

White Paper

USB Power Delivery Changes the Game

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Abstract

Connections between equipment for data transfer and power are being revolutionized by the adoption of 'USB Power Delivery', a version of USB that allows up to 100W to be passed in either direction. This white paper traces the history of the standard and its capabilities up to the present day with USB Type-C™ cables and connectors enabling 'Super-speed' communication while providing bi-directional power transfer for peripheral operation and battery charging. Practical advantages of USB Power Delivery are described along with the wider benefits of reduction in complexity and number of interconnections and their environmental impact. Integrated circuit solutions for the design of interfaces to control power flow are introduced.

USB Power Delivery origins

The Universal Serial Bus concept was born in 1994 with its origins in a forum of industry leaders - Intel, Microsoft, Compaq, Apple and Hewlett-Packard. The idea was to replace the proliferation of serial and parallel interfaces in computer systems that needed expansion cards and custom drivers with a Universal Serial Interface, USB, that was faster by far and was 'plug and play'. Initially the emphasis was on improved speed and interoperability but a couple of extra wires were added in with +5V power and return from the host. Only 100mA was available according to the original USB 1.0 specification but that was useful for a mouse or other very low power peripherals.

As data transfer speed requirements increased, the 12 megabits/second optimistically-termed 'full speed', of USB 1.0 became inadequate and USB 2.0 was introduced in 2000 with a leap to 480 megabits/second. A principle of USB design is backwards compatibility so USB 2.0 devices could operate at the lower rates down to 12 or even 1.5 megabits/second. USB 2.0 also upgraded the 5V power source capability to 500mA/2.5W which users soon found could be useful for charging batteries in portable devices such as cell phones. As this became a common use for a USB port, often with no data exchange at all, the founding organization 'USB Implementers Forum' (USB-IF)^[1] introduced USB 3.0 which, amongst other things increased power to 900mA/4.5W and introduced a mode 'CDP' (Charging Downstream Port). A battery charging specification (USB BC) was generated in 2007 which allowed yet higher current to 1.5A, or 7.5W at 5V. BC 1.2 in 2010 introduced a more robust specification for charging operation. International standardization of USB performance for data and power has now been formalized, IEC 62680-2-1:2015^[2] being the latest revision.

A feature of USB so far was that power could only be sourced from the host although data was bi-directional. The connector is 'hot' with 5V present continuously, meaning that two hosts in theory could interconnect and exchange data but would both try to apply power which could damage one or the other. Active devices that could source power at different current levels need to 'enumerate' with the peripheral to communicate what power is available and required, with this done over the data lines, interrupting their operation. Dedicated charging ports did not need enumeration, however. These disadvantages, along with the 7.5W power limit were problematic to further development of power sourcing over USB.

A parallel topic was the increasing complexity and compatibility problems seen interconnecting and powering peripherals that might be used with a PC or laptop. More devices started to use adapters or 'wall-warts' for AC power

conversion to perhaps 19V for a laptop or 12V for a printer or external hard drive. A desk top might look like **Figure 1** with multiple tangled and incompatible power and data cables.

