

## DC-DC Conversion Powering Schemes for the CMS Tracker Upgrade

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The CMS experiment foresees upgrades of its silicon pixel and strip detectors for the luminosity upgrade of the Large Hadron Collider (LHC), CERN. Due to an increase in the number of readout channels and higher complexity, larger currents will have to be provided to the detector. Since cable channels are difficult to access and space for cables is limited, this would lead to excessively large resistive power losses in the supply cables, which increase with the current squared. CMS has therefore chosen a novel powering scheme based on DC-DC converters, which allows power to be delivered at a higher voltage and consequently lower current. The development of low-mass, low-noise DC-DC converters for application in CMS is presented, including studies of switching noise, magnetic emissions and power efficiency as well as system tests with silicon strip and pixel modules. A scheme for the integration of DC-DC converters in the silicon pixel detector, currently foreseen to be exchanged around 2016, will be discussed.

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## 1. Introduction

During the next ten years, the LHC instantaneous luminosity will be raised in steps from the design luminosity of  $1 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  up to  $5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . To cope with the increased radiation levels and particle rates, the CMS collaboration foresees the installation of new pixel and strip detectors [1]. These devices will require more power, due to an increase both in the number of readout channels and in complexity. This power cannot be provided through the current cable plant and additional cables cannot be installed due to lack of space and limited access. A novel powering scheme based on on-detector DC-DC converters would allow this problem to be overcome: the power would be delivered at a higher voltage and lower current, reducing Ohmic losses in supply cables, which scale with the current squared. The currently preferred option are DC-DC buck converters, which are based on two power transistors, an inductor as energy storage element, and input and output filters. The load is periodically connected to, and disconnected from, the power source, and the output voltage is regulated via a feedback loop based on Pulse Width Modulation.

## 2. DC-DC Buck Converter Development and Integration

Buck converters have been developed for applications within the CMS tracker. Our most recent PIX\_V7 prototype (Fig. 1, left) is based on the radiation-tolerant AMIS2 buck converter ASIC by the CERN electronics group [2]. The inductor is a custom air-core (ferrites saturate in the CMS 3.8 T magnetic field) toroid with an inductance of 450 nH. Pi-filters are installed at the in- and output. The converters can deliver up to 3 A, tolerate input voltages of up to 12 V, and switch at 1.3 MHz. The footprint of the board is  $28 \times 16 \text{ mm}^2$ .

Currently the focus is on the application in the future pixel detector, to be installed in 2016/2017. The converters will be located on the pixel supply tube, outside the sensitive tracking volume and at a distance of 2 m from the pixel modules. The converters are configured to provide the analogue and digital supply voltages of 2.5 and 3.3 V, respectively. One pair of converters will power between one and four pixel modules. With an input voltage of about 12 V, a conversion ratio of around 4 will be realized. The converters will be installed on dedicated bus boards, and be cooled through a PCB backside contact, using thin CO<sub>2</sub> cooling pipes, as shown in Fig. 1.

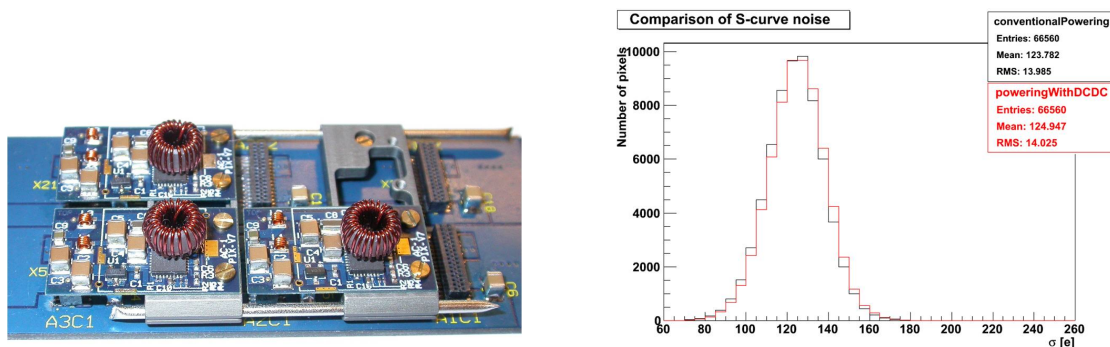
## 3. Performance of DC-DC Converters

The performance of the PIX\_V7 prototypes has been studied in detail [3].

The power efficiency has been measured as a function of load current and input voltage and amounts to 75-80 % for operating conditions as expected for the future pixel detector.

High frequency switching can lead to both conductive and radiative noise emissions; the latter is relevant since air-core inductors have to be used. Radiative noise emissions have been analyzed with a magnetic pick-up probe, and various types of shields have been developed and studied. For example, a low-mass aluminium shield with a thickness of 90  $\mu\text{m}$  (plus a thin layer of Cu/Ni to ease soldering) has been manufactured and found to eliminate noise emissions almost entirely.

Conductive noise emissions have been studied with an EMC set-up based on a current probe connected to a spectrum analyzer. Both Differential and Common Mode noise have been minimized by filter and PCB design and by segregation of noisy parts from quiet parts on the board.



**Figure 1:** Left: PIX\_V7 DC-DC converter prototypes, installed on a bus PCB, with a mock-up of the cooling. Right: Distributions of the width of the s-curve noise including all pixels from one module, for conventional powering (black) and powering via PIX\_V7 converters (red).

System tests with a current pixel module have been performed to study a potential degradation of the module performance due to the remaining noise level. The module noise, quantified as the width of the s-curve, has been measured when powered from a lab supply or from DC-DC converters. As visible from Fig. 1 (right), the noise is not increased by the use of DC-DC converters.

Finally the cooling performance was studied. Due to the finite converter efficiency the power dissipation is sizeable, and active cooling of the converters has to be provided. While the chip is cooled via a large ground surface on the PCB backside, the inductor is cooled via the shield, which is soldered to the ground plane and serves to transport the heat from the coil to the PCB backside. For this purpose, the shield is filled with heat conductive paste. Measurements showed that the temperature of both chip and coil is at most 15 K above the temperature of the cold surface to which the converter was attached. Without the shield, the temperature difference between coil and surface can reach up to 80 K. These measurements are confirmed by Finite Element calculations.

#### 4. Summary

A DC-DC converter based powering scheme is foreseen for the CMS pixel upgrade. The development of DC-DC converters for this purpose is well advanced, and our prototypes perform well. Future R&D will concentrate in particular on the reduction of the converter material, as required for an installation closer to the detector modules in a future strip tracker.

#### References

- [1] The CMS Collaboration, *Technical Proposal for the Upgrade of the CMS detector through 2020*, CERN-LHCC-2011-006.
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- [3] K. Klein et al., *Powering for Future Detectors: DC-DC Converters for the CMS Tracker Upgrade*, PoS(Vertex 2011) 041, and references therein.