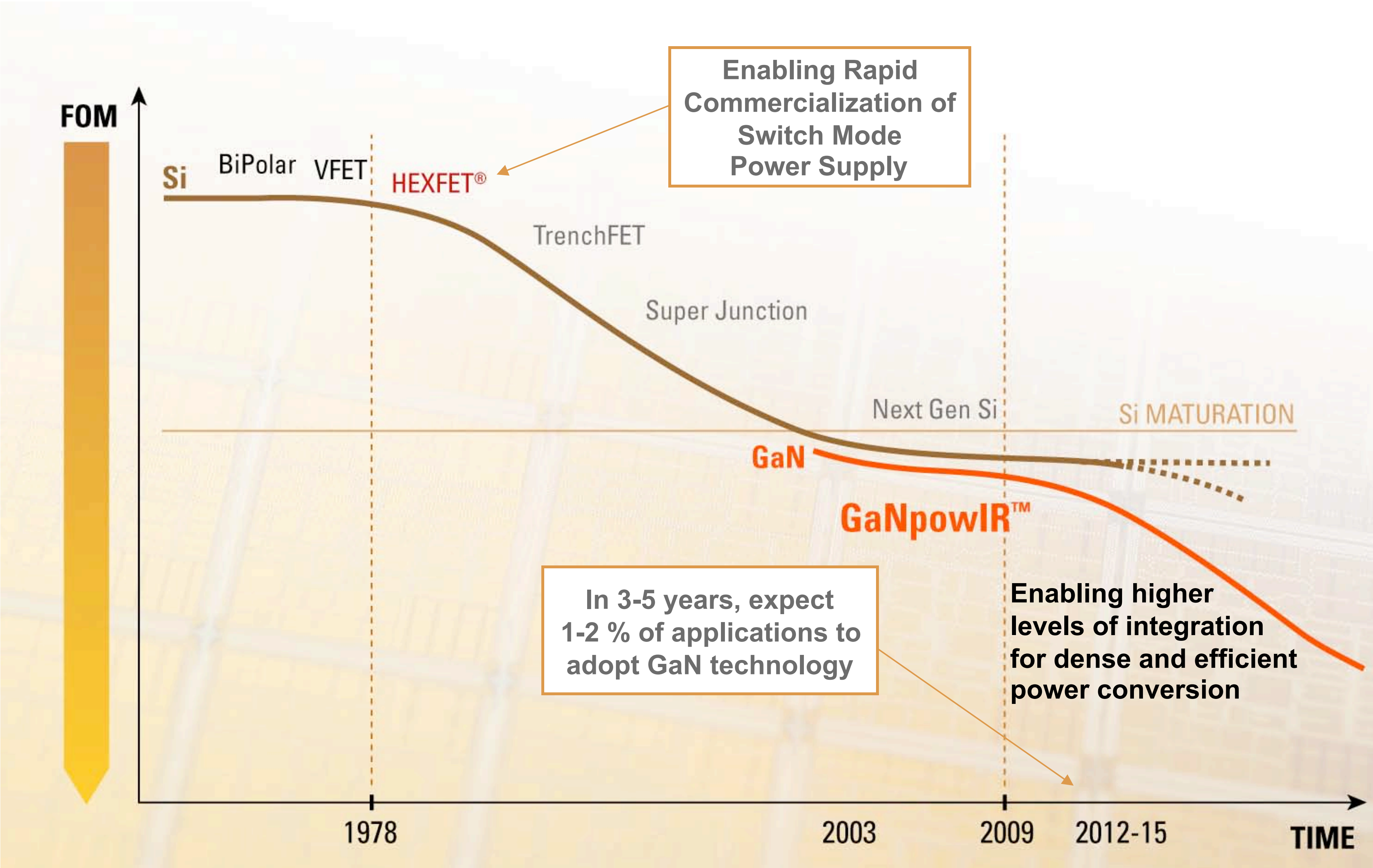
High Frequency GaN-Based Power Conversion Stages

Dr. Michael A. Briere

ACOO Enterprises LLC

Anatomy of a power device driven revolution in power electronics



GaNpowIR – An Introduction

- A Commercially Viable GaN-based power device platform
- The result of 5 years of R+D effort at IR
- Based on Proprietary GaN-on-Si Hetero-epitaxy
- Utilizes low cost high quality 150 mm Si wafer substrates
- Highest throughput (multi-wafer) epitaxial systems used
- Device manufacturing process is CMOS compatible
- Device structure and process leverages significant silicon expertise
- Standard high volume manufacturing disciplines applied
- Industry standard quality systems utilized
- Extensive intrinsic reliability studies performed
- Standard product reliability tests applied to device qualification

GaN Epitaxial Growth Commercial Requirements

Heterogeneous Growth is actually on AlN layer, which is grown on substrate.

To be competitive, epitaxial process and substrate cost must be

$< \$ 2 / cm^2$

High volume requires mature process platform

Current power device material demand

$> 10^7$ 6 inch wafers per year

Epitaxy for Commercialization of GaN Power Devices

MOCVD technology is the most mature and scalable to volume production. All commercial electronics have so far been produced with MOCVD systems (especially LED).

Silicon substrates are the most scalable and cost effective for volume production

Adequate epitaxial film uniformity, defect levels, device reliability and process cost structure must be achieved to permit the use of GaN on Si based devices to achieve widespread use in power electronics.

Device processing should be CMOS compatible to achieve commercially viability.

Power Delivery

Power Stage

POWER CONVERSION STAGE

Value realization in power conversion

Value = efficiency *density/cost

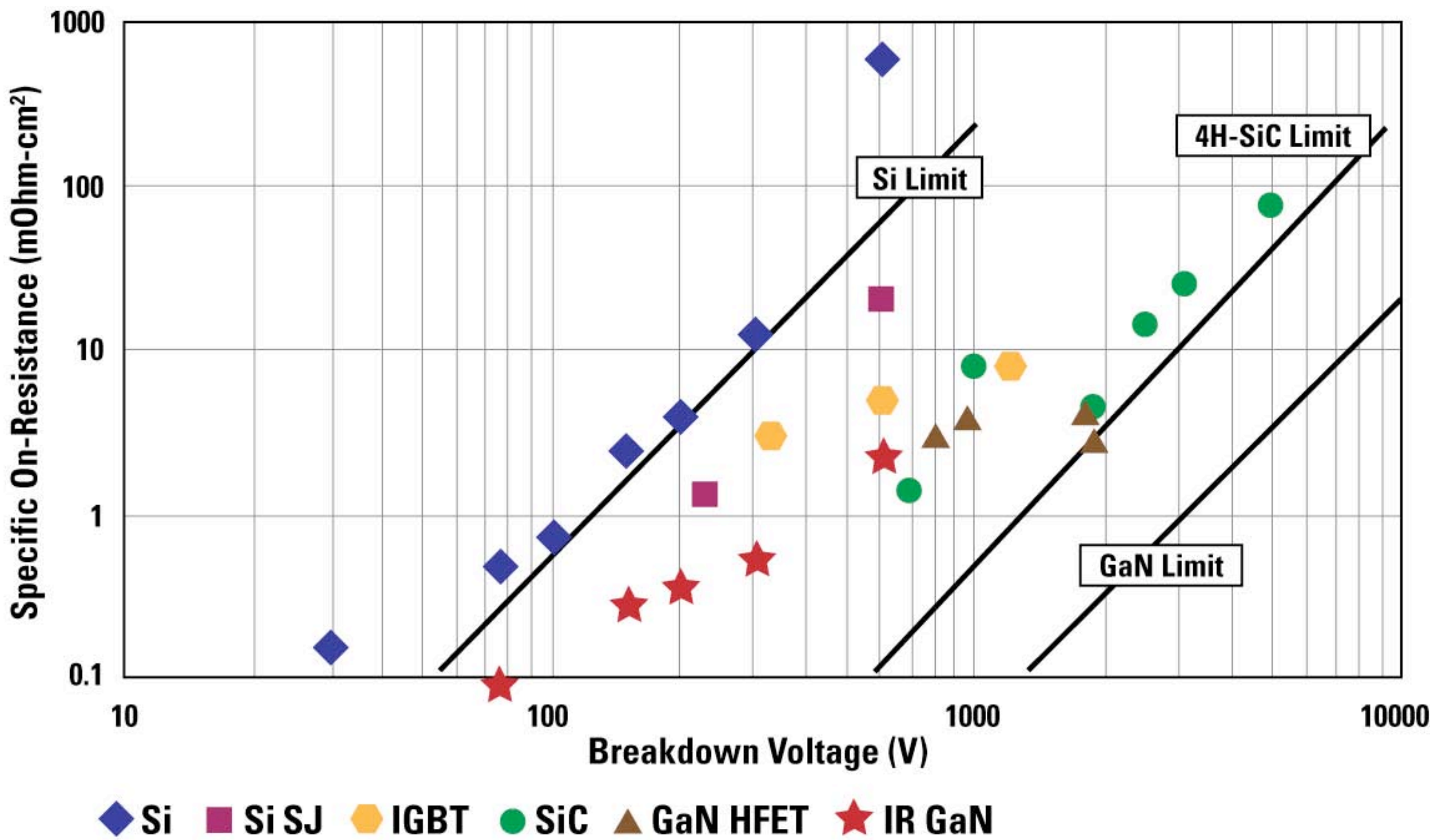
The value proposition is driven to a large measure by the performance of the power device.

