GaAs PowerStages for Very High Frequency Power Supplies

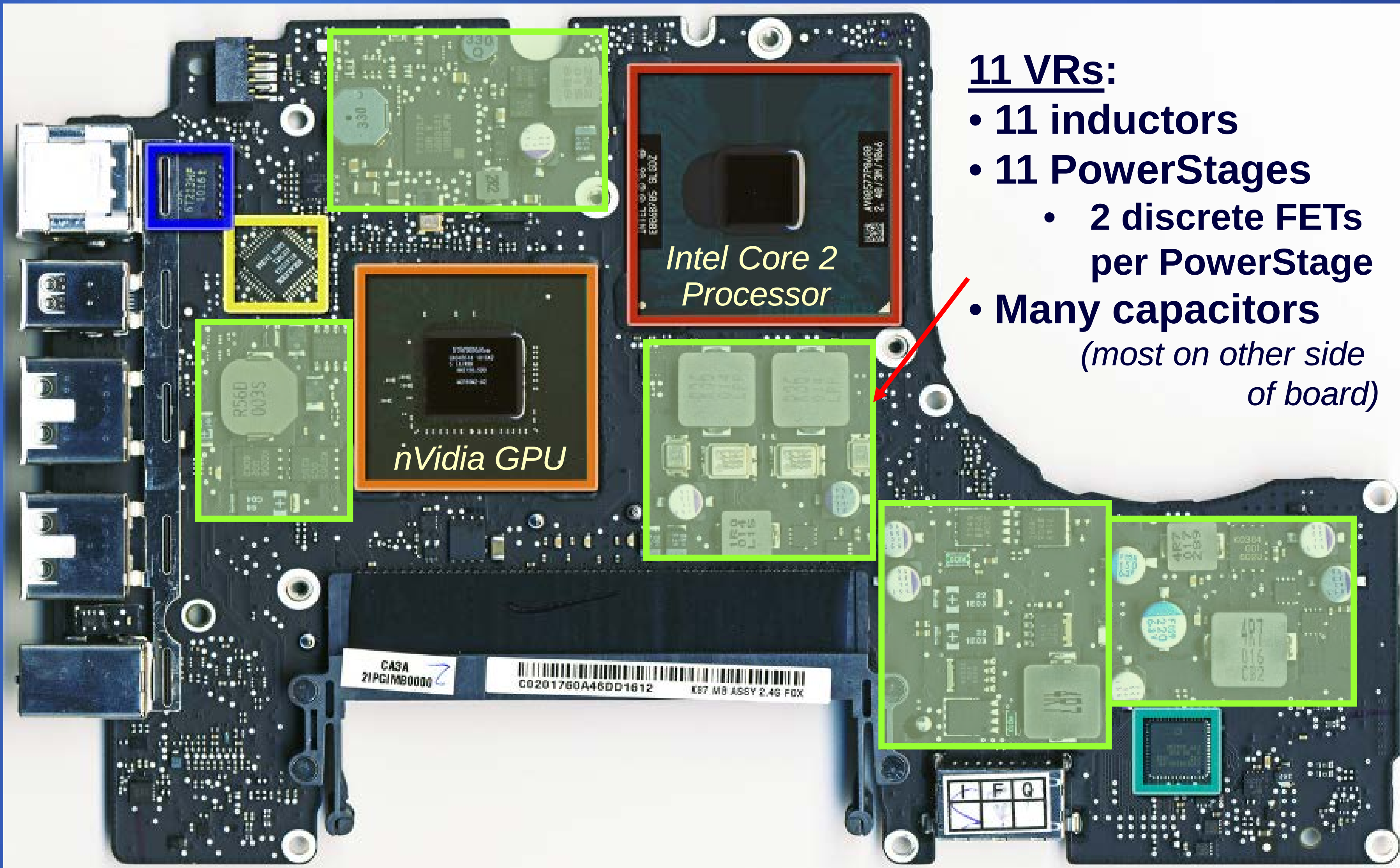
Greg Miller
Sr. VP - Engineering
Sarda Technologies
gmiller@sardatech.com

PWR SOC '12
Integrated Power Conversion and Power Management
next generation technology for emerging business opportunities
new technologies new applications new markets

Agenda

- Case for Higher Power Density Voltage Regulators
- Limitations of Silicon MOSFETs
- GaAs as a Technology Platform for Very High Frequency VRs
- Prototype Results
- PSiP Vision

Growing Problem - VRs Consume Large Area and Height



11 VRs:

- **11 inductors**
- **11 PowerStages**
  - **2 discrete FETs per PowerStage**
- **Many capacitors**
  (most on other side of board)

Example: Apple's MacBook Motherboard

Source: http://www.ifixit.com/Teardown/

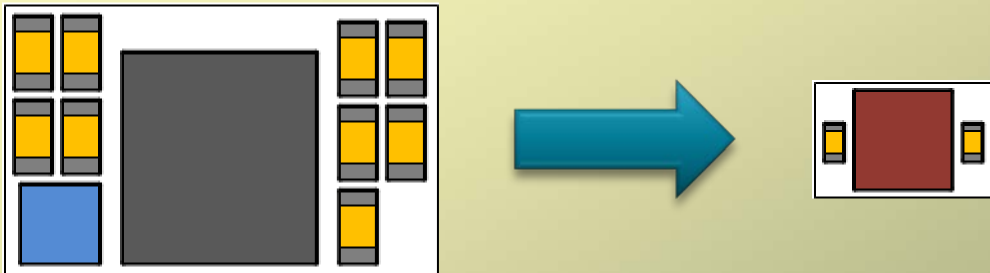
SARDA

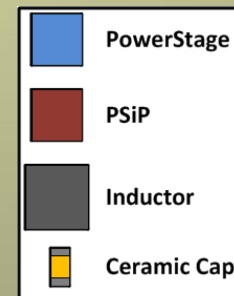
The Goal – Small, Efficient PowerStages and PSiPs

↑ Switching Frequency to ↑ Power Density

Best-in-class silicon-based VR

Dramatically Increase VR Switching Frequency





	1MHz	**50MHz**
Height	3mm	1mm height
Footprint	150mm^2	25mm^2

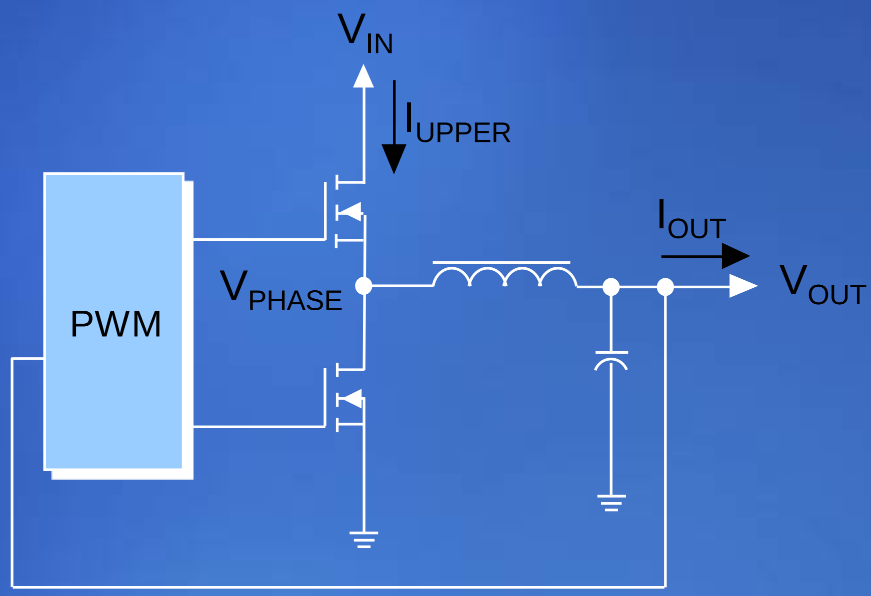
Example: ***12V$_{in}$***
1.2V$_{out}$
10A

