IMS2014 - Tampa Bay, Florida
Powering The Waves
RFIC2014, Tampa Bay
June 1-3, 2014

WSC: GaN-based Power Supplies and Power Supply Modulators for Efficient Powering of RF PAs

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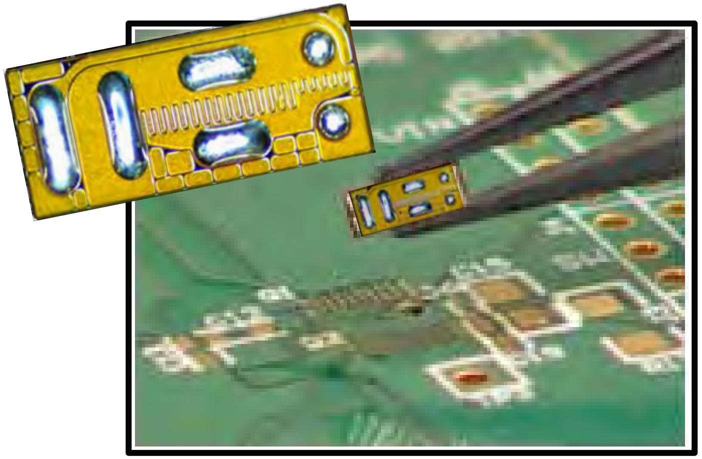
EPC
EFFICIENT POWER CONVERSION

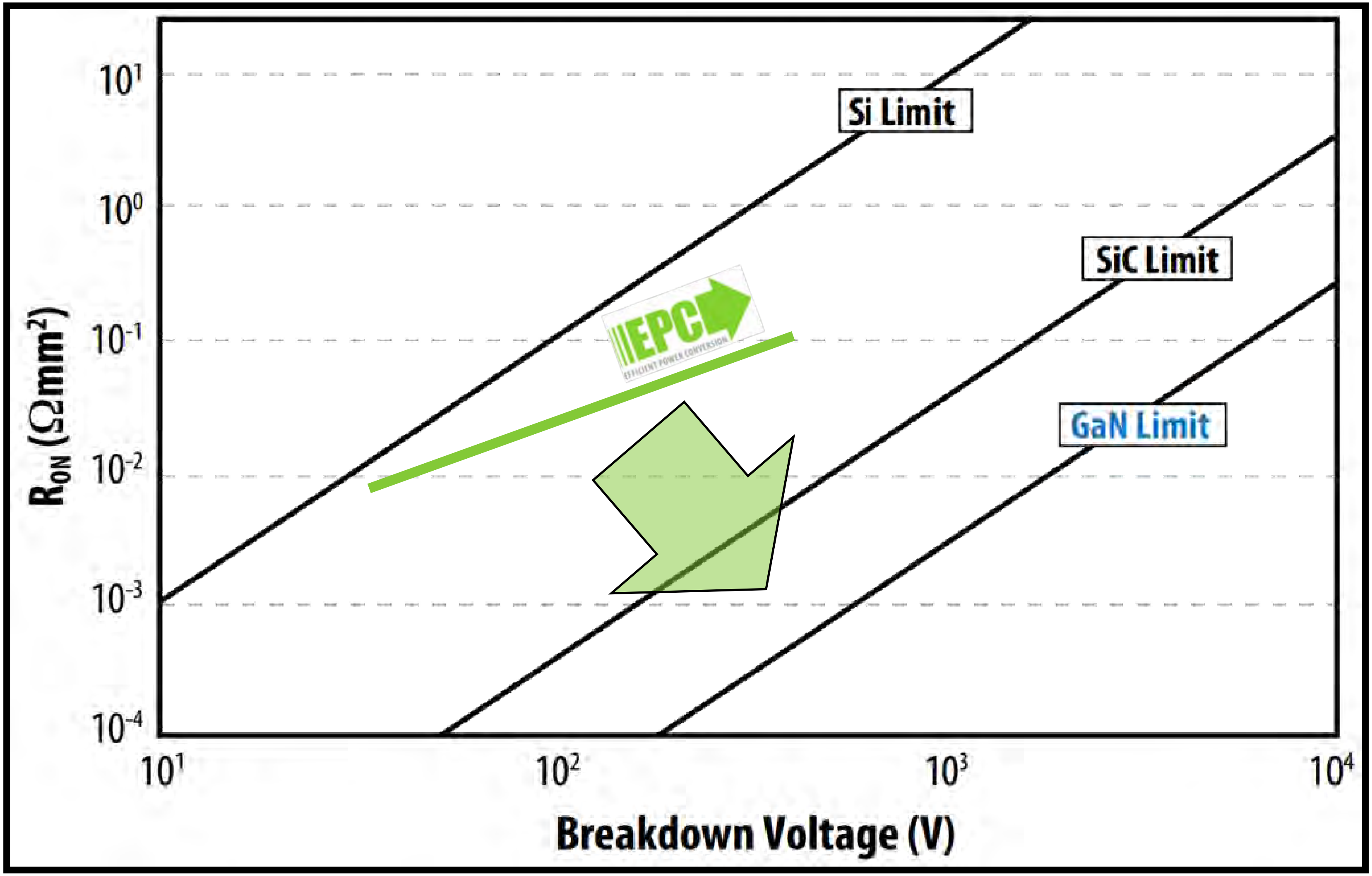
International Microwave Symposium
IEEE 1-6 June 2014, Tampa Bay, FL MTT-S

Agenda

- Background to eGaN FETs
- EPC8000 Series Parts
- Envelope Tracking
- Experimental Results
- Limiting Factors
- Summary



Why Gallium Nitride?

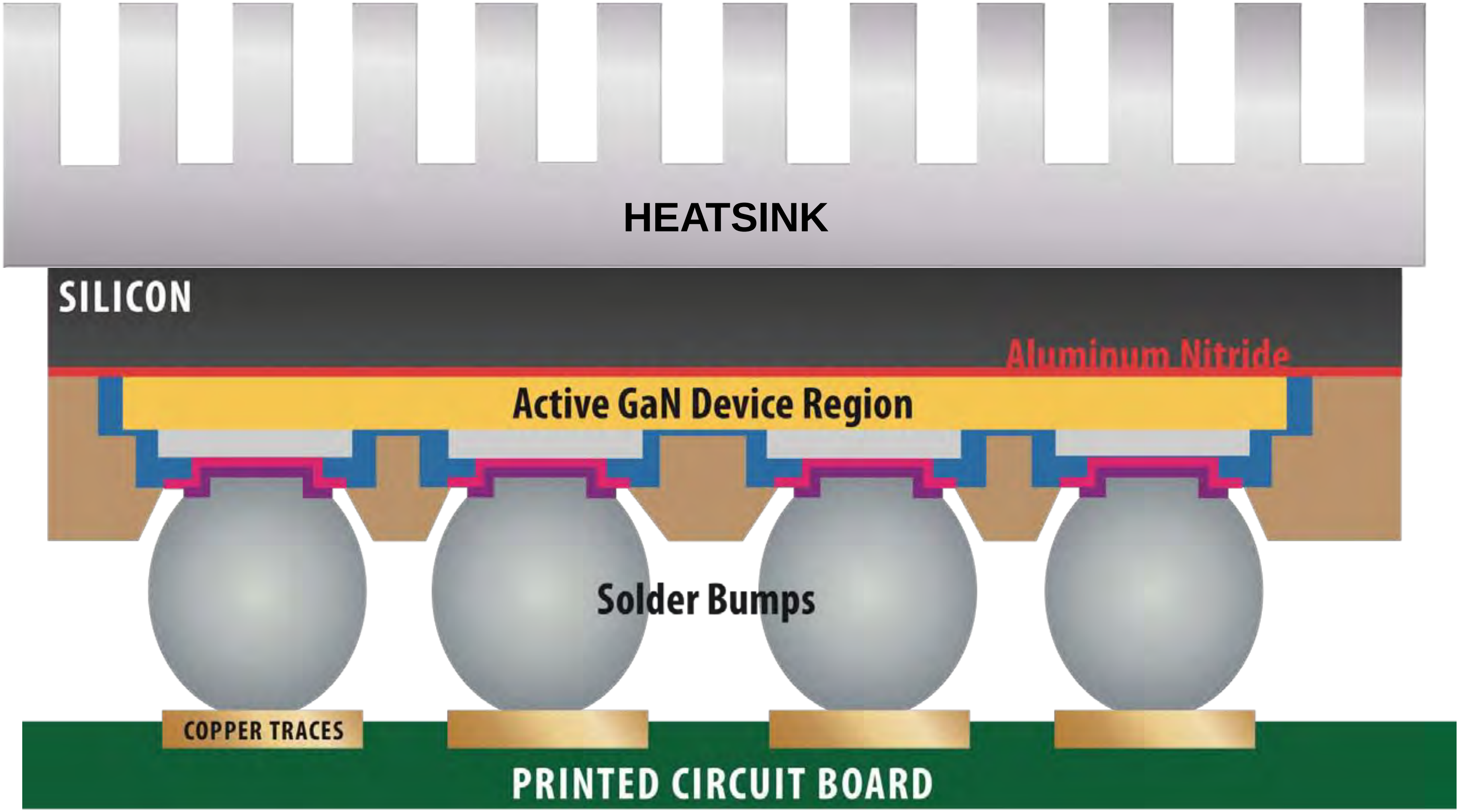


eGaN FETs are LGA

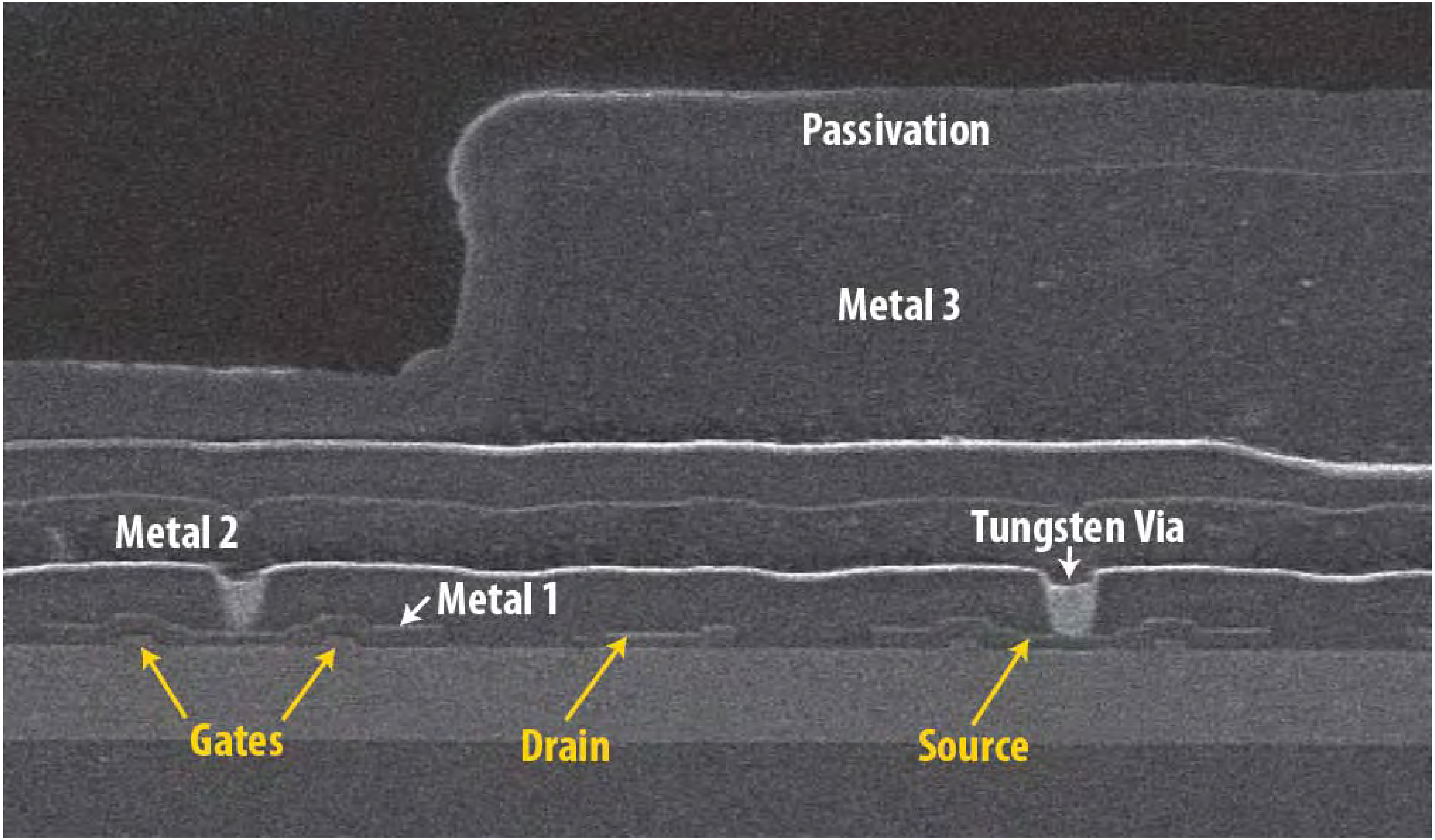
Land Grid Array

Solder bump under die

Flip Chip Assembly



Cross Section of an eGaN FET



Threshold vs. Temperature

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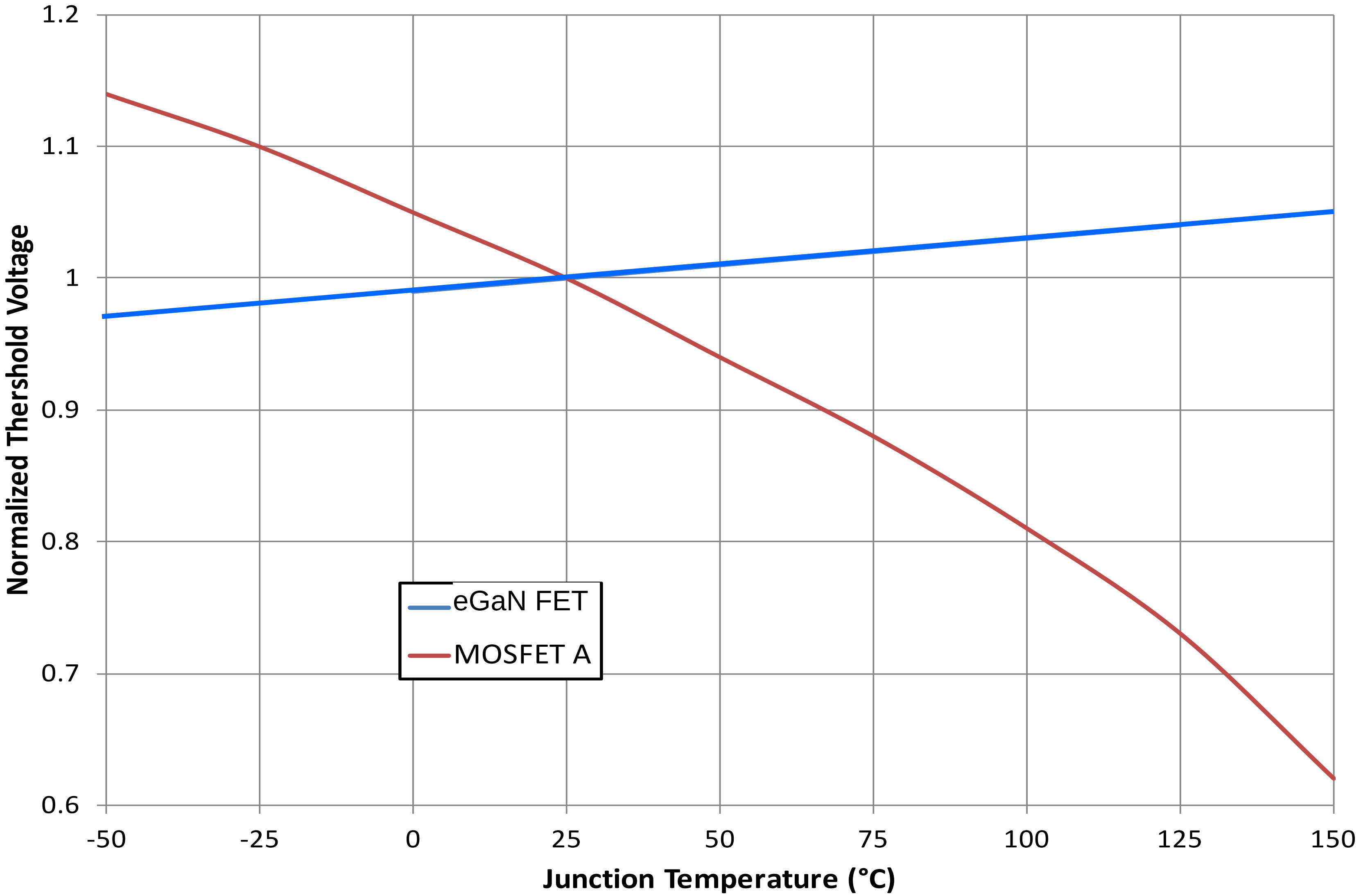

