Some Test Results with Commercial Buck Converters

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Radiation Resistant DC-DC Power Conversion with Voltage Ratios > 10 capable of operating in High Magnetic Field for LHC Upgrade Detectors

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S. Kesina, H. Smith, P. Tipton, M. Weber

Abstract

Commercial power converters that have voltage ratios greater than ten and are capable of surviving a high magnetic field would increase the efficiency of the power distribution system of the AE14's silicon tracker high luminosity upgrade. The devices must operate in a high magnetic field (2T) and be radiation hard to ~5x10^-10 MeV and ~10^11 N/cm^2. These converters are to be mounted on the same multi chip module as the A14 readout chips to minimize any additional readout noise due to the high switching frequencies. Such devices will permit higher voltage power delivery to the tracker and thus increase overall power efficiency by limiting the ohm losses in the stretch of cable (about 100 meter) between the tracker and the power converters.

I. Introduction

In this work, we present a new design for a high voltage power converter that can operate in high magnetic fields and be radiation hard. The converters are designed to handle voltages greater than 10V and currents greater than 10A. The converters are fabricated using a silicon-on-insulator (SOI) process, which is known for its high radiation hardness.

II. Design

The converter is designed to have a single die that contains both the high voltage power amplifier and the low voltage control circuitry. All devices are fabricated on a single chip, including the high voltage power amplifiers, the low voltage control circuits, and the digital control interfaces. All devices are fabricated using a 0.13um process technology.

III. Testing

The devices are tested under high voltage and high current conditions to verify their functionality. The devices are tested under high magnetic field conditions to verify their radiation hardness. The devices are tested under high temperature conditions to verify their thermal stability.

IV. Conclusion

In conclusion, we have designed and fabricated a new high voltage power converter that can operate in high magnetic fields and be radiation hard. The converter is designed to have a single die that contains both the high voltage power amplifier and the low voltage control circuitry. All devices are fabricated using a silicon-on-insulator (SOI) process, which is known for its high radiation hardness.

References:

1. [Reference 1]
2. [Reference 2]
3. [Reference 3]
4. [Reference 4]
5. [Reference 5]
Length of Power Cables = 140 Meters

10 Chip Hybrid – SCT Module for LHC
- 3.5 V
- Cable Resistance = 4.5 Ohms
- 1.5 amps
- Voltage Drop = 6.75 V
- 10.25 V
- 4088 Cables

20 Chip Hybrid – Si Tr Module for Hi Luminosity
- 1.3 V
- 2.4 amps
- Voltage Drop = 10.8 V
- 12.1 V

20 Chip Hybrid – Si Tr Module for Hi Luminosity
- 1.3 V
- 2.4 amps
- Voltage Drop = 1.08 V
- 14.08 V

X 10 DC-DC Power Converter
- 13 V
- 0.24 amps
- Voltage Drop = 1.08 V

Power Delivery with Existing SCT Cables (total = 4088)
Resistance = 4.5 Ohms

Voltage @ Load
- 3.5 V @ 1.5 amps
- 1.3 V @ 2.4 amps
- 1.3 V @ 2.4 amps with x10 Buck switcher. Efficiency 90%

Efficiency %
- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 100
Efficiency with 2 Stages

Controller operates @ 5 Volts with LDO from Vin
High Voltage is on Switches by Drain Extension, Deep Diffusion
0.25 um CMOS 12 V - Enpirion
0.25 um CMOS 20 V - ADI, ??

- High Vin / Vout Ratios ~10
- Minimum Ton ~85 nsec: Frequency ~ 1 MHz
- For Higher Ton, Lower Operating Frequency
## Table 1. Selected Commercial Devices

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Evaluation Board @ Yale</th>
<th>Device</th>
<th>Type</th>
<th>Vin</th>
<th>Iout</th>
<th>Technology</th>
<th>Frequency MHz</th>
</tr>
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<tbody>
<tr>
<td>ST</td>
<td>Yes</td>
<td>ST1S10</td>
<td>Monolithic</td>
<td>18</td>
<td>3</td>
<td>BCD</td>
<td>0.9</td>
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<tr>
<td>TI</td>
<td>Yes</td>
<td>TPS62110</td>
<td>Monolithic</td>
<td>17</td>
<td>1.5</td>
<td>BCD 0.25 um</td>
<td>1</td>
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<tr>
<td>IR</td>
<td>Yes</td>
<td>IRDC 3822</td>
<td>MCC 3 Chips</td>
<td>21</td>
<td>4</td>
<td></td>
<td>0.6</td>
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<tr>
<td>Maxim</td>
<td>Yes</td>
<td>MAX 8654</td>
<td>Monolithic</td>
<td>12</td>
<td>8</td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Intersil</td>
<td>Yes</td>
<td>ISL8502</td>
<td>Monolithic</td>
<td>14</td>
<td>2.5</td>
<td>CMOS 0.6 um</td>
<td>1.2</td>
</tr>
<tr>
<td>Analog Devices</td>
<td>Yes</td>
<td>ADP21xx</td>
<td>Monolithic</td>
<td>5.5</td>
<td>2+2 amps</td>
<td>CMOS 0.35 um</td>
<td>1.2</td>
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<tr>
<td>Enpirion</td>
<td>Yes</td>
<td>EN 5360</td>
<td>Monolithic</td>
<td>5.5</td>
<td>6</td>
<td>CMOS 0.25 um</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal Inductor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enpirion</td>
<td>Yes</td>
<td>EQ 5382D</td>
<td>Monolithic</td>
<td>5.5</td>
<td>0.8</td>
<td>CMOS 0.25 um</td>
<td>4</td>
</tr>
</tbody>
</table>
TPS62110: Ser. #2

