Powering the CMS Tracker at the SLHC

Introduction

At an upgraded LHC accelerator (SLHC) the number of interactions in CMS per bunch-crossing will increase from about 20 to about 400. A tracker in an upgraded CMS will have to continue to function at high efficiency without increasing the "Dead Material" in front of the calorimeter. This implies:

Tracker Granularity Increases:

The number of channels will increase in order to retain high track reconstruction efficiency.

Tracker Power Consumption Stays Constant:

Cooling pipes add dead material to the tracker. Reducing the amount of heat put into the heart of the detector reduces the dead material of the pipe work needed to remove it.

Supply Voltage Reduces:

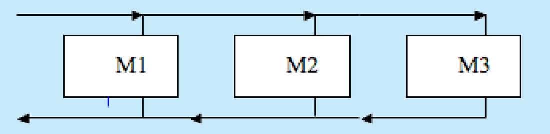
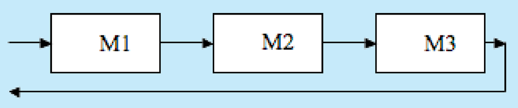
To avoid increasing the power consumption whilst increasing the granularity, the feature size of the readout chips will reduce: The supply current increases due to the increased channel count, but the supply voltage falls.

Novel Powering Schemes:

A large fraction of the power in the current tracker is dissipated in the power cables. With lower supply voltage the current power distribution

Serial Powering vs. DC-DC

There are two powering schemes proposed for the CMS tracker at the SLHC:

DC-DC Converters	Serial Powering
	
•Powered in parallel (as now) with higher voltage, hence lower current. •Need radiation hard DC-DC converters. (Rad-hard high voltage transistors challenging). •Inductor based converters need air cores and radiate EMI. •High efficiency (>85%) with air-core magnetic components and rad-hard switches will be tough.	•Modules powered in series (c.f. "Christmas Tree Lights"). •Current draw determined by the "hungriest" device. •Open circuit failure of a module disables entire chain. •Floating ground. •Lower EMI than switcher-based configurations.

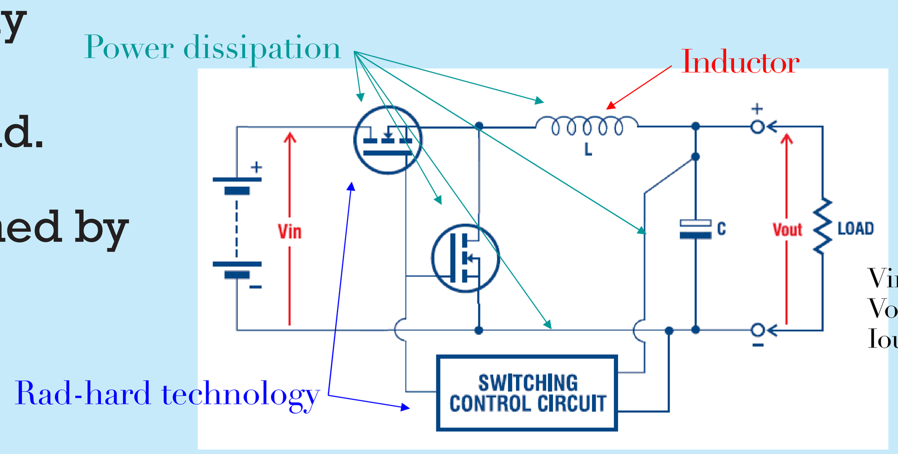
Buck Converter

•"Baseline" configuration for a CMS DC-DC tracker powering scheme.

•Energy drawn from supply and stored in an inductor then released into the load.

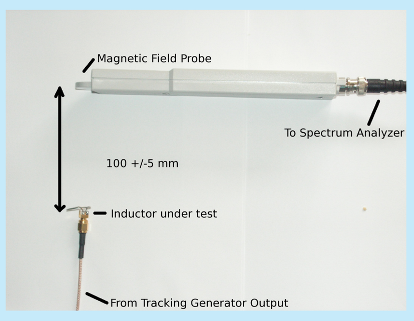
•Step-down ratio determined by switch duty-cycle.

•Concerned with keeping efficiency high in a rad-hard design with low EMI.



