



External Four-Input Feedback Integrator for Power Supplies

MAX1804

General Description

The MAX1804 feedback integrator is designed to improve voltage regulation in power-supply systems. The device corrects line- and load-regulation problems, and can be used to compensate for voltage drops in power-management distribution lines.

The regulation set point is determined by an external reference voltage applied at the ADJ pin. The difference between that reference and MAX1804 feedback is integrated, and a correction current is applied to the voltage regulator's feedback.

The MAX1804's four inputs allow voltage monitoring in several local and remote locations to correct for distribution losses caused by long traces, connectors, and switches. This eliminates the wasteful practice of permanently adjusting the regulator's output voltage high enough to correct for worst-case voltage drops. This is especially helpful in systems where the load current varies widely and portions of the load are often shut down or disconnected (for example, in notebook computers).

If a load switch is opened and the output voltage sensed at one input falls, the MAX1804 automatically disables that input and adjusts the regulator's output voltage to the lowest of remaining active inputs. If all inputs are disabled, the OUT pin is in a high-impedance state and makes no output voltage correction.

When $\overline{\text{SHDN}}$ is low, the MAX1804 draws less than 1 μA and its inputs and output are high impedance. The MAX1804 is available in a 10-pin μMAX package, about half the size of an 8-pin SOIC.

Features

- ◆ High Precision ($\pm 1\%$ max Error)
- ◆ Low Power (25 μA Supply Current)
- ◆ Automatic Input Disable
- ◆ Shutdown (1 μA max Supply Current)
- ◆ Inputs and Outputs High Impedance in Shutdown or When $V_+ = 0$
- ◆ +2.7V to +5.5V Supply Range
- ◆ 2.8V to 5.5V Regulation Adjust Range
- ◆ Parallelable for More than Four Inputs
- ◆ 10-Pin μMAX Package

Ordering Information

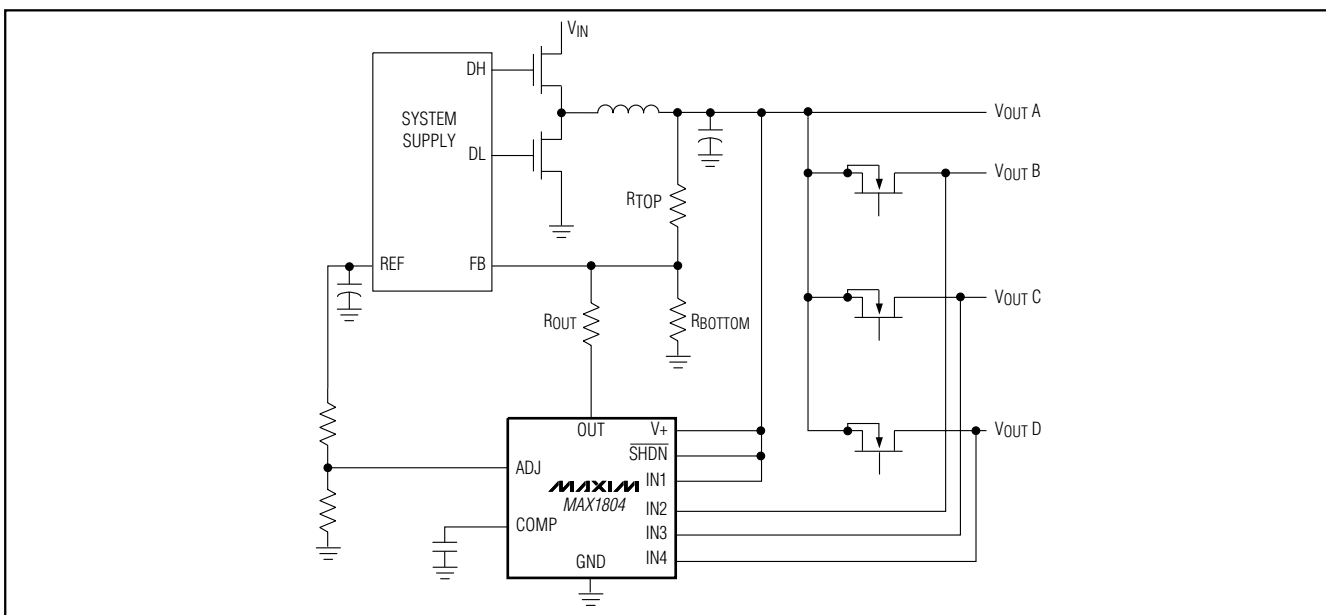
PART	TEMP. RANGE	PIN-PACKAGE
MAX1804EUB	-40°C to +85°C	10 μMAX

Pin Configuration appears at end of data sheet.

