`AN92554

Implementing Battery Charging Features Using HX3

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Associated Part Family: CYUSB330x, CYUSB331x, CYUSB332x

Related Application Notes: AN91378

AN92554 introduces the basics of USB battery charging and describes standard and proprietary battery charger detection mechanisms supported by HX3 on its upstream and downstream ports. This application note also helps you to understand the HX3-specific features like Ghost Charge and ACA-Dock, and provides the guidelines to implement various battery charging features.

Contents

1 Introduction

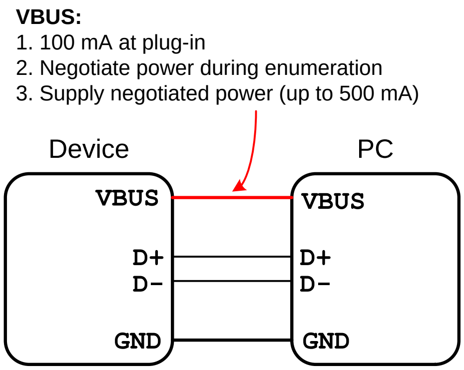
HX3 is a family of USB 3.0 hub controllers compliant with the USB 3.0 specification revision 1.0. HX3 supports SuperSpeed (SS), Hi-Speed (HS), Full-Speed (FS), and Low-Speed (LS) modes. In addition to implementing a USB 3.0 hub, the HX3 family includes advanced USB battery charging capabilities to meet the demand for battery charging over USB.

This app note focuses on the battery charging features of the HX3 product family. The app note begins with a description of VBUS powered devices, USB battery charging specification, overview of various USB battery chargers and HX3 family supporting different battery charging features. Finally, HX3-based evaluation kits is described, along with the guidelines for design and configuration of the charging features in HX3.

2 A Short History of USB Power

To make the USB technology user friendly, USB-IF has defined the specification to supply power to the connected USB devices over a USB cable along with data communication (also known as bus powered devices). This helps devices to draw power and also communicate over a single USB cable. Figure 1 shows an implementation of USB powered device.

Figure 1. USB Interface Signals

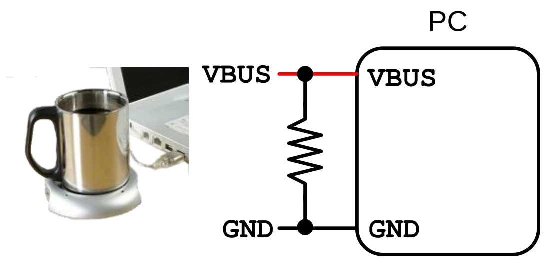


When plugged in to a USB host, a USB device can draw up to 100 mA. The device is required to communicate its specific information to the host during the USB enumeration process. During enumeration, the connected device informs the host about how much power it would require from VBUS. If the host is capable of providing the requested amount of power, it goes ahead and configures the device accordingly. For example, a device that requests 200 mA of current at 5 V would be configured if directly plugged into a PC's downstream port, but not if plugged into a bus-powered hub. This is because the PC can deliver up to 500 mA, but a bus-powered hub can deliver only 100 mA per downstream port as per USB specification.

For safety reasons, the USB specification requires over-current protection on all the downstream ports. The over-current protection circuit should remove the power when the aggregate current drawn by a gang of downstream ports exceeds the preset value. The specification also stipulates that an overcurrent fuse must be self-recovering for the best user experience.

This simple power scheme is effective if everything plugged into a USB port fully complies to the specification. However, the market quickly took over and vendors realized that a cheap source of power was sitting on every desktop and laptop. USB entered a phase, in which all types of devices were plugged into USB only to draw power—mug warmers, fans, mini-refrigerators and lamps to name a few. These devices make no connection to the data lines, D+ and D-, but draw all the power they want from VBUS. The typical load seen by the PC is a power resistor between VBUS and GND (Figure 2).

Figure 2. USB Port as Power Source



This unsupervised use of USB power is not good for a PC that is expected to manage power on an orderly basis. For example, the mug warmer can't do much with only 2.5 W of power (the "legal" 5 V @ 500 mA limit), so some of them draw 5 W, twice the legal limit. (5 W of heat also does not do much to heat coffee, so USB mug warmers are not popular). Increasing the wattage further risks blowing the thermal fuse that protects the USB ports, causing all of them to go dead until the fuse cools down and/or the PC is rebooted.

An excellent use of USB power is to charge cell phones and tablets from the USB connector. This eliminates the clutter of incompatible wall-warts and cables, requiring only the USB cable already used for data syncing. To manage charging, and to provide more than 500 mA of charging current, the USB-IF (USB Implementer's Forum) released the "Battery Charging Specification" version 1.2 in December 2010, here after abbreviated as "BC v1.2".

BC v1.2 specification allows compliant portable devices to charge with up to 1.5 A of current. It defines a new class of USB ports called Charging Downstream Ports that allow both charging up to 1.5 A of current and simultaneous data communication. In comparison, a wall adapter provides a Dedicated Charging Port, that is not capable of data communication.

Being able to charge from USB has also enabled the industry to eliminate proprietary wall adapters for most of the portable devices and phones. The Chinese Industry specification YD/T 1591-2006 mandated all phones sold in China to support detection of USB Dedicated Charging Port (implemented by shorting D+ and D- pins). As of 14 June 2007, all mobile phones applying for a license in China are required to use a USB port as a power source for battery charging. The European Union (EU) followed suit in 2009 to mandate the use of micro-USB connector as the standard port for charging devices sold in the EU.

3 Definition of Terms

Note: Electrical specifications noted below are explained in BC v1.2 Detection Mechanism.

Accessory Charger Adaptor (ACA): An ACA is an adaptor which allows simultaneous connection of a charger and another device to a single USB port.

ACA-Dock: An ACA-Dock is a docking station that has one upstream port, and optional downstream ports. The upstream port can be attached to a portable device, and is capable of sourcing I_{DEV_CHG} (1.5 A) to the portable device. An ACA-Dock signals that it is an ACA-Dock to the portable device by enabling V_{DM_SRC} (0.5 V to 0.7 V) on the D- pin during USB idle, and by pulling the ID (Identification) pin to ground through a resistance of R_{ID_A} (122 kΩ to 126 kΩ).

Apple Charging: Apple Charging is a proprietary charging standard supported by HX3 to charge Apple devices such as iPod, iPad or iPhone. If an Apple device is connected to a downstream port of HX3, the charging method works in two modes:

- **Apple Charging 1 A:** The Apple charger (HX3) holds its D- line at 2.7 V and D+ line at 2 V.
- **Apple Charging 2.1 A:** The Apple charger (HX3) holds its D+ line at 2.7 V and D- line at 2 V.

Charging Downstream Port (CDP): A Charging Downstream Port (CDP) is a downstream port that complies with the USB 2.0 definition of a host or a hub, and allows a connected portable device to draw a maximum current of I_{DEV_CHG} (1.5 A). A CDP outputs a voltage of V_{DM_SRC} (0.5 V to 0.7 V) on its D- line when it senses a voltage greater than V_{DAT_REF} (0.25 V) and less than V_{LGC} (0.8 V) on its D+ line.

Charging Port: A Charging Port is any port that can charge a battery powered device: a DCP, CDP, ACA-Dock, or ACA.

Dedicated Charging Port (DCP): A DCP is a downstream port that provides power to a portable device, but is not capable of enumerating the portable device. A DCP sources I_{DEV_CHG} (1.5 A) with a voltage of V_{CHG} (4.75 V to 5.25 V). A DCP indicates its type by placing a resistor between its D+ and D- pins with a maximum resistance of R_{DCP} (200 Ω). Typically, D+ and D- are shorted.

Ghost Charge™: Ghost Charge is a Cypress-proprietary charging method where a downstream port on HX3 emulates a DCP even though the upstream port is not connected to a host or a hub.

Standard Downstream Port (SDP): A Standard Downstream Port (SDP) refers to a downstream port that is compliant with the USB definition of a host or hub. An SDP pulls the D+ and D- to GND using 15 kΩ resistors and can provide 500 mA current when the device is configured.

A USB 3.0 downstream port can provide up to 900 mA current when the device is configured.

USB Charger: A USB charger is a device with a DCP such as a wall adapter or car power adapter.

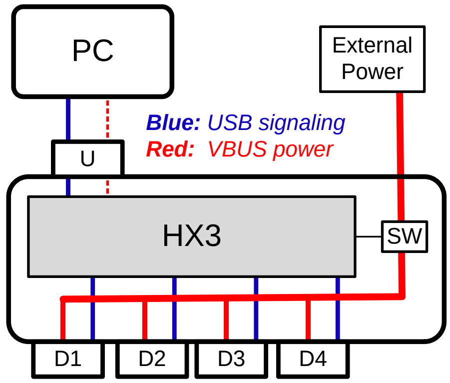
4 HX3 Variants

The HX3 family of hub controllers contains variants to handle various power topologies. The smallest-package versions are the CYUSB3302 (two downstream ports) and CYUSB3304 (four downstream ports) in 68-pin QFN packages.

4.1 Ganged Port Power switching

As shown in Figure 3, external power is routed to the downstream ports via a single power switch (SW). HX3 configuration is done using on-chip ROM for default values or an external I^2C EEPROM for custom code and/or configurations. Note that VBUS from the PC is used only to detect attachment (dotted line) and the external power unit supplies the VBUS power to the downstream ports. The external power supply in conjunction with BC v1.2 allows the plugged-in device (such as a phone) to charge at a higher current before enumeration.

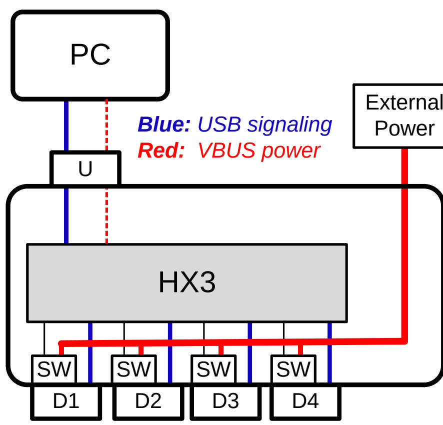
Figure 3. CYUSB3302/04: SuperSpeed Hub with Gang-Switched Charger Ports



4.2 Individual Port Power switching

Figure 4 illustrates the individual port power switching. This is supported by HX3 in an 88-QFN-package, which contains additional pins for individual power switches, and also pin-strap configuration capability. External power switches controlled by HX3 have a resistor-settable current limiting and overcurrent sensing functionality. The overcurrent condition is sensed by HX3 and reported back to the PC via the USB. HX3 also automatically shuts down any downstream port experiencing an overcurrent condition. For more details on the implementation of the external power switch controls, refer to How HX3 Asserts Power Control in a System.

Figure 4. CYUSB3312 (Two Downstream Ports) and CYUSB3314 (Four Downstream Ports) with Individually-Switched Charger Ports



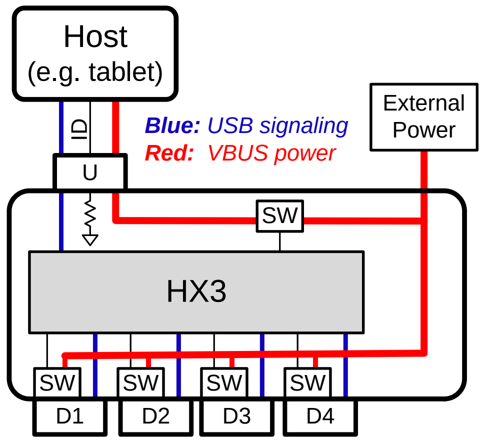
4.3 ACA Dock Charging

Many tablets have the USB port for charging and to function as a USB peripheral. Some newer tablets are available with the USB port that can operate either as a host or as a peripheral, known as dual-role, or OTG (On-The-Go).

In addition to serving as either a USB Host or peripheral (the “dual-role” part), an OTG device follows a signaling protocol by which a host and a peripheral could swap roles without disconnecting and re-connecting the USB cable. The normal USB connector has four pins (D+, D-, VBUS, and GND), whereas the OTG connector has five pins.

The additional fifth pin is an Identification (ID) pin, which was originally used to detect the role of the device (host or peripheral) . In the BC v1.2 specification, this ID pin is also used to detect the ACA-Dock capability. This detection is based on the resistor connected to the ID pin (Figure 5) on the hub’s upstream port. “ACA-Dock” stands for Accessory Charger Adapter-Dock, which is part of BC v1.2, described in detail later in this application note.

