Raychem

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Meeting USB (Universal Serial Bus) Overcurrent Protection Requirements Using PolySwitch Devices

ISO 9001

Meeting USB
Overcurrent Protection Requirements
Using PolySwitch Devices

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Introduction

Universal Serial Bus (USB) will allow PCs to be built in a more modular fashion and sold like home entertainment systems where people buy the specific components they want rather than a preconfigured system. The USB technology allows peripherals from printers to joysticks to seamlessly plug into a PC and prompts the computer to reconfigure itself to accept the new device. The USB bus utilizes a powered port architecture to accomplish these tasks. In the Plug-and-Play and Hot-plug environment, reliable and resettable overcurrent protection is a must.

Powered port protection architecture

USB relies on system flexibility and ease of use. The main drivers of the flexibility are Plug-and-Play and Hot-plug capabilities of the computer environment. Whether it is peripherals to the PC or functions to the peripheral in a USB bus, the ports of the system must be reliable to pass on data and power.

Powered ports require overcurrent protection. Underwriter's Laboratories (UL) and the International Electrotechnical Commission (IEC) have established standards for power sources for use with existing bus systems to provide overcurrent protection. UL1950, UL2950, and IEC950 are the primary agency specifications that govern the current output of power sources. Powered ports in computers (for example, SCSI, mouse, keyboard) have required overcurrent protection for several years.

In addition to safety agency standards, industry standards are also driving requirements for reliable products. Microsoft published the *Windows95 Hardware Design Guide*. The design guide promotes Plug-and-Play and the idea of a sealed PC box, where access to the inside of the box should not be required. The design requires resettable overcurrent protection for certain powered ports such as the SCSI port. Furthermore, the *PC98 Hardware Design Guide* requires overcurrent protection for terminator power (TERMPWR), citing positive-temperature-coefficient devices as an example of an overcurrent protection device to be used in the circuit.

The USB specification has continued the requirement for resettable overcurrent protection, referencing "poly fuses" (such as PolySwitch™ devices) as an appropriate method. An overwhelming majority of powered ports are currently protected by PolySwitch devices. The USB specification also endorses the concepts of Plug-and-Play and hot swapping, both of which lead to an increase of overcurrent scenarios. PolySwitch devices are a highly reliable, low cost solution to the needs of this environment.

PolySwitch Devices

General description
PolySwitch resettable fuses are polymeric positive temperature coefficient (PPTC) devices appropriate for self-powered and bus-powered Universal Serial Bus (USB) applications conforming to USB requirements. PolySwitch devices are suitable for both ganged port protection and individual port protection.

PolySwitch device features
- Conformity with USB Specification, Revision 1.0
- Compliance with:
  - UL1950/IEC950 safety requirements
  - Windows95 and PC97/98 standards
- Resettable protection
- UL-recognized safety device
- Low cost

Functional description
PolySwitch devices are series elements in a circuit (see Figure 1). The PolySwitch device protects the circuit by going from a low-resistance to a high-resistance state in response to an overcurrent (see Figure 2). This is called "tripping" the device. This change is the result of a rapid increase in the temperature of the device, caused by the generation of heat within the device by I^2R heating.

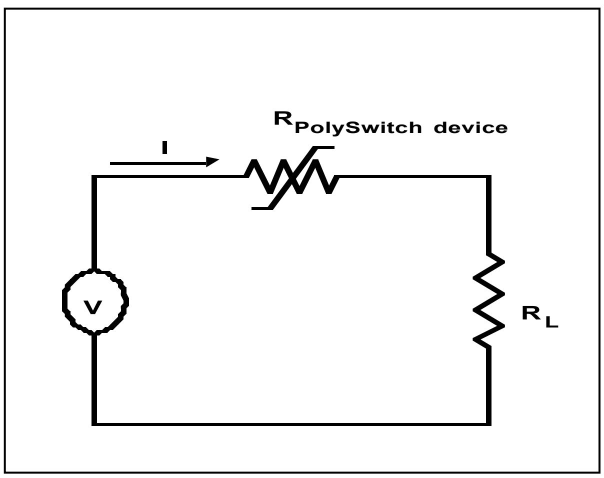


Figure 1. Circuit diagram with PolySwitch resettable fuse.

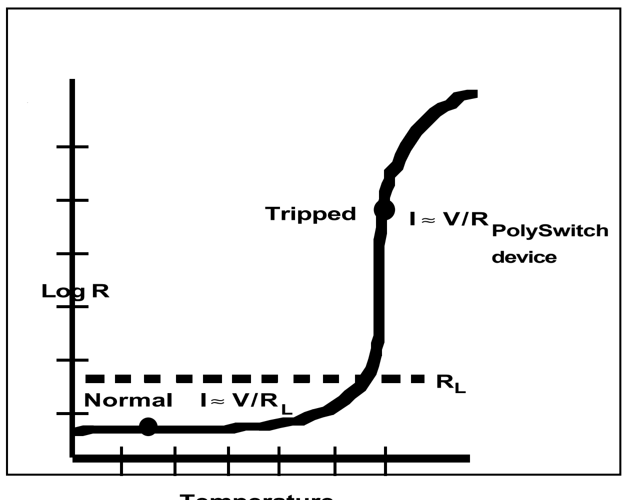


Figure 2. Operating curve for polymeric PTC device.

PolySwitch devices are available for a variety of operating currents. Each part is specified by "hold current," which is the maximum current at which the device will not trip (remain low in resistance) at 20°C. All of the devices have UL/CSA/TÜV safety agency recognition.

Universal Serial Bus (USB)
The goal of USB is to enable devices from different vendors to interoperate in an open architecture. USB features include ease of use for the end user, a wide range of workloads and applications, robustness, synergy with the PC industry, and low-cost implementation. Benefits include self-identifying peripherals, dynamically attachable and reconfigurable peripherals, multiple connections (support for concurrent operation of many devices), support for up to 127 physical devices, and compatibility with PC Plug-and-Play architecture.

Bus topology
The Universal Serial Bus connects USB devices with a USB host. There is only one USB host on any USB system. USB devices are classified either as hubs, which provide additional attachment

points to the USB, or as functions, which provide capabilities to the system (for example, a digital joystick). Hub devices are then classified as either Bus-Powered Hubs or Self-Powered Hubs.

A Bus-Powered Hub draws all of the power to any internal functions and downstream ports from the USB connector power pins. The hub may draw up to 500 mA from the upstream device. External ports in a Bus-Powered Hub can supply up to 100 mA per port, with a maximum of four external ports.

Self-Powered Hub power for the internal functions and downstream ports does not come from the USB, although the USB interface may draw up to 100 mA from its upstream connection, to allow the interface to function when the remainder of the hub is powered down. The hub must be able to supply up to 500 mA on all of its external downstream ports.

Electrical

The USB transfers signal and power over a four-wire cable. The differentially driven signaling occurs over two wires. The cable also carries Vbus and GND wires to deliver power to devices. Vbus is nominally +5 V at the source. USB Hub and Host devices must be protected from damage when a shorted or damaged downstream device is plugged into any USB Port. The most common problem is a damaged cable or connector which often results in a short-circuit being applied to a port when the cable is plugged into the Host or Hub. This will be a fairly “common” occurrence in the lifetime of a PC or Hub which is used for joysticks and other game controls, for example. As a result, USB Port short-circuit protection must be designed to be effective, reliable and resettable, as well as low-cost.

Overcurrent Protection

The USB specification (rev 1.0) states that overcurrent protection is required to prevent damage in the event of:

〈 catastrophic device failures
〈 software errors
〈 user actions, such as shorting the pins

Section 7.2.1 of the specification delineates the following USB overcurrent protection requirements:

〈 The designer must implement overcurrent protection for safety reasons.
〈 The overcurrent value cannot exceed 5 A.
〈 The design must allow an overcurrent to be reported to the software.

In summary, USB is a system that supports a Plug-and-Play environment with port loads of 100 mA and 500 mA at 5 V and with a multitude of devices having several powered ports. A typical desktop computer environment (Figure 3) shows where PolySwitch devices can provide economical and highly reliable protection for powered ports.

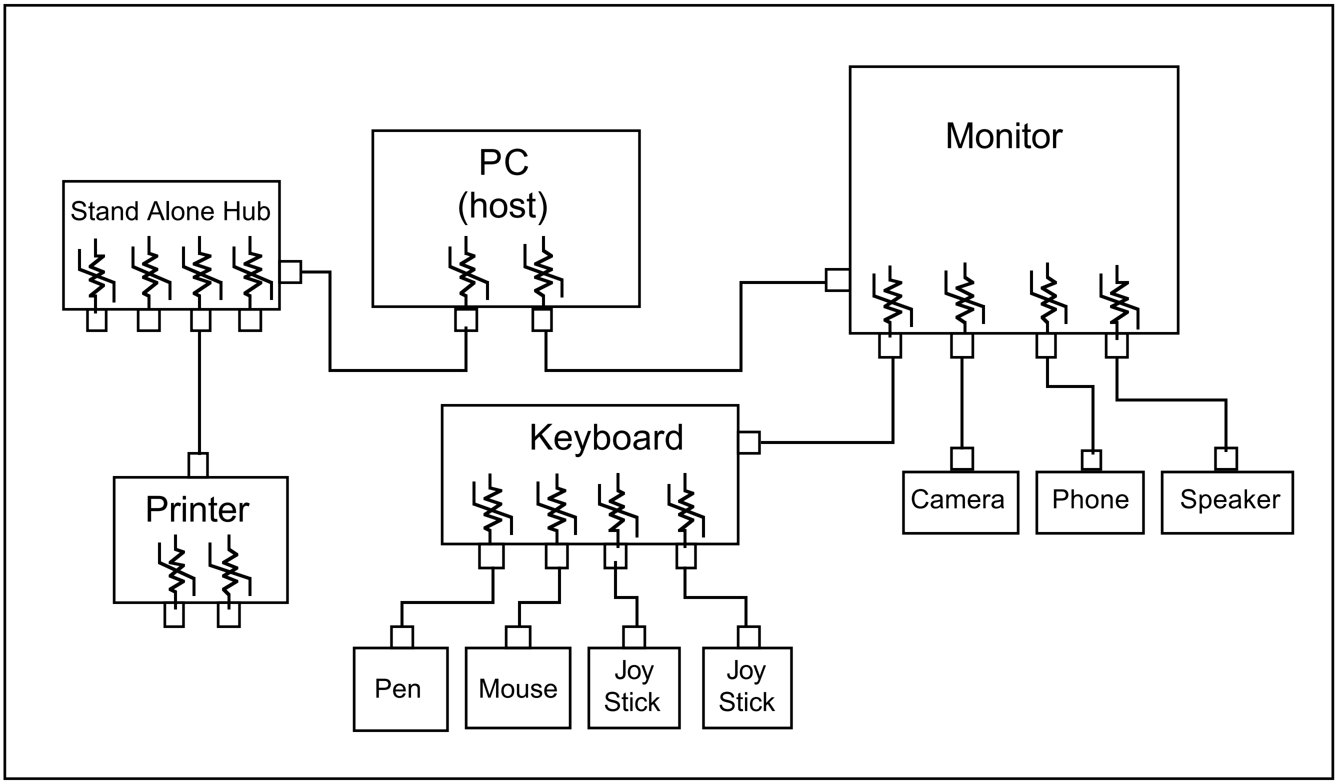


Figure 3. PolySwitch Circuit Protection in a typical computer environment.