Conversion architecture and control schemes are developed to take advantage of the capabilities of the power devices and mitigate their deficiencies.

Radically improved device performance therefore drives a revolution in power electronics in terms of both architectures and control schemes

Dramatic Improvements in Power Device FOM

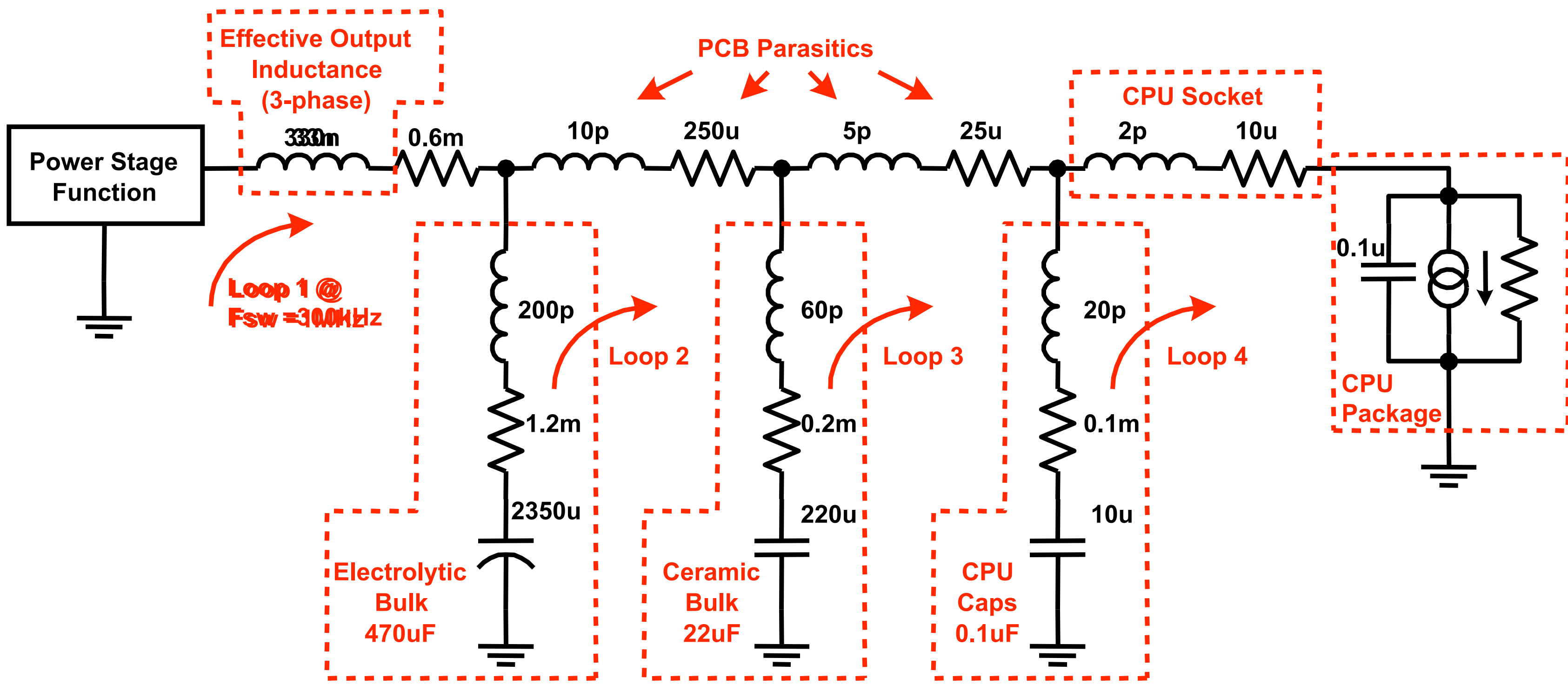
Comparison of R_{on} for Si, SiC, and GaN



Ecrit : Si = 20 V/µm , GaN = 300 V/ µm

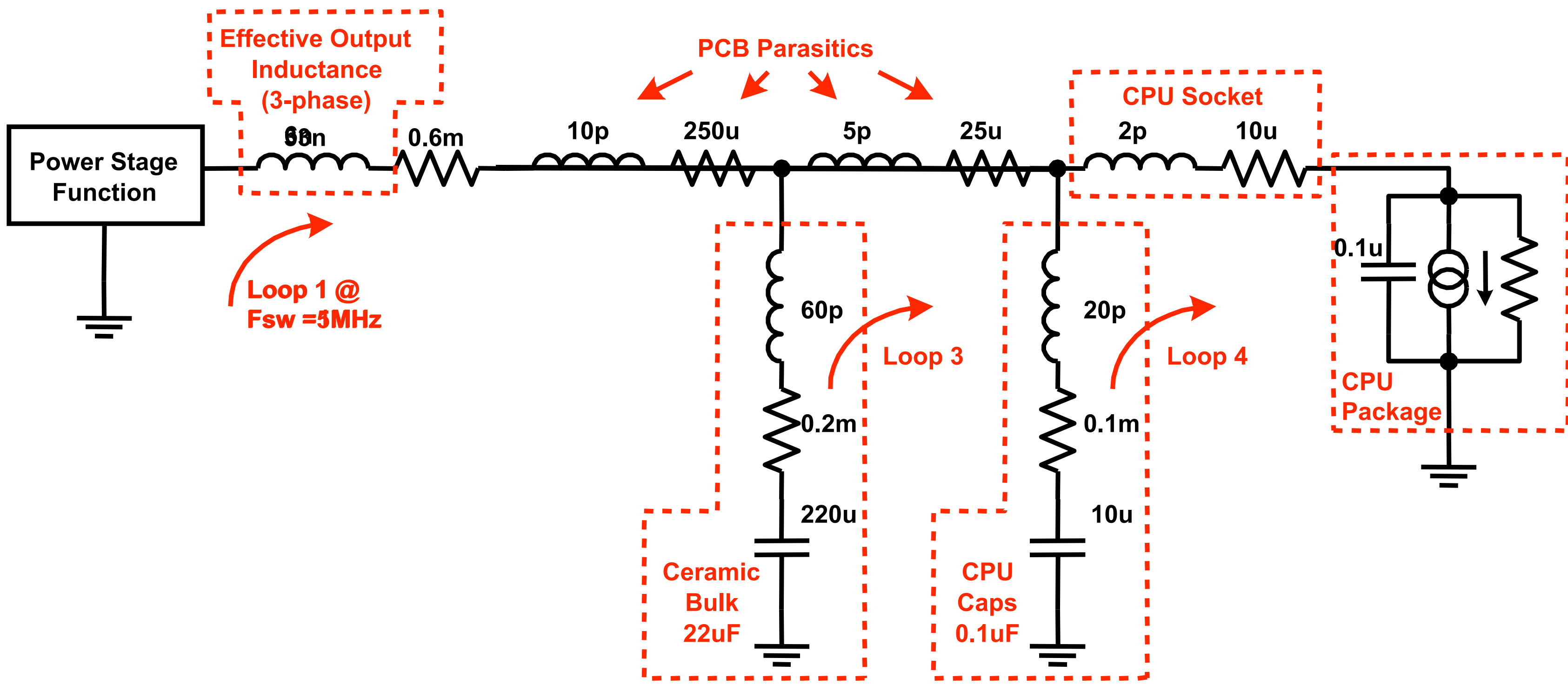
Application -- CPU Transient Current > 1000 A/µs

Low Frequency Leads to Parasitic Power Loss



Loop 1 di/dt < 350A/us Control Loop & Output Inductance	Loop 2 di/dt < 100A/us Electrolytic Bulk Capacitors	Loop 3 di/dt < 400A/us Ceramic Bulk Capacitors	Loop 4 di/dt > 1200A/us Ceramic Caps Underneath Socket

