than 10 µs).

7.2.4 Conclusions of the Test

The first two test objectives were:

- To verify if the Si9987 still works normally at a 3.3 V supply and in the temperature range from -30° to 60° C.
    - The Si9987 still works normally at a 3.3 V Supply and in a temperature range from -40° to 60° C.
- To verify if the A3901 works normally in a temperature range from -30° to 60° C.
    - The A3901 still works normally at a 3.3 V Supply and in a temperature range from -40° to 60° C.

The Si9987 passed the test with great success. It means that the Si9987 is able to drive the MTs with a 3.3 V power supply in the temperature range from - 30° to 60° C. Moreover its current range is $25\pm_{5}^{5}$ mA.

The A3901 passed the test with great success. It means that the Si9987 is able to drive the MTs with a 3.3 V power supply in the temperature range from - 30° to 60° C. Moreover its current range is $25\pm_{5}^{5}$ mA.

It is possible to satisfy the two requirements ADCS_MT_1 and ADCS_MT_4 concerning supply voltage and temperature range with both of these components.

The best component for this application is the A3901, because it provides a higher current with the same PWM rate. It is then recommended to choose the A3901 even if both of the HBs fit this application.

7.3 Magnetic Test for Magnetotorquers

A magnetic characterization of the MTs will be performed in the LMIS3 (Laboratoire de MIcroSystèmes 3) at the EPFL. Their installation is a cylinder which is a very good magnetic conductor. There is then no Earth MF (Magnetic Field) inside of it and a very low magnetic field can be determinate by differential measurements. Sensors with an accuracy of 1 nT were already characterized with this installation. Pavel Kejik is responsible for this facility and for a magnetic sensor specialist. He was contacted and it seems to be possible to perform tests in their laboratory. The magnetometers will also be characterized there.

According to him, there is no residual MF in SwissCube (no magnetic time constant). Actually there is no residual MF with a coil at all because it is directly proportional to the current. Moreover, the structure of the satellite which is made with aluminum is not a ferromagnetic conductor.

The waiting period before making MM measurements when the MTs are shouted down corresponds exactly to the electric time constant of the circuit.

7.4 Electromagnetic Compatibility Measurements

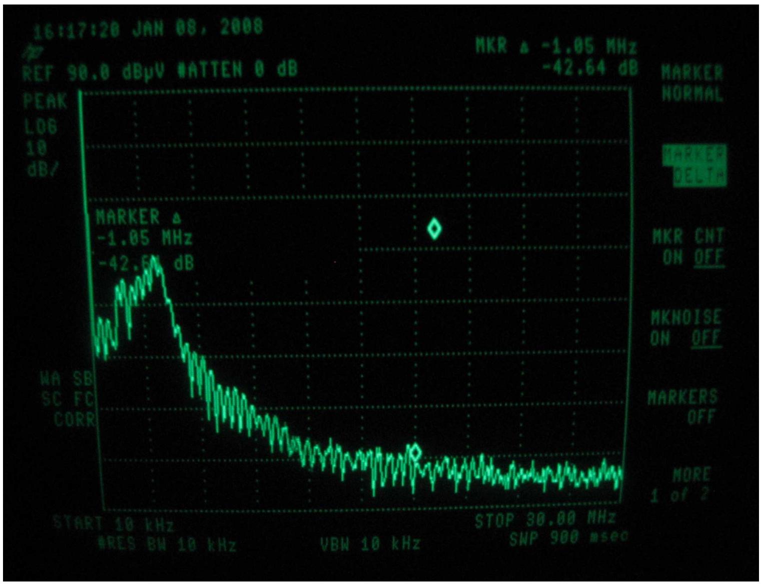


Figure 19 : Spectral EMC measurement for Si9987.

An EMC (ElectroMagnetic Compatibility) analysis was performed on the test board with an electromagnetic field probe and a spectral analyzer. The objective was to determine if the PWM signal, the HBs and the MTs are critical from the EMC point of view. Pictures of the spectral response were taken. The first one was taken a few millimeters above the Si9987 HBs (Figure 19), the second above the A3901 HB (Figure 20) and the last one above the MSP (Figure 21).

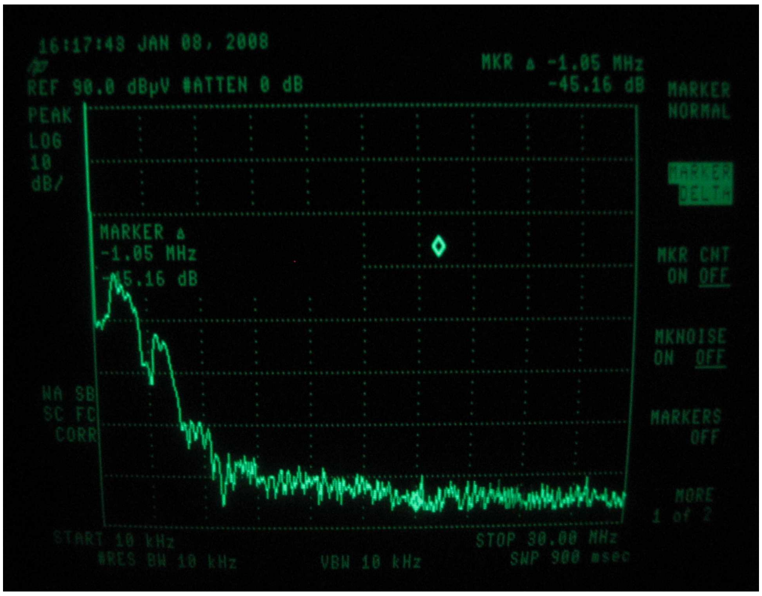


Figure 20 : Spectral EMC measurement above A3901.

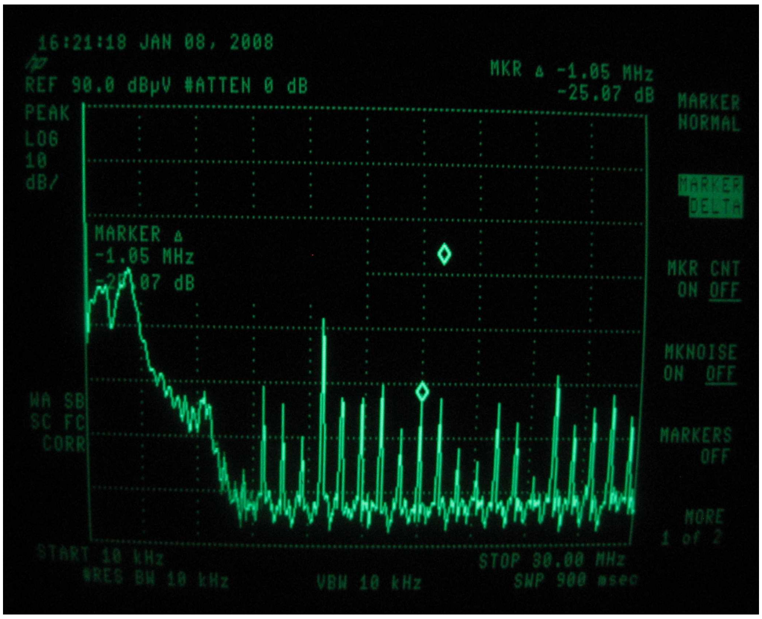


Figure 21 : Spectral EMC measurement above the MSP.

The conclusion of these measurements is that the HBs are absolutely not critical from the point of view of EMC. That is because of the MF which is too small for the Si9987 and for the A3901. Even the MSP emits a higher MF (Figure 21). It is also not a problem for PWM signals wires between the board and the coils.

8 Recommendations

8.1 Magnetotorquer Fabrication

There is a last modification to perform in the design of the MTs. It is the place where the space-qualified wires go out of the resin. This modification has to be done according to the Mechanical System Engineer.

Tests have to be performed to insure that all launcher requirements are respected (outgassing, vacuum, vibrations, …). If the design does not comply with these requirements, other solutions could be investigated. "For example they could be built using PCB stack" [R 7].

8.2 Electromagnetic Compatibility Analysis

One of the main difficulties with the electronic design is to not protect the sensitive analogue signals from perturbations. An EMC analysis review was performed with Werner Hirschi who is a specialist from the company "Montena". Here is a non-exhaustive list of modifications that must be made on the MT circuit:

- Complete separation between analogue and digital grounds. There should be only one point of connection between these two grounds to absolutely avoid loop in the circuit. If it is necessary, more than one mass of each type can be created.
- The analogue components have to be placed as far as possible from the digital and high power signals.
- The voltage reference of 1.25 V which is created by a 2.5 V reference (a REF3225 and a voltage divisor, section 6.2.6, page 20) shall be separated to absolutely avoid a pollution of the 2.5 voltage. It is then necessary to have one 2.5 V voltage reference for the MSP (typically a REF3225, Appendix D.3.6, page 96) and a 1.25 V voltage reference for current probes (typically a REF3212, Appendix D.3.6, page 96).
- An inductor should be added between the LDO output and the capacitor C_{MT18} (Appendix D.2.1, page 69). This capacitor is used as an energy reserve for the HBs when the PWM required peak energy. This reserve has to be calculated and this capacitor may be replaced. One possibility could be to put in parallel another lower capacitor.

Others modifications concerning the MSP and other parts of the ADCS are detailed in the ADCS System Engineer report [R 7].

8.3 Design Changes

The following points concern the differences between the design of the test board and the ADCS board.

- The voltage reference (REF3225) must be powered by the main supply and not by the LDO in the ADCS board.

- Only one type of HB is going to be used for the ADCS board. Only the Si9987 has to be removed.
- The shunt resistors have to be changed on the test board as soon as we receive the 1 Ω precision resistors.
- The current probes also have to be mounted on the test board as soon as we receive them.

8.4 Future Tasks and Tests

There is still a lot of work to perform for the development and tests of the ADCS board. The next steps regarding the actuators are:

- To implement new electronics pertaining to EMC analysis.
- To perform a test in order to characterize the magnetic field produced by the MTs.
- To implement and test the MT current regulator software. Note that the MTs have to be unpowered during the MM measurements. A dead time corresponding to the electronic time constant (time to empty the capacitors) of the circuit has to be included before beginning the MM measurements.
- To develop a magnetotorquer simulation model (it would even be interesting to have a model including the PWM generation, the HBs, the MTs and the current regulator algorithms).
- To integrate it in the ADCS and verify all requirements with tests.

9 CONCLUSION

During this project, the actuators part of the SwissCube ADCS was improved. Three new MTs were fabricated with improved electrical connections. A test board was designed and built with two kinds of HB, a PWM filter with higher current efficiency and current probes. A temperature range test permitted to show that the A3901 is the best HB to drive current in MTs in regards to the temperature range specified by the requirements. Moreover, measurements at the ambient temperature show that electronics should be able to fulfill all specifications.

The EMC analysis shows that there is still some little parts to change in the hardware of the actuators but that the most critical components are not going to be a problem for the satellite. These elements have to be taken into account for the next ADCS board generation.

There is still a lot of work to perform for the development and tests of the ADCS board. The next steps concerning the actuators are to implement new electronics, to characterize the magnetic field provided by the MTs, to implement and test the MT current regulator software and to develop a magnetotorquer simulation model. Finally, this part will be integrated in the ADCS and all requirements will be verified with tests.

Lausanne, January 10, 2008.

Laurent Hauser

10 ACKNOWLEDGMENTS

A special thanks the following people for their help, their advices and their work on this project.

Peter Bruelmeier

- Email: peter.bruehlmeier@epfl.ch
- Unit: ACI (Atelier des Circuits Imprimés), ACORT (Atelier de COnception, Réalisation et Test), EPFL.
- Contribution: Test board layout.

André Badertscher

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- Contribution: Test board SMD soldering.

Roland Dupuis

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- Contribution: Magnetotorquer fabrication.

Paolo Germano

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- Unit: LAI (Laboratoire d'Actionneurs Intégrés), EPFL.
- Contribution: Electronic facilities and very good advices.

Werner Hirschi

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- Contribution: EMC analysis.

Pavel Kejik

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- Unit: LMIS3 (Laboratoire de MIcroSystèmes 3), EPFL.
- Contribution: Magnetic tests.

11 TERMS, DEFINITIONS AND ABBREVIATED TERMS

11.1 Abbreviated terms

ADC	Analog to Digital Convertor
ADCS	Attitude Determination and Control System
CP	Current Probe
CTE	Coefficient of Thermal Expansion
CVCM	Collected Volatile Condensable Mass
EMC	ElectroMagnetic Compatibility
HB	H-Bridges
LDO	Low DropOut voltage regulator
MF	Magnetic Field
MSP	Mixed Signal Processor
MT	Magnetotorquers
OG	Outgassing
PCB	Printed Circuit Board
PWM	Pulse With Modulation
TML	Total Mass Loss

12 REFERENCES

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[R 3] M. Noca, G. Roethlisberger, F. Jordan, N. Scheidegger, T. Choueiri, B. Cosandier, F. George, M. Dumont, R. Krpoun : "SwissCube Phase B-C Project, Mission, Space and Ground System Overview", S3-B-C-SET-1-2-Mission_System_Overview.doc, EPFL, August 2007.

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[R 5] http://outgassing.nasa.gov/, December 2007

[R 6] http://fr.wikipedia.org/wiki/Bruit_thermique, December 2007

[R 7] H. Péter-Contesse: "SwissCube ADCS System Engineer", S3_Phase_B-C-ADCS-1-0-System_Engineering, EPFL, autumn 2007.

13 APPENDIX

Appendix A Magnetotorquer Fabrication

A.1 EPO-TEK 920 Specifications

Product Information Sheet

MATERIAL ID: **EPO-TEK® 920**
Date: 08/2007 **Per:**
Rev: III

Material Description:	A two component, high Tg, electrically insulating, thermally conductive epoxy designed for thermal management applications found in semiconductor, hybrid microelectronics, PCB, and optical industries. It can be an adhesive for mounting heat sinks and substrates, a seal for many types of packages, or a thermal potting compound. It is a NASA approved, low outgassing epoxy.
Number of Components:	Two
Mix Ratio by weight:	100:3
Cure Schedule (minimum)	150°C/5 Minutes - 120°C/10 Minutes - 100°C/20 Minutes
Specific Gravity:	--- Part A: 2.24 Part B: 1.02
Pot Life:	5 Hours
Shelf Life:	Six months at room temperature

NOTE: Container(s) should be kept closed when not in use. Filled systems should be stirred thoroughly before mixing and prior to use

MATERIAL CHARACTERISTICS: *To be used as a guide only, not as a specification. Data below is not guaranteed. Different batches, conditions and applications yield differing results; Cure condition: 150°C/1 hour*
* denotes test on lot acceptance basis

PHYSICAL PROPERTIES:			
*Color (before cure):	Part A: Grey Part B: Amber		
*Consistency:	Smooth paste	Die Shear @ 23°C:	≥ 15 Kg / 5100 psi
*Viscosity (23°C):		Degradation Temp:	343 °C
@ 20 rpm	13,000 - 20,000 cPs	Weight Loss:	
Thixotropic Index:	2.1	@ 200°C:	< 0.05 %
*Glass Transition Temp:	≥ 90 °C (Dynamic Cure 20—200°C /ISO 25 Min; Ramp -10—200°C @ 20°C/Min)	@ 250°C:	0.24 %
		@ 300°C:	0.77 %
Coefficient of Thermal Expansion (CTE):		Operating Temp:	
Below Tg:	24×10^{-6} in/in°C	Continuous:	- 55°C to + 200°C
Above Tg:	117×10^{-6} in/in°C	Intermittent:	- 55°C to + 300°C
Shore D Hardness:	90	Storage Modulus @ 23°C:	762,091 psi
Lap Shear @ 23°C:	> 2,000 psi	*Particle Size:	≤ 50 microns

ELECTRICAL AND THERMAL PROPERTIES:			
Thermal Conductivity:	0.97 W/mK	Dielectric Constant (1KHz):	5.19
Volume Resistivity @ 23°C:	$\geq 1 \times 10^{14}$ Ohm-cm	Dissipation Factor (1KHz):	0.008

OPTICAL PROPERTIES @ 23°C:			
Spectral Transmission:	N/A	Index of Refraction:	N/A

EPOXY TECHNOLOGY, INC.
14 FORTUNE DRIVE, BILLERICA, MA 01821 (978) 667-3805, FAX (978) 663-9782
WEB SITE: www.epotek.com

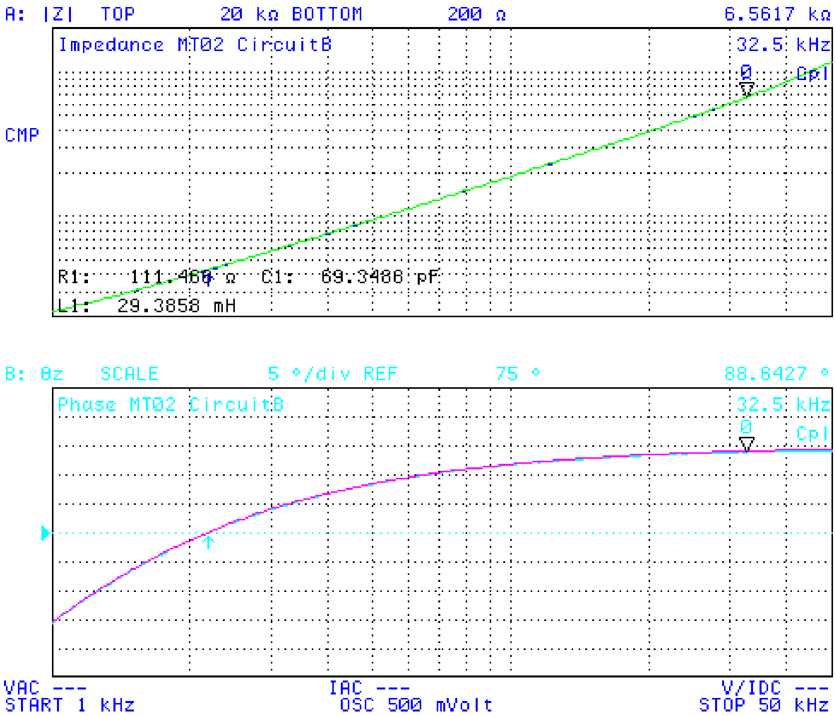
A.2 Resins Comparison Table

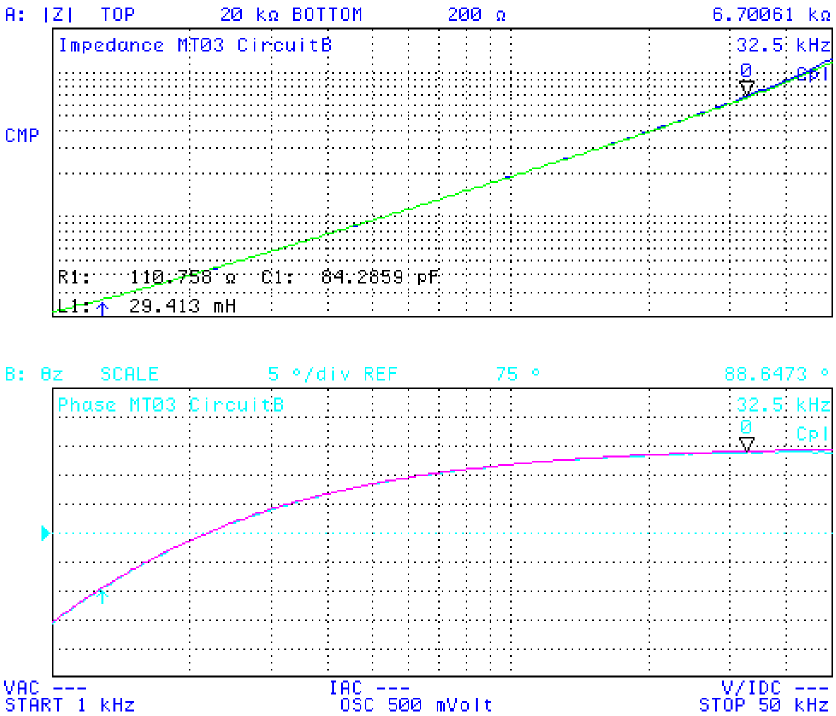
	Unit	EPO-TEK 920	Stycast 2057FR	Stycast 2057	Stycast 2850FT	EPOTEK H77	EPOTEK 920FL
Density	**g/cm³**	**2.24**	**1.58**	**1.64**	**2.19**	**2.7**	**2.52**
Viscosity	**Pa*s**	**13 - 20**	**4**	**< 7**	**5.6**	**06 - 12 Pas**	**8 - 12 Pas**
Cure Temperature	°C	100	25	25	25 - 65	100	100
Cure Time	Hours	0.3	16-24	24	2 -24 H	1	0.3
Temperature Range of use	**°C**	**- 55 to 200**	**- 40 to 130**	**- 65 to 105**	**-65 to 105**	**- 55 to 250**	**- 55 to 200**
TML	**%**	**0.65**	**0.72**	**0.72**	**0.58**	**0.22**	**?**
CVCM	**%**	**0.01**	**0.01**	**0.01**	**0.01**	**< 0.01**	**?**
Water absorption	%	?	0.2	0.3	0.02	?	?
Thermal conductivity	W/mK	0.97	0.4	0.4	1.02	0.66	0.89
Coeff of thermal expansion	**PPMm**	**24**	**67.5**	**45**	**39.4, 111.5**	**33**	**21**
Dielectric constant @1mHz	-	5.19	4.4	4.5	5.36	5.64	5.89
Catalyst			9	9	23 LV		

Table 9 : Comparison Table of Resins (Blue = requirements are satisfied, Red = requirements are not satisfied)

Appendix B Tests

B.1 Magnetotorquers Characteristics





B.2 Temperature Range Test for MT H-Bridges

SwissCube
Date : 13/01/2008
Issue : 1 Rev : 1
Page : 1 of 24

Phase B

Temperature Range Test for Magnetotorquer H-Bridges: Report

Prepared by:
Laurent Hauser

Checked by:

Approved by:

Swiss Institute of Technology (EPFL)
Lausanne
Switzerland

13/01/2008

Space Center

unine Hes·so Haute Ecole Spécialisée de Suisse occidentale EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1 RECORD OF REVISIONS

ISS/REV	Date	Modifications	Created/modified by
1/0	10/12/2007	Initial Issue	Laurent Hauser
1/1	13/01/2007	English corrections	Laurent Hauser

2 TERMS, DEFINITIONS AND ABBREVIATED TERMS

2.1 Abbreviated terms

ADCS	Attitude Determination and Control System
HB	H-Bridges
MSP	Mixed Signal Processor
MT	Magnetotorquers
PWM	Pulse With Modulation

3 TEST OBJECTIVES

The ADCS (Attitude Determination and Control System) actuators are three MTs (Magnetotorquers) powered by a PWM (Pulse With Modulation) signal. This signal is produced by a MSP (Mixed Signal Processor) and driven by HBs (H-Bridges) because the MSP cannot give enough current. Moreover, the MSP cannot provide negative voltage. During the design of the electronics, no HB satisfying all requirements were found.

