
USB Battery Charging with the USB253x/USB46x4/ USB3x13 Hub Controllers

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INTRODUCTION

The Universal Serial Bus (USB) is the most used computer interface in the world. It started as an expansion bus for personal computers, but has proliferated quickly due to its flexibility, performance, and hot plug capability. It is used by most portable electronic devices that require PC connectivity for file transfers. These devices include MP3 players, digital cameras, cellphones, and tablets. Since a standard USB downstream port can provide at least 500 mA of current, it was convenient to use it for charging these devices. This document describes how this current limit can be increased and how the USB253x/USB46x4/USB3x13 Hub Controller with RapidCharge can be used to implement a system solution to efficiently charge portable devices.

References

The following documents should be referenced when using this application note. See your Microchip representative for availability.

- *Microchip, USB253x/USB46x4/USB3x13 Datasheet Revision 1.0.*
- *USB-IF, Battery Charging Specification. Revision 1.2. December 7, 2010.*
- *USB-IF Universal Serial Bus Specification. Revision 2.0, April 27, 2000.*
- *YD/T 1591-2009 - Technical Requirements and Test Method for Power Adapter and Charging/Data Port of Mobile Telecommunication Terminal Equipment, Ministry of Industry and Information Technology of PRC. December 11, 2009*
- *Microchip, SMBus Slave Interface for the USB253x/USB3x13/USB46x4 Application Note. Rev. 1.0*

Definitions

- **Attach** - A downstream device is attached to a USB upstream port when there is a physical cable between the two.
- **Connect** - A downstream device is connected to a USB upstream port when there is a physical cable between the two and the device has pulled either D+ or D- high with a 1.5 kΩ resistor.
- **Dedicated Charging Port (DCP)** - A USB downstream port that outputs power for battery charging but it is not capable to enumerate a downstream device.
- **Charging Downstream Port (CDP)** - A USB downstream port that outputs power for battery charging and complies with the USB 2.0 specification for a USB host or hub downstream port.
- **Standard Downstream Port (SDP)** - A USB downstream port that complies with the USB 2.0 specification for a USB host or hub downstream port.
- **Accessory Charging Adapter (ACA)** - Is an adapter which allows a single USB device to be connected to a charger and another device at the same time.
- **Dead Battery** - A dead battery is defined as a battery with charge low enough as to prevent a device from successfully powering up.
- **Portable Device (PD)** - A portable device is a device which is compliant to the USB 2.0 specification and the BC1.2 specification and can draw charging current from USB.

USB BATTERY CHARGING

Overview

Any standard USB port can charge a device if the current required is < 500 mA (USB 2.0) or < 900 mA (USB 3.0). If the current required exceeds these limits then both the charging device and the charging port must follow a handshake protocol to ensure that enough current is available to charge. A downstream battery charging port is responsible for providing the proper handshake signaling to the charging device to indicate that it is attached to a charging port and can draw currents above the standard USB limits. The proper signaling varies depending on the portable device.

Non-Standard Battery Charging Solutions

There are many different methods that have been implemented by portable device manufacturers to identify a dedicated charger instead of a standard USB port. The most common method involves pulling the DP and DM lines up to voltage above the USB Full-Speed Single Ended Receiver.

Note:	USB Type-C ports also have a separate method of communicating charging capabilities. It is still permissible for a USB Type-C port to also perform BC1.2 handshakes; it is up to the device to detect the charging capability of the port using its preferred method and draw current accordingly.
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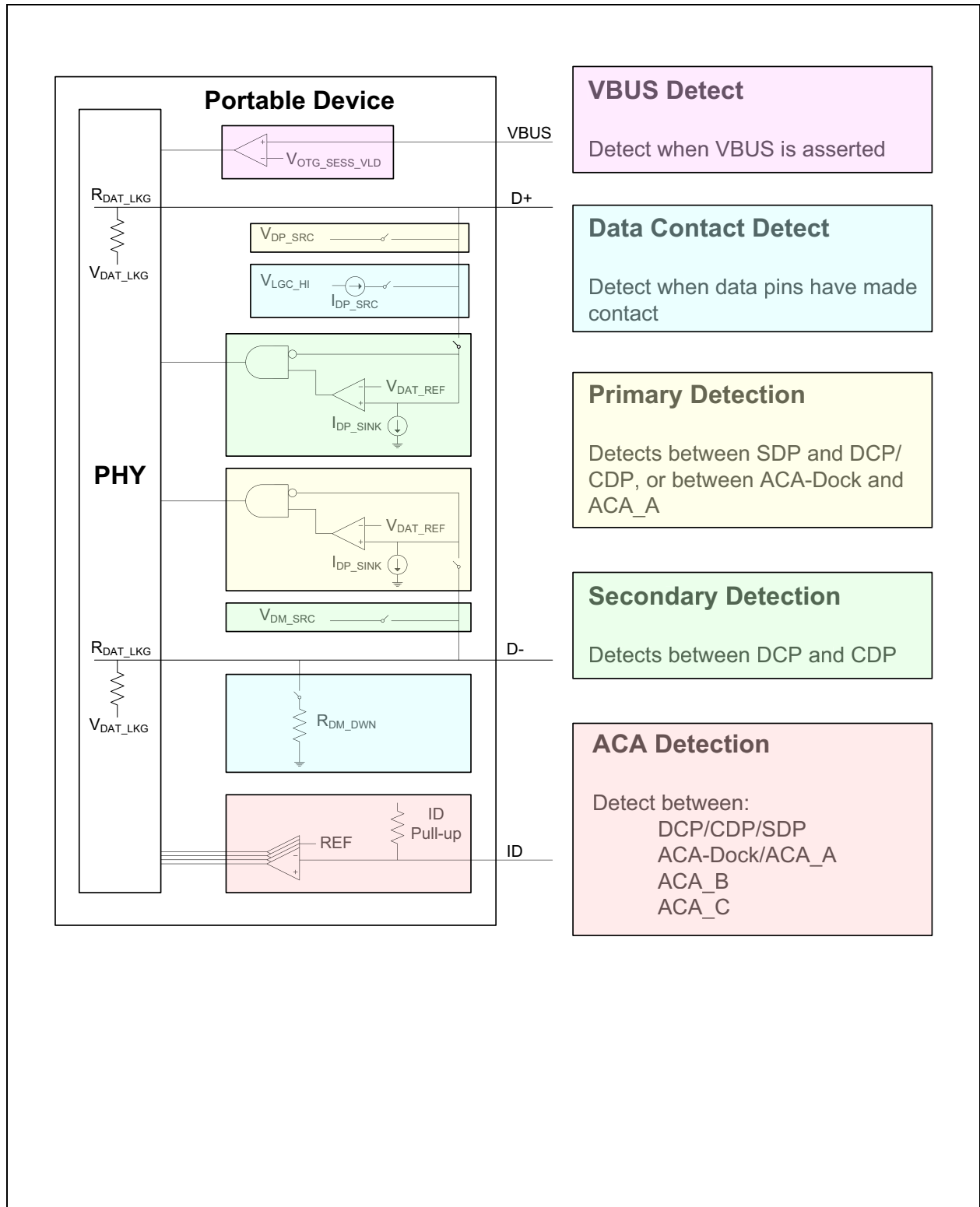
USB-IF BC1.2 Specification

The USB-IF Battery Charging Specification ([References](#)) defines current limits and protocols to allow portable devices to draw current from Host port, hub downstream ports, and dedicated chargers in excess of 500 mA (USB 2.0 port) or 900 mA (USB 3.0 port).

