Design Considerations for USB type C Power Delivery
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What will I get out of this session?

• Purpose:
  1. Learn more about USB-C Power Delivery (PD) requirements.
  2. Understand architecture of USB-C PD, AC/DC power sources.

• Part numbers mentioned:
  • UCC28740, UCC24636
  • TPS40303, TPS25740

• Reference designs mentioned:
  • PMP11451
  • PMP11372, PMP20172

• Relevant End Equipments:
  • USB Chargers
The USB Connectors

USB2.0
- Type-A
- Type-B
- Mini-B
- Micro-B

USB3.0
- Type-A
- Type-B
- Micro-B

One size for USB2.0, 3.0, 3.1
- USB2.0
- USB3.1
- DisplayPort
- Power Delivery

C-to-C, C-to-A and C-to-B cables are defined. C-to-DisplayPort are also available.
# Priority of Power Modes

<table>
<thead>
<tr>
<th>Precedence</th>
<th>Mode of Operation</th>
<th>Nominal Voltage</th>
<th>Maximum Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>USB PD</td>
<td>Up to 20 V</td>
<td>3A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 A w/ active cable</td>
</tr>
<tr>
<td></td>
<td>USB Type-C current @ 3A</td>
<td>5 V</td>
<td>3 A</td>
</tr>
<tr>
<td></td>
<td>USB Type-C current @ 1.5A</td>
<td>5 V</td>
<td>1.5 A</td>
</tr>
<tr>
<td></td>
<td>USB BC1.2</td>
<td>5 V</td>
<td>Up to 1.5 A</td>
</tr>
<tr>
<td></td>
<td>USB 3.1</td>
<td>5V</td>
<td>900 mA</td>
</tr>
<tr>
<td>Lowest</td>
<td>USB 2.0</td>
<td>5V</td>
<td>500 mA</td>
</tr>
</tbody>
</table>

- Highest USB PD: Up to 20 V, 3A, 5 A w/ active cable
- USB Type-C current @ 3A: 5 V, 3 A
- USB Type-C current @ 1.5A: 5 V, 1.5 A
- USB BC1.2: 5 V, Up to 1.5 A
- USB 3.1: 5 V, 900 mA
- USB 2.0: 5 V, 500 mA
USB-C Eco System

**Power Role**

- **Source-Only**
  - Wall Outlet
  - Charger
  - Power Bank

- **DFP** = Downward Facing Port
- **DRP** = Dual Role Power
- **DRD** = Dual Role Data
- **UFP** = Upward Facing Port

- **Sink-Only**
  - USB Powered Accessories

**Data Role**

- **Host**
  - Desktop PC/Server
  - USB Hub
  - Laptop

- **Device**
  - Monitor, TV
  - Docking Station
  - Desktop HDD
  - USB Hub
  - Mobile Devices
  - USB Devices Accessories
  - Mobile HDD
Focus on Source-Only Application

- There are many different applications that require different silicon solutions under the USB Type-C umbrella.
  - Laptops, docking station, monitors, tablets, etc.
- One benefit of the wide-spread adoption of this open standard is a realistic path to a universal charger and e-waste reduction.
  - One connector instead of the proliferation of different adaptors for different devices
  - 300,000 tons of e-waste goes to landfills every year (according to UN)
Monotonic Incremental Power Rule

• USB PD enforces voltage profiles as a function of max power.

• e.g., if the power advertised on a port > 27W; 5V, 9V, and 15V shall be offered.

• Other voltages may be offered, but must not exceed highest required voltage rail.
Typical PD Flow

- VBUS initially defaults to 5V, 500mA power supply
- USB Power Delivery negotiation over CC wire
- Power supplied over VBUS at the rate negotiated

5V → 5V → 20V
USB Type-C DFP PD Systems

- 5V Only
  - Single Port
- 5V Only
  - Multi-Port
- PD
  - Single Port
- PD
  - Multi-Port
5V Output Voltage Requirements

• Follow USB2.0 and 3.1 spec
• Range includes all of these error sources:
  • DC regulation accuracy
  • Line load regulation
  • Ripple
• Load Transients:
  • Stay within same range for 5V outputs
  • Test in 25% load step increments from:
    • Min load to max load
    • Max load to min load
  • Must pass this at receptacle

<table>
<thead>
<tr>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75V</td>
<td>5.5V</td>
</tr>
</tbody>
</table>
AC/DC 5V Only – Single Port

- Not much different from Type A adaptors
- More power than Type A (15W vs. 10W)
  - Requires synchronous rectifier in most cases
- Requires a port controller to advertise power and control disconnect switch
  - TPS25810 (integrated 30mΩ FET)
  - TUSB321 + external PFET
- Possible with PSR (Primary-Side Regulation)
  - No optocoupler for reduced cost
AC/DC Single Port – 5V Only : Design Example

