

## DESCRIPTION

The MP5991 is an integrated, monolithic controller and switch with a power MOSFET and other circuitry that allows it to work in standalone operation or to be controlled via a hot-swap controller. The device can drive up to 50A of continuous output current (I<sub>OUT</sub>) per device at room temperature, and up to 60A of continuous I<sub>OUT</sub> with air flow.

The device limits the backplane voltage drop by limiting the inrush current to the load while a circuit card is inserted into a live backplane power source. It limits the internal MOSFET current (I<sub>FET</sub>) by controlling the gate voltage (V<sub>GATE</sub>) via the current limit (I<sub>LIMIT</sub>) reference input and soft-start ramp.

The MP5991 provides many features to simplify system design, such as an integrated current mirror to monitor I<sub>OUT</sub> and the integrated on-die temperature sense. This eliminates the need for an external current-sense power resistor, power MOSFET, and temperature-sense device.

The IC detects the power MOSFET's gate, source, and drain short conditions. It also provides feedback to the hot-swap controller via the fault-reporting output (GOK). The MP5991 can operate in parallel for high-current applications. During start-up, all of the devices in parallel actively share current.

The MP5991 is available in an LGA-32 (5mmx5mm) package.

## FEATURES

- 4V to 16V Operating Input Voltage (V<sub>IN</sub>) Range
- Up to 50A Continuous Output Current (I<sub>OUT</sub>)
- Up to 60A Continuous I<sub>OUT</sub> with Air Flow
- Integrated Power MOSFET with 1mΩ R<sub>DS(ON)</sub>
- IMON Reporting (±1% Accuracy)
- Built-In MOSFET Driver
- 3.3V LDO Output
- Integrated Current Sense with Sense Output
- Configurable Over-Current Limit
- Configurable Short-Circuit Current Limit
- Built-In Insertion Delay
- Configurable Soft Start (SS)
- Output Short-Circuit Protection (SCP)
- Over-Temperature Protection (OTP)
- Built-In Fuse Health Reporting
- Fault Signal Output (GOK)
- Fault Type Indication (FLT\_TYPE)
- Supports Parallel Operation for High-Current Applications
- Integrated Intelli-Fuse Temperature Sense
- Available in an LGA-32 (5mmx5mm) Package

## APPLICATIONS

- Hot Swap
- PC Cards
- Disk Drives
- Servers
- Networking

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## TYPICAL APPLICATION

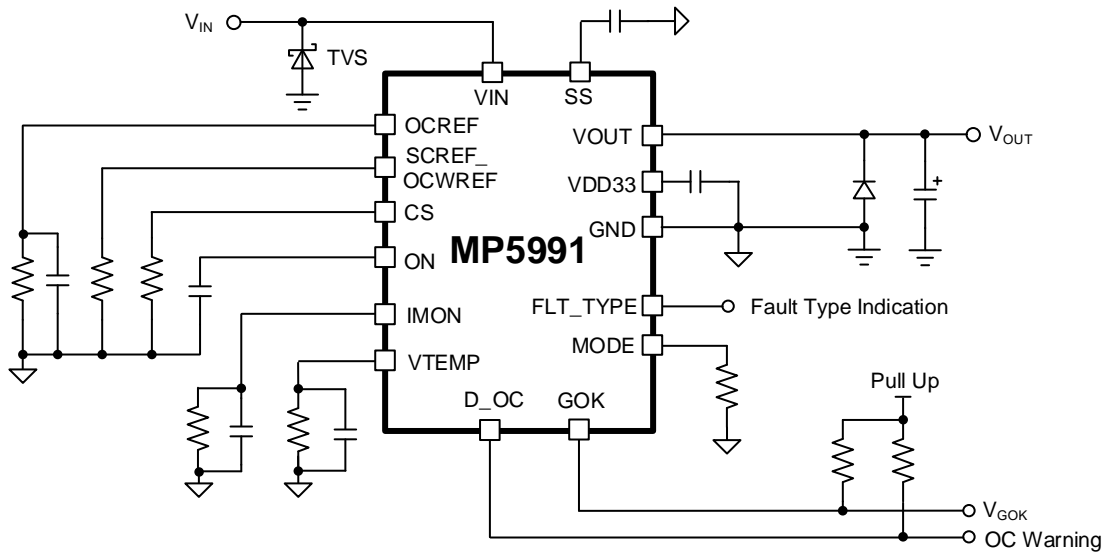


Figure 1: MP5991 Standalone Operation ( $R_{IMON} \geq R_{CS}$ )

TYPICAL APPLICATION (continued)

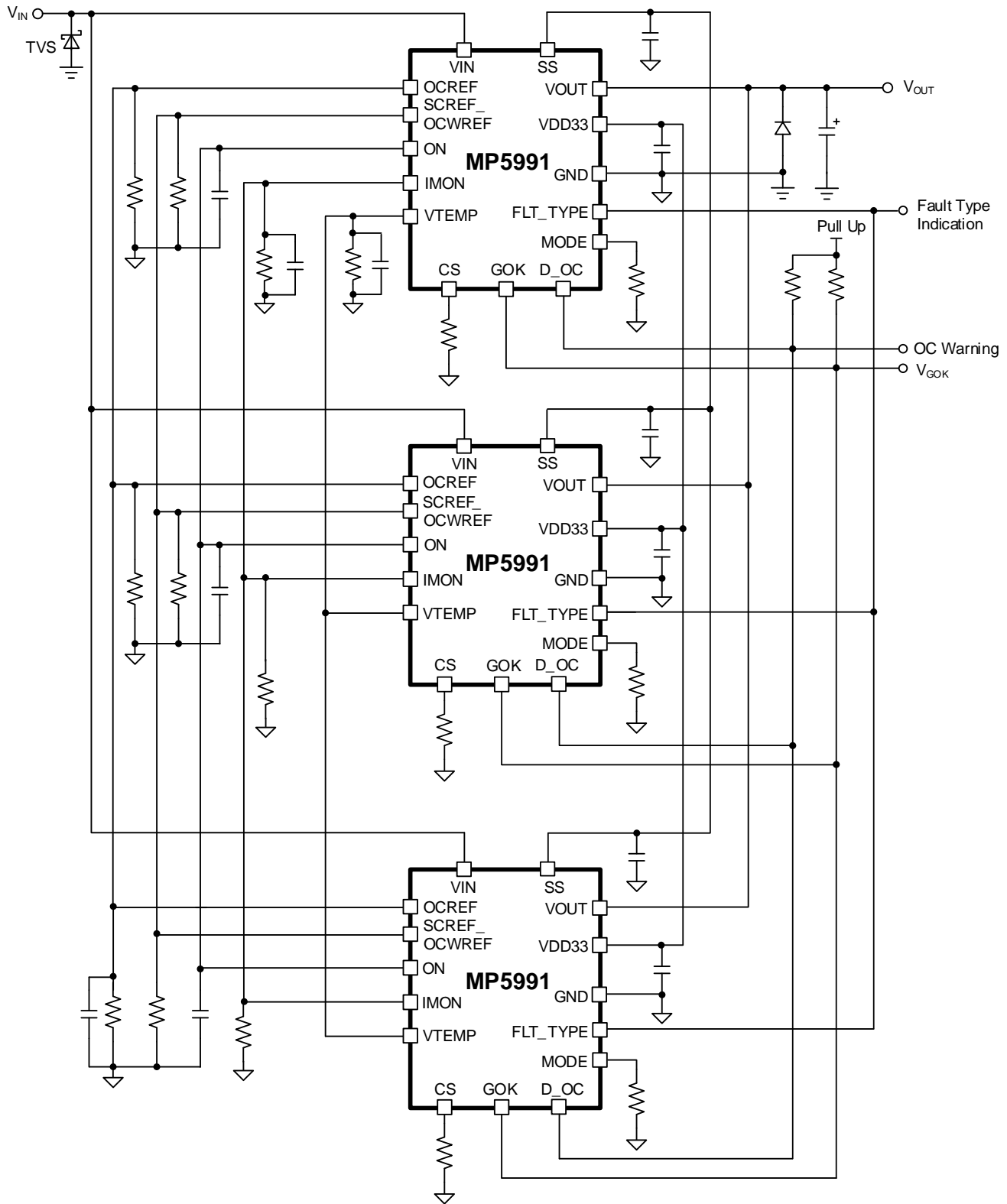


Figure 2: MP5991 3-Phase Parallel Operation

TYPICAL APPLICATION (continued)

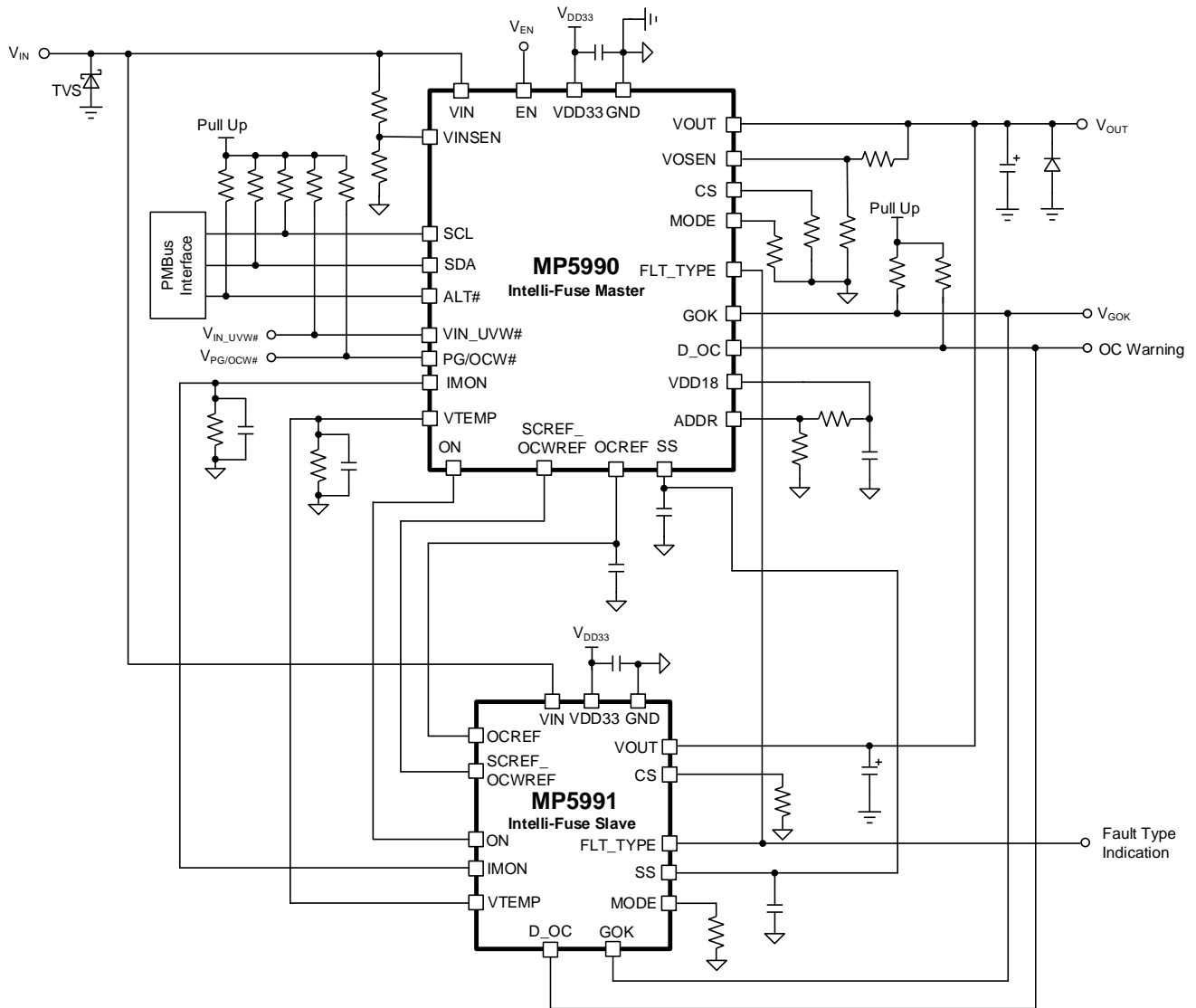
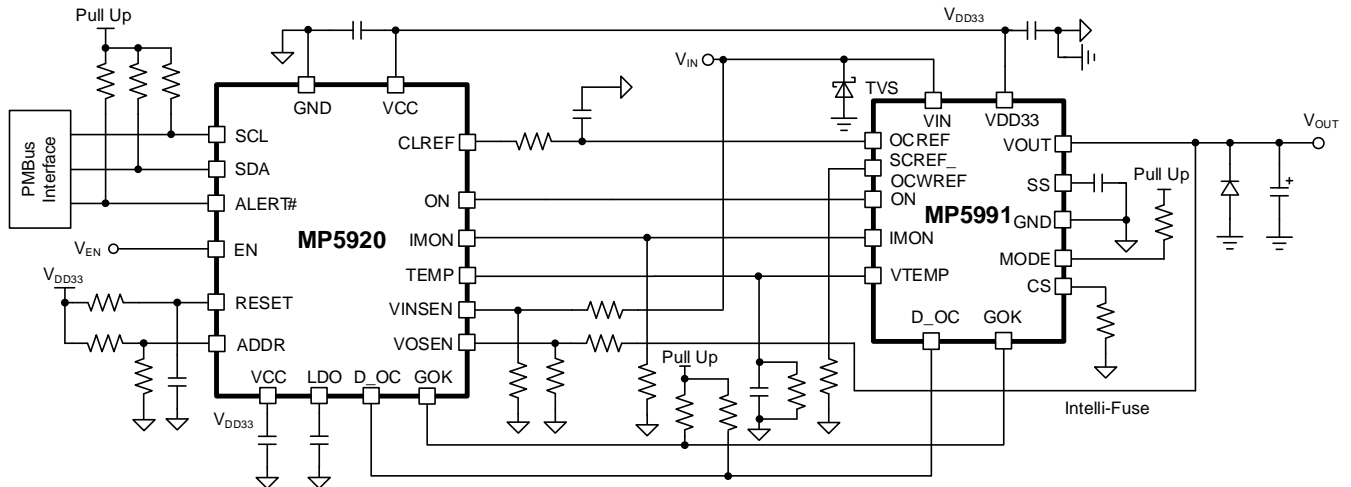


Figure 3: MP5990 and MP5991 Parallel Operation

**TYPICAL APPLICATION (continued)**



**Figure 4: MP5991 Controlled via a Hot-Swap Controller (e.g. MP5920)**

## ORDERING INFORMATION

Part Number*	Package	Top Marking	MSL Rating
MP5991GLU	LGA-32 (5mmx5mm)	<i>See Below</i>	3

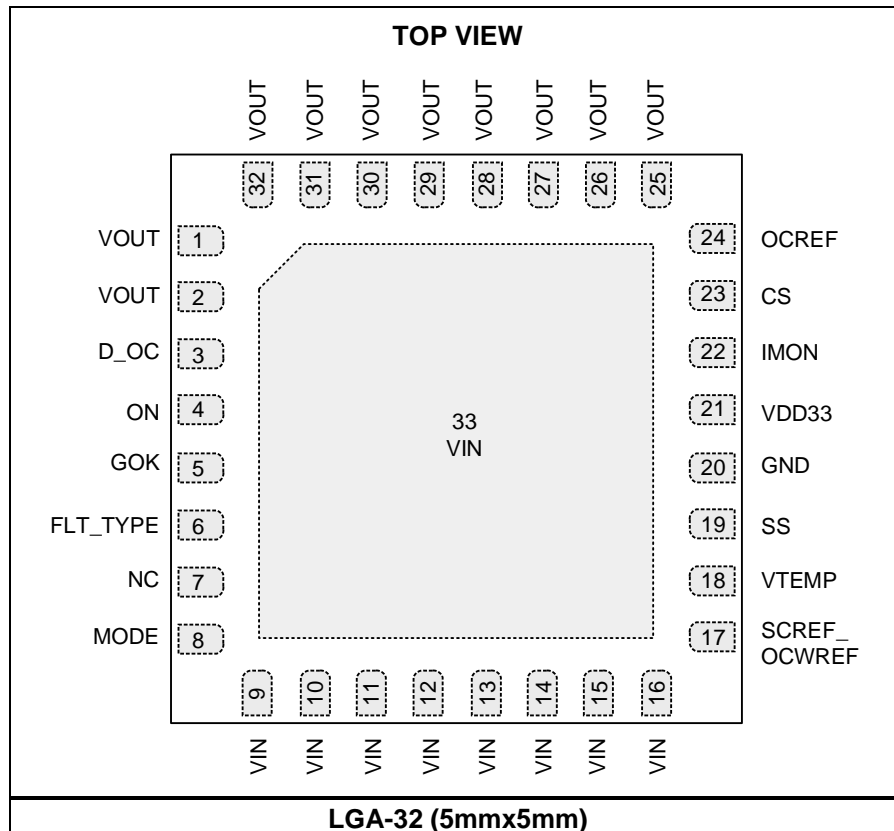
\* For Tape & Reel, add suffix -Z (e.g. MP5991GLU-Z).

