Powering of Detector Systems

Satish Dhawan, Yale University
Richard Sumner , CMCAMAC LLC

AWLC 2014, Fermilab
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Agenda

Prior / Current Status

- LDO Powering Efficiency
- Buck Converter
- Frequency limited by FeCo
- Commercial Devices limited by 200 KHz – 4 MHz - Core losses

Higher Frequency > smaller components

Wireless Charging, Intel 4th Generation Core

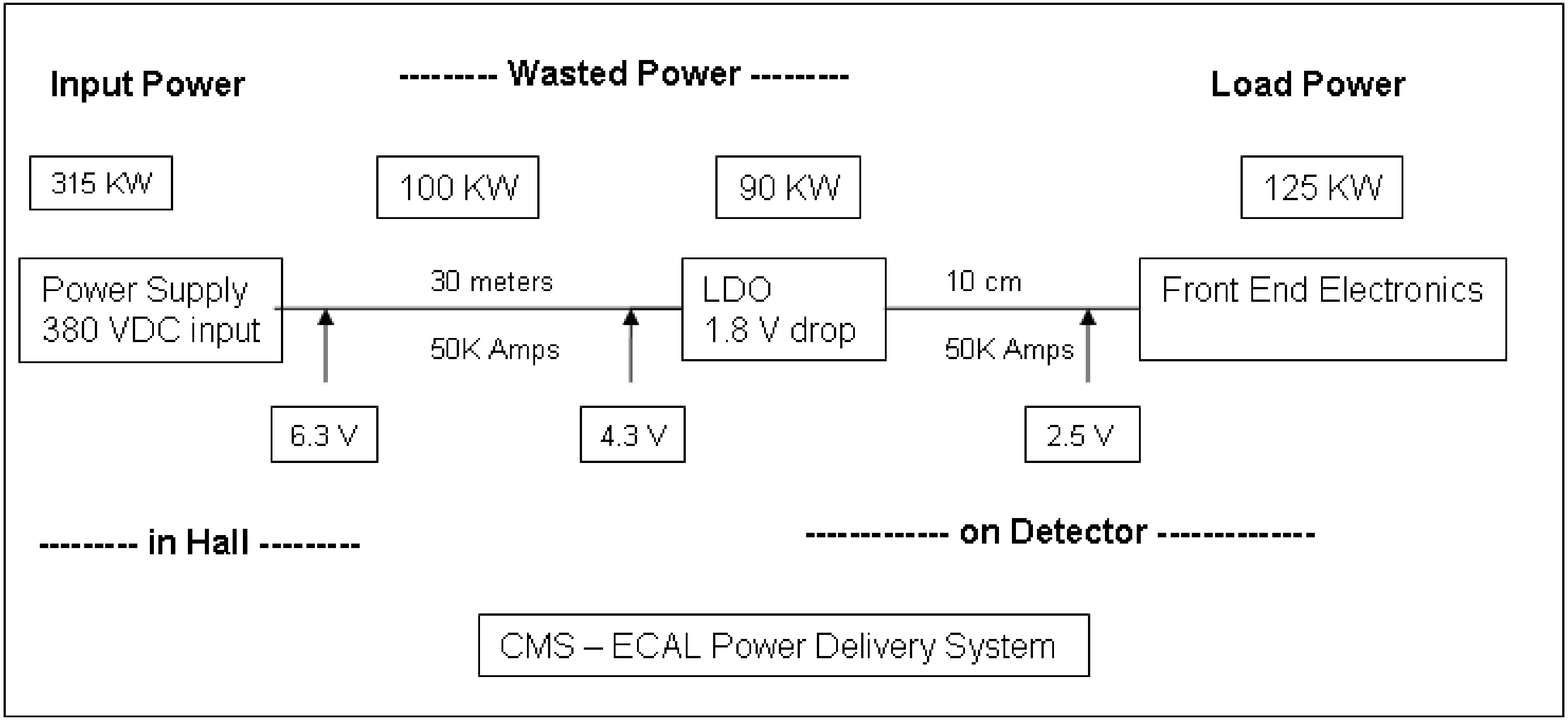
Air Core Toroid vs Planar (spirals). PC Traces @ > 100 MHz

Shielding Electrostatic & RF

ATLAS Tracker

Future

Power Efficiency _ Inefficiency _ Wasted Power



Power delivery Efficiency = 30 %

with Power for Heat Removal = 20 %

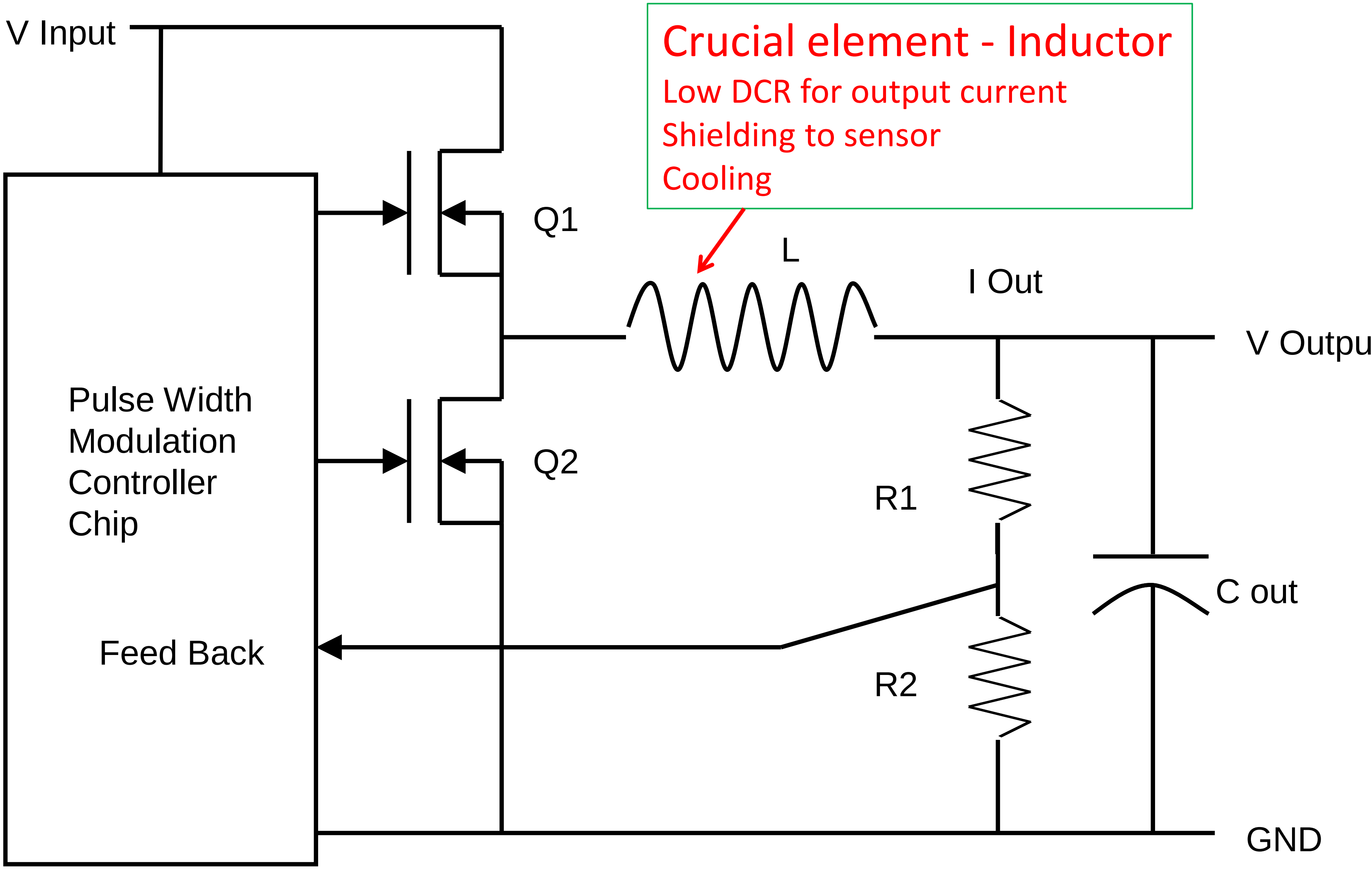
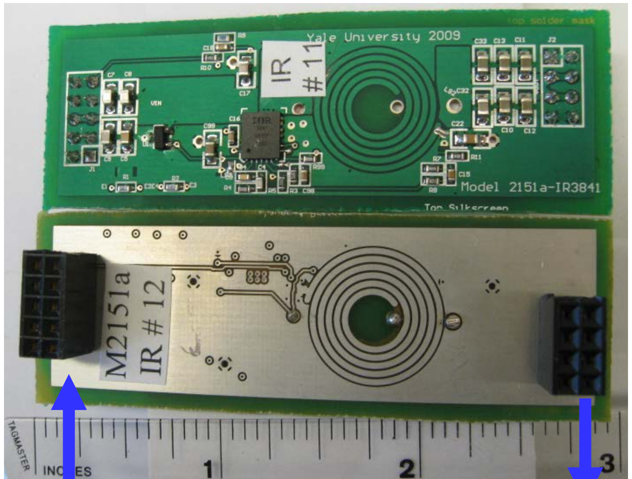


Fig SR

Synchronous Rectification

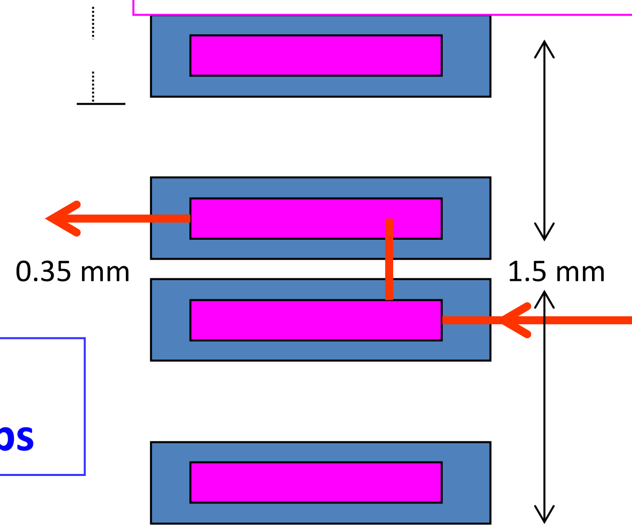
Plug In Card with Shielded Buck Inductor

