TEXAS INSTRUMENTS

TI *Live!* INDIA AUTOMOTIVE SEMINAR

LEANNE ZHANG, BOB MA

AUTOMOTIVE USB CHARGER CHALLENGES AND INNOVATIONS

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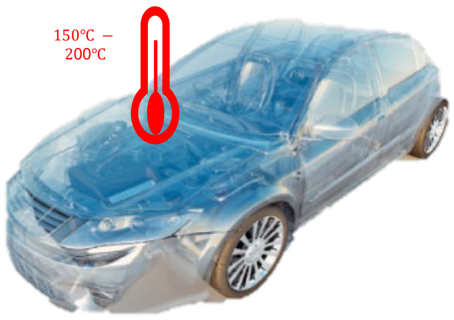
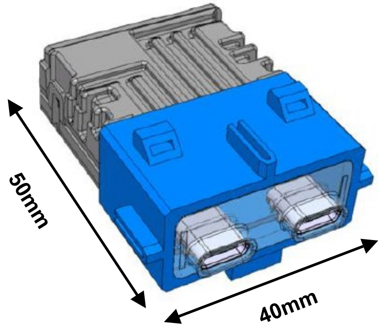
Automotive USB design challenges

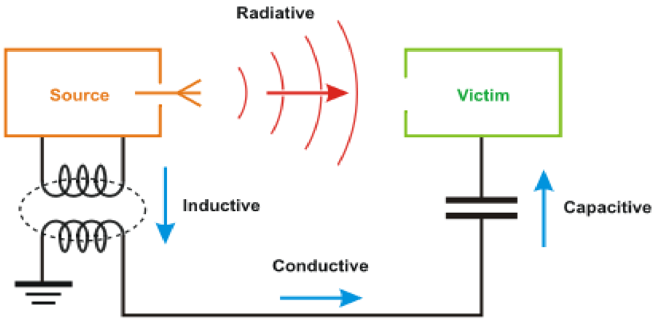
Charging circuit thermal



Small model, No airflow

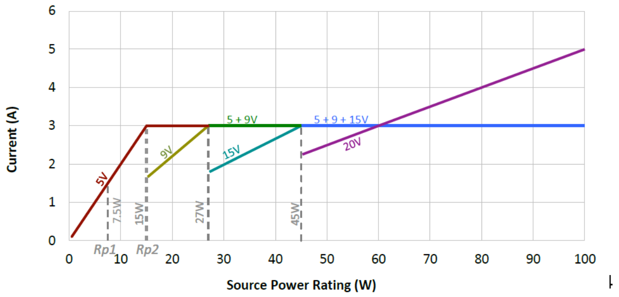


Electromagnetic Compatibility EMC



Compatibility for max power charging

Higher power density



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02

Excellent thermals confronting a warm environment

a. HotRod™ package contributes die heat dissipation

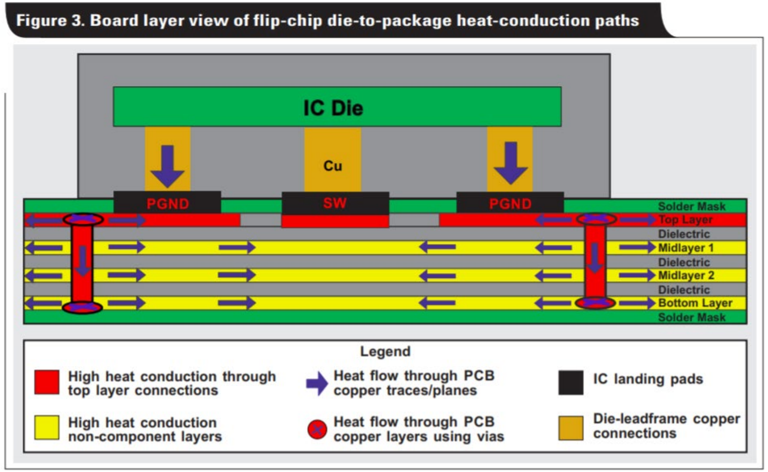
b. NTC smart thermal management

c. Good thermals with high efficiency

d. Real-life thermal test results

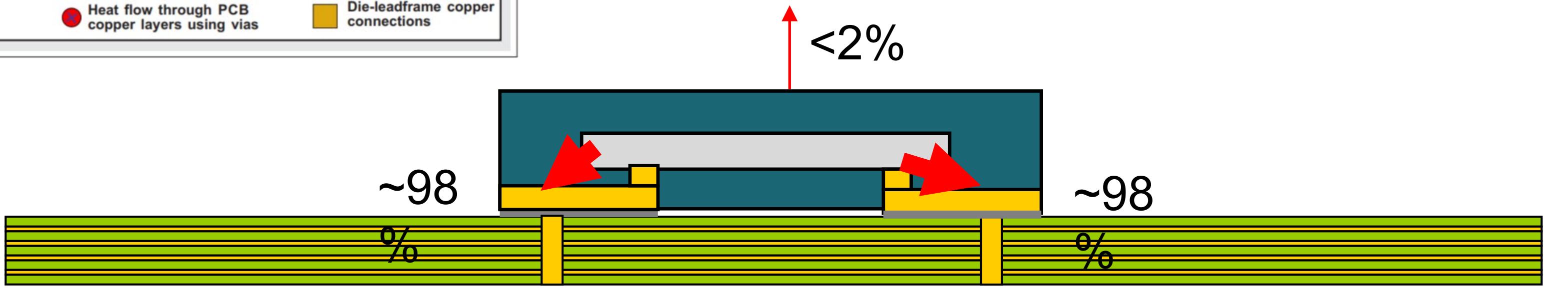
Achieving good thermals with VQFN-HR

- Good heat conduction through pin, wide copper planes

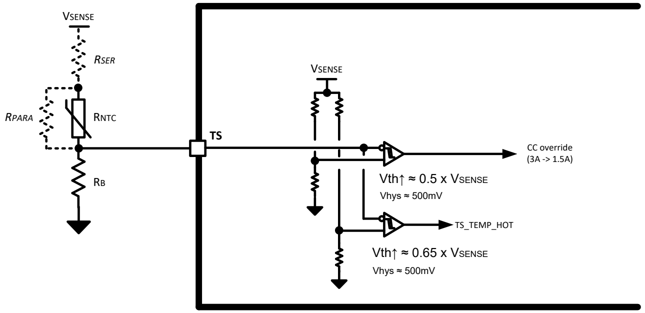


Thermal path for HotRod™

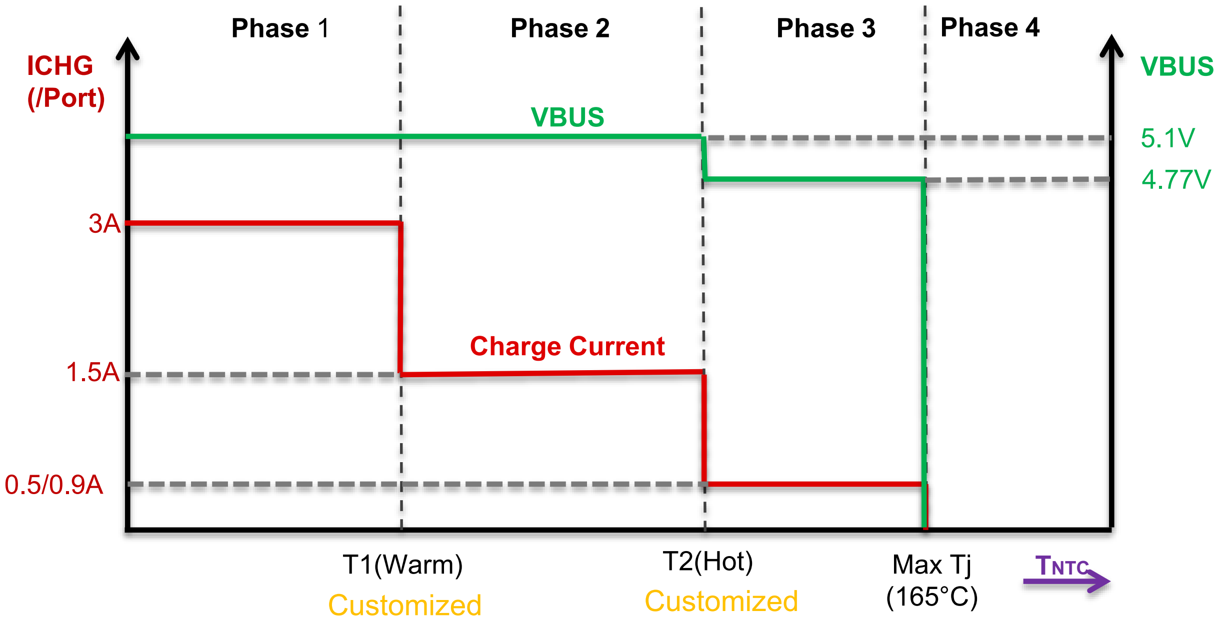
- **Flipped die on lead frame (HotRod™)**
- **Thermal design for these packages**
  - Large pads connected to power devices are essential to distribute heat.
  - Most of heat is through large pads because of metal routing but pins can also distribute heat
    - » PGND, GND, SW: most effective



Smart thermal management and load shedding

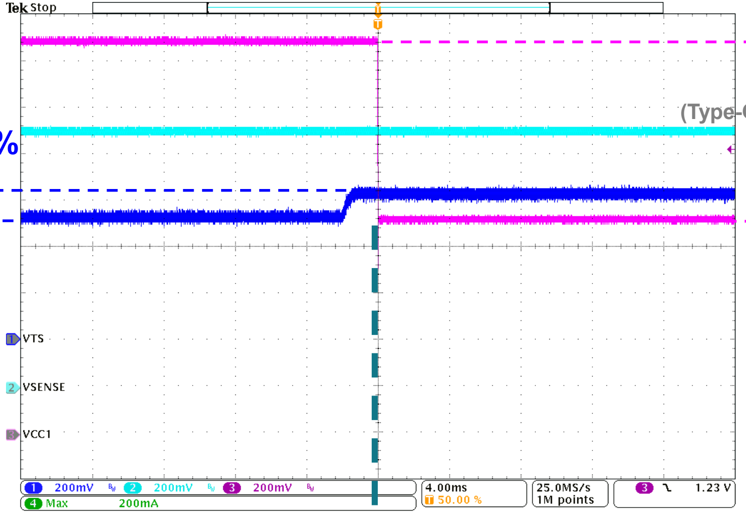


Phase	Description
Phase 1	Normal operation; Charge at full load
Phase 2	Temp Warm: Broad 1.5A type-C, reduce the current by half
Phase 3	Temp Hot: Broad Default USB mode; Reduce the BUS voltage to 4.77V
Phase 4	TDie rise to max Tj:Thermal shut down



Smart thermal management and load shedding

V_{TS} → >50%

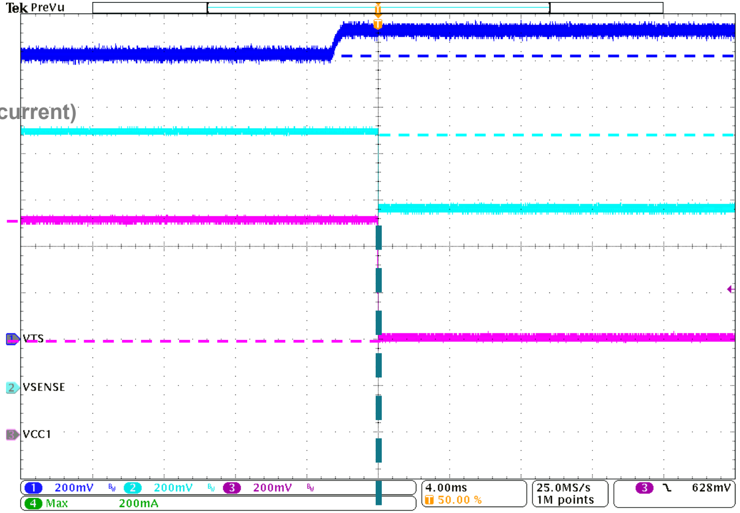


V_{CC1}

(Type-C broad current)

