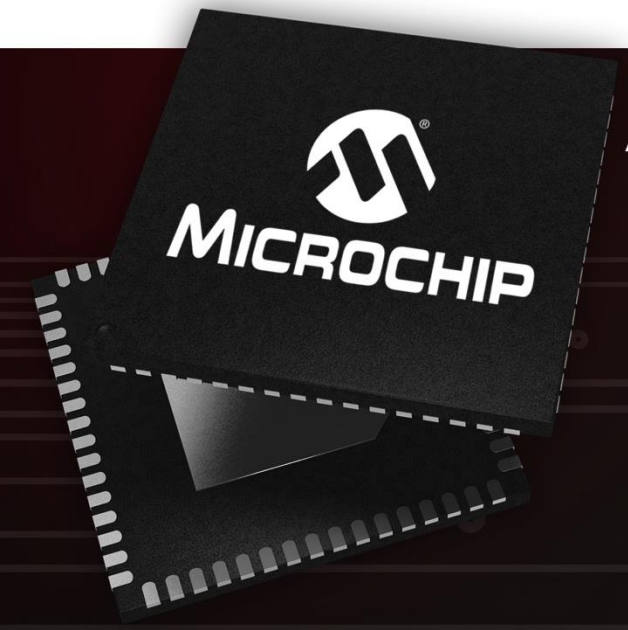
MICROCHIP



A Leading Provider of Microcontroller, Security, Mixed-Signal, Analog & Flash-IP Solutions




Presented by:
Frank Cho, Embedded Solutions Engineer
September 6, 2018

USB Type-C™ Interface: Technical Overview and Design

How to apply USB Type-C for Automotive and Consumer Electronics Markets

Agenda

- USB History and Overview
- USB Type-C™ Overview
- USB Type-C In Depth
- Power Delivery
- Alternate Modes
- USB Type-C System Overview

USB Specifications Revisions

Release name	Release date	Maximum transfer rate	Note
USB 0.8	December 1994	-	Prerelease
USB 0.9	April 1995	-	Prerelease
USB 0.99	August 1995	-	Prerelease
USB 1.0-RC	November 1995	-	Release Candidate
USB 1.0	January 1996	Low Speed (1.5 Mbit/s)	-
USB 1.1	August 1998	Full Speed (12 Mbit/s)	-
USB 2.0	April 2000	High Speed (480 Mbit/s)	-
USB 3.0	November 2008	SuperSpeed (5 Gbit/s)	Also referred as USB 3.1 Gen 1 and USB 3.2 Gen 1x1
USB 3.1	July 2013	SuperSpeed+ (10 Gbit/s)	Also referred as USB 3.1 Gen 2 and USB 3.2 Gen 2x1
USB 3.2	September 2017	SuperSpeed+ (20 Gbit/s)	Includes new USB 3.2 Gen 1x2 and USB 3.2 Gen 2x2 multi-link modes

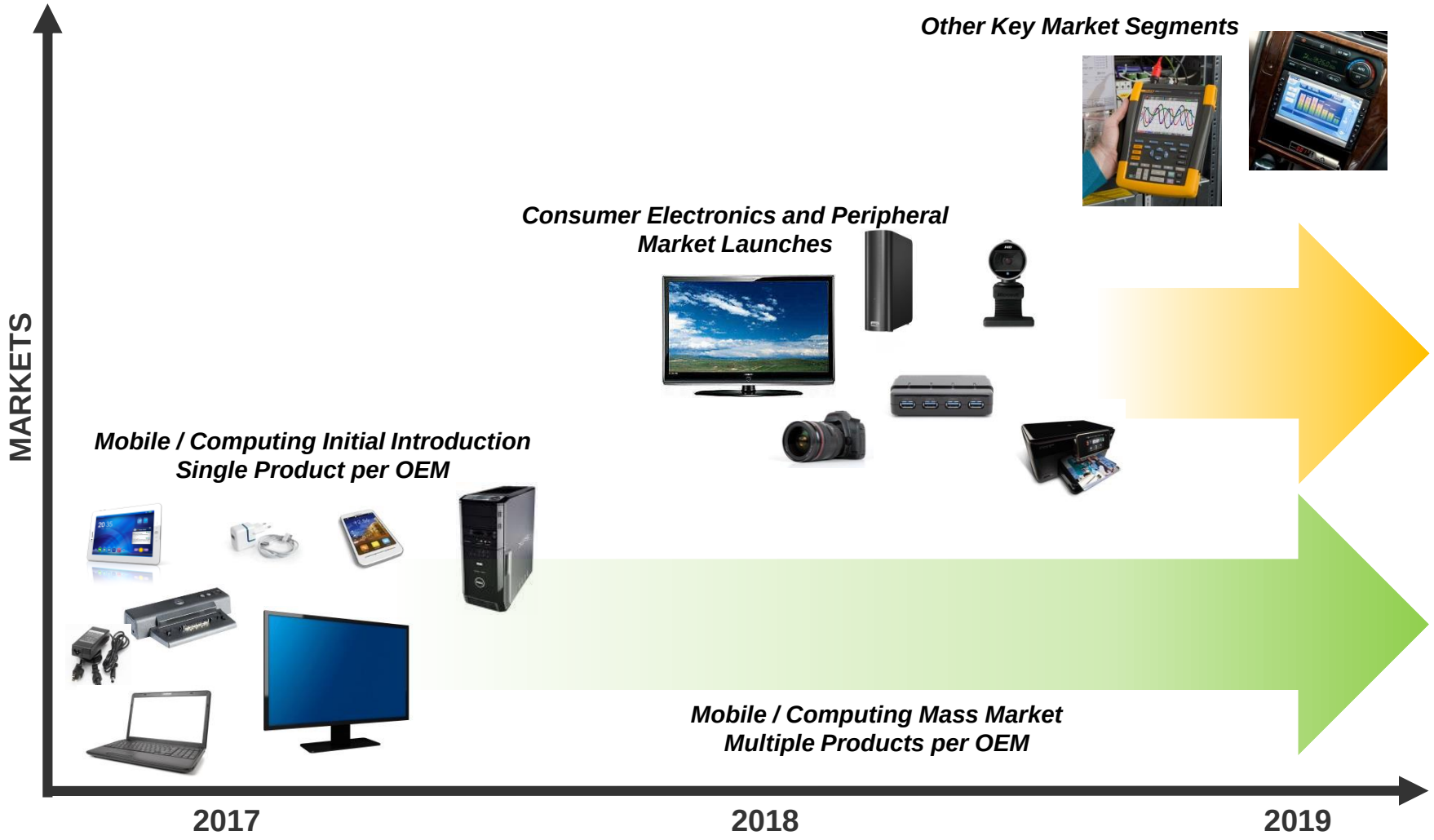
USB Connector Types

- **USB Connector Types**
  - Type A
  - Type B
  - Type Mini-A
  - Type Mini-B
  - Type Micro-A
  - Type Micro-B
  - Apple Lightning
  - Type Micro-B USB 3.0
  - USB Type-C™ (USB-C™)

USB Type-C™ Key Features

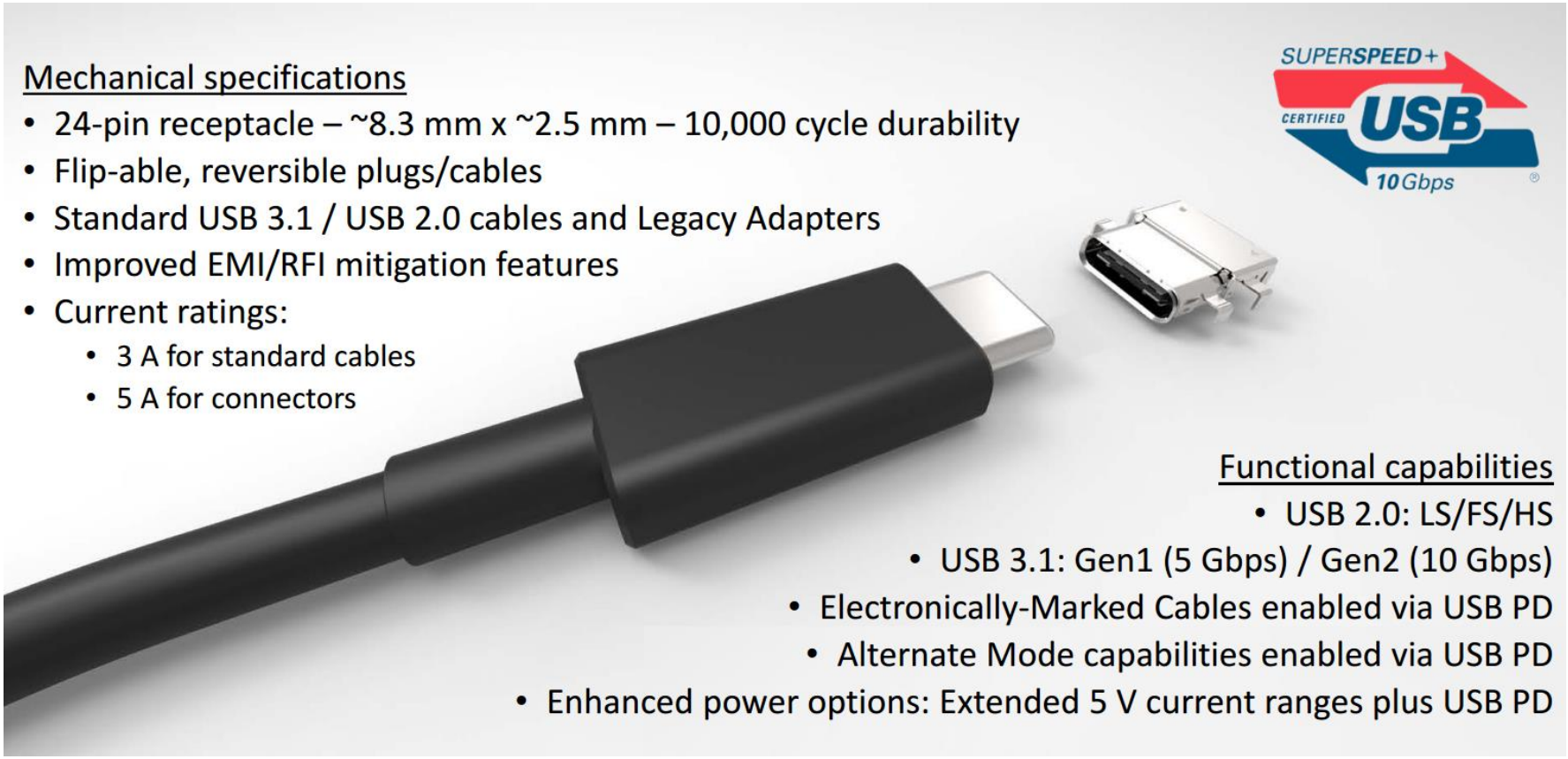
- Identical USB Type-C™ connectors on both ends
- Reversible, low-profile, connector
- +10 Gbps of data bandwidth
- Backwards compatible: Support for USB 2.0 signaling
- "Alternate Modes" allows 3rd party protocol, such as Thunderbolt, DisplayPort™, HDMI, and more!
- Optional: Power Delivery 3.0 (protocol) to deliver up to 100W