Applications

Remote Feedback Regulators
 High-Accuracy Regulators
 Desktop/Notebook Computers
 Servers and Workstations
 Subnotebooks and PDAs

Typical Operating Circuit



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ABSOLUTE MAXIMUM RATINGS

V+, IN1, IN2, IN3, IN4, OUT, ADJ, $\overline{\text{SHDN}}$ to GND.....-0.3V, +6V
 COMP to GND-0.3V, V+ +0.3V
 Continuous Power Dissipation (T_A = +70°C)
 10-Pin μ MAX (derate 8.3mW/°C above +70°C)667mW

Operating Temperature Extended Range-40°C to +85°C
 Junction Temperature+150°C
 Storage Temperature Range-65°C to +165°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

(T_A = 0°C to +85°C, V_{V+} = 3.3V, V_{ADJ} = 1.2V, V_{OUT} = 2V, C_{V+} = 0.1 μ F, C_{COMP} = 470pF. Typical values are at T_A = +25°C, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage Range (V+)		2.7		5.5	V
Shutdown Supply Current (V+)	$\overline{\text{SHDN}} = \text{GND}$		0.01	1	μ A
Quiescent Supply Current (V+)	$\overline{\text{SHDN}} = \text{V+}$		25	35	μ A
UVLO Threshold, Rising			2.5	2.6	V
UVLO Threshold, Falling		2.3	2.4		V
INTEGRATOR INPUTS IN1–IN4					
IN_ Voltage Range		0		5.5	V
IN_ Offset	V _{V+} = 2.7V to 5.5V	-15		15	mV
IN_ Scale Factor	V _{ADJ} = 0.7V to 1.4V	3.988	4.000	4.016	V/V
IN_ Transconductance	V _{IN_} = 4.75V to 4.85V, V _{COMP} = 1.3V	12	30	48	μ S
IN_ Bias Current	V _{IN_} = 4.8V		1.5	2.7	μ A
IN_ Shutdown Current	$\overline{\text{SHDN}} = \text{GND}$			0.2	μ A
IN_ Leakage Current	V _{V+} = 0, V $\overline{\text{SHDN}}$ = 0			0.2	μ A
IN_ Disable Threshold	V _{ADJ} = 0.7V to 1.4V, V _{ADJ} x 4, falling edge	87	90	93	%
IN_ Disable Threshold Hysteresis	V _{ADJ} = 0.7V to 1.4V, rising edge		50		mV
ADJ INPUT					
ADJ Voltage Range		0.7		1.4	V
ADJ Bias Current		-20		20	nA
ADJ Shutdown Current	$\overline{\text{SHDN}} = \text{GND}$			0.2	μ A
ADJ Leakage Current	V _{V+} = 0, V $\overline{\text{SHDN}}$ = 0			0.2	μ A
COMP OUTPUT					
COMP Source Current	V _{COMP} = 1.3V, V _{IN_} = 4.6V	1.6	2.0	2.4	μ A
COMP Sink Current	V _{COMP} = 1.3V, V _{IN_} = 5.0V	1.6	2.0	2.4	μ A
COMP Output Voltage Low	Sink 1 μ A, V _{IN_} = 5.0V			0.2	V
COMP Output Voltage High	Source 1 μ A, V _{IN_} = 4.6V	2.4			V
OUT OUTPUT					
OUT Output Voltage Low	I _{OUT} = 10 μ A, V _{IN_} = 4.6V			0.2	V
OUT Output Leakage Current	V $\overline{\text{SHDN}}$ = 0			0.1	μ A
	V _{V+} = 0			0.1	
	V _{IN_} = 5.0V			0.1	
OUT Transconductance	V _{COMP} = 1V to 2V	4	10	22	μ S

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ELECTRICAL CHARACTERISTICS (continued)

($T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$, $V_{V+} = 3.3\text{V}$, $V_{ADJ} = 1.2\text{V}$, $V_{OUT} = 2\text{V}$, $C_{V+} = 0.1\mu\text{F}$, $C_{COMP} = 470\text{pF}$. Typical values are at $T_A = 25^\circ\text{C}$, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
SHDN INPUT					
Logic Input Voltage High	$V_{V+} = 2.7\text{V}$ to 5.5V	2.0			V
Logic Input Voltage Low	$V_{V+} = 2.7\text{V}$ to 5.5V			0.6	V
Logic Input Current		-1		1	μA

ELECTRICAL CHARACTERISTICS

($T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$, $V_{V+} = 3.3\text{V}$, $V_{ADJ} = 1.2\text{V}$, $V_{OUT} = 2\text{V}$, $C_{V+} = 0.1\mu\text{F}$, $C_{COMP} = 470\text{pF}$.) (Note 1)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage Range (V+)		2.7		5.5	V
Shutdown Supply Current (V+)	$\overline{\text{SHDN}} = \text{GND}$			1	μA
Quiescent Supply Current (V+)	$\overline{\text{SHDN}} = \text{V+}$			35	μA
UVLO Threshold, Rising				2.6	V
UVLO Threshold, Falling		2.3			V
INTEGRATOR INPUTS IN1–IN4					
IN_ Voltage Range		0		5.5	V
IN_ Offset	$V_{V+} = 2.7\text{V}$ to 5.5V	-20		20	mV
IN_ Scale Factor	$V_{ADJ} = 0.7\text{V}$ to 1.4V	3.98		4.02	V/V
IN_ Transconductance	$V_{IN_} = 4.75\text{V}$ to 4.85V , $V_{COMP} = 1.3\text{V}$	12		60	μS
IN_ Bias Current	$V_{IN_} = 4.8\text{V}$			2.7	μA
IN_ Shutdown Current	$\overline{\text{SHDN}} = \text{GND}$			0.2	μA
IN_ Leakage Current	$V_{V+} = 0$, $V_{\overline{\text{SHDN}}} = 0$			0.2	μA
IN_ Disable Threshold	$V_{ADJ} = 0.7\text{V}$ to 1.4V , $V_{ADJ} \times 4$, falling edge	87		93	%
ADJ INPUT					
ADJ Voltage Range		0.7		1.4	V
ADJ Bias Current		-30		30	nA
ADJ Shutdown Current	$\overline{\text{SHDN}} = \text{GND}$			0.2	μA
ADJ Leakage Current	$V_{V+} = 0$, $V_{\overline{\text{SHDN}}} = 0$			0.2	μA
COMP OUTPUT					
COMP Source Current	$V_{COMP} = 1.3\text{V}$, $V_{IN_} = 4.6\text{V}$	1.6		2.4	μA
COMP Sink Current	$V_{COMP} = 1.3\text{V}$, $V_{IN_} = 5.0\text{V}$	1.6		2.4	μA
COMP Output Voltage Low	Sink $1\mu\text{A}$, $V_{IN_} = 5.0\text{V}$			0.2	V
COMP Output Voltage High	Source $1\mu\text{A}$, $V_{IN_} = 0.6\text{V}$	2.4			V
OUT Output Voltage Low	$I_{OUT} = 10\mu\text{A}$, $V_{IN_} = 4.6\text{V}$			0.2	V
OUT Output Leakage Current	$V_{\overline{\text{SHDN}}} = 0$			0.1	μA
	$V_{V+} = 0$			0.1	
	$V_{IN} = 5.0\text{V}$			0.1	
OUT Transconductance	$V_{COMP} = 1\text{V}$ to 2V	3		23	μS

