Automotive USB Type-C Charging Trends and Challenges

Power Interface

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TI Training

TI Training - Summary

Automotive USB Type-C Charging Trends and Challenge:

In this training we will briefly introduce current and future Automotive USB charging scenarios and go into details of system level design with new gen fully integrated USB Type-C device of TPS25830/1-Q1. Also we'll review schematics, system design guideline for cable compensation, short to battery protection and good eye diagram performance.

What you'll learn:
- Automotive USB-C charging trends and challenges
- Automotive USB-C Systems Design Considerations
- Learn how to design with fully integrated USB Type-C devices
  - **TPS25830-Q1**
  - **TPS25831-Q1**

RTM 1H19 !!

Training level: Intermediate

Course Details:
Audience: <Analog, Systems >

Specific TI Designs & Parts Discussed:
- TPS25830-Q1, TPS25831-Q1

Insert link to training

The Evolution of USB

| 1998 | 2000 | 2001 | 2008 | 2013 |

USB1.x
Low Speed
LS: 1.5Mbps
Full Speed
FS: 12Mbps

USB2.0
High Speed
HS:
480Mbps
FS, LS

USB OTG
Device can
be
Both Master
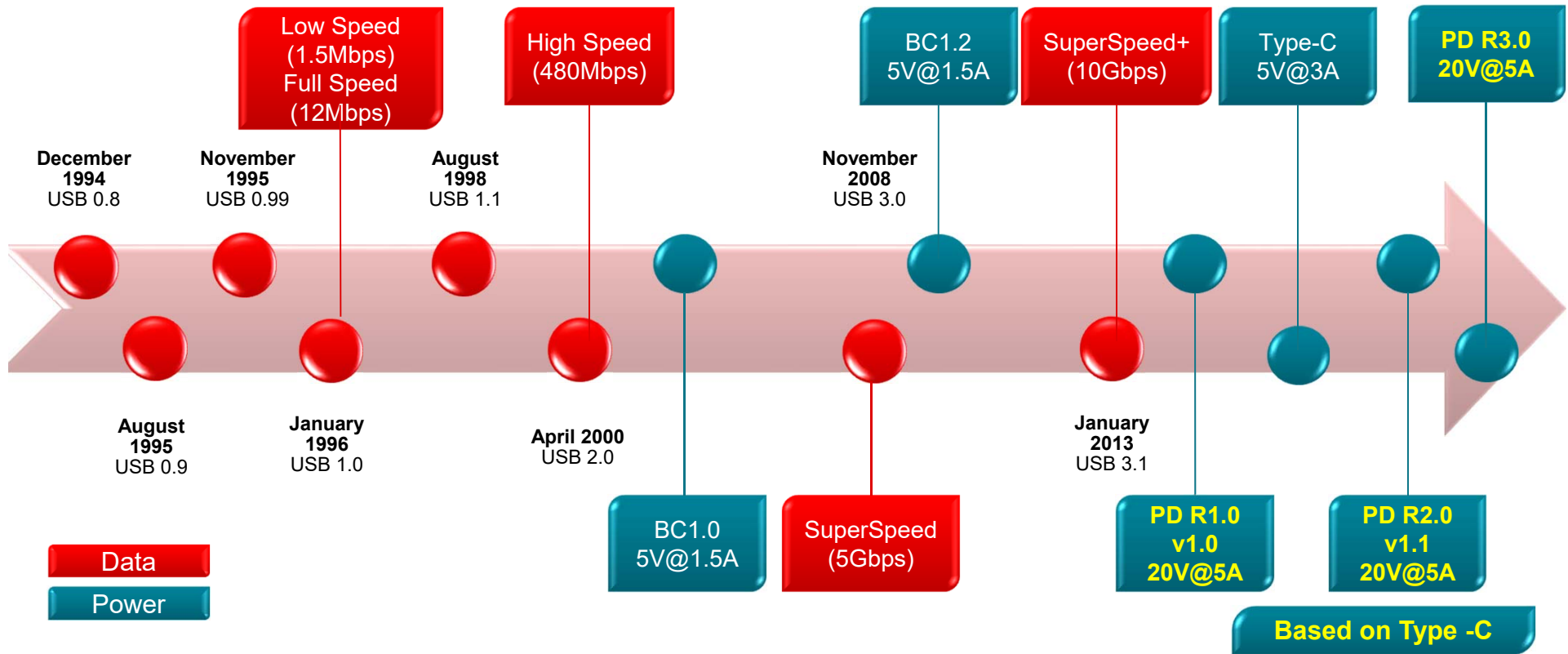and Slave

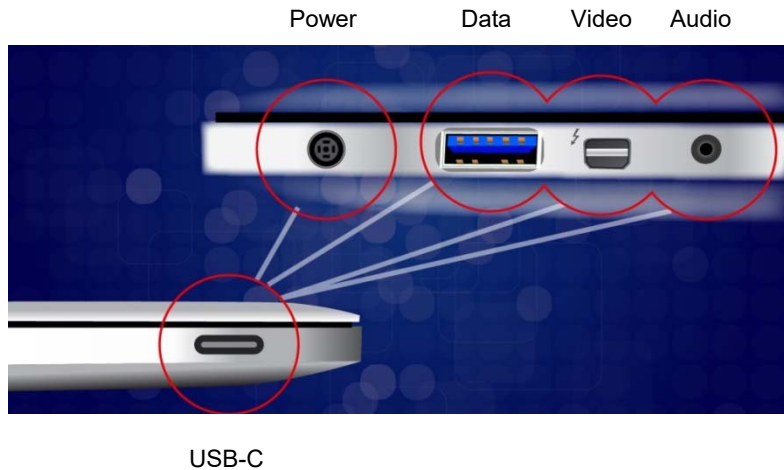**USB3.0**
**USB3.1 Gen
1**
Super Speed
SS: 5Gbps

USB3.1
Gen 2
Super
Speed+
SS+:
10Gbps

USB
Type-C

Evolution of USB Speed & Power

What is USB Type-C?

