AN 19.7

Battery Charging Using Microchip USB Transceivers

1.0 INTRODUCTION

The USB port has become the preferred method for charging for many of the industry's most popular Portable Devices. This Application Note focuses on designing with Microchip USB Transceivers for Battery Charger Detection and Battery Charging as they apply to Portable Devices.

The USB Battery Charging Specification defines a "Portable Device" as:

"A Portable Device is considered to be any USB or OTG device that is capable of operating from its own battery, and is also capable of drawing current from USB for the purposes of operating and/or charging its battery."

There are three distinct charging methods in the market today: The Dedicated Charger, the Standard Host Port, and the Charging Host Port. Microchip's line of USB Transceivers supports all of these charging methods.

Microchip participated in and supports the adoption and promotion of the USB-IF Battery Charging Specification.

1.1 References

Microchip USB Transceiver Data Sheets:

- USB331x
- USB332x
- USB333x

USB Battery Charging Specification, Revision 1.0

USB Battery Charging Specification, Revision 1.1

USB Specification, Revision 2.0

USB ECN "Suspend Current Limit Changes"

1.2 Definitions

SE0: "Single Ended Zero", USB D+/D- = 00 (Less than 0.8V)

SE1: "Single Ended One", USB D+/D- = 11 (Greater than 2.0V)

Linestate: The current logic state of the Full Speed Receivers

Linestate[0]: The current logic state of DP

Linestate[1]: The current logic state of DM

2.0 CHARGERS AND CURRENT SPECIFICATIONS

The maximum VBUS current that a charging device can consume is 1.5A, but this maximum current is dependent on both the device and the capability of the charging source. The *device* is responsible for insuring that the current does not exceed the limits defined in the USB Specification and the USB Battery Charging Specification.

2.1 Dedicated Charger (Dedicated Charging Port)

A Dedicated Charging Port is a downstream facing port on a device that outputs power through a USB connector, but is not capable of enumerating a downstream device. A Dedicated Charging Port is required to output at a minimum current of 500mA at a voltage of between 4.75V and 5.25V. Table 2-1 presents a list of the most common dedicated chargers and how they connect DP and DM.

TABLE 2-1: USB DEDICATED CHARGER TYPES

Charger	State of USB Signals
USB-IF	DP shorted to DM
“China Charger”	DP shorted to DM
Floating DP/DM	DP unconnected, DM unconnected
Pulled-up DP/DM	DP pulled up with 1.5k resistor, DM pulled up with 1.5k resistor

2.2 Charging when Connected to a Host

There are two types of host ports: The Standard Host Port and the Charging Host Port

From the perspective of battery charging and charger detection, a Standard Host Port is any downstream port that complies with the USB 2.0 definition of a host or hub. A Charging Host Port is a fully capable Standard Host Port with the ability to supply more charging current than a Standard Host port. A device attached to a Standard Host Port is only allowed to consume the amount of current negotiated during enumeration.

Table 2-2 summarizes how the USB 2.0 Specification defines the maximum VBUS current that a Portable Device may draw from a host.

TABLE 2-2: MAXIMUM VBUS CURRENT SUPPLIED BY USB HOSTS

Host Type	Suspended	Unconfigured / Not Suspended	Configured, HS Session	Configured, FS/LS Session
Standard Host	2.5 mA (Avg) (Note 2-1)	100 mA	500 mA	500 mA
Charging Host	2.5 mA (Avg) (Note 2-1)	1.5 A	900 mA	1.5 A

Note 2-1 Bus-powered hubs may consume up to 12.5 mA prior to configuration.

Once a device has enumerated, it must follow the USB rules for suspend, even when attached to a Charging Host Port.

3.0 DETECTING A CHARGING PORT USING THE USB331X AND USB332X

The USB331x and USB332x can detect a Charging Port using the resistive detection method which is described in this section. For backward compatibility, the USB333x can also use the detection methods described in this section. However, it is recommended that USB333x applications detect a Charging Port as described in Section 4.0.

USB Chargers and USB Hosts will present 5V (nominal) onto the VBUS terminal of the USB connector at all times. While in synchronous mode, the Link can detect SessValid in the RXCMD byte. In any of the non-synchronous modes, the Link must monitor the interrupt signal on DATA[3] as described in the Microchip USB Transceiver data sheet. When an interrupt occurs, the Link commands the Microchip USB Transceiver to exit Low Power Mode or Carkit Mode and then reads the USB Transceiver registers to discover what caused the interrupt.

Section 3.1 explains how to configure the Microchip USB Transceiver for charger detection using the resistive detection mechanism.

Section 3.2 and Section 3.3 describe how to detect the various types of chargers.

3.1 Configuring the Microchip Transceiver for Charger Detection

To detect a charger, the Microchip USB transceiver must:

- Configure DP/DM to be non-driving (tri-state) using the Full Speed Drivers.
- Enable the 125K Ohm pull-up resistors on DP and DM.

To do this, the following registers must be configured:

1. Write 0x49h to ULPI address 0x04 (Function Control Register) to tri-state DP/DM.
2. Set bit 4 at ULPI address 0x39 (ChargerPullupEnDP bit) to connect pull-up to DP.
3. Set bit 5 at ULPI address 0x39 (ChargerPullupEnDM bit) to connect pull-up to DM.

While it is acceptable to only enable the DP pull-up resistor, enabling both the DP and DM pullup will enable faster detection of a dedicated charger since it requires less time for the circuit to charge up to an SE1. The exception to this is the “Floating DP/DM” Dedicated Charger which *requires* that both DP and DM pullups be enabled.