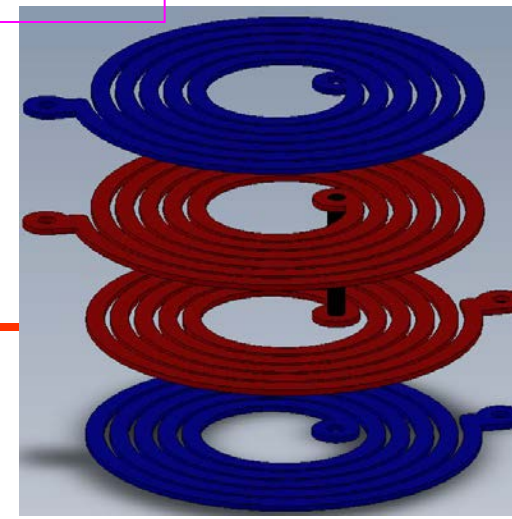


12 V

2.5 V
@ 6 amps

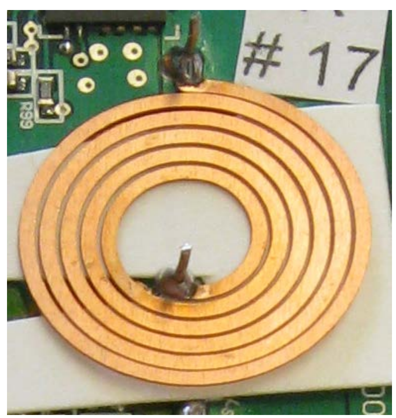
Coupled Air Core Inductor Connected in Series





Different Versions

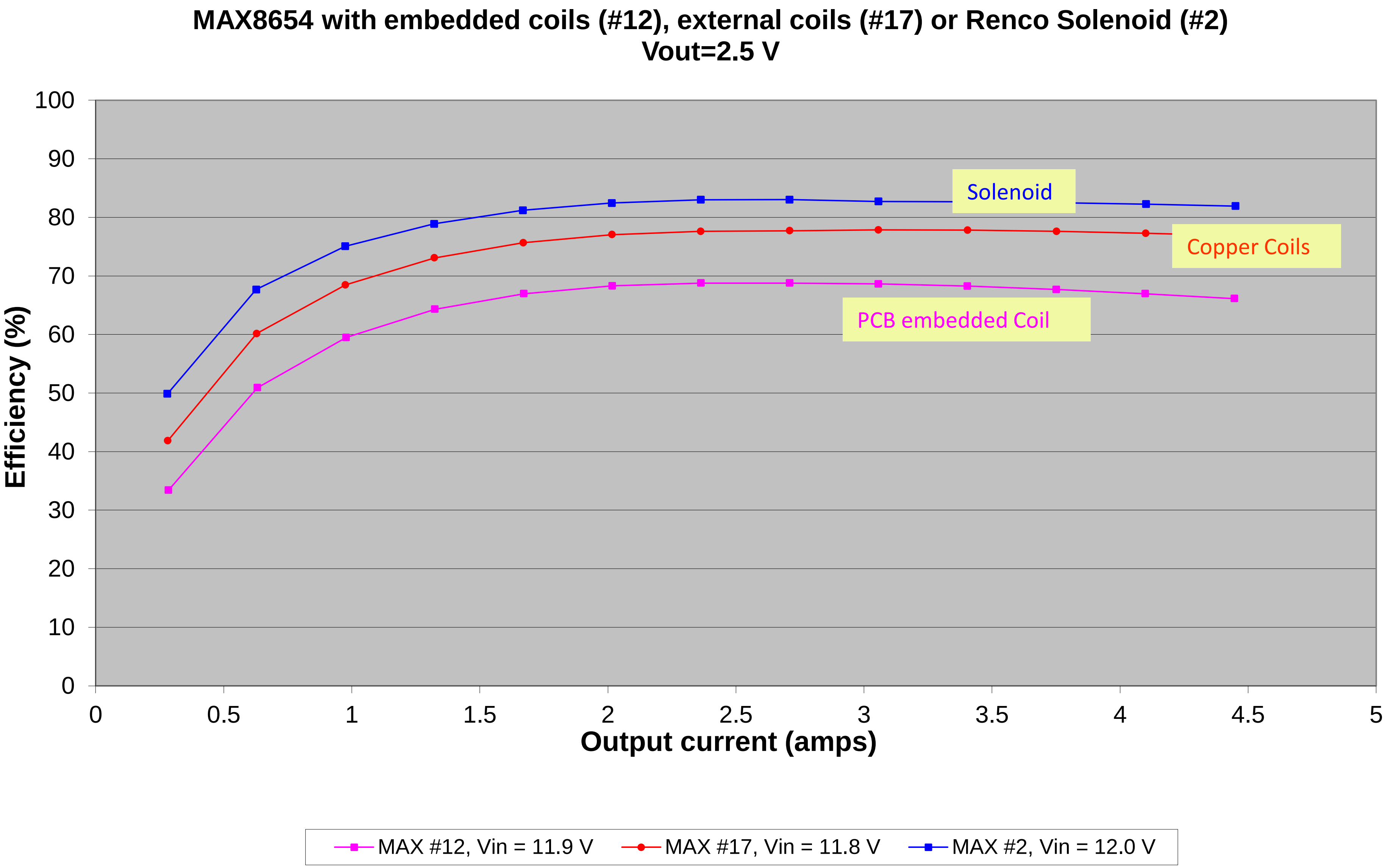
- ❖ Converter Chips
  - Max8654 monolithic
  - IR8341 3 die MCM
- ❖ Coils
  - Embedded 3oz cu
  - Solenoid 15 mΩ
  - Spiral Etched 0.25mm