Two design methodologies can be used for overcurrent protection: ganged or individual port protection (see Figures 4 and 5). Individual port protection provides the greatest system flexibility and the best design to meet USB electrical requirements. The most recent generation of USB controller chips has multiple overcurrent pins indicating that individual port protection is the most desired design architecture.

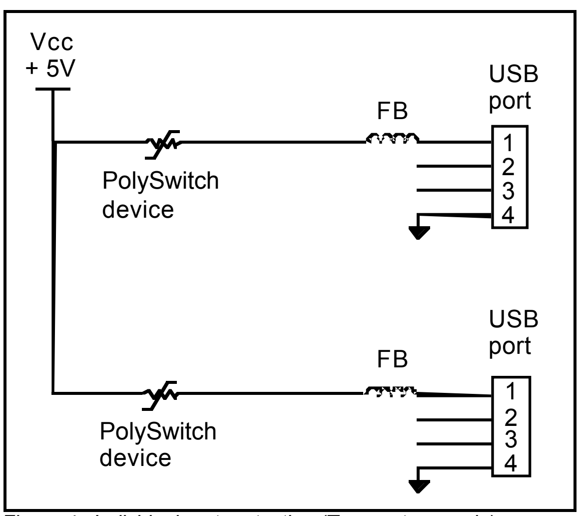


Figure 4. Individual port protection (Two-port example)

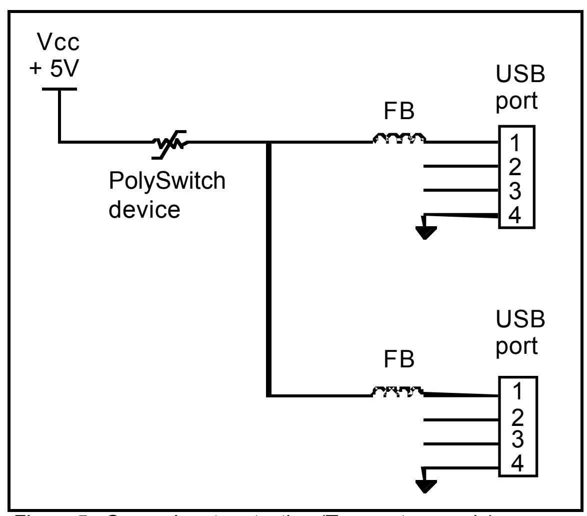


Figure 5. Ganged port protection (Two-port example)

Reporting overcurrent to the USB software

Overcurrents can be reported to the USB controller chip by laying a trace from the downstream side of the PolySwitch device to the overcurrent pin on the USB controller chip (see Figure 6).

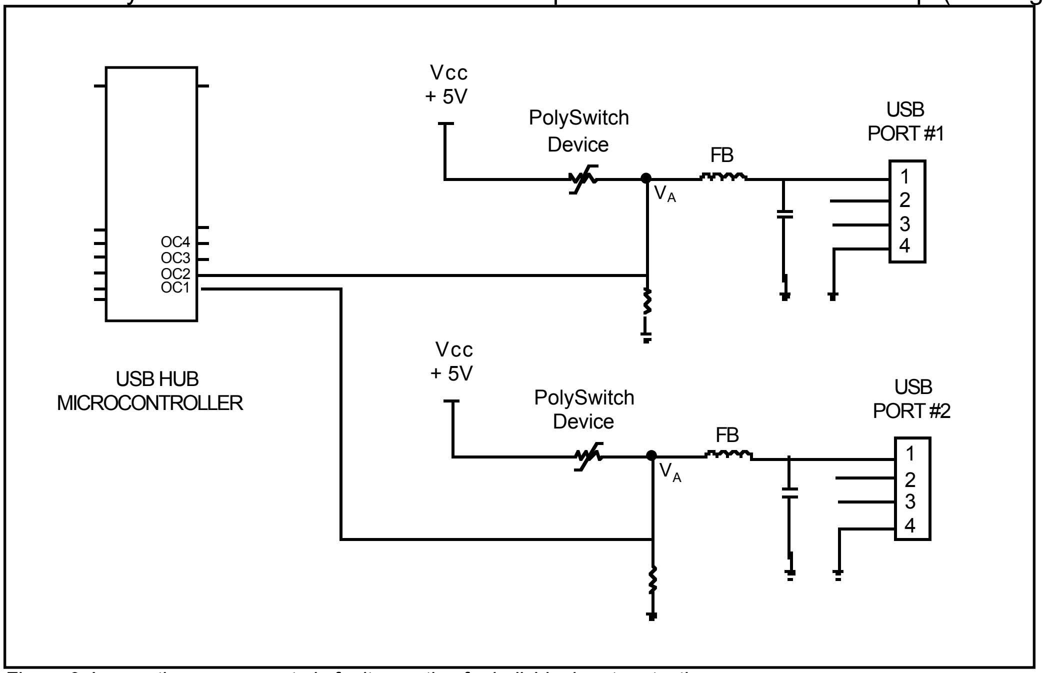


Figure 6. Low-active overcurrent pin fault reporting for individual port protection.

Under normal conditions, the voltage downstream of the PolySwitch device (V_A) will be ~5 V. In the event of a fault, V_A will be <1 V. This change in voltage signals a fault to the microprocessor with low-active overcurrent pins.

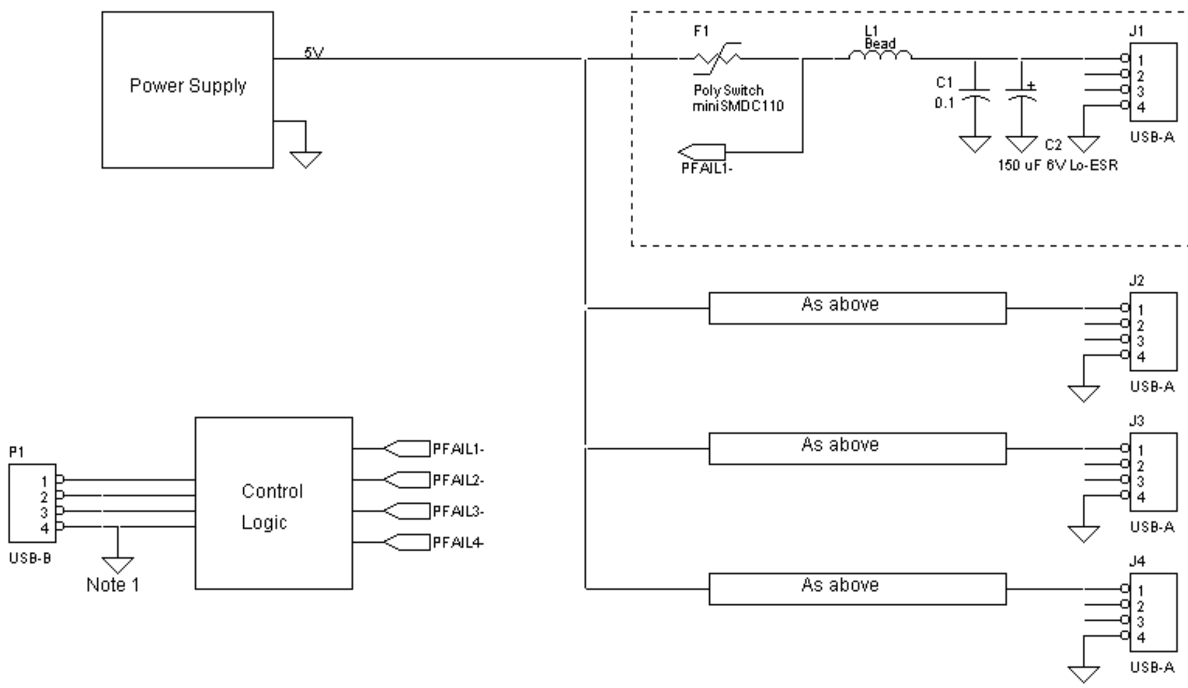
Design Examples

Four design examples are presented:

〈 Host/Self Powered Hub, Individual Port Protection (Figure 7)
〈 Host/Self Powered Hub, Ganged Port Protection (Figure 8)
〈 Bus Powered Hub, Individual Port Protection (Figure 9)
〈 Bus Powered Hub, Ganged Port Protection (Figure 10)

Host/Self Powered Hub, Individual Port Protection

Figure 7 shows a four-port Host/Self-Powered Hub with a PolySwitch miniSMDC110 device or RUSB120 device protecting each port. Individual port protection allows one port to become short-circuited without disabling the other three ports.