Power   Data   Video   Audio

USB-C
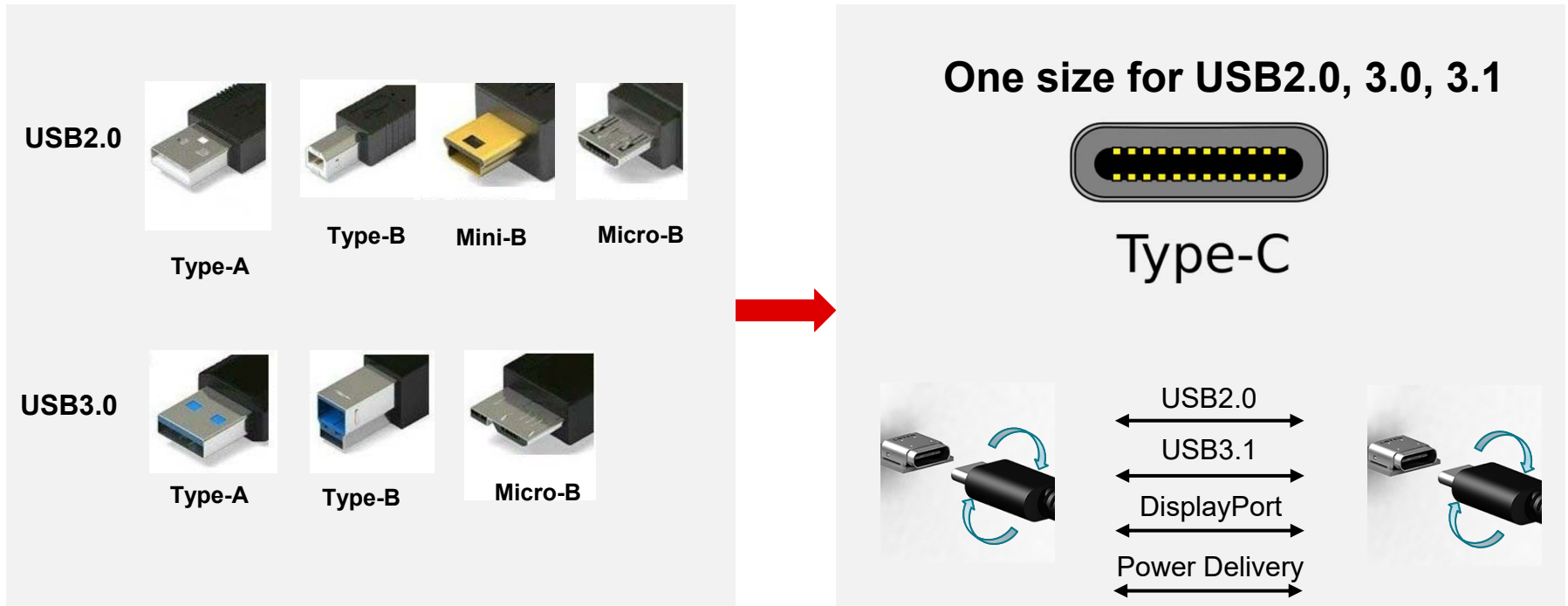
- USB Type C is a receptacle, plug, and cable standard
  - *electrically* compatible with existing USB
  - V_{MAX} = 5 V, I_{MAX} = 3 A
  - *Enables USB-PD*
    - V_{MAX} = 20 V, I_{MAX} = 5 A
    - Active Cable required if I > 3A

Features:

- **Small form factor connectors**

- **Flippable connectors and reversible cable that gives a more user friendly experience**

- **Supports USB 3.1 (10Gbps)**

- **New USB Type-C Current (5V / 1.5A / 3A)**

- **Supports USB PD (up to 20V / 5A)**

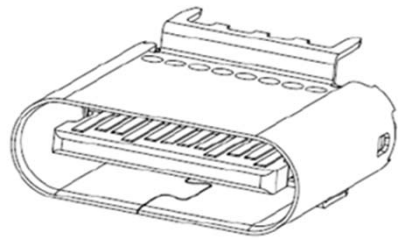- **Supports "Alternate Modes" through the same port (Display Port, HDMI, etc.)**

TI expects the Type-C connector will eventually replace most other USB connectors
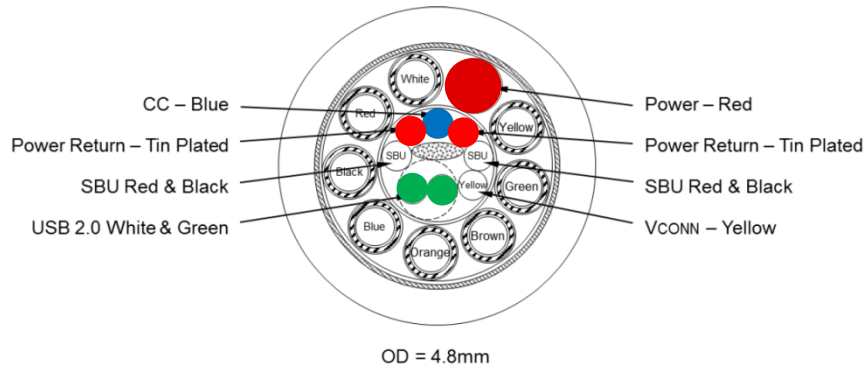
The USB Connectors

USB2.0

Type-A   Type-B   Mini-B   Micro-B

USB3.0

Type-A   Type-B   Micro-B

One size for USB2.0, 3.0, 3.1

Type-C

USB2.0

USB3.1

DisplayPort

Power Delivery

USB Type-C Hardware

Type-C Receptacle

Type-C Cable

Type-C Plug

CC – Blue
Power Return – Tin Plated
SBU Red & Black
USB 2.0 White & Green

Power – Red
Power Return – Tin Plated
SBU Red & Black
VCONN – Yellow

OD = 4.8mm

Coax are SS pairs – specific pairs not defined in cable

Basic Cable has only 6 wires
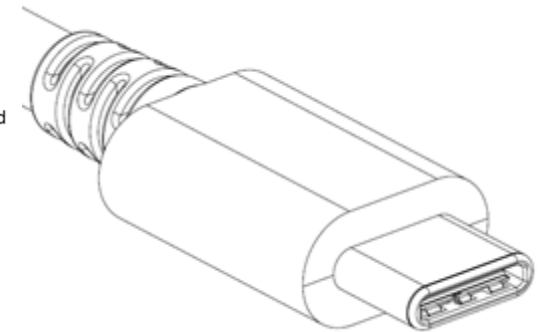
Figure 2-1 USB Type-C Receptacle Interface (Front View)

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1−	VBUS	CC1	D+	D−	SBU1	VBUS	RX2−	RX2+	GND
GND	RX1+	RX1−	VBUS	SBU2	D−	D+	CC2	VBUS	TX2−	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

Figure 2-2 USB Full-Featured Type-C Plug Interface (Front View)

A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	RX2+	RX2−	VBUS	SBU1	D−	D+	CC	VBUS	TX1−	TX1+	GND
GND	TX2+	TX2−	VBUS	VCONN			SBU2	VBUS	RX1−	RX1+	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

