USB Type-C/PD 101

Kevin Jones
Marketing & Applications Director at Texas Instruments
## USB Type-C/PD Overview

### What is Type-C/PD
USB-C/PD (Power Delivery) is a wide-spread interface that is scalable for power & signaling. It is a specification for a reversible-plug connector for USB devices and cabling.

### When to use Type-C/PD
- **Wall Outlet**: USB Hub
- **Desktop PC/Server**: USB Hub
- **Adapter**: Infotainment
- **Charger**: Laptop
- **Power Bank**: Monitor, TV
- **USB Devices**: Docking Station
- **Accessories**: Mobile/Desk, HDD
- **Mobile/Desk**: USB Powered Accessories

### Why Now?
- A single USB Type-C connector can deliver functions that several connectors provide today in our electronic gadgets.
- Standard type-c now offer more than twice of existing BC1.2 power and type-c PD now offer up to 100W of power.
- Supports increased demand of video and high data rates through alternate modes.
Universal Serial Bus (USB)
The interface of choice by billions

USB

2000

Hi-Speed USB

2000

USB On-the-go

2001

Superspeed USB

2008

SUPERSPEED+

USB 10 Gbps

2013

USB2.0
LS/FS

USB2.0
HS

USB2.0 OTG
Master/slave configurable

USB3.1 Gen1
LS/FS/HS/SS

USB3.1 Gen2
LS/FS/HS/SS/SS+

USB2.0 Signals
LS, FS & HS

USB3.1

SuperSpeed(+) Signals

D+
D-
V_{BUS}
GND

SSTX+
SSTX-
SSRX+
SSRX-

USB2.0 w 2-wire bi-directional interface

SuperSpeed(+) adds a dual-simplex data path with revised USB protocol

USB Speeds
Low Speed (LS): 1.5Mbps
Full Speed (FS): 12Mbps
High Speed (HS): 480Mbps
Super Speed (SS): 5Gbps
Super Speed+ (SS+): 10Gbps

• Standard A, B, mini B, micro A, B connectors
• Has host side & device side - not reversible
• Data through USB2 and SS pairs
• Power through $V_{BUS}$ - limited to 7.5W (using BC1.2)
• Non USB use case NOT allowed

Host

Device

USB Cable
Not reversible – host side and device side
USB Type-C: One Connector for All

Supports data, video and power in a single connector

USB Type-C Receptacle

USB Type-C symmetrical/reversible Cable

USB Type-C Flippable Plug

- USB Type-C or USB Type-C is a small form factor receptacle, plug, and cable standard
- Flippable connectors and reversible cable gives user friendly experience
- Type-C connector is compatible with existing USB protocols and expected to replace all Type-A and Type-B connectors
- Supports USB 3.1 (10Gbps)
- Native 15W (5V/3A) power support with option for up to 100W (20V/5A) using USB PD – faster charging
- Supports “Alternate Modes” such as Display Port Video through the same port
- USB Type-C removes the need for different plug/receptacle types for host and devices
**USB Type-C is a Physical Interface**

*Supports USB 2.0 or USB 3.1 or DisplayPort video or other protocols*

---

**USB Type-C is a connector/cable interface, not a new speed**

USB2, USB3.1 and Alt Mode function (DP video) can co-exist

---

**USB Only Applications**

- **USB Host**
  - **USB 2.0**
  - **CC Controller**

- **USB Device**
  - **USB 2.0**
  - **CC Controller**

**Data & Power**

**Alt Mode Applications**

- **USB Host**
  - **USB 2.0**
  - **X-Point Mux**
  - **USB SS/DP**
  - **PD Controller**

- **USB Device**
  - **USB 2.0**
  - **X-Point Mux**
  - **USB SS/DP**
  - **PD Controller**