V_{TS} → >65%

$V_{SENSE/BUS}$



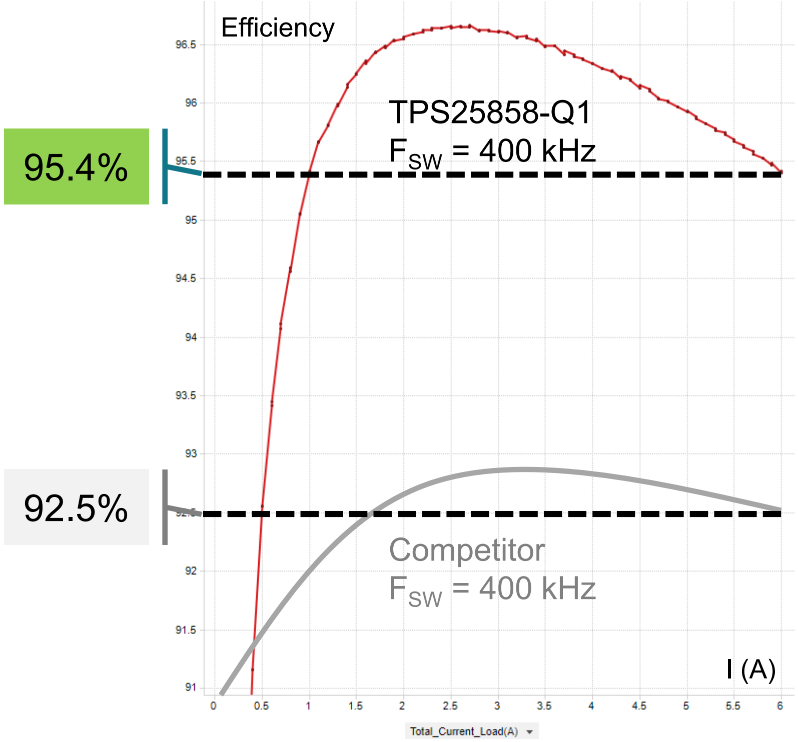
Type-C Broad 1.5A @ CC1/2

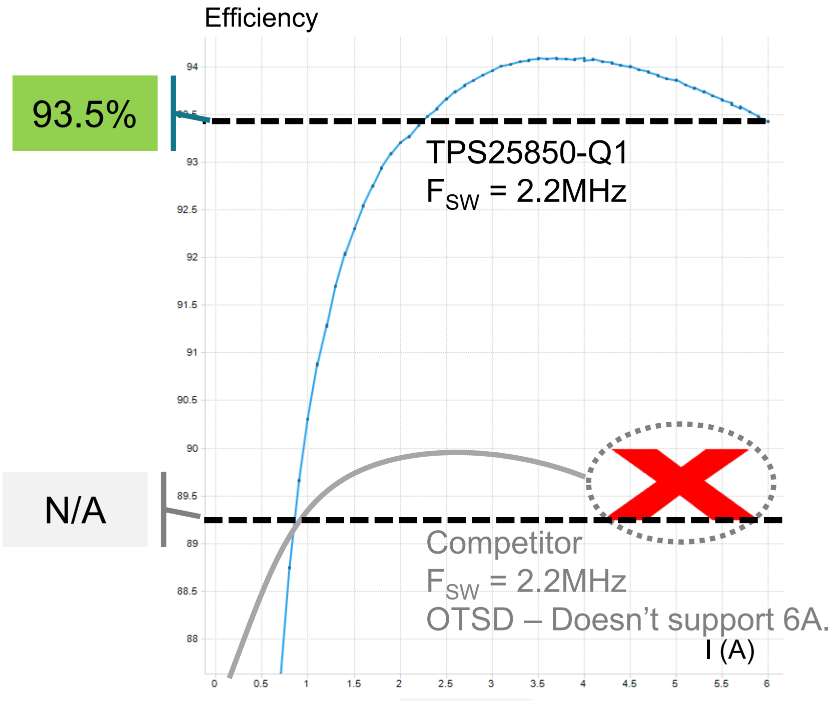
Type-C Broad 0.5A @ CC1/2
SENSE voltage drop to 4.77V

Temp Warm(T1)

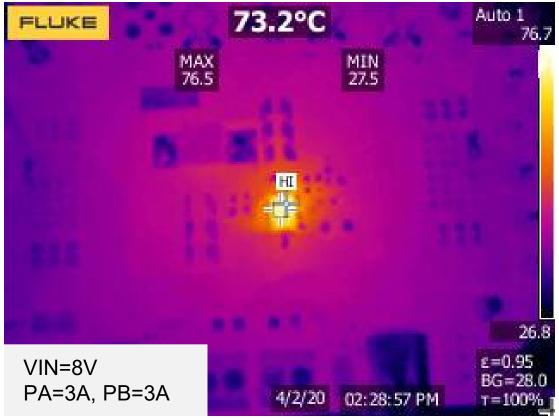
Temp Hot(T2)

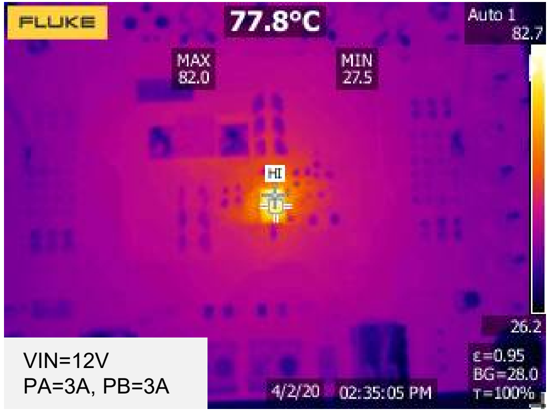
Good thermals with high efficiency

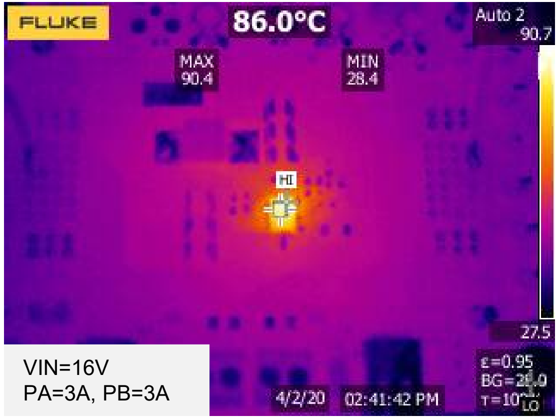




TPS25850-Q1 thermal @2S2Pboard, 2 MHz







Temp rise: 49.5°C

Temp rise: 55°C

Temp rise: 63.4°C

Support full load at 85°C ambient:

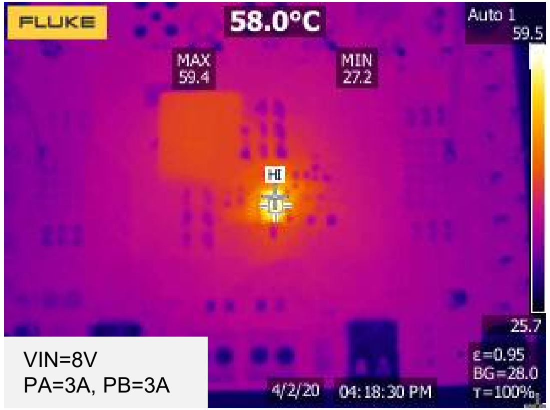
f_{SW} = 2.2MHz, VIN = 12V, TA = 25°C, Charge Current = 2*3A

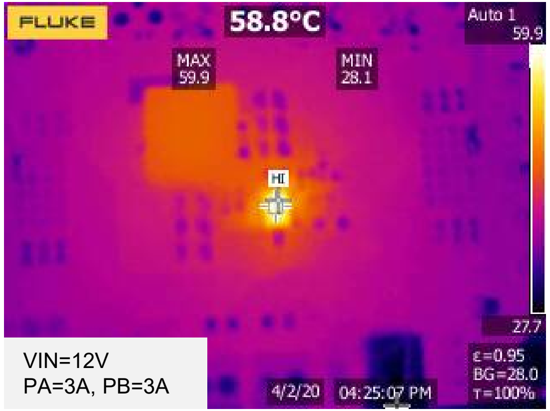
As $T_{Ambient}$ = 85°C, T_{Rise} = 55°C

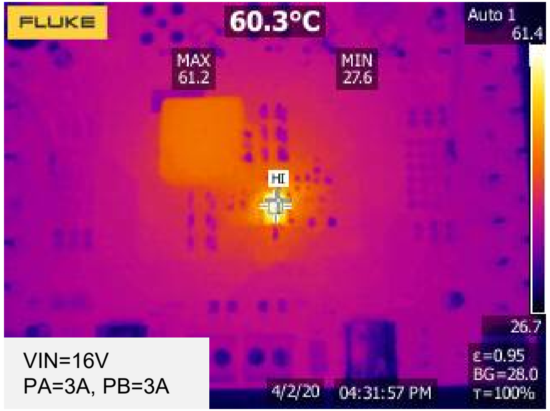
$T_j = T_{Ambient} + T_{Rise}$

T_j = 85°C+ 55°C = 140°C, < 150°C (recommended max T_j)

TPS25858-Q1 thermal @2S2Pboard, 400 kHz







Temp rise: 32.4°C

Temp rise: 32.9°C

Temp rise: 34.2°C

Support full load at 85°C ambient:

f_{SW} = 2.2MHz, VIN = 12V, TA = 25°C, Charge Current = 2*3A

As T_{Ambient} = 85°C, T_{Rise} = 33°C

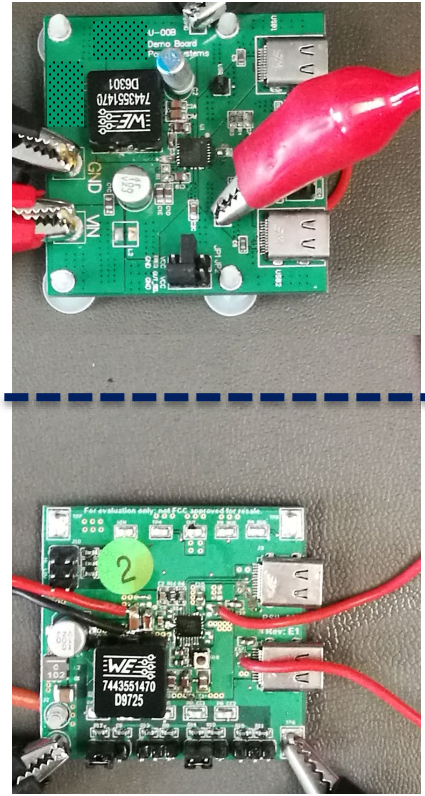
$T_j = T_{\text{Ambient}} + T_{Rise}$

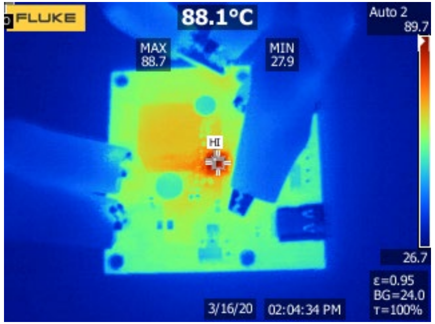
T_j = 85°C+ 33°C = 118°C, < 150°C (recommended max T_j)

