

TPD3S716-Q1 可提供可调电流限制、电池短路保护和其他短路保护的汽车类 USB 2.0 接口保护器件

1 特性

- 符合 AEC-Q100 标准 (1 级)
 - 工作温度范围: -40°C 至 $+125^{\circ}\text{C}$
- 提供功能安全
 - 可帮助进行功能安全系统设计的文档
- $V_{\text{BUS_CON}}$ 引脚上具有电池短路保护 (高达 18V) 和接地短路保护
- VD^{+} 和 VD^{-} 引脚上具有电池短路保护 (高达 18V) 和 V_{BUS} 短路保护
- 在 $V_{\text{BUS_CON}}$ 、 VD^{+} 、 VD^{-} 上提供 IEC 61000-4-2 ESD 保护
 - $\pm 8\text{kV}$ 接触放电
 - $\pm 15\text{kV}$ 气隙放电
- $V_{\text{BUS_CON}}$ 、 VD^{+} 和 VD^{-} 引脚上具有 ISO 10605 330pF、330 Ω ESD 保护
 - $\pm 8\text{kV}$ 接触放电
 - $\pm 15\text{kV}$ 气隙放电
- 低 R_{ON} nFET V_{BUS} 开关 (典型值为 63m Ω)
- 高速数据开关 (3dB 带宽为 1GHz)
- 可调节断续电流限制高达 2.4A
- 短暂过压响应时间
 - V_{BUS} 开关的典型值为 2 μs
 - 数据开关的典型值为 200ns
- 独立的 V_{BUS} 和数据使能引脚 (用于配置主机和客户端/OTG 模式)
- 故障输出信号
- 热关断特性
- 16 引脚 SSOP 封装 (4.9mm x 3.9mm), 直通布线

2 应用

- 终端设备
 - 音响主机
 - 后座娱乐系统
 - 远程信息处理
 - USB 集线器
 - 导航模块
 - 媒体接口
- 接口
 - USB 2.0

3 说明

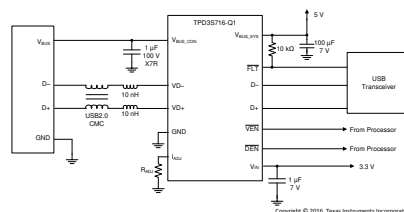
TPD3S716-Q1 是一套具有可调节电流限制功能的单芯片解决方案, 可为汽车应用中 USB 连接器的 V_{BUS} 和数据线路提供电池短路保护、短路保护以及 ESD 保护。集成的数据开关提供了出色的带宽, 能够在提供 18V 电池短路保护的同时最大限度地减少信号衰减。该器件具有 1GHz 的高带宽, 适用于一些采用 USB2.0 高速数据速率的应用, 如 Car Play。此外, 该器件还具有 720MHz 以上的附加带宽裕量, 有助于保持一个干净的 USB 2.0 眼图, 并且支持使用较长的不可分离电缆 (常见于汽车 USB 环境中)。电池短路保护可将内部系统电路隔离, 防止其受到 $V_{\text{BUS_CON}}$ 、 VD^{+} 和 VD^{-} 引脚上的任何过压情况的影响。在这些引脚上, TPD3S716-Q1 能够处理高达 18V 的过压情况 (热插拔和直流事件)。过压保护电路可提供业内一流的电池短路保护, 能够极为可靠地关断数据开关以保护上游电路免遭有害电压和电流尖峰的影响。

$V_{\text{BUS_CON}}$ 引脚还提供可调节的电流限制负载开关以及接地短路保护功能。该器件支持高达 2.4A 的 V_{BUS} 电流, 支持 USB BC1.2、USB Type-C 5V/1.5A 以及最高达 2.4A 的专用充电方案。独立的数据和 V_{BUS} 使能引脚可用于配置主机和客户端-OTG 模式。此外, TPD3S716-Q1 还在 $V_{\text{BUS_CON}}$ 、 VD^{+} 和 VD^{-} 引脚上集成了系统级 IEC 61000-4-2 和 ISO 10605 ESD 保护, 无需使用高电压、低容值的外部二极管。

器件信息(1)

器件型号	封装	封装尺寸 (标称值)
TPD3S716-Q1	SSOP (16)	4.90mm x 3.90mm

- (1) 如需了解所有可用封装, 请参阅数据表末尾的可订购产品附录。



典型应用原理图



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4 Revision History

Changes from Revision C (June 2016) to Revision D (August 2020)	Page
• 向 特性 部分添加了功能安全链接.....	1
• 更新了整个文档中的表格、图和交叉参考的编号格式.....	1
Changes from Revision B (April 2016) to Revision C (June 2016)	Page
• 将 特性 部分中的 可调节断续电流限制 从 1.7A 更改为 2.4A.....	1
• 更新了 说明 部分.....	1
• Changed <i>Current through V_{BUS} switch</i> from 1.7 A to 2.4 A.....	4
• Updated the R_{ADJ} minimum resistance to 57 k Ω in Recommended Operating Conditions table.....	4
• aDDED new current limit values to Electrical Characteristics table	5
• Updated 图 8-1	14
• Updated <i>I_{VBUS} Operating Maximum</i> in 图 9-7 to go up to 2.4 A.....	21
Changes from Revision A (April 2016) to Revision B (April 2016)	Page
• 更改了 电气特性 表.....	1
Changes from Revision * (March 2016) to Revision A (April 2016)	Page
• 将器件状态从 产品预发布 更改为 量产数据	1

5 Pin Configuration and Functions

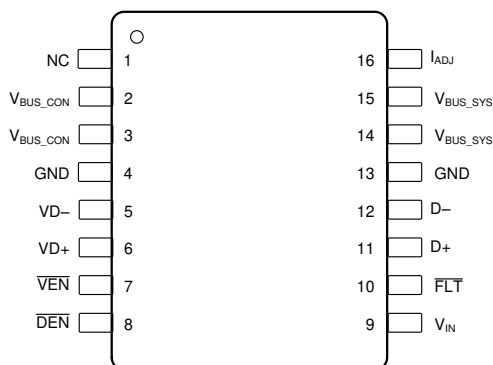


图 5-1. DBQ Package 16-Pin SSOP Top View

Pin Functions

PIN		TYPE	DESCRIPTION
NO.	NAME		
1	NC	NC	No connect, leave floating or connect to ground. Do not connect to V_{BUS_CON}
2	V_{BUS_CON}	O	Connect to USB connector V_{BUS} ; provides IEC 61000-4-2 ESD protection
3	V_{BUS_CON}	O	
4	GND	Ground	Connect to PCB ground plane
5	VD -	I/O	Connect to USB connector D - ; provides IEC 61000-4-2 ESD protection
6	VD+	I/O	Connect to USB connector D+; provides IEC 61000-4-2 ESD protection
7	$\overline{VEN}$	I	Enable Active-Low Input. Drive $\overline{VEN}$ low to enable the V_{BUS} path of the device. Drive $\overline{VEN}$ high to disable the V_{BUS} path of the device
8	$\overline{DEN}$	I	Enable Active-Low Input. Drive $\overline{DEN}$ low to enable the data path of the device. Drive $\overline{DEN}$ high to disable the data path of the device
9	V_{IN}	I	Connect to 3.3-V I/O. Controls the OVP threshold for VD+/VD -
10	$\overline{FLT}$	O	Open-Drain fault pin. See the Detailed Description section for operation
11	D+	I/O	Connect to the internal transceiver D+ pin
12	D -	I/O	Connect to the internal transceiver D - pin
13	GND	Ground	Connect to PCB ground plane
14	V_{BUS_SYS}	I	Connect to internal V_{BUS} plane
15	V_{BUS_SYS}	I	
16	I_{ADJ}	I	Connect to a resistor to GND to adjust the current limit threshold

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) ^{(1) (2)}

		MIN	MAX	UNIT
V _{BUS_CON}	Supply voltage from USB connector	– 0.3	18	V
V _{BUS_SYS}	Internal Supply DC voltage Rail on the PCB	– 0.3	6	V
VD+, VD –	Voltage range from connector-side USB data lines	– 0.3	18	V
D+, D –	Voltage range for internal USB data lines	– 0.3	V _{IN} + 0.3	V
V _{IN}	Voltage range for V _{IN} supply input	– 0.3	4	V
DEN	Voltage on enable pins		7	V
VEN			7	V
I _{BUS}	Maximum DC output current on V _{BUS_CON} pin ⁽³⁾		2.4	A
V _{IADJ}	Voltage range for I _{ADJ} pin	– 0.3	V _{BUS_SYS} + 0.3	V
V _{FLT}	Voltage range for the FLT pin	– 0.3	7	V
T _A	Operating free air temperature ⁽³⁾	– 40	125	°C
T _{STG}	Storage temperature	– 65	150	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) The algebraic convention, whereby the most negative value is a minimum and the most positive value is a maximum.
- (3) Thermal limits and power dissipation limits must be observed.

6.2 ESD Ratings—AEC Specification

		VALUE	UNIT
V _(ESD)	Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 ⁽¹⁾	V
		Charged-device model (CDM), per AEC Q100-011	

- (1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 ESD Ratings—IEC Specification

			VALUE	UNIT
V _(ESD)	Electrostatic discharge	IEC 61000-4-2, V _{BUS_CON} , VD+, VD – pins	Contact discharge ⁽¹⁾	V
			Air-gap discharge ⁽¹⁾	

- (1) See [Figure 7-2](#) for details on system level ESD testing setup.

6.4 ESD Ratings—ISO Specification

			VALUE	UNIT
V _(ESD)	Electrostatic discharge	ISO 10605 (330 pF, 330 Ω), V _{BUS_CON} , VD+, VD – pins	Contact discharge ⁽¹⁾	V
			Air-gap discharge ⁽¹⁾	

- (1) See [Figure 7-2](#) for details on system level ESD testing setup.

6.5 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V _{BUS_CON}	Supply voltage from USB connector			5.9	V
V _{BUS_SYS}	Internal supply DC voltage Rail on the PCB	4.75		5.9	V

6.5 Recommended Operating Conditions (continued)

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
VD+, VD -	Voltage range from connector-side USB data lines	0		V _{IN} + 0.3	V
D+, D -	Voltage range for internal USB data lines	0		V _{IN} + 0.3	V
V _{IN}	Voltage range for V _{IN} supply	3		3.6	V
I _{BUS}	Current through V _{BUS} switch ⁽¹⁾			2.4	A
$\overline{\text{VEN}}$, $\overline{\text{DEN}}$	Voltage range for enable	0		5.9	V
C _{SYS}	Input capacitance ⁽²⁾		100		μF
C _{LOAD}	Output load capacitance ⁽²⁾				μF
C _{VIN}	V _{IN} capacitance ⁽²⁾				μF
R _{ADJ}	Resistance of R _{ADJ} resistor ⁽²⁾	57			kΩ

- (1) Depending on your I_{BUS} current level, maximum operating junction temperature derating may be required. For I_{BUS} > 1.5A, care should be taken in the PCB design to improve the board's thermal coefficient. Please see both the [Power Dissipation and Junction Temperature](#) and [Layout Optimized for Thermal Performance](#) sections for more details.
- (2) See the [Figure 9-1](#) for configuration details.

6.6 Thermal Information

THERMAL METRIC ⁽¹⁾		TPD3S716-Q1	UNIT
		DBQ (SSOP)	
		16 PINS	
θ _{JA}	Junction-to-ambient thermal resistance	98.8	°C/W
θ _{JCTop}	Junction-to-case (top) thermal resistance	48.0	°C/W
θ _{JB}	Junction-to-board thermal resistance	41.6	°C/W
ψ _{JT}	Junction-to-top characterization parameter	8.5	°C/W
ψ _{JB}	Junction-to-board characterization parameter	41.2	°C/W
θ _{JCbot}	Junction-to-case (bottom) thermal resistance	N/A	°C/W
θ _{JA(Custom)}	See the Layout Optimized for Thermal Performance section	57.0	°C/W

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).