eGaN® FETs vs. MOSFETs

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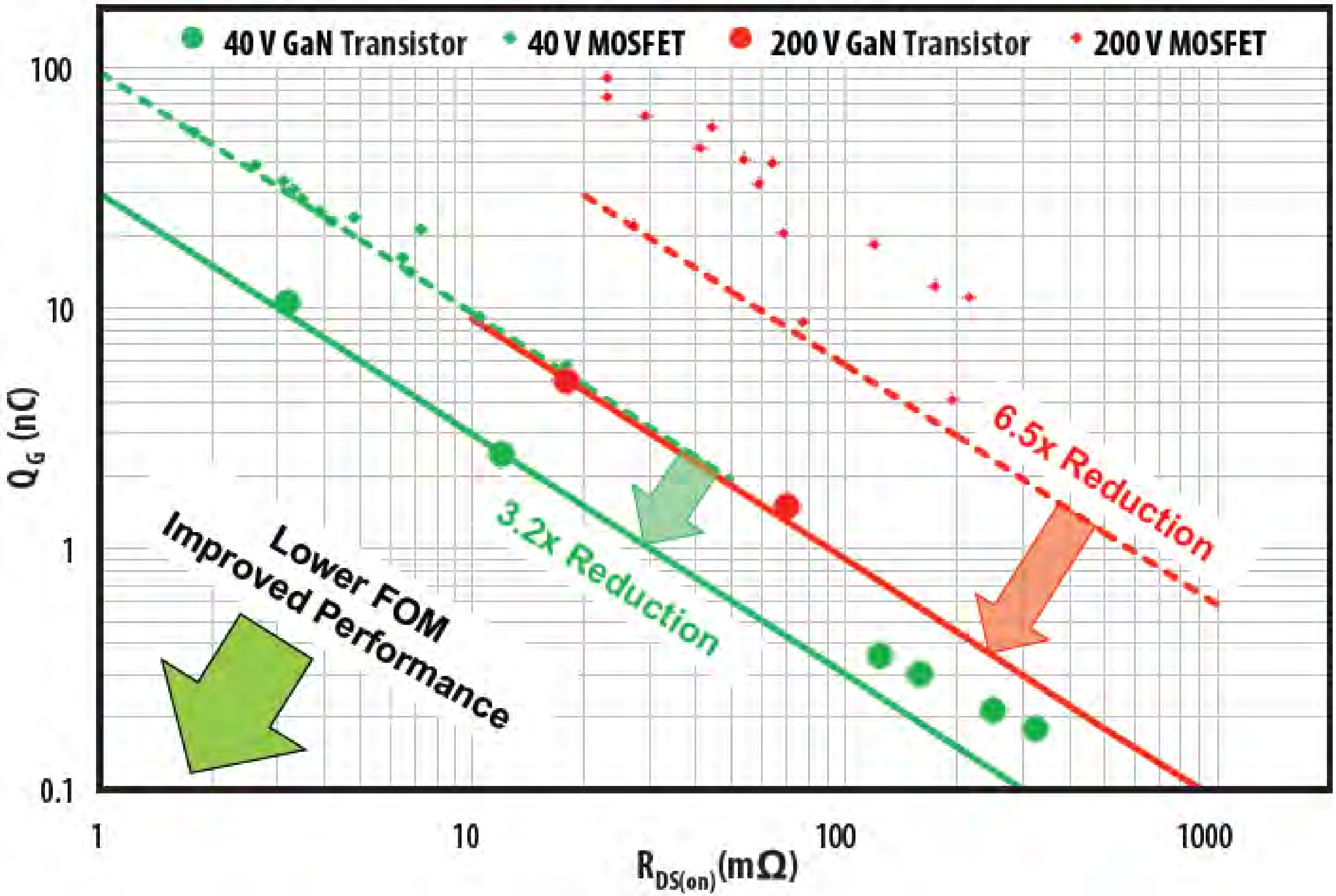
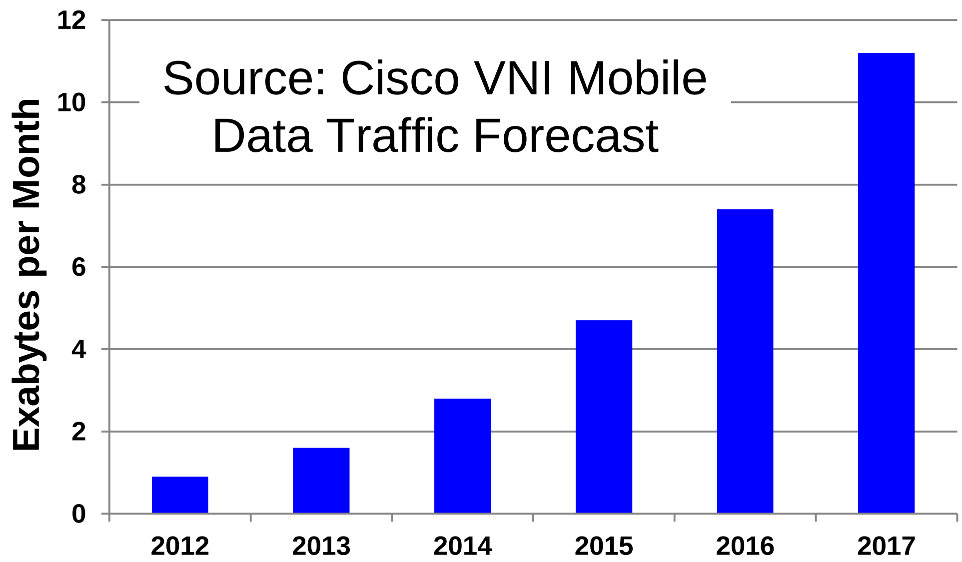
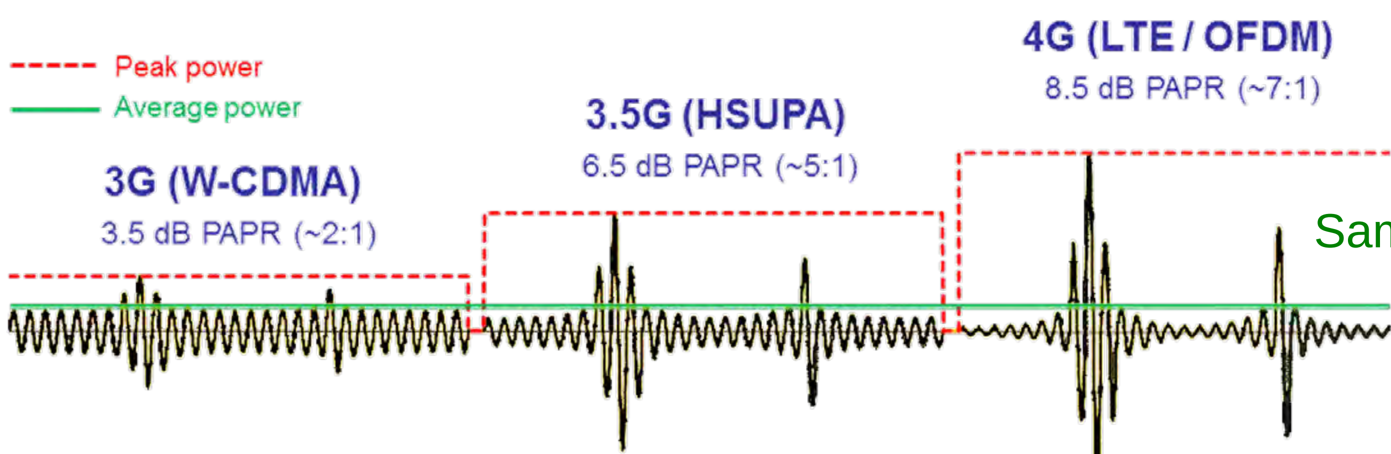


Why Envelope Tracking?



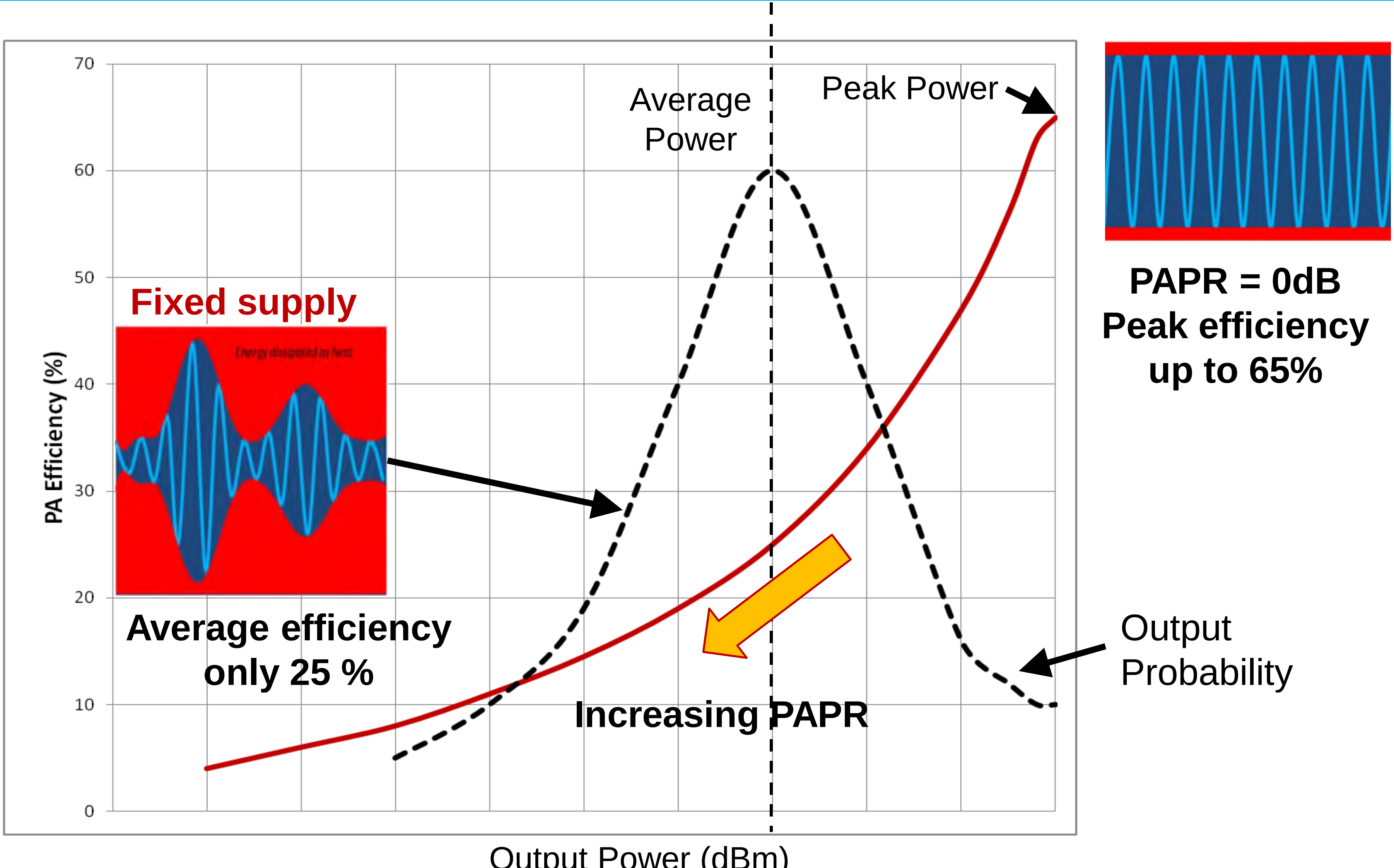
66% Compound annual growth rate



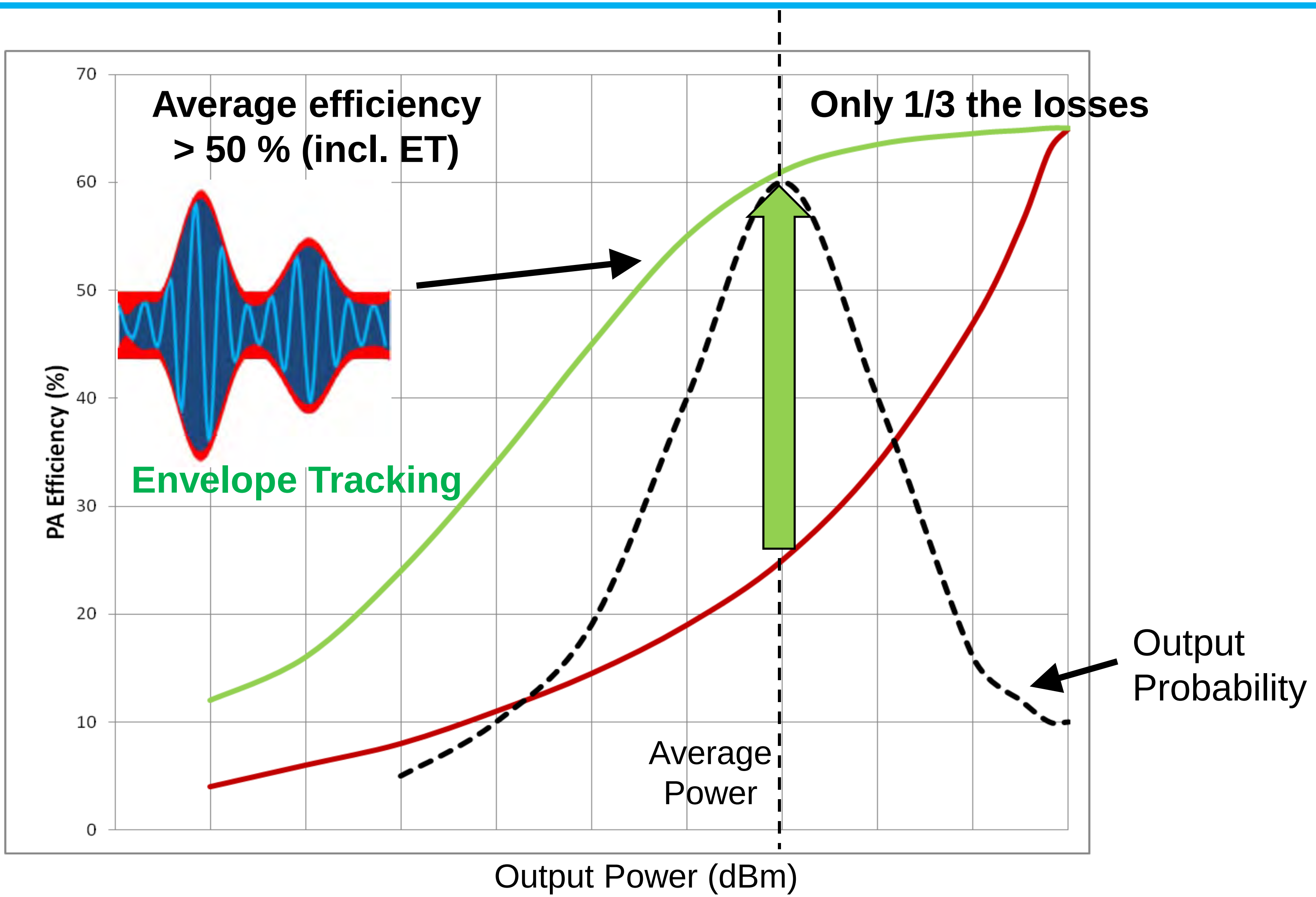
Same average

Reference: Nujira.com website

Effect of PAPR



Effect of Envelope Tracking



RFPA Standards*

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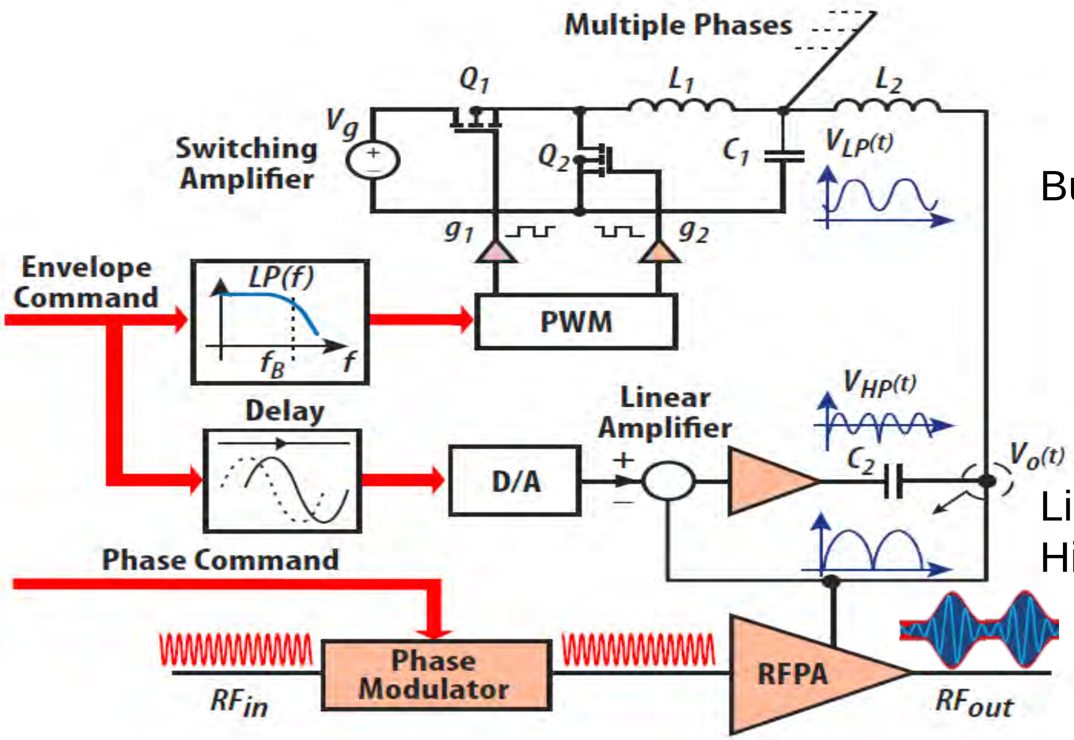
	Standard	Launched	Typ. Carrier BW (MHz)	Typ. Spectral Efficiency (bps/Hz)	Approx. PAPR(dB)
2G cellular	GSM	1991	0.2	0.17	0.0
2.75G cellular	GSM + EDGE	2003	0.2	0.33	3.5
3G cellular	WCDMA FDD	2001	5	0.51	7.0
Digital TV	DVB-T	1997	8	0.55	8.0
Wi-Fi	IEEE 802.11a/g	2003	20	0.90	9.0
WiMAX	IEEE 802.16d	2004	20	1.20	8.5
Wi-Fi	IEEE 802.11n	2007	20	2.40	9.0
3.5G cellular	HSDPA	2007	5	2.88	8.0
3.9G cellular	LTE	2009	20	8.00	10.0