3.2 Detecting a Dedicated Charger (Dedicated Charging Port)

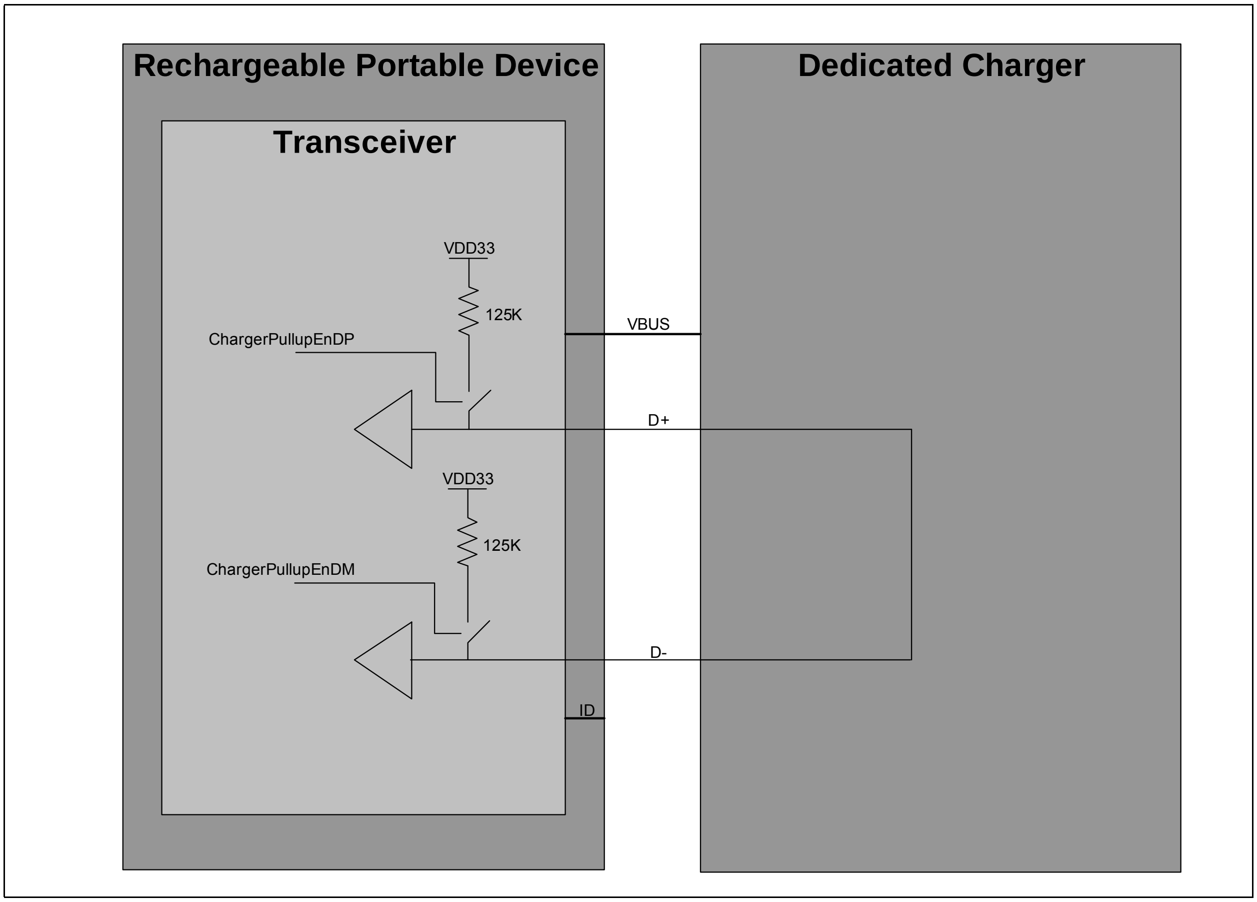
3.2.1 USB-IF COMPLIANT DEDICATED CHARGER

The USB-IF Battery Charging Specification states that:

“A Dedicated Charging Port is required to short the D+ line to the D- line.”

On Microchip products supporting the USB-IF Battery Charging Rev 1.0 Specification, the resistive detection method is used to detect a dedicated charger. FIGURE 3-1: on page 4 shows how the Battery Charging Specification defines how a dedicated charger is detected using the resistive detection method.

FIGURE 3-1: DEDICATED CHARGER, RESISTIVE DETECTION



To configure the Portable Device to detect a USB-IF Dedicated Charger, refer to the steps defined in Section 3.1.

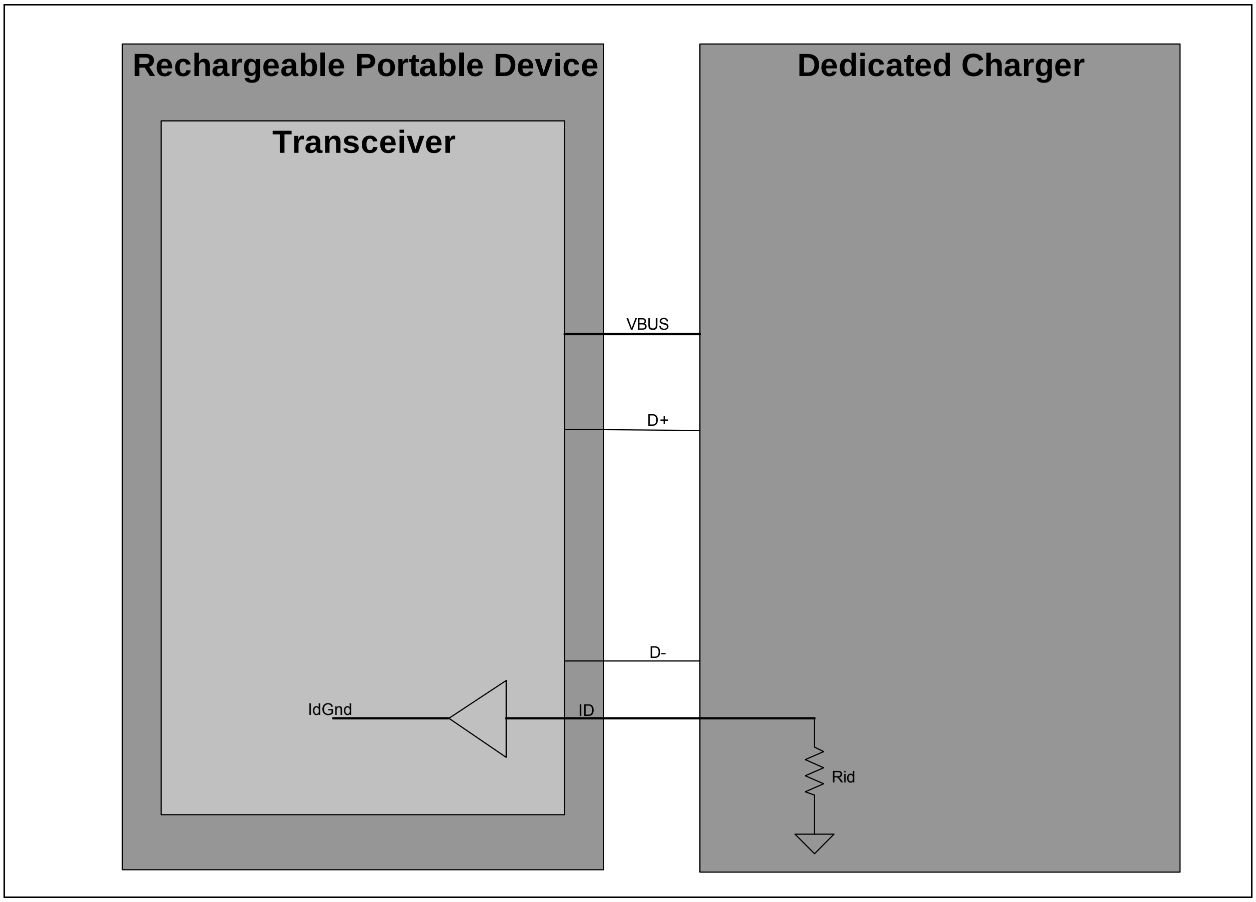
If bits [1:0] of ULPI address 0x15 equal SE1 while VBUS has been detected, then a dedicated charger has been detected. VBUS may be detected using the VbusValid bit in the Interrupt Status Register, or by another detection method external to the USB Transceiver.

