

High-Accuracy Step-Down Controller with Synchronous Rectifier for CPU Power

MAX798

General Description

The MAX798 high-performance, step-down DC-DC converter provides main CPU power in battery-powered systems. This buck controller achieves 96% efficiency by using synchronous rectification and Maxim's proprietary Idle Mode™ control scheme to extend battery life at full-load (up to 10A) and no-load outputs. The MAX798's high accuracy meets the demanding requirements of the latest-generation CPUs. Excellent dynamic response corrects output transients caused by the latest dynamic-clock CPUs within five 300kHz clock cycles. Unique bootstrap circuitry drives inexpensive N-channel MOSFETs, reducing system cost and eliminating the crow-bar switching currents found in some PMOS/NMOS switch designs.

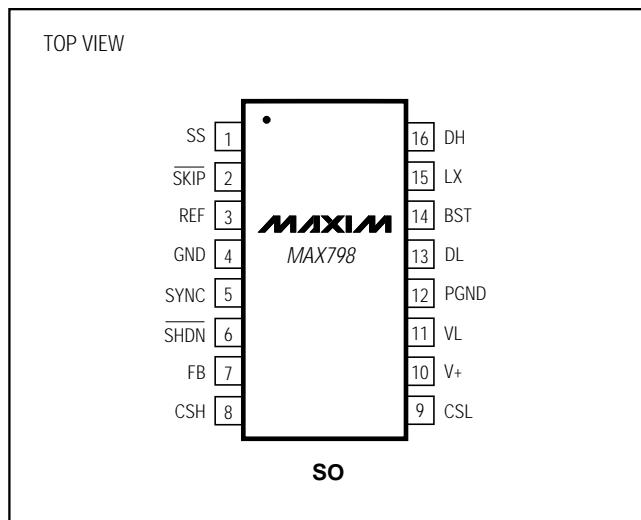
The MAX798 has a logic-controlled and synchronizable fixed-frequency pulse-width-modulating (PWM) operating mode, which reduces noise and RF interference in sensitive mobile-communications and pen-entry applications. The SKIP override input allows automatic switchover to idle-mode operation (for high-efficiency pulse skipping) at light loads, or forces fixed-frequency mode for lowest noise at all loads.

Applications

Notebook and Subnotebook Computers

PDAs and Mobile Communicators

Pin Configuration



Idle Mode is a trademark of Maxim Integrated Products.

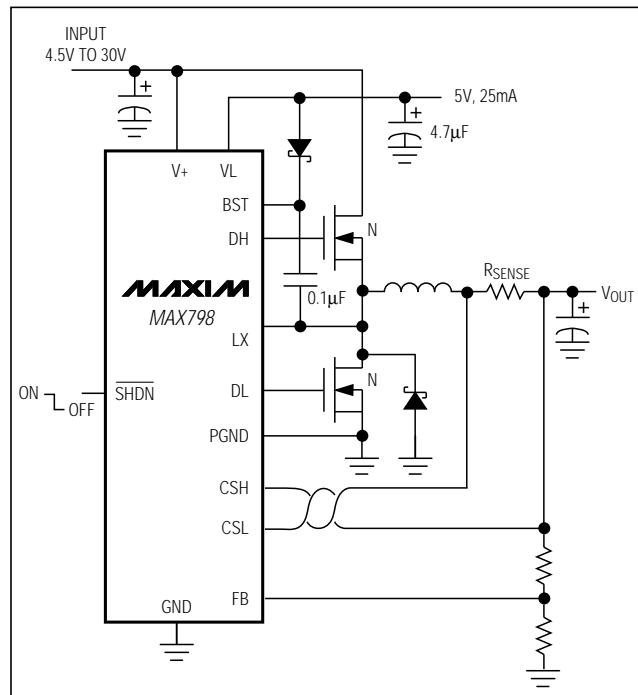
Features

- ♦ **96% Efficiency**
- ♦ **4.5V to 30V Input Range**
- ♦ **1.6V to 6V Adjustable Precision Output**
- ♦ **±0.4% Max Total Load-Regulation Error**
- ♦ **0.06%/V Max Line-Regulation Error**
- ♦ **5V Linear-Regulator Output**
- ♦ **Precision 2.505V Reference Output**
- ♦ **Automatic Bootstrap Circuit**
- ♦ **150kHz/300kHz Fixed-Frequency PWM Operation**
- ♦ **Programmable Soft-Start**
- ♦ **1.2mA Typical Quiescent Current (VIN = 12V, VOUT = 2.5V)**
- ♦ **1µA Typical Shutdown Current**

Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE |
|-----------|----------------|--------------|
| MAX798ESE | -40°C to +85°C | 16 Narrow SO |

Typical Operating Circuit



High-Accuracy Step-Down Controller with Synchronous Rectifier for CPU Power

ABSOLUTE MAXIMUM RATINGS

| | |
|--------------------------------------|---------------------|
| V+ to GND | -0.3V, +36V |
| GND to PGND | $\pm 2V$ |
| VL to GND | -0.3V, +7V |
| BST to GND | -0.3V, +36V |
| DH to LX | -0.3V, (BST + 0.3V) |
| LX to BST | -7V, +0.3V |
| SHDN to GND | -0.3V, +36V |
| SYNC, SS, REF, SKIP, DL to GND | -0.3V, (VL + 0.3V) |
| CSH, CSL to GND | -0.3V, +7V |
| VL Short Circuit to GND | Momentary |

| | |
|--|---------------------------------|
| REF Short Circuit to GND | Continuous |
| VL Output Current | 50mA |
| Continuous Power Dissipation ($T_A = +70^\circ C$) | 696mW |
| SO (derate 8.70mW/ $^\circ C$ above $+70^\circ C$) | 696mW |
| Operating Temperature Range | $-40^\circ C$ to $+85^\circ C$ |
| MAX798ESE | $-40^\circ C$ to $+85^\circ C$ |
| Storage Temperature Range | $-65^\circ C$ to $+160^\circ C$ |
| Lead Temperature (soldering, 10sec) | +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

($V_+ = +15V$, $GND = PGND = 0V$, $I_{VL} = I_{REF} = 0A$, $T_A = 0^\circ C$ to $+85^\circ C$, unless otherwise noted.)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|--|-------|-------|-----------|---------|
| STEP-DOWN CONTROLLER | | | | | |
| Input Supply Range | | 4.5 | | 30 | V |
| Nominal Adjustable Output Voltage Range | External resistor divider | 1.6 | | 6 | V |
| Feedback Voltage | $CSH - CSL = 40mV$, $\overline{SKIP} = VL$ | 1.576 | 1.6 | 1.624 | V |
| Load Regulation | $0mV < (CSH - CSL) < 80mV$, $\overline{SKIP} = VL$ | | | ± 0.4 | % |
| Line Regulation | $6V < V_+ < 30V$ | | 0.04 | 0.05 | %/V |
| Current-Limit Voltage | CSH - CSL, positive | 80 | 100 | 120 | mV |
| | CSH - CSL, negative | -40 | -100 | -160 | |
| SS Source Current | | 2.0 | 4.0 | 6.5 | μA |
| SS Fault Sink Current | | 2.0 | | | mA |
| INTERNAL REGULATOR AND REFERENCE | | | | | |
| VL Output Voltage | $SHDN = 2V$, $0mA < I_{VL} < 25mA$, $5.5V < V_+ < 30V$ | 4.75 | | 5.25 | V |
| VL Fault Lockout Voltage | Rising edge, hysteresis = 15mV | 3.8 | | 4.0 | V |
| VL/CSL Switchover Voltage | Rising edge, hysteresis = 25mV | 4.2 | | 4.7 | V |
| Reference Output Voltage | No external load (Note 1) | 2.463 | 2.505 | 2.537 | V |
| Reference Fault Lockout Voltage | Falling edge | 1.8 | | 2.3 | V |
| Reference Load Regulation | $0\mu A < I_{REF} < 100\mu A$ | | | 20 | mV |
| CSL Shutdown Leakage Current | $SHDN = 0V$, $CSL = 6V$, $V_+ = 0V$ or $30V$, $VL = 0V$ | 0.1 | | 1 | μA |
| V+ Shutdown Current | $SHDN = 0V$, $V_+ = 30V$, $CSL = 0V$ or $6V$ | 1 | | 5 | μA |
| V+ Off-State Leakage Current | $FB = CSH = CSL = 6V$, VL switched over to CSL | 1 | | 5 | μA |
| Dropout Power Consumption | $V_+ = 4V$, $CSL = 0V$ (Note 2) | 6.6 | | 10.5 | mW |
| Quiescent Power Consumption | $CSH = CSL = 6V$ | 6.4 | | 8.5 | mW |

High-Accuracy Step-Down Controller with Synchronous Rectifier for CPU Power

ELECTRICAL CHARACTERISTICS (continued)