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ELECTRICAL CHARACTERISTICS (continued)

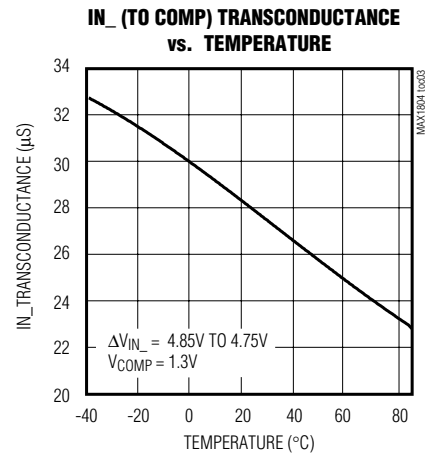
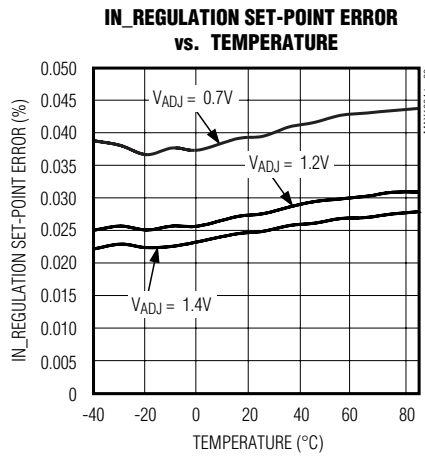
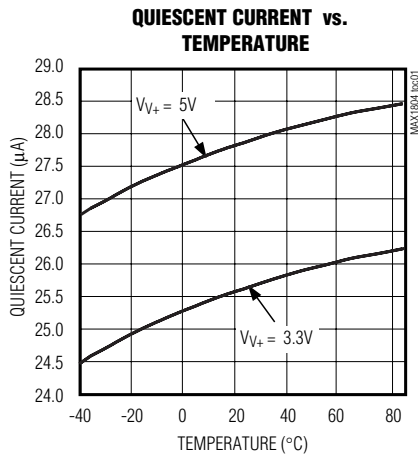
($T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$, $V_{V+} = 3.3\text{V}$, $V_{ADJ} = 1.2\text{V}$, $V_{OUT} = 2\text{V}$, $C_{V+} = 0.1\mu\text{F}$, $C_{COMP} = 470\text{pF}$.) (Note 1)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
SHDN INPUT					
Logic Input Voltage High	$V_{V+} = 2.7\text{V}$ to 5.5V	2.0			V
Logic Input Voltage Low	$V_{V+} = 2.7\text{V}$ to 5.5V			0.6	V
Logic Input Current		-1		1	μA

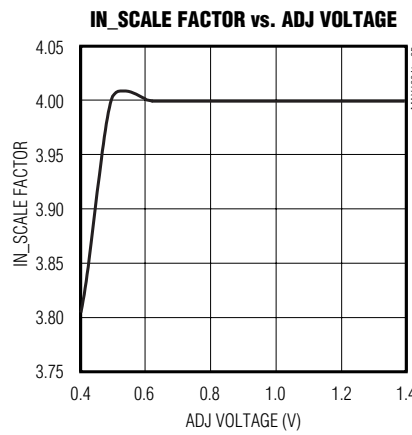
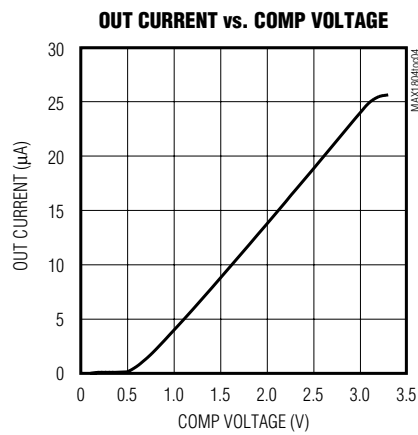
Note 1: Specifications to -40°C are guaranteed by design and not production tested.

