SEMTECH
Today's Results...Tomorrow's Vision

HotSwitch™ USB Power Distribution Switch With Shutdown

SC2041

DESCRIPTION

USB power distribution switches are high-side N-channel MOSFET switches with built-in overcurrent protection and low on-state resistance. The SC2041 switch is designed to meet the USB requirements for power switching and maintenance-free fault protection for self-powered & bus-powered hub applications. The SC2041 features low on-state resistance to meet the USB requirement for voltage drop and regulation. The switch is controlled by a shutdown input that is compatible with 3V and 5V logic. The device is active when the shutdown input is low. See SC2051 for an active high version. The device provides short circuit current limiting at a value of less than 1.0A, well below the USB limit of 5A. During an overcurrent condition the device provides a fault notification to signal the USB controller. An integrated thermal protection circuit automatically shuts the switch off when the junction temperature reaches its thermal limit. The switch remains off until the junction temperature drops approximately 20°C. The switch will continue to cycle on and off until the fault is removed. Inrush current limiting prevents voltage drop on an upstream port when the switch is enabled. An undervoltage lockout circuit guarantees the switch is initially off during start-up.

FEATURES

- Designed to meet USB specification revisions 1.1 and 2.0 power management requirements
- 500mA continuous load current
- High-side MOSFET switch with low $R_{DS(ON)}$
- Short-circuit current protection
- Internal thermal shutdown
- Undervoltage lockout
- Open drain fault output
- Soft start circuit with slow turn-on time
- Wide supply voltage range: 2.8V to 5.5V
- 2.5kV ESD rating (Human Body Model)
- Full industrial temperature range

APPLICATIONS

- Universal Serial Bus (USB) power management
- Self-powered or bus-powered USB hubs
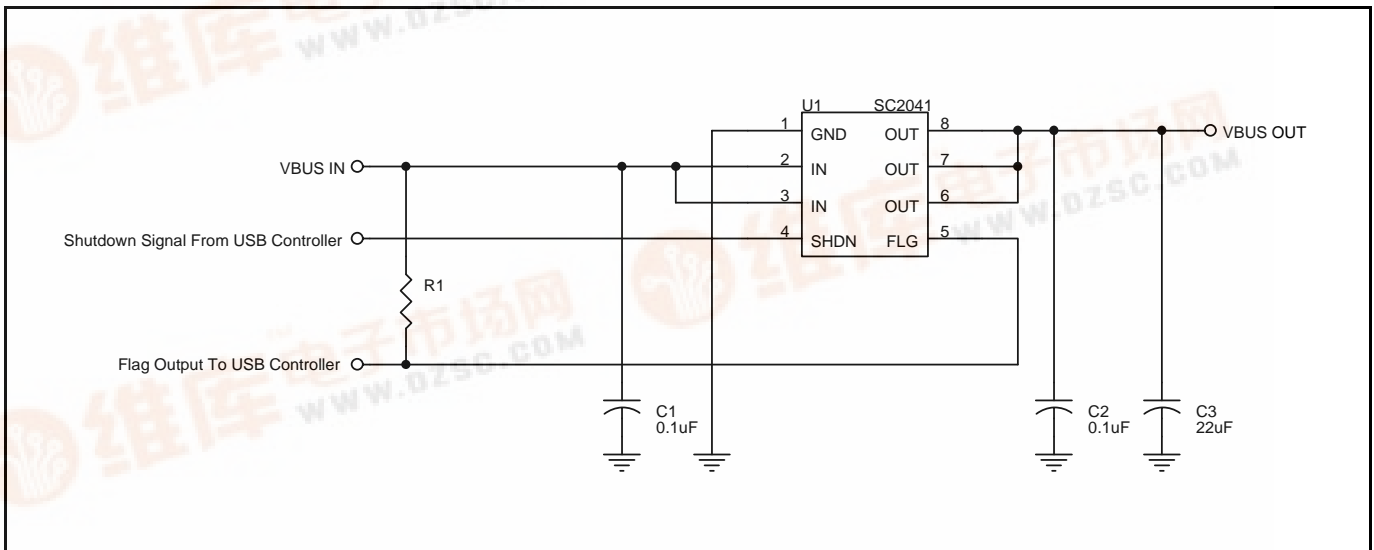- Root hubs in desktop PCs & servers
- Notebook PCs
- Peripherals

ORDERING INFORMATION

DEVICE[1]	PACKAGE
SC2041IS.TR	SO-8

Note:
(1) Only available in tape and reel packaging. A reel contains 2500 devices.

TYPICAL APPLICATION CIRCUIT

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ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Maximum	Units
Input Voltage Range	V_{IN}	-0.3 to +7	V
Output Voltage Range	V_{OUT}	-0.3 to +7	V
Shutdown Input	V_{EN}	-0.3 to +7	V
Flag Output	V_{FLG}	-0.3 to $(V_{IN} + 0.3)$	V
Continuous Output Current	I_O	Internally Limited	mA
Thermal Impedance Junction to Ambient	θ_{JA}	130	°C/W
Thermal Impedance Junction to Case	θ_{JC}	47	°C/W
Operating Ambient Temperature Range	T_A	-40 to +85	°C
Operating Junction Temperature Range	T_J	-40 to +125	°C
Storage Temperature Range	T_{STG}	-65 to +150	°C
Lead Temperature (Soldering, 10 seconds)	T_L	300	°C
ESD Rating (Human Body Model)	ESD	2.5	kV

ELECTRICAL CHARACTERISTICS

Unless specified: T_A = 25°C, V_{IN} = 5V, V_{SHDN} = GND, I_{OUT} = 500mA. Values in **bold** apply over the full operating temperature range.

| Parameter	Symbol	Conditions	Min	Typ	Max	Units
IN						
Supply Voltage Range	V_{IN}		**2.8**		**5.5**	V
Supply Current	I_Q	V_{IN} = 3.3V		85	130	µA
					200	
		V_{IN} = 5.0V		100	130	µA
					200	
		V_{SHDN} = V_{IN} = 5.5V (OFF)		0.1	**1**	µA
Power Switch						
On Resistance	r_{ON}	V_{IN} = 3.3V		85	105	mΩ
					150	
		V_{IN} = 5.0V		80	100	
					135	
OUT						
Output Leakage Current	$I_{L(OFF)}$	V_{IN} = V_{SHDN} = 5.5V, V_{OUT} = GND		0.01	**1**	µA
Output Turn On Delay	$t_{d(ON)}$	R_{OUT} = 10Ω, C_{OUT} = 1µF		0.9		ms
Output Turn On Rise Time	t_r	R_{OUT} = 10Ω, C_{OUT} = 1µF		1.7		ms
Output Turn Off Delay	$t_{d(OFF)}$	R_{OUT} = 10Ω, C_{OUT} = 1µF		20		µs
Output Turn Off Fall Time	t_f	R_{OUT} = 10Ω, C_{OUT} = 1µF		25		µs

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ELECTRICAL CHARACTERISTICS (Cont.)