(V₊ = +15V, GND = PGND = 0V, I_{VL} = I_{REF} = 0A, T_A = 0°C to +85°C, unless otherwise noted.)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|------------------------|--|----------|------|-----|-------|
| Oscillator Frequency | SYNC = REF | 270 | 300 | 330 | kHz |
| | SYNC = 0V or 5V | 125 | 150 | 175 | |
| SYNC High Pulse Width | | 200 | | | ns |
| SYNC Low Pulse Width | | 200 | | | ns |
| SYNC Rise/Fall Time | Guaranteed by design | | 200 | | ns |
| Oscillator Sync Range | | 195 | 340 | | kHz |
| Maximum Duty Cycle | SYNC = REF | 89 | 91 | | % |
| | SYNC = 0V or 5V | 93 | 96 | | |
| Input High Voltage | SYNC | VL - 0.5 | | | V |
| | SHDN, SKIP | 2.0 | | | |
| Input Low Voltage | SYNC | 0.8 | | | V |
| | SHDN, SKIP | 0.5 | | | |
| Input Current | SHDN, 0V or 30V | 2 | | | µA |
| | SYNC, SKIP | 1 | | | |
| | CSH, CSL, CSH = CSL = 4V, device not shut down | 50 | | | |
| | FB, FB = 1.6V | | ±100 | | nA |
| DL Sink/Source Current | DL forced to 2V | 1 | | | A |
| DH Sink/Source Current | DH forced to 2V, BST - LX = 4.5V | 1 | | | A |
| DL On-Resistance | High or low | | 7 | | Ω |
| DH On-Resistance | High or low, BST - LX = 4.5V | | 7 | | Ω |

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ELECTRICAL CHARACTERISTICS

($V_+ = +15V$, $GND = PGND = 0V$, $I_{VL} = I_{REF} = 0A$, $T_A = -40^\circ C$ to $+85^\circ C$, unless otherwise noted.) (Note 3)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|--|-------|-------|---------|----------|
| STEP-DOWN CONTROLLER | | | | | |
| Input Supply Range | | 5.0 | 30 | | V |
| Nominal Adjustable Output Voltage Range | External resistor divider | 1.6 | 6.0 | | V |
| Feedback Voltage | $CSH - CSL = 40mV$, $\overline{SKIP} = VL$ | 1.560 | 1.6 | 1.640 | V |
| Load Regulation | $0mV < (CSH - CSL) < 80mV$, $\overline{SKIP} = VL$ | | | ± 1 | % |
| Line Regulation | $6V < V_+ < 30V$ | | 0.04 | 0.06 | %/V |
| Current-Limit Voltage | CSH - CSL, positive | 70 | 130 | | mV |
| | CSH - CSL, negative | -40 | -100 | -160 | |
| INTERNAL REGULATOR AND REFERENCE | | | | | |
| VL Output Voltage | $SHDN = 2V$, $0mA < I_{VL} < 25mA$, $5.5V < V_+ < 30V$ | 4.7 | 5.3 | | V |
| VL Fault Lockout Voltage | Rising edge, hysteresis = 15mV | 3.75 | 4.05 | | V |
| VL/CSL Switchover Voltage | Rising edge, hysteresis = 25mV | 4.15 | 4.75 | | V |
| Reference Output Voltage | No external load (Note 1) | 2.438 | 2.505 | 2.562 | V |
| Reference Load Regulation | $0\mu A < I_{REF} < 100\mu A$ | | | 30 | mV |
| V+ Shutdown Current | $SHDN = 0V$, $V_+ = 30V$, $CSL = 0V$ or $6V$ | | 1 | 10 | μA |
| V+ Off-State Leakage Current | $FB = CSH = CSL = 6V$, VL switched over to CSL | | 1 | 10 | μA |
| Quiescent Power Consumption | $CSH = CSL = 6V$ | | 6.4 | 9.1 | mW |
| OSCILLATOR AND INPUTS/OUTPUTS | | | | | |
| Oscillator Frequency | SYNC = REF | 250 | 300 | 350 | kHz |
| | SYNC = 0V or 5V | 110 | 150 | 190 | |
| SYNC High Pulse Width | | 250 | | | ns |
| SYNC Low Pulse Width | | 250 | | | ns |
| Oscillator Sync Range | | 210 | 320 | | kHz |
| Maximum Duty Cycle | SYNC = REF | 88 | 91 | | % |
| | SYNC = 0V or 5V | 92 | 96 | | |
| DL On-Resistance | High or low | | | 7 | Ω |
| DH On-Resistance | High or low, $BST - LX = 4.5V$ | | | 7 | Ω |

Note 1: Since the reference uses VL as its supply, V+ line-regulation error is insignificant.

