Power Converters: Why commercial world is betting on Gallium Nitride (GaN) to replace Silicon

Satish K Dhawan
Yale University

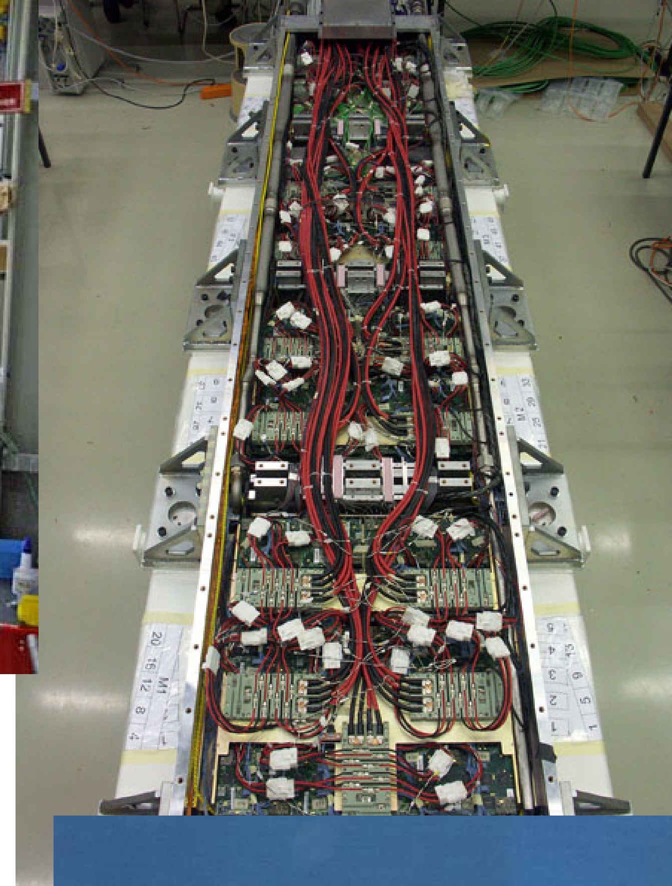
1 Oodle = 10,000 amps

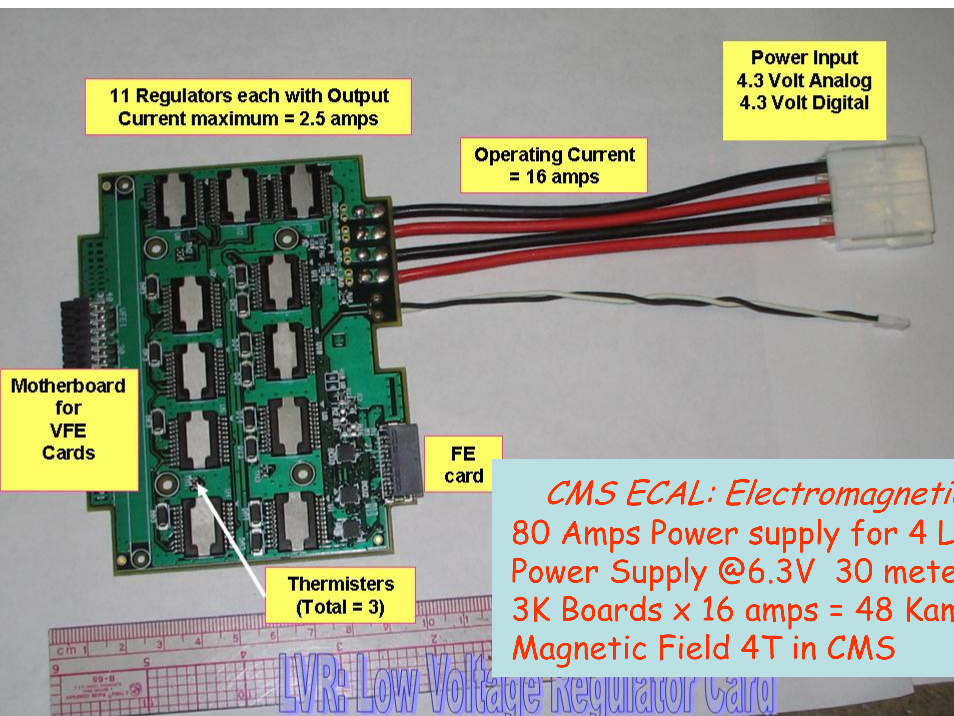
CERN: PH-ESE Electronics Seminars
Tuesday 14 September 2010
09:00 to 10:00 (Europe/Zurich) Bldg:13-2-005

Agenda

- CMS ECAL Powering 2.5 V @ 50,000 amps
- DC-DC Converters
- Commercial Device 100 Mrads- Beginners luck
- ATLAS Upgrade work. Embedded Air Coil PCB
- Why Thin Oxide for Radiation
- Why go beyond Silicon. 15 V LDMOS
- GaN Wide band Gap material. RF & Power Switching
- Data Centers 400V DC distribution
- Companies involved with GaN Product Development
- Advantage of this development
- Conclusions

Collaborators:
Yale University: Keith Baker, Hunter Smith
Brookhaven National Laboratory: Hucheng Chen, James Kierstead, Francesco Lanni, David Lynn, Sergio Rescia,





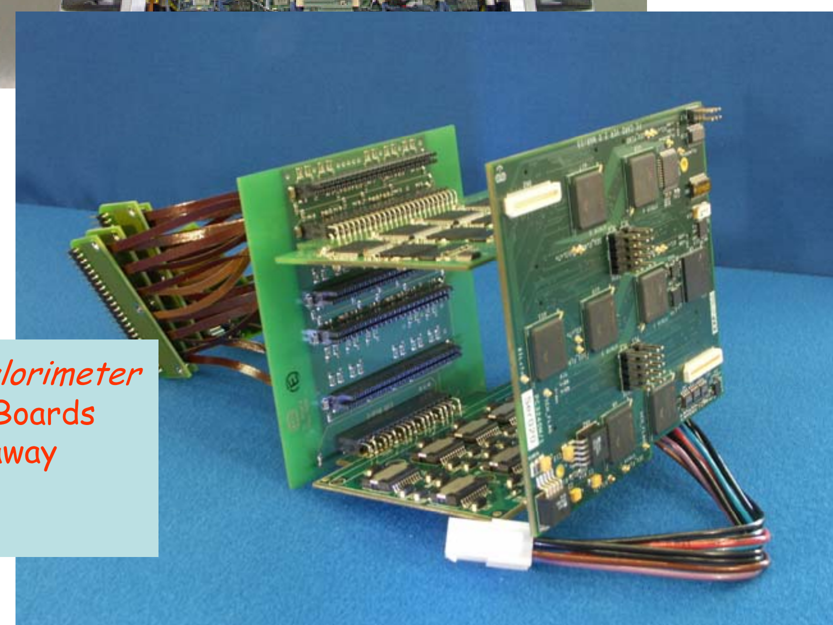
CMS ECAL: Electromagnetic Calorimeter

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



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

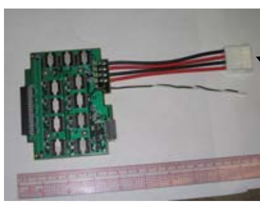
50 mm^2 (AWG 00)

2x16 mm^2 (AWG 6)

1 to 3 m

SM: Super Module

Junction Box

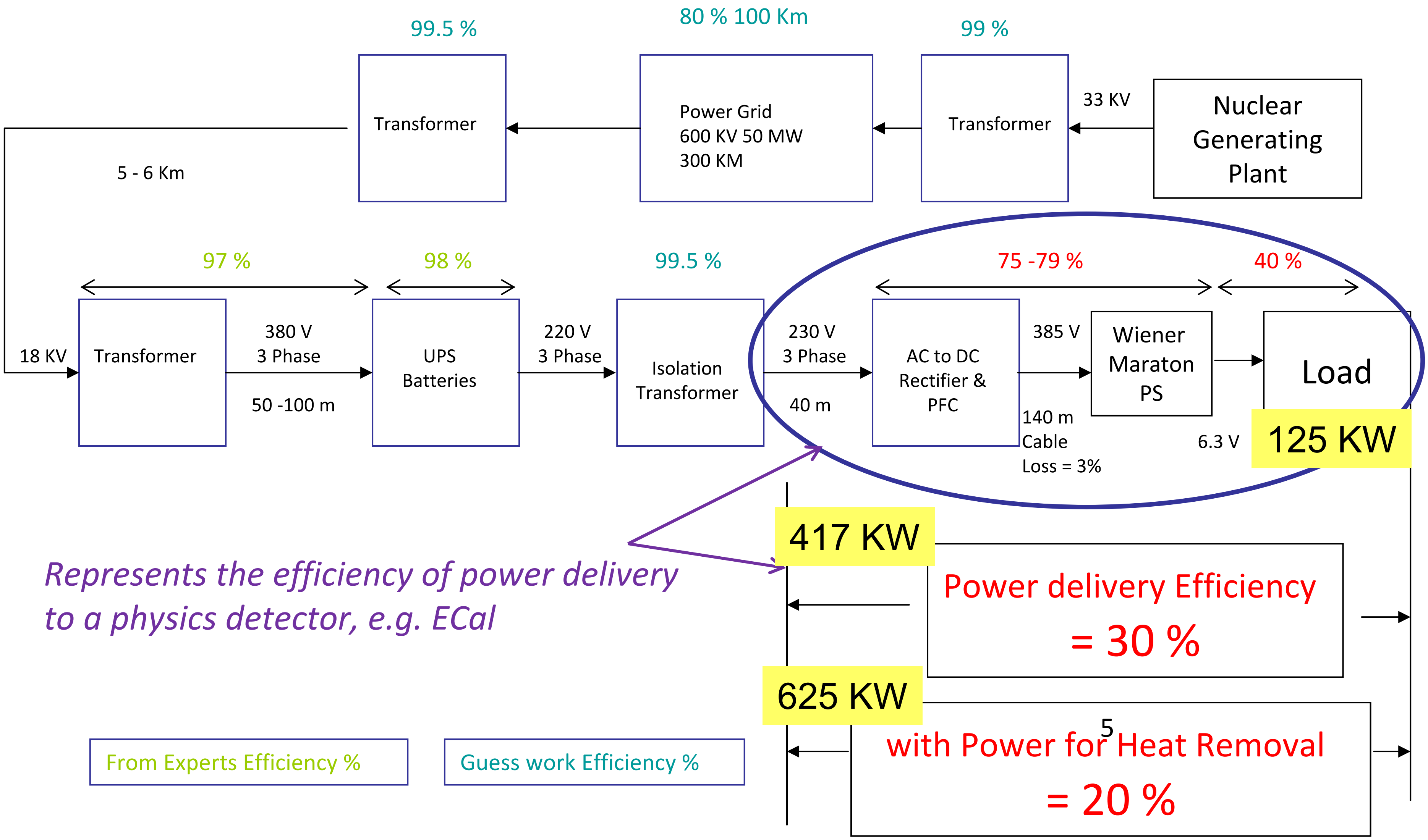


4.3 V

2.5V
64 amps
160 W

4 LVR Boards

Power Chain Efficiency for CMS ECAL



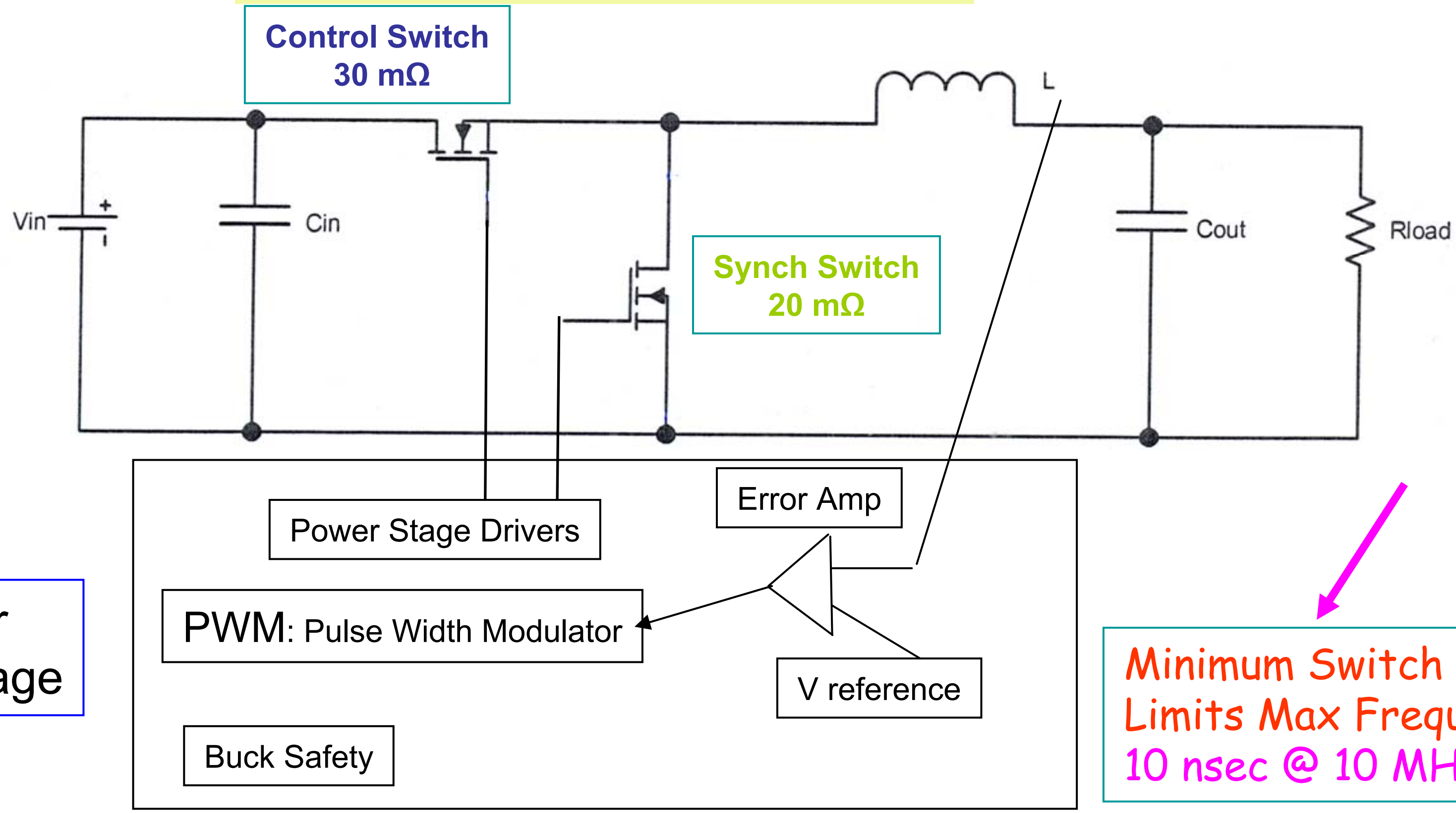
It takes 2 watts of power to remove 1 watt of heat load

Can we do better?