USB Type-C/PD Market Trend



**** NOTE:*** *Products shown here are intended to be generic and for the sole purpose of demonstrating the TYPE of application only. It shall NOT be misconstrued to represent the launch of a certain OEM brand, or actual model with intended solution.*

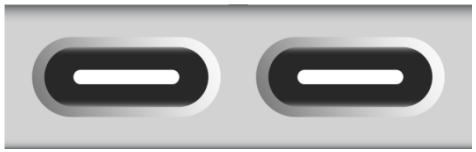
USB Type-C™ Summary



Source: www.usb.org

Downstream Facing Port (DFP)

- **What is a DFP?**
  - A Host Port
- **Preferred Role is Source**
- **Example**
  - Laptop / Desktop
  - Automotive Console



Upstream Facing Port (UFP)

- **What is a UFP?**
  - A Device Port
- **Preferred Role is Sink**
- **Example**
  - Mouse / Keyboard
  - Flash Drive

Dual Role Port

- **A Hub has both UFP and DFP**
  - A Hub UFP acts as a Sink
  - A Hub DFP is a Source
- **Example**
  - Stand alone USB Hub
  - Dock with Embedded Hub
  - Monitor with Embedded Hub

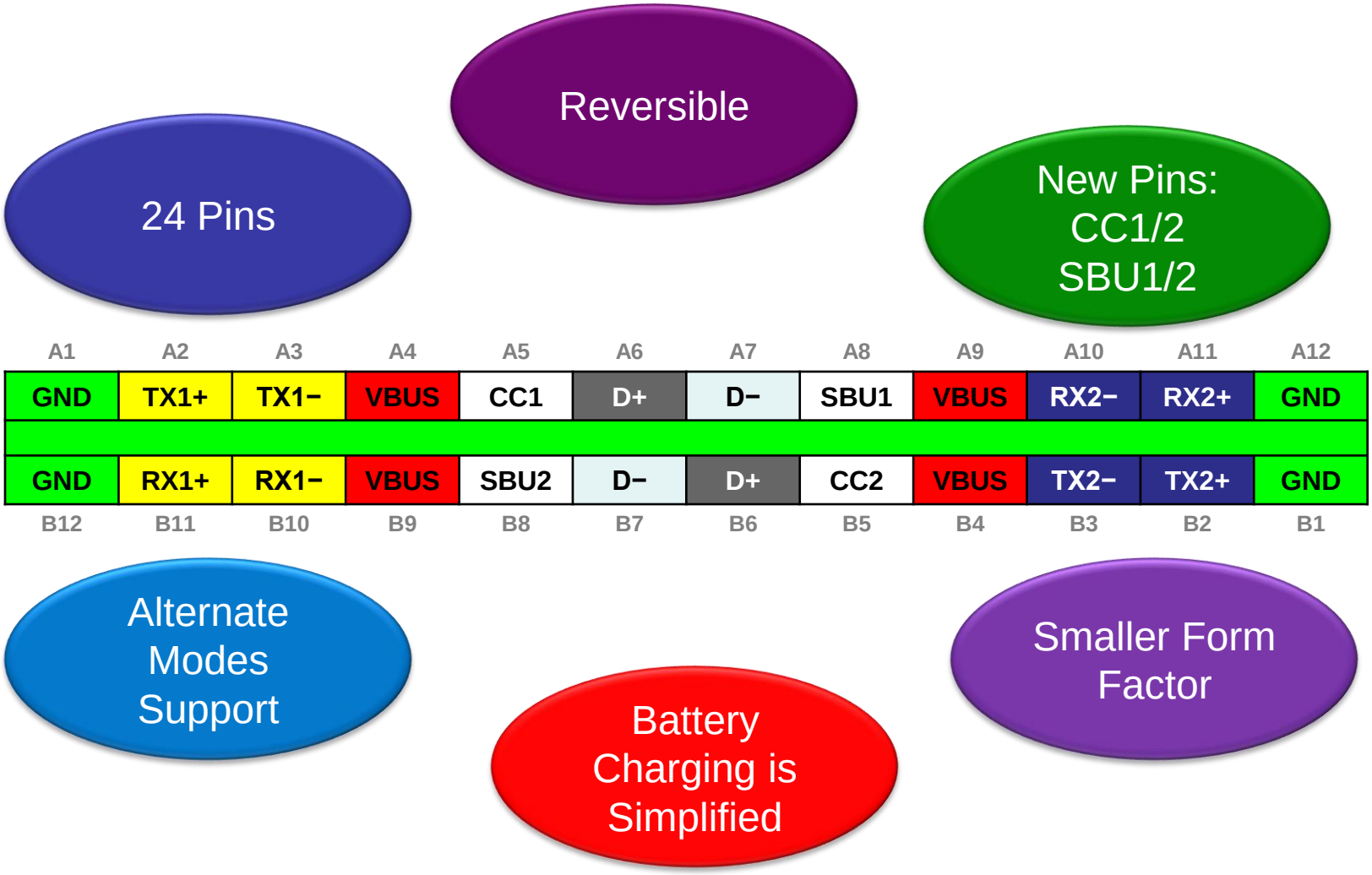
USB Power Delivery

- **USB Power Delivery (USB PD)**
  - When you want to source/sink more than 15W you need to negotiate between the DFP and UFP
  - This is accomplished with a 1 wire USB PD serial protocol
  - USB PD is what “unlocks” the USB Type-C™ cable and can allow for up to 100W of power to be sourced

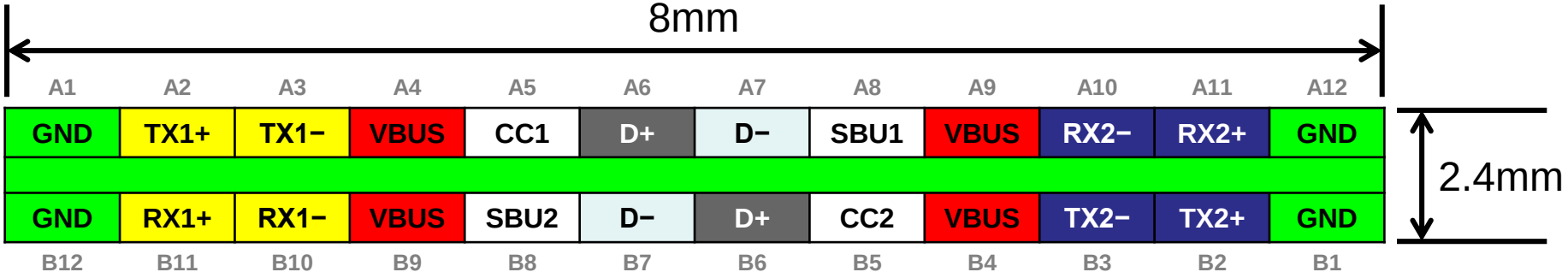
Alternate Modes

- **Alternate Modes**
  - Also negotiated using the USB PD one-wire serial protocol
  - Allows other standard protocols onto the cable (e.g. HDMI, Display Port, MHL, Thunderbolt)
  - Enabled using protocol handshake through structured vendor defined messages (VDM)
  - Alternate Modes are associated with Vendors (e.g. by VID) or by Standards groups/entities (e.g. by SID).
    - We call the plurality of VIDs and SIDs that can exist within a PD device: “SVIDs”

USB Type-C™ Pinout



USB Type-C™ Signal Summary



Rx1n/Rx1p = Differential Pair 1
Tx1n/Tx1p = Differential Pair 1
} SuperSpeed Lane 1

Rx2n/Rx2p = Differential Pair 1
Tx2n/Tx2p = Differential Pair 1
} SuperSpeed Lane 2

SBU1,2 = Side Band Use (Alternate Modes)

Dp, Dn = USB 2.0 Highs Speed Data Lines

VBUS = 5.0V to 20V (USB Power Delivery)

VCONN = 5.0V on CC line for Active Cables

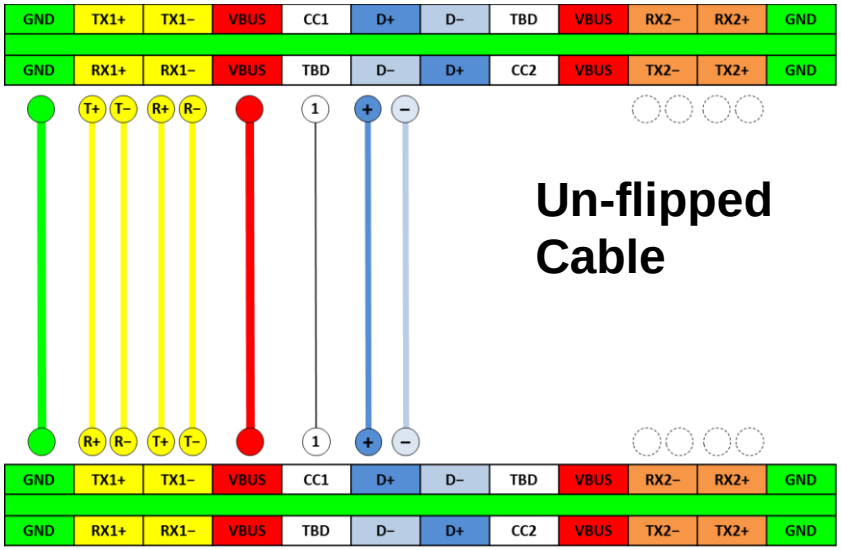
CC1, CC2 = Configuration Channel

Source: www.usb.org

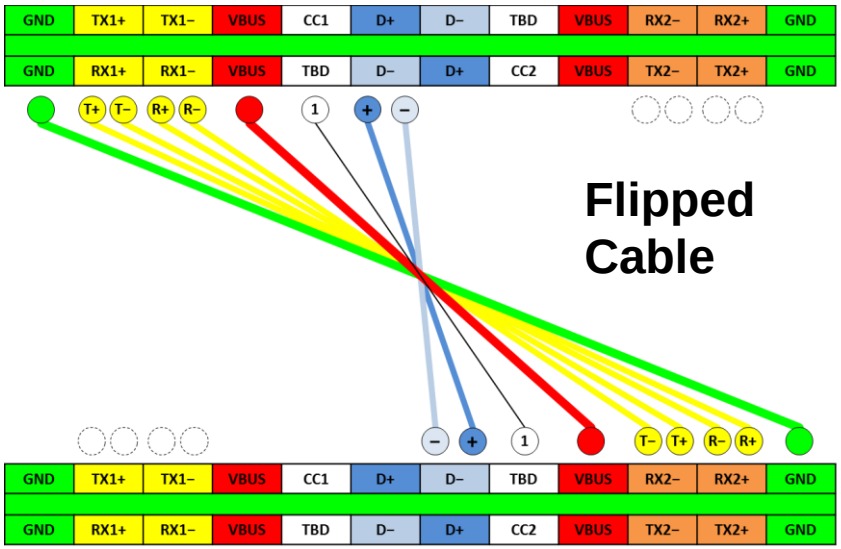
Reversible - This Matters!