Note 2: At very low input voltages, quiescent supply current can increase due to excess PNP base current in the VL linear regulator. This occurs only if V+ falls below the preset VL regulation point (5V nominal). The typical maximum quiescent current in dropout will not exceed 16mA.

Note 3: All $-40^\circ C$ to $+85^\circ C$ specifications above are guaranteed by design.

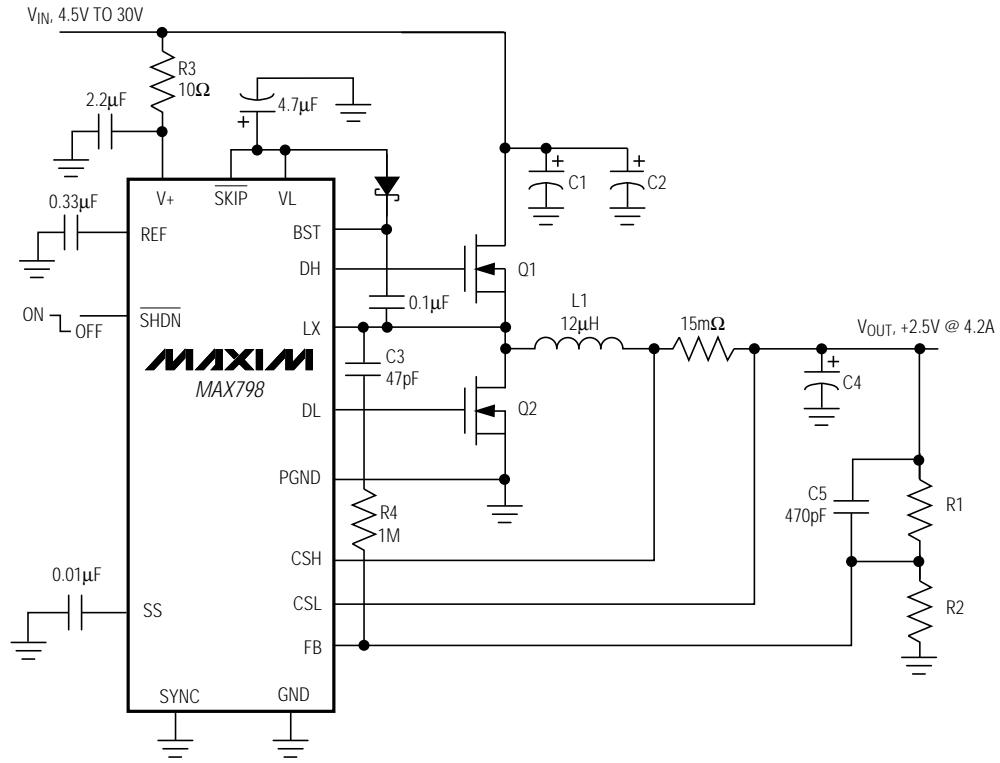
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Pin Description

| PIN | NAME | FUNCTION |
|-----|-------------|---|
| 1 | SS | Soft-Start Timing Capacitor Connection. Ramp time to full current limit is approximately 1ms/nF. |
| 2 | SKIP | Disables pulse-skipping mode when high. Connect to GND for normal use. Don't leave SKIP unconnected. With SKIP grounded, the device will <i>automatically</i> change from pulse-skipping operation to full PWM operation when the load current exceeds approximately 30% of maximum. |
| 3 | REF | Reference Voltage Output. Bypass to GND with 0.33 μ F minimum. |
| 4 | GND | Low-Noise Analog Ground and Feedback Reference Point |
| 5 | SYNC | Oscillator Synchronization and Frequency Select. Tie to GND or VL for 150kHz operation; tie to REF for 300kHz operation. A high-to-low transition begins a new cycle. Drive SYNC with 0V to 5V logic levels (see the <i>Electrical Characteristics</i> table for V_{IH} and V_{IL} specifications). SYNC capture range is 195kHz to 340kHz. |
| 6 | SHDN | Shutdown Control Input, active low. Logic threshold is set at approximately 1V (V_{TH} of an internal N-channel MOSFET). Tie SHDN to V+ for automatic start-up. |
| 7 | FB | Feedback Input. Regulates at $FB = 1.6V$. Connect FB to a resistor divider to set the output voltage. |
| 8 | CSH | Current-Sense Input, high side. Current-limit level is 100mV referred to CSL. |
| 9 | CSL | Current-Sense Input, low side |
| 10 | V+ | Battery Voltage Input (4.5V to 30V). Bypass V+ to PGND close to the IC with a 0.1 μ F capacitor. Connects to a linear regulator that powers VL. |
| 11 | VL | 5V Internal Linear-Regulator Output. VL is also the supply voltage rail for the chip. VL is switched to the output voltage via CSL ($V_{CSL} > 4.5V$) for automatic bootstrapping. Bypass to GND with 4.7 μ F. VL can supply up to 5mA for external loads. |
| 12 | PGND | Power Ground |
| 13 | DL | Low-Side Gate-Drive Output. Normally drives the synchronous-rectifier MOSFET. Swings 0V to VL. |
| 14 | BST | Boost Capacitor Connection for high-side gate drive (0.1 μ F) |
| 15 | LX | Switching Node (inductor) Connection. Can swing 2V below ground without hazard. |
| 16 | DH | High-Side Gate-Drive Output. Normally drives the main buck switch. DH is a floating driver output that swings from LX to BST, riding on the LX switching-node voltage. |

