Report on DC-DC Converters for HEP and the Role of GaN FETS

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Yale University

KEK Detector Technology Seminar, Tsukuba, Japan
October 1 , 2012

Agenda

- Power efficiency issues / problems CMS-ECAL Example
- What can we do?
- Buck Converter commercial Rad Hard Converter
- Noise Tests or Air coils with ATLAS Trackers

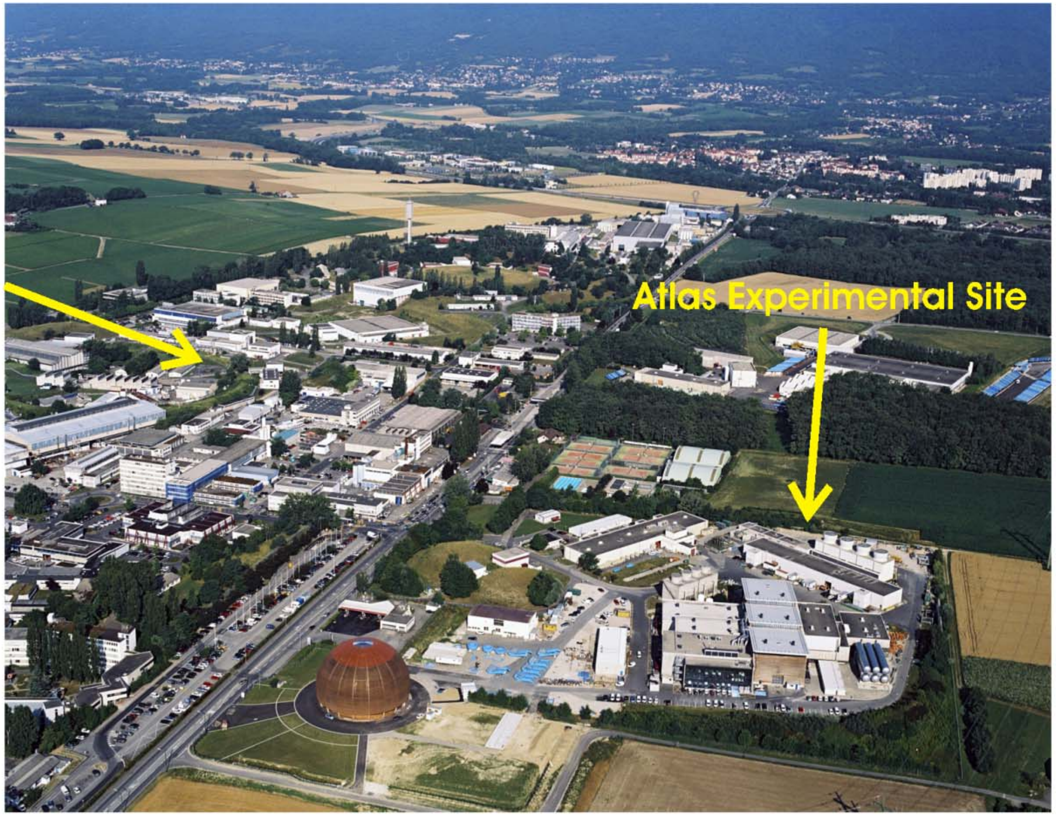
- Why need Thin Oxide
- GaN: Radiation Test Results Wide band Gap materials
- Air Coils from 2000 – Present
- GaN companies - Why Commercial Interest?
- MCM Modules – Future

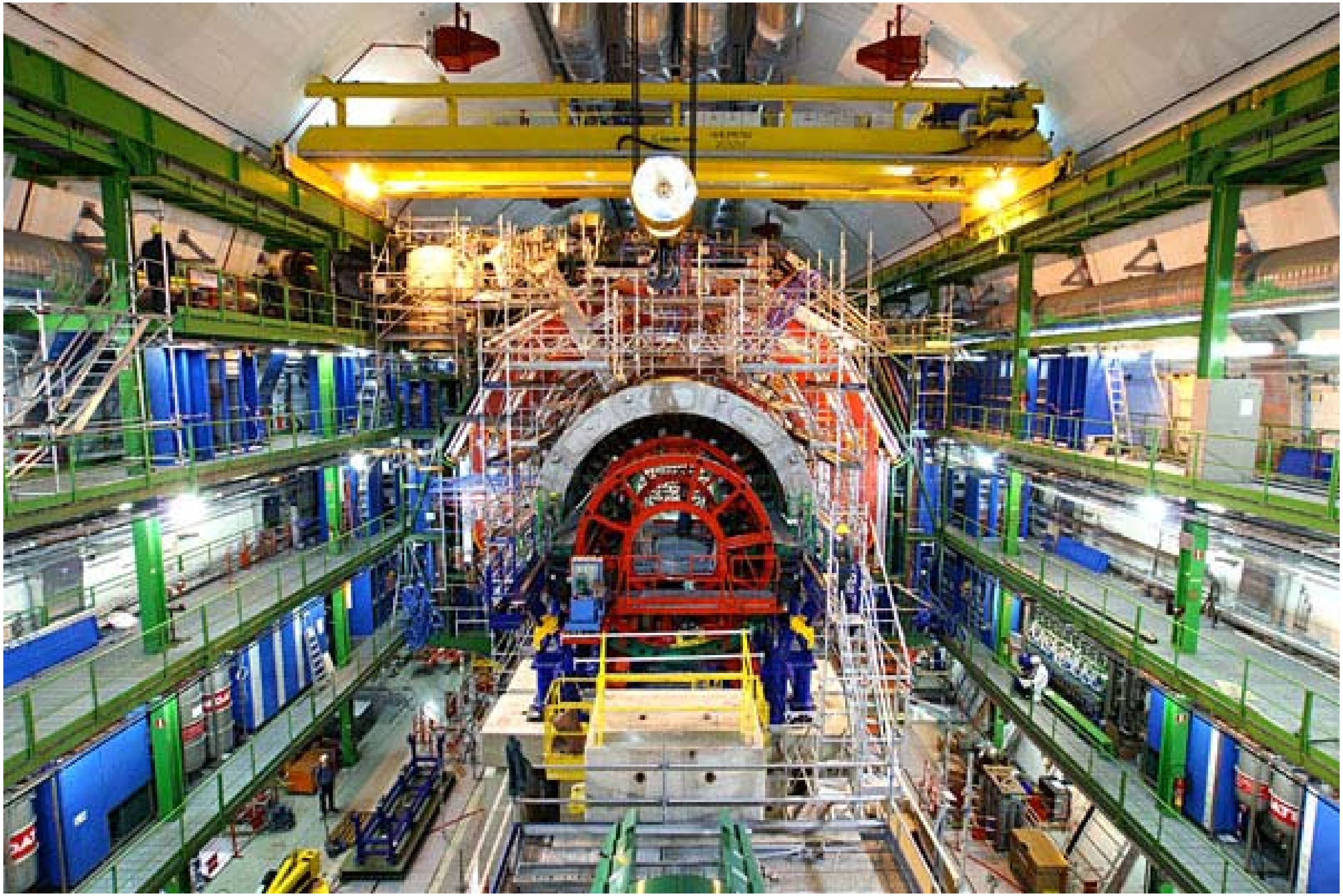
- SiD Detector for ILC 48V > 5V >1V
- Silicon strip Detector @ Yale for Noise Tests
- Remarks

Atlas Experiment

- Collaboration of ~1800 physicists from 150 universities and laboratories from 35 countries

Main CERN Site

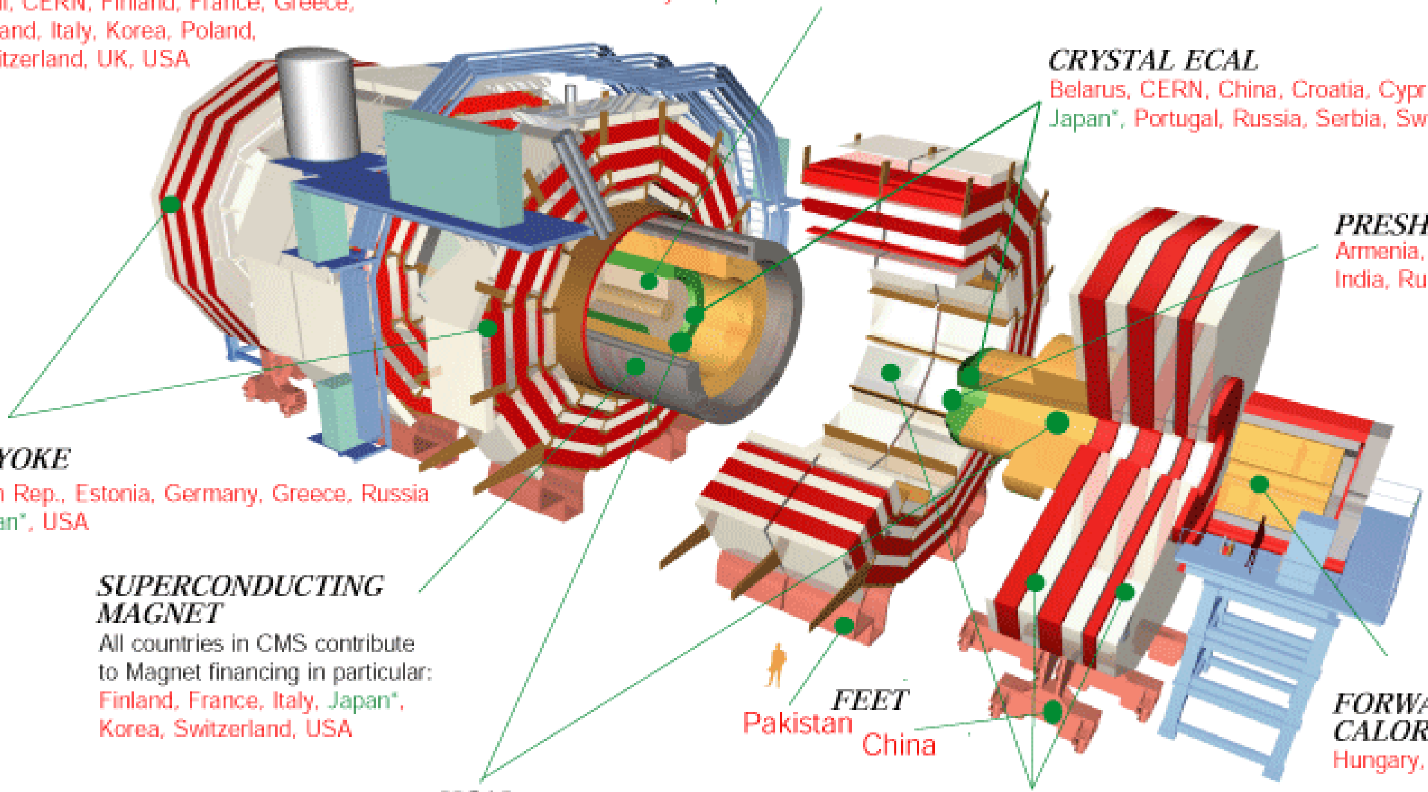




CMS Detector

CMS Outreach

37 Countries, 155 Institutes, 2000 scientists (including about 400 students)   October 2006



TRIGGER, DATA ACQUISITION & OFFLINE COMPUTING
Austria, Brazil, CERN, Finland, France, Greece, Hungary, Ireland, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Mexico, New Zealand, Switzerland, UK, USA

CRYSTAL ECAL
Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Serbia, Switzerland, UK, USA

PRESHOWER
Armenia, CERN, Greece, India, Russia, Taiwan

RETURN YOKE
Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET
All countries in CMS contribute to Magnet financing in particular: Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan China

FORWARD CALORIMETER
Hungary, Iran, Russia, Turkey, USA

HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Georgia, Russia, Ukraine, Uzbekistan
HO: India

MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Colombia, Korea, Pakistan, Russia, USA

* Only through industrial contracts

Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla

CMS ECAL: 50,000 amps.

Power Supply
6.3 V

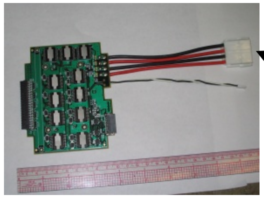
64 Amps

30 m

# of Power Supplies ~ 700
# of ST LDO Chips = 35 K LHC Radiation Hard made by ST Microelectronics
# of LVR Cards = 3.1 K.

Yale: Designed, built, burn-in and Tested.

SM: Super Module



4.3 V

Junction Box

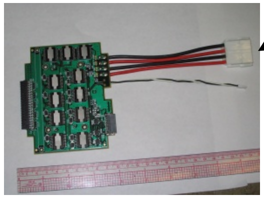
2x16 mm^2 (AWG 6)

1 to 3 m

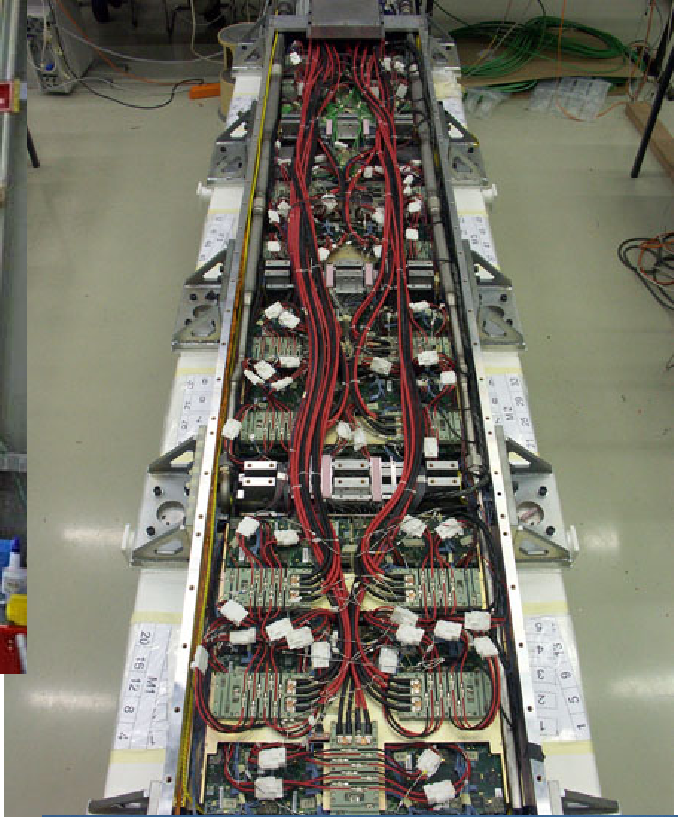
Vdrop = 2V
Pd = 128 W

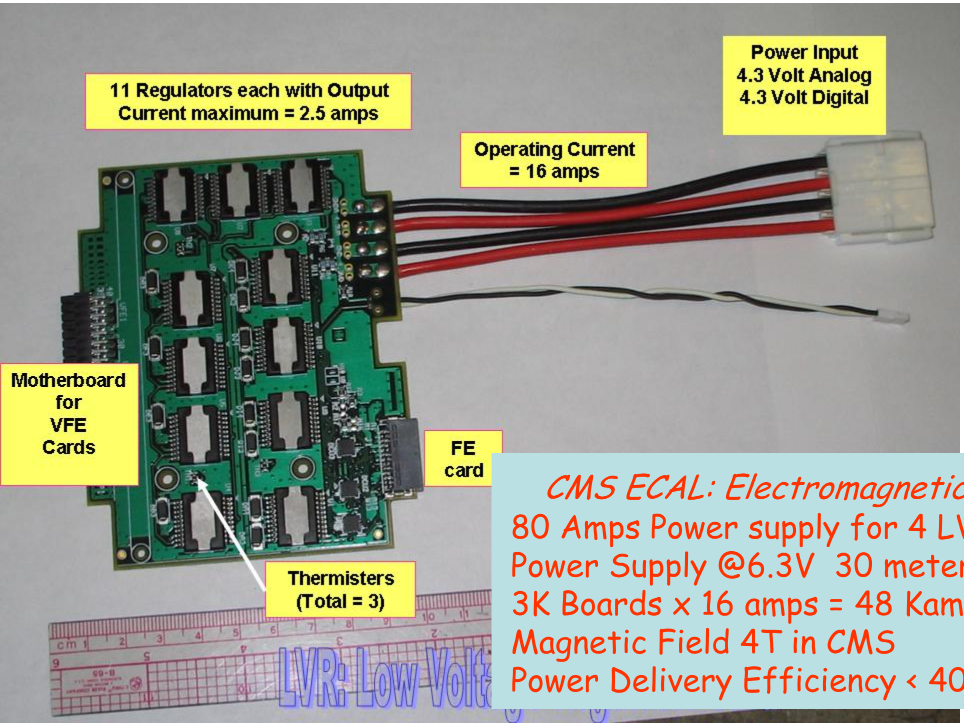
50 mm^2 (AWG 00)

2.5V
64 amps
160 W



4 LVR Boards





11 Regulators each with Output Current maximum = 2.5 amps

Power Input
4.3 Volt Analog
4.3 Volt Digital

Operating Current = 16 amps

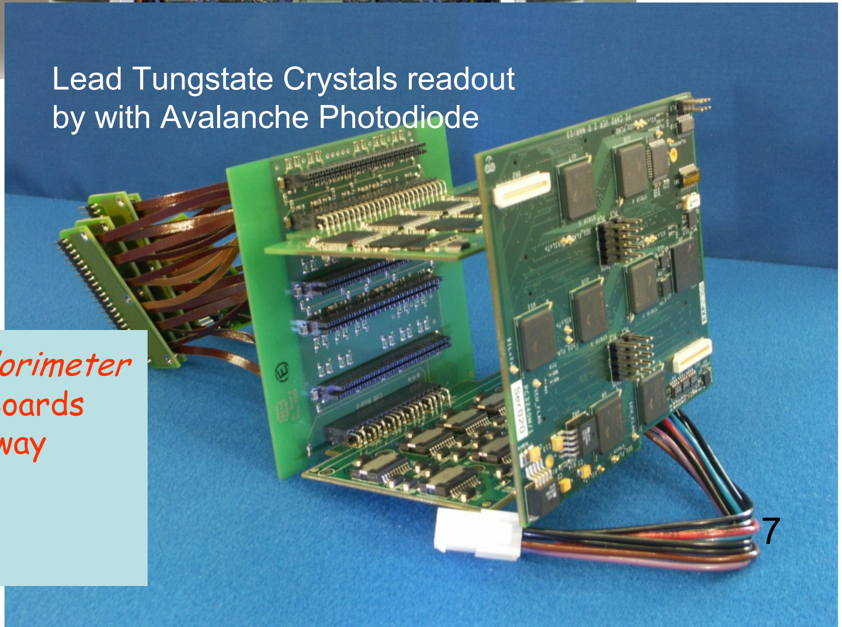
Motherboard for VFE Cards

FE card

Thermisters (Total = 3)

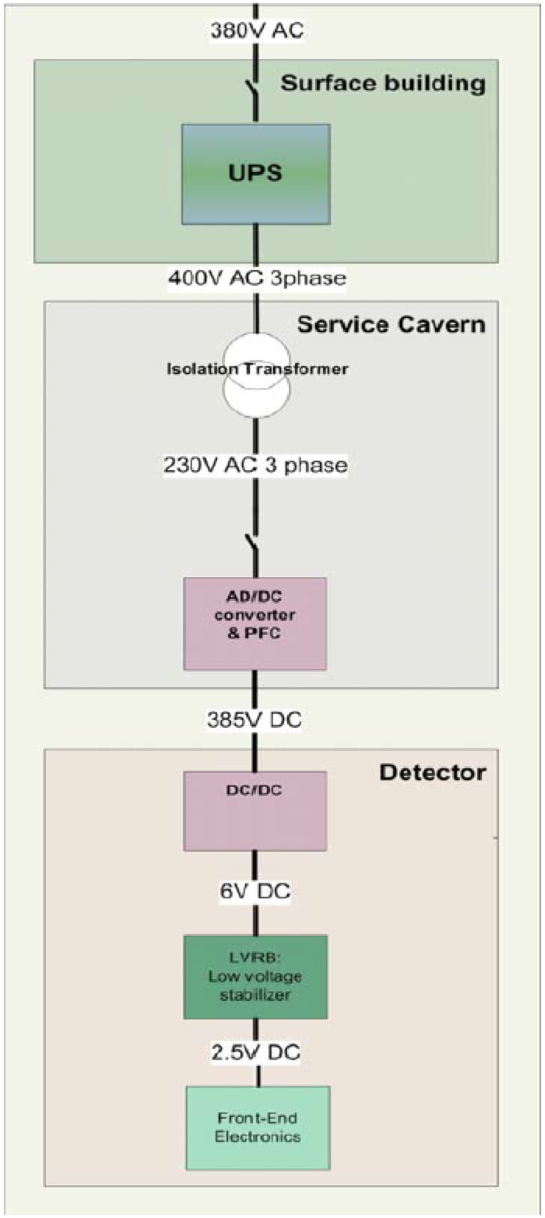
CMS ECAL: Electromagnetic Calorimeter

80 Amps Power supply for 4 LVR Boards
Power Supply @6.3V 30 meters away
3K Boards x 16 amps = 48 Kamps
Magnetic Field 4T in CMS
Power Delivery Efficiency < 40 %



