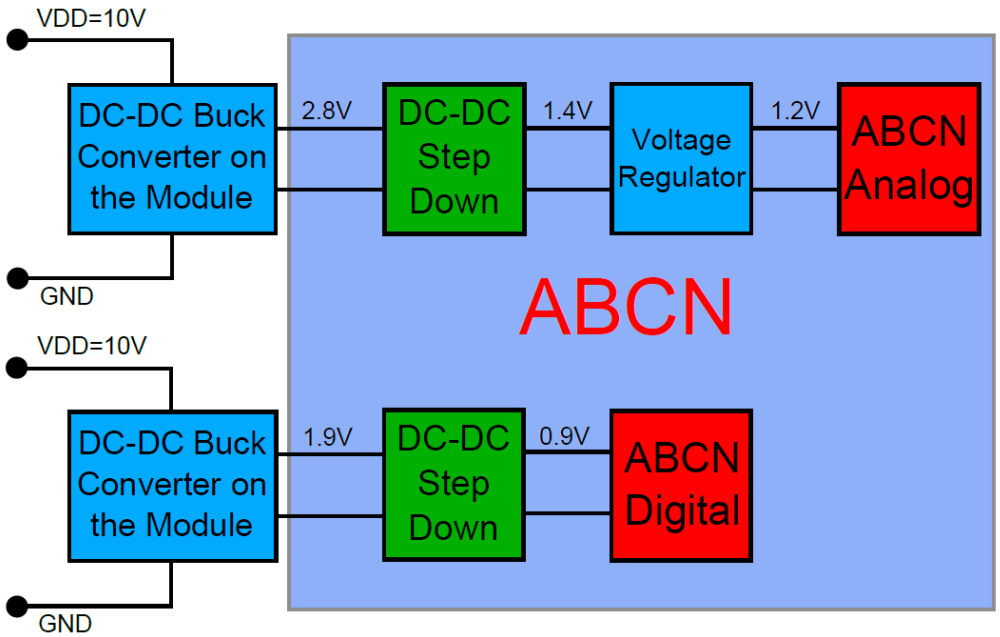
Status of the switched capacitor DC-DC converters for the upgraded LHC trackers

Michał Bochenek

Outline

- (Very) short overview of SC DC-DC converters
- DCDC013 test setup
- Results from the measurements:
  - time response of the converters
  - frequency, transfer and output characteristics
- Future plans
- Conclusions

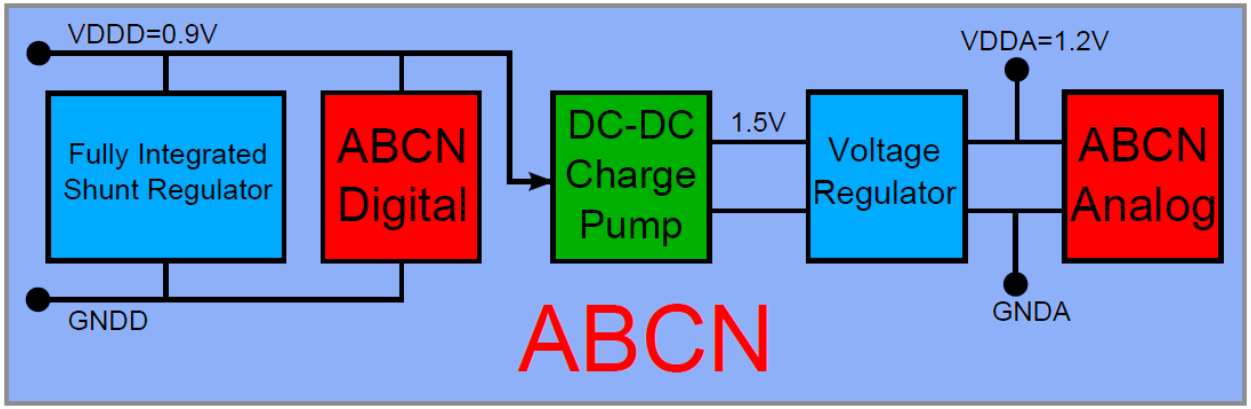
Switched capacitor DC-DC converters in powering schemes for the silicon tracker upgrade



Initial schemes from the start of the project.

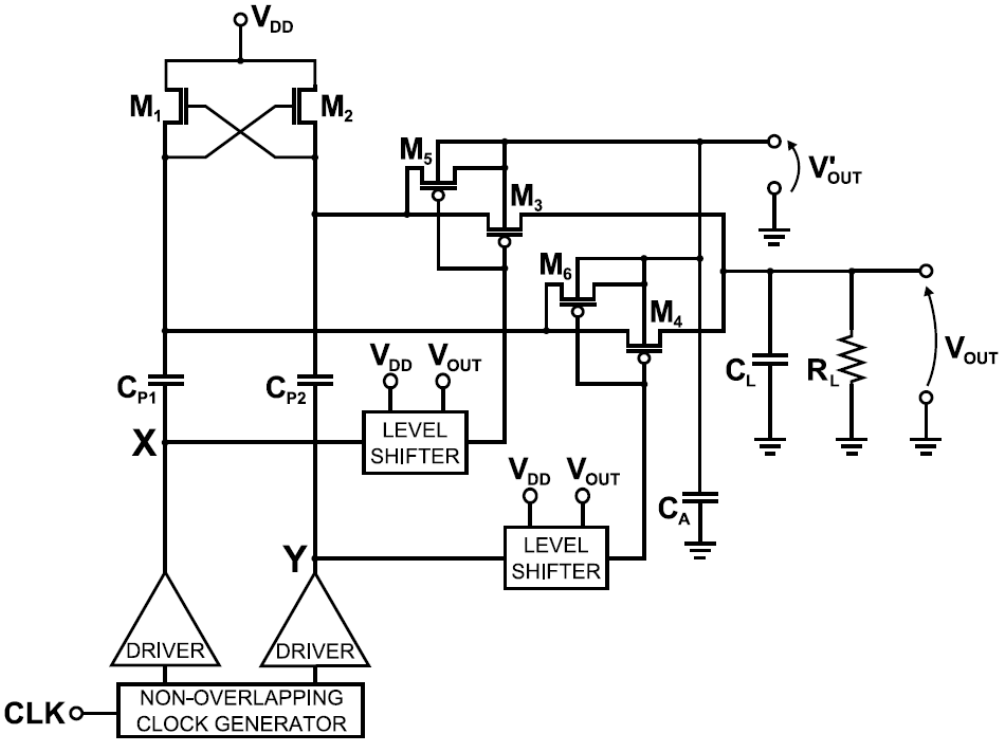
DC-DC conversion technique

Serial powering scheme



SC DC-DC converters: an overview

Step-up converter



Project assumptions:
- V_{IN} = 0.9 V
- V_{OUT} = 1.55 V
- I_{OUT} ≈ 30 mA

Design parameters:
- $C_{P1/P2}$ = 470 nF
- C_L = 470 nF
- f_s = 500 kHz

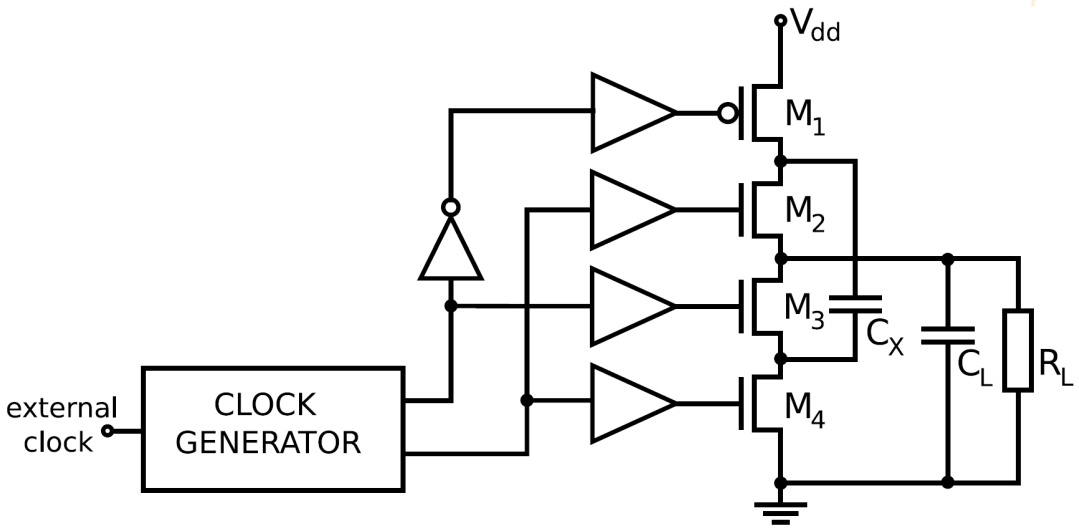
Efficiency (SPICE) = 85%
Efficiency (measurement) = 84%

Step-down converter

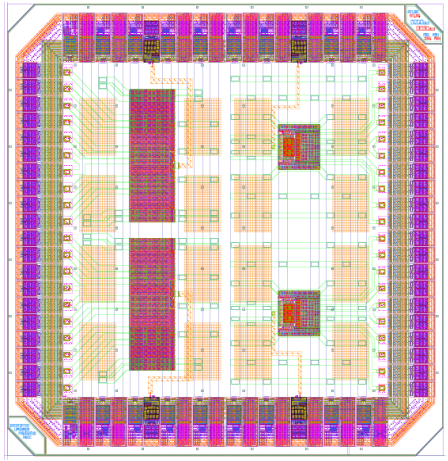
Project assumptions:
- V_{IN} = 1.9 V
- V_{OUT} = 0.9 V
- I_{OUT} ≈ 60 mA