- Up to 20 MHz Carrier bandwidth required
- Required ET supply BW about 5x higher than carrier BW

*Ref: www.open-et.org website

Envelope Tracking Supply

- **ET power supply topologies vary**
  - Open loop boost – full BW required
  - Closed loop linear-assisted Buck*

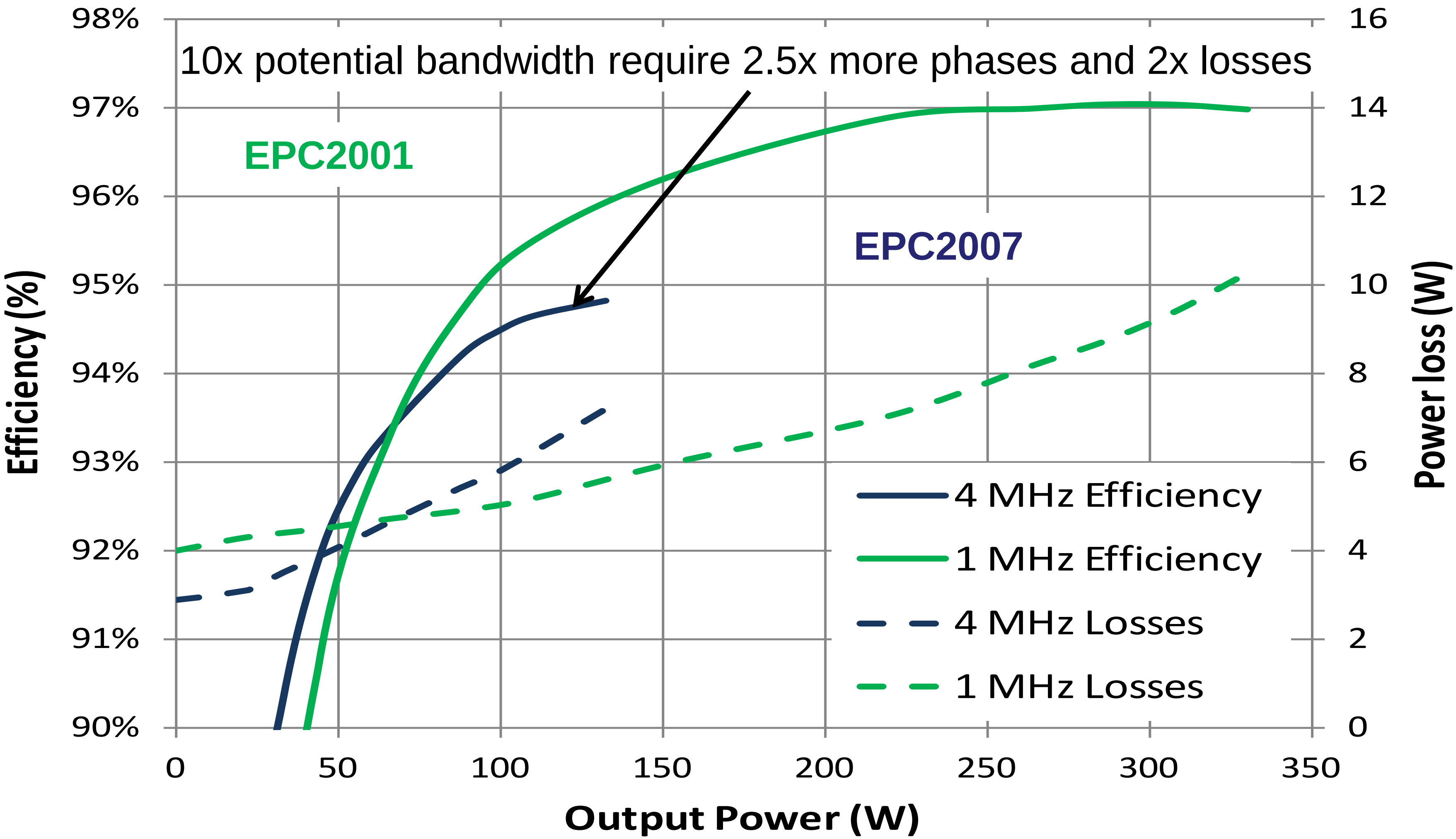


Buck ~ 10% Bandwidth
~ 90% Power

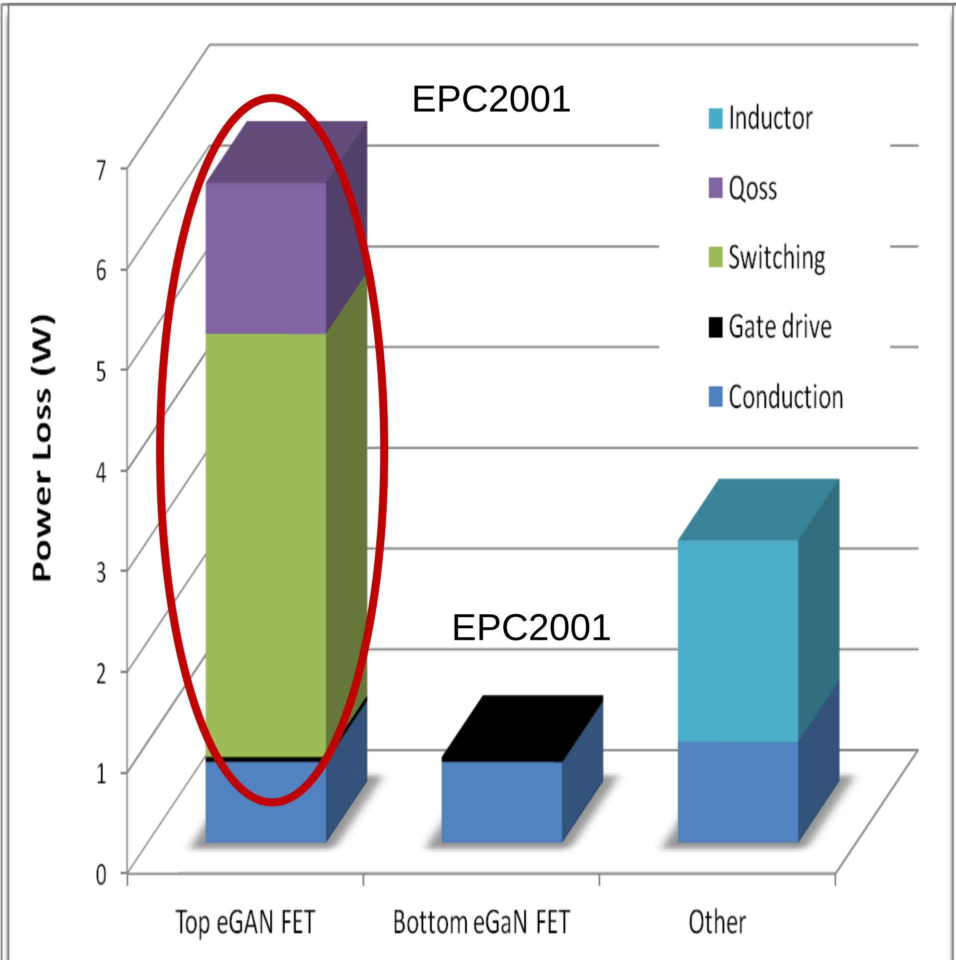
Linear AMP ~ 10% Power
Highest 90% of Bandwidth

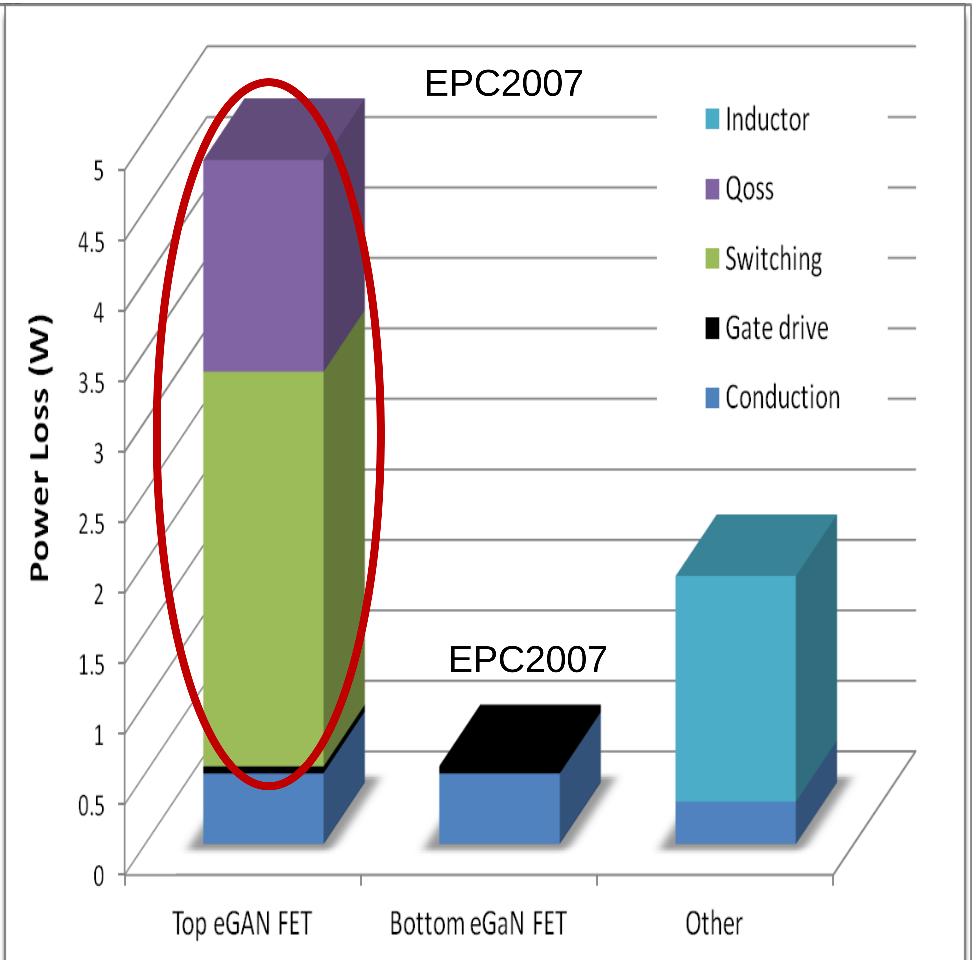
*V. Yousefzadeh, et. Al, Efficiency optimization in linear-assisted switching power converters for envelope tracking in RF power amplifiers, ISCAS 2005

Initial Efficiency Results



Loss Breakdown





1 MHz EPC9002

4 MHz EPC9006

Future die size optimization possible

Lower Voltage ET Results*

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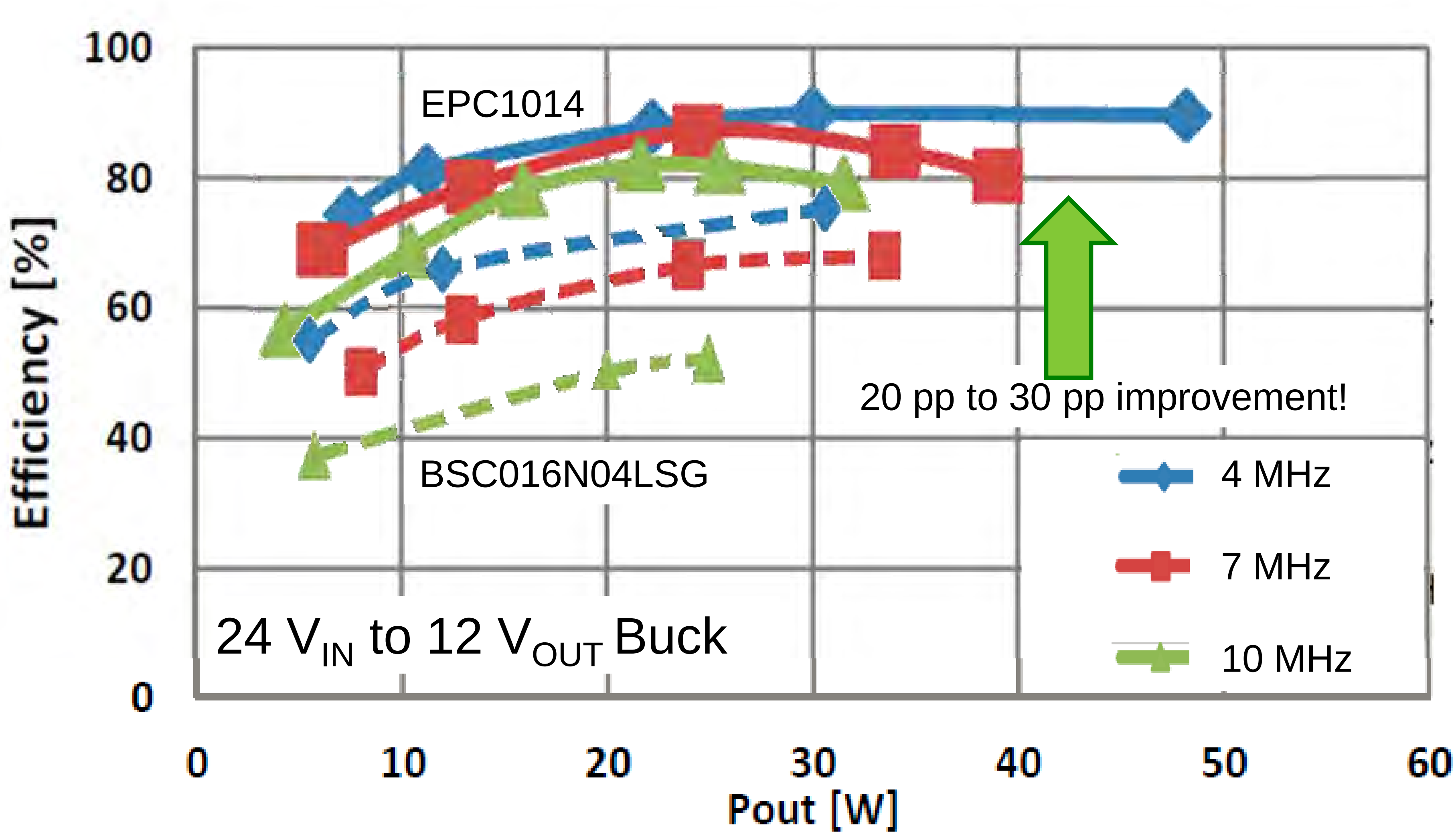


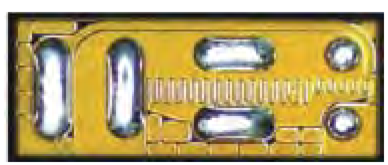
*D. Čučak, et. al, "Application of eGaN FETs for highly efficient Radio Frequency Power Amplifier", CIPS 2012

Higher Frequency Lower Power Devices

- **Improve Device Bandwidth**
- **Reduce device size**
- **Minimize Q_{GD} / HS-FOM**
- **Complete dv/dt immunity**
- **Minimize gate loop inductance**
- **Minimize power loop inductance**
- **Separate gate and power loops**

