Envelope Tracking GaN Power Supply for 4G Cell Phone Base Stations

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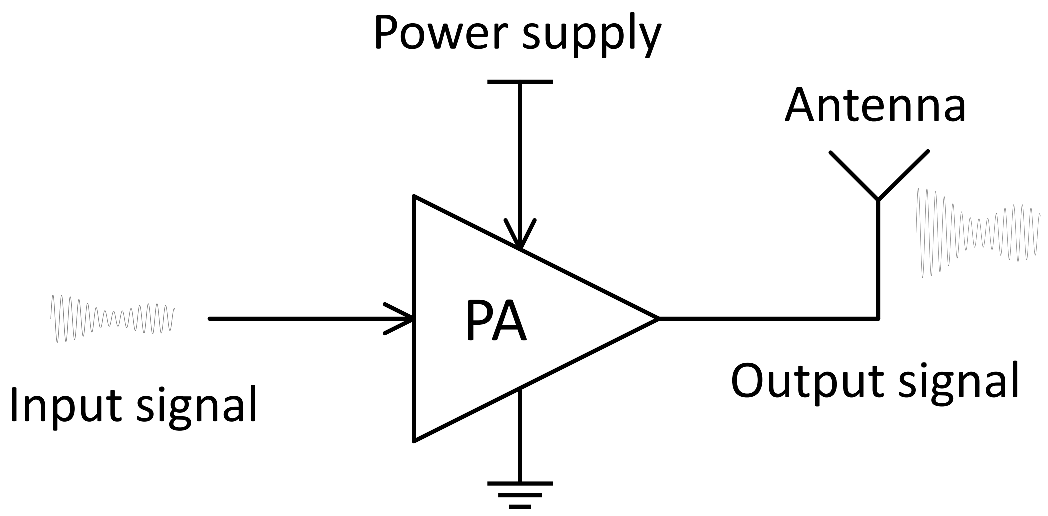
[2] Efficient Power Conversion Corporation

Outline

- ET power supply background
- Design guidelines
- Experimental results

Wirelessly connected world

- 74% growth in global mobile traffic in 2015*
- 4G traffic exceeded 3G traffic for the first time in 2015*

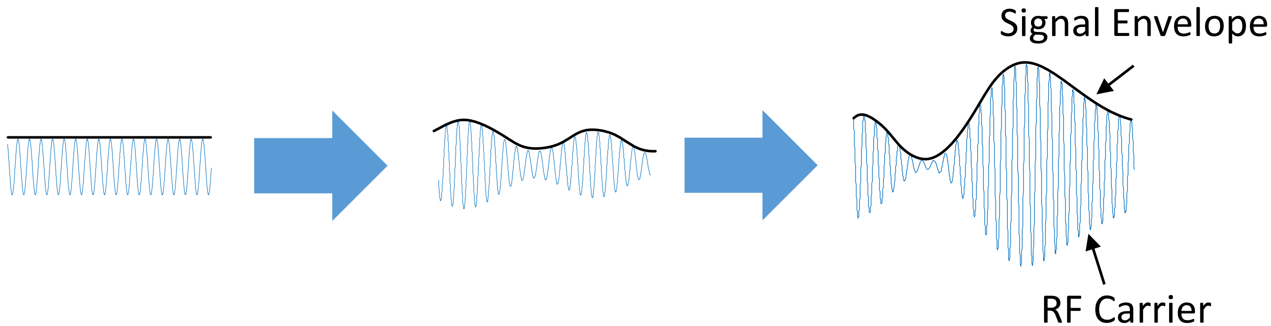


*Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020

Faster means higher PAR

Peak-to-Average Ratio (PAR)

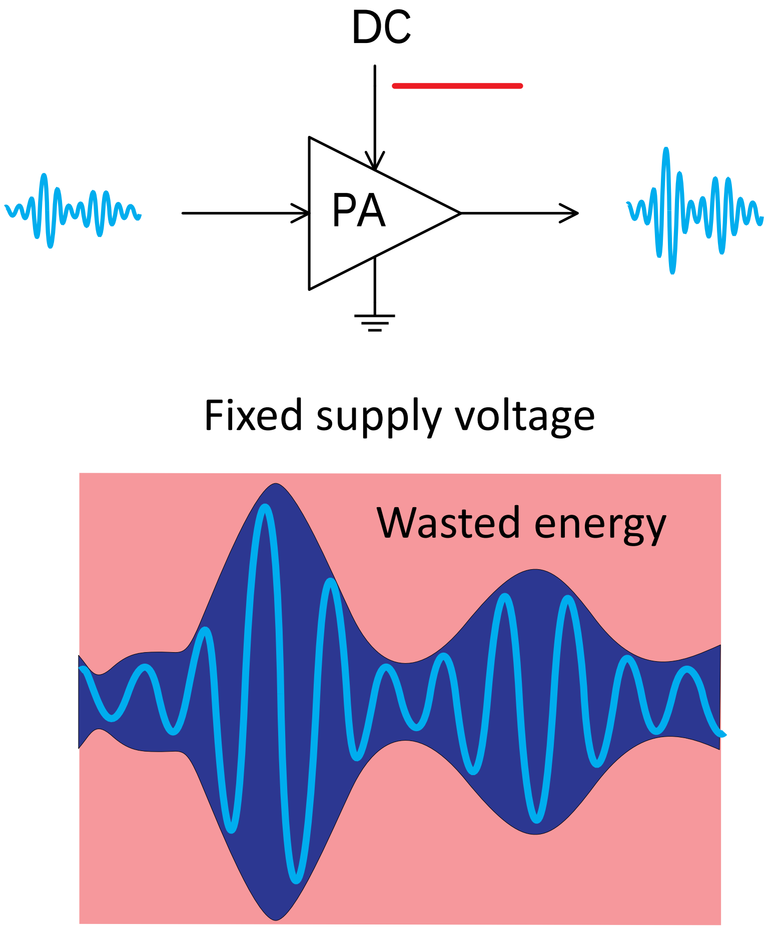
	GSM	EDGE	WCDMA	LTE
Link Speed	Faster →			
Bandwidth* [MHz]	0.2	0.2	5	**20**
Envelope PAR* [dB]	0	3.4	10.6	**~12**