The first one, a Si9987 (Appendix B) satisfies the temperature range (-40 to 70 °C) but not the supply voltage (only 3.8 to 13.2 V) requirements. Some preliminary simple tests were performed at ambient temperature and they show that the device is working at a 3.3 V supply voltage. The second HB, an A3901 (Appendix C) satisfies the supply voltage but not the temperature range requirements.

It was then decided to mount the two HBs on a test board and to test which one is best. A temperature range test was performed in order to make the final choice.

Thus the test objective is to verify the two following requirements for the two HBs:

4_ADCS_32_03	**Thermal design**
	The thermal design of the ADCS board shall ensure that all components are maintained within their qualification temperature range throughout the lifetime of the subsystem.
	Thermal Analysis
	3_SSR_32_02
4_ADCS_43_01	**Supply voltage**
	The ADCS shall use [3.3V] +/- [7%].
	EPS.
	3_SSR_31_16

The more specific purposes of the test are:

- To verify if the Si9987 still works normally at a 3.3 V supply and in the temperature range from -30° to 60° C.
- To verify if the A3901 works normally in a temperature range from -30° to 60° C.

4 IDENTIFICATION AND CONFIGURATION OF THE TEST ARTICLE

This test will be performed on the ADCS actuators test board. This is a list of all components needed for this test:

- 1x ADCS actuator test board (Figure 1)
- 2x MT (Figure 2)
- 1x Power Supply
- 2x Current meter (Figure 4)
- 1x Thermometer
- 1x Oscilloscope (Figure 3)
- 1x Camera

Figure 1 : ADCS actuators test board.

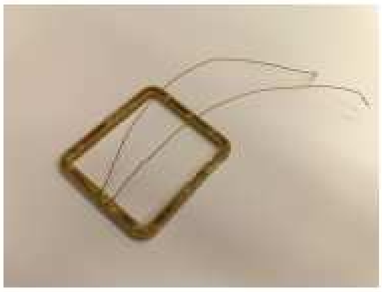


Figure 2 : Magnetotorquer.

Figure 3 : Oscilloscope.

Figure 4 : Current meter.

The configuration for this test setup is shown in Figure 6 and its principle is illustrated by a bloc scheme in Figure 5. The test board was situated in the chamber and the other instruments (power supply, current meter and oscilloscope) and the MTs outside.

The thermometer used will be placed in such a way that it could give the temperature of the component (and not of the chamber). The position of other components is not important. The configuration of the test article will be the same before and after test.

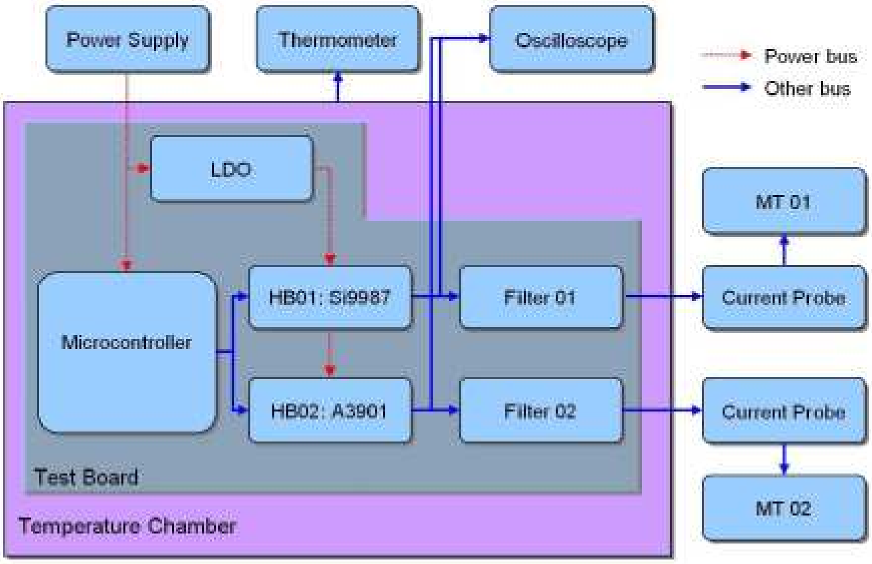


Figure 5 : Principle of the temperature range test for magnetotorquer H-Bridges.

Figure 6 : Picture of the test setup.

5 TEST SET-UP IDENTIFICATION

5.1 Test facility and data handling

This test will be performed in the LMTS (Microsystems for Space Technologies Laboratory) in Neuchâtel using the thermal chamber showed in Figure 7.

Figure 7 : Thermal chamber.

5.2 Ground support equipment and manuals

A power supply will be used to power the test board (3.3 V) during the test.

The thermal chamber is an "ESPEC Bench-Top Type Temperature and Humidity Chamber" and its characteristics are given in the following table:

Name	ESPEC SH-241
Temperature range	-40 to 150 °C
Humidity range	30 to 95 % RH

5.3 Instruments (including accuracy and calibration data)

Two current meters will measure the current in each of the MT during the test. Current data will be manually recorded by an operator. The characteristics of the current meter are shown in the following table:

Name	Normameter MP12
Measure range	± 1 A
Precision	± 0.2 %

Temperature data will be manually recorded by an operator using the thermometer of the chamber.

An oscilloscope will show the two PWM signals created by the HBs. The voltage will be visually controlled by an operator. The characteristics of the oscilloscope are shown in the following table:

Name	LeCroy LT224
Measure range	± 400 V (Impedance of 1 MΩ)
Accuracy	1 / 256 (8 bits)
Vertical precision	± 0.5 %
Horizontal precision	0.002 %

No particular calibration is needed for the current meter, nor for the thermometer or for the oscilloscope.

5.4 Adapters and Interfaces

Cables will be used to interface the ADCS test board with the instruments outside of the chamber, (Figure 5), namely:

- Vcc: Positive power supply between the power supply and the ADCS board.
- Gnd: Ground of the power supply between the power supply and the ADCS board.
- I_{01}: Between the ADCS board output 01 and current meter 01.
- I_{02}: Between the ADCS board output 02 and current meter 02.
- V_{01}^{+}: Between the output voltage of HB 01 and oscilloscope.

- V_{01}^-: Between the output voltage of HB 01 and oscilloscope.
- V_{02}^+: Between the output voltage of HB 02 and oscilloscope.
- V_{02}^-: Between the output voltage of HB 02 and oscilloscope.

6 TEST CONDITIONS

6.1 Test levels and duration

Requirements for the electronic of ADCS are:

Main power supply	3.3 ± 0.23	V
Temperature range (electronic)	-30 to +60	°C
Max current in the magnetotorquers	-25 to +25	mA

The microcontroller is programmed to deliver a PWM with a duty cycle of 95 % with a 3.3 V power supply. This duty cycle corresponds to a current of 26.1 mA in numeric simulations.

All cables will be connected according to (Figure 5).

The temperature will be changed from -40 °C to 70 °C with steps of approximately 10 °C. For each step, the temperature will be stabilised first, and then the temperature and both currents of MT 01 and MT 02 will be measured. The PWM curves will be observed on the oscilloscope and every anomaly will be mentioned in a table. The observations should focus on the general shape of the curve (oscillations) and on the time needed to increase the voltage from 0 V (Gnd) to nominal voltage. A picture of the oscilloscope will also be taken in order to permit a visual comparison after the test.

The process is not automatic. For each step an operator is needed to change the temperature, write the measurements (I_{01}, I_{02}, T), picture number and comments about PWM in a table (section 10.1, page 14).

The duration of a step is the time needed for temperature and current to be stabilized. It is not important to begin with a low or high temperature. Only one sample for each temperature step in needed.

6.2 Tolerances

Precisions for temperatures are required only for maximum and minimum temperatures. Tolerances are indicated here:

- Minimum temperature: -40^{+1}_{-5} °C
- Maximum temperature: 70^{+5}_{-1} °C
- Temperature: ± 5 °C
- Time: ± 20 %

6.3 Data acquisition

Acquisition of data will be done manually by lecturing measurement instruments.

7 STEP BY STEP INSTRUCTION FOR OPERATION

7.1 Test preparation

N°	Task description	Operator
01	Programming the microcontroller	➽ (LH)
03	Put the ADCS test board in the temperature chamber	➽ (LH)
04	Verifying that the power supply is off	➽ (LH)
05	Connecting Vcc cable	➽ (LH)
06	Connecting Gnd cable	➽ (LH)
07	Connecting I_{MT01} cable	➽ (LH)
08	Connecting I_{MT02} cable	➽ (LH)
09	Connecting V_{MT02} cables	➽ (LH)
10	Connecting V_{MT02} cables	➽ (LH)
11	Check all connection according to (Figure 5)	➽ (LH)

12	Increase supply voltage to 3.3 V	➽ (LH)
13	Check that both currents in MT are 20 mA	➽ (LH)
14	Close the chamber	➽ (LH)

7.2 Test performances

Step	T [°C]	Task description	Operator
15	22	Cool to -40 °C.	➽ (LH)
16	-40	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
17	-40	Heat to -30 °C.	➽ (LH)
18	-30	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
19	-30	Heat to -20 °C.	➽ (LH)
20	-20	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
21	-20	Heat to -10 °C.	➽ (LH)
22	-10	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
23	-10	Heat to 0 °C.	➽ (LH)
24	0	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
25	0	Heat to 10 °C.	➽ (LH)
26	10	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
27	10	Heat to 20 °C.	➽ (LH)
28	20	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
29	20	Heat to 30 °C.	➽ (LH)
30	30	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
31	30	Heat to 40 °C.	➽ (LH)
32	40	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
33	40	Heat to 50 °C.	➽ (LH)

34	50	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
35	50	Heat to 60 °C.	➽ (LH)
36	60	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
38	60	Heat to 70 °C.	➽ (LH)
40	70	Measure I_{01}, I_{02}, T, picture of PWM and comments.	➽ (LH)
42	70	Start cool to ambient temperature.	➽ (LH)

7.3 Pass-fail criteria

The success criteria for the Si9987 is the ability to drive the MT with a 3.3 V power supply in the temperature range from - 30° to 60° C. The accepted current range is $25\pm_{5}^{5}$ mA.

The success criteria for the A3901 is the ability to drive the MT with a 3.3 V power supply in the temperature range from - 30° to 60° C. The accepted current range is $25\pm_{5}^{5}$ mA.

7.4 Past test activities

After the test, a treatment of data will be performed in order to plot a graph with two curves of current for Si9987 and A3901 in function of the temperature (section 10.1, page 14). Oscilloscope screen pictures could also be observed in details.

The final choice of the HB will be done according to the best graph results. The best "voltage-temperature" graph is the nearest curve to a constant 25 mA. The best "voltage-time" graph is the curve with the best PWM looks.

8 SAFETY AND SECURITY INSTRUCTIONS

The Safety and security instructions shall be determined with the facility's owner.

9 STAFF REQUIRED AND RESPONSIBILITY

- Laurent Hauser: Responsible for the ACDS actuators.
- Renato Krpoun: Responsible for the facility.

10 TEST RESULTS

10.1 Measurement

During the test, the temperature was changed from -40 °C to 70 °C with steps of approximately 10 °C. For each step, the temperature and both currents of MT 01 and MT 02 were measured and the PWM curves were also observed on the oscilloscope.

The observations focused on the general shape of the curve (oscillations) and on the time needed to increase the voltage from 0 V (Gnd) to nominal voltage. A picture of the oscilloscope was taken in order to permit a visual comparison after the test.

The process was not automatic. For each step an operator changed the temperature, wrote the measurements (I_{01}, I_{02}, T), picture numbers and comments about PWM in Table 1.

Step [°C]	Temp. [°C]	I_{MT01} [mA] Si9987	I_{MT02} [mA] A3901	Picture number (CD) (Temperature °C)	Comments about PWM
-40	-40	22.10	23.21	27, 28 (-40.2°)	No particular observation
-30	-30	22.09	23.21	25, 26 (-32.5, -33.3°)	No particular observation
-20	-20	22.08	23.22	23, 24 (22, -22.7°)	No particular observation
-10	-10	22.08	23.22	20, 29 (-11.5, -9.8°)	No particular observation
0	0	22.08	23.22	31, 32 (0.9, 3.4°)	No particular observation
10	10	22.08	23.22	33, 34 (10, 11.9°)	No particular observation
20	20	22.07	23.20	35, 36 (20.4, 21.2°)	No particular observation
30	30	22.06	23.19	37, 38 (32.1, 33.1°)	No particular observation
40	40	22.04	23.17	39, 40 (41.8, 42.4°)	No particular observation

50	50	21.98	23.11	41, 42 (49.3, 50°)	No particular observation
60	60	22.00	23.12	43, 44 (59.7, 61°)	No particular observation
70	70.5	21.98	23.10	45, 46 (70°)	No particular observation

Table 1 : Temperature Range Tests Measurements.

10.1.1.1 Current

The current I_{MT01} and I_{MT02} provided by the HBs are represented in Figure 8.

Figure 8 : Graph of the current driven by the H-Bridges.

Firstly, the current is much lower than what was expected with theoretical simulations. It is explained by the neglected effects, the imprecision of components and the resistance of wires (which are in this test much longer than in the final version).

The second element to underline is that the current provided by the A3901 is always higher than by the Si9987. This is due to the internal HB rising time.

Finally, both currents do not change a lot in the temperature range from – 40° C to 70° C. The difference between maximum and minimum current is 0.12 mA for the two HBs. This value also corresponds to maximum and minimum temperatures. Therefore the current depends on the temperature, but its variations are very low. The test was successful for the Si9987 and for the A3901.

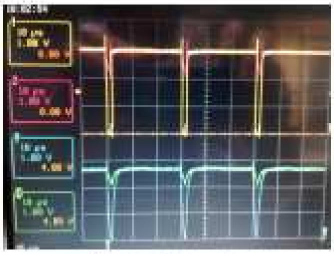
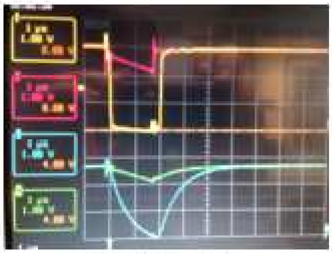
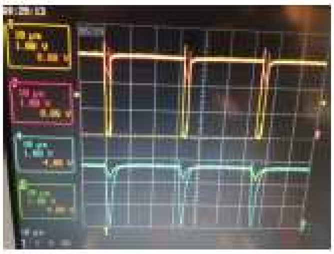
Table 2 summarizes the measurements from a statistical and thermal point of view.

	Current [mA]			Current [mA]		
	Min I	Average I	Max I	- 40 ° C	20 ° C	70 ° C
Si9987	21.98	22.05	22.10	22.10	22.07	21.98
A3901	23.10	23.18	23.22	23.21	23.20	23.10

Table 2 : Statistical Comparison of the Current Provided by H-Bridges.

10.1.1.2 PWM

All pictures taken during the test are available in Appendix A (page 19). Table 3 shows some of them for minimum, ambient and maximum temperatures (about – 40° C, 20° C and 70° C). The temperature indicated was measured exactly when the picture was taken.

Temp. [° C]	Picture	Temp. [° C]	Picture
-40.2°	 1 V / div & 10 µs / div	-40.2°	 1 V / div & 1 µs / div
21.2°	 1 V / div & 10 µs / div	20.4°	 1 V / div & 1 µs / div

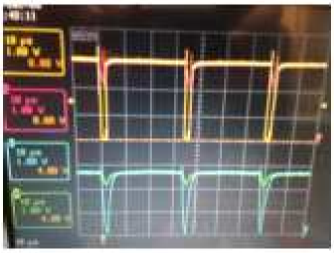
70°	 1 V / div & 10 µs / div	70°	 1 V / div & 2 µs / div
Legend	Yellow : Si9987 output voltage Red : A3901 output voltage Blue : Magnetotorquer voltage MT01 (powered by Si9987) Green : Magnetotorquer voltage MT02 (powered by A3901)		

Table 3 : Picture of the PWM Curve Measured During the Temperature Range Test.

These pictures show that there is no relevant change in the PWM curve in this range of temperatures.

Note that the PWM curves are very different for the Si9987 and the A3901's one. The Si9987 provides a nice PWM and its voltage passes through zero on every cycle. The A3901 provides a smoother signal and its voltage is never equal to zero. It is probably due to the kind of HB transistors and it is also the reason why the current average is always higher. A disadvantage of the A3901 is that the electric time constant is longer but it is still short (less than 10 µs).

11 CONCLUSIONS

The first two test objectives were:

- To verify if the Si9987 still works normally at a 3.3 V supply and in the temperature range from -30° to 60° C.
  - ➢ The Si9987 still works normally at a 3.3 V Supply and in a temperature range from -40° to 60° C.
- To verify if the A3901 works normally in a temperature range from -30° to 60° C.
  - ➢ The A3901 still works normally at a 3.3 V Supply and in a temperature range from -40° to 60° C.

The Si9987 passed the test with great success. It means that the Si9987 is able to drive the MTs with a 3.3 V power supply in the temperature range from - 30° to 60° C. Moreover its current range is $25\pm^{5}_{5}$ mA.

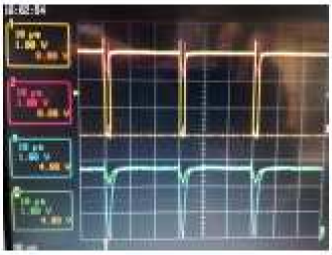
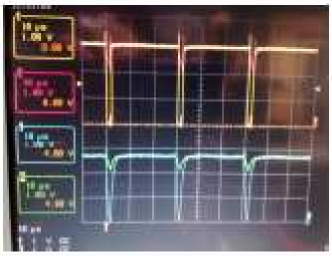
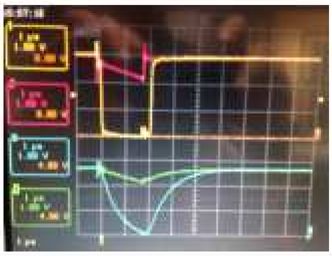
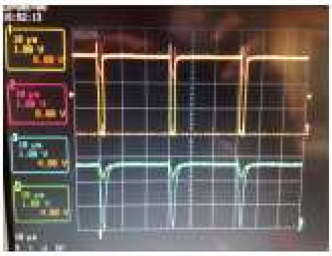
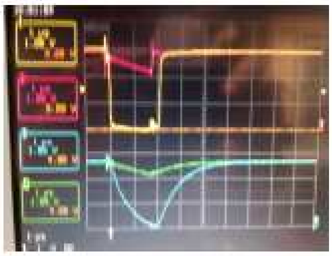
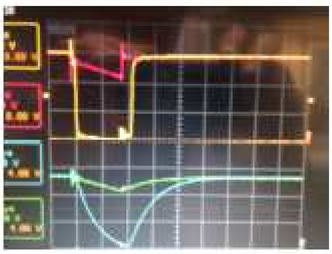
The A3901 passed the test with great success. It means that the Si9987 is able to drive the MTs with a 3.3 V power supply in the temperature range from - 30° to 60° C. Moreover its current range is $25\pm^{5}_{5}$ mA.

