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

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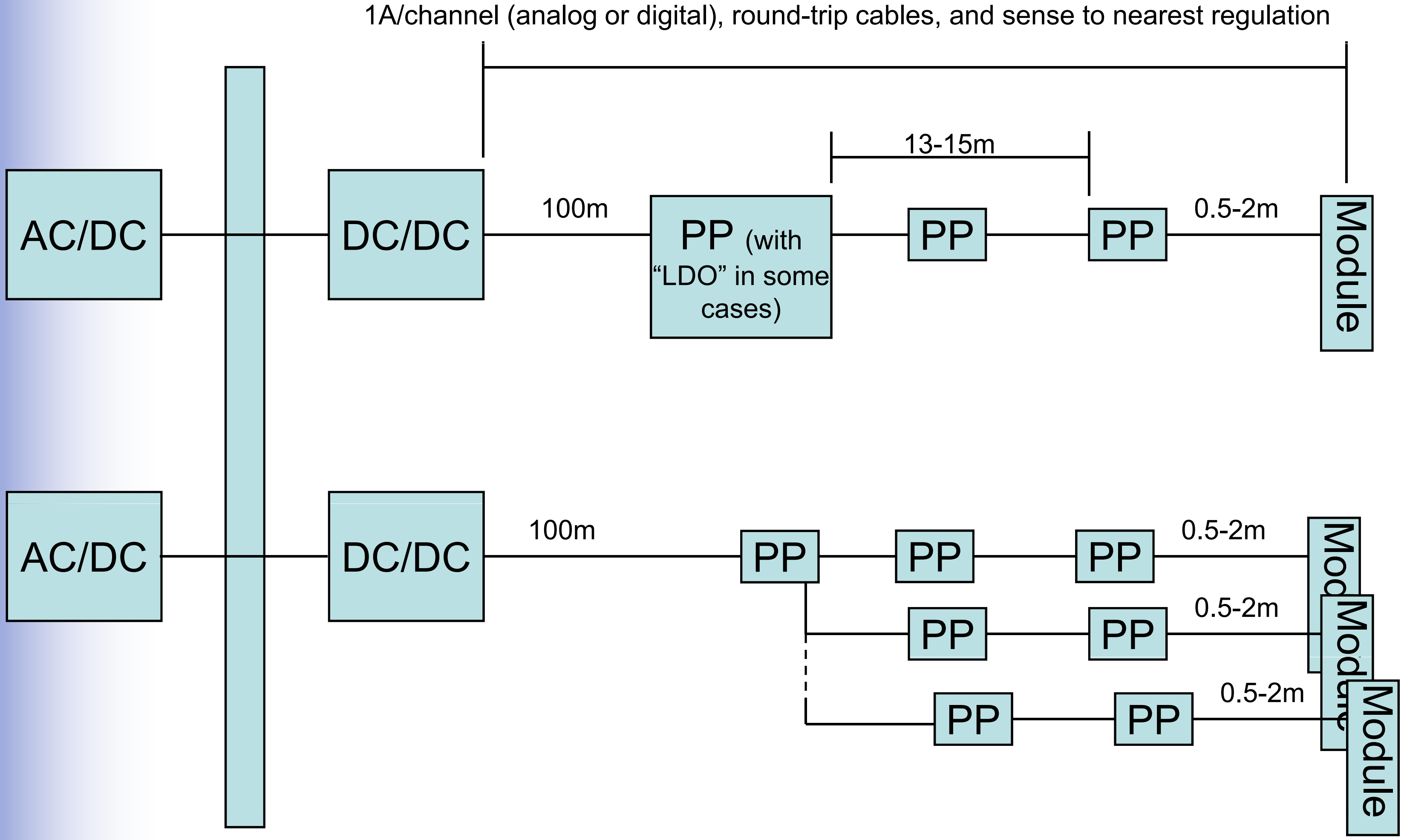
Working environment

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

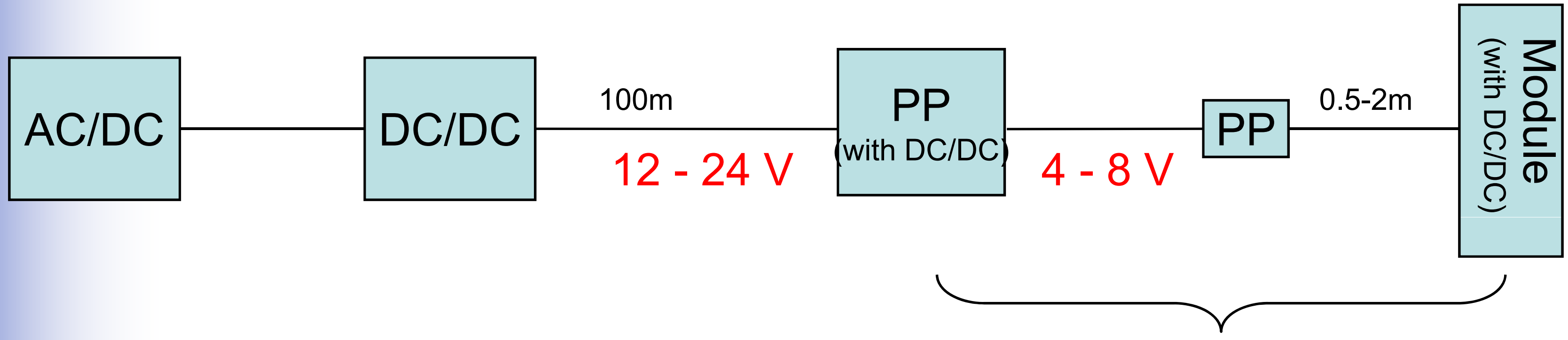
► High level of radiation will be reached inside the detectors:

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

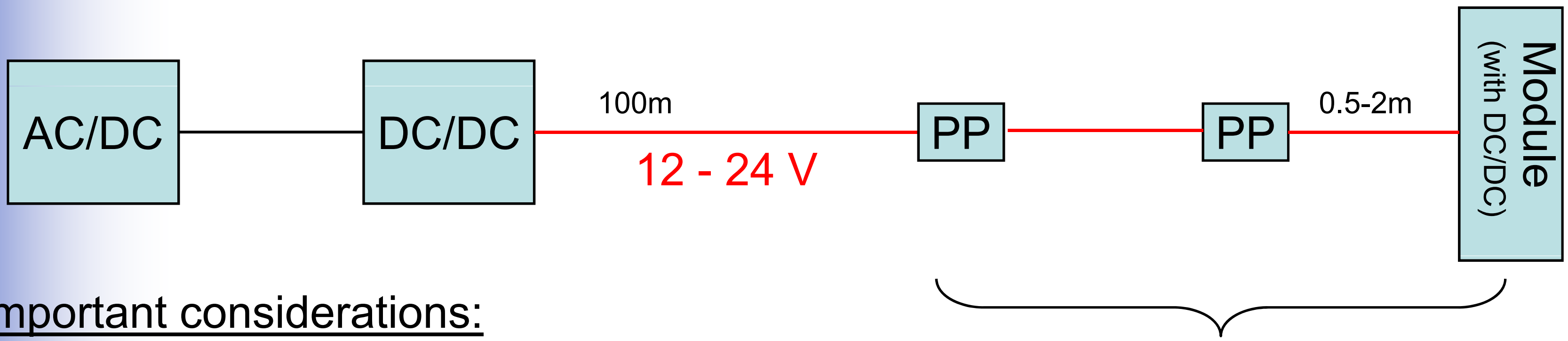
Present power distribution schemes in trackers



Possible solutions



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

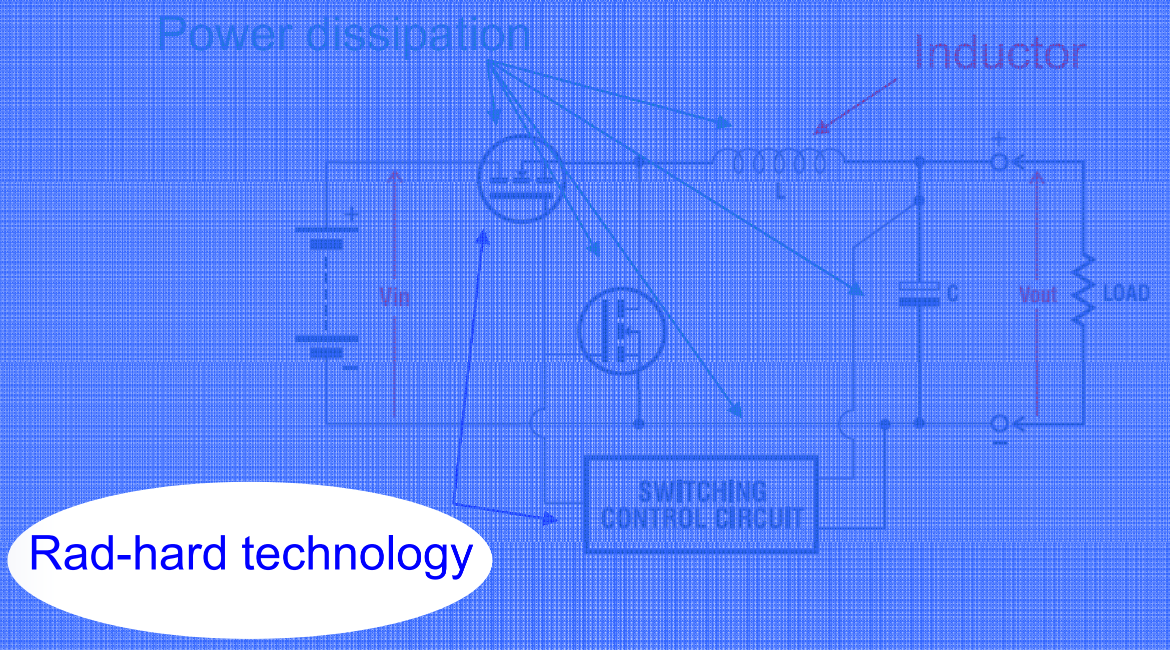


<u>Important considerations:</u>
Magnetic field, Radiation and Material Budget, plus EMI if inductor-based DC/DC

