



# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

**MAX8737**

## General Description

The MAX8737 dual high-power linear regulator controllers use external n-channel MOSFETs to generate two independent low-voltage supplies for notebook computers. The MAX8737 delivers low output voltages from 0.5V to 2.5V ( $\pm 5\text{mV}$  no-load accuracy). The external components allow scalable current design with loads up to 5A with excellent load regulation (1%). The regulator operates from a low input voltage, which also reduces the power dissipation in the external n-channel MOSFET. The controller powers the external MOSFET gate driver from the standard 5V system supply.

The MAX8737 includes current and thermal limits to prevent damage to the linear regulator. The MAX8737 uses an external resistive divider to fold back the current limit, reducing the overall power dissipation. The MAX8737 uses an external resistive-divider in series with the current-sense input (CS<sub>-</sub>), providing foldback current-limit protection, and effectively reducing the short-circuit power dissipation.

An output undervoltage timeout is available for low-cost applications that omit the current-sense resistor. The output undervoltage (UVP) timing depends on the magnitude of the voltage at V<sub>OUT</sub>. The UVP detects and shuts down the LDO if the output voltage drops out of regulation. The controller uses an adjustable reference input (REFIN<sub>-</sub>) to set the nominal output voltage (V<sub>OUT</sub>), which minimizes the cost and makes the stability independent of the output voltage.

Each linear regulator features an adjustable soft-start function, and generates a delayed power-good (PGOOD) signal that signals when the linear regulator is in regulation. The MAX8737 is a low-cost solution requiring few external components and is available in a small, 4mm x 4mm, 16-pin thin QFN package.

## Applications

Notebook and Desktop Computers  
Point-of-Load Regulators  
VMCH and VCCP CPU Supplies  
Low-Voltage Bias Supplies  
Servers

## Features

- ◆ Low-Cost Dual Linear Regulators
- ◆ Output Voltage Accuracy  $\pm 5\text{mV}$
- ◆ Independent 0.5V to 2.5V Reference Inputs
- ◆ Foldback Current-Limit Protection
- ◆ Output Undervoltage-Lockout Protection
- ◆ Thermal Limit (Internal Sensor)
- ◆ 1.0V to 5.5V Input Supply Voltage (External FET Drain)
- ◆ 5V Bias Supply Voltage
- ◆ Independent Power-Good Open-Drain Outputs
- ◆ Independent Enable Inputs
- ◆ Soft-Shutdown Output Discharge
- ◆ Low Supply Current (0.5mA)
- ◆ 5 $\mu\text{A}$  (max) Shutdown Supply Current

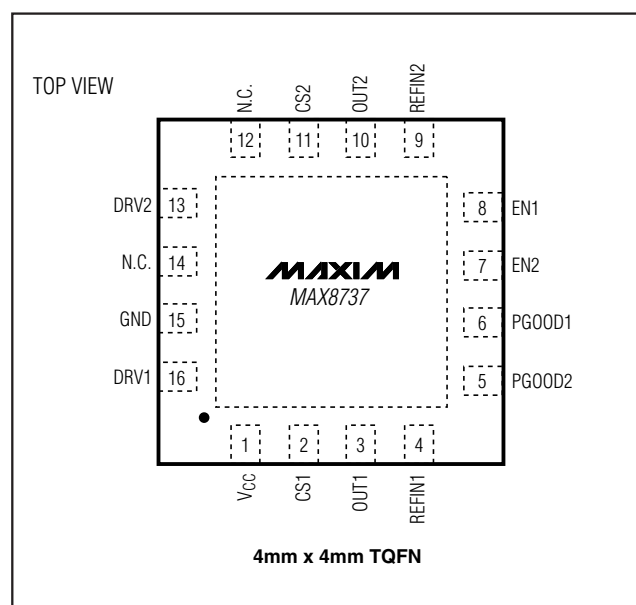
## Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX8737ETE	-40°C to +85°C	16 Thin QFN-EP* 4mm x 4mm
MAX8737ETE+	-40°C to +85°C	16 Thin QFN-EP* 4mm x 4mm

\*EP = Exposed pad.

+Denotes lead-free packaging.

## Pin Configuration



# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## ABSOLUTE MAXIMUM RATINGS

V<sub>CC</sub> to GND .....-0.3V to +6V  
 OUT1, OUT2 to GND .....-0.3V to +6V  
 REFIN1, REFIN2, PGOOD1, PGOOD2, EN1,  
 EN2 to GND .....-0.3V to +6V  
 DRV1, DRV2, CS1, CS2 to GND .....-0.3V to (V<sub>CC</sub> + 0.3V)  
 Continuous Power Dissipation (T<sub>A</sub> = +70°C)  
 16-Pin 4mm x 4mm Thin QFN (derated 25mW/°C  
 above +70°C) .....2000mW

Operating Temperature Range

MAX8737ETE .....-40°C to +85°C  
 Junction Temperature .....+150°C  
 Storage Temperature Range .....-65°C to +150°C  
 Lead Temperature (soldering, 10s) .....+300°C

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 in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

(V<sub>CC</sub> = 5V, EN<sub>-</sub> = CS<sub>-</sub> = V<sub>CC</sub>, V<sub>REFIN</sub> = 1.0V, T<sub>A</sub> = 0°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS		
Supply Voltage Range	V <sub>CC</sub>		4.75		5.50	V		
V <sub>CC</sub> Undervoltage Lockout Threshold		Rising edge, 200mV hysteresis (typ)	4.1	4.35	4.6	V		
V <sub>CC</sub> Quiescent Supply Current	I <sub>CC</sub>	EN1 = EN2 = V <sub>CC</sub>		0.5	1	mA		
V <sub>CC</sub> Shutdown Supply Current		EN1 = EN2 = GND		0.1	5	μA		
REFIN to OUT Offset Voltage	V <sub>OUT_</sub>		-5		+5	mV		
OUT_ Input Bias Current	I <sub>OUT_</sub>		-1		+1	μA		
DRIVERS								
DRV_ Output Voltage Swing (Note 1)		Output high; V <sub>OUT_</sub> = V <sub>REFIN_</sub> - 25mV, I <sub>LOAD</sub> = 1mA	V <sub>CC</sub> - 0.3	V <sub>CC</sub> - 0.05		V		
		Output low; V <sub>OUT_</sub> = V <sub>REFIN_</sub> + 25mV, I <sub>LOAD</sub> = 1mA		0.03	0.3			
DRV_ Maximum Sourcing Current		V <sub>OUT_</sub> = V <sub>REFIN_</sub> - 25mV; V <sub>DRV</sub> = 3V	6	14		mA		
DRV_ Maximum Sinking Current		V <sub>OUT_</sub> = V <sub>REFIN_</sub> + 25mV; V <sub>DRV</sub> = 3V	6	14		mA		
OUT_ to DRV_ Transconductance (Large Signal)	G <sub>MDRV</sub>			0.8		S		
DRV_ Power-Supply Rejection Ratio		10Hz < f < 10kHz, I <sub>DRV</sub> = 1mA, C <sub>DRV</sub> = 10nF		-80		dB		
DRV_ Soft-Start Charging Current	I <sub>SOFT</sub>		40	170	400	μA		
REFERENCE INPUT								
REFIN_ Voltage Range	V <sub>REFIN_</sub>	V <sub>CC</sub> = 4.75V to 5.5V	0.5		2.5	V		
REFIN_ Input Bias Current	I <sub>REFIN_</sub>	V <sub>REFIN_</sub> = 0 to 2.5V	-100	-10	+100	nA		
FAULT PROTECTION								
Thermal Shutdown Threshold	T <sub>SHDN</sub>	Hysteresis = 20°C		+125		°C		
Current-Limit Threshold	V <sub>ILIM</sub>	V <sub>CS_</sub> - V <sub>OUT_</sub>	T <sub>A</sub> = 0°C to +85°C		7	10	13	mV
			T <sub>A</sub> = +85°C		7.5	10	12.5	
CS_ Input Current			-1		+1		μA	
Linear Regulator UVP Threshold (Slow)	UVP(SLOW)	With respect to V <sub>REFIN</sub> ; CS_ = V <sub>CC</sub>	72	80	88		%	