Note 1: Ground is common power/signal ground, not Host chassis ground. Ground is referred to Host Vbus cable ground only

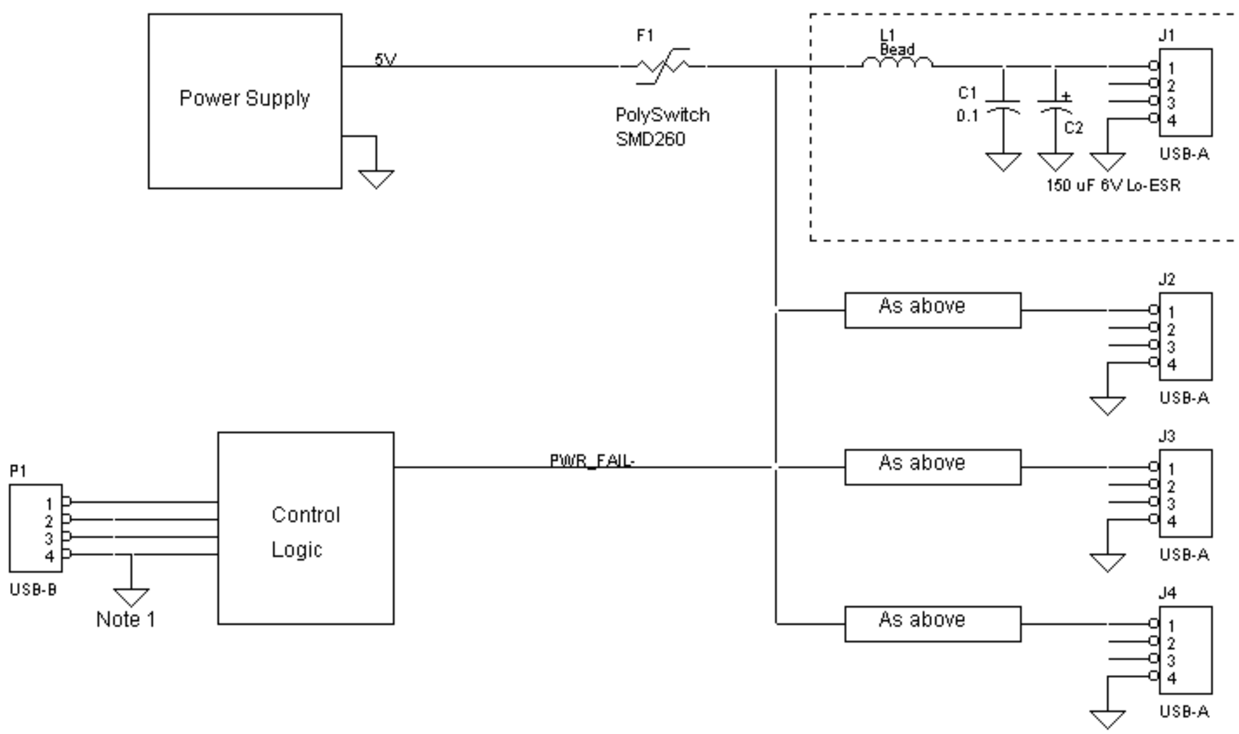
Note 2: Only Vbus power connections shown

	Surface Mount	Through-hole
C1, C3, C5, C7	0.1 uF Panasonic ECUV1E104ZFX	Panasonic ECUS1J104MEA
C2, C4, C6, C8	150 uF Lo-ESR Nichicon UWF0J151MBT	Panasonic EEUFA1V151)
F1, F2, F3, F4	Raychem miniSMDC110 PolySwitch device	Raychem RUSB120 PolySwitch device
L1, L2, L3, L4	Ferrite Bead >50 ohms@100MHz Steward 28F0121-1SR	Steward 28L0138-20R

Figure 7. Host/Self Powered Hub individual port protection schematic

Host/Self Powered Hub, Ganged Port Protection

Figure 8 illustrates a ganged protection scheme for a Host/Self-Powered Hub. Here a PolySwitch SMD260 device or RUSB250 device protects the four downstream ports from short-circuit conditions.



Note 1: Ground is common power/signal ground, not Host chassis ground. Ground is referred to Host Vbus cable ground only

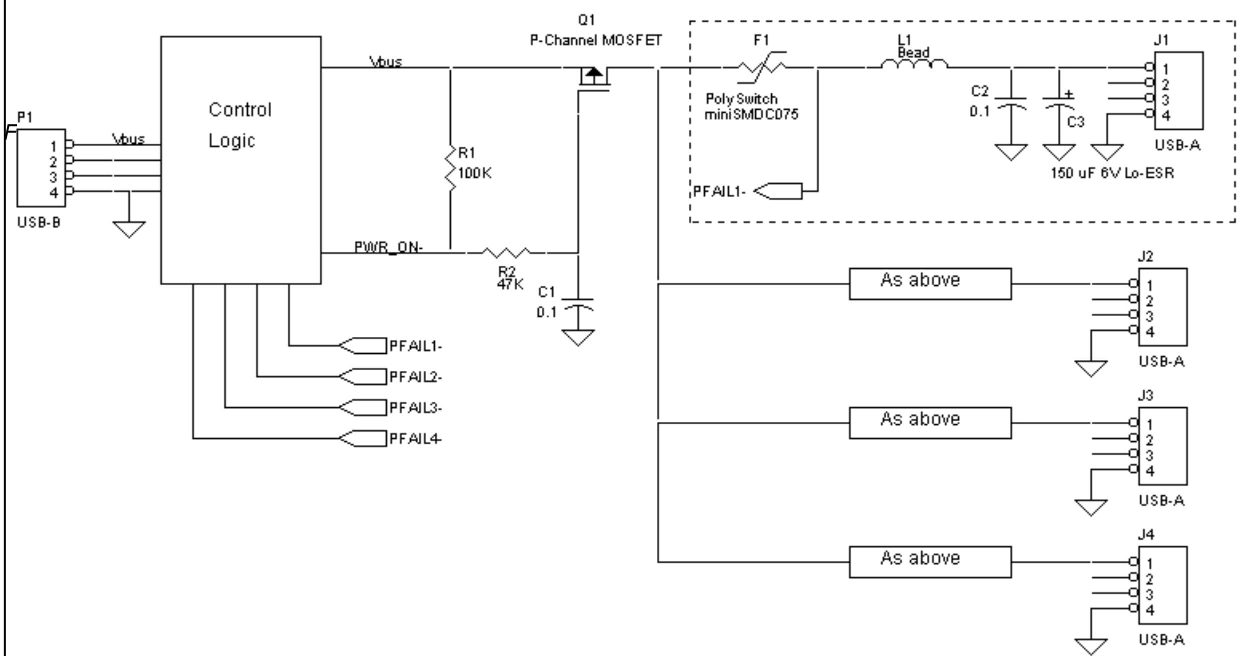
Note 2: Only Vbus power connections shown

	Surface Mount	Through-hole
C1, C3, C5, C7	0.1 uF Panasonic ECUV1E104ZFX	Panasonic ECUS1J104MEA
C2, C4, C6, C8	150 uF Lo-ESR Nichicon UWF0J151MBT	Panasonic EEUFA1V151
F1	Raychem SMD260 PolySwitch device	Raychem RUSB250 PolySwitch device
L1, L2, L3, L4	Ferrite Bead >50 ohms@100mHz Steward 28F0121-1SR	Steward 28L0138-20R

Figure 8. Host/Self-Powered Hub ganged port protection

Bus Powered Hub, Individual Port Protection

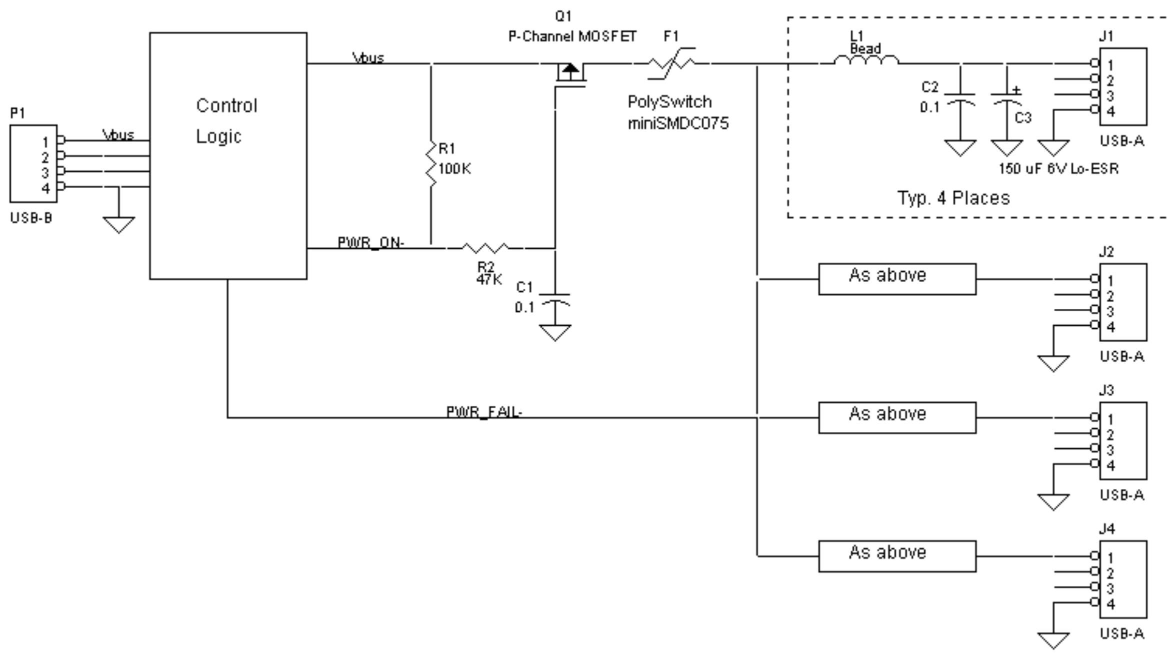
Figure 9 shows four ports with a PolySwitch miniSMDC075 device or RUSB075 device protecting each port. Individual port protection allows one port to become short-circuited without disabling the other three ports. Included are the optional soft-start components R2 and C1.



C1, C2, C4, C6, C8	0.1 uF Panasonic ECUV1E104ZFX	Panasonic ECUS1J104MEA
C3, C5, C7, C9	150 uF Lo-ESR Nichicon UWF0J151MBT	Panasonic EEUFA1V151)
F1, F2, F3, F4	Raychem miniSMDC075 PolySwitch device	Raychem RUSB090 PolySwitch device
L1, L2, L3, L4	Ferrite Bead >50 ohms@100mHz Steward 28F0121-1SR	Steward 28L0138-20R
Q1	P-Channel Logic MOSFET Temic Si9434DY	equivalent

Bus Powered Hub, Ganged Port Protection

Figure 10 uses the PolySwitch miniSMDC075 device or RUSB075 device to protect the four downstream ports in a ganged protection scheme.



