

USB Type-C[®] System Overview

Enabling connections for data, display and power

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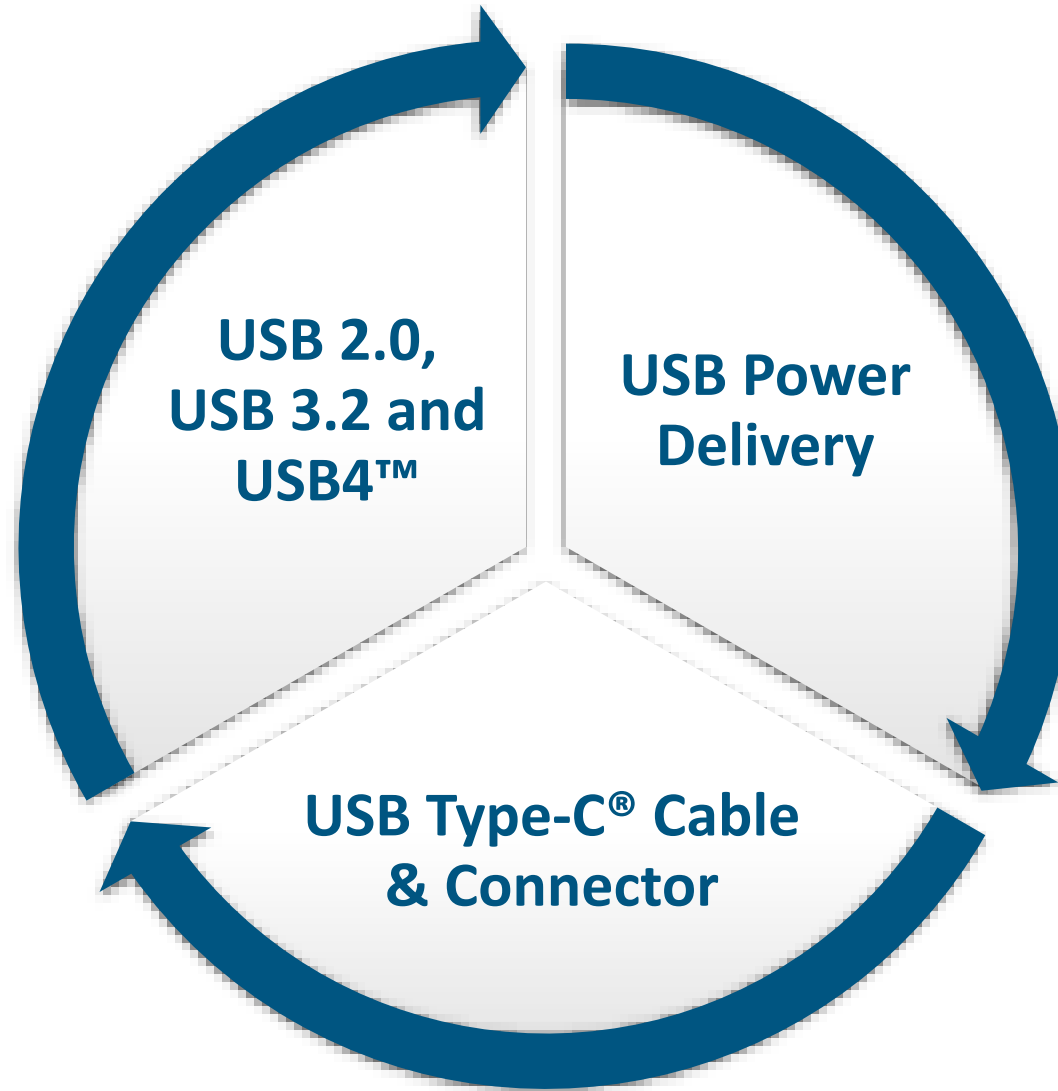
USB Developer Days 2019 – Taipei, Taiwan

November 19, 2019



Performance

Delivers up to 40 Gbps – supporting all of your data transfer and display needs



Power

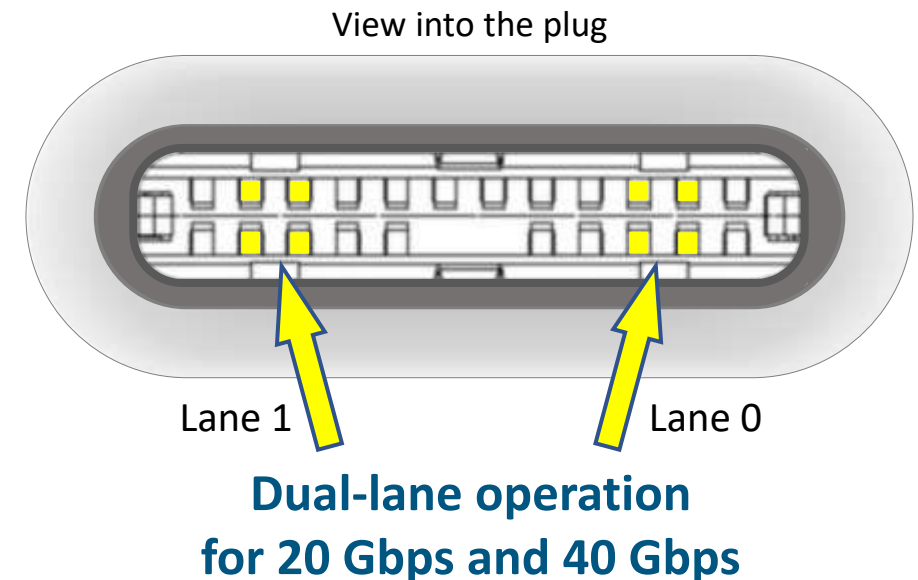
Delivers up to 100W – power and charging for all your devices

Convenience

Robust, slim connector with reversible plug orientation and cable direction

USB4™ – Extending USB on Multiple Vectors

- Enables the next generation of USB performance over existing USB Type-C cable plug/wires
 - **Doubles performance** and **extends protocol to display and load/store applications**
 - New signaling rates and encoding **for use on existing cables**
 - Gen2 (10 Gbps) works over all existing full-featured cables including Gen1 cables
 - Gen3 (20 Gbps) requires higher performance Gen3 cables
- USB4 builds on USB 3.2
 - **Enhanced SuperSpeed USB tunneling on a new USB4-specific transport**
 - **DisplayPort and PCIe supported** via separate tunnels with configurable bandwidth management
- USB4 discovery and entry relies on USB PD protocol
 - USB4 power requires a USB PD Explicit Contract



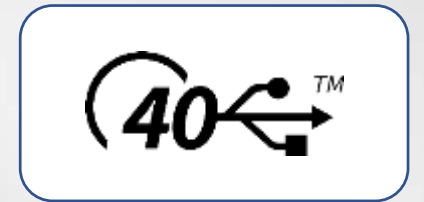
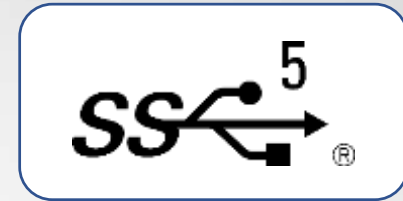
Presentation Agenda

- USB Type-C[®] Fundamentals
- Delivering Power
 - USB4 Power Requirements
- USB4[™] Discovery and Entry
 - Device and Cable Discovery/Entry
 - USB4 Hub connections

USB Type-C[®] – Summary Characteristics

Mechanical specifications

- 24-pin receptacle – ~8.3 mm x ~2.5 mm – 10,000 cycle durability
- Flip-able, reversible plugs/cables
- Standard **USB4[™]** / USB 3.2 / USB 2.0 cables and Legacy Adapters
- Improved EMI/RFI mitigation features
- Current ratings:
 - 3 A for standard cables
 - 5 A for connectors



