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TIDA-00288 4-Port USB 3.0 Hub Reference Design

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Design Resources

TIDA-00288	Tool Folder Containing Design Files
TPD6E05U06	ESD Diodes
TUSB8041RGC	4 Port USB Hub
TPS2003CDRC	USB Power Switch
TPS2546	USB Power Switch
LMR10510XMF	Voltage Regulator
TPS22910AYZVR	Load Switch

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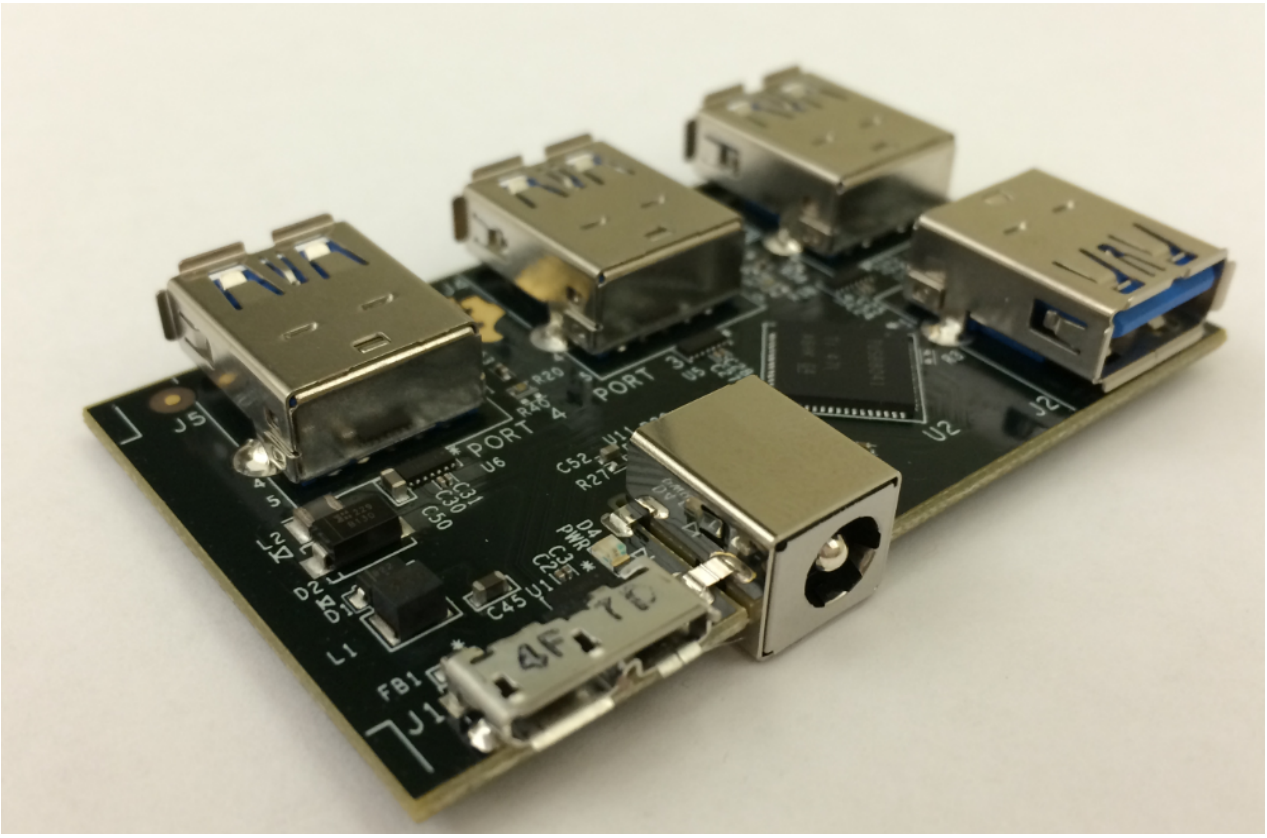
Design Features

The TIDA-00288 is a fully functioning 4-Port USB3.0 hub:

- Supports individual port power control
- ESD protection on both upstream and downstream ports
- Operates as a bus-powered device or from an external power source.
- Supports operation as an USB 3.0 and USB 2.0 device

Featured Applications

- Computer systems
- Docking stations
- Monitors
- Set-top boxes



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1 Circuit Description

This USB 3.0 hub design is a four-port USB 3.0 compliant hub. The design provides simultaneous SuperSpeed and high-speed/full-speed connections on the upstream port, and SuperSpeed, high-speed, full- speed, or low-speed connections on the downstream ports. The hub design provides power control for each downstream port and overcurrent protection.

2 Theory of Operation

A block diagram of the design in Figure 1 shows a USB 3.0 hub with the Micro-B upstream port and 4 USB 3.0 TypeA downstream ports. Power for the design is shown as ESD protection elements on the upstream and downstream sides of the hub. A unique power control circuit is shown, enabling the DC power to be applied after USB power up without interruption of communication. Downstream port current limiting is provided by either a TPS2003C (dual channel, current-limited power distribution switch) on ports 1 and 2, or by one of two TPS2546 (USB charging port controller and power switch) on ports 3 and 4.

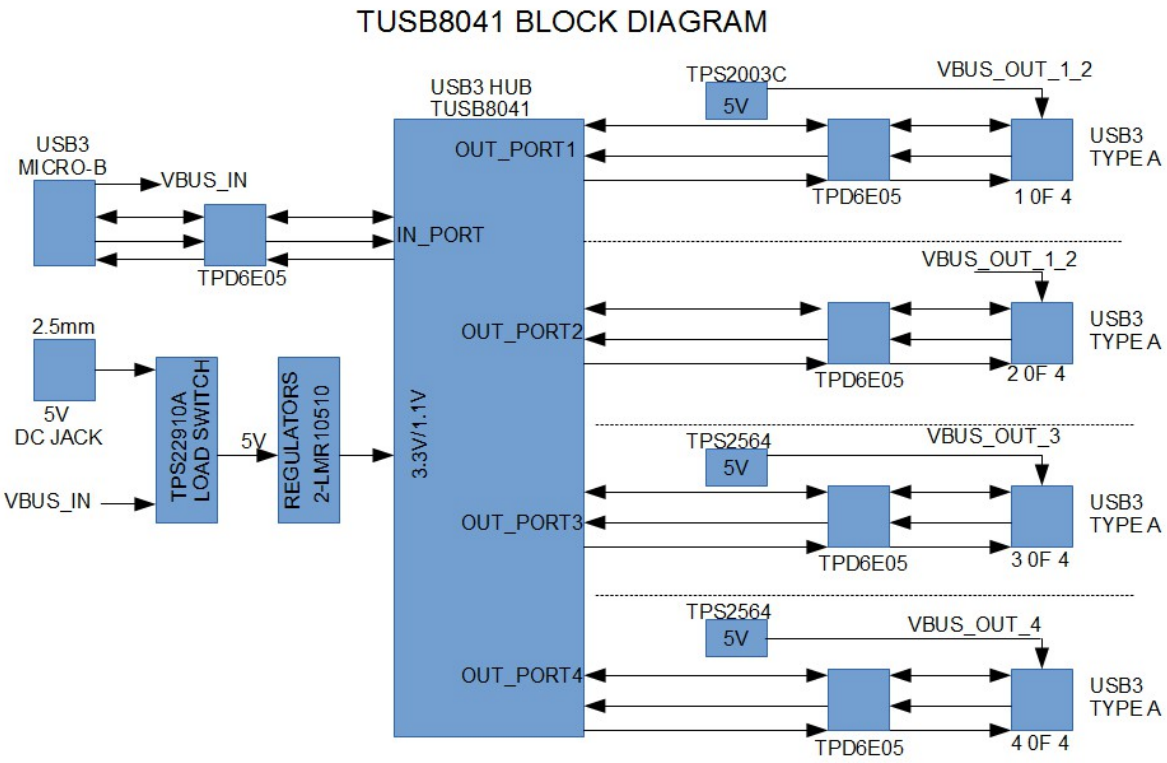


Figure 1. TUSB8041 Functional Block Diagram

2.1 TUSB8041

The TUSB8041 is a four port USB 3.0 compliant hub chip. It provides simultaneous SuperSpeed and high/full speed connections on both the upstream and downstream ports. When the upstream port is connected to a computer that supports only highspeed or full speed connections, the downstream ports disable their SuperSpeed support and the SuperSpeed devices connect at high speed or full speed.

The hub supports either ganged or per-port power switching, over-current protection, and battery charging.

The USB 3.0 hub is configured at the de-assertion of RESET. Refer to Table 1 for the default values.

Table 1. TUSB8041 Power-on Reset Settings

Downstream port power management	Enabled
Power control	Signals are active high
Power port control	Ports are individually controlled
Hub-controlled battery charging	Enabled on ports 1 and 2

2.2 System Power

The main power on the board is 5 V. Figure 2 shows the block diagram for the 5 V switching circuit. The 5 V originates from either the upstream USB port, or from an external DC power cube. Power is switched between the two sources by a TPS22910A (low ON resistance load switch). The TPS22910A is rated at 2 Amps and used to switch the upstream voltage in or out of the circuit. When the power cube is plugged into the board, the load switch isolates the upstream voltage from the board 5 V. The DC power cube is rated at 5 V / 5 Amps and is connected to the board through a 2.5 mm center positive DC power jack.

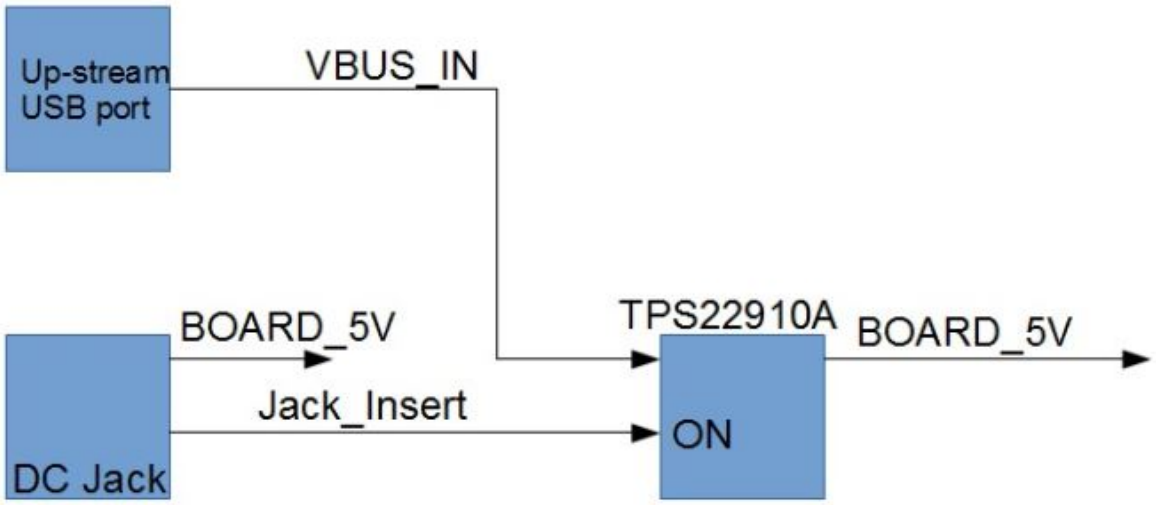


Figure 2. 5 V Power Switching

2.3 Downstream USB Power Delivery

Power delivery for ports 1 and 2 is controlled from the TPS2003C (dual channel current limited switch). Power enable for these ports comes from the USB hub. Rated current for the part is 2 Amps of total current, and is controlled by operating in a constant current mode when the output exceeds the current-limit threshold. Downstream battery charging is enabled by the pull-up resistors on EN_PORT1 and EN_PORT2. The TUSB8041 provides the signatures on the D+/D- (USB 2.0) lines to support different charging schemes.

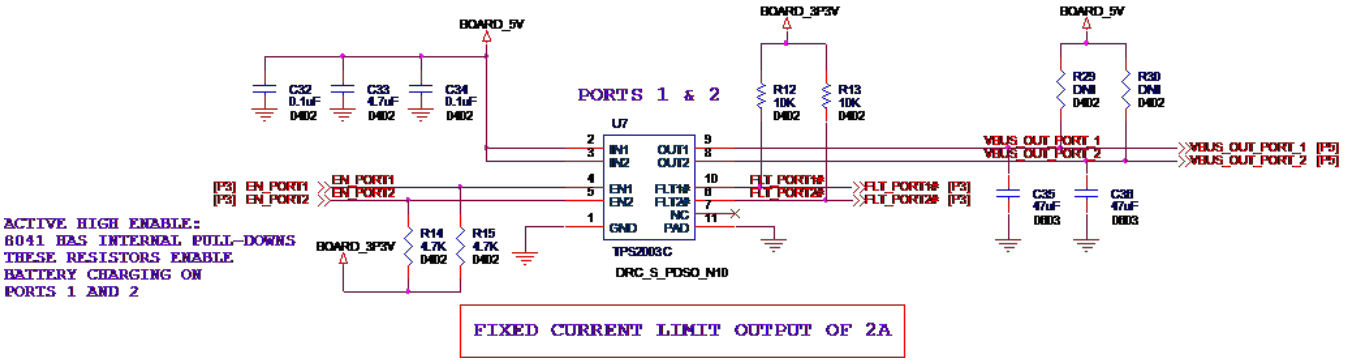


Figure 3. Ports 1 and 2 Power Delivery

Depending on the state of the upstream connection, the downstream ports will either be in CDP mode or Auto mode. When the upstream port is connected, ports 1 and 2 are in CDP mode. With the upstream port disconnected, ports 1 and 2 are in TUSB8041 Auto mode.