## TOP MARKING

**MPSYYWW**  
**MP5991**  
**LLLLLLL**

MPS: MPS prefix  
 YY: Year code  
 WW: Week code  
 MP5991: Part number  
 LLLLLLL: Lot number

## PACKAGE REFERENCE



## PIN FUNCTIONS

Pin #	Name	Description
1, 2, 25, 26, 27, 28, 29, 30, 31, 32	VOUT	<b>Output voltage.</b> The VOUT pin is connected to the source of the integrated power MOSFET.
3	D_OC	<b>Over-current indication digital output.</b> The D_OC pin is an open-drain output. In standalone mode, D_OC is pulled low once the V <sub>CS</sub> voltage (V <sub>CS</sub> ) exceeds 85% of the OCREF voltage (V <sub>OCREF</sub> ). In slave mode, D_OC is pulled low once V <sub>CS</sub> exceeds the OCWREF voltage (V <sub>OCWREF</sub> ).
4	ON	<b>MOSFET on/off control.</b> Pull the ON pin above 1.4V to turn the power MOSFET on; pull ON below 1.2V to turn it off. Do not float ON.
5	GOK	<b>Intelli-Fuse fault reporting output.</b> The GOK pin is an open-drain output. If a fault occurs, then GOK is pulled low and latches. The following faults that can trigger GOK: an input over-voltage (OV) fault, an output over-current (OC) fault, a short circuit (SC) fault, an over-temperature (OT) fault, or a MOSFET health fault.
6	FLT_TYPE	<b>Intelli-Fuse fault type indication output.</b> If a fault occurs, then the FLT_TYPE pin indicates a voltage level based on the fault type.
7	NC	<b>Not connected.</b> Float the NC pin.
8	MODE	<b>Mode selection.</b> Connect a resistor between the MODE and GND pins to select the operation mode (latch-off mode, hiccup mode, or slave mode).
9, 10, 11, 12, 13, 14, 15, 16, 33	VIN	<b>System input power supply.</b> The VIN pin is connected to the drain of the MOSFET.
17	SCREF_ OCWREF	<b>Multifunctional (short-circuit current limit and over-current warning reference in slave mode).</b> The SCREF_OCWREF pin is a multifunctional pin. To select the short-circuit current limit (I <sub>LIMIT_SC</sub> ), the MP5991 samples the SCREF voltage (V <sub>SCREF</sub> ) during the MOSFET turn-on insertion delay time (t <sub>ON_DELAY</sub> ). Then the device can set I <sub>LIMIT_SC</sub> to 40A, 60A, 80A, 100A, or 120A. SCREF_OCWREF is also used as the OC warning reference in slave mode.
18	VTEMP	<b>Junction temperature sense output.</b> Place a ≤1nF capacitor and a ≥10kΩ resistor in parallel on the VTEMP pin.
19	SS	<b>Soft-start time setting.</b> An external capacitor connected to the SS pin sets the soft-start time (t <sub>SS</sub> ). The internal circuitry controls the output voltage (V <sub>OUT</sub> ) slew rate during start-up.
20	GND	<b>Signal ground.</b>
21	VDD33	<b>Internal 3.3V LDO output.</b> Place a ≥1μF decoupling capacitor close to the VDD33 and GND pins.
22	IMON	<b>Current monitor output.</b> The IMON pin reports the current flowing through the power device. Connect a resistor between the IMON and GND pins to generate the IMON voltage (V <sub>IMON</sub> ). Place a 2.2nF to 100nF capacitor in parallel to reduce noise and maintain a smooth voltage.
23	CS	<b>Current-sense output.</b> V <sub>CS</sub> is compared to V <sub>OCREF</sub> to determine the OC limit. The CS pin is also used to assert D_OC. If V <sub>CS</sub> exceeds 85% of V <sub>OCREF</sub> in standalone mode, then D_OC is pulled low. If V <sub>CS</sub> exceeds V <sub>OCWREF</sub> in slave mode, then D_OC is pulled low. Connect a resistor between the CS and GND pins to generate V <sub>CS</sub> .
24	OCREF	<b>Current-limit reference voltage input.</b> Connect a 1nF to 10nF capacitor between the OCREF and GND pins to reduce noise and maintain a smooth voltage.

**ABSOLUTE MAXIMUM RATINGS** <sup>(1)</sup>

V <sub>IN</sub> (DC).....	-0.3V to +20V
V <sub>IN</sub> (1μs).....	24V
V <sub>IN</sub> (25ns).....	29V
V <sub>OUT</sub> .....	-0.3V to +20V
All other pins .....	-0.3V to +4.2V
Continuous power dissipation (T <sub>A</sub> = 25°C) <sup>(2)</sup>	5.68W
Junction temperature .....	150°C
Lead temperature .....	260°C
Storage temperature.....	-65°C to +155°C

**ESD Ratings** <sup>(3)</sup>

Human body model (HBM) .....	Class 1C
Charged device model (CDM).....	Class C2B

**Recommended Operating Conditions** <sup>(4)</sup>

Operating input voltage (V <sub>IN</sub> ).....	4V to 16V
Operating junction temp (T <sub>J</sub> )....	-40°C to +125°C

<b>Thermal Resistance</b> <sup>(5)</sup>	<b>θ<sub>JA</sub></b>	<b>θ<sub>JC</sub></b>
LGA-32 (5mmx5mm) .....	22.....	10.8 . °C/W

**Notes:**

- 1) Exceeding these ratings may damage the device.
- 2) The maximum allowable power dissipation is a function of the maximum junction temperature T<sub>J</sub> (MAX), the junction-to-ambient thermal resistance θ<sub>JA</sub>, and the ambient temperature T<sub>A</sub>. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P<sub>D</sub> (MAX) = (T<sub>J</sub> (MAX) - T<sub>A</sub>) / θ<sub>JA</sub>. Exceeding the maximum allowable power dissipation can produce an excessive die temperature, which may cause the device to go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
- 3) Followed ANSI/ESDA/JEDEC JS-001 for HBM and ANSI/ESDA/JEDEC JS-002 for CDM.
- 4) The device is not guaranteed to function outside of its operating conditions.
- 5) Measured on JESD51-7, 4-layer PCB.



## ELECTRICAL CHARACTERISTICS

V<sub>IN</sub> = 12V, R<sub>CS</sub> = 2kΩ, R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

Parameters	Symbol	Condition	Min	Typ	Max	Units
<b>Supply Current</b>						
Quiescent current	I <sub>Q</sub>	Intelli-Fuse is on, no load		2.5	2.9	mA
		Fault protection, latch-off mode		2.3	2.7	mA
		Intelli-Fuse is off, V <sub>ON</sub> = 0V, V <sub>IN</sub> = 12V		2.3	2.7	mA
		Intelli-Fuse is off, V <sub>ON</sub> = 0V, V <sub>IN</sub> = 16V		2.3	2.7	mA
<b>VDD33 Regulator and Under-Voltage Lockout (UVLO) Protection</b>						
VDD33 regulator output voltage	V <sub>DD33</sub>	I <sub>VDD33</sub> = 0mA	3.2	3.3	3.4	V
		I <sub>VDD33</sub> = 25mA	3.17	3.27	3.37	V
		I <sub>VDD33</sub> = 40mA	3.16	3.26	3.36	V
VDD33 under-voltage lockout (UVLO) rising threshold	V <sub>DD33_UVLO_RISING</sub>		2.55	2.7	2.85	V
VDD33 UVLO falling threshold	V <sub>DD33_UVLO_FALLING</sub>		2.15	2.3	2.45	V
VDD33 UVLO hysteresis	V <sub>DD33_UVLO_HYS</sub>			400		mV
<b>V<sub>IN</sub> UVLO Protection and Over-Voltage Protection (OVP)</b>						
V <sub>IN</sub> UVLO rising threshold	V <sub>IN_UVLO_RISING</sub>		3.05	3.2	3.35	V
V <sub>IN</sub> UVLO falling threshold	V <sub>IN_UVLO_FALLING</sub>		2.55	2.7	2.95	V
Over-voltage protection	V <sub>OVP</sub>		17	18.5	20	V
OVP hysteresis	V <sub>OVP_HYS</sub>	Auto-retry		1		V
<b>Power MOSFET</b>						
On resistance	R <sub>DS(ON)</sub>	T <sub>J</sub> = 25°C, I <sub>FET</sub> = 2A		1	1.25	mΩ
		T <sub>J</sub> = 125°C, I <sub>FET</sub> = 2A		1.35	1.7	mΩ
Off-state leakage current	I <sub>OFF</sub>	V <sub>IN</sub> = 16V, MOSFET is off			1	μA
<b>MOSFET On/Off Control (ON)</b>						
Internal ON current	I <sub>ON</sub>		3.2	4.2	5.2	μA
ON input rising threshold	V <sub>ON_RISING</sub>	V <sub>ON</sub> is rising	1.3	1.4	1.5	V
ON input falling threshold	V <sub>ON_FALLING</sub>	V <sub>ON</sub> is falling	1.1	1.2	1.3	V
MOSFET turn-on hysteresis	V <sub>ON_HYS</sub>			200		mV
MOSFET turn-on insertion delay time	t <sub>ON_DELAY</sub>	V <sub>DD33</sub> > V <sub>DD33_UVLO_RISING</sub> , V <sub>IN</sub> > V <sub>IN_UVLO_RISING</sub>	0.8	1.3	1.8	ms
ON blanking time	t <sub>ON_BLANK</sub>	V <sub>ON</sub> recycling	0.7	1	1.5	ms
<b>Current Monitor Output (IMON)</b>						
IMON sense gain	g <sub>IMON</sub>	I <sub>IMON</sub> / I <sub>OUT</sub> , I <sub>OUT</sub> > 4A,	9.9	10	10.1	μA/A
IMON sense offset		I <sub>OUT</sub> > 4A	-0.6		+0.6	μA
<b>Current-Sense Output (CS)</b>						
Current-sense gain	g <sub>CS</sub>	I <sub>CS</sub> / I <sub>OUT</sub> , I <sub>OUT</sub> > 4A	9.6	10	10.4	μA/A
Current-sense gain offset		I <sub>OUT</sub> > 4A	-1		+1	μA

**ELECTRICAL CHARACTERISTICS (continued)**
**V<sub>IN</sub> = 12V, R<sub>CS</sub> = 2kΩ, R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.**

Parameters	Symbol	Condition	Min	Typ	Max	Units
<b>Over-Current (OC) Limit Reference (OCREF)</b>						
Internal OCREF current	I <sub>OCREF</sub>	Standalone mode	9	10	11	μA
		Slave mode		0		μA
OCREF clamp voltage	V <sub>OCREF_CLAMP</sub>	V <sub>SS_CLAMP</sub> at V <sub>OUT</sub> < 80% of V <sub>IN</sub> , T <sub>J</sub> = 25°C	570	635	699	mV
		V <sub>SS_CLAMP</sub> at V <sub>OUT</sub> < 80% of V <sub>IN</sub> , T <sub>J</sub> = 125°C	340	440	570	mV
		V <sub>OUT</sub> ≥ 80% of V <sub>IN</sub>	1.9	2	2.1	V
OCREF operating voltage <sup>(6)</sup>	V <sub>OCREF</sub>		0.3		1.8	V
OCREF OC regulation timer	t <sub>OC_REG</sub>	V <sub>OUT</sub> ≥ 90% of V <sub>IN</sub> , V <sub>OCREF</sub> ≥ 0.3V		220		μs
<b>Short-Circuit Current Limit Reference (SCREF)</b>						
Internal SCREF current	I <sub>SCREF</sub>	Standalone mode, T <sub>A</sub> = 25°C	9	10	11	μA
		Standalone mode, T <sub>A</sub> = -40 to +125°C	9	10	11	μA
		Slave mode		0		μA
Short-circuit current limit SCREF voltage range	V <sub>SCREF</sub>	I <sub>LIMIT_SC</sub> = 40A		0	0.16	V
		I <sub>LIMIT_SC</sub> = 60A	0.24	0.3	0.36	V
		I <sub>LIMIT_SC</sub> = 80A	0.48	0.6	0.72	V
		I <sub>LIMIT_SC</sub> = 120A	0.96	1.2	1.44	V
		I <sub>LIMIT_SC</sub> = 100A	1.68			V
Short-circuit current limit <sup>(6)</sup>	I <sub>LIMIT_SC</sub>	V <sub>SCREF</sub> > 1.6V		100		A
Short-circuit protection (SCP) response time <sup>(6)</sup>	t <sub>SCP</sub>			200		ns
Short-circuit start-up protection timer	t <sub>SC_TIMER</sub>	V <sub>OUT</sub> < 1/8 x V <sub>IN</sub> , I <sub>FET</sub> is regulated by V <sub>SS_CLAMP</sub>		2.1	3.2	ms
<b>Temperature Sense (VTEMP)</b>						
Temperature sense gain <sup>(6)</sup>				8.7		mV/°C
Temperature sense output <sup>(6)</sup>		T <sub>J</sub> = 25°C		370		mV
<b>Soft Start (SS)</b>						
SS current	I <sub>SS</sub>	V <sub>IN</sub> = 12V, I <sub>SS</sub> is dependent on V <sub>IN</sub> , R <sub>SS</sub> = 0.8MΩ	13	15	17	μA
SS low voltage	V <sub>SS_LOW</sub>	SS is pull low internally via R <sub>SS</sub> , I <sub>SINK</sub> = 10mA			0.2	V
SS leakage current	I <sub>LKG_SS</sub>	V <sub>ON</sub> = 0V, V <sub>SS</sub> = 3.3V, MOSFET is off			1	μA
<b>GOK Output and Comparator</b>						
Output low voltage	V <sub>GOK_LOW</sub>	I <sub>SINK</sub> = 10mA			0.3	V
GOK leakage current	I <sub>LKG_GOK</sub>	V <sub>GOK</sub> = 3.3V			1	μA
GOK internal pull-up resistor	R <sub>GOK</sub>			370		kΩ
GOK comparator falling threshold	V <sub>GOK_FALLING</sub>	Fault status	1.05	1.16	1.3	V
GOK comparator hysteresis	V <sub>GOK_HYS</sub>			900		mV
GOK fault delay time			1	3	5	μs

**ELECTRICAL CHARACTERISTICS (continued)**
**V<sub>IN</sub> = 12V, R<sub>CS</sub> = 2kΩ, R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.**

