**General Description**

The MAX8664 dual-output PWM controller is a low-cost, high-performance solution for systems requiring dual power supplies. It provides two individual outputs that operate 180° out-of-phase to minimize input current ripple, and therefore, capacitance requirements. Built-in drivers are capable of driving external MOSFETs to deliver up to 25A output current from each channel. The MAX8664 operates from a 4.5V to 28V input voltage source and generates output voltages from 0.6V up to 90% of the input voltage on each channel. Total output regulation error is less than ±0.8% over load, line, and temperature.

The MAX8664 operates with a constant switching frequency adjustable from 100kHz to 1MHz. Built-in boost diodes reduce external component count. Digital soft-start eliminates input inrush current during startup. The second output has an optional external REFIN2, facilitating tracking supply applications. Each output is capable of sourcing and sinking current, making the device a great solution for DDR applications.

The MAX8664 employs Maxim’s proprietary peak voltage-mode control architecture that provides superior transient response during either load or line transients. This architecture is easily stabilized using two resistors and one capacitor for any type of output capacitors. Fast transient response requires less output capacitance, consequently reducing total system cost. The MAX8664B latches off both controllers during a fault condition, while the MAX8664A allows one controller to continue to function when there is a fault in the other controller.

**Features**

- ±0.8% Output Accuracy Over Load and Line
- Operates from a Single 4.5V to 28V Supply
- Simple Compensation for Any Type of Output Capacitor
- Internal 6.5V Regulator for Gate Drive
- Integrated Boost Diodes
- Adjustable Output from 0.6V to 0.9 x Vin
- Digital Soft-Start Reduces Inrush Current
- 100kHz to 1MHz Adjustable Switching
- 180° Out-of-Phase Operation Reduces Input Ripple Current
- Overcurrent and Overvoltage Protection
- External Reference Input for Second Controller
- Prebiased Startup Operation

**Ordering Information**

<table>
<thead>
<tr>
<th>PART</th>
<th>PIN PACKAGE</th>
<th>PKG CODE</th>
<th>FAULT ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX8664A</td>
<td>20 QSOPT</td>
<td>E20-1</td>
<td>Independent</td>
</tr>
<tr>
<td>MAX8664B</td>
<td>20 QSOPT</td>
<td>E20-1</td>
<td>Joint</td>
</tr>
</tbody>
</table>

Note: This device operates over the -40°C to +85°C operating temperature range.
+Denotes lead-free package.

**Applications**

- Desktop and Notebook PCs
- Graphic Cards
- ASIC/CPU/DSP Power Supplies
- Set-Top Box Power Supply
- Printer Power Supply
- Network Power Supply
- POL Power Supply

Pin Configuration appears at end of data sheet.
**Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response**

### ABSOLUTE MAXIMUM RATINGS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN to GND</td>
<td></td>
<td>-0.3V to +30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VL to GND</td>
<td></td>
<td>-0.3 to +8V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN, BST_ to VL</td>
<td></td>
<td>-0.3V to +30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCC, FB_, PWRGD to GND</td>
<td></td>
<td>-0.3V to +6V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VL to VCC</td>
<td></td>
<td>-2V to +8V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGND to GND</td>
<td></td>
<td>-0.3V to +30V</td>
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<td></td>
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<tr>
<td>DL_ to PGND</td>
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<td>-0.3V to (VVL + 0.3V)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DH_ to PGND</td>
<td></td>
<td>-0.3V to (VBST_ + 0.3V)</td>
<td></td>
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<tr>
<td>BST_ to GND</td>
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<td>-0.3V to 38V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BST_ to LX</td>
<td></td>
<td>-0.3V to +8V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LX_ to PGND</td>
<td></td>
<td>-1V (-2.5V for &lt; 50ns transient) to +30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DH_ to LX</td>
<td></td>
<td>-0.3V to (VBST_ + 0.3V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILIM_ to GND</td>
<td></td>
<td>-0.3V to (VIN + 0.3V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILIM_ to LX</td>
<td></td>
<td>-0.6V to +30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSC/EN12, REFIN2 to GND</td>
<td></td>
<td>-0.3V to (VCC + 0.3V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VL Continuous Current</td>
<td></td>
<td>-325mARMS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCC Continuous Current</td>
<td></td>
<td>10mARMS</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Continuous Power Dissipation</td>
<td>(TA = +70°C) (Note 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-Pin QSOP (derate 11.0mW°C above +70°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td></td>
<td>-40°C to +85°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction Temperature</td>
<td></td>
<td>+150°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td></td>
<td>-65°C to +150°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Temperature (soldering, 10s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Package mounted on a multilayer PCB.

