

TPS2640 具有集成反向输入极性保护功能的 42V、2A 电子保险丝

1 特性

- 工作电压为 4.2V 至 42V，绝对最大值为 45V
- 集成反向输入极性保护，低至 -42V
 - 无需额外元件
- 总 RON 为 150mΩ 的集成背对背 MOSFET
- 0.1A 至 2.23A 可调节电流限制 (1A 时精度为 ±5%)
- 借助适用的 TVS 在浪涌期间提供负载保护 (IEC 61000-4-5)
- IMON 电流指示器输出 (精度为 ±8.5%)
- 低静态电流，工作时为 300 μA，关断时为 20 μA
- 可调节的 UVLO、OVP 切断、输出压摆率控制
- 反向电流阻断
- 采用易于使用的 16 引脚 HTSSOP 和 24 引脚 VQFN 封装
- 可选电流限制故障响应选项 (自动重试、闭锁、断路器模式)

2 应用

- 工厂自动化中的 HMI 电源保护
- 防火安全系统
- 电子恒温器和可视门铃
- 工业 PC
- 升降机

3 说明

TPS26400 器件是一款设计紧凑、功能丰富的高压电子保险丝，具有一整套保护功能。4.2V 至 42V 的宽电源电压输入范围可实现对众多常用直流总线电压的控制。该器件可以承受并保护由高达 ±42V 的正负电源供电的负载。集成的背对背 FET 提供反向电流阻断功能，因此该器件适用于在电源故障和欠压条件下要求保持输出电压的系统。负载、电源和器件保护具有许多可调特性，包括过流、输出压摆率和过压、欠压阈值。TPS26400 内部可靠的保护控制模块以及高额定电压有助于简化针对浪涌保护的系统设计。

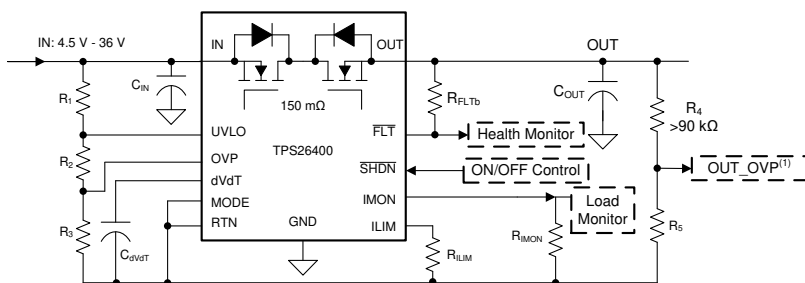
借助关断引脚，可以从外部控制内部 FET 的启用/禁用，还可以将器件置于低电流关断模式。为实现系统状态监视和下游负载控制，器件提供故障和精密电流监视输出。MODE 引脚有助于在三个限流故障响应 (断路器模式、闭锁模式和自动重试模式) 之间灵活地对器件进行配置。

该器件可采用 5mm × 4.4mm、16 引脚 HTSSOP 封装和 5mm × 4mm、24 引脚 VQFN 封装；额定温度范围为 -40°C 至 +125°C。

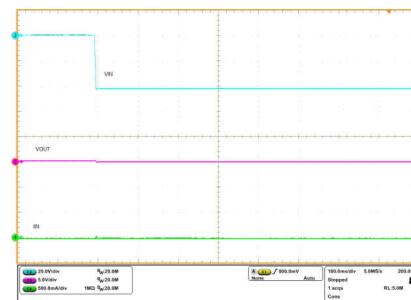
器件信息

器件型号	封装 ⁽¹⁾	封装尺寸 (标称值)
TPS26400	HTSSOP (16)	5.00mm × 4.40mm
TPS26400	VQFN (24)	5.00mm × 4.00mm

(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。



简化原理图



具有 -42V 输入的反向极性保护



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4 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision * (November 2020) to Revision A (June 2021)	Page
• Removed the "Selecting the \pm Vs Supplies for TPS26610" section.....	29

5 Device Comparison

PART NUMBER	OVERVOLTAGE PROTECTION	OVER LOAD FAULT RESPONSE WITH MODE = OPEN
TPS26400	Overvoltage cut-off, adjustable	Circuit breaker with auto-retry

6 Pin Configuration and Functions

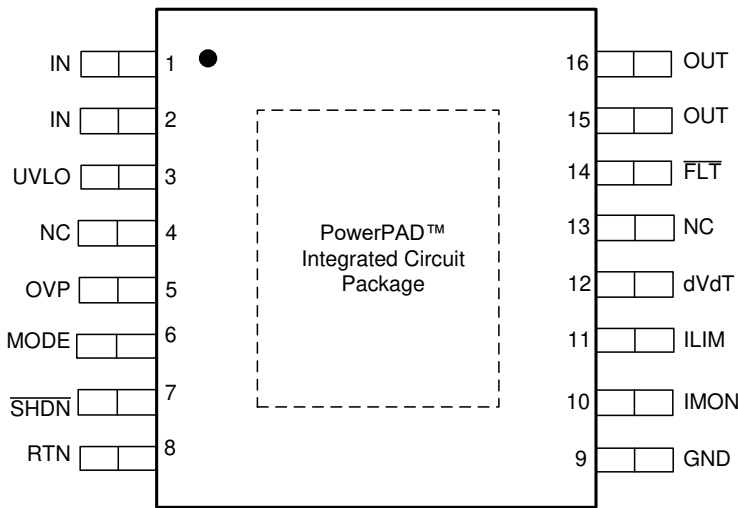


图 6-1. PWP Package 16-Pin HTSSOP Top View

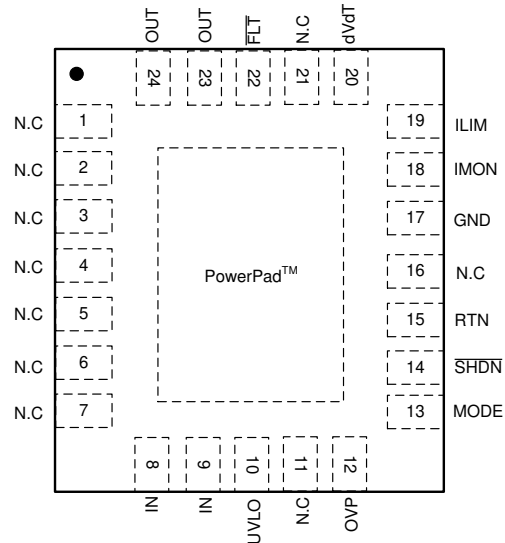


图 6-2. RHF Package 24-Pin VQFN Top View

表 6-1. Pin Functions

NAME	PIN		TYPE	DESCRIPTION
	HTSSOP	VQFN		
dVdT	12	20	I/O	A capacitor from this pin to RTN sets output voltage slew rate See the Hot Plug-In and In-Rush Current Control section.
FLT	14	22	O	Fault event indicator. It is an open drain output. If unused, leave floating.
GND	9	17	—	Connect GND to system ground.
ILIM	11	19	I/O	A resistor from this pin to RTN sets the overload and short-circuit current limit. See the Overload and Short Circuit Protection section.
IMON	10	18	O	Analog current monitor output. This pin sources a scaled down ratio of current through the internal FET. A resistor from this pin to RTN converts current to proportional voltage. If unused, leave it floating.
IN	1	8	Power	Power input and supply voltage of the device.
	2	9		
MODE	6	13	I	Mode selection pin for over load fault response. See the Device Functional Modes section.

表 6-1. Pin Functions (continued)

NAME	PIN		TYPE	DESCRIPTION
	TPS26400			
	HTSSOP	VQFN		
N.C	4	1-7	—	No connect.
	13	11		
		16		
		21		
OUT	15	23	Power	Power output of the device.
	16	24		
OVP	5	12	I	Input for setting the programmable overvoltage protection threshold. An overvoltage event turns off the internal FET and asserts FLT to indicate the overvoltage fault. Connect OVP pin to RTN pin externally to select the Factory set $V_{(IN)}$ overvoltage trip level. See Overvoltage Protection (OVP) section.
PowerPad™	—	—	—	PowerPad must be connected to RTN plane on PCB using multiple vias for enhanced thermal performance. Do not use PowerPad as the only electrical connection to RTN. For Programmable overvoltage clamp, connect the resistor ladder from Vout to OVP to RTN.
RTN	8	15	—	Reference for device internal control circuits.
SHDN	7	14	I	Shutdown pin. Pulling SHDN low makes the device to enter into low power shutdown mode. Cycling SHDN pin voltage resets the device that has latched off due to a fault condition.
UVLO	3	10	I	Input for setting the programmable undervoltage lockout threshold. An undervoltage event turns off the internal FET and asserts FLT to indicate the power-failure. Connect UVLO pin to RTN pin to select the internal default threshold.

7 Specifications

over operating free-air temperature range (all voltages referred to GND (unless otherwise noted))⁽¹⁾

7.1 Absolute Maximum Ratings

		MIN	MAX	UNIT
IN, IN-OUT	Input voltage	- 45	45	V
IN, IN-OUT (10 ms transient), T _A = 25°C		- 55	55	V
[IN, OUT, FLT, UVLO, SHDN] to RTN		- 0.3	45	V
[OVP, dVdT, ILIM, IMON, MODE] to RTN		- 0.3	5	V
RTN		- 45	0.3	V
I _{FLT} , I _{dVdT} , I _{SHDN}	Sink current		10	mA
I _{dVdT} , I _{ILIM} , I _{IMON}	Source current	Internally limited		
T _J	Operating junction temperature	- 40	150	°C
	Transient junction temperature	- 65	T _(TSD)	°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 and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

7.2 ESD Ratings

		VALUE	UNIT
V _(ESD) Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±1000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	±250	

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
 (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

over operating free-air temperature range (all voltages referred to GND (unless otherwise noted))

7.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
IN	Input voltage	- 42		42	V
UVLO, OUT, FLT		0		42	
OVP, dVdT, ILIM, IMON, SHDN		0		4	
ILIM	Resistance	5.36		120	kΩ
IMON		1			
IN, OUT	External capacitance	0.1			μF
dVdT		10			
T _J	Operating junction temperature	- 40	25	125	°C

7.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TPS2640		UNIT
		PWP (HTSSOP)	RHF (VQFN)	
		16 PINS	24 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	38.6	30.2	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	22.7	20.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	18.2	7.6	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.5	0.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	18	7.6	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	1.5	1.7	°C/W

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

7.5 Electrical Characteristics

$-40^{\circ}\text{C} \leq T_A = T_J \leq +125^{\circ}\text{C}$, $V_{(IN)} = 24\text{ V}$, $V_{(SHDN)} = 2\text{ V}$, $R_{(ILIM)} = 120\text{ k}\Omega$, $IMON = \overline{FLT} = \text{OPEN}$, $C_{(OUT)} = 1\ \mu\text{F}$, $C_{(dVdT)} = \text{OPEN}$. (All voltages referenced to GND, (unless otherwise noted))

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY VOLTAGE						
$V_{(IN)}$	Operating input voltage		4.2		42	V
$V_{(PORR)}$	Internal POR threshold, rising		3.9	4	4.1	V
$V_{(PORHys)}$	Internal POR hysteresis		250	275	300	mV
$I_{Q(ON)}$	Supply current	Enabled: $V_{(SHDN)} = 2\text{ V}$	190	300	390	μA
$I_{Q(OFF)}$		$V_{(SHDN)} = 0\text{ V}$	11	20	33	μA
$I_{(VINR)}$	Reverse input supply current	$V_{(IN)} = -42\text{ V}$, $V_{(OUT)} = 0\text{ V}$			66	μA
UNDERVOLTAGE LOCKOUT (UVLO) INPUT						
$V_{(IN_UVLO)}$	Factory set $V_{(IN)}$ undervoltage trip level	$V_{(IN)}$ rising, $V_{(UVLO)} = 0\text{ V}$	14.25	14.9	15.75	V
		$V_{(IN)}$ falling, $V_{(UVLO)} = 0\text{ V}$	13.25	13.8	14.75	
$V_{(SEL_UVLO)}$	Internal UVLO select threshold		180	200	240	mV
$V_{(UVLOR)}$	UVLO threshold voltage, rising		1.175	1.19	1.225	V
$V_{(UVLOF)}$	UVLO threshold voltage, falling		1.08	1.1	1.125	V
$I_{(UVLO)}$	UVLO input leakage current	$0\text{ V} \leq V_{(UVLO)} \leq 42\text{ V}$	-100	0	100	nA
LOW IQ SHUTDOWN (SHDN) INPUT						
$V_{(SHDN)}$	Output voltage	$I_{(SHDN)} = 0.1\ \mu\text{A}$	2	2.7	3.4	V
$V_{(SHUTF)}$	SHDN threshold voltage for low IQ shutdown, falling		0.55	0.76	0.94	V
$I_{(SHDN)}$	Leakage current	$V_{(SHDN)} = 0.4\text{ V}$	-10			μA
OVERVOLTAGE PROTECTION (OVP) INPUT						
$V_{(IN_OVP)}$	Factory set $V_{(IN)}$ overvoltage trip level	$V_{(IN)}$ rising, $V_{(OVP)} = 0\text{ V}$	31	32.6	34	V
		$V_{(IN)}$ falling, $V_{(OVP)} = 0\text{ V}$	28.5	30.3	31.5	
$V_{(SEL_OVP)}$	Internal OVP select threshold		180	200	240	mV
$V_{(OVPR)}$	Overvoltage threshold voltage, rising		1.17	1.19	1.225	V
$V_{(OVPF)}$	Overvoltage threshold, falling		1.085	1.1	1.125	V
$I_{(OVP)}$	OVP input leakage current	$0\text{ V} \leq V_{(OVP)} \leq 4\text{ V}$	-100	0	100	nA
OUTPUT RAMP CONTROL (dVdT)						
$I_{(dVdT)}$	dVdT charging current	$V_{(dVdT)} = 0\text{ V}$	4	4.7	5.5	μA
$R_{(dVdT)}$	dVdT discharging resistance	$V_{(SHDN)} = 0\text{ V}$, with $I_{(dVdT)} = 10\text{ mA}$ sinking		14		Ω
$GAIN_{(dVdT)}$	dVdT to OUT gain	$V_{(OUT)}/V_{(dVdT)}$	23.75	24.6	25.5	V/V
CURRENT LIMIT PROGRAMMING (ILIM)						
$V_{(ILIM)}$	ILIM bias voltage			1		V
$I_{(OL)}$	Overload current limit	$R_{(ILIM)} = 120\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 1\text{ V}$	0.085	0.1	0.115	A
		$R_{(ILIM)} = 12\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 1\text{ V}$	0.95	1	1.05	
		$R_{(ILIM)} = 8\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 1\text{ V}$	1.425	1.5	1.575	
		$R_{(ILIM)} = 5.36\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 1\text{ V}$	2.11	2.23	2.35	
$I_{(OL_R-OPEN)}$		$R_{(ILIM)} = \text{OPEN}$, open resistor current limit (single point failure test: UL60950)			0.055	
$I_{(OL_R-SHORT)}$		$R_{(ILIM)} = \text{SHORT}$, shorted resistor current limit (single point failure test: UL60950)			0.095	
$I_{(CB)}$	Circuit breaker detection threshold	$R_{(ILIM)} = 120\text{ k}\Omega$, MODE = open	0.045	0.073	0.11	A
		$R_{(ILIM)} = 5.36\text{ k}\Omega$, MODE = open	2	2.21	2.4	

7.5 Electrical Characteristics

$-40^{\circ}\text{C} \leq T_A = T_J \leq +125^{\circ}\text{C}$, $V_{(IN)} = 24\text{ V}$, $V_{(\overline{\text{SHDN}})} = 2\text{ V}$, $R_{(ILIM)} = 120\text{ k}\Omega$, $\overline{\text{IMON}} = \overline{\text{FLT}} = \text{OPEN}$, $C_{(OUT)} = 1\ \mu\text{F}$, $C_{(dVdT)} = \text{OPEN}$. (All voltages referenced to GND, (unless otherwise noted))

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$I_{(SCL)}$ Short-circuit current limit	$R_{(ILIM)} = 120\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 5\text{ V}$	0.08	0.1	0.12	A
	$R_{(ILIM)} = 8\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 5\text{ V}$	1.425	1.5	1.575	
	$R_{(ILIM)} = 5.36\text{ k}\Omega$, $V_{(IN)} - V_{(OUT)} = 5\text{ V}$	2.11	2.23	2.35	
$I_{(FASTRIP)}$ Fast-trip comparator threshold			$1.87 \times I_{(OL)} + 0.015$		A
CURRENT MONITOR OUTPUT (IMON)					
$GAIN_{(IMON)}$ Gain factor $I_{(IMON)}: I_{(OUT)}$	$0.1\text{ A} \leq I_{(OUT)} \leq 2\text{ A}$	72	78.28	85	$\mu\text{A/A}$
PASS FET OUTPUT (OUT)					
$R_{(ON)}$ IN to OUT total ON resistance	$0.1\text{ A} \leq I_{(OUT)} \leq 2\text{ A}$, $T_J = 25^{\circ}\text{C}$	140	150	160	$\text{m}\Omega$
	$0.1\text{ A} \leq I_{(OUT)} \leq 2\text{ A}$, $T_J = 85^{\circ}\text{C}$			210	
	$0.1\text{ A} \leq I_{(OUT)} \leq 2\text{ A}$, $-40^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$	80	150	250	
$I_{(kg_{(OUT)})}$ OUT leakage current in Off state	$V_{(IN)} = 42\text{ V}$, $V_{(\overline{\text{SHDN}})} = 0\text{ V}$, $V_{(OUT)} = 0\text{ V}$, sourcing			12	μA
	$V_{(IN)} = 0\text{ V}$, $V_{(\overline{\text{SHDN}})} = 0\text{ V}$, $V_{(OUT)} = 24\text{ V}$, sinking			11	
	$V_{(IN)} = -42\text{ V}$, $V_{(\overline{\text{SHDN}})} = 0\text{ V}$, $V_{(OUT)} = 0\text{ V}$, sinking			50	
$V_{(REVTH)}$ $V_{(IN)} - V_{(OUT)}$ threshold for reverse protection comparator, falling		-15	-10	-5	mV
$V_{(FWDTH)}$ $V_{(IN)} - V_{(OUT)}$ threshold for reverse protection comparator, rising		85	96	110	mV
FAULT FLAG (FLT): ACTIVE LOW					
$R_{(FLT)}$ $\overline{\text{FLT}}$ pull-down resistance	$V_{(OVP)} = 2\text{ V}$, $I_{(FLT)} = 5\text{ mA}$ sinking	40	85	160	Ω
$I_{(FLT)}$ $\overline{\text{FLT}}$ input leakage current	$0\text{ V} \leq V_{(FLT)} \leq 42\text{ V}$	-200		200	nA
THERMAL SHUT DOWN (TSD)					
$T_{(TSD)}$ TSD threshold, rising			157		$^{\circ}\text{C}$
$T_{(TSDhyst)}$ TSD hysteresis			10		$^{\circ}\text{C}$
MODE					
$MODE_SEL$ Thermal fault mode selection	MODE = 402 k Ω to RTN				Current limiting with latch
	MODE = Open				Circuit breaker mode with auto-retry
	MODE = Short to RTN				Current limiting with auto-retry

7.6 Timing Requirements

-40°C ≤ T_A = T_J ≤ +125°C, V_(IN) = 24 V, V_(SHDN) = 2 V, R_(ILIM) = 120 kΩ, IMON = FLT = OPEN, C_(OUT) = 1 μF, C_(dVdT) = OPEN. (All voltages referenced to GND, (unless otherwise noted))

			MIN	NOM	MAX	UNIT
IN AND UVLO INPUT						
UVLO_ _{tON} (dly)	UVLO turnon delay	UVLO ↑ (100 mV above V _(UVLOR)) to V _(OUT) = 100 mV, C _(dVdT) = open		250		μs
		UVLO ↑ (100 mV above V _(UVLOR)) to V _(OUT) = 100 mV, C _(dVdT) ≥ 10 nF, [C _(dVdT) in nF]		250 + 14.5 × C _(dVdT)		μs
UVLO_ _{tOFF} (dly)	UVLO turnoff delay	UVLO ↓ (100 mV below V _(UVLOF)) to FLT ↓		10		μs
SHUTDOWN CONTROL INPUT (SHDN)						
t _{SD} (dly)	SHUTDOWN exit delay	SHDN ↑ to V _(OUT) = 100 mV, C _(dVdT) ≥ 10 nF, [C _(dVdT) in nF]		250 + 14.5 × C _(dVdT)		μs
		SHDN ↑ to V _(OUT) = 100 mV, C _(dVdT) = open		250		μs
	SHUTDOWN entry delay	SHDN ↓ (below V _(SHUTF)) to FLT ↓		10		μs
OVER VOLTAGE PROTECTION INPUT (OVP)						
t _{OVP} (dly)	OVP exit delay	OVP ↓ (20 mV below V _(OVPF)) to V _(OUT) = 100 mV		200		μs
	OVP disable delay	OVP ↑ (20 mV above V _(OVPR)) to FLT ↓		6		μs
CURRENT LIMIT						
t _{FASTTRIP} (dly)	Fast-trip comparator delay	I _(OUT) > I _(FASTTRIP)		250		ns
REVERSE PROTECTION COMPARATOR						
t _{REV} (dly)	Reverse protection comparator delay	(V _(IN) - V _(OUT)) ↓ (100-mV overdrive below V _(REVTH)) to internal FET turn OFF		1.5		μs
		(V _(IN) - V _(OUT)) ↓ (10-mV overdrive below V _(REVTH)) to FLT ↓		45		
t _{FWD} (dly)		(V _(IN) - V _(OUT)) ↑ (10-mV overdrive above V _(FWDTH)) to FLT ↑		70		
THERMAL SHUTDOWN						
t _{retry}	Retry delay in TSD			512		ms
OUTPUT RAMP CONTROL (dVdT)						
t _{dVdT}	Output ramp time	SHDN ↑ to V _(OUT) = 23.9 V, with C _(dVdT) = 47 nF		10		ms
		SHDN ↑ to V _(OUT) = 23.9 V, with C _(dVdT) = open		1.6		
FAULT FLAG (FLT)						
t _{CB} (dly)	FLT assertion delay in circuit breaker mode	MODE = OPEN, delay from I _(OUT) > I _(OL) to FLT ↓		4		ms
t _{CBretry} (dly)	Retry delay in circuit breaker mode	MODE = OPEN		540		ms
t _{PGOODF}	PGOOD delay (de-glitch) time	Falling edge		875		μs
t _{PGOODR}		Rising edge, C _(dVdT) = open		1400		
		Rising edge, C _(dVdT) ≥ 10 nF, [C _(dVdT) in nF]		875 + 20 × C _(dVdT)		

7.7 Typical Characteristics

-40°C ≤ T_A = T_J ≤ +125°C, V_(IN) = 24 V, V_(SHDN) = 2 V, R_(ILIM) = 120 kΩ, IMON = $\overline{\text{FLT}}$ = OPEN, C_(OUT) = 1 μF, C_(dVdT) = OPEN (unless stated otherwise).

