Low-cost implementation of USB Type-C™

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Incorporate USB Type-C into an existing platform at minimal cost while using just one device.

The USB Type-C™ or USB-C™ connector interface offers a reversible cable, and a flippable plug, with power delivery of up to 100W for USB 3.1 and alternate-mode support. However, system designers must choose features carefully to keep their system's overall cost reasonable. Many low-cost Type-C systems only have USB 2.0 and a native Type-C power capability of 15W. In this paper, I discuss a one-chip solution for these Type-C implementations. The solution provides channel configuration (CC) functions with a dual-role port (DRP) capability so it can be used for low- and mid-range implementation for portable applications such as smartphones, tablets, phablets, notebooks, hubs, docks, automotive infotainment, external hard disks and other peripherals.

USB Type-C probably created the most interest and buzz at its inception compared to any other connector interface. This is no surprise given that the interface promises to consolidate data, power and video on a single connector. Interestingly, this appears to be history repeating itself when 20 years ago USB 1.0 allowed fragmented electronics to communicate with each other through a single-connector/cable interface – ushering in a new era of communication. Since then, USB has remained one of the most popular connector interfaces in electronics.

While USB 2.0 streamlined power-charging for electronic gadgets, we still have to pack a number of chargers in our suitcases when traveling because laptops, tablets, phones, cameras, personal electronics all have different power requirements. Imagine using just one charger to satisfy the needs for all these gadgets! USB Type-C introduces a native power capability of 15W and an enhanced capability when adding USB power delivery (USB-PD), allowing power charging up to 100W. That's plenty for most of our electronic toys. With ever more power-efficient semiconductor chips, hopefully, we will not have to revisit this topic in the foreseeable future.

USB Type-C provides native support for USB 2.0 and 10 Gbps USB 3.1 data communications with options to support alternate-mode (AM) through USB-PD. Native uncompressed video content, such as display port, is easily supported through Type-C using one of the alternate-mode options. ***Table 1*** summarizes USB Type-C options.

Parameter	Channel configuration Controller	USB-PD
Power	15W	100W
USB 2.0 and 3.1	Yes	Yes
Video	No	Yes

Table 1: USB Type-C options with a native channel configuration controller versus USB-PD

USB Type-C introduces new connectors for both receptacles and plugs that are smaller, thinner and more robust. These new cables can be plugged into a host or device in either direction, while still maintaining a traditional USB host/client relationship. The plug can connect into a receptacle up-side-up or upside-down (flippable). This flexibility and simplicity does add some level of complexity and cost of system implementation by platforms. While the new eco-system provides more options for implementations such as enhanced power, alternate modes, higher data throughputs and so on, system designers must choose which capabilities they need to implement in order to keep their overall system cost to an acceptable limit. These are all important factors for maintaining a positive user experience to which USB users have become so accustomed. For many systems, USB 2.0 speed and Type-C native power delivery of up to 15W is good enough, considering reasonable use case and implementation cost.

USB 2.0

USB 2.0 is a 4-wire interface with two data (D+, D–), one ground (GND), and one power (V_{BUS}®) pin. The interface is half-duplex and supports three data throughput speeds: low-speed (LS) at 1.5 Mbps; full-speed (FS) at 12 Mbps; and high-speed (HS) at 480 Mbps. USB 2.0 establishes a point-to-point interface between a host and client device (or hub) where a host controls the bus and provides 5V and 500 mA power though a V_{BUS} wire to an attached device. Additional power using USB battery charging (BC 1.2) is possible, but at the expense of more complexity and hardware. Popular USB 2.0 connectors include Type-A, Type-B and micro/mini A/B receptacles and plugs.

USB On-the-Go (OTG) introduces a fifth pin (ID) into the interface through micro A/B connectors. This fifth pin allows certain devices such as a mobile phone to alter its role between client device and host. It acts as a client when connected to a PC and as a host when connected to various USB media storage devices.