Lead Tungstate Crystals readout by with Avalanche Photodiode

20th Century State of Power Distribution – *LHC Detectors*



380V AC

↓

400V AC

↓

230V AC

↓

385V DC

↓

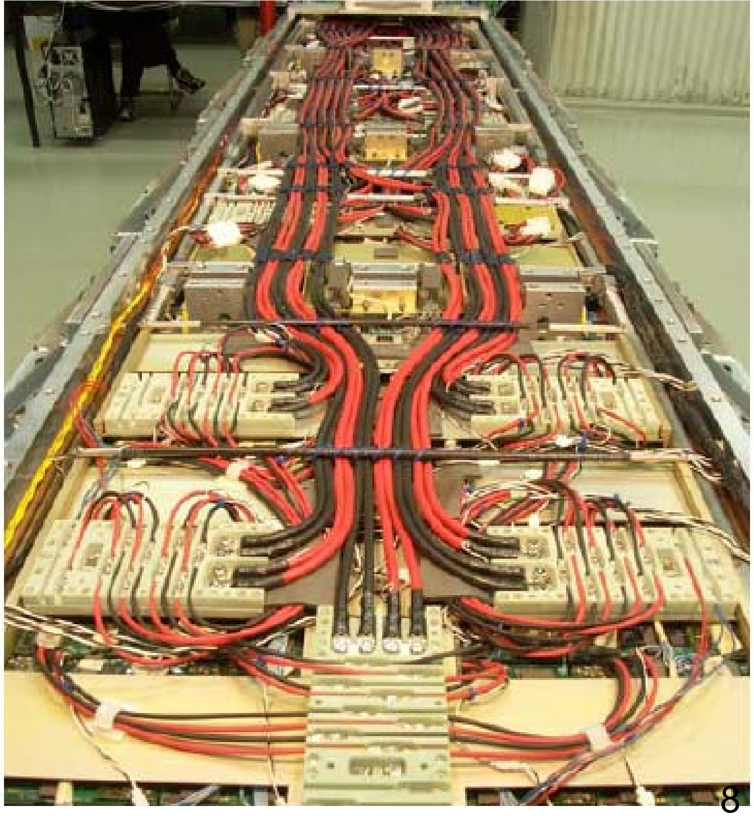
6V DC

↓

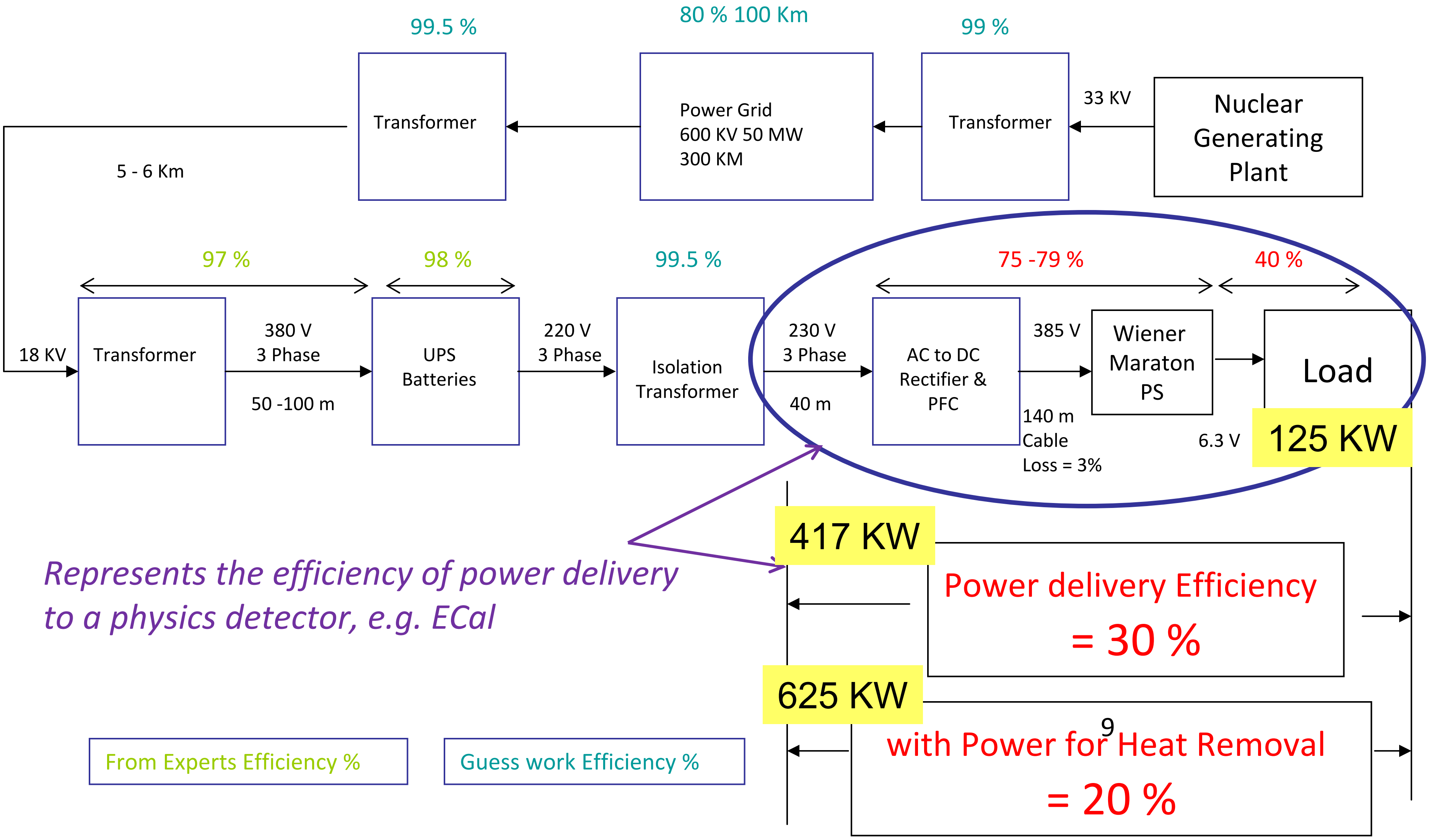
2.5V DC

ECAL readout system:

- Concept 1990's
- designed in ~2000
- produced in 2001-2007
- commissioned in 2006-2007



Power Chain Efficiency for CMS ECAL



Nuclear Generating Plant

33 KV

Transformer 99 %

Power Grid 600 KV 50 MW 300 KM — 80 % 100 Km

Transformer 99.5 %

5 - 6 Km

18 KV

Transformer 97 %

380 V 3 Phase 50 -100 m

UPS Batteries 98 %

220 V 3 Phase

Isolation Transformer 99.5 %

230 V 3 Phase 40 m

AC to DC Rectifier & PFC 75 -79 %

385 V

140 m Cable Loss = 3%

Wiener Maraton PS 40 %

6.3 V

Load

125 KW

417 KW

Power delivery Efficiency = 30 %

625 KW

with Power for Heat Removal = 20 %

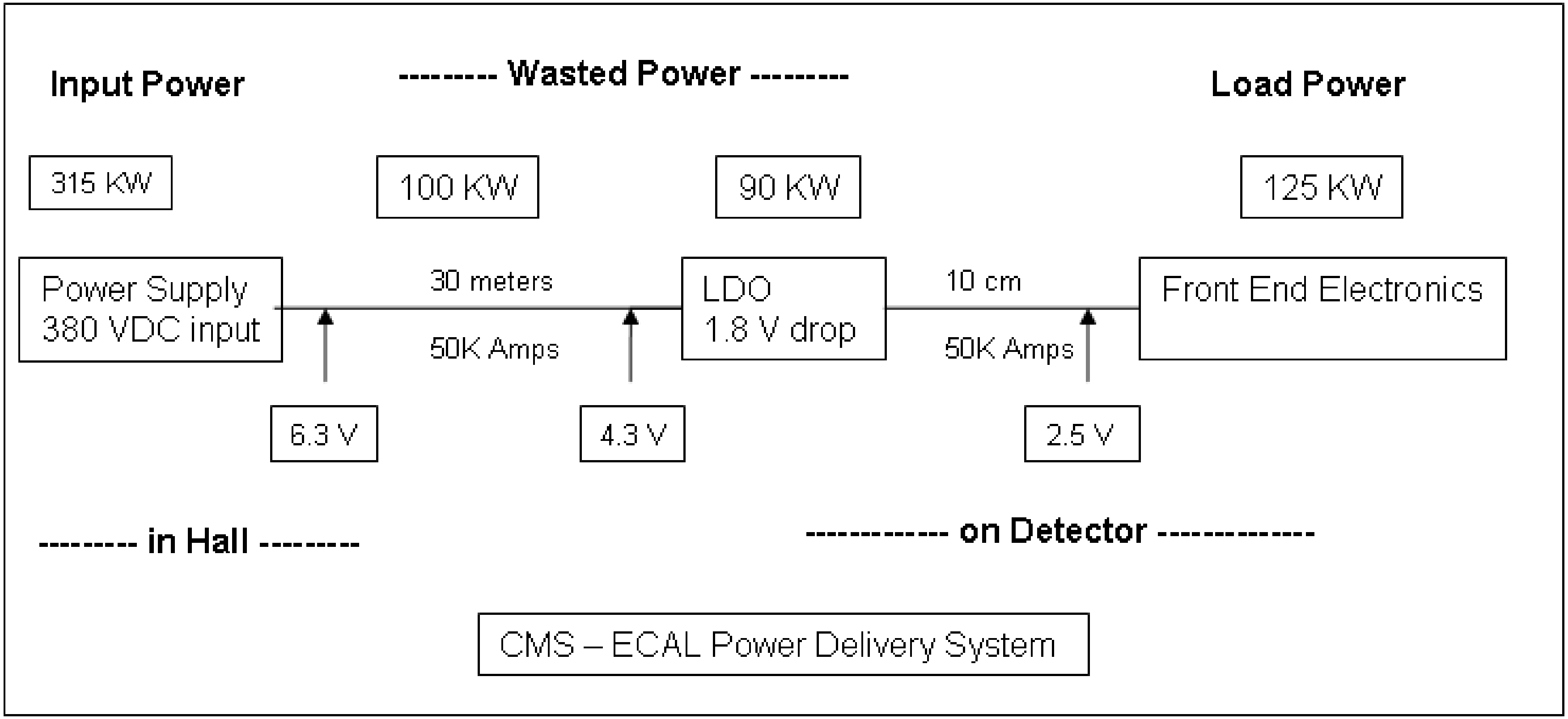
Represents the efficiency of power delivery to a physics detector, e.g. ECal

From Experts Efficiency %

Guess work Efficiency %

It takes 2 watts of power to remove 1 watt of heat load

Power Efficiency _ Inefficiency _ Wasted Power



Input Power

--------- Wasted Power ---------

Load Power

315 KW

100 KW

90 KW

125 KW

Power Supply
380 VDC input

30 meters

50K Amps

LDO
1.8 V drop

10 cm

50K Amps

Front End Electronics

6.3 V

4.3 V

2.5 V

--------- in Hall ---------

------------ on Detector -------------

CMS – ECAL Power Delivery System

CMS Project done, so Funding ended
DoE decided Yale change from CMS > ATLAS

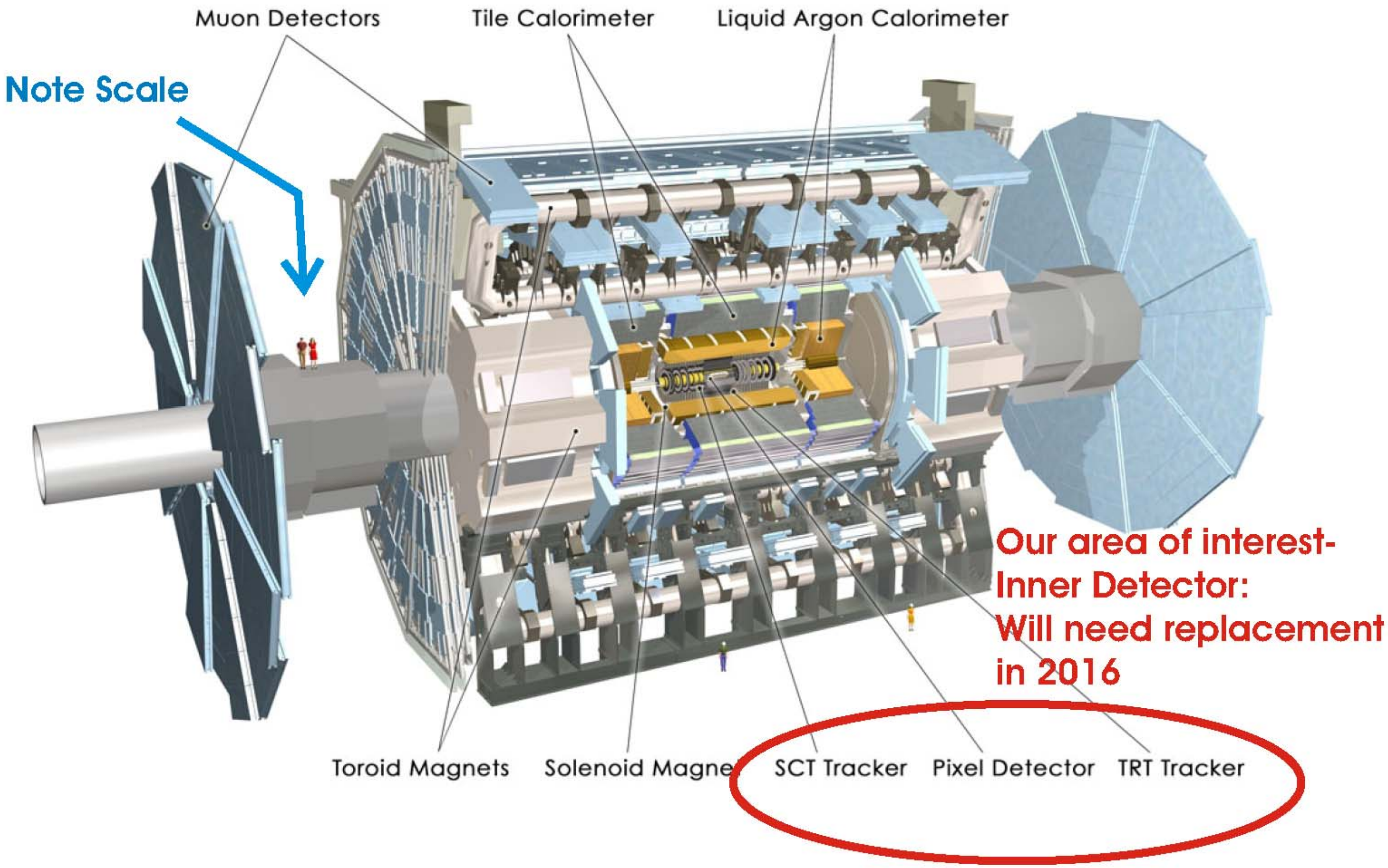
Is there a better way to deliver power?

But Need a project, so picked ATLAS Silicon tracker Upgrade with DC-DC.
After 2 years management decision use Serial Power instead of DC-DC.

Had small SiD ILC 3 year grant. Winding down.
Spring 2011 CDR&D Proposal with ANL,BNL, Fermilab, SLAC. Reviewers say it is too expensive
September 2012: Submitted a smaller 2 year proposal for Air Core Coil developments

Power is difficult, so why waste money – some one will do it ?

Atlas Detector Consists of Many Sub-Detectors



Note Scale

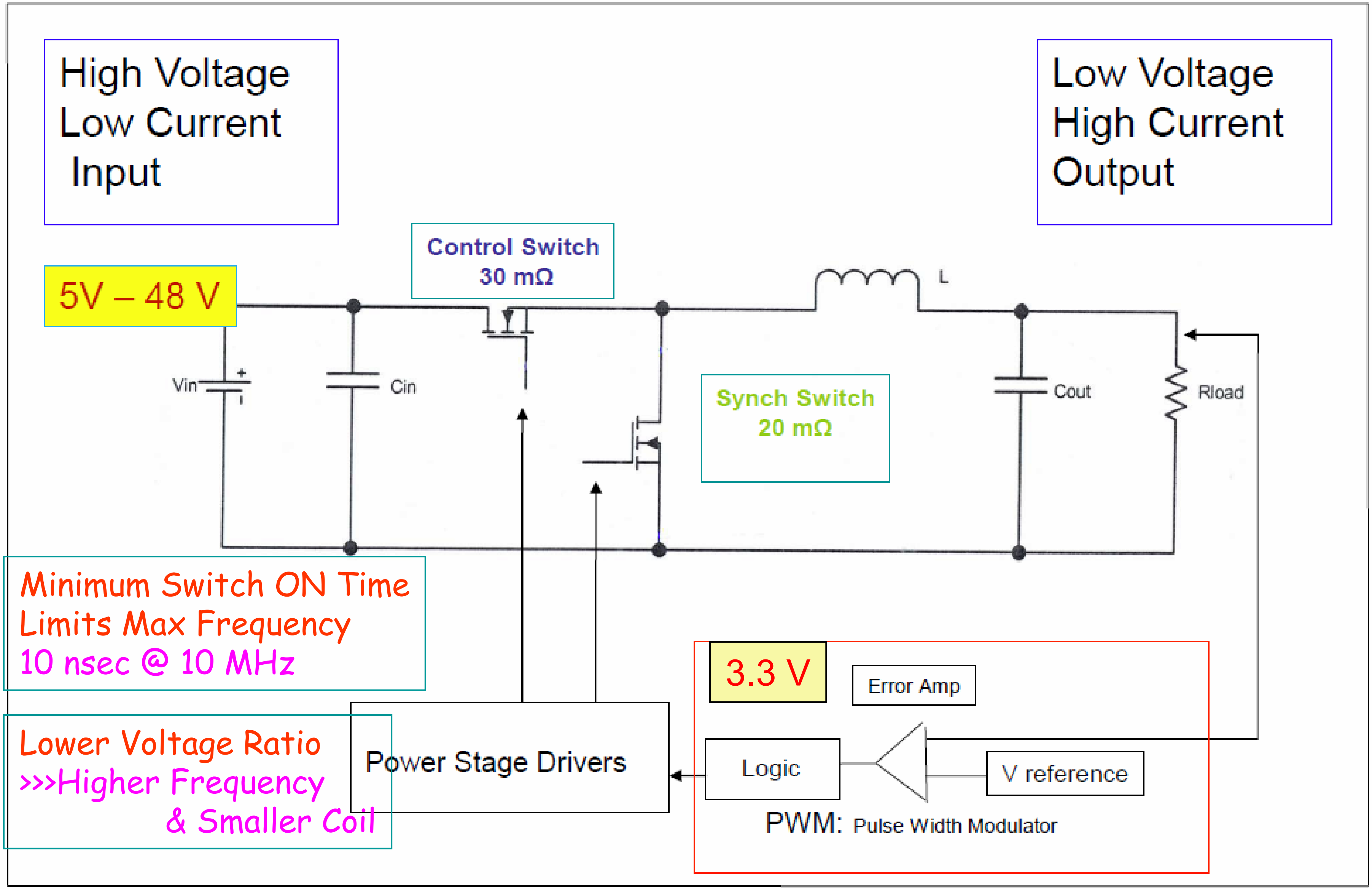
Our area of interest-
Inner Detector:
Will need replacement
in 2016

Wish List

- Buck or Boost Converter.
- Voltage ratio =10:1 or Higher.
- 4 Tesla > No magnetic material
- Air Core Inductors
- Radiation Hardness. We had zero experience.
  Experts advice custom ICs with sub-micron Lithography.

