Technical article

Overview of USB Type-C and Power Delivery technologies

Introduction

The USB Type-C™ and Power Delivery technologies have revolutionized cable connectivity with the ability to carry all manner of data, including video, as well as negotiate and supply up to 100 W power to charge connected equipment.

Less cables, less connectors and more universal chargers are just some of the principal benefits.

Indeed, USB Type-C cables and connectors support up to 15 W (5 V at 3 A), which rises to 100 W (up to 20 V at 5 A) with the USB Power Delivery feature.

1 Main characteristics

The USB Implementer Forum (USB-IF) introduces these complementary specifications:

1. the USB Type-C™ receptacle, plug and cable specification rev. 1.3
2. the USB Power Delivery (PD) specification rev. 3.0 that allows two PD compliant entities to exchange up to 100 W.

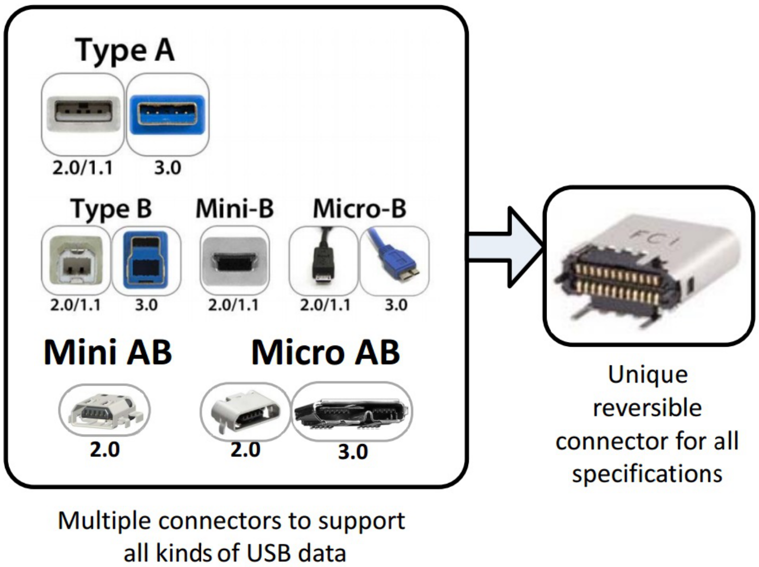
Any system embedding a USB Type-C receptacle or plug which is designed to implement a USB Power Delivery application such as a single port device, a multi-port hub or a simple cable is based on these specifications.

USB Type-C is intended for a wide range of applications like chargers, computers, displays and mobile phones, while USB-PD allows many advanced features, such as the ones listed below:

- power role negotiation
- power sourcing and consumption level negotiation
- electronically marked cable identification
- vendor-specific message exchange
- alternate-mode negotiation, allowing different communication protocols to be routed onto the reconfigurable pins of the USB Type-C connectors

The cables use the same male connector on both ends.

Figure 1. USB plug form factors



The USB Type-C connector covers all the features provided by the previous generation USB plugs in a single connector, rendering USB usage easier and more flexible. It supports all protocols from USB2.0 onward, including power capability.

The USB Type-C connection allows ports to operate in host-mode only, device-mode only or dual-role data. Both data and power roles can be independently and dynamically swapped using the USB PD protocol.

2 USB Type-C™ pin map

USB Type-C™ plugs and receptacles are 24-pin connectors with two groups of pin connections arranged so as to ensure pinout reversibility for any connection.

- The symmetrical connections: are:
  - eight power pins: V_{BUS}/GND
  - USB2.0 differential pairs (D+/D-)
- The asymmetrical connections are:
  - two sets of Tx/Rx signal paths supporting USB3.1 data rates
  - two configuration channels (CC lines) for the discovery, configuration and management of USB Type-C Power Delivery features
  - two sideband use (SBU lines) signals for analog audio modes used in alternate mode

