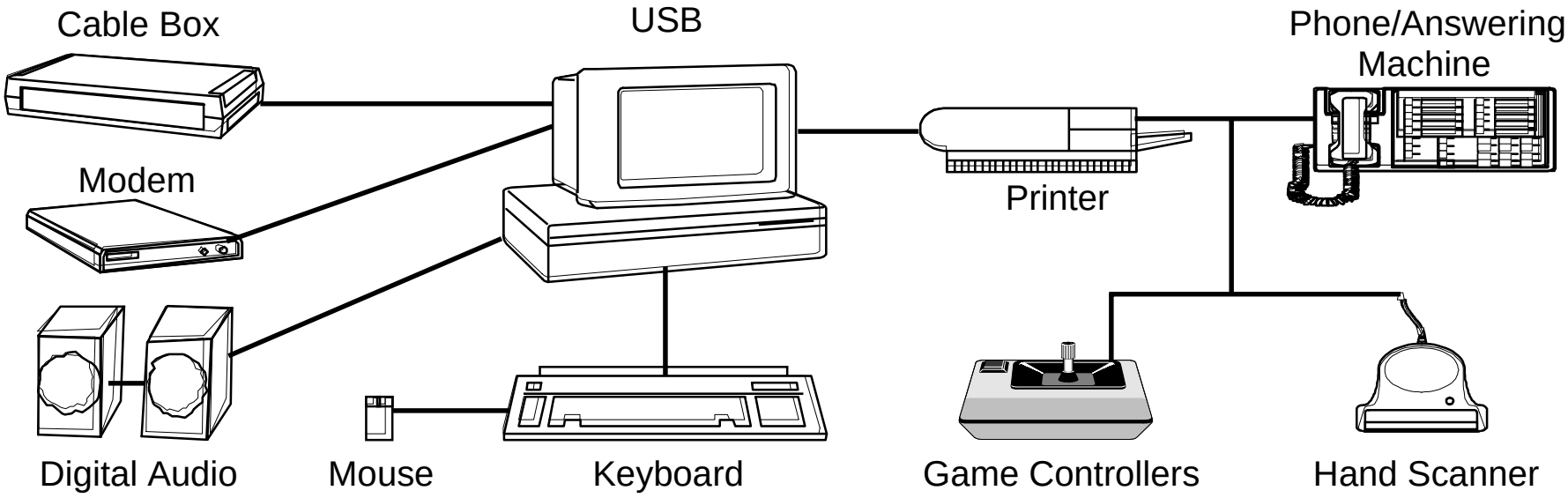
Universal Serial Bus



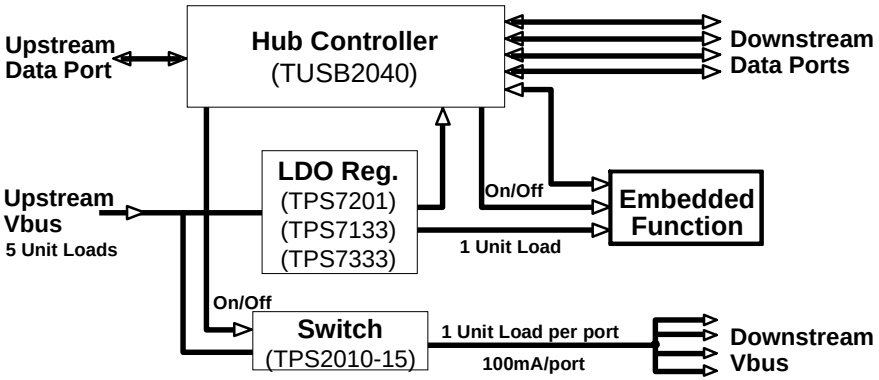
USB

Jonathan M Bearfield
j-bearfield1@ti.com
972-480-3734

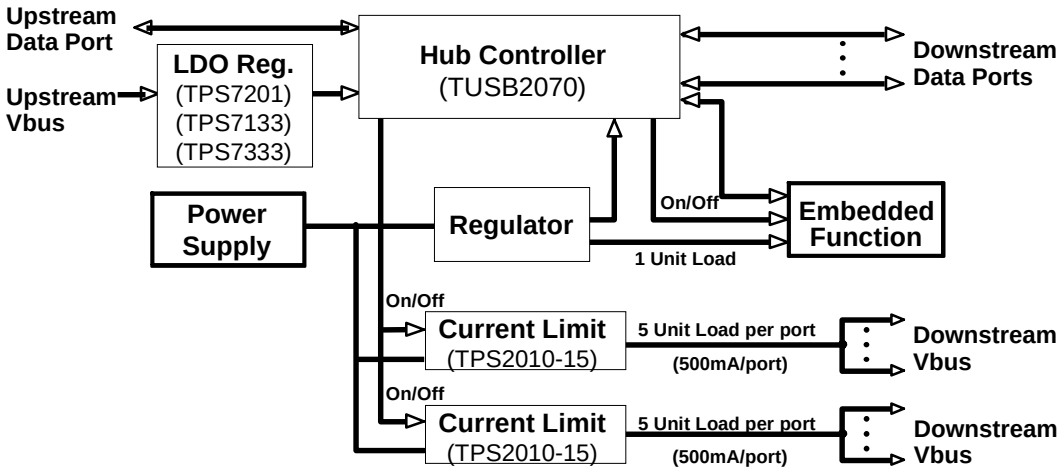
TEXAS INSTRUMENTS

Hub - Power Distribution Requirements

USB Bus-Powered Hub



USB Self-Powered Hub



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.

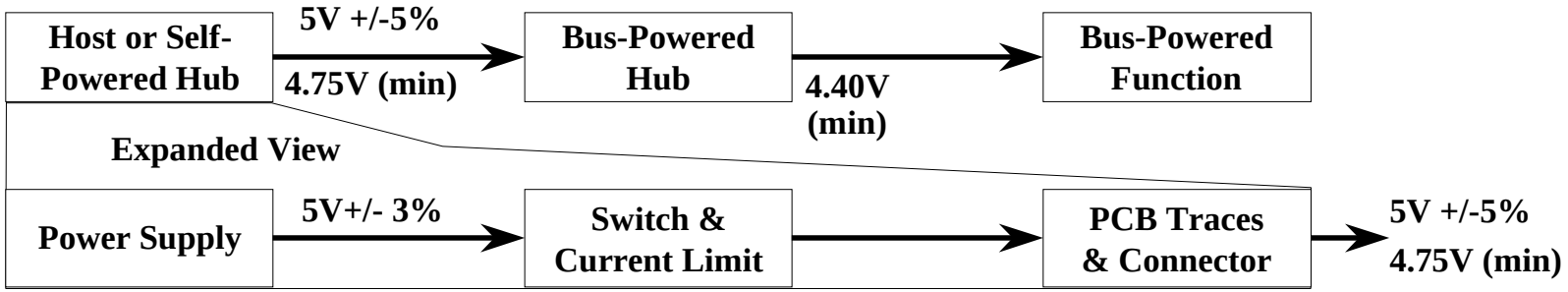
Low Powered Function:
1 Unit Load = 100mA

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.

USB Voltage Requirements



Host Power Supply Requirements:

Output Regulation - +5%/-7%
Power Supply Regulation - 5%
PCB/ Connector Voltage Drop - 25mV

HUB Interconnect Requirements:

Maximum Voltage Drop = 350mV (USB Spec)
Maximum Cable Length = 5.0m (USB Spec)
Cable resistance (20 Awg.) = 0.036 Ohm/m

Based on these requirements the maximum allowable switch resistance is 150mOhm for a 500mA USB port.

$$r_{DS(on)} \leq 150\text{mOhm}$$

The requirements shown are taken directly from sections 6 and 7 of the USB specification, and the general PC power supply requirements. The limits shown are all minimum requirements and/or maximum allowable tolerances.

Working within general power supply limitations and the USB specification a maximum $r_{DS(on)}$ for the switch/current limit device used in the system is 150mOhm. On resistances higher than this, like those found in polyfuses, would consume power in excess of the specified USB voltage budget. Lower values for $r_{DS(on)}$ would allow for increases in other system tolerances over time and temperature.

