
CERTIFIED USB
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USB Power Usage

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Presentation Scope

- This presentation is given as general guidance
- USB Compliance can change
  - Check www.usb.org for details
- E-mail TechAdmin@usb.org with questions

Overview

- Definitions
- Voltage
- Current
- Platform Power Designs
- Battery Charging from USB
- Battery Charge Compliance Testing
- Recommendations / Requirements

Definitions

- A-Device
  - Attached to the ‘A’ end of the cable
  - “downstream” ports
- B-Device
  - Attached to the ‘B’ end of the cable
  - “upstream” ports

Definitions

- Bus Power:
  - B-Device
    - draws power from USB cable
- Self-Power
  - B-Device
    - does not draw power from USB cable
  - bmAttributes field of the Standard Configuration Descriptor

Definitions

- Low-Power
  - *B-Device*:
    - Consumes 100mA (I_{CCLPF}) or less operating current.
    - bMaxPower field in the Standard Configuration Descriptor
  - *A-Device*:
    - Defines a downstream port that is guaranteed to source only 100mA (I_{CCUPT}) sustained.
      - May provide as little as 4.40V on V_{BUS}
    - Examples
      - Bus-powered hubs offer low-power downstream ports only
      - OTG A-Devices may be low-power

Definitions

- High-Power
  - *B-Device*:
    - Consumes more than 100mA operating current.
    - bMaxPower field in the Standard Configuration Descriptor
    - Must be able to enumerate at 4.40V on V_{BUS}
  - *A-Device*:
    - A downstream port that can source 500mA sustained.
    - Must provide at least 4.75V on V_{BUS}
    - Self-powered hubs and all root ports must offer high-power downstream ports
    - OTG may be high-power or low-power

Definitions

- Attach
  - B-Device with upstream plug physically inserted into a downstream USB port
  - pull-up not asserted
- Connect
  - B-Device is attached
  - pull-up asserted
  - enumerated by the host system
- Disconnect
  - B-Device that was connected, but is now simply attached without its pull-up asserted

V_{BUS} Voltage

- Maintaining valid voltage is important
  - B-Devices could inadvertently disconnect or malfunction
  - Primary cause for low voltage is high current demands from B-Device
- USB-IF tests downstream ports for their ability to maintain valid voltage during high current demands

V_{BUS} Voltage: Drop Test

- Ensures a downstream port can maintain valid voltage during an attach
- Performed with maximum constant current load on every port
  - All downstream high-power ports must maintain 4.75V – 5.25V with a load of 500mA
  - All downstream low-power ports must maintain 4.40V – 5.25V with a load of 100mA

V_{BUS} Voltage: Drop Test

- Common Failures
  - Power and ground traces too skinny
  - Harness AWG number too high
  - Polymeric Temperature Coefficient (PTC) fuse sized too low
  - Supply voltage too low
  - Poor load regulation

V_{BUS} Voltage: Droop Test

- Ensures all downstream ports are able to maintain valid voltage during an Inrush event on one port
- Performed with maximum constant current load on every port except one where a worse case inrush event (device attach) is simulated
  - All downstream high-power ports must maintain 4.75V – 5.25V with a load of 500mA
  - All downstream low-power ports must maintain 4.40V – 5.25V with a load of 100mA
  - In addition to the above requirements, the voltage swing must not exceed 330mV at each port

V_{BUS} Voltage: Droop Test

- Common Failures
  - Insufficient bulk capacitance near port
  - PTC fuse downstream of bulk capacitance
  - Use of high- Equivalent Series Resistance (ESR) capacitor

Back-Voltage Test

- B-devices are never allowed to drive current upstream
- USB-IF tests upstream ports to ensure that voltage is not applied to any line
  - Voltage is measured on each pin of an upstream port
  - With device powered on, measurement taken before and after being connected to a downstream port
- Test done on *all* B-Devices (bus- and self-powered)

V_{BUS} Current

- USB-IF examines current consumed by all B-Devices to ensure it is within specified limits
  - Oscilloscope used to measure current spikes
  - Ammeter used to measure current consumed
    - Ammeter provides ~ 1 second averaging
- Device state and bMaxPower value determine maximum allowable current
- Compliance defines 4 device states…

