Powering of Future Detector Electronics - commercial solutions?

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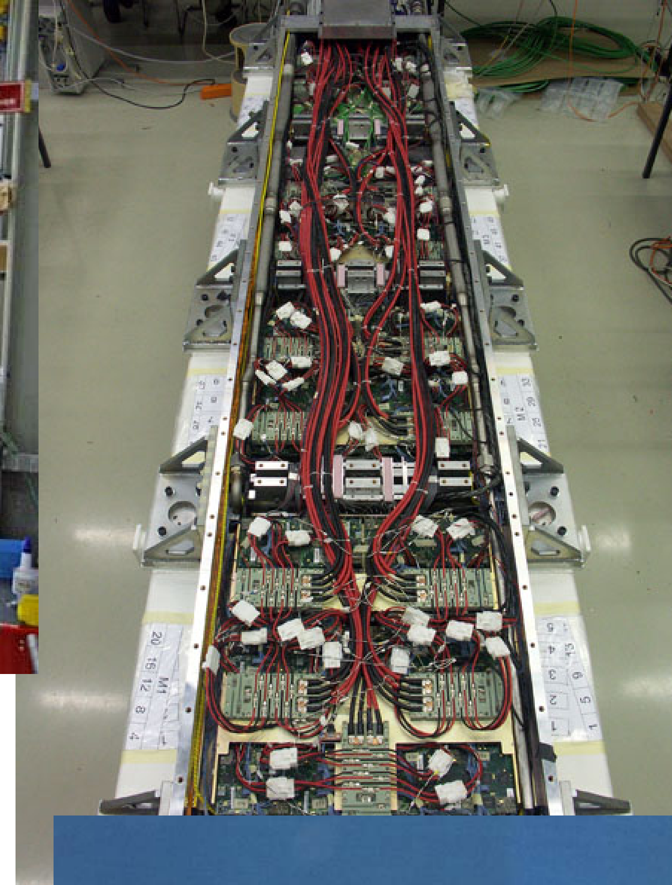
Yale University

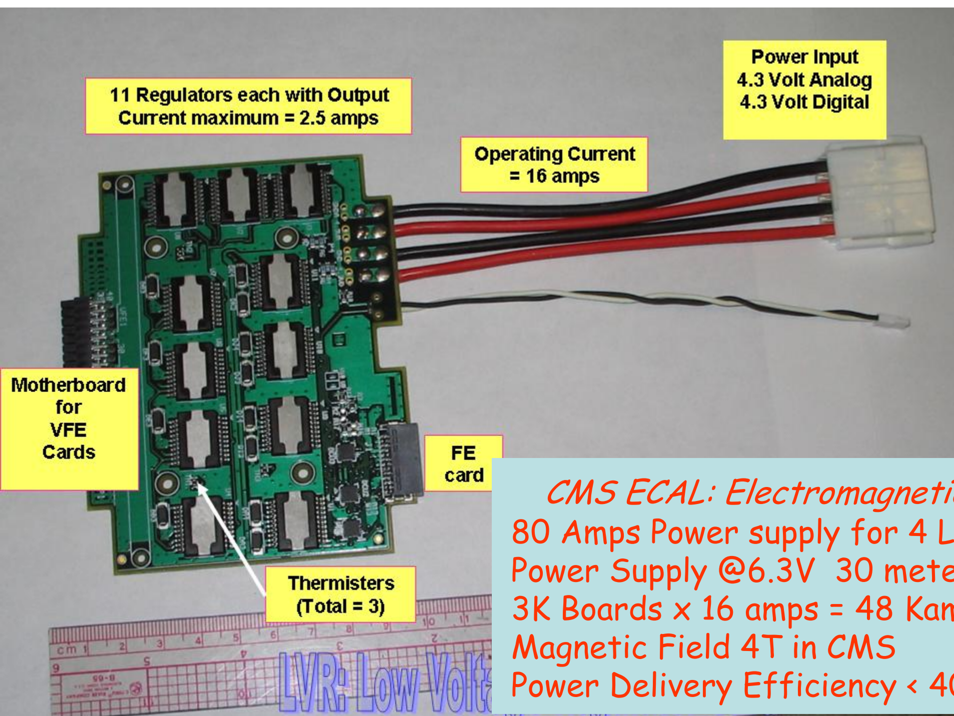
SiD Workshop at Argonne National Laboratory
June 3-5, 2010

Agenda

- Power efficiency issues / problems CMS-ECAL Example
- What can we do?
- A commercial Rad Hard Converter - EN5360 can still buy it
- Buck Converter
- Plug in cards with Air Coil
- Noise Test with Detectors
- Magnetic Field 7 T – no effect
- Why need Thin Oxide
- LDMOS: Radiation Test Results
- GaN Wide band Gap materials
- Converters 36V – 1.2V & 48V -1.8
- Industry Developments & Market Trends
- Power Pulsing for SiD
- Power Supply Current Reduction
- Remarks / Milestones

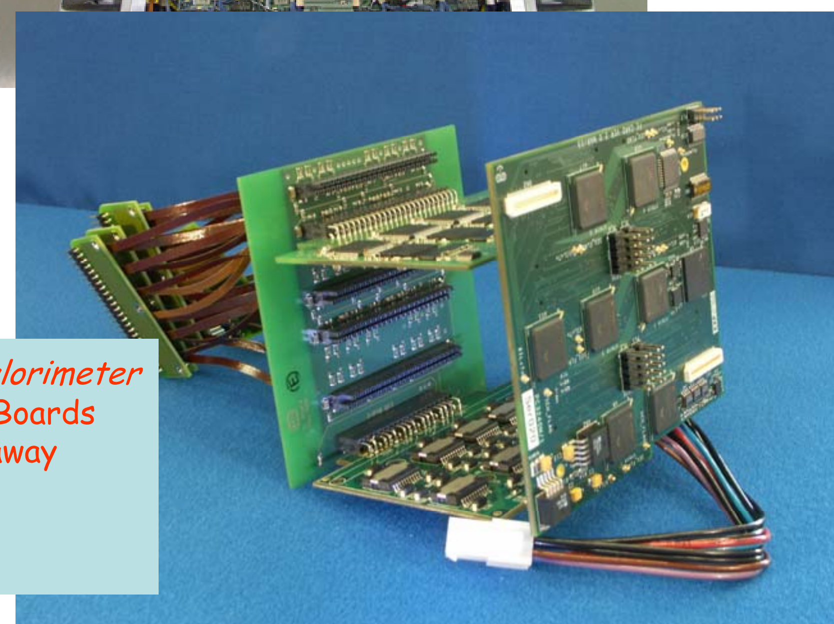
Collaborators:
Yale University: Keith Baker, Hunter Smith





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 %



CMS ECAL: 5 Oodles (50 Kamps) .

Power Supply output = 315 KW
Power loss in Leads to SM = 100 KW
Power loss in Regulator Card = 90 KW
Power Delivered @ 2.5 V = 125 KW

1 Oodle = 10,000 amps

# 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.

Power Supply
6.3 V

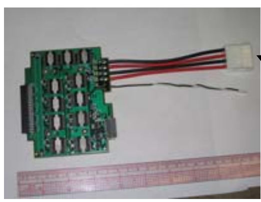
64 Amps

30 m

Vdrop = 2V
Pd = 128 W

50 mm^2 (AWG 00)

SM: Super Module



4.3 V

Junction Box

2x16 mm^2 (AWG 6)

