# Inductor-based switching converter for low voltage power distribution in LHC upgrades

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# Working environment

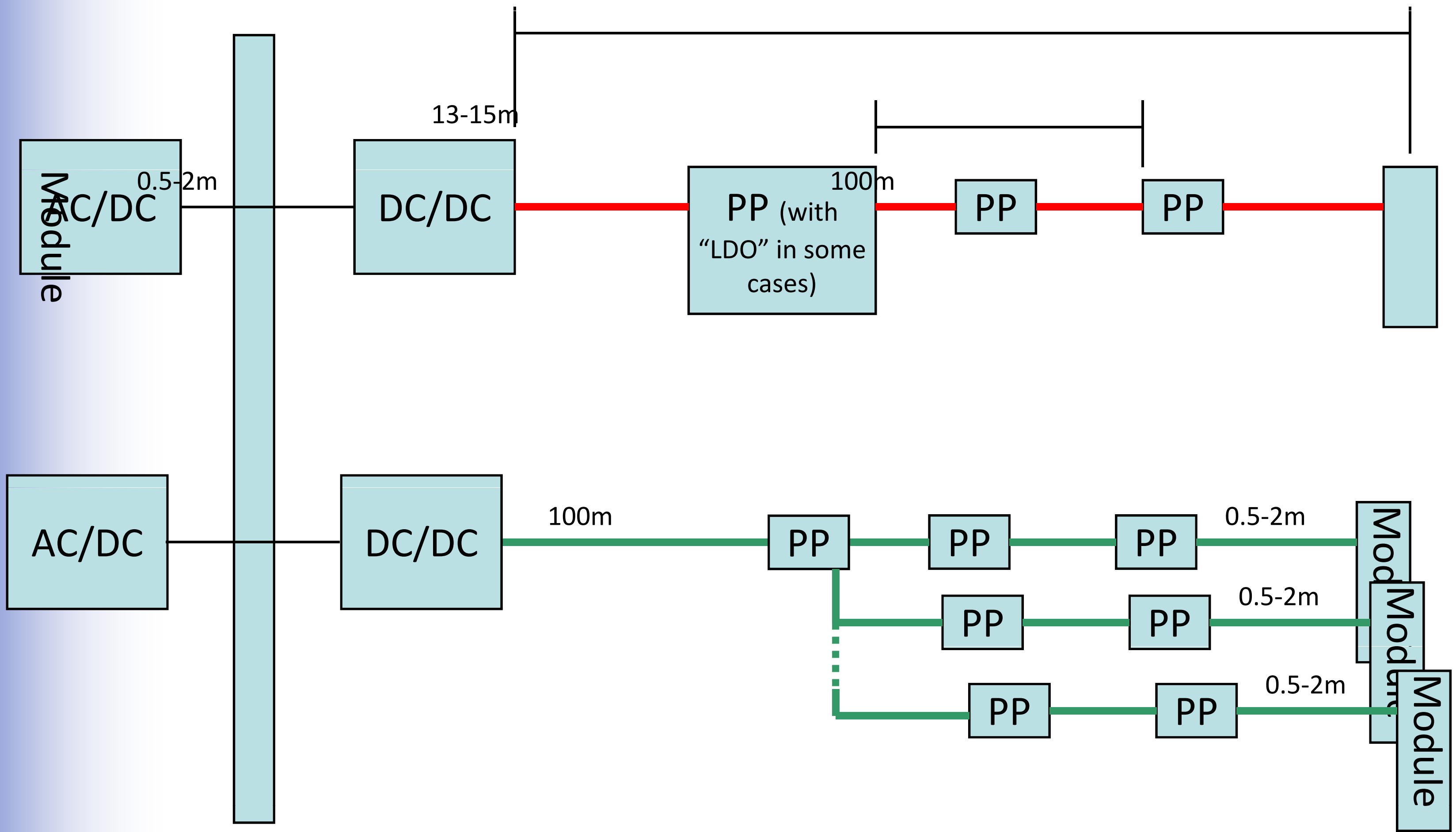
► High magnetic field (up to 4T in CMS, 2T in ATLAS)

► High level of radiation will be reached inside the detectors:

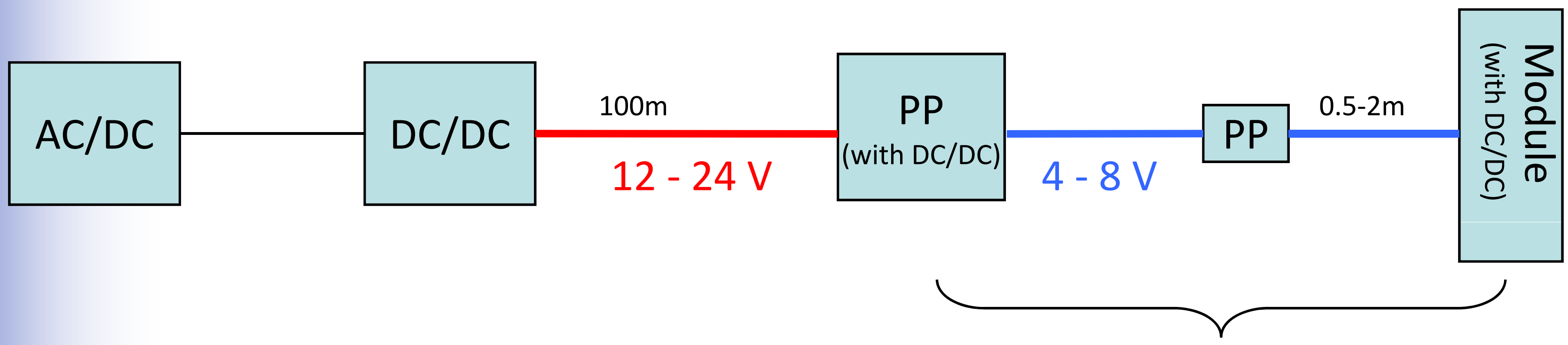
LHC doses probably increased x 5 – 10 so we can extrapolate to hundreds of Mrad in several Tracker location, decreasing to ten(s) in the outer Trackers