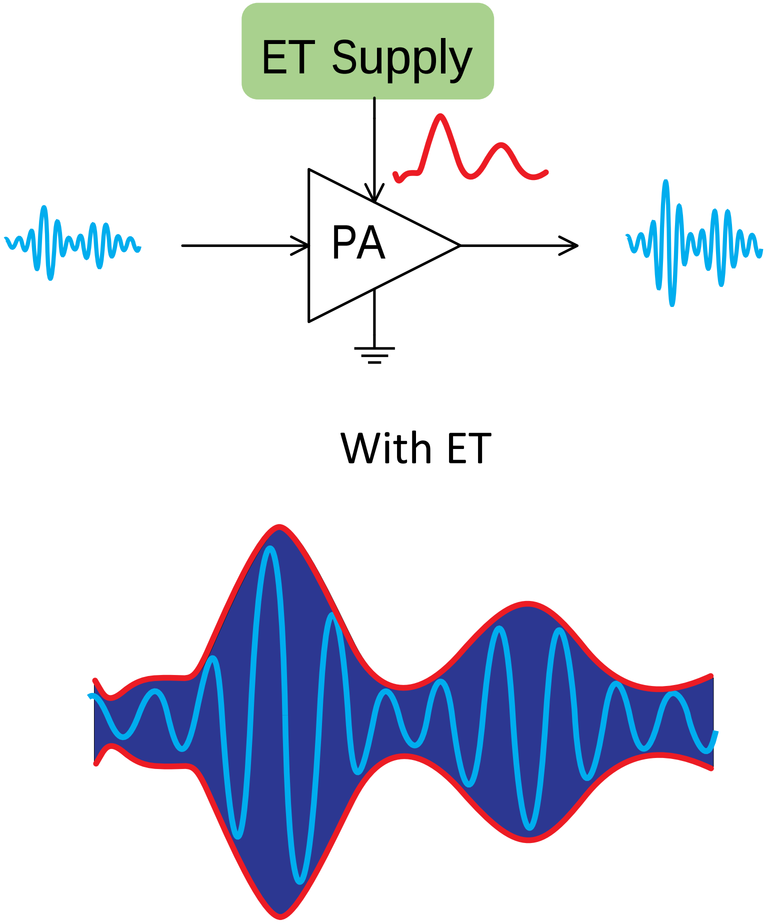


* Source: 3GPP and Wikipedia – Spectral efficiency

PA efficiency

- PA efficiency is low with fixed supply voltage
- ET improves efficiency





Picture reference: Nujira.com

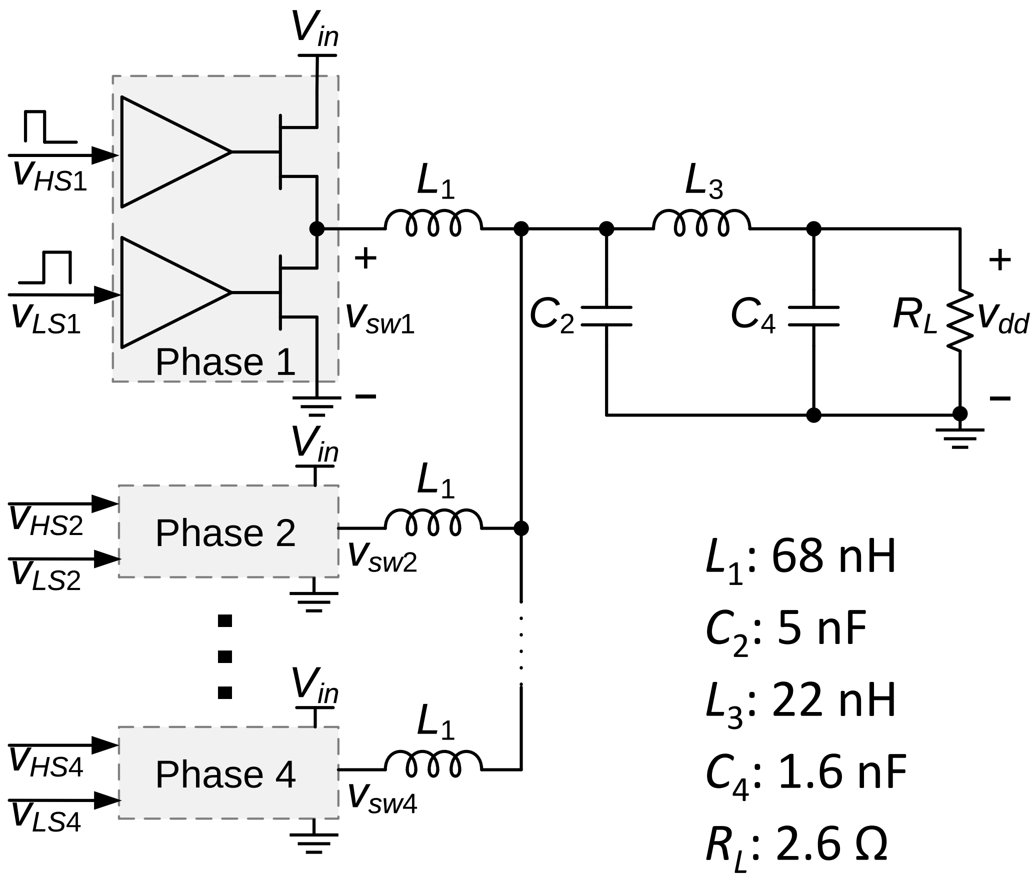
Envelope tracking power supply

- Introduced in 1928 [1]
- ET in phone (low power), 2014
- ET in base station
  - Si, 10 MHz bandwidth, 8-phase switcher [2]
  - GaN?
- This work:
  - Technology: GaN
  - Bandwidth: 20 MHz (4G LTE)
  - Efficiency: > 90%
  - Power: 60 W

[1] R. Heising, “Wave varying and transmitting,” US Patent, 1928
[2] M. Norris and D. Maksimovic, “10 MHz large signal bandwidth, 95% efficient power supply for 3G-4G cell phone base stations,” in Proc. IEEE 27th APEC, Feb. 2012, pp. 7–13.

Topology: synchronous buck converter

- Multi-phase (bandwidth and power)
- Zero-Voltage Switching (efficiency and current balancing)
- R_L as the load -- representing a saturated PA



