Low-cost implementation of USB Type-C™

Anwar Sadat, Ph.D.
Systems Manager
High Speed Interface
Texas Instruments
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Channel configuration Controller</th>
<th>USB-PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>15W</td>
<td>100W</td>
</tr>
<tr>
<td>USB 2.0 and 3.1</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Video</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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
cost 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 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.

*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](image-url)
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.

### Table 2: Device power class with recommended settings

<table>
<thead>
<tr>
<th>Power class</th>
<th>Example devices</th>
<th>State machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always source</td>
<td>Charger</td>
<td>SRC</td>
</tr>
<tr>
<td>Usually source</td>
<td>Laptop, battery pack</td>
<td>Try.SRC</td>
</tr>
<tr>
<td>Dual</td>
<td>Tablet</td>
<td>DRP</td>
</tr>
<tr>
<td>Usually sink</td>
<td>Phone</td>
<td>Try.SNK</td>
</tr>
<tr>
<td>Always sink</td>
<td>Portable drive, accessory</td>
<td>SNK</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mobile device</th>
<th>Typical battery capacity (mAh)</th>
<th>Native Type-C charge time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone</td>
<td>6 Wh</td>
<td>30</td>
</tr>
<tr>
<td>Phablet</td>
<td>10 Wh</td>
<td>50</td>
</tr>
<tr>
<td>Mini tablet</td>
<td>15 Wh</td>
<td>75</td>
</tr>
<tr>
<td>Full-size tablet</td>
<td>30 Wh</td>
<td>150</td>
</tr>
</tbody>
</table>

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

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.

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

![Figure 4: Typical DRP implementation](image)

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 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.

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.

<table>
<thead>
<tr>
<th>Port pin</th>
<th>High</th>
<th>Low</th>
<th>Mid (NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported features</td>
<td>DFP only</td>
<td>UFP only</td>
<td>DRP</td>
</tr>
<tr>
<td>Port attach/detach</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Cable orientation (through I²C)</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Current advertisement</td>
<td>•</td>
<td>• (DFP)</td>
<td></td>
</tr>
<tr>
<td>Current detection</td>
<td>•</td>
<td>• (UFP)</td>
<td></td>
</tr>
<tr>
<td>Accessory modes (audio and debug)</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Active cable detection</td>
<td>•</td>
<td>• (DFP)</td>
<td></td>
</tr>
<tr>
<td>I²C/GPIO</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Legacy cables</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>VBUS detection</td>
<td>•</td>
<td>•</td>
<td>• (UFP)</td>
</tr>
<tr>
<td>Dead battery wake-up</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>ID emulation</td>
<td>•</td>
<td>• (DFP)</td>
<td></td>
</tr>
<tr>
<td>Try.SRC</td>
<td>•</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Try.SNK</td>
<td></td>
<td>•</td>
<td></td>
</tr>
</tbody>
</table>

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
Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has the all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products
- **Audio**
  - www.ti.com/audio
- **Amplifiers**
  - amplifier.ti.com
- **Data Converters**
  - dataconverter.ti.com
- **DLP® Products**
  - www.dlp.com
- **DSP**
  - dsp.ti.com
- **Clocks and Timers**
  - www.ti.com/clocks
- **Interface**
  - interface.ti.com
- **Logic**
  - logic.ti.com
- **Power Mgmt**
  - power.ti.com
- **Microcontrollers**
  - microcontroller.ti.com
- **RFID**
  - www.ti-rfid.com
- **OMAP Applications Processors**
  - www.ti.com/omap
- **Wireless Connectivity**
  - www.ti.com/wirelessconnectivity

### Applications
- **Automotive and Transportation**
  - www.ti.com/automotive
- **Communications and Telecom**
  - www.ti.com/communications
- **Computers and Peripherals**
  - www.ti.com/computers
- **Consumer Electronics**
  - www.ti.com/consumer-apps
- **Energy and Lighting**
  - www.ti.com/energy
- **Industrial**
  - www.ti.com/industrial
- **Medical**
  - www.ti.com/medical
- **Security**
  - www.ti.com/security
- **Space, Avionics and Defense**
  - www.ti.com/space-avionics-defense
- **Video and Imaging**
  - www.ti.com/video

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2015, Texas Instruments Incorporated