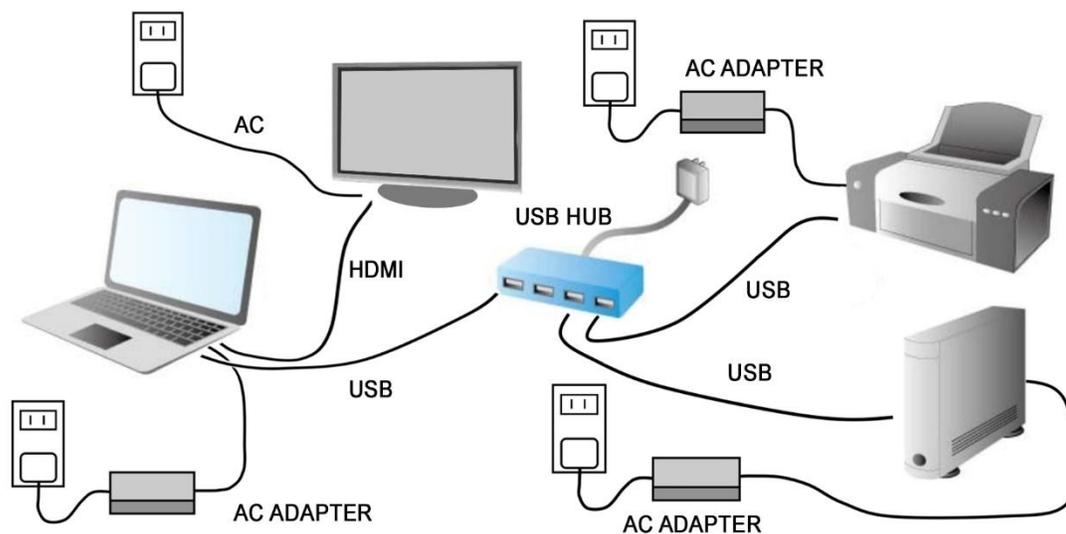


Figure 1. Interconnections before USB PD

When travelling, several heavy adapters and chargers might be needed along with foreign mains socket converters. The problem of E-waste also came to the fore with average households accumulating boxes of cables and obsolete adapters that didn't match the latest gadgets bought. The variety of USB connectors that had emerged also didn't help with 'standard', 'mini', 'micro' form factors in type A, B and AB. USB 3.0 also introduced a 'superspeed' transfer mode which started at 5 Gigabits/second and increased to 10 Gigabits/second with revision 3.1. This required yet another suite of cables and connectors with nine wires in the USB 'standard' and 'micro' formats.

Capabilities of USB Power Delivery Introduced

To address the power limit situation, USB 'Power Delivery' specification USB PD 1.0 was conceived and released in 2012 by the USB Implementers Forum, USB-IF. In this, the output voltage is now variable from 5V to 20V and with a negotiated current of up to 5A giving a potential 100W in total. This opened up the tantalizing possibility of charging laptops directly from a USB port or powering peripherals like monitors over USB cables, eliminating the separate mains connection. The specification includes detail of the enumeration between devices to ensure that over-voltage is not applied and current is limited to what is required only. Initially the source outputs 5V, deemed as safe for all legacy devices and limits power to 10W. Thereafter, negotiation takes place to set one of five standard 'profiles'. See **Table 1**.

Source Output Power (W)	Current at: (A)				
	+5V	+9V	+15V	+20V	
0.5 - 15	0.1 – 3.0	N/A	N/A	N/A	
15 - 27	3.0 (15W)	1.67 – 3.0	N/A	N/A	
27 - 45		3.0 (27W)	1.8 – 3.0		
45 - 60			3.0 (45W)	2.25 – 3.0	
60 - 100				3.0 – 5.0	

Table 1. USB PD profiles

Another significant change was to separate the enumeration function from the data wires – with standard Type A and B USB connectors, all negotiation now takes place by manipulation of the power line VBUS, making data transfer and power delivery entirely independent. Additionally, USB PD 1.0 allowed energy transfer in both directions giving flexibility in sharing of power between devices. For example, an AC powered monitor can also charge a laptop through its USB connection or a laptop charging from AC mains or operating from its battery can also power the monitor through USB PD.

In practice, because all legacy USB connector types up to this point had a 'hot' 5V applied all the time from a source, it was not possible to use the bi-directional power flow capability without resorting to a non-USB compliant arrangement.

USB Type-C™ Connectors Enable More Functionality

The solution to extracting the full potential of the USB PD specification is the 'USB Type-C™' connector (**Figure 2**). USB Type-C™ and USB-C™ are trademarks of USB Implementers Forum. With 24 connections in a 'flippable' format, the connector is smaller than types A and B with a plug height of just 2.4mm, ideal for slim-line products. As USB Type-C™ connectors can handle 'alternate modes' such as DisplayPort™ over USB-C™, fewer types of connectors are needed on laptops for example.

Now separate power adapters are not necessarily needed with power provided from perhaps the laptop and distributed via the USB Type-C™ cables to the monitor and other peripherals. The video signal for the monitor could also use the HDMI™ 'alternate mode' connections in the cable. A desktop might now look like **Figure 3** with just one connection to AC mains and otherwise all cables identical types.



