AN1905

USB Battery Charging with the USB57xx Hub Controller Family

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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 USB57xx 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, USB57xx Data Sheet.
- USB-IF, Battery Charging Specification. Revision 1.2. December 7, 2010.
- USB-IF Universal Serial Bus Revision 3.1 Specification
- 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 USB57x4 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 is not capable of enumerating 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 less than 500 mA for USB 2.0, or less than 900 mA for USB 3.1 Gen 1. If the current required exceeds these limits, both the charging device and the charging port must follow a handshake protocol to ensure enough current is available to charge. A downstream battery charging port is responsible for providing the proper handshake signaling to the charging device, indicating 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.

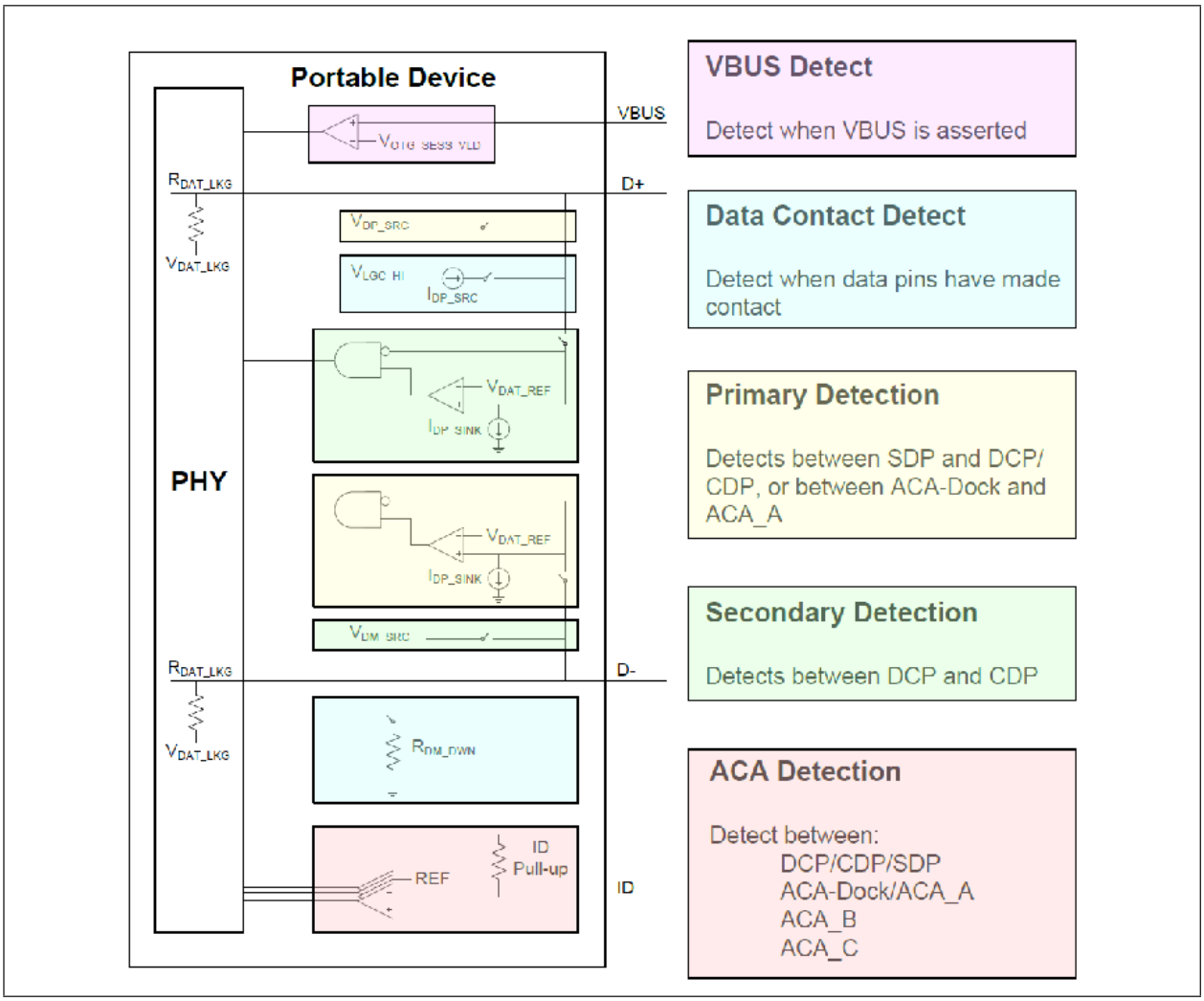
USB-IF BC1.2 Specification

The USB-IF Battery Charging Specification (see References) defines current limits and protocols to allow portable devices to draw current from the Host port, hub downstream ports, and dedicated chargers in excess of 500 mA (USB 2.0 port) or 900 mA (USB 3.1 Gen 1 port).

CHARGER DETECTION

The Portable Device (PD) is responsible for charger detection. Figure 1 details the charger detection hardware required.