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

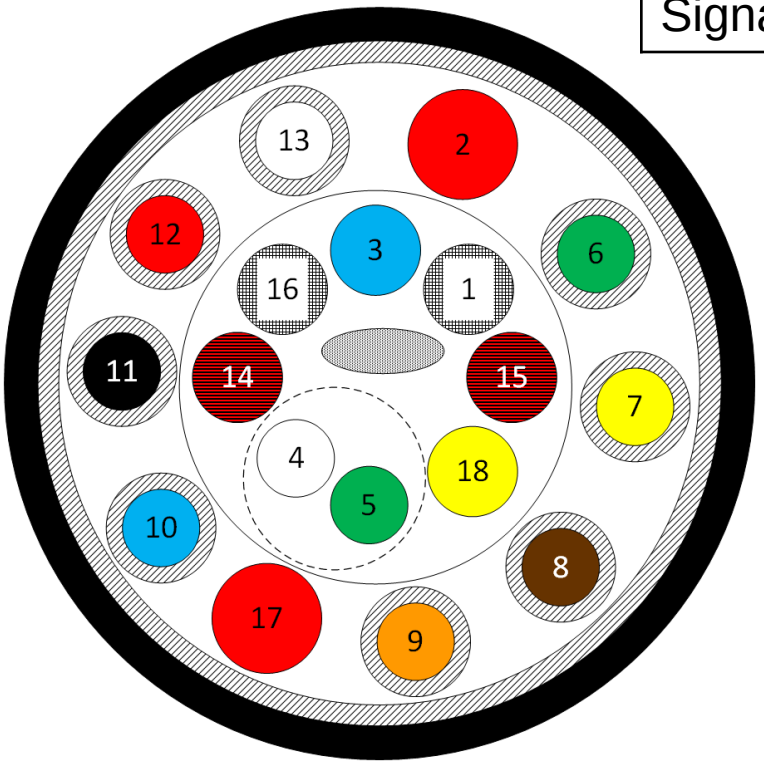
Consumer can plug either way



Connections resolved by Host/Device



USB Type-C™ Cable



Wire	1	2	3
Signal	GND	VBUS	CC

4	5	6
USB 2.0 DP	USB 2.0 DM	SS pair #1 (+)

7	8	9
SS pair #1 (-)	SS pair #2 (+)	SS pair #2 (-)

10	11	12
SS pair #3 (+)	SS pair #3 (-)	SS pair #4 (+)

13	14	15
SS pair #4 (-)	SBU1**	SBU2**

16	17	18
GND*	VBUS*	VCONN**

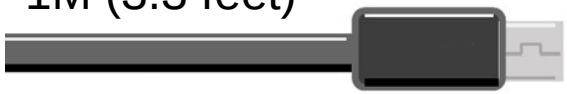
Shielded

*** Optional**

**** Needed for Full-Featured Type-C Cables**

USB Cable Length Limitations

1M (3.3 feet)



USB3.1 Gen2 Super Speed
Data Rate: 10 Gbps (up to 4K video)
Power: 100W
Compatible with USB3.0 and 2.0

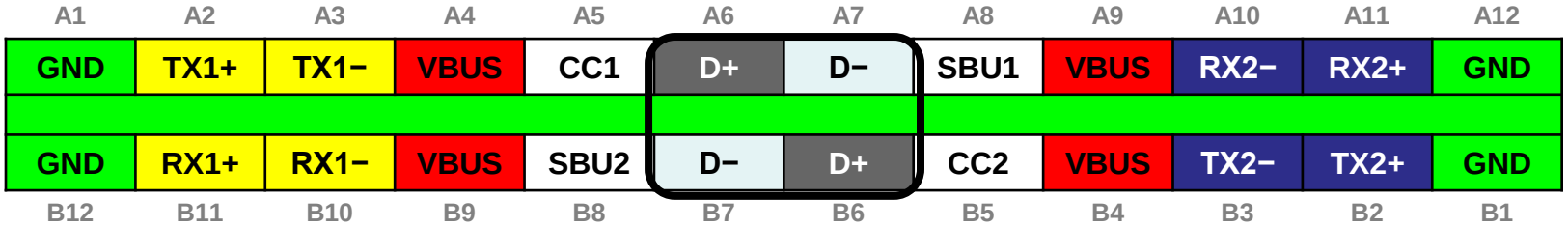
3M (9.8 feet)

USB3.1 Gen1 Super Speed
Data Rate: 5 Gbps (up to 4K video)
Power: 100W
Compatible with USB3.0 and 2.0

4M (13 feet)

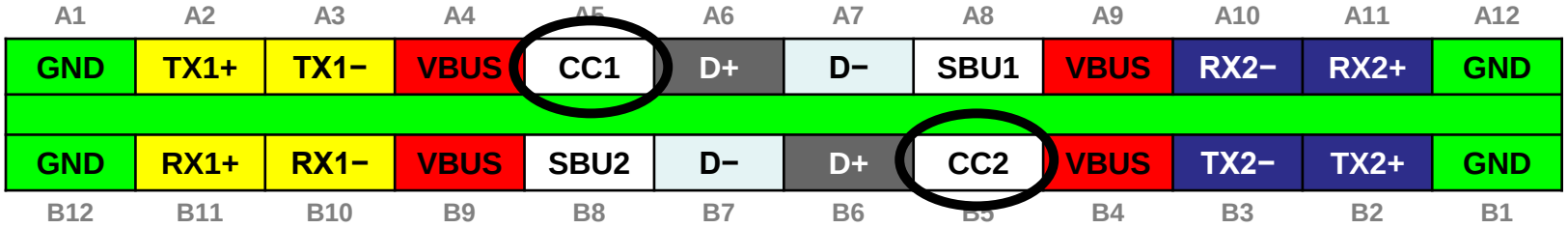
USB2.0 High Speed
Data Rate: 480 Mbps
Power: 15W
Compatible with USB1.1

Pins D+/D-



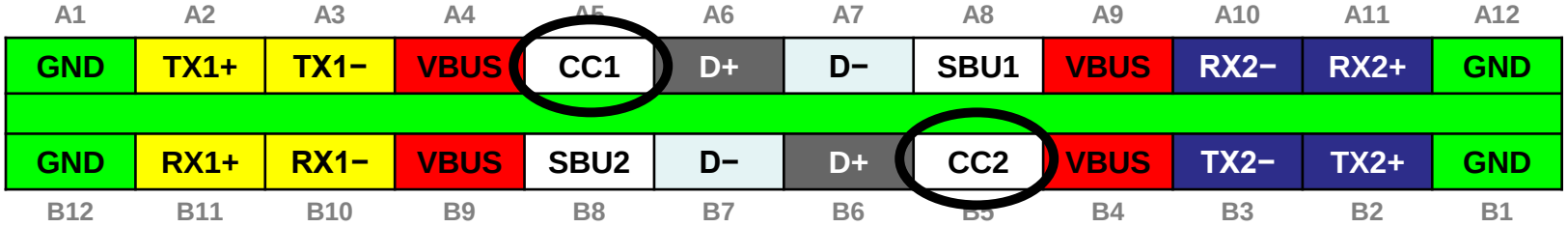
- **Data pins – USB High Speed**
  - These pins support standard USB 2.0 data signaling
  - Provides backwards compatibility using a simple plug converter/adapter
  - Used in USB 3.x for host/device messaging and diagnostics for Alternate Modes (i.e. Billboarding).

New Pins – CC1 & CC2



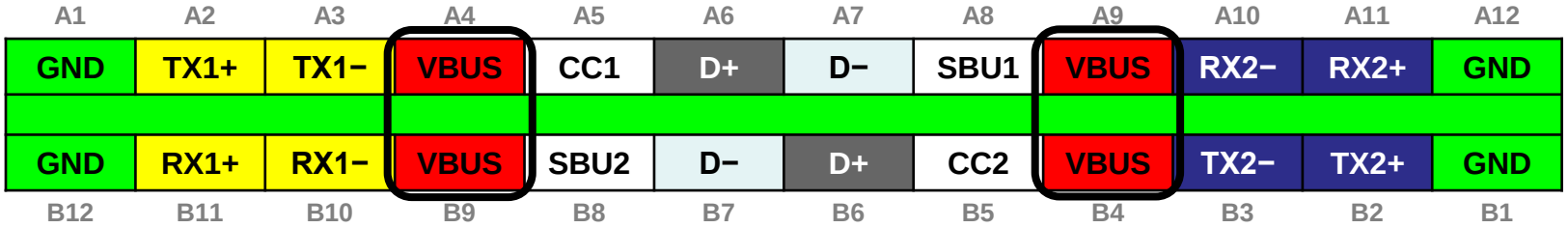
- **Configuration Control pins**
  - Attach/Detach detection
  - Determination of plug orientation
  - Initial Port role determination (power source/sink)
  - USB PD Type C Communication (For PD)
    - Modification of initial port roles
    - Negotiation of USB PD power contracts
  - Management of Functional Extensions (For PD)
    - Structured Vendor Defined Messages (VDM)
  - Alternate mode negotiation

New Pins – VCONN



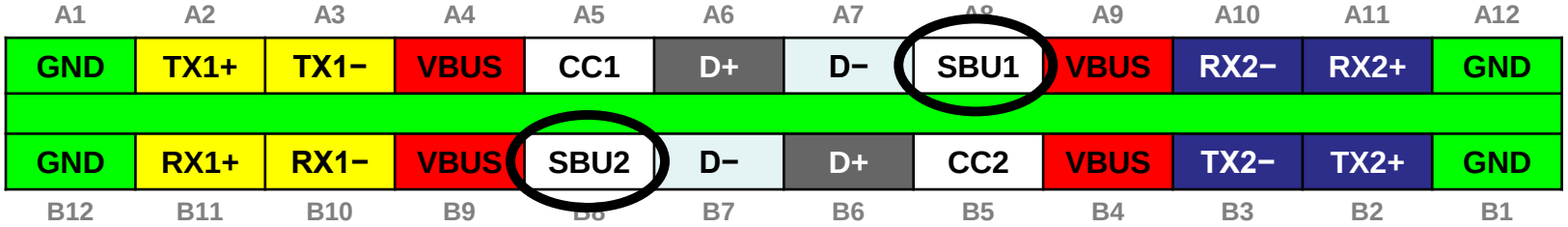
- **VCONN**
  - Once a connection to a host is established, the CCx receptacle pin not connected to the CC wire of the Type-C™ cable is designated as **VCONN**.
  - VCONN is supplied by the DFP by default
  - The VCONN SRC **must** supply 3-5.5V fixed voltage, and guarantee >1W power availability. This is used to supply power to “active” cables.