Defined USB Type-C to Legacy Connector Cables

Table 3-2 USB Type-C Legacy Cable Assemblies

Cable Ref	Plug 1[4]	Plug 2[4]	USB Version	Cable Length	Current Rating	USB Type-C Electronically Marked[3]
AC2-3	USB 2.0 Standard-A	USB 2.0 Type-C[1]	USB 2.0	≤ 4 m	3 A	Optional
AC2-5	USB 2.0 PD Standard-A				5 A	Required
AC3G2-3	USB 3.1 Standard-A	USB Full-Featured Type-C[1]	USB 3.1 Gen2	≤ 1 m	3 A	Optional
AC3G2-5	USB 3.1 PD Standard-A				5 A	Required
CB2-3	USB 2.0 Type-C[2]	USB 2.0 Standard-B	USB 2.0	≤ 4 m	3 A	Optional
CB2-5		USB 2.0 PD Standard-B			5 A	Required
CB3G2-3	USB Full-Featured Type-C[2]	USB 3.1 Standard-B	USB 3.1 Gen2	≤ 1 m	3 A	Optional
CB3G2-5		USB 3.1 PD Standard-B			5 A	Required
CmB2	USB 2.0 Type-C[2]	USB 2.0 Mini-B	USB 2.0	≤ 4 m	500 mA	Optional
CµB2-3	USB 2.0 Type-C[2]	USB 2.0 PD Micro-B	USB 2.0	≤ 2 m	3 A	Optional
CµB3G2-3	USB Full-Featured Type-C[2]	USB 3.1 PD Micro-B	USB 3.1 Gen2	≤ 1 m	3 A	Optional

For most up-to-date table please refer to the USB Type-C Specification document at usb.org

Automotive USB Ports
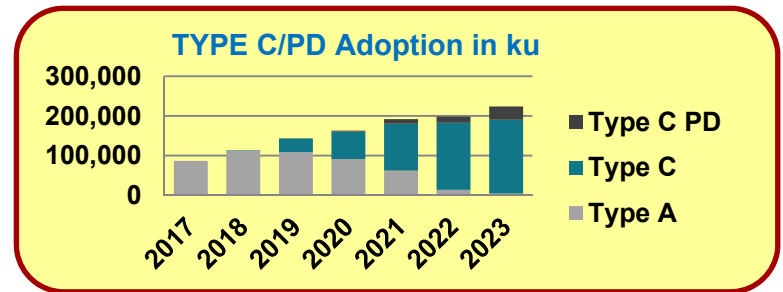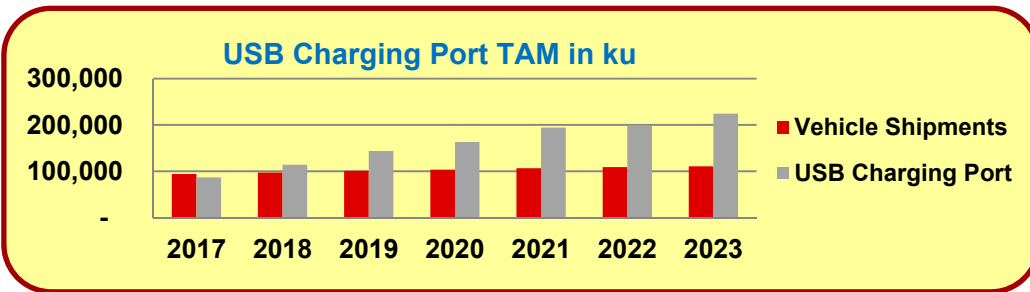## Today and in the Future

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Market Trends

Rear Seat 2 USB
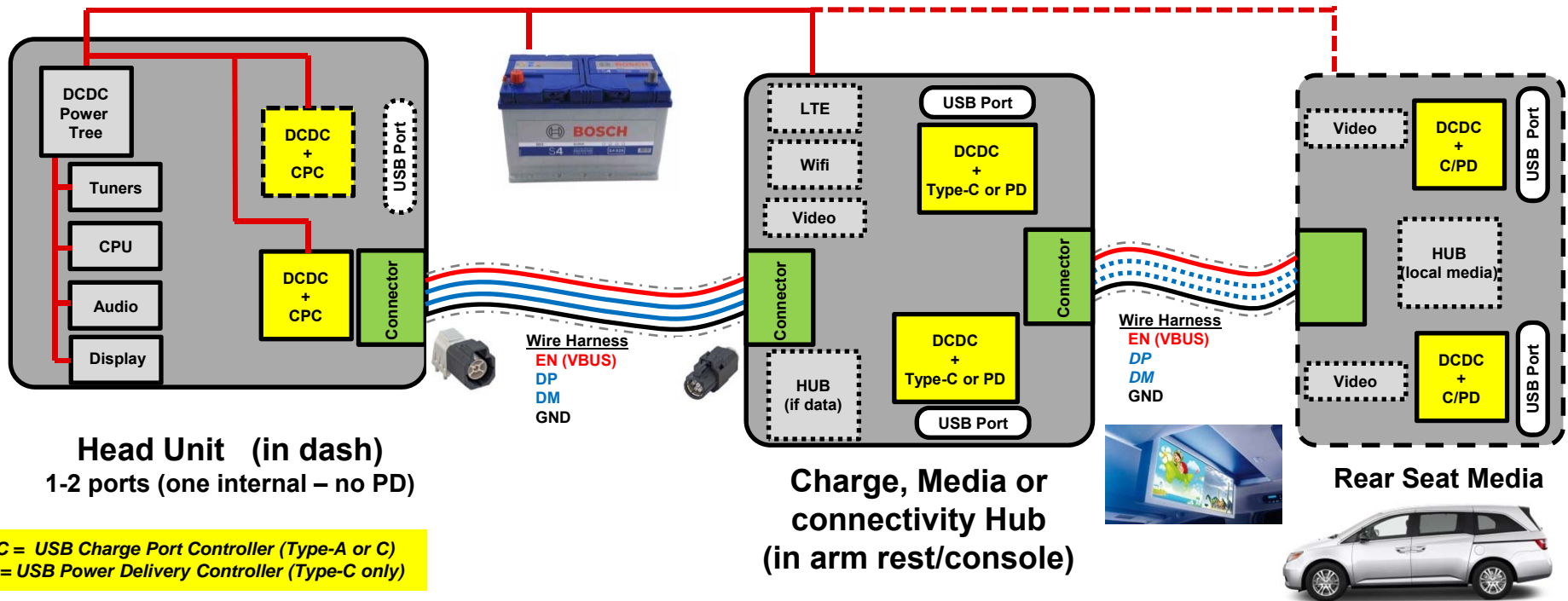
Front Armrest USB

Head Unit USB

Below Head Unit USB

Glove Compartment USB

Rear Seat Ports		
MIN	TYP	MAX
1	2	4

Armrest/Console		
MIN	TYP	MAX
1	2	4

Head Unit Ports		
MIN	TYP	MAX
1	1	2

USB Charging Port TAM in ku

■ Vehicle Shipments
■ USB Charging Port

2017 2018 2019 2020 2021 2022 2023

TYPE C/PD Adoption in ku

■ Type C PD
■ Type C
■ Type A

2017 2018 2019 2020 2021 2022 2023

⇨ *On average > 1 USB port per vehicle (2018) and growing as infotainment becomes more advanced*

USB PD mainly found in armrest/console (media HUB) or rear seat (RSE). Too much power for HU.

