



Journées VLSI – FPGA – PCB et Outils CAO de l'IN2P3
15 – 17 Mai 2018

Shunt Regulator for ATLAS ITK Modules' Serial Powering

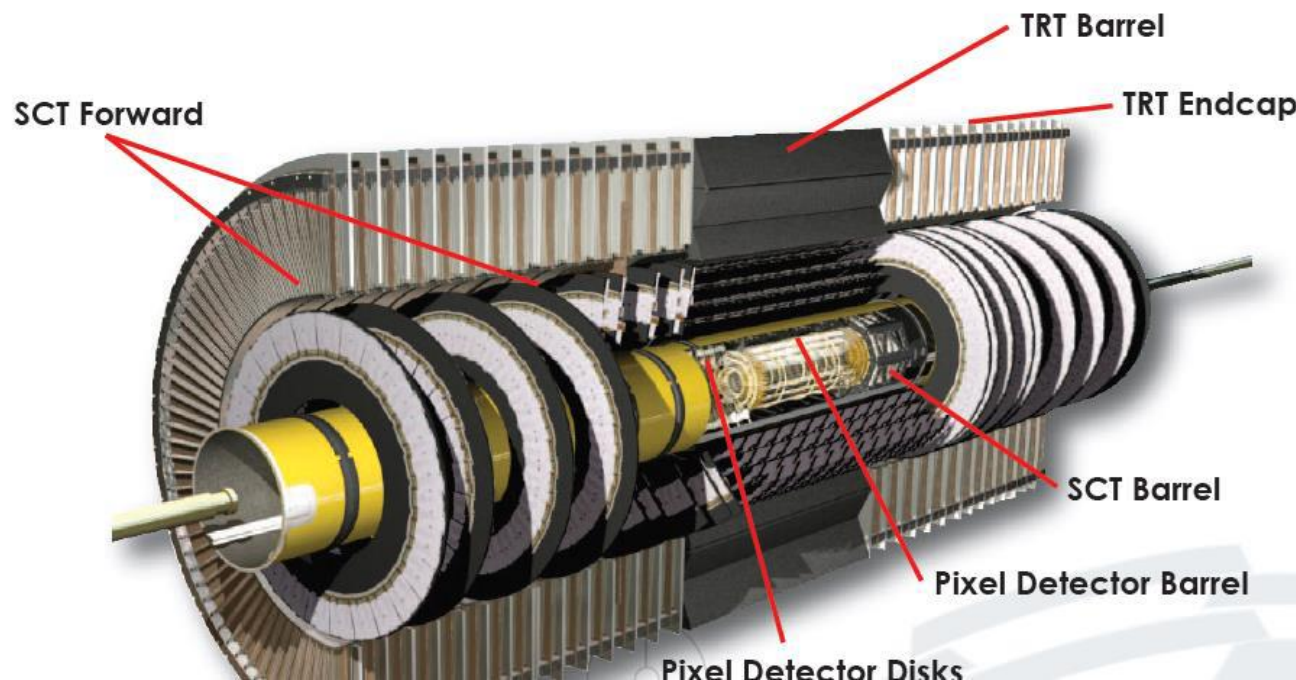
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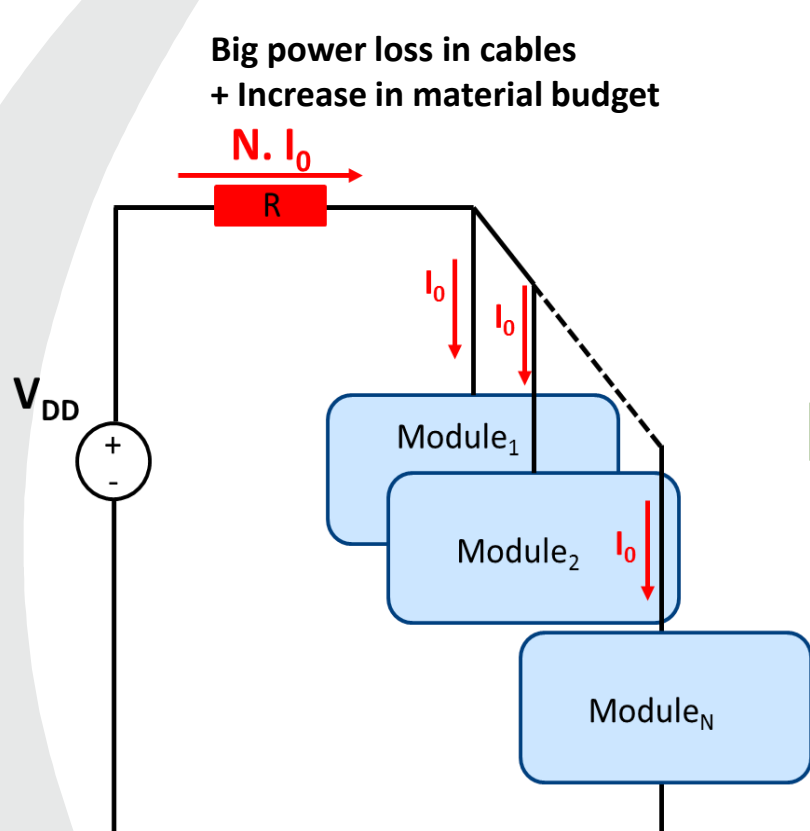
- **Why do we need serial powering?**
 - **Specifications**
- **Schematic and theoretical model**
- **Simulation results**
- **Conclusion**