Ultra High Frequency eGaN® FETs

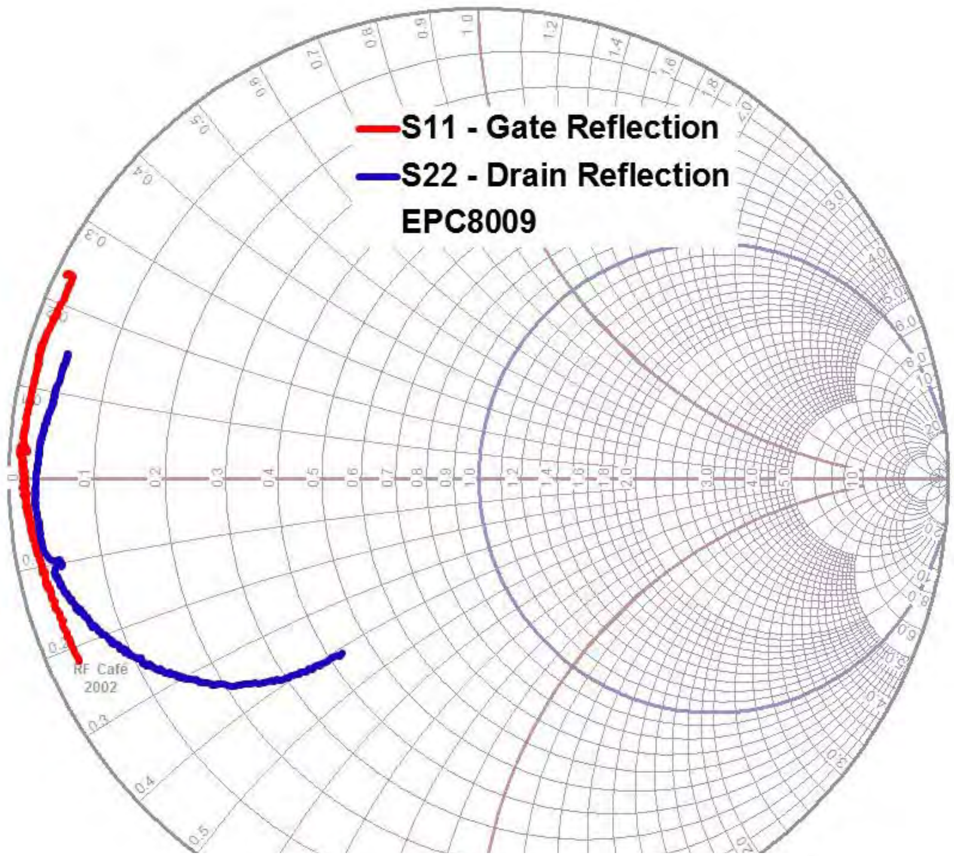
EPC Part No.	BV (V)	Max. $R_{DS(ON)}$ (mΩ) (V_{GS} = 5V, I_D = 0.5 A)	Min. Peak Id (A) (Pulsed, 25 °C, T_{pulse} = 300 µs)	Typical Charge (pC)					Typical Capacitance (pF) (V_{DS} = 20 V; V_{GS} = 0 V)		
				Q_G	Q_{GD}	Q_{GS}	Q_{OSS}	Q_{RR}	C_{ISS}	C_{OSS}	C_{RSS}
EPC8004	40	125	7.5	358	31	110	493	0	45	17	0.4
EPC8007	40	160	6	302	25	97	406	0	39	14	0.3
EPC8008	40	325	2.9	177	12	67	211	0	25	8	0.2
EPC8009	65	138	7.5	380	36	116	769	0	47	17	0.4
EPC8005	65	275	3.8	218	18	77	414	0	29	9.7	0.2
EPC8002	65	530	2	141	9.4	59	244	0	21	5.9	0.1
EPC8003	100	300	5	315	34	110	1100	0	38	18	0.2
EPC8010	100	160	7.5	354	32	109	1509	0	47	18	0.2



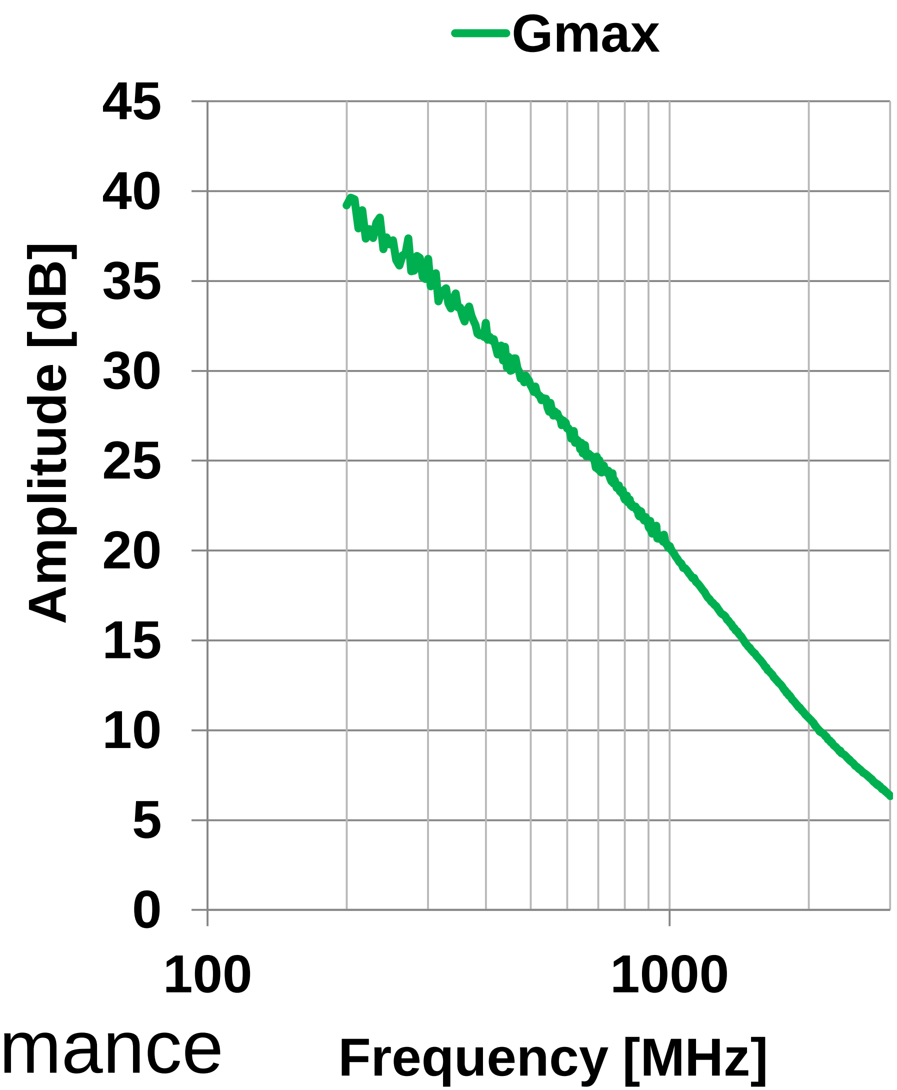
2.05 mm x 0.85 mm

* Preliminary Data – Subject to Change without Notice

Small Signal Performance



Bias: 30 V, 500 mA



Designed for switching Performance

Large Signal Performance

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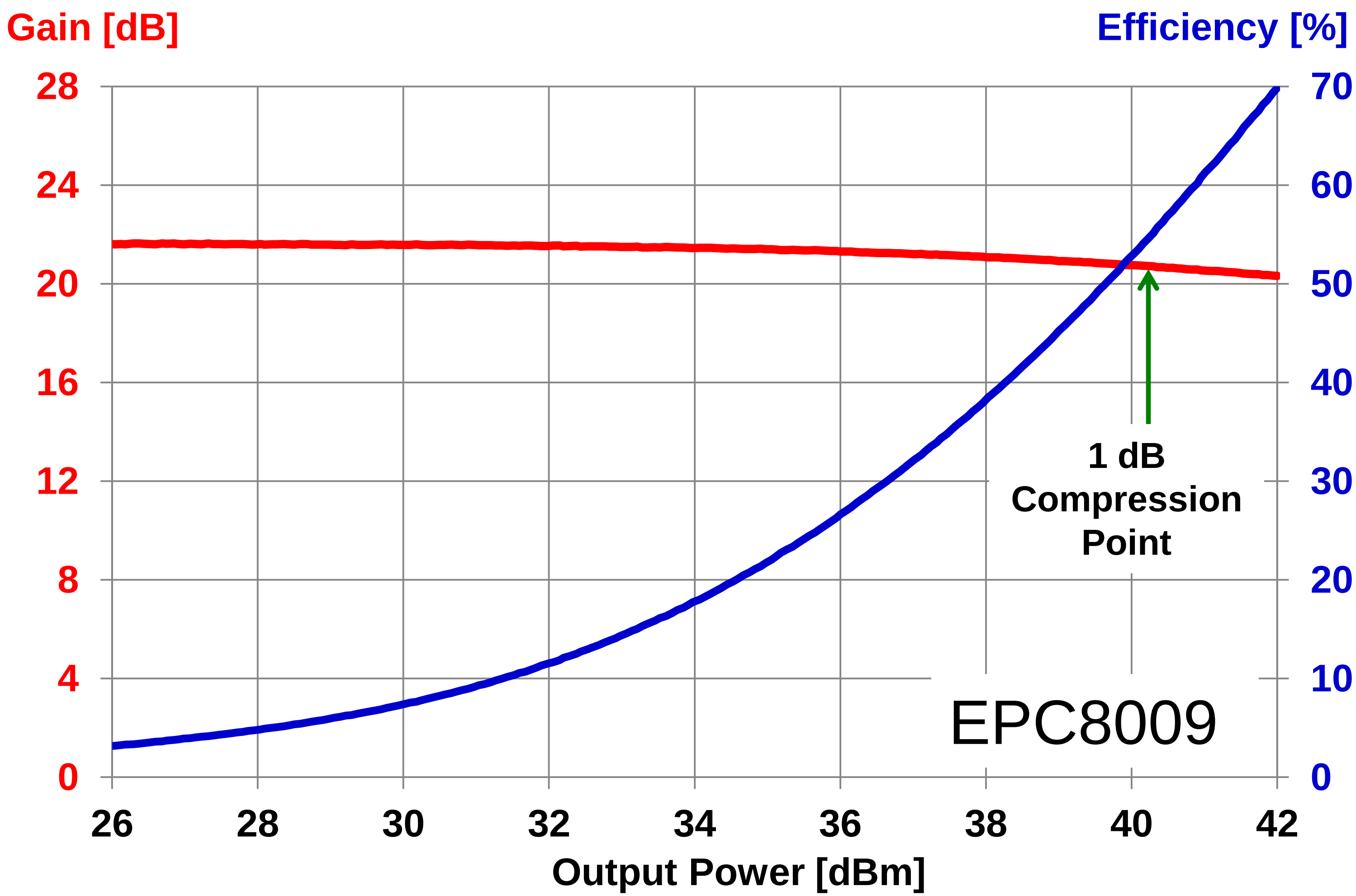
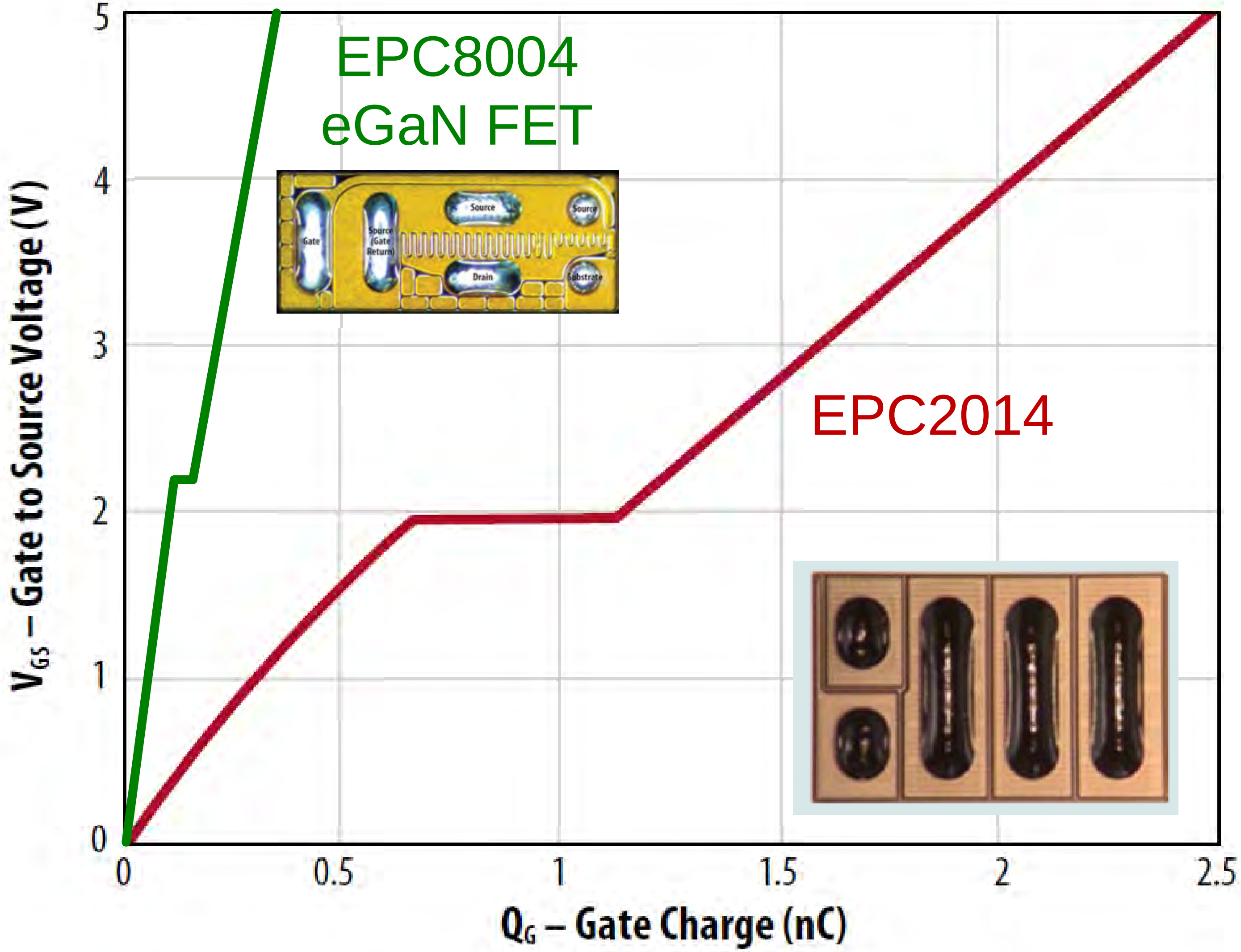
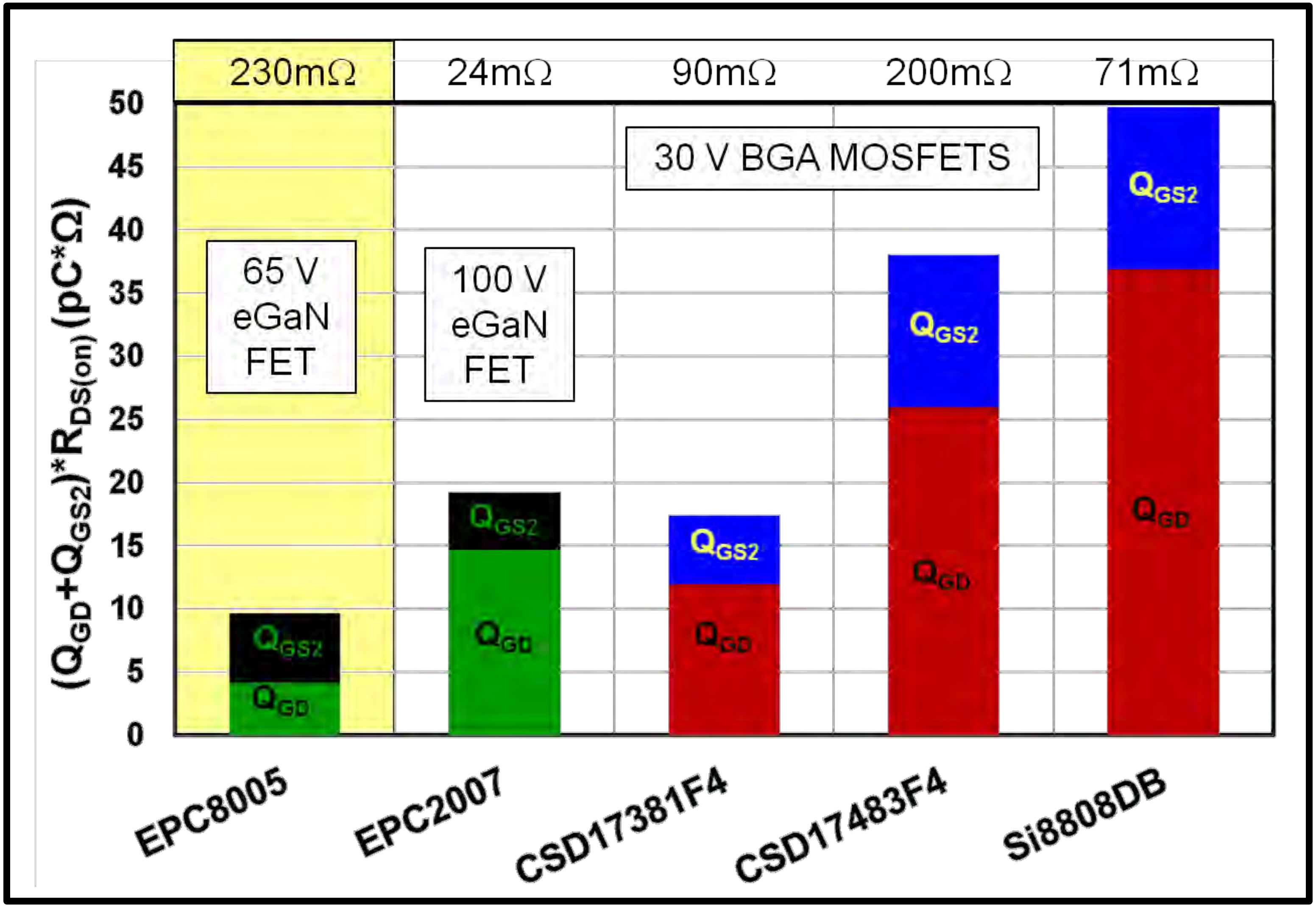


