European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

Development of radiation-tolerant linear voltage regulators and on-detector DC-DC conversion

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CERN – PH/MIC

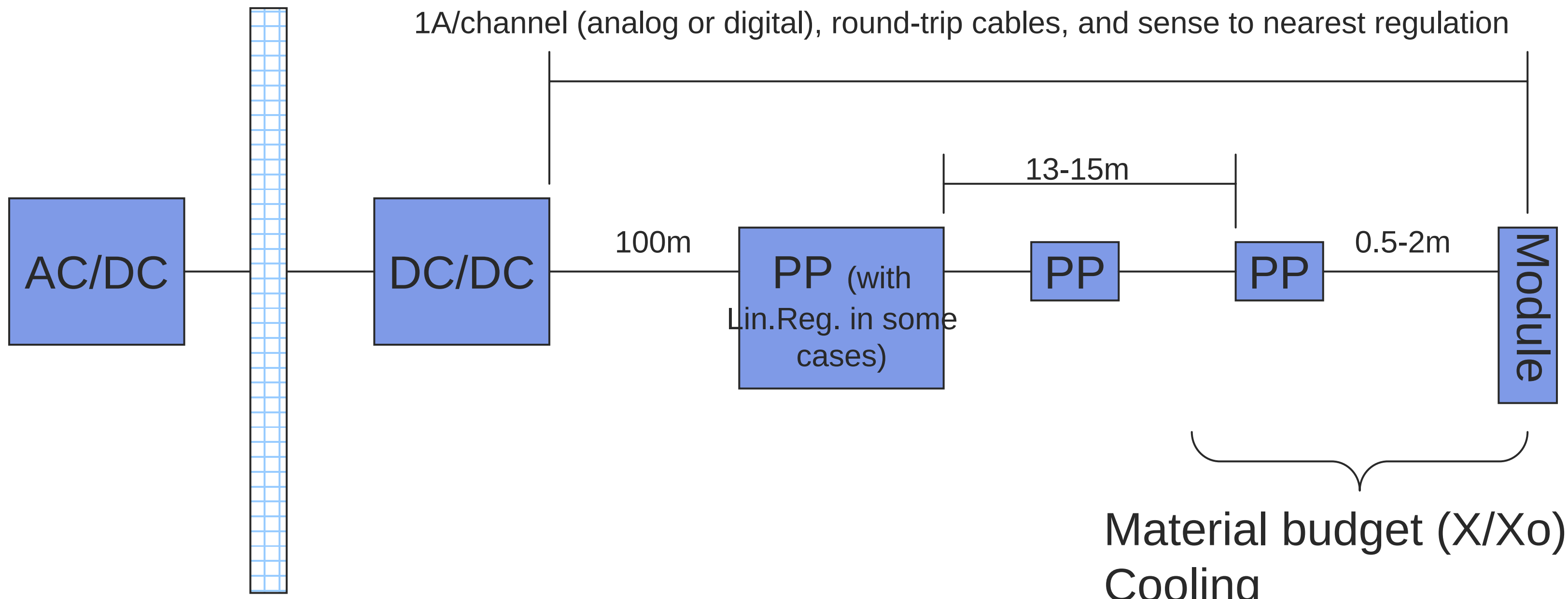
Outline

The power distribution puzzle in LHC upgrades (trackers)

DC-DC converters with air-core inductors

Low Drop Out regulators (LDO)

Present power distribution schemes (in trackers)