ATLAS ITK Pixel Detector Upgrade For HL-LHC (Operation in 2026)

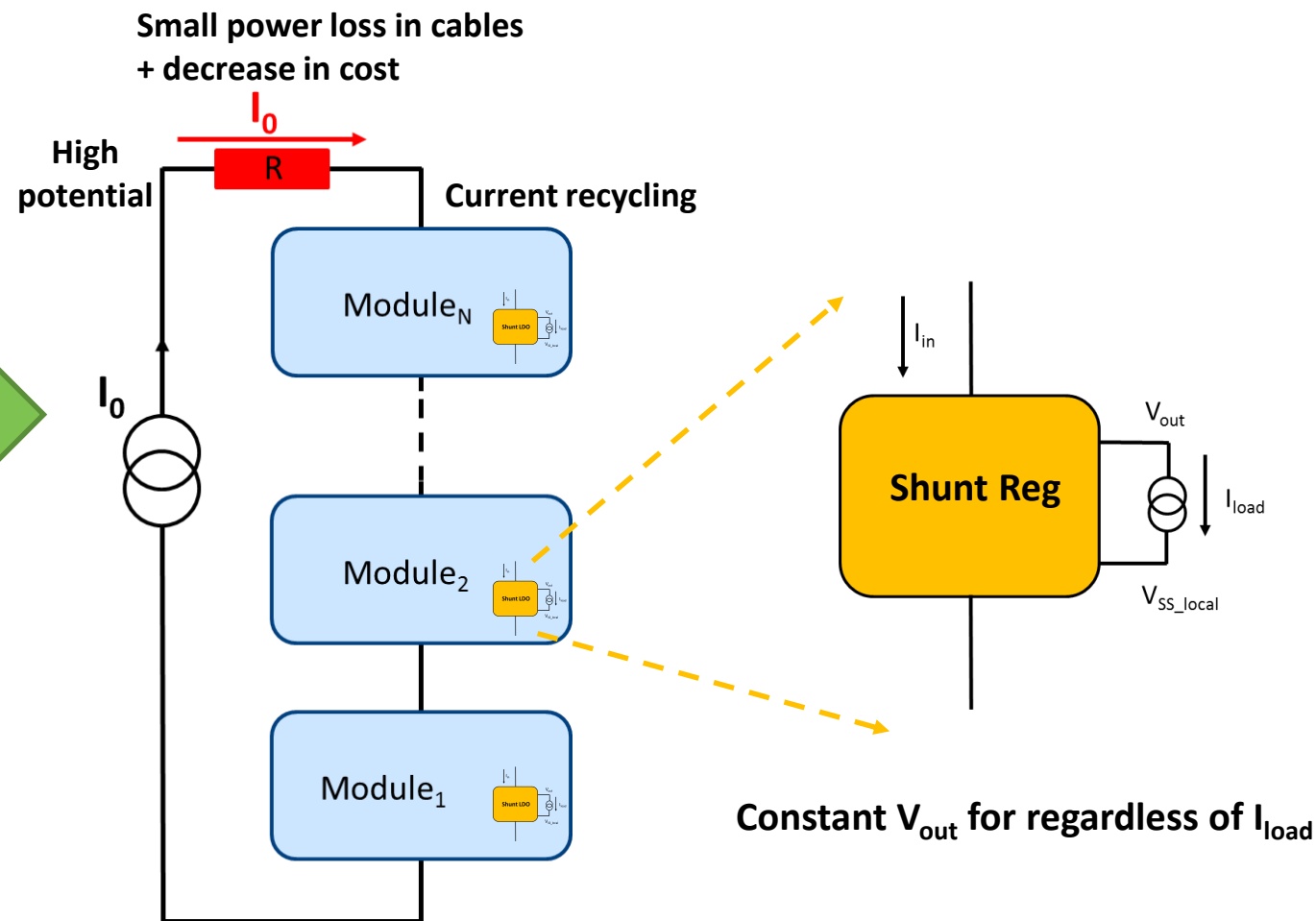
- Hybrid detectors for inner layers (RD53 collaboration)
- Monolithic detectors for the outer layer (HV-CMOS collaborations)
- Serial powering for all modules