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Q1, Q2 = SILICONIX Si4410DY or IRF7413
 C1, C2 = 10µF/30V SANYO OS-CON (30SA10)
 C3 = 470µF/4V SPRAGUE 594D SERIES (594D477X0004R2T)
 L1 = SUMIDA CDRH127 120
 R1 = 6.49kΩ, 1%
 R2 = 11.5kΩ, 1%
 f = 150kHz

Figure 1. Standard Application Circuit

Detailed Description

The MAX798 is a BiCMOS, switch-mode power-supply controller designed primarily for buck-topology regulators in battery-powered applications where high accuracy, high efficiency, and low quiescent supply current are critical. The MAX798 also works well in other topologies such as boost, inverting, and CUK due to the flexibility of its floating high-speed gate driver. Light-load efficiency is enhanced by automatic idle-mode operation—a variable-frequency pulse-skipping

mode that reduces losses due to MOSFET gate charge. The step-down power-switching circuit consists of two N-channel MOSFETs, a rectifier, and an LC output filter. The output voltage is the average of the AC voltage at the switching node, which is adjusted and regulated by changing the duty cycle of the MOSFET switches. The gate-drive signal to the N-channel high-side MOSFET must exceed the battery voltage and is provided by a flying capacitor boost circuit that uses a 100nF capacitor connected between BST and LX.

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The MAX798 contains the following seven major circuit blocks, which are shown in Figure 2.

PWM Controller Blocks:

- Multi-Input PWM Comparator
- Current-Sense Circuit
- PWM Logic Block
- Gate-Driver Outputs

Bias Generator Blocks:

- +5V Linear Regulator
- Automatic Bootstrap Switchover Circuit
- +2.505V Reference