Typical Operating Characteristics

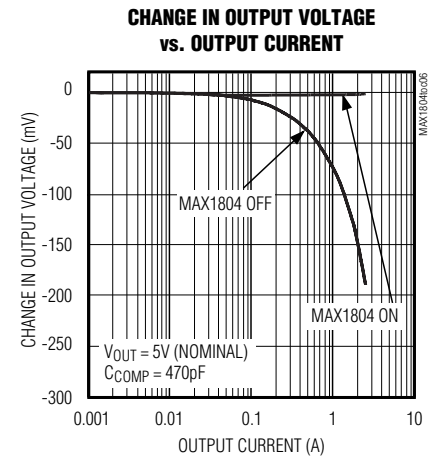
($V_{V+} = V_{SHDN} = 3.3\text{V}$, $V_{ADJ} = 1.2\text{V}$, $V_{OUT} = 2\text{V}$, $C_{COMP} = 470\text{pF}$, $T_A = +25^{\circ}\text{C}$, unless otherwise noted.)



NOTE: Circuit of Figure 1.



NOTE: Circuit of Figure 1.



NOTE: Application Circuit of Figure 2.

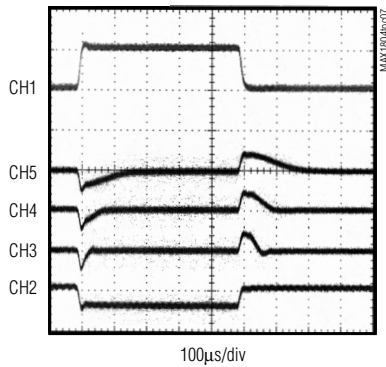
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Typical Operating Characteristics (continued)

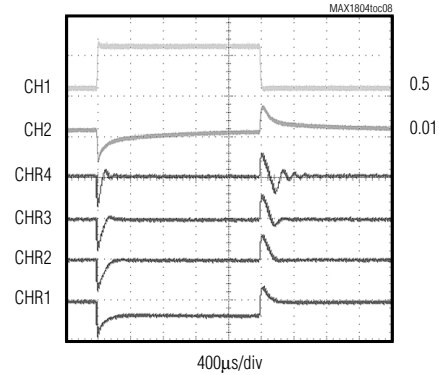
($V_{V+} = V_{SHDN} = 3.3V$, $V_{ADJ} = 1.2V$, $V_{OUT} = 2V$, $C_{COMP} = 470pF$, $T_A = +25^\circ C$, unless otherwise noted.)

**LOAD TRANSIENT RESPONSE
(APPLICATION CIRCUIT OF FIGURE 2)**



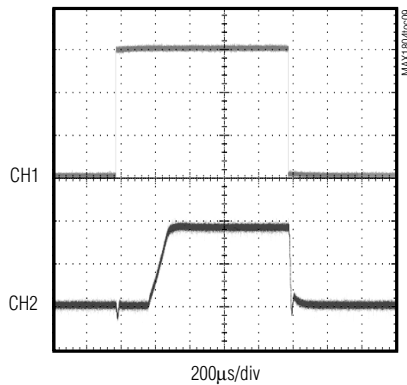
CH1 = I_{LOAD} ; 1.00A/div
 CH5 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 1000pF$)
 CH4 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 470pF$)
 CH3 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 220pF$)
 CH2 = V_{IN1} ; 500mV/div; AC-COUPLED (MAX1804 DISABLED)
 V_{IN} (MAX1653) = 8V

LOAD TRANSIENT RESPONSE



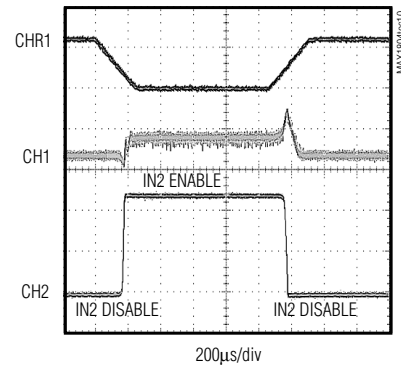
CH1 = I_{LOAD} ; 500mA/div
 CH2 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 0.047\mu F$)
 CHR4 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 1000pF$)
 CHR3 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 2200pF$)
 CHR2 = V_{IN1} ; 500mV/div; AC-COUPLED ($C_{COMP} = 4700pF$)
 CHR1 = V_{IN1} ; 500mV/div; AC-COUPLED (MAX1804 DISABLED)
 V_{IN} (MAX603) = 8V
NOTE: Circuit of Figure 3.

STARTUP/SHUTDOWN WAVEFORM



CH1 = \overline{SHDN} ; 2V/div
 CH2 = V_{IN2} ; 200mV/div; DC OFFSET = 4.7V
 $I_{LOAD} = 0.5A$
 V_{IN} (MAX1653) = 8V
NOTE: Circuit of Figure 2.

AUTOMATIC INPUT DISABLE WAVEFORM



CHR1 = $V_G(PFET)$; 5V/div
 CH1 = V_{IN1} ; 200mV/div; DC OFFSET = 4.8V
 CH2 = V_{IN2} ; 2V/div
 V_{IN} (MAX1653) = 8V
NOTE: Circuit of Figure 2.