Unless specified: T_A = 25°C, V_{IN} = 5V, V_{SHDN} = GND, I_{OUT} = 500mA. Values in **bold** apply over the full operating temperature range.

| Parameter	Symbol	Conditions	Min	Typ	Max	Units
Current Limit						
Short Circuit Current Limit	I_{CL}	V_{OUT} = GND	**0.60**	0.85	**1.10**	A
Current Limit Trip Threshold	$I_{TH(CL)}$			1.5		A
SHDN						
High Level Input Voltage	V_{IH}	2.8V ≤ V_{IN} ≤ 5.50V	**2.4**			V
Low Level Input Voltage	V_{IL}	2.8V ≤ V_{IN} ≤ 5.50V			**0.8**	V
Input Current	I_{SHDN}	V_{SHDN} = V_{IN} = 5.5V, V_{OUT} = OPEN			**1**	μA
		V_{SHDN} = GND, I_{OUT} = 0mA, V_{OUT} = OPEN			**1**	
Undervoltage Lockout						
UVLO Threshold	V_{UVLO}	V_{IN} rising		2.7		V
		V_{IN} falling		2.4		V
FLG						
Output Resistance	r_{FLG}	I_{FLG} = 10mA, V_O = GND, Switch ON			**50**	Ω
Leakage Current (OFF)	I_{FLG}	V_{FLG} = 5.0V, Switch OFF			**1**	μA
Over Temperature Protection						
High Trip Level	T_{HI}			150		°C
Hysteresis	T_{HYST}			20		°C

TIMING DIAGRAM: OUTPUT TURN ON/OFF DELAY TIMES AND RISE/FALL TIMES
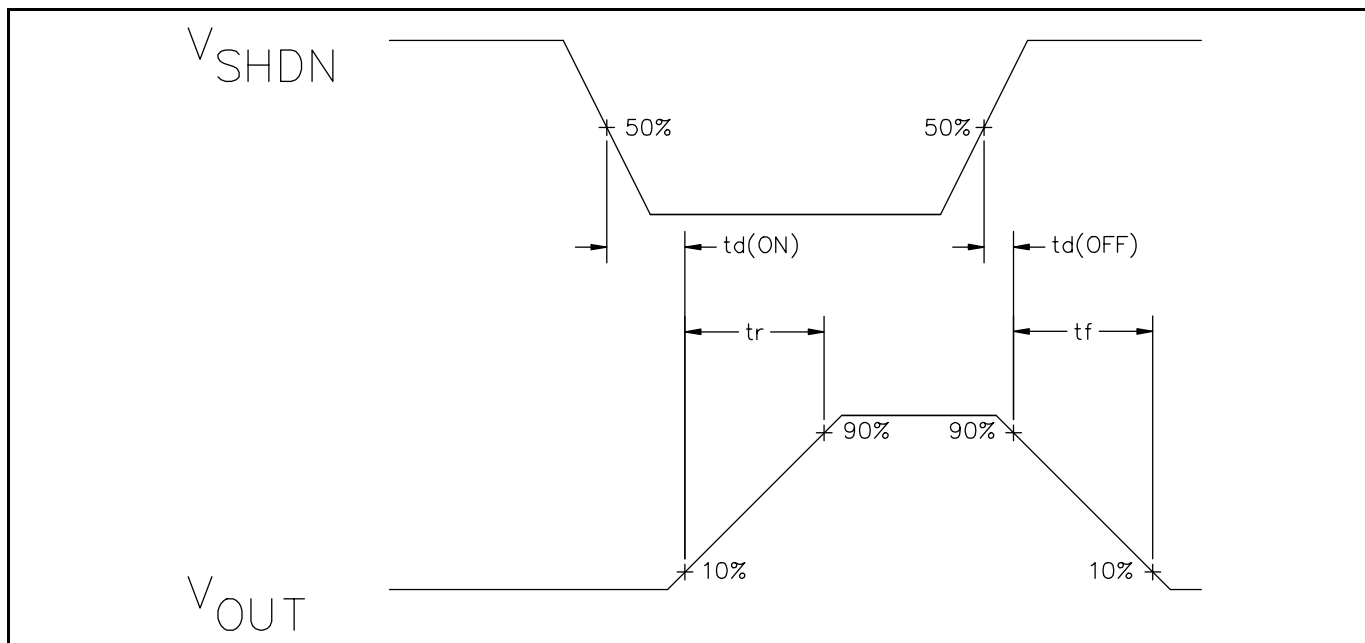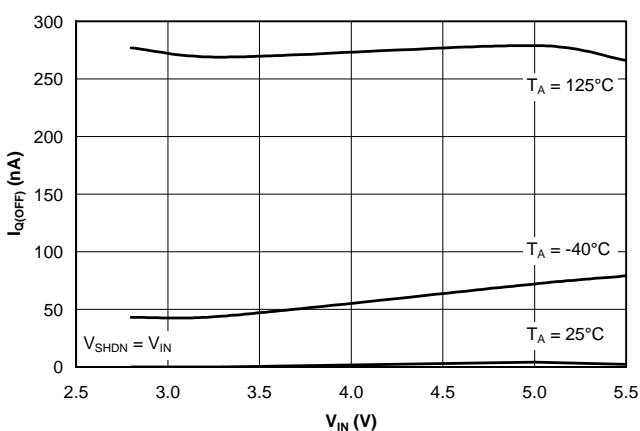
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BLOCK DIAGRAM
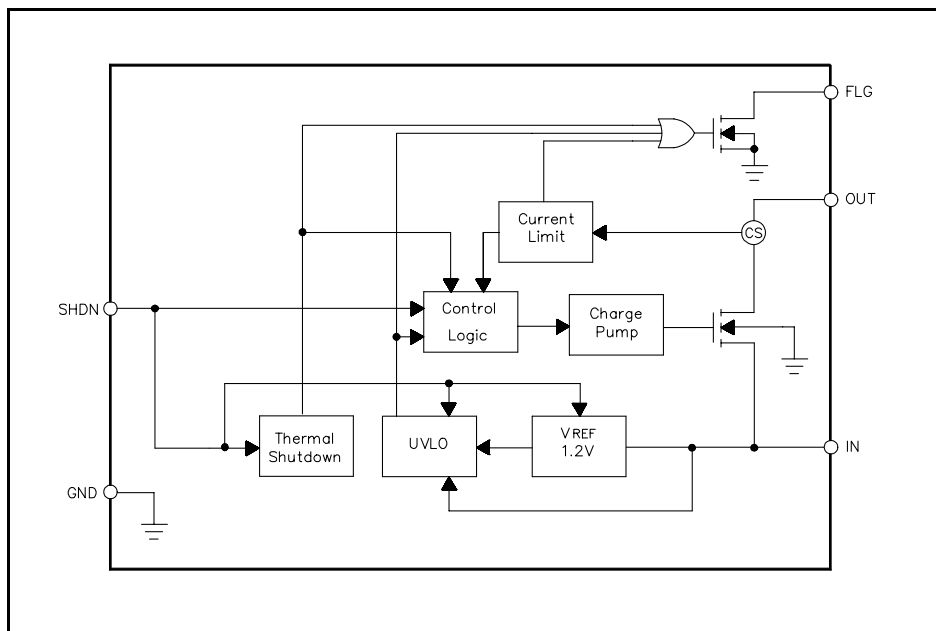
PIN CONFIGURATION

Top View

(8-Pin SOIC)
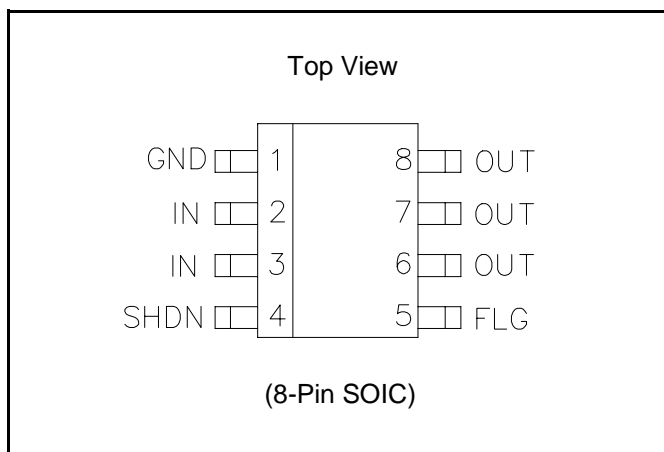
PIN DESCRIPTION

Pin #	Pin Name	Pin Function
1	GND	Ground.
2, 3	IN	Input voltage: drain of N-channel power MOSFET. Connect to supply voltage.
4	SHDN	Shutdown input: TTL compatible. N-channel power MOSFET is turned on when this pin is pulled low.
5	FLG	Error flag output: FLG is asserted active low during a fault condition (overcurrent, input undervoltage or thermal shutdown).
6, 7,8	OUT	Power switch output: source of N-channel power MOSFET. Connect to load.