VBUS Pins



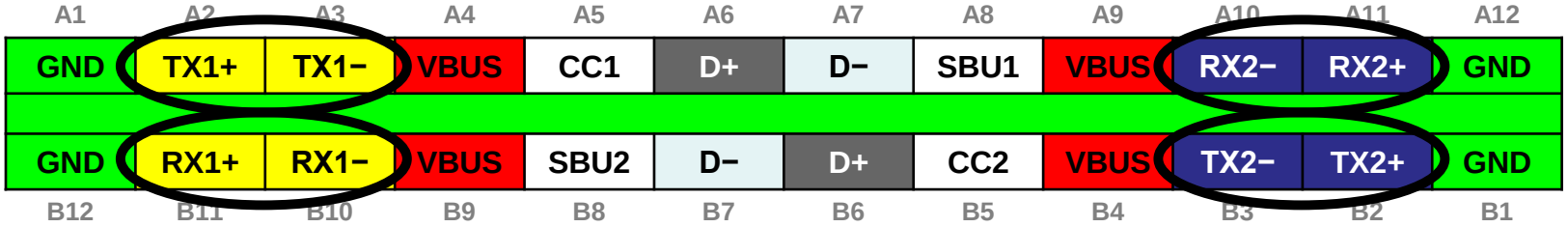
- **Bus Voltage**
  - Similar to VBUS in USB 2.0 – Power supplied from host to devices
  - Can source USB-Default/1.5A/3A @ 5V for non-PD applications
  - Using the CC lines a host and device can negotiate VBUS to support up to 20V@5A (100W)

New Pins – SBU1 & SBU2



- **Side Band Use**
  - Limited for use by Audio Adapter Accessories and Alternate Modes (e.g. AUX for Display Port)
- **Two individual 50 Ohm single-ended signal wires available in Full-Featured USB Type-C™ cables**

New Pins – TXx/RXx Data

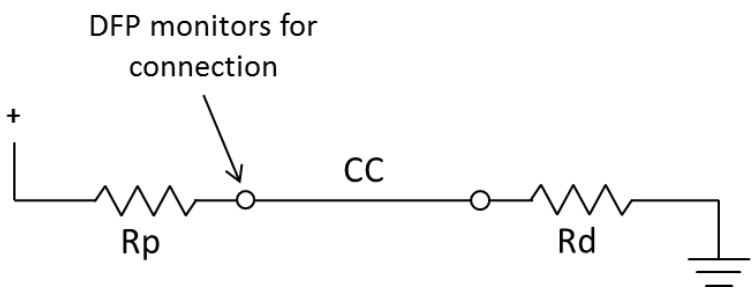


- **Super Speed Transmit/Receive**
  - A Tx+/- and Rx+/- differential pair can each support up to 10 Gbps of bandwidth (full-duplex), 8b/10b encoded
  - USB 3.1 Gen1 Superspeed (5 Gbps) actual throughput is 460 MB/s after overhead
  - USB 3.1 Gen 2 SuperSpeed Plus (10 Gbps) actual throughput is 1.1 GB/s
  - For USB3.1 Gen1/Gen2, only one set of TX/RX pairs is active
  - For USB3.2 (20 Gbps) both sets of Rx/Tx pairs are active
  - These Rx/Tx data lines can be repurposed to support Alternate Modes that are negotiated over the CC lines

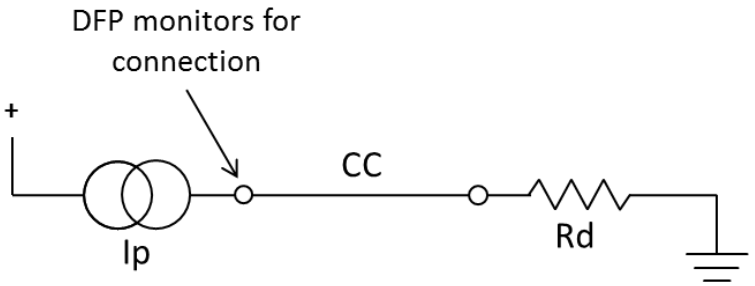
VBUS Source Current Advertisement

- **USB Type-C™ Current**
  - **Rp**: Host Side **Pull-up** Resistor
  - **Rd**: Device Side **Pull-down** Resistor

By Resistor Voltage Divider



Or by Current Source



Source Current Advertising

- Max Current capabilities are now communicated via a simple voltage divider over the CC pins.
  - Legacy 500mA/900mA, 1.5A or 3.0A is communicated by the **Rp** (Pull-up) resistor selection.
  - A UFP/Sink must detect the 5V current advertisement by using a precision **Rd** (pull-down) on its CC pins.

3A: 1.31V < *CC* < 2.04

1.5A: 0.70V < *CC* < 1.23V

Default: 0.25V < *CC* < 0.66V

  - This voltage divider can also be used to determine connector orientation and attach-detection

USB Type-C™ Current

- SRC/DFP Rp CC Termination Requirements

SRC/DFP Advertisement	Current Source to 1.7 – 5.5V	Resistor Pull-Up to 4.75 – 5.5V	Resistor Pull-Up to 3.3V ± 5%
Default USB Power	80 µA ± 20%	56 kΩ ± 20%	36 kΩ ± 20%
1.5A @ 5V	180 µA ± 8%	22 kΩ ± 5%	12 kΩ ± 5%
3.0A @ 5V	330 µA ± 8%	10 kΩ ± 5%	4.7 kΩ ± 5%

- SNK/UFP Rd CC Termination Requirements

Rd Implementation	Nominal Value	Can use > Default USB Power?	Max Pin Voltage
± 20% resistor to GND	5.1 kΩ	No	2.18V
± 10% resistor to GND	5.1 kΩ	Yes	2.04V

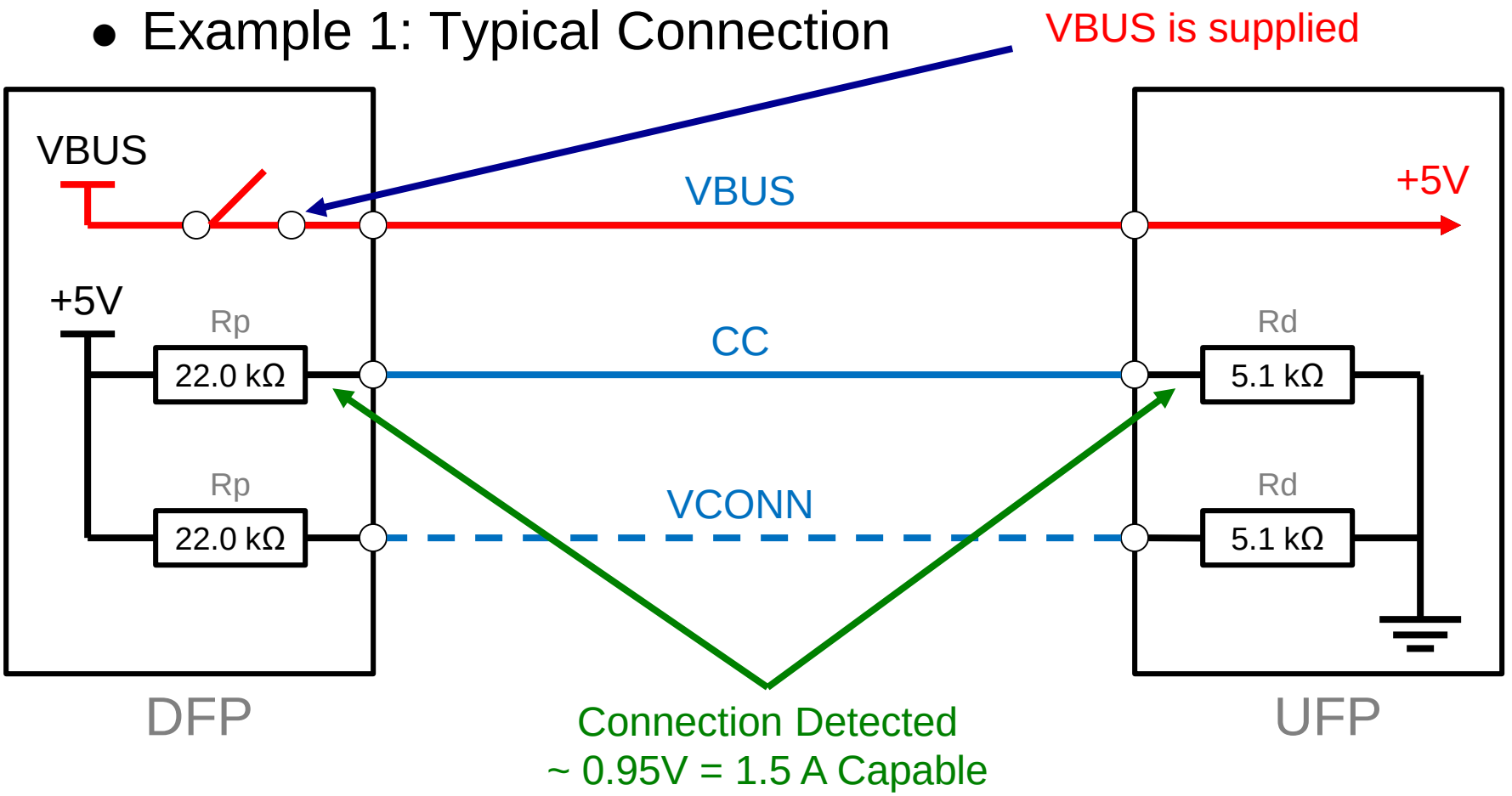
VCONN

- **Once the connector orientation is determined, the unused CC line can have VCONN applied to power an active/electronically marked cable**
- **When is VCONN required?**

D+/D-	SSTX/SSRX	> 3A	VCONN Required?
No	No	No	No
Yes	No	No	No
Yes	Yes	No	Required to source 1W VCONN
No	No	Yes	Required to source 1W VCONN
Yes	No	Yes	Required to source 1W VCONN
Yes	Yes	Yes	Required to source 1W VCONN

