Webinar

Advancing the next-generation satellite power architecture

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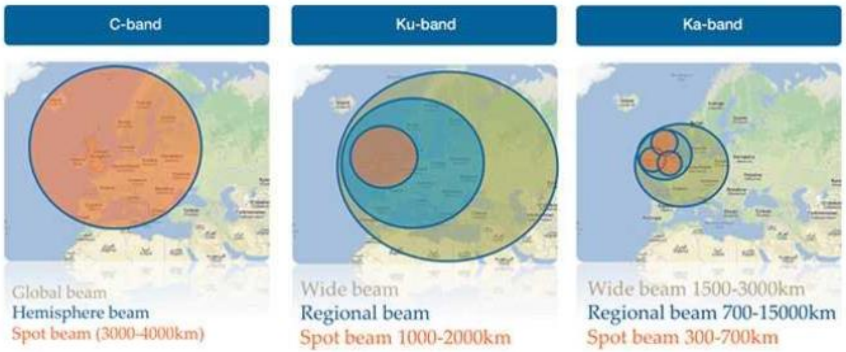
Driving need for higher power density

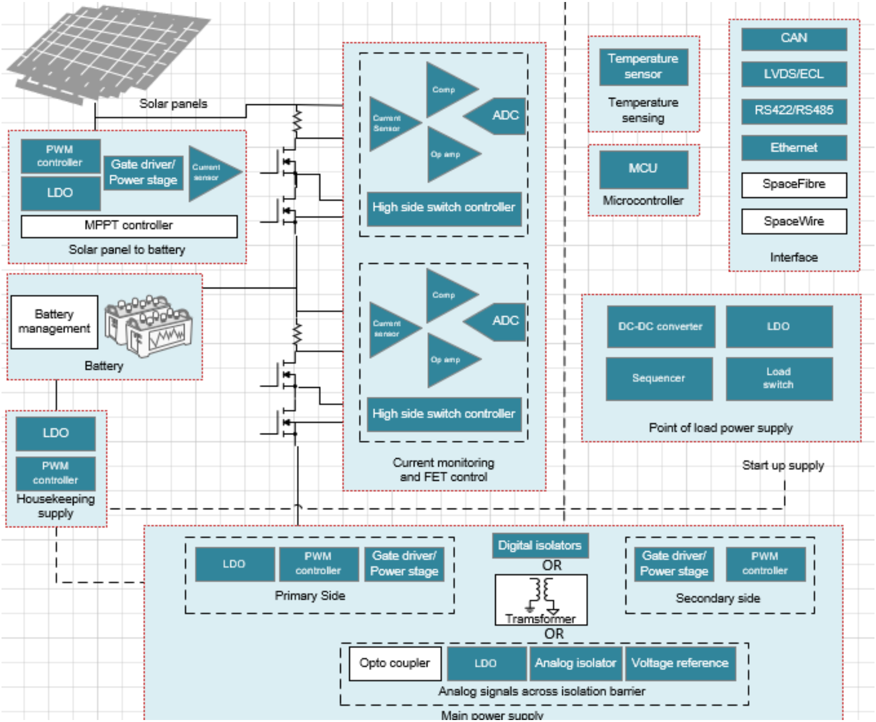
- The use of more Ku& Ka-band have been a significant driver to ***higher bandwidth connections***. This has also led to the deployment of ***much higher channel*** satellites.



- This coupled with increased local processing in earth observation satellites have created a need for much higher power demands yet the overall satellites are or similar size or smaller.

- So the need for the ***highest possible power density of the power distribution subsystem*** is more critical than ever.

Satellite electrical power system (EPS)



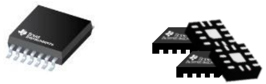
- EPS are complex as they need support dozens of different wattage subsystems across the entire satellite
  - Energy generation
  - Energy storage (batteries)
  - Propulsion
  - A wide range of both low wattage and in some cases some very high wattage payloads.

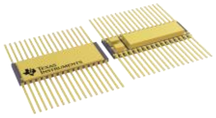
TI space product grades

Same radiation levels, same qualification, different package

LEO Missions

GEO Missions





Rad Tolerant Plastic
TI Space Enhanced Plastic
-SEP

Rad Hard Plastic
QML Class P
-SP

Rad Hard Hermetic
QML Class V
-SP

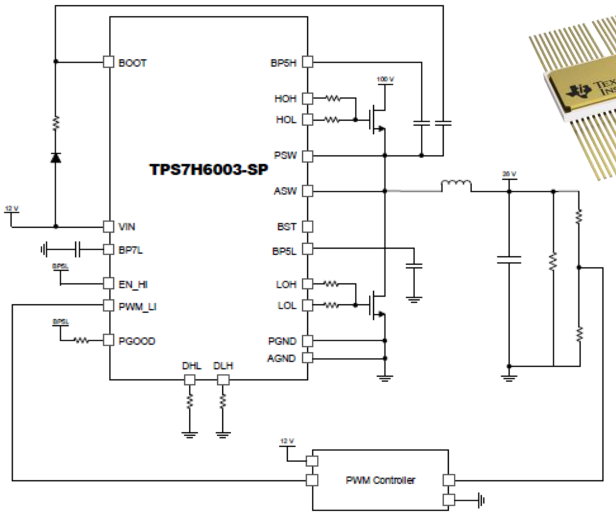
Pin-to-pin compatible, different radiation levels

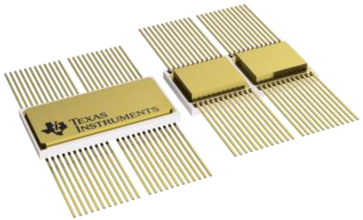
Packaging	Plastic	Plastic	Ceramic / Metal Can
Mil. Spec	Vendor Item Drawing	Standard Microcircuit Drawing	
Burn- in	No	Yes	Yes
TID Char	**30 – 50 krad(Si)**	**< - - - - - - - - - - - - - - 50 – 300 krad(Si) - - - - - - - - - - - - - - - - - - >**	
TID RLAT	**20, 30, or 50 krad(Si)**	**< - - - - - - - - - - - Non-RHA, 50, 100, or 300 krad(Si) - - - - - - - - - - >**	
SEL	**43 MeV·cm²/mg**	**< - - - - - - - - - - - - - - ≥ 60 MeV·cm²/mg - - - - - - - - - - - - - - - - - - >**	

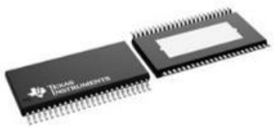
TPS7H6003/13/23-SP, TPS7H6005/15/25-SP/-SEP
Rad-hard & rad-tolerant family of GaN half-bridge gate drivers

Radiation performance

- QMLV & QMLP radiation: TID 100-krad(Si) ELDRS-free, SET/SEFI characterized and SEL/SEB/SEGR immune up to 75 MeV.cm2/mg
- -SEP radiation: TID 50-krad(Si) ELDRS-free, SET/SEFI characterized and SEL/SEB/SEGR immune up to 43 MeV.cm2/mg







Product Value Proposition

The TPS7H60xx-SP/-SEP supports the wide range of voltages across the satellite EPS. Designed with compelling TID/SEE performance.