- Is there a better way to distribute power ?
- High Radiation
- Magnetic Field 4 T
- Load ~1 V Oodles of current
- Feed High Voltage and Convert - *like AC power transmission*
- Commercial Technologies – *No Custom ASIC Chips*
- Learn from Semiconductor Industry
- Use Company Evaluation Boards for testing

Synchronous Buck Converter

Power Stage - High Volts

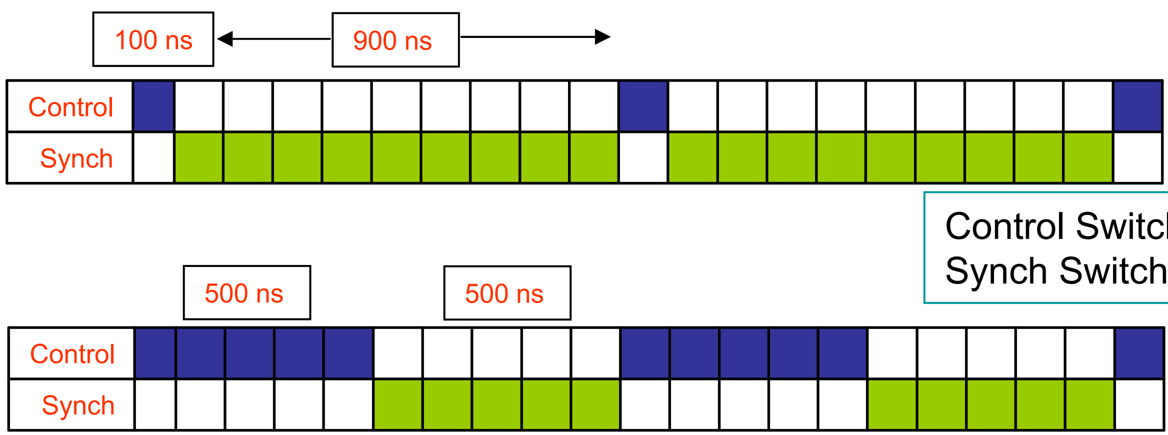


Controller Low Voltage

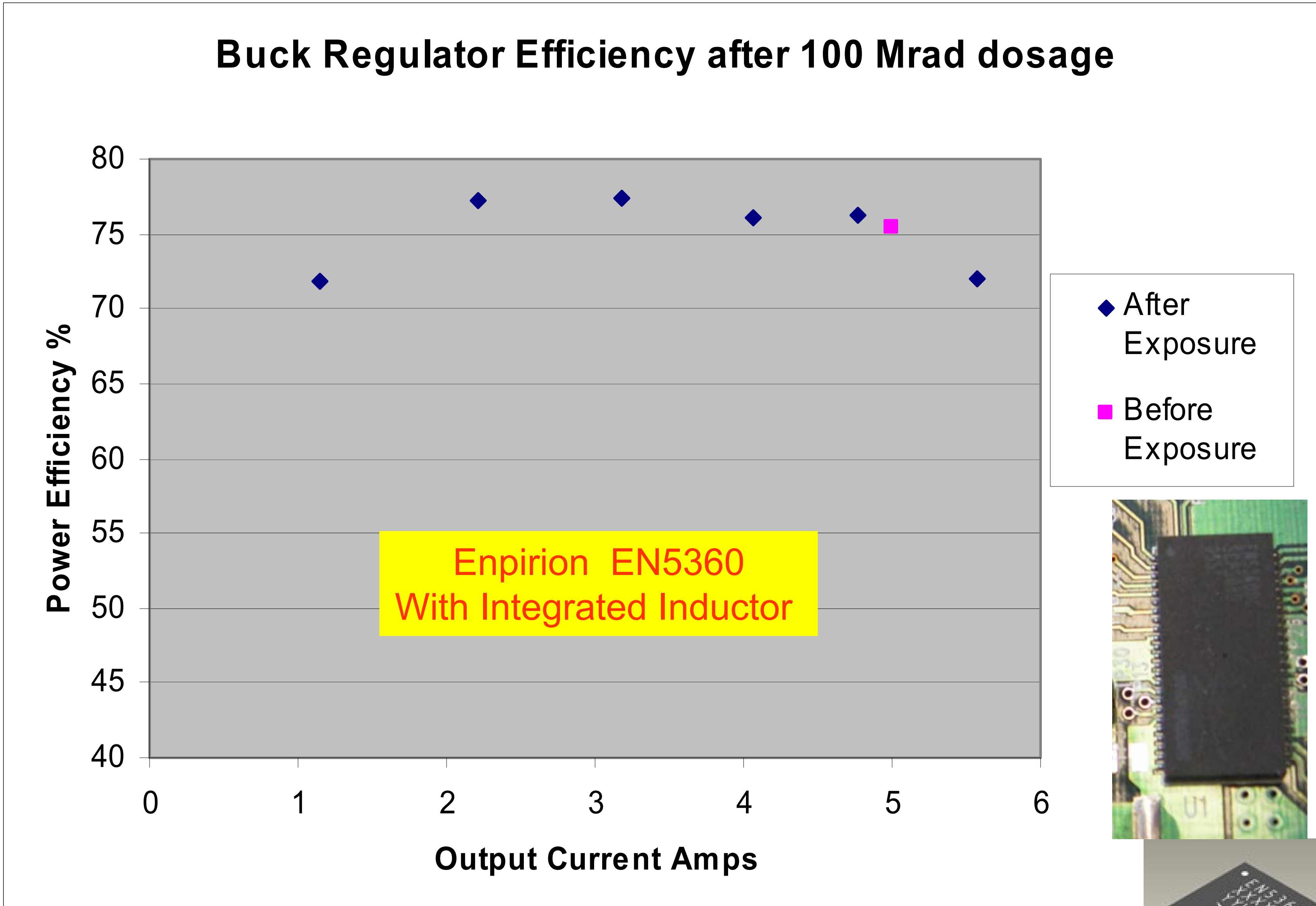
Minimum Switch ON Time
Limits Max Frequency
10 nsec @ 10 MHz

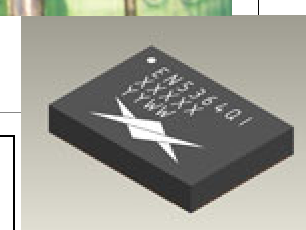
Vout = 11%

Vout = 50%



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





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

ATLAS Si Tracker

Length of Power Cables = 140 Meters

LHC Solution

10 Chip Hybrid – SCT Module for LHC

3.5 V

1.5 amps

Cable Resistance = 4.5 Ohms

4088 Cables

10.25 V

Voltage Drop = 6.75 V

Counting House

sLHC Solution

20 Chip Hybrid – Si Tr Module for Hi Luminosity

1.3 V

2.4 amps

X 4 DC-DC Power Converter

5.2 V

Current Reduced by 4 (losses by 16)

EN5360

Commercial Solution

It is still available

Silicon Technology Limit

(Radiation limited)

20 Chip Hybrid – Si Tr Module for Hi Luminosity

1.3 V

2.4 amps

X 10 DC-DC Power Converter

Current Reduced by 10 (losses by 100)

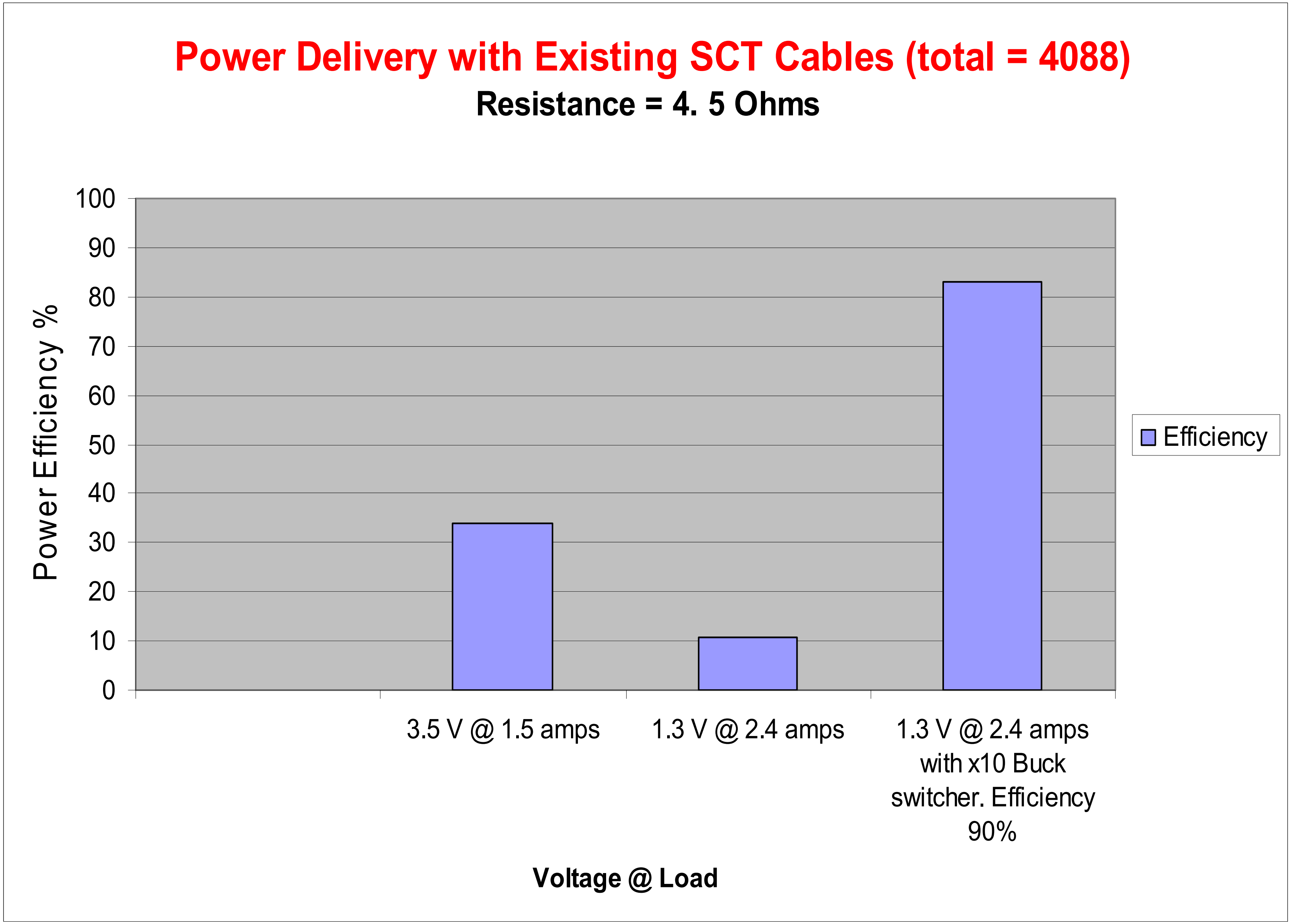
13 V

14.08 V

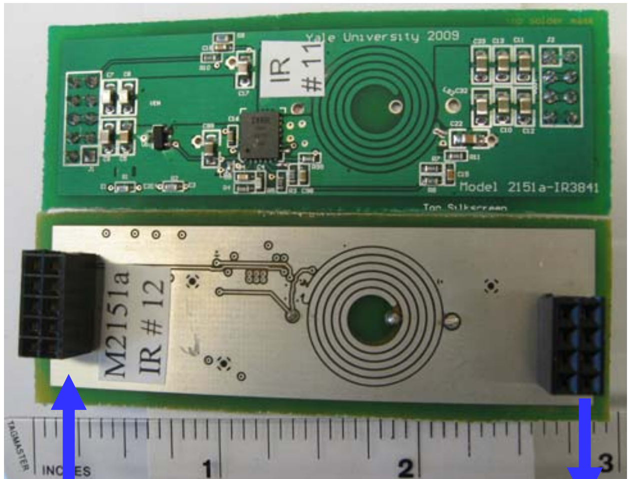
Voltage Drop = 1.08 V

0.24 amps

> X 40 with Gallium Nitride Transistors


Power Delivery with Existing SCT Cables (total = 4088)
Resistance = 4. 5 Ohms
Power Efficiency %
100
90
80
70
60
50
40
30
20
10
0
3.5 V @ 1.5 amps
1.3 V @ 2.4 amps
1.3 V @ 2.4 amps with x10 Buck switcher. Efficiency 90%
Voltage @ Load
Efficiency

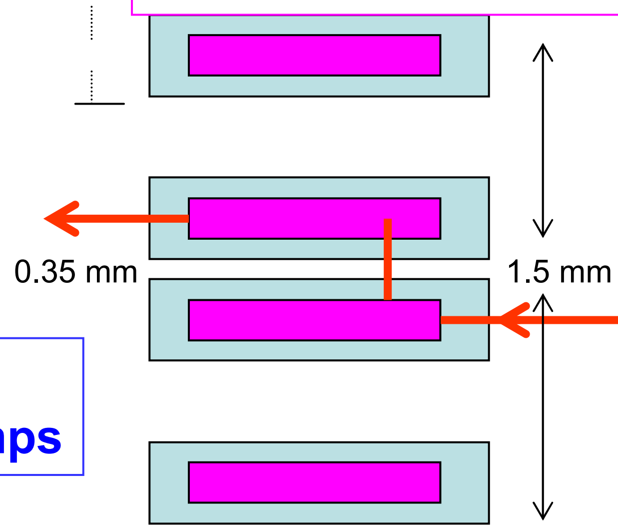
Plug In Card with Shielded Buck Inductor

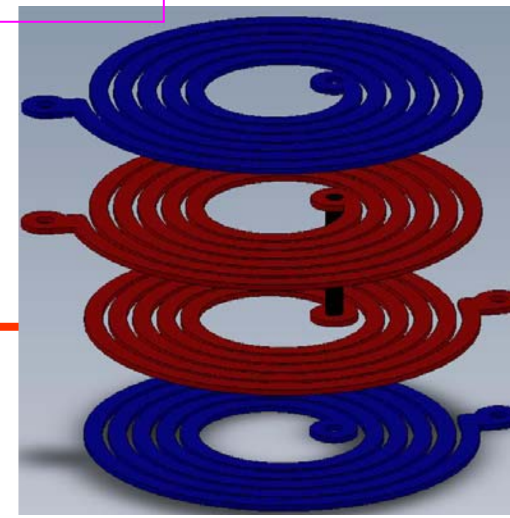


12 V

2.5 V
@ 6 amps

Coupled Air Core Inductor Connected in Series





Different Versions

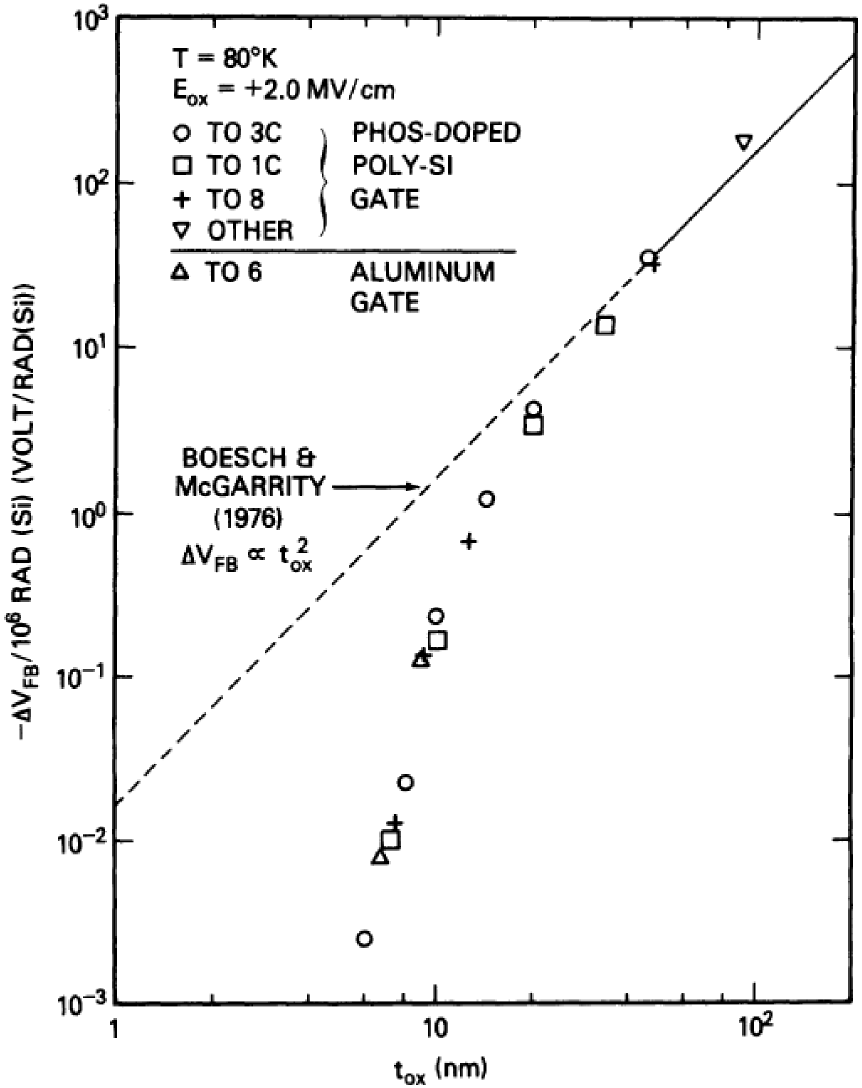
- Converter Chips
  - Max8654 monolithic
  - IR8341 3 die MCM
- Coils
  - Embedded 3oz cu
  - Solenoid 15 mΩ
  - Spiral Etched 0.25mm