The TUSB8041 supports three of the most common USB charging schemes found in popular hand-held media and cellular devices:

- USB Battery Charging Specification BC1.2
- Chinese Telecommunications Industry Standard YD/T 1591-2009
- Divider Mode

BC1.2 lists three different port types as listed below:

- Standard Downstream Port (SDP) – data only
- Charging Downstream Port (CDP) – charging and data
- Dedicated Charging Port (DCP) – charging only

BC1.2 defines a charging port as a downstream-facing USB port that provides power for charging portable equipment, thus under this definition CDP and DCP are defined as charging ports.

Table 2 shows the differences between these ports.

Table 2. Operating Modes

Port Type	Supports USB 2.0 Communication	Max Allowable Current
SDP (USB2.0)	Yes	0.5 Amps
SDP (USB3.0)	Yes	0.9 Amps
CDP	Yes	1.5 Amps
DCP	No	1.5 Amps

Power delivery for ports 3 and 4 is controlled by TPS2546 (USB charging port controller and power switch). The TPS2546 provides the signatures on the D+/D- (USB 2.0) lines to support different charging schemes.

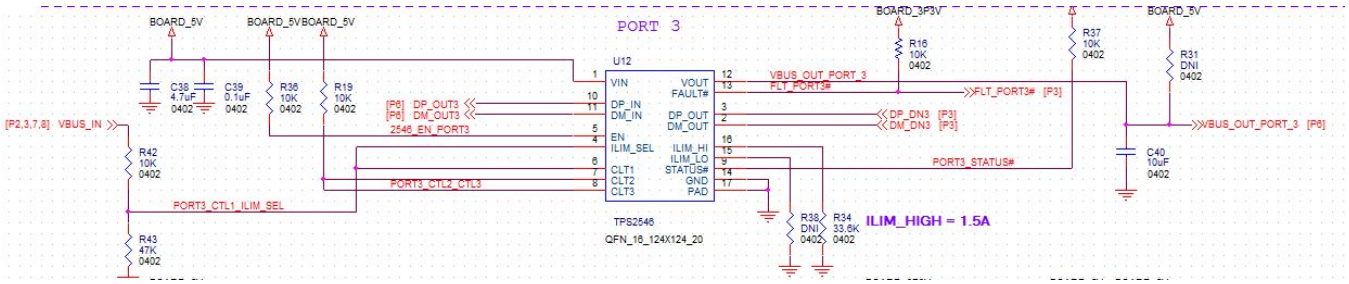


Figure 4. Ports 3 and 4 Power Delivery

Depending on the state of the upstream connection, the downstream ports are either in CDP mode or DCP Auto mode. When the upstream port is connected, ports 3 and 4 are in CDP mode. With the upstream port disconnected, ports 3 and 4 are in DCP Auto mode.

The TPS2546 supports four of the most common USB charging schemes found in popular hand-held media and cellular devices:

- USB Battery Charging Specification BC1.2
- Chinese Telecommunications Industry Standard YD/T 1591-2009
- Divider Mode
- 1.2 V Mode

BC1.2 lists three different port types as listed below:

- Standard Downstream Port (SDP)
- Charging Downstream Port (CDP)
- Dedicated Charging Port (DCP)

BC1.2 defines a charging port as a downstream-facing USB port that provides power for charging portable equipment. Under this definition, CDP and DCP are defined as charging ports.

Table 3 shows the differences between these ports.

Table 3. Operating Modes

Port Type	Supports USB 2.0 Communication	Max Allowable Current
SDP (USB2.0)	Yes	0.5 Amps
SDP (USB3.0)	Yes	0.9 Amps
CDP	Yes	1.5 Amps
DCP	No	1.5 Amps

3 Component Selection

All components contained in this design are chosen to provide a low-cost solution when purchased in large quantities, while minimizing component count and maintaining performance to satisfy the design criteria.

3.1 Hub Selection

The TUSB8041 was chosen as a low cost 4 port USB 3.0 hub. It supports USB 3.0 and USB 2.0 for both upstream and downstream ports. Battery charging is supported as is per-port or ganged power switching. An OTP ROM is included for custom, third-party VID/PID and device configuration. There are no special drivers required for this hub.

3.2 Downstream Power Switches

There are two different current-limited power distribution switches used to control the downstream VBUS power. Ports 1 and 2 are controlled by the TPS2003C part capable of switching 2 Amps of total current. The output enable is active high. Ports 3 and 4 are controlled by separate TPS2546, single port, USB charging port controllers. The controller is set to switch 1.5 Amps of current (set by resistor R34 for port 3 and R20 on port 4). Two modes of operation are supported, CDP and DCP Auto modes. CDP mode, Charging Downstream port, is a standard USB 3.0 port that can supply 1.5 Amps of current. In DCP mode, Dedicated Charging port, there is no USB data communication, but the port can supply up to 1.5 Amps charging current.

3.3 ESD Components

ESD protection for all USB ports is supplied by the TPD6E05U06 device. This part provides ESD protection for three differential pairs at data speeds of up to 6 GBps, and has low capacitance of 0.5 pF. Each USB port uses one of these parts to protect the port. The package allows for 'straight through' routing and is placed as close to the USB connector as possible.

3.4 4-Port Power

The main power for the board is +5 V. This can be supplied from either the upstream USB port or from an external power cube. The DC power cube is rated at 5 V / 5 Amps, and is connected to the board through a 2.5 mm center-positive DC power jack (J6). Board_5V is switched by a TPS22910 (low ON resistance load switch – U11). The switch has an ON pin that is active low. See Figure 5 for the power sub-system block diagram. When the power cube is plugged into the board, the JACK_INSERT line turns the TPS22910 (low ON resistance load switch) to the off position, allowing the BOARD_5V to be isolated from VBUS_IN. When no power cube is plugged into the power jack, the JACK_INSERT signal turns the TPS22910 to the on position and connects VBUS_IN to the BOARD_5V. The voltages for the TUSB8041 hub are generated from two different LMR10510 step-down voltage regulators. As shown in Figure 5, U9 takes the BOARD_5V and regulates it down to 3.3 V. The circuit was designed using TI's Webench Design Tool, and selected for the small PCB footprint and low component cost. U10 generates the 1.1 V power rail used for the TUSB8041 core voltage from the 3.3 V power rail.

3.5 External Power Cube

Due to upstream power constraints, an external power adapter may be required. An upstream USB 3.0 port can supply 5 V at 900 mAmps, or 4.5 Watts of power. The TUSB8041 consumes about 1 Watt of power. If any of the four downstream USB ports require more than 3.5 Watts of power, an external power cube will be required. The 4 port hub is designed to accept a 5 V, 5 Amps, center positive, 2.5 mm AC/DC adapter. The following are two sources of approved power cubes:

- SL Power #CENB1040A0503F01
- CUI Inc #ETMA050400UD

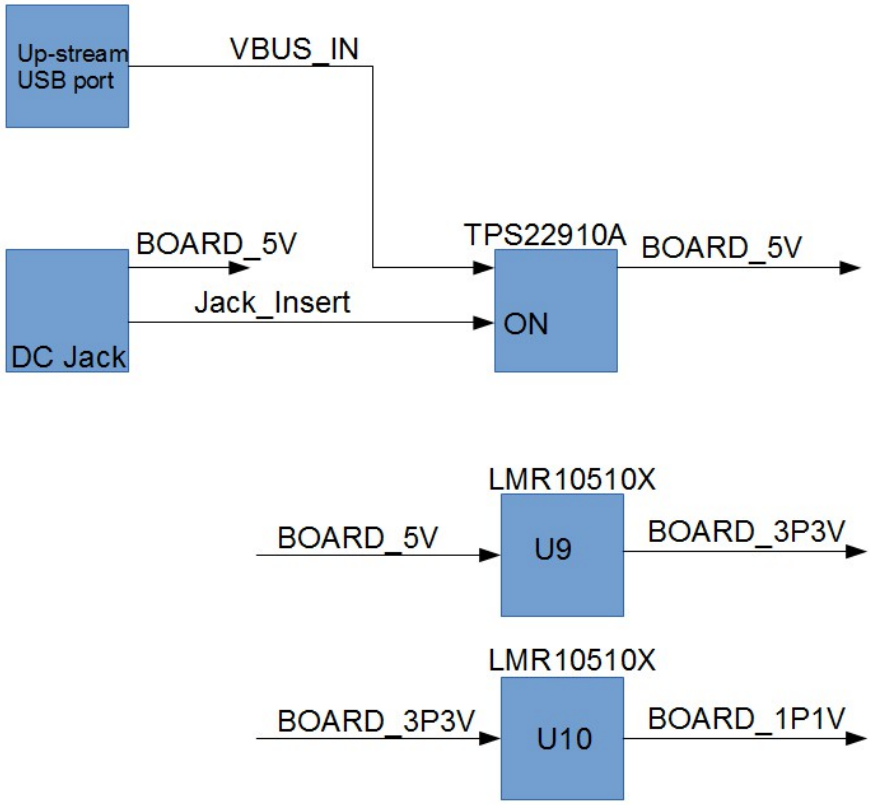


Figure 5. Power Sub-System Block Diagram

4 PCB Design

The PCB stack-up design was chosen to accommodate the 90 ohm impedance of USB 3.0 signal traces. A trace width of 4.4 mils and differential pair spacing of 5 mils is used with this layout. All USB 3.0 traces are routed on the top side of the board, and references a solid ground plane on layer 2. Layer 3 is the power layer and includes 5 V, 3.3 V and 1.1 V supplies. The bottom side, layer 4, is used for all other routes.