Figure 2. USB Type-C™ connector

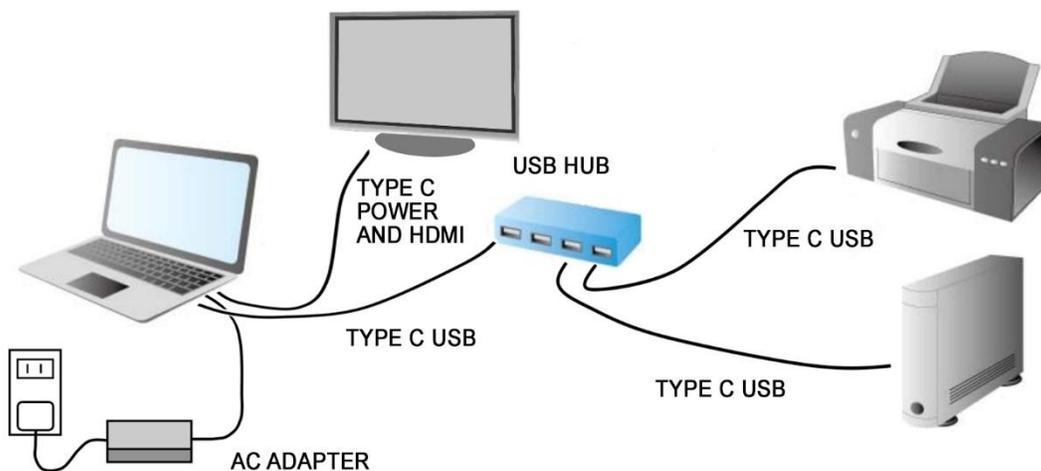


Figure 3. USB Type-C™ connections avoid multiple cable types and power adapters

The connector is now 'cold', in that devices interconnected now do not impose any voltage until source and sink have been identified. This facilitates bi-directional power flow which can seamlessly change direction, identified as Fast Role Swap (FRS) – a power bank for example, can have a single USB Type-C™ connection to a laptop which automatically switches from charge to discharge. A Programmable Power Supply (PPS) function is also available which allows either fixed voltages for the power connection (5V, 9V, 12V, 20V) or a programmable value which allows

fine control of charging applications for maximum efficiency. Lithium-Ion batteries for example, are best charged initially at constant current with slowly increasing voltage, followed by constant voltage. With the fixed voltage of non-USB PD applications, the charge would need to be controlled at the battery with a dissipating regulator. With PPS, the source switched-mode power supply can be programmed to do the same with little or no change in efficiency. Standard IEC 63002^[3] defines the protocols for monitoring and controlling an External Power Supply (EPS).

USB PD with USB Type-C™ cables also enables built-in safety management to cover eventualities such as a non-compliant device requesting higher current than its cable can withstand. Connected devices and cables can be identified as USB-IF compliant and if found not to be, only legacy levels of power are allowed, 5V 0.5A.

Looking at the USB Type-C™ connector pinning, **Figure 4**, configuration channels CC1 and CC2, are used to identify cable orientation, source and sink current direction and power level negotiation. The ability to 'flip' the connector or mate it in either orientation is facilitated by the symmetrical placement of GND, VBUS and the legacy USB 2.0 connections. High speed data lines TX1+/-, TX2+/-, RX1+/-, RX2+/- are not interchangeable though, so the connected device must detect orientation and route the data lines through a multiplexer to direct the data accordingly. USB 3.1 only uses four of the superspeed lines and the others are reserved for future use or can be used for the alternate modes. Examples would be routing DisplayPort video signals through the connector when used with a monitor. Other possibilities include HDMI, Thunderbolt™, MHL or PCIe®. The SBU pins are not used for USB but can, for example, be AUX connections in display port applications.

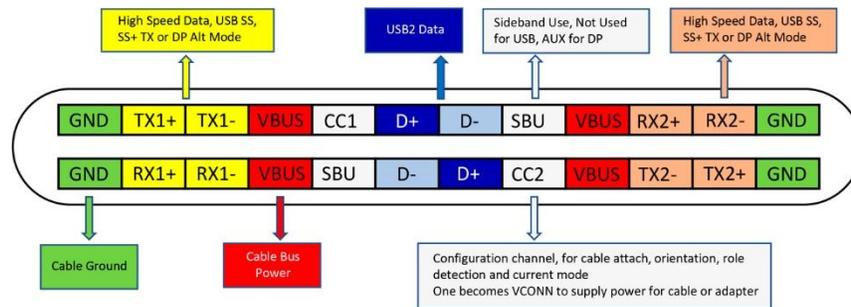


Figure 4. USB Type-C™ connector pin allocation

The cable used with USB Type-C™ connectors is shown in cross section in **Figure 5**. Compliant cables incorporate an 'E Marker', which returns information to controllers about the manufacturer, the cable specification and more, a valuable guard against counterfeiting.