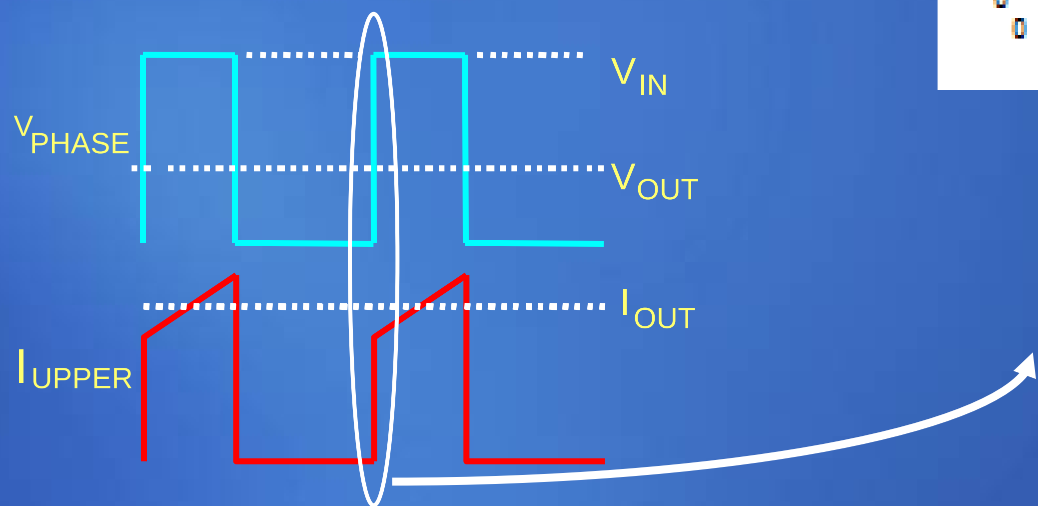
Large, thick L's
Single Phase
Slow Response

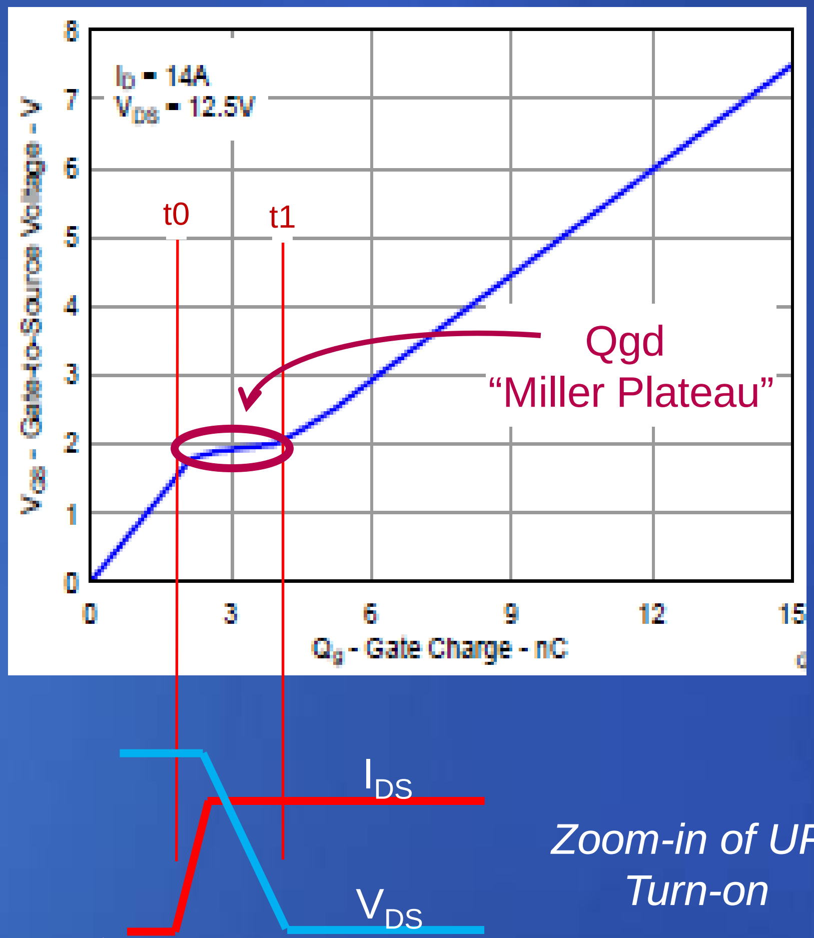
Integrated L's
Multiphase
Fast Response

How Do We Turn this Goal into Reality?

MOSFET Switching Losses Constrain Fsw of VR







Zoom-in of UFET Turn-on

Turn-on/off Losses Occur During Miller Plateau Region

→ *Function of FET Qgd*

<u>Common MOSFET Figure of Merit:</u>

FOM = Rds(on) * Qg

<u>Better</u>: FOM2 = Rds(on) * Qgd

→ *But…Qgd ~ scales with Qg, so FOM is still a good indicator*

Compound Semiconductors Enable Efficient High Fsw VRs

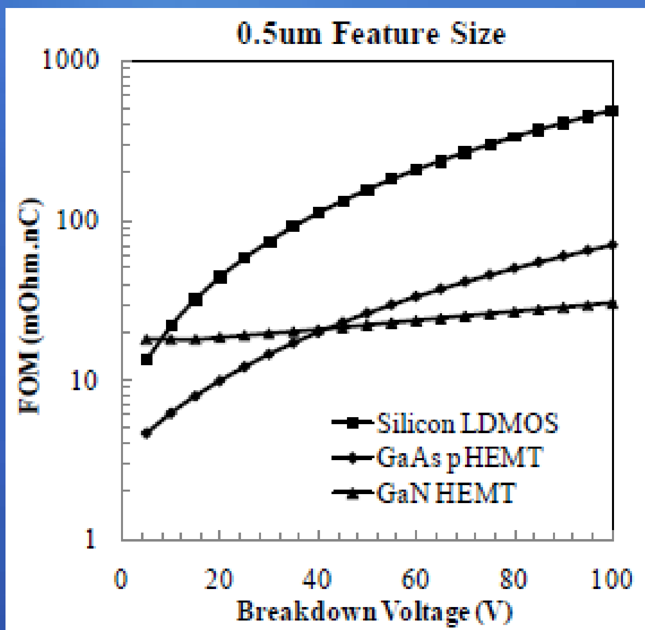
Compound Semiconductors (GaN, SiC, GaAs, etc) Have the Capabilities to Enable Efficient Very High Frequency (VHF) Power Converters

Attributes:

- Wide Bandgap Material
- High Electron Mobility
- Low Capacitance
- Low Gate Charge
- No Body Diode

A lot of recent Focus and Attention on GaN on Silicon as the enabling Compound Semiconductor material

…to name a few

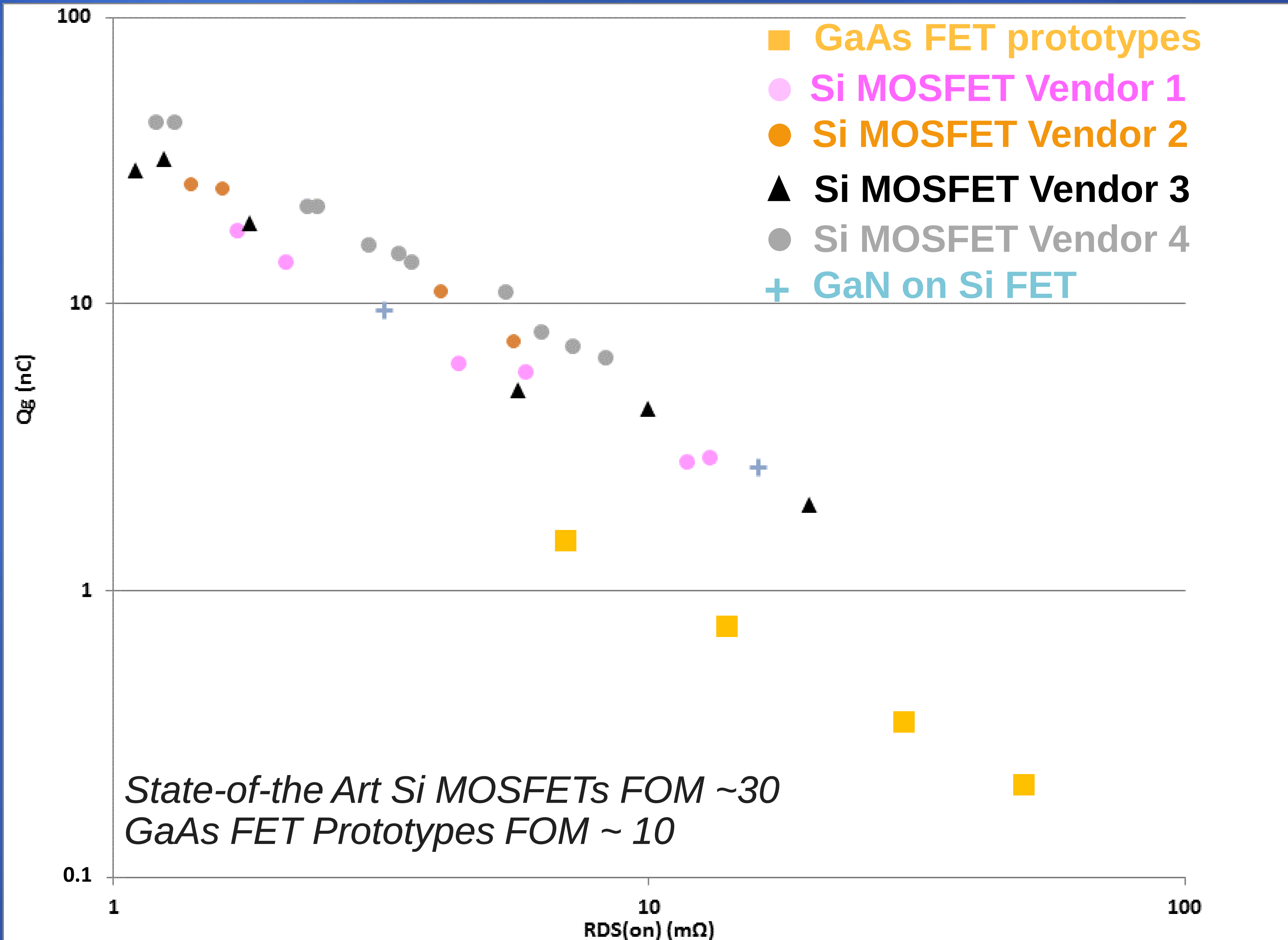


Our Belief:

- GaAs is Superior to GaN in Low Voltage (<20V) Applications
- GaN has Tremendous Opportunities in Higher Voltage Applications

Chow, et al: "Integrated High Frequency Power Conversion using GaAs pHEMTs" (PwrSOC2010)

GaAs FET has Dramatically Lower FOM than Silicon



SARDA

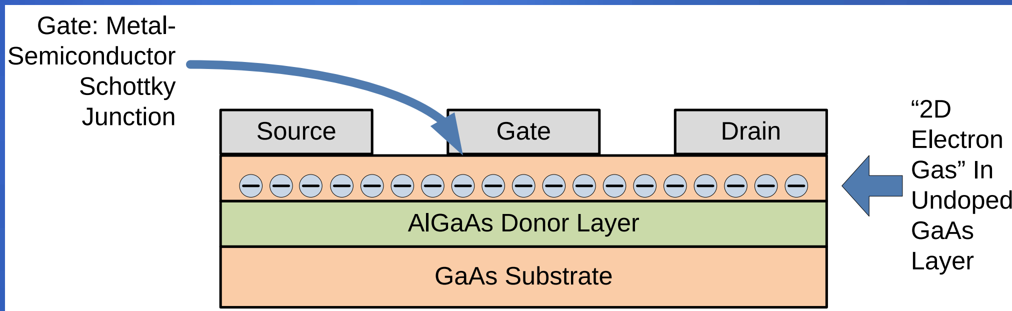
GaAs FETs are Outstanding for VHF Low Voltage VRs

		Silicon MOSFETs	GaN on Silicon FETs	Prototype GaAs FETs
$R_{DS(on)}$*Area	mΩ-mm^2	40+ (lateral) 10 to 20 (vertical)	>20	14
$R_{DS(on)}$*Q_G	mΩ-nC	30 to 100+	>20	10
Electron Mobility	cm^2/Vs	1,400	1,800	8,500
Input Voltage (max)	V	200	600	20
Body Diode		Yes	No	No
Temperature Coefficient	%/ºC	0.4	0.2	0.2
Manufacturing Scalability		• Production for 30+ years	• Immature technology • Low volume production	• Production for 30+ years • Multiple GaAs foundries

So…What has been Holding Back the Industry from Employing GaAs?

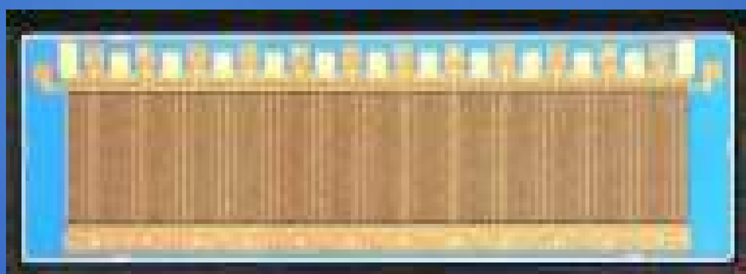
- Cost - Higher Unit Area Cost than Silicon
  - Has prevented GaAs from successful commercialization in power conversion
- Inherently Depletion-mode Devices
  - Complicates gate drive
  - Enhancement mode devices possible with some tradeoffs

Lower Cost GaAs FETs



Basic Structure:
Pseudomorphic High Electron Mobility Transistor (pHEMT)

Conventional GaAs Die for RF Application



Fujitsu 50 W L-Band FET
W_g = 86mm
$A = 4mm^2$

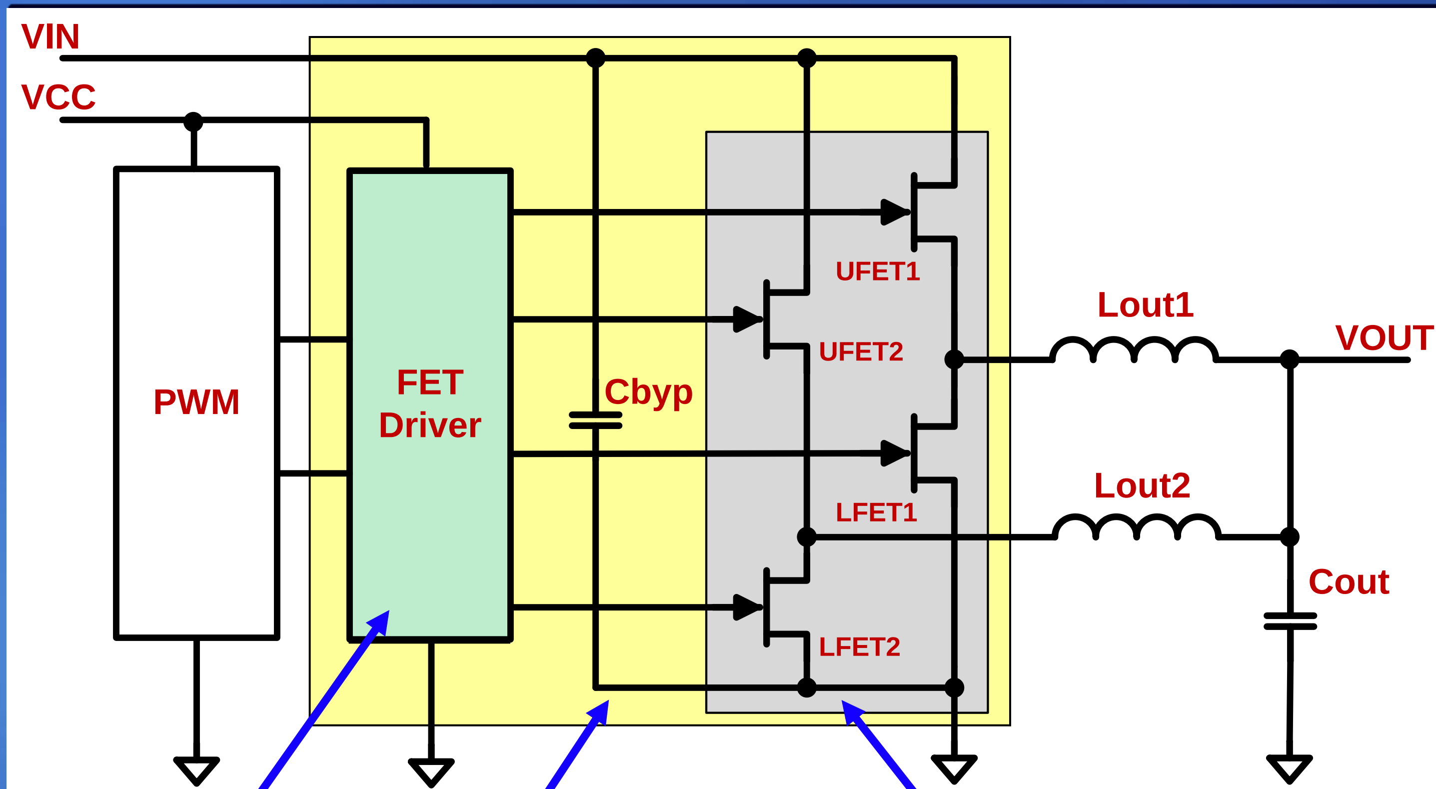
Sarda's GaAs Die

Prototype Die
W_g = 86mm
$A = 0.74mm^2$
$R_{DS(on)} = 17\ m\Omega$

Reducing Specific On-resistance makes GaAs Cost-effective for Power conversion

Highly Integrated PowerStage

Handles GaAs FET Drive Requirements



CMOS IC

- Drivers

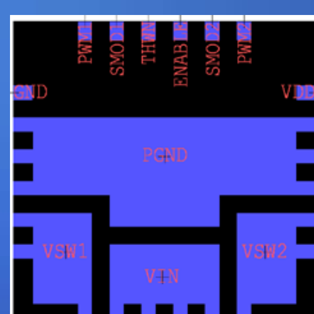
3-D SiP

(system in package)