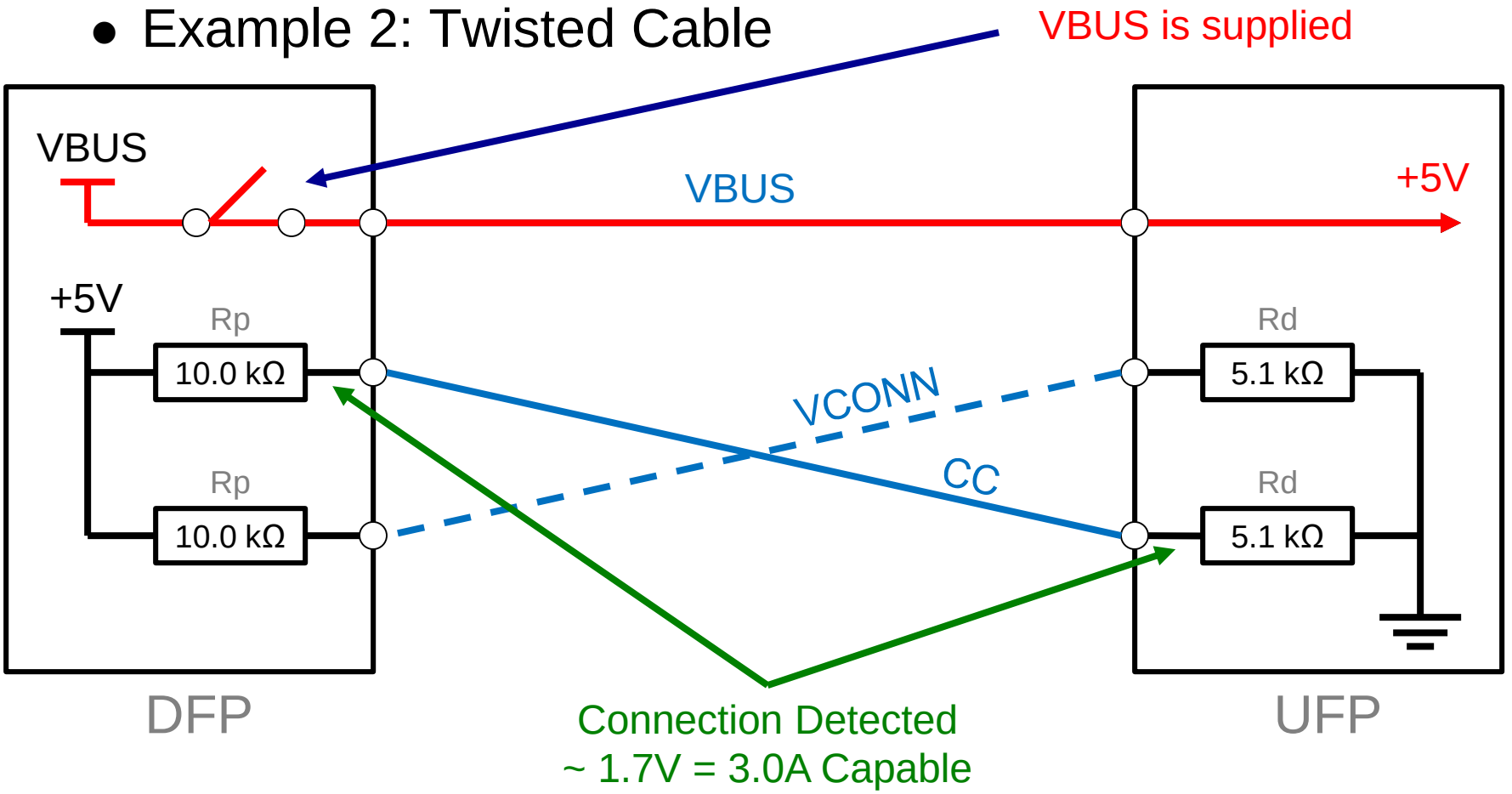
Typical Connection

- **Type-C™ Current (Passive Cable, No PD)**
  - Example 1: Typical Connection



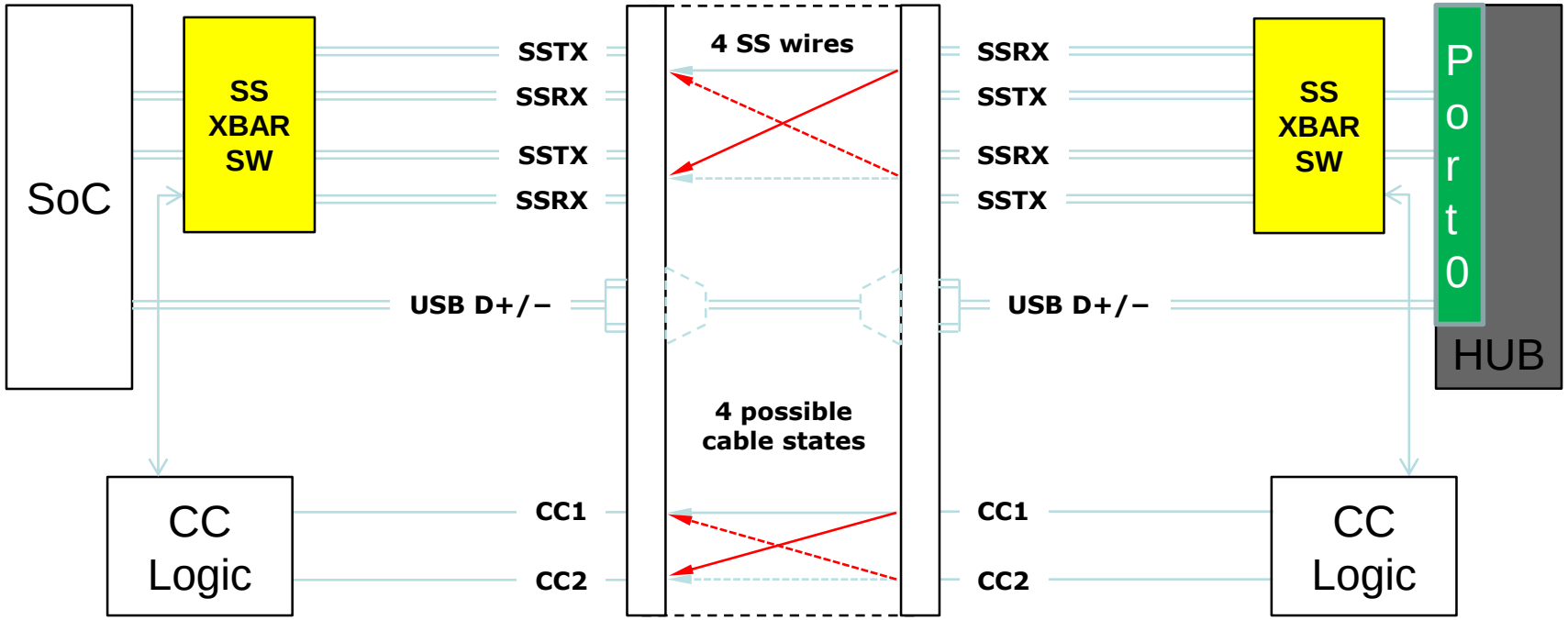
Flipped Cable Connection

- **Type-C™ Current (Passive Cable, No PD)**
  - Example 2: Twisted Cable



Reversible – Adds Cost!

- Connections resolved by Host and Device
- Needs 2 to 1 SuperSpeed switch

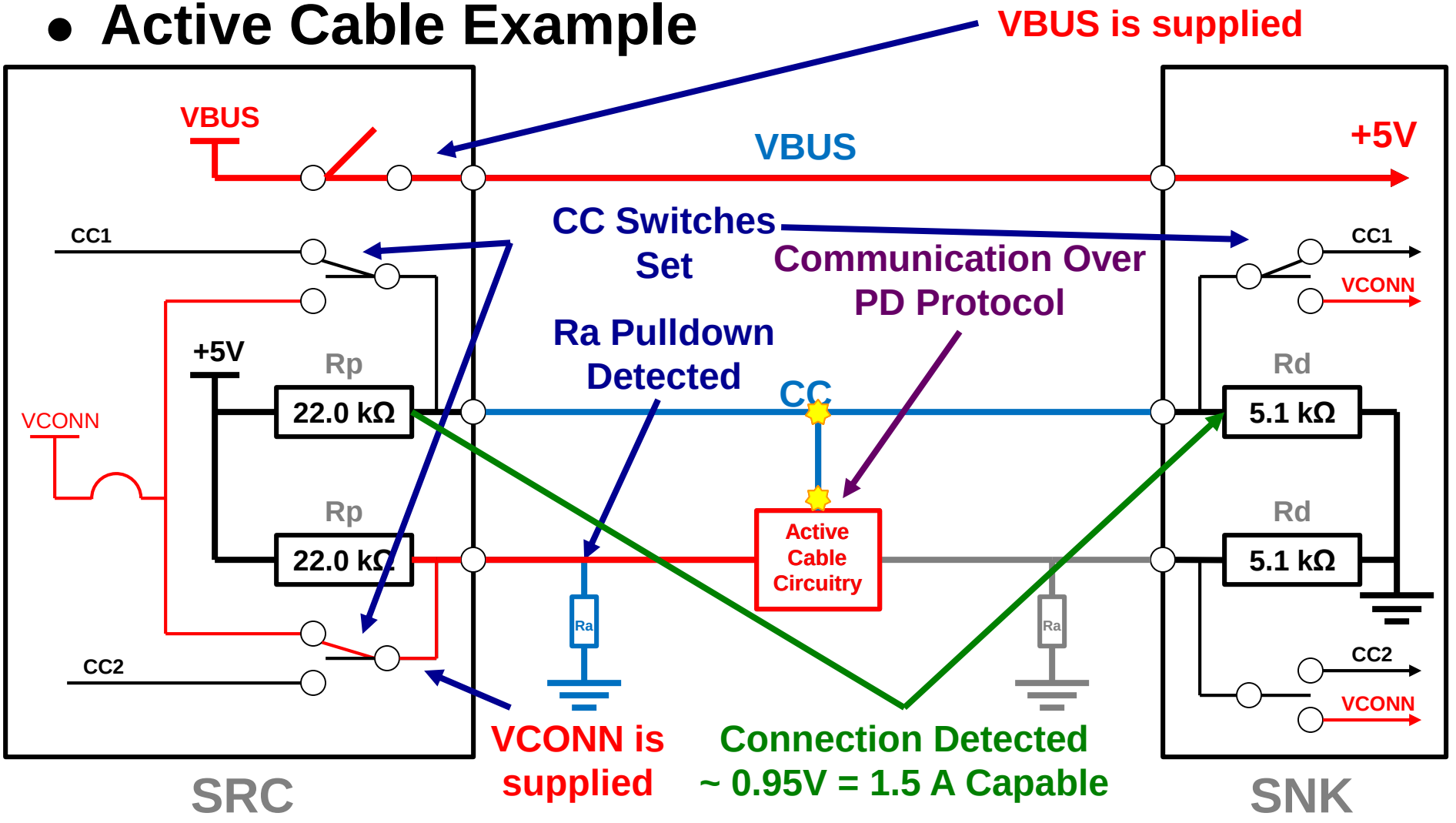


Electronically Marked Cables "E-Marked"

- A *Pull-Down* resistor Ra (800Ω-1.2kΩ) within the cable on VCONN/CC indicates the presence of an E-Marked cable.
- E-Marked Cables must support Power Delivery protocol over the CC wire
- The "E-Marker" communicates cable characteristics to the SRC or SNK
- VCONN is used to power circuits within the cable plug (5V @ 250 mA minimum)
- Alternately, E-Marked cables can be powered off of VBUS

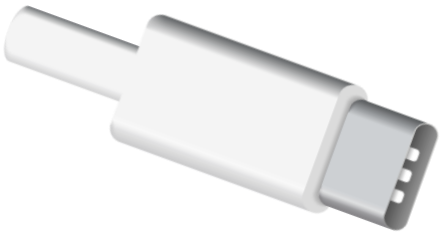
Attach Detection (PD)