Magnetic Field of Inductors

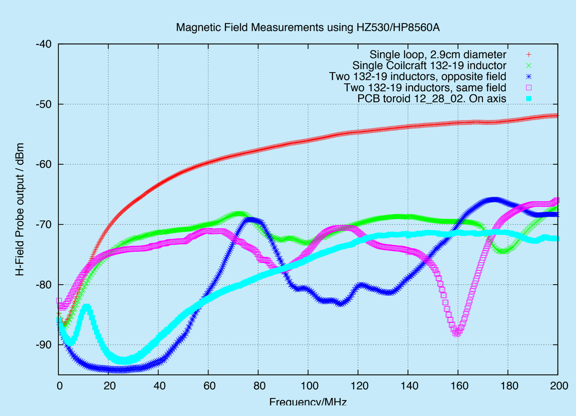
•Excite inductor with signal from tracking generator inside a spectrum analyzer. Measure signal from a magnetic field probe.



•A relative not absolute measure (probe calibration not given, fields affected by nearby conductors).

•Can reduce magnetic field far from inductor by changing the geometry, but retain inductance.

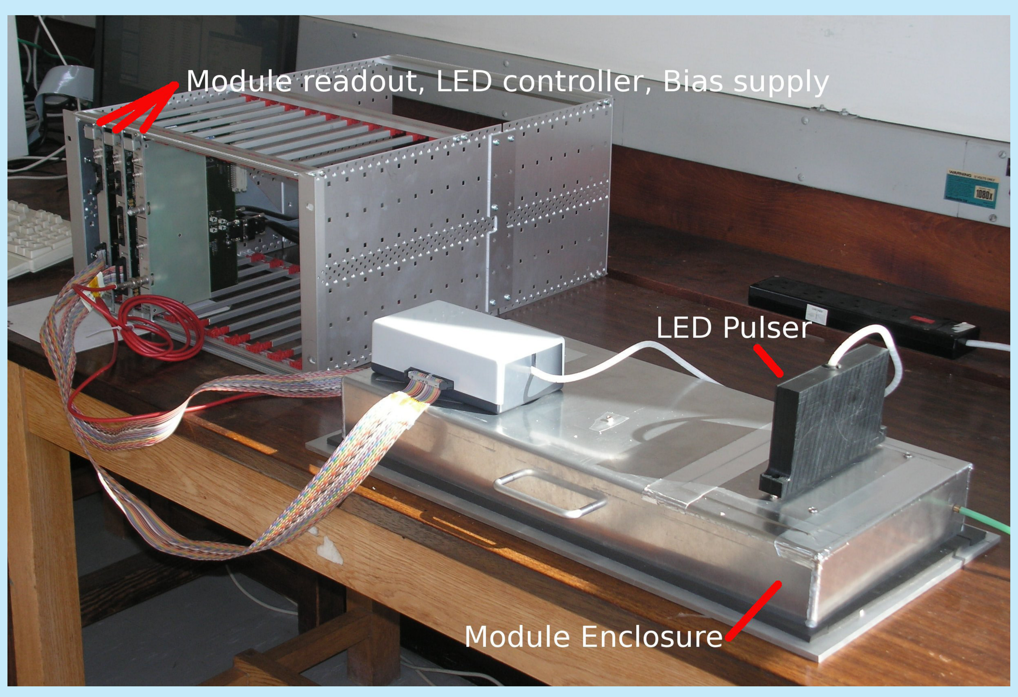
Configuration	Inductance/nH	Magnetic Field at 20MHz (arb units)
Single Coilcraft 132-19	477	-75dB
Two 132-19, parallel field	940	-75dB
Two 132-19, anti-parallel field	915	-94dB



Module Tests

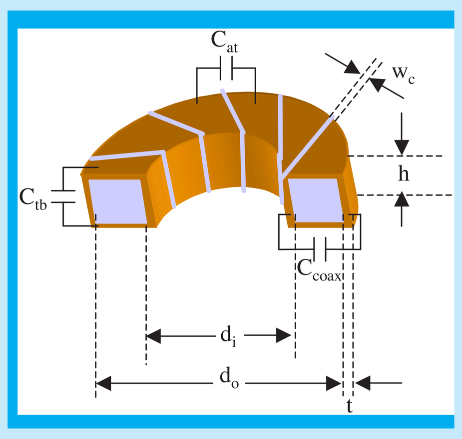
•Standard CMS tracker-module test-stand being commissioned in Bristol (components provided by UC Santa Barbara)

•Facilities to measure and inject noise and incorporate prototype DC-DC converters will be incorporated.