L_1: 68 nH

C_2: 5 nF

L_3: 22 nH

C_4: 1.6 nF

R_L: 2.6 Ω

Switching frequency f_s

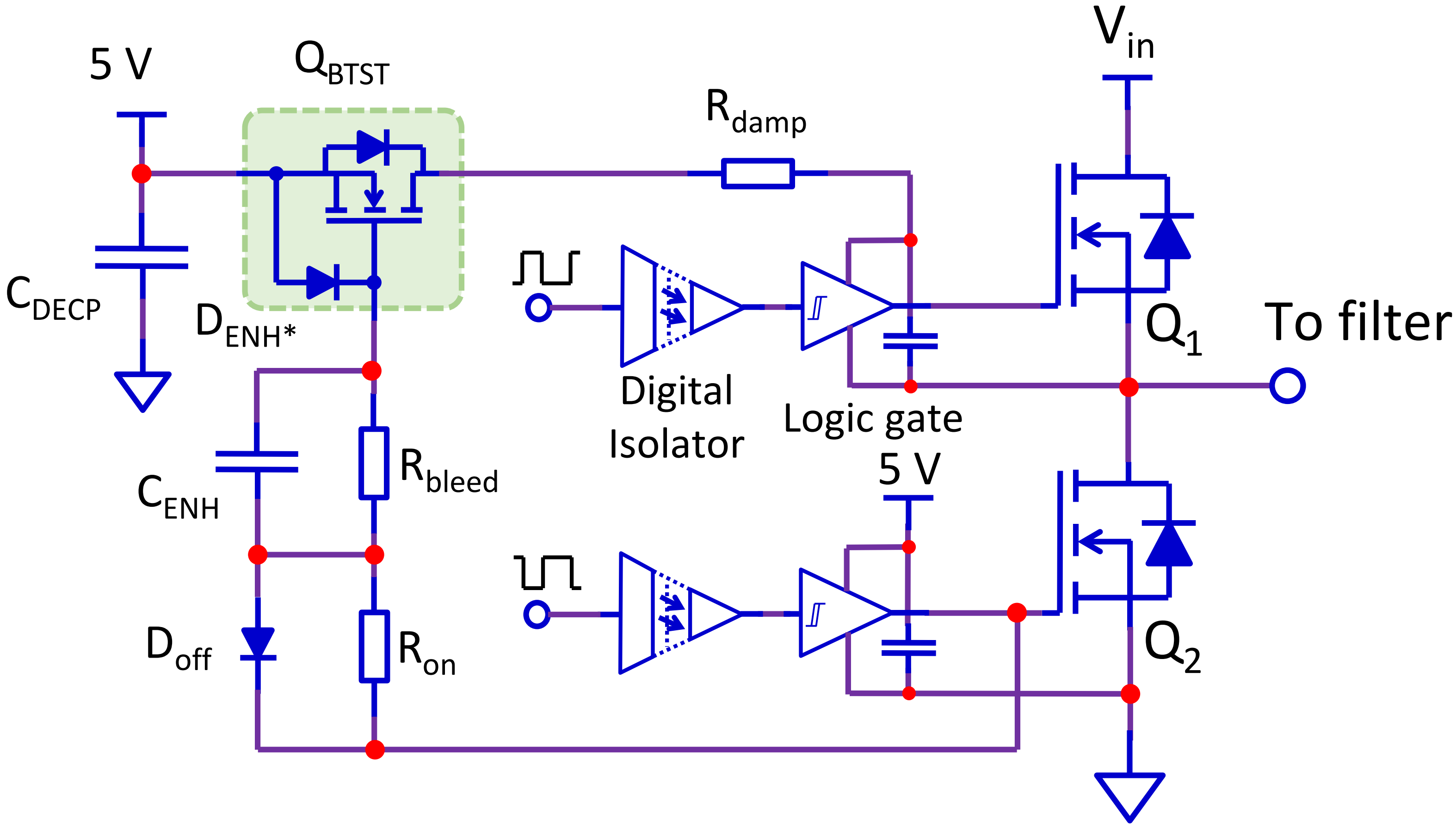
- $f_s = 10 \times \mathrm{BW}$ with 2nd order filter
- $f_s = 5 \times \mathrm{BW}$ with 4th order filter

- BW required: 20 MHz
- (Effective) switching frequency: 100 MHz
- 4-phase converter, per-phase switching frequency: 25 MHz

1. Half-bridge gate driver for eGaN FETs at 25 MHz?
2. How to get high efficiency at 25 MHz?

Gate driver with synchronous bootstrap FET[3]

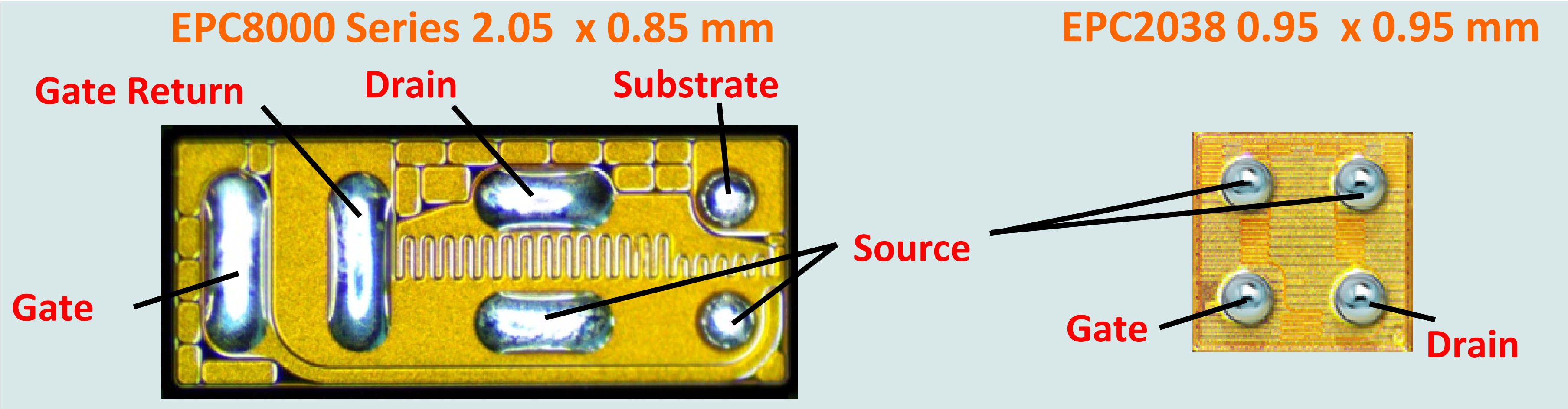
- Use synchronous eGaN FET bootstrap for high side supply
- Use digital isolator for signal level shifting



[3] M. A. de Rooij, *Wireless Power Handbook*, Second Edition, El Segundo, October 2015, ISBN 978-0-9966492-1-6.