Spiral Coils Resistance in mΩ

	Top	Bottom
3 Oz PCB	57	46
0.25 mm Cu Foil	19.4	17

Noise Tests Done: sLHC SiT prototype, 20 μm AL Shield



From Fermilab Talk 041310

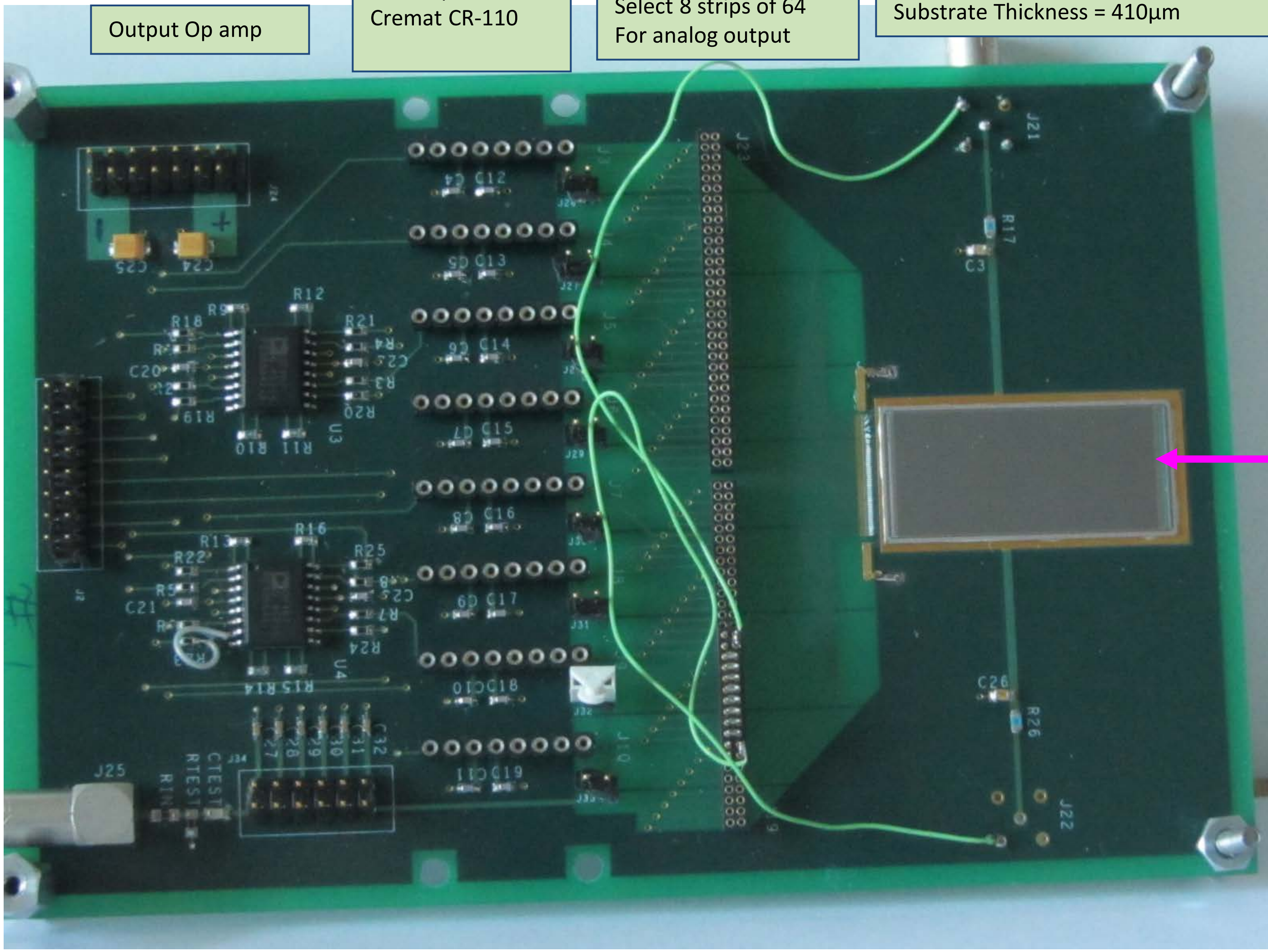
Test Silicon Strip Detector

Output Op amp

Charge Sensitive
Pre-amp
Cremat CR-110

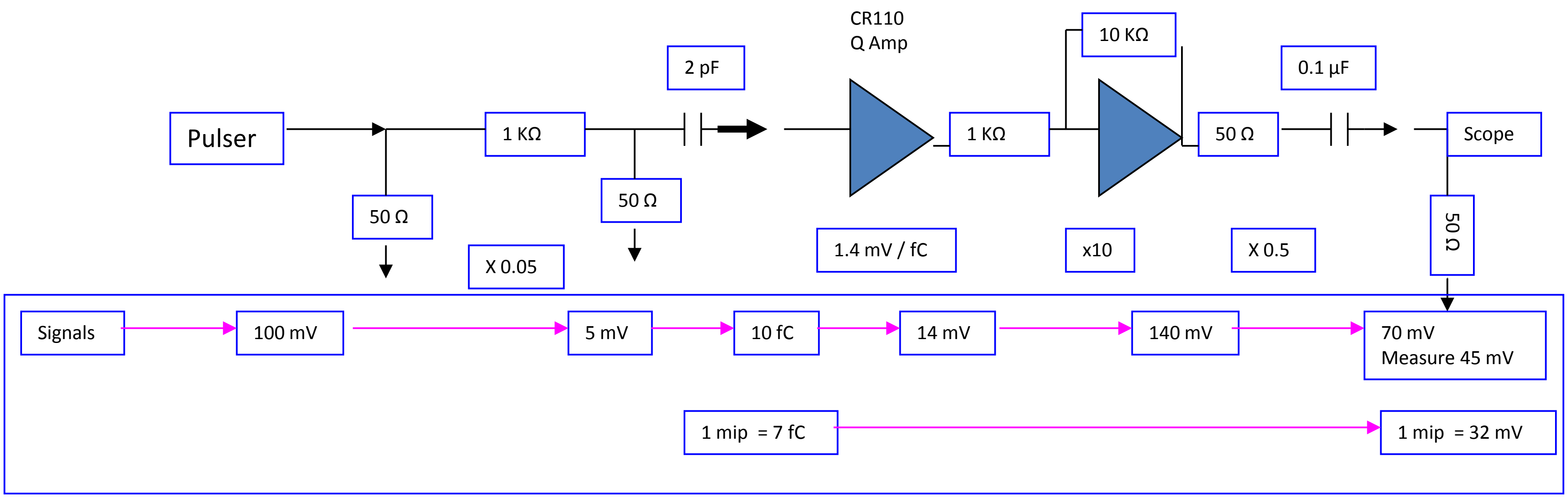
Switch Matrix
Select 8 strips of 64
For analog output

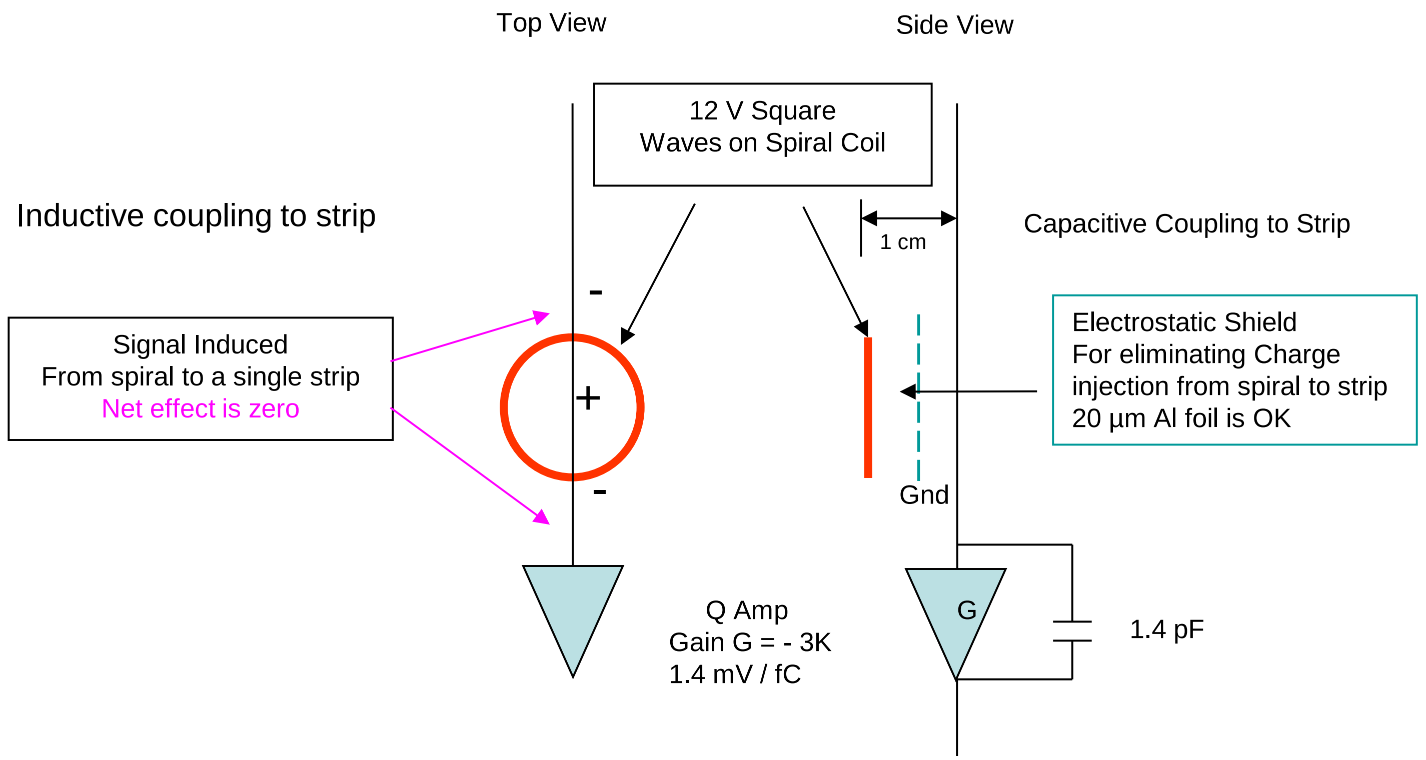
GLAST Sensor [Nucl & Instr Meth A 541 (2005) 29-39]
64 strips- 228 µm pitch
Size 15mm x 35mm
Substrate Thickness = 410µm



64 Parallel Al Strips
Length = 35 mm
Width = 56µm
Pitch = 228 µm

Signal Chain





Why do we need electrostatic Shield ?

Parallel Plate Capacitance in pF = 0.225 x A x K / Distance

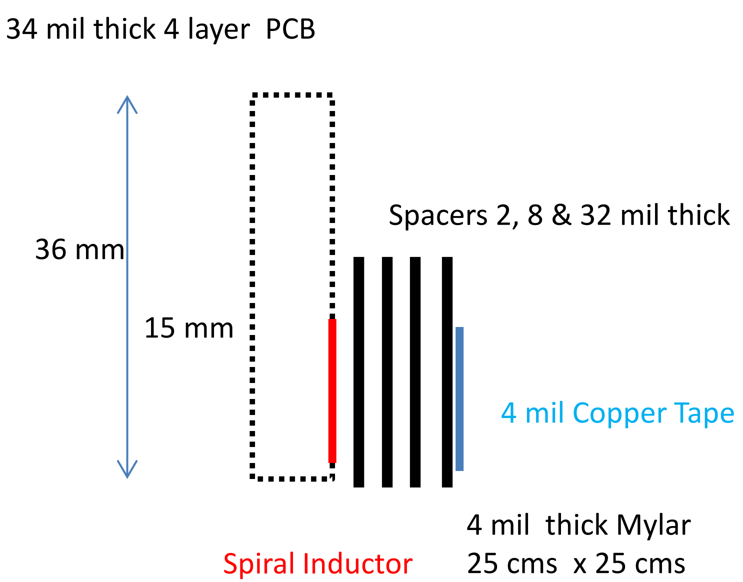
	Inches	C in femto farads
Area =	1	
Distance =	0.4	500
GLAST = .5 x 1.3	0.6	
per strip= 0.6 /48	0.0125	6.25

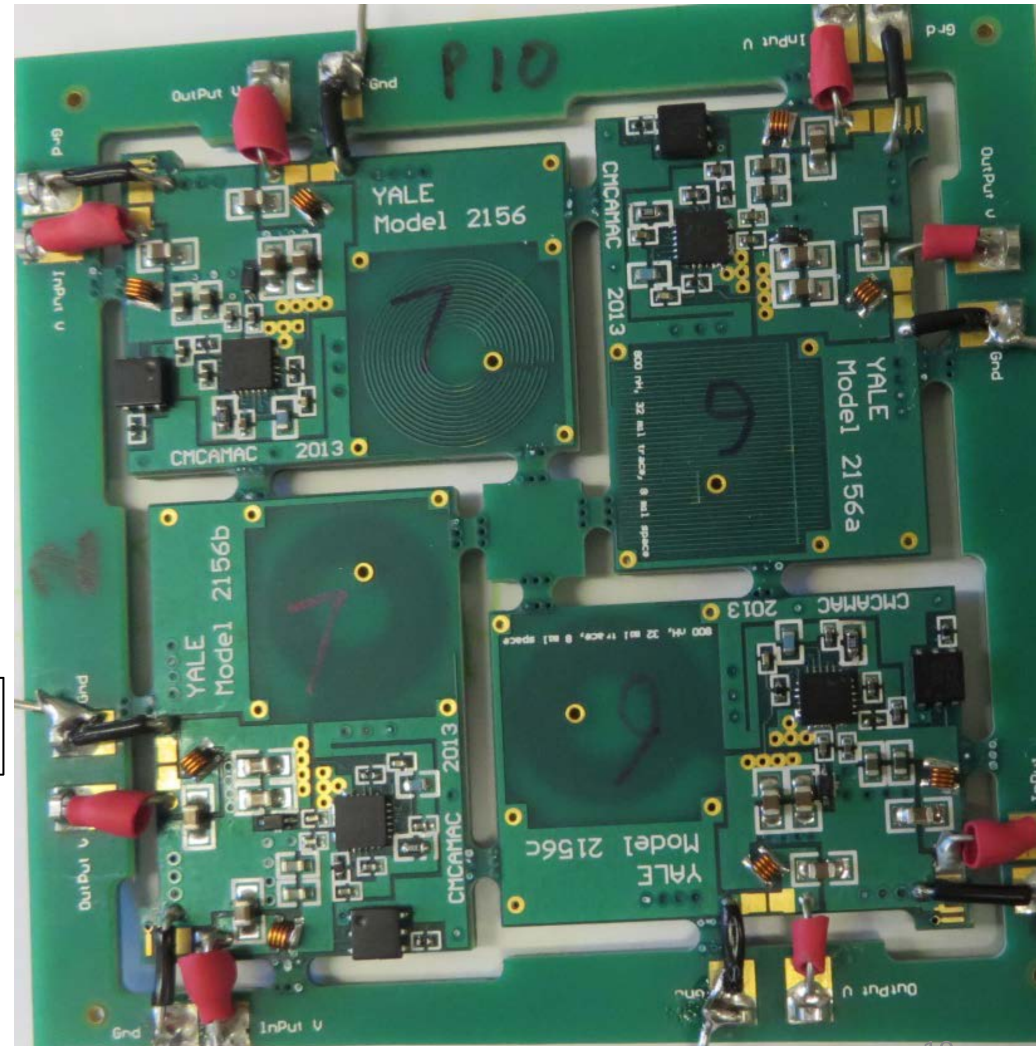
1 volt swing on spiral coil will inject Q= 6 femto Coulombs