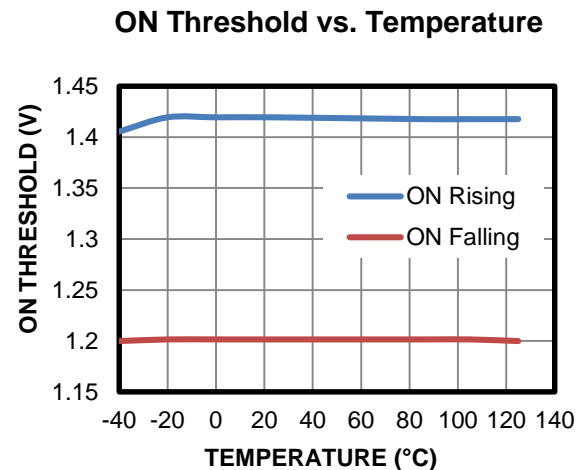
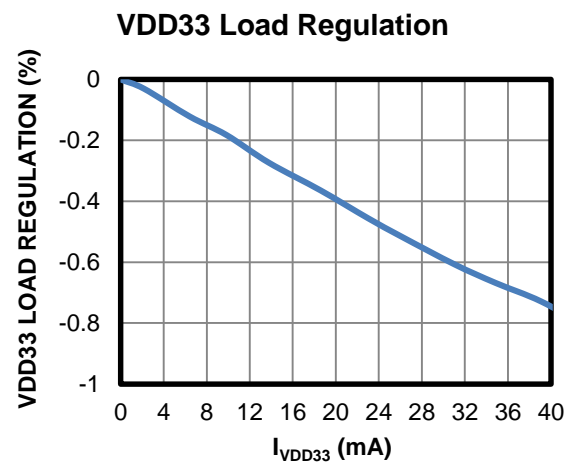
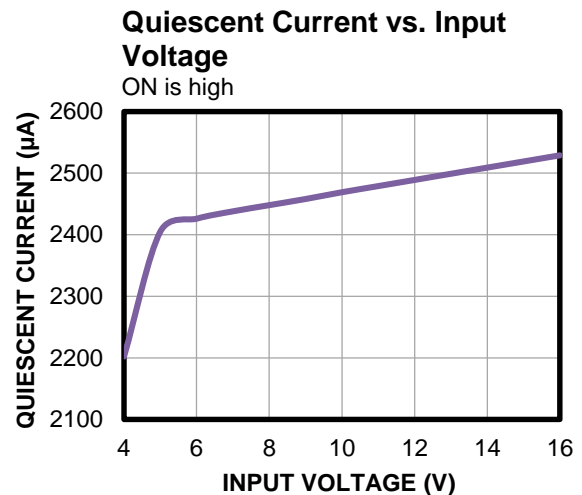
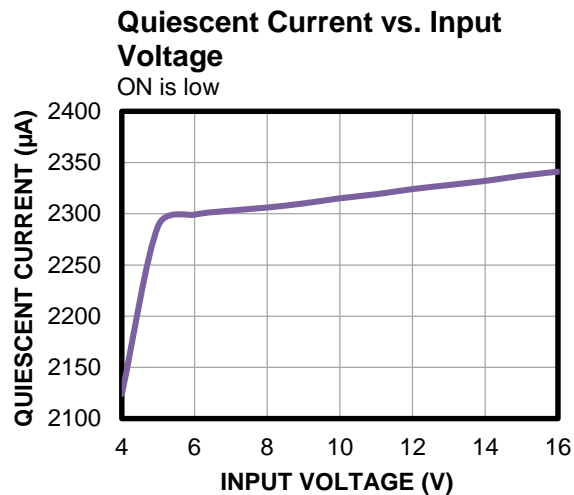
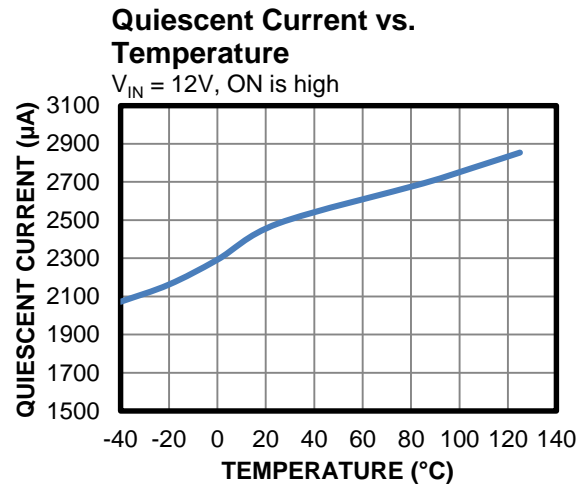
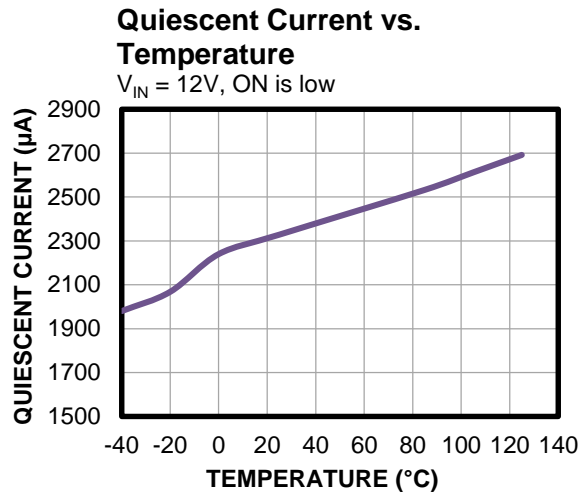
Parameters	Symbol	Condition	Min	Typ	Max	Units
<b>D_OC Output</b>						
Output low voltage	V <sub>D_OC_LOW</sub>	I <sub>SINK</sub> = 10mA			0.3	V
D_OC leakage current	I <sub>LKG_D_OC</sub>	V <sub>D_OC</sub> = 3.3V			1	μA
D_OC high to low threshold (OC warning)	V <sub>D_OC_TH</sub>	Standalone mode, V <sub>OUT</sub> ≥ 90% of V <sub>IN</sub> , 0.3V ≤ V <sub>OCREF</sub> ≤ 1.8V	0.8	0.85	0.9	V <sub>CS</sub> / V <sub>OCREF</sub>
		Slave mode, V <sub>OUT</sub> ≥ 90% of V <sub>IN</sub> , 0.3V ≤ V <sub>OCWREF</sub> ≤ 1.8V	0.95	1	1.05	V <sub>CS</sub> / V <sub>OCWREF</sub>
<b>MOSFET Short Detection</b>						
MOSFET drain-to-source (DS) short entry threshold	V <sub>OUT_DS_ENTRY</sub>	Measured at V <sub>OUT</sub> during start-up	85	90	95	% of V <sub>IN</sub>
MOSFET DS short recovery threshold	V <sub>OUT_DS_RECOVERY</sub>	Measured at V <sub>OUT</sub> during start-up	65	70	75	% of V <sub>IN</sub>
Gate-to-source (GS) short protection delay time <sup>(6)</sup>	t <sub>GS_DELAY</sub>	V <sub>SS</sub> > V <sub>CC</sub> - 0.7V	200	250	300	ms
<b>Fault Type Indication Output (FLT_TYPE) (6 Indication Types)</b>						
Short-circuit FLT_TYPE voltage <sup>(6)</sup>	V <sub>FLT_TYPE_SC</sub>	SCP		1.5		V
OC fault FLT_TYPE voltage	V <sub>FLT_TYPE_OC</sub>	OCP during SS or normal operation	1.16	1.2	1.24	V
OT/OV fault FLT_TYPE voltage	V <sub>FLT_TYPE_OT/OV</sub>	V <sub>IN</sub> OVP and OTP	0.865	0.9	0.935	V
MOSFET DS/GS short FLT_TYPE voltage	V <sub>FLT_TYPE_DS/GS</sub>	MOSFET DS/GS short	0.57	0.6	0.63	V
GOK fault FLT_TYPE voltage	V <sub>FLT_TYPE_GOK</sub>	GOK fault	0.275	0.3	0.325	V
FLT_TYPE voltage for other conditions	V <sub>FLT_TYPE_OTHER</sub>		0.08	0.1	0.12	V
<b>Thermal Shutdown</b>						
Thermal shutdown threshold <sup>(6)</sup>	T <sub>SD</sub>			145		°C
<b>Mode Selection (MODE)</b>						
MODE current	I <sub>MODE</sub>		9	10	11	μA
Hiccup mode with 250ms auto-retry delay	V <sub>MODE1</sub>	R <sub>MODE</sub> = 30kΩ, t <sub>RETRY</sub> = 250ms	0.24	0.3	0.36	V
Hiccup mode with 500ms auto-retry delay	V <sub>MODE2</sub>	R <sub>MODE</sub> = 0Ω, t <sub>RETRY</sub> = 500ms		0	0.16	V
Hiccup mode with 1s auto-retry delay	V <sub>MODE3</sub>	R <sub>MODE</sub> = 60kΩ, t <sub>RETRY</sub> = 1s	0.48	0.6	0.72	V
Slave mode	V <sub>MODE4</sub>	R <sub>MODE</sub> = 120kΩ	0.96	1.2	1.44	V
Latch-off mode	V <sub>MODE5</sub>	MODE is pulled up to VDD33	1.68			V

**Notes:**

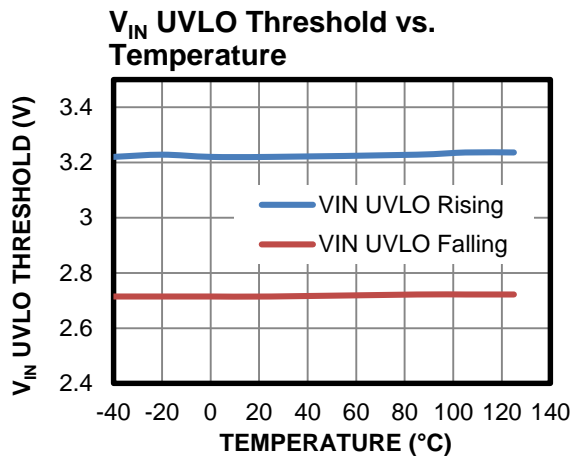
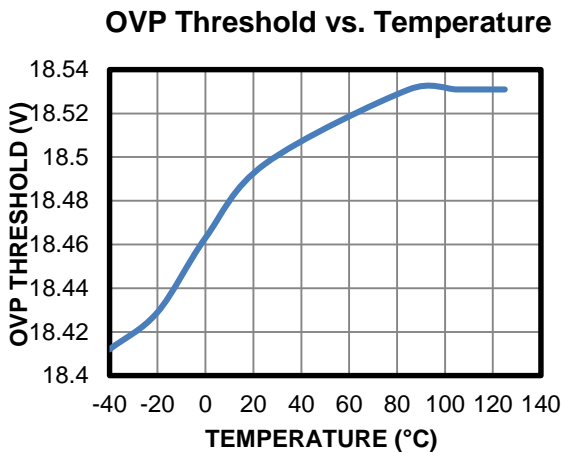
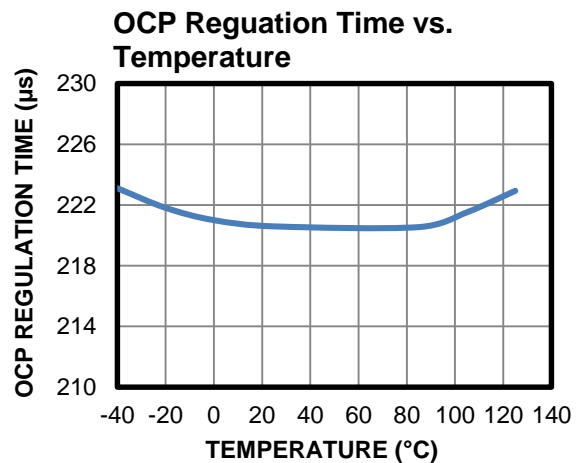
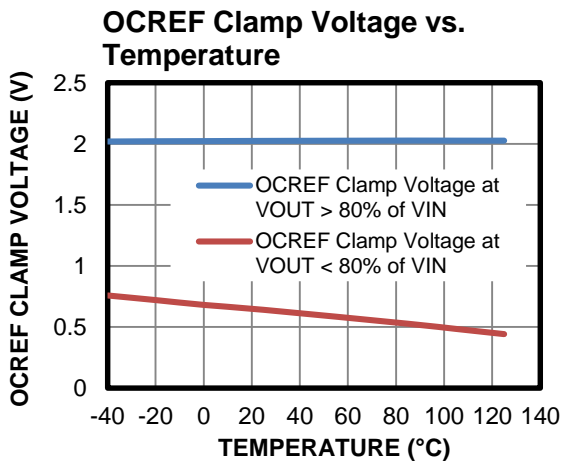
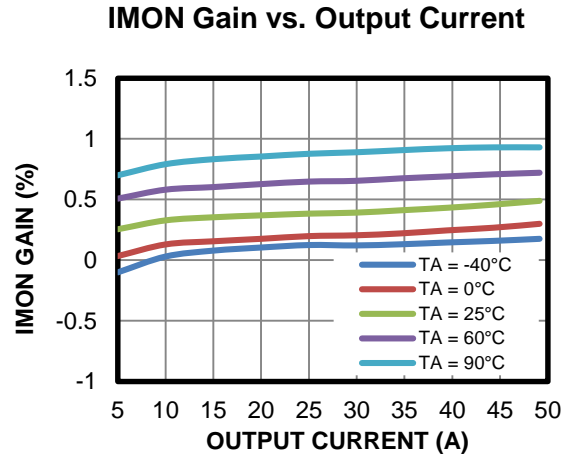
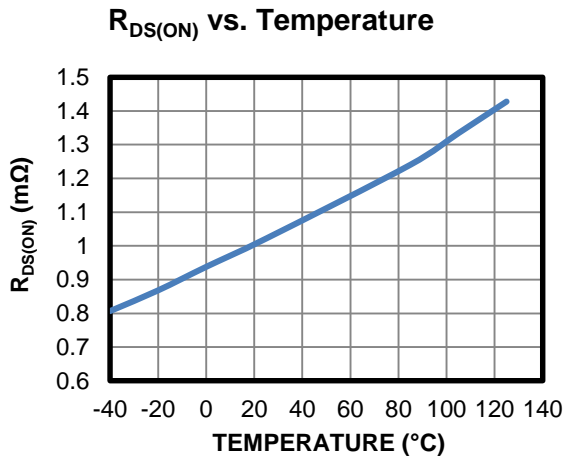
6) Guaranteed by design.

## TYPICAL CHARACTERISTICS

V<sub>IN</sub> = 12V, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

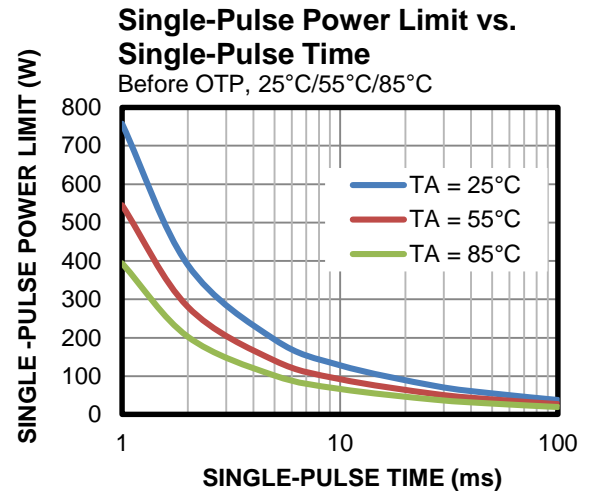
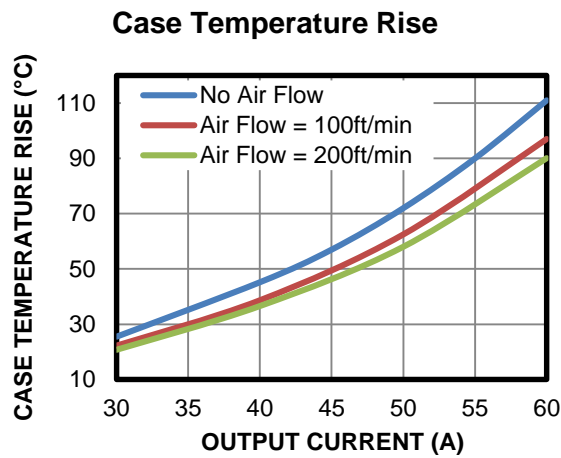
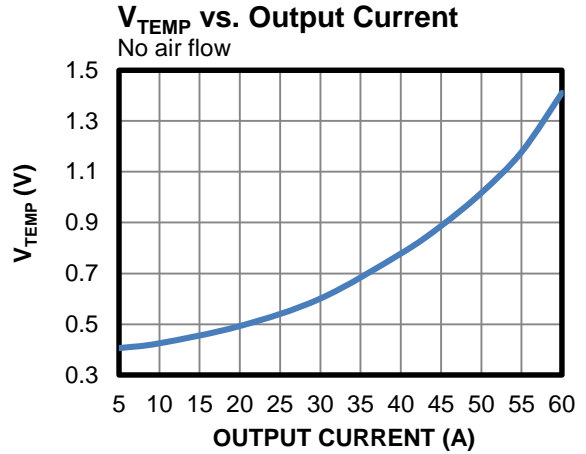
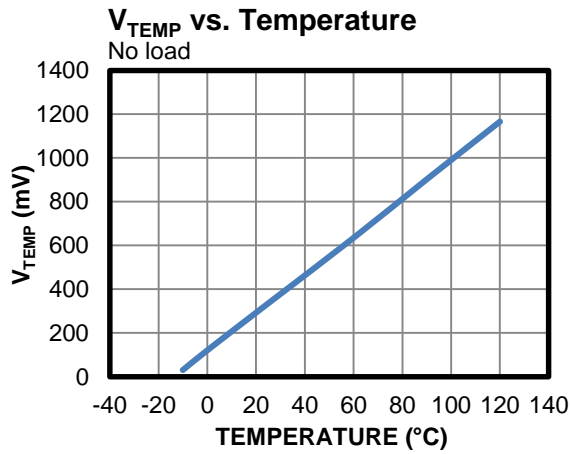


**TYPICAL CHARACTERISTICS (continued)**

 V<sub>IN</sub> = 12V, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.