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

(VIN = 12V, ROSC/EN12 to GND = 56.1kΩ, REFIN2 = VCC, TA = -40°C to +85°C, unless otherwise noted. Typical values are at TA = +25°C.) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPPLY VOLTAGES</td>
<td>IN Supply Voltage IN = VL = VCC</td>
<td>4.5</td>
<td>5.5</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VL Output Voltage 7.2V &lt; VIN &lt; 28V</td>
<td>6.10</td>
<td>6.6</td>
<td>6.75</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VCC Output Voltage 7.2V &lt; VIN &lt; 28V</td>
<td>4.5</td>
<td>5.0</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Reference Accuracy</td>
<td>0.5930</td>
<td>0.600</td>
<td>0.6070</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Standby Supply Current</td>
<td>0.095</td>
<td>0.2</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>Operating Supply Current</td>
<td>1.4</td>
<td>2.5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>REGULATOR SPECIFICATIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference Accuracy</td>
<td>T_A = 0°C to +85°C</td>
<td>0.5955</td>
<td>0.600</td>
<td>0.6045</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>T_A = -40°C to +85°C</td>
<td>0.5930</td>
<td>0.600</td>
<td>0.6070</td>
<td>V</td>
</tr>
<tr>
<td>FB_ Regulation Accuracy</td>
<td>VREFIN2 = VCC</td>
<td>0.5962</td>
<td>0.600</td>
<td>0.6048</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VREFIN2 = 1.000V</td>
<td>0.5925</td>
<td>0.600</td>
<td>0.6075</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VREFIN2 to Internal Reference</td>
<td>2</td>
<td>VCC - 0.7</td>
<td>VCC - 0.3</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Switchover Threshold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REFIN2 Maximum Program Voltage</td>
<td></td>
<td>1.3</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>REFIN2 Disable Threshold</td>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td>mV</td>
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<tr>
<td>FB Input Bias Current</td>
<td>VFB = 0.5V</td>
<td>3</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>REFIN2 Bias Current</td>
<td>VREFIN2 = 0.65V</td>
<td>3</td>
<td></td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td>FB Propagation Delay</td>
<td>FB rising to DH falling</td>
<td>50</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

ELECTRICAL CHARACTERISTICS (continued)

(V_IN = 12V, ROSEN12 to GND = 56.1kΩ, REFIN2 = V_CC, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROTECTION FEATURES</td>
<td>V_FB1 rising</td>
<td>0.75</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V_FB2 rising, V_REFIN2 ≤ 1.3V</td>
<td></td>
<td>REFIN2</td>
<td>+ 0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power-Good (PWRGD) Threshold</td>
<td>V_REFIN2 = V_CC, V_FB_rising, MAX8664B</td>
<td>0.500</td>
<td>0.525</td>
<td>0.550</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V_FB1 rising, MAX8664A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hysteresis</td>
<td></td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>High-Side Current-Sense Program Current (Note 3)</td>
<td>T_A = +85°C</td>
<td>60</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T_A = +25°C</td>
<td>44</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>ILIM Leakage</td>
<td>T_A = +25°C</td>
<td>0.1</td>
<td>1.0</td>
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<tr>
<td></td>
<td></td>
<td>T_A = +85°C</td>
<td></td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High-Side Current-Sense Overcurrent Trip Adjustment Range</td>
<td></td>
<td></td>
<td>0.05</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Internal Soft-Start Time</td>
<td>ROSEN12 = 56.1kΩ, 400kHz</td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REFIN2 Internal Pulldown Resistance</td>
<td>Engaged momentarily at startup</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal-Shutdown Threshold</td>
<td>Junction temperature</td>
<td></td>
<td>+160</td>
<td></td>
</tr>
<tr>
<td>DRIVER SPECIFICATIONS</td>
<td>Sourcing current,</td>
<td>V_L = 6.5V</td>
<td>1.35</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID_H = -50mA</td>
<td>V_IN = V_IN = V_CC = 5V</td>
<td>1.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sinking current,</td>
<td>V_L = 6.5V</td>
<td>0.9</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID_H = 50mA</td>
<td>V_IN = V_IN = V_CC = 5V</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sourcing current,</td>
<td>V_L = 6.5V</td>
<td>1.3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID_L = -50mA</td>
<td>V_IN = V_IN = V_CC = 5V</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sinking current,</td>
<td>V_L = 6.5V</td>
<td>0.6</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID_L = 50mA</td>
<td>V_IN = V_IN = V_CC = 5V</td>
<td>0.7</td>
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</tr>
<tr>
<td></td>
<td>Dead Time for Low-Side to High-Side Transition</td>
<td>V_L = 6.5V</td>
<td>13</td>
<td>25</td>
<td>43</td>
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<tr>
<td></td>
<td></td>
<td>V_WL = 5V</td>
<td>28</td>
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<tr>
<td></td>
<td>DH Minimum On-Time</td>
<td></td>
<td></td>
<td>70</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>BST Current</td>
<td>V_RST - V_LX = 7V, V_LX = 28V, V_FB = 0.55V</td>
<td>1.25</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OSC/EN12 not connected</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Internal Boost Switch Resistance</td>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>PWM CLOCK OSCILLATOR</td>
<td>PWM Clock-Frequency Accuracy</td>
<td></td>
<td></td>
<td>-15</td>
<td>+15</td>
</tr>
<tr>
<td></td>
<td>PWM Clock-Frequency Adjustment Range</td>
<td>ROSEN12 = 226kΩ to 22.6kΩ</td>
<td>100</td>
<td>1000</td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>OSC/EN12 Disable Current</td>
<td></td>
<td></td>
<td>1.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Note 2: Specifications at -40°C are guaranteed by design and not production tested.