# Present power distribution schemes in trackers

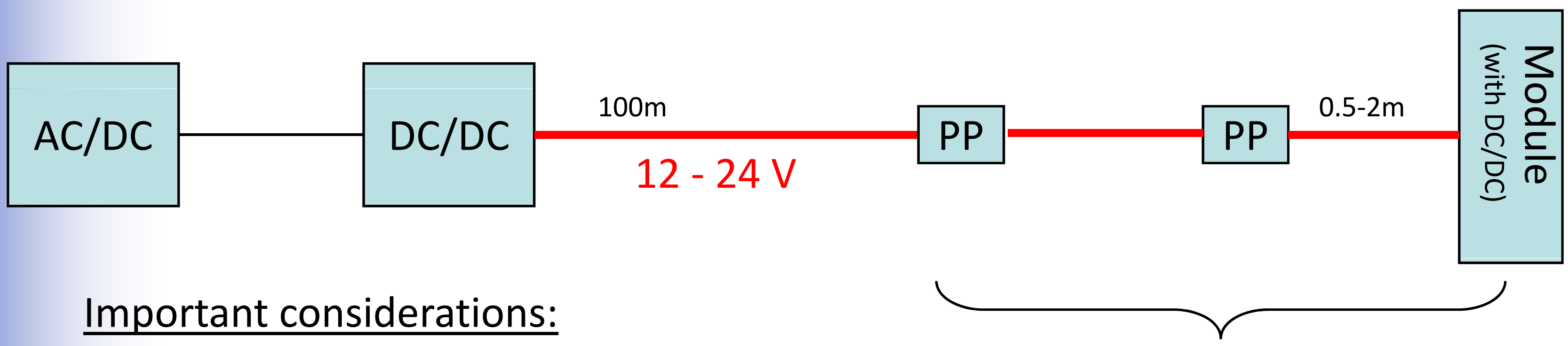
1A/channel (analog or digital), round-trip cables, and sense to nearest regulation



# Possible solutions




Same cables as today can bring more power,
It requires efficient DC/DC on module for cooling

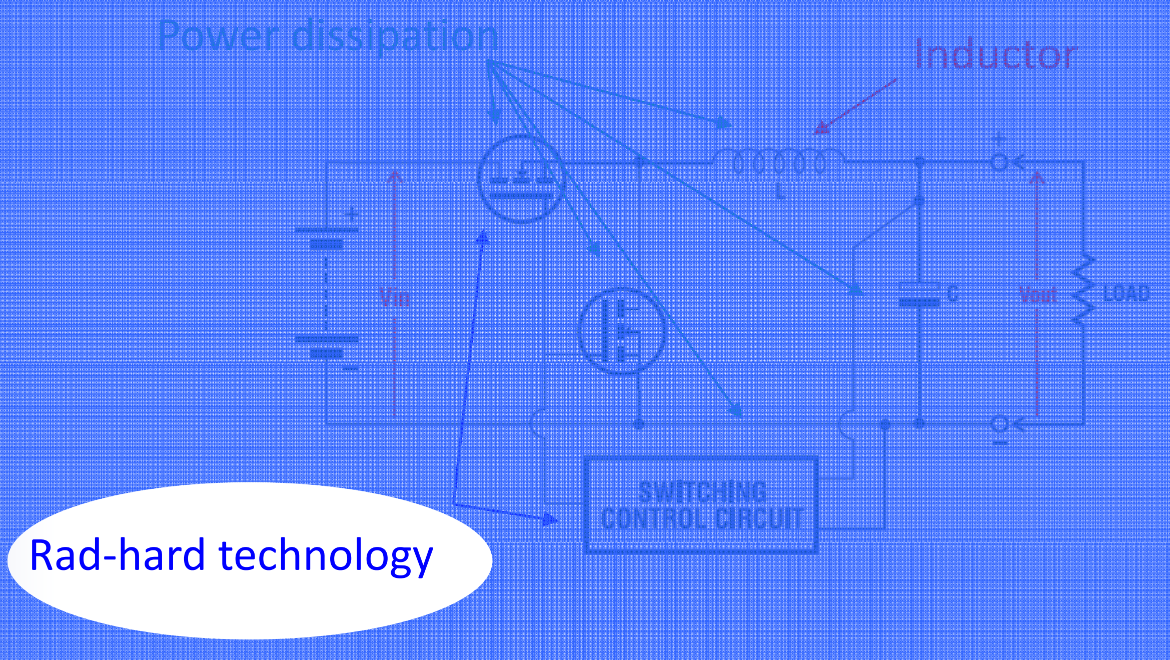



Important considerations:
Magnetic field, Radiation and Material Budget, plus EMI if inductor-based DC/DC

Small cables can bring all the power
It requires efficient DC/DC

# DC-DC: Work in progress

- Aiming at demonstrating the feasibility of a fully integrated (except L and passive components) DC-DC buck converter




Vin=12-24 V
Vout=1.5-3V
Iout=1-2A

# Selection of a technology

- Design and test of transistors of a 0.35 µm technology usually employed in automotive application

- Several different transistor topologies available for high-V applications (lateral, vertical)

- It needs to be radiation tolerant

# Radiation Tolerant NMOS

The main radiation-induced problem for the NMOS is the source-drain leakage current due to the radiation-induced trapping of positive charges in the thick lateral oxide

It is necessary to modify the layout of the NMOS in order to make them radiation tolerant.