---

**Power**

**Data, Power & Video**

---

**Texas Instruments**
USB Type-C Plug
Symmetrical, flippable, versatile

Features:
- Single USB 2.0 Bus pair through the cable, D+ are connected internally, as are D-
- USB 3.1 (Tx/Rx pair) high speed data buses for USB SS (+) or Alt Mode
- CC1/CC2 in receptacle assume role of CC or $V_{\text{CONN}}$:
  - CC is the configuration channel for the type-C interface
  - $V_{\text{CONN}}$ powers electronics in the USB Type-C plug once cable configuration is complete.
- $V_{\text{BUS}}$ Buses enable power delivery up to 100W total
- Two ‘SBU’ – “Sideband use” buses for Alt Mode

USB Type-C Full-Feature Plug Interface

<table>
<thead>
<tr>
<th></th>
<th>GND</th>
<th>RX2+</th>
<th>RX2-</th>
<th>VBUS</th>
<th>SBU</th>
<th>D-</th>
<th>D+</th>
<th>CC</th>
<th>VBUS</th>
<th>TX1-</th>
<th>TX1+</th>
<th>GND</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GND</td>
<td>TX2+</td>
<td>TX2-</td>
<td>VBUS</td>
<td>$V_{\text{CONN}}$</td>
<td>D+</td>
<td>D-</td>
<td>SBU</td>
<td>VBUS</td>
<td>RX1-</td>
<td>RX1+</td>
<td>GND</td>
</tr>
</tbody>
</table>

Texas Instruments
USB Type-C Receptacle

**Power, USB 2.0, USB 3.1, & Alt Mode video (DP) coexist**

Channel Configuration Pins (CC1/CC2)
- Receptacle has two CC pins
- One CC wire pass through the cable
- Used for cable attach, orientation, role detection and current mode functions
- Unused CC pin is used for VCONN power

Selecting Data Signals
- Flippability of USB Type-C Plug requires appropriate selection of:
  - USB 3.1 SS signals
  - USB 2.0 HS signals
  - Receptacles have two pairs of D+ and D- pins
- If stub connected (D+ to D+ and D- to D-) no mux needed
- OK at 480Mbps.
- USB 3.1 SS signals can not be stub connected due to signal integrity requiring selection mux.
**USB Type-C Channel Configuration**

*Simple way to accommodate flippable, symmetrical & reversible cable*

---

**Simple resistor divider network between host and device**
- DFP pulls-up the CC pin with $R_p$
- UFP pulls-down the CC pin with $R_d$
- 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 $R_d$ ($R_p$) on the other side
- DFP/UFP can detect plug orientation by monitoring which CC line is active
- DFP uses different $R_p$ (or current source) values to advertise its current provider capability. USB default, 1.5A or 3A

**Data & power roles**
- By default DFP (host) is power source and UFP (device) is 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 $R_a$ to request VCONN power

---

**Type-C Data Roles:**
- Downstream Facing Port (DFP) - Host
- Upstream Facing Port (UFP) - Device
- Dual Role Port (Dual role data DRD & 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

---

**Diagram Notes:**
- *Note only one CC wire through cable*
- DFP monitors for connection and orientation
- UFP monitors for connection, orientation, and current

---

**Diagram Elements:**
- **DFP**
- **UFP**
- **CC**
- **Rp**
- **Rd**
- **Ra**

---

**Texas Instruments**
USB Type-C Alternate Mode

Extends beyond USB data

<table>
<thead>
<tr>
<th>A12</th>
<th>A11</th>
<th>A10</th>
<th>A9</th>
<th>A8</th>
<th>A7</th>
<th>A6</th>
<th>A5</th>
<th>A4</th>
<th>A3</th>
<th>A2</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>GND</td>
<td>RX2+</td>
<td>RX2-</td>
<td>VBUS</td>
<td>SBU1</td>
<td>D-</td>
<td>D+</td>
<td>CC</td>
<td>VBUS</td>
<td>TX1-</td>
<td>TX1+</td>
<td>GND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GND</th>
<th>TX2+</th>
<th>TX2-</th>
<th>VBUS</th>
<th>V_conn</th>
<th>SBU2</th>
<th>VBUS</th>
<th>RX1-</th>
<th>RX1+</th>
<th>GND</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>B2</td>
<td>B3</td>
<td>B4</td>
<td>B5</td>
<td>B6</td>
<td>B7</td>
<td>B8</td>
<td>B9</td>
<td>B10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What is Alt Mode?
- Alternate use of USB Type-C interface for non-USB functions
- USB2 must be preserved
- USB PD must be used to negotiate an alternate mode
- **Definition**: Operation defined by a vendor or standards organization that is associated with a SVID assigned by the USB-IF. Entry and exit into and from an Alternate Mode is controlled by the USB PD Structured VDM Enter Mode and Exit Mode commands