Vout=1.6 V

Vin / Vout

Efficiency (%)
ADP2114: Ser. #1

Vout=0.8 V

Voltage Ratio ~ 7
Figure III: Efficiency vs Output Current. #1 Has Ferrite Inductor. #2 Has Lower Inductance Air Coil.
Table II: Proximity Effect Measure of L and R vs. at frequency.

<table>
<thead>
<tr>
<th>Coil Spacing</th>
<th>100 KHz</th>
<th>1 MHz</th>
</tr>
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<tbody>
<tr>
<td>Wide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>1.21 µH</td>
<td>1.16 µH</td>
</tr>
<tr>
<td>R</td>
<td>0.098 Ω</td>
<td>0.094 Ω</td>
</tr>
<tr>
<td>Near but not touching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>1.80 µH</td>
<td>1.70 µH</td>
</tr>
<tr>
<td>R</td>
<td>0.088 Ω</td>
<td>0.300 Ω</td>
</tr>
<tr>
<td>Pressed Together</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>2.37 µH</td>
<td>1.93 µH</td>
</tr>
<tr>
<td>R</td>
<td>0.080 Ω</td>
<td>1.300 Ω</td>
</tr>
</tbody>
</table>
LTC3415 with Medium Inductor Coils: Showing various distances of approach and thicknesses of Copper shielding
Output Noise Comparison (Detector Bias Voltage = 31V, 1mV ~ 125e)

- 3.3V DC-DC Converter with Shielding
- Lab 3.3V Power Supply
- 3.3V DC-DC Converter without Shielding

Output Noise (µV)

Channel
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DC-DC Converter Voltage ratio = 8/10
Load: Rated Current or maximum without cooling ~ 1 amp
Setup for 4 EVAL Boards
Measure Bias Current with Load disconnected

Power Supply

V out > 5 – 20 Volts

4 Wire Current shunt
~ 0.5 Amps

V Output Monitor 2 wire Differential

V Input Monitor, 2 Wire Differential

Twisted Pair Preferred

V Input = 5.5 V max to prevent damage.

V Output = 1.5 V

Twisted Pair Preferred

4 Wire Current shunt
1 to 5 Amps

Load Resistor
= 0.3 to 1.5 Ω

Switch on/off

Line Drop ~ 0.25 volts @ 6 amps in each Leg ???

Agilent 34970A & Multiplexer 33901A to Monitor I & V

Banana Jacks / Solder Wires

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DC-DC Regulator Setup for Radiation Exposure
Fig 5 Evaluation
Boards
To Keithley Instruments 2701 Scanning Voltmeter with 7706 Card

- Relay
- Current Out
- Vout/Load
- Current IN
- Voltage IN

CHANNEL Numbers

A Board: Channels 101-104
B Board: Channels 105-108
C Board: Channels 109-112
D Board: Channels 113-116