4.1 PCB Layout

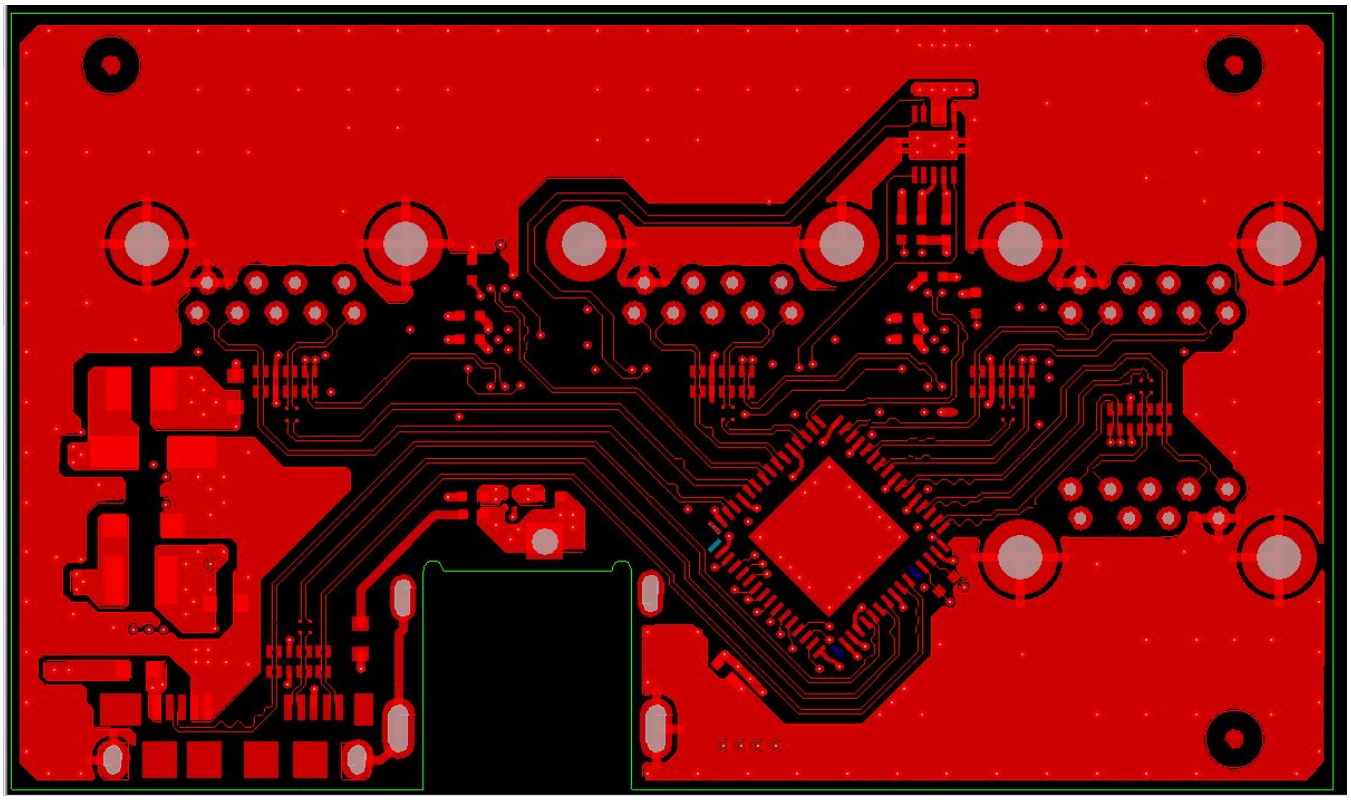


Figure 6. Top Layer – USB3.0 Routes

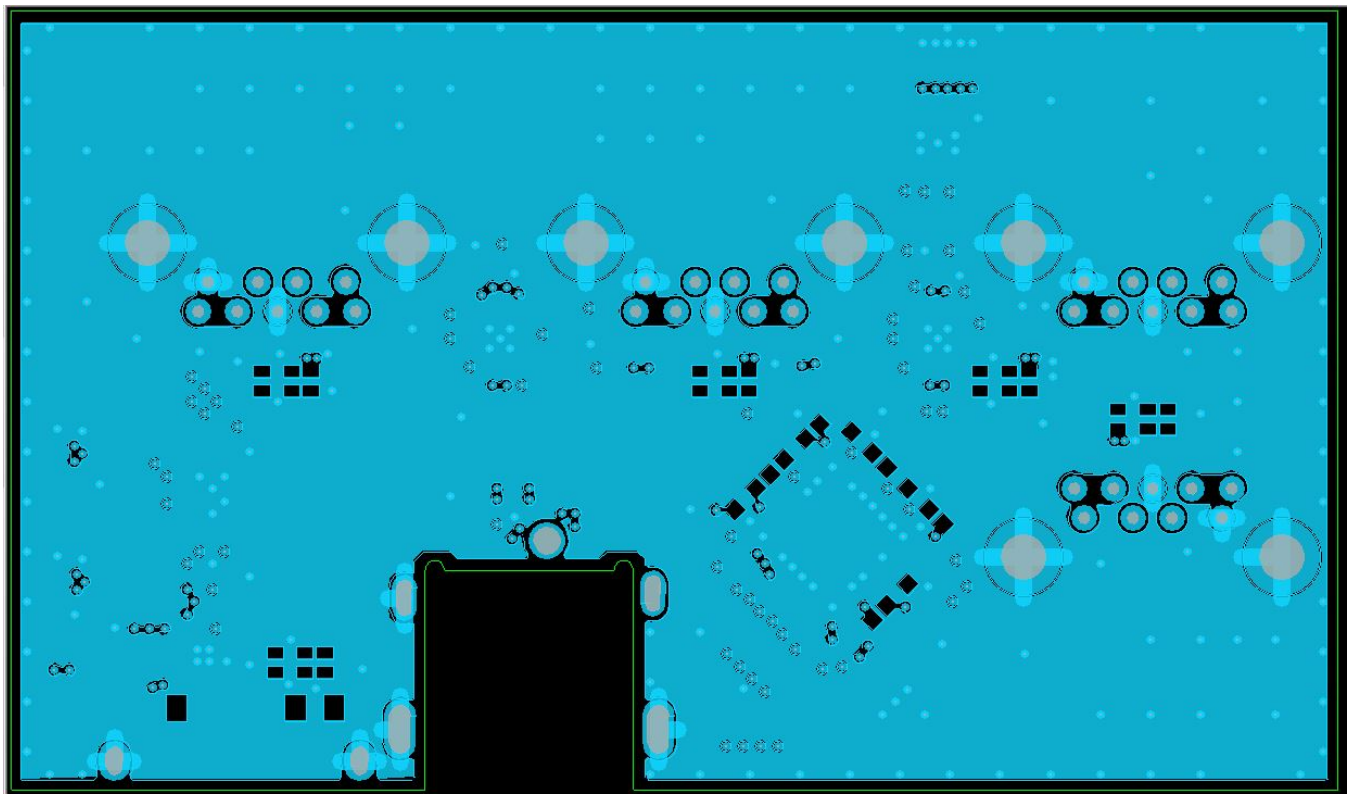


Figure 7. Layer 2 – Ground Plane

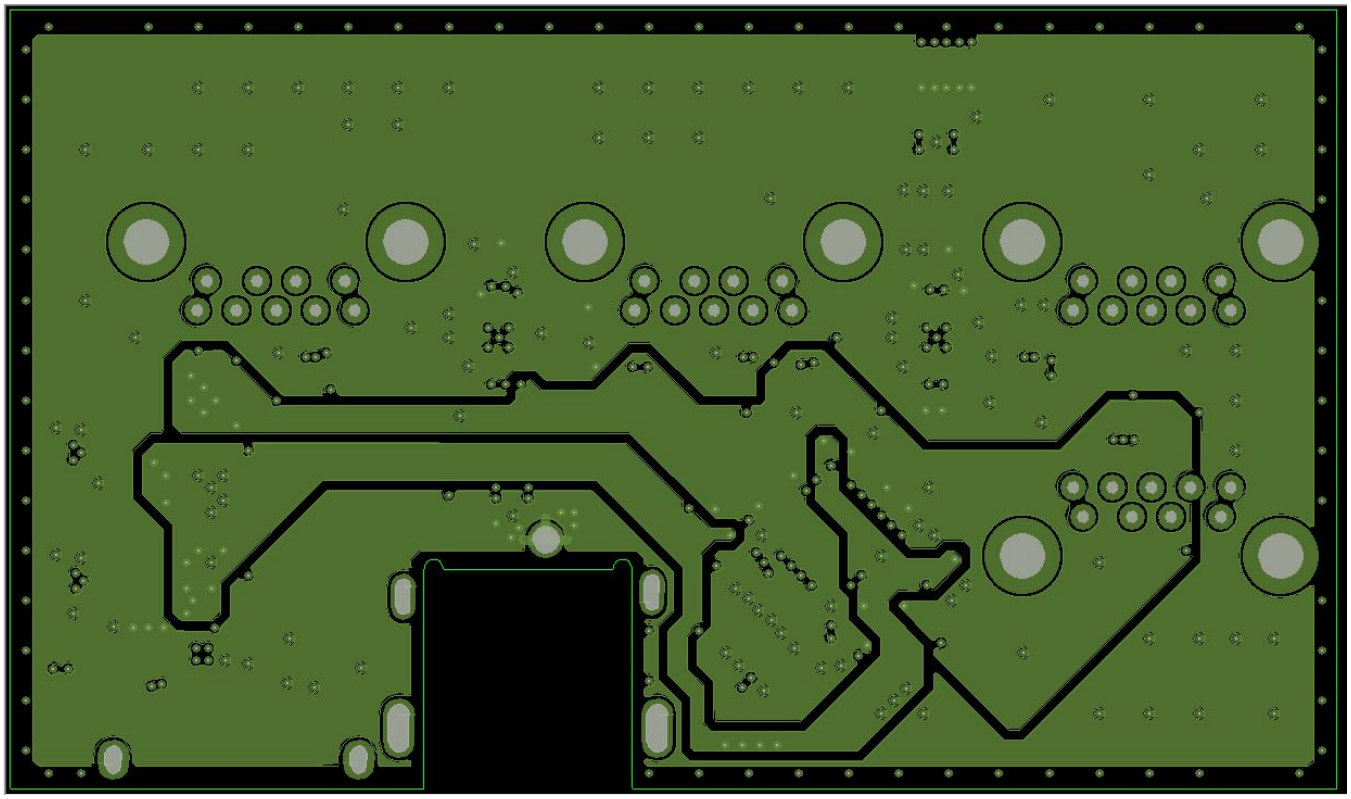


Figure 8. Layer 3 – Power Plane

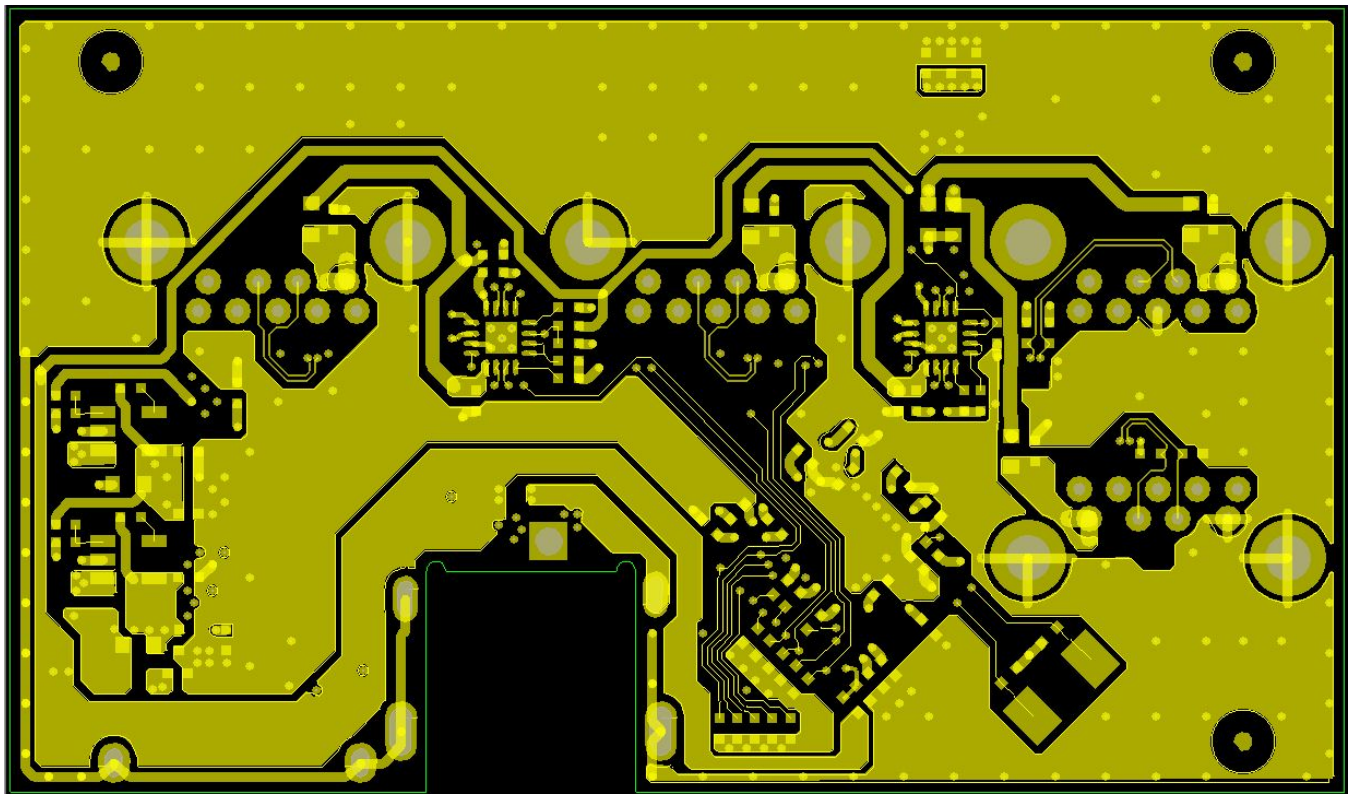


Figure 9. Bottom Side - Routing

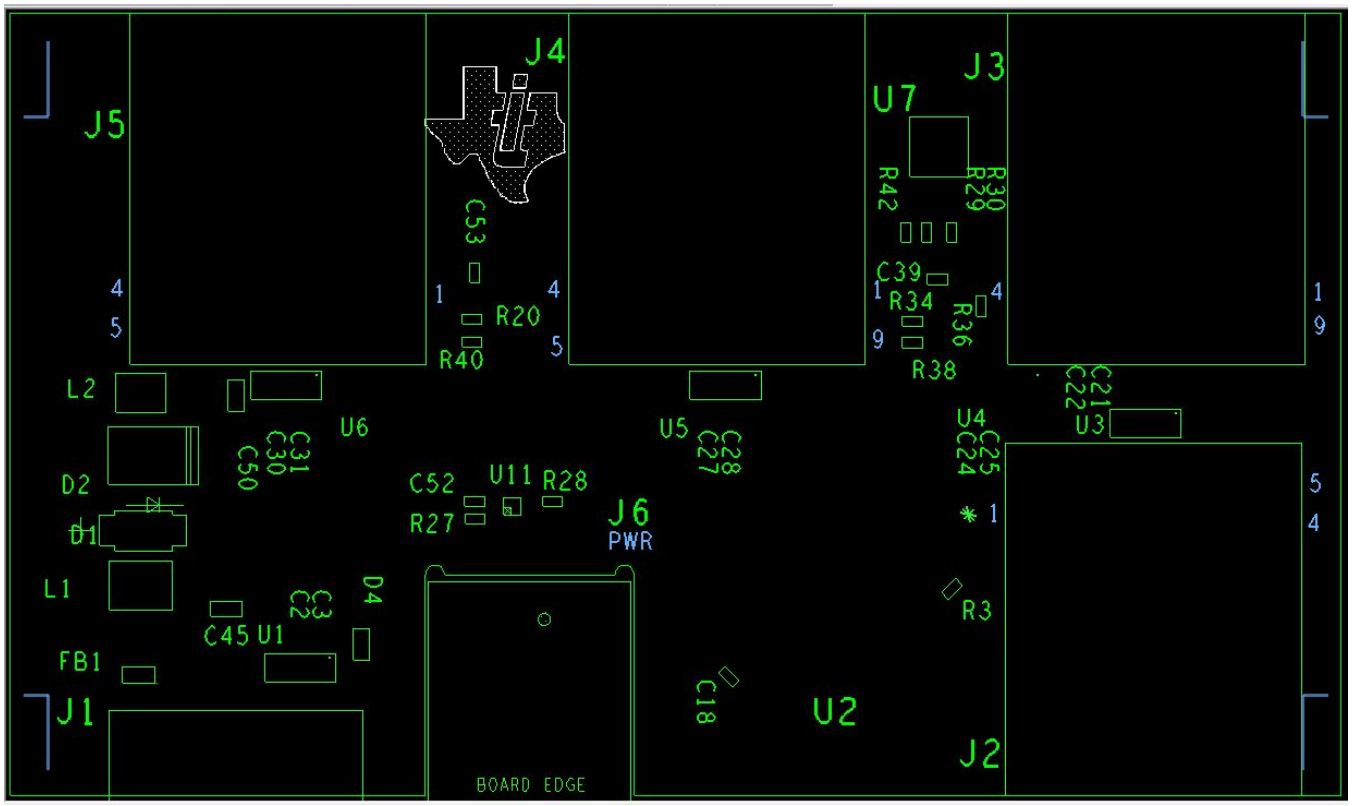


Figure 10. Top Side Silkscreen

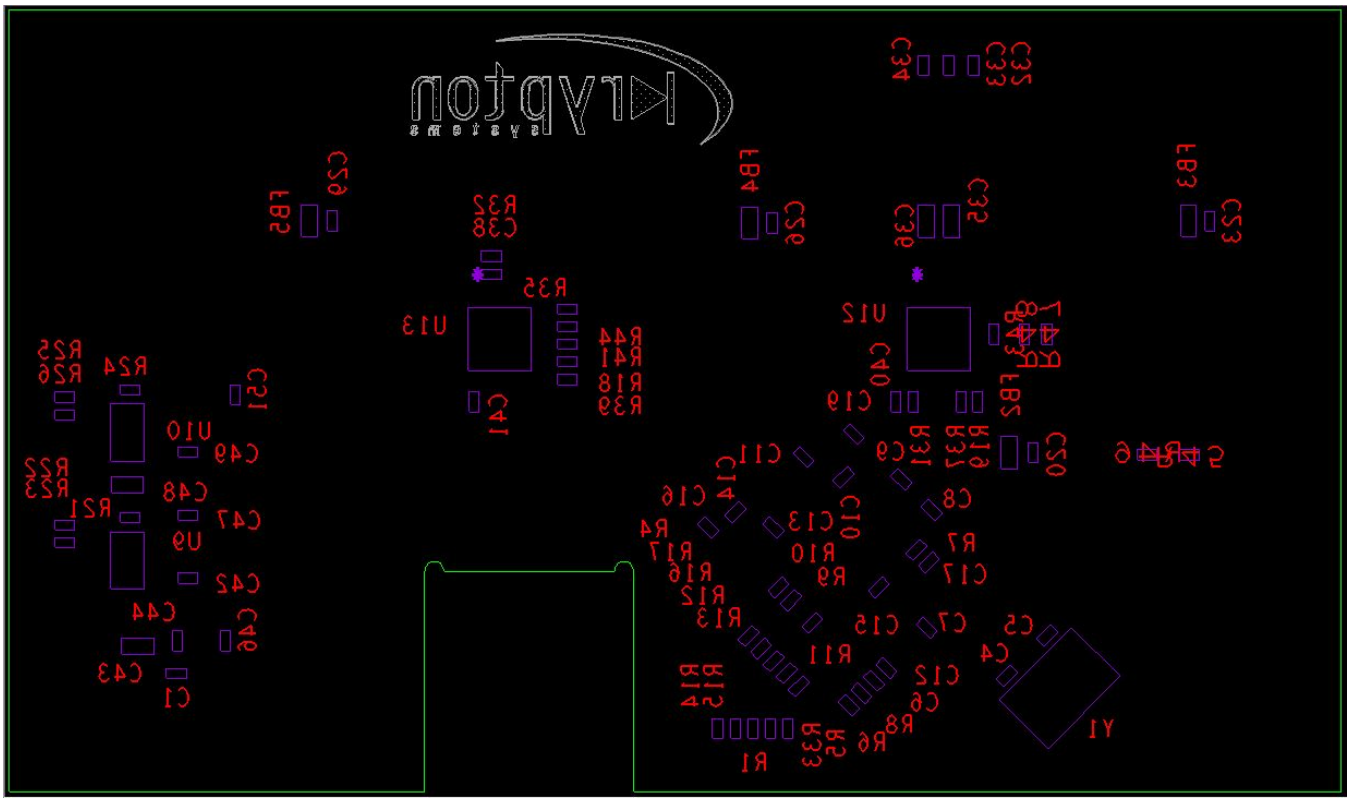


Figure 11. Bottom Side Silkscreen

4.2 Layout Guidelines