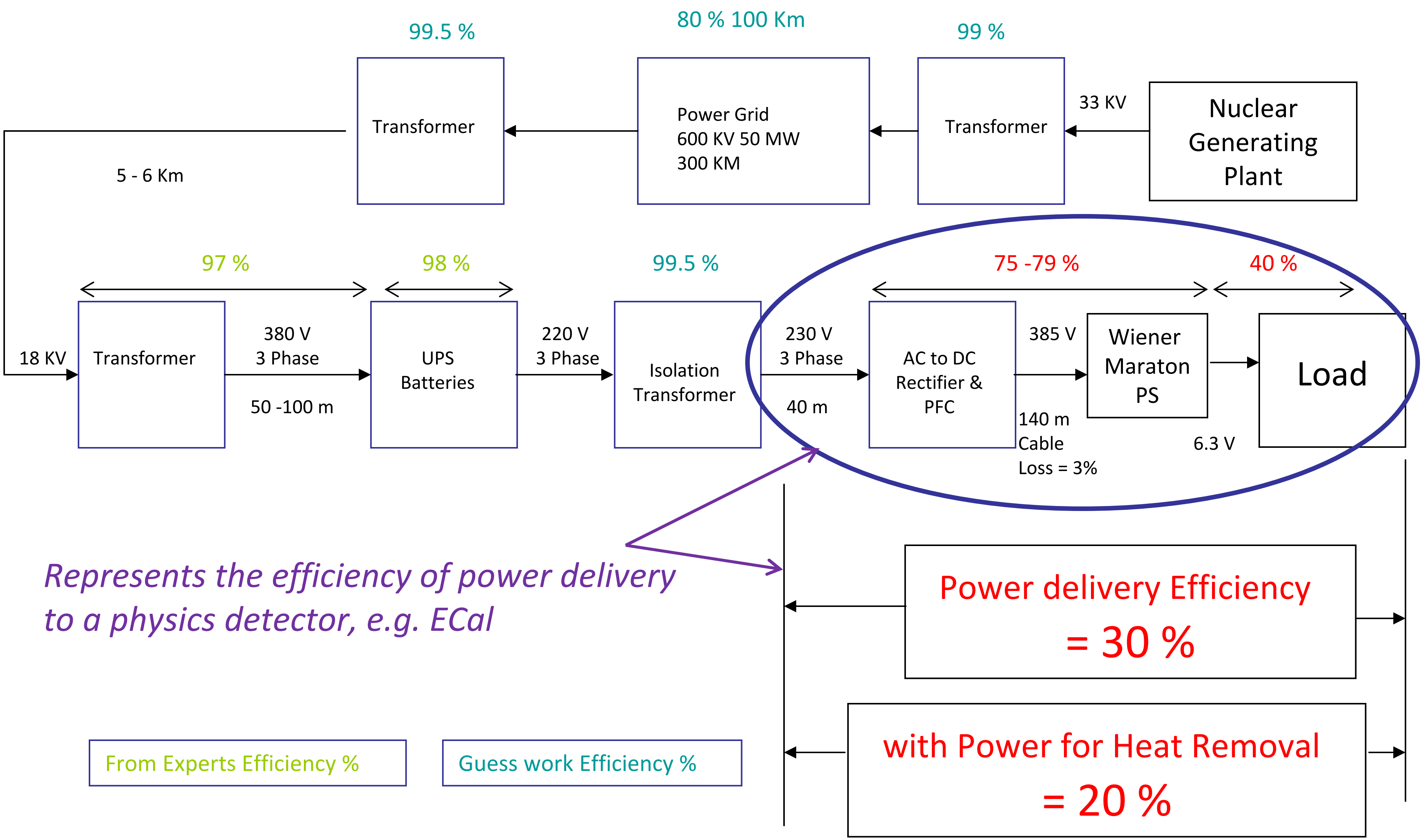
1 to 3 m

2.5V
64 amps
160 W

4 LVR Boards

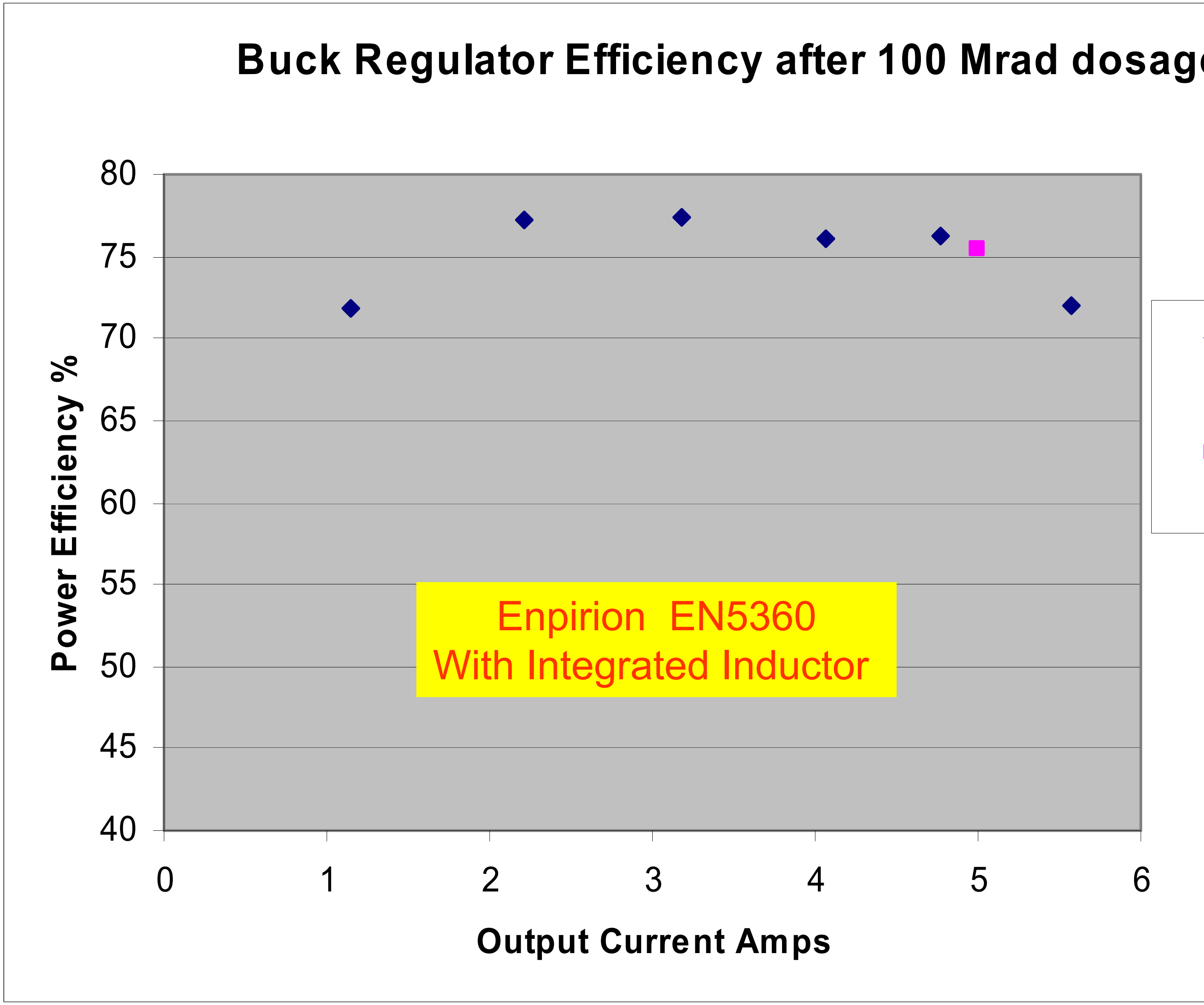
Power Delivery Efficiency = 40%
NOT INCLUDED
1. Power Supply efficiency
2. Water cooling
3. Removal of Waste heat
4. Air Conditioning

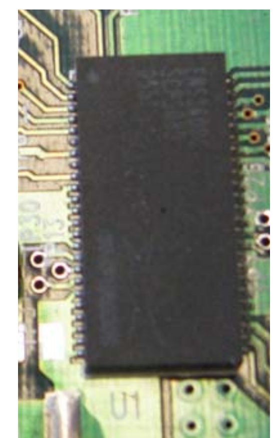
Power Chain Efficiency for CMS ECAL

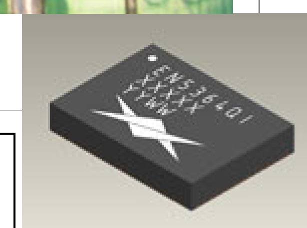


What can we do?

- Is there a better way to distribute power for physics detectors ?
  - Learn from Semiconductor Industry
  - Use Commercial Technologies – *No Custom ASIC Chips*
- How do we handle these unique environments
  - High Radiation
  - Magnetic Field > 2 T
  - Load ~1 V & Oodles *(=10 Kamps)* of current
- Feed High Voltage and Convert - *like AC power transmission*







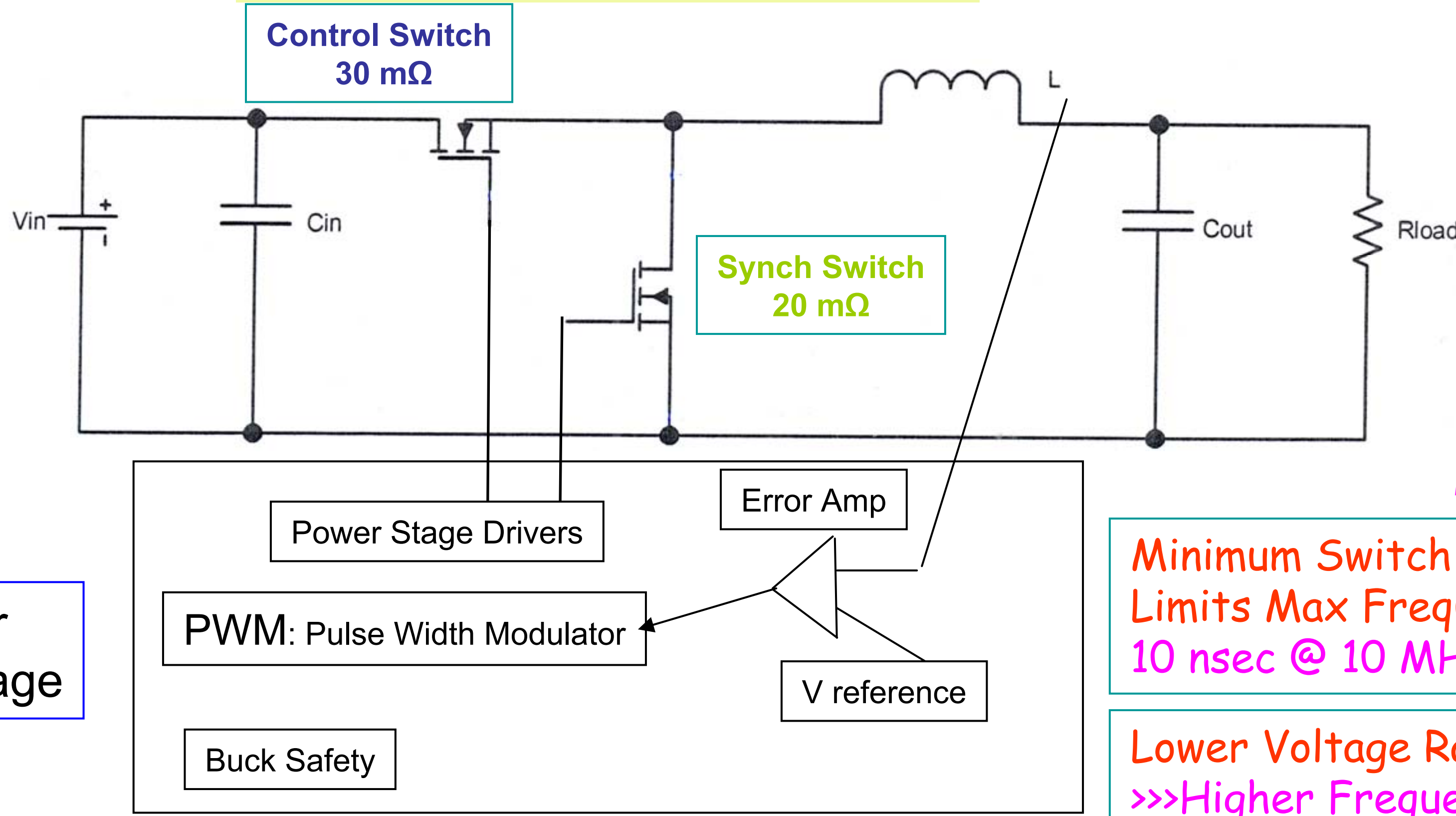
Found out at Power Technology conference 0.25 µm Lithography

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

Synchronous Buck Converter

Power Stage - High Volts

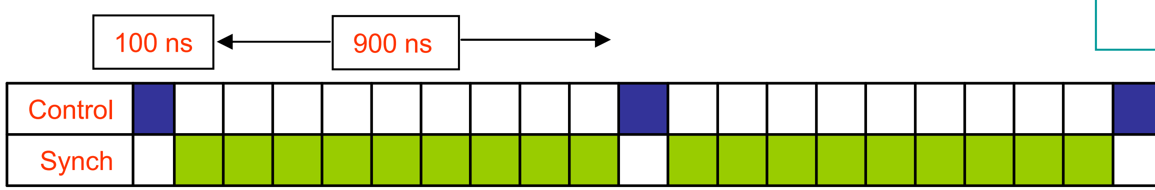
Controller Low Voltage



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

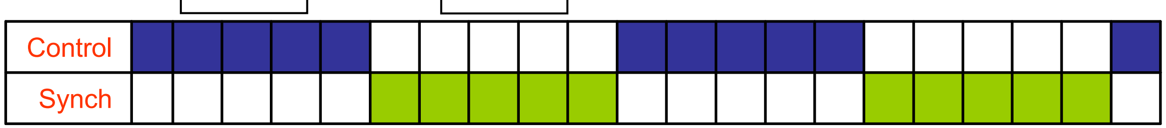
Lower Voltage Ratio
>>>Higher Frequency
& Smaller Coil

Vout = 11%

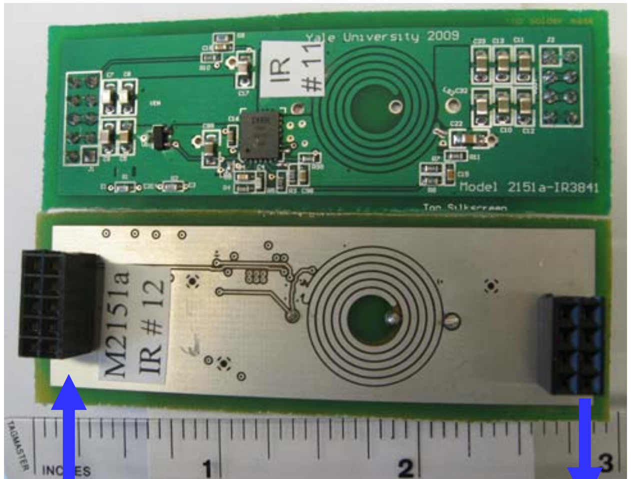


Control Switch: Switching Loss > I^2
Synch Switch: Rds Loss Significant

Vout = 50%



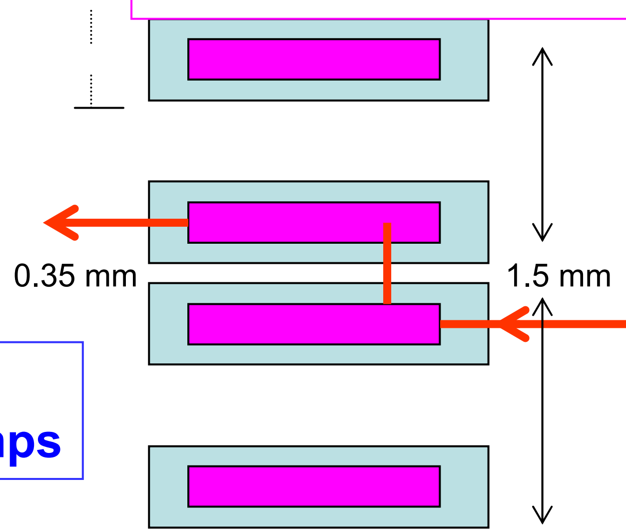
Plug In Card with Shielded Buck Inductor