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

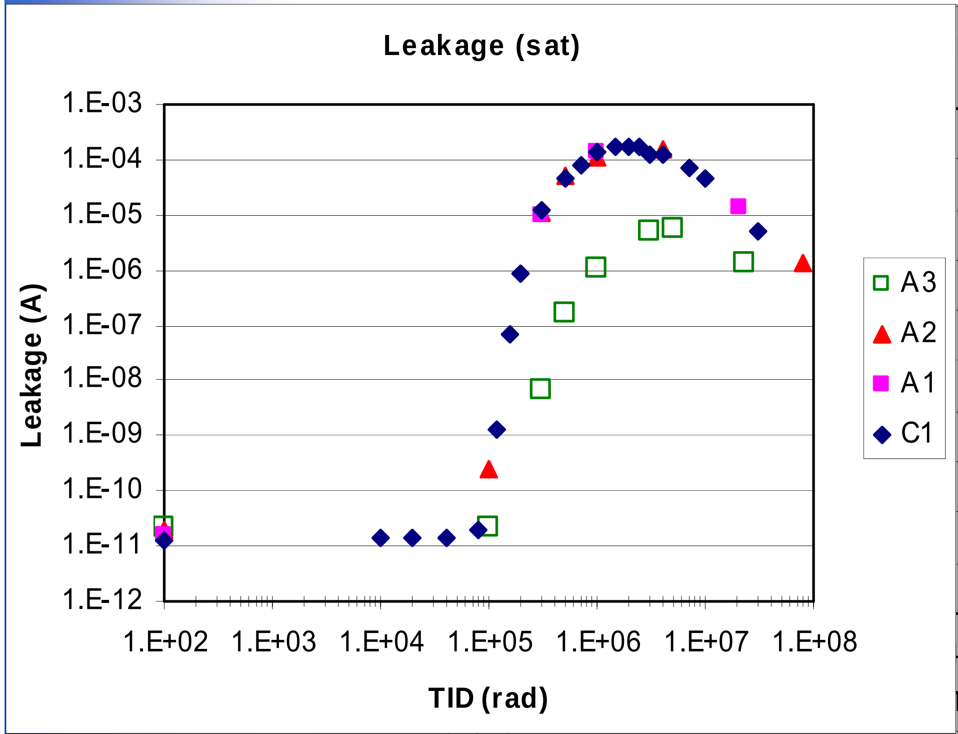
- Design and test of transistors of a 0.35 μm technology usually employed in automotive application
- Several different transistor topologies available for high-V applications (lateral, vertical)
- It needs to be radiation tolerant

Radiation Tolerant NMOS

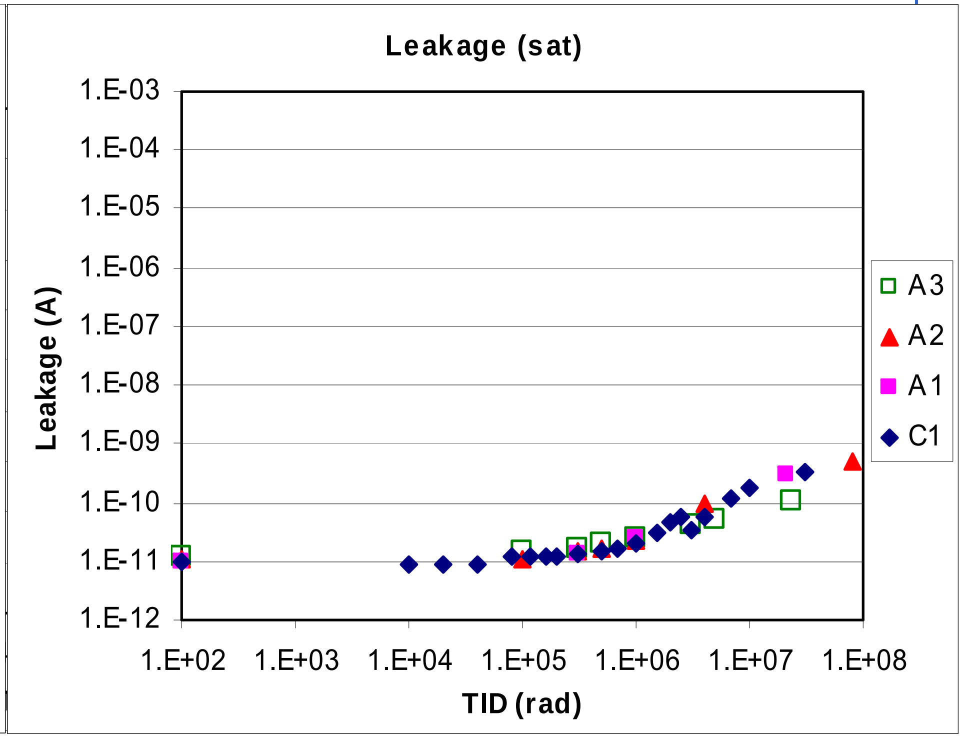
The main radiation-induced problem for the NMOS is the source-drain leakage current due to the radiation-induced trapping of positive charges in the thick lateral oxide