500 MHz, Class A, Bias = 30 V, 500 mA

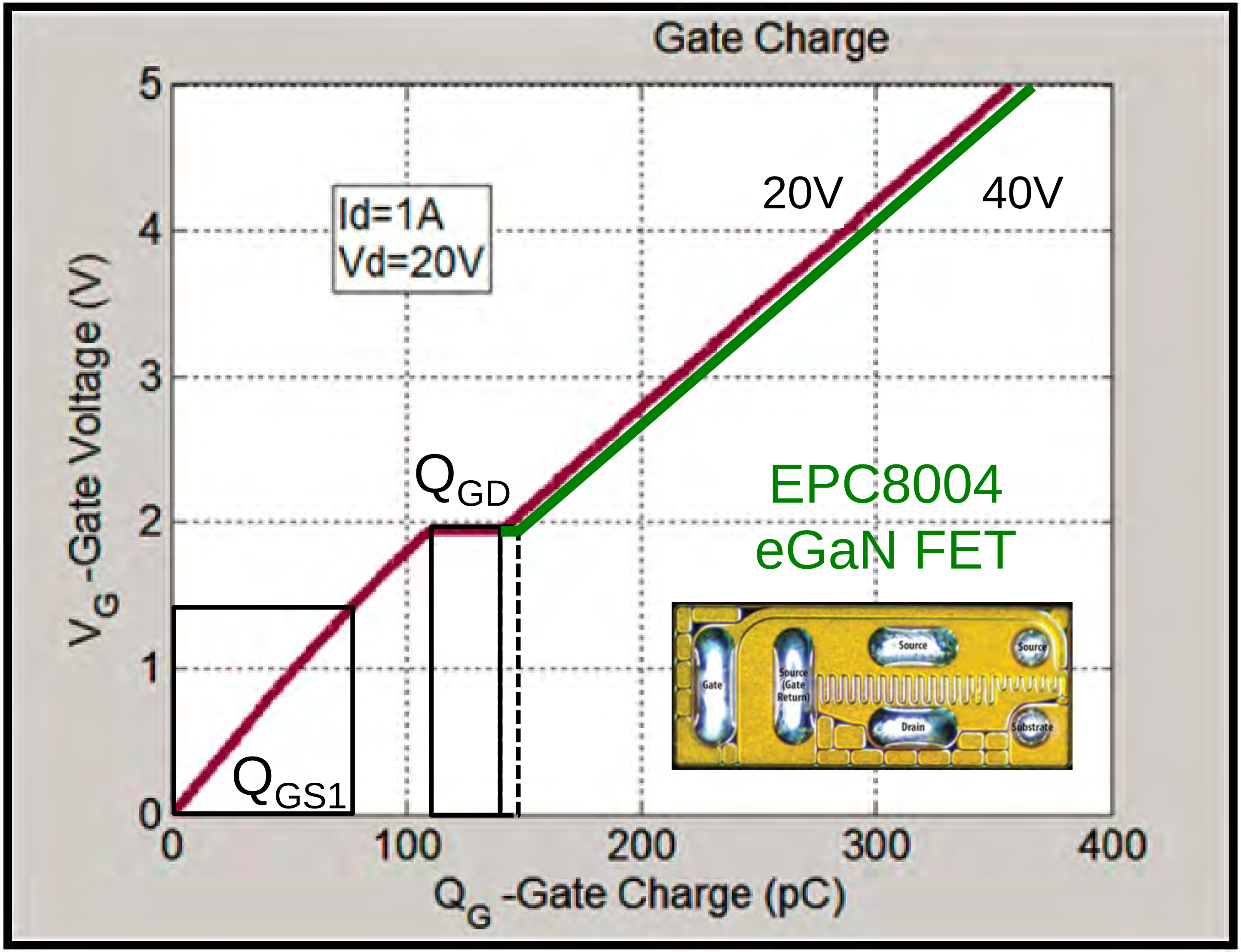
Die Size - Gate Charge



Hard Switching FOM

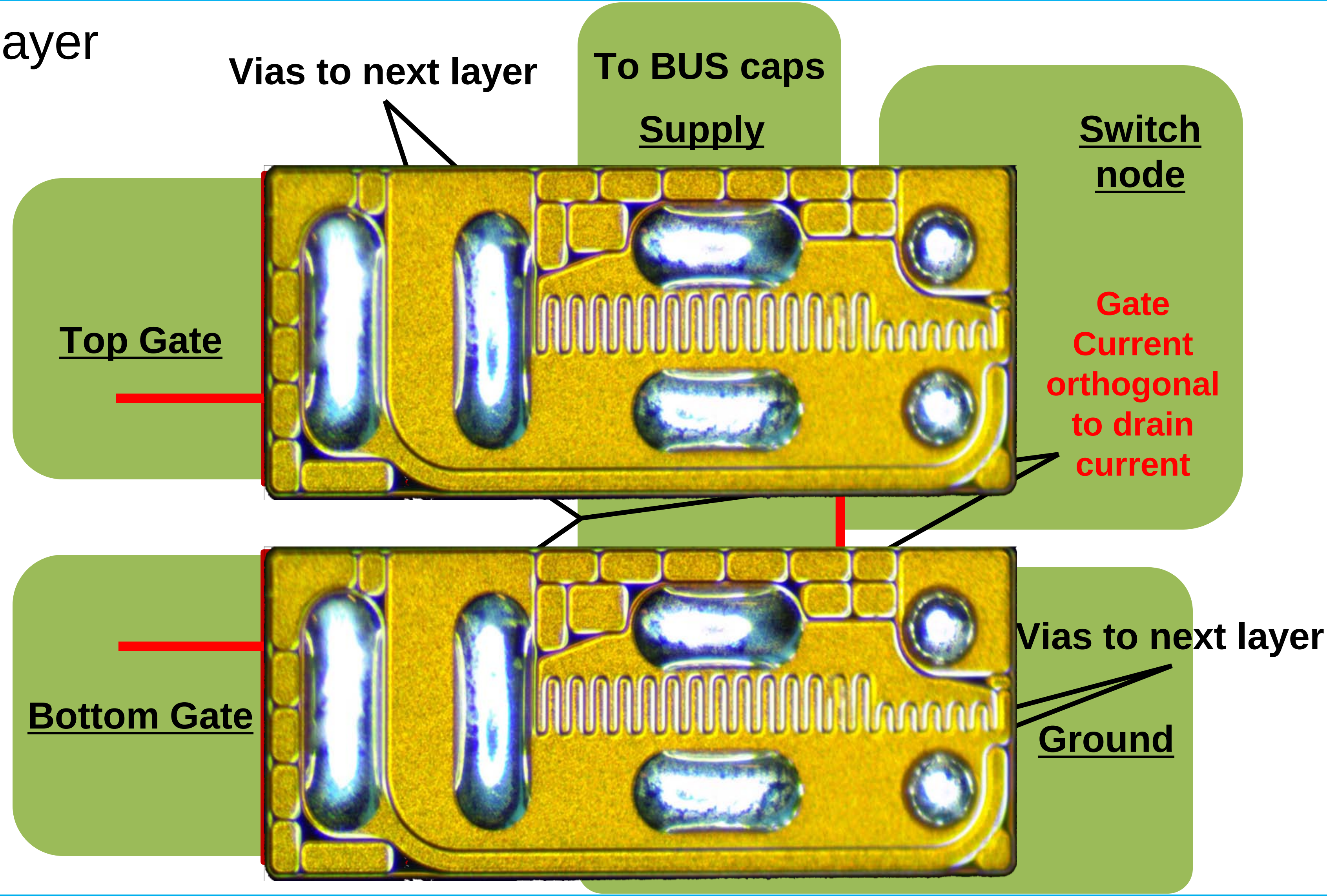


dv/dt Immunity



Low Parasitic Layout

Top Layer



Low Parasitic Layout

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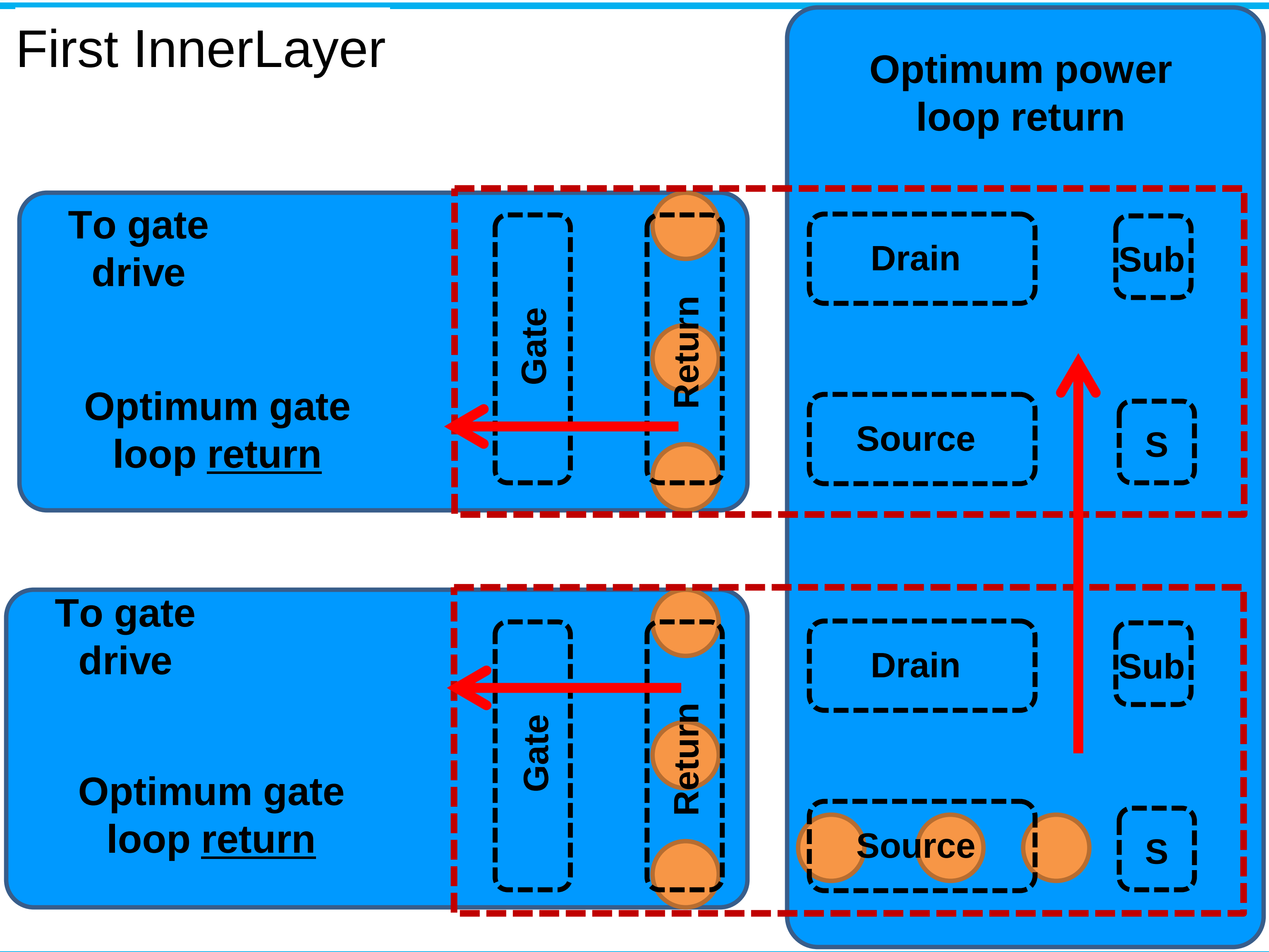
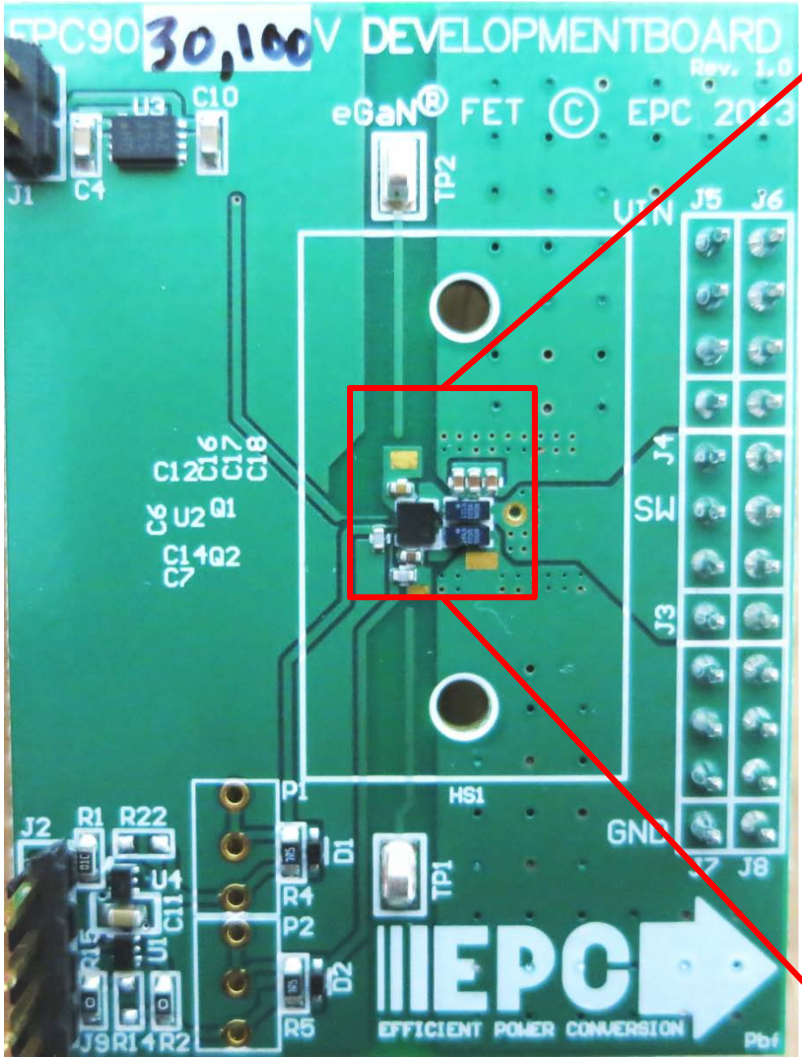
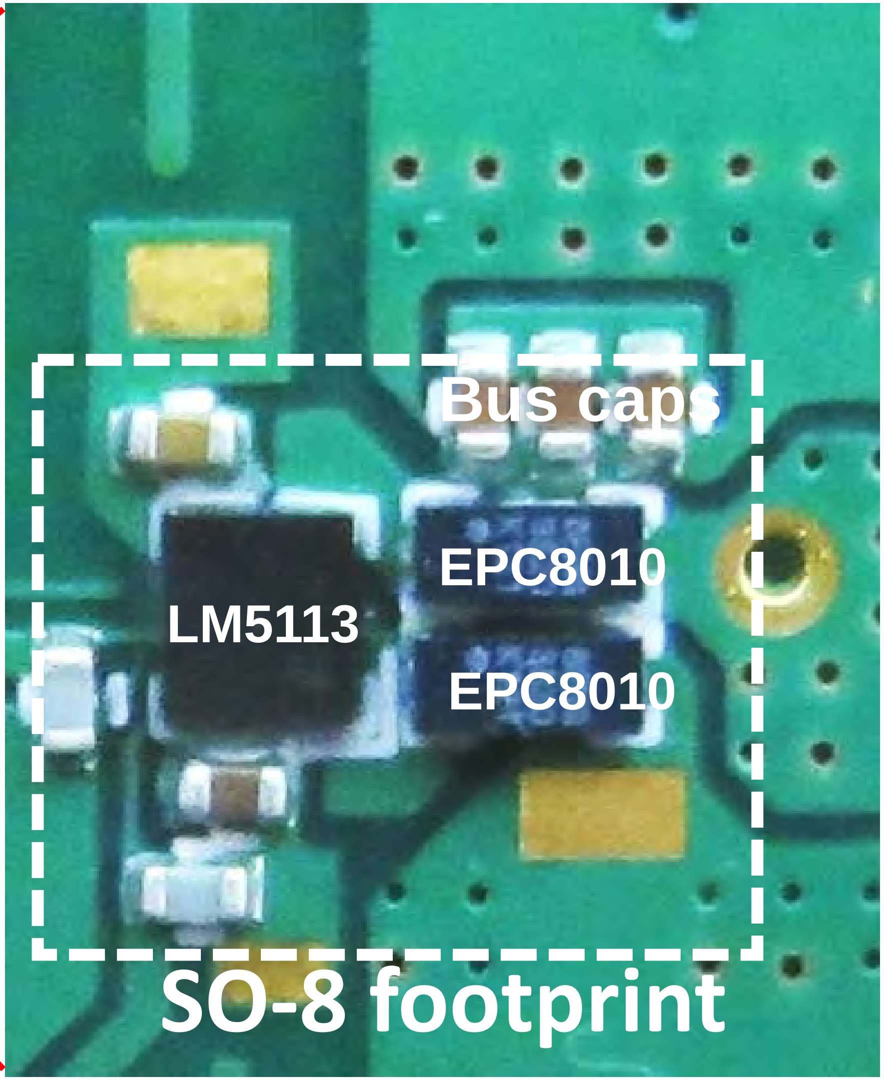
First InnerLayer

