Power Management
What is Power Management

- **Power Budgeting**
  - Evaluate Device Requirements

- **Device Power States**
  - On, Standby, Suspend, Off

- **Global System Power States**
  - On, Standby, Suspend, Hibernate, Off, Critical Off
  - Current Change Request

Diagram:
- Cable Box
- Modem
- Digital Audio
- Mouse
- Keyboard
- USB
- Printer
- Game Controllers
- Hand Scanner
- Phone/Answering Machine
Power Budget

- **Unit Loads**
  - Low & High Power Sources
  - Low & High Bus-Powered Devices

- **Power sources**
  - Bus powered
  - AC powered
  - Battery powered

Device Power States

- Off, Low power, High power
- Standby - Reduced power
- Suspend - Lowest power state
  - Normal device operation ceases
  - Increased response time
- Device may wakeup the system
  - External event may restart system

Hubs

- **Power Type**
  - Self Powered
  - Bus Powered
    - 4 external ports (max)
- **HUB Types**
  - Standalone
  - Compound
    - Embedded Device
    - External Ports
Hot Attach

- Inrush limiting
- Attach detection
- System Notification
- Device Enumeration
- Device Configuration
- Power Allocation

Device Removal

- Removal Detection
  - Transfer failure
  - Bus management
- Bandwidth Deallocation
- Power Deallocation
- Unloading Device Driver

Monitor (Powered Hub) — Printer (Powered Hub)
System Suspend

DEVICE REQUIREMENTS:
- All USB devices must support Suspend
- Max. suspend current <500ua
  - Bus termination ~320ua
- Device maintains state information
- Optional Remote wakeup

DRIVER REQUIREMENTS
- Connect to USB PM services
  - Suspend request
  - Suspend grant
  - Critical off
  - Resume notification
  - Optional
    - Save device specific info.
    - Selective suspend

USB SERVICES:
- Interface to O/S Power Management
- Notify Drivers of PM event
  - Responsible for sequencing
- Shutdown USB after all drivers suspend

- Restart activity on resume or wakeup
- Notify Drivers of Resume event
- Enumerate bus to detect device changes
Suspend vs Hibernation

SUSPEND
- System software suspends the device by turning off the device port in the upstream hub
- Device suspends when it detects lack of bus activity (3ms)
- Device wakeup request
  - Detected via USB bus poll
- Driver notified by bus enumerator

HIBERNATION (Class Specific)
- To USB device drivers, hibernation looks like suspend, except, device state is lost
- System may transition directly to hibernation from suspend
- Device driver responsible for saving device data needed to resume the device
Active Power Control

- Host sets device power policy
- Contract between driver and device
  - Minimize power consumption
- Device Design Guidelines
  - Stop clock idle detection
  - Idle time-outs
  - Multiple operational power levels
    - i.e., disk rotational rates, TX power level
- Device Driver Guidelines
  - Suspend device during idle time
  - Device idle timers minimize bus traffic
  - Tradeoff performance vs. power
  - Comprehend latency of power level (i.e., spin up time)
Device Powering

Low Power bus
powered device

100 ma (max)

Device

High power bus
powered device

500 ma (max)
100ma @ power up

Device Controller

Device Core

Locally powered device

Optional Upstream power

Device

Local Power Supply

➢ Operating Power Levels
   ➢ Low Power: 100mA or less
   ➢ High Power: 500mA or less  (Power up at 100mA or less)
   ➢ Local Power: No power limit, may draw power from bus
Voltage Drop/Droop Requirements

- Must consider cumulative voltages drops in cables, connectors, pc board traces, current limit devices, etc.

- \( V_{BUS\,(min)} \) determined by \( V_{DROP} \) and \( V_{DROOP} \)
  - \( V_{DROP} \) caused by IR drop in cables, connectors, etc
  - \( V_{DROOP} \) caused by inrush current during hot plug

- \( V_{BUS\,(min)} \) set by \( V_{CC\,(in)} \) voltage regulator
  - Assumes a 500mv dropout for a 3.3V ± 5% regulator
  - \( V_{BUS\,(min)} = 4.0V \) measured at regulator input

- Must consider different topologies
  - Host to high-power device or bus-powered hub
  - Host through bus-powered hub to low-power device
$$V_{\text{DROP}} : \text{Host to Self-powered Hub}$$

- Power Supply 5.00v +/- 5%
- Host can drop 100mV
  - traces, ferrite beads, connector, current limit device
- Detachable cable can drop 250mV max @ 500mA
- Bus-powered device may drop 50mV max
  - traces, connectors, etc
**V\_DROP : Host to Low-powered Device**

- Bus-powered hub with integral cable can drop 250mV max.
  - connector, traces, power distribution switch, ferrite beads, etc.
- To meet system power distribution requirements the Bus-powered Hub may require an integral cable.
**$V_{DROOP}$ & Inrush Current Limiting**