TPS25858 thermal on compact board

Competitor EVM

50mm*50mm



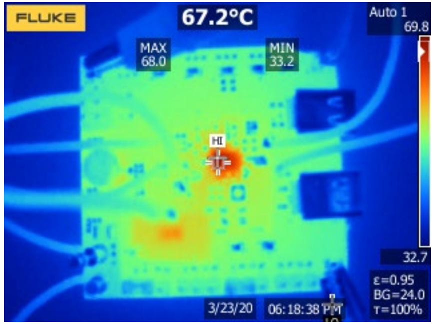


Competitor
VIN=12V, IBUS=2*3A

Max Temp = 88.7°C
Trise = **63.7°C**

TPS25858-Q1 EVM

45mm*45mm



Board size: 20% smaller
Board temp: 20°C cooler

TPS25858-Q1
VIN=12V, IBUS=2*3A

Max Temp = 68°C
Trise = **43°C**

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03

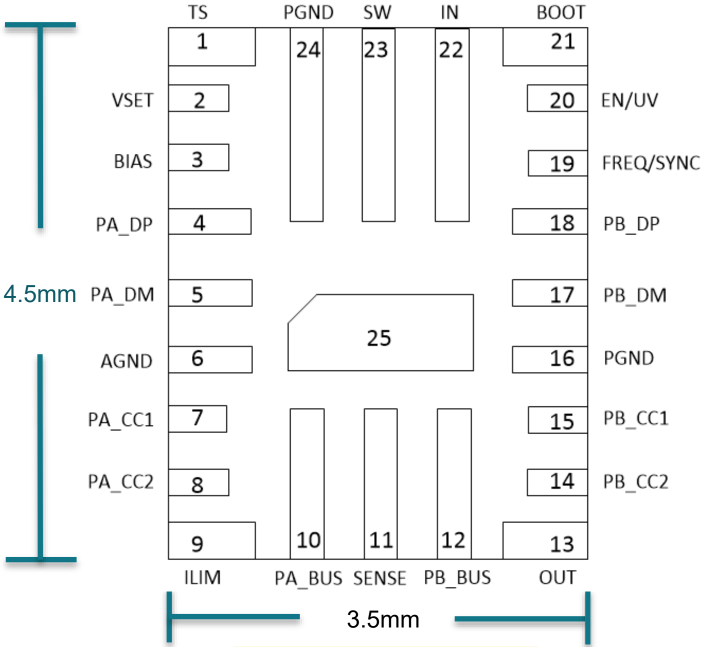
Small solution size

a. **Small package size with HotRod™**

b. **High integration assists small solution size**

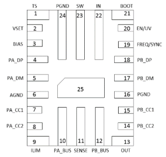
c. **2MHz operation enable smallest solution size**

TPS2585x small package size

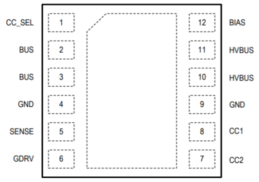


TPS25850/8-Q1

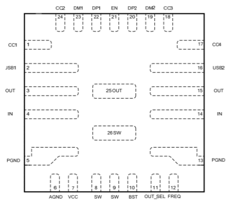
- TI's smallest package size for dual USB-C charging
- Benefits from HR package:
  - ➢ High power density
  - ➢ Good theta JA
  - ➢ Low parasitic compare to bounding wire improve EMI
- EMI friendly pinout



TPS25850/8-Q1
3.5mm x 4.5mm

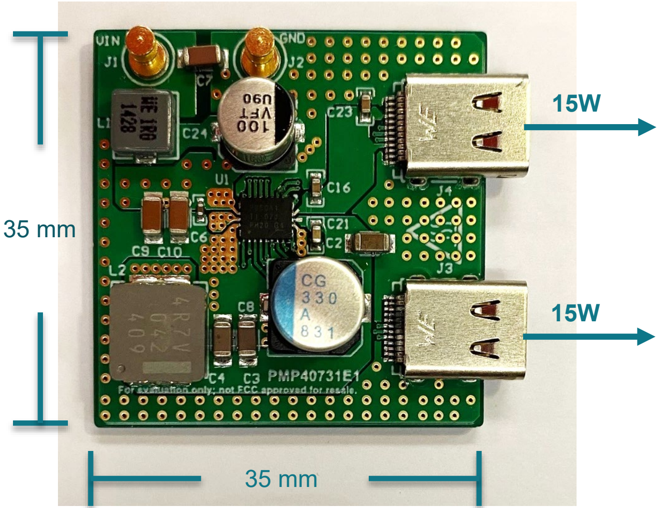


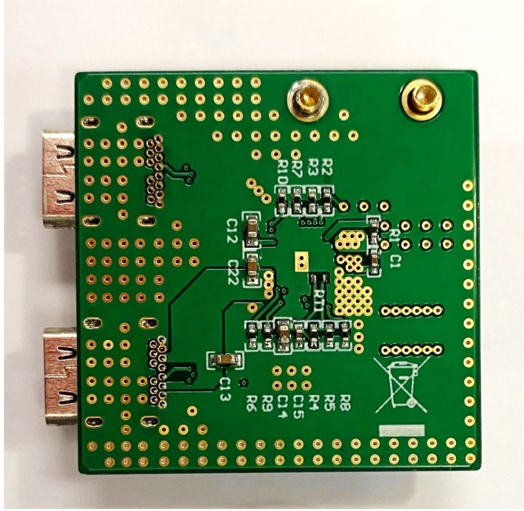
Competitor 1
5.0mm x 3.5mm



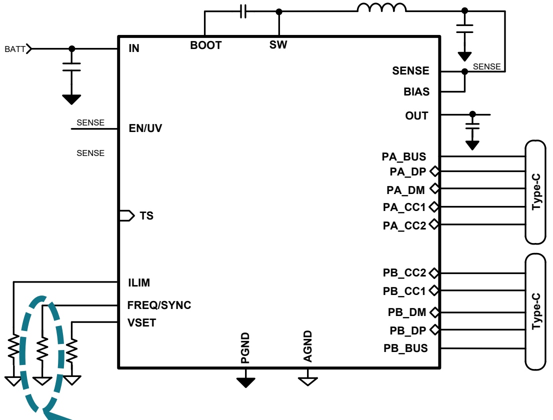
Competitor 2
5.0mm x 5.0mm

High integration, small solution size: PMP40731



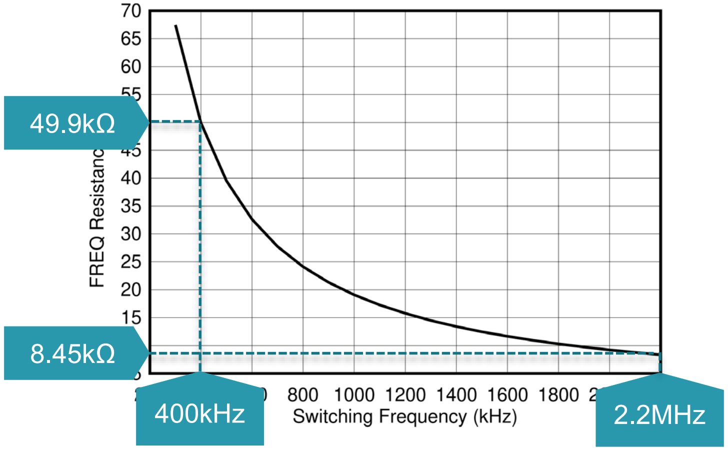


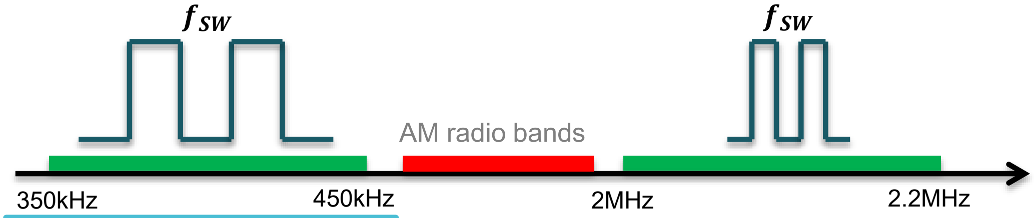
Operating frequency (f_{SW}) setting: 400 kHz ~2.2 MHz



Adjustable f_{SW} by selecting the correct R_{FREQ}

$$R_{FREQ}(k\Omega) = 26660 \times f_{SW}^{-1.0483}\ (kHz)$$

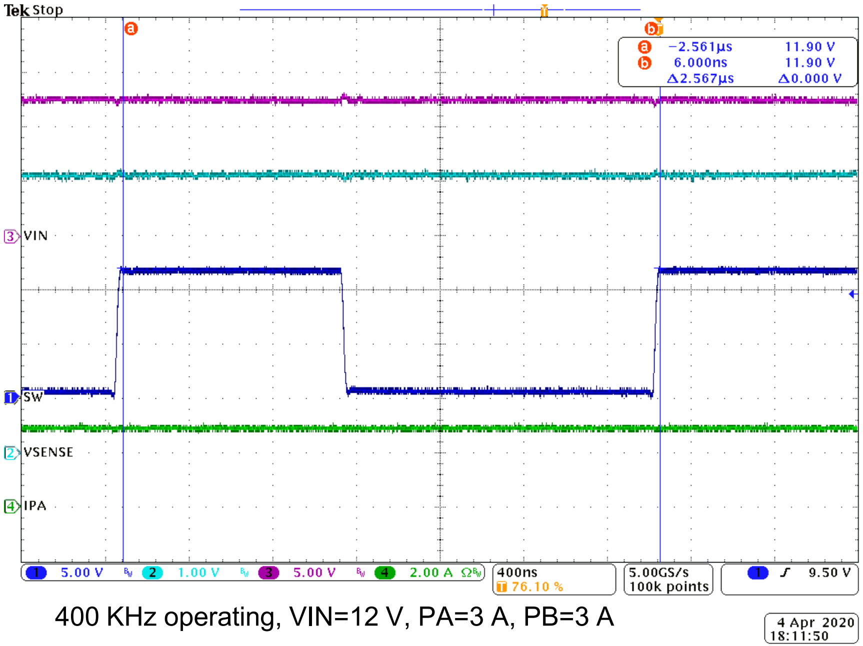




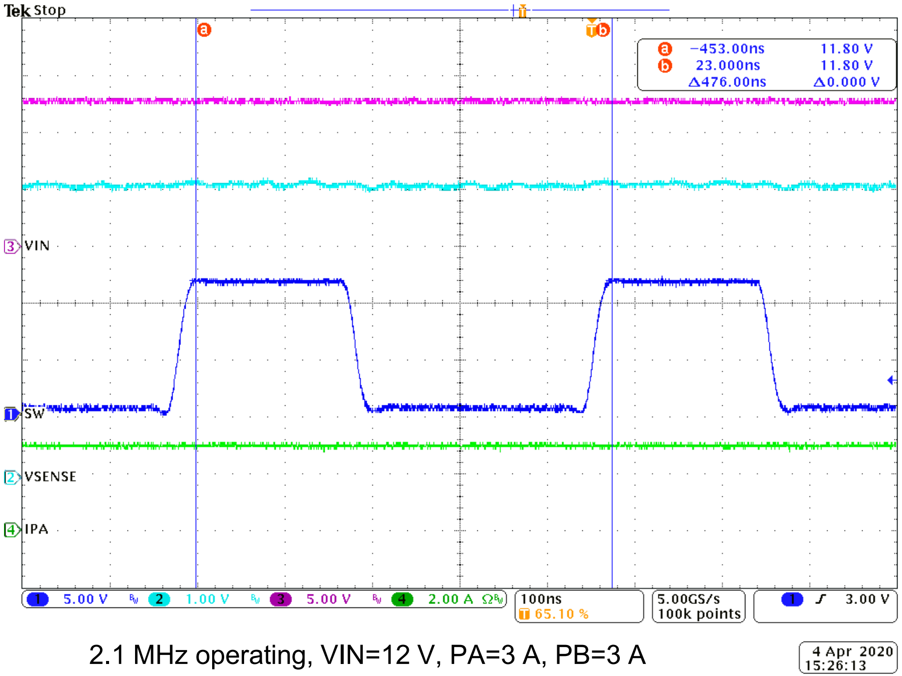
Recommended operating frequency for TPS25858-Q1

Recommended operating frequency for TPS25850-Q1

Remarkable performance at 2.1-MHz operation

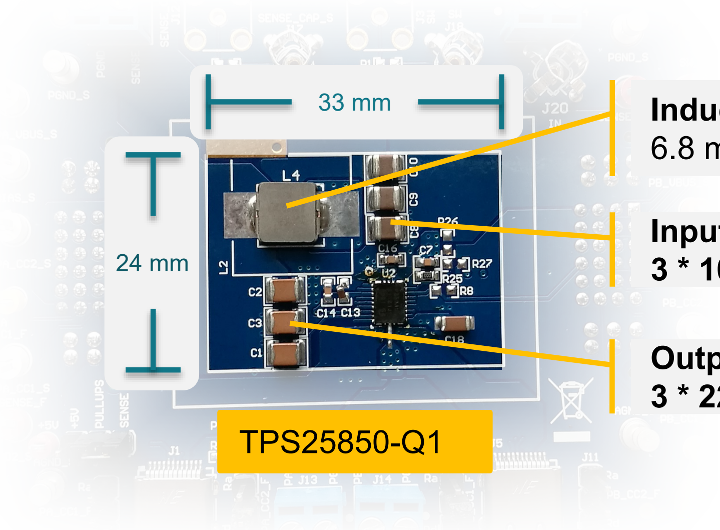


400 KHz operating, VIN=12 V, PA=3 A, PB=3 A



2.1 MHz operating, VIN=12 V, PA=3 A, PB=3 A

2-MHz operation enables smallest solution size



Inductor 0.68 μH
6.8 mm * 6.4 mm

Input cap
3 * 10 μF + 0.1 μF

Output cap (SENSE pin)
3 * 22 μF

$$L_{MIN} = \frac{V_{IN\_MAX} - V_{OUT}}{I_{OUT} \times K_{IND}} \times \frac{V_{OUT}}{V_{IN\_MAX} \times f_{SW}}$$