System Calculations

HUB Interconnect Calculations:

Max. Voltage Drop = 350mV (USB Spec)
Max. Cable Length = 5.0m (USB Spec)
Cable resistance = 0.036 Ohm/m
(20 AWG)

$$V_{HUB} \geq V_{switch} + 4 * V_{Connector} + 2 * V_{Cable}$$

Solve for $r_{DS(on)}$: $r_{DS(on)} \leq \frac{V_{Switch}}{I_{max}}$

@ I_{max} = 500mA

Example:

$V_{Switch} = I_{max} * (R_{PCB} + r_{DS(on)}) = 100mV$ **(by definition)**

$V_{Connector} = I_{max} * R_{Connector} = 15mV$

$V_{Cable} = I_{max} * R_{Cable}$, $R_{Cable} = 5m * .036$ Ohm/m

$$r_{DS(on)} \leq \frac{100mV}{500mA} \leq 200mOhm$$

(PC Board & Switch Resistance Combined)

Host Calculations:

Output Regulation - 5%
Power Supply Regulation - 3%
PCB/ Connector Voltage Drop - 25mV

$$V_{reg} < V_{PSreg} + V_{PCB} + (I_O * r_{DS(on)})$$

Solve for $r_{DS(on)}$: $r_{DS(on)} \leq \frac{V_{reg} - V_{PSreg} - V_{PCB}}{I_O}$

Example:

V_{reg} = 5% of 5V = 250mV, $I_{o(HP)}$ = 500mA
V_{PSreg} = 3% of 5V = 150mV, $V_{out(min)}$ = 4.75V
V_{PCB} = 25mV

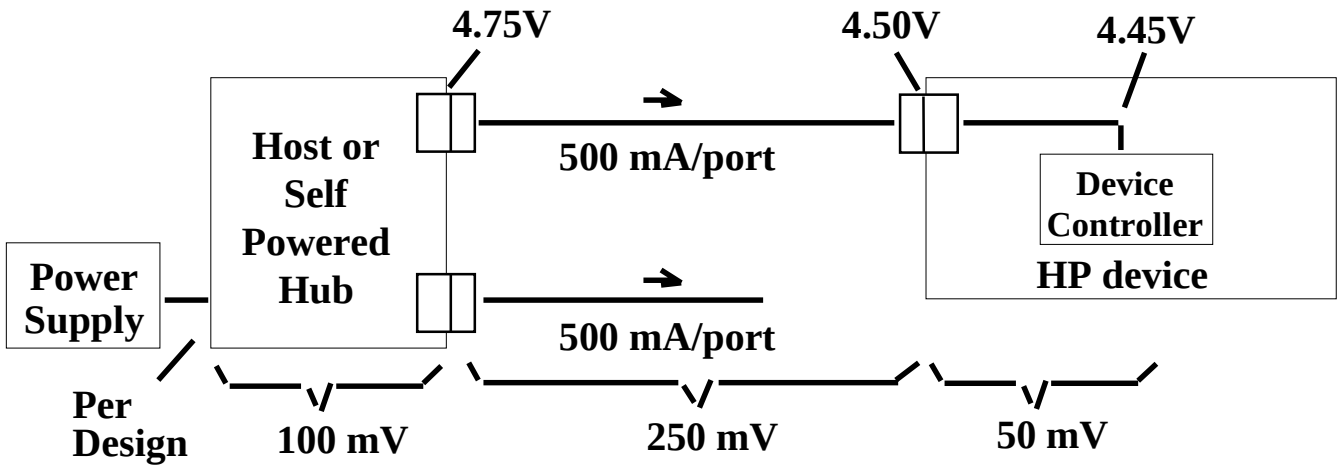
$$r_{DS(on)} \leq \frac{250mV - 150mV - 25mV}{500mA}$$