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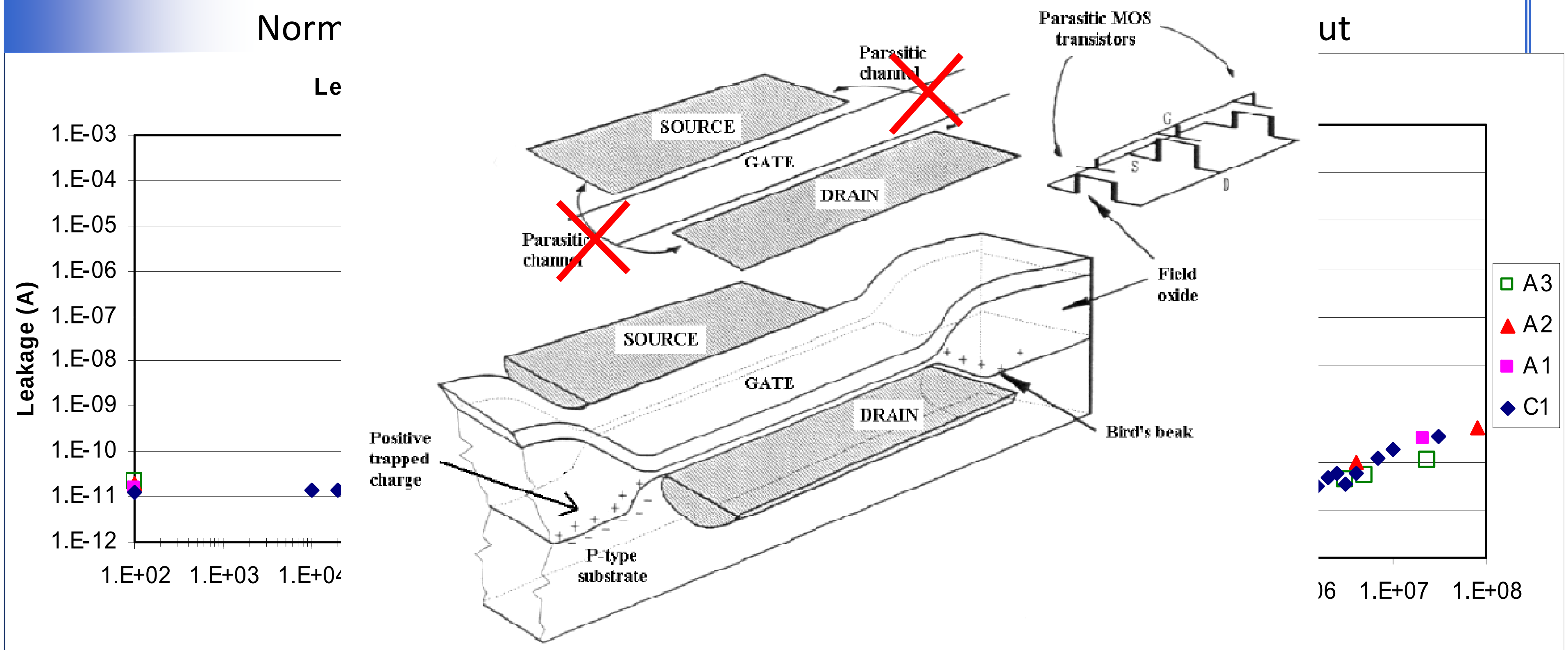

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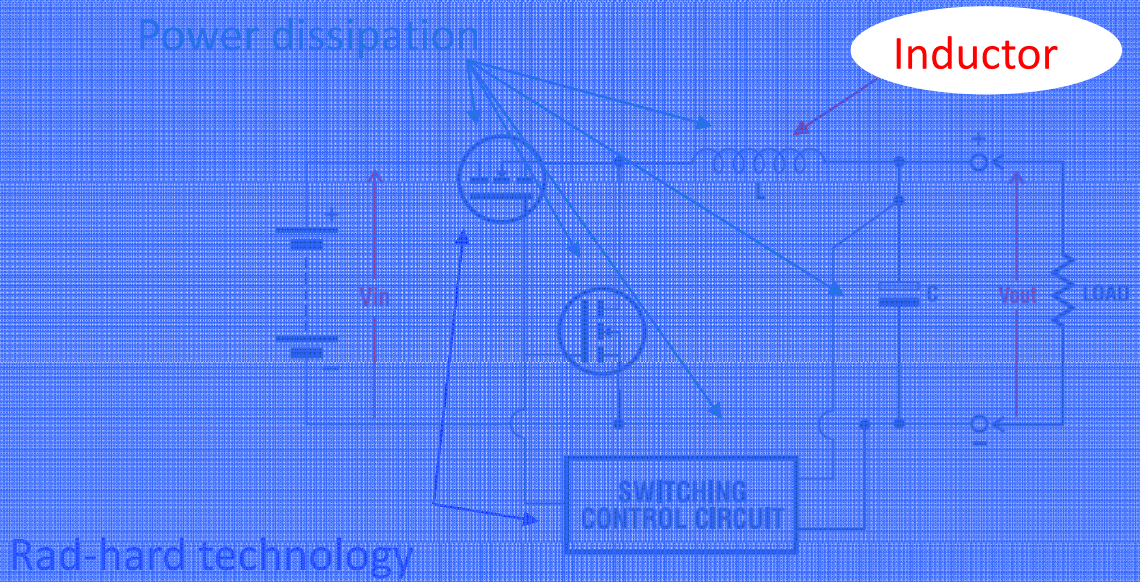