Charge from one minimum ionizing particle (1 mip) = 7 femto Coulombs

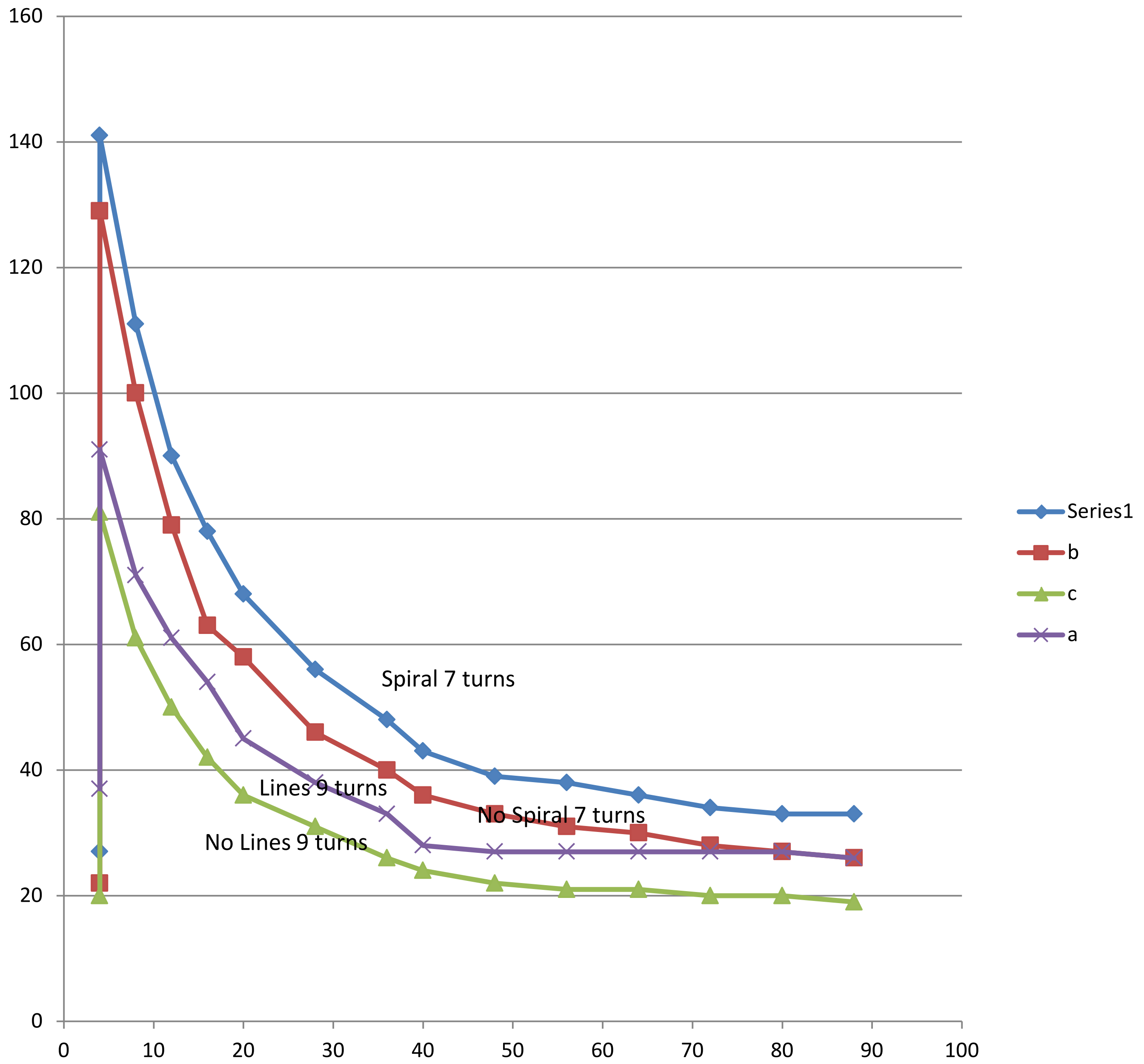
RF shielding

Measurement of RF field (by eddy current loss) vs distance



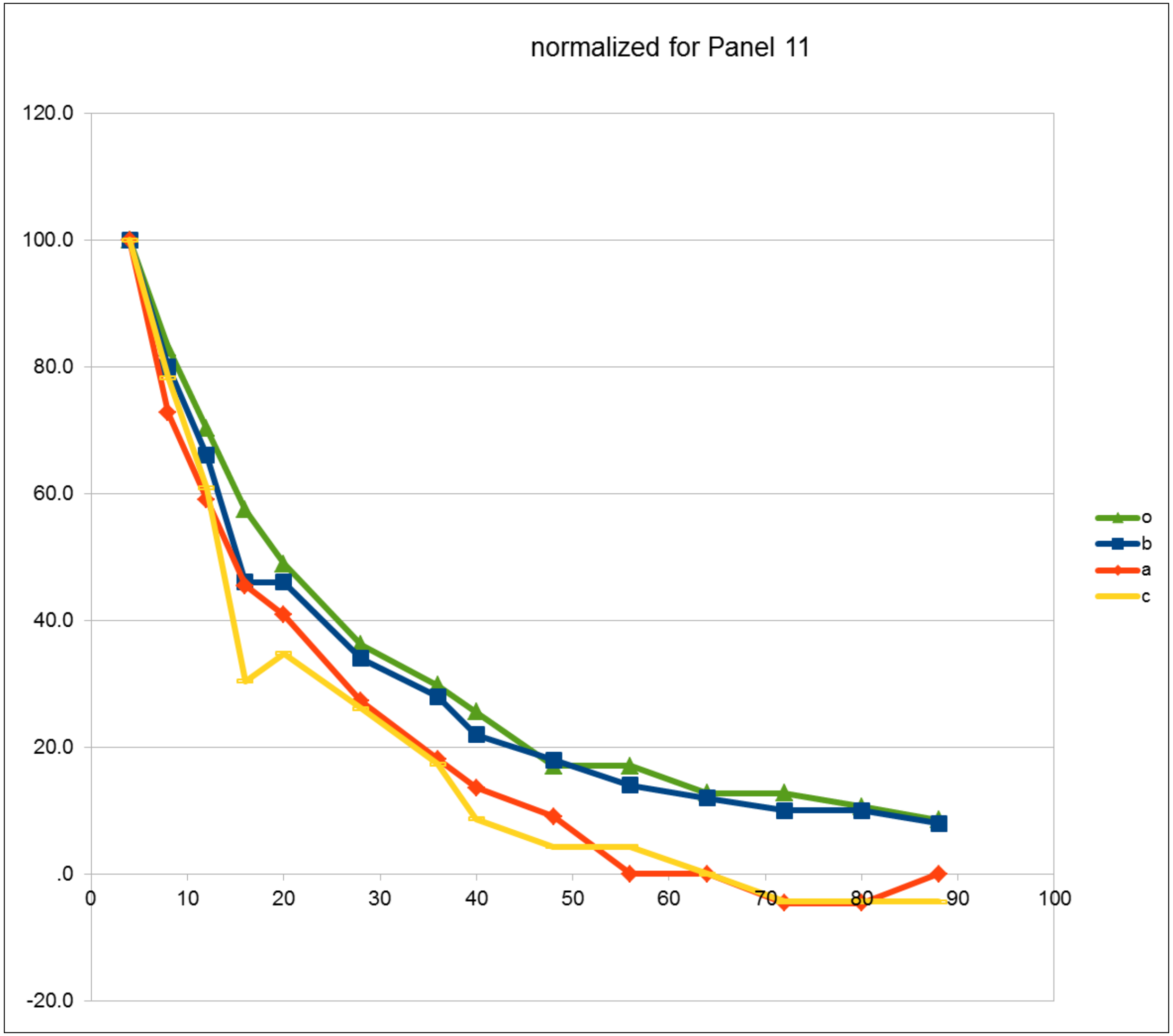


Measure IC current vs distance between spiral & copper tape
Put finger pressure between copper tape and PCB



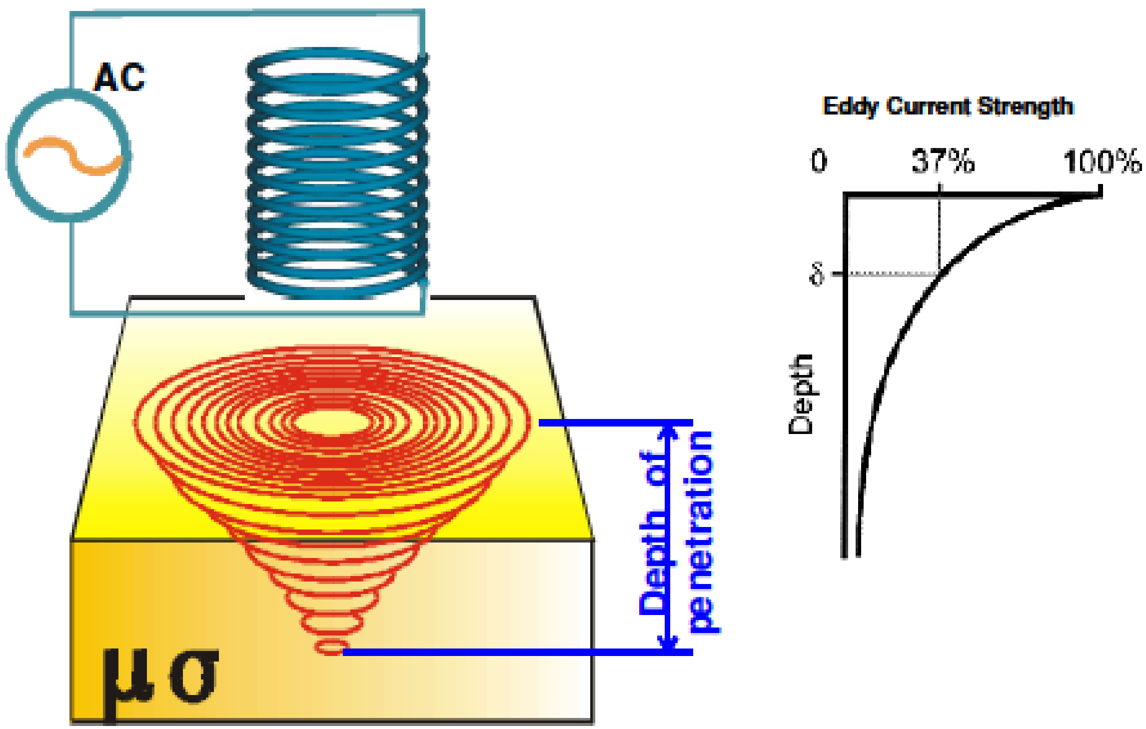
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Spiral 7 turns
Lines 9 turns
No Spiral 7 turns
No Lines 9 turns
Series1
b
c
a