$$\leq 150mOhm$$

Voltage Drop/Droop Requirements

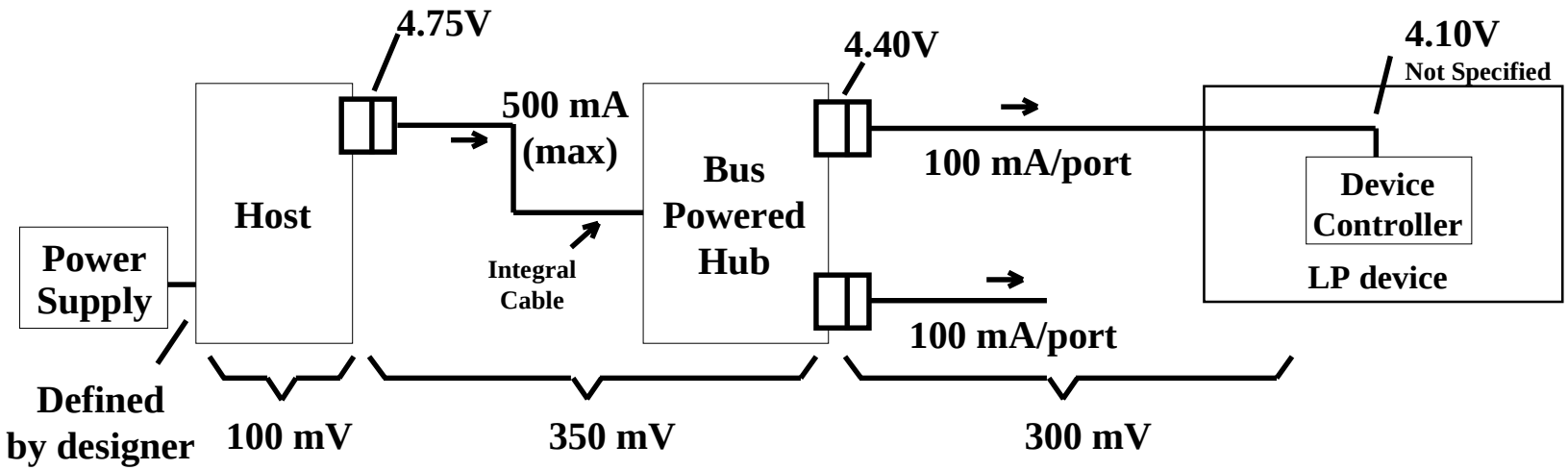
- Must consider cumulative voltages drops in cables, connectors, pc board traces, current limit devices, etc.
- $V_{BUS(min)}$ determined by V_{DROP} and V_{DROOP}
  - V_{DROP} caused by IR drop in cables, connectors (Steady State)
  - V_{DROOP} caused by inrush current during hot plug (Transient)
- $V_{BUS(min)}$ set by $V_{CC(in)}$ voltage regulator at EOL device
  - Assumes a 500mV dropout for a 3.3V ± 5% regulator
  - $V_{BUS(min)}$ = 4.1V measured at device connector
- Must consider different topologies
  - Host to high-power device or bus-powered hub
  - Host through bus-powered hub to low-power device

V_{DROP} : Host to Self-powered Hub



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

Voltage Drop - Host thru Hub to BP-device

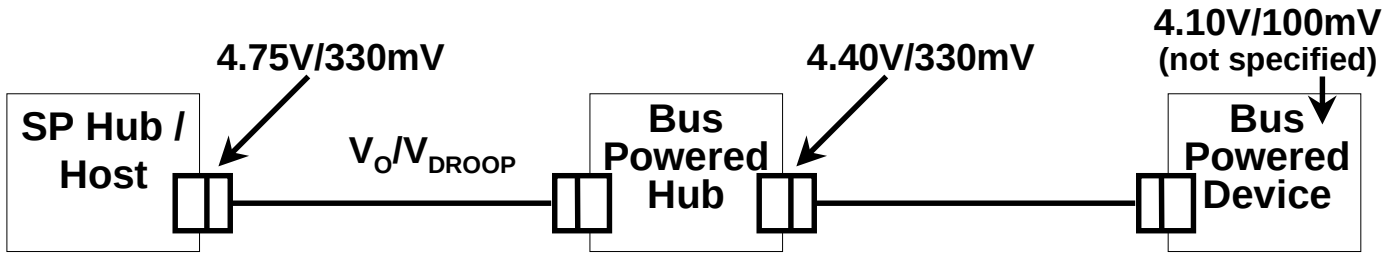


- **Bus-powered hub with integral cable can drop 350mV max.**
  - **connector, traces, power distribution switch, ferrite beads, etc**
- **Bus-powered Hub can use and/or distribute up to 500mA**
- **To meet worst case system power distribution requirements the Bus-powered Hub may need an integral cable.**

Voltage Droop and Inrush Current

USB DESIGN REQUIREMENTS:

- 330mV max. V_{DROOP} when hot-plugging
- USB devices must draw less than 100mA from the V-bus during hot-plug
- Maximum hot-plug load at downstream cable end is 10μF in parallel with 44Ω
- Downstream ports must be bypassed with no less than a 120μF tantalum capacitor
- Bus-powered Hubs must provide surge limiting
  - soft start when enabling downstream ports