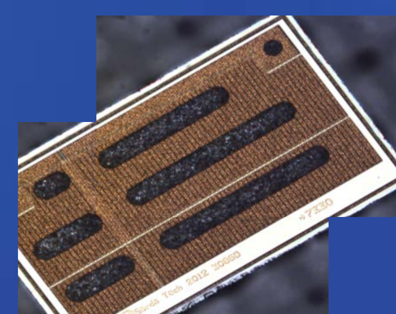
- Integrates performance-critical components for high Fsw
- 4x4x1.3mm QFN

GaAs IC

- Integrates many high-speed FETs monolithically (lateral devices)
- Minimizes stray inductance



Unique 3D packaging, but in standard QFN footprint



Prototype GaAs FET Characterization

Parameter			*GaAs FET*
Breakdown voltage	BV_{DSS}	V	18
On-resistance	$R_{DS(on)}$	mΩ	13.7
Gate charge total	Q_g	nC	0.79
Gate-to-drain charge	Q_{gd}	nC	0.3
Reverse recovery charge	Q_{rr}	nC	0
Output Capacitance	C_{OSS}	pF	60
Rise time	t_R	ns	2.9
Fall time	t_F	ns	0.75

FOM = 10.8

FOM2 = 4.1

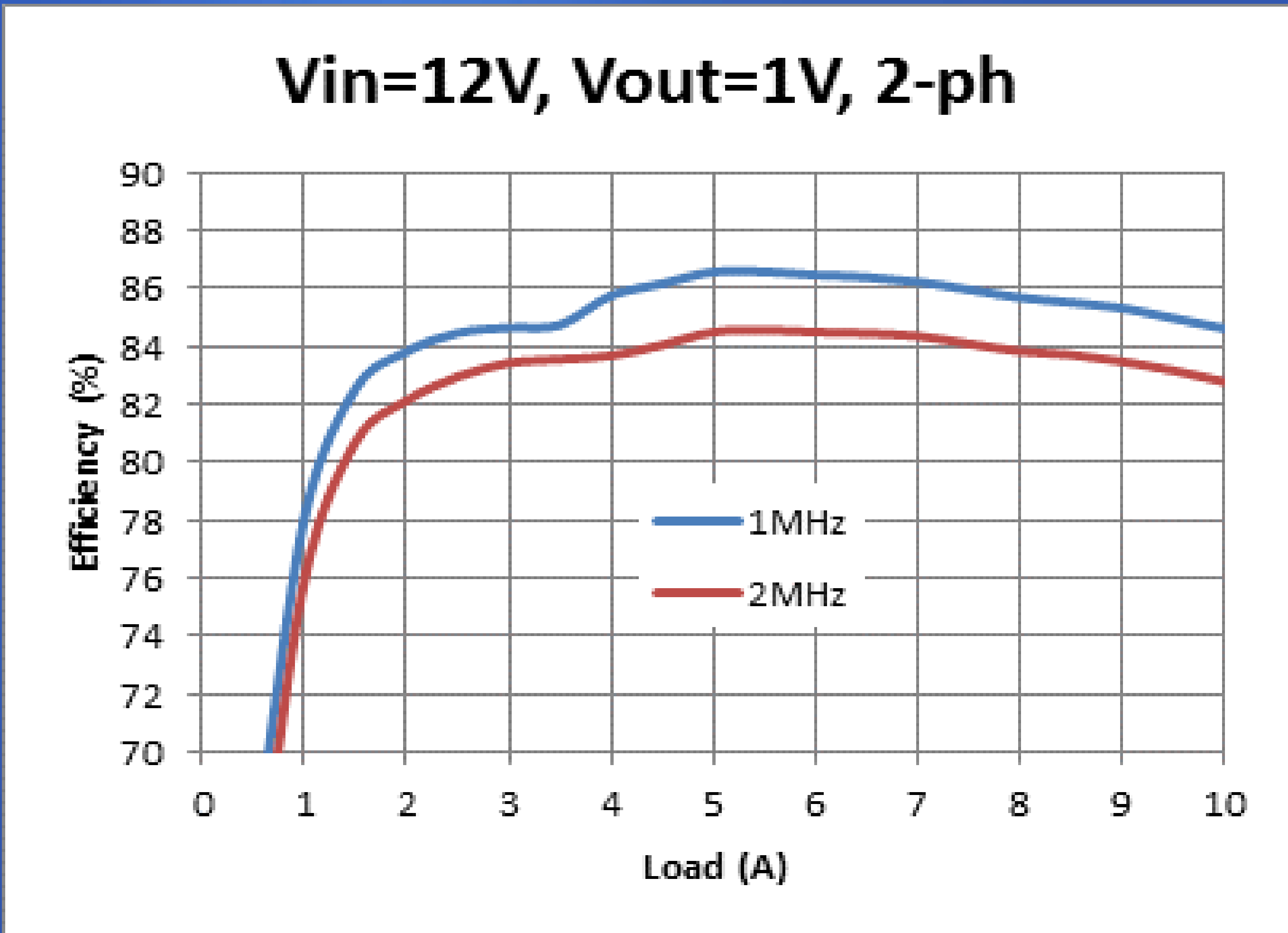
No Body Diode

Fast rise/fall times
(also function of Driver)

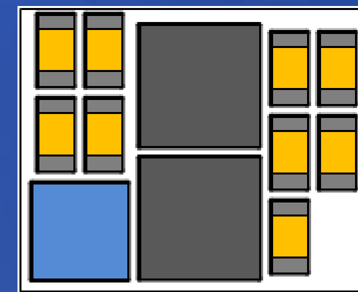
Prototypes Manufactured in Standard High-Volume pHEMT 0.5μ Process