Sander Mos: Zero Iron Power Supply http://www.nikhef.nl/~sanderm/zips/index.html

Buck Converter



High Voltage
Low Current
Input

Low Voltage
High Current
Output

5V – 48 V

Control Switch
30 mΩ

Synch Switch
20 mΩ

Minimum Switch ON Time
Limits Max Frequency
10 nsec @ 10 MHz

Lower Voltage Ratio
>>>Higher Frequency
& Smaller Coil

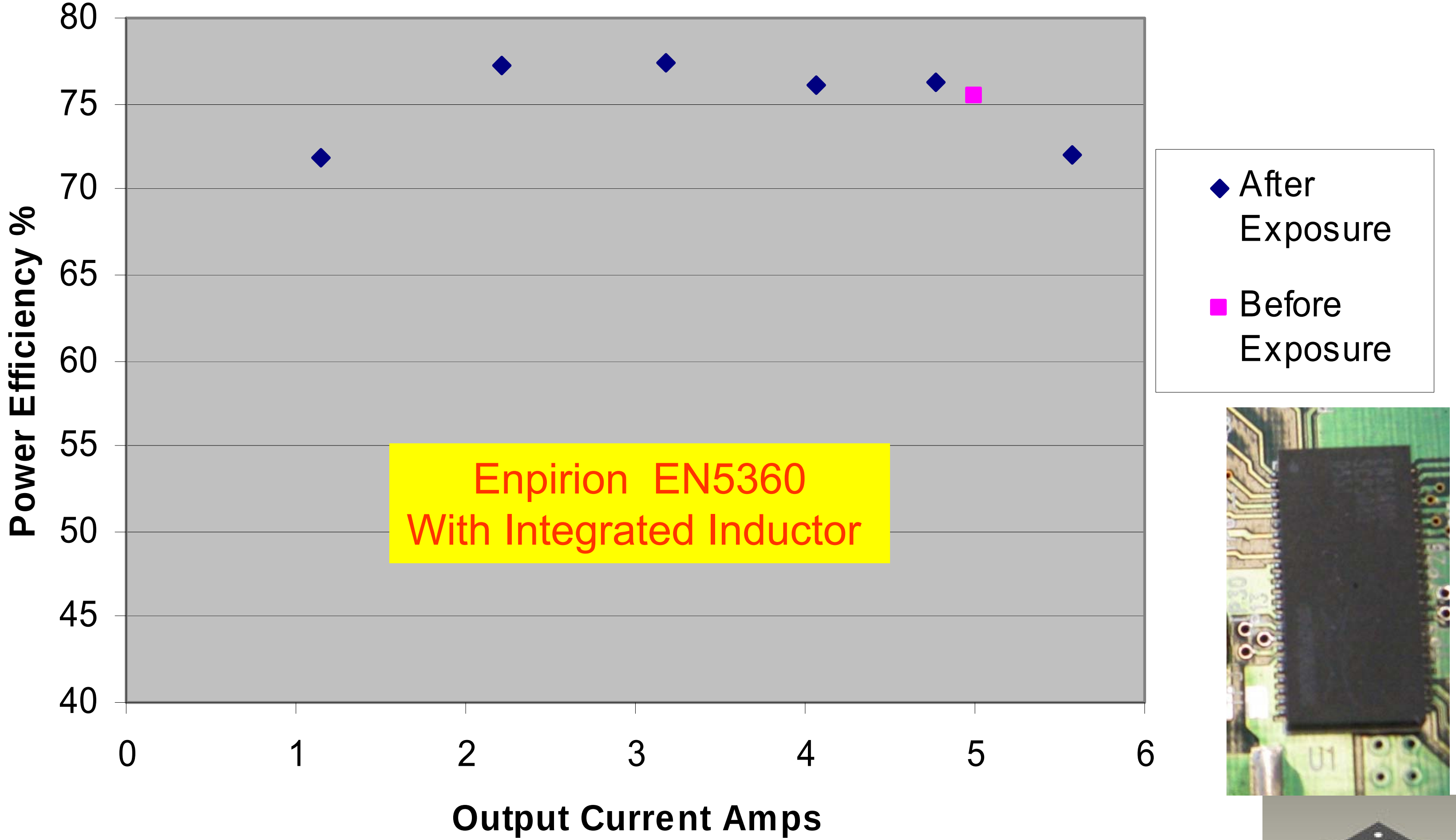
Power Stage Drivers

3.3 V

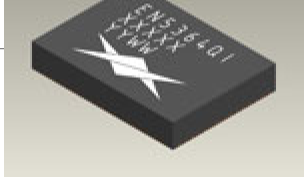
PWM: Pulse Width Modulator

Industry: Integrate different technologies, power handling into suitable packages

Buck Regulator Efficiency after 100 Mrad dosage



Enpirion EN5360
With Integrated Inductor



Found out at Power Technology conference 0.25 µm Lithography

- Irradiated Stopped on St. Valentines Day 2007
- We reported @ TWEPP 2008 - IHP was foundry for EN5360

DC-DC with Air Coil

Magnetic Field Effect

7 Tesla Field Chemistry Department Super Conducting Magnet in Persistence Mode

Effect:
Vout = 3.545 Outside
Vout = 3.546 Edge of magnet
Vout = 3.549 Center of magnet

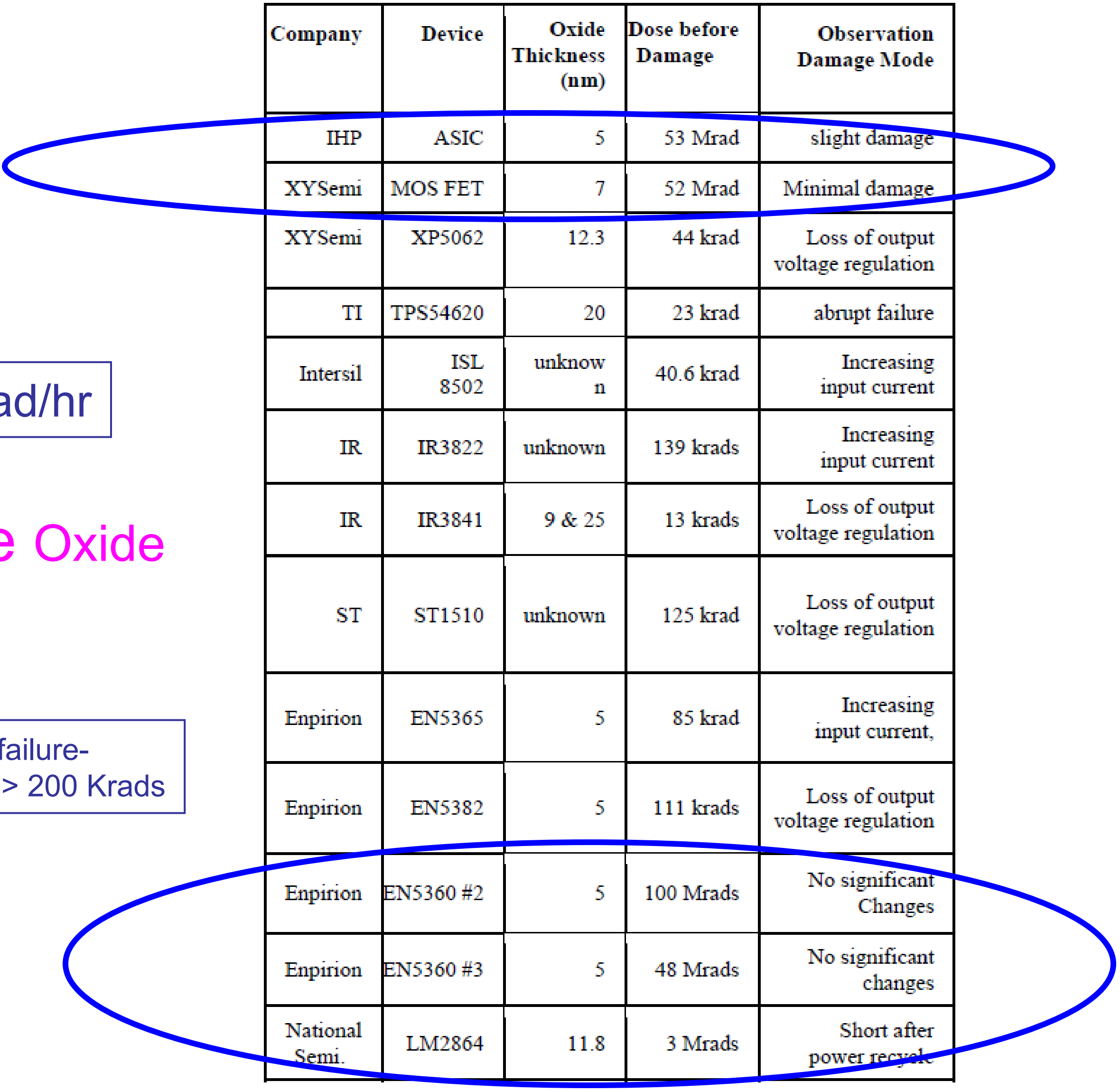
Change= Increased Vout 1 part in 900 at 7T

Ionizing Radiation Results – Commercial Converters

Dose rate= 0.2 Mrad/hr

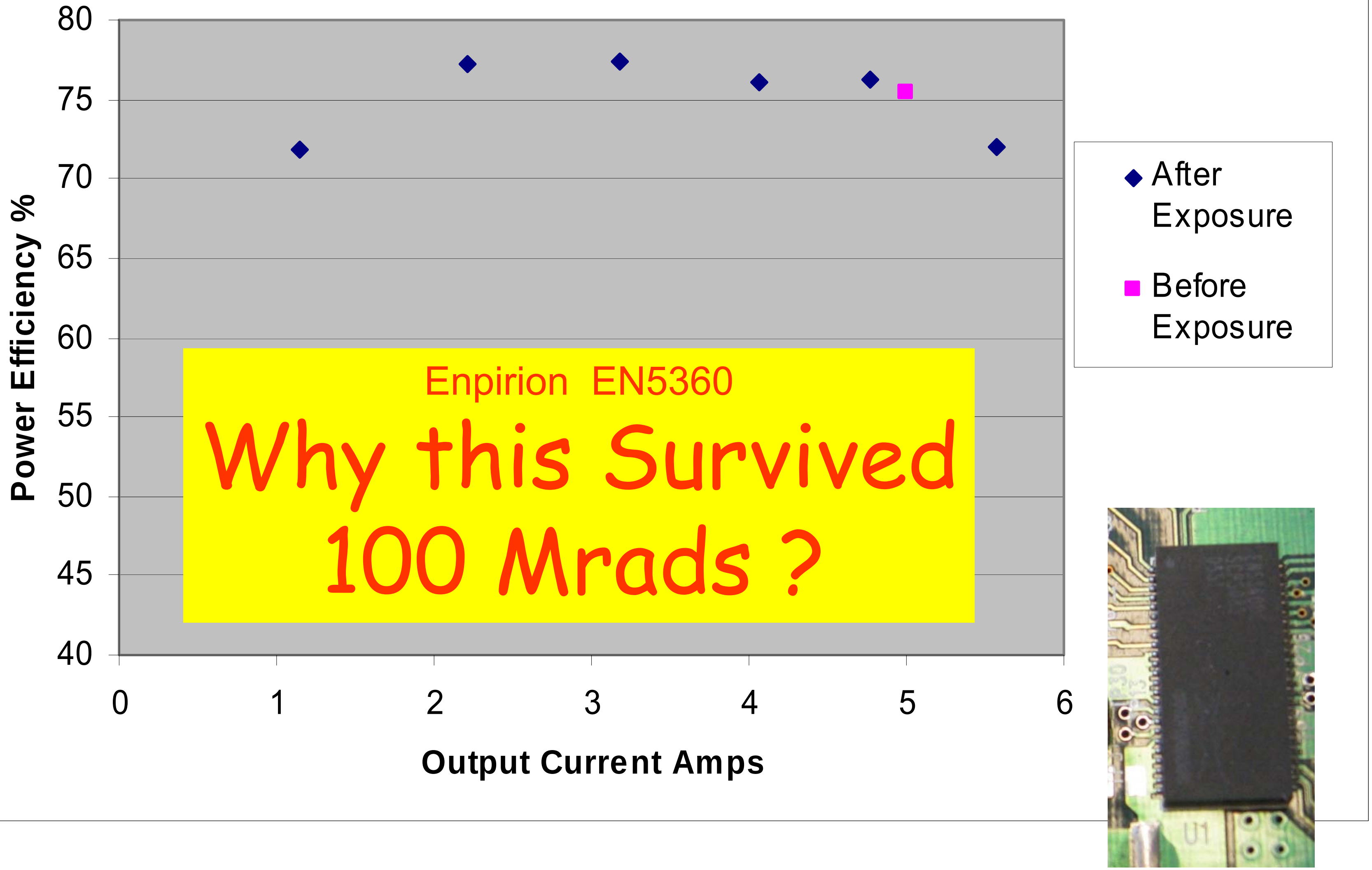
5- 12 nm Gate Oxide

Many more tested but similar failure-
Thin oxide converters survive > 200 Krads



Company	Device	Oxide Thickness (nm)	Dose before Damage	Observation Damage Mode
IHP	ASIC	5	53 Mrad	slight damage
XYSemi	MOS FET	7	52 Mrad	Minimal damage
XYSemi	XP5062	12.3	44 krad	Loss of output voltage regulation
TI	TPS54620	20	23 krad	abrupt failure
Intersil	ISL 8502	unknown	40.6 krad	Increasing input current
IR	IR3822	unknown	139 krads	Increasing input current
IR	IR3841	9 & 25	13 krads	Loss of output voltage regulation
ST	ST1510	unknown	125 krad	Loss of output voltage regulation
Enpirion	EN5365	5	85 krad	Increasing input current,
Enpirion	EN5382	5	111 krads	Loss of output voltage regulation
Enpirion	EN5360 #2	5	100 Mrads	No significant Changes
Enpirion	EN5360 #3	5	48 Mrads	No significant changes
National Semi.	LM2864	11.8	3 Mrads	Short after power recycle

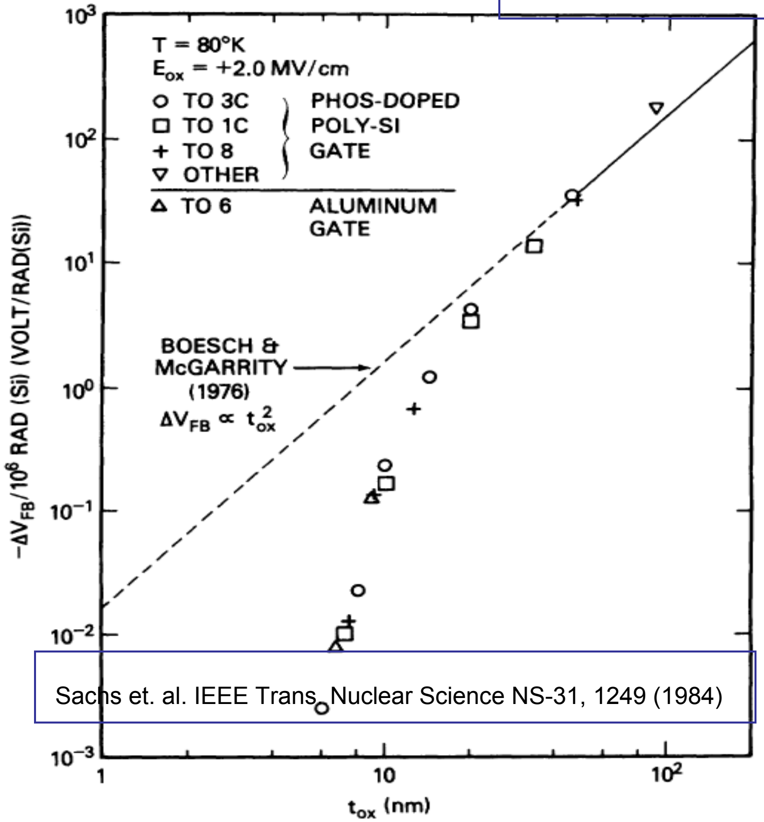
Buck Regulator Efficiency after 100 Mrad dosage



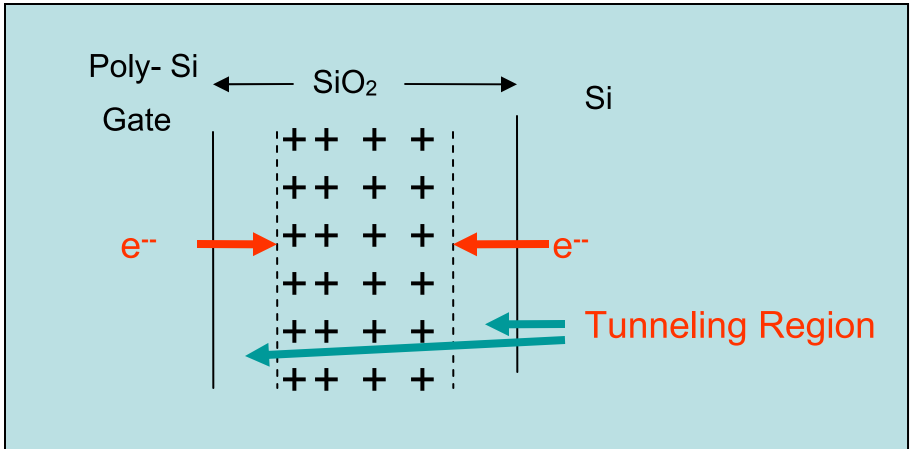
Enpirion EN5360

Why this Survived 100 Mrads ?

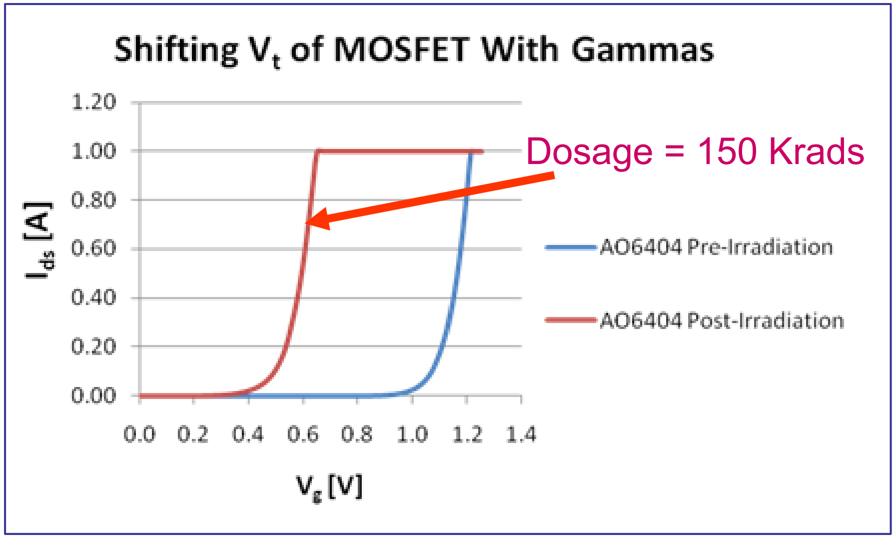
Threshold Shift vs Gate Oxide Thickness



Sachs et. al. IEEE Trans. Nuclear Science NS-31, 1249 (1984)



Hole removal process by tunneling in thin-oxide MOS Structures



Necessary condition for Radiation Hardness

Thin Gate Oxide

But not sufficient

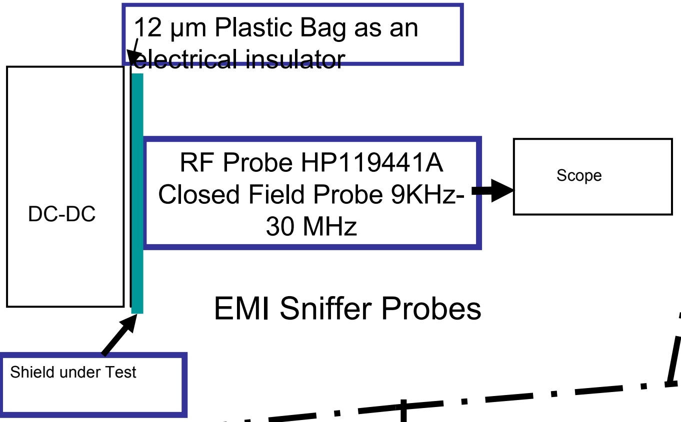
IHP: Epi free, High resistivity substrate, Higher voltage, lower noise devices

Dongbu: Epi process on substrate, lower voltage due to hot carriers in gate oxide

Book. Timothy R Oldham "Ionizing Radiation Effects in MOS Oxides" 1999 World Scientific