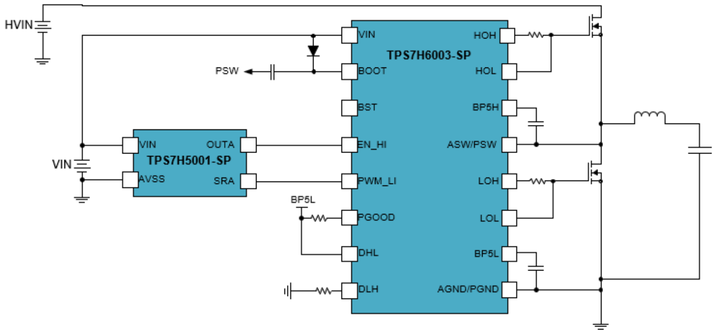
Features

- TPS7H6003-SP, TPS7H6005-SP/-SEP VIN 200V
- TPS7H6013-SP, TPS7H6015-SP/-SEP VIN 60V
- TPS7H6023-SP, TPS7H6025-SP/-SEP VIN 22V
- VIN = 10 to 14 V (8.5V UVLO)
- Integrated 5V LDOs for both high-side and low-side GaN FETs
- fSW ≥ 5-MHz, 1.3-A peak source current, 2.5-A peak sink current
- 30-ns typical propagation delay and 5.5-ns typical delay matching
- Split outputs for adjustable turn-on and turn-off times

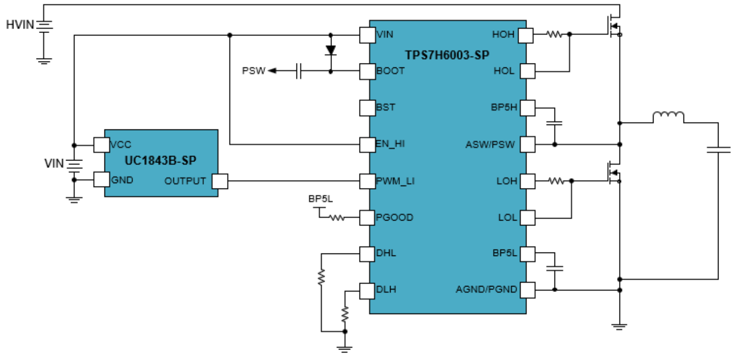
Package & links to technical content

- QMLV: CFP (HBX) 48-pin 8.5mm x 16.8mm
- QMLP/-SEP package HTSSOP (DCA) 56-pin 6.1mm x 14.0mm
- TPS7H60x3-SP product folders: 6003 LINK, 6013 LINK, 6023 LINK
- TPS7H60x5-SP product folders: 6005 LINK, 6015 LINK, 6025 LINK
- TPS7H60x5-SEP product folders: 6005 LINK, 6015 LINK, 6025 LINK

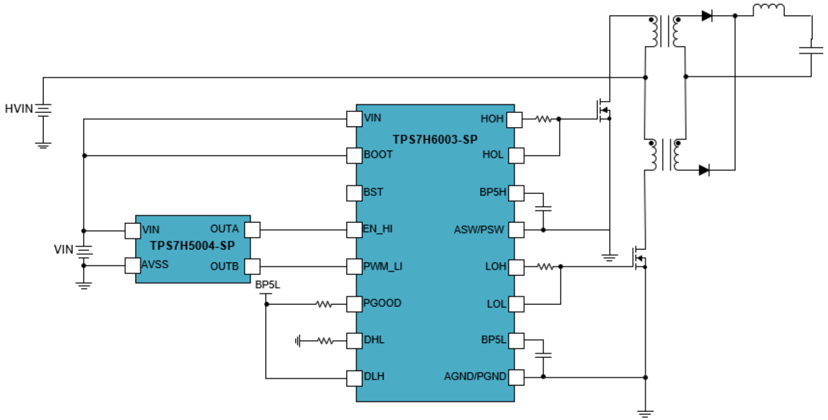
TPS7H60xx-SP/-SEP input modes



Independent input mode with TPS7H500x-SP/-SEP

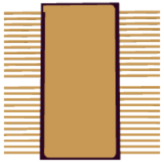
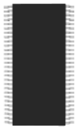
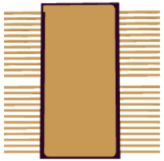
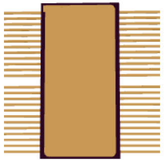


PWM mode with UC1843B-SP



Dual low-side configuration used in push-pull converter

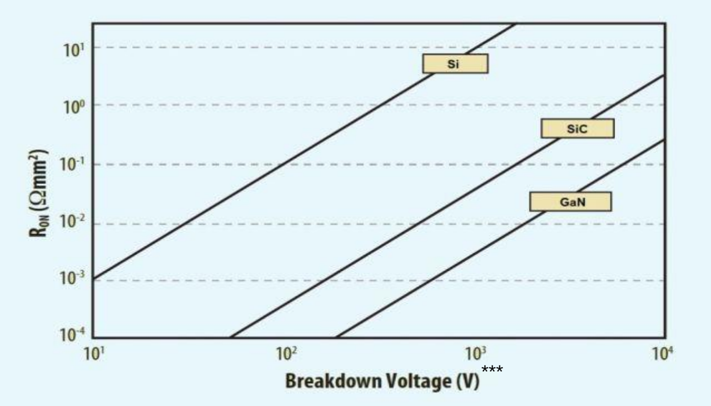
Family of devices for 200V, 60V & 22V supply rails

	Rad-hard QMLV 100krad & 75MeV	Rad-hard QMLP 100krad & 75MeV	Rad-tolerant – SEP 50krad & 43MeV
TPS7H6003-SP & TPS7H6005-SP/-SEP <u>200V Half Bridge</u>	**TPS7H6003-SP**  48-pin Ceramic 8.5 x 16.8 mm 142.8 mm^2	**TPS7H6005-SP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2	**TPS7H6005-SEP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2
TPS7H6013-SP & TPS7H6015-SP/-SEP <u>60V Half Bridge</u>	**TPS7H6013-SP**  48-pin Ceramic 8.5 x 16.8 mm 142.8 mm^2	**TPS7H6015-SP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2	**TPS7H6015-SEP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2
TPS7H6023-SP & TPS7H6025-SP/-SEP <u>22V Half Bridge</u>	**TPS7H6023-SP**  48-pin Ceramic 8.5 x 16.8 mm 142.8 mm^2	**TPS7H6025-SP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2	**TPS7H6025-SEP**  56-pin HTSSOP Plastic 6.1 x 14.1 mm 86 mm^2

Dimensions are body size

Faster, smaller, higher efficiency GaN for Space

- GaN products already outperform silicon MOSFETs



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- GaN is inherently more radiation tolerant for TID than silicon MOSFETs

- Heavy ions performance must still be taken into consideration

- Upcoming GaN-based FET products from numerous vendors are showing even better capabilities such as conductive and switching behavior, voltage rating, radiation hardness, etc.