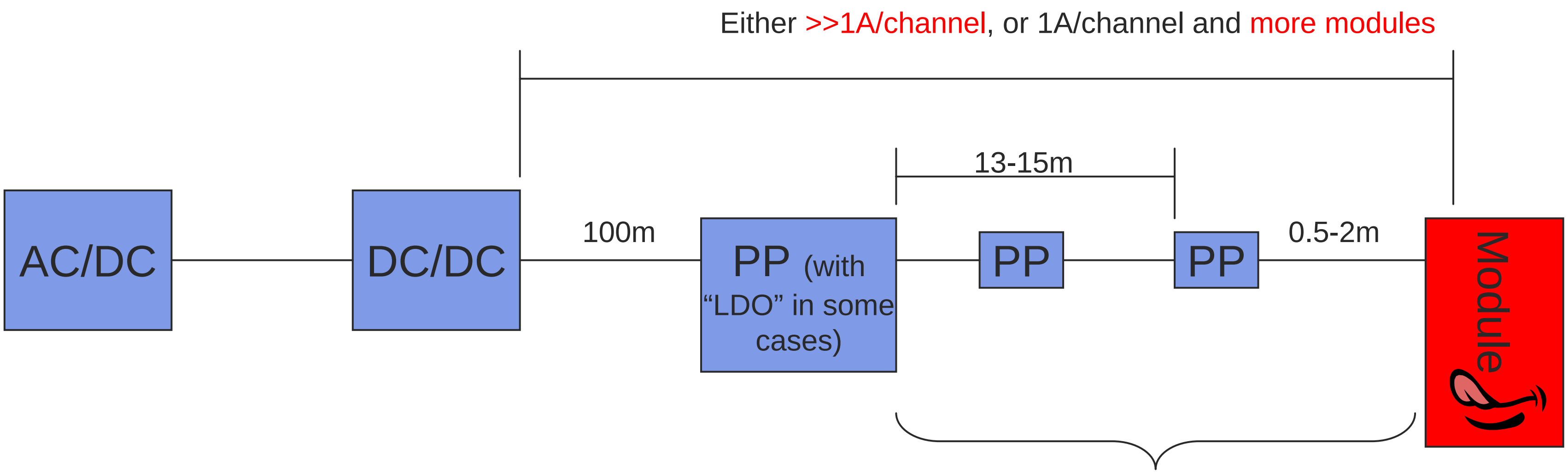
Material budget (X/Xo)
Cooling

Cable crowding
Radiation
Magnetic field

Other general constraints:
Overall efficiency
Cost
Reliability (single point of failure)

LHC upgrades - Requirements

More channels required, at lower Vdd, hence overall more current!



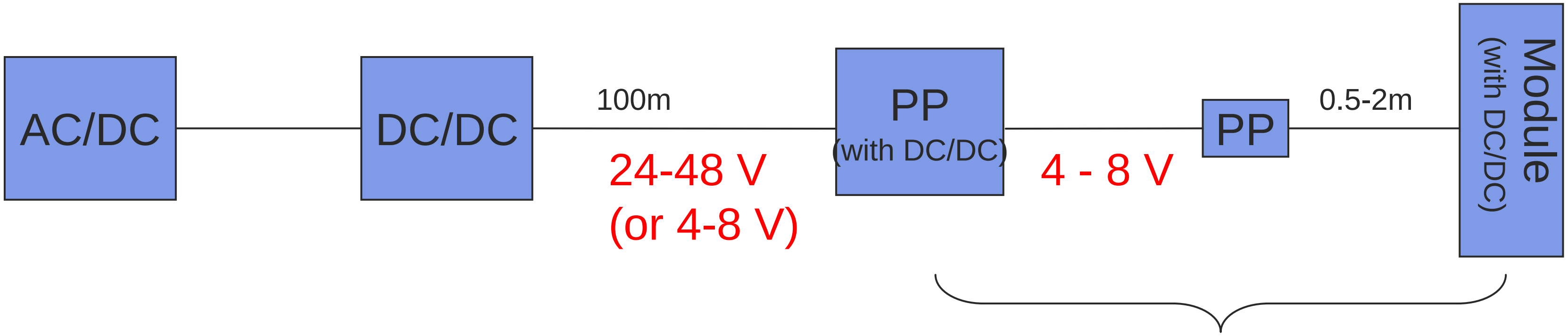
<u>More or thicker cables:</u>

Material budget !

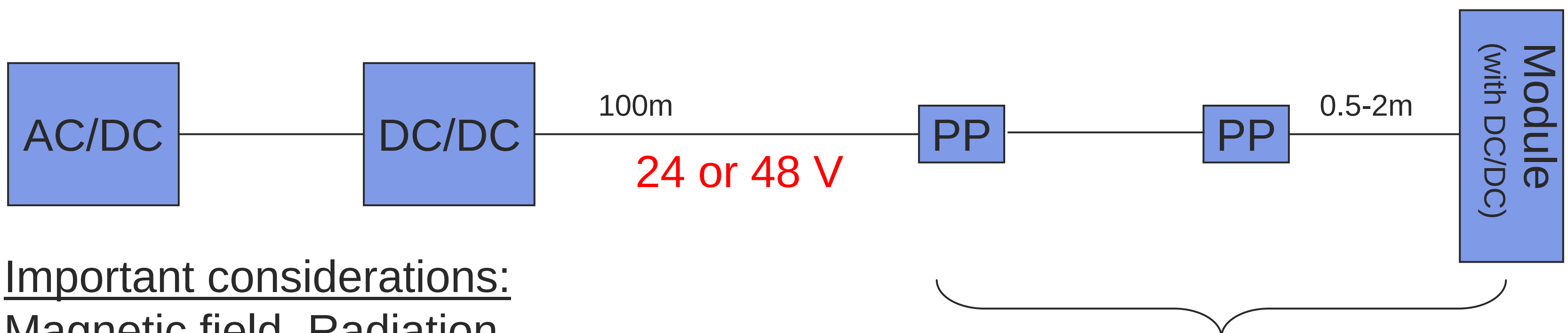
Cooling !

