Switched Capacitor DC-DC converters

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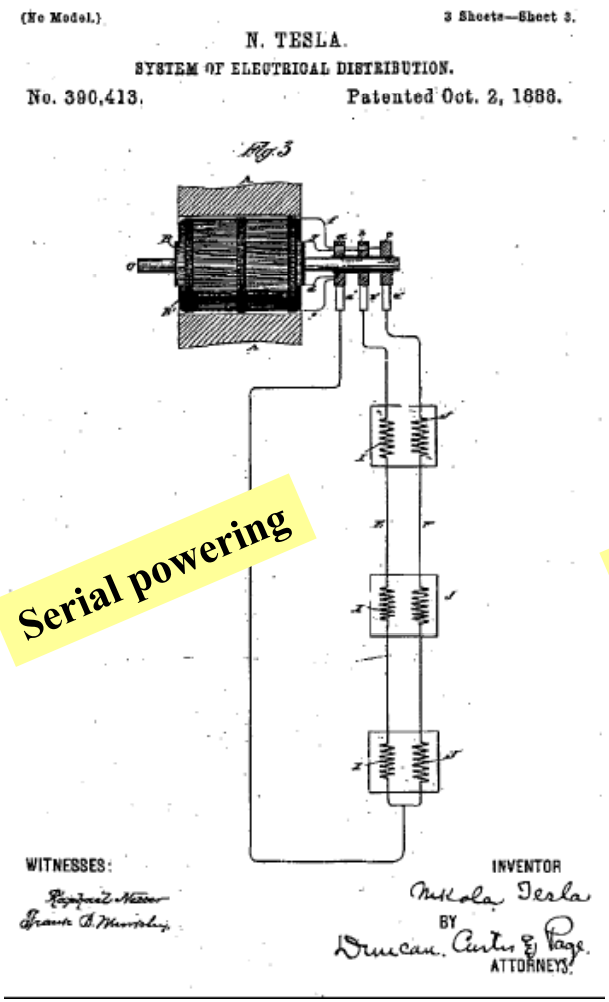
Power lines

- Problem of “long” distance electrical power distribution is not new
- The novelty is that “long” is getting shorter
- The relevant distance scale turns out to be the load operating voltage
- Wrong units? Voltage is driven by oxide thickness: units of length.
- => Miniaturization inside IC also affects distances outside IC!
- Eventually all power distribution distances become “long”
- Voltage conversion inside IC is being pursued in/for industry
    - See for example http://www.bioee.ee.columbia.edu/
  - This option has found little interest in our community so far.
  - Probably can get away without it for one more scaling generation

Options well known,


(No Model.) 3 Sheets—Sheet 3.

N. TESLA.

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 390,413. Patented Oct. 2, 1888.

Fig 3

WITNESSES:

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page.

ATTORNEYS.

Serial powering

Switched capacitors

- Once accepted that we are dealing with long distance power transmission
  - Most ideas discussed today can be found in patents filed by Tesla well before 1900.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF AND APPARATUS FOR ELECTRICAL CONVERSION AND DISTRIBUTION.

SPECIFICATION forming part of Letters Patent No. 462,418, dated November 3, 1891.

Application filed February 4, 1891. Serial No. 380,182. (No model.)

To all whom it may concern:

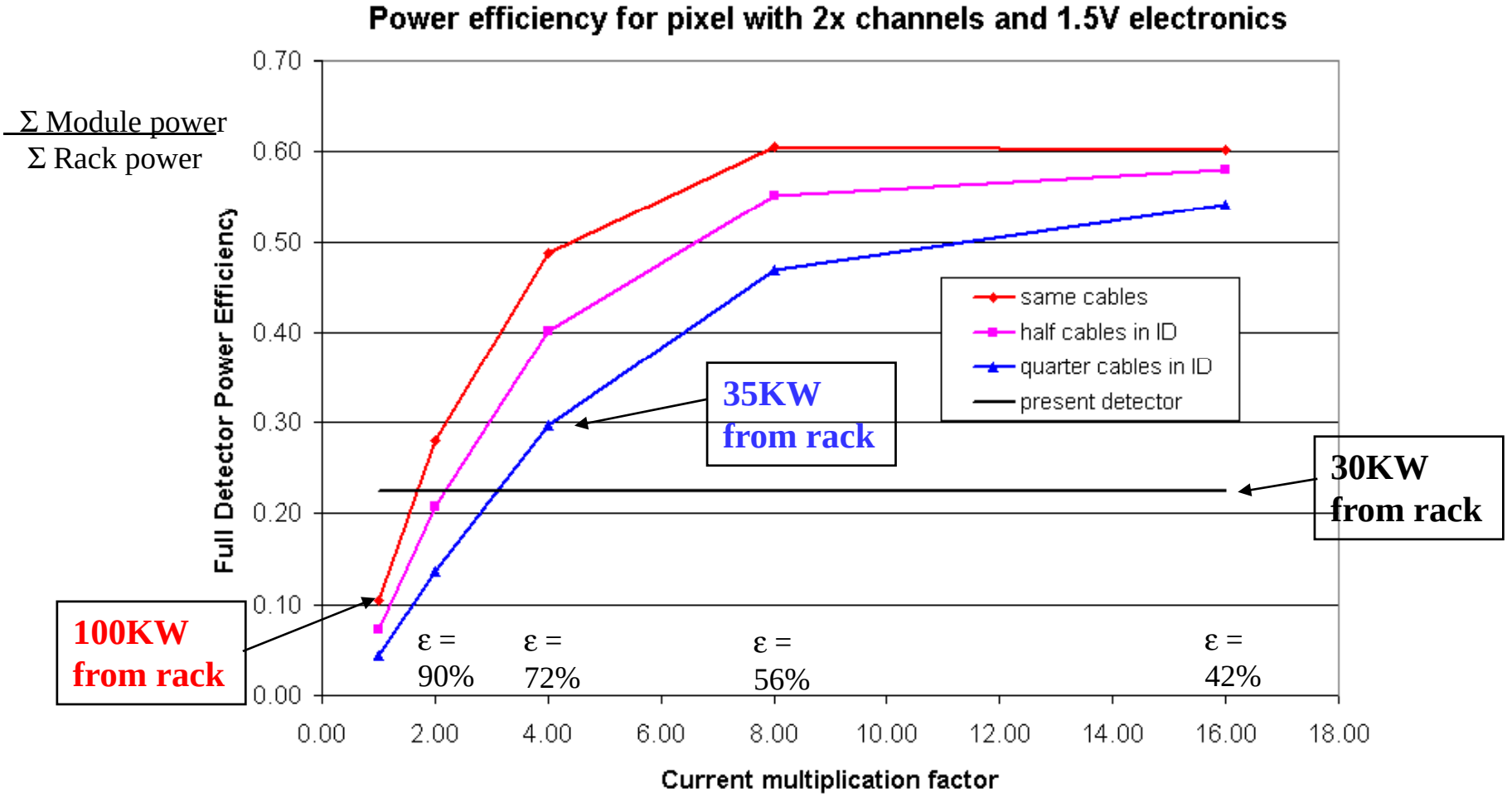
Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, re-

each impulse, alternation, or oscillation of the current extremely small. To the many difficulties in the way of effecting this mechanically, as by means of rotating switches

In the working circuit, by reason of the condenser action, the current impulses or discharges of high tension and small volume are converted into currents of lower tension and greater volume.

Scaling from present pixel detector

with same cable plant down to PP2



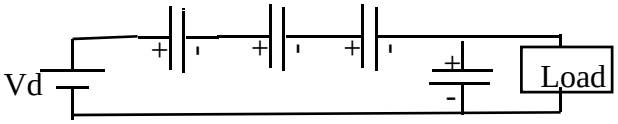
Why switched capacitors?