Toroidal Inductor: In PCB

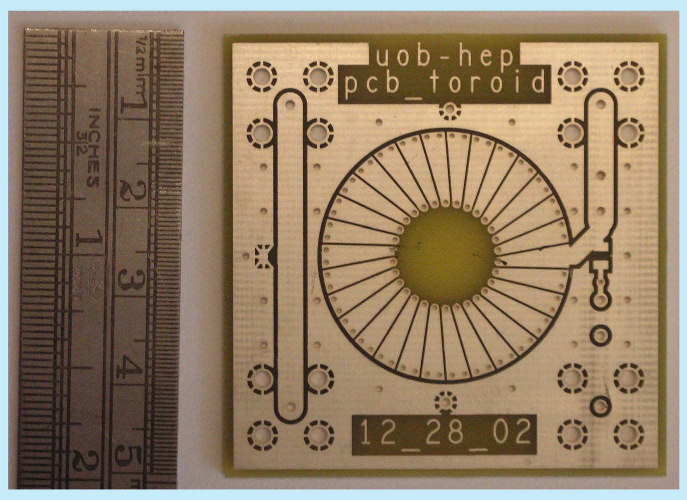
•Toroids have much lower stray field than solenoids.



•Many commercial DC-DC converters use magnetic components fabricated into the PCB. Normally a planar transformer with a ferrite core to increase the inductance.

•For a toroid: $L \sim (N^2 h \mu_0 / 2\pi) \ln(d_o/d_i)$

•A prototype PCB based toroidal inductor has been constructed in a standard low-cost 2-layer process. 250nH , 200mΩ.



•An inductor suitable for a CMS tracker module DC-DC supply (>500nH , <100mΩ) would need multiple layers and heavier plating.

Transformer-Based Converter

•Inductor-based DC-DC converters store energy in magnetic field. Transformer-based converters transfer energy from primary to secondary with magnetic field (current in secondary largely cancels field from primary)

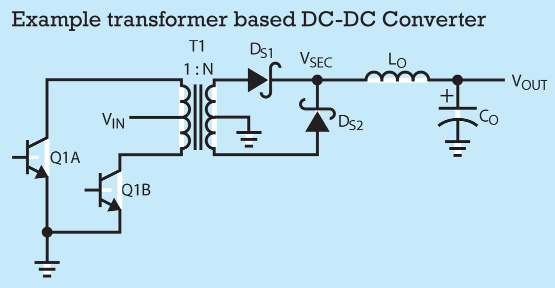
•Screening reduces field further with only small resistive losses.

• Switches operated at almost 50% duty cycle - can operate at higher frequency than equivalent buck circuit

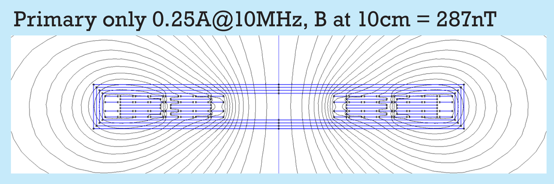
• Output voltage determined by turns ratio and switch duty cycle or switching frequency (resonant converter)

•Prototype 8-layer 4:1 planar transformer constructed and being evaluated

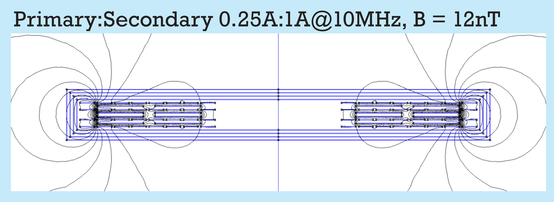
Example transformer based DC-DC Converter



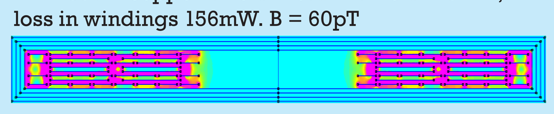
Primary only 0.25A@10MHz, B at 10cm = 287nT



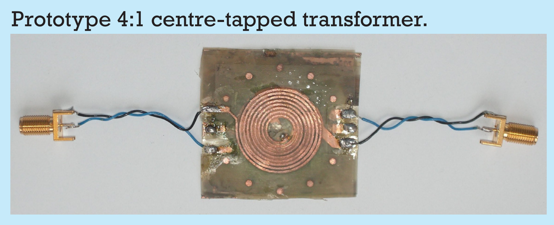
Primary:Secondary 0.25A:1A@10MHz, B = 12nT



With 35um copper shield. Loss in shield = 3mW, loss in windings 156mW. B = 60pT



Prototype 4:1 centre-tapped transformer.



References

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Serial Powering: Marc Webber, *"Silicon Trackers for the Super-LHC"*, Nuclear Physics B - Proceedings Supplements Volume 172, October 2007, Pages 269-272 Proceedings of the 10th Topical Seminar on Innovative Particle and Radiation Detectors

Radiation Hard Buck converters: Stafano Michelis et. al. *"Inductor based switching DC-DC converter for low voltage power distribution in SLHC"*, Proceedings of the Topical Workshop on Electronics for Particle Physics, Prague, 2007

David Cussans, George Ford, Christopher Hill, TWEPP, Naxos, 15-19 Sept, 2008