

## HOT SWAP POWER MANAGER FOR REDUNDANT –48-V SUPPLIES

### 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

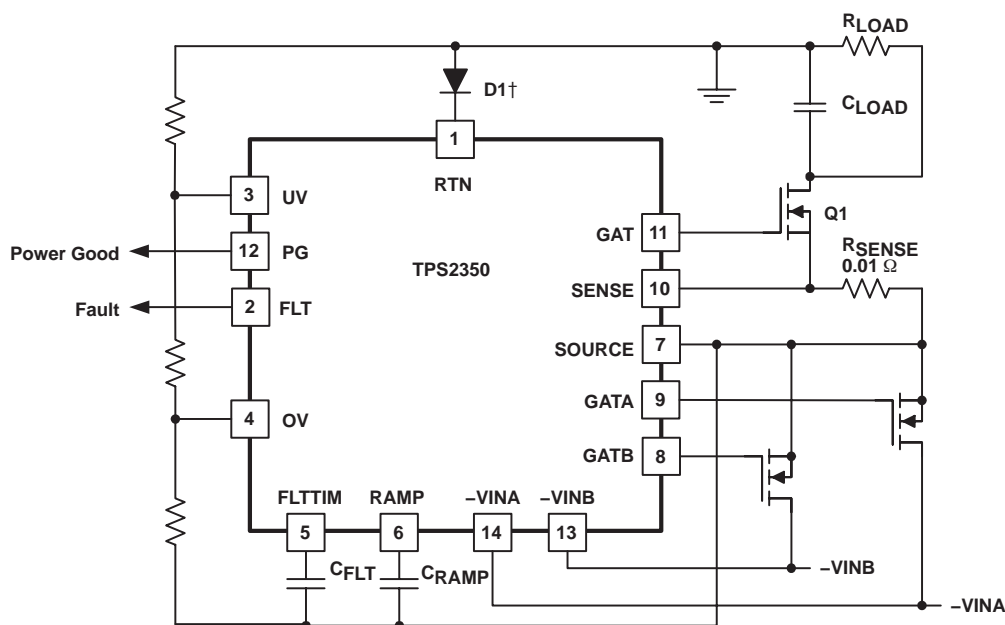
### DESCRIPTION

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



† D1 optional per application requirements.

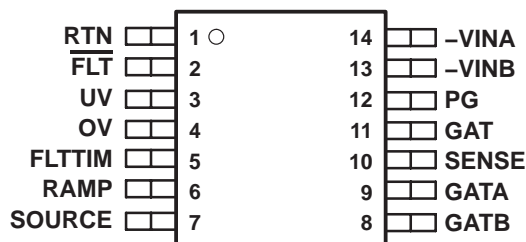
**ABSOLUTE MAXIMUM RATINGS**over operating free-air temperature (unless otherwise noted)<sup>(1)</sup>

PARAMETER	TPS2350	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, $\overline{\text{FLT}}$ , PG (2)(3)	–0.3 to 100	
Continuous output current, $\overline{\text{FLT}}$ , PG	10	mA
Continuous total power dissipation	TBD	°C
Operating junction temperature range, T <sub>J</sub>	–55 to 125	
Storage temperature range, T <sub>stg</sub>	–65 to 150	
Lead temperature soldering 1,6 mm (1/16 inch) from case for 10 seconds	260	

(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 k $\Omega$  minimum series resistance. Range limited to –0.3V to 80V from low impedance source.

**SOIC/TSSOP-14 PACKAGE  
(TOP VIEW)****ELECTROSTATIC DISCHARGE  
(ESD) PROTECTION**

	MIN	UNIT
Human body model (HBM)	2	kV
Charged device model (CDM)	1.5	

**AVAILABLE OPTIONS**

T <sub>A</sub>	PACKAGE	PART NUMBER
–40°C to 85°C	SOIC–14(4)	TPS2350D
	TSSOP–14(4)	TPS2350PW

(4) 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

**DISSIPATION RATING TABLE**

PACKAGE	T <sub>A</sub> < 25 °C POWER RATING	DERATING FACTOR ABOVE T <sub>A</sub> = 25 °C	T <sub>A</sub> = 85 °C POWER RATING
SOIC–14	750 mW	7.5 mW/°C	300 mW
TSSOP–14	750 mW	7.5 mW/°C	300 mW

**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<sub>A</sub> = –40 °C to 85 °C (unless otherwise noted)†‡

**Input Supply**

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
I <sub>CC1A</sub> Supply current	–VINA = –48 V, –VINB = 0 V		1000	1500	μA
I <sub>CC2A</sub> Supply current	–VINA = –80 V, –VINB = 0 V			2000	
I <sub>CC1B</sub> Supply current	–VINB = –48 V, –VINA = 0 V		1000	1500	
I <sub>CC2B</sub> Supply current	–VINB = –80 V, –VINA = 0 V			2000	
V <sub>UVLO_I</sub> Internal UVLO threshold voltage	To GAT pull up	–11.8	–10	–8.0	V
V <sub>HYST</sub> Internal UVLO hysteresis voltage		50	240	500	mV

**Overvoltage and Undervoltage Inputs (OV and UV)**

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>THUV</sub> 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 <sub>HYSUV</sub> UV hysteresis	UV = –45.5 V	–11	–10	–9	μA
I <sub>ILUV</sub> UV low-level input current	UV = –47 V	–1		1	
V <sub>THOV</sub> OV threshold voltage, OV rising, to –VINA	To GAT pull up	1.376	1.400	1.426	V
I <sub>HYSOV</sub> OV hysteresis	OV = –45.5 V	–11.1	–10	–8.6	μA
I <sub>ILOV</sub> OV low-level input current	OV = –47 V	–1		1	