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TYPICAL CHARACTERISTICS

On-State Quiescent Current vs. Junction Temperature vs. Input Voltage
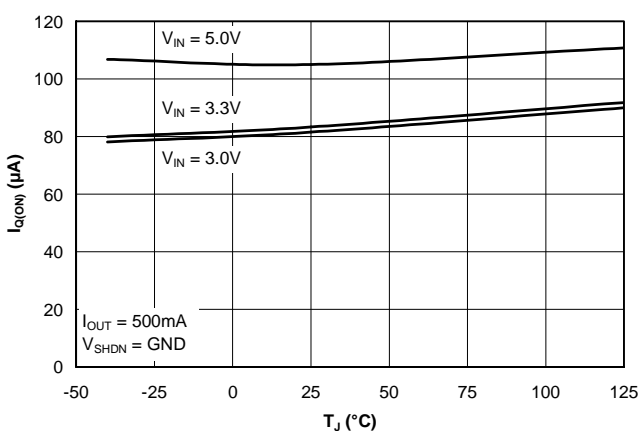
On-State Quiescent Current vs. Input Voltage
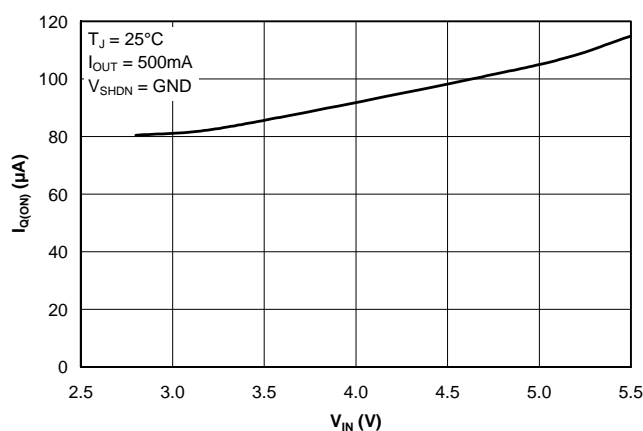
Off-State Quiescent Current vs. Input Voltage vs. Junction Temperature

Power Switch On Resistance vs. Junction Temperature vs. Input Voltage
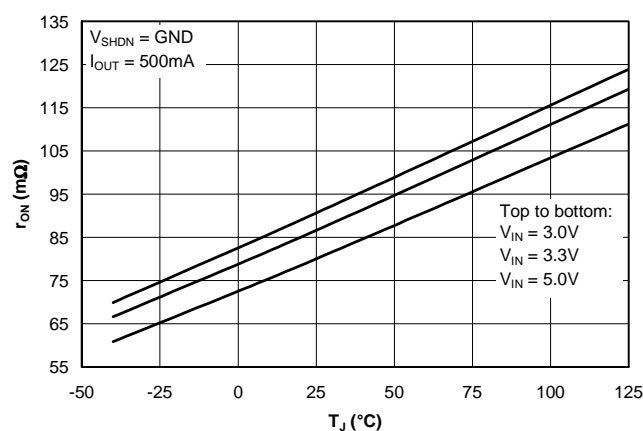
Power Switch On Resistance vs. Input Voltage vs. Junction Temperature
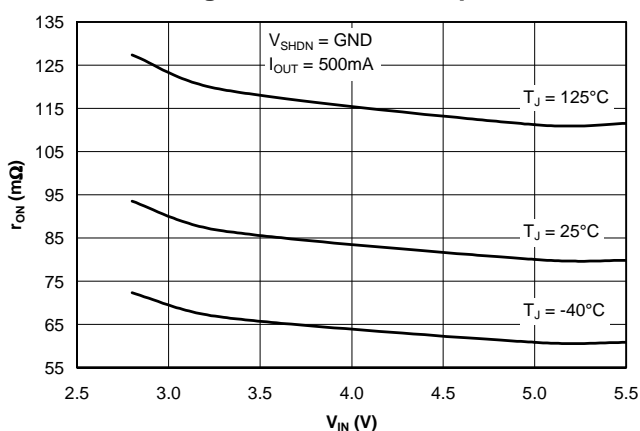
Output Turn-On Rise Time vs. Input Voltage vs Junction Temperature
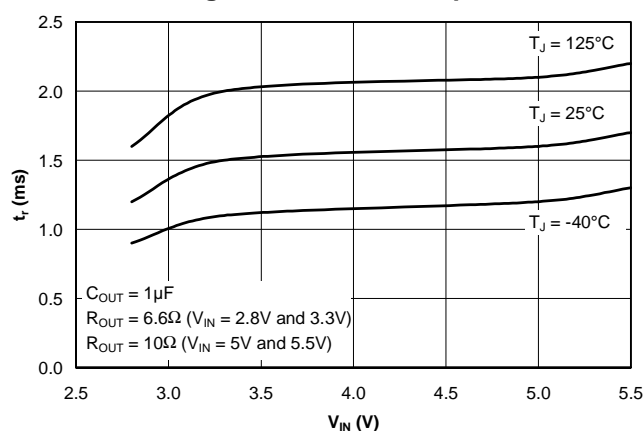
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TYPICAL CHARACTERISTICS (Cont.)

Short Circuit Current Limit vs. Input Voltage vs. Junction Temperature

$V_{SHDN} = V_{IN}$
$V_{OUT} = GND$

Top to bottom:
$T_J = -40°C$
$T_J = 25°C$
$T_J = 125°C$

I_{CL} (A) vs V_{IN} (V)
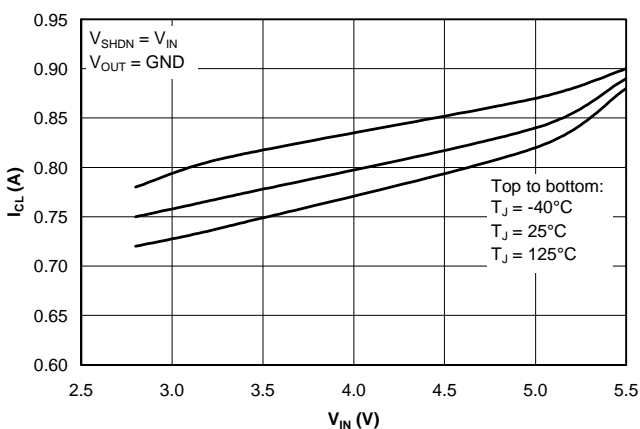
Short Circuit Current Limit vs. Junction Temperature vs. Input Voltage

$V_{IN} = 5.0V$
$V_{IN} = 3.3V$
$V_{IN} = 3.0V$

$V_{SHDN} = V_{IN}$
$V_{OUT} = GND$

I_{CL} (A) vs T_J (°C)
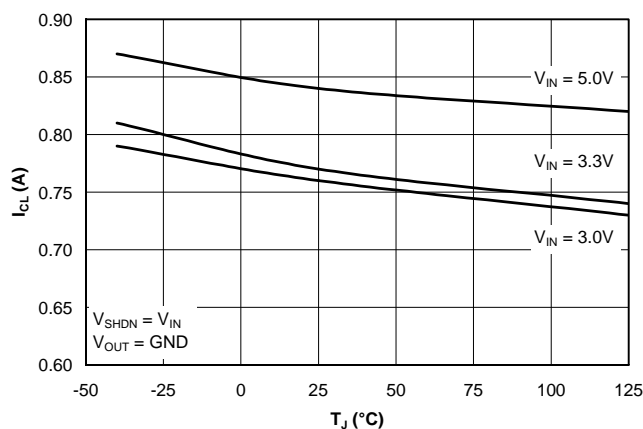
Current Limit Trip Threshold vs. Junction Temperature vs. Input Voltage