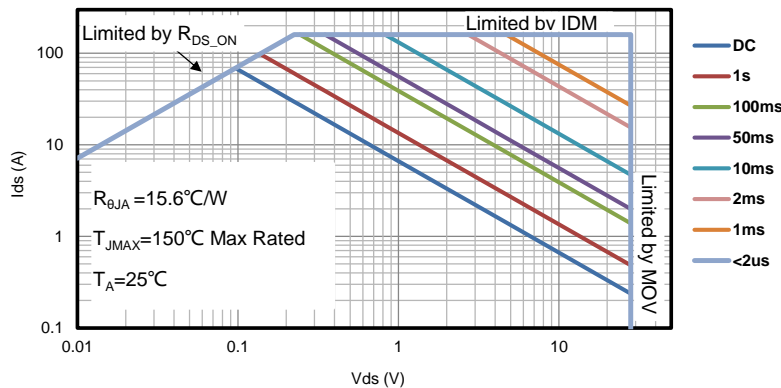
### TYPICAL CHARACTERISTICS (continued)

V<sub>IN</sub> = 12V, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.



#### Safe Operation Area (SOA)

Tested on the EV5991-V-4PHASE-00A  
(11cmx15cm), 4-layer PCB, 2oz per layer

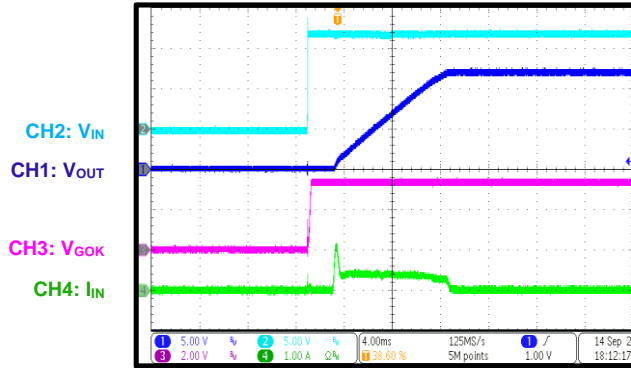


## TYPICAL PERFORMANCE CHARACTERISTICS

V<sub>IN</sub> = 12V, C<sub>OUT</sub> = 330μF, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

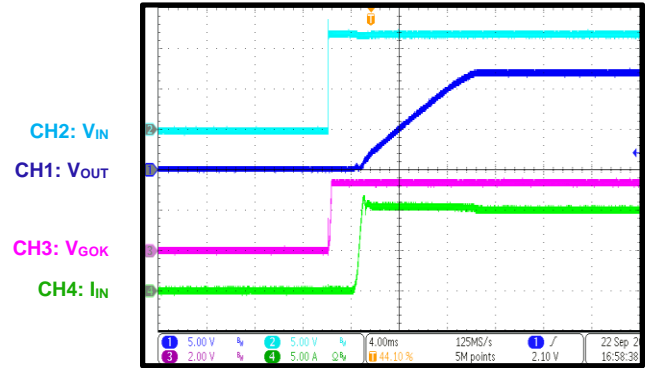
**VIN Hot Plug**

I<sub>OUT</sub> = 0A



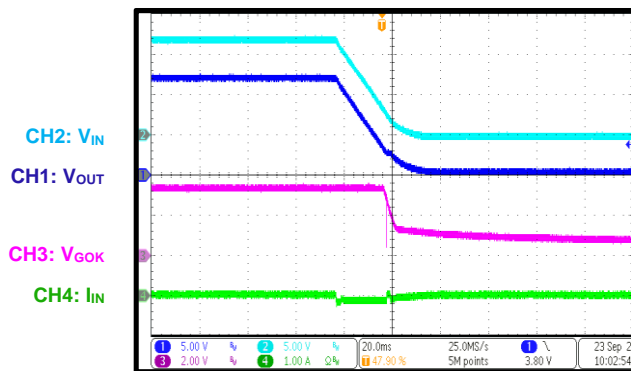
**VIN Hot Plug**

I<sub>OUT</sub> = 10A



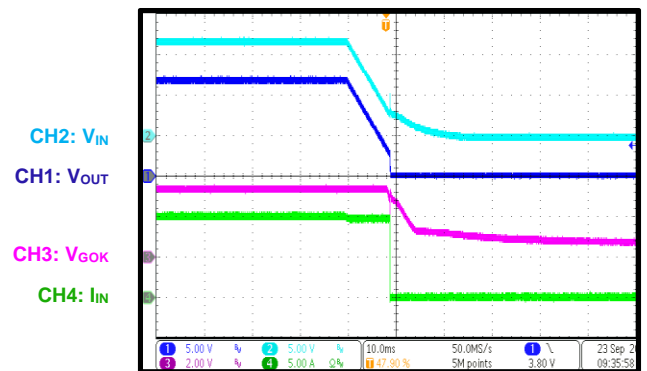
**Shutdown through VIN**

I<sub>OUT</sub> = 0A



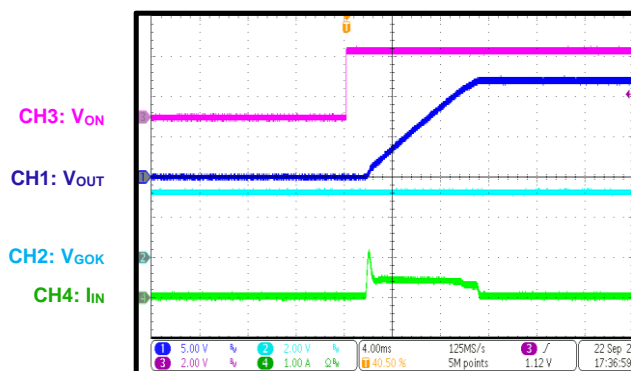
**Shutdown through VIN**

I<sub>OUT</sub> = 10A



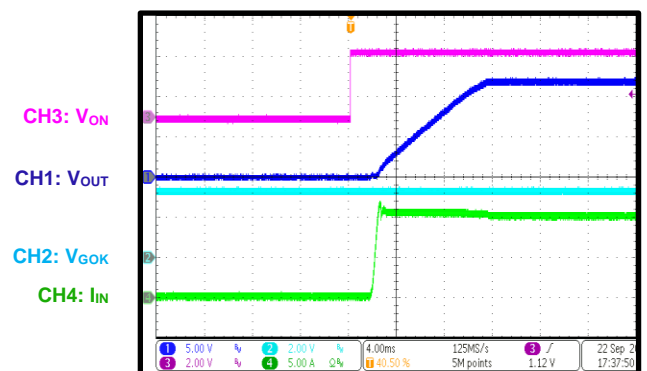
**Start-Up through ON**

I<sub>OUT</sub> = 0A



**Start-Up through ON**

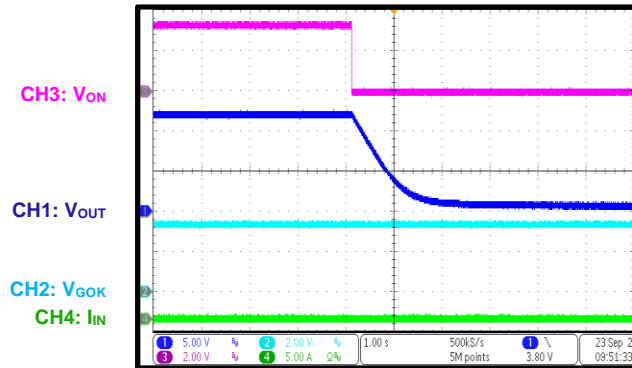
I<sub>OUT</sub> = 10A

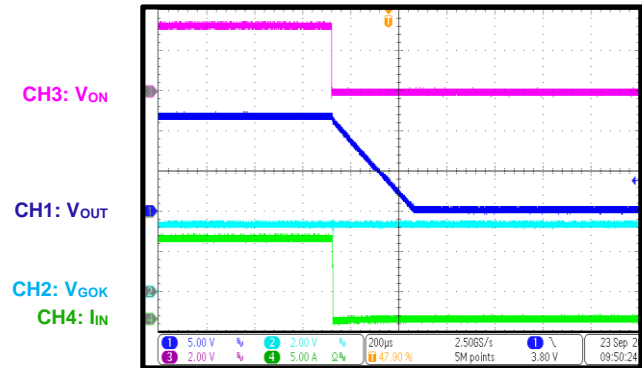


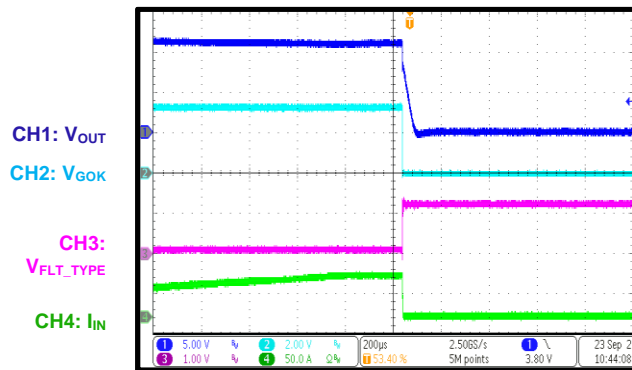
**TYPICAL PERFORMANCE CHARACTERISTICS (continued)**

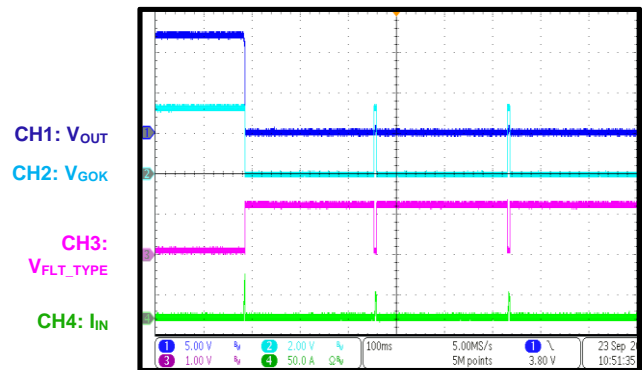
 V<sub>IN</sub> = 12V, C<sub>OUT</sub> = 330μF, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

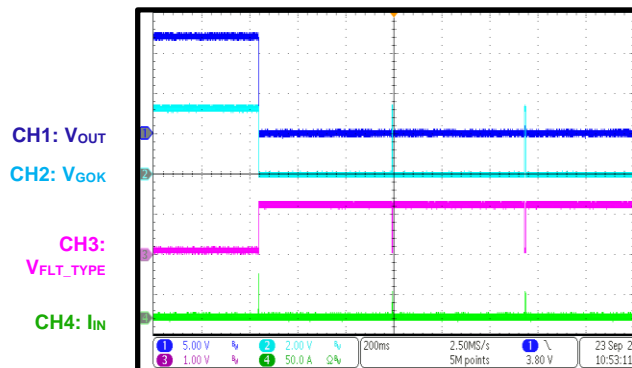
**Shutdown through ON**

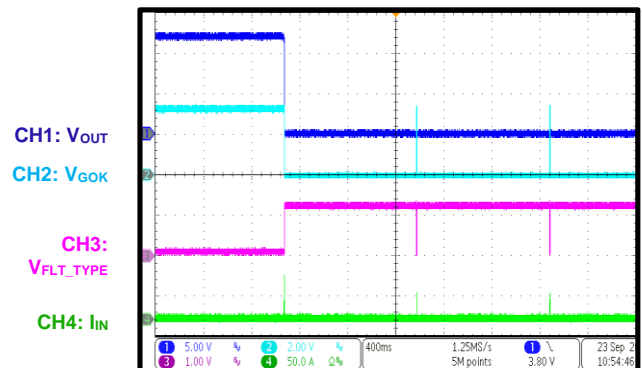
 I<sub>OUT</sub> = 0A

**Shutdown through ON**

 I<sub>OUT</sub> = 10A

**Over-Current Protection**

 I<sub>LIMIT</sub> = 50A, latch mode

**Over-Current Protection**

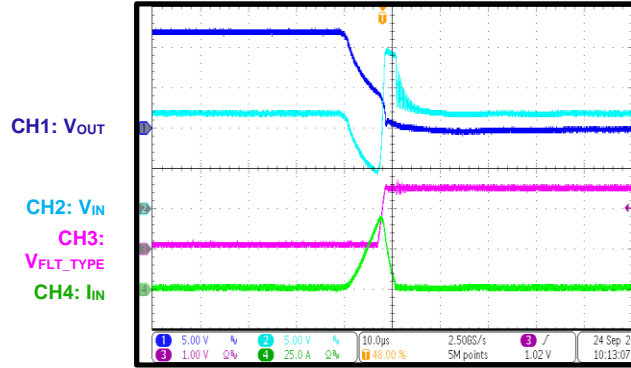
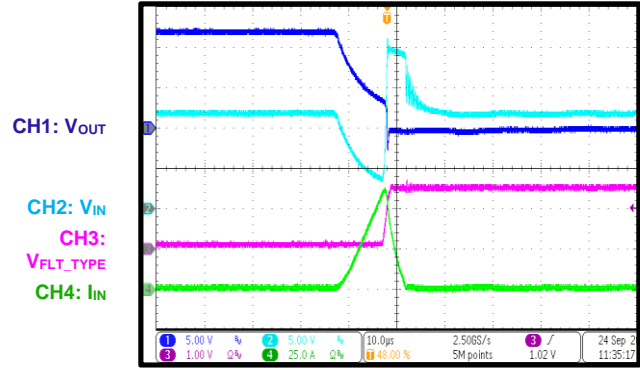
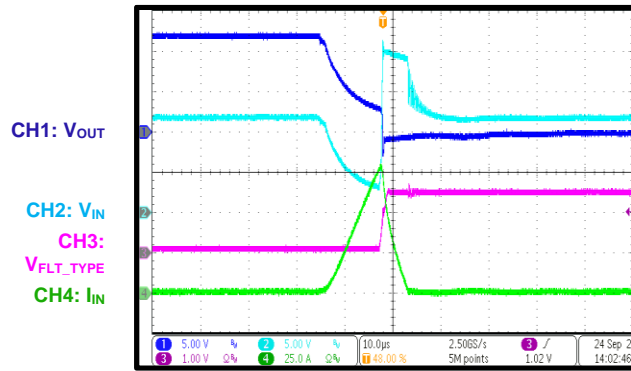
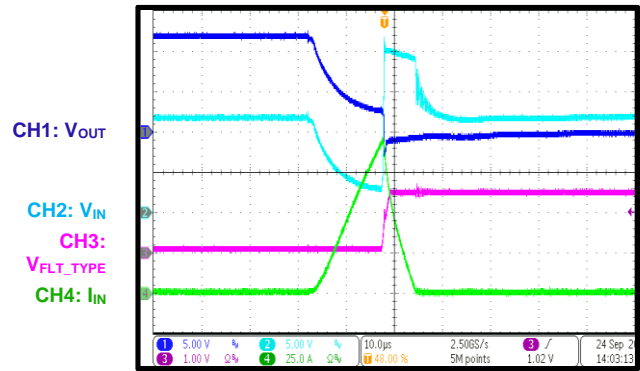
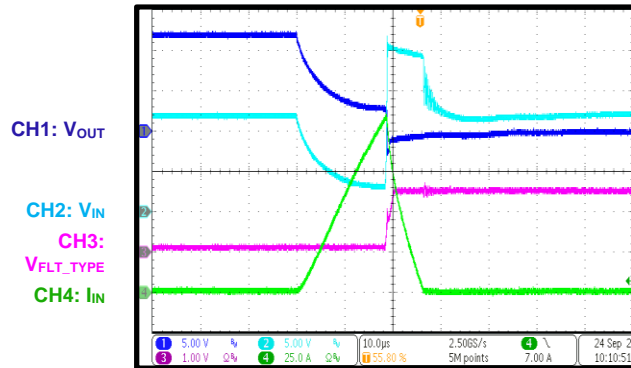
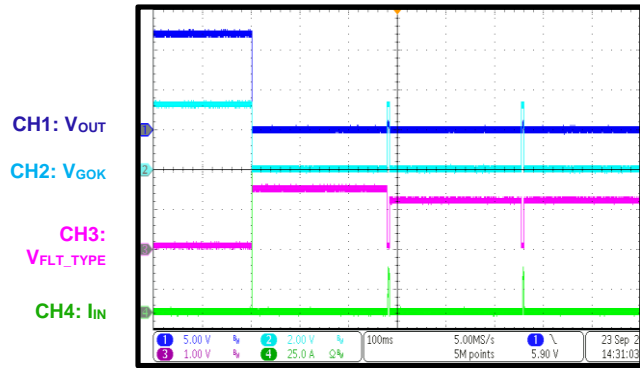
 I<sub>LIMIT</sub> = 50A, hiccup mode, t<sub>RETRY</sub> = 250ms