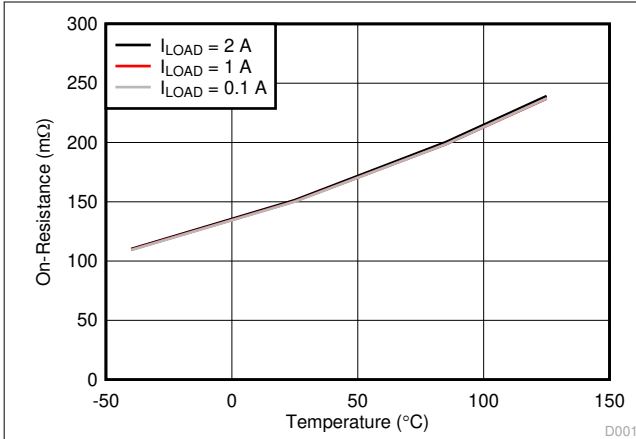


图 7-1. On-Resistance vs Temperature Across Load Current

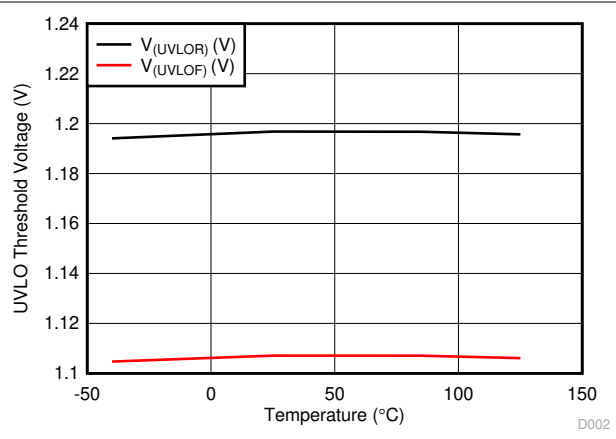


图 7-2. UVLO Threshold Voltage vs Temperature

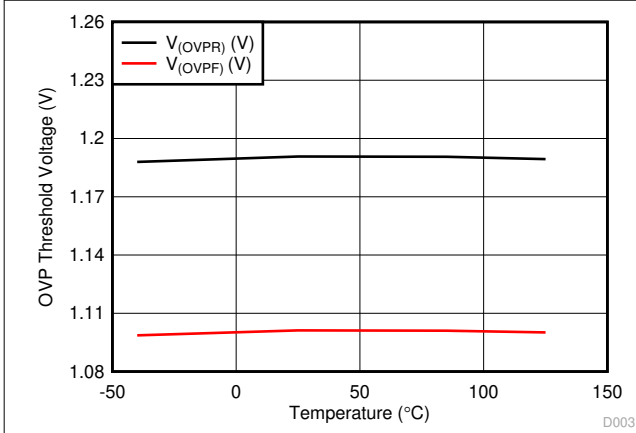


图 7-3. OVP Threshold Voltage vs Temperature

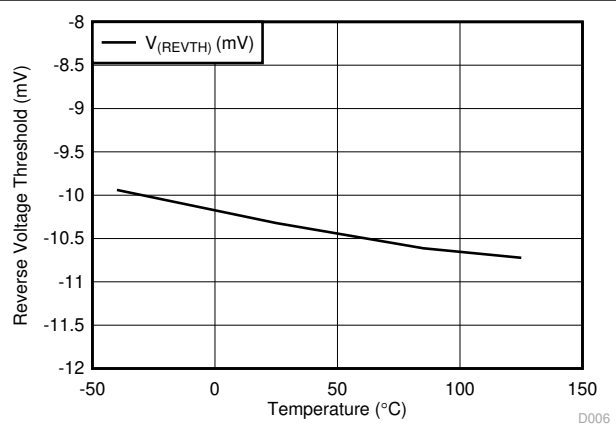


图 7-4. Reverse Voltage Threshold vs Temperature

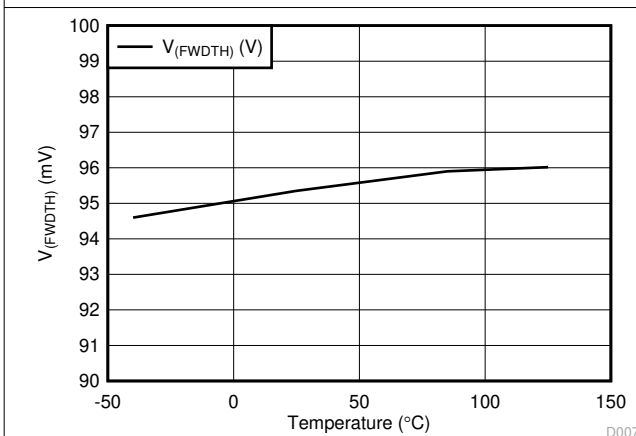


图 7-5. V_(FWDTH) vs Temperature

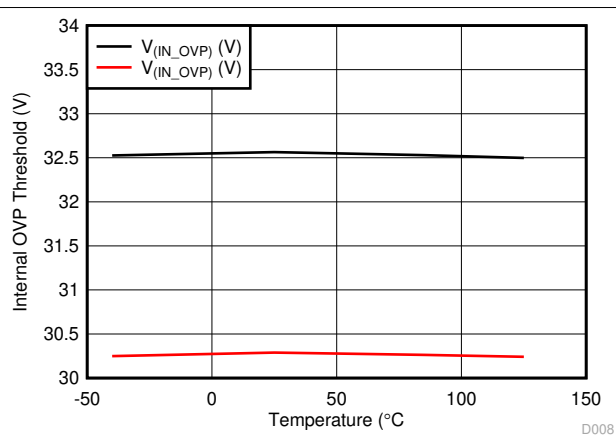


图 7-6. Internal OVP Threshold vs Temperature

7.7 Typical Characteristics (continued)

$-40^{\circ}\text{C} \leq T_A = T_J \leq +125^{\circ}\text{C}$, $V_{(IN)} = 24\text{ V}$, $V_{(SHDN)} = 2\text{ V}$, $R_{(ILIM)} = 120\text{ k}\Omega$, $\overline{\text{IMON}} = \overline{\text{FLT}} = \text{OPEN}$, $C_{(OUT)} = 1\ \mu\text{F}$, $C_{(dVdT)} = \text{OPEN}$ (unless stated otherwise).

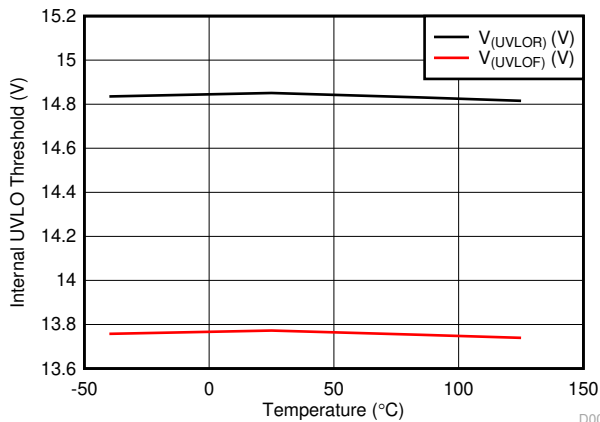


图 7-7. Internal UVLO Threshold vs Temperature

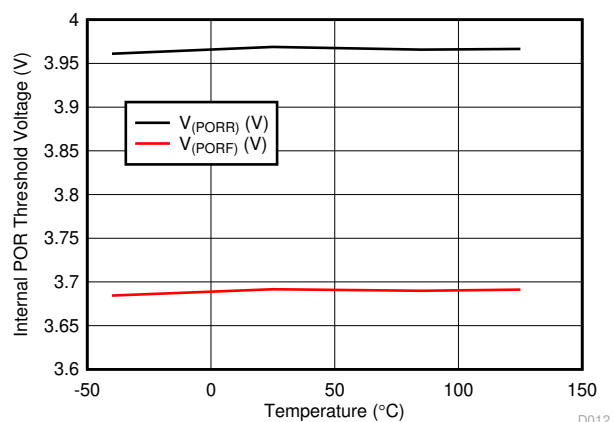


图 7-8. Internal POR Threshold Voltage vs Temperature

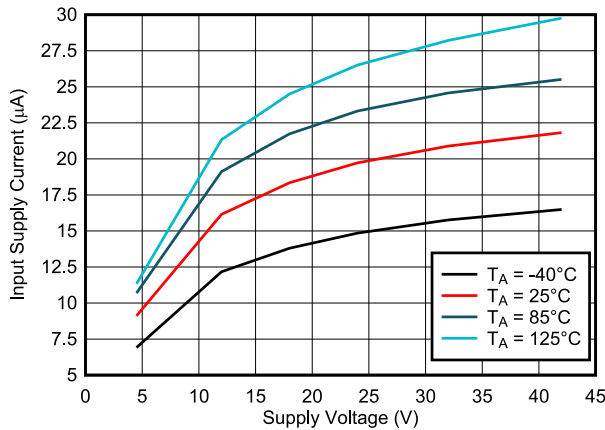


图 7-9. Input Supply Current vs Supply Voltage in Shutdown

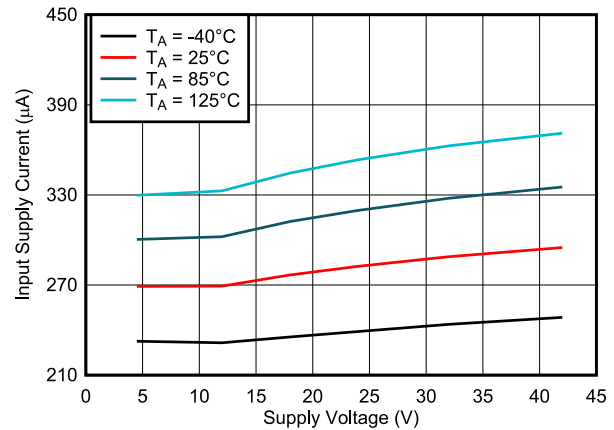


图 7-10. Input Supply Current vs Supply Voltage During Normal Operation

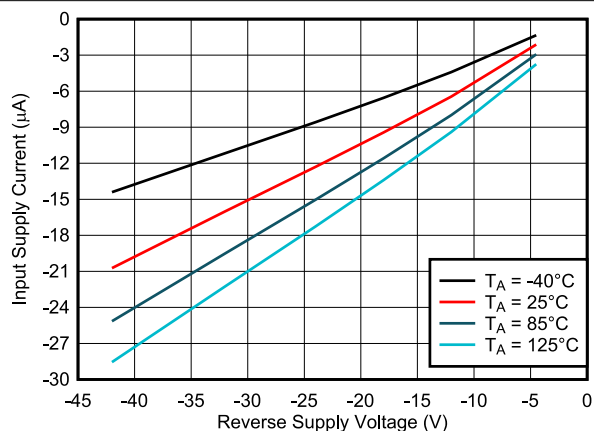


图 7-11. Input Supply Current vs Reverse Supply Voltage, $-V_{(IN)}$

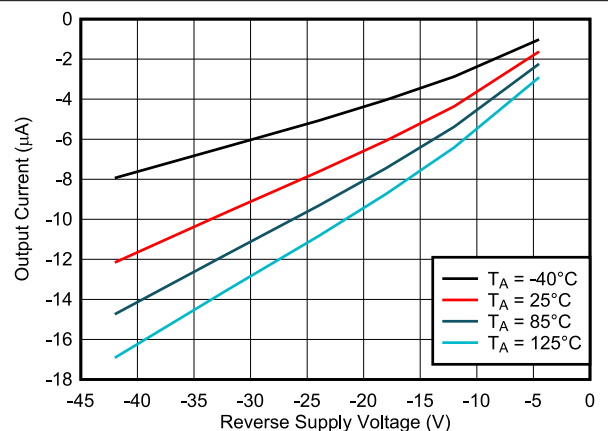


图 7-12. Output Current vs Reverse Supply Voltage, $-V_{(IN)}$

7.7 Typical Characteristics (continued)

-40°C ≤ T_A = T_J ≤ +125°C, V_(IN) = 24 V, V_(SHDN) = 2 V, R_(ILIM) = 120 kΩ, I_{MON} = $\overline{\text{FLT}}$ = OPEN, C_(OUT) = 1 μF, C_(dVdT) = OPEN (unless stated otherwise).

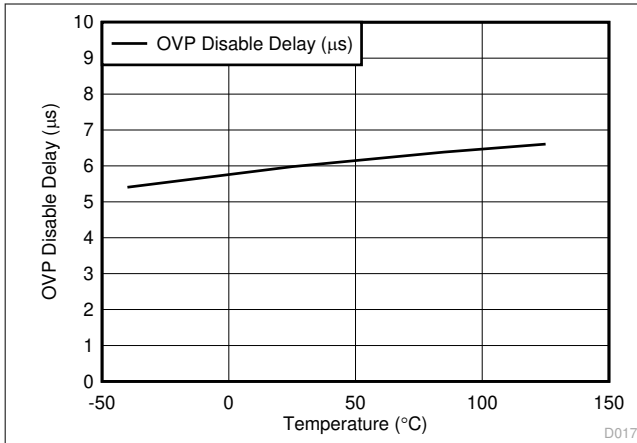


图 7-13. OVP Disable Delay vs Temperature

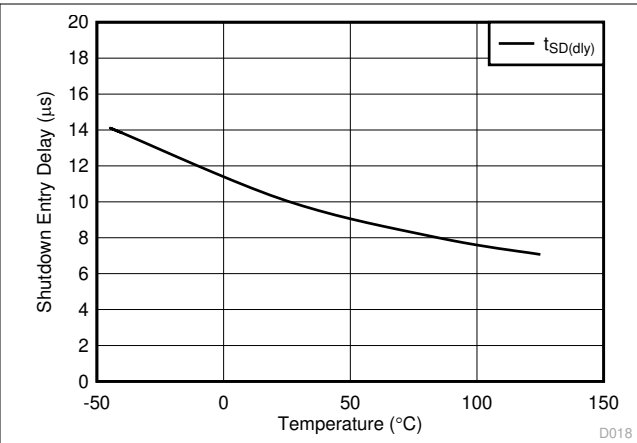


图 7-14. Shutdown Entry Delay vs Temperature

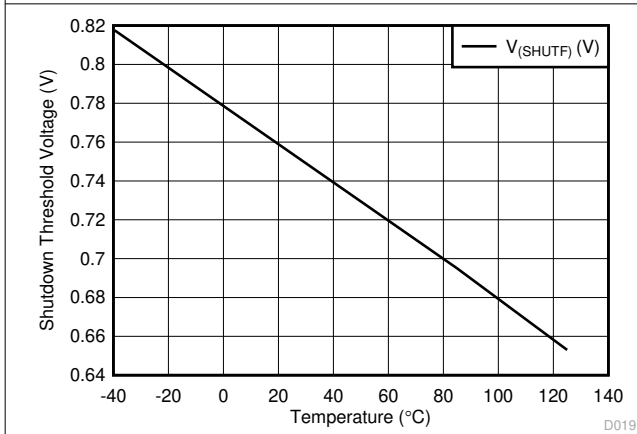


图 7-15. Shutdown Threshold Voltage vs Temperature

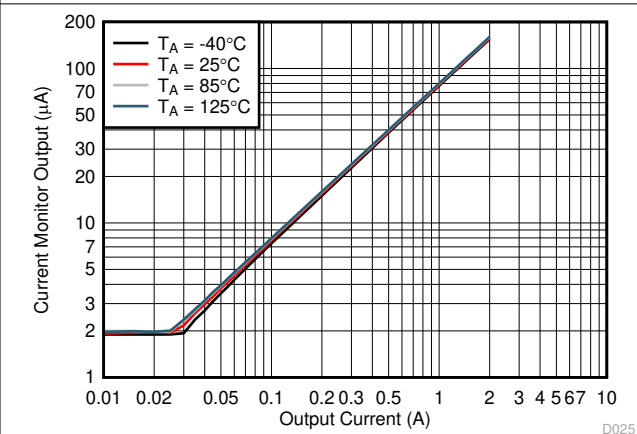


图 7-16. Current Monitor Output vs Output Current

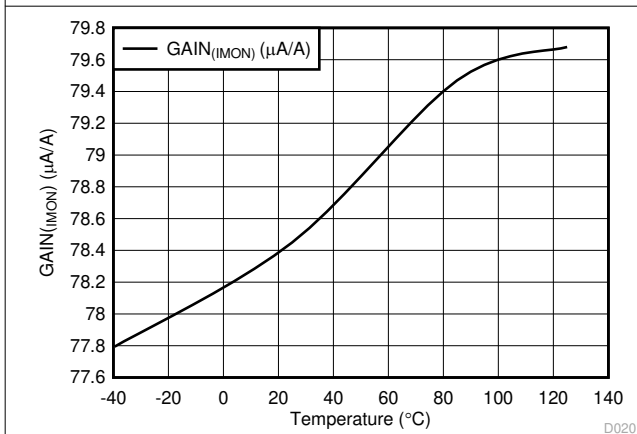


图 7-17. GAIN_(IMON) vs Temperature

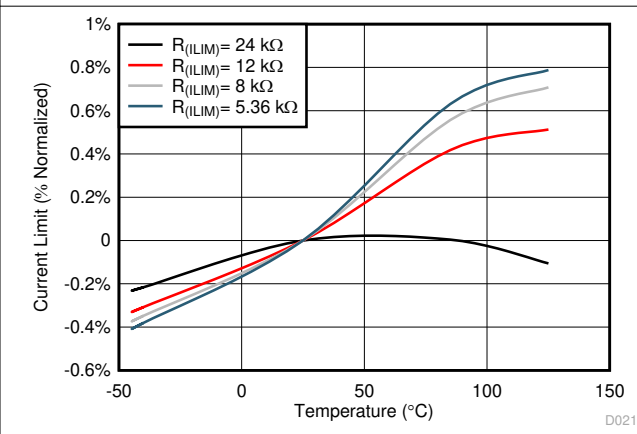


图 7-18. Current Limit (% Normalized) vs Temperature

7.7 Typical Characteristics (continued)

-40°C ≤ T_A = T_J ≤ +125°C, V_(IN) = 24 V, V_(SHDN) = 2 V, R_(ILIM) = 120 kΩ, IMON = $\overline{\text{FLT}}$ = OPEN, C_(OUT) = 1 μF, C_(dVdT) = OPEN (unless stated otherwise).