Note 3: This current linearly compensates for the MOSFET temperature coefficient.
Typical Operating Characteristics

(Circuit of Figure 2, 600kHz, VIN = 12V, VOUT1 = 2.5V, VOUT2 = 1.8V, TA = +25°C, unless otherwise noted.)
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Typical Operating Characteristics (continued)
(Circuit of Figure 2, 600kHz, $V_{IN} = 12V$, $V_{OUT1} = 2.5V$, $V_{OUT2} = 1.8V$, $T_A = +25^\circ C$, unless otherwise noted.)
## Pin Description

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DH1</td>
<td>High-Side MOSFET Driver Output for Controller 1. Connect DH1 to the gate of the high-side MOSFET. DH1 is low in shutdown and UVLO.</td>
</tr>
<tr>
<td>2</td>
<td>LX1</td>
<td>External Inductor Connection for Controller 1. Connect LX1 to the switching node of the MOSFETs and inductor. Make sure LX1 is close to the source of the high-side MOSFET(s) to form a Kelvin connection for high-side current sensing. LX1 is high impedance during monotonic startup and shutdown.</td>
</tr>
<tr>
<td>3</td>
<td>BST1</td>
<td>Boost Capacitor Connection for the High-Side MOSFET Driver for Controller 1. Connect a 0.22µF ceramic capacitor from BST1 to LX1.</td>
</tr>
<tr>
<td>4</td>
<td>DL1</td>
<td>Low-Side MOSFET Driver Output for Controller 1. Connect DL1 to the gate of the low-side MOSFET(s) for controller 1. DL1 is low in shutdown and UVLO.</td>
</tr>
<tr>
<td>5</td>
<td>VL</td>
<td>Low-Side Gate Drive Supply and Output of the 6.5V Linear Regulator. Connect a 4.7µF ceramic capacitor from VL to PGND. When using a 4.5V to 5.5V supply, connect VL to IN. VL is the input to the VCC supply. Do not load VL when IC is disabled.</td>
</tr>
<tr>
<td>6</td>
<td>PGND</td>
<td>Power Ground. Connect to the power ground plane. Connect power and analog grounds at a single point near the output capacitor’s ground.</td>
</tr>
<tr>
<td>7</td>
<td>DL2</td>
<td>Low-Side MOSFET Driver Output for Controller 2. Connect DL2 to the gate of the low-side MOSFET(s) for controller 2. DL2 is low in shutdown and UVLO.</td>
</tr>
<tr>
<td>8</td>
<td>BST2</td>
<td>Boost Capacitor Connection for the High-Side MOSFET Driver for Controller 2. Connect a 0.22µF ceramic capacitor from BST2 to LX2.</td>
</tr>
<tr>
<td>9</td>
<td>LX2</td>
<td>External Inductor Connection for Controller 2. Connect LX2 to the switching node of the MOSFETs and inductor. Make sure LX2 is close to the source of the high-side MOSFET(s) to form a Kelvin connection for high-side current sensing. LX2 is high impedance during monotonic startup and shutdown.</td>
</tr>
<tr>
<td>10</td>
<td>DH2</td>
<td>High-Side MOSFET Driver Output for Controller 2. Connect DH2 to the gate of the high-side MOSFET(s) for controller 2. DH2 is low in shutdown and UVLO.</td>
</tr>
<tr>
<td>11</td>
<td>ILIM2</td>
<td>Current-Limit Set for Controller 2. Connect a resistor from the drain of the high-side MOSFET(s) to ILIM2. See the Setting the Overcurrent Threshold section.</td>
</tr>
<tr>
<td>12</td>
<td>FB2</td>
<td>Feedback Input for Controller 2. Connect FB2 to the center of a resistor-divider connected between the output of controller 2 and GND to set the desired output voltage. ( V_{FB2} ) regulates to ( V_{REFIN2} ) or the internal 0.6V reference. To use the internal reference, connect ( V_{REFIN2} ) to VCC.</td>
</tr>
<tr>
<td>13</td>
<td>REFIN2</td>
<td>External Reference Input for Controller 2. To use the internal 0.6V reference, connect ( V_{REFIN2} ) to VCC. To use an external reference, connect ( V_{REFIN2} ) through a resistor (&gt; 1kΩ) to a reference voltage between 0V and 1.3V. An RC lowpass filter is recommended when using an external reference and soft-start is not provided by the external reference. For tracking applications, connect ( V_{REFIN2} ) to the center of a resistor voltage-divider between the output of controller 1 and GND (see Figure 3). Connect ( V_{REFIN2} ) to GND to disable controller 2.</td>
</tr>
<tr>
<td>14</td>
<td>OSC/EN12</td>
<td>Switching Frequency Set Input. Connect a 22.6kΩ to 226kΩ resistor from OSC/EN12 to GND to set the switching frequency between 1000kHz and 100kHz. Connect a switch in series with this resistor for enable/shutdown control. When the switch is open, the IC enters low-power shutdown mode. In shutdown, OSC/EN12 is internally driven to approximately 800mV.</td>
</tr>
<tr>
<td>15</td>
<td>IN</td>
<td>Internal 6.5V Linear Regulator Input. Connect IN to a 7.2V to 28V supply, and connect a 0.47μF or larger ceramic capacitor from IN to PGND. When using a 4.5V to 5.5V supply, connect IN to VL.</td>
</tr>
<tr>
<td>16</td>
<td>GND</td>
<td>Analog Ground. Connect to the analog ground plane. Connect the analog and power ground planes at a single point near the output capacitor’s ground.</td>
</tr>
</tbody>
</table>
**Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response**