**Linear Current Amplifier (LCA)**

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>OH</sub> High level output, GAT–SOURCE	SENSE = SOURCE	11	14	17	V
I <sub>SINK_f</sub> GAT sink current in fault	SENSE – SOURCE = 80 mV, GAT = –43 V, FLTTIME = 5 V	30	75		mA
I <sub>SINK_I</sub> GAT sink current in linear mode	SENSE – SOURCE = 80 mV, GAT = –43 V, FLTTIME = 2 V		5	10	
I <sub>IN</sub> SENSE input current	0.0 V < SENSE – SOURCE < 0.2 V	–1		1	μA
V <sub>REF_K</sub> Reference clamp voltage, SENSE – SOURCE	RAMP – SOURCE = 6 V	34	42	50	mV
V <sub>IO</sub> Input offset voltage, SENSE – SOURCE	RAMP – SOURCE = 0 V	–7		9	

**Ramp Generator**

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
I <sub>SRC1</sub> RAMP source current, slow turn-on rate	RAMP – SOURCE = 0.25 V	–800	–550	–300	nA
I <sub>SRC2</sub> RAMP source current, normal rate	RAMP – SOURCE = 1 V and 3 V	–11.3	–10	–8.5	μA
V <sub>OL</sub> Low-level output voltage	UV = SOURCE			5	mV
A <sub>v</sub> Voltage gain, relative to SENSE	0 V < RAMP – SOURCE < 5 V	9.5	10	10.7	mV/V

† All voltages are with respect to RTN unless otherwise stated.

‡ Currents are positive into and negative out of the specified terminal.

## 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<sub>A</sub> = –40 °C to 85 °C (unless otherwise noted)†‡

### Overload Comparator

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>TH_OL</sub> SENSE current overload threshold		100	120	140	mV
t <sub>RSP</sub> Response time	SENSE – SOURCE = 200 mV	2	4	7	μs

### Fault Timer

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>OL</sub> FLTTIM low-level output voltage, to –VINA	UV = –48 V			5	mV
I <sub>CHG</sub> FLTTIM charging current, current limit mode	FLTTIM – SOURCE = 2 V	–54	–50	–41	μA
V <sub>FLT</sub> FLTTIM fault threshold voltage to SOURCE		3.75	4.00	4.25	V
V <sub>RST</sub> Fault reset threshold to SOURCE			0.5		
I <sub>DSG</sub> 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		1.0%	1.5%	
I <sub>RST</sub> FLTTIM discharge current, timer reset mode	FLTTIM – SOURCE = 2 V, SENSE = V		1		mA

### Logic Outputs (FLT, PG)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
I <sub>OHFLT</sub> FLT high-level output leakage current	UV = –48 V, FLT – SOURCE = 80 V	–10		10	μA
I <sub>OHPG</sub> PG high-level output leakage current	UV = –45 V, PG – SOURCE = 80 V	–10		10	
R <sub>DS(on)</sub> FLT ON resistance	SENSE – SOURCE = 80 mV, FLTTIM – SOURCE = 5 V, I(FLT) = 1 mA		50	80	Ω
R <sub>DS(on)</sub> PG ON resistance	UV = –48 V, I <sub>O</sub> (PG) = 1 mA		50	80	

### Supply Selector

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>THA</sub> Threshold voltage, –VINA falling	–VINB = –48 V, –VINA falling	–48.45	–48.40	–48.35	V
V <sub>THB</sub> Threshold voltage, –VINB falling	–VINA = –48 V, –VINB falling	–48.45	–48.40	–48.35	
I <sub>SINK</sub> GATA sink current	–VINA = 0 V, –VINB = –48 V, GATA = –41 V	30	80		mA
I <sub>SOURCE</sub> GATA source current	–VINA = –48 V, –VINB = –0 V, GATA = –41 V		–50	–20	μA
I <sub>SINK</sub> GATB sink current	–VINA = –48 V, –VINB = –0 V, GATB = –41 V	30	80		mA
I <sub>SOURCE</sub> GATB source current	–VINA = 0 V, –VINB = –48 V, GATB = –41 V		–50	–20	μA
V <sub>OLA</sub> GATA low voltage to –VINA	–VINA = 0 V, –VINB = –48 V			0.1	V
V <sub>OLA</sub> GATA high voltage to –VINA	–VINA = –48 V, –VINB = 0 V	11	14	17	
V <sub>OLB</sub> GATB low voltage to –VINB	–VINA = –48 V, –VINB = 0 V			0.1	
V <sub>OLB</sub> GATB high voltage to –VINB	–VINA = 0 V, –VINB = –48 V	11	14	17	

† All voltages are with respect to RTN unless otherwise stated.

‡ Currents are positive into and negative out of the specified terminal.

## TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
$\overline{\text{FLT}}$	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

**$\overline{\text{FLT}}$ :** 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).  $\overline{\text{FLT}}$  is cleared when both supplies drop below the UV-comparator threshold or one supply exceeds the OV-comparator threshold. The  $\overline{\text{FLT}}$  output is pulled to the lower of –VINA and –VINB. The  $\overline{\text{FLT}}$  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 k $\Omega$ .

**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  $\overline{\text{FLT}}$  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  $I_{\text{MAX}} \leq 42 \text{ mV}/R_{\text{SENSE}}$ . 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.

**PIN DESCRIPTIONS (cont.)**

**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 k $\Omega$ .

**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<sub>SENSE</sub>. 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.