A Typical System – USB (2020+ SOP)

Head Unit   (in dash)
1-2 ports (one internal – no PD)

Charge, Media or connectivity Hub (in arm rest/console)

Rear Seat Media

CPC = USB Charge Port Controller (Type-A or C)
PD = USB Power Delivery Controller (Type-C only)

Wire Harness
EN (VBUS)
DP
DM
GND

TI Automotive USB Charging Roadmap Overview

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Automotive USB Charging Block Diagram

Battery

| DC/DC Converter | USB Power Switch | S2B & ESD Protection | VBUS / D+ / D- / CC1 / CC2 / RX/TX |

USB Charging Controller
BC1.2
Type-C
Type-C w/ PD

USB Connector

Host — **USB Hub** — **MUX/Redriver**

DC/DC Converter
LMR14030-Q1 (bk)
LMR3635-Q1 (bk)
LM5175-Q1 (bk-bst)

USB Power Switch
TPS20xx-Q1
TPS255x-Q1
TPS256x-Q1

USB Charging Controller
TPS2549/900-Q1 (BC1.2)
TPS25810/A-Q1 (Type-C)

ESD & S2B
TPD2S70x-Q1
TPD3S71x-Q1
TPD6S300 *
TPDxEyyy-Q1

Integrated Solutions
TPS25830/1-Q1 *
(Type-C)
SOP: 1Q2019

* Roadmap Device

Examples: TPS2549-Q1
SOP: Now
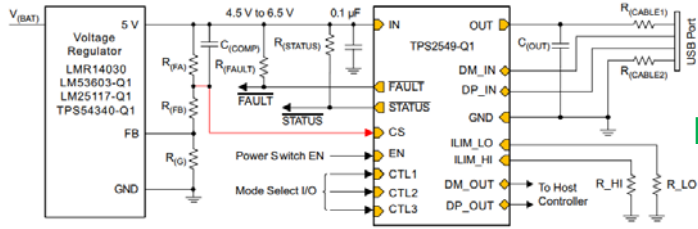
A-Port
BC1.2
Droop Compensation

TPS25810-Q1
SOP: Now
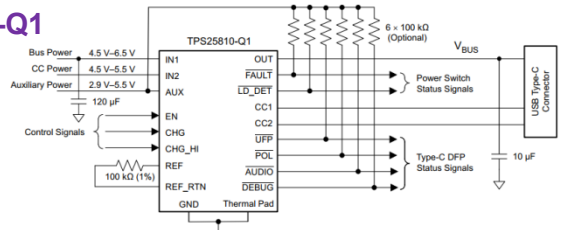
C-Port
Type-C

TPS25830/1-Q1 *
SOP: 1Q2019
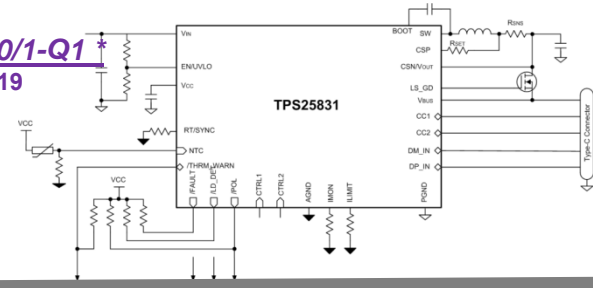
C-Port
DC/DC
Type-C

System Design
with TPS25830-Q1 and TPS25831-Q1

Two Large Challenges for Automotive

- *HEAT DISSIPATION*
  - *Home Electronics, PE, Industrial, Comms typically have less extreme thermal environments than Automotive applications*
  - *Higher Power levels and higher power densities of USB-C complicate Automotive solutions*

- *Voltage Droop Across 5V Wires From DC/DC to USB Port*
  - *This problem is somewhat unique to Automotive Apps*
  - *Most USB Apps have the USB Port quite close to the DC/DC.*
    - *Not so in Automotive*
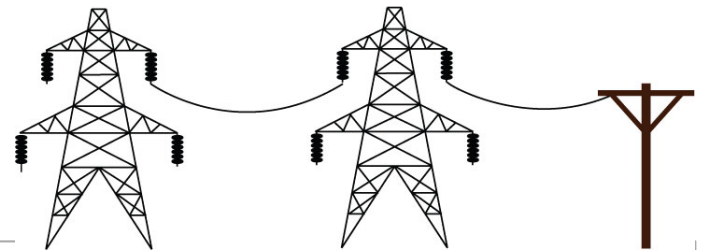
VBUS droop across long cables
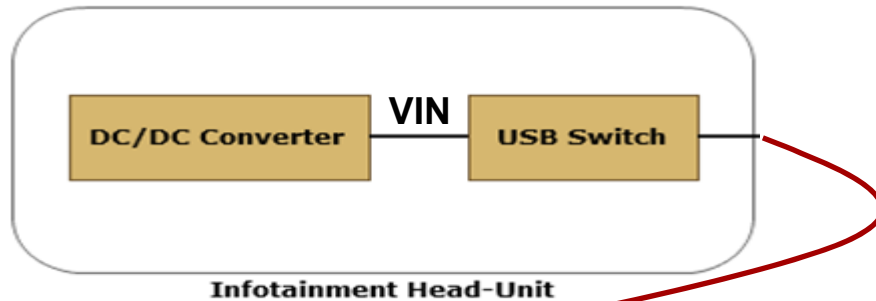
Internal Cable from Head-Unit Socket to remote USB port, may be up to several meters!
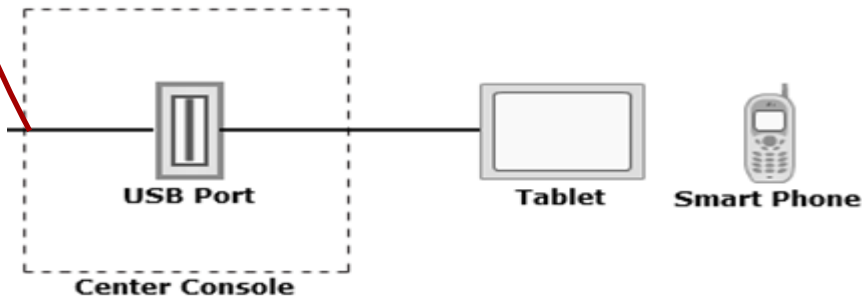
➤ **2 meter Internal Cable Spec**