Example of Alt Modes
- DisplayPort (DP)
- Thunderbolt
- PCI Express
- MHL
- HDMI (in work for dongle/cable)

Can you create your own alternate mode?
- Option 1: create an official alternate mode approved by USB-IF (will be given a SID, standard ID)
- Option 2: Get a VID from USB-IF and create a non-official alternate mode (you must own both sides of the system for this to work)
USB PD Alternate Mode Negotiation

Scope Trace between a Dock and Notebook establishing a USB PD Contract

USB Power Delivery Analyzer with TPS6598x Firmware
(A Dock acting as a DFP/Source & Notebook acting as the UFP/Sink)
DisplayPort as USB Type-C Alternate Mode

Bringing high resolution video

Need for signal Muxes
- Selection of active USB SS signals depending on plug orientation
- Merging of Alt Mode signals into SS signal pairs
- Flexibility of SS signal versus Alt Mode signals
- Signal Mux can be a physical device (most use case today) or done inside a processor (supporting both USB and Alt Mode through same pins)

DisplayPort as Alt Mode
- DisplayPort is most popular Alt mode today supporting high resolution video
- Signal mux allows following options for system depending on application need:
  - USB SS RX/TX only
  - USB SS RX/TX & 2 lanes of DP video
  - 4 lanes of DP video
- DP AUX signals use SBU1 and SBU2 signal pins
- DP HPD signal is embedded into USB PD message
Broad portfolio of TI’s USB-C/PD products

**Standard Type-C (15W max)**
- **Products**
  - TUSB320/1/2
  - TPS25810
  - TPS25820/1

**Type-C & PD Power Provider**
- **Products**
  - TPS25740/1
  - TUSB421

**Type-C & Full PD Power, Data, Video**
- **Products**
  - TPS6598x
  - TUSB422
  - TPS25725
  - TUSB546/2

**Differentiation**
- Turn key solution & smallest solution size in DFP > 15W power provider (TPS25810)
- Turn key solution & smallest solution size & cost in DFP < 7.5W power provider (TPS25820/1)
- Smallest device size & lowest device cost (TUSB320/1/2)

**Companion Products**
- **Products**
  - Battery
  - DC/DC
  - MCU
  - AC/DC
  - Protection
  - FET

**Winning Applications**
- Handset
- Laptop/PC
- Powerbank
- Wall Charger
- Car charger

**Winning Application**
- Wall Charger
- Adapter
- Car charger
- Powerbank

**Winning Application**
- Laptop/PC
- Monitor
- Tablet
- Dock/Dongle
- Infotainment

**Differentiation**
- Only company to offer full ecosystem for total solution
- Wide range of TI-Designs cover many end applications

**Winning Application**
- Laptop/PC
- Monitor
- Tablet
- Dock/Dongle
- Infotainment

**Companion Products**
- **Products**
  - Battery
  - DC/DC
  - MCU
  - AC/DC
  - Protection
  - FET
USB Type-C and PD Ecosystem

