Realisation of Serial Powering of ATLAS pixel modules

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Abstract

Modern pixel detectors for the next generation of high energy collider experiments like LHC use readout electronics in deep sub micron technology. Chips in this technology need a low supply voltage of 2 V to 2.5 V and a high current to achieve the desired performance. The high supply current leads to significant voltage drops in the long and low mass supply cables so that voltage fluctuations at the chips result, when the supply current changes. This problem scales with the number of modules when they are connected in parallel with the power supplies. Therefore, the parallel powering scheme imposes severe constraints on a detector with respect to voltage fluctuations and cable mass. An alternative powering scheme connects several modules in series resulting in a higher supply voltage but a lower current consumption of the chain and therefore a much lower voltage drop in the cables. In addition the amount of cables needed to supply the detector is vastly reduced. The concept and features of serial powering are presented and studies of the implementation of this technology as an alternative for the ATLAS pixel detector are shown. Measurements and comparisons of the performance of several modules powered in parallel as well as in series will be presented. This serial powering concept was found to be a viable and attractive alternative for powering in future large scale pixel vertex detectors or for LHC upgrade pixel detectors.

1. Introduction

Most particle physics experiments at future colliders plan to use a pixel detector as the central tracking device. In the LHC experiments so called ‘hybrid pixel’ detectors are used. The basic component is a module that consists of a silicon sensor connected to several front end chips via bump bonds. All components have to operate in a harsh radiation environment fluences up to $1 \cdot 10^{15} n_{eq} \cdot cm^{-2}$ over the full lifetime of the experiments. To achieve the necessary radiation tolerance all new readout systems are done in a deep sub micron technology that proved to be radiation tolerant when special design rules are used. One of the characteristics of this technology are the low nominal supply voltage of around 2 V and the sensitivity against voltage spikes above ≈ 4 V.

Due to the low mass and the length of the cables required by the experiment the voltage drop along the cables is significant and in the order of several times the supply voltage. This leads to a rising supply voltage at the front end chips when the current consumption of the chips drops with the risk to destroy the chip. Therefore the requirements for the diameter of the power leads are contradicting: large to minimize the voltage drop on the lines on one hand, and small to limit the material inside the active area on the other hand.

The goal of the development of *serial powering* is to significantly reduce both, the current consumption of pixel detectors and the number of power lines. The

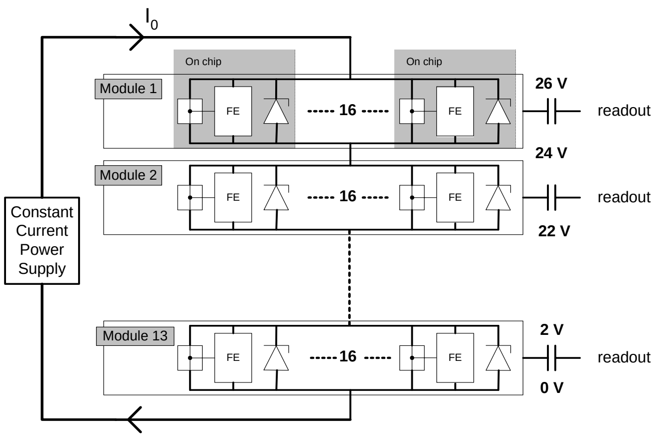

Fig. 1. Schematic of a serial powering set-up. A constant current power supply generates a current I_0. This current is fed in a chain of modules each equipped with regulators to generate the supply voltages

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next section presents the basic principle of serial powering of pixel modules and the implementation of this technology for the example of the ATLAS pixel detector.

2. Basic Scheme

Fig. 1 illustrates the basic scheme of serial powering. A constant current power supply generates a current I_0, equal to the maximum current consumption of one module. This current is fed into a chain of several modules. Each module has a regulator for each supply voltage, generating the supply voltage out of the constant current. The ground of the first module is connected to the supply voltage of the next module. Thus all modules are on a different DC potential and an AC coupling for the readout signals is necessary. In the shown example two different types of regulators are used. A shunt regulator, which works like a Zener diode, transforms the constant current into the digital supply voltage and a linear 3-point regulator derives the analogue supply voltage from the digital voltage.