Eliminate Cost, Size, Improve Reliability

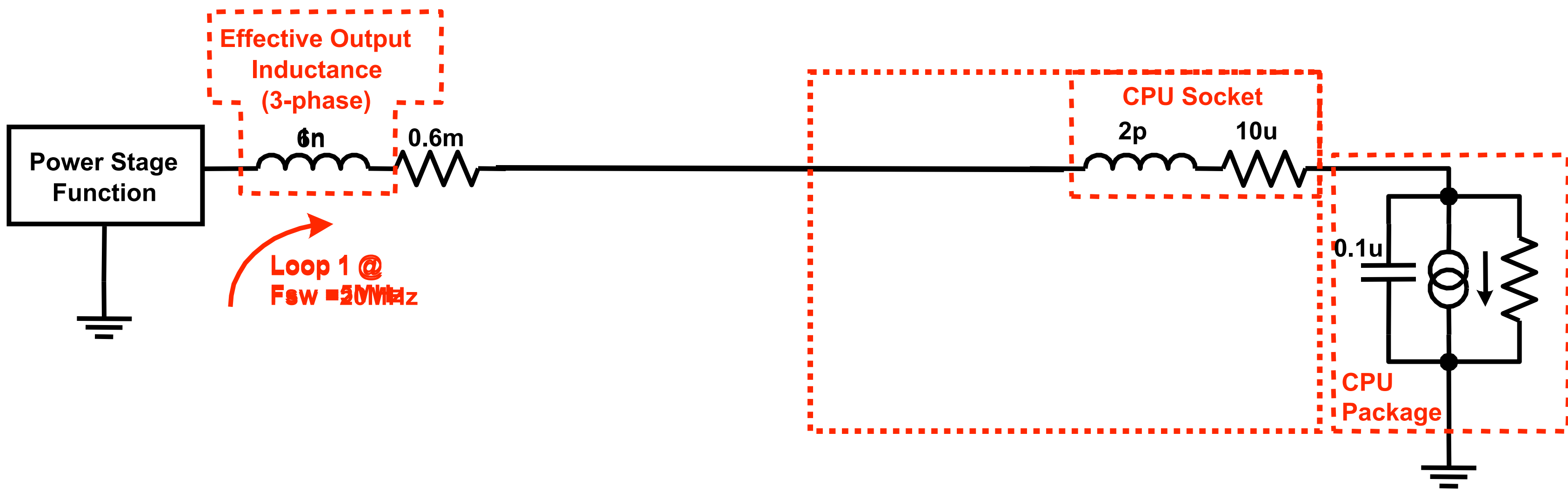


Loop 1 di/dt ≈ 1500A/us
Control Loop & Output Inductance

Loop 3 di/dt < 400A/us
Ceramic Bulk Capacitors

Loop 4 di/dt > 1200A/us
Ceramic Caps Underneath Socket

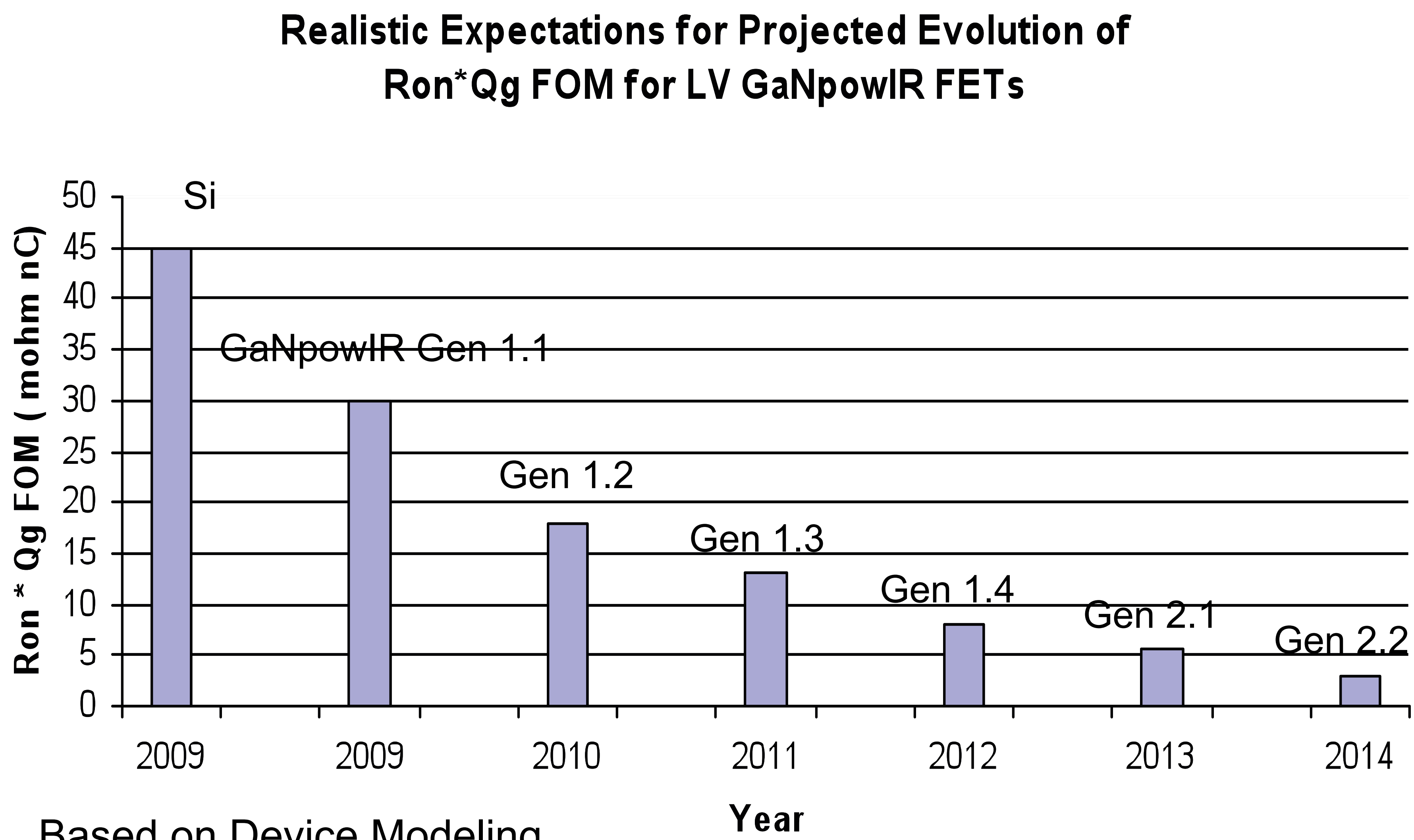
Eliminate Board Parasitics and Wasted Space



The Power Stage Function becomes part of the CPU Socket!

Loop 1 di/dt ≈ 6500A/us
Control Loop & Output Inductance

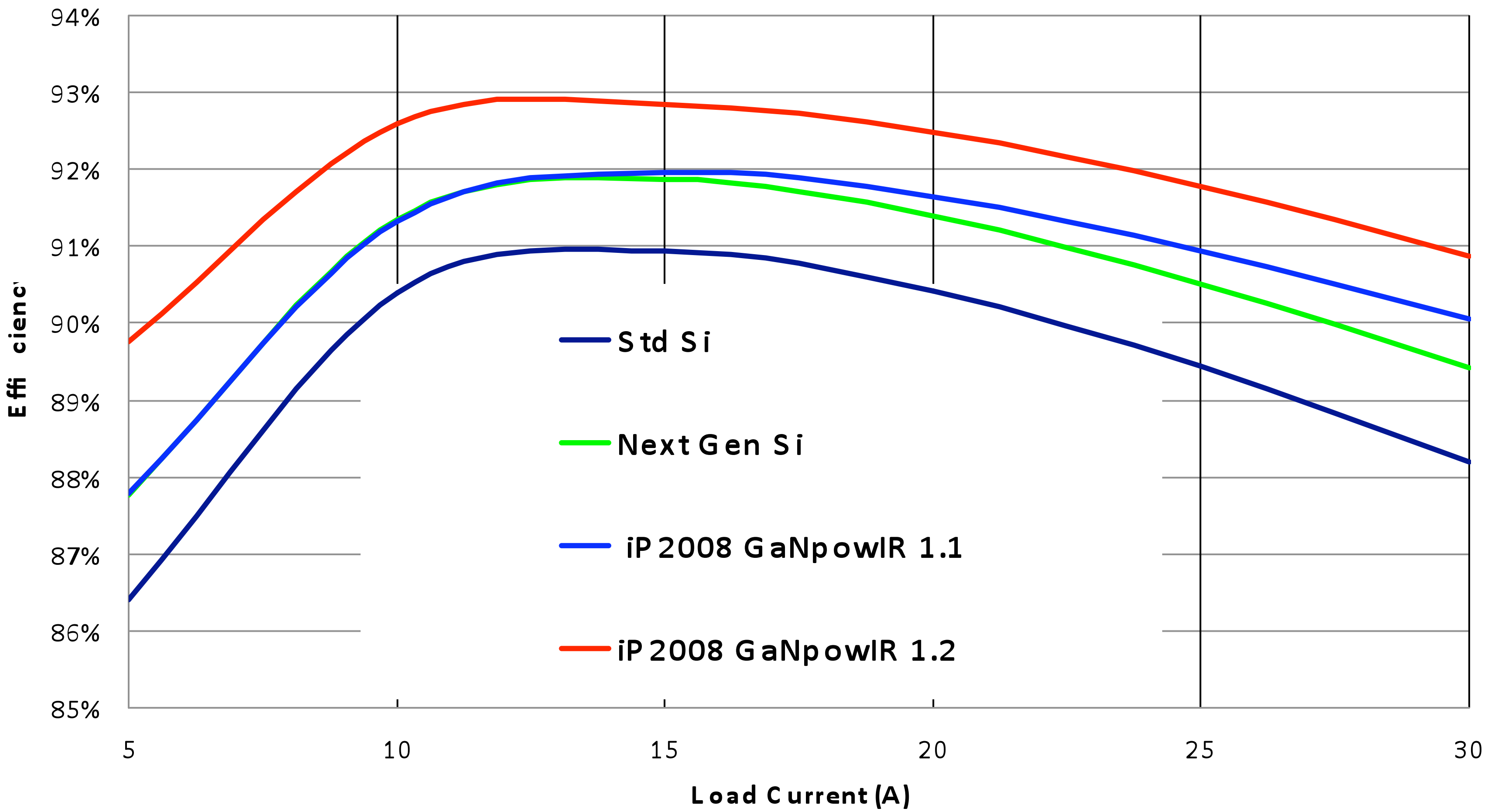
Breaking the Compromise – Radical Improvement in RQ



