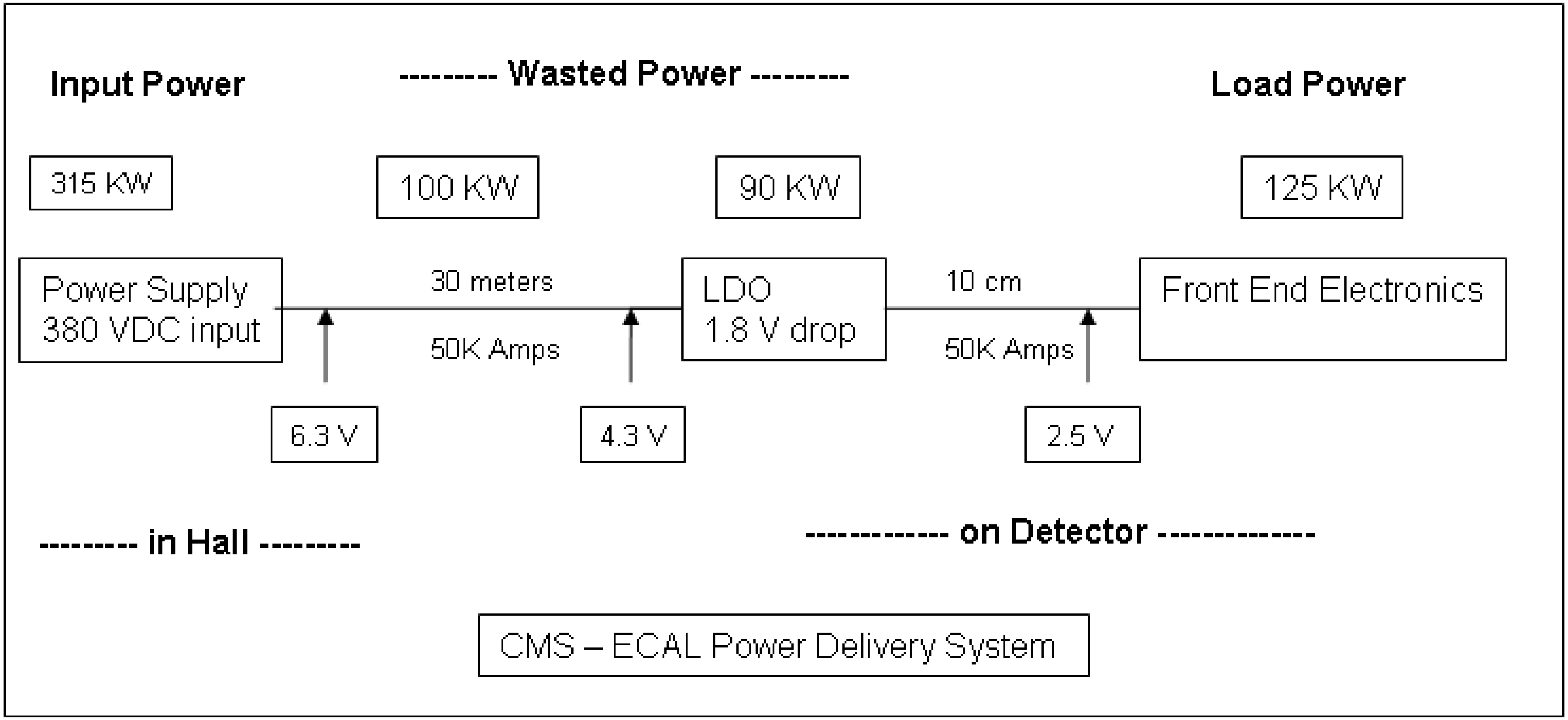
SiD Powering Status

Satish K Dhawan
Yale University
Satish.Dhawan@Yale.edu

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

SiD Workshop @ SLAC **National Accelerator Laboratory**
December 14-16, 2011

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

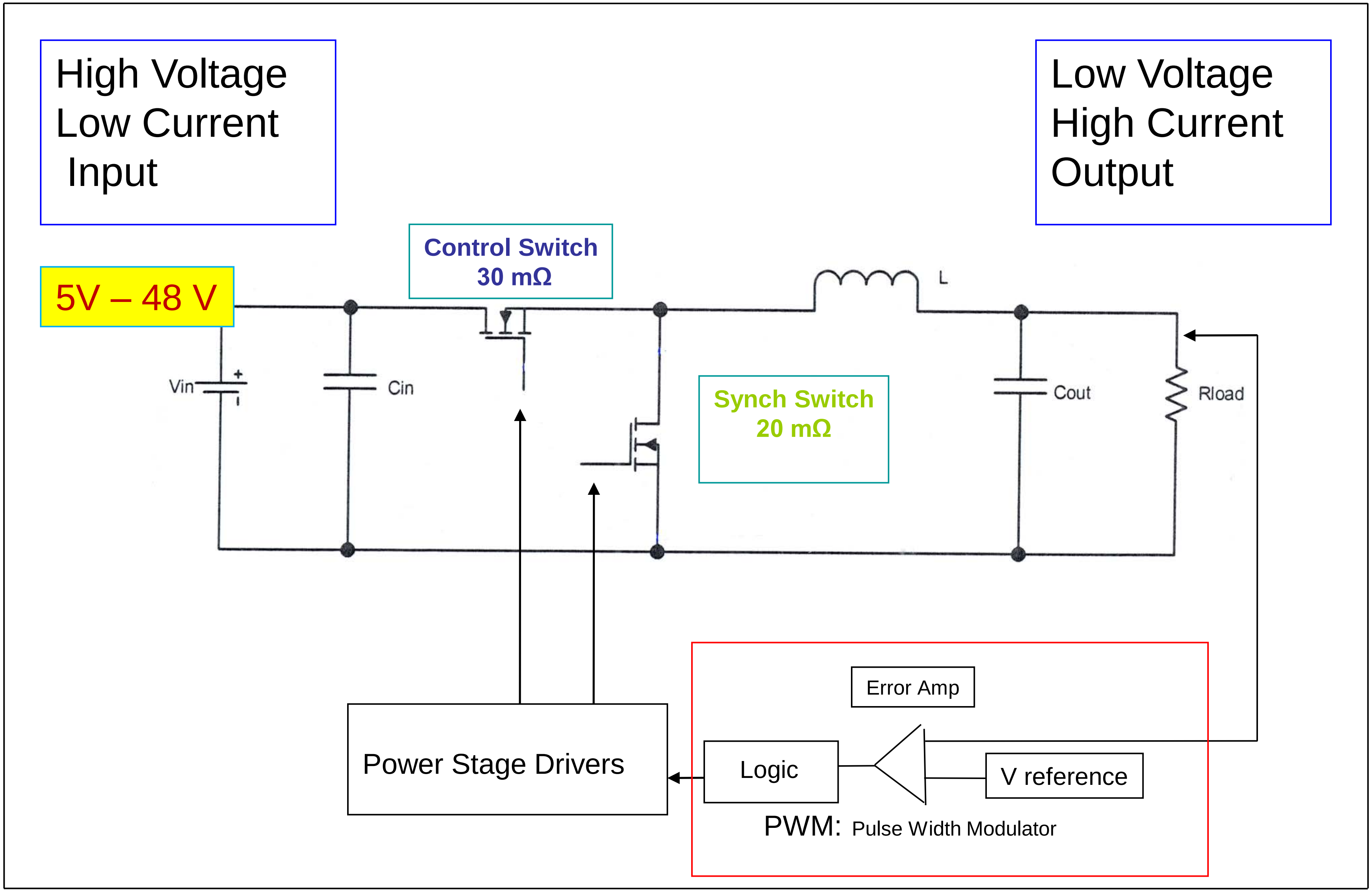
2.5 V

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

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

CMS – ECAL Power Delivery System

Buck Converter



High Voltage
Low Current
Input

Low Voltage
High Current
Output

5V – 48 V

Control Switch
30 mΩ

Synch Switch
20 mΩ

Power Stage Drivers

Error Amp

Logic

V reference

PWM: Pulse Width Modulator

Industry: Integrate different technologies, power handling into suitable packages

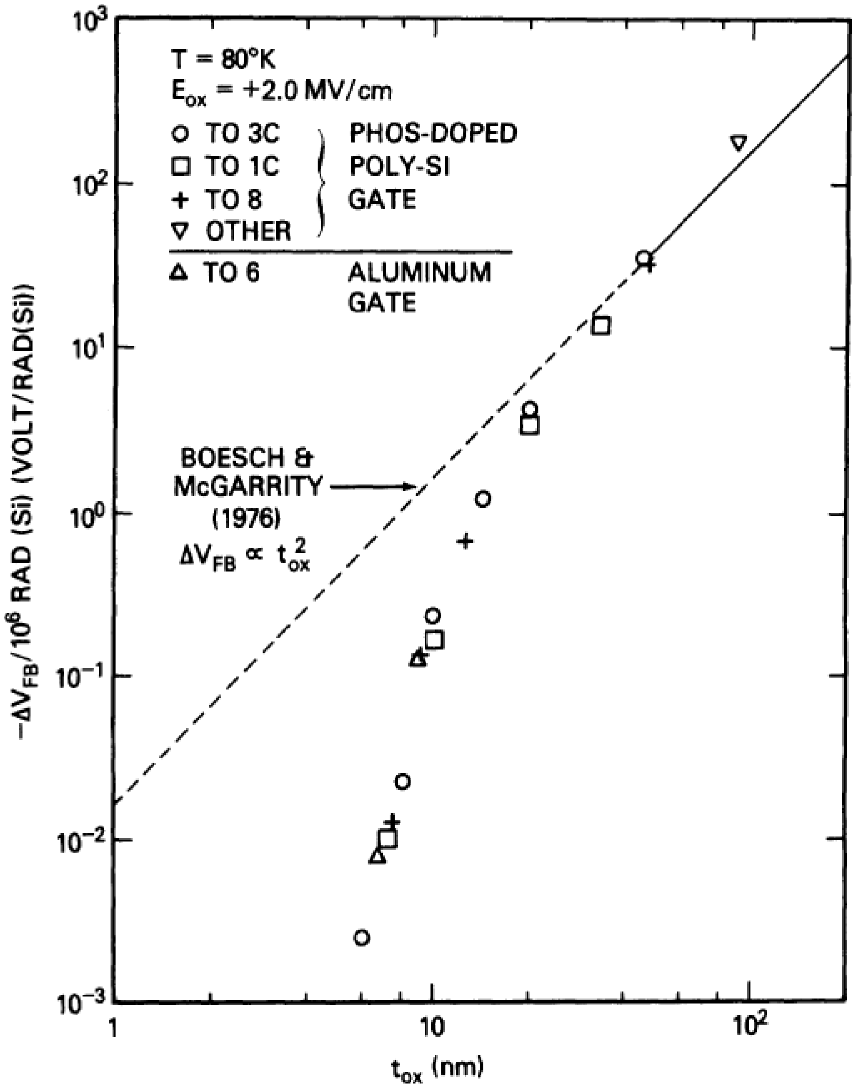
Thin Oxide Devices (non IBM)