Key features of TI's GaN half-bridge gate drivers

Range of voltages

- 200V gate driver for applications around the energy generation (solar) or electric propulsion subsystems
- 60V gate driver for power distribution & controller units (PDCU)
- 22V gate driver for high-current payload applications

- **Eliminates cross conduction risk**
- Interlock protection to ensure no possibility of cross conduction (high side & low side FETs on at same time) in both the half-bridge gate driver and the new PWM controller family

- **Precise control of turn-on & turn-off times for GaN FETs**
- Ability to precisely control the high speed GaN FETs to ensure a stable and reliable power supply

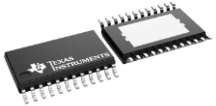
TPS7H5001/2/3/4-SP, TPS7H5005/6/7/8-SEP

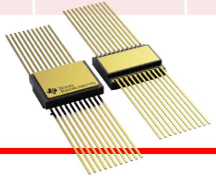
Rad-hard & rad-tolerant family of PWM controllers

Radiation performance

- QMLV & QMLP radiation: TID 100-krad(Si) ELDRS-free, SET/SEFI characterized and SEL/SEB/SEGR immune up to 75 MeV-cm2/mg
- -SEP radiation: TID 50-krad(Si) ELDRS-free , SET/SEFI characterized and SEL/SEB/SEGR immune up to 43 MeV-cm2/mg

Device	# of Primary outputs	# of SRA outputs	Programmable Dead time setting	Programmable Leading Edge Blanking	Duty-Cycle options
TPS7H5001-SP TPS7H5005-SEP	2	2	Yes	Yes	50%, 75%, 100%
TPS7H5002-SP TPS7H5006-SEP	1	1	Yes	Yes	75%, 100%
TPS7H5003-SP TPS7H5007-SEP	1	1	No	No	75%, 100%
TPS7H5004-SP TPS7H5008-SEP	2	0	N/A	Yes	50%





Product Value Proposition

The TPS7H500x-SP/-SEP supports the wide range of power topologies across the satellite EPS. Designed with compelling TID/SEE performance.

Features

- 0.6 V ±1% VREF accuracy over load, line, temperature and TID
- Configurable switching frequency from 100 kHz to 2 MHz
- Synchronous rectification outputs, dead time (PS and SP) and duty cycle limit configurable (leading edge blanking)
- Configurable soft start, EN (UVLO), FAULT (OCP, OVP and OTP) slope compensation and current limit, Hiccup OCP mode

Package & links to technical content

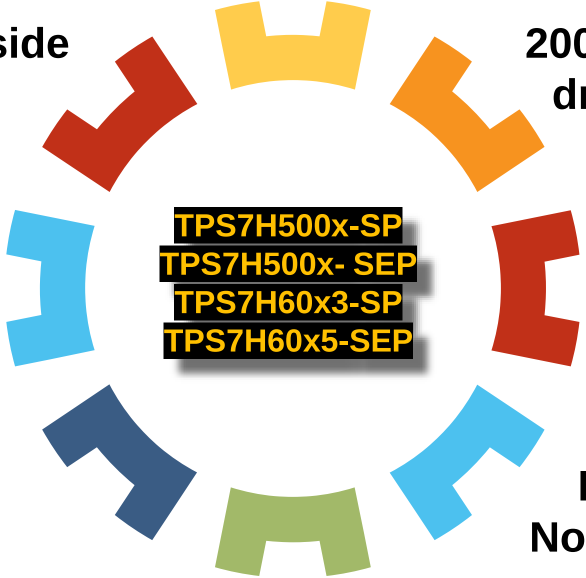
- QMLV: CFP (HFT) 22-pin (body) 6.2mm x 7.7mm
- QMLP/-SEP: Plastic HTSSOP (PWP) 24-pin (body) 4.4mm x 7.8mm
- Product folder: TPS7H5001-SP, 5002-SP, 5003-SP, 5004-SP
- Product folder: TPS7H5005-SEP, 5006-SEP, 5007-SEP, 5008-SEP

Flexibility by design

Rad hard (-SP)
Rad tolerant (-SEP)

Half-Bridge or dual low-side driver configurations

200V, 60V or 22V driver options



Single-phase or multi-phase topologies

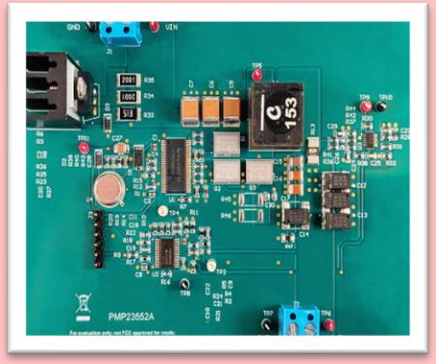
QMLV Ceramic (-SP)
QMLP Plastic (-SP)

Numerous PWM price points

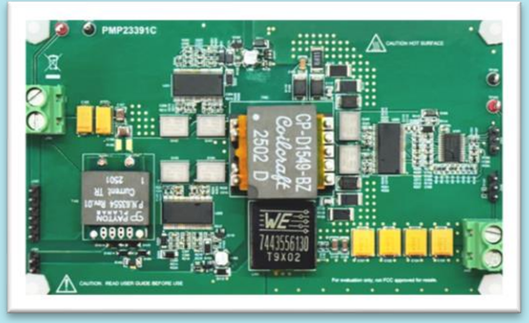
Isolated topologies
Non-isolated topologies

Can interface to
Silicon MOSFETs or GaN FETs

TI power supply reference kits



High voltage: Rad-hard or rad-tolerant 300W non-isolated GaN based sync buck 50-150V (nominal 100V) to 28V@12A



High wattage: Rad-hard or rad-tolerant 300W non-isolated GaN based soft-switched sync full-bridge 22-36V (nominal 28V) to 12V@25A

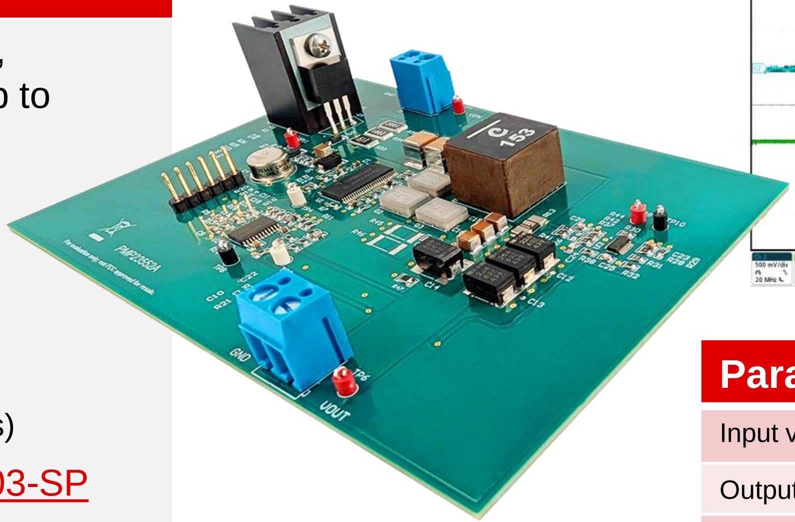
High current: Rad-hard or rad-tolerant 35W non-isolated GaN based single-phase sync buck 10-14V (nominal 12V) to 0.8V@44A

Two example power reference kits

PMP23552 Rad-hard/Rad-tolerant high-voltage sync buck

Features

- Radiation: TID 100-krad(Si), SEL/SEB/SEGR immune up to 75 MeV.cm^2/mg
- Space-grade GaN based
- 95% efficiency @ 100V Vin
- SYNC input available
- Optional self-bias circuit (higher efficiency w/external bias)
- TPS7H5001-SP, TPS7H6003-SP
- TPS7H5005-SEP, TPS7H6005-SEP
- EPC Space GaN FETs