- Commercial DC-DC down-converters for power applications are all inductive.
  - (Switched capacitors used to step-up voltage at low power to drive displays, etc.)
- Why then study switched capacitors for power?
  - Cannot use ferrites in magnetic field => performance penalty for magnetic converters
  - Fringe AC magnetic fields may produce pickup in detectors (must study case-by-case)
  - Ceramic capacitor miniaturization makes great advances year after year (air-core inductors cannot be improved).
  - Over-voltage safety considerations

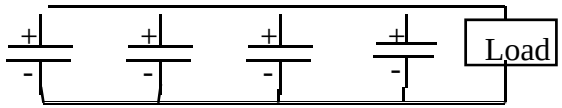
Test configuration used: divide-by-4 stack

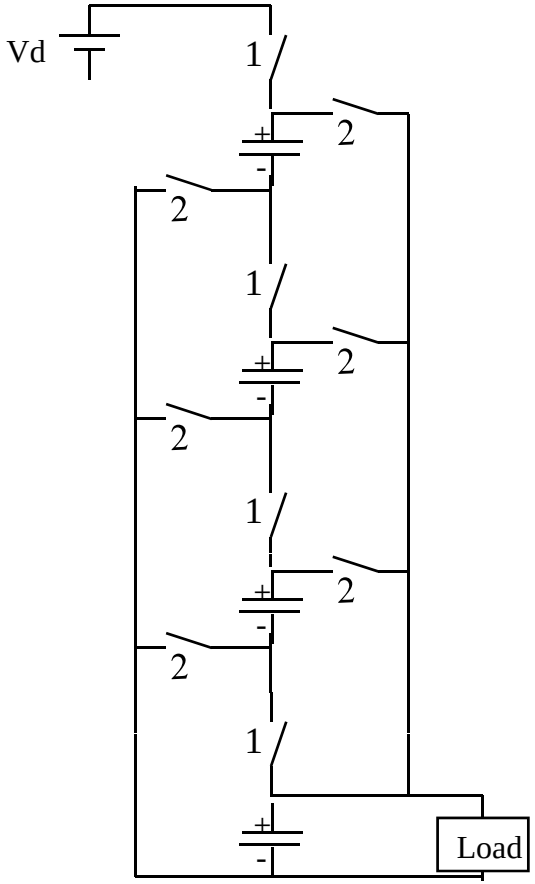
4 capacitors – 10 switches

- Phase 1 - Charge



- Phase 2 - Discharge





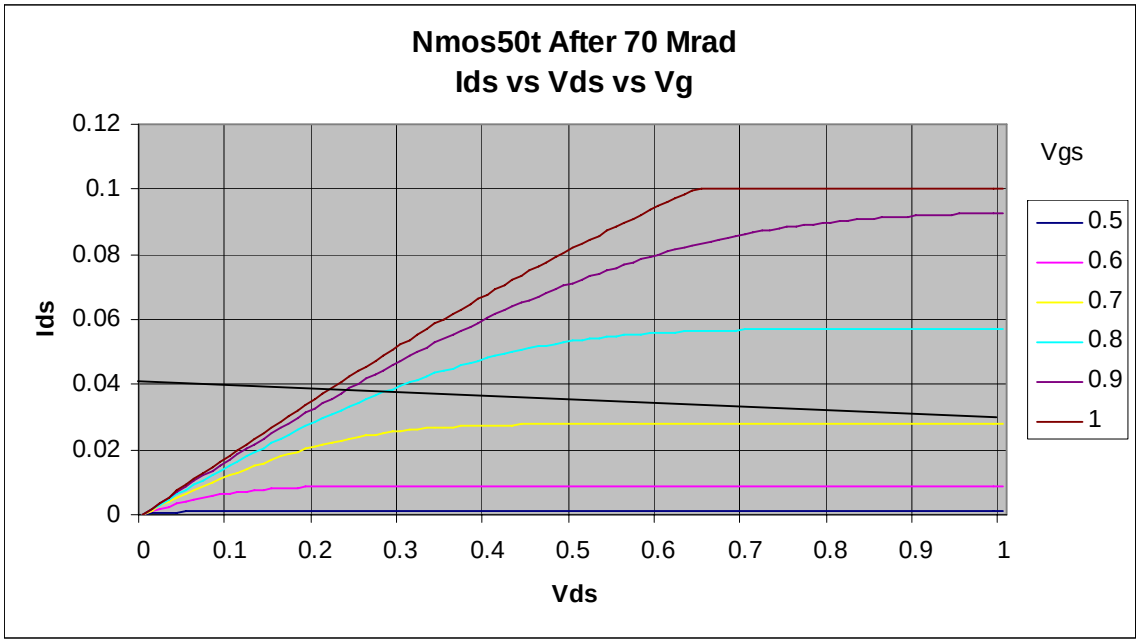
Other configurations