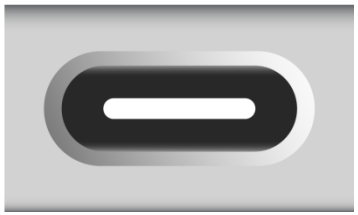
- Active Cable Example



Types of USB Type-C™ Ports

1) Source-only
2) Source (Default)*
3) Sink-only
4) Sink (Default)*
5) DRP: Toggling
6) DRP: Sourcing UFP/Device*
7) DRP: Sinking DFP/Host*



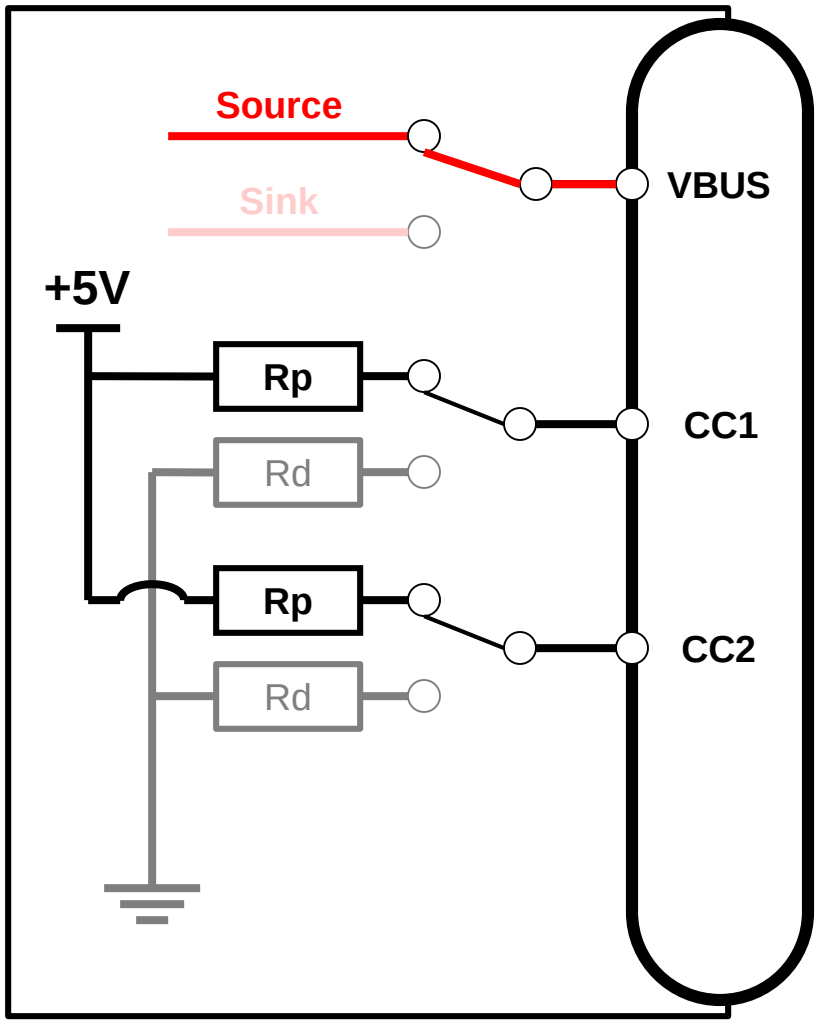


*** Power Delivery Required**

USB Type-C™ Dual Role Power

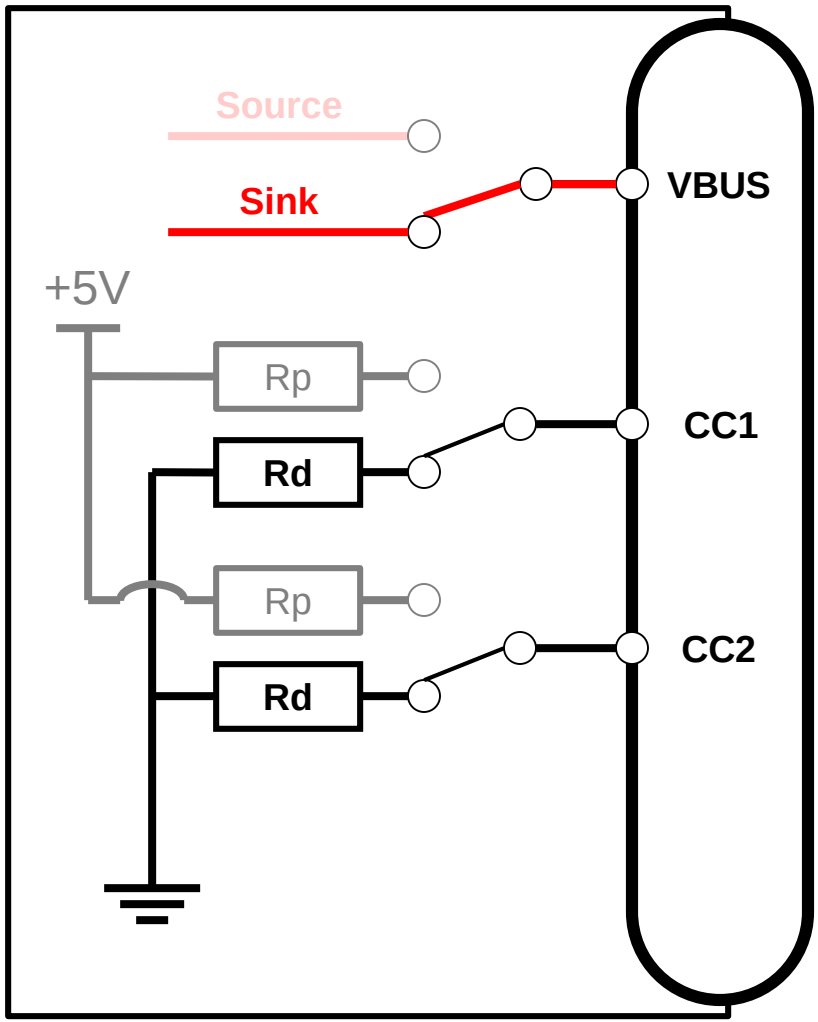
- **What is a DRP?**
- **A port that is capable of either Source/DFP or Sink/UFP**
  - When disconnected, a DRP constantly flips between Source and Sink in an attempt to make a connection
  - Achieved by:
    - Connecting Rp (pull-ups) to CC1/CC2 when Source
    - Connecting Rd (pull-downs) to CC1/CC2 when Sink
  - Designers can control the “duty cycle” of switching to make resolving a preferred role more likely