$Set\ f_{SW} = 2.1MHz \qquad Give\ K_{IND} = 0.3$

$=> \quad L_{MIN} = 0.68\ \mu H$

2MHz vs 400KHz comparison			
Device		TPS25850	TPS25858
f_{SW}		2.1MHz	400KHz
BOM	**Inductor**	0.68uH	3.3uH
	Cout	3*22uF	3*47uF or 10uF+10uF+330uF
	Summary	-	L& C cost higher
Solution size	**IC**	25mm²	25mm²
	Inductor	43.5mm²	168.96mm²
	Capacitors	121.28mm²	152.16mm²
	Others		
	Total	~190mm² (~45%↓)	~346mm²

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04

Compatibility for different charging schemes

a. USB BC1.2 overview

b. Apple® /Samsung® charging

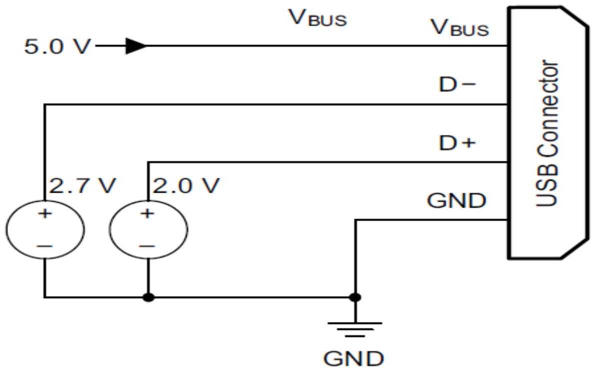
c. USB Type-C™ charging

USB battery charging 1.2

BC 1.2 defines the type of charger, handshaking, allowable current draws, and PD decision-making flowchart that defines the interaction between PD and host charger.

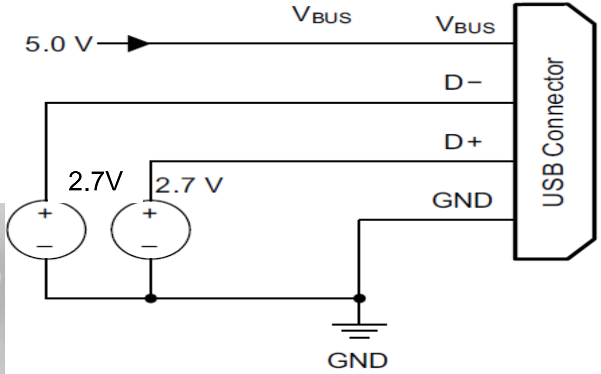
BC1.2 Port Type	Definition	5V Current Capability	Comments
Standard Downstream Port (SDP)	Compliant USB 2.0 port. No special charging capability	100 mA until authenticated by USB controller, then 500 mA. (USB port controller handles this authentication – NOT the USB power switch.)	Most USB 2.0 ports provide 1A or more, but there is no absolute way for a USB2.0 client to know this. Most devices just assume the power is there and draw what they need.
Dedicated Charging Port (DCP)	Wall wart charger. No data communication capability	Up to 1.5 A current	Wall wart chargers don't have a USB data transceiver or controller, but will need a small amount of handshaking, as defined by the BC1.2 standard, to let the client know "for sure" up to 1.5A of current is available.
Charging Downstream Port (CDP)	A USB 2.0 compliant port with intelligent charging capability	Up to 500 mA current if authenticated as SDP or up to 1.5 A current if authenticated as CDP.	CDPs can vary the amount of current available based on their power. For example, a notebook PC may limit power draw to 500mA on battery power (by responding to the PD as a SDP) – or allow 1.5A of draw when the AC adapter is present (by authenticating as a CDP). Data communications is allowed following the handshake as a CDP.

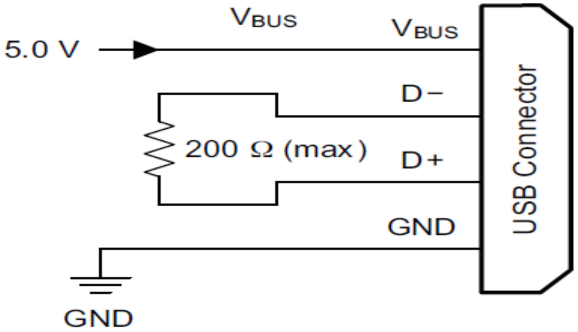
Different charging schemes



Apple ® iPhone®

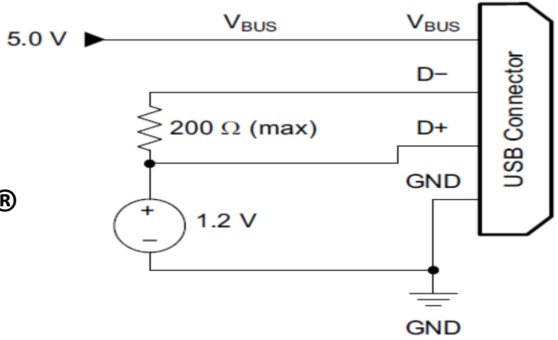
Apple ® iPad®





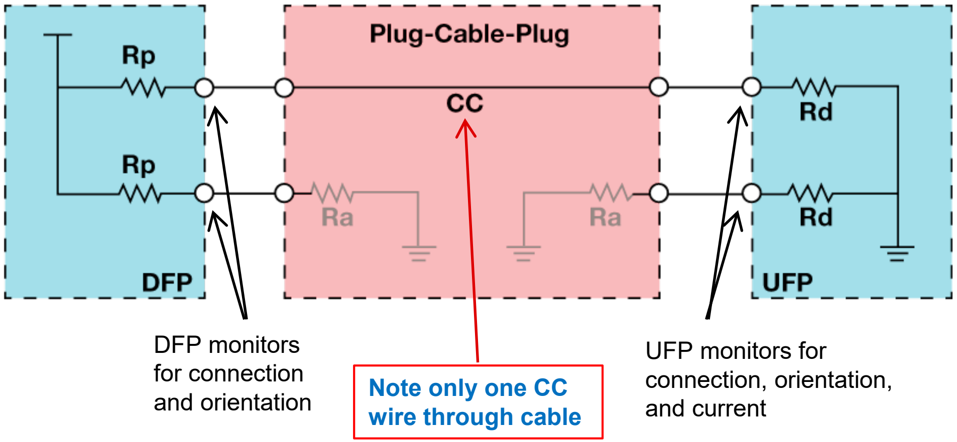
BC 1.2

Samsung®



USB Type-C channel configuration

Simple way to accommodate flippable, symmetrical & reversible cable



Type-C Data roles:

- Downstream facing Port (**DFP**) - Host
- Upstream facing Port (**UFP**) - Device
- Dual-role port (dual-role data **DRD** and dual-role power **DRP**) switch between DFP and UFP

Type-C power roles:

- **Source** - a provider of power when connected
- **Sink** - a consumer of power when connected

Simple resistor divider network between host and device

- DFP pulls up the CC pin with Rp
- UFP pulls down the CC pin with Rd
- DRD/P alternates between DFP and UFP

One CC wire in the cable

- DFP(UFP) can detect attachment of UFP (DFP) if active CC line has a Rd (Rp) on the other side
- DFP/UFP can detect plug orientation by monitoring which CC line is active
- DFP uses different Rp (or current source) values to advertise its current provider capability. USB default, 1.5A or 3A

Data and power roles

- By default DFP (host) is a power source and UFP (device) is a power sink
- USB PD can be used to change these roles

VCONN power

- DFP provides VCONN power (1W minimum) at the unused CC pin for electronics inside cable
- Cable installs pull-down resistor Ra to request VCONN power

USB Type-C power modes

Flexible and modular power-delivery methods

USB Type-C can be used to deliver power via a number of different protocols:

Precedence	Mode of Operation	Nominal Voltage	Maximum Current
Highest	USB PD	Up to 20 V	Up to 5 A
	USB Type-C current @ 3A	5 V	3 A
	USB Type-C current @ 1.5A	5 V	1.5 A
	USB BC1.2	5 V	Up to 1.5 A
	USB 3.1		900 mA
Lowest	USB 2.0		500 mA

Port power roles

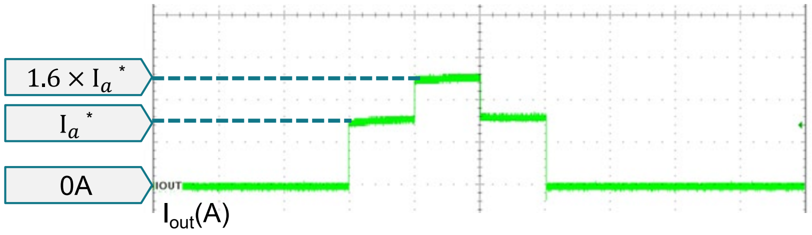
Following the introduction of USB PD, port power roles are now defined separately from the port data roles.

- **Provider:** device can only provide power
- **Consumer:** device can only receive power
- **Consumer provider:** the device can act as either a consumer or provider. This is only possible for devices that support USB PD

Capable of delivering up to 100W over one USB Type-C port!

Compatible with MFi OCP

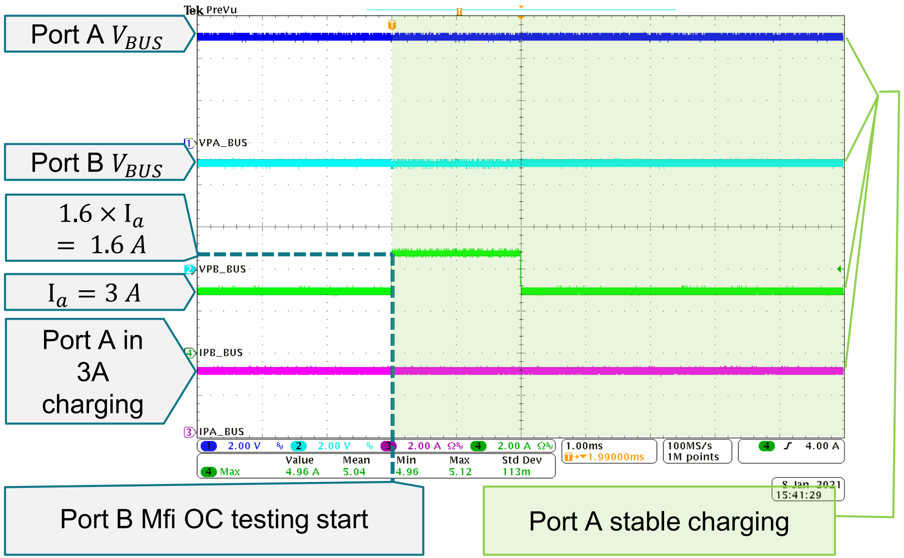
Apple® MFi OC Test standard



* I_a: nominal accessory/USB charger output current.

Test conditions	
Type-C port	$I_a = 3000\ mA$ $1.6 \times I_a = 4800\ mA$
Type-A port	$I_a = 2400\ mA$ $1.6 \times I_a = 3840\ mA$
Lighting device power during testing	> 2 V

Real-life test result with TPS25850 (Type-C)



PASS MFi certification

Condition: Port A in stable 3A USB charging; Apply MFi OCP to Port B.

Results: Otput 5V, 3A; Port B support 4.8A @2ms pulse current, VPB_BUS is stable.