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = 5V$ ,  $EN_{-} = CS_{-} = V_{CC}$ ,  $V_{REFIN} = 1.0V$ ,  $T_A = 0^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = +25^{\circ}C$ .)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Linear Regulator UVP Threshold (Fast)	UVP(FAST)	With respect to $V_{REFIN}$ ; $CS_{-} = V_{CC}$	54	60	66	%
Slow Short-Circuit Timer Duration	tUVP(SLOW)	With respect to $V_{REFIN}$ ; $CS_{-} = V_{CC}$		75		$\mu s$
Fast Short-Circuit Timer Duration	tUVP(FAST)	With respect to $V_{REFIN}$ ; $CS_{-} = V_{CC}$		5		$\mu s$
Discharge-Mode On-Resistance $OUT_{-} Pin$	$R_{OUT}$			10		$\Omega$
<b>INPUTS AND OUTPUTS</b>						
$EN_{-}$ Input Low Level					0.6	V
$EN_{-}$ Input High Level		Rising edge, 200mV (typ) hysteresis	1.6			V
Enable Leakage Current			-1		+1	$\mu A$
Power-Good Trip Threshold (Lower)		With respect to error comparator threshold, hysteresis = 4% (falling edge)	-15	-12	-9	%
Power-Good Startup Delay				2		ms
Power-Good Propagation Delay	tPGOOD	$OUT_{-}$ forced 2% beyond PGOOD_ trip threshold		1		$\mu s$
Power-Good Output Low Voltage		$I_{SINK} = 4mA$			0.3	V
Power-Good Trip Current		$V_{OUT_{-}} = 1.0V$ (PGOOD_ high impedance),				$\mu A$

## ELECTRICAL CHARACTERISTICS

( $V_{CC} = 5V$ ,  $EN_{-} = CS_{-} = V_{CC}$ ,  $V_{REFIN} = 1.0V$ ,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage Range	V <sub>CC</sub>		4.75		5.50	V
V <sub>CC</sub> Undervoltage Lockout Threshold		Rising edge 200mV hysteresis (typ)	4.1		4.6	V
V <sub>CC</sub> Quiescent Supply Current	I <sub>CC</sub>	EN1 = EN2 = V <sub>CC</sub>			1.5	mA
V <sub>CC</sub> Shutdown Supply Current		EN1 = EN2 = GND			5	μA
REFIN to OUT Offset Voltage	V <sub>OUT_</sub>		-7		+7	mV
DRIVERS						
DRV_ Output Voltage Swing (Note 1)		Output high; V <sub>OUT_</sub> = V <sub>REFIN_</sub> - 25mV; I <sub>LOAD</sub> = 1mA	V <sub>CC</sub> - 0.3		0.3	V
		Output low; V <sub>OUT_</sub> = V <sub>REFIN_</sub> + 25mV: I <sub>LOAD</sub> = 1mA				
DRV_ Maximum Sourcing Current		V <sub>OUT_</sub> = V <sub>REFIN_</sub> - 25mV; V <sub>DRV</sub> = 3V	3.5			mA
DRV_ Maximum Sinking Current		V <sub>OUT_</sub> = V <sub>REFIN_</sub> + 25mV; V <sub>DRV</sub> = 3V	3.5			mA
DRV_ Soft-Start Charging Current	I <sub>SOFT</sub>		40		400	μA

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = 5V$ ,  $EN_{-} = CS_{-} = V_{CC}$ ,  $V_{REFIN} = 1.0V$ ,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted.) (Note 2)

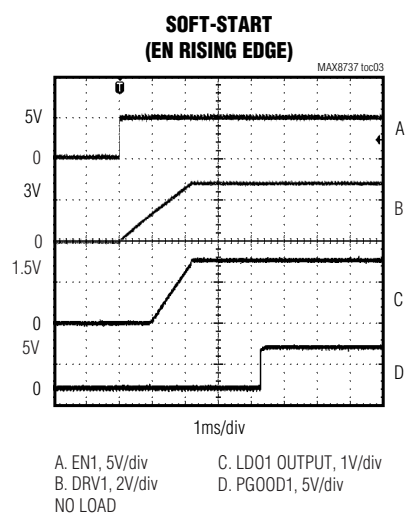
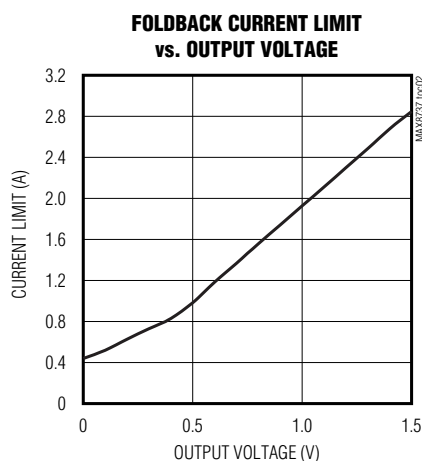
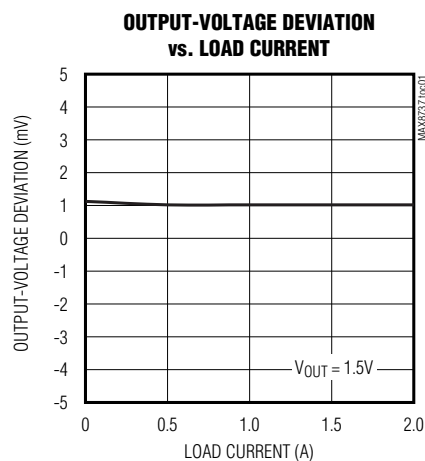
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>REFERENCE INPUT</b>						
REFIN_ Voltage Range	$V_{REFIN\_}$	$V_{CC} = 4.75V$ to $5.5V$	0.5		2.5	V
<b>FAULT PROTECTION</b>						
Current-Limit Threshold	$V_{ILIM}$	$V_{CS_{-}} - V_{OUT_{-}}$	6.5		13.5	mV
Linear Regulator UVP Threshold (Slow)	$UVP_{(SLOW)}$	With respect to $V_{REFIN}$ ; $CS_{-} = V_{CC}$	72		88	%
Linear Regulator UVP Threshold (Fast)	$UVP_{(FAST)}$	With respect to $V_{REFIN}$ ; $CS_{-} = V_{CC}$	54		66	%
<b>INPUTS AND OUTPUTS</b>						
EN_ Input Low Level					0.6	V
EN_ Input High Level			1.6			V
Power-Good Trip Threshold (Lower)		With respect to error comparator threshold, hysteresis = 4% (falling edge)	-15		-9	%
Power-Good Output Low Voltage		$I_{SINK} = 4mA$			0.3	V

**Note 1:** Low threshold n-channel MOSFET is required for 2.5V ( $\pm 2\%$ ) output.

**Note 2:** Specifications to  $-40^{\circ}C$  are guaranteed by design, not production tested.

## Typical Operating Characteristics

(Circuit of Figure 1,  $T_A = +25^{\circ}C$ , unless otherwise noted.)

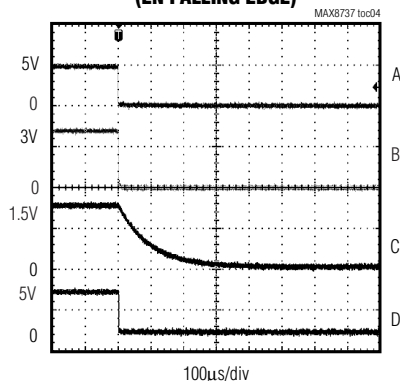


# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## Typical Operating Characteristics (continued)

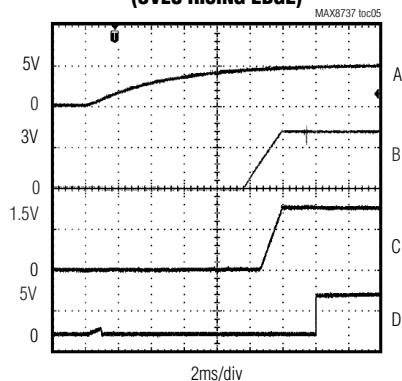
(Circuit of Figure 1,  $T_A = +25^\circ\text{C}$ , unless otherwise noted.)