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

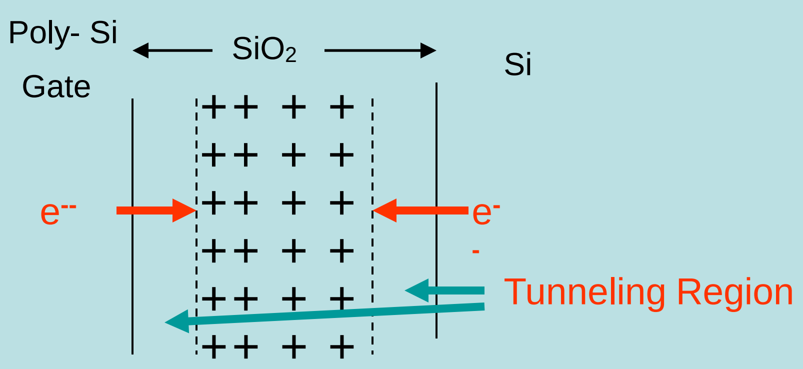
Necessary condition for Radiation Hardness - Thin Gate Oxide

This limits operating voltage to < 5 volts
LDMOS extends this to ~ 15 Volts

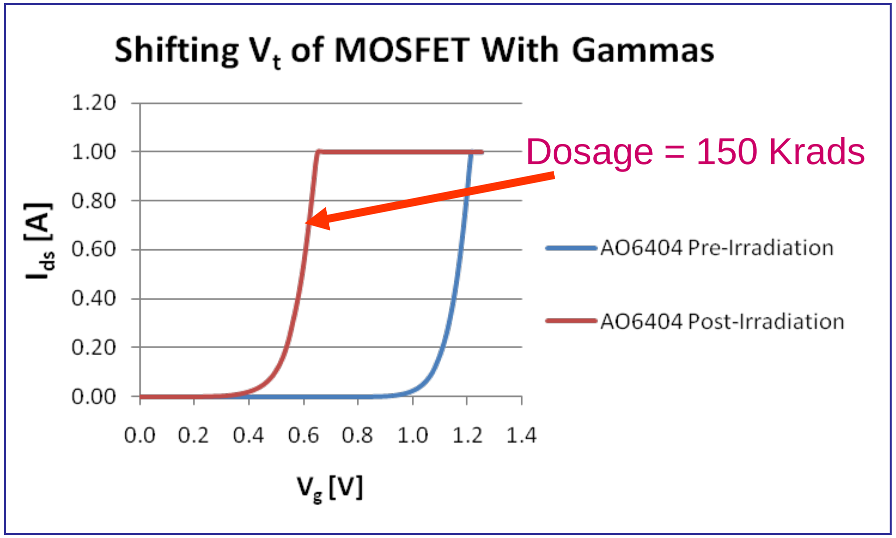
Threshold Shift vs Gate Oxide Thickness



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



Hole removal process by tunneling in thin-oxide MOS Structures



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

Wide Band Gap Materials

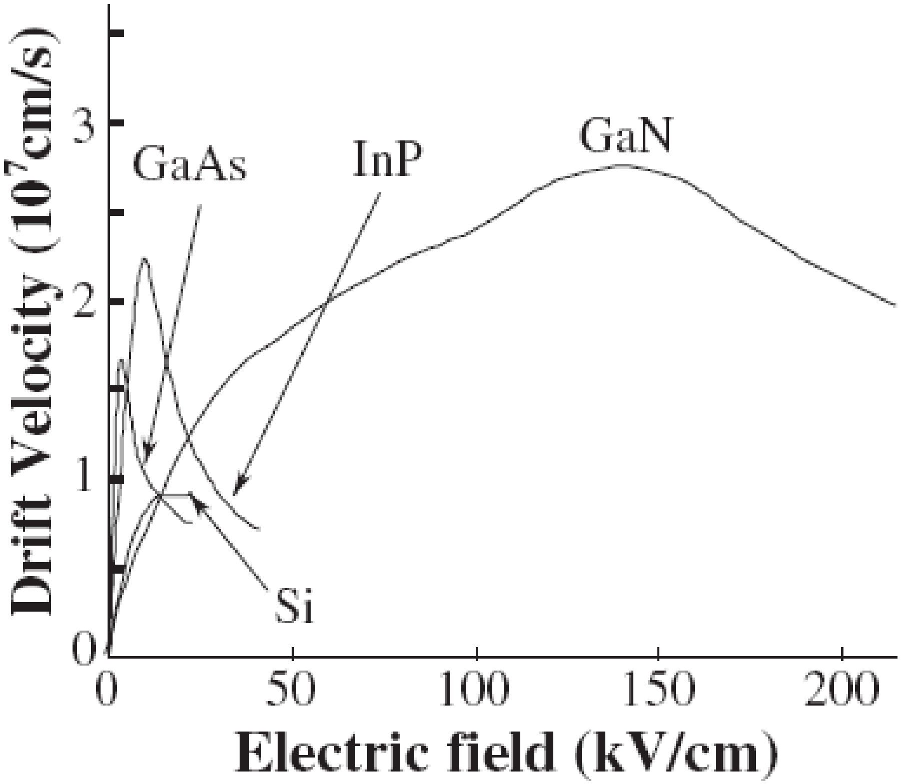


Fig. 8. Dependence of drift velocity of semiconductors on electric field. GaAs and InP have high mobilities (slope of drift velocity–electric field relation in the low-electric-field region); however, their drift velocities decrease in the high-electric-field region. On the other hand, GaN shows high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

Radiation Results – RF GaN & EPC GaN on Si

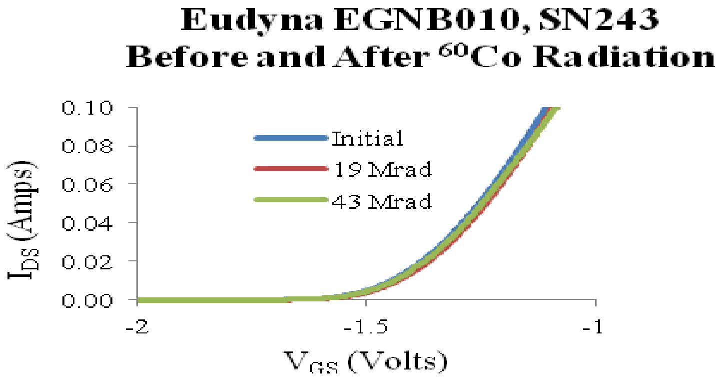


Fig. 7. Eudyna EGNB010 GaN HEMT, VGS versus IDS at VDS = 10 volts and selected doses of 60Co gamma radiation. Little change is apparent even after 43 Mrad of ionizing radiation.

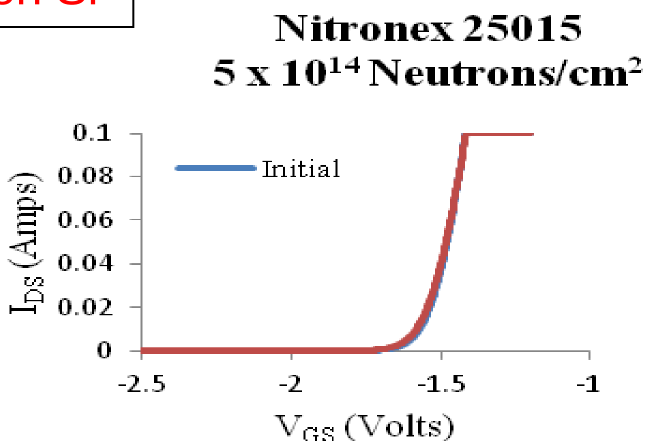


Fig. 6. Nitronex 25015 HEMT irradiate with 5 x 1014 neutrons (1 MeV equivalent). Little change is observed in the response.

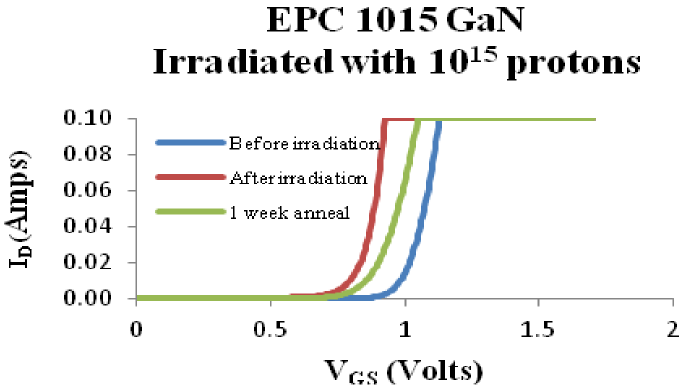
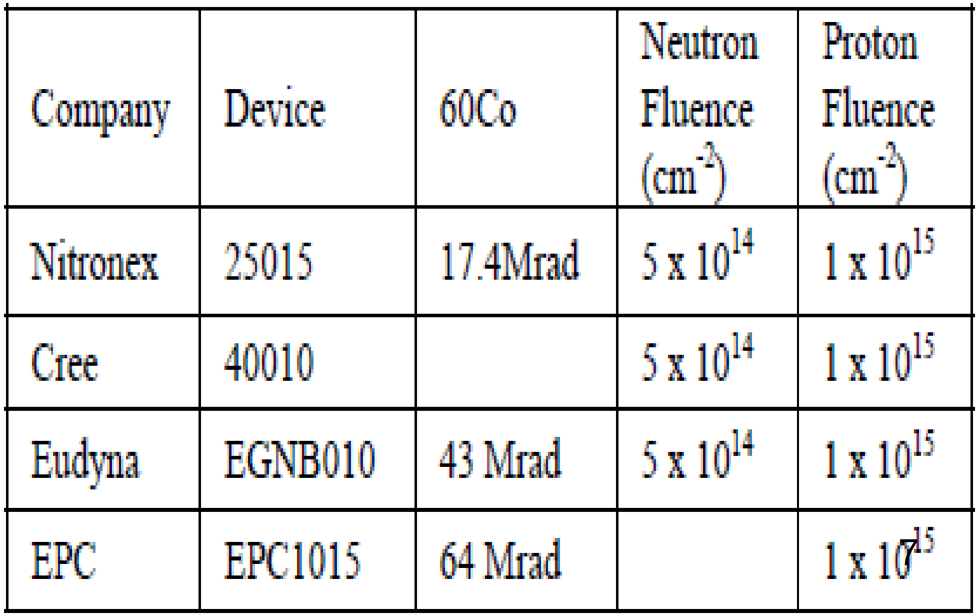