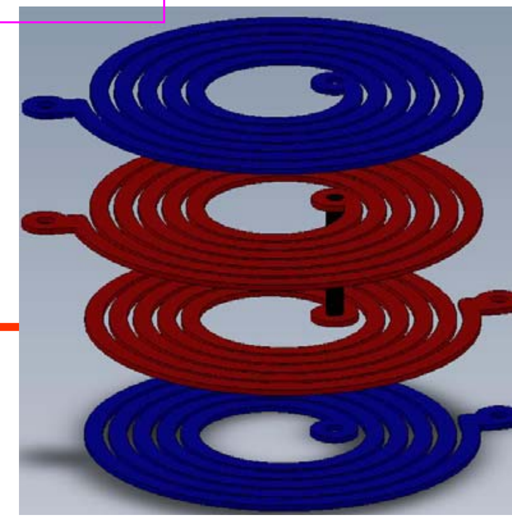


12 V

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

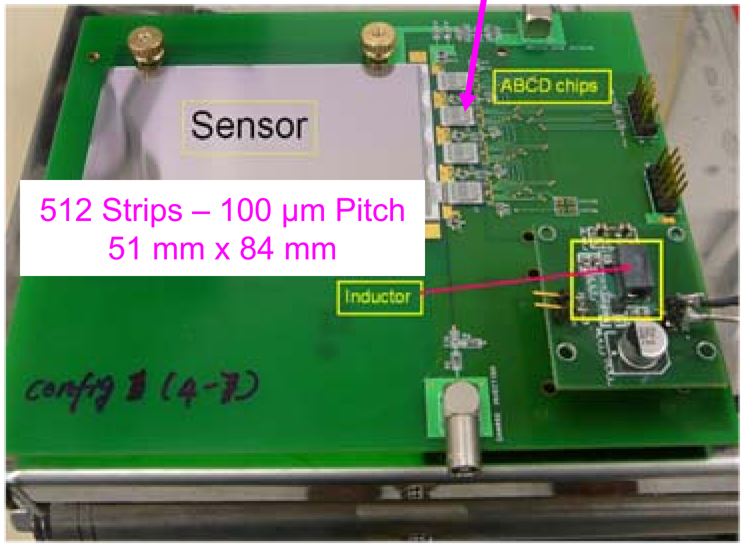
Spiral Coils Resistance in mΩ

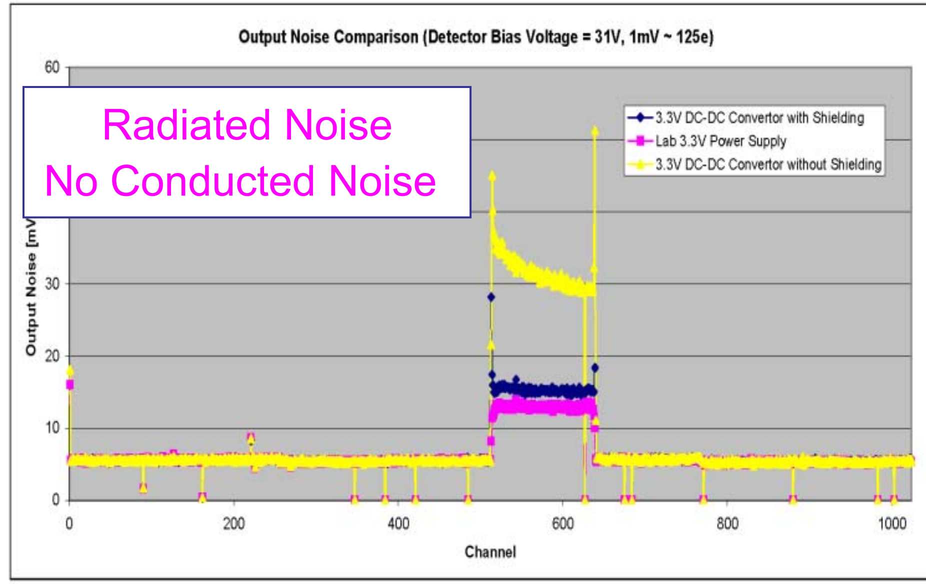
	Top	Bottom
3 Oz PCB	57	46
0.25 mm Cu Foil	19.4	17

Noise Tests with Silicon Sensors

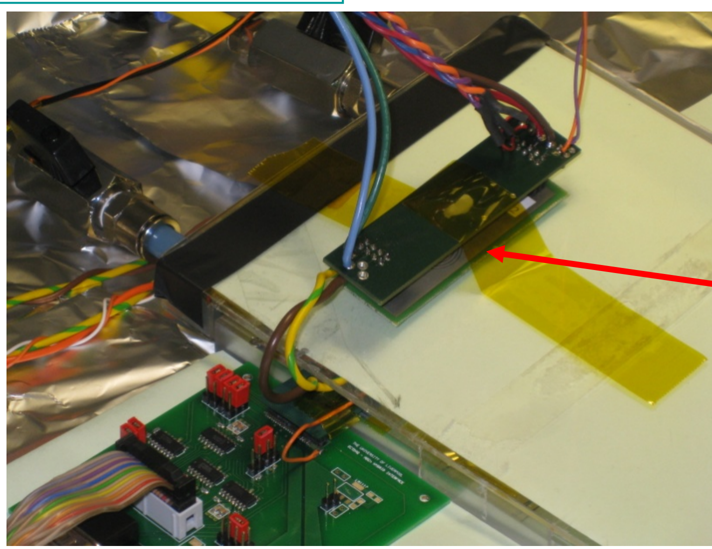
Test @ BNL

Only One Chip Bonded





Test @ Liverpool

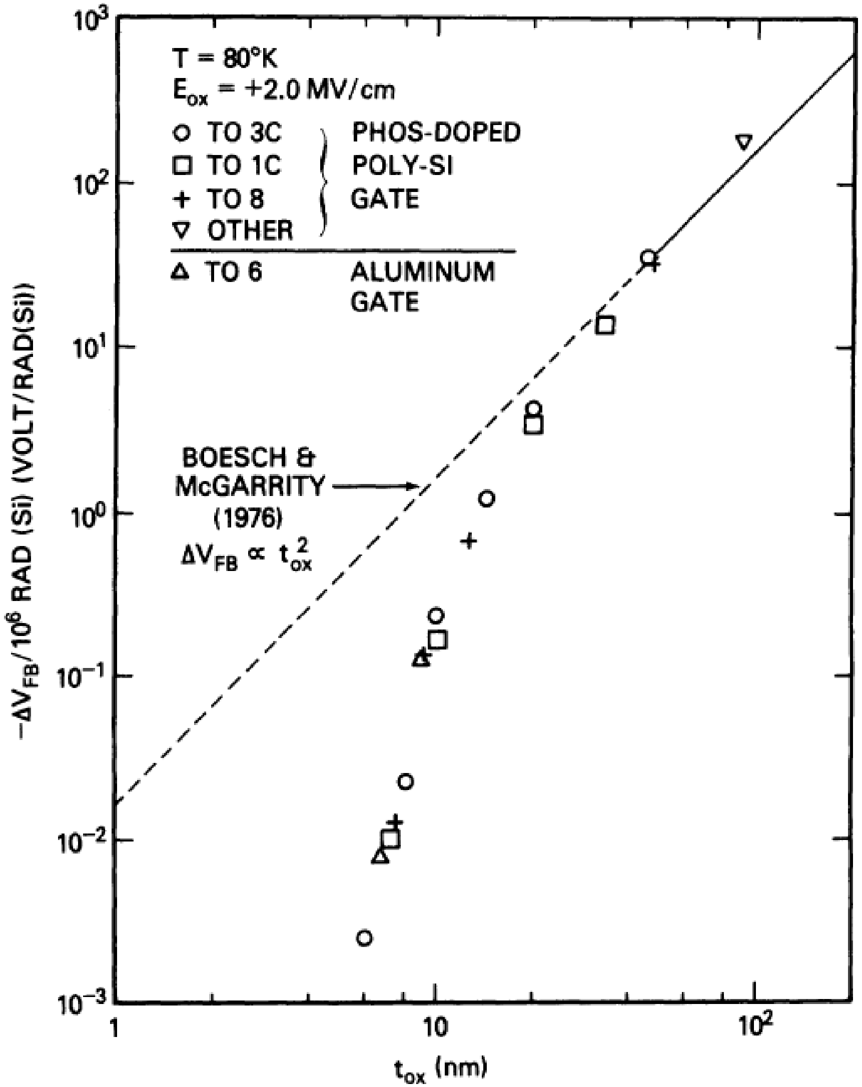


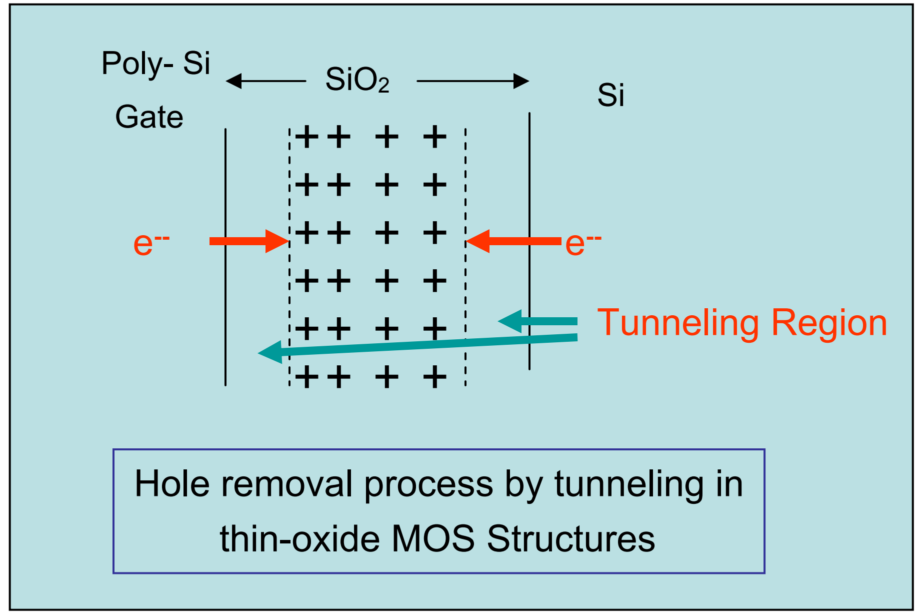
Plug in Card
1 cm from Coil facing Sensor

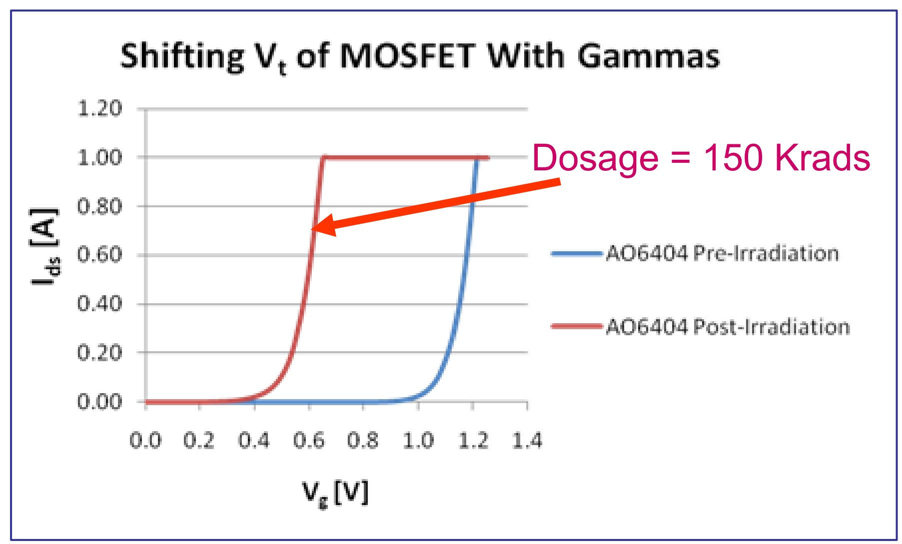
20 µm Al foil shielding

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

Threshold Shift vs Gate Oxide Thickness







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

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

CERN ASICs

Mantra: Deep sub micron is more rad hard

Why ?