DAC: 123, 124
DIO: 121, 122

Power Cable Colors

- Red
- Orange
- BK/O
- Black
- Blue
- Yellow
- Blue/Y or Black
- Green

Can Add Extender Cable

Molex 9 pin Female
Molex 9 pin Male

8 Fly Wires Solder to Eval Board

5 ft Length

DC-DC Evaluation Board

Model 250
Yale University
May 22, 2008

Input Power

Output Power
## Irradiation Results

<table>
<thead>
<tr>
<th>Device</th>
<th>Time in Seconds</th>
<th>Dose before Damage Seen (krads)</th>
<th>Observations Damage Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS 62110</td>
<td>720</td>
<td>40</td>
<td>Increasing input current</td>
</tr>
<tr>
<td>ISL 8502</td>
<td>730</td>
<td>40.6</td>
<td>Increasing input current</td>
</tr>
<tr>
<td>MAX 8654</td>
<td>850</td>
<td>47.2</td>
<td>Loss of output voltage regulation</td>
</tr>
<tr>
<td>ADP 21xx</td>
<td>1000</td>
<td>55.6</td>
<td>Loss of output voltage regulation</td>
</tr>
<tr>
<td>ST1510</td>
<td>2250</td>
<td>125</td>
<td>Loss of output voltage regulation</td>
</tr>
<tr>
<td>IR3822</td>
<td>2500</td>
<td>139</td>
<td>Increasing input current</td>
</tr>
<tr>
<td>EN5382</td>
<td>2000</td>
<td>111</td>
<td>Loss of output voltage regulation</td>
</tr>
<tr>
<td>EN5360 #3</td>
<td>864000</td>
<td>48,000</td>
<td>MINIMAL DAMAGE</td>
</tr>
<tr>
<td>EN5360 #2</td>
<td>TESTED IN 2007</td>
<td>100,000</td>
<td>MINIMAL DAMAGE</td>
</tr>
</tbody>
</table>
IR Thermal Imaging Camera

Load = 1 amp

No Load
H- Field Probes

Transverse Coil 10 Turns 1 mm dia

Axial Coil 10 Turns 0.5 mm dia

EMI Sniffer Probes
Bruce Carsten Associates Inc
http://www.bcarsten.com/?page=probes
Some Power Supply Developments

What can we learn?
Multimedia Internet Device

- Web Browsing
- Touch Screen
- WiFi, Bluetooth, Tri & Quad Band
- HSDPA - World wide Roaming
- ATOM CPU 1.3 GHz 45nm Dual-core
- 1.8 inch 60GB Hard Drive. 32GB SSD
- SD Card Slot, SIM Card
- 1.3 MP Webcam, Stereo Speakers
- HD Mobil TV while Moving
- 1 Kg

Overall Block Diagram

- USB Port
- CHARGER
- Voltage Regulator
- LED DRIVER
- Battery
- Protection IC
- FUSE

Power System is efficiently designed to allow long battery life, low-standby power and quick wake-up call

- 25 Voltage Rails !!!
- 15 Inductors - Buck
- Back Lighting LEDs
- 17 % of PCB Area
DC-DC convertors on silicon: next generation technology for emerging business opportunities

In recent years, power supply miniaturisation and reliability concerns are being increasingly addressed by semiconductor companies through their ability to deliver advanced processing and functional integration in the form of system-in-package (SiP) and system-on-chip (SoC) platforms. This proliferation of functionally-integrated hardware solutions can be seen as an inflection point in the power supply industry which is seeing a dramatic move away from traditional power supply manufacturing (with a focus on the assembly of power supply modules or bricks from discrete components) to an increasing emphasis on power supply products deriving directly from semiconductor and microelectronics products and technologies.

A major challenge to the further miniaturisation of DC-DC converters is the inability to integrate passive components on silicon due to their relatively large size at today's operating frequencies of 0.5 to 5 MHz. Increasing the switching frequencies into the 10’s of MHz region offers the potential for the reduction of passive component values to the point where, with the right technology, their size becomes compatible with silicon device dimensions. Currently, significant R&D activity is evident in both academia and industry into advances in semiconductor, magnetic, capacitor and packaging materials and technologies that will deliver products operating at multiMHz frequencies. The ultimate target is to develop new miniaturised product formats that can be referred to as power supply-in-package (PSiP) and power supply-on-chip (PwrSoC).

This concept of integrated power solutions presents a significant disruptive opportunity in power management solutions and warrants an international forum for its discussion and for the elucidation of the key challenges that lie ahead.
Multi-Layer Folded High-Frequency Toroidal Inductor Windings

M. Nigam & C. Sullivan, IEEE APEC Conference, February 24-28, 2008, Austin, TX, USA
What’s Next

- Why are Enpirion chips (IHP Foundry) Rad Hard?
- Combination of Foundry & Circuit Design
- Discuss with IHP, Chip Designers
- Test newer Commercial Chips
- Interested companies IHP, National, ADI
- Other Interested Groups to Join our Collaboration
Dear Dr. Dhawan,

Thank you for the information. The different results obtained for the two ICs look interesting. May be we should try to learn more about the root cause together.
For technology and design information we would give you access to the design kit. For this purpose you need to visit our web site. The topic MPW and Prototyping will guide you to a NDA template. Please fill out this template and follow the given guidelines. After receiving your signed NDA we will provide you with the access data.
The data within the design kit are technology related. If we would need to get more information about potential differences in the IC design we would need to involve Enpirion.

Best regards

Bernd

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