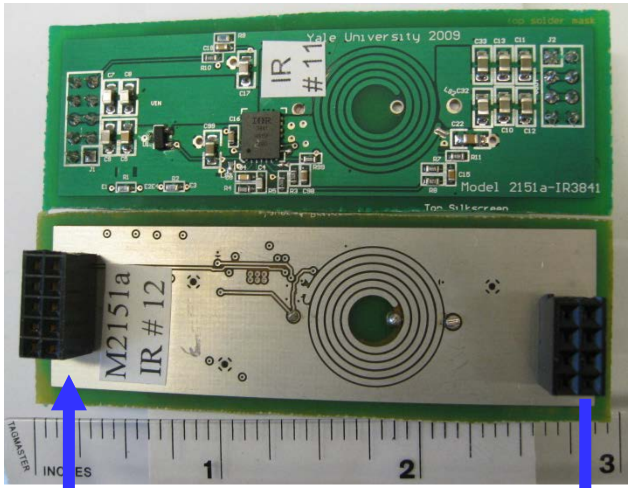
Fig. 8. EPC 1015 HEMT before and after 1015 protons/cm2. During exposure VDS = 24V with a 1 kOhm resistor current limiting the channel to 24 mA. The device was “clocked” with a VGS = 4 V at a 1 kHz frequency

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}

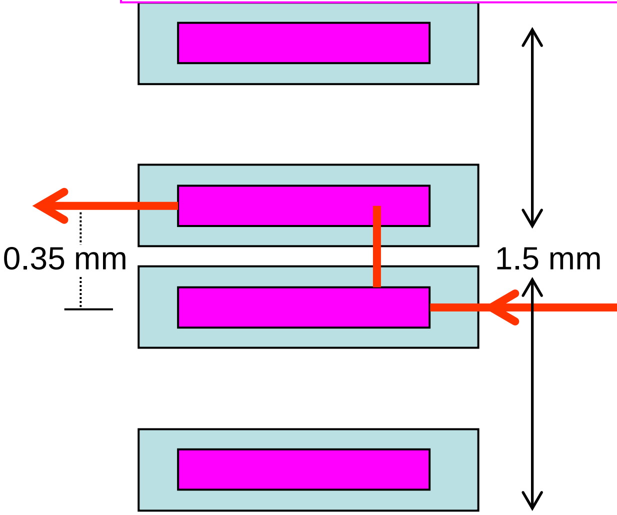
Plug In Card with Shielded Buck Inductor

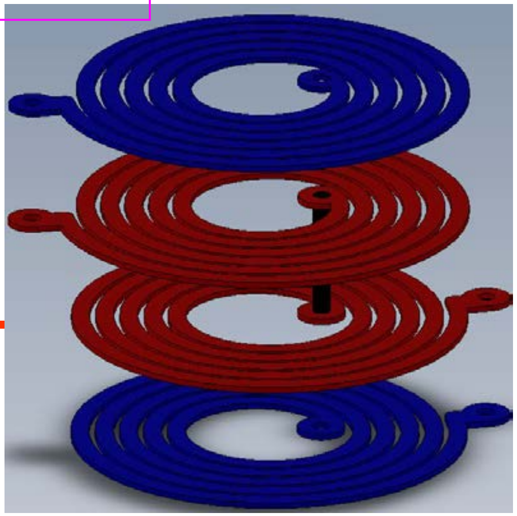


12 V

2.5 V
@ 6 amps

Coupled Air Core Inductor
Connected in Series



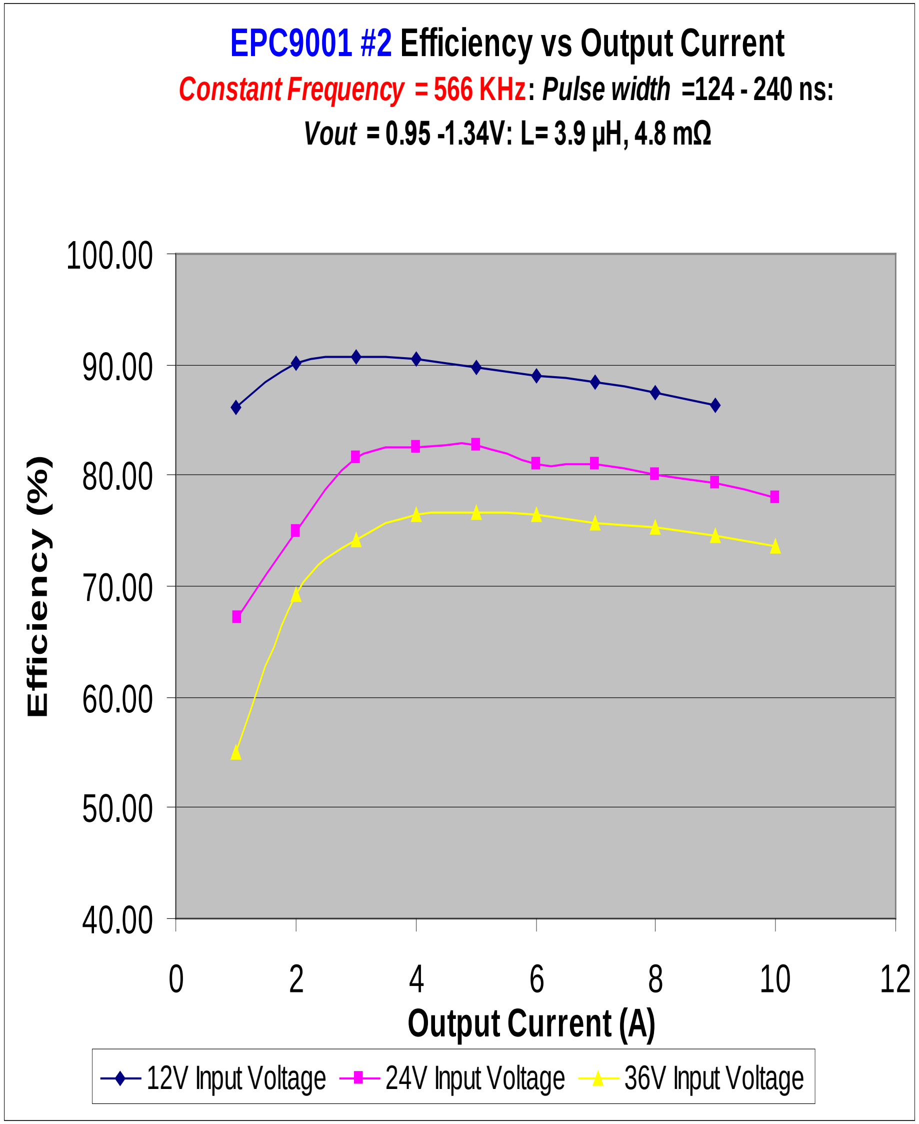


Inductance ~ 0.6 µH

Replace pcb coil with copper foil

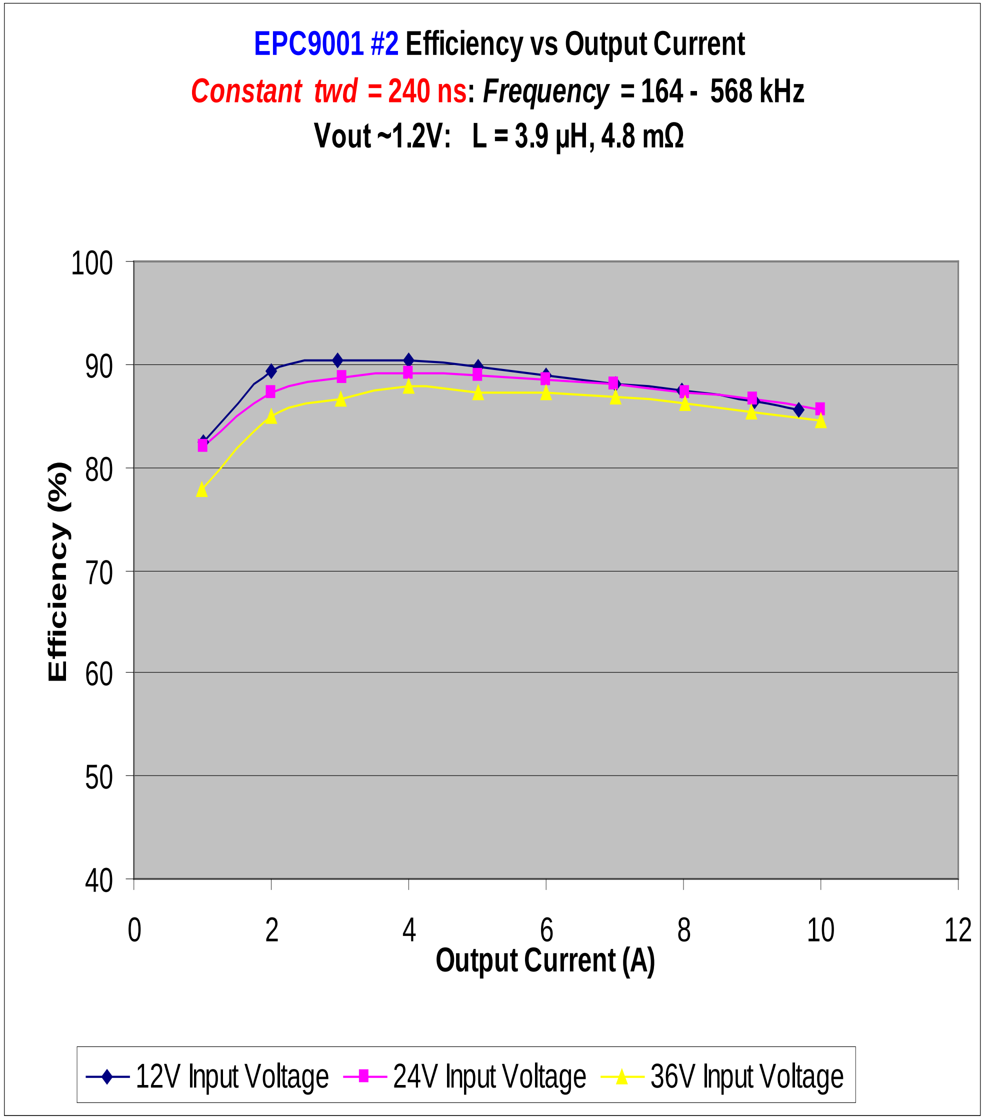
	Spiral Coils Resistance in mΩ	
	Top	Bottom
3 Oz	57	46
0.25 mm Cu	19.4	17

: epc 1015 – 40V: Efficiency with constant frequency and constant on pulse with inputs of 12, 24 & 36 Volts.