All USB 3.0 and 2.0 lines must be routed as controlled impedance, high speed differential pairs. Minimize the use of vias and 90 degree corners in the routing of the high speed lines. Assure the high speed lines reference a solid ground plane, and the plane is void of cuts and splits to prevent impedance discontinuities.

4.3 PCB Stack-up

Figure 12 shows the PCB stack-up used for the TIDA-00288 reference design.

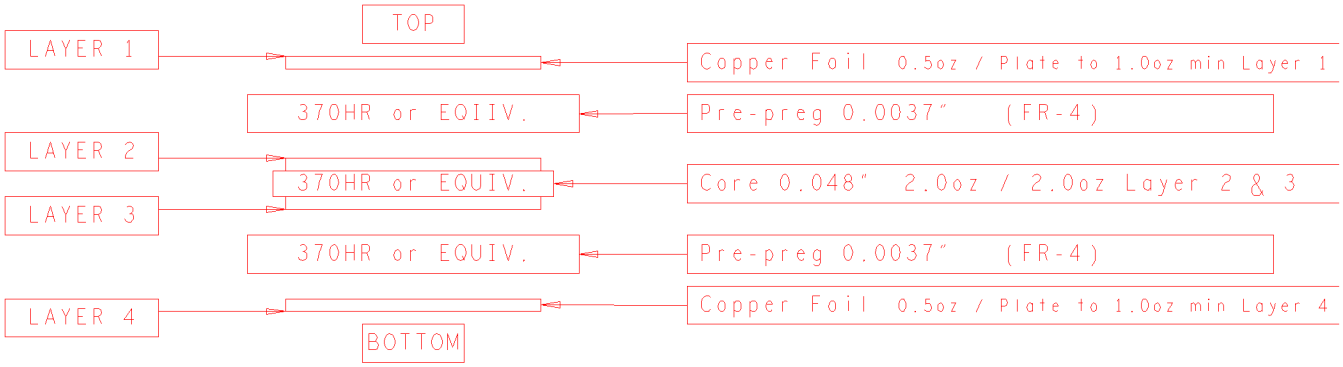
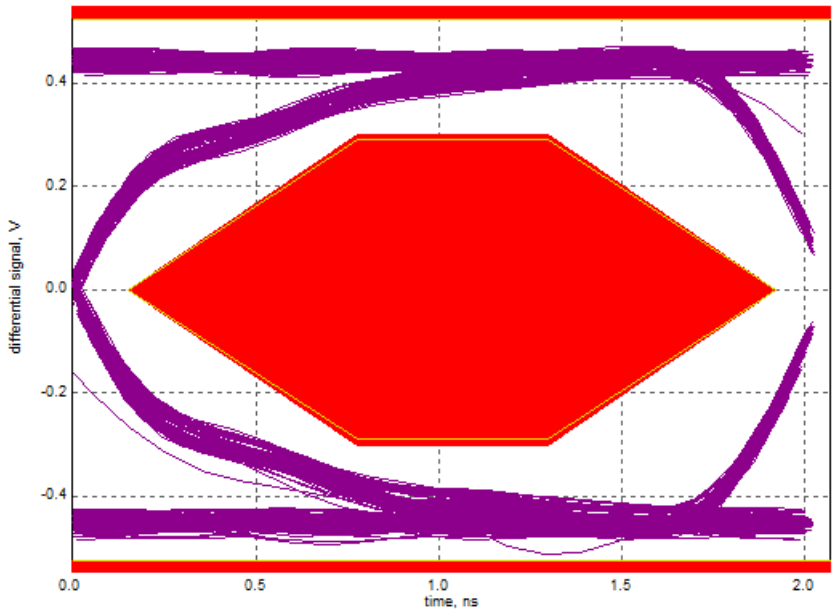