CHARGER DETECTION

The portable device (PD) is responsible for charger detection, [Figure 1](#) shows the charger detection hardware required.

FIGURE 1: CHARGER DETECTION HARDWARE

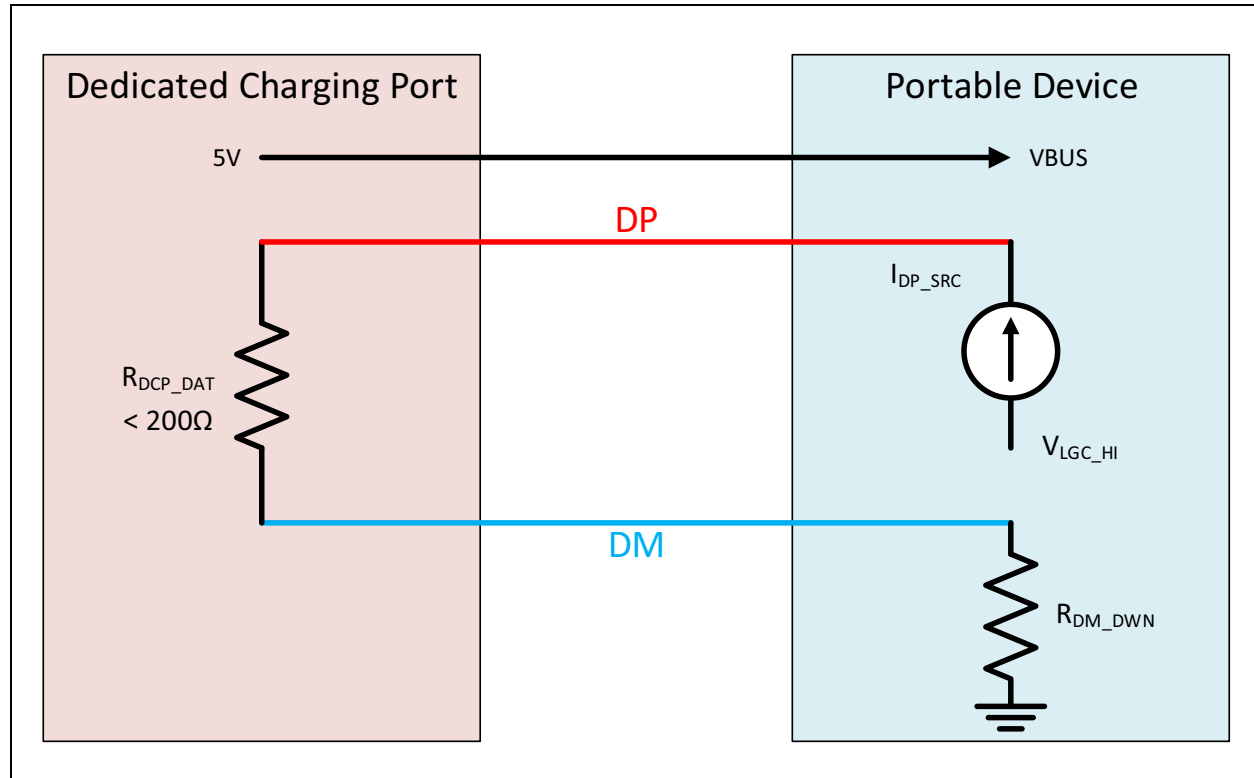


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There are five functional blocks as follows:

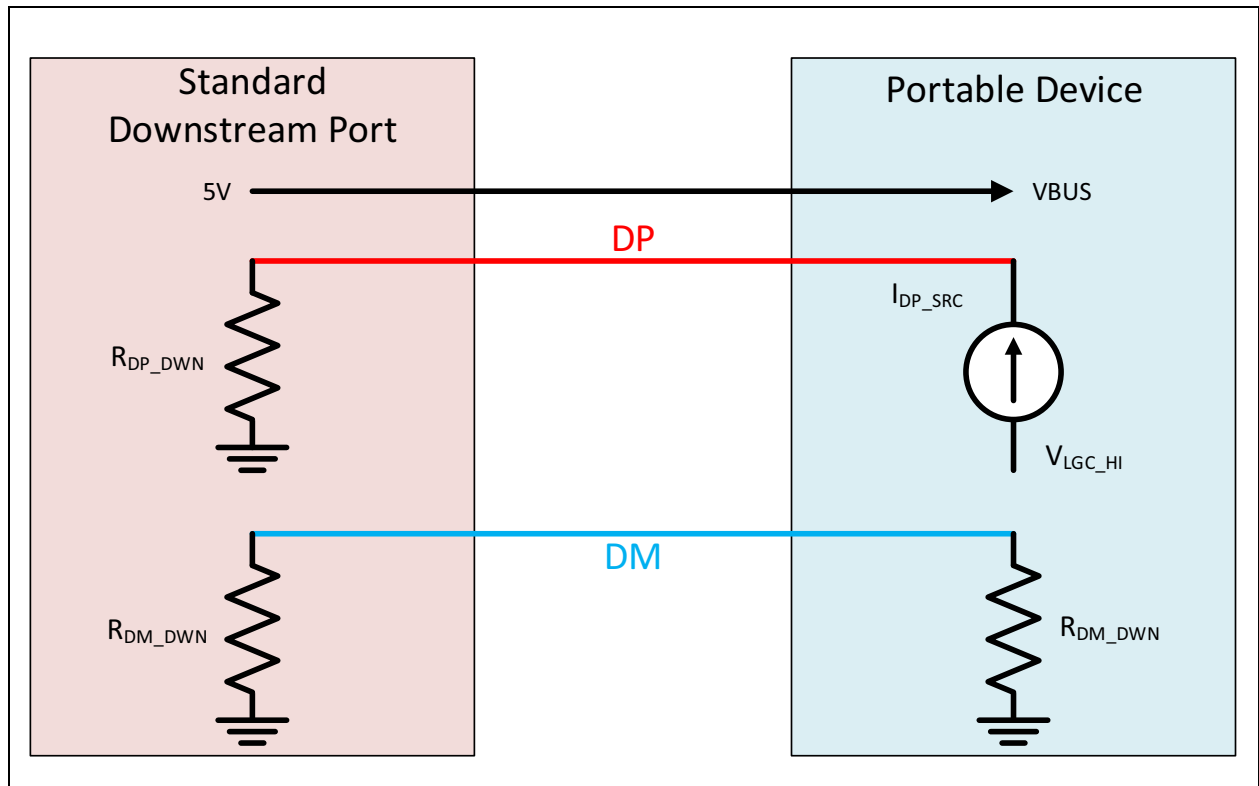
1. **VBUS Detect** - A portable device (PD) includes a session valid comparator, VBUS has to be above the $V_{OTG_SESS_VLD}$ threshold before the charger detection is initiated.
2. **Data Contact Detect (DCD)** - This is an optional block used to confirm that the data lines made contact during attachment. A current source I_{DP_SRC} on D+ and a pulldown resistor R_{DM_DWN} on D- are turned on. If the D+ line voltage drops, this indicates that data lines are attached to a charging port or a standard port and the logic proceeds to start **Primary Detection**.
 - a) Figure 2 shows the DCD circuit when attached to a DCP port. Note that the D+ voltage will drop because it will be connected to pull-down resistor R_{DM_DWN} through R_{DCP_DAT} .