6.7 Electrical Characteristics

over operating free-air temperature range, $\overline{\text{VEN}} = 0\text{ V}$, $\overline{\text{DEN}} = 0\text{ V}$, V_{BUS_SYS} = 5 V, V_{IN} = 3.3 V, VD+/VD - /D+/D - /V_{BUS_CON} = float (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY CURRENT CONSUMPTION					
I _{VBUS_SLEEP}	V _{BUS} Sleep current consumption	Measured at V _{BUS_SYS} pin, $\overline{\text{VEN}} = 5\text{ V}$, $\overline{\text{DEN}} = 5\text{ V}$	45	150	μA
I _{VBUS}	V _{BUS} Operating current consumption	Measured at V _{BUS_SYS} pin	285	380	μA
I _{VIN}	Leakage current for V _{IN}	Measured at V _{IN} pin, V _{IN} = 3.6 V	12	20	μA
I _{ON(LEAK)}	Leakage into V _{BUS_SYS} while shorted to battery and powered on	Measured flowing into V _{BUS_SYS} pin, V _{BUS_SYS} = 5 V, V _{BUS_CON} = 18 V	225	300	μA
I _{OFF(LEAK)}	Leakage through V _{BUS} path while shorted to battery and unpowered	Measured flowing out of V _{BUS_SYS} pin, V _{BUS_SYS} = 0 V, V _{BUS_CON} = 18 V		50	μA
I _{D(OFF_LEAK)}	Leakage out of data path while shorted to battery and unpowered	Measured flowing out of D+ or D - pins, V _{BUS_SYS} = 0 V, VD+ or VD - = 18 V, V _{IN} = 0 V, D+/D - = 0 V	- 1	1	μA
I _{D(ON_LEAK)}	Leakage out of data path while shorted to battery and powered on	Measured flowing out of D+ or D - pins, V _{BUS_SYS} = 5 V, VD+ or VD - = 18 V, V _{IN} = 3.3 V, D+/D - = 0 V	- 1	1	μA
I _{VD(OFF_LEAK)}	Leakage into data path while shorted to battery and unpowered	Measured flowing in to VD+ or VD - pins, V _{BUS_SYS} = 0 V, VD+ or VD - = 18 V, V _{IN} = 0 V, D+/D - = 0 V		85	μA

6.7 Electrical Characteristics (continued)

over operating free-air temperature range, $\overline{VEN} = 0\text{ V}$, $\overline{DEN} = 0\text{ V}$, $V_{BUS_SYS} = 5\text{ V}$, $V_{IN} = 3.3\text{ V}$, $VD+/VD- /D+/D- /V_{BUS_CON} = \text{float}$ (unless otherwise noted)

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
I _{VD(ON_LEAK)}	Leakage into data path while shorted to battery and powered on		Measured flowing in to VD+ or VD – pins, V _{BUS_SYS} = 5 V, VD+ or VD – = 18 V, V _{IN} = 3.3 V D+/D – = 0 V			85	μA
V _{IN} PIN							
V _{UVLO(RISING)}	Undervoltage lockout rising for V _{IN}	V _{IN}	Ramp V _{IN} up until V _{BUS} and Data FETs turn on, VEN = 0 V, DEN = 0 V	2.6	2.7	2.9	V
V _{UVLO(FALLING)}	Undervoltage lockout falling for V _{IN}		Ramp V _{IN} down until V _{BUS} and Data FETs turn off, VEN = 0 V, DEN = 0 V	2.5	2.6	2.8	
VEN, DEN, FLT PINS							
V _{IH}	High-level input voltage	VEN, DEN	Set VEN (DEN) = 0 V; Sweep VEN (DEN) to 1.4 V; Measure when V _{BUS} (Data) FET turns off	1.2			V
V _{IL}	Low-level input voltage	VEN, DEN	Set VEN (DEN) = 3.3 V; Sweep VEN (DEN) from 3.3 V to 0.5 V; Measure when V _{BUS} (Data) FET turns on			0.8	V
I _{IL}	Input Leakage Current	VEN, DEN	V _(VEN) (V _(DEN)) = 3.3 V ; Measure Current into VEN (DEN) pin			1	μA
V _{OL}	Low-level output voltage	FLT	I _{OL} = 3 mA			0.4	V
OCP CIRCUIT—V _{BUS}							
I _{LIM}	Overcurrent limit, R _{ADJ} = 280 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	505		620	mA
I _{LIM}	Overcurrent limit, R _{ADJ} = 158 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	0.905		1.1	A
I _{LIM}	Overcurrent limit, R _{ADJ} = 143 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	1.005		1.2	A
I _{LIM}	Overcurrent limit, R _{ADJ} = 93.1 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	1.505		1.8	A
I _{LIM}	Overcurrent limit, R _{ADJ} = 76.8 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	1.8		2.16	A
I _{LIM}	Overcurrent limit, R _{ADJ} = 66.5 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	2.105		2.57	A
I _{LIM}	Overcurrent limit, R _{ADJ} = 57.6 kΩ ± 1%	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	2.405		2.93	A
I _{LIM}	Overcurrent limit, I _{ADJ} = GND	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	550	700	850	mA
I _{LIM}	Overcurrent limit, I _{ADJ} = V _{BUS_SYS}	V _{BUS}	Progressively load V _{BUS_CON} until device asserts FLT	1.1	1.4	1.7	A
OVER TEMPERATURE PROTECTION							
T _{SD(RISING)}	The rising over-temperature protection shutdown threshold	V _{BUS_SYS} = 5 V, VEN = 0 V, DEN = 0 V, No Load on V _{BUS_CON} , T _A stepped up until FLT is asserted		150	165	180	°C
T _{SD(FALLING)}	The falling over-temperature protection shutdown threshold	V _{BUS_SYS} = 5 V, VEN = 0 V, DEN = 0 V, No Load on V _{BUS_CON} , T _A stepped down from T _{SD(RISING)} until FLT is deasserted		125	130	142	°C
T _{SD(HYST)}	The over-temperature protection shutdown threshold hysteresis	T _{SD(RISING)} – T _{SD(FALLING)}		10	35	55	°C
OVP CIRCUIT—V _{BUS}							
V _{OVP(RISING)}	Input overvoltage protection threshold	V _{BUS_CON}	Increase V _{BUS_CON} from 5 V to 7 V. Measure when FLT is asserted	5.6	5.8	6	V
V _{HYS(OVP)}	Hysteresis on OVP	V _{BUS_CON}	Difference between rising and falling OVP thresholds on V _{BUS_CON}		50		mV
V _{OVP(FALLING)}	Input overvoltage protection threshold	V _{BUS_CON}	Decrease V _{BUS_CON} from 7 V to 5 V. Measure when FLT is deasserted	5.52	5.75	5.98	V
V _{REV_SUPPLY(RISING)}	Reverse supply detection threshold	V _{BUS_CON} – V _{BUS_SYS}	Set V _{BUS_SYS} to 5 V. Increase V _{BUS_CON} from V _{BUS_SYS} to V _{BUS_SYS} + 300 mV. Measure the value of V _{BUS_CON} – V _{BUS_SYS} when FLT asserts. 25°C ≤ T _A ≤ 125°C	140	200	260	mV

6.7 Electrical Characteristics (continued)

over operating free-air temperature range, $\overline{VEN} = 0\text{ V}$, $\overline{DEN} = 0\text{ V}$, $V_{BUS_SYS} = 5\text{ V}$, $V_{IN} = 3.3\text{ V}$, $VD+/VD- / D+/D- / V_{BUS_CON}$ = float (unless otherwise noted)

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
V _{REV_SUPPLY(FALLING)}	Reverse supply detection threshold	V _{BUS_CON} – V _{BUS_SYS}	Set V _{BUS_SYS} to 5 V. Decrease V _{BUS_CON} from V _{BUS_SYS} + 300 mV to V _{BUS_SYS} . Measure the value of V _{BUS_CON} – V _{BUS_SYS} when $\overline{\text{FLT}}$ deasserts. 25°C ≤ T _A ≤ 125°C	70	120	165	mV
V _{REV_SUPPLY(HYST)}	Hysteresis on reverse supply detection	V _{BUS_CON} – V _{BUS_SYS}	Difference between rising and falling reverse supply detection thresholds		80		mV
V _{UVLO(SYS_RISING)}	Undervoltage lockout rising for V _{BUS_SYS}	V _{BUS_SYS}	V _{BUS_SYS} voltage rising from 0 V to 5 V	3.1	3.3	3.6	V
V _{HYS(UVLO_SYS)}	V _{BUS_SYS} UVLO Hysteresis	V _{BUS_SYS}	Difference between rising and falling UVLO thresholds on V _{BUS_SYS}	50	75	100	mV
V _{UVLO(SYS_FALLING)}	Undervoltage lockout falling for V _{BUS_SYS}	V _{BUS_SYS}	V _{BUS_SYS} voltage falling from 5 V to 2.9 V	3	3.2	3.5	V
V _{SHRT(RISING)}	Short-to-ground comparator rising threshold	V _{BUS_CON}	Increase V _{BUS_CON} voltage from 0 V until the device transitions from the short-circuit to over-current mode of operation	2.5	2.6	2.7	V
V _{SHRT(FALLING)}	Short-to-ground comparator falling threshold	V _{BUS_CON}	Set V _{BUS_SYS} = 5 V; V _{IN} = 3.3 V; $\overline{\text{VEN}}$ = 0 V, $\overline{\text{DEN}}$ = 0 V; Decrease V _{BUS_CON} voltage from 5 V until the device transitions from the over-current to short-circuit mode of operation	2.4	2.5	2.6	V
V _{SHRT(HYST)}	Short-to-ground comparator hysteresis	V _{BUS_CON}	Difference between V _{SHRT(RISING)} and V _{SHRT(FALLING)}		125		mV
I _{SHRT}	Short-to-ground current source	V _{BUS_CON}	Current sourced from V _{BUS_SYS} when device is in short-circuit mode	150		350	mA
OVP CIRCUIT—VD+/VD –							
V _{OVP(RISING)}	Input overvoltage protection threshold	VD+/VD –	Increase VD+ or VD – (with D+ and D –) from 3.3 V to 4.5 V. Measure the value at which $\overline{\text{FLT}}$ is asserted	V _{IN} + 0.6	V _{IN} + 0.8	V _{IN} + 1	V
V _{HYS(OVP)}	Hysteresis on OVP	VD+/VD –	Difference between rising and falling OVP thresholds on VD+/VD –		50		mV
V _{OVP(FALLING)}	Input overvoltage protection threshold	VD+/VD –	Decrease VD+ or VD – (with D+ or D –) from 4.5 V to 2 V. Measure the value at $\overline{\text{FLT}}$ is deasserted	V _{IN} + 0.525	V _{IN} + 0.75	V _{IN} + 0.975	V
SHORT TO BATTERY							
V _(VBUS_STB)	V _{BUS} hotplug short-to-battery tolerance	V _{BUS_CON}	Charge battery-equivalent capacitor to test voltage then discharge to pin under test through a 1 meter, 18 gauge wire. (See Figure 7-1 for more details)			18	V
V _(DATA_STB)	Data line hotplug short-to-battery tolerance	VD+/VD –				18	V
DATA LINE SWITCHES—VD+ to D+ or VD – to D –							
C _{ON}	Equivalent On Capacitance		Capacitance of D+/D – switches when enabled – measure on connector side at VD _x = 0.4 V		6.9		pF
R _{ON}	On Resistance		Measure resistance between D+ and VD+ or D – and VD –, voltage between 0 V and 0.4 V		4	6.5	Ω
R _{ON(Flat)}	On Resistance flatness		Measure resistance between D+ and VD+ or D – and VD –, sweep voltage between 0 V and 0.4 V		0.2	1	Ω
BW _{ON}	On Bandwidth (– 3dB)		Measure S ₂₁ bandwidth from D+ to VD+ or D – to VD – with voltage swing = 400 mVpp, V _{CM} = 0.2 V		910		MHz
BW _{ON_DIFF}	On Bandwidth (– 3dB)		Measure S _{PD21} bandwidth from D+ to VD+ and D – to VD – with voltage swing = 800 mVpp differential, V _{CM} = 0.2 V		1050		MHz
X _{talk}	Crosstalk		Measure S ₂₁ bandwidth from D+ to VD – or D – to VD+ with voltage swing = 400 mVpp. Make sure to terminate open sides to 50 ohms. f = 480 MHz		– 28		dB
nFET SWITCH—V _{BUS}							
R _(DISCHARGE)	Output discharge resistance		$\overline{\text{VEN}}$ = 5 V, $\overline{\text{DEN}}$ = 5 V, Set V _{BUS_CON} = 5 V and measure current flow to ground		18	30	kΩ

6.7 Electrical Characteristics (continued)

over operating free-air temperature range, $\overline{VEN} = 0\text{ V}$, $\overline{DEN} = 0\text{ V}$, $V_{BUS_SYS} = 5\text{ V}$, $V_{IN} = 3.3\text{ V}$, $VD+/VD- /D+/D- /V_{BUS_CON} = \text{float}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
R_{ON}	V_{BUS} path ON resistance	$V_{BUS_CON} = 5\text{ V}$, $I_{OUT} = 1.5\text{ A}$. See 图 9-8 for a plot of the maximum V_{BUS} R_{ON} possible at a given junction temperature		63	135	m Ω