Choosing FETs

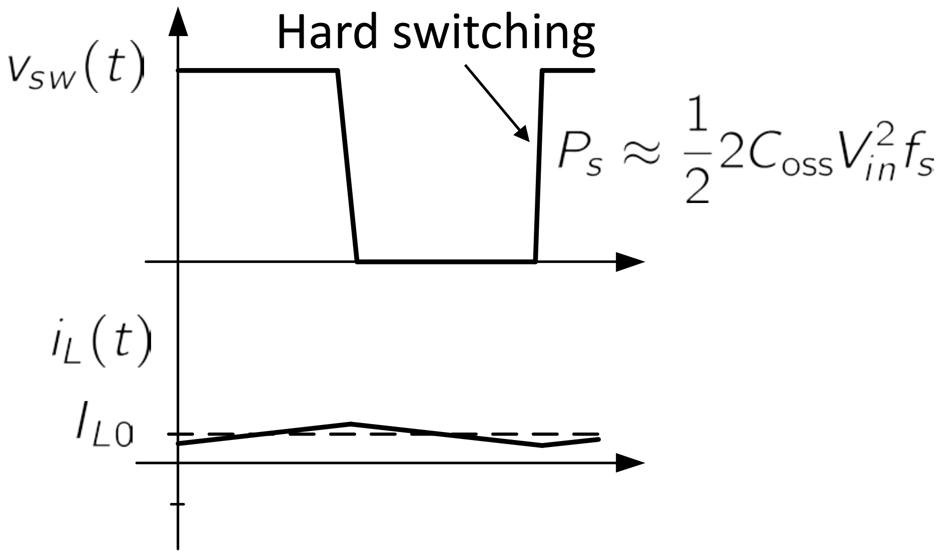
- Synchronous bootstrap FET: EPC2038
- Main power FETs: EPC8000 series with 40 V rating

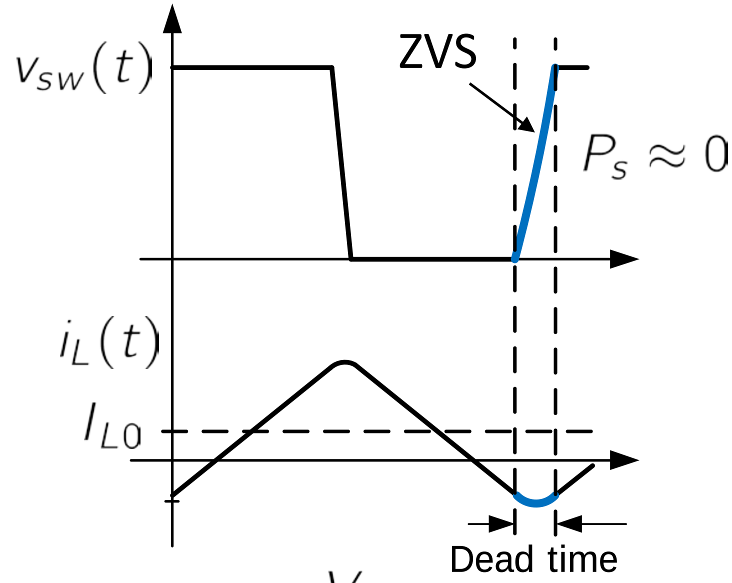


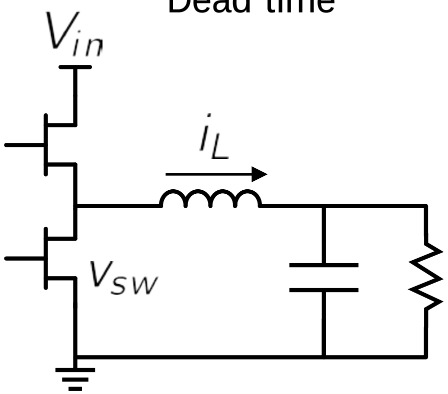
EPC Part Number	Package (mm)	V_{DS} (V)	$R_{DS(on)}$ @5V (mΩ)	Q_G @5 V Typ. (pC)	Q_{GS} Typ. (pC)	Q_{GD} Typ. (pC)	Q_{OSS} (pC)	I_D (A)
EPC2038	BGA 0.9x0.9	100	2800	44	16	5	140	0.5
EPC8004	LGA 2.05x0.85	40	110	370	120	47	630	2.7
EPC8007	LGA 2.05x0.85	40	160	302	97	25	406	3.8
EPC8008	LGA 2.05x0.85	40	325	177	67	12	211	2.7

Improving efficiency (1) – FETs

- Conduction loss ($P_c = I_{\mathrm{RMS}}^2 R_{\mathrm{on}}$) vs. switching loss (P_s)







- Use analytical loss model similar to [4]

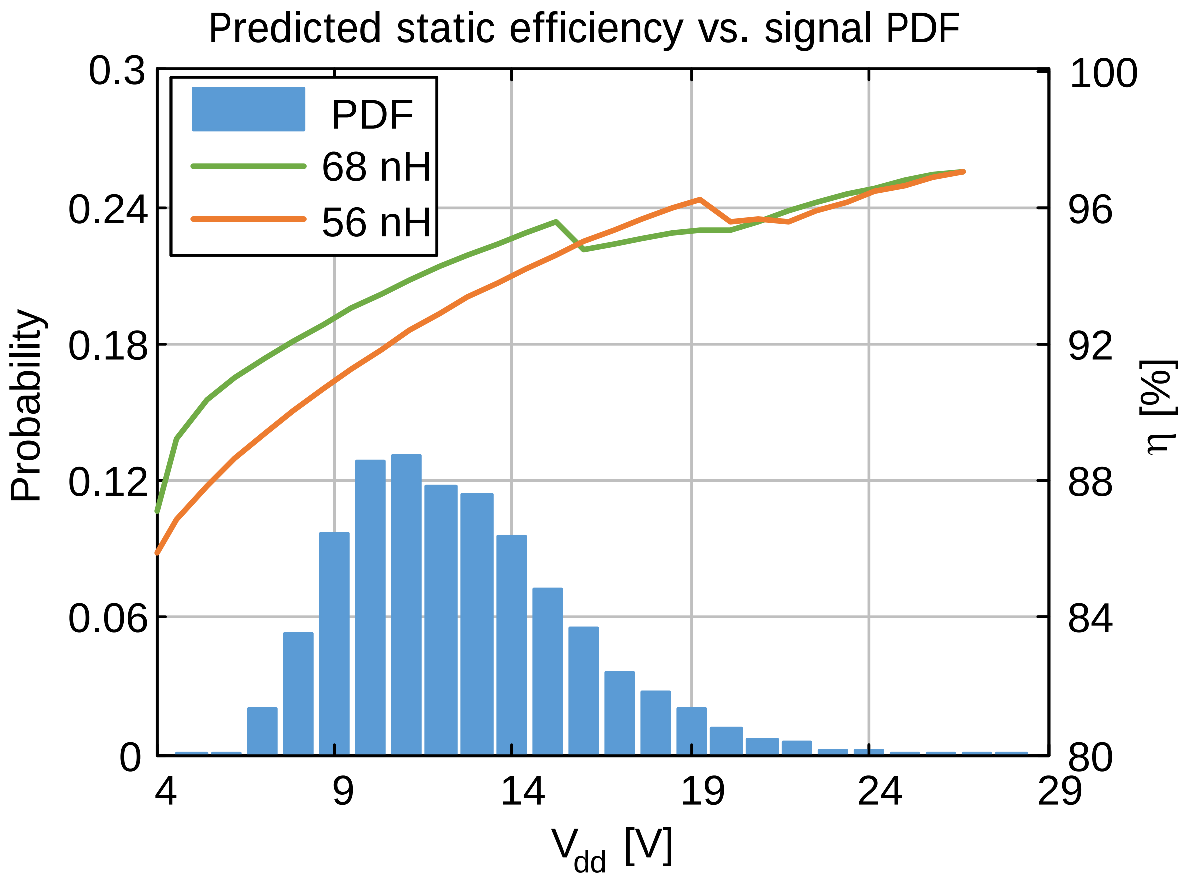
- Result: EPC8004

[4] Y. Zhang, M. Rodriguez and D. Maksimovic, “Very High Frequency PWM Buck Converters Using Monolithic GaN Half-Bridge Power Stages with Integrated Gate Drivers,” *IEEE Trans. Power Electron.*, 2016