Figure 12. PCB Stack-up

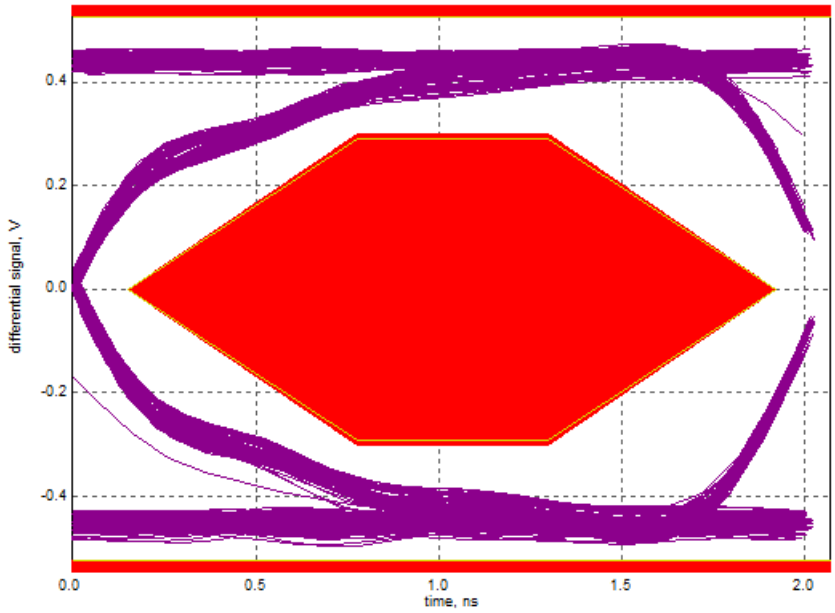
5 Verification and Measured Performance

5.1 Compliance Testing

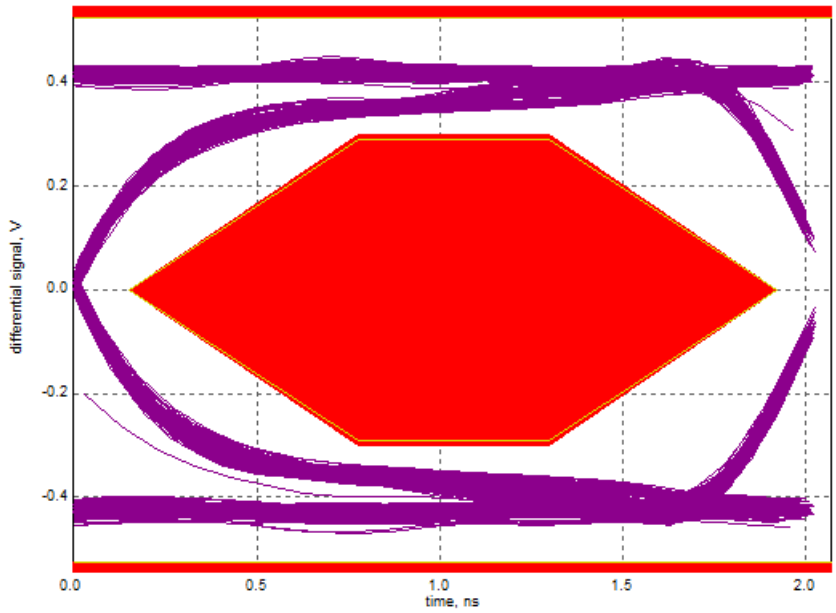
5.1.1 USB 2.0 – Downstream Port 1



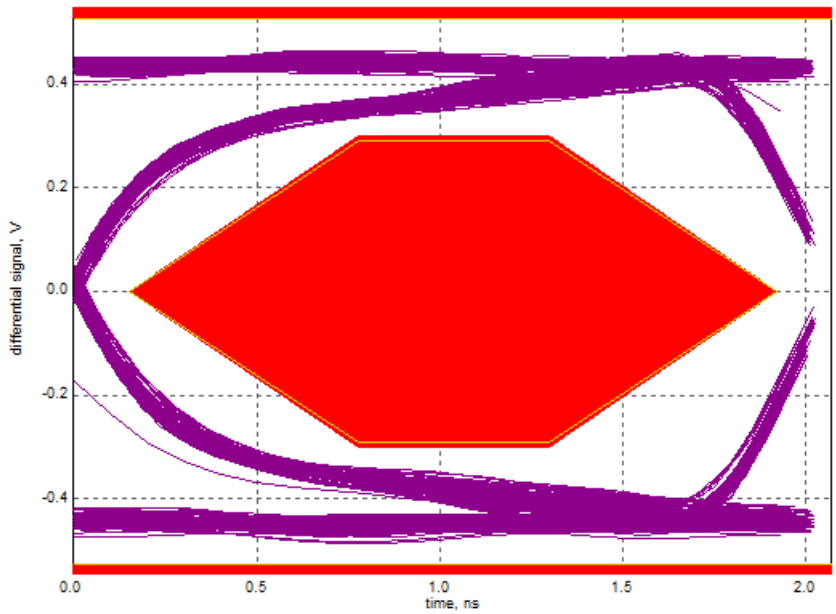
5.1.2 USB 2.0 – Downstream Port 2



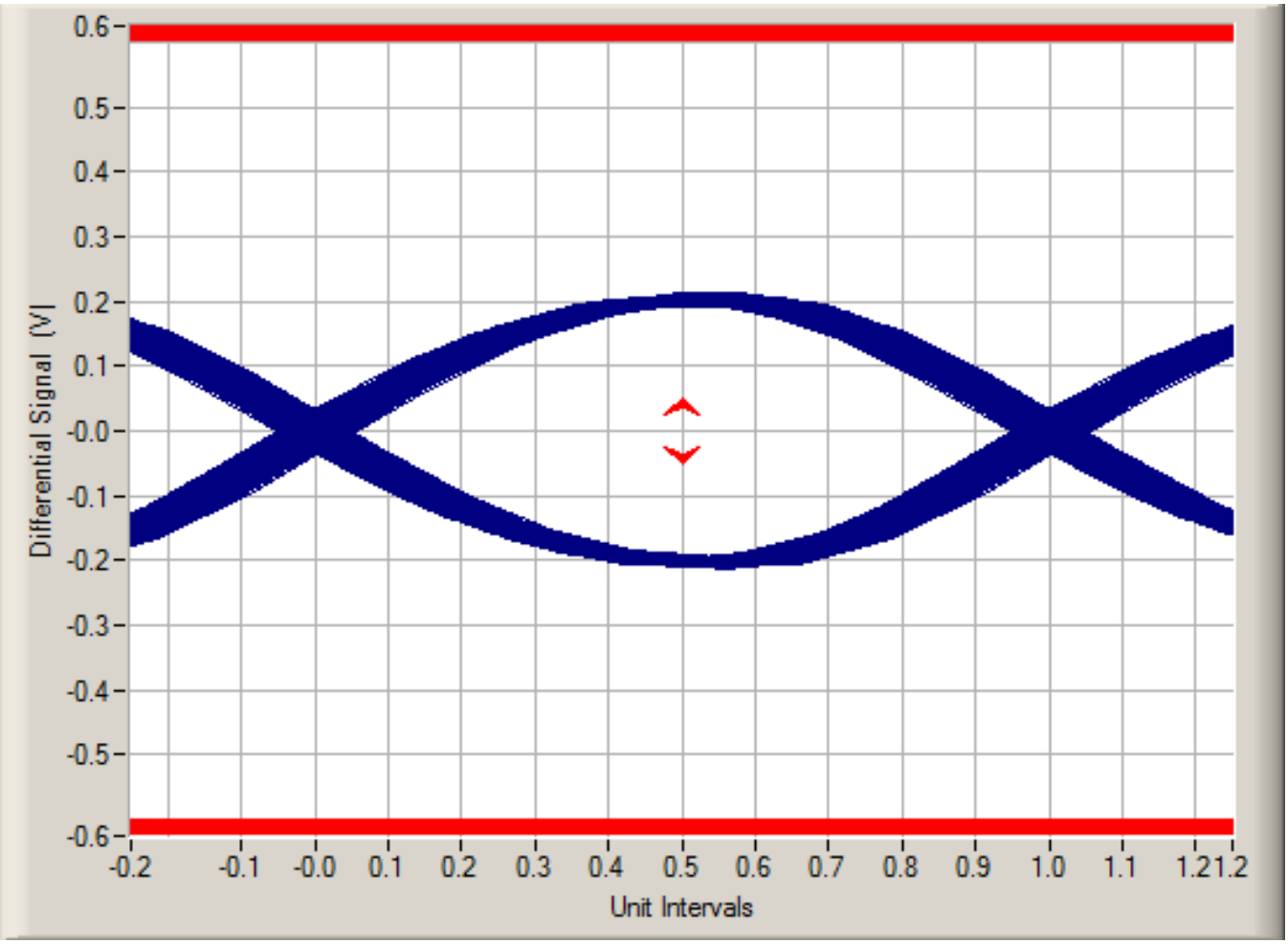
5.1.3 USB 2.0 – Downstream Port 3



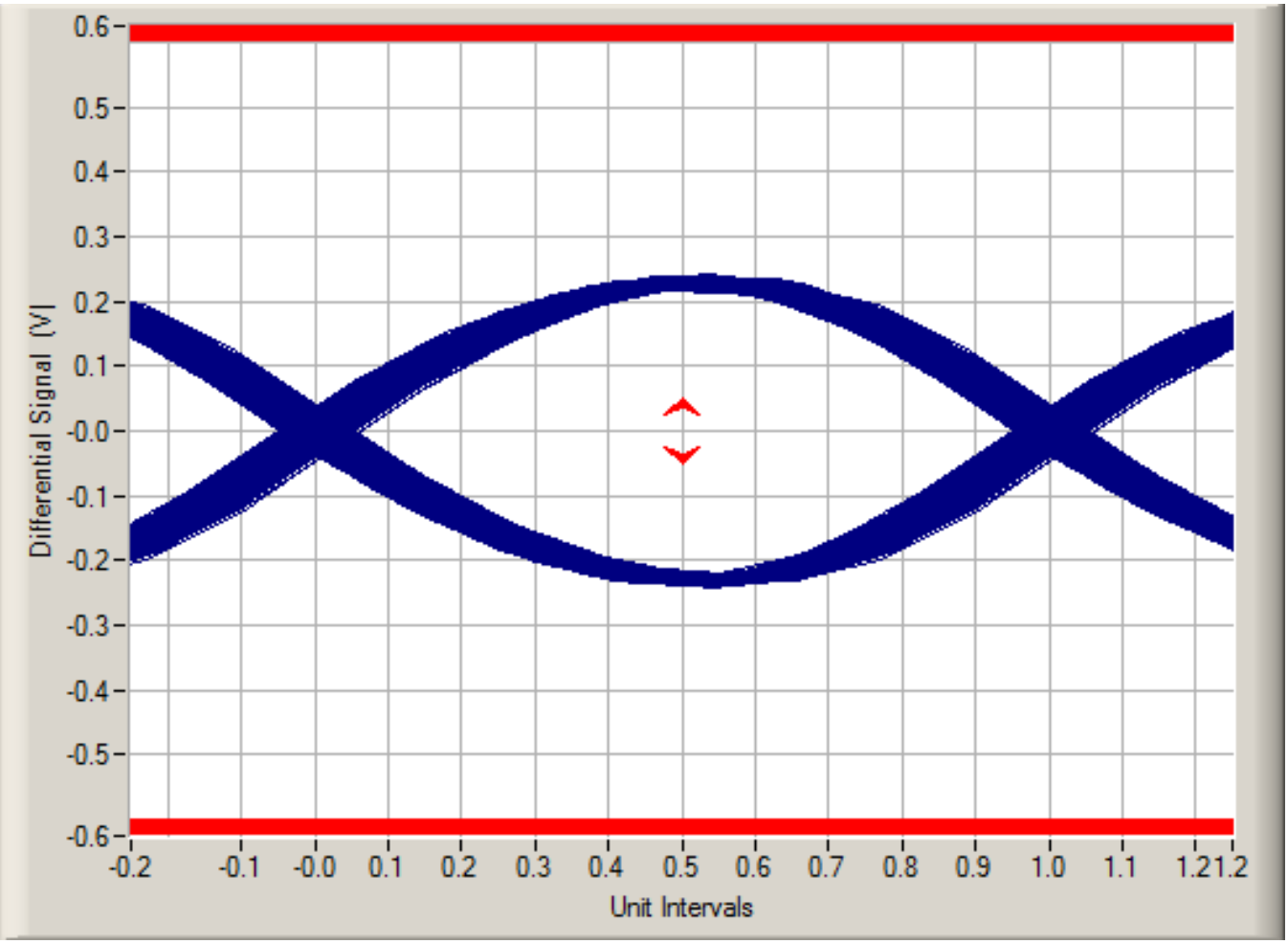
5.1.4 USB 2.0 – Downstream Port 4



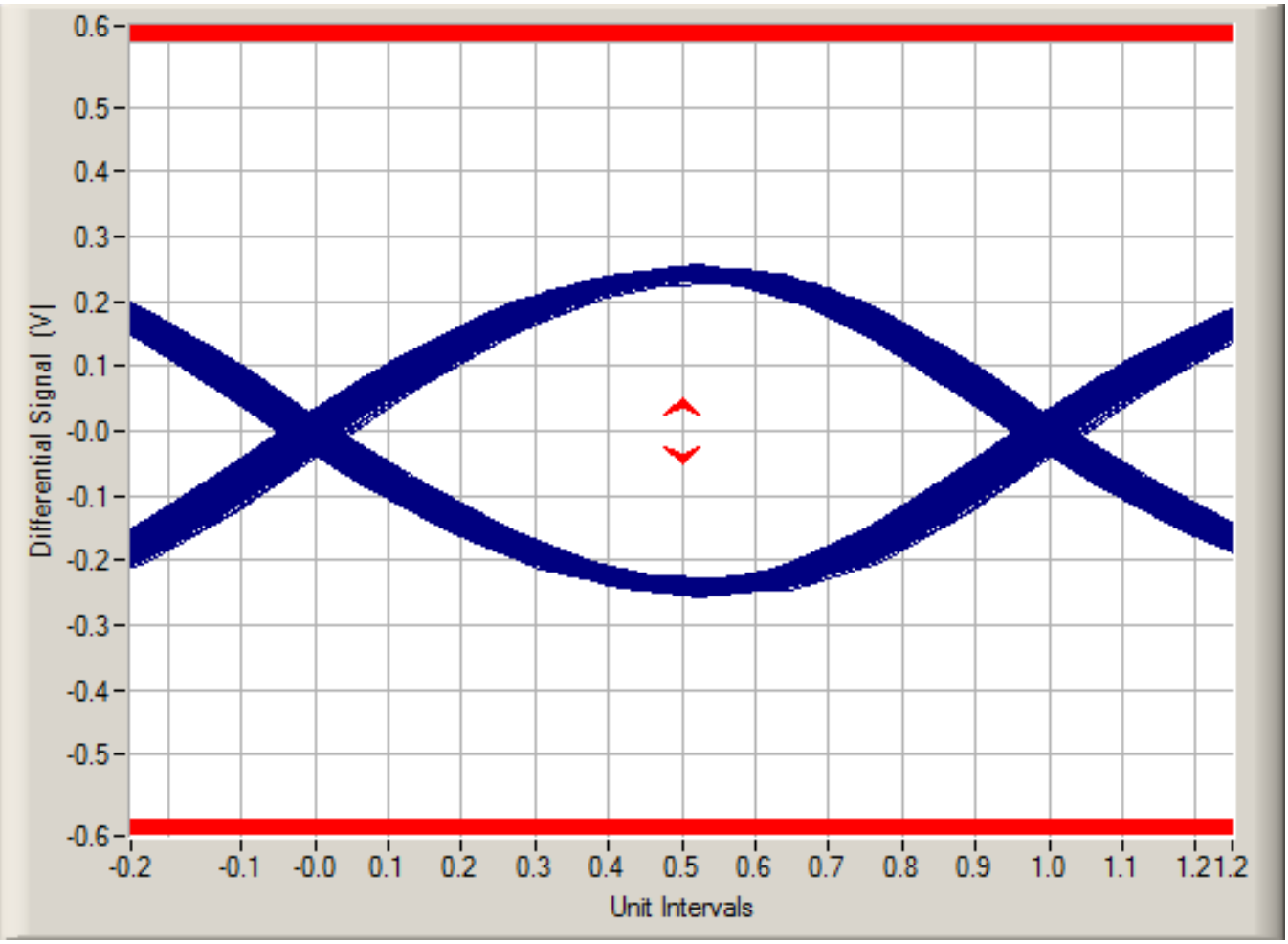
5.1.5 USB 3.0 – Downstream Port 1



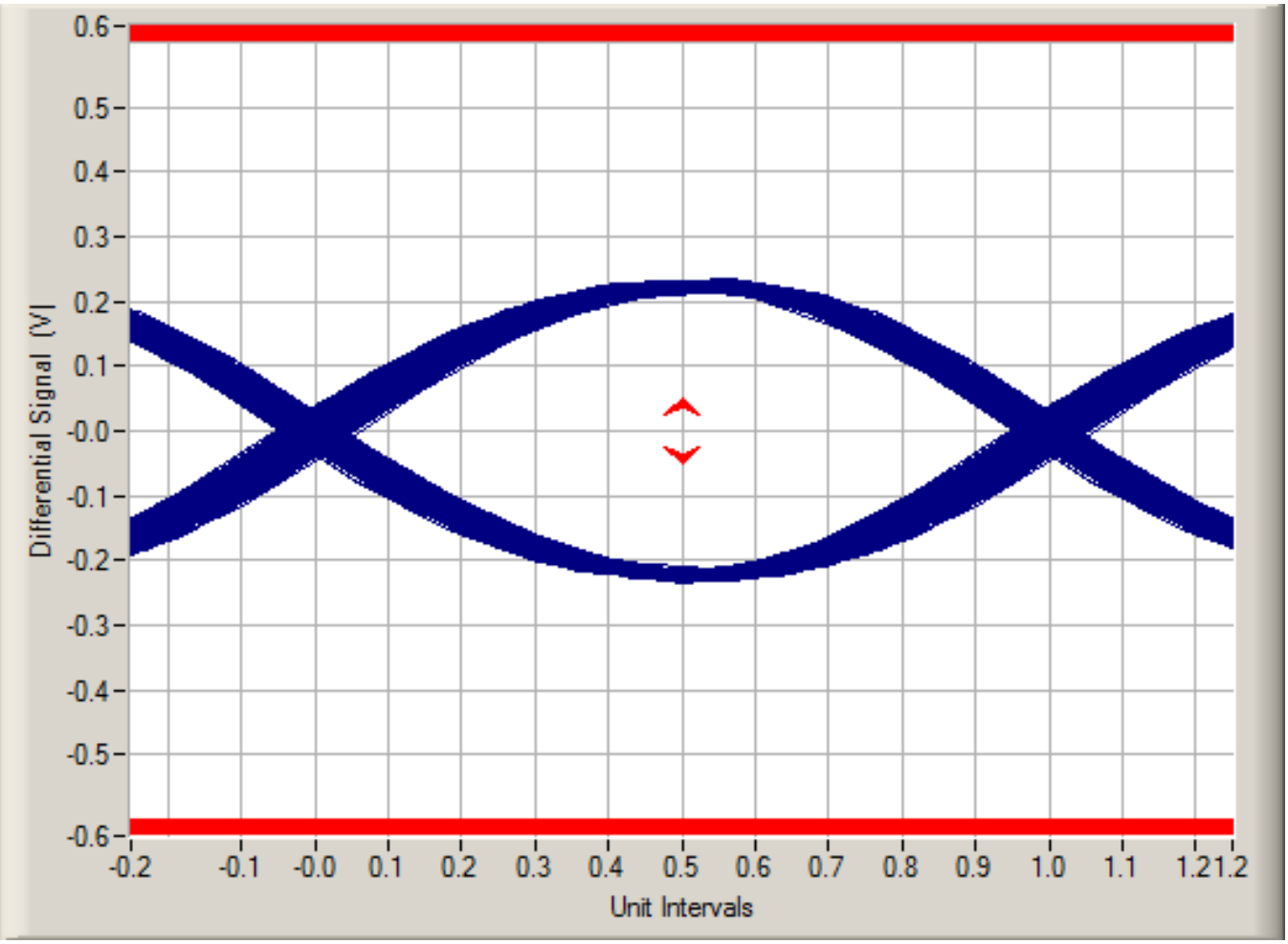
5.1.6 USB 3.0 – Downstream Port 2



5.1.7 USB 3.0 – Downstream Port 3



5.1.8 USB 3.0 – Downstream Port 4



6 Design Options

This section discusses different design options evaluated for this project that give the designer flexibility to modify the design.

