DCDC converters for the upgrade of the LHC experiments

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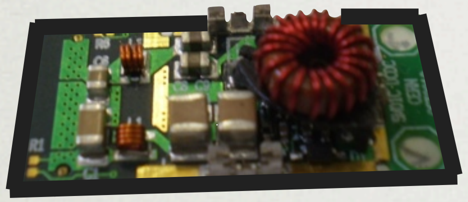
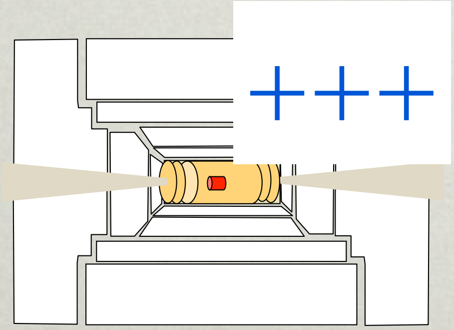
http://cern.ch/project-dcdc

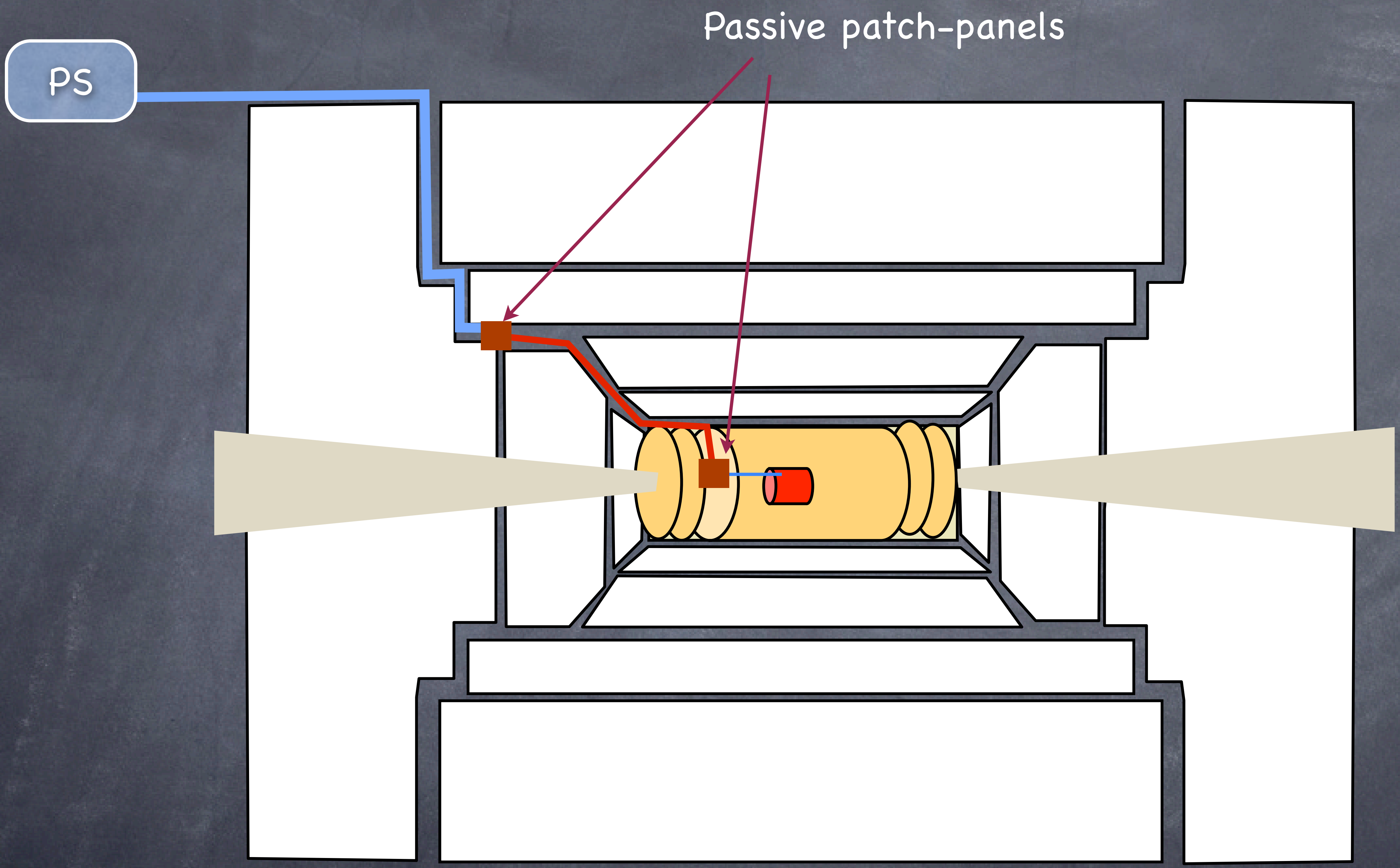
Motivation for the development of radiation and magnetic field tolerant DCDC converters



What are the components of a full DCDC converter? Do we have them all by now?



In summary, what can a DCDC converter bring to a detector system



Conceptual representation of the power distribution system typically used in the LHC experiments

Power loss in cables: $P_{Loss} = R_{cable} I^2$

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The electronics load (the FE boards) needs power at a precise voltage $P_{Load}=V_{Load}I_{Load}$

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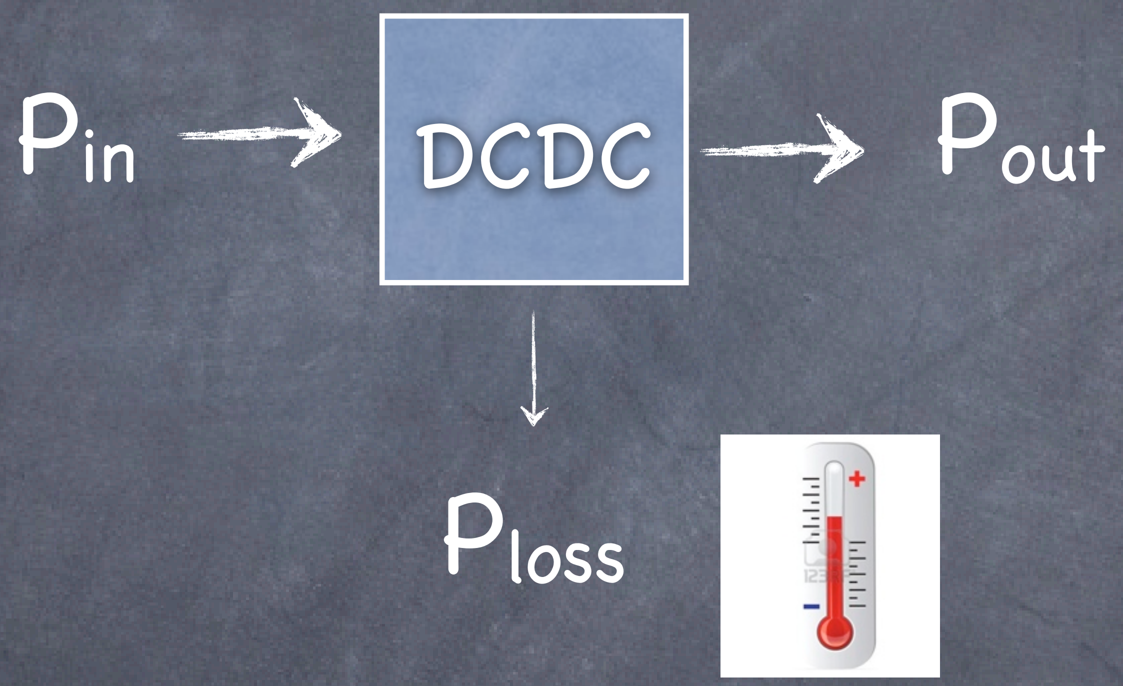
The electronics load (the FE boards) needs power at a precise voltage $P_{Load}=V_{Load}I_{Load}$

$P_{in}=V_{in}I_{cable}$ → iConv → $P_{out}=V_{Load}I_{Load}$

iConv is magic because $P_{in}=P_{out}$

Therefore if $V_{in}>V_{Load}$, $I_{cable}>I_{Load}$

Waiting for the iConv, a DCDC converter can do the job with the drawback of some power loss



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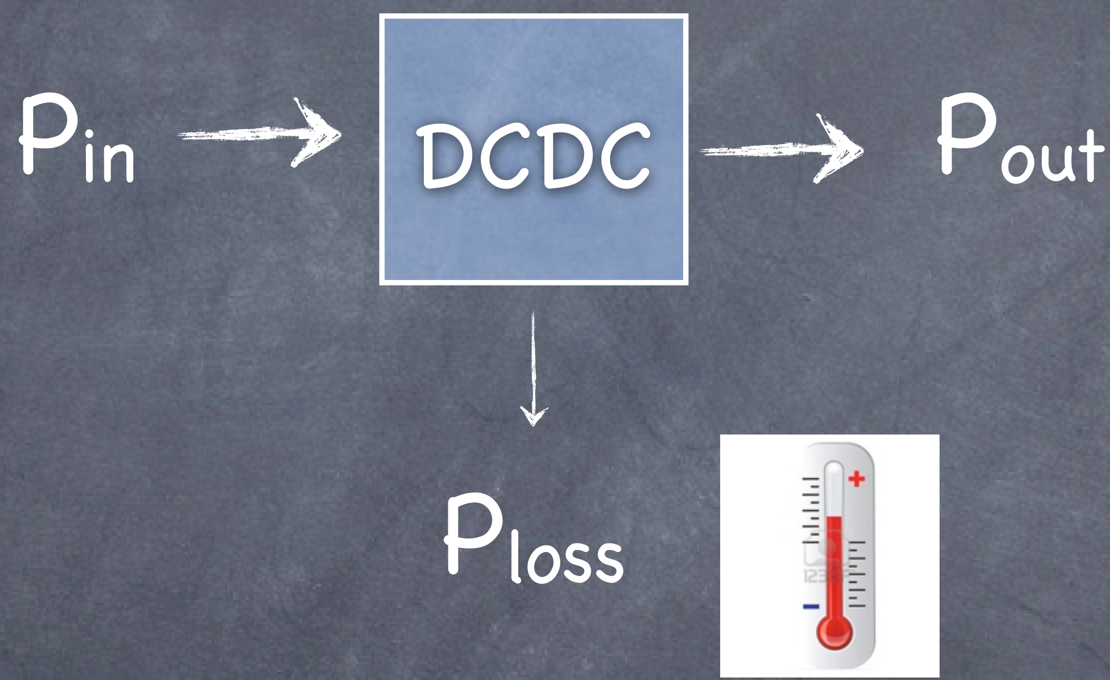


… but some ‘magic’ is still required: the DCDC needs to function in the radiation and magnetic field of the experiments

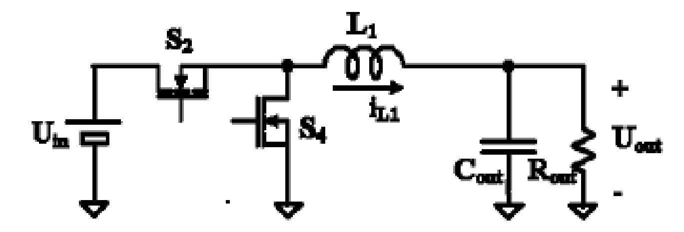


Figure 1: Topology of the buck converter

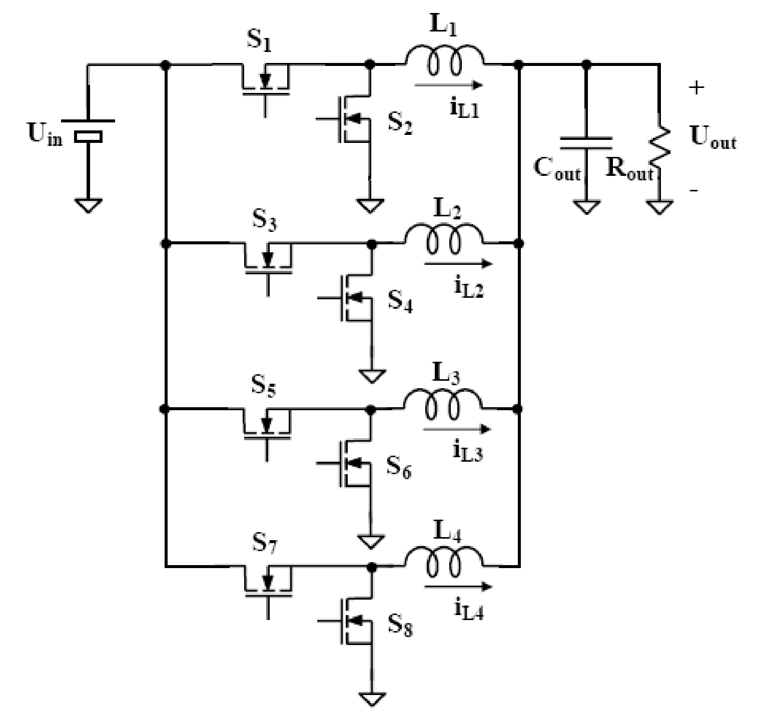


Figure 2: Topology of the 4-phase interleaved buck converter

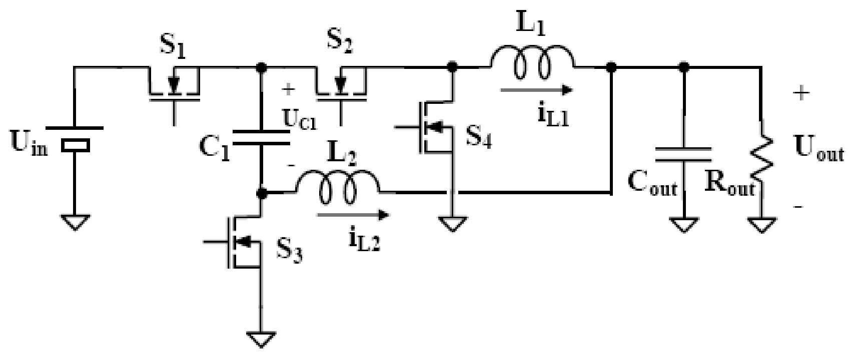


Figure 3: Topology of the two phase interleaved buck with integral voltage divider