$V_{IN} = 5.0V$
$V_{IN} = 3.3V$
$V_{IN} = 3.0V$

$V_{SHDN} = V_{IN}$
$V_{OUT} = GND$

$I_{TH(CL)}$ (A) vs T_J (°C)
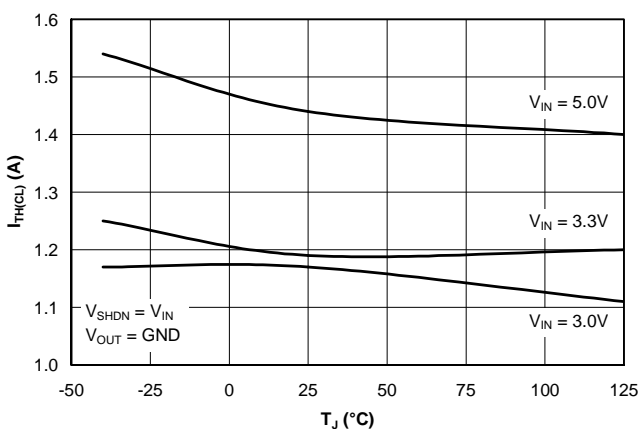
Shutdown Threshold vs. Input Voltage vs. Junction Temperature

Top to bottom:
$T_J = -40°C$
$T_J = 25°C$
$T_J = 125°C$

$V_{TH(SHDN)}$ (V) vs V_{IN} (V)
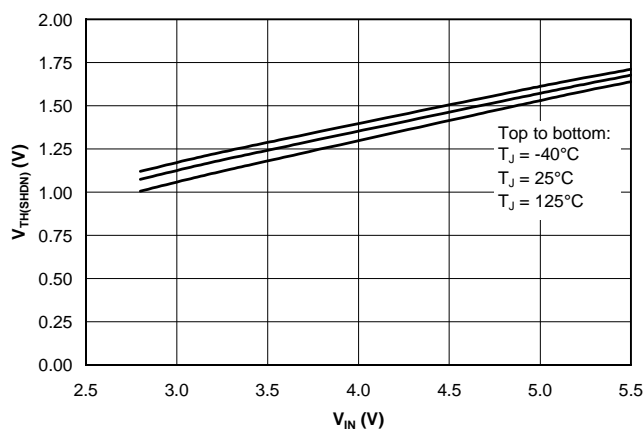
Error Flag Output Resistance vs. Input Voltage vs. Junction Temperature

Top to bottom:
$T_J = 125°C$
$T_J = 25°C$
$T_J = -40°C$

$I_{FLG} = 10mA$
$V_{OUT} = GND$
Switch ON

r_{FLG} (Ω) vs V_{IN} (V)
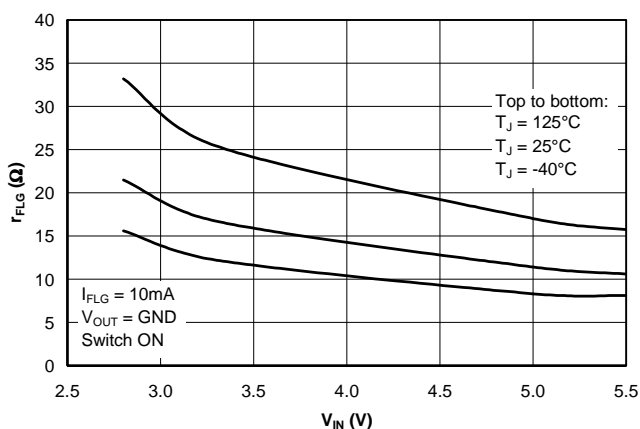
Undervoltage Lockout vs. Junction Temperature

V_{IN} rising
V_{IN} falling

V_{UVLO} (V) vs T_J (°C)

6
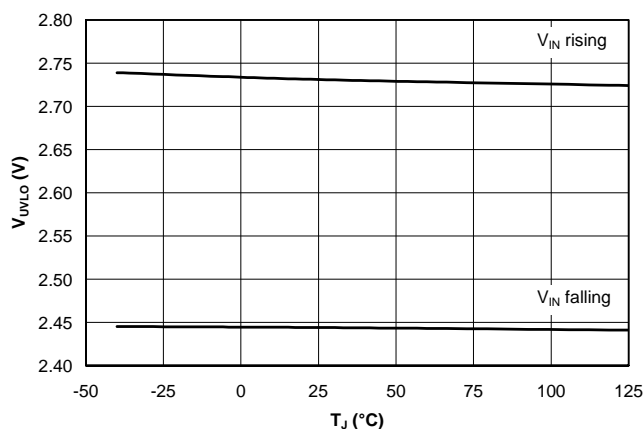
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TYPICAL CHARACTERISTICS (Cont.)

Figure 1: Output Turn On Delay and Rise Time with 0.1µF Output Capacitor and No Load

Top Trace: V_{SHDN}, 5V/div.
Bottom Trace: V_{OUT}, 2V/div.
Timebase: 1ms/div.
V_{IN} = 5V, R_{OUT} = open, C_{OUT} = 0.1µF
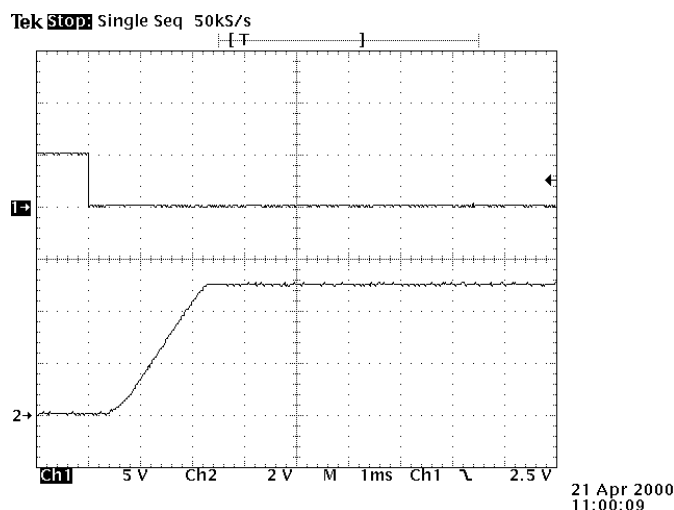
Figure 2: Output Turn On Delay and Rise Time with 1µF Output Capacitor and 10Ω Load

Top Trace: V_{SHDN}, 5V/div.
Bottom Trace: V_{OUT}, 2V/div.
Timebase: 1ms/div.
V_{IN} = 5V, R_{OUT} = 10Ω, C_{OUT} = 1µF
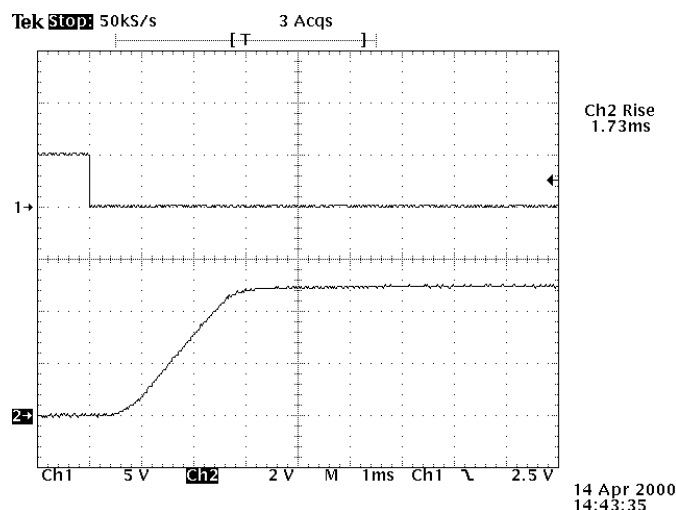
Figure 3: Output Turn Off Delay and Fall Time with 1µF Output Capacitor and 10Ω Load