Eddy Current Loss vs Distance between Spiral to Copper Tape



Current in mA   Distance in mils

Diagram 1: Eddy Current Field Depth of Penetration & Density



electrical conductive sample

Skin effect arises when the Eddy Currents flowing in the test object at any depth produce magnetic fields which oppose the primary field, thus reducing the net magnetic flux and causing a decrease in current flow as the depth increases.

Alternatively, Eddy Currents near the surface can be viewed as shielding the coil's magnetic field, thereby weakening the magnetic field at greater depths and reducing induced currents.

Eddy Current is used in the inspection of ferromagnetic and non-ferromagnetic materials. The principle of Eddy Current based inspection is explained below.

http://www-personal.engin.umd.umich.edu/~chrismi/

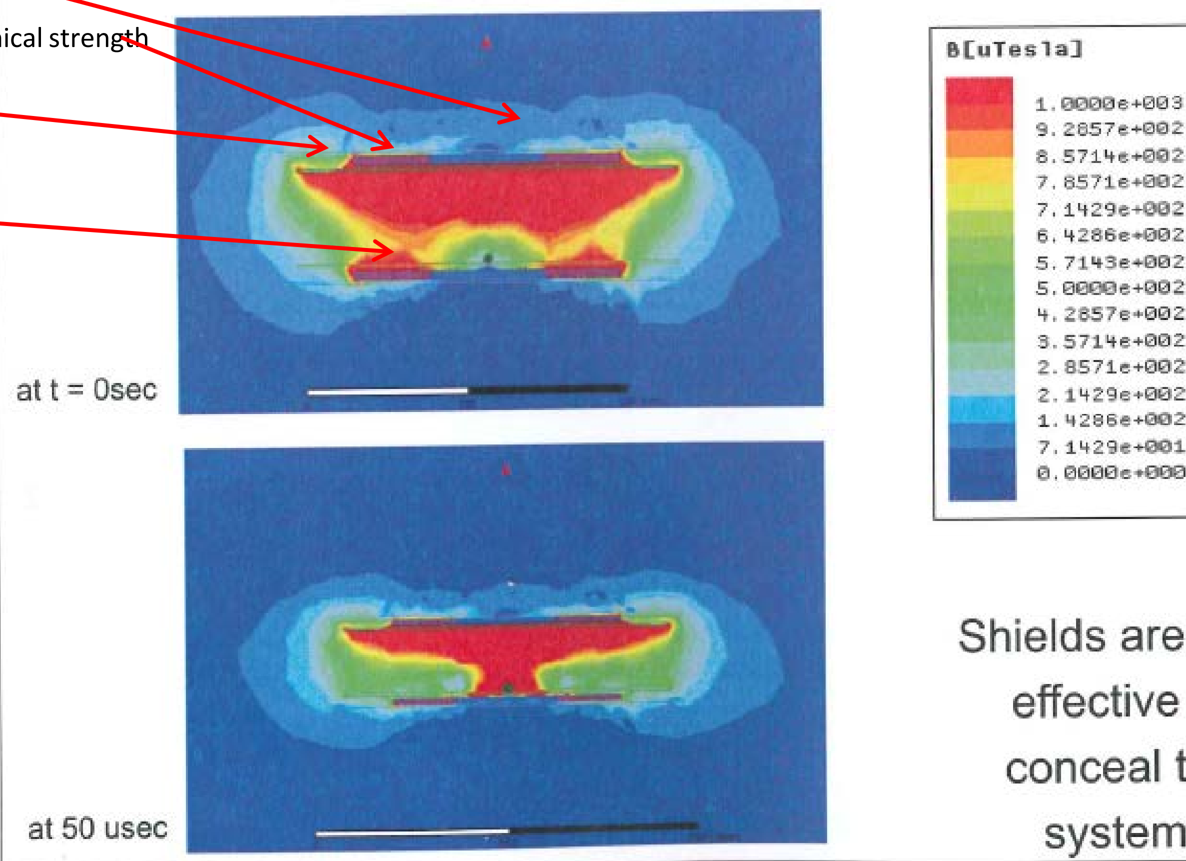
Effect of the shield in the systems

Car Metal

Al Plate 600 mm x 800mm 1 mm thick for mechanical strength

Coil - Top

Coil - Bottom



Shields are very effective to conceal the system.

Frequency = 85 KHz
Power transmitted = 10KW
Inefficiency without Al shield = 20 %
Inefficiency with Al shield = 1 %
Power loss in Car metal without Al shield = 2 KW > 15C rise in temperature
Power loss in Al shield = 0.1 KW

Wireless Power Groups

- Automobile Charging
- Cell phone Mats - 3 Groups. Each has > 50 companies involved
- Wireless Kitchen - ISM Band 6.78 MHz & multiples. GaN

Intel 4th Generation Core Processor: June 2013

- Input = 1.8V
- Maximum Current = 700 Amps
- Output ~ 1 V Multiple Domains – up to 16 Phases
- Turn output On when needed
- Inductors on Die / on Package
- Efficiency = 90%

TABLE I. COMPARISON OF FIVR TO PREVIOUSLY REPORTED INTEGRATED VOLTAGE REGULATORS

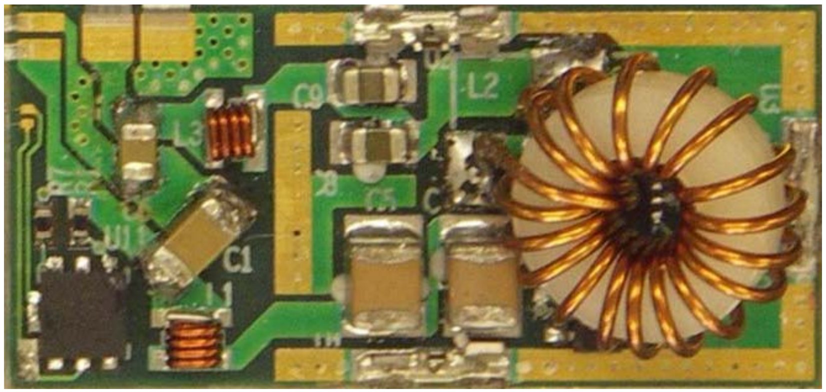
Parameter	G. Schrom et al., 2010 [2]	T. DiBene et al., 2010 [3]	N. Sturcken et al., 2012 [4]	This Work
Process node	130 nm	90 nm	45 nm	22 nm
Switching Frequency	60 MHz	100 MHz	80 MHz	140 MHz
Unity Gain Freq	5 MHz	Not Published	Not Published	80MHz
Efficiency	85-88%, 3.3V:1.0V	76%	83%, 1.5V:1.0V	90%, 1.7V:1.05V
Total Output Imax capability	50 A	Limited by first stage and thermals (Up to 400 A)	1.2 A	Limited by first stage and thermals (Up to 700 A)
Imax/VR die area	1.3 A/mm^2	8 A/mm^2	1.7 A/mm^2	31 A/mm^2
Voltage rail count	4	20	1	8 to 31
Phase count	16	320	4	49 to 360
Integration level	MCM[a]	MCM[a]	Integrated into network die	Integrated into CPU die
Inductor technology	Package trace, & magnetic discrete	Magnetic thin-film on VR die	Discrete wire-wound air core	2D array of package trace
Capacitor type	Ceramic package caps	Ceramic package caps	Die Cap	Die Cap - MIM
Cout per Max Amp	2000 nF/A	not published	15 nF/A	7 nF/A

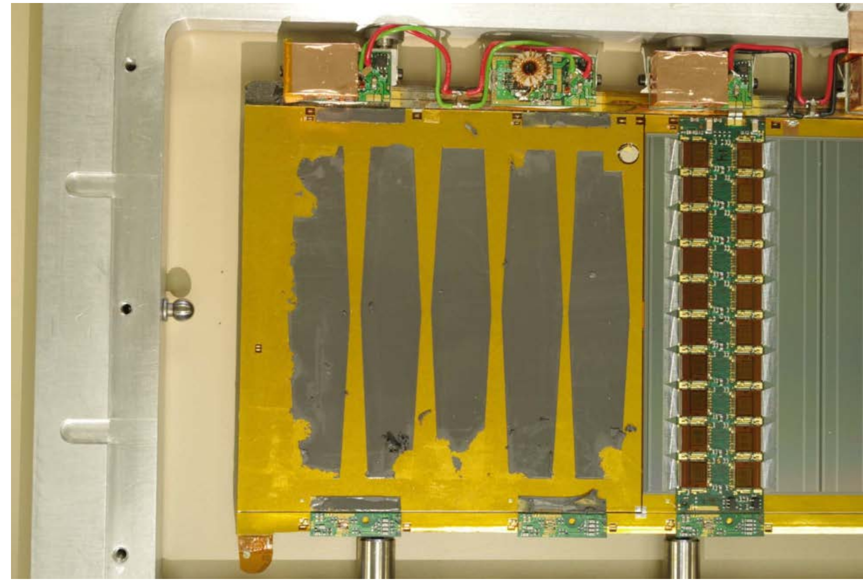
[a] MCM – Multi Chip Module – the active circuitry is on a separate die assembled on the same package

