Tracker Powering Points

Satish Dhawan, Yale University
Richard Sumner, CMCAMAC LLC
System Testing

- DcDc Converter @ Yale. Tracker work stopped in 2009
- Thickness of Converters – Shield thickness!
- Tests @ Yale with FEAST 2 Chip mini-Module
- ATLYS readout
- Reduce mass/noise by using Fiber Carbon composite
  (it works at higher frequencies but may be marginally useful at 2 MHz)

Prospects for Future

- Lower Mass @ 5 MHZ
- Topology Change Charge pump, Buck or something else?
- GaN
US Atlas Decided in favor of Serial Power. Funding > zero
CERN Developed Toroid Inductors & FEAST Chip
UK Groups (Liverpool & RAL).
  Requested a design with the YALE Planar Inductor.
Compare using the same commercial Chip as Toroid Design
Ver. 1
- Spirals with LTC Chip
- Same Circuit as for Toroid but different PCB Layout

stackup, 2156, 2156a, 2156b, 2156c
thick, 487, 792, 486, 811 nanohenries
thin, 481, 796, 492, 816

2156 and 2156b 7 turns, b has spiral shield 2156a and 2156c 9
turns, c has straight lines shield
Inductance lower with Shield

Satish Dhawan
Yale University
May 18, 2013
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

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

US ATLAS Moved towards Dc-Dc.

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
2 MHz 10 Volts

Dc_Dc Converter

Parasitic Capacitance

EM
Bonding Wires act as the Secondary of the Transformer

Noise Couplings

Thin Al Foil

Si Strips – Q amps

Readout + DAQ

Bonding Wire Loops

Why do we need electrostatic shield?
Parallel Plate Capacitance in pF = 0.225 x A x K / Distance

<table>
<thead>
<tr>
<th>Area</th>
<th>Distance</th>
<th>GLAST</th>
<th>per strip</th>
<th>C in femto farads</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
<td>0.6</td>
<td>0.6 / 48</td>
<td>500</td>
</tr>
</tbody>
</table>

1 volt swing on spiral coil will inject Q = 6 femto Coulombs
Charge from one minimum ionizing particle (1 mip) = 7 femto Coulombs
Each Converter PCB 10 mm x 63 mm. Different Coil Configuration
Channel D: Embedded Coil with 2 via: 687 nH, 83 mΩ
Channel C: Embedded Coil with 1 via: 703 nH, 83 mΩ
Channel B: External Coil: Wurth 540 nH* with short Leads
Channel A: External Coil: Wurth 540 nH* with short Leads
* With BK Precision LCR Meter
Toroid VS Planar Coil

Lower Mutual Coupling if turns are further apart but adds to DC Resistance

Toroid Inductor with Shield on toroid height = 8 mm

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

Wurth Coil 5 mm x 8 mm
9 turns (3 layers with 3 turs)
750 nH
July 2015

Coils squeezed in one direction for Mechanical
## Comparison of toroidal inductor and planar inductor

<table>
<thead>
<tr>
<th></th>
<th>toroid coil</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>toroid radius</td>
<td>coil radius</td>
<td>turns</td>
<td>wire length</td>
<td>R</td>
<td>wire dia</td>
<td>volume</td>
<td>mass</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td></td>
<td>mm</td>
<td>mOhms</td>
<td>mm</td>
<td>cubic mm</td>
<td>grams</td>
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<tr>
<td>toroid coil</td>
<td>4.5</td>
<td>1.7</td>
<td>32</td>
<td>413</td>
<td>342</td>
<td>32.5</td>
<td>0.48</td>
<td>129</td>
</tr>
<tr>
<td>planar coil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>coil length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>same L, same Ohms</td>
<td>1.0</td>
<td>5.4</td>
<td>6</td>
<td>415</td>
<td>203</td>
<td>34.4</td>
<td>0.36</td>
<td>58</td>
</tr>
<tr>
<td>Same L, same mass of Copper</td>
<td>1.0</td>
<td>5.4</td>
<td>6</td>
<td>415</td>
<td>203</td>
<td>8.5</td>
<td>0.72</td>
<td>115</td>
</tr>
<tr>
<td>same mass, same Ohms</td>
<td>1.0</td>
<td>5.5</td>
<td>9</td>
<td>967</td>
<td>311</td>
<td>33.0</td>
<td>0.46</td>
<td>111</td>
</tr>
</tbody>
</table>
Ver 3  Squeezed Oval shape for 130 nm Stave design

Yale RLS 1
Using Bigger components for hand soldering

Wurth Elektronik
Custom Wound
3 turns x 3 layers = 9 turns
Produced > 100 pieces
Inductor / coil
740 nH / 38.5 mΩ

ABC130 Pwr Bd Plus MUX Liverpool
Using smallest components
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.