- Many capacitor arrangements are possible with different advantages
  - Minimum number of capacitors for a given ratio (less than for stack)
  - Minimum voltage drop across switches (more than for stack), etc.
- Problem has been solved in general:
  Makowski, D. Maksimovic, "Performance limits of switched capacitor DC-DC converters," IEEE PESC, 1995 Record, pp. 12151221)

First prototype test chip

- 50V (s-d) 0.35μm HV CMOS process
- Minimum size (adequate for ~100mA)
- Switch transistors only- no auxiliary circuitry
- Learned about process simulation, radiation hardness, and bulk isolation
- Did not work as a useful converter due to bulk isolation problems
- Results presented at 12th Workshop on Electronics for LHC and Future Experiments, http://ific.uv.es/lecc06/

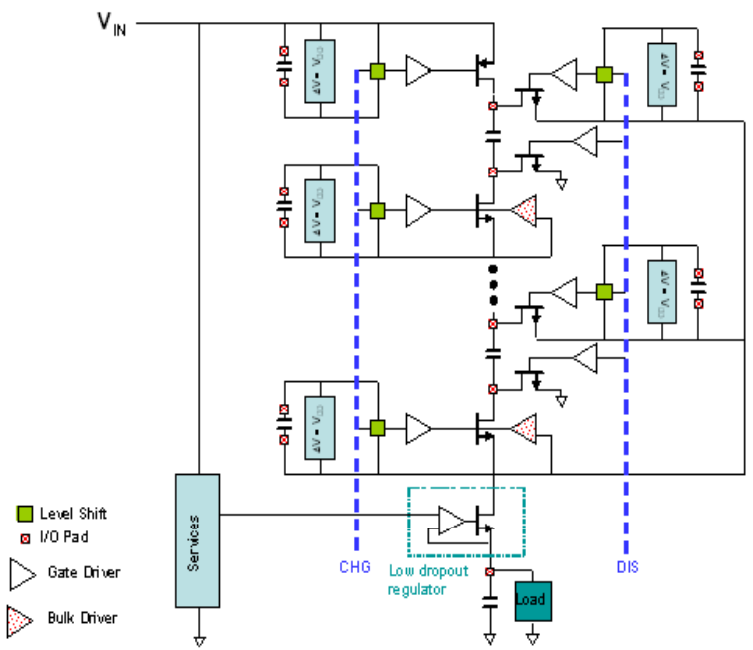
HV Transistor characteristics after irradiation