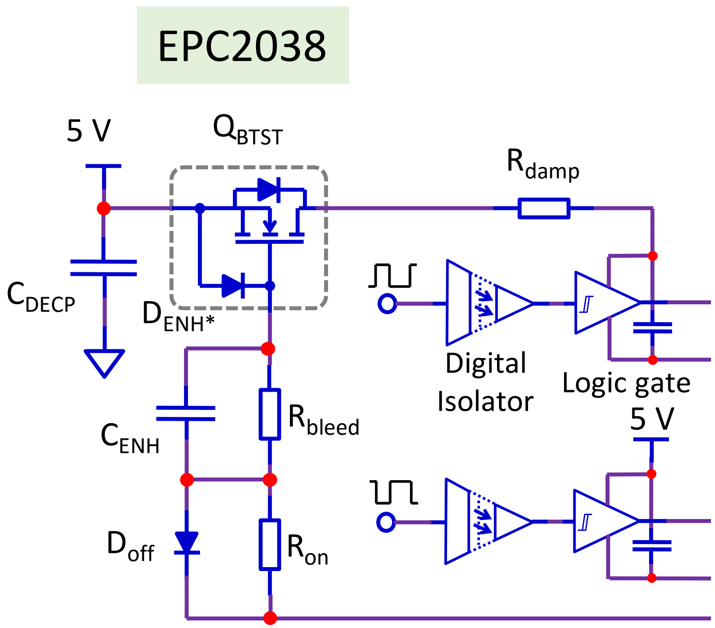
Improving Efficiency (2) – ZVS Inductor

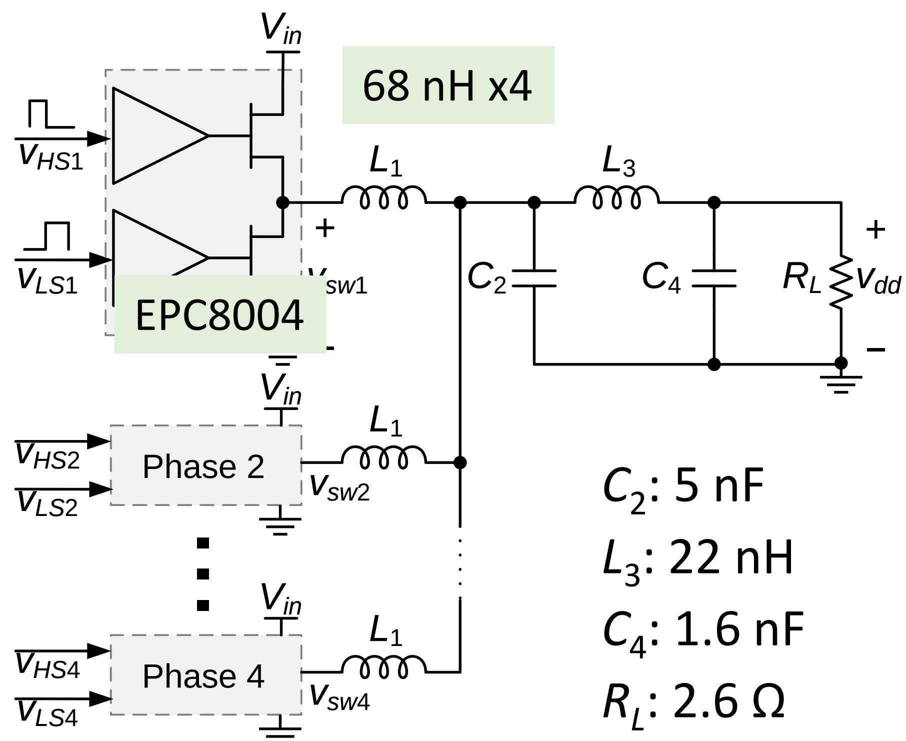
Wide output voltage range (5 – 28 V)

1. 68 nH: 94.5% predicted tracking average efficiency
2. 56 nH: 93.7% predicted tracking average efficiency



Final Design





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EPC8004	LGA 2.05x0.85	40	110	370	120	47	630	2.7
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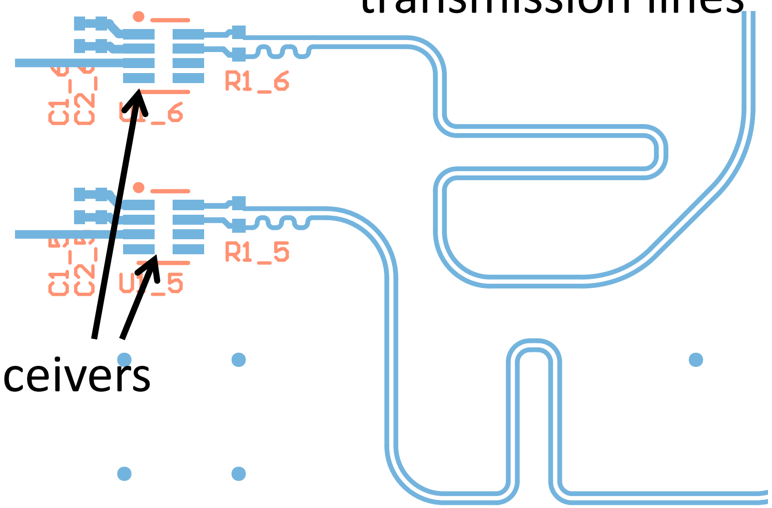
PCB Design