Cable crowding!

Possible solutions based on DC-DC



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

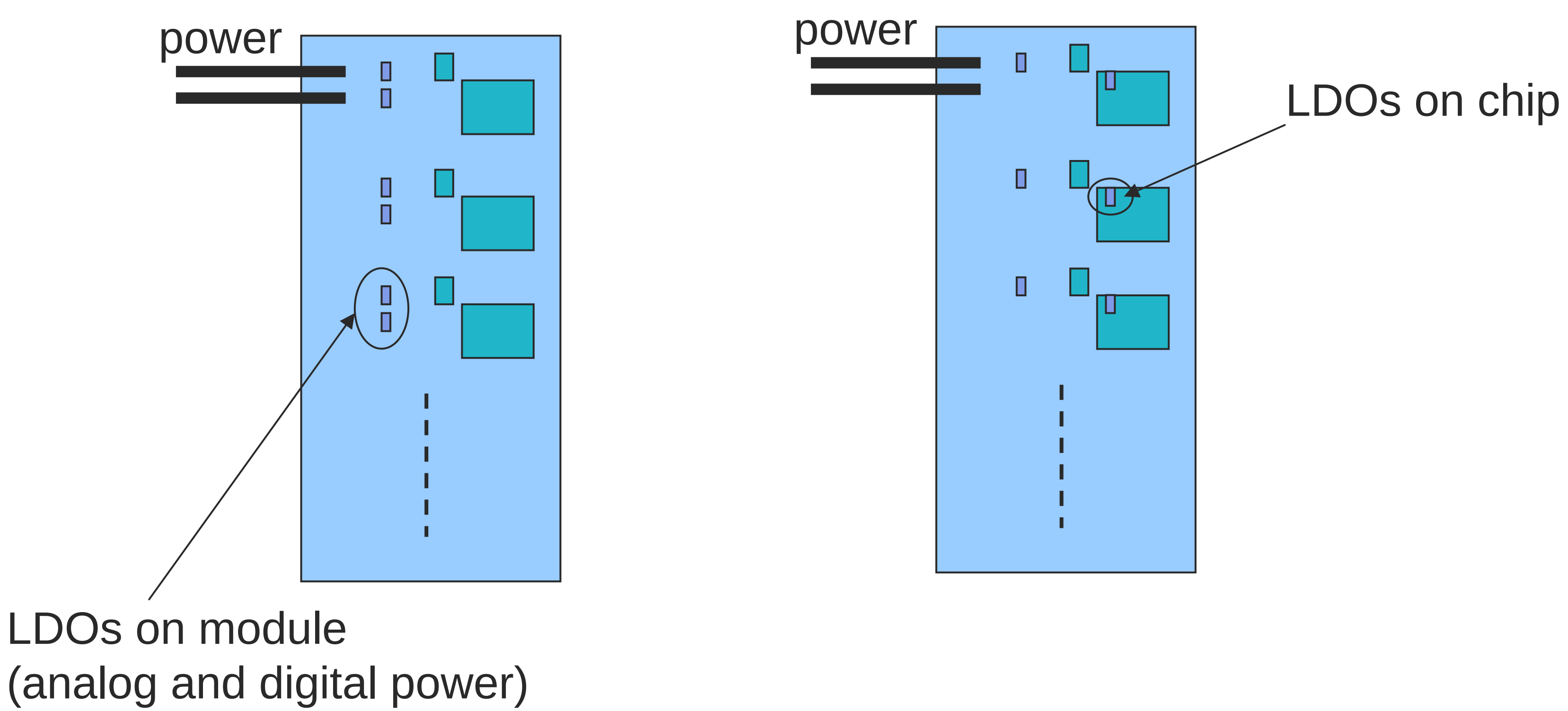


<u>Important considerations:</u>
Magnetic field, Radiation
and Material Budget, Noise, plus
EMI if inductor-based DC/DC

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

On-module or on-chip…

To filter switching noise and/or provide local regulation and protection (over-I, over-V, over-T), LDOs will be very useful – BUT they need to be radiation-hard!



