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Characterization and sample testing of the LHC4913 positive voltage regulator for the LHCb Silicon Tracker

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Abstract

In this note, we report on a characterization of the LHC4913 positive voltage regulator. We tested the behaviour on different cable types and their influence on the voltage regulation and possible oscillations. Furthermore, sample testing of the production batch for the LHCb Silicon Tracker subdetector has been performed for a cable representative to a Silicon Tracker installation with a load comparable to the front-end hybrid power consumption.

1 Overview

In order to supply power to various front-end electronics, voltage regulators are needed, placed at best close to the load. For the environment of the LHC experiments, this means high radiation doses as well as high neutron fluences. Because commercial regulators fail under these conditions, the rad-hard positive voltage regulator LHC4913 was developed by the CERN microelectronics group. This regulator has been radiation tested by other groups within the LHC community to withstand the expected doses in LHCb. The LHCb Silicon Tracker is planning to use this voltage regulator for providing on-detector power supply to the front-end electronics. A characterization and sample testing was performed on the production batch, which was delivered in December 2002. In this note, we describe the circuit diagram used for characterization of the regulator and the results of the sample testing performed on the delivered batch to ensure its suitability for use in production.

2 Basic specifications

In this section, the basic specifications of the LHC4913 voltage regulator are described, with particular emphasis on the specific needs in the LHCb Silicon Tracker. For a more detailed description of the device, consult the LHC4913 datasheet [1].

The LHC4913 is a linear positive voltage regulator with a low drop voltage rated for a maximum current of 3 A. It is protected against over-current and over-temperature and therefore needs cooling when delivering higher currents. The output voltage can be set by two resistors attached to the ADJ input. An inhibit input is available for switching the power by the experiment control system (ECS). For supplying distant loads, the LHC4913 is equipped with a sense input.

In the LHCb Silicon Tracker, we use the LHC4913 in three different voltage configurations: +2.5 V, +3.3 V and +5 V. The components, which are planned to be supplied with the different voltages are listed in Table 1, as well as the separation of analogue and digital voltages.

Table 1: Voltages needed in the LHCb Silicon Tracker.

Voltage [V]	analogue/ digital	component	power consumption per device [W]	power consumption per service box [W]
2.5	analogue	Beetle FE-Chip	0.625	52.5
2.5	digital		0.125	10.5
5.0	analogue	AD8129 differential receiver	0.050	16.8
2.5	analogue	TSA0801 ADC	0.050	16.8
2.5	digital		0.018	6.0
2.5	digital	GOL serializer	0.400	33.6
2.5	digital	QPLL	0.025	0.7
3.3	digital	TTCrx	0.200	0.2
3.3	digital	SPECS	0.330	0.2

3 Characterization

To establish a test setup resembling the planned Silicon Tracker electrical layout, we had a look at the planned partitioning of detector as described in the TDR [2]. A key parameter is the modularity of the Silicon Tracker. A silicon strip detector will be read out by three Beetle front-end chips sitting on a common hybrid. As this is the smallest group, which could be power cycled, it is currently planned to supply the digital and analogue power bus of a readout hybrid by a single regulator each. This results in a number of two regulators per detector ladder with a 2 W load on the analogue 2.5 V line and 0.4 W on the digital line. As this is well within the maximum current which can be delivered by the regulator, we chose the Beetle analogue 2.5 V supply to be a typical regulator load for the following testing. Because any power dissipation inside the detector box complicates the cooling of the silicon detectors, our current design plans to locate the voltage regulators in the service box, located on the mounting frame of a tracking station. This also simplifies cooling, as the service box is outside the detector acceptance. However, this results in a distance of approximately 3 m between the regulators and the load. Consequently, we included testing loads attached to the regulators with similar cables to determine the functionality and stability of this configuration.

The circuit used for characterization of the regulator is based on the circuit described in the datasheet[1] (Figure 1). To study the effects of line resistance in both sense and power lines, we included the possibility to exchange these components on the test board. The regulator load was also exchangeable to allow for studies of any load current dependent effects. To measure the load current, a 0.1 Ω resistor was placed in series to the load resistor, with an oscilloscope probe measuring the voltage across it. The regulated voltage was measured with a second probe across the combination of load and current measurement resistor.