VBUS resistance (mΩ)	$= \Delta V/I_{LOAD}$	112
GND resistance (mΩ)	$= \Delta V/I_{LOAD}$	84
Total (mΩ)		196

➤ I_{MAX} **allowed to avoid UVLO**

TPS2546 EVM (VIN)-iPad3	5V	5.1V	5.2V	5.3V	5.4V
Without Cable	1.86A	2A	2.04A	-	-
With Cable	**1.28A**	1.42A	1.51A	1.65A	1.73A

Example – Head Unit

Key Customer Careabouts:
• **Charging w/ Data (carplay)**
• **Droop compensation**
• **Protection**
• **Data BW (Eye pattern)**

Head Unit Solution – TPS25830-Q1:
• **CDP mode to support data**
• **Droop compensation on VBUS**
• **Short to battery & IEC ESD on USB pins**
• **Market proven eye diagram performance**

Head Unit Type-C Port

Cable compensation

5.xV

12V VBAT

DC/DC Converter

Rsns

CSA

Droop Comp

Current Limit

Mode Control DCP/CDP/SDP Type-C

Protection

VBAT(ext)/GND

VBUS/GND
VBUS/GND
VBUS/GND
VBUS/GND

VBUS
D+
D-
CC1
CC2
GND

12V VBAT

Regulator 3.3V

Host/Hub

D+
D-

Regulator

Example – Media Hub

Power Path
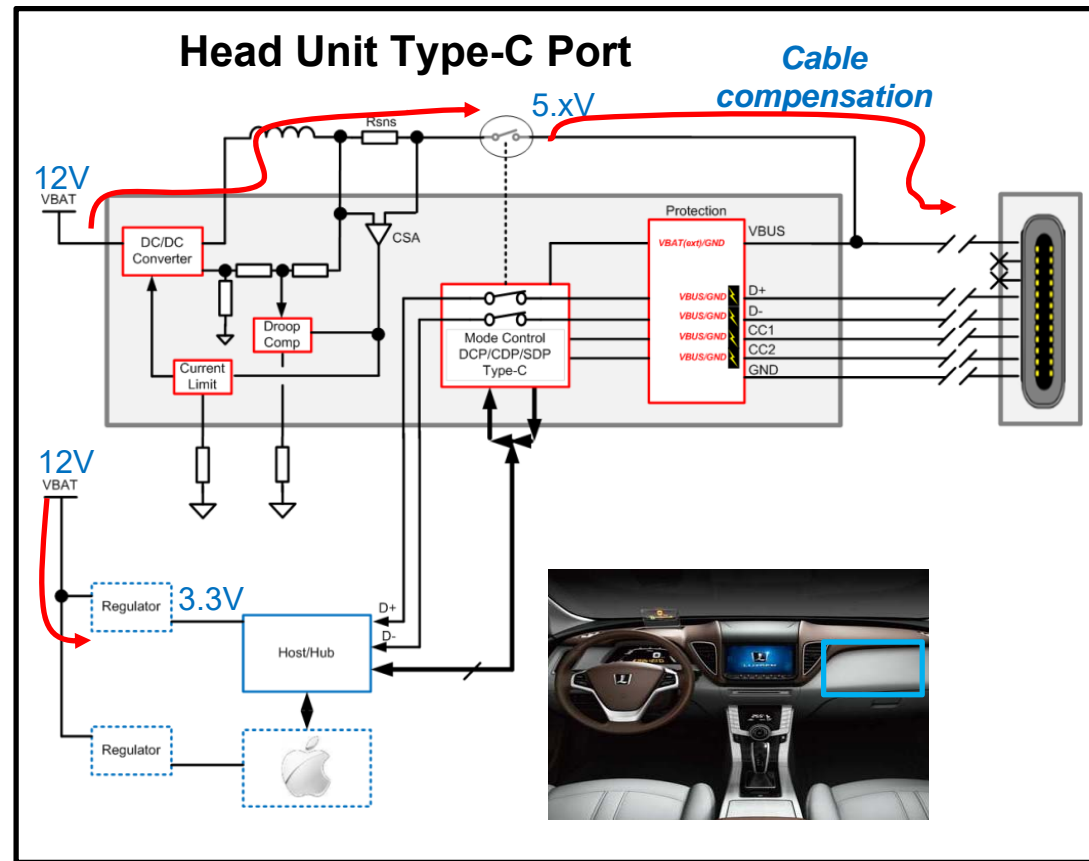
Key Customer Careabouts:
- **Efficiency / Size**
- **Data Communication**
- **Droop compensation**
- **Protection**
- **Data BW (Eye pattern)**

Media Hub Solution – TPS25830-Q1:
- **DCDC output can supply other circuit to achieve better efficiency & size**
- **CDP mode to support data**
- **Droop compensation on VBUS**
- **Short to battery & IEC ESD on USB pins**
- **Market proven eye diagram performance**