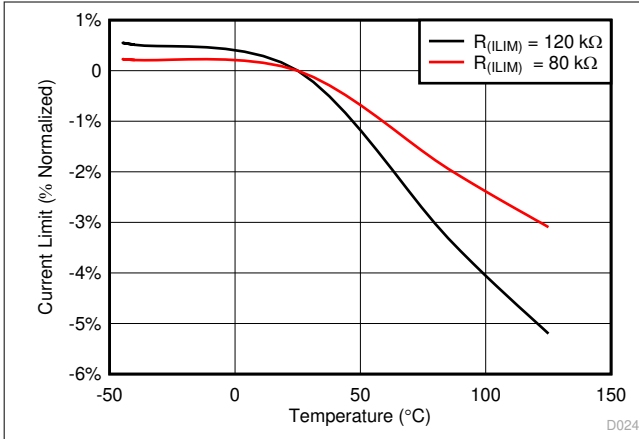


图 7-19. Current Limit (% Normalized) vs Temperature

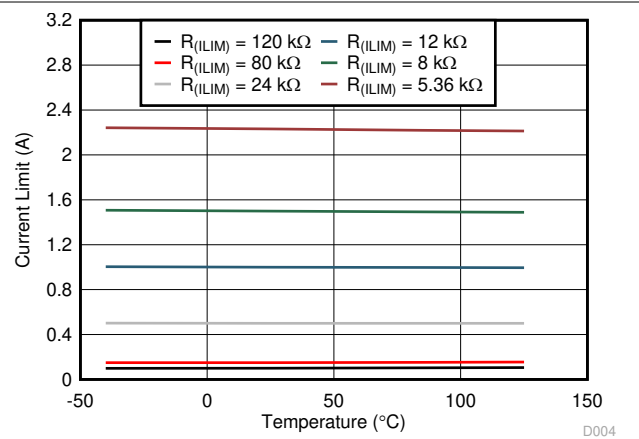


图 7-20. Reverse Voltage Threshold vs Temperature

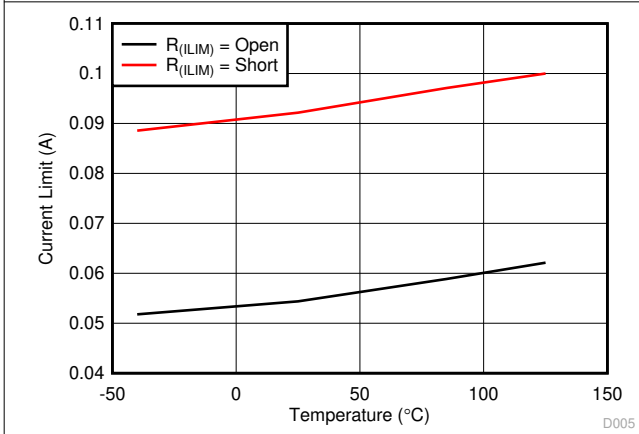


图 7-21. Current Limit for R_(ILIM) = Open and Short vs Temperature

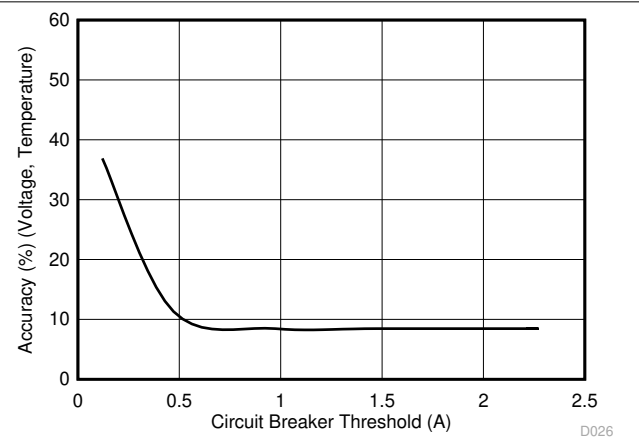


图 7-22. Circuit Breaker Threshold Accuracy vs Circuit Breaker Threshold I_(CB)

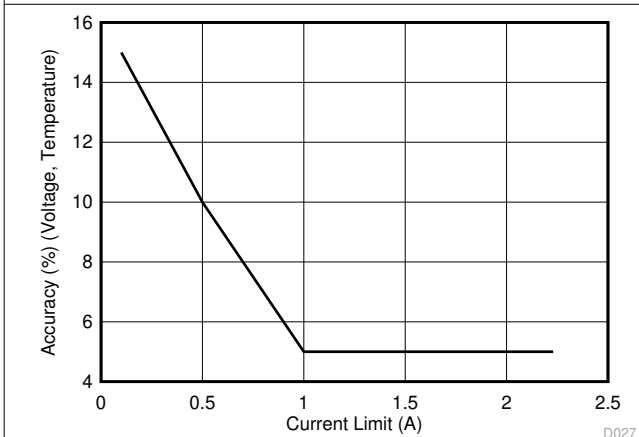


图 7-23. Current Limit Accuracy vs Current Limit, I_(OL)

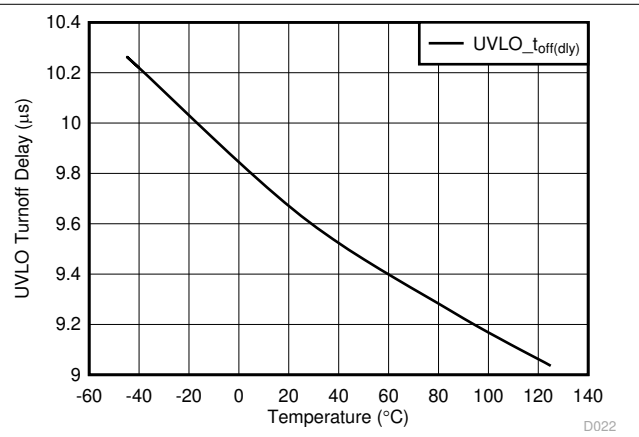


图 7-24. UVLO Turnoff Delay vs Temperature

7.7 Typical Characteristics (continued)

-40°C ≤ T_A = T_J ≤ +125°C, V_(IN) = 24 V, V_(SHDN) = 2 V, R_(ILIM) = 120 kΩ, I_{MON} = $\overline{\text{FLT}}$ = OPEN, C_(OUT) = 1 μF, C_(dVdT) = OPEN (unless stated otherwise).

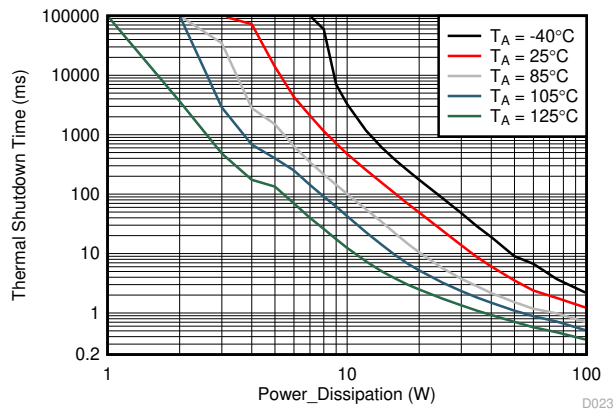


图 7-25. Thermal Shutdown Time vs Power Dissipation

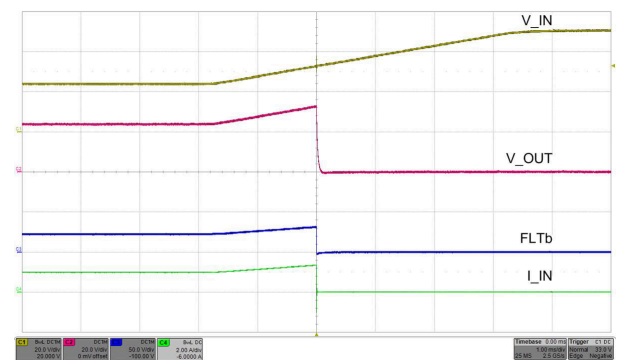


图 7-26. OVP Overvoltage Cut-Off Response

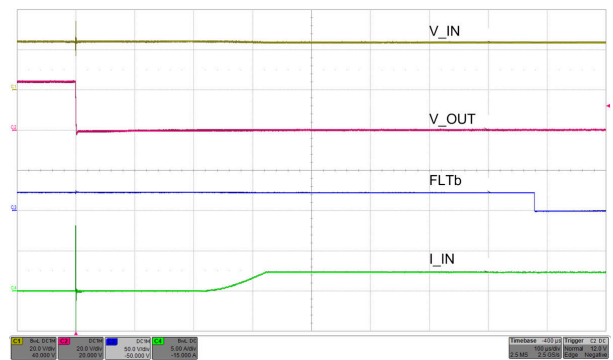


图 7-27. Hot-Short: Fast Trip Response and Current Regulation

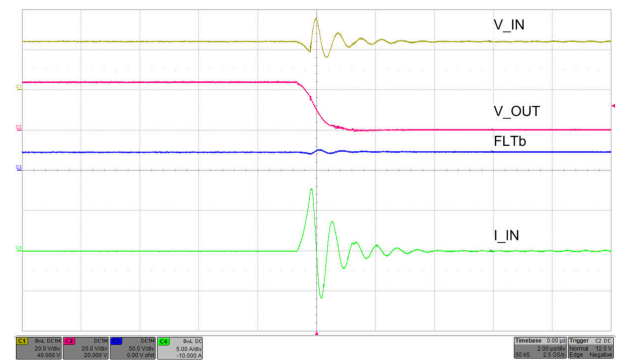


图 7-28. Hot-Short: Fast Trip Response (Zoomed)

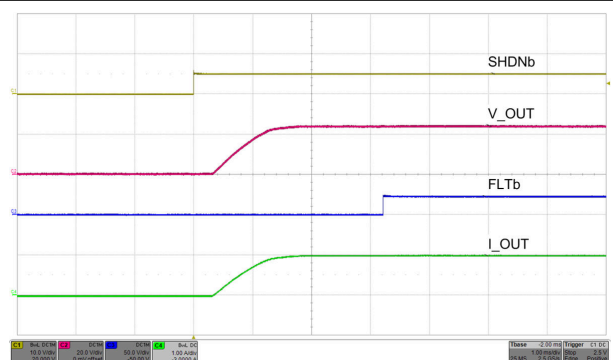


图 7-29. Turnon Control With SHDN

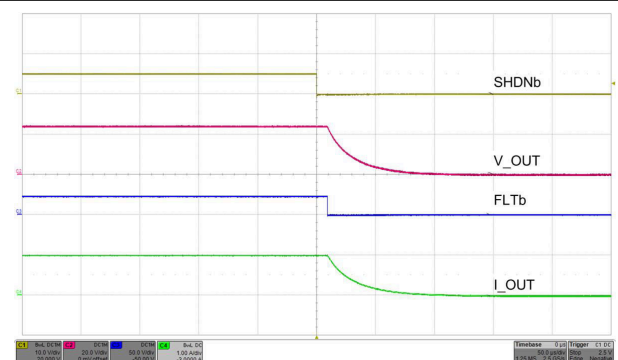


图 7-30. Turnoff Control With SHDN

8 Parameter Measurement Information

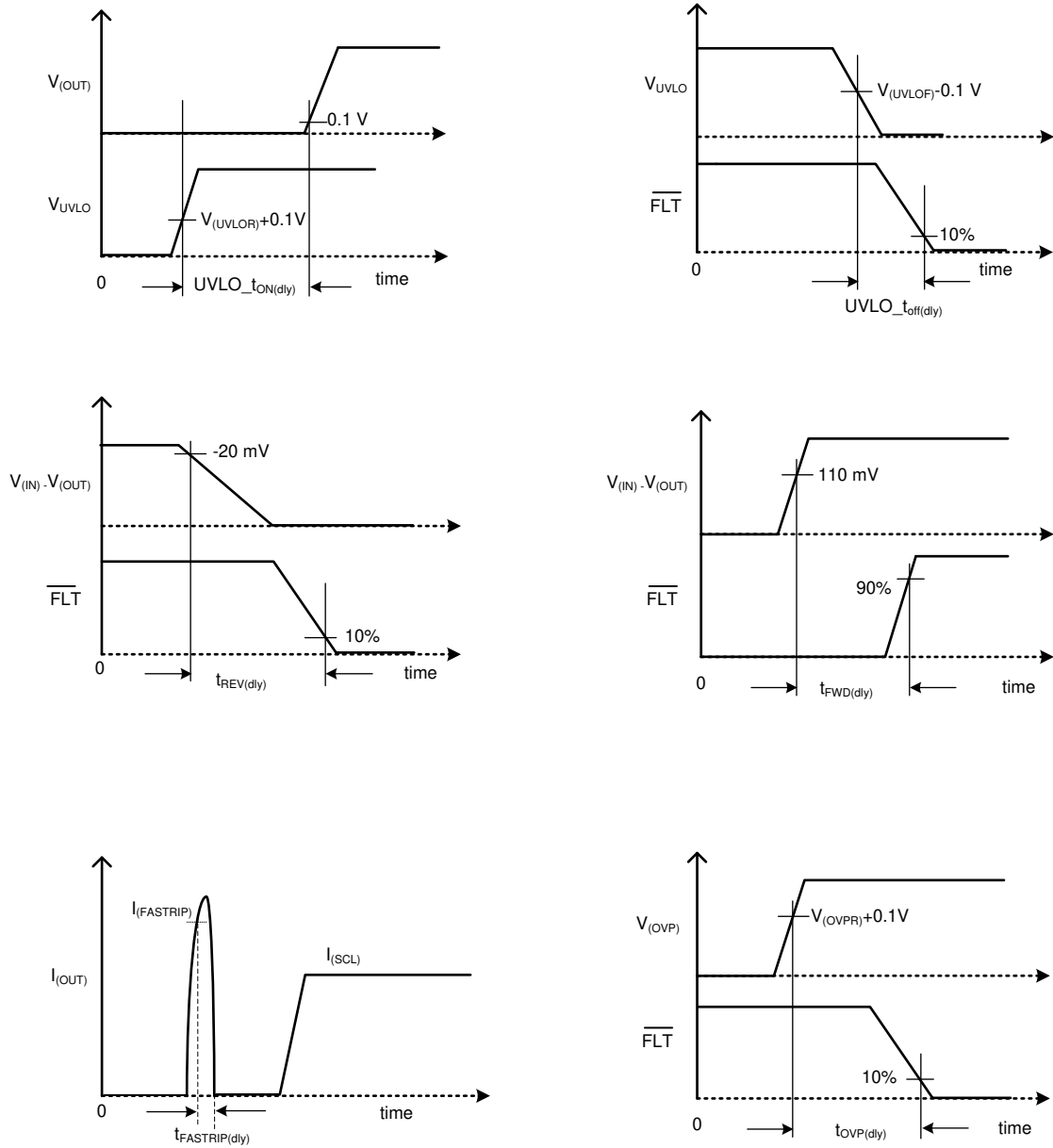


图 8-1. Timing Waveforms

9 Detailed Description

9.1 Overview

The TPS26400 is a high voltage industrial eFuse with integrated back-to-back MOSFETs and enhanced built-in protection circuitry. It provides robust protection for all systems and applications powered from 4.2 V to 42 V. The device can withstand ± 42 -V positive and negative supply voltages without damage. For hotpluggable boards, the device provides hot-swap power management with in-rush current control and programmable output voltage slew rate features. Load, source and device protections are provided with many programmable features including overcurrent, overvoltage, undervoltage. The precision overcurrent limit ($\pm 5\%$ at 1 A) helps to minimize over design of the input power supply, while the fast response short circuit protection 250 ns (typical) immediately isolates the faulty load from the input supply when a short circuit is detected.

The internal robust protection control blocks of the TPS26400 along with its ± 42 -V rating helps to simplify the system designs for the surge compliance ensuring complete protection of the load and the device.

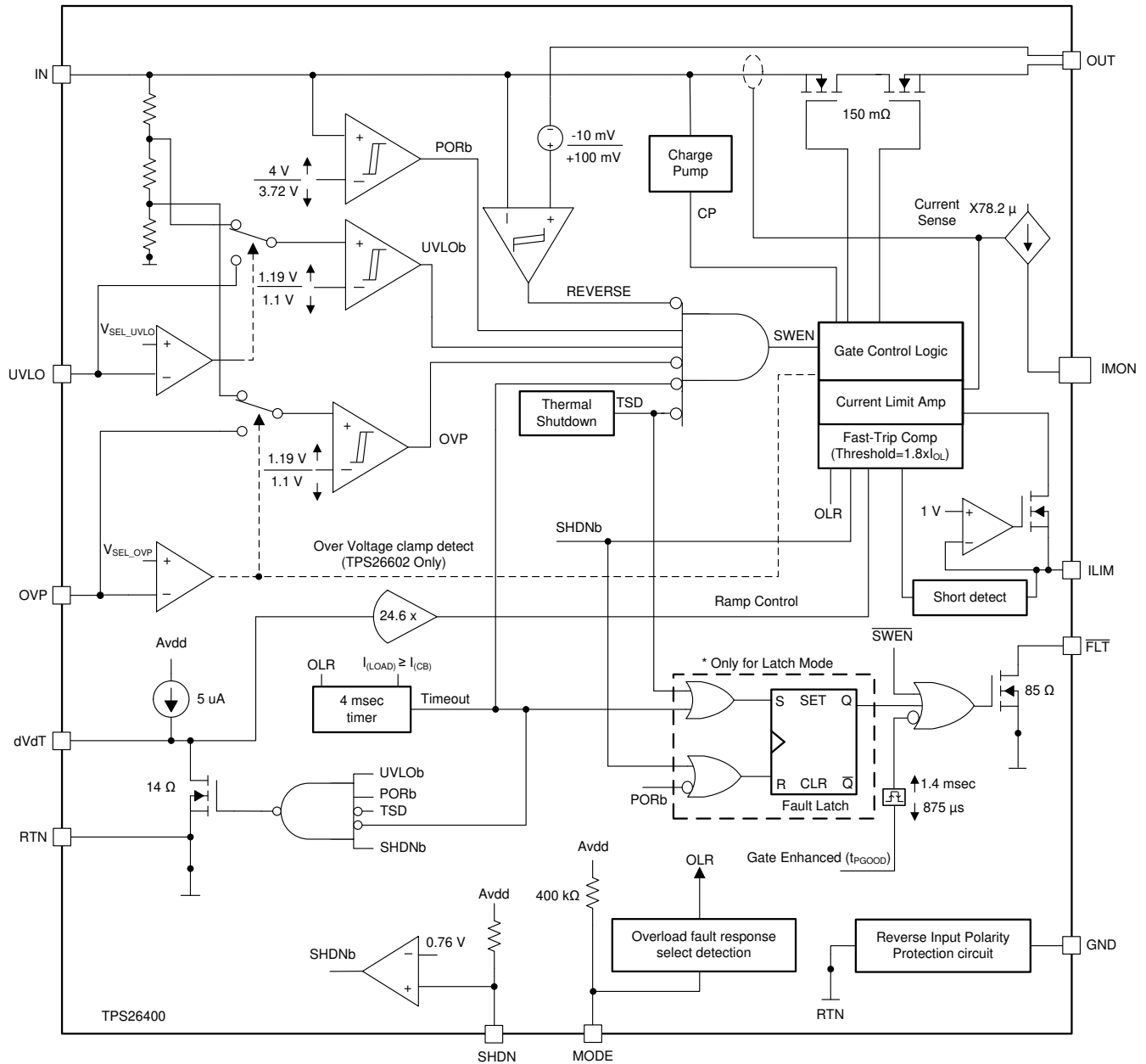
The device provides precise monitoring of voltage bus for brown-out and overvoltage conditions and asserts fault signal for the downstream system. The TPS26400 monitor functions threshold accuracy of $\pm 3\%$ ensures tight supervision of the supply bus, eliminating the need for a separate supply voltage supervisor chip.

The device monitors V(IN) and V(OUT) to provide true reverse current blocking when a reverse condition or input power failure condition is detected. The TPS26400 is also designed to control redundant power supply systems. A pair of TPS26400 devices can be configured for Active ORing between the main power supply and the auxiliary power supply (see the [System Examples](#) section).

Additional features of the TPS26400 include:

- Current monitor output for health monitoring of the system
- Electronic circuit breaker operation with overload timeout using MODE pin
- A choice of latch off or automatic restart mode response during current limit fault using MODE pin
- Over temperature protection to safely shutdown in the event of an overcurrent event
- De-glitched fault reporting for brown-out and overvoltage faults
- Look ahead overload current fault indication (see the [Look Ahead Overload Current Fault Indicator](#) section)

9.2 Functional Block Diagram



9.3 Feature Description

9.3.1 Undervoltage Lockout (UVLO)

Undervoltage comparator input. When the voltage at UVLO pin falls below $V_{(UVLOF)}$ during input power fail or input undervoltage fault, the internal FET quickly turns off and \overline{FLT} is asserted. The UVLO comparator has a hysteresis of 90 mV. To set the input UVLO threshold, connect a resistor divider network from IN supply to UVLO terminal to RTN as shown in [Figure 9-1](#).

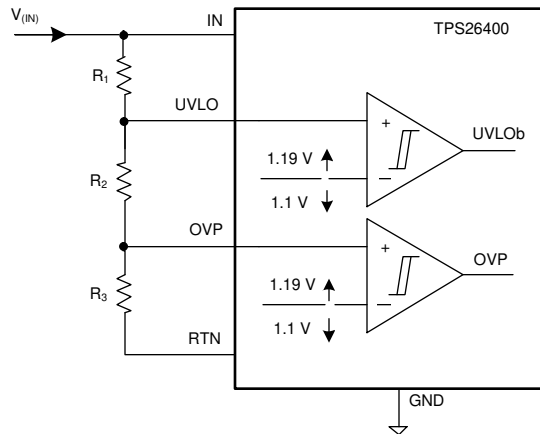


图 9-1. UVLO and OVP Thresholds Set by R_1 , R_2 and R_3

The TPS2640 also features a factory set 15-V input supply undervoltage lockout $V_{(IN_UVLO)}$ threshold with 1-V hysteresis. This feature can be enabled by connecting the UVLO terminal directly to the RTN terminal. If the Under-Voltage Lock-Out function is not needed, the UVLO terminal must be connected to the IN terminal. UVLO terminal must not be left floating.