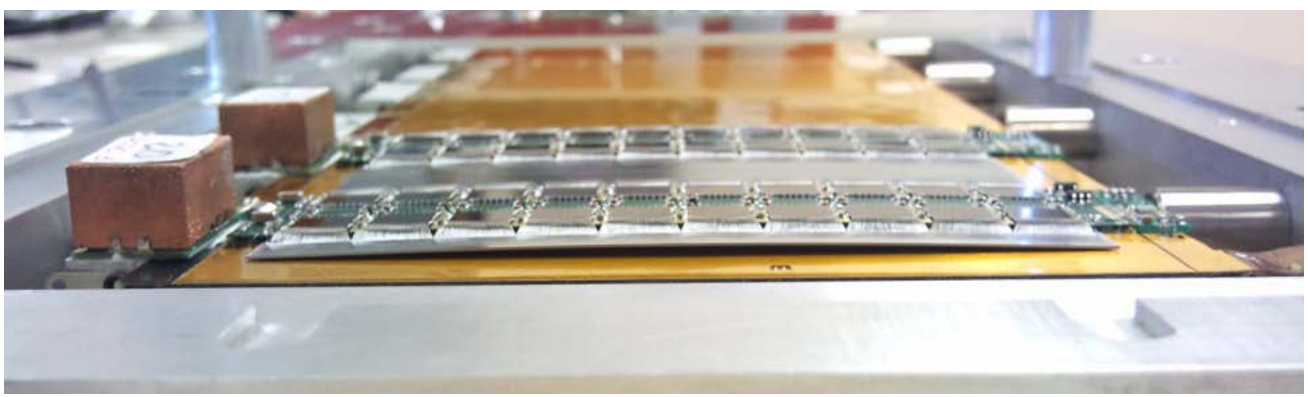
Mac Pro Air !!!

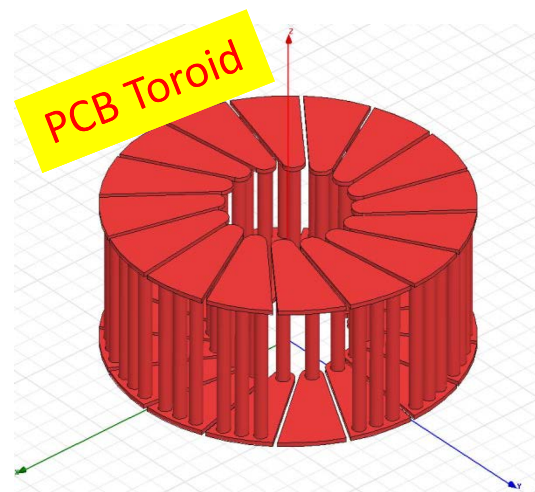
ATLAS DC-DC Powered Stave

STV10 DC-DC Convertor From CERN group
Based on commercial LT chip
10V in, 2.6V out, up to 5A









Peter W Phillips
STFC RAL

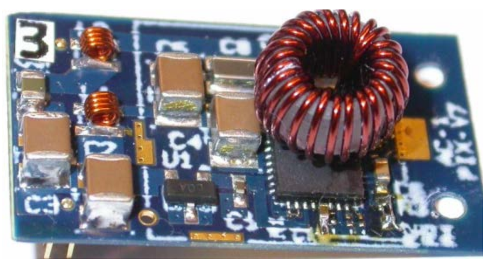
14/11/11

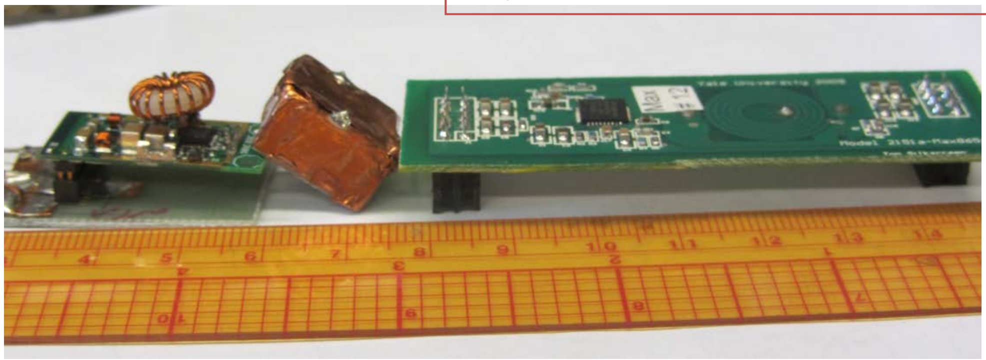
Last Proposal to DoE to develop Inductors

Another air core Toroid solution

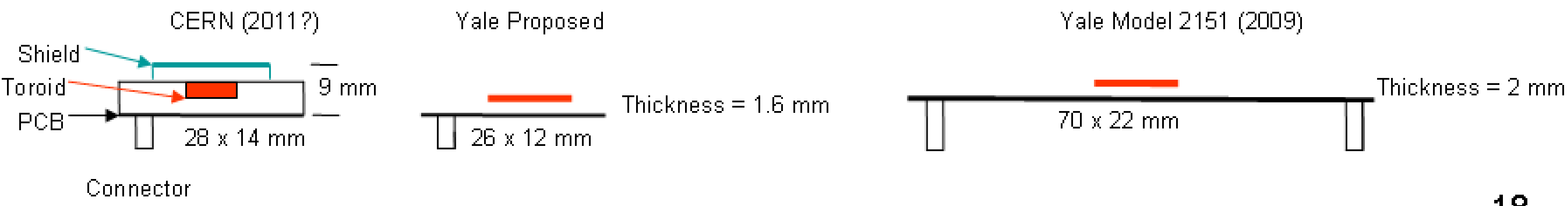
An air core Toroid solution with shield

2009 Yale Solution with Embedded air core Spiral inductors in a 4 layer Standard PCB. Not shown an electrostatic 10 µm Al foil Shield





Yale version can be made same size as the Toroid solution by changing power connectors



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Thickness excludes power connector

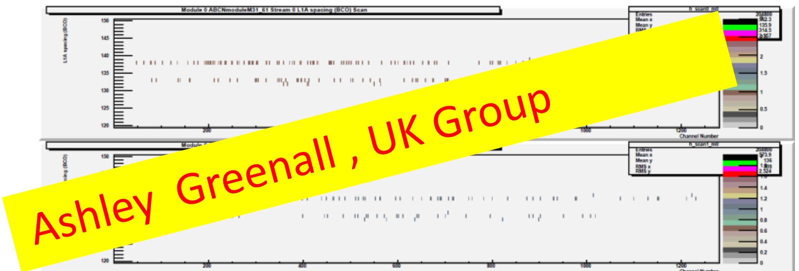
Generic / Project funding???

Planar Coil – "Up Close and Personal"

Double Trigger Noise (DTN)

With Toroid Converter

Reference measurement (CERN STV10 converter) @ 0.5fC

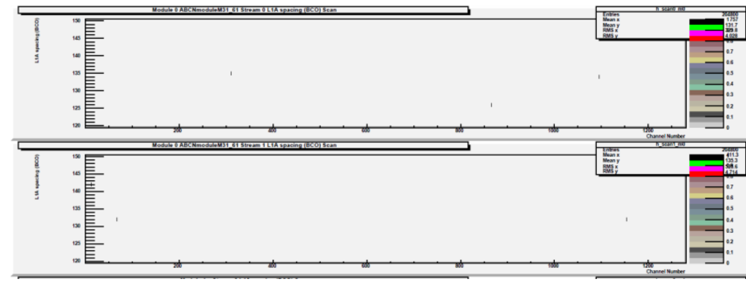


- CERN converter registers zero occupancy until 0.5fC, then registers 528/244 hits

Above picture is Double trigger noise
i.e. after a hit ; spurious counts are registered

With Planar Converter

Approx <3mm from wire bonds with improved reference @ 0.5fC



- For conducted noise configuration, Planar coil registers zero occupancy(even at 0.5fC)
- Only when close to asics are hits registered, 3/2 counts at 0.5fC, see above

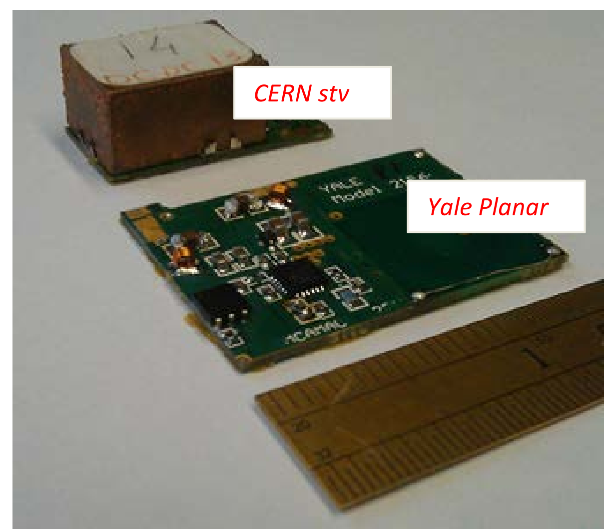
Comments inserted by Yale University

Noise in Electrons Measured @ Liverpool

cern stv10 noise 589, 604 average = 601
yale planar noise 587, 589 average = 588
noise with dc supplies (no dcdc) = 580
assuming the noise adds in quadrature, extract noise due to dcdc converter:
cern stv10 Additional noise = 157
yale planar Additional noise = 96
Planar Converter uses the same components except Inductor coil

Thickness of stv = 8 mm vs 3mm for Planar

Shield to Silicon strips are Electrostatics & Eddy current
Bottom side shield 2 mm from Planar coil traces
Can be mounted on the sensor with 50 µm Kapton
Cooling via sensor