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Pin Description

NAME	PIN	FUNCTION
IN1	1	Sense Input 1. Connect to one of up to four inputs to be monitored. If IN ₋ is the lowest active input, IN ₋ will be regulated at 4 x V _{ADJ} . If IN ₋ is less than 90% of the regulation set point (4 x V _{ADJ}), it is automatically disabled.
IN2	2	Sense Input 2
IN3	3	Sense Input 3
IN4	4	Sense Input 4
ADJ	5	Regulation Adjustment Input. The voltage at this input adjusts the regulation set point of IN1–IN4. There is a 4x scale factor between V _{ADJ} and the regulation set point.
GND	6	Ground
COMP	7	Integrator Capacitor Connection. Connect a capacitor (>100pF) to GND to set the integrator time constant. See <i>Integrator Gain-Bandwidth Product and Regulator Stability</i> section.
OUT	8	Open-Drain Output. Can sink at least 10μA if any of the inputs remain below the regulation set point. Connect OUT to the feedback point of the regulator-divider resistors. If OUT is connected through a resistor, its value relative to the regulator's feedback-divider values sets the maximum positive adjustment range. See <i>Setting the Maximum Regulator Output Adjustment Increase</i> section.
$\overline{\text{SHDN}}$	9	Shutdown Control Input. When $\overline{\text{SHDN}}$ is low, the device is off and the supply current is reduced to about 10nA. All inputs are in high-impedance state. When $\overline{\text{SHDN}}$ is high, the device is on.
V+	10	Power-Supply Input. Bypass with 0.1μF capacitor to GND.

Detailed Description

The MAX1804 is a precision external feedback integrator used for tight point-of-load regulation in power-management systems. The dynamic regulation of the output is still controlled by the power-supply regulator. The MAX1804 is used only to fine tune the output voltage, removing load- and line-regulation errors and voltage drops across switches and connectors that occur in the power-supply distribution line.

The MAX1804 includes four remote-sense inputs and an output that connects to a voltage regulator's feedback divider. It can be used with any regulator or controller with a high-impedance feedback input. Its OUT pin sinks current to increase the regulator's set point so that the four IN₋ inputs are at or above MAX1804's regulation set point, which is four times the voltage applied to the ADJ pin. The MAX1804 monitors the input signals and compares the lowest to the voltage set point. The error between the input signal and the set point is integrated. The MAX1804 output stage generates a current based on the integrator output to adjust the regulator's output voltage to meet the set point.