**Pin Description (continued)**

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>VCC</td>
<td>Internal Analog Supply. VCC regulates to 1.5V below VIL. Connect a 1µF ceramic capacitor from VCC to GND. When using a 4.5V to 5.5V supply, connect a 10Ω resistor from VCC to IN. VCC is used to power the IC’s internal circuitry.</td>
</tr>
<tr>
<td>18</td>
<td>PWRGD</td>
<td>Open-Drain Power-Good Output. PWRGD is high impedance when controllers 1 and 2 (using the internal reference) are in regulation. PWRGD is low if the outputs are out of regulation, if there is a fault condition, or if the IC is shut down. PWRGD does not reflect the status of output 2 in the MAX8664A or when REFIN2 is connected to an external reference in the MAX8664B.</td>
</tr>
<tr>
<td>19</td>
<td>FB1</td>
<td>Feedback Input for Controller 1. Connect FB1 to the center of a resistor-divider connected between the output of controller 1 and GND to set the desired output voltage. VFB1 regulates to 0.6V.</td>
</tr>
<tr>
<td>20</td>
<td>ILIM1</td>
<td>Current-Limit Set for Controller 1. Connect a resistor from the drain of the high-side MOSFET(s) to ILIM1. See the Setting the Overcurrent Threshold section.</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 1. Functional Diagram
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

**Detailed Description**

The MAX8664 dual-output PWM controller is a low-cost solution for dual power-supply systems. It provides two individual outputs that operate 180° out-of-phase to minimize input capacitance requirements. Built-in drivers are capable of driving external MOSFETs to deliver up to 25A of current from each output. The MAX8664 operates from a 4.5V to a 5.5V or a 7.2V to 28V input and generates output voltages from 0.6V up to 90% of the input voltage on each channel. Total output error is less than ±0.8% over load, line, and temperature.

The MAX8664 operates with a constant switching frequency adjustable from 100kHz to 1MHz. Built-in boost diodes reduce external component count. Digital soft-start eliminates input inrush current during startup. The second output has an optional REFIN2 input that takes an external reference voltage, facilitating tracking supply applications. Each output is capable of sourcing and sinking current. Internal 6.5V and 5V linear regulators provide power for gate drive and internal IC functions. The MAX8664 has built-in protection against output overvoltage, overcurrent, and thermal faults. The MAX8664B latches off both controllers during a fault condition, while the MAX8664A allows one controller to continue to function when there is a fault in the other controller.

The MAX8664 employs Maxim’s proprietary peak-voltage mode control architecture that provides superior transient response during either load or line transients. This architecture is easily stabilized using two resistors and one capacitor for any type of output capacitors. Fast transient response requires less output capacitance, consequently reducing total system cost.

**Internal Linear Regulators**

The internal VL low-dropout linear regulator of the MAX8664A and MAX8664B provides the 6.5V supply used for the gate drive. Connect a 4.7µF ceramic capacitor from VL to PGND. When using a 4.5V to 5.5V input supply, connect both controllers directly to IN.

The 5V supply used to power IC functions (VCC) is generated by an internal 1.5V shunt regulator from VL. Connect a 2.2µF ceramic capacitor from VCC to GND. When using a 4.5V to 5.5V input supply, connect VCC to IN through a 10Ω resistor.

**High-Side Gate-Drive Supply (BST_)**

The gate-drive voltage for the high-side MOSFETs is generated using a flying capacitor boost circuit. The capacitor between BST_ and LX_ is charged to the VL voltage through the integrated BST_ diode during the low-side MOSFET on-time. When the low-side MOSFET is switched off, the BST_ voltage is shifted above the LX_ voltage to provide the necessary turn-on voltage (VGS) for the high-side MOSFET. The controller closes a switch between BST_ and DH_ to turn the high-side MOSFET on.

**Voltage Reference**

An internal 0.6V reference sets the feedback regulation voltage. Controller 1 always uses the internal reference. An external reference input is provided for controller 2. To use the external reference, connect a 0 to 1.3V supply to REFIN2. This facilitates tracking applications. To use the internal 0.6V reference for controller 2, connect REFIN2 to VCC.

**Undervoltage Lockout (UVLO)**

When the VCC supply voltage drops below the UVLO threshold (3.15V falling typ), the undervoltage lockout (UVLO) circuit inhibits the switching of both controllers, and forces the DL and DH gate drivers low. When VCC rises above the UVLO threshold (3.5V rising typ), the controllers begin the startup sequence and resume normal operation.