Present activities within PH-MIC

Feasibility study for the development of an integrated DC-DC buck converter based on air-core inductors

Design of an LDO in 130nm CMOS technology capable of satisfying the radiation tolerance requirements for LHC upgrades. This work is in collaboration with the Ecole Polytechnique Federale de Lausanne, EPFL (1 “stagiaire” for 5 months)

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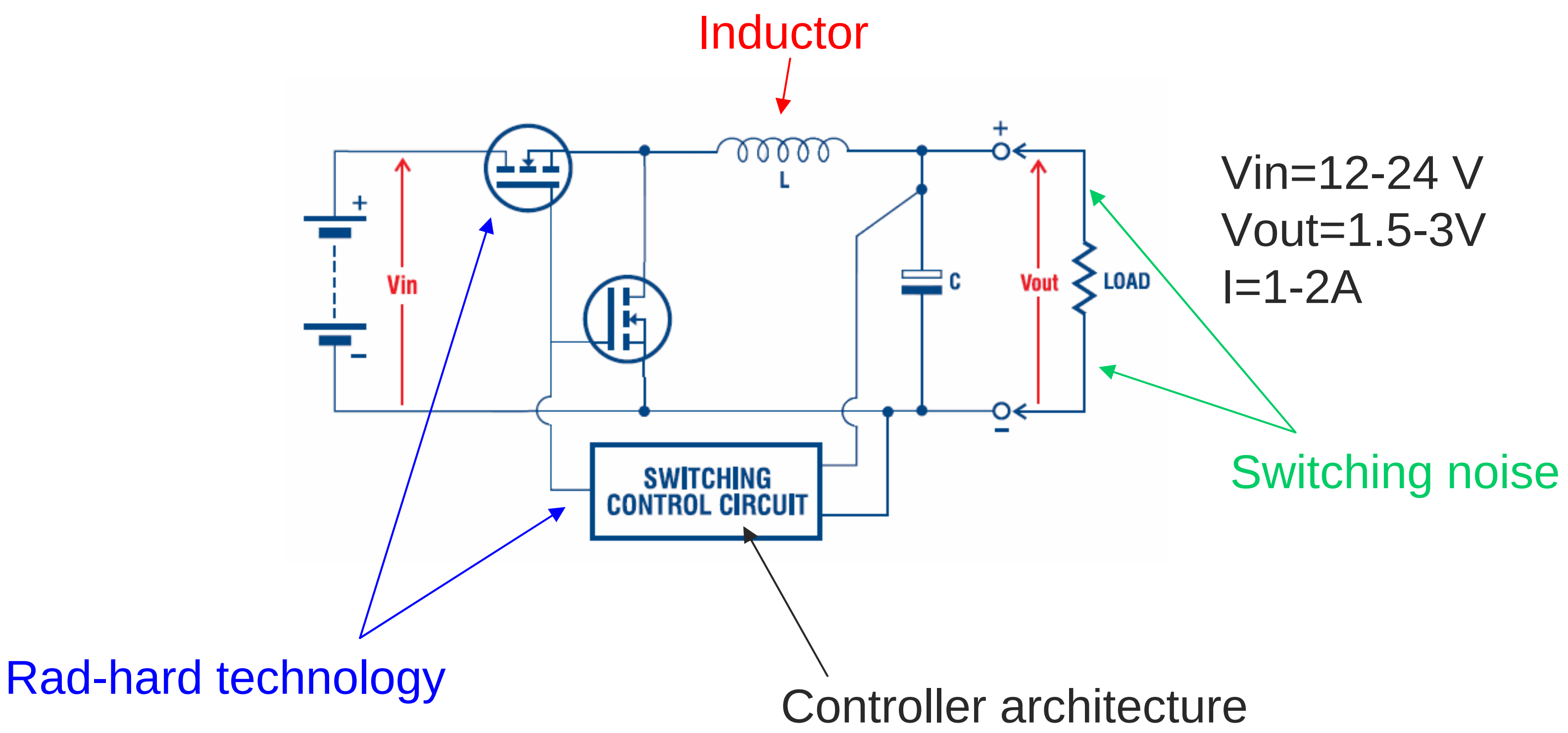
DC-DC: Work in progress

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



Selection of a technology

Design and test of transistors in a commercial technology used in automotive applications