Figure 2. **USB Type-C plug**

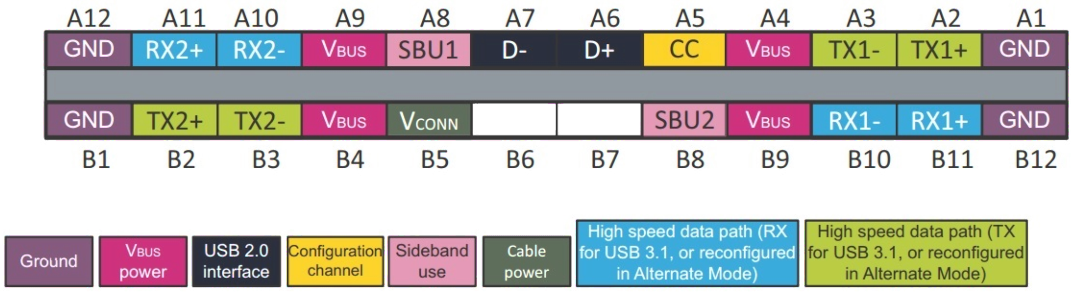


Figure 3. **USB Type-C receptacle pinout**

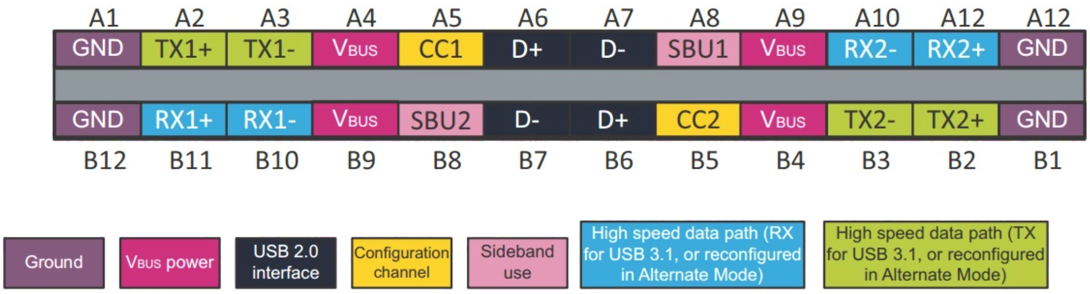


Table 1. **USB Type-C pinout description**

Pin	Receptacle signal	Plug signal	Description	Comment
A1	GND	GND	Ground return	Can be up to 5 A split into four pins
A2	TX1+	TX1+	USB3.1 data lines or Alternate	10-Gbyte TX differential pair in USB 3.1
A3	TX1-	TX1-		
A4	V_{BUS}	V_{BUS}	Bus power	Max power is 100 W (20 V - 5 A) split into four pins
A5	CC1 or V_{CONN}	CC	Configuration channel or power for active or electronically marked cable	In V_{CONN} configuration, min power is 1 W
A6	D+	D+	USB2.0 datalines	-
A7	D-	D-		-
A8	SBU1	SBU1	Sideband Use (SBU)	Alternate mode only

Pin	Receptacle signal	Plug signal	Description	Comment
A9	V_{BUS}	V_{BUS}	Bus power	Max power is 100 W (20 V - 5 A) split into four pins
A10	RX2-	RX2-	USB3.1 datalines or Alternate	10-Gbyte RX differential pair in USB 3.1
A11	RX2+	RX2+		
A12	GND	GND	Ground return	Can be up to 5 A split into four pins
B1	GND	GND	Ground return	Can be up to 5 A split into four pins
B2	TX2+	TX2+	USB3.1 datalines or Alternate	10-Gbyte RX differential pair in USB 3.1
B3	TX2-	TX2-		
B4	V_{BUS}	V_{BUS}	Bus power	Max power is 100 W (20 V - 5 A) split into four pins
B5	CC2 or V_{CONN}	V_{CONN}	Configuration channel or power for active or electronically marked cable	In V_{CONN} configuration, min power is 1 W
B6	D+	-	USB2.0 datalines	USB Data+ line
B7	D-	-		USB Data- line
B8	SBU2	SBU2	Sideband Use (SBU)	Alternate mode only
B9	V_{BUS}	V_{BUS}	Bus power	Max power is 100 W (20 V - 5 A) split into four pins
B10	RX1-	RX1-	USB3.1 datalines or Alternate	10-Gbyte RX differential pair in USB 3.1
B11	RX1+	RX1+		
B12	GND	GND	Ground return	Can be up to 5 A split into four pins

3 Port configurations

As stated in the USB Type-C™ and USB Power Delivery specifications, any port can be assigned a data role (DFP or UFP) and a power role (source, sink or DRP):

- a Source is a USB Power Delivery Port supplying power; on an attach event, it assumes the DFP and VCONN Source roles
- a Sink is a USB Power Delivery Port consuming power; on an attach event, it assumes the UFP role
- a Dual-Role Power Port (DRP) supports both Source and Sink roles

The Source and Sink roles, DFP and UFP roles, and the VCONN Source role can all be subsequently swapped.