**SOFT-STOP  
(EN FALLING EDGE)**



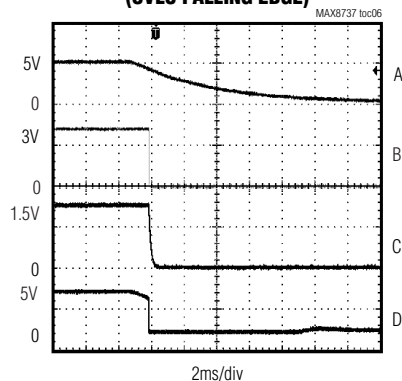
A. EN1, 5V/div  
B. DRV1, 2V/div  
C. LDO1 OUTPUT, 1V/div  
D. PGOOD1, 5V/div  
NO LOAD

**SOFT-START  
(UVLO RISING EDGE)**



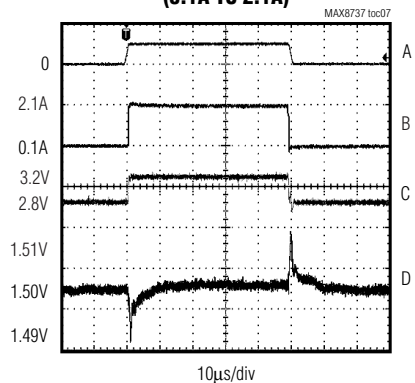
A. 5V BIAS ( $V_{CC}$ ), 5V/div  
B. DRV1, 2V/div  
C. LDO1 OUTPUT, 1V/div  
D. PGOOD1, 5V/div  
NO LOAD,  $EN = V_{CC}$

**SOFT-STOP  
(UVLO FALLING EDGE)**



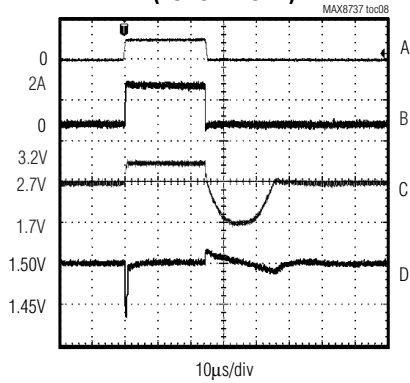
A. 5V BIAS ( $V_{CC}$ ), 5V/div  
B. DRV1, 2V/div  
C. LDO1 OUTPUT, 1V/div  
D. PGOOD1, 5V/div  
NO LOAD,  $EN = V_{CC}$

**LOAD TRANSIENT  
(0.1A TO 2.1A)**



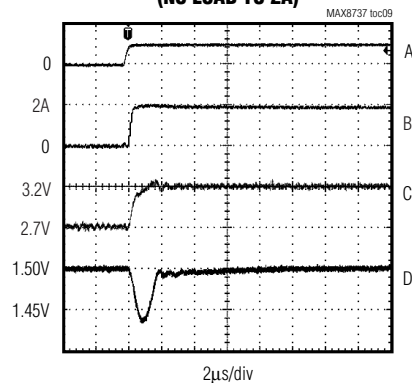
A. CONTROL SIGNAL  
B. LOAD CURRENT, 2A/div  
C. DRV1, 500mV/div  
D. LDO1 OUTPUT VOLTAGE, 10mV/div

**LOAD TRANSIENT  
(NO LOAD TO 2A)**



A. CONTROL SIGNAL  
B. LOAD CURRENT, 2A/div  
C. DRV1, 1V/div  
D. LDO1 OUTPUT VOLTAGE, 50mV/div

**LOAD TRANSIENT  
(NO LOAD TO 2A)**

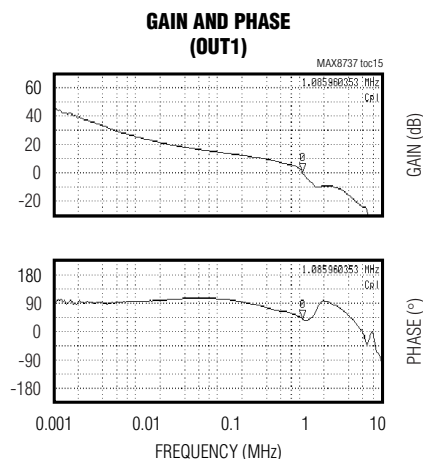
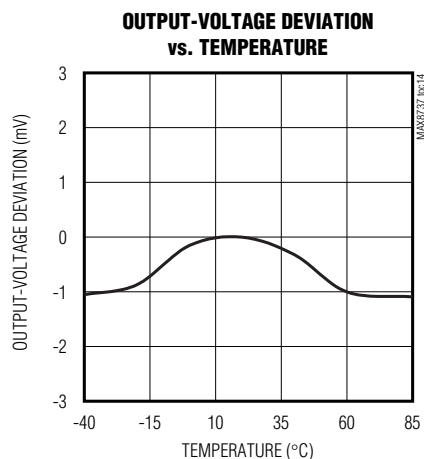
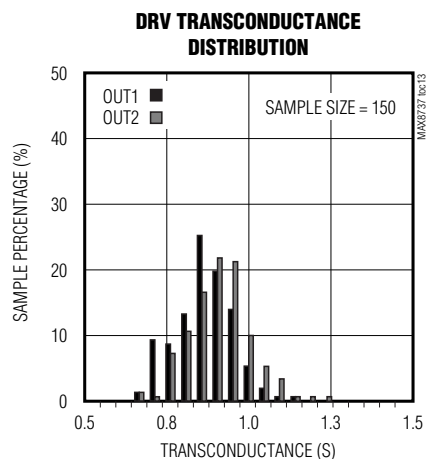
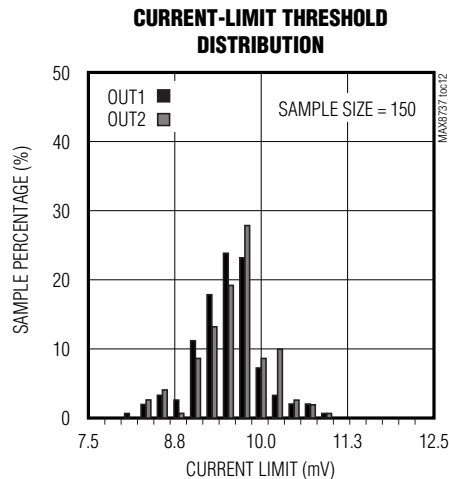
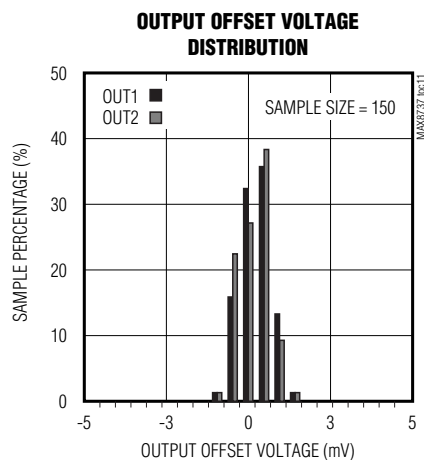
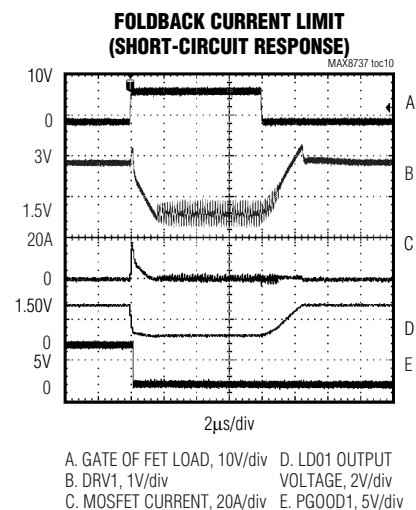


A. CONTROL SIGNAL  
B. LOAD CURRENT, 2A/div  
C. DRV1, 1V/div  
D. LDO1 OUTPUT VOLTAGE, 50mV/div

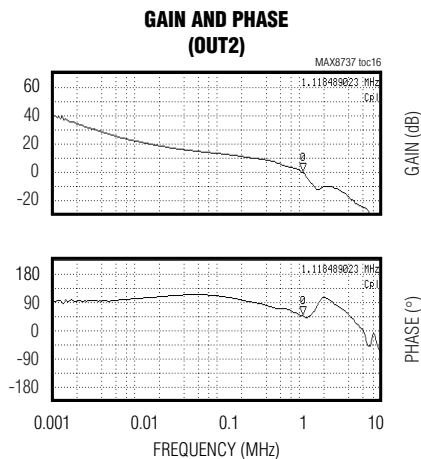
# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## Typical Operating Characteristics (continued)

(Circuit of Figure 1,  $T_A = +25^\circ\text{C}$ , unless otherwise noted.)