MAX798

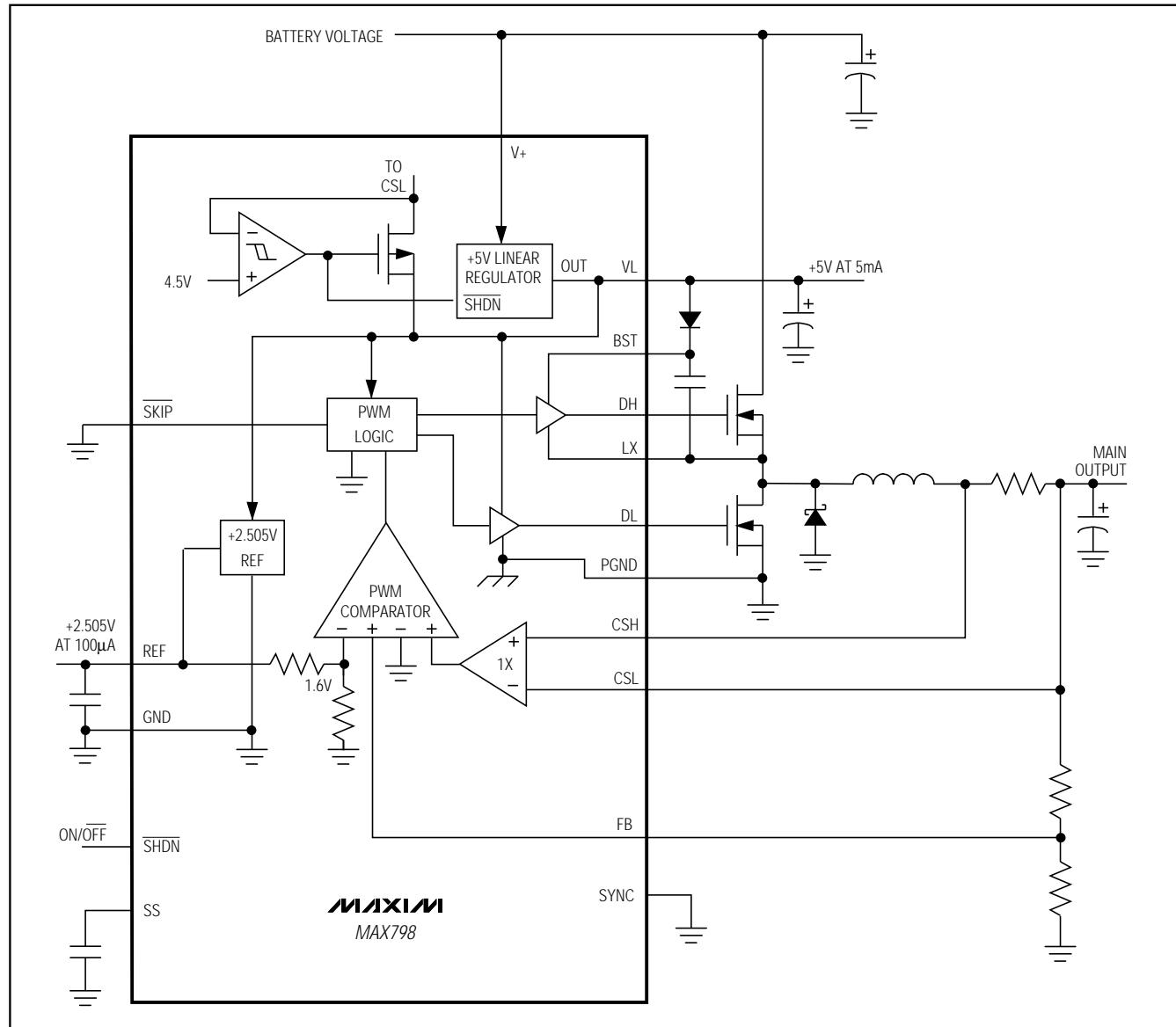


Figure 2. Functional Diagram

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These internal IC blocks aren't powered directly from the battery. Instead, a +5V linear regulator steps down the battery voltage to supply both the IC internal rail (VL pin) as well as the gate drivers. The synchronous-switch gate driver is directly powered from +5V VL, while the high-side-switch gate driver is indirectly powered from VL via an external diode-capacitor boost circuit. An automatic bootstrap circuit turns off the +5V linear regulator and powers the IC from its output voltage if the output is above 4.5V.

PWM Controller Block

The heart of the current-mode PWM controller is a multi-input open-loop comparator that sums three signals: output voltage error signal with respect to the reference voltage, current-sense signal, and slope compensation ramp (Figure 3). The PWM controller is a direct summing type, lacking a traditional error amplifier and the phase shift associated with it. This direct-summing configuration approaches the ideal of cycle-by-cycle control over the output voltage.

For more comprehensive information on the MAX798 internal blocks, please refer to the MAX796/MAX797/MAX799 data sheet.

Applications Information

Powering VL from a +5V Supply

If the circuit's output voltage is greater than the VL/CSL switchover voltage, the IC automatically bootstraps and runs off its output. Running from the high-efficiency output rather than the VL linear regulator is particularly desirable if the input voltage is high. If the output is not greater than the VL/CSL switchover threshold, efficiency can be improved by powering VL from another efficient system supply (Figure 4).

VL can be connected directly to a +5V supply, provided its maximum excursions are within a 4.5V to 6V range and the main output voltage's maximum is less than 4.2V. If the circuit's output voltage is greater than 4.2V, the IC can activate its internal bootstrap switch and connect the circuit output to VL.

Adjusting the Output Voltage

The output voltage is set by an external resistor divider between the output voltage and GND, with the midpoint connected to FB (Figure 5). The output voltage can be adjusted from 1.6V to 6V, according to the formula in Figure 5. Recommended R2 values range from $5\text{k}\ \Omega$ to $100\text{k}\Omega$. For best noise immunity, place R1 and R2 close to FB. For a 1.6V output, connect the output voltage directly to FB.

Remote sensing of the output voltage is easily achieved by connecting the top of R1 and, if desired, the bottom of R2, to the remote sense point.