10A, 2-phase PowerStage Module - Predicted Performance

With Auto Phase Dropping



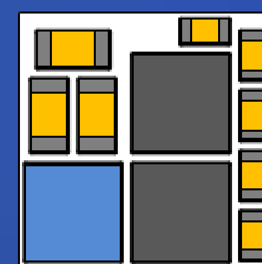
1MHz



L height: 3mm

14x11mm

2MHz



L height: 2mm

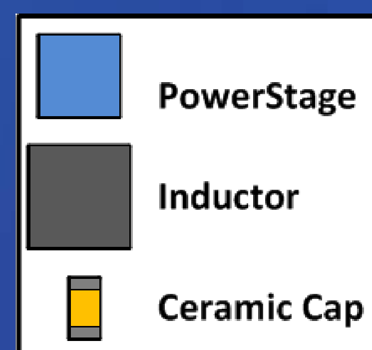
10x10mm

GaAs: 2-ph Monolithic

UFETs: Rdson = 50mΩ
Qg = 0.2nC
LFETs: Rdson = 13mΩ
Qg = 0.8nC

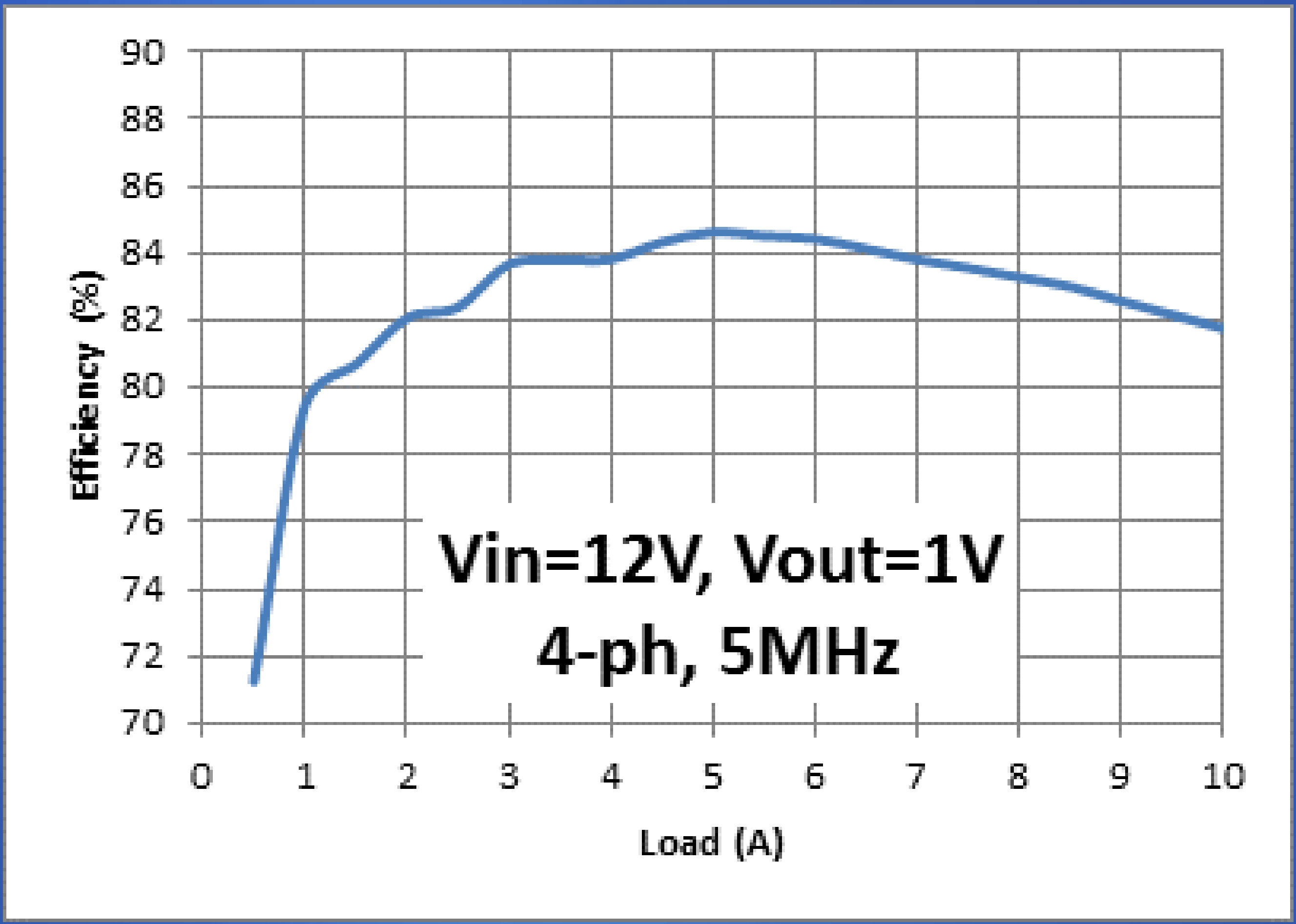
Inductors: Vishay IHLP2020CZ-11
(1MHz) 470nH, 5.4mΩ
5 x 5 x 3mm

Vishay IHLP1616BZ-11
(2MHz) 220nH, 6.5mΩ
4 x 4 x 3mm

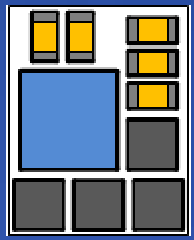


10A, 4-phase Module Predicted Performance

Same GaAs FET Die Size Segmented for 4-Phase



5MHz



L height: 1mm

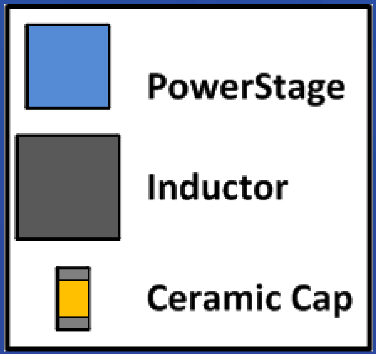
7x9mm

<u>GaAs</u>: 4-ph Monolithic

UFETs: Rdson = 100mΩ
Qg = 0.1nC

LFETs: Rdson = 26mΩ
Qg = 0.4nC

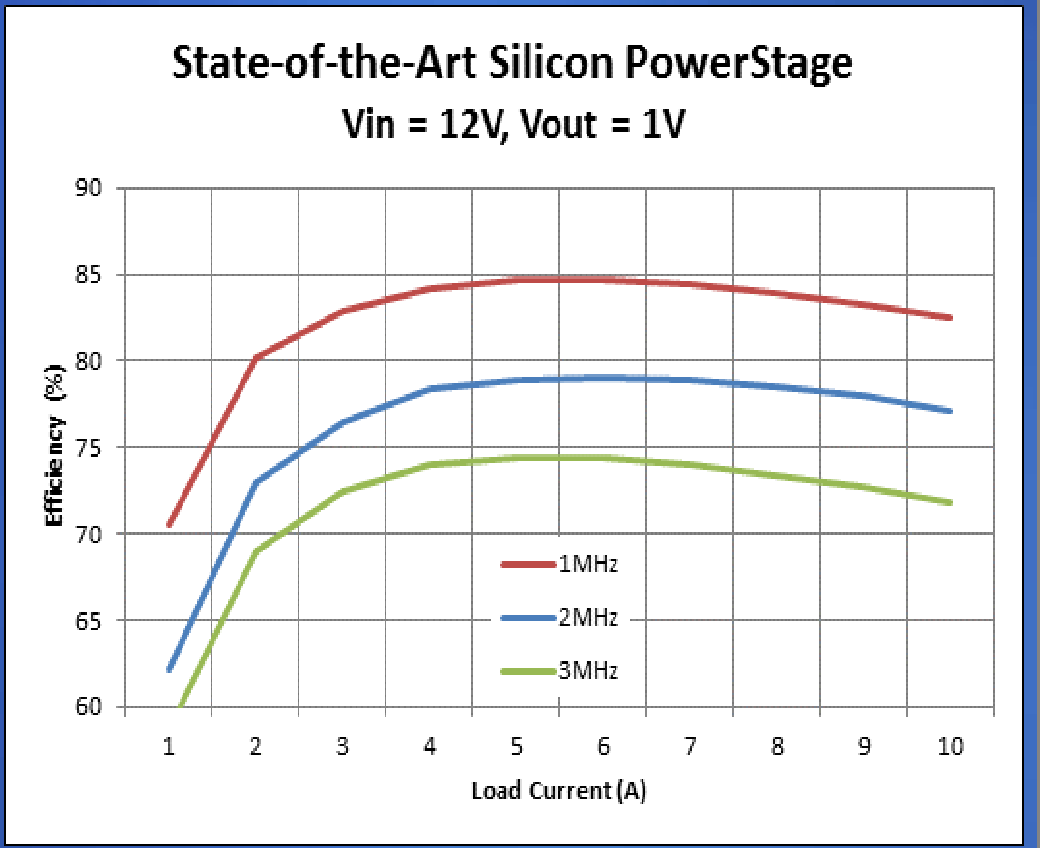
<u>Inductors</u>: Coilcraft XPL2010-201
200nH, 24mΩ
1.9 x 2 x 1mm