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

Normal Layout



Enclosed Layout



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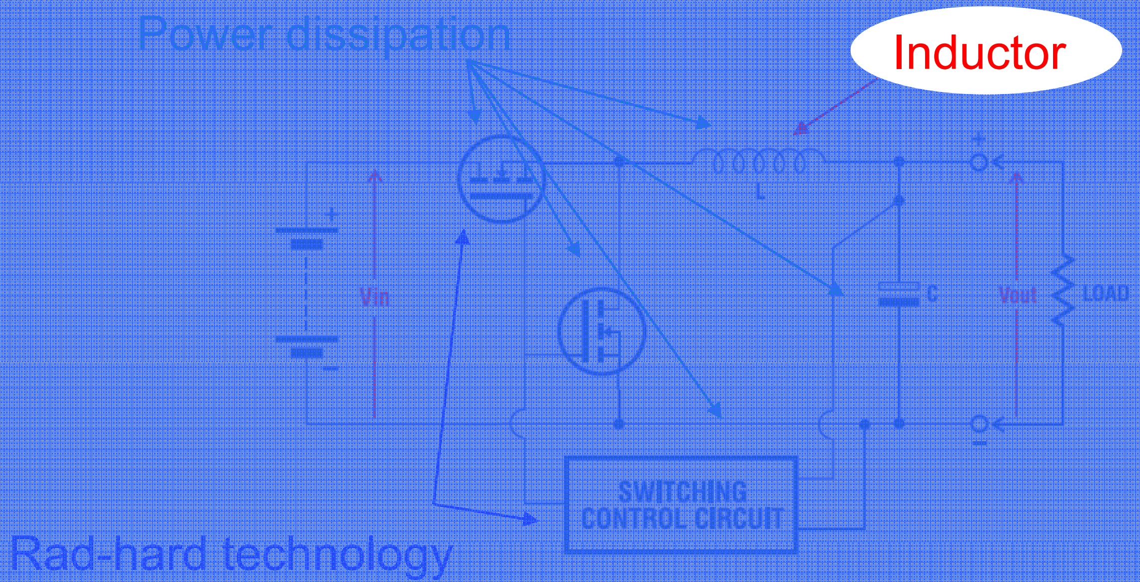

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Inductors

- 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

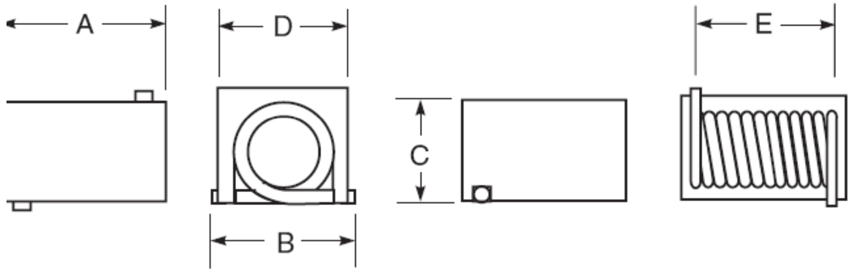
A Critical Comparison of Ferrites with other Magnetic Materials, 2000

Inductors

Different commercial choices

Coilcraft

Inductance[2] (nH)	DCR max[5] (mOhm)	Irms[6] (A)
90	15	3.5
206	30	3.0
380	50	2.5
538	90	2.0



A max	B max	C max	D	E
10,55	6,60	5,97	5,74 ±0,08	7,98 ±0,51

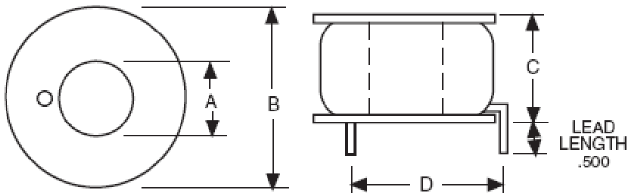
RL-1233

RL-1238, RL-1239

AIR CORE INDUCTORS

BOBBIN WOUND

RL-1233 Renco Part No.	L ±15%* µH	RDC Max. (Ohms)	Suggested RMS Current Rating
RL-1233-0.56	.56	0.006	8.0
RL-1233-1.2	1.2	0.010	8.0
RL-1233-3.3	3.3	0.016	8.0
RL-1233-8.2	8.2	0.026	8.0



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

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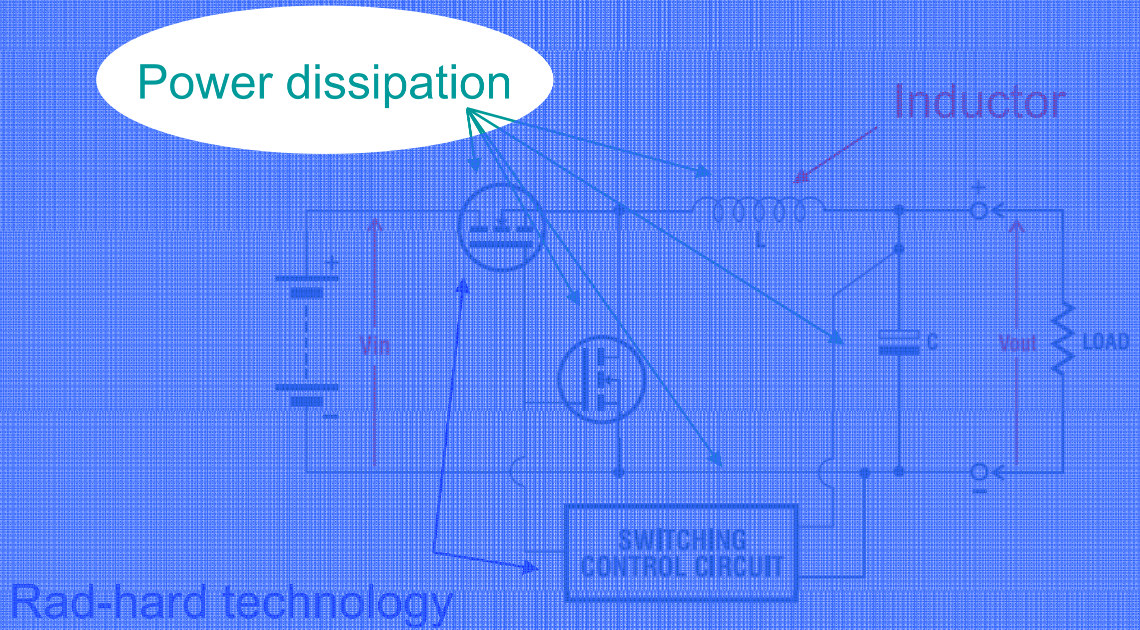