Design parameters:
- C_L = 200 nF
- C_X = 1 µF
- f_s = 1 MHz

Efficiency (SPICE) = 96%
Efficiency (measurement) = 91%

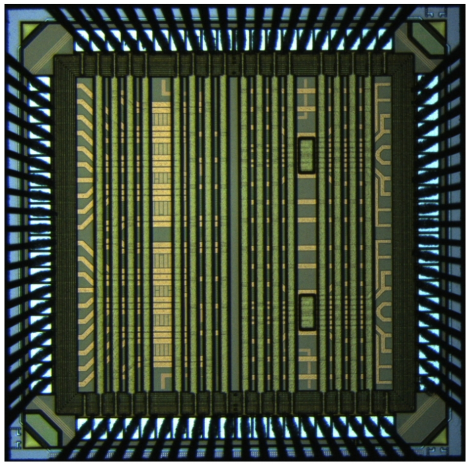


Long way to obtain the results from the converters

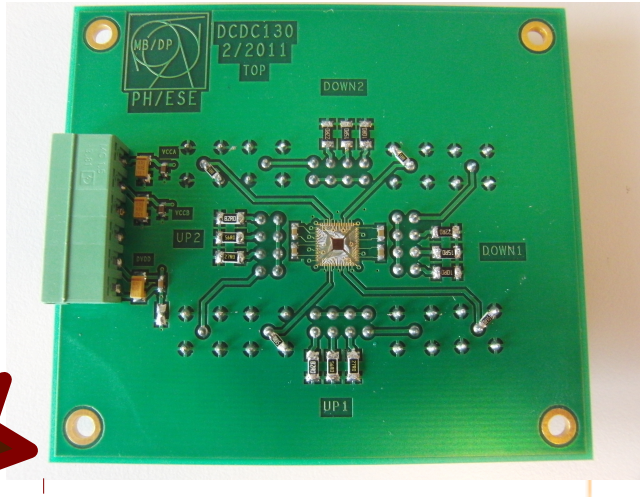


May 2010
(Submission)

TWEPP 2010

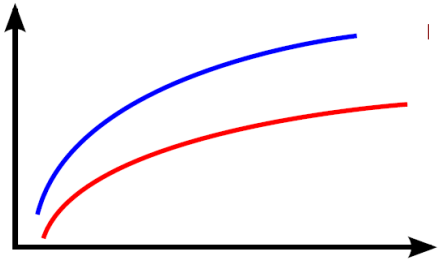


February 2011
(ASICs at CERN)



April 2011
(tests)

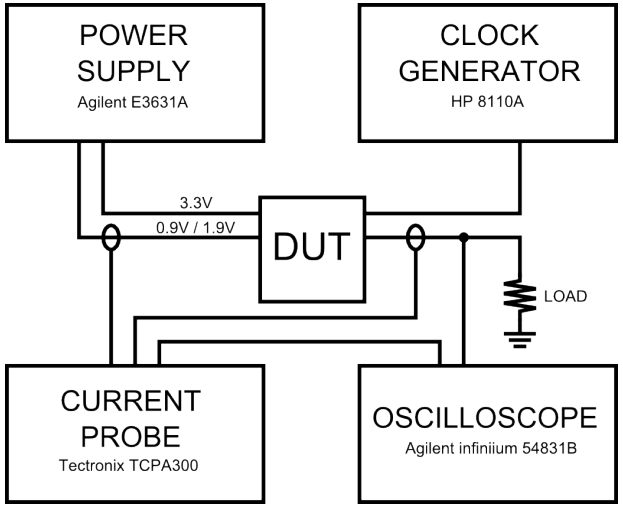
TWEPP 2011



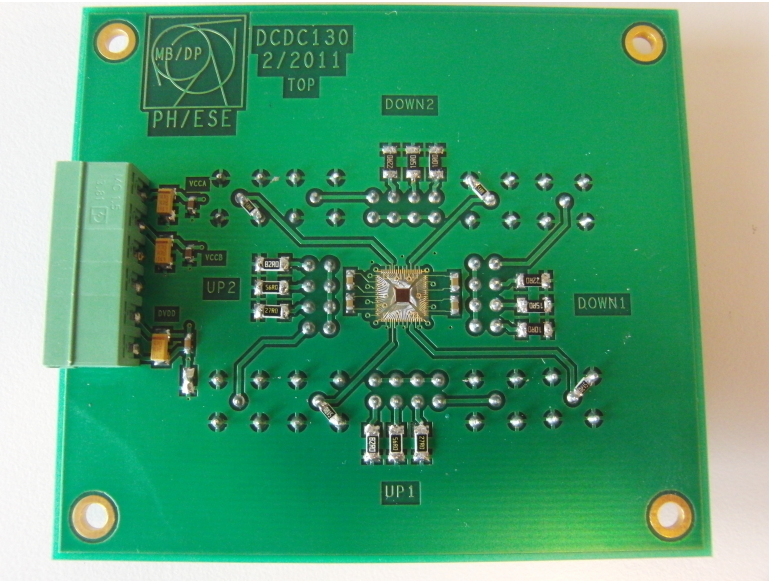
Conclusions,
improvements
and
new ideas

Setup

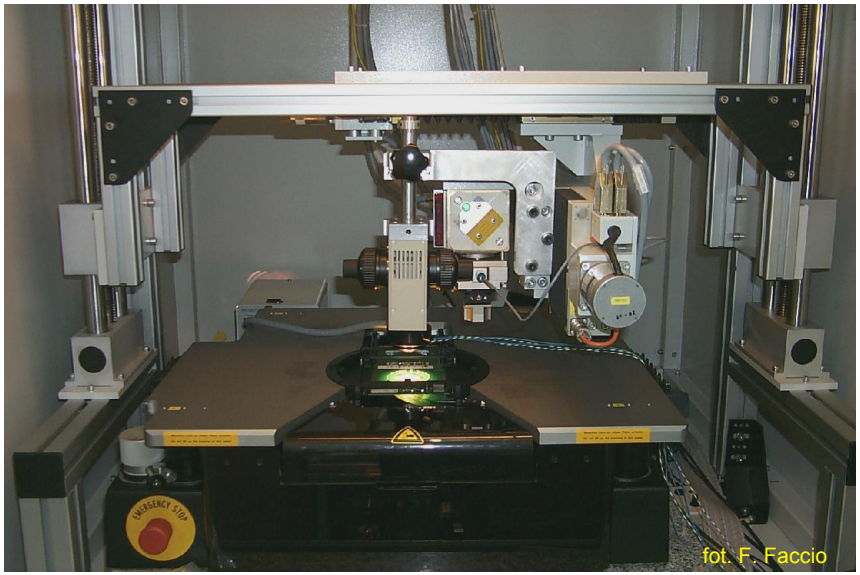
Schematic diagram of the setup used in DCDC013 measurements



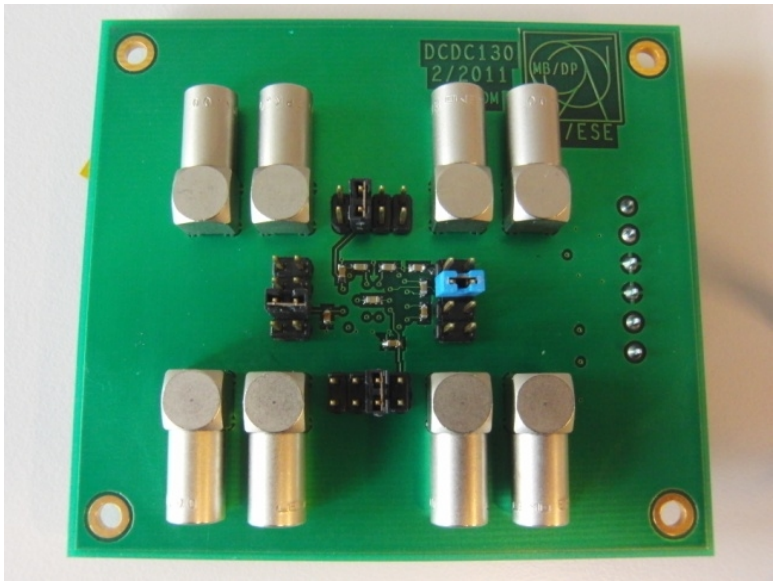
PCB for DCDCo13 tests (top)



Irradiation cabinet containing the X-ray system

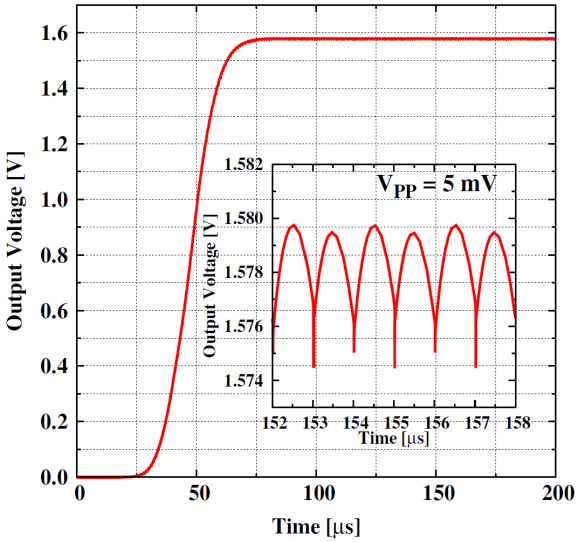


PCB for DCDCo13 tests (bottom)