FIGURE 2: DATA CONTACT DETECT ON A DCP



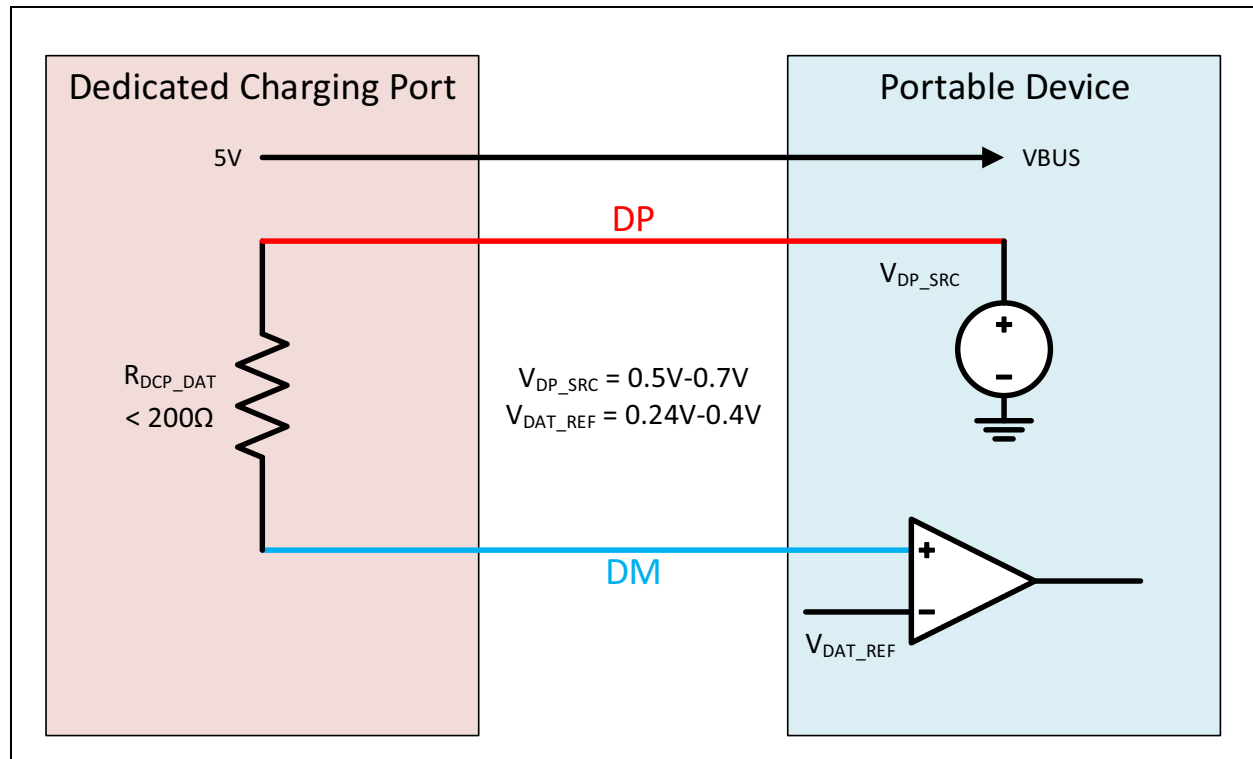
- b) Figure 3 shows the DCD circuit when attached to an SDP port or a CDP port. In this case the D+ voltage will drop because it will be connected to pull-down resistor R_{DP_DWN} .

FIGURE 3: DATA CONTACT DETECT ON A SDP



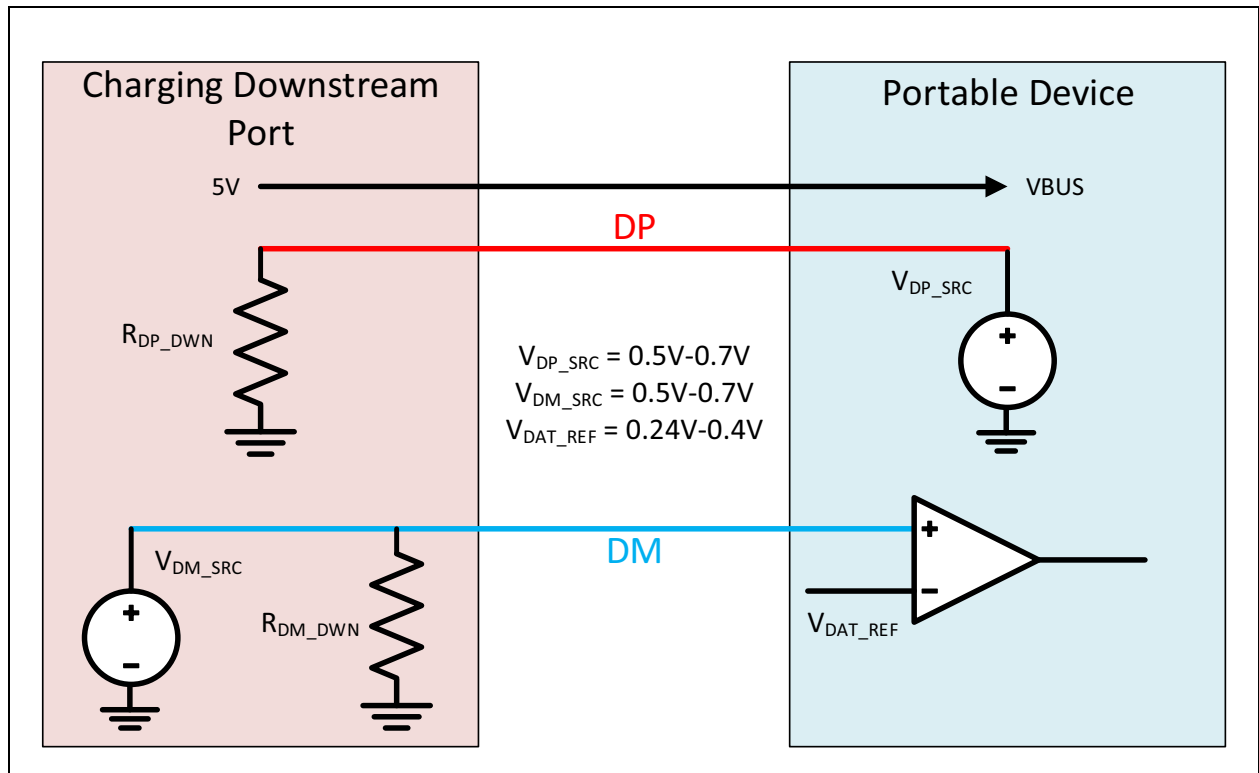
3. **Primary Detection** - A BC1.x compatible PD is required to implement primary detection, which is used to distinguish between an SDP and a charging port. When a PD is attached and powered, the PD enables V_{DP_SRC} and I_{DM_SINK} .
 - a) If the PD is attached to a DCP (Figure 4), V_{DP_SRC} is reflected onto D- through resistor $R_{DCP_DAT} < 200\ \Omega$. If $D- > V_{DAT_REF}$, the PD may conclude it is attached to a DCP or a CDP. Some non BC1.2 PDs pull D+/D- high, which may cause this detection to fail.