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

Layout "modified" to increase radiation tolerance

Comparison between the available MOS transistors

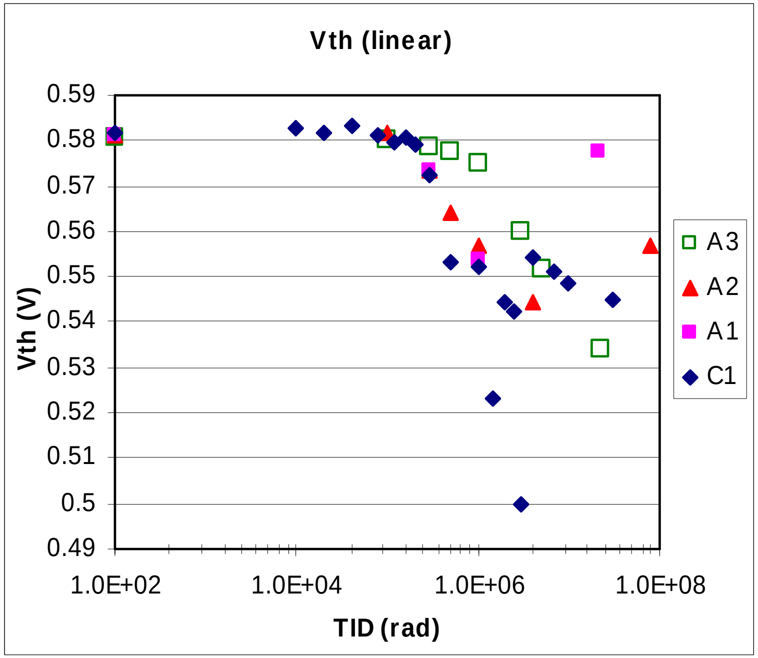
Parameters	NMOS	PMOS	Units
Ron*W@V_{GS}=3.3V, V_{DS}=0.5V	25	42	KΩ.μm
Cgs/W @ V_{GS}=0V, V_{DS} =0V	1.5	17.5	fF/um
Cgd/W @ V_{GS}=0V, V_{DS} =0V	8.5	37.5	fF/um
Cgs/W @ V_{GS}=0V, V_{DS} =15V	1.5	17.5	fF/um
Cgd/W @ V_{GS}=0V, V_{DS}=15V	0.125	0.337	fF/um

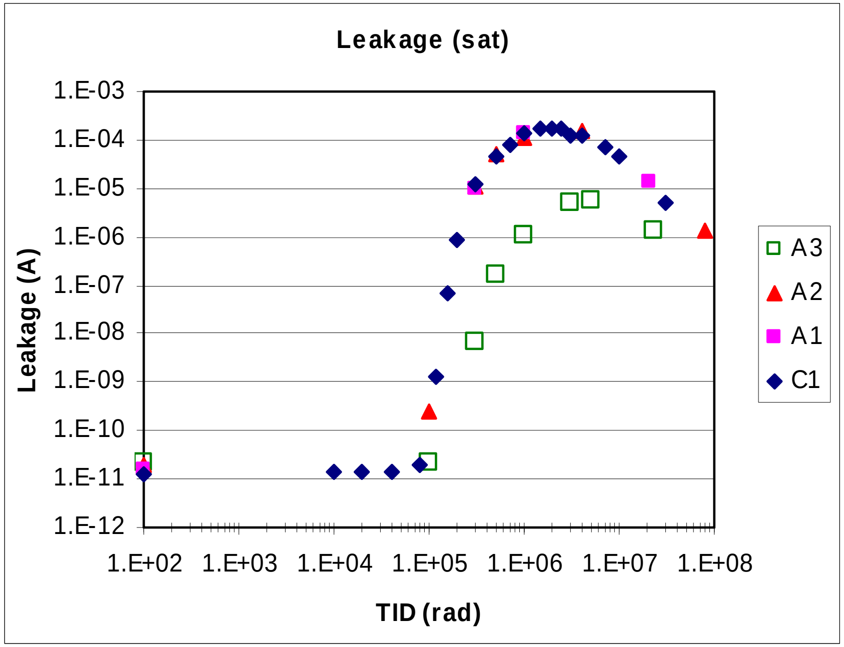
NMOS better performance (lower gate and R_{on} power dissipation)

Difficult to drive in the buck converter configuration (the main switch has the source floating => need of a bootstrap)

NMOS transistors (vertical)

The main radiation-induced problem for the NMOS is the source-drain leakage current. Irradiation in all cases under bias, with Vgs=2 or 3.3V and Vds=0 or 14V.