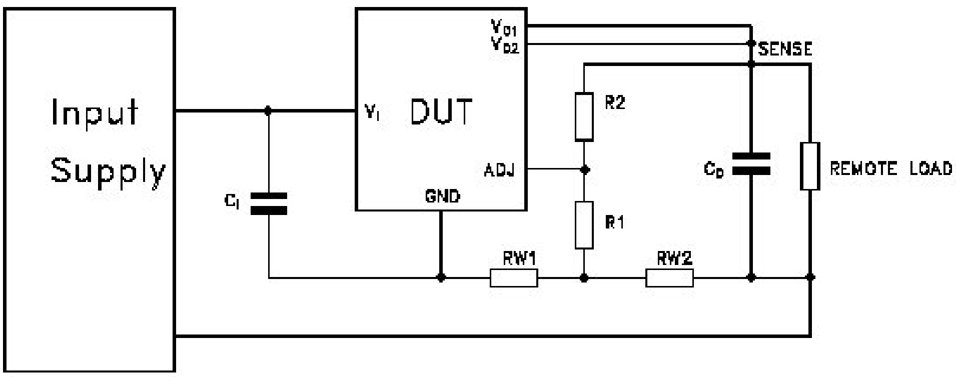

Figure 1: Basic schematic for the LHC4913 regulator.

3.1 Regulator setup

The following paragraphs describe the setting up of the regulator for an initial testing of the load behaviour when using long cables. This was done only on a single sample to gain experience when using the regulator.

Inhibit Pin By applying a HIGH level to the inhibit pin, the user can switch off the regulator. This has been tested by scanning the inhibit input voltage range and check the regulators operation. It has been found, that the device switched on at voltages smaller than 1.1 V, which is in accordance to the maximum guaranteed voltage of 0.8 V quoted in the specifications. The regulator switches off at voltages above 1.7 V, which is as well below the quoted 2.4 V of the datasheet.

SH-CNTRL Pin The SH-CNTRL pin gives the user control over the current limit built into the regulator. In case of excessive current, the regulation shuts down and the regulated voltage decreases. The limit can be set externally by a resistor R_{sh} connected from the SH_CNTRL pin to the input voltage.

In Figure 2, the current limit is plotted for different applied resistor values. As the regulation is turned off when reaching approximately 66 % of the preset current limit, it is suggested to set the current limit 50 % higher than expected for a worst case operation scenario. This secures the availability of a stabilized voltage for all operation modes.

OCM Pin When being driven into the overcurrent protection, the regulator signalizes this by pulling the OCM pin down to a voltage of 0.4 V. It is at the input voltage, when the regulator is in normal operation.

ADJ Pin For the ease of testing, we chose to apply a 1:1 resistor divider to the ADJ pin. According to the datasheet, this results in an output voltage of twice the reference voltage of 1.245 V. As this 2.45 V was close enough to the 2.5 V level, which was subject to be tested, we stayed with this divider rather than optimizing for accurate 2.5 V output voltage. It will be shown later, that the output voltage rises with rising load current, so staying slightly below the targeted 2.5 V seems to be appropriate.

3.2 Load attached with cables

From experience, it is known that, while regulators can keep the output voltage stable when connected directly to the load, this is not guaranteed for distant loads, where most regulators tend to develop oscillations. To investigate this, we used three cable sets with different cross sections and lengths. This influences the cable inductance as well as the series resistance, providing very different loads seen by the regulator. In addition, we characterized the performance for different load currents.

Cable 1 The first cable set consisted of two cables, one for the power lines and one for the sense lines. While both had a cross section of 0.14 mm^2, the sense line had a length of 40 m and the power line only 27 m. This resulted in line resistances of 6 Ω and 3.8 Ω respectively.

This setup produced oscillations in the order of 2-3 V, which disappeared when increasing the load current (Figure 3). Hardly any difference could be seen, whether the cable was wound on a spool or rolled out. By applying the capacitance at the regulator between V_{out} and GND instead of connecting it parallel to the load, the current needed for non-oscillating operation became larger.

Cable 2 The second cable was of the same cross section as before (0.14 mm^2) but included 4 different signal lines, i.e. power as well as sense lines were combined in one cable. In addition, we limited the cable length to 5 m, which is still well beyond the 3 m planned for installation in the LHCb experiment. The results are shown in Figure 4.

Again we observed oscillations, which only disappeared when drawing high currents. When moving the additional capacitance away from the regulator directly to the load itself, the performance improved significantly with a capacitor of 4.7 μF being sufficient for a stable operation at 1 A current. However, we observed a oscillation at a capacity of 11 μF. We believe that this is most likely some resonance with this very specific type of cable and length since for higher and lower values of capacity, the oscillation disappeared quite rapidly. We also observed slightly improved stability when increasing the input capacitance from 100 nF to 10 μF.