## TYPICAL CHARACTERISTICS

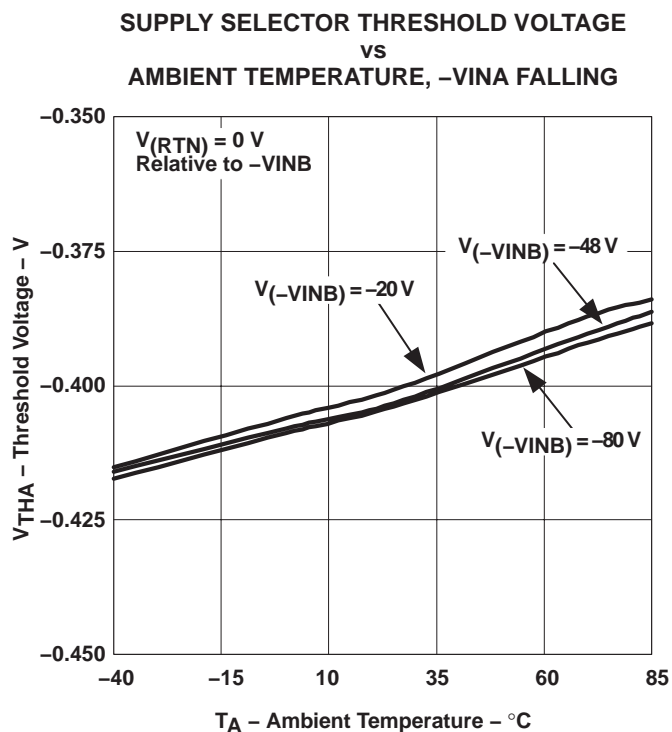


Figure 1

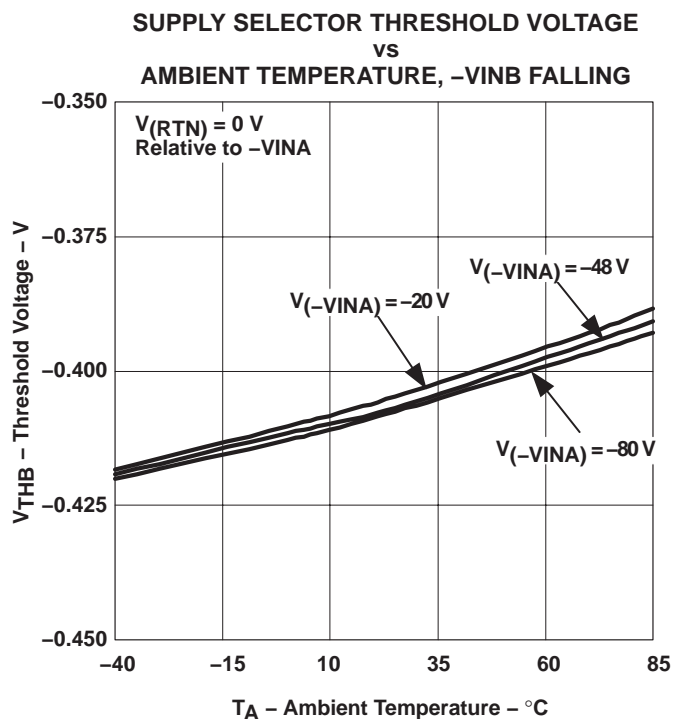


Figure 2

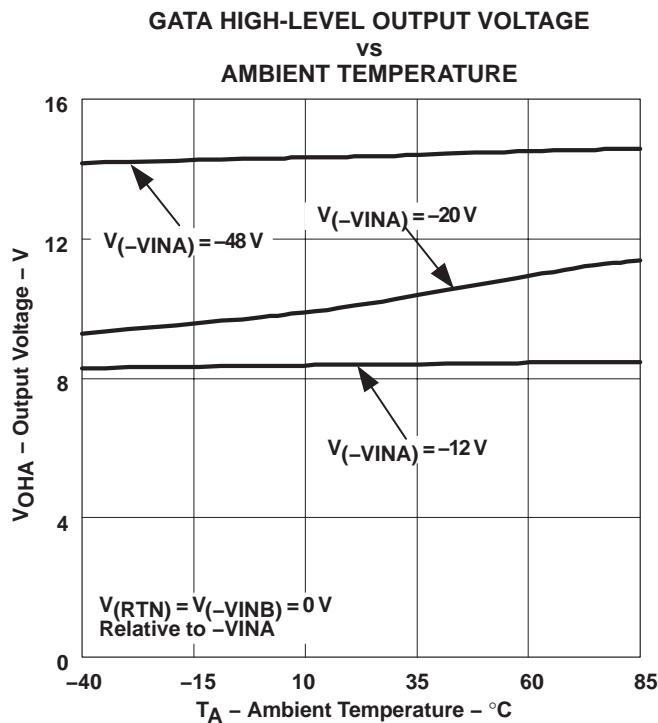