FIGURE 4: PRIMARY DETECTION, DCP



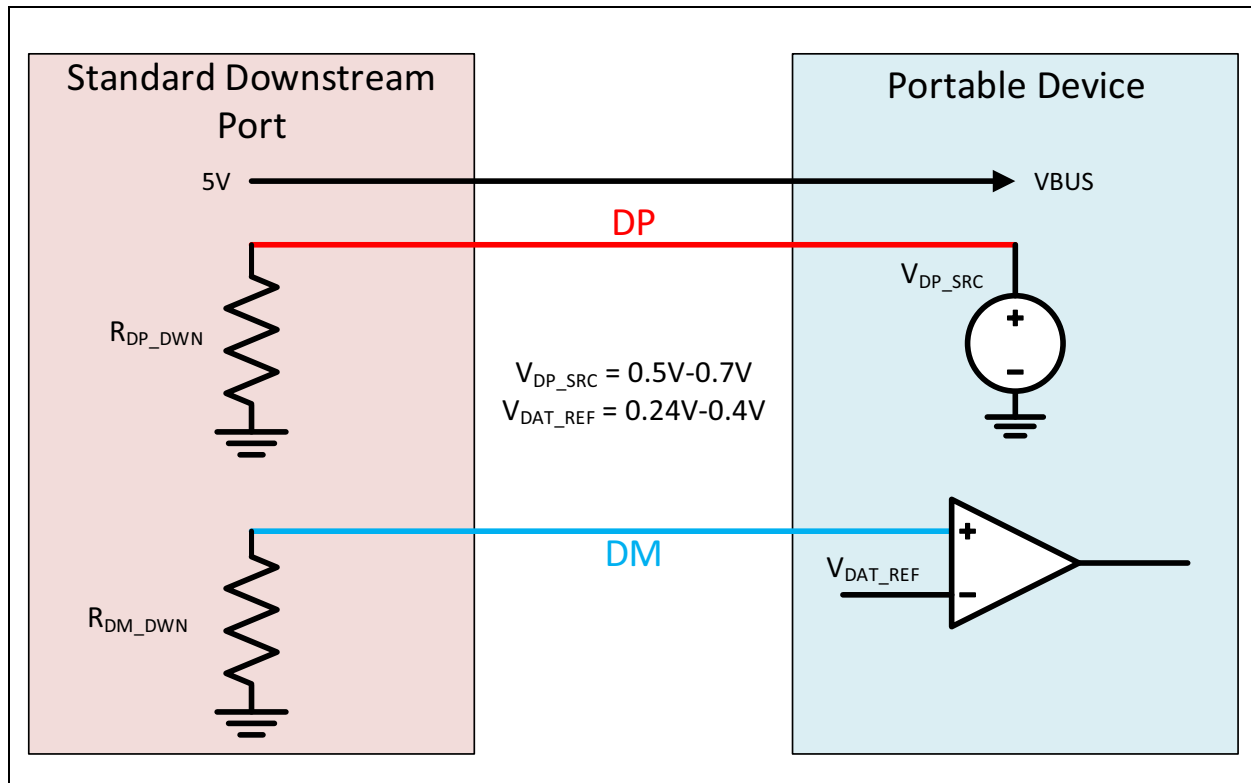
- b) If the PD is attached to a CDP (Figure 5), the CDP detects $D+ > V_{DAT_REF}$ and turns on V_{DM_SRC} which drives up the D- line. If $D- > V_{DAT_REF}$, the PD is attached to a CDP or DCP.

FIGURE 5: PRIMARY DETECTION, CDP



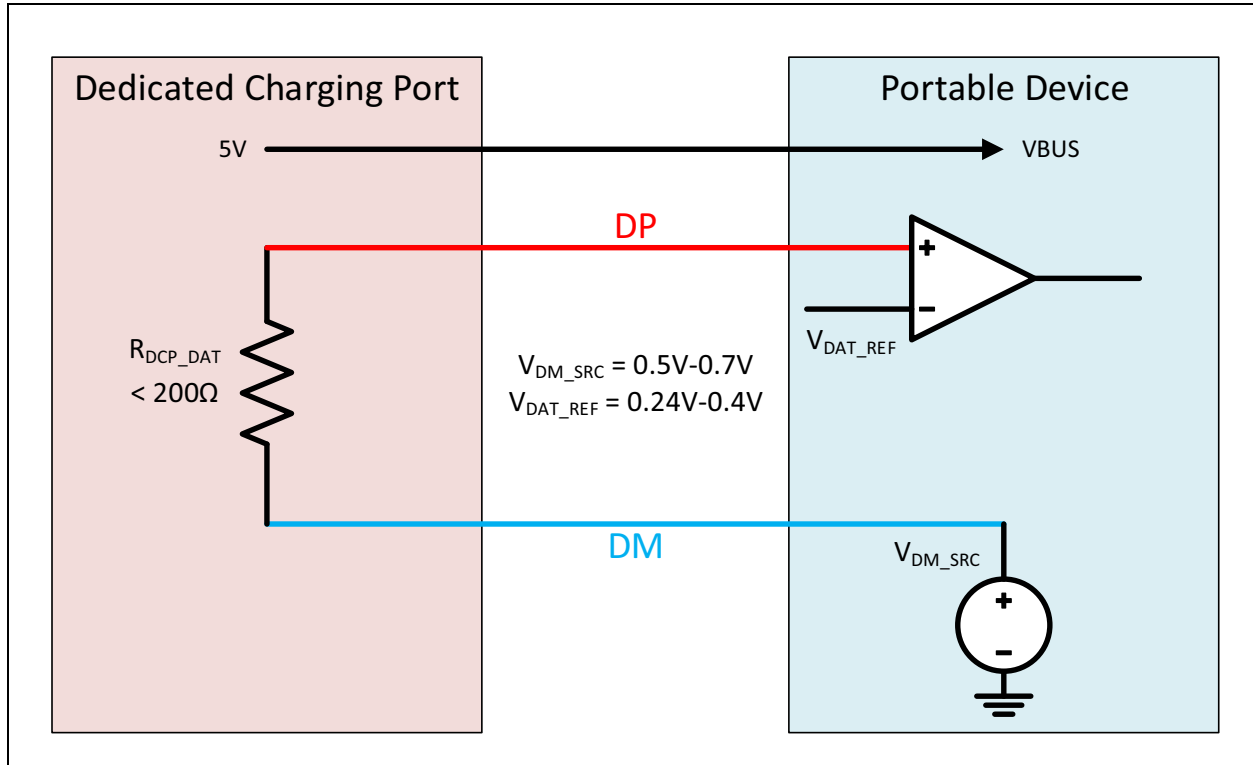
- c) If the PD is attached to an SDP (Figure 6), $D^- < V_{DAT_REF}$ due to pulldown R_{DM_DWN} and the PD may conclude it is attached to an SDP.