**DESIGN REQUIREMENTS:**
- 330mV max. $V_{DROOP}$ when hot-plugging to SP Hub
- Maximum load at downstream cable end is 10µF in parallel with 44Ω
- Output port power lines must be bypassed with no less than a 120µF tantalum capacitor
- Bus-powered Hubs must provide surge limiting
  - Soft start when enabling downstream ports

![Diagram showing SP Hub/Host, Bus Powered Hub, and Bus Powered Device with voltages 4.75V/330mV, 4.40V/330mV, and 4.10V.]
Hub Power Dist. Requirements

**USB Bus-Powered Hub**

- **Hub Controller** (TUSB2040)
- **LDO Reg.**
  - TPS7201
  - TPS7133
  - TPS7333
- **Embedded Function**
- **Switch** (TPS2010-15)
- **Upstream Vbus**
  - 5 Unit Loads
- **On/Off**
- **1 Unit Load per port**
- **100mA/port**
- **Downstream Vbus**
- **Upstream Data Port**
- **Downstream Data Ports**

**Bus-Powered Hubs:**
Draws all power from USB connector power pins

**Self-Powered Hubs:**
Internal function and downstream port power does not come from USB.

**Low Powered Function:**
1 Unit Load = 100mA

**High Powered Function:**
5 Unit Loads = 500mA

**USB Switch Application:**
The Host and all Self-powered hubs must implement over-current protection. They must detect the overcurrent condition and report it to the USB Host Controller. The controller will then remove power to that port.

**LDO Regulator:**
Each hub must run on 3.3V. The Vbus supplies 5V nom and inputs may be as low as 4.40V. A 500mV max dropout voltage is recommended.
**Polyfuses vs MOSFET Switches**

<table>
<thead>
<tr>
<th></th>
<th>Polyfuse</th>
<th>MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report Overcurrent Condition</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Fast Response Time</td>
<td>NO (150ms)</td>
<td>YES (45μs)</td>
</tr>
<tr>
<td>Limit Output Current &lt; 5A</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Meets $V_{\text{DROP}}$ Requirements (90mV)</td>
<td>YES 2.5A Device</td>
<td>YES</td>
</tr>
<tr>
<td>Meets $V_{\text{DROOP}}$ Requirements (330mV)</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Enabled/Disabled by Controller</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

**Complete Polyfuse Solution with Enable and Over Current Response**

Polyfuses do **NOT** meet all of the requirements of the USB specification

Intelligent MOSFET switches do meet all of the requirements of the USB specification
TPS2014/15 Power Dist. Switches

**TPS2014/15**

- High-Side MOSFET Switch
  - 95 mΩ max r $DS_{(on)}$ (5.5-V input)
  - TPS2014: 0.6A continuous, 1.2A current limit
  - TPS2015: 1.0A continuous, 2.0A current limit
- 2V Logic Compatible Enable Input

**Overcurrent and Thermal Protection**

- Overcurrent logic output
- 4.0V to 5.5V Operating Range (7V max)
  (Due to UVLO)
- Controlled Rise and Fall Times limits
  Current Surges and minimizes EMI.

**Undervoltage Lock-Out Guarantees the Switch is Off at Power Up**

- Thermal Protection
- 10μA Maximum Standby Current

**Applications**
- USB Bus-Powered and Self-Powered Hubs
- Hot insertion applications
- Power Distribution

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**Maintenance Free Over-Current and Thermal Protection**
Non-Ganged Hub Power Dist.

BOM for Non-Ganged Configuration:
- TUSB2040 QTY 1
- TPS75240 QTY 2
- TPS7133 QTY 1
- TPS2014 QTY 4
- Ferrite Beads: None
- Cap, 150uF (USB req.) QTY 4
- Cap, 1000uF (option) QTY 1
- Cap, 1uF QTY 4

PROS:
- Lower Current Devices
- No Ferrite Beads Required
- Good Voltage Droop Response
- Faults only shut down the Port affected (most user friendly)

CONS:
- Highest Cost solution
Ganged Hub Power Distribution

BOM for Ganged Configuration:
- TUSB2040 QTY 1
- SN75240 QTY 2
- TPS7133 QTY 1
- TPS2023 QTY 1
- Ferrite Beads QTY 8
- Cap, 150uF (USB req.) QTY 4
- Cap, 1000uF (option) QTY 1
- Cap, 1uF QTY 1

PROS:
- Most Cost Effective
- Lowest IC Count

CONS:
- Fault on one port shuts down switch, and all ports go down
- Ferrite Beads required (adds impedance between outputs, lowers V-droop)
- Higher current devices required (4 X 500mA = 2A min, with 5A UL max)
Summary

- USB power management was designed in from the start
- Well suited for power managed desktop & laptop computers
- Illegal topologies gracefully rejected
- Designs must pay strict attention to $V_{\text{DROP}}$ and $V_{\text{DROOP}}$ req.
- Current limit devices, power switches, and LDO regulators are required by the USB spec.
- Polyfuse, in general, are not an adequate current limit device for power management