Figure 5. CYUSB3324/6/8: SuperSpeed Hub, ACA-Dock



5 Overview of USB Battery Chargers

5.1 Types of Chargers

5.1.1 Proprietary Chargers

Many devices follow the BC v1.2 specification. However, there is an installed base of devices that follow proprietary handshake protocols for battery charging. These proprietary protocols, often introduced by popular portable device manufactures, are referred to as proprietary chargers. These chargers allow the portable devices to distinguish dedicated chargers or “wall-warts” connected to their USB ports from standard USB ports.

A standard USB port includes four terminals: D+, D-, VBUS and GND. In all these charging methods, VBUS provides the charging current and GND provides the return path from the portable device. The D+ and D- wires carry the signaling that allows the connected device to distinguish a charger from a standard USB port. In a standard downstream (DS) port, the D+ and D- lines are both pulled down by 15 kΩ resistors. Proprietary chargers alter this behavior of D+ and D- lines to allow a connected portable device to detect a charger. The following sections outline a few of the popular proprietary chargers.

5.1.2 Dedicated Chargers

In dedicated chargers, the charging method is implemented either by shorting D+ and D- lines or by connecting a low-value resistor between the D+ and D- lines. The USB-IF BC v1.2 DCP detection method is also implemented this way. The dedicated charging port can be used only for charging and there is no USB data communication between the device and the charger, host or hub.

5.1.3 Apple Chargers

Apple devices (iPod, iPhone, and iPad) follow a proprietary charger detection method to distinguish a charger from a standard USB port. In this method, a specific non-zero voltage is applied to the D+ and D- pins to indicate the charger capability. Table 1 shows the voltage on the D+ and D- lines provided by Apple chargers to indicate current capabilities of the charger.

Table 1. Various Apple Chargers

Voltage on D+ (V)	Voltage on D- (V)	Charging Current (A)	Comments
2	2	0.5	Not in use[1]. First-generation Apple Chargers.
2	2.7	1	1 A Apple Chargers
2.7	2	2.1	2.1 A Apple Chargers
2.7	2.7	2.4	2.4 A Apple Chargers[1]

[1] Not supported in HX3 Silicon.

5.1.4 Samsung Chargers

Samsung devices follow multiple charging methods. Some Samsung devices (Samsung Galaxy Tablets) use a proprietary charging method in which the D+ and D- pins are biased to the same potential (~1.2 V). The Samsung Galaxy S series (S3, S4) devices follow the USB-IF BC v1.2 charging standard for DCP, CDP, and SDP mode of operations.

5.1.5 Other Proprietary Chargers

In addition to the proprietary outlined earlier in this section, there are other proprietary chargers such as the ones followed by older devices from Sony, Blackberry, etc. in the market.

5.2 USB-IF BC v1.2 Charging Standard

When a portable device is attached to a USB host or a hub, the USB 2.0 specification requires that the portable device must draw current less than:

- 2.5 mA if the bus is suspended
- 100 mA if the bus is not suspended and not configured
- 500 mA if the bus is not suspended and configured by the host to draw 500 mA

For portable devices to charge without being configured or to follow the rules of suspend mode operation, a protocol is required for the device to distinguish a charging port from a standard port. USB-IF BC v1.2 standard provides such a mechanism. Table 2 summarizes the charging current capabilities when a portable device follows the USB specification.

Table 2. USB Power Standards

Specification		Current	Power
USB 2.0 (SDP)		500 mA (when configured by host)	2.5 W
USB 3.0 (SDP)		900 mA (when configured by host)	4.5 W
Battery Charging Specification v1.2	CDP	1.5 A	7.5 W
	DCP	0.5 A–1.5 A	2.5 W–7.5 W
	ACA-Dock	1.5 A	7.5 W

The detection of the various BC v1.2 charging mechanism is discussed in detail in BC v1.2 Detection Mechanism.

6 HX3 Battery Charging Features

HX3 supports various battery charging methods for devices connected to both its downstream and upstream ports. In addition to BC v1.2, HX3 supports the following battery charging features

- Apple charging: Apple’s proprietary charging method used in iPad, iPhone, and iPod.
- Ghost Charge™: Cypress-proprietary feature wherein each downstream (DS) port can emulate a Dedicated Charging Port (DCP) like a wall charger, when a host is not connected to HX3’s upstream (US) port.
- Accessory Charger Adapter Dock (ACA-Dock): Enables charging and simultaneous data transfer for a smart phone or a tablet acting as a host compliant with BC v1.2.

This section describes how HX3 controls power to the downstream and upstream devices and the types of battery charging support on these ports.

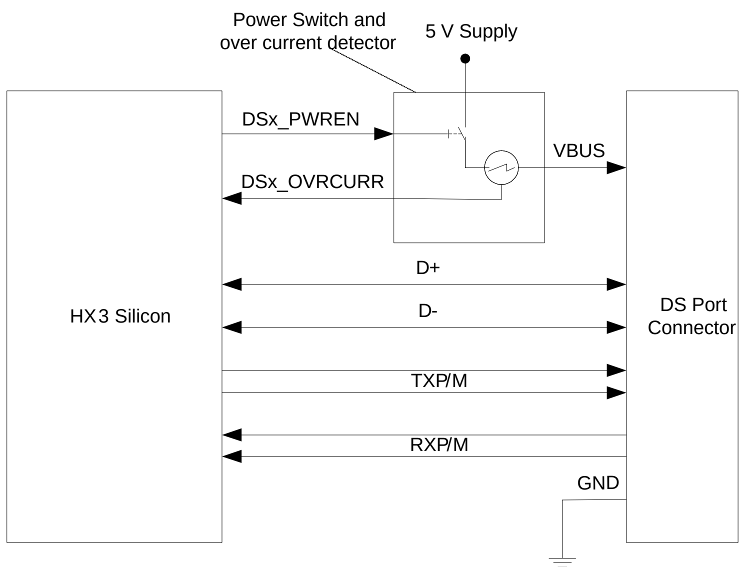
6.1 How HX3 Asserts Power Control in a System

Figure 6 shows a typical system-level implementation of how HX3 controls power for a single downstream port. It shows the HX3 silicon, downstream (DS) port connector, and a power switch that controls power to the downstream port.

A local 5 V supply passes through the power switch to supply VBUS to the downstream port. The power switch is controlled by the HX3 power enable (DSx_PWREN) signal.

HX3 accepts an overcurrent indication (DSx_OVRCURR), which it uses to turn OFF power to the port and inform the host of the error condition. Re-powering the port depends on the host and the Operating System. If the overcurrent signal is asserted while HX3 is not connected to a host, HX3 re-powers the port after removal of the overcurrent fault. An external power switch asserts the overcurrent signal if the device connected to the port consumes more current than the limit set by the power switch. For example, the Texas Instruments TPS2560DRC uses an ILIM pin to set the current limit using an external resistor.

Figure 6. Connection between Hub Controller and Downstream Port (Connector)



6.2 Factors Affecting Charging Current to a Portable Device

The charging current to a portable device is limited by the following:

1. The negotiation between the charger's downstream port and the portable device being charged.
2. The system power supply feeding the downstream port power switch, the current-carrying capacity of the power switch, and the over-current limit set in the power switch.
3. The device's charging current requirements. Although the specification states maximum charging current, there are devices that could charge at levels lower or higher than the specified limit. System designers should be aware of this, and design the system for higher capacity than required by the spec if necessary.

The charging current also varies with the charge state of the device's battery. In the case of Li-ion rechargeable batteries, the charging current is lower at low-charged and nearly fully-charged states of the battery, and higher between these limits. Figure 7 shows the typical charging profile of a Li-ion battery.

6.2.1 HX3 Charging Support on Downstream Ports

USB ports may be used for data communication only or for charging only or for both data communication and charging simultaneously. Therefore, based on the system requirement, HX3's downstream ports can be configured to act as one of the following:

- Standard downstream port (SDP)
- Charging downstream port (CDP)
- Dedicated charging port (DCP)

Figure 7. Charging Profile of a Li-Ion Battery

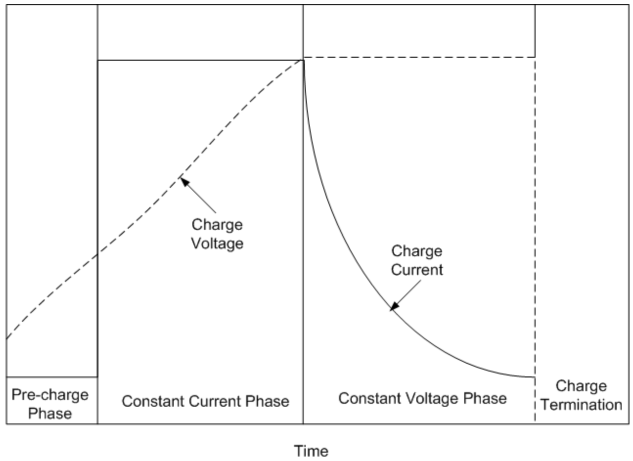


Table 3 summarizes the downstream port configuration options supported by HX3. The ports can be configured using the Cypress Blaster Plus utility as explained in the Blaster Plus User Guide.

HX3 provides both global and independent (for each individual port) port power configuration options to control charging support (SDP, CDP, or DCP). The global configuration option "*BC_ENABLE*" is used to control the charging support of all the downstream ports. When it is cleared, all downstream ports act as SDP.

When "*BC_ENABLE"* is set to "1", the charging support on each individual downstream port depends on the port's configuration options "*DCP_EN" and "CDP_EN*". The default configuration setting is highlighted in Table 3.

Table 3. Charging Configuration Options on HX3 Downstream Ports

BC_ENABLE	Port BC Configuration		Port Type
	DCP_EN	CDP_EN	
0	X	X	SDP
1	0	0	SDP
1	0	1	CDP
1	1	X	Apple/DCP

6.2.2 HX3 Switching Between Different Charging Configurations

According to its internal settings (Table 3), HX3 downstream ports act as either an SDP, a CDP, or a DCP when HX3 is connected to a host. When disconnected from the host, the downstream ports act as a DCP (Ghost Charge).

HX3 changes the role of its downstream ports on detection of a change in the upstream connection and also provides opportunity to the devices connected on its downstream ports to switch its role to match the HX3 port type. In compliance with BC v1.2 specification, HX3 goes through the following steps to force the attached portable devices to renegotiate the charging mechanism when HX3 changes the role of the downstream port:

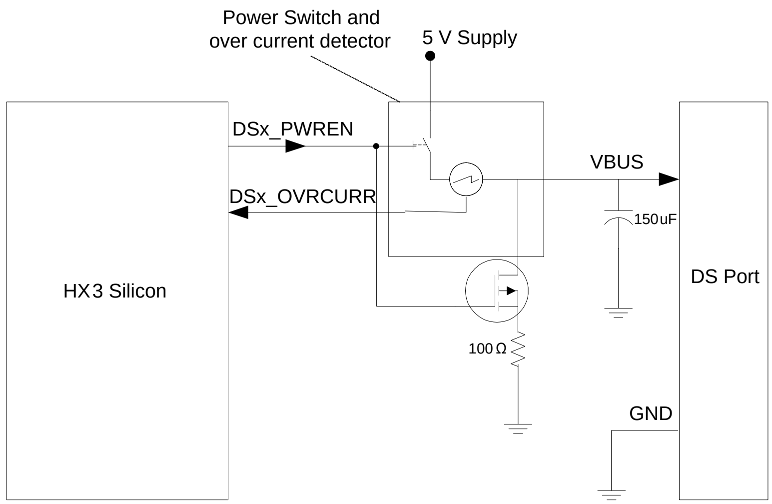
- Stop driving VBUS
- Wait for 600 ms
- Start driving VBUS

After VBUS is stopped, the 600 ms wait time allows the downstream port's VBUS to discharge to V_{BUS_LKG} (0.7 V) by combining the times allowed by the spec for a) VBUS not driven - T_{VLD_VLKG} (500 ms) and b) VBUS to be reapplied - T_{VBUS_REAPP} (100 ms).

In hub system designs, it is recommended that the hub itself provides a discharge path for VBUS on the downstream ports to discharge below VBUS_LKG as the connected portable devices may not discharge the VBUS within T_{VLD_VLKG}. This discharge also ensures a VBUS power cycle for connected non-charging devices.

The discharge mechanism is illustrated in Figure 8, which is an enhancement of Figure 6. As shown in Figure 8, the VBUS discharge can be accomplished by connecting VBUS (output of the power switch) through a 100 Ω discharge resistor and a transistor or FET to ground.