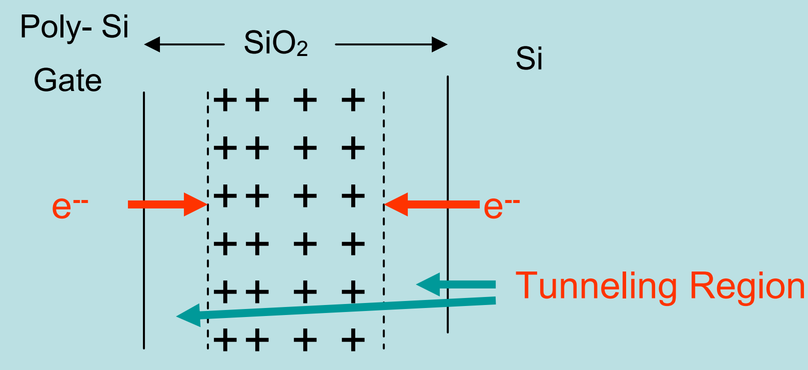
Spiral Coils Resistance in mΩ

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

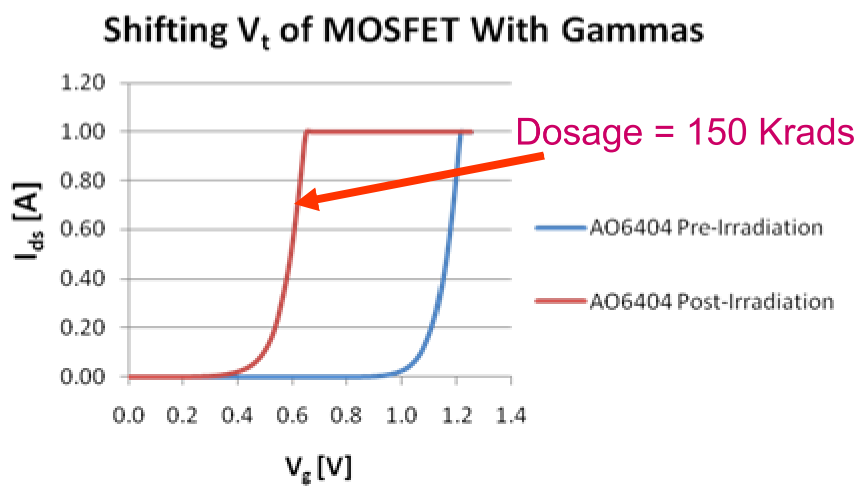
Noise Tests Done: sLHC SiT prototype, 20 μm AL Shield

Threshold Shift vs Gate Oxide Thickness





Hole removal process by tunneling in thin-oxide MOS Structures



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

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

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

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

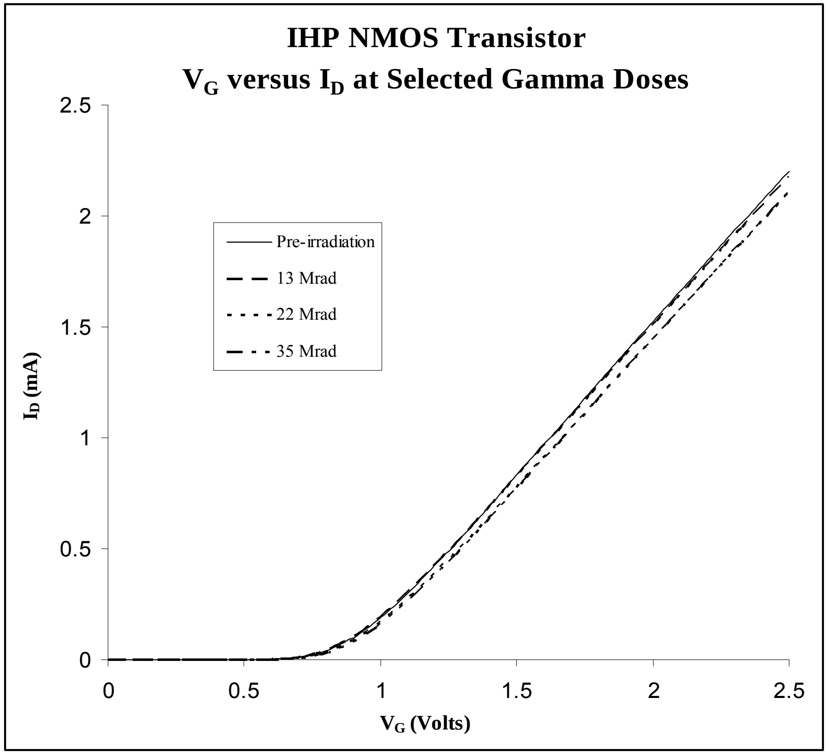
Mixed signal power designs from TI, TSMC, IBM etc - 0.18 μm & 0.13 μm
Automobile Market. Voltage ratings 10 - 80 Volts
Deep sub-micron but thick oxide

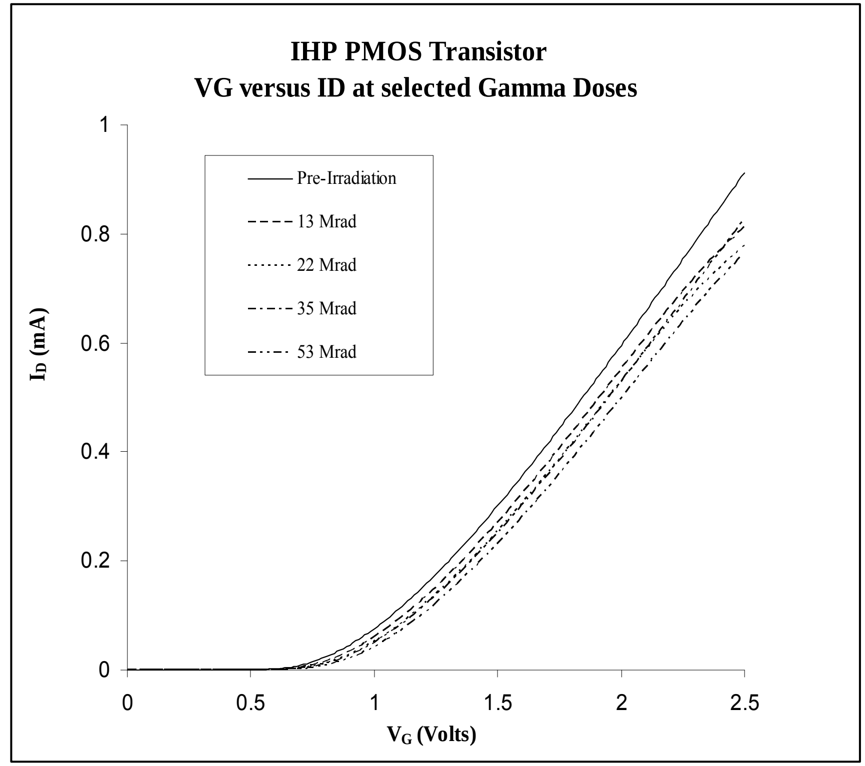
Controller : Low Voltage

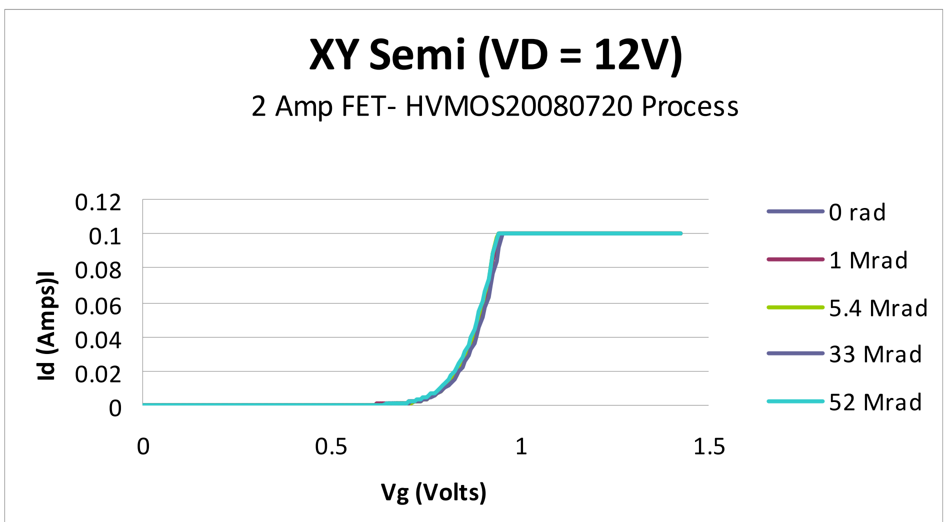
High Voltage: Switches – some candidates HV & Thin oxide

RF Process LDMOS, Drain Extension, Deep Diffusion etc

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


IHP NMOS Transistor
V_G versus I_D at Selected Gamma Doses
I_D (mA)
V_G (Volts)
0
0.5
1
1.5
2
2.5
Pre-irradiation
13 Mrad
22 Mrad
35 Mrad


IHP PMOS Transistor
VG versus ID at selected Gamma Doses
I_D (mA)
V_G (Volts)
0
0.2
0.4
0.6
0.8
1
0.5
1.5
2
2.5
Pre-Irradiation
13 Mrad
22 Mrad
35 Mrad
53 Mrad


XY Semi (VD = 12V)
2 Amp FET- HVMOS20080720 Process
Id (Amps)I
Vg (Volts)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.5
1
1.5
0 rad
1 Mrad
5.4 Mrad
33 Mrad
52 Mrad

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		2Q2010
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

Why we got into GaN?

This paper

The aim of our investigation was the test of our standard AlGaN/GaN HFET devices for reliability simulating a mission of 10–100 years in space environment. This paper describes the results of irradiation with protons and heavy ions like carbon, oxygen and iron at 68 MeV and 2 MeV on a series of devices from the same wafer. The fluences were varied in a wide range between and cm .

Proton and Heavy Ion Irradiation Effects on AlGaN/GaN HFET Devices
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 53, NO. 6, DECEMBER 2006

A few days after reading this paper in early 2008. there was IMWS in Boston
There were many companies pedaling GaN RF transistors – Cellular Market
We could not pass up an opportunity to test GaN for physics

Gallium Nitride Devices Tests 2009

RF GaN 20 Volts & 0.1 amp

❖ 8 pieces: Nitronex NPT 25015: GaN on Silicon

✓ Done Gamma, Proton & Neutrons

✓ 65 volts Oct 2009 — 48V Converter ?

❖ 2 pieces: CREE CGH40010F: GaN on siC

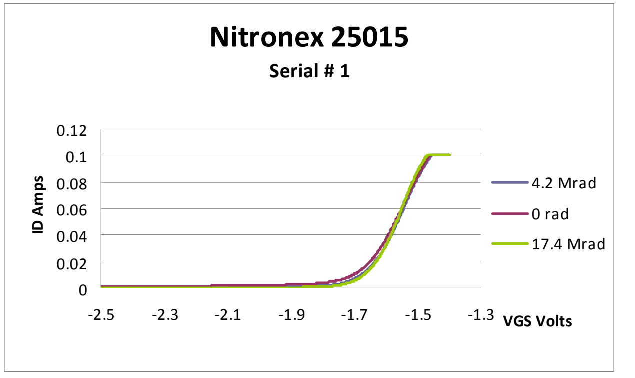
❖ 6 pieces: Eudyna EGNB010MK: GaN on siC

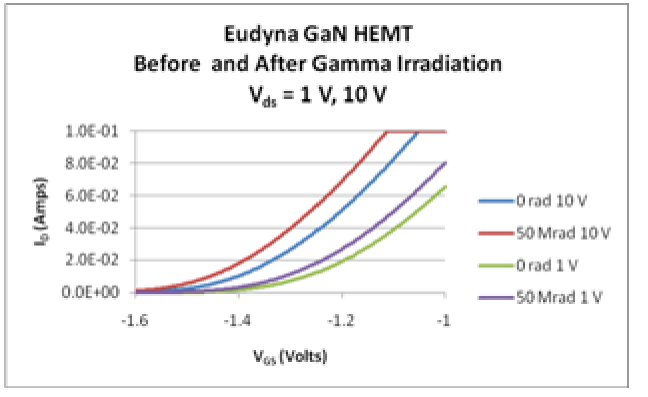
✓ Done Neutrons

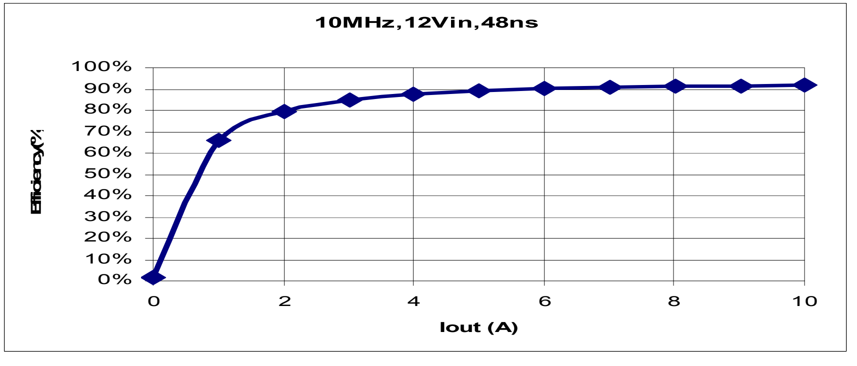
Switch GaN

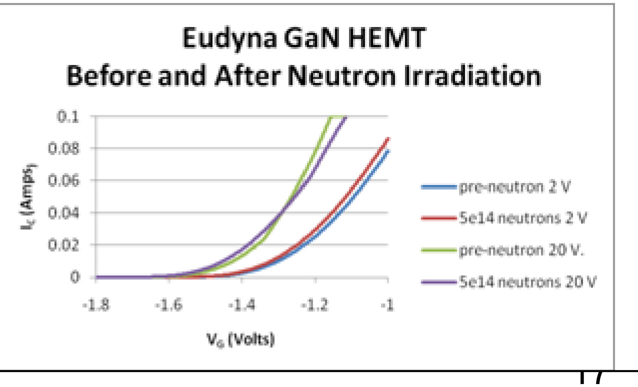
❖ International Rectifier GaN on Silicon

Under NDA. *Good efficiency to >12 MHz* Driver limited









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

Oscillations in SPA @ >>1 GHz

Electrical Properties of Wide Bandgap Semiconductors Compared With Si and GaAs

Material	E_g (eV)	ε_s	μ_n (cm^2/Vs)	E_c (MV/cm)	v_{sat} (10^7 cm/s)	n_i (cm^{-3})	BFOM*
Si	1.12	11.8	1350	0.3	1.0	1.5×10^{10}	1
GaAs	1.42	13.1	8500	0.4	2.0	1.8×10^{6}	17
4H-SiC	3.26	10	720	2.0	2.0	8.2×10^{-9}	134
6H-SiC	2.86	9.7	370	2.4	2.0	2.4×10^{-5}	115
2H-GaN	3.44	9.5	900	3.0	2.5	1.0×10^{-10}	537

E_g, bandgap; ε_s, dielectric constant; μ_n, electron mobility; E_c, critical electric field; v_{sat}, saturation velocity; n_i, intrinsic carrier density.
*BM=$\varepsilon\mu E_c^3$, BFOM was normalized by the BM of Si.