Top Trace: V_{OUT}, 5V/div.
Bottom Trace: I_{OUT}, 0.5A/div.
Timebase: 100ms/div.
V_{IN} = 5V, R_{OUT} ramping from open to 1.1Ω, C_{OUT} = 22µF
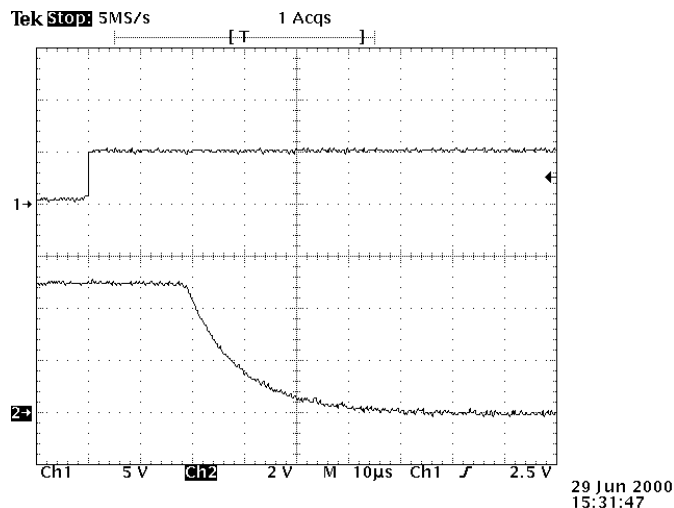
Figure 4: Current Limit and Trip Threshold With Ramped Load on Enabled Device

Top Trace: V_{OUT}, 5V/div.
Bottom Trace: I_{OUT}, 0.5A/div.
Timebase: 100ms/div.
V_{IN} = 5V, R_{OUT} ramping from open to 1.1Ω, C_{OUT} = 22µF

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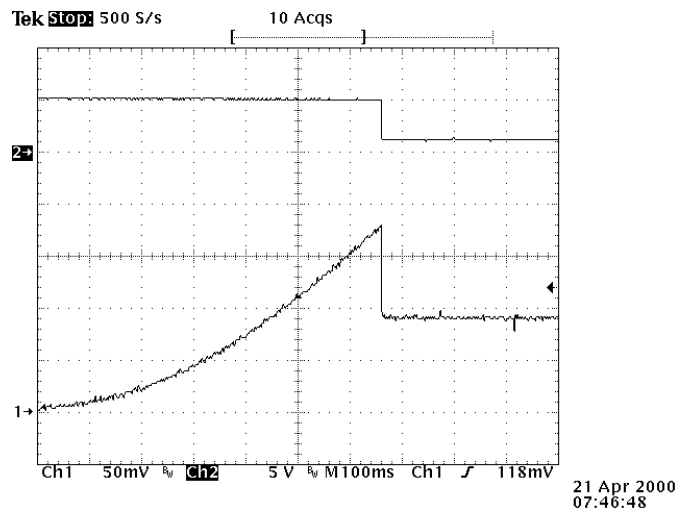
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TYPICAL CHARACTERISTICS (Cont.)

Figure 5: Current Limit and Trip Threshold With Ramped Load on Enabled Device
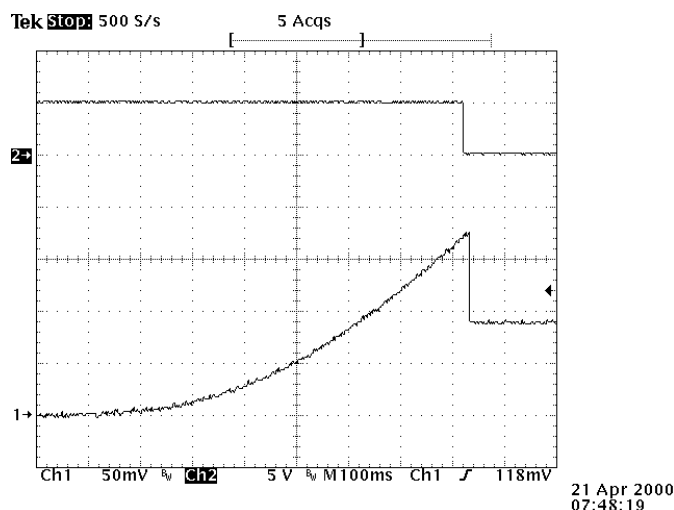
Top Trace: V_{FLG}, 5V/div.
Bottom Trace: I_{OUT}, 0.5A/div.
Timebase: 100ms/div.
V_{IN} = 5V, R_{OUT} ramping from open to 1.1Ω, C_{OUT} = 22μF

Figure 6: Short Circuit Current, Device Enabled Into Short
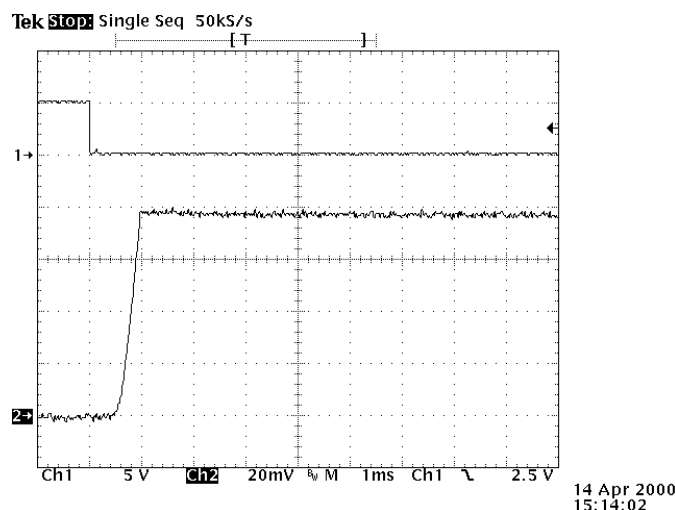
Top Trace: V_{SHDN}, 5V/div.
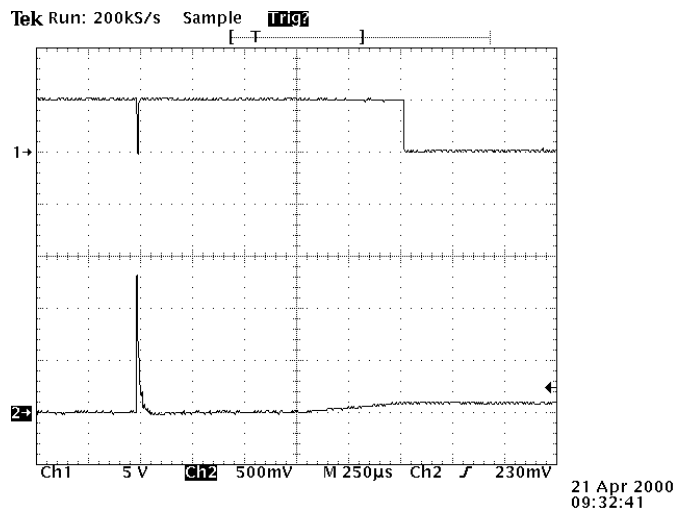Bottom Trace: I_{OUT}, 0.2A/div.
Timebase: 1ms/div.
V_{IN} = 5V, R_{OUT} = 0Ω

Figure 7: Short Circuit Current, Short Applied to Enabled Device

Top Trace: V_{FLG}, 5V/div.
Bottom Trace: I_{OUT}, 5A/div.
Timebase: 250μs/div.
V_{IN} = 5V, R_{OUT} = 0Ω, C_{OUT} = 22μF
Note initial output current spike from output capacitor discharge