Figure 8. HX3 Downstream Port Power Connection with VBUS Discharge Path



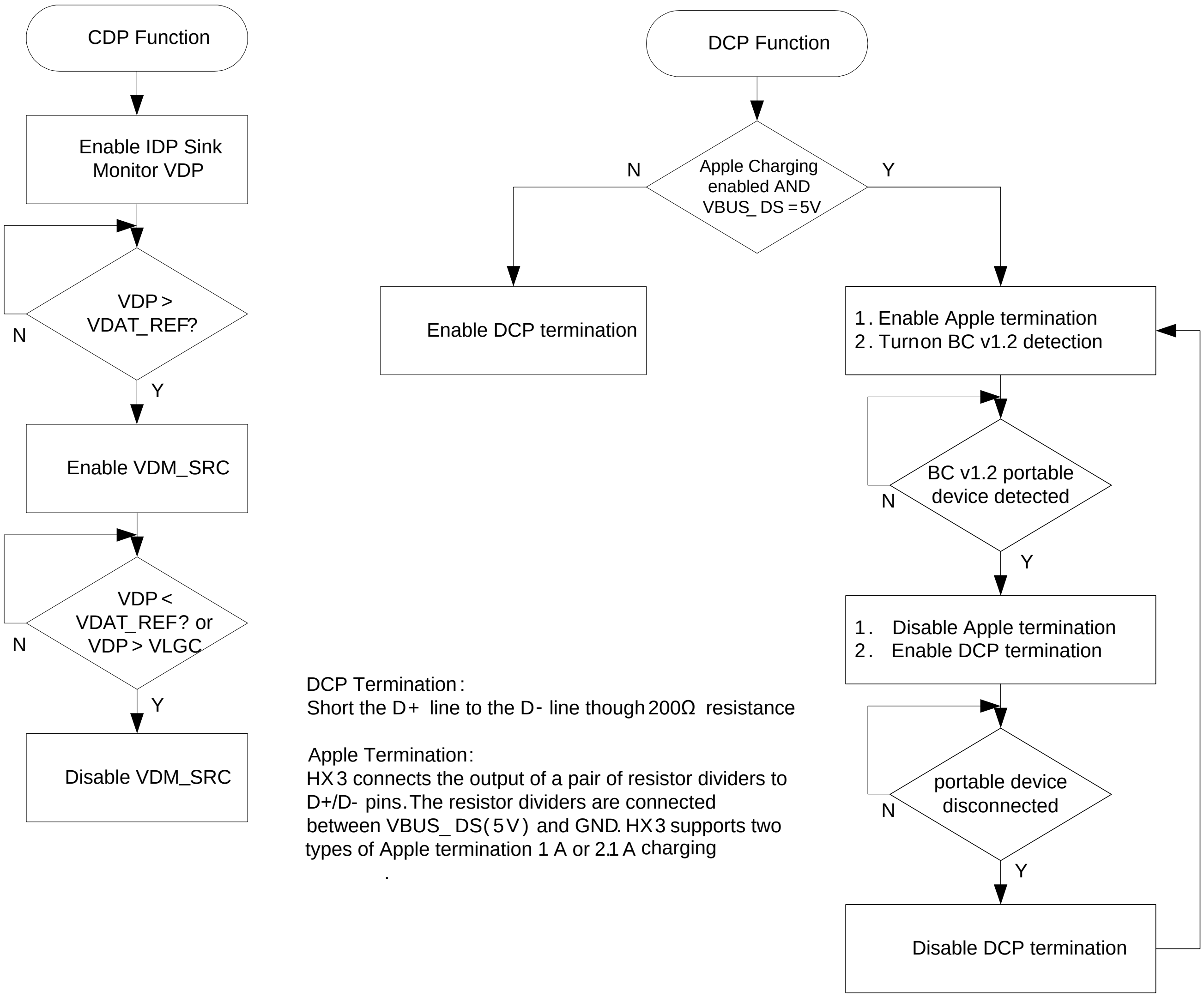
The discharge path is turned on when power enable is de-asserted. This can also be accomplished by using power switches that have built-in discharge capability. Figure 8 also shows a 150 µF capacitor on the VBUS output of the downstream port to meet the inrush current requirement as per the USB specification.

Every time a change in host connection is detected, HX3 evaluates the charger configurations shown in Table 3 and switches its role following the role-change procedure described above.

The conditions and the sequence of HX3 switching between different charging methods is shown in Figure 9. The CDP and DCP functions referred in Figure 9 are elaborated in Figure 10.

Figure 9. Flow Chart of HX3 Switching Between Charging Methods

Figure 10. Flow Chart of the HX3 Charger Handshake Procedure



7 HX3 Charging Support on Upstream Port

The upstream port of the hub can act as a standard hub upstream port or an ACA-Dock port. The HX3 family of products is available in both variants. Refer to the product selector guide in the HX3 data sheet to select the product supporting the ACA-Dock feature.

Standard Hub Upstream Port: A standard hub upstream port monitors VBUS to detect the attachment to a host or a hub. A bus-powered hub uses VBUS as the power source for its operation.

ACA-Dock: A standard hub connects to an upstream host and allows charging of downstream-connected devices. An ACA-Dock adds the capability to charge the (upstream) host. This allows portable devices with USB hosts (for example, tablets) to connect to its USB peripherals as usual, while the ACA-Dock (HX3) simultaneously charges both host and peripheral(s).

An ACA-Dock therefore provides VBUS power to the upstream port (host), in contrast to a standard hub receiving VBUS power from the host. ACA-Docks are detected using the fifth pin in the USB connector.called the ID pin. The ACA-Dock should connect the ID pin with RID_A (124 kΩ as per BC v1.2 specification) to ground. This enables the portable devices supporting ACA capability to act as a host and to draw current from VBUS.

The difference in the system design between a standard port and ACA-Dock is shown in Figure 11. When configured to act as ACA-Dock, HX3 provides the same power controls to the upstream port as it does to the downstream ports.

HX3 provides a power enable (US_PWREN) signal to control the power switch connected between the 5 V supply and VBUS of the upstream port. It also accepts an overcurrent indicator (US_OVCURR) to turn OFF the power when an overcurrent fault occurs on the upstream port.

In Figure 11, it should be noted that in a standard upstream port implementation, the resistor divider in the upstream port VBUS allows fast discharge of the line when VBUS is turned off by an upstream host or hub.

To inform the upstream portable device that it is attached to an ACA-Dock, HX3 outputs a voltage of V_{DM_SRC} (0.6 V) on D- as follows:

- HX3 starts outputting V_{DM_SRC} if D+ and D- lines are at idle J for a time of $T_{CP\_VDM\_EN}$ (200 ms). Note that idle J for low speed is D- > VIHZ (min) and D+ < VIL (max), and full speed is D+ > VIHZ (min) and D- < VIL (max).
- HX3 stops outputting V_{DM_SRC} within $T_{CP\_VDM\_DIS}$ (10 ms) of any USB activity on D+ and D- lines

The flow chart shown in Figure 12 depicts the HX3 ACA-Dock negotiation procedure to enable the portable device to detect that it is connected to an ACA-Dock so that the portable device can act as a host and simultaneously charge.

For additional details on the implementation of the ACA-Dock feature with HX3, refer to this Knowledge Base Article.

Figure 11. HX3 Upstream Port System Design for a Standard Port (Left) vs. an ACA-Dock (Right)

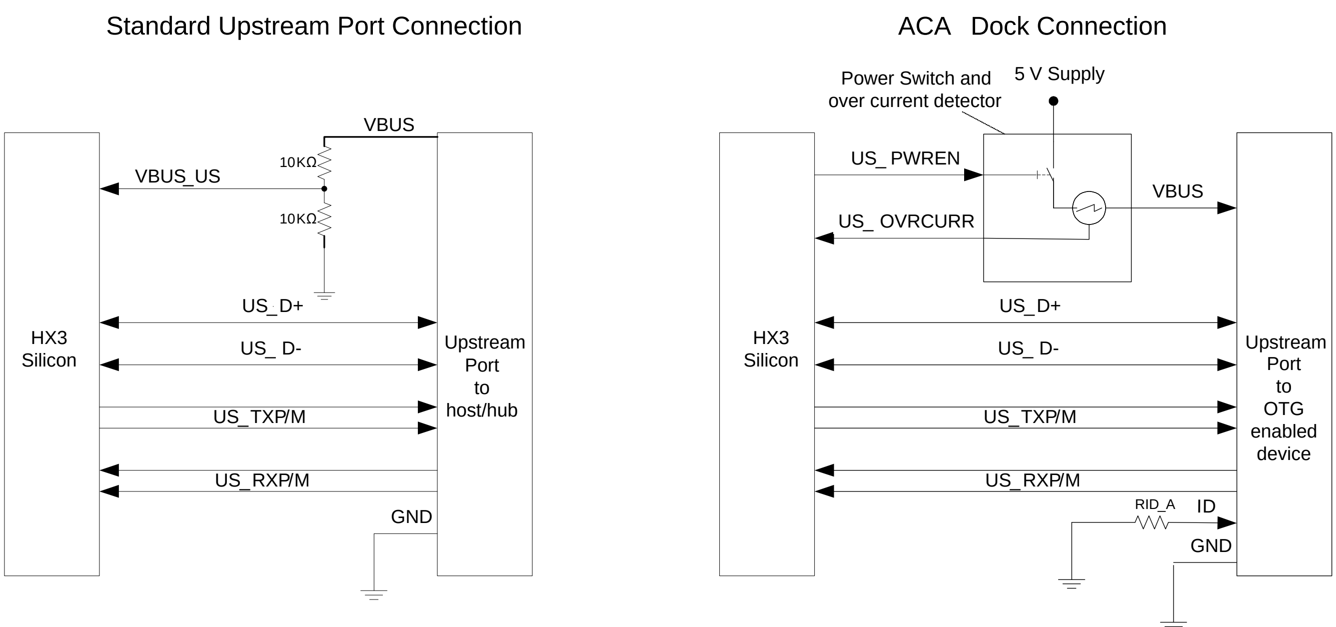
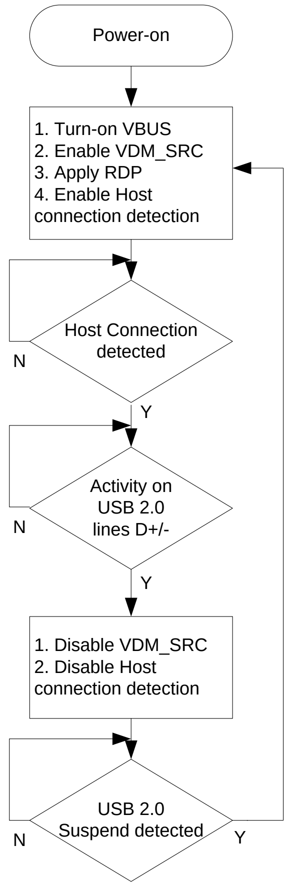


Figure 12. HX3 ACA-Dock Handshake Procedure



7.1 Ghost Charge™

Ghost Charge is a Cypress-proprietary feature that allows HX3's downstream ports to act as a dedicated charging port when the upstream port is not connected to a host, or when the host hibernates.

Similar to all other battery charging features, this feature can be enabled globally for all DS ports or independently for each downstream port. The configuration options for Ghost Charge are summarized in Table 4.

If the global "*GHOST_CHARG_EN*" configuration bit is set to "1", all downstream ports are enabled for Ghost Charge. To enable Ghost Charge on an individual downstream port, both the global Battery Charging Enable bit "*BC_ENABLE*" and the DCP Enable bit "DCP_EN" of the individual DS port must be set to "1". In the default configuration of HX3, all downstream ports are configured to enable Ghost Charge as shown in the highlighted row in Table 4. A user may want to disable Ghost Charging to prevent charging during hibernation.

Refer to Section 3.3 of the Blaster Plus User Guide for instructions to enable or disable the Ghost Charge feature in HX3.

Table 4. HX3 Downstream Port Configuration as DCP When Host not attached

Global Config		Port BC Config	Apple/ DCP
GHOST_CHARGE_EN	BC_ENABLE	DCP_EN	
0	0	X	N
0	1	0	N
0	1	1	Y
1	X	X	Y

7.2 Configuring Various Charging Methods with Blaster Plus

The Blaster Plus utility can be used to change the configuration bits in HX3 and save the updated configuration into the I^2C EEPROM attached to HX3 I^2C bus. HX3 will read the contents of the EEPROM on power-up and override the default configuration. Table 5 summarizes HX3's configuration options related to charging that can be modified with the Blaster Plus utility.