Functional capabilities

- USB 2.0: LS/FS/HS
- USB 3.2: Gen1 (5 Gbps) / Gen2 (10 Gbps)
- **USB4[™]: Gen2 (10 Gbps) / Gen3 (20 Gbps) x 2**
- Electronically-Marked Cables enabled via USB PD
 - Alternate Mode capabilities enabled via USB PD
- Enhanced power options: Extended 5 V current ranges plus USB PD

USB Type-C[®] Specification – Release 2.0

1. Primary Referenced Specifications
 - USB 2.0 Specification
 - USB 3.2 Specification
 - USB4™ Specification, Version 1.0
 - USB Power Delivery Specification, Revision 3.0 (V2.0)
 - DisplayPort™ Alt Mode, Version 1.0b
2. Overview
 - Informative functional overview
3. Mechanical Requirements
 - Connector and cable definitions
 - Electro-mechanical performance requirements (USB4 Gen3 added)
4. Functional Requirements
 - Pin and signal requirements
 - Configuration channel requirements
 - Power requirements
5. USB4 Discovery and Entry
 - USB4-specific product functional and power requirements
 - Cable discovery and entry
 - Host, hub and device discovery and entry
6. Active Cables
 - Currently only covers up to USB 3.2 ← USB4 update in work, expected later this year

Appendices

- A. Audio Adapter Accessory Mode
- B. Debug Accessory Mode
- C. USB Type-C Digital Audio
- D. Active Cable Thermal Guidelines
- E. Alternate Modes ← relocated from Chap 5
- F. Thunderbolt™ 3 Compatibility Discovery and Entry

USB Type-C[®] Signal Summary

Signal Group	Signal	Description
USB 3.2 / USB4™	TXp1, TXn1 RXp1, RXn1 TXp2, TXn2 RXp2, RXn2	SuperSpeed USB / USB4 serial data interface: one transmit diff pair and one receive diff pair per lane Two pin sets to enable x2 operation
USB 2.0	Dp1, Dn1 Dp2, Dn2	USB 2.0 serial data interface Two pin sets, one wire set to enable plug flipping
Configuration	CC1, CC2 (receptacle) CC (plug)	CC channel in the plug used for connection detect, interface configuration, and USB PD comm channel
Auxiliary signals	SBU1, SBU2	Sideband Use; SBTX / SBRX for USB4 operation
Power	VBUS	USB bus power
	VCONN (plug)	USB plug power from Source via the “unused” CC1 or CC2 receptacle pin
	GND	USB cable return current path

USB Type-C[®] Configuration Channel (CC)

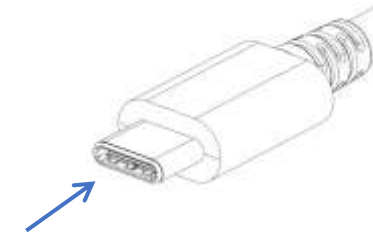
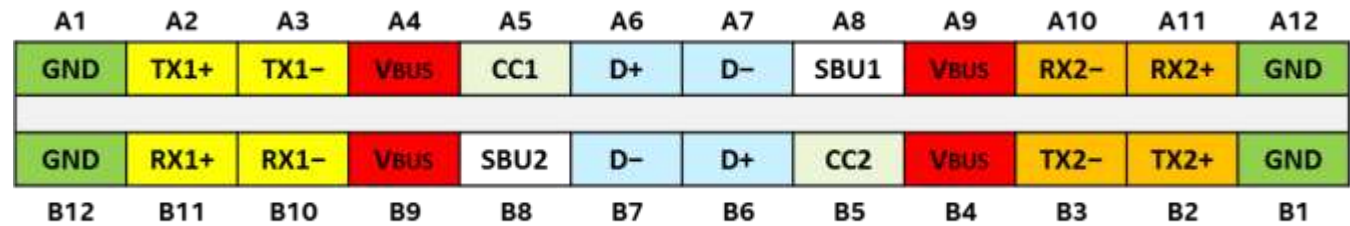
- ✓ Detect attach of USB ports
- ✓ Establish Source and Sink roles between two attached ports
 - Initially synonymous with Host and Device roles
- ✓ Discover and configure VBUS
- ✓ Discover and configure VCONN
- ✓ Resolve cable orientation and twist connections to establish USB data bus routing
 - *Also establishes Lane 0 for USB 3.2 and USB4™*
- ✓ *Discover and enter USB4 operation using USB PD protocol*
- ✓ Discover and configure optional Alternate and Accessory modes using USB PD protocol

USB Type-C[®] – Functional Model

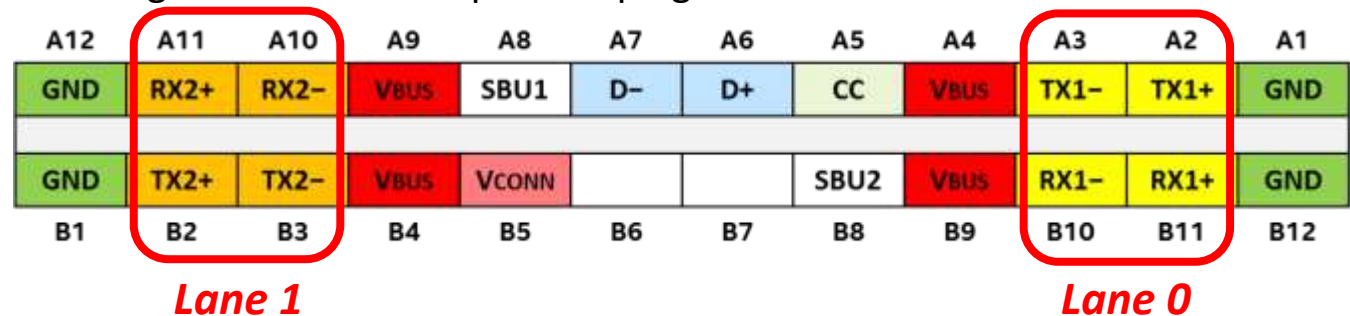
- USB 3.2 / *USB4™* data bus
 - Two sets of TX/RX pin pairs, supports x1 and x2 operation
- USB 2.0 data bus
 - Two pin sets on host, one set on device – strapped together within the host and device
- Two power buses
 - VBUS and VCONN
- Two sideband pins (SBU1/SBU2)
 - *SBTX / SBRX for USB4*
- CC – Configuration Channel
 - Two CC pins in connector
 - One CC wire in cable



Looking into the product receptacle:

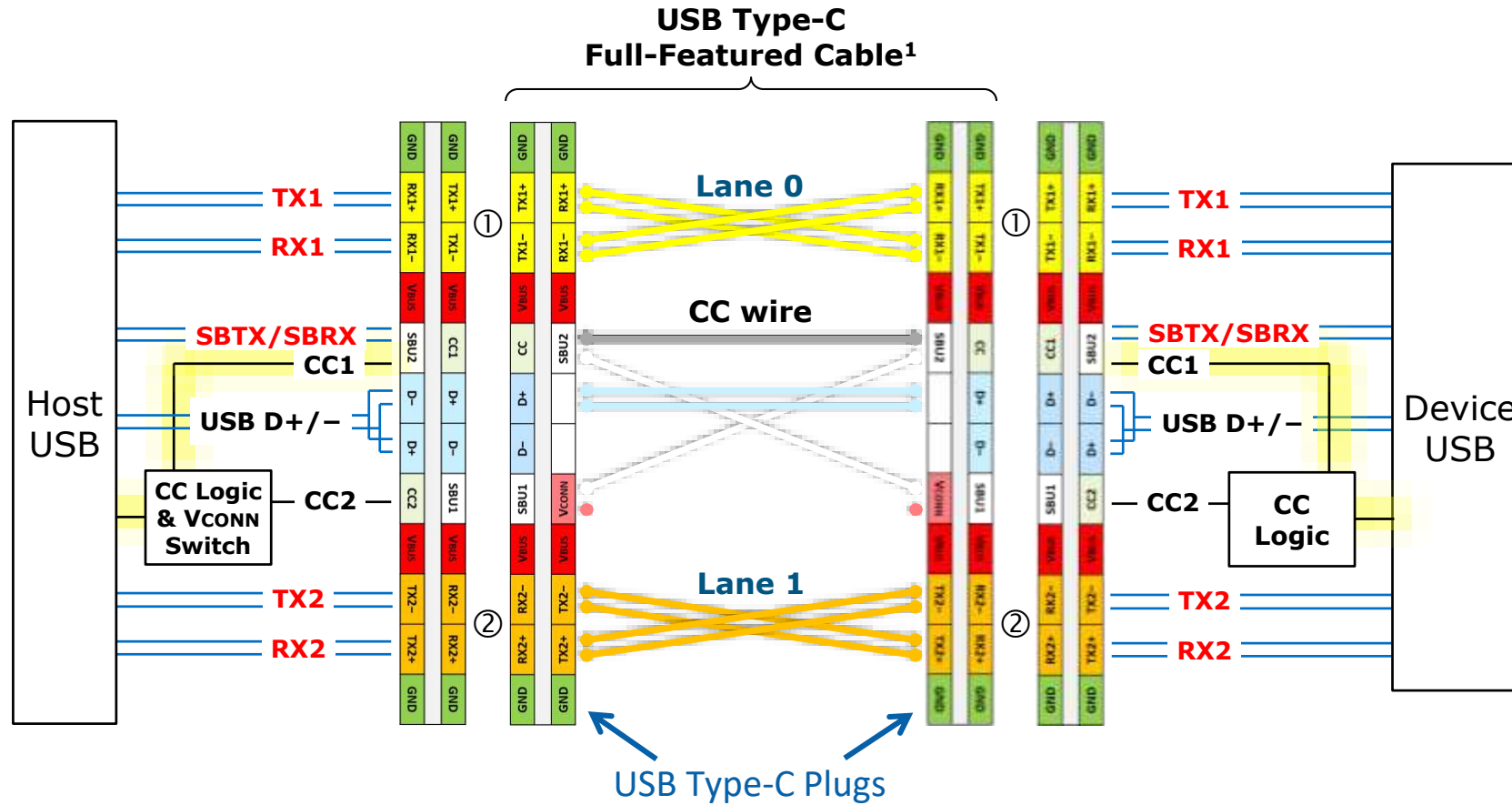


Looking into the cable or product plug:



USB Type-C[®] – Functional Model

- USB Type-C Full-Featured Cable supports all USB operating modes

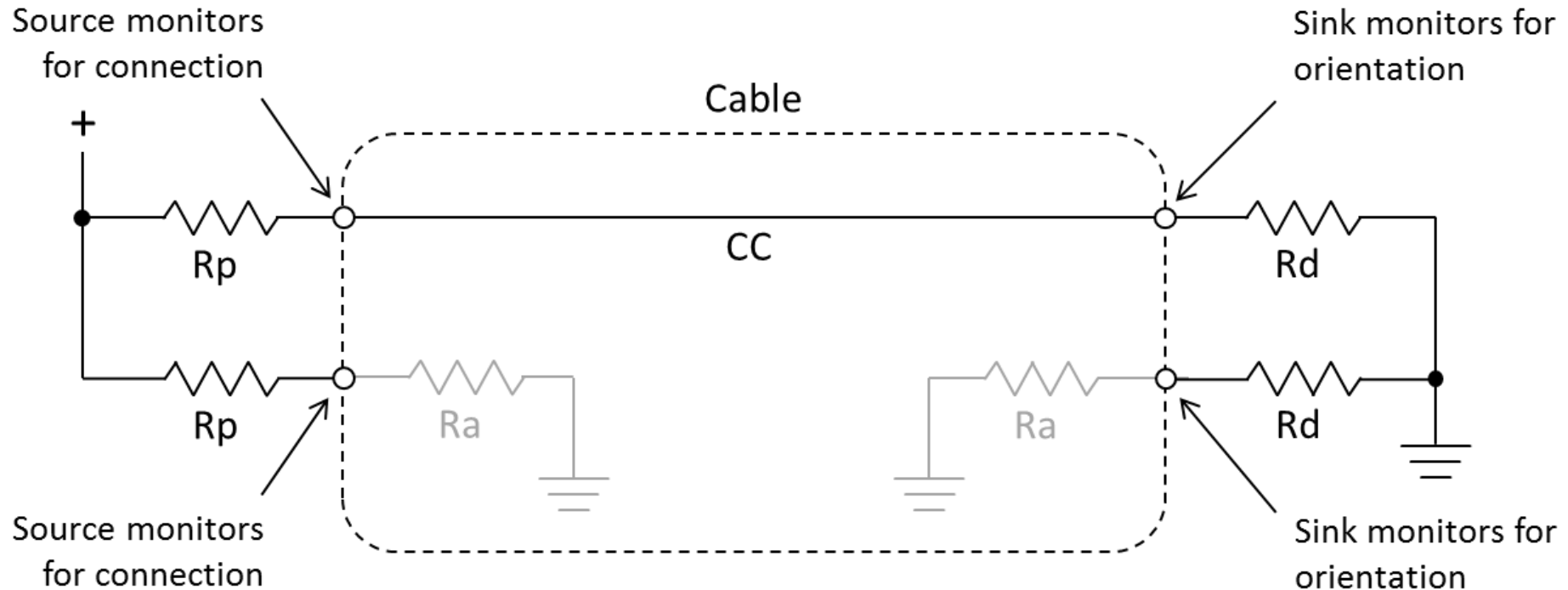


Note: 1. Required VBUS and Ground wires not shown in this illustration

Understanding USB Type-C[®] port behaviors

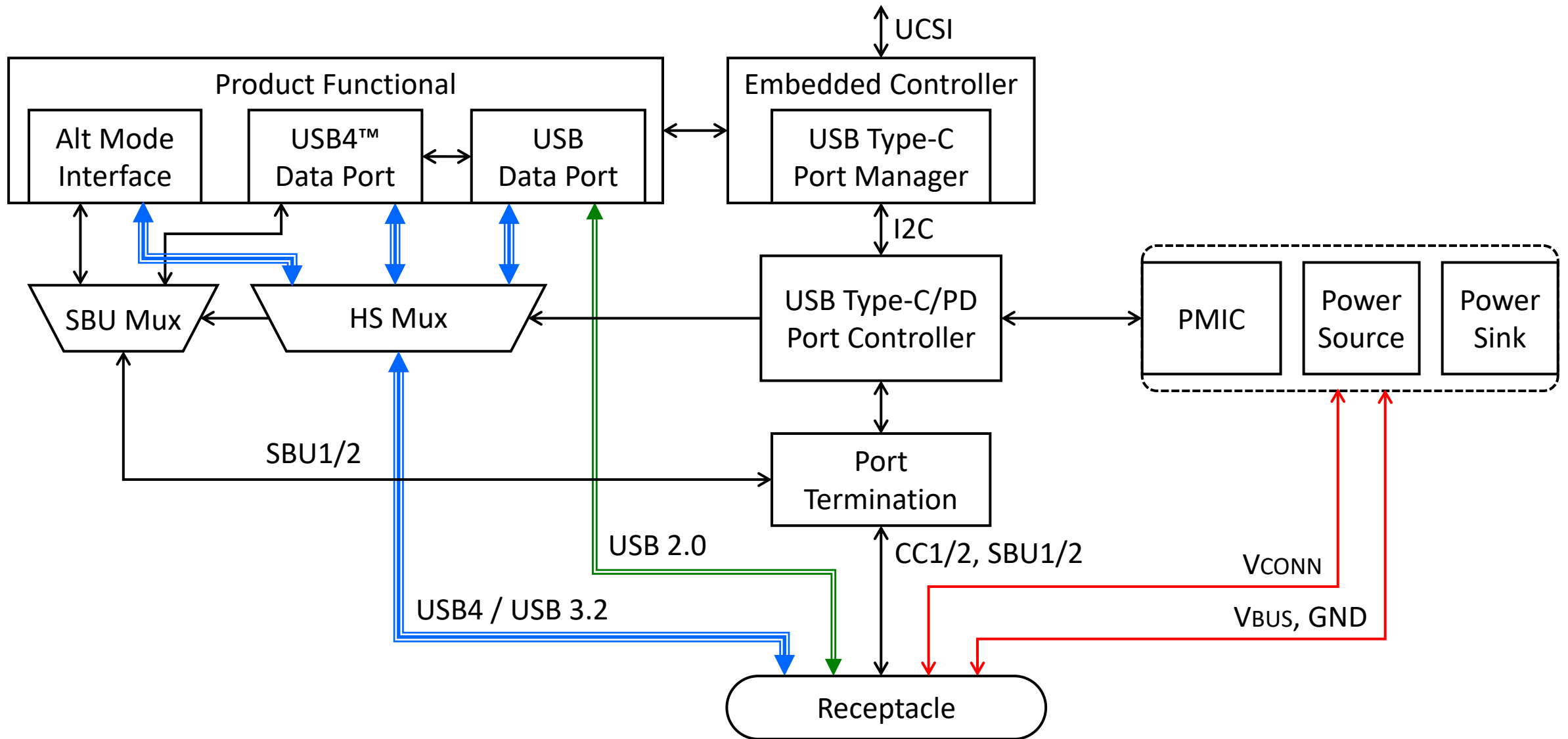
- Power roles:
 - Source – typical of host or hub downstream ports
 - Sink – typical of device upstream ports
 - Dual-Role Power (DRP) – can be either a Source or a Sink ← *hosts typically moving to here*
- Data roles:
 - DFP-mode only – typical of host or hub downstream ports
 - UFP-mode only – typical of device upstream ports
 - Dual-Role Data – typical of “on-the-go” ports ← *hosts typically moving to here*
- Roles can be dynamically swapped using USB PD
 - Power role swap, data role swap, VCONN swap

USB Type-C® – Pull-Up/Pull-Down CC Model

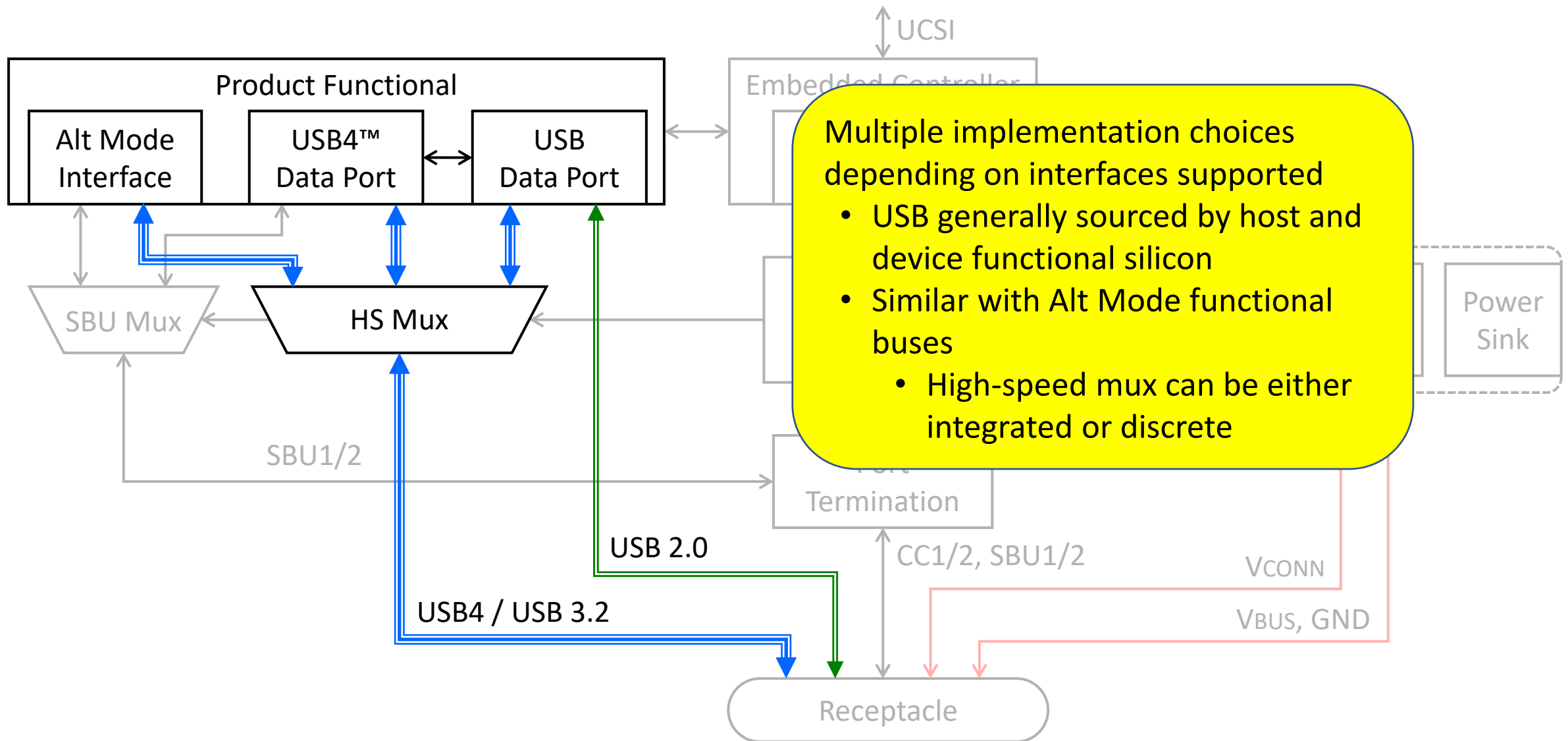


- Host side can substitute current sources for R_p
- Powered cables and accessories introduce R_a at the “unwired” CC pins which are used to indicate the need for V_{CONN}