Figure 3

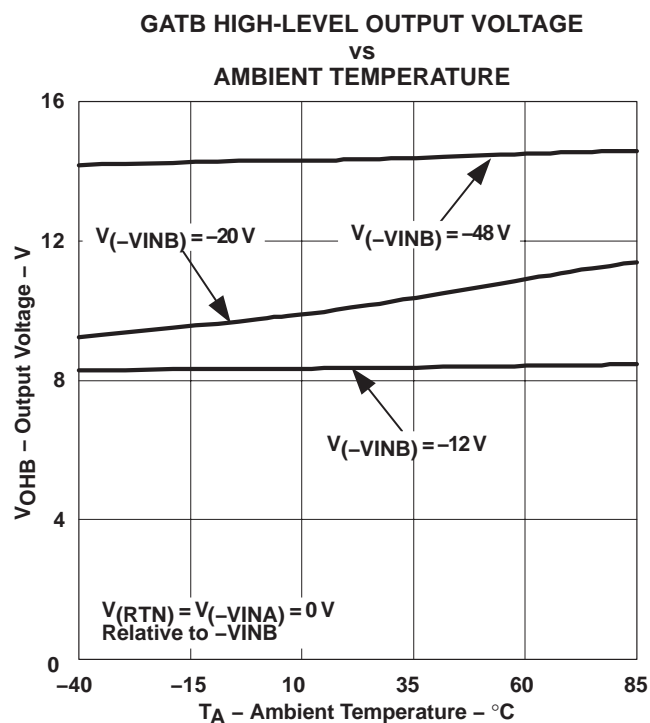


Figure 4



## TYPICAL CHARACTERISTICS

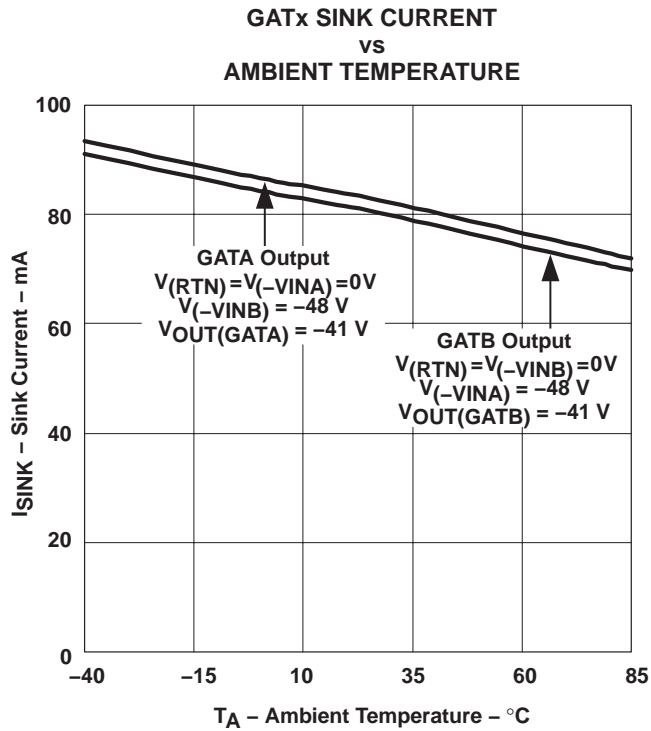