USB Type-C

Let's look at more details about USB Type-C. ***Figure 1*** shows a USB Type-C plug. The receptacle allows ultra-thin platform implementations such as notebook PCs and smartphones with a maximum mounted receptacle size of less than 3-mm high by 8.4-mm wide. Type-C receptacles are the same in both client and host systems. The Type-C cable has identical plugs at both ends, making it symmetric.

Figure 1: USB Type-C plug.

Figure 2 shows a USB Type-C receptacle pin map. The 24-pin interface is arranged in a symmetrical fashion and includes four pins for USB 2.0, eight pins (four pairs) for SuperSpeed USB, and two pins for alternate-mode, side-band signals. Additionally, two pins are used for channel configurations and USB-PD communications, four pins for V_{BUS}, and four pins for GND. The connectors and cable assembly are defined such that SuperSpeed USB differential pairs can carry data up to 20 Gbps. While a receptacle must have all 24 pins, a Type-C USB 2.0 plug-and-cable assembly has only 12 signals, thus reducing cost.

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1-	VBUS	CC1	D+	D-	SBU1	VBUS	RX2-	RX2+	GND
GND	RX1+	RX1-	VBUS	SBU2	D-	D+	CC2	VBUS	TX2-	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

Figure 2: USB Type-C receptacle pin map (front view).
Source: Courtesy of Type-C specifications

A typical system implementation shorts two D+ and two D– signals with stub connections. This eliminates the need for a multiplexer (Mux) to accommodate a flippable plug. Such a stubbed connection for SuperSpeed USB signals is not feasible due to signal integrity concerns requiring two receiver (RX) and transceiver (TX) 2:1

multiplexers. This connection probably consists of one chip at each end of a Type-C interface, one at the host side, and one at the client device side. If an alternate mode is used, the Mux configuration becomes more complicated and requires cross-point switches.

Channel configuration

USB Type-C incorporates a CC through which it establishes a USB link between a downstream-facing port (DFP) and an upstream-facing port (UFP). A DFP port can be used as a host and the UFP as a device in traditional USB port definition. The CC function is used for the following determinations:

- **DFP-to-UFP attach/detach detection.**
- **Plug orientation.**
- **DFP-to-UFP (host-to-device) and power relationship (provider/consumer) detection. Without USB-PD, by default, a DFP (source) provides a UFP (sink) that consumes power.**
- **USB Type-C V_{BUS} current advertisement (provider) or detection (consumer).**
- **While attached, power and data roles can be changed only through USB-PD.**

Even though a receptacle has two CC pins, CC1 and CC2, only a single CC wire is connected through the cable. While traditional USB ports determine host/device relationships using mechanical characteristics of receptacle and plugs, in USB Type-C with same connectors at both ends, a DFP has a pull-up and a UFP has a pull-down on the CC lines. Monitoring the CC lines for specified voltage provides the orientation and attachment detection.

A DFP uses different resistor pull-up (or current source) values to advertise its current provider capability. On the other hand, a UFP detects how much current it can consume by applying a pull-down resistor and performing a voltage comparison. Three power settings are possible for a USB 2.0 interface without USB-PD: 500 mA; 1.5A; and 3A with 5V on V_{BUS}.

Type-C also defines a dual-role port (DRP) that alternately identifies itself as a DFP and UFP until a stable attached state is established. If a DRP is paired with an UFP or DFP, it takes the role of a DFP or UFP, respectively. If two DRP are paired the outcome is random, but can be influenced by two optional features: Try.SRC and Try.SNK. A DRP with Try.SRC preference tries to establish itself as a DFP (source), and with Try.SNK preference as a UFP (sink). These features are particularly important to ensure the power provider/consumer relationship