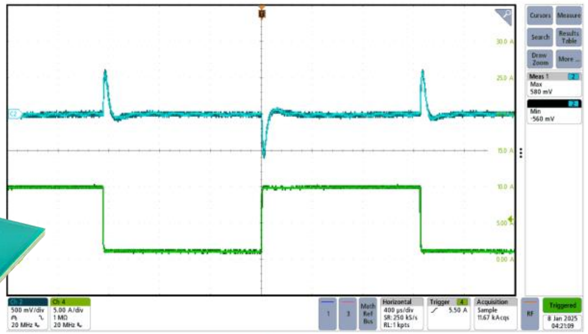
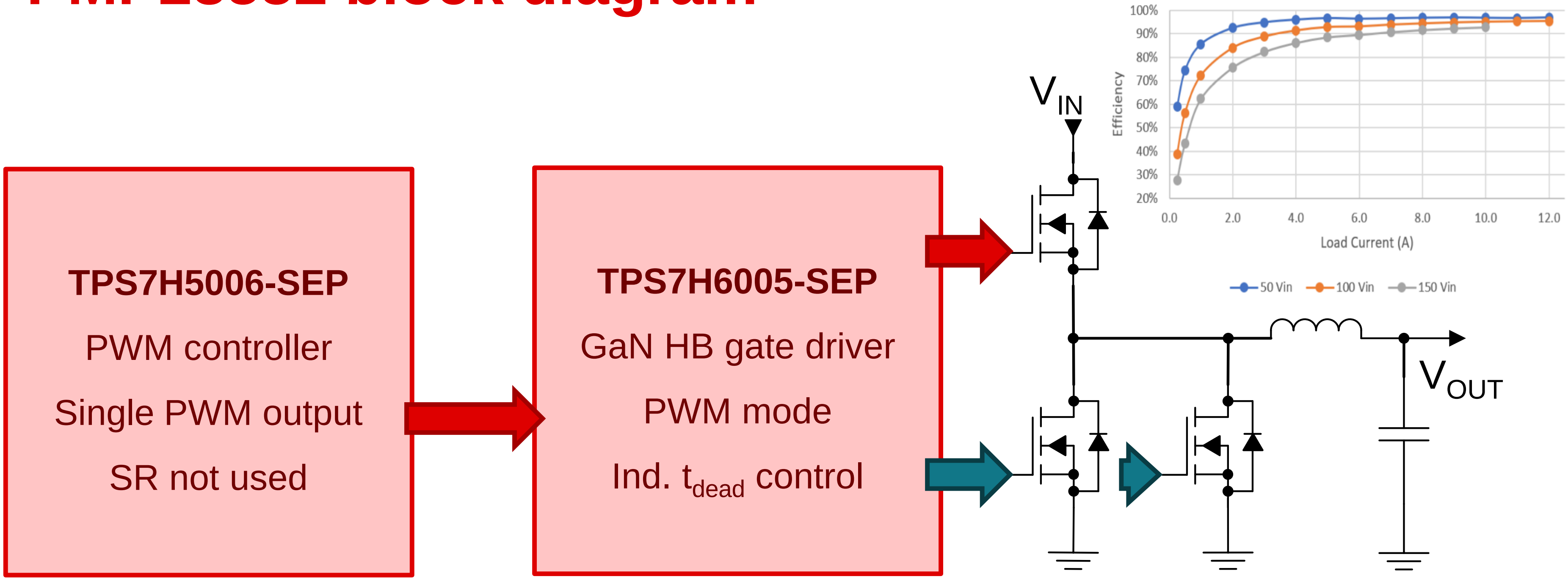


Figure 3-9. Load Transient, 100V_{IN}, 1A to 10A

Parameter	Specification
Input voltage	50 V to 150 V
Output Voltage	28 V
Output Current	12A
Switching frequency	250 kHz
Efficiency (100Vin)	95.3%

For test report, design files, and more: https://www.ti.com/tool/PMP23552

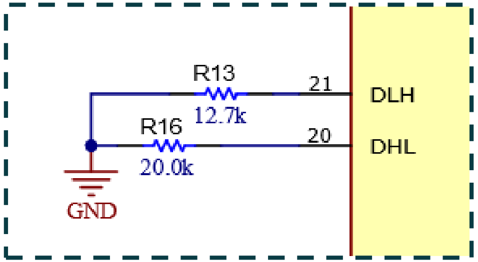
PMP23552 block diagram

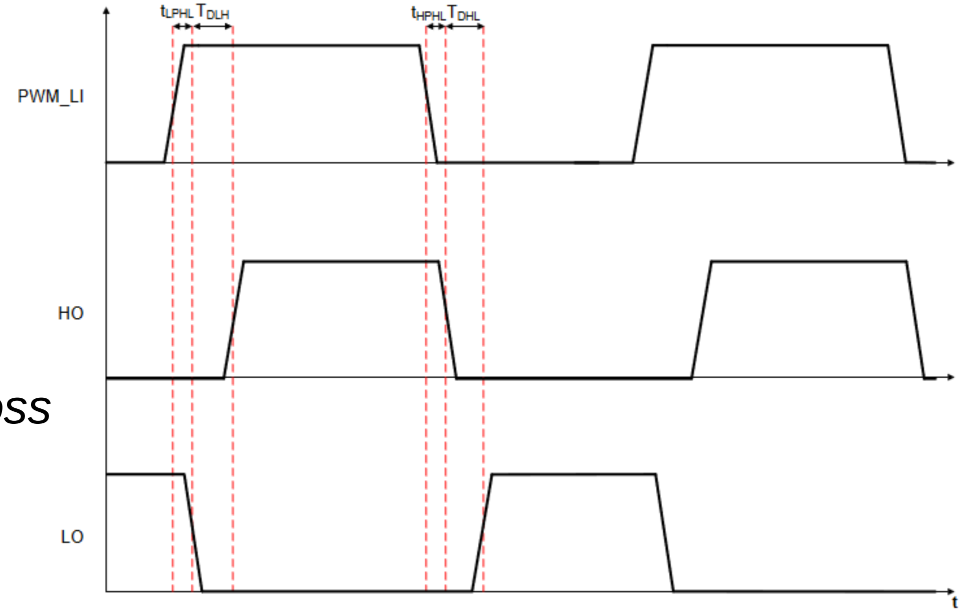


Two low-side FETs for improved efficiency

Independent dead-time

- Separate settings for high-to-low and low-to-high transitions
  - Range of 5 to 100 ns
- Slower ~ less ringing
- Faster ~ reduce switching loss
  - *Critical for GaN 3rd quadrant loss*





GaN vs. Silicon FETs

Comparing GaN FET from PMP23552 with closest Si FET alternative

Parameter	Ex Si FET	Ex GaN FET	Benefit
Rating	100 krad(Si)	100 krad(Si)	Still able to match IC rating with Si
Package dimension	18.0mm x 13.5mm	8.2mm x 5.7mm	*Each GaN FET is 1/5 the size!*
$R_{DS,on}$	28 mOhm	14.5 mOhm	Higher current capability
C_{OSS}	949 pF	640 pF	Less switching loss
C_{ISS}	8120 pF	1313 pF	Easier to drive *(with the correct driver!)*
V_{miller}	6.2 V	2.3 V	
V_{SD}	1.2 V	1.7 V*	*GaN does not have a true body diode, 3rd quadrant losses take place of Si body diode loss