USB Type-C™ Source



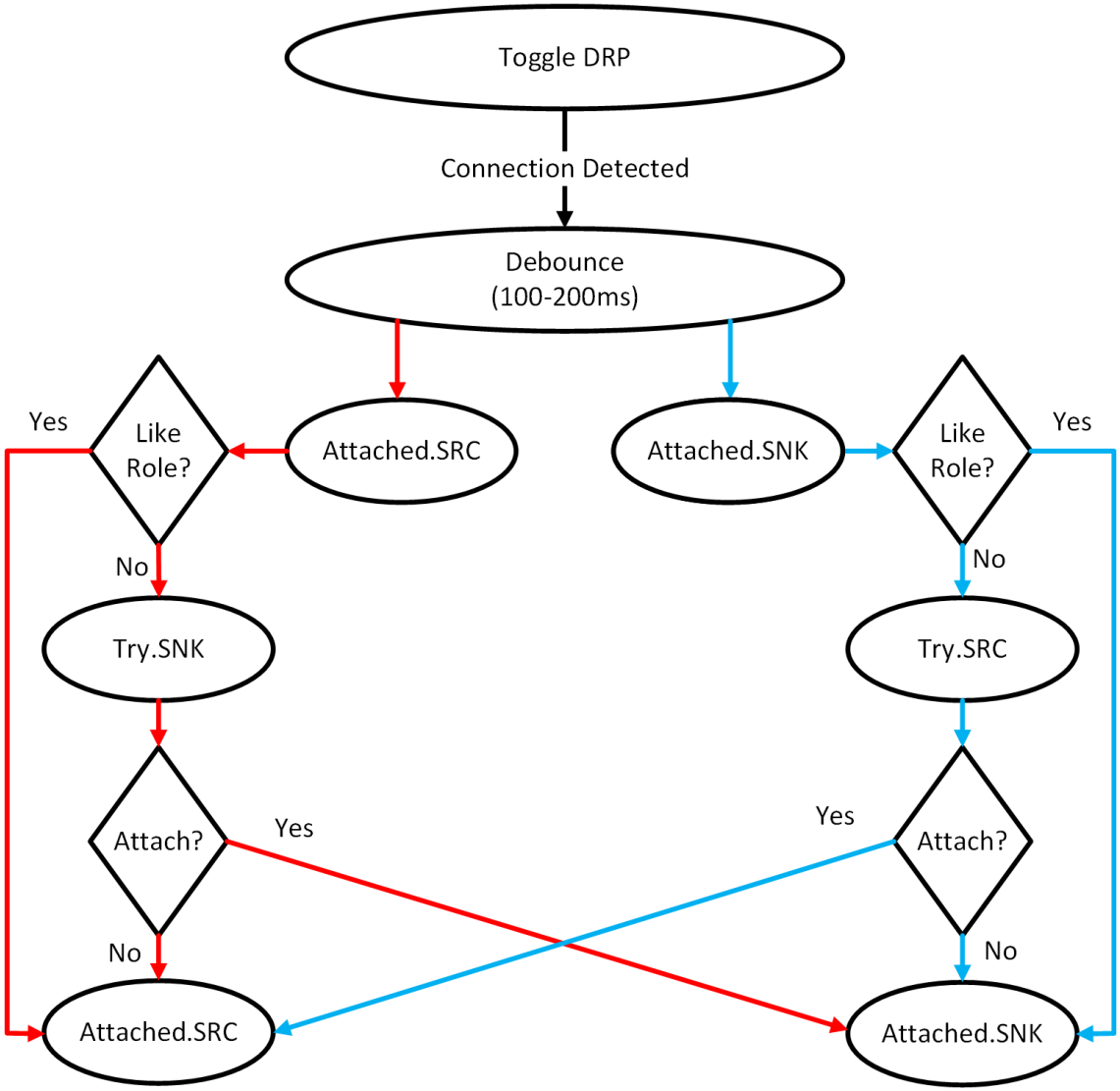
- DRP – In Source Mode

USB Type-C™ Sink



- DRP – In Sink Mode

DRP State Machine



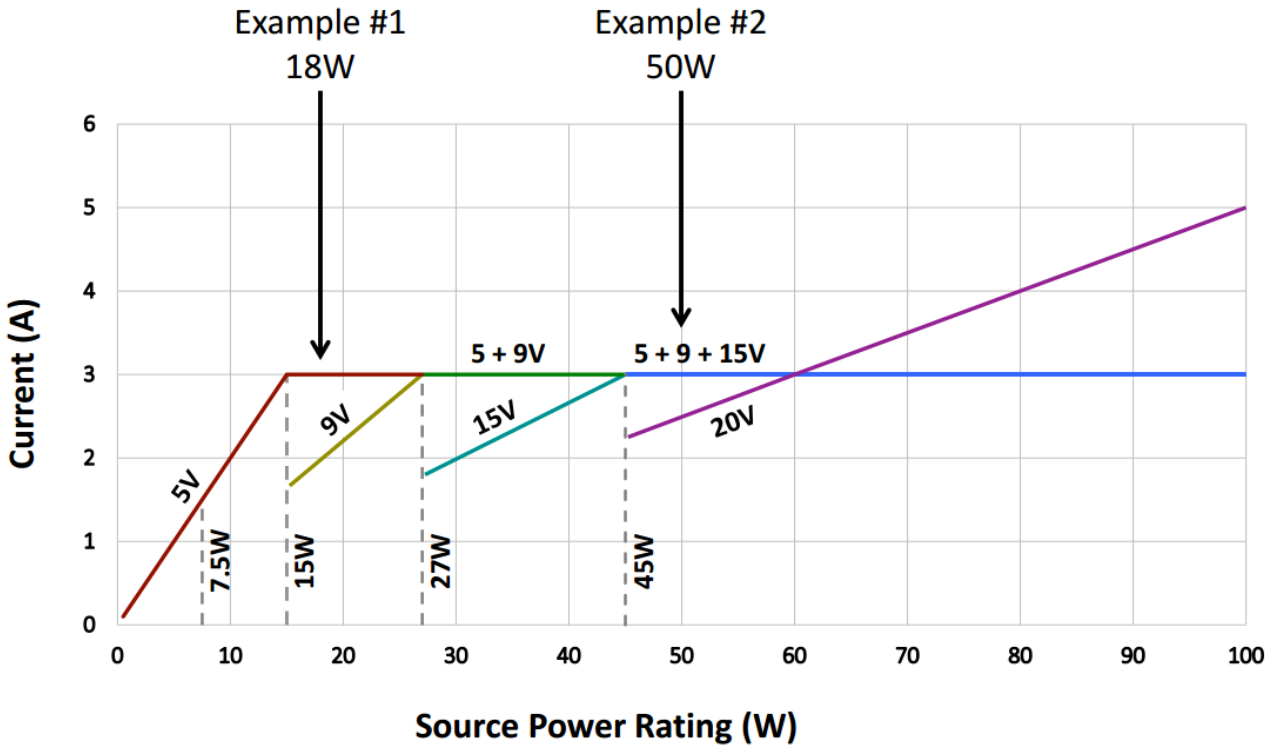
USB Type-C™ Power Options

- **Power Supply Options**
  - The USB Type-C™ interconnect is compatible with:

Mode of Operation	Nominal Voltage	Maximum Current	Notes
USB2.0	5V	500mA	USB2.0 Spec
USB3.1	5V	900mA	USB3.1 Spec
USB BC1.2	5V	Up to 1.5A	Legacy Charging
Type-C™ Current (non-PD)	**5V**	**1.5A (7.5W)**	**Supports higher power devices**
Type-C Current (non-PD)	**5V**	**3.0A (15W)**	**Supports higher power devices**
USB Power Delivery	**Configurable up to 20V**	**Configurable up to 5A**	**Directional control and power level management**

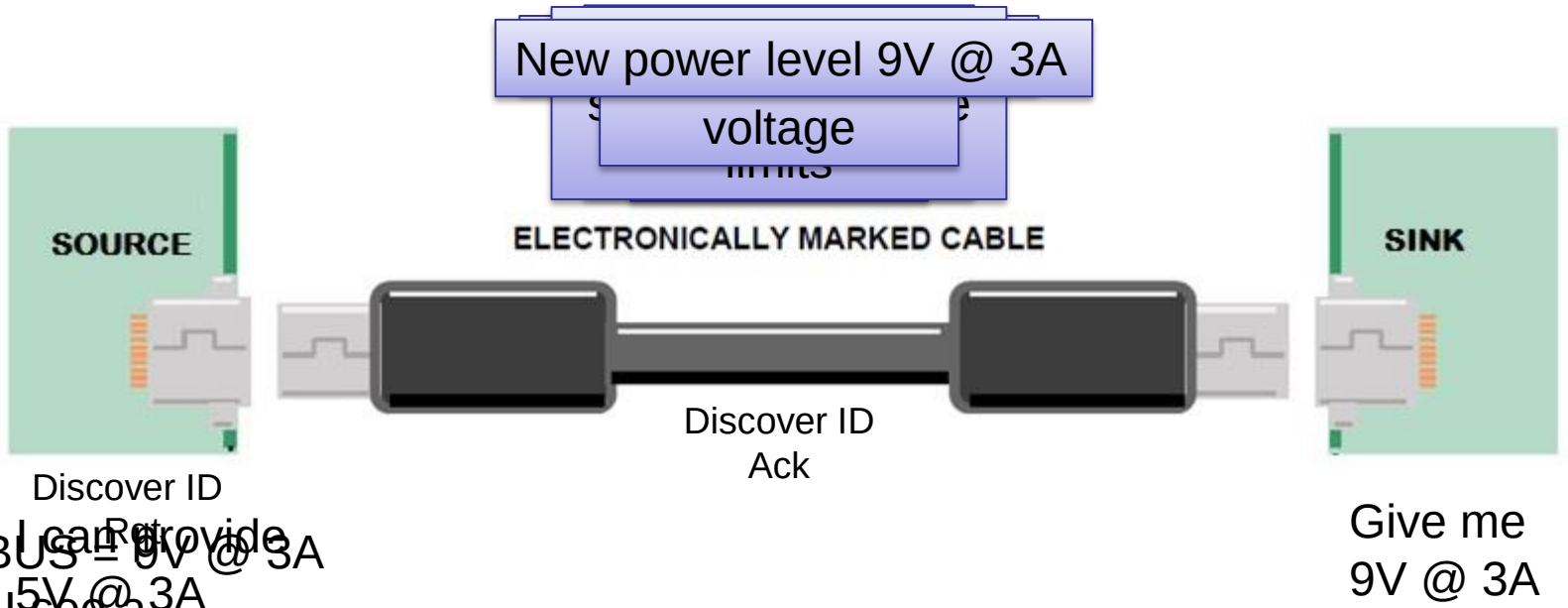
USB Type-C™ Power Rules

- Defined in the USB PD specification
- Examples:
  1. 18W power rating = 5V up to 3A + 9V up to 2A
  2. 50W power rating = 5V up to 3A + 9V up to 3A + 15V up to 3A + 20V up to 2.5A



Source: www.usb.org

PD Contract Negotiation



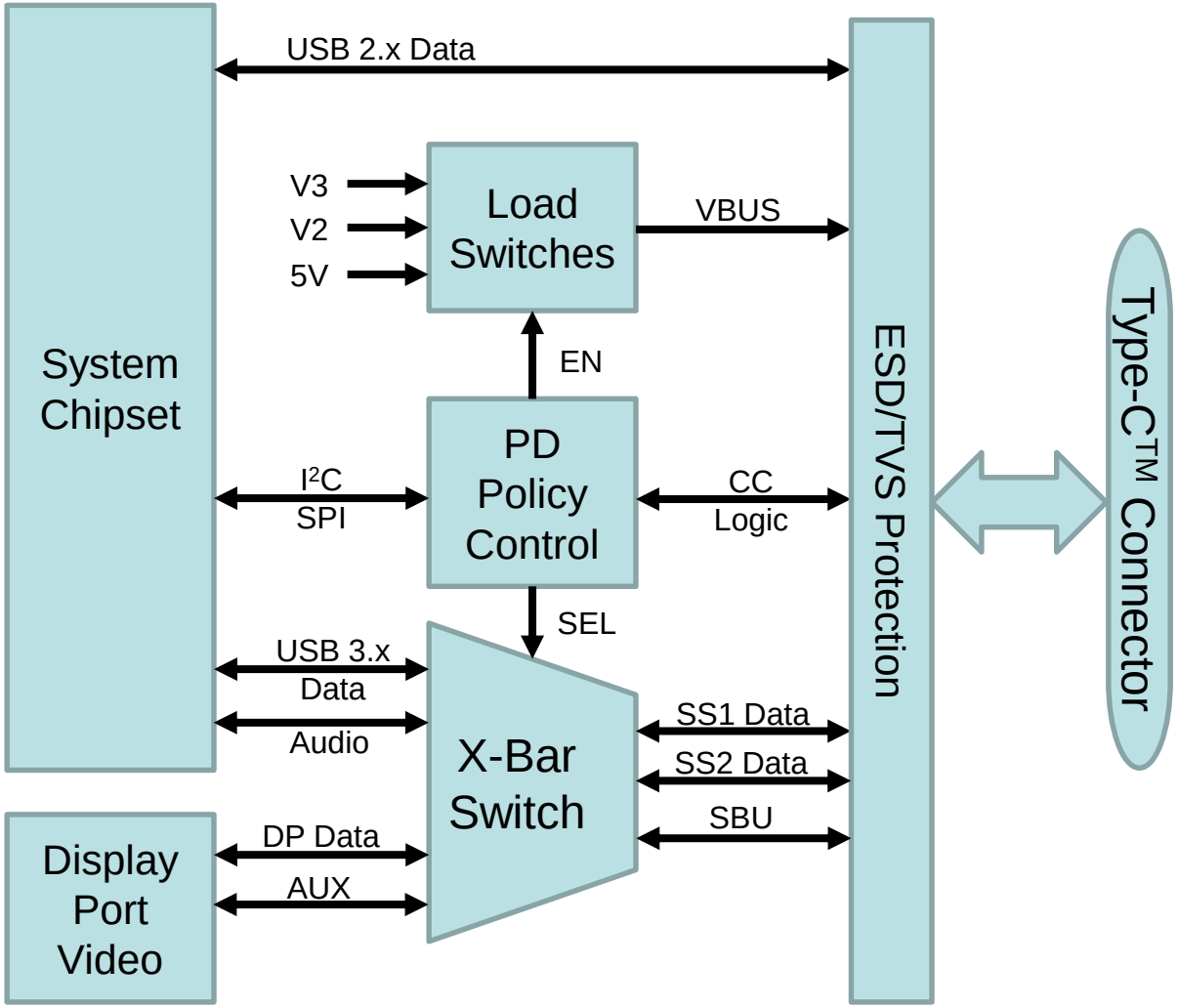
Type-C™ Primary System Components

- **PD Controller**
  - Implements Type-C state machines
  - Implements PD physical layer, protocol layer, policy engine, and/or policy manger
  - Can be split between a front-end and micro (TCPCI)
- **Power Switching**
  - Provides power protection required by PD standard
  - Isolates source path from sink path
  - Data Switching
  - Provides orientation support for data lines
  - Multiplexes alternate mode signals