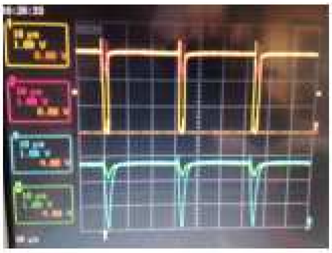
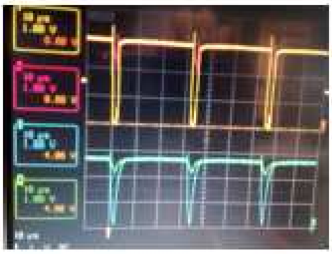
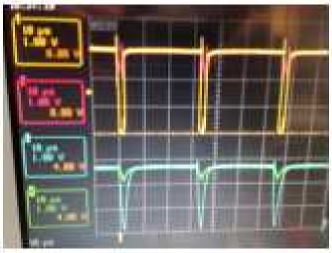
It is possible to satisfy the two requirements 4_ADCS_32_03 and 4_ADCS_43_01 concerning supply voltage and temperature range with both of these components.

The best component for this application is the A3901, because it provides a higher current with the same PWM rate. It is then recommended to choose the A3901 even if both of the HBs fit this application.

12 APPENDIX

Appendix A Pictures

Temperature [° C]	Picture	Temperature [° C]	Picture
-40.2°		-40.2°	
-32.5°		-33.3°	
-22.7°		-22°	
-11.5°		-13°	

3.4°		0.9°	
10°		11.9°	
21.2°		20.4°	
32.1°		33.1°	
42.4°		41.8°	

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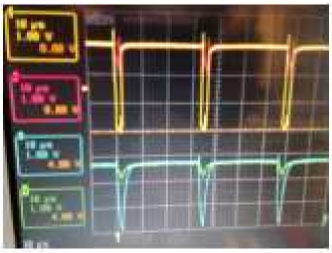
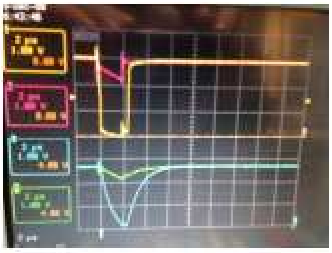
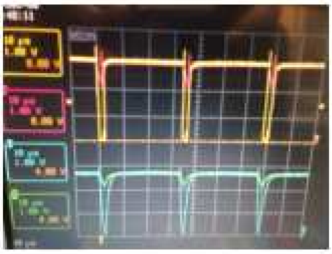
49.3°		50°	
61°		59.7°	
70°		70°	

Ref.: **S3_Phase_B-C_1-1_TempRange_Test_HB.doc**

(...)

Appendix C Simulation with MATLAB

C.1 Calculation of the Transfer Function

C.1.1 M-File "MT_TransFonct.m"

```
% MT_TransFonct.m
% Created by Laurent Hauser
% November 2007
% Modified by
%-------------------------------------------------------------------------

clear all, close all;

%Filter
RMT01=10
CMT06=1e-6
%Current Probe
RMT04=1
%MagnetoTorquers
Rmt=109.2
Lmt=29.4e-3

UinMax=3.3
w=2*pi*[0:1:5e5];

%Impedance
Zmt=Rmt+j*w*Lmt;
Zshunt=RMT04*w./w;
ZCft=1./(j*w*CMT06);
ZRft=RMT01*w./w;

%Filter function
F=ZCft./(ZRft+ZCft);                                        %U'/Uin
%Transfert fonction
H=(Zmt.*ZCft)./((ZRft.*ZCft)+((ZRft+ZCft).*(Zmt+Zshunt)));  %Umt/Uin
%Transconductance
G=H./Zmt;                                                   %Imt/Uin

%Cutoff frequency
Tconstant=(RMT01*CMT06)
Wcutoff=1/Tconstant;
Fcutoff=Wcutoff/(2*pi)

%Gain at 32.5kHz
GainF=20*log10(abs(F(32500)))
GainU=20*log10(abs(H(32500)))
GainI=20*log10(abs(G(32500)))

%figure
subplot(3,2,1);
semilogx(w/2/pi,20*log10(abs(F)));
xlabel('f [Hz]'); ylabel('H [dB]');
grid;
title('Bode: F=Uprime/Uin New');

%figure
subplot(3,2,3);
semilogx(w/2/pi,20*log10(abs(H)));
xlabel('f [Hz]'); ylabel('H [dB]');
grid;
```

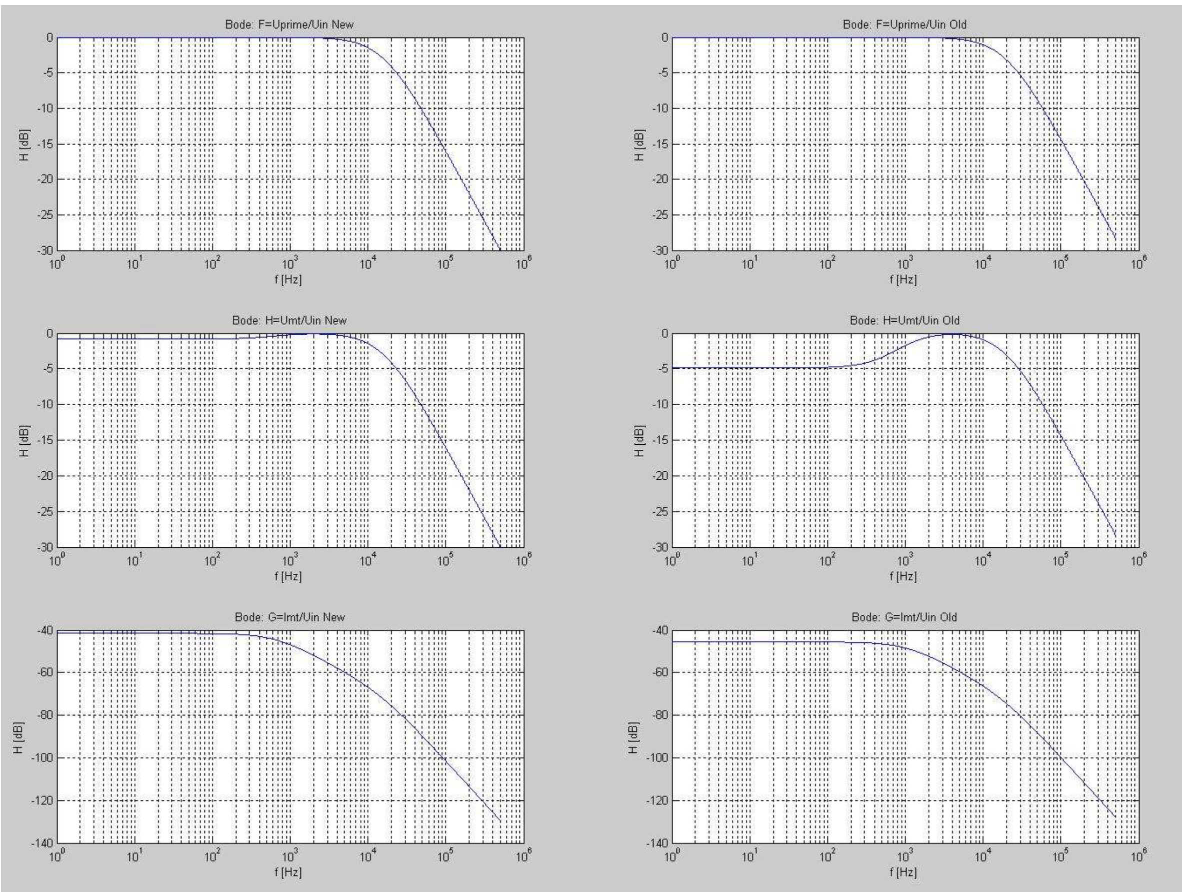
```
title('Bode: H=Umt/Uin New');

%figure
subplot(3,2,5);
semilogx(w/2/pi,20*log10(abs(G)));
xlabel('f [Hz]'); ylabel('H [dB]');
grid;
title('Bode: G=Imt/Uin New');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Filter
RMT01=82
CMT06=0.1e-6
%Current Probe
RMT04=0
%MagnetoTorquers
Rmt=109.2
Lmt=29.4e-3

UinMax=3.3
w=2*pi*[0:1:5e5];

%Impedance
Zmt=Rmt+j*w*Lmt;
Zshunt=RMT04*w./w;
ZCft=1./(j*w*CMT06);
ZRft=RMT01*w./w;

%Filter function
F=ZCft./(ZRft+ZCft);                                        %U'/Uin

%Transfert fonction
H=(Zmt.*ZCft)./((ZRft.*ZCft)+((ZRft+ZCft).*(Zmt+Zshunt)));  %Umt/Uin
%Transconductance
G=H./Zmt;                                                   %Imt/Uin

%Cutoff frequency
TconstantOld=(RMT01*CMT06)
WcutoffOld=1/TconstantOld;
FcutoffOld=WcutoffOld/(2*pi)

%Gain at 32.5kHz
GainFOld=20*log10(abs(F(32500)))
GainUOld=20*log10(abs(H(32500)))
GainIOld=20*log10(abs(G(32500)))

%figure
subplot(3,2,2);
semilogx(w/2/pi,20*log10(abs(F)));
xlabel('f [Hz]'); ylabel('H [dB]');
grid;
title('Bode: F=Uprime/Uin Old');

%figure
subplot(3,2,4);
semilogx(w/2/pi,20*log10(abs(H)));
xlabel('f [Hz]'); ylabel('H [dB]');
grid;
title('Bode: H=Umt/Uin Old');

%figure
subplot(3,2,6);
semilogx(w/2/pi,20*log10(abs(G)));
xlabel('f [Hz]'); ylabel('H [dB]');
```

```
grid;
title('Bode: G=Imt/Uin Old');
```

C.1.2 Result of "MT_TransFonct.m"

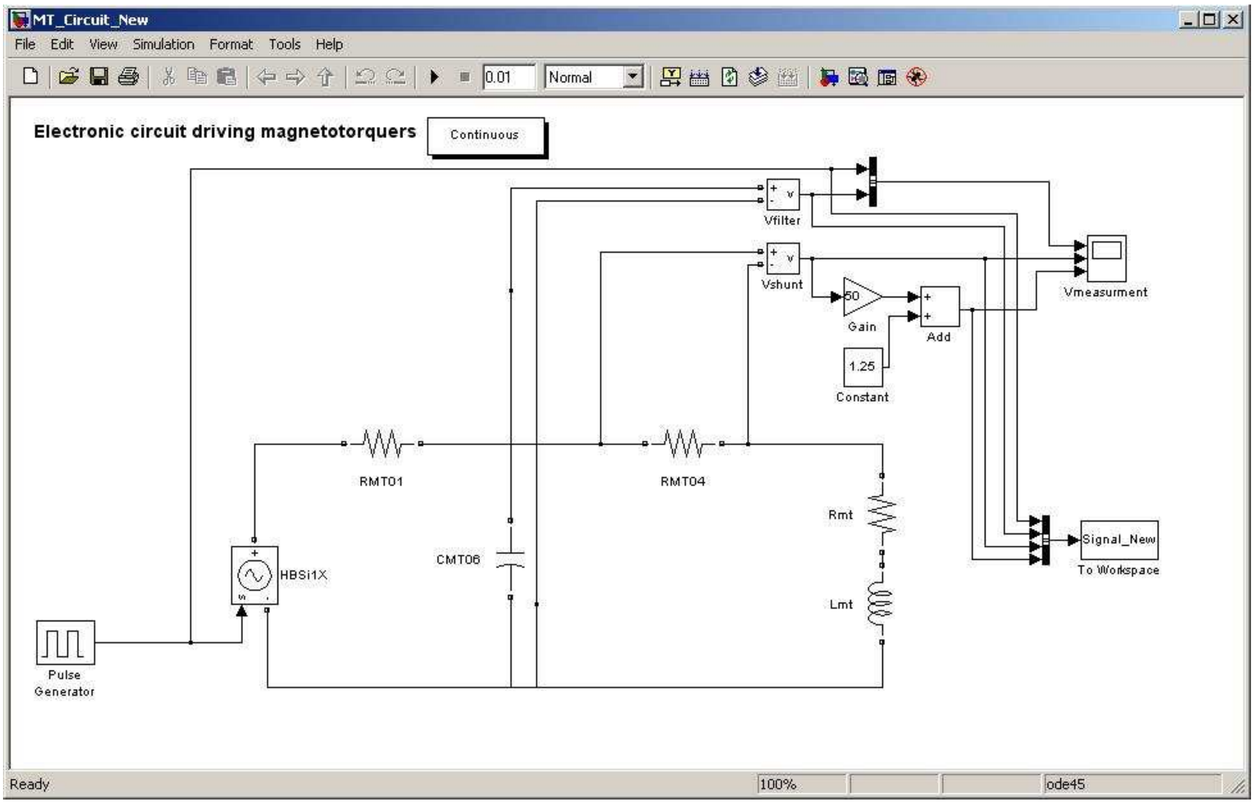
```
>> MT_TransFonct

RMT01 = 10
CMT06 = 1.0000e-006
RMT04 = 1
Rmt =  109.2000
Lmt =    0.0294
Fcutoff = 1.5915e+004
Tconstant = 1.0000e-005
GainF =   -7.1346
GainU =   -7.1290
GainI = -82.6984

RMT01 = 82
CMT06 = 1.0000e-007
RMT04 = 0
Rmt = 109.2000
Lmt = 0.0294
FcutoffOld = 1.9409e+004
TconstantOld = 8.2000e-006
GainFOld = -5.8020
GainUOld = -5.7503
GainIOld = -81.3197
```

C.1.3 Graph of "MT_TransFonct.m"



C.2 Simulink Model

C.2.1 Picture of the Model

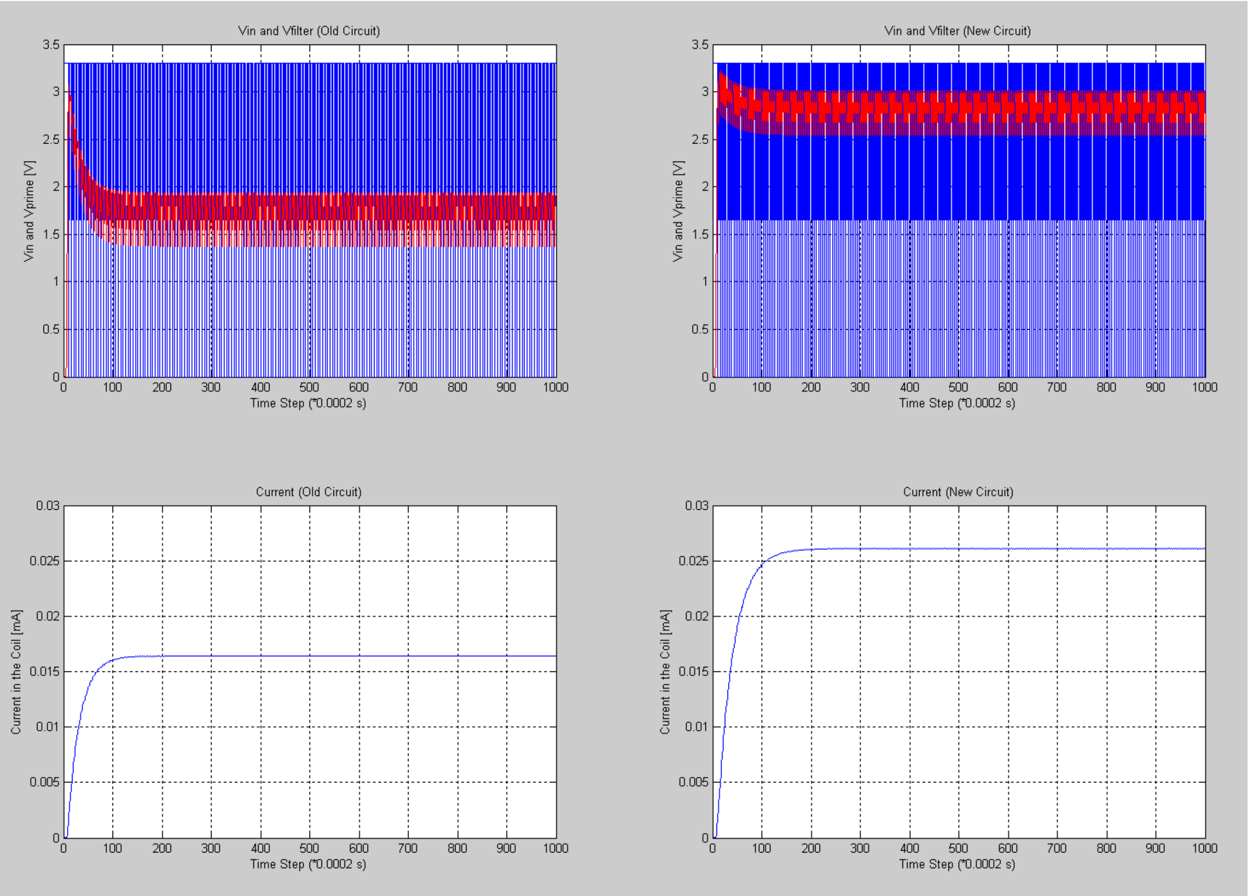


C.2.2 M-File "MT_FilterCompare_95PWM.m"

```
% MT_FilterCompare_95PWM.m
% Created by Laurent Hauser
% November 2007
% Modified by
%------------------------------------------------------------------------

clear all; close all;

load Signal_New_95PWM.mat;
load Signal_Old_95PWM.mat;

VinOld=Signal_Old(:,1);
VfilterOld=Signal_Old(:,2);
ImtOld=Signal_Old(:,3);

VinNew=Signal_New(:,1);
VfilterNew=Signal_New(:,2);
ImtNew=Signal_New(:,3);

subplot(2,2,1);
plot(VinOld(1:1000),'b');
hold;
plot(VfilterOld(1:1000),'r');
xlabel('Time Step (*0.0002 s)'); ylabel('Vin and Vprime [V]');
grid;
title('Vin and Vfilter (Old Circuit)');
```

```
subplot(2,2,3);
plot(ImtOld(1:1000),'b');
xlabel('Time Step (*0.0002 s)'); ylabel('Current in the Coil [mA]');
grid;
title('Current (Old Circuit)');

subplot(2,2,2);
plot(VinNew(1:1000),'b');
hold;
plot(VfilterNew(1:1000),'r');
xlabel('Time Step (*0.0002 s)'); ylabel('Vin and Vprime [V]');
grid;
title('Vin and Vfilter (New Circuit)');

subplot(2,2,4);
plot(ImtNew(1:1000),'b');
xlabel('Time Step (*0.0002 s)'); ylabel('Current in the Coil [mA]');
grid;
title('Current (New Circuit)');
```

C.2.3 Graph of "MT_FilterCompare_95PWM.m"



Appendix D Electronics

D.1 Design

D.1.1 Current Probe Design with INA170

Description	Unit		Value	Value	Comment
Power supply	**V**		3.3		
Electronic Circuit					
Current (max)	mA	+/-	25	25	
Shunt resistor	Ohm		10	10	
Shunt voltage (max)	V	+/-	0.25	0.25	env. 0.125
ADC Characteristics					
Supply voltage	V		3.3		
Min ADC input voltage	V		0		
Max ADC input voltage	V		2.5		
Current Probe INA170					
INA170 Gain	uA/V		1000	1000	
Reference Voltage	V		1.25	1.25	
Offset resistor	Ohm		5000	5000	
Output resistor	Ohm		5000	5000	
Voltage offset	V		1.25	1.25	
Current offset	mA		0.25	0.25	
Output voltage	V		1.25	1.25	
Output current	mA		0.5	0.5	
Total output voltage	V		2.5	2.5	
ADC Input Voltage	V		***2.5***	***2.5***	
Output Resistance (without ampli)					
ADC Input resitance	Ohm		2000		
Total resitance	Ohm		5000		
Reel output resistance	Ohm		3000		
Reference Voltage					
Power supply	V		3.3		
Output voltage	V		1.25		
Gain	V/V		0.37879		
Up resistor	Ohm		10000		
Down resistor	Ohm		6097.56		

D.1.2 Current Probe Design with MAX4072

(Electronic Calculation Table.xls)

Description	Unit		Dim Value	Final Value	Comment	
Physic Constant						
pi			3.1416	3.1416		
Bolzmann cst	J/K		1E-23	1E-23		
Supply Voltage	V		3.3	3.3		
Electronic Circuit						
Filter resistance	Ohm		10	10		
Filter capacity	uF		1	1		
Current	mA	+/-	25	25		
Shunt resistor	Ohm		1	1		
Shunt voltage	V	+/-	0.025	0.025	~=	0.075
ADC Characteristics						
Supply voltage	V		3.3	3.3		
Min input voltage	V		0	0		
Max input voltage	V		2.5	2.5		
Current Probe MAX4072						
Gain	V/V		50	50	50 or 100	
Reference Voltage	V		1.25	1.25		
Amplified Voltage	V		1.25	1.25		
ADC Input Voltage	V		2.5	2.5		
Ref. Voltage REF3212	V		1.25	1.25		
Noise						
Bande passante	Hz		19409	19409		
Temperature	°C		60	60	-30 à +60	
Temperature	K		333.15	333.15		
Current noise	mA		1E-07	1E-07		
Voltage noise	mV		0.0001	0.0001		
Voltage variation	mV		2E-05	2E-05		
Max Output Error	%		10	10		

D.1.3 Voltage Divisor Design

(Electronic Calculation Table.xls)