EPC9001 #2 Efficiency vs Output Current

Constant Frequency = 566 KHz: *Pulse width* =124 - 240 ns:

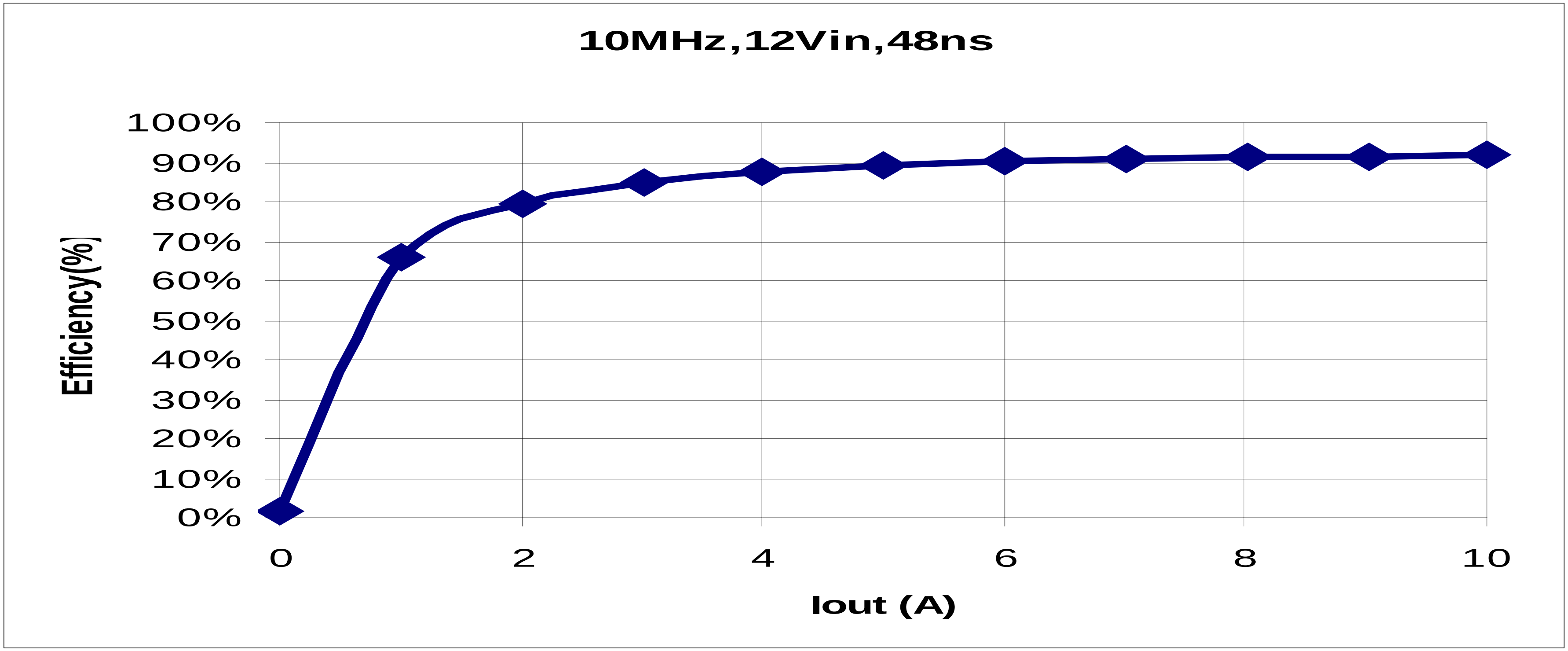
Vout = 0.95 -1.34V: L= 3.9 µH, 4.8 mΩ


EPC9001 #2 Efficiency vs Output Current

Constant twd = 240 ns: *Frequency* = 164 - 568 kHz

Vout ~1.2V: L = 3.9 µH, 4.8 mΩ

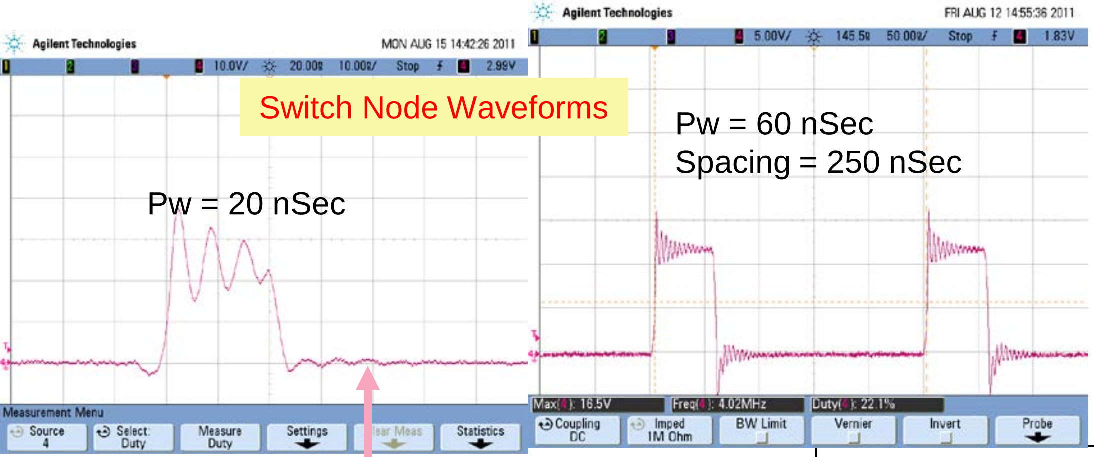
Frequency Response IR's Engineering sample in 2009
Half Bridge with CMOS Driver