Why do we need serial powering?

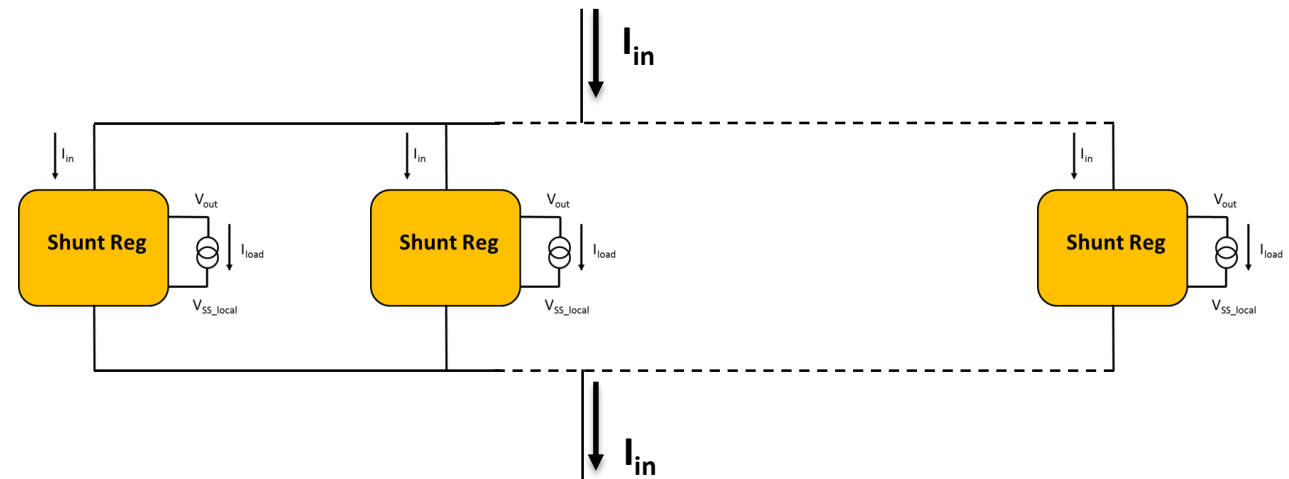


In the present ATLAS pixel detector, the power efficiency is around 20%



Increases power efficiency and reduces material budget

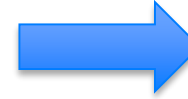
- **Stability for all possible values of C_L without an off-chip capacitor**
 - $C_L = [\text{pF} - 100 \text{ nF}]$ depending on the circuit to be powered
- **Equal current distribution in a parallel operation scheme**
 - 4 chips/ module, 1 regulator /chip
- **Modular structure**
 - $I_{in} = 10 \text{ mA/module}$, to be distributed as needed