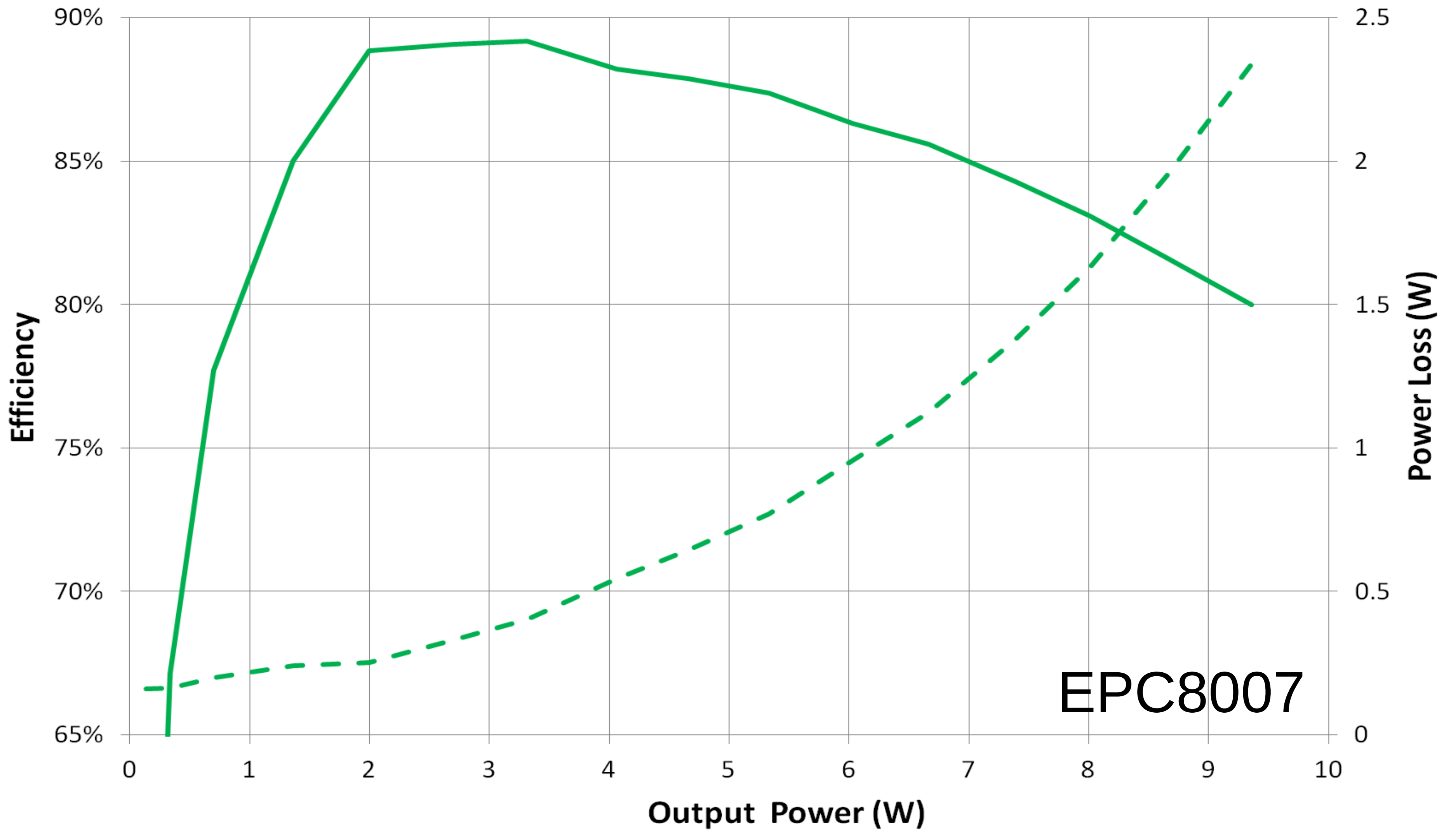


ET Prototype Board



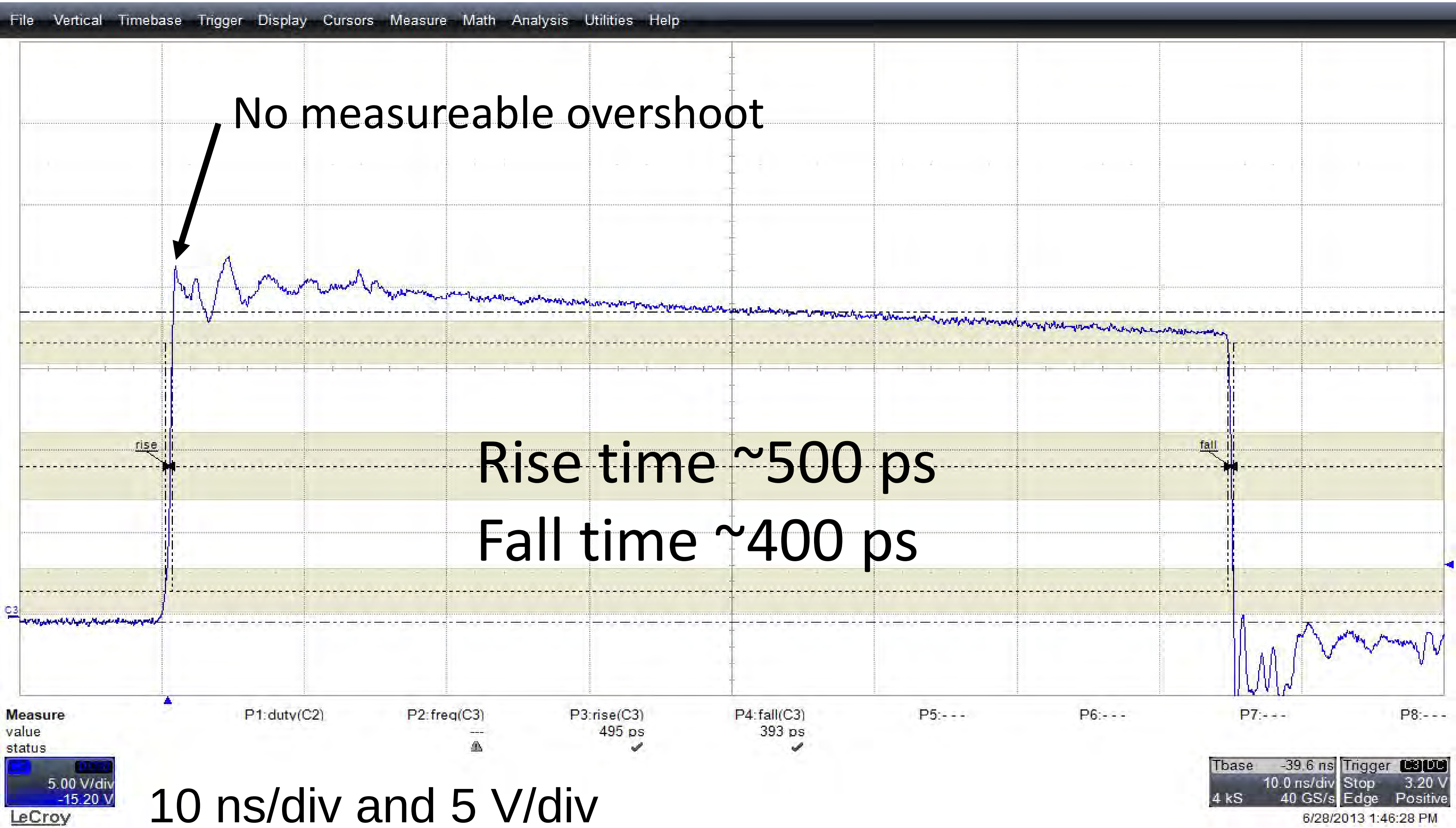


15 V_{IN} to 3.3 V_{OUT}, 10 MHz



20 V_{IN} at 4 A_{OUT}

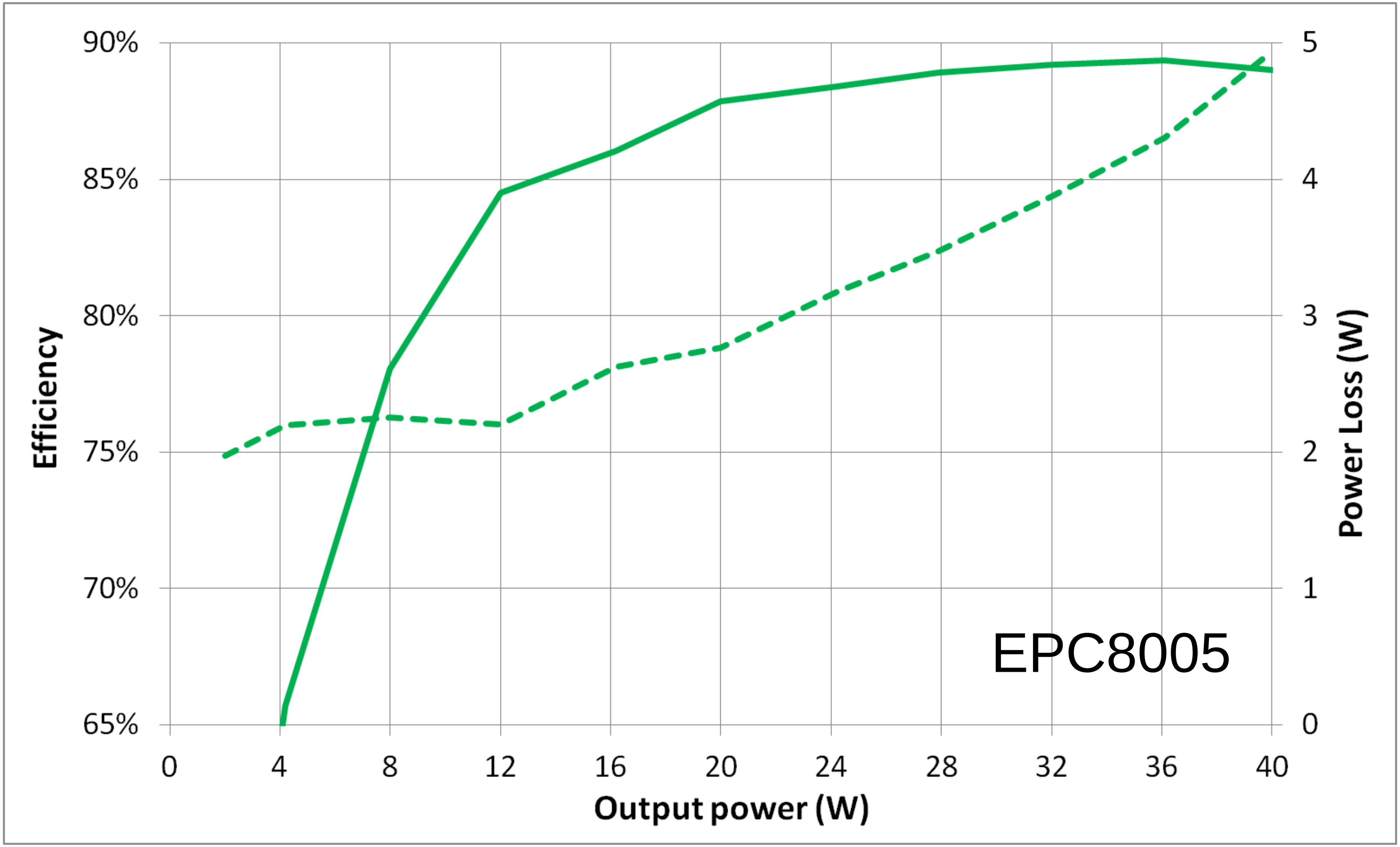
RFIC 2014



10 ns/div and 5 V/div

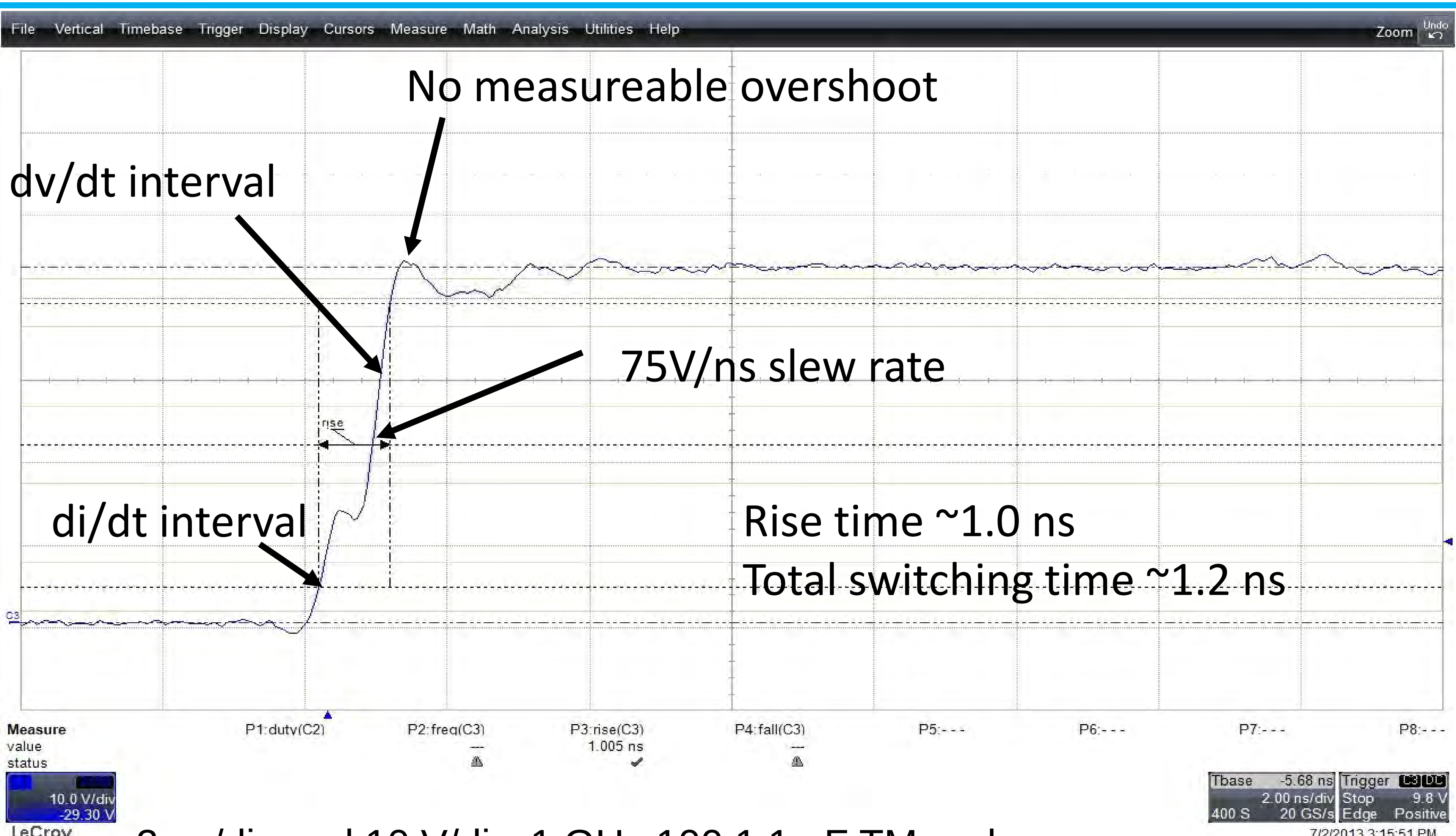
42 V_{IN} to 20 V_{OUT}, 10 MHz

RFIC 2014



42 V_{IN} at 1 A_{OUT}

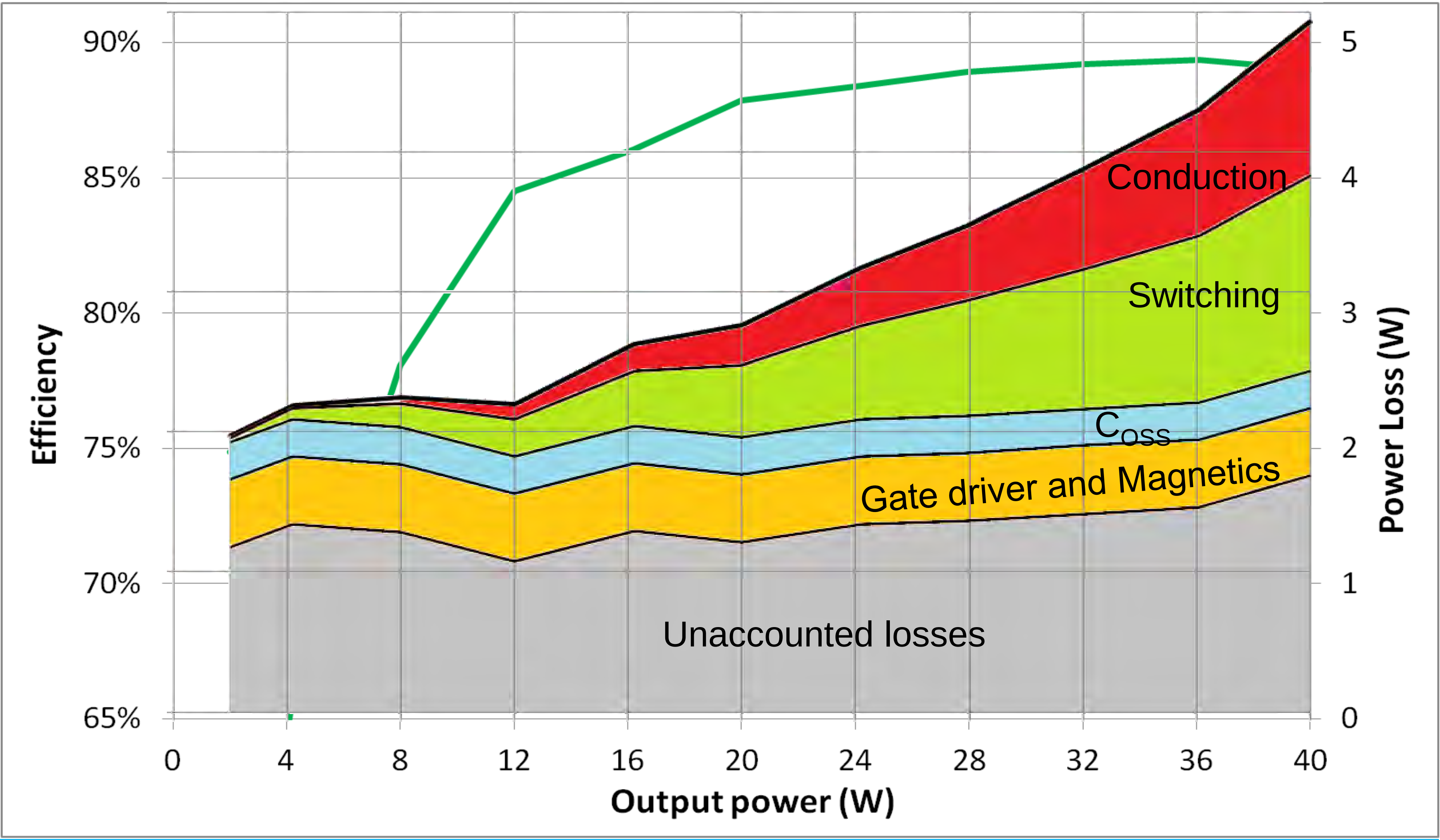
RFIC 2014



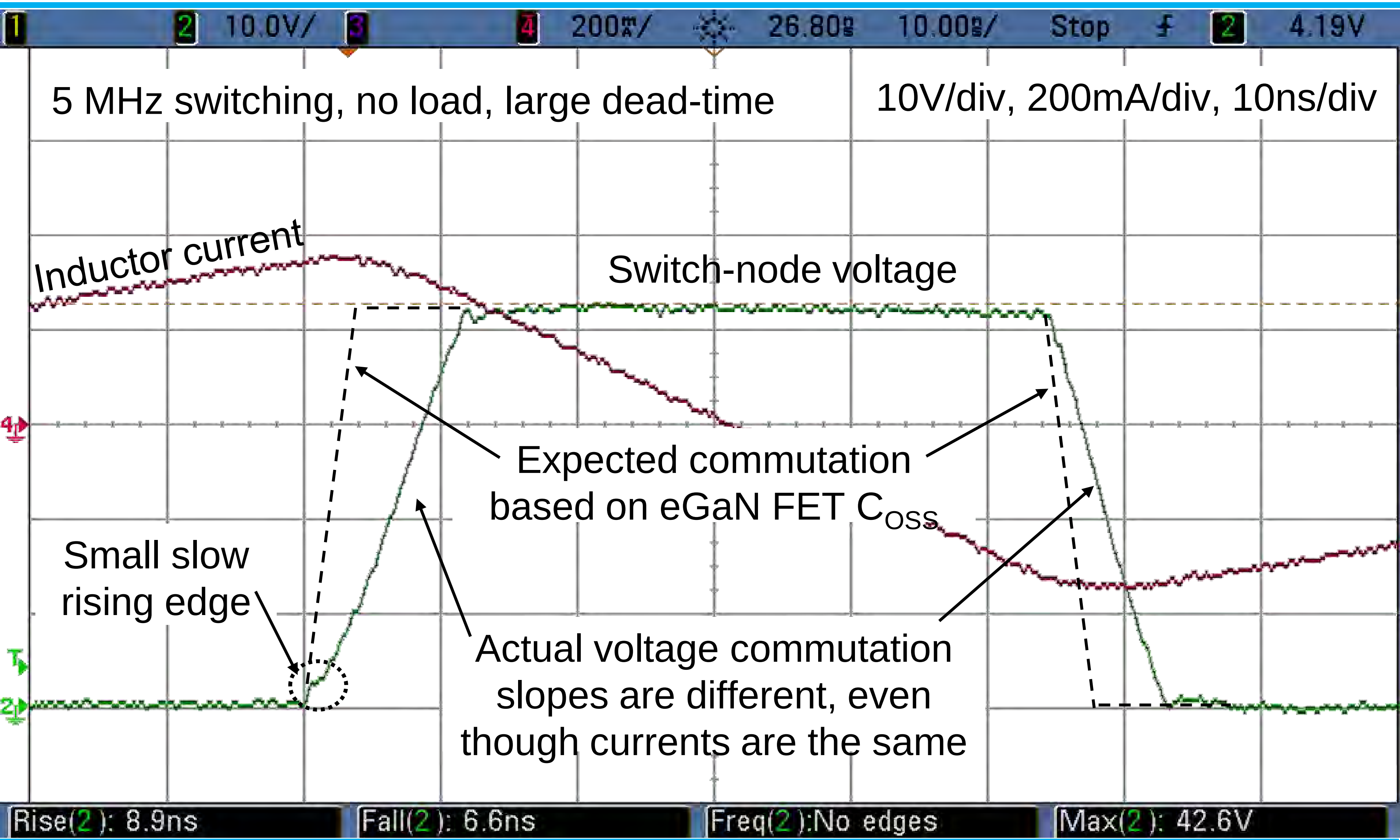
2 ns/div and 10 V/div, 1 GHz 100:1 1 pF TM probe