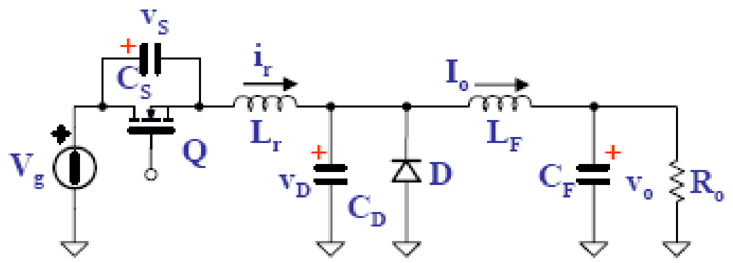
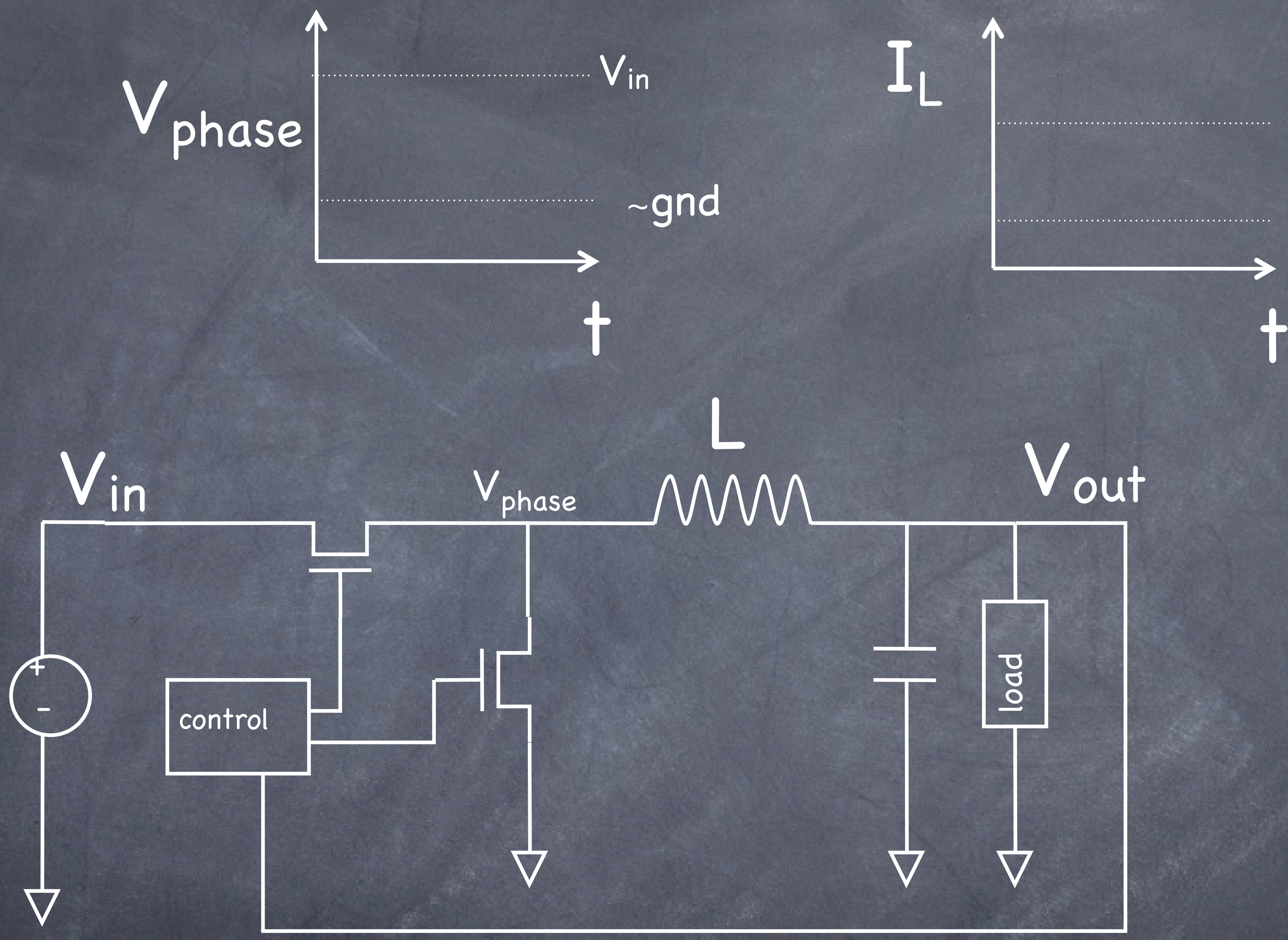
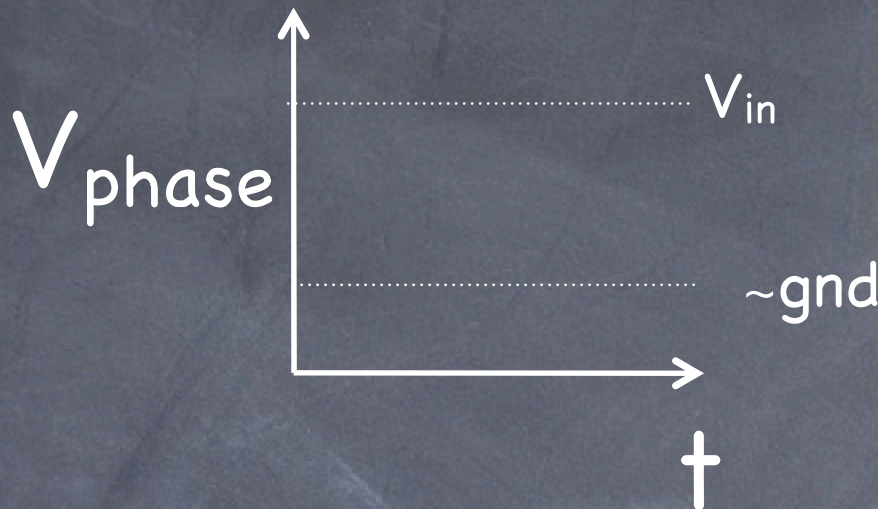
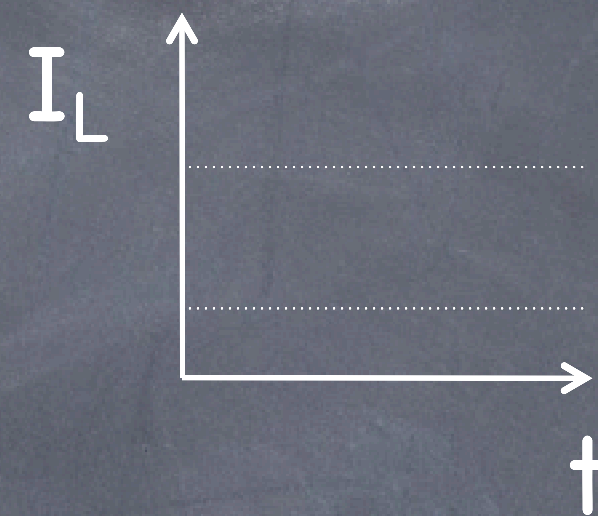


Figure 4: Topology of a multi-resonant buck converter

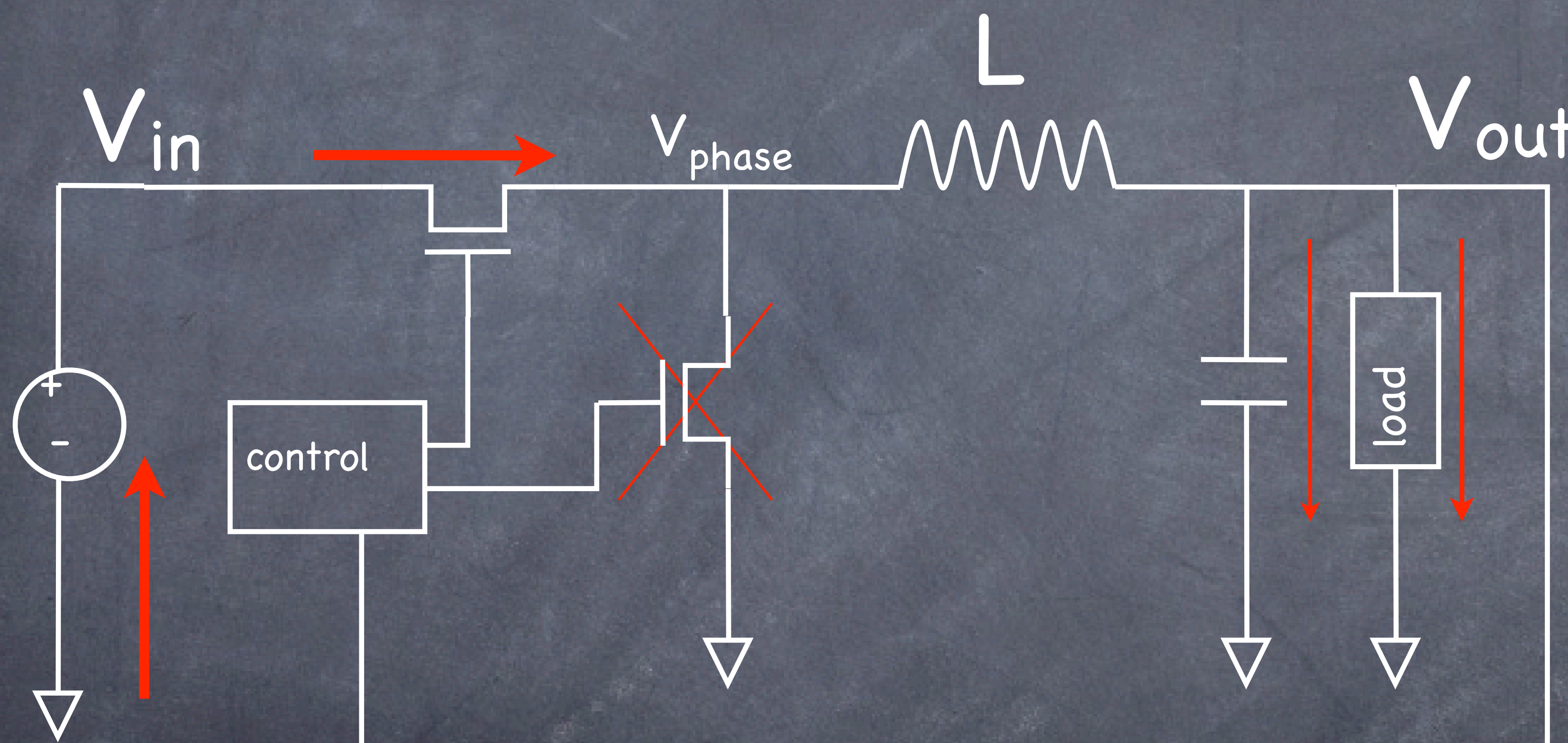


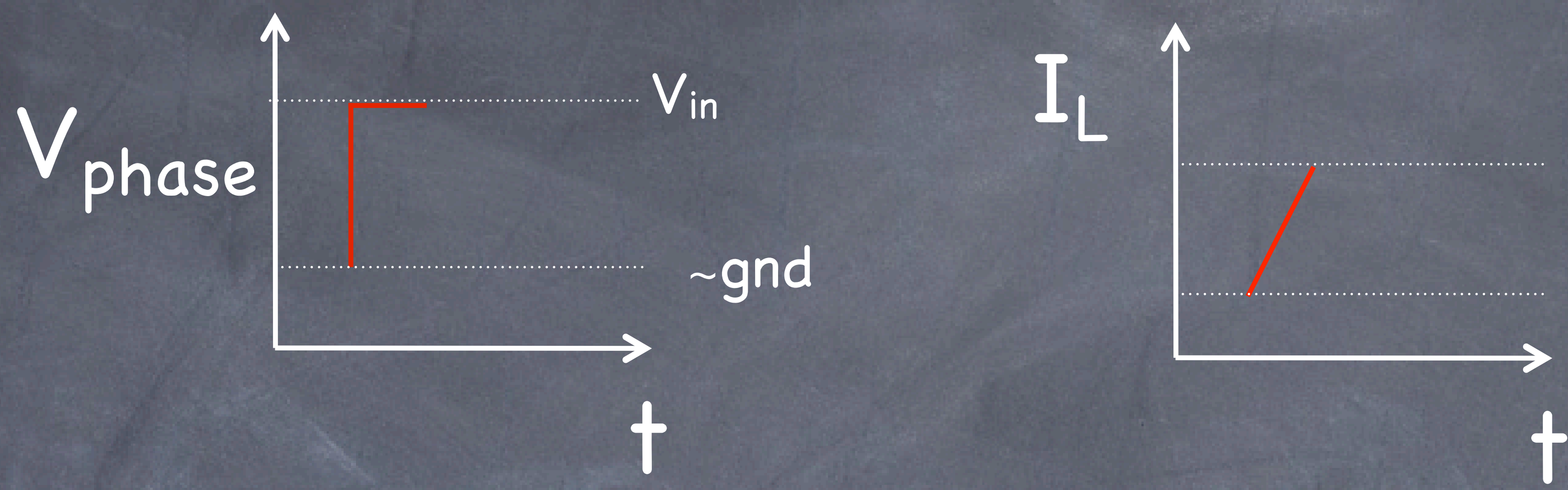
V phase
V in
~gnd
t
I L
t
L
V in
V phase
V out
+
-
control
load