Depending on the length of the cable and the type of components attached to the DP/DM in the portable device, the time that it takes DP/DM to charge up to SE1 can vary. Therefore, the end product must be designed to accommodate these delays.

3.2.2 DETECTING A DEDICATED CHARGER USING ID RESISTOR DETECTION

Some dedicated charger products ground the ID pin or use a resistance between the ID pin and ground as a method for the Portable Devices to determine the charging current capability of the charger. Microchip USB Transceivers offer a method for detecting and measuring this resistance through the use of the RID Converter feature. The example where a charger uses this ID resistance is shown in FIGURE 3-2: Dedicated Charger with RID Identification on page 5, and this section describes the method to detect this type of dedicated charger using an Microchip USB Transceiver.

FIGURE 3-2: DEDICATED CHARGER WITH RID IDENTIFICATION



In preparation for testing if a charger grounds the ID pin, the USB Transceiver must be configured as described in Section 3.1, "Configuring the Microchip Transceiver for Charger Detection".

1. VBUS is detected when the dedicated charger is plugged into the Portable Device. In synchronous mode, VBUS is detected and the USB Transceiver sends an RXCMD to the Link (SessValid='1'). (In a non-synchronous mode, the Link monitors the ULPI interrupt bit DATA[3] to detect when a cable is attached. The interrupt is asserted when VBUS crosses the threshold where the USB comparators in the transceiver assert SessValid or VbusValid. The USB Transceiver must then be put into synchronous mode by having the Link assert STP.)
2. The Link must read the USB Interrupt Status register (address 0x13h) to determine the source of the interrupt. If VbusValid or SessValid are '1', then a cable has been connected.
3. If bit 4 of the USB Interrupt Status register is a '0', then ID has been pulled down or grounded.
4. Disable the 100k pull-up resistor IdPullup by setting bit 0 of the OTG Control Register (Address 0x0A) to '0'.
5. To detect when the RID converter has completed its detection sequence, set the RidIntEn (Address 0x1D, bit 5) to a '1'.
6. Start the RID Converter operation by setting bit 4 of the Vendor RID Conversion Register (Address 0x36) to '1'.
7. The method for detecting when the RID conversion is complete using the RID Converter Interrupt depends on whether the Transceiver is in synchronous mode or a non-synchronous mode.
   a) When the Transceiver is in synchronous ULPI mode, an RXCMD will be generated with bit 7 of the RXCMD byte set (high) indicating that an interrupt has occurred.
   b) When the Transceiver is in a non-synchronous mode (i.e. Low Power Mode, Carkit Mode), the asynchronous DATA[3] interrupt will be set (high). (See Note 3-1)

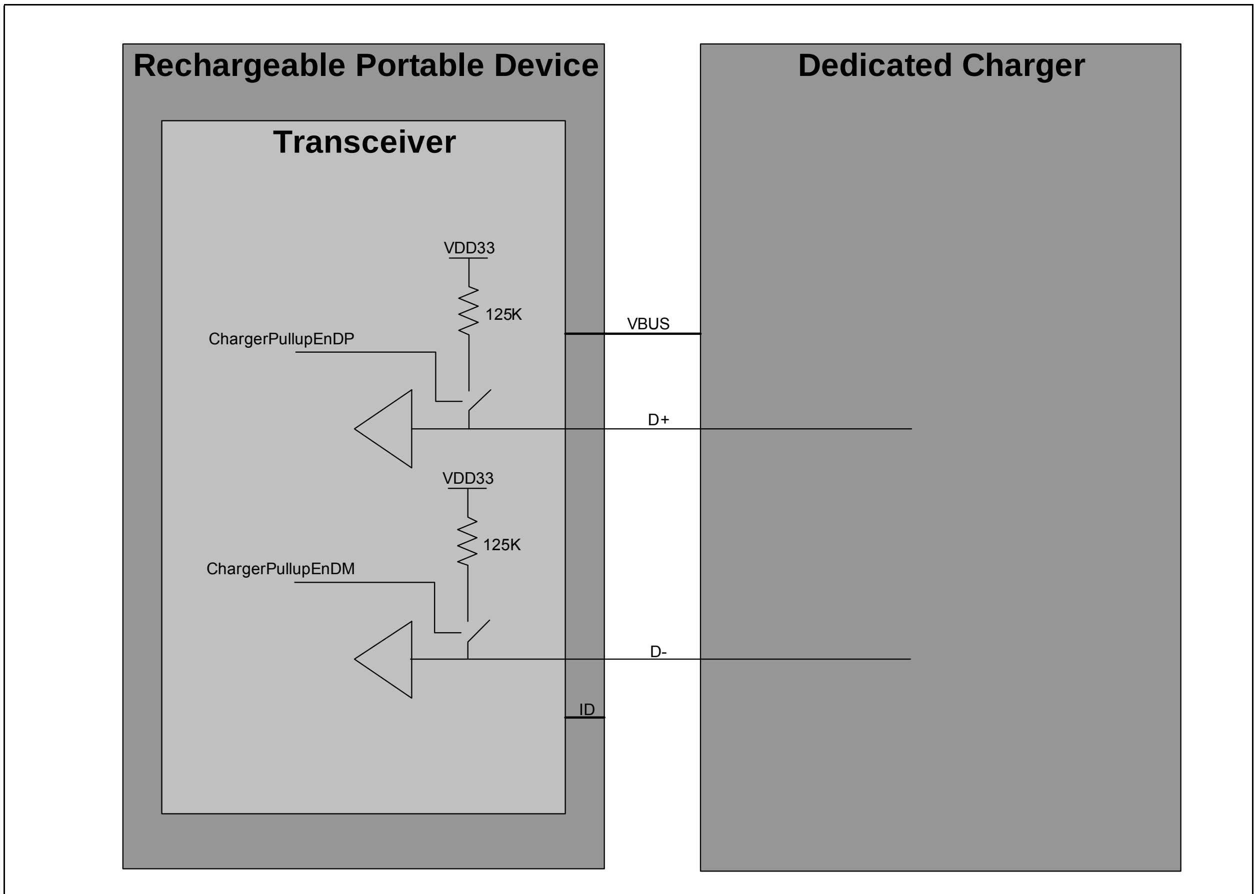
8. The value of the RID Resistor has been calculated. The value of the RID Resistor is the RidValue and is read from the Vendor RID Conversion Register (Address 0x36, bits [2:0]). The bit mapping to the specific RID resistor value is contained in the Microchip USB Transceiver Data Sheet.