	Surface Mount	Through-hole
R1	100K 1/8 W 10%	equivalent
R2	47K 1/8 W 10%	equivalent
C1, C2, C4, C6, C8	0.1 uF Panasonic ECUV1E104ZFX	Panasonic ECUS1J104MEA
C3, C5, C7, C9	150 uF Lo-ESR Nichicon UWF0J151MBT	Panasonic EEUFA1V151
F1	Raychem miniSMDC075 PolySwitch device	Raychem RUSB090 PolySwitch device
L1, L2, L3, L4	Ferrite Bead >50 ohms@100mHz Steward 28F0121-1SR	Steward 28L0138-20R
Q1	P-Channel Logic MOSFET (Temic Si9434DY)	

Figure 10. Bus-Powered Hub ganged port protection

Design Considerations

Host/Self-Powered Hub

Output Filter Capacitor
The USB Specification 1.0 indicates that “no less than a 120 uF tantalum capacitor” must be used on the Vbus output of each downstream port. Tests were carried out to determine the effects of “Capacitor output” geometry versus “Ferrite output” with respect to meeting voltage droop and EMI requirements. Far better droop performance was obtained with the output-capacitor (150 uF) downstream of the ferrite bead due to the lowered effective impedance as seen by the output connector. The “Ferrite output” configuration, with the ferrite bead “downstream” of the output capacitor is more commonly seen in EMI protection geometries, but measurements indicated that EMI protection was excellent in either geometry. At lower frequencies (<20 mHz) the “output capacitor” geometry was actually better, and at higher frequencies there was little difference between geometries.

Ferrite Beads
A ferrite bead in series with the Vbus pin is usually necessary to lower EMI radiation down the USB cable. The series resistance of the bead and its RF impedance are the important criteria. A “bead-on-a-wire” configuration is selected primarily for its low series DC resistance. These devices are available in both thru-hole and SMD (bead-on-a-strap) configurations. Any ferrite bead with 50 ohms or more impedance at 100 mHz will work. The designs in this analysis use the Steward 28L0138-20R leaded bead which is specified at 97 ohms at 100 mHz. The DC resistance is a fraction of a milliohm (similar to a short piece of 22 Ga wire). The “Capacitor output” geometry, where the output capacitor follows the ferrite bead, is the preferred geometry for excellent droop characteristics at the downstream port. This configuration is used in the layout design examples.

Overcurrent Protection
The USB specification 1.0 requires overcurrent protection in either an individual or ganged protection scheme. A UL recognized safety device facilitates agency testing and provides high reliability. Along with meeting safety requirements, the protection device should protect the equipment from damage, for example, protect PCB traces from burning. In addition, the protection device must not nuisance trip, for example, during a Hot-plug event. Using PolySwitch devices in an individual port protection scheme provides an optimal design for a downstream power connection. When a fault occurs on a port and that port’s PolySwitch device trips, the adjacent ports remain functional. Individual port protection also allows the designer to select a smaller and faster acting device.

Bus-Powered Hub

Power Switch
The hub controller supplies a software controlled on/off signal from the host. Power to downstream ports must have on/off signal switching capability to power off all downstream ports when the hub comes out of of power-up, or when it receives a reset on its root port. A low RdsOn MOSFET must be selected for power switching. Selection of a MOSFET should include a 50 milliohm or less RdsOn resistance, logic-level gate, and a 3 A or higher current rating. A P-Channel MOSFET is usually employed as the initial logic level of most control microprocessors’ output pins is weakly pulled high. The P-Channel MOSFET is turned on by driving its gate low; the default state of the MOSFET should be off. Example P-Channel MOSFETS that fit the above criteria are the Temic Si9434DY and the IRC IRF7404. A weak external pullup may be used if desired. (See Figure 8, R1).

Overcurrent Protection
As with any powered port, short circuits and equipment damage can occur and should be a concern. During a short circuit event, current can get high enough to cause damage to the Bus-Powered Hub. PolySwitch devices are appropriate in individual or ganged port protection schemes and provide Bus-Powered Hub designs protection at the port to protect the MOSFET during a fault.

Soft Start
Section 7.2.4.1 of the USB Specification requires inrush current-limiting when switching downstream power. This applies to Bus-Powered Hubs, where the Vbus voltage could droop significantly if measures are not taken to “soft start” the downstream power. A simple RC network (See Figure 9, R2 and C1) will provide an inexpensive solution to limiting inrush current. Figure 11 shows Vbus rising sharply without soft-start whereas Figure 12 shows a much more gradual rise with soft-start implemented.

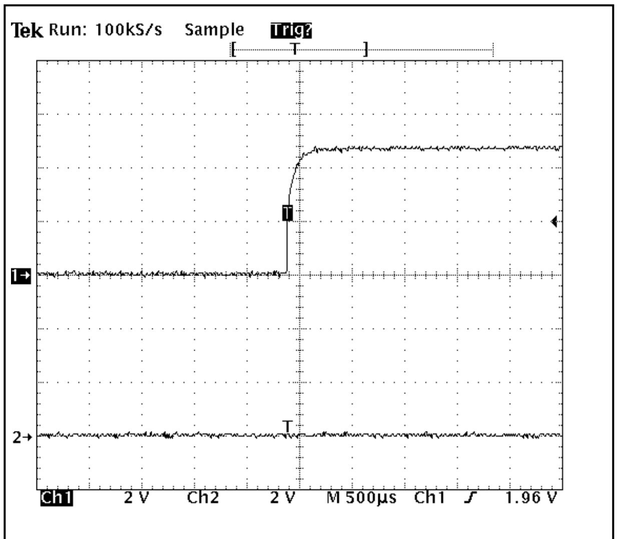


Figure 11. Downstream Vbus without soft start

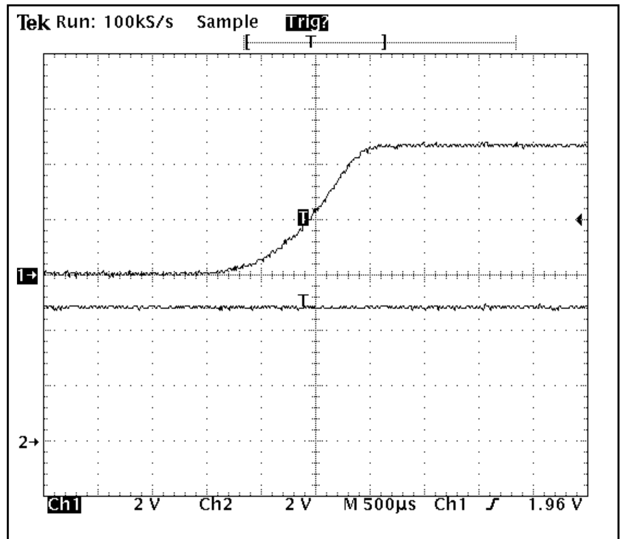


Figure 12. Downstream Vbus with soft start

Pulse-Width-Modulation of the PWR_ON- pin may be used in place of the Resistor-Capacitor network to provide the necessary soft start. The control microprocessor is programmed to drive the pin to zero in a step-wise fashion over a few milliseconds. Figure 13 illustrates the behavior of the pulses.

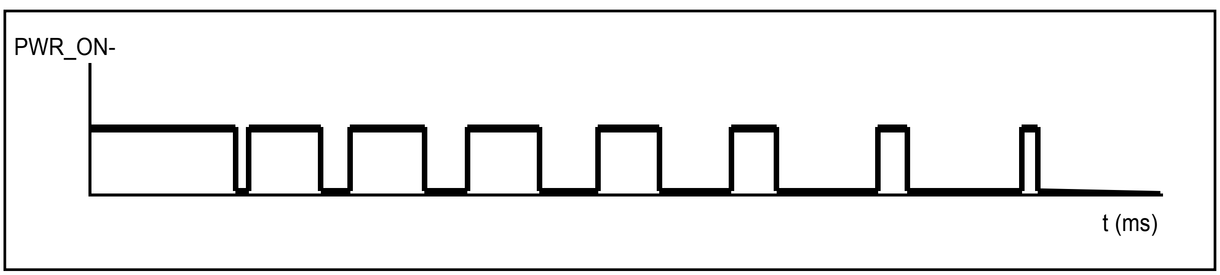


Figure 13. Pulse-Width Modulation soft-start

Layout
In order to meet the voltage drop, droop, and EMI requirements in the Specification, careful PCB layout is necessary. The following guidelines must be considered:

1. Keep all Vbus traces as short as possible and use at least 50 mil, 1 oz. copper for all Vbus traces.
2. Avoid vias as much as possible. If vias are necessary, make them as large as feasible.
3. Place the output capacitor and ferrite beads as close to the USB connectors as possible.
4. If using a Vbus switch, place it close to the USB connectors.
5. Use a separate ground and power planes if possible.
6. If using separate planes, separate the power plane into switched (downstream) and unswitched (logic or upstream) sections.

Voltage Drop

The USB Specification states a minimum port output voltage (VOUT) in two locations on the bus, 4.75 V out of a Self-Powered Hub Port and 4.40 V out of a Bus-Powered Hub Port. For Self-Powered Hubs, designers typically use a 5 V ± 2% power supply or kick-up the voltage to 5.0 V minimum. The latter approach allows for a 500 mΩ resistance budget for an individually protected Self-Powered Hub Port. The following examples show how typical designs meet USB voltage drop requirements; Monte Carlo simulation data is available.

Power Supply	5 V supply ± 2% or kick up to 5.0 V minimum	**PolySwitch Device**
Trace	5mΩ/inch (1oz-0.05in)	160 mΩ miniSMDC110
Ferrite Bead	5mΩ per bead	80 mΩ RUSB120
Cable/Connector	500 mΩ (5 m 20AWG cable)	50 mΩ SMD260
FET	80 mΩ	40 mΩ RUSB250
		300 mΩ miniSMDC075
		150 mΩ RUSB075

Self-Powered Hub (individual port)

Power Supply		5.000 V
- Trace	20 mΩ x 0.5 A =	0.010
- Ferrite Bead	5 mΩ x 0.5 A =	0.003
- miniSMDC110	160 mΩ x 0.5 A =	0.080
VOUT		**4.907 V**

Self-Powered Hub (ganged 2 port)

Power Supply		5.000 V
- Trace	5 mΩ x (1 A & 0.5 A) =	0.015
- Ferrite Bead	5 mΩ x 0.5 A =	0.003
- SMD260	50 mΩ x 1 A =	0.050
VOUT		**4.932 V**

Bus-Powered Hub (individual port)

Upstream VMIN		4.750 V
- Cable/Connectors	500 mΩ x 0.5 A =	0.250
- Trace	20 mΩ x (0.5 A & 0.1 A) =	0.004
- Ferrite Bead	5 mΩ x 0.1 A =	0.001
- FET	80 mΩ x 0.4 A =	0.032
- miniSMDC075	300 mΩ x 0.1 A =	0.030
VOUT		**4.433 V**

Bus-Powered Hub (ganged 2 port)

Upstream VMIN		4.750 V
- Cable/Connectors	500 mΩ x 0.5 A =	0.250
- Trace	20 mΩ x (0.5 A, 0.4 A, 0.1 A) =	0.006
- Ferrite Bead	5 mΩ x 0.1 A =	0.001
- FET	80 mΩ x 0.4 A =	0.032
- miniSMDC075	300 mΩ x 0.2 A =	0.060
VOUT		**4.401 V**

The Voltage Drop analysis is duplicated for the RUSB through-hole devices below.