The device also implements an internal power ON reset (POR) function on the IN terminal. The device disables the internal circuitry when the IN terminal voltage falls below internal POR threshold $V_{(PORF)}$. The internal POR threshold has a hysteresis of 275 mV.

9.3.2 Overvoltage Protection (OVP)

The TPS2640 incorporate circuitry to protect the system during overvoltage conditions. A voltage more than $V_{(OVPR)}$ on OVP pin turns off the internal FET and protects the downstream load. To program the OVP threshold externally, connect a resistor divider from IN supply to OVP terminal to RTN as shown in 图 9-1. The TPS2640 also feature a factory set 33-V Input overvoltage cut off $V_{(IN_OVP)}$ threshold with a 2-V hysteresis. This feature can be enabled by connecting the OVP terminal directly to the RTN terminal. 图 7-26 illustrates the overvoltage cut-off functionality.

Programmable output overvoltage clamp can also be achieved using TPS26400 by connecting the resistor ladder

from V_{out} to OVP to RTN as shown in 图 9-2 . This results in clamping of output voltage close to OVP setpoint by resistors R_4 and R_5 . as shown in 图 9-3. This scheme will also help in achieving minimal system I_q during off state. For this OVP configuration, use $R_4 > 90 \text{ k}\Omega$.

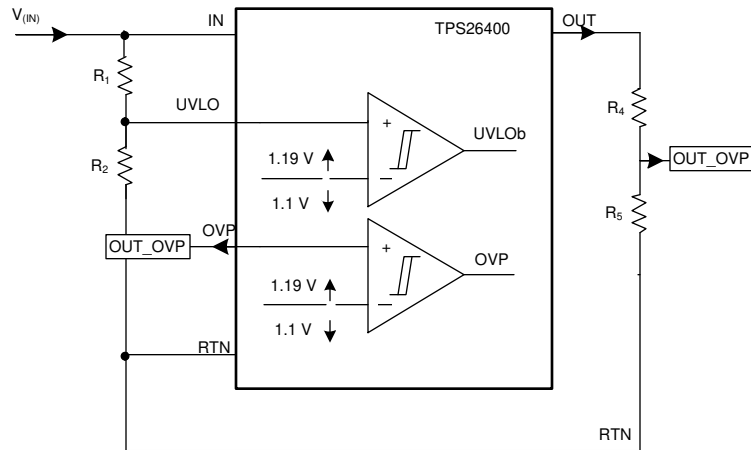


图 9-2. Programmable Output OV Clamp

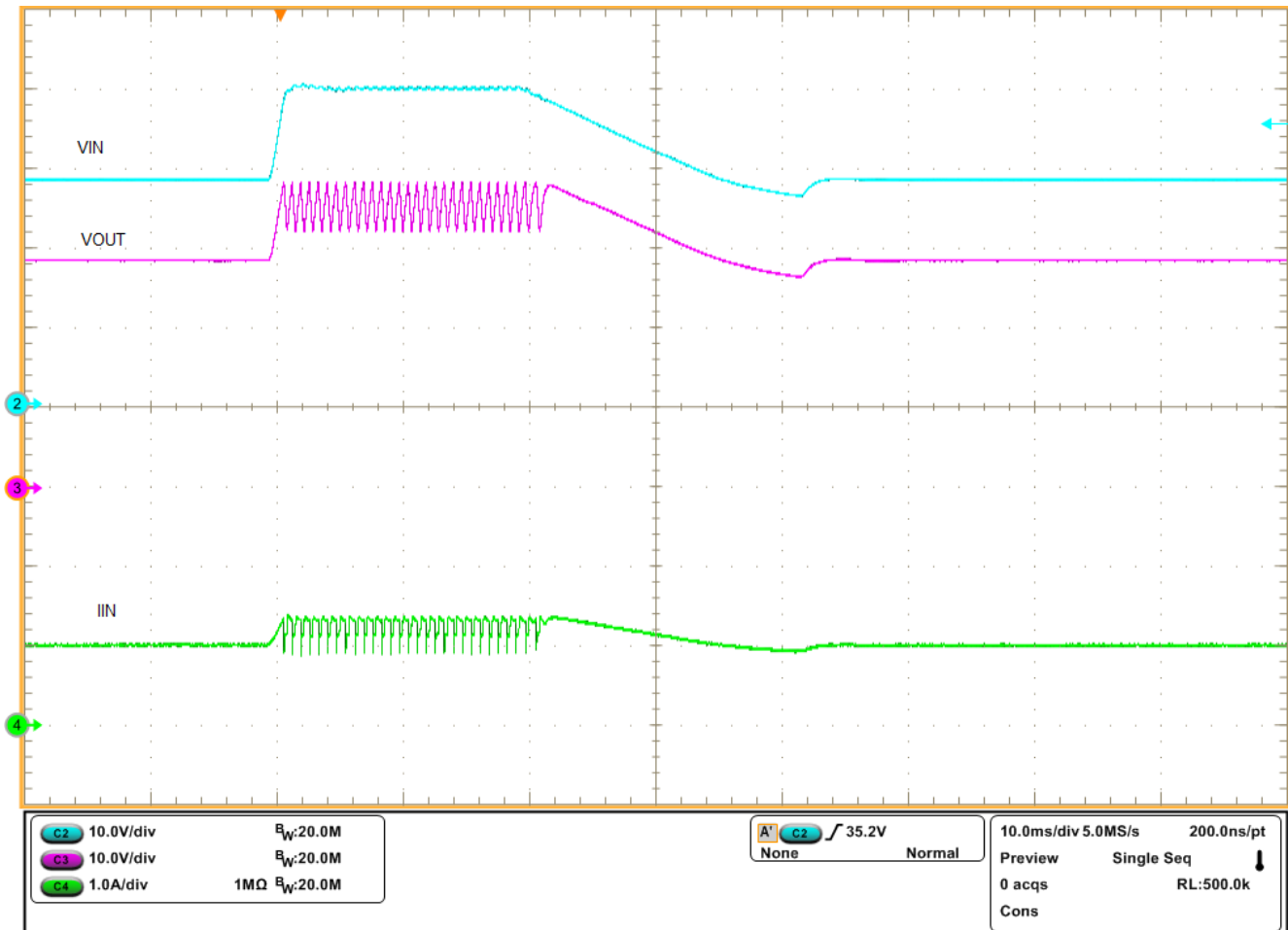
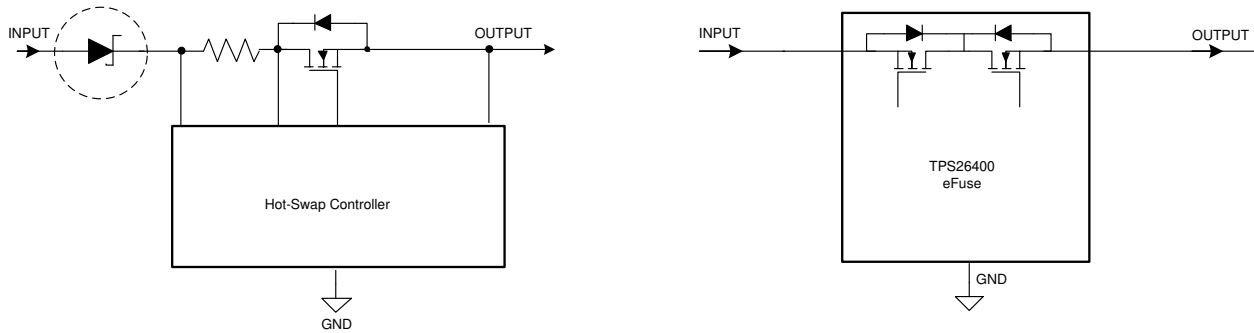


图 9-3. Programmable Output Overvoltage Clamp Response

9.3.3 Reverse Input Supply Protection

To protect the electronic systems from reverse input supply due to miswiring, often a power component like a schottky diode is added in series with the supply line as shown in 图 9-4. These additional discretes result in a lossy and bulky protection solution. The TPS26400 devices feature fully integrated reverse input supply

protection and does not need an additional diode. These devices can withstand - 42 V reverse voltage without damage. 图 9-5 illustrates the reverse input polarity protection functionality.



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图 9-4. Reverse Input Supply Protection Circuits - Discrete vs TPS26400

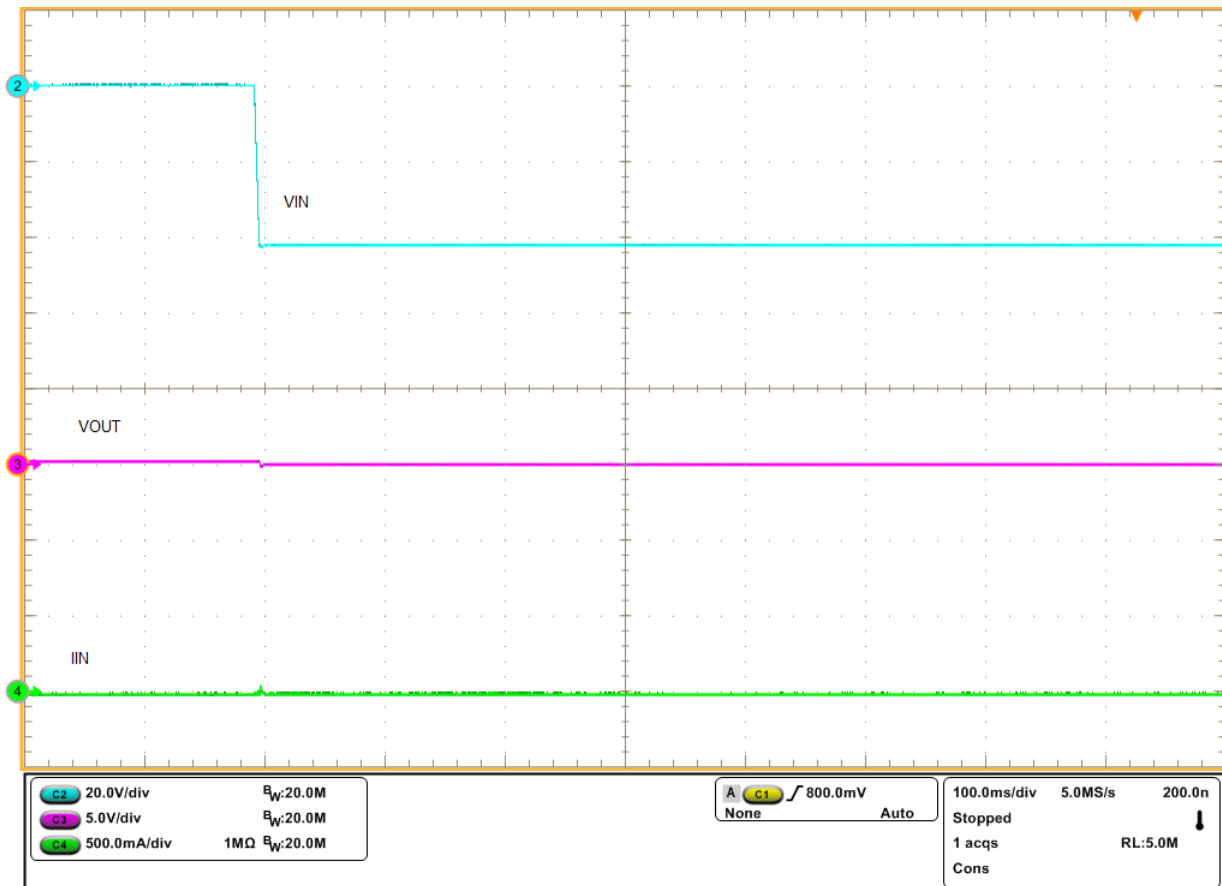


图 9-5. Reverse Input Supply Protection at - 42 V

9.3.4 Hot Plug-In and In-Rush Current Control

The device is designed to control the in-rush current upon insertion of a card into a live backplane or other "hot" power source. This limits the voltage sag on the backplane's supply voltage and prevents unintended resets of the system power. The controlled start-up also helps to eliminate conductive and radiative interferences. An external capacitor connected from the dVdT pin to RTN defines the slew rate of the output voltage at power-on as shown in 图 9-6 and 图 9-7.

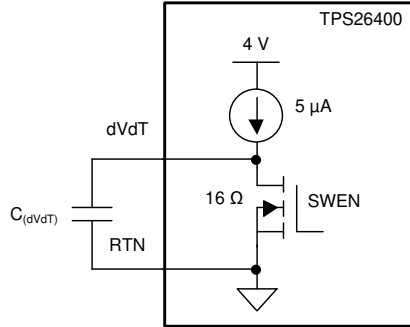


图 9-6. Output Ramp Up Time t_{dVdT} is Set by $C_{(dVdT)}$

The dVdT pin can be left floating to obtain a predetermined slew rate (t_{dVdT}) on the output. When the terminal is left floating, the devices set an internal output voltage ramp rate of 23.9 V/1.6 ms. A capacitor can be connected from dVdT pin to RTN to program the output voltage slew rate slower than 23.9 V/1.6 ms. Use [方程式 1](#) and [Equation 2](#) to calculate the external $C_{(dVdT)}$ capacitance.

[方程式 1](#) governs slew rate at start-up.

$$I_{(dVdT)} = \left(\frac{C_{(dVdT)}}{\text{Gain}_{(dVdT)}} \right) \times \left(\frac{dV_{(OUT)}}{dt} \right) \quad (1)$$

where

- $I_{(dVdT)} = 4.7 \mu A$ (typical)
- $\frac{dV_{(OUT)}}{dt}$
- $\text{Gain}_{(dVdT)} = \text{dVdT to } V_{OUT} \text{ gain} = 24.6$

The total ramp time (t_{dVdT}) of $V_{(OUT)}$ for 0 to $V_{(IN)}$ can be calculated using [方程式 2](#).

$$t_{dVdT} = 8 \times 10^3 \times V_{(IN)} \times C_{(dVdT)} \quad (2)$$

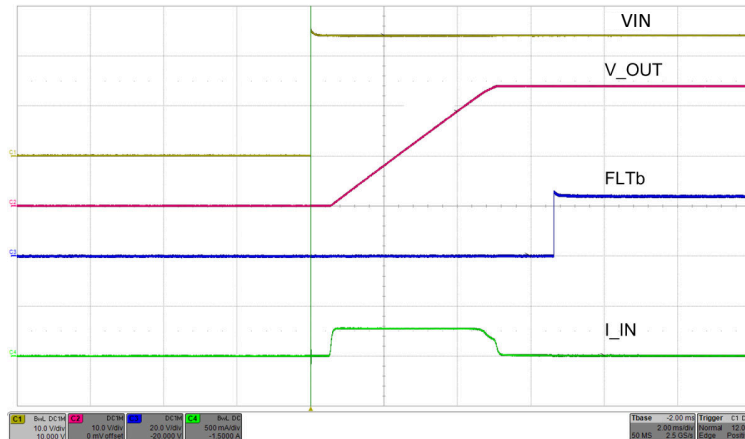


图 9-7. Hot Plug-In and In-Rush Current Control at 24-V Input

9.3.5 Overload and Short Circuit Protection

The device monitors the load current by sensing the voltage across the internal sense resistor. The FET current is monitored during start-up and normal operation.

9.3.5.1 Overload Protection

The device offers following choices for the overload protection fault response:

- Active current limiting (Auto-retry/Latch-off modes)
- Electronic Circuit Breaker with overload timeout (Auto-retry)

See the configurations in [Table 1](#) to select a specific overload fault response.

表 9-1. Overload Fault Response Configuration Table

MODE PIN CONFIGURATION	OVERLOAD PROTECTION TYPE	DEVICE
Open	Electronic circuit breaker with auto-retry	TPS26400
Shorted to RTN	Active current limiting with auto-retry	TPS26400
A 402-k Ω resistor across MODE pin to RTN pin	Active current limiting with latch-off	TPS26400

9.3.5.1.1 Active Current Limiting

When the active current limiting mode is selected, during overload events, the device continuously regulates the load current to the overcurrent limit $I_{(OL)}$ programmed by the $R_{(ILIM)}$ resistor as shown in [方程式 3](#).

$$I_{OL} = \frac{12}{R_{(ILIM)}} \quad (3)$$

where

- $I_{(OL)}$ is the overload current limit in Ampere
- $R_{(ILIM)}$ is the current limit resistor in k Ω

During an overload condition, the internal current-limit amplifier regulates the output current to $I_{(LIM)}$. The FLT signal assert after a delay of 875 μ s. The output voltage droops during the current regulation, resulting in increased power dissipation in the device. If the device junction temperature reaches the thermal shutdown threshold ($T(TSD)$), the internal FET is turn off. The device configured in latch-off mode stays latched off until it is reset by either of the following conditions:

- Cycling $V(IN)$ below $V(PORF)$
- Toggling \overline{SHDN}

Whereas the device configured in auto-retry mode, commences an auto-retry cycle 512 ms after $T_J < [T(TSD) - 10^\circ\text{C}]$. The FLT signal remains asserted until the fault condition is removed and the device resumes normal operation. [图 9-8](#) and [图 9-9](#) illustrates behavior of the system during current limiting with auto-retry functionality.

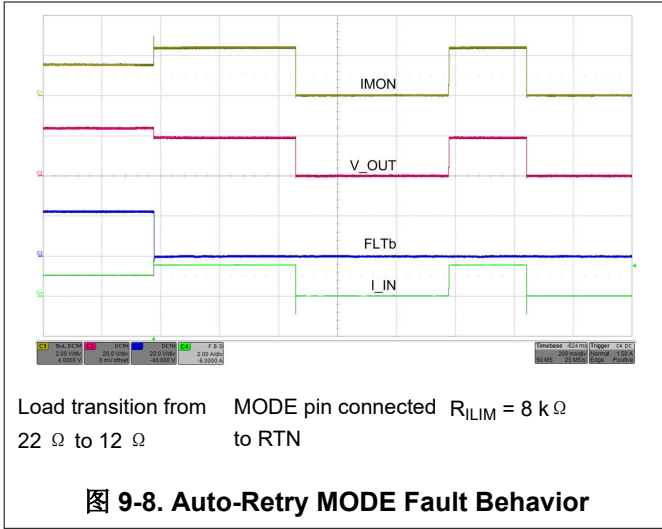


图 9-8. Auto-Retry MODE Fault Behavior



图 9-9. Response During Coming Out of Overload Fault

9.3.5.1.2 Electronic Circuit Breaker with Overload Timeout, MODE = OPEN

In this mode, during overload events, the device allows the overload current to flow through the device until $I_{(LOAD)} < I_{(FASTRIP)}$. The circuit breaker threshold $I_{(CB)}$ can be programmed using the $R_{(ILIM)}$ resistor as shown in 方程式 4.

$$I_{(CB)} = \frac{12}{R_{(ILIM)}} + 0.03A \quad (4)$$

where

- $I_{(CB)}$ is circuit breaker current threshold in Ampere
- $R_{(ILIM)}$ is the current limit resistor in $k\Omega$

An internal timer starts when $I_{(CB)} < I_{(LOAD)} < I_{(FASTRIP)}$, and when the timer exceeds $t_{CB(dly)}$, the device turns OFF the internal FET and FLT is asserted. After the internal FET is turned off,

the device commences an auto-retry cycle after 540 ms. The FLT signal remains asserted until the fault condition is removed and the device resumes normal operation. 图 9-10 and 图 9-11 illustrate behavior of the system during electronic circuit breaker with auto-retry functionality.