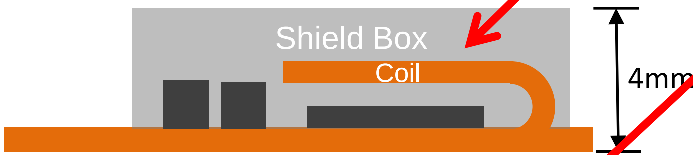
3-Feb-14	Comparison of Coils for DC-DC Converters						
3:30 PM							
Yale University							
Model		CERN AMIS5MP Data Sheet	Yale 9 mm ID proto coil	Yale 9 mm ID proto coil	Yale 9 mm ID estimated	Yale 6 mm ID Model 2156	Yale 6 mm ID Model 2156a
coil shape		oval toroid	2 layer spiral	2 layer spiral	2 layer spiral	2 layer spiral	2 layer spiral
Total number of turns		29	8	6	6	7	9
conductor		Cu wire	Cu wire	Cu wire	Cu wire	pcb trace	pcb trace
equivalent wire gauge		25	22	22	25	28	29
Coil dimensions	mm	10 x 15	14.5 OD	13 OD	12 OD	14.5 OD	15.5 OD
thickness	mm	4.00	1.80	1.80	1.20	0.50	0.50
Inductance	nH	430	836	469	469	487	811
DC Resistance	mOhms	39	18	13	26	47	83
Weight grams	Grams	0.537	0.978	0.702	0.360	0.203	0.220
Length of Wire	mm	370	336	240	240	221.000	307.000
Power Loss in Coil @ 4 Amps	Watts	0.608	0.288	0.208	0.416	0.752	1.328
normalized weight		1.00	1.82	1.31	0.67	0.38	0.41
normalized power loss		1.00	0.47	0.34	0.68	1.24	2.18
DC DC ripple current in inductor	RMS Amps	0.657	0.340	0.602	0.602	0.580	0.348

Note: the Inductor ripple current produces the AC magnetic field, which must be shielded from the sensors

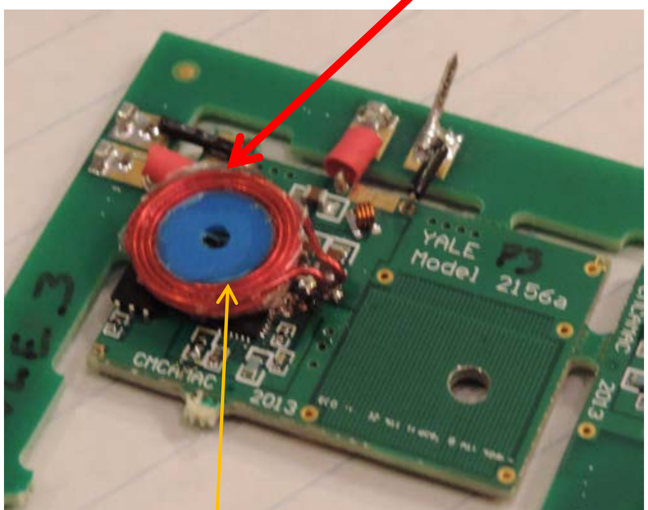
No magnetic materials

PCB size = 8 mm x 26 mm

Proposed Thinner Converter: Coil

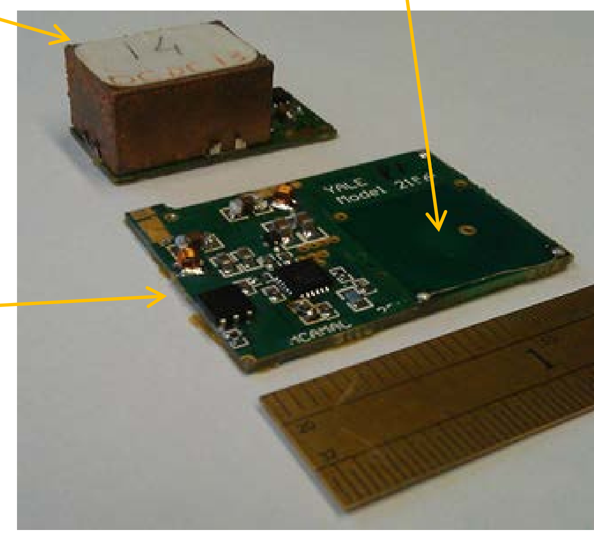


Question on Air Core Coil (change to oval shape as width is limited)
Take this coil and squeeze/ stretch it to 8 mm x 26 mm.
wire size 24 - 28 AWG Frequency 2 MHz; Later 10 MHz
L = 800 nH
Losses are limited by DCR and not ACR.
# of turns =?
ACR & DCR with wire Gauge



Toroid Inductor with Shield on toroid
height = 8 mm

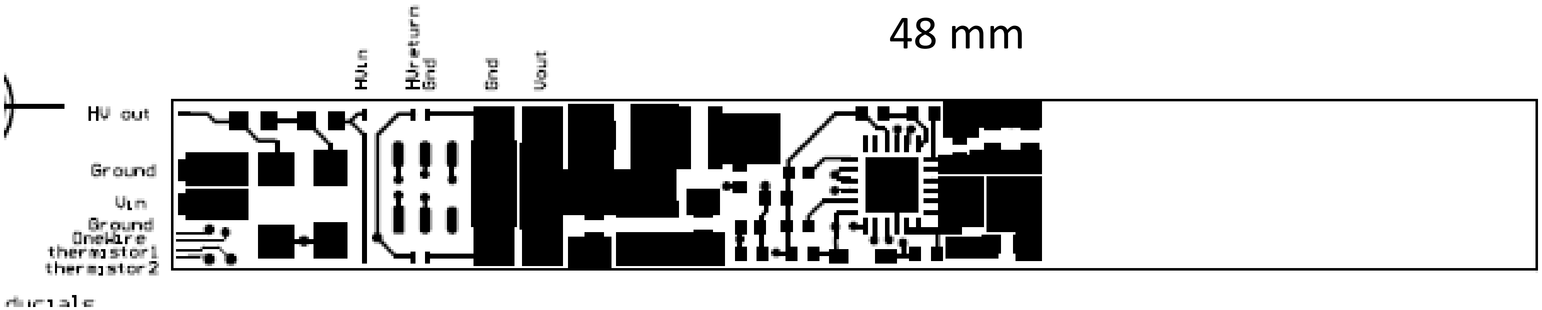
Embedded Spirals
Disabled for the hand wound coil
Height = 2 mm plus shield



Yale Model 2156a
PCB size 24mm x 36 mm
Coil size 16 mm dia. Embedded in 4 layer PCB. Inner 2 layer spirals are in series is the inductor.
2 versions: Total 6 or 9 turns
Hand wound coil (Short solenoid) is 24 AWG. Lower DCR for same inductance

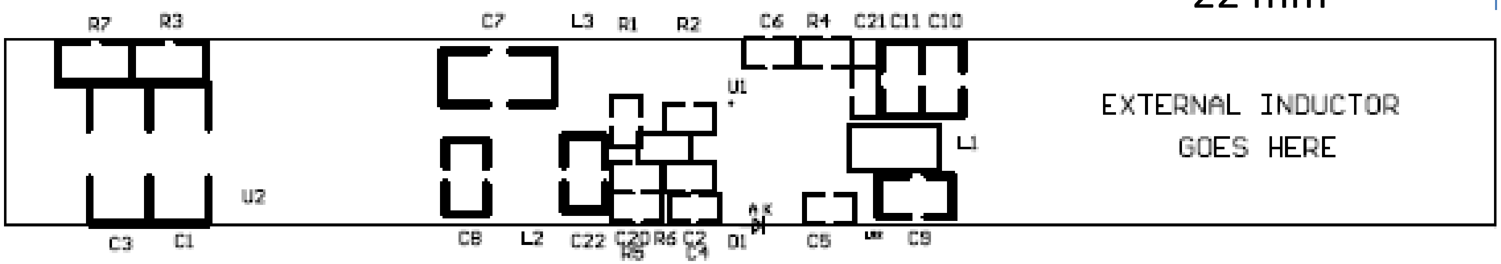
Work in Progress

48 mm



8 mm

22 mm



8 mm

Coil to fit in 8 mm x 22mm

Embed in PCB?

Winding Frame
8 mm x 22 mm
Slot in middle to hold wire

AWG 24

g-2 Ribbon 9 mils x 90 mils

5 turns. Inductance = 715 nH
DCR = <100 mΩ

Lower Inductance

- 2 turns vs 5 turns
- Higher Ripple current
- Shield distance is higher
- More lost power in shield

Simulations

s. Kalani UCL; UK Atlas Group

We want to understand the efficiency costs of the external shield for the planar coils.

For a given planar coil we would like a plot of the energy loss in the shields as a function of distance from the coil. There should be a shield on each side of the coil placed symmetrically. The inductance of the coil changes as the distance to the shields changes. Since the ripple current is inversely proportional to the inductance this must be included in the calculation.

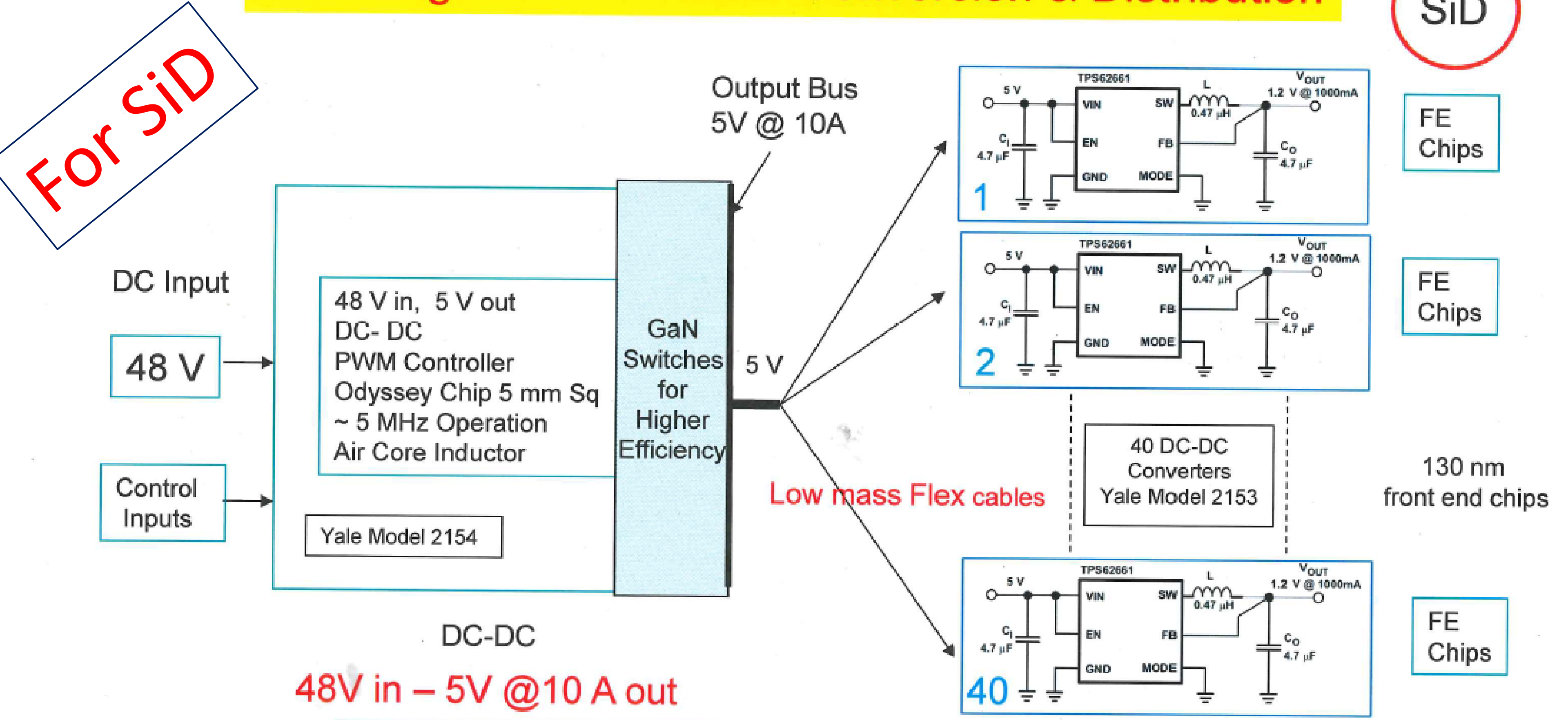
I expect that the energy loss in the shield will be linearly proportional to the ripple current but we should check this by simulating two different ripple currents for the same configuration.