FIGURE 6: PRIMARY DETECTION, SDP



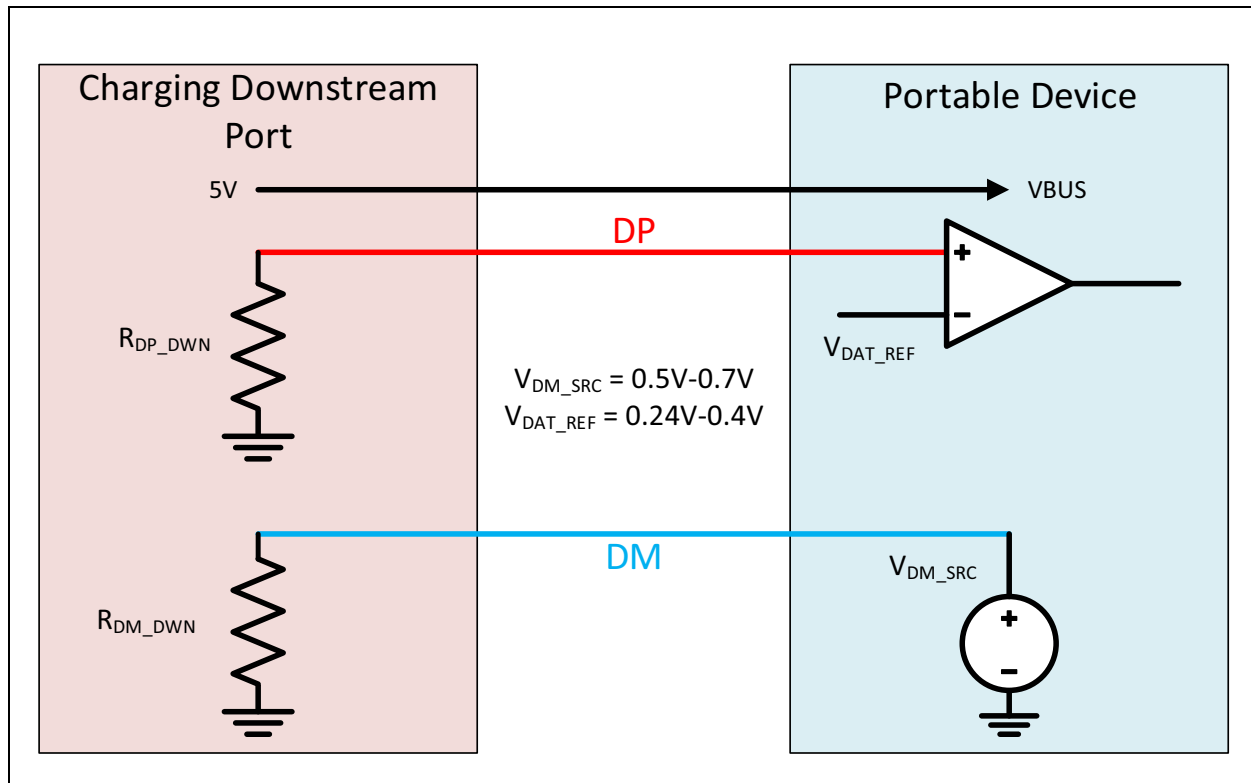
4. **Secondary Detection** - Secondary detection is used to distinguish between a DCP and a CDP port. The PD enables voltage source V_{DM_SRC} .
- a) If the PD is attached to a DCP (Figure 7), V_{DM_SRC} is reflected on D+ through resistor $R_{DCP_DAT} < 200\ \Omega$. If $D+ > V_{DAT_REF}$, the PD can assume it is attached to a DCP.

FIGURE 7: SECONDARY DETECTION, DCP



- b) If the PD is attached to a CDP (Figure 8), $D+ < V_{DAT_REF}$, due to pulldown R_{DP_DWN} and the PD may conclude it is attached to a CDP.

FIGURE 8: CDP SECONDARY DETECTION



5. **ACA Detection** - ACA detection support for a PD is optional, and only PD devices with a USB Micro-AB connector can support ACA detection as detection is done by measuring the resistance of the ID pin. For more details on ACA and ACA dock detection, refer to the BC1.2 (References) specification.

USB253X/USB46X4/USB3X13 DOWNSTREAM BATTERY CHARGING

Portable Devices and Charging

Portable devices may exhibit slightly different behaviors depending upon their battery charging detection methodology. The following parameters are not explicitly defined in the BC1.2 specification and hence will vary slightly from device to device:

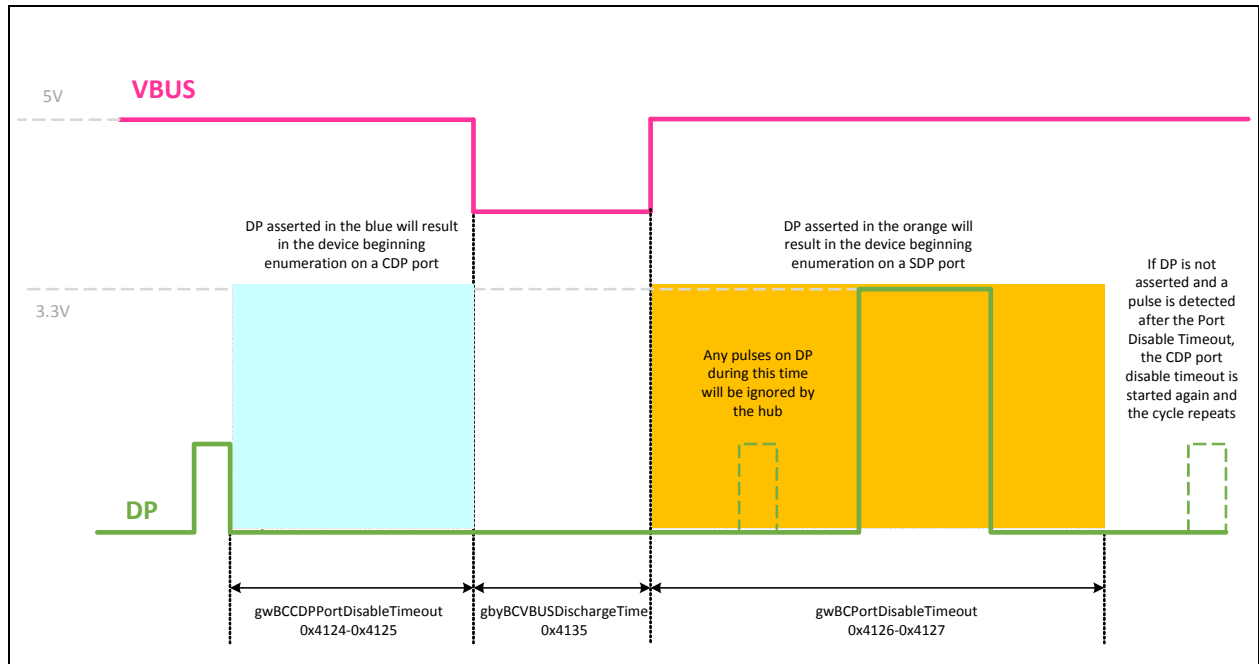
- A vendor specific charger detection method may be implemented before or after BC1.2 detection
- Duration of primary BC1.2 detection pulse
- If secondary detection is done or not done
- Duration of secondary BC1.2 detection pulse
- Period of time between BC1.2 detection pulse(s) and DP assertion for enumeration

Battery Charging Reconfigurability

In V1.2 of the Battery Charging specification the charging downstream port (CDP) was introduced. A CDP port allows data communication while also charging at a higher current. After primary detection, portable devices that are ready for enumeration within the USB-IF specified time can bypass secondary detection. PDs that are not ready for enumeration

must enter secondary detection. Microchip smart hubs have an advanced battery charging algorithm to maximize the number of devices that will enumerate while the port is configured to operate in CDP mode. [Figure 9](#) below explains how this advanced checking algorithm behaves.

FIGURE 9: BATTERY CHARGING TIMERS



The cycle in [Figure 9](#) above can be summarized as follows:

- A low amplitude battery charger detection pulse on DP is detected
- gwBCCDPPortDisableTimeout begins a counter to determine how long a port stays in CDP mode
 - If DP is not asserted during this time, the hub will toggle VBUS
- gbyBCVBUSDischargeTime begins determining how long the PRTWx/PRTCTLx signal output from the USB hub will be driven low.
- VBUS is restored to 5V after the hub's PRTWx/PRTCTLx is re-asserted high.
- gwBCPortDisableTimeout begins a counter to determine how long the port remains in SDP mode
 - All BC detection pulses on DP at this time are ignored
 - If DP is asserted to 3.3V during this time, the device will enumerate
- If DP is not asserted during cycle, the overall BC state machine will reset and start again.