**TI Part #** | **Description**
--- | ---
TPS65981/Q1 | Industrial and Auto-qualified USB-C/PD port controller (DRP) w/ Pwr FETs up to 100W and HS Mux
TPS65982 | USB-C/PD port controller (DRP) w/Pwr FETs up to 100W and HS Mux for Thunderbolt™ hosts
TPS65983 | USB-C/PD port controller (DRP) for Thunderbolt devices
TPS65986 | USB-C/PD port controller (DRP) w/Pwr FETs up to 60W and HS Mux
TPS65988 | USB-C/PD port controller (DRP) w/Pwr FETs up to 60W
TPS25740/1 | USB-C/BD w/gate drivers for ext Pwr FETs w/Fixed PD manager as Power provider (DFP)
TPS25810 | USB-C <15W controller w/Pwr FETs, Vbus Discharge & IEC ESD as Power provider (DFP)
TUSB320/1 | USB-C <15W controller (DRP)

- "USB-C/PD" is a wide-spread scalable interface for power & signaling
- Barrier to entry for a complete solution is high – Type-C & PD specs are ~800 pages and continue to evolve!
- The diagram details elements in a complete system. Semiconductor suppliers are taking different approaches to implement:
  - TI has process & design expertise in all fundamental blocks - power, digital control, signal chain, ESD
USB Type-C and PD Ecosystem

TPS65982 - USB Type-C Port Power Switch with USB-PD Controller & HS Mux

- Supports all Type-C High Current Modes
  - Integrated Port Power Switches up to 20V @ 3A
  - Supports optional bi-directional external power NMOS FETs
  - Integrated Dead Battery LDO
- Fully compliant USB PD Baseband modem per USB PD2.x
  - BMC encoder/decoder, Physical Layer with CRC
  - No external MCU needed includes Port Policy Manager
- Performs all CC pin functions w Integrated Vconn
  - Cable Detection and Cable Orientation
  - No external Vconn components needed
- Integrated HS Mux & Alternate Mode Support
  - CC/2, SBU1/2, USB TP/TN, USBBP/BN
  - USB 2.0 Endpoint for Billboard & Flash Update
  - Display Port, Thunderbolt™, PDIO, QuickSwap, MHL
- Flexible system interfaces
  - I2C Slave/Master, SPI, Simple connection to HD3SS460 SS Mux for Display Port/USB3.0
- Easy to use 6 x 6 mm, non HDI uBGA ZQZ 96pin, 0.5mm pitch

Legend

- Basic Type-C/ PD Function
- Power
- Data/Video
- Protection
USB Type-C and PD Ecosystem

TPS65981/Q2 - USB Type-C Port Power Switch with USB-PD Controller & HS Mux

- Supports all Type-C High Current Modes
  - Integrated Port Power Switches up to 20V @ 3A
  - Supports bi-directional external power NMOS FETs
- Fully compliant USB PD Baseband modem per USB PD2.x
  - BMC encoder/decoder
  - Physical Layer with CRC
  - Policy and Policy Engine
- Performs all CC pin functions
  - Cable Detection and Cable Orientation
- Integrated HS Mux & USB 2.0 Endpoint
  - CC/2, SBU1/2, USB TP/TN, USBBP/BN
  - Support for Guest Port Protocols
    - Display Port
- Flexible system interfaces
  - I2C Slave/Master, SPI, Simple connection to HD3SS460 SS Mux for Display Port/USB3.0
- Easy to use 8x8mm 56pin QFN
- Commercial (-40 to 85), Industrial (-40 to 105), and Automotive (-40 to 125) temp ranges
- Easy to use 8x8mm 56pin QFN (Q2 will have Wettable Flanks)
TPS65982 USB Type C – Notebook – 5A, 3 Power Paths
TPS65982 USB Type C – Dock System

ESD

AFE
PD PHY

Power Manager

CC Analog
HS MUX
USB EP

SS MUX

HD3SS460

TPS65982

DC/DC convertor
20V → 15V/12V/5V

~ 20V Input

5A

USB HUB

DC/DC convertor
20V → 5.0V

5.0V

DC/DC convertor
20V → 3.3V

3.3V

Add Another USB-C/PD Port w TPS65986

Display Port

DP 1:2 Switch Re-driver

5.0V

TX1/RX1

TX2/RX2

D+/D-

D+/D-

TX/RX

HDMI

GPIO

AMSEL

POL

EN

USB Hub

USB

Type-C

Type-C

Type-C

Type-A

Type-A
TPS65982 USB Type C Monitor – DP, USB3.1 & Charger

- VBUS
- CC
- SBU
- D-
- D+
- TX1/RX1
- TX2/RX2
- AFE
- PD PHY
- Power Manager
- CC Analog
- USB EP
- CC
- HS MUX
- VCON
- D+/D-
- TX1/RX1
- TX2/RX2
- SS MUX
- HD3SS460
- Alternate Mode Display Port
- Display Port
- USB 3.1