Good efficiency to >12 MHz Driver limited

International Rectifier: Supplied sample board under NDA

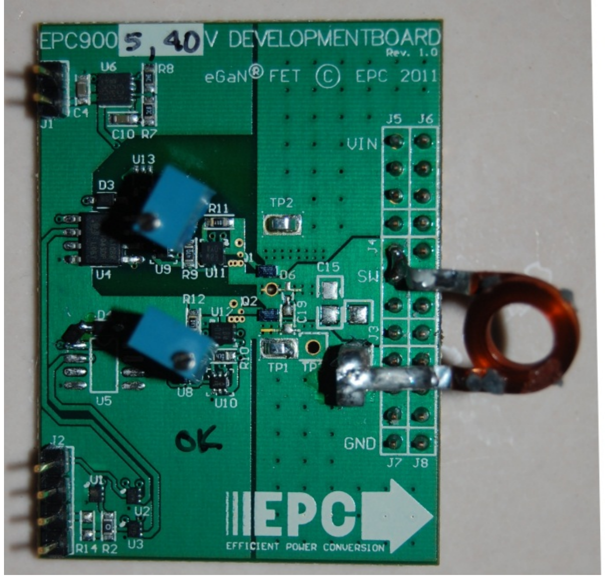
eGaN with discrete & LM5113 Driver



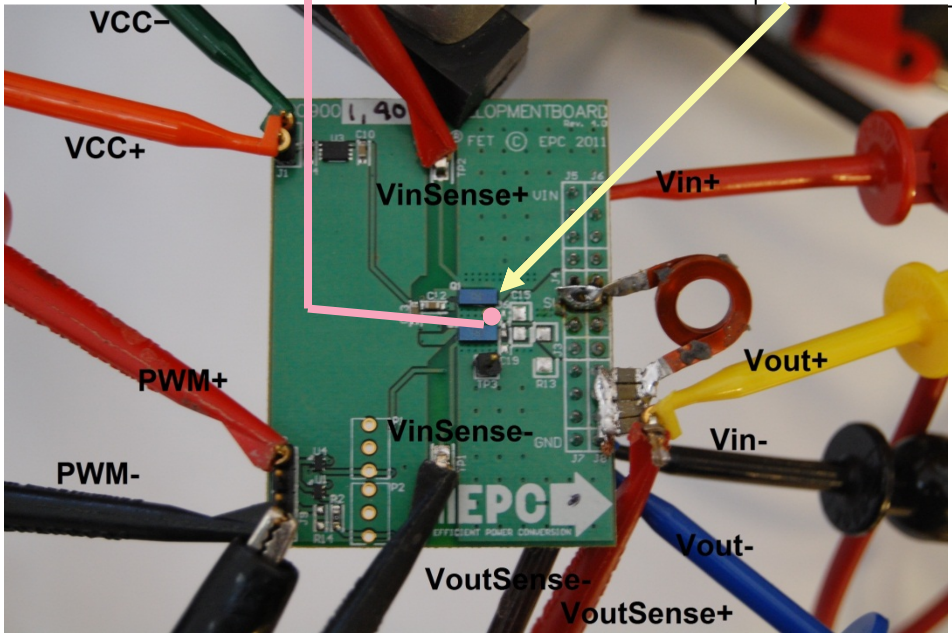
Switch Node Waveforms

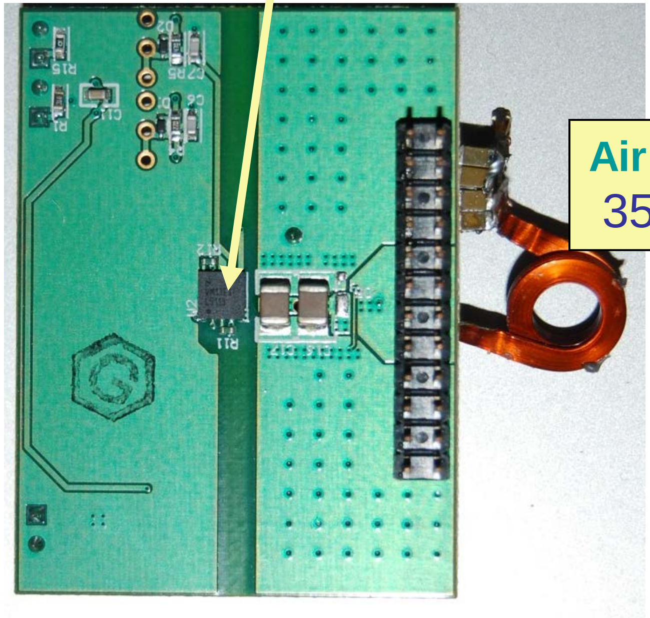
Pw = 20 nSec

Pw = 60 nSec
Spacing = 250 nSec



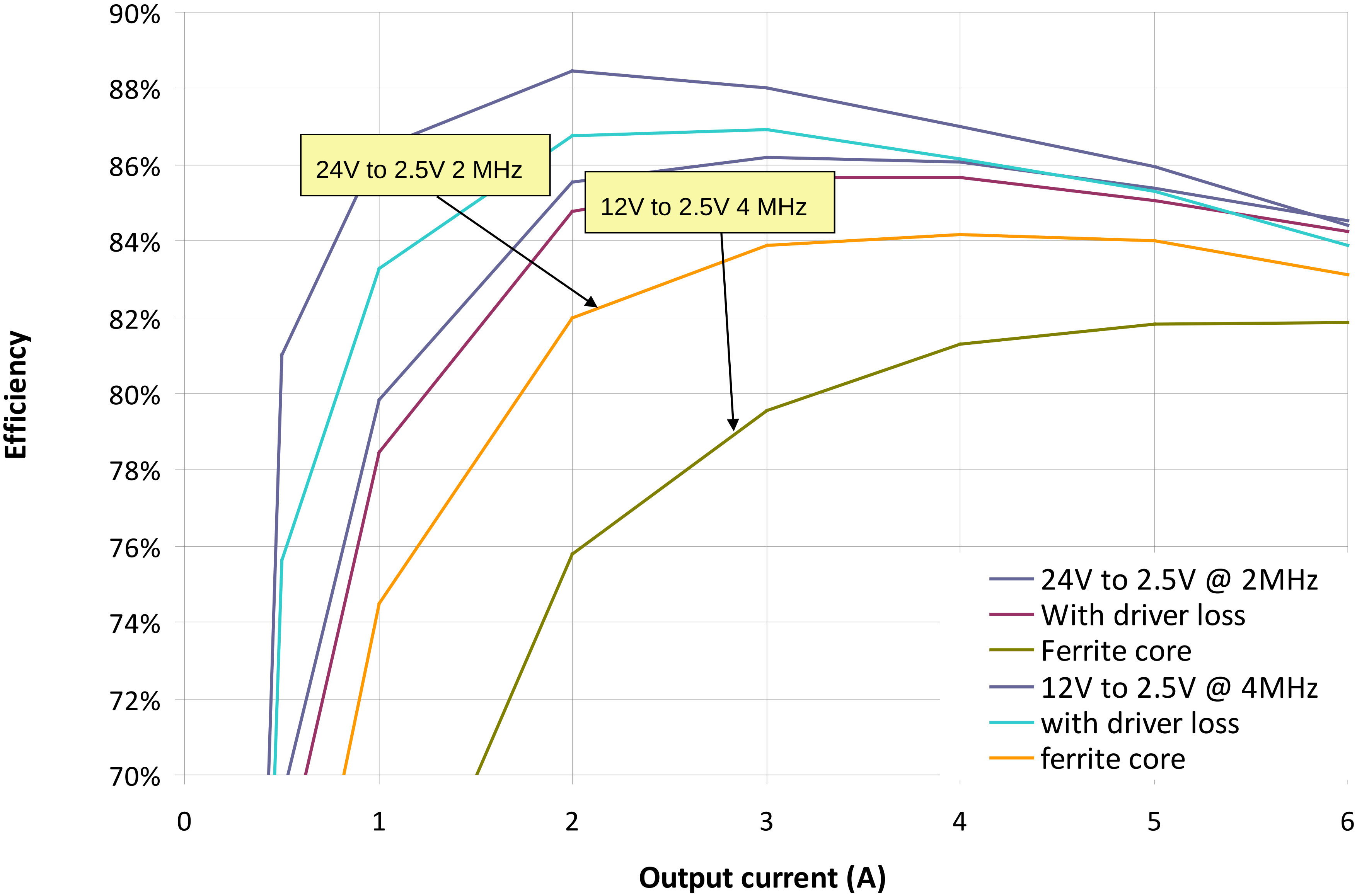
National eGaN Driver LM5113 on Bottom
eGaN on Top side





Air Core Coil
355 nH

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

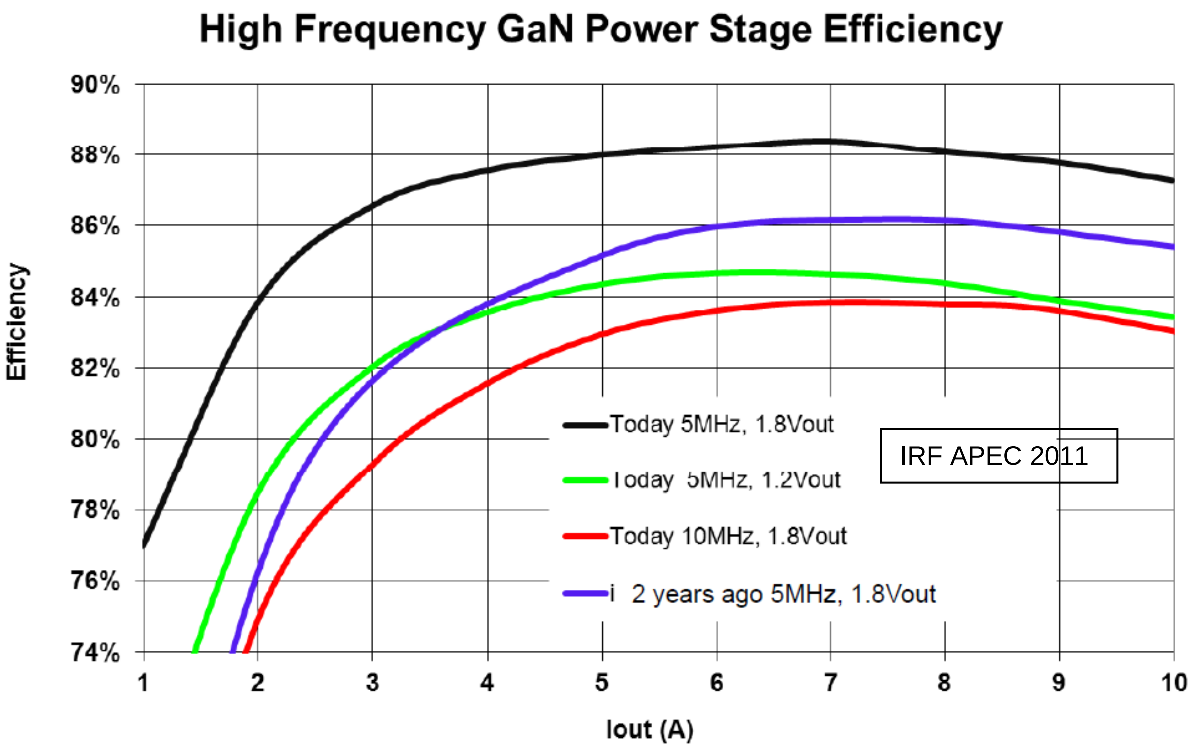


24V to 2.5V 2 MHz

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



IRF APEC 2011

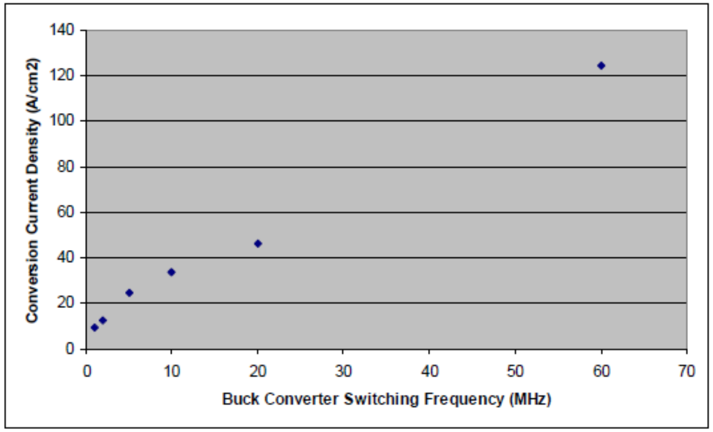
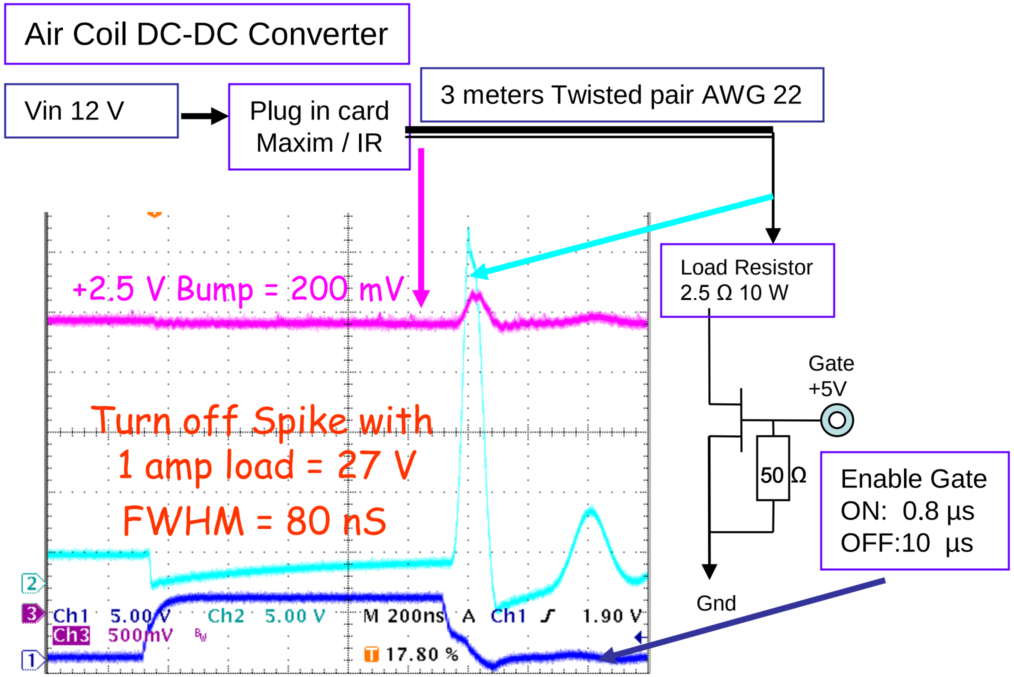


Figure 1: Conversion Current Density for a four phase 120 A, 12 Vin to 1.2 Vout buck converter vs switching frequency.