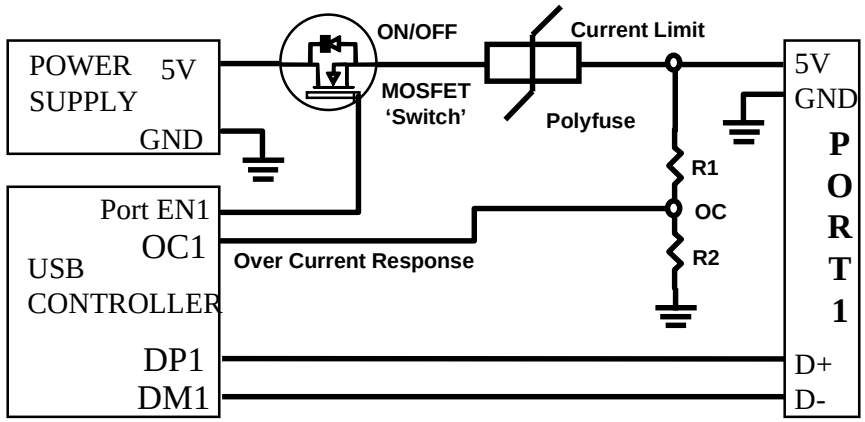


Polyfuses vs MOSFET Switches

	Polyfuse	MOSFET
Report Overcurrent Condition	NO	YES
Fast Response Time	NO (150ms)	YES (45µs)
Limit Output Current < 5A	YES	YES
Meets V_{DROP} Requirements (80mV)	2.5A Device	YES
Enabled/Disabled by Controller	NO	YES

Complete Polyfuse Solution with Enable and Over Current Response

Polyfuses do <u>NOT</u> meet all of the requirements of the USB specification or application



Intelligent MOSFET switches do meet all of the requirements of the USB specification and application

Non-Ganged Hub Power Dist.

Non-Ganged Configuration:

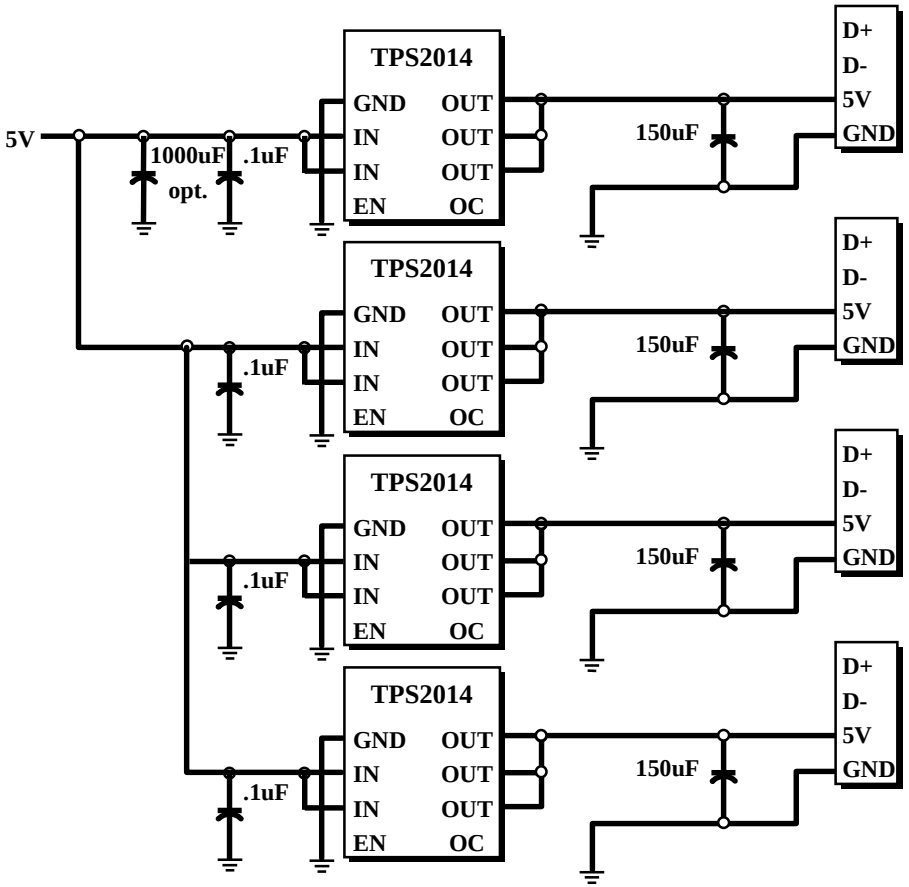
Power Dist. Switch	**QTY 4**
Ferrite Beads	**None**
Cap, 150µF (USB req.)	**QTY 4**
Cap, 1000µF (option)	**QTY 1**
Cap, .1µF	**QTY 4**