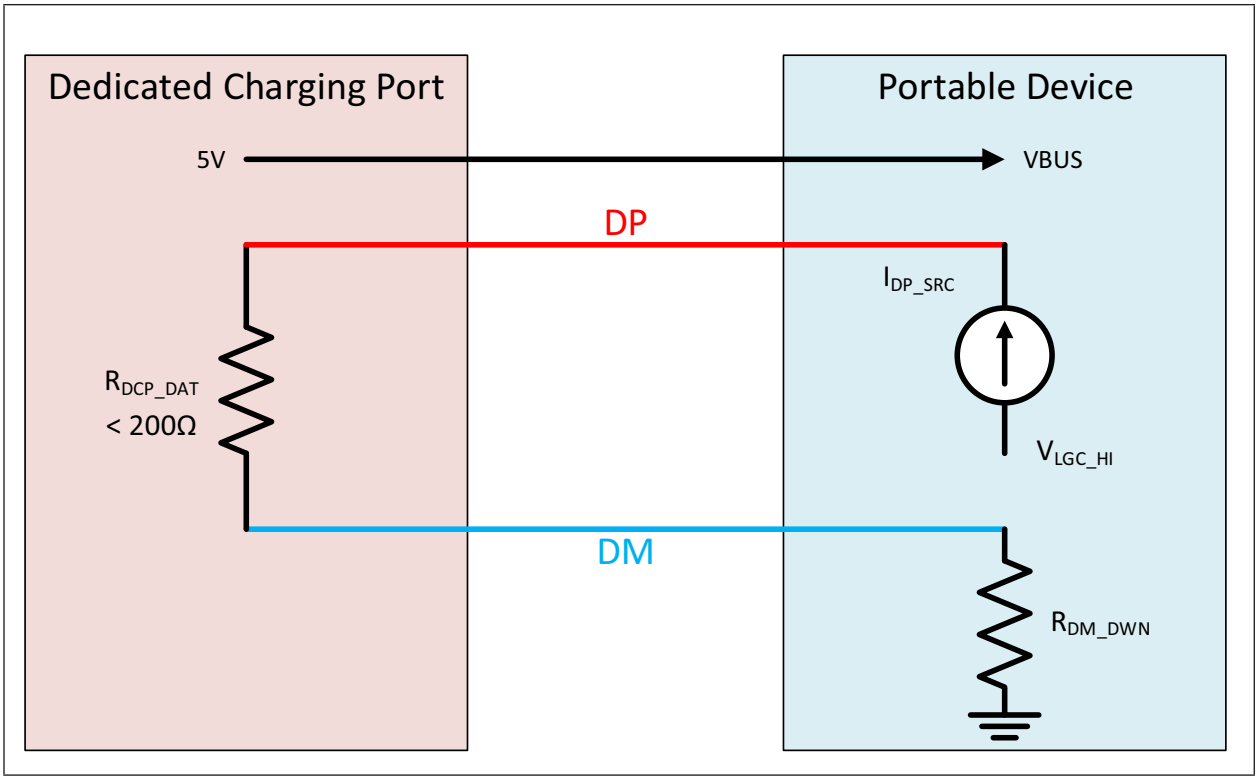
FIGURE 1: CHARGER DETECTION HARDWARE



There are five functional blocks as follows:

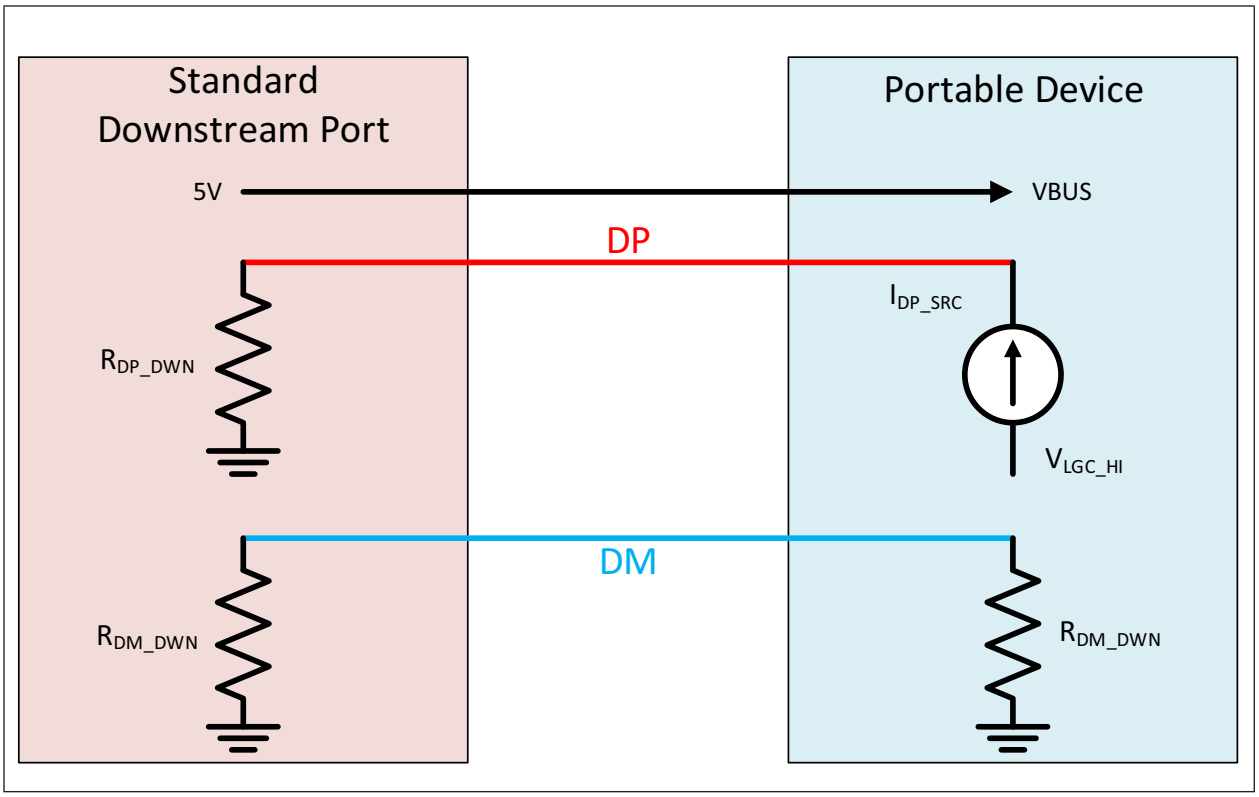
1. **VBUS Detect** - A Portable Device (PD) includes a session valid comparator. VBUS must be above the VOTG_SESS_VLD threshold before the charger detection is initiated.
2. **Data Contact Detect (DCD)** - This optional block is used to confirm the data lines have made contact during attachment. A current source IDP_SRC on D+ and a pulldown resistor RDM_DWN on D- are turned on. If the D+ line transitions low, this indicates that data lines are attached to either 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. D+ will transition low because it will be connected to pull-down resistor RDM_DWN through RDCP_DAT.

FIGURE 2: DATA CONTACT DETECT ON A DCP



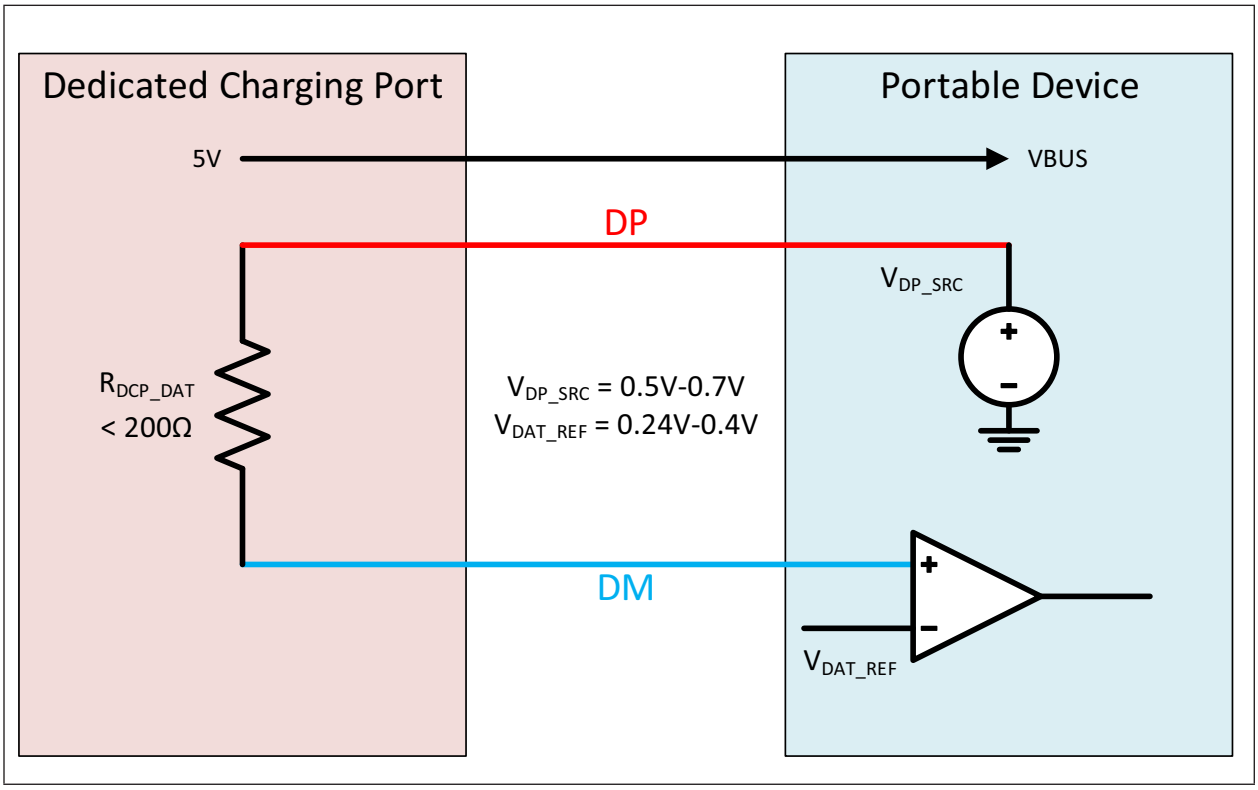
b) Figure 3 shows the DCD circuit when attached to an SDP or CDP port. In this case, D+ will transition low because it is connected to pull-down resistor R_{DP_DWN}.