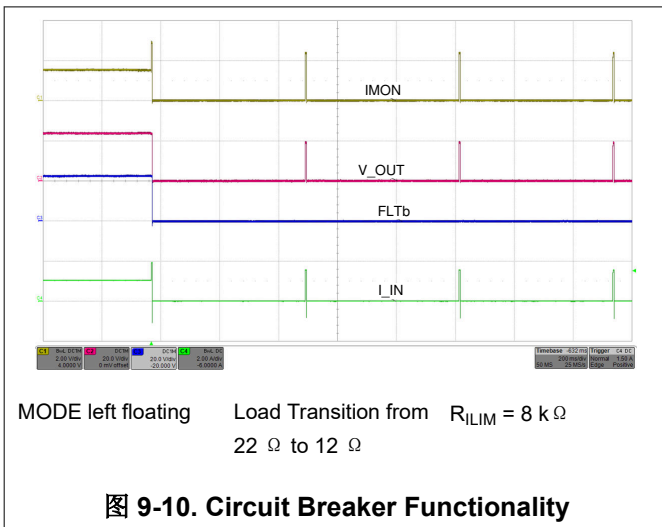


图 9-10. Circuit Breaker Functionality

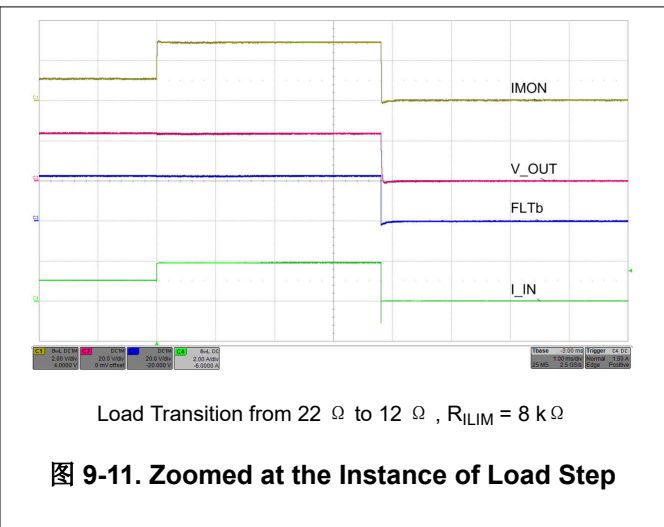
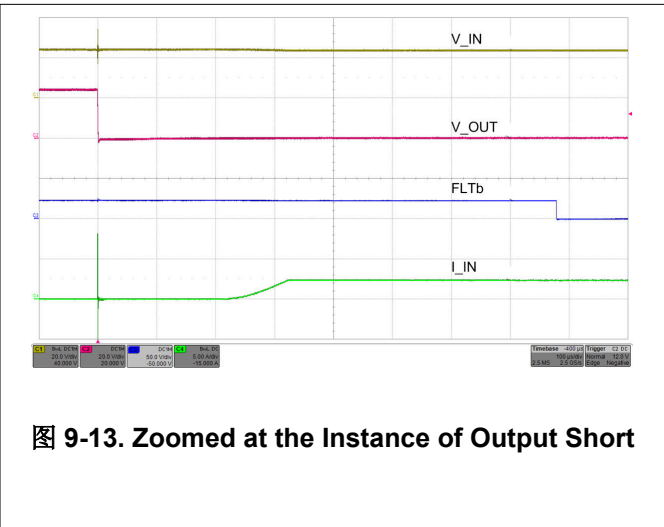
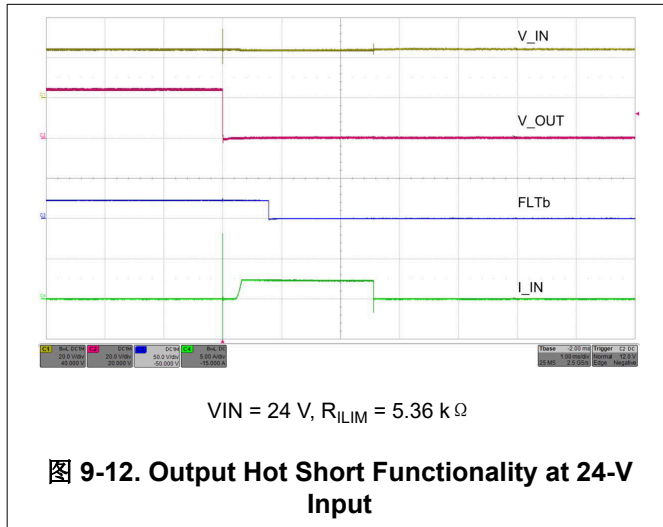


图 9-11. Zoomed at the Instance of Load Step

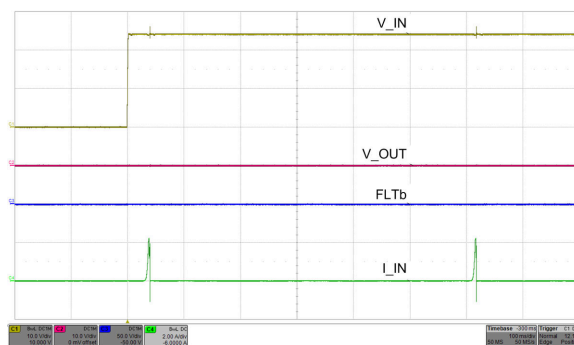
9.3.5.2 Short Circuit Protection

During a transient output short circuit event, the current through the device increases very rapidly. As the current limit amplifier cannot respond quickly to this event due to its limited bandwidth, the device incorporates a fast-trip comparator, with a threshold $I_{(FASTRIP)}$. The fast-trip comparator turns off the internal FET within 250 ns (typical), when the current through the FET exceeds $I_{(FASTRIP)}$ ($I_{(OUT)} > I_{(FASTRIP)}$), and terminates the rapid short-circuit peak current. The fast-trip threshold is internally set to 87% higher than the programmed overload current limit ($I_{(FASTRIP)} = 1.87 \times I_{(OL)} + 0.015$). The fast-trip circuit holds the internal FET off for only a few microseconds, after which the device turns back on slowly, allowing the current-limit loop to regulate the output current to $I_{(OL)}$. Then, device behaves similar to overload condition. 图 9-12 和 图 9-13 illustrate the behavior of the system when the current exceeds the fast-trip threshold.



9.3.5.2.1 Start-Up With Short-Circuit On Output

When the device is started with short-circuit on the output, it limits the load current to the current limit $I_{(OL)}$ and behaves similar to the overload condition. 图 9-14 illustrates the behavior of the device in this condition. This feature helps in quick isolation of the fault and hence ensures stability of the DC bus



MODE pin connected to RTN
 $V_{IN} = 24\text{ V}, R_{LIM} = 5.36\text{ k}\Omega$

图 9-14. Start-Up With Short on Output

9.3.5.3 FAULT Response

The \overline{FLT} open-drain output asserts (active low) under following conditions:

- Fault events such as undervoltage, overvoltage, over load, reverse current and thermal shutdown conditions

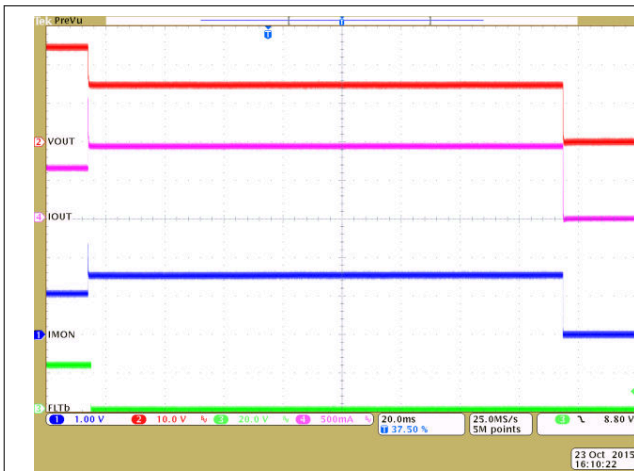
- When the device enters low current shutdown mode when SHDN is pulled low
- During start-up when the internal FET GATE is not fully enhanced

The device is designed to eliminate false reporting by using an internal "de-glitch" circuit for fault conditions without the need for an external circuitry.

The $\overline{\text{FLT}}$ signal can also be used as Power Good indicator to the downstream loads like DC-DC converters. An internal Power Good (PGOOD) signal is OR'd with the fault logic. During start-up, when the device is operating in dVdT mode, PGOOD and $\overline{\text{FLT}}$ remains low and is de-asserted after the dVdT mode is completed and the internal FET is fully enhanced. The PGOOD signal has deglitch time incorporated to ensure that internal FET is fully enhanced before heavy load is applied by the downstream converters. Rising deglitch delay is determined by $t_{\text{PGOOD(decl)}} = \text{Maximum} \{ (875 + 20 \times C_{(\text{dVdT})}), t_{\text{PGOODR}} \}$, where $C_{(\text{dVdT})}$ is in nF and $t_{\text{PGOOD(decl)}}$ is in μs . $\overline{\text{FLT}}$ can be left open or connected to RTN when not used. $V_{(\text{IN})}$ falling below $V_{(\text{PORF})} = 3.72\text{ V}$ resets $\overline{\text{FLT}}$.

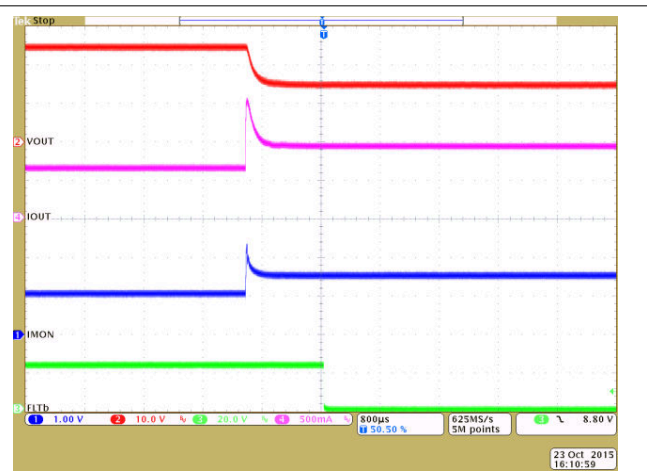
9.3.5.3.1 Look Ahead Overload Current Fault Indicator

With the device configured in current limit operation and when the overload condition exists for more than t_{PGOODF} , 875 μs (typical), the $\overline{\text{FLT}}$ asserts to warn of impending turnoff of the internal FETs due to the subsequent thermal shutdown event. 图 9-15 and 图 9-16 depict this behavior. The $\overline{\text{FLT}}$ signal remains asserted until the fault condition is removed and the device resumes normal operation.



RILIM = 12 k Ω RILIM = 12 k Ω Load transient event
MODE pin connected from 37 Ω to 15 Ω
to RTN

图 9-15. Output Turnoff Due to Thermal Shutdown With FLT Asserted in Advance



RILIM = 12 k Ω RILIM = 12 k Ω Load transient event
MODE pin connected from 37 Ω to 15 Ω
to RTN

图 9-16. Look Ahead Overload Current Fault Indication

9.3.5.4 Current Monitoring

The current source at IMON terminal is internally configured to be proportional to the current flowing from IN to OUT. This current can be converted into a voltage using a resistor $R_{(\text{IMON})}$ from IMON terminal to RTN terminal. The IMON voltage can be used as a means of monitoring current flow through the system. The maximum voltage range ($V_{(\text{IMONmax})}$) for monitoring the current is limited to minimum of $([V_{(\text{IN})} - 1.5\text{ V}, 4\text{ V}])$ to ensure linear output. This puts a limitation on maximum value of $R_{(\text{IMON})}$ resistor and is determined by 方程式 5.

$$R_{(\text{IMONmax})} = \frac{\text{Min} [(V_{(\text{IN})} - 1.5), 4\text{ V}]}{1.8 \times I_{(\text{LIM})} \times \text{GAIN}_{(\text{IMON})}} \quad (5)$$

The output voltage at IMON terminal is calculated using 方程式 6 and Equation 7.

For $I_{OUT} > 50$ mA,

$$V_{(IMON)} = [I_{(OUT)} \times GAIN_{(IMON)}] \times R_{(IMON)} \quad (6)$$

where,

- $GAIN_{(IMON)}$ is the gain factor $I_{(IMON)}:I_{(OUT)} = 78.4 \mu A/A$ (Typical)
- $I_{(OUT)}$ is the load current
- $I_{(MON_OS)} = 2 \mu A$ (Typical)

For $I_{OUT} < 50$ mA (typical), use Equation 7.

$$V_{(IMON)} = (I_{(MON_OS)}) \times R_{(IMON)} \quad (7)$$

This pin must not have a bypass capacitor to avoid delay in the current monitoring information. In case of reverse input polarity fault, an external 100-k Ω resistor is recommended between IMON pin and ADC input to limit the current through the ESD protection structures of the ADC.

9.3.5.5 IN, OUT, RTN, and GND Pins

The device has two pins for input (IN) and output (OUT). All IN pins must be connected together and to the power source. A ceramic bypass capacitor close to the device from IN to GND is recommended to alleviate bus transients. The recommended input operating voltage range is 4.2 to 42 V. Similarly all OUT pins must be connected together and to the load. $V_{(OUT)}$, in the ON condition, is calculated using Equation 8.

$$V_{(OUT)} V_{(IN)} - (RON) \times I_{(OUT)} \quad (8)$$

Where,

- RON is the total ON resistance of the internal FETs.

GND pin must be connected to the system ground. RTN is the device ground reference for all the internal control blocks. Connect the TPS26400 support components: $R_{(ILIM)}$, $C_{(dVdT)}$, $R_{(IMON)}$, $R_{(MODE)}$ and resistors for UVLO and OVP with respect to the RTN pin. Internally, the device has reverse input polarity protection block between RTN and the GND terminal. Connecting RTN pin to GND pin disables the reverse input polarity protection feature and the TPS26400 gets permanently damaged when operated under this fault event.

9.3.5.6 Thermal Shutdown

The device has a built-in overtemperature shutdown circuitry designed to protect the internal FETs, if the junction temperature exceeds $T_{(TSD)}$. After the thermal shutdown event, depending upon the mode of fault response, the device either latches off or commences an auto-retry cycle 512 ms after $T_J < [T_{(TSD)} - 10^\circ C]$. During the thermal shutdown, the fault pin \overline{FLT} pulls low to indicate a fault condition.

9.3.5.7 Low Current Shutdown Control (\overline{SHDN})

The internal FETs and hence the load current can be switched off by pulling the \overline{SHDN} pin below 0.76 V threshold with a micro-controller GPIO pin or can be controlled remotely with an opto-isolator device as shown in [图 9-17](#) and [图 9-18](#). The device quiescent current reduces to 20 μA (typical) in shutdown state. To assert \overline{SHDN} low, the pull down must sink at least 10 μA at 400 mV. To enable the device, \overline{SHDN} must be pulled up to at least 1 V. Once the device is enabled, the internal FETs turn on with dVdT mode.

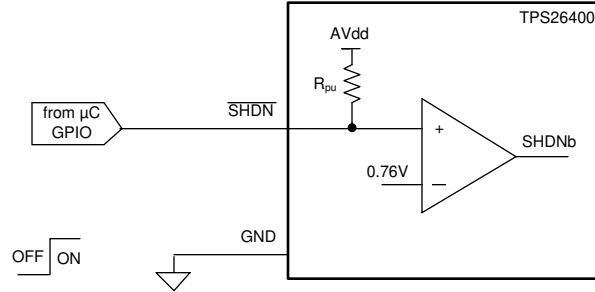


图 9-17. Shutdown Control

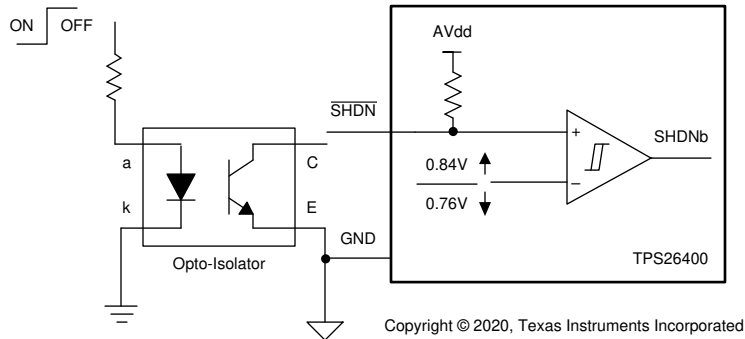


图 9-18. Opto-Isolator Shutdown Control

9.4 Device Functional Modes

Different operational modes of the device are explained in 表 9-2.

表 9-2. Device Operational Differences Under Different MODE Configurations

MODE/PIN CONFIGURATION	MODE CONNECTED TO RTN (CURRENT LIMIT WITH AUTO-RETRY)	A 402-k Ω RESISTOR CONNECTED BETWEEN MODE AND RTN PINS (CURRENT LIMIT WITH LATCHOFF)	MODE PIN = OPEN (CIRCUIT BREAKER WITH AUTO-RETRY)
Start-up	Inrush current controlled by dVdT		
	Inrush limited to $I_{(OL)}$ level as set by $R_{(ILIM)}$	Inrush limited to $I_{(OL)}$ level as set by $R_{(ILIM)}$	Inrush limited to $I_{(OL)}$ level as set by $R_{(ILIM)}$
			Fault timer runs when current is limited to $I_{(OL)}$
			Fault timer expires after $t_{CB(dly)}$ causing the FETs to turnoff
	If $T_J > T_{(TSD)}$, device turns off		
Overcurrent response	Current is limited to $I_{(OL)}$ level as set by $R_{(ILIM)}$	Current is limited to $I_{(OL)}$ level as set by $R_{(ILIM)}$	Current is allowed through the device if $I_{(LOAD)} < I_{(FASTTRIP)}$
	Power dissipation increases as $V_{(IN)} - V_{(OUT)}$ increases	Power dissipation increases as $V_{(IN)} - V_{(OUT)}$ increases	Fault timer runs when the current increases above $I_{(OL)}$
			Fault timer expires after $t_{CB(dly)}$ causing the FETs to turnoff
	Device turns off when $T_J > T_{(TSD)}$	Device turns off when $T_J > T_{(TSD)}$	Device turns off if $T_J > T_{(TSD)}$ before timer expires
	Device attempts restart 540 ms after $T_J < [T_{(TSD)} - 10^\circ\text{C}]$	Device remains off	TPS26400 device attempts to restart 540 ms after $T_J < [T_{(TSD)} - 10^\circ\text{C}]$

表 9-2. Device Operational Differences Under Different MODE Configurations (continued)

MODEPIN CONFIGURATION	MODE CONNECTED TO RTN (CURRENT LIMIT WITH AUTO-RETRY)	A 402-k Ω RESISTOR CONNECTED BETWEEN MODE AND RTN PINS (CURRENT LIMIT WITH LATCHOFF)	MODE PIN = OPEN (CIRCUIT BREAKER WITH AUTO-RETRY)
Short-circuit response	Fast turnoff when $I_{(LOAD)} > I_{(FASTRIP)}$		
	Quick restart and current limited to $I_{(OL)}$, follows standard start-up		

10 Application and Implementation

Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

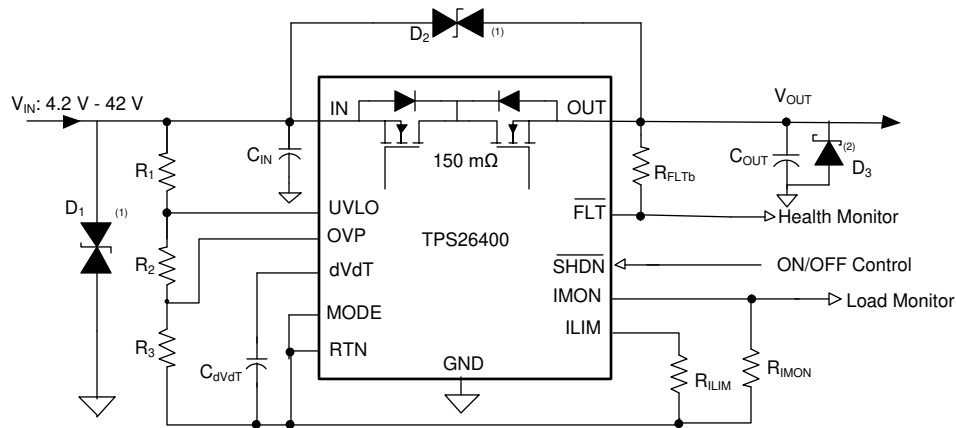
10.1 Application Information

The TPS26400 is an industrial eFuse, typically used for Hot-Swap and Power rail protection applications. It operates from 4.2 V to 42 V with programmable current limit, overvoltage, undervoltage and reverse polarity protection. The device aids in controlling in-rush current and provides robust protection against reverse current and filed miss-wiring conditions for systems such as PLCs, Industrial PCs, Control and Automation and Sensors. The device also provides robust protection for multiple faults on the system rail.

The [Detailed Design Procedure](#) section can be used to select component values for the device.

A spreadsheet design tool [TPS26400 Design Calculator](#) is available in the web product folder.

10.2 Typical Application



Note

1. Optional TVS Diodes (D1 and D2) for Power Line Surge IEC61000-4-5 [± 500 V, 2 Ω].
2. Optional Schotky Diode (D3) for output short circuit protection with inductive loads and cables.

图 10-1. 24-V, 1-A eFuse Input Protection Circuit for Industrial PLC CPU

10.2.1 Design Requirements

Table 3 shows the Design Requirements for current input protection with TPS26610.

表 10-1. Design Requirements

DESIGN PARAMETER		EXAMPLE VALUE
$I_{(IN)}$	Input current	± 20 mA
$V_{(IN)}$	Input voltage	$-V_s$ to 50 V
$V_{(OUT)}$	OutPut voltage	$\pm V_s$
$I_{(LIM)}$	Current limit	± 30 mA
R_{Burden}	Burden resistance	50 to 250 Ω

10.2.2 Detailed Design Procedure

10.2.2.1 Step by Step Design Procedure

To begin the design process, the designer needs to know the following parameters:

- Input operating voltage range
- Maximum output capacitance
- Maximum current limit
- Load during start-up
- Maximum ambient temperature

This design procedure below seeks to control junction temperature of the device in both steady state and start-up conditions by proper selection of the output ramp-up time and associated support components. The designer can adjust this procedure to fit the application and design criteria.