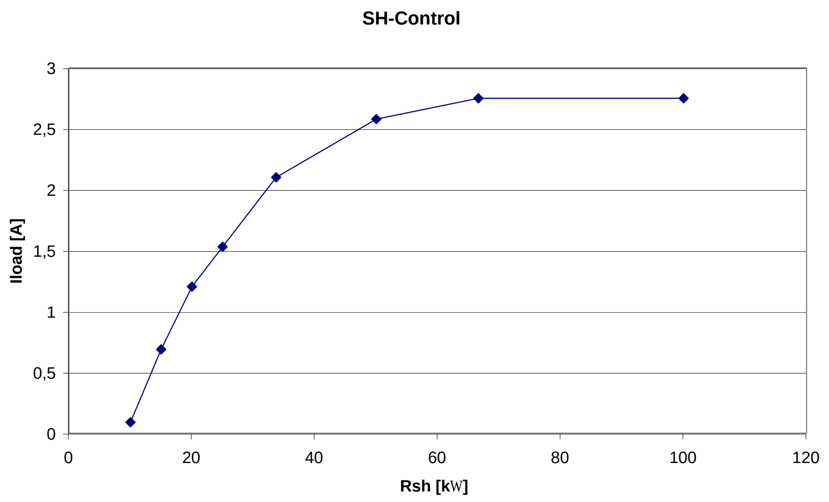

Figure 2: current limit vs. R_{sh} value.

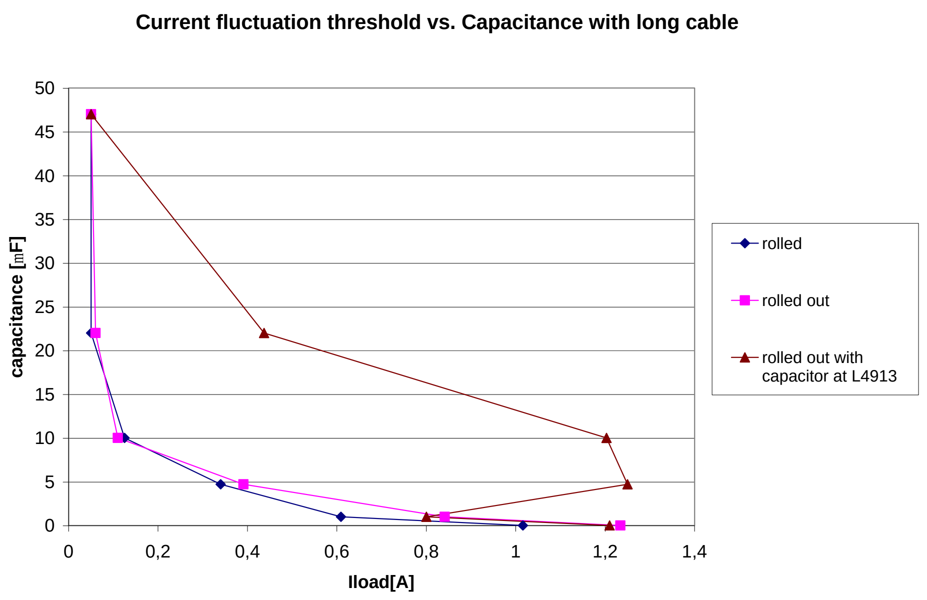

Figure 3: Oscillation current limit vs. capacitor at load.