Noise Tests with Silicon Sensors

Test @ Yale



12 µm Plastic Bag as an electrical insulator

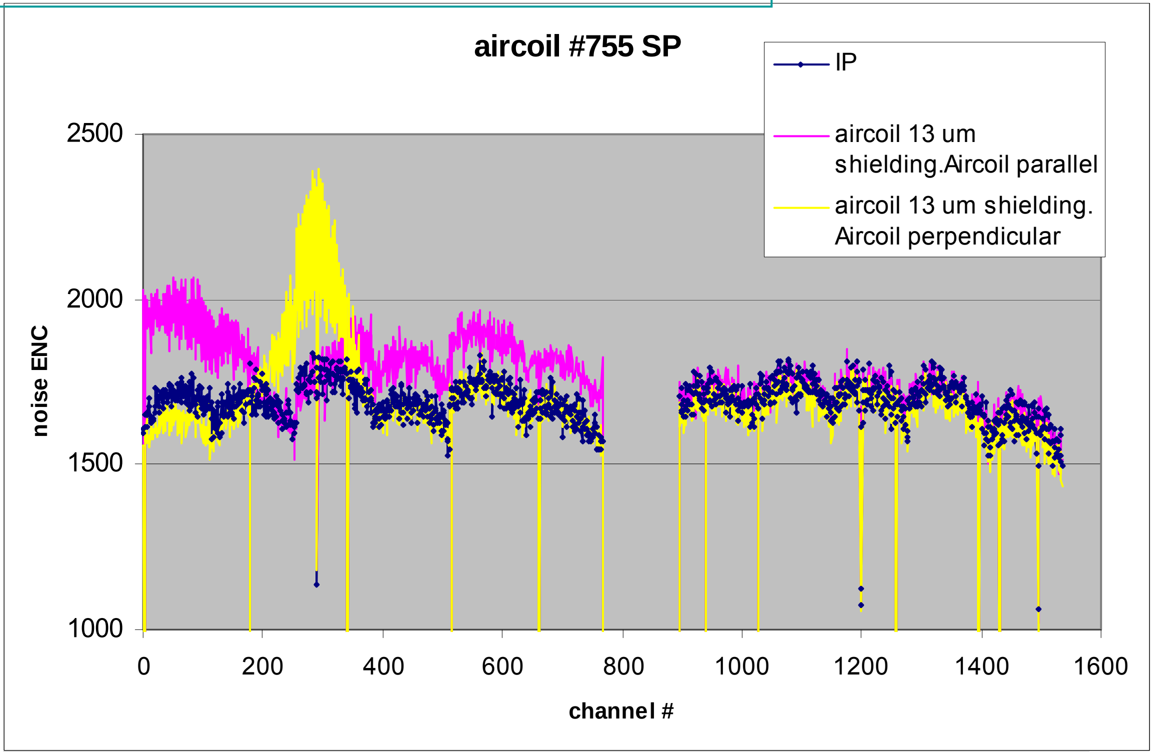
DC-DC

RF Probe HP119441A Closed Field Probe 9KHz-30 MHz

Scope

EMI Sniffer Probes

Shield under Test

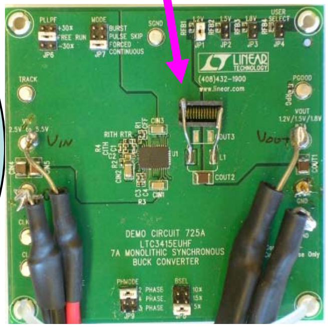


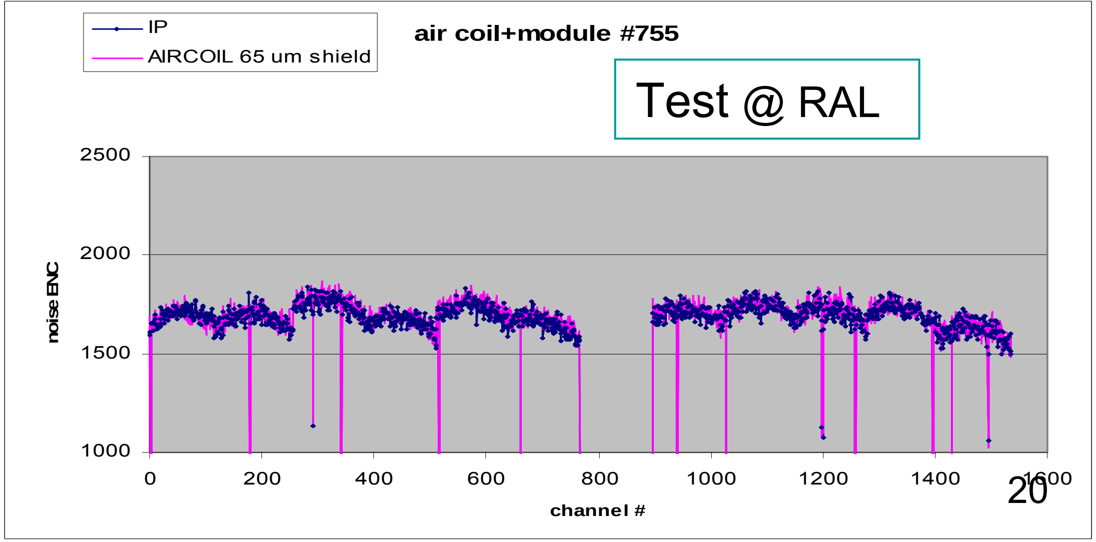
aircoil #755 SP

Test @ BNL

RHIC
Polarimeter
Silicon Sensor
With
Analog Readout'
Noise on Scope

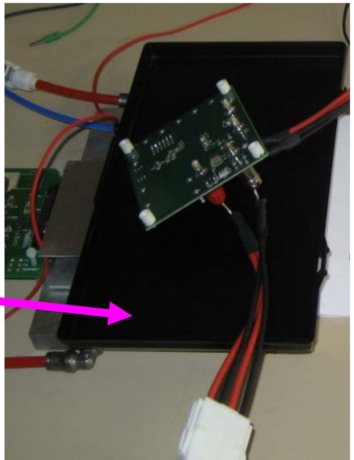
Air Core Solenoid





air coil+module #755

Test @ RAL



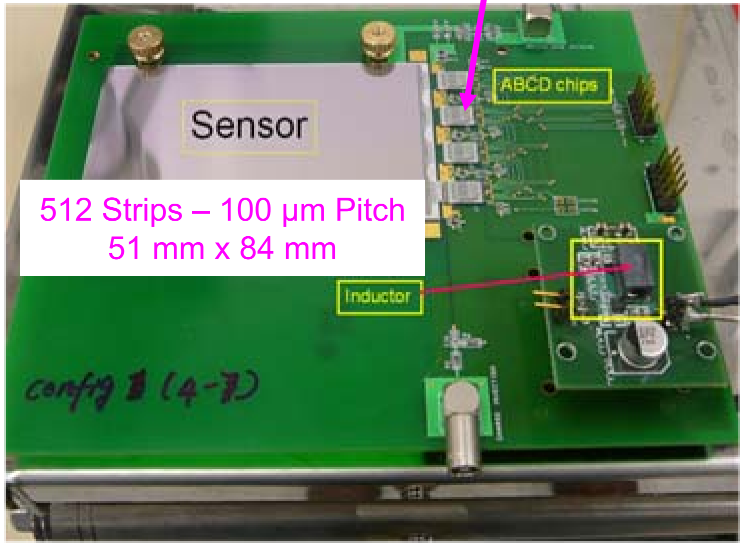
ATLAS Si Tracker
Module
12 ABCD Chips
2 Sensors

Protected by plastic

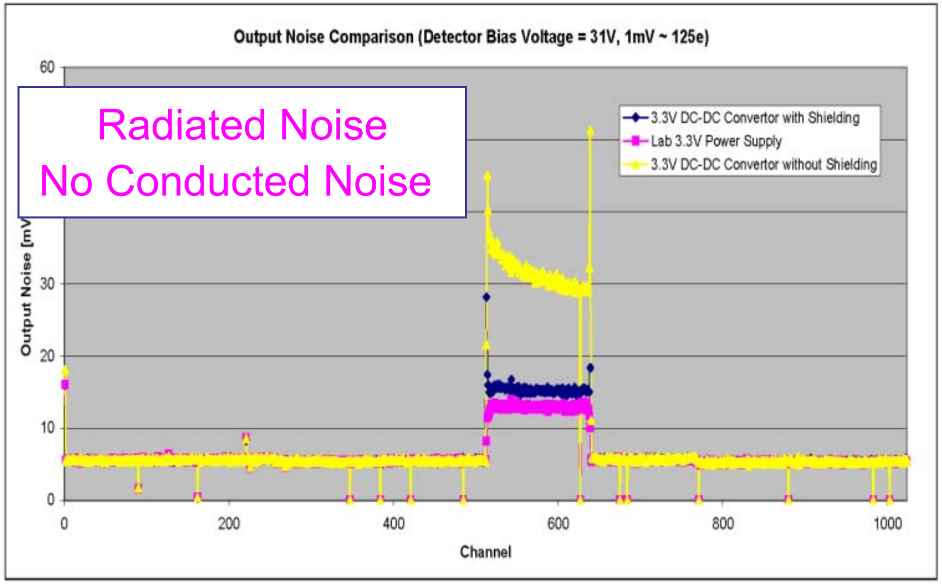
Noise Tests with Silicon Sensors

Test @ BNL

Only One Chip Bonded

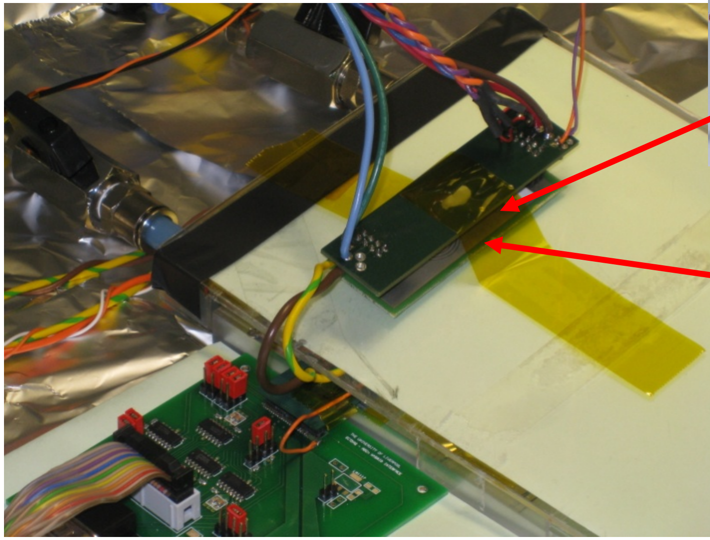


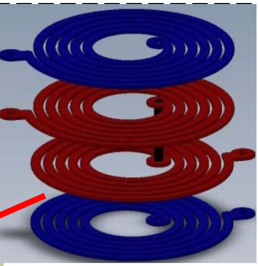
512 Strips – 100 µm Pitch
51 mm x 84 mm



Radiated Noise
No Conducted Noise

Test @ Liverpool September 2009





Spiral Inductor

Plug in Card
1 cm from Coil
facing Sensor

20 µm Al foil
shielding

Coil Type	Power	Input Noise electrons rms
Solenoid	DC - DC	881
Solenoid	Linear	885
Spiral Coil	DC - DC	666
Spiral Coil	Linear	664

Can We Have
High Radiation Tolerance & Higher Voltage Together ???

Controller PWM : Low Voltage

High Voltage: Switches –

5- 7 nm Gate Oxide supports 5 V operation

LDMOS, Drain Extension, Field Plates – Reduce Electric Field under Gate (recent work 3 nm > 12 V operating: 7 nm > 70 V power FETs)

>> 20 Volts HEMT GaN on Silicon, Silicon Carbide, Sapphire

GaN

Wide Band Gap Materials

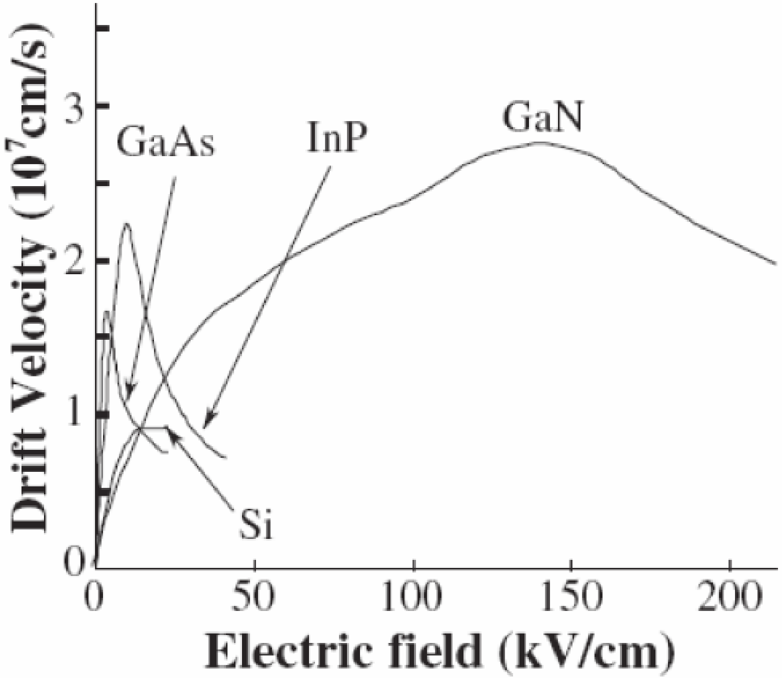


Fig. 8. Dependence of drift velocity of semiconductors on electric field. GaAs and InP have high mobilities (slope of drift velocity–electric field relation in the low-electric-field region); however, their drift velocities decrease in the high-electric-field region. On the other hand, GaN shows high drift velocity in the high-electric-field region.

H. Okumura. Present Status and Future of Widegap Semiconductor High-Power Devices, Jpn. J. Appl. Vol. 45. No. 10A (2006)

Radiation Results – RF GaN & EPC GaN on Si

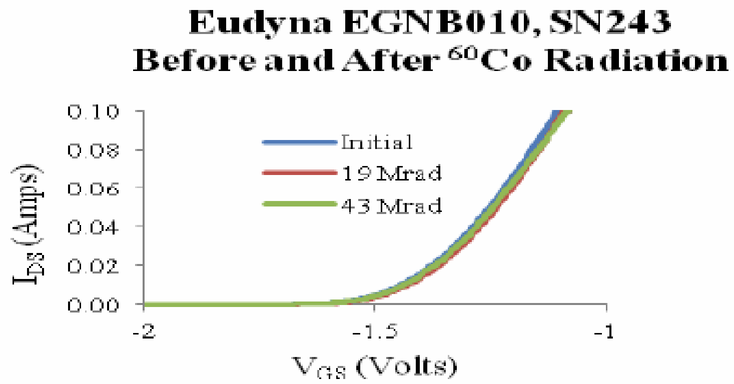


Fig. 7. Eudyna EGNB010 GaN HEMT, VGS versus IDS at VDS = 10 volts and selected doses of 60Co gamma radiation. Little change is apparent even after 43 Mrad of ionizing radiation.

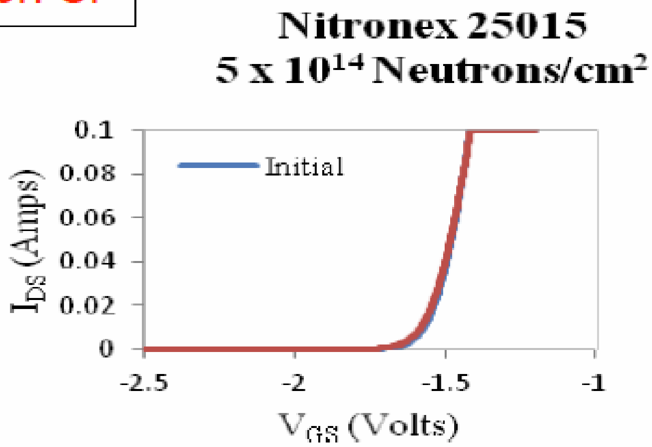


Fig. 6. Nitronex 25015 HEMT irradiate with 5 x 1014 neutrons (1 MeV equivalent). Little change is observed in the response.

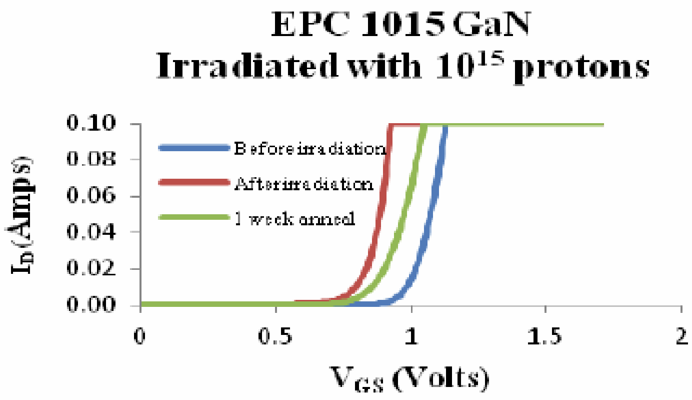


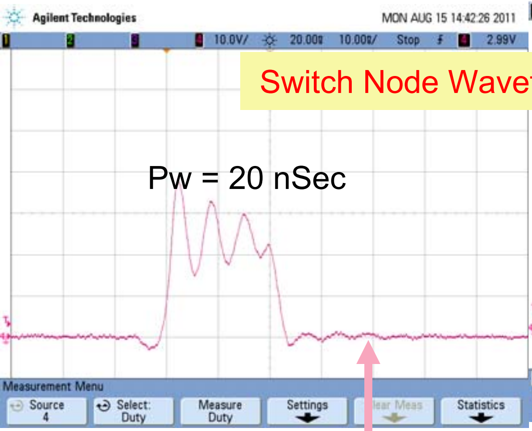
Fig. 8. EPC 1015 HEMT before and after 1015 protons/cm2. During exposure VDS = 24V with a 1 kOhm resistor current limiting the channel to 24 mA. The device was "clocked" with a VGS = 4 V at a 1 kHz frequency

TABLE III Radiation Testing Matrix for GaN Devices

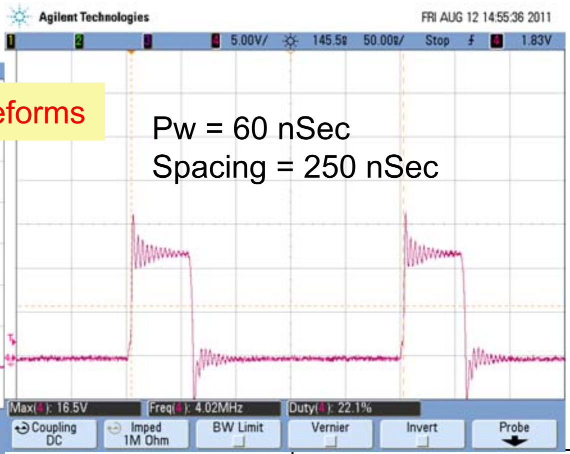
Company	Device	60Co	Neutron Fluence (cm^{-2})	Proton Fluence (cm^{-2})
Nitronex	25015	17.4Mrad	5 x 10^{14}	1 x 10^{15}
Cree	40010		5 x 10^{14}	1 x 10^{15}
Eudyna	EGNB010	43 Mrad	5 x 10^{14}	1 x 10^{15}
EPC	EPC1015	64 Mrad		1 x 10^{15}

eGaN with discrete & LM5113 Driver

Switch Node Waveforms

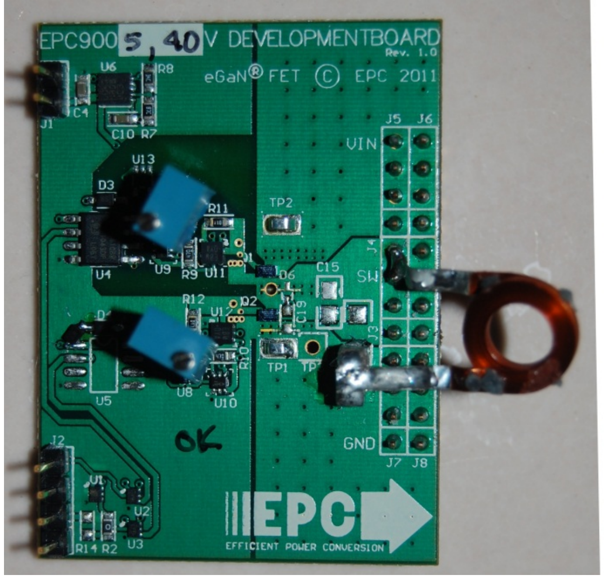


Pw = 20 nSec

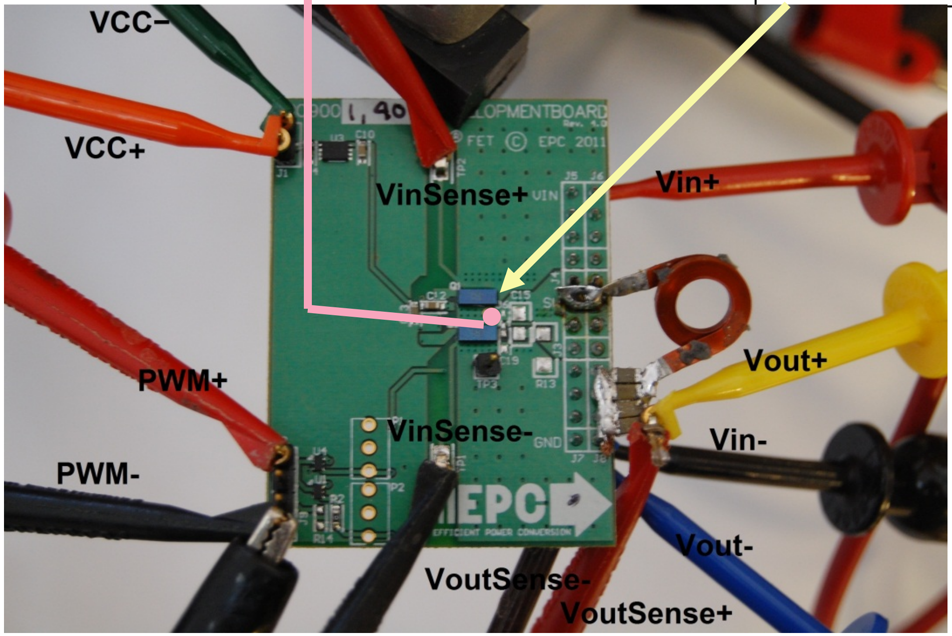


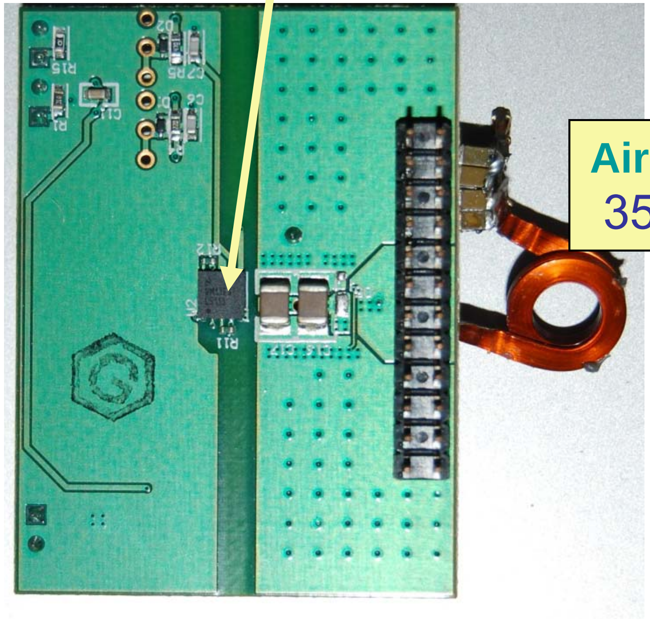
Max(4): 16.5V
Freq(4): 4.02MHz
Duty(4): 22.1%