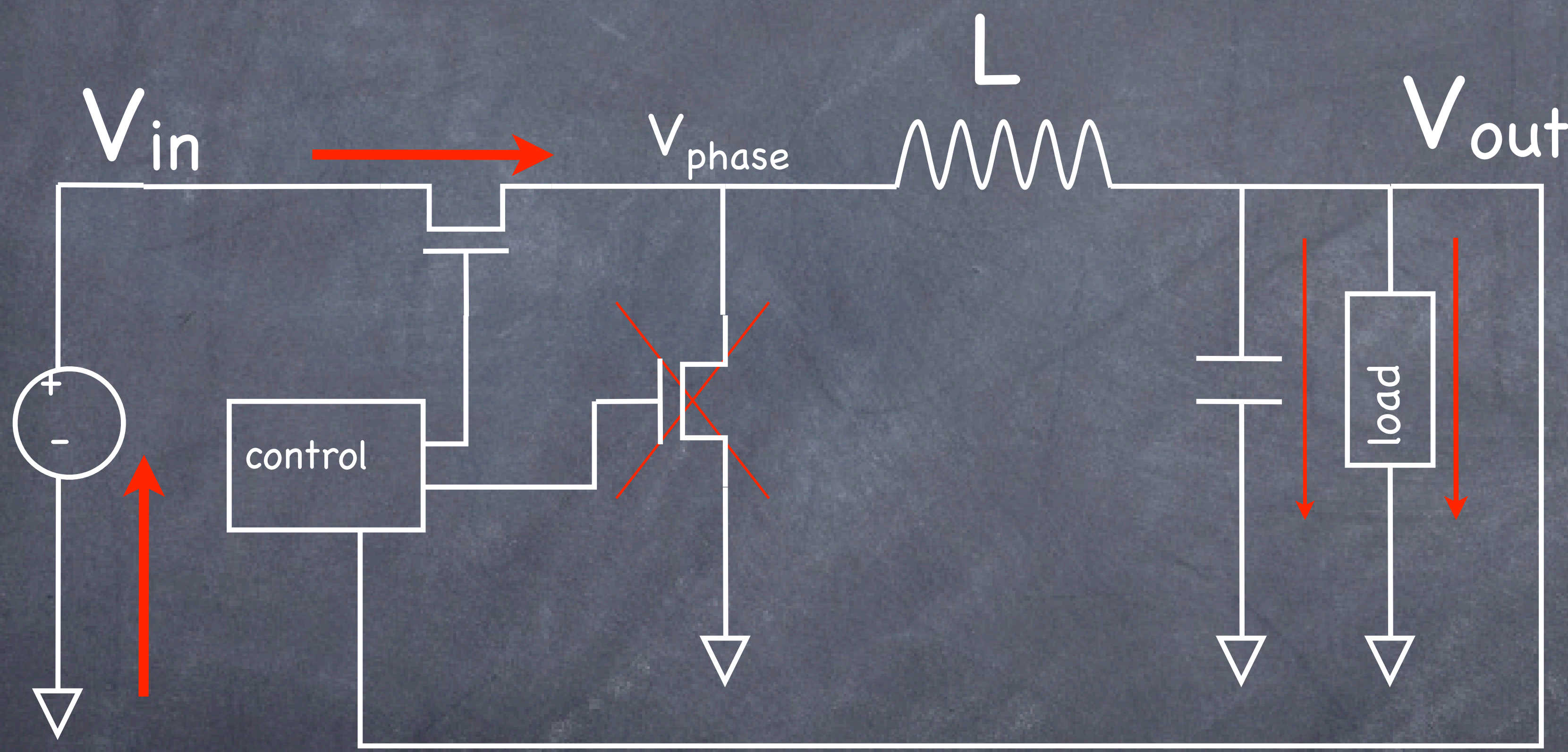


1

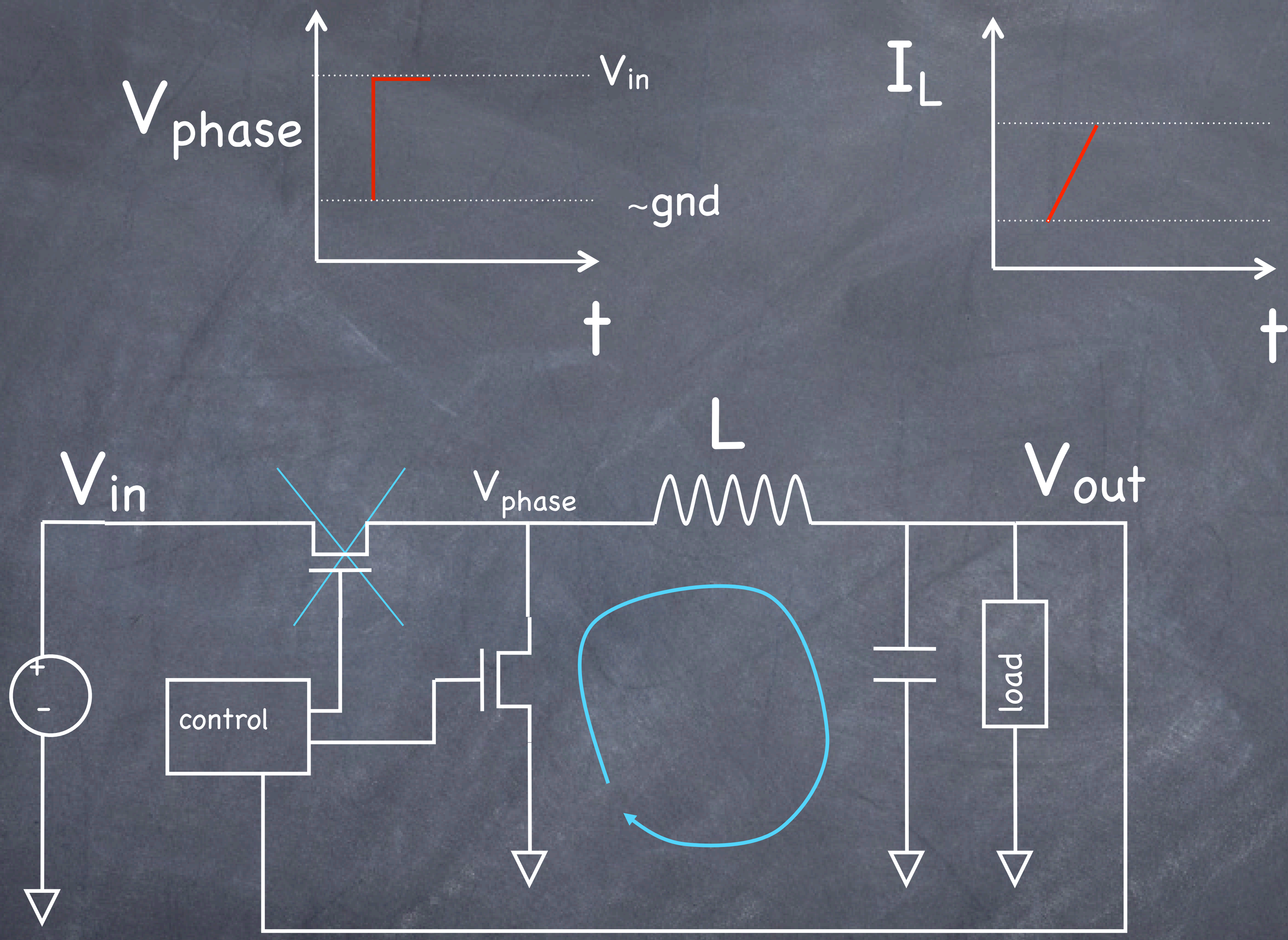


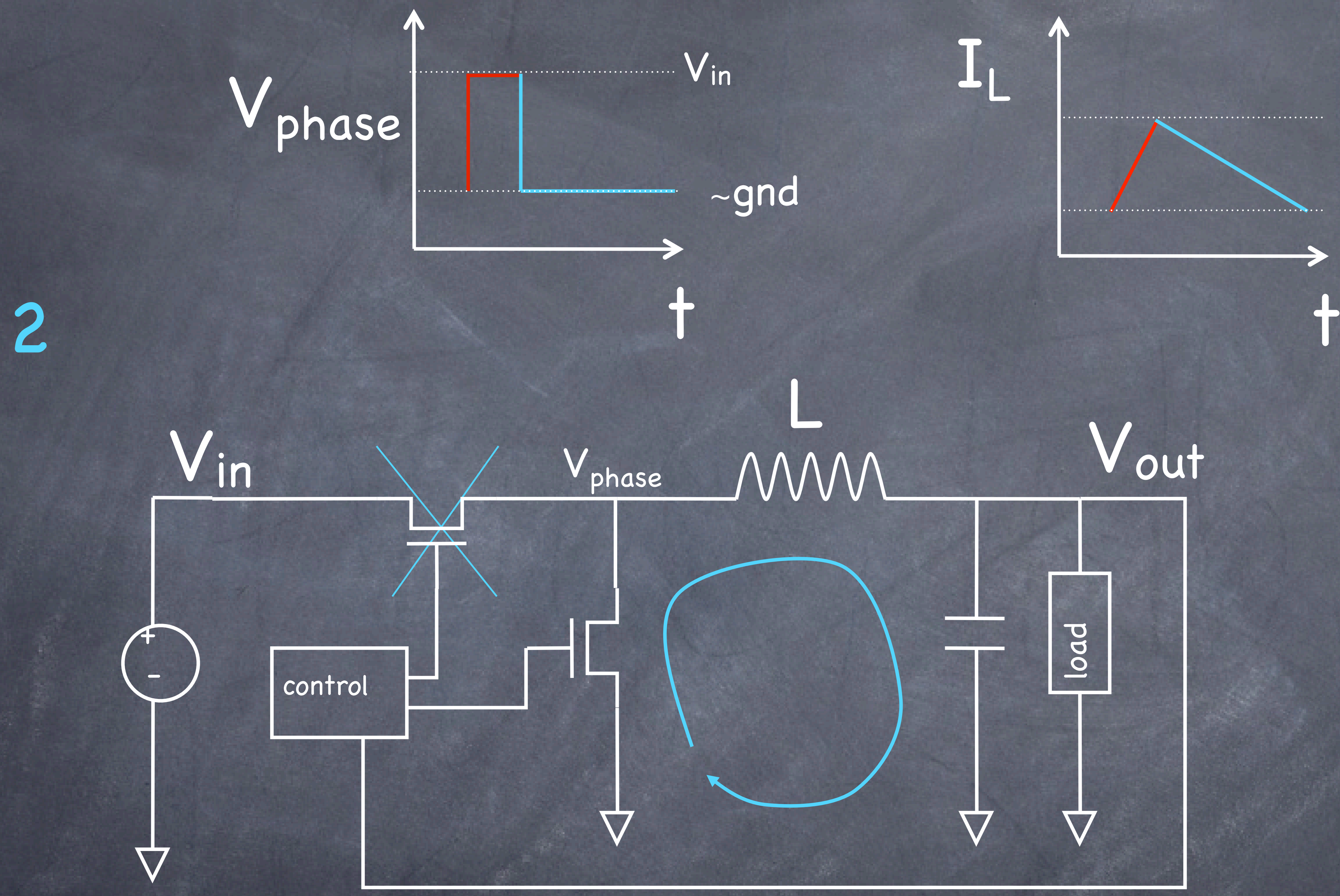


1

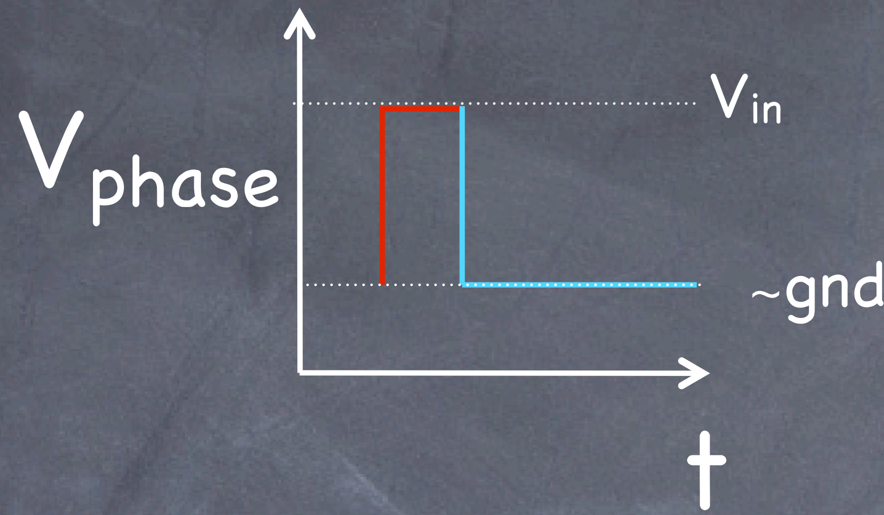


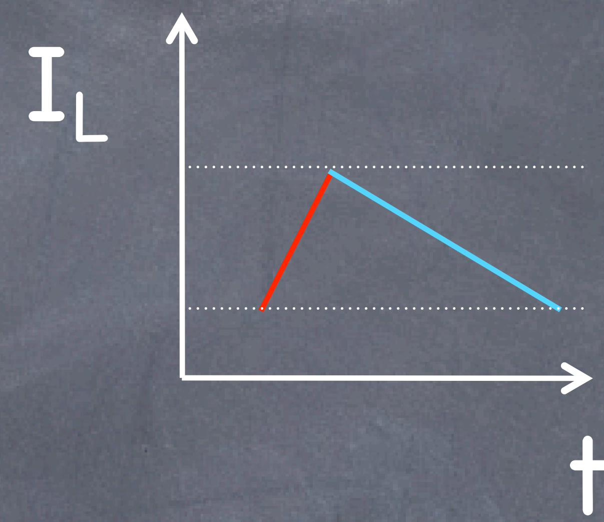
2



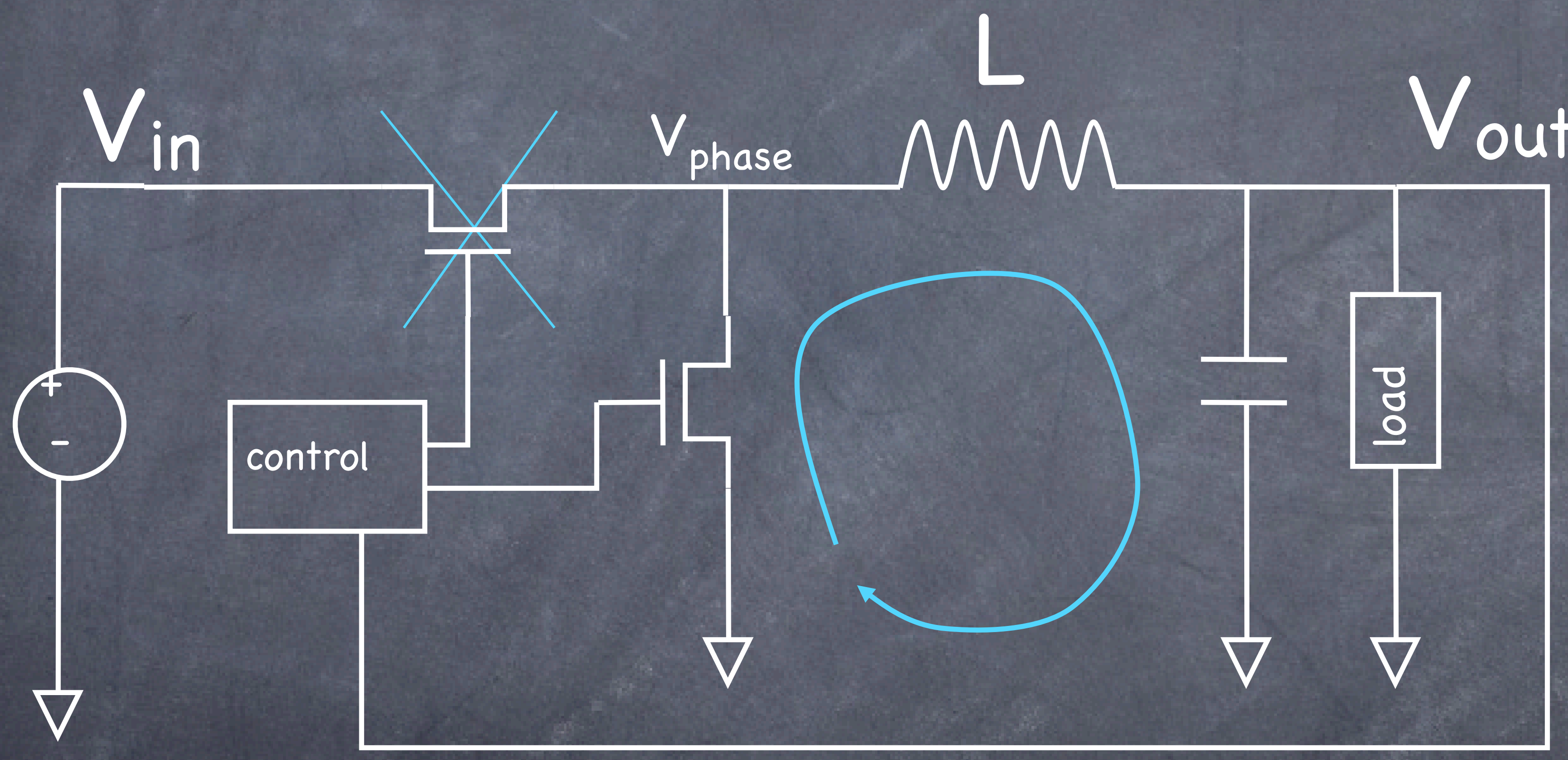


Vphase
Vin
~gnd
t
IL
t
2
L
Vin
Vphase
Vout
control
load

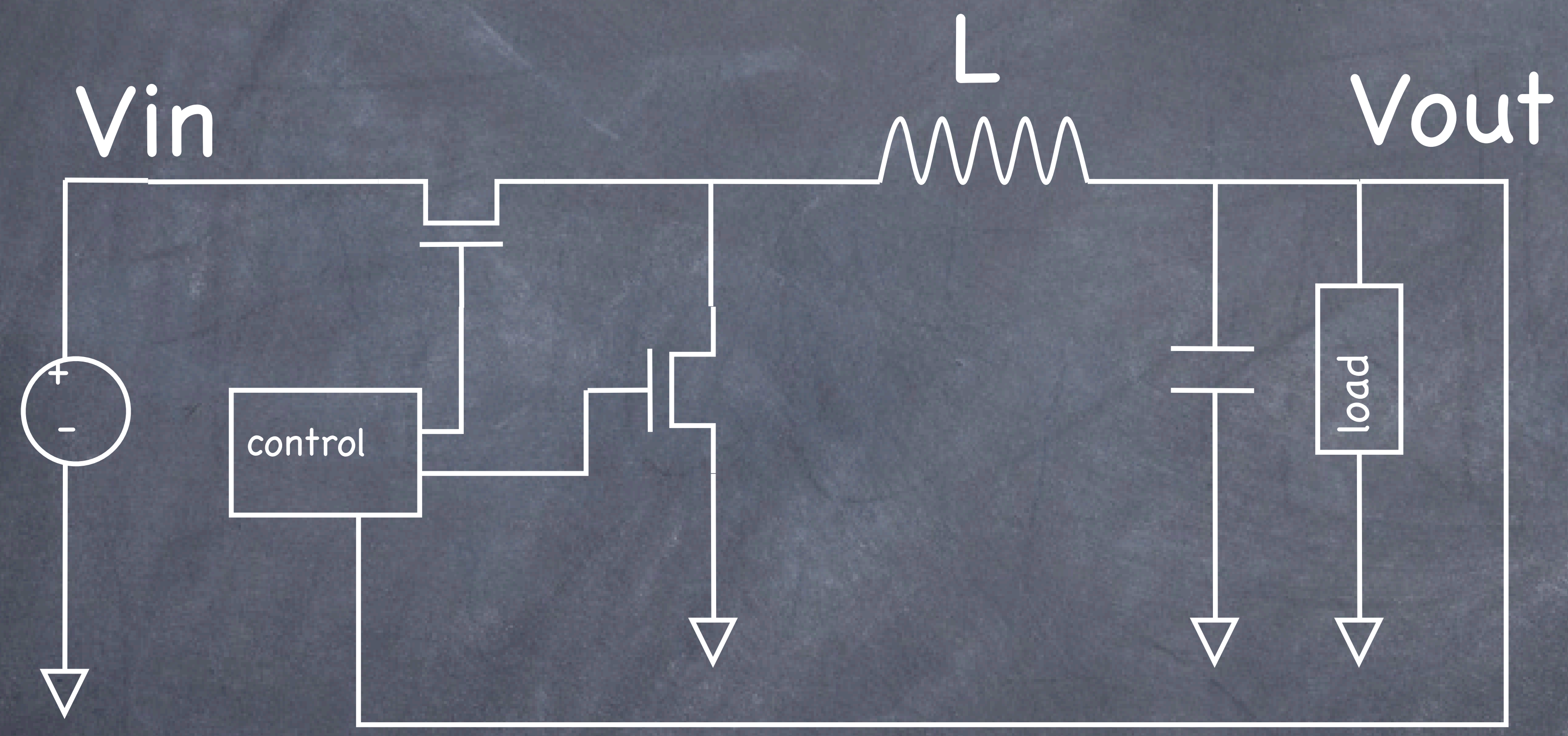




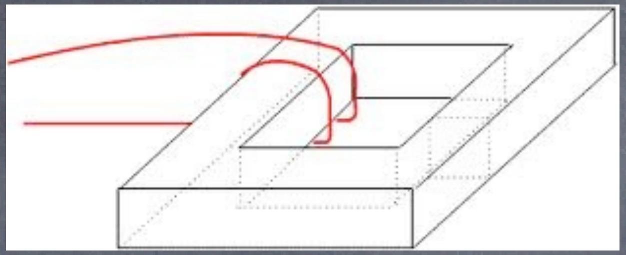
2



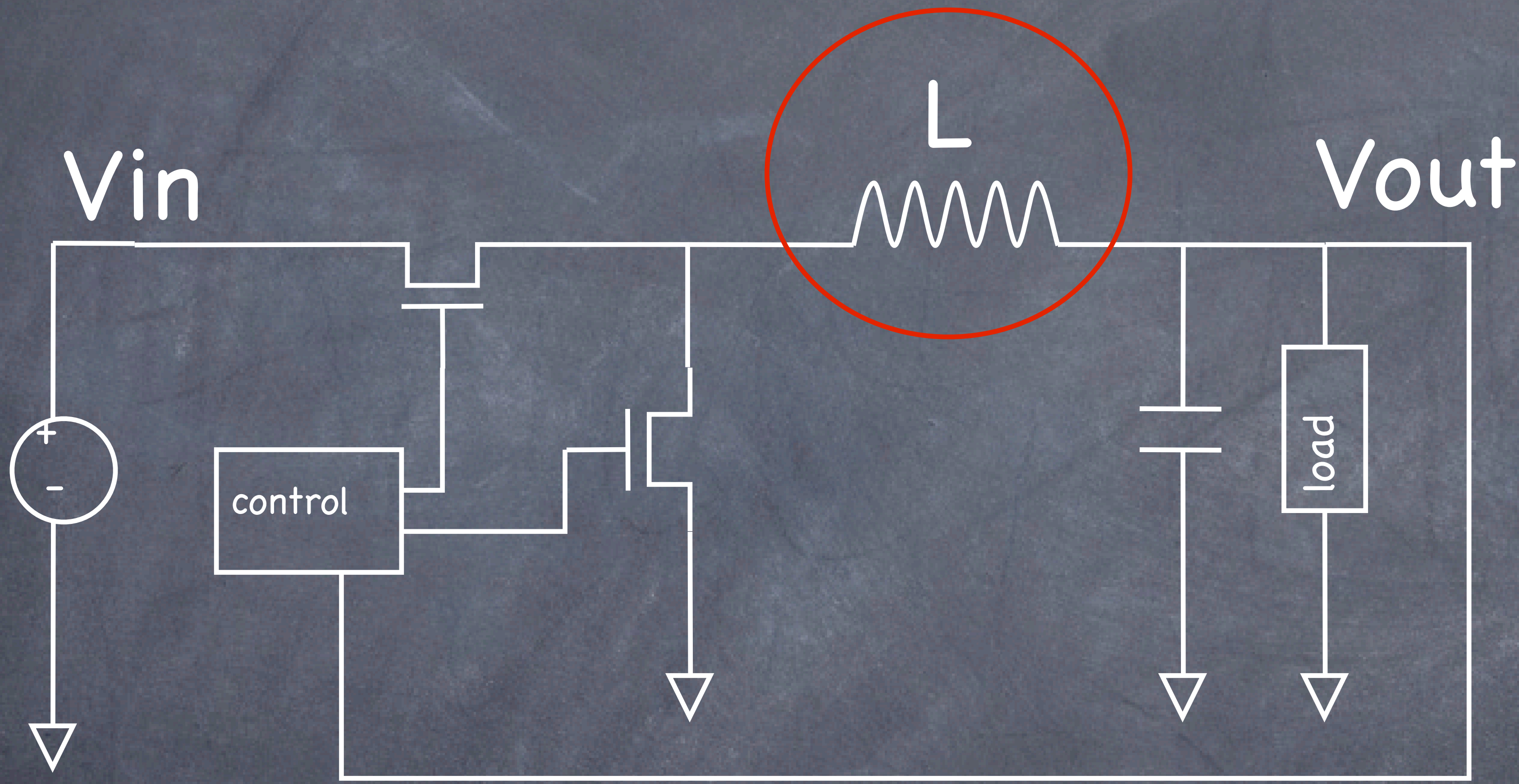
$$\frac{V_{out}}{V_{in}} = \text{Duty cycle}$$