Based on Device Modeling

Application : High Current LV POL (VRM)

Can Achieve > 91 % efficiency from 10A to 100 A – 4 phase



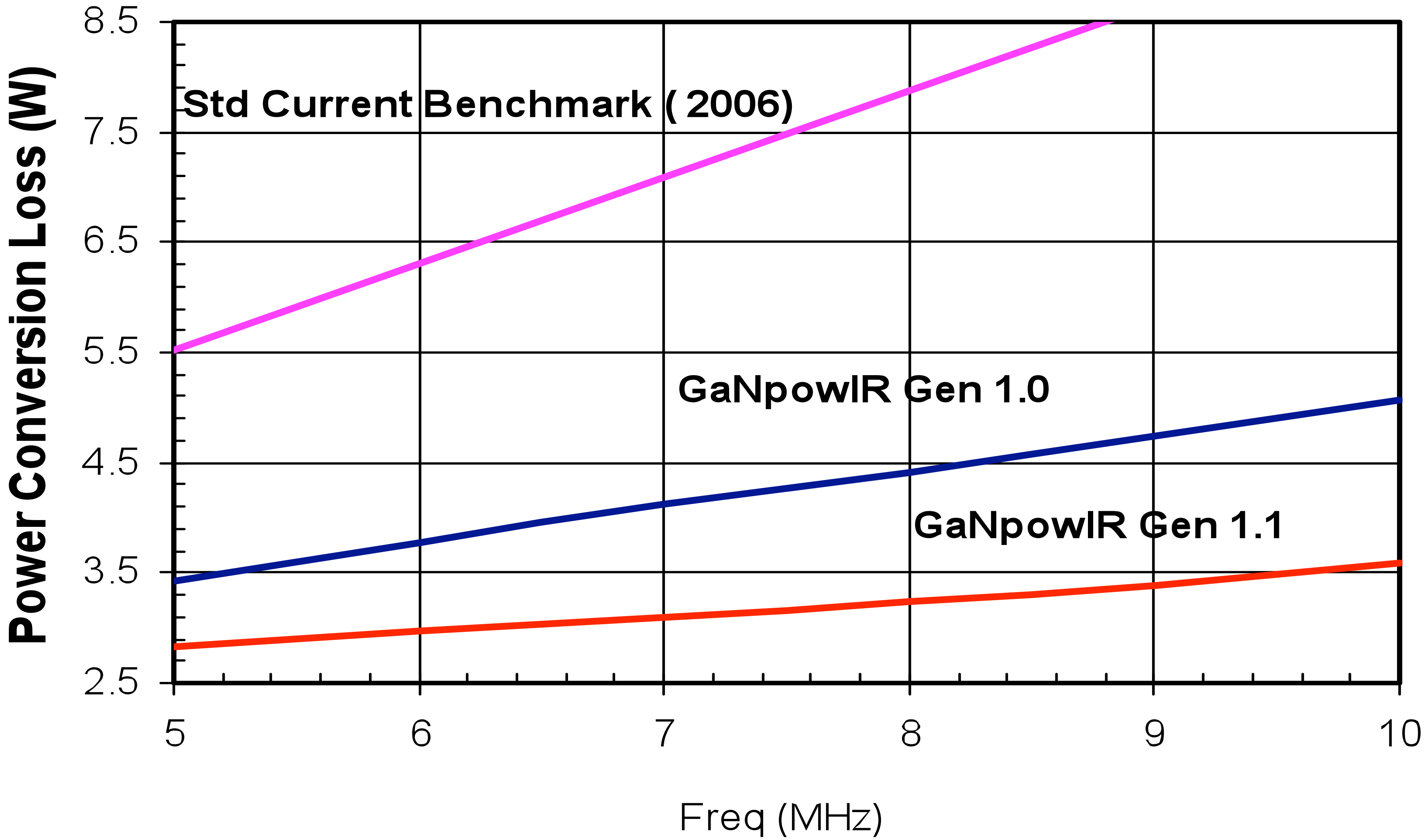
700 kHz Vin =12 V, Vout = 1.2 V

Circuit Simulations

Flattening the Power Loss Curve

Enabling High Density LV Point of Load Converters

12V to 2V, 10A Load, Power Conversion Loss



Application: POL- Early Prototypes realize potential of GaN

6 times Higher Frequency over Si Solution with similar efficiency !

Linear Tech POL Si Solution:
15 mm x 15 mm

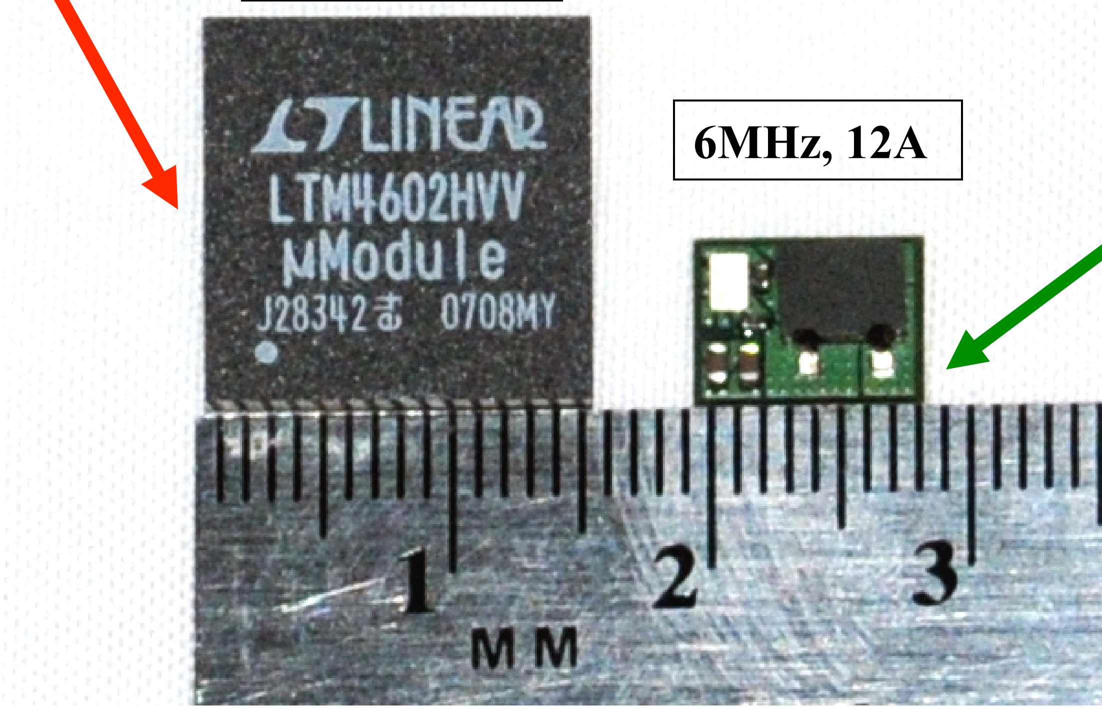
1MHz, 10A

IR GaNpowIR

Gen 1.1 Solution:
6 mm x 9 mm….