FIGURE 3: DATA CONTACT DETECT ON A SDP



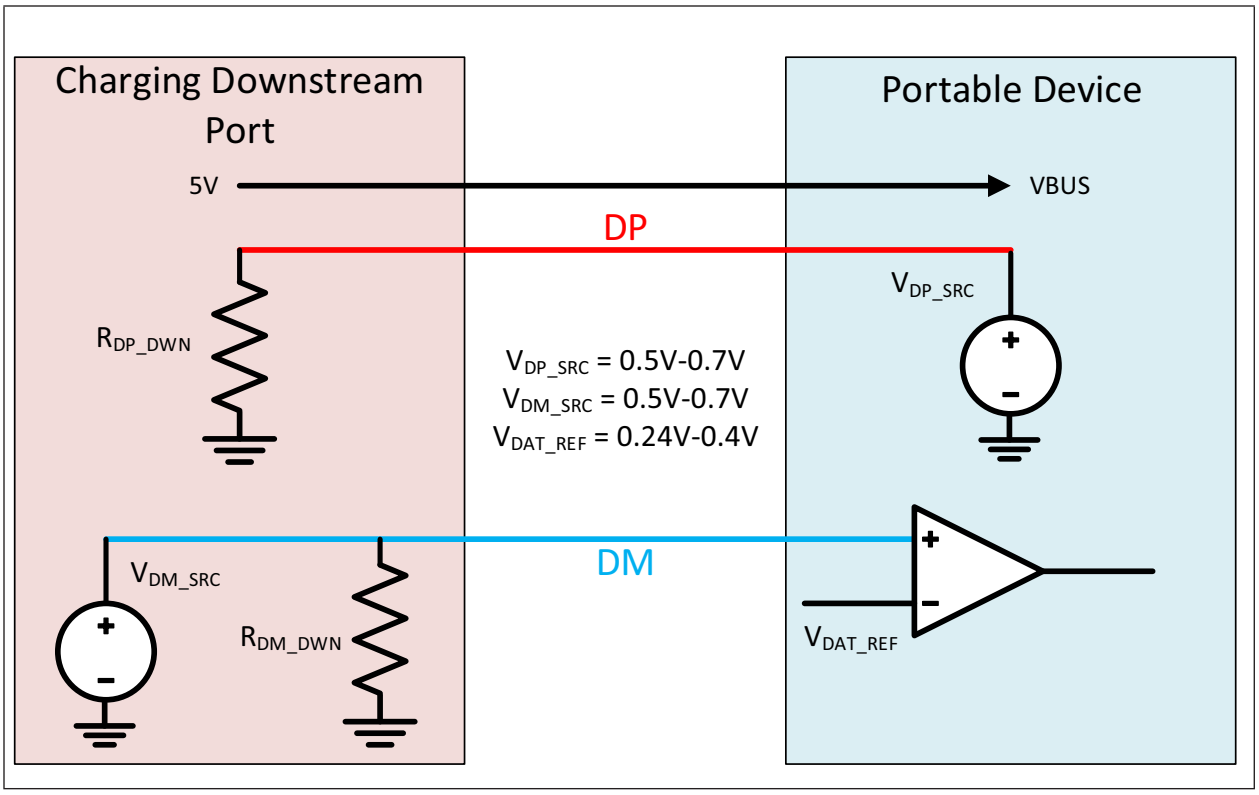
3. **Primary Detection** - A PD is required to implement primary detection, which is used to distinguish between an SDP and a charging port. When a PD is attached and powered, the PD enables V_{DP_SRC} and I_{DM_SINK}.
   a) If the PD is attached to a DCP (Figure 4), V_{DP_SRC} is reflected on D- through resistor R_{DCP_DAT} < 200 Ω. If D- is greater than V_{DAT_REF}, the PD can assume 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



