Hot Swap Power Manager for Redundant –48-V Supplies

Check for Samples: TPS2350

FEATURES

- **Replaces OR-ing Diodes**
- **Operating Supply Range of –12 V to –80 V**
- **Withstands Transients to –100 V**
- **Programmable Current Limit**
- **Programmable Linear Inrush Slew Rate**
- **Programmable UV/OV Thresholds**
- **Programmable UV and OV Hysteresis**
- **Fault Timer to Eliminate Nuisance Trips**
- **Power Good and Fault Outputs**
- **14-Pin SOIC and TSSOP Package**

APPLICATIONS

- **–48-V Distributed Power Systems**
- **Central Office Switching**
- **ONET**
- **Base Stations**

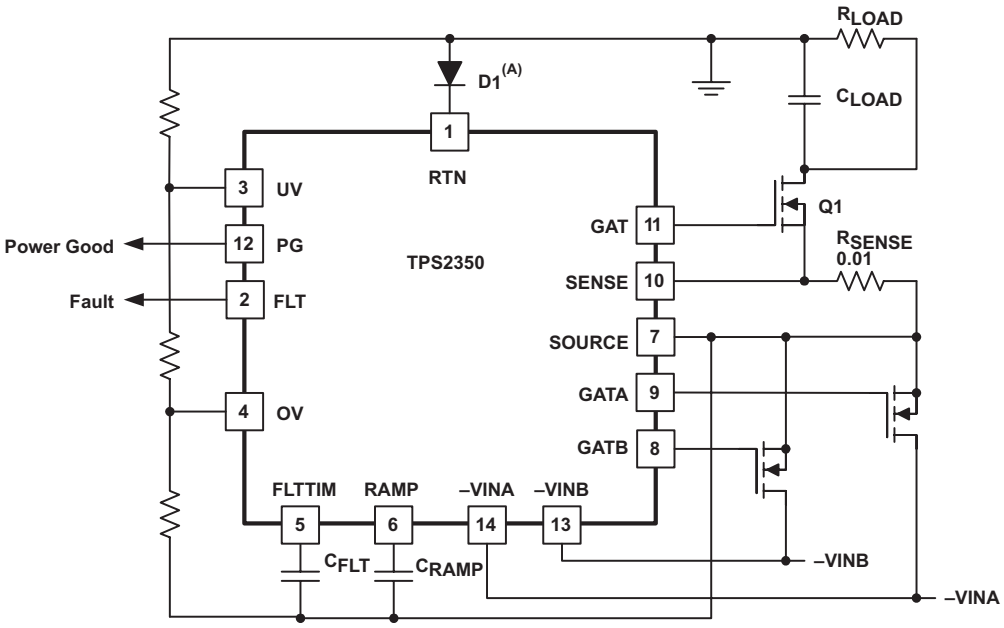
DESCRIPTION

The TPS2350 is a hot swap power manager optimized for replacing OR-ing diodes in redundant power –48-V systems. The TPS2350 operates with supply voltages from –12 V to –80 V, and withstands spikes to –100 V.

The TPS2350 uses two power FETs as low voltage drop diodes to efficiently select between two redundant power supplies. This minimizes system power dissipation and also minimizes voltage drop through the power management chain.

The TPS2350 also uses a third power FET to provide load current slew rate control and peak current limiting that is programmed by one resistor and one capacitor. The device also provides a power good output to enable down-stream power converters and a fault output to indicate load problems.

TYPICAL APPLICATION DIAGRAM



A. D1 optional per application requirements.

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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of the Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

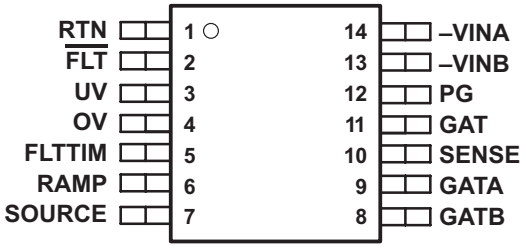
ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature (unless otherwise noted)(1)

		VALUE	UNIT
Input voltage range, RTN(2)		–0.3 to 100	V
Input voltage range, –VINA to –VINB		–100 to 100	
Input voltage range, FLTTIM, RAMP, SENSE, OV, UV(2)		–0.3 to 15	
Output voltage range, $\overline{FLT}$, PG(2)(3)		–0.3 to 100	
Continuous output current, $\overline{FLT}$, PG		10	mA
Continuous total power dissipation		See the Thermal Information table	
Electrostatic Discharge	Human body model (HBM)	2	kV
	Charged device model (CDM)	1.5	
Operating junction temperature range, T_J		–55 to 125	°C
Storage temperature range, T_{stg}		–65 to 150	

(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.
(2) All voltages are with respect to the more negative of –VINA and –VINB (unless otherwise noted).
(3) With 10 kΩ minimum series resistance. Range limited to –0.3V to 80V from low impedance source.

SOIC/TSSOP-14 PACKAGE
(TOP VIEW)



Device Information

T_A	PACKAGE(1)	PART NUMBER
–40°C to 85°C	SOIC–14(2)	TPS2350D
	TSSOP–14(2)	TPS2350PW

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) The D and PW packages are also available taped and reeled. Add an R suffix to the device type (i.e. TPS2350DR).

RECOMMENDED OPERATING CONDITIONS

	MIN	NOM	MAX	UNIT
Input supply, –VINA, –VINB to RTN	–80	–48	–12	V
Operating junction temperature range	–40		85	°C

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THERMAL INFORMATION

THERMAL METRIC[1]		TPS2350		UNITS
		D (14 PINS)	PW (14 PINS)	
θ_{JA}	Junction-to-ambient thermal resistance	95.9	120.8	°C/W
θ_{JB}	Junction-to-board thermal resistance	51.5	62.8	
θ_{JCtop}	Junction-to-case (top) thermal resistance	50.7	n/a	
ψ_{JT}	Junction-to-top characterization parameter	8.3	1	
ψ_{JB}	Junction-to-board characterization parameter	51.1	56.5	

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

ELECTRICAL CHARACTERISTICS

–VINA = –48 V, –VINB = 0 V, UV = 2.5 V, OV = 0.5 V, SENSE = 0 V, RAMP = 0 V, SOURCE = more negative of –VINA and –VINB, all outputs unloaded, T_A = –40°C to 85°C (unless otherwise noted)[1][2]

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input Supply						
I_{CC1A}	Supply current	–VINA = –48 V, –VINB = 0 V		1000	1500	µA
I_{CC2A}	Supply current	–VINA = –80 V, –VINB = 0 V			2000	
I_{CC1B}	Supply current	–VINB = –48 V, –VINA = 0 V		1000	1500	
I_{CC2B}	Supply current	–VINB = –80 V, –VINA = 0 V			2000	
V_{UVLO_I}	Internal UVLO threshold voltage	To GAT pull up	–11.8	–10	–8.0	V
V_{HYST}	Internal UVLO hysteresis voltage		50	240	500	mV
Overvoltage and Undervoltage Inputs (OV and UV)						
V_{THUV}	UV threshold voltage, UV rising, to –VINA	To GAT pull up, 25°C	1.391	1.400	1.409	V
		To GAT pull up, 0 to 70°C	1.387	1.400	1.413	
		To GAT pull up, –40 to 85°C	1.384	1.400	1.419	
I_{HYSUV}	UV hysteresis	UV = –45.5 V	–11	–10	–9	µA
I_{ILUV}	UV low-level input current	UV = –47 V	–1		1	
V_{THOV}	OV threshold voltage, OV rising, to –VINA	To GAT pull up	1.376	1.400	1.426	V
I_{HYSOV}	OV hysteresis	OV = −45.5 V	–11.1	–10	–8.6	µA
I_{ILOV}	OV low-level input current	OV = –47 V	–1		1	µA
Linear Current Amplifier (LCA)						
V_{OH}	High level output, GAT–SOURCE	SENSE = SOURCE	11	14	17	V
I_{SINK_f}	GAT sink current in fault	SENSE – SOURCE = 80 mV, GAT = –43 V, FLTTIME = 5 V	30	75		mA
I_{SINK_I}	GAT sink current in linear mode	SENSE – SOURCE = 80 mV, GAT = –43 V, FLTTIME = 2 V		5	10	
I_{IN}	SENSE input current	0.0 V < SENSE – SOURCE < 0.2 V	–1		1	µA
V_{REF_K}	Reference clamp voltage, SENSE – SOURCE	RAMP – SOURCE = 6 V	34	42	50	mV
V_{IO}	Input offset voltage, SENSE – SOURCE	RAMP – SOURCE = 0 V	–7		9	
Ramp Generator						
I_{SRC1}	RAMP source current, slow turn-on rate	RAMP − SOURCE = 0.25 V	–800	–550	–300	nA
I_{SRC2}	RAMP source current, normal rate	RAMP – SOURCE = 1 V and 3 V	–11.3	–10	–8.5	µA
V_{OL}	Low-level output voltage	UV = SOURCE			5	mV
A_V	Voltage gain, relative to SENSE	0 V < RAMP – SOURCE < 5 V	9.5	10	10.7	mV/V

(1) All voltages are with respect to RTN unless otherwise stated.
(2) Currents are positive into and negative out of the specified terminal.