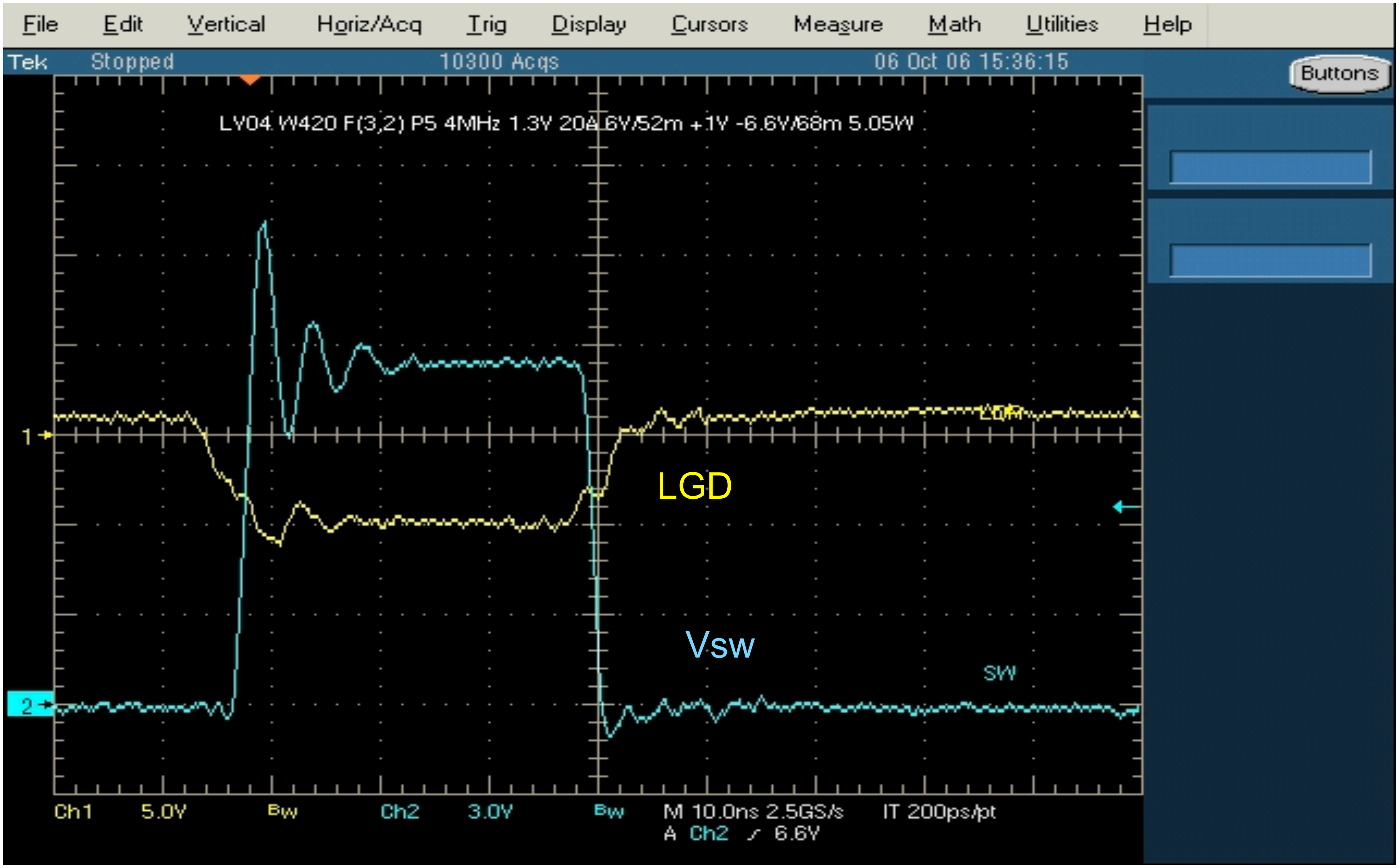
75 +% Smaller!

6MHz, 12A



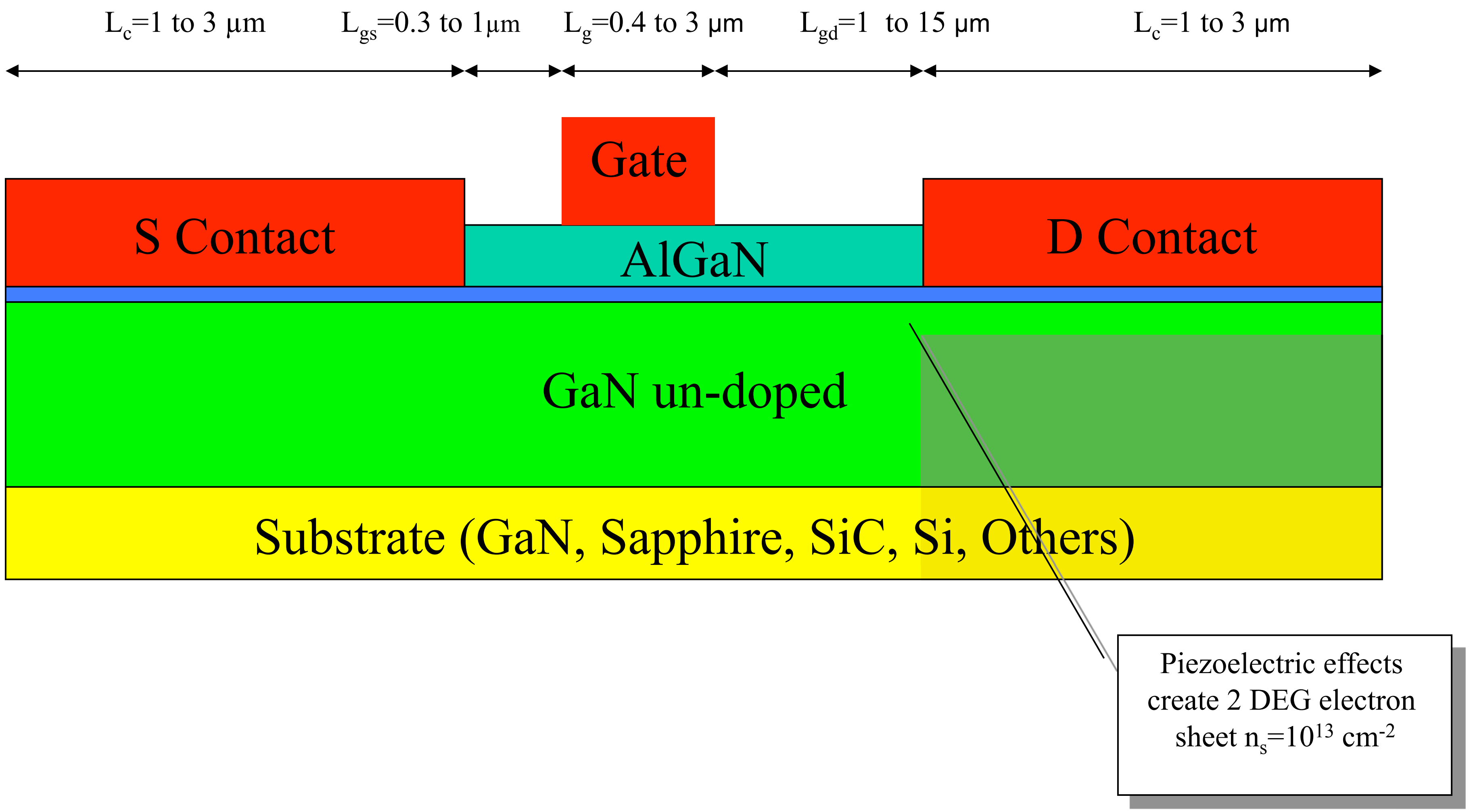
Output Inductor Integrated with Power Stage
η = 85 %
12 V to 1.2 V