M.A. Briere IEDM 2010

Power Pulsing Tests



Air Coil DC-DC Converter

Vin 12 V

Plug in card
Maxim / IR

3 meters Twisted pair AWG 22

Load Resistor
2.5 Ω 10 W

Enable Gate
ON: 0.8 µs
OFF:10 µs

+2.5 V Bump = 200 mV

Turn off Spike with
1 amp load = 27 V
FWHM = 80 nS

Control turnoff overshoot by

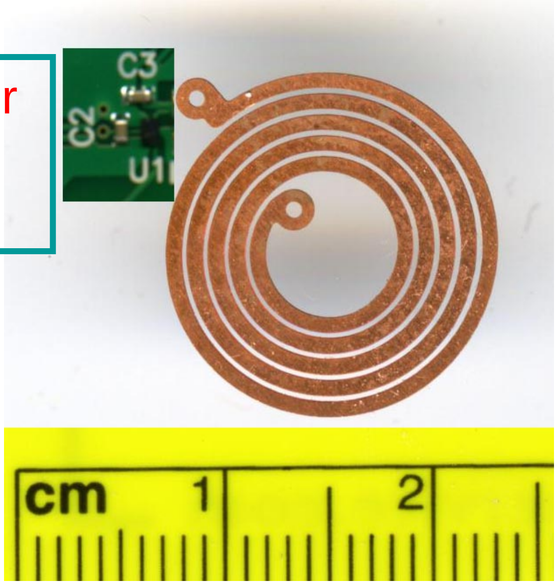
1. Slow turnoff
2. Capacitors on both sides
3. Low impedance power cables

Electron Linear Collider produce low radiation

but material in the interaction regions must be minimized

- High Frequency operation for lower coil size / material
- Commercial cell phone converters 6 - 8 MHz, 1 amp, 5.5 Vin
- 1 -2 turn coil
- Fabricate PCB & Test
- Power Supply in a Package
- Coil simulation needs collaborators ??
- Coil may be buried in the detector PCB
- Feasibility report due summer 2012

2x2 mm Controllers for
Portable devices
2 – 8 MHz 5.5 Volts



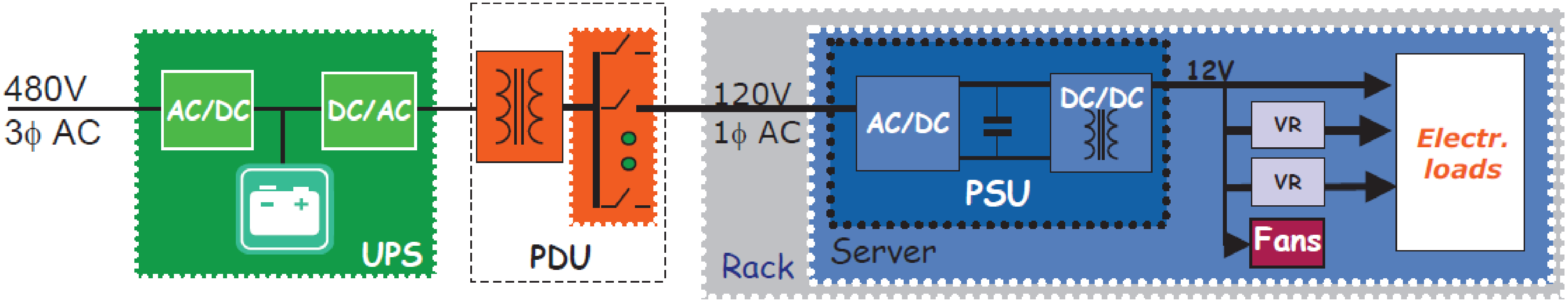
Spiral for 1 MHz
So it will shrink
Aluminum coil ?

High Volume Developments Driving Innovation

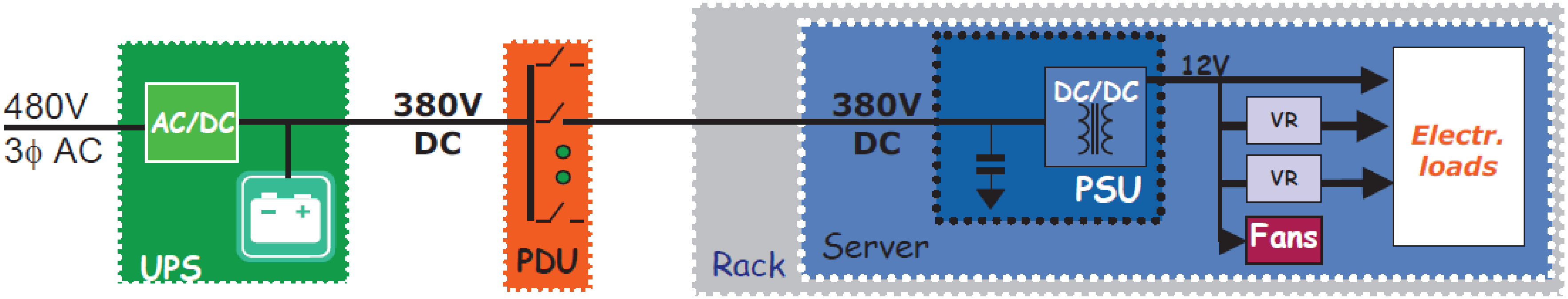
- ❖ Data Centers 380 V Distribution to Racks > 48 /12 V > PCBs
- ❖ Portable Devices
  - – smart phones, iPads, ultra notebooks

- ➢ GaN RF ~ 100 W Power Amplifiers – Cellular Base stations
- ➢ GaN MMICs Monolithic Microwaves Integrated Circuits

Data Centers: Silicon Solutions
Efficiency Improvement with DC 380 Volts

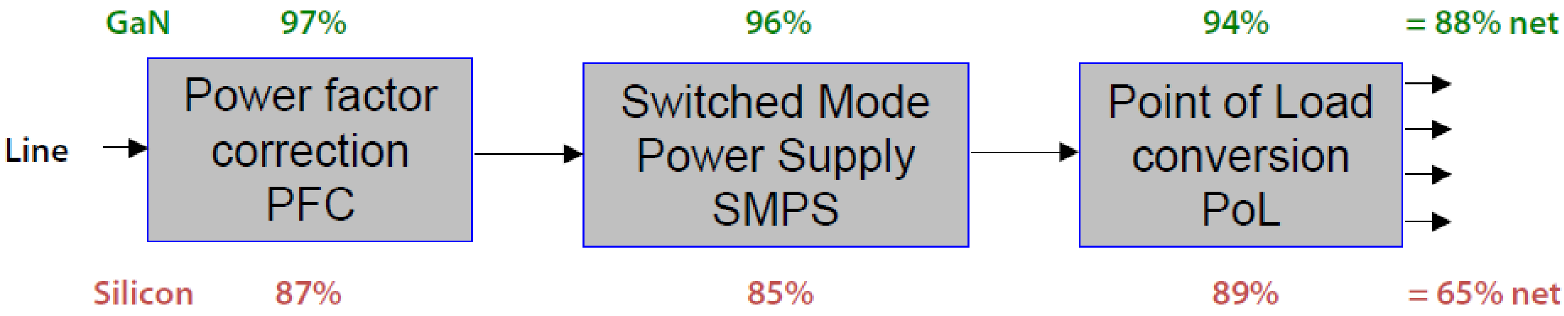


90% x 97% x 90% x 86% = 67%



97% x 99% x 94% x 86% = 76%

Data Centers: GaN Solutions



GaN 97% 96% 94% = 88% net

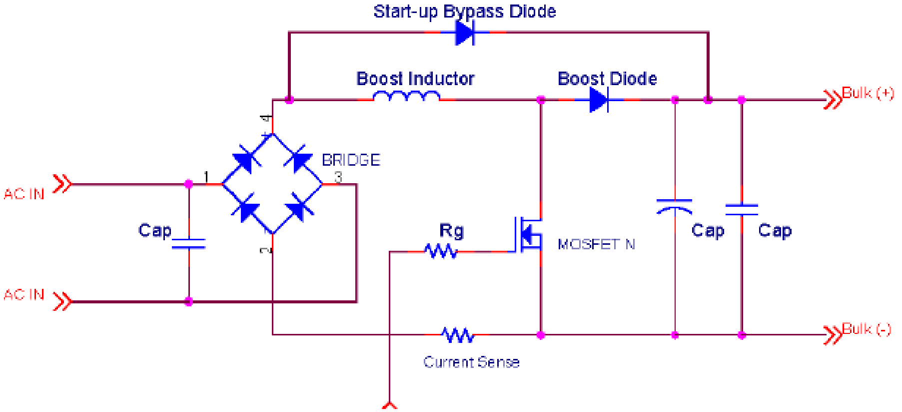
Line → Power factor correction PFC → Switched Mode Power Supply SMPS → Point of Load conversion PoL →

Silicon 87% 85% 89% = 65% net

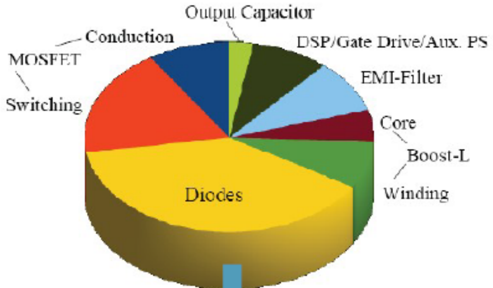
Overall efficiency - Silicon = 65% **Total losses = 157 Watts**