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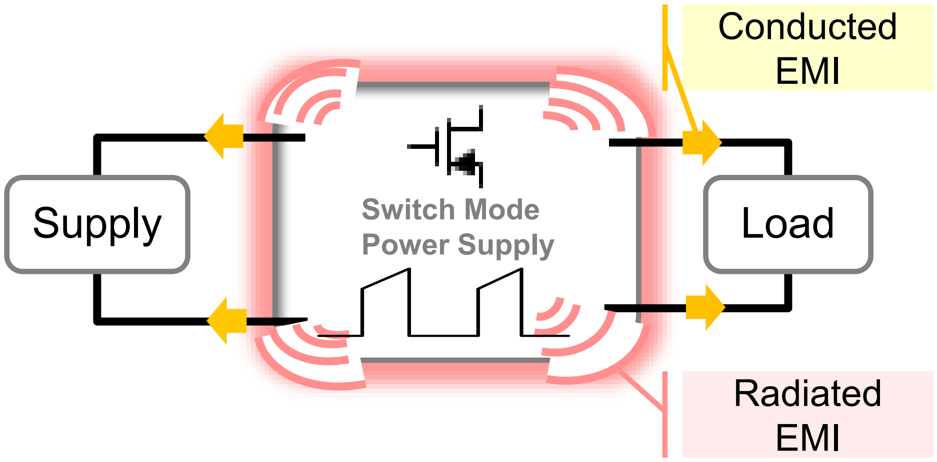
EMI optimization

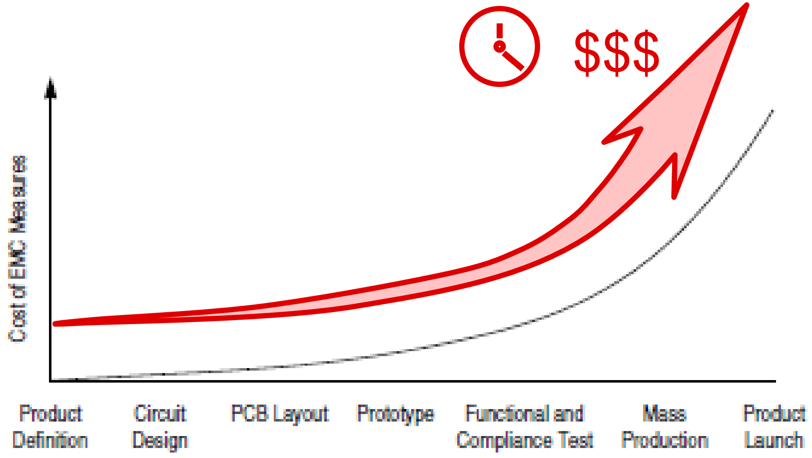
a. EMI basics

b. Design / layout tips to optimize EMI

c. Real-life example: TPS2585x EMI optimization

EMI in switch-mode power supplies





Early EMC consideration helps reduce test and redesign effort and cost.

Goal: **EMI** noise generation ↓ **EMC** noise compatibility ↑

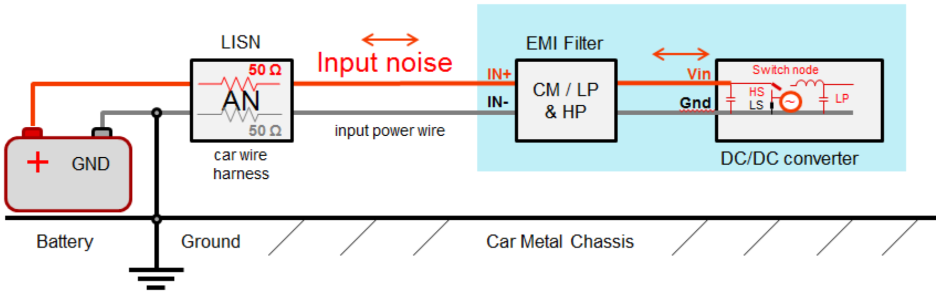
Two EMI tests for CISPR 25

Conducted testing

Measures voltage ripple on input harness

a) EUT is close to the measuring apparatus – the harness is short

b) Measured quantity is voltage, dBµV



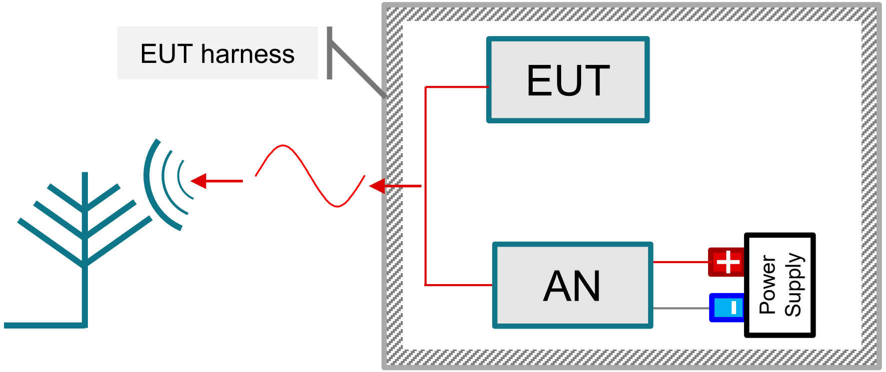
Radiated testing

Measures electric field near the EUT and harness

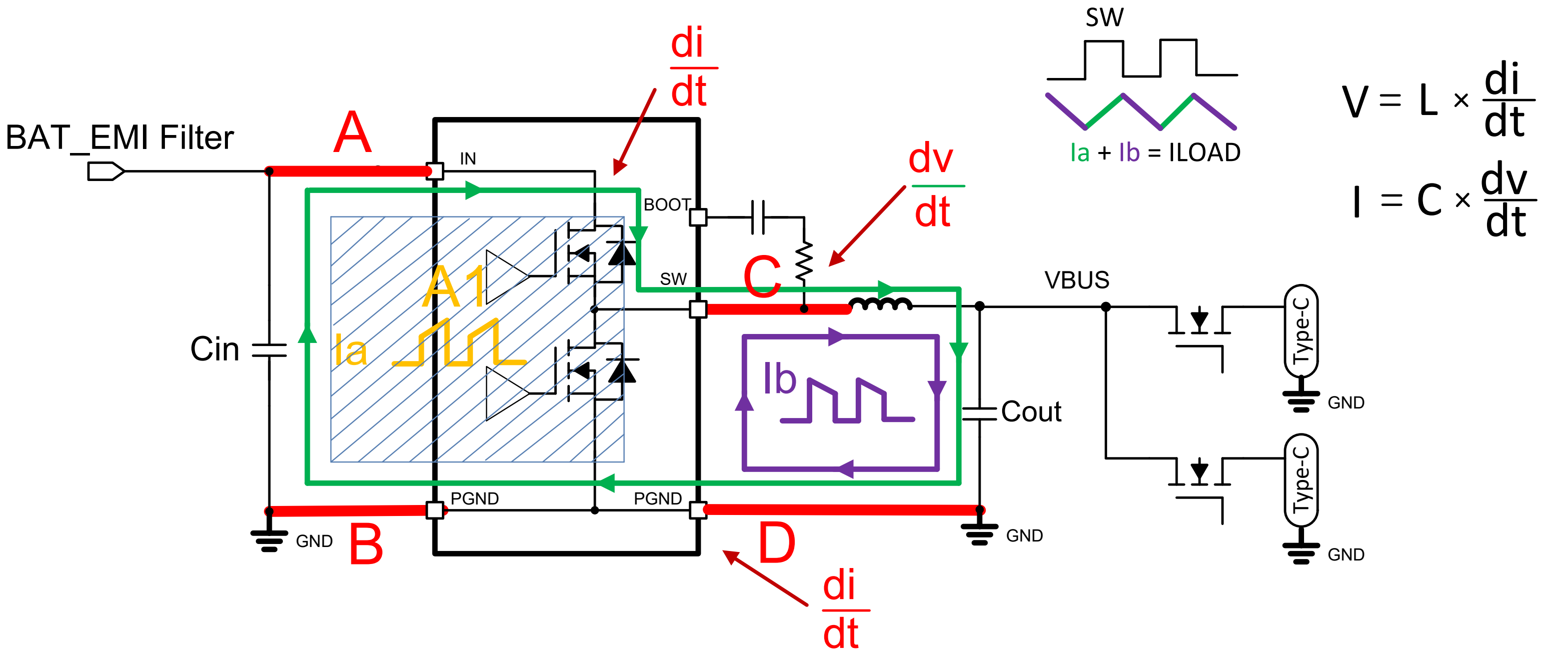
a) The EUT and harness are approximately 1 m from the antenna

b) Measured quantity is electric field dBµV/ m

c) Over most frequencies of interest for DC/DC conversion, this is not a far field measurement



What can we do in PCB layout? TPS25850 example

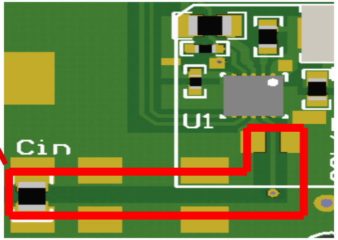


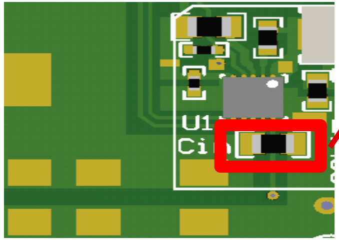
- Minimize critical path area: trace A, B, C, D
  - Cin as close as possible to the VIN and PGND
  - Inductor as close as possible to the SW node
- To ensure no breaks in the power ground, make it short and wide

Critical path area comparison

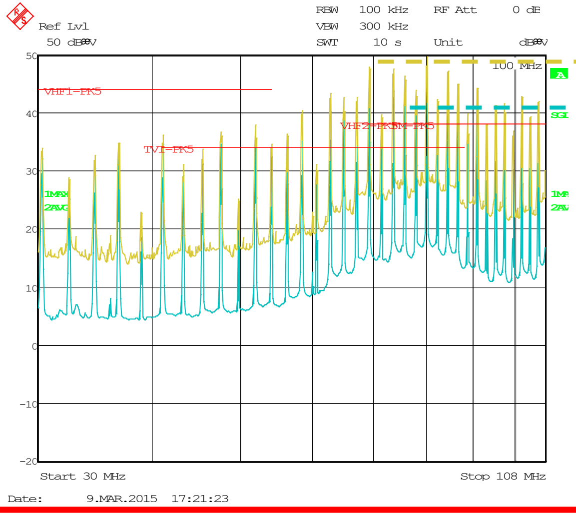
Critical path area reduction – Smaller loop area, better EMI (single Cin)