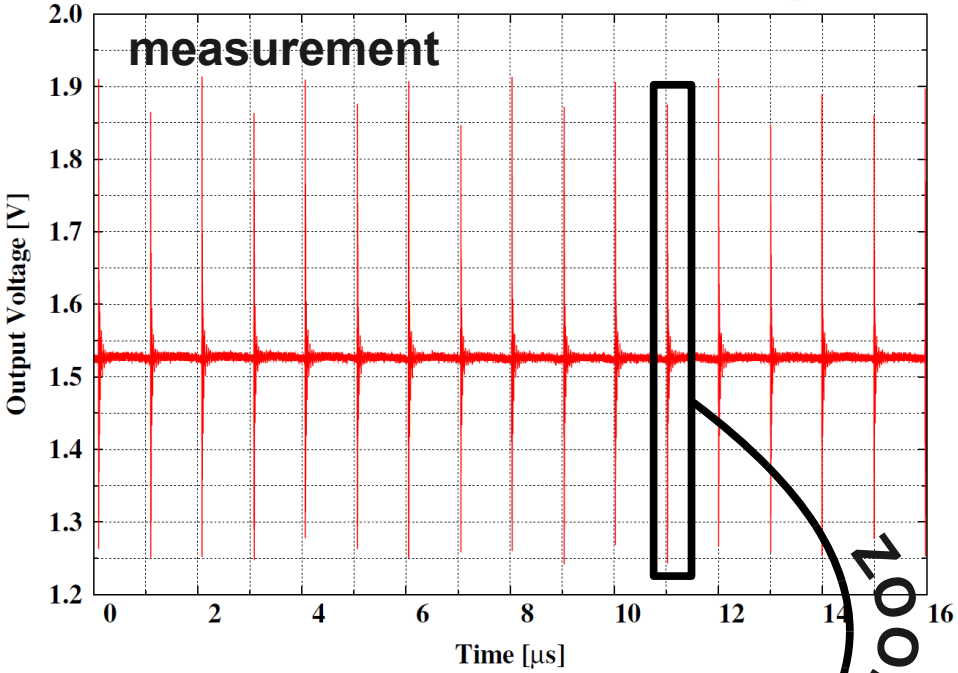


Step-up converter: time response

simulation (no parasitics)

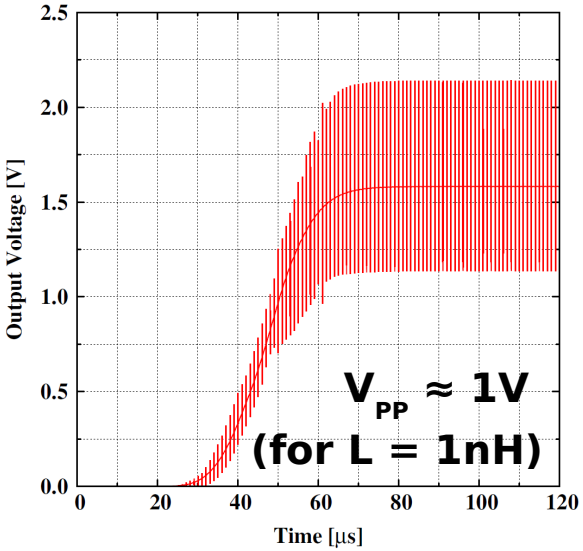


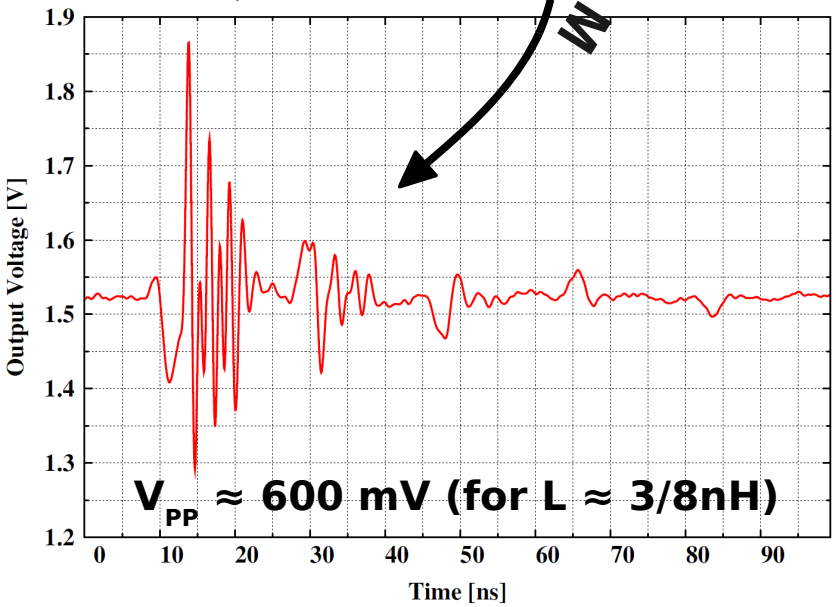
measurement



- f_s = 500 kHz
- I_{OUT} ≈ 30 mA
- V_{OUT} = 1.53 V
- η = 84 %

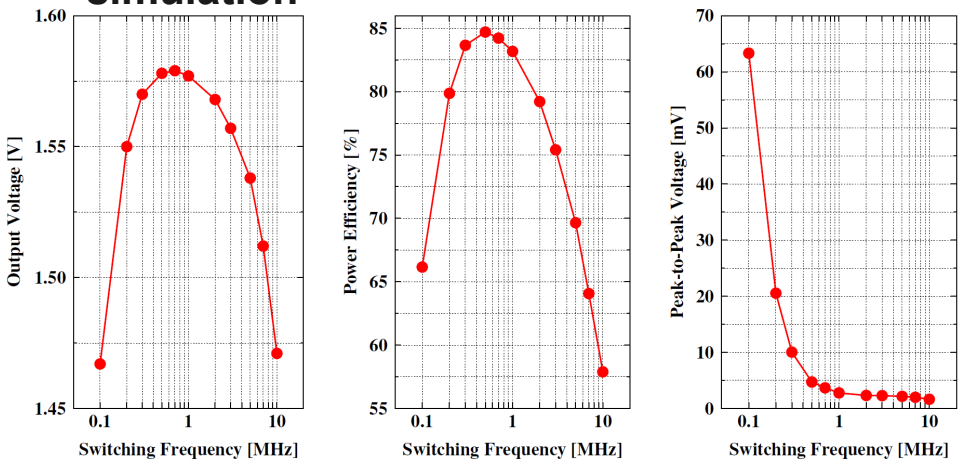
simulation (with parasitics)