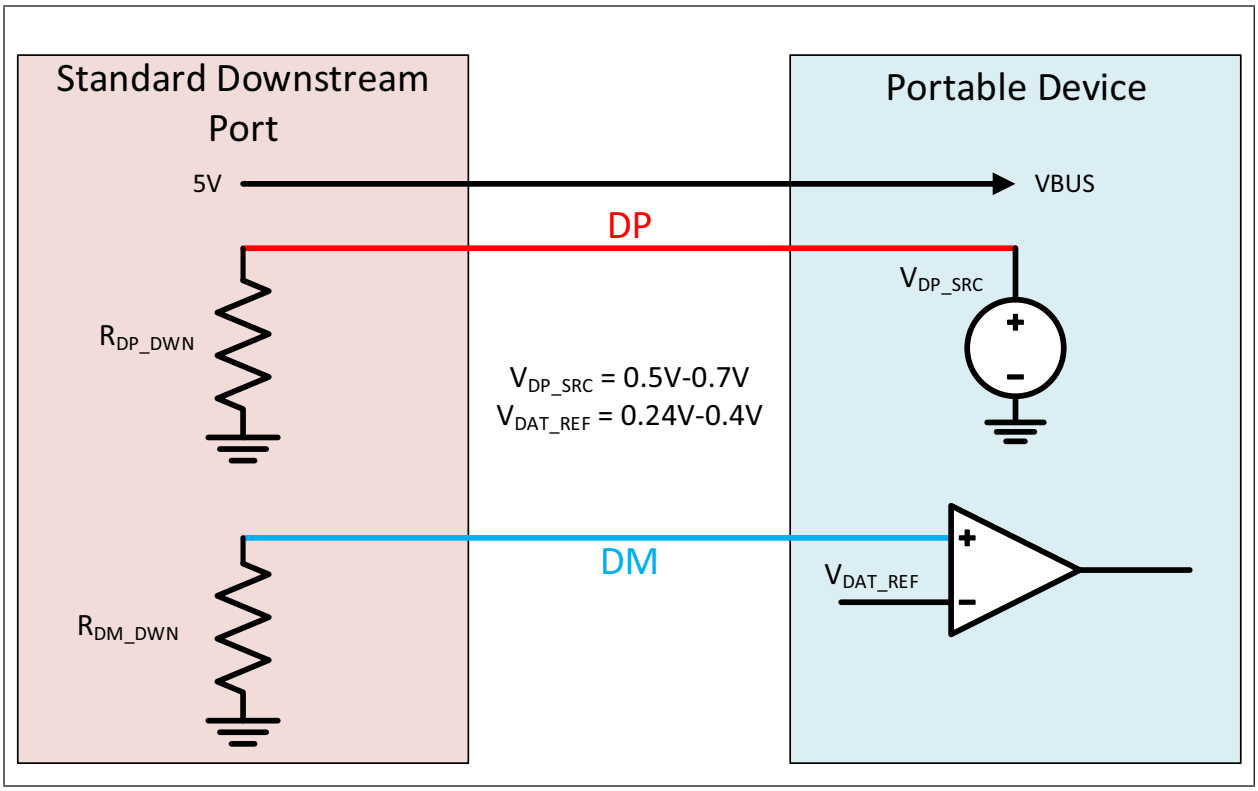
b) If the PD is attached to a CDP(Figure 5), the CDP detects D+ is greater than V_{DAT_REF} and turns on V_{DM_SRC}, which drives up the D- line. If D- is greater than V_{DAT_REF}, the PD is attached to a CDP or DCP.