**Over-Current Protection**

 I<sub>LIMIT</sub> = 50A, hiccup mode, t<sub>RETRY</sub> = 500ms

**Over-Current Protection**

 I<sub>LIMIT</sub> = 50A, hiccup mode, t<sub>RETRY</sub> = 1s




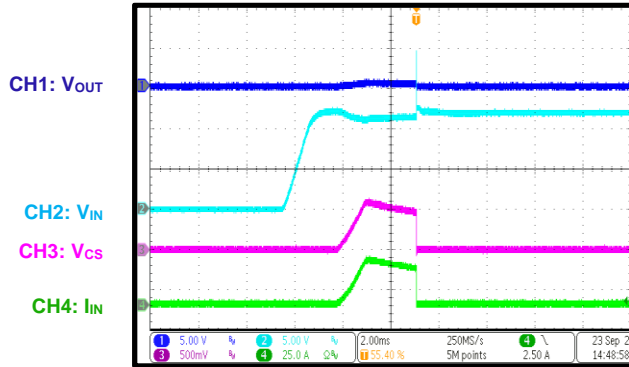
**TYPICAL PERFORMANCE CHARACTERISTICS (continued)**
 $V_{IN} = 12V$ ,  $C_{OUT} = 330\mu F$ ,  $R_{CS} = R_{IMON} = 2k\Omega$ ,  $T_A = 25^\circ C$ , unless otherwise noted.

**Short-Circuit Protection**
 $I_{LIMIT} = 40A$ , latch mode

**Short-Circuit Protection**
 $I_{LIMIT} = 60A$ , latch mode

**Short-Circuit Protection**
 $I_{LIMIT} = 80A$ , latch mode

**Short-Circuit Protection**
 $I_{LIMIT} = 100A$ , latch mode

**Short-Circuit Protection**
 $I_{LIMIT} = 120A$ , latch mode

**Short-Circuit Protection**
 $I_{LIMIT} = 100A$ , hiccup mode,  $t_{RETRY} = 250ms$ 


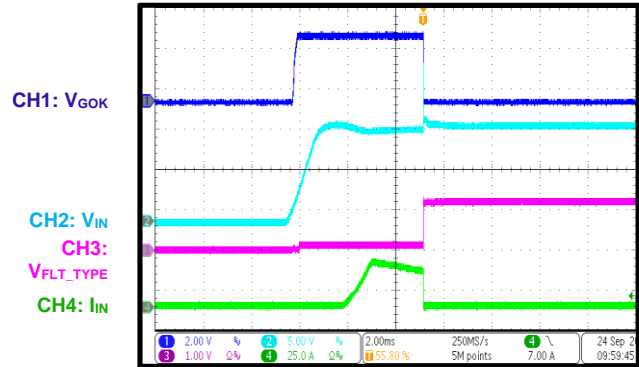
## TYPICAL PERFORMANCE CHARACTERISTICS (continued)

V<sub>IN</sub> = 12V, C<sub>OUT</sub> = 330μF, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

**Short-Circuit Start-Up**

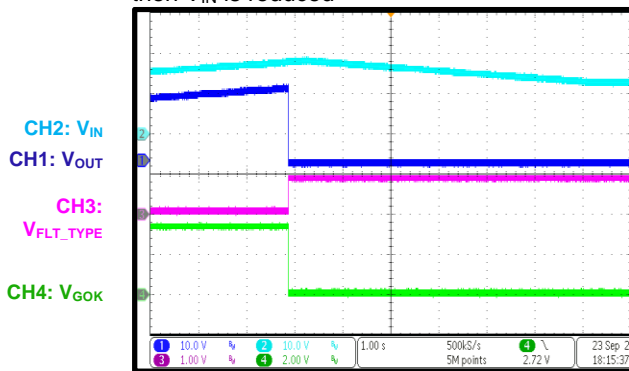


**Short-Circuit Start-Up**



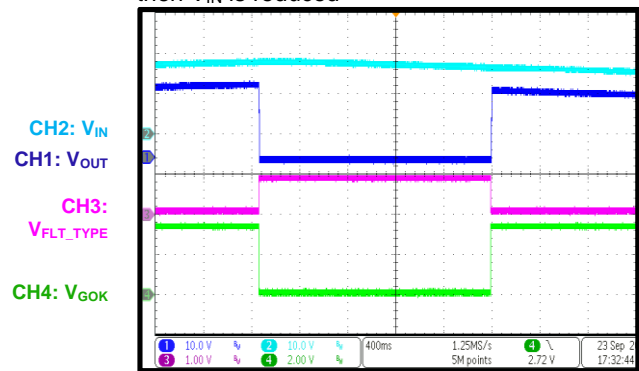
**V<sub>IN</sub> OVP in Latch Mode**

Latch mode, 18.5V applied to V<sub>IN</sub>, then V<sub>IN</sub> is reduced



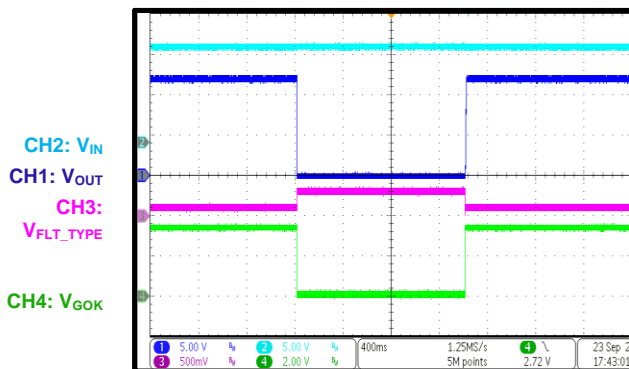
**V<sub>IN</sub> OVP in Hiccup Mode**

Hiccup mode, 18.5V applied to V<sub>IN</sub>, then V<sub>IN</sub> is reduced



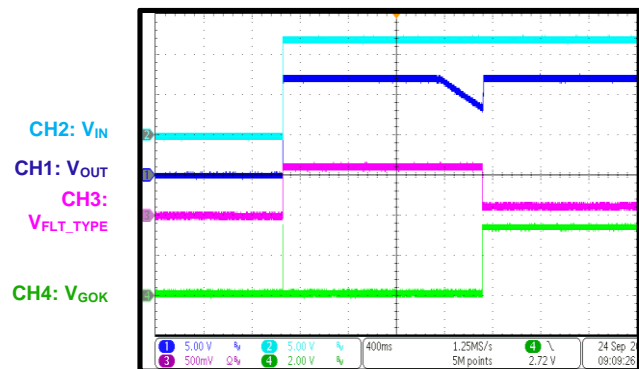
**GOK Fault**

GOK is pulled to GND, then GOK is pulled high



**DS Short**

Start-up with DS short, then DS short is removed

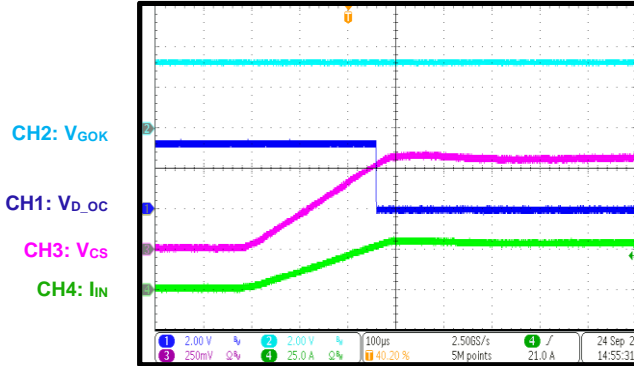


### TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V<sub>IN</sub> = 12V, C<sub>OUT</sub> = 330μF, R<sub>CS</sub> = R<sub>IMON</sub> = 2kΩ, T<sub>A</sub> = 25°C, unless otherwise noted.

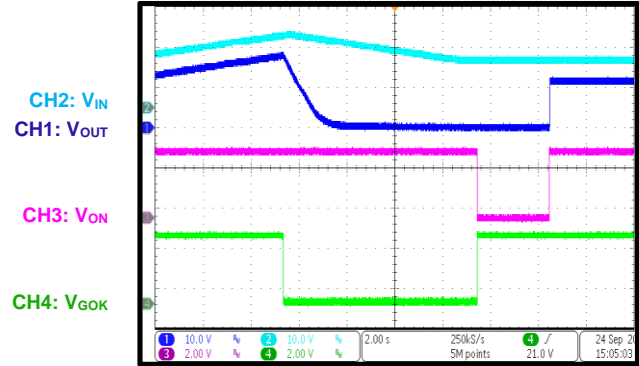
#### D\_OC Status

Normal operation, V<sub>OCREF</sub> = 0.6V, increase load, D\_OC is pulled low once V<sub>CS</sub> = 0.51V



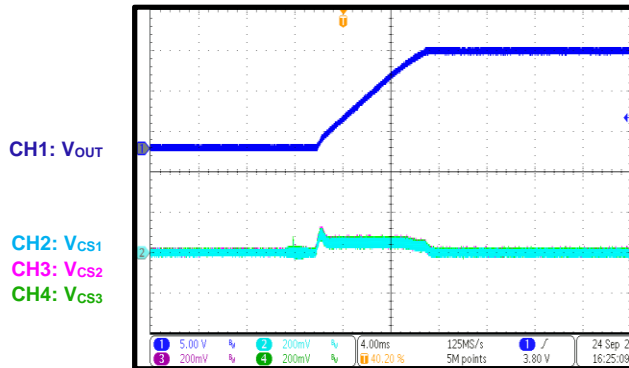
#### ON Signal to Clear Fault Status

Latch mode, apply V<sub>IN</sub> to trigger OVP, then reduce V<sub>IN</sub> to 12V, then cycle the power on ON



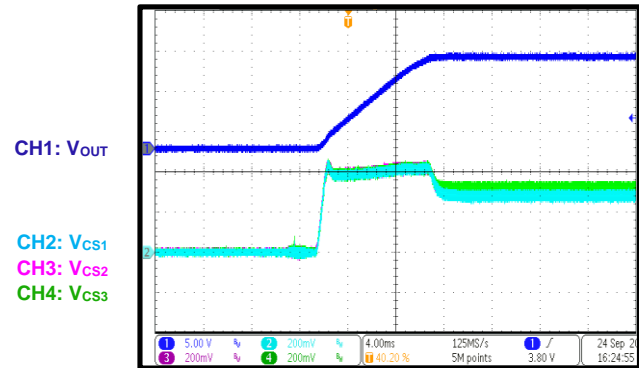
#### Current Balance during Start-Up

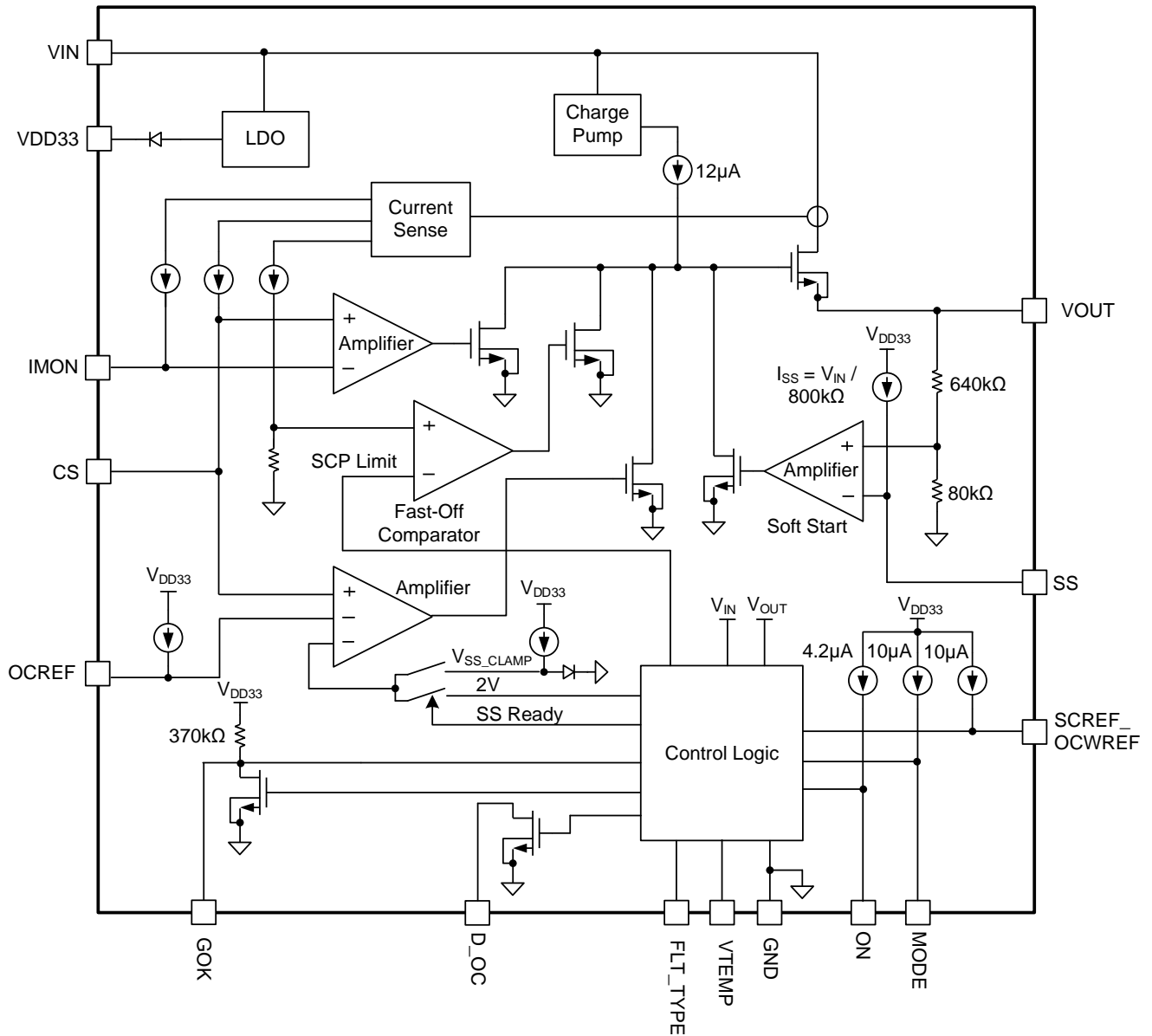
MP5991 3-phase parallel operation, R<sub>IMON</sub> = R<sub>CS</sub> (per MP5991), I<sub>OUT</sub> = 0A



#### Current Balance during Start-Up

MP5991 3-phase parallel operation, R<sub>IMON</sub> = R<sub>CS</sub> (per MP5991), I<sub>OUT</sub> = 45A



**FUNCTIONAL BLOCK DIAGRAM**

**Figure 5: Functional Block Diagram**

## OPERATION

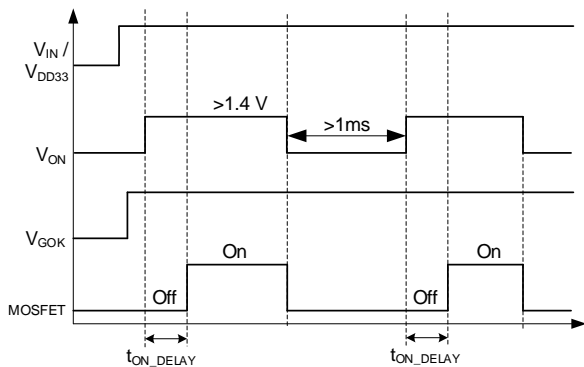
The MP5991 is a monolithic Intelli-Fuse device with an integrated, 1mΩ R<sub>DS(ON)</sub> power MOSFET that is ideally suited for multi-fuse hot-swap applications. The MP5991 can operate alone or can be controlled via a hot-swap controller for multi-fuse operation. It can drive up to 50A of continuous output current (I<sub>OUT</sub>) per device at room temperature, and up to 60A of continuous I<sub>OUT</sub> with air flow.