Note 3-1 When designing with the USB331x, refer to USB331x Anomaly Sheet.

3.2.3 DETECTING A DEDICATED CHARGER WITH FLOATING DP AND DM

Some dedicated charger products elect to leave DP and DM floating, as shown in Figure 3-3, and this section describes the method to detect this type of dedicated charger using a Microchip USB Transceiver.

FIGURE 3-3: DEDICATED CHARGER, FLOATED DP/DM



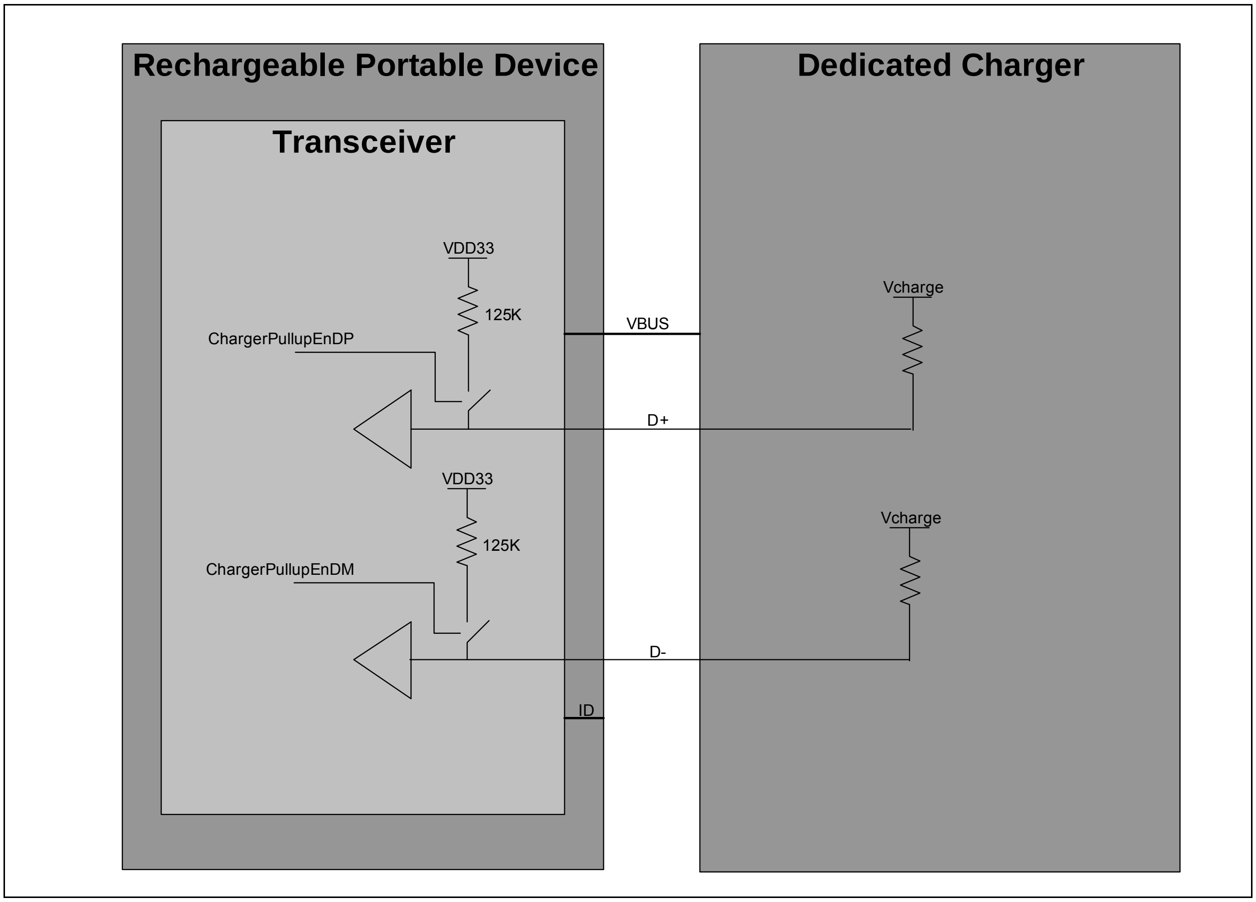
In preparation for testing if a dedicated charger has floating DP and DM pins in the USB connector, the USB Transceiver must be configured as described in Section 3.1. To detect a dedicated charger that floats DP and DM:

1. VBUS is detected when the dedicated charger is plugged into the Portable Device. In synchronous mode, VBUS is detected and the USB Transceiver sends an RXCMD to the Link (SessValid='1'). In a non-synchronous mode, the Link monitors the ULPI interrupt bit DATA[3] to detect when a cable is attached. This is detected by VBUS being detected on the cable and the USB comparators in the transceiver asserting SessValid or VbusValid.
2. If bits [1:0] of ULPI address 0x15 equals '11', then a dedicated charger has been detected.

3.2.4 DETECTING A DEDICATED CHARGER WITH PULL-UPS ON DP AND DM

Some dedicated charger products elect to pull-up DP and DM with resistors, as shown in Figure 3-4, and this section describes the method to detect this type of dedicated charger using a Microchip USB Transceiver. Generally, these pullups will be greater than 100k in value and they usually pull DP and DM up to VBUS or to 3.3V.