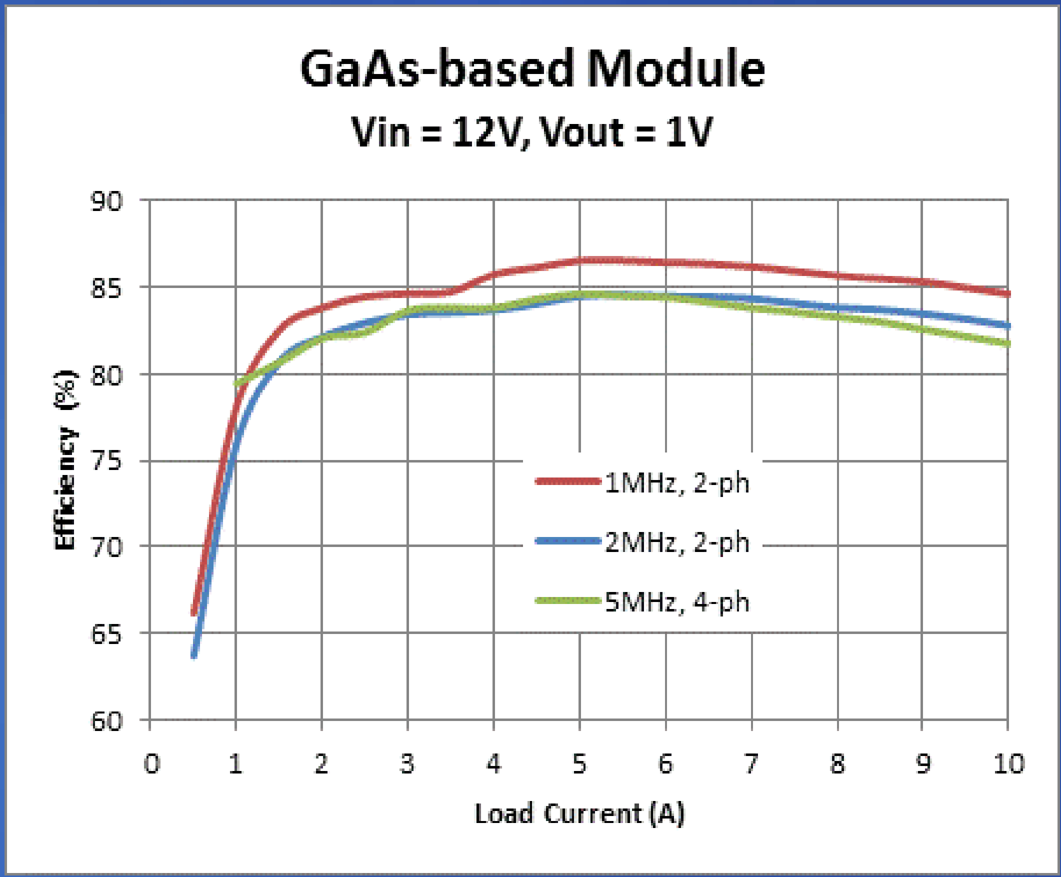
SARDA

GaAs Enables Efficient VHF Operation

Predicted VR Efficiency, including Inductor Loss



Note: **green curve is 3MHz**

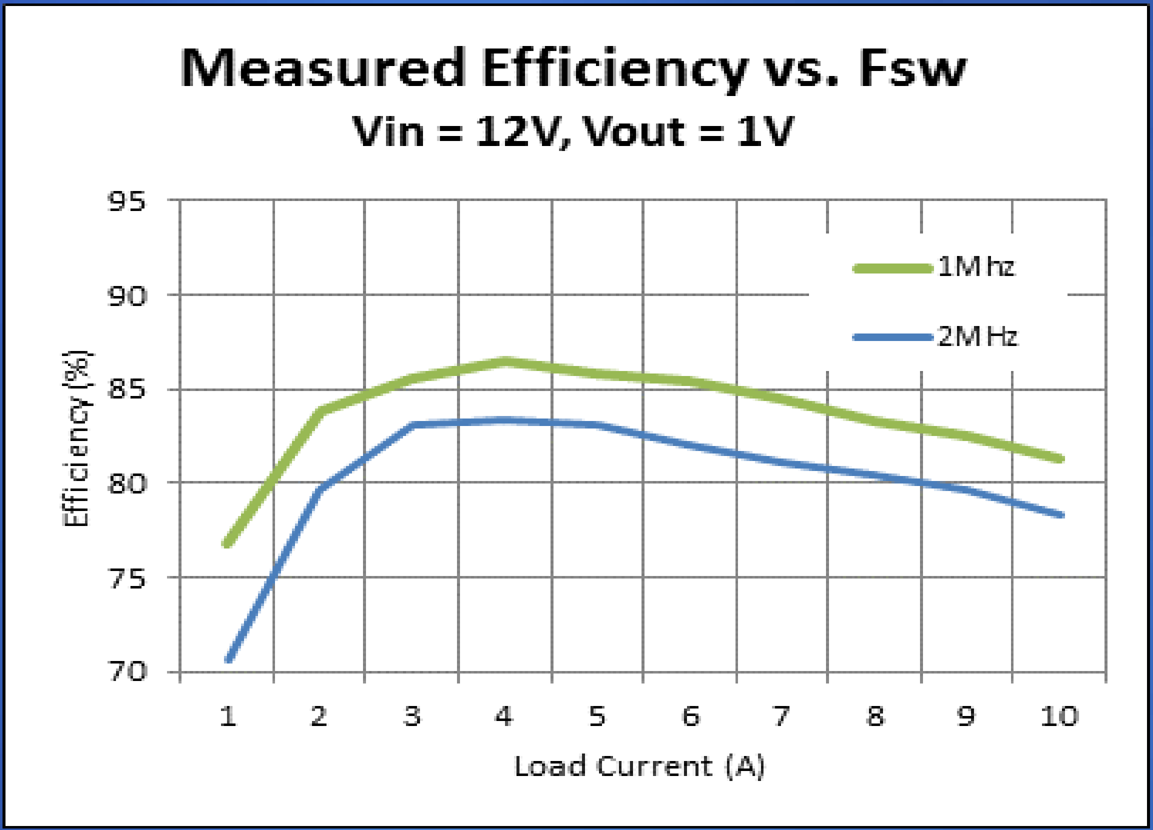


Note: **green curve is 5MHz**

- Demonstrates why silicon MOSFETs are not typically pushed beyond 1MHz for this application

- GaAs reduces FET switching losses
- GaAs enables small multiphase topology monolithically – also key to reducing switching and inductor losses

GaAs Technology Proven Using Feasibility Boards

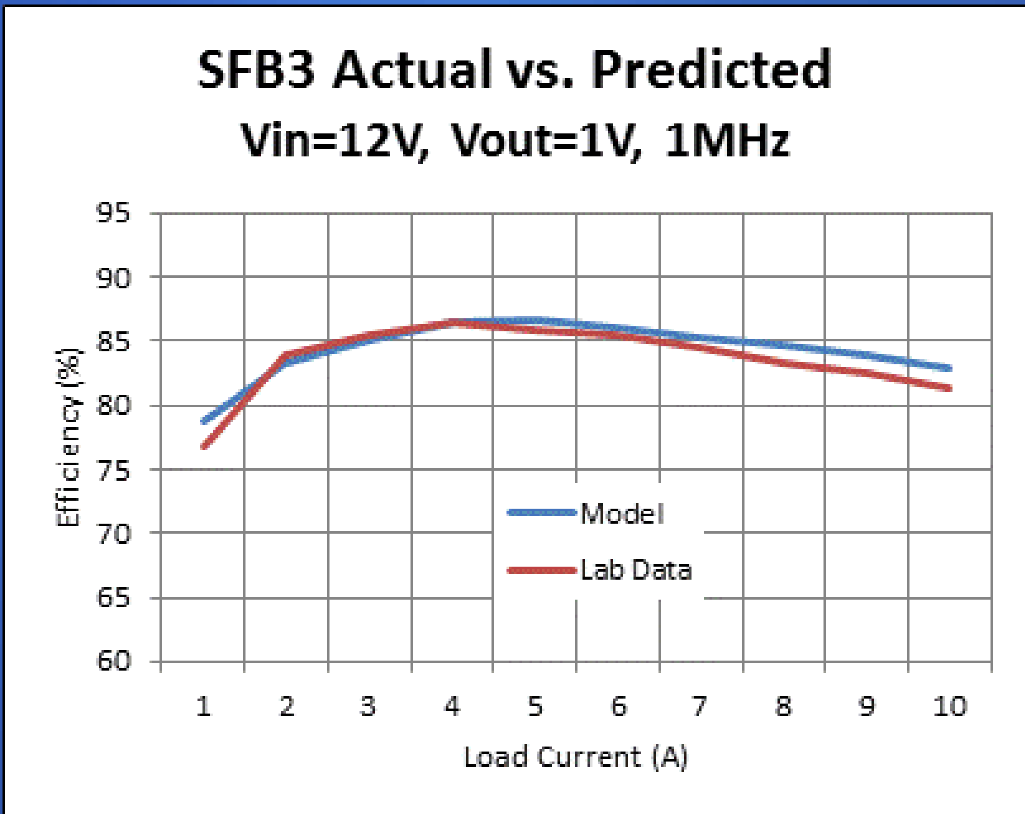


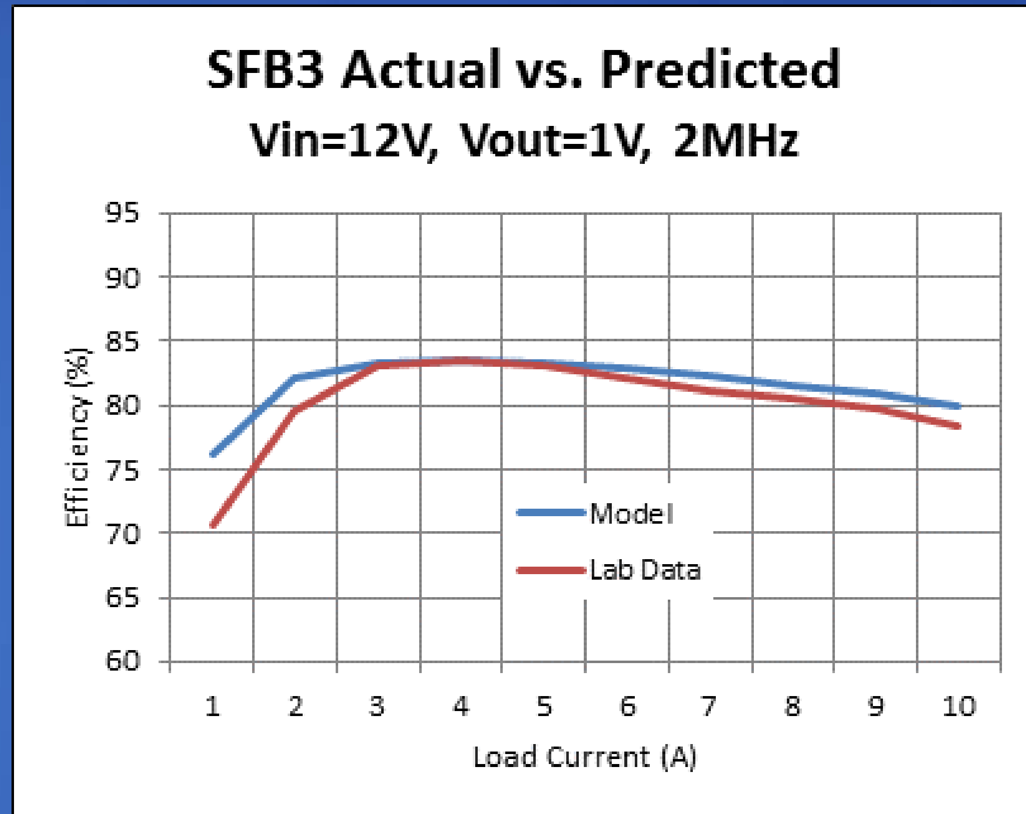
Buck converter circuit using Sarda's GaAs FETs
(12Vin, 1Vout, up to 10A)