IBM Foundry Oxide Thickness			
Lithography	Process	Operating	Oxide
	Name	Voltage	Thickness
			nm
0.25 µm	6SF	2.5	5
		3.3	7
0.13 µm	8RF	1.2 & 1.5	2.2
		2.2 & 3.3	5.2

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

Higher radiation tolerance needs thin oxide
while higher voltage needs thicker oxide – Contradiction ?

Controller : Low Voltage

High Voltage: Switches – some candidates HV & Thin oxide

LDMOS, Drain Extension, Deep Diffusion etc

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

LDMOS Structure

Laterally Diffused
Drain Extension

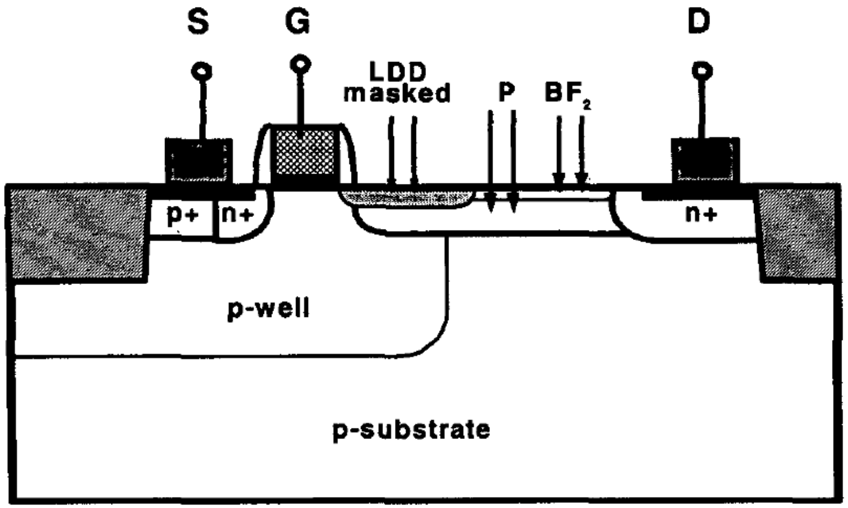


Fig.1: Schematic cross-section of the RF-LDMOS transistor.

High Voltage / high Frequency
Main market. Cellular base stations

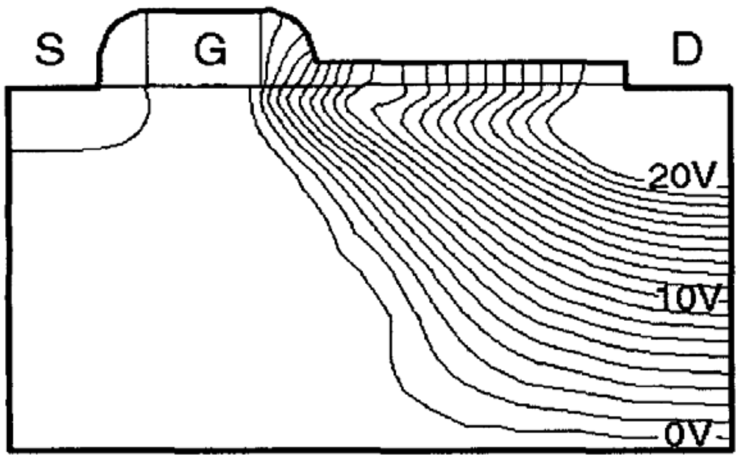


Fig.3a: Potential distribution at the highest operating voltage (20V) with $V_G = 0V$ (LDMOS 3 from Table 1).

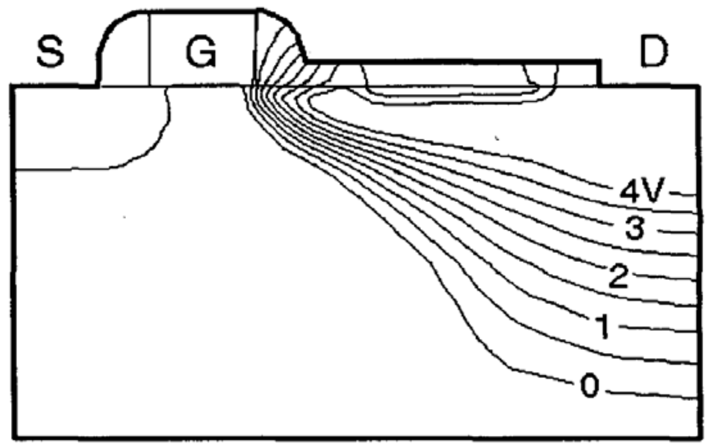
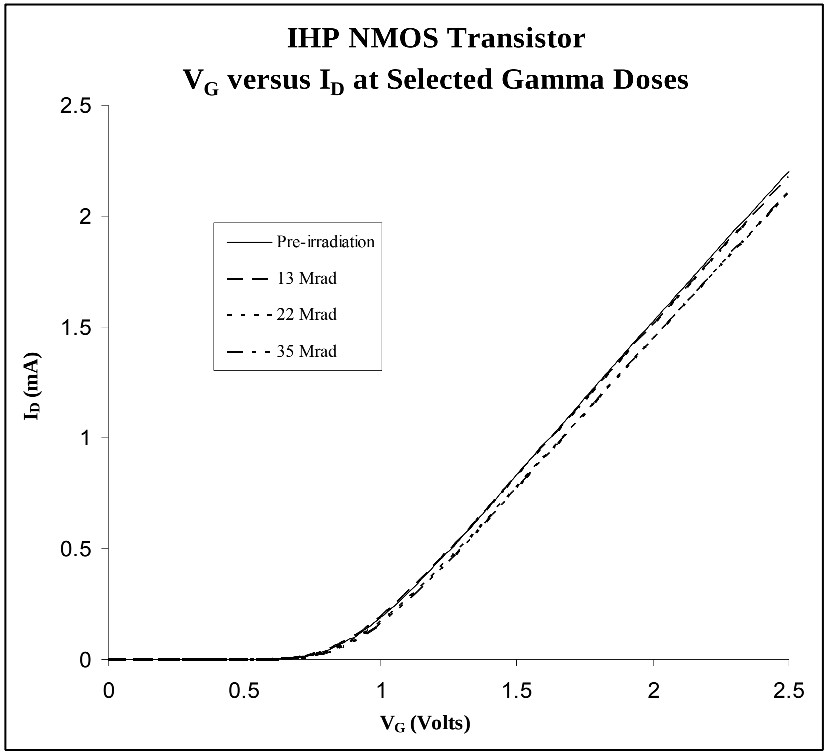
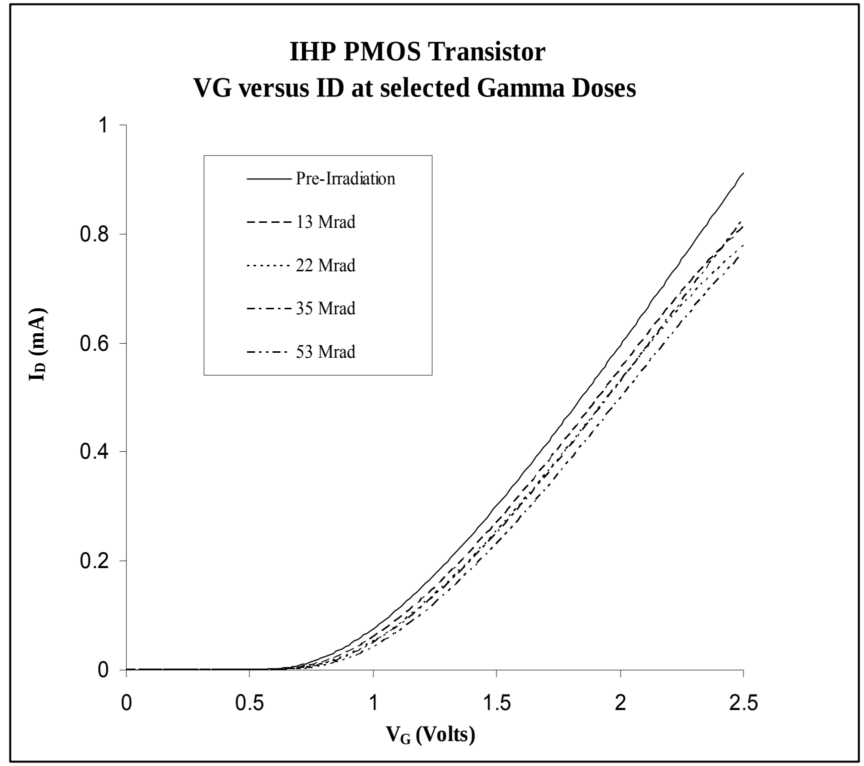
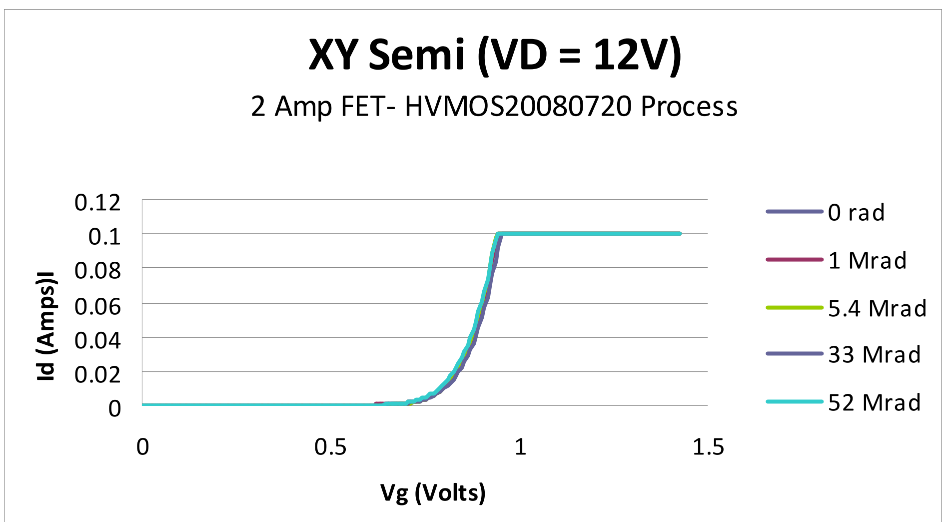


Fig.3b: Potential distribution at the lowest operating voltage (4V) with $V_G = 0V$ (LDMOS 3 from Table 1).