Media Hub with Type-C Port

5.xV

Cable Compensation

12V

VBAT

DC/DC Converter

CSA

Droop Comp

Current Limit

Mode Control DCP/CDP/SDP Type-C

Protection

VBAT(ext)/GND   VBUS

VBUS/GND   D+
VBUS/GND   D-
VBUS/GND   CC1
VBUS/GND   CC2
           GND

5.xV   **3.3V**

Regulator

Host/Hub   D+
            D-

Regulator
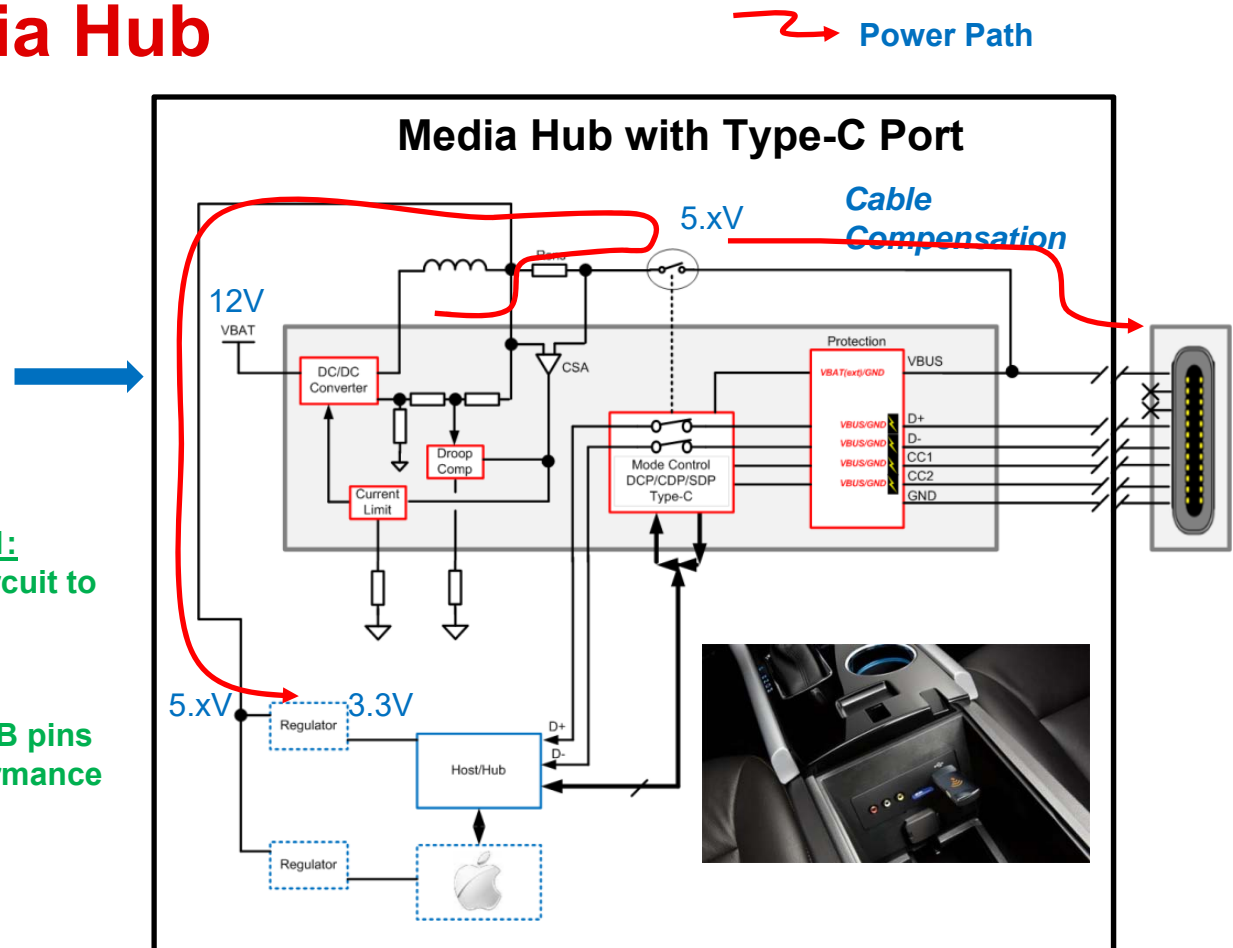
Example – Rear Seat Charger

Key Customer Careabouts
- Cost
- Efficiency
- Type-C / DCP Auto
- Droop compensation
- Protection

Rear Seat Charger Solution – TPS25831-Q1:

- >94% efficiency @ 400kHZ
- Droop compensation on VBUS
- Short to battery & IEC ESD on USB pins

Type-C Port Rear Seat Charger w/Droop Comp

1-3 m cable

VBAT

DC/DC Converter

Rsns

CSA

Droop Comp

Current Limit

Mode Control DCP/CDP/SDP Type-C

Protection

VBAT(ext)/GND

VBUS

VBUS/GND — D+
VBUS/GND — D-
VBUS/GND — CC1
VBUS/GND — CC2
GND

Control & Fault Pins

USB Port Power Supply

1-3 m cable

TYPE-C

Remote Port
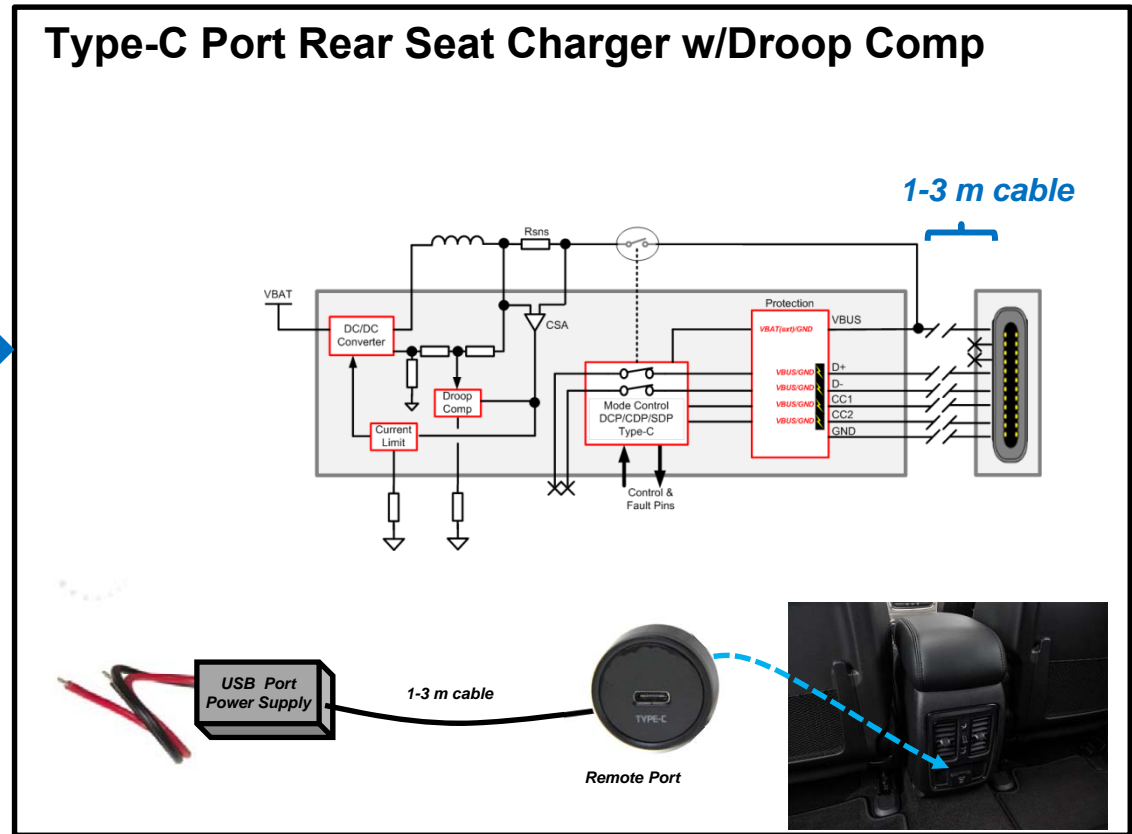
Example – Local Type A Port

Key Customer Careabouts
- Cost
- Efficiency
- BC1.2 Compatibility
- Short to VBAT Protection