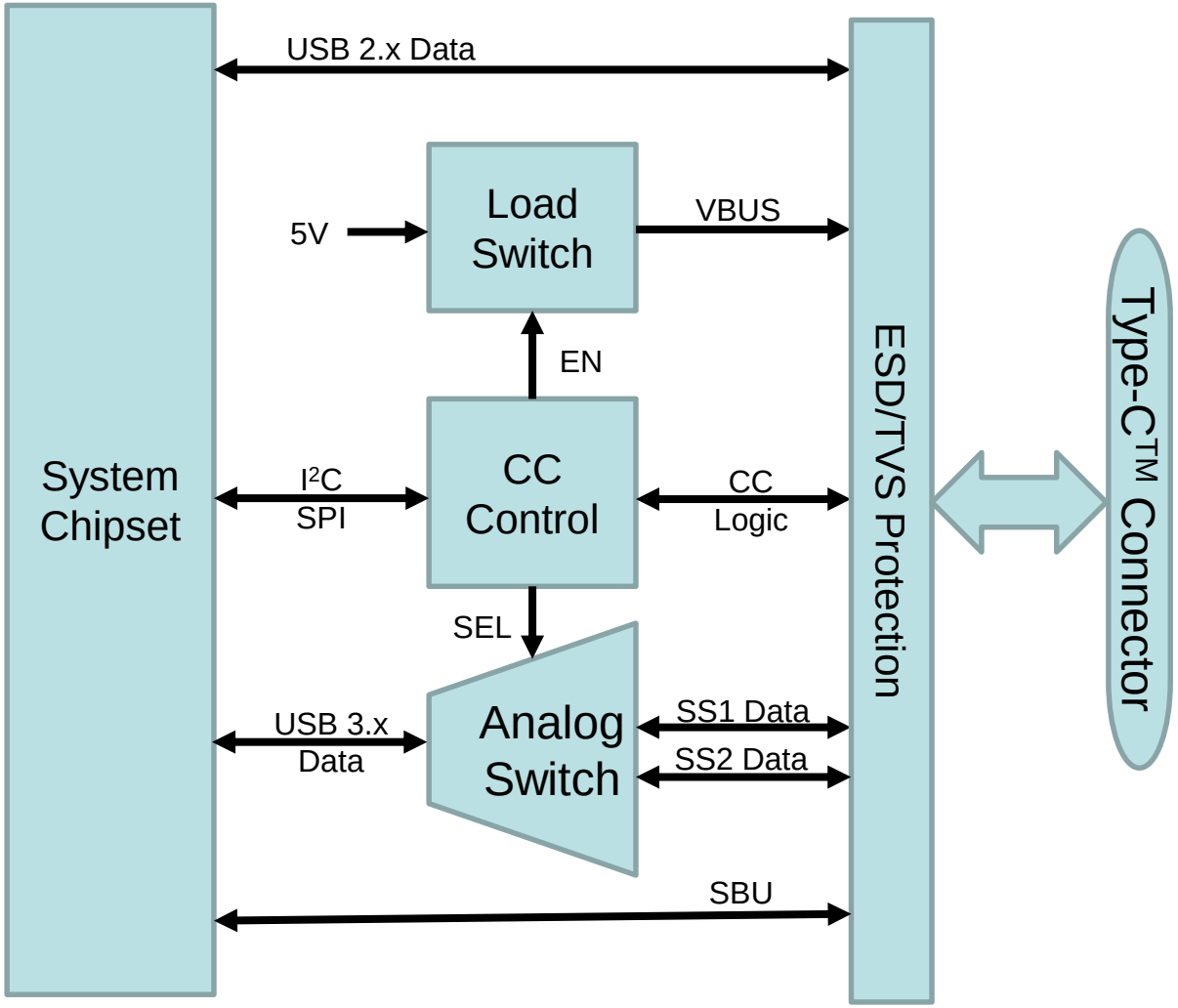
Type-C™ Primary System Components

- **High Speed Analog Switch/MUX**
  - Implements connector flip for USB SS signals
  - Needed for supporting alternate modes such as Display Port
- **Signal Conditioning**
  - VBUS load switches should incorporate TVS protection
  - ESD protection should be implemented for high speed data signals, CC and SBU
  - For longer cables or poor PCB layouts, signal regenerators may be implemented to restore eye diagrams

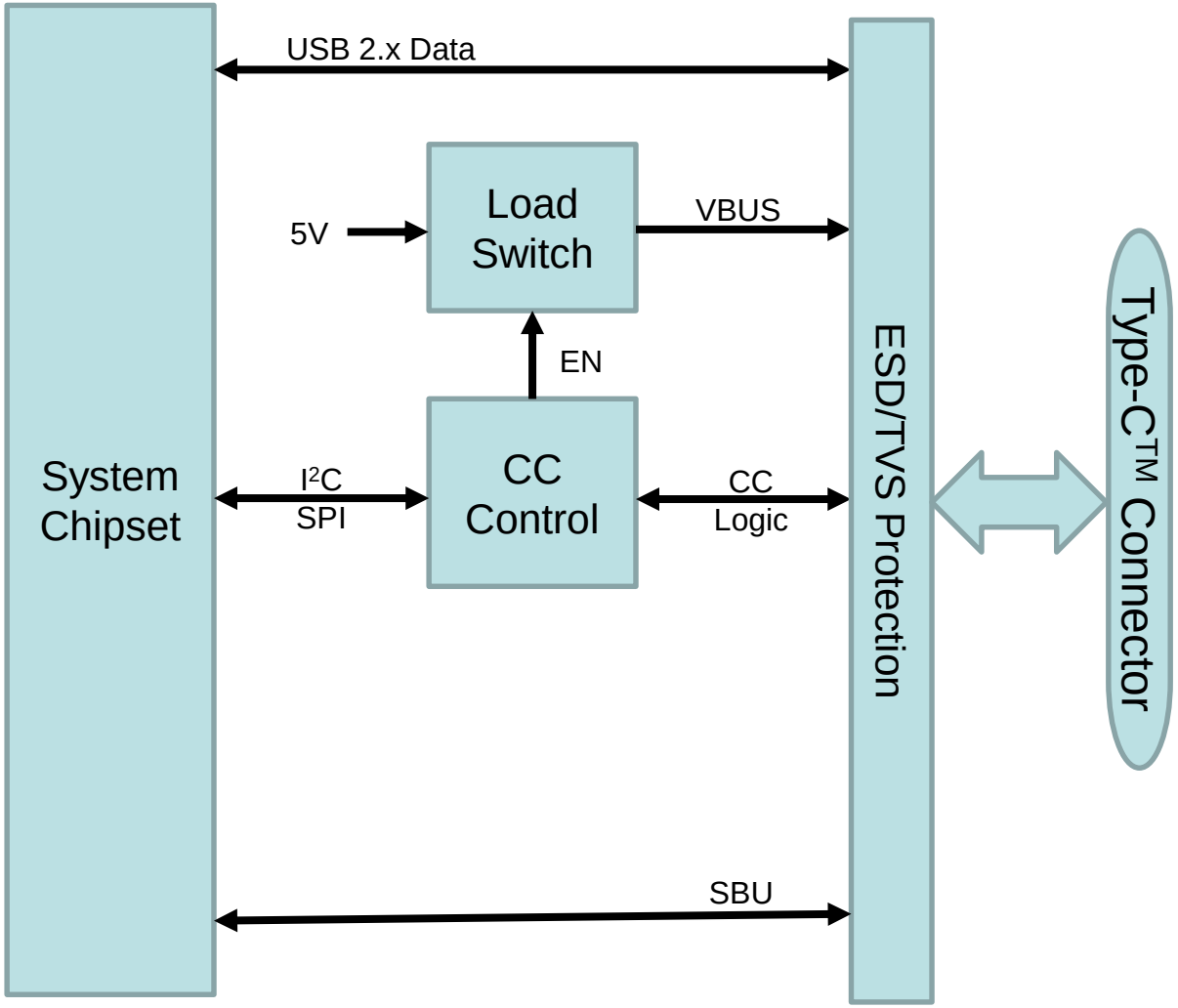
System Solution: PD + Alternate Mode Support



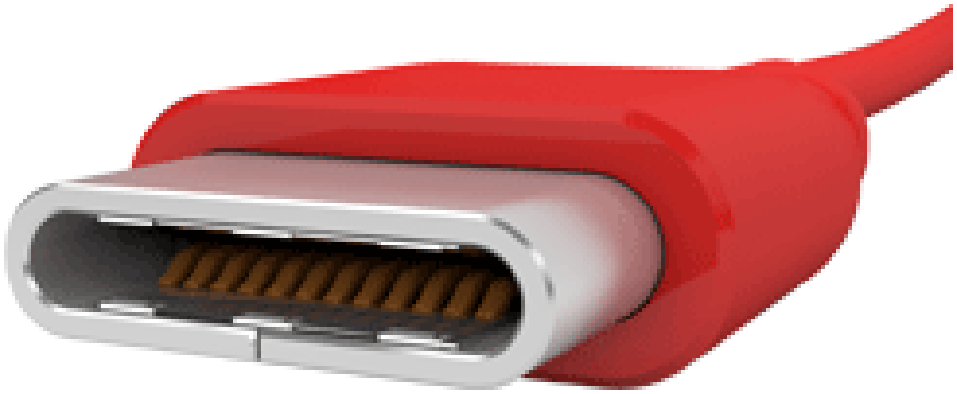
System Solution: Type-C™ (≤15W) + USB3.1



System Solution: Type-C™ (≤15W) + USB2.0



USB Type-C™ Wrap-Up



Questions

- **Are USB Type-C™ ports *required* to support USB 3.1 (10Gbps)?**
  - No!
- **Are USB Type-C ports *required* to support 100W?**
  - No!
- **Are USB Type-C ports *required* to support Alternate Modes?**
  - No!

Summary

- **USB Type-C™ Connectivity Overview**
- **USB Type-C Use Cases**
- **USB Type-C Design Considerations**
- **Power Delivery Brief Overview**
- **USB Type-C Summary:**
  - Easier to plug in
  - Power capabilities greatly improved
  - Versatile: Supports alternate modes
  - Users will love it!

Acronyms

- BC = Battery Charging
- BMC = Bi-phase Mark Coding
- CC = Communication Channel
- DFP = Downstream Facing Port
- DP = DisplayPort
- DRP = Dual Role Power (correct usage) – (*Sometimes referred to as Dual Role “Port”)
- HDMI = High Definition Multimedia Interface
- PD = Power Delivery
- Ra = Pull-down (Active Cable)
- Rd = Pull-down (CC)
- Rp = Pull-up (CC)
- SBU = Side Band Use
- SOP = Start of Packet
- TID = Test Identification (Number)
- UFP = Upstream Facing Port
- USB = Universal Serial Bus
- USB-IF = USB Implementers Forum
- VCONN = New Term used for USB Type-C

Thank You