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ELECTRICAL CHARACTERISTICS (continued)

–VINA = –48 V, –VINB = 0 V, UV = 2.5 V, OV = 0.5 V, SENSE = 0 V, RAMP = 0 V, SOURCE = more negative of –VINA and –VINB, all outputs unloaded, T_A = –40°C to 85°C (unless otherwise noted)(1)(2)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Overload Comparator						
V_{TH_OL}	SENSE current overload threshold		100	120	140	mV
t_{RSP}	Response time	SENSE – SOURCE = 200 mV	2	4	7	µs
Fault Timer						
V_{OL}	FLTTIM low-level output voltage, to –VINA	UV = –48 V			5	mV
I_{CHG}	FLTTIM charging current, current limit mode	FLTTIM – SOURCE = 2 V	–54	–50	–41	µA
V_{FLT}	FLTTIM fault threshold voltage to SOURCE		3.75	4.00	4.25	V
V_{RST}	Fault reset threshold to SOURCE			0.5		
I_{DSG}	FLTTIM Discharge current, retry mode	FLTTIM – SOURCE = 2 V		0.38	0.75	µA
D	Output duty cycle during retry cycles	SENSE – SOURCE = 80 mV, FLTTIM − SOURCE = 2 V		1%	1.5%	
I_{RST}	FLTTIM discharge current, timer reset mode	FLTTIM − SOURCE = 2 V, SENSE = 2 V		1		mA
Logic Outputs ($\overline{FLT}$, PG)						
I_{OHFLT}	$\overline{FLT}$ high-level output leakage current	UV = –48 V, FLT – SOURCE = 80 V	–10		10	µA
I_{OHPG}	PG high-level output leakage current	UV = –45 V, PG – SOURCE = 80 V	–10		10	
$R_{DS(on)}$	$\overline{FLT}$ ON resistance	SENSE–SOURCE = 80 mV, FLTTIM–SOURCE = 5 V, I($\overline{FLT}$) = 1 mA		50	80	Ω
$R_{DS(on)}$	PG ON resistance	UV = –48 V, I_O(PG) = 1 mA		50	80	
Supply Selector						
V_{THA}	Threshold voltage, –VINA falling	–VINB = –48 V, –VINA falling	–48.45	–48.40	–48.35	V
V_{THB}	Threshold voltage, –VINB falling	–VINA = –48 V, –VINB falling	–48.45	–48.40	–48.35	
I_{SINK}	GATA sink current	–VINA = 0 V, –VINB = –48 V, GATA = –41 V	30	80		mA
I_{SOURCE}	GATA source current	–VINA = –48 V, –VINB = –0 V, GATA = –41 V		–50	–20	µA
I_{SINK}	GATB sink current	–VINA = –48 V, –VINB = –0 V, GATB = –41 V	30	80		mA
I_{SOURCE}	GATB source current	–VINA = 0 V, –VINB = –48 V, GATB = –41 V		–50	–20	µA
V_{OLA}	GATA low voltage to –VINA	VINA = 0 V, –VINB = –48 V			0.1	V
V_{OLA}	GATA high voltage to –VINA	–VINA = –48 V, –VINB = 0 V	11	14	17	
V_{OLB}	GATB low voltage to –VINB	–VINA = –48 V, –VINB = 0 V			0.1	
V_{OLB}	GATB high voltage to –VINB	–VINA = 0 V, –VINB = –48 V	11	14	17	

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PIN FUNCTIONS

PIN		I/O	DESCRIPTION
NAME	NO.		
$\overline{FLT}$	2	O	Open-drain, active-low indication that the part is in fault.
FLTTIM	5	I/O	Connection for user programming of the fault timeout period.
GAT	11	O	Gate drive for external N-channel FET that ramps load current and disconnects in the event of a fault.
GATA	9	O	Gate drive for external N-channel FET that selects –VINA.
GATB	8	O	Gate drive for external N-channel FET that selects –VINB.
OV	4	I	Over voltage sense input.
PG	12	O	Open-drain, active-high indication that the power FET is fully enhanced.
RAMP	6	I/O	Programming input for setting the inrush current slew rate.
RTN	1	I	Supply return (ground).
SENSE	10	I	Positive current sense input.
SOURCE	7	I/O	Negative current sense input.
UV	3	I	Under voltage sense input.
–VINA	14	I	Negative supply input A.
–VINB	13	I	Negative supply input B.

PIN DESCRIPTIONS

$\overline{FLT}$: Open-drain, active-low indication that TPS2350 has shut down due to a faulted load. This happens if the load current stays limited by the linear current amplifier for more than the fault time (time to charge the FLTTIM capacitor). $\overline{FLT}$ is cleared when both supplies drop below the UV-comparator threshold or one supply exceeds the OV-comparator threshold. The $\overline{FLT}$ output is pulled to the lower of –VINA and –VINB. The $\overline{FLT}$ output is able to sink 10 mA when in fault, withstand 80 V without leakage when not faulted, and withstand transients as high as 100 V when limited by a series resistor of at least 10 kΩ.

FLTTIM: Connection for user programming of the fault timeout period. An external capacitor connected from FLTTIM to SOURCE establishes the timeout period to declare a fault condition. This timeout protects against indefinite current sourcing into a faulted load, and also provides a filter against nuisance trips from momentary current spikes or surges. TPS2350 define a fault condition as voltage at the SENSE pin at or greater than the 42-mV fault threshold. When a fault condition exists, the timer is active. The devices manage fault timing by charging the external capacitor to the 4-V fault threshold, then subsequently discharging it at approximately 1% the charge rate to establish the duty cycle for retrying the load. Whenever the fault latch is set (timer expired), GAT and $\overline{FLT}$ are pulled low.

GAT: Gate drive for an external N-channel protection power MOSFET. When either input supply is above the UV threshold and both are below the OV threshold, gate drive is enabled and the device begins charging the external capacitor connected to RAMP. RAMP develops the reference voltage at the non-inverting input of the internal LCA. The inverting input is connected to the current sense node, SENSE. The LCA acts to slew the pass FET gate to force the SENSE voltage to track the reference. The reference is internally clamped to 42 mV, so the maximum current that can be sourced to the load is determined by the sense resistor value as $I_{MAX} \leq 42\ mV/R_{SENSE}$. Once the load voltage has ramped up to the input dc potential and current demand drops off, the LCA drives GAT 14 V above SOURCE to fully enhance the pass FET, completing the low-impedance supply return path for the load.

GATA: Gate drive for an external N-channel power MOSFET to select –VINA. When –VINA is more negative than –VINB, GATA is pulled 14 V above –VINA, turning on the –VINA power FET. When –VINB is more negative than –VINA, GATA is pulled down to –VINB, turning off the –VINA power FET.

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GATB: Gate drive for an external N-channel power MOSFET to select –VINB. When –VINB is more negative than –VINA, GATB is pulled 14 V above –VINB, turning on the –VINB power FET. When –VINA is more negative than –VINB, GATB is pulled down to –VINA, turning off the –VINB power FET.

PG: Open-drain, active-high indication that load current is below the commanded current and the power FET is fully enhanced. When commanded load current is more than the actual load current, the linear current amplifier (LCA) will raise the power MOSFET gate voltage to fully enhance the power MOSFET. At this time, the PG output will go high. This output can be used to enable a down-stream dc-to-dc converter. The PG output is pulled to the lower of –VINA and –VINB. The PG output is able to sink 10 mA when in fault, withstand 80 V without leakage when power is not good, and withstand transients as high as 100 V when limited by a series resistor of at least 10 kΩ.

OV: Over voltage comparator input. This input is typically connected to a voltage divider between RTN and SOURCE to sense the magnitude of the more negative input supply. If OV is less than 1.4 V above SOURCE, UV is more than 1.4 V above SOURCE, and there is no fault, the linear current amp will be enabled. In the event of a fault, pulling OV high or UV low will reset the fault latch and allow restarting. OV can also be used as an active-low logic enable input. The over-voltage comparator hysteresis is programmed by the equivalent resistance seen looking into the divider at the OV input.

RAMP: Programming input for setting inrush current and current slew rate. An external capacitor connected between RAMP and SOURCE establishes turn-on current slew rate. During turn-on, TPS2350 charges this capacitor to establish the reference input to the LCA at 1% of the voltage from RAMP to SOURCE. The closed-loop control of the LCA and the pass FET maintains the current-sense voltage from SENSE to SOURCE at the reference potential, so the load current slew rate is directly set by the voltage ramp rate at the RAMP pin. When fully charged, RAMP can exceed SOURCE by 6 V, but the reference is internally clamped to 42 mV, limiting load current to 42 mV/R_{SENSE}. When the output is disabled via OV, UV, or due to a load fault, the RAMP capacitor is discharged and held low to initialize for the next turn on.

RTN: Positive supply input. For negative voltage systems, this pin connects directly to the return node of the input power bus.

SENSE: Current sense input. An external low-value resistor connected between SENSE and SOURCE is used to monitor current magnitude. There are two internal device thresholds associated with the voltage at the SENSE pin. During ramp-up of the load capacitance or during other periods of excessive demand, the linear current amp (LCA) will regulate this voltage to 42 mV. Whenever the LCA is in current regulation mode, the capacitor at FLTTIM is charging and the timer is running. If the LCA is saturated, GAT is pulled 14 V above SOURCE. At this time, a fast fault such as a short circuit can cause the SENSE voltage to rapidly exceed 120 mV (the overload threshold). In this case, the GAT pin is pulled low rapidly, bypassing the fault timer.

SOURCE: Connection to the sources of the input supply negative rail selector FETs and the negative terminal of the current sense resistor. The supply select comparator will turn on the appropriate power FET to connect SOURCE to the more negative of –VINA and –VINB.

UV: Under voltage comparator input. This input is typically connected to a voltage divider between RTN and SOURCE to sense the magnitude of the more negative input supply. If UV is more than 1.4 V above SOURCE, OV is less than 1.4 V above SOURCE, and there is no fault, the linear current amp will be enabled. In the event of a fault, pulling UV low or OV high will reset the fault latch and allow restarting. UV can also be used as an active high logic enable input. The under-voltage comparator hysteresis is programmed by the equivalent resistance seen looking into the divider at the UV input.

–VINA: Negative supply input A. This pin connects directly to the first input supply negative rail.

–VINB: Negative supply input B. This pin connects directly to the second input supply negative rail.