Figure 8: Current Limit, 1.1Ω Load Applied to Enabled Device
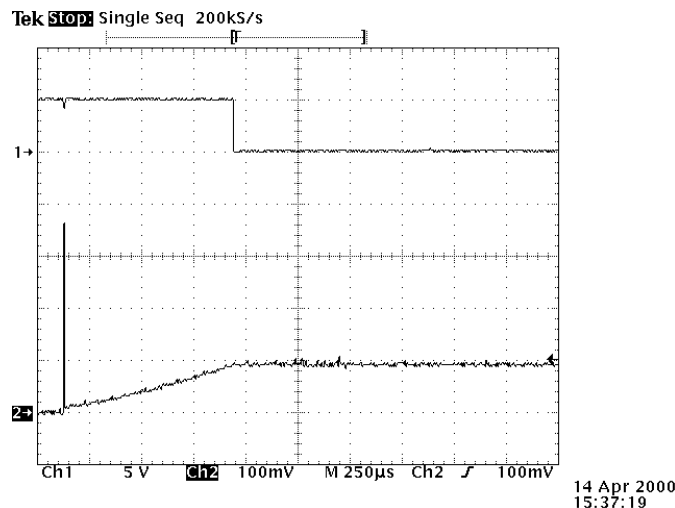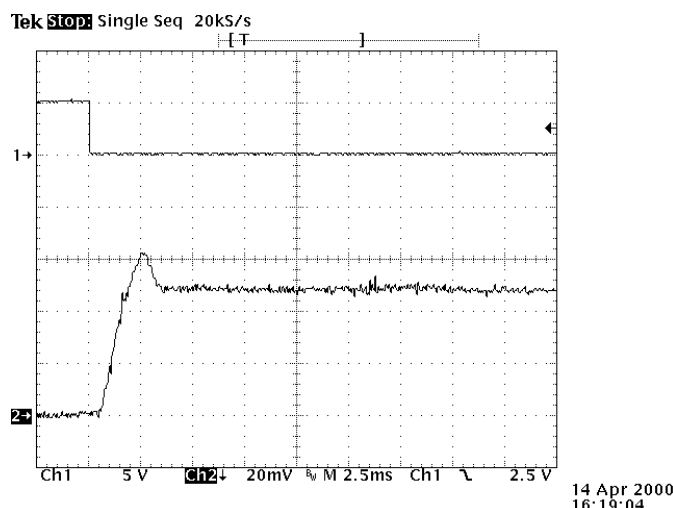

Top Trace: V_{FLG}, 5V/div.
Bottom Trace: I_{OUT}, 1A/div.
Timebase: 250μs/div.
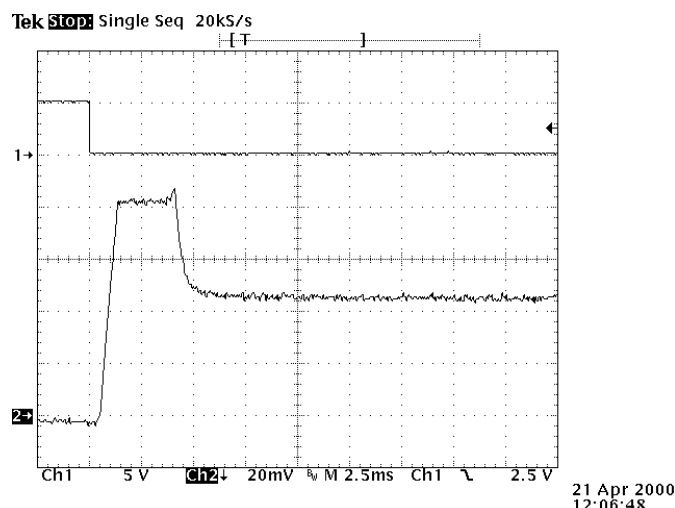V_{IN} = 5V, R_{OUT} = 1.1Ω, C_{OUT} = 1μF

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TYPICAL CHARACTERISTICS (Cont.)

Figure 9: Inrush Current, Device Enabled Into 100µF and 10Ω

Tek Stop: Single Seq 20kS/s

Ch1   5 V   Ch2↓   20mV   M 2.5ms Ch1 ⌐   2.5 V
14 Apr 2000
16:19:04

Top Trace: V_{SHDN}, 5V/div.
Bottom Trace: I_{OUT}, 0.2A/div.
Timebase: 2.5ms/div.
V_{IN} = 5V, R_{OUT} = 10Ω, C_{OUT} = 100µF

Figure 10: Inrush Current, Device Enabled Into 470µF and 10Ω

Tek Stop: Single Seq 20kS/s

Ch1   5 V   Ch2↓   20mV   M 2.5ms Ch1 ⌐   2.5 V
21 Apr 2000
12:06:48

Top Trace: V_{SHDN}, 5V/div.
Bottom Trace: I_{OUT}, 0.2A/div.
Timebase: 2.5ms/div.
V_{IN} = 5V, R_{OUT} = 10Ω, C_{OUT} = 470µF

APPLICATIONS INFORMATION

Theory Of Operation

The SC2041 is a current limited 80mΩ power switch with error reporting and enable features. The power switch is an N-channel MOSFET with its gate driven by an internal charge pump. The switch has been de-signed to turn on slowly (1.7ms typical) to minimize inrush currents at turn-on.

The Shutdown pin (SHDN) is compatible with 3V or 5V logic, and when pulled high, shuts off the power switch, causing the device to enter a very low power shutdown mode, where it will draw less than 1µA from the supply. While enabled, the SC2041 draws only 100µA from the supply.

The power switch has current limit detection circuitry which will limit the current through the switch to 0.85A (typical) and reduce the output voltage accordingly. When current limit is entered, the open drain Flag pin (FLG) is asserted low, indicating a fault condition. If an overcurrent or short condition is continuous, the power dissipation in the switch will cause the junction temper-ature to rise, triggering the thermal protection circuitry

to shut the switch down (at T_J = 150°C typical). This will shut off the output current altogether, and also cause the Flag pin to be asserted low. Once the junction temperature has dropped by 20°C (typical), the device will start up once more in a controlled manner.

The SC2041 will operate from supply voltages as low as 2.8V, and internal undervoltage lockout circuitry ensures that the power switch will be turned off at power-up, even if the device is enabled. Once the UVLO threshold voltage (2.7V typical) is reached, the switch will turn on (if enabled) and slowly ramp up the output.

The SC2041 has been designed for use in USB appli-cations such as:
1) hosts or self-powered hubs that need to current limit downstream ports and report overcurrent conditions;
2) bus-powered hubs that need to be able to switch power to downstream ports, limit inrush currents at power-up (to less than a 44Ω resistor in parallel with a 10µF capacitor) and power-up and draw less than 100mA;
3) bus-powered functions that need to limit inrush currents at power-up (to less than a 44Ω resistor in parallel with a 10µF capacitor) and power-up and draw less than 100mA.

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APPLICATIONS INFORMATION (Cont.)

Component Selection - General

A 0.1µF or greater ceramic bypass capacitor is recommended at the device input. This should be placed
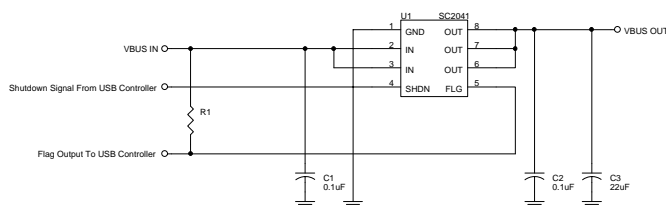
close to the input pin (IN) and routed directly to ground. A low ESR electrolytic capacitor is recommended at the output, higher values should be used for heavy loads to reduce ringing at the output (and hence input). Bypass the output with a 0.1µF to 1µF ceramic capacitor to improve immunity to short circuit transients.

Shutdown

The shutdown pin (SHDN) input is a 3V or 5V compatible enable/disable. Pulling this pin high shuts down the power switch and the SC2041 will draw < 1µA from the supply. Pulling this pin low will enable the device.

Error Flag

The error flag (FLG) output is an open drain N-channel MOSFET. Its output is pulled low during overcurrent, input undervoltage and thermal shutdown conditions. Connection of high capacitance loads to the output can cause momentary overcurrent conditions due to inrush current and trigger false error flag assertion. This can be reduced by using low ESR output capacitors to provide a low impedance source for hot-plug events. The addition of an RC filter between FLG and the USB controller can resolve this easily. This pin also requires a pull-up resistor for a high signal when not asserted.

