Serial powering for the Phase 2 upgrade of the CMS pixel detector

Vasilije Perovic  on behalf of the CMS Collaboration
- Instantaneous luminosity (design) to increase 7.5x

- **A number of technical novelties are needed**  
  *(Talk by S. Orfanelli on CMS Inner Tracker upgrade)*
Some of the challenges for the Phase 2 Inner Tracker

- High luminosity
  → Radiation-hard design

- Increased latency and hit rate
  - Smaller feature size (65nm CMOS)
  - Increased granularity
  → High supply current
    (~2 A /chip, ~30 kA total)

- Good tracking performance
  → Low mass design

Serial powering has never been attempted before in a HEP experiment.

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Serial powering

Parallel powering (current detector)

\[ I_o = nI_m \]

Power loss in parallel powering \( \sim n^2I_m^2R_C \)

Serial powering (Phase 2 detector)

\[ I_0 = I_m \]

Power loss in serial powering \( \sim I_m^2R_C \)
Serial powering

- Constant input current
- Different local grounds → on-chip reference needed
Serial powering

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- High Voltage distributed in parallel
  - Planar sensors (*talk by G.Steinbrueck*) can work with this
  - 3D sensors (*talk by M.Meschini*) require higher HV granularity
Serial powering

Possible forward bias with HV off (can be avoided)
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  → Modules with parallel-powered chips
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- Different local grounds  
  → **on-chip reference** needed

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  → Modules with parallel-powered chips

- **Ohmic load to the supply**
Serial powering – Shunt LDO regulator

- Constant voltage from the constant supply current
- Shunt + Low Dropout Regulator → ohmic behaviour is seen by the power supply
Serial powering – Shunt LDO regulator

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Serial powering

- Modules \(\rightarrow\) **serial powering**
- Chips on modules \(\rightarrow\) **parallel powering**
- HV distribution \(\rightarrow\) **parallel** and referenced to the local grounds in the **serial** chain
- Communication is **AC coupled** to **parallel-powered** readout electronics with **DC-DC converters**.

*We will essentially use a **mixed powering scheme**.*
Prototype test chip – RD53A

- Joint ATLAS and CMS effort
- About ½ size of the final chip (~1 A current)
- 65 nm CMOS technology

- Three powering modes:
  - Shunt LDO
  - LDO (no shunt)
  - Direct
Serial Powering – RD53A SLDO regulator

- **05A5_in**
- **05A5_analog**
- **05A5_digital**

Voltage $V_{in}$ vs. current $I_{in}$ at different levels:
- 1.0V
- 1.4V
- 1.2V
- $V_{offset}$

$V_{in}$, RD53A

$V_{analog}$

$V_{digital}$
Serial Powering – RD53A SLDO regulator

![Graph showing Vout vs. Iin for different input currents and voltage levels. The graph includes lines for 0.5A_in, 0.5A_analog, and 0.5A_digital, with voltage levels at 1.4V, 1.2V, and 2.0V.](image-url)
RD53A SLDO operation

Individual operation

Parallel operation
RD53A SLDO operation

Individual operation

Parallel operation

![Graph showing individual and parallel operation of RD53A SLDO operation.](image-url)
RD53A SLDO operation

- Can fail if input is ramped  →  fixed in RD53B (next version)
RD53A prototype modules
RD53A module SLDO operation

[Graphs showing the relationship between voltage (V) and current (Iin) for different ROCs (ROC0, ROC1, ROC2, ROC3).]
Serially powered RD53A modules

Pixel-by-pixel difference between serially powered and single modules

Module input voltage

- Ramp up
- Ramp down

Serially powered RD53A modules

Module input voltage
Summary

- High-Luminosity LHC will run at a luminosity increased by a factor of 7.5 compared to the current one
- CMS detector will undergo an upgrade to be able to cope with this increase
- Serial powering is one of the required novelties to meet these requirements

- RD53A prototype readout chip has been developed (joint ATLAS and CMS)
- Serially powered quad modules have been built
  - Serial powering is robust w.r.t. noise
  - Parallel powering on each module is beneficial for startup
  - Hysteresis is beneficial in preventing unwanted oscillations

- A chain of prototype modules has been operated and serial powering scheme successfully deployed.

- A lot of work ahead!
BACKUP