Step-up converter: frequency characteristics

simulation



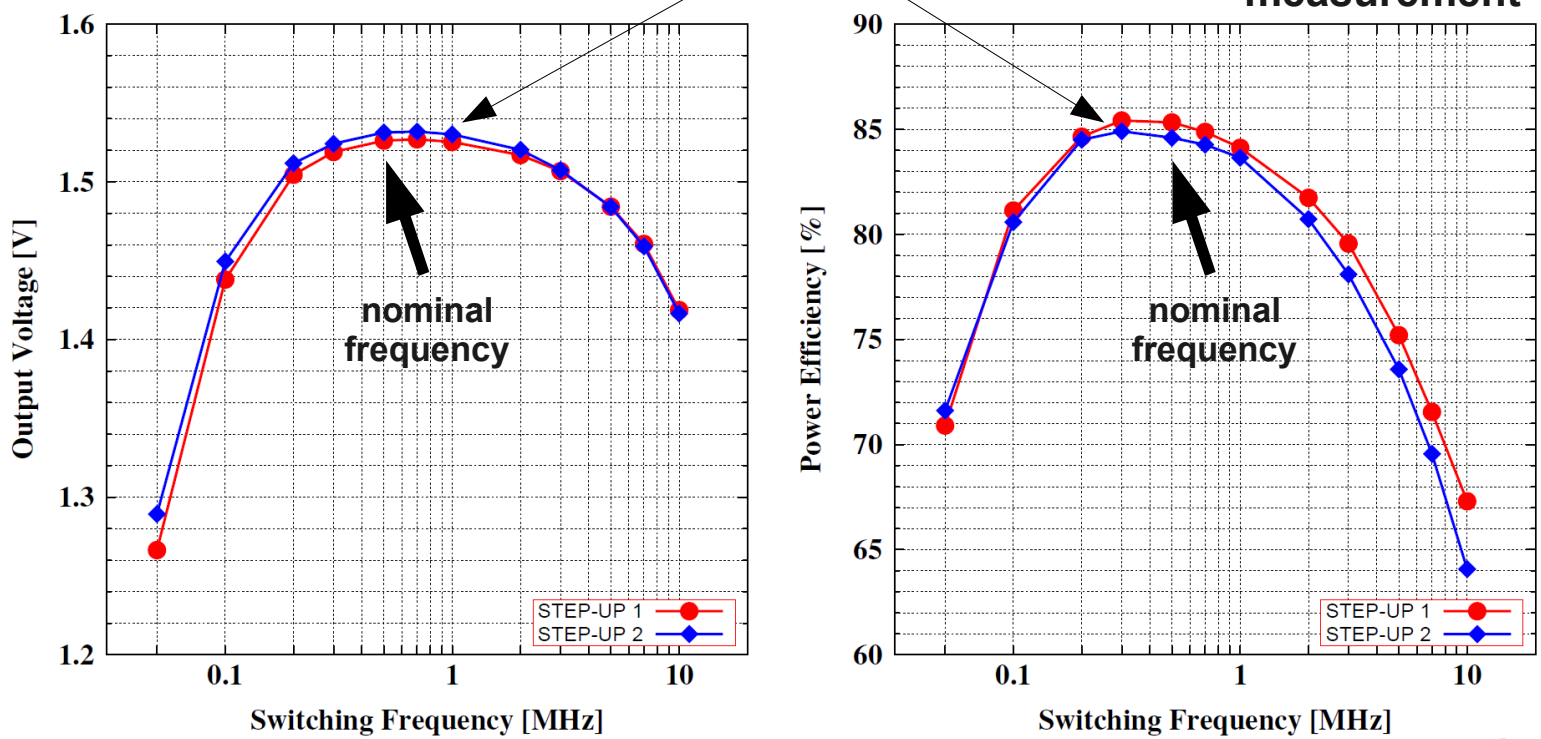
V_{IN} = 0.9 V

R_L = 56 Ω

f_s : 50 kHz → 10 MHz

No need for a precise clock

measurement



@f_s = 500 kHz

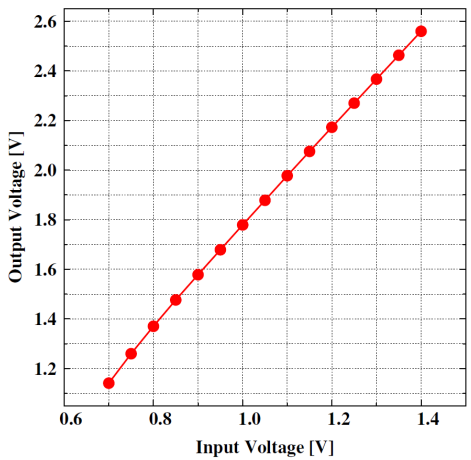
$V_{OUT(MAX)}$ = 1.53 V

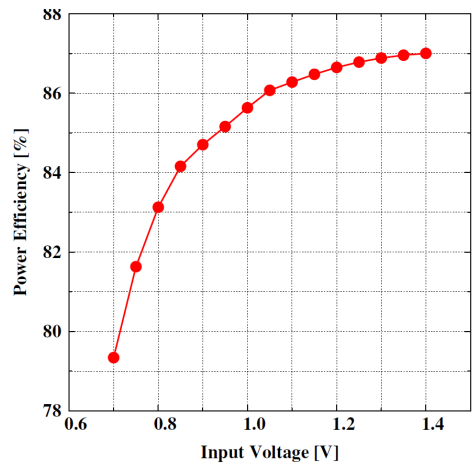
I_{OUT} ≈ 30 mA

η_{OUT} ≈ 84%

Step-up converter: transfer characteristics

simulation

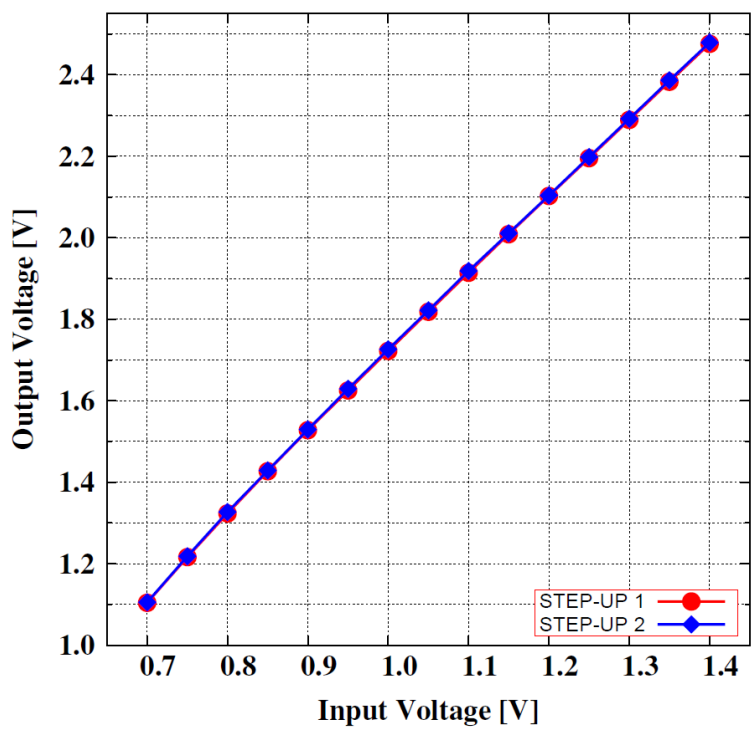


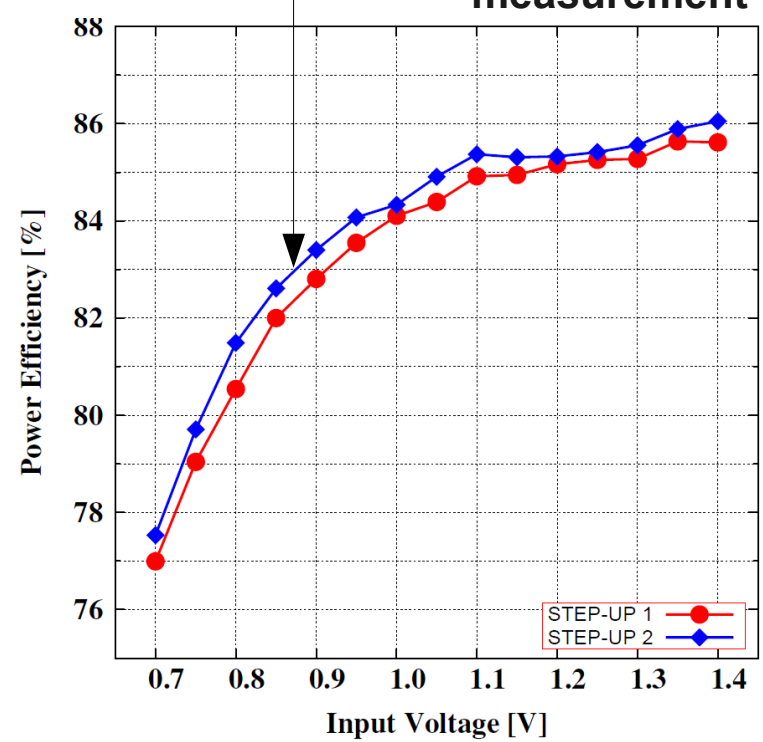


V_{IN} = 0.7 V → 1.4 V
V_{OUT} = 1.1 V → 2.5 V
R_L = 56 Ω
f_s = 500 kHz

Rapid increase of a driving capability

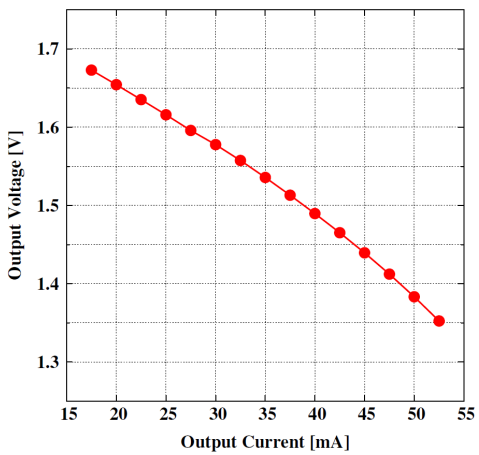
measurement

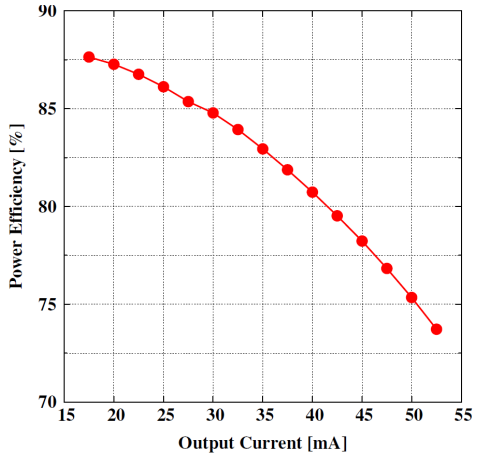