UCC28740
Primary Side Flyback Controller w/ Opto Feedback

CSD18503Q5A
40V SR FET

Type C Port, Port Controller On Daughter Card

UCC24636 SR Controller w/ Diode Emulation
AC/DC Single Port – 5V Only : Design Example
AC/DC 5V Only – Multi-Port

- Can be a mixture of Type A and Type C ports
- Each Type C port needs a port controller
- Total power level >15W
  - Definitely needs SR
- Secondary-side regulation recommended
  - Difficult to maintain regulation on all ports
AC/DC Multi-Port – 5V Only : Design Example

AC INPUT -> 25W Isolated AC/DC Flyback

5V/3A Type-C Port Controller TPS25810 -> 3A Type-C Port

2A Current Limiting Switch TPS2559 -> 2A Type-A Port

(Texas Instruments)
PD Regulation Requirements

- Range includes all of these error sources:
  - DC regulation accuracy
  - line load regulation
  - Ripple

- Must pass this at receptacle

- NV = new voltage

- If NV = 5V: Follow USB2.0 and 3.1 spec

<table>
<thead>
<tr>
<th>NV</th>
<th>vSrcNew Min</th>
<th>vSrcNew Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 V</td>
<td>4.75 V</td>
<td>5.5 V</td>
</tr>
<tr>
<td>9 V</td>
<td>8.55 V</td>
<td>9.45 V</td>
</tr>
<tr>
<td>15 V</td>
<td>14.25 V</td>
<td>15.75 V</td>
</tr>
<tr>
<td>20 V</td>
<td>19.0 V</td>
<td>21.0 V</td>
</tr>
</tbody>
</table>
PD Voltage Transition Requirements

- If $NV > 5V$
  - $v_{\text{SrcNew}} = +/\!-/\! 5\% \text{ of } NV$
  - $v_{\text{SrcValid}} = v_{\text{SrcNew}} +/\!-/\! 0.5V$
- $v_{\text{SrcSlewPos}} < 30\text{mV/us}$
- $t_{\text{SrcSettle}} = 275\text{ms}$
- $t_{\text{SrcReady}} = 285\text{ms}$
PD Load Transient Requirements

- Stay within vSrcValid
- Return to vSrcNew within 5ms
- Test in 25% load steps from:
  - min load to max load
  - max load to min load
- Must pass at receptacle
AC/DC PD – Single Port

• Flyback is the best topology choice:
  • Tolerant of wide output voltage variations
  • Simple and low cost
  • Good efficiency and low standby power

• Secondary-side regulation is required to adjust output voltage

• Aux winding voltage is proportional to output voltage
  • VDD to the primary controller may need to be clamped
AC/DC Single Port – PD : Design Example
AC/DC Single Port – PD : Design Example
AC/DC Single-Port – PD: Design Example

- UCC28740, UCC24636, TPS25740 Flyback with SR and PD Control
- 5V/12V/20V 60W, 92% Efficiency
AC/DC PD – Multi-Port

• Complicated because...
  • Must support multiple voltages simultaneously

• But, luckily...
  • Power/voltage contracts can be renegotiated at any time

• Possible architectures:
  • Generate multiple voltage rails and mux to ports
  • Generate intermediate bus and post regulate each port

• Power path management
  • Simple two port systems can be designed using built-in features of TPS25740
  • 3+ port systems require a microprocessor
5V/9V/15V PD with Multiple Ports - Muxing

90W Isolated Triple Output AC/DC Converter

AC INPUT

5V/9V/15V 3A Type-C Port Controller

5V/9V/15V 3A Type-C Port Controller

3A Type-C Port

3A Type-C Port

- Good efficiency
- Poor regulation
- Complicated AC/DC design
- Difficult to control voltage slew rates
- Poor utilization of AC/DC power capabilities
5V/9V/15V PD with Multiple Ports – Intermediate Bus

- Good regulation
- Simple, low-cost AC/DC converter
- Full control of individual port voltages
- Poor utilization of AC/DC power capabilities
5V/9V/15V PD with Multiple Ports – Port Power Management

- Good regulation
- Simple, low-cost AC/DC converter
- Full control of individual port voltages
- Greatly reduced size
- Reduced power capabilities
AC/DC Multi-Port – PD: Design Example

- PMP11372, [www.ti.com/tool/PMP11372](http://www.ti.com/tool/PMP11372)
- UCC28740, UCC24636, Flyback with SR
- 17V/36W, 93% Efficiency

- PMP20172, [www.ti.com/tool/PMP20172](http://www.ti.com/tool/PMP20172)
- TPS40303, TPS25740, Sync Buck & PD Control
- 5V/9V/15V 36W, >98% Efficiency
Conclusions

• Understand the Type-C and PD rules before designing
• 5V only systems are fairly straightforward
• Single port PD solutions require:
  • Clamping circuit on VDD
  • Port controller
  • Disconnect FET
• Multiple port PD solutions benefit from:
  • Two stage approach
  • Smart port power management
  • High efficiency
  • High power density