Nariaki Ikeda et al. GaN Power Transistors on Si Substrates for Switching Applications. Proceedings of the IEEE, Vol. 98, No. 7, July 2010
B. J. Baliga, BPower semiconductor device figure of merit for high-frequency applications IEEE Electron Device Lett., vol. 10, p. 455, Oct. 1989.

Table I: Physical characteristics of Si and main wide bandgap semiconductors [1-3].

Property	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap, E_g (eV)	1.12	1.43	3.03	3.26	3.45	5.45
Dielectric constant, ε_r[1]	11.9	13.1	9.66	10.1	9	5.5
Electric Breakdown Field, E_c (kV/cm)	300	400	2500	2200	2000	10000
Electron Mobility, μ_n ($cm^2/V \cdot s$)	1500	8500	500 80	1000	1250	2200
Hole Mobility, μ_p ($cm^2/V \cdot s$)	600	400	101	115	850	850
Thermal Conductivity, λ (W/cm·K)	1.5	0.46	4.9	4.9	1.3	22
Saturated Electron Drift Velocity, v_{sat} ($\times 10^7$ cm/s)	1	1	2	2	2.2	2.7

[1] $\varepsilon = \varepsilon_r \cdot \varepsilon_o$ where $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Burak Ozpine et al Comparisson of Wide bandgap Semiconductors for Power Applications, ONRL epe_2003_wide_bandgap

Table II: Main figures of merit for wide-bandgap semiconductors compared with Si [2].

aliga FOM RA_ Cost

ET Switching Speed

FET Power Handling

ET Power Switching

polar Power Switching

	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
JFM	1.0	1.8	277.8	215.1	215.1	81000
BFM	1.0	14.8	125.3	223.1	186.7	25106
FSFM	1.0	11.4	30.5	61.2	65.0	3595
BSFM	1.0	1.6	13.1	12.9	52.5	2402
FPFM	1.0	3.6	48.3	56.0	30.4	1476
FTFM	1.0	40.7	1470.5	3424.8	1973.6	5304459
BPFM	1.0	0.9	57.3	35.4	10.7	594
BTFM	1.0	1.4	748.9	458.1	560.5	1426711

JFM : Johnson's figure of merit is a measure of the ultimate high frequency capability of the material.

BFM : Baliga's figure of merit is a measure of the specific on-resistance of the drift region of a vertical FET

FSFM : FET switching speed figure of merit

BSFM : Bipolar switching speed figure of merit

FPFM : FET power handling capacity figure of merit

FTFM : FET power switching product

BPFM : Bipolar power handling capacity figure of merit

BTFM : Bipolar power switching product

Burak Ozpineci et al Comparisson of Wide-bandgap Semiconductors for Power Applications, ORNL epe_2003_wide_bandgap

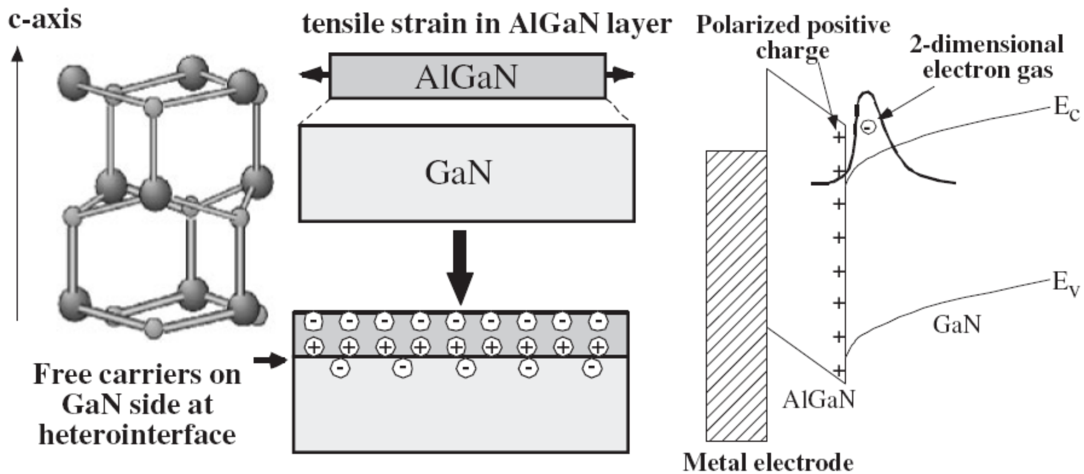


Fig. 6. AlGaN/GaN heterostructure and its band diagram. When the AlGaN layer is under tensile strain, free carriers are accumulated at the heterointerface owing to the piezoelectric effect caused by the strain, and a spontaneous polarization effect.

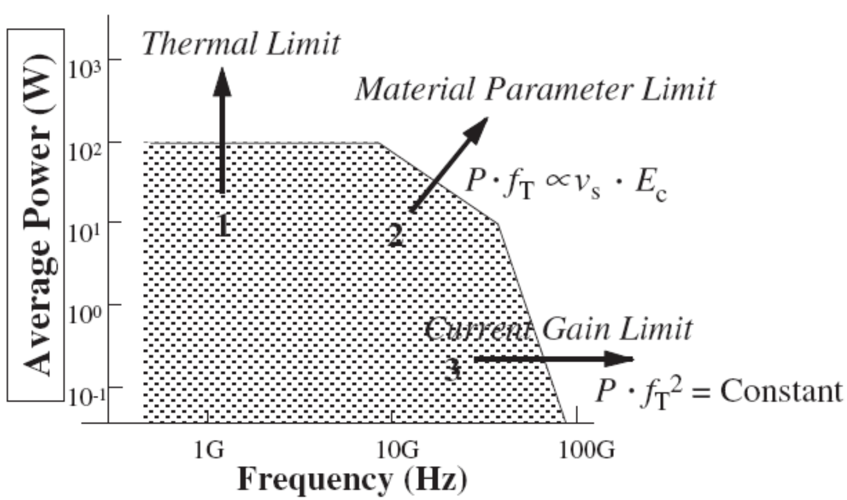


Fig. 7. Restrictions of HF devices in terms of output power and frequency. The limiting factors for HF device operation are thermal restriction, material property restriction and current gain restriction, for the respective regions shown in the figure.

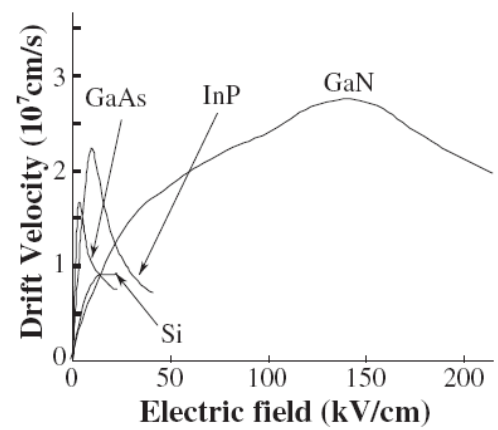


Fig. 8. Dependence of drift velocity of semiconductors on electric field. GaAs and InP have high mobilities (slope of drift velocity–electric field relation in the low-electric-field region); however, their drift velocities decrease in the high-electric-field region. On the other hand, GaN shows high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

GaN History

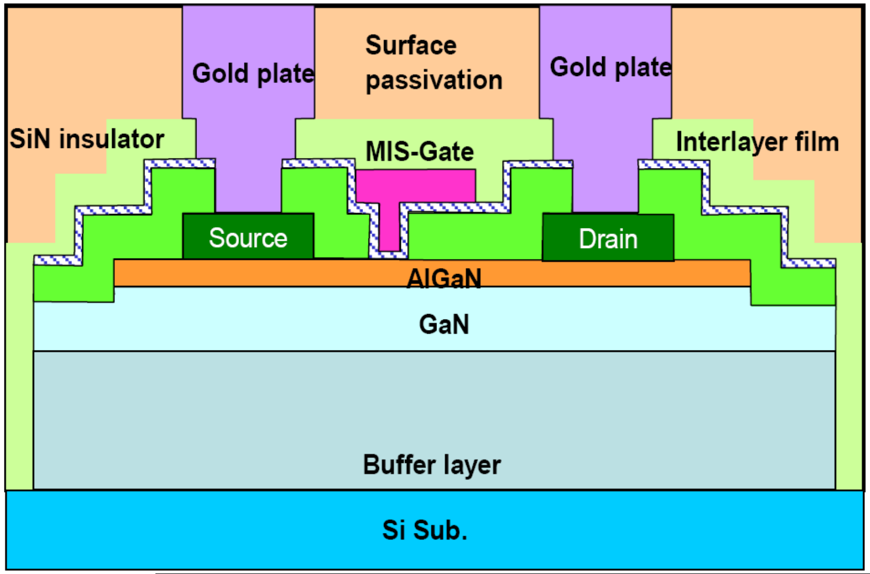
1975: A Phenomenon lead to HEMT. T. Mimura et.al.
1994: High electron mobility reported AlGaN/Gan interface – M. A. Khan et.al.
2004: Eudyna GaN on SiC RF 5 GHz Power amplifier Cellular Base stations.
2005: Nitronex GaN on Si RF Power amplifier Cellular Base stations

June, 2009: EPC announced GaN on Si for power. 20 - 200 V. E-mode
March, 2010: Start selling thru Digikey
Feb 2010: IR announced GaN on Si for power 12 V parts- Engineering samples

2010: Single Crystal by Ammono - IEEE Spectrum July 2010
3 inch GaN substrates becoming available in Japan

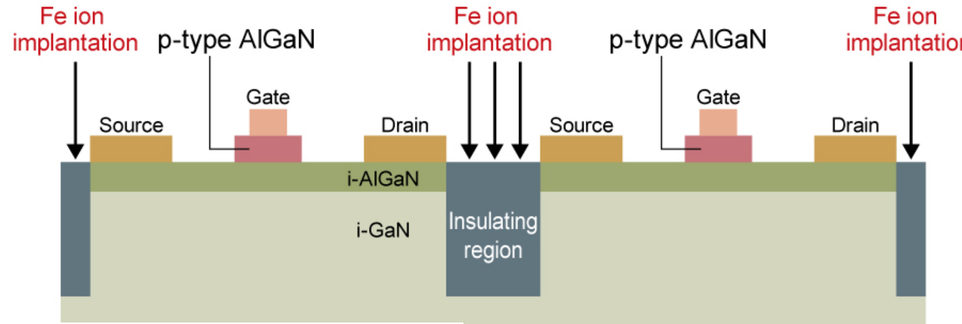
GaN RF transistors have been displacing Si LDMOS transistors
- Cellular base stations
EPC: First supplier of GaN for DC-DC converters. Available thru Digikey
International Rectifier: d-Mode with driver

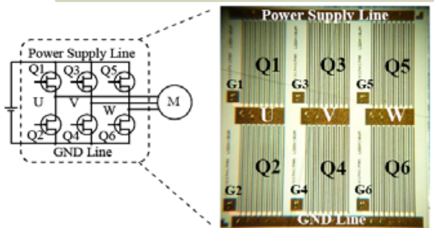
Recently Published Devices



D- Mode

HFET device structure on Si substrate.
R&D Association Fuji Electric and Furukawa Electric
Ikeda et al. Proceedings of IEEE Vol. 98. No.7. July 2010

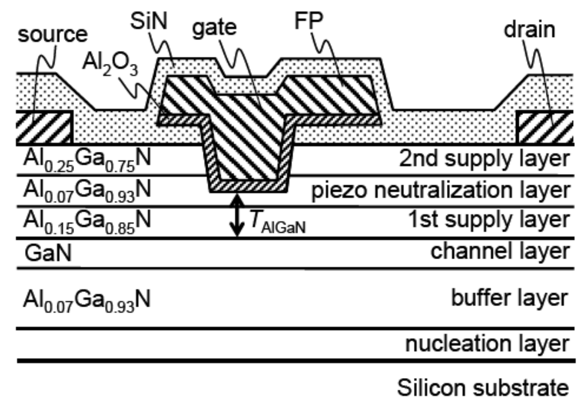




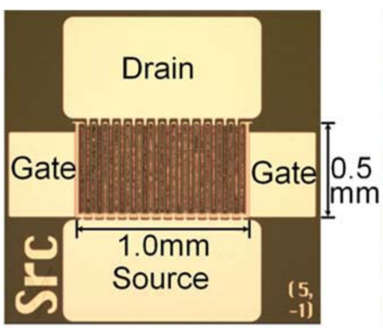
Uemoto, **Panasonic** IEDM 09-168

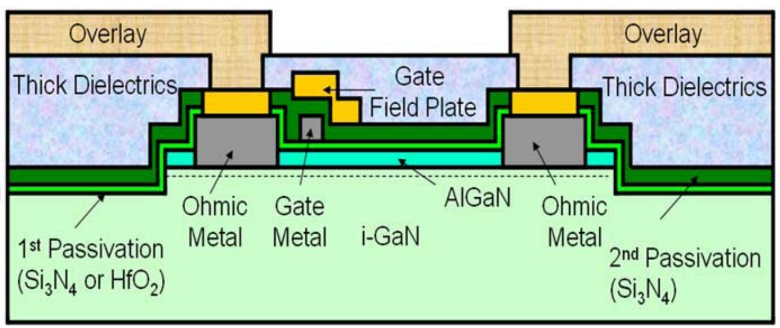
Inverter for Air Conditioning Motor

e- Mode



e- Mode



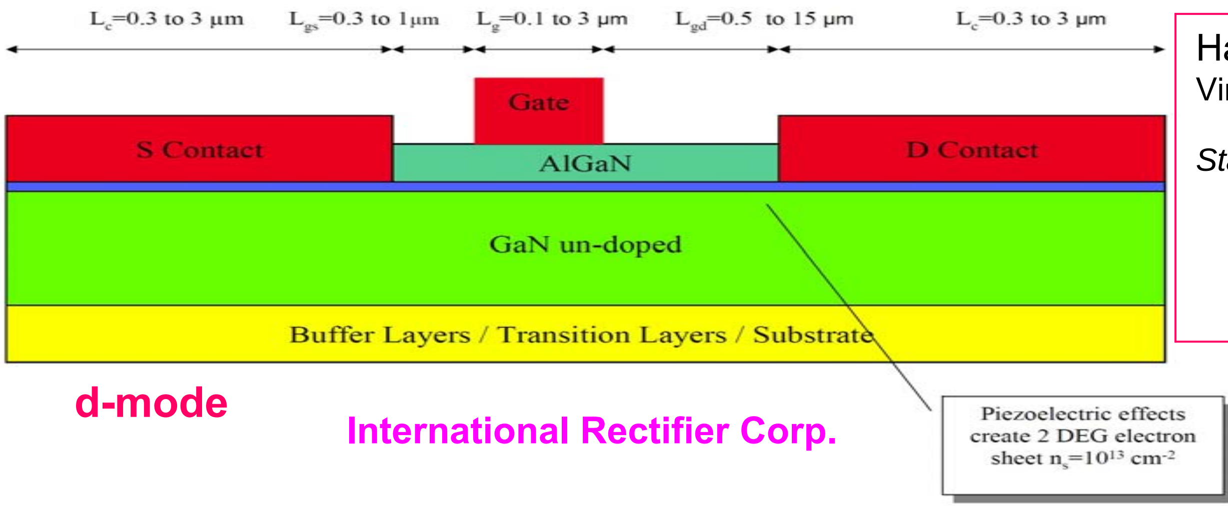


D- Mode

K. Ota: Nano Electronics Res Lab. **NEC** IEDM 09- 154

Velox Semiconductor: (Being acquired by **Power Integrations** - $300M company)
IEEE ELECTRON DEVICE LETTERS, VOL. 30, NO. 10, OCTOBER 2009
600 V @ 5.5 A