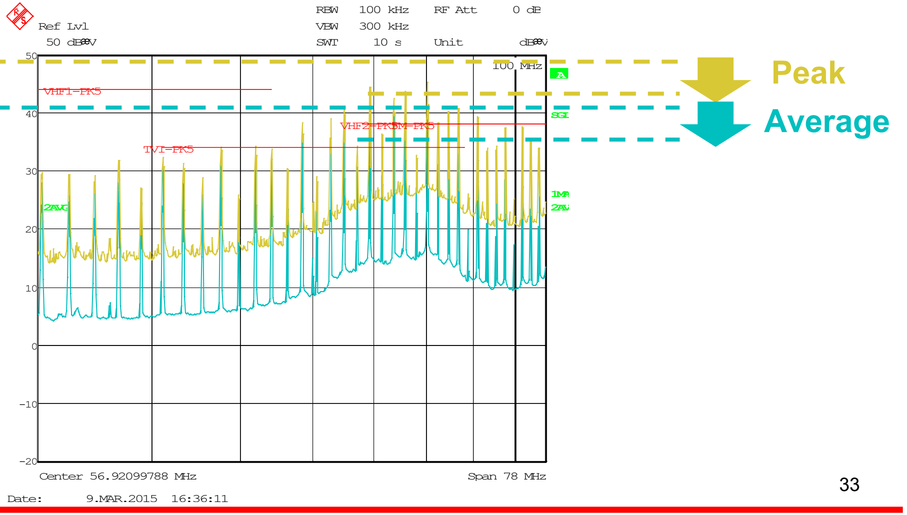
3 times larger loop area





smaller loop area

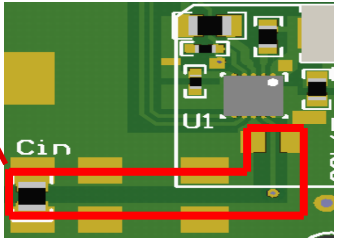


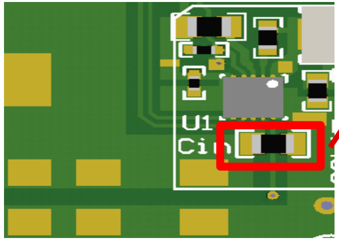


Critical path area comparison

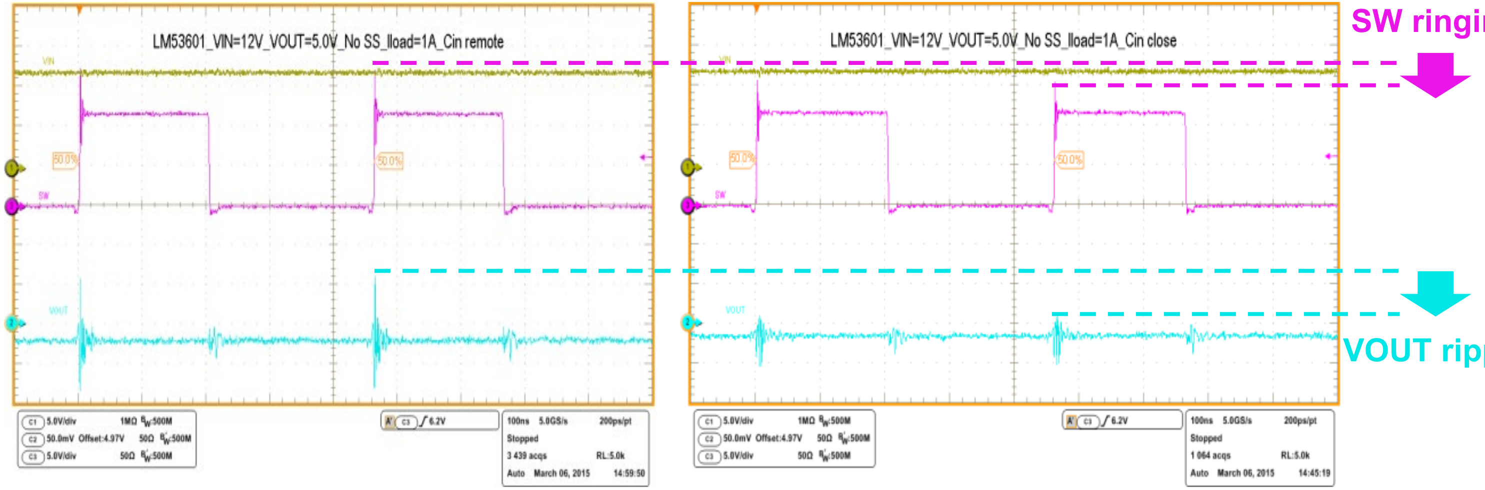
Critical path area reduction – Smaller loop area, better EMI (single Cin)

3 times larger loop area





smaller loop area



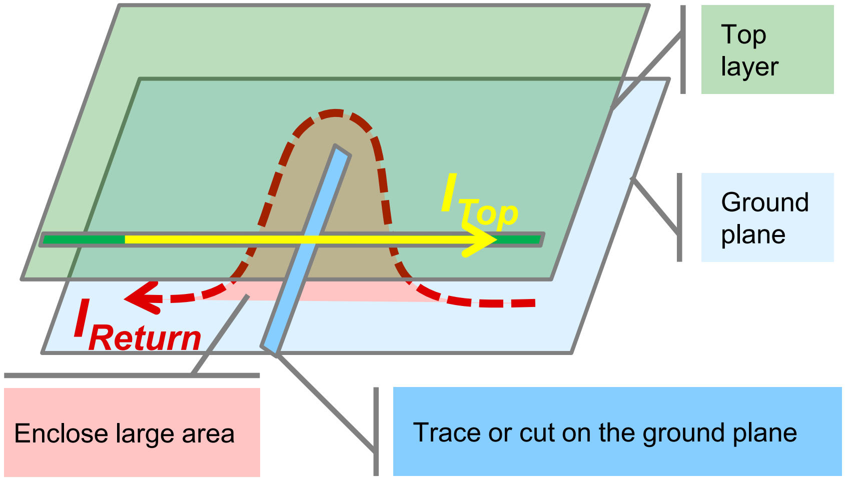
SW ringing

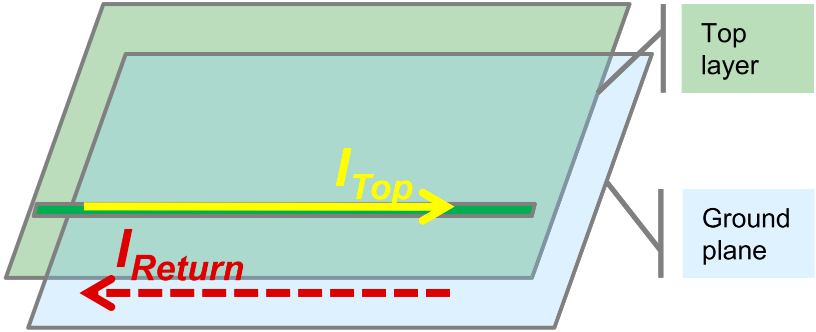
VOUT ripple

Layout consideration for ground

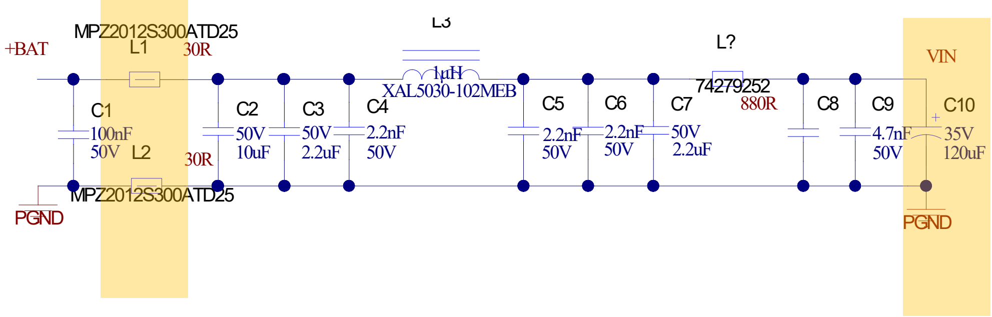
EMI mitigation by grounding PCB L\layout –

Unbroken ground plane, shortest return path, least impedance path, better EMI

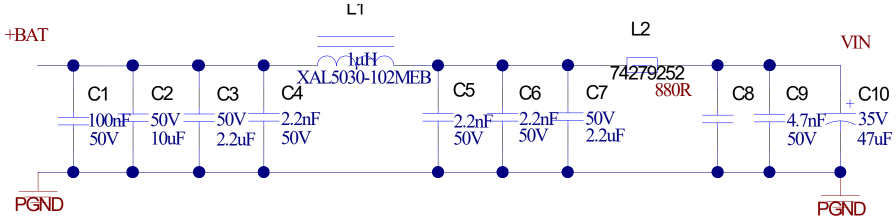




Differential-mode EMI filter design

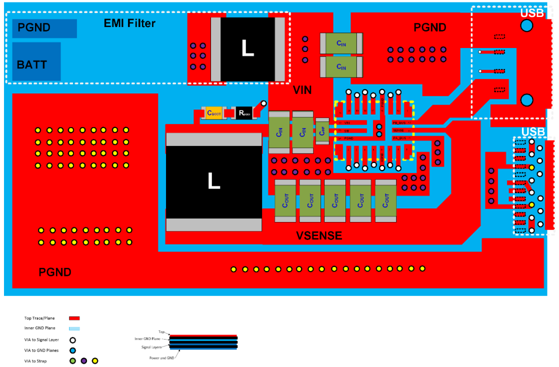


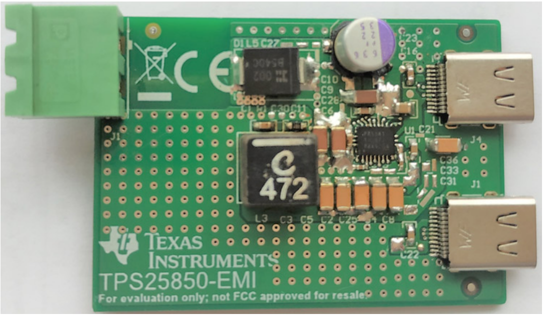
EMI filter selection for 2-MHz operating

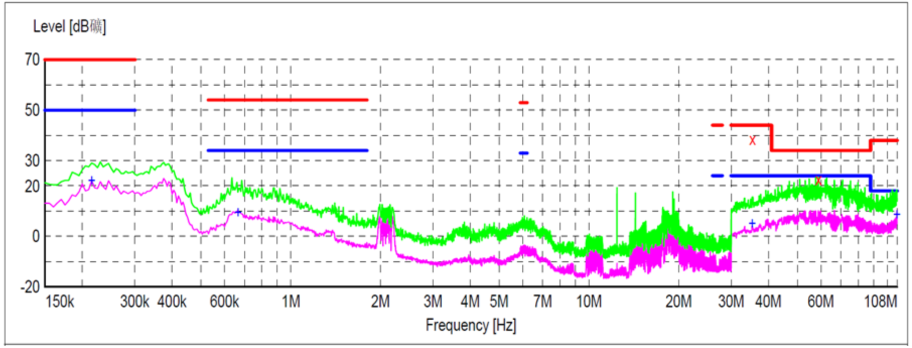


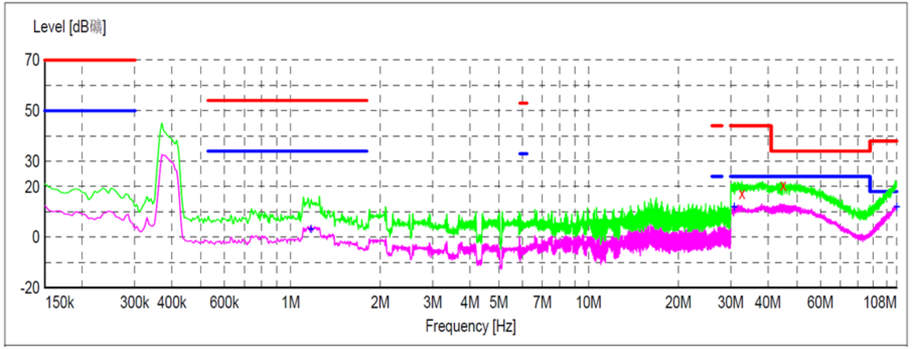
EMI filter selection for 400-KHz operating

Recommended EMI optimized layout





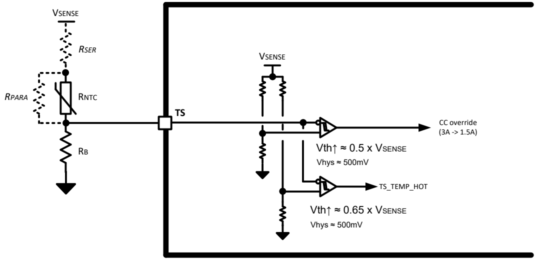




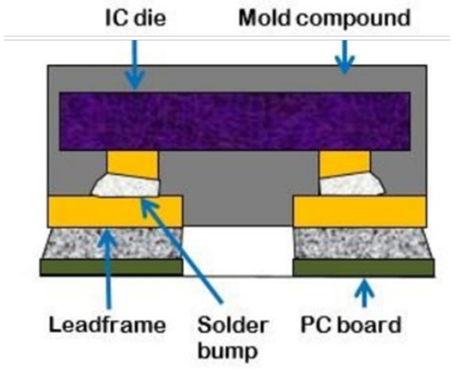
TPS25850 **2.1 MHz** EMI: CISPR25 CLASS5 PASS
https://www.ti.com/tool/PMP40723