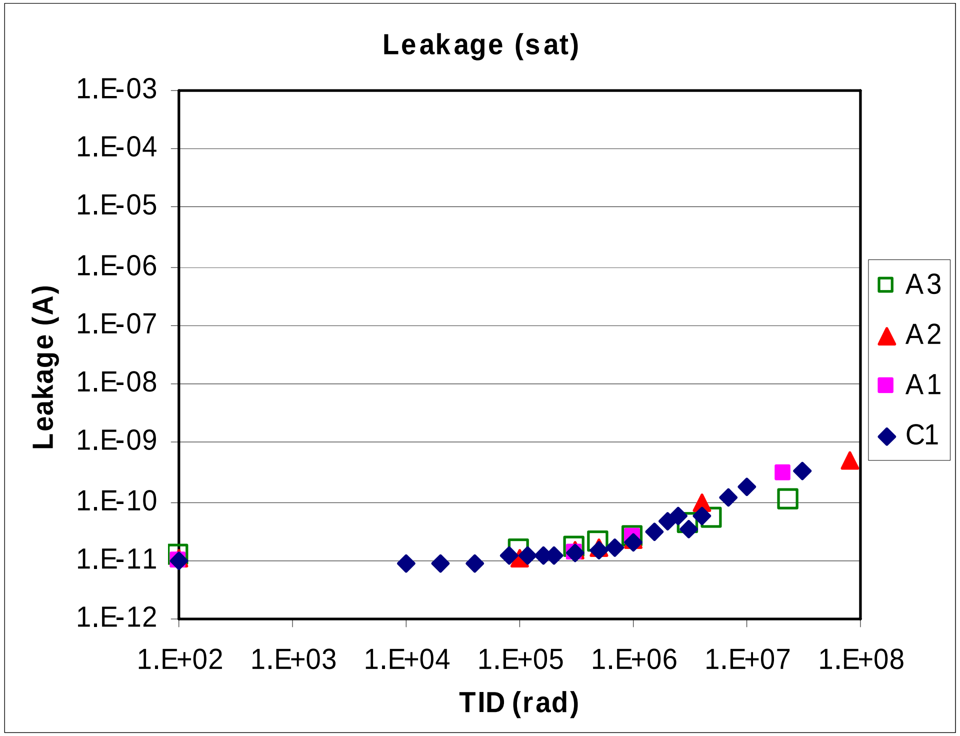




Vds=30V during measurement

NMOS transistors (vertical)

But leakage current can be effectively controlled with smart layout techniques



Vds=30V during measurement

Inductor core material

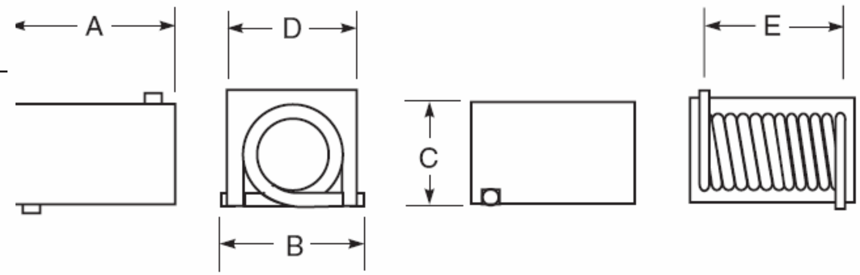
Inductor: need of air core inductor because of high magnetic field (up to 4 T for CMS); ferromagnetic materials additionally can distort the static magnetic field

Material	*Max. μ*	*Sat B(T)*
Coldrolled steel	*2,000*	*2,1*
Iron	*5,000*	*2,15*
Purified iron	*180,000*	*2,15*
4% Silicon-iron	*30,000*	*2,0*
45 Permalloy	*25,000*	*1,0*
Hipernik	*70,000*	*1,6*
Monimax	*35,000*	*1,5*
Permendur	*5,000*	*2,45*
2V Permendur	*4,500*	*2,4*
Hiperco	*10,000*	*2,42*