6.8 Timing Characteristics

over operating free-air temperature range, $\overline{VEN} = 0\text{ V}$, $\overline{DEN} = 0\text{ V}$, $V_{BUS_SYS} = 5\text{ V}$, $V_{IN} = 3.3\text{ V}$, $D+/D- = 45\text{ }\Omega$ to GND, $VD+/VD- /V_{BUS_CON} = \text{float}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
ENABLE PIN						
t_{ON_HOST}	Host mode enable on time	Time between $\overline{VEN}$ and $\overline{DEN}$ asserted low and V_{BUS} and Data FETs turn on, $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		5.7		ms
t_{ON_CLIENT}	Client mode enable on time	Time between $\overline{DEN}$ asserted low and Data FETs turn on. $\overline{VEN}$ remains high		2.4		ms
t_{OFF_HOST}	Host mode disable time	Time between $\overline{VEN}$ and $\overline{DEN}$ deasserted high and V_{BUS} and Data FETs turn off, $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		30		μs
t_{OFF_CLIENT}	Client mode disable time	Time between $\overline{DEN}$ deasserted high and Data FETs turn off. $\overline{VEN}$ remains high		5		μs
$t_{HOST_TO_CLIENT}$	Host to Client mode transition time	Time between $\overline{VEN}$ deasserted high and V_{BUS} FET turns off. $\overline{DEN}$ remains low, $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		70		μs
$t_{CLIENT_TO_HOST}$	Client to Host mode transition time	Time between $\overline{VEN}$ asserted low and V_{BUS} FET turns on. $\overline{DEN}$ remains low, $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		3.4		ms
OVER CURRENT PROTECTION						
t_{BLANK}	Overcurrent blanking time	Time from overcurrent condition until $\overline{FLT}$ assertion and V_{BUS} FET turn off			2	ms
t_{RETRY}	Overcurrent retry time	Time from overcurrent FET shut off until FET turns back on		100		ms
t_{RECV}	Overcurrent recovery time	Time from end of t_{RETRY} until $\overline{FLT}$ deassertion if overcurrent condition is removed		8		ms
OVER VOLTAGE PROTECTION						
$t_{OVP_response}$	OVP Response time - V_{BUS}	Measured from OVP Condition to FET turnoff		2	4	μs
$t_{OVP_response}$	OVP Response time - data switches	Measured from OVP Condition to FET turnoff		200		ns
$t_{OVP_FLT_ASSERT}$	OVP $\overline{FLT}$ assertion time	Measured from an OVP Condition to $\overline{FLT}$ assertion		14		μs
SHORT TO GROUND PROTECTION						
t_{SHRT}	Short to ground response time	Time from short condition until current falls below 120% of I_{SHRT} , $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		2	4	μs
t_{SHRT_FLTZ}	Short to ground $\overline{FLT}$ assertion time	Time from short condition until $\overline{FLT}$ is asserted, $C_{V_{BUS_CON}} = 0\text{ }\mu\text{F}$		20		μs
REVERSE SUPPLY DETECTION						
$t_{REV_SUPPLY_BLANK}$	Reverse supply blanking time	Time from reverse current condition until $\overline{FLT}$ assertion			2	ms

6.9 Typical Characteristics

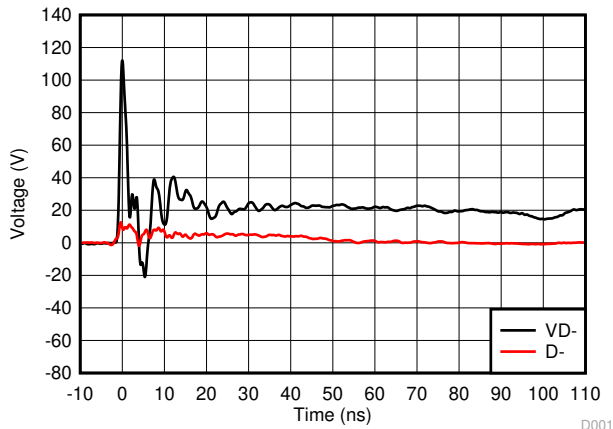


图 6-1. 8-kV IEC Contact Waveform

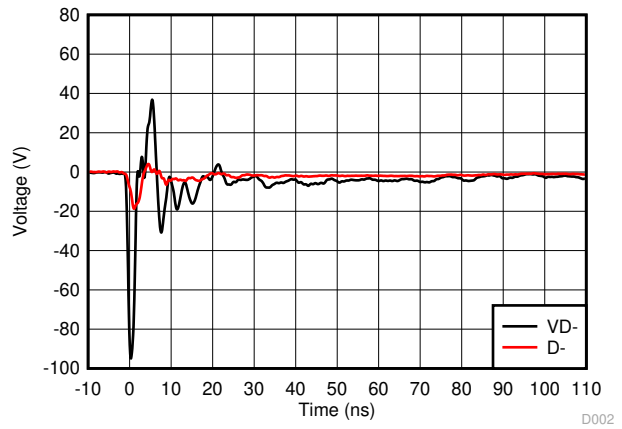


图 6-2. -8-kV IEC Contact Waveform

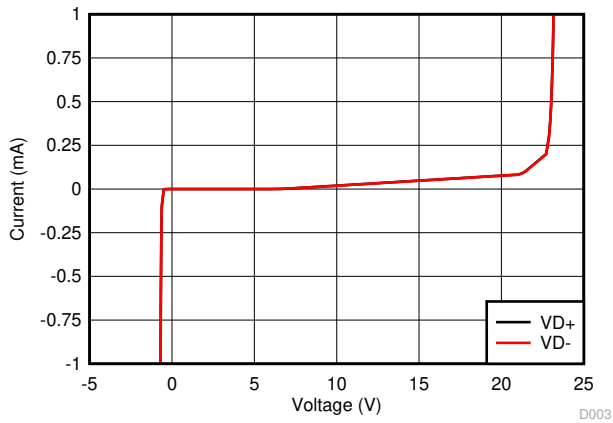


图 6-3. Data Line I-V Curve

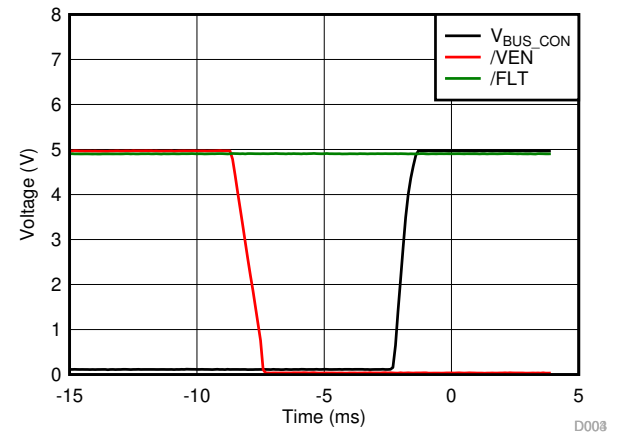


图 6-4. V_{BUS} t_{ON} Time

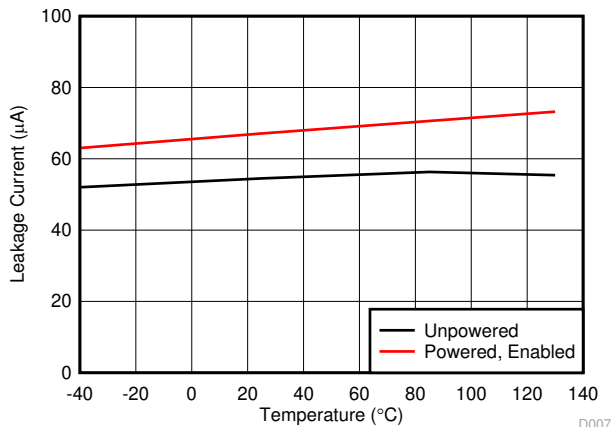


图 6-5. $VD_{\pm}$ Leakage Current at 18-V across Temperature

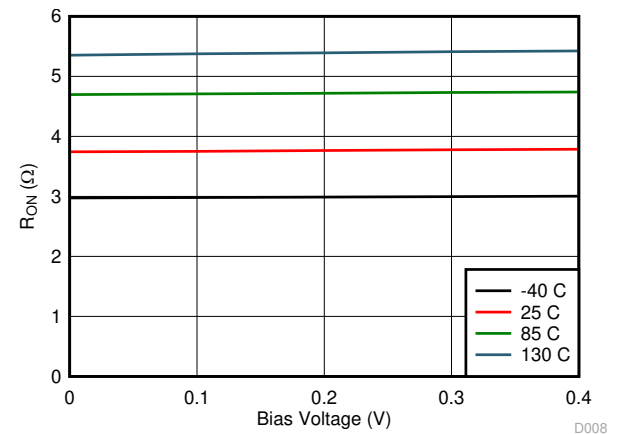


图 6-6. Data Switch R_{ON} vs Bias Voltage

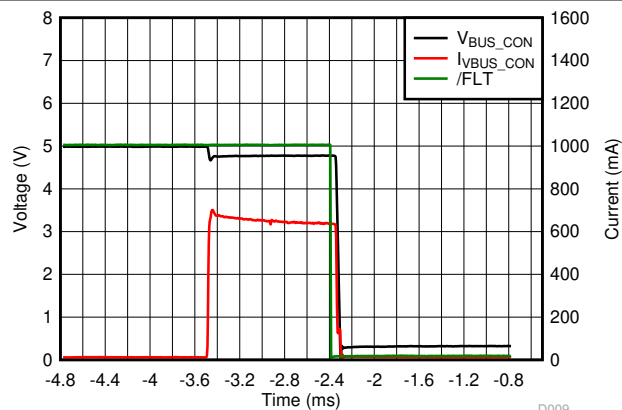
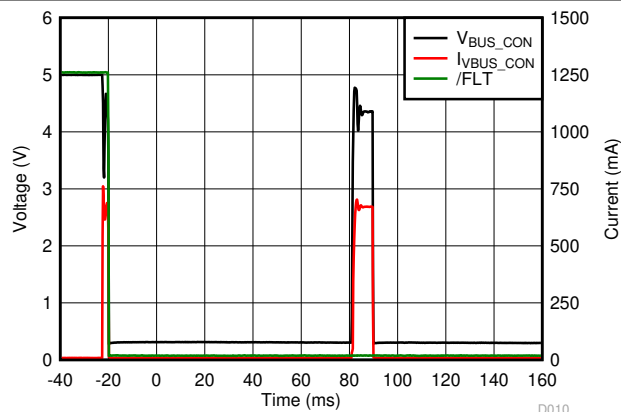
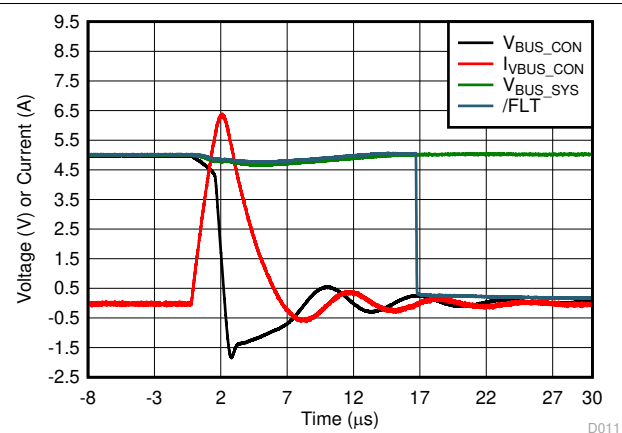
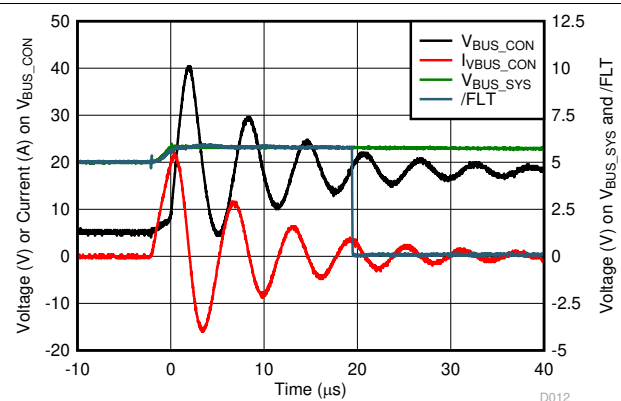
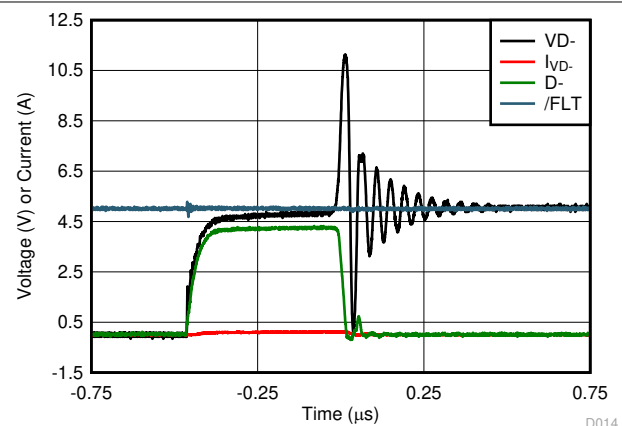
图 6-7. Overcurrent t_{BLANK} Response Waveform图 6-8. Overcurrent $t_{\text{BLANK_RETRY}}$ Response Waveform图 6-9. V_{BUS} Short-to-Ground Response Waveform图 6-10. V_{BUS} Short-to-18 V Response Waveform