iP2007 Switching Waveforms at 4 MHz Vin = 12 V, Vout = 1.3 V, Iout = 20 A

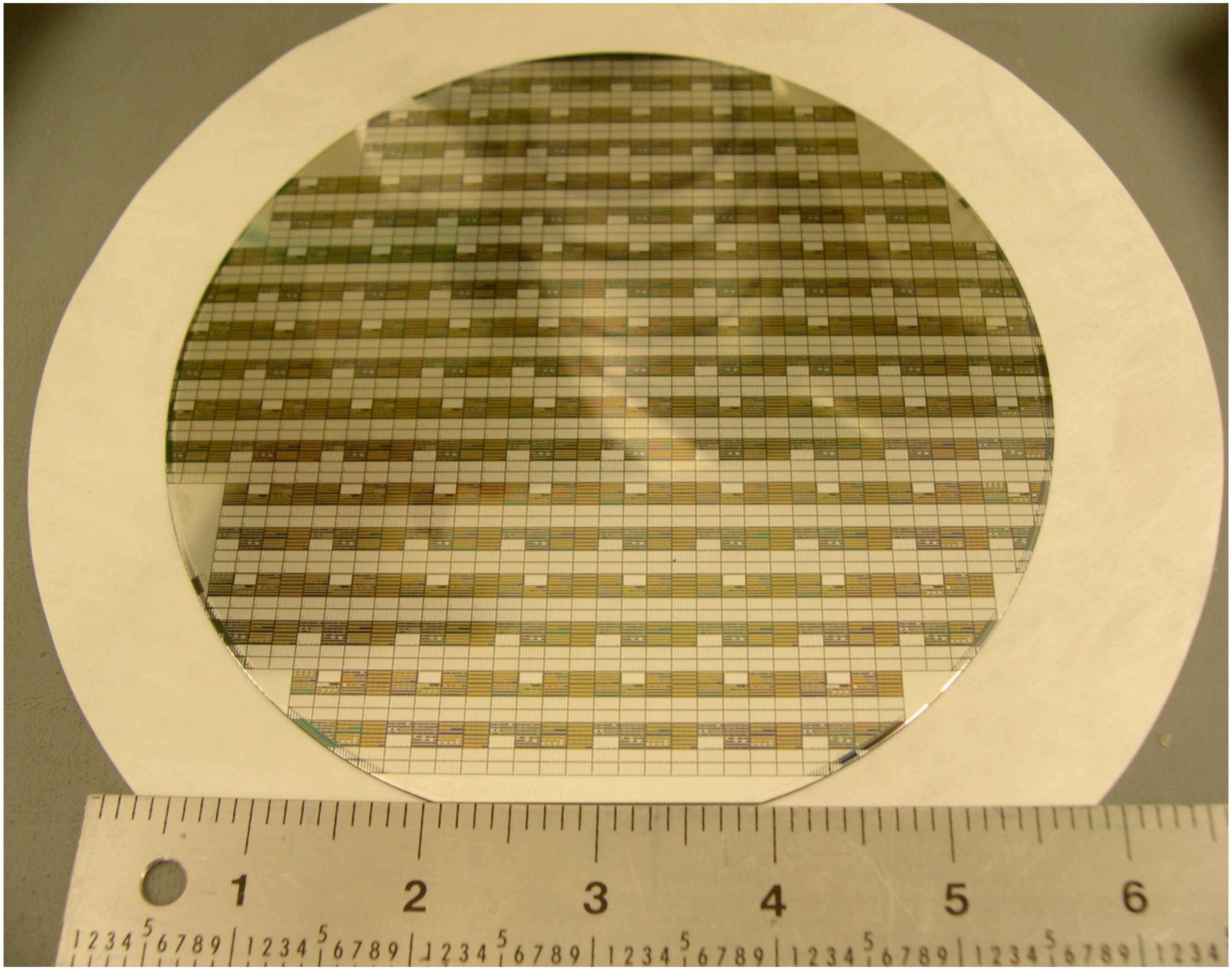


iP2007 Vsw at 4MHz

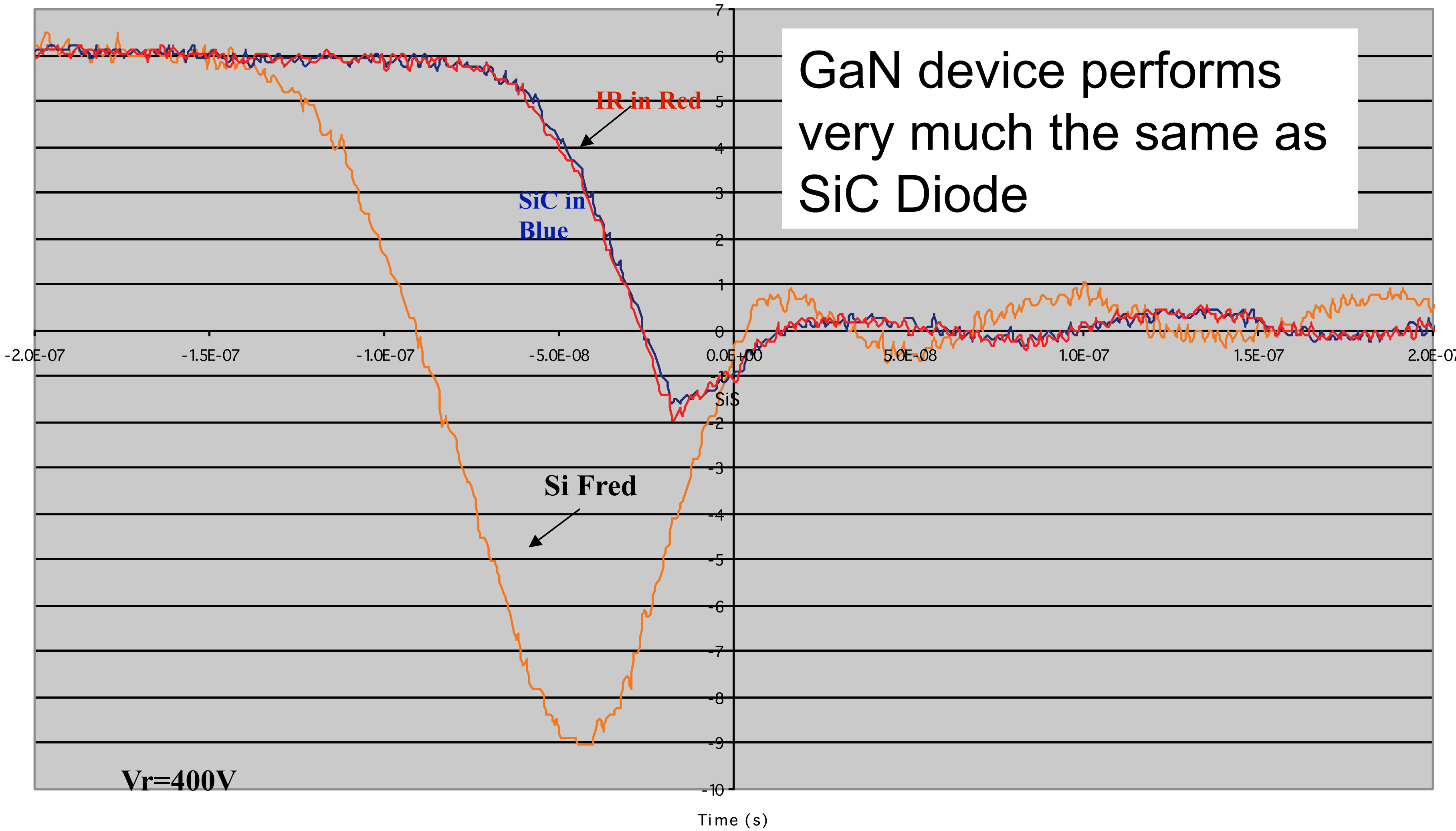
GaN based HEMT basic device structure



6” GaNpowIR Device Fabrication

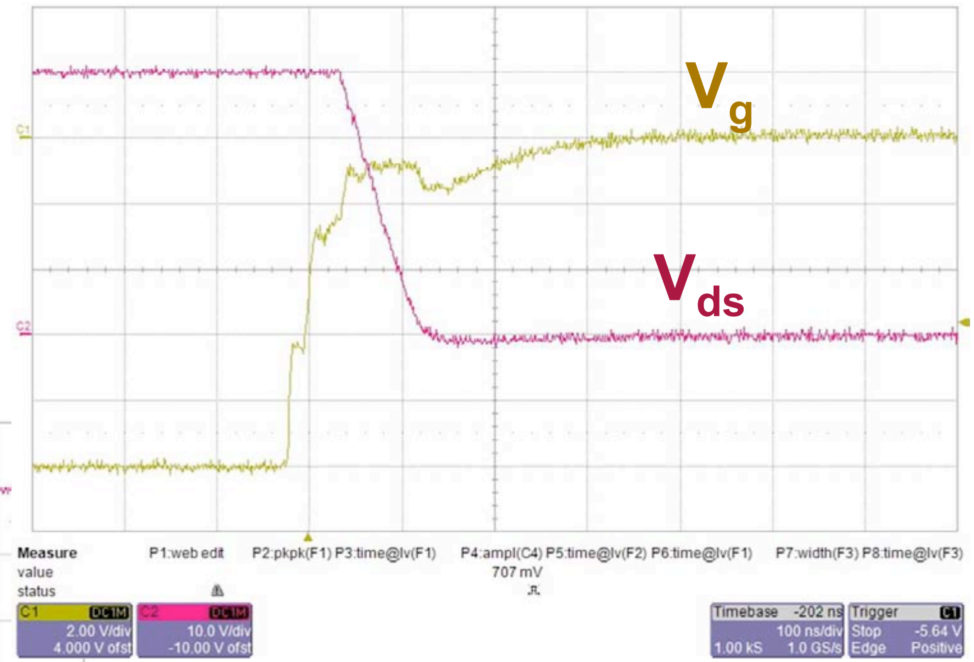


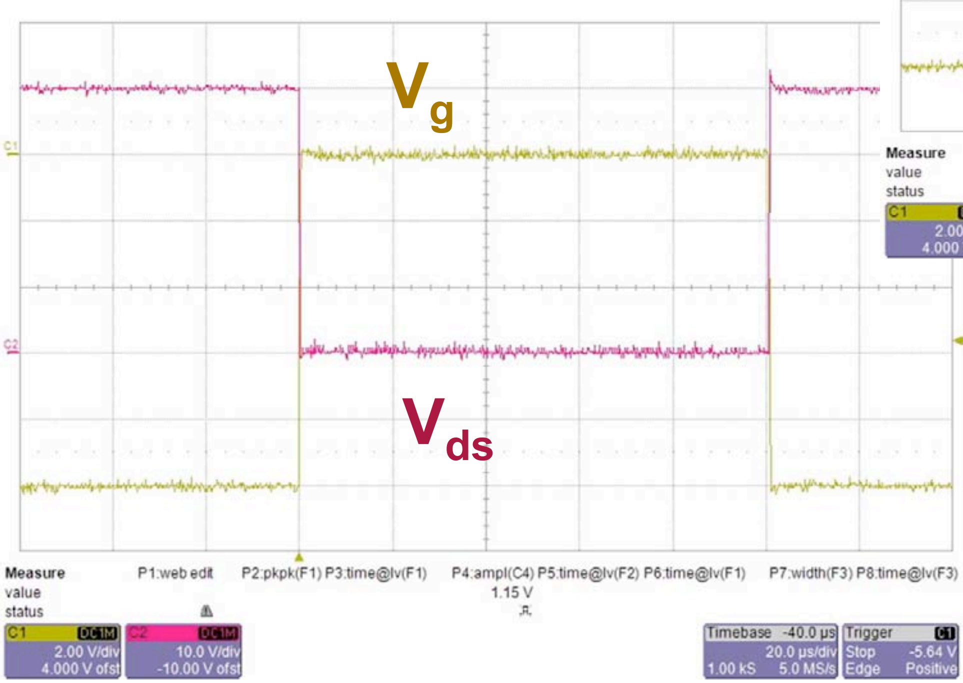
Comparison of IR prototype GaN HV diode function Qrr and SiC