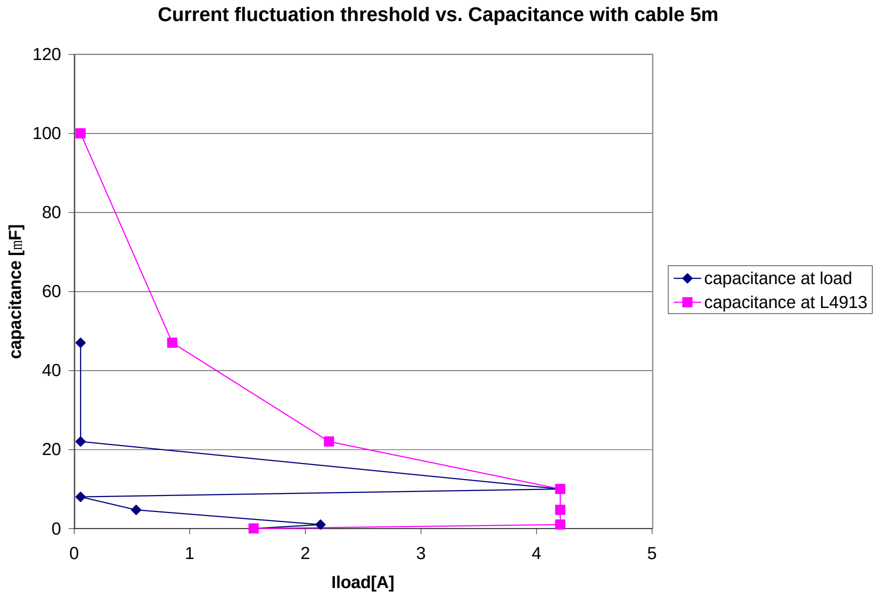

Figure 4: Oscillation current limit vs. applied capacitor.

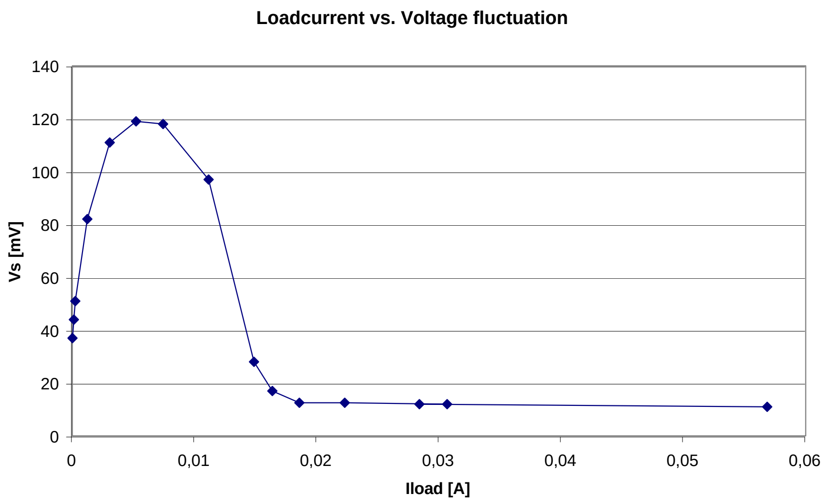

Figure 5: Oscillation for low current operation.

Furthermore, the regulator tends to oscillation when drawing very low currents. In Figure 5, the peak-to-peak value of the oscillation is shown for different load currents. This behaviour is known for voltage regulators and is normally not critical, as long as the minimum operational current is high enough for stable operation. This oscillation could be suppressed by applying a constant load of 33.3 Ω, which results in a base current of 75 mA. No further low current instability was observed. As the minimum current foreseen for circuits in the experiment is well above this value, this should not pose a problem to the final experimental setup.

A significant improvement in cable oscillation performance was observed when a capacitor (CVS) between the regulator output pins and the sense return line was used. By choosing a value of 1 μF, the oscillation disappeared completely. This was also the case when the cables were replaced by resistors for the sense and power lines of 10 Ω and 1 Ω respectively.

Cable 3 To further close in on a possible cable type for installation in the experiment, we also tested a cable with rather small cross section. We chose a cable from CERN stores (04.21.51.704.4), which is a AWG30 (0.05 mm^2) cross section cable with two signal pairs. One pair was used as power lines, the other for the sense lines. Again, the cable length was fixed to 5 m. The resistance was measured to be 1.8 Ω for a single line. With a load current of 1 A, no oscillation could be observed for the same setup as used for Cable 2.

We therefore selected this setup to be our testbench for testing the complete number of samples for suitability for the Silicon Tracker.

4 Complete sample testing

For the LHCb Silicon Tracker, 3100 positive voltage regulators have been delivered in December 2002. These were packaged in 10 lots of 310 parts each. Within each lot, the devices were packaged in 10 antistatic plastic tubes of 31 parts each. To get a representative sample of the whole order while keeping the number of parts to be tested low, we decided to pick two parts per lot, which were taken from two different tubes. To maintain traceability, all parts were labeled according to the lot (1-10) and the tube (A,B) from which they had been taken.

The parts were all assembled on individual testboards with the circuit shown in Figure 6. Except for the additional 1 μF capacitor between the output pins and the sense line, the 33.3 Ω base current resistor and the increased input capacitor of 10 μF, this is still the circuit as published in the regulator datasheet. The boards were tested for low-current stability and regulated voltage as well as for stability and regulated voltage when delivering 1 A current. The function of the Inhibit-pin was also verified. The results are shown in Table 2.