Un-configured State

- B-Device is un-configured before receiving SetConfiguration( ) from host
- Any B-Device can consume an average of 100mA or less
  - regardless of value in bMaxPower field
- Test performed with device attached to a Windows based host running USBCV utility
  - USBCV can prevent an attached device from being enumerated and configured

Configured State

- B-Device is configured after receiving SetConfiguration( ) from host (without driver)
- B-Device may consume no more average current than specified in bMaxPower field
- Test performed with device attached to a Windows based host running USBCV utility
  - USBCV prevents OS from loading driver for an enumerated device

Operating State

- B-Device is enumerated, configured, and has its driver loaded
  - USBCV is *not* used for this test
- All functions and features are active during current measurement
- B-Device may consume no more average current than as specified in the bMaxPower field

Suspended State

- All B-Devices must support Suspend
  - Triggered by observing > 3ms idle on data lines
- A low power state where average current consumption is 2.5mA or less
  - USBCV is not used for this test
- Host system is placed into S3 suspend where V_{BUS} is powered
  - Average current measured and must not exceed 2.5mA
- Guideline: Make suspend current as low as possible

Suspended State

- Brief and intermittent current spikes permitted during suspend.
  - Average current should still stay below 2.5mA
- At any time the current spike cannot exceed the device's power classification
  - Low-power <= 100mA
  - High-power <= 500mA
- Wake enabled devices may consume bMaxPower current up to 10ms prior to asserting resume signal
  - must still limit the inrush current on VBUS

Suspended State

- If device is doing crucial work, suspend requests may be denied by the application or driver
  - Must display a message denying suspend if user requested
- Common Failures
  - Device driver not power management aware
  - External interfaces (flash memory, network cables, etc.) still powered
- All non-essential components should be powered off

Inrush Current

- Inrush is a large current spike that occurs when a B-Device is attached
  - Caused by device's capacitance and power-up
- Excessive inrush current can cause voltage on adjacent downstream ports to droop
- Compliance tests all B-Devices' inrush event
  - Must comply with current transients in Section 7.2

Transient Current

- **Brief and intermittent large current spikes permitted on USB**
  - **Can significantly exceed 500mA**
  - **Very short duration (Tens of microseconds)**
  - ***Average* current must stay within limits**
- **Current spike should not exceed 50µCoulombs**

  $It <= VC <= Q$ where

  I = current; t = time; V = Voltage; C = capacitance

  Q = coulombs

Over-current Protection

- Required on all downstream facing ports for safety reasons
- Not to be used for enforcing specification limits
  - Must not be activated by valid current spikes
  - Recommend at least 1.5A for 100µs before activation
- Over-current must be reported to the host
  - Corrective repair by end-user not permitted
  - Reboot, reset, etc. OK

Platform Power Designs

- Today's PCs implement advanced power management using ACPI
  - Driven by Energy Star, …
  - Intel's Instantly Available PC (IAPC)
  - Microsoft's OnNow Initiative
- Reduced power states commonly called Sleep, Standby, or Suspend
- Standard power supply losses overwhelm power savings of sleep states
  - Need high-efficiency power supplies

Platform Power Designs

- Dual Mode Power Supplies offer a low-power, high-efficiency mode for additional power savings
  - Power capability may be as low as 720mA @ 5V
  - Power may be shared among PC components: Memory, PME#, USB, and others
- Implemented by nearly all PC vendors

Platform Power Designs

- PCs implement ACPI
  - ↗ Advanced Configuration and Power Interface
  - S0 = On
  - S1 = Light sleep mode, USB V_{BUS} still powered
  - S3 = Deep sleep mode, USB V_{BUS} may or may not be powered based on existence of remote wakeup enabled device
  - S4 = Hibernate
  - S5 = Off

Platform Power Designs

- S3 Suspend
  - Notebooks almost always turn USB V_{BUS} off
  - Desktops may or may not turn off V_{BUS}
  - OS determines when to power USB V_{BUS}
    - Powered only when remote wakeup enabled device exists on USB
  - V_{BUS} has limited power capability in S3
    - Care must be taken to not overwhelm power supply