Bypassing and Compensation Components

The MAX798 is designed to deliver a more accurate output voltage than the MAX797. A major source of the MAX797's output error is the decrease in output voltage with increasing load. This error is greatly reduced in the MAX798 by increasing the gain of the voltage-sense signal relative to the current-sense signal. As a result of this increased gain, the MAX798 is slightly more noise sensitive than the MAX797, and requires some small compensation components as well. On the other hand, output capacitor ESR requirements can be greatly relaxed compared to the MAX797, with the limiting factor being the maximum total output voltage ripple that the application can tolerate.

To control noise problems, place the bypass capacitors on REF, VL, and V+ as close as possible to the IC, and use a 10Ω series resistor (R3, Figure 1) on V+ to form a small lowpass filter. Feed-forward components (R4, C3, and C5) are chosen for stable switching at 150kHz with the components shown. For 300kHz switching and a $4.7\mu\text{H}$ inductor, use $R4 = 470\text{k}\ \Omega$ and $C5 = 220\text{pF}$. Keep the components that connect to FB (R4, C5, R1, R2) close to the IC's FB pin.

Design Procedure

With the exception of the items previously mentioned, follow the design procedure for the MAX797. The MAX796/MAX797/MAX799 data sheet contains all necessary information on component values, component selection, layout, and additional applications.

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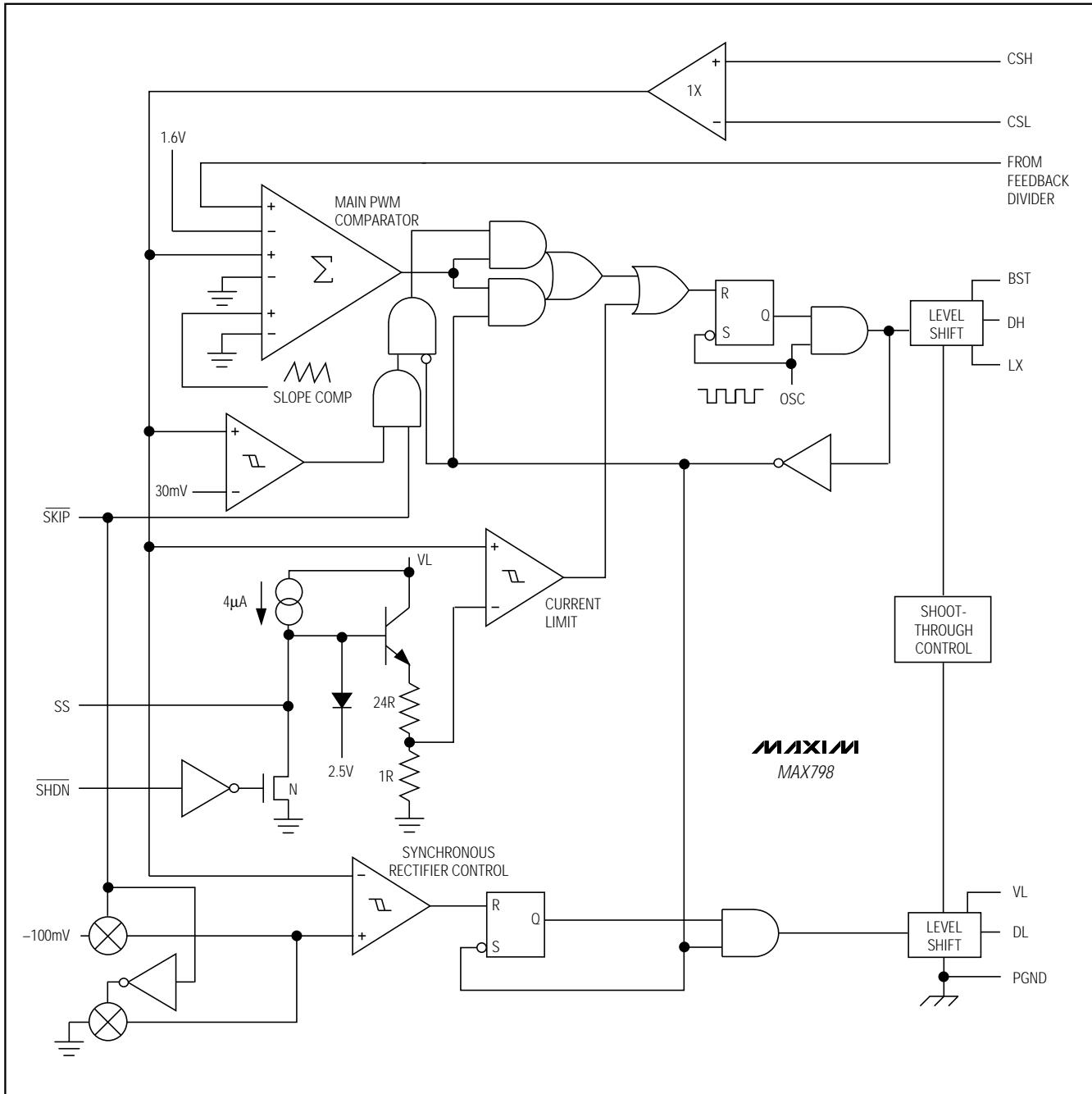