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Power losses

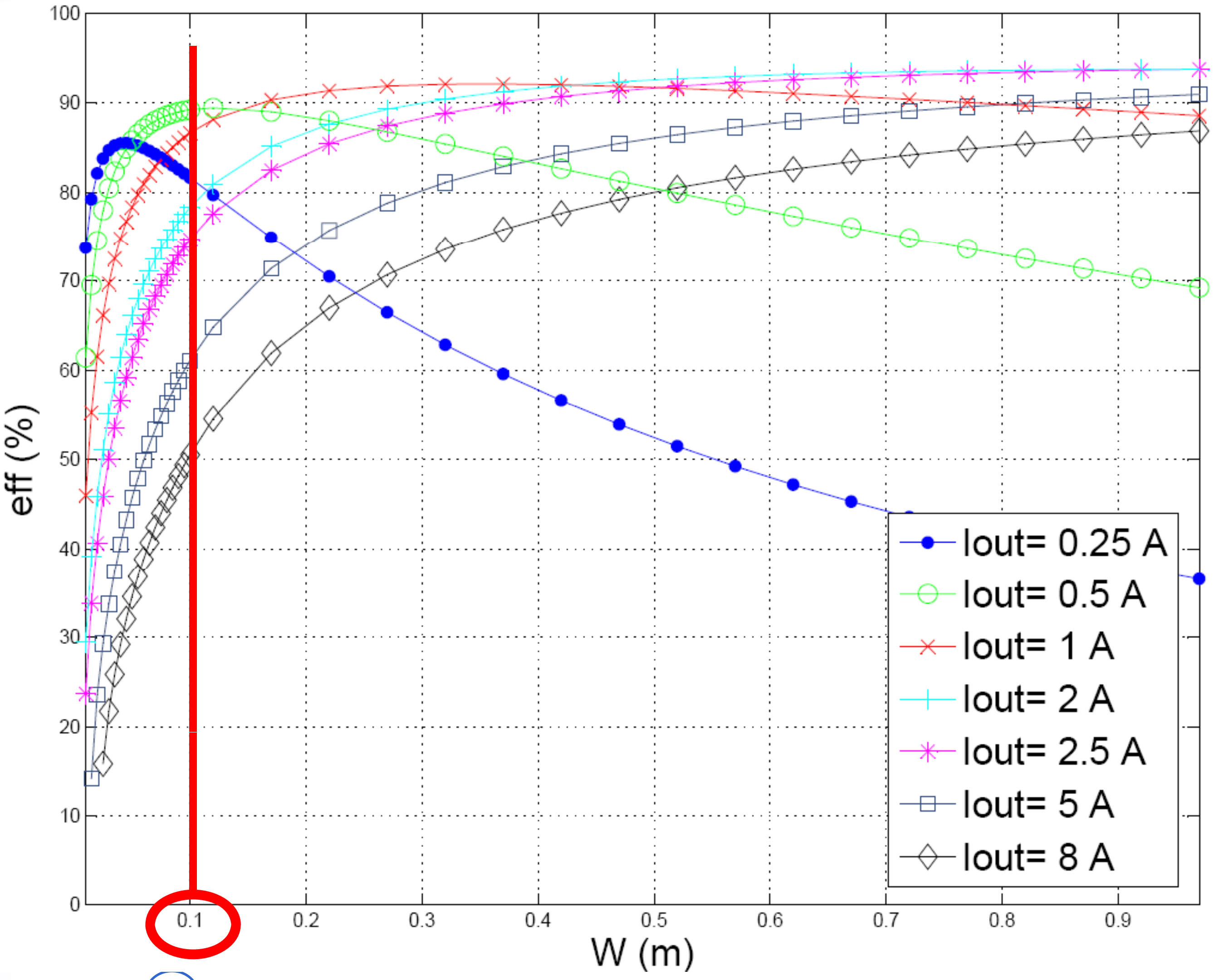
There are power losses in the circuit due to the non-ideal component.

