Technical Notes
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USB Smartphone and Battery Charging

This Note describes USB port specifications and important design considerations for manufacturers that include USB ports in their products. It is intended as an introduction to the complex world of USB devices and technical issues involved with USB battery charging.

See also www.lightingglobal.org for additional Technical and Eco Design Notes

Introduction

USB (Universal Serial Bus) has become a widely adopted standard to connect battery powered devices to a computer or dedicated charger. Most cell phones, smartphones, computer tablets, and other portable battery-powered devices have USB ports that can charge the portable device's onboard battery and communicate (when necessary) to the host device/charger. In order to work properly, the portable device and the charger must be configured to allow the proper charge current to flow from the charger to the device.

The evolution of renewable energy products from small, simple lighting devices to larger Solar Home Systems (SHS) has frequently involved adding a USB charge port. The increasingly larger batteries in portable USB devices require faster charge currents, and this in turn requires USB charge ports to be appropriately designed to correctly supply the necessary signals and power needed by the portable device. Simple 5V power supplied to a USB receptacle is no longer sufficient to charge many smartphone and tablet devices.

This Technical Note will describe USB battery charging from the perspective of a Solar Home System or other renewable energy product seeking to provide power to a battery powered USB device. Descriptions of current USB specifications, as well as a brief history of the evolution of the USB standard, will be followed by a discussion of hardware and other considerations. An emphasis will be placed on smartphone and tablet charging.

USB basics

Specifications for USB devices are controlled by the USB Implementers Forum, Inc. (USB-IF), a non-profit corporation founded by computer industry stakeholders. The *Universal Serial Bus Specification Revision 1.0* (USB 1.0) was first released in 1996 and has since undergone a number of revisions. Engineering Change Notices (ECNs) are added to existing revisions and published twice yearly. The latest revision as of July 2017 is the *Universal Serial Bus 3.1 Specification Revision 1.0* (USB 3.1).

USB started as a communication interface. The major revisions are associated with the speed of the communication, and USB components are encouraged by USB-IF to use the various speed categories to describe their products (Table 1).

Table 1. USB speed categories

Revision	data speed category	data speed (bps)
USB 1.1	low, full	1.5M, 12M
USB 2.0	low, full, high	up to 480M
USB 3.0	low, full, high, SuperSpeed	up to 5G
USB 3.1	low, full, high, SuperSpeed, SuperSpeedPlus	up to 10G

USB power was originally intended as a feature to enable peripherals such as computer mice and keyboards to operate without separate, stand-alone power supplies. As USB devices proliferated and device performance has increased, USB specifications have changed to keep up with the increased demands of speed and power delivery. At the same time, the USB specification has focused on retaining backwards compatibility among the various revisions so that older devices and cables will continue to work with newer systems.

USB cables

The original USB 2.0 hardware cable styles consist of plug and receptacle combinations that have 4 pins and a ground shield (Table 2). **+5V VBUS** and ground lines supply power, and data is carried by a twisted wire pair with **+D** and **-D** designation. The host connection is made with a USB Standard-A connector, and device-side connections are made with Standard-B, Mini-B, and Micro-B connectors (Figure 1).

Table 2. USB 2.0 wire designations

Pin #	Name	Function	Color
1	VBUS	+5V	Red
2	D-	Data positive	White
3	D+	Data negative	Green
4	GND	ground	Black
Shell	Shield	noise reduction	n/a

USB 3.0 introduced more data lines and faster speeds which required additional wires and an expanded plug/receptacle. USB 3.1 followed with increased shielding requirements on the cable to support yet more speed under the SuperSpeedPlus designation. In 2009, the European Union introduced a specification for a **common external power supply** (common EPS) requiring that all mobile phones sold in Europe must accept a Micro USB-B plug (adaptors can be used to allow other proprietary cables such as Apple's Lightning connector).

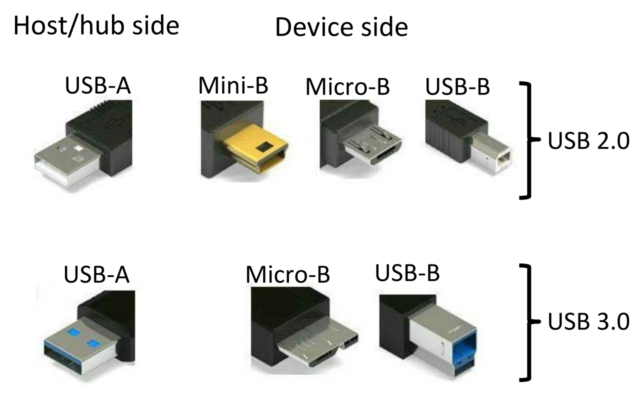

Figure 1. USB A and B connector types

When a USB device is connected to a host with a USB cable, the host attempts to communicate to the device in a process called **enumeration**. Successful enumeration allows the host and device to negotiate a safe power level that the device can draw. It is the responsibility of the USB device to limit the power it draws. The host is responsible for maintaining the proper **VBUS** voltage and supporting current levels according to the connection type.

