On-chip DC-DC charge pump for ATLAS FE-I4

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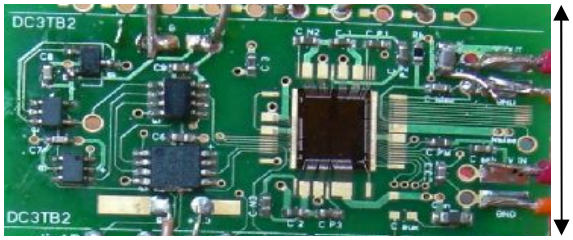
DC-DC converters for pixels

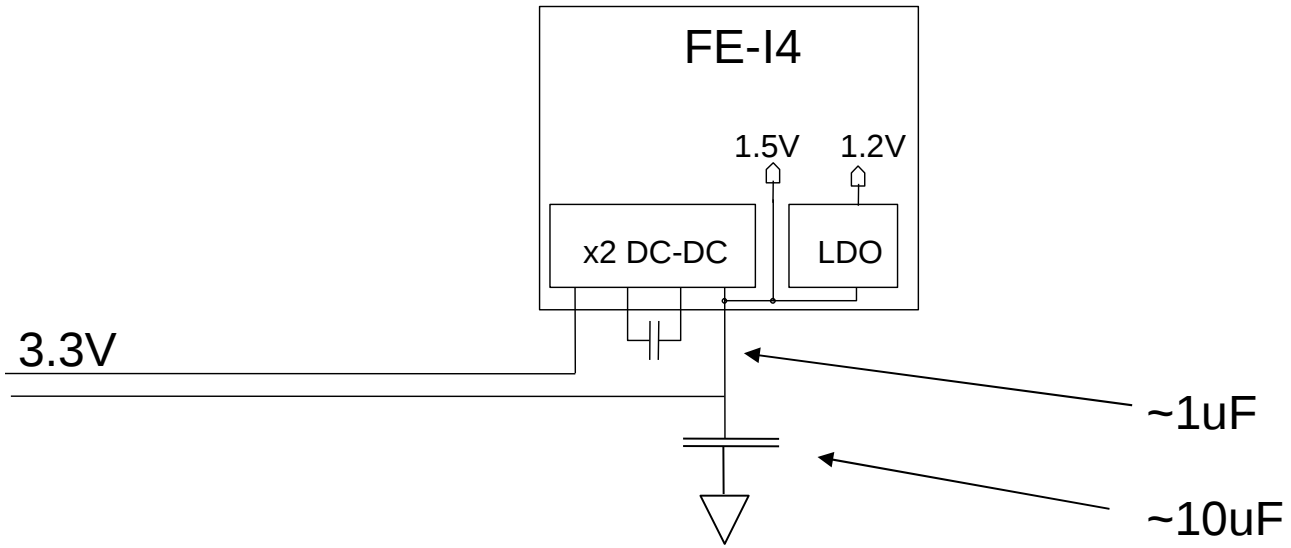
- Figure of merit (FOM) for silicon detectors: (Load resistance) x (active area)
  - of order 10 $\Omega.cm^2$ for pixel detectors and 100 $\Omega.cm^2$ for strips
- FOM for converters: $\varepsilon/(1-\varepsilon)$ x (output resistance) x (rad. Thickness) x area
  - Ratio of converter/detector FOMs gives radiation thickness penalty for using converters in active area
- x4 discrete charge pump made in 2007
  - FOM = 4%RL.$\Omega.cm^2$ at 80% efficiency