- **Shield Thiness** \( \approx \) Conductivity of Shield
- **Power Loss** \( \approx \) Resistivity of Shield Material
Eddy Current Shield Measurements

Idc Change ≈ Eddy Losses

The Shields

Far Side Shield H3H: Half Oz/ 3 mil thick/ Half Oz

4 Types of Near Side Shield
1. Half Oz/ 3 mil thick/ Half Oz
2. One Oz/ 3 mil thick/ One Oz
3. One Oz/ 5 mil Thick/ Zero Oz
4. One Oz/ 10μm/ One Oz
PGS (Pyrolytic Highly Oriented Graphite Sheet) is made of graphite with a structure that is close to a single crystal, which is achieved by the heat decomposition of polymeric film. PGS is a competitive conductive sheet with high thermal conductivity.

Intrigued by this Chart
Attenuates High Frequencies
Air

9 µm cu

Vertical scale is different

Oxford Carbon

P4 Fermilab

P7 PGS

RLS1 converter

Wurth Coil

Sample Material/ Attenuator

Beehive H Field Probe 100A 0.4 inch Dia.
To TDS 3014B Scope

H Field Attenuation with Gap Material
Resistance vs Frequency
HP 4191A Impedance Analyzer 1-1000 MHz

![Graph showing resistance vs frequency with different materials and frequencies.]

- Air Ohms
- Carbon strip Ohms
- P4
- P7
- P14
- H/3/H

Coil Under Test
With SMA connector
Real part of Z vs frequency

Inductance vs Frequency

Yale Hand Held BK Precision LCR Meter Shows no effect
Maximum Frequency 100 KHz
Measure DC Current drawn by Feast2 chip vs Shield material and distance/gap from top of coil

<table>
<thead>
<tr>
<th>Wurth Coil Shield</th>
<th>Current (mA)</th>
<th>Spacers</th>
<th>FR4 Spacers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Black Mylar = 6 mils each &gt; total = ~30 mils</td>
<td>32 mils</td>
</tr>
<tr>
<td>Air</td>
<td>30.650</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon strip</td>
<td>37.010</td>
<td>35.72</td>
<td>34.75</td>
</tr>
<tr>
<td>P4: Fermilab</td>
<td>37.160</td>
<td>36.08</td>
<td>35.11</td>
</tr>
<tr>
<td>P7: Pyrolytic</td>
<td>37.810</td>
<td>36.25</td>
<td>34.46</td>
</tr>
<tr>
<td>P14: 9 µm Cu</td>
<td>37.860</td>
<td>34.12</td>
<td>33</td>
</tr>
<tr>
<td>H/5/H</td>
<td>33.440</td>
<td>32.62</td>
<td>32.26</td>
</tr>
</tbody>
</table>

**DC-DC input current (no load)**

- **Air**
- **Carbon strip**
- **P4: Fermilab**
- **P7: Pyrolytic**
- **P14: 9 µm Cu**
- **H/5/H**
Coil on Top may induce noise into FEAST Chip via the wire bonds & PCB Traces.

130nm Mini Module

Wire bonds: secondary of transformer for H field

Liverpool Power Board with Shield down

x-ray of Feast2 Chip

Coil on Top may induce noise into FEAST Chip via the wire bonds & PCB Traces

Yale RLS1 Power Bd. with Shield down

Atlys Board + Interface
Seek Ashley & Peter’s Help

RLS1 with P4(grounded) with 9 µm Cu Foil added & grounded

Yale Run 62 Test Results – August 07, 2015

RLS1 with P4 (grounded)

Yale Run 61 Test Results – August 07, 2015
• With shielding we replicate noise numbers as quoted by Ashley
• Slope should be the other way around
• Understand pickup sensitivity of the sensors

Further Work
Investigate / Goals
Shield with Carbon+Copper
(Carbon closer to Inductor)
Acknowledgements

Adrian Au
Savannah Thais

DR. Eric Paulson
Prof. Keith Baker
Prof. Steven Lamoreaux
THE END
Questions Please?

Back up Slides
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

Yale University
March 21, 2014