- *Discrete GaAs FET implementation:*
  (1) 14mΩ upper FET
  (2) 14mΩ lower FET
- *Discrete driver implemented – deadtime adjustability via potentiometers*
- *Low Cu thickness PCB – due to fine pitch geometries of GaAs prototypes with Cu pillars*

SARDA

Accuracy of Efficiency Model



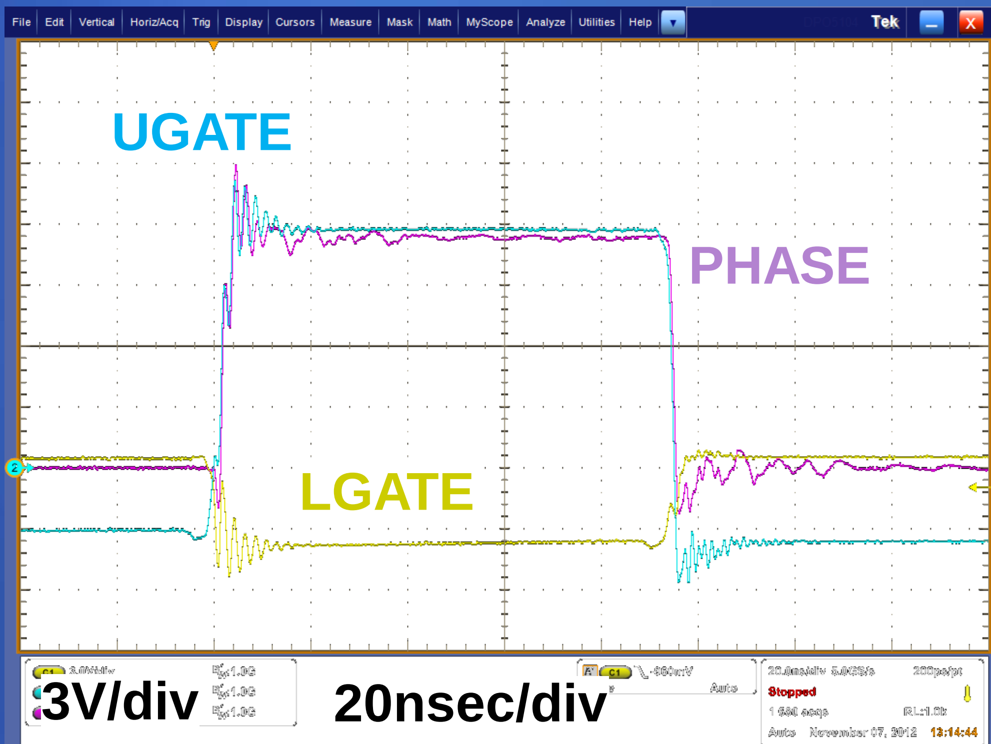


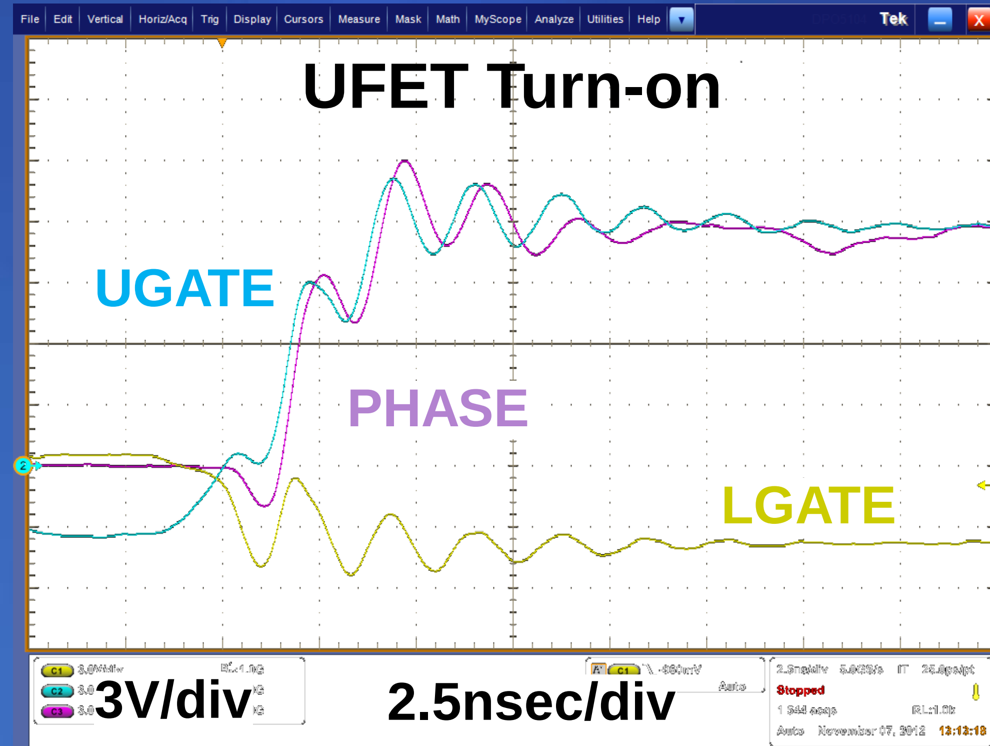
Provides Level of Confidence in Hitting Predicted Performance