Overcurrent

There are three overcurrent situations to be considered:
1) the output is already short before the device is enabled or power is applied. In this case, the SC2041 immediately detects the short, and the output current will slowly ramp up to the current limit value, and FLG will assert low. Refer to Figure 6 on page 8.
2) a short occurs while the device is enabled. In this case, very high current may flow initially while the

overcurrent circuitry reacts. Once the current limit circuitry trips, the current is limited to 0.85A and FLG is asserted low. Refer to Figure 7 on page 8.
3) the load gradually increases beyond 500mA. In this case, the current will be allowed to rise until it reaches the Current Limit Trip Threshold, at which point the current will drop back to 0.85A and FLG will assert low. Refer to figures 4 and 5 on page 7 and 8.

Thermal Sensing

An internal thermal shutdown circuit turns off the power switch when the die temperature exceeds 150°C (typical). The FLG pin asserts low signaling a fault condition. Built-in hysteresis prevents the switch from turning back on until the die temperature has cooled approximately 20°C. The switch will continue to cycle on and off until the fault condition is removed. The thermal sense circuit functions only when the switch is enabled.

Undervoltage Lockout

An undervoltage lockout circuit monitors the input voltage and prevents the power switch from turning on until the input voltage (IN) exceeds 2.7V (typical). If the input voltage falls and drops below 2.4V (typical), the undervoltage circuitry turns off the power switch and the FLG pin asserts low. The undervoltage lockout functions only when the switch is enabled.

Thermal Considerations

Since the on-resistance of the power switch is so low, the SC2041 can pass large currents without requiring a large package to dissipate the heat. The worst-case power dissipation (under normal operating conditions) is given by:

$$P_{D(MAX)} = (I_{OUT})^2 \bullet r_{ON(MAX)}$$

So for I_{OUT} = 500mA and $r_{ON(MAX)}$ = 150mΩ (at V_{IN} = 3.3V), the maximum power dissipation is:

$$P_{D(MAX)} = (0.5)^2 \bullet 0.150 = 37.5 mW$$

The junction temperature can be calculated using the following equation:

$$T_J = T_A + \theta_{JA} \bullet P_{D(MAX)}$$

Inserting T_A = 85°C, θ_{JA} = 130°C/W (package thermal impedance for minimum line widths and no internal

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APPLICATIONS INFORMATION (Cont.)

power planes) and $P_{D(MAX)}$ = 37.5mW, we calculate the worst-case T_J to be:

$$T_J = 85 + 130 \bullet 0.0375 = 90°C$$

Thus it can be seen that this device does not require any additional copper area for heatsinking under normal operating conditions. Sustained overcurrents or short circuits will rapidly heat T_J > 150°C, thus activating the thermal shutdown circuitry.

Layout Considerations

The ceramic bypass capacitors for IN and OUT should be connected as close to the relevant device pins as possible. The bulk output capacitors required by the USB specification should be placed close to the USB connector to provide a low impedance source for hot plug purposes. Ferrite beads should be placed on the V_{BUS} and Ground pins of the downstream connectors to reduce the droop on adjacent ports during hot plug events.
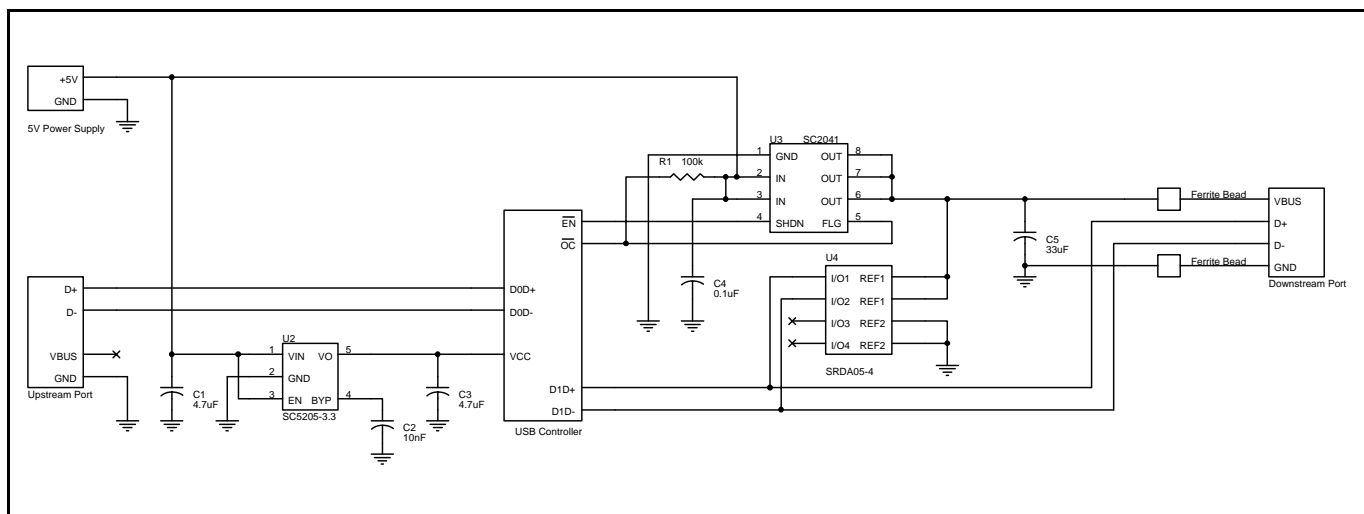
TYPICAL APPLICATIONS CIRCUITS

Self-Powered Hub, Individual Port Power Management:

A self-powered hub must supply a continuous 500mA of current to each downstream port. Since an internal power supply is used to supply the power, self-powered hubs are required to implement overcurrent protection for safety. The self-powered hub must also have a method to detect and report fault conditions to the USB controller. The circuit below utilizes the SC2041 to provide individual port overcurrent protection & power switching for maximum port protection. Under fault conditions, the SC2041 provides the short-circuit current limiting function and has a fault flag logic output

for notifying the hub controller. The USB hub can use the SC2041 to remove power from the faulty port, allowing the other ports to operate normally.

Since USB is a hot insertion and removal system, USB ports are subject to electrostatic discharge (ESD). The SRDA05-4 provides ESD protection on the downstream data and power lines. Each device will protect two USB ports. With proper layout the port is hardened to greater than 15kV, meeting the requirements of IEC 1000-4-2. The SC5205 LDO regulator is used to power the hub controller from the hub's 5V power supply.

Notes:
(1) One port only shown for simplicity.
(2) 33µF output capacitor assumes four downstream ports for this hub, therefore meeting the USB specification requirement of 120µF minimum capacitance per hub.
(3) The SRDA05-4 shown would also protect lines D2D+ and D2D-.

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TYPICAL APPLICATIONS CIRCUITS (Cont.)

Bus-Powered Hub, Ganged-Port Power Management:

A bus-powered hub distributes power and data from an input port to downstream ports. It must supply a continuous 100mA of current to each downstream port. A bus-powered hub must be able to switch power to downstream ports to prevent illegal device hook-up. Inrush current limiting is also required to prevent power supply drooping. The circuit below utilizes the SC2041 to provide ganged port power switching, inrush current limiting and overcurrent protection for maximum port protection. In a ganged switch configuration, all ports are switched simultaneously. Under fault conditions,

the USB controller will remove power to all of the ganged ports. For individual port management, additional SC2041s may be used.