图 6-11. Data Switch Short-to-5 V Response Waveform

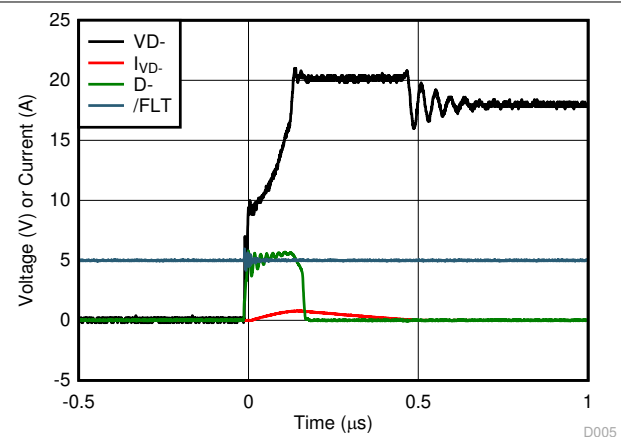


图 6-12. Data Switch Short-to-18 V Response Waveform

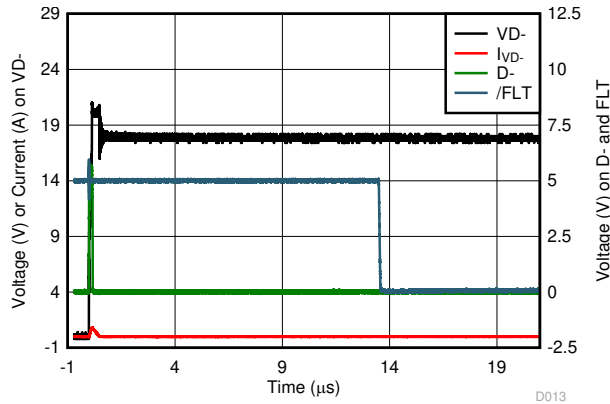


图 6-13. Data Switch Short-to-18 V Response Waveform (Long)

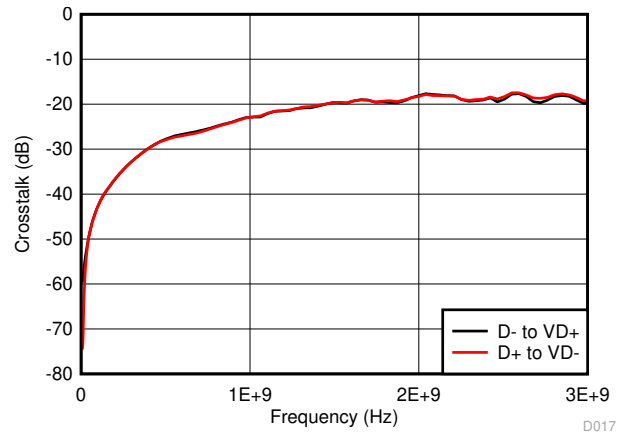


图 6-14. Data Switch Crosstalk

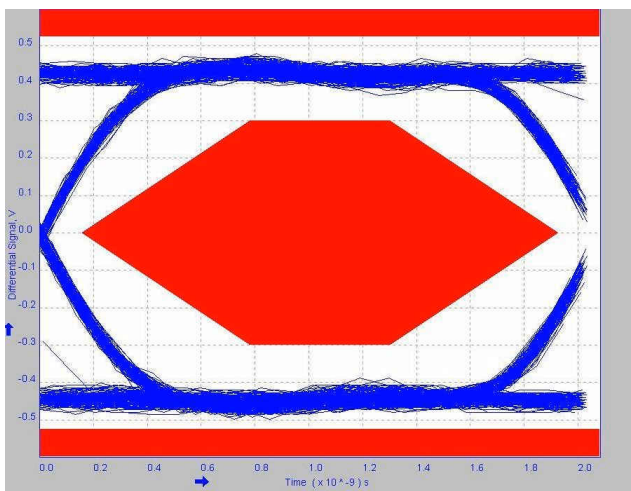


图 6-15. USB2.0 Eye Diagram (no TPD3S716-Q1)

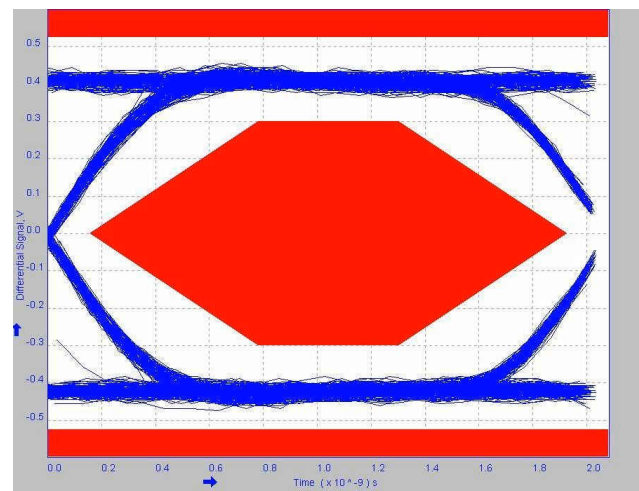


图 6-16. USB2.0 Eye Diagram (with TPD3S716-Q1)

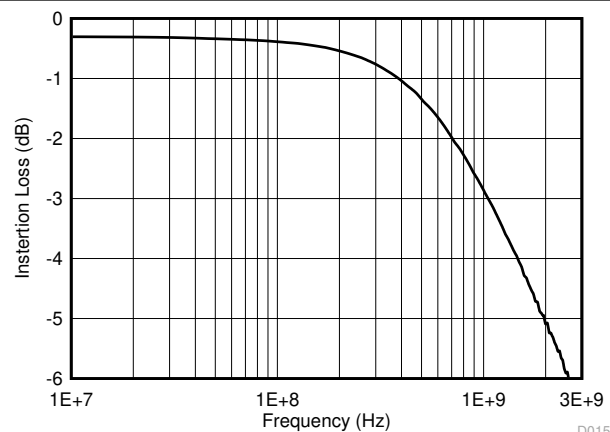


图 6-17. Data Switch Differential Bandwidth

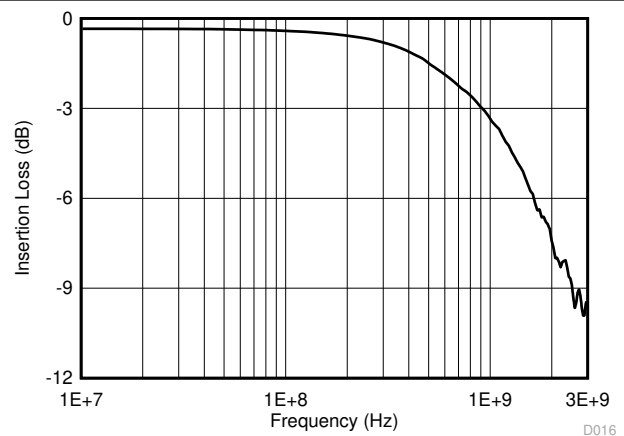
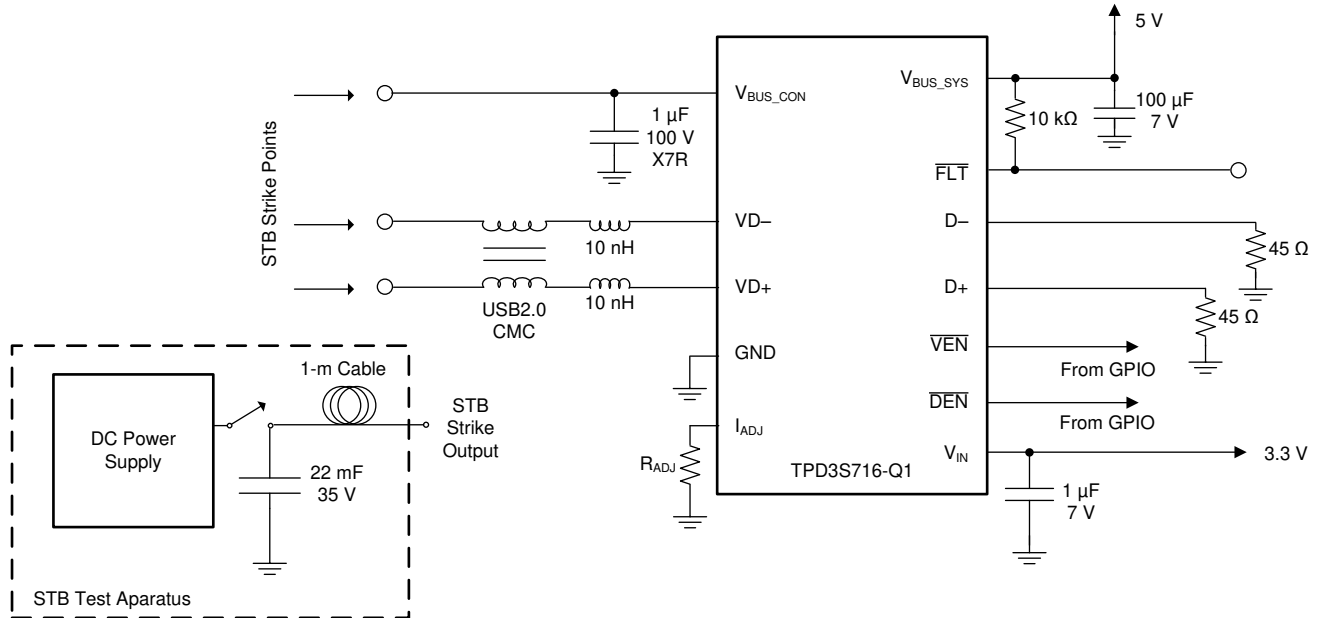


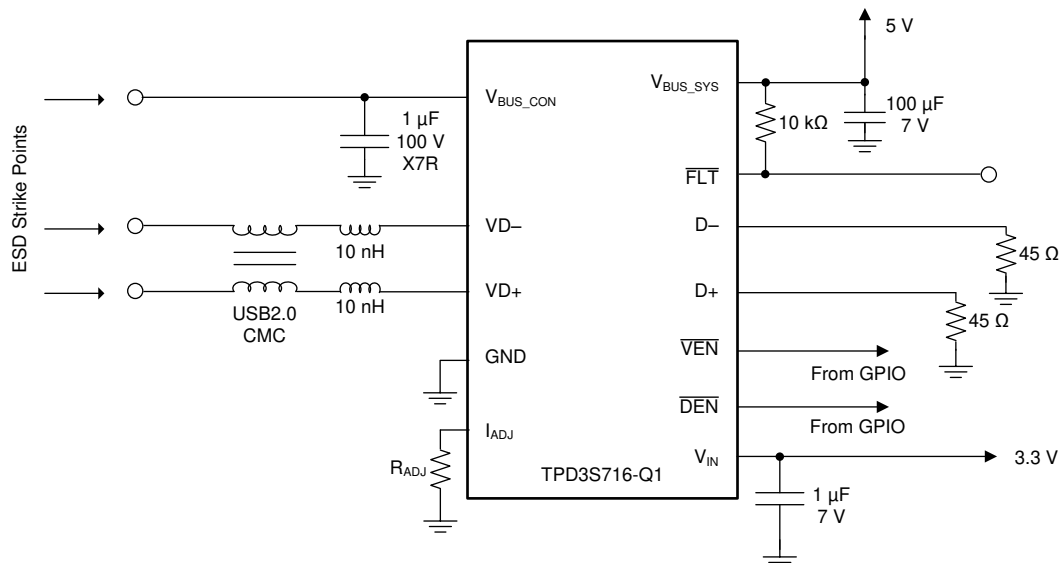
图 6-18. Data Switch Single-Ended Bandwidth

7 Parameter Measurement Information



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图 7-1. Short-to-Battery System Test Setup



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图 7-2. ESD System Test Setup

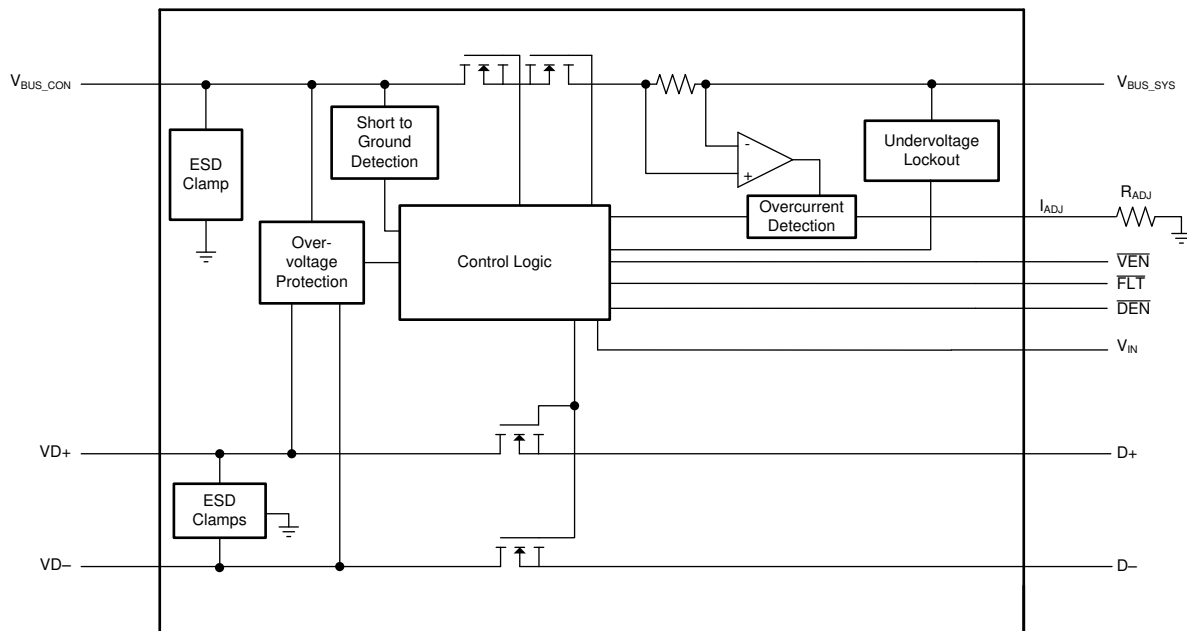
8 Detailed Description

8.1 Overview

The TPD3S716-Q1 provides a single-chip ESD protection and over voltage protection solution for automotive USB interfaces. It offers short to battery protection up to 18 V and short to ground protection on V_{BUS_CON} . The TPD3S716-Q1 also provides a $\overline{FLT}$ pin that indicates to the system if a fault condition has occurred. The TPD3S716-Q1 offers ESD clamps on the V_{BUS_CON} , $VD+$, and $VD-$ pins, therefore eliminating the need for external TVS clamp circuits in the application.