Thermal testing

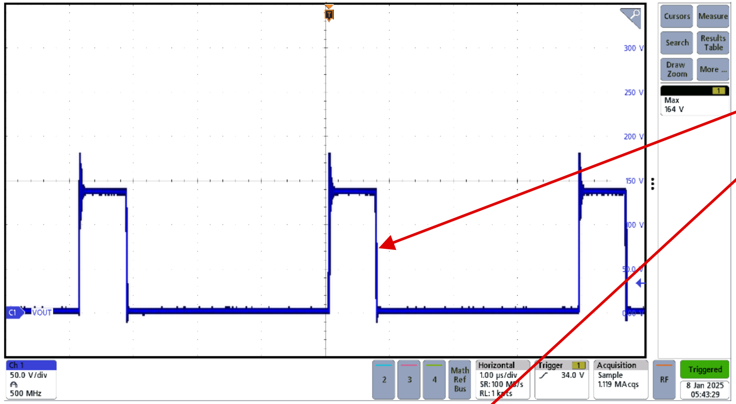
Measurements	
Sp1	52.0 °C
Sp2	66.2 °C
Sp3	34.6 °C
Sp4	44.3 °C
Sp5	41.8 °C
Sp6	44.0 °C
Sp7	34.9 °C
Sp8	30.1 °C

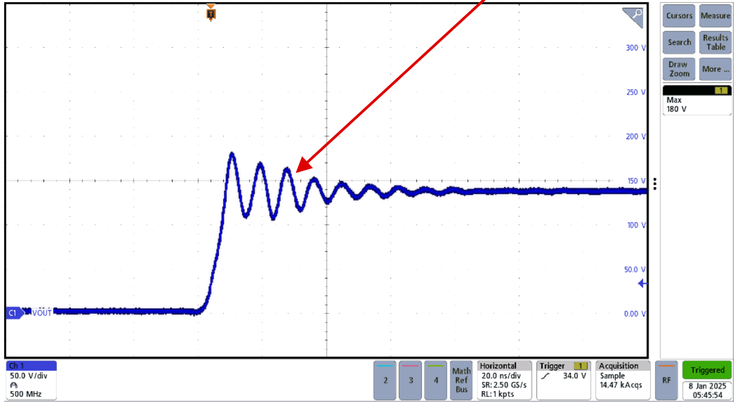
Parameters	
Emissivity	0.95
Refl. temp.	20 °C

100V input, full load, local airflow

Meas.	Component
Sp1	Inductor (L1)
Sp2	High-Side GaN FET (Q1)
Sp3	Half-Bridge Gate Driver (U1)
Sp4	Low-Side GaN FET (Q2)
Sp5	Low-Side GaN FET (Q3)
Sp6	Fault Sense Resistor (R14)
Sp7	Op-amp (U3)
Sp8	PWM Controller (U2)

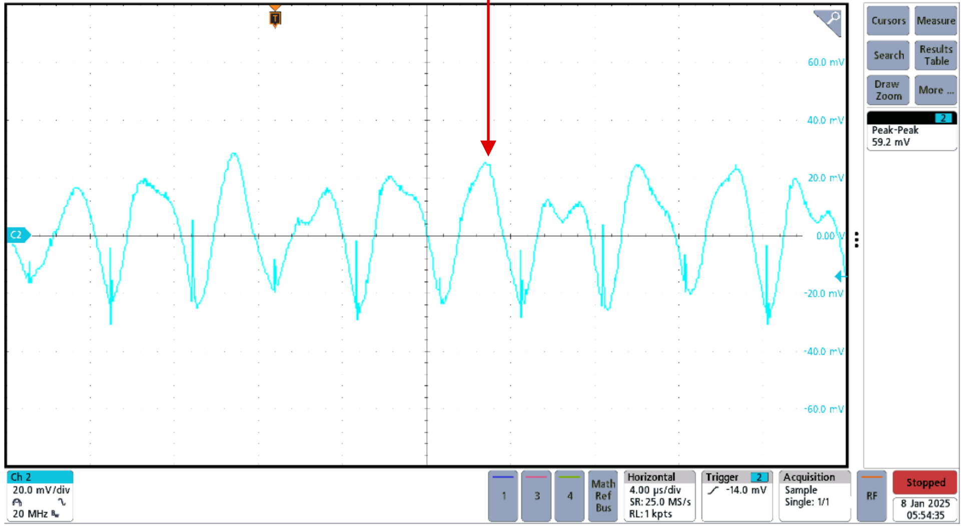
Additional waveforms





Minimal ringing on GaN FETs

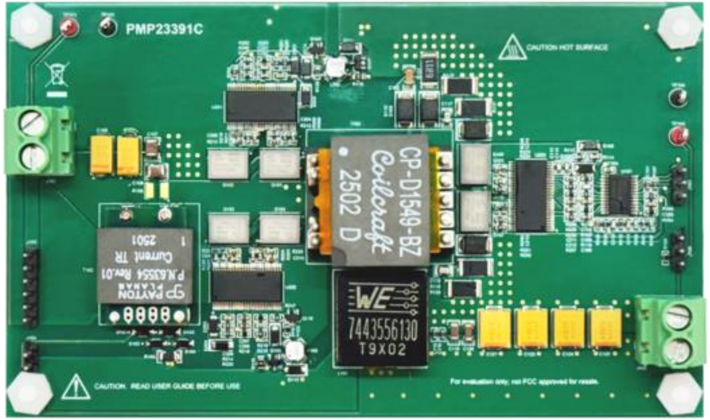
<60mV peak-to-peak output ripple



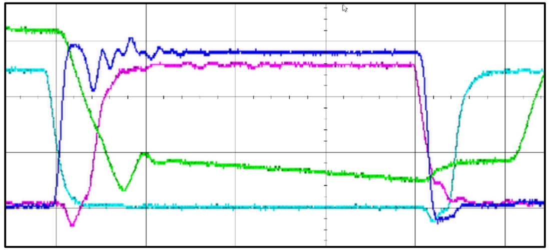
PMP23391 PWM Zero Voltage Switch full-bridge

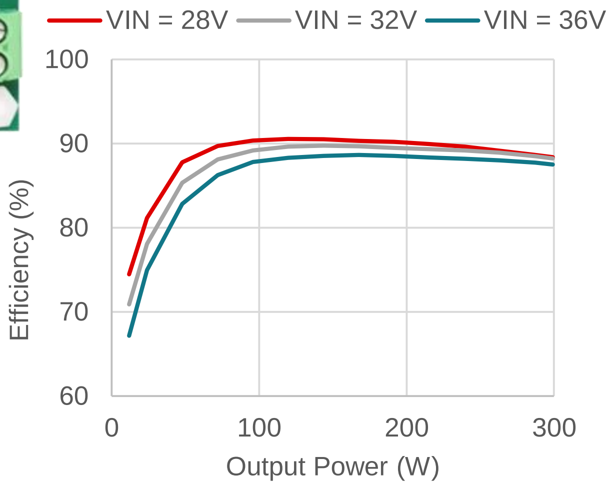
Features

- PWM zero voltage switching (ZVS) sync full-bridge using GaN FETs for higher power density
- ~92% efficiency @ 28V Vin
- Secondary-side control with synchronous rectification
- Low-profile planar transformer
- 3.5” x 5” PCB
- GEO setup: TPS7H5001-SP, TPS7H6013-SP x3, EPC Space GaN FETs
- LEO setup: TPS7H5005-SEP, TPS7H6015-SEP x3, EPC Space GaN FETs