Step-up converter: output characteristics

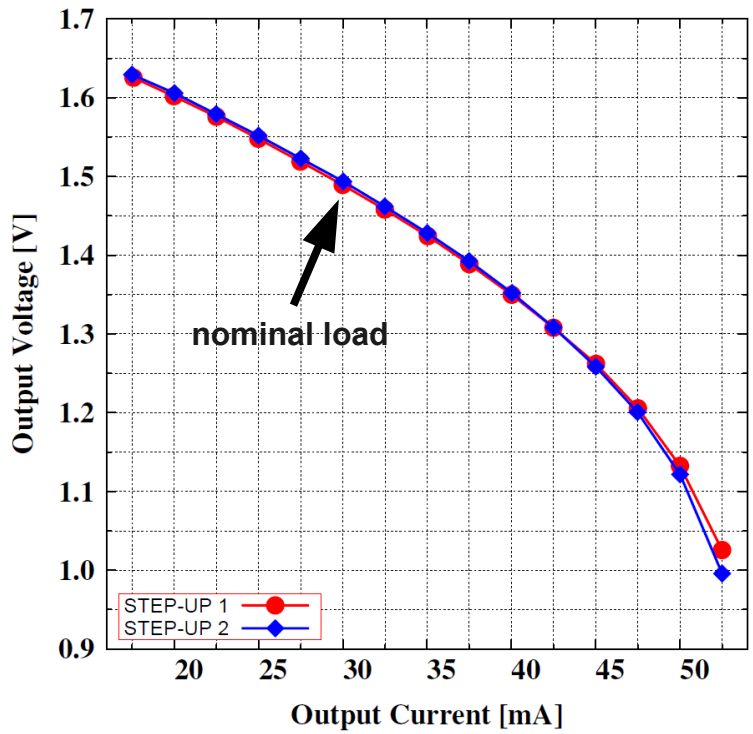
simulation

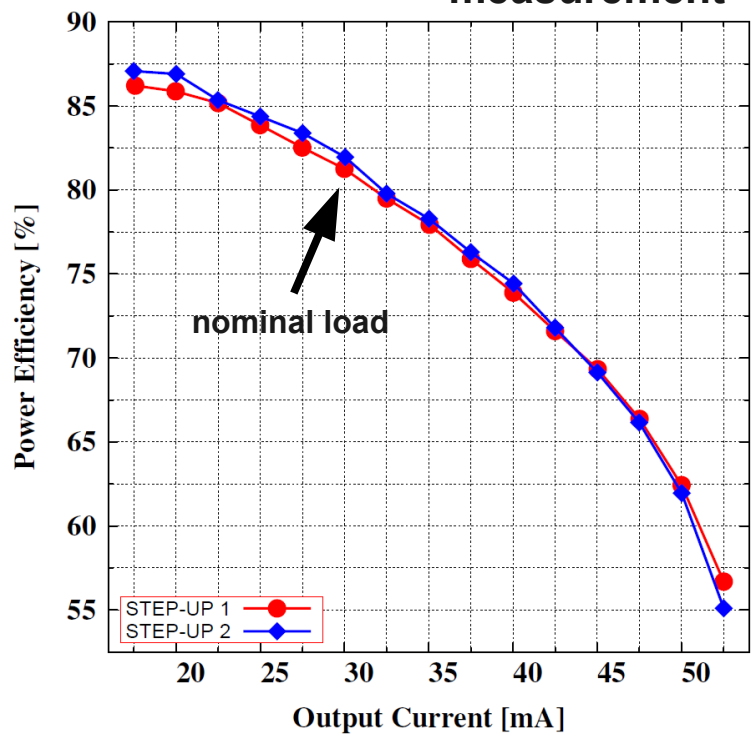




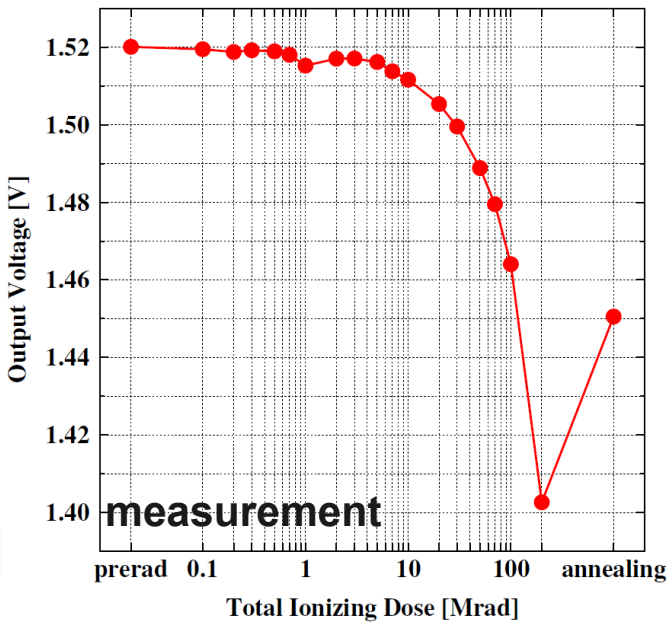
V_{IN} = 0.9 V
f_S = 500 kHz
I_{OUT} : 17 mA → 55 mA
$R_{OUT(SIM)}$ = 8 Ω
$R_{OUT(MEAS)}$ = 10 Ω

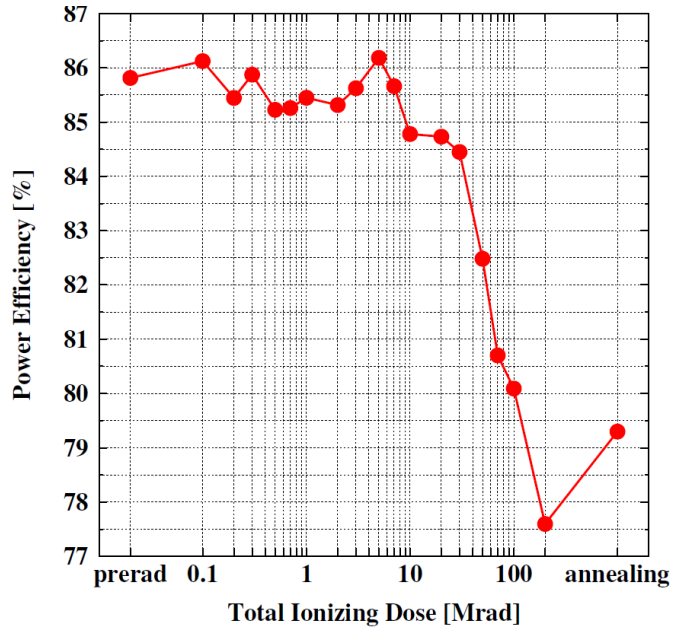
measurement





Step-up converter: irradiation tests



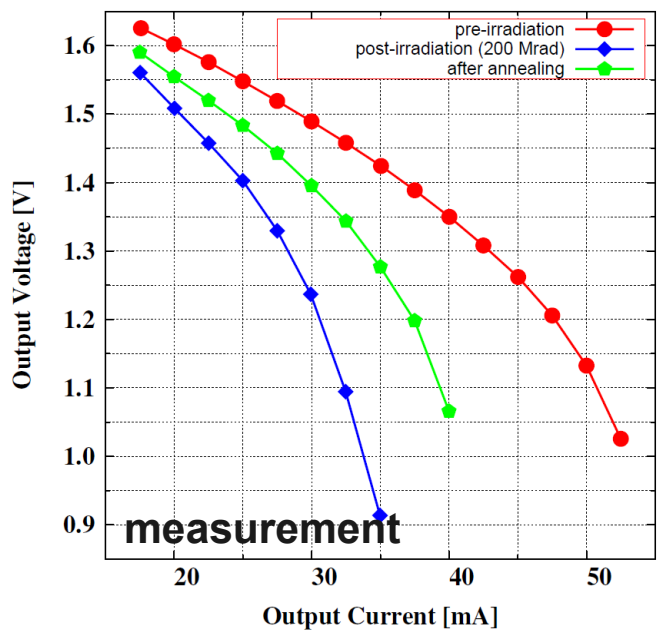


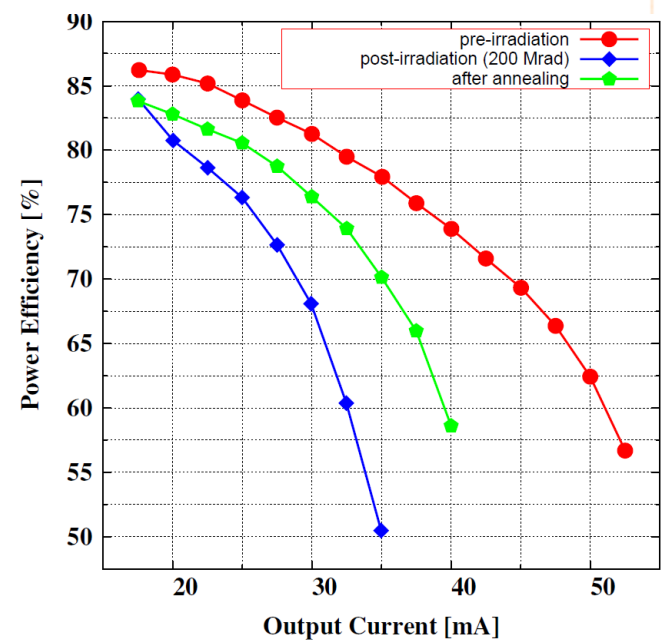
Irradiation:
- X-ray photons
- up to 200 Mrad

Annealing:
- at 100°C
- for one week

Step-up output characteristic:
- Before irradiation,
- After irradiation,
- After annealing.

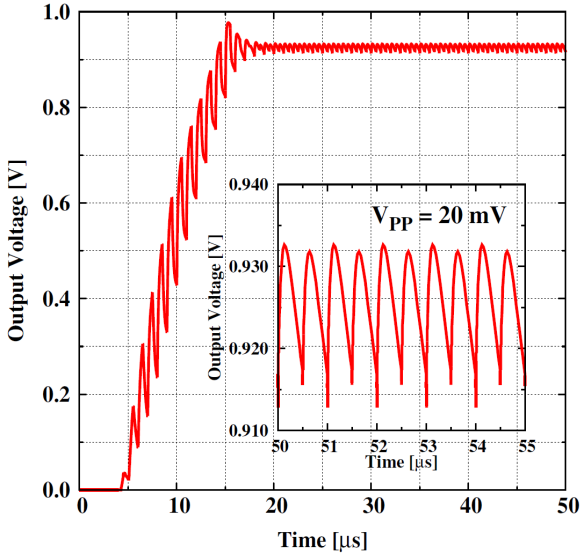
The increase of the output impedance is visible.