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TYPICAL CHARACTERISTICS

SUPPLY SELECTOR THRESHOLD VOLTAGE vs AMBIENT TEMPERATURE, −VINA FALLING

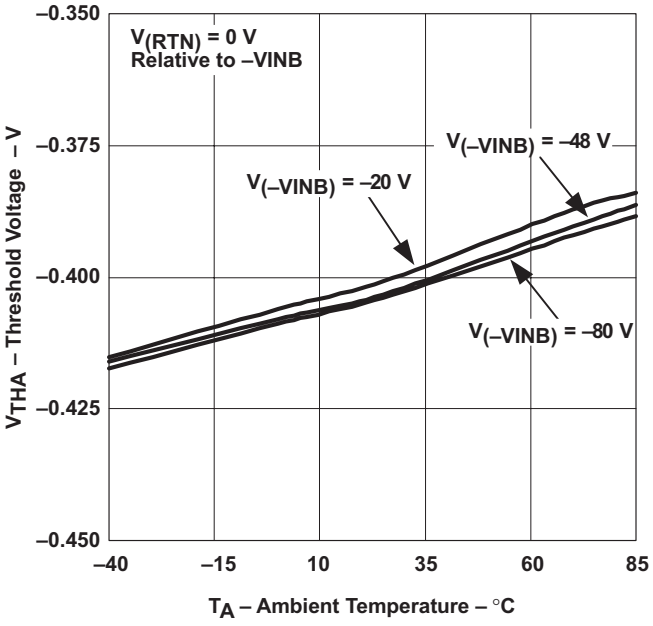

Figure 1.

SUPPLY SELECTOR THRESHOLD VOLTAGE vs AMBIENT TEMPERATURE, −VINB FALLING

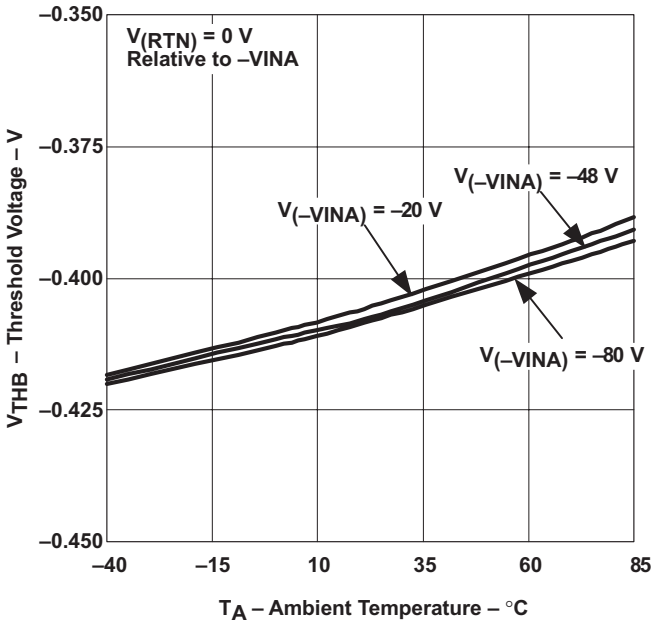

Figure 2.

GATA HIGH-LEVEL OUTPUT VOLTAGE vs AMBIENT TEMPERATURE

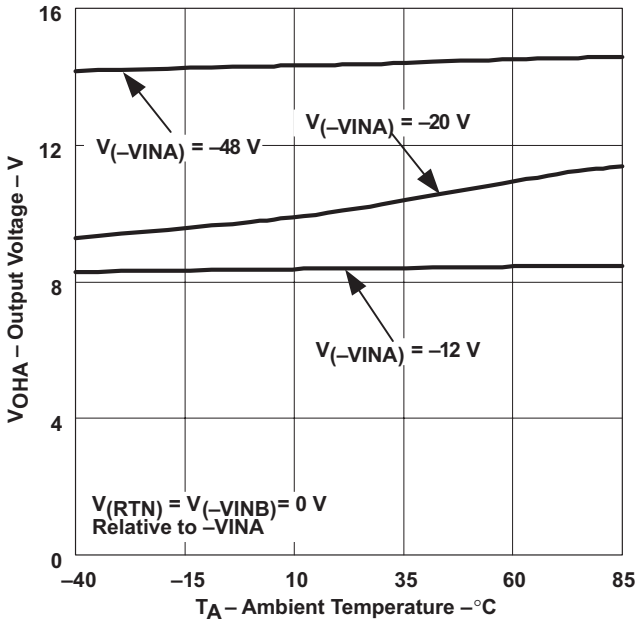

Figure 3.

GATB HIGH-LEVEL OUTPUT VOLTAGE vs AMBIENT TEMPERATURE

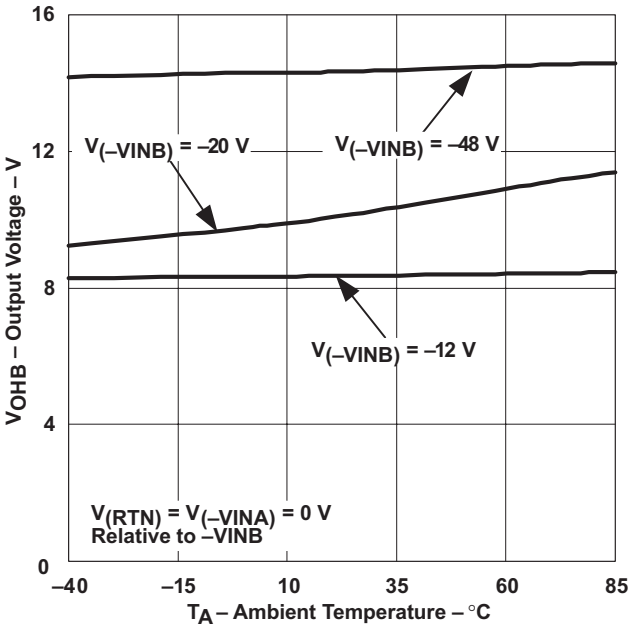

Figure 4.

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TYPICAL CHARACTERISTICS

GATx SINK CURRENT
vs
AMBIENT TEMPERATURE

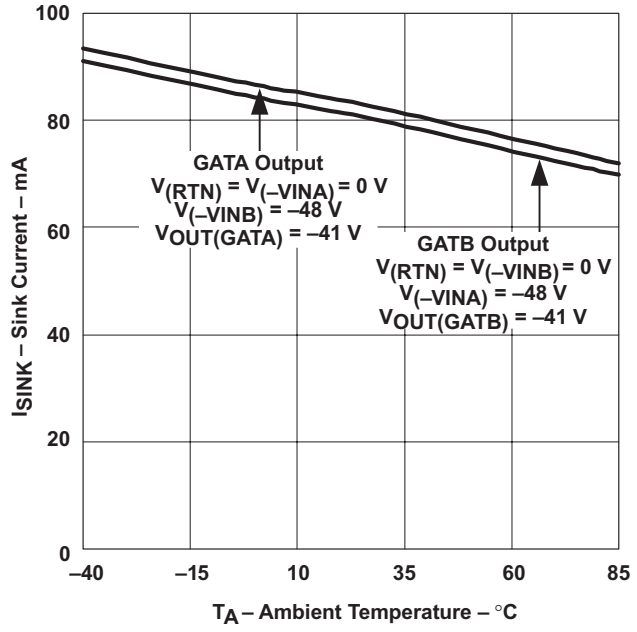

Figure 5.

SUPPLY CURRENT
vs
AMBIENT TEMPERATURE

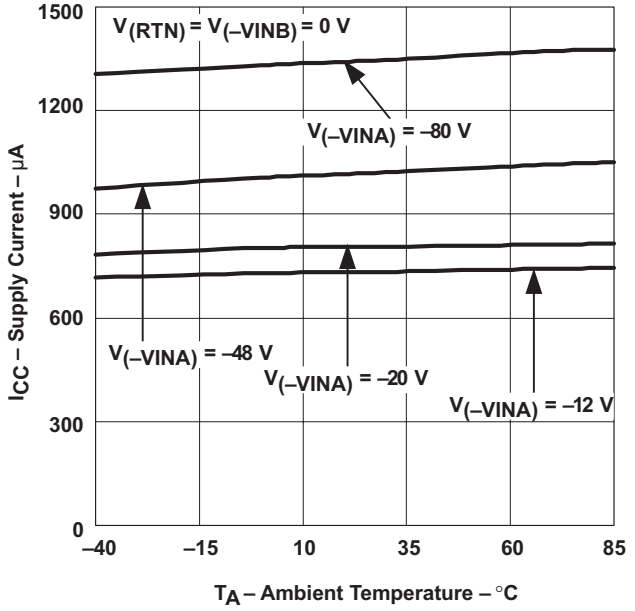

Figure 6.

VOLTAGE COMPARATOR THRESHOLDS
vs
AMBIENT TEMPERATURE

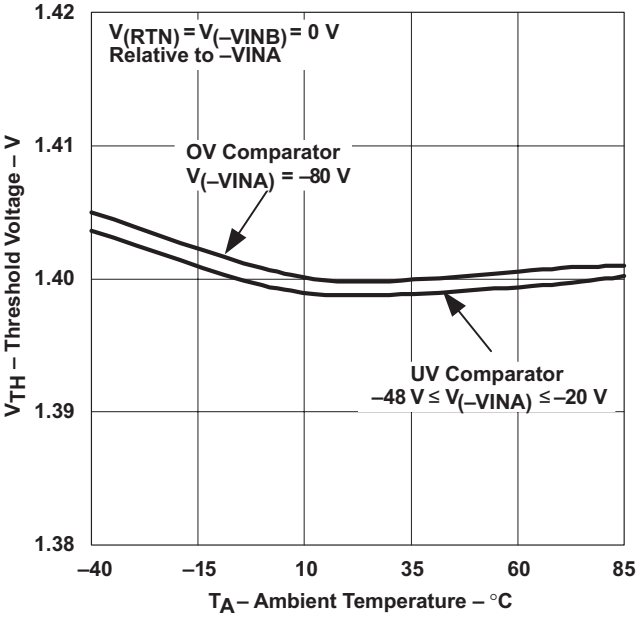

Figure 7.