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

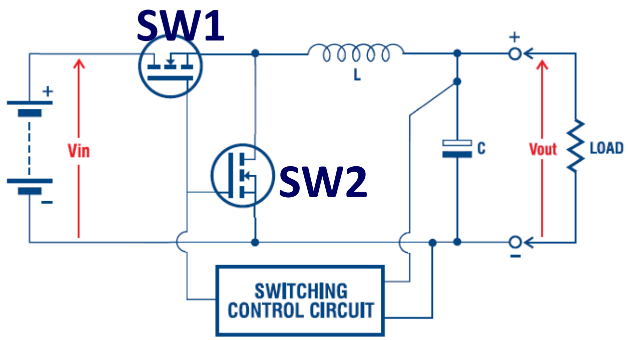
1. on R_{on} and R_{ind}, parasitic resistances of the switch and inductor, respectively;
2. on charging the gate capacitance;
3. on conduction to ground;
4. on the control circuit.

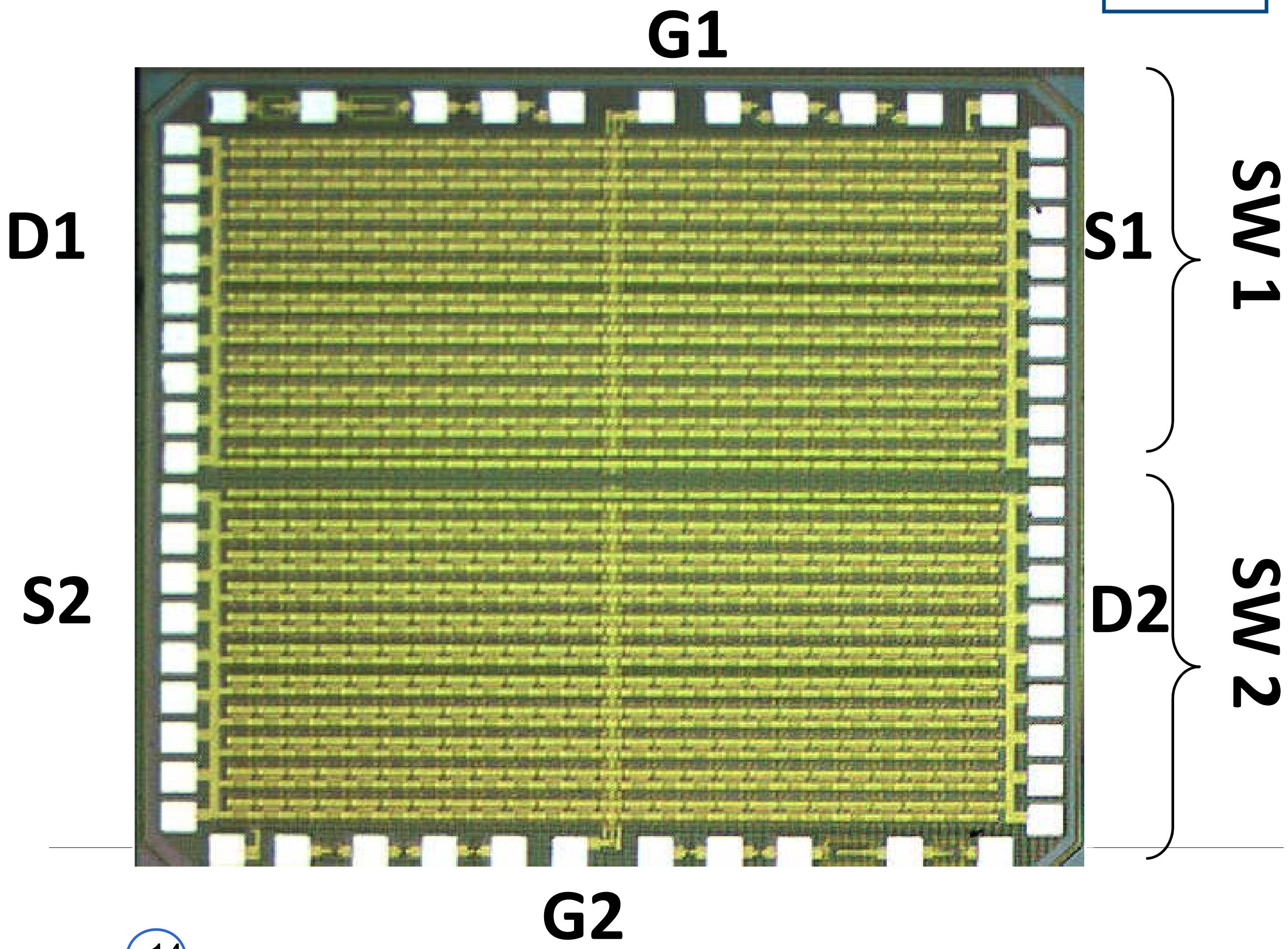