1.5V OUTPUT, 1A LOAD,  $C_{OUT} = (1) 10\mu\text{F}$  1206 16V CERAMIC



1.05V OUTPUT, 2A LOAD,  $C_{OUT} = (1) 22\mu\text{F}$  1206 6V CERAMIC

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

MAX8737

## Pin Description

PIN	NAME	FUNCTION
1	V <sub>CC</sub>	Analog and Driver Supply Input. Connect to the system supply voltage (+5.0V). Bypass V <sub>CC</sub> to analog ground with a 1μF or greater ceramic capacitor.
2	CS1	Positive Current-Sense Input for LDO1. To enable (foldback) current limit, connect CS1 to the positive terminal of the current-sense element as shown in Figure 1. The MAX8737 driver reduces the gate voltage when the 10mV (typ) current-limit threshold is exceeded. When CS1 is connected to V <sub>CC</sub> , the MAX8737 disables the current-limit protection and enables the output undervoltage protection (see the <i>UVP Short-Circuit Protection</i> section).
3	OUT1	Output Feedback-Sense, Negative Current-Sense, and Discharge Input for LDO1. Connect directly to the linear regulator output. When LDO1 is disabled, OUT1 is discharged through an internal 10Ω FET to GND.
4	REFIN1	External Reference Input for LDO1. REFIN1 sets the main output regulation voltage (V <sub>OUT1</sub> = V <sub>REFIN1</sub> ).
5	PGOOD2	Open-Drain Power-Good Output for LDO2. PGOOD2 is low when the output voltage is more than 12% (typ) below the normal regulation point, during soft-start, and in shutdown. Approximately 2ms (typ) after OUT2 reaches the regulation voltage (REFIN2), PGOOD2 becomes high impedance as long as the output remains in regulation.
6	PGOOD1	Open-Drain Power-Good Output for LDO1. PGOOD1 is low when the output voltage is more than 12% (typ) below the normal regulation point, during soft-start, and in shutdown. Approximately 2ms (typ) after OUT1 reaches the regulation voltage (REFIN1), PGOOD1 becomes high impedance as long as the output remains in regulation.
7	EN2	Enable Input for LDO2. Connect EN2 to V <sub>CC</sub> for always ON. When EN2 is pulled low, the linear regulator shuts down and pulls the output to ground.
8	EN1	Enable Input for LDO1. Connect EN1 to V <sub>CC</sub> for always ON. When EN1 is pulled low, the linear regulator shuts down and pulls the output to ground.
9	REFIN2	External Reference Input for the Secondary Regulator (LDO2). REFIN2 sets the main output regulation voltage (V <sub>OUT2</sub> = V <sub>REFIN2</sub> ).
10	OUT2	Output Sense, Negative Current-Sense Input, and Discharge Input for the Secondary Regulator (LDO2). Connect directly to the linear regulator output. When the LDO2 is disabled, OUT2 is discharged through an internal 10Ω FET to GND.
11	CS2	Positive Current-Sense Input for LDO2. To enable (foldback) current limit, connect CS2 to the positive terminal of the current-sense element as shown in Figure 1. The MAX8737 driver reduces the gate voltage when the 10mV (typ) current-limit threshold is exceeded. When CS2 is connected to V <sub>CC</sub> , the MAX8737 disables the current-limit protection and enables the output undervoltage protection (see the <i>UVP Short-Circuit Protection</i> section).
12, 14	N.C.	Not Internally Connected
13	DRV2	External N-Channel Gate Drive for LDO2
15	GND	Ground. <b>Connect the thin QFN backside pad to GND.</b>
16	DRV1	External N-Channel Gate Drive for LDO1
—	EP	Exposed Pad. Connect the thin QFN backside pad to GND.

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## Detailed Description

The MAX8737 is a dual, low-dropout, external n-channel linear regulator controller for low-voltage notebook computer power supplies. The linear regulator provides a 0.5V to 2.5V ( $\pm 5\text{mV}$  no-load) output for powering the low-voltage supplies to desktop and notebook CPU chipsets (VCCP and VCC\_MCH). The regulator operates from low input voltage, which also reduces the power dissipation in the external n-channel MOSFET. The controller powers the external MOSFET gate driver from the standard 5V system supply.

The controller features independent enable inputs (EN<sub>1</sub>), PGOOD outputs (PGOOD<sub>1</sub>), input undervoltage lockout (UVLO), and output undervoltage protection (UVP). The controller uses an adjustable reference input (REFIN<sub>1</sub>) to set the nominal output voltage (VOUT<sub>1</sub>), which minimizes the cost and makes the stability independent of the output voltage. An output UVP timing depends on the magnitude of the voltage at VOUT<sub>1</sub>. The UVP detects and shuts down the LDO if the output voltage drops below the nominal output voltage (VREFIN<sub>1</sub>). Each linear regulator features an adjustable soft-start function, and generates a delayed PGOOD signal that signals when the linear regulator is in regulation. The MAX8737 uses an external resistor-divider in series with the current-sense input (CS<sub>1</sub>), providing foldback current-limit protection, and effectively reducing the short-circuit power dissipation. The MAX8737 is available in a thin QFN package to reduce the thermal impedance, and improve the thermal coupling between the controller and the external MOSFETs.

### REFIN Input

The low-cost linear regulator uses an adjustable reference input (REFIN<sub>1</sub>) to set the nominal output voltage, which minimizes cost and simplifies the stability—the stability calculation is independent of VOUT<sub>1</sub>. The output voltage accuracy depends on the accuracy of the source generating the REFIN voltage. Multiple accurate references are typically available elsewhere in the system (such as the switching regulator providing the low-voltage input supply). If lower output accuracy is acceptable, divide down and filter another regulated output voltage supply.

To set output voltage, select R2 = 100k $\Omega$  and select R1 using the following formula:

$$R1 = \left( \frac{V_{REF}}{V_{REFIN\_}} - 1 \right) R2$$

## Soft-Start

When the LDO is activated, the respective DRV<sub>1</sub> is pulled up from GND with a typical soft-start current of 170 $\mu\text{A}$ . The soft-start current limits the output voltage slew rate and also limits the initial current spike through the external n-channel MOSFET. The slew rate is also limited by the compensation capacitance used at the DRV<sub>1</sub> pin.

The maximum drain current during startup is the ratio of COUT to CCOMP, multiplied by the soft-start current ISOFT of 170 $\mu\text{A}$  (typ).

## Enable and Power Good

The MAX8737 has independent enable control inputs (EN1, EN2). Drive EN1 high to enable output 1. Drive EN2 high to enable output 2. When EN<sub>1</sub> is driven low, the corresponding DRV<sub>1</sub> and PGOOD<sub>1</sub> pins are pulled to GND, and the output is discharged through a 10 $\Omega$  switch.

There are two independent PGOOD<sub>1</sub> outputs indicating the supply status. PGOOD<sub>1</sub> is pulled high 2ms after the controller is enabled (EN<sub>1</sub> is pulled high and VCC exceeds its UVLO threshold), and the output is in regulation. If either output is out of regulation, the respective PGOOD<sub>1</sub> goes low immediately. The MAX8737 pulls PGOOD<sub>1</sub> low if the output voltage drops below the lower trip threshold of -12% (typ) or when VCC is in UVLO or when EN<sub>1</sub> is pulled low.