L
Vin
Vout
+
-
control
load

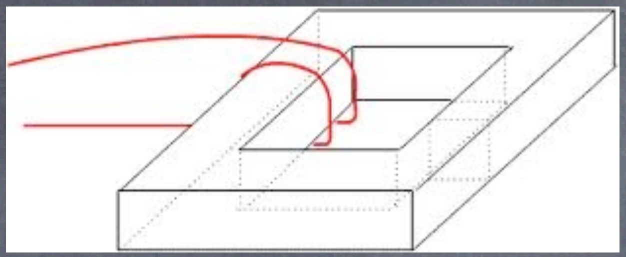
Ferromagnetic core



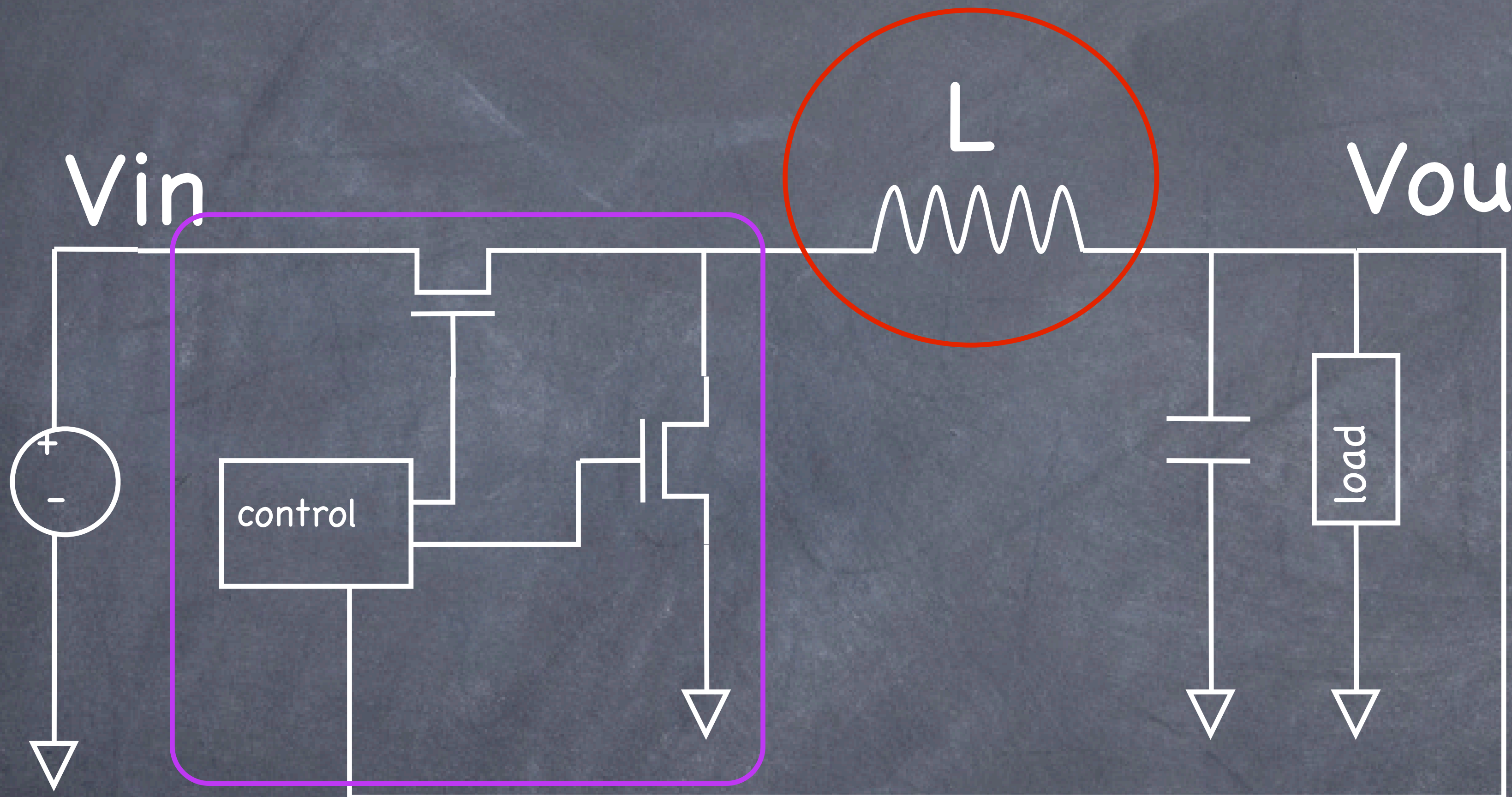
Air core



Ferromagnetic core



Air core



Qualification required for radiation effects:
TID, displacement damage, SEEs

Electrical specs

Input voltage	10-12V
Output voltage	1.2-3.3V
Output current	up to 3A*
Efficiency	>80% (for V_{out}=2.5V)
Conducted and radiated noise compatible with installation in close proximity to FE electronics and detectors	

* We will know the real output current limit soon, with measurements of a mature ASIC in a realistic configuration (cooling)

Mechanical specs

Small size (footprint, height)
Small contribution to material budget
Connectable to cooling system

Environmental specs

TID tolerance	250 Mrad
Displacement damage	$2.5 \cdot 10^{15}$ n/cm^2 (1MeV equivalent)
SEE	Absence of destructive SEEs and Vout transients when tested with heavy ions up to an LET of 30 MeVcm^{2}mg^{-1}
Magnetic field	4 T
Temperature of cooling pad	-30 to +10 °C

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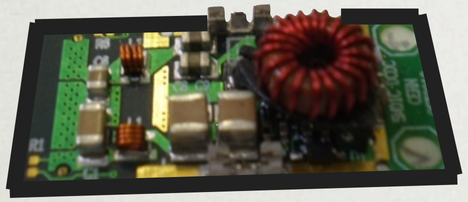

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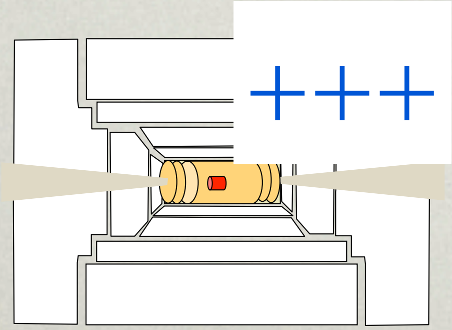
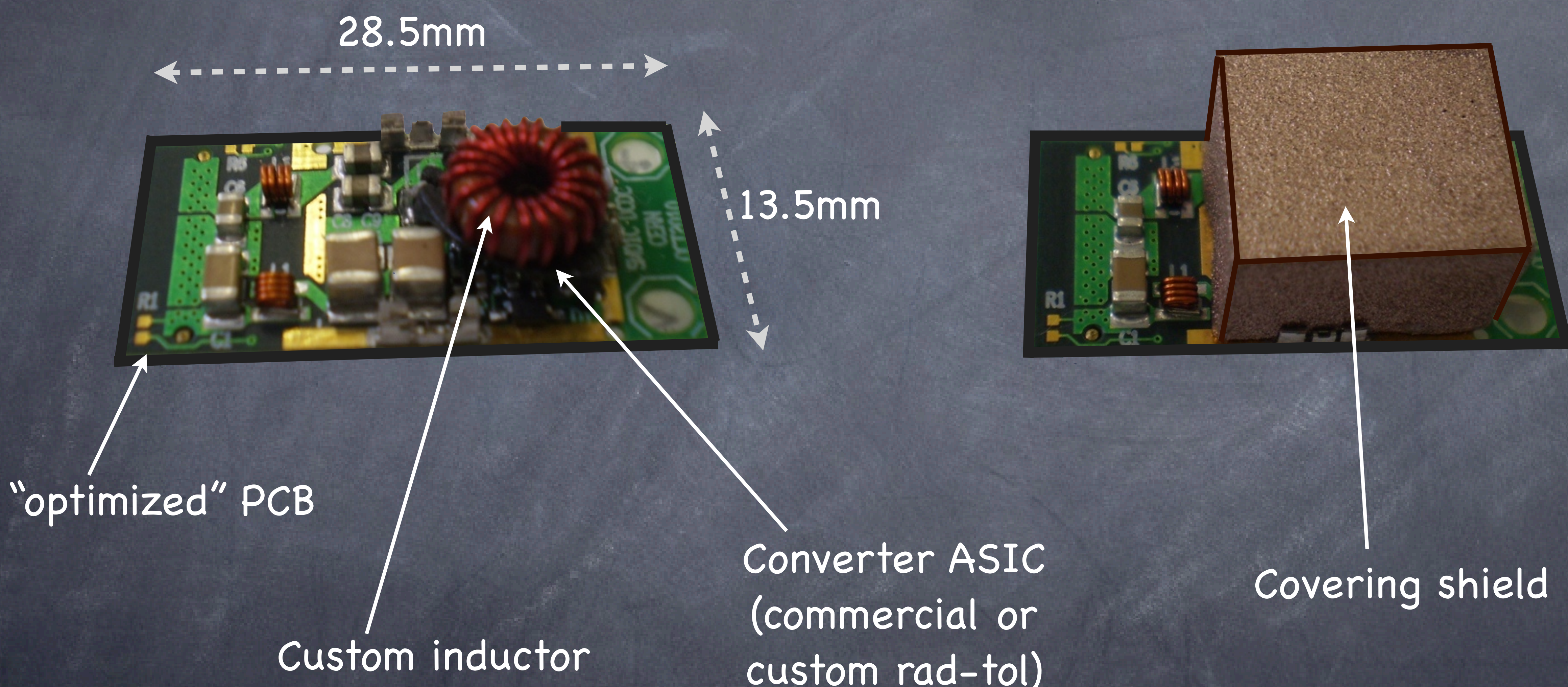


In summary, what can a DCDC converter bring to a detector system

Example prototype of a full DCDC



Steps for ASIC design:

1. pre-selection of CMOS technology
2. design of ASIC prototypes
3. verify electrical and radiation performance on ASIC prototypes

	AMIS2	IHP1	IHP2	AMIS4
Full control loop	✓	✓	✓	✓
Dead times' handling	Fixed	Adaptive (QSW)	Adaptive (QSW and CCM, sharp transition)	Adaptive (QSW and CCM, smooth transition)
On-chip regulator(s)	No	No	✓	✓
Soft Start	Simple RC	Simple RC with comparators	Full sequence with comparators	State machine
Over-I protection	No	No	✓	✓
Over-T protection	No	No	No	✓
Under-V disable	No	No	No	✓

↕ Used in system tests

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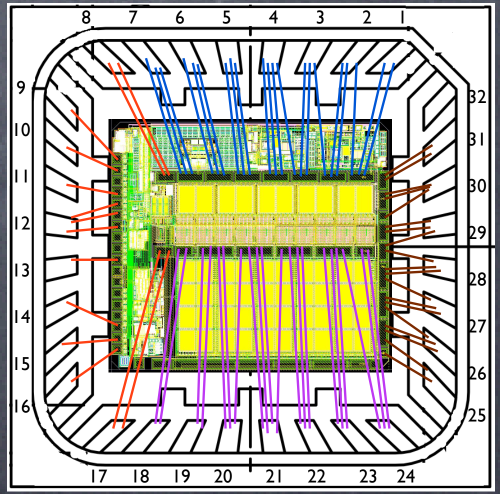
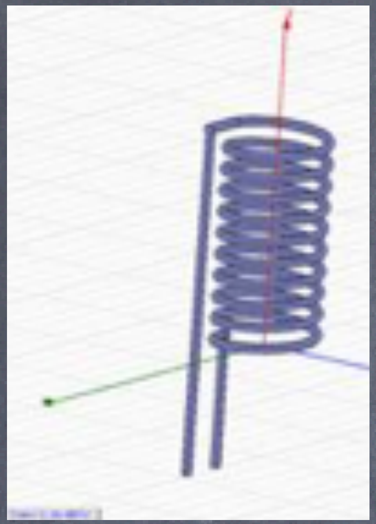
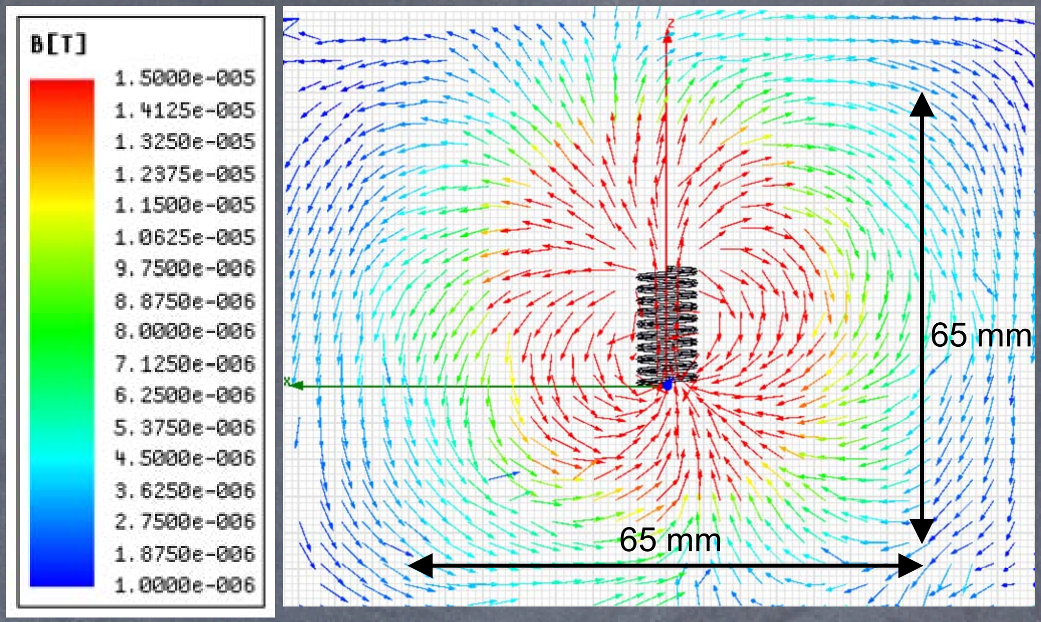
Packaged in QFN32



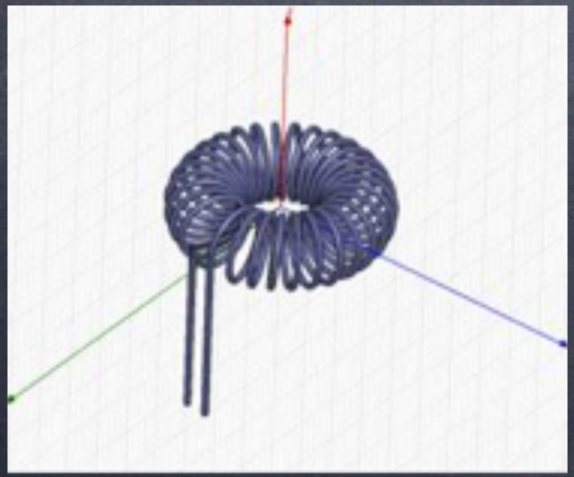
↕ Tape-out Jan2011
Expected early summer