Figure 5

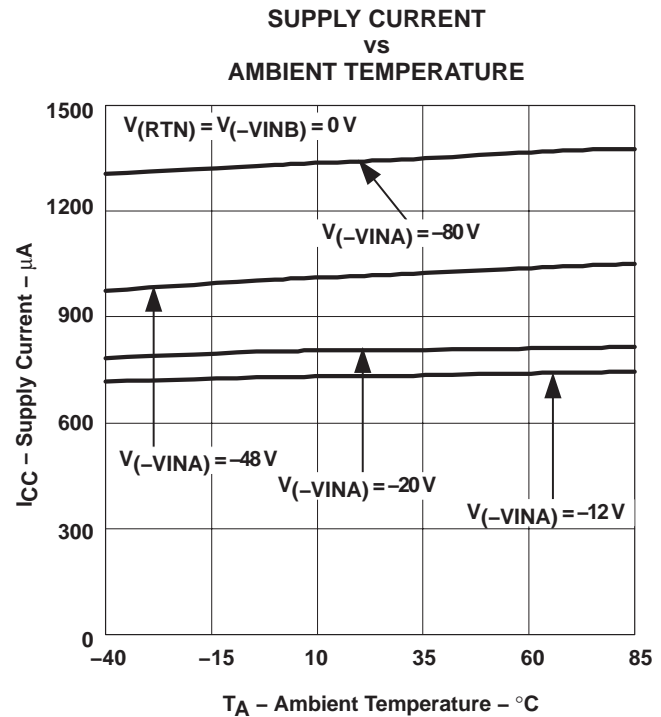


Figure 6

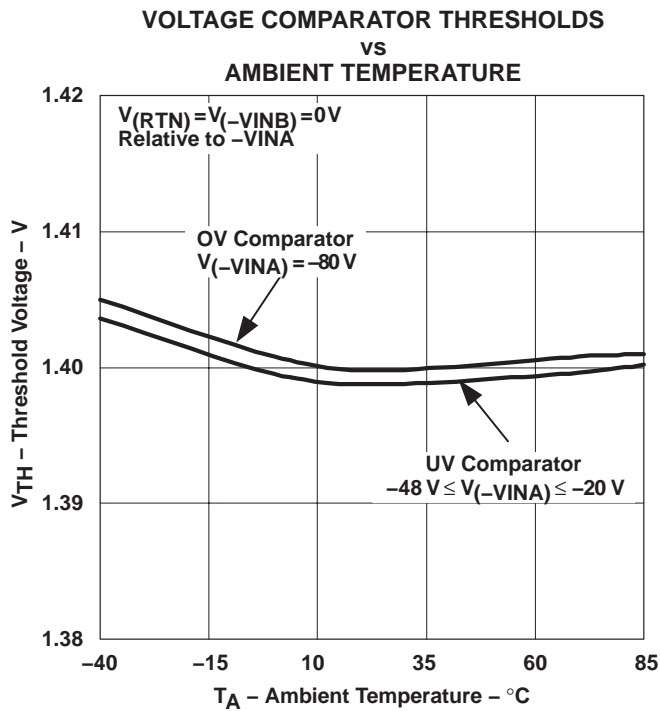


Figure 7

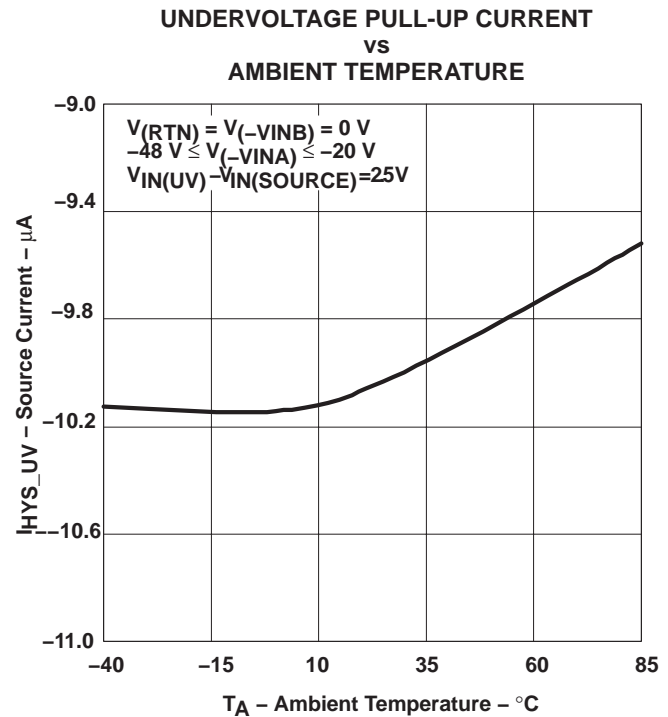