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

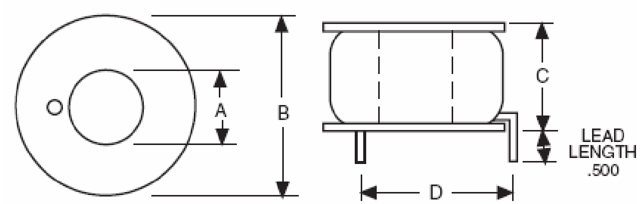


A max	B max	C max	D	E
10,55	6,60	5,97	5,74 ±0,08	7,98 ±0,51

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

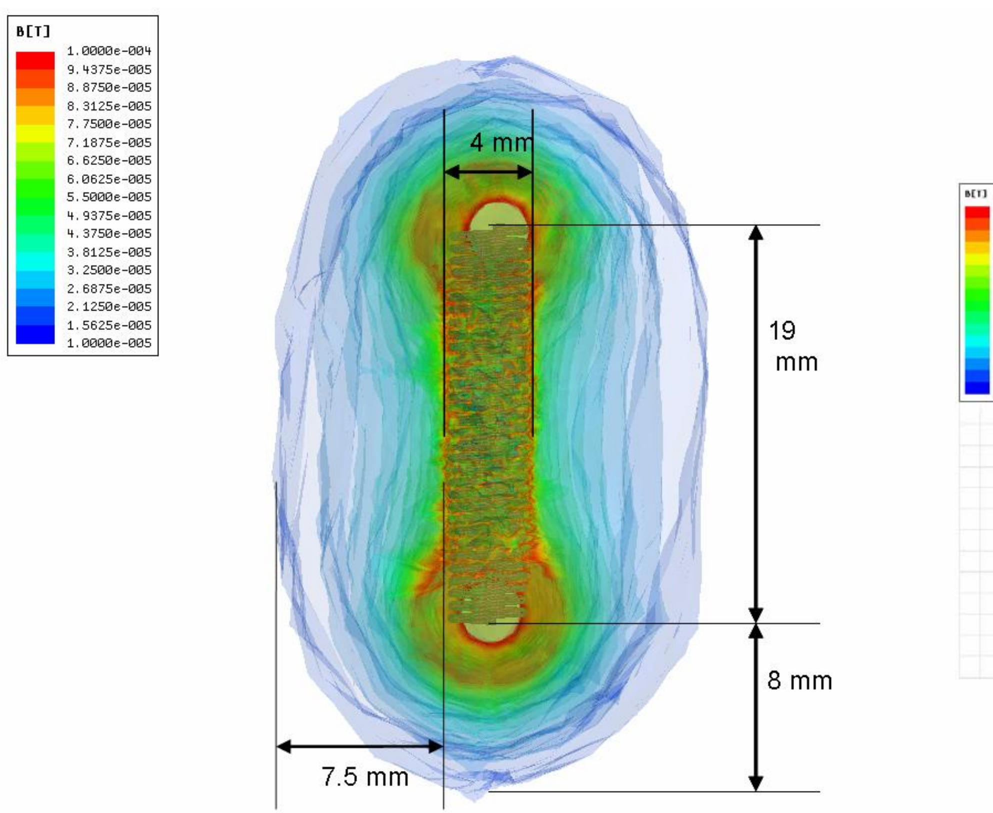
Study of noise implications

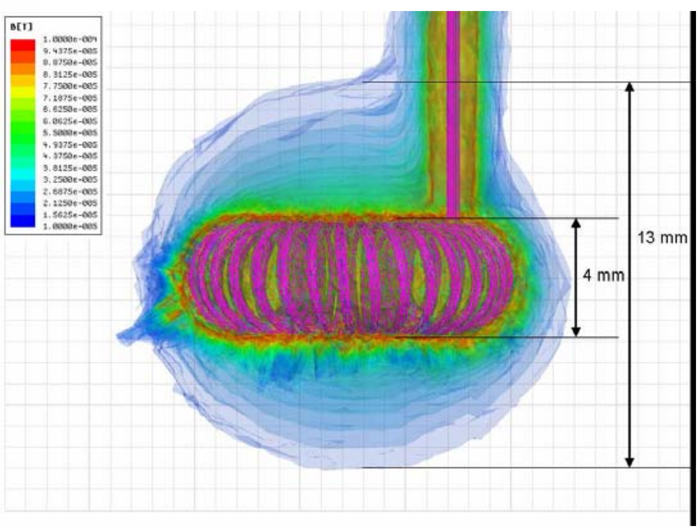
Simulation of magnetic field to have a feeling of the physical extension of the field

Hardware implementation of a DC-DC converter based on commercial components (controller, switchers, inductors). Evolutive concept where each component can be replaced by a custom developed one.

Simulation of magnetic field

Simulation of magnetic field for I=1A in 500nH air core-inductors (solenoid or toroid)