42 V_{IN}, 20 V_{OUT}, 10 MHz

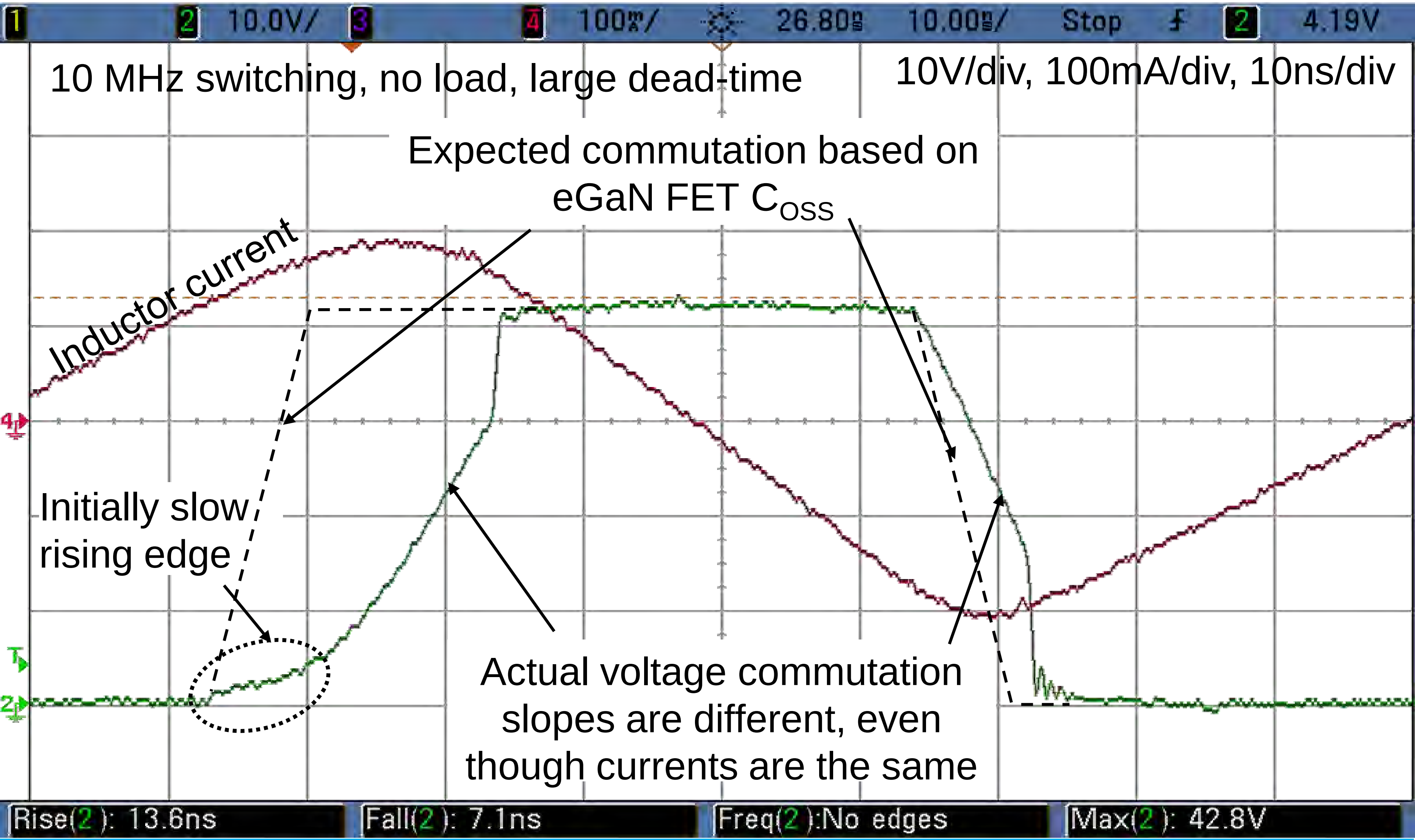
RFIC 2014



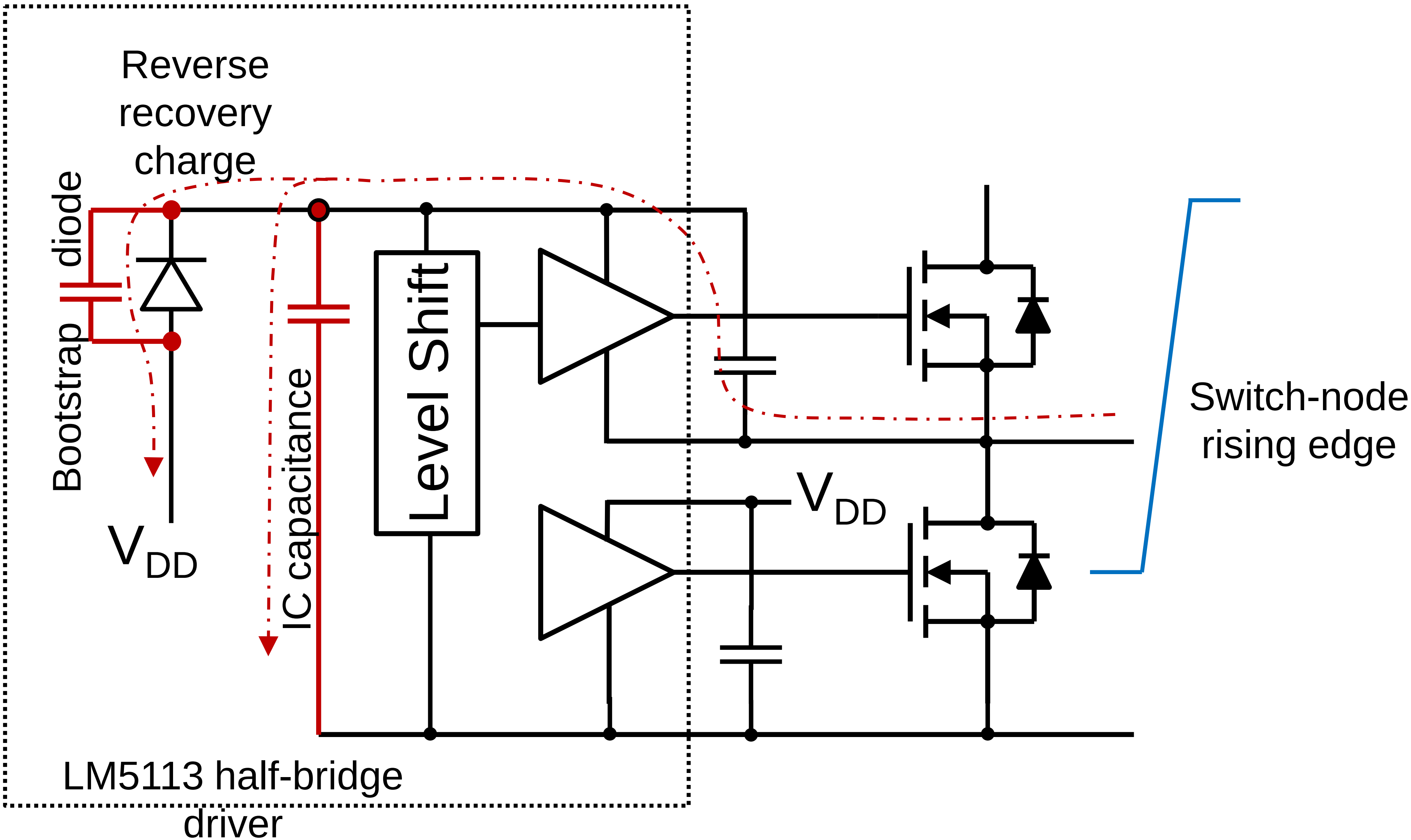
Loss Investigation



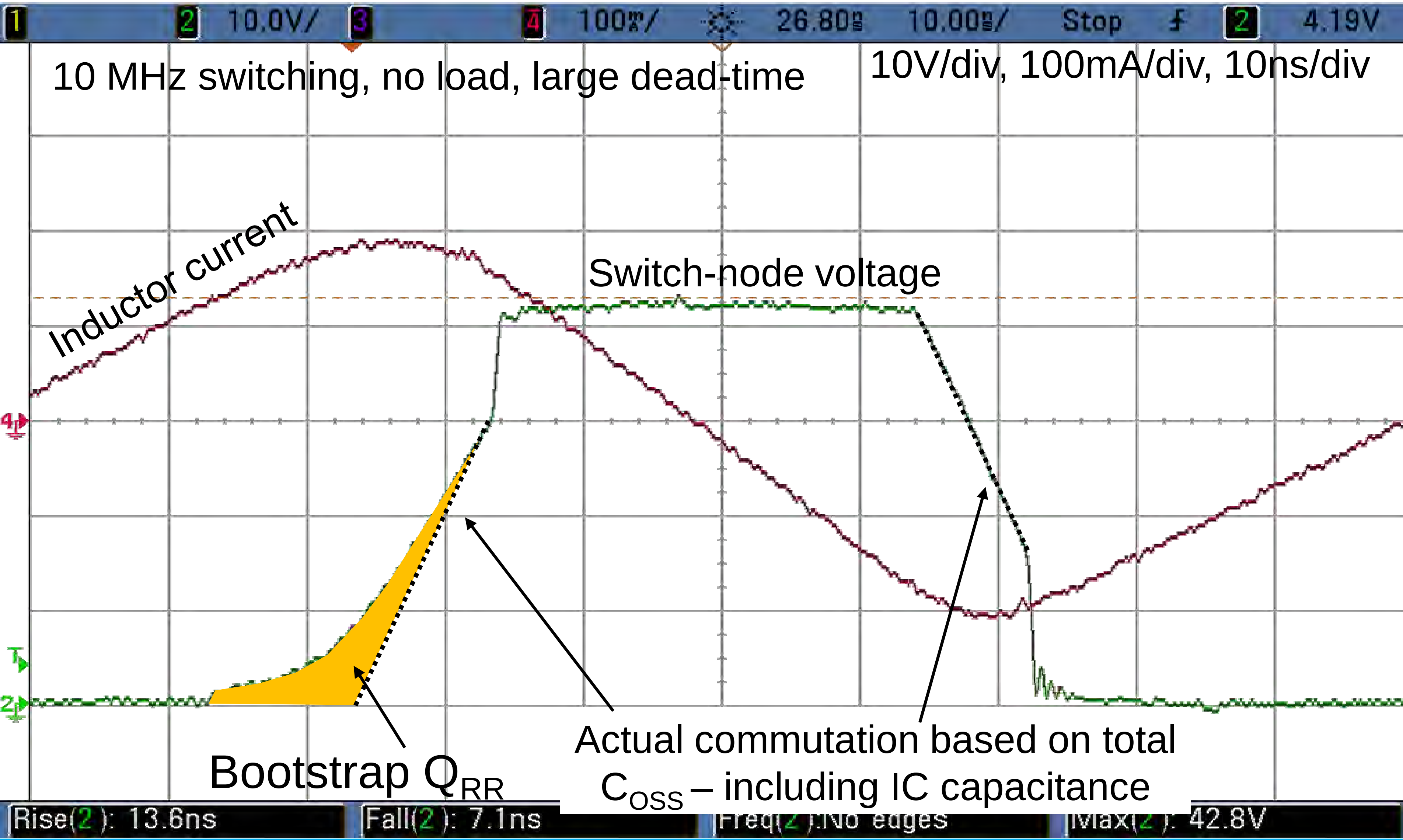
No-load Switching



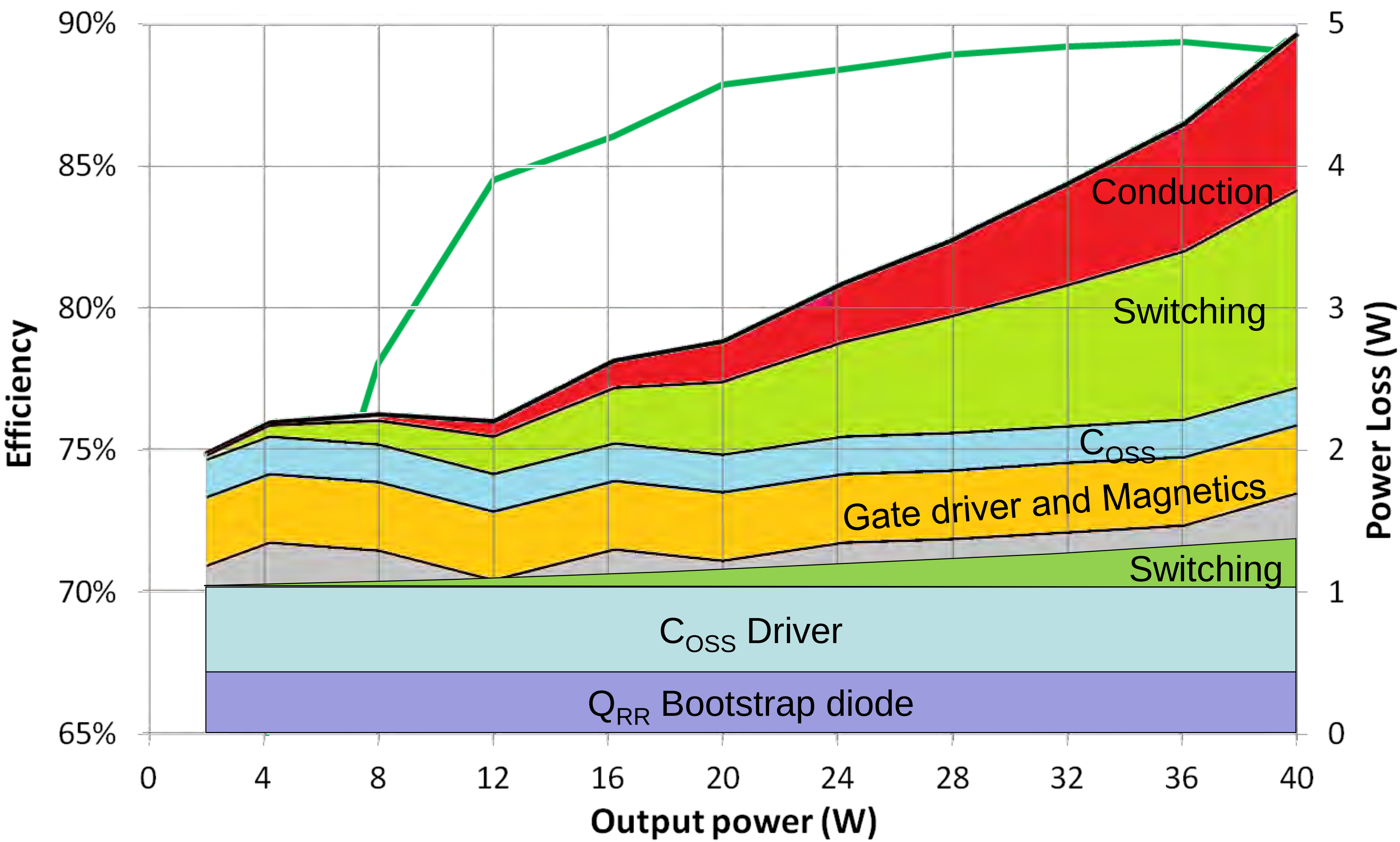
Parasitic Losses



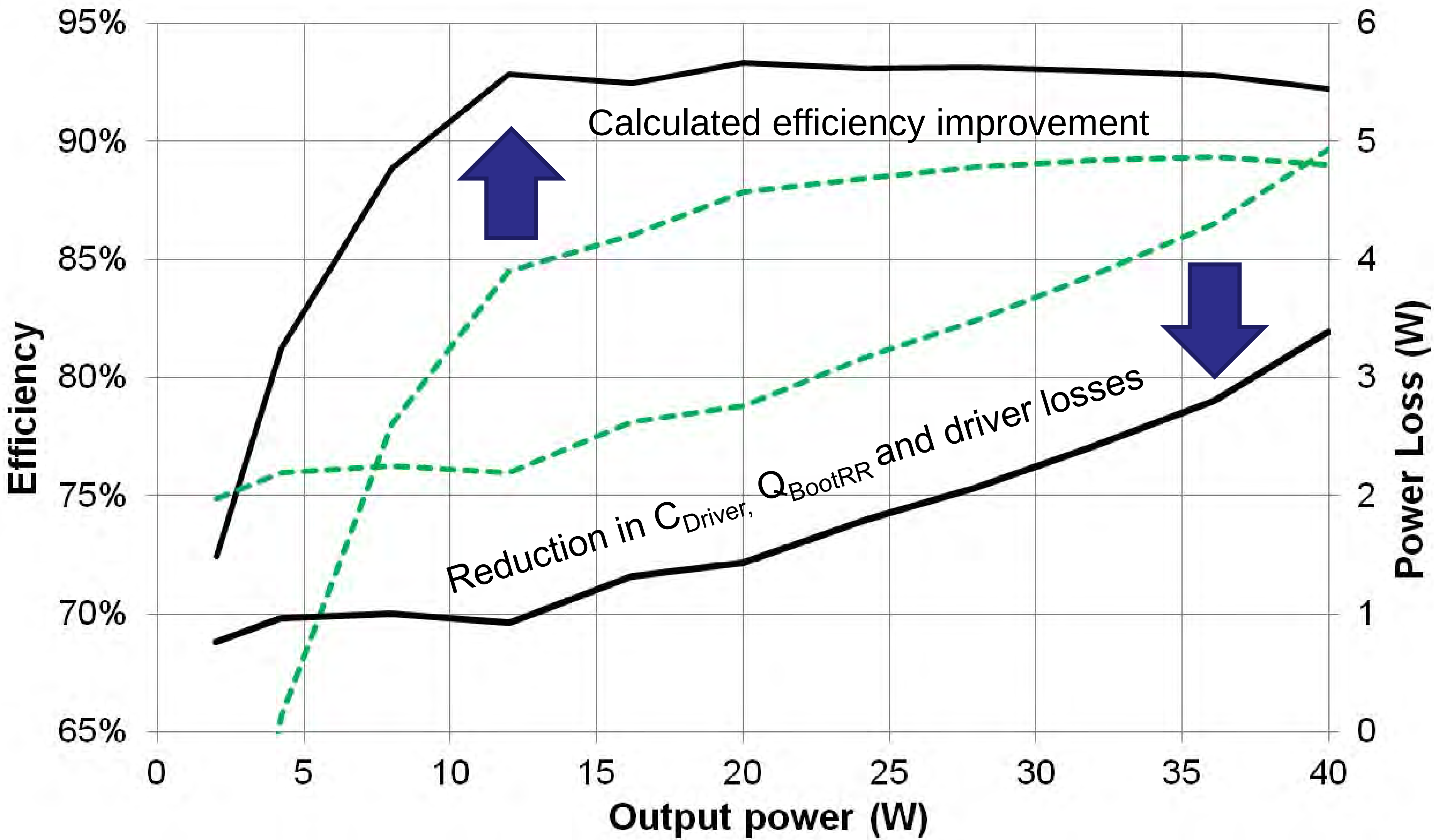
Loss Breakdown



42 V_{IN}, 20 V_{OUT}, 10 MHz



eGaN FET Limited Efficiency



Point of Load Buck Converter

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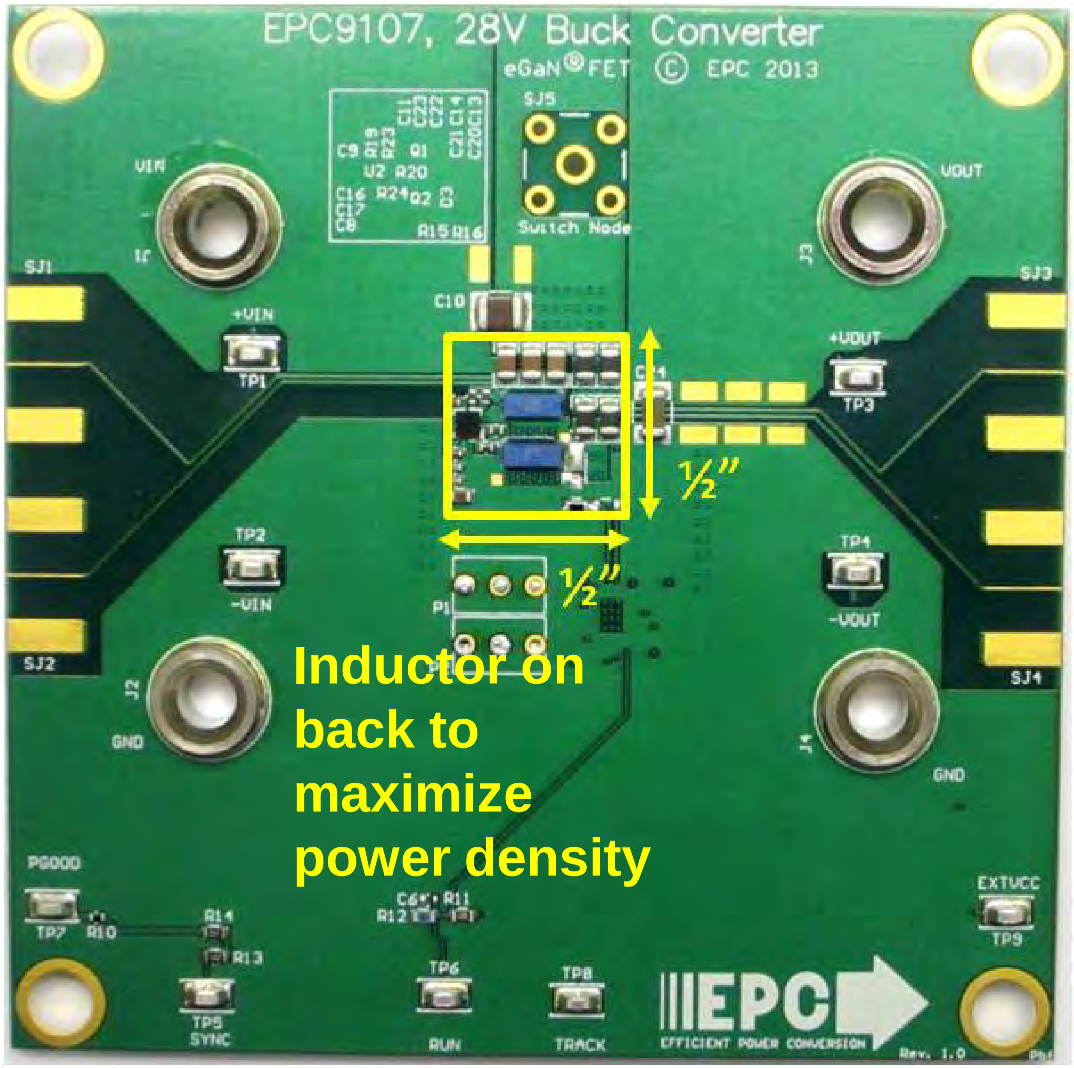
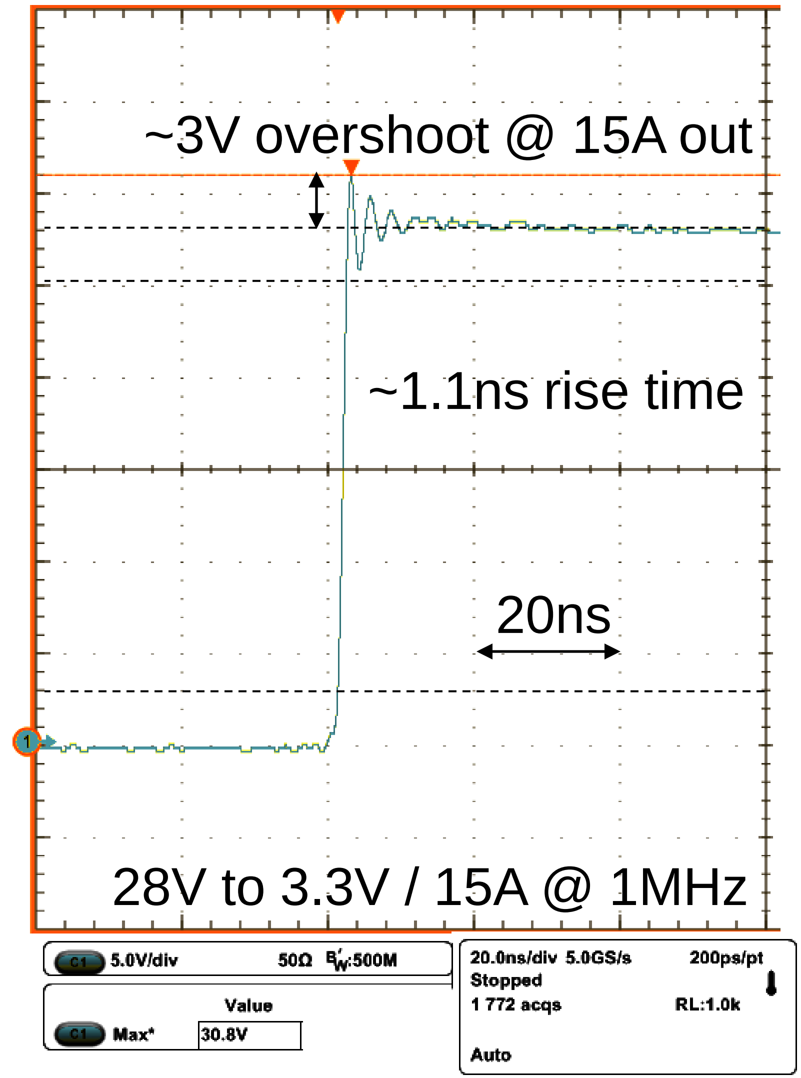
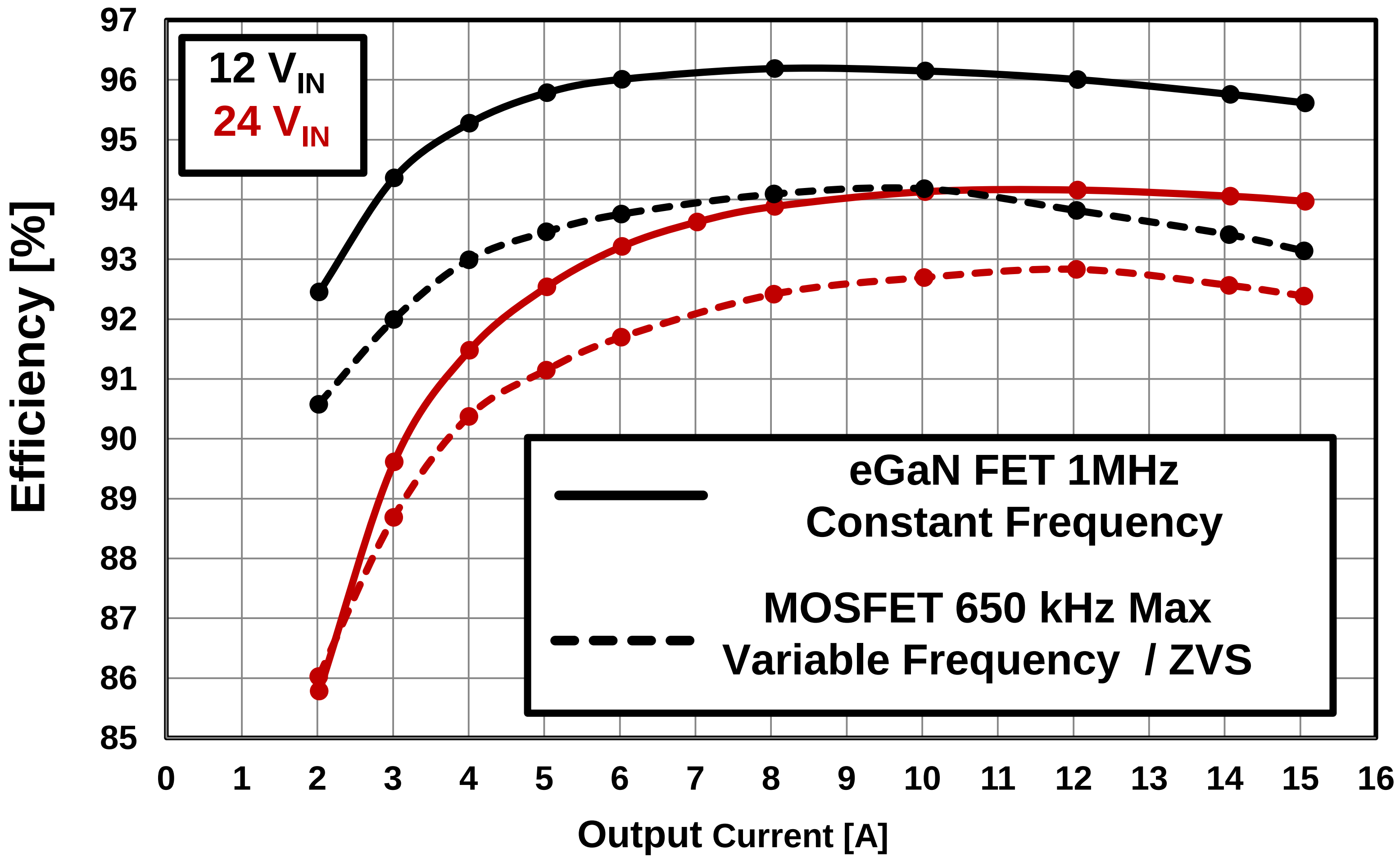




EPC9107 Efficiency Results



V_{OUT} = 3.3 V, f_{SW} = 1 MHz,

GaN Switch/Synchronous Rect.: EPC2015, Driver LM5113

Device Summary

- **EPC8000 eGaN FETs proven up to 10 MHz**
- **New devices enable higher switching frequencies**
- **Switching 42V, 40W at 10MHz at 89% possible**
- **Driver parasitics limit performance**
  - **Doubles light load losses**
- **Gate driver improvements will allow further increase in switching frequency**

Power Supply Summary

- **EPC8000 eGaN FETs enable High Frequency Power modulation.**
- **Superior FoM of eGaN FETs allow higher efficiency at higher frequencies.**
  - **Applicable to 42 V and 28 V DC to DC converters.**
  - **Enables very low duty cycle conversion**
- **eGaN FETs reduce energy cost.**

The end of the road for silicon…..

is the beginning of the eGaN FET journey!