6.1 ESD Protection

The TPD6E05U06 part was chosen to provide ESD protection on this design, due to it's small size, capability to provide protection of up to three differential pairs, and low capacitance. The package allows for 'flow through' routing. Another option is to use three single package parts for each USB connector (TPD2EUSB30). This allows for more flexibility in board routing.

6.2 TUSB8041 Options

The TUSB8041 has an interface for an optional I2C EEPROM or SMBUS host. This can store vendor information and other start-up parameters. An I2C EEPROM, such as the AT24C04 or a SMBUS host, can be connected to the serial interface for this purpose, but is not a design requirement. In this design, a 24 Mhz fundamental frequency crystal was used to generate the clock (CTS Frequency Controls #445C25D24M00000). Optionally, a 24 Mhz oscillator can be used and connected to XI pin (pin 62). Table 4 lists the options for the TUSB8041 that are set at the rising edge of the Grst# pin (pin 50).

Table 4. Power-on Reset Options

Signal Name (pin #)	Default	Condition
PWRCTL/BATEN 1-4 (pins 36, 35, 33 and 32)	Pull-Down	0 = Battery charging not supported 1 = Battery charging supported
SMBUSz/SS_SUSPEND (pin 39)	Pull-Up	0 = SMBbus enabled 1 = I2C enabled
FULLPWRMGMT/SMBA1/SS_UP (pin 40)	Pull-Down	0 = Downstream power switching supported 1 = Downstream power switch not supported
PWRCTL_POL (pin 41)	Pull-Up	0 = PWRCTL polarity is active low 1 = PWRCTL polarity is active high
GANGED/SMBA2/HS_UP (pin 42)	Pull-Down	0 = Individual port power control supported 1 = Ganged power control supported
AUTOENZ/HS_SUSPEND (pin 45)	Pull-Up	0 = Auto mode is enabled on all ports enabled for battery charging. 1 = Auto mode is disabled

6.3 Power Delivery Options

There are several options for providing power to downstream USB ports. For ports 1 and 2, the TPS2003C was used to reduce component count. Even in this family there are other options that would be viable solutions, with rated currents from 0.5 to 2 Amps. On ports 3 and 4, the TPS2546 was used to control USB charging. This part provides more capabilities than the TPS2003C, and can supply up to 3 Amps current.

6.4 Power Options

The TUSB8041 requires 1.1 V for core logic, and 3.3 V for I/O logic. The current requirements are in the datasheet, and Texas Instruments has many power solutions. The Simple Switcher design was chosen for low component count and low cost. By using two of the same part, cost was kept to a minimum. Visit TI's Webench Designer for other power options. The load switch used for isolating VBUS_IN and Board_5V is another option. The upstream port can only supply 900 mAmps, which may not be enough to power the logic on the board and 1 or 2 downstream ports. Adding an external power cube overcomes the limited current from the upstream connector.