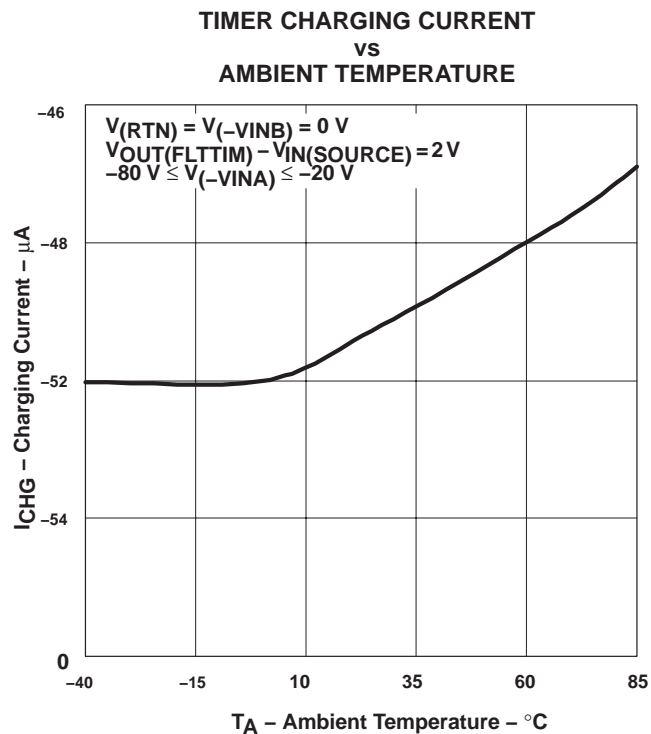
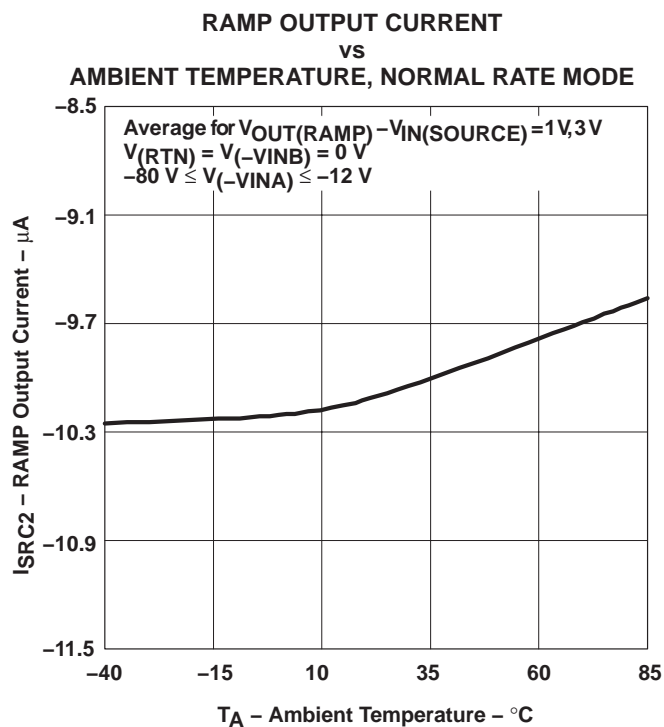
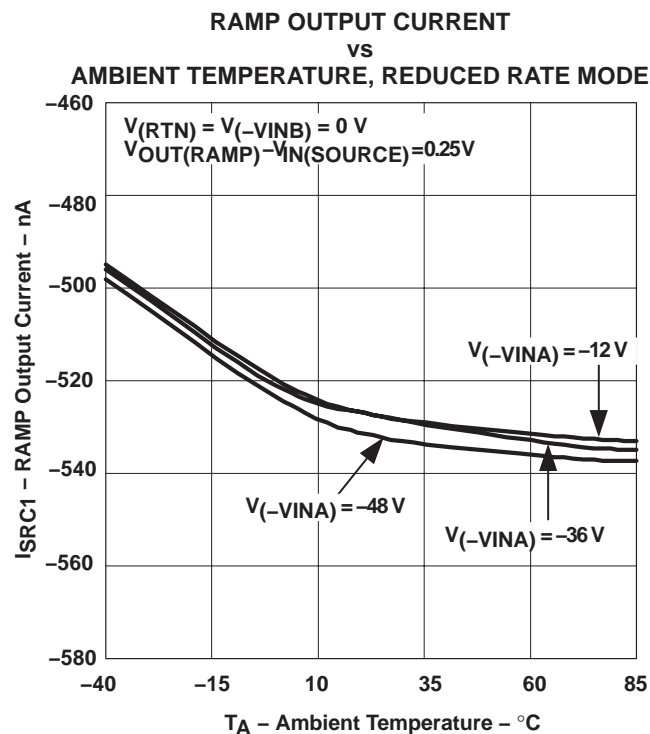
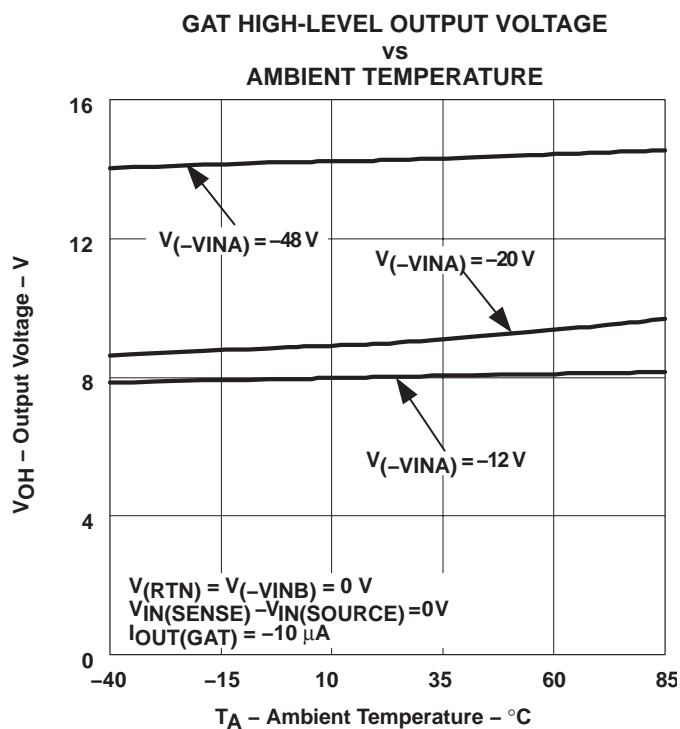