Efficiency vs I_{out} and W

with V_{in}=24V, V_{out}=2.8V, R_{ind}=6mΩ and L=538nH

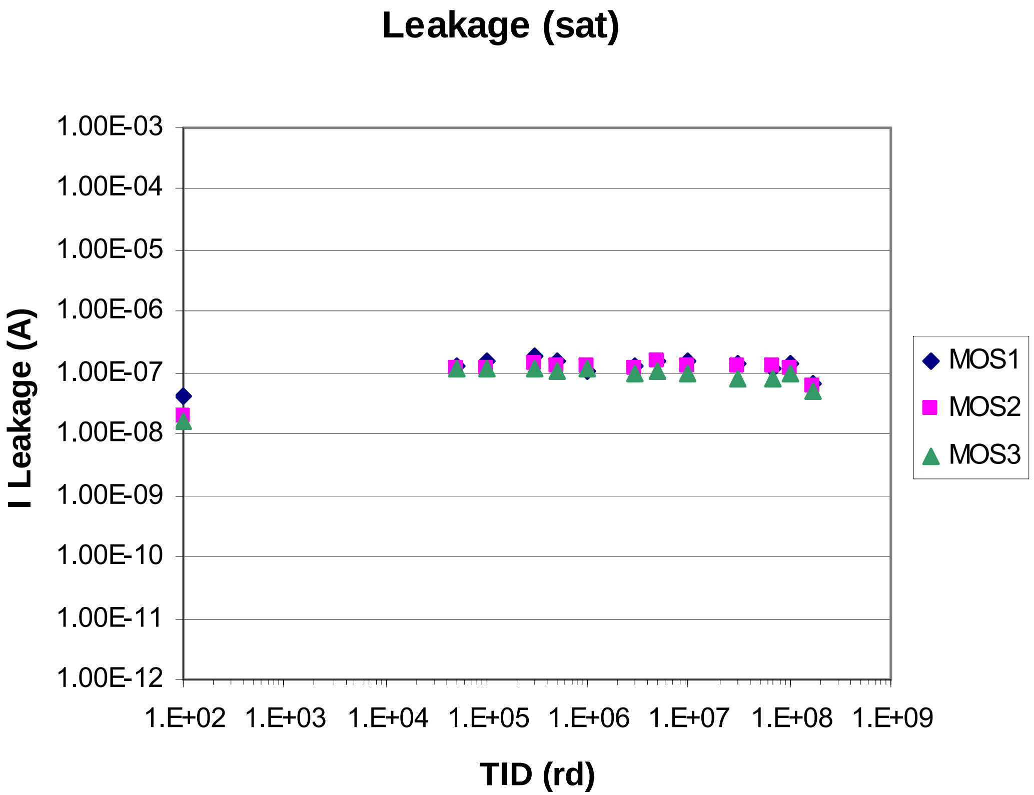


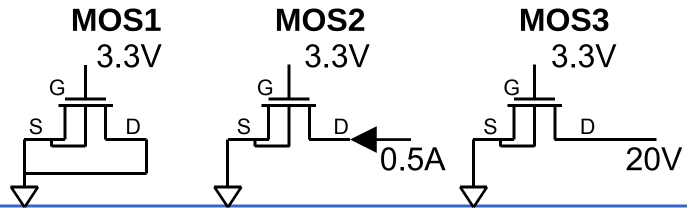
NMOS design W=0.1m





NMOS irradiation tests





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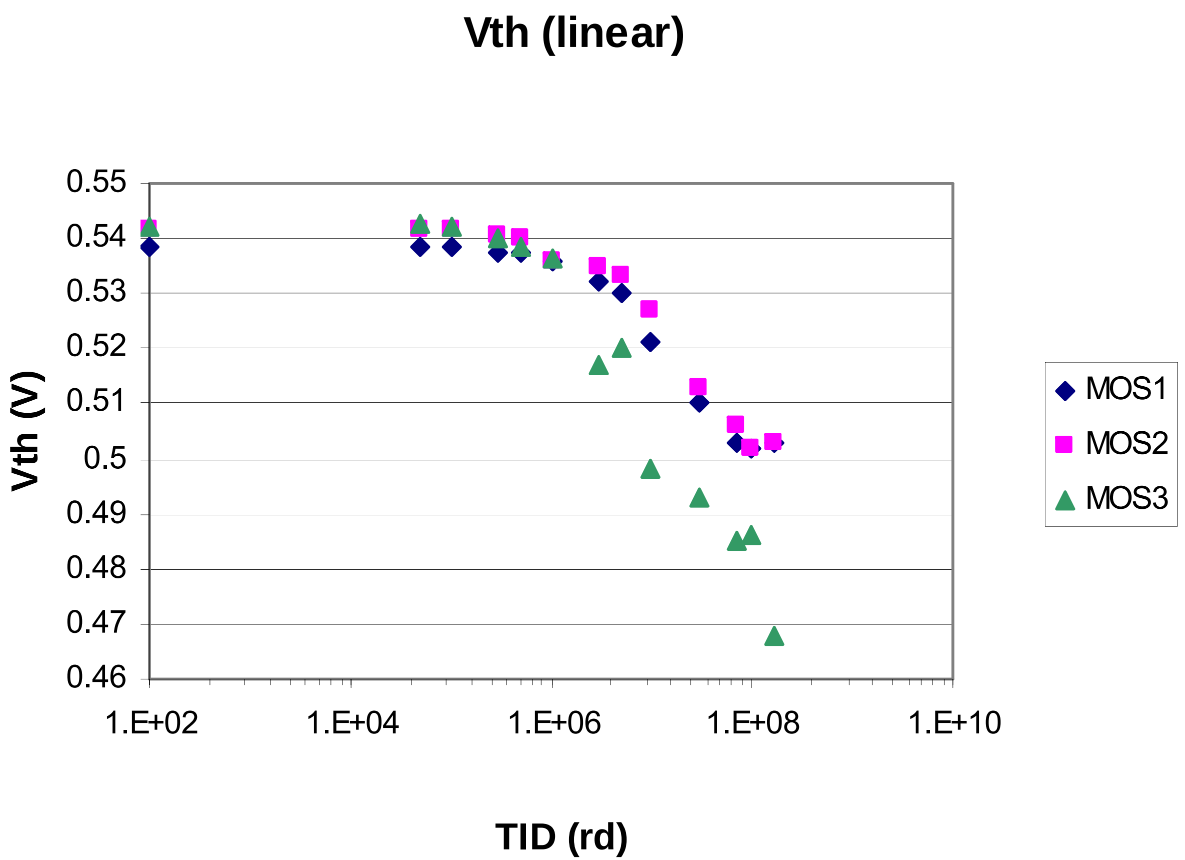