High performance RF LDMOS transistors with 5 nm gate oxide in a 0.25 µm SiGe:C BiCMOS technology: IHP Microelectronics
Electron Devices Meeting, 2001. IEDM Technical Digest. International
2-5 Dec. 2001 Page(s):40.4.1 - 40.4.4







VI Curves after Gamma irradiations

Thin Oxide Devices (non IBM)

Company	Device	Process	Foundry	Oxide	Dose before	Observation
		Name/ Number	Name	nm	Damage seen	Damage Mode
IHP	ASIC custom	SG25V GOD **12 V**	IHP, Germany	5		Minimal Damage
XySemi	FET 2 amps	HVMOS20080720 **12 V**	China	7		Minimal Damage
XySemi	XP2201	HVMOS20080720 **15 V**	China	12 / 7		1Q2010
Enpirion	EN5365	CMOS 0.25 µm	Dongbu HiTek, Korea	5	64 Krads	
Enpirion	EN5382	CMOS 0.25 µm	Dongbu HiTek, Korea	5	111 Krads	
Enpirion	EN5360 #2	SG25V (IHP)	IHP, Germany	5	100 Mrads	Minimal Damage
Enpirion	EN5360 #3	SG25V (IHP)	IHP, Germany	5	48 Mrads	Minimal Damage

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

Gallium Nitride Devices Tested in 2009

RF GaN 20 Volts & 0.1 amp

- ❖ 8 pieces: Nitronex NPT 25015: GaN on Silicon
  - ✓ Done Gamma, Proton & Neutrons
  - ✓ 65 volts Oct 2009