Parameter	Specification
Input voltage	22 V to 36 V
Output voltage	12 V
Output current	25 A max
Switching frequency	500 kHz (Primary)
Output ripple	108mV peak-to-peak

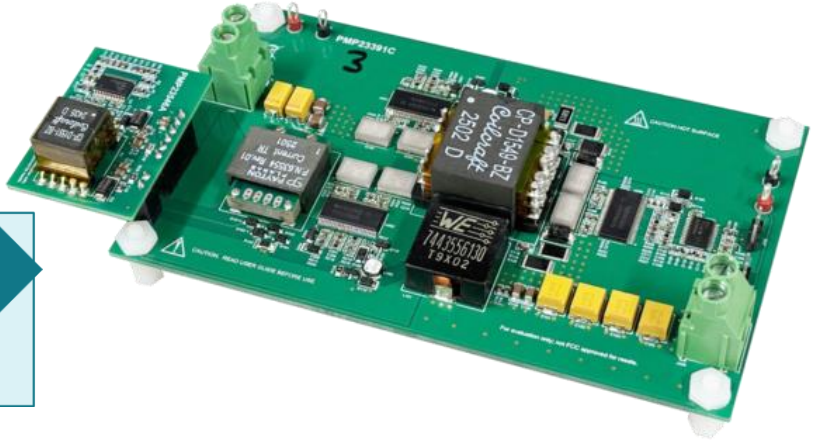


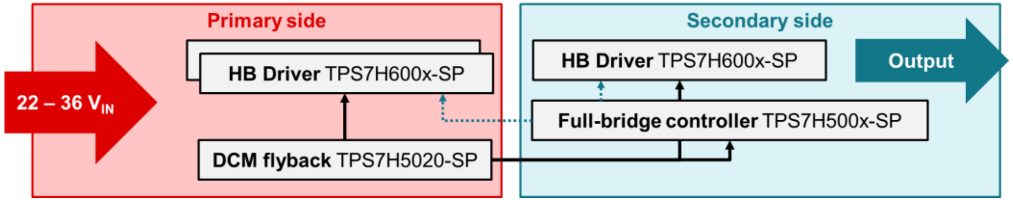


For test report, design files, and more: PMP23391

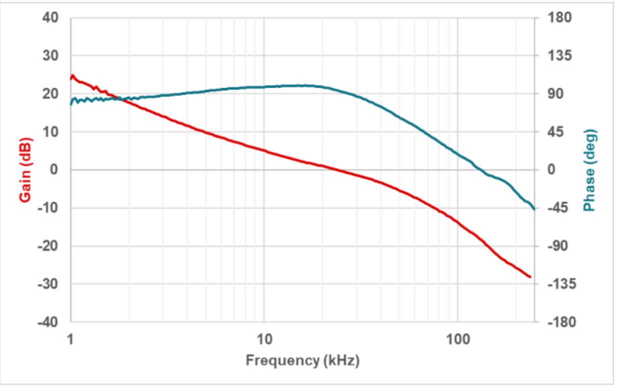
Faster response time with secondary-side control

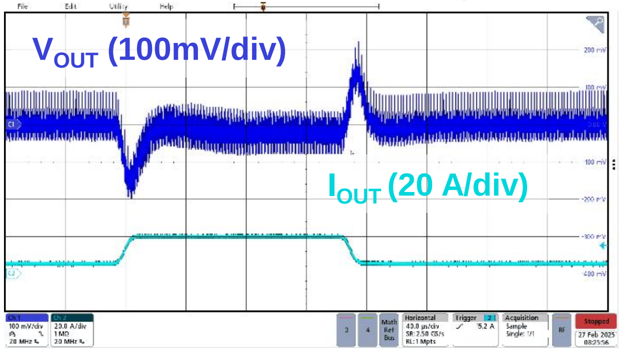
- Bias provided by flyback converter referenced on primary side (PMP23546)





- Coupled-inductor circuit used to send OUTA/B PWM to primary side
- V_{OUT} sensed directly
  - **Greater bandwidth!**
  - 23.86 kHz, 94.219°$_{Phase}$