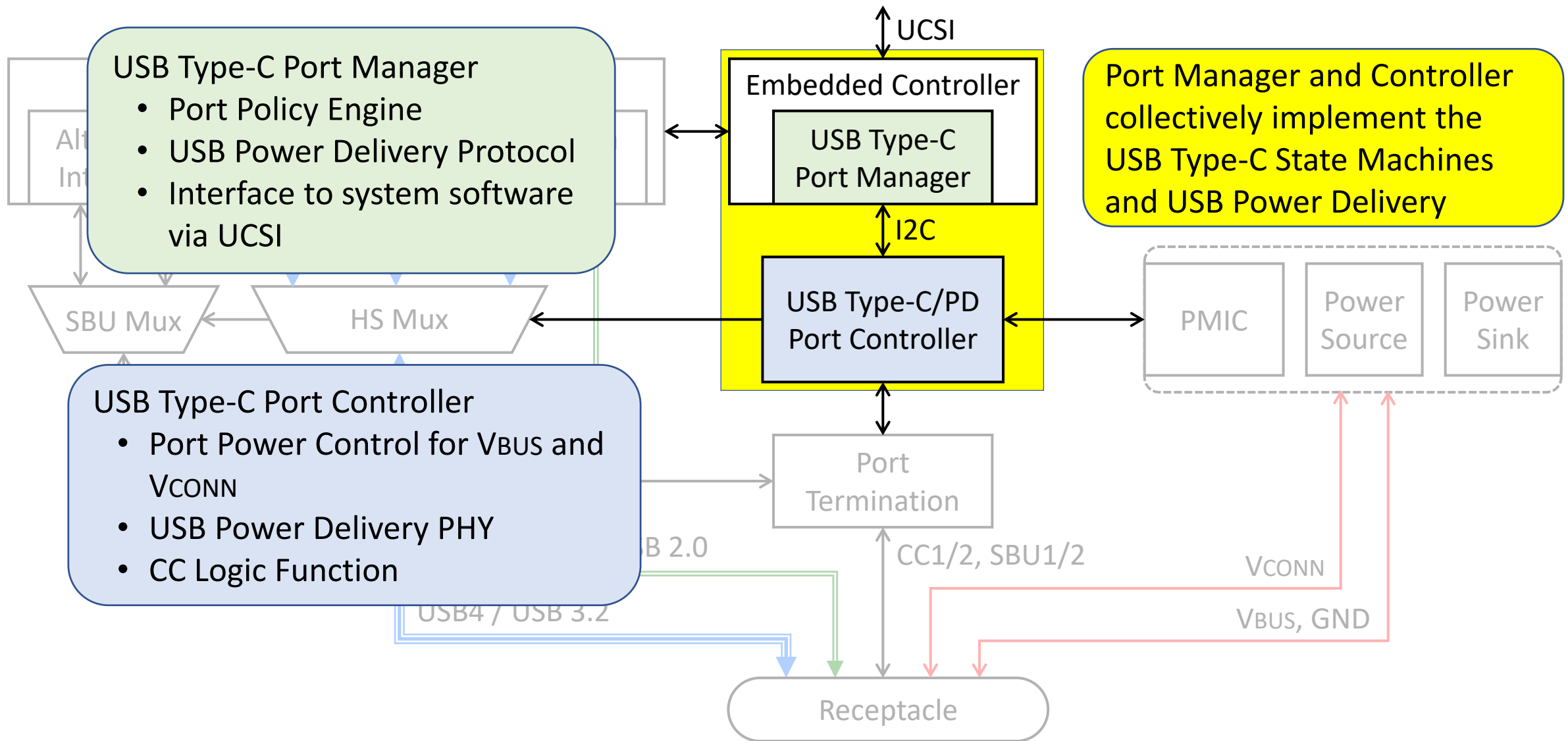
Basic USB Type-C® System Implementation Model



Data Bus Interface Implementation



USB Type-C® Port Controller



Presentation Agenda

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USB Type-C® Power

- All solutions required to support Default USB Power appropriate to product – as defined by USB 2.0, USB 3.2 and **USB4™** (as defined in the USB Type-C spec)

Precedence	Mode of Operation		Nominal Voltage	Maximum Current
Highest ↓ Lowest	USB PD (including USB4)		Configurable	5 A
	USB Type-C Current @ 3.0 A		5 V	3.0 A
	USB Type-C Current @ 1.5 A		5 V	1.5 A
	<i>USB BC 1.2</i>		<i>5 V</i>	<i>Up to 1.5 A</i>
	Default USB Power	USB 3.2 x2 operation		5 V
USB 3.2 x1 operation		5 V	900 mA*	
USB 2.0		5 V	500 mA*	

* Current available depends on device and bus operating state, e.g. unconfigured, low power, high power, suspend.

USB4™ Power Requirements

- USB4 operation requires **VBUS** power provided using a USB PD Explicit Contract
- USB4 Source Power Requirements: minimally provide **7.5 W (5 V @ 1.5 A)** on each port
- USB4 Sink Power Requirements
 - Devices allowed only up to 250 mA on VBUS when the Source advertises Default USB power prior to establishing a PD Explicit Contract
 - Devices have to be capable of operating with a Source that only delivers 7.5 W
 - Higher levels of performance / functionality can require more power
- Device Suspend Behavior
 - Devices are required to support Suspend when the USB4 link is in the disabled state (CLd) with the USB Suspend Supported Flag set by the Source
 - Suspend power limits:
 - Device not capable of remote wake or not enabled for remote wake: 25 mW
 - Device supports and is enabled for remote wake: 50 mW
- **VCONN Source requirement remain 1.5 W**

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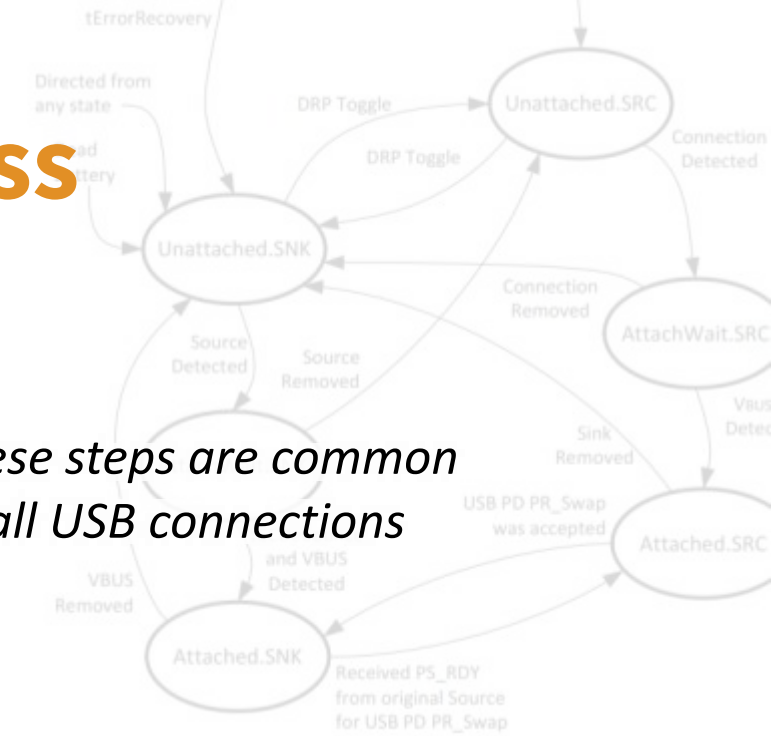
USB4™ Discovery and Entry

- USB Type-C® functionally defaults to USB 2.0 and USB 3.2 if no additional functionality is discovered
- Extended functionality requires USB PD processes to discover
 - USB4 operation
 - Alternate modes: Thunderbolt™ 3, DisplayPort, etc.
 - VCONN-Powered Accessories (VPAs)
- Prior to USB4 or Alternate Mode discovery, USB PD first requires an Explicit Power Contract to be in place