Self-Powered Hub (individual port)

Power Supply		5.000 V
- Trace	20 mΩ x 0.5 A =	0.010
- Ferrite Bead	5 mΩ x 0.5 A =	0.003
- RUSB120	80 mΩ x 0.5 A =	0.040
VOUT		**4.947 V**

Self-Powered Hub (ganged 4 port)

Power Supply		5.000 V
- Trace	5 mΩ x (2 A & 0.5 A) =	0.025
- Ferrite Bead	5 mΩ x 0.5 A =	0.003
- RUSB250	80 mΩ x 1 A =	0.080
VOUT		**4.892 V**

Bus-Powered Hub (individual port)

Upstream VMIN		4.750 V
- Cable/Connectors	500 mΩ x 0.5 A =	0.250
- Trace	5 mΩ x (0.5 A & 0.1 A) =	0.002
- Ferrite Beads	5 mΩ x 0.1 A =	0.001
- FET	80 mΩ x 0.4 A =	0.032
- RUSB075	150 mΩ x 0.1 A =	0.015
VOUT		**4.450 V**

Bus-Powered Hub (ganged 4 port)

Upstream VMIN		4.750 V
- Cable/Connectors	500 mΩ x 0.5 A =	0.250
- Trace	5 mΩ x (0.5 A, 0.4 A, 0.1 A) =	0.006
- Ferrite Bead	5 mΩ x 0.1 A =	0.001
- FET	80 mΩ x 0.4 A =	0.032
- RUSB075	150 mΩ x 0.4 A =	0.060
VOUT		**4.401 V**

Voltage Droop
The following Voltage Droop analysis is divided into two parts, Standard USB Voltage Droop and Short Circuit Voltage Droop.

Standard USB Voltage Droop
Voltage Droop occurs during a hot plug event as the result of the connection of a peripheral and its uncharged input bulk capacitance to a USB port. For a few tens of µs the host must supply high current into the peripheral until its bulk capacitance is charged to Vbus, creating a capacitive divider between the host's bulk capacitance and that of the just-plugged-in USB peripheral.

A standard test (see Figure 14) has been developed by the USB Implementor's Forum (USB-IF) to ensure compliance with the USB specification of limiting Voltage Droop to 0.330 V maximum on a Hub. The Standard Voltage Droop Test uses a set of standard loads and test sequences to determine the voltage droop experienced by one USB port when another USB port is "Hot-plugged."

The test setup uses a two-port USB configuration. Port 2 has a 500 mA load (100 mA load for Bus-Powered Hubs) with a 4.7 uF shunt capacitance on the end of a certified 1-meter USB cable. The test procedure is as follows:

1. The static voltage at both the power supply and the Port 2 Vbus point are measured.
2. A 100 mA load with a 10 uF shunt is plugged into Port 1 while a recording oscilloscope monitors the voltage at Port 2.
3. The droop (in the form of a brief transient pulse) is displayed on the oscilloscope, and the peak droop voltage is measured on the oscilloscope trace.

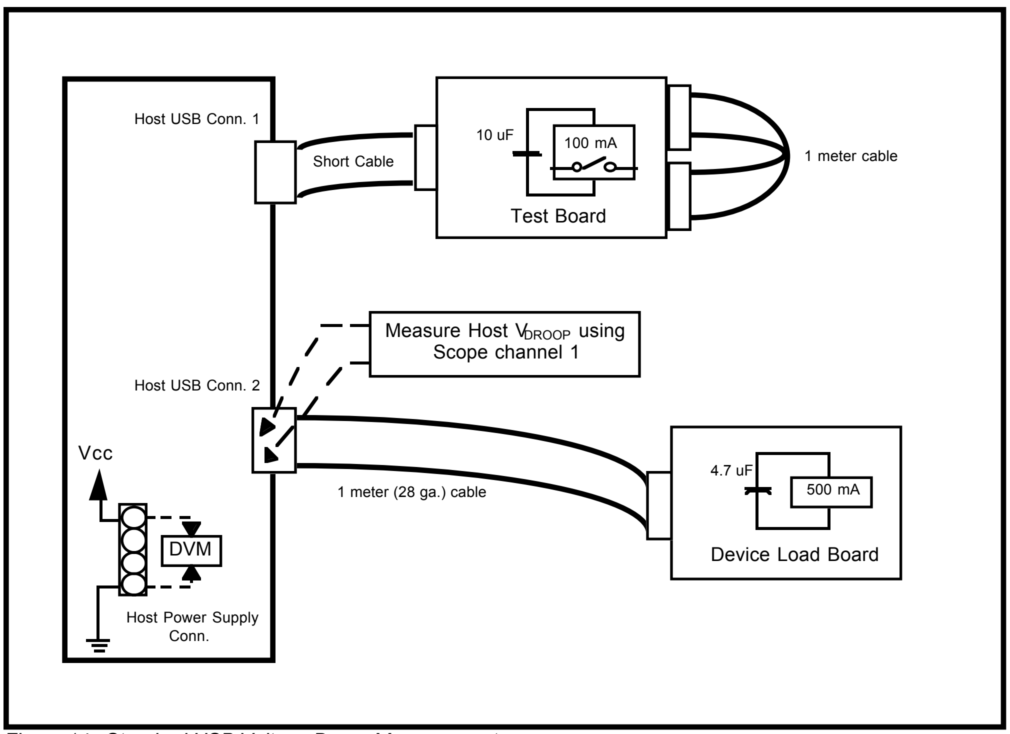


Figure 14. Standard USB Voltage Droop Measurement

Six different PolySwitch devices were tested. Worst case results for each device are shown in Table 1A.

Device	Vdroop (V)	Powered Hub	Port Protection
miniSMDC110	0.116	Self	Individual
RUSB120	0.140	Self	Individual
SMD260	0.204	Self	Ganged
RUSB250	0.196	Self	Ganged
miniSMDC075	0.092	Bus	Individual
RUSB075	0.116	Bus	Individual

Table 1A Standard Voltage Droop Test

The test data in Table 1A demonstrate the Voltage Droop is lower than the USB specification maximum (0.330 V). Designs using PolySwitch devices meet the Voltage Droop requirement.

Figures 15 and 16 illustrate the circuits used for the individual port protection and ganged port protection Standard Voltage Droop tests. Figures 17 through 22 show typical oscilloscope traces obtained during the testing.