2 Commercial Device Companies



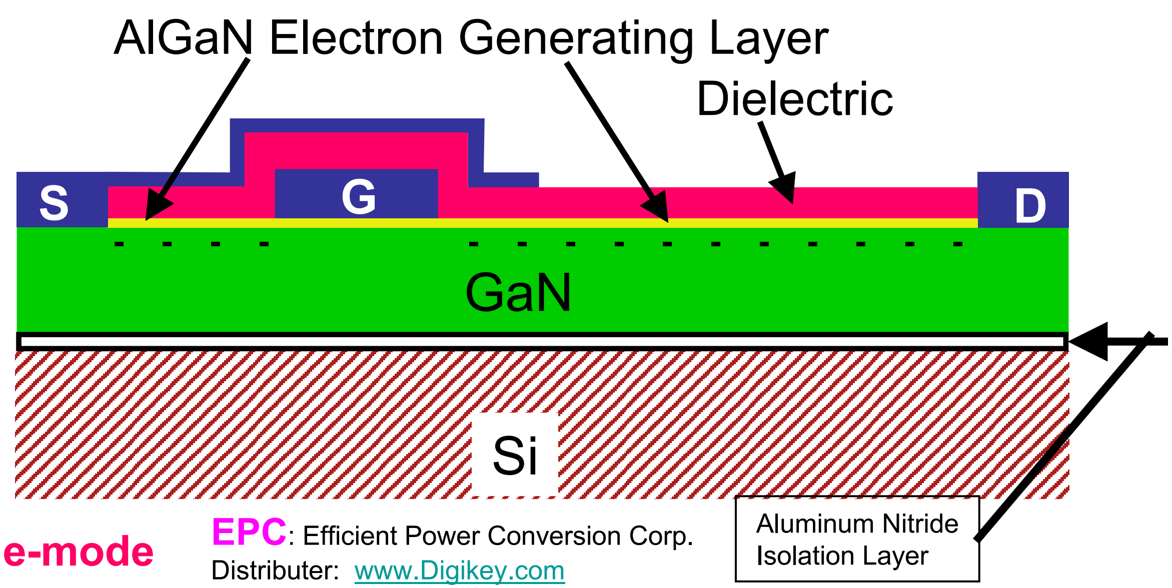
Half bridge Power Stage with Driver
Vin = 7 -13.2 V Vout = 0.6 – 5.5 V

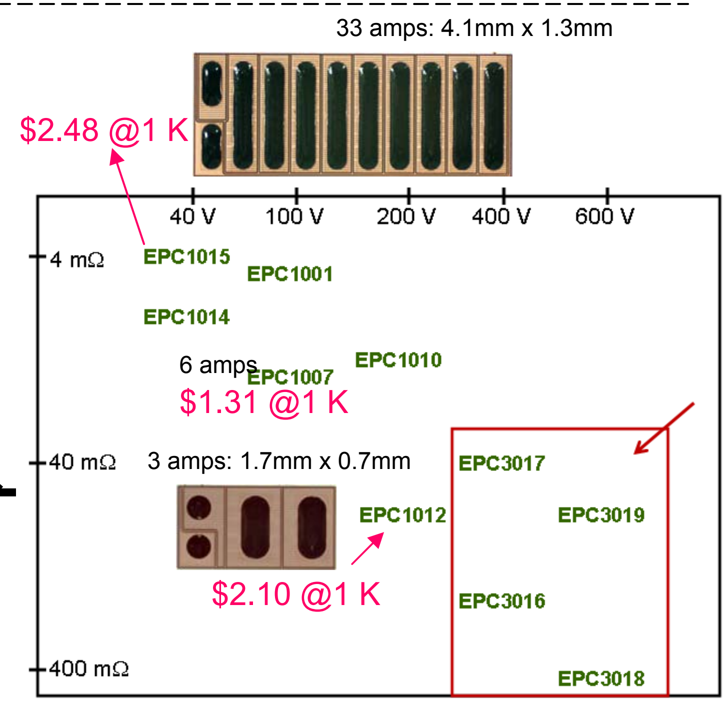
Status: Sampling Special Customers
Delivery 2Q2011

iP2010 30A $9 @ 2.5K
iP2011 20A $6 @ 2.5K

d-mode

International Rectifier Corp.



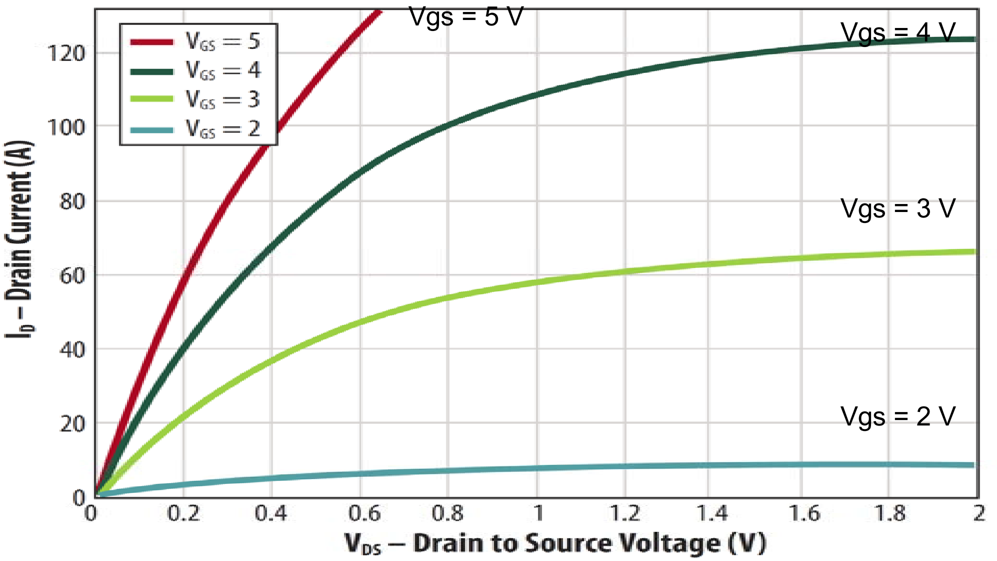


e-mode

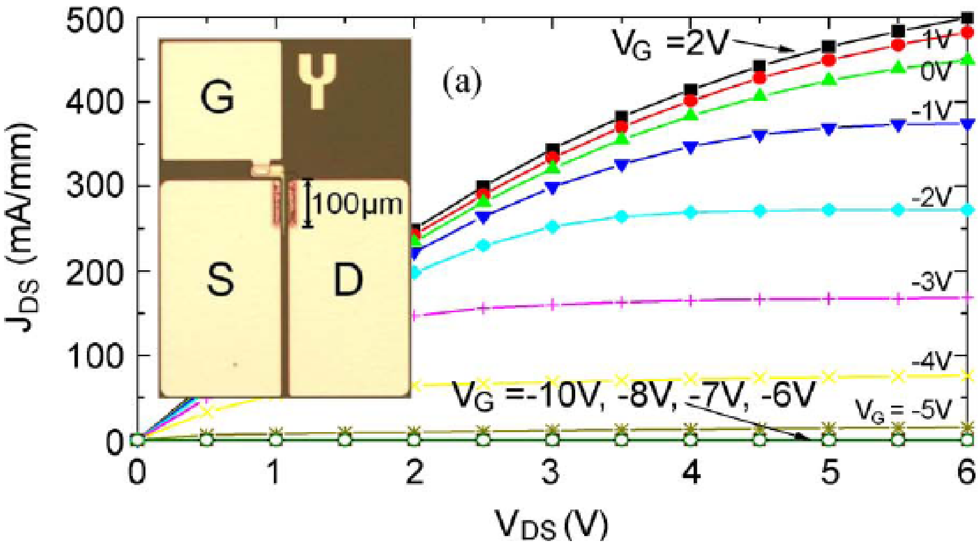
EPC: Efficient Power Conversion Corp.
Distributer: www.Digikey.com

Depletion & Enhancement Mode Devices

Enhancement Mode – Normally OFF

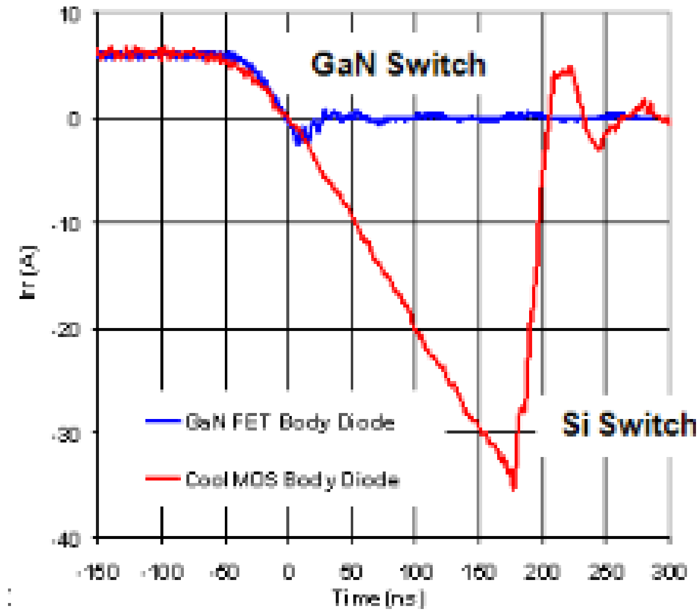


Depletion Mode – Normally ON



X. Xin et al: IEEE Electron Device Letters, Vol.30, No. 10, October 2009

GaN No Reverse Recovery



D-mode Rds lower by 2 but need to drive gate with Negative voltage drive

A comparison between Silicon and GaN characteristics

	Typical 100V Silicon	100V eGaN™
Maximum gate-source voltage	±20 V	+6 V and -5 V
Avalanche capable	Yes	Not rated
Reverse-direction 'diode' voltage	~1 V	~1.5 V to 2.5 V
Body-diode reverse-recovery charge	High	None
Gate-to-source leakage	A few nanoamps	A few milliamps
Gate threshold	2 V to 4 V	0.7 V to 2.5 V
Internal gate resistance	>1 Ω	<0.6 Ω
dV/dt capacitance (Miller) ratio Q_{GD}/Q_{GS}	0.6 to 1.1	1.1
Change in $R_{DS(ON)}$ from 25°C to 125°C	>+70%	<+50%
Change in V_{TH} from 25°C to 125°C	-33%	-3%