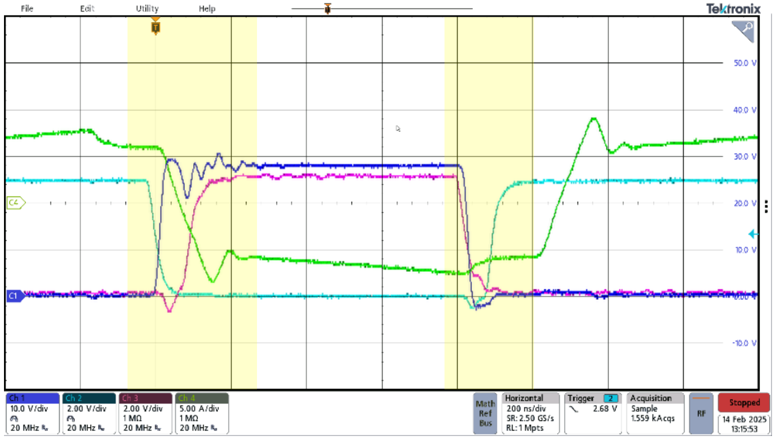


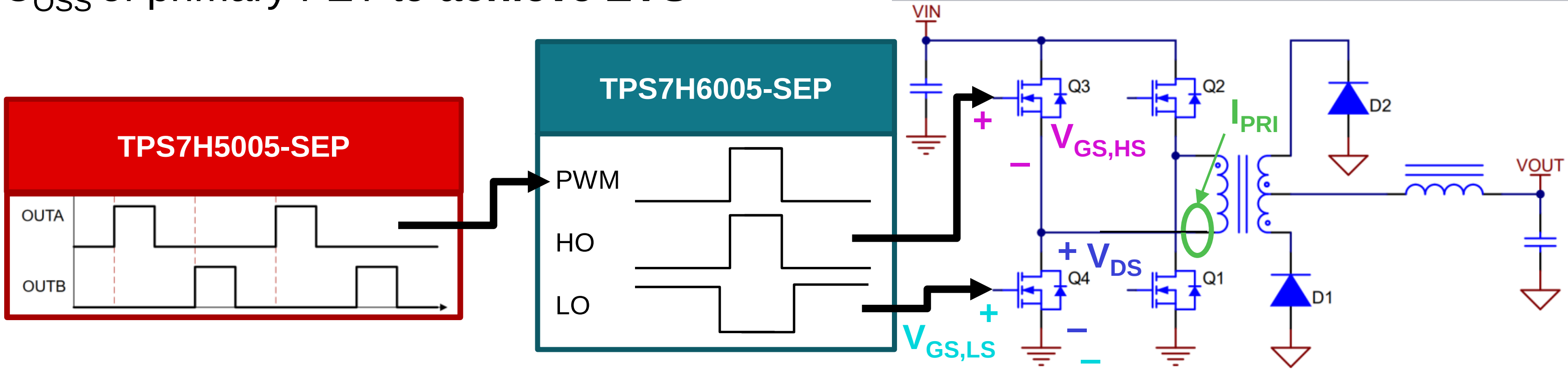


40us/div time scale

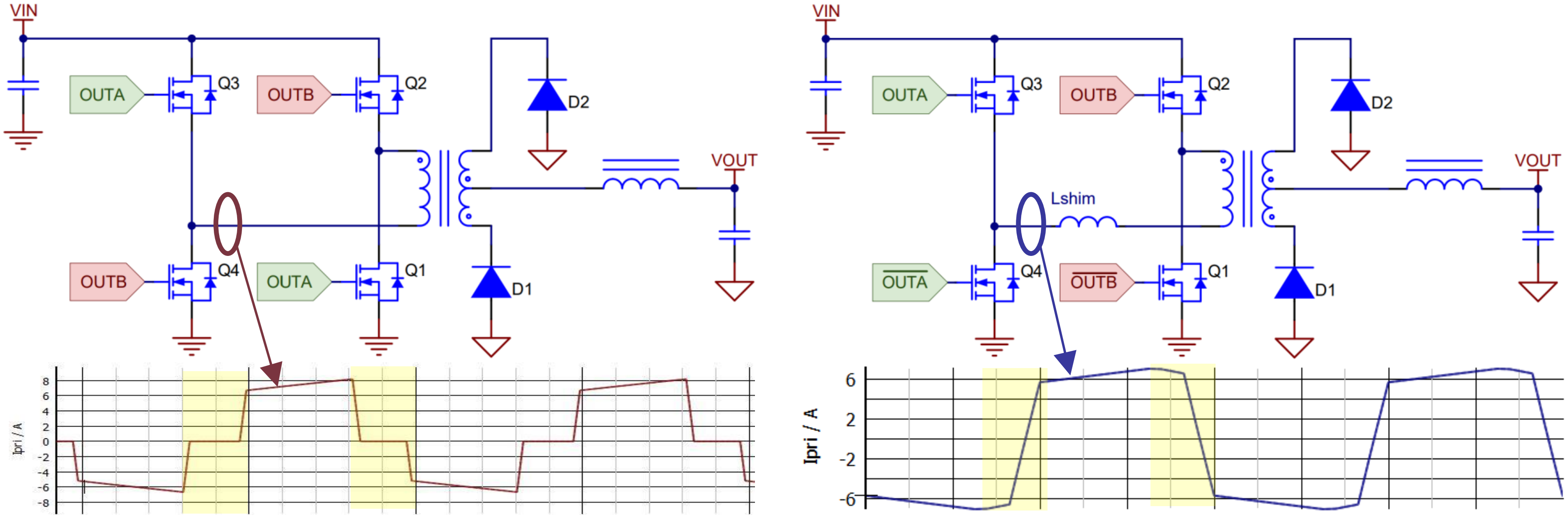
Zero voltage switching (ZVS) with PWM controller

- OUTA/B from TPS7H5005-SEP control timing of high-side FETs and SR
- TPS7H6005-SEP set to **PWM mode**, low-side FETs on when OUTA/B low
- When both low-side FETs are on, **circulating current** in I_{PRI} discharges C_{OSS} of primary FET to **achieve ZVS**





Hard-switched vs. complementary driven

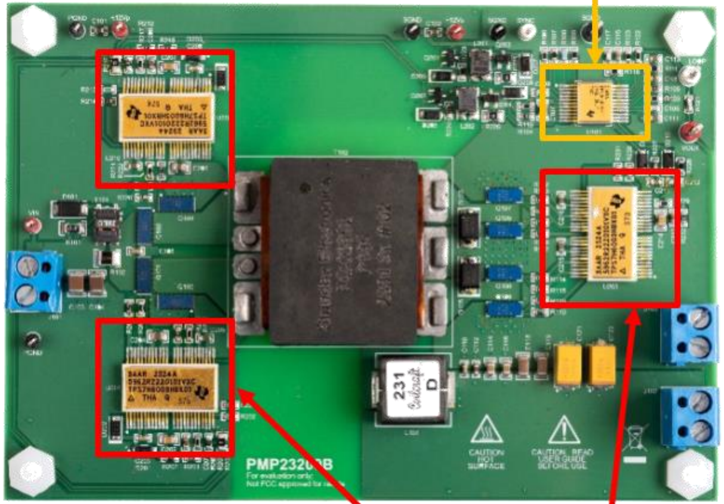


- Same power stage*, different PWM logic for primary-side FETs
- Additional **free-wheeling current** with complementary-driven allows for ZVS