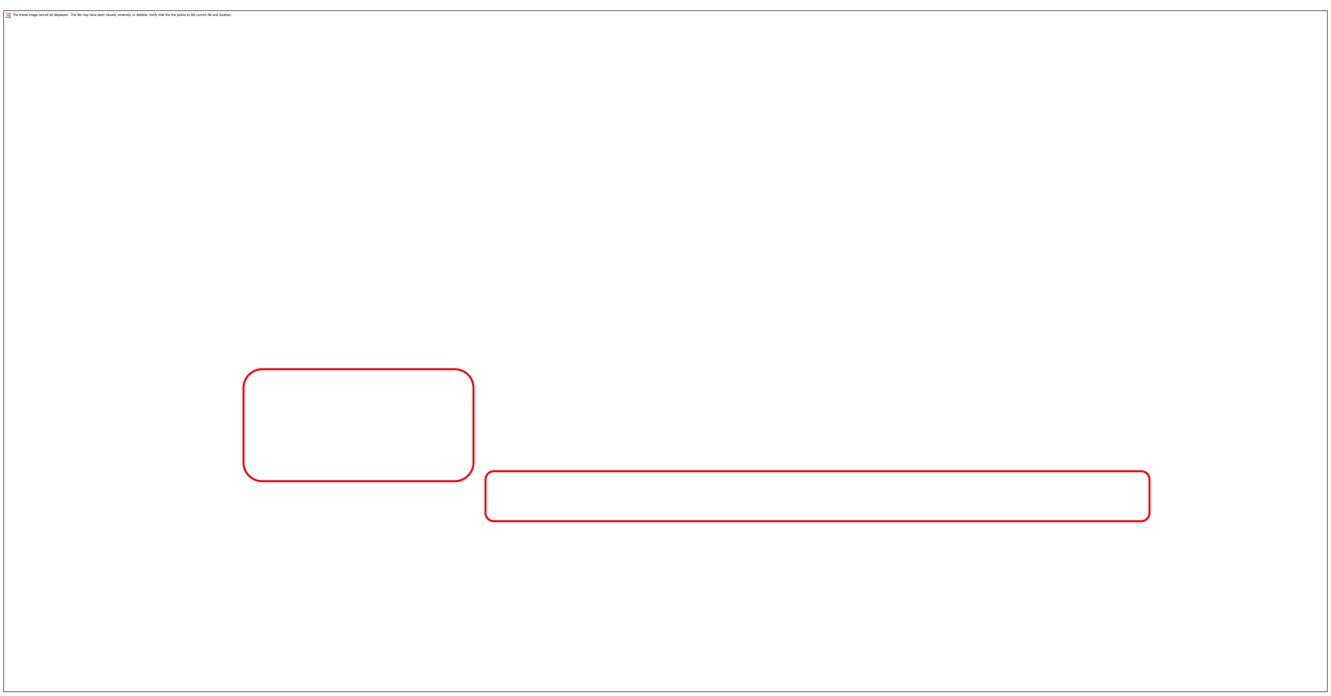
The "Allowed access" field of the table shows the features and options that can be set or cleared. For example, in parts that do not support the ACA-Dock feature, this feature cannot be set. However, if the parts support the ACA-Dock feature, Blaster Plus can be used to disable this feature.

Table 5. HX3 Charging Configuration Options with Blaster Plus

Configurations		**Default Value**	**Allowed Access**	
			Set to "1"	**Clear to "0"**
Global Configuration	ACA_DOCK	Product selection	N	Y
	GHOST_CHARGE_EN	1	N	Y
	BC_ENABLE	1	N	Y
	APPLE_XA	0	Y	Y
Port wise Configuration	DCP_EN	0	Y	Y
	CDP_EN	1	Y	Y

As shown in Figure 13, the Blaster Plus tool displays the default values read from the HX3 device. Options that are not accessible for modification are grayed out. Refer to the Blaster Plus user guide for more information about invoking the tool and programming the EEPROM.

Figure 13. Blaster Plus Showing Charging Configuration Options



7.3 HX3 Development Kits

The following HX3 development kits are available to evaluate HX3 features:

- CY4609 – HX3 68QFN Development Kit
- CY4603 – HX3 88QFN Development Kit
- CY4613 – HX3 88QFN Development Kit with ACA-Dock support

Table 6 compares power control and battery charging features in these kits.

Table 6. Comparison of Power Control and Battery Charging Features of HX3 Kits

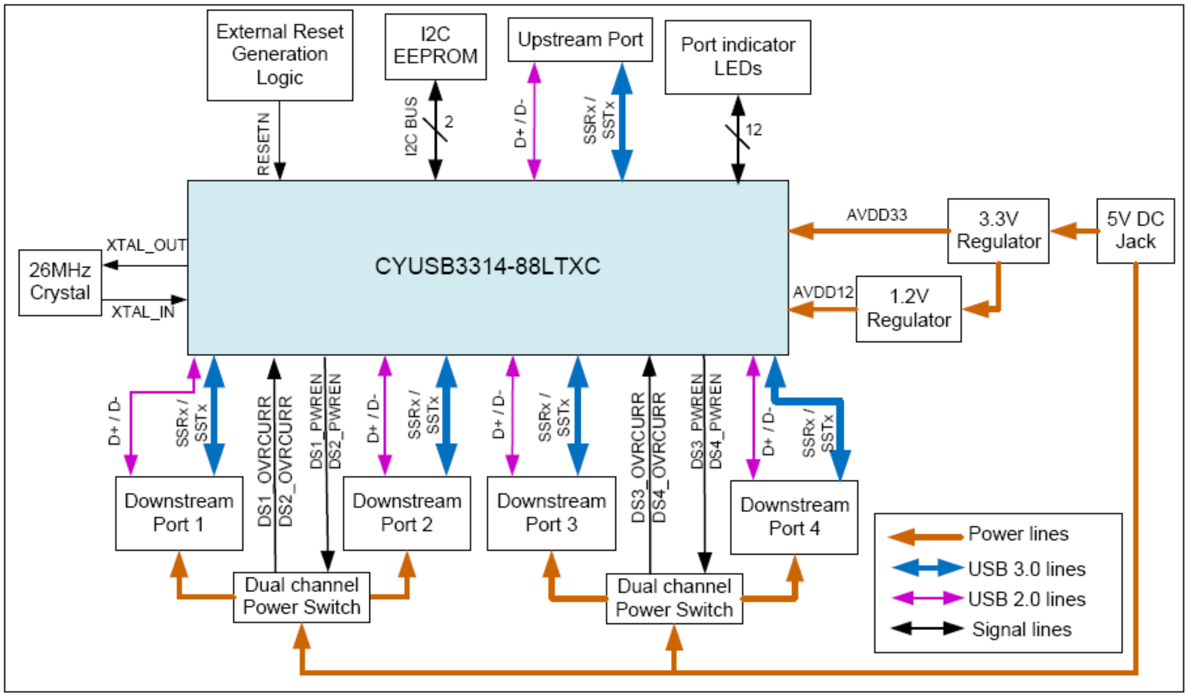
Features	HX3 Development Kit (DVK)		
	CY4609	**CY4603**	**CY4613**
HX3 part number	CYUSB3304-68LTXC	CYUSB3314-88LTXC	CYUSB3328-88LTXC
Power control mode to DS ports	Ganged	Individual	Individual
AC power adapter included in the kit	5 V, 4 A	5 V, 4 A	12 V, 3 A
Battery Charging – CDP mode	Yes	Yes	Yes
Battery Charging – SDP mode	Yes	Yes	Yes[2]
Battery Charging – DCP mode	Yes	Yes	Yes[2]
Apple charging – 1 A mode	Yes	Yes	Yes[2]
Apple charging – 2.1 A mode	Yes	Yes	Yes[2]
Ghost Charge mode	Yes	Yes	Yes[2]
ACA-Dock mode in US port	No	No	Yes
Power switches to the DS ports	Yes. One power switch controls all DS ports.	Yes. Two dual-channel power switches in individual power modes.	Yes. Three dual-channel power switches in individual power modes.
Power switches to the US ports	No	No	Yes
Downstream maximum charging current[3]	4.85 A for all 4 DS ports together	2.1 A per downstream port[3]	2.1 A per downstream port[3]
Upstream maximum charging current[3]	N/A	N/A	2.1 A[3]

[2] In CY4613, battery charging is supported in standard USB 3.0 ports and standard USB 2.0 ports only. Battery charging is not supported in Shared Link™ SuperSpeed ports. (Shared Link is a Cypress-proprietary feature that doubles the number of USB ports, creating eight ports from a 4-port hub. For more details, refer to the HX3 datasheet.)

[3] CY4609 and CY4603 kits come with 5-V, 4-A AC adapters. The charging current in all DS ports together should not exceed 3 A with the supplied AC adapter. The CY4613 kit comes with a 12-V, 3-A AC adapter to support higher power requirements. The charging current in all DS and US ports together should not exceed 5 A with this AC adapter. If a higher charging current is required, use a higher-capacity AC adapter.

8 Battery Charging Hardware Implementation in CY4603 kit

Figure 14. CY4603 DVK Block Diagram



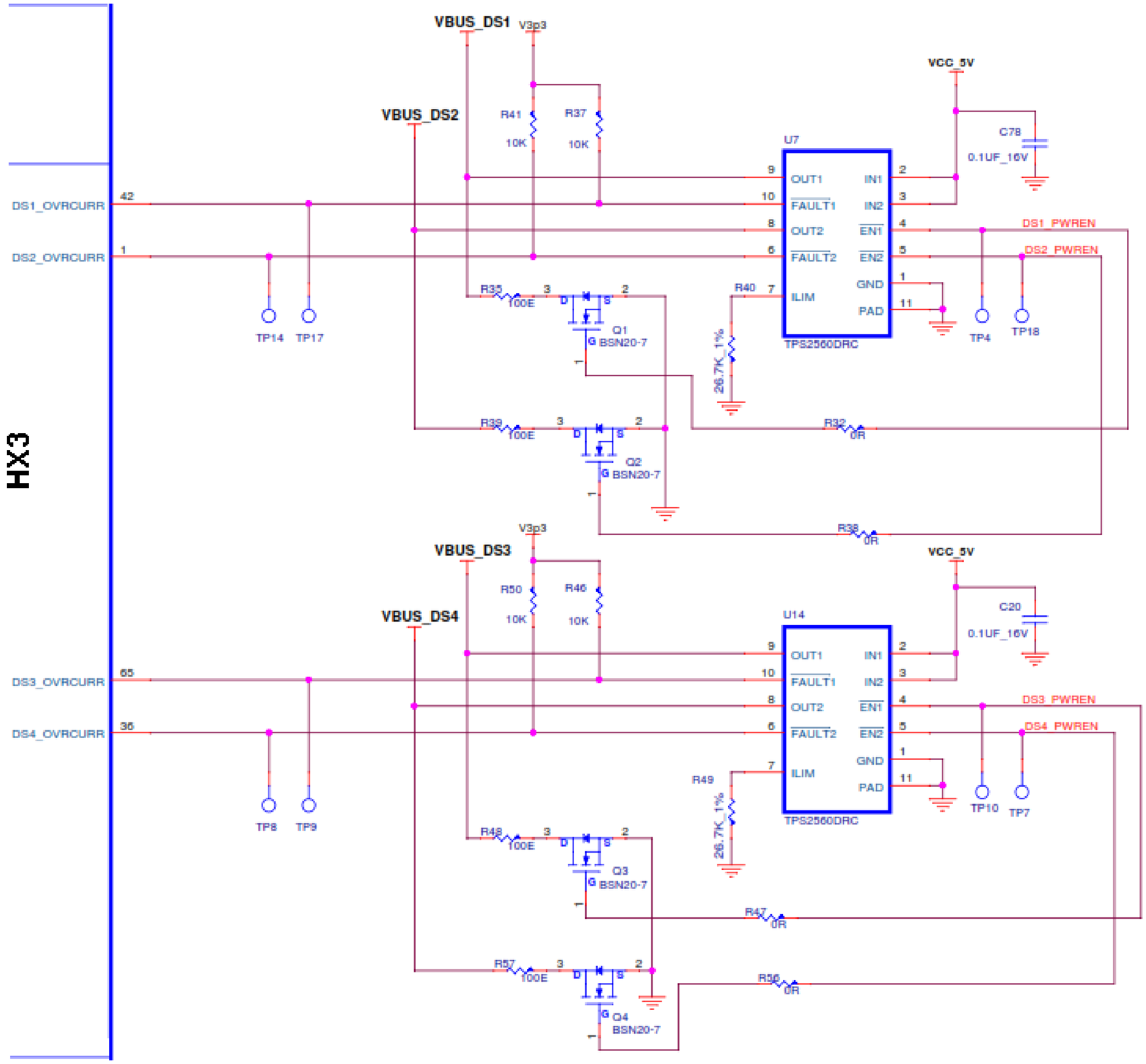
The CY4603 kit supports BC v1.2, Ghost Charge and Apple charging in all the downstream ports. As shown in Figure 14, CY4603 uses two dual-channel power switches, which allow monitoring of overcurrent conditions in each downstream port and shutdown that port when there is an overcurrent condition.

8.1 Hardware Design Considerations

Figure 15 shows the battery charging circuit of the CY4603 kit. It should be noted that the hardware examples explained in this section are with the 88-QFN part (CYUSB3314).