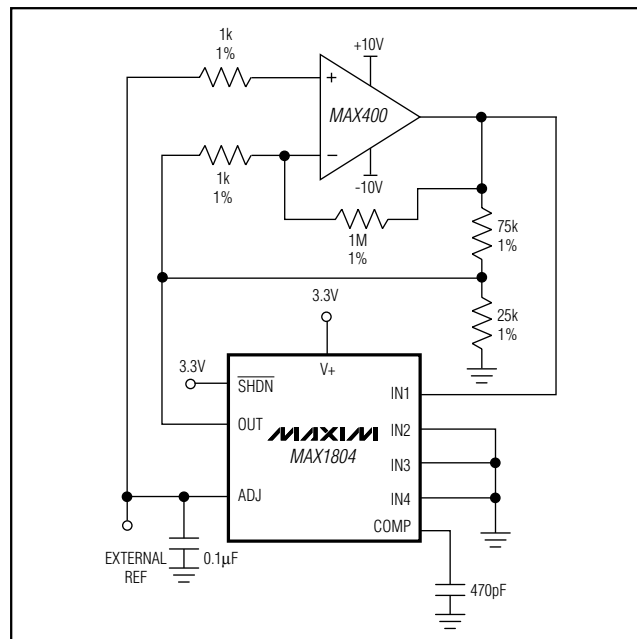


Figure 1. Test Circuit for MAX1804 IN₋ Regulation Set Point

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MAX1804

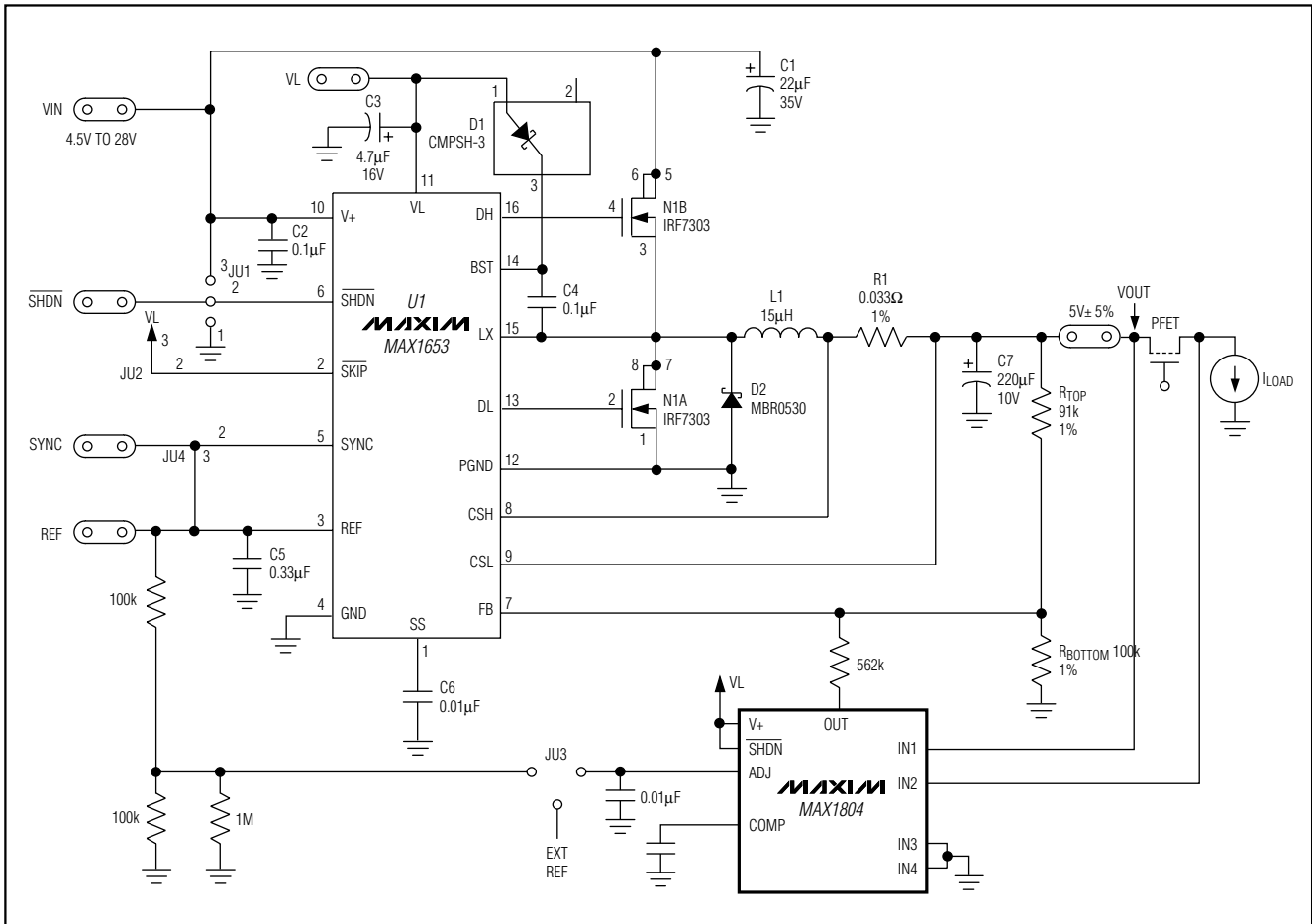


Figure 2. Application Circuit with Step-Down Regulator

The MAX1804 only sinks current at OUT (Figure 4). The maximum sink current and maximum regulator voltage increase are limited by the minimum guaranteed OUT current of 10µA. The maximum regulator output voltage increase can be further limited by including a resistor between OUT and the feedback point of the regulator.

If any of the IN_n inputs fall to 90% of the regulation set point, they are automatically disabled and OUT continues to regulate according to the lowest remaining active input. See *Automatic Input Disable*.

Adjusting the Regulation Set Point

The MAX1804 monitors the voltage at the IN₁–IN₄ sense inputs and regulates the lowest active input to four times the reference voltage at ADJ. The IN₁–IN₄ regulation set point is calculated as:

$$V_{IN_} = 4 \times V_{ADJ}$$

The total error in the MAX1804 regulation set point is:

$$\text{total percentage error} = [(IN_ \text{ scale factor} \times V_{ADJ} + IN_ \text{ offset}) / (4 \times V_{ADJ})] \times 100\%$$

The maximum IN_n voltage is 5.5V. Use the MAX1804 for higher output voltages by using an external divider to divide down the desired output voltage at the IN₁–IN₄ pins. Since the IN_n input bias current is fairly high (1.5µA typ), choose the resistive divider accordingly.

Automatic Input Disable

The MAX1804 has an input buffer stage that monitors the sense inputs (IN₁–IN₄) and connects the lowest to its internal integrator (Figure 4). Each input is compared to 90% of the set point. If the input falls below this value, the input buffer is disabled and the output voltage is adjusted according to the lowest of the remaining active inputs (see *Automatic Input Disable* in *Typical Operating Characteristics*). If all four sense

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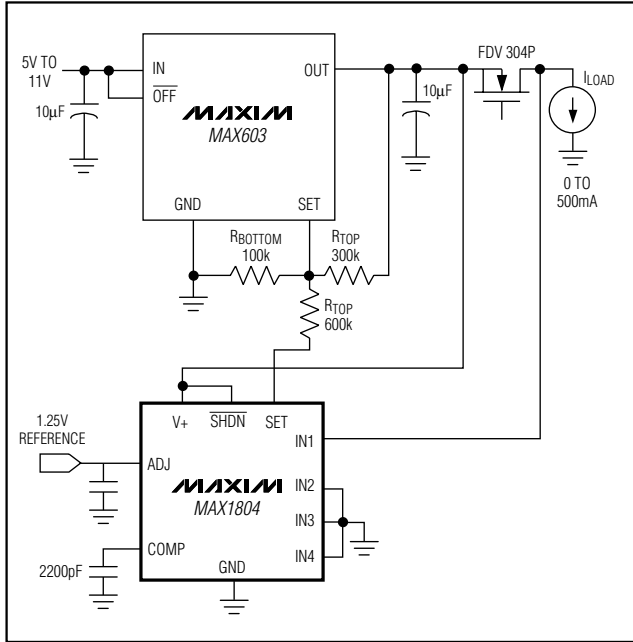


Figure 3. MAX1804 Used with Linear Regulator

inputs are disabled, OUT is high impedance. Connect any unused input to GND.