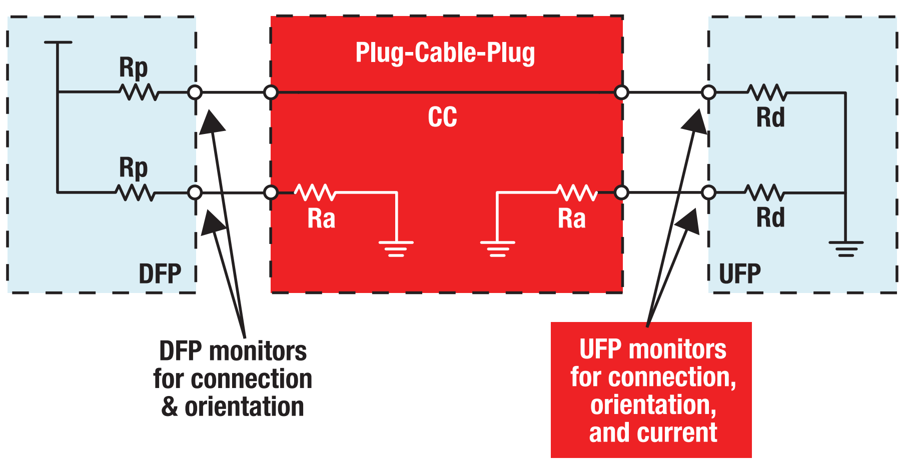

Figure 3: Channel configuration pull-up/down model

makes sense in the eco-system such that, for example, a DRP phone does not start charging a DRP notebook. For the best user experience for an overall Type-C ecosystem, it is important that all connected equipment use an appropriate power role. ***Table 2*** suggests the appropriate state machine setting for a given product.

Power class	Example devices	State machine
Always source	Charger	SRC
Usually source	Laptop, battery pack	Try.SRC
Dual	Tablet	DRP
Usually sink	Phone	Try.SNK
Always sink	Portable drive, accessory	SNK

Table 2: Device power class with recommended settings

How much is enough?

As mentioned, USB Type-C can handle 15W of power natively without additional USB-PD protocol. How much power is 15W? This is six times the standard USB 2.0 charging, and 1.5 times the fastest USB BC 1.2 rate. How fast can a mobile device charge itself at 15W? ***Table 3*** shows some calculations. In reality, charging time depends on

Mobile device	Typical battery capacity (mAh)	Native Type-C charge time (mins)
Smartphone	6 Wh	30
Phablet	10 Wh	50
Mini tablet	15 Wh	75
Full-size tablet	30 Wh	150

Table 3. Charge time for typical mobile devices from 15W power source

many different factors. For simplicity, however, 80 percent power efficiency is assumed here for our illustration.

Is 15W USB Type-C capability good enough? For most low- and mid-range portable implementations, the answer is probably yes, considering additional cost and complexity to implement USB-PD.

Some applications do require a lot of data and video throughput. For portable gadgets, however, end users often do not expect this much. The most common use of a USB port for a mobile phone or tablet is transferring pictures, music and video into a PC or to sync our device. USB 2.0 provides 480-Mbps throughput. With all overheads counted, you can probably get 40 MB data transfer per second – which is likely enough for everyday use.

Typically, a mobile device has a DRP role such that it can be a power sink for charging when connected to a PC. Conversely, it can function as a source when it is paired with a flash drive. ***Figure 4*** shows a typical USB 2.0 implementation of a DRP. Note how the system implementation remains mostly unchanged with a CC controller chip that emulates the ID signal of a standard OTG implementation. It is important to mention that USB Type-C enables a mobile device to be dual-role capable (host or client), as well as be a power source or sink.