10.2.2.2 Undervoltage Lockout and Overvoltage Set Point

The undervoltage lockout (UVLO) and overvoltage trip point are adjusted using an external voltage divider network of R1, R2 and R3 connected between IN, UVLO, OVP and RTN pins of the device. The values required for setting the undervoltage and overvoltage are calculated by solving [方程式 9](#) and [方程式 10](#).

$$V_{(OVPR)} = \frac{R_3}{R_1 + R_2 + R_3} \times V_{(OV)} \quad (9)$$

$$V_{(UVLOR)} = \frac{R_2 + R_3}{R_1 + R_2 + R_3} \times V_{(UV)} \quad (10)$$

For minimizing the input current drawn from the power supply $\{I_{(R123)} = V_{(IN)}/(R_1 + R_2 + R_3)\}$, it is recommended to use higher value resistance for R₁, R₂ and R₃.

However, the leakage current due to external active components connected at resistor string can add error to these calculations. So, the resistor string current, I_(R123) must be chosen to be 20x greater than the leakage current of UVLO and OVP pins.

The UVLO and the OVP pins can also be connected to the RTN pin to enable the internal default V_(OV) = 33 V and V_(UV) = 15 V.

The power failure is detected on falling edge of the supply. This threshold voltage is 7.5% lower than the rising threshold, V_(UV). The voltage at which the device detects power fail can be calculated using [Equation 12](#).

$$V_{(PFAIL)} = 0.925 \times V_{(UV)} \quad (11)$$

10.2.2.3 Programming Current Monitoring Resistor—R_{IMON}

The voltage at IMON pin V_(IMON) represents the voltage proportional to the load current. This can be connected to an ADC of the downstream system for health monitoring of the system. The R_(IMON) must be configured based on the maximum input voltage range of the ADC used. R_(IMON) is set using [方程式 12](#).

$$R_{(IMON)} = \frac{V_{(IMONmax)}}{I_{(LIM)} \times 75 \times 10^{-6}} \quad (12)$$

For I_(LIM) = 1 A, and considering the operating voltage range of ADC from 0 V to 2.5 V, V_(IMONmax) is 2.5 V and R_(IMON) is determined by [方程式 13](#).

$$R_{(IMON)} = \frac{2.5}{1 \times 75 \times 10^{-6}} = 33.3k\Omega \quad (13)$$

Selecting the $R_{(IMON)}$ value less than determined ensures that ADC limits are not exceeded for maximum value of the load current. Choose the closest standard 1% resistor value: $R_{(IMON)} = 33.2 k\Omega$.

If current monitoring up to $I_{(FASTRIP)}$ is desired, $R_{(IMON)}$ can be reduced by a factor of 1.8 as shown in 方程式 5.

10.2.2.4 Setting Output Voltage Ramp Time—(t_{dVdT})

For a successful design, the junction temperature of the device must be kept below the absolute-maximum rating during dynamic (start-up) and steady state conditions. The dynamic power dissipation is often an order magnitude greater than the steady state power dissipation. It is important to determine the right start-up time and the in-rush current limit for the system to avoid thermal shutdown during start-up with and without load.

The ramp-up capacitor $C_{(dVdT)}$ is calculated considering the two possible cases:

10.2.2.4.1 Case 1: Start-Up Without Load—Only Output Capacitance $C_{(OUT)}$ Draws Current During Start-Up

During start-up, as the output capacitor charges, the voltage difference across the internal FET decreases, and the power dissipation decreases. Typical ramp-up of the output voltage, inrush current and instantaneous power dissipated in the device during start-up are shown in 图 10-2. The average power dissipated in the device during start-up is equal to the area of triangular plot (red curve in 图 10-3) averaged over t_{dVdT} .

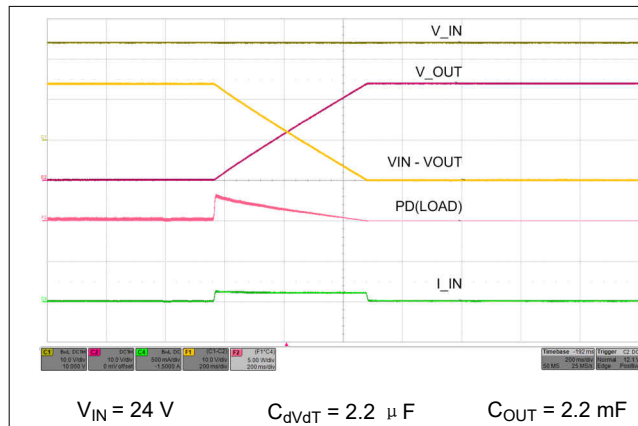


图 10-2. Start-Up Without Load

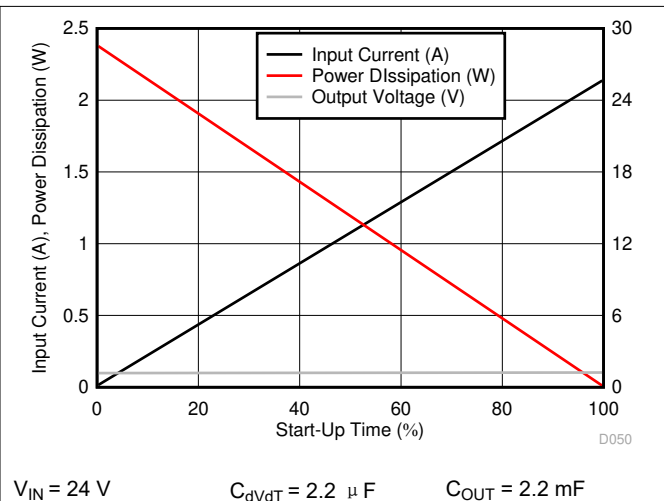


图 10-3. $PD_{(INRUSH)}$ Due to Inrush Current

The inrush current is determined as shown in 方程式 14.

$$I = C \times \frac{dV}{dT} \geq I_{(INRUSH)} = C_{(OUT)} \times \frac{V_{(IN)}}{t_{dVdT}} \quad (14)$$

Average power dissipated during start-up is given by 方程式 15.

$$PD_{(INRUSH)} = 0.5 \times V_{(IN)} \times I_{(INRUSH)} \quad (15)$$

Equation 15 assumes that the load does not draw any current until the output voltage reaches its final value.

Choose the closest standard value: 2.2- μ F/16-V capacitor.

The inrush power dissipation is calculated, using 方程式 21.

$$P_{D(INRUSH)} = 0.5 \times V_{(IN)} = I_{(INRUSH)} 1.2W \quad (21)$$

where

- $V_{(IN)} = 24 V$
- $I_{(INRUSH)} = 0.1 A$

Considering the start-up with 48- Ω load, the additional power dissipation, is calculated using 方程式 22.

$$P_{D(LOAD)} = \left(\frac{1}{6}\right) \times \frac{V_{(IN)}^2}{R_{L(SU)}} = 2 W \quad (22)$$

where

- $V_{(IN)} = 24 V$
- $R_{L(SU)} = 48 \Omega$

The total device power dissipation during start-up is given by 方程式 23.

$$P_{D(STARTUP)} = P_{D(INRUSH)} + P_{D(LOAD)} = 3.2W \quad (23)$$

where

- $P_{D(INRUSH)} = 1.2 W$
- $P_{D(LOAD)} = 2 W$

The power dissipation with or without load, for a selected start-up time must not exceed the thermal shutdown limits as shown in 图 10-6 .

From the thermal shutdown limit graph, at $T_A = 85^\circ C$, thermal shutdown time for 3.2 W is close to 28000 ms. It is safe to have a minimum 30% margin to allow for variation of the system parameters such as load, component tolerance, input voltage and layout. Selected 2.2- μ F C_{dVdT} capacitor and 528-ms start-up time (t_{dVdT}) are within limit for successful start-up with 48- Ω load.

Higher value $C_{(dVdT)}$ capacitor can be selected to further reduce the power dissipation during start-up.

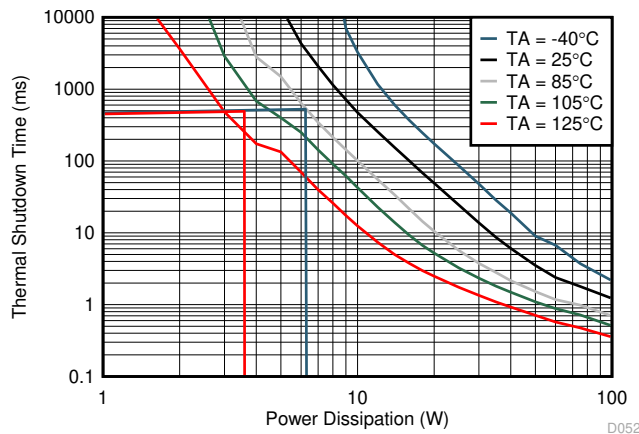


图 10-6. Thermal Shutdown Time vs Power Dissipation

10.2.2.4.3 Support Component Selections— R_{FLTb} and $C_{(IN)}$

The R_{FLTb} serves as pull-up for the open-drain fault output. The current sink by this pin must not exceed 10 mA (see the [Absolute Maximum Ratings](#) table). Typical resistance value in the range of 10 kΩ to 100 kΩ is

recommended for RFLTb. The C_{IN} is a local bypass capacitor to suppress noise at the input. Typical capacitance value in the range of $0.1 \mu\text{F}$ to $1 \mu\text{F}$ is recommended for $C_{(IN)}$.

10.2.3 Application Curves

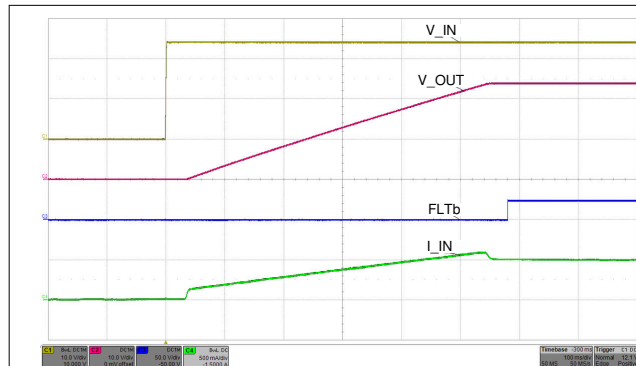


图 10-7. Start-Up With VIN—48-Ω Load

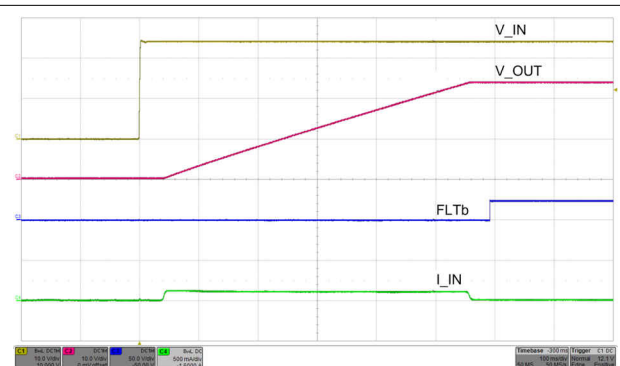


图 10-8. Start-Up With VIN—No Load

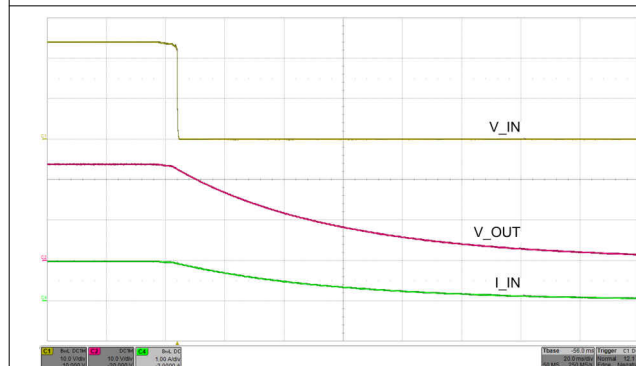


图 10-9. Power Fail With 24-Ω Load—Supports 1-A Load for 10-ms Power Fail

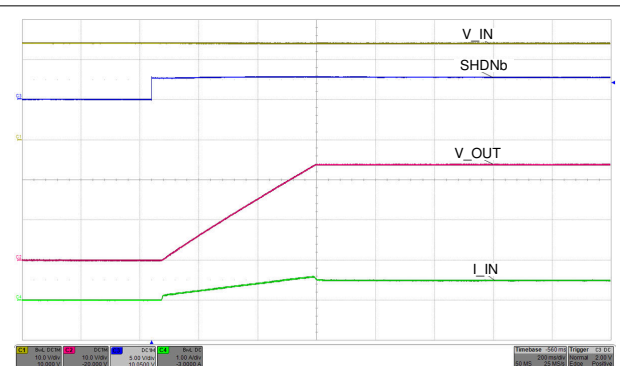


图 10-10. Start-Up With Shutdown Pin—48-Ω Load

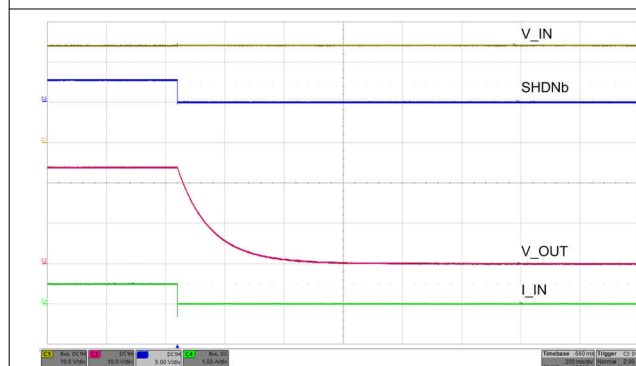


图 10-11. Power Down With Shutdown Pin—48-Ω Load

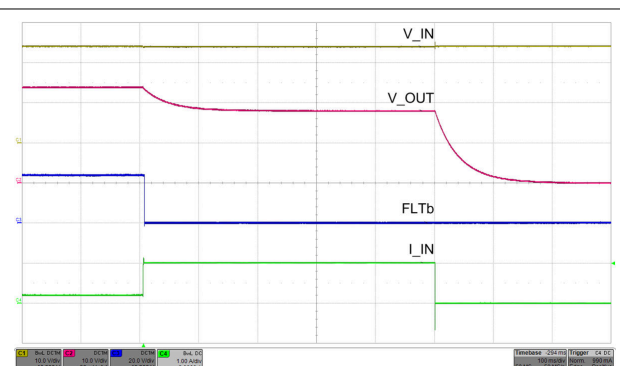
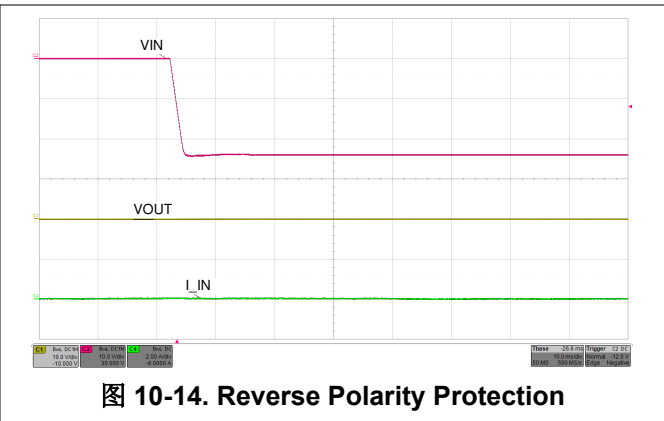
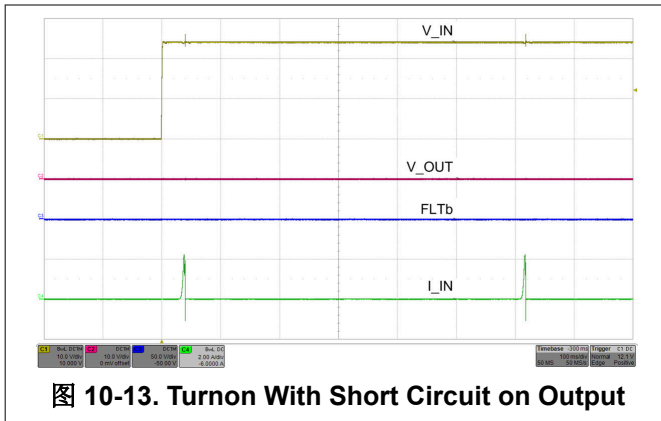


图 10-12. Over Load Response—Load Stepped from 100-Ω to 18-Ω Load



10.3 System Examples

10.3.1 Active ORing Operation

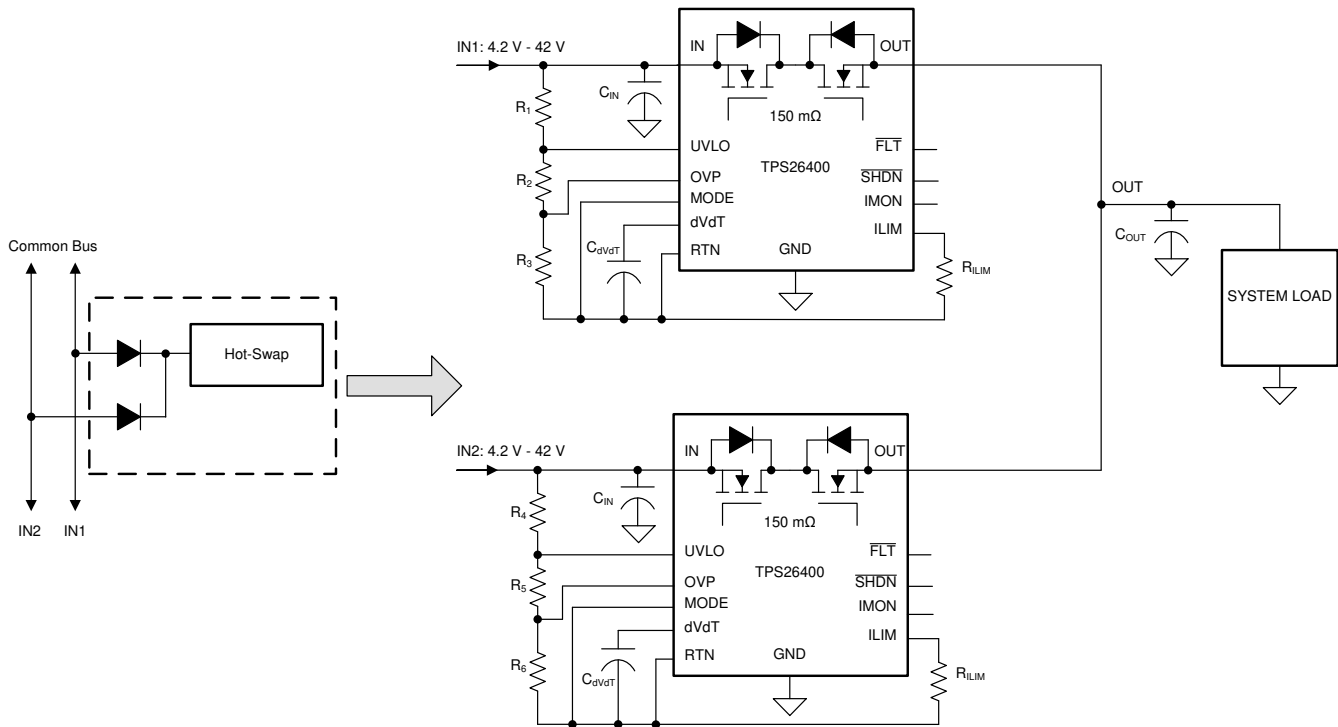


图 10-15 shows a typical redundant power supply configuration of the system. Schottky ORing diodes have been popular for connecting parallel power supplies, such as parallel operation of wall adapter with a battery or a hold-up storage capacitor. The disadvantage of using ORing diodes is high voltage drop and associated power loss. The TPS26400 with integrated, N-channel back to back FETs provide a simple and efficient solution.

A fast reverse comparator controls the internal FET and it is turned ON or OFF with hysteresis as shown in 图 10-16. The internal FET is turned off within 1.5 μ s (typical) as soon as $V_{(IN)} - V_{(OUT)}$ falls below -110 mV. It turns on within 40 μ s (typical) once the differential forward voltage $V_{(IN)} - V_{(OUT)}$ exceeds 100 mV. 图 10-17 and 图 10-18 show typical switch-over waveforms of Active ORing implementation using the TPS26400.