Wherever applicable, consideration of other kits and parts are called out separately. For more details of other kits, refer to HX3 DVK User Guide, which is common across the HX3 kits.

Figure 15. Power Switch Implementation in CY4603



8.2 Hardware Recommendations

1: Selecting the Power Switch: HX3 pins DSx_PWREN and DSx_OVRCURR interface to external power switches. These pins are used to control power switches and sense overcurrent conditions. The maximum current to DS ports can be configured through the power switch. Refer to the datasheet of the selected power-switch for details on setting overcurrent limits.

The power switches should be selected based on the maximum current required for DS ports. The CY4603 kit works in individual power mode, and each DS port current is limited to 2.1 A in the kit. This kit uses a dual-channel power switch (part number – “TPS2560DRC”), which is capable of an output current of 2.8 A per channel.

CYUSB330x parts support ganged-power mode, which allows one power switch to control power to all DS ports. The CY4609 kit uses a single-channel power switch (part number – “TPS2556DRBT”).The CY4609 kit output current from the power switch is limited to 4.85 A.

2: Pull-Up or Pull-Down on DSx_PWREN and DSx_OVRCURR: The active-state polarity of the DSx_PWREN and DSx_OVRCURR pins are configurable in HX3 based on the power switch requirements. If the power switch requires an active HIGH control, then pull DSx_PWREN low with 10 kΩ resistors. On the other hand, if the power switch requires an active LOW control, then pull DSx_PWREN high with 10 kΩ resistors.

3: Power Supply: The main power supply should be rated adequately to supply the operating current for HX3 and charging current for all downstream ports.

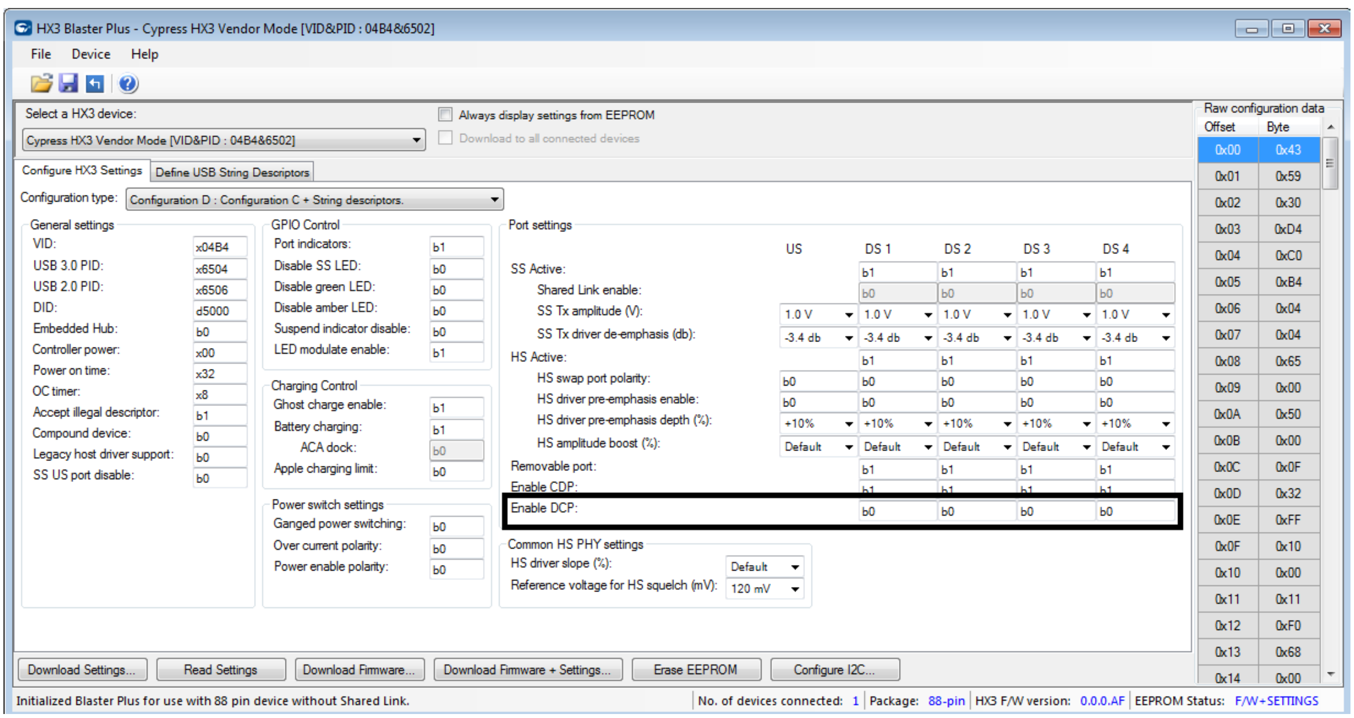
8.3 Demonstration of Battery Charging Feature in CY4603 kit

The detailed instructions to set up and operate CY4603 battery charging feature is available in the CY4603 Quick Start Guide.

All HX3 DVKs (CY4609, CY4603, and CY4613) are configured to support the CDP mode on DS ports. The choice of charging method (CDP or SDP) used to charge the portable device connected to the DS port is automatically determined by HX3 through the standard handshake mechanism explained in USB-IF BC v1.2 Charging Standard BC v1.2 Detection Mechanism.

By default, DCP mode is disabled in HX3 DVK when connected to a host. DCP mode can be enabled for any of the downstream ports using the Cypress Blaster Plus tool (Figure 16). Refer to the Blaster Plus user guide for details on updating HX3 parameters using the Blaster Plus tool. After DCP mode is enabled, a port cannot be used for data communication.

Figure 16. Blaster Plus Screenshot to "Enable DCP"



9 BC v1.2 Compliance Testing

BC v1.2 compliance tests can be conducted using the MQP Packet – Master USB – PET Protocol and Electrical Tester, which is USB-IF certified. This equipment comes with a GraphicUSB tool which contains a library of tests based on BC v1.2. Refer to the MQP user manual for compliance-testing instructions.

10 Limitations of HX3 Battery Charging

USB based charging and charger detection methods are rapidly evolving. The particular mechanism used inside a portable device to detect a charger varies widely among different device manufacturers and sometimes even among different devices from the same manufacturer. The following is a summary of limitations of the HX3 battery charging support. See Appendix A: Troubleshooting Guide for more information.

- Samsung-proprietary chargers (D+/D- pins biased to ~1.2 V)
- Apple 2.4 A chargers (D+/D- pins biased at 2.7 V)

11 Summary

This application note began by introducing the evolution of USB battery charging from proprietary chargers to a universal battery charging specification from the USB-IF that is employed in the present generation of smart phones, tablets, and other portable devices. It then introduced HX3, a SuperSpeed hub with charging capabilities. HX3 charging complies with the current USB charging specification, and supports unique features such as Ghost Charge and ACA-Dock. HX3 system design guidelines along with a troubleshooting guide are presented to ensure the maximum power reaches the device with minimal losses in the power switches, connectors and cables.

As the USB port becomes the de facto port for charging devices requiring less than 10 W, a newer standard called USB-PD (USB – Power Delivery) is being introduced where power up to 100 W (and VBUS 20 V) can be delivered. Cypress is well-positioned to provide the next generation of products supporting USB-PD to make USB port as the power of choice.

12 References

1. HX3 Datasheet (001-73643)
2. Battery Charging Specification revision 1.2, Dec. 7, 2010
3. Technical Requirement and Test Method of Charger and Interface for Mobile Telecommunication Terminal Equipment, YD/T 1591-2006, Dec. 14, 2006
4. Universal Serial Bus Revision 3.1 Specification, Jul. 26, 2013
5. Universal Serial Bus Revision 2.0 Specification, Apr. 27, 2000
6. HX3 Blaster Plus User Guide (001-90185)

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Appendix A. Troubleshooting Guide

This section answers frequently asked questions regarding HX3 battery charging support.

1. What are the battery charging capabilities and limitations of HX3?

There is no limitation in HX3 with respect to battery charging current. The charging current of the downstream ports and the upstream port are controlled by the external power switches as explained in the HX3 Battery Charging Features section.

The different battery charging methods are summarized in Table 7.

Table 7. Charge Current Capability of Various Battery Chargers

Battery Chargers	Max Charging Current	CY4609, CY4603, and CY4613 kits Max Charging Current
BC v1.2 (Charging Downstream Port)	1.5 A	1.5 A
Custom BC v1.2 (Charging Downstream Port)	1.5 A	1.5 A (See Questions 2,3)
Apple Charging (1 A Mode)	1 A	1 A
Apple Charging (2.1 A Mode)	2.1 A	2.1 A
Apple Charging (2.4 A Mode)	2.4 A	NA
Samsung Charging Standard	2.4 A	1.5 A
ACA-Dock (Upstream Charging)	1.5 A	1.5 A
Dedicated Charging Port	1.5 A	1.5 A (See Questions 2,3)
YD/T 1591-2006	1.5 A	1.5 A (See Questions 2,3)
Standard USB 3.0 DS Port	900 mA	900 mA
Standard USB 2.0 DS Port	500 mA	500 mA

2. What is Custom BC v1.2 Charging? How does HX3 support custom charging?

Custom BC v1.2 Charging: This indicates that the device connected to the downstream port identifies itself as a Charging device but the current drawn exceeds the 1.5 A limit (I_{DEV_CHG}) as per BC v1.2.

HX3 is involved in the handshake with the portable device connected to the DS port, but the actual current driven to the DS ports is determined by the external power switch and the capacity of the power supply.

For example, consider the CY4603 schematic. The CY4603 kit uses two dual-channel TPS2560 power switches. These switches have an adjustable current limit settings that can be set from 250 mA–2.8 A. In CY4603 kit, the current limit of TPS2560 is set at 2.1 A. Therefore, the maximum current supplied by CY4603 kit is 2.1 A per port.

3. What are the risks involved in using Custom BC v1.2 Charging (drawing more than 1.5A)?

According to the USB 3.1 specification, the maximum voltage drop of the VBUS line at the connector of the DS device is 450 mV when the maximum current (900 mA) is being supplied on the VBUS line.

The 450 mV drop is due to the following resistance:

- Contact resistance of the connectors (30 mΩ)
- Equivalent series resistance of the USB cable (3 meters = 380 mΩ)

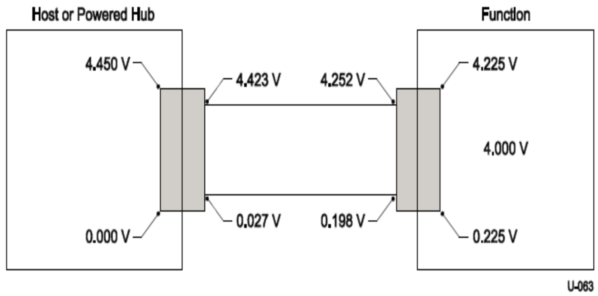
USB 3.0: maximum voltage drop assuming 0.9 A = 2 * (0.9 A * (190 mΩ + 30 mΩ * 2)) = 450 mV

BC v1.2: maximum voltage drop assuming 1.5 A = 2 * (1.5 A * (190 mΩ + 30 mΩ * 2)) = 750 mV

Custom BC v1.2: maximum voltage drop assuming 2.1 A = 2 * (2.1 A * (190 mΩ + 30 mΩ * 2)) = 910 mV

There is a risk that a custom BC v1.2 charging design will not be able to supply proper VBUS voltage to the portable device if the charging current causes a higher voltage drop. The system power supply has to be designed considering the steady state voltage drops due to the connector and cable resistances and the current requirement of the portable device. Figure 17 shows the steady state voltage drops under worst-case condition.

Figure 17. Voltage Drop at Various Locations from Host or Hub to a Device (Worst-case Topology)



(Source: USB 3.1 Specification)

4. How do I modify CY4609, CY4603, and CY4613 kits to drive greater than 2.1 A of current?

The CY4609, CY4603, and CY4613 kits support a maximum current source of 2.1 A out of the box. These kits can be modified to support a current drive of 2.4 A by adjusting the current limit of the TPS2560 power switches. The current limit can be configured by modifying on-board resistor values.

Choice of Resistor: Designing the current limiting resistor value for a specific current is available in the TPS2560 Power Switch datasheet (http://www.ti.com/lit/ds/slvs930a/slvs930a.pdf)

"Table 1: Common RILIM Resistor Selections" defines the mapping between the nominal current limit and the resistor value.

CY4609 Kit: Change the resistor R3 to make all the four DS ports to support higher currents. The location of the resistor is available at page 5 of the CY4609 schematic.

CY4603 Kit: Change the resistors R40 and R49 to make all the four DS ports to support higher currents. The location of the resistor is available at page 6 of the CY4603 schematic.