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

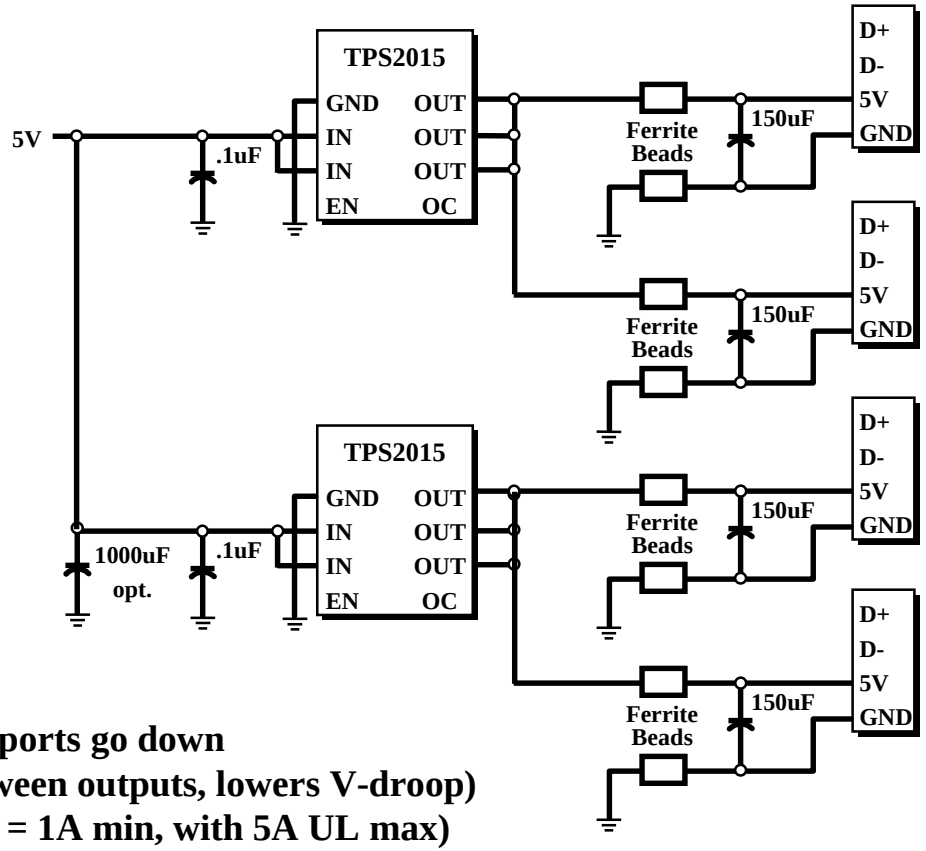


NOTE: Low drop-out Voltage Regulators may be required for powering Hub Controller from the USB V-bus

Ganged Hub Power Distribution

Ganged Configuration:

Power Dist. Switch	**QTY 2**
Ferrite Beads	**QTY 8**
Cap, 150µF(USB req.)	**QTY 4**
Cap, 1000µF (option)	**QTY 1**
Cap, .1µF	**QTY 1**



PROS:

Most Cost Effective
Lowest IC Count

CONS:

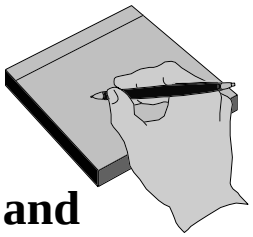
Fault on one port shuts down switch, and all ports go down
Ferrite Beads required (adds impedance between outputs, lowers V-droop)
Higher current devices required (2 X 500mA = 1A min, with 5A UL max)

NOTE: Low drop-out Voltage Regulators will be required for powering Hub Controller from the USB V-bus

USB - The TI Advantage

TI has a Complete USB Hub Solution:

- **TUSB2040/70 Hub Controllers**
- **TPS7XXX LDO Voltage Regulators**
- **TPS2014/15 Power Distribution Switches**
- **SN75240 Dataline Transient Suppresser**
  - **Each area with a customer/spec driven roadmap**