Note: There is only one Source Port and one Sink Port in each PD connection between Port Partners.

Note: USB data capability as well as the capability to provide VCONN are not mandatory.

3.1 Source Port (provider)

This port is able to supply power over V_{BUS} (5 V to 20 V and up to 5 A), and must assert a pull-up resistor (Rp) resistor on the configuration channel (CC) pins.

RELATED LINKS

4 USB Type-C and Power Delivery architecture on page 6
5 CC pins: port termination characteristics on page 8

3.2 Sink Port (consumer)

This port is able to consume power over V_{BUS} (from 5 V to 20 V and up to 5 A) and must assert a pull-down resistor (Rd) on the CC pins.

RELATED LINKS

4 USB Type-C and Power Delivery architecture on page 6
5 CC pins: port termination characteristics on page 8

3.3 Dual-Role Power (DRP) Port

A Dual-Role Power Port (DRP) can operate as either a fixed Source or a Sink port, or alternate between the two roles through the USB PD Power Role Swap command.

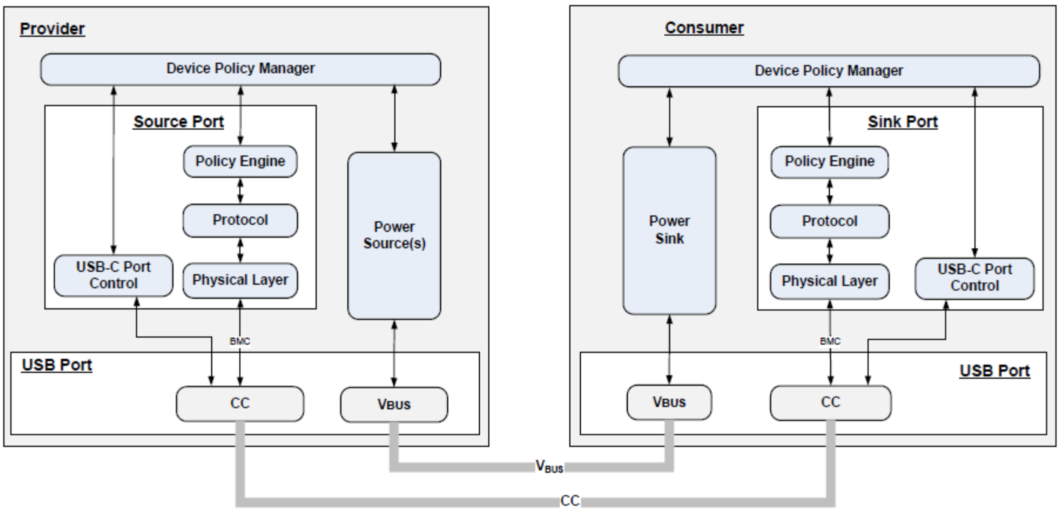
4 USB Type-C and Power Delivery architecture

The USB Power Delivery specification defines the stack architecture with all its layers managing a PD device.

Dual-Role Power devices need to physically combine Provider and Consumer elements into a single device.

Providers can contain multiple Source Ports, each with their own communications stack and USB-C Port control.

Figure 4. USB Power Delivery architecture



In the figure above, when a Provider and a Consumer are connected, they start to communicate through the configuration channel (CC), while the Source supplies the Sink through the V_{BUS} path. Even though USB-PD establishes the Source or Sink and DFP or UFP roles, the application may swap these roles on request.

4.1 Device Policy Manager (DPM)

The Device Policy Manager (DPM) deals with the USB Power Delivery resources used by one or more ports on the basis of the local device policy. It interacts with the Policy Engine and USB-C Port control blocks of the device to implement the local policies for each port.

4.2 Policy Engine (PE)

The Policy Engine (PE) interacts directly with the DPM to determine which local policy to apply. Its role is to drive the message sequences according to the sent message and its expected response.

It allows power negotiation by establishing an explicit contract for power exchange. The acceptance or the refusal of a request depends on the response of the DPM with respect to a specific power profile.

The PE also handles the flow of vendor defined messages, allowing the discovery, entry and exit of modes supported by the provider and consumer sides.