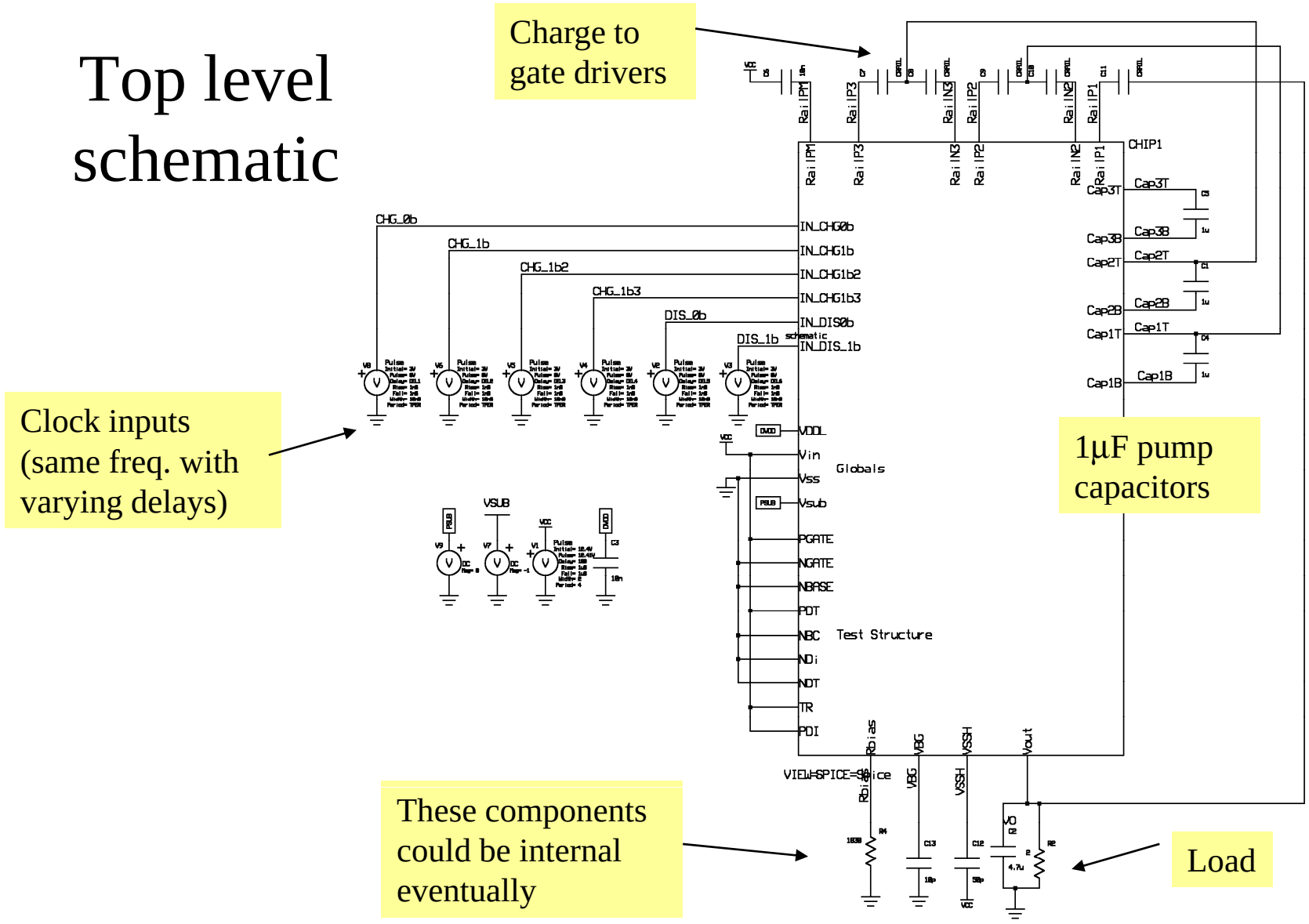
- The most important result is that the drain source resistance has increased by about 10%
- Measured Rds also exceeded model predictions even before irradiation.
- => Increased switch size.