USB port definitions

USB system components are divided into several categories. A **USB host**, often a computer (but also a renewable energy product), has a **root hub** and at least one **USB port** that can supply power and (optionally) data. A **hub** has one **upstream** port to communicate with the host and one or more **downstream** ports to attach to devices or another hub (in a base case, the host and root hub are a single unit and the upstream port between the host and root hub is internal). A **USB device** is some type of electronic device that has a function and is connected downstream from a USB host or hub. Examples of USB devices typically include phones, computer mice, keyboards, printers, cameras, speakers, monitors, and other electronic hardware that communicates with the USB host (and sometimes draws power). In the case of battery charging, a USB root hub (or an external hub) can be configured to supply power to a device without the need to communicate, though this may prevent some devices from charging at their maximum rate.

There are five different port types in terms of power transfer between a hub and a device:

- Standard Downstream Port (SDP)
- Dedicated Charging Port (DCP)
- Charging Downstream Port (CDP)
- Accessory Charger Adaptor (ACA)
- ACA-Dock

Standard Downstream Port (SDP)

An SDP can be either a USB 2.0 or USB 3.1 type port depending on the wiring configuration and available speed of the host or device. In cases of a USB 2.0 host/device connected to a USB 3.1 host/device, the lower USB 2.0 limits apply. Hubs are further categorized as either low power or high power. When a device is attached to a hub, the default state is low power. After successful enumeration, the hub and device can enter a high power state if this is supported by both the hub and device. These power levels are summarized in Table 3.

Table 3. Low and high power USB SDP ports

Hub type	port current	VBUS min (V)	VBUS max (V)
USB 2.0 low power	100 mA	4.4	5.5
USB 2.0 high power	500 mA	4.75	5.5
USB 3.1 low power	150 mA	4.45	5.5
USB 3.1 high power	900 mA	4.45	5.5

These charge current levels can be exceeded if the port is a charging type port outlined in the following charging port definitions:

Dedicated Charging Port (DCP)

A DCP supplies up to 1.5A to its downstream port. With this port type, no enumeration is required between device and port. The D+ and D- pins in the hub's DCP port are shorted (200ohm max connection). A device attached to a DCP may draw a current between 0.5 and 1.5A, so the DCP should be capable of maintaining that power level.

Since no enumeration is required, DCP's represent a very simple configuration for battery charging. Many stand-alone chargers employ this configuration, and 1.5A is adequate for most smartphone charging needs. Proprietary chargers like those found in some Apple and Samsung products, particularly tablets, may not charge (or may charge very slowly at low power levels) from DCP's (see **Proprietary USB Chargers** below).

Charging Downstream Port (CDP)

A CDP also supplies up to 1.5A, but unlike a DCP (the similarity in initials is unfortunate), this port type is intended as a communications port and requires enumeration.

Accessory Charger Adaptor

ACAs were developed to allow a device (like a smartphone) with a single USB port to be connected to both a peripheral device and a USB charger. This situation arises, for example, when a battery powered host (for example, a smartphone with one USB connector) is being used with a device (such as a headset). If the user also wants to charge the phone while using the headset, an ACA can be used.

In this example, the smartphone, headset, and a USB charger are all connected to the ACA. The ACA allows the charger to charge the smartphone, and also allows the smartphone to communicate with the headset. This is a specific, though useful, case where the limitations of a single USB connector on a device can be overcome to allow full functionality of communication and battery charging.

ACA-Dock

An ACA-Dock is a type of ACA that has a vendor specific charger connection intended for use with a specific device.

USB battery charging specifications

Battery Charging Specification Revision 1.2 (BC1.2)

The different port types described in the above section were first defined in the *Battery Charging Specification Revision 1.2* (BC1.2) published in 2010. In addition to the port definitions, BC1.2 specifies primary and secondary charge port detection sequences and port specific performance requirements. These include required operating range, undershoot, detection signaling, and connectors for each port type. Also included are dead, weak, and good battery charge conditions, port shutdown procedures, and other details associated with battery charging.

BC1.2 was published after USB 2.0 but before USB 3.1 and so the information in BC1.2 refers to USB 2.0. The specification is, however, consistent and compatible with USB 3.1.

USB Power Delivery and USB-Type C

USB Power Delivery Specification was introduced as an answer to ever increasing power and data needs of USB devices. Revision 3.0 (USB PD rev 3.0 v1.1) was released in January 2017. USB PD allows for bi-directional power transfers up to 100 watts (20V, 5A).