UNDERVOLTAGE PULL-UP CURRENT
vs
AMBIENT TEMPERATURE

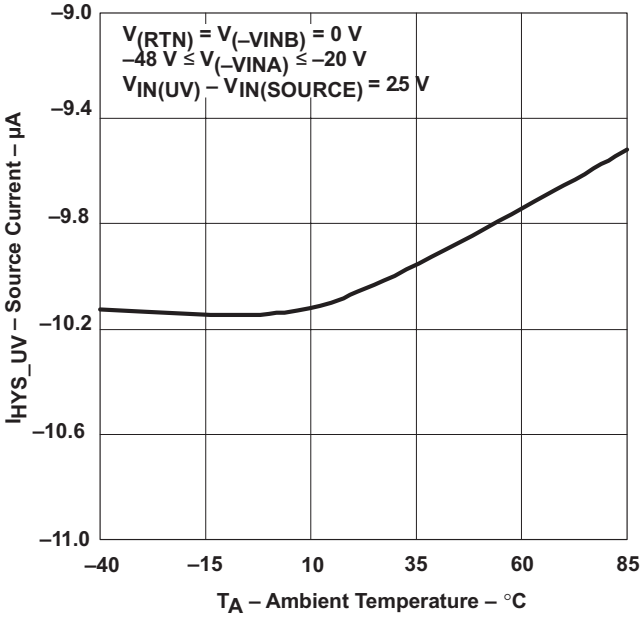

Figure 8.

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TYPICAL CHARACTERISTICS

GAT HIGH-LEVEL OUTPUT VOLTAGE vs AMBIENT TEMPERATURE

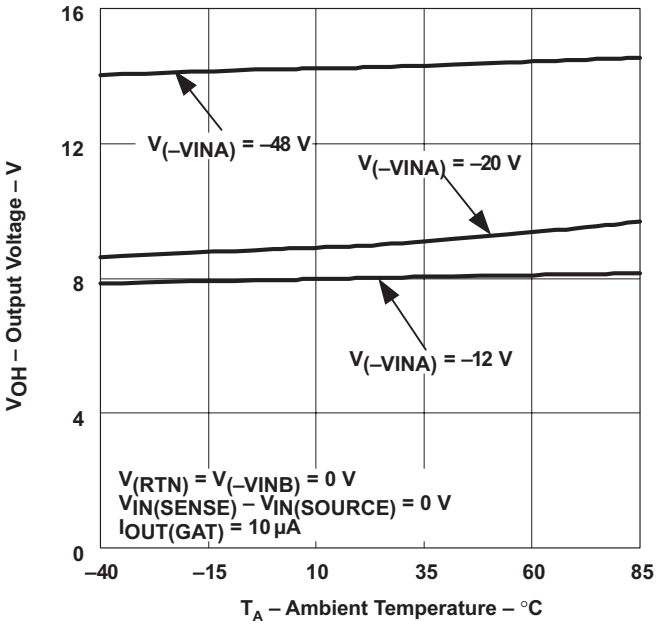

Figure 9.

RAMP OUTPUT CURRENT vs AMBIENT TEMPERATURE, REDUCED RATE MODE

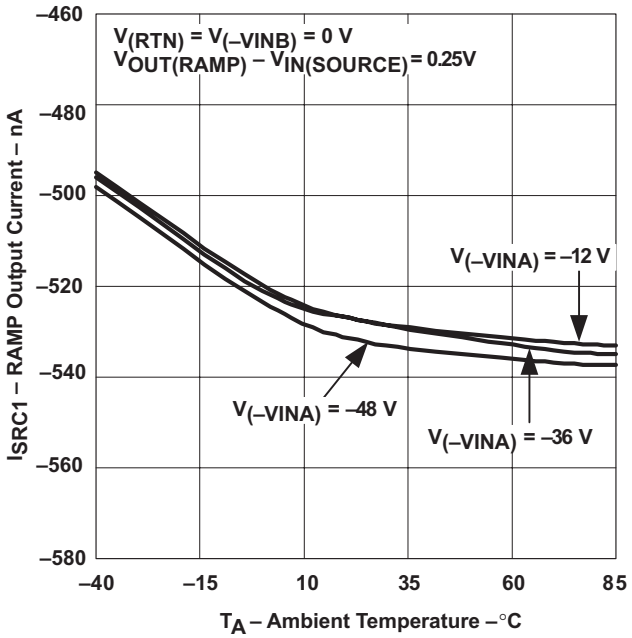

Figure 10.

RAMP OUTPUT CURRENT vs AMBIENT TEMPERATURE, NORMAL RATE MODE

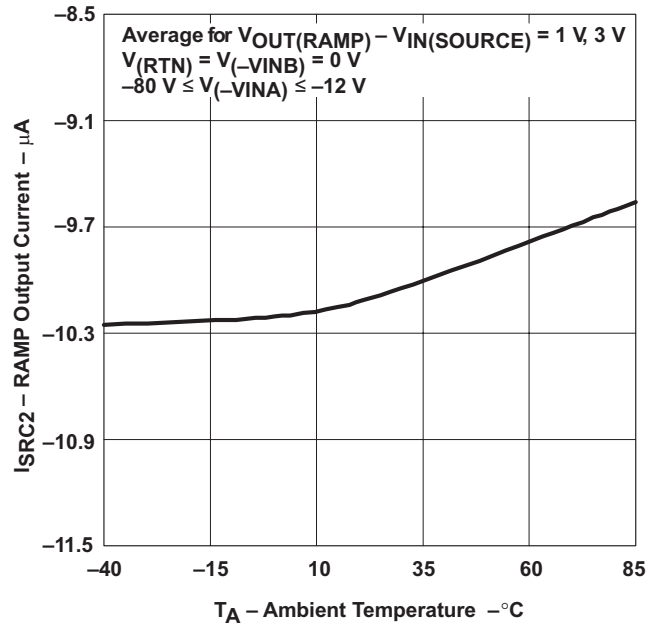

Figure 11.

TIMER CHARGING CURRENT vs AMBIENT TEMPERATURE

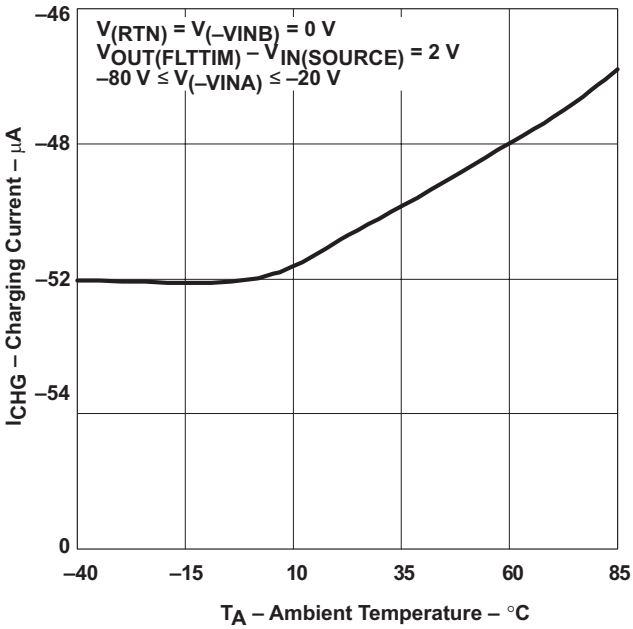

Figure 12.

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TYPICAL CHARACTERISTICS

TIMER DISCHARGE CURRENT vs AMBIENT TEMPERATURE

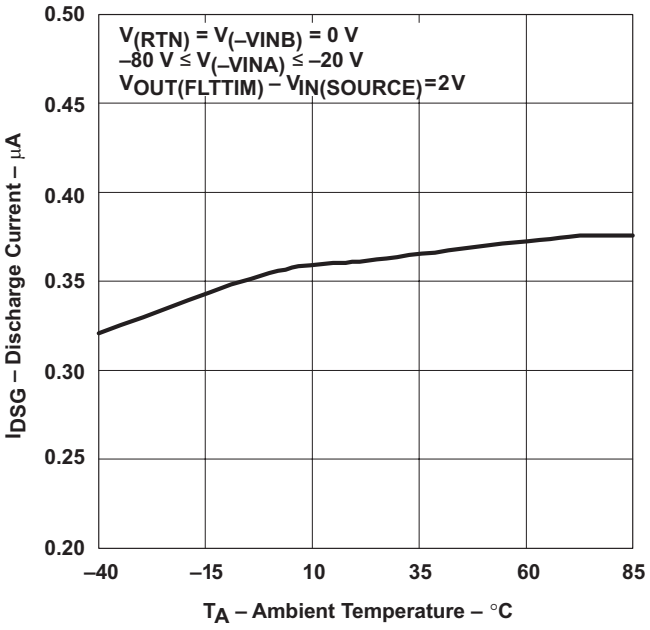

Figure 13.

FAULT LATCH THRESHOLD VOLTAGE vs AMBIENT TEMPERATURE

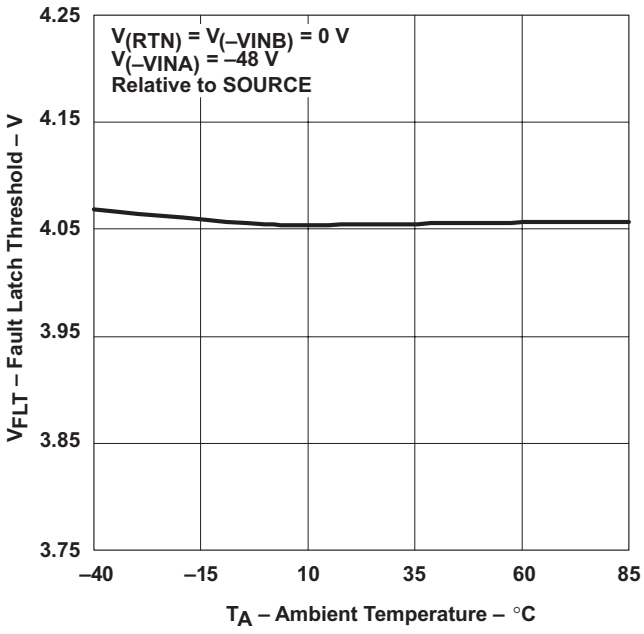

Figure 14.