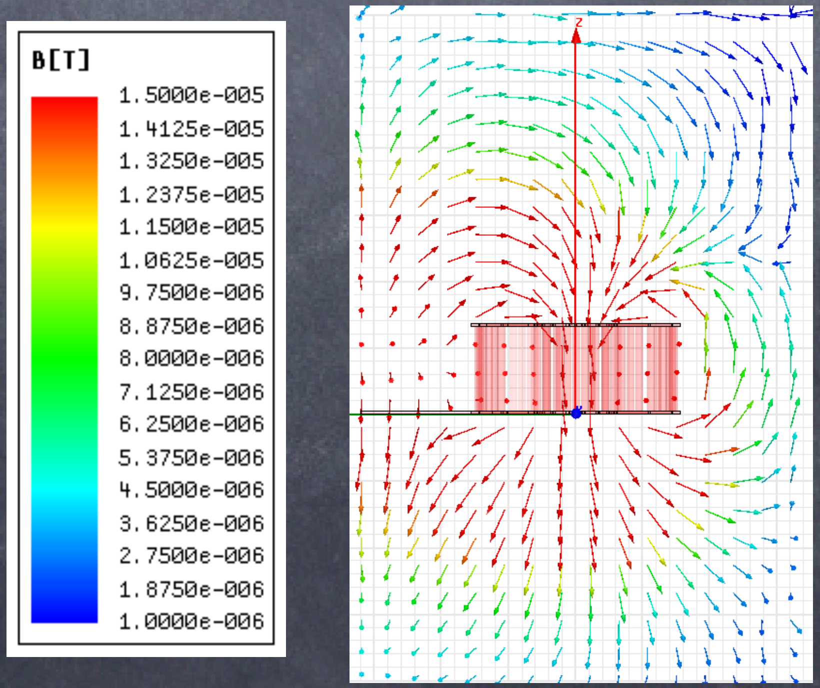
Solenoid

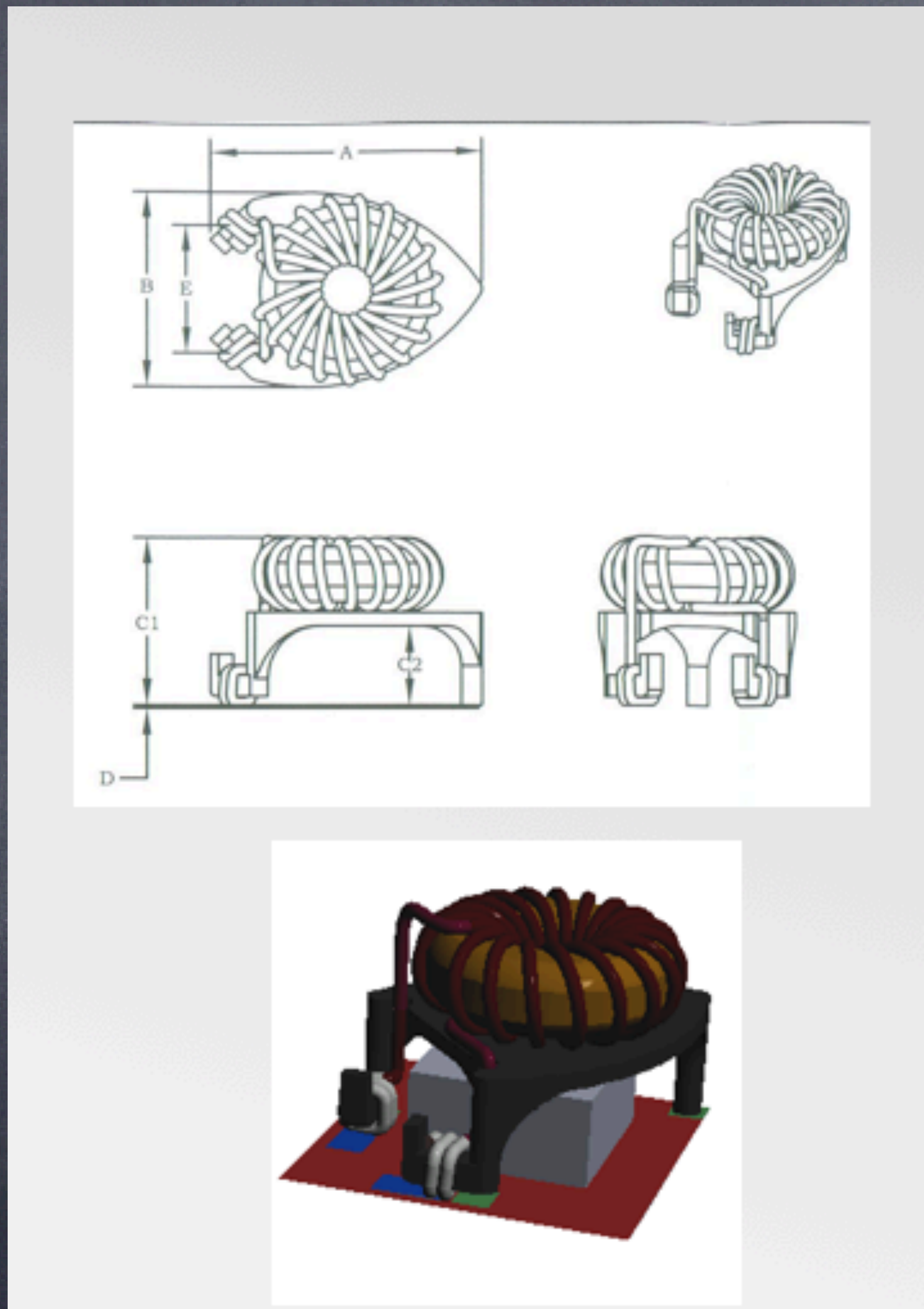




Toroid



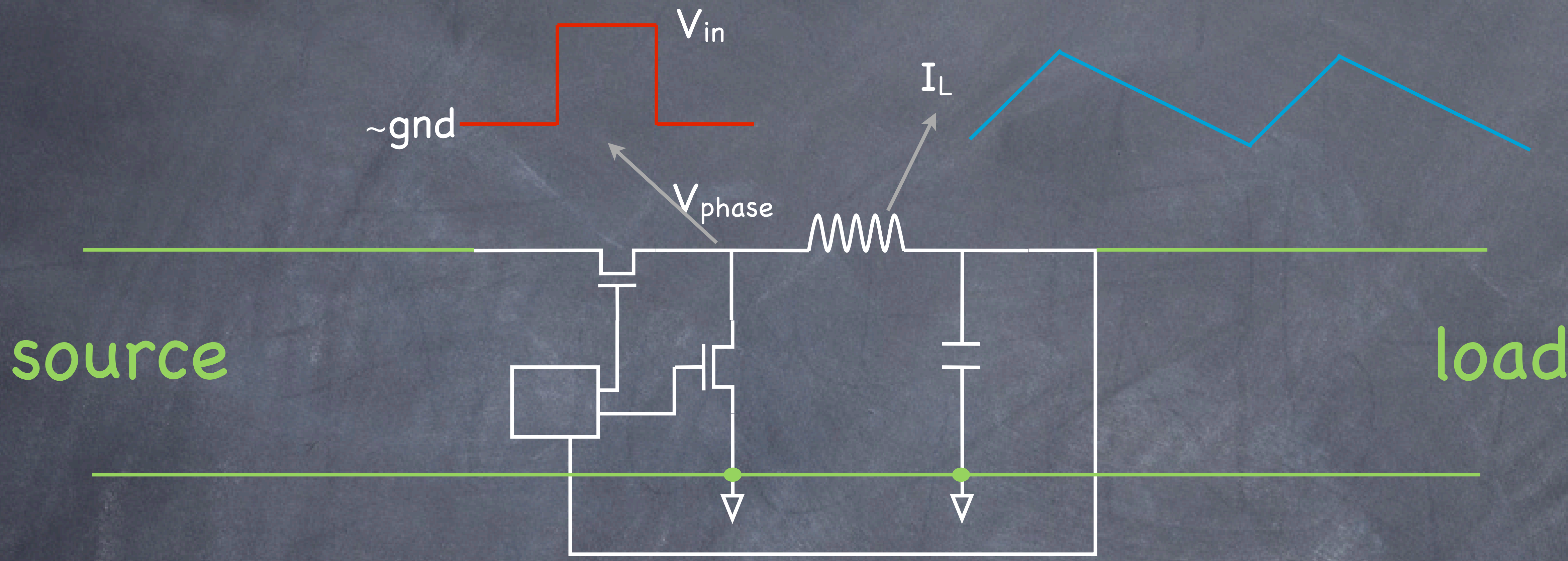


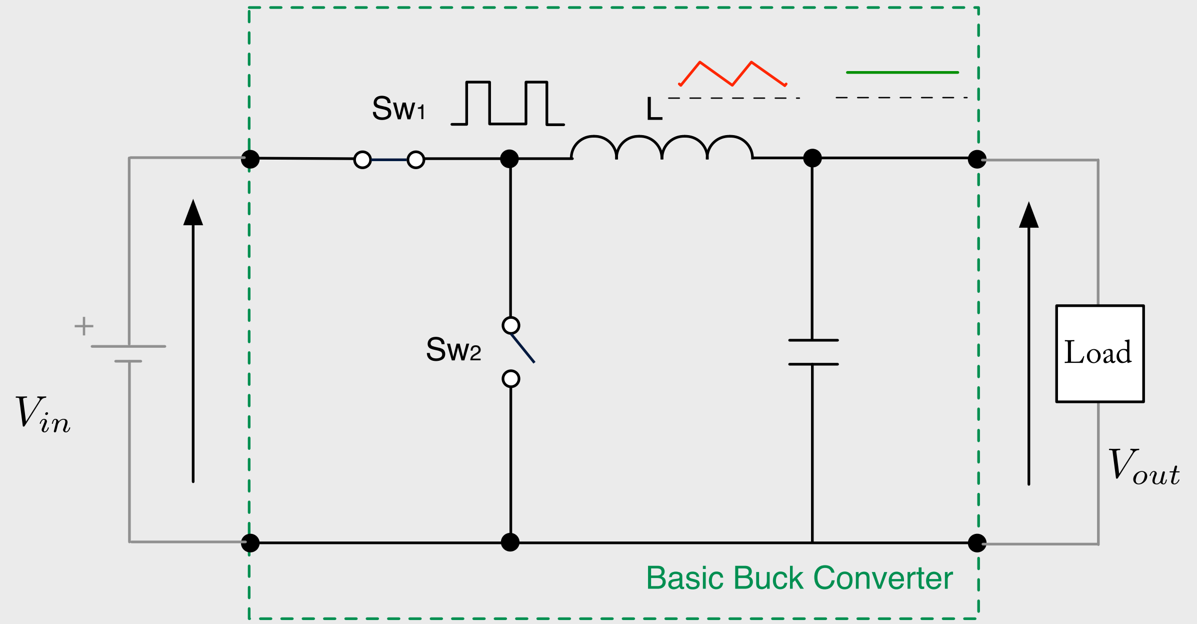


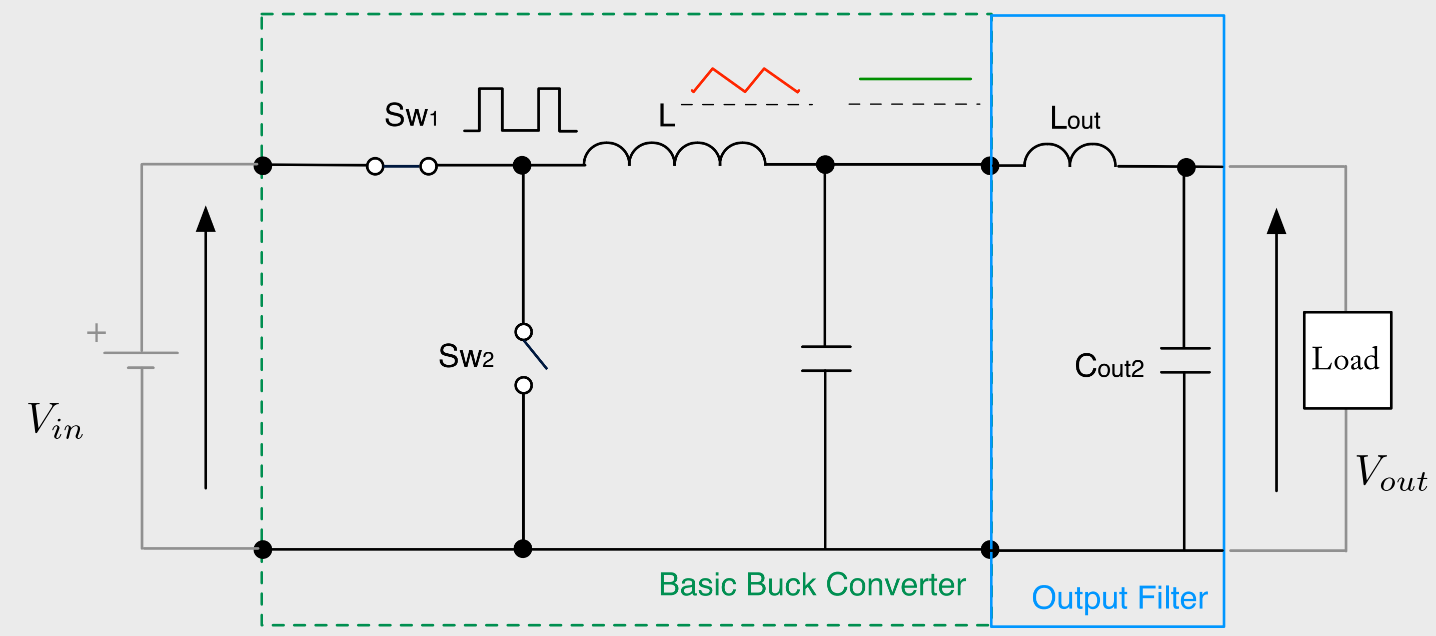
Coilcraft design

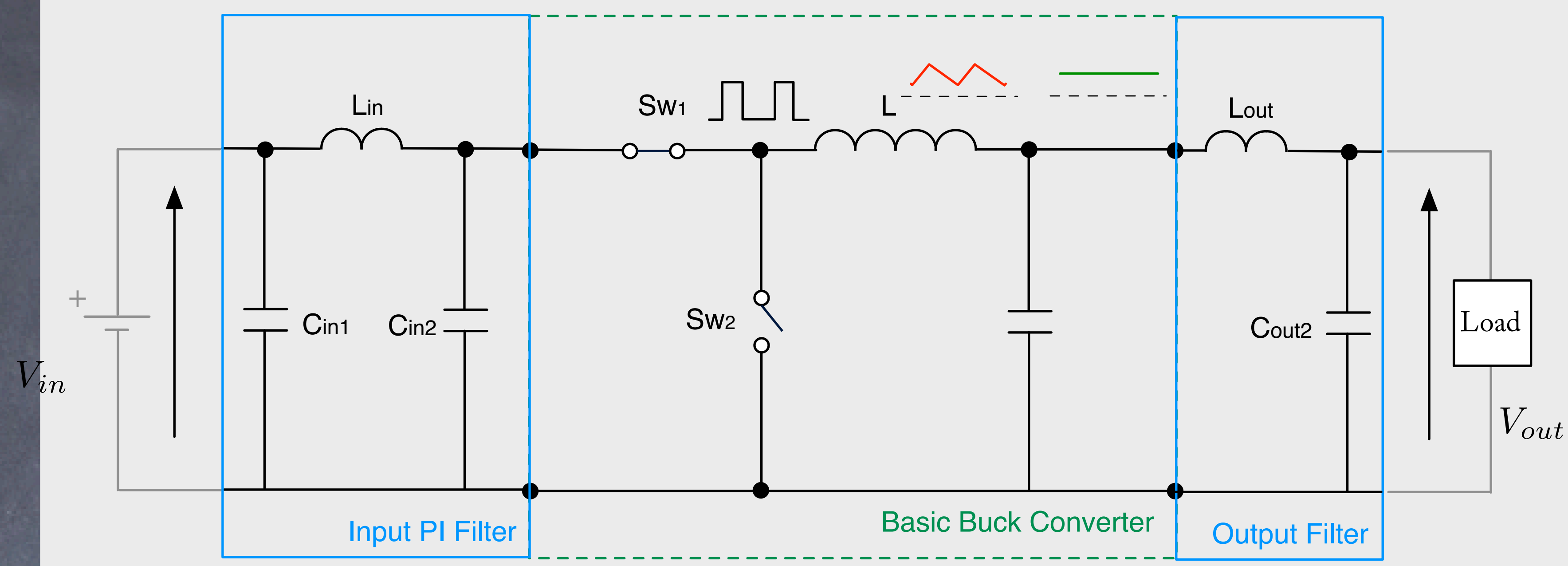
L=220 nH

ESR=30mΩ

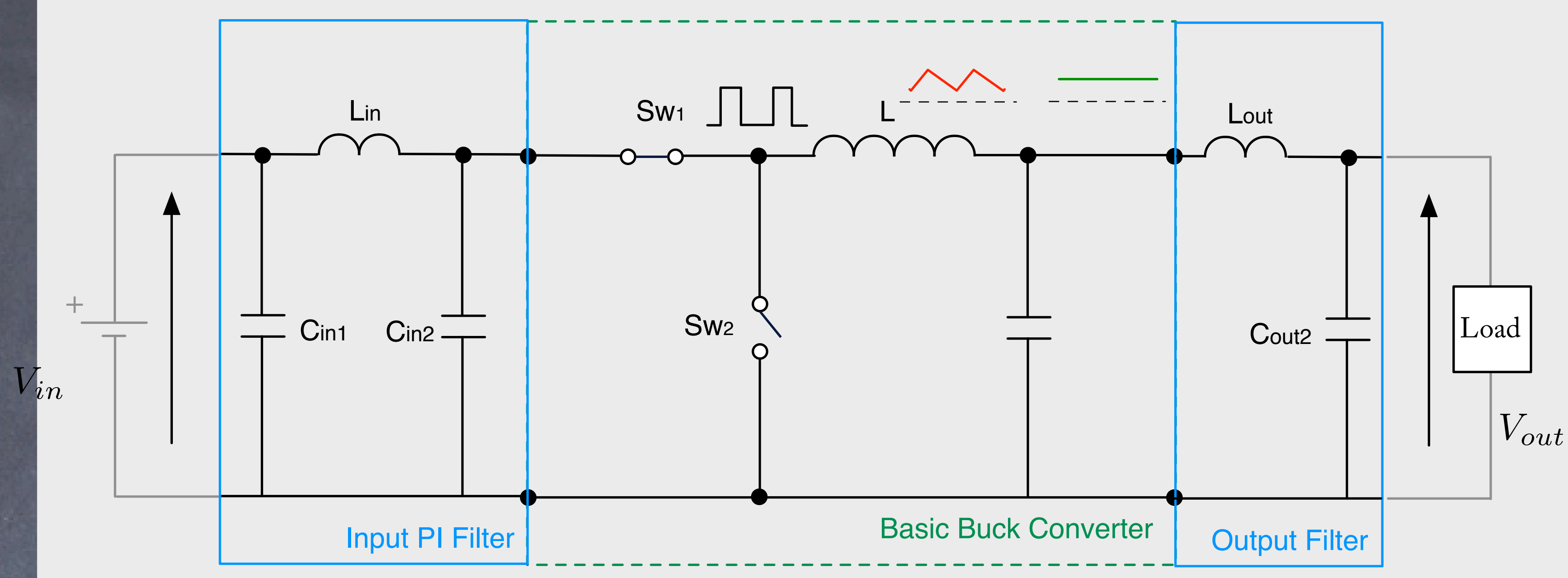

Vin
~gnd
IL
Vphase
source
load


Sw1
L
+
V_{in}
Sw2
Load
V_{out}
Basic Buck Converter

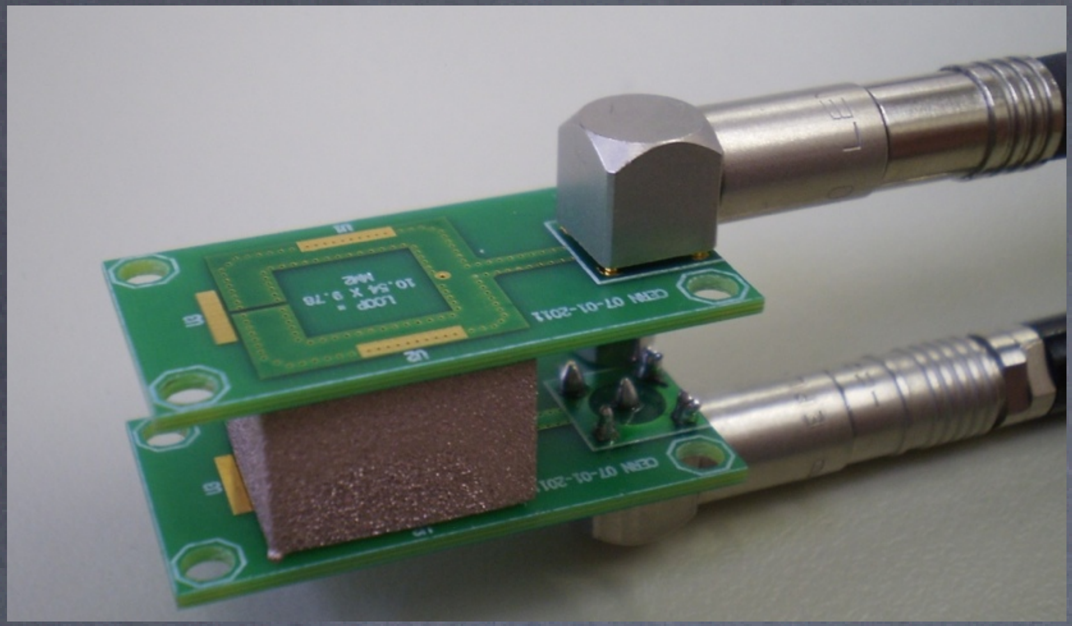

Sw1
L
Lout
Sw2
Cout2
Load
V_{in}
V_{out}
Basic Buck Converter