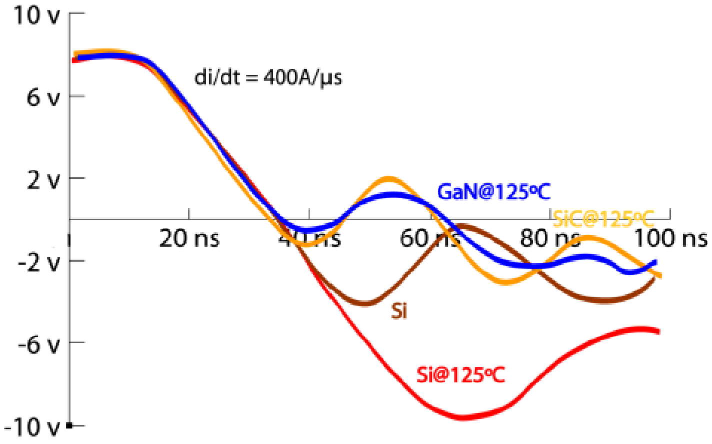
- GaN = 88% **Total losses = 54 Watts**

GaNSystemsInc



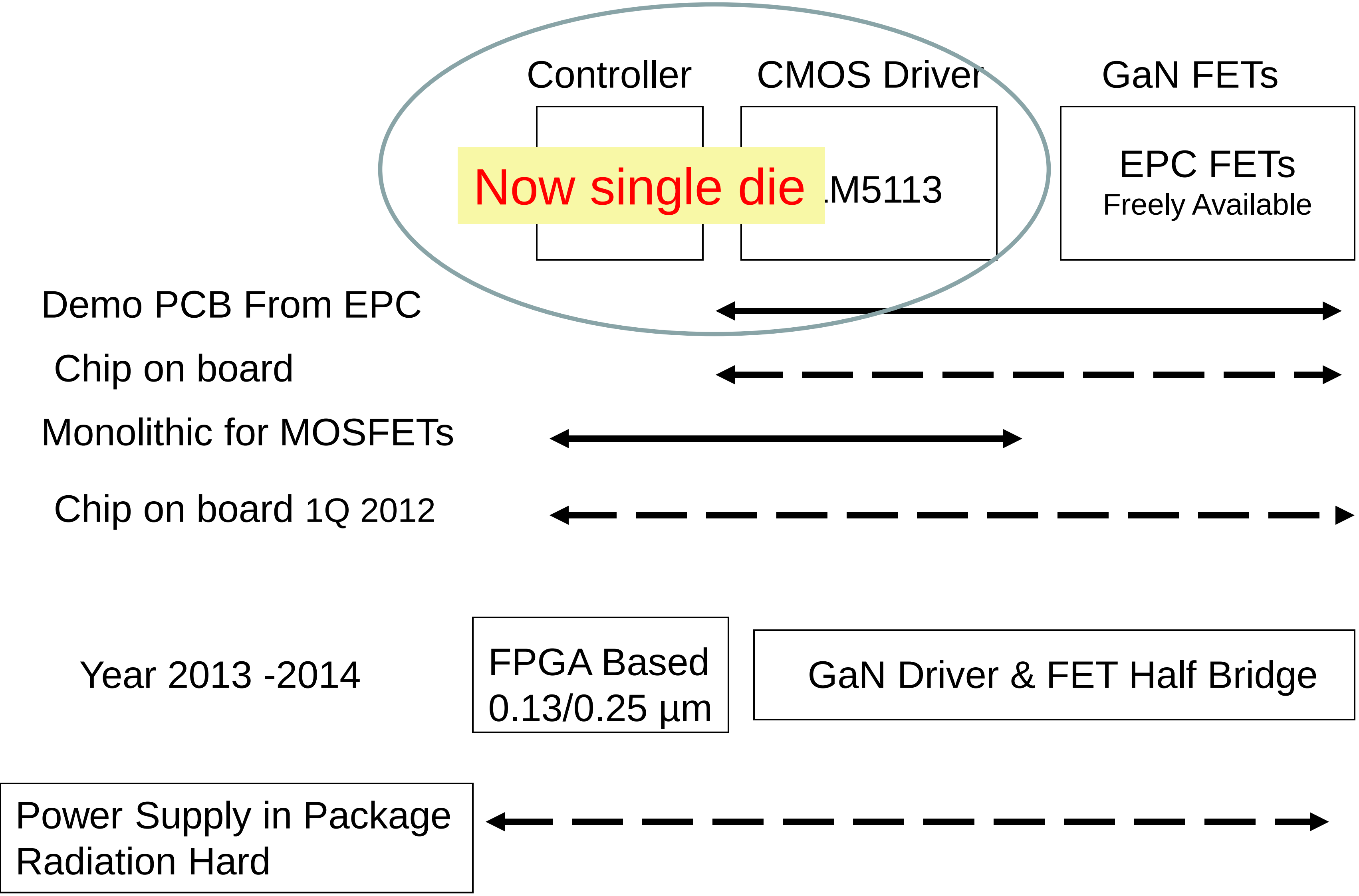
Loss Distribution





- **Zero charge storage**
- **Temperature Stable**

Market Trend



Controller

CMOS Driver

GaN FETs

Now single die

M5113

EPC FETs
Freely Available

Demo PCB From EPC

Chip on board

Monolithic for MOSFETs

Chip on board 1Q 2012

Year 2013 -2014

FPGA Based
0.13/0.25 µm

GaN Driver & FET Half Bridge

Power Supply in Package
Radiation Hard

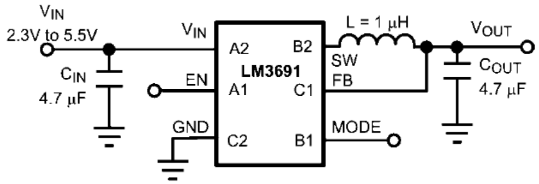


Fig P1. 1 amp 4 MHz Buck Converter with External Inductor
Thin Micro SMD 1.6 mm x 1.3mm x 0.6mm LMZ3691

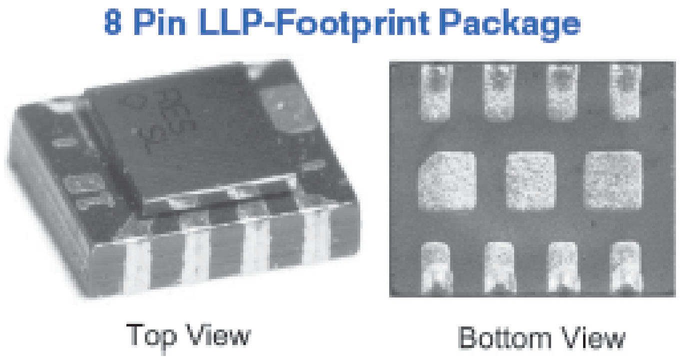


Fig P2. 1 amp 2 MHz Buck Converter with onboard LTCC Inductor
Nano Module 3.0mmx 2.5mm x 1.2mm LMZ10501

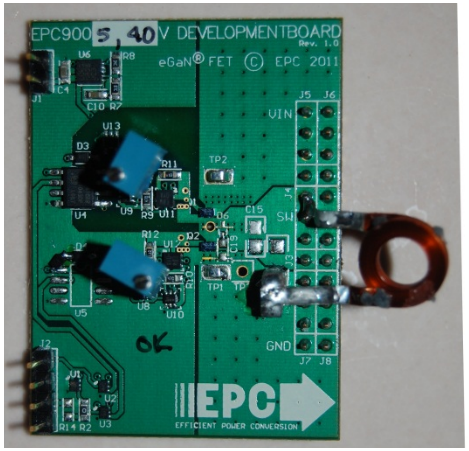


Fig P4. eGaN with Discrete Driver & Air Core Inductor 4 MHz.
Buck Converter 12V > 2.5V 6 amps *EPC Company*

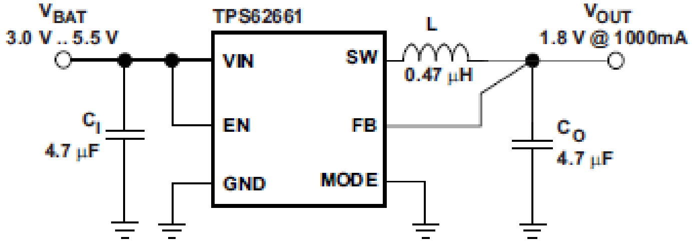


Fig P5. 1 amp 6 MHz Buck Converter with External Inductor
6 pin CSP (chip Scale package)