TPS25858 **400 KHz** EMI: CISPR25 CLASS5 PASS
https://www.ti.com/tool/PMP40680

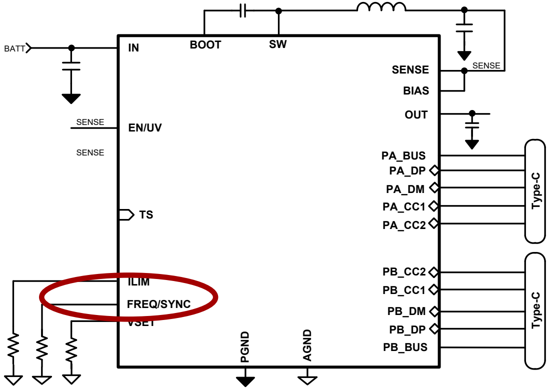
Smart thermal management

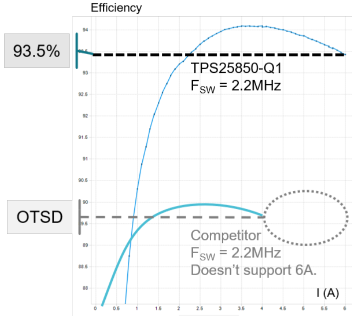


VQFN-HR

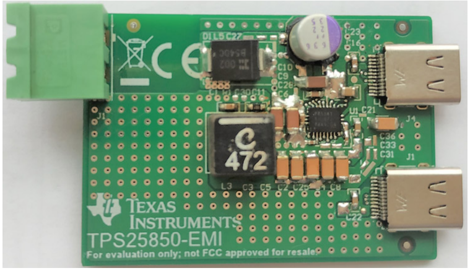


Stable operating 2.1MHz f_{SW}





EMI reference design



EMI standard : CISPR 25 Class5
PMP40723 FSW = 2.2MHz PASS
PMP40680 FSW = 400kHz PASS

TPS25850/8: Dual-3A USB Type-C charging ports controller

Features

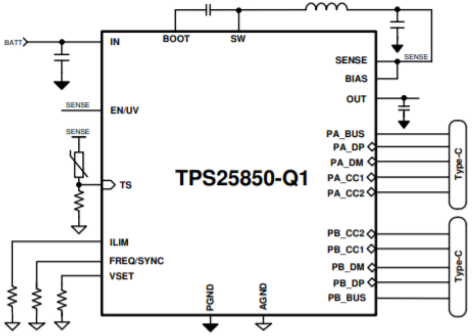
- 5.5-26 V Input operating voltage range
- Maximum 36 V input voltage
- Integrated high-power DC/DC Buck converter, power VCONN internally
- FSW: 200 KHz~ 2.4 MHz FPWM with spread spectrum
- Total efficiency
  - 93.4% at 2.1 MHz, 2*3 A load, 13.5 V VIN (TPS25850)
  - 94.5% at 400 kHz, 2*3 A load, 13.5 V VIN (TPS25858)
- Selectable output voltage: 5.1V, 5.17V, 5.3V, 5.4V
- Cable compensation when VBUS set to 5.17 V
- USB Type-C Charging Port Control & BC1.2 DCP schemes, support Divider3 and 1.2 V/1.2 V modes
- Programmable USB short current limit: ±15% accuracy over temperature
- Low EMI and low switching noise
- Low dropout voltage to support 5.5V input with 5.1V output
- Smart thermal management:
  - Thermal management with adjustable threshold
  - Thermal shutdown
- Package: 3.5 mm-by-4.5 mm HotRod™-25

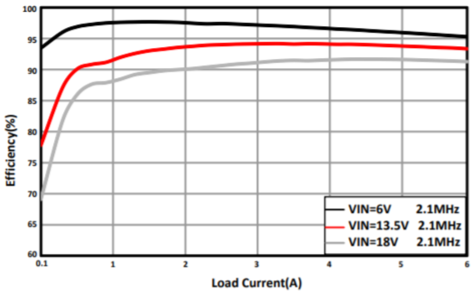
Applications

- Automotive Type-C USB charging ports
- USB media hubs and remote ports

Benefits

- Low EMI and low switching noise meet CISPR25 class 5 standard
- Direct-to-VBAT connection
- Supports dual 3 A Type-C
- Optimizes device charging





TPS25852/9: Dual-3A USB Type-C charging ports controller

Features

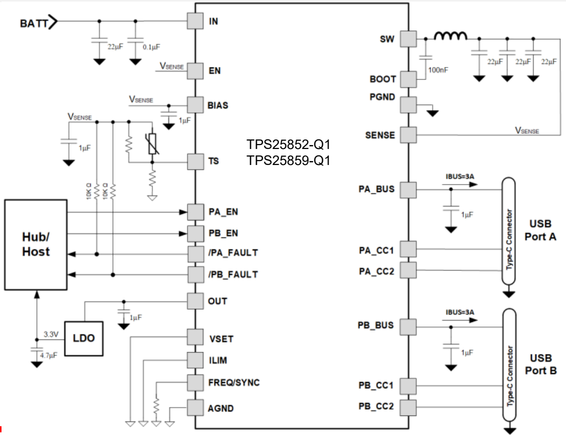
- 5.5-26 V input operating voltage range (Max 36 V)
- Integrates high power DC/DC buck converter and power VCONN internally
- FSW: 200 KHz~2.4 MHz FPWM with Spread-Spectrum
- Total efficiency
  - 93.4% at 2.1 MHz, 2*3 A load, 13.5V VIN (TPS25852)
  - 94.5% at 400 kHz, 2*3 A load, 13.5V VIN (TPS25859)
- Selectable output voltage: 5.1 V, 5.17 V, 5.3 V, 5.4 V
- Cable compensation when VBUS set to 5.17V
- USB Type-C Charging Port Control
- USB ports ON/OFF control
- Programmable USB short current limit: ±15% accuracy over temperature
- Low dropout voltage to support 5.5 V input with 5.1 V output
- Smart thermal management:
  - Thermal management with adjustable threshold
  - Thermal shutdown
- Fault Detection:
  - VBUS OC
  - Thermal shutdown
- Package: 3.5 mm by 4.5 mm HotRod™-25

Applications

- Automotive Type-C USB Charging Ports
- USB Media Hubs & Remote Ports

Benefits

- Low EMI and low switching noise meet CISPR25 class 5 standard
- Direct-to-VBAT connection
- Supports dual 3 A Type-C
- Optimizes device charging



TPS25850/2-Q1 typical application diagram

26V operating voltage; Max 36V input voltage

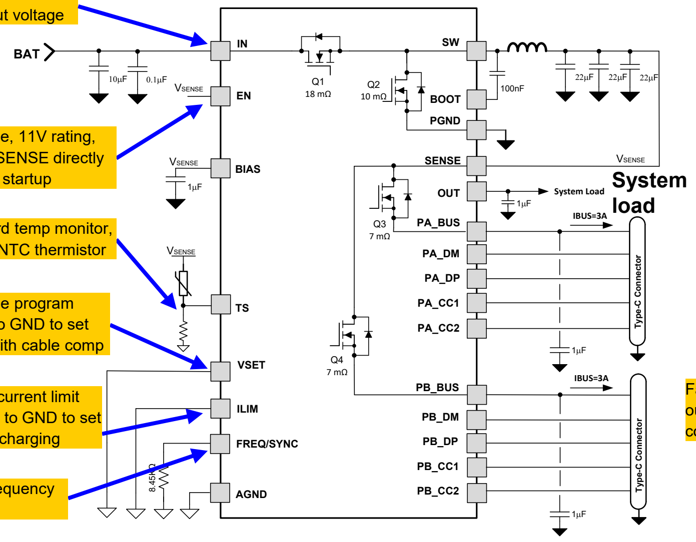
Device Enable, 11V rating, connect to VSENSE directly for automatic startup

External/board temp monitor, connect to a NTC thermistor

Output voltage program input; Short to GND to set 5.17V VBUS with cable comp

USB charge current limit setting; Short to GND to set 3.55A for 3A charging

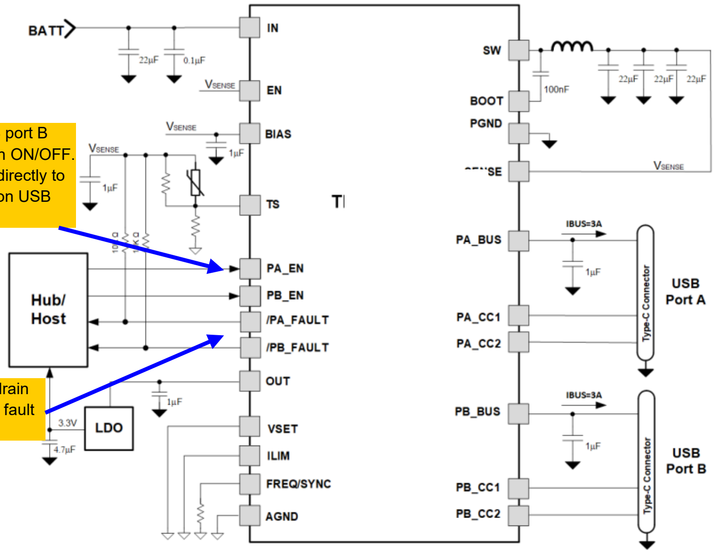
Switching Frequency programming



TPS25850-Q1

To control the USB port B channel load switch ON/OFF. Be tied to SENSE directly to automatically turn on USB port.

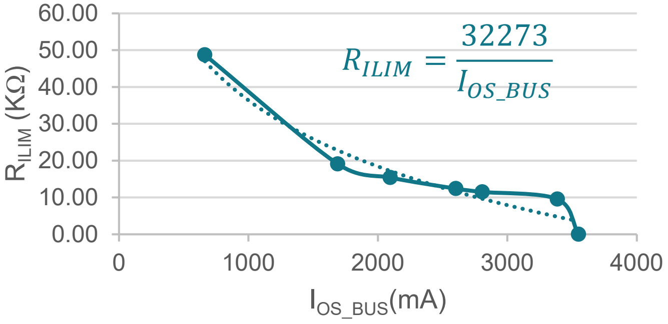
Fault indication, open-drain output, asserted during fault conditions