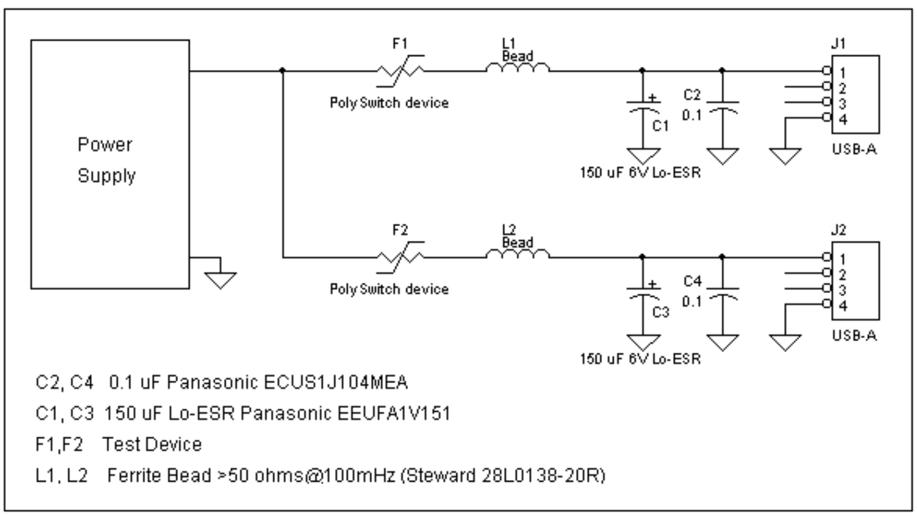


Figure 15. Individual Port Protection

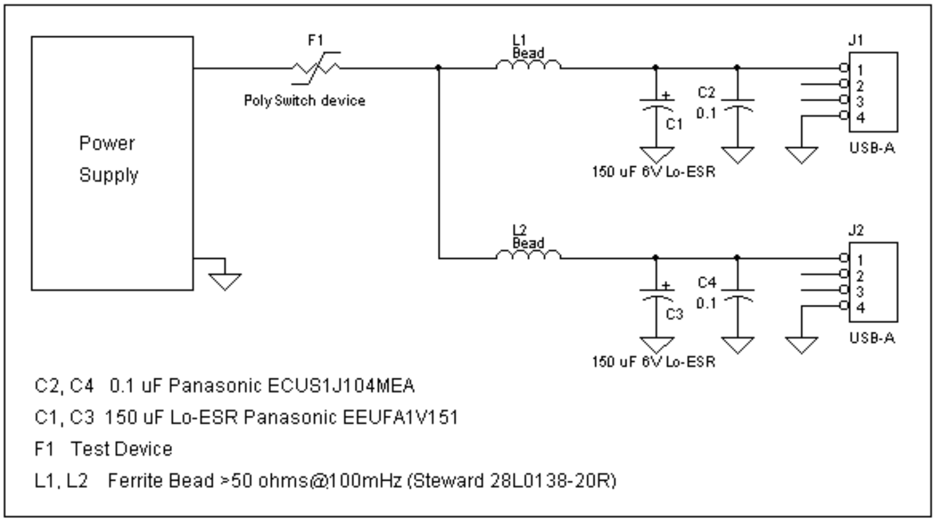


Figure 16. Ganged Port Protection

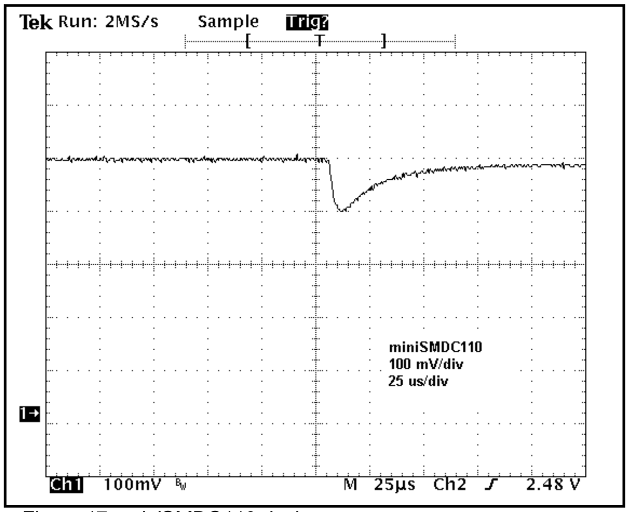


Figure 17. miniSMDC110 device

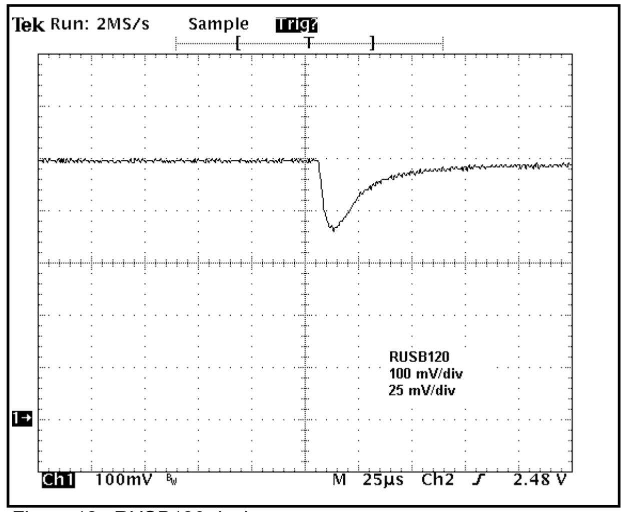


Figure 18. RUSB120 device

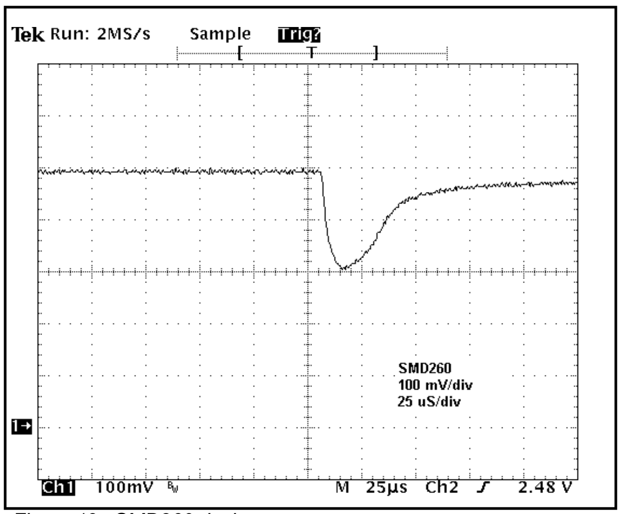


Figure 19. SMD260 device

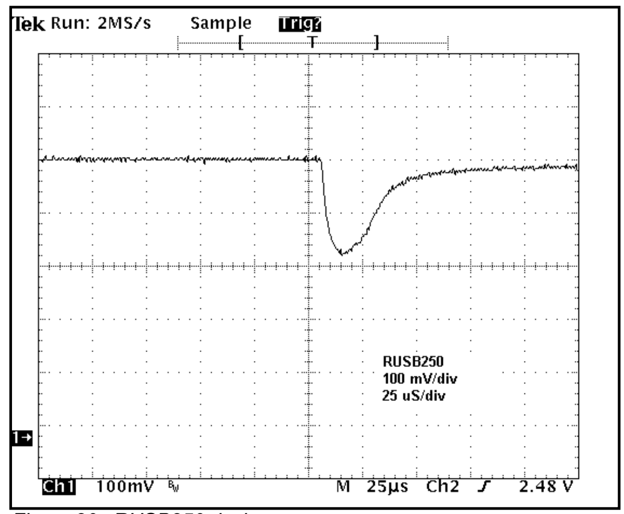


Figure 20. RUSB250 device

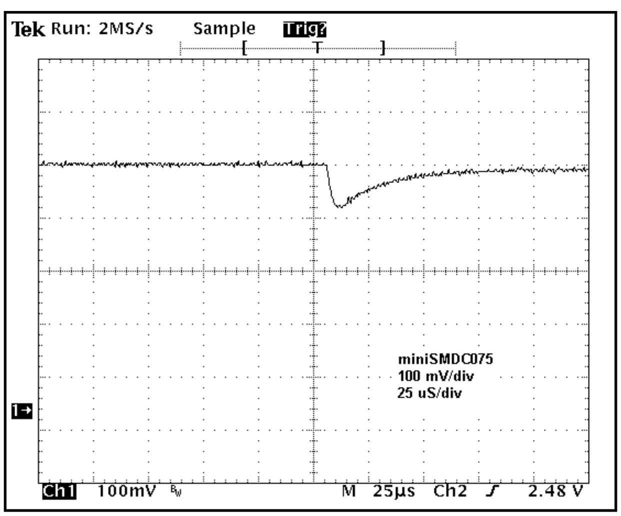


Figure 21. miniSMDC075 device

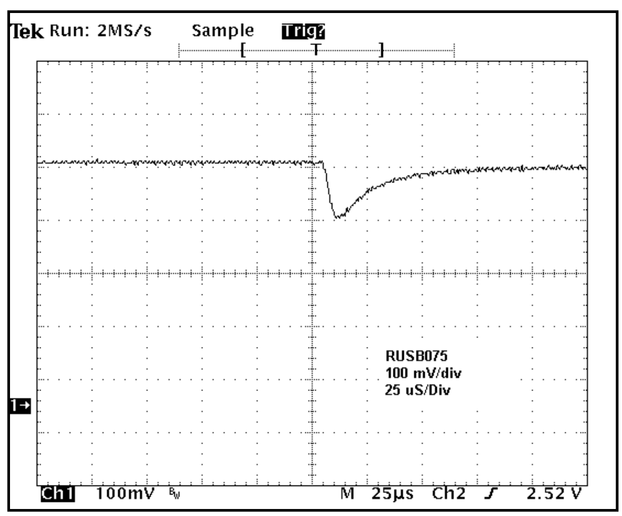


Figure 22. RUSB075 device

Short Circuit Voltage Droop
If one USB Hub downstream port is accidentally short-circuited, it is desirable that the other downstream ports keep functioning normally. While this behavior is not required by the USB Specification 1.0, it is achievable in a reliable, economical manner using PolySwitch resettable fuses.

When a port is short-circuited, a very large current load is imposed on the power supply which is providing the bus power. This large load causes the remaining ports to experience a transitory droop in bus supply voltage until the overcurrent device on the shorted port reacts. Once the device trips, the remaining ports are isolated from the shorted port. Several design configurations were tested for port protection and short-circuit power supply droop. Four PolySwitch devices commonly used for USB port protection were tested: miniSMDC075, miniSMDC110, RUSB120 and RUSB075. All four devices meet the voltage droop requirements of >4.00V.

The following criteria were used in designing the short-circuit protection circuits:

1. Each downstream port must be individually protected.
2. A shorted port must not deliver more than 5 A within 60 seconds of being shorted (UL).
3. The remaining ports should not drop their supply voltage below 4.0 Volts at the input to the downstream device during the period before the overcurrent device reacts.
4. The overall design should be as inexpensive as possible.

Notes on Criteria

The first item above is self-explanatory. Commonly referred to as an “individual” protection scheme, it is the preferred configuration for USB Hubs. For ganged protection, where one overcurrent device protects all downstream ports, this discussion is irrelevant since a short on one port trips the single overcurrent device and disables the whole bus. Most designers use individual port protection because of this limitation with ganged protection.

The second item is required by several certification agencies, and is met with the overcurrent device configurations.

The third item is the key voltage droop requirement. The voltage regulator in the downstream peripheral must be able to supply power to its USB micro-controller in order to have the peripheral remain operating. Assuming a worst case low dropout, linear voltage regulator of 5% output voltage tolerance and a 500 mV dropout, the input voltage to the device must be:

$$V_o > (3.3)*(1.05) + 0.5 \text{ V} = 3.965 \text{ V}$$

The value rounds up to 4.00 V for simplicity. Thus, the input voltage must not drop below 4.00 V, even when a short on an adjacent port causes the supply voltage to droop. Using tighter tolerance voltage regulators will, of course, allow the voltage to droop lower than 4.00 V and still have a functioning peripheral.

The fourth item is a very strong requirement. USB designs will often be produced in very large quantities. If $0.10 can be saved in a design, and 1,000,000 items are produced, the profit picture on the item will be improved by $100,000. This means that saving even a few cents on a given design can be worth many hours of design cost improvement. This is why, for instance, the tolerances of voltage regulators are set wide, so as to reduce cost.

Figure 23 illustrates the circuit used for the Short Circuit Voltage Droop tests and Figure 24 shows the Short Circuit Voltage Droop test points.