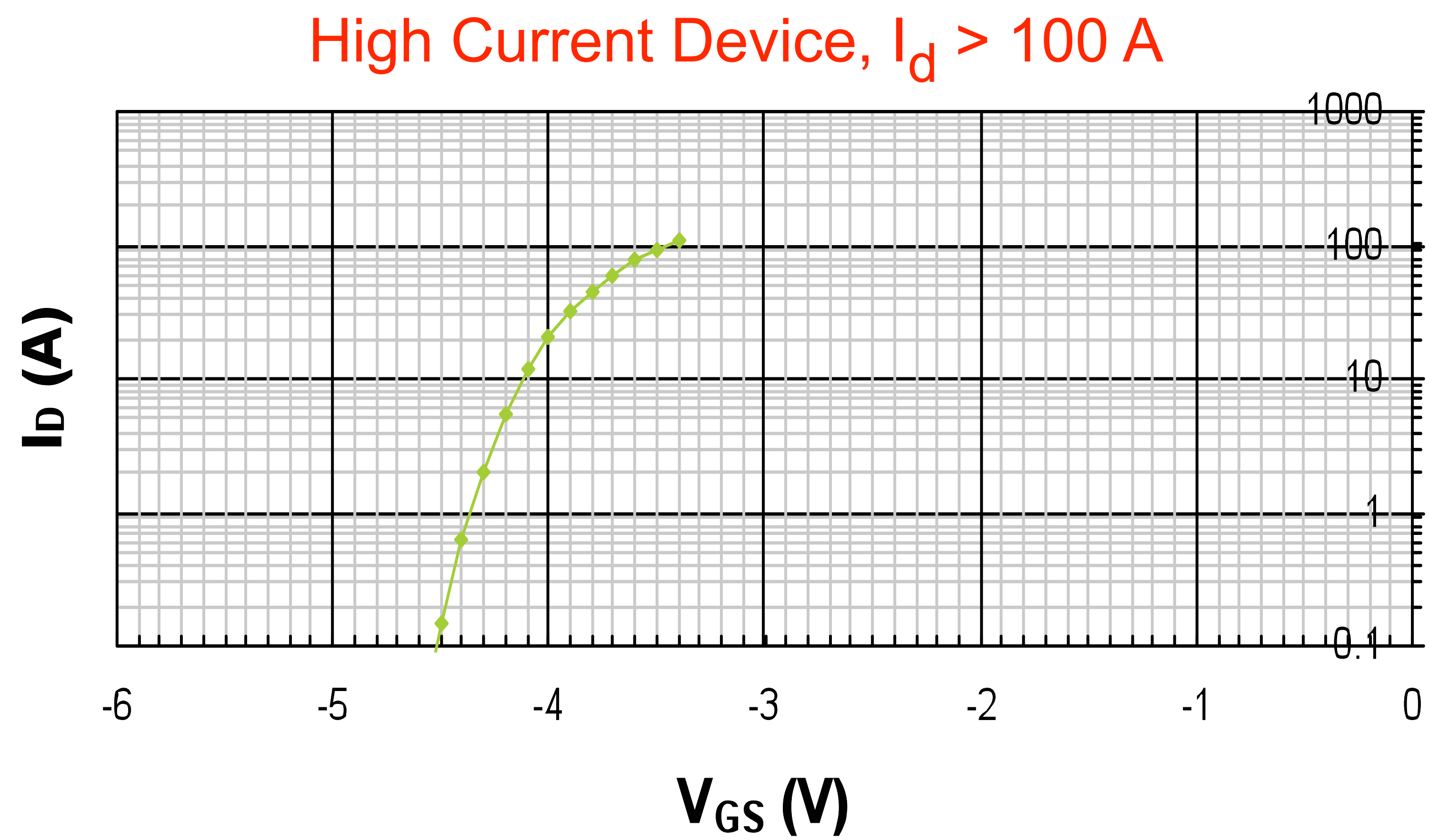
Early 150 V MV Device: Dynamic Rdson Measurement

- No sign of dynamic Rdson is seen.
-





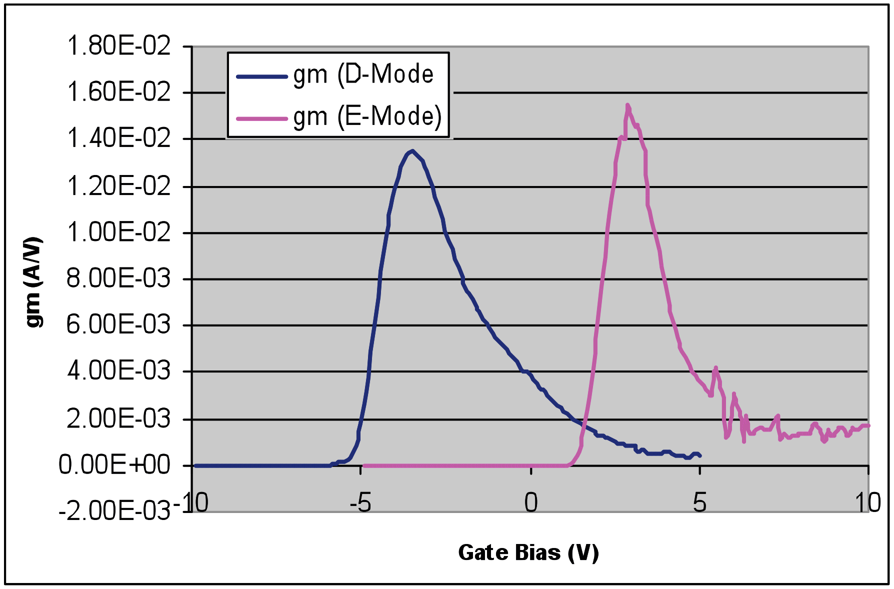
Transfer Characteristics of Large Early LV GaN HEMT