Pw = 60 nSec
Spacing = 250 nSec



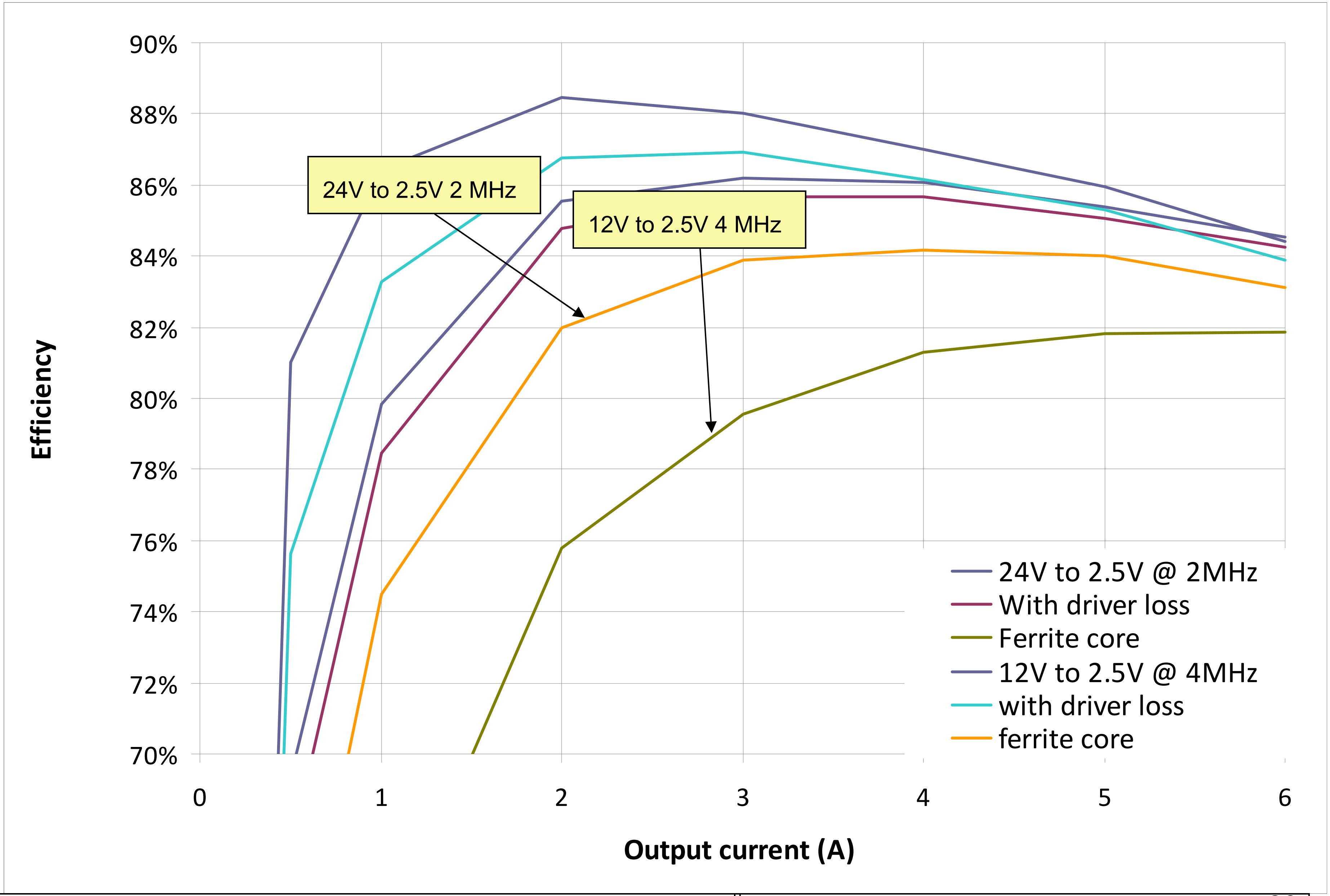
National eGaN Driver LM5113 on Bottom
eGaN on Top side





Air Core Coil
355 nH

Aircoil *EPCOS-B82559A0392A013* 3.9 µH / 355 nH without Ferrite. 5 mΩ



24V to 2.5V 2 MHz

12V to 2.5V 4 MHz

Aircoil *EPCOS-B82559A0392A013* 3.9 µH / 355 nH without Ferrite. 5 mΩ

MnZn Ferrite Coil 744308euro33 377 nH 0.37 mΩ

Air Coils

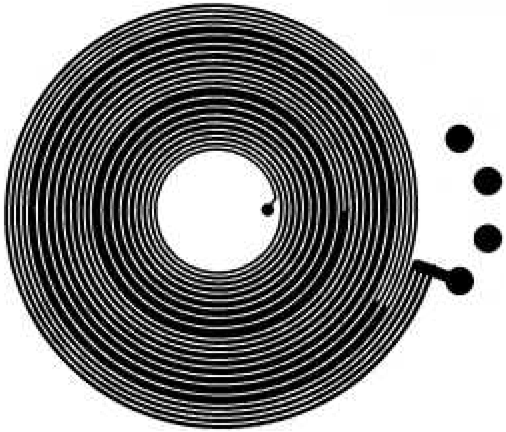
Year 2000

Zero **I**ron **P**ower **S**upply

S. Mos Sanderm: NIKHEF

Figure 2 size of the converter (111x60x29mm, without connector and screws)

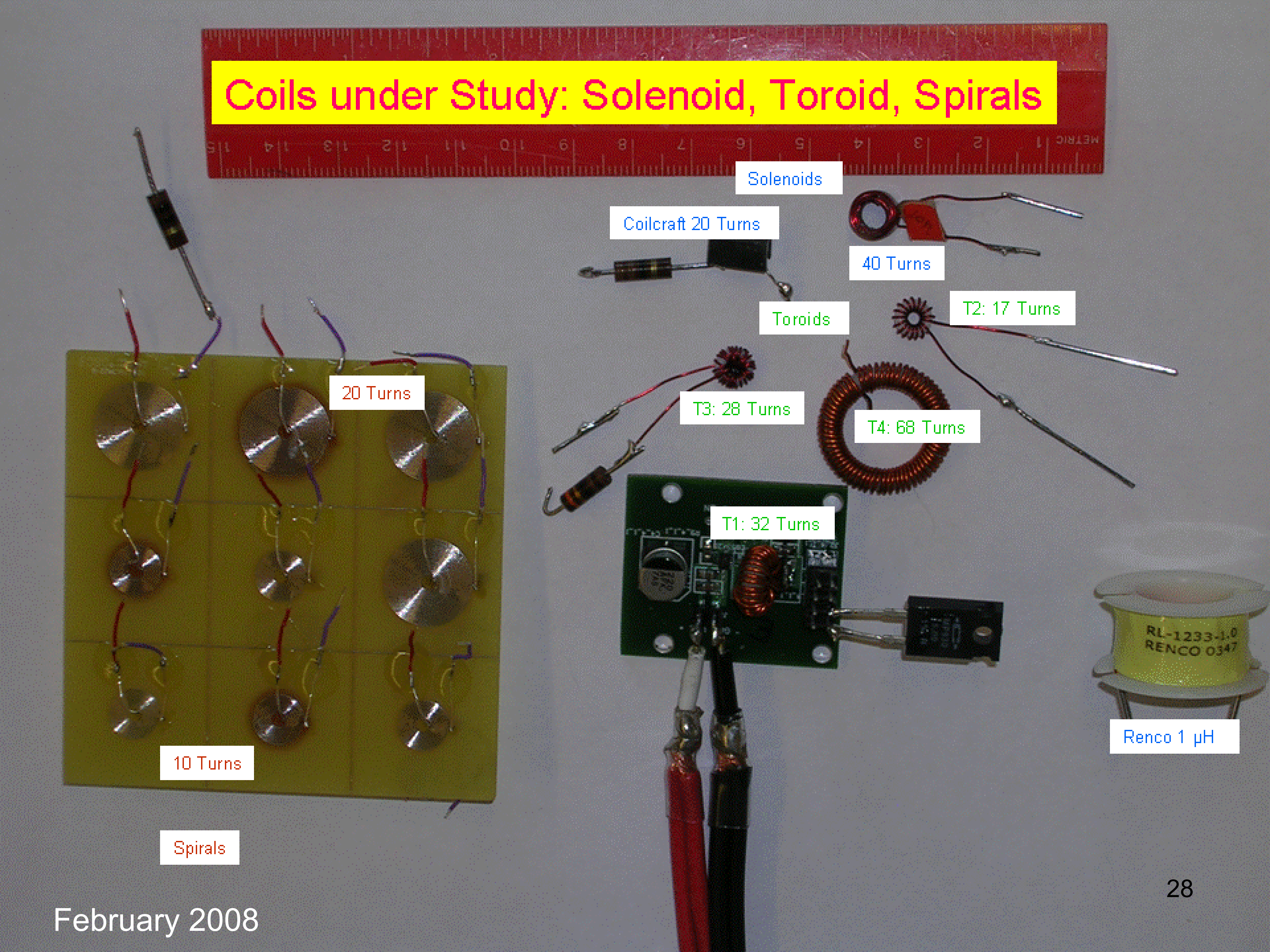
Vin = 18 V
Vout = 5 V
Pout = 2.5 W
Efficiency = 76%



Transformer
1 – 5 MHz

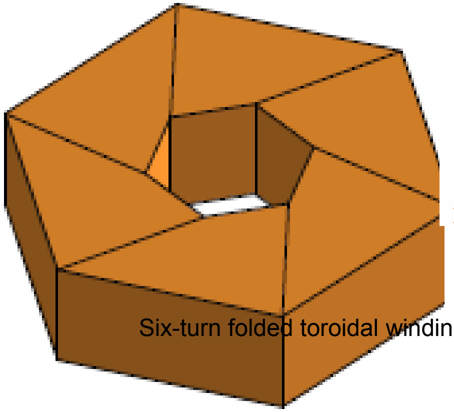
http://www.nikhef.nl/~sanderm/zips/index.html
http://www.nikhef.nl/~sanderm/zips/Zero_Iron_Power_Supply_r1.pdf

Coils under Study: Solenoid, Toroid, Spirals



February 2008

Coils



Six-turn folded toroidal winding

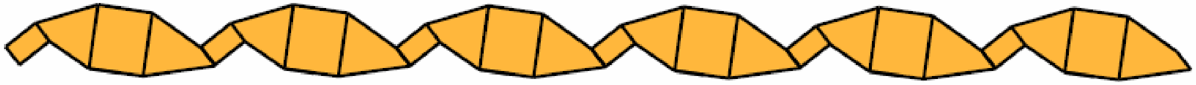


Fig. 2. Six-turn folded-foil toroidal winding layout.

Nigam & Sullivan: Multi-Layer Folded High-Frequency Toroidal Inductor Windings
IEEE Applied Power Electronics Conference, Feb. 2008, pp. 682–688

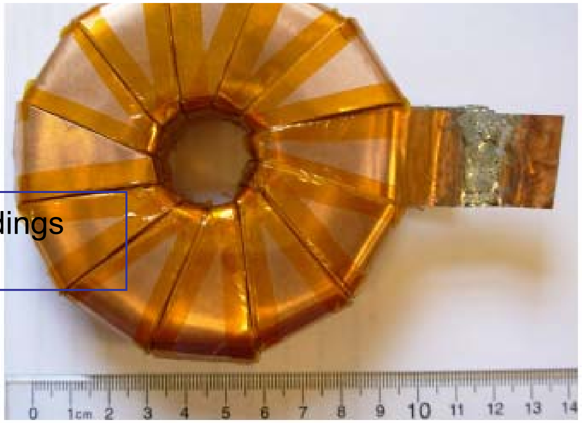


Fig. 6. Photograph of prototype.

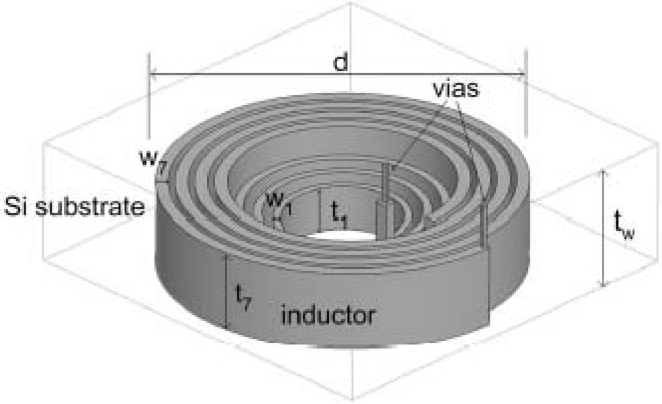
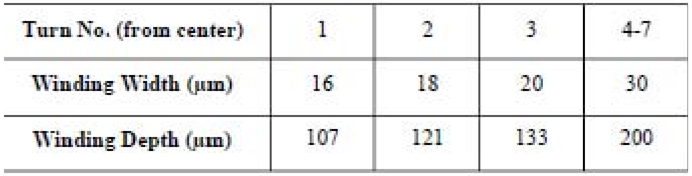


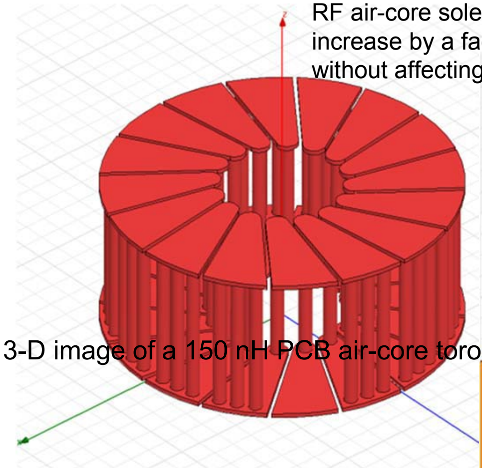
Fig. 4: Schematic 3-D view of TSECPI.

TABLE 1. WINDING DIMENSIONS FOR TSECPI

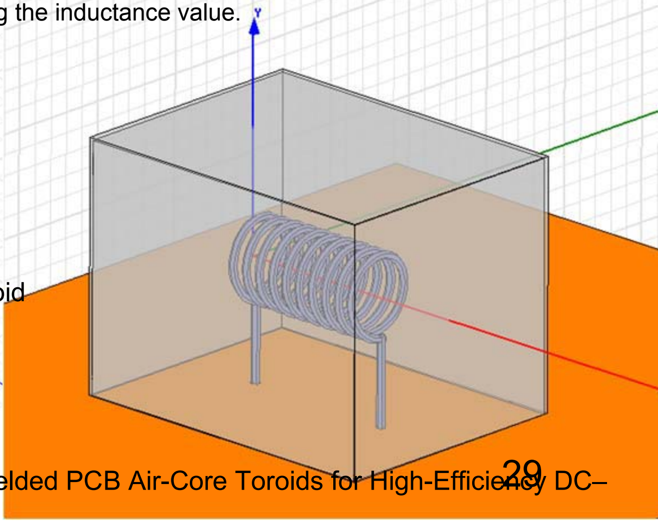


Turn No. (from center)	1	2	3	4-7
Winding Width (μm)	16	18	20	30
Winding Depth (μm)	107	121	133	200

X. Fang et al "A New Embedded Inductor for ZVS DC-DC Converter Applications"
Proceedings of the 2012 24th International Symposium on Power Semiconductor Devices and ICs 3-7 June 2012 - Bruges, Belgium



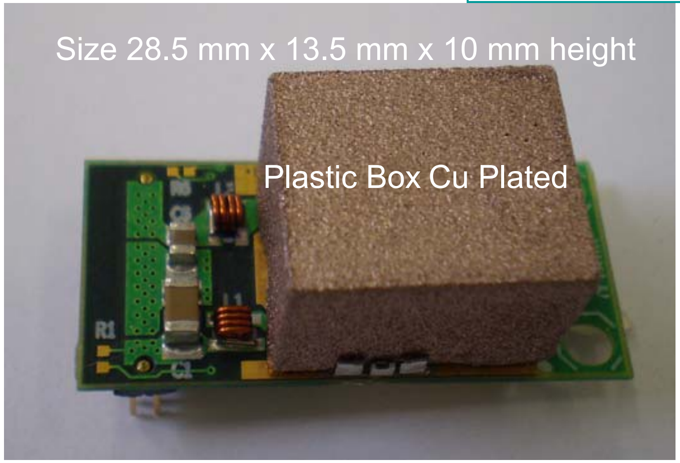
3-D image of a 150 nH PCB air-core toroid



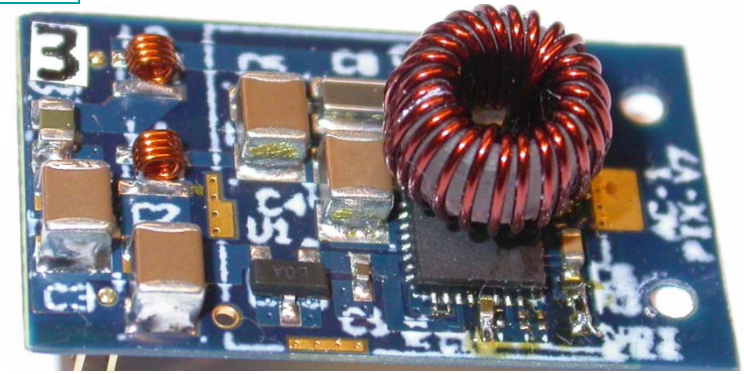
RF air-core solenoid under test with aluminum shield. The volume increase by a factor 9 is due to the necessity of reducing the noise emission without affecting the inductance value.

S. Orlando: Optimization of Shielded PCB Air-Core Toroids for High-Efficiency DC–DC Converters
IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 7, JULY 2011

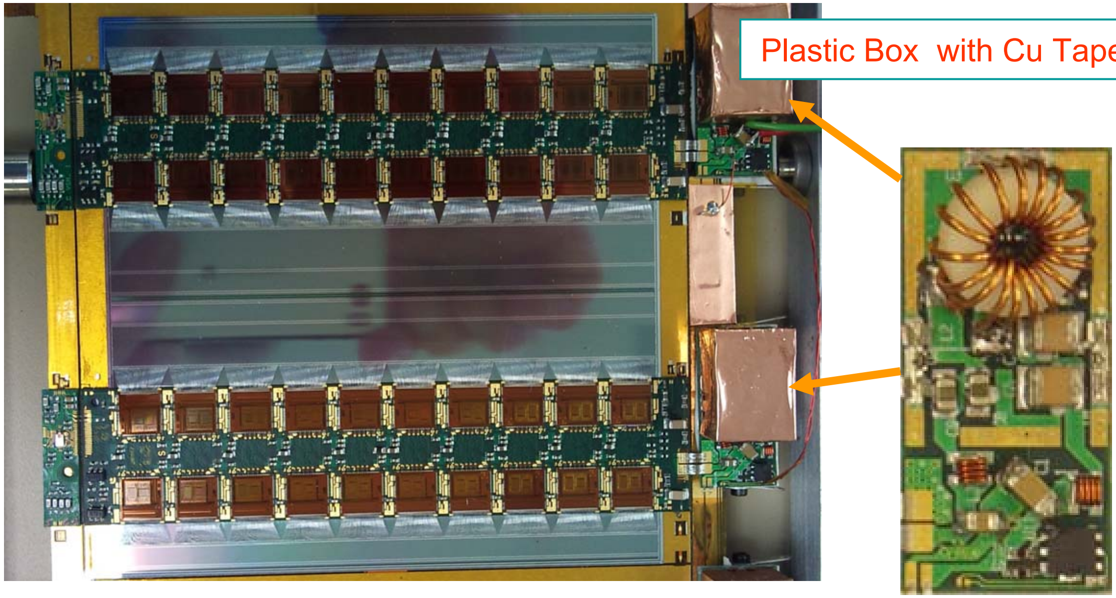
Converters with Toroid



F. Faccio: Development of DCDC converters @ CERN
http://project-dcdc.web.cern.ch/project-DCDC/public/Documents/SM01C%20Datasheet.pdf

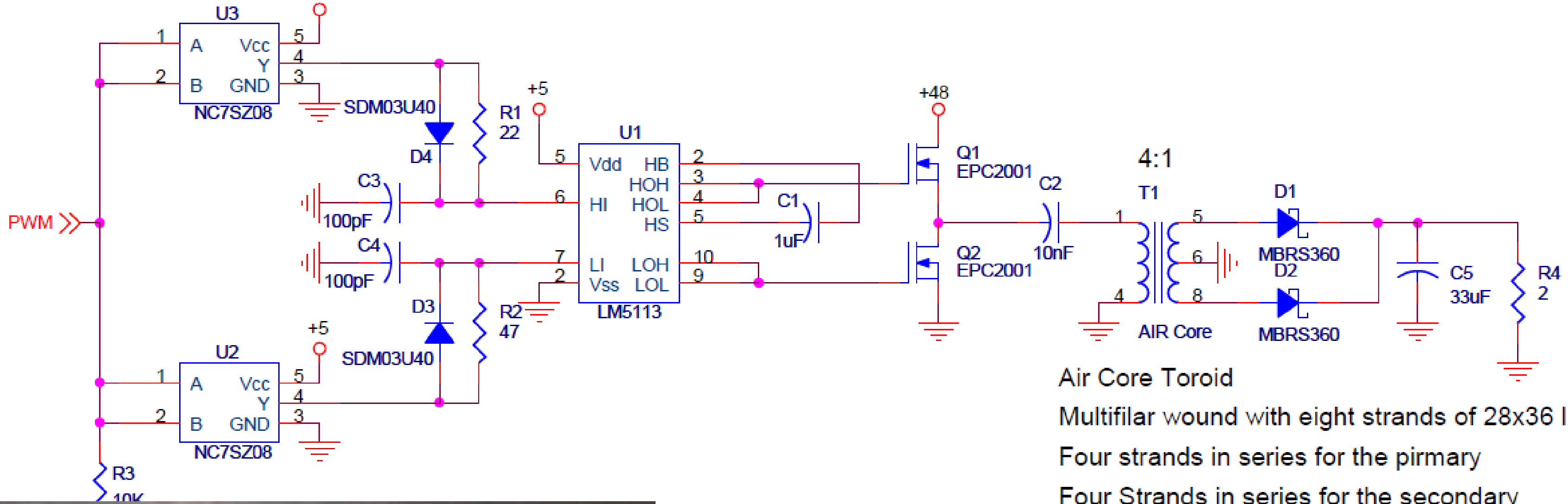


Katja Klein: DC-DC Converter Development for the CMS Pixel Upgrade
https://indico.cern.ch/conferenceDisplay.py?confId=127662