- ❖ 2 pieces: CREE CGH40010F: GaN on siC

- ❖ 6 pieces: Eudyna EGNB010MK: GaN on siC
  - ✓ Done Neutrons

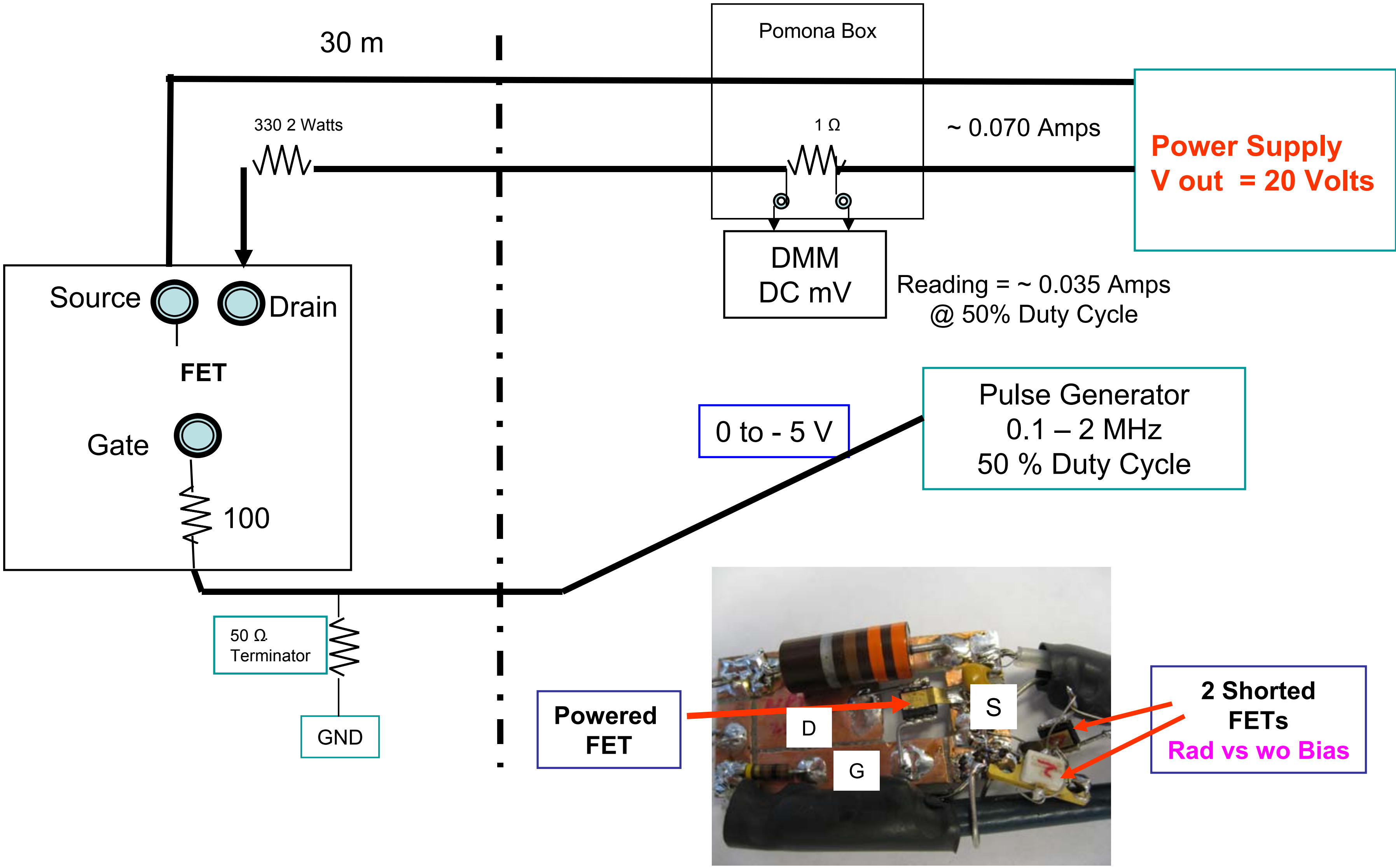
Switch GaN

- ❖ International Rectifier GaN on Silicon
  Under NDA

Gamma: @ BNL
Protons: @ Lansce
Neutrons: @ U of Mass Lowell

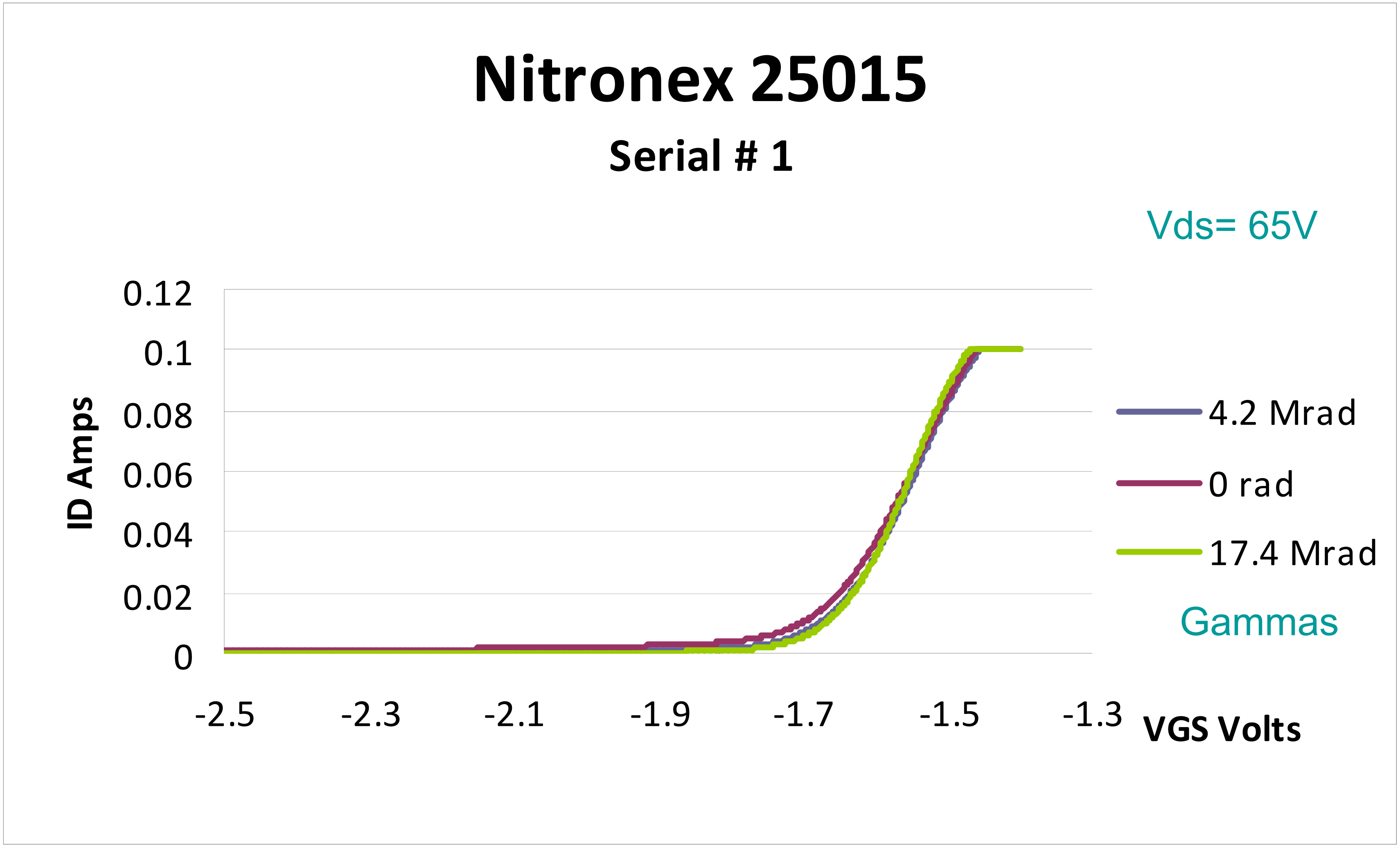
Bias during Radiation

Max operating V & I Limit Power by duty cycle



FET Setup for Proton Radiation Exposure

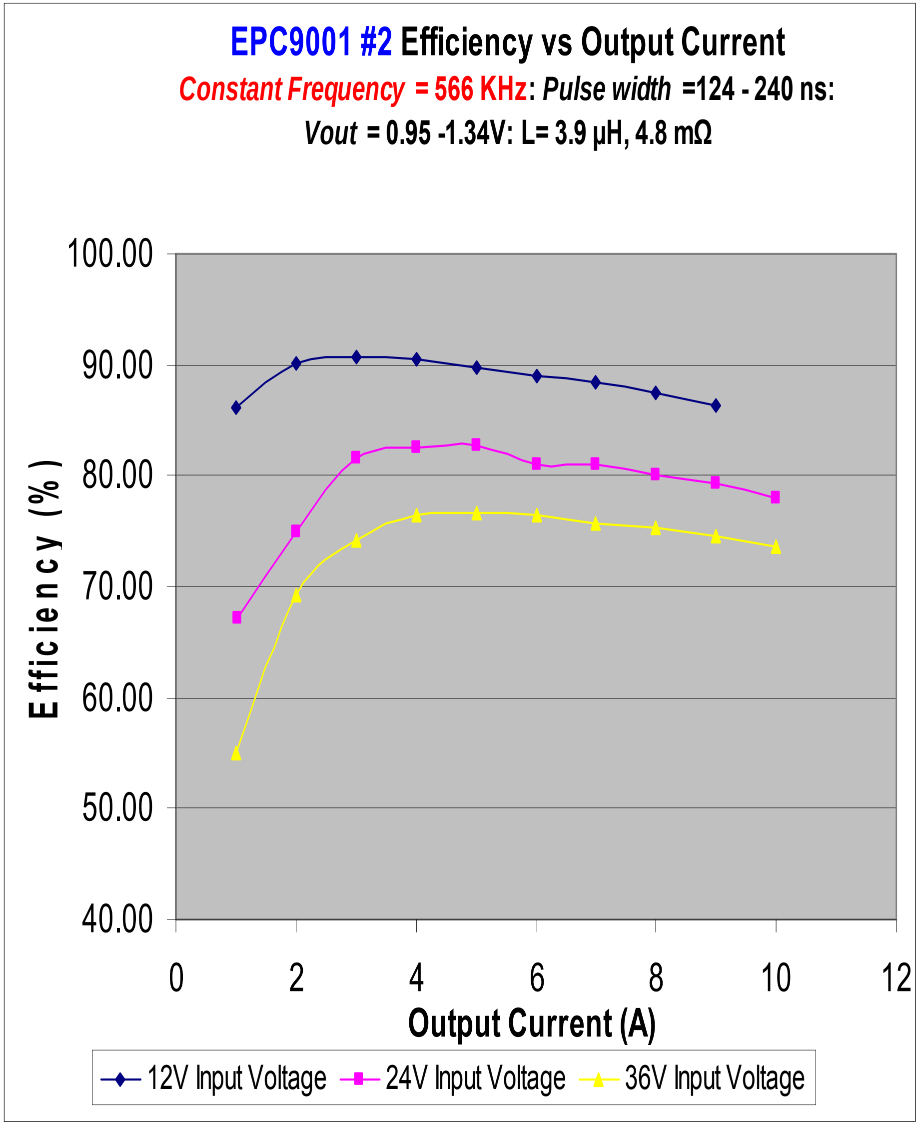
Satish Dhawan, Yale University

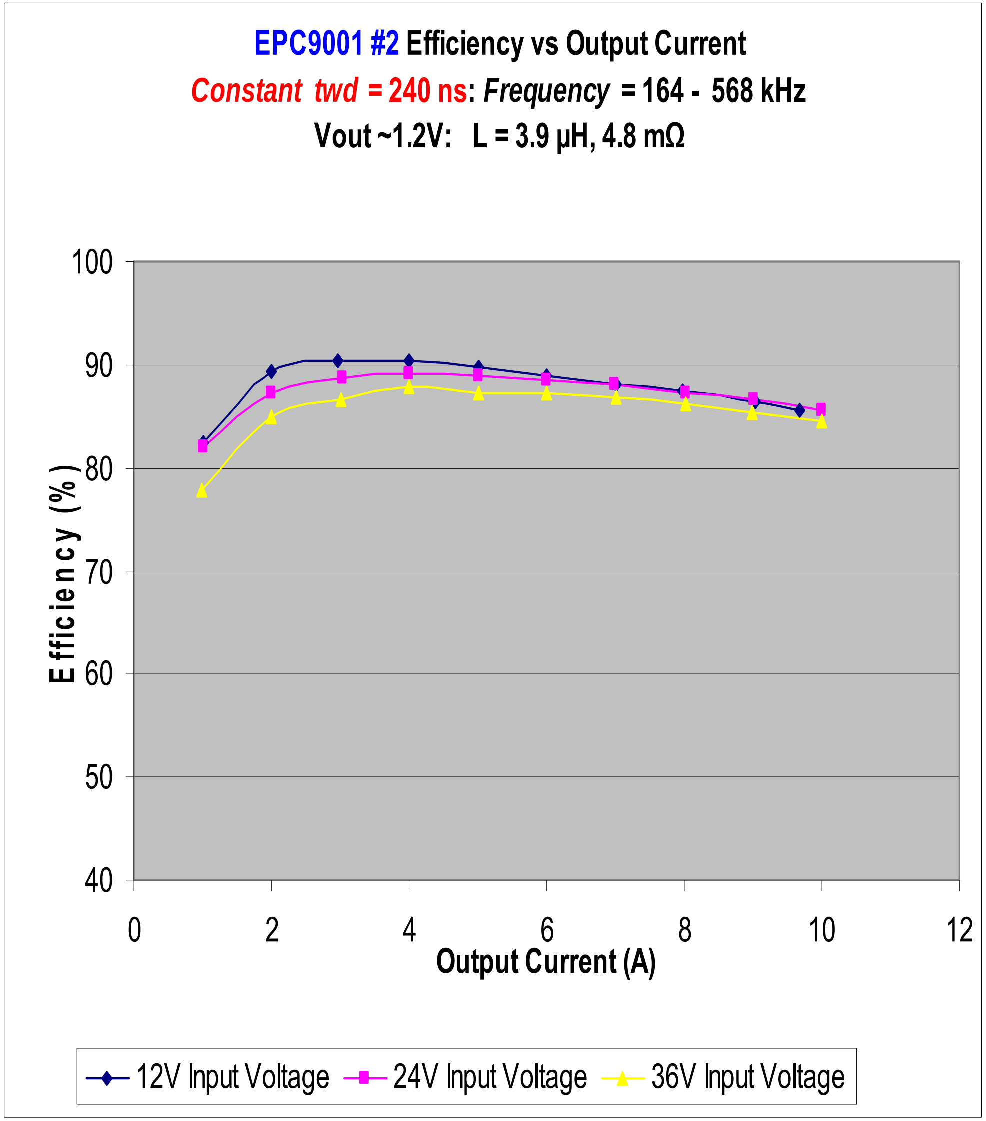


200 Mrads of Protons had no effect – switching 20 V 0.1 Amp
Parts still activated after 7 months

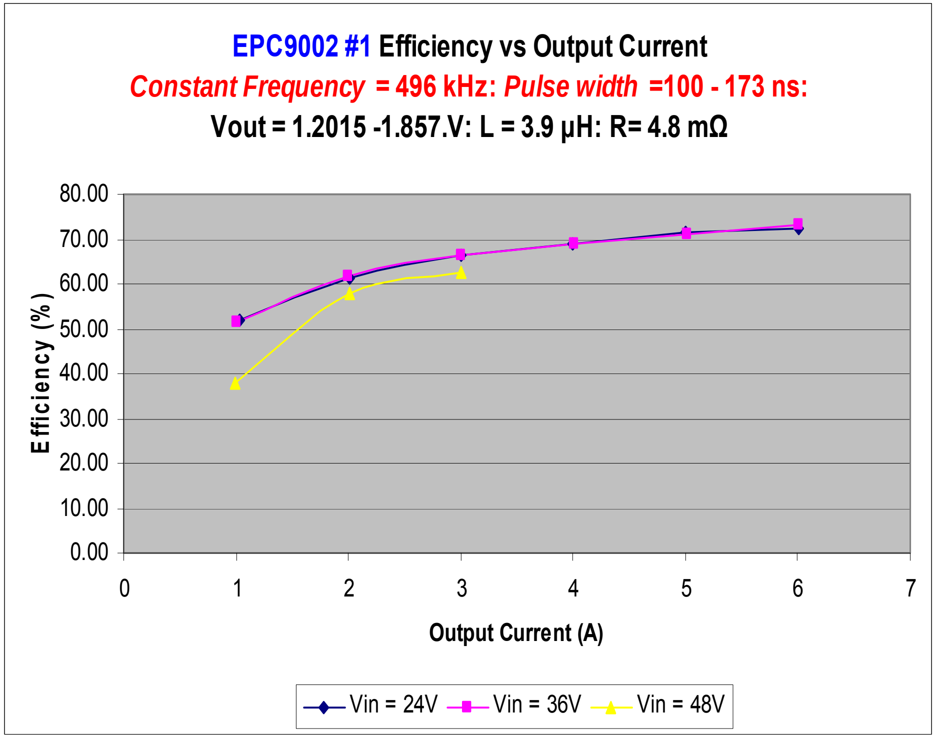
New GaN Devices for Power Switching

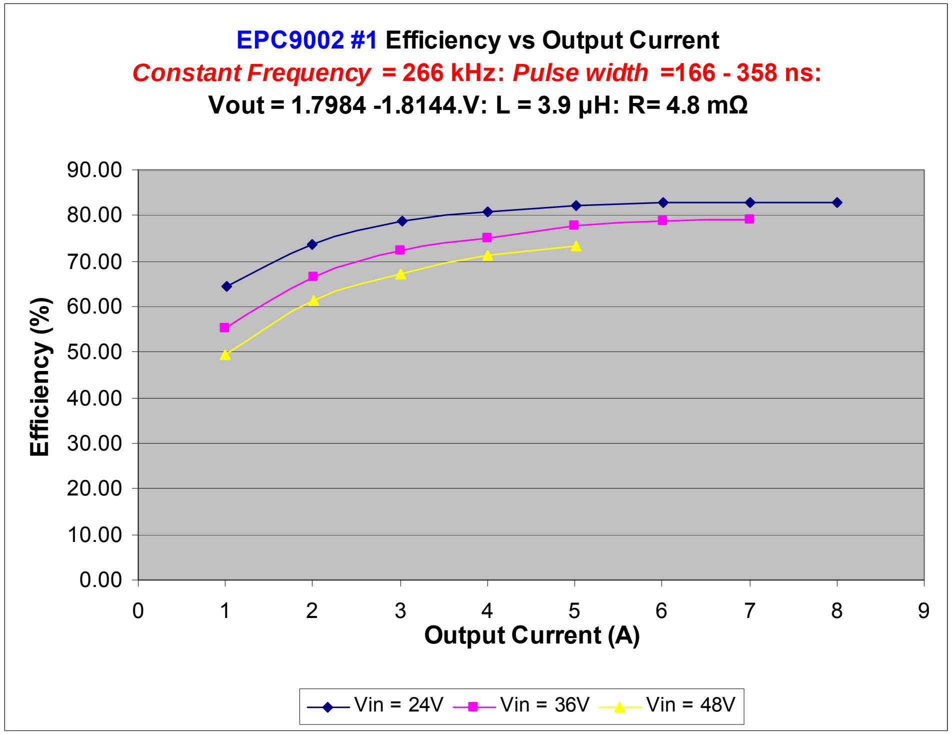
: Converter Efficiency Inputs = 12, 24 & 36 volts
output ~ 1.2 v



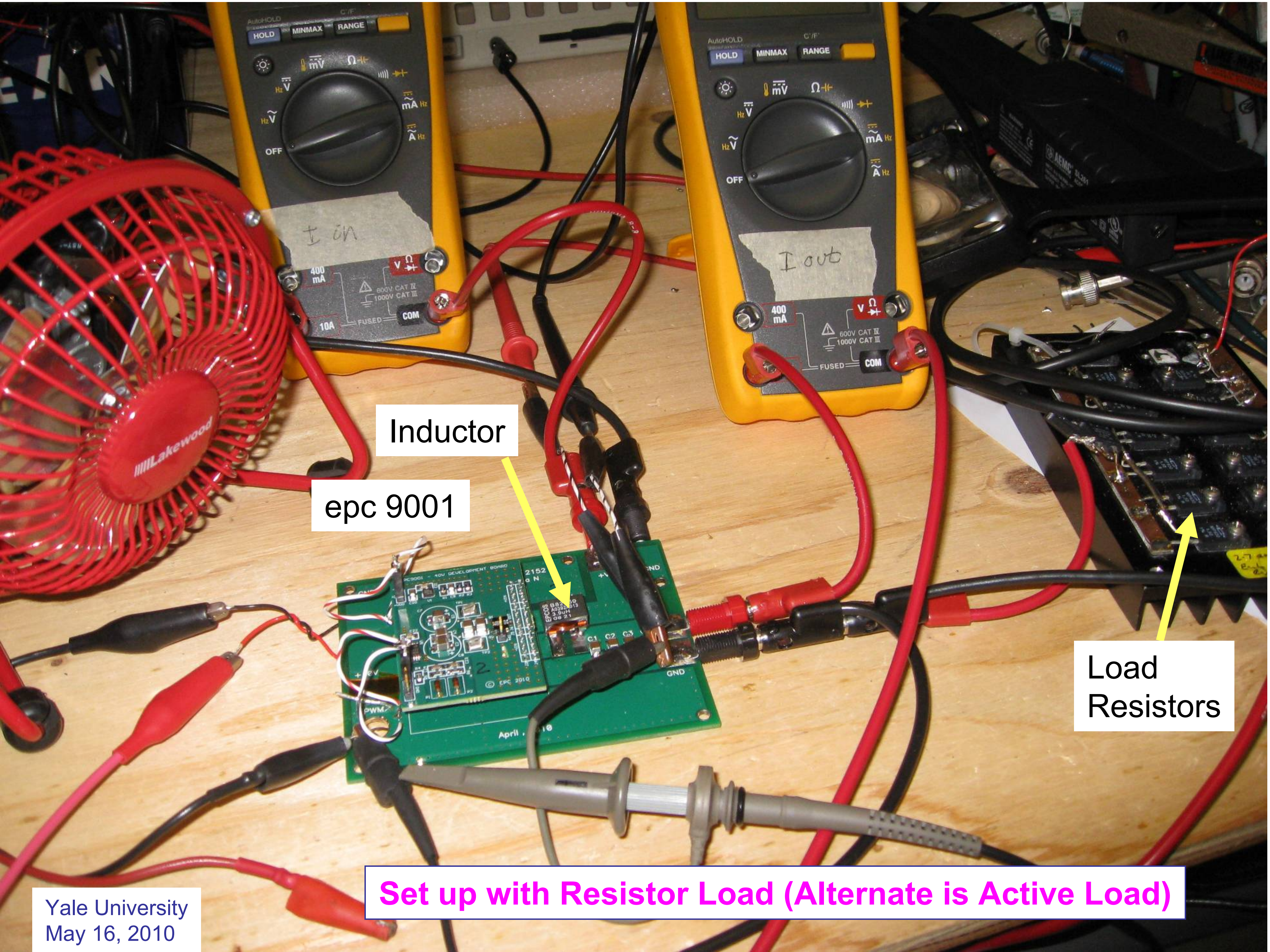


Converter Efficiency Inputs = 24 & 36 volts output ~ 1.8 v





Longer On Time improves efficiency (Lower Frequency)



Set up with Resistor Load (Alternate is Active Load)