4.3 Protocol layer (PRL)

The protocol layer drives message construction, transmission, reception and acknowledgment. It allows the monitoring of message flows and the detection of communication errors.

The protocol layer builds and sends messages according to indications from the Policy Engine, and forwards responses to those messages back to the Policy Engine.

4.4 Physical layer (PHY)

The physical layer is responsible for sending and receiving messages across the CC wire. It is responsible for managing data over the wire, avoiding collisions and detecting errors in the messages through a Cyclic Redundancy Check (CRC).

5 CC pins: port termination characteristics

The Configuration Channel (CC) pins are used in the discovery, configuration and management of connection across a USB Type-C™ cable, as well as a communication channel for the PHY layer of the USB Power Delivery.

There are two CC pins in each receptacle, but only one is connected through the cable to establish communication. The other pin can be re-assigned as the V_{CONN} pin for powering electronics in the USB Type-C™ plug of electronically-marked cables.

Specific Rd and Rp resistor values connected to CC pins allow single role or dual role system configuration. The attachment and orientation detection operations are carried out through CC lines through these resistors:

- a source must assert Rp pull-up resistors on both CC pins
- a sink must assert Rd pull-down resistors on both CC pins
- a DRP port is equipped with both Rp pull-up resistors and Rd pull-down resistors on its CC pins and is able to dynamically assert the appropriate resistors when the role is fixed by the application according to the operated power role
- a full-featured USB Type-C cable must assert Ra pull-down resistors on the V_{CONN} pin

The following table provides the values to be used for Rp or current source.

Table 2. Source CC termination (Rp) requirements

Source Current Capability	Current Source to 1.7V - 5.5V	Rp pull-up to 3.3V ±5%	Rp pull-up to 4.75V - 5.5V
Default USB power	80μA ±20%	36kΩ ±20%	56kΩ ±20%
1.5A @5V	180μA ±8%	12kΩ ±5%	22kΩ ±5%
3.0A @5V	330μA ±8%	4.7kΩ ±5%	10kΩ ±5%

Rp resistors connected to both CC pins may be pulled-up to 3.3 V or 5 V. The resistor value is chosen on the basis the device port supplying capability. Moreover, if the source role is operated, the Rp resistors can be replaced by current sources.

The following table provides the values to be used for Rd or Sink CC termination.

Table 3. Sink CC termination (Rd) requirements

Rd setting	Nominal Value	Max Voltage on pin	Power Capability detection
±20% voltage clamp	1.1V	1.32V	No
±20% resistor to GND	5.1kΩ	2.18V	No
±10% resistor to GND	5.1kΩ	2.04V	Yes

Rd resistors may be implemented in multiple ways.

6 Power options

Regarding power exchange, any device with a Type-C™ connector but not compliant with the Power Delivery specification must still be able to support 5 V with one of the specific current capabilities.

A device that does support Power Delivery and is designed to manage high power loads may support up to 20 V at 5 A (100 W).

Table 4. Power options

<table>
<tr><th>Mode of operation</th><th>Nominal voltage</th><th>Maximum current</th><th>Maximum power</th><th>Note</th></tr>
<tr><td>USB 2.0</td><td rowspan="5">5V</td><td>500 mA</td><td>2.5W</td><td rowspan="2">Default current based on specification</td></tr>
<tr><td>USB 3.1</td><td>900 mA</td><td>4.5W</td></tr>
<tr><td>USB BC1.2</td><td>up to 1.5A</td><td rowspan="2">7.5W</td><td>Legacy charging</td></tr>
<tr><td>USB Type-C™ current at 1.5 A</td><td>1.5 A</td><td rowspan="2">Support high power devices</td></tr>
<tr><td>USB Type-C™ current at 3 A</td><td>3A</td><td>15W</td></tr>
<tr><td>USB PD</td><td>up to 20V</td><td>up to 5A</td><td>100W</td><td>Directional control and power level management</td></tr>
</table>

RELATED LINKS

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7 Cable attachment and detachment detection and orientation