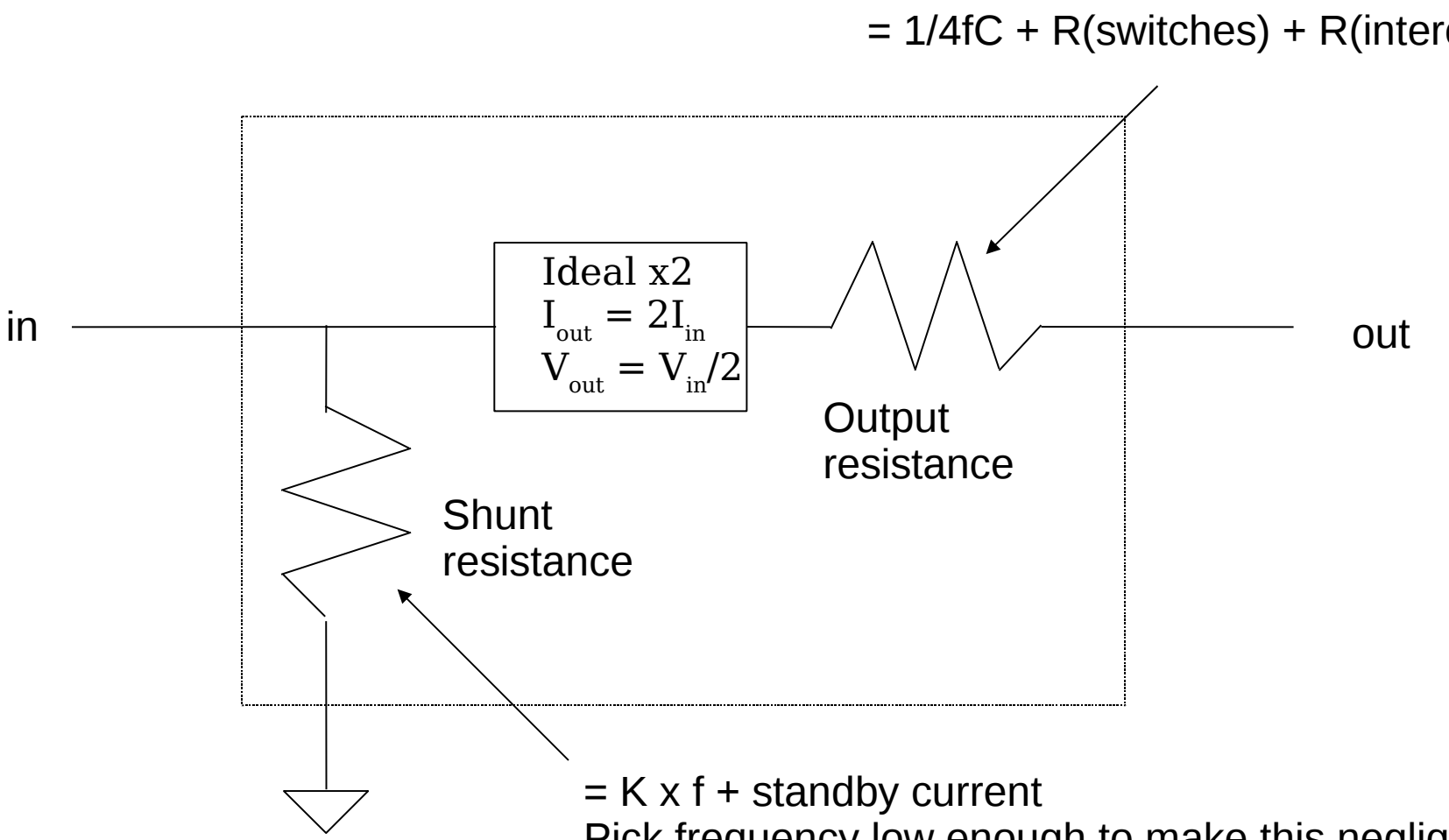
- Expected that with continued development could reduce FOM by factor of 2 in this type of device (2%RL.$\Omega.cm^2$)
  - Material penalty >0.2% per layer considered too severe for pixels.
- Therefore gave up on discrete converters for use inside pixel active volume
- Instead, prototyped x2 internal converter in FE-I4 test chip (received from MOSIS in June 2008)