The TPD3S716-Q1 has internal circuitry that controls the turnon of the internal nFET switches. An internal oscillator controls the timers that enable the switches and resets the open-drain $\overline{FLT}$ output. If V_{BUS_CON} and $VD+/VD-$ are less than V_{OVP} , the switches are enabled. After an internal delay the charge-pump starts-up and turns on the internal nFET switches through a soft start. At any time, if any of the external USB pins rise above their respective V_{OVP} thresholds, the nFET switches are turned OFF and the $\overline{FLT}$ pin is pulled LOW.

8.2 Functional Block Diagram



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8.3 Feature Description

8.3.1 AEC-Q100 Qualified

The TPD3S716-Q1 is an automotive qualified device according to the AEC-Q100 standards. The TPD3S716-Q1 is qualified to operate from -40 to $+125^{\circ}\text{C}$ ambient temperature.

8.3.2 Short-to-Battery and Short-to-Ground Protection on V_{BUS_CON}

The V_{BUS_CON} pin is protected against shorts to battery and shorts to ground.

If a voltage on V_{BUS_CON} is detected as too low (below the V_{SHRT} threshold) after the device is enabled, the device enters short-circuit protection mode and asserts $\overline{FLT}$. It sources the I_{SHRT} current until it detects the voltage rising above the V_{SHRT} threshold, where it resumes standard operating mode and deasserts $\overline{FLT}$.

If a voltage above the V_{OVP} threshold is detected by the device, it shuts off all FETs and assert a fault on the $\overline{FLT}$ pin. When the excessive voltage is removed, the device automatically re-enables and $\overline{FLT}$ deasserts.

8.3.3 Short-to-Battery and Short-to- V_{BUS} Protection on $VD+$, $VD-$

The $VD+$ and $VD-$ pins are protected against shorts to battery and shorts to bus. The OVP threshold on the $VD+$ and $VD-$ pins is low enough that it protects against shorts to V_{BUS} .

When a voltage above the V_{OVP} threshold is detected by the device, it shuts off all FETs and asserts a fault on the FLT pin. When the excessive voltage is removed, the device automatically re-enables and FLT deasserts.

8.3.4 ESD Protection on V_{BUS_CON} , $VD+$, $VD-$

The protected pins (V_{BUS_CON} , $VD+$, $VD-$) are tested to pass the IEC 61000-4-2 ESD standard up to Level 4 ESD protection. Additionally, these pins are tested against ISO 10605 with the 330-pF, 330- Ω equivalent network. This guarantees passing of at least ± 8 -kV contact discharge and ± 15 -kV air gap discharge according to both standards. See 图 7-2 for the test set-up used for testing IEC 61000-4-2 and ISO 10605.

8.3.5 Low R_{ON} nFET V_{BUS} Switch

The V_{BUS} switch has a low R_{ON} that provides minimal voltage droop from system to connector. Typical resistance is 63 m Ω and is specified for 135 m Ω at 150°C junction temperature.

8.3.6 High Speed Data Switches

The D+ and D- switches have a very low capacitance and a high bandwidth (1-GHz typical), allowing for a clean USB 2.0 eye diagram.

8.3.7 Adjustable Hiccup Current Limit up to 2.4-A

The V_{BUS} path of this device has an integrated overcurrent protection circuit. The current limit threshold for the overcurrent protection is adjustable via an external resistor R_{ADJ} to GND on the I_{ADJ} pin. 方程式 1 到 方程式 3 approximate the minimum, nominal, and maximum current limit values for TPD3S716-Q1 assuming a 1% tolerant resistor:

$$I_{LIM(TYP)} = 143 \times R_{ADJ}^{-0.983} \quad (1)$$

$$I_{LIM(MIN)} = 129 \times R_{ADJ}^{-0.981} - 0.02 \quad (2)$$

$$I_{LIM(MAX)} = 141.5 \times R_{ADJ}^{-0.962} + 0.015 \quad (3)$$

where

- $I_{LIM(TYP)}$ is the nominal current limit value in (A)
- $I_{LIM(MIN)}$ is the minimum current limit value in (A)
- $I_{LIM(MAX)}$ is the maximum current limit value in (A)
- R_{ADJ} is the nominal resistor to GND on the I_{ADJ} pin in (Ω)

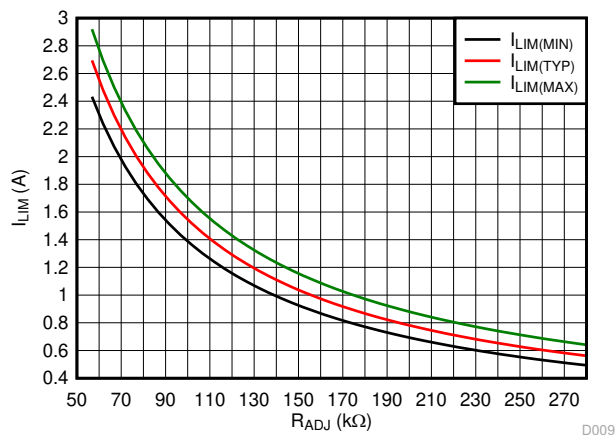


图 8-1. TPD3S716-Q1 Current Limit Thresholds vs. R_{ADJ}

方程式 1, 方程式 2 和 方程式 3 are useful for approximating the current limit threshold of TPD3S716-Q1; however, they do not constitute as part of TI's published device specifications for purposes of TI's product warranty. For the officially tested current limit threshold values, see the [Electrical Characteristics](#) table.

When the V_{BUS} current exceeds the overcurrent threshold, the device goes into a fault state where it limits the current to the overcurrent threshold value and asserts the $\overline{FLT}$ pin. After a short blanking time, the device cycles on and off to try to check if the connected device is still in overcurrent.

8.3.8 Fast Over-Voltage Response Time

The over-voltage FETs are designed to have a fast turnoff time to protect the upstream SoC as quickly as possible. Typical response time for complete turnoff is 2 μ s for the V_{BUS} path and 200 ns for the data path.

8.3.9 Independent V_{BUS} and Data Enable Pins for Configuring both Host and Client/OTG Mode

The TPD3S716-Q1 has two enable inputs to turn on and off the device's internal FETs. The $\overline{VEN}$ pin disables and enables the V_{BUS} path. The $\overline{DEN}$ pin disables and enables the data path. Independent control of the V_{BUS} and data paths enables the TPD3S716-Q1 to be configured for both USB Host and Client/OTG mode. See [表 8-1](#).

8.3.10 Fault Output Signal

The TPD3S716-Q1 has a fault pin, $\overline{FLT}$ that indicates when there is any sort of fault condition because of an OVP, OCP, short-circuit, reverse-current, or thermal shutdown event occurring.

8.3.11 Thermal Shutdown Feature

In the event that the device exceeds the maximum allowable junction temperature, the thermal shutdown circuit disables the V_{BUS} and data switches and assert the fault pin low.

8.3.12 16-Pin SSOP Package

The TPD3S716-Q1 is packaged in a standard 16-pin SSOP leaded package.

8.3.13 Reverse Current Detection

If V_{BUS_CON} exceeds V_{BUS_SYS} by a voltage greater than $V_{REV_SUPPLY(RISING)}$ for $t_{REV_SUPPLY_BLANK}$, then TPD3S716-Q1 detects this reverse current condition and asserts the fault pin. When $V_{BUS_CON} - V_{BUS_SYS}$ falls below $V_{REV_SUPPLY(FALLING)}$, the fault pin is deasserted and TPD3S716-Q1 enters back into its normal operating mode.

8.4 Device Functional Modes

8.4.1 Normal Operation

The TPD3S716-Q1 operates in normal operation modes when enabled, both V_{BUS_SYS} and V_{IN} are above their UVLO thresholds, and the device is not in any fault conditions. 表 8-1 shows the normal operating modes of the TPD3S716-Q1.

表 8-1. Device Normal Operating Mode Table

MODE	VEN	DEN	V_{BUS} PATH	DATA PATH
USB Host	0	0	ON	ON
Power Only	0	1	ON	OFF
USB Client/OTG	1	0	OFF	ON
Disabled	1	1	OFF	OFF

8.4.2 Overvoltage Condition

When the $VD+$, $VD-$, or V_{BUS_CON} pins exceed their OVP threshold, the device enters the overvoltage state. All FETs are disabled and the $\overline{FLT}$ pin is asserted. When the protected pins drop below their OVP threshold, the device automatically turns back on and deasserts the $\overline{FLT}$ pin. An overvoltage condition is only detected on an enabled path. For example, if the data path is enabled and the V_{BUS} path is disabled (USB Client/OTG mode), if an overvoltage condition occurs on V_{BUS_CON} , the fault pin is not be asserted. However, because the FETs of disabled paths are already turned off, proper protection from overvoltage conditions are still guaranteed by the device on disabled paths.

8.4.3 Overcurrent Condition

When the current through the V_{BUS} path exceeds the I_{LIM} current threshold, the device enters into the overcurrent state. The TPD3S716-Q1 limits current to the I_{LIM} threshold by dropping voltage across the V_{BUS} FET to maintain constant current. When it continues to sense an overcurrent condition for the blanking time (t_{BLANK}), the device disables itself for the retry time (t_{RETRY}) and then retry automatically for the retry time (t_{BLANK_RETRY}). In the event that the current is below the overcurrent threshold, the device deasserts fault and resumes normal operation.

8.4.4 Short-Circuit Condition

If the voltage on the V_{BUS_CON} side is pulled below the V_{SHRT} threshold while the device is enabled, the TPD3S716-Q1 enters the short-circuit mode. It sources a constant current of I_{SHRT} until it rises above the V_{SHRT} threshold. When that occurs, the device automatically re-enters normal operation and deasserts the fault pin.

8.4.5 Device Logic Table

表 8-2 shows the TPD3S716-Q1 logic table.

表 8-2. TPD3S716-Q1 Logic Table

Mode	VEN	DEN	V _{BUS_CON}	VDx	I _{VBUS}	V _{BUS_SYS} , V _{IN}	T _J	FLT	V _{BUS} PATH	DATA PATH
Unpowered	X	X	X	X	None	< UVLO	X	H	OFF	OFF
Disabled	H	H	X	X	None	> UVLO	< TSD	H	OFF	OFF
Host	L	L	< OVP & < V _{BUS_SYS} + 200 mV(typical) & > V _{SHRT}	< OVP	< OCP	> UVLO	< TSD	H	ON	ON
Client/OTG	H	L	X	< OVP	None	> UVLO	< TSD	H	OFF	ON
Power Only	L	H	< OVP & < V _{BUS_SYS} + 200 mV(typical) & > V _{SHRT}	X	< OCP	> UVLO	< TSD	H	ON	OFF
Thermal Shutdown	X	X	X	X	None	> UVLO	> TSD	L	OFF	OFF
Host: V _{BUS} OVP Fault	L	L	> OVP	X	None	> UVLO	< TSD	L	OFF	OFF
Host: Data OVP Fault	L	L	X	> OVP	None	> UVLO	< TSD	L	OFF	OFF
Host: OCP Fault	L	L	< OVP & < V _{BUS_SYS} + 200 mV(typical) & > V _{SHRT}	X	> OCP	> UVLO	< TSD	L	CURRENT LIMITED, AUTO-RETRY	AUTO-RETRY
Host: Short-Circuit Fault	L	L	< V _{SHRT}	X	X	> UVLO	< TSD	L	CURRENT LIMITED 250 mA (typical)	OFF
Host: RCP Fault	L	L	< OVP & > V _{BUS_SYS} + 200 mV (typical)	X	X	> UVLO	< TSD	L	ON	ON
OTG: Data OVP Fault	H	L	X	> OVP	None	> UVLO	< TSD	L	OFF	OFF
Power Only: V _{BUS} OVP Fault	L	H	> OVP	X	None	> UVLO	< TSD	L	OFF	OFF
Power Only: OCP Fault	L	H	X	X	> OCP	> UVLO	< TSD	L	CURRENT LIMITED, AUTO-RETRY	OFF
Power Only: Short-Circuit Fault	L	H	< V _{SHRT}	X	X	> UVLO	< TSD	L	CURRENT LIMITED 250 mA (typical)	OFF
Power Only: RCP Fault	L	H	< OVP & > V _{BUS_SYS} + 200 mV (typical)	X	X	> UVLO	< TSD	L	ON	OFF