The gwBCCDPPortDisableTimeout, gbyBCVBUSDischargeTime, and gwBCPortDisableTimeout timers are all configurable via registers.

gwBCCDPPortDisableTimeout - This timer is indicated in units of 10 milliseconds. It is a timer from when the BC handshake is first detected to when the hub will check if a device has asserted DP to 3.3V to signal it is ready to be enumerated. The time between the battery charger detection waveform and DP assertion to 3.3V varies from device to device. Some devices may support CDP but fail to assert DP to 3.3V before this timer expires. If this becomes an issue for the particular application or design, this timer may be made greater than the default value.

gbyBCVBUSDischargeTime (0x4135) - This timer is the duration of time that the hub will drive its port power control pin low before transitioning to SDP mode.

gwBCPortDisableTimeout (0x4126-0x4127) - This timer determines how long the hub will try SDP mode before reverting back to CDP mode.

TABLE 1: TIMER VALUES

Register Name	Location	Default Value	Alternate Recommended Value
gwBCCDPortDisableTimeout	0x4124-0x4125	3s	3s
gbyBCVBUSDischargeTime	0x4135	600 ms	1.2s
gwBCPortDisableTimeout	0x4126-0x4127	600 ms	2.05s

RapidCharge Battery Charging

The RapidCharge feature enables the developer to simultaneously support both BC1.2 charging and some vendor-specific protocols to maximize support for the widest number of devices. Because vendor-specific charging protocols are not usually compatible with DP/DM communication, this feature may only be enabled when the hub is operating in stand-alone mode without a USB host connected.

When there is no upstream VBUS_DET signal present, and consequently no USB host connected on the upstream port, the downstream battery charging enabled ports may operate as RapidCharge ports if configured to do so. The RapidCharge enabled ports will exit this mode if the upstream port has a host connection.

Upon entering RapidCharge mode, the USB253x/USB46x4/USB3x13 will enter a vendor specific SE1 charging mode and the port presents the configured SE1 voltage levels on DP and DM. If an SE1 device is attached, it will passively detect the SE1 levels and begin to charge. The port will not be able to detect the presence of the SE1 device. The port remains in SE1 charging mode while the SE1-compatible portable device (PD) is charging.

If a BC 1.2 device is attached, its IDM_SINK current source during the BC1.x handshake will pull the D- line low during primary battery charger detection. Likewise, China-mode capable charging devices have been observed to pull the DM line low upon attach. When the hub detects the DM line being pulled low, it concludes that a BC1.2 device is attached and switches to BC1.2 DCP/China mode of operation.

Upon switching to DCP/China mode, the downstream port cycles PRTPWR for more than 600 ms (as described in section 4.1.3 of Battery Charging Specification, Revision 1.2), enters DCP mode by shorting DP to DM (through 200Ω resistor). If China mode is also enabled through configuration, the hub applies a weak 125 kΩ pull-up from the internal 3.3V regulator to DP.

Battery Charging Modes

In the terminology of the USB battery charging specification (see [Definitions](#)), if a USB downstream port is configured to support battery charging, the port is a Charging Downstream Port (CDP) if it can enumerate the device, or Dedicated Charging Port (DCP) if it cannot enumerate a device. If the port is not configured to support battery charging, the port is a Standard Downstream Port (SDP).

RapidCharge expands on the Dedicated Charging Port mode by adding more profiles based on devices that are in the market. [Table 2, "Downstream Port Types"](#) details the different battery charging modes:

TABLE 2: DOWNSTREAM PORT TYPES

USB ATTACH TYPE	CHARGING CURRENT	DP/DM PROFILE
SDP (Standard Downstream Port)	0.5A	15 kΩ pull-down on DP and DM
CDP (Charging Downstream Port)	1.5A	100 μA sink on DP and 600 mV on DM
RapidCharge	Varies	Varies
SE1 1A	1.0A	DP = 2.0V DM = 2.7V
SE1 2A	2.0A	DP = 2.7V DM = 2.0V
DCP (Dedicated Charging Port)	1.5A	Short DP and DM with 200 Ω
China	2.0A	Short DP and DM with 200 Ω Pull Up DP to 3.3V with 125 kΩ

Battery Charging Configuration

The USB253x/USB46x4/USB3x13 downstream ports can be enabled for battery charging by adding a pullup resistor (10 k Ω) on the battery charging configuration strap (BC_ENx) for corresponding port x. These straps are sampled at reset. If they are sampled high, the corresponding port is enabled for battery charging. For specific pin locations, refer to the device's datasheet ([References](#)).

Battery charging can also be enabled by use of the battery charging configuration registers that reside in the USB253x/USB46x4/USB3x13. These configuration registers are used by the internal ROM firmware to configure the battery charging functionality for each port. These registers can be modified by a configuration programmed in the One Time Programmable (OTP) memory using the Protouch tool (see [ProTouch Programming Tool](#)). The battery charging configuration registers default to 0x00 at reset if the configuration strap pullups are not present and to 0xD3 for the corresponding port if the BC_EN strap is present. There is a configuration register for each port. The configuration register fields can be found in the SMBus Slave application note found in the references section ([References](#)).

Battery Charging Operation in CDP Mode

The battery charging enabled ports will exit DCP mode and enter CDP mode if the upstream port receives a host connection. On detection of the USB host SET_ADDRESS command, any BC enabled port will be turned off for at least 600 mS before it is turned on again. If the host sends a command to turn on port power before this time, the command will be delayed appropriately. If the command is received after the timer has expired, it will be executed immediately. In this mode the port power will be controlled by the USB host. Overcurrent events in CDP mode will be reported to the host.

The battery charging enabled ports will exit this mode and go into DCP mode if the upstream port loses the host connection or VBUS goes away. During the transition, any BC enable port will be turned off then on again.

VBUS Voltage Drop and Battery Charging

During battery charging as the current output is increased the VBUS voltage will drop due to resistive losses. The RDS ON resistance of the MOSFET on a typical port power controller (PPC) could be as high as 140 m Ω . At 1A this is 140 mV, if the input to the PPC is 5V, VBUS will be 4.86V. Some battery charging devices may not charge at high current if VBUS drops significantly below 5V, also the battery will charge faster at a higher voltage. For these reasons it is highly recommended to provide 5.2V at the input of the PPC. With 5.2V at the PPC input and a 1A load VBUS would be 5.06V.

System Level Considerations

ATTACHED VERSUS CONNECTED

When enabled, Battery Charging is supported in all states when attached and powered but not connected, this means that battery charging is supported at all times there is power.

HOST CONTROL OF BATTERY CHARGING

There is no specified handshake between the Hub and Host to support battery charging on the downstream ports. Battery charging on the downstream port is a completely local event, with no reporting done to the host.

CHARGING WHILE SUSPENDED OR UNCONFIGURED

Battery charging is supported while the system is suspended or unconfigured. USB-IF requires low current consumption on VBUS while in suspend, but not from other supplies. The only requirement is for bus powered devices which does not apply to a charging Hub.

Managing Overcurrent

The USB253x/USB46x4/USB3x13 is responsible for managing overcurrent shutdown (OCS) events. For battery charging ports, PRT_PWR is driven high (asserted) after hardware initialization.

If an OCS event occurs, the PRT_PWR is negated. When the Hub is configured in ganged port power control, all PRT_PWR pins will be negated. With individual control, only the PRT_PWR that experienced the OCS event will be negated.