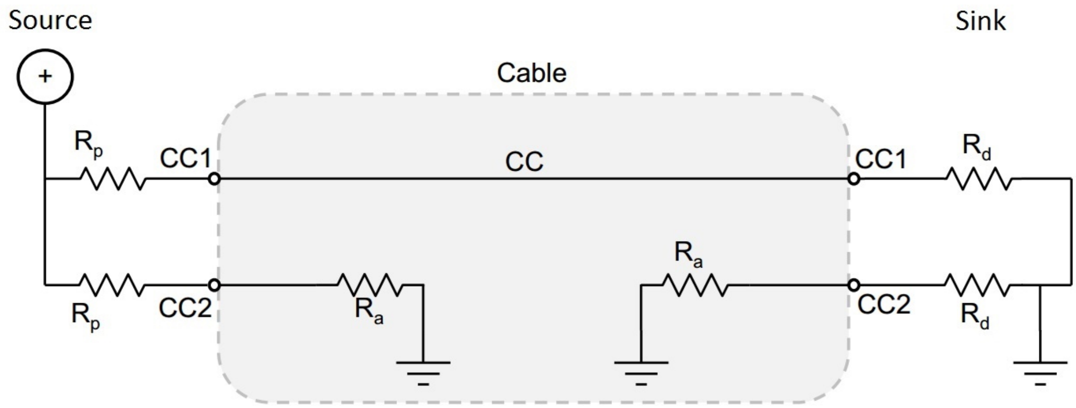
As stated in the USB Type-C specification, it is mandatory to determine the orientation of an attachment; i.e., when one of the two CC pins detects a valid Rp or Rd connection.

To detect an attachment, the source monitors both CC pins.

The pins are floating when nothing is attached, but when the sink is attached via the cable, one CC line of the source is directly pulled-down (through the sink Rd), signaling that a connection has been made (see Figure 5. Pull up/down CC detection).

Hence, once connection is established, a voltage divider is set between source pull-up resistor Rp and sink pull-down resistor Rd, fixing the voltage level on the CC line for the communication signals.

Figure 5. **Pull up/down CC detection**



At the same time, the orientation of the plug, and consequently of the cable, is defined according to which CC line (CC1 or CC2) detects a valid resistance after the attach event.

The figure above shows an unflipped cable orientation.

Moreover, the full-featured cable, exposing an Ra resistor, connects the V_{CONN} pins to ground.

8 Power negotiation

When a connection is made and the respective roles have been assigned, the source and the sink begin with a 5 V VBUS, and then negotiate a new contract for the power objects: the selected configuration channel (CC) allows them to establish communication and negotiate the power according to the protocol described in USB Power Delivery specification.

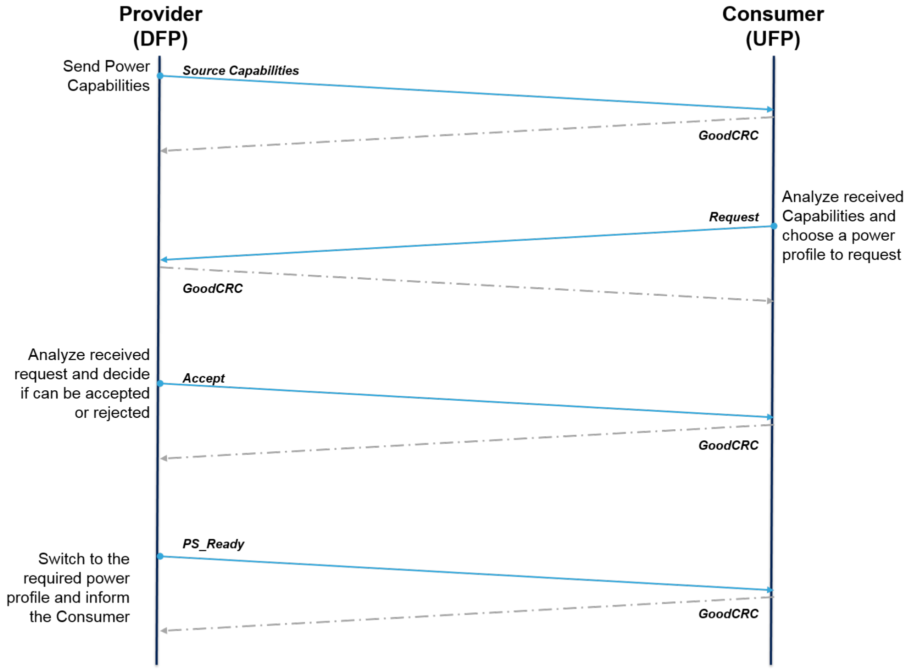
All the devices equipped with USB Type-C™ are able to provide up to 15 W (5 V and up to 3 A) power via the V_{BUS} path, but every subsequent request for delivering or receiving power from 15 W to 100 W must be negotiated according to the USB Power Delivery protocol.