USB4™ Discovery and Entry Process

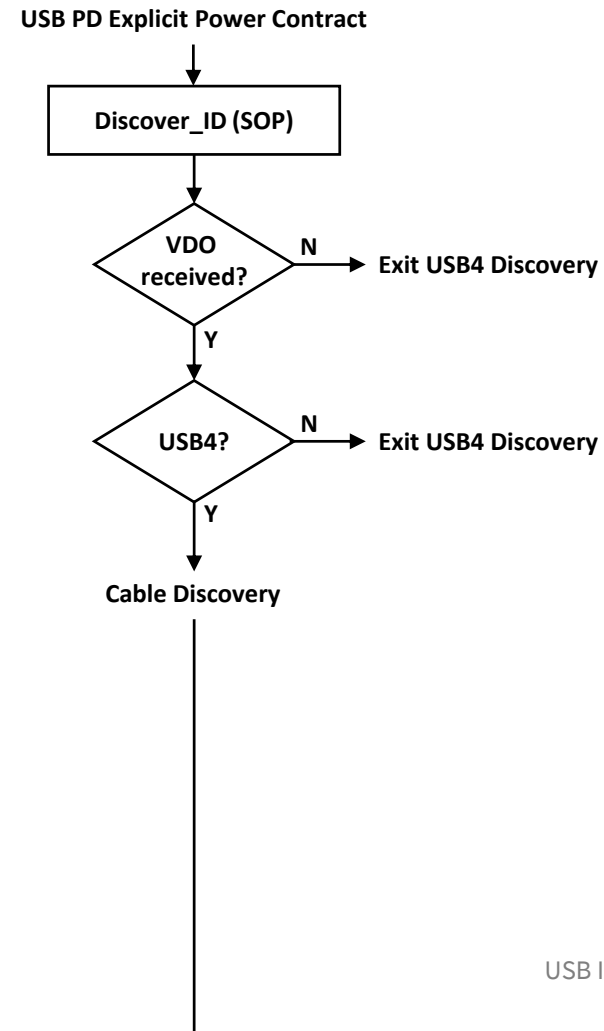
1. CC Connection State Machines resolve Source/Sink and initial data roles (DFP/UFP)
 2. Initial VBUS and VCONN power is supplied
 3. USB PD is used to establish a power contract between the port partners
 4. USB PD **Discover Identity** is used by the DFP to identify port partner (SOP) capabilities
 5. USB PD **Discover Identity** is used by the DFP to identify cable (SOP') capabilities
 6. If the cable and port partner both support USB4 operation, the DFP issues USB PD **Enter_USB** messages to both the cable and port partner to enter USB4 operation
-
7. If both port partners are Dual-Role-Data (DRD) capable, either the DFP or UFP can optionally initiate a data-role swap in order to exchange host (master) and device (slave) roles

These steps are common to all USB connections



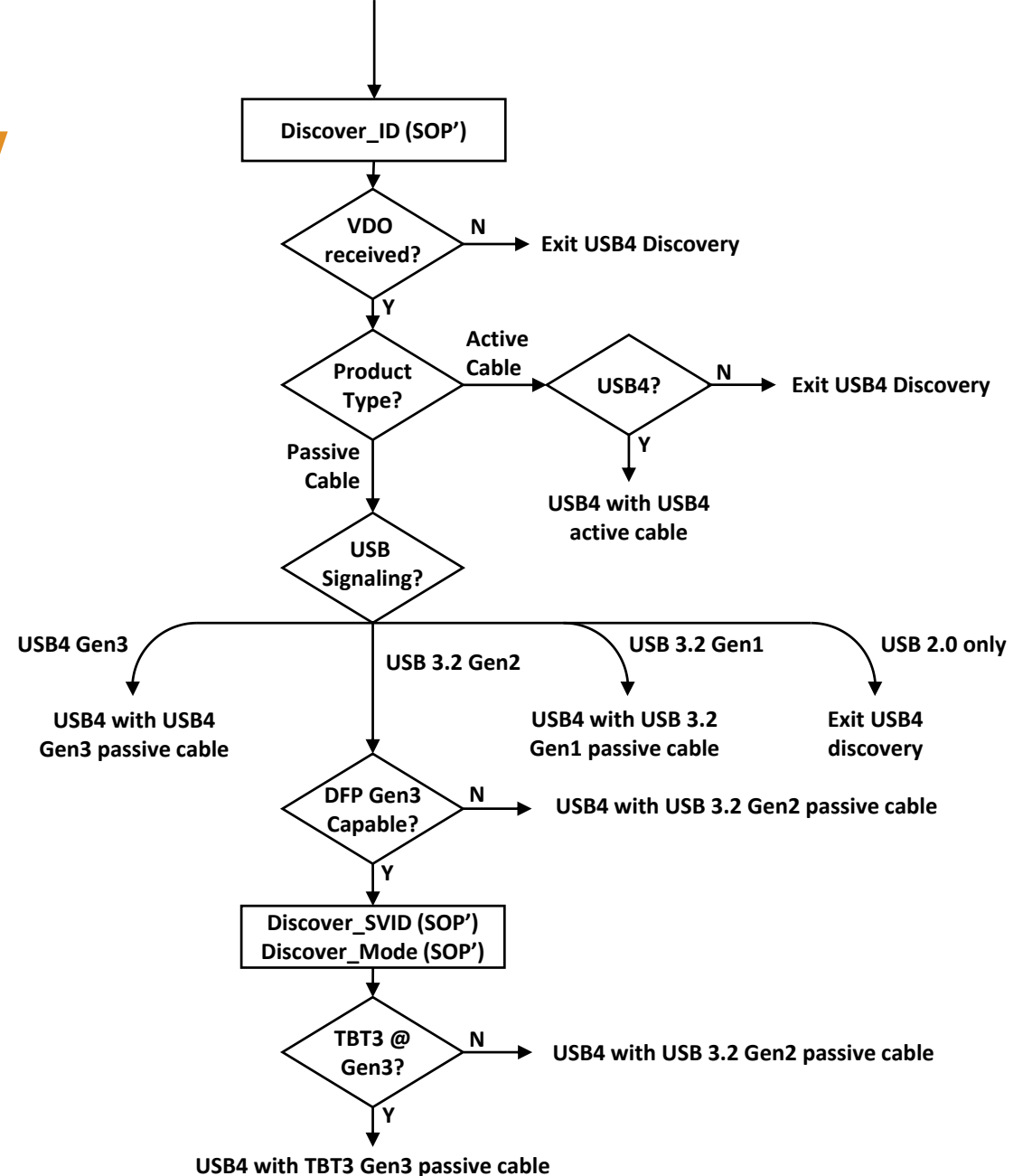
USB4™ Device Discovery

- A USB PD Explicit Power Contract required prior to USB4 device discovery begins
- Starts with use of USB PD **Discovery Identity** by the DFP to the SOP
 - Devices that don't respond are presumed not USB4-compatible
- UFP ID Header and VDO responses used to determine level of USB4 compatibility
 - Product type (hub, peripheral)
 - Device capabilities
 - Alt Mode support
 - Device speed
 - Power requirements



USB4™ Cable Discovery

- Starts with use of USB PD **Discovery Identity** by the DFP to the SOP'
- Cables that don't respond with VDO are considered not USB4-compatible
- VDO responses used to determine level of compatibility
 - Cable type and signaling speed field
- Special case: Thunderbolt™ 3 Gen3 passive cables when connected to USB4 DFP
 - USB PD Alt Mode discovery used