Since USB is a hot insertion and removal system, USB ports are subject to electrostatic discharge (ESD). The SRDA05-4 provides ESD protection on the downstream data and power lines. Each device will protect two USB ports. With proper layout the port is hardened to greater than 15kV, meeting the requirements of IEC 1000-4-2. On the upstream port, the SR05 provides ESD protection to the above levels for one line pair. The SC5205 LDO regulator is used to power the hub controller from the upstream bus.
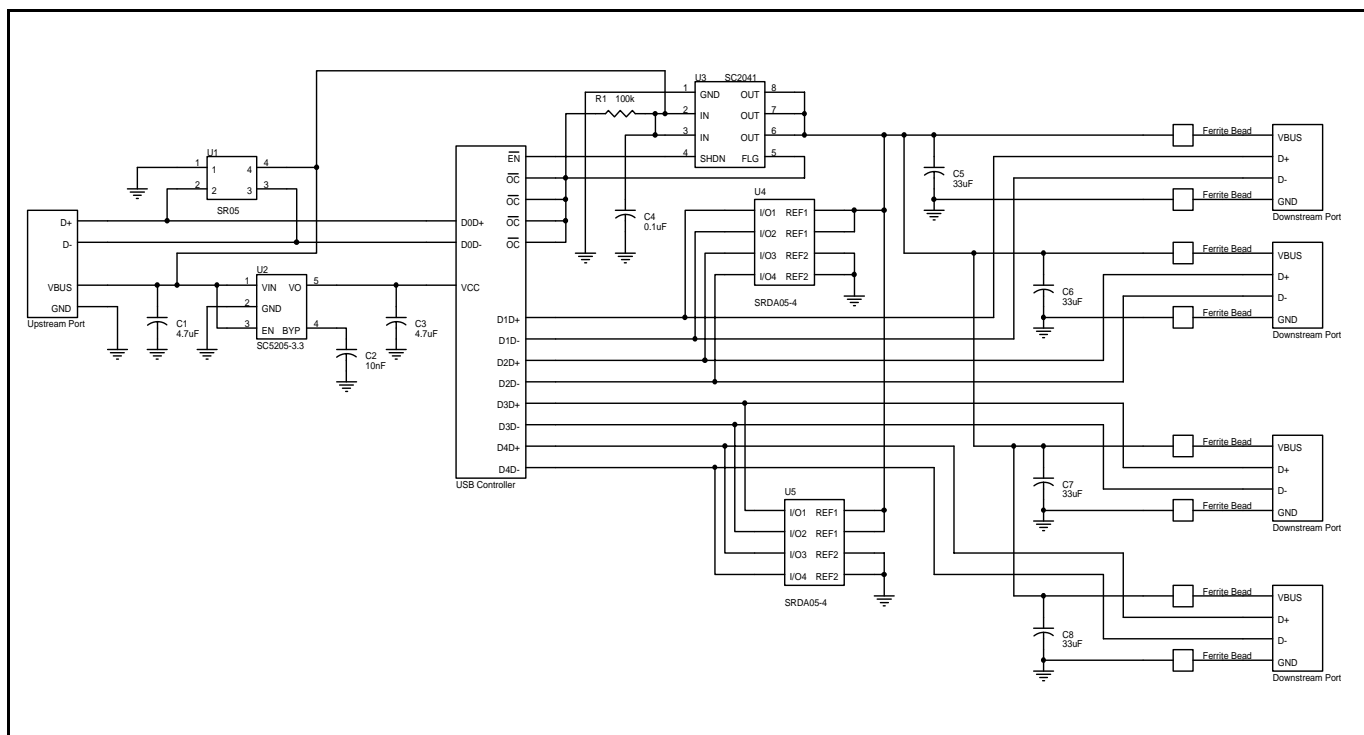
Note:
(1) 33µF output capacitor per port meets the USB specification minimum capacitance requirement of 120µF per hub.

TYPICAL APPLICATIONS CIRCUITS (Cont.)

High-Power or Low-Power Bus-Powered Function:

Both low-power and high-power bus-powered functions must draw less than 100mA at startup. At this time, they must also present a load of less than the parallel combination of a 44Ω resistor and a 10µF capacitor. After startup, high powered functions may then draw up to 500mA. The circuit below utilizes the SC2041 to provide inrush current limiting and power switching for the internal function.

Since USB is a hot insertion and removal system, USB ports are subject to electrostatic discharge (ESD). The SR05 provides ESD protection on the upstream data and power lines. With proper layout the port is hardened to greater than 15kV, meeting the requirements of IEC 1000-4-2. The SC5205 LDO regulator is used to power the hub controller from the upstream bus.
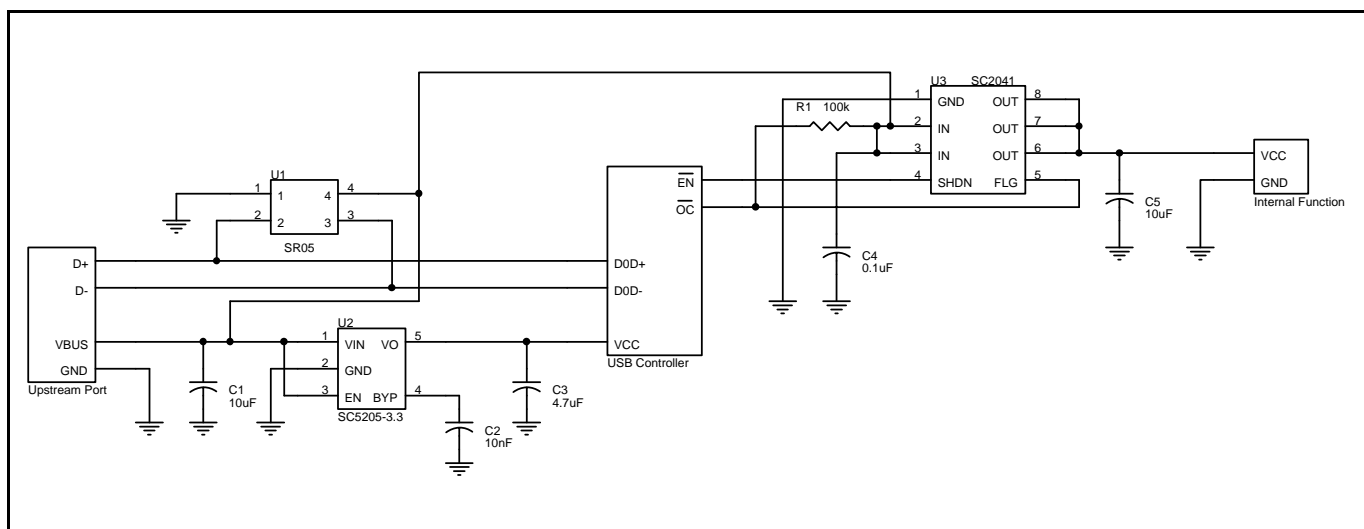
Note:
(1) 33µF output capacitor per port meets the USB specification minimum capacitance of 120µF per hub.

July 18, 2000

OUTLINE DRAWING - SO-8

JEDEC
REF: MS-012AA

DIM^N	INCHES		MM		NOTE
	MIN	MAX	MIN	MAX	
A	.188	.197	4.80	5.00	
B	.149	.158	3.80	4.00	
C	.228	.244	5.80	6.20	
D	.050	BSC	1.27	BSC	
E	.013	.020	0.33	0.51	
F	.004	.010	0.10	0.25	
H	.053	.069	1.35	1.75	
J	.011	.019	0.28	0.48	
K	.007	.010	.19	.25	
L	0°	8°	0°	8°	
M	.016	.050	0.40	1.27	

LAND PATTERN - SO-8

DIM^N	INCHES		MM		NOTE
	MIN	MAX	MIN	MAX	
C	–	.19	–	5.00	–
D	–	.15	–	3.81	–
E	–	.05	–	1.27	–
G	.10	.11	2.60	2.80	–
X	.02	.03	.60	.80	–
Y	–	.09	–	2.40	–
Z	–	.29	7.20	7.40	–

② GRID PLACEMENT COURTYARD IS 12x16 ELEMENTS (6 mm X 8mm) IN ACCORDANCE WITH THE INTERNATIONAL GRID DETAILED IN IEC PUBLICATION 97.

① CONTROLLING DIMENSION: MILLIMETERS

ECN00-1199