Second prototype

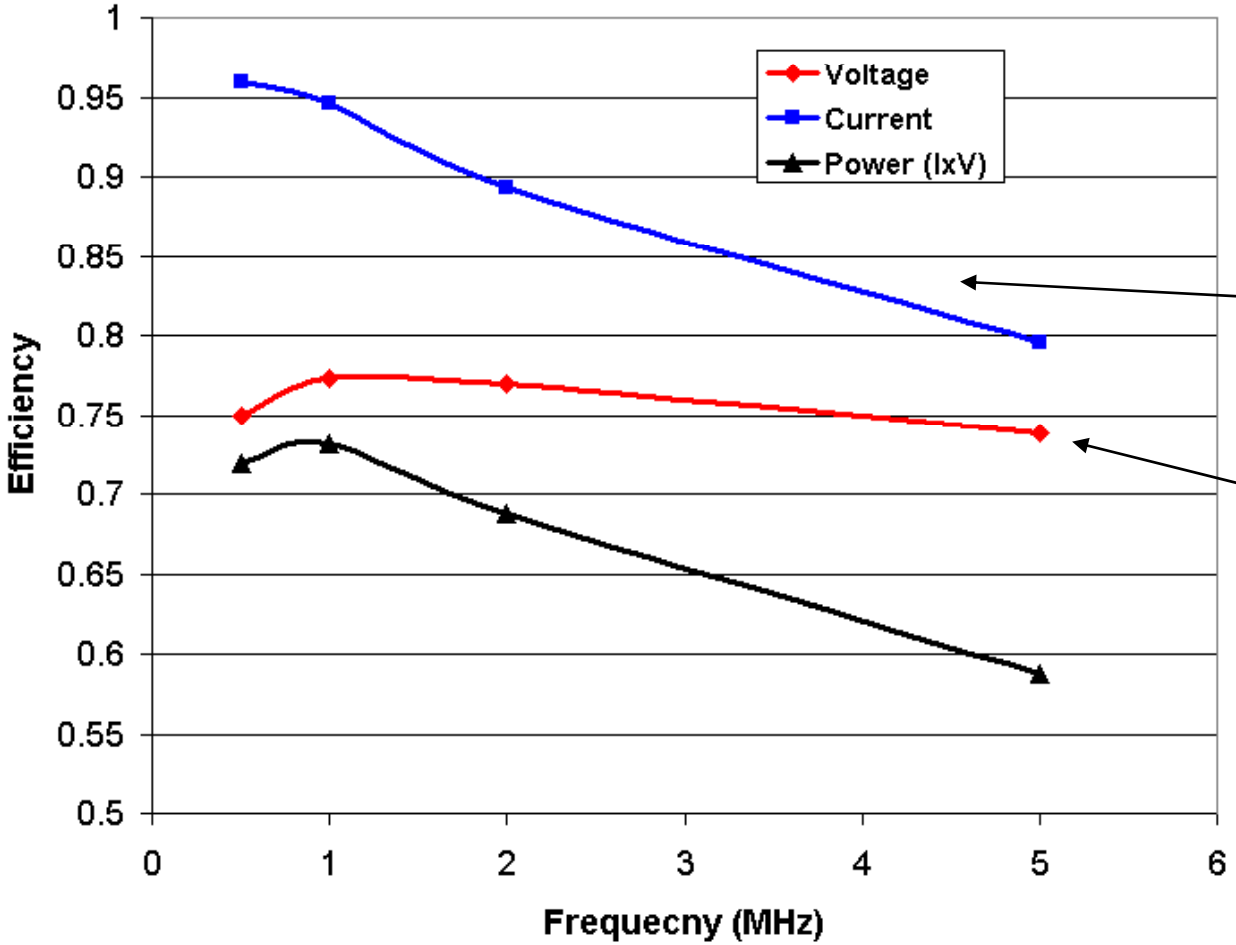
- Same 50V 0.35µm HV CMOS process
- Submitted February 2007 (expected back in May)
- Sized for 1A output.
  4.3 x 4.9 mm
- Contains auxiliary circuits
- All capacitors external
- All clocks external