Figure 8



## TYPICAL CHARACTERISTICS



TYPICAL CHARACTERISTICS

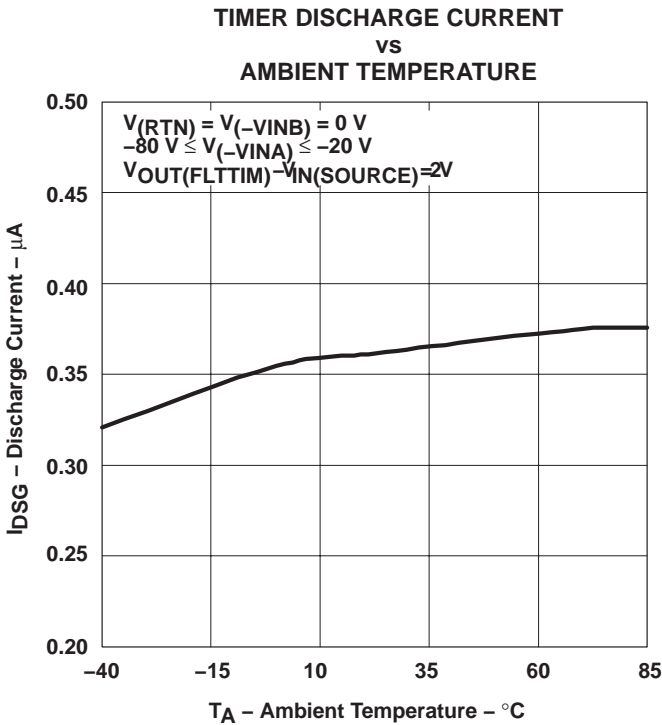


Figure 13

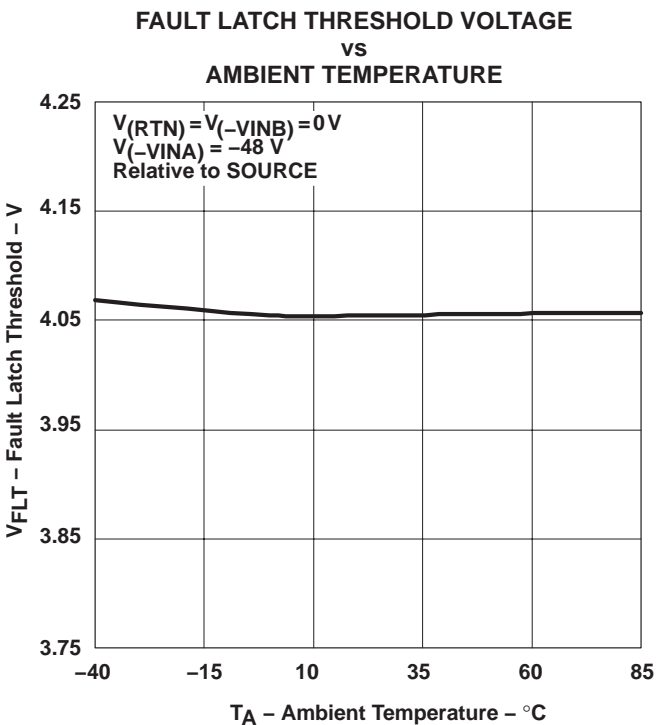
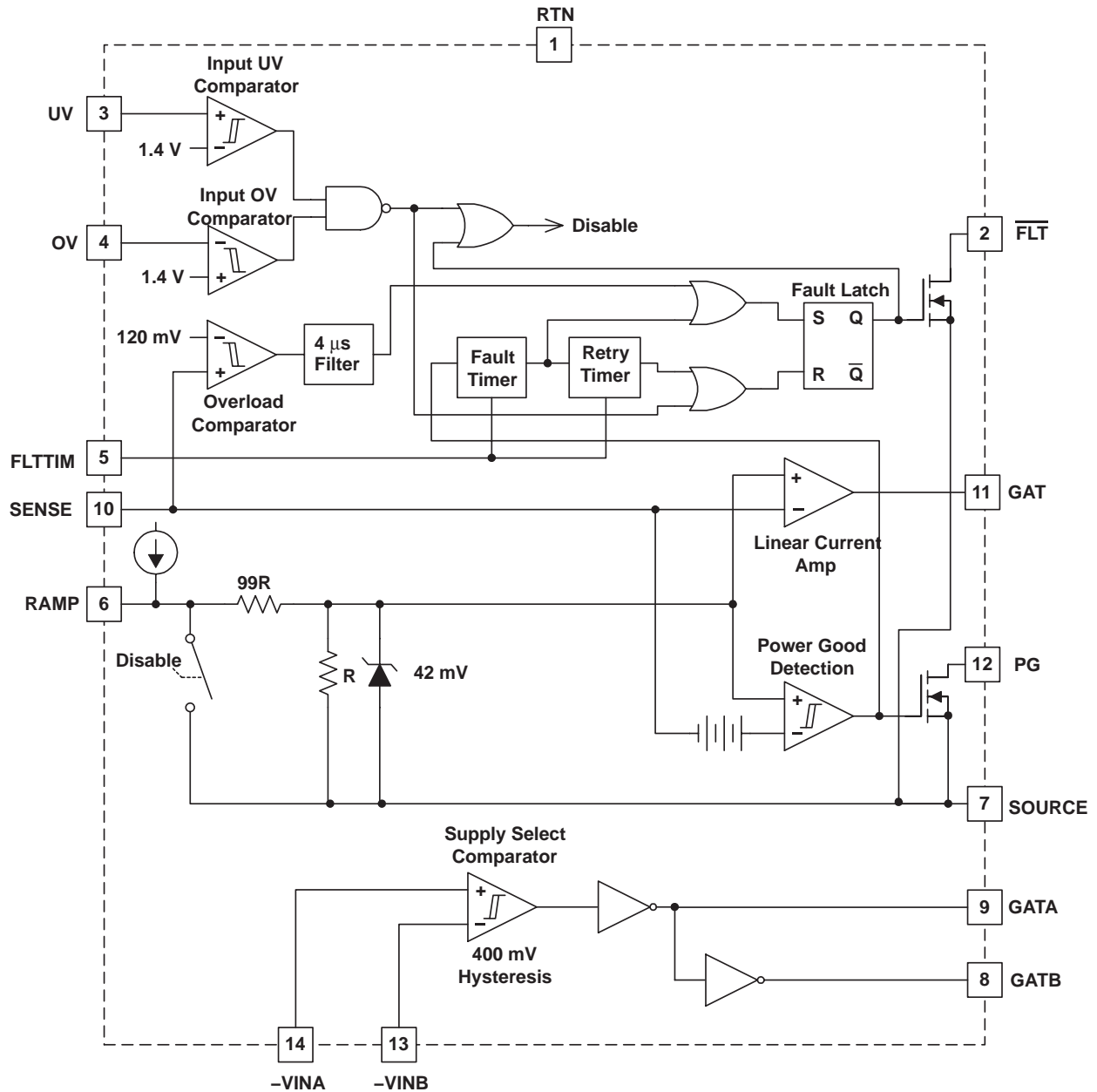