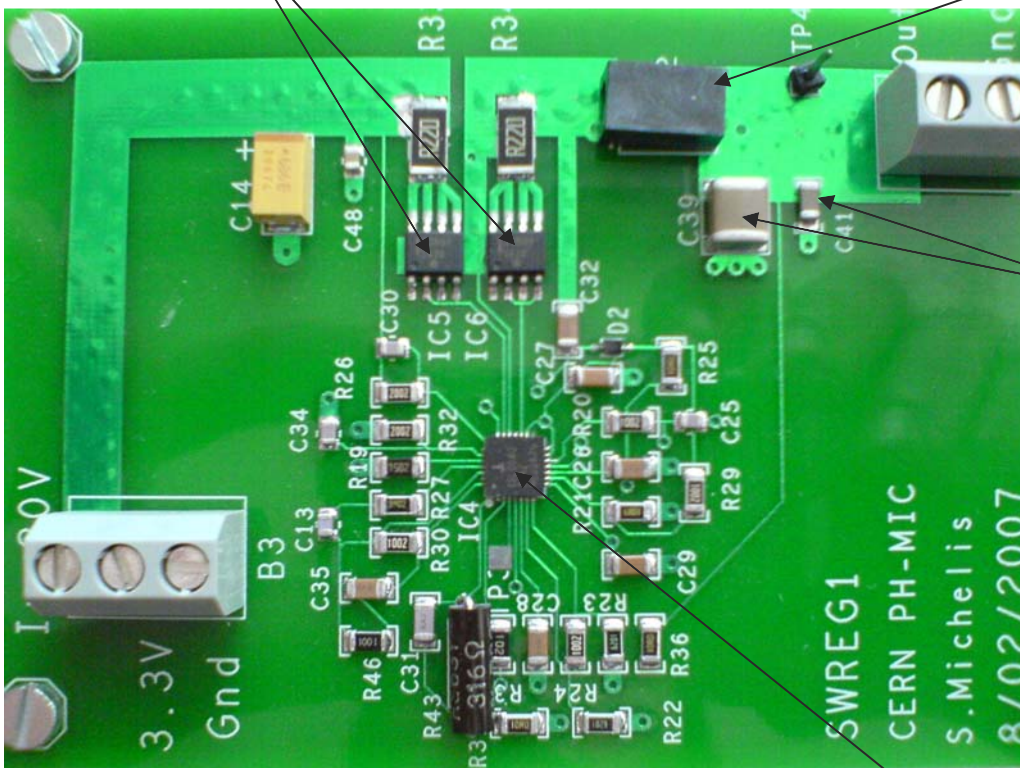


Scale 10-100uT

Hardware implementation

switchers

500nH inductor

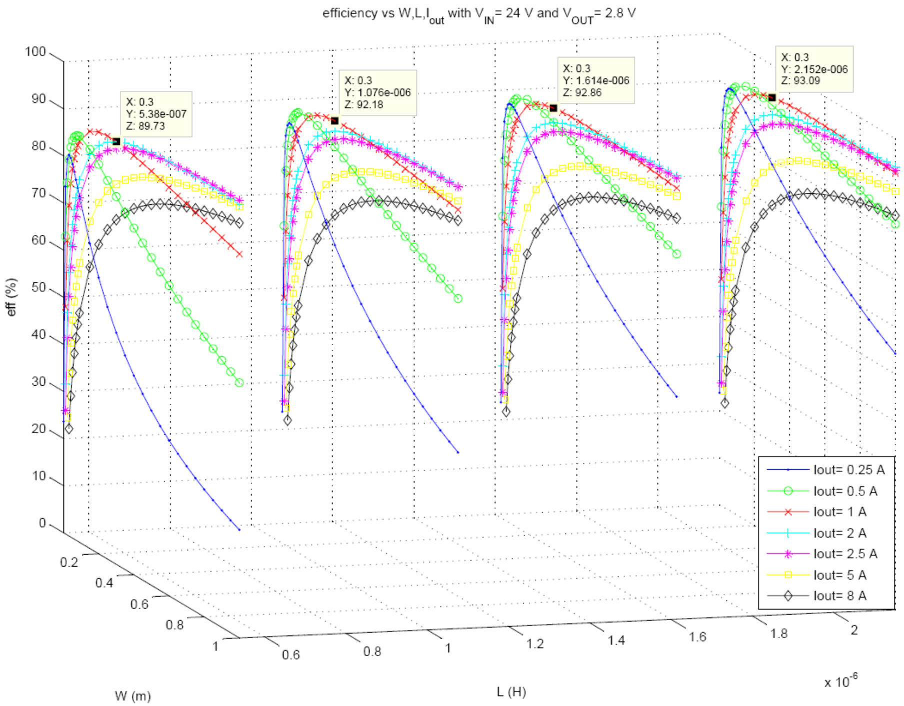


Out capacitors

controller

Selection of an architecture for the controller

Evaluation of the losses, and optimization



Review of the adequate architectures and choice

Full-custom implementation in an ASIC

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Design of LDO linear regulator

2 concepts carried on in parallel:

- Stand-alone component (300mA, Vout=1-1.5V)
- On-chip macro (150mA, Vout=1.2V)

Both in 130nm CMOS technology, and designed to be radiation tolerant

Macros will be validated and can be modified for different specs

Conclusion

Developments aiming at solving the power distribution problem with integrated components:

- Integrated DC-DC buck converter (Vin=12-24V, I=1-2A)
  - Based on air-core inductor and use of high-V CMOS technology with radiation tolerant design
- LDOs
  - Stand-alone component, I=300mV
  - On-chip “IP block”

Work is in progress in both areas, and an R&D programme is being finalized