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Theoretical Model

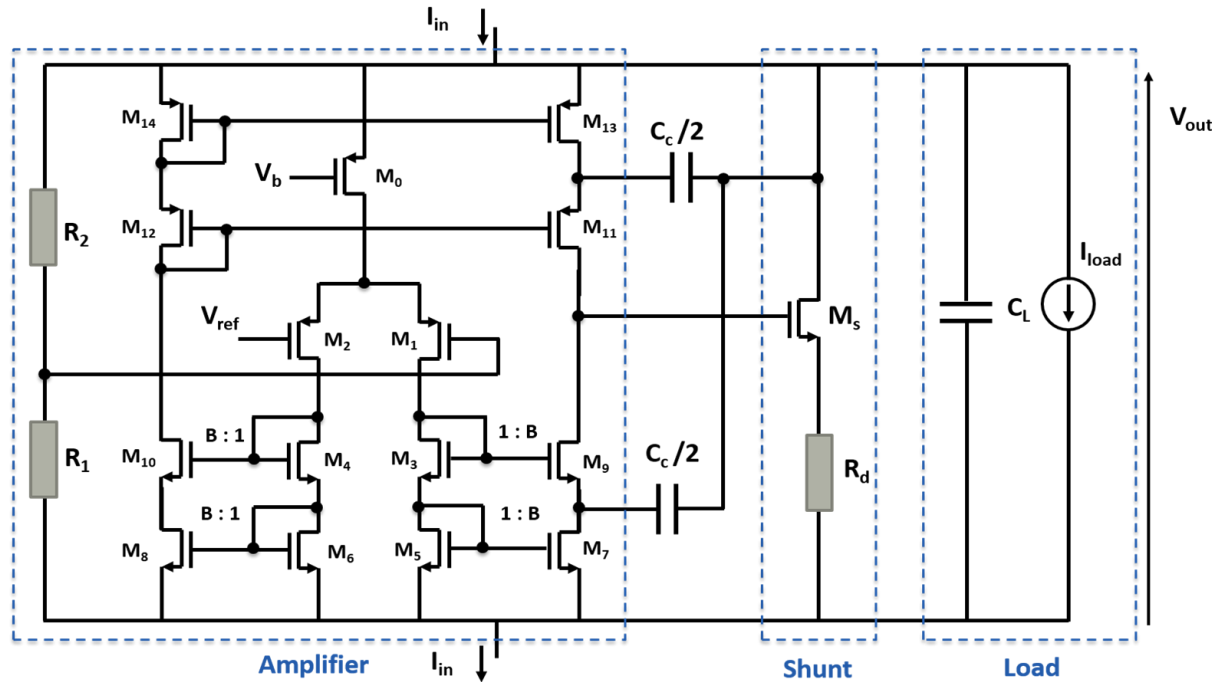
$$\frac{V_{out}}{I_{load}} = -R_0 \frac{\left[1 + \frac{s}{z_1}\right]}{1 + 2\zeta \frac{s}{\omega_0} + \frac{s^2}{\omega_0^2}}$$



$$R_0 = \frac{1}{\alpha g m_s B g m_1 R_A}$$

$$z_1 = \frac{1}{R_A C_A}$$

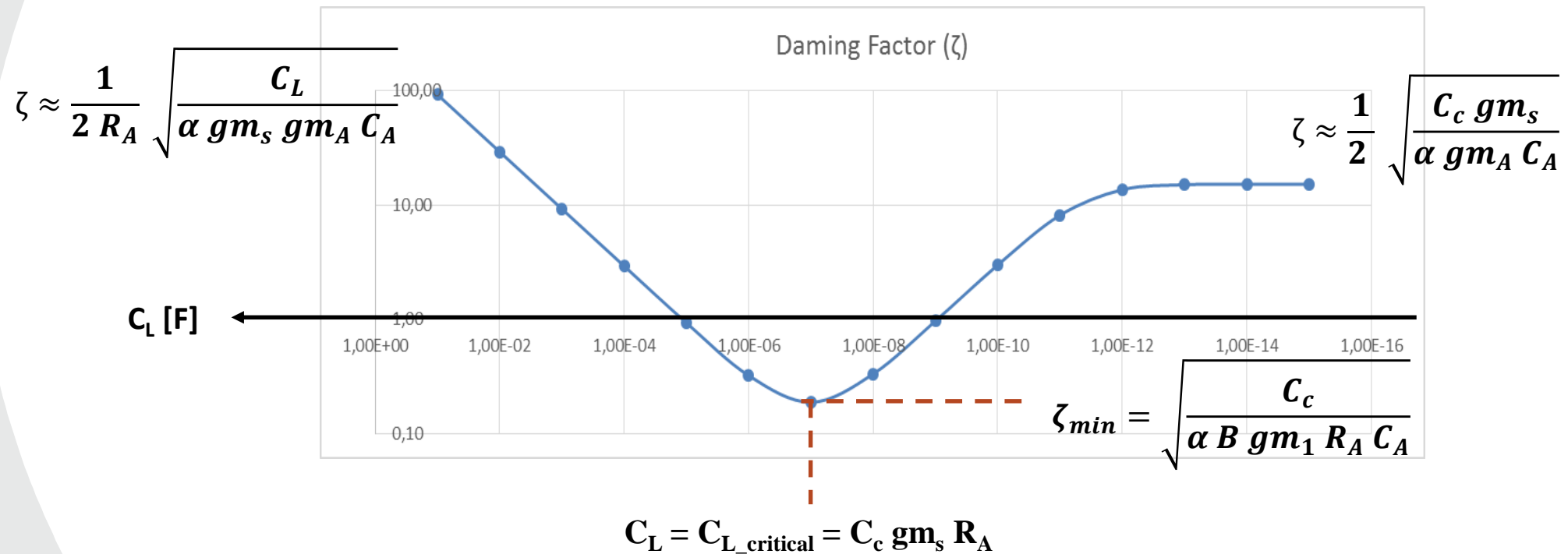
$$\omega_0 = \sqrt{\frac{\alpha g m_s B g m_1}{C_A(C_L + C_c)}}$$