The device limits the backplane voltage drop by limiting the inrush current to the load while a circuit card is inserted into a live backplane power source. It also provides an integrated current mirror to monitor I<sub>OUT</sub> and the integrated on-die temperature sense. This eliminates the need for an external current-sense power resistor, power MOSFET, and temperature-sense device.

The MP5991 monitors the current and temperature to feedback information to the processor or controller. It limits the internal MOSFET current (I<sub>FET</sub>) by controlling the gate voltage (V<sub>GATE</sub>) via the current limit (I<sub>LIMIT</sub>) reference input and soft-start ramp.

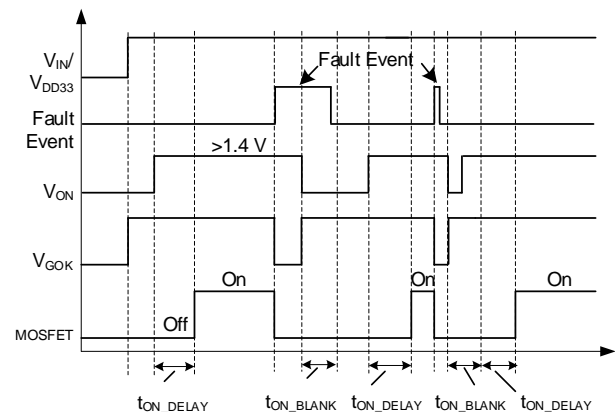
### MOSFET On/Off Control (ON)

The ON pin turns the power MOSFET on and off. Pull ON above 1.4V to turn the MOSFET on; pull ON below 1.2V to turn it off. There is a fixed t<sub>ON\_DELAY</sub> (1.3ms) that starts once ON exceeds 1.4V. The MOSFET remains off until t<sub>ON\_DELAY</sub> is finished. If a fault does not occur, the ON pin can turn the MOSFET on after 1.3ms. Figure 6 shows the MOSFET on/off control for when GOK is pulled up to VDD33.



**Figure 6: MOSFET On/Off Control**

If a fault occurs, the GOK is pulled low and the device shuts down. The fault status is cleared and GOK is pulled high once ON is pulled low, regardless of whether the fault is removed. If the fault is removed while ON is low, pull ON above 1.4V after a blanking time (t<sub>ON\_BLANK</sub>) (1ms) can start up the device, regardless of which mode it is in (either latch-off mode or hiccup mode). Figure 7 shows the MOSFET on/off control if a fault occurs.



**Figure 7: MOSFET On/Off Control if a Fault Occurs**

In standalone mode, the C<sub>ON</sub> can be used for automatic start-up via the internal pull-up current source (4.2μA). If the MP5991 is paired with an Intelli-Fuse master or controller, then ON is controlled via the master or controller.

### Soft Start (SS)

A soft-start capacitor (C<sub>SS</sub>) determines the soft-start time (t<sub>SS</sub>). If ON is pulled high and t<sub>ON\_DELAY</sub> finishes, a constant-current source proportional to V<sub>IN</sub> charges C<sub>SS</sub>. V<sub>OUT</sub> rises at a similar slew rate to V<sub>SS</sub>.

C<sub>SS</sub> can be calculated with Equation (1):

$$C_{SS} \text{ (nF)} = \frac{9 \times t_{SS} \text{ (ms)}}{R_{SS}} \quad (1)$$

Where R<sub>SS</sub> is 0.8MΩ.

For example, a 100nF capacitor sets t<sub>SS</sub> to 8.9ms. If the load capacitance is extremely large, the current required to maintain the preset t<sub>SS</sub> should exceed the current limit (I<sub>LIMIT</sub>).

Then the rise time is controlled by the load capacitor and I<sub>LIMIT</sub>. Float the SS pin to generate a fast ramp-up voltage. A current source (12μA) pulls up the MOSFET gate. The gate charge current controls the V<sub>OUT</sub> rise time, and t<sub>SS</sub> is about 1.5ms, which is the minimum V<sub>OUT</sub> t<sub>SS</sub>.

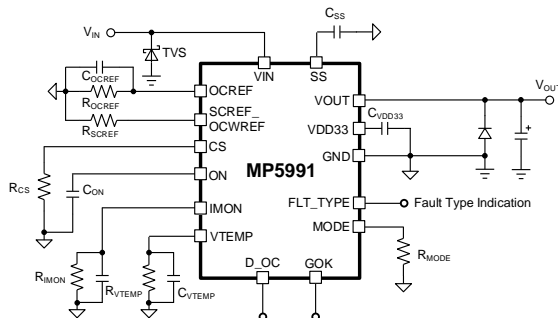
If multiple MP5991s are operating in parallel, then their SS pins should be connected. This controls the soft-start slew rate for all of the devices in parallel during soft start.

### Start-Up Sequence

For hot-swap applications where V<sub>IN</sub> rises immediately, V<sub>GATE</sub> should be pulled low during V<sub>IN</sub> plug-in with high dv/dt. The MP5991 has two operation modes: standalone mode and slave mode.

#### Standalone Mode

In standalone mode, connect an external capacitor (C<sub>ON</sub>) between the ON and GND pins for automatic start-up. Figure 8 shows a typical application circuit of the MP5991 in standalone mode.

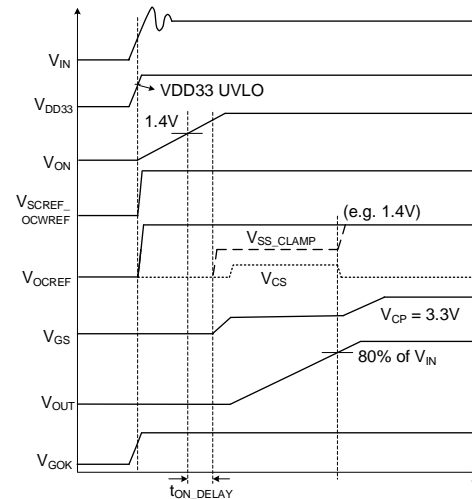


**Figure 8: MP5991 Typical Application Circuit in Standalone Mode**

The internal current source (4.2μA) charges C<sub>ON</sub> once the VDD33 voltage (V<sub>DD33</sub>) exceeds its UVLO rising threshold. ON can also be pulled up to VDD33 externally. The OCREF current (I<sub>OCREF</sub>) (10μA) determines the over-current (OC) limit (I<sub>LIMIT\_OC</sub>) level via the OCREF resistor (R<sub>OCREF</sub>). The SCREF current (I<sub>SCREF</sub>) (10μA) determines I<sub>LIMIT\_SC</sub> level via the SCREF resistor (R<sub>SCREF</sub>).

Once V<sub>ON</sub> exceeds 1.4V and t<sub>ON\_DELAY</sub> finishes, the MOSFET is charged by the internal 12μA charge pump. The MOSFET turns on once the gate-to-source (GS) voltage (V<sub>GS</sub>) exceeds its threshold (V<sub>GS\_TH</sub>), and V<sub>OUT</sub> rises. If the external current-limit reference voltage (V<sub>OCREF</sub>)

exceeds the internal V<sub>SS\_CLAMP</sub>, then the actual current-limit reference is clamped internally at V<sub>SS\_CLAMP</sub> (see Figure 9). If the external V<sub>OCREF</sub> is below V<sub>OCREF\_CLAMP</sub>, then the current-limit reference is determined by V<sub>OCREF</sub>.

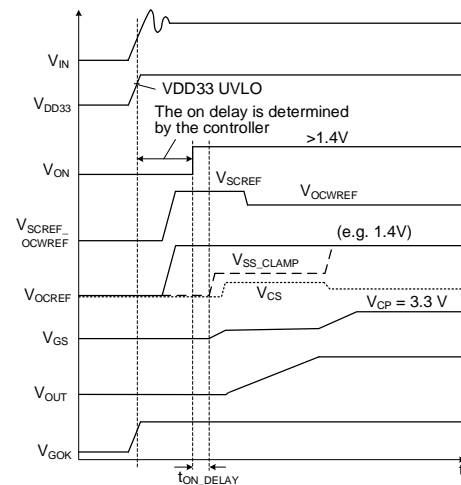


**Figure 9: Start-Up in Standalone Mode**

#### Slave Mode

If the MP5991 is controlled by a hot-swap master or controller (e.g. design with the MP5990), then the part should be configured to operate in slave mode. In slave mode, V<sub>OCREF</sub>, V<sub>SCREF</sub>, and the OCWREF voltage (V<sub>OCWREF</sub>) are configured via the controller.

The MOSFET remains off until V<sub>ON</sub> is pulled high. If V<sub>ON</sub> goes high and t<sub>ON\_DELAY</sub> finishes, then the MOSFET is charged by the internal 12μA charge pump. V<sub>OUT</sub> rises once V<sub>GS</sub> exceeds V<sub>GS\_TH</sub> (see Figure 10).



**Figure 10: Start-Up while the MP5991 is Controlled via a Hot-Swap Controller**

If I<sub>LOAD</sub> is high, then the maximum CS voltage (V<sub>CS</sub>) is clamped at V<sub>SS\_CLAMP</sub> during soft start.

If the ON signal from the hot-swap controller remains high, then the MP5991 can also be turned on or off via the VIN pin.

### Current-Sense Output (CS)

The CS pin provides a current proportional to the current flowing through the device (I<sub>OUT</sub>). V<sub>CS</sub> is used for OC limiting, OC warning indication, and parallel operation with start-up current balancing. The current-sense gain is 10μA/A while the MOSFET is on fully. The current-sense resistor (R<sub>CS</sub>) is used to generate V<sub>CS</sub>. I<sub>CS</sub> can be calculated with Equation (2):

$$I_{CS} = I_{OUT} \times 10\mu A/A \quad (2)$$

Then V<sub>CS</sub> can be calculated with Equation (3):

$$V_{CS} = I_{CS} \times R_{CS} \quad (3)$$

Once V<sub>CS</sub> exceeds the OCREF I<sub>LIMIT</sub> threshold, the internal circuitry regulates V<sub>GATE</sub> to maintain a constant I<sub>FET</sub>.

### Current Monitor Output (IMON)

The MP5991 provides a high-accuracy power MOSFET current monitor output (IMON). The gain of the current monitor (g<sub>IMON</sub>) is 10μA/A. Connect a resistor (R<sub>IMON</sub>) between the IMON and GND pins. The IMON voltage (V<sub>IMON</sub>) range (0V to 1.8V) is required to keep the IMON current (I<sub>IMON</sub>) linearly proportional to I<sub>FET</sub>. I<sub>IMON</sub> can be calculated with Equation (4):

$$I_{IMON} = I_{OUT} \times 10\mu A/A \quad (4)$$

Then V<sub>IMON</sub> can be calculated with Equation (5):

$$V_{IMON} = I_{IMON} \times R_{IMON} \quad (5)$$

The current monitor output can be used by the master or controller to accurately monitor the I<sub>OUT</sub>. Place a 2.2nF to 100nF capacitor between the IMON and GND pins to reduce noise and maintain a smooth indicator voltage.

### Current Balancing for Parallel Operation

Multiple MP5991 devices can be used in parallel for higher-current applications. The current balance loop balances the start-up current for each active channel. Connect the IMON pins of all devices for current balancing.

The sensed current from each active IMON pin is summed together, and then divided by the

number of active channels. The resulting average I<sub>LOAD</sub> provides a measure of the total I<sub>LOAD</sub>. The MP5991's current balance is achieved by comparing the sensed CS current (I<sub>CS</sub>) in each device to the average current, which creates an appropriate V<sub>GATE</sub> adjustment for each Intelli-Fuse during start-up. The equivalent average R<sub>IMON</sub> (R<sub>IMON\_AVG</sub>) can be calculated with Equation (6):

$$R_{IMON\_AVG} = R_{CS} / N \quad (6)$$

Where N is the number of active MP5991s.

Start-up current balancing is essential for improved thermal performance during parallel operation. Good current sharing reduces power loss by dissipating it across the devices and across a larger area.

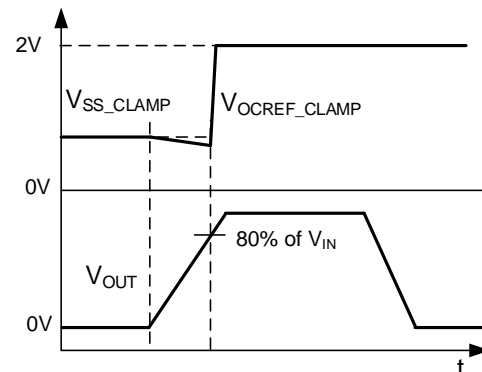
### Over-Current Limit Reference (OCREF)

The MP5991's I<sub>LIMIT</sub> is set by V<sub>OCREF</sub> and the external R<sub>CS</sub>. V<sub>CS</sub> is compared to V<sub>OCREF</sub> via an amplifier to regulate V<sub>GATE</sub>. This prevents the Intelli-Fuse current from exceeding I<sub>LIMIT</sub> set by the reference. V<sub>OCREF</sub> is set by the OCREF pin via a resistor (R<sub>OCREF</sub>). V<sub>OCREF</sub> can be calculated with Equation (7):

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

Where I<sub>OCREF</sub> is 10μA.

To protect the MP5991 from overheating during start-up, the OCREF pin has internal clamp voltage (V<sub>OCREF\_CLAMP</sub>) that is determined by V<sub>IN</sub> and V<sub>OUT</sub> (see Figure 11).



**Figure 11: OCREF Clamp Voltage**

If V<sub>OUT</sub> is below 80% of V<sub>IN</sub>, then V<sub>OCREF\_CLAMP</sub> is equal to V<sub>SS\_CLAMP</sub> (about 635mV with a negative temperature coefficient). If V<sub>OUT</sub> exceeds 80% of V<sub>IN</sub>, then V<sub>OCREF\_CLAMP</sub> is 2V.