Transmission line delay match

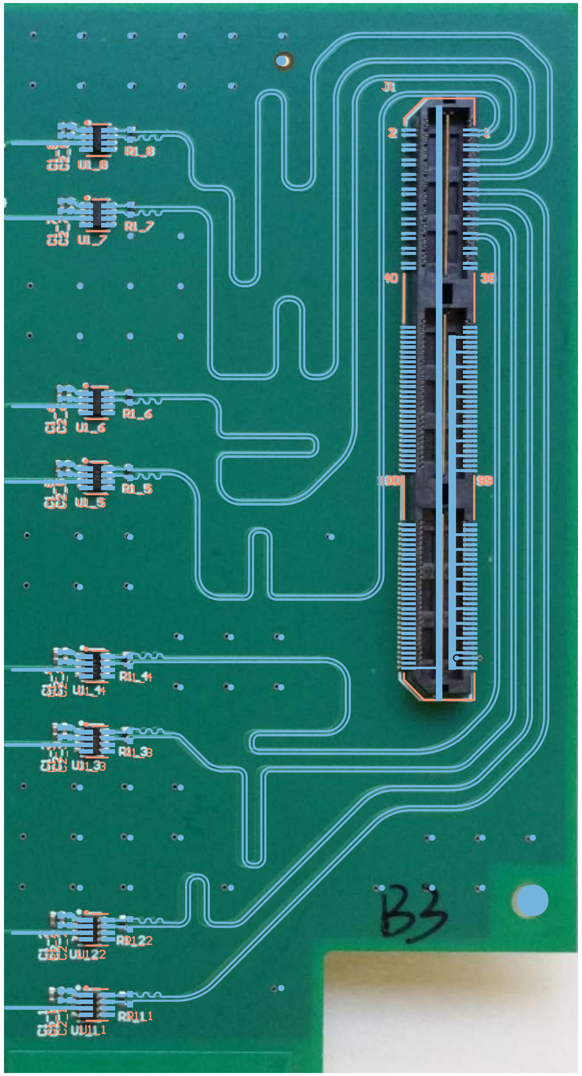
- Accurate dead time (improve efficiency)
- Low distortion