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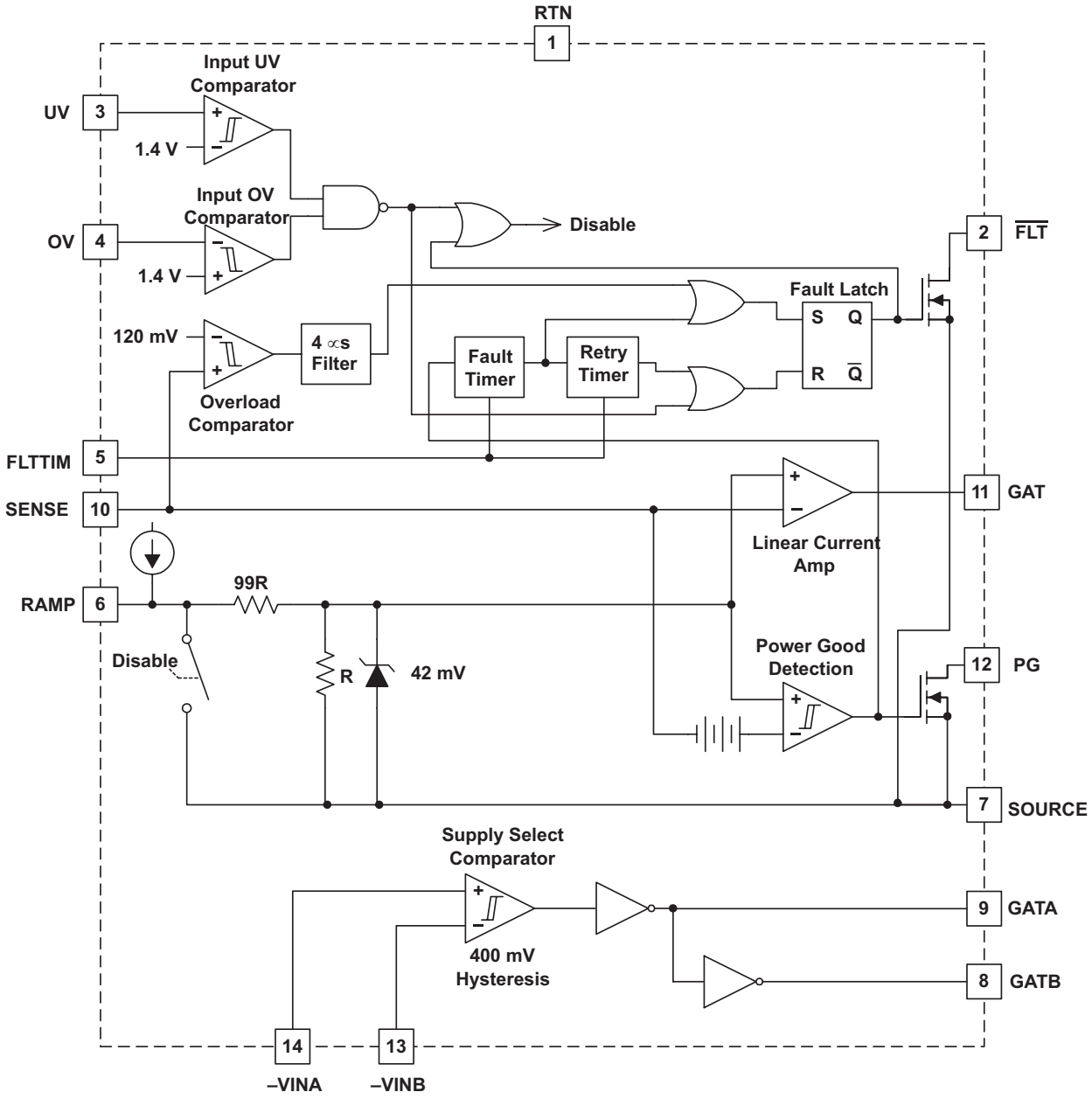
FUNCTIONAL BLOCK DIAGRAM



APPLICATION INFORMATION

Supply Section

The supply selection comparator selects between –VINA and –VINB based on which supply has a larger magnitude. To prevent chattering between two nearly identical supplies, the supply selection comparator has 400 mV of hysteresis. This prevents supply noise or ripple from tripping the comparator and should be adequate for most systems. Hysteresis is set to 400 mV to give the highest noise margin without allowing conduction in the body diodes of the supply selection FETs.

For systems with many cards, high current cards, or long cables between the power and the load, the voltage loss in the cable can be significant. If the supplies are close to the same magnitude, then the voltage loss in the cable could cause enough drop to exceed the supply selection comparator hysteresis. In this case, the supply selection comparator hysteresis must be increased.

TPS2350 allows you to increase the hysteresis of the supply selection comparator with external resistors, limited to the threshold of the external FETs. Figure 15 shows a system with higher hysteresis, set by R4, R5, R6 and R7. The resistors act as a simple multiplier to increase the voltage differential required to switch the comparator. For example, for R4 = R5 = 40 kΩ, and R6 = R7 = 20 kΩ, the hysteresis is approximately 1.2 V. Because of the large hysteresis, the supply selection power FETs are replaced with dual power FETs, configured so that the body diodes can never conduct. The GATA and GATB outputs are able to switch dual FETs, so no additional drive or logic circuits are required.

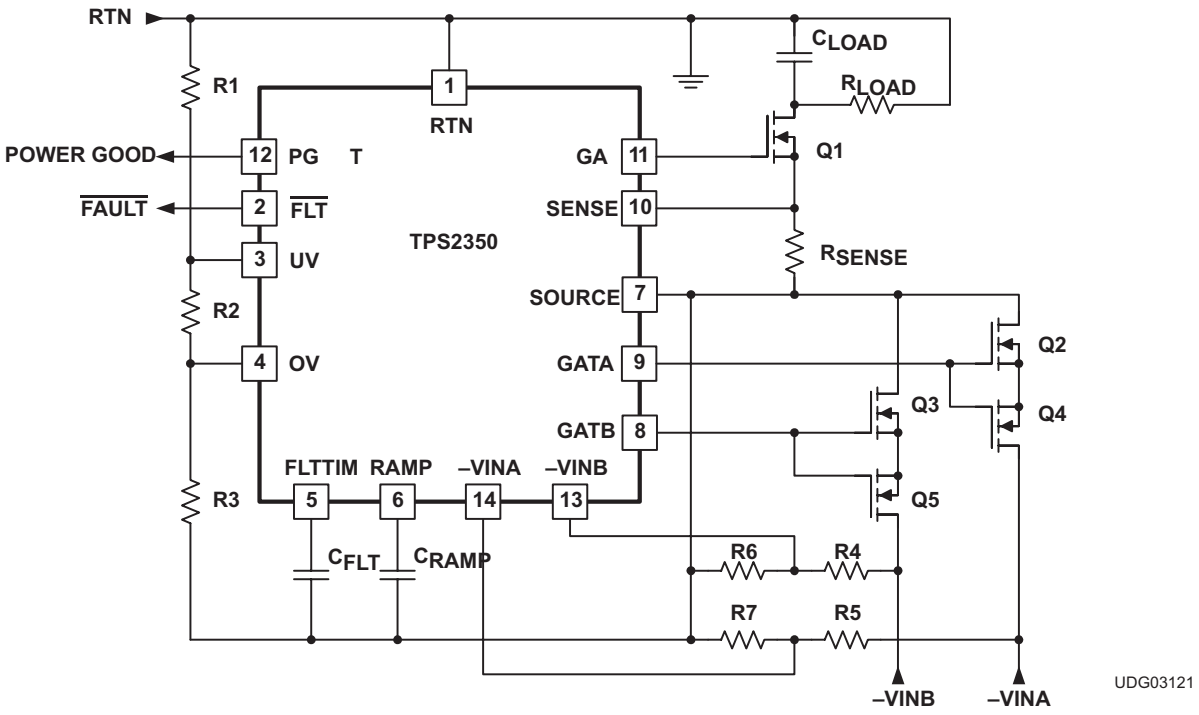


Figure 15. Typical Application to Develop Higher Supply Comparator Hysteresis

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APPLICATION INFORMATION

Setting the Sense Resistor Value

Due to the current-limiting action of the internal LCA, the maximum allowable load current for an implementation is easily programmed by selecting the appropriate sense resistor value. The LCA acts to limit the sense voltage V_{SENSE} to its internal reference. Once the voltage at the RAMP pin exceeds approximately 4 V, this limit is the clamp voltage, V_{REF_K}. Therefore, a maximum sense resistor value can be determined from Equation 1.

$$R_{SENSE} \leq \frac{34mV}{I_{MAX}} \quad (1)$$

where

- R_{SENSE} is the resistor value
- I_{IMAX} is the desired current limit

When setting the sense resistor value, it is important to consider two factors, the minimum current that may be imposed by the TPS2350, and the maximum load under normal operation of the module. For the first factor, the specification minimum clamp value is used, as seen in Equation 1. This method accounts for the tolerance in the sourced current limit below the typical level expected (42 mV/R_{SENSE}). (The clamp measurement includes LCA input offset voltage; therefore, this offset does not have to be factored into the current limit again.) Second, if the load current varies over a range of values under normal operating conditions, then the maximum load level must be allowed for by the value of R_{SENSE}. One example of this is when the load is a switching converter, or brick, which draws higher input current, for a given power output, when the distribution bus is at the low end of its voltage range, with decreasing draw at higher supply voltages. To avoid current limit operation under normal loading, some margin should be designed in between this maximum anticipated load and the minimum current limit level, or $I_{IMAX} > I_{LOAD(max)}$, for Equation 1.

For example, using a 10-mΩ sense resistor for a nominal 2-A load application provides a minimum of 1.4 A of overhead for load variance/margin. Typical bulk capacitor charging current during turn-on is 4.2 A (42 mV/ 10 mΩ).

Setting the Inrush Slew Rate

The TPS2350 device enables user-programming of the maximum current slew rate during load start-up events. A capacitor tied to the RAMP pin (C_{RAMP} in the typical application diagram) controls the di/dt rate. Once the sense resistor value has been established, a value for C_{RAMP}, in microfarads, can be determined from Equation 2.

$$C_{RAMP} = \frac{11.3}{100 \times R_{SENSE} \times \left(\frac{di}{dt}\right)_{(max)}} \quad (2)$$

where

- R_{SENSE} is the sense resistor value in Ω
- $(di/dt)_{(max)}$ is the desired maximum slew rate in A/s

For example, if the desired slew rate for the typical application shown is 1500 mA/ms, the calculated value for C_{RAMP} is about 7500 pF. Selecting the next larger standard value of 8200 pF provides some margin for capacitor and sense resistor tolerances.