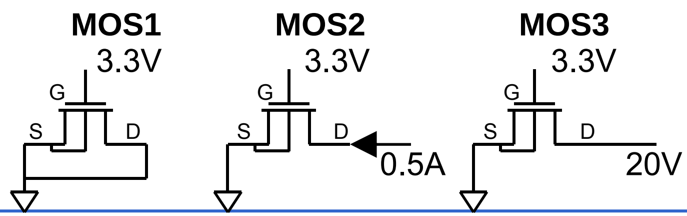

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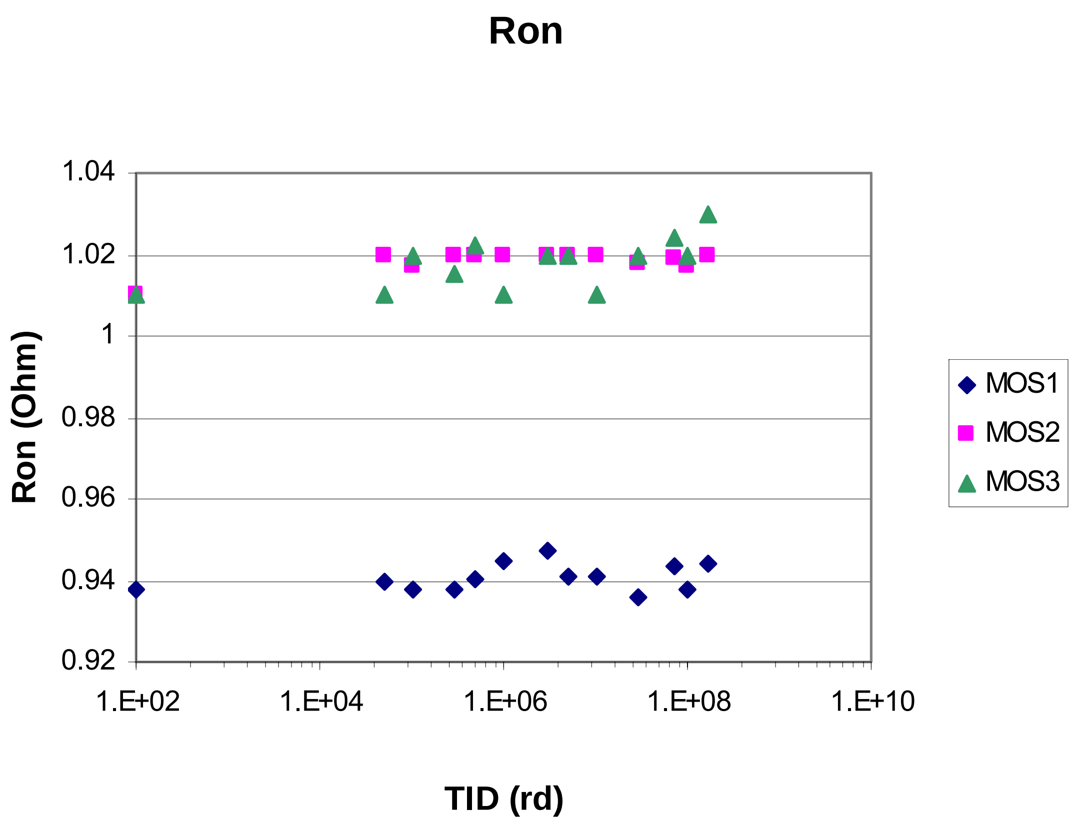

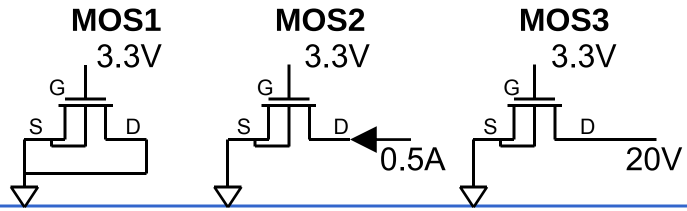

Conclusions

We have demonstrated that the Buck converter can be tolerant to:

- radiations (use of modified NMOS)
- magnetic field (use of Air-core inductors)

It can reach an efficiency above 80%

Big transistors can be fabricated with high yield

Evaluation of EMI is in progress

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