## Soft-Stop

The MAX8737 enables a soft-stop function that discharges the output through an internal 10 $\Omega$  switch when EN<sub>1</sub> is driven low or VCC is in UVLO. The discharge time of the output depends on the output capacitance, output load, and the exact resistance of the internal discharge switch. To slow down the discharge rate, add resistance in series with the OUT<sub>1</sub> pin.

## 5.0V Bias Supply (Vcc)

The linear regulator operates with very low input voltages. VIN may be as low as 1.2V, so a secondary 5V supply is required to provide sufficient bias to the gate drivers. Locally decouple the VCC input with 1 $\mu\text{F}$  or greater of ceramic capacitance.

## Current Limit

The MAX8737 features a current limit that monitors the voltage across the current-sense resistor, which limits VCS<sub>1</sub> - VOUT<sub>1</sub> to 10mV (typ). However, in case of a short-circuit condition, the power dissipation across the external FET will be extremely high. To protect the external FET, the MAX8737 uses an external resistive divider (see Figure 1) to fold back the current limit, reducing the overall power dissipation. The foldback



# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

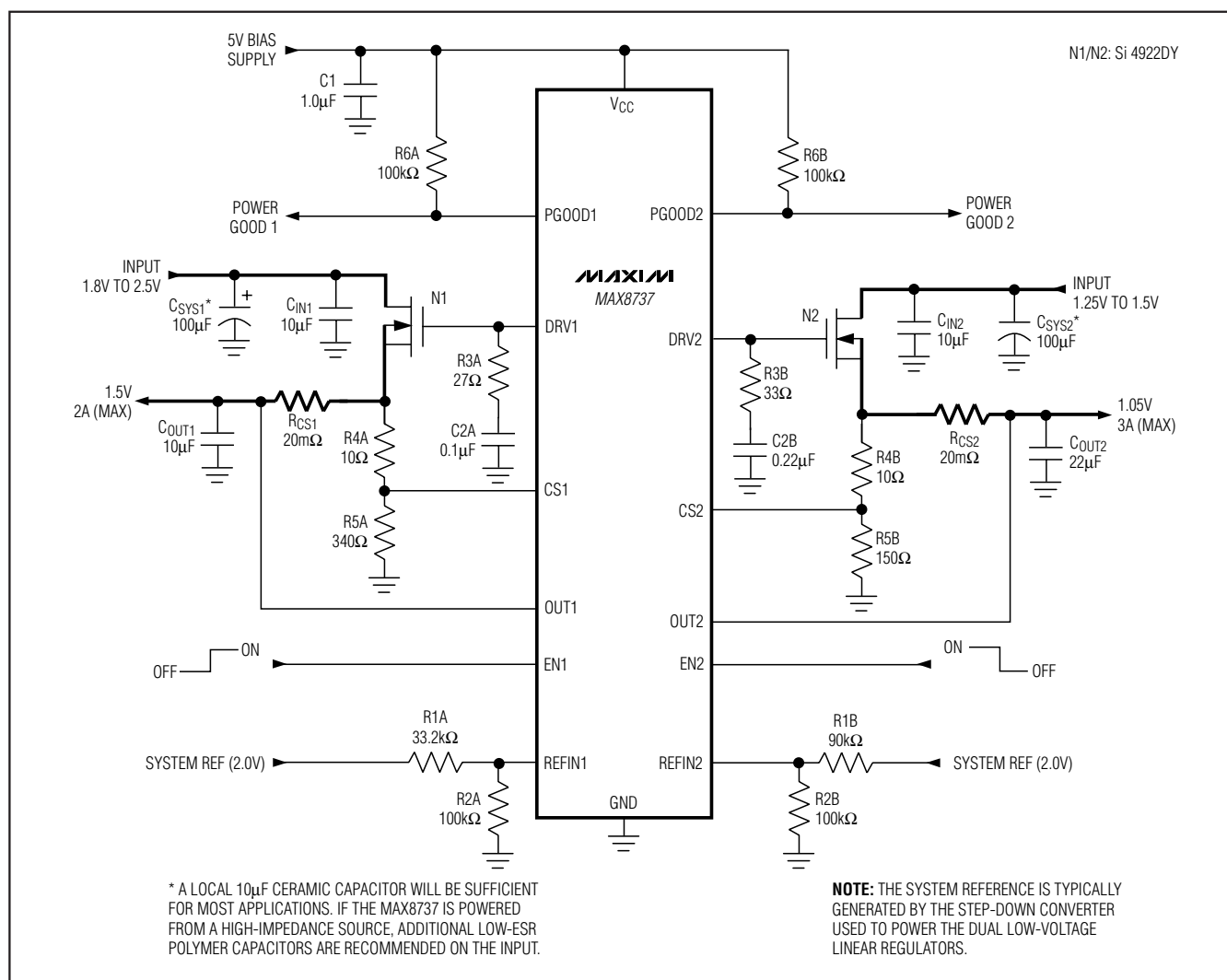


Figure 1. Typical Operating Circuit with Current Limit

resistor network is calculated using the short-circuit current ( $I_{SHORT}$ ), the maximum load current ( $I_{MAX}$ ), current-sense resistor ( $R_{CS}$ ), the 10mV ( $\pm 3$ mV) current-limit threshold ( $V_{ILIM}$ ), and the external reference input ( $REFIN_{_}$ ). See Figure 3:

- 1) Pick the  $R_{CS}$  requirement for maximum short-circuit current:

$$R_{CS} = V_{ILIM} / I_{SHORT}$$

- 2) Select  $R_1 = 10\Omega$  and select  $R_2$  using the following formula:

$$R_2 = \frac{(V_{REFIN} + V_{ILIM})R_1}{I_{MAX}R_{CS} - V_{ILIM}}$$

## UVP Short-Circuit Protection

There are two levels of short-circuit UVP available in the controller. When the current-limit protection is not used ( $CS_{_} = V_{CC}$ ), the output undervoltage timeout protection is enabled, which protects the regulator against short circuits. Output UVP timing depends on the magnitude of the output voltage drop. To clear the UVP fault latch, toggle the respective  $EN_{_}$  input, or cycle  $V_{CC}$  below its  $UVLO$  threshold.