**Output Overcurrent Protection**

When the MAX8664 detects an overcurrent condition, DH is immediately pulled low. If the overcurrent condition persists for four consecutive cycles, the controller latches off and both DH_ and DL_ are pulled low. During soft-start, when FB_ is less than 300mV, the controller latches off on the first overcurrent condition. The protection circuit detects an overcurrent condition by sensing the drain-source voltage across the high-side MOSFET(s).
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

The threshold that trips overcurrent protection is set by a resistor connected from ILIM_ to the drain of the high-side MOSFET(s). ILIM_ sinks 50µA (typ) through this resistor. When the drain-source voltage exceeds the voltage drop across this resistor during the high-side MOSFET(s) on-time, an overcurrent fault is triggered. To prevent glitches from falsely tripping the overcurrent protection, connect a filter capacitor (0.01µF typically) in parallel with the overcurrent-setting resistor.

Output Overvoltage Protection (OVP)
During an overvoltage event on one or both of its outputs, the MAX8664 latches off the controller. This occurs when the feedback voltage exceeds its normal regulation voltage by 150mV for 10µs. In this state, the low-side MOSFET(s) are on and the high-side MOSFET(s) are off to discharge the output. To clear the latch, cycle EN or the input power.

Thermal-Overload Protection
Thermal-overload protection limits total power dissipation in the MAX8664. When the junction temperature exceeds +160°C, an internal thermal sensor shuts down the device, pulling DH_ and DL_ low for both controllers. To restart the controller, cycle EN or the input power.

Power-Good Output (PWRGD)
PWRGD is an open-drain output that is pulled low when the output voltage rises above the PWRGD upper threshold or falls below the PWRGD falling threshold. PWRGD is held low in shutdown, when VCC is below the UVLO threshold, during soft-start, and during fault conditions. PWRGD does not reflect the status of controller 2 in the MAX8664A, or when REFIN2 is connected to an external reference with either version. See Table 1 for PWRGD operation of the circuits of Figures 2–5 during fault conditions. For logic-level output voltages, connect an external pullup resistor between PWRGD and the logic power supply. A 100kΩ resistor works well in most applications.

Fault-Shutdown Modes
When an overvoltage or overcurrent fault occurs on one controller of the MAX8664A, the second controller continues to operate. With the MAX8664B, a fault in one controller latches off both controllers automatically, and PWRGD is pulled low. See Table 1 for the fault-shutdown modes of the circuits shown in Figures 2–5.

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>MAX8664A (INDEPENDENT)</th>
<th>MAX8664B (JOINT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONTROLLER 1 FAULT</td>
<td>CONTROLLER 2 FAULT</td>
</tr>
<tr>
<td>Figure 2, Figure 5 (Independent)</td>
<td>Controller 2 remains on. PWRGD is pulled low.</td>
<td>Controller 1 remains on. PWRGD remains high.</td>
</tr>
<tr>
<td>Figure 3 (Tracking)</td>
<td>Controller 2 shuts down. PWRGD is pulled low.</td>
<td>Controller 1 remains on. PWRGD remains high.</td>
</tr>
<tr>
<td>Figure 4 (Sequenced)</td>
<td>Controller 2 shuts down. PWRGD is pulled low.</td>
<td>Controller 1 remains on. PWRGD remains high.</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 2. Low-Cost, 600kHz Typical Application Circuit
**Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response**

Table 2. Component List for Figure 2

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C3, C20, C21</td>
<td>4</td>
<td>10µF ±20%, 16V X5R ceramic capacitors (1206)</td>
</tr>
<tr>
<td>C4</td>
<td>1</td>
<td>1000µF ±20%, 16V electrolytic capacitor (8mm diameter, 20mm height)</td>
</tr>
<tr>
<td>C5, C12</td>
<td>2</td>
<td>1500µF, 50V C0G ceramic capacitors (0603)</td>
</tr>
<tr>
<td>C6–C11</td>
<td>6</td>
<td>47µF ±20%, 6.3V X5R ceramic capacitors (1206)</td>
</tr>
<tr>
<td>C13, C15</td>
<td>2</td>
<td>0.22µF ±10%, 25V X7R ceramic capacitors (0603)</td>
</tr>
<tr>
<td>C14</td>
<td>1</td>
<td>4.7µF ±10%, 6.3V X5R ceramic capacitor (0805)</td>
</tr>
<tr>
<td>C16, C19</td>
<td>2</td>
<td>0.01µF ±10%, 50V X7R ceramic capacitors (0603)</td>
</tr>
<tr>
<td>C17</td>
<td>1</td>
<td>1µF ±20%, 16V X5R ceramic capacitor (0603)</td>
</tr>
<tr>
<td>C18</td>
<td>1</td>
<td>1µF ±20%, 6.3V X5R ceramic capacitor (0603)</td>
</tr>
<tr>
<td>C22, C23</td>
<td>2</td>
<td>0.1µF ±20%, 16V X7R ceramic capacitors (0603)</td>
</tr>
<tr>
<td>C25, C26</td>
<td>2</td>
<td>680pF, 50V C0G ceramic capacitors (0603)</td>
</tr>
<tr>
<td>C27</td>
<td>1</td>
<td>0.47µF ±10%, 16V ceramic capacitor (0603)</td>
</tr>
<tr>
<td>L1, L2</td>
<td>2</td>
<td>1µH inductors TOKO FDV0630-1R0M</td>
</tr>
<tr>
<td>N1–N4</td>
<td>4</td>
<td>n-channel MOSFETs (8-pin SO) International Rectifier IRF7821</td>
</tr>
<tr>
<td>N9</td>
<td>1</td>
<td>n-channel MOSFET (SOT23) Central 2N7002</td>
</tr>
<tr>
<td>R1</td>
<td>1</td>
<td>2.74kΩ ±1% resistor (0603)</td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td>301kΩ ±1% resistor (0603)</td>
</tr>
<tr>
<td>R3, R6</td>
<td>2</td>
<td>51.1kΩ ±1% resistors (0603)</td>
</tr>
<tr>
<td>R4, R7</td>
<td>2</td>
<td>3.92kΩ ±1% resistors (0603)</td>
</tr>
<tr>
<td>R5</td>
<td>1</td>
<td>1.15kΩ ±1% resistor (0603)</td>
</tr>
<tr>
<td>R8</td>
<td>1</td>
<td>1.82kΩ ±1% resistor (0603)</td>
</tr>
<tr>
<td>R9</td>
<td>1</td>
<td>10kΩ ±5% resistor (0603)</td>
</tr>
<tr>
<td>R10</td>
<td>1</td>
<td>39.2kΩ ±1% resistor (0603)</td>
</tr>
<tr>
<td>R37, R38</td>
<td>2</td>
<td>3Ω ±5% resistors (0805)</td>
</tr>
<tr>
<td>U1</td>
<td>1</td>
<td>MAX8664 (20-pin QSOP)</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 3. 500kHz Tracking Circuit for DDR2 Applications
## Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Table 3. Component List for Figure 3