Voltage Divisor

Inputs

Voltage In	2.50	V
Voltage Out	1.25	V
Bias current	0.10	uA

Calculation

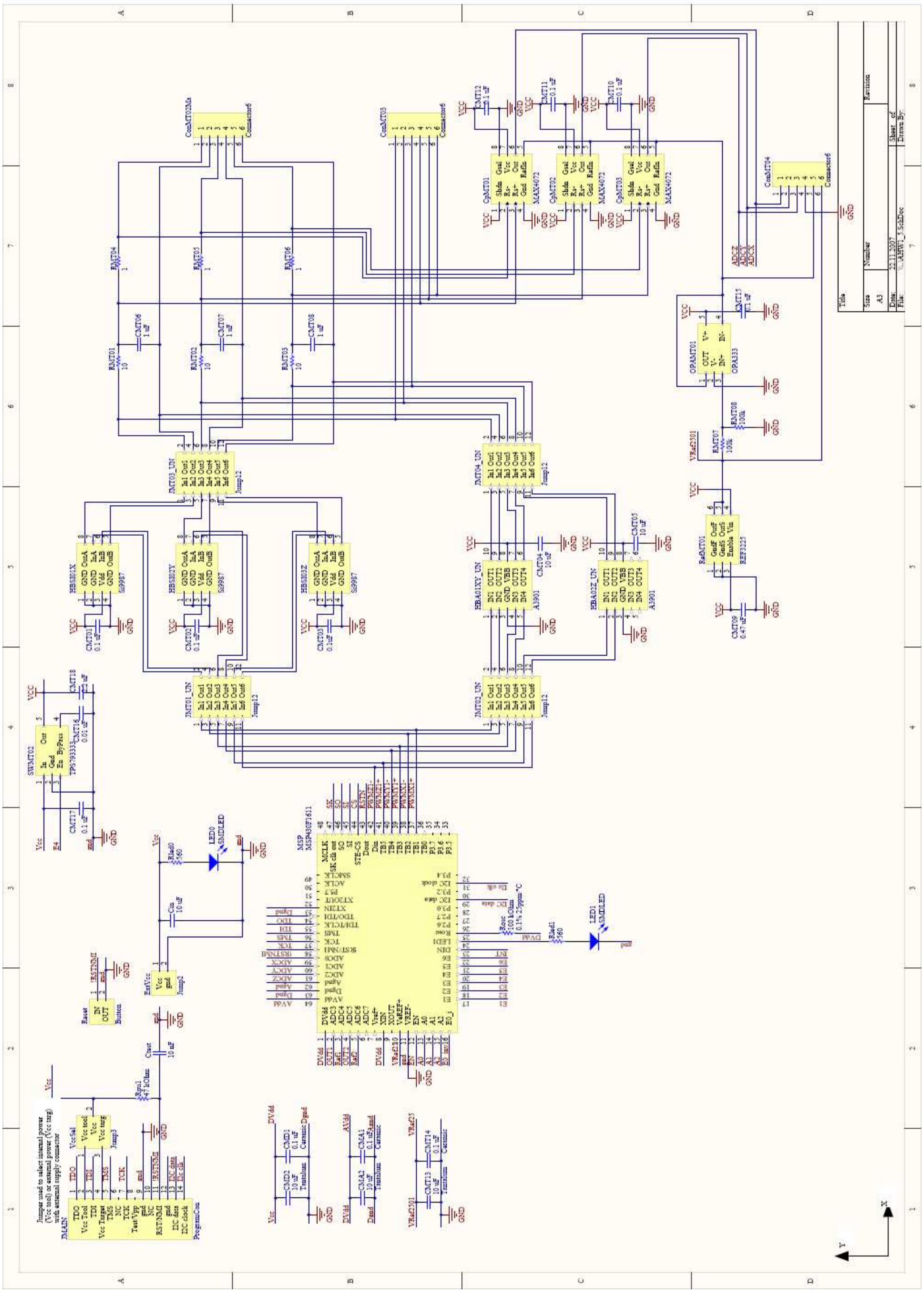
Gain	0.50	V
Current	0.01	mA
Total resistance	250000.00	Ohm
Down resitor	125000.00	Ohm
Up resitor	125000.00	Ohm
Total power	0.00	W

Output

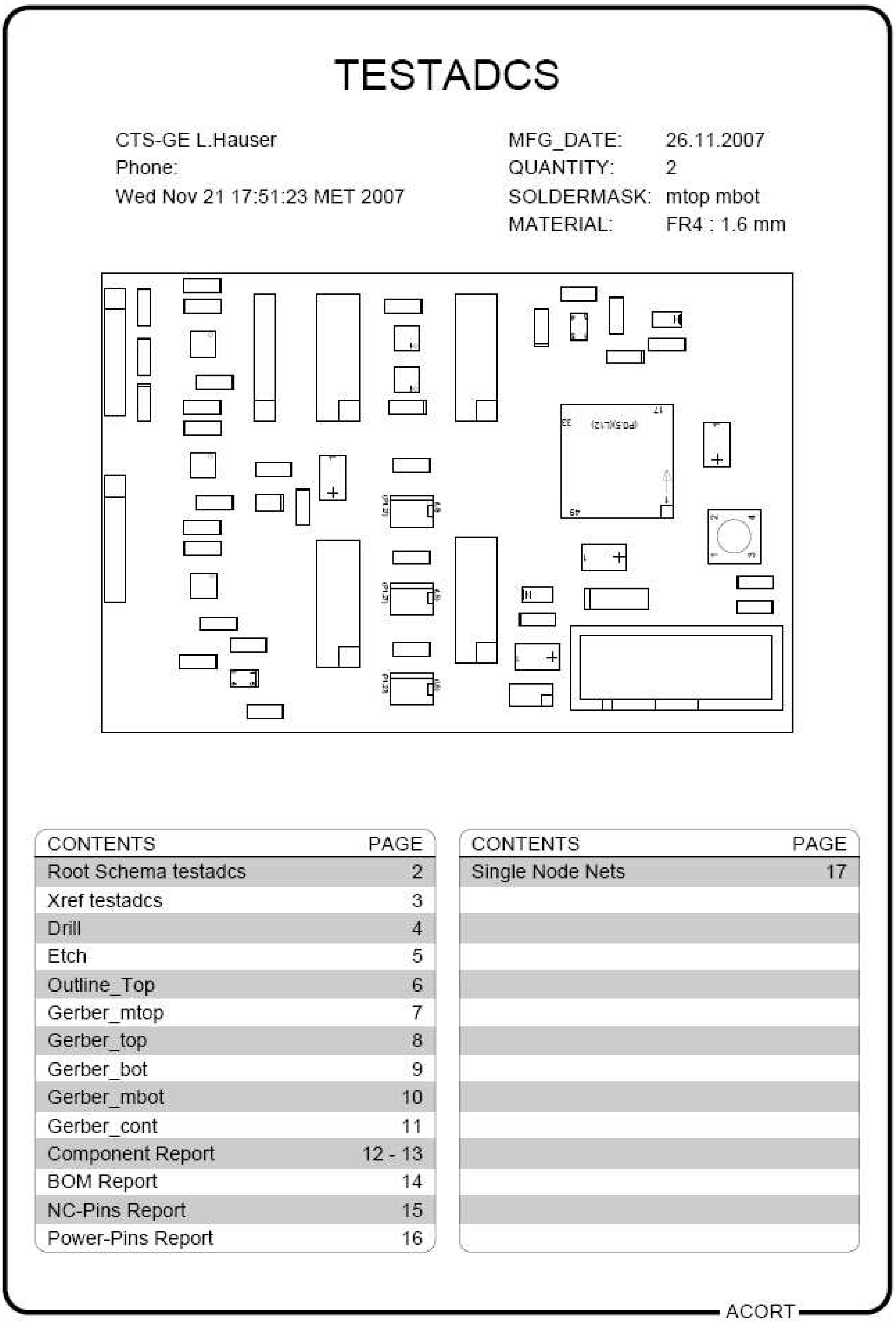
Up resistor	125000.00	Ohm
Down resistor	125000.00	Ohm
Current	0.01	mA
Total power	0.00	W

D.2 Test Board

D.2.1 Circuit



D.2.2 Footprint

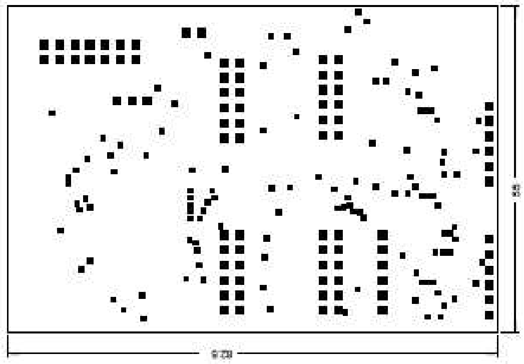


TESTADCS

CTS-GE L.Hauser
Phone:
Wed Nov 21 17:51:23 MET 2007

MFG_DATE: 26.11.2007
QUANTITY: 2
SOLDERMASK: mtop mbot
MATERIAL: FR4 : 1.6 mm

ACORT

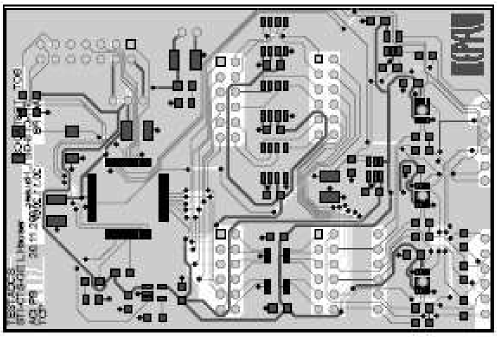


DRILL CHART			
FIGURE	SIZE	PLATED	QTY
■	0.401	PLATED	111
■	0.889	PLATED	85
■	1.1	PLATED	3

TITRE:TESTADCS	LABORATOIRE:STI-CTS-GE	DATE:20.11.2007
	ENGINEER:L.Hauser	EPFL-ACORT-PB

EPFL ACORT Wed 21.11.2007 17:51 Drawing name = TESTADCS Scale = 1.00 1.000 Inch =

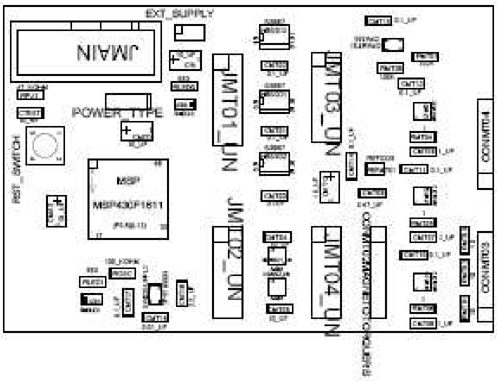
Page 4



TITRE:TESTADCS	LABORATOIRE:STI-CTS-GE	DATE:20.11.2007
	ENGINEER:L.Hauser	EPFL-ACORT-PB

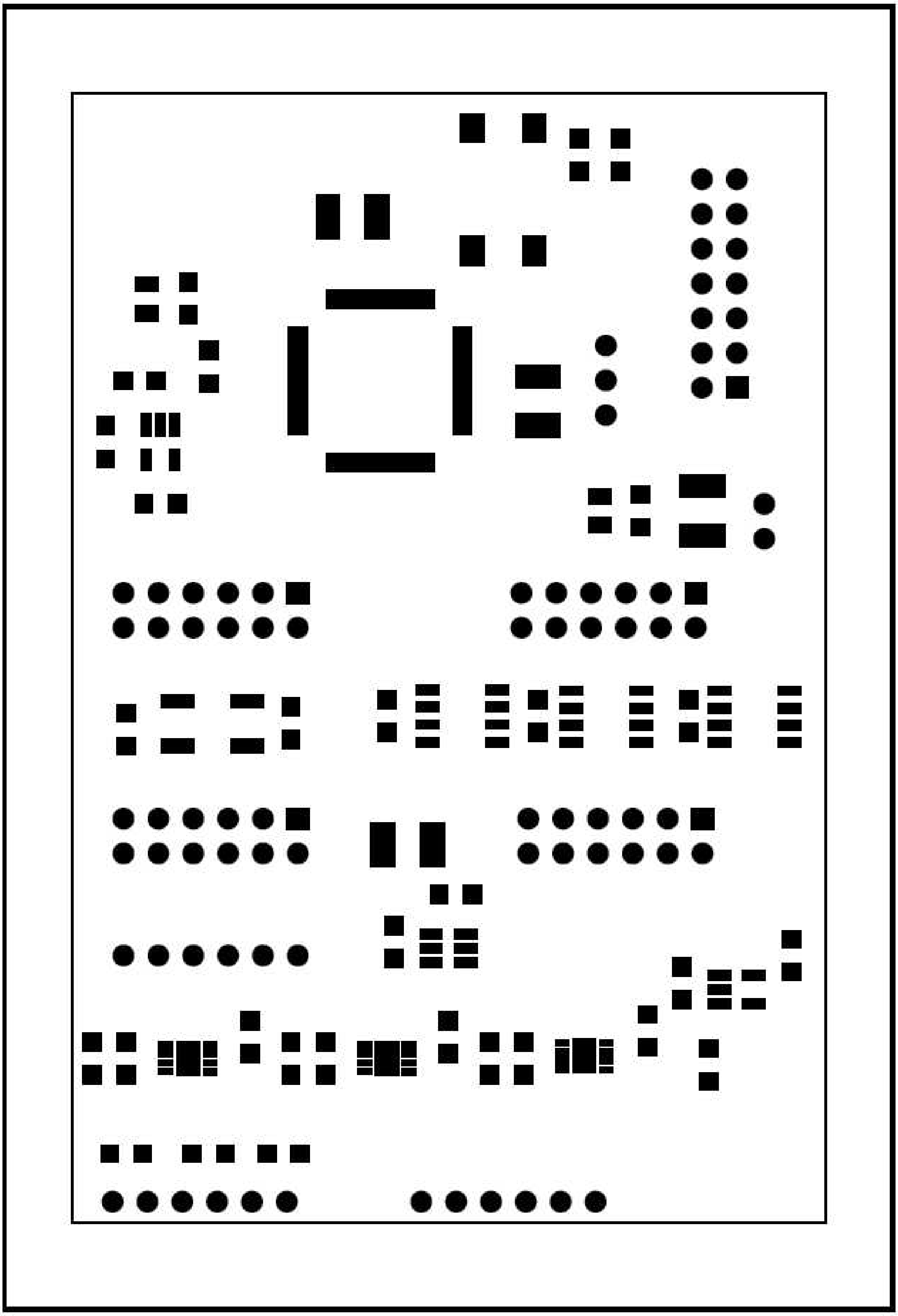
EPFL ACORT Wed 21.11.2007 17:51 Drawing name = TESTADCS Scale = 1.00 1.000 Inch =

Page 5

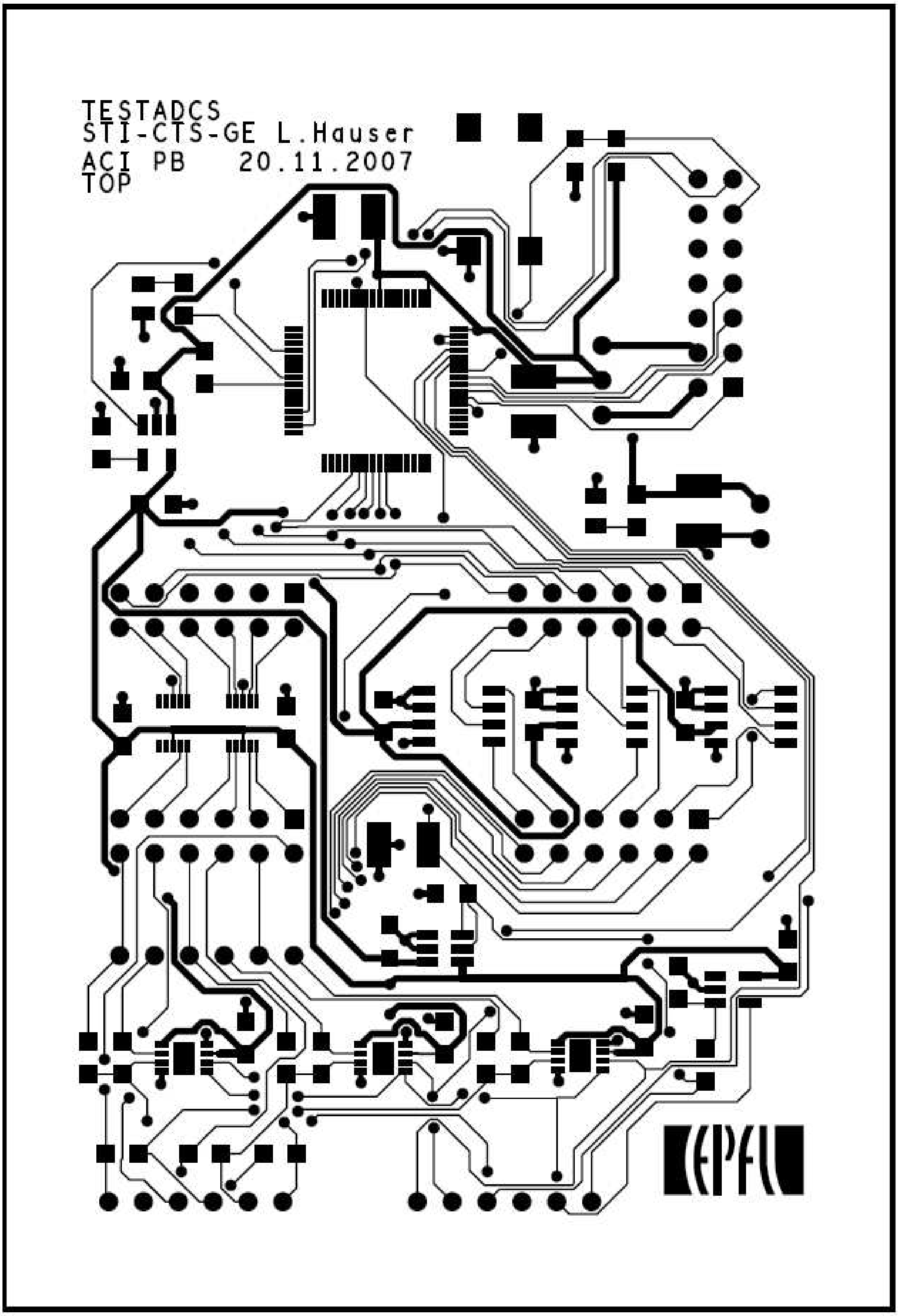


TITRE:TESTADCS	LABORATOIRE:STI-CTS-GE	DATE:20.11.2007
	ENGINEER:L.Hauser	EPFL-ACORT-PB

EPFL ACORT Wed 21.11.2007 17:51 Drawing name = TESTADCS Scale = 1.00 1.000 Inch = Page 6



EPFL ACORT Wed Nov 21 17:51:17 2007 Project = testados File = testados_gloss,mtop Scale = 2.8 0.357142857142857 cm =



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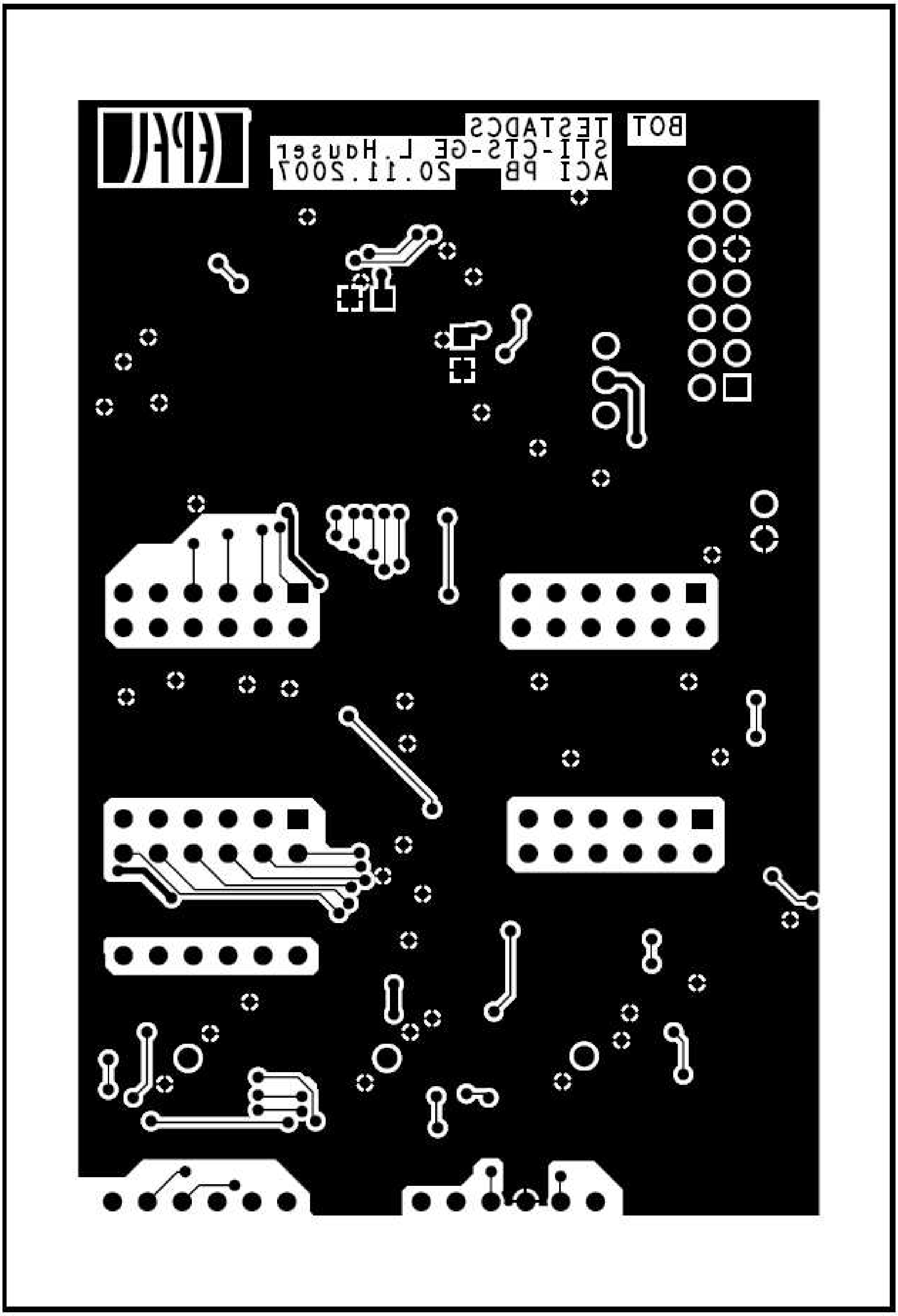