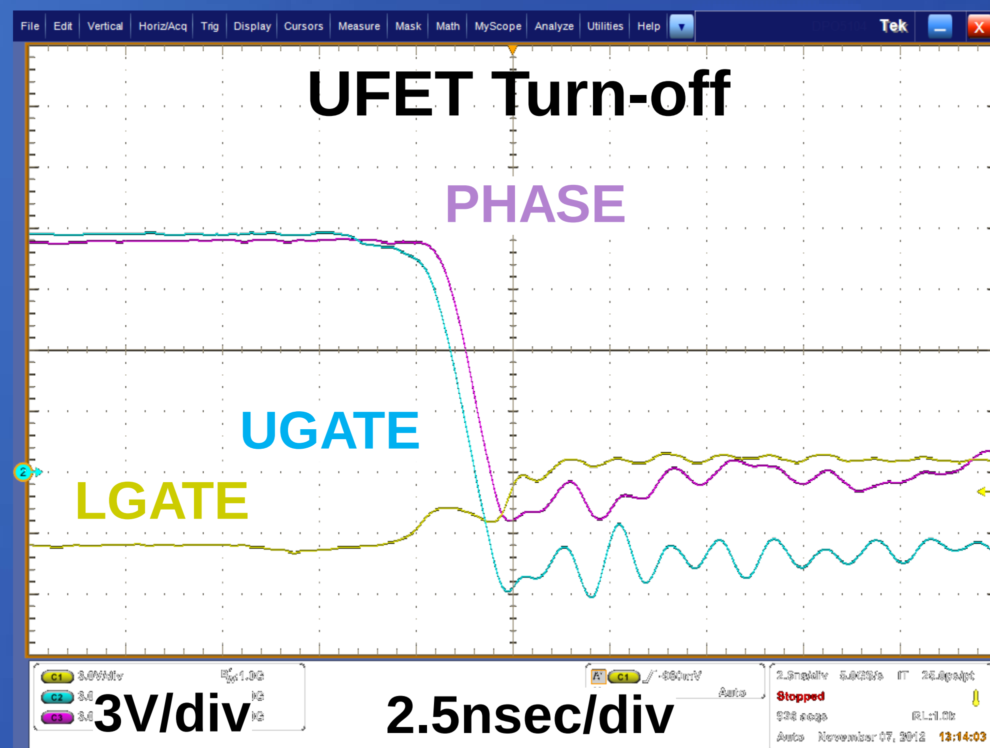
SARDA

Feasibility Board Waveforms

- Discrete Implementation

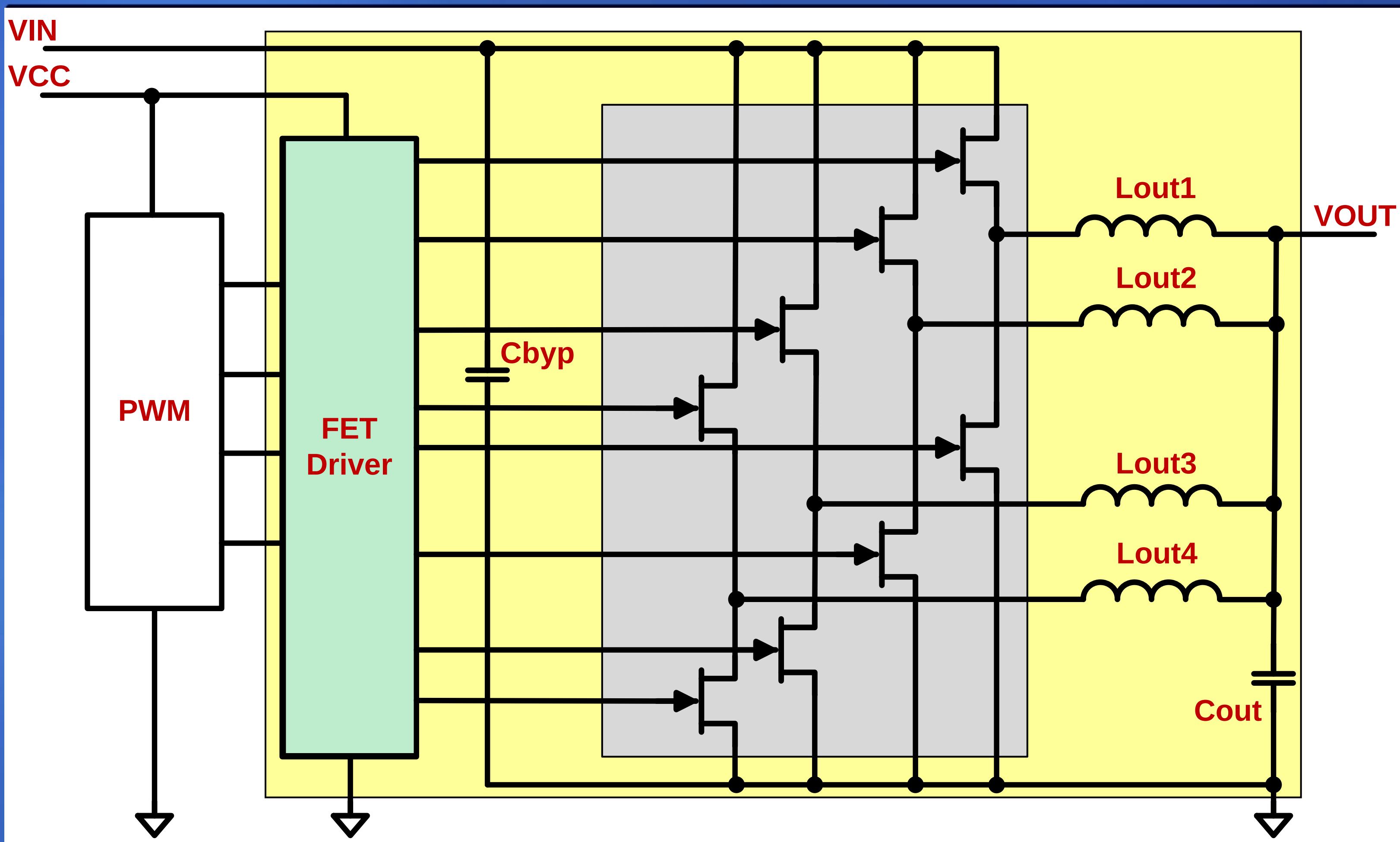






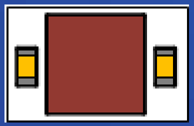
Turn-on time ~ 4nsec
Turn-off time ~ 2nsec

VHF PSiP with Integration of Output Filter



Increase Fsw and Phase Count to ~50MHz to Integrate Output Filter (L_{out} and C_{out})

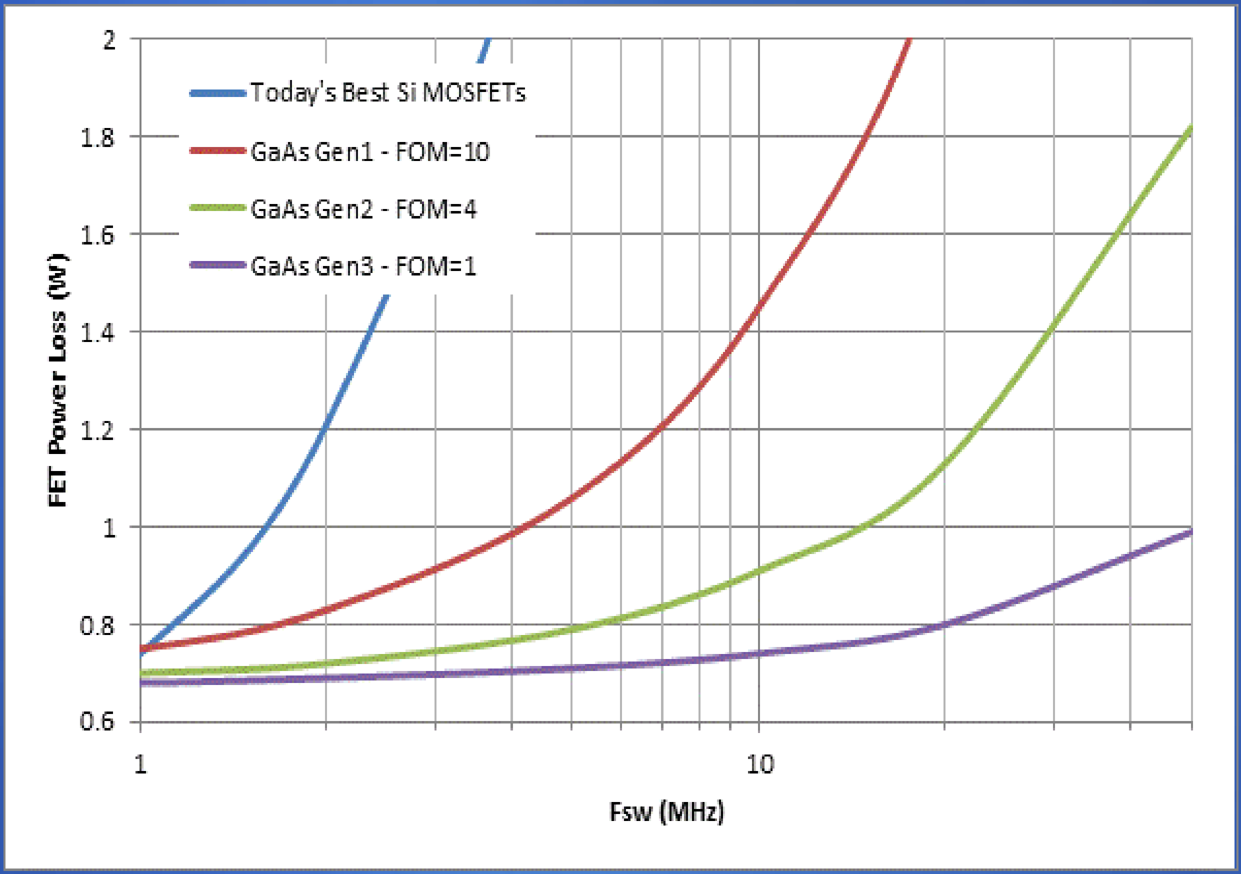
→ *GaAs is an Enabling Technology for this Vision!*



6x4x1mm

What Will it Take to Get There?

- **Very Low FOM FETs**



Case Study
Vin = 12V
Vout = 1V
Iout = 5A

- **GaAs Gen1** – 2 years to commercialize PowerStage
- **Gen 2, 3** – within 3-5 years *(no new fundamental process or material R&D)*

- **Multiphase Operation**
  - *Many Small PowerStages, Inductors*
- **High Levels of Integration**
  - *Magnetics and Packaging Innovation*

SARDA

Summary

- **GaAs Can Enable the PSiP Vision!**
  - **Small VRs Operating Efficiently at VHF**
    - **5MHz is First Step**
    - **Roadmap to 50MHz+**
  - **Employ Multiphase Architecture**
    - **Lateral GaAs FET Device Structure**
  - **3-D Packaging with Integrated Magnetics**