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C15</td>
<td>2</td>
<td>0.01µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C2, C3, C16, C17</td>
<td>4</td>
<td>10µF, 16V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C4</td>
<td>1</td>
<td>1000µF/16V aluminum electrolytic capacitor Rubycon 16MBZ1000M</td>
</tr>
<tr>
<td>C5</td>
<td>1</td>
<td>1µF, 16V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C6</td>
<td>1</td>
<td>1µF, 10V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C7, C18</td>
<td>2</td>
<td>0.22µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C8</td>
<td>1</td>
<td>0.015µF, 10V X7R ceramic capacitor</td>
</tr>
<tr>
<td>C9, C10</td>
<td>2</td>
<td>470µF, 2.5V POS capacitors Sanyo 2R5TPD470M</td>
</tr>
<tr>
<td>C11, C22</td>
<td>2</td>
<td>10µF, 6.3V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C12</td>
<td>1</td>
<td>1000pF, 10V X7R ceramic capacitor</td>
</tr>
<tr>
<td>C13</td>
<td>1</td>
<td>4.7µF, 10V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C14, C23</td>
<td>2</td>
<td>2200pF, 25V X7R capacitors</td>
</tr>
<tr>
<td>C19</td>
<td>1</td>
<td>4700pF, 10V X7R capacitor</td>
</tr>
<tr>
<td>C20, C21</td>
<td>2</td>
<td>680µF, 2.5V POS capacitors Sanyo 2R5TPD680M</td>
</tr>
<tr>
<td>L1</td>
<td>1</td>
<td>0.56µH, 4.6mΩ inductor Panasonic ETQP4LR56WFL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2</td>
<td>1</td>
<td>0.47µH, 1.2mΩ inductor TOKO FDV0603-R47M</td>
</tr>
<tr>
<td>N1, N2</td>
<td>2</td>
<td>n-channel MOSFETs IRLR7821 (D-Pak)</td>
</tr>
<tr>
<td>N3, N4</td>
<td>2</td>
<td>n-channel MOSFETs IRLR9907Z (D-Pak)</td>
</tr>
<tr>
<td>N5</td>
<td>1</td>
<td>n-channel MOSFET IRF7807Z (8-pin SO)</td>
</tr>
<tr>
<td>N6</td>
<td>1</td>
<td>n-channel MOSFET IRF7821 (8-pin SO)</td>
</tr>
<tr>
<td>N7</td>
<td>1</td>
<td>n-channel MOSFET 2N7002 (SOT23)</td>
</tr>
<tr>
<td>R1</td>
<td>1</td>
<td>3.16kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td>24.3kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R3, R13</td>
<td>2</td>
<td>10kΩ ±1% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R4</td>
<td>1</td>
<td>3.57kΩ ±5% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R5</td>
<td>1</td>
<td>3.0Ω ±5% resistor (0603)</td>
</tr>
<tr>
<td>R6, R7</td>
<td>2</td>
<td>1kΩ ±1% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R8</td>
<td>1</td>
<td>2.74kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R9</td>
<td>1</td>
<td>10kΩ ±5% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R10</td>
<td>1</td>
<td>44.2kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R11</td>
<td>1</td>
<td>14.7kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R12</td>
<td>1</td>
<td>2.0Ω ±5% resistor (0402 or 0603)</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 4. 1MHz Application Circuit with All Ceramic Capacitors and Sequenced Outputs
**Table 4. Component List for Figure 4**