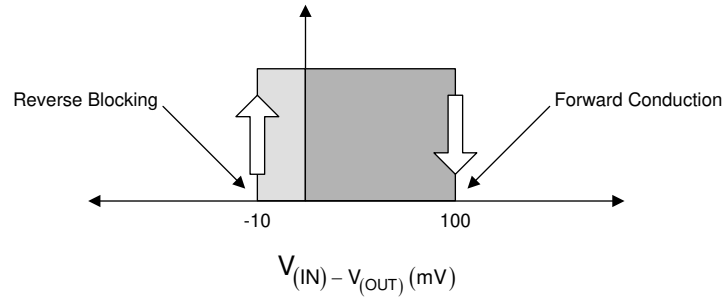


图 10-16. Active ORing Thresholds

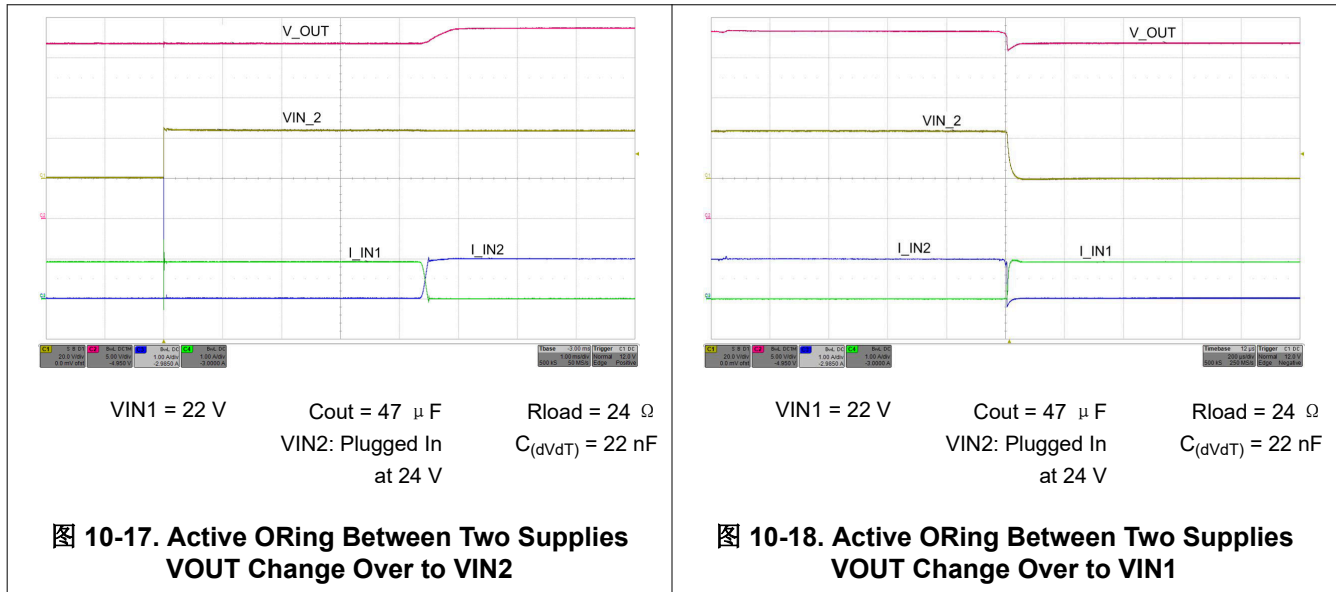


图 10-17. Active ORing Between Two Supplies VOUT Change Over to VIN2

图 10-18. Active ORing Between Two Supplies VOUT Change Over to VIN1

Note

All control pins of the un-powered TPS26400 device in the Active ORing configuration will measure approximately 0.7 V drop with respect to GND. The system micro-controller should ignore IMON and FLT pin voltage measurements of this device when these signals are being monitored.

10.3.2 Field Supply Protection in PLC, DCS I/O Modules

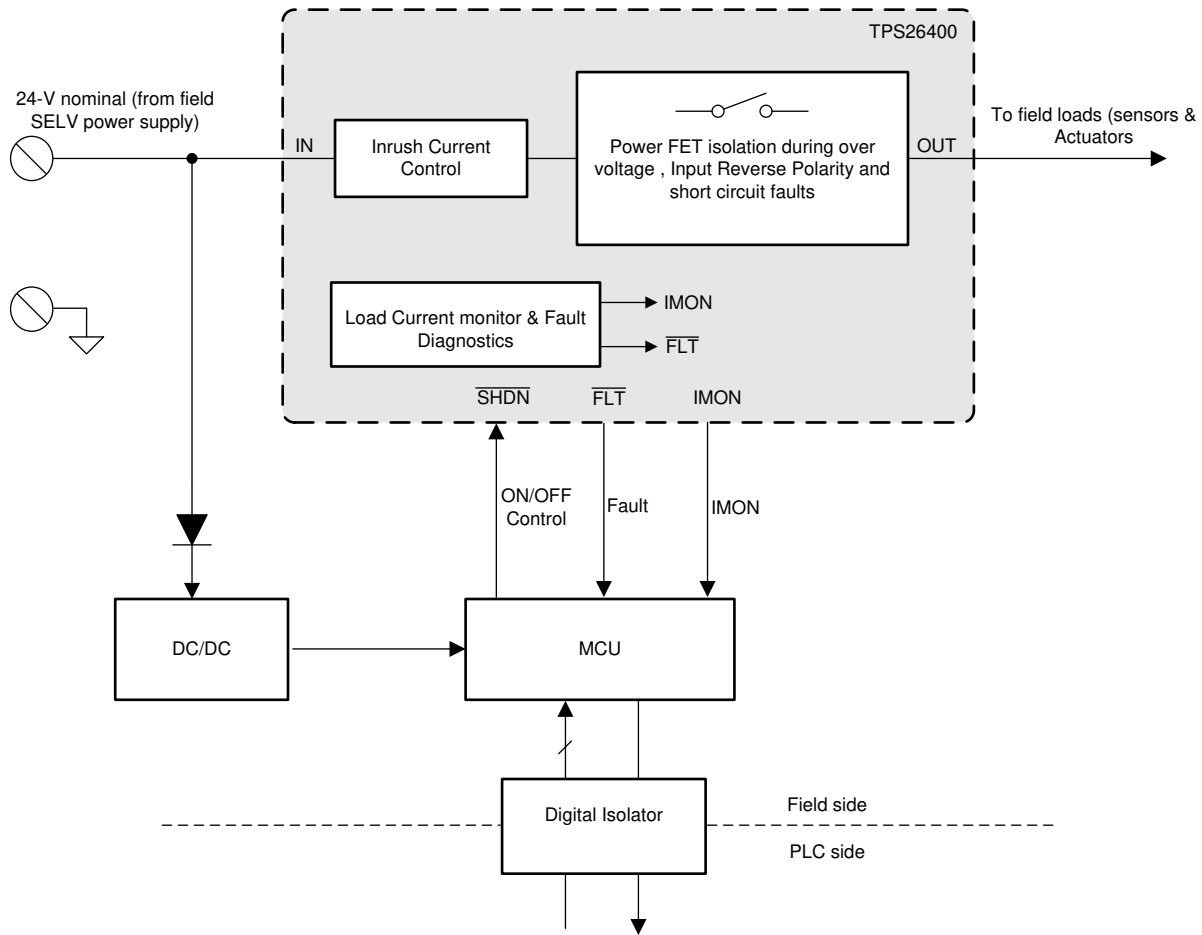


图 10-19. Power Delivery Circuit Block Diagram in I/O Modules

The PLC or Distributed Control System (DCS) I/O modules are often connected to an external field power supply to support higher power requirements of the field loads like sensors and actuators. Power-supply faults or miswiring can damage the loads or cause the loads not to operate correctly. The TPS2640 can be used as a front end protection circuit to protect and provide stable supply to the field loads. Under voltage, Over voltage and reverse polarity protection features of the TPS2640 prevent the loads to experience voltages outside the operating range, which can permanently damage the loads.

Field power supply is often connected to multiple I/O modules and is capable of delivering more current than a single I/O module can handle. Overcurrent protection scheme of the TPS2640 limits the current from the power supply to the module so that the maximum current does not rise above what the board is designed for. Fast short circuit protection scheme isolates the faulty load from the field supply quickly and prevents the field supply to dip and cause interrupts in the other I/O modules connected to the same field supply. High accurate ($\pm 5\%$ at 1 A) current limit facilitates more I/O modules to be connected to field supply. Load current monitor (IMON) and fault indication (FLT) features facilitate continuous load monitoring.

The TPS2640 also acts as a smart diode with protection against reverse current during output side miswiring. Reverse current can potentially damage the field power supply and cause the I/O modules to run hot or may cause permanent damage.

If the field power supply is connected in reverse polarity (which is not unlikely as field power supplies are usually connected with screw terminals), field loads can permanently get damaged due to the reverse voltage. The reverse polarity protection feature of the TPS2640 prevents the reverse voltage to appear at the load side.

10.3.3 Simple 24-V Power Supply Path Protection

With the TPS26400, a simple 24-V power supply path protection can be realized using a minimum of three external components as shown in the schematic diagram in 图 10-20. The external components required are: a $R_{(ILIM)}$ resistor to program the current limit, $C_{(IN)}$ and $C_{(OUT)}$ capacitors.

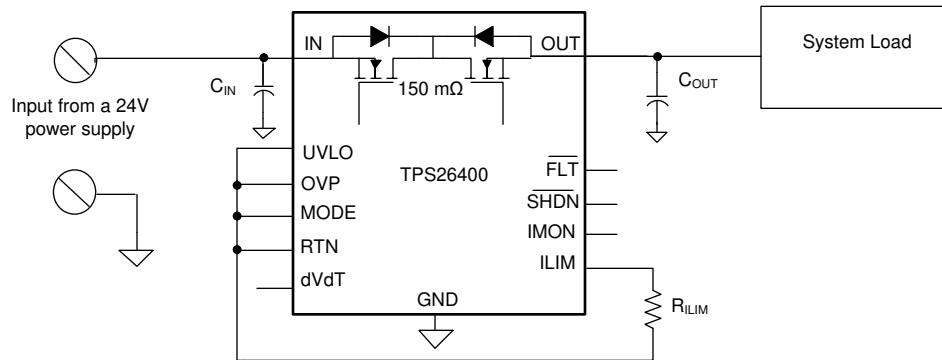


图 10-20. TPS26400 Configured for a Simple 24-V Supply Path Protection

Protection features with this configuration include:

- Load and device protection from reverse input polarity fault down to -42V
- 15 V (typical) rising under voltage lock-out threshold
- 33 V (typical) rising overvoltage cut-off threshold
- Inrush current control with 24-V/1.6-ms output voltage slew rate
- Reverse Current Blocking
- Accurate current limiting with Auto-Retry

10.4 Do's and Dont's

- Do not connect RTN to GND. Connecting RTN to GND disables the Reverse Polarity protection feature
- Connect the TPS26400 support components $R_{(ILIM)}$, $C_{(dVdT)}$, $R_{(IMON)}$, $R_{(MODE)}$ and UVLO, OVP resistors with respect to RTN pin
- Connect device PowerPAD to the RTN plane for an enhanced thermal performance

11 Power Supply Recommendations

The TPS26400 eFuse is designed for the supply voltage range of $4.2\text{ V} \leq V_{\text{IN}} \leq 42\text{ V}$. If the input supply is located more than a few inches from the device, an input ceramic bypass capacitor higher than $0.1\ \mu\text{F}$ is recommended. Power supply must be rated higher than the current limit set to avoid voltage droops during overcurrent and short circuit conditions

11.1 Transient Protection

In case of short circuit and over load current limit, when the device interrupts current flow, input inductance generates a positive voltage spike on the input and output inductance generates a negative voltage spike on the output. The peak amplitude of voltage spikes (transients) is dependent on value of inductance in series to the input or output of the device. Such transients can exceed the **Abolsute Maximum Ratings** of the device if steps are not taken to address the issue.

Typical methods for addressing transients include

- Minimizing lead length and inductance into and out of the device
- Using large PCB GND plane
- Schottky diode across the output to absorb negative spikes
- A low value ceramic capacitor (C_{IN}) to approximately $0.1\ \mu\text{F}$ to absorb the energy and dampen the transients.

The approximate value of input capacitance can be estimated with [方程式 24](#).

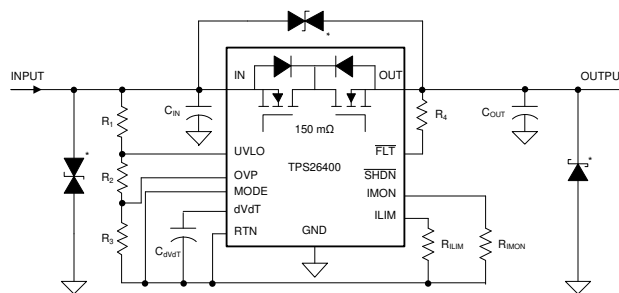
$$V_{\text{spike(Absolute)}} = V_{\text{(IN)}} + I_{\text{(Load)}} \times \sqrt{\frac{L_{\text{(IN)}}}{C_{\text{(IN)}}}} \quad (24)$$

where

- $V_{\text{(IN)}}$ is the nominal supply voltage
- $I_{\text{(LOAD)}}$ is the load current
- $L_{\text{(IN)}}$ equals the effective inductance seen looking into the source
- $C_{\text{(IN)}}$ is the capacitance present at the input

Some applications may require additional Transient Voltage Suppressor (TVS) to prevent transients from exceeding the **Abolsute Maximum Ratings** of the device. These transients can occur during positive and negative surge tests on the supply lines. In such applications it is recommended to place atleast $1\ \mu\text{F}$ of input capacitor to limit the falling slew rate of the input voltage within a maximum of $15\text{ V}/\mu\text{s}$.

The circuit implementation with optional protection components (a ceramic capacitor, TVS and schottky diode) is shown in [图 11-1](#).



A. Optional components needed for suppression of transients

图 11-1. Circuit Implementation With Optional Protection Components

12 Layout

12.1 Layout Guidelines

- For all the applications, a 0.1 μ F or higher value ceramic decoupling capacitor is recommended between IN terminal and GND.
- The optimum placement of decoupling capacitor is closest to the IN and GND terminals of the device. Care must be taken to minimize the loop area formed by the bypass-capacitor connection, the IN terminal, and the GND terminal of the IC. See [Figure 12-1](#) and [Figure 12-2](#) for PCB layout examples with HTSSOP and VQFN packages respectively.
- High current carrying power path connections must be as short as possible and must be sized to carry at least twice the full-load current.
- RTN, which is the reference ground for the device must be a copper plane or island.
- Locate all the TPS26400 support components $R_{(ILIM)}$, $C_{(dVdT)}$, $R_{(IMON)}$, and MODE, UVLO, OVP resistors close to their connection pin. Connect the other end of the component to the RTN with shortest trace length.
- The trace routing for the $R_{(ILIM)}$ and $R_{(IMON)}$ components to the device must be as short as possible to reduce parasitic effects on the current limit and current monitoring accuracy. These traces must not have any coupling to switching signals on the board.
- Protection devices such as TVS, snubbers, capacitors, or diodes must be placed physically close to the device they are intended to protect, and routed with short traces to reduce inductance. For example, a protection Schottky diode is recommended to address negative transients due to switching of inductive loads, and it must be physically close to the OUT and GND pins.
- Thermal Considerations: When properly mounted, the PowerPAD package provides significantly greater cooling ability. To operate at rated power, the PowerPAD must be soldered directly to the board RTN plane directly under the device. Other planes, such as the bottom side of the circuit board can be used to increase heat sinking in higher current applications. Designs that do not need reverse input polarity protection can have RTN, GND and PowerPAD connected together. PowerPAD in these designs can be connected to the PCB ground plane.

12.2 Layout Example

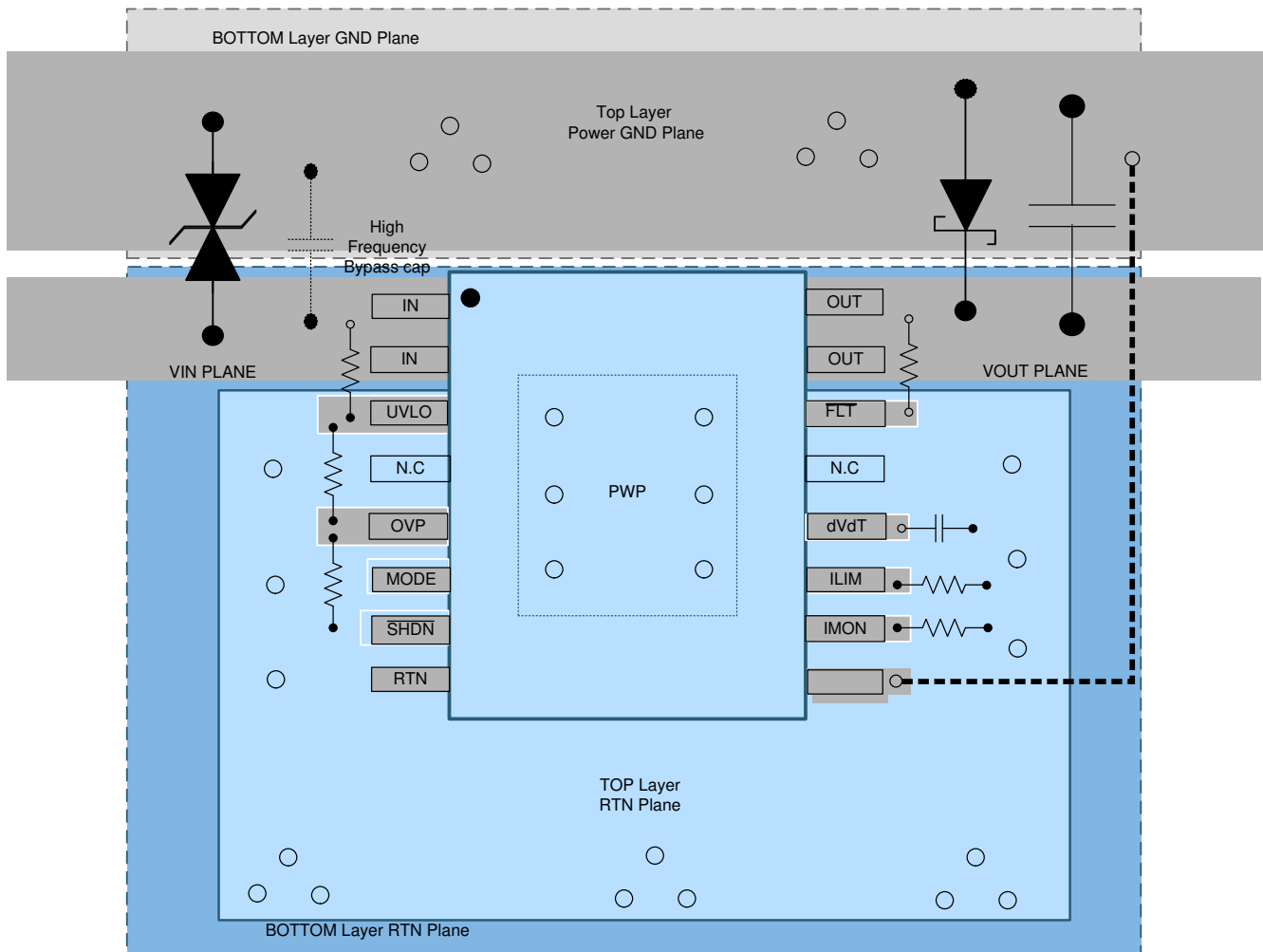
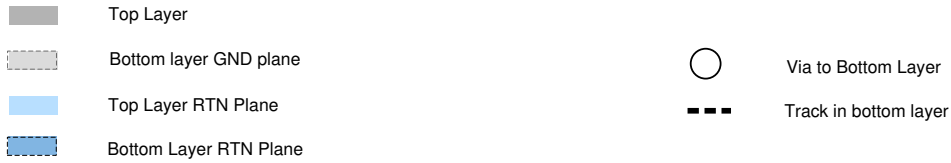


图 12-1. Typical PCB Layout Example With HTSSOP Package With a 2 Layer PCB

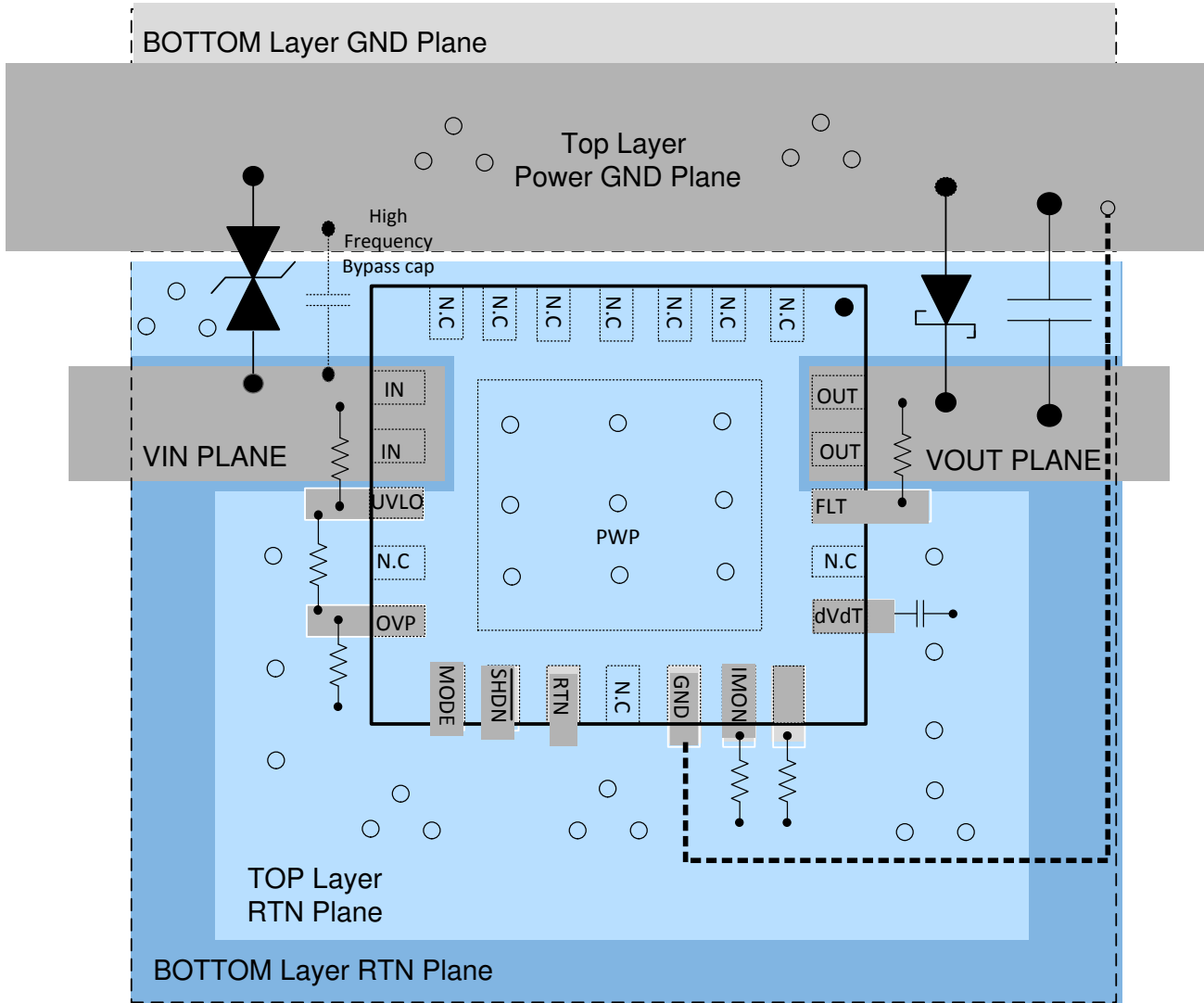


图 12-2. Typical PCB Layout Example With VQFN Package With a 2 Layer PCB

13 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

13.1 Device Support

For TPS26400 PSpice Transient Mode, see [SLVMDF4](#).