100 Ω differential transmission lines



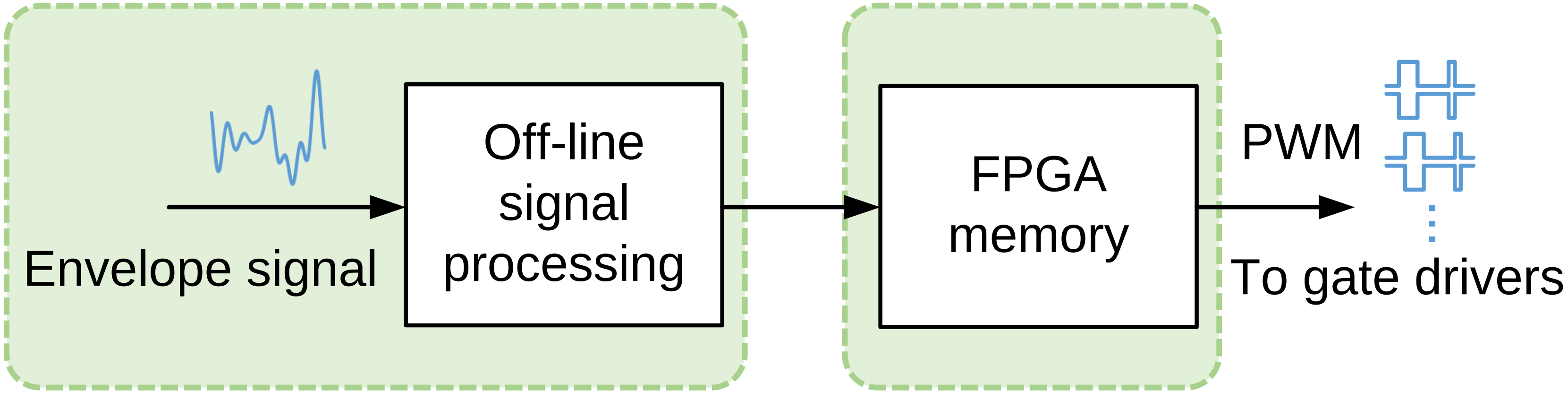
LVDS receivers

Phase 2 zoom in

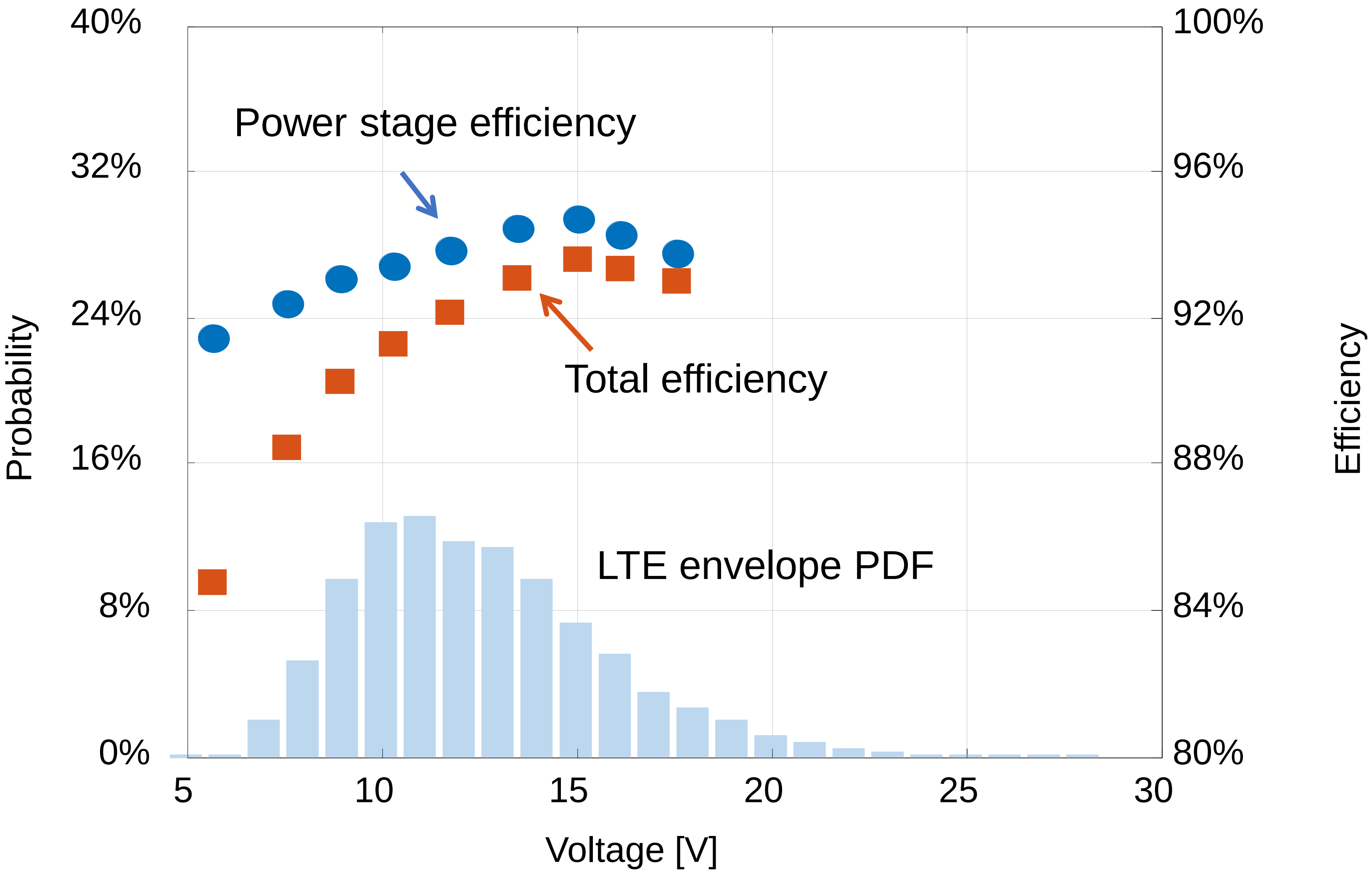


Test Setup

- Envelope signal generated using 20 MHz LTE (OFDM) modulation
- Digital ‘on/off’ signals stored in FPGA memory
- 4.8 Gbps (~200 ps resolution) FPGAs:
  - Altera Stratix IV or Arria V