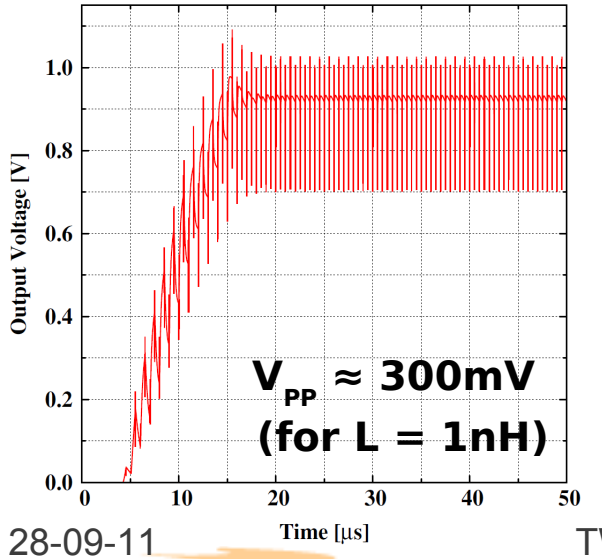


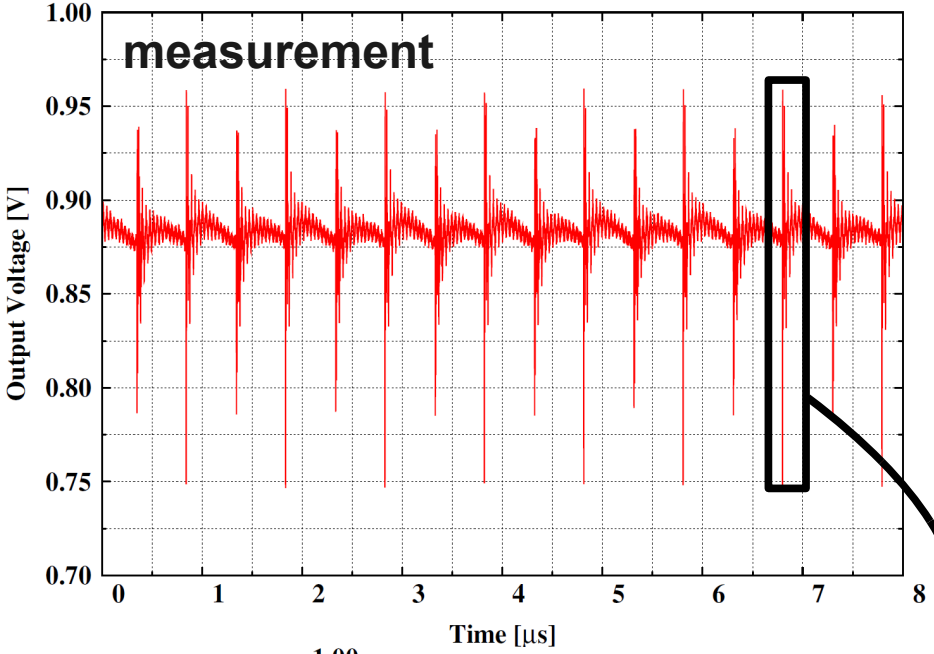
Step-down converter: time response

simulation (no parasitics)

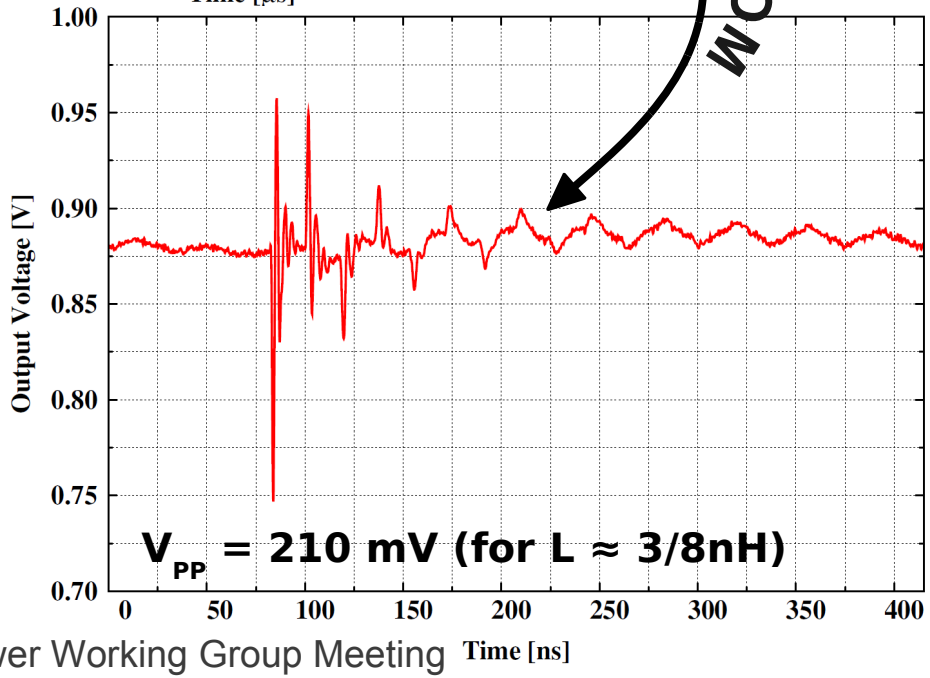


simulation (with parasitics)





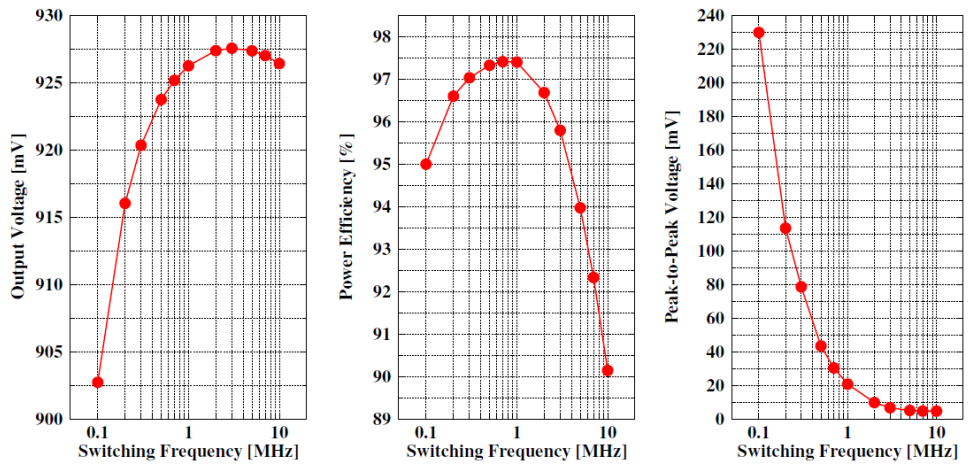
ZOOM



- f_S = 1 MHz,
- I_{OUT} ≈ 60 mA,
- V_{OUT} ≈ 0.88 V,
- η ≈ 91 %.