Plastic Box with Cu Tape for Shielding

ATLAS Stavelet Update: Upgrade- Peter Phillips



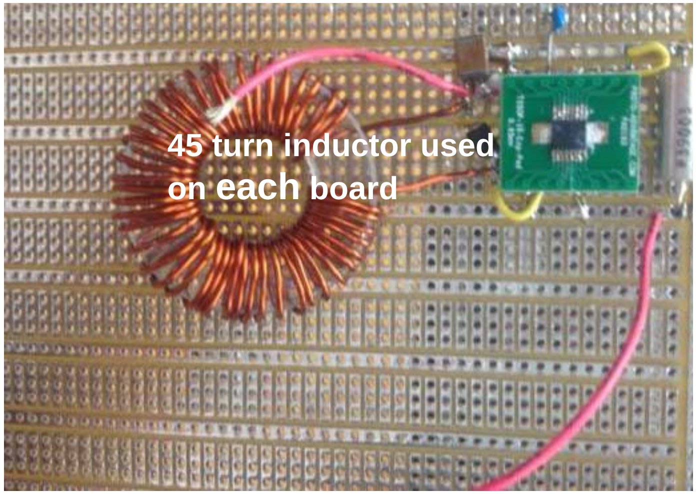
Air Core Toroid

Multifilar wound with eight strands of 28x36 litz wire

Four strands in series for the pirmary

Four Strands in series for the secondary

Hexafilar Transformer
with Litz wire 28x36
ID= 25 mm



45 turn inductor used
on each board

Sten Hansen: Fermilab

GaN Target Markets

Applications of 600 V GaN Devices

1. AC to 380 V with Power Factor Correction (PFC)
2. 380 V – 48 V Isolated converter
3. Motor Drive PWM
   15 KHz is audible
   100 KHz is not audible & 5% higher Efficiency

Applications of < 200 V GaN Devices

1. 48 V to 1-12 V Converters. Smaller size compare to Silicon
2. 12 V to 1 V Point of Load regulator
3. Power Supply on a chip - High Frequency operation
4. Wireless Power – Battery Chargers

Enhancement Mode: Can make low voltage devices
Depletion mode: Can't make low voltage devices because
the Cascode does not work

GaN Company: EPC

PRODUCT BRIEF eGaN® FET Low Voltage Family

eGaN FETs Save Space

By combining the smaller-size eGaN FETs and their ability to efficiently operate at much higher frequencies, point-of-load (POL) converters can be made smaller and realize higher transient response capability. In this example the eGaN FET-based system is 34% smaller (184 mm² vs. 121 mm²) and operates at 800 kHz with no efficiency penalty.

Size comparison between 300 kHz MOSFET buck (Red) and 800 kHz eGan FET buck (Orange)

eGaN FET Low Voltage Product Family

Part Number	Package (mm)	RoHS & Halogen Free	$T_{J(MAX)}$ (°C)	V_{DS}	V_{GS} (max)	Max $R_{DS(ON)}$ @5V_{GS}	Q_G typ (nC)	Q_{GS} typ (nC)	Q_{GD} typ (nC)	Q_{OSS} typ (nC)	V_{TH} typ	Q_{RR} (nC)	I_D (A)
EPC2015	LGA 4.1x1.6	Yes	150	40	6	4	10.5	3.0	2.2	18.5	1.4	0	33
EPC2014	LGA 1.7x1.1	Yes	150	40	6	16	2.5	0.67	0.48	4.8	1.4	0	10
EPC2001	LGA 4.1x1.6	Yes	125	100	6	7	8.0	2.3	2.2	35	1.4	0	25
EPC2007	LGA 1.7x1.1	Yes	125	100	6	30	2.1	0.5	0.6	10	1.4	0	6
EPC2010	LGA 3.6x1.6	Yes	125	200	6	25	5.0	1.3	1.7	40	1.4	0	12
EPC2012	LGA 1.7x0.9	Yes	125	200	6	100	1.5	0.33	0.57	11	1.4	0	3

Development Boards

Part Number	Description	V_{DS} (max)	I_D (max RMS)	Featured Product	Schematic	Gerber	Bill of Materials
EPC9001	Half Bridge Plus Driver	40	15	EPC2015	Yes	Yes	Yes
EPC9002	Half Bridge Plus Driver	100	10	EPC2001	Yes	Yes	Yes
EPC9003	Half Bridge Plus Driver	200	5	EPC2010	Yes	Yes	Yes
EPC9004	Half Bridge Plus Driver	200	3	EPC2012	Yes	Yes	Yes
EPC9005	Half Bridge Plus Driver	40	7	EPC2014	Yes	Yes	Yes
EPC9006	Half Bridge Plus Driver	100	5	EPC2007	Yes	Yes	Yes

Demo Circuits

Part Number	Description	V_{IN}	V_{OUT}	I_{OUT}	Featured Product	Schematic	Gerber	Bill of Materials
EPC9101	19 V to 1.2 V Buck Converter	8V-19V	1.2V	18 A	EPC2015/ EPC2014	Yes	Yes	Yes
EPC9102	48 V to 12 V Brick Converter	36V -60V	12V	17 A	EPC2001	Yes	Yes	Yes

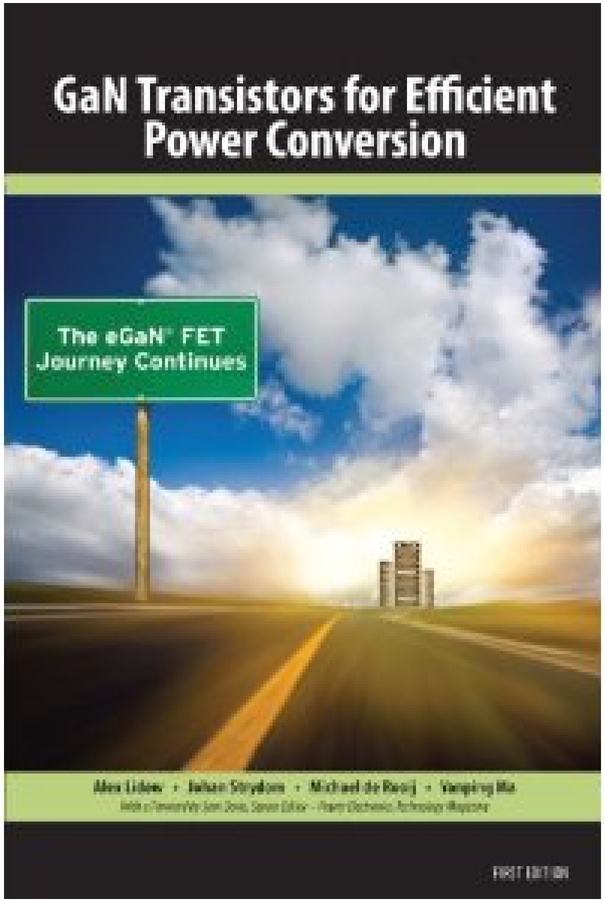
EPC
EFFICIENT POWER CONVERSION

Purchasing eGaN FET Products

EPC Products are distributed exclusively through Digi-Key.

Digi-Key CORPORATION

eGaN is a registered trademark of Efficient Power Conversion Corporation, Inc.



GaN Transistors for Efficient Power Conversion

Alex Lidow • Johan Strydom • Michael de Rooij • Yanping Ma

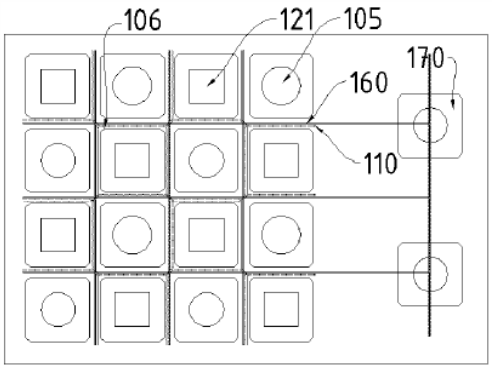
FIRST EDITION

eGaN® FETs for Space Applications

Radiation Tolerant Enhancement Mode Gallium Nitride (eGaN®) FET Characteristics

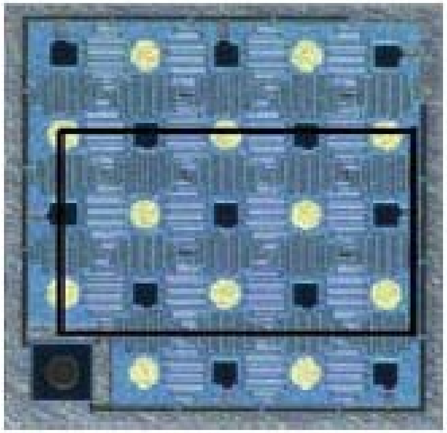
Sold @ Amazon.com

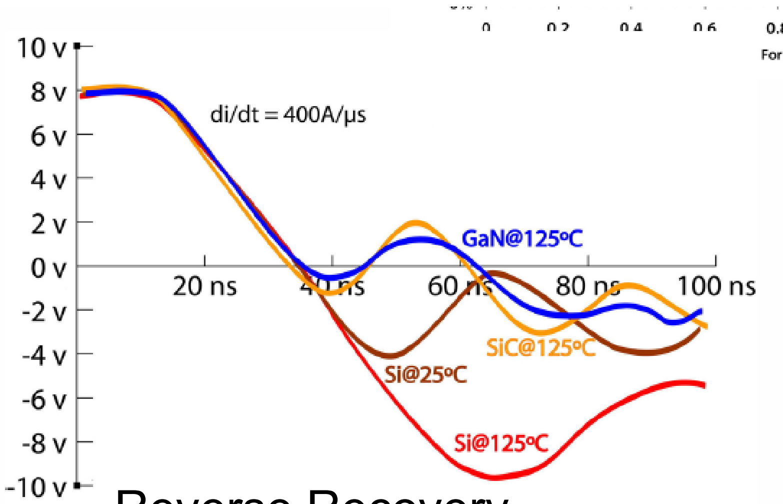
GaN Company: **GaN Systems**



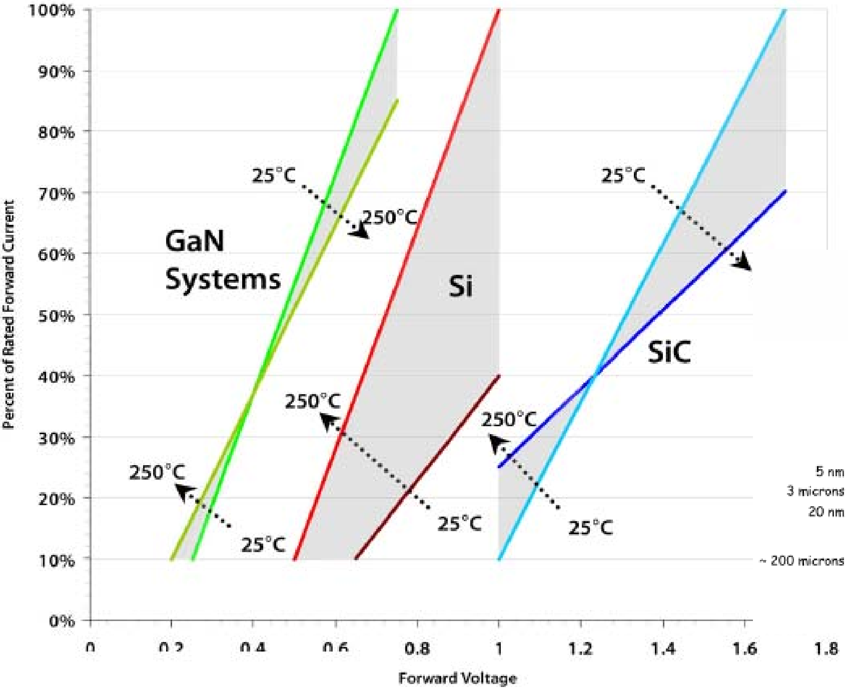
Island Technology

2mm x 2mm 1200 V 24 A

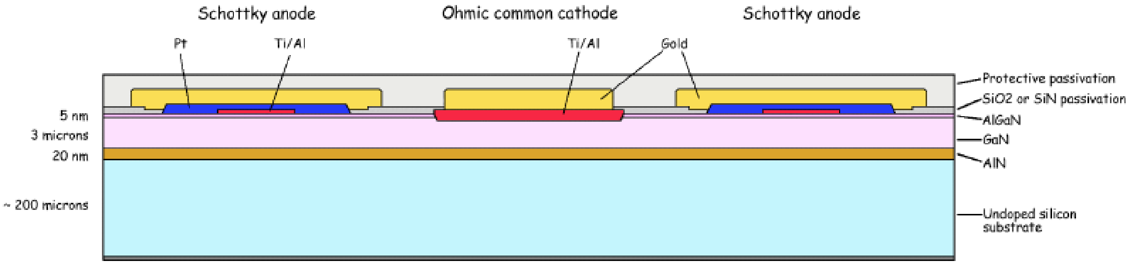




Reverse Recovery



The low forward voltage of our first devices is due to the dual metal Schottky diode arrangement incorporated in our designs

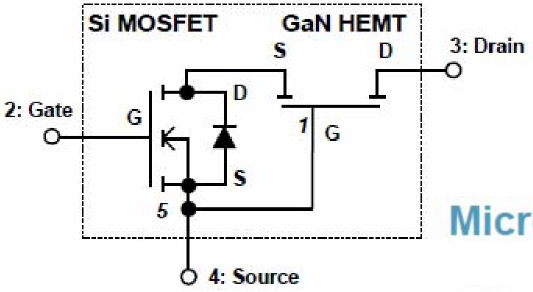


GaN Company: MicroGan

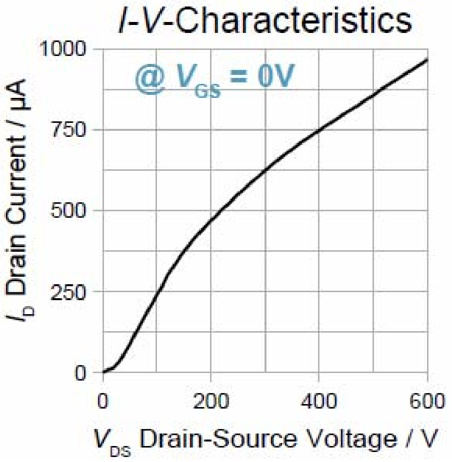
MicroGaN 600V N-OFF Switch

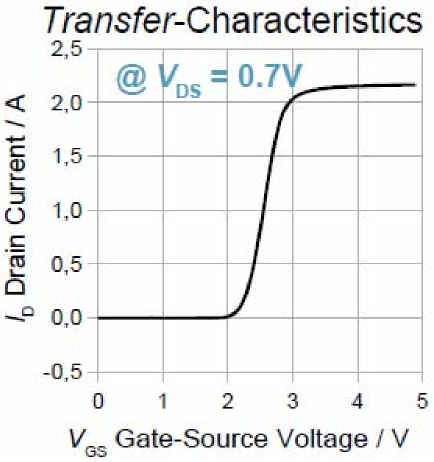
C_{OSS} = 42pF

R_{DSon} = 320mΩ



5LD TO-263



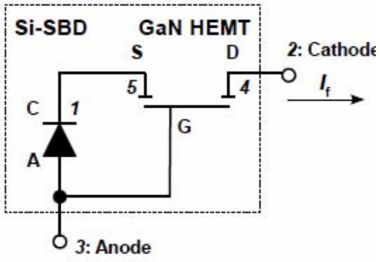


MicroGaN 600V Schottky Barrier Diode

Q_D = 18.6nC

V_b = 0.3V

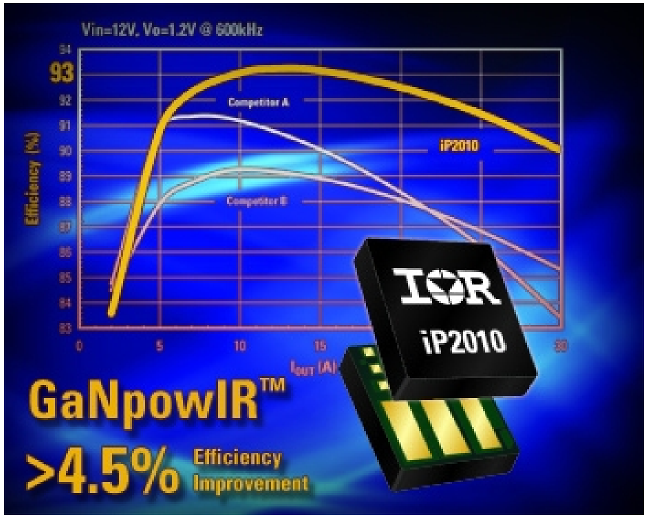
I_F = 4A



5LD TO-263

GaN Company: International Rectifier

GaN on Si



6 times Higher Frequency over Si Solution with similar efficiency !

Silicon based POL :
15 mm x 15 mm

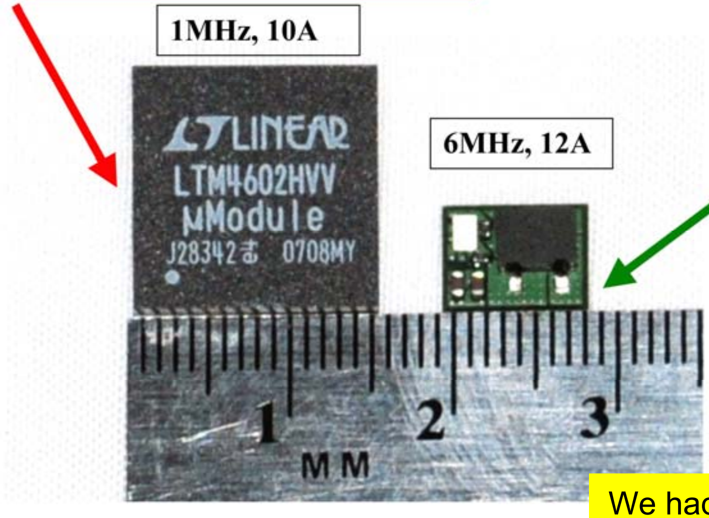
1MHz, 10A

IR GaNpowIR

Gen 1.1 Solution:
6 mm x 9 mm….

75 +% Smaller!