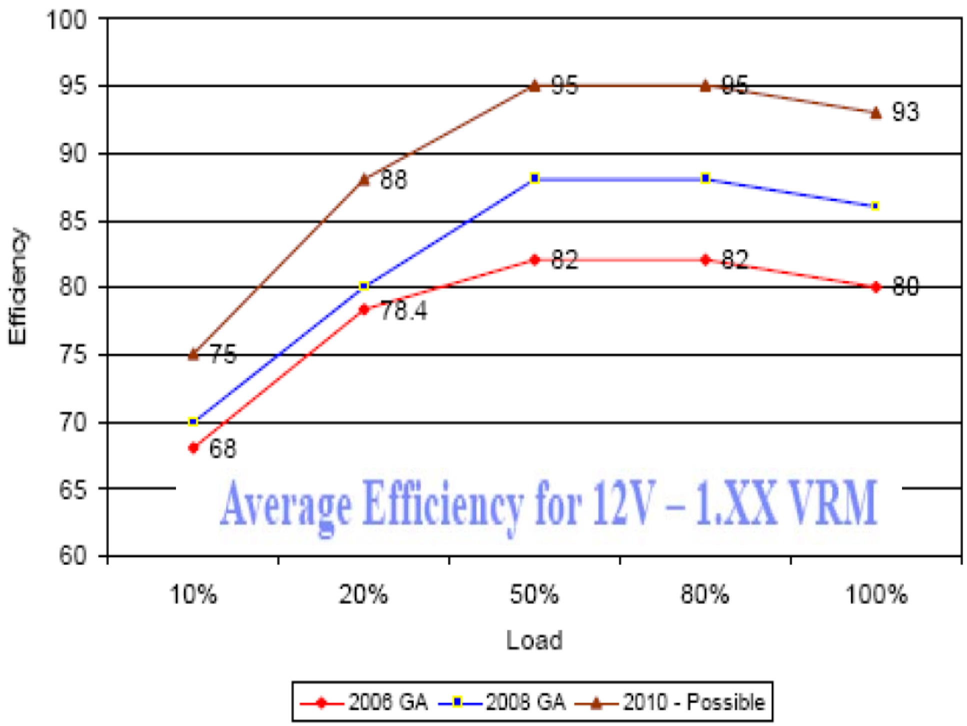
PSMA: Road Maps
Power Supply Manufacturer Association
Yale University is member

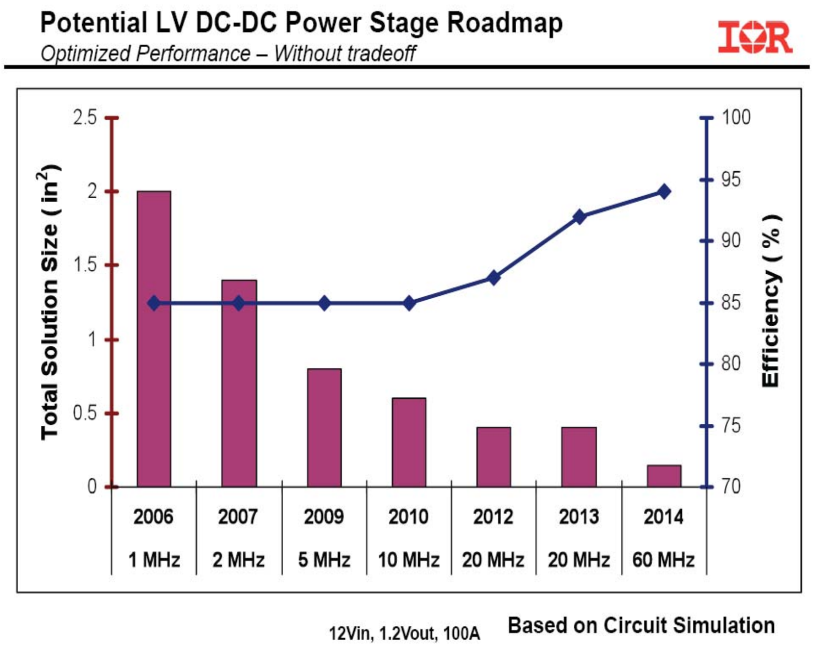
What is happening outside HEP ?

Server Power System Distribution from IBM

1. **AC Distribution - 208/230/115V**
   - Servers, Blade Servers, Workstations
2. **12V DC Distribution**
   - Blade Server Chassis, Low end and Midrange Servers, Workstations
3. **48V Distribution in a Rack**
   - High End Server Applications
4. **350V DC Distribution in a Server Rack or a Rectifier Cabinet**
   - Main Frame Servers

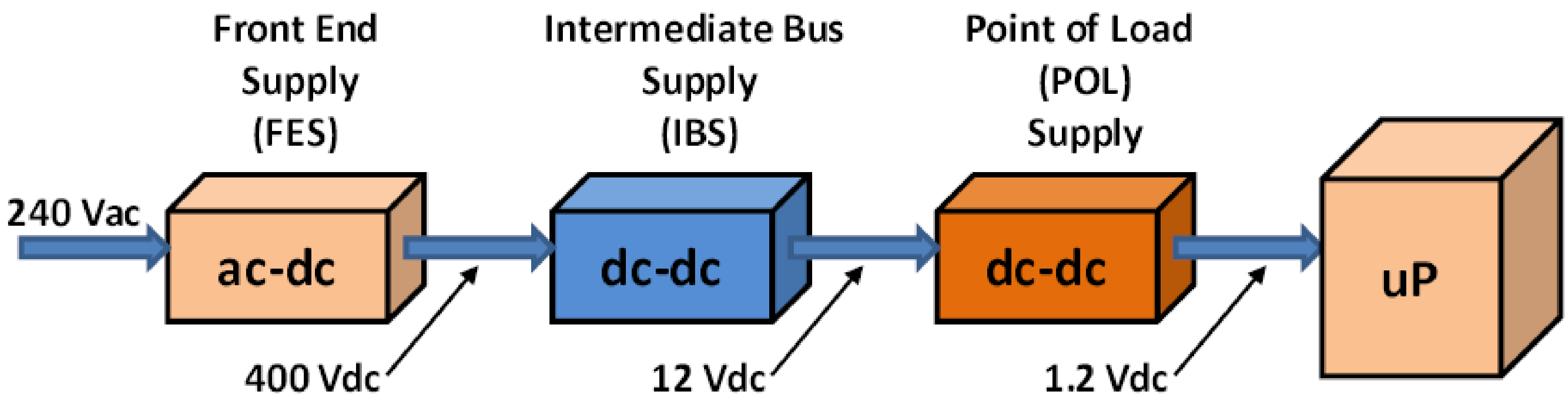
International Workshop on Power Supply On Chip
Sept 22nd - 24, 2008
Cork, Ireland





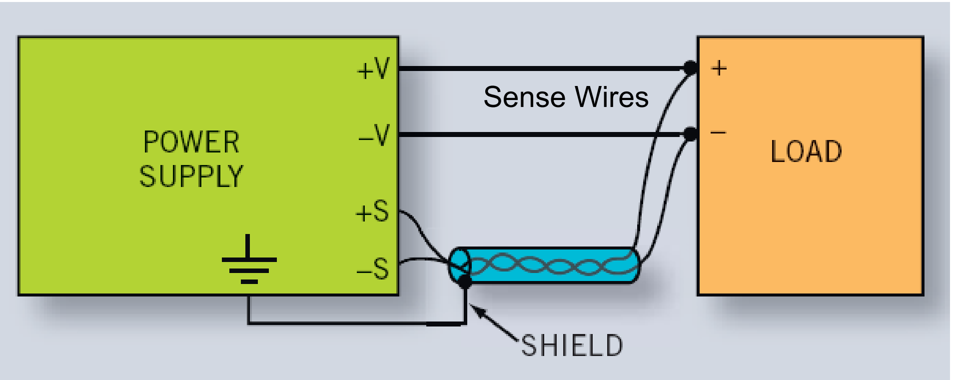
12Vin, 1.2Vout, 100A Based on Circuit Simulation

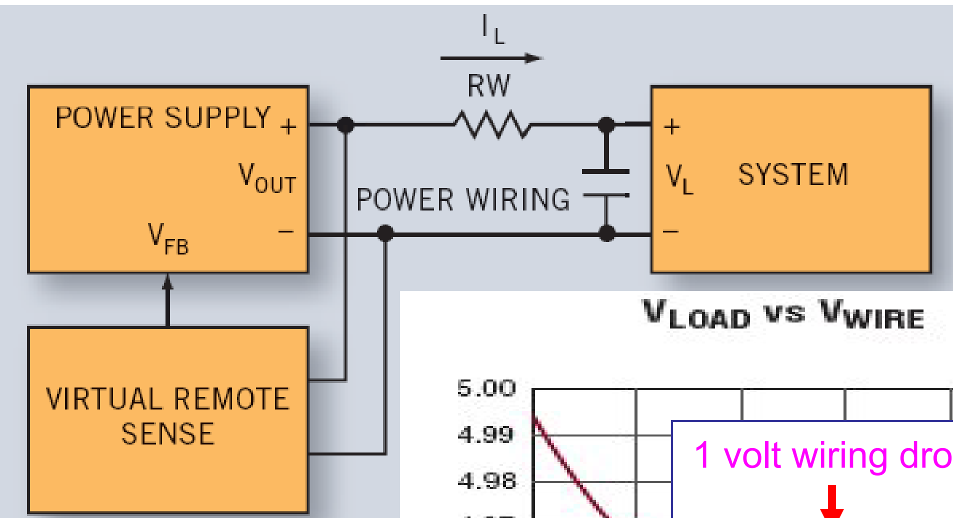
AC - DC Power Efficiency Challenge
by IBM September 2007

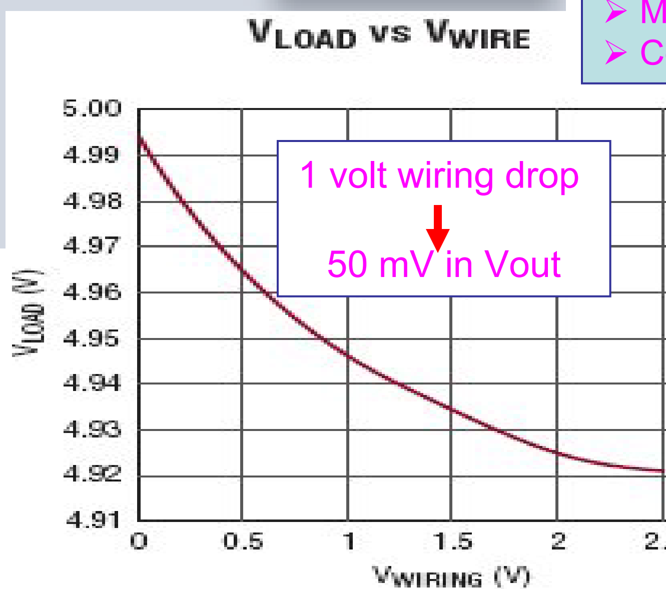


	FES	IBS	POL	Plug-to-Processor
Recent	93%	95%	88%	78%
Best Immediate	95%	98%	90%	84%
	IBM Challenge			***90%***
Needed	98%	98%	94%	***90%***

Remote Sense for SiD with wires & Impedance Measurement







LT4180 Virtual Sense Controller

1. Measure Vout
2. Reduce current by 10%
3. Measure new Vout after settling time

Note: do this quickly, so voltage at remote load does not change (large C at load to ensure this)