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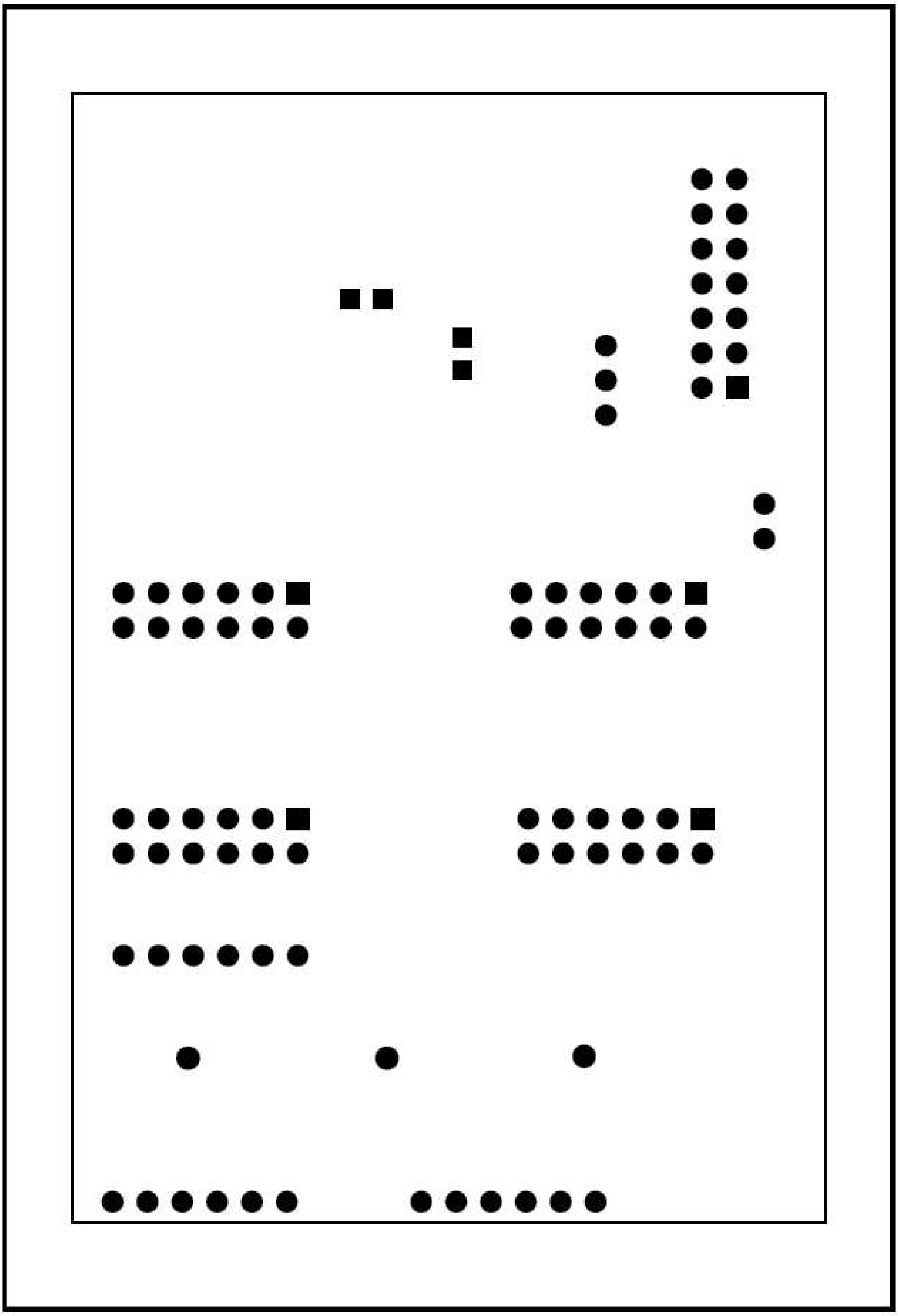

EPFL ACORT Wed Nov 21 17:51:17 2007 Project = testadcs File = testadcs_gloss,mbot Scale = 2.8 0.357142857142857 cm =

Component Report TESTADCS

testadcs_gloss Wed Nov 21 17:51:24 MET 2007

Ref Des	Device Type	Value	Package Type	x	y	ang	Mir	Remark
CIN	10UF	10_UF	CP_1412	58.000	11.500	180.000	NO	
CMA1	0_1UF	0.1_UF	0805	33.500	27.000	90.000	YES	
CMA2	10UF	10_UF	CP_1412	32.500	33.000	90.000	NO	
CMD1	0_1UF	0.1_UF	0805	40.500	23.000	180.000	YES	
CMD2	10UF	10_UF	CP_1412	46.000	19.500	180.000	NO	
CMT01	0_1UF	0.1_UF	0805	46.000	-3.500	0.000	NO	
CMT02	0_1UF	0.1_UF	0805	57.000	-3.500	0.000	NO	
CMT03	0_1UF	0.1UF	0805	35.000	-3.500	0.000	NO	
CMT04	10UF	10_UF	0805	28.000	-4.000	0.000	NO	
CMT05	10UF	10_UF	0805	16.000	-4.500	0.000	NO	
CMT06	1UF	1_UF	0805	42.500	-28.500	0.000	NO	
CMT07	1UF	1_UF	0805	28.000	-28.500	0.000	NO	
CMT08	1UF	1_UF	0805	13.500	-28.500	0.000	NO	
CMT09	0_47UF	0.47_UF	0805	35.500	-20.000	0.000	NO	
CMT10	0_1UF	0.1_UF	0805	25.000	-27.000	0.000	NO	
CMT11	0_1UF	0.1_UF	0805	39.500	-27.000	0.000	NO	
CMT12	0_1UF	0.1_UF	0805	54.000	-26.500	0.000	NO	
CMT13	10UF	10_UF	CP_1412	36.500	-12.900	90.000	NO	
CMT14	0_1UF	0.1_UF	0805	40.000	-16.500	90.000	NO	
CMT15	0_1UF	0.1_UF	0805	64.500	-21.000	0.000	NO	
CMT16	0_01UF	0.01_UF	0805	14.500	16.500	0.000	NO	
CMT17	0_1UF	0.1_UF	0805	17.000	21.000	90.000	NO	
CMT18	2_2UF	2.2_UF	0805	18.500	12.000	270.000	NO	
CONMT03	CONNECTOR6	CONNECTOR6	JUMP6	15.000	-39.000	0.000	NO	
CONMT04	CONNECTOR6	CONNECTOR6	JUMP6	37.500	-39.000	0.000	NO	
CONMT02MAGNETOTORQUERS	CONNECTOR6	CONNECTOR6	JUMP6	28.500	-21.000	180.000	NO	
CPMT01	MAX4072	MAX4072	TDFN3X3_8	49.380	-28.360	0.000	NO	
CPMT02	MAX4072	MAX4072	TDFN3X3_8	35.000	-28.500	0.000	NO	
CPMT03	MAX4072	MAX4072	TDFN3X3_8	20.500	-28.500	0.000	NO	
CTEST	10NF	10_NF	0805	49.000	37.500	180.000	NO	
EXT_SUPPLY	EXTERNAL_SUPP	EXTERNAL_SUPPLY	JUMP2	62.500	12.000	180.000	NO	
HBA01XY_UN	A3901	A3901	TDFN3X3_10	24.780	-4.040	270.000	NO	
HBA02Z_UN	A3901	A3901	TDFN3X3_10	19.700	-4.040	270.000	NO	
HBSI01X	SI9987	SI9987	SO8	61.800	-3.540	0.000	NO	
HBSI02Y	SI9987	SI9987	SO8	50.960	-3.540	0.000	NO	
HBSI03Z	SI9987	SI9987	SO8	40.500	-3.500	0.000	NO	
JMAIN	MAINCONNECTOR	MAIN_CONNECTOR	CPMD14	60.500	20.500	90.000	NO	
JMT01_UN	JUMP12	JUMP12	DIP12_1	57.500	5.500	180.000	NO	
JMT02_UN	JUMP12	JUMP12	DIP12_1	28.500	5.500	180.000	NO	
JMT03_UN	JUMP12	JUMP12	DIP12_1	58.000	-11.000	180.000	NO	
JMT04_UN	JUMP12	JUMP12	DIP12_1	28.500	-11.000	180.000	NO	
LED0	SMDLED	SMDLED	SMDLED	50.500	11.500	180.000	NO	
LED1	SMDLED	SMDLED	SMDLED	17.500	27.000	0.000	NO	
MSP	MSP430F1611	MSP430F1611	STQFP64	34.500	21.000	270.000	NO	
OPAMT01	OPA333	OPA333	SOT23_5	60.500	-23.500	0.000	NO	
POWER_TYPE	POWER_TYPE	POWER_TYPE	JUMP3	53.500	18.500	90.000	NO	
REFMT01	REF3225	REF3225	SOT23_6	39.500	-20.500	0.000	NO	
RLED0	560	560	0805	53.500	11.500	180.000	NO	
RLED1	560	560	0805	20.500	27.000	0.000	NO	
RMT01	10	10	0805	16.000	-35.500	90.000	NO	
RMT02	10	10	0805	22.000	-35.500	90.000	NO	
RMT03	10	10	0805	27.500	-35.500	90.000	NO	
RMT04	1	1	0805	45.000	-28.500	180.000	NO	
RMT05	1	1	0805	30.500	-28.500	180.000	NO	
RMT06	1	1	0805	16.000	-28.500	180.000	NO	
RMT07	100K	100K	0805	58.500	-29.000	0.000	NO	
RMT08	100K	100K	0805	56.500	-23.000	0.000	NO	
ROSC	100KOHM	100_KOHM	0805	22.000	22.000	0.000	NO	

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Component Report TESTADCS

testadcs_gloss Wed Nov 21 17:51:24 MET 2007

Ref Des	Device Type	Value	Package Type	x	y	ang	Mir	Remark
RPU1	47KOHM	47_KOHM	0805	52.000	37.500	0.000	NO	
RST_SWITCH	RST	RST	POUSMD3	43.500	35.000	180.000	NO	
SW02SUPPLY	TPS793333	TPS793333	SOT23_5	18.500	16.500	270.000	NO	

Total Component count 61

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(...)

D.2.3 Component List

Nbre		Name	Value	Footprint	Package
Prog Connector					
	1	Connector JMAIN		CPMD14	
	1	Jumper 3pin		JUMP3	
	1	Resistor	47k	805	
	1	Capacitor	10n	805	
Supply led block					
	1	Led		SMDLED	
	1	Resistor	560	805	
	1	Capacitor	10u	CP_1412	
	1	Jumper 2pin		JUMP2	
MSP block					
	1	Reset Button		POUSMD3	
	3	Capacitor Tantalum	10u	CP_1412	
	3	Capacitor Ceramic	0.1u	805	
	1	MSP430F1611		S-PQFP_G64	
	1	Resistor	100k, 0.1%, 25ppm/°	805	
	1	Led		SMDLED	
	1	Resistor	560	805	
LDO block					
	1	TPS793333		SOT23_5	
	1	Capacitor	0.1u	805	
	1	Capacitor	0.01u	805	
	1	Capacitor	2.2 u	805	
H-Bridges					
	4	Jumper 12pin		DIP12_1	
	3	Capacitor	0.1u	805	
	3	Si9987		SO8	
	2	Capacitor	10u	805	
	2	A3901		TDFN3X3_10	
Magnetotorquers circuits					
	3	Resistor	10	805	
	3	Capacitor	1u	805	
	3	Resistor	1, 1%, 100ppm/°	805	
	1	Connector 6pin		JUMP6	
	2	Connector 6pin		JUMP6	
Current probe block					
	3	MAX4072		QFN3X3_8	
	3	Capacitor	0.1u	805	
Reference voltage					
	1	REF3225		SOT23_6	
	1	Capacitor	0.47u	805	
	2	Resistor	100k, 0.1%, 25ppm/°	805	
	1	OPA333		SOT23_5	
	1	Capacitor	0.1u	805	

D.3 Components

D.3.1 H-Bridge Si9987

VISHAY

Si9987
Vishay Siliconix

Buffered H-Bridge

FEATURES

- 1.0-A H-Bridge
- 500-kHz Switching Rate
- Shoot-Through Limited
- TTL Compatible Inputs
- 3.8- to 13.2-V Operating Range
- Surface Mount Packaging

APPLICATIONS

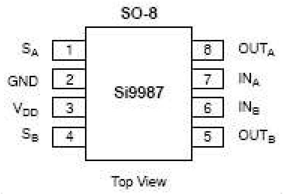
- VCM Driver
- Brushed Motor Driver
- Stepper Motor Driver
- Power Converter
- Optical Disk Drives
- Power Supplies
- High Performance Servo

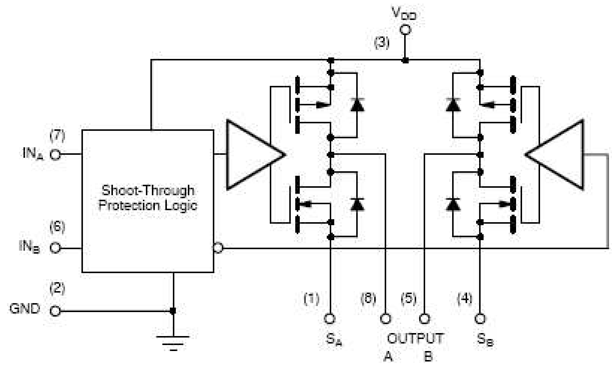
DESCRIPTION

The Si9987 is an integrated, buffered H-bridge with TTL compatible inputs and the capability of delivering a continuous 1.0 A @ V_{DD} = 5.0 V (room temperature) at switching rates up to 500 kHz. Internal logic prevents the upper and lower outputs of either half-bridge from being turned on simultaneously. Unique input codes allow both outputs to be forced low (for braking) or forced to a high impedance level.

The Si9987 is available in an 8-Pin SOIC package, specified to operate over a voltage range of 3.8 V to 13.2 V, and the commercial temperature range of 0 to 70°C (C suffix) and −40 to 85°C (D suffix). The Si9987 is available in lead free.

FUNCTIONAL BLOCK DIAGRAM, PIN CONFIGURATION AND TRUTH TABLE





TRUTH TABLE

IN_A	IN_B	OUT_A	OUT_B
1	0	1	0
0	1	0	1
0	0	0	0
1	1	HiZ	HiZ

ORDERING INFORMATION

Part Number	Temperature Range	Package
Si9987CY-T1	0 to 70°C	Tape and Reel
Si9987DY-T1	−40 to 85°C	
Si9987CY-T1—E3	0 to 70°C	Lead Free Tape and Reel
Si9987DY-T1—E3	−40 to 85°C	
Si9987CY	0 to 70°C	Bulk (tubes)
Si9987DY	−40 to 85°C	

Si9987

Vishay Siliconix

VISHAY

ABSOLUTE MAXIMUM RATINGS[a]

Voltage on any pin with respect to ground . . . . –0.3 V to V_{DD} +0.3 V
Voltage on pins 5, 8 with respect to GND . . . . –1 V to V_{DD} +1 V
Voltage on pins 1, 4 . . . . –0.3 V to GND +1 V
Maximum V_{DD} . . . . 15 V
Peak Output Current . . . . 1.5 A
Storage Temperature . . . . –65 to 150°C
Maximum Junction Temperature (T_J) . . . . 150°C
Power Dissipation[b] . . . . 1 W
θ_{JA} . . . . 100°C/W

Continuous I_{OUT} Current (T_J = 135°C)[c]
T_A = 25°C . . . . ± 1.02 A
T_A = 70°C . . . . ± 0.75 A
T_A = 85°C . . . . ± 0.65 A
Operating Temperature Range
Si9987CY . . . . 0 to 70°C
Si9987DY . . . . –40 to 85°C

Notes
a. Device mounted with all leads soldered or welded to PC board.
b. Derate 10 mW/°C above 25°C.
c. $T_J = T_A + (P_D \times \theta_{JA})$. P_D = Power Dissipation .

RECOMMENDED OPERATING RANGE

V_{DD} . . . . 3.8 V to 13.2 V
Maximum Junction Temperature (T_J) . . . . 135°C

SPECIFICATIONS

Parameter	Symbol	Test Conditions Unless Specified V_{DD} = 3.8 to 13.2 V, S_A @ GND, S_B @ GND		Limits Min[a]	Typ[b]	Max[a]	Unit
Input							
Input Voltage High	V_{INH}			2			V
Input Voltage Low	V_{INL}					1	V
Input Current with Input Voltage High	I_{INH}	V_{IN} = 2 V				1	µA
Input Current with Input Voltage Low	I_{INL}	V_{IN} = 0 V		–1			µA
Output							
Output Voltage High[c]	V_{OUTH}	I_{OUT} = –1 A	V_{DD} = 10.8 V	10.40	10.56		V
			V_{DD} = 4.5 V	4.00	4.20		
		I_{OUT} = –500 mA	V_{DD} = 10.8 V	10.60	10.68		
			V_{DD} = 4.5 V	4.25	4.35		
		I_{OUT} = –300 mA, V_{DD} = 3.8 V		3.63	3.70		
Output Voltage Low[c]	V_{OUTL}	I_{OUT} = 1 A	V_{DD} = 10.8 V		0.24	0.40	
			V_{DD} = 4.5 V		0.30	0.50	
		I_{OUT} = 500 mA	V_{DD} = 10.8 V		0.12	0.20	
			V_{DD} = 4.5 V		0.15	0.25	
		I_{OUT} = 300 mA, V_{DD} = 3.8 V			0.10	0.17	
Output Leakage Current Low	I_{OLL}	$IN_A = IN_B \geq$ 2 V, $V_{OUT} = V_{DD}$ = 13.2 V			0	10	µA
Output Leakage Current High	I_{OLH}	V_{OUT} = 0, V_{DD} = 13.2 V		–10	0		µA
Output V Clamp High	V_{CLH}	$IN_A = IN_B \geq$ 2 V	I_{OUT} = 100 mA		V_{DD} +0.7	V_{DD} +0.9	V
Output V Clamp Low	V_{CLL}		I_{OUT} = –100 mA	–0.9	–0.7		V
Supply							
V_{DD} Supply Current	I_{DD}	IN = 100 kHz, V_{DD} = 5.5 V			1.8	2.5	mA
		$IN_A = IN_B$ = 4.5 V, V_{DD} = 5.5 V			75	125	µA
Dynamic							
Propogation Delay Time	T_{PLH}	V_{DD} = 5 V			300		nS
	T_{PHL}				100		

Notes
a. The algebraic convention whereby the most negative value is a minimum and the most positive a maximum, is used in this data sheet.
b. Typical values are for DESIGN AID ONLY, not guaranteed nor subject to production testing.
c. Maximum value measured at T_J = 135°C. Typical value measured at $T_J = T_A$ = 25°C (pulse width ≤ 300 µsec, duty cycle ≤ 2%).

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2

Document Number: 70864
S-40132—Rev. D, 16-Feb-04

(…)

D.3.2 H-Bridge A3901

Allegro MicroSystems, Inc.

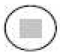
A3901

Dual Full Bridge Low Voltage Motor Driver

Features and Benefits

- Low $R_{DS(on)}$ outputs
- Full- and half-stepping capability
- Small package
- Forward, reverse, and brake modes for dc motors
- Sleep mode with zero current drain
- PWM control up to 250 kHz
- Crossover-current protection
- Thermal shutdown (TSD)

Package: 10 Contact DFN (suffix EJ)



Approximate Scale 1:1

Description

The A3901 is a dual full-bridge motor driver, designed for low voltage portable applications involving bipolar stepper or brush dc motors. The outputs have been optimized for low voltage drop, with currents up to ±400 mA (±800 mA with outputs paralleled) and an operating voltage range of 2.5 to 5.5 V.