TI is writing the book and handing you solutions

TI devices meet the USB specification requirements for low & high powered ports

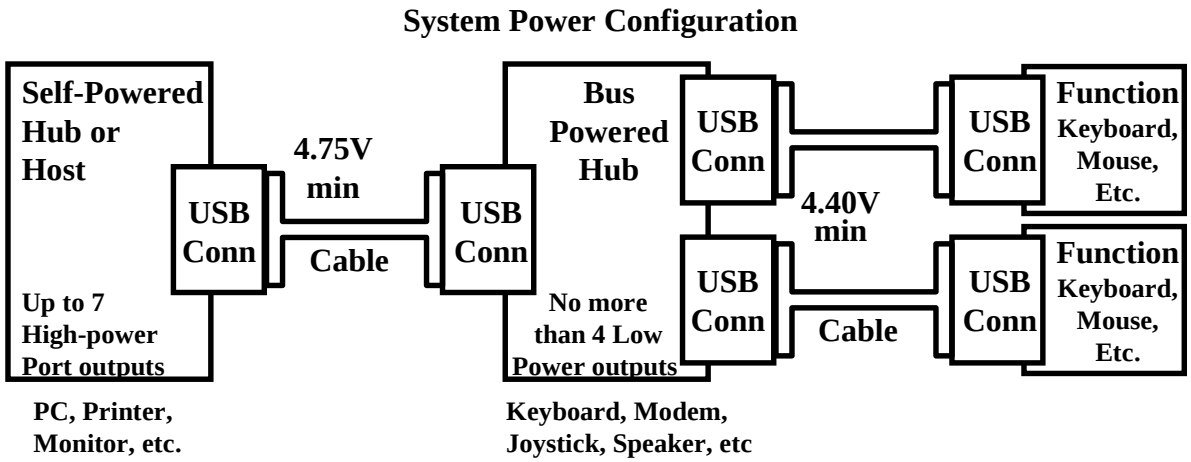
TPS2014/15 max. supply current is one of the industries lowest

TPS2014/15 output rise time is one of the industries slowest, this further limits unwanted surge currents at turn on

TPS2014/15 are pinned out for easy implementaion

Summary

- USB power management was designed in from the start
- Illegal topologies gracefully rejected
- Designs must pay strict attention to V_{DROP} and V_{DROOP} req.
- Current limit devices, power switches, and LDO regulators are required by the USB spec.
- Polyfuses, in general, are not an adequate current limit device for power management

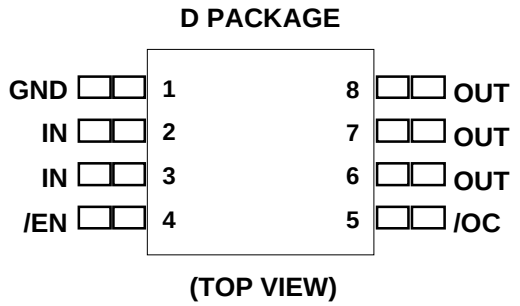


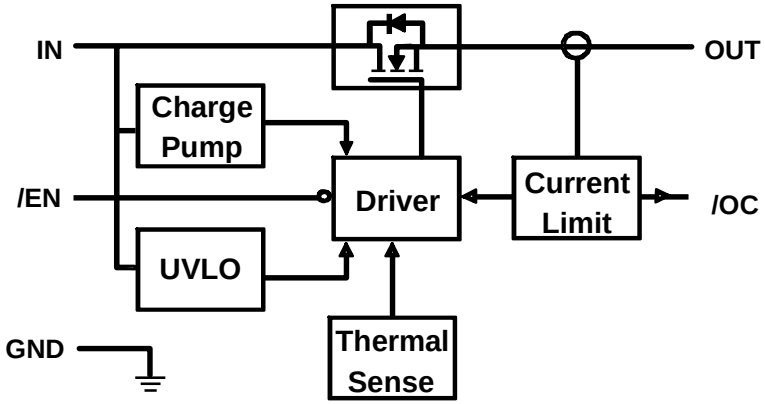
TPS2014/15 Power Distribution Switches

TPS2014/15

- High-Side MOSFET Switch
  - 95 m Ω 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**
  With 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
- 10µ A Maximum Standby Current

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





Maintenance Free Over-Current and Thermal Protection

TEXAS INSTRUMENTS