* = additional shim inductance allows for control over when ZVS occurs

Same chip-set, better performance

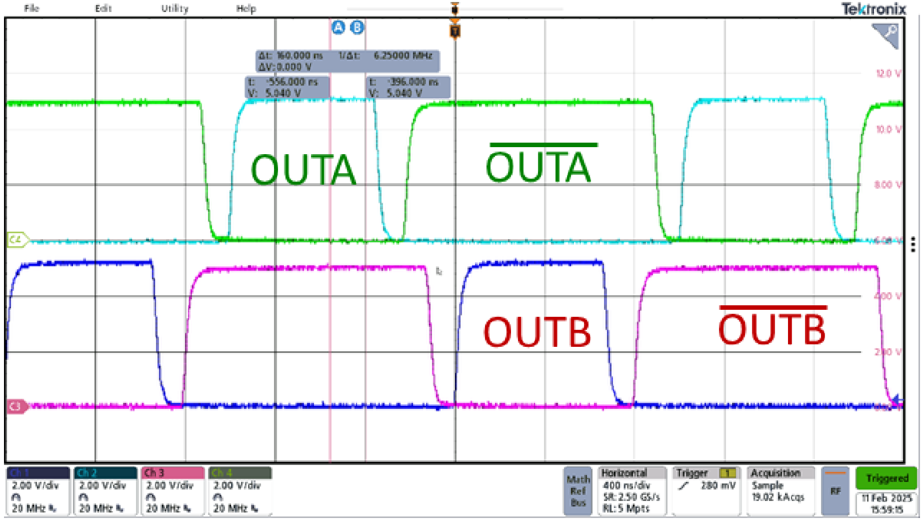
TPS7H5001-SP
PWM controller



TPS7H6003-SP
Half-bridge driver

Experiment: take hard-switch full-bridge,

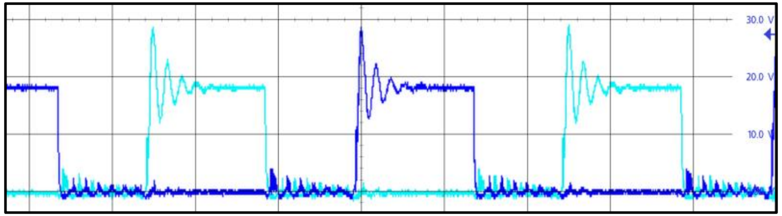
Change logic to *complementary*



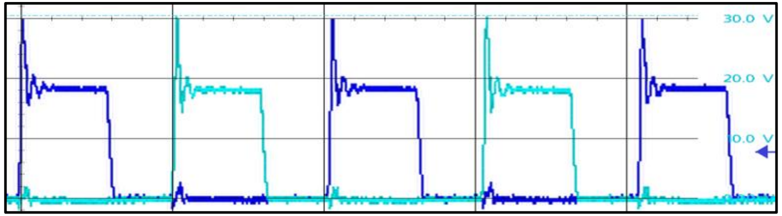
Same chip-set, better performance

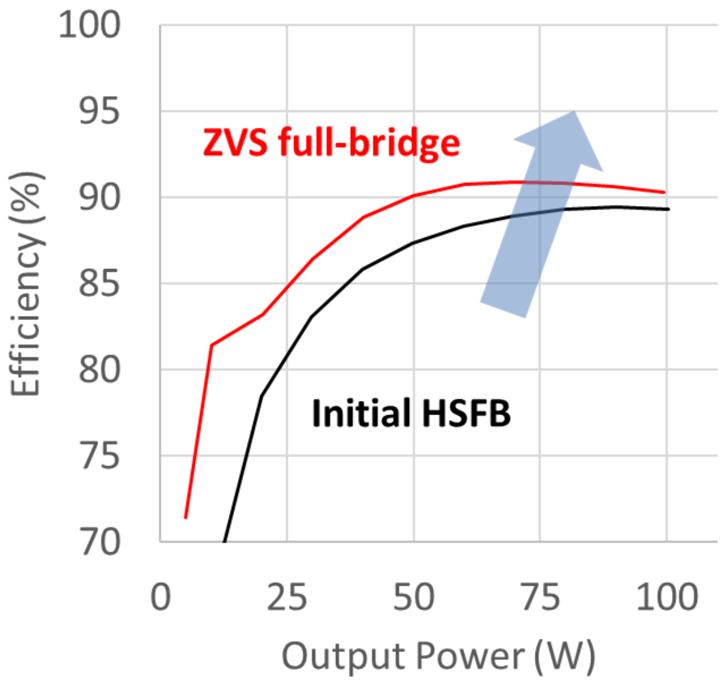
- Noticeable increase in efficiency
  - 2-4% across load
  - **Same BOM** for both data sets
    - Improvements could be made in optimizing dead-times and adding shim inductor

Secondary switch nodes from HSFB

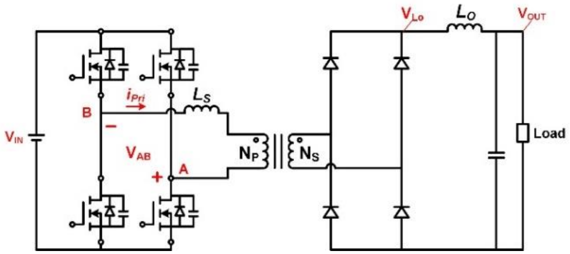


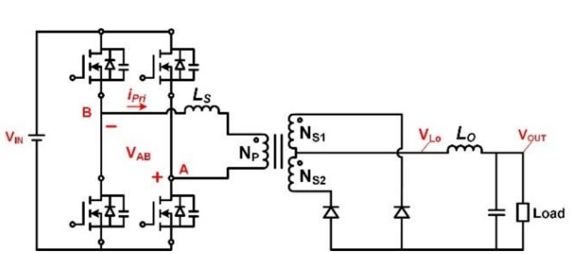
Secondary switch nodes with ZVS

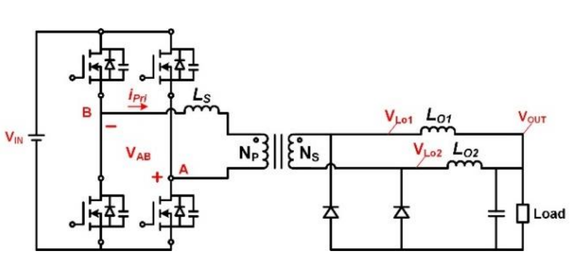




Scalability – different secondary configurations







Full bridge	Center tapped	Current doubler
Better transformer utilization	Lower transformer utilization	Better transformer utilization
Additional FETs and drivers	Lowest component count	Additional magnetic components
Good for high V_{OUT}	Balanced performance	**Good for high I_{OUT}**

Current reference designs using TPS7H5005-SEP

show *center-tapped* secondary configuration

Getting started

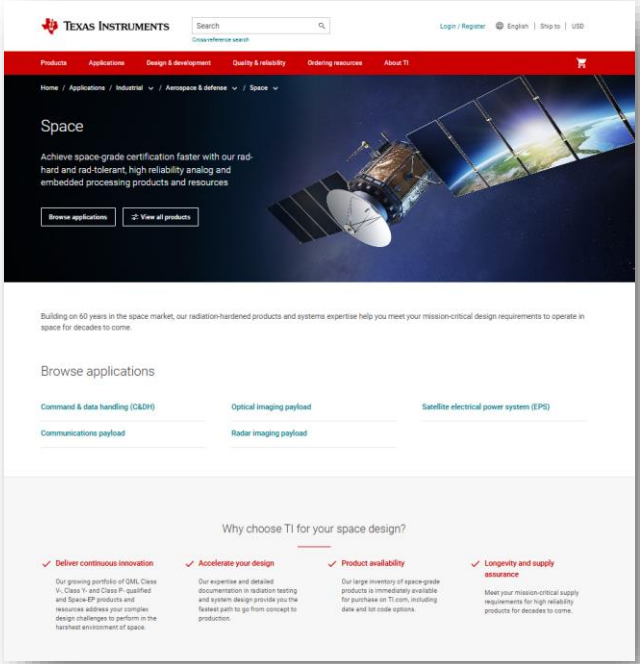
You can start evaluating this device leveraging the following:

Product folders	TPS7H6003-SP, TPS7H6013-SP, TPS7H6023-SP, TPS7H6005-SEP, TPS7H6015-SEP, TPS7H6025-SEP
Reference designs	PMP23200, PMP23389, PMP23391, PMP23546
Customer training series	T-60 Space Video series
Design tools and models	TPS7H60xx-SP PSpice Transient Model TPS7H60xx-SP SIMPLIS Model
Evaluation kits	TPS7H6003EVM-CVAL, TPS7H6013EVM-CVAL, TPS7H6023EVM-CVAL, TPS7H6005EVM, TPS7H6015EVM, TPS7H6025EVM

Thank you – Open Q&A

All space resources

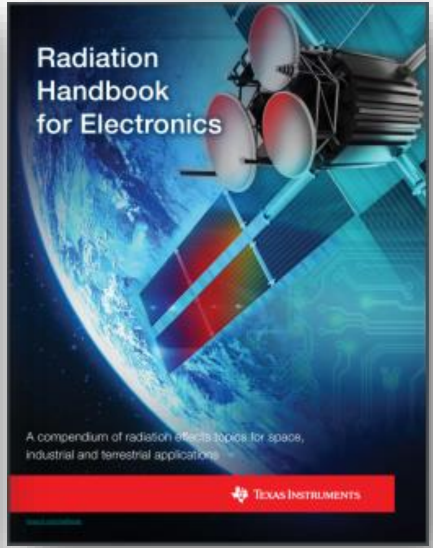
ti.com/**space**



Our space guides

2025 TI Space Products Guide

ti.com/**spaceguide**



Radiation Handbook for Electronics

ti.com/**radbook**

Texas Instruments

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