FE-I4 charge pump DC-DC converter

- FE-I4 full chip predicted nominal current is 0.6A at 1.5V (A+D)
- R=V/I is 2.5 Ohms
- DC-DC output resistance must be 0.25 Ohms for 90% efficiency
- FOM very small- just one added external capacitor: 0.4%RL.Ω.cm^2

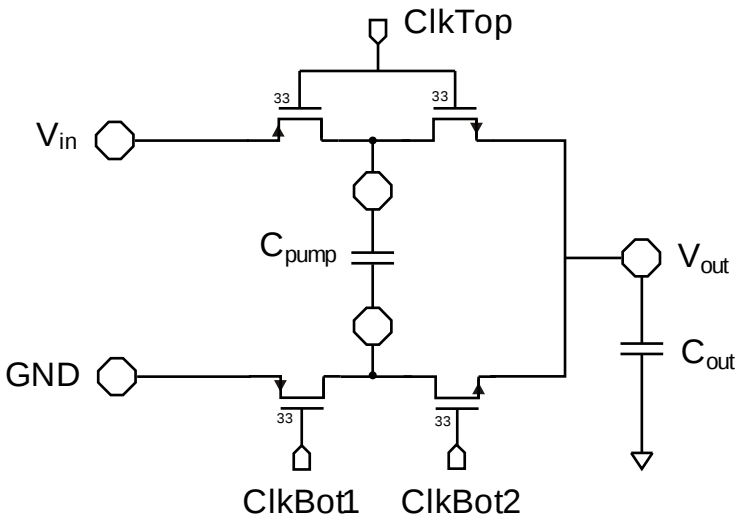


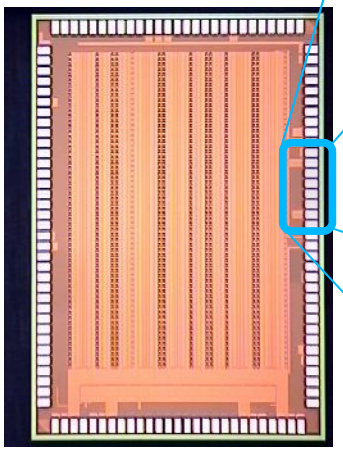