FIGURE 5: PRIMARY DETECTION, CDP



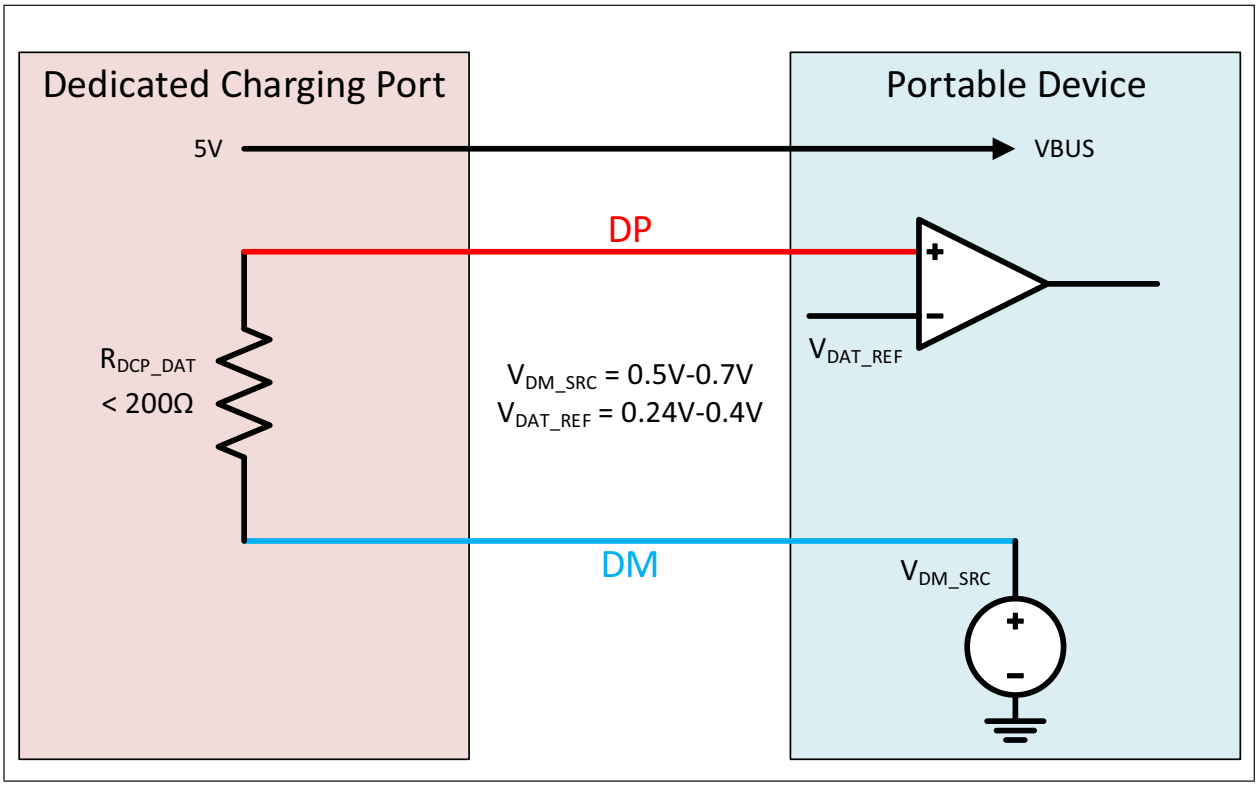
c) If the PD is attached to an SDP(Figure 6), D- is less than V_{DAT_REF} due to pulldown R_{DM_DWN}, and the PD assumes it is attached to an SDP.

FIGURE 6: PRIMARY DETECTION, SDP



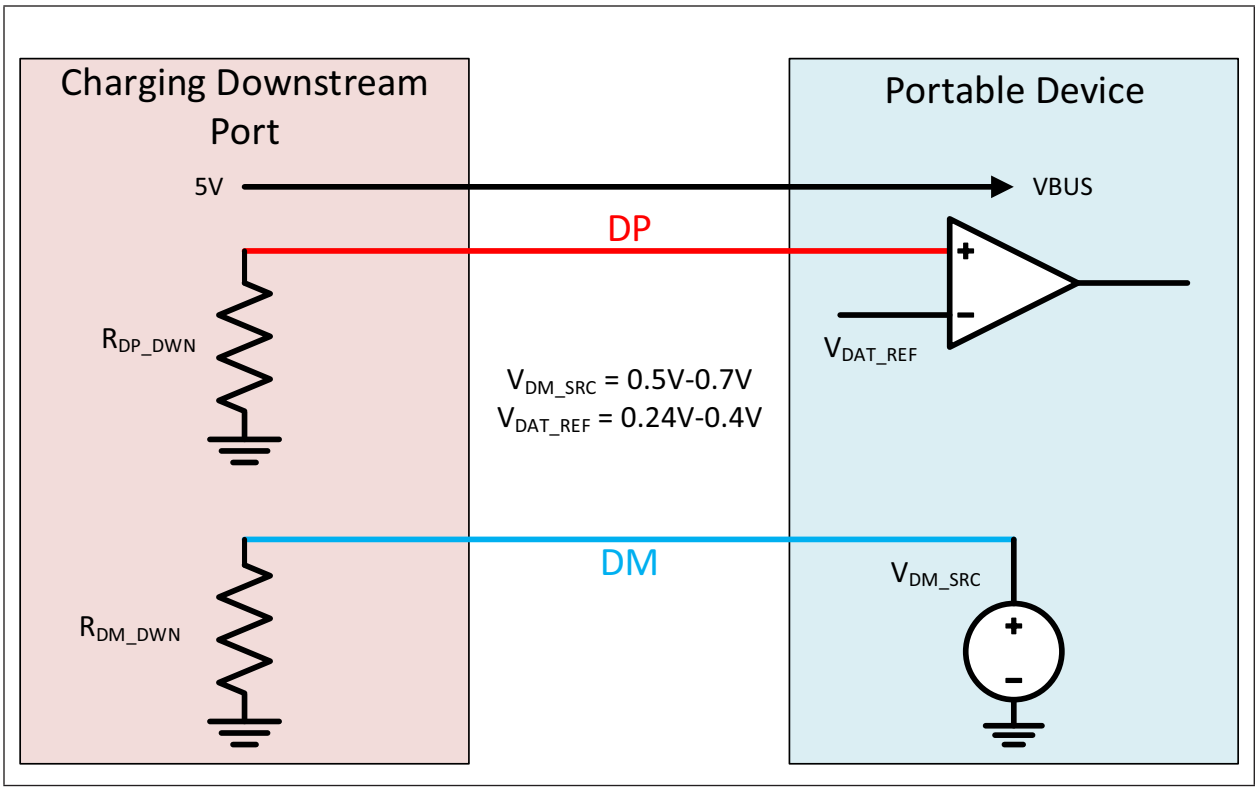
4. **Secondary Detection** - Secondary detection is used to distinguish between a DCP and CDP port. The PD enables voltage source V_{DM_SRC} and current sink I_{DP_SINK}.
   a) If the PD is attached to a DCP (Figure 7), V_{DM_SRC} is reflected on D+ through resistor R_{DCP_DAT} < 200 Ω. If D+ is greater than V_{DAT_REF}, the PD can assume it is attached to a DCP. Some non-BC1.2 PDs pull D+/D- high, which may cause this detection to fail.