If  $V_{OCREF}$  is below  $V_{OCREF\_CLAMP}$ , then the current-limit reference voltage is determined by  $V_{OCREF}$ . If  $V_{OCREF}$  exceeds  $V_{OCREF\_CLAMP}$ , then the current-limit reference voltage is determined by  $V_{OCREF\_CLAMP}$ .

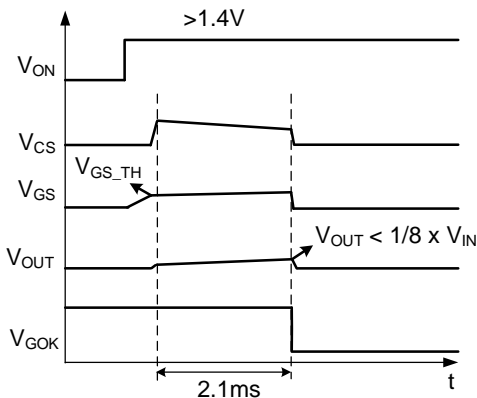
The desired  $I_{LIMIT}$  is a function of  $R_{CS}$ , the current-sense gain ( $g_{CS}$ ) and  $V_{OCREF}$ .  $I_{LIMIT}$  can be calculated with Equation (8):

$$I_{LIMIT} = \frac{V_{OCREF}}{g_{CS} \times R_{CS}} \quad (8)$$

$I_{LIMIT}$  can exceed the maximum load current ( $I_{LOAD\_MAX}$ ) during normal operation to allow for tolerances in the current-sense value.

### Over-Current Protection (OCP) during Start-Up

Once  $V_{CS}$  exceeds  $V_{OCREF}$  during soft start,  $V_{GATE}$  is regulated to maintain a constant  $I_{FET}$ . If  $V_{OUT}$  is below ( $1/8 \times V_{IN}$ ), and  $I_{FET}$  is regulated by  $V_{SS\_CLAMP}$  for 2.1ms, then the MOSFET latches off, and GOK is pulled low (see Figure 12).



**Figure 12: Failed Start-Up with Output Hard Short**

### OCP during Normal Operation

If  $V_{OUT}$  exceeds 80% of  $V_{IN}$ , then  $V_{OCREF\_CLAMP}$  is pulled to 2V, and  $V_{GATE}$  is close to the internal charge pump voltage ( $V_{CP}$ ). Once soft start is complete, the MP5991 begins normal operation.

Once  $V_{CS}$  (configured via an external resistor) exceeds  $V_{OCREF}$ , the internal circuitry regulates  $V_{GATE}$  to maintain a constant current on the MOSFET. To limit  $I_{OUT}$ , the MOSFET's  $V_{GS}$  is regulated between 3.3V and 1V. The response time is about 14μs.  $I_{OUT}$  may have a small overshoot during this response time.

If  $I_{OUT}$  exceeds  $I_{LIMIT}$ , then the internal fault timer (220μs) starts. If  $I_{OUT}$  drops below  $I_{LIMIT}$  within the fault timer period, then the device resumes normal operation. If  $I_{OUT}$  exceeds  $I_{LIMIT}$  for 220μs, then the MOSFET latches off, and GOK is pulled low.

If an OC fault occurs, then the GOK and SS pins are pulled low, and FLT\_TYPE outputs 1.2V to indicate an OC fault.

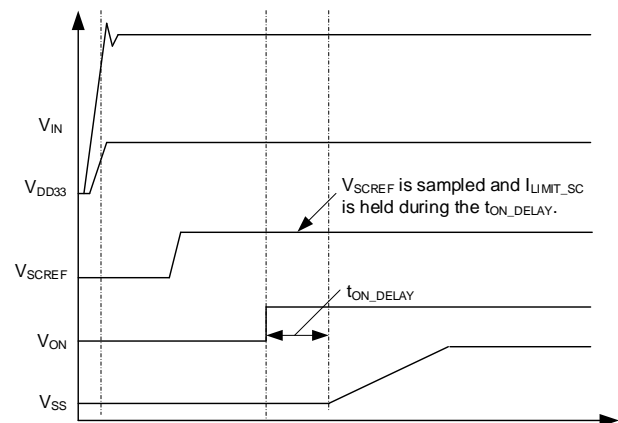
In latch-off mode, cycle the power on  $V_{IN}$ ,  $V_{DD33}$ , or ON to reset FLT\_TYPE to 0.1V. This initiates a soft start, and then MOSFET turns on.

In hiccup mode, the device attempts to initiate a new soft start automatically, and GOK is pulled high after a retry delay time ( $t_{RETRY}$ ). FLT\_TYPE continues to indicate an OC fault during  $t_{RETRY}$ . FLT\_TYPE is reset to 0.1V after  $t_{RETRY}$ .

### Short-Circuit Current Limit (SCREF)

If  $I_{LOAD}$  increases rapidly due to a short circuit, the current may exceed  $I_{LIMIT}$  significantly before the hot-swap control loop can respond. Once the Intelli-Fuse current reaches the short-circuit current limit ( $I_{LIMIT\_SC}$ ), a fast turn-off circuit in the Intelli-Fuse is enabled to turn the MOSFET off. The total short-circuit response time is about 200ns. If  $I_{FET}$  exceeds  $I_{LIMIT\_SC}$ , GOK is pulled low.

To determine  $I_{LIMIT\_SC}$ , the MP5991 samples the SCREF voltage ( $V_{SCREF}$ ) once the ON voltage ( $V_{ON}$ ) exceeds its rising threshold during the  $t_{ON\_DELAY}$  (see Figure 13).



**Figure 13: SCREF Voltage Sampling to Determine the Short-Circuit Current Limit**

$I_{LIMIT\_SC}$  is held once  $t_{ON\_DELAY}$  is finished. Changing  $V_{SCREF}$  after  $t_{ON\_DELAY}$  does not affect



I<sub>LIMIT\_SC</sub>. Cycle the power on VIN, VDD33, or ON to enter another t<sub>ON\_DELAY</sub> and set a new I<sub>LIMIT\_SC</sub>.

The MP5991 provides five types of short-circuit current levels that can be selected via the SCREF pin. Table 1 shows the selectable short-circuit current limits for different SCREF voltages in standalone mode (the recommended R<sub>SCREF</sub> value is also shown for when V<sub>SCREF</sub> is generated by R<sub>SCREF</sub>).

**Table: 1 Short-Circuit Current Limit Selection for Different V<sub>SCREF</sub> in Standalone Mode**

V <sub>SCREF</sub> (V)	R <sub>SCREF</sub>	I <sub>LIMIT_SC</sub> (A)
<0.16	Pulled to GND	40
0.24 to 0.36	30kΩ	60
0.48 to 0.72	60kΩ	80
0.96 to 1.44	120kΩ	120
>1.68	200kΩ	100

In latch-off mode, cycle the power on VIN, VDD33, or ON to reset FLT\_TYPE to 0.1V. This initiates a soft start, and then MOSFET turns on.

In hiccup mode, the device attempts to retry automatically, and GOK is pulled high after t<sub>RETRY</sub>. FLT\_TYPE continues to indicate an SC fault during t<sub>RETRY</sub>. FLT\_TYPE is reset to 0.1V after t<sub>RETRY</sub>.

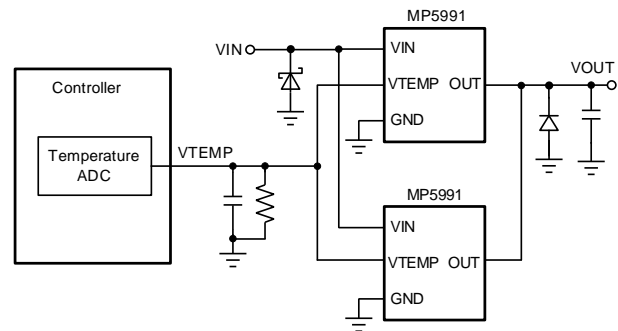
### Temperature-Sense Output (VTEMP)

The VTEMP pin reports the junction temperature (T<sub>J</sub>) while there is no thermal gradient on the IC. If V<sub>DD33</sub> exceeds its UVLO rising threshold, then VTEMP is a voltage output proportional to T<sub>J</sub>. The VTEMP voltage (V<sub>TEMP</sub>) is 8.7mV/°C, and has a 152.5mV offset. V<sub>TEMP</sub> can be calculated with Equation (9):

$$V_{TEMP} = T_J \times 8.7mV + 152.5mV \quad (9)$$

For example, if T<sub>J</sub> is 100°C, then V<sub>TEMP</sub> is 1.022V. If V<sub>TEMP</sub> is 0V, then T<sub>J</sub> is -18°C. The total temperature-sense range is -18°C to +150°C. If T<sub>J</sub> drops below -18°C, then V<sub>TEMP</sub> is 0V.

During multi-fuse operation, the VTEMP pins of each Intelli-Fuse can be connected to the controller's temperature monitor pin. Connect a ≤1nF capacitor and a ≥10kΩ resistor in parallel on VTEMP. Figure 14 shows the temperature sense function during multi-fuse parallel operation.



**Figure 14: Temperature Sense during Multi-Fuse Parallel Operation**

### Mode Selection (MODE)

The MP5991 provides both latch-off mode and hiccup mode for the following protections: input over-voltage protection (OVP), output over-current protection (OCP), short-circuit protection (SCP), over-temperature protection (OTP), and MOSFET GS short protection. The MODE pin selects either latch-off mode or hiccup mode with t<sub>RETRY</sub>. MODE also determines whether the MP5991 operates in slave mode.

In slave mode, the part operates with the following conditions:

- The internal I<sub>OCREF</sub> (10μA) and I<sub>SCREF</sub> (10μA) are disabled, so V<sub>OCREF</sub> and V<sub>SCREF</sub> are controlled by controller.
- The internal V<sub>OCREF\_CLAMP</sub> remains active, and the soft-start clamp voltage (V<sub>SS\_CLAMP</sub>) controls the soft-start current-limit threshold
- The internal ON current (I<sub>ON</sub>) 4.2μA is disabled.
- If V<sub>CS</sub> exceeds V<sub>OCWREF</sub>, then D\_OC is pulled low. D\_OC is not pulled low if V<sub>CS</sub> exceeds 85% of V<sub>OCREF</sub>.
- Hiccup mode or latch-off mode and t<sub>RETRY</sub> are selected via the controller.

If the device exceeds either the V<sub>DD33</sub> or V<sub>IN</sub> UVLO rising threshold, then the MODE pin is detected. Once a mode is selected, it is held until the power on VDD33 or VIN is cycled again.

Table 2 on page 26 shows the mode selection and t<sub>RETRY</sub> for common resistor values.

**Table 2: Mode Selection**

R <sub>MODE</sub>	Protection Mode	Retry Delay Time
Pulled to GND	Hiccup mode	500ms
30kΩ	Hiccup mode	250ms
60kΩ	Hiccup mode	1s
120kΩ	Slave mode	
Pulled to VDD33 or floating	Latch-off mode	

### GOK Reporting

The GOK pin is an open-drain with an internal weak pull-up, active-low signal that reports Intelli-Fuse faults. If a fault occurs, GOK is pulled low. Pull GOK up to the VDD33 via a 10kΩ to 100kΩ resistor. During start-up, the GOK voltage (V<sub>GOK</sub>) rises according to V<sub>DD33</sub>.

The MP5991 also provides a comparator on the GOK pin to control the MOSFET. If V<sub>GOK</sub> drops below 1.16V, the system see this as a fault, and the MOSFET turns off.

### D\_OC Reporting

The D\_OC pin is an open-drain, active-low output that reports OC warnings while V<sub>OUT</sub> exceeds 90% of V<sub>IN</sub>. If V<sub>CS</sub> exceeds 85% of V<sub>OCREF</sub> in standalone mode, then D\_OC is pulled low. If V<sub>CS</sub> drops below 85% of V<sub>OCREF</sub>, then D\_OC is pulled high. In slave mode, this threshold is determined by V<sub>OCWREF</sub>, not 85% of the V<sub>OCREF</sub>. Pull D\_OC up to VDD33 via a 10kΩ to 100kΩ resistor.

### Fault Type Indication (FLT\_TYPE)

The MP5991 reports the fault type via a voltage on the FLT\_TYPE pin. Table 3 shows the FLT\_TYPE voltage (V<sub>FLT\_TYPE</sub>) for each fault condition.

**Table 3: Fault Type Indication**

Fault Types	FLT_TYPE Voltage
Short circuit	1.5V
OC fault during normal operation or during SS	1.2V
OT fault or V <sub>IN</sub> OV fault	0.9V
GS/DS short	0.6V
GOK fault	0.3V
Other statuses	0.1V

Do not short FLT\_TYPE to ground. V<sub>FLT\_TYPE</sub> indicates the associated value only while the

fault is present and the MOSFET is off. For example, if an OC fault occurs, the FLT\_TYPE outputs 1.2V after the fault timer (220μs) ends and the MOSFET turns off.

A higher V<sub>FLT\_TYPE</sub> indicates a more serious fault has occurred in the system. If multiple faults occur at the same time, then FLT\_TYPE outputs the voltage for the most serious fault. For example, if an OC fault and an OT fault occur simultaneously, then FLT\_TYPE outputs 1.2V to indicate the OC fault (the more serious fault).

In multi-fuse operation, the FLT\_TYPE pins of each Intelli-Fuse can be connected together to indicate the highest-priority fault in the entire system.

### Other Fault Protections

#### Over-Temperature Protection (OTP)/Thermal Shutdown

The MP5991 senses the MOSFET's junction temperature (T<sub>J</sub>) internally. If T<sub>J</sub> exceeds the thermal shutdown threshold (about 145°C), then the device shuts down. The GOK and SS pins are pulled low, and FLT\_TYPE outputs 0.9V (if there are no other higher-priority faults have occurred).

In latch-off mode, cycle the power on V<sub>IN</sub>, VDD33, or ON to reset FLT\_TYPE to 0.1V. This initiates a soft start, and then MOSFET turns on.

Once T<sub>J</sub> drops below 100°C in hiccup mode, the device attempts to retry automatically, and GOK is pulled high after t<sub>RETRY</sub>. FLT\_TYPE continues to indicate an OT fault during t<sub>RETRY</sub>. FLT\_TYPE is reset to 0.1V after t<sub>RETRY</sub>.

#### V<sub>IN</sub> Over-Voltage Protection (OVP)

The MP5991 monitors V<sub>IN</sub> to determine whether an over-voltage (OV) fault has occurred. If V<sub>IN</sub> exceeds 18.5V, then the MOSFET turns off, and the GOK and SS pins are pulled low. If no other higher-priority faults have occurred, then FLT\_TYPE outputs 0.9V to indicate an OV fault.

In latch-off mode, cycle the power on V<sub>IN</sub>, VDD33, or ON to reset FLT\_TYPE to 0.1V. This initiates a soft start, and then MOSFET turns on.

Once V<sub>IN</sub> drops below 17.5V in hiccup mode,

the device attempts to retry automatically, and GOK is pulled high after  $t_{RETRY}$ . FLT\_TYPE continues to indicate an OV fault during  $t_{RETRY}$ . FLT\_TYPE is reset to 0.1V after  $t_{RETRY}$ .

### Damaged Intelli-Fuse MOSFET Detection

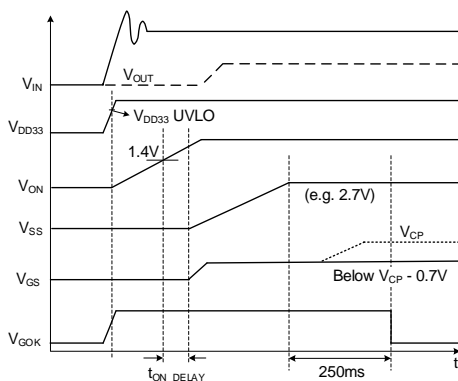
The MP5991 can detect a shorted pass MOSFET during start-up. Once  $V_{DD33}$  exceeds its UVLO rising threshold and  $V_{ON}$  exceeds its rising threshold (1.4V), the device treat output voltages that exceed 90% of  $V_{IN}$  during the  $t_{ON\_DELAY}$  as a short. This is called a drain-to-source (DS) short. GOK is pulled low once the device detects that  $V_{OUT}$  has exceeded 90% of  $V_{IN}$  during start-up, and FLT\_TYPE outputs 0.6V to indicate a DS short. The DS short is non-latch fault, regardless of the operation mode. GOK is pulled high once the DS short is removed and the device detects that  $V_{OUT}$  is below 70% of  $V_{IN}$ . Then FLT\_TYPE is reset to 0.1V. The MP5991 initiates a soft start and resumes normal operation.