Top level schematic



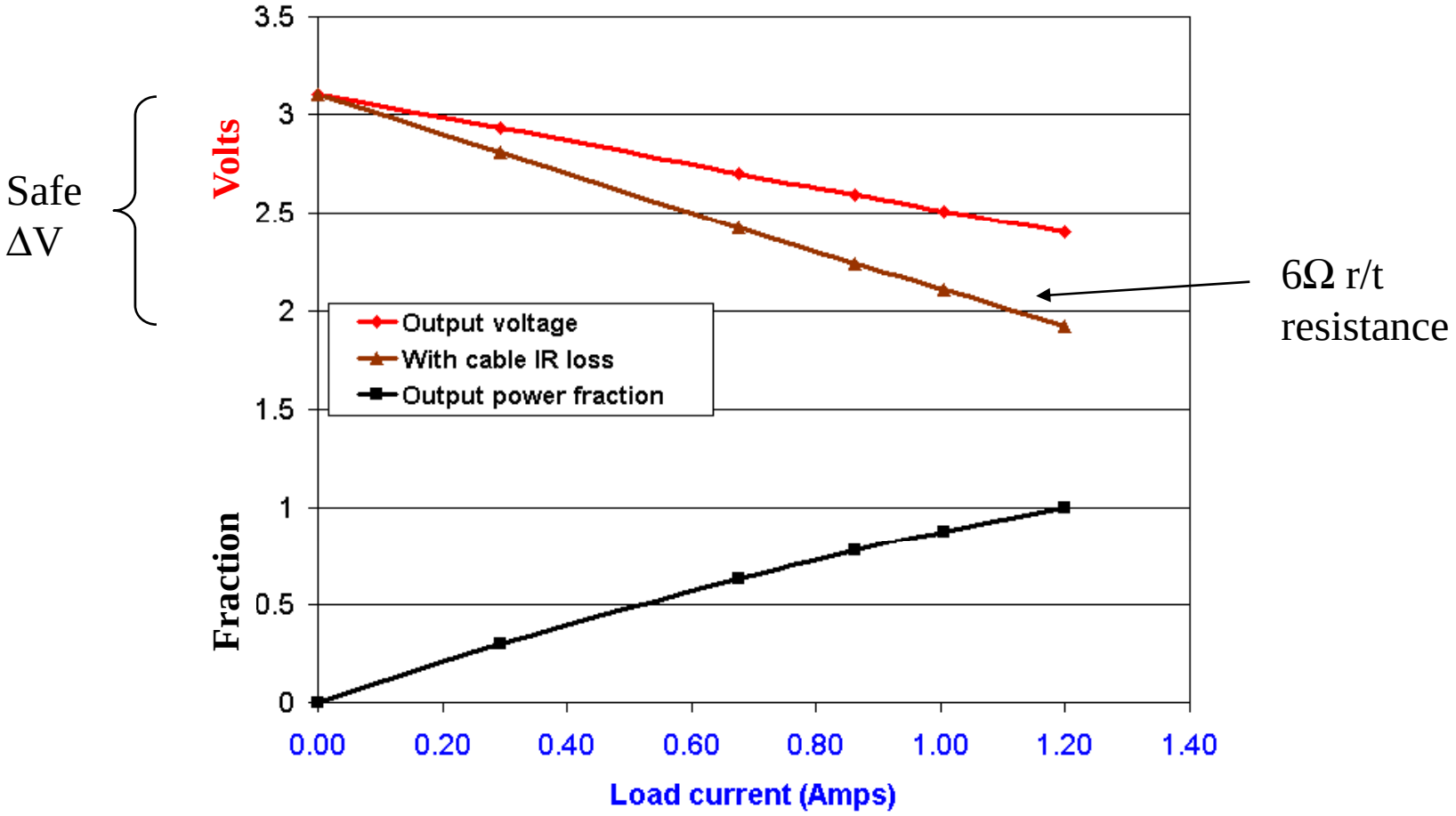
Simulation results 1



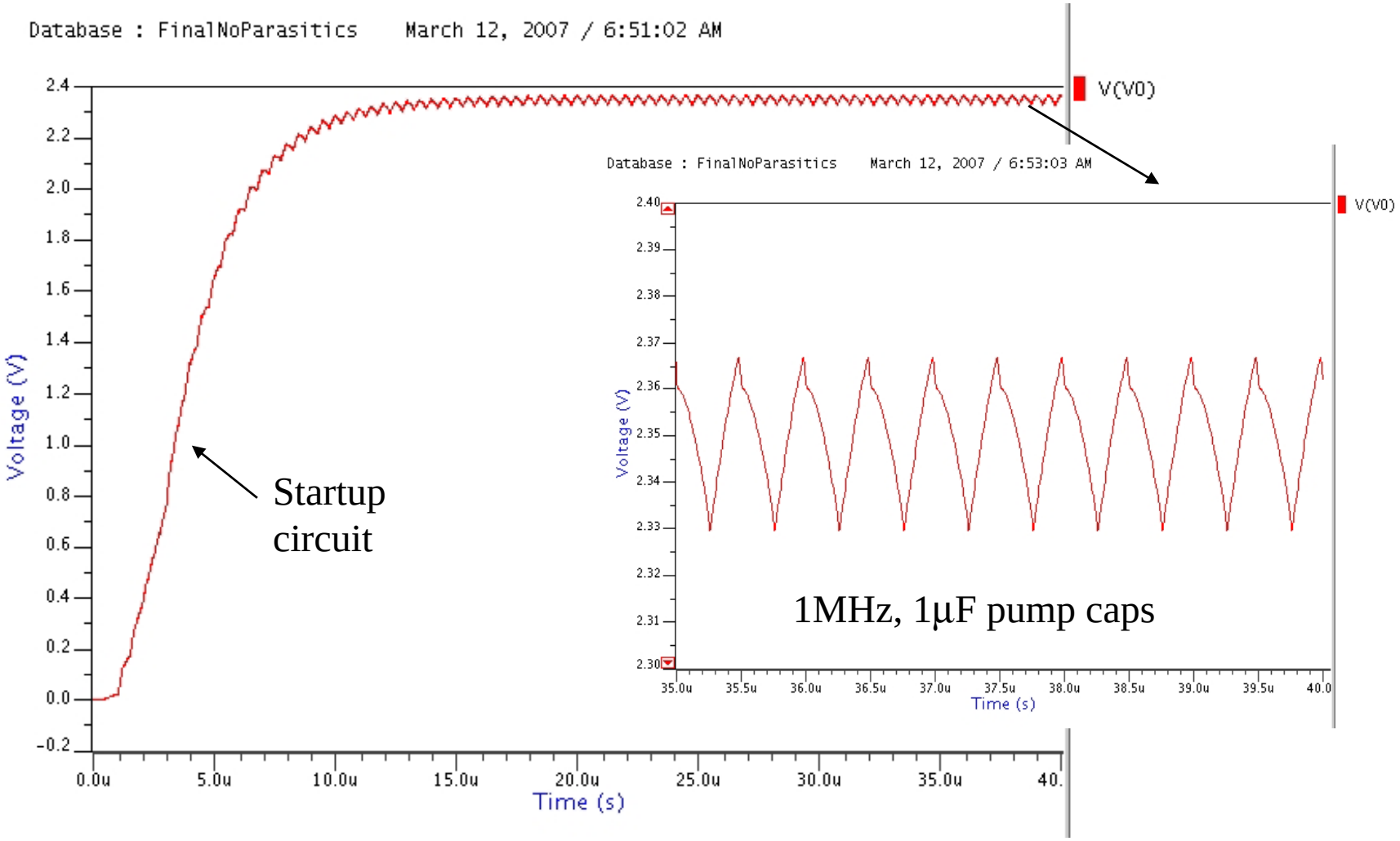
Charge lost in switch parasitics

Dominated by switch resistance

Simulation results 2



Simulation results 3



Conclusion

- Performance of demonstrator 1A chip meets scaling needs in simulation
- Radiation degrades performance- size switches (or current output) for desired end-of-life efficiency.
- Given clock frequency and load, Vout is controlled by Vin.
- Miniaturization not yet optimized (eg. many external components)
- Control circuitry and architecture will evolve after experience
- Plan to use this prototype to power pixel modules and strip stave prototypes.