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

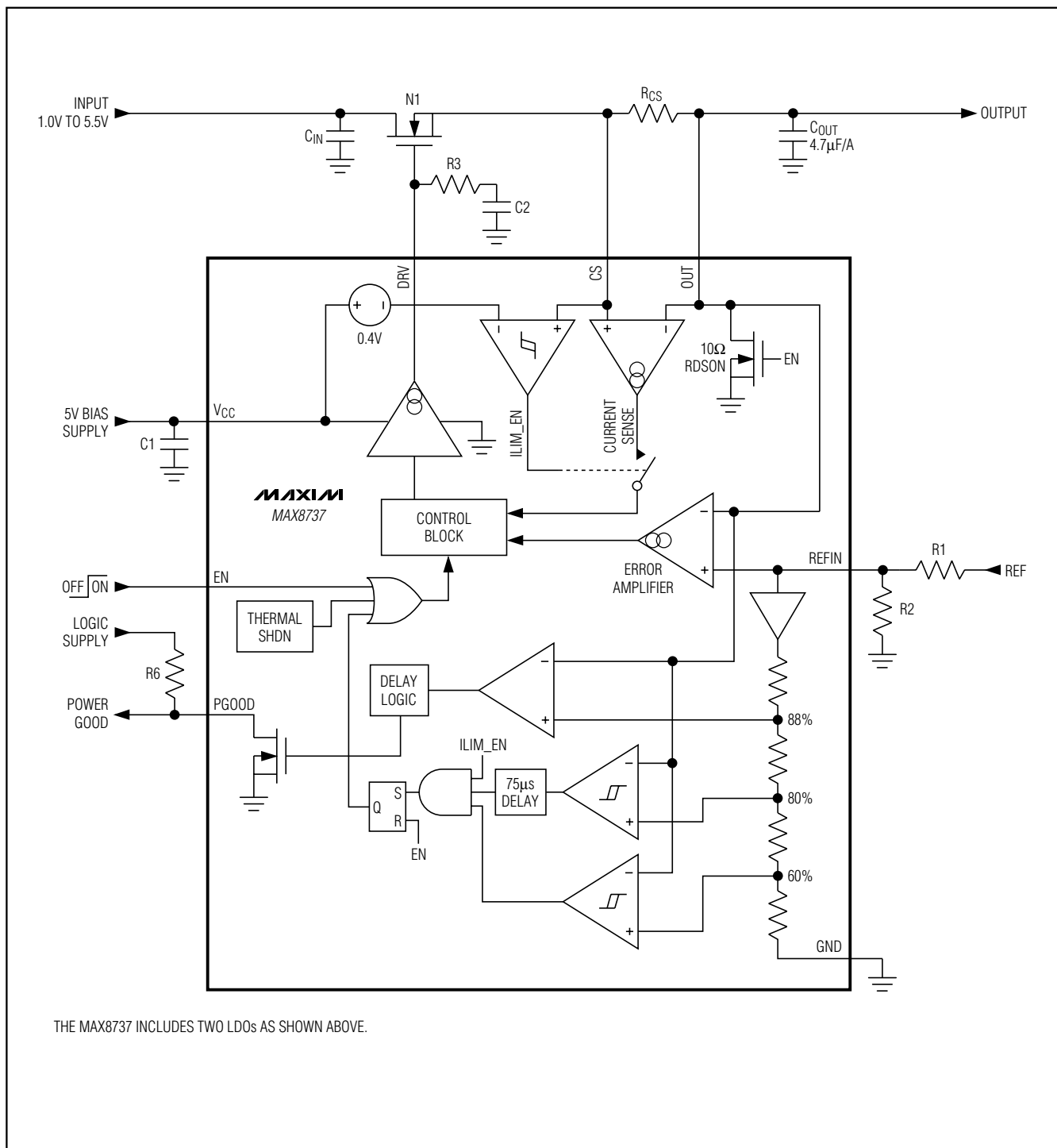


Figure 2. Functional Diagram

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

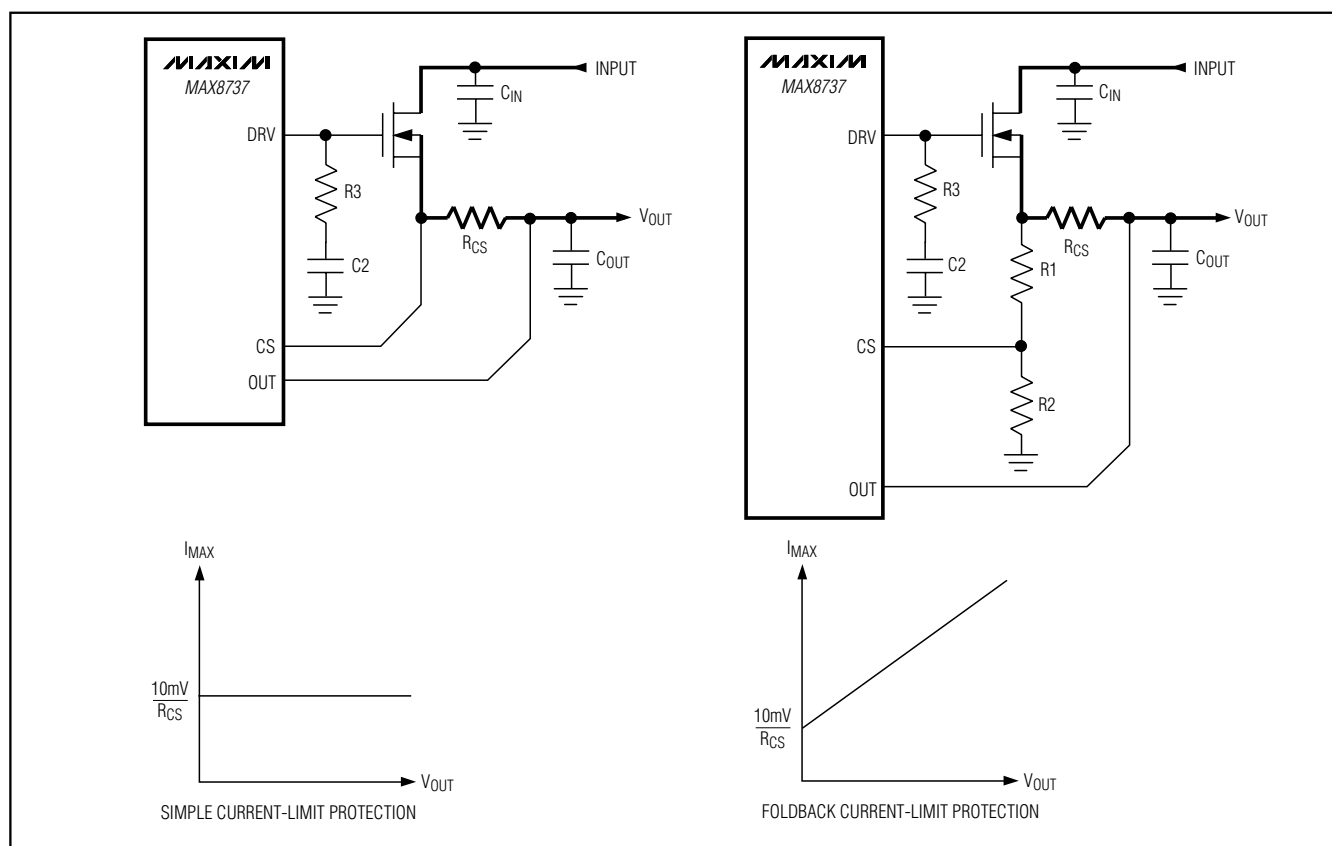


Figure 3. Current-Limit Protection

## Slow UVP

If the output drops below 80% of the nominal output voltage ( $V_{REFIN}$ ) for 75 $\mu$ s, the MAX8737 shuts down the LDO and pulls the DRV\_ pin to ground. If the output voltage returns above 80% of the nominal output voltage ( $V_{REFIN}$ ) within the 75 $\mu$ s, the controller ignores the load transient.

## Fast UVP

If the output voltage drops below 60% of the nominal output voltage ( $V_{REFIN}$ ) for approximately 5 $\mu$ s, the MAX8737 immediately shuts down and pulls the DRV\_ pin to ground. If the output voltage returns above 80% of the nominal output voltage ( $V_{REFIN}$ ) within the 5 $\mu$ s, the controller ignores the load transient.

## Thermal Protection

The MAX8737 is available in a thin QFN package to reduce the thermal impedance, and improve the thermal coupling between the controller and the external MOSFETs. When the controller's junction temperature exceeds  $T_J = +125^\circ\text{C}$  (max), a thermal sensor turns off

the external pass transistor, allowing the system to cool. The thermal sensor turns the pass transistor back on once the controller's junction temperature drops by approximately 20 $^\circ\text{C}$ .

## Design Procedure

### Input Capacitor Selection ( $C_{IN}$ )

Typically, the MAX8737 is powered from the output of a step-down regulator, effectively providing a low-impedance source. A local 10 $\mu$ F ceramic capacitor at  $V_{IN}$  and a 1.0 $\mu$ F ceramic capacitor at  $V_{BIAS}$  should be sufficient for most applications. If the linear regulator is connected to a high-impedance input, low-ESR polymer capacitors are recommended on the input.

### Output Capacitor Selection ( $C_{OUT}$ )

To maintain stability and provide good transient response, the MAX8737 requires 4.7 $\mu$ F/A (4.7 $\mu$ F minimum) of low ESR ceramic capacitor at the output. The regulator remains stable with capacitances higher than the minimum. When selecting the output capacitor to

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

provide good transient response, the capacitor's ESR should be minimized:

$$\Delta V_{OUT} = \Delta I_{OUT} \times ESR$$

where  $\Delta I_{OUT}$  is the maximum peak-to-peak load current step, and  $\Delta V_{OUT}$  is the transient output-voltage tolerance.