Figure 14

## FUNCTIONAL BLOCK DIAGRAM



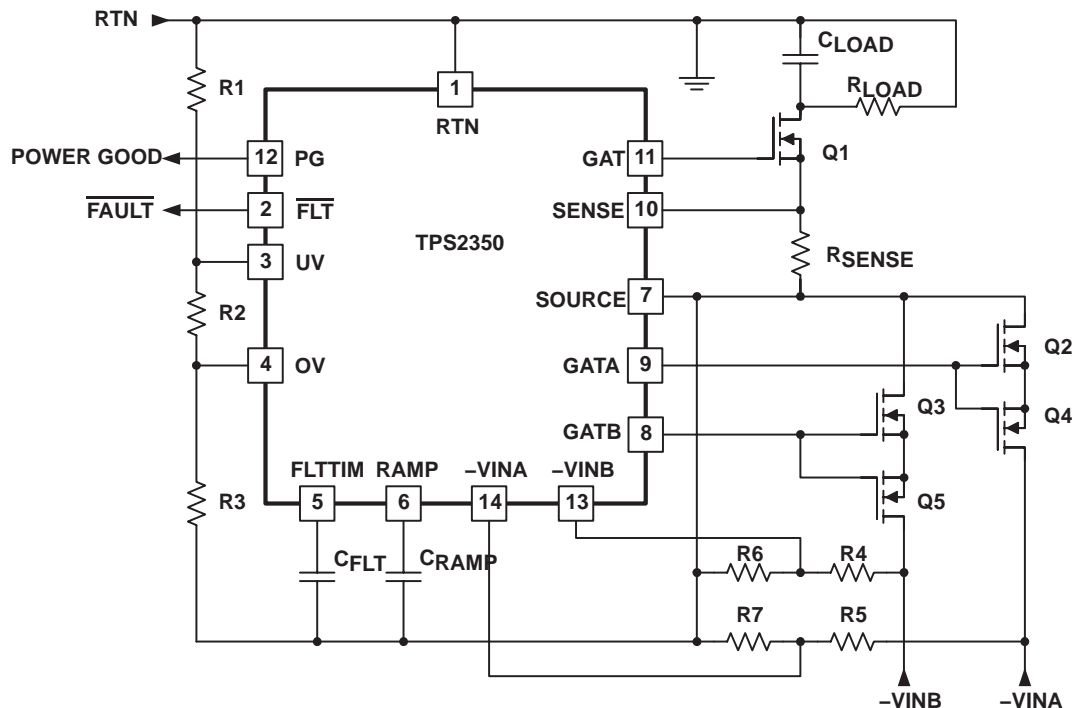
## APPLICATION INFORMATION

## SUPPLY SECTION

The supply selection comparator selects between  $-V_{INA}$  and  $-V_{INB}$  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  $R4 = R5 = 40\text{ k}\Omega$ , and  $R6 = R7 = 20\text{ k}\Omega$ , 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.



UDG-03121

Figure 15. Typical Application to Develop Higher Supply Comparator Hysteresis

## 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).

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

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-m $\Omega$  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 m $\Omega$ ).

### 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  $\Omega$
- $(di/dt)_{(max)}$  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- $\mu$ A charging source.

## 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- $\mu$ F for  $C_{FLT}$ . This minimum requirement overrides any smaller results of equations (7) and (8) below.

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  $I_{MAX}$ . 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)

$$t_{SS} = 1260 \times C_{RAMP} \quad (3)$$

where

- $t_{SS}$  is the soft-start period in ms
- $C_{RAMP}$  is given in  $\mu$ F

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

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

where

- $V_{LSS}$  is the load voltage reached during soft-start
- $i_{AVG}$  is 3.18  $\mu$ A 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.

## 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  $I_{MAX}$  is determined from equation (5).

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

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  $\mu F$

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

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

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

where

- $C_{FLT(MIN)}$  is the recommended capacitor value, in  $\mu$ -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- $\mu F$  input capacitor ( $C_{LOAD}$ ), equations (3) and (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, equations (6) and (8) are used to determine  $C_{FLT(MIN)}$ , and the result is approximately 0.039- $\mu F$ .

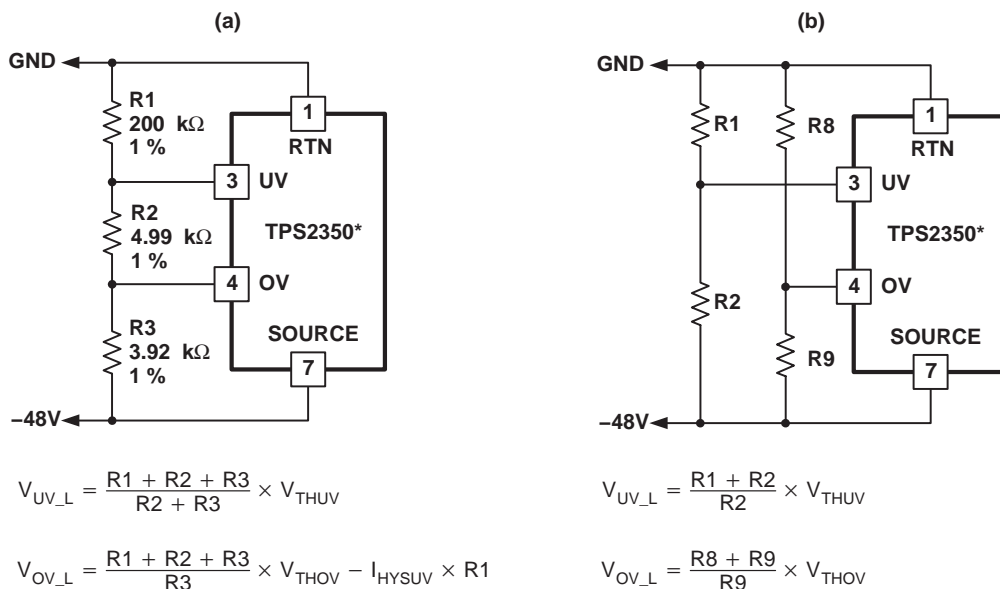


## APPLICATION INFORMATION

## 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.



\*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).

$$R1 = \frac{V_{HYS\_UV}}{10 \mu A} \quad (9)$$

where

- $V_{HYS\_UV}$  is the undervoltage hysteresis value

## 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  $R1 = 200 \text{ k}\Omega$  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, equations (10) and (11) produce  $R2 = 4.909 \text{ k}\Omega$  (4.99 k $\Omega$  selected) and  $R3 = 3.951 \text{ k}\Omega$  (3.92 k $\Omega$  selected), as shown. For the selected values, the expected nominal supply thresholds are  $V_{UV\_L} = 32.8 \text{ V}$ ,  $V_{UV\_H} = 30.8 \text{ V}$ , and  $V_{OV\_L} = 72.6 \text{ V}$ . The hysteresis of the overvoltage threshold, as seen at the supply inputs, is given by the quantity  $(10 \mu\text{A}) \times (R1 + R2)$ . For the majority of applications, this value is very nearly the same as the UV hysteresis, since typically  $R1 \gg R2$ .

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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