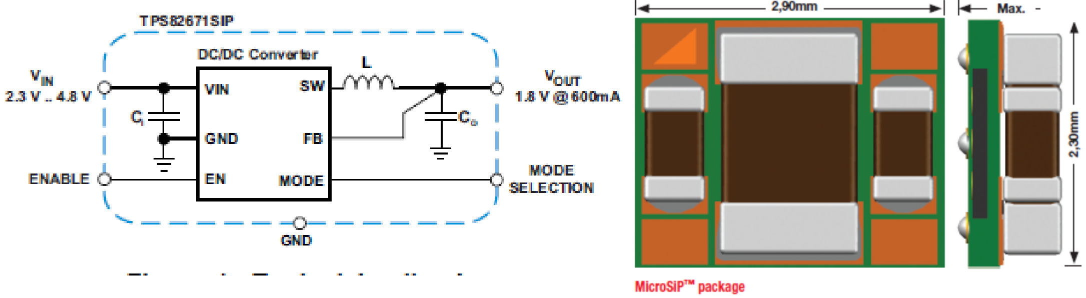
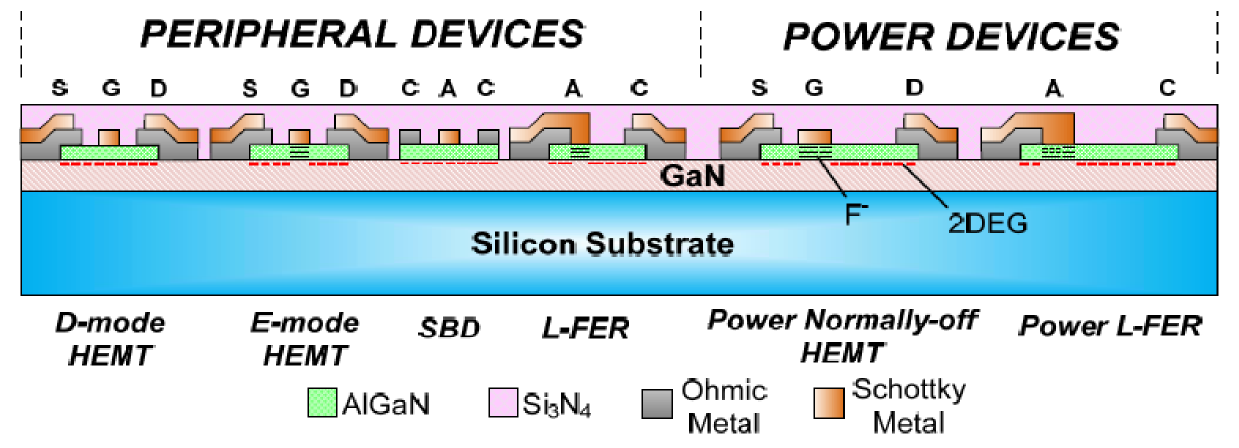
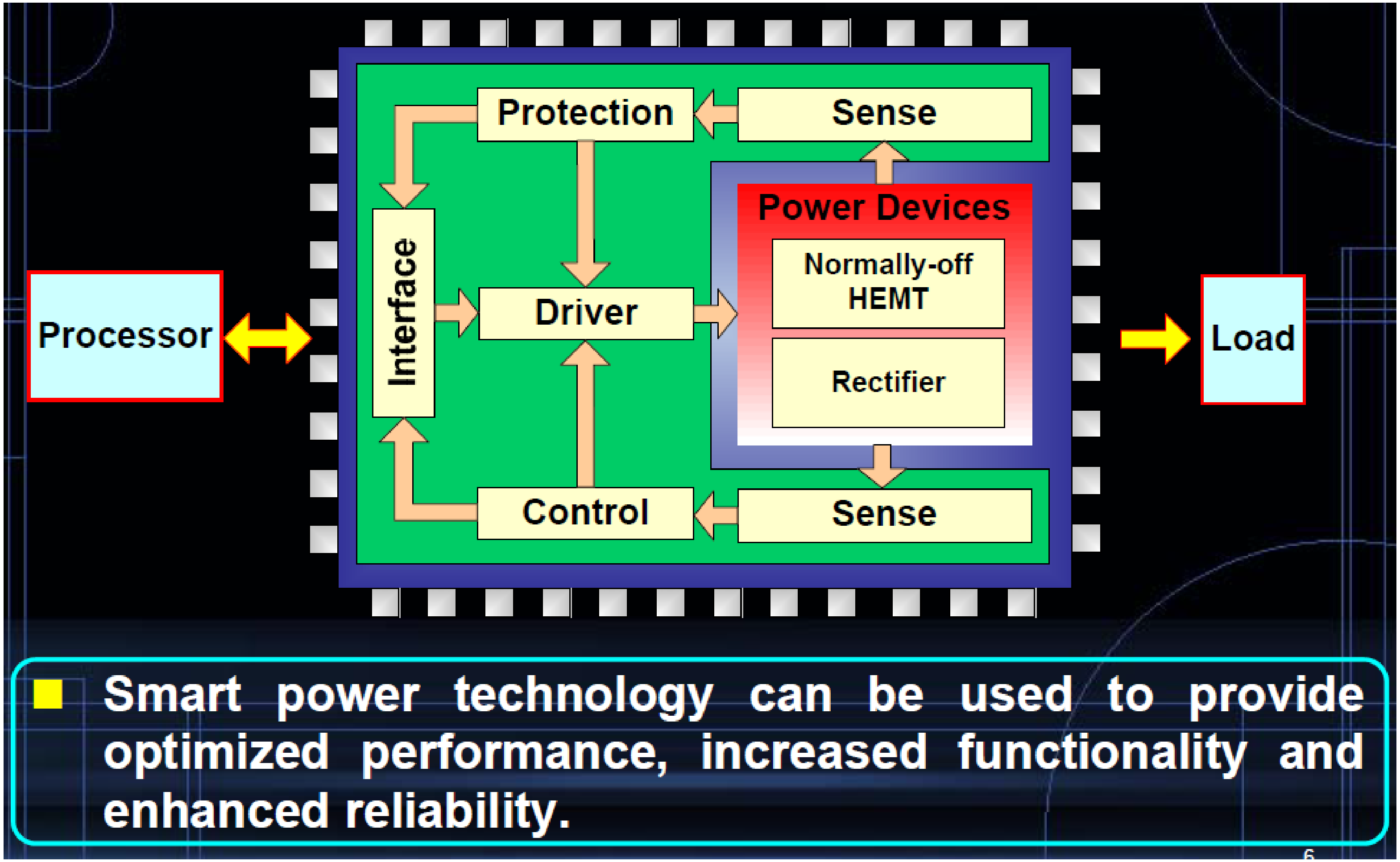


Fig P3. 0.6 amp 5.5 MHz Buck Converter with onboard Inductor
MicroSiP 3.0mmx 2.3mm x 1.0mm TPS82671SiP

GaN Smart Power Technology Platform



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



Processor

Interface

Protection

Sense

Driver

Power Devices

Normally-off HEMT

Rectifier

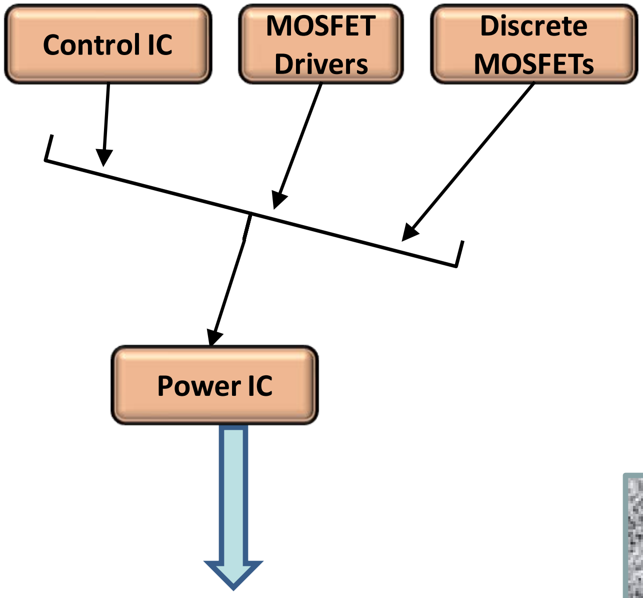
Control

Sense

Load

- Smart power technology can be used to provide optimized performance, increased functionality and enhanced reliability.

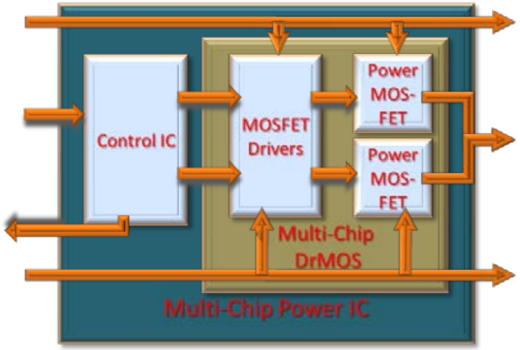
Integrated Voltage Reference & Comparator Circuits… Kevin Chen et al ISPSD 2009
Hong Kong University of Science & Technology

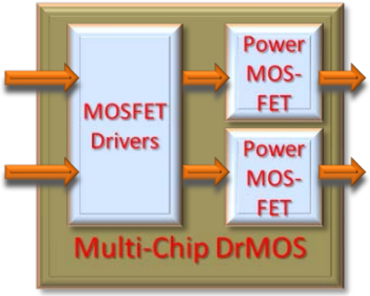


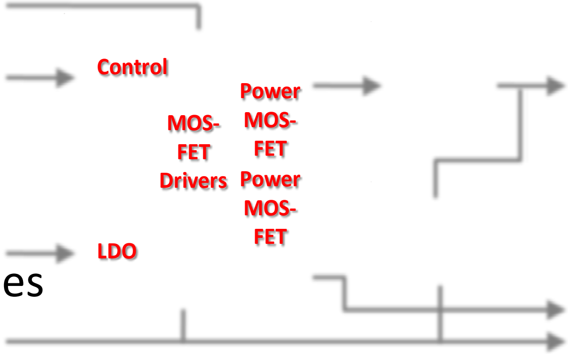
Integrated Inductor

Integrated Capacitor

Technological Wall





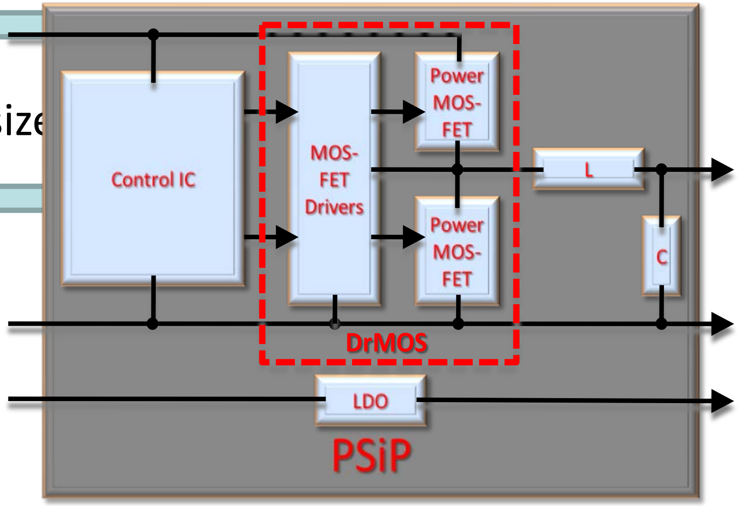


Incompatible Processes

Advanced Packaging

Oversize

Semiconductor Integration



Arnold Alderman & Ada Cheng. APEC 2011

Summary

- Work with Industry at a Scientific level
- We can’t afford the marketing people who wants to sell 1 million parts / month
- Power Supply on a chip Developments PwrSoc
- Power Supply in a package Developments PSiP
- Portable devices may need 20 MHz air core Converters - 5 Volts
- Next decade GaN monolithic High frequency & Voltage Power conversion

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