Type A port Solution – TPS2584x-Q1:

- >94% efficiency @ 400kHZ
- Market Proven BC1.2 compatibility
- Short to battery & IEC ESD on USB pins
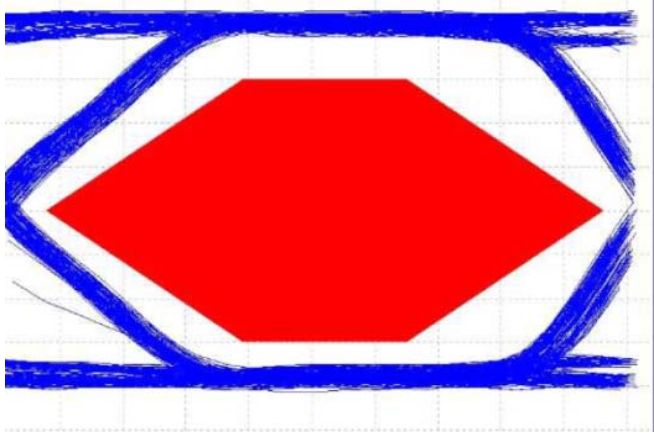

Local Type-A port
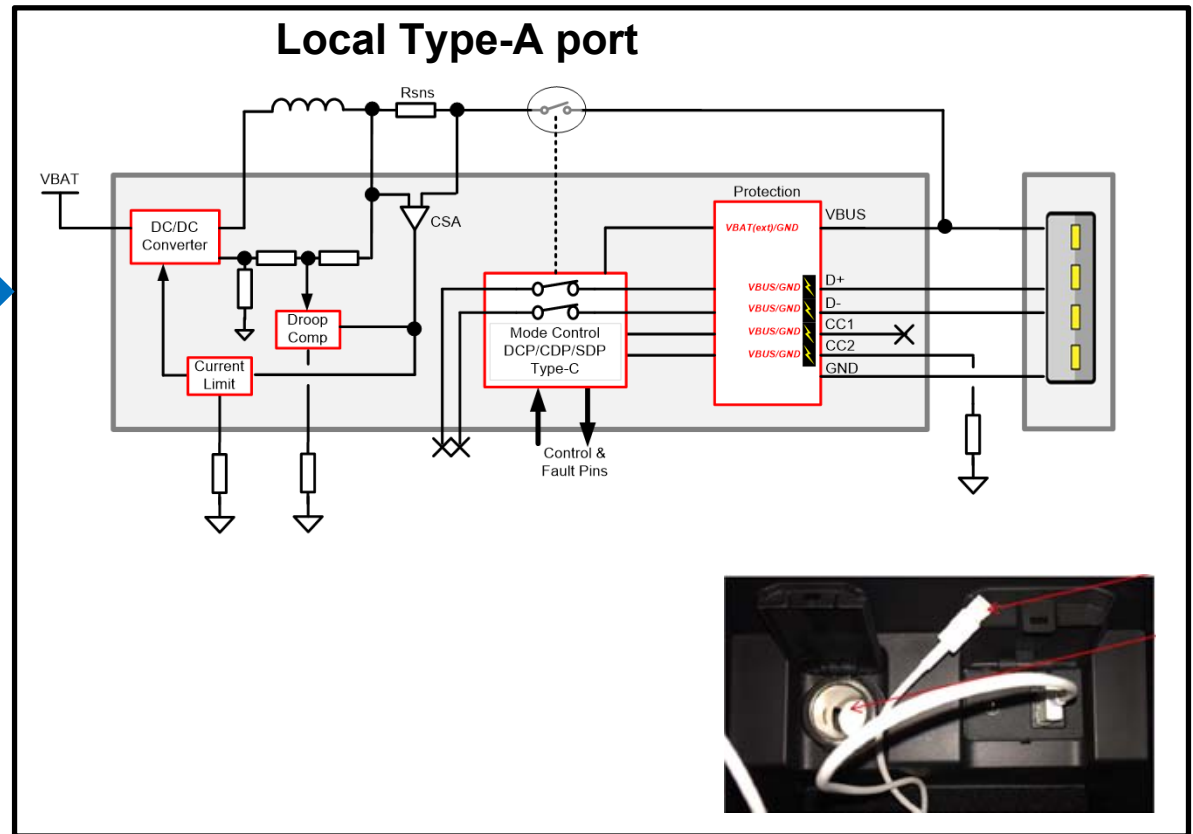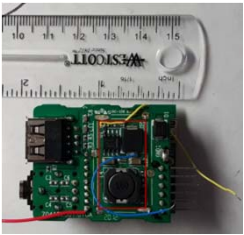
How to use TPS2583x-Q1 to supply other circuit
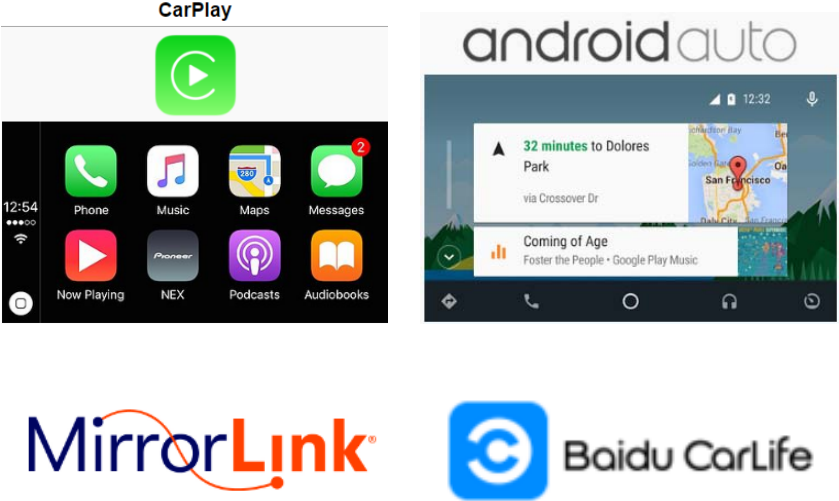
DCDC output of TPS2583x-Q1 needs to be isolated from VBUS fault to supply other circuit