USB4™ Cable Compatibility Summary

	Rated Signaling	USB4 Operation	Response to Discover Identity
USB Type-C® Full-Featured Cables (Passive)	USB 3.2 Gen1	20 Gbps	USB 3.2 Gen1 (001b) in Passive Cable VDO
	USB 3.2 Gen2	20 Gbps	USB 3.2 Gen2 (010b) in Passive Cable VDO
	USB4 Gen3	40 Gbps	USB4 Gen3 (011b) in Passive Cable VDO
Thunderbolt™ 3 Cables (Passive)	TBT3 Gen2	20 Gbps	USB 3.2 Gen1 (001b) or USB 3.2 Gen2 (010b) in Passive Cable VDO
	TBT3 Gen3	40 Gbps	USB 3.2 Gen2 (010b) in Passive Cable VDO + TBT3 Gen3 in Discover Mode VDO
USB Type-C Full-Featured Cables (Active)¹	USB4 Gen2	20 Gbps	USB4 Gen2 (010b) in Active Cable VDO
	USB4 Gen3	40 Gbps	USB4 Gen3 (011b) in Active Cable VDO

¹ SuperSpeed USB active cables do not support USB4-compatible operation whereas USB4 active cables do support SuperSpeed USB

USB4™ Operational Entry

- USB4 devices allow up to one second from Sink attach for the receipt of the **Enter_USB** message
 - If fails, device falls back to USB 3.2/USB 2.0 and exposes a USB Billboard Class Device
- Once USB4 cable and device is confirmed, USB4 entry uses USB PD **Enter_USB** message
 - Sent to cable (SOP', SOP'' if present) and then device (SOP)
 - **Enter_USB** Message for USB4 entry includes:
 - USB Mode to enter: USB4
 - USB4 DRD capable or not
 - Cable info regarding speed and current rating
 - Tunneling support: DisplayPort™ and PCIe
 - TBT3 support or not
 - Host present ← *used by upstream hubs to inform downstream hubs of host connection status*
- USB4 Operation is defined by the USB4 Specification
 - Covers training links, configuring routers and paths, tunnel operation, etc.

During and Exiting USB4™ Operation

- During USB4 Operation
 - USB PD Explicit Power Contracts may be re-negotiated
 - USB PD **Data_Reset** command can be used to initiate an exit from USB4
 - Alternate Modes that do not reconfigure the port interface may be discovered and entered in parallel to USB4 operation
- Using USB PD **Data_Reset** command for exiting USB4 Operation includes following steps:
 - USB PD **Data_Reset** command is issued to SOP to reset the data bus, reset the cable and exit any Alternate Modes while preserving the power on VBUS
 - USB4 and Alt Mode entry one second timeouts are reset
 - Port re-enters the discovery and entry process
 - DFP typically uses a revised capabilities list (e.g., no USB4) for a new post-reset connection

USB4™ – Alternate Mode Support

- USB4 specification enables products to support DP Alt Mode and Thunderbolt™ Alt Mode
 - Even allowed on USB4 hub downstream ports
- Some Alternate Modes are required for the first three years of USB4 certification
 - DisplayPort™ Alt Mode 1.0b (with Multi-Function support)¹ required on:
 - USB4 Hosts DFPs that support DP tunneling
 - USB4 Hub DFPs and USB4-based Dock² DFPs
 - Thunderbolt™ 3 Alt Mode compatibility as defined in the USB4 spec required on:
 - USB4 Hubs DFPs and USB4-based Dock² DFPs
 - USB4-based Docks² UFP

¹ First connected display support required, simultaneous additional displays support optional (across all display-capable connectors)

² USB4-based Dock = USB4 Hub + additional non-USB connectors and/or user-visible functions (e.g. storage, display, etc.)

USB4™ Hub Connections

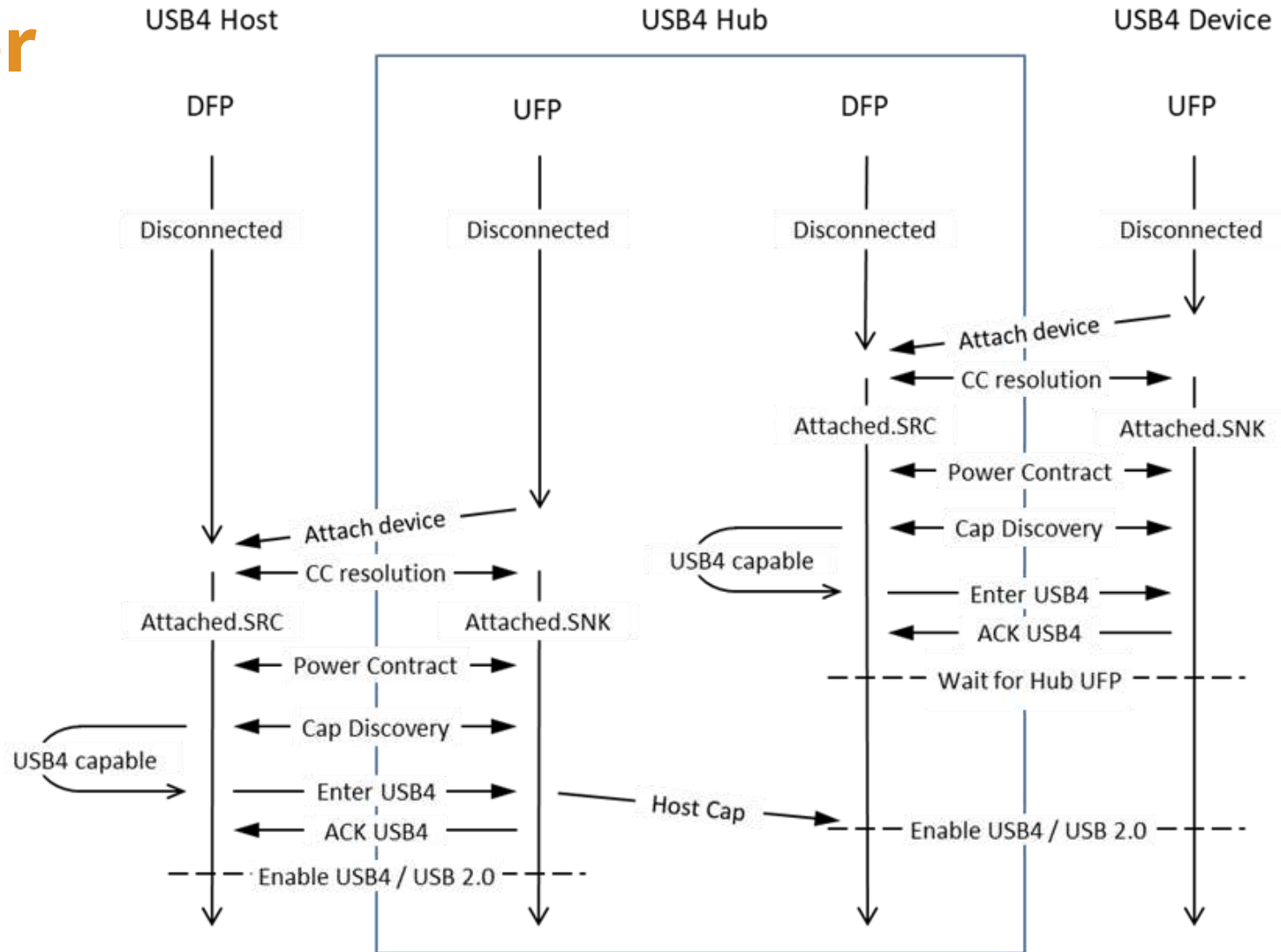
- USB4 hub connections have complexities over the host to device connection process
 - Behaviors vary based on if a path to the USB4 host exists when the hub detects device attaches
 - Prior to a host being presence, hub DFP connections are made *speculatively* based on highest available capabilities between the hub and device