USB-Type C (USB-C) cables are the latest hardware addition to the USB cable universe. USB-C cables are reversible in the receptacle (i.e. not polarized) and reversible end-to-end, making them very simple to use because no orientation at all is necessary when connecting devices. Charger detection is accomplished with the addition of a dedicated Configuration Channel (CC) wire. Although USB PD is not strictly limited to USB-C cables, significant limitations are present with older USB-A and USB-B cables that try to use USB PD.

Though the Power Delivery specification was first introduced in 2012, it has taken a number of years for the USB PD to catch on. 2017 has seen a marked rise in USB-C devices with PD features and this trend is expected to continue as the benefits of this system become apparent to consumers. USB PD and USB-C cables represent the future of USB, and while it may take some time for legacy connectors to disappear, eventually USB is likely to become synonymous with USB-C type cables.

Non-standard (proprietary) USB chargers

Not all devices with USB type connections adhere to USB-IF specifications but instead are designed with proprietary chargers that have manufacturer specific configurations. These devices have USB connectors, but they may charge slowly (or not at all) when used with USB 2.0 or USB 3.1 type chargers. Larger devices in particular (e.g. tablets) are known to have issues with other manufacturers chargers because they have higher capacity batteries and larger current draws when running. Examples of proprietary charge methods include those from Apple, Samsung, Qualcomm (Quick Charge), and Intel (Thunderbolt 3) among others. In some cases, these systems are also compatible with USB BC1.2 or USB PD.

Apple

Apple implements a proprietary charge scheme by using resistor dividers to hold the D+ and D- data pins at specific voltage levels. When an Apple device is connected to an Apple charger, the device will sense these voltage levels and set its charge current accordingly. If other voltages are detected, the device may choose a lower charge level or possibly not charge at all. These Apple chargers use resistor dividers to hold the D+/D- lines at 2 and 2.7V to indicate the charger capability (Table 4).

Table 4. Apple charger voltages

D+ voltage (V)	D- voltage (V)	Charge current (mA)
2	2	500
2	2.7	1000
2.7	2	2100
2.7	2.7	2400

Samsung

Samsung Galaxy S series tablet chargers short the D+ and D- lines (the same as a DCP) but then hold both these lines at 1.2V.

Nokia

Lighting Global internal testing has found that older Nokia cell phones, still prevalent in some markets, require a minimum 5.3V before they will accept a charge. Manufacturers interested in supporting these older Nokia models should test their USB ports to ensure compatibility, and set the port voltage accordingly. Providing a dedicated port for these phones is also a possibility.

Qualcomm Quick Charge

Qualcomm Quick Charge is a proprietary charge algorithm found on certain Android and Windows mobile devices. Quick Charge was designed to exceed the charge rates of standard USB protocols. Quick Charge 4, released in December 2016, is compatible with USB PD and USB-C specifications, while previous versions are not.

Thunderbolt 3

Thunderbolt 3 is a platform that offers higher speed (40 Gbps) and is compatible with USB PD. Thunderbolt 3 has been released by Intel with a perpetual free license to any manufacturer who wants to use it.

Other proprietary platforms

Phone and device manufacturers that use proprietary charging include LG and HTC (QuickCharge), Motorola (TurboPower), OnePlus (DashCharging) charging and others.[11]

USB Adaptor Emulators/Charging Port Controllers

Several electronics manufacturers offer integrated circuits (ICs) that can provide device detection and automatic configuration to allow charging at a device's maximum rate. These emulator ICs can simplify the design of a USB charger and serve as drop-in components to handle the enumeration and charger detection stages of a host/device connection. Emulator chips are designed to be compatible with many device types and may or may not include add-on features for controlling the port. Though they represent an added cost, these ICs have the potential to significantly shorten the USB port design process.

Summary

The evolution of the USB specifications from "a data interface capable of supplying limited power to a primary provider of power with a data interface"[4] has required additional layers of complexity to keep up with the advance of device requirements. Backwards compatibility remains a priority to sustain the USB standard, reduce the proliferation of electronic waste, and prevent obsolete cables and chargers from depressing the use of the protocol by device manufacturers.

Manufacturers of renewable energy products that include USB charge ports should be familiar with the battery charging and power delivery specifications in the various USB standards. This will help in the design of these ports, and following the specifications will increase the likelihood of their products successfully charging a higher number of devices. For manufacturers that seek to charge as many USB devices as possible, extensive testing may be necessary to ascertain the charge performance of their products with the very large number of rechargeable USB devices currently in use.

After many years with the original USB-A and USB-B connection types, the industry is now pursuing a single cable, USB-C, that will meet the vast set of requirements of the many electronic devices sold into the market. USB-C devices that use the USB-PD protocols are starting to appear in greater numbers, and while it remains to be seen how much of the market migrates to the new standard, the past few years have seen increased adoption by major computer and device manufacturers.

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