Media Hub with Type-C Port

Power Path
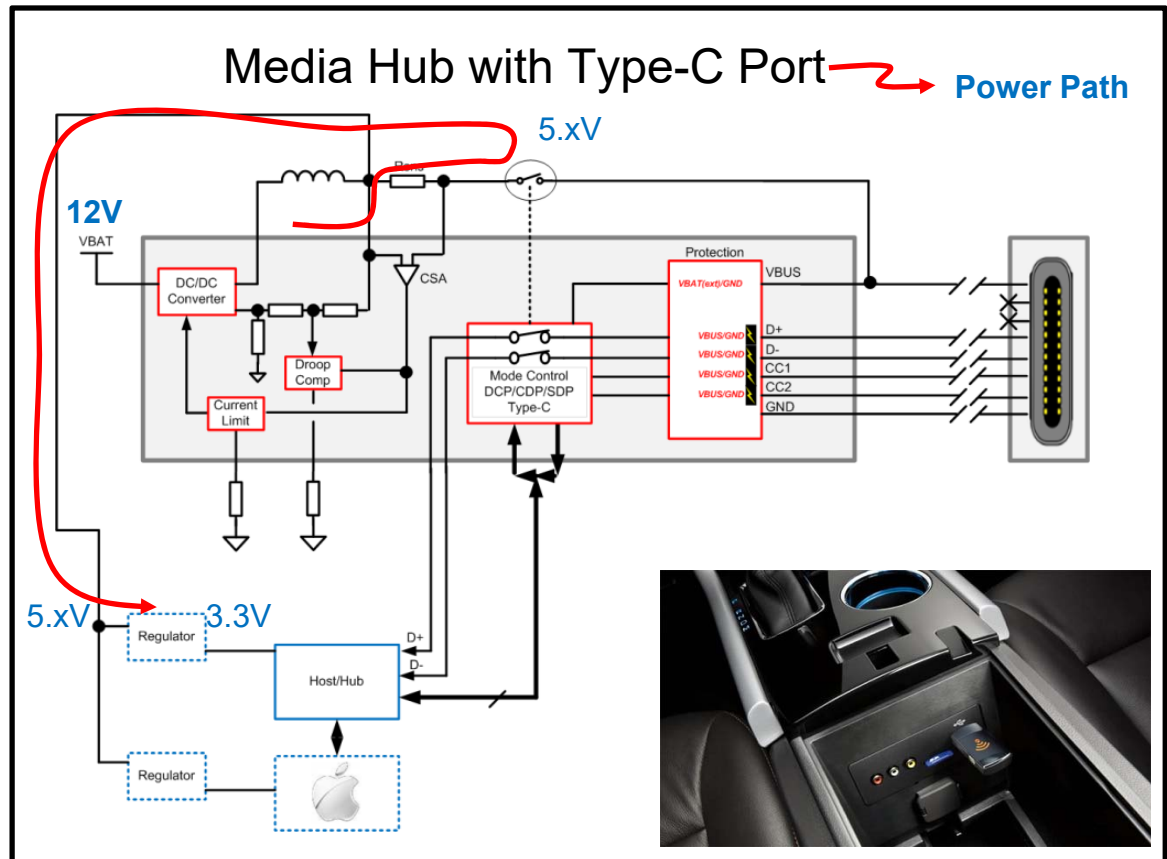
Thermal Management using TPS25831-Q1

Media Hubs / Charge Ports	Problem
	Small size->Thermal concern **Dynamic Thermal Management Reduces P_{DIS} as NTC Temp increases.**

How is the eye diagram performance of TPS25830-Q1

Smart Phone Projection Standards	Problem
	Eye diagram is critical

TPS25830-Q1 Data BW Performance – Eye Diagram

	I_{BUS} = 0A	I_{BUS} = 2.5A
TPS25830-Q1 **fsw = 2MHz**		
LMR14030 + **TPS254900** **fsw = 2MHz**		
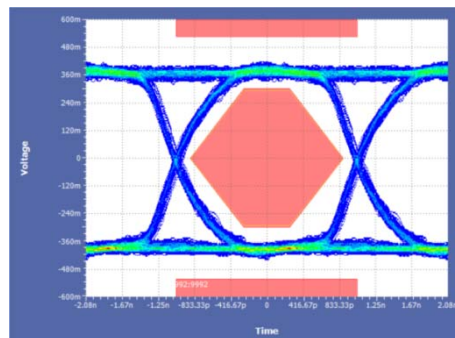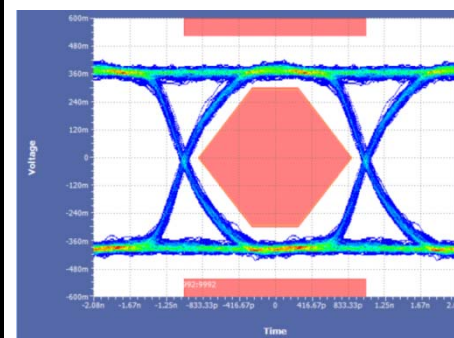
Note:
- **TPS25830 EVM has both A and C connectors populated ⇨ not as optimal for signal integrity as TPS254900 PCB.**
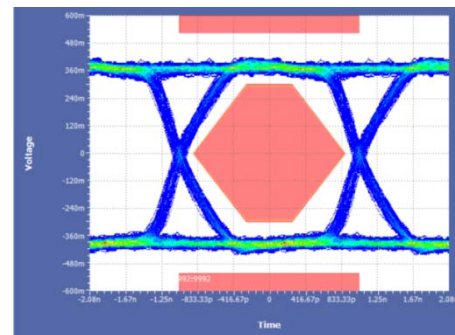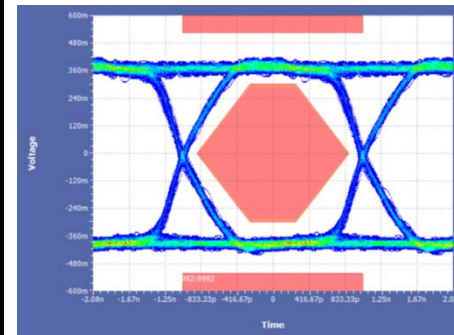
Thank you

Where to go for more information

Who to contact

- Tina Liang, Product Marketing, tina-liang@ti.com   (Shenzhen)
- Jim Bird, PME, (US) (james_bird@ti.com) (US – Manchester)
- Michael Tan, Applications Engineer (Shenzhen)
- John Perry, System Engineer, johnp@ti.com (US – Dallas)
- Feifei Shen, System Manager, feifei-shen@ti.com (Shenzhen)

Web Landing Pages:

- http://www.ti.com/lsds/ti/power-management/usb-power-and-charging-port-controllers-overview.page
- http://www.ti.com/power-management/usb-charging-port-controllers/automotive-usb-power-solution.html
- http://www.ti.com/product/TPS25830-Q1?keyMatch=TPS25830-Q1&tisearch=Search-EN-Everything (Coming soon)

TI E2E Community

- External Forum: http://e2e.ti.com/support/USB

TEXAS INSTRUMENTS

Thank you

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