Equivalent circuit

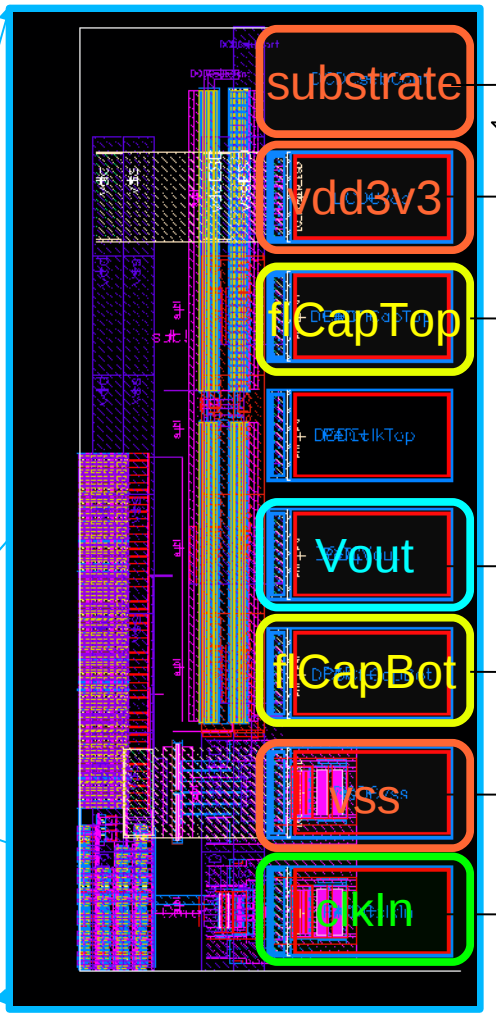


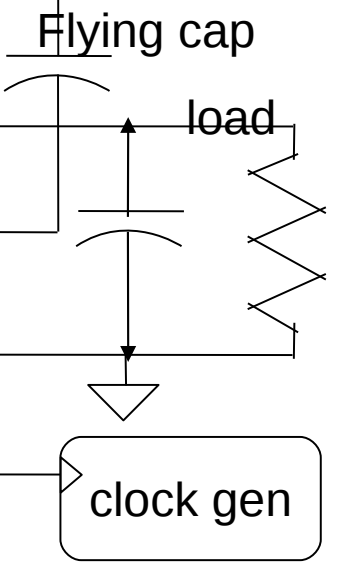
Converter built into 2008 test chip

- Schematic level output resistance is 2.2 Ohms for switches only.
- Circuit footprint is 20K um^2 (i.e. nothing)





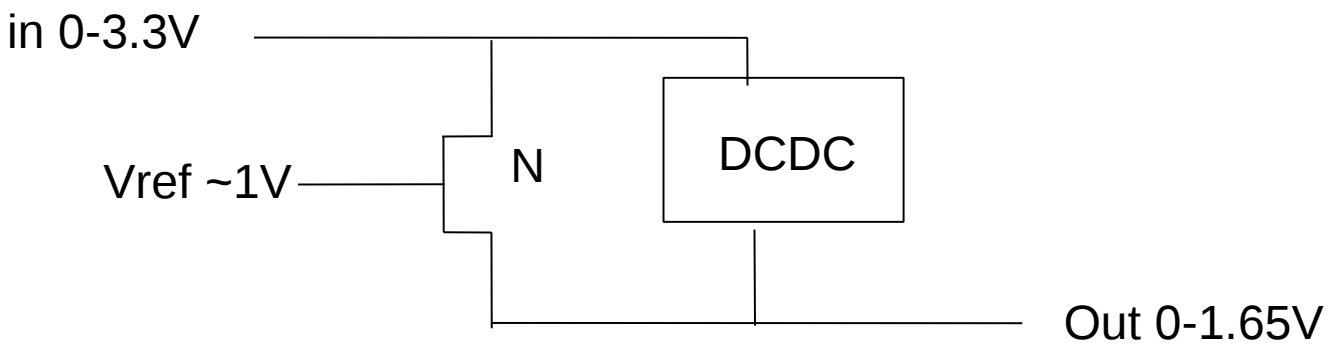




3.3V transistors!
Drawn with enclosed layout.