7 Schematics

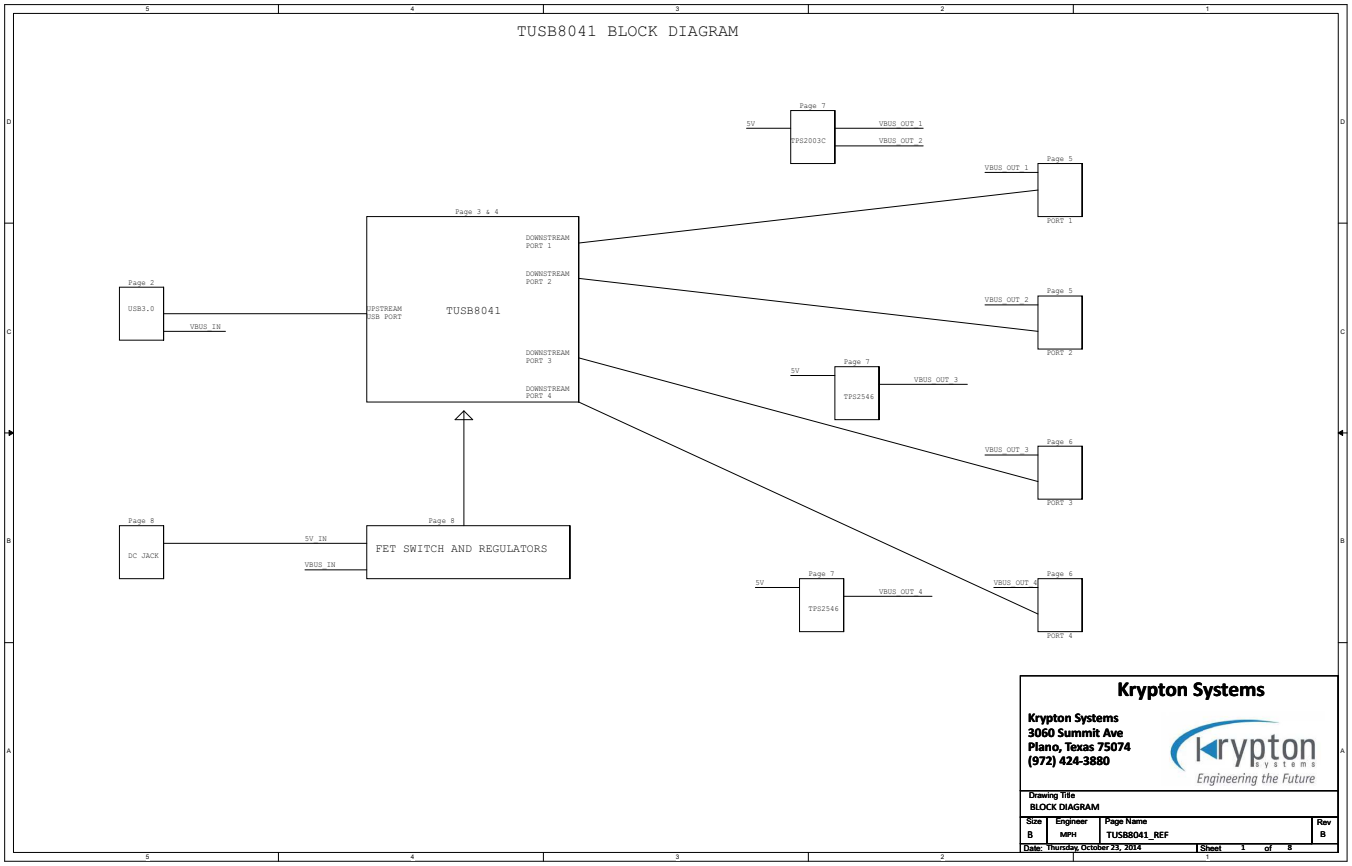


Figure 13. Schematic 1

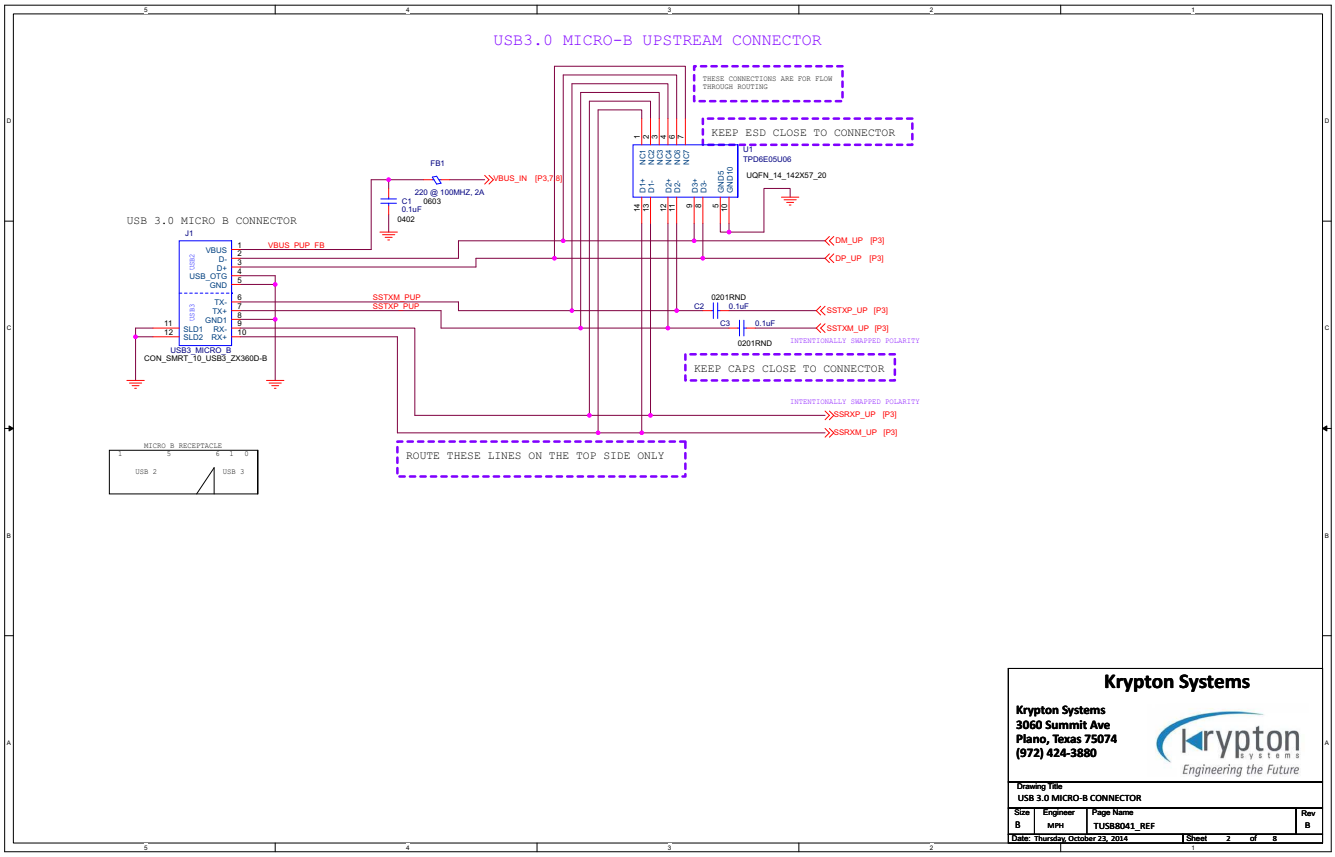


Figure 14. Schematic 2

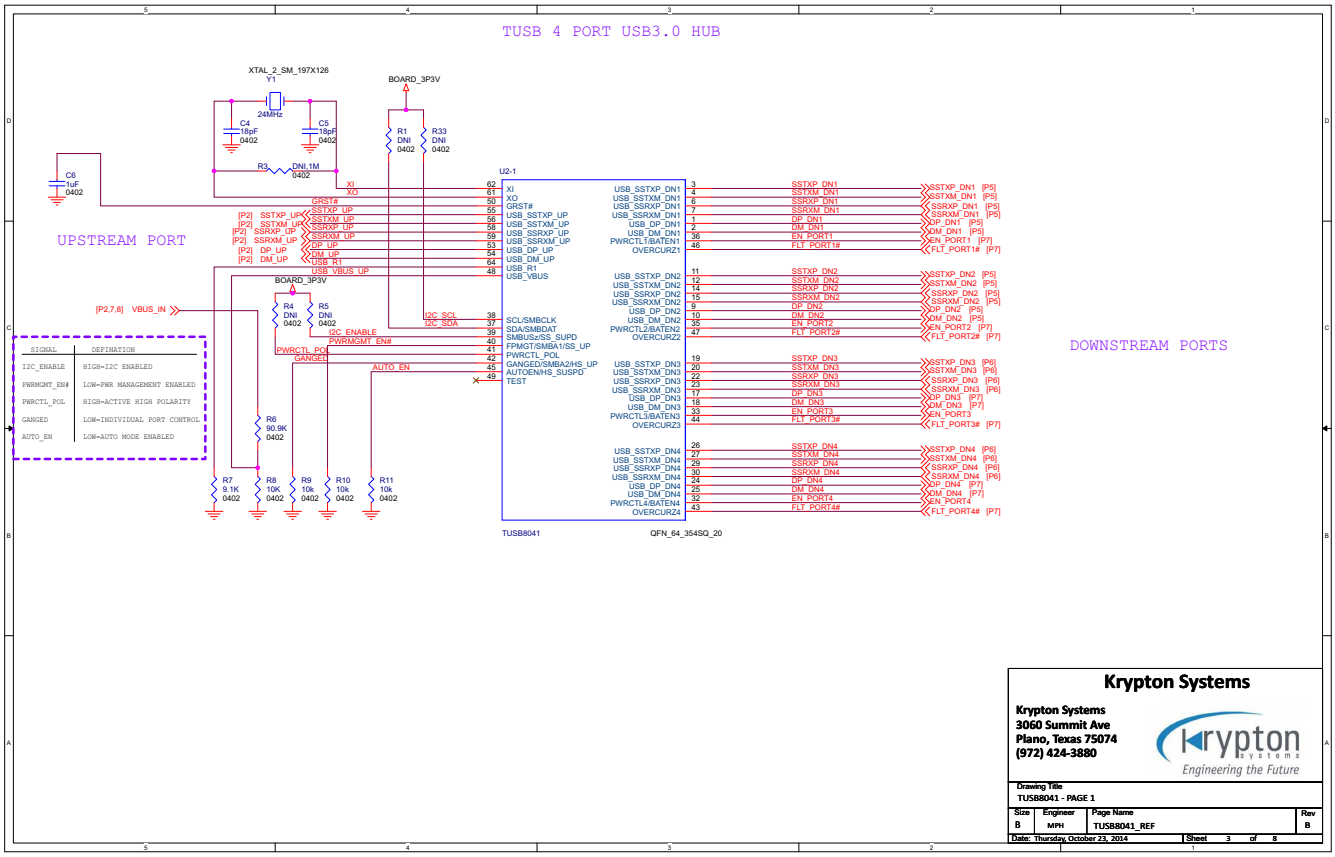


Figure 15. Schematic 3

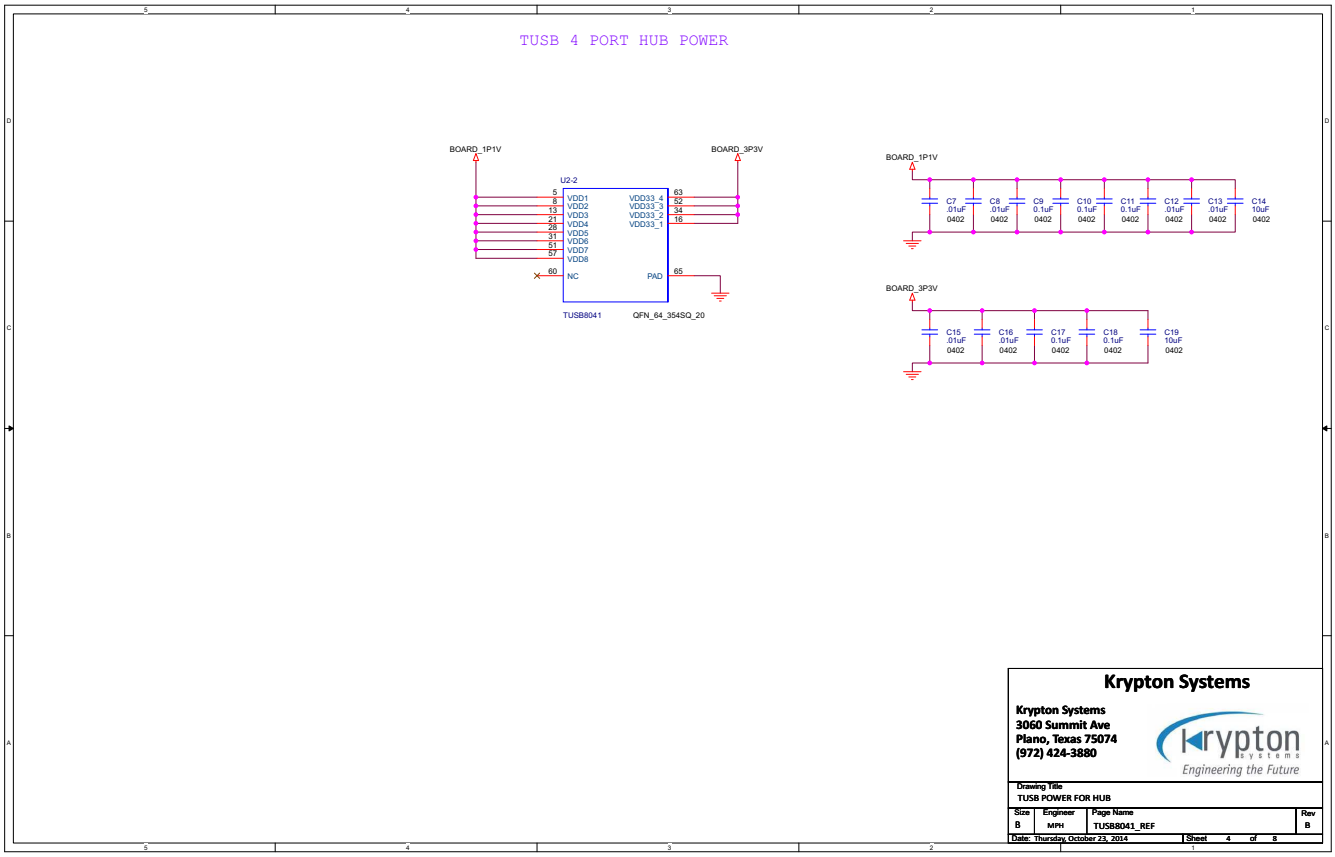


Figure 16. Schematic 4

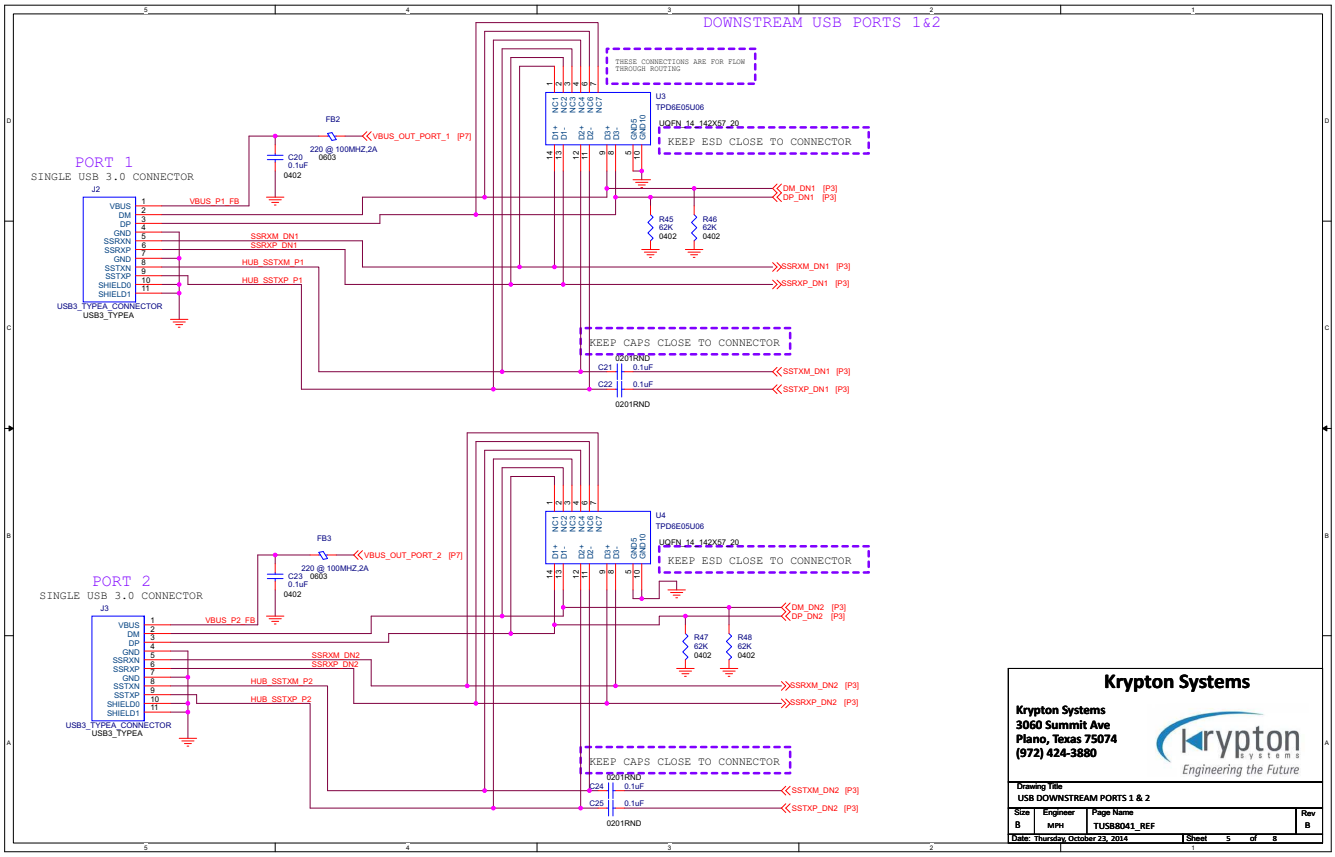


Figure 17. Schematic 5

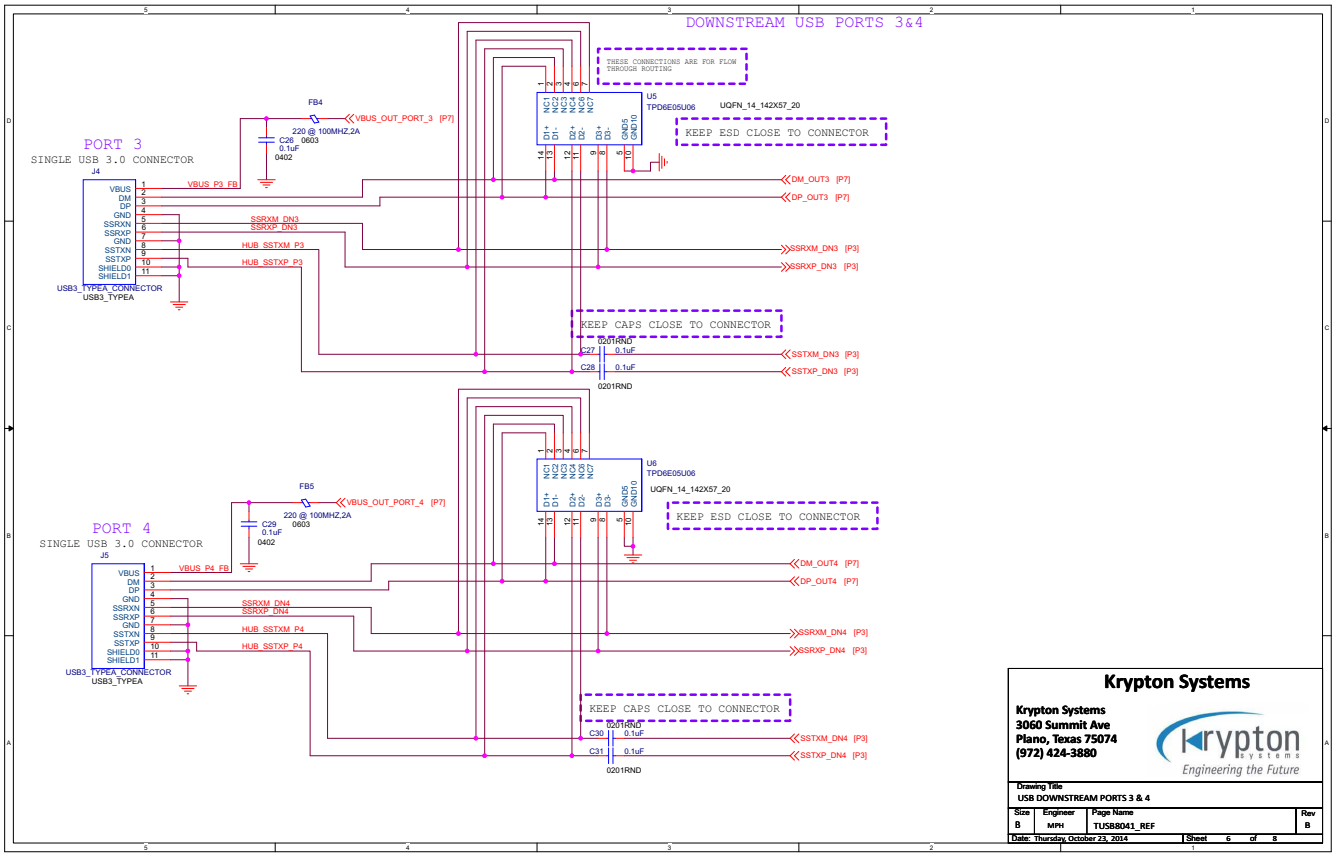


Figure 18. Schematic 6

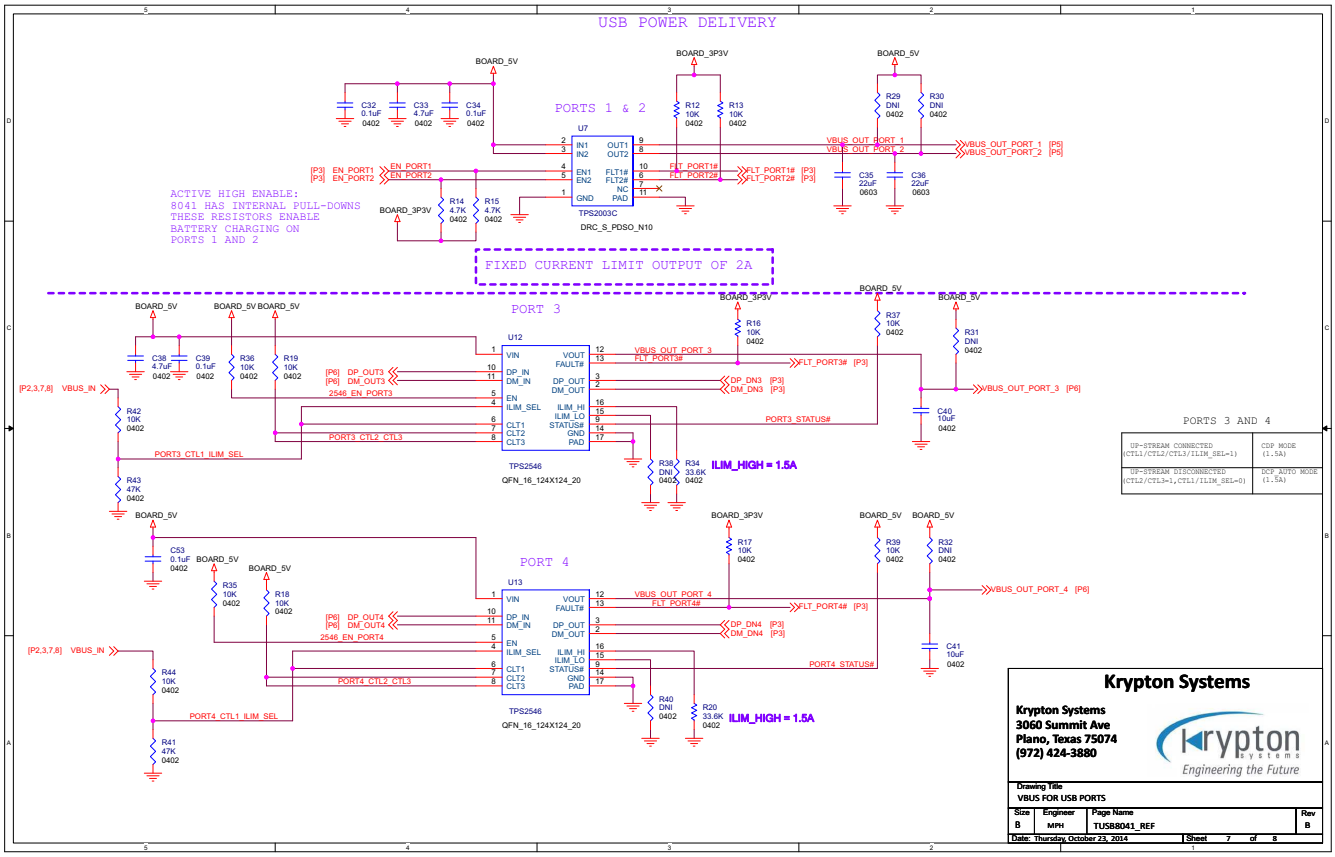


Figure 19. Schematic 7

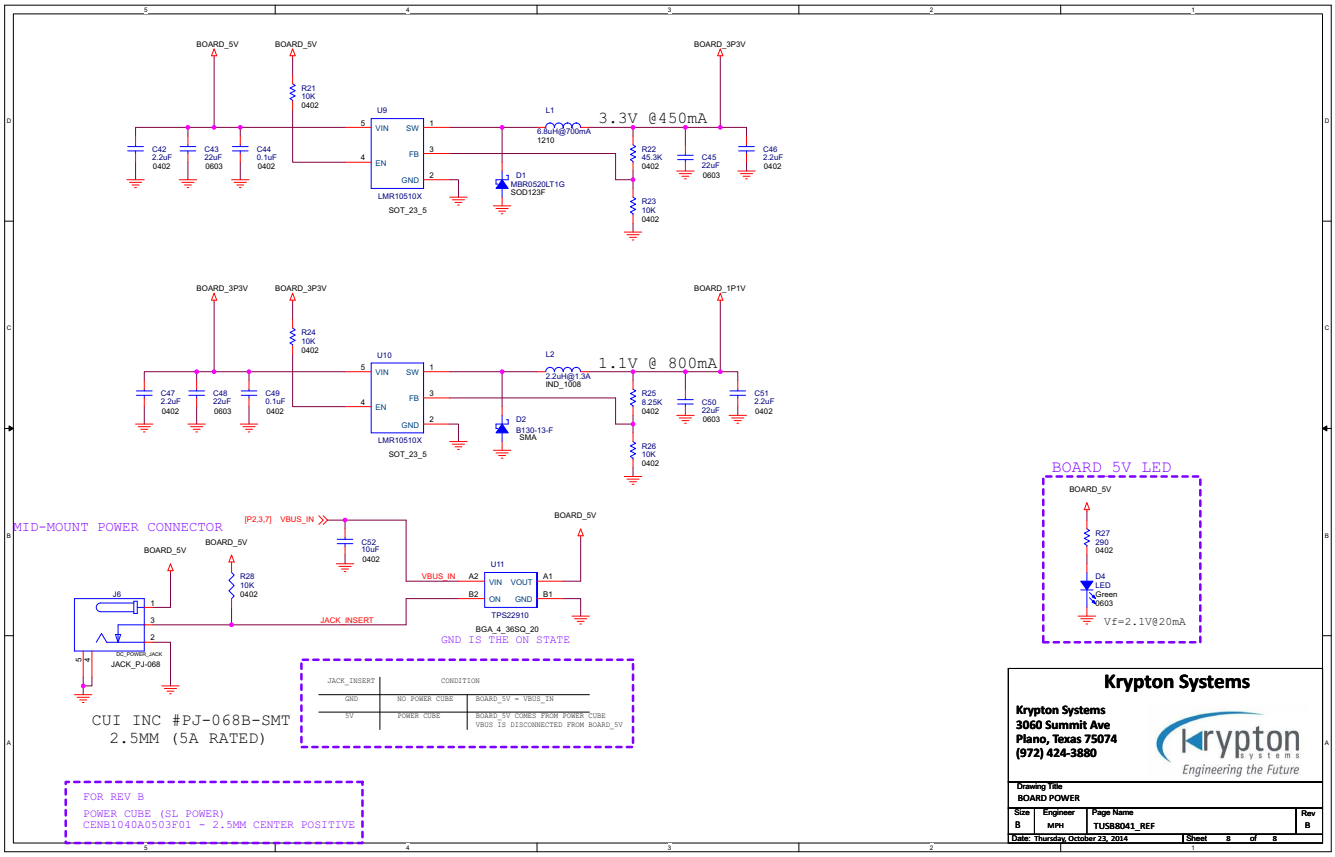


Figure 20. Schematic 8

8 Bill of Materials

Table 5. BOM

Item	Qty	Reference	Value	Part Description	Manufacturer	Manufacturer Part Number	PCB Footprint
1	10	C2, C3, C21, C22, C24, C25, C27, C28, C30, C31	0.1 µF	Capacitors 0.1 µF; 0201; X5R; 20%; 6.3 V	TDK	C0603X5R0J104M030BC	0201
2	16	C1, C9, C10, C11, C17, C18, C20, C23, C26, C29, C32, C34, C53, C39, C44, C49	0.1 µF	Capacitors 0.1 µF; 0402; X7R; 10%; 16 V	TDK	C1105X7R1C104K	0402
3	1	C6	1.0 µF	Capacitors 1.0 µF; 0402; X5R; 10%; 10 V	Taiyo Yuden	LMK105BJ105KV-F	0402
4	6	C7, C8, C12, C13, C15, C16	10000 pF	Capacitors 10000 pF; 0402; X7R; 10%; 50 V	Murata	GRM155R71H103KA88D	0402
5	5	C14, C19, C40, C41, C52	10 µF	Capacitors 10 µF; 0402; X5R; 20%; 6.3 V	Samsung	CL05A106MQ5NUNC	0402
6	2	C4, C5	18 pF	Capacitors 18 pF; 0402; C0G (NPO); 5%; 50 V	Murata	GRM1555C1H180JZ01D	0402
7	4	C42, C46, C47, C51	2.2 µF	Capacitors 2.2 µF; 0402; X5R; 20%; 6.3 V	TDK	C1005X5ROJ225M	0402
8	2	C33, C38	4.7 µF	Capacitors 4.7 µF; 0402; X5R; 10%; 6.3 V	TDK	C1005X5ROJ475K	0402
9	6	C43, C45, C48, C50, C35, C36	22 µF	Capacitors 22 µF; 0603; X5R; 20%; 6.3 V	TDK	C1608X5ROJ226M	0402
10	21	R8, R9, R10, R11, R12, R13, R21, R23, R24, R26, R28, R16, R17, R18, R19, R35, R36, R37, R39, R42, R44	10.0k	Resistors 10.0k; 0402; 1/10W; 1%	Panasonic	ERJ-2RKF1002	0402
11	4	R45, R46, R47, R48	61.9k	Resistors 61.9k; 0402; 1/16W; 1%	Panasonic	ERJ-2RKF6192X	0402
12	1	R27	301	Resistors 301; 0402; 1/10W; 1%	Panasonic	ERJ-2RKF3010X	0402
13	2	R20, R34	33.2k	Resistors 33.2k; 0402; 1/16W; 0.5%	Panasonic	RR0510P-3322-D	0402
14	2	R14, R15	4.70k	Resistors 4.70k; 0402; 1/16W; 1%	Vishay Dale	CRCW04024K70FKED	0402
15	1	R22	45.3k	Resistors 45.3k; 0402; 1/16W; 1%	Panasonic	ERJ-2RKF4532X	0402
16	2	R41, R43	47.0k	Resistors 47.0k; 0402; 1/10W; 1%	Panasonic	ERJ-2RKF4702X	0402