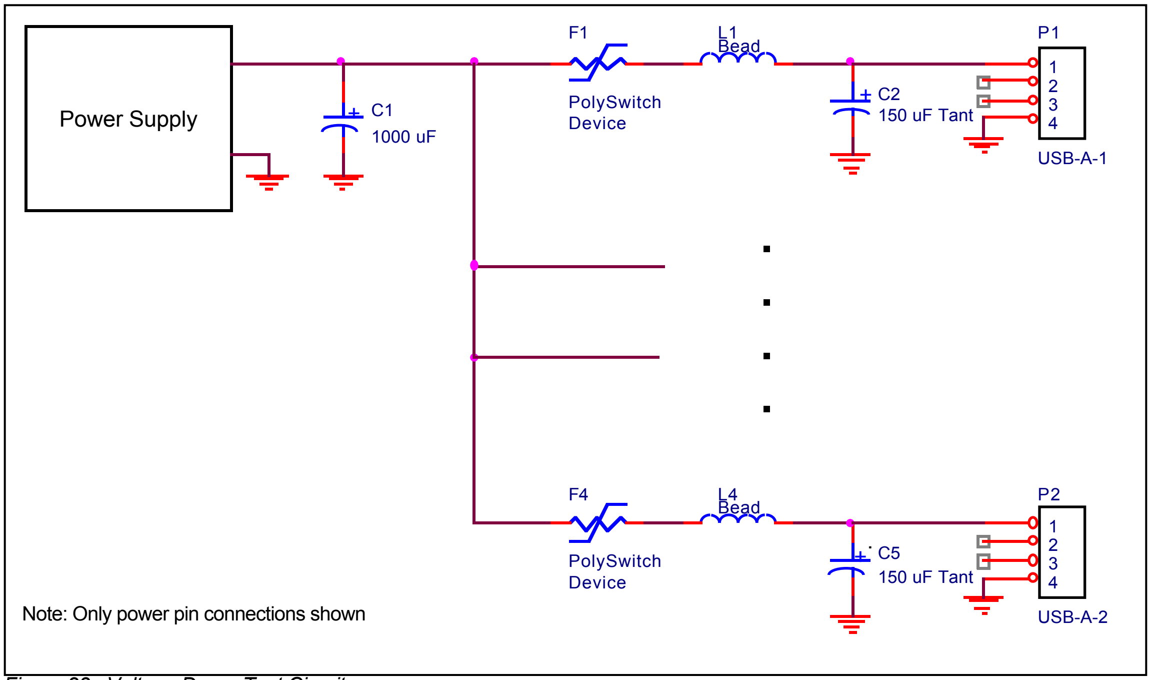


Figure 23. Voltage Droop Test Circuit

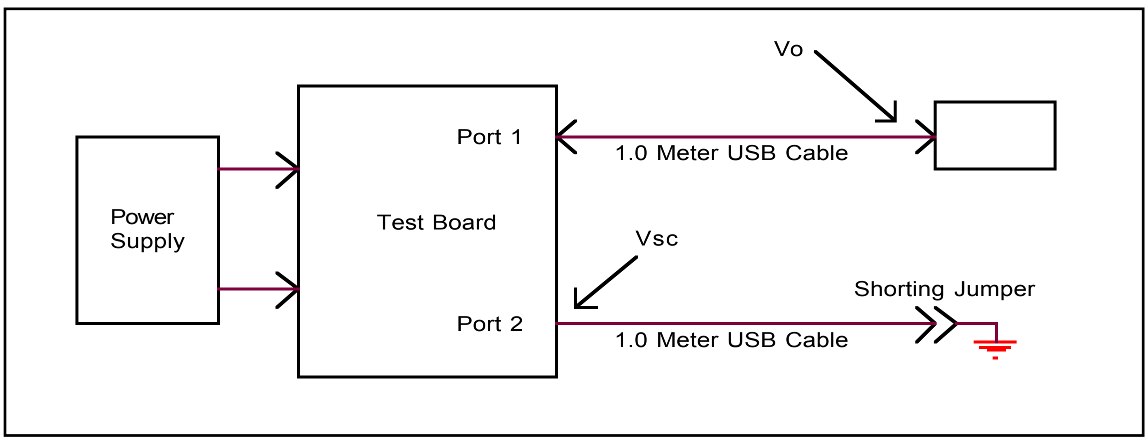


Figure 24. Voltage Droop Test Measurement Locations

The test procedure is as follows:
1. Set power supply voltage output to 4.750 V (HP 6541A or eq.)
2. Connect 500 ma test load to Port 1.
3. Turn on power supply and allow to stabilize.
4. Connect Oscilloscope to point Vo and Vsc at source end.
5. Short Port 2 with jumper, recording Oscilloscope trace.

Four different PolySwitch device types were tested. Worst case results are shown below (Table 1B).

PolySwitch device	Vo (min)	t-Trip
RUSB075	4.201	45 ms
RUSB120	4.088	50 ms
miniSMDC075	4.472	20 ms
miniSMDC110	4.428	45 ms

Table 1B Short Circuit Voltage Droop Test Results

Notes to Table 1B

1. Vo(min) is the minimum droop voltage measured on one port when the second port was shorted.
2. t-Trip is the time it took the PolySwitch device to go into the high-impedance state.

The test data show that the miniSMDC075 device is the best performing device. Considering voltage drop requirements in addition to the voltage droop requirements, the miniSMDC110 device is the recommended device and meets both requirements. For thru-hole designs, the PolySwitch RUSB120 device meets the design criteria and is the recommended device. In summary, all five devices meet the design criteria of >4.00 V. With the design configuration used in these tests, excellent port short-circuit protection is provided at a very low cost-per-port.

The following graphs show typical oscilloscope traces obtained during the testing; top trace: Vo, bottom trace: Vsc

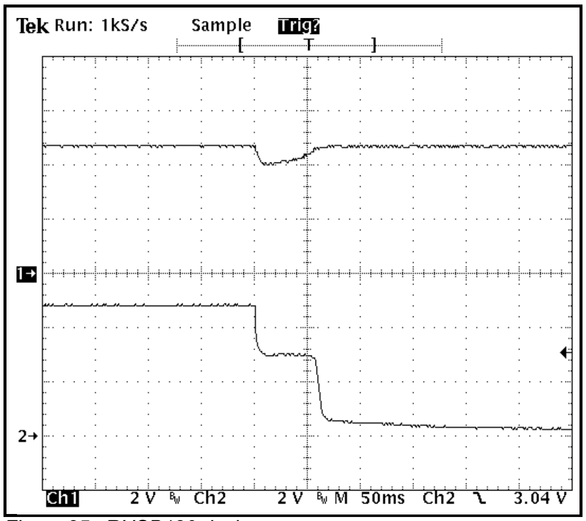


Figure 25. RUSB120 device

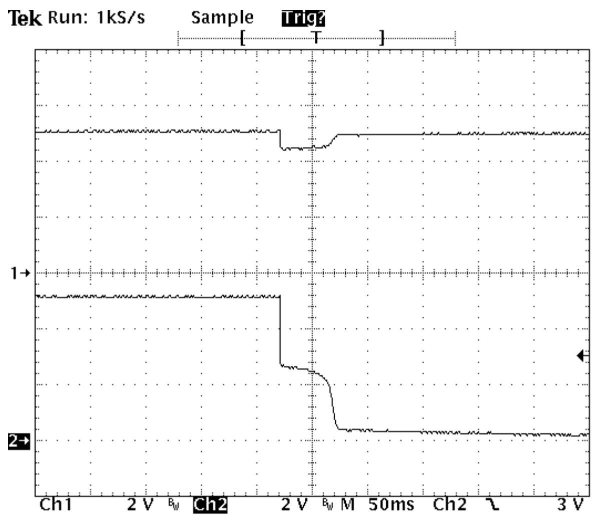


Figure 26. RUSB075 device

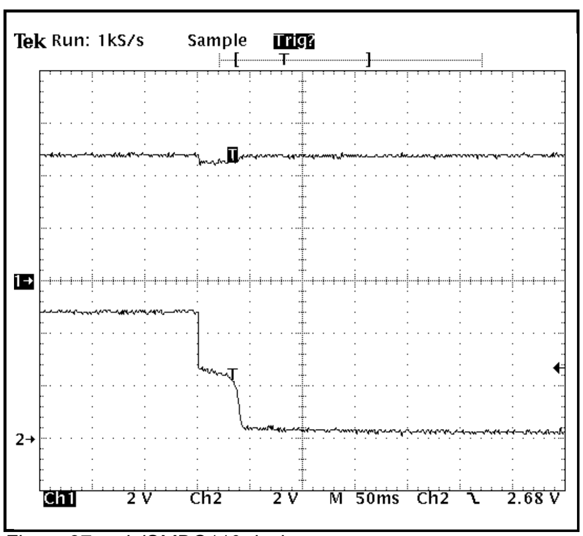


Figure 27. miniSMDC110 device

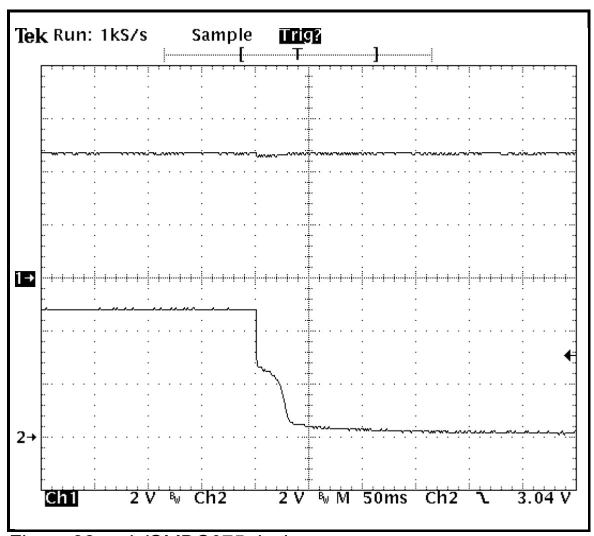


Figure 28. miniSMDC075 device

PolySwitch Device Overview

PolySwitch devices are available in both surface-mount (SMT) and through-hole packages (Figure 29).

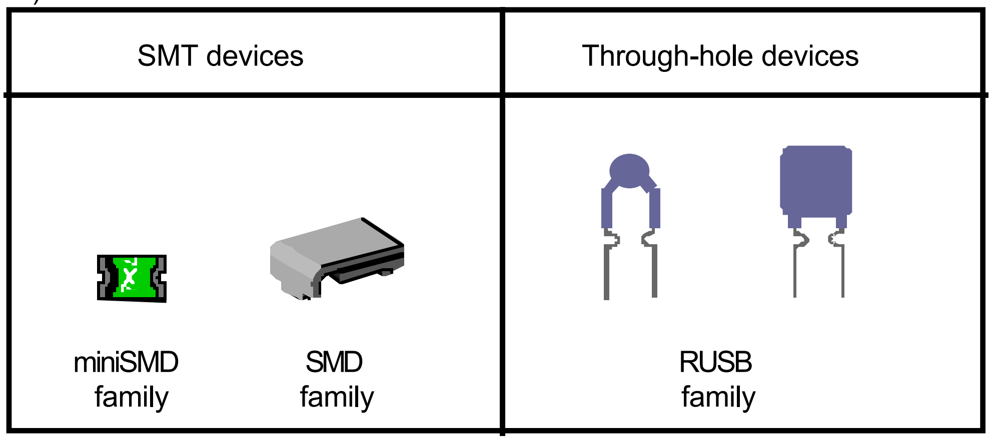


Figure 29. PolySwitch device configurations

PolySwitch device selection

Table 2 provides recommendations for device selection.