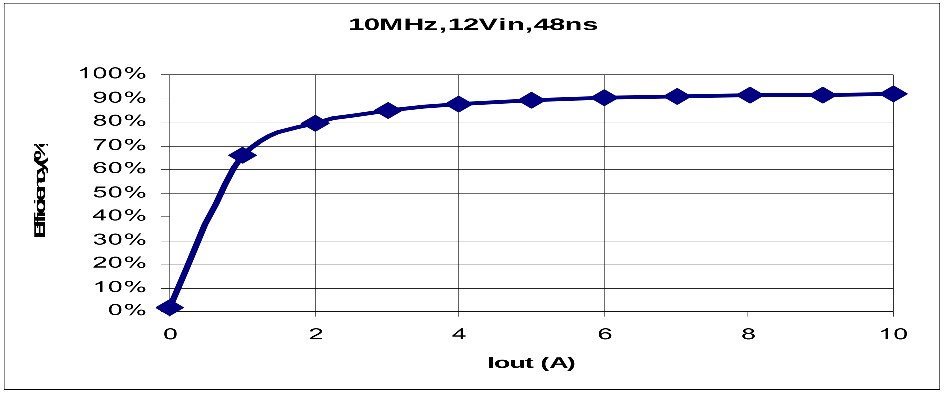
6MHz, 12A



Output Inductor
Integrated with
Power Stage

We had a later version
of the Engineering sample

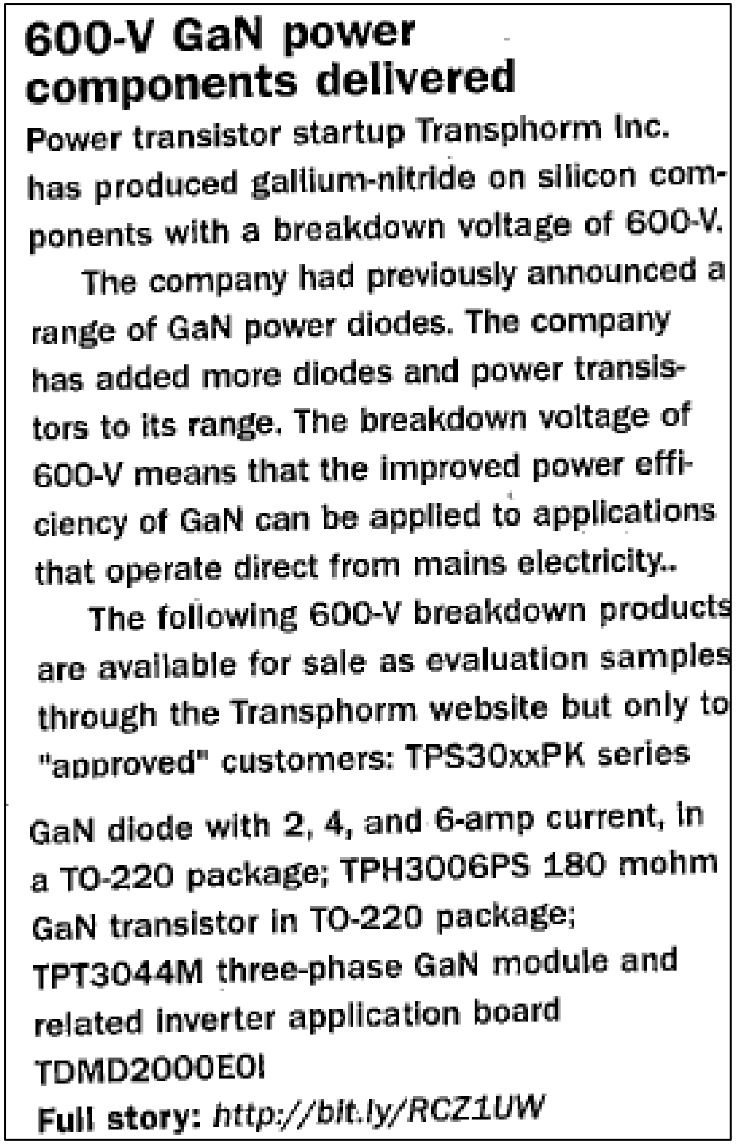
Part Number iP2010TRPBF
Vin + 7 – 13.20.6 (V)Vout Range
Vout = 0.6 – 5.5 V
Iout = 20 A.
Frequency 250 kHz – 3 MHz
Size = 7.7 x 6.5mm LGA - 5.530250 – 3,000



600 V in Development

GaN Company: Transphorm

Company backed by $63 million from Quantum Strategic Partners Ltd. and existing venture investors Kleiner Perkins, Google Ventures, Foundation Capital, and Lux Capital



600-V GaN power components delivered

Power transistor startup Transphorm Inc. has produced gallium-nitride on silicon components with a breakdown voltage of 600-V.

The company had previously announced a range of GaN power diodes. The company has added more diodes and power transistors to its range. The breakdown voltage of 600-V means that the improved power efficiency of GaN can be applied to applications that operate direct from mains electricity..

The following 600-V breakdown products are available for sale as evaluation samples through the Transphorm website but only to "approved" customers: TPS30xxPK series

GaN diode with 2, 4, and 6-amp current, in a TO-220 package; TPH3006PS 180 mohm GaN transistor in TO-220 package; TPT3044M three-phase GaN module and related inverter application board TDMD2000E0I

Full story: *http://bit.ly/RCZ1UW*

Transphorm Inc. today announced the JEDEC qualification of the company's TPH2006PS, GaN HEMT on SiC substrate, making it the industry's first qualified 600V HEMT device. The TPH2006PS, based on its patented, high-performance EZ-GaN™ technology, combines low switching and conduction losses resulting in reduced energy loss of up to 50% compared to conventional silicon-based power conversion designs, today. The TO-220-packaged device features RDS(on) of 150 mΩ, Qrr of 42 nC and high frequency switching capability that enables compact, lower cost systems September 13, 2012

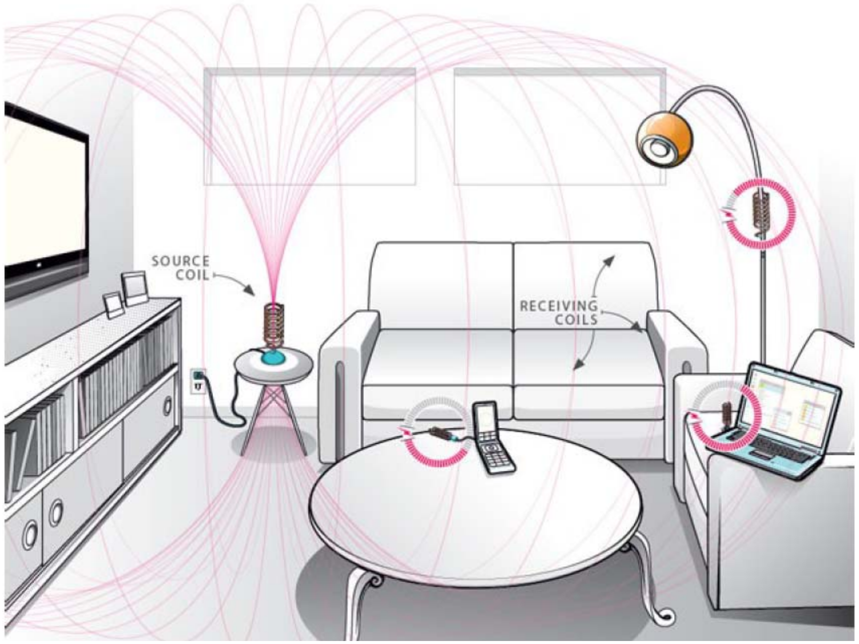
Transphorm awarded for advancing GaN power technology

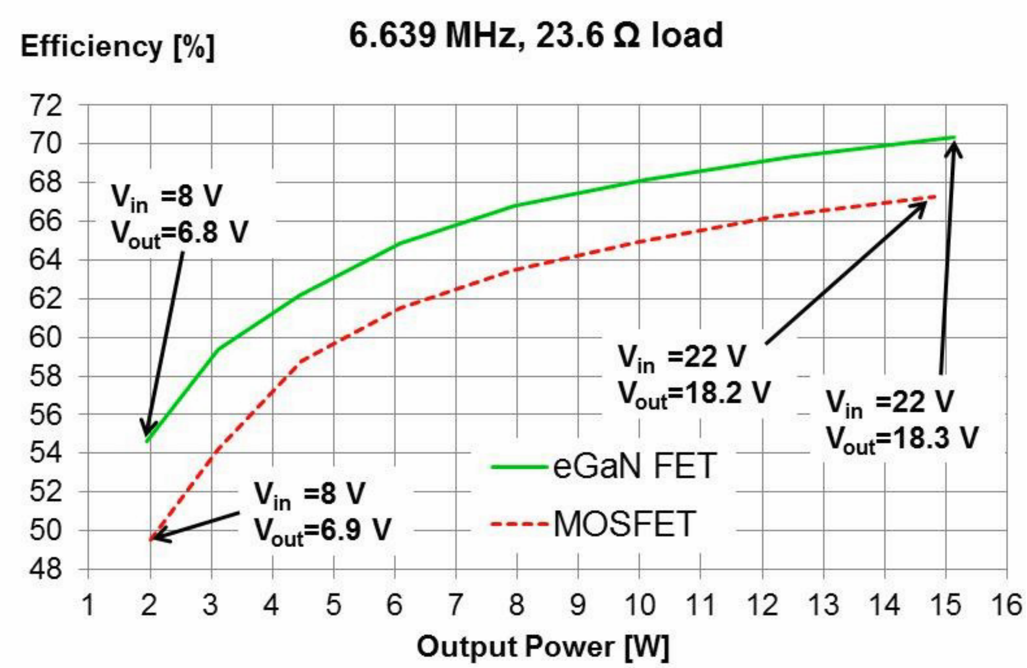
Sep 19, 2012

The innovator of gallium nitride design and process technologies has been honoured for enabling implementation of highly-efficient power conversion systems

Transphorm has been selected by the World Economic Forum as a 2013 Technology Pioneer, citing the company's innovations in GaN technology

Wireless Power





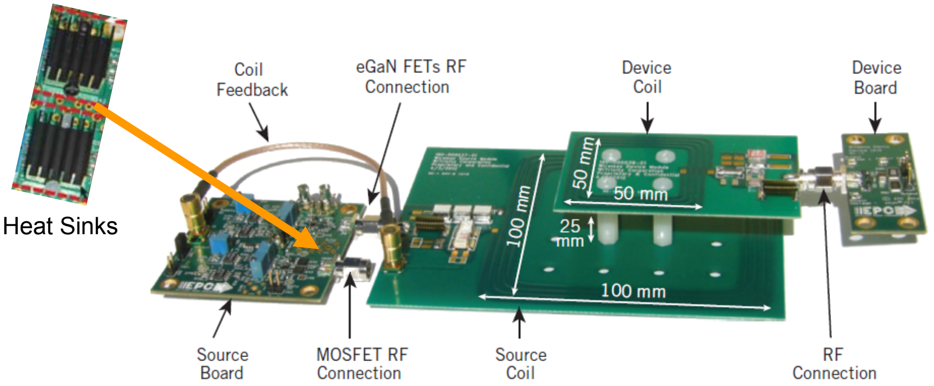
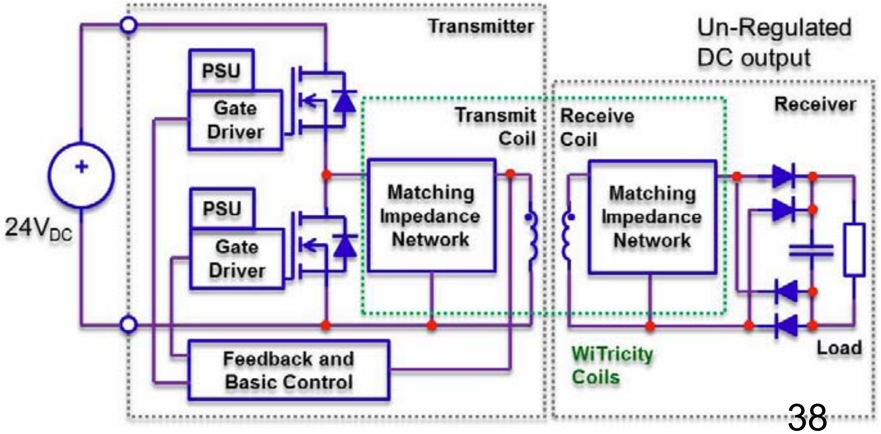
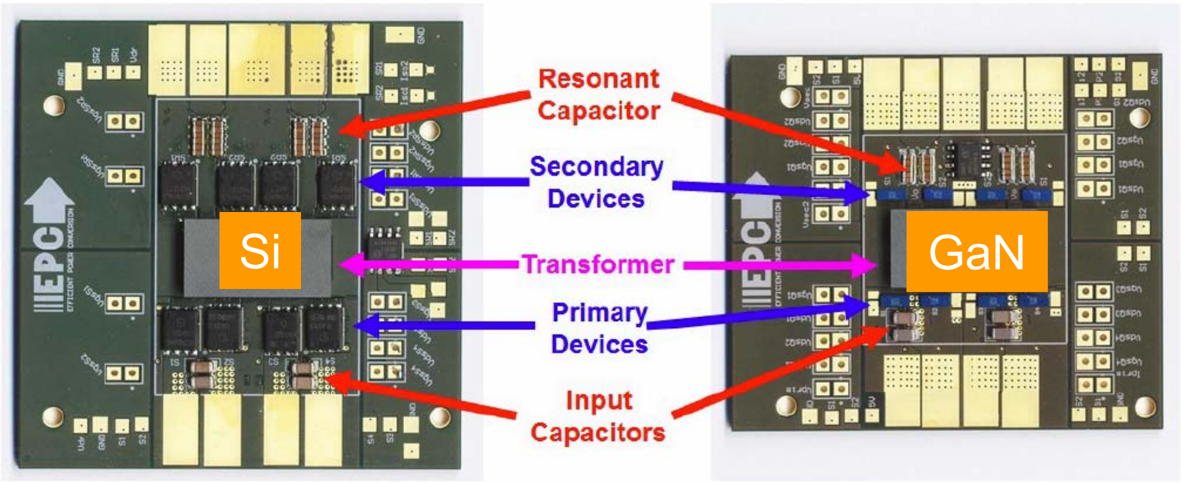


Fig. 3. Wireless energy system setup, with 50Ω SMA connectors used to interconnect each board. Boards were co-developed by EPC and WiTricity.

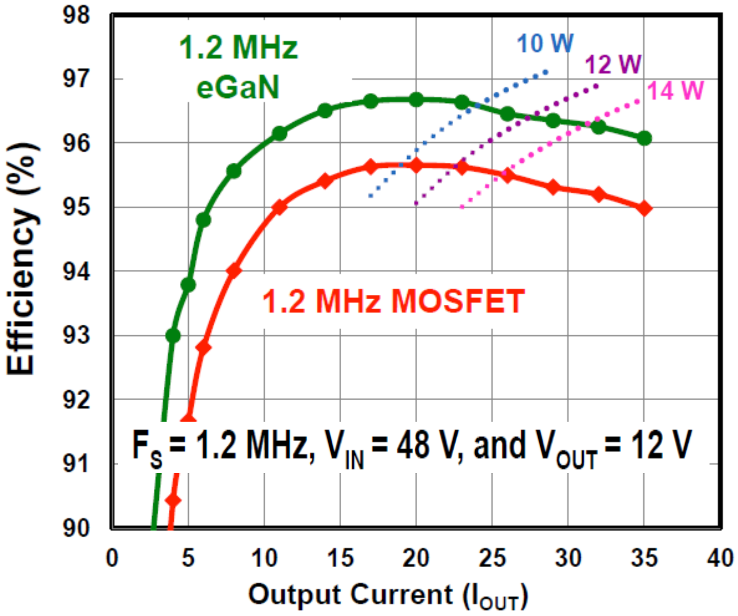


Ref: WiTricity & EPC

GaN Vs MOSFET Resonant Converters

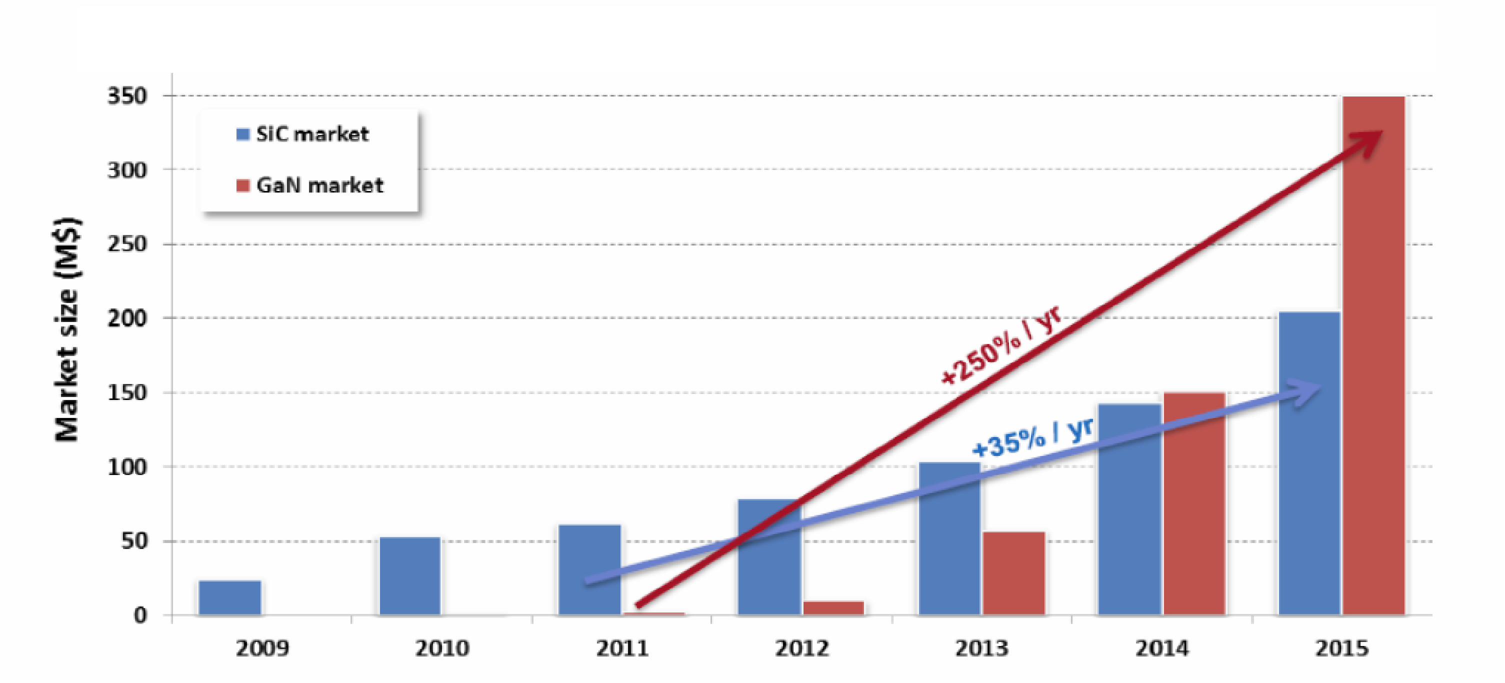


Converters
Hard Switch: ???
Resonant: ?????