$$\zeta = \frac{C_c g m_s R_A + C_L}{2 R_A} \sqrt{\frac{1}{\alpha g m_s B g m_1 C_A(C_L + C_c)}}$$

Stability Study

$$\text{damping factor } \zeta = \frac{C_c \, g m_s \, R_A + C_L}{2 \, R_A} \sqrt{\frac{1}{\alpha \, g m_s \, B \, g m_1 \, C_A (C_L + C_c)}}$$



If $\zeta_{min} > 0$ then stability is guaranteed for all values of C_L

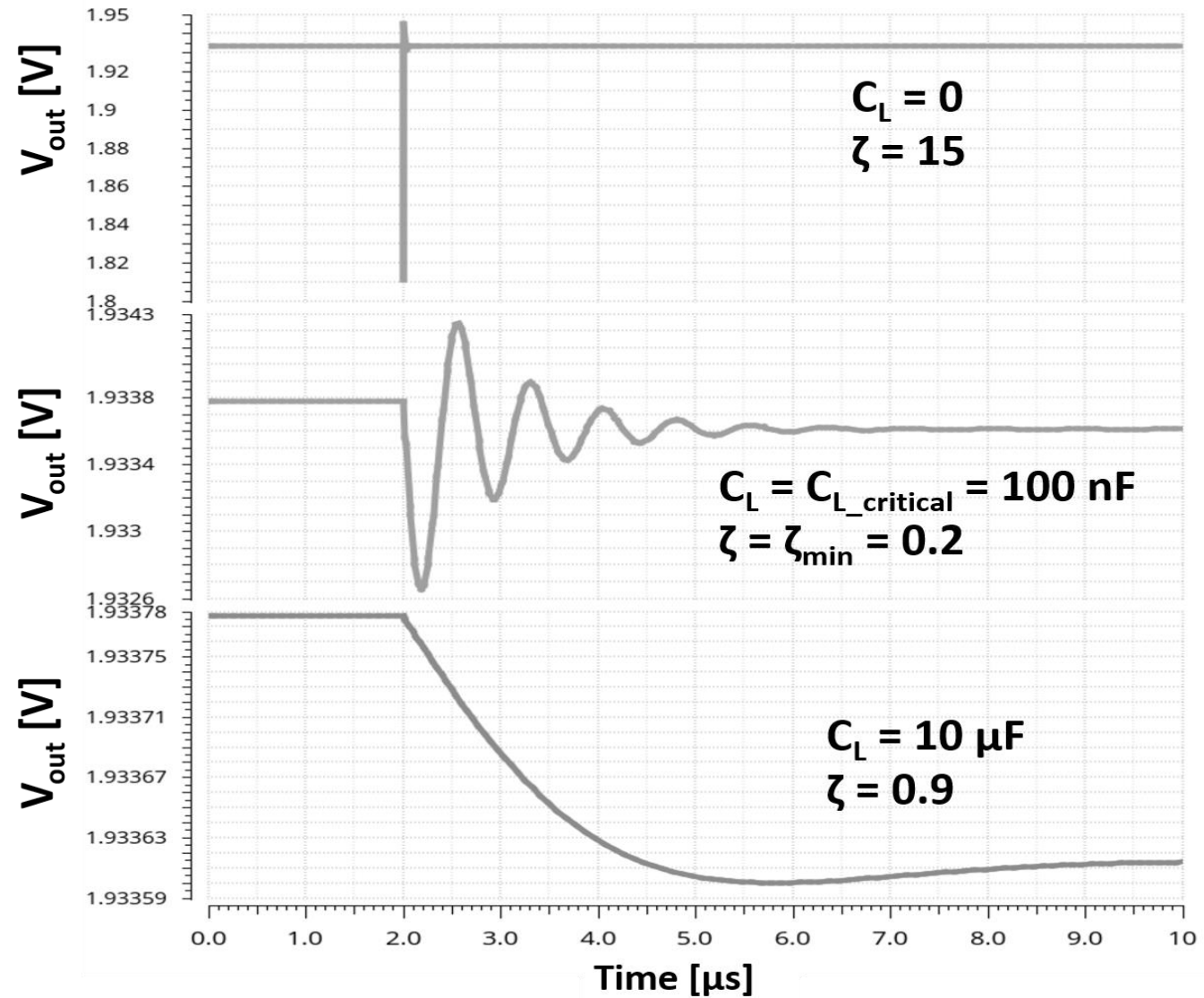
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Transient Simulation