For TPS26400 Design Calculator, see [SLVRBG7](#).

13.2 Documentation Support

13.2.1 Related Documentation

For related documentation see the following:

- [TPS26400-02EVM: Evaluation Module for TPS26400 User's Guide](#)
- [Power Multiplexing Using Load Switches and eFuses](#)

13.3 接收文档更新通知

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13.4 支持资源

[TI E2E™ 支持论坛](#) 是工程师的重要参考资料，可直接从专家获得快速、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可获得所需的快速设计帮助。

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13.5 Trademarks

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13.6 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

13.7 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

14 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.

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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)
TPS26400PWPR	Active	Production	HTSSOP (PWP) 16	2000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	26400
TPS26400PWPR.A	Active	Production	HTSSOP (PWP) 16	2000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	26400
TPS26400PWPRG4	Active	Production	HTSSOP (PWP) 16	2000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	26400
TPS26400PWPRG4.A	Active	Production	HTSSOP (PWP) 16	2000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	26400
TPS26400RHFR	Active	Production	VQFN (RHF) 24	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS 26400
TPS26400RHFR.A	Active	Production	VQFN (RHF) 24	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS 26400
TPS26400RHFRG4	Active	Production	VQFN (RHF) 24	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS 26400
TPS26400RHFRG4.A	Active	Production	VQFN (RHF) 24	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS 26400

(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.

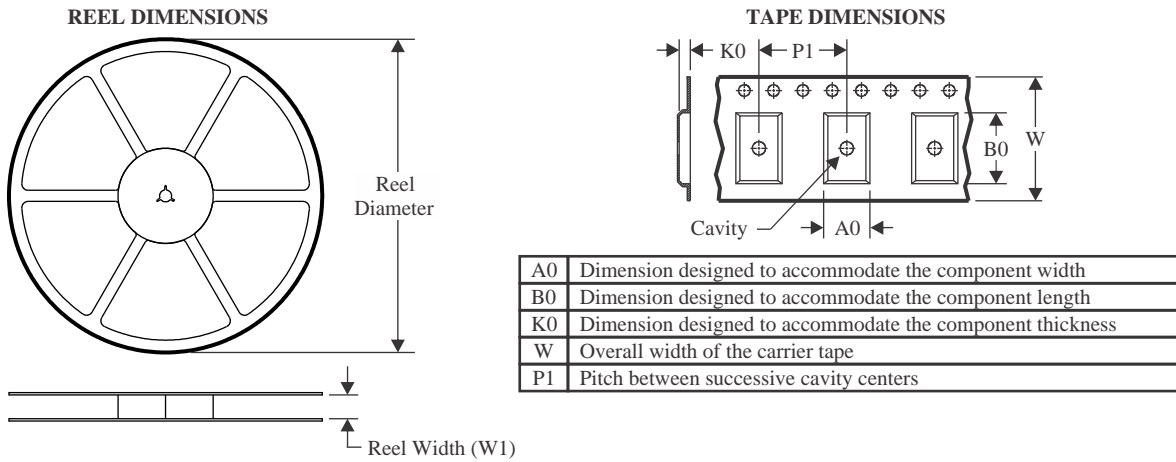
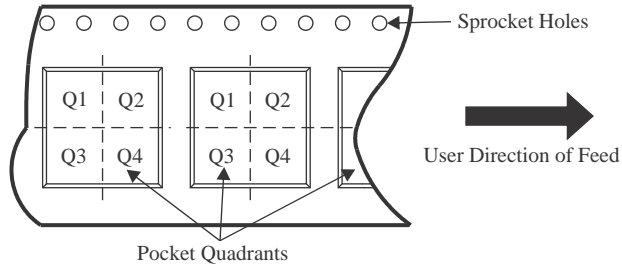
(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will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

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE


*All dimensions are nominal

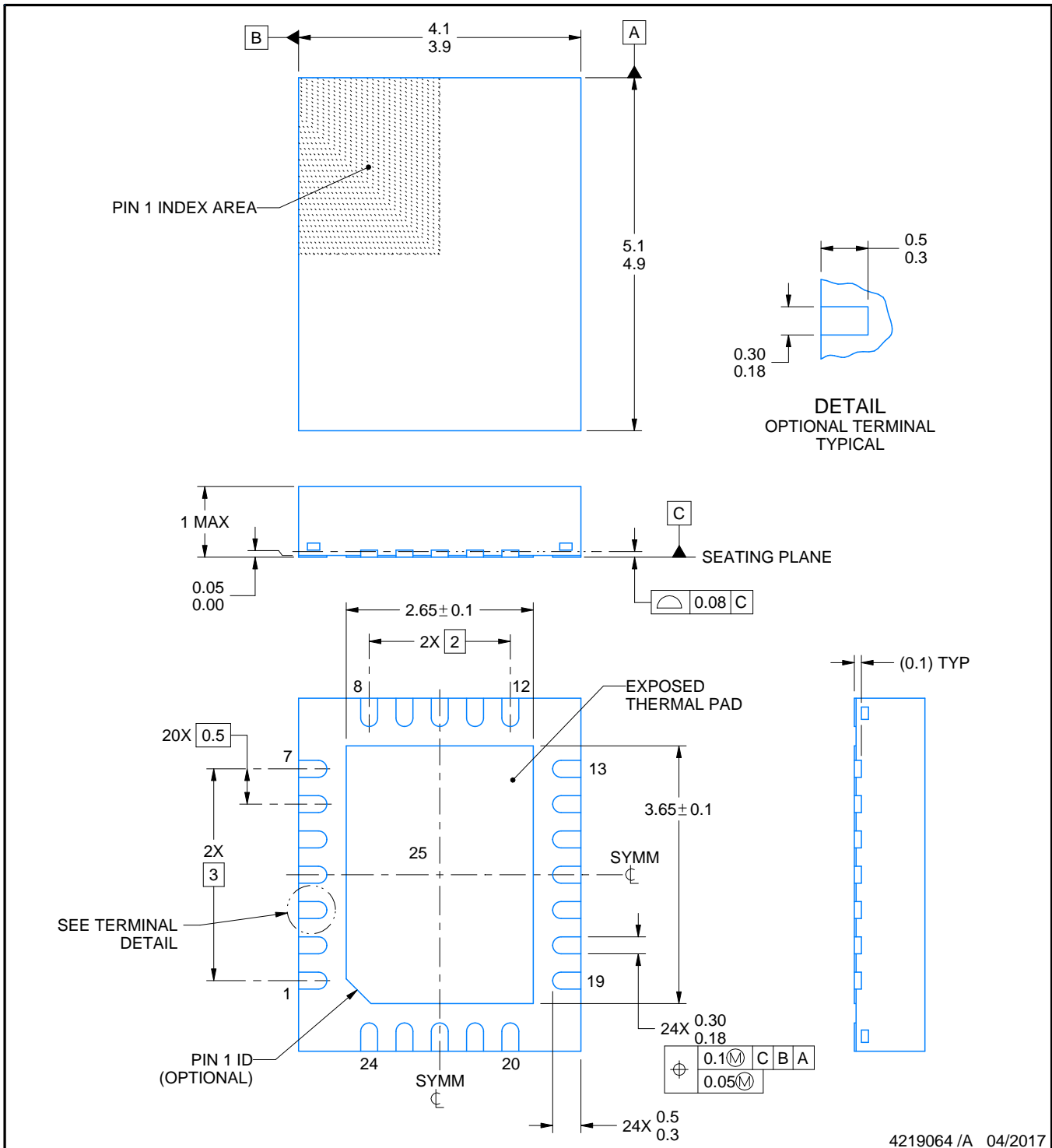
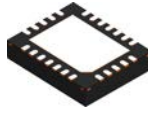
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS26400PWPR	HTSSOP	PWP	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TPS26400PWPRG4	HTSSOP	PWP	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TPS26400RHFR	VQFN	RHF	24	3000	330.0	12.4	4.3	5.3	1.3	8.0	12.0	Q1
TPS26400RHFRG4	VQFN	RHF	24	3000	330.0	12.4	4.3	5.3	1.3	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)
TPS26400PWPR	HTSSOP	PWP	16	2000	350.0	350.0	43.0
TPS26400PWPRG4	HTSSOP	PWP	16	2000	350.0	350.0	43.0
TPS26400RHFR	VQFN	RHF	24	3000	367.0	367.0	35.0
TPS26400RHFRG4	VQFN	RHF	24	3000	367.0	367.0	35.0



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NOTES:

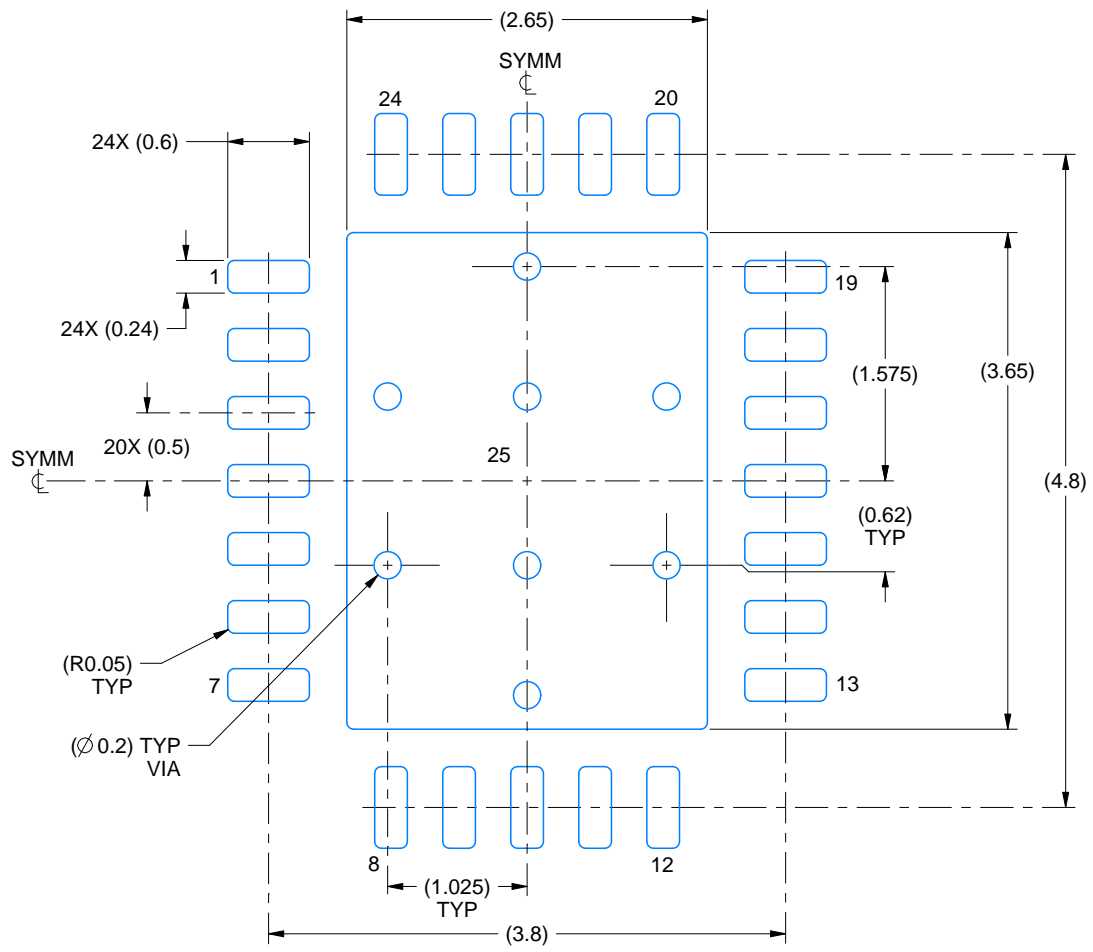
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

EXAMPLE BOARD LAYOUT

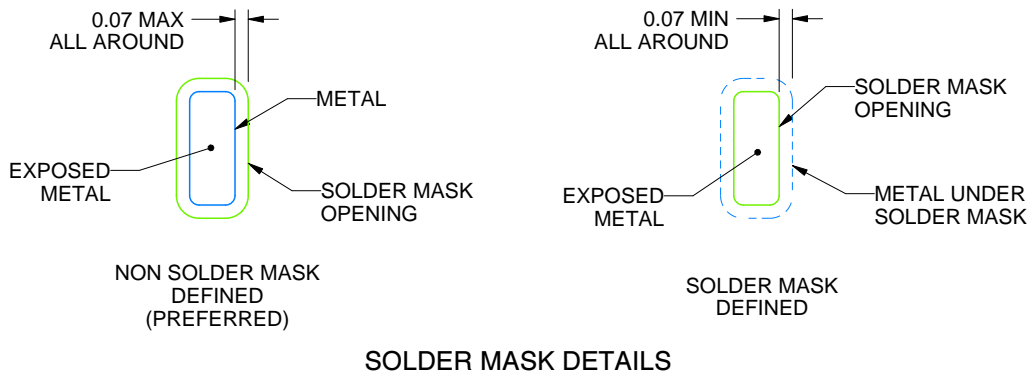
RHF0024A

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:18X



SOLDER MASK DETAILS

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NOTES: (continued)

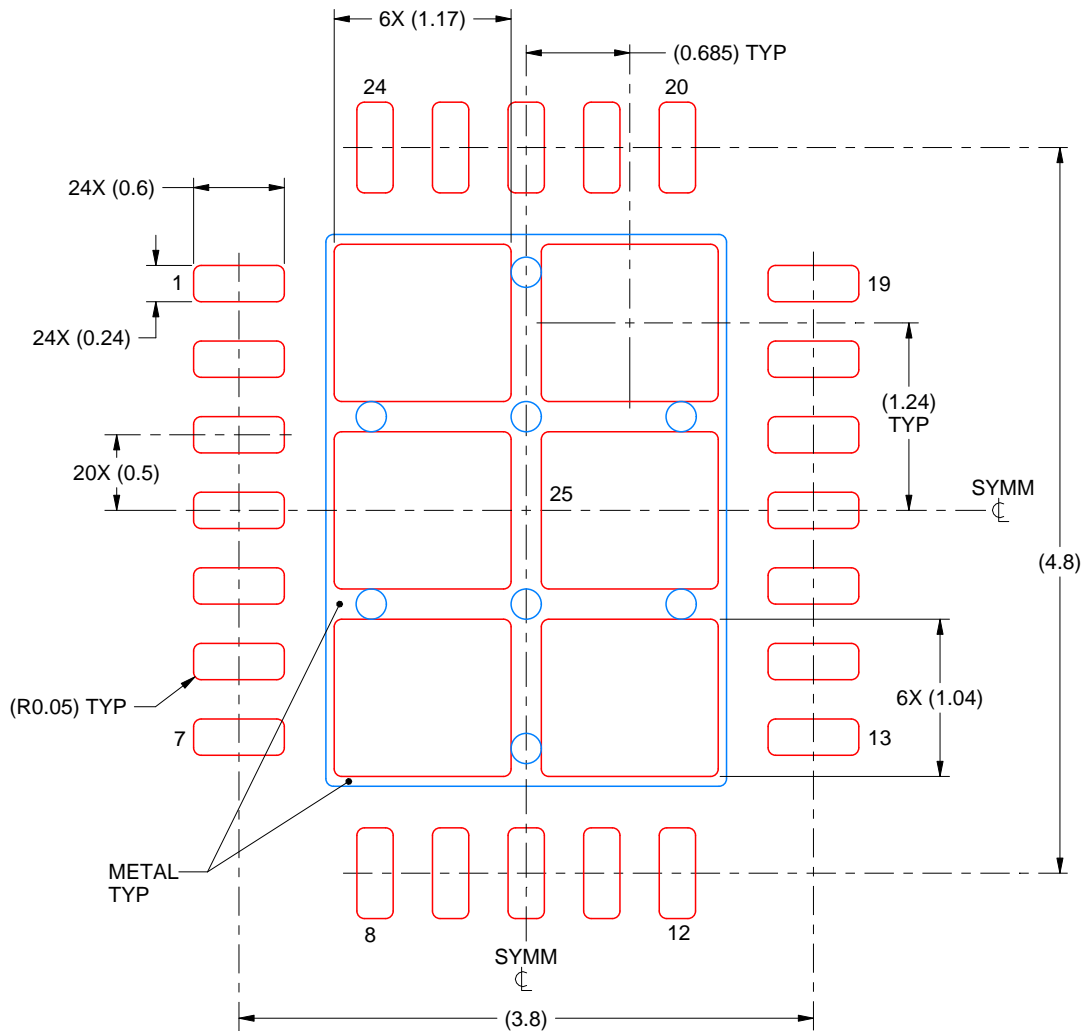
- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

EXAMPLE STENCIL DESIGN

RHF0024A

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



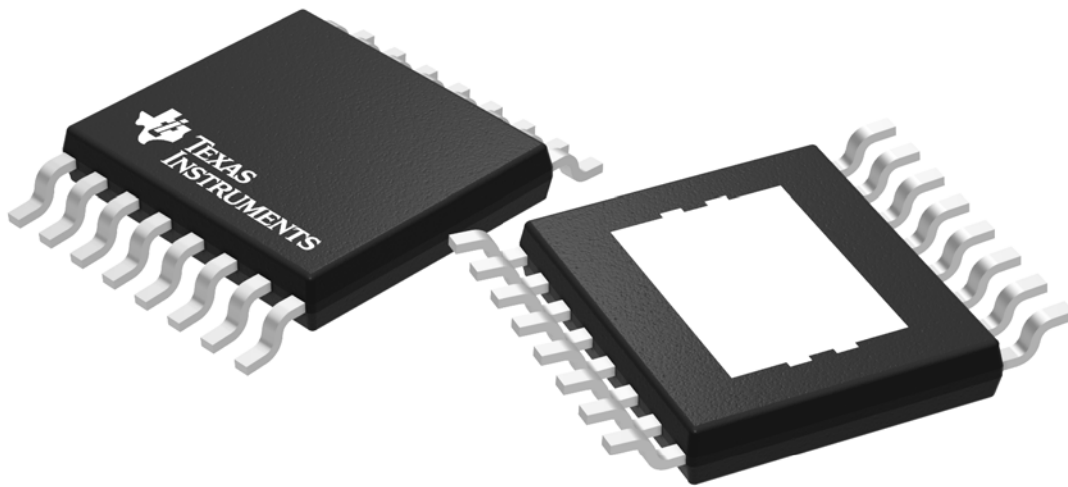
SOLDER PASTE EXAMPLE
 BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 25
 75% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
 SCALE:20X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

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