	Surface-mount device	Alternatives
Self-Powered Hub		
Individual	miniSMDC110	SMD260
Ganged: 4 ports	SMD260	SMD250
Ganged: 3 ports	SMD260	SMD250
Ganged: 2 ports	SMD260	SMD150 to SMD260
Bus-Powered Hub		
Individual	miniSMDC075	miniSMDC050 to miniSMDC110
Ganged: 4 ports	miniSMDC075	SMD125, miniSMDC110
Ganged: 3 ports	miniSMDC075	SMD125, miniSMDC110
Ganged: 2 ports	miniSMDC075	miniSMDC110
	Through-hole device	**Alternatives**
Self-Powered Hub		
Individual	RUSB120	RUSB075, RUSB160
Ganged: 4 ports	RUSB250	–
Ganged: 3 ports	RUSB185	RUSB250
Ganged: 2 ports	RUSB135	RUSB160
Bus-Powered Hub		
Individual	RUSB075	RXE050 to RUSB120
Ganged: 4 ports	RUSB075	RXE075 to RUSB120
Ganged: 3 ports	RUSB075	RXE065 to RUSB120
Ganged: 2 ports	RUSB075	RXE050 to RUSB120

Table 2. Recommendations for selected PolySwitch devices

Device electrical characteristics

Table 3 provides the electrical characteristics of PolySwitch devices suitable for USB-powered port protection in Host/Self-Powered Hubs and Bus-Powered Hubs. Figure 30 illustrates the typical time-to-trip for the devices most commonly used for USB individual port protection compared to the time-to-damage of a circuit board trace. A 1.0-oz 20-mil trace is used in the figure, even though a 1.0-oz 50-mil trace is recommended, to show that the PolySwitch devices have sufficient margin to protect even a smaller trace.

Part number	**Form factor**	**Hold current** A (20°C)	**Resistance** Ω (typical)
miniSMDC050	SMT	0.50	0.700
miniSMDC075	SMT	0.75	0.300
miniSMDC110	SMT	1.10	0.160
SMD125	SMT	1.25	0.175
SMD150	SMT	1.50	0.180
SMD200	SMT	2.00	0.090
SMD250	SMT	2.50	0.060
SMD260	SMT	2.60	0.050
RXE050	Through-hole	0.50	0.800
RXE065	Through-hole	0.65	0.500
RUSB075	Through-hole	0.75	0.150
RUSB090	Through-hole	0.90	0.120
RUSB110	Through-hole	1.10	0.100
RUSB120	Through-hole	1.20	0.080
RUSB135	Through-hole	1.35	0.080
RUSB160	Through-hole	1.60	0.070
RUSB185	Through-hole	1.85	0.060
RUSB250	Through-hole	2.50	0.040

Table 3. Electrical characteristics of selected PolySwitch devices

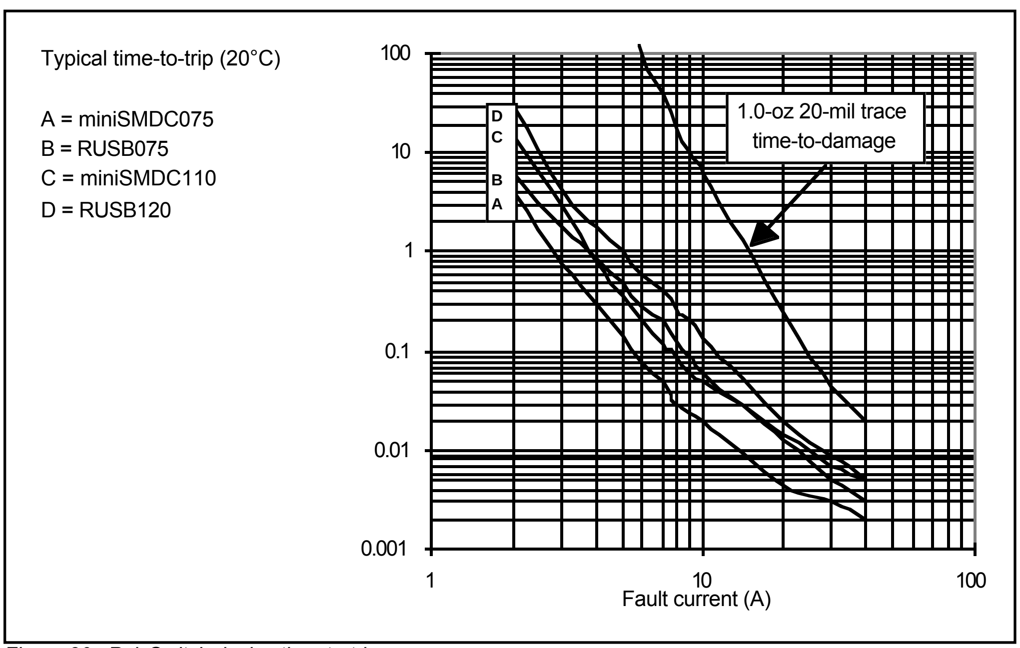


Figure 30. PolySwitch device time-to-trip

Using PolySwitch devices with MOSFETs

USB overcurrent protection requirements can be met using a PolySwitch device only (Figure 31). Hub Descriptor Offset 3, description D1..D0: Power Switching Mode, set to “1X” identifies this configuration to the host. Some designers wish to add functionality to their design by adding a MOSFET (Figure 32). This design provides functionality similar to that of a silicon switch (see Figure 33), yet offers a more reliable and lower-cost design. Hub Descriptor Offset 3 set to “00” (ganged port protection) or “01” (individual port protection) identifies this configuration to the host. Hosts and Self-Powered Hub designs typically use the Figure 31 or 32 configuration; Bus-Powered Hub designs typically use the Figure 32 configuration.

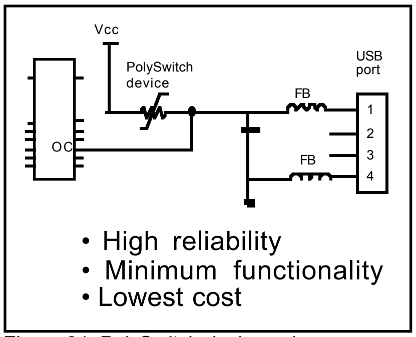


Figure 31. PolySwitch device only

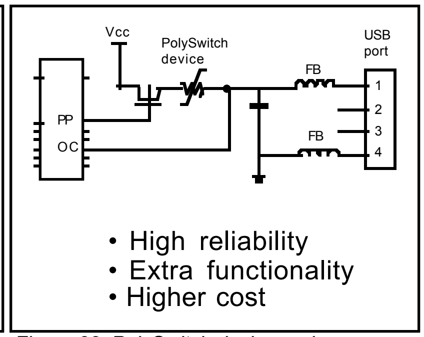


Figure 32. PolySwitch device and a MOSFET

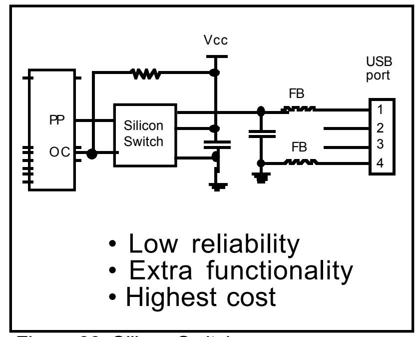


Figure 33. Silicon Switch

Other Overcurrent Protection Technology Solutions

PolySwitch devices are the best solution for overcurrent protection. Other non-resettable or more expensive approaches to overcurrent protection design include:

1. Fuses (fusible-link type)
2. Active-circuitry (Silicon-based current limiters).
3. CPTC (Ceramic Positive Temperature Coefficient) devices (thermistors)
4. Circuit-breakers, thermal and magnetic

Fusible-link fuses are a low cost alternative but not a viable option as the only protection where short-circuit operation is expected. A blown fuse renders the device or USB port inoperable until the fuse is replaced. Most low-cost fuse solutions are board-mounted, and are not field-replaceable which means the unit has to be sent out for warranty service. The cost to both the customer and the manufacturer in the fuse-only case is usually prohibitive. Fuses are often employed in combination with active-circuit protection devices described below. Additionally, “one-use” fuses can weaken in the Plug-and-Play/Hot Plug environment causing them to blow unnecessarily. Most important is that they are not resettable, a virtual requirement in today’s designs.

Active-circuitry solutions offer current-limiting USB power switches based on active circuitry in single-chip form. These current-limiting “high-side MOSFET switches” allow both foldback current limiting and power switching in a single package. The foldback current limiting feature of this type of chip allows a form of short-circuit protection. These type of devices do have significant drawbacks. Silicon switchs have in-rush current problems - they trip too fast. This is particularly troublesome with highly capacitive, high current loads like CCD cameras and scanners. Furthermore, multiple hot plugs of a USB peripheral can also result in the silicon switch nuisance tripping. In multi-port silicon switches, a fault in one port can cause the adjacent ports to shut down because of internal heating in the silicon package. Thus, only expensive, one-port (not multiple port) protection devices could be used for providing individual port protection. The most important disadvantage of silicon switches may be their failure mode. In short-circuit conditions this kind of device cycles in a “thermal-rise shutdown cycle” mode to prevent switch junction meltdown. Depending on the thermal properties of the package and mounting, such rapid under-power thermal cycling can lead to device failure, typically in short-circuit mode leaving the system with no protection. Active-circuit short-circuit protection devices are therefore usually protected themselves with an additional fuse-device of some kind. This oscillation during faults, also creates noise and EMI problems. Moreover, silicon devices are not a UL-recognized safety device. Finally, another important consideration is cost -- silicon switches generally are a much more expensive solution.

Ceramic PTC thermistors are resettable and are of moderate cost but typically do not have a low-enough series resistance to be employed as USB port overcurrent protection. They are also fairly linear in operation during overload temperature rise, and do not have a fuse-like “trip” which quickly cuts the power to the shorting device.

Circuit breakers of either the thermal or magnetic type provide resettable protection but are much too expensive for a high volume mass-produced USB product.

Conclusion

Used by leading computer and peripheral manufacturers to protect powered ports, PolySwitch devices have become the standard solution for overcurrent protection. The devices comply with Windows 95 and PC98 standards and meet the UL1950/IEC950 safety requirements. The variety of part numbers available allow the designer to select the specific device needed to meet USB requirements and the specific requirements of the circuit design. PolySwitch devices provide the lowest-price resettable solution with the highest reliability in a UL recognized package.

Raychem

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Fax 86/20/8385-6139

China, Hong Kong
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Fax 852/2735-1185

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