CY4613 Kit: Change the resistors R3, R5, R10, and R11 to make the US port and all the four DS ports to support higher currents. The location of the resistors is available at page 6 of the CY4613 schematic.

5. The CY4609, CY4603, and CY4613 kits do not charge the devices connected to the downstream (DS) ports at the maximum charging current. Why?

There are two possible reasons:

- The type of device connected on the DS port constrains the charging current it can accept. Refer to Question 1 for summary of battery chargers.
- The power supply used on the CY4609, CY4603, and CY4613 can drive a maximum of 4 A, which is shared across all DS ports. If you have CDP-compliant devices connected on all four DS ports, a maximum current of 1 A can be driven on each DS port.

6. What data transfer rate does HX3 support when a USB 3.0 Host is connected to the US port in ACA-Dock mode?

HX3 supports the full USB 3.0 data rate of 5 Gbps.

7. How do I know if a portable device supports OTG?

In CY4613 kit, remove the J27 jumper and short the middle pin of the J27 jumper to the 4th pin of J23 (connect RID to ground). If the portable device connected to the US port of CY4613 enumerates, then the portable device supports the USB OTG functionality.

8. Will the ACA-Dock feature work on all portable devices that support OTG?

Not all OTG-capable portable devices supports the ACA-Dock feature.

The following instructions help you identify if an OTG- capable portable device supports the ACA-Dock feature.

- Make sure the CY4613 board is set up for the ACA-Dock functionality (Refer Step 9 of the CY4613 Quick Start Guide) .
- Remove Jumper J26.
- Connect the portable device to the US port of CY4613 and check the voltage on pin 1 of Jumper J26.
- If the measured voltage is ~5 V, then the portable device does not support the ACA-Dock feature; if the value is ~0 V, then the ACA-Dock feature is supported.

The expected behavior of portable devices which support the OTG feature and the ACA-Dock mode is the simultaneous data transfer and US charging.

The expected behavior of portable devices which support the OTG feature, but does not support the ACA-Dock mode is data transfer only and no US charging.

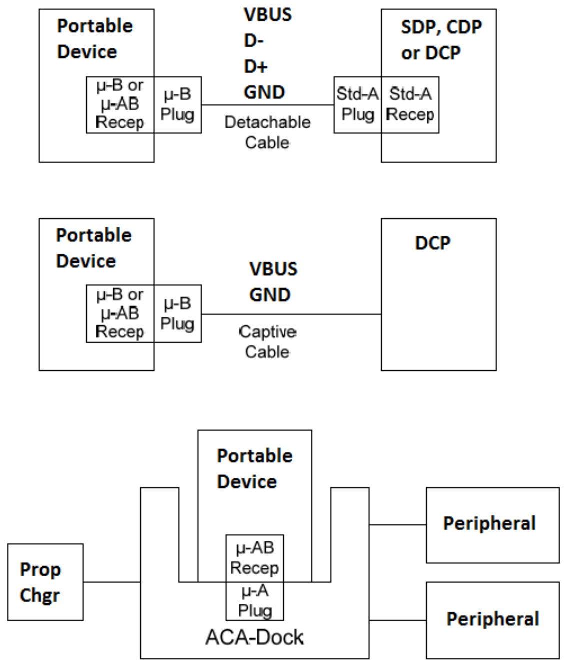
For more details on testing the ACA-Dock feature with the CY4613 kit, refer to this Knowledge Base Article

Appendix B. BC v1.2 Detection Mechanism

This appendix introduces the various detection mechanism and protocol followed by the portable devices and the chargers supporting BC v1.2. First, different connectivity configurations are shown. Next, the various mechanisms required to implement detection of a charger are introduced. Finally, the steps necessary to distinguish between an SDP and charging port and to differentiate CDP and DCP charging ports are introduced.

Figure 18 shows several examples of how a portable device can be connected to an SDP or a charging port. In the first example, the portable device is connected to an SDP, a DCP, or a CDP using a Standard -A[4] to micro-B[5] cable. In the second example, a captive cable from the DCP is connected to a portable device. In the third example, an ACA-Dock is connected to a portable device. In this case, there is no cable between the dock and the device, but the dock contains a captive micro-A plug. The ACA-Dock requires a power source which is indicated by the “Prop Chgr” in Figure 18.

Figure 18. Examples of a Portable Device Connected to an SDP or a Charging Port



(Source: USB-IF Battery Charging Specification v1.2)

B.1 Charging Port Detection

Figure 18 shows the various charger blocks (CDP, DCP, SDP, ACA-Dock) that a portable device requires to detect when connected to a charging port. The charger blocks perform five main functions described as follows.

B.1.1 VBUS Detect

The portable device must have a session-valid comparator which is used to detect the condition when VBUS is greater than the session-valid threshold (0.8 V–4 V) in the portable device.

[4] Standard –A is a USB plug type that connects to the “downstream port” of a host or a hub.

[5] Micro –B is a USB plug type that connects to the portable device.

B.1.2 Data Contact Detect (DCD)

This is an optional block to check whether the portable device data pins have made contact during an attach event. As shown in Figure19, IDP_SRC (25 µA–175 µA) on D+ and RDM_DWN (15 kΩ) on D- are turned ON. If the D+ line goes LOW, then it indicates that the portable device is connected to either a charging port or a standard port and the primary detection is checked thereafter. If DCD is not implemented, the portable device waits up to 900 ms before proceeding to performing primary detection. HX3 does not support DCD.

B.1.3 Primary Detection

A portable device is required to implement primary detection, which is used to distinguish between a standard port and a charging port.

Primary Detection DCP

Figure 20 shows the detection mechanism when a portable device is connected to a dedicated charging port (DCP). In this mode, the portable device turns on VDP_SRC (0.5 V–0.7 V) on D+ and checks the voltage on D-. Because D+ and D- are shorted on the DCP with < 200 Ω, the voltage on D- will be close to VDP_SRC. The voltage on D- is compared with VDAT_REF (0.25 V–0.4 V). If D- is greater than VDAT_REF, then the portable device is attached to either a DCP or a CDP.

Primary Detection CDP

Figure 21 shows the detection mechanism when a portable device is connected to a charging downstream port (CDP). During primary detection, the portable device applies VDP_SRC to the D+ line and turns on IDM_SINK (25 µA–175 µA). The portable device compares the voltage on D- with VDAT_REF. If the voltage on D- is greater than VDAT_REF, then the portable device can proceed to determine if it is connected to a DCP or a CDP.

There are two options for CDP to behave when a portable device is not connected. In the first option, VDM_SRC (0.5 V–0.7 V) on the CDP should be enabled within 200 ms of a disconnect and disabled within 10 ms of a connect.

In the second option, the CDP compares the D+ voltage to VDAT_REF (0.25 V–0.4 V) and to VLGC (0.8 V–2 V). If the D+ voltage is less than VDAT_REF or greater than VLGC, the VDM_SRC on the D- line is disabled. When D+ voltage is greater than VDAT_REF and less than VLGC, the CDP enables VDM_SRC on the D- line. HX3 supports the second option.

Primary Detection SDP

Figure 22 shows the detection mechanism when a portable device is connected to a standard downstream port (SDP). During primary detection, the portable device applies VDP_SRC to the D+ line and turns on IDM_SINK. The D- line is pulled LOW through RDM_DWN.

The portable device compares the voltage on D- to VDAT_REF. When connected to an SDP, the D- line is less than VDAT_REF, indicating to the portable device that it is connected to an SDP.

Primary Detection ACA-Dock

Figure 23 shows the detection mechanism when a portable device supporting ACA detection is connected to an ACA-Dock. An ACA-Dock is a docking station that has one upstream port, and optional downstream ports.

When an ACA-Dock is powered and no device is connected to its upstream port, the pins on the micro-A plug are biased as follows.

Table 8. Biasing of Pins on the Micro-A Plug

Pin	Biasing
VBUS	VCHG (4.75 V–5.25 V)
D+	VDP_UP (3 V–3.6 V)
D-	VDM_SRC (0.5 V–0.7 V)
ID	RID_A (122 KΩ–126 KΩ) [6]
GND	GND

[6] For portable devices not supporting the std RID_A value, refer to http://www.cypress.com/?id=4&rID=96822

The VBUS pin is powered because the ACA-Dock is ready to provide power to the portable device connected on its upstream port. The ACA-Dock pulls D+ to VDP_UP (3 V–3.6 V) through a 1.5 kΩ resistor because VBUS is greater than VOTG_SESS_VALID (0.8 V–4 V). The ACA-Dock enables VDM_SRC on its D- line whenever D+ and D- are inactive (idle J state) for a duration of 200 ms. It should disable the VDM_SRC within 10 ms of any activity on the D+ and D- lines.

The portable device supporting ACA detection determines if it is connected to an ACA-Dock based on the following conditions:

- VBUS > VOTG_SESS_VALID (0.8 V–4 V)
- D+ at VLGC_HI (2.0 V–3.6 V)
- VDAT_REF (0.25 V–0.4 V) < D- < VLGC (0.8 V–2.0 V)
- ID at RID_A

B.1.4 Secondary Detection

Secondary detection is used to distinguish a DCP from a CDP by the portable device. Portable devices that are not ready to enumerate within 900 ms are required to support secondary detection. Portable devices that are ready to enumerate can bypass secondary detection.

Secondary Detection DCP

Figure 24 shows the secondary-detection mechanism when a portable device is connected to a DCP. During secondary detection, the portable device applies VDM_SRC to the D- line, turns on IDP_SINK, and compares the voltage on D+ line to VDAT_REF. Because the voltage on the D+ line is close to D- as they are shorted with less than 200 Ω, the voltage on D+ line is greater than VDAT_REF. If the portable device detects that the voltage at the D+ line is greater than VDAT_REF, then it knows that it is attached to a DCP.

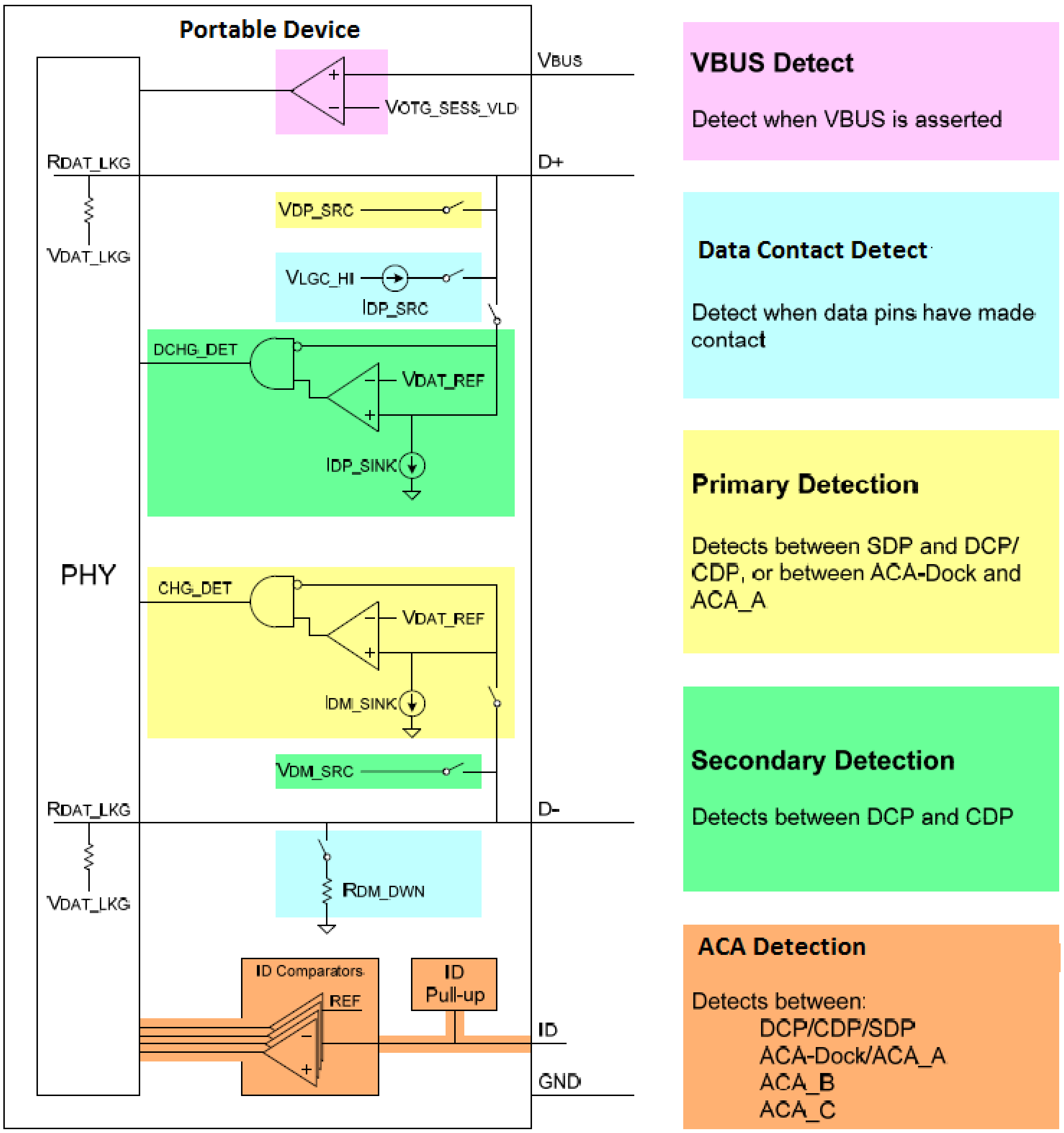
Secondary Detection CDP

Figure 25 shows the secondary detection mechanism when a portable device is connected to a CDP. During secondary detection, the portable device applies VDM_SRC to the D- line, turns on IDP_SINK, and compares the voltage on the D+ line to VDAT_REF. Because the voltage on the D+ line is close to GND as it is pulled LOW using RDP_DWN
(15 KΩ), the voltage on the D+ line is less than VDAT_REF. If the portable device detects that the voltage on the D+ line is less than VDAT_REF, then it knows that it is attached to a CDP.