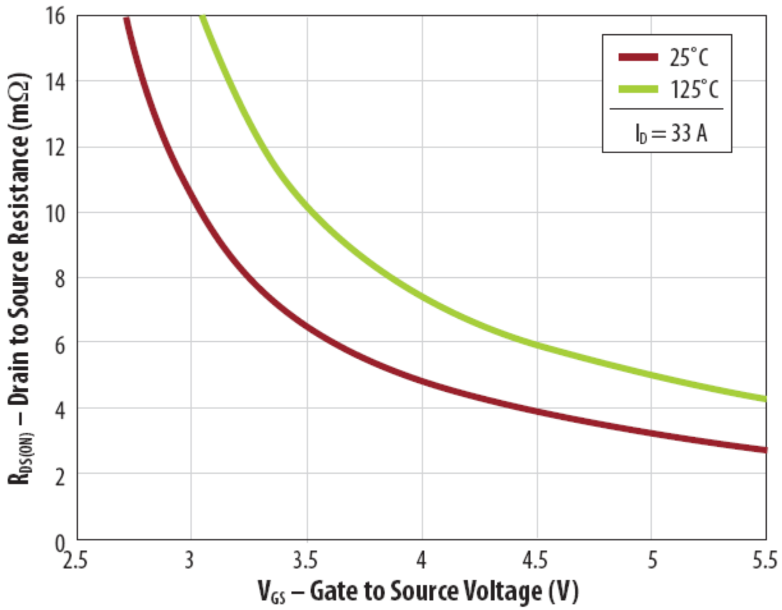
0

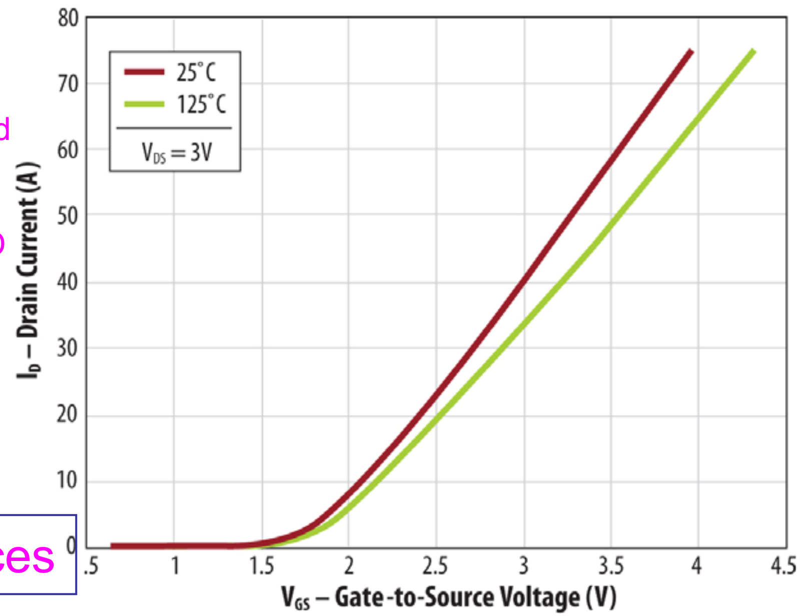
H

L

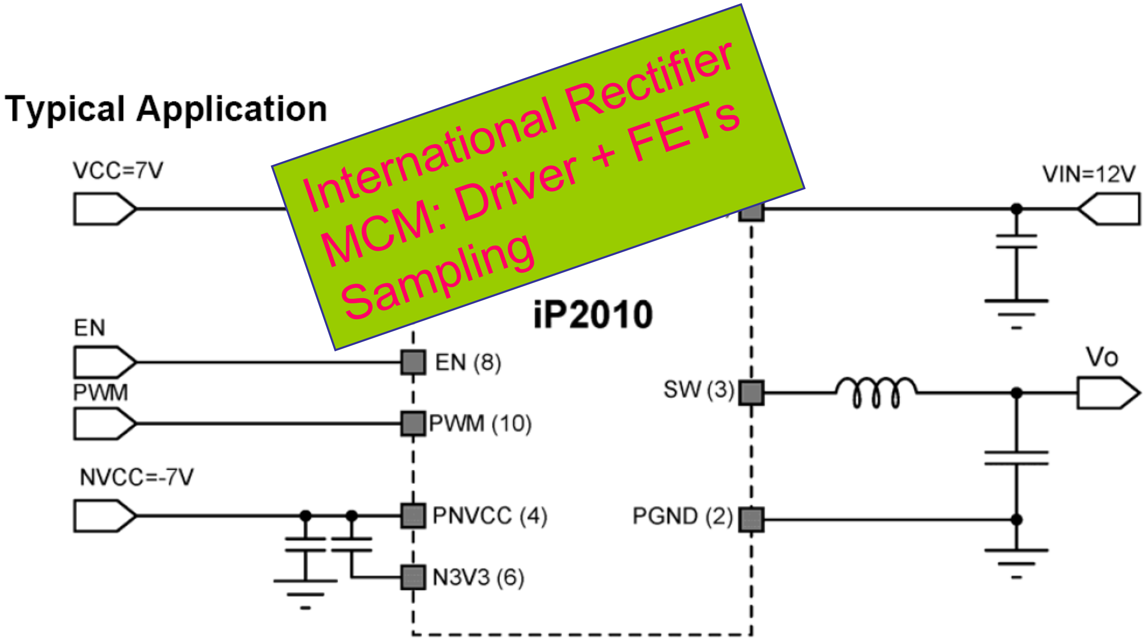
Need Low R to GND

Figure 4: $R_{DS(ON)}$ vs V_G for Various Temperature



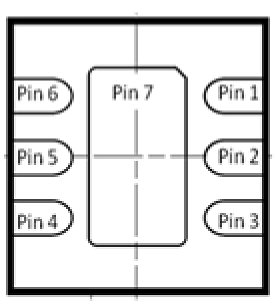


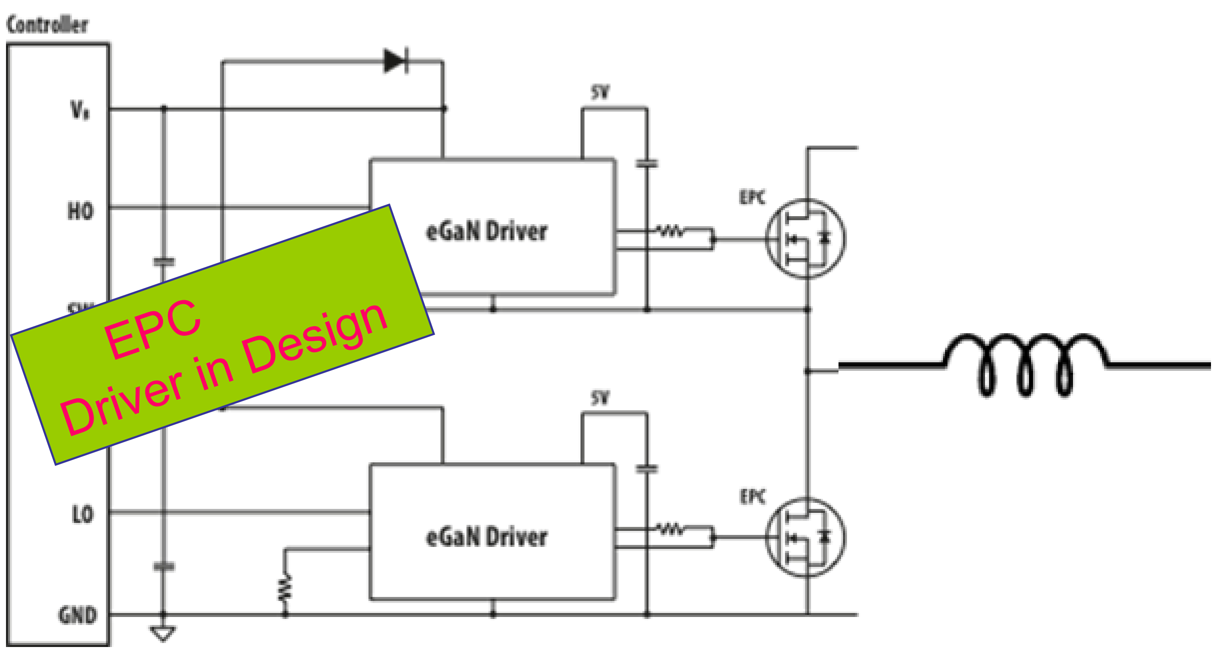
Better current sharing in parallel devices



For Buck Converter Add

- PWM
- Inductor
- Caps





eGaN friendly interface gate driver in 6-pin DFN package (bottom view)

Who is this EPC Company- Never heard of it?

❖Startup near Los Angeles, CA airport – 11 employees + Consultants ~ 20
❖Started by Alex Lidow. Ex CEO of International Rectifier. His father founded IR
❖Foundry – Episil Inc – is well established in Taiwan
❖Process: Epitaxial growth on standard CMOS Silicon substrate
❖Location: El Segundo, CA, 909 N. Sepulveda Blvd

1 mile away

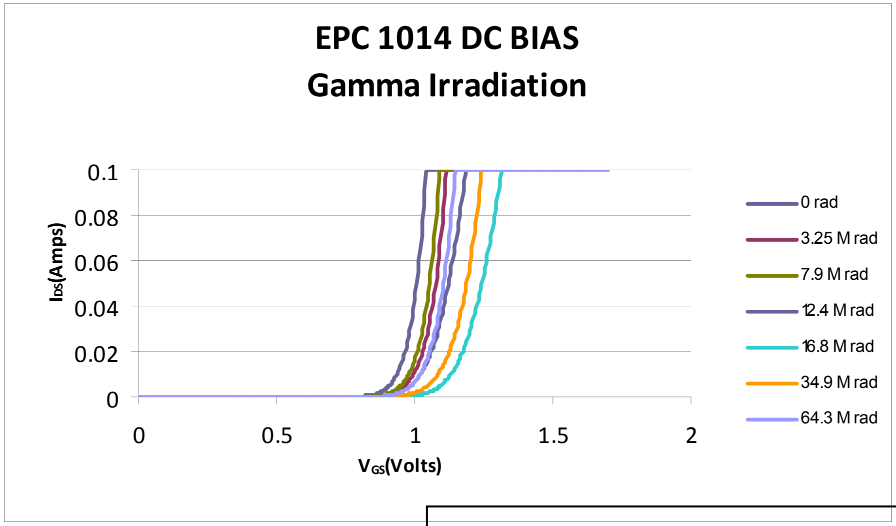
❖International Rectifier: 101 N. Sepulveda Blvd. - GaN for power conversion
❖Anagenesis Inc: 222 N. Sepulveda Blvd – Market Strategy Development

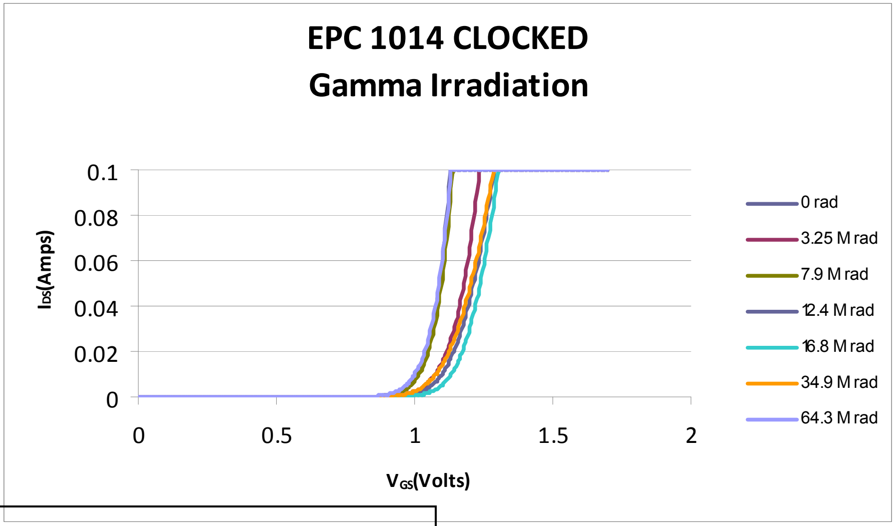
100 miles away

❖ Transphorm Inc Developing 600 V GaN Switches
❖CREE: Santa Barbara Technology Center GaN BlueLED's
❖ University of California, Santa Barbara
❖ *In San Jose:* Eudyna – RF GaN on SiC (Technical Support & Marketing)

3000 miles away

❖ Nitronex – RF GaN-on-silicon
❖ Velox: 600 V GaN-on-sapphire Switches
❖ CREE: RF GaN on SiC, SiC FETs, Blue LEDs,
❖ North Carolina State University

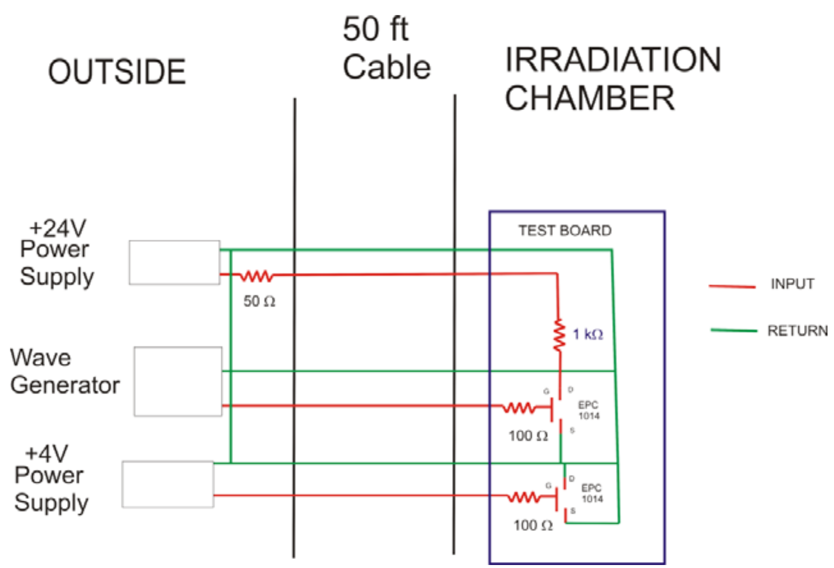




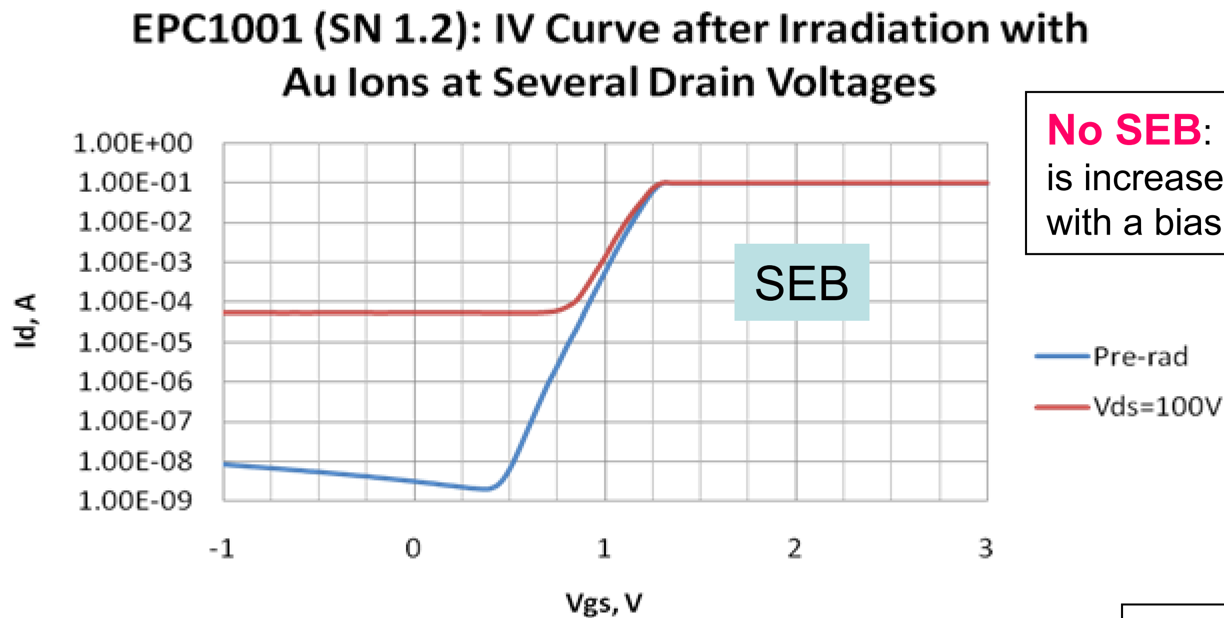
During Gamma Irradiation DC BIAS 4 VOLTS, VDS = 0
Fluence rate= 5 mega M rad/day

Proton Irradiation

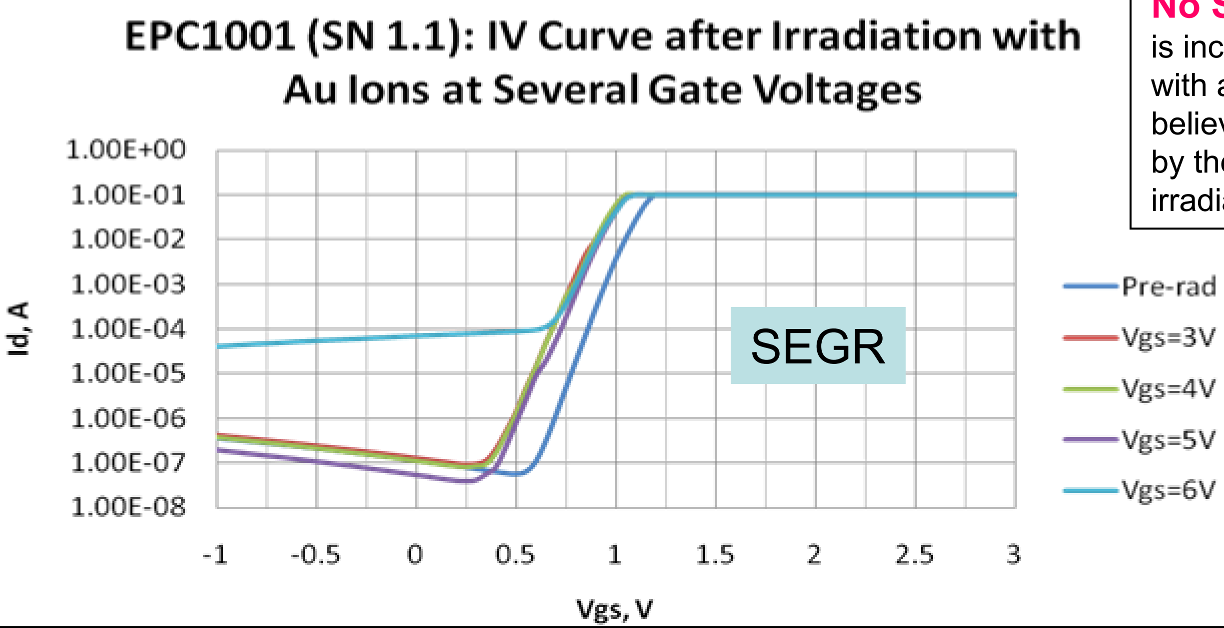
The run went well, we left your board in the beam until it reached approximately 1x10^15 p/cm^2 (800 MeVp). The initial measurement ov voltage across the 50 ohm resistor was 0.645V, and the final measurement was 0.643V. Readings were taken after every entry to remove samples from the blue room (7 times) and they were always between 0.643V - 0.645V. I'm sure Leo Bitteker has your shipping information but you may want to send him a reminder in a couple of weeks.