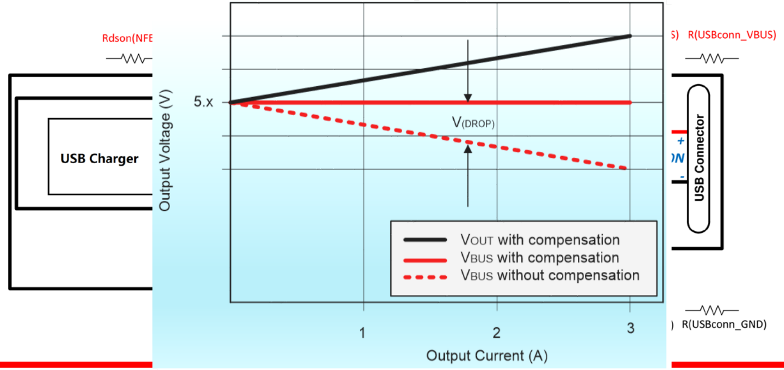
TPS25852-Q1

TPS25850-Q1 family key features

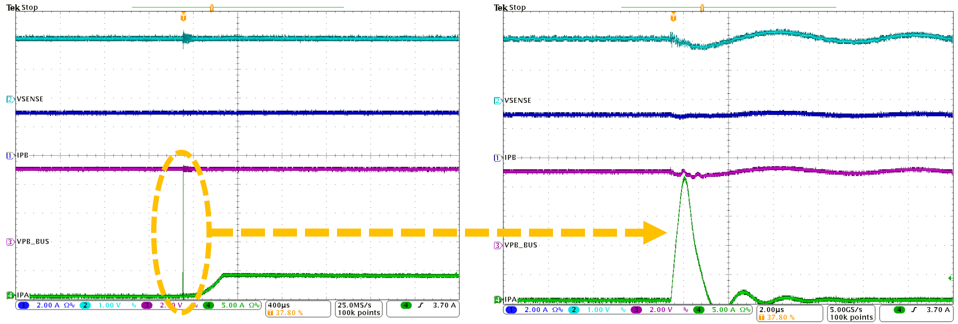
ILIM: Adjustable Current Limit



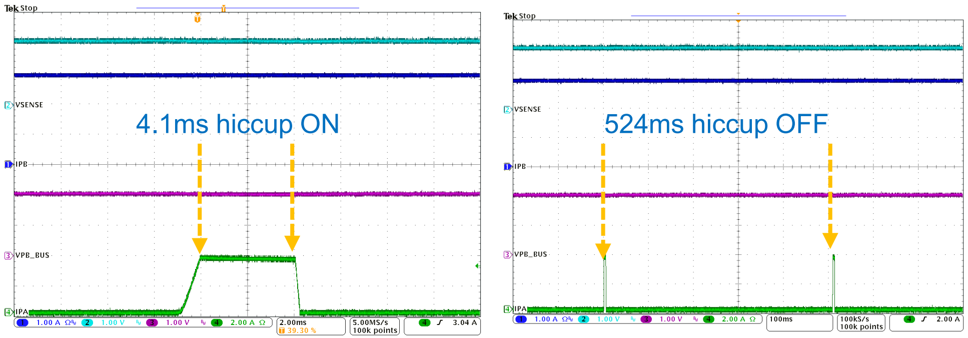
Cable compensation



Short to Ground protection

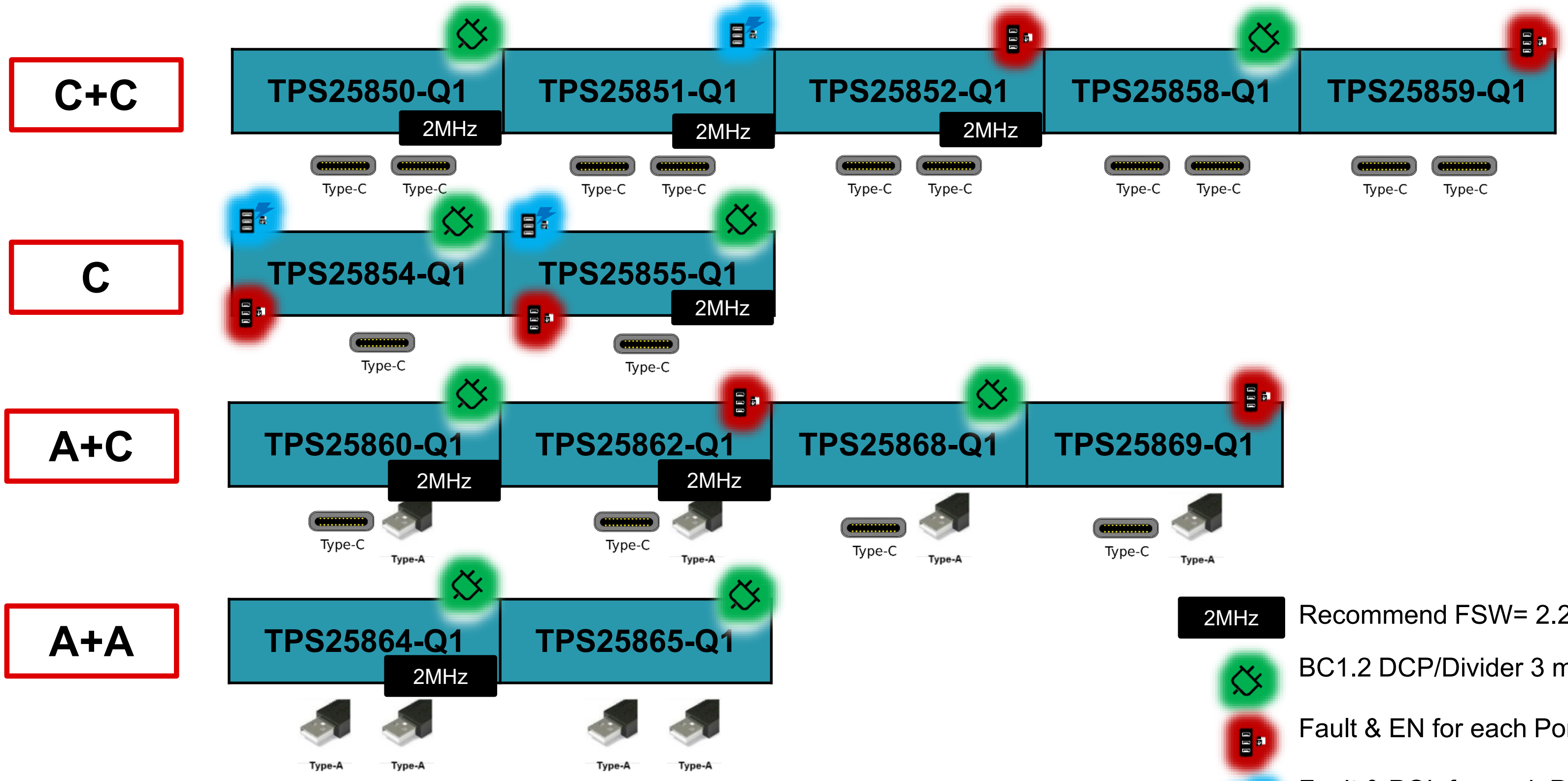


USB port in Overload Hiccup



Contents

TPS2585x-Q1 family overview



2MHz — Recommend FSW= 2.2MHz

BC1.2 DCP/Divider 3 mode

Fault & EN for each Port

Fault & POL for each Port

**Short to GND to set the default 2.84-A current limit for Type A port*

All-in-one USB-C and USB-A charging port products

Single USB-C and USB-A charging port solution (DCP & CDP, integrated sync buck DC/DC)

PN	Port Type	BC1.2 Mode(s) Supported	Fault Indication	Short to Battery protection	IEC ESD	Thermal Mgmt.	MFi OCP	fsw	Package
TPS25830A	C	SDP/CDP	Yes	Yes	Yes	n/a	Yes	300kHz to 2.2MHz	VQFN (32) 5mm x 5mm
TPS25832A	C	SDP/CDP	Yes	No	Yes	n/a	Yes	300kHz to 2.2MHz	
TPS25840	A	SDP/CDP	Yes	Yes	Yes	n/a	Yes	300kHz to 2.2MHz	
TPS25842	A	SDP/CDP	Yes	No	Yes	n/a	Yes	300kHz to 2.2MHz	
TPS25846	A	SDP/CDP	Yes	Yes	Yes	n/a	Yes	300kHz to 2.2MHz	
TPS25831	C / A	DCP	Yes	Yes	Yes	NTC Adj.	No	300kHz to 2.2MHz	
TPS25833	C / A	DCP	Yes	No	Yes	NTC Adj.	No	300kHz to 2.2MHz	
TPS25854	C / A	DCP	Yes	No	No	NTC Adj.	Yes	200kHz to 800kHz	VQFN-HR (25) 3.5mm x 4.5mm
TPS25855	C / A	DCP	Yes	No	No	NTC Adj.	Yes	200kHz to 3MHz	

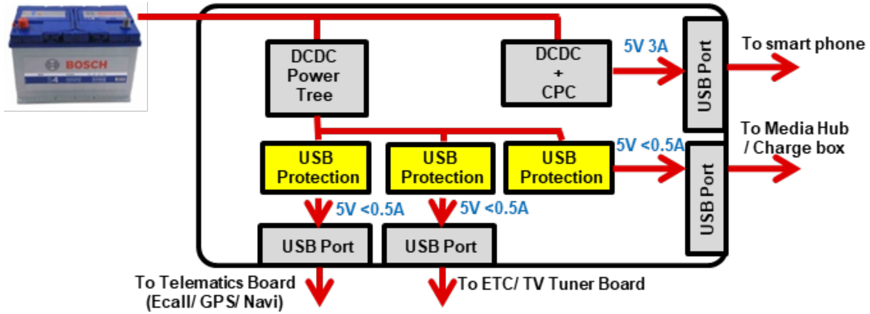
Dual USB-C and USB-A charging port solution (DCP, integrated Sync buck DC/DC)

PN	Port Type	BC1.2 Mode(s) Supported	Fault Indication	Short to Battery protection	IEC ESD	Thermal Mgmt.	MFi OCP	Fsw	Package
TPS25850	C + C	DCP	No	No	No	Yes	Yes	200 kHz to 3 MHz	VQFN-HR (25) 3.5mm x 4.5mm
TPS25858	C + C	DCP	No	No	No	Yes	Yes	200 kHz to 800 kHz	
TPS25851	C + C	No	Yes	No	No	Yes	Yes	200 kHz to 3 MHz	
TPS25852	C + C	No	Yes	No	No	Yes	Yes	200 kHz to 3 MHz	
TPS25859	C + C	No	Yes	No	No	Yes	Yes	200 kHz to 800 kHz	
TPS25860	A + C	DCP	No	No	No	Yes	Yes	200 kHz to 3 MHz	
TPS25868	A + C	DCP	No	No	No	Yes	Yes	200 kHz to 800 kHz	
TPS25862	A + C	DCP	Yes	No	No	Yes	Yes	200 kHz to 3 MHz	
TPS25869	A + C	DCP	Yes	No	No	Yes	Yes	200 kHz to 800 kHz	
TPS25864	A + A	DCP	No	No	No	Yes	Yes	200 kHz to 3 MHz	
TPS25865	A + A	DCP	No	No	No	Yes	Yes	200 kHz to 800 kHz	

Automotive USB 2.0 short-to-battery protection

Part number	V_{BUS}	D+/D-	Current limit fixed or adj.	I_{LIM} accuracy	Flow-through layout	OTG/client mode	Package
TPD3S716	1-Ch 18V Short-to-Battery	2-Ch 18V Short-to-Battery	Adj. 0.5 – 2.1A	10%	Yes	Yes	SSOP-16 (DBQ)
TPD3S714	1-Ch 18V Short-to-Battery	2-Ch 18V Short-to-Battery	Fixed 0.6A	20%	None	None	SSOP-16 (DBQ)
TPD3S713	1-Ch 18V Short-to-Battery	2-Ch 18V Short-to-Battery	Adj. 0.05A - 0.5A	13.5% @ 200mA	None	Yes	WQFN -20
TPD2S703	None	2-Ch 18V Short-to-Battery	None	None	Yes	None	DGS-10 DSK-10
TPD2S701	None	2-Ch 7V Short-to-V_{BUS}	None	None	Yes	None	DGS-10 DSK-10

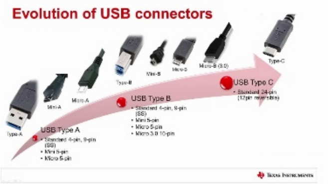
End Equipment

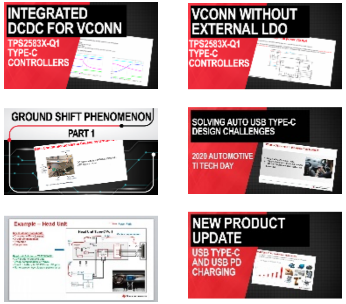


More training video

Texas Instruments

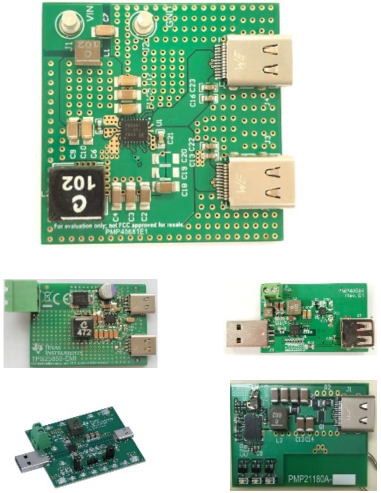
USB automotive collateral and design support





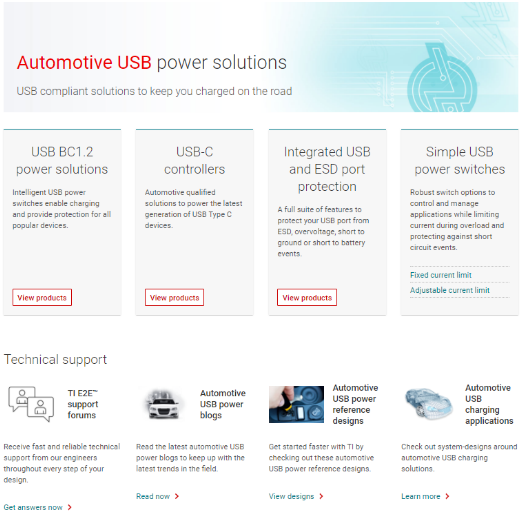
Video Series

- Video series on Auto USB
- Introduce the important technical factor to consider when designing auto USB charging port



Reference Designs

- 50+ TI Designs from SEM (TIDA) and PDS (PMP) on Auto USB
- showcases a system implementation of various single or dual port USB Type-C/A charger.



Product Portfolio

- All of Q100 devices for USB power solution
- provides easy-to-use USB-A and USB-C/PD charging port solution with high efficiency, low EMI, and robust protection in Automotive application

Q&A

TEXAS INSTRUMENTS