Figure 3. PWM Controller Detailed Block Diagram

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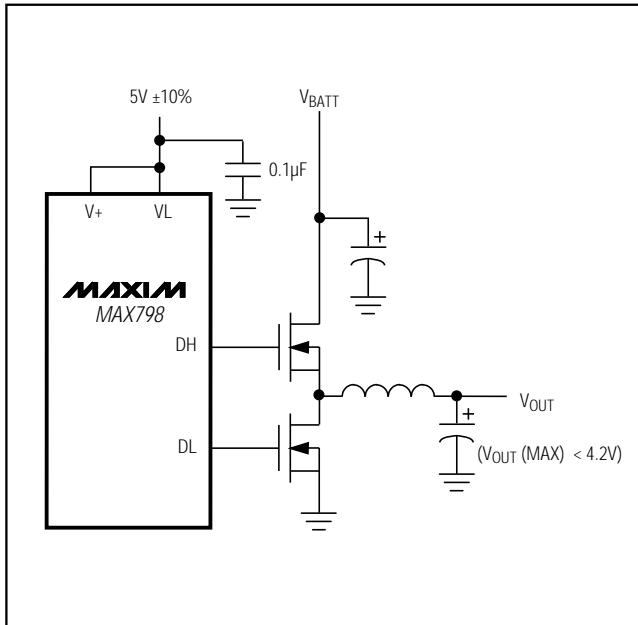


Figure 4. Powering VL from a Separate +5V Supply

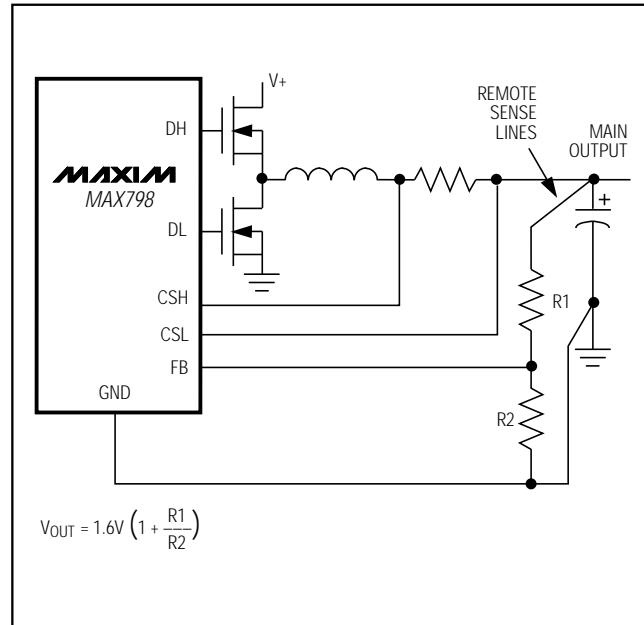


Figure 5. Adjusting the Output Voltage

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Chip Information

TRANSISTOR COUNT: 1008

MAX798

Package Information

| DIM | INCHES | | MILLIMETERS | |
|-----|--------|-------|-------------|------|
| | MIN | MAX | MIN | MAX |
| A | 0.053 | 0.069 | 1.35 | 1.75 |
| A1 | 0.004 | 0.010 | 0.10 | 0.25 |
| B | 0.014 | 0.019 | 0.35 | 0.49 |
| C | 0.007 | 0.010 | 0.19 | 0.25 |
| E | 0.150 | 0.157 | 3.80 | 4.00 |
| e | 0.050 | | 1.27 | |
| H | 0.228 | 0.244 | 5.80 | 6.20 |
| L | 0.016 | 0.050 | 0.40 | 1.27 |

| DIM | PINS | INCHES | | MILLIMETERS | |
|-----|------|--------|-------|-------------|-------|
| | | MIN | MAX | MIN | MAX |
| D | 8 | 0.189 | 0.197 | 4.80 | 5.00 |
| D | 14 | 0.337 | 0.344 | 8.55 | 8.75 |
| D | 16 | 0.386 | 0.394 | 9.80 | 10.00 |

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NOTES

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