Gamma Irradiation done @ BNL Gamma Facility *James Kierstead July 2010*
Proton Irradiation @ LANSCE, Los Alamos National Lab. *August 2010*



No SEB: but the drain current leakage is increased after irradiation with Au ions with a bias of Vds = 100V and Vgs = 0V



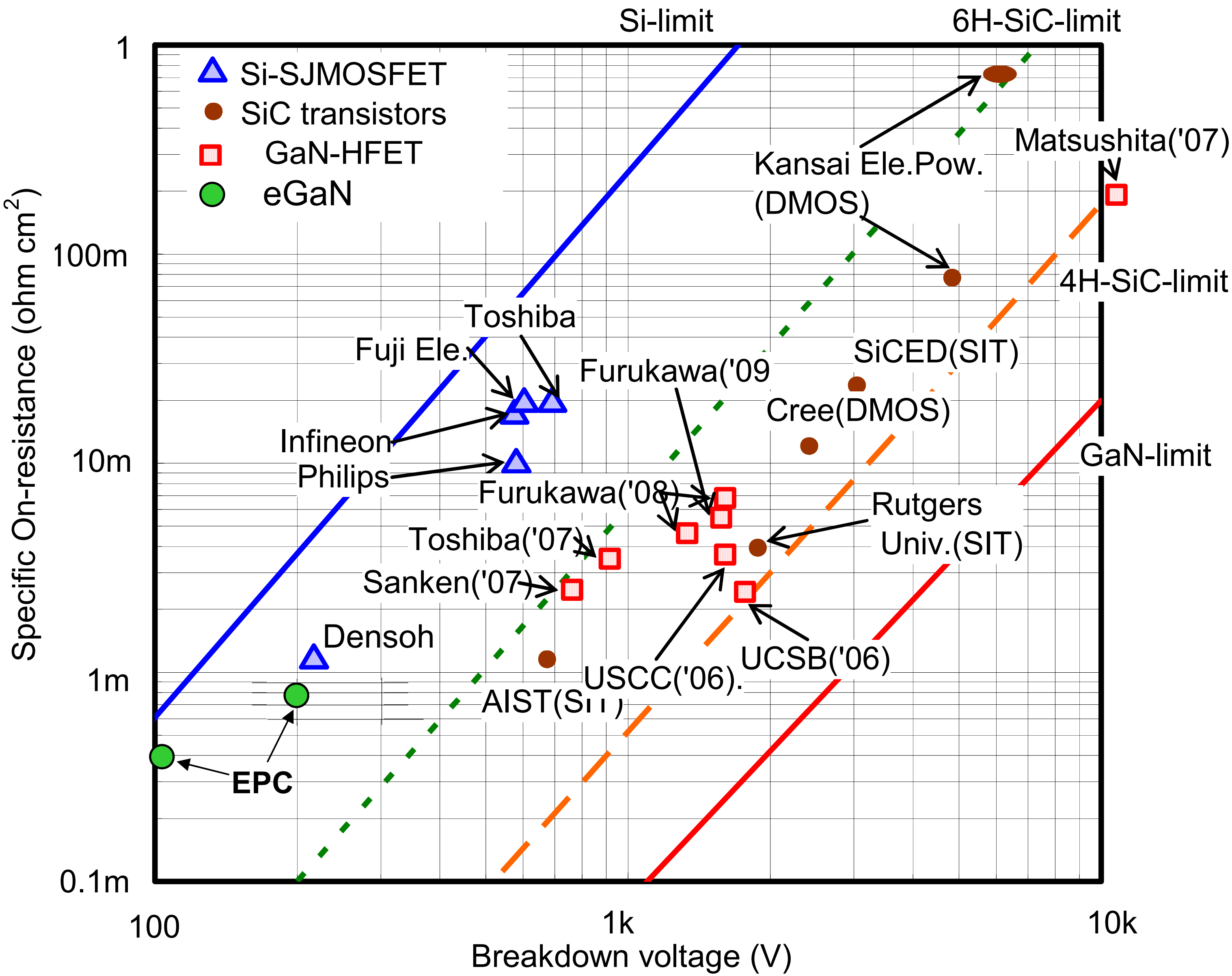
No SEGR, but the drain current leakage is increased after irradiation with Au ions with a bias of Vgs = 6V and Vds = 0V. It is believed increased leakage this is caused by the large gate bias, not by heavy ion irradiation

Yale University

Irradiation done @ Texas A&M University by Sandia National Laboratories *Joseph Brandon Witcher August 2010*

Die Cost: Ω / Area

BFOM: Conduction Loss



Production Device

Best- Academic- made one transistor work

Company: Can produce but does not meet all target product specifications

Why so much interest in GaN ?

Power Efficiency

IBM Challenge
Data Center Usage
Consumer
Portable Gadgets

Telecom Central Office Energy Consumption

Country	Network	Energy Consumption	% of Country Total Energy Consumption
USA	**Verizon 2006**	**8.9 TWh**	**0.24%**
Japan	**NTT Group 2007**	**5.54 TWh**	**1%**
Italy	**Telecom Italia 2005**	**2 TWh**	**1%**
France	**France Telecom-Orange 2006**	**2 TWh**	**0.4%**
Spain	**Telefonica 2006**	**1.42 TWh**	**0.6%**

Global electricity consumption of telecom industry estimated at 1%:

164 billion kWh

More than the total electricity consumption of Iran, Turkey or Sweden

Enough to power 1.6 million homes

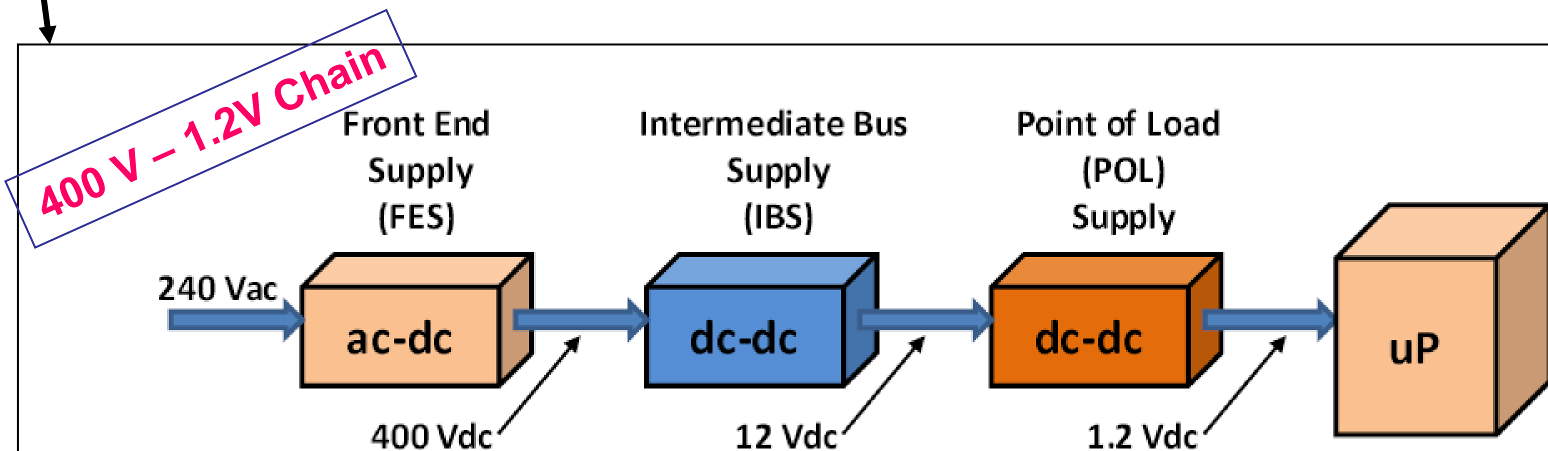
110.7 million tons of CO2 (equivalent to the annual emissions of 29 million cars !)

Source: Emerson Network Power and NTT

ELECTRIC POWER RESEARCH INSTITUTE

GaN High Efficiency Power Switching Applications

- Data Center: Efficiency sensitive / More CPU power in same vault
  400 V DC (+/-200 V) Power distribution: 12 V – 1 V converters.
  - IEC SMB SG4, IEC TC64, ETSI EE, The Green Grid -Power sub working group
- AC Line > DC power converters 600V   5 - 20 amps. Low vampire power
- Electric Vehicles 600 /900 V 100 kwatts
- Railways 8 KV SiC FETs, SiC diodes

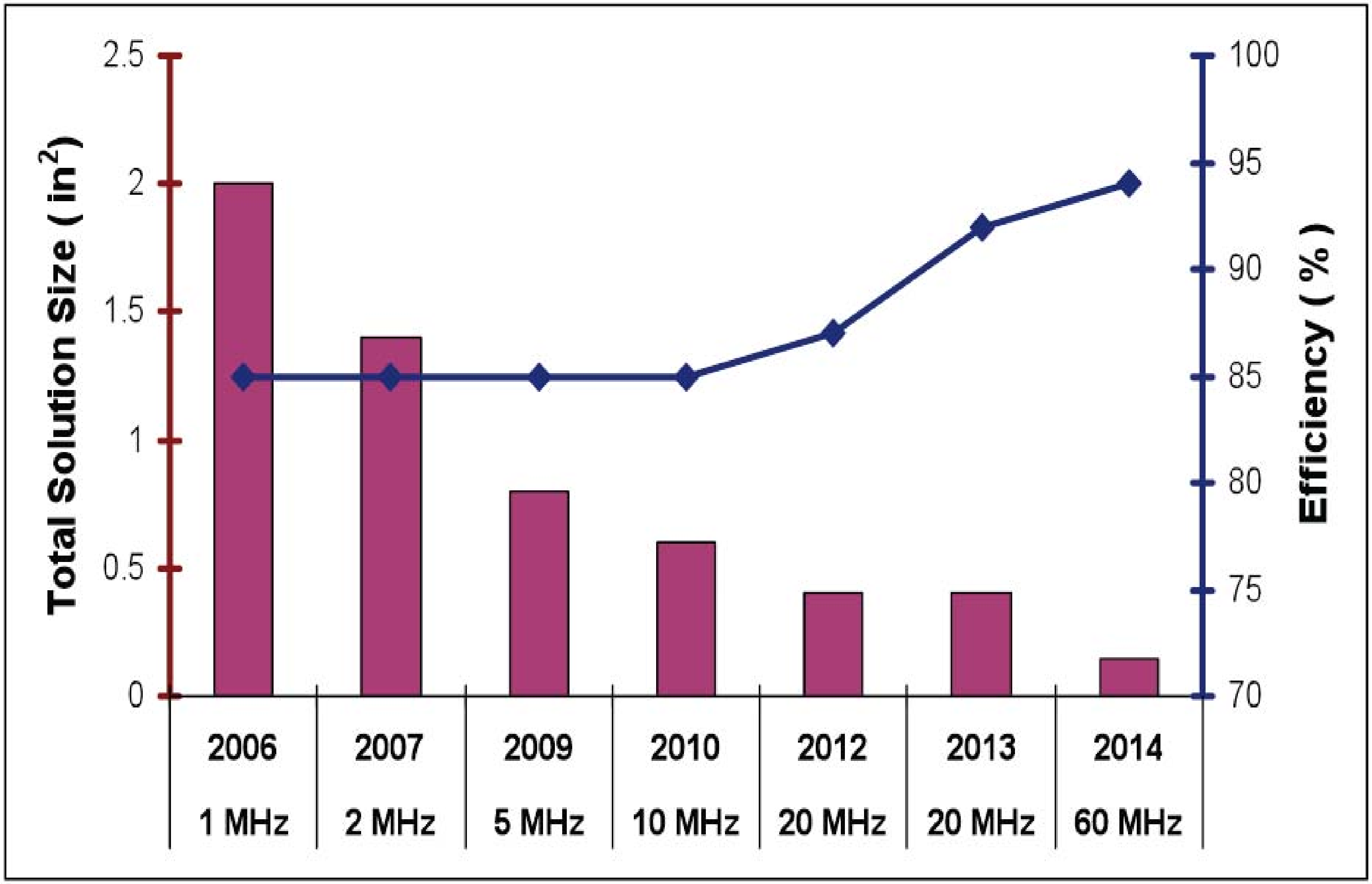


	FES	IBS	POL	Plug-to-Processor
Recent	93%	95%	88%	78%
Best Immediate	95%	98%	90%	84%
	IBM Challenge			***90%***
Needed	98%	98%	94%	***90%***

Arnold Alderman: Bodos Power Systems April 2010.   Randy Malik IBM Digital Forum 2007

Potential LV DC-DC Power Stage Roadmap

Optimized Performance – Without tradeoff



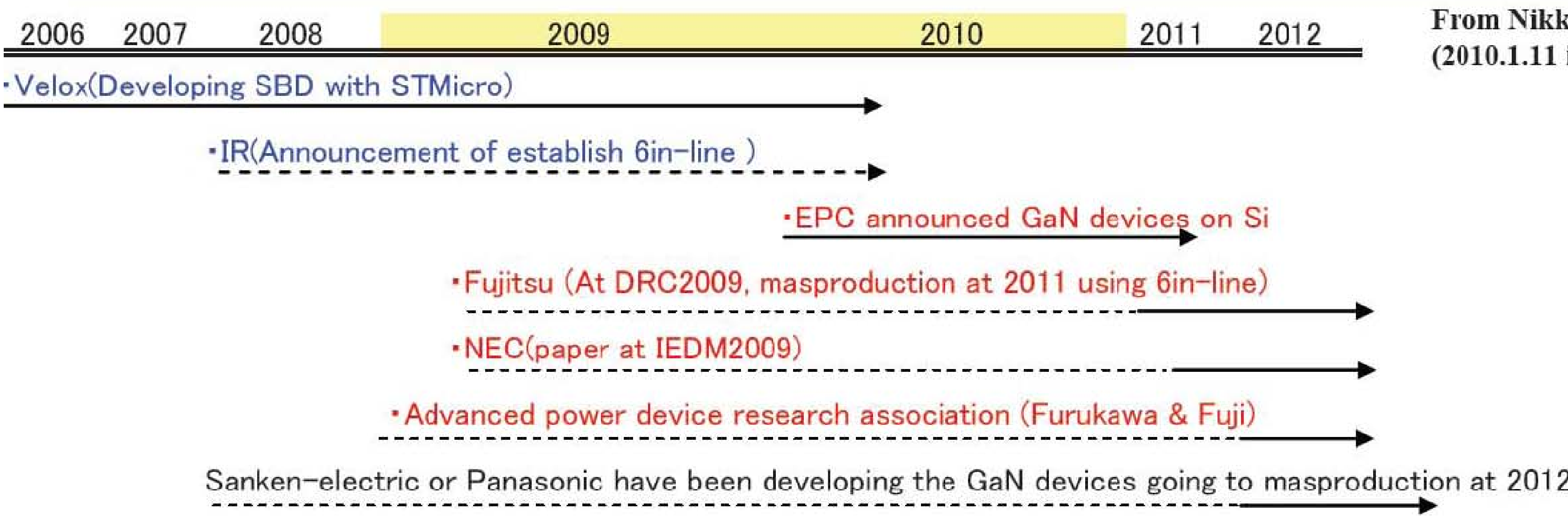
12Vin, 1.2Vout, 100A **Based on Circuit Simulation**

For high frequency Integrate a GaN Driver into Power Stage !