Output Filter



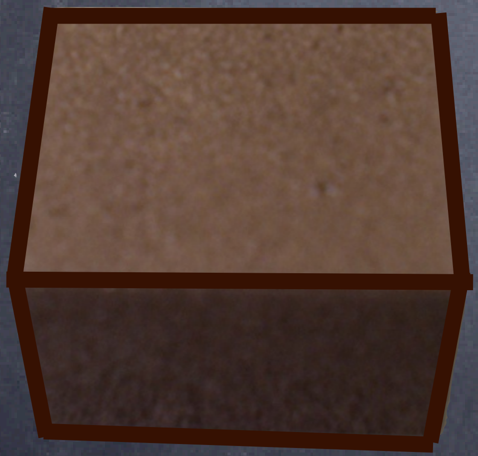
Lin
Cin1
Cin2
Sw1
Sw2
L
Lout
Cout2
Load
V_{in}
V_{out}
Input PI Filter
Basic Buck Converter
Output Filter



Component selection and placement



Different constructions and thickness (t)

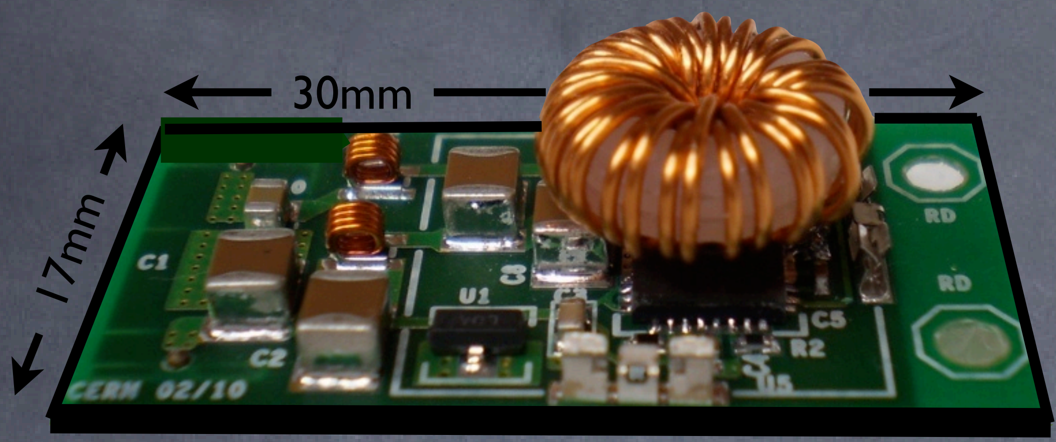


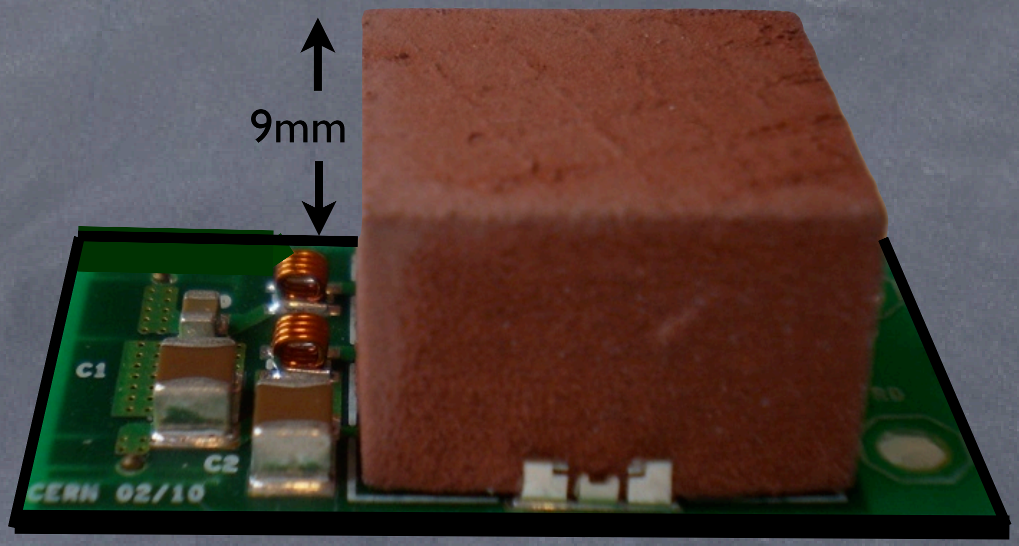
Painted Shield
t = ?

Tape Shield
t = 35 µm

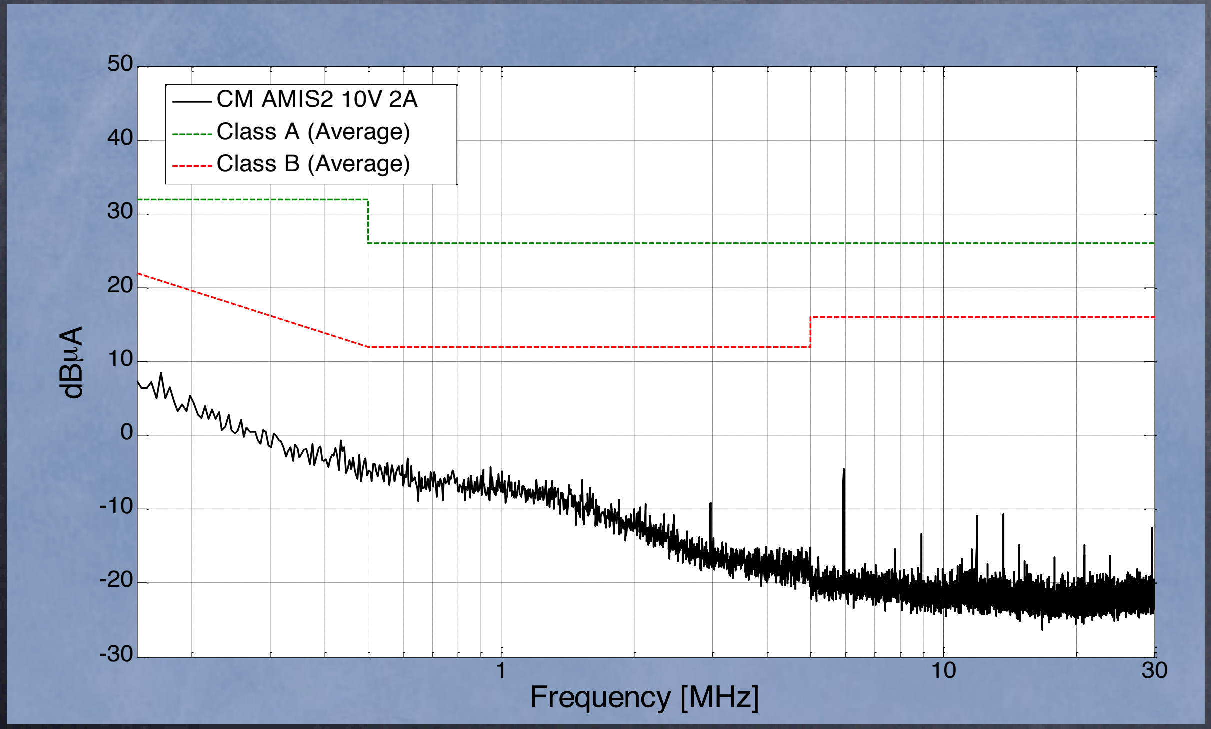
Coated Shield
10 < t < 100 µm

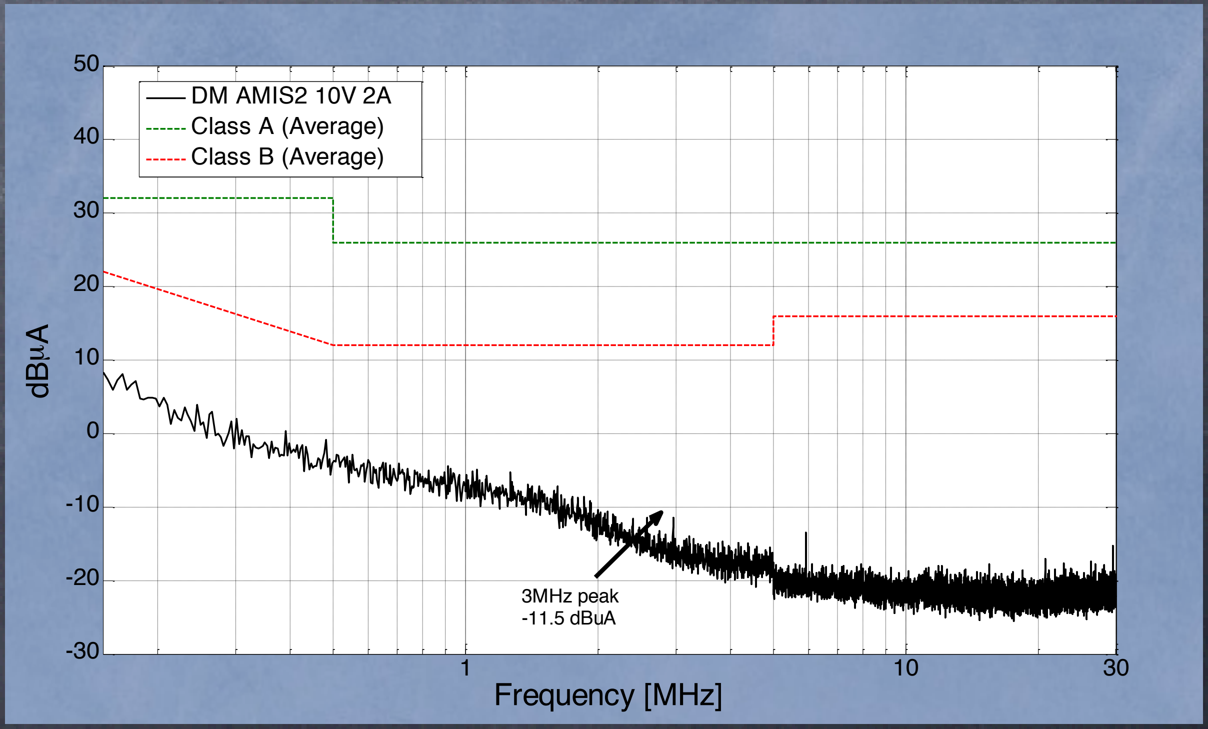
This prototype uses the AMIS2 ASIC (rad tolerant)