Platform Power Designs

- B-Device must use minimal power during suspend so that power supply has capacity to resume the system
  - Impossible for B-Device to know what S*x* state is in use.
  - Impossible for B-Device to know capabilities of power supply

Platform Power Designs

- Dual Mode Power Supplies
  - Testing shows ability to handle 3A for 500ms
  - Switch from V_{AUX} to standard supply takes ~250ms
- Remote wakeup enabled devices may consume bMaxPower no longer than 10ms prior to asserting resume signal

Battery Charging from USB

- OTG has defined standards for embedded USB hosts
- Expectation is most embedded hosts will be battery powered

  Ex. Cell phones and MP3 players
- Battery usage on USB is not addressed

Battery Charging from USB

- USB was never intended to charge batteries
  - The USB-IF does not sanction charging batteries from USB
- However, the USB 2.0 Specification does not prohibit charging batteries off USB
  - The USB-IF does not want to deny certification from vendors who successfully charge batteries

Certification Requires Devices to Comply with the Specification while Charging Batteries

Battery Charging from USB

- When to charge from V_{BUS}
  - Anytime when the device is configured by the host
- When activating charge circuitry, current spike must stay within specification
  - Drained or depleted batteries crave high current

Battery Charging from USB

- When NOT to charge from V_{BUS}
  - Do not attempt to charge while suspended
    - Compliance allows 2.5mA only which is insufficient for charging batteries
    - Auxiliary power supply has limited power capability
  - Do not attempt to charge upon attach
    - The downstream port may be suspended!
    - Un-configured current may be drawn no longer than 220ms after attaching to a suspended port
      - After detecting a valid VBUS level (4.01V)
      - Section 7.1.7.3 of the USB 2.0 Specification

$$T_{SIGATT} + T_{ATTDB} + T_{DETRST} + T_{2SUSP} = 220ms$$

Battery Charging from USB

- Upon attach, a device should confirm that it is attached to an active downstream port.
- Two options for detecting an active port
  1. Connect and wait for a reset from the host
     - If a reset does not occur, then enter suspend mode
  2. "Look" upstream for Start of Frames (SOF)
     - No need to connect to "see" bus activity
     - If no SOFs are detected, go directly to suspend
     - If SOFs are seen, then 100mA un-configured current may be drawn
       - The device must still connect within 100ms (T_{SIGATT})

Battery Charge Compliance

- Vendors whose devices charge batteries from USB must submit with “dead” batteries
  - “Dead” means that the device is unable to turn on
- Tests performed with “dead” battery
  - Inrush Current
  - Average current draw from four device states
    - Un-configured, Configured, Operating and Suspended

Recommendations

- Implement “soft start”
  - Sequentially power on device components
- Do not allow battery to become “dead”
  - Allow sufficient residual charge to remain in battery to enable connection to USB

Requirements

- For USB battery charging devices
  - Report as Bus-Powered in bmAttributes
- Do not change bMaxPower value dynamically
  - Must disconnect then connect to change
- Multiple connections to a single host is not permitted
  - Do not attempt to draw power from more than one USB port

For More Information

Visit the USB-IF OTG Web Site:
http://www.usb.org/developers/onthego/

"Universal Serial Bus Specification," Revision 2.0, April 27, 2000
http://www.usb.org/developers/docs/usb_20.zip

"Universal Serial Bus Implementers Forum Full and Low Speed Electrical and Interoperability Compliance Test Procedure," Revision 1.3, February 2004
http://www.usb.org/developers/docs/USB-IFTestProc1_3.pdf

"Instantly Available Power Managed Desktop PC Design Guide," Revision 1.2, 9/25/98
http://www.intel.com/technology/IAPC/downloads/iapcdgrev1_2.htm

"Implementing USB Wakeup & ACPI S3 on ICH-based Systems,"
http://www.intel.com/technology/IAPC/USB_Wakeup.pdf

USB Power Usage Questions?


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