FIGURE 3-4: DEDICATED CHARGER, PULL-UPS ON DP/DM



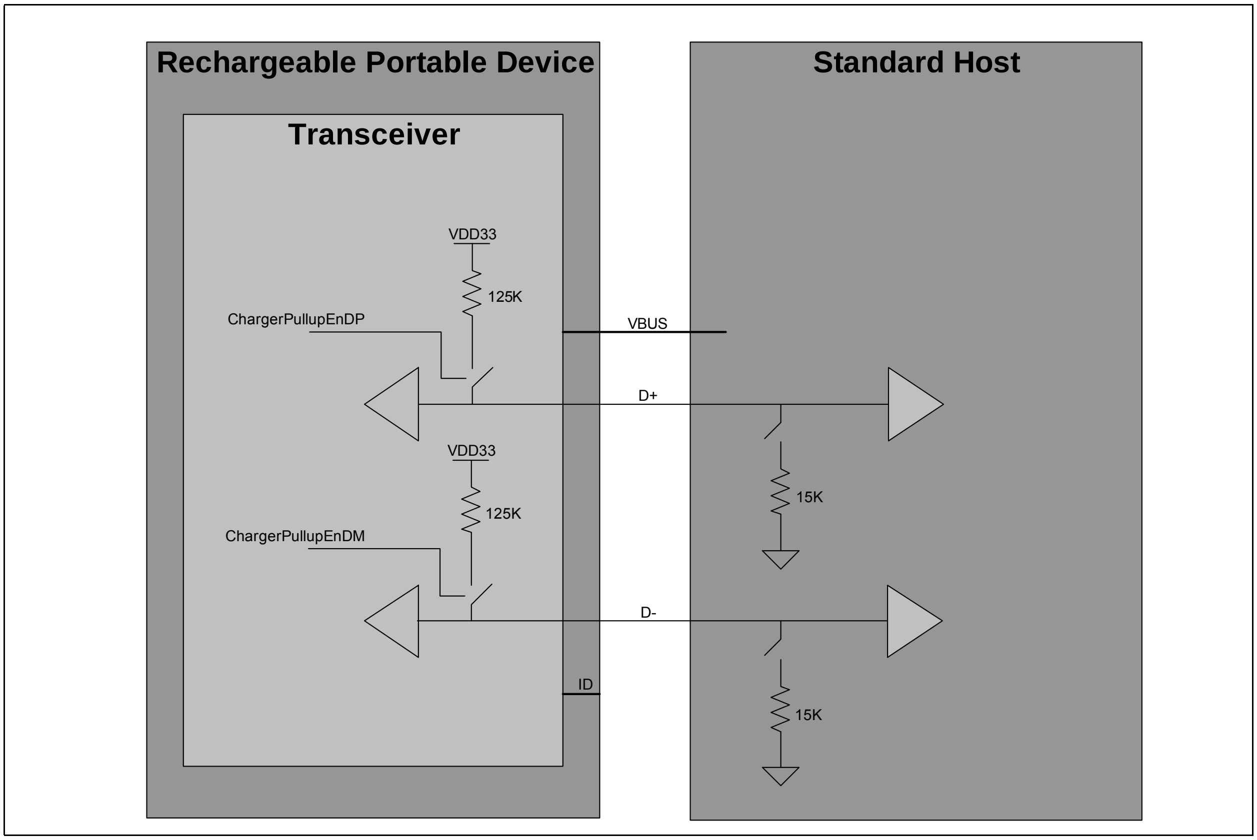
In preparation for testing if a charger has pull-up resistors DP and DM pins in the USB connector, the USB Transceiver must be configured as described in Section 3.1. To detect a dedicated charger that has pull-ups on DP and DM:

1. VBUS is detected when the dedicated charger is plugged into the Portable Device. In synchronous mode, VBUS is detected and the USB Transceiver sends an RXCMD to the Link (SessValid='1'). In a non-synchronous mode, the Link monitors the ULPI interrupt bit DATA[3] to detect when a cable is attached. This is detected by VBUS being detected on the cable and the USB comparators in the transceiver asserting SessValid or VbusValid.
2. If bits [1:0] of ULPI address 0x15 equals an SE1, then a dedicated charger has been detected.

3.3 Detecting a Standard Host

The main difference between a Dedicated Charger and a Standard Host is that the Standard Host will have 15k pull-down resistors on D+/D-, as shown in Figure 3-5 to indicate an SE0 when the Portable Device is connected to the host. The 15k pull-down resistors are strong enough to produce an SE0 (DP and DM < 0.8V) when the 125k pull-up resistors are enabled.

FIGURE 3-5: STANDARD HOST PORT (PC)

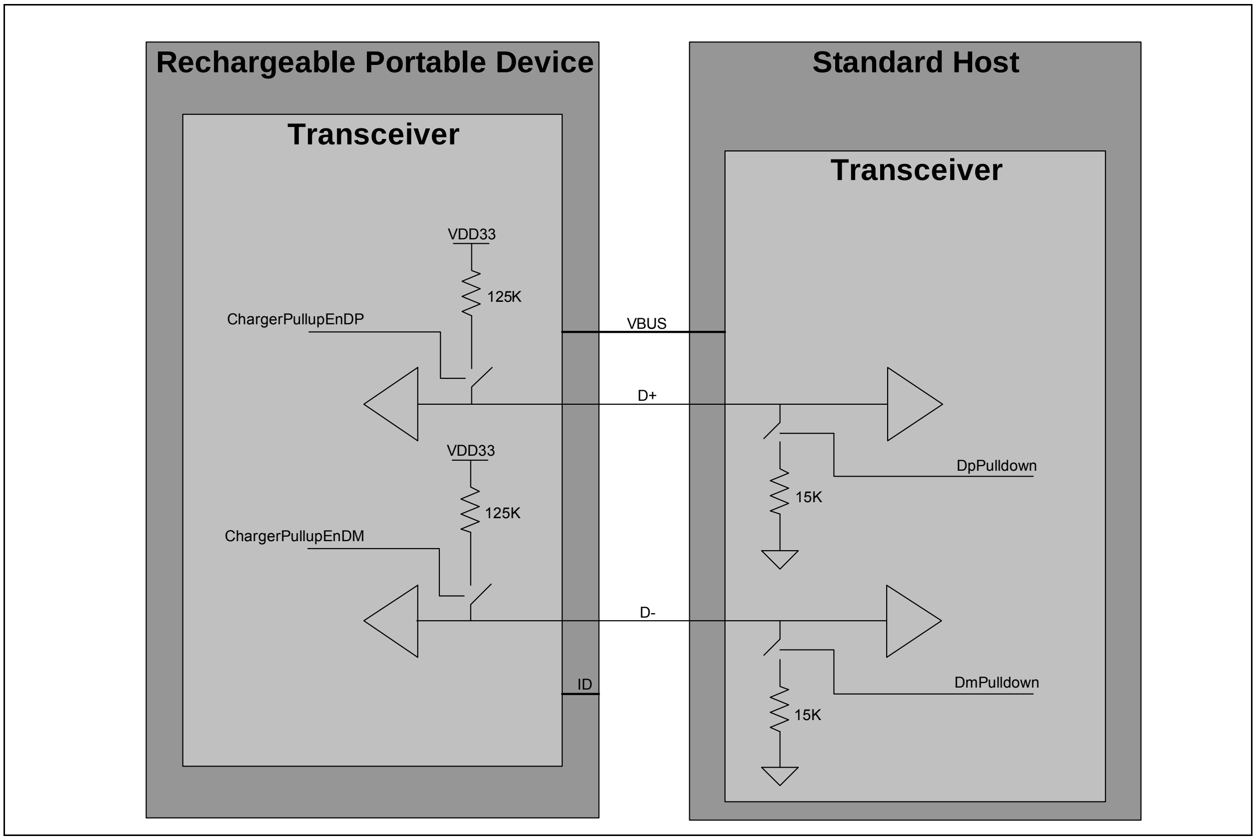


To configure the Portable Device to detect a Standard Host, refer to the steps defined in Section 3.1.

If bits [1:0] of ULPI address 0x15 equals SE0, then a host has been detected.

In the case of an Embedded Host, a Microchip USB Transceiver may be used, and Figure 3-6 shows how the 15k pull-down resistors are controlled via DpPullup and DmPulldown.