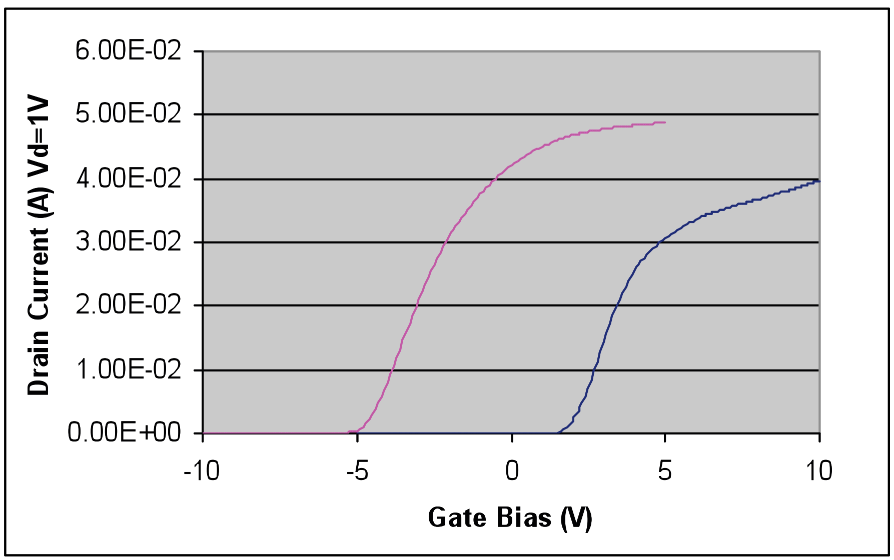


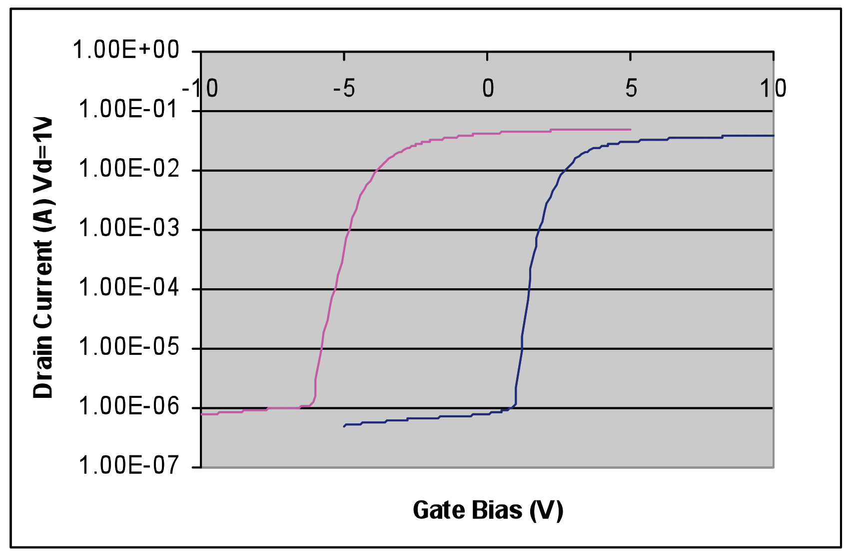
(Wg/Lg=1.6m/0.4um), AA = 7 mm^2

Ta = 25 °C

Early Enhancement Mode Device Results







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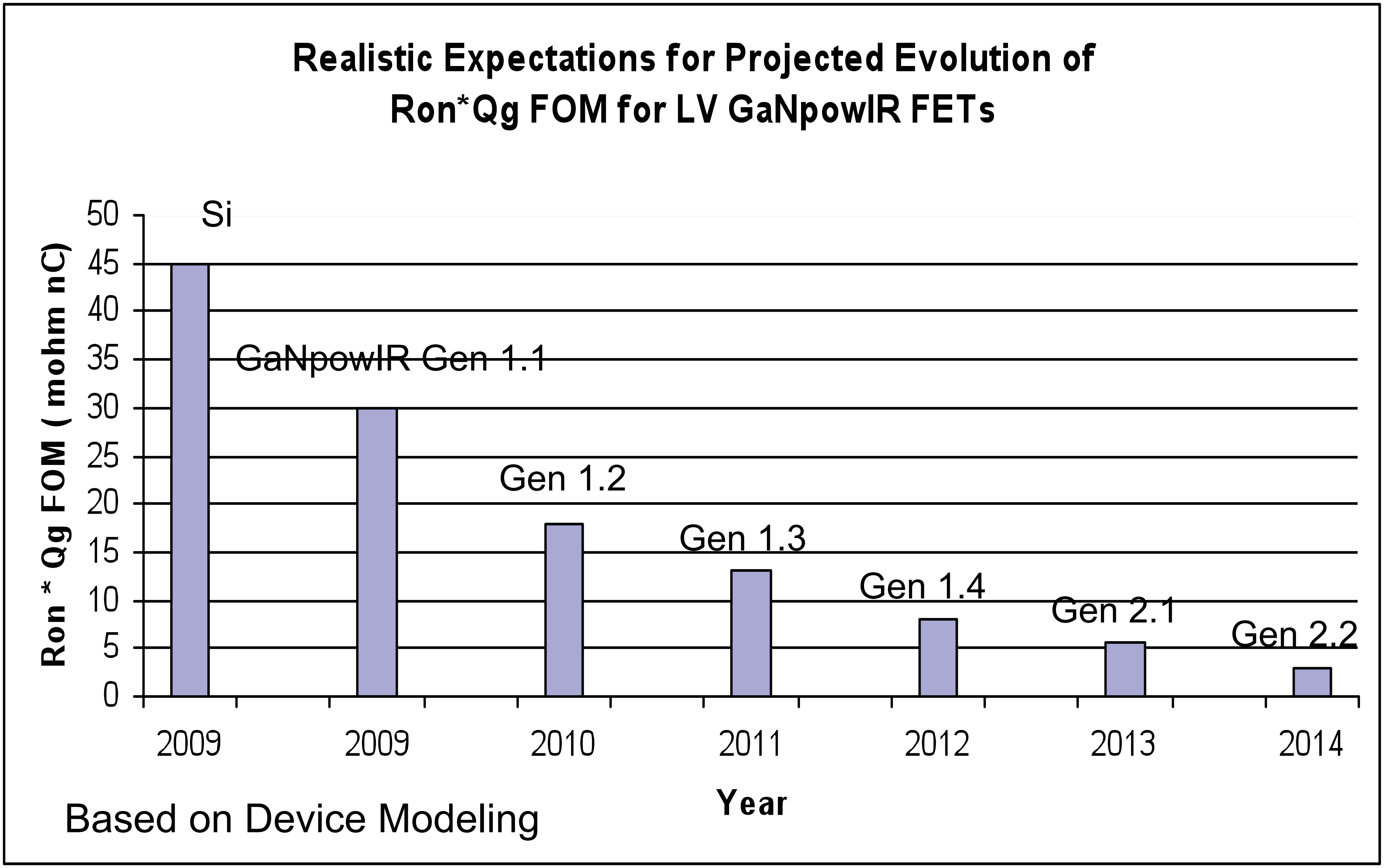
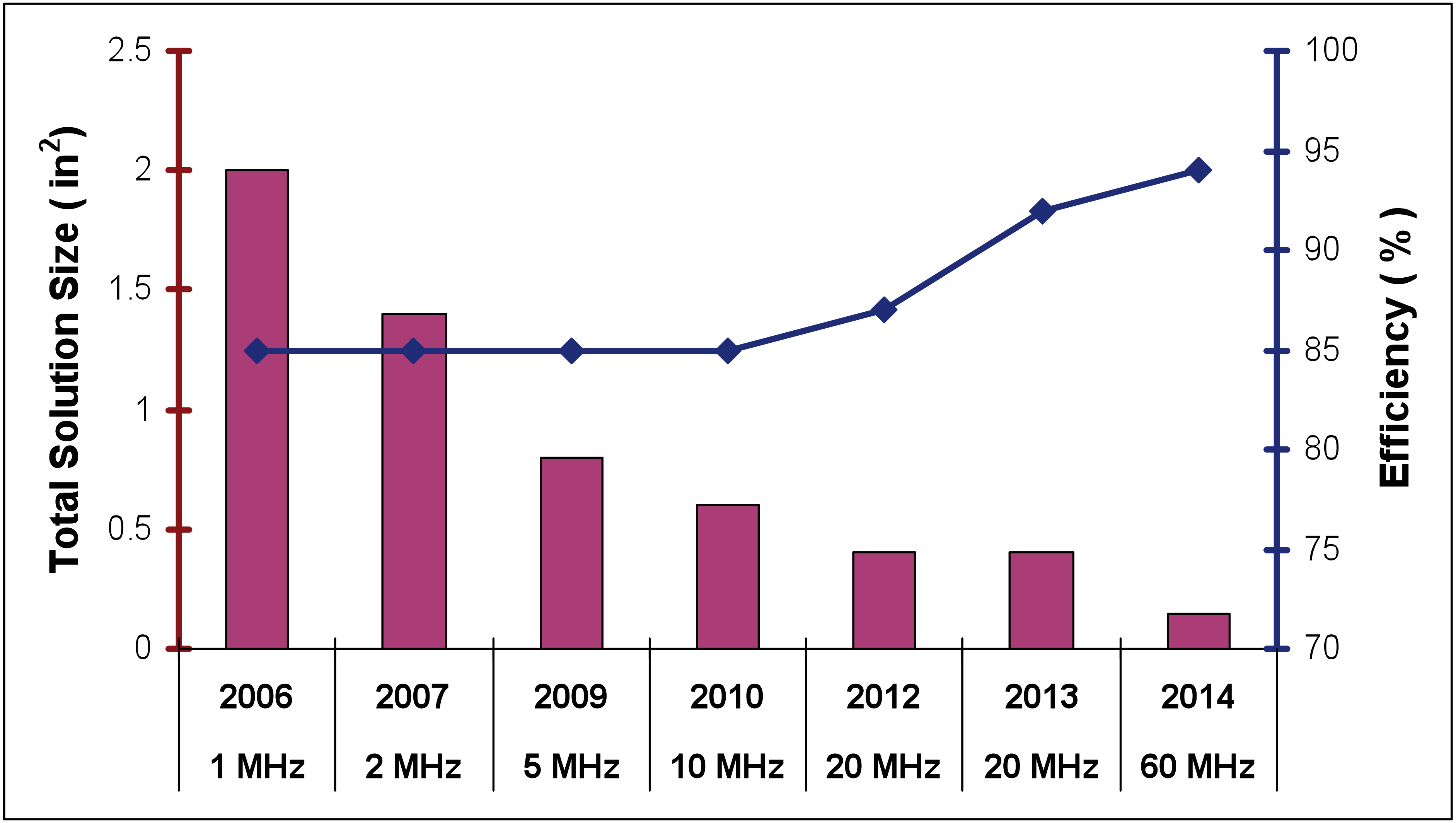


Potential LV DC-DC Power Stage Roadmap

Optimized Performance – Without tradeoff



12Vin, 1.2Vout, 100A

Based on Circuit Simulation

A Challenge for Magnetic Element Research for 2013

Density :

Freq : 10 to 100 MHz (L> 20 to 2 nH)

$J > 5$ A/ mm^2

Efficiency

Rs < 5 mohmmm^2

Summary

Achieving significantly improved density at high efficiency and commercially viable costs requires increased switching frequecy and a higher degree of integration of the power conversion stage.

Silicon based power devices are reaching their inherent performance limitations.

New power devices based on new materials such as SiC and GaN are clearly leading candidates to achieve breakthrough performance gains

Since solution costs are fundamental to adoption, it appears that SiC will have only a marginal role to play in the larger volume of power device materials requirements ($< 10^6$ out of $> 10^9$ cm^{-2})

GaN based devices (HEMT) on silicon substrates look like a promising candidate to meet this opportunity.

High density magnetic components, capable of supporting high currents with low loss are required for conversion switching frequencies > 10 MHz

Thank You

for

Your Kind Attention