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# Inductors

- Inductor: need of air core inductor because of high magnetic field for CMS (up to 4 T) and ATLAS (up to 2 T)

| Material | Initial Perm. µo | B max (T) | Operating Frequencies |
|---|---|---|---|
| Fe | 250 | 2,2 | 60-1000 Hz |
| Si-Fe (unoriented) | 400 | 2,0 | 60-1000 Hz |
| Si-Fe (oriented) | 1500 | 2,0 | 60-1000Hz |
| 50-50 Ni Fe (grain-oriented) | 2000 | 1,6 | 60-1000Hz |
| AMORPHOUS Alloy B | 3000 | 1,5-1,6 | to 250 kHz |
| High Flux powder | 14 to 160 | 1,5 | 10 kHz to 1 MHz |
| Kool Mu ® powder | 26 to 125 | 1,0 | to 10 MHz |
| Iron powder | 5 to 80 | 1,0 | 100 kHz-100 MHz |
| 79 Permalloy | 12,000 to 100,000 | 8 to 1,1 | 1 kHz-75kHz |
| AMORPHOUS Alloy E | 20,000 | 0.5-0.65 | to 250 kHz |
| Ferrite-MnZn | 750 To 15,000 | 0.3 to 0.5 | 10 kHz-2 MHz |
| Ferrite-NiZn | 10 to 1500 | 0.3 to 0.5 | 200 kHz-100MHz |
| Permalloypowder | 14 to 550 | 0.3 | 10 kHz-1 MHz |

A Critical Comparison of Ferrites with other Magnetic Materials, 2000

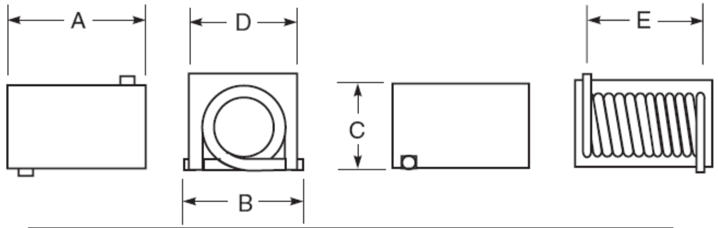
*Stefano Michelis*

# Inductors

## Different commercial choices

### Coilcraft


| Inductance (nH) | DCR max (mOhm) | Irms (A) |
|---|---|---|
| 380 | 50 | 2,5 |
| 538 | 90 | 2 |

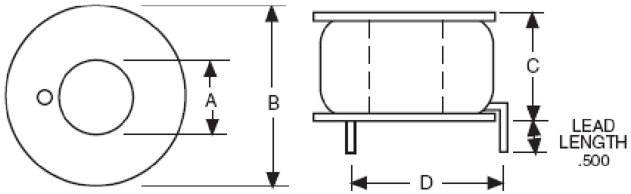



| A | B | C | D | E |
|---|---|---|---|---|
| 10mm | 6mm | 6mm | 5mm | 8mm |

### Renco electronics

**RL-1233**
**RL-1238, RL-1239**
**AIR CORE INDUCTORS**
BOBBIN WOUND

| Inductance (nH) | DCR max (mOhm) | Irms (A) |
|---|---|---|
| 560 | 6 | 8 |
| 1200 | 10 | 8 |




| A | B | C | D |
|---|---|---|---|
| 16mm | 30mm | 14mm | 21mm |

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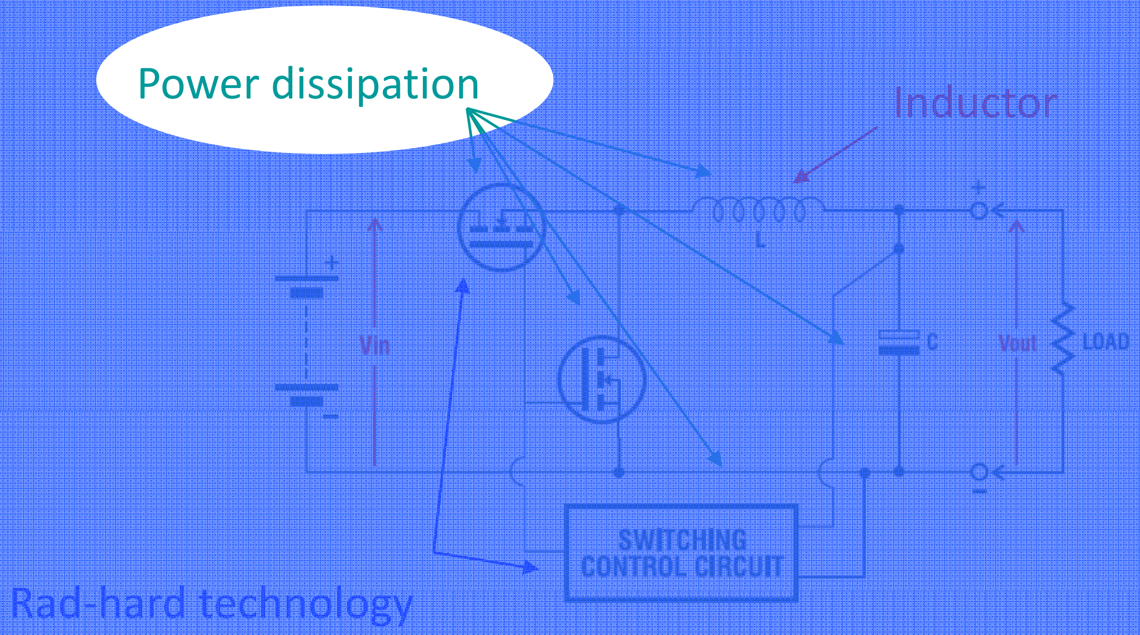