FIGURE 3-6: STANDARD HOST PORT (EMBEDDED HOST)



Newer Microchip USB Transceivers, including the USB333x, feature the ability to detect a Charging Host. The method for detecting a Charging Host is described in Section 4.3.

3.4 Detecting a Charger in While in Low Power Mode

In Portable Device applications, it is common to put the USB331x or USB332x Transceiver into Low Power Mode while the USB cable is unplugged. It is possible to detect a charger while the USB Transceiver is in Low Power Mode, and the following instructions present an example of how to do this:

1. Set bit 4 at ULPI address 0x39 (ChargerPullupEnableDP bit) to connect pull-up to DP
2. Set bit 5 at ULPI address 0x39 (ChargerPullupEnableDM bit) to connect pull-up to DM
3. Clear bit 6 at ULPI address 0x4 (SuspendM bit) to enter Low Power Mode.
4. The Link monitors the ULPI interrupt bit DATA[3] to detect when a cable is attached. A cable attach is detected when the transceiver asserts SessValid when VBUS rises above 2.0V.
5. Prior to waking up the transceiver, Linestate can be checked while in Low Power Mode to verify that Linestate = SE1 (dedicated charger) or SE0 (host).
6. Wake up the USB Transceiver by having the Link assert STP.
7. The Link must read the USB Interrupt Status register to determine the source of the interrupt. If SessValid is ‘1’, then a cable has been connected.
8. If bits [1:0] of ULPI address 0x15 equals SE1, then a Dedicated Charger has been detected.
9. If bits [1:0] of ULPI address 0x15 equals SE0, then a host has been detected.

4.0 DETECTING A CHARGING PORT USING THE USB333X

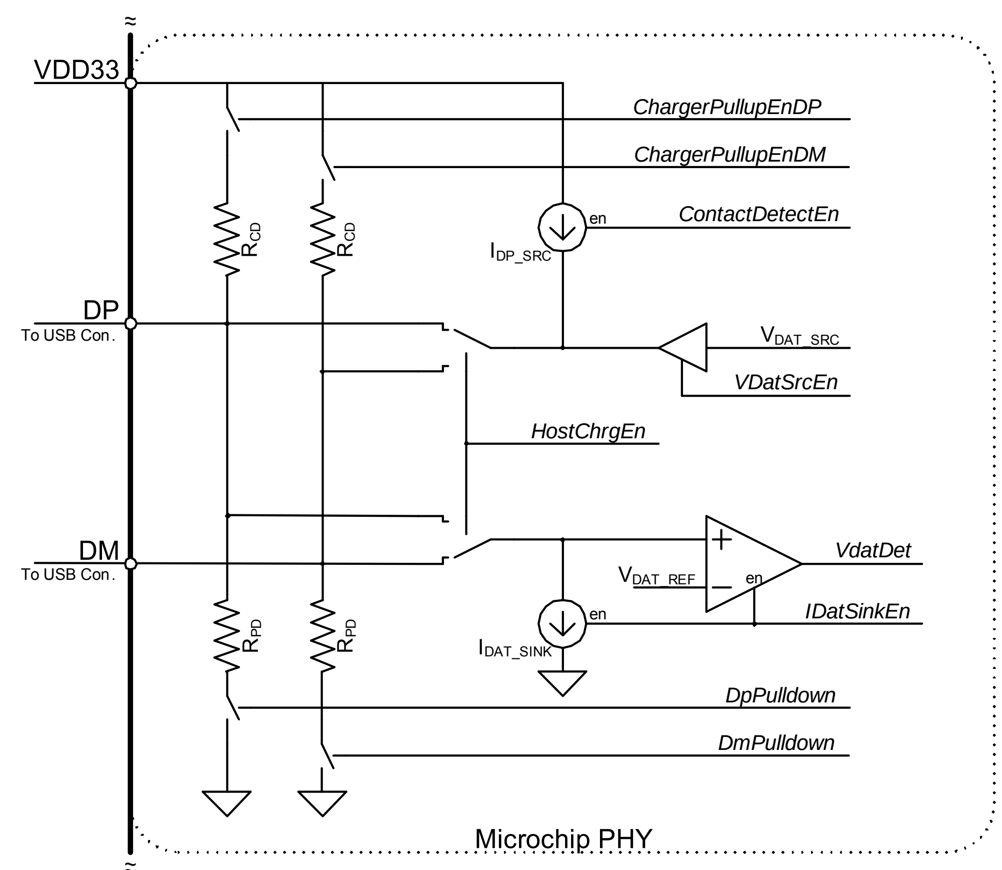
The USB333x is compliant with Revision 1.1 of the USB Battery Charging Specification. This enables the USB333x to detect both a Charging Host as well as a Standard Host.

To enable backward software compatibility of the USB333x, all of the charger detection methods described in Section 3.0, "Detecting a Charging Port Using the USB331x and USB332x" can be used with the USB333x.

4.1 USB333x Charger Detection Circuit and Configuration

The USB333x can detect a USB Charger, detect a USB Host/Charger or behave as a USB Host/Charger. The charger detection circuitry is shown in Figure 4-1.

FIGURE 4-1: USB333X CHARGER DETECTION BLOCK DIAGRAM



Note: The *signal names in italics type* in Figure 4-1 correspond to bits in the ULPI register set.

The *VdatDet* output is qualified with the Linestate[1:0] value. If the Linestate is not equal to 00 the *VdatDet* signal will not assert. The bits in Table 4-1 are contained in the USB-IF Charger Detection Register at address 0x32.

TABLE 4-1: USB CHARGER SETTING VS. MODES

Charger Detection Modes	VDATSRCEN	IDATSINKEN	CONTACTDETEN	HOSTCHRGEN	DPPULLDOWN	DMPULLDOWN
Device Connect Detect (The Connect Detect setting in Table 4-2 must be followed)	0	0	1	0	0	1
Device Charger Detection	1	1	0	0	0	0
Device USB Operation	0	0	0	0	0	0
Charging Host Port, no charging device attached and SE0 (*VdatDet* = 0)	0	1	0	1	1	1
Charging Host Port, charging device attached (*VdatDet* = 1)	1	1	0	1	1	1
Charging Host Port USB Operation	0	0	0	1	1	1

Table 4-2 is an excerpt from the full DP/DM Termination vs. Signaling Mode table presented in the USB333x Data Sheet.