The TPS2350 initiates ramp capacitor charging, and consequently load current slewing, at a reduced rate. This reduced rate applies until the voltage on the RAMP pin is about 0.5 V. The maximum di/dt rate, as set by Equation 2, is effective once the device switches to a 10-µA charging source.

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APPLICATION INFORMATION

Setting the Fault Timing Capacitor

The fault timeout period is established by the value of the capacitor connected to the FLTTIM pin, C_{FLT}. The timeout period permits riding out spurious current glitches and surges that may occur during operation of the system, and prevents indefinite sourcing into faulted loads. However, to ensure smooth voltage ramping under all conditions of load capacitance and input supply potential, the minimum timeout should be set to accommodate these system variables. To do this, a rough estimate of the maximum voltage ramp time for a completely discharged plug-in card provides a good basis for setting the minimum timer delay. This section presents a quick procedure for calculating the timing capacitance requirement. However, for proper operation of the TPS2350, there is an absolute minimum value of 0.01-µF for C_{FLT}. This minimum requirement overrides any smaller results of Equation 7 and Equation 8.

Due to the three-phase nature of the load current at turn-on, the load voltage ramp has potentially three distinct phases. This profile depends on the relative values of load capacitance, input DC potential, maximum current limit and other factors. The first two phases are characterized by the two different slopes of the current ramp; the third phase, if required to complete load charging, is the constant-current charging at IMAX. Considering the two current ramp phases to be one period at an average di/dt simplifies calculation of the required timing capacitor.

For the TPS2350, the typical duration of the soft-start period, t_{SS}, is given by Equation 3.

$$t_{SS} = 1260 \times C_{RAMP} \tag{3}$$

where

- t_{SS} is the soft-start period in ms
- C_{RAMP} is given in µF

During this current ramp period, the load voltage magnitude which is attained is estimated by Equation 4.

$$V_{LSS} = \frac{i_{AVG}}{2 \times C_{LOAD} \times C_{RAMP} \times 100 \times R_{SENSE}} \times (t_{SS})^2 \tag{4}$$

where

- V_{LSS} is the load voltage reached during soft-start
- I_{AVG} is 3.18 µA for the TPS2350
- C_{LOAD} is the load capacitance in Farads
- t_{SS} is the soft-start period in s

The quantity I_{AVG} in Equation 4 is a weighted average of the two charge currents applied to C_{RAMP} during turn-on, considering the typical output values.

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APPLICATION INFORMATION

If the result of Equation 4 is larger than the maximum input supply value, then the load can be expected to charge completely during the inrush slewing portion of the insertion event. However, if this voltage is less than the maximum supply input, $V_{IN(MAX)}$, the HSPM transitions to the constant-current charging of the load. The remaining amount of time required at IMAX is determined from Equation 5.

$$t_{CC} = \frac{C_{LOAD} \times \left(V_{IN(MAX)} - V_{LSS}\right)}{\frac{V_{REF_K(MIN)}}{R_{SENSE}}} \quad (5)$$

where

- t_{CC} is the constant-current voltage ramp time, in seconds
- $V_{REF_K(MIN)}$ is the minimum clamp voltage, 34 mV

With this information, the minimum recommended value timing capacitor C_{FLT} can be determined. The delay time needed will be either a time t_{SS2} or the sum of t_{SS2} and t_{CC}, according to the estimated time to charge the load. The quantity t_{SS2} is the duration of the normal rate current ramp period, and is given by Equation 6.

$$t_{SS2} = 0.35 \times C_{RAMP} \quad (6)$$

where

- C_{RAMP} is given in µF

Since fault timing is generated by the constant-current charging of C_{FLT}, the capacitor value is determined from either Equation 7 or Equation 8, as appropriate.

$$C_{FLT(MIN)} = \frac{54 \times t_{SS2}}{3.75} \quad (7)$$

$$C_{FLT(MIN)} = \frac{54 \times \left(t_{SS2} + t_{CC}\right)}{3.75} \quad (8)$$

where

- $C_{FLT(MIN)}$ is the recommended capacitor value, in µ-Farads
- t_{SS2} is the result of Equation 6, in seconds
- t_{CC} is the result of Equation 5, in seconds

Continuing this calculation example, using a 220-µF input capacitor (C_{LOAD}), Equation 3 and Equation 4 estimate the load voltage ramping to approximately –45 V during the soft-start period. If the module should operate down to –72-V input supply, approximately another 1.4 ms of constant-current charging may be required. Therefore, Equation 6 and Equation 8 are used to determine $C_{FLT(MIN)}$, and the result is approximately 0.039-µF.

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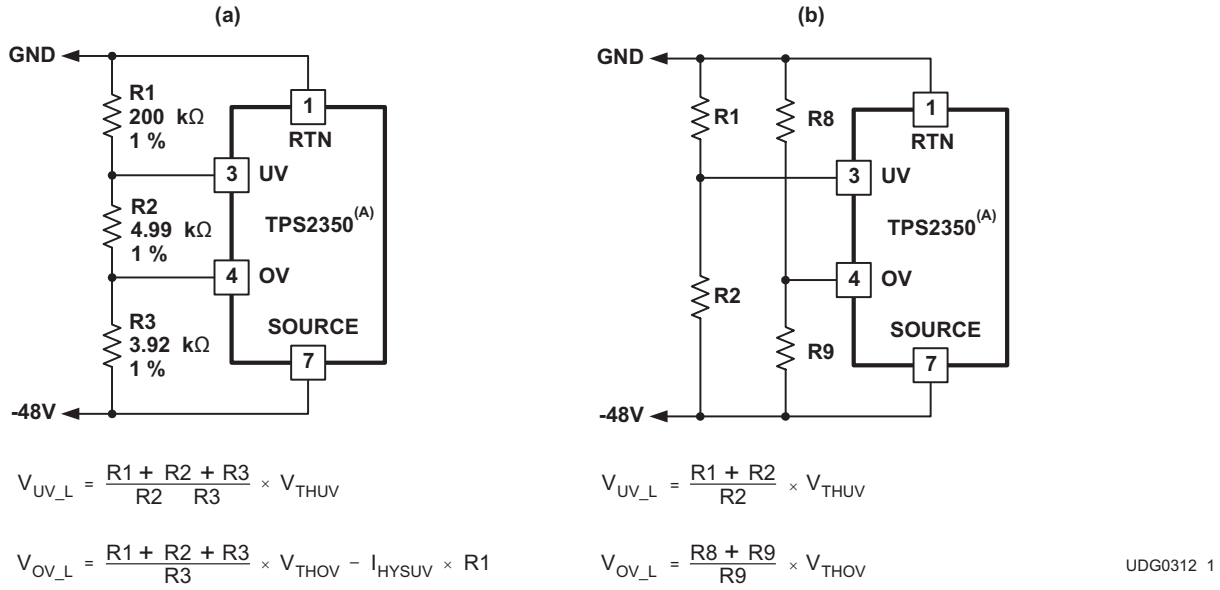
APPLICATION INFORMATION

Setting the Undervoltage and Overvoltage Thresholds

The UV and OV pins can be used to set the undervoltage (V_{UV}) and overvoltage (V_{OV}) thresholds of the hot swap circuit. When the input supply is below V_{UV} or above V_{OV}, the GAT pin is held low, disconnecting power from the load, and the PG output is deasserted. When input voltage is within the UV/OV window, the GAT pin drive is enabled, assuming all other input conditions are valid for turn-on.

Threshold hysteresis is provided via two internal sources which are switched to either pin whenever the corresponding input level exceeds the internal 1.4-V reference. The additional bias shifts the pin voltage in proportion to the external resistance connected to it. This small voltage shift at the device pin is gained up by the external divider to input supply levels.



A. Additional details omitted for clarity

Figure 16. Programming the Undervoltage and Overvoltage Thresholds

The UV and OV thresholds can be individually programmed with a three-resistor divider connected to the TPS2350 as shown in the typical application diagram, and again in Figure 16a. When the desired trip voltages and undervoltage hysteresis have been established for the protected board, the resistor values needed can be determined from the following equations. Generally, the process is simplest by first selecting the top leg of the divider (R1 in the diagram) needed to obtain the threshold hysteresis. This value is calculated from Equation 9.

$$R1 = \frac{V_{HYS_UV}}{10\,\mu A} \tag{9}$$

where

- V_{HYS_UV} is the undervoltage hysteresis value

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APPLICATION INFORMATION

For example, assume the typical application design targets have been set to undervoltage turn-on at 33 V (input supply rising), turn-off at 31 V (input voltage falling), and overvoltage shutdown at 72 V. Then Equation 9 yields R1 = 200 kΩ for the 2-V hysteresis. Once the value of R1 is selected, it is used to calculate resistors R2 and R3.

$$R2 = \frac{1.4 \times R1}{(V_{UV_L} - 1.4)} \times \left[1 - \frac{V_{UV_L}}{(V_{OV_L} + 10^{-5} \times R1)}\right] \quad (10)$$

$$R3 = \frac{1.4 \times R1 \times V_{UV_L}}{(V_{UV_L} - 1.4) \times (V_{OV_L} + 10^{-5} \times R1)} \quad (11)$$

where

- V_{UV_L} is the UVLO threshold when the input supply is low; i.e., less than V_{UV}, and
- V_{OV_L} is the OVLO threshold when the input supply is low; i.e., less than V_{OV}

Again referring to the Figure 17a schematic, Equation 10 and Equation 11 produce R2 = 4.909 kΩ (4.99 kΩ selected) and R3 = 3.951 kΩ (3.92 kΩ selected), as shown. For the selected values, the expected nominal supply thresholds are V_{UV_L} = 32.8 V, V_{UV_H} = 30.8 V, and V_{OV_L} = 72.6 V. The hysteresis of the overvoltage threshold, as seen at the supply inputs, is given by the quantity (10 µA) × (R1 + R2). For the majority of applications, this value is very nearly the same as the UV hysteresis, since typically R1 >> R2.