9 Application and Implementation

Note

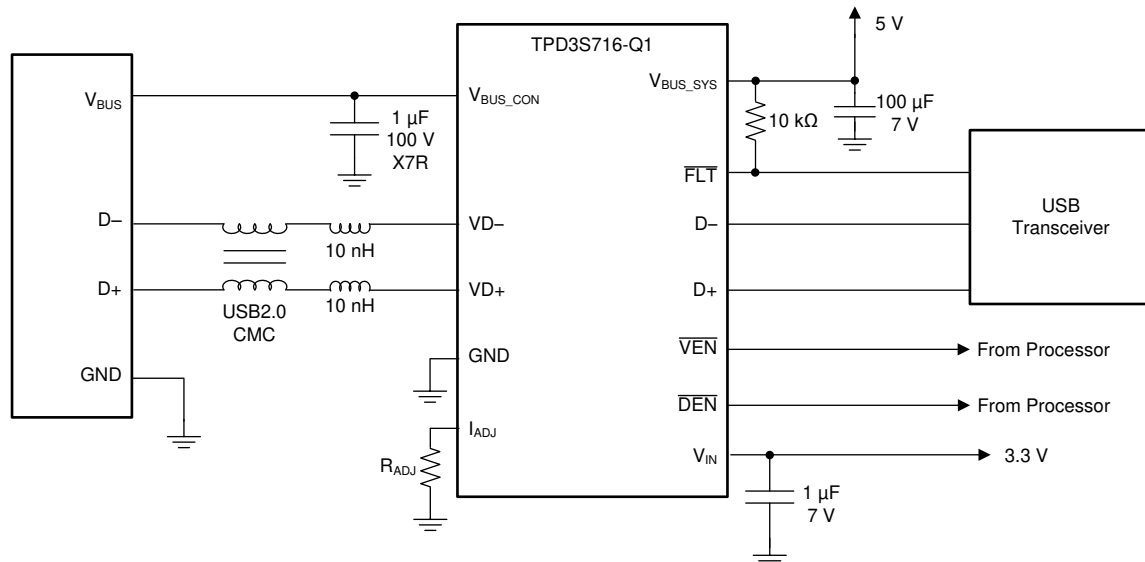
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9.1 Application Information

The TPD3S716-Q1 offers fully featured automotive USB2.0 protection including short-to-battery, overcurrent, and ESD protection. Care must be taken during the implementation to make sure the device provides adequate protection to the system.

9.2 Typical Application

图 9-1 shows a fully featured USB2.0 high speed port, with an 18-V short-to-battery requirement on the connector side.



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图 9-1. Typical Application Configuration for TPD3S716-Q1

9.2.1 Design Requirements

表 9-1 shows the TPD3S716-Q1 input parameters for this application example.

表 9-1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Short-to-battery tolerance on VD ⁺ , VD ⁻ , V _{BUS_CON}	18 V
Max current in normal operation on V _{BUS}	1.5 A
Current Limit Setting on V _{BUS}	1.505 A (minimum)
Maximum Ambient Temperature Requirement	105°C
USB Data Rate	480 Mbps

9.2.2 Detailed Design Procedure

The following parameters must be known to the designer to begin the design process:

- Short-to-battery tolerance on connector pins
- Maximum current in normal operation on V_{BUS}
- Maximum operating ambient temperature
- USB Data Rate

9.2.2.1 Short-to-Battery Tolerance

The TPD3S716-Q1 is capable of handling up to 18 V DC on the $VD+$, $VD-$, and V_{BUS_CON} pins. In the event of a short-to-battery on V_{BUS_CON} , significant ringing would be expected because of the hot plug-like nature of the short-to-battery event. In typical ceramic capacitor configurations, a standard RLC response is expected which results in a ringing of nearly two times the applied DC voltage. The TPD3S716-Q1 is capable of withstanding the transient ringing from hot plug-like events, assuming some precautions are taken.

Careful capacitor selection on the V_{BUS_CON} pin must be observed. A capacitor with a low derating percentage under the applied voltages must be used to prevent excess ringing. In the example, a 1- μ F, 100-V tolerant ceramic X7R capacitor is used. It is best practice to carefully select the capacitors used in this circuit to prevent derating-based voltage spikes under hot plug events. See [图 9-4](#) and [图 9-5](#) to compare ringing of a 50-V capacitor to a 100-V capacitor. [图 9-6](#) shows the 100-V capacitor with the TPD3S716-Q1 installed.

Another alternative to a high rated ceramic capacitor is to implement either a standard R-C snubber circuit, or a small external TVS diode. Depending on the short-to-battery tolerance needed, no special precautions may be needed.

9.2.2.2 Maximum Current on V_{BUS}

The TPD3S716-Q1 is capable of operating up to 2.4 A maximum DC current. In this example, the maximum current for USB2.0 BC1.2 of 1.5 A has been chosen.

9.2.2.3 Power Dissipation and Junction Temperature

This section demonstrates how to analyze the power dissipation and junction temperature of the TPD3S716-Q1 to validate that the application requirements of an $I_{V_{BUS}}$ operating current level of 1.5 A and a maximum operating ambient temperature of 105 °C can be met.

It is good design practice to estimate power dissipation and maximum expected junction temperature of TPD3S716-Q1. This is important to insure the device does not go into thermal shutdown in normal operation and that the long term reliability of the device is maintained. Using [方程式 4](#) to [方程式 6](#), the system designer can control choices of the device's proximity to other power dissipating devices and the design of the printed circuit board (PCB). These have a direct influence on maximum junction temperature. Other factors, such as airflow and maximum ambient temperature, are often determined by system considerations. It is important to remember that these calculations do not include the effects of adjacent heat sources, and enhanced or restricted air flow. Addition of extra PCB copper area around these devices is recommended to reduce the thermal impedance and maintain the junction temperature as low as practical.

For TPD3S716-Q1, the operating junction temperature must be kept below 150°C in order to prevent the device from going into thermal shutdown. [方程式 4](#) is used to calculate the junction temperature of the device:

$$T_J = T_A + [(I_{OUT}^2 \times R_{ON}) \times R_{\theta JA}] \quad (4)$$

where

- I_{OUT} = Rated OUT pin current (A)
- R_{ON} = Power path on-resistance at an assumed T_J (Ω)
- T_A = Maximum ambient temperature (°C)
- T_J = Maximum junction temperature (°C)
- $R_{\theta JA}$ = Thermal resistance (°C/W)

This application example requires an $I_{V_{BUS}}$ operating current level of 1.5 A. TPD3S716-Q1 has maximum junction temperature derating requirements depending on the maximum operating current of the device according to [方程式 5](#):

$$T_{J(MAX)} = -15.6 \times (I_{V_{BUS(MAX OPERATING)}}) + 161.5 \text{ (}^{\circ}\text{C)} \quad (5)$$

where

- $T_{J(MAX)}$ = Maximum allowed junction temperature ($^{\circ}\text{C}$)
- $I_{V_{BUS(MAX OPERATING)}}$ = Maximum $I_{V_{BUS}}$ operating current (A)

See [图 9-7](#) for a plot of the reliability curve equation. Using this equation, 138.1°C is the maximum allowed junction temperature in this application.

This example requires a maximum operating ambient temperature of 105°C . To determine if this can be supported using [方程式 4](#), the maximum V_{BUS} path R_{ON} must be determined. [方程式 6](#) calculates the maximum V_{BUS} path R_{ON} possible for TPD3S716-Q1 for a given junction temperature:

$$R_{ON(MAX)} = (T_J + 183.15) / 2726.7 \text{ (}\Omega\text{)} \quad (6)$$

where

- $R_{ON(MAX)}$ = Maximum V_{BUS} R_{ON} at a given junction temperature (Ω)
- T_J = Device junction temperature ($^{\circ}\text{C}$)

See [图 9-8](#) for a plot of the maximum V_{BUS} path R_{ON} vs. Junction Temperature curve. Using the above equation, the maximum V_{BUS} R_{ON} possible for TPD3S716-Q1 at 138.1°C is $R_{ON(MAX)} = 0.118 \Omega$.

Using the calculated parameters for this example and the standard datasheet $R_{\theta JA}$ for TPD3S716-Q1, the maximum operating ambient temperature possible in this example is $T_A = 111^{\circ}\text{C}$. Because this is greater than the application requirement of 105°C , TPD3S716-Q1 can safely be operated at 1.5 A with $R_{\theta JA} = 98.8 \text{ (}^{\circ}\text{C/W)}$. If the resulting ambient temperature in the above calculations resulted in a $T_A < 105^{\circ}\text{C}$, methods for improving $R_{\theta JA}$ would need to be taken. See the [Layout Optimized for Thermal Performance](#) section for guidelines on improving $R_{\theta JA}$ for TPD3S716-Q1. The example given in the [Layout Optimized for Thermal Performance](#) yields an $R_{\theta JA} = 57 \text{ (}^{\circ}\text{C/W)}$. Excellent thermal performance of TPD3S716-Q1 can be achieved with the proper PCB layout.

9.2.2.4 USB Data Rate

The TPD3S716-Q1 is capable of operating at the maximum USB2.0 High Speed data rate of 480-Mbps because of the high data switch bandwidth of 1-GHz (typical). In this design example the maximum data rate of 480-Mbps has been chosen.

9.2.3 Application Curves

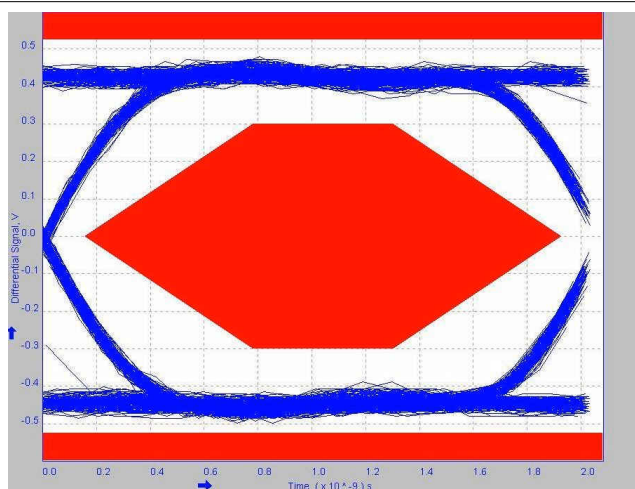


图 9-2. USB2.0 Eye Diagram (Board only, Through Path)

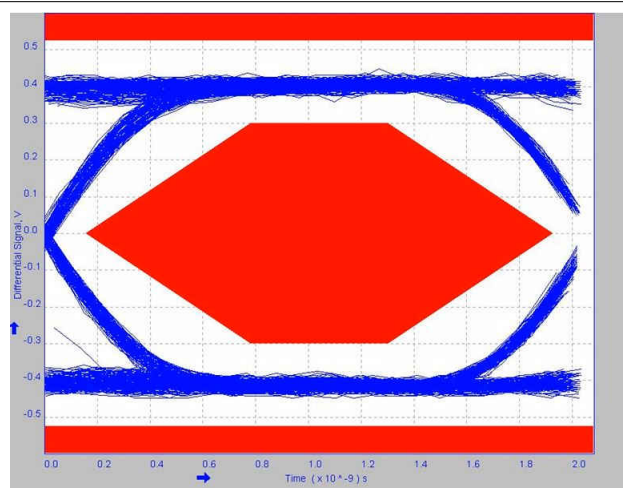


图 9-3. USB2.0 Eye Diagram (System from Typical Application Schematic)

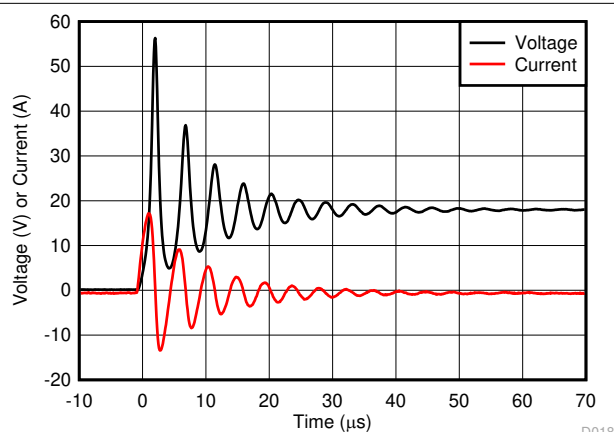


图 9-4. 50-V, 1-μF X7R Ceramic Shorted to 18-V (Not Recommended)