Loss Power
Output limited by Heat Removal

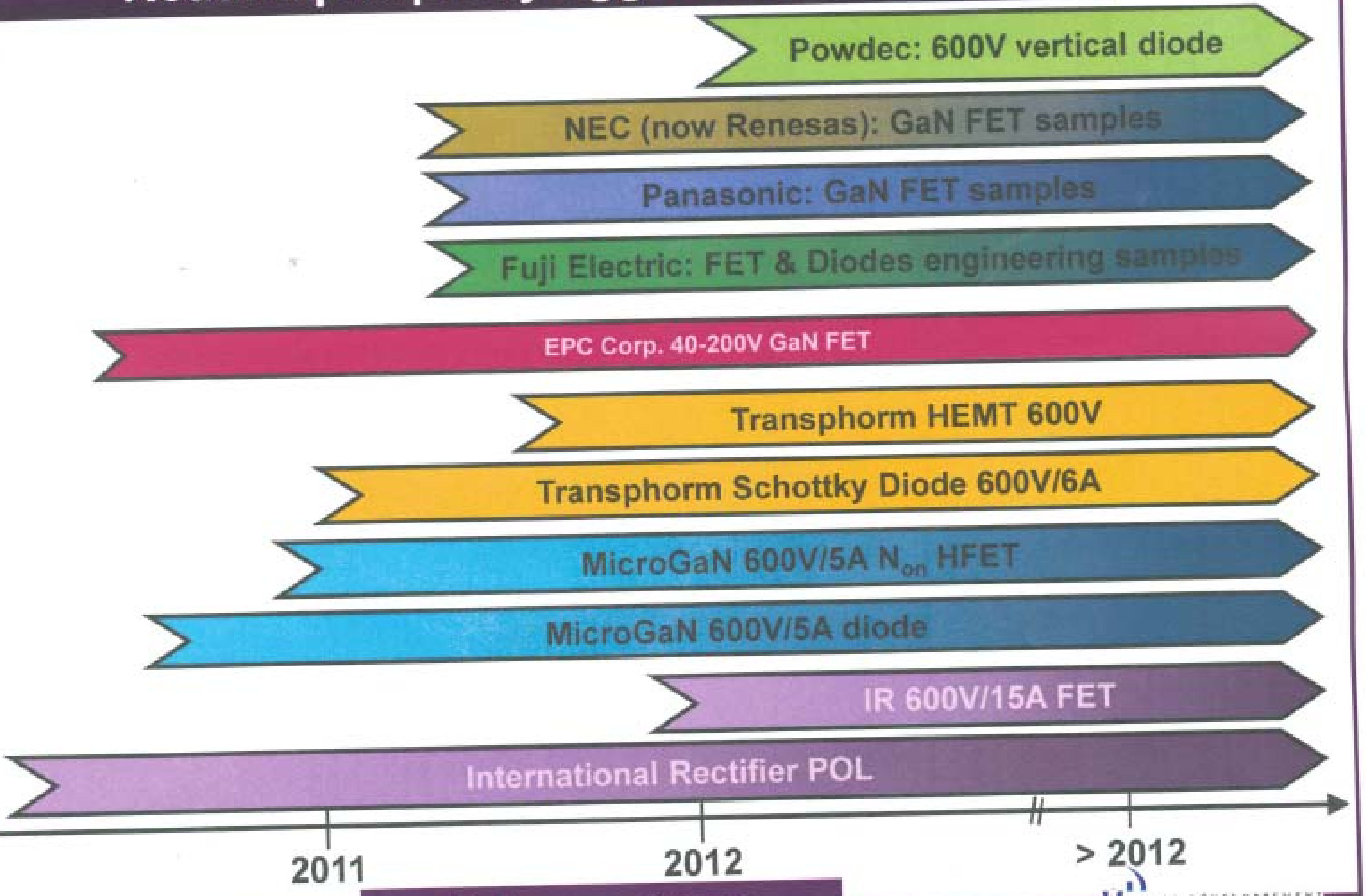
GaN Market Projection



Total = $350M for GaN in 2015

Source: Yole Development

2010 was the start for GaN power products.
Roadmap is pretty aggressive


Powdec: 600V vertical diode

NEC (now Renesas): GaN FET samples

Panasonic: GaN FET samples

Fuji Electric: FET & Diodes engineering samples

EPC Corp. 40-200V GaN FET

Transphorm HEMT 600V

Transphorm Schottky Diode 600V/6A

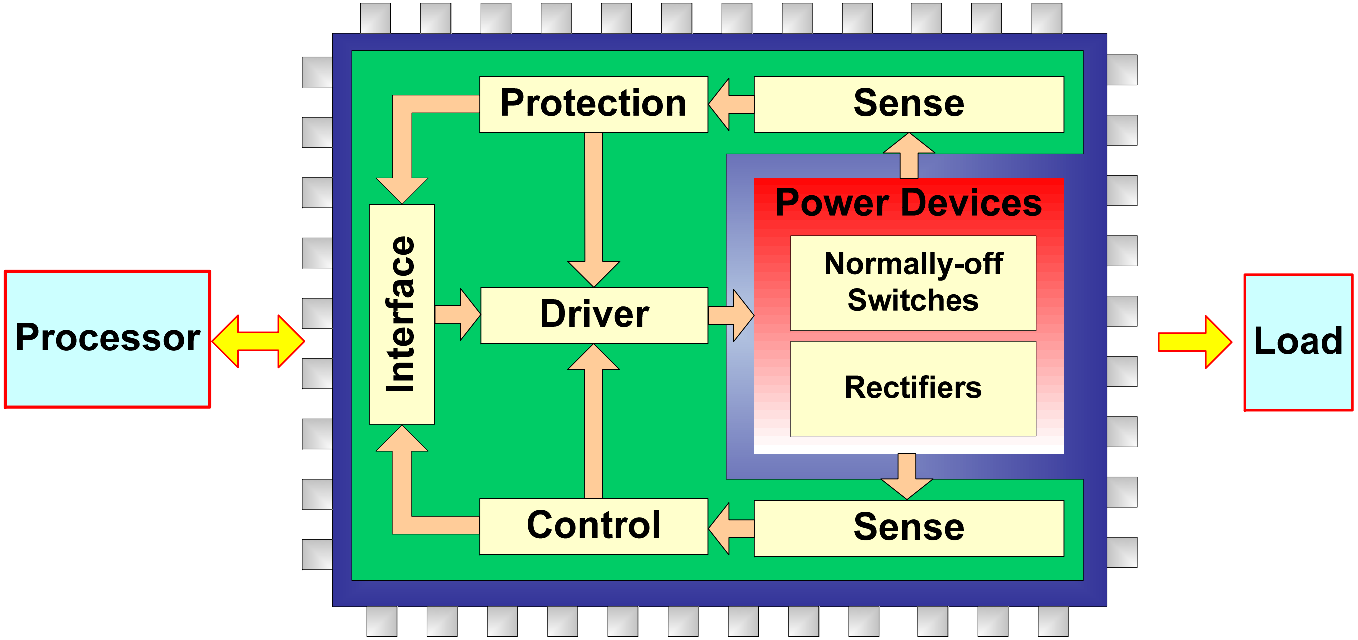
MicroGaN 600V/5A N_{on} HFET

MicroGaN 600V/5A diode

IR 600V/15A FET

International Rectifier POL

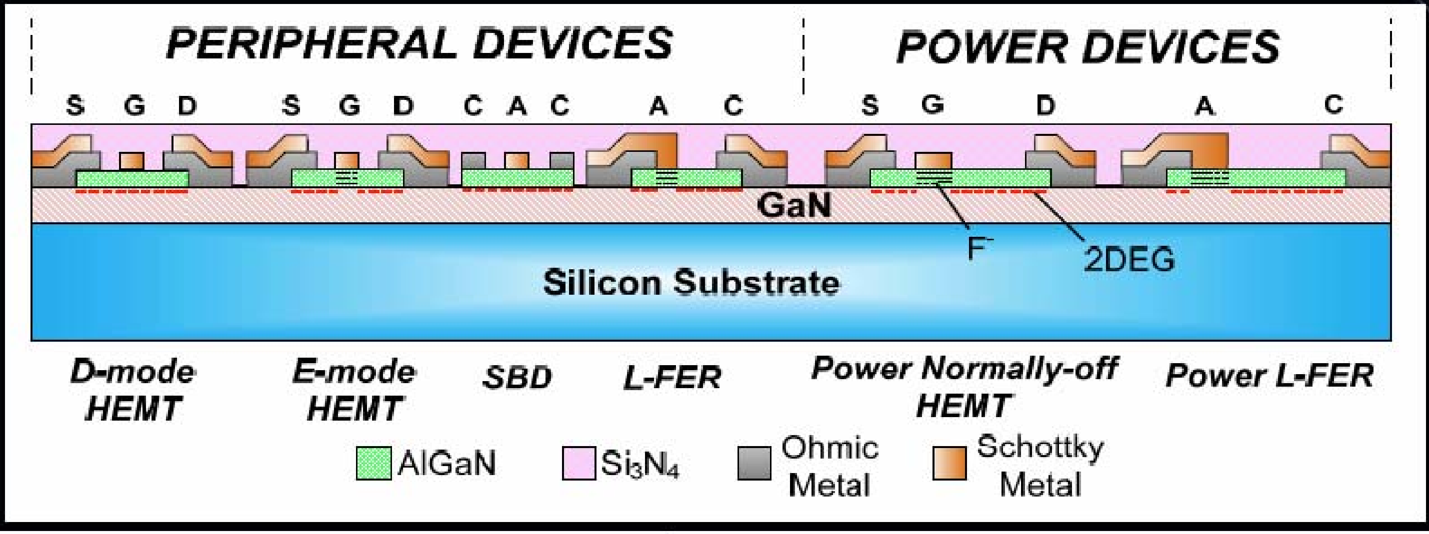
Implementation of GaN power modules



- **Multi-chip modules:** GaN(power)+Si CMOS (peripheral circuits)
→ quick design turn-around, development is underway
→ *operating temperature limit set by Si*
- **All-GaN single-chip solution**: long development time for GaN digital/analog ICs, wide temperature range

42

GaN Smart Power Technology Platform

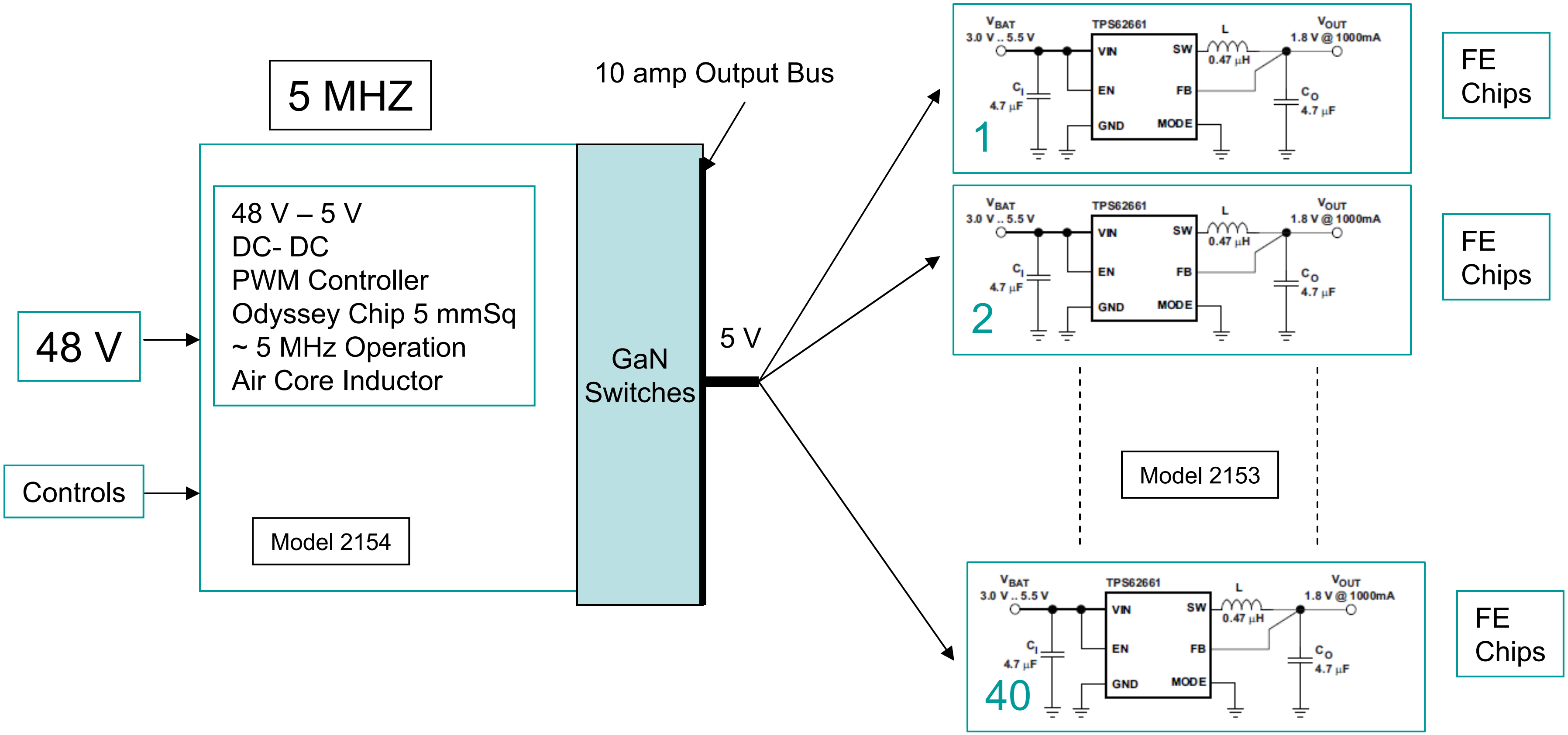


Power Devices	Smart Part	
❖ Normally-off HEMT ❖ Lateral Field-Effect Rectifier (L-FER)	**Digital:** Direct-coupled FET logic (DCFL)	**Analog:** Sensing & Protection

Model 2153 & 2154

2 Step Power Converter Distribution

20 MHZ



5 MHZ

10 amp Output Bus

48 V

Controls

48 V – 5 V
DC- DC
PWM Controller
Odyssey Chip 5 mmSq
~ 5 MHz Operation
Air Core Inductor

Model 2154

GaN
Switches

5 V

1

2

40

FE
Chips

FE
Chips

FE
Chips

Model 2153

Standard 6 BGA csp package
0.4 mm pitch
Air Core Inductor

48V – 5V 10 amps

5V – ~ 1.2V 1 amp: 40 Loads

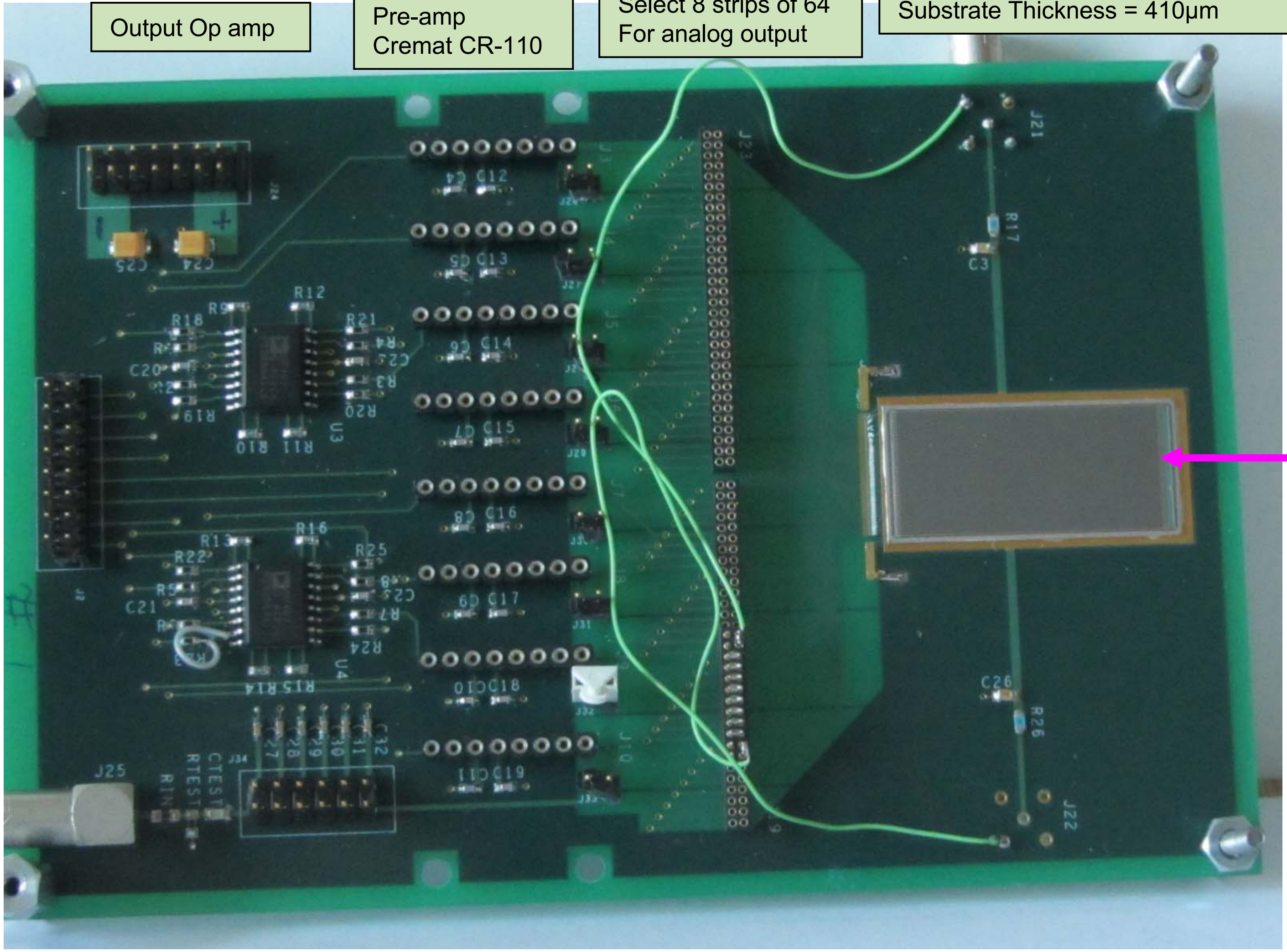
Test Silicon Strip Detector with Analog Readout

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

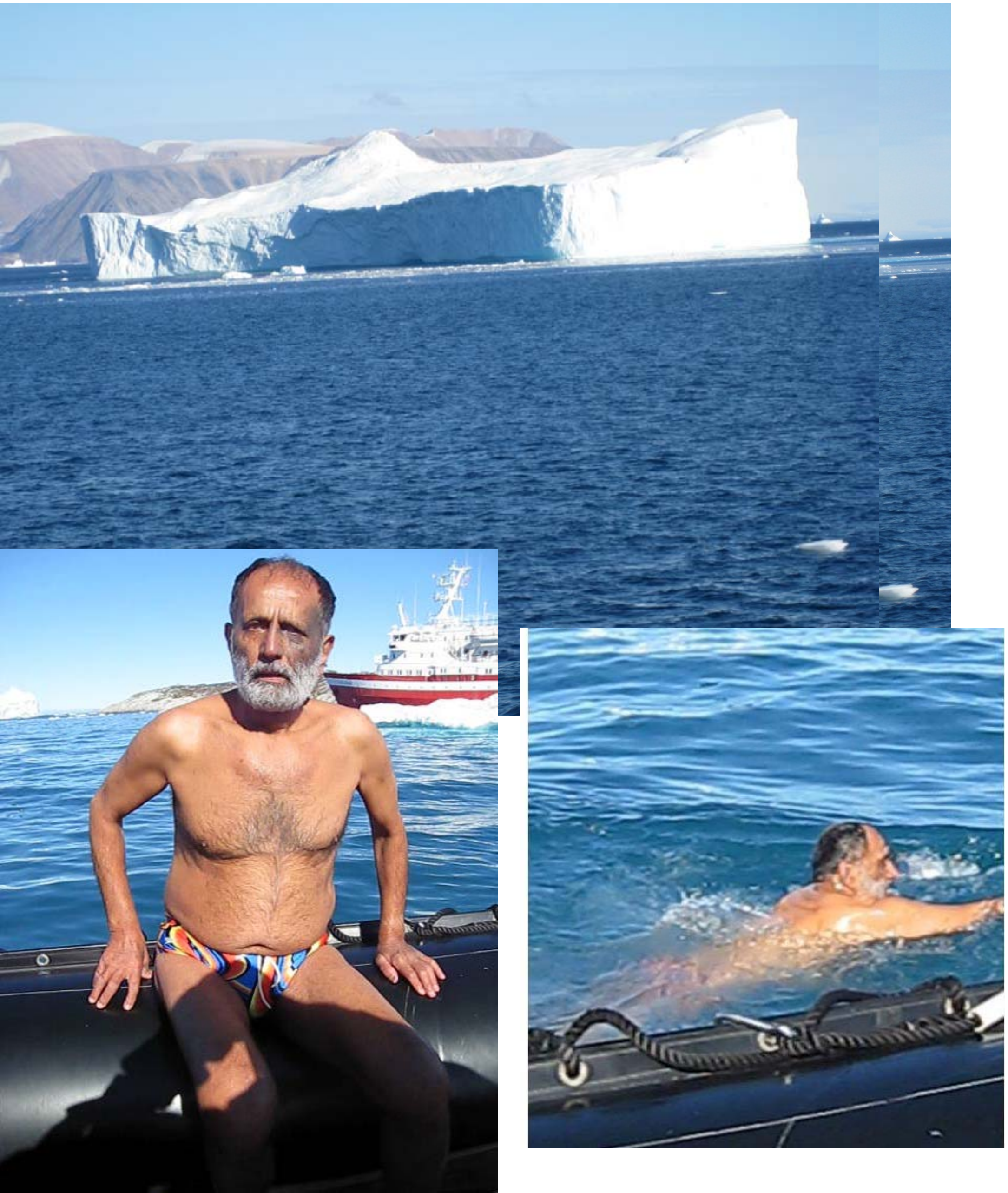


64 Parallel Al Strips
Length = 35 mm
Width = 56µm
Pitch = 228 µm

Summary/ Conclusions

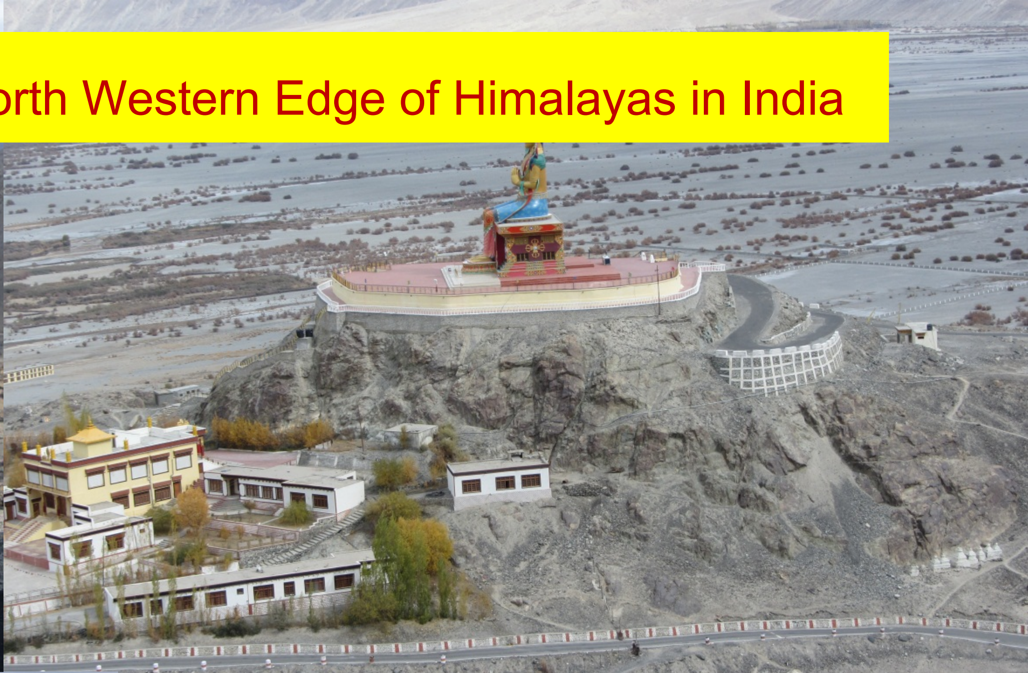
- Portable Devices will have big impact on Physics Power Distribution
- First Stage: Single Die with air core Inductor on Die/PCB
- Second Stage: MCM with PWM , Power Switch with Driver & Inductor
- Power Delivery 380 V DC from Power Cavern to isolated BUCK Converter & then 48 V into Detector
- Improve power efficiency – Glaciers are melting > Good / Bad ?

Greenland. What a view & Swimming next to Icebergs is Great



Recent New York Times Report
Soon no summer ice
Glacier melting ? Expose minerals

LADAKH- North Western Edge of Himalayas in India



2011

Prayer Flags

Working on Physics Power Supply Is not considered Glamorous

Top of the World is Cool but lonely !
Let us keep it cool with highly efficient PS
Swimming is Great at the North Pole

On the way to North Pole 2001

More Details: http://shaktipower.sites.yale.edu Click on Recent seminars/

END

http://shaktipower.sites.yale.edu/