- RPU_DP_EN activates the 1.5kΩ DP pull-up resistor
- RPU_DM_EN activates the 1.5kΩ DM pull-up resistor
- RPD_DP_EN activates the 15kΩ DP pull-down resistor
- RPD_DM_EN activates the 15kΩ DM pull-down resistor
- HSTERM_EN activates the 45Ω DP and DM High Speed termination resistors

TABLE 4-2: DP/DM TERMINATION VS. SIGNALING MODE

Signaling Mode	ULPI Register Settings					USB333x Termination Resistor Settings				
	XCVRSELECT[1:0]	TERMSELECT	OPMODE[1:0]	DPPULLDOWN	DMPULLDOWN	RPU_DP_EN	RPU_DM_EN	RPD_DP_EN	RPD_DM_EN	HSTERM_EN
Charger Detection										
Connect Detect	01b	0b	00b	0b	1b	0b	0b	0b	1b	0b

4.2 USB333x USB-IF Charger Detection Register

This section presents the USB333x USB-IF Charger Detection Register (Address = 32h).

Field name	Bit	Access	Default	Description
VDatSrcEn	0	rd/w	0	V_{DAT_SRC} voltage enable 0b: Disabled 1b: Enabled
IDatSinkEn	1	rd/w	0	I_{DAT_SINK} current sink and V_{DAT_DET} comparator enable 0b: Disabled, V_{DAT_DET} = 0. 1b: Enabled
ContactDetectEn	2	rd/w	0	I_{DP_SRC} Enable 0b: Disabled 1b: Enabled
HostChrgEn	3	rd/w	0	Enable Charging Host Port Mode. 0b: Portable Device 1b: Charging Host Port. When the charging host port bit is set the connections of V_{DAT_SRC}, I_{DAT_SINK}, I_{DP_SRC}, and V_{DAT_DET} are reversed between **DP** and **DM**.
VdatDet	4	rd	0	V_{DAT_DET} Comparator output. *IdatSinkEn* must be set to 1 to enable the comparator. 0b: No voltage is detected on **DP** or *Linestate[1:0]* is not equal to 00b. 1b: Voltage detected on **DP**, and *Linestate[1:0]* = 00b. **Note:** *VdatDet* can also be read from the Carkit Interrupt Status register.
Reserved	5-7	rd		Read only, 0.

Note: The charger detection should be turned off before beginning USB operation. USB333x USB-IF Charger Detection Register Bits 2:0 should be set to 000b.

4.3 Detecting a Charging Port

1. Portable Devices can be charged while plugged into a Host PC. With a Charging Host, the Portable Device can use a larger current to charge up its battery relative to a Standard Host. To detect a Charging Host or Dedicated Charging Port:
2. When a cable connection is made, VBUS is detected and the USB Transceiver sends an RXCMD to the Link (SessValid='1').
3. Enable the V_{DAT_DET} comparator by setting IDatSinkEn='1' (bit 1 of the USB-IF Charger Detection Register, address 0x32).
4. Device puts 0.7V on DP by setting VDatSrcEn='1' (bit 0 in the USB-IF Charger Detection Register, address 0x32).
5. Charging Host detects >0.4V on DP and applies 0.7V to DM.
6. USB Transceiver detects >0.4V on DM and sets the VdatDet bit to '1' and sends an RXCMD to the Link with the "alt_int" bit set. VdatDet is set in both the USB-IF Charger Detection register and the Carkit Interrupt Status register.
7. Once the Portable Device knows that it is attached to a Charging Port, it can distinguish between a Dedicating Charging Port and a Charging Host Port by pulling either DP or DM to a logic high. If the Portable Device is attached to a Dedicated Charging Port, then the other data line will go high as well since DP is shorted to DM. If the Portable Device is attached to a Charging Host Port, then the other data line will stay low.

Note: To detect Dedicated Charging Ports that are not defined in the USB-IF Battery Charging Specification, refer to the resistive detection methods described in Section 3.2.2, Section 3.2.3, or Section 3.2.4.

8. If the Portable Device has determined that it is plugged into a Charging Host Port, it may turn on the 1.5k pull-up on DP to begin device enumeration. The current supplied by the Charging Host depends on the connection speed that is negotiated, as shown in Table 2-2. For a High Speed USB session, the Portable Device can draw up to 900mA. For a Full Speed USB session, the Portable Device can draw up to 1.5A.

   The *device* is responsible for insuring that the current does not exceed the limits defined in the USB Specification and the USB Battery Charging Specification.

   The timing associated with this algorithm described in this section is presented in Section 4.4, "Charger Detection Timing".

4.4 Charger Detection Timing

The detailed charger detection timing diagrams presented in this section are taken from the USB Battery Charging Specification, Revision 1.1.