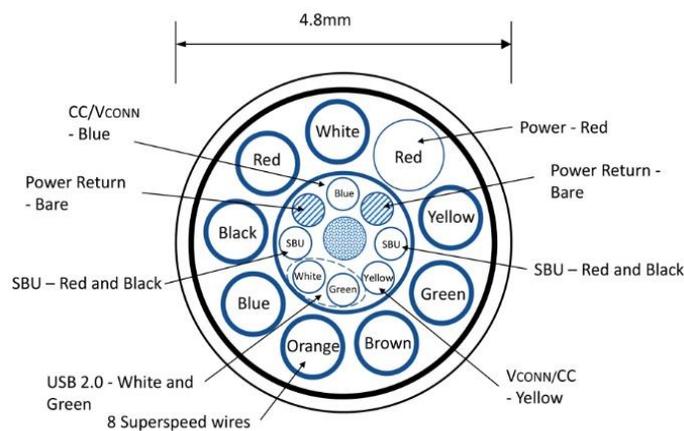


Figure 5. USB Type-C™ cable cross section

Controllers Implement the Features of USB PD

With flexibility comes the requirement to monitor and control the power flow and data connections so there must be an active controller in devices at each end of a USB PD system. Let's look at a typical scenario of an AC adapter connected to a device by a compliant USB Type-C™ cable, **Figure 6**.

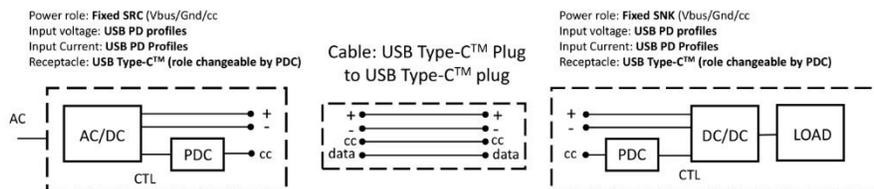


Figure 6. Portable device and AC adapter USB PD application

After the connection is made, 5V is applied to VBUS, marked '+', and by pull-up or down resistors on the CC lines, the adapter on the left is identified as a source and the device on the right as a sink. Communication now starts and the 'E-marker' in the cable is interrogated, an XID identifier checked against a 'white list' of approved products and the current carrying capacity (3A or 5A) of the cable identified. This is termed the C-AUTH function. Negotiation then follows, with the source stating its power capability and the sink, its requested voltage and current. On agreement of compatibility, the source voltage is raised to the appropriate level. Voltage, current and temperature are monitored at both source and sink, with source power reduced if a problem is detected. Another scenario is typical of a cell phone being charged from an AC/DC adapter through USB PD, **Figure 7**. Charger on the left, cell phone on the right.

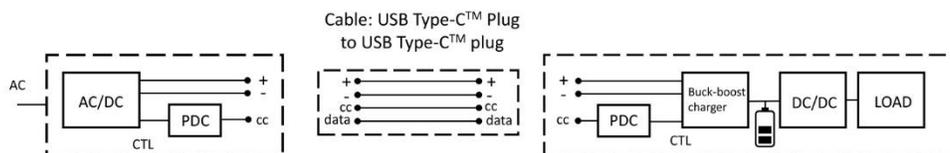


Figure 7. Typical USB PD application of device and charger with USB Type-C™ cable

When power flow needs to be bi-directional, a similar 'handshaking' occurs with each device initially 'toggling' between source and sink states until direction of required current is established.

USB PD Needs Device Controllers

Given the complexity of monitoring and control needed, integrated controller solutions have been developed which include the Fast Role Swap and programmable Power Supply features. Devices can include the fault condition monitoring of over-voltage, current and temperature and even the C-AUTH function of validating the authenticity of cables and connected devices. MCU internal functionality can support the C-AUTH function and internal flash memory can be re-written with changes to product specifications and XIDs. Having this degree of intelligence in the controller enables compliance with Energy Star® and EuP specifications for low power PC peripheral systems by fine adjustment of dissipation in connected devices through monitoring and setting of bus voltages. Parts can be self-contained with an on-chip oscillator and as small as the R9J02G012^[4] device from [Renesas](#) for example, at 3.6 x 3.1mm in a BGA package. A particular feature of this device is that it is capable of firmware update over the USB Type-C™ cable for upgrade and maintenance.

For the source power requirements, AC-DC or DC-DC converters are needed that can be monitored and controlled according to the USB PD specification. Integrated solutions are again available. For example, the AC-DC adapter in Figures 6 and 7 may be based on a flyback circuit which has Pulse Width Modulation (PWM) control to set the fixed output voltage or variable for PPS applications. Parts such as the Renesas RAA23016^[5] have an internal switching

MOSFET which can provide up to 60W at 95% efficiency and, when used with a USB PD controller such as the R9J02G012, form an integrated solution using minimal board area. Parts in the Renesas ISL95338 range are also available for the buck-boost regulator function^[6] using a versatile structure of external switching MOSFETs. Parts such as the Renesas ISL9241^[7] can perform battery charging and battery power sourcing as well as buck-boost DC-to-DC power conversion.