- DC/DC converter: 5V – 20V → 3.3V
- DC/DC converter: 5V – 20V → 5V
- Add Another USB-C/PD Port w TPS65986
Faulty USB Type-C Cables

- Influx of new low cost USB Type-C cables to market from many different vendors and cable manufacturers
- In a survey of USB Type-C cables available on Amazon, **28% of cables were not compliant to USB-IF specification.** (Google Engineer Benson Leung: 20/71 cables out of specification)
- Starting March 2016, Amazon has issued a ban on any non-compliant USB Type-C cables
- Despite Amazon’s ban there is still a risk of end user’s purchasing non-compliant USB Type-C cables from cable manufacturers


Miswired USB Type A-C Cable

For Rp when implemented in the USB Type-C plug on a USB Type-C to **USB 3.1 Standard-A Cable Assembly**, a USB Type-C to **USB 2.0 Standard-A Cable Assembly**, a USB Type-C to **USB 2.0 Micro-B Receptacle Adapter Assembly** or a USB Type-C captive cable connected to a USB host, a value of 56 kΩ ± 5% shall be used, in order to provide tolerance to IR drop on VBUS and GND in the cable assembly.
Potential Failure Mechanisms

- **Non-Compliant Adapter/Cable:**
  - Adaptors from China put out VBUS 20V before PD negotiation. This can damage Type C ports designed for 5V only on VBUS, and CC if pulled up to 5V VBUS rail and VBUS switch fails as short.
  - Pull up at far end on C to C or C to A can cause CC lines to see 20V if the adapter is not designed properly and pulls CC up to VBUS that starts at 20V.

- **Mechanical Twist**
  - Pitch of the connector pins are small, mechanical twist can cause CC & SBU lines to short with VBUS.

- **Debris**
  - Debris getting into the connector can cause CC & SBU lines to short with VBUS.
USB Type-C Ecosystem

TPD8S300 - USB Type-C CC, SBU, D+/D- protector for Short-to-VBUS & IEC ESD Events

- One-Chip protection solution for USB Type-C Ports CC, SBU, and D+/D- lines
- 4-Channels of Short-to-VBUS Over Voltage Protection (CC1, CC2, SBU1, SBU2): 30V Tolerant OVP FETs
- 8-Channels of IEC 61000-4-2 ESD Protection (CC1, CC2, SBU1, SBU2, DP_T, DM_T, DP_B, DM_B)
  - ±8kV Contact, ±15kV Air-Gap
- CC1, CC2 FETs 600mA capable for passing VCONN power:
  - Worst case 250mV drop across FETs @ 125C (500mA)
- Integrated R_D pull down on CC for Dead Battery Support
- 3mm x 3mm QFN Package Options
- 3.5mm x 3.5mm QFN Package Option for Q1 version

Functional Samples available Now!
More Information

- USB Type-C Specifications
  - [http://www.usb.org/developers/usbtypec/](http://www.usb.org/developers/usbtypec/)

- USB PD Specifications
  - [http://www.usb.org/developers/powerdelivery/](http://www.usb.org/developers/powerdelivery/)

- USB 3.1 Specifications
  - [http://www.usb.org/developers/docs/](http://www.usb.org/developers/docs/)

- USB Billboard Specifications
  - [http://www.usb.org/developers/docs/devclass_docs/](http://www.usb.org/developers/docs/devclass_docs/)

- TI Type-C page

- TI E2E Online Community
  - [e2e.ti.com](http://e2e.ti.com)
Thank you