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# Power losses

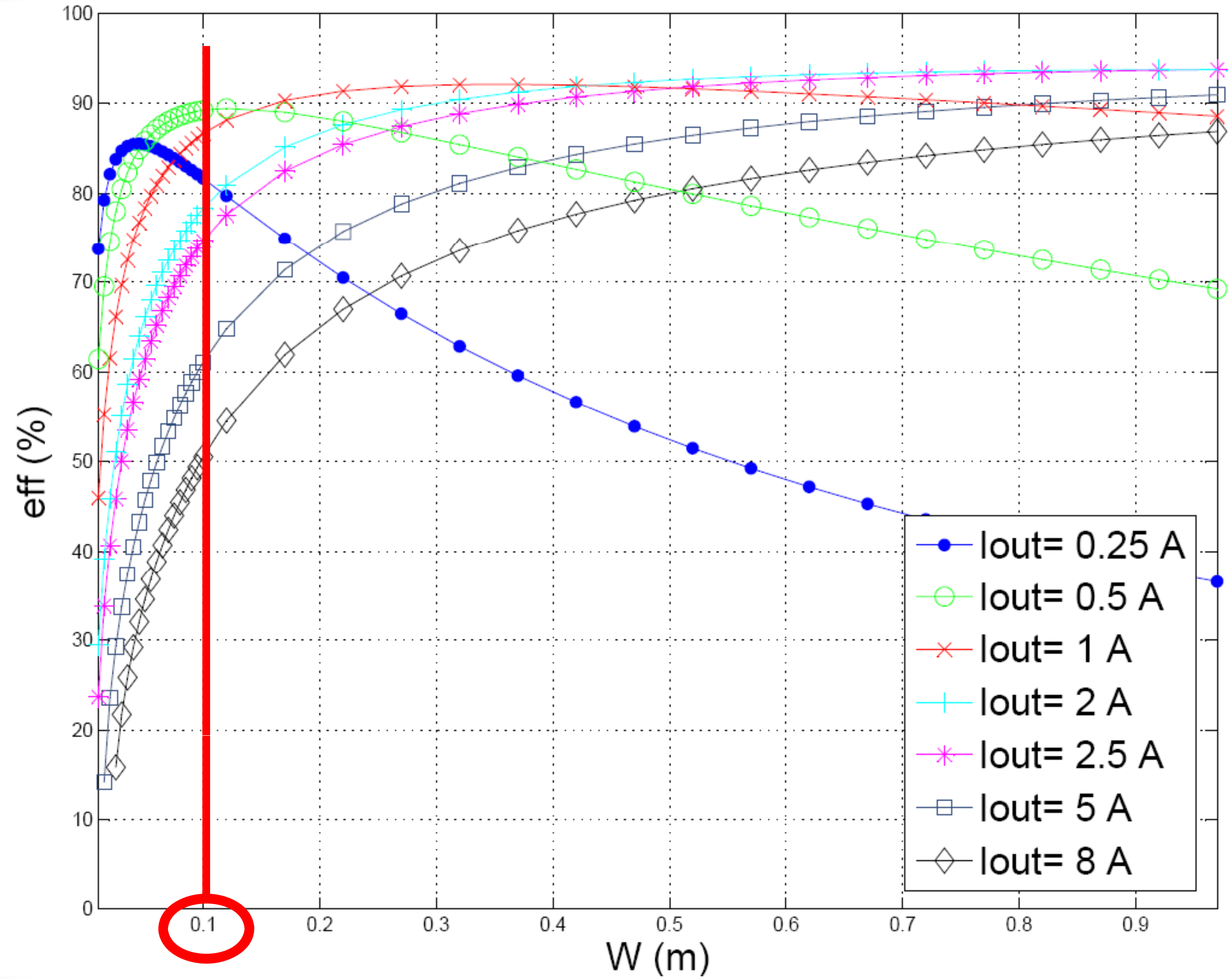
There are power losses in the circuit due to the non-ideal component.

Mainly there are three losses that it is necessary to consider:

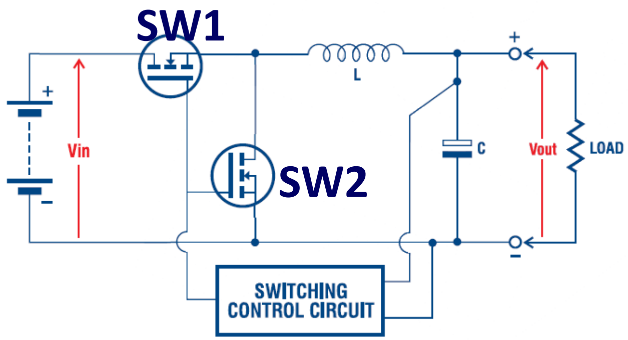
1. on $R_{on}$ and $R_{ind}$, parasitic resistances of the switch and inductor, respectively;
2. on charging the gate capacitance;
3. on the control circuit.