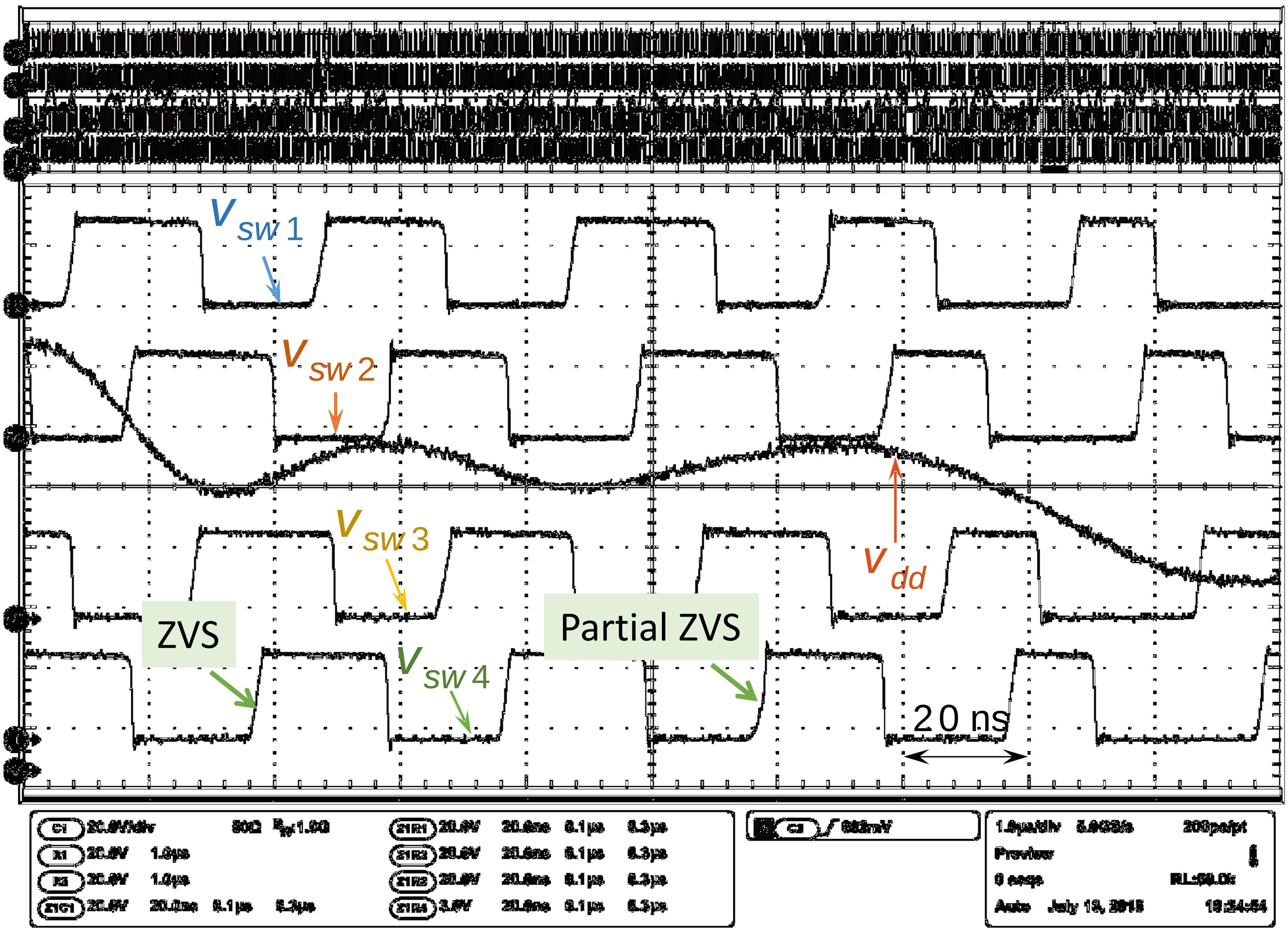


Efficiency

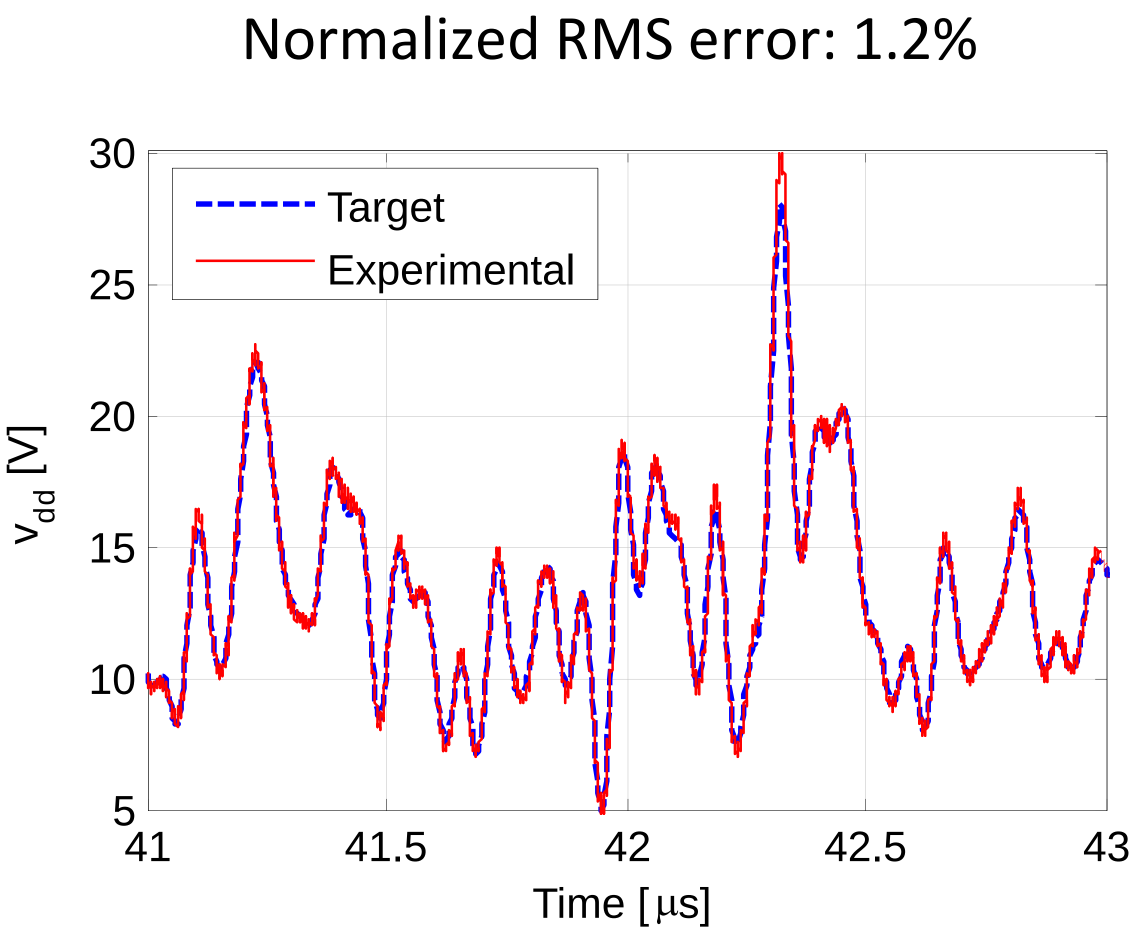


Power stage efficiency
Total efficiency
LTE envelope PDF
Probability
Efficiency
Voltage [V]
40%
32%
24%
16%
8%
0%
100%
96%
92%
88%
84%
80%
5
10
15
20
25
30

Oscilloscope Waveform

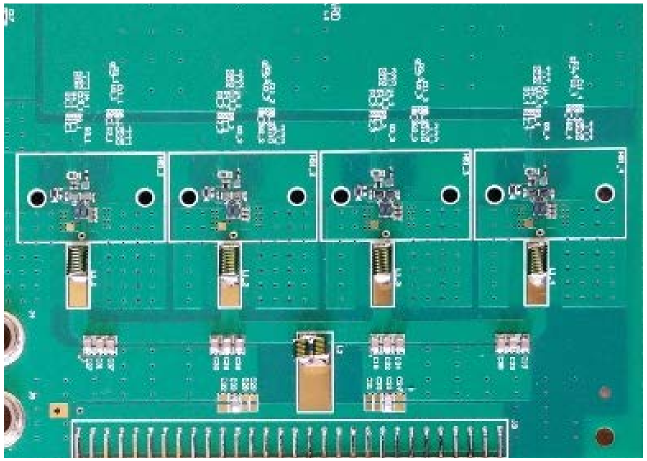


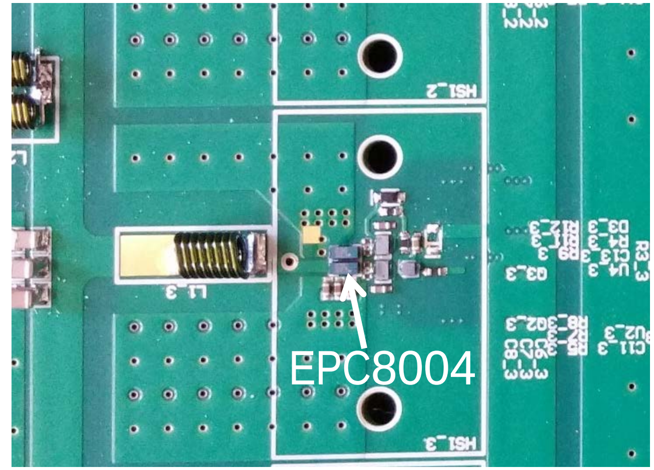
Waveform Comparison

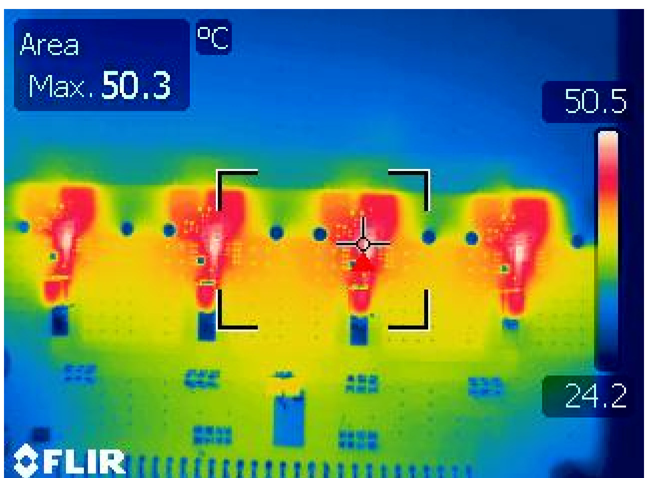


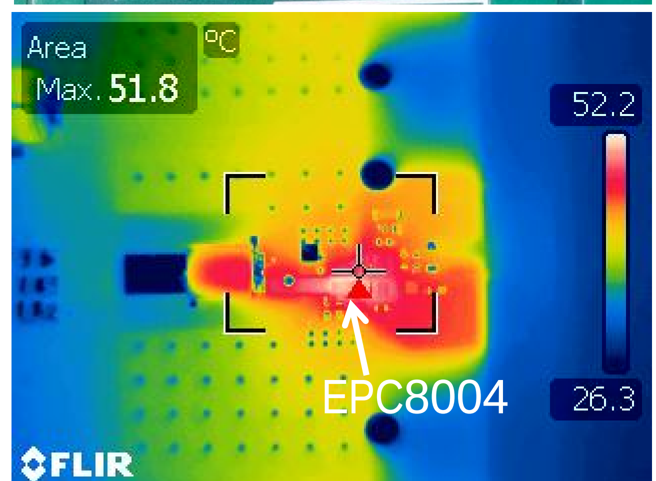
Thermal

- No heat sink, no fan
- Phase current balancing verified









Summary

- ET – Improves PA efficiency
- ET supply for 4G cell phone base stations
  - eGaN FETs – low C_{ISS}, C_{OSS}, fast switching time
  - 20 MHz bandwidth, 60 W average, 92% efficiency
  - Power level Scalable

Thank you! Questions?