For each coil configuration we would like to plots, inductance and energy loss over a range of shield distances from 0.5 mm to 10 mm with appropriate step sizes. The energy loss plot should be for 1 amp at the 10 mm spacing, with the current increasing as the inductance decreases. The frequency should be 2 MHz. Use five mill thick copper for the shields.

Start with the standard nine turn two layer coil and see how it goes. After that we will want to try other coil configurations and possibly other shield thickness and material.

Two Stage DC-DC Power Conversion & Distribution

SiD



DC-DC

48V in – 5V @10 A out

Fewer of these modules
further from the detector/sensors

DC-DC

5V in – 1.2V @1 A out

Many of these modules
close to the detector/sensors
Low mass chip scale package
small Air Core Inductor.
Test 6, 9 and 20 MHz
Converters

Status

Model 2153: Prototype for coil configurations under Test
Model 2153: Odyssey Chip Eval Board under NDA

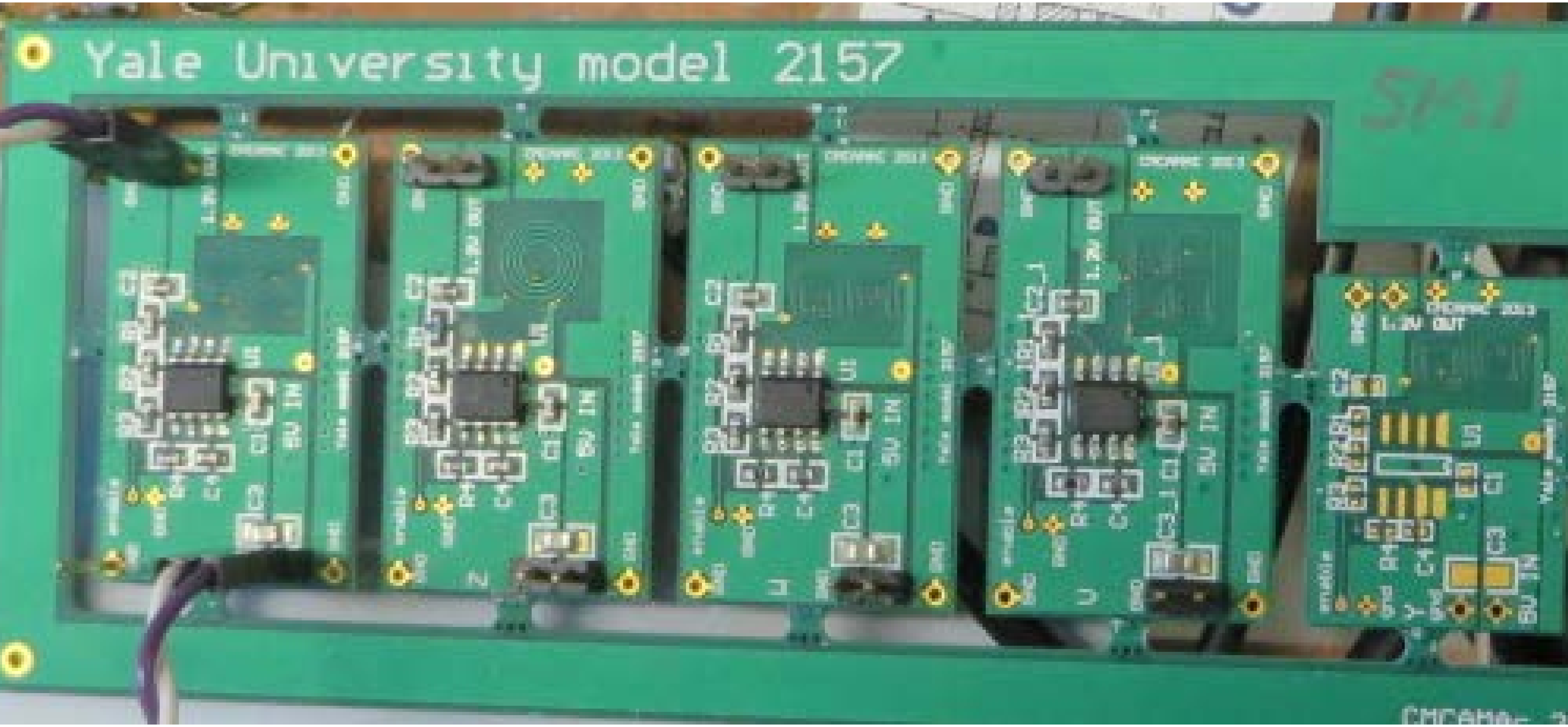
Yale University
Model 2153 & 2154

10
May 2012

High Frequency
Input = 5 V

Semtech SC220: 20 MHz 0.6 Amps:
North / South Coils for far Field cancellation
DCR becomes a problem

Enpirion EL711: 18 MHz 0.6 Amps



GaN Update

- 600 Volt is the holy grail
- EPC is the only one delivering Devices thru distribution
- LM5113: driver for eGaN
- 1Q2015: Half bridge. (2LM5113 + FETS) in 6 mmx 5mm x 1.5mm. 5 -10 MHz External PWM
- GaN driver on FET Die Several companies. Panasonic Roadmap 2016

For GaN NDA

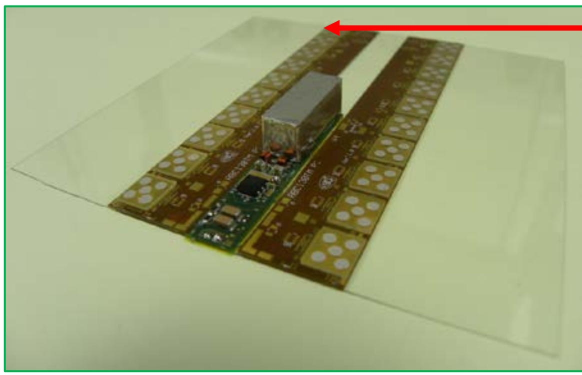
Why Yale design needs GaN

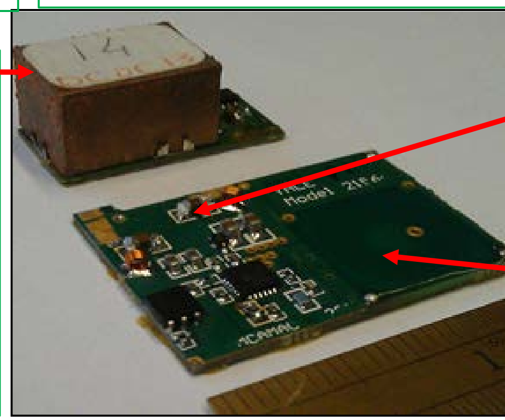
- No magnetic materials – All instruments in 4 Tesla magnetic field
- Design Goal = Size of converter 8 mm x 26 mm x 4 mm thickness including eddy current shield
- Vin = 12 V: Vout = 2.5 V / 1.5 V: I_out = 3 Amps Frequency = 2 MHz
- Toroid leak H fields: Spiral /Planar 2 layer 9 turn > Inductance = 800 nH
- Need Low DCR & Lower mass to reduce noise created by protons passing thru inactive material
- Lower ripple current limits H field range > thinner package
- Why GaN ? High frequency > smaller inductor & passives. Smaller foot print

Current Design / Status

CERN design size is ok but thickness = 9 mm

Yale design thickness is ok. Foot print Ok for circuit only but no room for inductor

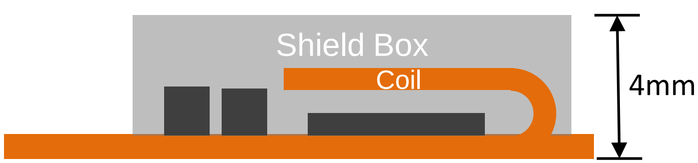




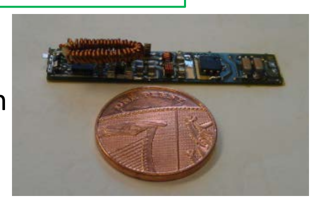
Size of PCB = 23 mm x 35 mm x 1.5 mm plus shield

Spiral inductor embedded in 4 layer PCB. Spirals are 15 mm dia.

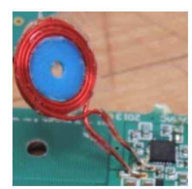
New Design



Fold Coil > Squeeze 2 layer spiral to oval shape



Oval Aircore Toroid



Short Solenoid > Low DCR

What GaN Buys us

Higher operating frequency
> smaller air core inductor & lower DCR
Higher efficiency > Lower heat loss
Smaller package *PowerSoC technology*

Yale University
April 15, 2014

Closing Remarks

- 48 V into Detector: 2 Stages
- IC 2 step: 12 V > 1.2V High efficiency
- GaN: Driver on Die may be Rad Tolerant
- Need lower power loss in detector