Setting the Maximum Regulator Output Voltage Increase

The ratio between the maximum guaranteed OUT current of 10µA and the current in the regulator's feedback resistive divider determines the maximum increase. The maximum increase in the regulator output voltage depends on the regulator's upper feedback resistor (R_{TOP}) and the sink current into OUT:

$$\Delta V_{OUT(MAX)} = I_{OUT(MAX)} \times R_{TOP}$$

The maximum adjust current $I_{OUT(MAX)}$ can be further limited with a resistor (R_{OUT}) between OUT and the feedback point of the regulator (see *Typical Operating Circuit*):

$$I_{OUT(MAX)} = V_{FB} / R_{OUT}$$

where V_{FB} is the voltage at the regulator's feedback point.

Therefore:

$$\Delta V_{OUT(MAX)} = V_{FB} \times R_{TOP} / R_{OUT}$$

and:

$$R_{OUT} = V_{FB} \times R_{TOP} / \Delta V_{OUT(MAX)}$$

Place the regulator's feedback resistors and R_{OUT} close to the regulator's feedback pin to reduce noise pickup at the regulator's feedback point, which can cause unstable switching in the regulator (Figure 5).

Shutdown Mode

\overline{SHDN} is a logic input that, when held low, places the MAX1804 in its low-power shutdown mode, reducing the supply current to 10nA (typ). The IN1–IN4, OUT, and ADJ are high impedance when the MAX1804 is in shutdown or when V_+ is removed. Connect \overline{SHDN} to V_+ for normal operation.

Undervoltage Lockout

The MAX1804 has an undervoltage lockout (UVLO) feature that deactivates the device when the supply voltage at V_+ goes below 2.4V; IN1–IN4, OUT, and ADJ go to high impedance and do not affect the regulator operation. Hysteresis holds the device in lockout until the supply voltage at V_+ rises above 2.6V.

Integrator Gain-Bandwidth Product and Regulator Stability

The MAX1804 gain-bandwidth (GBW) product is set by the external capacitor on COMP:

$$GBW = [4 \times (IN_transconductance)] / (2\pi \times C_{COMP})$$

The bandwidth is typically 40kHz with a 470pF capacitor on COMP.

For system stability, the integrator GBW product is typically set below the regulator circuit's crossover frequency, if known. Switching regulators typically have crossover frequencies well below their switching frequencies. Setting the MAX1804's GBW product too high can cause regulator loop instability, typically evidenced by ringing after transients. Setting the GBW product unnecessarily low will slow the MAX1804's loop response to transients, although the regulator's loop transient response will remain unaffected (see Load Transient Response in *Typical Operating Characteristics*).

Often the regulator's crossover frequency varies with load and is not easily found. If the regulator's crossover frequency is unknown, the MAX1804's gain-bandwidth product can be chosen empirically. Start with a fairly low capacitor value (470pF is a good starting point) and increase the value until the circuit is stable with all loads. Then increase the value further to ensure design margin. If transient response is unimportant, choose a large COMP capacitor value (such as 2200pF), thereby maximizing stability.

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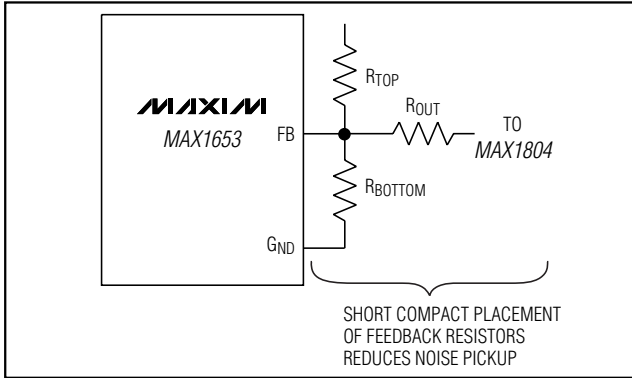


Figure 5. Proper Layout of Feedback Resistors for Regulator

Applications Information

Layout Information

Proper layout is essential due to high current levels and switching waveforms that generate noise. Place the regulator's feedback resistors and R_{OUT} (from the regulator feedback point to OUT of MAX1804) close to the regulator's feedback point to prevent noise pickup (Figure 5). Minimize leakage of the COMP capacitor and traces around COMP because they cause IN_{-} set-point errors according to the IN_{-} transconductance. A leakage of I_{COMP} at COMP will result in an error given by:

$$IN_{-} \text{ error voltage} = I_{COMP} / (IN_{-} \text{ transconductance})$$

For a typical value of IN_{-} transconductance of $30\mu S$, a leakage of $0.1\mu A$ will result in an IN_{-} error voltage of $3mV$ in the set point.

Design Example (Step-Down Converter Application)

Figure 2 is an example of an application circuit using the MAX1804 for point-of-load regulation when using a step-down controller (MAX1653). Use the following design procedure to optimize the basic schematic. Begin the design by establishing the following:

- Input voltage to the MAX1653 controller (7V to 20V)
- Typical output voltage and accuracy of MAX1653 ($5V \pm 5\%$)

This gives a target of:

$$V_{OUT, \min} = 5V - 5\% = 4.75V$$

To minimize power dissipation, set regulator output $V_{OUT, R} = 4.8V$ with MAX1653 feedback resistors.

Choose feedback resistors (R_{TOP} and R_{BOTTOM}) for about $25\mu A$ current in the resistive divider for noise immunity.

Therefore:

$$(R_{TOP} + R_{BOTTOM}) = 4.8V / 25\mu A = 192k\Omega$$

For the MAX1653, the voltage at its feedback point $V_{FB} = 2.5V$.