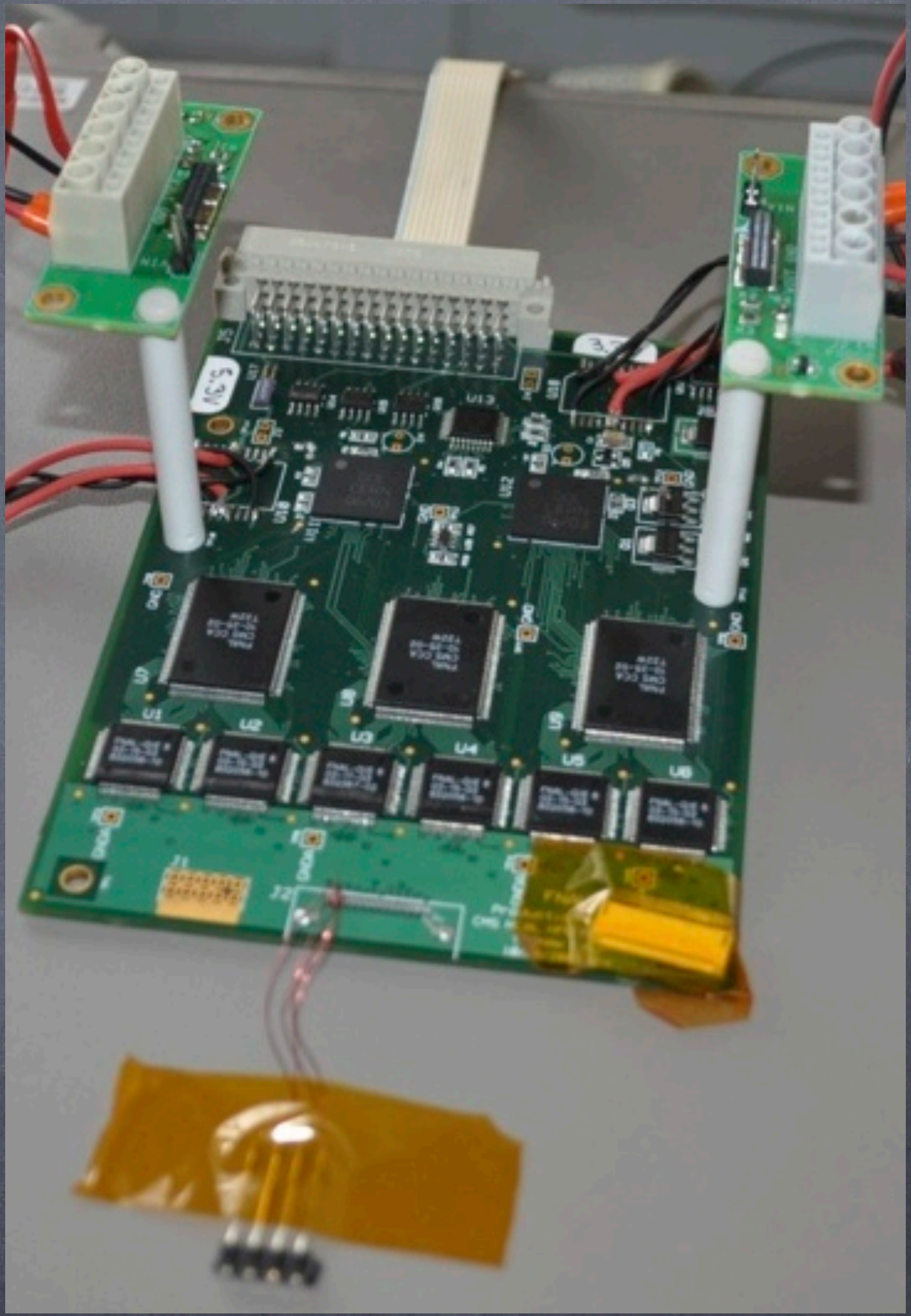


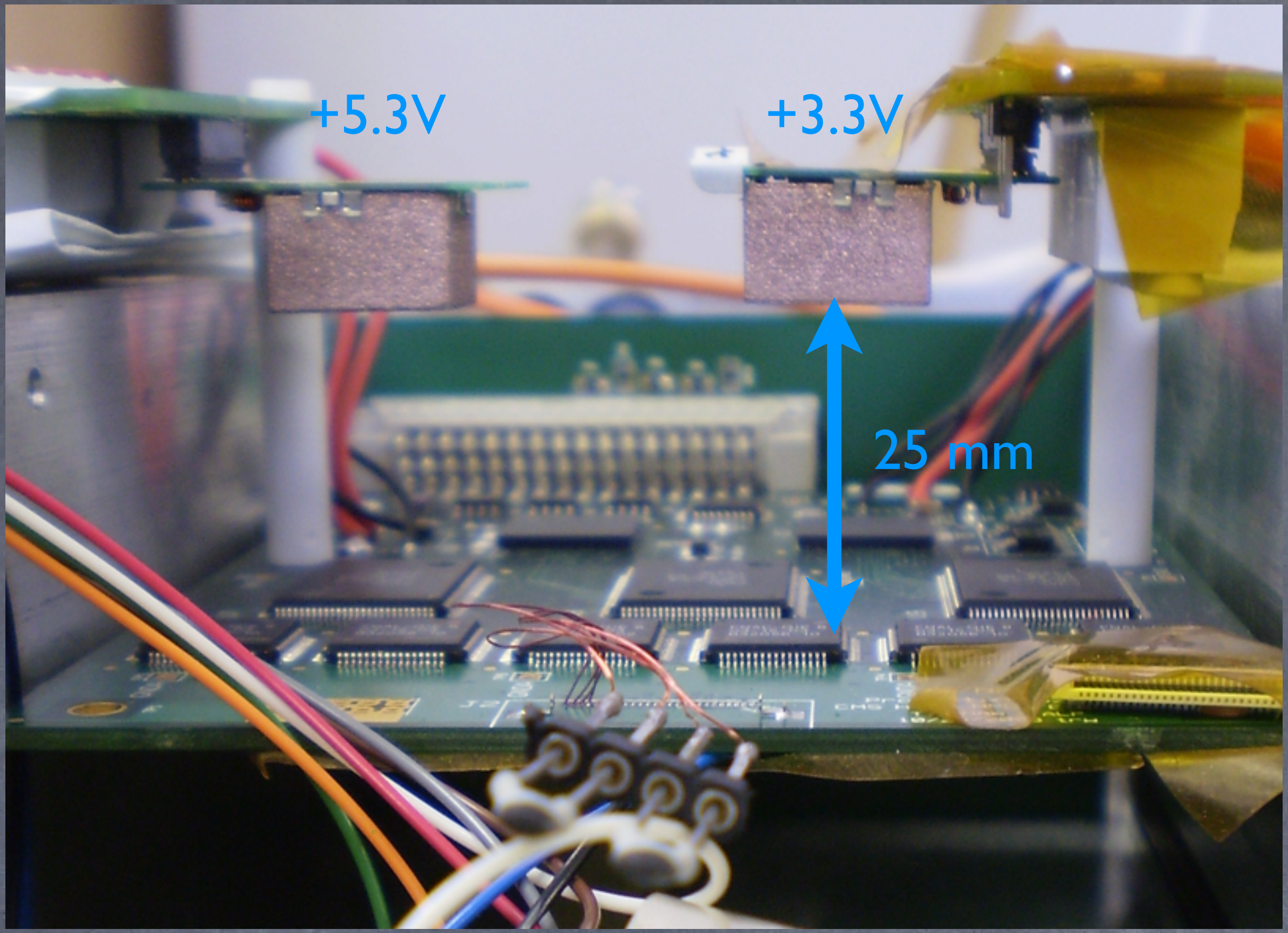
Measured output noise (current) for Vin=10V, Vout=2.5V, Iout=2A.
Note that 0 dBμA = 1μA

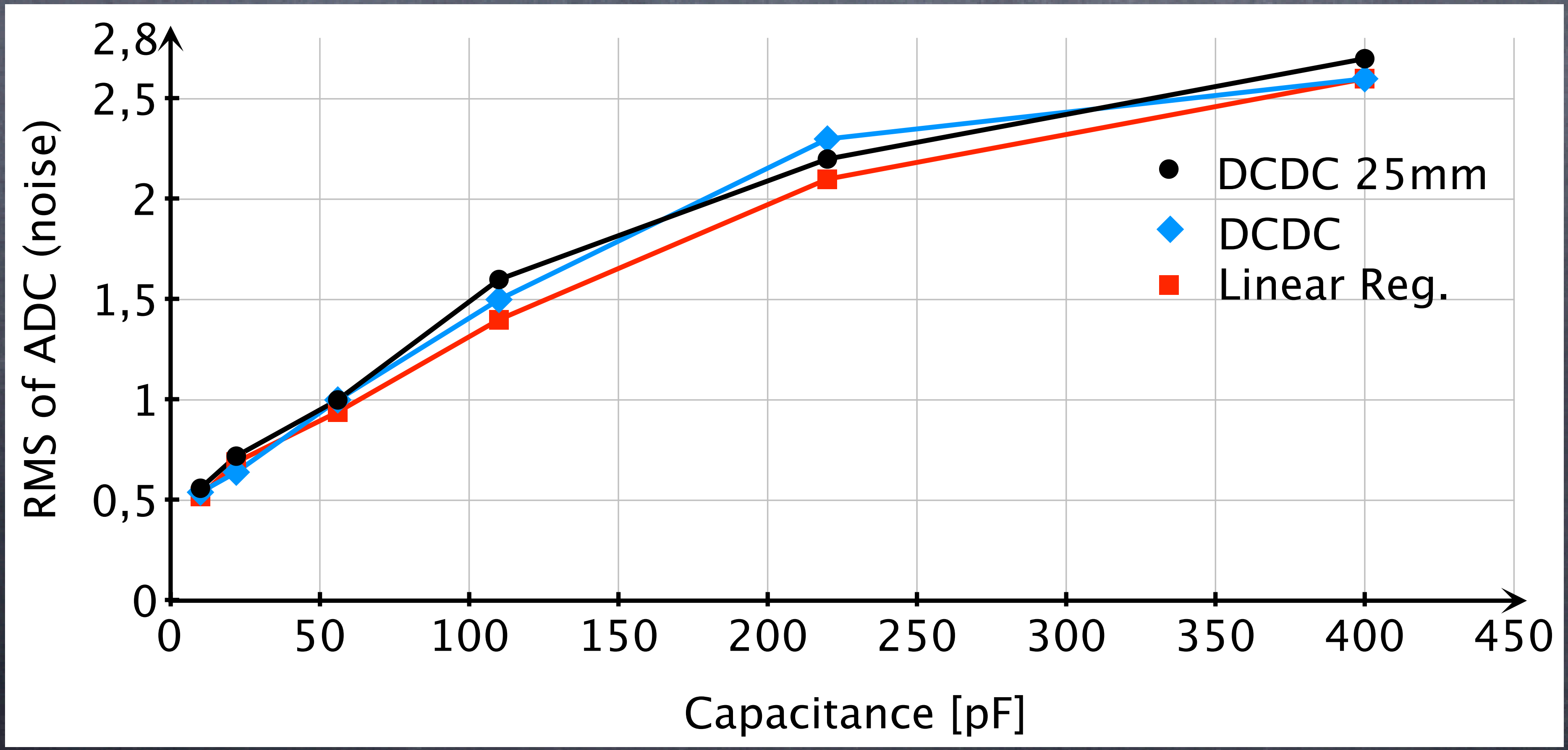




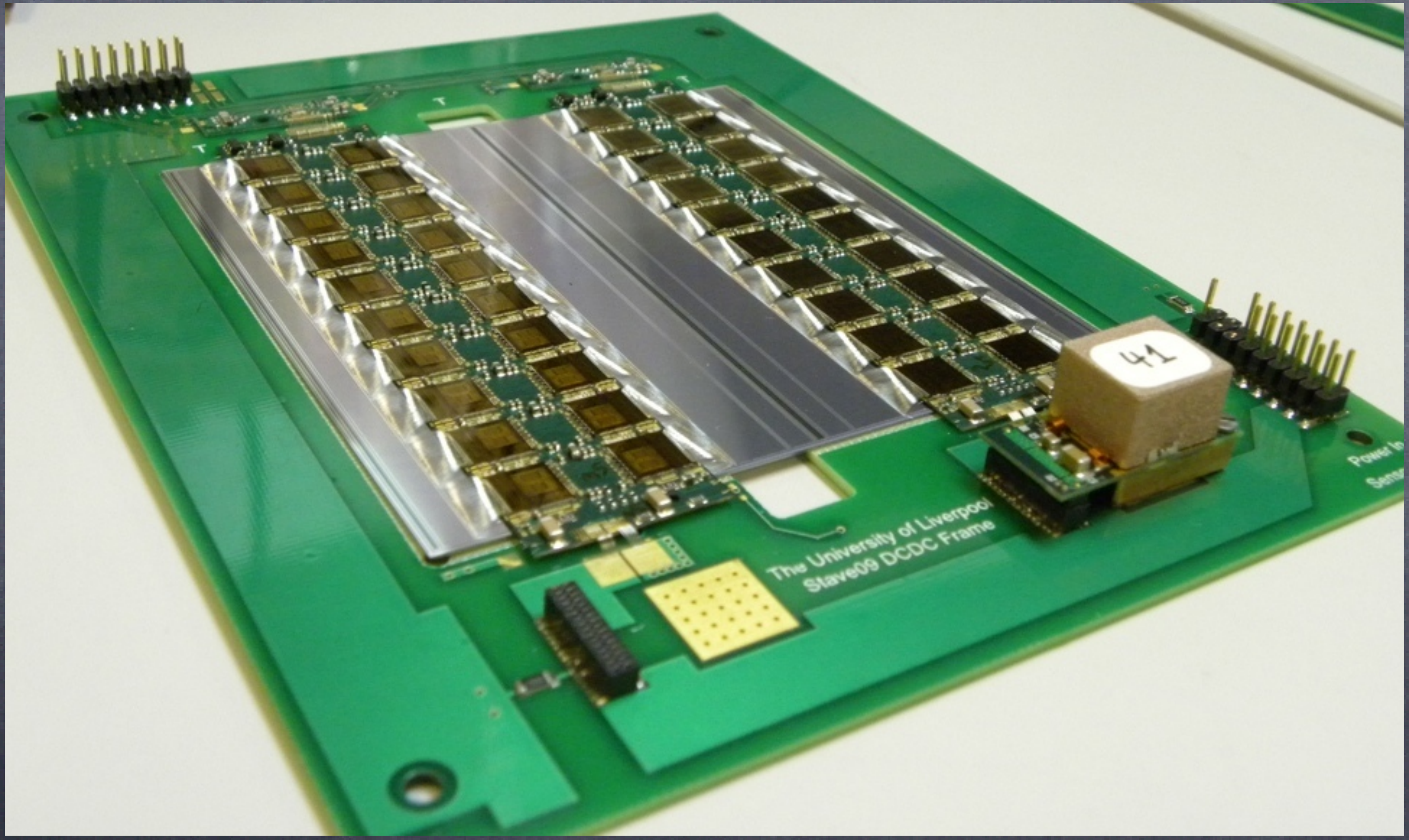
Test with FEE
Hcal CMS

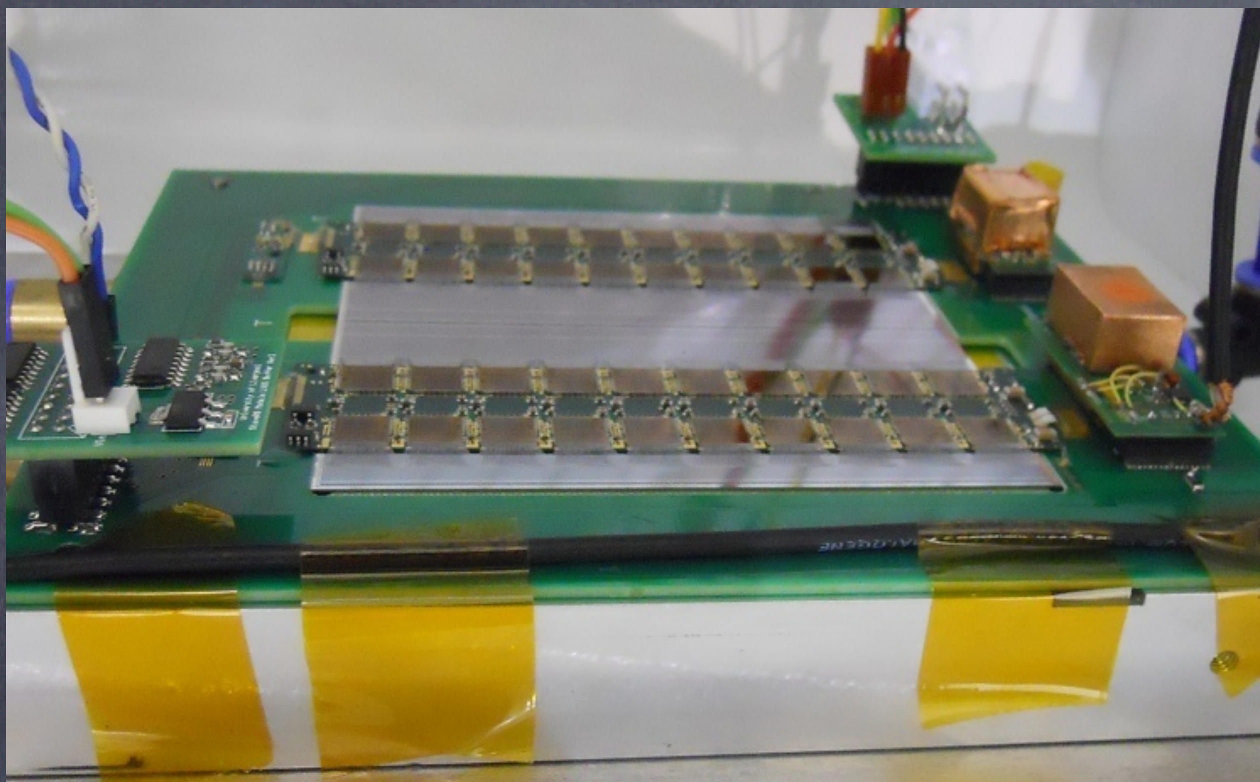


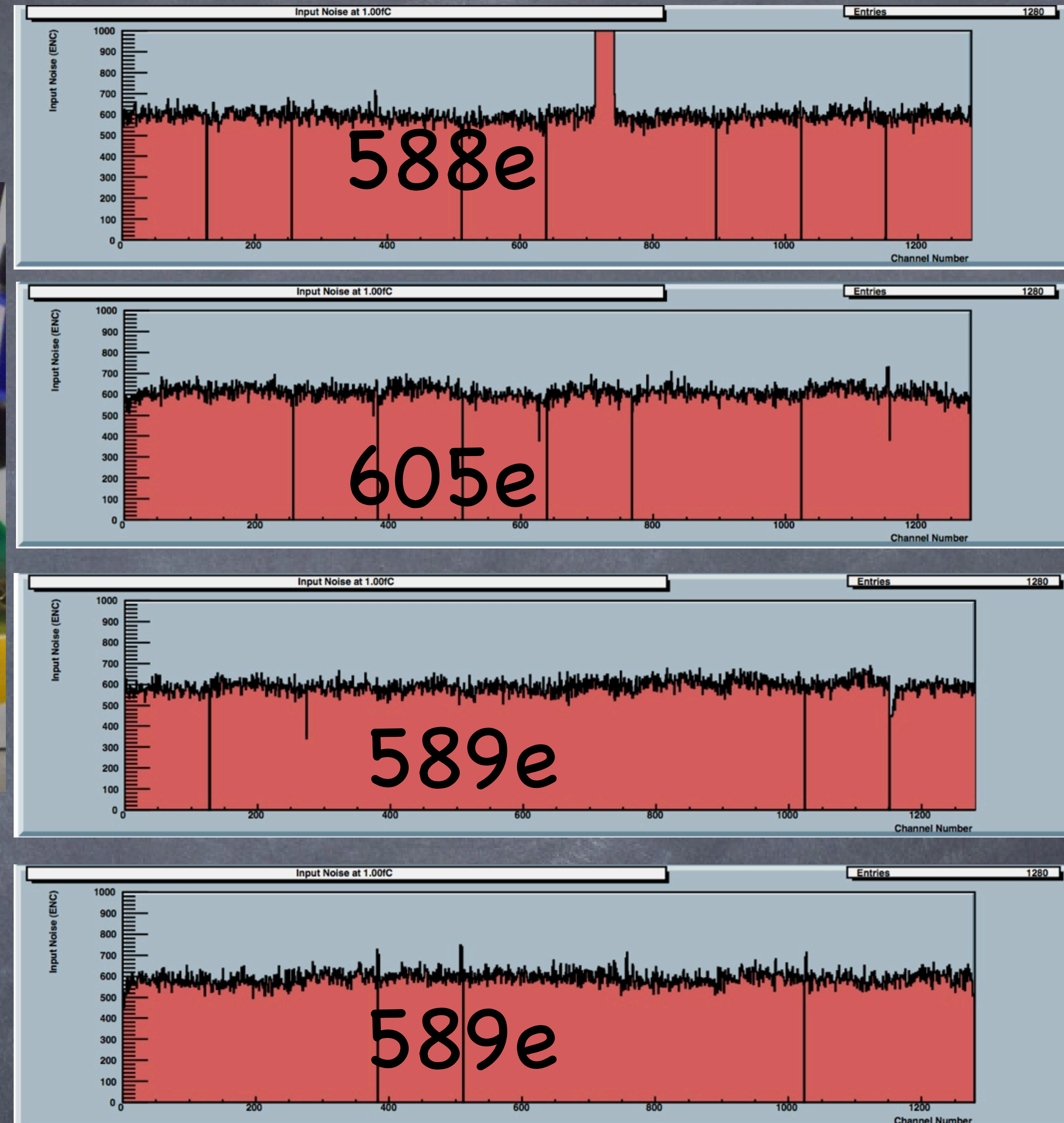

+5.3V
+3.3V
25 mm


RMS of ADC (noise)
Capacitance [pF]
DCDC 25mm
DCDC
Linear Reg.
0
0,5
1
1,5
2
2,5
2,8
0
50
100
150
200
250
300
350
400
450