Status of GaN player

Prepared by Dr. Nariaki Ikeda
of Advanced Power Device Research Association

Company	Detail of Target or status
Fujitsu Laboratory	Mass-production level in 2011(fiscal)~2012 in the medium Vb over 600V using Si or SiC substrate (representative by Fujitsu Micro-elect.)
Furukawa and Fuji Electric	Commercial use at 2011(fiscal)
International Rectifiers	Commercial use from 2010 Beginning of product is lower Vb such several tens of voltage
NEC (Renesus)	Deliver Sample at 2011(fiscal)
Panasonic	Commercial use at 2011(fiscal)
Rohm	Deliver Sample at 2011(fiscal), also developing GaN native substrate
Sanken Electric	Trial manufacture of Vb over 800 V



From Nikkei electronics
(2010.1.11 in Japanese)

JPCA Show 2010


2010年 6/9 WED 第1892号

THE SEMICONDUCTO

半導体産

この人に聞く! 半導体トップインタビュー

富士通セミコンダクター(株) 代表取締役社長 岡田 晴基 氏

300mmを月産2万枚に増強

国内半導体大手12社の業績推移

Fujitsu

President

H. Okada

Fujitsu
President H. Okada
GaN Power Devices.
150/ 200 mm Fab lines

Ship samples mid 2010
Production start end 2010

Factory: Aizuwakamatsu

Market:
Mobile, Auto, TV & Industrial


JPCA Show 2010特集 1、6~8面

ラージエレクトロニクスショー2010特集 16面

平坦化技術特集(CMP装置・材料) 1、10~15面

GaNデバイス量産へ

パナソニック 10年度内有力

Panasonic

Ishiguro

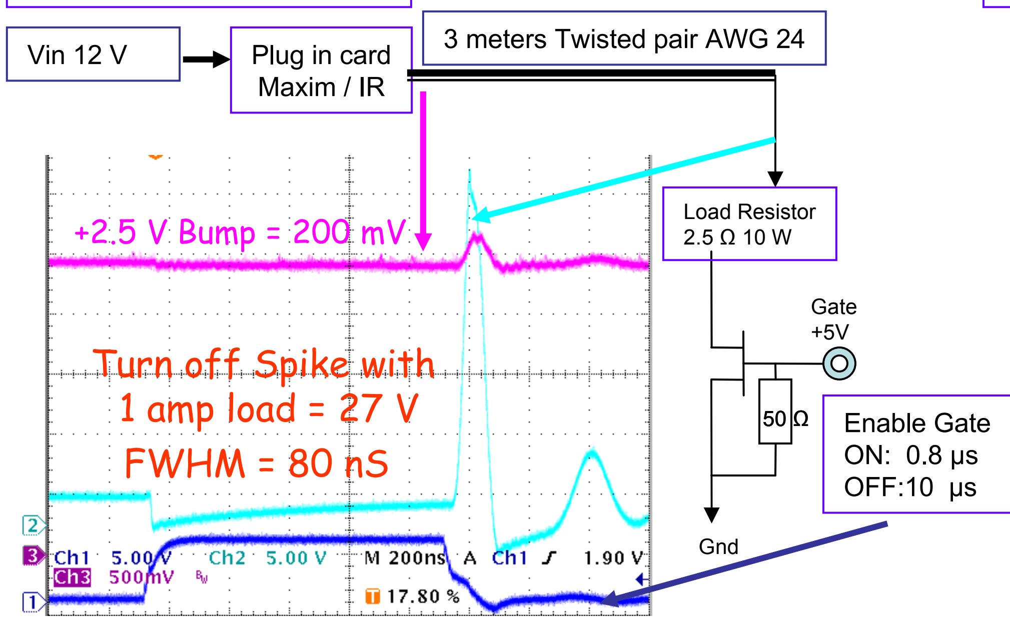
President of Panasonic

Panasonic
New President: Mr. Ishiguro
Deliver Products FY2010

Market: White Appliances
Air Conditioners, Washer, Dryers

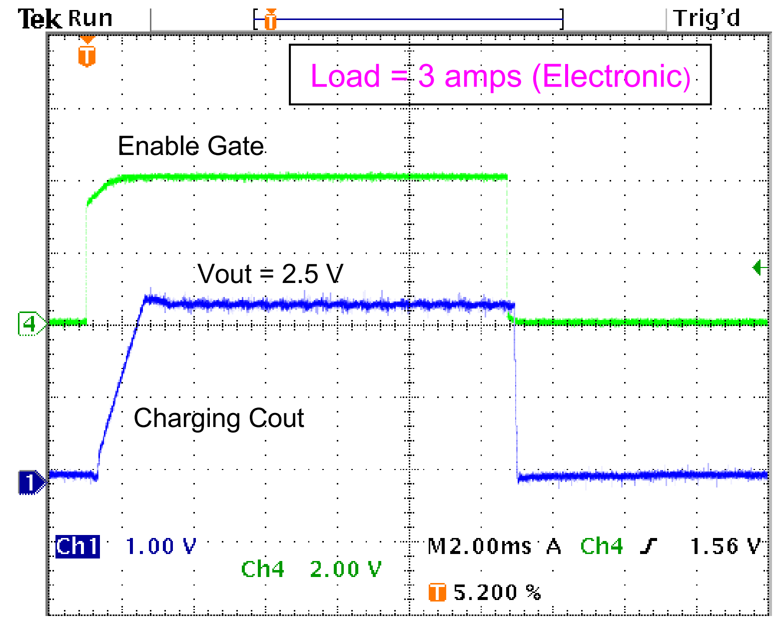
Pulsing Load

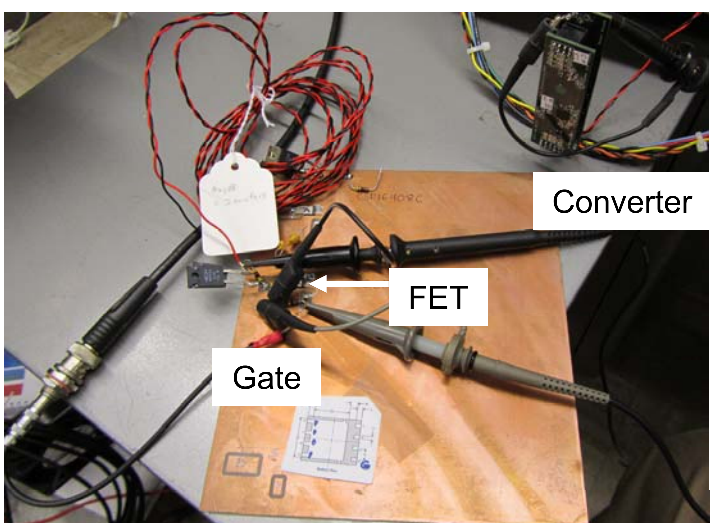
Air Coil DC-DC Converter

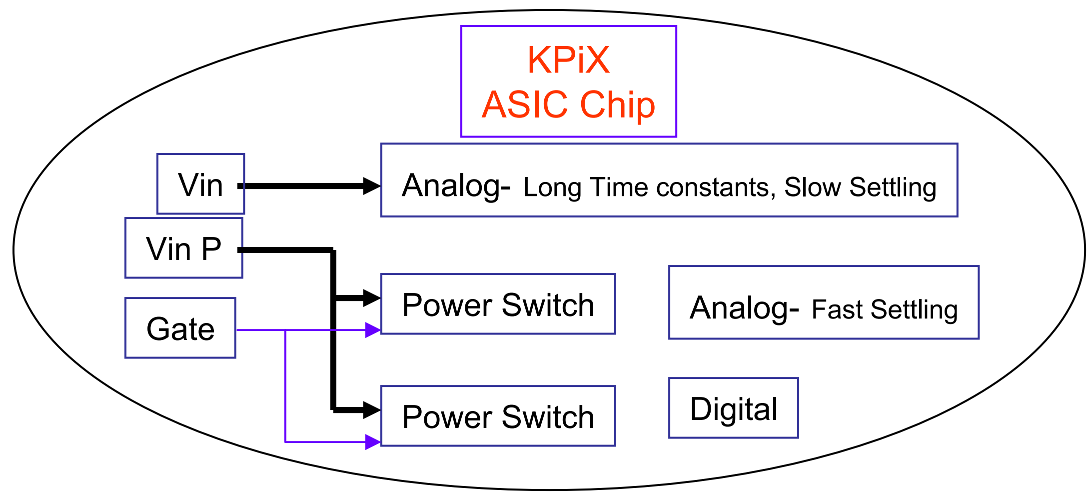


Pulsing Converter

Air Coil DC-DC Converter







ILC SiD Powering Pulsing Development

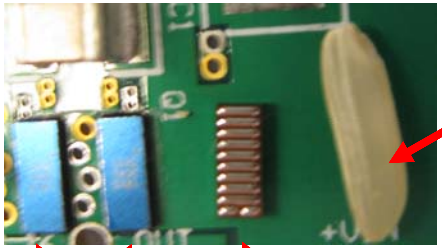
What can be achieved by this Development ?

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

- Silicon ÷10 Current Reduction
  Power Loss reduced by 100

- GaN ÷ 50 Current Reduction
  Power Loss reduced by 2500

Thermal Challenge



Summary: Power Delivery for HEP Detectors & Colliders

- Early work at Intel central research lab's AIR Core Coils.
- Bell labs / Lucent investigators started Enpirion (maker of the commercial chip that happens to be Radiation Hard)
- Radiation Hardness: Silicon LDMOS 15 V Few amps
- Gallium Nitride could be a game changer: 100 Volts, tens of amps.
- Opportunity for Linear Collider Beam line power supplies
- Gallium Nitride: US companies developing for Power switching market.
  Japanese companies - Consumer, Auto, Industrial
  Europe companies – IGBT Replacement, Device R&D - EMEC
- Yale Ideas: Physics Converters to run in radiation and magnetic fields.

Working on Power Supply Is not Glamorous

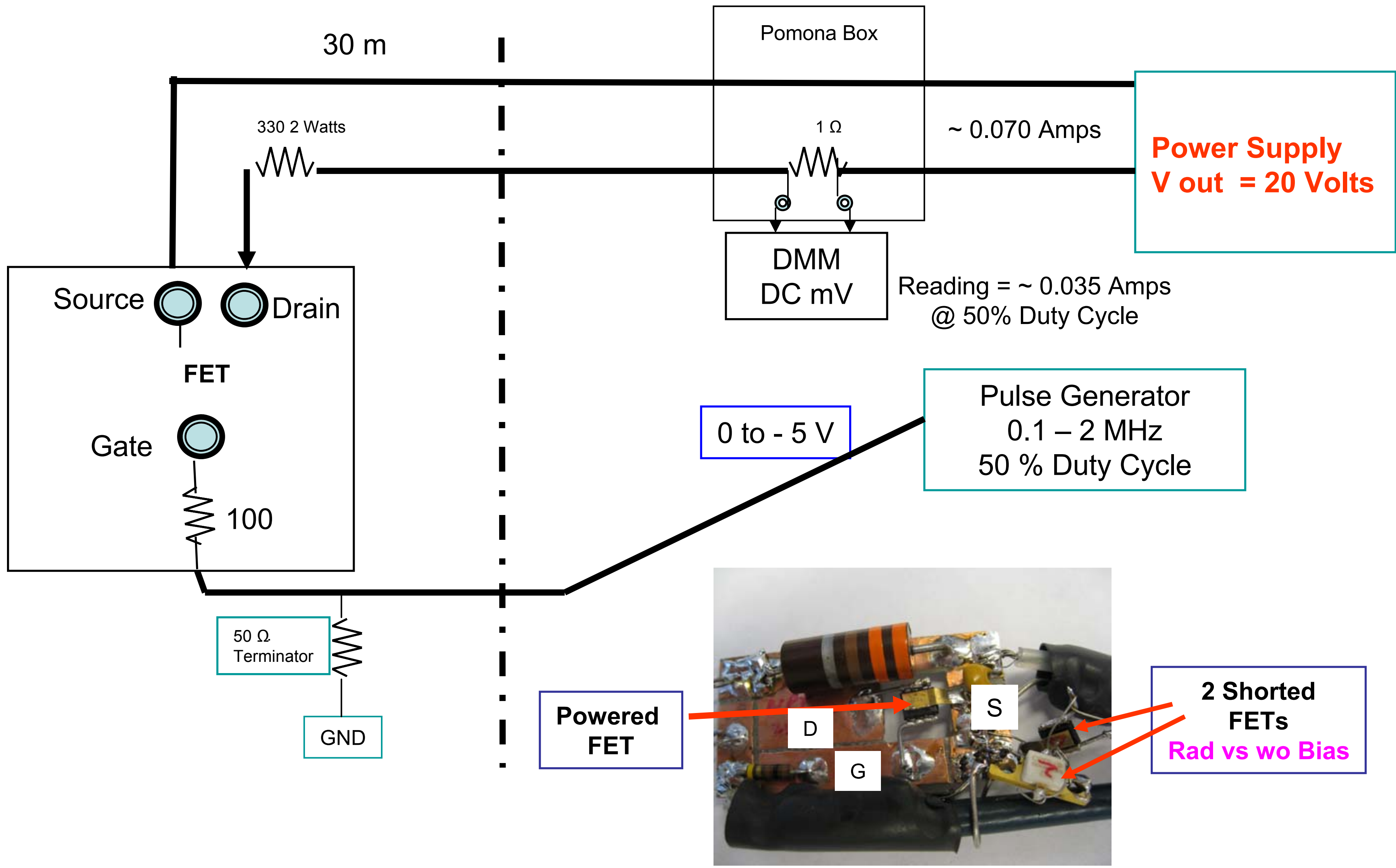
Top of the World is Cool but lonely !
Let us keep it cool with highly efficient PS
Swimming is Great at the North Pole
Last month Fairbanks was 33 C – Bye Bye Glaciers !

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

Backup Slides

Bias during Radiation

Max operating V & I Limit Power by duty cycle



Satish Dhawan, Yale University

July 28. 2009

FET Setup for Proton Radiation Exposure