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C14, C15</td>
<td>2</td>
<td>0.01µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C2, C16</td>
<td>2</td>
<td>1µF, 6.3V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C3, C4, C17, C18</td>
<td>4</td>
<td>10µF, 6.3V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C5, C12</td>
<td>2</td>
<td>1µF, 10V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C6</td>
<td>1</td>
<td>4.7µF, 10V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C7, C19</td>
<td>2</td>
<td>0.22µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C8, C21</td>
<td>2</td>
<td>820pF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C9, C10, C22, C23</td>
<td>4</td>
<td>47µF, 6.3V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C11, C24</td>
<td>2</td>
<td>0.1µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C13, C20</td>
<td>2</td>
<td>2200pF, 25V X7R ceramic capacitors</td>
</tr>
</tbody>
</table>

**DESIGNATION** | **QTY** | **DESCRIPTION** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2</td>
<td>2</td>
<td>0.2µH, 2.4mΩ inductors TOKO FDV0603-R20M</td>
</tr>
<tr>
<td>N1–N4</td>
<td>4</td>
<td>n-channel MOSFETs IRF7821 (8-pin SO)</td>
</tr>
<tr>
<td>N5</td>
<td>1</td>
<td>n-channel MOSFET 2N7002 (SOT23)</td>
</tr>
<tr>
<td>Q1</td>
<td>1</td>
<td>Transistor, bipolar, npn Central CMST3904</td>
</tr>
<tr>
<td>R1, R11</td>
<td>2</td>
<td>3.33kΩ ±1% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R2, R14</td>
<td>2</td>
<td>17.4kΩ ±1% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R3, R15</td>
<td>2</td>
<td>10kΩ ±1% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R4</td>
<td>1</td>
<td>3.16kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R5</td>
<td>1</td>
<td>10.0kΩ ±5% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R6, R13</td>
<td>2</td>
<td>2.0Ω ±5% resistors (0603)</td>
</tr>
<tr>
<td>R7, R8, R10</td>
<td>3</td>
<td>10kΩ ±5% resistors (0402 or 0603)</td>
</tr>
<tr>
<td>R9</td>
<td>1</td>
<td>47kΩ ±5% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R12</td>
<td>1</td>
<td>22.6kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R16</td>
<td>1</td>
<td>6.34kΩ ±1% resistor (0402 or 0603)</td>
</tr>
</tbody>
</table>
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 5. 300kHz Circuit with 7.2V to 20V Input
**Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response**

**Table 5. Component List for Figure 5**

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C13</td>
<td>2</td>
<td>0.01µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C2, C3, C14, C15</td>
<td>4</td>
<td>10µF, 25V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C5</td>
<td>1</td>
<td>1µF, 25V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C6</td>
<td>1</td>
<td>1µF, 10V X5R ceramic capacitor</td>
</tr>
<tr>
<td>C7, C16</td>
<td>2</td>
<td>0.22µF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C8, C17</td>
<td>2</td>
<td>4700pF, 10V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C9, C18</td>
<td>2</td>
<td>470µF/2.5V POSCAP capacitors Sanyo 2R5TPD470M6</td>
</tr>
<tr>
<td>C10, C19</td>
<td>2</td>
<td>10µF, 6.3V X5R ceramic capacitors</td>
</tr>
<tr>
<td>C11, C20</td>
<td>2</td>
<td>1000pF, 25V X7R ceramic capacitors</td>
</tr>
<tr>
<td>C12</td>
<td>1</td>
<td>4.7µF, 10V X5R ceramic capacitor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QTY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2</td>
<td>2</td>
<td>1.43µH, 4.52mΩ inductors Panasonic ETQP3H1E4BFA</td>
</tr>
<tr>
<td>N1–N4</td>
<td>4</td>
<td>n-channel MOSFETs IRF7821 (8-pin SOs)</td>
</tr>
<tr>
<td>N5</td>
<td>1</td>
<td>n-channel MOSFET 2N7002 (SOT23)</td>
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<tr>
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<tr>
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<tr>
<td>R4</td>
<td>1</td>
<td>5.36kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R5, R10</td>
<td>2</td>
<td>2.0Ω ±5% resistors (1206)</td>
</tr>
<tr>
<td>R6</td>
<td>1</td>
<td>2.26kΩ ±1% resistor (0402 or 0603)</td>
</tr>
<tr>
<td>R7</td>
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</tr>
<tr>
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<td>R9</td>
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<td>25.5kΩ ±1% resistor (0402 or 0603)</td>
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<tr>
<td>R12</td>
<td>1</td>
<td>9.53kΩ ±1% resistor (0402 or 0603)</td>
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**Power-Up and Sequencing**

The MAX8664 features an OSC/EN12 input that is used both for setting the switching frequency and as an enable input for both controllers. A resistor from OSC/EN12 to GND sets the switching frequency, and when OSC/EN12 is high impedance, both controllers enter low-power shutdown mode. This is easily achieved with a transistor between the resistor and GND. Figure 6a shows the startup configuration with independent outputs. With REFIN2 connected to VCC, both controllers use the internal reference.

For tracking applications, connect REFIN2 to the center of a resistive voltage-divider between the output of controller 1 and GND. See Figure 6b. In this application, the output of regulator 2 tracks the output voltage of controller 1. The voltage-divider resistors set the VOUT2/VOUT1 ratio. A typical tracking application is for the VTT supply of DDR memory.