FIGURE 4-2: HIGH SPEED CHARGER DETECTION TIMING

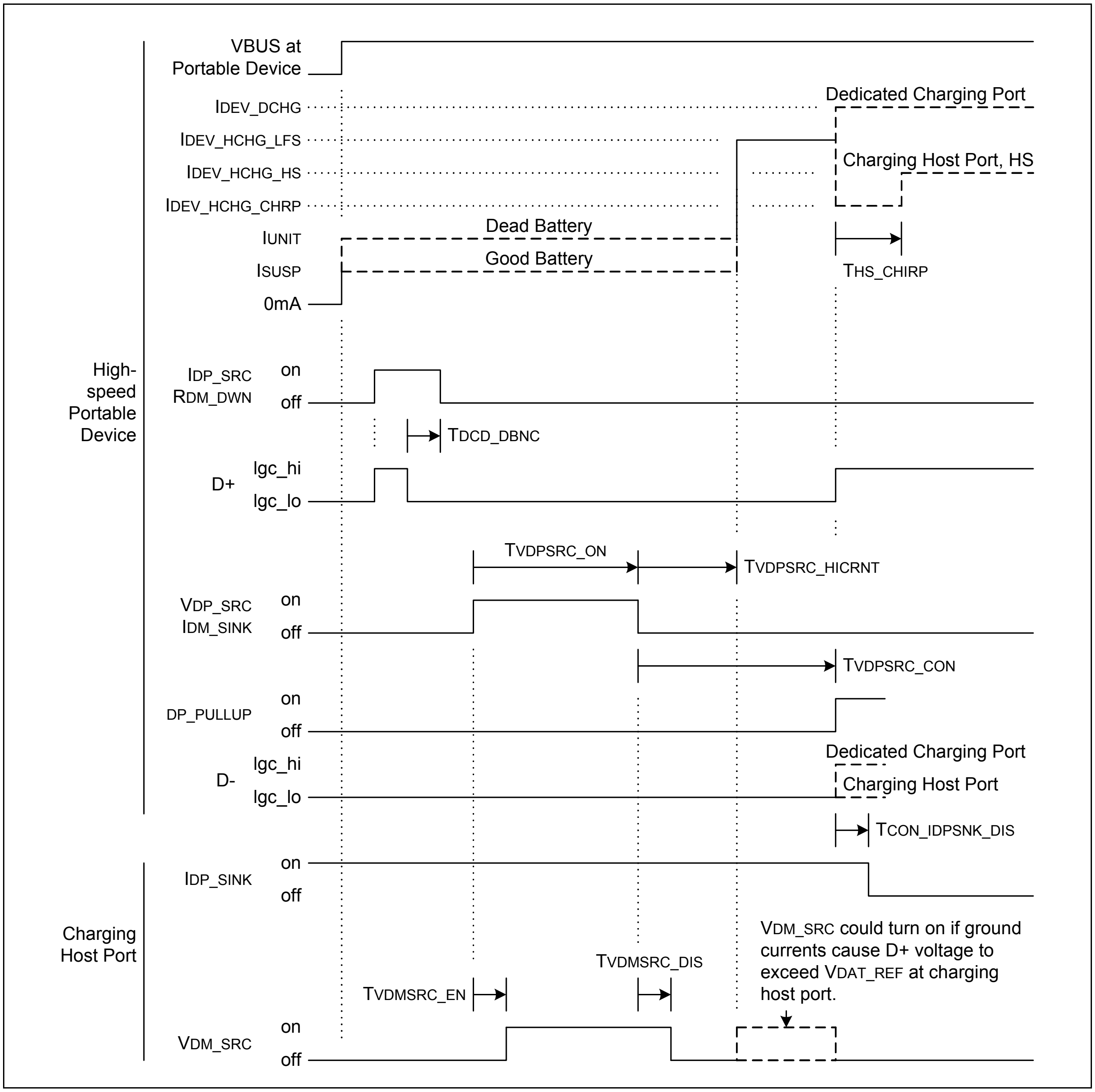
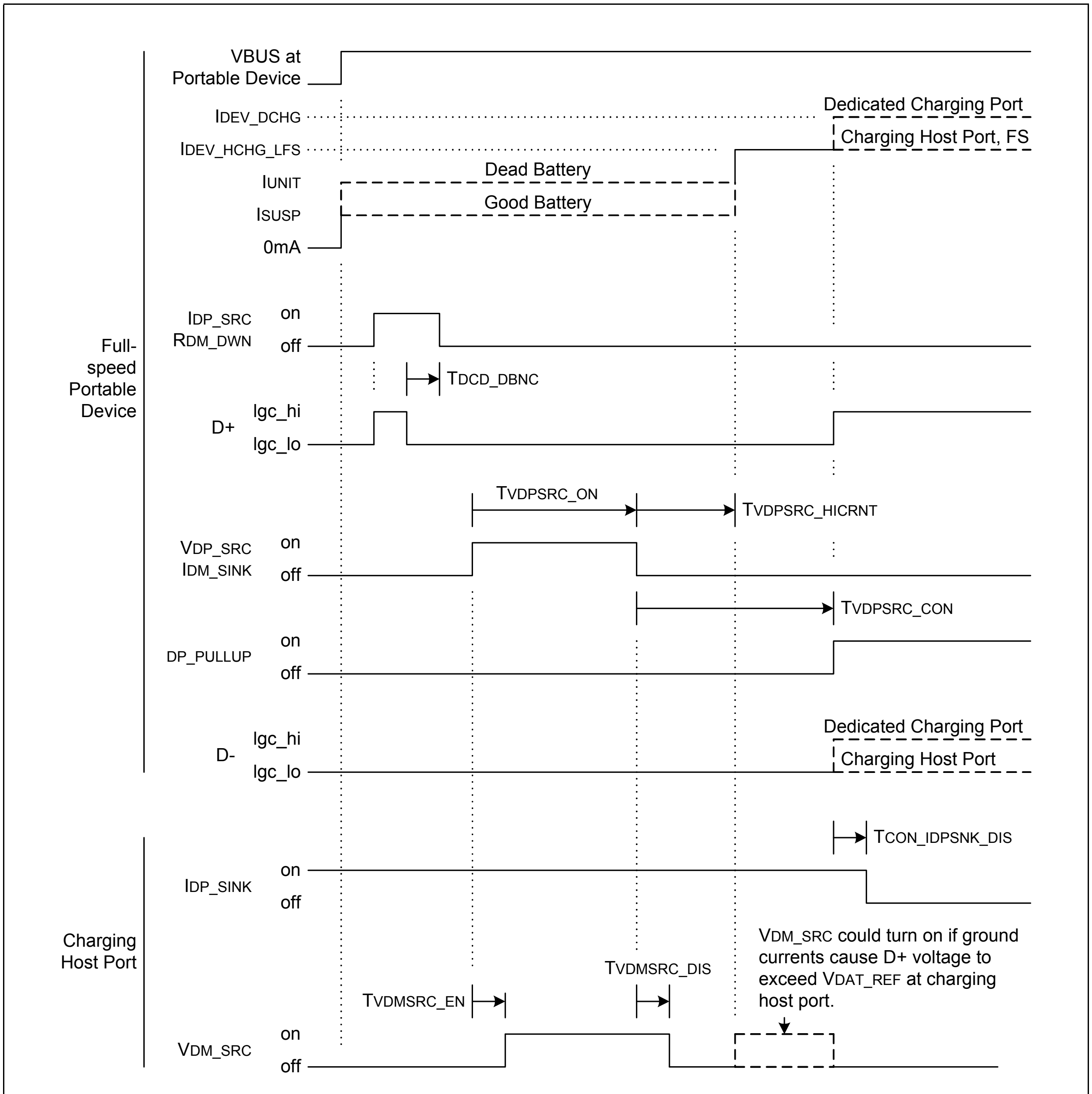


FIGURE 4-3: FULL SPEED CHARGER DETECTION TIMING



The charger detection timing for a FS Portable Device is the same as for that of a HS portable device, except that after the Portable Device connects, it can continue drawing up to IDEV_HCHGR_LFS (1.5A) from VBUS.

5.0 MICROCHIP USB TRANSCEIVER CHARGER DETECTION SELECTION GUIDE

Microchip offers a family of ULPI USB Transceivers that support the various methods of battery charging, and their capabilities are shown in the following table:

TABLE 5-1: ULPI TRANSCEIVERS

Mode Supported	USB333x	USB332x	USB331x
Dedicated Charger	Yes	Yes	Yes
Standard Host	Yes	Yes	Yes
Charging Host	Yes	No (Note 5-1)	No (Note 5-1)

Note 5-1 These products will connect to a Charging Host, but make not distinction between a Standard Host and Charging Host. Therefore, Portable Devices with these USB transceivers will be limited to the charging currents defined for a Standard Host, as defined in Table 2-2, “Maximum VBUS Current Supplied By USB Hosts,” on page 2.

APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision Level & Date	Section/Figure/Entry	Correction
DS00002950A (02-11-19)	REV A replaces previous SMSC version Rev. 1.0 (11-26-12)	
Rev. 1.0 (11-26-12)	Document co-branded: Microchip logo added, modification to legal disclaimer	
Rev. 1.0 (03-10-09)	Initial document creation	

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
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