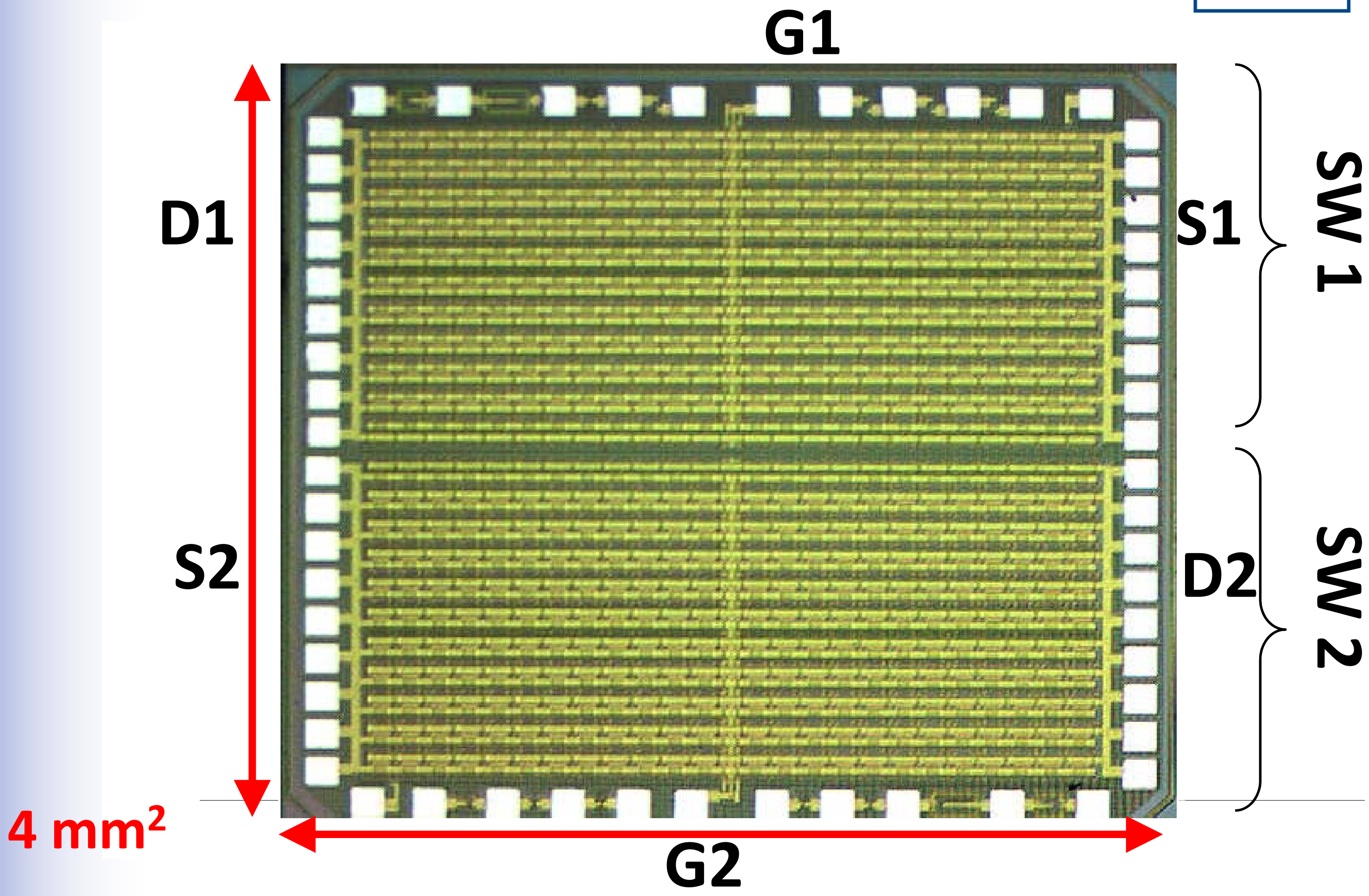
# Efficiency vs $I_{out}$ and W

with $V_{in}$=24V, $V_{out}$=2.5V, $R_{ind}$=6mΩ and L=700nH

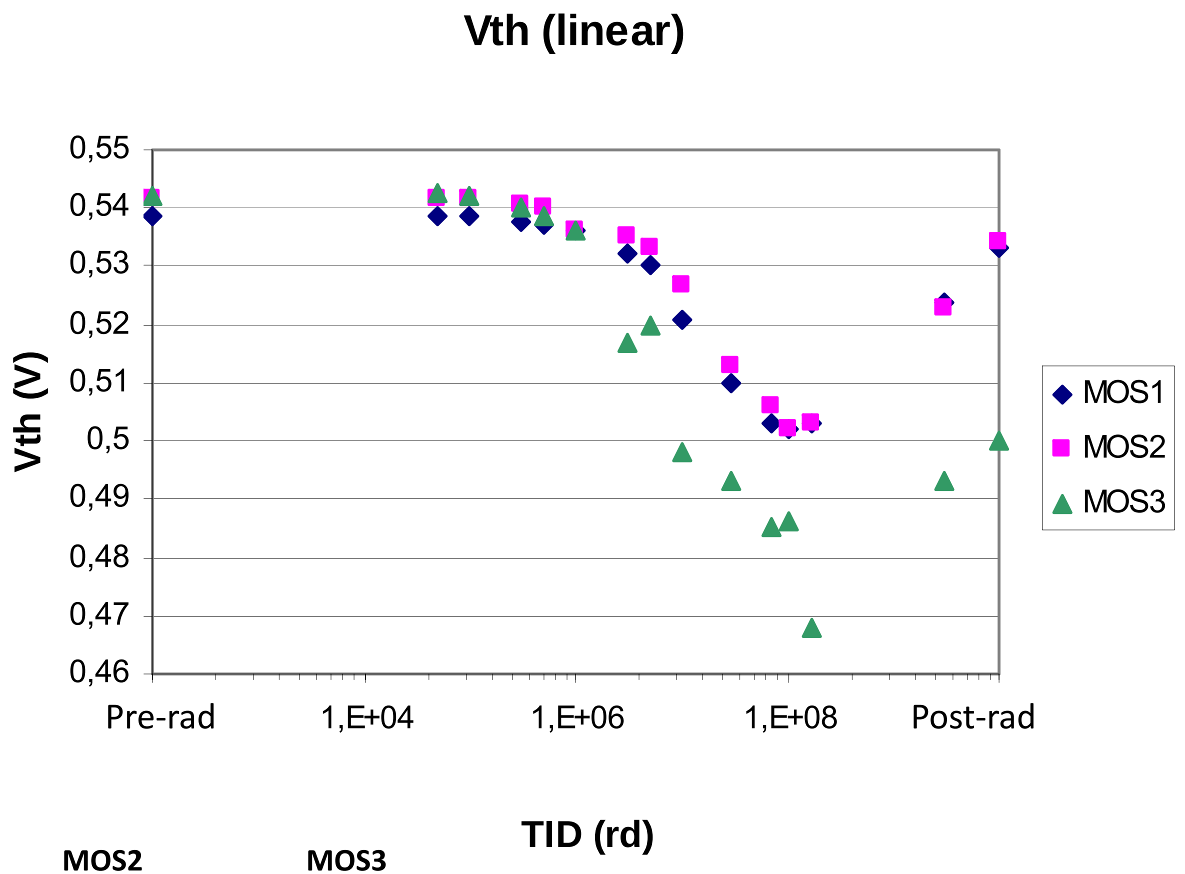


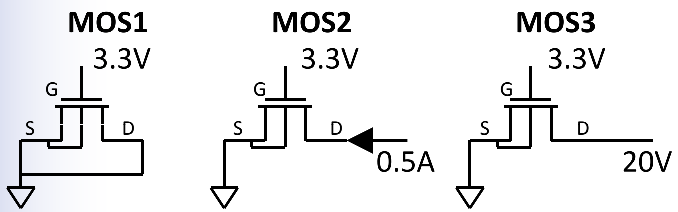
# NMOS design W=0.1m



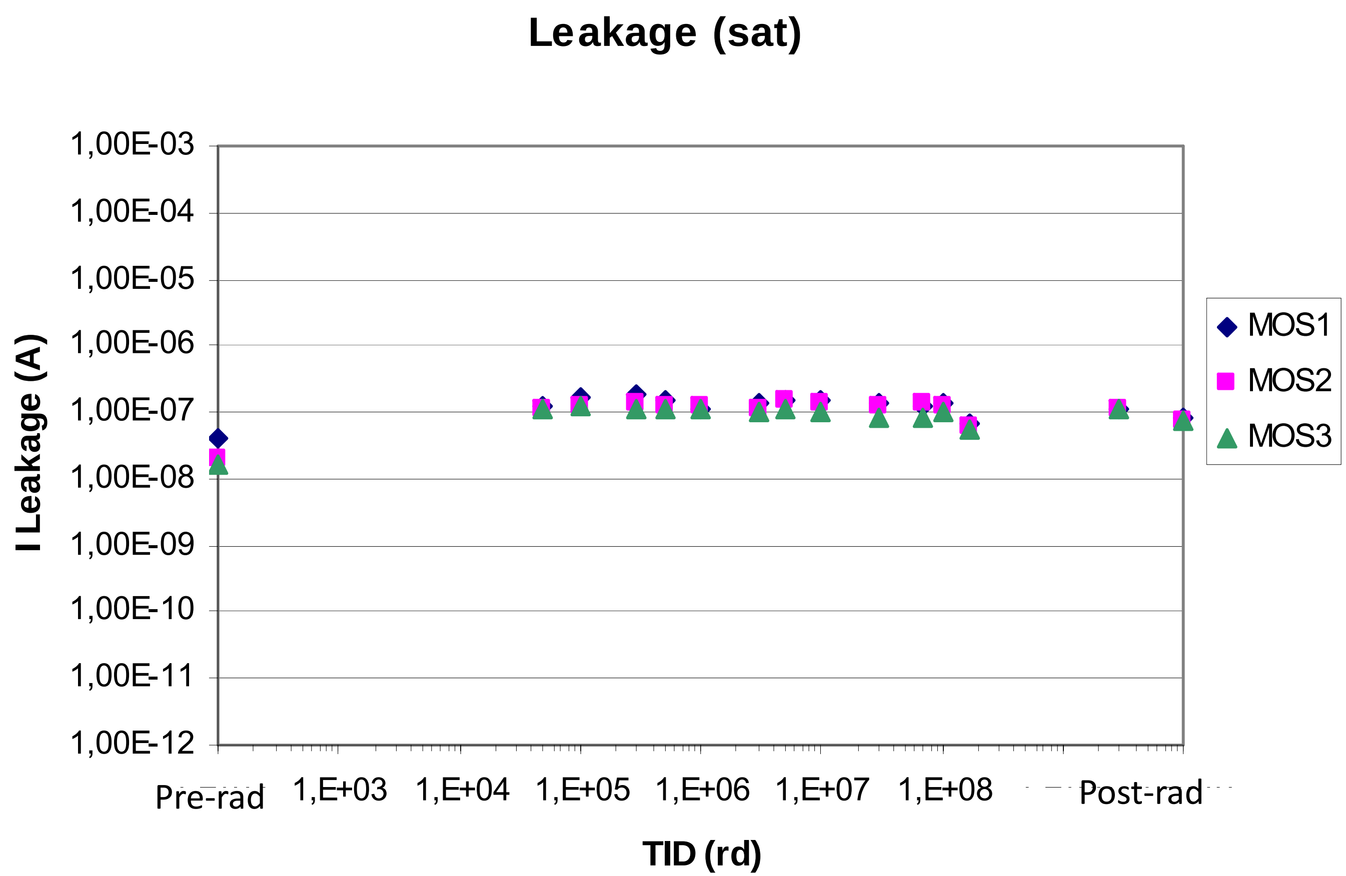



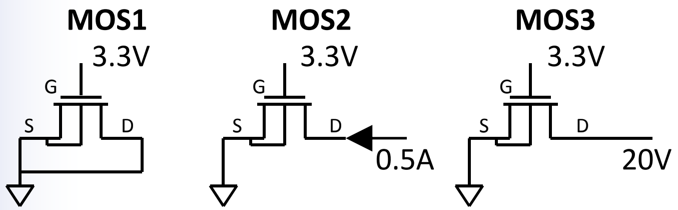