B.1.5 ACA Detection

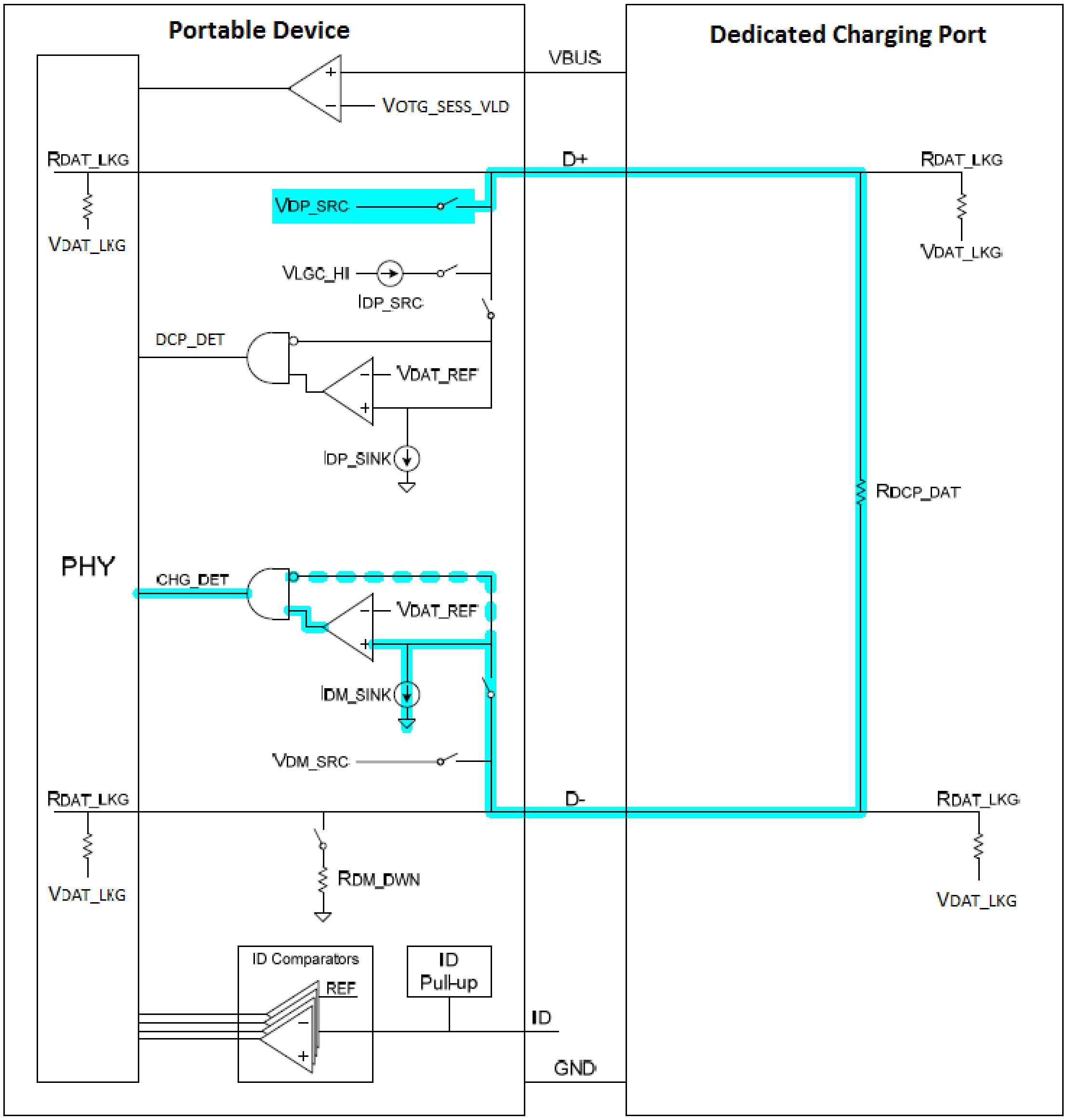
ACA detection for portable devices is optional. Only portable devices that have a micro-AB receptacle can support ACA detection because the ACA OTG port has a captive cable termination in a micro-A plug as shown in Figure 18 (third example).

Figure19. Charger Detection Hardware



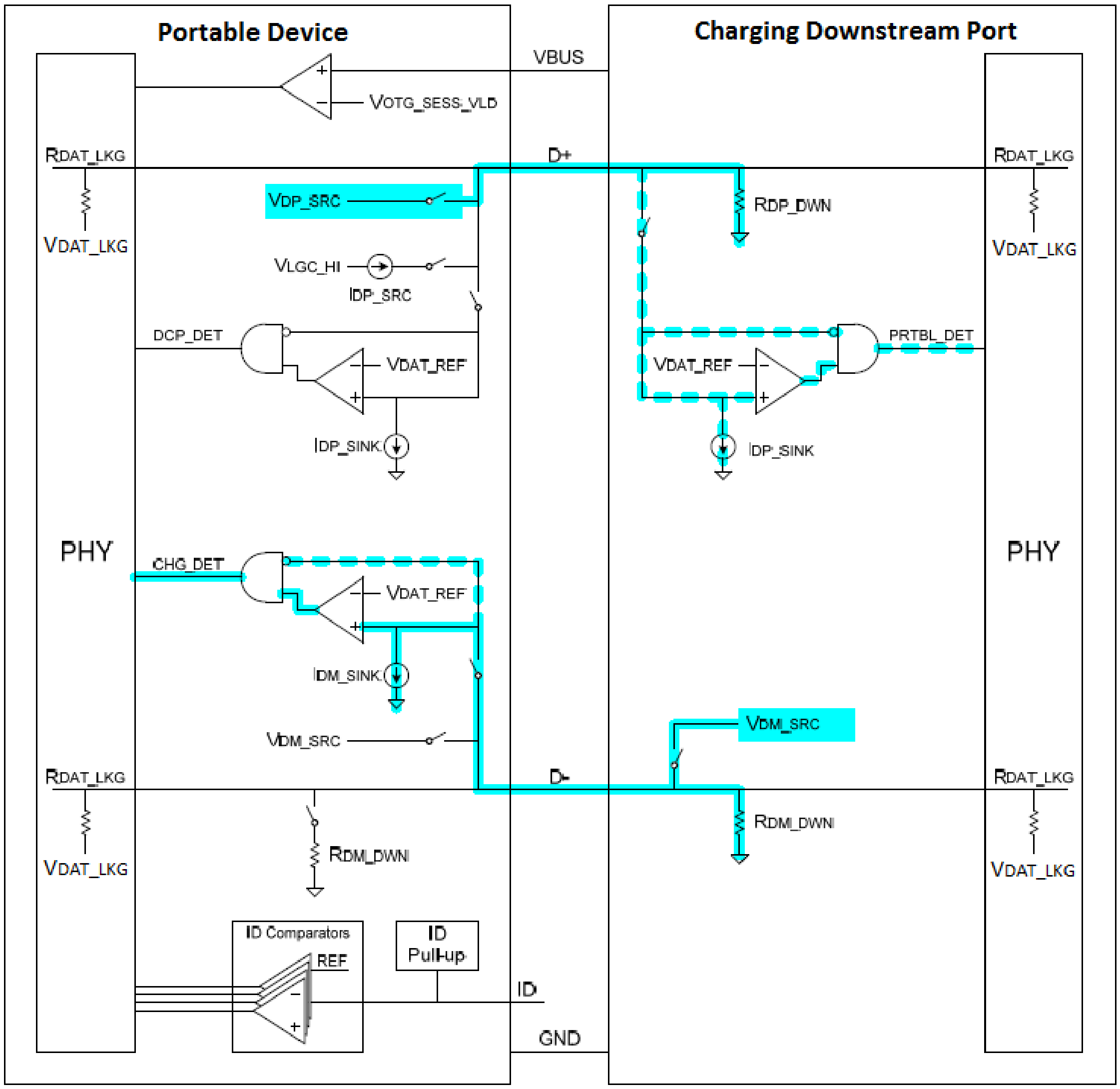
(Source: USB-IF Battery Charging Specification v1.2)

Figure 20. Primary Detection – DCP



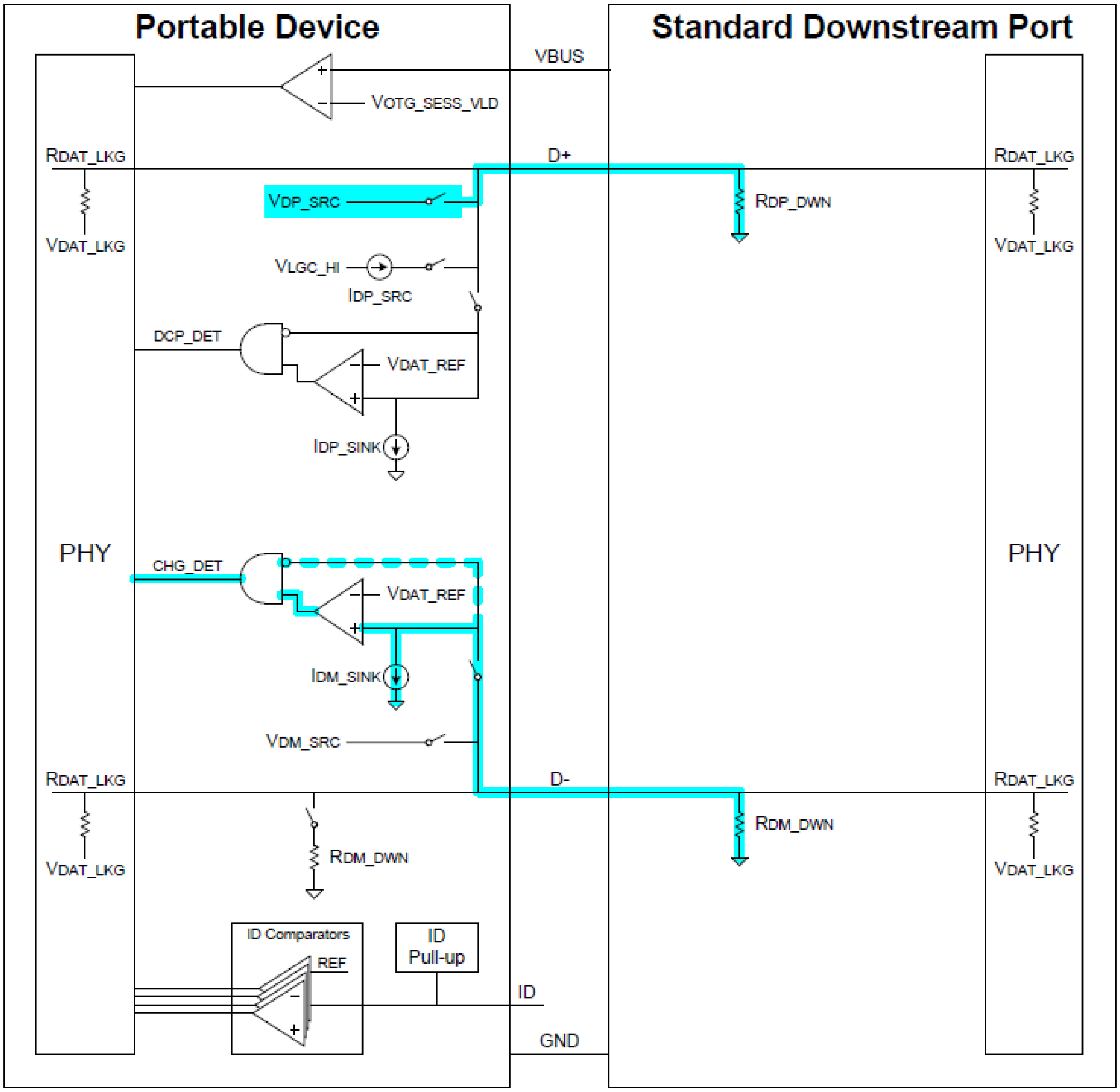
(Source: USB-IF Battery Charging Specification v1.2)