If more independent control is needed for the OVLO hysteresis, there are several options. One option is to use separate dividers for both the UV and OV pins, as shown in Figure 16b. In this case, once R1 and R8 have been selected for the required hysteresis per Equation 9, and values for the bottom resistors in the divider (R2 and R9 in Figure 16b) can be calculated using Equation 12.

$$R_{XVLO} = \frac{V_{REF}}{(V_{XV_L} - V_{REF})} \times R_{(TOP)} \quad (12)$$

where

- R_{XVLO} is R2 or R9
- $R_{(TOP)}$ is R1 or R8 as appropriate for the threshold being set
- V_{XV_L} is the under (V_{UV_L}) or overvoltage (V_{OV_L}) threshold at the supply input, and
- V_{REF} is either V_{THUV} or V_{THOV} from the specification table, as required for the resistor being calculated.

Reverse Voltage Protection

In some applications, it may be necessary to protect the TPS2350 against reverse polarity supply connections or input transients. If the potential at either the –VINA or –VINB pin rises above that of the RTN pin, device damage may result. If the application environment is such that these conditions are anticipated, a small-signal diode should be inserted between the supply return bus and the TPS2350 RTN pin, as shown in the Typical Application diagram. A 75-V to 100-V rated device (VRRM), such as MMBD4148 or BAV19, is recommended.

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TPS2350D	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
TPS2350DG4	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
TPS2350DR	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples
TPS2350DRG4	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples
TPS2350PW	ACTIVE	TSSOP	PW	14	90	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
TPS2350PWG4	ACTIVE	TSSOP	PW	14	90	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
TPS2350PWR	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples
TPS2350PWRG4	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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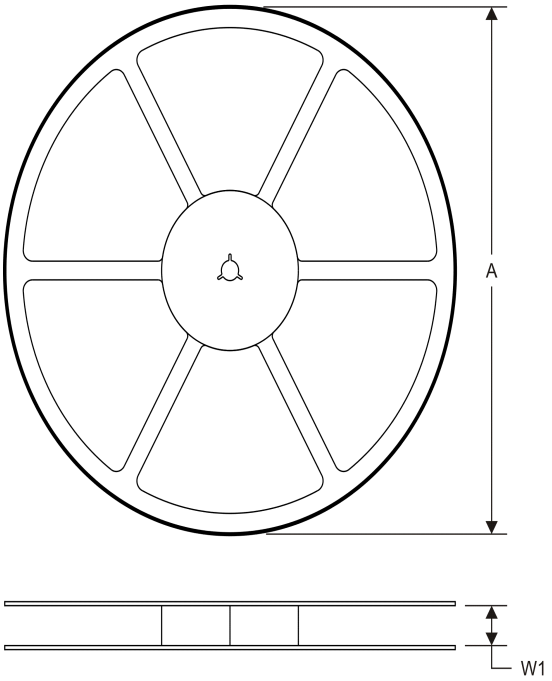
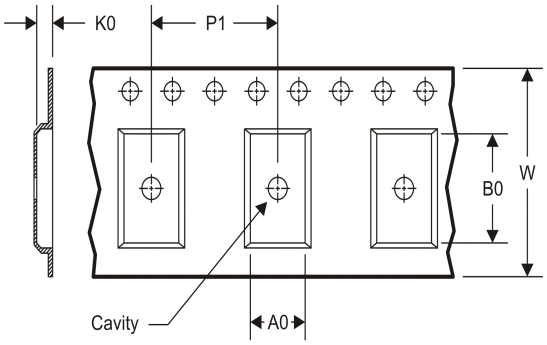


TAPE DIMENSIONS



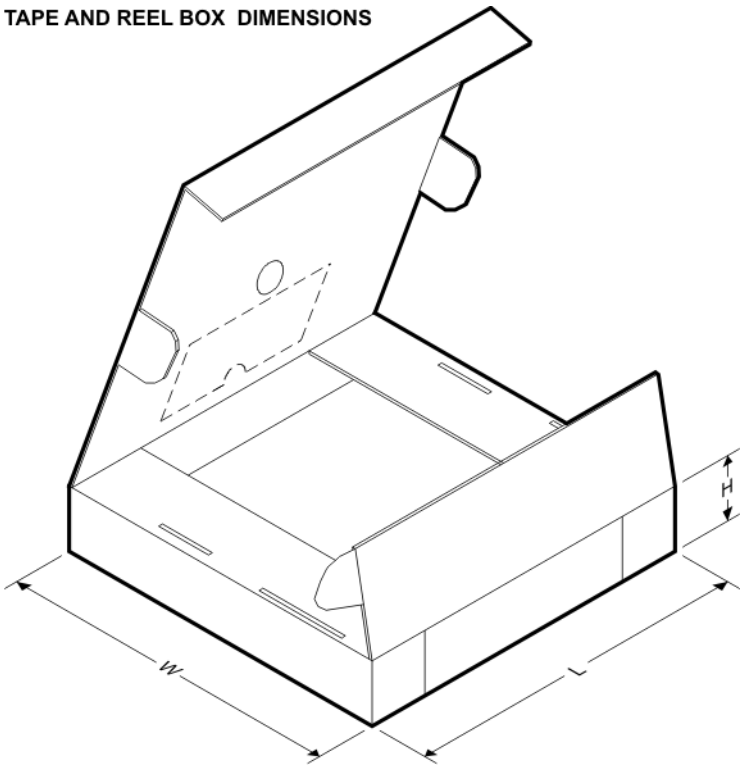
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

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
TPS2350DR	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1
TPS2350PWR	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

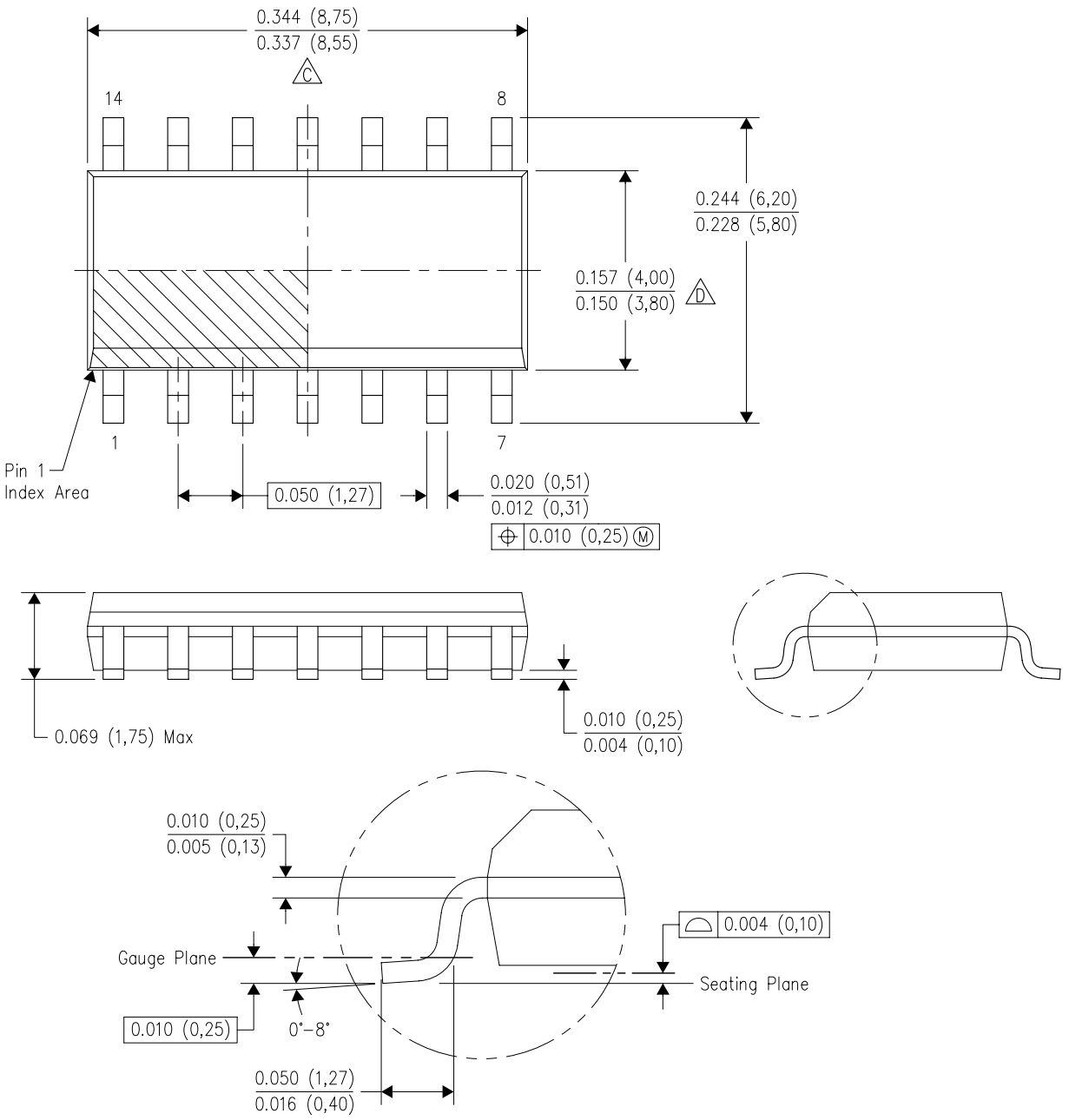
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