# NMOS irradiation tests – Threshold Votage



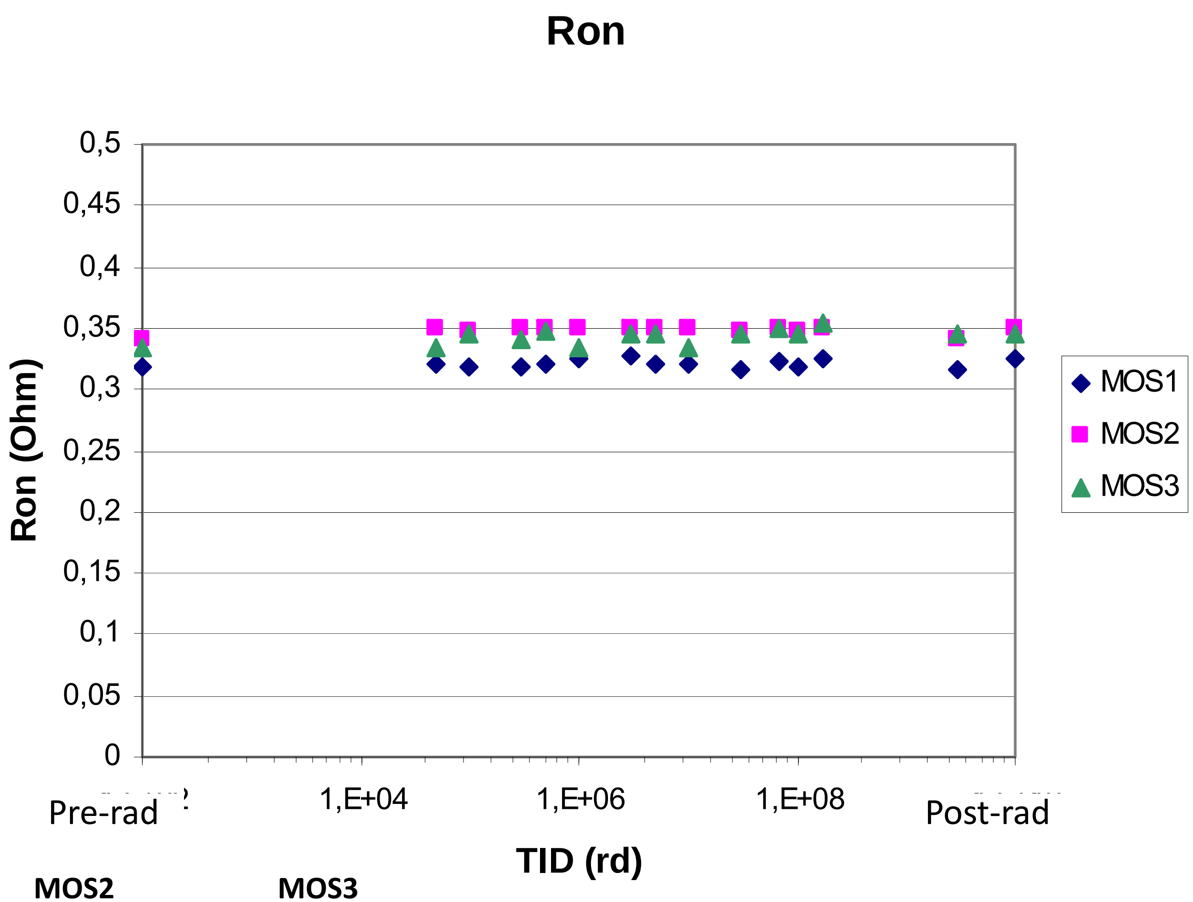



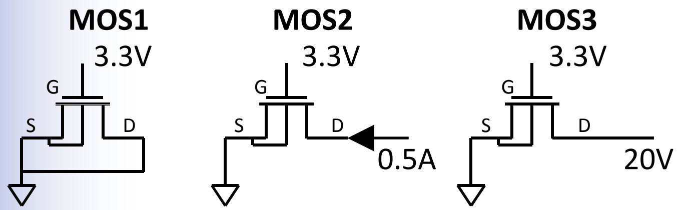
# NMOS irradiation tests – Leakage Current



# NMOS irradiation tests - $R_{on}$



# Conclusions

We have demonstrated that:

1. the technology can be tolerant to TID up to at least 180Mrd and switch transistors of the required size can be integrated
2. Air core inductor can be used in such high DC magnetic field
3. efficiency above 80% is achievable

Evaluation of EMI is in progress

- choosing dedicate architecture and inductor shape
- making measures and trying to standardize the measurement process.