An OCS event is acknowledged and reported to the Host when the Hub is enumerated. After an OCS event, the USB253x/USB46x4/USB3x13 will always deassert PRT_PWR.

Note: The USB3813 do not include individual port control enable signals for each port. Because of this, if one port has an over current event, all ports will be disabled.

RAPIDCHARGE MODE OVERCURRENT

If there is an overcurrent event in RapidCharge mode, the port is turned off for one second, then re-enabled. If the OCS event persists, the cycle is repeated for a total of three times. If after three attempts the OCS still persists, the cycle is still repeated, but with a retry interval of ten seconds. Continuous retries prevent defective devices from disabling the port.

CDP, SDP MODE OVERCURRENT

In CDP or SDP mode there is a USB host present, port power is controlled by the USB host, and OCS events are handled by the host.

The OCS event does not have to be registered. When and if the hub is connected to a host, the host will initialize the hub and turn on its port power. If the overcurrent condition still exist, the host will be notified.

ProTouch Programming Tool

The ProTouch tool is a developed tool used for configuration and programming of the USB253x/USB46x4/USB3x13 Hub controller. It can be used for development and prototyping where a single part is programmed or for multiple parts in a manufacturing environment. For more information refer to the Protouch MPT User Manual ([References](#)).

USB253X/USB46X4/USB3X13 UPSTREAM BATTERY CHARGER DETECTION

Overview

The USB253x/USB46x4/USB3x13 hub controller includes the capability for USB upstream battery charger detection, which is used for implementing portable devices with USB charging. To have the best possibility of detecting the presence of a charger, it is important to detect not only USB-IF BC1.2 compliant chargers but also SE1 chargers and chargers compliant with the Chinese Telecommunications Industry battery charger specification YD/T 1591-2009. The USB253x/USB46x4/USB3x13 implements a universal charger detection sequence that includes all these protocols for charger detection.

Charger Detection Types

The detection sequence is intended to identify chargers which conform to the Chinese Telecommunications Industry charger specification, chargers which conform to the USB-IF Battery Charger Specification 1.2, and single ended 1 chargers (SE1). The types of chargers detected is shown in [Table 3](#).

TABLE 3: CHARGERS COMPATIBLE WITH UPSTREAM DETECTION

USB ATTACH TYPE	DP/DM PROFILE	CHARGERTYPE
DCP (Dedicated Charging Port)	Shorted < 200 Ω	001
CDP (Charging Downstream Port)	VDP reflected to VDM	010 (EnhancedChrgDet = 1)
SDP (Standard Downstream Port) USB Host or downstream hub port	15 k Ω pull-down on DP and DM	011
SE1 Charger Low Current Charger	DP=2.0 V DM=2.0 V	100
SE1 Charger High Current Charger	DP=2.0 V DM=2.7 V	101
SE1 Super High Current Charger	DP=2.7 V DM=2.0 V	110

Once the charger detection sequence is initiated, the device provides feedback to the system through the SMBus run-time registers, the INT_N, and the CHRGET outputs. An external microcontroller can access these registers via the I2C/SMBus interface. Refer to the SMBus Slave Interface for the USB253x/USB3x13/USB46x4 application note ([References](#)) for SMBus register details.

The type of the detected charger is returned in the ChargerType field in the Upstream Battery Charger Detection (UP_B-C_DET) Register. The CHG_DET field encodes the current that can be drawn from the USB upstream port.

The CHG_DET bits are reflected in the CHRGET pins (USB3813 only), these are useful for situations where the processor cannot access these registers, such as with a dead battery condition. These pins can be connected to external hardware, for example a power management IC (PMIC).

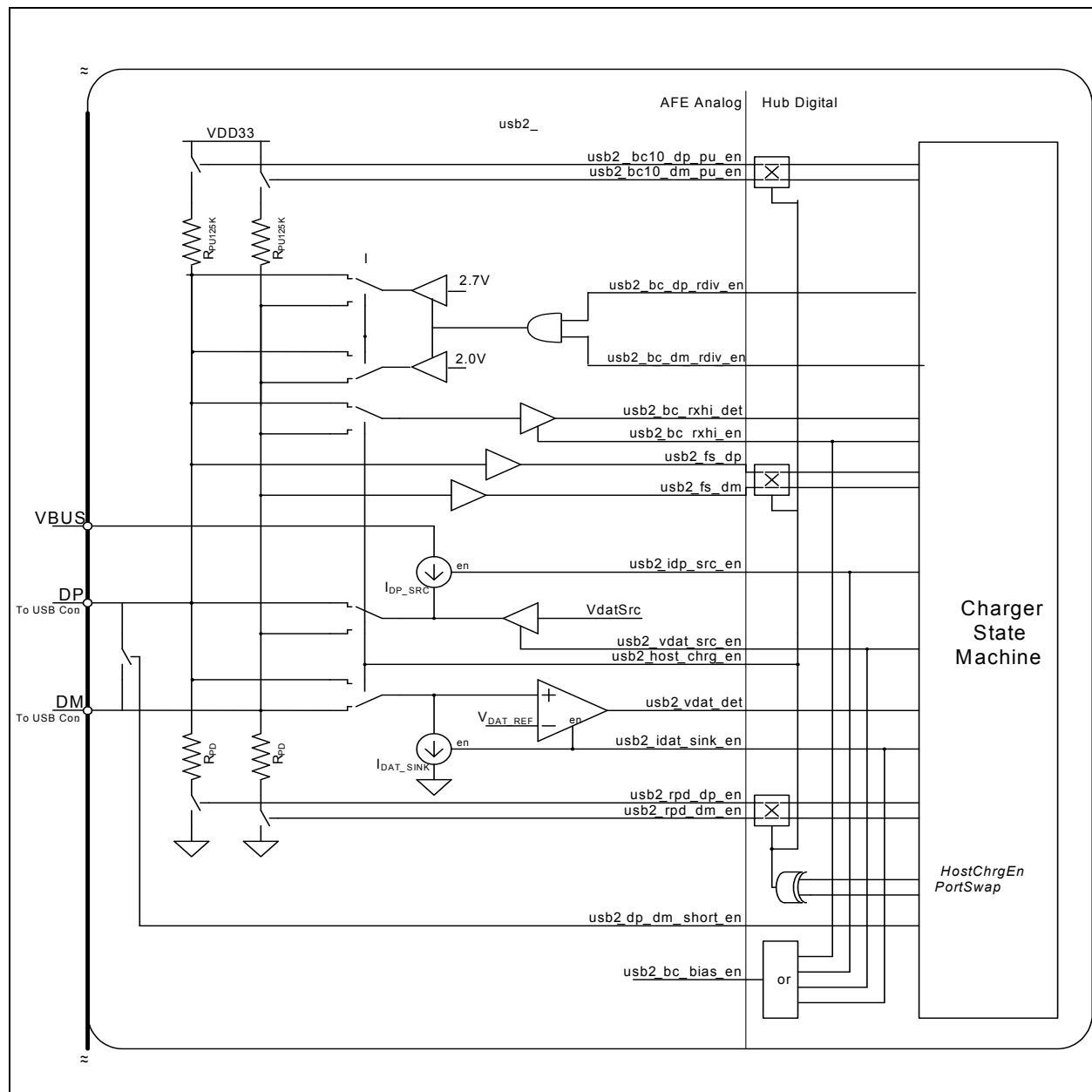
There are some registers like the Upstream Custom Battery Charger Control (UP_CUST_BC_CTL) and the Upstream Custom Battery Charger Status (UP_CUST_BC_STAT) available for implementing custom charger detection algorithms.