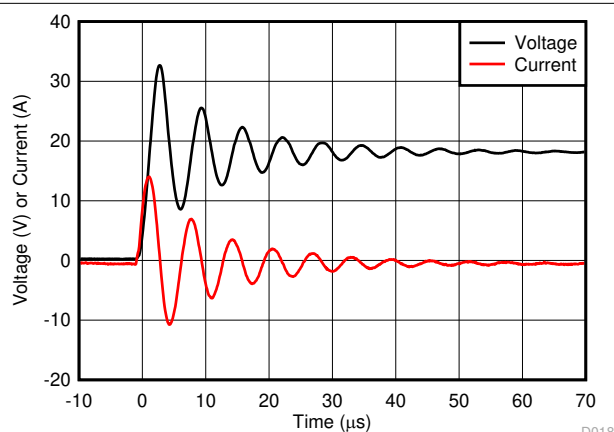


图 9-5. 100-V, 1-μF X7R Ceramic Shorted to 18 V

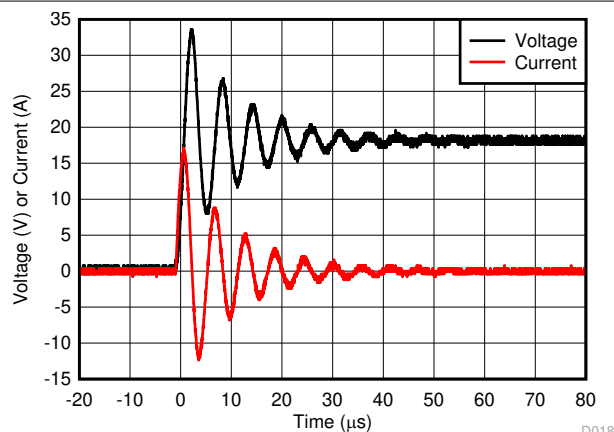


图 9-6. TPD3S716-Q1 and 100-V, 1-μF X7R Shorted to 18 V (Powered Off)

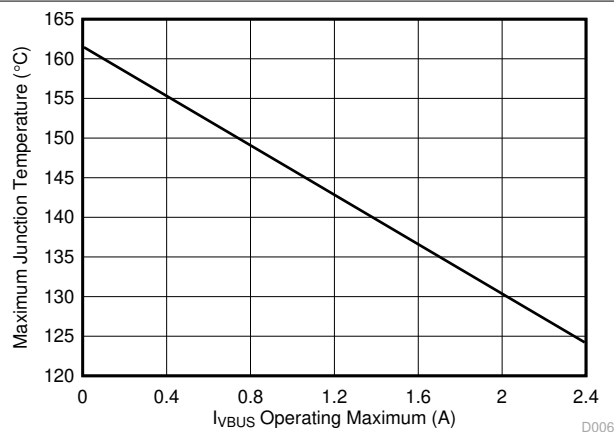


图 9-7. TPD3S716-Q1 I_{VBUS} Temperature Derating Curve

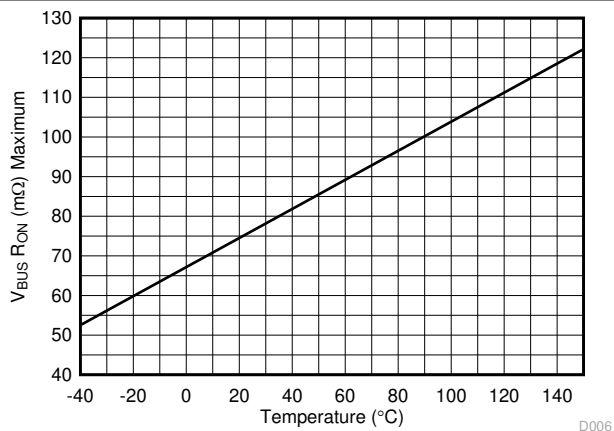


图 9-8. TPD3S716-Q1 Maximum $V_{BUS} R_{ON}$ vs. Junction Temperature

10 Power Supply Recommendations

10.1 V_{BUS} Path

The V_{BUS_SYS} pins provide power to the chip and supply current through the load switch to V_{BUS_CON}. A 100-μF bulk capacitor is recommended on V_{BUS_SYS} to supply the USB port and maintain compliance. A 1-μF capacitor is recommended on the V_{BUS_CON} pin with adequate voltage rating to tolerate short-to-battery conditions. A supply voltage above the UVLO threshold for V_{BUS_SYS} must be supplied for the device to power on.

10.2 V_{IN} Pin

The V_{IN} pin provides a voltage reference for the data switch OVP level as well as a bypass for ESD clamping. A 1-μF capacitor must be placed as close to the pin as possible and the supply must be set to be above the UVLO threshold for V_{IN}.

11 Layout

11.1 Layout Guidelines

Proper routing and placement maintains signal integrity for high-speed signals. The following guidelines apply to the TPD3S716-Q1:

- Place the bypass capacitors as close as possible to the V_{IN}, V_{BUS_SYS}, and V_{BUS_CON} pins. Capacitors must be attached to a solid ground. This minimizes voltage disturbances during transient events such as short-to-battery, ESD, or overcurrent conditions.
- High speed traces (data switch path) must be routed as straight as possible and any sharp bends must be minimized.

Standard ESD recommendations apply to the VD+, VD–, and V_{BUS_CON} pins as well:

- The optimum placement is as close to the connector as possible.
 - EMI during an ESD event can couple from the trace being struck to other nearby unprotected traces, resulting in early system failures.
 - The PCB designer must minimize the possibility of EMI coupling by keeping any unprotected traces away from the protected traces which are between the TVS and the connector.
- Route the protected traces as straight as possible.
- Eliminate any sharp corners on the protected traces between the TVS and the connector by using rounded corners with the largest radii possible.
 - Electric fields tend to build up on corners, increasing EMI coupling.

11.2 Layout Example

 11-1 shows a full layout for a standard USB2.0 port. A common mode choke and inductors are used on the high speed data lines, and the requisite bypassing caps are placed on V_{BUS_CON}, V_{BUS_SYS}, and V_{IN}.

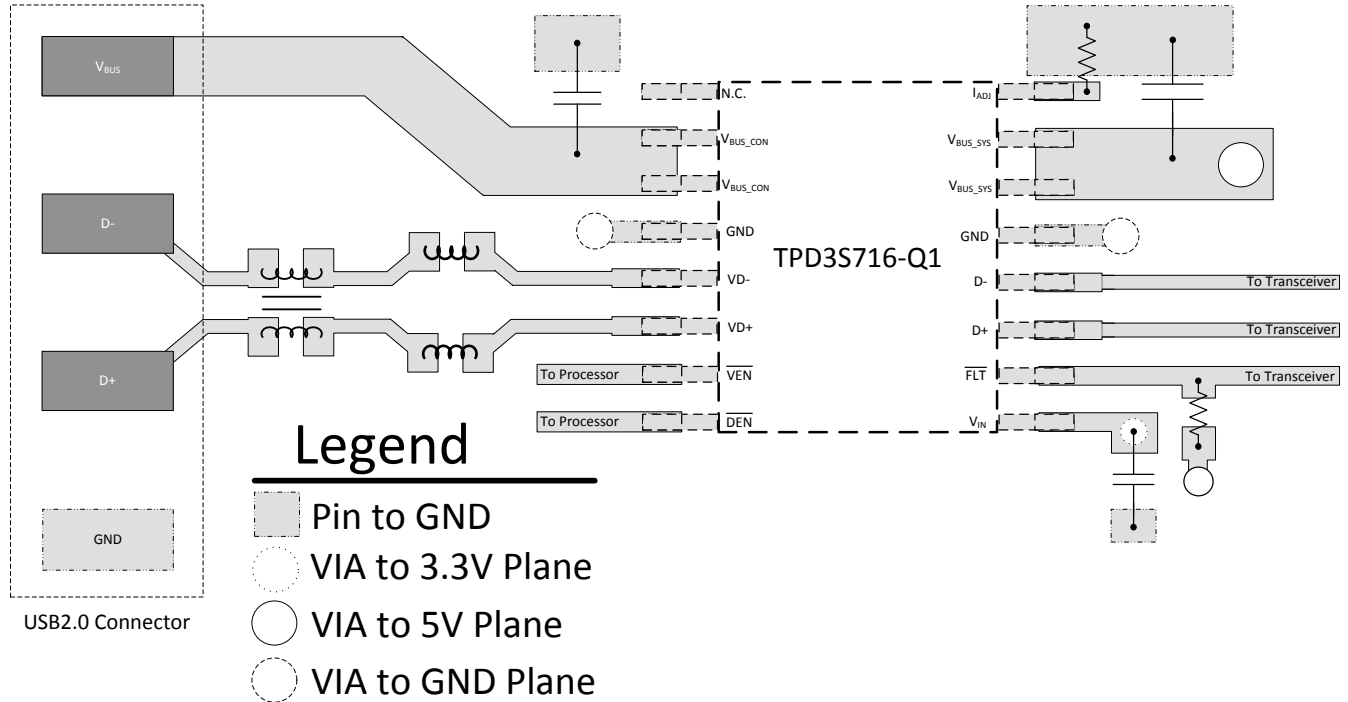


图 11-1. Typical Layout Example for TPD3S716-Q1

11.3 Layout Optimized for Thermal Performance

图 11-2 和 图 11-3 显示来自一个为最佳热性能优化的实际 PCB 设计。此 PCB 布局具有 6 层（2 信号层和 4 平面层）。2 个信号层是 PCB 的外层，由 2-oz 铜制成，4 个内部平面层由 1-oz 铜制成。使用此 PCB 布局产生了 $R_{\theta JA(CUSTOM)} = 57$ (°C/W)。图像包含铜迹和铜块用于路由设备电源、GND 和信号引脚的大致尺寸。优化设备热性能的一个关键策略是尽可能最大化铜迹和铜块用于路由设备电源、GND 和信号引脚的面积。另一个关键策略是最大化 PCB 金属层的铜重量。这个例子证明，通过正确的 PCB 布局，TPD3S716-Q1 可以实现卓越的热性能。

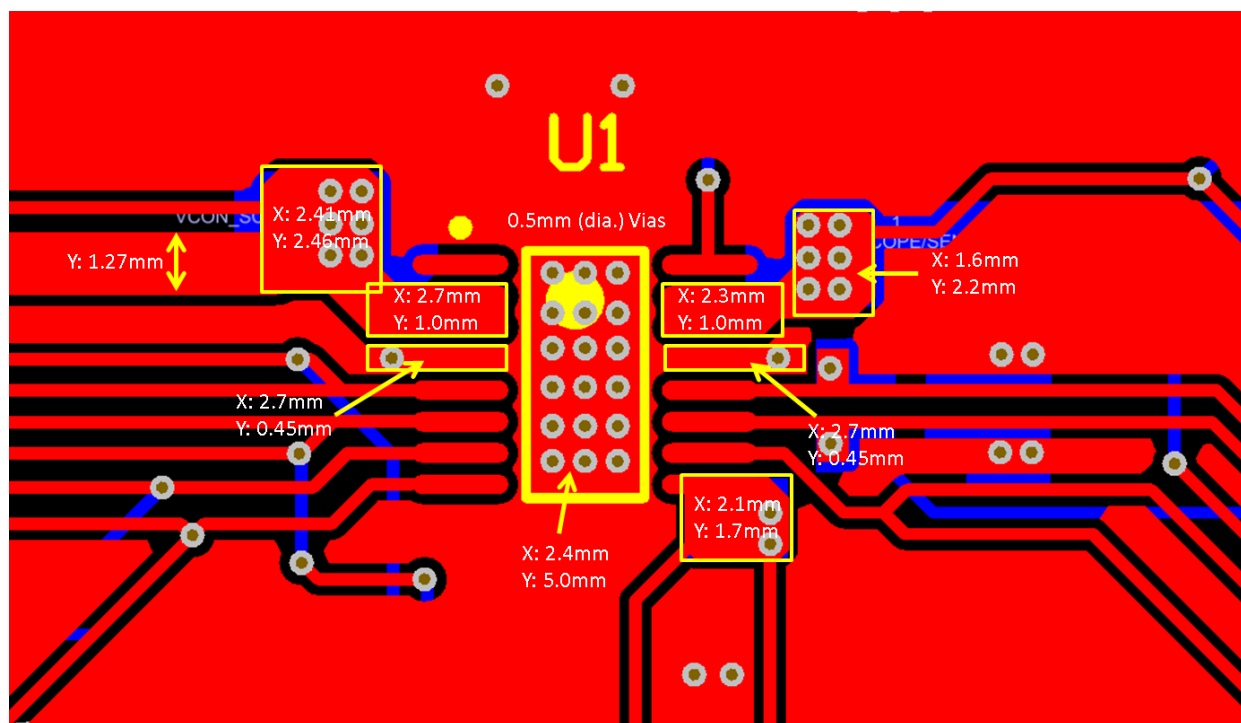


图 11-2. Thermally Optimized PCB Layout Top Layer

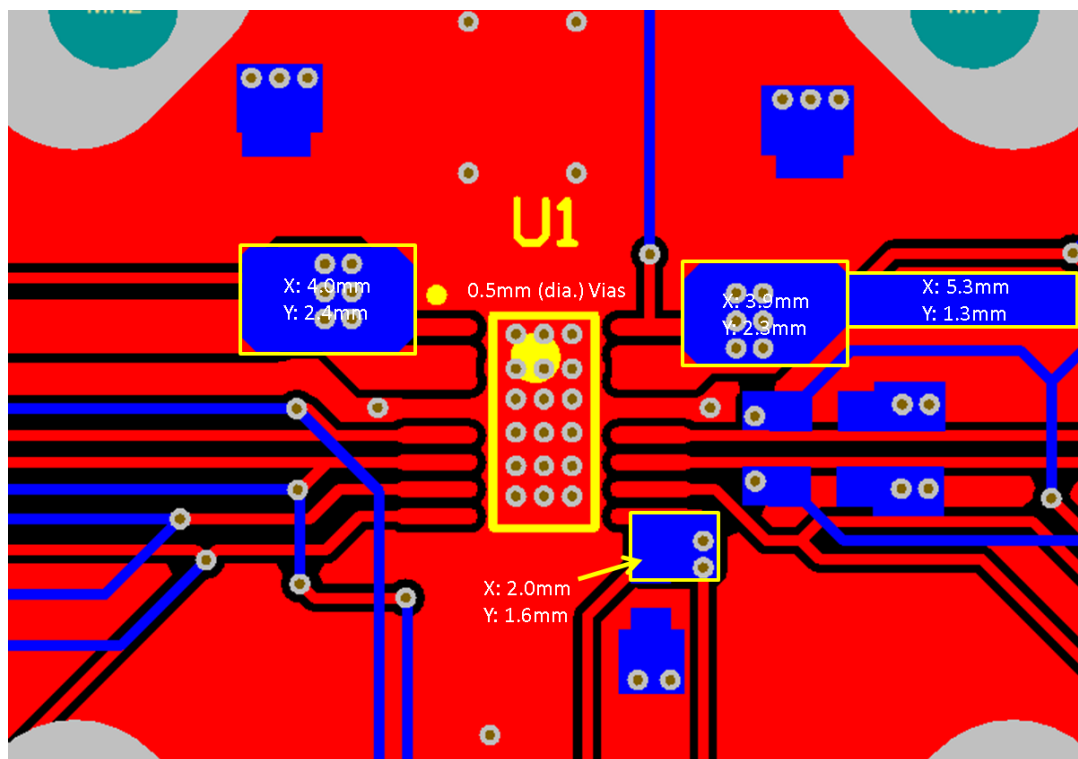


图 11-3. Thermally Optimized PCB Layout Bottom Layer

12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

For related documentation see the following:

TPD3S716-Q1 Evaluation Module, [SLVUAL9](#)

12.2 支持资源

[TI E2E™ 中文支持论坛](#)是工程师的重要参考资料，可直接从专家处获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题，获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的[使用条款](#)。

12.3 Trademarks

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

12.5 术语表

[TI 术语表](#) 本术语表列出并解释了术语、首字母缩略词和定义。

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TPD3S716QDBQRQ1	Active	Production	SSOP (DBQ) 16	2500 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	RJ716Q
TPD3S716QDBQRQ1.A	Active	Production	SSOP (DBQ) 16	2500 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	RJ716Q
TPD3S716QDBQRQ1.B	Active	Production	SSOP (DBQ) 16	2500 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	RJ716Q

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

⁽²⁾ **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

⁽⁴⁾ **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

⁽⁶⁾ **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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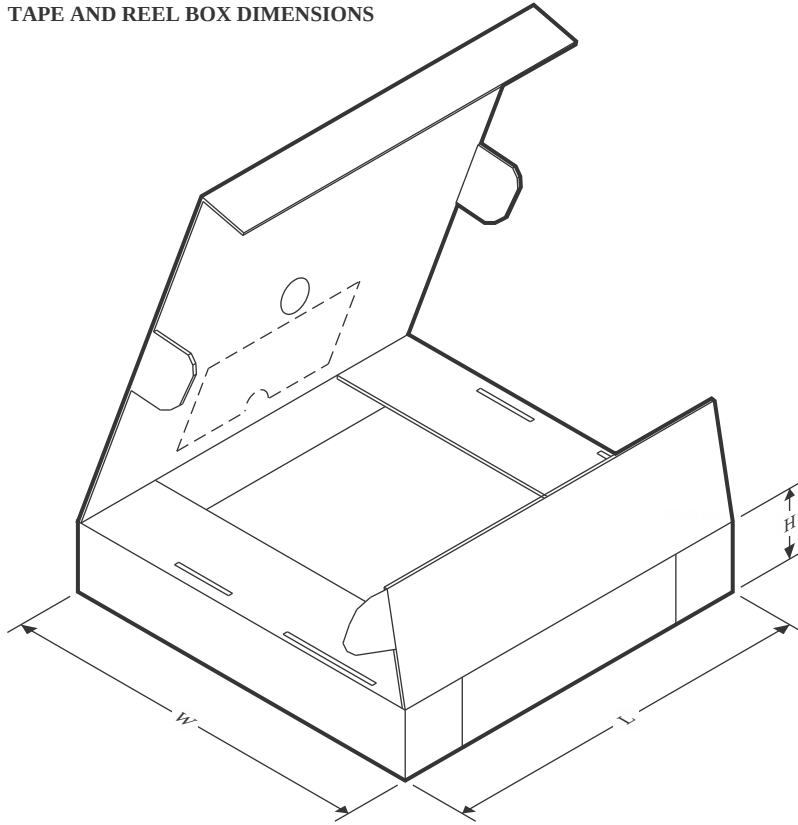
TAPE AND REEL INFORMATION



*All dimensions are nominal

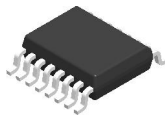
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPD3S716QDBQRQ1	SSOP	DBQ	16	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPD3S716QDBQRQ1	SSOP	DBQ	16	2500	353.0	353.0	32.0

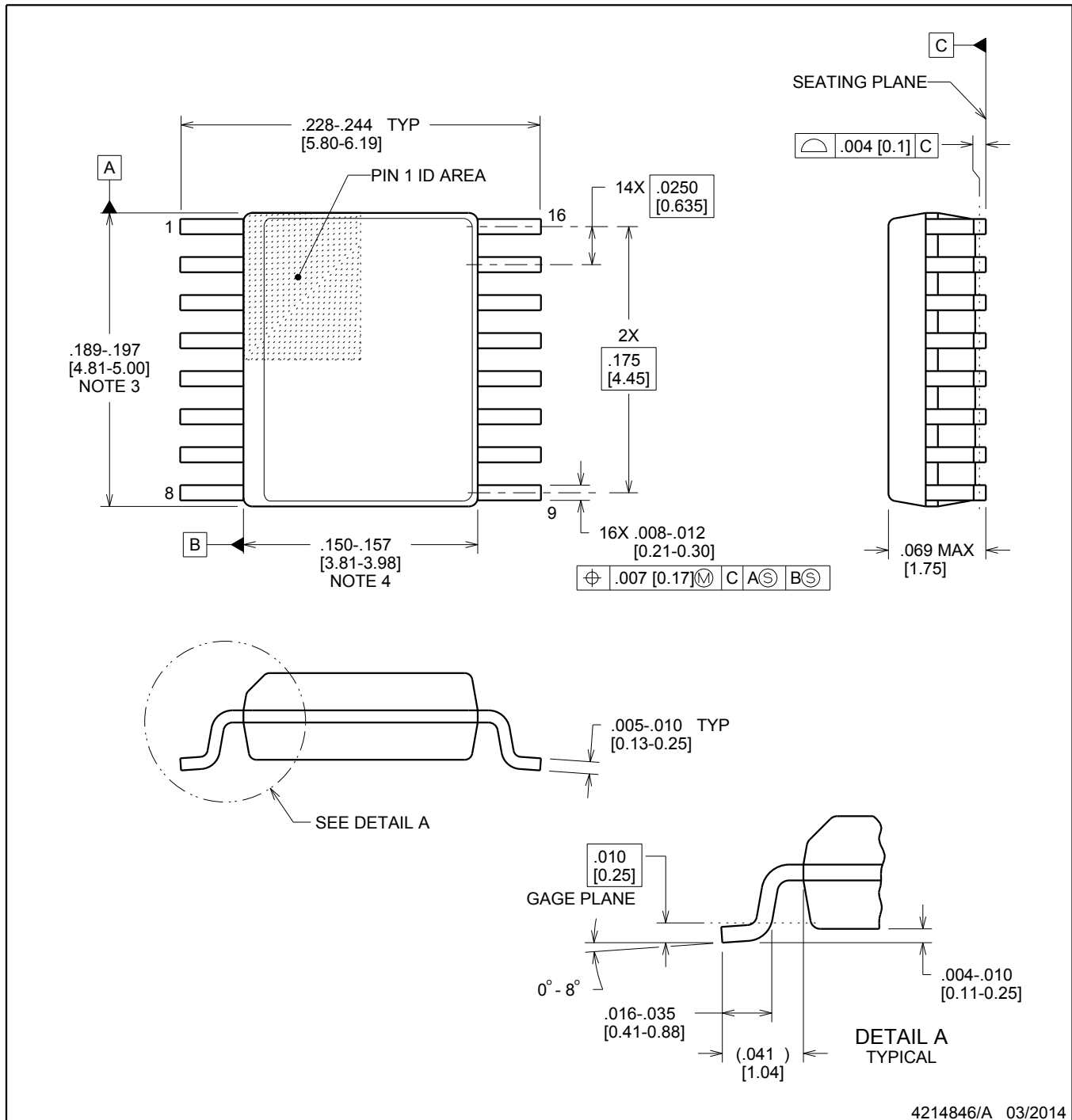


DBQ0016A

PACKAGE OUTLINE

SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



4214846/A 03/2014

NOTES:

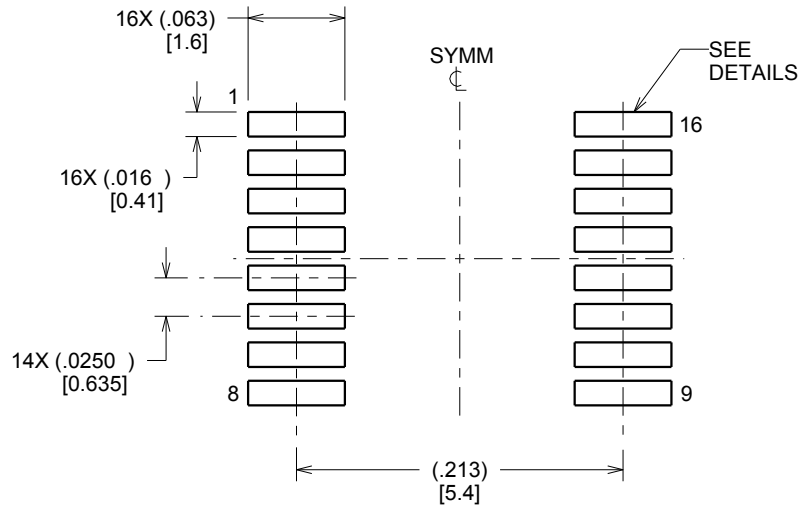
- Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
- This drawing is subject to change without notice.
- This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 inch, per side.
- This dimension does not include interlead flash.
- Reference JEDEC registration MO-137, variation AB.

EXAMPLE BOARD LAYOUT

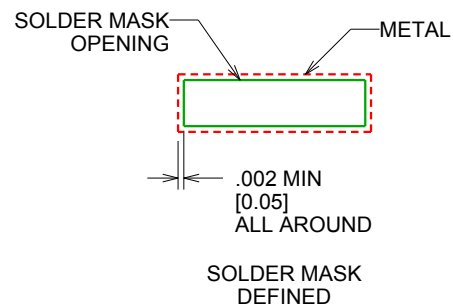
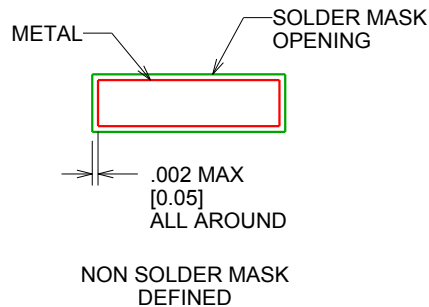
DBQ0016A

SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:8X



SOLDER MASK DETAILS

4214846/A 03/2014

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

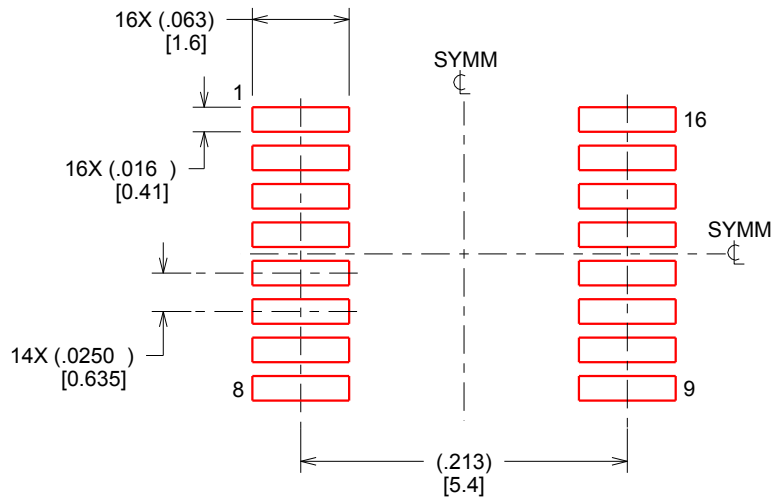
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

DBQ0016A

SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.127 MM] THICK STENCIL
SCALE:8X

4214846/A 03/2014

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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最后更新日期：2025 年 10 月