Step-down converter: frequency characteristics

simulation



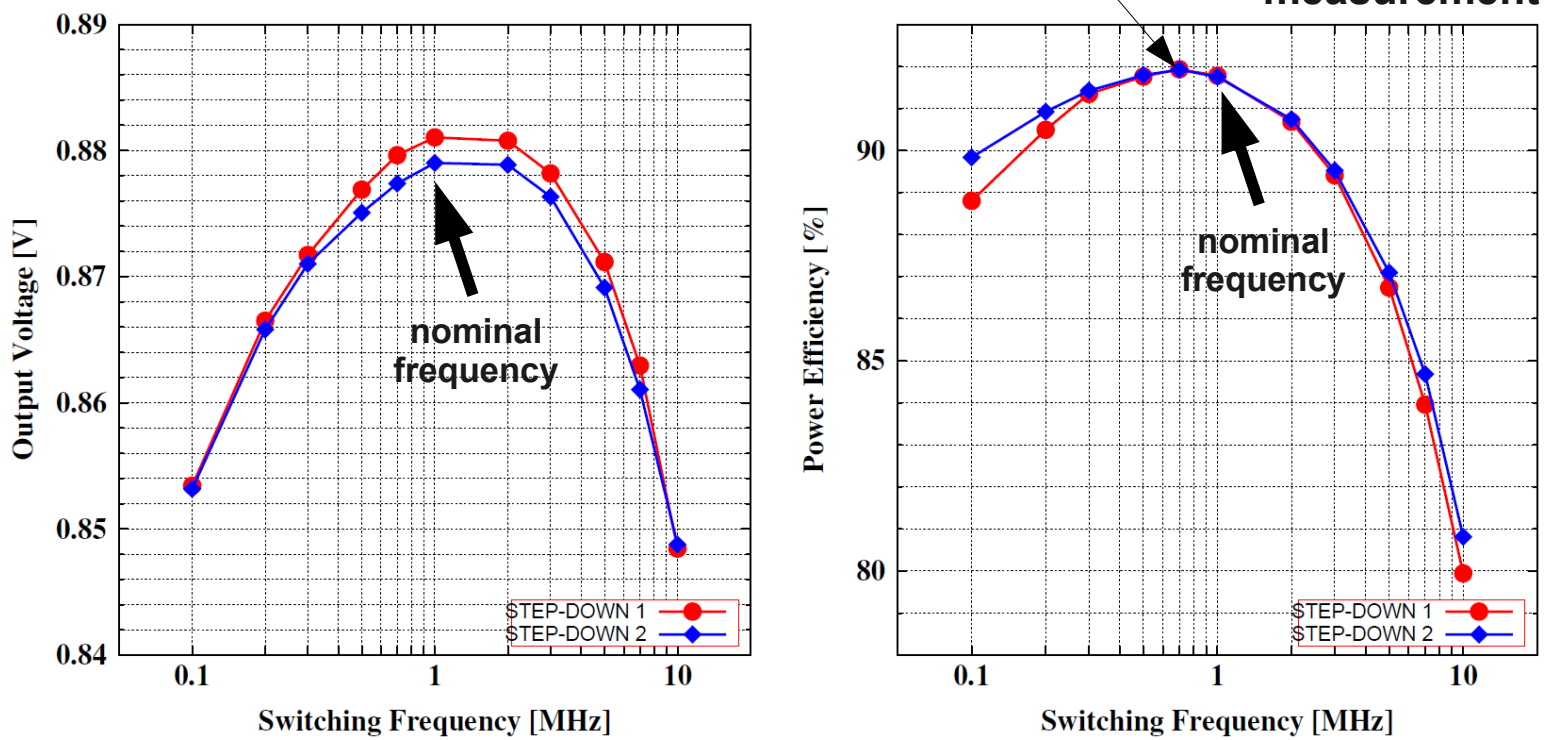
V_{IN} = 1.9 V

R_L = 15 Ω

f_s : 100 kHz → 10 MHz

Optimal f_s slightly lower

measurement



@f_s = 1 MHz

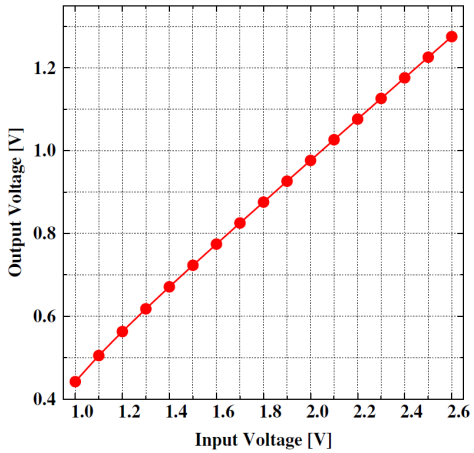
$V_{OUT(MAX)}$ = 0.88 V

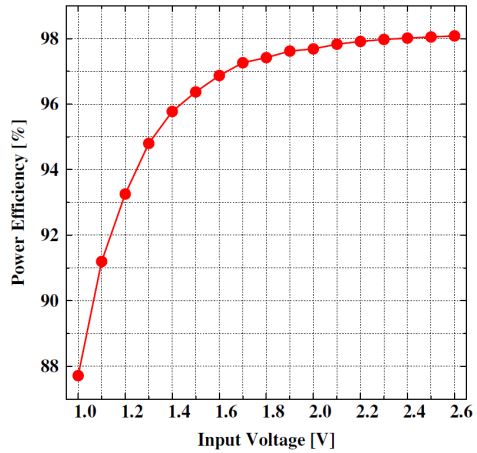
I_{OUT} ≈ 60 mA

η_{OUT} ≈ 91%

Step-down converter: transfer characteristics

simulation





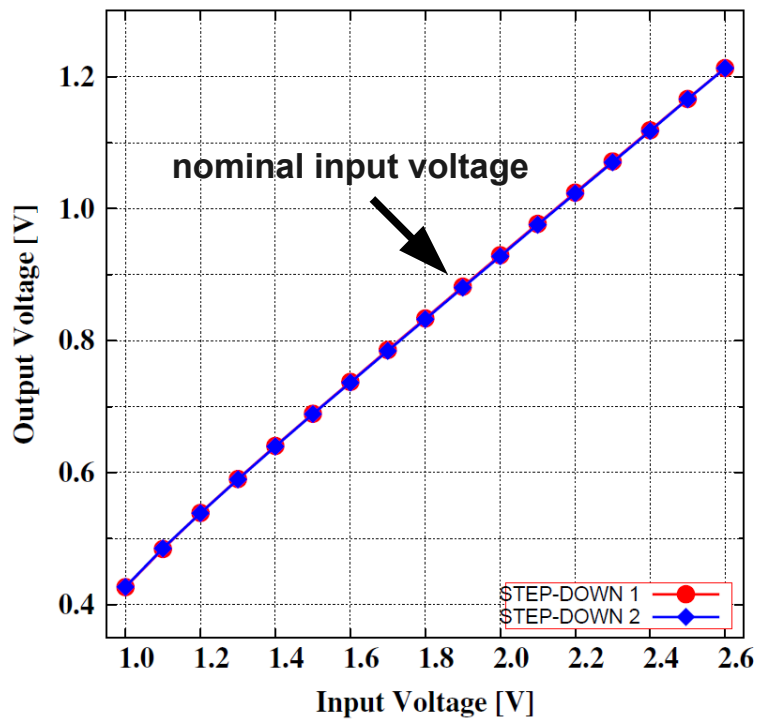
V_{IN} = 1.0 V → 2.6 V

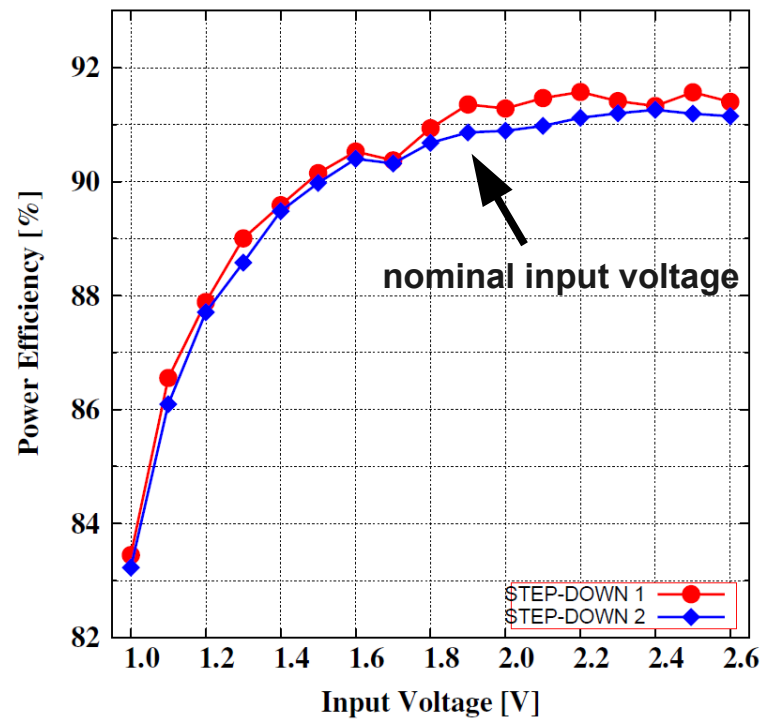
V_{OUT} = 0.43 V → 1.21 V

R_L = 15 Ω

f_S = 1 MHz

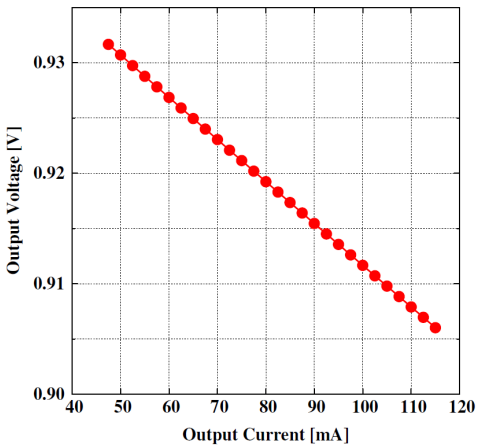
measurement

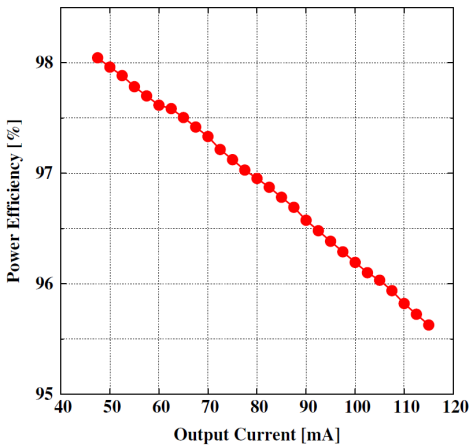




Step-down converter: output characteristics

simulation





V_{IN} = 1.9 V

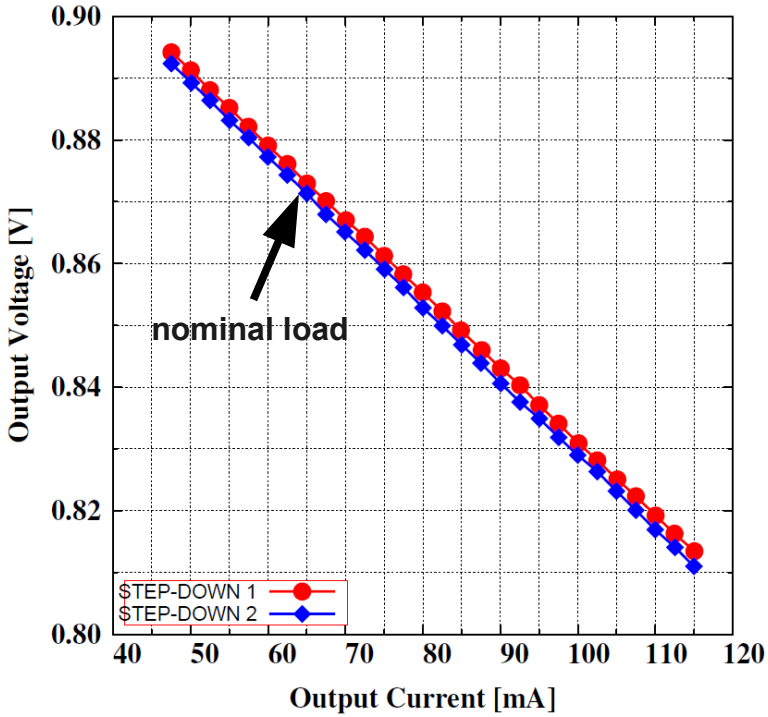
f_S = 1 MHz

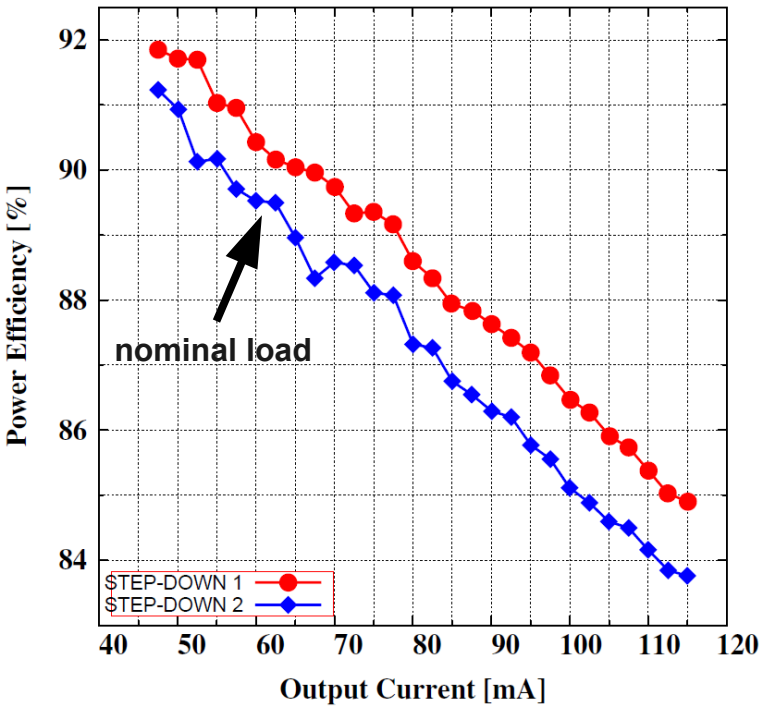
I_{OUT} : 45 mA → 115 mA

$R_{OUT(SIM)}$ = 0.4 Ω

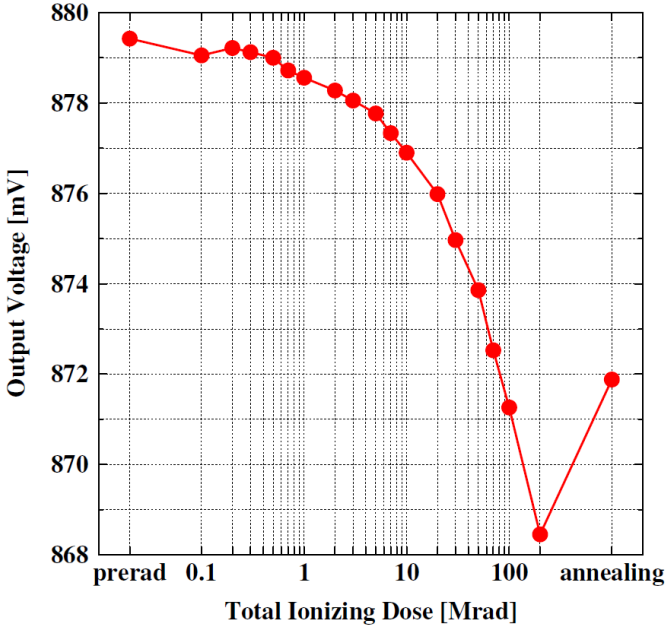
$R_{OUT(MEAS)}$ = 1.2 Ω

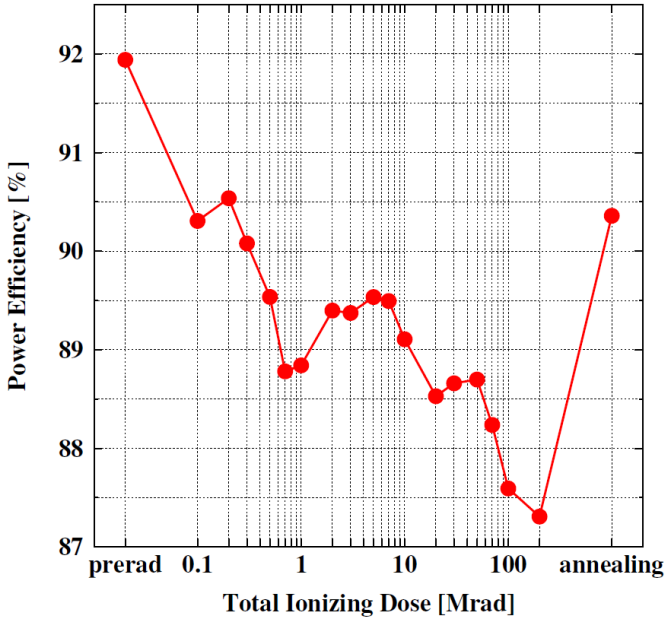
measurement





Step-down converter: irradiation tests



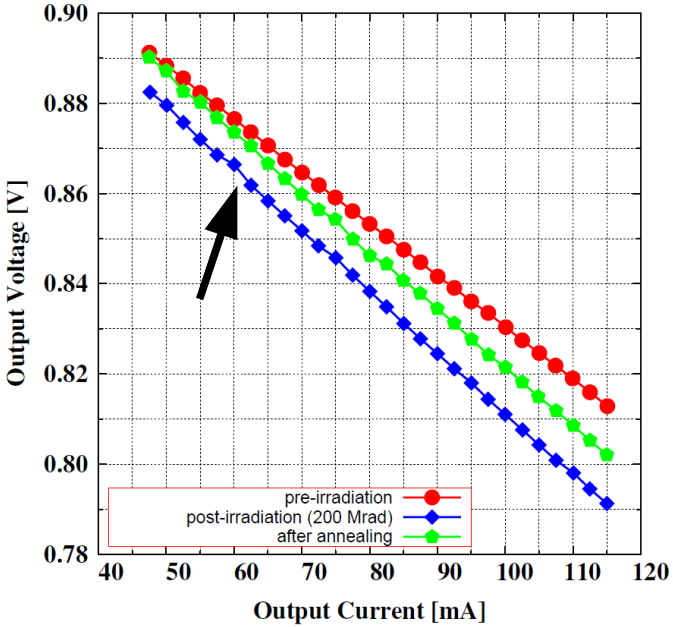


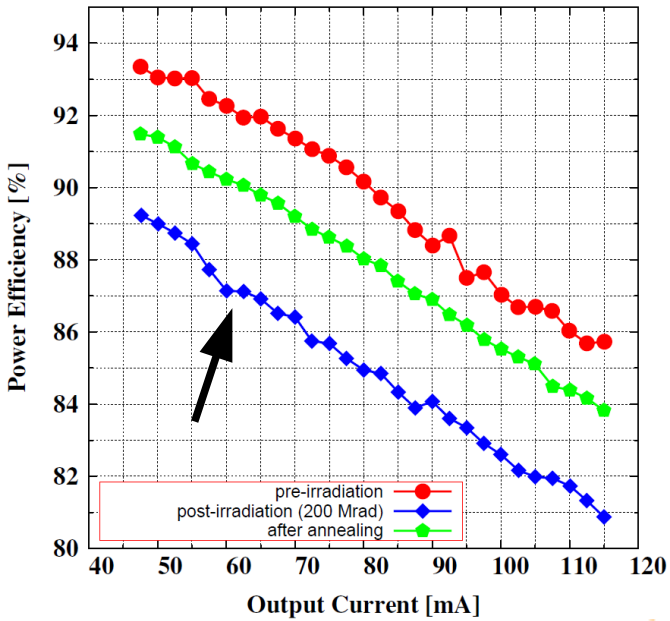
Irradiation:
- **X-ray photons**
- **up to 200 Mrad**

Annealing:
- **at 100°C**