## Regulator Compensation

The compensation network ( $R3$ ,  $C2$ ) is customizable and depends on load and MOSFET characteristics:

- Use of ceramic output capacitors with low  $R_{ESR}$  to ensure stability and minimize ESR voltage drop at load step
- Strength of the external n-channel MOSFET ( $g_M$ ), its forward transconductance ( $g_{FS}$ ), and the gate-to-source capacitance ( $C_{GS}$ )
- The driver transconductance ( $G_{MDRV}$ ) of the integrated circuit driver
- Load current range (including the minimum load):  $I_{MIN}$  to  $I_{MAX}$

## Recommended Procedure

Use the  $C_{GS}$ ,  $g_{FS}$ ,  $I_D$  from the chosen transistor data sheet and use the equation below to translate the measured  $g_{FS}$  to  $g_M$  for normal operation:

- 1) Determine the LDO transconductance using the MOSFET's forward transconductance ( $g_{FS}$ ), and the drain current ( $I_D$ ) used to test the selected MOSFET:

$$g_M = g_{FS} \sqrt{\frac{I_{MAX}}{I_D}}$$

- 2) Calculate the compensation resistor based on the output capacitor ( $C_{OUT}$ ), the MOSFET's gate-to-source capacitance ( $C_{GS} = C_{ISS} - C_{RSS}$ ), and the minimum driver transconductance:

$$R3 = \sqrt{\frac{C_{OUT}}{C_{GS} g_M \times 0.5S}}$$

- 3) Calculate the compensation capacitance using the minimum load current ( $I_{MIN}$ ) and compensation resistor value calculated above:

$$C2 = \frac{2V_T C_{OUT}}{I_{MIN} G_{MDRV} (R3)^2}$$

where  $V_T = 25mV$ .

**Example:** The example below is used to demonstrate the stability calculation for the application circuit in Figure 1.

- 1) Choose  $V_{OUT} = 1.05V$  and  $I_{MAX} = 3A$  and the minimum load can be determined from the foldback current-limit resistance:

$$I_{MIN} = \frac{V_{OUT}}{R1 + R2} \approx 6mA$$

- 2) For the selected MOSFET (Si4922DY),  $C_{GS} = 2000pF$  at  $1.5V$ , and  $g_{FS} = 30S$  at  $I_D = 8.8A$ :

$$g_M = 30S \sqrt{\frac{3A}{8.8A}} = 17.5S$$

- 3) The output capacitor must be at least  $4.7\mu F/A$ . Therefore the design must use a minimum  $14.1\mu F$  capacitor. The closest standard capacitor value is  $22\mu F$ .
- 4) Based on the above operating conditions and component selection, the compensation resistor value should be:

$$R3 = \sqrt{\frac{22\mu F}{2nF \times 17.5S \times 0.5S}} = 35\Omega$$

- 5) Finally, select the compensation capacitor value:

$$C2 = \frac{2 \times 25mV \times 22\mu F}{6mA \times 1S \times (35\Omega)^2} = 0.15\mu F$$

## External MOSFET Selection

The MAX8737 uses an n-channel MOSFET as the series pass transistor instead of a p-channel MOSFET to reduce cost. The selected MOSFET must have a gate threshold voltage (at the required max load) that meets the following criteria:

$$V_{GS\_MAX} \leq V_{CC} - V_{OUT}$$

where  $V_{CC}$  is the controller bias voltage, and  $V_{GS\_MAX}$  is the maximum gate voltage required to yield the on-resistance ( $R_{DS\_ON}$ ) specified by the manufacturer's data sheet. Make sure that input-to-output voltage meets the condition below to avoid entering dropout, where output voltage starts to decrease and any ripple on the input also passes through to the output.  $R_{DS\_ON}$  has a positive temperature coefficient (approximately

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

0.5%/°C); therefore, the value of  $R_{DS(on)}$  at the highest operating junction temperature should be used:

$$V_{IN\_MIN} - V_{OUT\_MAX} \geq I_{MAX}(R_{DS(on)\_MAX} + R_{CS})$$

where  $V_{IN\_MIN}$  is the minimum input voltage at the drain of the MOSFET.

## MOSFET Power Dissipation

The maximum power dissipation of the MAX8737 depends on the thermal resistance of the external n-channel MOSFET package, the board layout, the temperature difference between the die and ambient air, and the rate of airflow. The power dissipated in the MOSFET is:

$$P_{DIS} = I_{OUT}(V_{IN} - V_{CSP})$$

The maximum allowable power dissipation is determined by the following formula:

$$R_{DIS(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JC} + \theta_{CA}}$$

where  $T_{J(MAX)}$  is the maximum junction temperature (+150°C),  $T_A$  is the ambient temperature,  $\theta_{JC}$  is the thermal resistance from the die junction to the package case, and  $\theta_{CA}$  is the thermal resistance from the case through the PC board, copper traces, and other materials to the surrounding air. Standard 8-pin SO MOSFETs are typically rated for 2W, while new power packages (PowerPAK™, DirectFET™, etc.) can achieve power dissipation ratings as high as 5W. For optimum power dissipation, use a large ground plane with good thermal contact to ground and use wide input and output traces. Extra copper on the PC board increases thermal mass and reduces the thermal resistance of the board. See Figure 4.

## PC Board Layout Guidelines

Due to the high-current paths and tight output accuracy required by most applications, careful PC board layout is required. An evaluation kit (MAX8737EVKIT) is available to speed design. **It is important to keep all traces as short as possible to minimize the high-current trace dimensions to reduce the effect of undesirable parasitic inductance.** The MOSFET dissipates a fair amount of heat due to the high currents involved, especially during large input-to-output voltage differences. To dissipate the heat generated by the MOSFET, make power traces very wide with a large amount of copper area. An efficient way to achieve good power dissipation on a surface-mount package is to lay out copper areas directly under the MOSFET package on multiple layers and connect the areas through vias. Use a ground plane to minimize impedance and inductance.

In addition to the usual high-power considerations, here are four tips to ensure high output accuracy:

- Ensure that the feedback connection to  $C_{OUT}$  is short and direct.
- Place the reference input resistors next to the  $REFIN_{-}$  pin.
- Place  $R_C$  and  $C_C$  next to the  $DRV_{-}$  pin.
- Ensure  $REFIN_{-}$  and  $DRV_{-}$  traces are away from noisy sources to ensure tight accuracy.

PowerPAK is a registered trademark of Vishay Siliconix.

DirectFET is a trademark of International Rectifier Corp.