The following sections detail the sequence followed for battery charger detection depending on whether the automatic default sequence is utilized, or external MCU control is utilized.

Charger Detection Circuitry

The charger detection circuitry shown in [Figure 10](#) is used to detect the type of charger attached to the upstream USB connector.

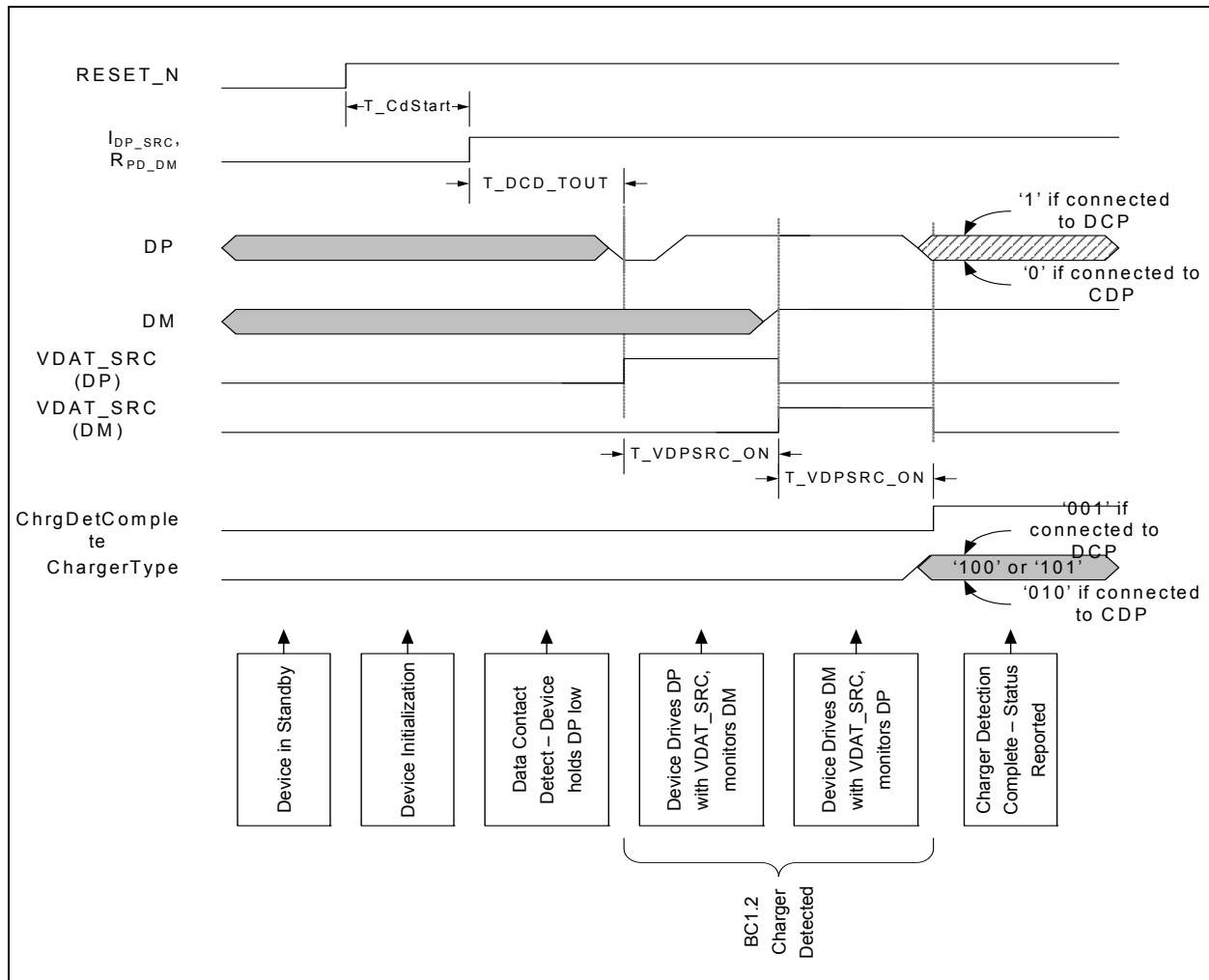
FIGURE 10: UPSTREAM BATTERY CHARGING DETECTION CIRCUITRY



Automatic Charger Detection

In order to detect the charger, the device applies and monitors voltages on the USBUP_DP and USBUP_DM pins. The flowchart in [Figure 11](#) details the charger detection sequence.

FIGURE 12: CHARGER DETECTION TIMING - SE1 FOLLOWED BY ENHANCED BC1.2



Battery Charger Detection Sequence - External Control

An external processor can override the automatic charger detection sequence by modifying the SMBus runtime battery charging registers. Because the start of battery charging detection is set to occur by default, the processor must write to the battery charging control register or the configuration interlock register to disable the automatic sequence before the sequence begins. If the automatic sequence is disabled, the processor can still initiate it manually by writing a 1 to the START_CHG_DET bit of the Upstream Battery Charging Detect (UP_BC_DET) register.

System Considerations

All USB253x/USB46x4/USB3x13 devices support upstream battery charge detection, but the USB3816 also includes a dead battery feature, which forces the device to go into the BCINIT state if the REFCLK is not present within 4ms after reset is negated. The BCINIT state is designed to manage the dead battery condition. The Hub will update the battery charging status before entering a low power state.

SUMMARY

USB Battery Charging provides a convenient mechanism for recharging batteries on portable devices such as cell-phones and tablets. The USB-IF published the BC1.2 Battery Charging Specification to help standardize the protocols used between chargers and charging devices to safely enable battery charging. The Microchip USB253x/USB46x4/

USB3x13 Hub Controller with RapidCharge provides battery charging protocols that include legacy, SE1, Chinese Telecommunications Industry YD/T 1591-2009, and USBIF BC1.2 to implement a battery charging solution supporting devices from Apple®, Samsung, and most other devices.

The Microchip USB253x/USB46x4/USB3x13 Hub Controller also supports battery charger detection for use in portable devices that require USB charger detection capability.

APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision Level & Date	Section/Figure/Entry	Correction
Rev. C (03-29-17)	All	- Updated Sales Listing and cover pages. - Various minor formatting issues addressed. - Various typographical and grammatical issues addressed.
	Section , "USB253x/USB46x4/USB3x13 Downstream battery charging," on page 10	- Updated section - Updated figures
Rev. B (9-9-14)	Section , "VBUS Voltage Drop and Battery Charging," on page 13	Added section.
Rev. A (4-29-14)	DS00001722A replaces the previous SMSC version, Revision 1.1.	
Rev. 1.2 (8-27-14)	Section , "VBUS Voltage Drop and Battery Charging," on page 13	Added section.
Rev. 1.1 (12-04-13)	Section , "Definitions," on page 1	Updated definitions.
	Section , "Overview," on page 2, Section , "Non-Standard Battery Charging Solutions," on page 2	Entirely updated.
	Section , "Charger Detection," on page 3, Figure 2, and Figure 3	Updated item 2 and 4 descriptions. Updated listed figures.
	Section , "USB253x/USB46x4/USB3x13 Downstream battery charging," on page 10	Updated entirety of chapter.
	Section , "USB253x/USB46x4/USB3x13 Upstream Battery Charger Detection," on page 14	Updated entirety of chapter.
Rev. 1.0 (06-06-13)	Document release	

NOTES:

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