FIGURE 7: SECONDARY DETECTION, DCP



b) If the PD is attached to a CDP (Figure 8), D+ will be less than V_{DAT_REF}, due to pulldown R_{DP_DWN}, and the PD can assume it is attached to a CDP.

FIGURE 8: CDP SECONDARY DETECTION



5. **ACA Detection** - ACA detection support for a PD is optional. 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 specification (see References).

Alternative 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.

USB57XX DOWNSTREAM BATTERY CHARGING

Portable Devices and Charging

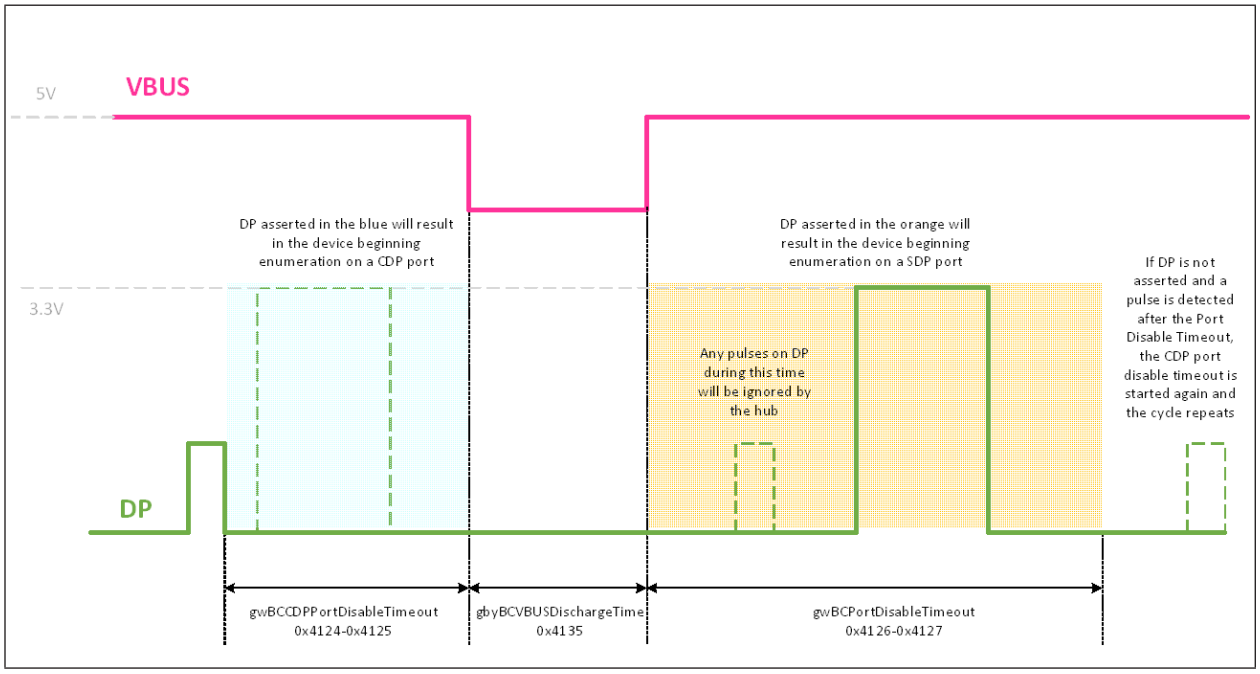
While most portable devices follow USB-IF BC1.2 standards, some devices use vendor specific protocol to initiate charging. Portable devices may exhibit slightly different behaviors depending upon their battery charging detection capabilities. The following parameters are not explicitly defined in the 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
- 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. To support CDP mode, a secondary detection phase of the battery charging handshake was introduced. CDP support is optional, and there are many devices which opt not to support CDP; these devices will only perform the primary detection phase. These devices do not have the ability to enumerate while charging at higher current. Microchip smart hubs have an advanced battery charging algorithm to ensure that all downstream devices will enumerate while the port is configured to operate in CDP mode. Figure X 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 asserted during this time it will enumerate on a CDP port
- gbyBCVBUSDischargeTime begins determining how long the PRTPWRx/PRTCTLx signal output from the USB hub will be driven low.
- VBUS is restored to 5V after the hub's PRTPWRx/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, a pulse will begin the cycle again