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

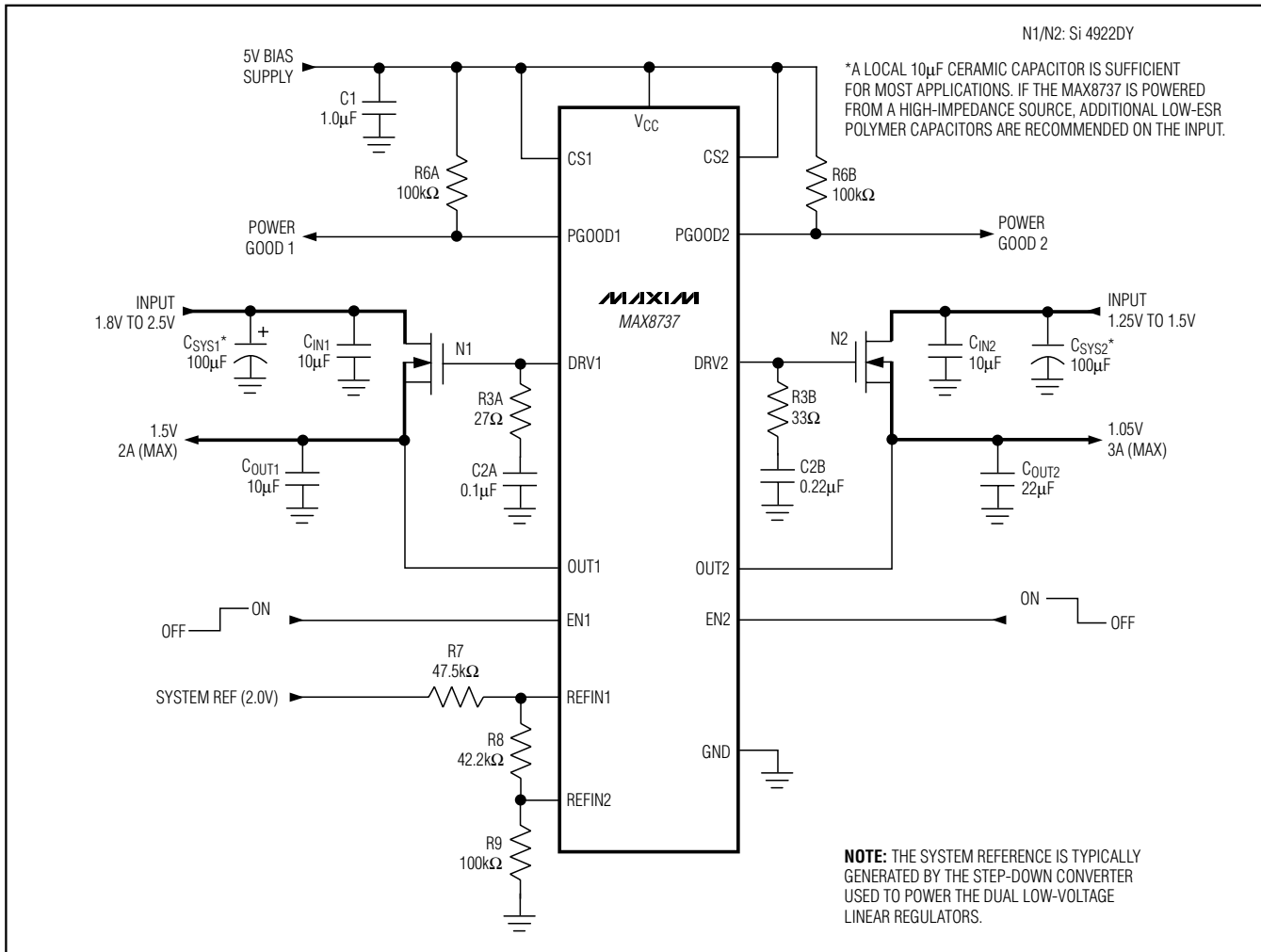


Figure 4. Typical Operating Circuit with Output Undervoltage Protection

## Chip Information

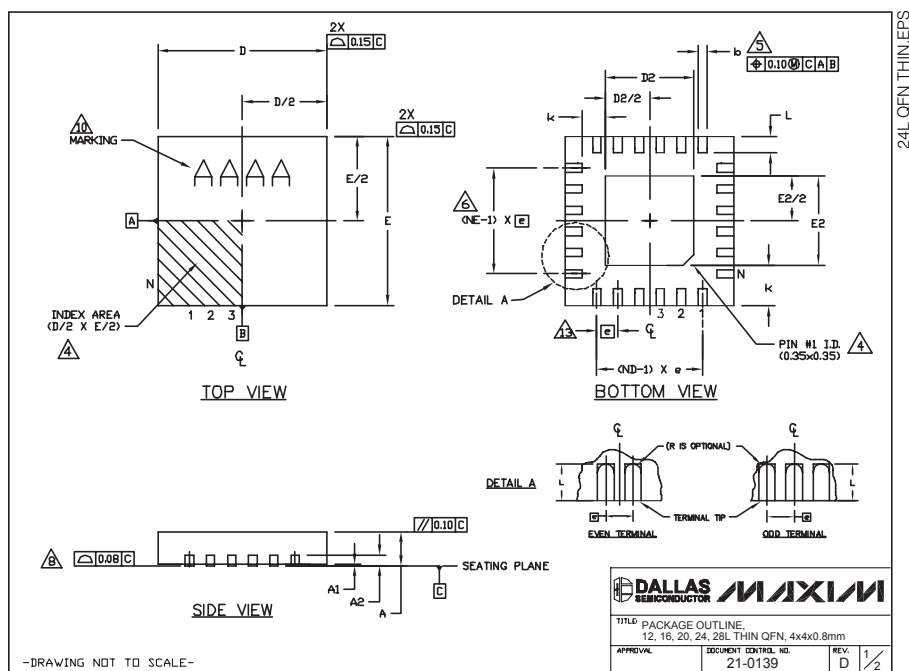
TRANSISTOR COUNT: 1562

PROCESS: BiCMOS

# Dual, Low-Voltage Linear Regulator Controllers with External MOSFETs

## Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to [www.maxim-ic.com/packages](http://www.maxim-ic.com/packages).)



COMMON DIMENSIONS												
PKG REF.	12L 4x4			16L 4x4			20L 4x4			24L 4x4		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.70	0.75	0.90	0.70	0.75	0.90	0.70	0.75	0.90	0.70	0.75	0.90
A1	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05
A2	0.20 REF			0.20 REF			0.20 REF			0.20 REF		
b	0.85	0.30	0.35	0.85	0.30	0.35	0.80	0.25	0.30	0.80	0.25	0.30
D	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
E	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
e	0.80 BSC.			0.65 BSC.			0.50 BSC.			0.50 BSC.		
k	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-
L	0.45	0.55	0.65	0.45	0.55	0.65	0.45	0.55	0.65	0.30	0.40	0.50
N	12			16			20			24		
ND	3			4			5			6		
NE	3			4			5			6		
WGGG VGG	VGG3			VGGC			WGGD-1			WGGD-2		

EXPOSED PAD VARIATIONS												
PKG CODES	D2			E2			DOWN BONDS ALLOWED					
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.						
T1244-2	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T1244-3	1.95	2.10	2.25	1.95	2.10	2.25	YES					
T1244-4	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T1644-2	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T1644-3	1.95	2.10	2.25	1.95	2.10	2.25	YES					
T1644-4	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T2044-1	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T2044-2	1.95	2.10	2.25	1.95	2.10	2.25	YES					
T2044-3	1.95	2.10	2.25	1.95	2.10	2.25	NO					
T2444-1	2.45	2.60	2.63	2.45	2.60	2.63	NO					
T2444-2	1.95	2.10	2.25	1.95	2.10	2.25	YES					
T2444-3	2.45	2.60	2.63	2.45	2.60	2.63	YES					
T2444-4	2.45	2.60	2.63	2.45	2.60	2.63	NO					
T2844-1	2.50	2.60	2.70	2.50	2.60	2.70	NO					

NOTES:

- DIMENSIONING & TOLERANCING CONFORM TO ASME Y14.5M-1994.
- ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
- N IS THE TOTAL NUMBER OF TERMINALS.
- THE TERMINAL #1 IDENTIFIER AND TERMINAL NUMBERING CONVENTION SHALL CONFORM TO JEDEC 95-1 SPP-012. DETAILS OF TERMINAL #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE TERMINAL #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE.
- DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TIP.
- ND AND NE REFER TO THE NUMBER OF TERMINALS ON EACH D AND E SIDE RESPECTIVELY.
- DEPOPULATION IS POSSIBLE IN A SYMMETRICAL FASHION.
- COPLANARITY APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
- DRAWING CONFORMS TO JEDEC MO220, EXCEPT FOR T2444-1, T2444-3, T2444-4 AND T2844-1.
- MARKING IS FOR PACKAGE ORIENTATION REFERENCE ONLY.
- COPLANARITY SHALL NOT EXCEED 0.08mm
- WARPAGE SHALL NOT EXCEED 0.10mm
- LEAD CENTERLINES TO BE AT TRUE POSITION AS DEFINED BY BASIC DIMENSION "e", ±0.05.

MAXIM SEMICONDUCTOR

TITLE: PACKAGE OUTLINE  
12, 16, 20, 24, 28L THIN QFN, 4x4x0.8mm

APPROVAL: 21-0139

REV: D 2/2

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