There are applications where power conversion needs to be bi-directional. A good example is a ‘power bank’ connected by USB Type-C™ cables to a portable device, **Figure 8**.

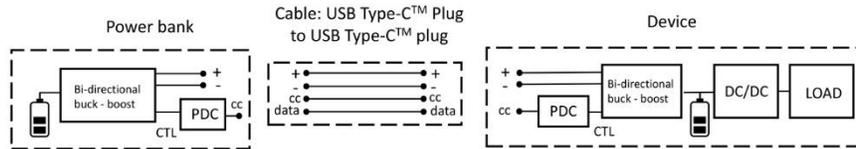


Figure 8. Power bank USB PD application

When the power bank is charging, a voltage within the USB PD range of 5V – 20V is supplied from the device with the final lithium-ion battery cell voltage derived from a step-down ‘buck’ converter in the power bank. When the power bank is required to provide power, a ‘boost’ converter supplies a higher voltage back to the original source within the USB PD range. Fortunately, there is a buck-boost converter topology that can perform both functions in one power stage **Figure 9**.

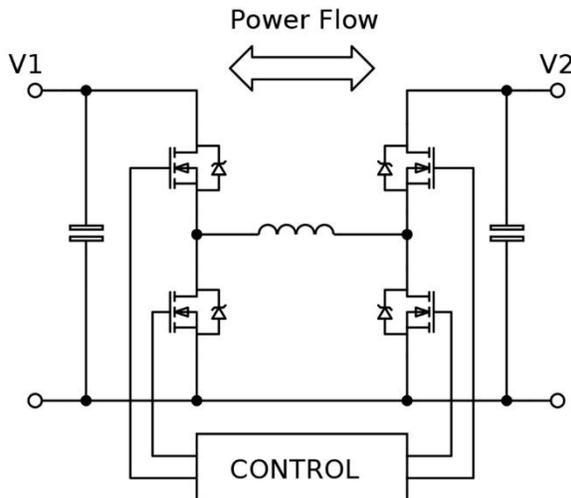


Figure 9. Buck-Boost converter configuration

By setting combinations of the MOSFETS permanently on or off while switching the others under PWM control, the functions of boost or buck can be achieved in either direction.

The boost conversion ensures that the voltage delivered back to the portable device remains in the USB PD range even as the battery discharges to a low value. A PWM controller is needed for the buck-boost converter, with parts available from Renesas which integrate with their USB PD controllers and provide seamless role reversal from source to sink, buck to boost, with all the necessary fault monitoring included.

Reference design kits are invaluable for developing USB PD solutions, customizing performance to the requirements of the application through firmware. Versions available from Renesas currently are: a generic power sink, a multi-port USB PD Buck-boost DC/DC module and a one-port power bank (battery pack). With the integrated facility to re-write flash memory in the Renesas controllers, debugging is easy and updates to a completed design are easily achieved through the USB connection.

Components in a USB PD system can qualify for accreditation in a USB IF compliance program, which provides a guarantee of performance to the USB specifications. Products that comply are added to the Integrators List and can be licensed to show the USB-IF logo. The website www.usb.org features a free-to-view document library, developer information and details of their compliance program. A product search is provided to identify products that meet the USB-IF compliance requirements. All Renesas USB PD products are compliant, enabling end products to be the same and show the compliance logo.

Conclusion

USB PD is a revolution in the powering of devices that applies from cell phones through to power-hungry laptops and monitors. The technology promises a reduction in cabling and the number of power sources needed with consequent savings in energy, cost and waste in the environment. Protection against hazards comes with the package along with many user convenience advantages. Implementing USB PD solutions has never been easier with integrated suites of controllers from companies such as Renesas. Comprehensive design guidelines and application information is available on their website www.renesas.com.

References

- [1] USB Implementers Forum www.usb.org
- [2] IEC 62680-2-1: 2015 Universal serial bus interfaces for data and power
- [3] IEC 63002: Identification and communication interoperability method for external power supplies used with portable computing devices
- [4] Renesas R9J02G012 <https://www.renesas.com/eu/en/products/renesas-usb-power-delivery-family/c30-group/r9j02g012.html>
- [5] Renesas RAA230161 <https://www.renesas.com/products/renesas-usb-power-delivery-family/u30-group/raa230161.html>
- [6] Renesas ISL95338 <https://www.renesas.com/us/en/products/power-management/battery-management-systems/multiple-cell-battery-chargers/device/ISL95338.html>
- [7] Renesas ISL9241 <https://www.renesas.com/us/en/products/power-management/battery-management-systems/multiple-cell-battery-chargers/device/ISL9241.html>