Choose $R_{TOP} = 91k\Omega$ and therefore, $R_{BOTTOM} = 100k\Omega$.

If the desired adjustment range is $+400mV$, max OUT current (MAX1804) is given by:

$$I_{OUT}(MAX) = 0.4V / 91k\Omega = 4.4\mu A$$

$$R_{OUT} = V_{FB} / I_{OUT}(MAX) = 2.5V / 4.4\mu A = 562k\Omega$$

To guarantee that the output will not go below the target of $4.75V$, including all error sources, set the MAX1804 nominal regulation point to $4.85V$.

Since:

$$IN_{-} \text{ scale factor} = 4 \times V_{ADJ}, V_{ADJ} = 1.2125V$$

Divide the reference voltage down and bypass as required if using the MAX1653 reference voltage as shown in Figure 2. Assuming 0.1% resistor accuracy and using the MAX1653 reference, the error budget can be calculated as:

Reference Accuracy	-1.6%
ADJ Divider Accuracy	-0.2%
Scale Factor Error	-0.4%
<u>IN_{-} Offset Voltage (-15mV)</u>	<u>-0.3%</u>
Total	-2.5%

This gives a worst-case output voltage of $4.73V$, which is below the target of $4.75V$. The most-significant error source is the MAX1653 reference. Therefore, use a better reference, if available, in the system or increase the V_{ADJ} to increase the worst-case output voltage to $4.75V$.

The MAX1653 works well with the MAX1804's GBW product set at $40kHz$, so use a $470pF$ capacitor on COMP.

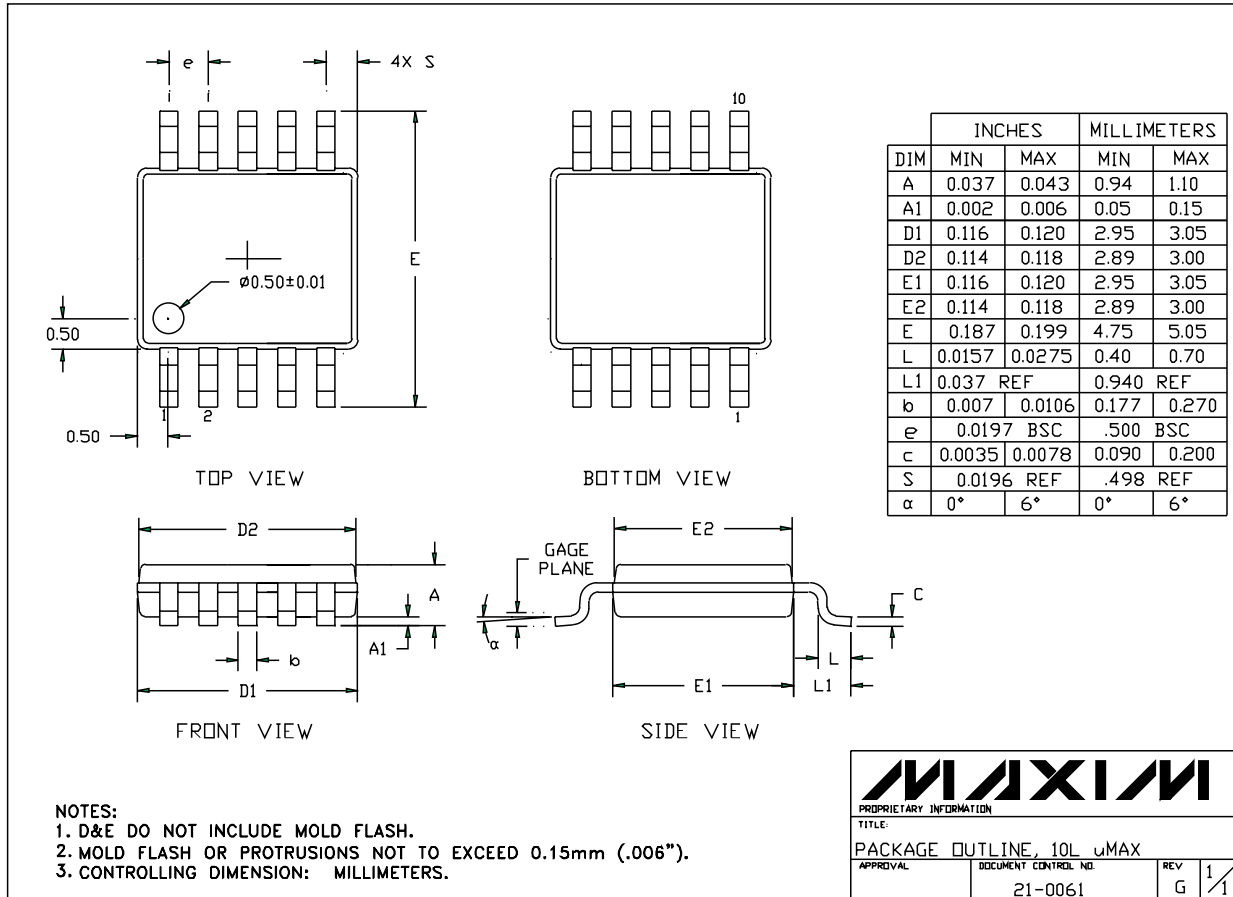
Chip Information

TRANSISTOR COUNT: 636

External Four-Input Feedback Integrator for Power Supplies

Package Information

MAX1804



Note: MAX1804 does not feature exposed pads

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