The messages exchanged between a source (provider) and sink (consumer) are illustrated in Figure 6. Message flow during power negotiation.

1. Initially, the source dispatches a `Source Capabilities` message to inform the port partner (sink) of its power capabilities.
2. The sink then sends a `Request` for one of the advertised power profiles.
3. The source accepts or rejects this request according to its power balance.
4. If confirmed, the source sends an `Accept` to the sink.
5. The source then switches to the requested power profile and sends a `PS_Ready` confirmation message.

Each received message is acknowledged with a `GoodCRC` to confirm correct reception. Incorrect reception should be ignored and persistent communication errors should trigger a soft reset to reset protocol parameters and re-establish communication. If the error persists, a hard reset is performed.

Figure 6. Message flow during power negotiation



RELATED LINKS

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9 Alternate modes and billboard device class

The USB Power Delivery specification supports alternate modes (Alt Mode) to transfer high-speed data over Type-C™ cables using protocols like:

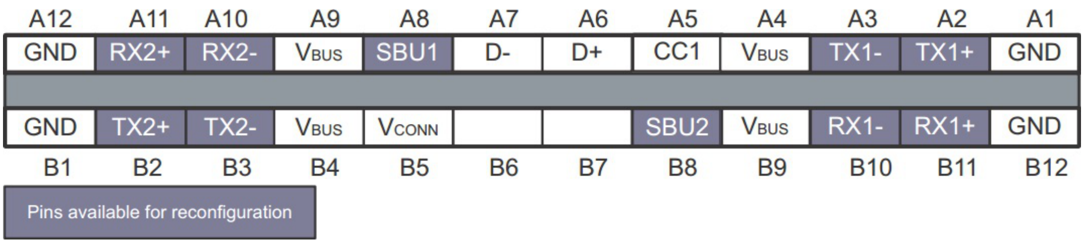
- High-Definition Multimedia Interface (HDMI)
- DisplayPort (DP)
- Peripheral Component Interconnect Express (PCI Express)
- Ethernet over twisted pair (Base-T Ethernet)
- Mobile High-Definition Link (MHL)

Alternate modes allow Type-C hosts and devices to incorporate additional functions, exploiting USB PD structured vendor defined messages (Structured VDMs) to manage typical display controller selection mechanisms: discover, enter, exit, configure, status update and attention.

As alternate modes do not traverse the USB hub topology, they may only be used between a directly connected host and device.

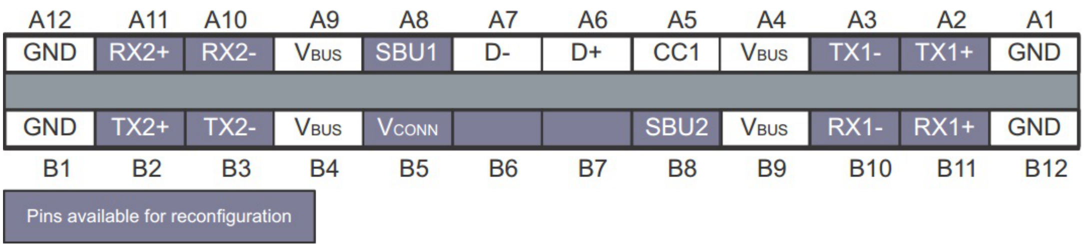
Structured VDMs may also be used for re-assignment of the pins that the USB Type-C connector exposes.

Figure 7. Pins available for reconfiguration on the plug of the full-featured cable



The following figure shows the pins available for reconfiguration with direct connect applications. There are three more pins because this configuration is not limited by the cable wiring.

Figure 8. Pins available for reconfiguration on the receptacle for direct connect applications



Where no equivalent USB functionality is implemented, the device must provide a USB interface exposing a USB billboard device class to identify the device. This is not required for non-user facing modes (e.g., diagnostic modes).

The USB billboard device class definition describes how to communicate the alternate modes supported by a device container to a host system, including string descriptors that provide supporting information in a human-readable format.

Revision history

Table 5. **Document revision history**

Date	Version	Changes
10-May-2018	1	Initial release.

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