The four inputs (IN1 to IN4) can control a bipolar stepper motor in full- or half-step mode, or dc motors in forward, reverse, or brake mode. The inputs can be PWMed for current or speed control at frequencies up to 250 kHz.

Internal protection circuitry includes thermal shut down (TSD) and crossover (shoot-through) protection.

The A3901 is supplied in a 3 x 3 x 0.75 mm nominal, 10-lead DFN package, with exposed thermal pad (package "EJ"). This small footprint package is lead (Pb) free, with 100% matte tin leadframe plating.

Typical Application

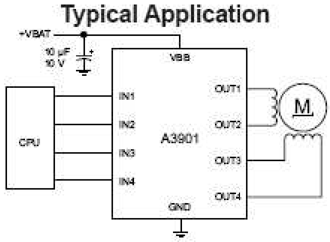


Figure 1. Typical stepper motor control

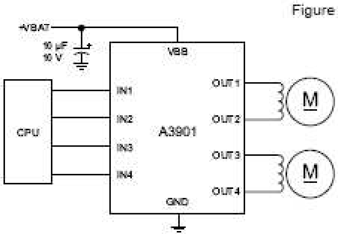


Figure 2. Typical dual dc motor control

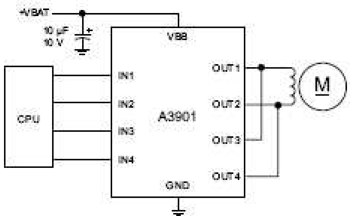


Figure 3. Typical single dc motor control (paralleled outputs)

3901-DS, Rev. 2

A3901 *Dual Full Bridge Low Voltage Motor Driver*

Selection Guide

Part Number	Packing
A3901SEJTR-T	Tape and reel, 1500 pieces/reel

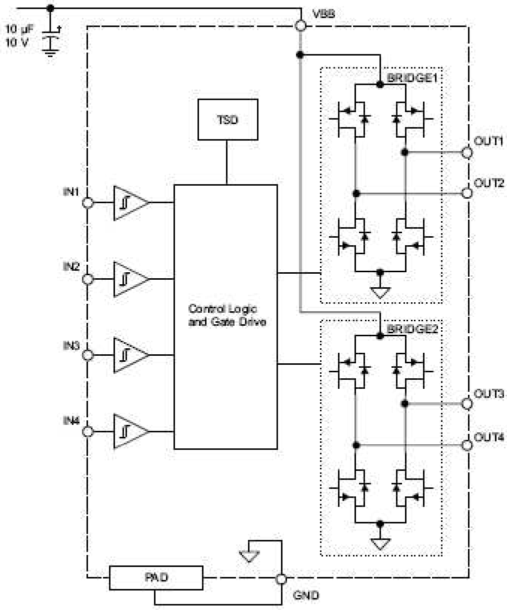
Absolute Maximum Ratings

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Load Supply Voltage	V_{BB}		–	–	7	V
Output Current per Channel*	I_{OUT}		–	–	400	mA
Logic Input Voltage Range	V_{IN}		–0.3	–	6	V
Junction Temperature	T_J		–	–	150	°C
Storage Temperature Range	T_S		–40	–	150	°C
Operating Temperature Range	T_A		–20	–	85	°C

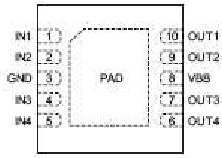
*Output current rating may be limited by duty cycle, ambient temperature, and heat sinking. Under any set of conditions, do not exceed the specified current rating or a junction temperature of 150°C.

A3901 *Dual Full Bridge Low Voltage Motor Driver*

Functional Block Diagram



Terminal Diagram



Number	Name	Description
1	IN1	Logic input 1
2	IN2	Logic input 2
3	GND	Ground terminal
4	IN3	Logic input 3
5	IN4	Logic input 4
6	OUT4	Bridge2 output to load
7	OUT3	Bridge2 output to load
8	VBB	Load supply terminal
9	OUT2	Bridge1 output to load
10	OUT1	Bridge1 output to load
–	Pad	Exposed pad for thermal dissipation; connect to GND externally

A3901 *Dual Full Bridge Low Voltage Motor Driver*

ELECTRICAL CHARACTERISTICS at T_A=25°C, and V_{BB} = 2.5 to 5.5 V, unless noted otherwise

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Output On Resistance	$R_{DS(on)}$	Source driver, V_{BB} = 3 V, I_{OUT} = 300 mA	–	1.8	2.1	Ω
		Source driver, V_{BB} = 5 V, I_{OUT} = 300 mA	–	1.2	1.4	Ω
		Sink driver, V_{BB} = 3 V, I_{OUT} = 300 mA	–	1.2	1.4	Ω
		Sink driver, V_{BB} = 5 V, I_{OUT} = 300 mA	–	0.8	1.0	Ω
Clamp Diode		I = 300 mA	–	–	1.5	V
Motor Supply Current	I_{BB}	All outputs PWMed at 20 kHz	–	0.6	–	mA
		Sleep mode, V_{BB}= 3 V	–	–	100	nA
		Sleep mode, V_{BB}= 5 V	–	<50	500	nA
Logic Input Voltage	$V_{IN(1)}$		$V_{BB}/2$	–	–	V
	$V_{IN(0)}$		–	–	0.5	V
Logic Input Current	$I_{IN(1)}$	V_{IN} = 2.0 V	–	<100	500	nA
	$I_{IN(0)}$	V_{IN} = 0.5 V	–	<–100	–500	nA
Input Voltage Hysteresis	V_{hys}		–	150	–	mV
Propagation Delay	$t_{pd(on)}$	Input Low to Sink On, Input High to Source On	–	130	–	ns
	$t_{pd(off)}$	Input High to Sink Off, Input Low to Source Off	–	50	–	ns
Crossover Delay	t_{COD}		–	80	–	ns
Thermal Shut Down Temperature	T_J		–	150	–	°C
Thermal Shut Down Hysteresis	T_{Jhys}		–	10	–	°C

THERMAL CHARACTERISTICS				
Characteristics	Symbol	Test Conditions	Rating	Unit
Package Thermal Resistance*	$R_{\theta JA}$	Measured on 4-layer board based on JEDEC standard	45	°C/W
		Measured on 2-layer board with copper limited to solder pads and 0.88 in². of copper on each side	65	°C/W

*Additional thermal information is available on the Allegro Web site.

Allegro MicroSystems, Inc.
115 Northeast Cutoff, Box 15036
Worcester, Massachusetts 01615-0036 (508) 853-5000
www.allegromicro.com

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D.3.3 Current Probe MAX4072

19-2423; Rev 2; 1/03

MAXIM

Bidirectional, High-Side, Current-Sense Amplifiers with Reference

MAX4069–MAX4072

General Description

The MAX4069–MAX4072 low-cost, bidirectional, high-side, current-sense amplifiers are ideal for monitoring battery charge and discharge currents in notebooks, cell phones, and other portable equipment. They feature up to 24V input common-mode voltage range, low 100µA supply current (which drops to only 10µA in shutdown), and a total output error of less than 1.5%. The wide 1.35V to 24V input common-mode range is independent of the supply voltage, ensuring that the current-sense feedback remains accurate even when connected to a battery pack in deep discharge.

To achieve maximum flexibility, an external current-sense resistor is used along with a Gain Select pin to choose either 50V/V or 100V/V. A single output pin continuously monitors the transition from charge to discharge and avoids the need for a separate polarity output. The MAX4070 contains an internal 2.5V reference. The charging current is represented by an output voltage from 2.5V to V_{CC}, while discharge current is given from 2.5V to GND. The MAX4071 is similar, but with a reference voltage of 1.5V. The MAX4069 has an adjustable reference voltage, set by two external resistors. The MAX4072 has an input for an external reference.

The MAX4069/MAX4071/MAX4072 operate from a 2.7V to 24V single supply. The MAX4070 operates from a 3.6V to 24V single supply. All devices are specified over the automotive operating temperature range, -40°C to +125°C. The MAX4070/MAX4071/MAX4072 are available in 8-pin µMAX and 8-pin thin QFN packages. The MAX4069 is available in a 10-pin µMAX package.

Applications

- Notebook Fuel Gauging
- Smart-Battery Packs/Chargers
- Motor Control
- Power-Management Systems
- Cell-Phone Battery-Current Monitoring

Selector Guide

PART	REFERENCE	SUPPLY VOLTAGE RANGE (V)	COMMON-MODE RANGE (V)
MAX4069	ADJUSTABLE	2.7 to 24	1.35 to 24
MAX4070	2.5V	3.6 to 24	1.35 to 24
MAX4071	1.5V	2.7 to 24	1.35 to 24
MAX4072	EXTERNAL	2.7 to 24	1.35 to 24

Pin Configurations appear at end of data sheet.

Features

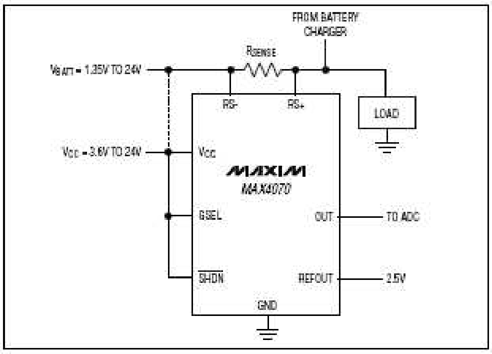
- ♦ Bidirectional, Compact, Current-Sense Solution
- ♦ Total Output Error Less than 1.5%
- ♦ Selectable Gain of 50V/V or 100V/V
- ♦ Wide 1.35V to 24V Common-Mode Range Independent of Supply Voltage
- ♦ 2.7V to 24V Single-Supply Operation
- ♦ Internal Precision Reference
  - Adjustable (MAX4069)
  - 2.50V (MAX4070)
  - 1.50V (MAX4071)
- ♦ Low 100µA Supply Current
- ♦ 10µA Supply Current in Shutdown
- ♦ Available in Space-Saving Packages
  - 8-Pin Thin QFN (MAX4070/MAX4071/MAX4072)
  - 8-Pin µMAX (MAX4070/MAX4071MAX4072)
  - 10-Pin µMAX (MAX4069)

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4069AUB	-40°C to +125°C	10 µMAX	—
MAX4070AUA	-40°C to +125°C	8 µMAX	—
MAX4070ATA	-40°C to +125°C	8 Thin QFN-EP*	ABN
MAX4071AUA	-40°C to +125°C	8 µMAX	—
MAX4071ATA	-40°C to +125°C	8 Thin QFN-EP*	ABO
MAX4072AUA	-40°C to +125°C	8 µMAX	—
MAX4072ATA	-40°C to +125°C	8 Thin QFN-EP*	ABP

*EP = Exposed paddle.

Typical Operating Circuit



For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

Bidirectional, High-Side, Current-Sense Amplifiers with Reference

MAX4069–MAX4072

ABSOLUTE MAXIMUM RATINGS

V_{CC}, RS+, RS- to GND ....-0.3V to +26V
OUT to GND ....-0.3V to Lesser of (V_{CC} + 0.3V) or 15V
Differential Input Voltage (V_{RS+} - V_{RS-}) ....±0.3V
GSEL, $\overline{SHDN}$, REFOUT, REFIN
and ADJ to GND....................................-0.3V to (V_{CC} + 0.3V)
OUT Short-Circuit Duration to GND
or to Lesser of (V_{CC} or 15V) ....Continuous
REFOUT Short Circuit to V_{CC} or GND.......................Continuous
Current into Any Pin ....±20mA

Continuous Power Dissipation (T_A = +70°C)
8-Pin μMAX (derate 4.5 mW/°C above +70°C) 362mW
8-Pin Thin QFN (derate 24.4mW/°C above +70°C) ...1951mW
10-Pin μMAX (derate 5.6 mW/°C above +70°C) 444.4mW
Operating Temperature Range ....-40°C to +125°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{RS+} = V_{RS-} = V_{CC} = 2.7V to 24V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, I_{REFOUT} = 0, $V_{\overline{SHDN}}$ = V_{CC}, V_{GSEL} = GND, V_{REFIN} = 2.5V (MAX4072), T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C and at V_{CC} = V_{RS+} = 12V.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Voltage Range (Note 3)	V_{CC}	MAX4069/MAX4071/MAX4072 (Note 4)		2.7		24	V
		MAX4070		3.6		24	
Input-Referred Offset Voltage (Note 5)	V_{OS}	V_{CC} = V_{RS+} = V_{RS-} = 12V	T_A = +25°C		0.08	0.25	mV
			T_A = -40°C to +85°C			0.8	
			T_A = T_{MIN} to T_{MAX}			1	
Common-Mode Input Range	CMVR	Guaranteed by CMRR test		1.35		24	V
Common-Mode Rejection Ratio	CMRR	1.35V ≤ V_{RS+} = V_{RS-} ≤ 24V, V_{CC} = 12V		100	120		dB
Supply Current	I_{CC}	V_{CC} = V_{RS+} = V_{RS-} = 24V, R_L = open, T_A = T_{MIN} to T_{MAX}			100	250	μA
Shutdown Supply Current	$I_{CC\ \overline{SHDN}}$	V_{CC} = V_{RS+} = V_{RS-} = 5.5V, $\overline{SHDN}$ = GND, T_A = +25°C			9		μA
		V_{CC} = V_{RS+} = V_{RS-} = 24V, $\overline{SHDN}$ = GND			10	30	
Leakage Current		V_{RS+} = V_{RS-} = 24V, V_{CC} = 0V			0.1	0.5	μA
Input Bias Current	I_{RS+}, I_{RS-}	V_{CC} = V_{RS+} = V_{RS-} = 24V		0	2.4	5	μA
Recommended Full-Scale Sense Voltage (Note 6)	V_{SENSE}	Gain = 50V/V			75		mV
		Gain = 100V/V			50		

Bidirectional, High-Side, Current-Sense Amplifiers with Reference

MAX4069–MAX4072

ELECTRICAL CHARACTERISTICS (continued)

($V_{RS+} = V_{RS-} = V_{CC}$ = 2.7V to 24V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, I_{REFOUT} = 0, $V_{\overline{SHDN}} = V_{CC}$, V_{GSEL} = GND, V_{REFIN} = 2.5V (MAX4072), $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C and at $V_{CC} = V_{RS+}$ = 12V.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Total OUT Voltage Error (Note 7)		V_{SENSE} = 75mV, $V_{CC} = V_{RS+}$ = 12V, gain = 50	T_A = +25°C		±0.25	±1.0	%
			T_A = -40°C to +85°C			±1.5	
			$T_A = T_{MIN}$ to T_{MAX}			±2.0	
		V_{SENSE} = 50mV, $V_{CC} = V_{RS+}$ = 12V, gain = 100	T_A = +25°C		±0.25	±1.0	
			T_A = -40°C to +85°C			±1.5	
			$T_A = T_{MIN}$ to T_{MAX}			±2.5	
		MAX4069/MAX4070/ MAX4072: V_{SENSE} = -35mV, $V_{CC} = V_{RS+}$ = 12V, gain = 50	T_A = +25°C		±0.4	±1.0	
			T_A = -40°C to +85°C			±2.0	
			$T_A = T_{MIN}$ to T_{MAX}			±3.0	
		MAX4069/MAX4070/ MAX4072: V_{SENSE} = -17.5mV, $V_{CC} = V_{RS+}$ = 12V, gain = 100	T_A = +25°C		±0.8	±2.0	
			T_A = -40°C to +85°C			±4.0	
			$T_A = T_{MIN}$ to T_{MAX}			±6	
		MAX4071: V_{SENSE} = -15mV, $V_{CC} = V_{RS+}$ = 12V, gain = 50	T_A = +25°C		±1.0	±2.5	
			T_A = -40°C to +85°C			±4.0	
			$T_A = T_{MIN}$ to T_{MAX}			±6.0	
		MAX4071: V_{SENSE} = -7.5mV, $V_{CC} = V_{RS+}$ = 12V, gain = 100	T_A = +25°C		±2.0	±5	
			T_A = -40°C to +85°C			±10	
			$T_A = T_{MIN}$ to T_{MAX}			±15	
		V_{SENSE} = 3mV, V_{CC} = 12V, V_{RS+} = 12V	T_A = +25°C		±3		

Bidirectional, High-Side, Current-Sense Amplifiers with Reference

MAX4069–MAX4072

ELECTRICAL CHARACTERISTICS (continued)

($V_{RS+} = V_{RS-} = V_{CC}$ = 2.7V to 24V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, I_{REFOUT} = 0, $V_{\overline{SHDN}} = V_{CC}$, V_{GSEL} = GND, V_{REFIN} = 2.5V (MAX4072), $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C and at $V_{CC} = V_{RS+}$ = 12V.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
OUT Voltage High	$V_{CC} - V_{OH}$	I_{OUT} = 10µA, V_{SENSE} = 100mV, $V_{RS+} = V_{CC}$	MAX4071, V_{CC} = 2.7V		65	150	mV
			MAX4069/MAX4070/ MAX4072, V_{CC} = 3.6V		65	150	
		I_{OUT} = 500µA, V_{SENSE} = 100mV, $V_{RS+} = V_{CC}$	MAX4071, V_{CC} = 2.7V		90	250	
			MAX4069/MAX4070/ MAX4072, V_{CC} = 3.6V		90	250	
OUT Voltage Low	V_{OL}	I_{OUT} = -10µA, V_{SENSE} = -100mV, $V_{RS+} = V_{CC}$	MAX4071, V_{CC} = 2.7V		5	20	mV
			MAX4069/MAX4070/ MAX4072, V_{CC} = 3.6V		5	20	
		I_{OUT} = -500µA, V_{SENSE} = -100mV, $V_{RS+} = V_{CC}$	MAX4071, V_{CC} = 2.7V		100	250	
			MAX4069/MAX4070/ MAX4072, V_{CC} = 3.6V		100	250	
-3dB Bandwidth	BW	V_{SENSE} = 50mV, V_{CC} = 12V, C_L = 100pF	Gain = 50V/V		100		kHz
			Gain = 100V/V		40		
Gain	A_V	GSEL = GND			50		V/V
		GSEL = V_{CC}			100		
Capacitive-Load Stability					100		pF
Power-Supply Rejection Ratio	PSRR	V_{CC} = 2.7V to 24V (MAX4069/MAX4071/MAX4072), V_{CC} = 3.6V to 24V (MAX4070)		100	120		dB
Logic Low Voltage (GSEL, $\overline{SHDN}$)	V_{IL}	V_{CC} = 3.6V or 24V				0.6	V
Logic High Voltage (GSEL, $\overline{SHDN}$)	V_{IH}	V_{CC} = 3.6V or 24V		2			V
Gain-Select Input Current	I_{GSEL}	GSEL = V_{CC} = 24V or GND			0.01	1	µA
Shutdown Input Current	$I_{\overline{SHDN}}$	$\overline{SHDN}$ = V_{CC} = 24V			3	12	µA
		$\overline{SHDN}$ = GND, V_{CC} = 24V			0.01	1	

Bidirectional, High-Side, Current-Sense Amplifiers with Reference

ELECTRICAL CHARACTERISTICS (continued)

($V_{RS+} = V_{RS-} = V_{CC}$ = 2.7V to 24V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, I_{REFOUT} = 0, $V_{\overline{SHDN}} = V_{CC}$, V_{GSEL} = GND, V_{REFIN} = 2.5V (MAX4072), $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C and at $V_{CC} = V_{RS+}$ = 12V.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
REFOUT (MAX4069/MAX4070/MAX4071)							
Reference Output Voltage	V_{REF}	MAX4069, V_{CC} = 12V (Note 2)	T_A = +25°C	2.44	2.49	2.54	V
			$T_A = T_{MIN}$ to T_{MAX}	2.39		2.59	
		MAX4070, V_{CC} = 12V	T_A = +25°C	2.45	2.5	2.55	
			$T_A = T_{MIN}$ to T_{MAX}	2.40		2.60	
		MAX4071, V_{CC} = 12V	T_A = +25°C	1.47	1.5	1.53	
			$T_A = T_{MIN}$ to T_{MAX}	1.44		1.56	
Reference Output Voltage Temperature Coefficient	TCV_{REF}	V_{CC} = 12V	-40°C ≤ T_A ≤ +85°C		15		ppm/°C
			$T_A = T_{MIN}$ to T_{MAX}		20		
Load Regulation	$\Delta V_{REFOUT}/\Delta I_{REF}$	I_{REFOUT} = 0 to 500µA			2		mV/mA
		I_{REFOUT} = 0 to -100µA			4		
Line Regulation	$\Delta V_{REF}/\Delta V_{CC}$	2.7V ≤ V_{CC} ≤ 24V			20		µV/V
REF Capacitive-Load Stability					500		pF
Reference Adjust Voltage Threshold	V_{ADJ}	MAX4069, V_{CC} = 12V			1.230		V
Reference Output Voltage Range		MAX4069, range adjustable with R1 and R2, V_{CC} = 12V			V_{ADJ} to +4		V
Reference Adjust Input Current	I_{ADJ}	MAX4069, V_{CC} = 12V, V_{ADJ} = 1.23V			100		nA
REFIN (MAX4072 only)							
Input-Voltage Range		V_{CC} = 12V		1		4	V
Input Current		REFIN = 2.5V, V_{CC} = 12V		-60		+20	µA

Note 1: All devices are 100% tested at T_A = +25°C. Limits over temperature are guaranteed by design.
Note 2: R1 = 215kΩ, R2 = 210kΩ for the MAX4069 only (see *Functional Diagram*). This sets REFOUT to 2.49V nominal.
Note 3: Guaranteed by the PSRR test.
Note 4: The REFOUT voltage for the MAX4069 should be set such that it does not exceed V_{CC} - 1.1V. Similarly, the maximum REFIN voltage for the MAX4072 should also be less than V_{CC} - 1.1V.
Note 5: Input-Referred Offset Voltage is defined as the voltage difference between OUT and REFOUT, divided by the selected gain of either 50 or 100, when $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V.
Note 6: The negative full-scale sense voltage is limited by the voltage range of OUT from V_{REFOUT} to GND.
Note 7: Total OUT Voltage Error is the sum of offset voltage and gain errors. The output voltage is measured relative to the reference (REFOUT or REFIN).