3. Example

To illustrate the advantages of serial powering in comparison to a parallel approach, the aspects of both techniques are discussed for the example of the ATLAS pixel detector.

Table 1. Comparison between serial vs. standard powering for 13 modules

	Noise [e]	Thresh [e]	Dispersion [e]
Module 1	220	3300	101
Module 2	212	3413	120
With Caps	149	3072	50

Tab. 1 shows the difference between parallel and serial powering for one stave of 13 modules in the number of power supplies, external regulators, the number of cables, the power consumption of the modules and in the cables. The calculations show that, for the example of ATLAS pixels, serial powering needs no external regulators, 52 times fewer cables, and nearly 3 times less power than conventional powering.

4. Prototyping results

The prototyping of serial powering for the ATLAS pixel detector is divided into several stages. The first tests were done with a series of external regulators and full modules equipped with radsoft prototype FE-chips. In the second stage several different regulators were implemented into the front end chip in DSM 0.25 µm technology and the performance of one module with different regulators was compared with a standard powered module. In the third stage the measurements were extended to a full chain of six modules with two modules data taking at the same time.

4.1. Comparison of different regulator configurations on one module

Table 2: Measured noise, threshold, threshold dispersion and timewalk of one module with different configurations of power regulators

	Serial powering	Standard powering
No. of ps / ext. reg.	1 / 0	6 / 13
No. of cables	2	104
Power on module	78 W	68 W
Power in cable	19 W	191 W
Sum	97 W	260 W

In total five different power regulators are implemented in the latest version of the front-end chip: three shunt regulators with different threshold voltages and two programmable linear regulators with different output voltages. The regulators were used in two different ways to power the module with a constant current: a) a shunt regulator providing the digital supply voltage and a linear regulator generating the analogue voltage; b) a shunt regulator generating a higher supply voltage fed into two linear regulators providing the two supply voltages of the FE-chips.

The two different constant current powering schemes and the normal powering with a constant voltage were tested on one module. The results are summarized in table 2. The use of the internal regulators cause a significant increase in the noise and the threshold dispersion of the module. After filter capacitors were added to one chip, i.e. using a filtering similar to normal powering, the noise and the threshold dispersion decreased for this chip and were even better than for the normally powered module.

4.2. Multi-module-test of serial powering

Table 3: Measured noise, threshold, threshold dispersion of two modules operating at the same time in a chain of six modules

	Noise [e]	Thresh [e]	Dispersion [e]	Timewalk [e]
Normal powering	159	3175	48	1300
Two Linear	170	3081	83	989
One Linear	200	3414	117	871
With caps	123	3067	45	886

Six modules set up in the scheme with one shunt regulator and one linear regulator were powered with a constant current in a chain. Three of these modules were connected to the readout system and generated data during the tests. For two out of the three modules the data is summarized in table 3. An increase of 10 % in noise and threshold dispersion was observed compared to the single operation of the modules. Again one of the chips of one module was connected to the usual filter capacitors with a vast improvement of the performance. This chip has noise, threshold and threshold dispersion similar to a module powered with a constant voltage.

Fig. 2. Picture of a system test of six serially powered ATLAS-pixelmodules on a stave

Conclusions

Serial powering has the potential to largely simplify service and powering of semiconductor modules. It significantly reduces the power, the number of power supplies and cables resulting in lower cost and material of the detector. A concept has been developed for serial powering the ATLAS pixel detector and found to be a viable alternative for future pixel vertex detectors or LHC upgrades. This concept was tested on one module with different configurations of regulators and in a small system test with six modules in a chain. An initially observed decrease in performance was shown to be caused by missing decoupling capacitors. With adequate decoupling of one chip its performance is absolutely comparable to a module powered with a constant voltage,