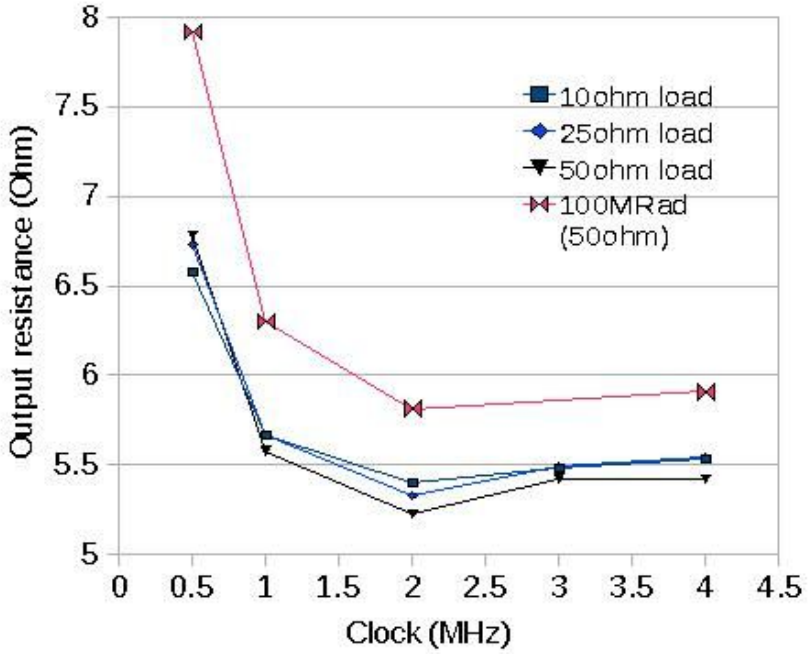
Making use of nice features

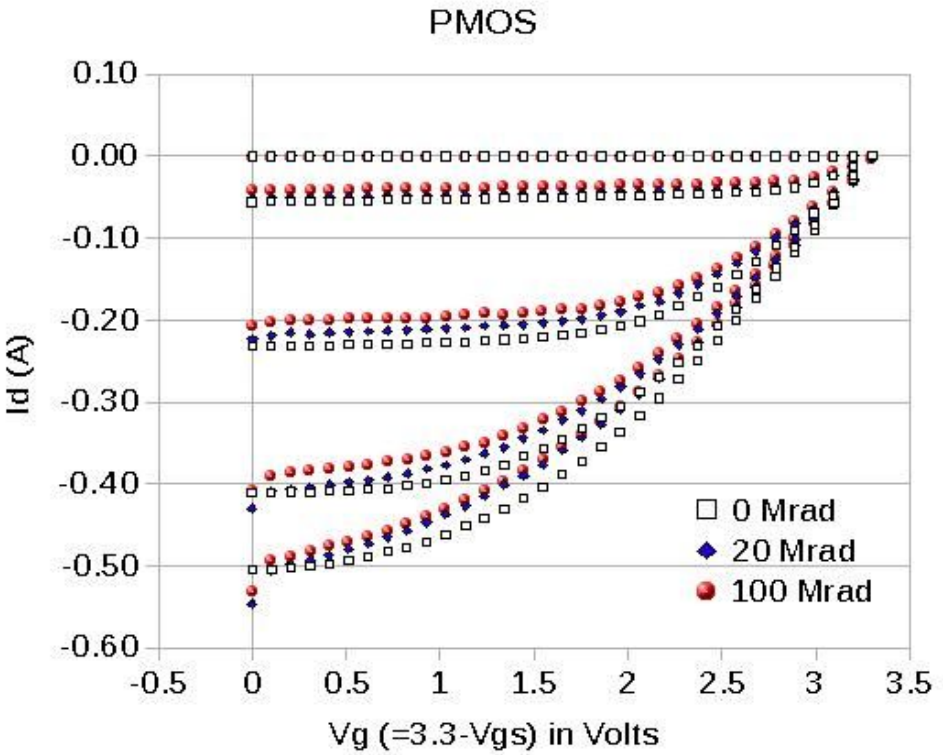
- Operates at constant frequency and duty cycle (simply divide down the 40MHz clock to drive it)
- Output voltage is a function of input voltage.
  - Maintain full control of chip voltage from the outside
  - No need for control lines or “intelligence”
  - Add a simple linear device so that chip voltage is controlled over full range (0 to max)
  - Chip is still powered even without clock (good for startup and failure recovery)



THE question for this converter

- Are the 3.3V transistors rad hard enough?
- Note that the requirements for use as switches are mild. Damage does not lead to failure, but to performance degradation, which if not very large can be compensated for in the design
- First proton irradiation to 100MRad in September 08. Next scheduled for Dec. 08





Conclusion

- In 2007-2008 moved from discrete DC-DC to internal x2 device.
- Internal device is better suited for low mass pixel layer hopes.
- Design and operation are extremely simple.
- Main question is radiation hardness of 3.3V EL transistors.
  - Being addressed with existing prototype.
  - 100MRad results show tolerable degradation.
- Functional studies also in progress.
  - No noise increase observed when powering chip with DC-DC converter instead of directly with LV supply.