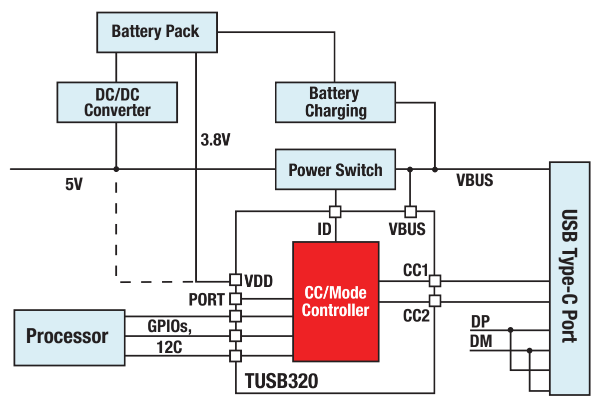

Figure 4: Typical DRP implementation

A USB 2.0 Type-C port in a laptop or wall charger most likely will be a DFP with a power provider role. Why does a laptop have a 15W USB 2.0 port? The answer depends on the overall cost and power budget of a system with multiple Type-C ports because not all of them can be full-featured. A typical implementation of a DFP is illustrated in ***Figure 5***. Even though the port is not taking a dual-role, the ID signal is useful for controlling the power FET.

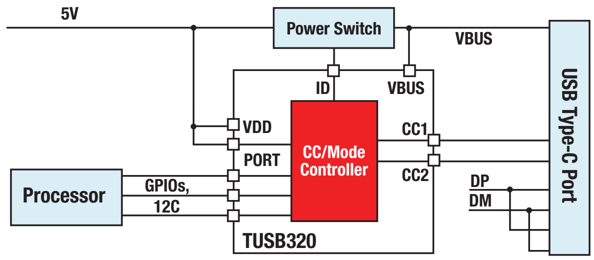

Figure 5: Typical DFP implementation

Figure 6 shows typical implementation of a UFP. This configuration is common for a portable hard disk, some mobile phones, upstream port of a USB 2.0 hub, a watch, accessories and peripherals.

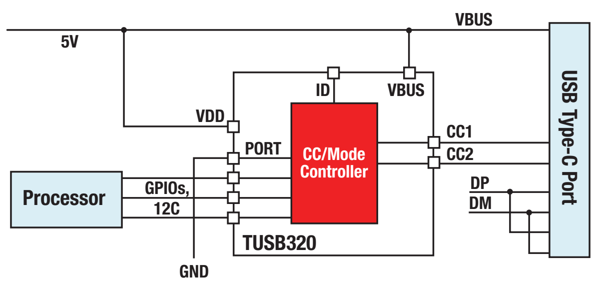

Figure 6: Typical UFP implementation

One-chip solution for USB 2.0

One device that can provide a single-chip implementation of USB 2.0 is the TUSB320 from Texas Instruments. When using this device, converting an existing USB 2.0 into Type-C is not as complicated as it may appear. You just swap the connector and add a CC controller such as the TUSB320, and you are almost done. All application examples illustrated on ***Figures 4-6*** can be implemented using this device for DRP, DFP and UFP, respectively. The device can be configured by GPIOs. Using I²C is optional, but provides additional functions that a system designer might find useful. The device provides an I²C interrupt signal for a microprocessor in order to reduce constant polling. Any event that changes the state of the host-client interface will be notified.

TI's DRP port controller provides CC logic and can be configured as a DFP, UFP or DRP for portable applications.

Port pin	High	Low	Mid (NC)
Supported features	DFP only	UFP only	DRP
Port attach/detach	•	•	•
Cable orientation (through I2C)	•	•	•
Current advertisement	•		• (DFP)
Current detection		•	• (UFP)
Accessory modes (audio and debug)	•	•	•
Active cable detection	•		• (DFP)
I²C/GPIO	•	•	•
Legacy cables	•	•	•
V_{BUS} detection	•	•	• (UFP)
Dead battery wake-up	•	•	•
ID emulation	•		• (DFP)
Try.SRC			•
Try.SNK			•

Table 4: USB Type-C connector interface lists features supported by mode

The device alternates, presenting itself as a DFP or UFP, according to the Type-C specification. The CC logic block monitors the CC1 and CC2 pins for pull-up or pull-down resistances to determine when a USB port is attached and its role. CC logic also advertises or detects Type-C current-mode default, mid or high, depending on the role detected. A list of supported features is summarized in ***Table 4.***

References

1. USB Type-C specification

2. TUSB320 datasheet

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