### Power MOSFET is Not Fully On

If the following conditions are met once the part starts up and  $V_{OUT}$  starts to ramp up, it means the power MOSFET is not fully on:

- $V_{SS}$  exceeds  $V_{DD33} - 0.7V$
- $V_{GS}$  is below  $V_{CP} - 0.7V$
- No OC faults have occurred
- No SC faults have occurred

The MP5991 stops regulating and the MOSFET turns off after 250ms. The GOK and SS pins are pulled low, and FLT\_TYPE outputs 0.6V to indicate a GS short has occurred (see Figure 15).



**Figure 15: Power MOSFET is Not Fully On in Latch-Off Mode**

In latch-off mode, cycle the power on  $V_{IN}$ ,  $V_{DD33}$ , or ON to reset FLT\_TYPE to 0.1V. This initiates a soft start, and then MOSFET turns on.

In hiccup mode, the device attempts to retry automatically, and GOK is pulled high after  $t_{RETRY}$  ends. FLT\_TYPE continues to indicate a GS short fault during  $t_{RETRY}$ . FLT\_TYPE is reset to 0.1V after  $t_{RETRY}$ .

### GOK Fault

The MP5991 provides a comparator on the GOK pin to control the MOSFET. If  $V_{GOK}$  drops below 1.16V, then the system sees this as a fault, and the MOSFET turns off after a delay time (10μs). FLT\_TYPE outputs 0.3V to indicate a GOK fault.

The GOK fault is non-latch fault. Once  $V_{GOK}$  exceeds 2.06V, the device initiates a soft start and resumes normal operation. FLT\_TYPE resets to 0.1V.

For standalone operation, GOK has an internal pull-up resistor (370kΩ) to avoid falsely triggering a GOK fault when there is not an external pull-up resistor.

### Under-Voltage Lockout (UVLO) Protection

The MP5991 has two under-voltage lockout (UVLO) protections:  $V_{DD33}$  UVLO with a 2.7V rising threshold, and  $V_{IN}$  UVLO with a 3.2V rising threshold. The device starts up once both  $V_{DD33}$  and  $V_{IN}$  exceed their respective rising thresholds. The MP5991 shuts down if either  $V_{DD33}$  or  $V_{IN}$  drops below its UVLO (2.3V and 2.7V, respectively).  $V_{DD33}$  UVLO and  $V_{IN}$  UVLO are non-latch protections.

### Input and Output Transient Protection

Parasitic inductance in the input circuitry can cause the hot-swap system to experience positive transients on the input during a hot plug or during rapid shutdown with a high current. To reduce input transients, a transient voltage suppressor (TVS) diode may be required on the input to limit transient voltages below the absolute maximum ratings.

Inductance in the output circuitry can cause the output to experience negative transients during rapid turn-off with a high current. If a transient causes the output to drop further, then the MOSFET may not turn off properly.

An output voltage clamp diode is required on the output to limit negative transients. Select a Schottky diode with a low forward voltage.

### Parallel Operation

The MP5991 can work in parallel operation to support higher currents (maximum 20-phase operation). The following connections and conditions are required to support multi-phase parallel operation (see Figure 2 on page 3 for more details):

- Connect the VIN pins to the same input bus
- Connect the VOUT pins to the same output bus
- Tie the ON pins together for start-up sequence control
- Tie the SS pins together for soft-start sequence control
- Tie the GOK pins together for system fault control
- Design the current-sense resistor (R<sub>CS</sub>) to have the same resistance in each phase
- Tie the IMON pins together, and design the total system's IMON resistance to equal R<sub>CS</sub> / N (where N is the number of phases) for soft-start current-balance control
- Tie the OCREF pins together
- Select the same mode for all phases
- Tie the VTEMP pins together to report the highest T<sub>J</sub> of all the phases
- Tie the FLT\_TYPE pins together to indicate the highest-priority fault

## APPLICATION INFORMATION

### Selecting the Current-Limit Resistor (R<sub>CS</sub>)

The MP5991's over current limit (I<sub>LIMIT</sub>) should exceed the normal I<sub>LOAD\_MAX</sub>. This allows for tolerances in the current-sense value. I<sub>LIMIT</sub> can be calculated with Equation (10):

$$I_{LIMIT} = \frac{V_{OCREF}}{R_{CS}} \times 10^5 \text{ (A)} \quad (10)$$

Where V<sub>OCREF</sub> is the OCREF voltage while the MOSFET operates in linear mode.

If R<sub>CS</sub> is 3kΩ and V<sub>OCREF</sub> is 1.2V, then I<sub>LIMIT</sub> is 40A. If V<sub>OCREF</sub> is 0.3V, then I<sub>LIMIT</sub> is 10A.

### Current-Limit Reference Voltage (OCREF)

The OCREF pin sets the current-limit reference via the hot-swap controller in slave mode or via a resistor connected to ground in standalone mode. I<sub>OCREF</sub> (10μA) sets V<sub>OCREF</sub> in standalone mode. Place a 1nF to 10nF capacitor between the OCREF and GND pins to reduce noise and maintain a smooth indicator voltage.

During normal operation, V<sub>OCREF</sub> can be set between 0.3V and 1.8V to configure I<sub>LIMIT</sub> either low or high while R<sub>CS</sub> is fixed.

### Current Monitor Setting (IMON)

The MP5991 provides a power MOSFET current-monitoring function. Connect a resistor (R<sub>IMON</sub>) between the IMON and GND pins to set the I<sub>OUT</sub> gain.

In a single-fuse application, R<sub>IMON</sub> should be ≥R<sub>CS</sub>. If the device is used in a multi-fuse parallel application, the start-up current balance per device can be achieved by connecting the IMON pins together.

The equivalent average IMON resistance (R<sub>IMON\_AVG</sub>) can be calculated with Equation (6).

Figure 16 shows the IMON and CS connections of multiple MP5991s in a multi-fuse parallel application.

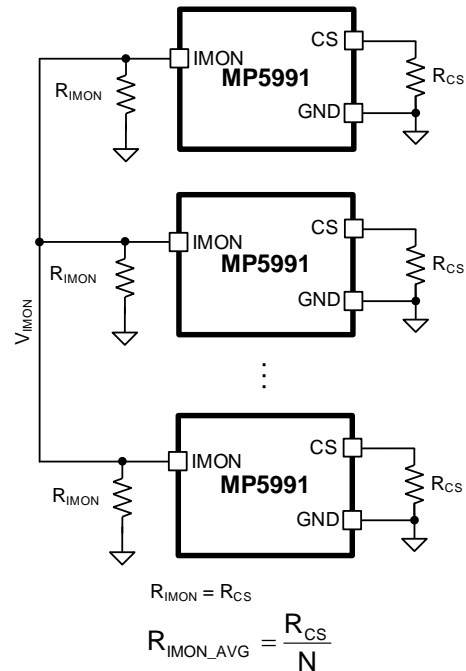


Figure 16: IMON and CS Connections in Multi-Fuse Parallel Application

### Maximum Output Current

The MP5991 can drive up to 50A of continuous I<sub>OUT</sub> per device at room temperature, and up to 60A I<sub>OUT</sub> with air flow. Figure 17 shows the case temperature rise at different air flow conditions.

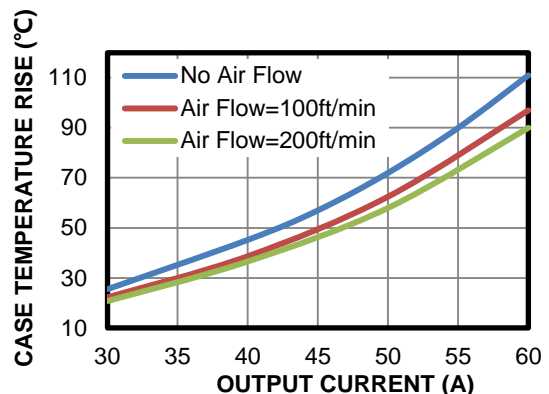
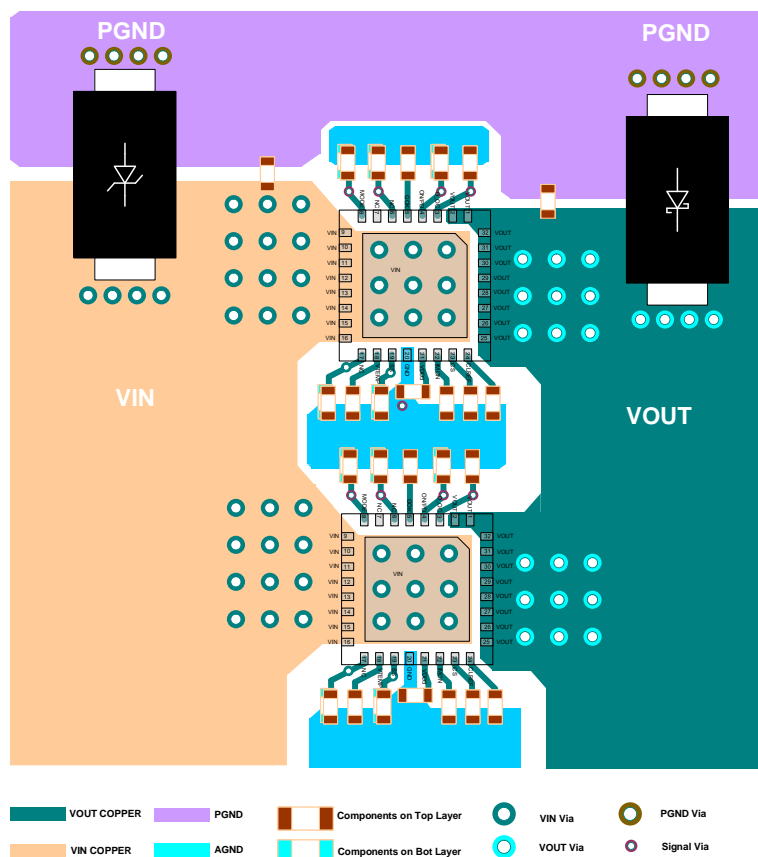


Figure 17: Case Temperature Rise

### PCB Layout Guidelines

Efficient PCB layout is critical for stable operation. A 4-layer layout is strongly recommended for improved thermal performance. For the best results, refer to Figure 18 and follow the guidelines below:

1. Place the IC close to the VIN to minimize trace inductance.
2. Place a small input capacitor (e.g. 100nF) close to VIN and GND to minimize transients on the input. <sup>(7)</sup>
3. Place a 1μF capacitor as close to VDD33 as possible.
4. Route the high-current path and the return path between the input and the load close to each other in parallel to minimize loop inductance.
5. Place an analog signal ground (AGND) plane locally in the IC.
6. Connect the AGND plane to PGND planes at a single point.
7. If the MP5991 is controlled via a hot-swap controller, connect all of the IC's AGNDs to the controller's reference ground.
8. Place multiple vias on the board to improve better thermal performance.
  - a. Place  $\geq 9$  vias on the bottom of the VIN pad.
  - b. Place  $\geq 12$  vias close to the VIN pads at the edge of the IC.
  - c. Place  $\geq 9$  vias close to VOUT pads.



**Figure 18: Recommended PCB Layout**

VIN TVS Diode PN: SMDJ13A

VOUT Diode PN (Standalone Operation): MBRA340T3G

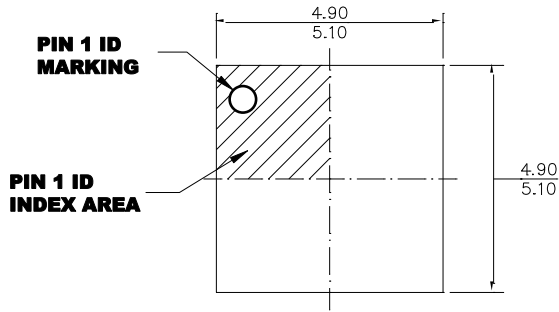
VOUT Diode PN (Parallel Operation): MBRS540T3G

**Note:**

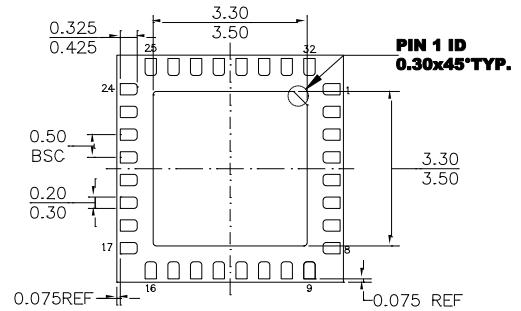
- 7) Transient voltages can occur on the input if the MOSFET is turned off by a large I<sub>LOAD</sub>.

PACKAGE INFORMATION

LGA-32 (5mmx5mm)



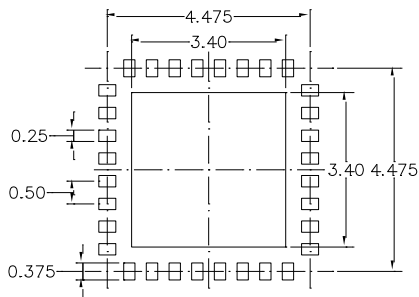
**TOP VIEW**



**BOTTOM VIEW**



**SIDE VIEW**

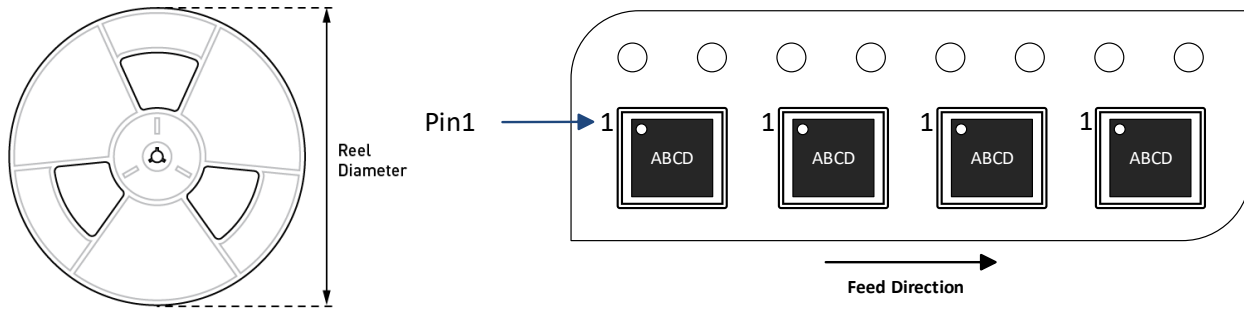


**RECOMMENDED LAND PATTERN**

**NOTE:**

- 1) ALL DIMENSIONS ARE IN MILLIMETERS.
- 2) LEAD COPLANARITY SHALL BE 0.10 MILLIMETERS MAX.
- 3) JEDEC REFERENCE IS MO-303.
- 4) DRAWING IS NOT TO SCALE.

### CARRIER INFORMATION



Part Number	Package Description	Quantity/ Reel	Quantity/ Tube	Quantity/ Tray	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MP5991GLU-Z	LGA-32 (5mmx5mm)	5000	N/A	N/A	13in	12mm	8mm



## REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	4/27/2022	Initial Release	-

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[LM5066IPMHX/NOPB](#) [TPS259824LNRGER](#) [TPS259823LNRGER](#) [NU6-II 60kA/385V 4P](#) [NU6-G 40kA/275V 4P](#) [NU6-II 40kA/385V 2P](#)  
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