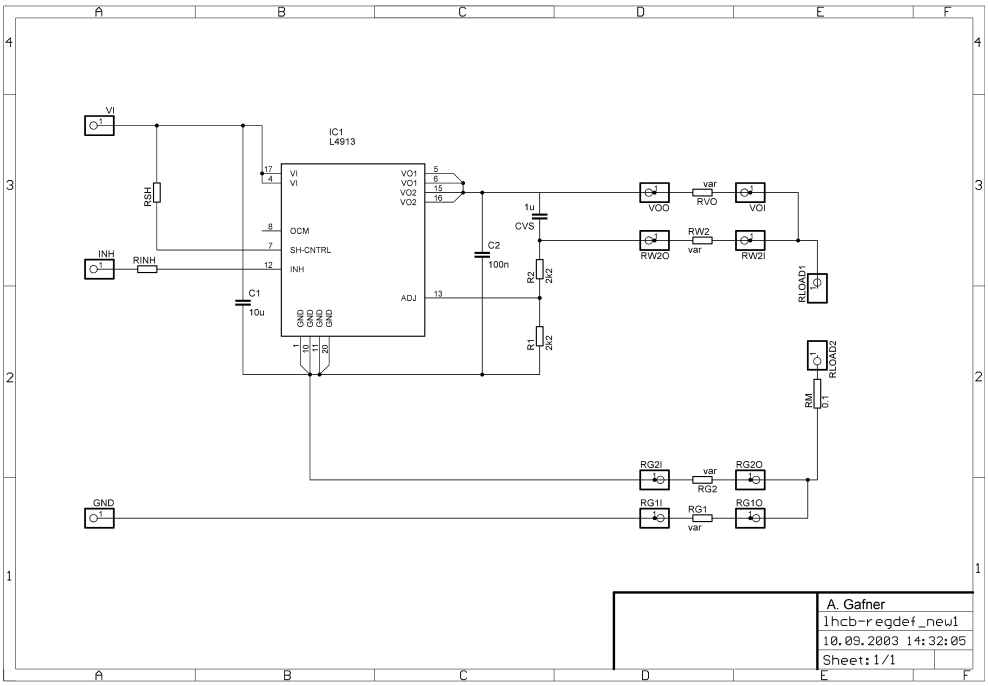

Figure 6: test circuit for the LHC4913.

Table 2: results of regulator sample testing.

Sample	Vout[V] @ I=0.03 A	Vout[V] @ I=1 A	Error[V]	Oscillation	INH-Pin
1A	2,429	2,456	0,003	no	good
1B	2,434	2,464	0,003	no	good
2A	2,445	2,473	0,003	no	good
2B	2,444	2,482	0,003	no	good
3A	2,415	2,453	0,003	no	good
3B	2,468	2,510	0,003	no	good
4A	2,430	2,478	0,003	no	good
4B	2,453	2,497	0,003	no	good
5A	2,441	2,477	0,003	no	good
5B	2,446	2,483	0,003	no	good
6A	2,447	2,490	0,003	no	good
6B	2,448	2,490	0,003	no	good
7A	2,449	2,496	0,003	no	good
7B	2,441	2,487	0,003	no	good
8A	2,429	2,474	0,003	no	good
8B	2,437	2,485	0,003	no	good
9A	2,455	2,507	0,003	no	good
9B	2,465	2,509	0,003	no	good
10A	2,467	2,508	0,003	no	good
10B	2,431	2,480	0,003	no	good
Mean	2,444	2,485			

No tested device was out of specifications or showed instability.

5 Conclusion

A detailed characterization of the LHC4913 positive voltage regulator was performed for a single sample. Good performance concerning regulation stability for long cables was found when applying minor changes to the schematics proposed in the datasheet. For this upgraded schematic, sample testing of 20 units was performed for the LHCb Silicon Tracker production batch of 3100 units. All tested units have been found to work within the specification. We therefore conclude the suitability of the available production batch for use in the Silicon Tracker.

References

[1] ST Microelectronics, LHC4913 datasheet, August 2002, http://lhc-voltage-regulator.web.cern.ch/lhc-voltage-regulator/Specifications/L4913ds_updatedSpecs_August_2002.pdf

[2] LHCb Collaboration, LHCb Inner Tracker Technical Design Report, November 2002, CERN-LHCC-2002-029