- **for one week**

Relative voltage drop after irradiation is less than 1.5%.

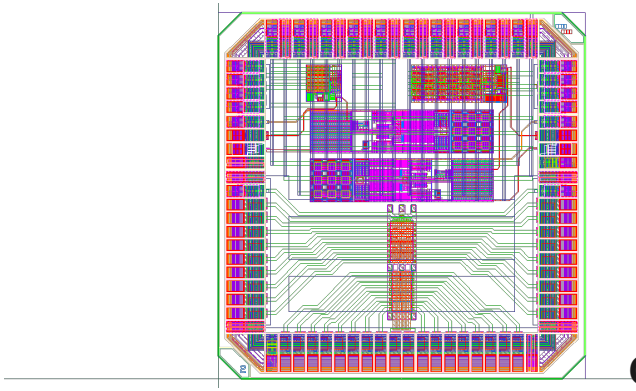
Observed small increase of the output impedance.





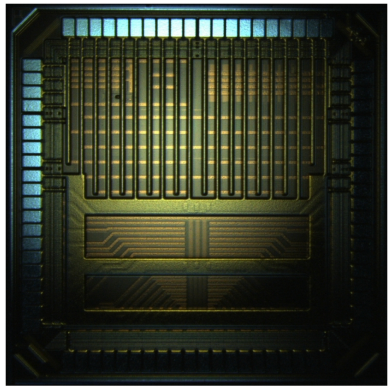
Future plans

The 2x2 mm^2 "VREG013" includes 2 Low Drop-Out (LDO) regulators with p-channel and n-channel pass device



Submitted in February 2011

Delivered to CERN in June 2011



Plans for combined tests of the front-end electronics with SC DC-DC converters and linear regulators.

Three chips on the PCB:
- SCT front-end (SCT32T130)
- SC DC-DC converters (DCDC013)
- Linear regulators (VREG013)

Conclusions

The voltage spikes observed at the output of the converters can be significantly reduced by:

- Chip bump bonded to the hybrid,
- Capacitors bump bonded directly to the DC-DC chip.

A new design of fully integrated switched capacitor DC-DC multiphase converters seems to be promising.

In order to avoid the efficiency drop after the irradiation, the use of **E**nclosed **L**ayout **T**ransistors (**ELT**s) in the final design should be considered.

SC DC-DC converters exist and operate with high power efficiency, up to 84% for the step-up converter and around up to 91% for the step-down converter.