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D.3.4 Current Probe INA170

Burr-Brown Products from Texas Instruments

INA170

SBOS193D – MARCH 2001 – REVISED JANUARY 2006

High-Side, Bidirectional CURRENT SHUNT MONITOR

FEATURES

- COMPLETE BIDIRECTIONAL CURRENT MEASUREMENT CIRCUIT
- WIDE SUPPLY RANGE: 2.7V to 40V
- SUPPLY-INDEPENDENT COMMON-MODE VOLTAGE: 2.7V TO 60V
- RESISTOR PROGRAMMABLE GAIN SET
- LOW QUIESCENT CURRENT: 75µA (typ)
- MSOP-8 PACKAGE

APPLICATIONS

- CURRENT SHUNT MEASUREMENT: Automotive, Telephone, Computers, Power Systems, Test, General Instrumentation
- PORTABLE AND BATTERY-BACKUP SYSTEMS
- BATTERY CHARGERS
- POWER MANAGEMENT
- CELL PHONES

DESCRIPTION

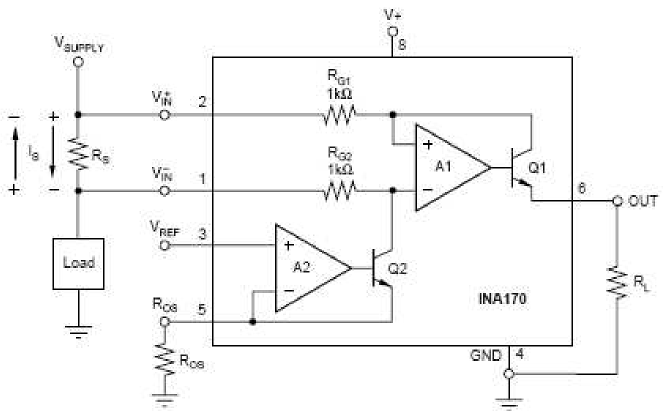
The INA170 is a high-side, bidirectional current shunt monitor featuring a wide input common-mode voltage range, low quiescent current, and a tiny MSOP-8 package.

Bidirectional current measurement is accomplished by output offsetting. The offset voltage level is set with an external resistor and voltage reference. This permits measurement of a bidirectional shunt current while using a single supply for the INA170.

Input common-mode and power-supply voltages are independent. Input voltage can range from +2.7V to +60V on any supply voltage from +2.7V to +40V. Low 10µA input bias current adds minimal error to the shunt current.

The INA170 converts a differential input voltage to a current output. This current develops a voltage across an external load resistor, setting any gain from 1 to over 100.

The INA170 is available in an MSOP-8 package, and is specified over the extended industrial temperature range, –40°C to +85°C with operation from –55°C to +125°C.



ABSOLUTE MAXIMUM RATINGS(1)

Supply Voltage, V+ to GND	–0.3V to 40V
Analog Inputs, Common Mode(2)	–0.3V to 75V
Differential $(V_{IN}^{+}) - (V_{IN}^{-})$	–40V to 2V
Analog Output, Out(2)	–0.3V to 40V
Input Current Into Any Pin	10mA
Operating Temperature	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Junction Temperature	+150°C

NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied. (2) The input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 10mA.

ELECTROSTATIC DISCHARGE SENSITIVITY

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

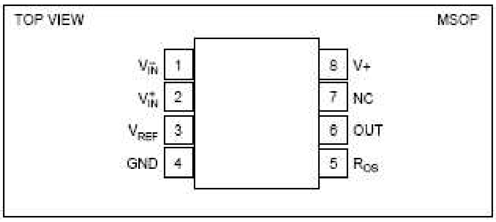
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
INA170EA	MSOP-8	DGK	–40°C to +85°C	INA170EA	INA170EA/250	Tape and Reel, 250
"	"	"	"	"	INA170EA/2K5	Tape and Reel, 2500

NOTE: (1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

PIN CONFIGURATION



PIN DESCRIPTION

PIN	DESIGNATOR	DESCRIPTION
1	V_{IN}^{-}	Inverting Input
2	V_{IN}^{+}	Noninverting Input
3	V_{REF}	Reference Voltage Input
4	GND	Ground
5	R_{OS}	Offset Resistor
6	OUT	Output
7	NC	No Connection
8	V+	Supply Voltage

ELECTRICAL CHARACTERISTICS

At T_A = –40°C to +85°C, V_S = 5V, V_{IN}^+ = 12V, R_{OUT} = 25kΩ, unless otherwise noted.

PARAMETER	CONDITION	INA170EA			UNITS
		MIN	TYP	MAX	
INPUT					
Full-Scale Sense (Input) Voltage	$V_{SENSE} = V_{IN}^+ - V_{IN}^-$		100	500	mV
Common-Mode Input Range		+2.7		+60	V
Common-Mode Rejection	V_{IN}^+ = +2.7V to +60V, V_{SENSE} = 50mV	100	120		dB
Offset Voltage(1) RTI			±0.2	±1	mV
vs Temperature	T_{MIN} to T_{MAX}		1		µV/°C
vs Power Supply	V+ = +2.7V to +60V, V_{SENSE} = 50mV		0.1	10	µV/V
Input Bias Current	V_{IN}^+, V_{IN}^-		10		uA
OFFSETTING AMPLIFIER					
Offsetting Equation	$V_{OS} = (R_L/R_{OS})\ V_{REF}$				
Input Voltage		1		V_S – 1	V
Input Offset Voltage			±0.2	±1	mV
vs Temperature	T_{MIN} to T_{MAX}		10		µV/°C
Programming Current through R_{OS}		0		1	mA
Input Impedance			10^{10} || 4		Ω || pF
Input Bias Current	V_{IN}^+, V_{IN}		+10		nA
OUTPUT					
Transconductance	V_{SENSE} = 10mV to 150mV	0.990	1	1.01	mA/V
vs Temperature	V_{SENSE} = 100mV		50		nA/°C
Nonlinearity Error	V_{SENSE} = 10mV to 150mV		±0.01	±0.1	%
Total Output Error	V_{SENSE} = 100mV		±0.5	±2	%
Output Impedance			1 || 5		GΩ || pF
Voltage Output					
Swing to Power Supply, V+			(V+) – 0.9	(V+) – 1.2	V
Swing to Common Mode, V_{CM}			V_{CM} – 0.6	V_{CM} – 1.0	V
FREQUENCY RESPONSE					
Bandwidth	R_{OUT} = 10kΩ		400		kHz
Settling Time (0.1%)	5V Step, R_{OUT} = 10kΩ		3		µs
NOISE					
Output-Current Noise Density			20		pA/√Hz
Total Output-Current Noise	BW = 100kHz		7		nA RMS
POWER SUPPLY					
Operating Range	V+	+2.7		+40	V
Quiescent Current	V_{SENSE} = 0, I_O = 0		75	125	µA
TEMPERATURE RANGE					
Specification, T_{MIN} to T_{MAX}		–40		+85	°C
Operating		–55		+125	°C
Storage		–65		+150	°C
Thermal Resistance, θ_{JA}			150		°C/W

NOTE: (1) Defined as the amount of input voltage, V_{SENSE}, to drive the output to zero.

(…)

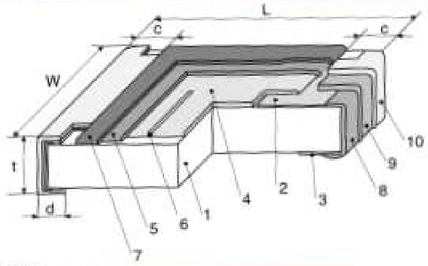
D.3.5 Shunt Resistor SR732ATBK1R00F

KOA *Your Passive Solution*

LOW OHM

THICK FILM
CURRENT SENSING CHIP
SR73

LOW OHM



STRUCTURE

1 Ceramic substrate
2 Top termination (Ag Pd)
3 Bottom termination (Ag
4 Resistive layer
5 Glass layer
6 Trimming cut
7 Protective layer
8 End termination
9 Diffusion barrier (Ni)
10 Solder plating

IDENTIFICATION

PRODUCT CODE	COATING COLOR	MARKING
SR73 1E	Indigo	None
SR73 1J (1%)		
SR73 1J (2%, 5%)		White, 3 digits
SR73 2A…W3A (2%, 5%)		
SR73 2A…W3A (0.5%, 1%)		White, 4 digits

Products with Pb-free terminations meet RoHS requirements

TYPE DESIGNATION (HOW TO ORDER)

SR73	2A	T	TD	R475	F
PRODUCT CODE	STYLE 1E…W3A	TERMINATION SURFACE MATERIAL T: Sn L: Sn/Pb (G: Au)	TAPING* *Please see "PACKAGING"	NOMINAL RESISTANCE D, F: 4 digits J, G: 3 digits	TOLERANCE D: ±0.5% F: ±1% G: ±2% J: ±5%

FEATURES

- RuO_2 thick film resistor element
- Anti-leaching nickel barrier terminations
- High reliability and performance with T.C.R. ±100 ppm/K and resistance tolerance ±1%
- Also available with gold plated electrodes in size 2A (0.1Ω…10Ω)
- Rated ambient temperature: + 70° C
- Operating temperature range: - 55° C … + 150° C
- The most suitable current detecting resistor for power supply, motor circuits etc.
- Ideal for use in computers, HDD, cellular phones, motor circuits etc.
- Suitable for reflow and wave soldering
- Meets or exceeds IEC 60 115-8, JIS C 5201-8
- Lab Kit available

DIMENSIONS (mm)

SIZE	TYPE	L	W	c	d	t
0402	SR73 1E	$1.0\ ^{+0.1}_{-0.05}$	$0.5\ ^{+0.1}_{-0.05}$	0.25 ± 0.1	0.25 ± 0.1	0.35 ± 0.1
0603	SR73 1J	1.6 ± 0.2	$0.8\ ^{+0.15}_{-0.1}$	0.35 ± 0.1	0.35 ± 0.1	0.45 ± 0.1
0805	SR73 2A	2.0 ± 0.2	1.25 ± 0.1	0.4 ± 0.2	$0.3\ ^{+0.2}_{-0.1}$	0.5 ± 0.1
1206	SR73 2B	3.2 ± 0.2	1.6 ± 0.2	0.5 ± 0.3	$0.4\ ^{+0.2}_{-0.1}$	0.6 ± 0.1
1210	SR73 2E		2.6 ± 0.2			
2010	SR73 W2H*	5.0 ± 0.2	2.5 ± 0.2		0.65 ± 0.15*	
2512	SR73 W3A*	6.3 ± 0.2	3.1 ± 0.2			

* SR73 2H and SR73 3A are also still available (different "d" dimensions = $0.4\ ^{+0.2}_{-0.1}$ mm)

Specifications given herein may be changed at any time without prior notice. Please confirm technical specifications before you order and/or use.

RATING

SIZE	TYPE	T.C.R. (ppm/K)	POWER*1 RATING	MAX. WORKING VOLTAGE	MAX. OVERLOAD VOLTAGE	RESISTANCE RANGE D(±0.5%)E96·E24	F (±1%) E96·E24	G (±2%) E24	J (±5%) E24
0402	SR73 1E	± 200	0.125 W (0.166 W)*2	1.11 V	2.79 V	–	0.51 Ω ~ 10 Ω*3	0.51 Ω ~ 10 Ω	0.51 Ω ~ 10 Ω
		± 300				–	0.2 Ω ~ 0.47 Ω*3	0.2 Ω ~ 0.47 Ω	0.2 Ω ~ 0.47 Ω
		± 500				–	0.1 Ω ~ 0.18 Ω*3	0.1 Ω ~ 0.18 Ω	0.1 Ω ~ 0.18 Ω
0603	SR73 1J	± 200	0.2 W	1.41 V	3.53 V	–	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω
0805	SR73 2A	± 100	0.25 W (0.33 W)*2	1.58 V	3.95 V	0.15 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω	—	—
		± 200				–	—	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω
		± 500				–	—	—	0.051 Ω ~ 0.091 Ω
		± 800				–	—	—	0.030 Ω ~ 0.047 Ω
1206	SR73 2B	± 100	0.33 W (0.5 W)*2	1.81 V	4.54 V	0.15 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω	—	—
		± 200				–	—	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω
		± 500				–	—	—	0.056 Ω ~ 0.091 Ω
		± 800				–	—	—	0.030 Ω ~ 0.051 Ω
1210	SR73 2E	± 100	0.5 W (0.66 W)*2	2.23 V	5.59 V	–	0.1 Ω ~ 10 Ω	—	—
		± 200				–	—	0.1 Ω ~ 10 Ω	0.047 Ω ~ 10 Ω
		± 500				–	—	—	0.036 Ω ~ 0.043 Ω
		± 1000				–	—	—	0.024 Ω ~ 0.033 Ω
2010	SR73 W2H	± 100	0.75 W	2.73 V	6.84 V	–	0.1 Ω ~ 10 Ω		—
		± 200				–	—	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω
		± 500				–	—	—	0.056 Ω ~ 0.091 Ω
		± 800				–	—	—	0.033 Ω ~ 0.051 Ω
2512	SR73 W3A	± 100	1.0 W	3.16 V	7.90 V	–	0.1 Ω ~ 10 Ω	—	—
		± 200				–	—	0.1 Ω ~ 10 Ω	0.1 Ω ~ 10 Ω
		± 500				–	—	—	0.056 Ω ~ 0.091 Ω
		± 800				–	—	—	0.039 Ω ~ 0.051 Ω

*1: For resistors operated at an ambient temperature of +70°C or above, the power rating shall be derated.
*2: Please contact KOA if the part is used at marked, increased power.
*3: SR73 1E only in E24 values.
Rated voltage = $\sqrt{\text{Power rating x resistance value}}$ or max. working voltage, whichever is lower.

D.3.6 Voltage Reference REF3225

Burr-Brown Products from Texas Instruments

REF3212, REF3220
REF3225, REF3230
REF3233, REF3240

SBVS058B – JUNE 2005 – REVISED FEBRUARY 2006

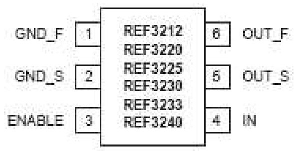
4ppm/°C, 100µA, SOT23-6 SERIES VOLTAGE REFERENCE

FEATURES

- EXCELLENT SPECIFIED DRIFT PERFORMANCE:
  7ppm/°C (max) at 0°C to +125°C
  20ppm/°C (max) at –40°C to +125°C
- MICROSIZE PACKAGE: SOT23-6
- HIGH OUTPUT CURRENT: ±10mA
- HIGH ACCURACY: 0.01%
- LOW QUIESCENT CURRENT: 100µA
- LOW DROPOUT: 5mV

APPLICATIONS

- PORTABLE EQUIPMENT
- DATA ACQUISITION SYSTEMS
- MEDICAL EQUIPMENT
- TEST EQUIPMENT



DESCRIPTION

The REF32xx is a very low drift, micropower, low-dropout, precision voltage reference family available in the tiny SOT23-6 package.

The small size and low power consumption (120µA max) of the REF32xx make it ideal for portable and battery-powered applications. This reference is stable with any capacitive load.

The REF32xx can be operated from a supply as low as 5mV above the output voltage, under no load conditions. All models are specified for the wide temperature range of –40°C to +125°C.

AVAILABLE OUTPUT VOLTAGES

PRODUCT	VOLTAGE
REF3212	1.25V
REF3220	2.048V
REF3225	2.5V
REF3230	3.0V
REF3233	3.3V
REF3240	4.096V

ABSOLUTE MAXIMUM RATINGS(1)

Input Voltage	+7.5V
Output Short-Circuit	Continuous
Operating Temperature	−55°C to +135°C
Storage Temperature	−65°C to +150°C
Junction Temperature	+150°C
ESD Rating	
Human Body Model	4kV
Charged Device Model	1kV
Machine Model	400V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.

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

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

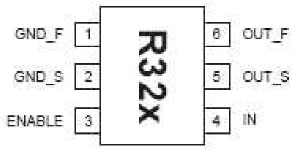
PACKAGE/ORDERING INFORMATION(1)

PRODUCT	OUTPUT VOLTAGE	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
REF3212	1.25V	SOT23-6	DBV	R32A
REF3220	2.048V	SOT23-6	DBV	R32B
REF3225	2.5V	SOT23-6	DBV	R32C
REF3230	3.0V	SOT23-6	DBV	R32D
REF3233	3.30V	SOT23-6	DBV	R32E
REF3240	4.096V	SOT23-6	DBV	R32F

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

PIN CONFIGURATION

Top View SOT23



NOTE: The location of pin 1 on the REF32xx is determined by orienting the package marking as shown in the diagram above.

ELECTRICAL CHARACTERISTICS

Boldface limits apply over the listed temperature range.

At T_A = +25°C, I_{LOAD} = 0mA, and V_{IN} = 5V, unless otherwise noted.

PARAMETER	CONDITIONS	REF32xx MIN	REF32xx TYP	REF32xx MAX	UNIT
REF3212 (1.25V)					
OUTPUT VOLTAGE, V_{OUT}		1.2475	1.25	1.2525	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		17		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		24		µV$_{RMS}$
REF3220 (2.048V)					
OUTPUT VOLTAGE, V_{OUT}		2.044	2.048	2.052	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		27		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		39		µV$_{RMS}$
REF3225 (2.5V)					
OUTPUT VOLTAGE, V_{OUT}		2.495	2.50	2.505	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		33		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		48		µV$_{RMS}$
REF3230 (3V)					
OUTPUT VOLTAGE, V_{OUT}		2.994	3	3.006	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		39		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		57		µV$_{RMS}$
REF3233 (3.3V)					
OUTPUT VOLTAGE, V_{OUT}		3.293	3.3	3.307	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		43		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		63		µV$_{RMS}$
REF3240 (4.096V)					
OUTPUT VOLTAGE, V_{OUT}		4.088	4.096	4.104	V
Initial Accuracy		–0.2	0.01	0.2	%
NOISE					
Output Voltage Noise	f = 0.1Hz to 10Hz		53		µV$_{PP}$
Voltage Noise	f = 10Hz to 10kHz		78		µV$_{RMS}$

REF3212, REF3220
REF3225, REF3230
REF3233, REF3240

TEXAS INSTRUMENTS
www.ti.com

SBVS058B – JUNE 2005 – REVISED FEBRUARY 2006

ELECTRICAL CHARACTERISTICS (continued)

Boldface limits apply over the listed temperature range.

At T_A = +25°C, I_{LOAD} = 0mA, and V_{IN} = 5V, unless otherwise noted.

PARAMETER		CONDITIONS	REF32xx MIN	REF32xx TYP	REF32xx MAX	UNIT
REF3212 / REF3220 / REF3225 / REF3230 / REF3233 / REF3240						
OUTPUT VOLTAGE TEMP DRIFT	dV_{OUT}/dT					
		0°C ≤ T_A ≤ +125°C		**4**	**7**	**ppm/°C**
		−40°C ≤ T_A ≤ +125°C		**10.5**	**20**	**ppm/°C**
LONG-TERM STABILITY		0 to 1000h		55		ppm
LINE REGULATION		V_{OUT} + 0.05(1) ≤ V_{IN} ≤ 5.5V	−65	15	+65	ppm/V
LOAD REGULATION	dV_{OUT}/dI_{LOAD}					
Sourcing		0mA < I_{LOAD} < 10mA, V_{IN} = V_{OUT} + 250mV(1)	−40	3	40	µV/mA
Sinking		−10mA < I_{LOAD} < 0mA, V_{IN} = V_{OUT} + 100mV(1)	−60	20	60	µV/mA
THERMAL HYSTERESIS(2)	dT					
First cycle				100		ppm
Additional cycles				25		ppm
DROPOUT VOLTAGE(1)	$V_{IN}-V_{OUT}$	**0°C ≤ T_A ≤ +125°C**		**5**	**50**	**mV**
OUTPUT CURRENT	I_{LOAD}	V_{IN} = V_{OUT} + 250mV(1)	−10		10	mA
SHORT-CIRCUIT CURRENT	I_{SC}					
Sourcing				50		mA
Sinking				40		mA
TURN-ON SETTLING TIME		to 0.1% at V_{IN} = 5V with C_L = 0		60		µs
ENABLE/SHUTDOWN						
	V_L	Reference in Shutdown mode	0		0.7	V
	V_H	Reference is active	0.75 × V_{IN}		V_{IN}	V
POWER SUPPLY		I_L = 0				
Voltage	V_{IN}		V_{OUT} + 0.05(1)		5.5	V
Current	I_Q	ENABLE > 0.75 x V_{IN}		100	120	µA
Over-temperature		**0°C ≤ T_A ≤ +125°C**		**115**	**135**	**µA**
Shutdown	I_S	ENABLE < 0.7V		0.1	1	µA
TEMPERATURE RANGE						
Specified			−40		+125	°C
Operating			−55		+135	°C
Storage			−65		+150	°C
Thermal resistance, SOT23-6	θ_{JA}			200		°C/W

(1) The minimum supply voltage for the REF3212 is 1.8V.
(2) Thermal hysteresis procedure is explained in more detail in the *Applications Information* section.
(3) Load regulation is using force and sense lines; see the *Load Regulation* section for more information.