USB4 / TBT3 Alt Mode / DP Alt Mode / USB 3.2 / USB 2.0

- Once the host appears, hub adjusts its downstream connections as needed to align with host capabilities
 - If a DFP connection needs to change, hub uses either USB PD **Data_Reset** command or entering the **ErrorRecovery** state to reset the connection followed by discovering only connections compatible with the USB4 host
 - USB PD **Enter_USB** messages get propagated with updated capabilities list to downstream hubs

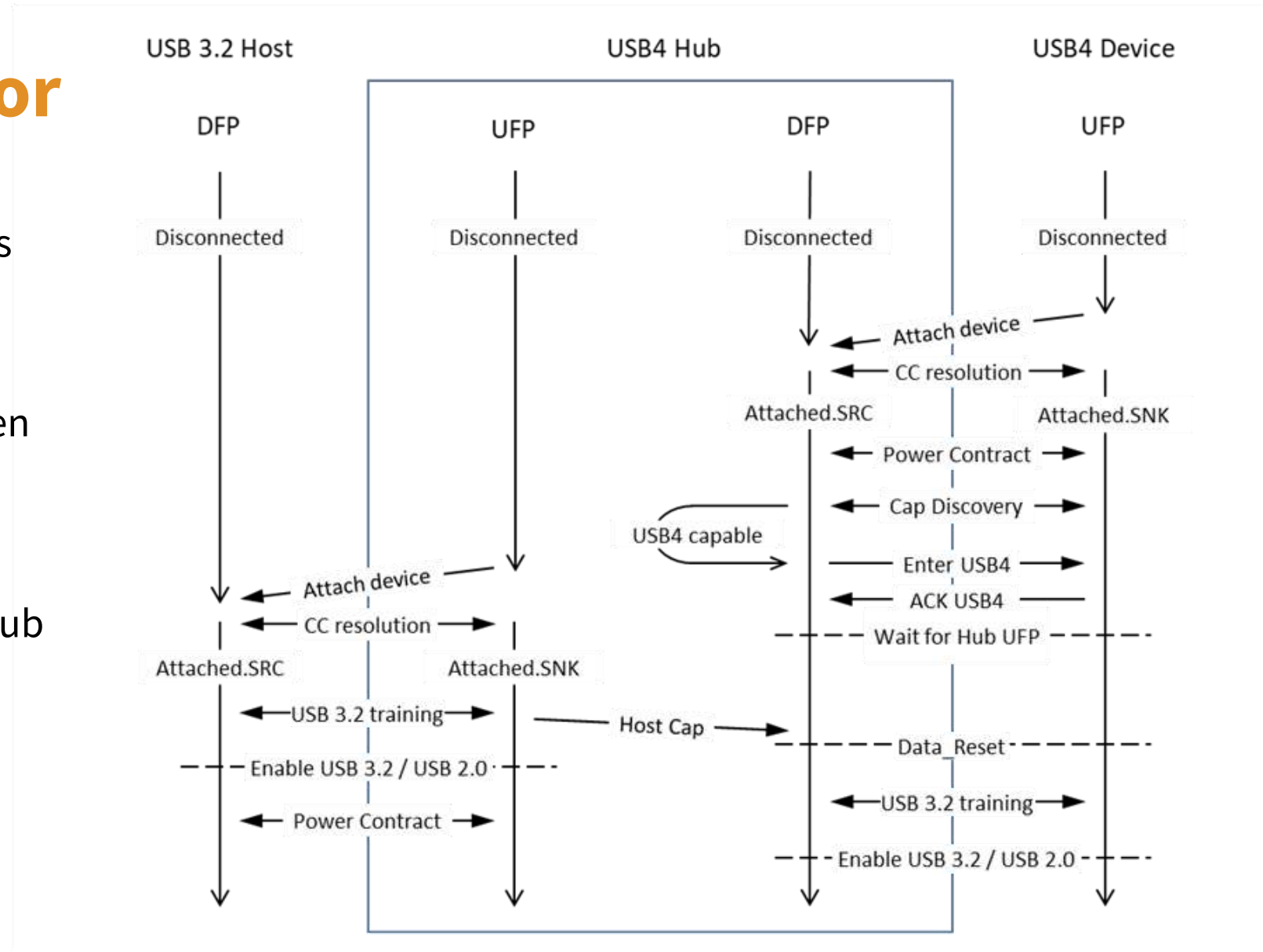
USB4™ Hub Port Connection Behavior

- USB Type-C® specification illustrates a number of cases as guidance
- The case shown here is for when everything supports USB4
 - Simplest case where connection order really isn't critical



USB4™ Hub Port Connection Behavior

- USB Type-C® specification illustrates a number of cases as guidance
- The case shown here is for when the host turns out to be only capable of USB 3.2
 - The speculative USB4 connection between the hub and device has to be reset

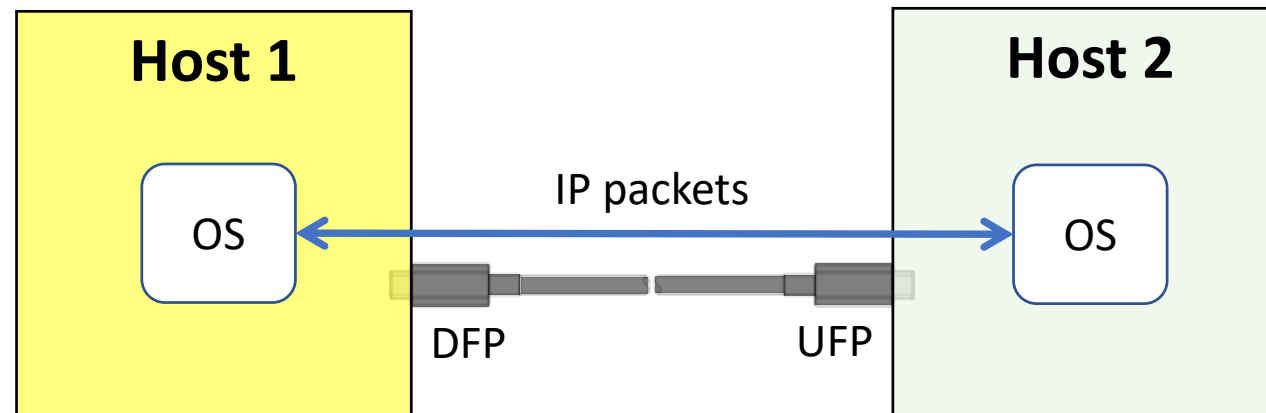


USB4™ Device Fallback Requirements

- USB4 devices that are connected to USB 3.2 or USB 2.0 hosts are required to fall back to USB 3.2 and/or USB 2.0 operation
- When falling back, each peripheral function of the USB4 device shall map to equivalent USB device class operation whenever possible
 - Performance is allowed to scale down to be appropriate to lower speed bus
 - Examples of mappable device classes: Audio, Mass Storage, Networking, HID, etc.
- For USB4 peripheral functions based on DisplayPort™ and PCIe protocol tunneling that do not map to a USB device class equivalent, an appropriate USB Billboard Device Class is to be exposed
 - Examples:
 - PCIe functions that should map includes storage applications
 - PCIe functions that don't map includes external graphics adapters

USB4™ Host-to-Host Connections

- USB4 Host-to-Host connections are possible via a USB4 Inter-Domain Link
 - A Host-to-Host connection always resolves to a DFP to UFP connection
 - At least one of the USB4 hosts has to be DRP/DRD capable
- Once connected, a USB4 specification addendum defines how to establish a Host-to-Host tunnel and exchange IP packets over the USB4 transport
 - Implementation is software based



Time for Q&A