Figure 21. Primary Detection – CDP



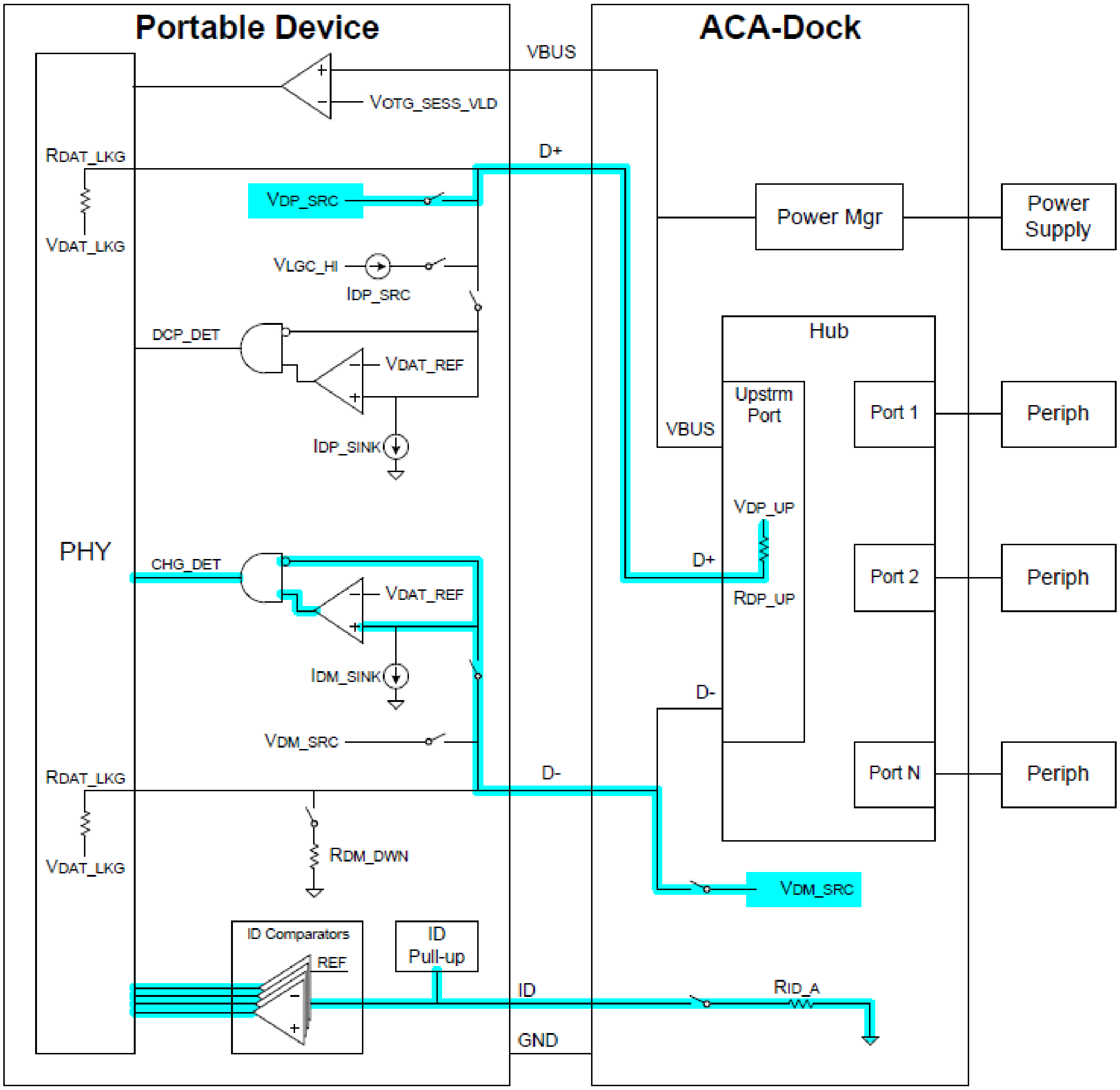
(Source: USB-IF Battery Charging Specification v1.2)

Figure 22. Primary Detection -- SDP



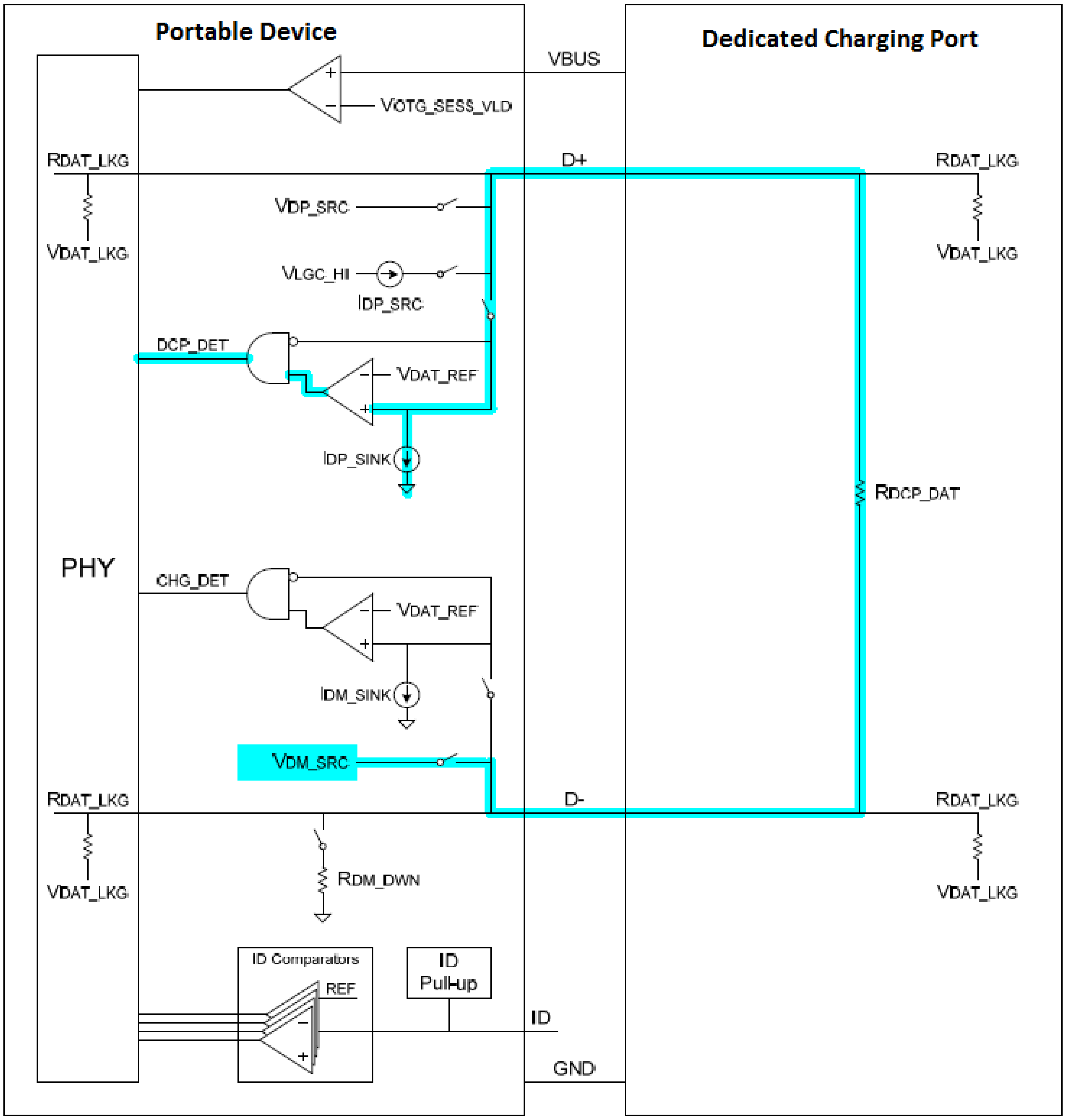
(Source: USB-IF Battery Charging Specification v1.2)

Figure 23. Primary Detection -- ACA-Dock



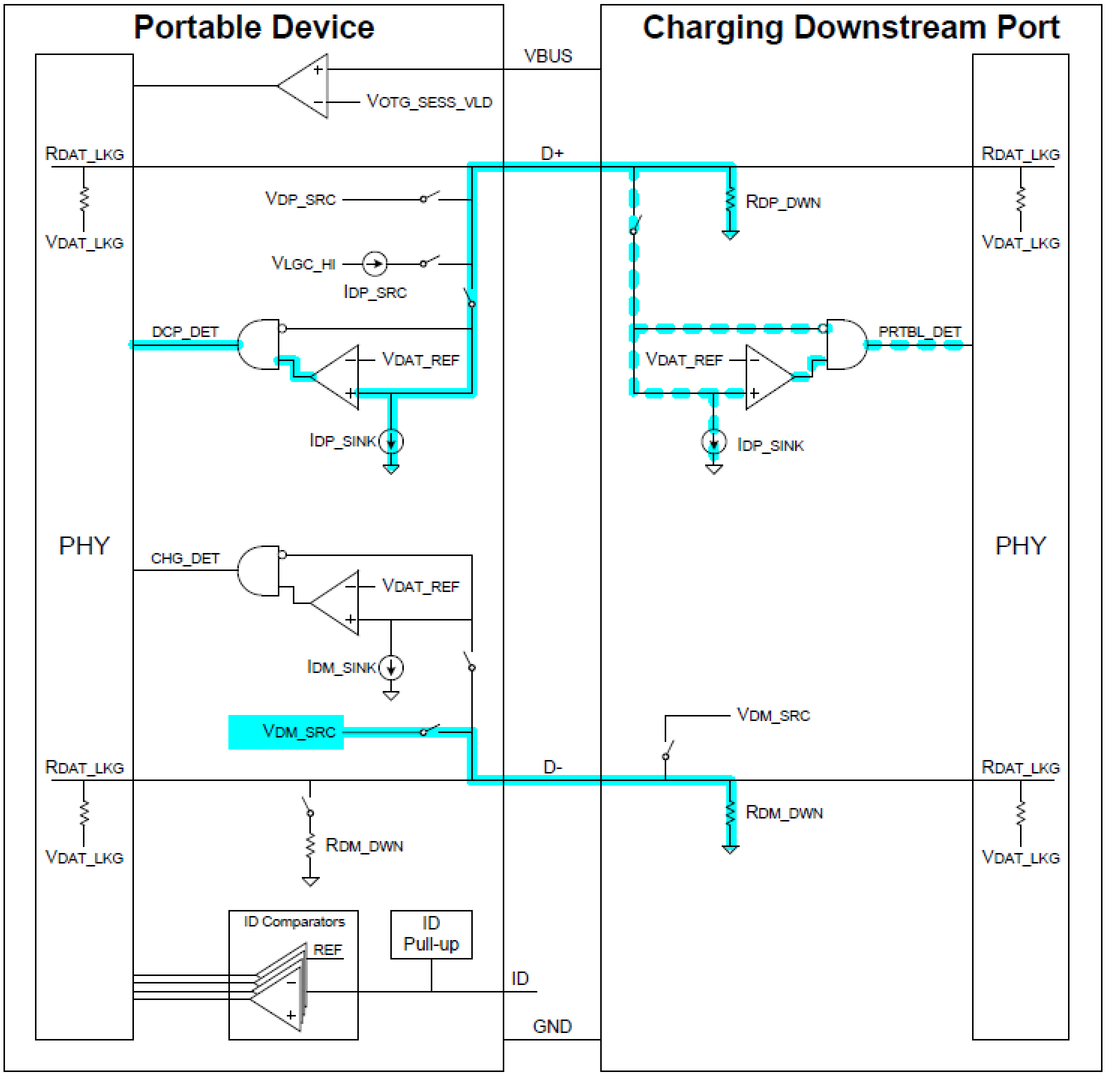
(Source: USB-IF Battery Charging Specification v1.2)

Figure 24. Secondary Detection – DCP



(Source: USB-IF Battery Charging Specification v1.2)

Figure 25. Secondary Detection CDP



(Source: USB-IF Battery Charging Specification v1.2)

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**	4481475	HBM	09/03/2014	New Application Note
*A	5705529	AESATMP9	04/21/2017	Updated logo and copyright.
*B	5873051	HBM	09/05/2017	Updated template

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