4

(...)

D.3.7 Operational Amplifier OPA333

Burr-Brown Products from Texas Instruments

OPA333
OPA2333

SBOS351C–MARCH 2006–REVISED MAY 2007

1.8V, *micro*POWER CMOS OPERATIONAL AMPLIFIERS Zerø-Drift Series

FEATURES

- LOW OFFSET VOLTAGE: 10μV (max)
- ZERO DRIFT: 0.05μV/°C (max)
- 0.01Hz to 10Hz NOISE: 1.1μV$_{PP}$
- QUIESCENT CURRENT: 17μA
- SINGLE-SUPPLY OPERATION
- SUPPLY VOLTAGE: 1.8V to 5.5V
- RAIL-TO-RAIL INPUT/OUTPUT
- *micro*SIZE PACKAGES: SC70 and SOT23

APPLICATIONS

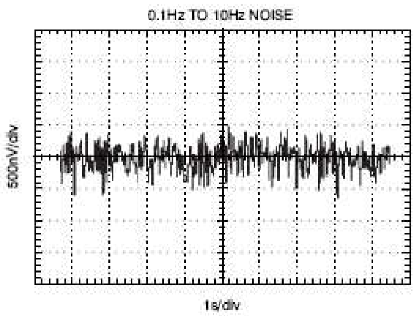
- TRANSDUCER APPLICATIONS
- TEMPERATURE MEASUREMENTS
- ELECTRONIC SCALES
- MEDICAL INSTRUMENTATION
- BATTERY-POWERED INSTRUMENTS
- HANDHELD TEST EQUIPMENT

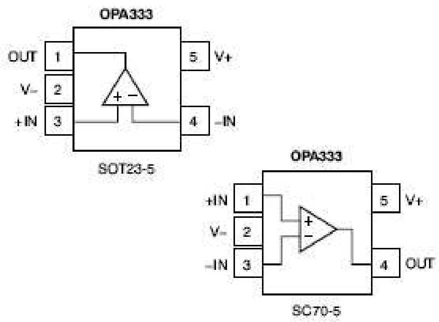
DESCRIPTION

The OPA333 series of CMOS operational amplifiers uses a proprietary auto-calibration technique to simultaneously provide very low offset voltage (10μV max) and near-zero drift over time and temperature. These miniature, high-precision, low quiescent current amplifiers offer high-impedance inputs that have a common-mode range 100mV beyond the rails and rail-to-rail output that swings within 50mV of the rails. Single or dual supplies as low as +1.8V (±0.9V) and up to +5.5V (±2.75V) may be used. They are optimized for low-voltage, single-supply operation.

The OPA333 family offers excellent CMRR without the crossover associated with traditional complementary input stages. This design results in superior performance for driving analog-to-digital converters (ADCs) without degradation of differential linearity.

The OPA333 (single version) is available in the SC70-5, SOT23-5, and SO-8 packages. The OPA2333 (dual version) is offered in DFN-8 (3mm × 3mm), MSOP-8, and SO-8 packages. All versions are specified for operation from –40°C to +125°C.





Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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

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

ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
OPA333	SOT23-5	DBV	OAXQ
	SC70-5	DCK	BQY
	SO-8	D	O333A
OPA2333	SO-8	D	O2333A
	DFN-8	DRB	BQZ
	MSOP-8	DGK	OBAQ

(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS(1)

	OPA333, OPA2333	UNIT
Supply Voltage	+7	V
Signal Input Terminals, Voltage(2)	–0.3 to (V+) + 0.3	V
Signal Input Terminals, Voltage(2)	±10	mA
Output Short-Circuit(3)	Continuous	
Operating Temperature	–40 to +150	°C
Storage Temperature	–65 to +150	°C
Junction Temperature	+150	°C
ESD Ratings:		
Human Body Model (HBM)	4000	V
Charged Device Model (CDM)	1000	V
Machine Model (MM)	400	V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.
(2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.3V beyond the supply rails should be current limited to 10mA or less.
(3) Short-circuit to ground, one amplifier per package.

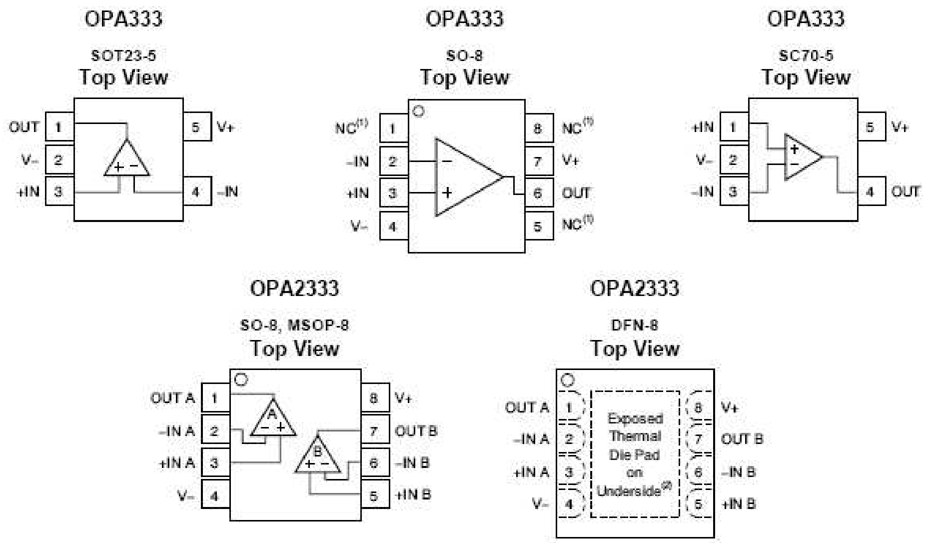
ELECTRICAL CHARACTERISTICS: V_S = +1.8V to +5.5V

Boldface limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to V_S/2, V_{CM} = V_S/2, and V_{OUT} = V_S/2, unless otherwise noted.

PARAMETER		TEST CONDITIONS	OPA333, OPA2333 MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
Input Offset Voltage	V_{OS}	V_S = +5V		2	10	μV
vs Temperature	**dV_{OS}/dT**			**0.02**	**0.05**	**μV/°C**
vs Power Supply	**PSRR**	**V_S = +1.8V to +5.5V**		**1**	**5**	**μV/V**
Long-Term Stability(1)				See (1)		
Channel Separation, dc				0.1		μV/V
INPUT BIAS CURRENT						
Input Bias Current	I_B			±70	±200	pA
over Temperature				**±150**		**pA**
Input Offset Current	I_{OS}			±140	±400	pA
NOISE						
Input Voltage Noise, f = 0.01Hz to 1Hz				0.3		$μV_{PP}$
Input Voltage Noise, f = 0.1Hz to 10Hz				1.1		$μV_{PP}$
Input Current Noise, f = 10Hz	i_n			100		fA/√Hz
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range	V_{CM}		(V–) – 0.1		(V+) + 0.1	V
Common-Mode Rejection Ratio	**CMRR**	**(V–) – 0.1V < V_{CM} < (V+) + 0.1V**	**106**	**130**		**dB**
INPUT CAPACITANCE						
Differential				2		pF
Common-Mode				4		pF
OPEN-LOOP GAIN						
Open-Loop Voltage Gain	**A_{OL}**	**(V–) + 100mV < V_O < (V+) – 100mV, R_L = 10kΩ**	**106**	**130**		**dB**
FREQUENCY RESPONSE						
Gain-Bandwidth Product	GBW	C_L = 100pF		350		kHz
Slew Rate	SR	G = +1		0.16		V/μs
OUTPUT						
Voltage Output Swing from Rail		R_L = 10kΩ		30	50	mV
over Temperature		**R_L = 10kΩ**			**70**	**mV**
Short-Circuit Current	I_{SC}			±5		mA
Capacitive Load Drive	C_L		See Typical Characteristics			
Open-Loop Output Impedance		f = 350kHz, I_O = 0		2		kΩ
POWER SUPPLY						
Specified Voltage Range	V_S		1.8		5.5	V
Quiescent Current Per Amplifier	I_Q	I_O = 0		17	25	μA
over Temperature					**28**	**μA**
Turn-On Time		V_S = +5V		100		μs
TEMPERATURE RANGE						
Specified Range			–40		+125	°C
Operating Range			–40		+150	°C
Storage Range			–65		+150	°C
Thermal Resistance	$θ_{JA}$					°C/W
SOT23-5				200		°C/W
MSOP-8, SO-8				150		°C/W
DFN-8				50		°C/W
SC70-5				250		°C/W

(1) 300-hour life test at +150°C demonstrated randomly distributed variation of approximately 1μV.

PIN CONFIGURATIONS

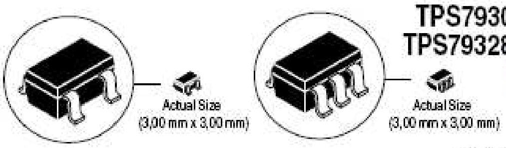


1. NC denotes no internal connection.
2. Connect thermal die pad to V–.

(…)

D.3.8 Low-Dropout Voltage Regulator TPS79333

TEXAS INSTRUMENTS



TPS79301, TPS79318, TPS79325
TPS79328, TPS793285, TPS79330
TPS79333, TPS793475

SLVS348C – JULY 2001 – REVISED APRIL 2002

ULTRALOW-NOISE, HIGH PSRR, FAST RF 200-mA LOW-DROPOUT LINEAR REGULATORS

FEATURES

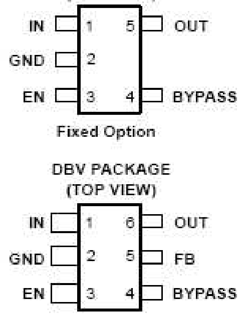
- 200-mA Low-Dropout Regulator With EN
- Available in 1.8-V, 2.5-V, 2.8-V, 2.85-V, 3-V, 3.3-V, 4.75-V, and Adjustable
- High PSRR (70 dB at 10 kHz)
- Ultralow Noise (32 µV)
- Fast Start-Up Time (50 µs)
- Stable With a 2.2-µF Ceramic Capacitor
- Excellent Load/Line Transient
- Very Low Dropout Voltage (112 mV at Full Load, TPS79330)
- 5-Pin SOT23 (DBV) Package

APPLICATIONS

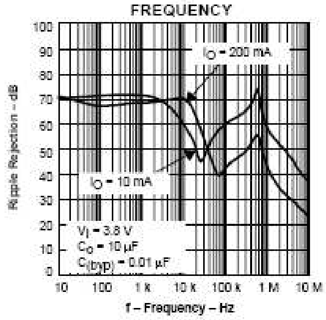
- Cellular and Cordless Telephones
- VCOs
- RF
- Bluetooth™, Wireless LAN
- Handheld Organizers, PDA

DESCRIPTION

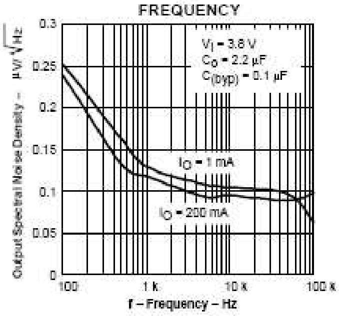
The TPS793xx family of low-dropout (LDO) low-power linear voltage regulators features high power supply rejection ratio (PSRR), ultralow noise, fast start-up, and excellent line and load transient responses in a small outline, SOT23, package. Each device in the family is stable, with a small 2.2-µF ceramic capacitor on the output. The TPS793xx family uses an advanced, proprietary BiCMOS fabrication process to yield extremely low dropout voltages (e.g., 112 mV at 200 mA, TPS79330). Each device achieves fast start-up times (approximately 50 µs with a 0.001-µF bypass capacitor) while consuming very low quiescent current (170 µA typical). Moreover, when the device is placed in standby mode, the supply current is reduced to less than 1 µA. The TPS79328 exhibits approximately 32 μV_{RMS} of output voltage noise with a 0.1-µF bypass capacitor. Applications with analog components that are noise sensitive, such as portable RF electronics, benefit from the high PSRR and low-noise features as well as the fast response time.



TPS79328
RIPPLE REJECTION
vs
FREQUENCY



TPS79328
OUTPUT SPECTRAL NOISE DENSITY
vs
FREQUENCY



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TEXAS INSTRUMENTS
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AVAILABLE OPTIONS

T_J	VOLTAGE	PACKAGE	PART NUMBER	SYMBOL
–40°C to 125°C	1.2 to 5.5 V	SOT23 (DBV)	TPS79301DBVR†	PGVI
	1.8 V		TPS79318DBVR†	PHHI
	2.5 V		TPS79325DBVR†	PGWI
	2.8 V		TPS79328DBVR†	PGXI
	2.85 V		TPS793285DBVR†	PHII
	3 V		TPS79330DBVR†	PGYI
	3.3 V		TPS793333DBVR†	PHUI
	4.75 V		TPS793475DBVR†	PHJI

† The DBVR indicates tape and reel of 3000 parts.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)‡

Input voltage range (see Note 1) . . . . –0.3 V to 6 V
Voltage range at EN . . . . –0.3 V to V_I + 0.3 V
Voltage on OUT . . . . –0.3 V to 6 V
Peak output current . . . . internally limited
ESD rating, HBM . . . . 2 kV
ESD rating, CDM . . . . 500 V
Continuous total power dissipation . . . . See Dissipation Rating Table
Operating virtual junction temperature range, T_J . . . . –40°C to 150°C
Operating ambient temperature range, T_A . . . . –40°C to 85°C
Storage temperature range, T_{stg} . . . . –65°C to 150°C

‡ Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.

DISSIPATION RATING TABLE

BOARD	PACKAGE	$R_{\theta JC}$	$R_{\theta JA}$	DERATING FACTOR ABOVE T_A = 25°C	$T_A \le$ 25°C POWER RATING	T_A = 70°C POWER RATING	T_A = 85°C POWER RATING
Low K§	DBV	63.75 °C/W	256 °C/W	3.906 mW/°C	391 mW	215 mW	156 mW
High K¶	DBV	63.75 °C/W	178.3 °C/W	5.609 mW/°C	561 mW	308 mW	224 mW

§ The JEDEC low K (1s) board design used to derive this data was a 3-inch x 3-inch, two layer board with 2 ounce copper traces on top of the board.
¶ The JEDEC high K (2s2p) board design used to derive this data was a 3-inch x 3-inch, multilayer board with 1 ounce internal power and ground planes and 2 ounce copper traces on top and bottom of the board.

electrical characteristics over recommended operating free-air temperature range EN = V_I, T_J = –40 to 125 °C, $V_I = V_{O(typ)}$ + 1 V, I_O = 1 mA, C_o = 10 µF, $C_{(byp)}$ = 0.01 µF (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_I Input voltage (see Note 2)				2.7		5.5	V
I_O Continuous output current (see Note 3)				0		200	mA
T_J Operating junction temperature				–40		125	°C
Output voltage	TPS79301	0 µA< I_O < 200 mA, (see Note 4)	1.22 V ≤ V_O ≤ 5.2 V,	0.98 V_O		1.02 V_O	V
	TPS79318	T_J = 25°C			1.8		V
		0 µA< I_O < 200 mA,	2.8 V < V_I < 5.5 V	1.764		1.836	
	TPS79325	T_J = 25°C			2.5		V
		0 µA< I_O < 200 mA,	3.5 V < V_I < 5.5 V	2.45		2.55	
	TPS79328	T_J = 25°C			2.8		V
		0 µA< I_O < 200 mA,	3.8 V < V_I < 5.5 V	2.744		2.856	
	TPS793285	T_J = 25°C			2.85		V
		0 µA< I_O < 200 mA,	3.85 V < V_I < 5.5 V	2.793		2.907	
	TPS79330	T_J = 25°C			3		V
		0 µA< I_O < 200 mA,	4 V < V_I < 5.5 V	2.94		3.06	
	TPS79333	T_J = 25°C			3.3		V
		0 µA ≤ I_O < 200 mA,	4.3 V < V_I < 5.5 V	3.234		3.366	
	TPS793475	T_J = 25°C			4.75		V
		0 µA< I_O < 200 mA,	5.25 V < V_I < 5.5 V	4.655		4.845	
Quiescent current (GND current)		0 µA< I_O < 200 mA,	T_J = 25°C		170		µA
		0 µA< I_O < 200 mA				220	µA
Load regulation		0 µA< I_O < 200 mA,	T_J = 25°C		5		mV
Output voltage line regulation ($\Delta V_O/V_O$) (see Note 5)		V_O + 1 V < V_I ≤ 5.5 V,	T_J = 25°C		0.05		%/V
		V_O + 1 V < V_I ≤ 5.5 V				0.12	
Output noise voltage (TPS79328)		BW = 200 Hz to 100 kHz, I_O = 200 mA, T_J = 25°C	$C_{(byp)}$ = 0.001 µF		55		μV_{RMS}
			$C_{(byp)}$ = 0.0047 µF		36		
			$C_{(byp)}$ = 0.01 µF		33		
			$C_{(byp)}$ = 0.1 µF		32		
Time, start-up (TPS79328)		R_L = 14 Ω, C_o = 1 µF, T_J = 25°C	$C_{(byp)}$ = 0.001 µF		50		µs
			$C_{(byp)}$ = 0.0047 µF		70		
			$C_{(byp)}$ = 0.01 µF		100		
Output current limit		V_O = 0 V,	See Note 4	285		600	mA
Standby current		EN = 0 V,	2.7 V < V_I < 5.5 V		0.07	1	µA
High level enable input voltage		2.7 V < V_I < 5.5 V		2			V
Low level enable input voltage		2.7 V < V_I < 5.5 V				0.7	V
Input current (EN)		EN = 0		–1		1	µA
Input current (FB) (TPS79301)		FB = 1.8 V				1	µA

NOTES: 2. To calculate the minimum input voltage for your maximum output current, use the following formula: $V_I(min) = V_O(max) + V_{DO}$ (max load)

3. Continuous output current and operating junction temperature are limited by internal protection circuitry, but it is not recommended that the device operate under conditions beyond those specified in this table for extended periods of time.

4. The minimum IN operating voltage is 2.7 V or $V_{O(typ)}$ + 1 V, whichever is greater. The maximum IN voltage is 5.5 V. The maximum output current is 200 mA.

5. If $V_O \le 2.5$ V then V_{Imin} = 2.7 V, V_{Imax} = 5.5 V:

$$\text{Line Reg. (mV)} = (\%/V) \times \frac{V_O\left(V_{Imax} - 2.7\ V\right)}{100} \times 1000$$

If $V_O \ge 2.5$ V then $V_{Imin} = V_O + 1$ V, V_{Imax} = 5.5 V.

TPS79301, TPS79318, TPS79325
TPS79328, TPS793285, TPS79330
TPS79333, TPS793475
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electrical characteristics over recommended operating free-air temperature range EN = V_I, T_J = –40 to 125 °C, $V_I = V_{O(typ)}$ + 1 V, I_O = 1 mA, C_o = 10 µF, $C_{(byp)}$ = 0.01 µF (unless otherwise noted) (continued)

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT
Power supply ripple rejection	TPS79328	f = 100 Hz,	T_J = 25°C,	I_O = 10 mA		70		dB
		f = 100 Hz,	T_J = 25°C,	I_O = 200 mA		68		
		f = 10 kHz,	T_J = 25°C,	I_O = 200 mA		70		
		f = 100 kHz,	T_J = 25°C,	I_O = 200 mA		43		
Dropout voltage (see Note 6)	TPS79328	I_O = 200 mA,		T_J = 25°C		120		mV
		I_O = 200 mA					200	
	TPS793285	I_O = 200 mA,		T_J = 25°C		120		
		I_O = 200 mA					200	
	TPS79330	I_O = 200 mA,		T_J = 25°C		112		
		I_O = 200 mA					200	
	TPS79333	I_O = 200 mA,		T_J = 25°C		102		mV
		I_O = 200 mA					180	
	TPS793475	I_O = 200 mA,		T_J = 25°C		77		mV
		I_O = 200 mA					125	
UVLO threshold		V_{CC} rising			2.25		2.65	V
UVLO hysteresis		T_J = 25°C		V_{CC} rising		100		mV

NOTE 6: IN voltage equals V_O(typ) – 100 mV; The TPS79325 dropout voltage is limited by the input voltage range limitations.

(…)