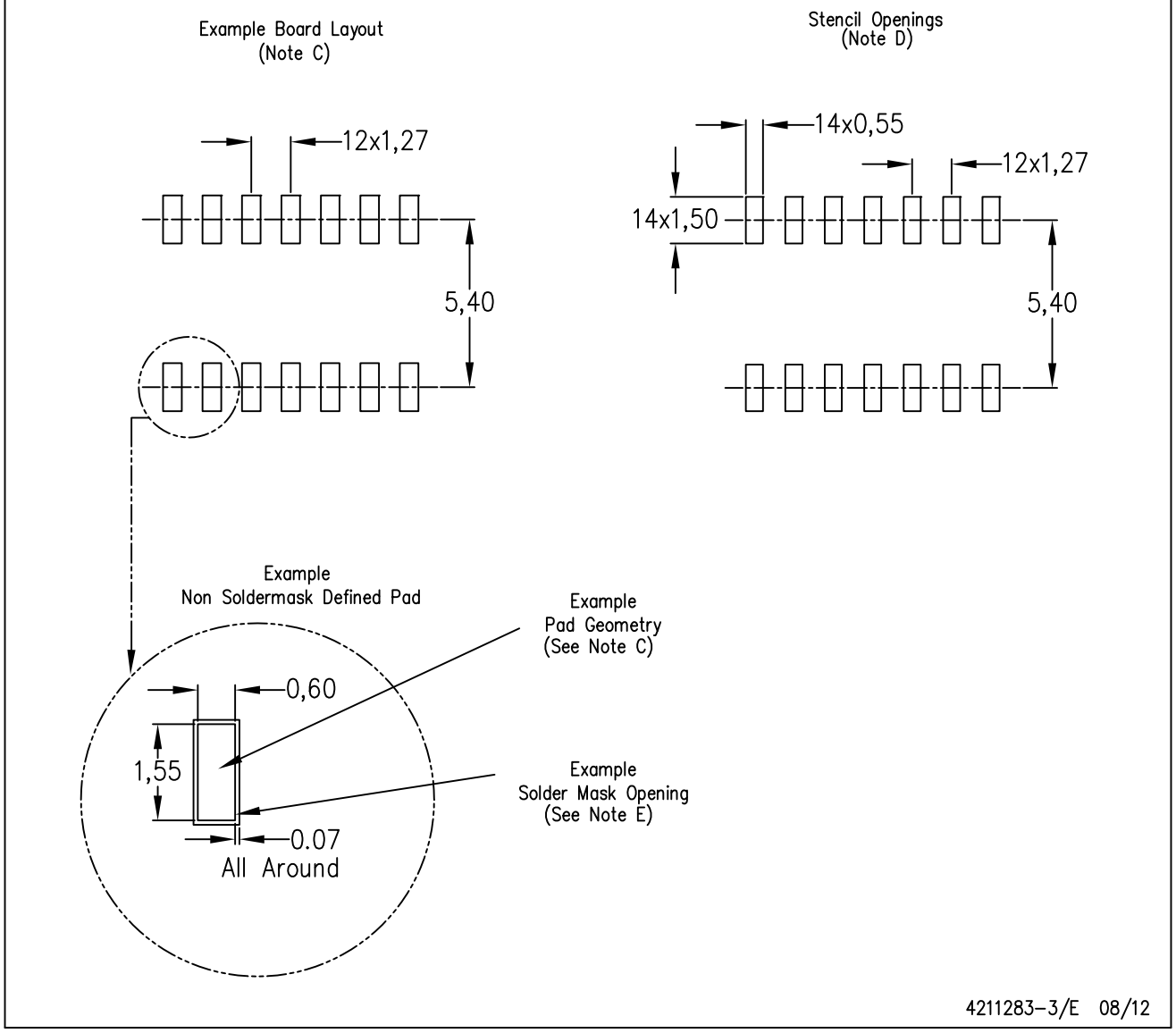
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS2350DR	SOIC	D	14	2500	367.0	367.0	38.0
TPS2350PWR	TSSOP	PW	14	2000	367.0	367.0	35.0

D (R–PDSO–G14) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AB.

D (R–PDSO–G14) PLASTIC SMALL OUTLINE



NOTES:
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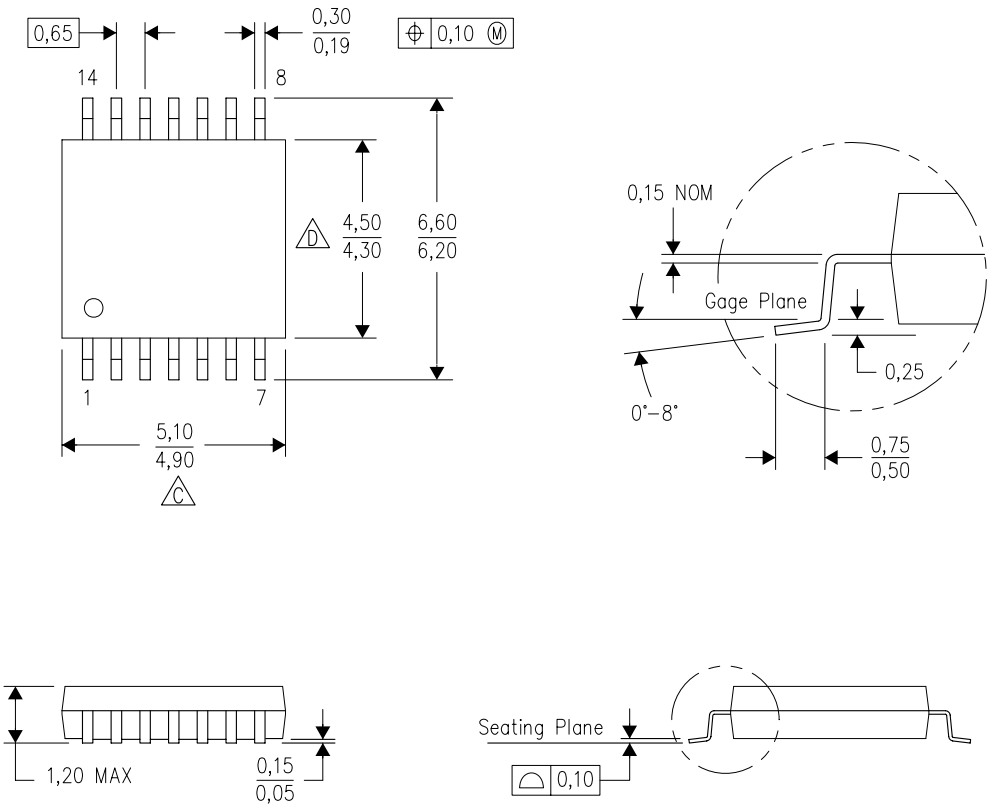
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PW (R–PDSO–G14) PLASTIC SMALL OUTLINE



4040064–3/G 02/11

NOTES:
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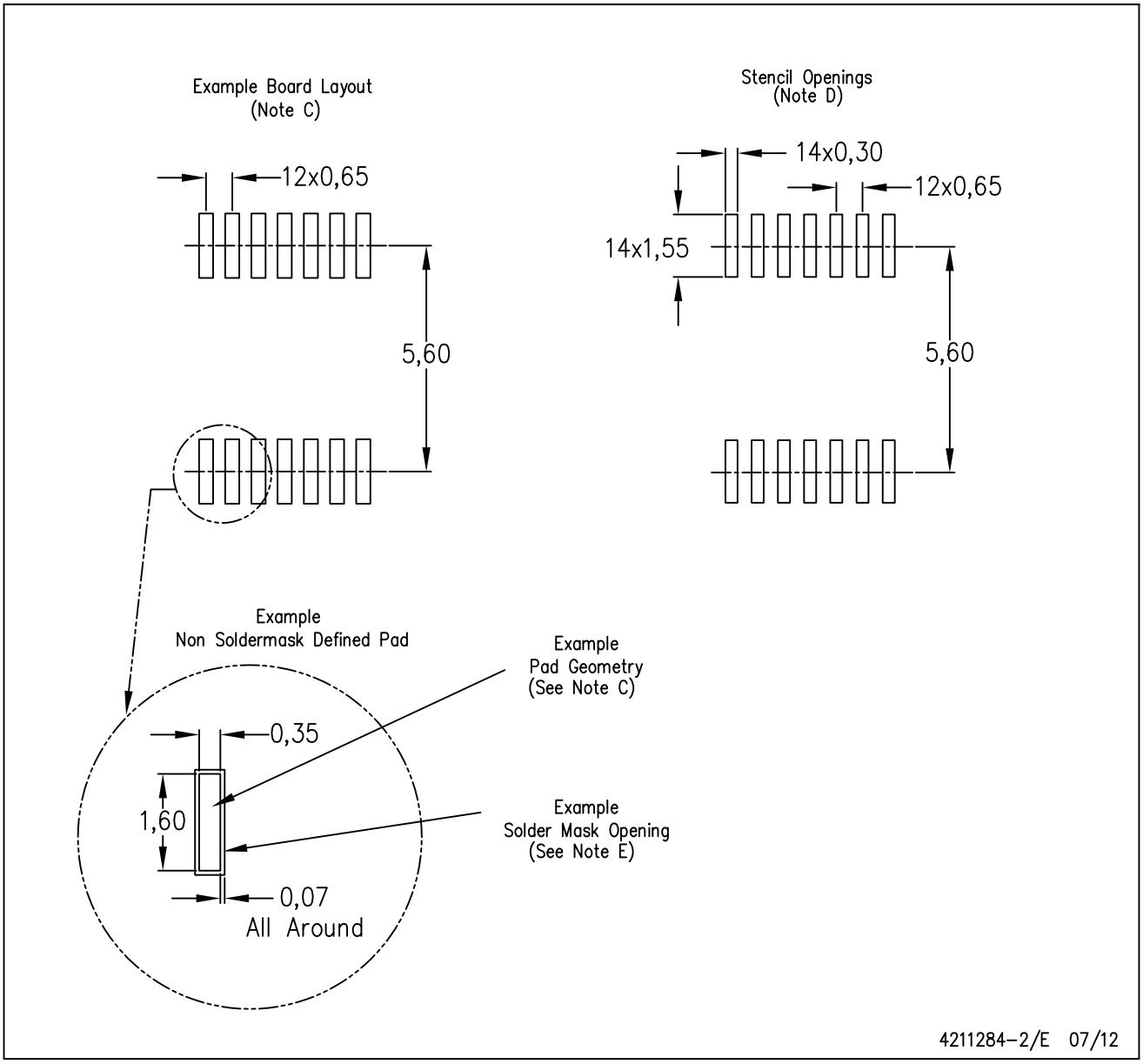
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
E. Falls within JEDEC MO–153

PW (R–PDSO–G14) PLASTIC SMALL OUTLINE



NOTES:
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E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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