4. Calculate resistance of wires (effectively)
5. Set new Vout so load voltage is OK
6. Repeat

Pulsed Power Schemes

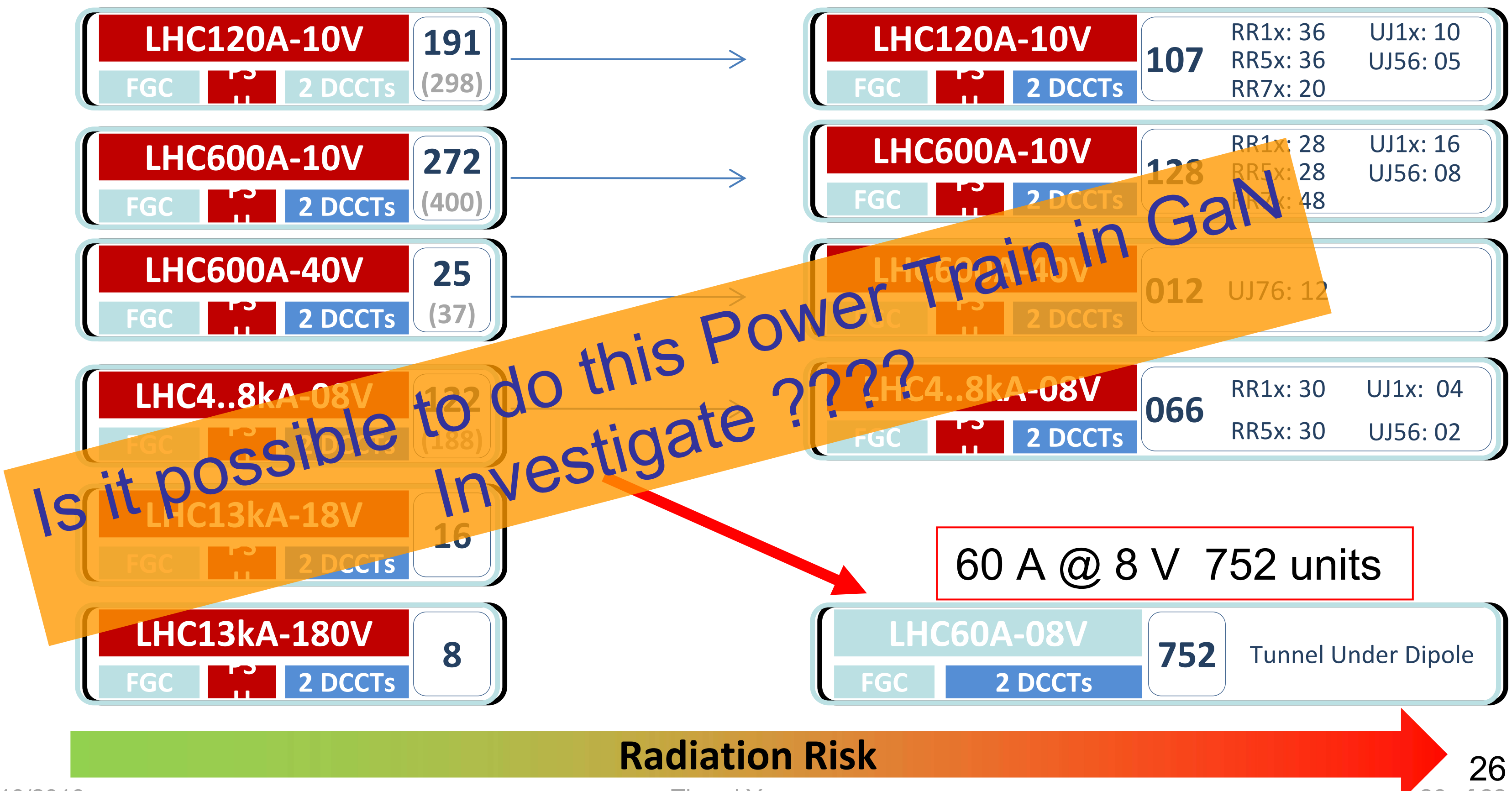
- Make impedance measurement before beam Bunches
- Copper wires temperature effect with pulsed power ??

Impedance measurement is used for Li batteries remaining charge for Netbooks, hand held gadgets etc.

CONVERTERS INSTALLED

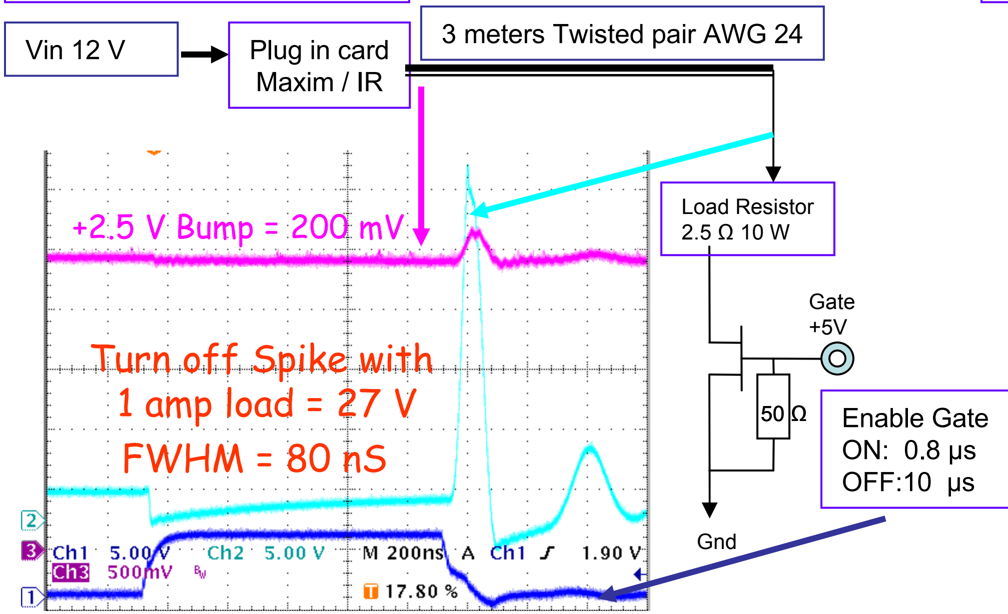
CERN - Chamonix 2010 Report

- **LHC CONVERTERS VS RADIATION *[2010]***
  - Rad Tolerant Design *or* standard Design with low Rad sensitivity (safe components)
  - Standard Design *and* Rad sensitivity unknown (too many components, sub-assemblies...)



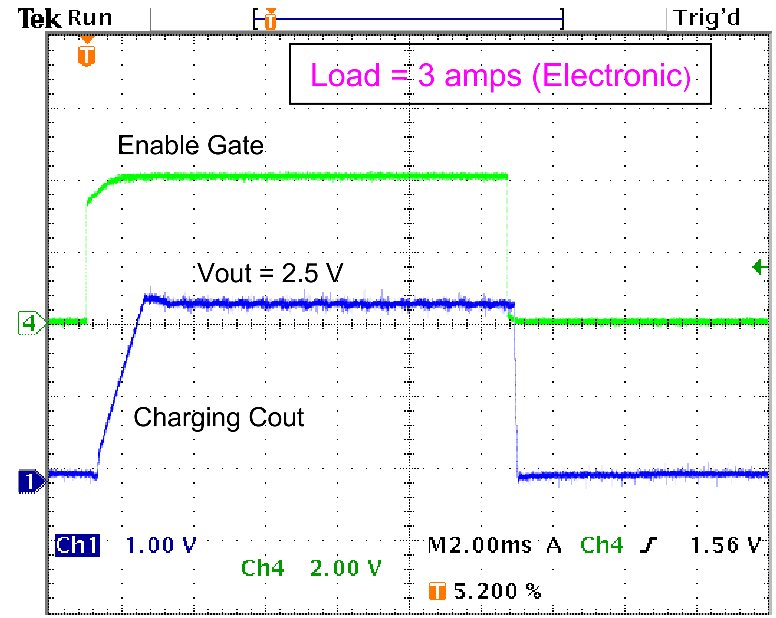
Pulsing Load

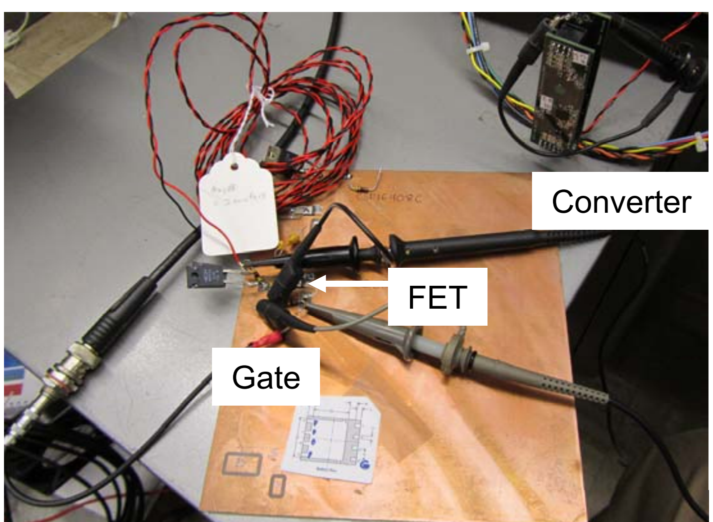
Air Coil DC-DC Converter

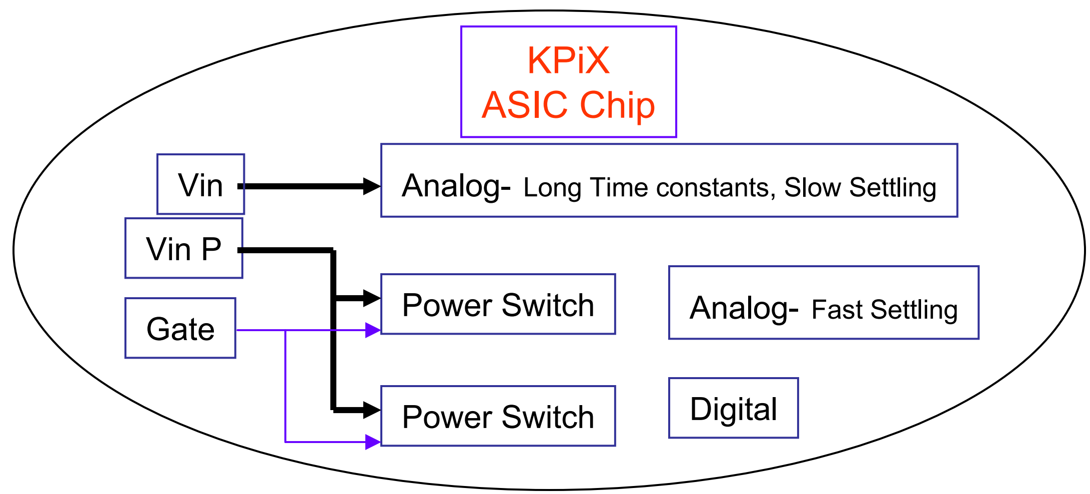


Pulsing Converter

Air Coil DC-DC Converter



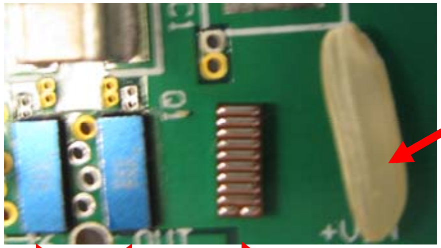




SiD Powering Pulsing

Power Delivery to HEP Detectors

- Need Increase in Power Delivery Efficiency for environment & budget
- Energy and Power are high priorities of current (and future) administration
- Power will be critical for next generation of HEP experiments: power bill and physics reach
- Radiation Hardness: Silicon LDMOS 15 V few amps
- Gallium Nitride could be a game changer: 100 Volts, tens of amps. Opportunity for Beam line power supplies
- Increase emphasis on Power Electronics in US is needed. In Asia it is a Glamorous field. Best and the brightest going into this. Tremendous Economic opportunity
- In US no support for this type of R&D. In general, limited support for generic detector R&D.
- This R&D is needed for a viable US HEP program.



A grain of Basmati Rice
4 watts

GaN FETs
40 V 33 A 4mΩ

FET Solder side

28

What can be achieved by DC-DC Developments ?

- Current Reduction from Power Supply by DC-DC near Load
  Losses > $Current^2$ x Resistance

- with Silicon : a Current Reduction of 10 achievable
- with GaN: a Current Reduction 50 possible

- Increase Power Delivery Efficiency by > x2 CMS example

- Remote Sense for SiD
- Lower Voltage ratio > > Higher Frequency Air Coil


Working on Power Supply
Is not 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
More Details: http://shaktipower.sites.yale.edu/