17	1	R25	8.25k	Resistors 8.25k; 0402; 0.063W; 1%; 50 V	Venkel	CR0402-16W-8251FT	0402
18	1	R7	9.09k	Resistors 9.09k; 0402; 1/16W; 1%; 75 V	Venkel	CR0402-16W-9091FT	0402
19	1	R6	90.9k	Resistors 90.9k; 0402; 1/16W; 1%	Yageo	RC0402FR-0790K9L	0402
20	5	FB1, FB2, FB3, FB4, FB5	220	Filters 220; 0603; 2A; %;	Murata	BLM18EG221SN1D	0603
21	5	U1, U3, U4, U5, U6	TPD6E05U06RVZR	Circuit Protection TPD6E05U06RVZR; 14-UFDFN; %; 14 V	Texas Instruments	TPD6E05U06RVZR	14-UFDFN
22	1	L2	2.2 µH	Inductors_Coils_Chokes 2.2 µH; 1008; 1.3 A; 20%	Murata	LQM2HPN2R2MGOL	1008
23	1	L1	6.8 µH	Inductors_Coils_Chokes 6.8 µH; 1210; 700 mA; 20%	TDK	NLCV32T-6R8M-PFR	1210
24	1	D4	LED - Green Clear	Optoelectronics LED - Green Clear ; 0805; 35 mcd; 20%; 2 V	Lite-On	LTST-C170KGKT	0805
25	1	D1	MBR0520LT1G	Discrete Semiconductor Products MBR0520LT1G; SOD-123; 500 mA; %; 20 V	ON Semiconductor	MBR0520LT1G	SOD-123
26	1	D2	Single	Discrete Semiconductor Products Single; SMA; 1A; %; 30 V	Diodes Inc.	B130-13-F	SMA
27	1	U7	TPS2003CDRC	Integrated Circuits TPS2003CDRC; 10-SON; ; %	Texas Instruments	TPS2003CDRC	10-SON
28	2	U12, U13	TPS2546RTET	Integrated Circuits TPS2546RTET; 16-WQFN; ; %	Texas Instruments	TPS2546RTET	16-WQFN
29	1	U11	TPS22910AYZV	Integrated Circuits TPS22910AYZV; 4-XFBGA, DSBGA; ; %	Texas Instruments	TPS22910AYZV	4-XFBGA, DSBGA
30	1	U2	TUSB8041	Integrated Circuits TUSB8041; 64-QFN; ; %	Texas Instruments	TUSB8041	64-QFN

Table 5. BOM (continued)

Item	Qty	Reference	Value	Part Description	Manufacturer	Manufacturer Part Number	PCB Footprint
31	2	U9, U10	LMR10510XMF/NOPB	Integrated Circuits LMR10510XMF/NOPB; SOT-23-5; ; %	Texas Instruments	LMR10510XMF/NOPB	SOT-23-5
32	1	Y1	24 MHz	Crystals & Oscillators 24 MHz; 5.00 mm x 3.20 mm; 18 pF; 20%;	CTS-Frequency Controls	445C25D24M00000	5.00 mm x 3.20 mm
33	1	J6	Power jack R/A	Connectors Power jack R/A; ; ; %;	Cui Inc	PJ-068B-SMT	
34	4	J2, J3, J4, J5	USB 3.0 - A Type	Connectors USB 3.0 - A Type; 16.5 x 13.8 x 7.0; 85°C; %; 30 V	FCI	10017835-002LF	16.5 x 13.8 x 7.0
35	1	J1	USB - microUSB Type	Connectors USB - microUSB Type; SMT; %	Hirose	ZX360D-B-10P	SMT
36	11	R1, R4, R5, R29, R30, R31, R32, R33, R38, R40	DNI	DNI	N/A	N/A	0402
37	1	R3	DNI	DNI	N/A	N/A	0402

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