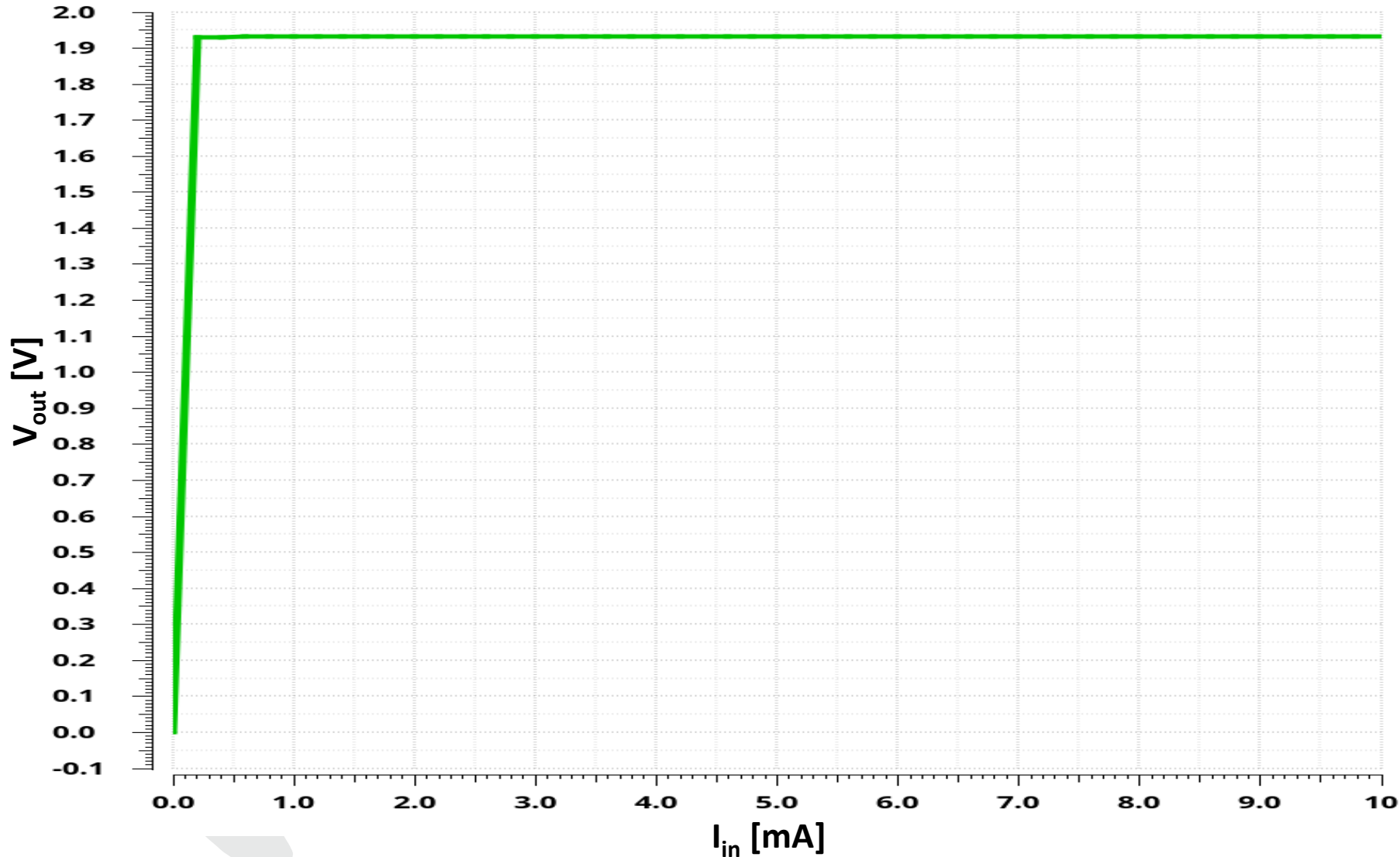
TJ CMOS 0.18 μm technology

- $C_c = 4 \text{ pF}$
- Step excitation on $I_{\text{load}} = 1 \text{ mA}$

System stable for
 $C_L = [0 - 10 \mu\text{F}]$

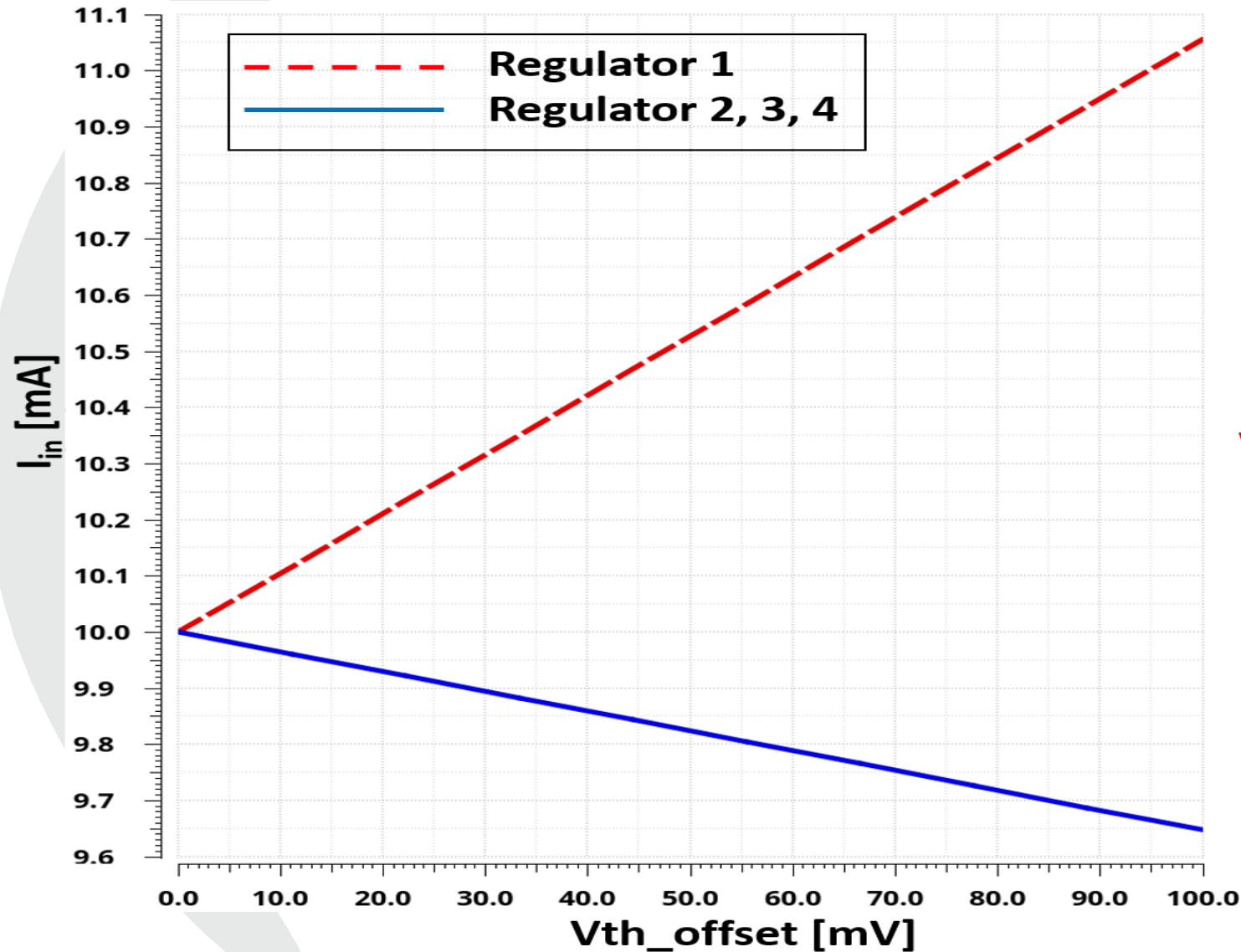


DC Simulation

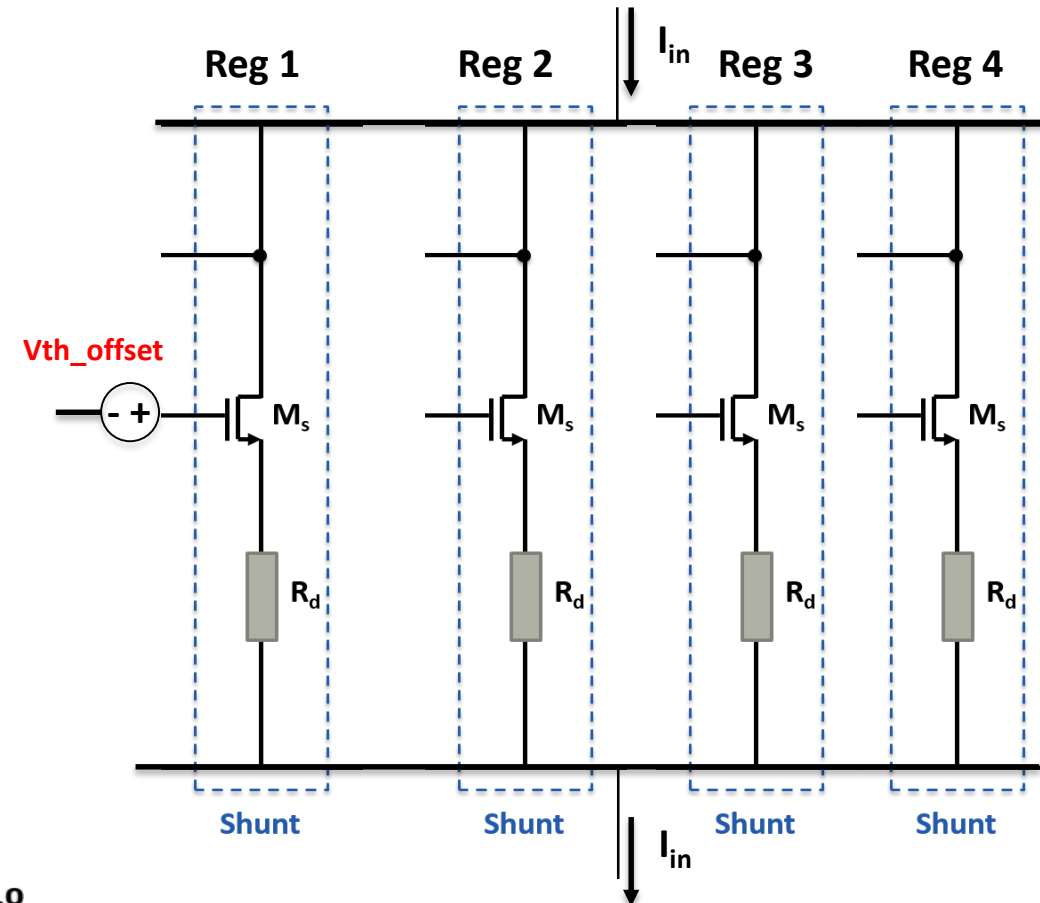


In DC, the regulator acts as an ideal voltage source in series with $R_0 = 175 \text{ m}\Omega$

The amplifier consumes $200 \text{ }\mu\text{A}$
Power efficiency: 98%



- Current mismatch < 10.5 % for Regulator 1 and < 3.5% for Regulator 2, 3, 4



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- A shunt regulator is designed for ATLAS ITK modules' serial powering
- The regulator is stable for all C_L [0 – 10 μ F] without an off-chip capacitor, and with a damping factor > 0.2 in all cases
- In DC, the regulator acts as an ideal voltage source with a 175 m Ω series resistance
- Current mismatch over 4 regulators is less than 11% for a voltage offset up to 100 mV
- The circuit is scheduled for fabrication in TowerJazz 0.18 μ m CMOS technology in August 2018