The gwBCCDPPortDisableTimeout, gbyBCVBUSDischargeTime, and gwBCPortDisableTimeout timers are all configurable via registers, as in Table 1, "Timer Values".

gwBCCDPortDisableTimeout - 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 and 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. It is important to know that increasing this value too much can cause the USB57x4 hub to fail the USB 3.0 compliance testing for certain time sensitive tests.

gwBCPortDisableTimeout (0x4126-0x4127) - This timer determines how long the hub will stay in 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	600ms	1.2s
gwBCPortDisableTimeout	0x4126-0x4127	600ms	2.05s

RapidCharge Battery Charging

The RapidCharge feature enables the developer to simultaneously support both BC1.2 charging and 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 standalone 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.

With USB57xx hubs, the RapidCharge mode will also be entered if the hub is suspended and remote wakeup is disabled.

Upon entering RapidCharge mode, the USB57xx 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 I_{DM_SINK} current source 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 200 Ω 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 on 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	100uA sink on DP and 600mV 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
SE1 2.4A	2.4A	DP = 2.7V DM = 2.7V
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 USB57xx downstream ports can be enabled for battery charging by applying a strap resistor to the CFG_BC_EN strap pin. This strap is sampled at reset according to Table 3, "Battery Charging Strap Options":

TABLE 3: BATTERY CHARGING STRAP OPTIONS

Resistor	Strap To	Encoding
200k	GND	No Battery Charging enabled.
200k	VDD33	Battery Charging enabled on Port 1.
10k	GND	Battery Charging enabled on Ports 1 and 2.
10k	VDD33	Battery Charging enabled on Ports 1-3.
10	GND	Battery Charging enabled on all ports.

For specific pin locations, refer to the device's data sheet (see References).

Battery charging can also be enabled by use of the battery charging configuration registers that reside in the USB57xx. 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 pull-ups are not present, or to 0xD5 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 (see References).

Battery Charging Indicators

The USB57xx has additional digital pins that can be configured as battery charging indicators, as discussed in Table 4, "Battery Charging Indicators". When configuration 5 is selected with the CFG_STRAP pin, PF1-4 become indicators for the battery charging state. When battery charging is enabled, the PF pin will drive high. In CDP mode, the pin will drive low if a primary detection handshake is detected. The pin will not drive if battery charging is disabled.

TABLE 4: BATTERY CHARGING INDICATORS

PF Pin	DCP	CDP
PF1 - Port 1	1 = BC Enabled 0 = NA Z = BC Disabled	1 = BC Enabled 0 = BC1.2 handshake detected Z = BC Disabled
PF2 - Port 2	1 = BC Enabled 0 = NA Z = BC Disabled	1 = BC Enabled 0 = BC1.2 handshake detected Z = BC Disabled
PF3 - Port 3	1 = BC Enabled 0 = NA Z = BC Disabled	1 = BC Enabled 0 = BC1.2 handshake detected Z = BC Disabled
PF4 - Port 4	1 = BC Enabled 0 = NA Z = BC Disabled	1 = BC Enabled 0 = BC1.2 handshake detected Z = BC Disabled

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. Over-current 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 is removed. During the transition, any BC enable port will be turned off then on again.

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 a downstream port is a completely local event, with no reporting done to the host.

CHARGING WHILE SUSPENDED OR UNCONFIGURED

The hub will transition downstream ports to DCP mode when in the suspended state when the following conditions are met:

- DEVICE_REMOTE_WAKEUP is cleared.
- There is no USB 2.0 device attached to the downstream port.
- There is no USB 3.1 Gen 1 device attached to the downstream port.

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. This means that a bus powered hub cannot have battery charging enabled.

Managing Over-current

The USB57xx is responsible for managing over-current shutdown (OCS) events. For battery charging ports, PRTPWR is driven high (asserted) after hardware initialization.
If an OCS event occurs, the PRTPWR is negated. When the Hub is configured in ganged port power control, all PRTPWR pins will be negated. With individual control, only the PRTPWR 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

USB57xx will always deassert PRT_PWR.

RAPIDCHARGE MODE OVER-CURRENT

If there is an over-current 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 OVER-CURRENT

If there is a USB host present in CDP or SDP mode, 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 over-current 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 USB57xx 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 (see References).

SUMMARY

USB Battery Charging provides a convenient mechanism for recharging batteries on portable devices such as cellphones 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 USB57xx 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 USB57xx 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
DS00001905C (04-26-17)	All	• Updated Sales Listing and cover pages. • Various minor formatting issues addressed.
	USB57xx Downstream Battery Charging	• Updated section • Updated figures
DS00001905B (07-01-15)	All	• Updated “USB 3.0” references to “USB 3.1 Gen 1” throughout the document • Updated USB specification reference
DS00001905A (03-10-15)	Initial document release	

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