Test with Frame Module ATLAS SCT prototype (Liverpool)







Hybrid	Linear regulator [ENC]	DCDC STV10 [ENC]
62	570	588
	596	605
61	585	589
	591	599

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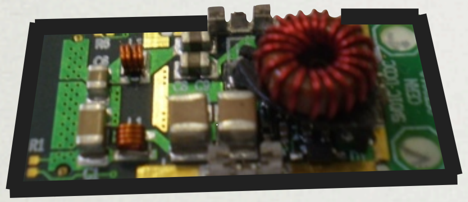

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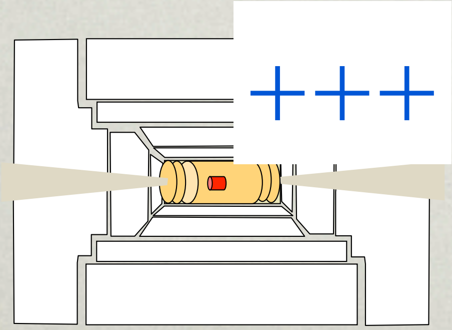
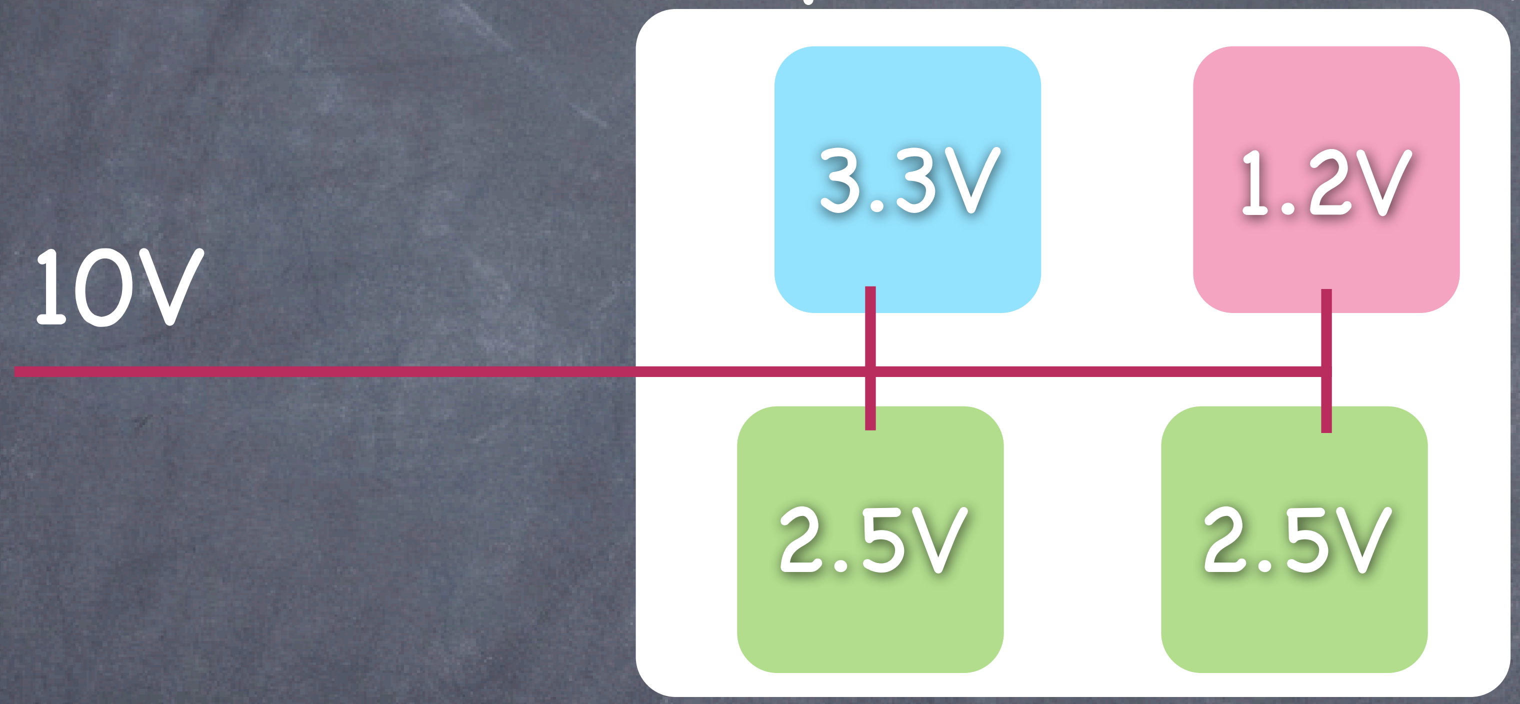
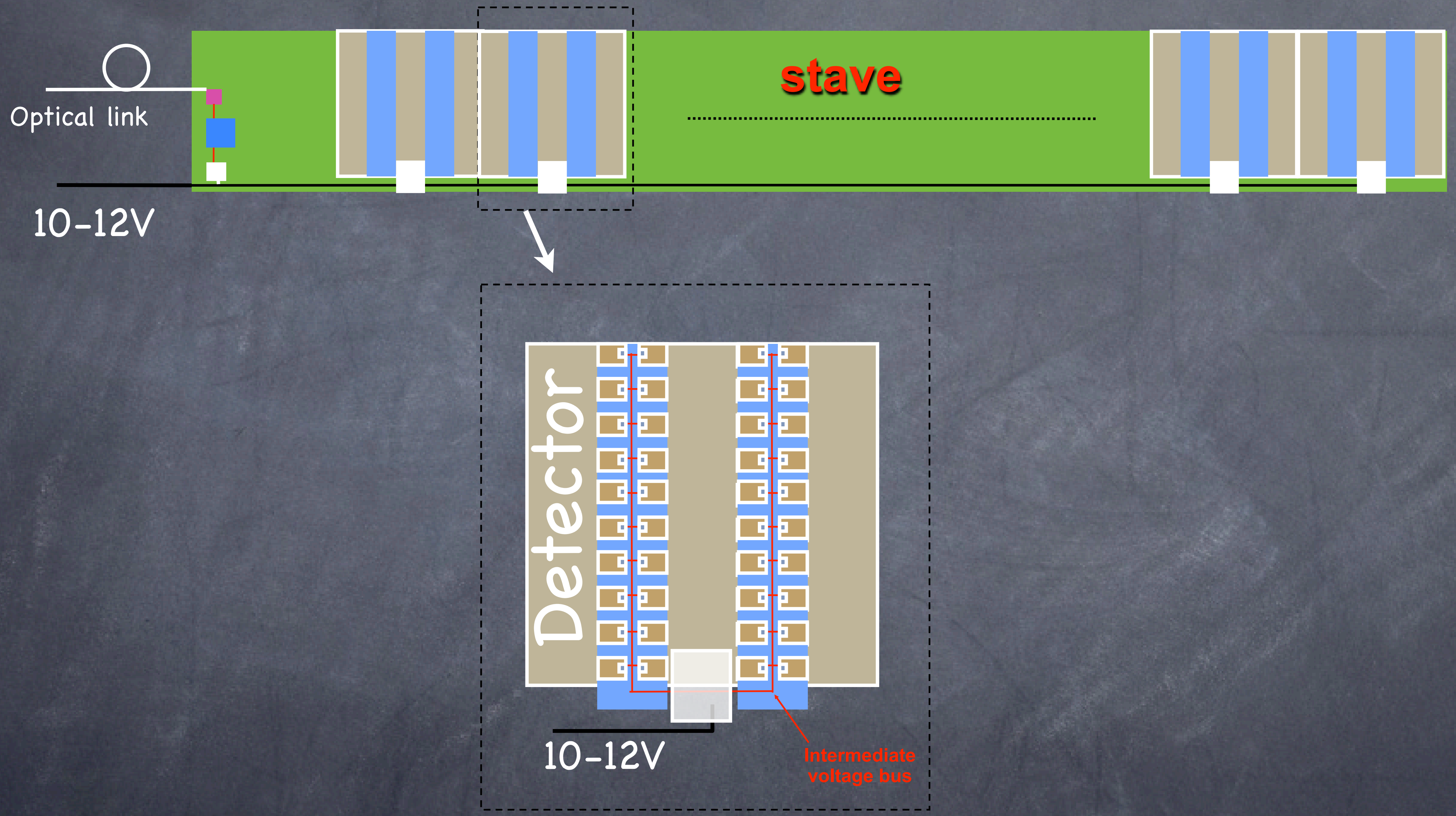


In summary, what can a DCDC converter bring to a detector system

The use of DCDC converters on-detector enables power distribution at higher voltage, hence lower current in the cables
It also adds local voltage regulation
With its high efficiency, it is far superior to a linear regulator for the above purpose (large conversion ratio)
A power distribution system with DCDC converters can be build modular, which allows for progressive and selective turn-on and -off of portions. It can also be built using cascaded conversion stages for higher efficiency. Additionally, different load voltages can be locally generated from a unique power bus

FE board or portion of a system

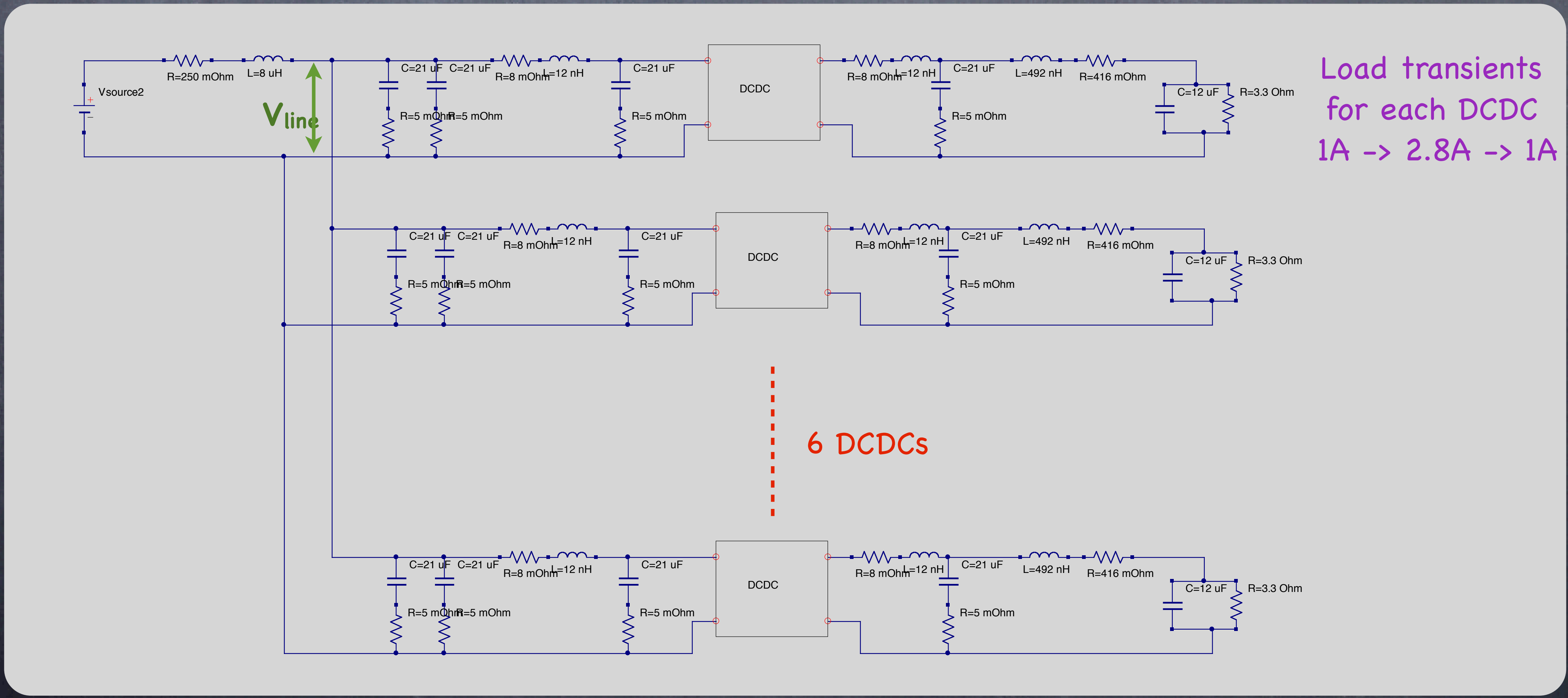




Optical link
10-12V
stave
Detector
10-12V
Intermediate voltage bus

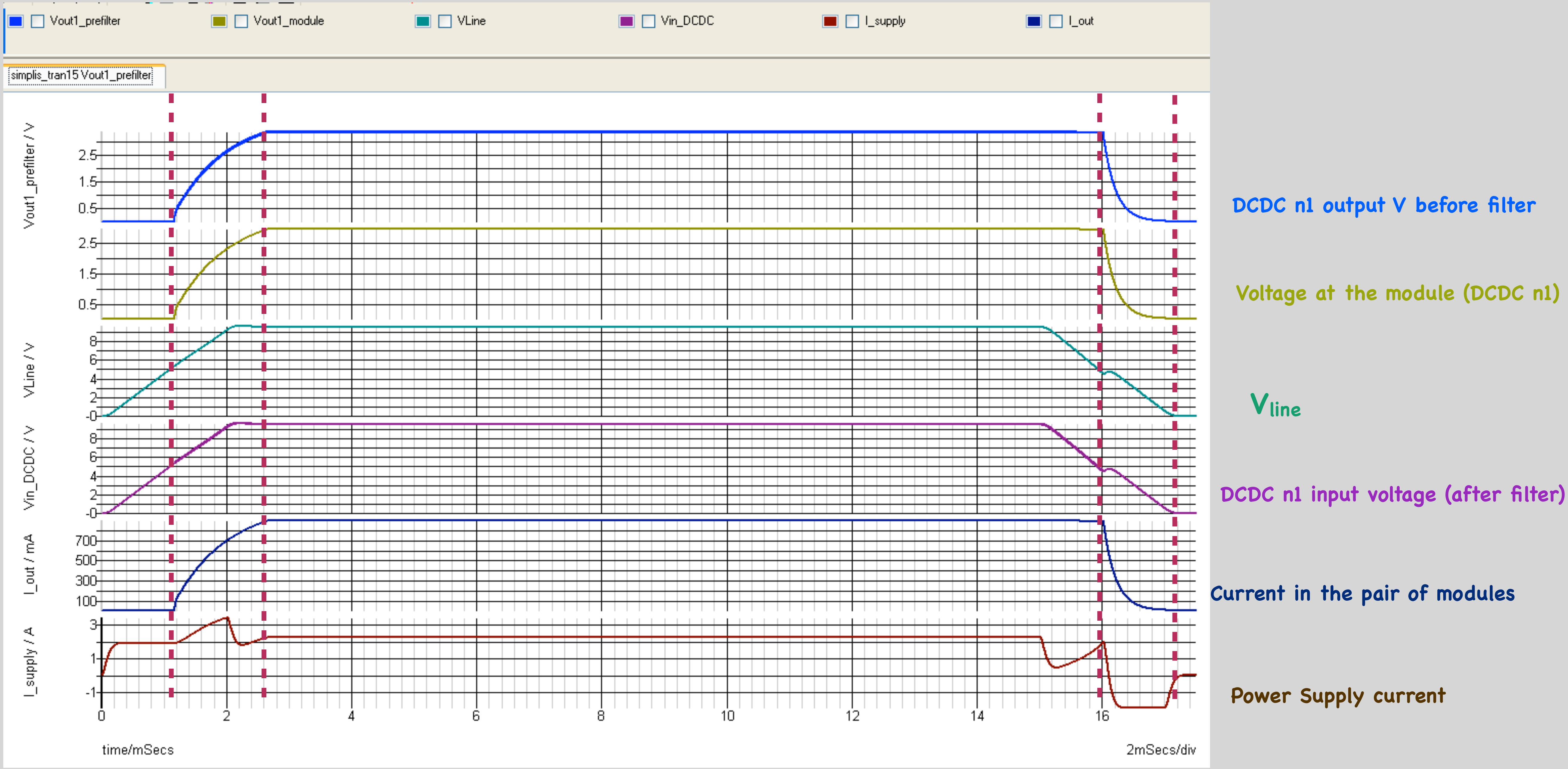
CMS pixels upgrade phase 1

- The full distribution scheme (with ideal PS) is studied, using the best available estimates
- The case studied below is an unreal worst-case configuration



Power-on & power-off of full PS channel

- Voltage ramp from the PS (rise & fall time 2ms) to turn-on and -off all 6 converters loaded with an equivalent 1A current



Conclusion

- DCDC converters are required for the upgrade of the LHC experiments, already at phase1
- They enable power distribution at higher voltage, decreasing the current on the cables. A modular distribution system can be designed, facilitating partitioning of domains from an individual supply bus
- The development of full DCDC converters satisfying the requirements of the LHC experiments is well advanced. With the availability of more mature ASICs, in a few months, all the basic elements and required skills will be available (as far as we can judge now)