Figure 6c shows one method of sequencing the outputs. Output 1 rises first. When PWRGD goes high, the transistors allow the external reference to drive REFIN2 and output 2 rises. The circuit in Figure 6d functions similarly, except the enable signal is supplied externally instead of being driven by the PWRGD signal.

**Figure 6a. Two Independent Output Startup and Shutdown Waveforms**
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

Figure 6b. Ratiometric Tracking Startup and Shutdown Waveforms

Figure 6c. Sequencing Startup and Shutdown Waveforms
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**Design Procedure**

**Setting the Switching Frequency**
Connect a resistor from OSC/EN12 to GND to set the switching frequency between 100kHz and 1000kHz. Calculate the resistor value (R10 in Figures 2–5) as follows:

\[
R10 = \frac{2.24 \times 10^{10}}{f_s} \text{ (Ω)}
\]

**Inductor Selection**
There are several parameters that must be examined when determining which inductor is to be used. Input voltage, output voltage, load current, switching frequency, and LIR. LIR is the ratio of inductor-current ripple to maximum DC load current (I_{LOAD(MAX)}). A higher LIR value allows for a smaller inductor, but results in higher losses and higher output ripple. A good compromise between size and efficiency is an LIR of 0.3. Once all the parameters are chosen, the inductor value is determined as follows:

\[
L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_s \times I_{LOAD(MAX)} \times LIR}
\]

where \( f_s \) is the switching frequency. Choose a standard value inductor close to the calculated value. The exact inductor value is not critical and can be adjusted to make trade-offs among size, cost, and efficiency. Lower inductor values minimize size and cost, but they also increase the output ripple and reduce the efficiency due to higher peak currents. On the other hand, higher inductor values increase efficiency, but eventually resistive losses due to extra turns of wire exceed the benefit gained from lower AC current levels. This is especially true if the inductance is increased without also increasing the physical size of the inductor. Find a low-loss inductor having the lowest possible DC resistance that fits the allotted dimensions. The chosen inductor’s saturation current rating must exceed the peak inductor current determined as:

\[
I_{PEAK} = I_{LOAD(MAX)} + \frac{LIR}{2} \times I_{LOAD(MAX)}
\]

**Output Capacitor**
The key selection parameters for the output capacitor are the actual capacitance value, the equivalent series resistance (ESR), the equivalent series inductance (ESL), and the voltage-rating requirements. These parameters affect the overall stability, output voltage ripple, and transient response. The output ripple has three components: variations in the charge stored in the output capacitor, the voltage drop across the capacitor’s ESR, and ESL caused by the current into and out of the capacitor. The maximum output voltage ripple is estimated as follows:
The output voltage ripple as a consequence of the ESR, ESL, and output capacitance is:

\[
V_{\text{RIPPLE}} = V_{\text{RIPPLE(ESR)}} + V_{\text{RIPPLE(ESL)}} + V_{\text{RIPPLE(C)}}
\]

where \( V_{\text{RIPPLE(ESR)}} = \frac{I_{\text{P-P}} \times \text{ESR}}{L \times \text{ESL}} \)

\( V_{\text{RIPPLE(ESL)}} = \frac{V_{\text{IN}}}{L \times \text{ESL}} \times \text{ESL} \)

\( V_{\text{RIPPLE(C)}} = \frac{I_{\text{P-P}}}{8 \times C_{\text{OUT}} \times f_s} \)

These equations are suitable for initial capacitor selection, but final values should be chosen based on a prototype or evaluation circuit. As a general rule, a smaller ripple current results in less output-voltage ripple. Since the inductor ripple current is a factor of the inductor value and input voltage, the output-voltage ripple decreases with larger inductance, and increases with higher input voltages. Ceramic, tantalum, or aluminum polymer electrolytic capacitors are recommended. The aluminum electrolytic capacitor is the least expensive; however, it has higher ESR and ESL. To compensate for this, use a ceramic capacitor in parallel to reduce the switching ripple and noise. For reliable and safe operation, ensure that the capacitor’s voltage and ripple-current ratings exceed the calculated values.

The response to a load transient depends on the selected output capacitors. After a load transient, the output voltage instantly changes by \( \text{ESR} \times \Delta I_{\text{LOAD}} \). Before the controller can respond, the output voltage deviates further depending on the inductor and output capacitor values. After a short period of time (see the Typical Operating Characteristics), the controller responds by regulating the output voltage back to its nominal state. The controller response time depends on its closed-loop bandwidth. With a higher bandwidth, the response time is faster, thus preventing the output voltage from further deviation from its regulating value.

**Setting the Output Voltages and Voltage Positioning**

Figure 7 shows the feedback network used on the MAX8664. With this configuration, a portion of the feedback signal is sensed on the switched side of the inductor (\( \text{LX} \)), and the output voltage droops slightly as the load current is increased due to the DC resistance of the inductor (DCR). This allows the load regulation to be set to match the voltage droop during a load transient (voltage positioning), reducing the peak-to-peak output voltage deviation during a load transient, and reducing the output capacitance requirements.

To set the magnitude of the voltage positioning, select a value for \( R_2 \) in the 8kΩ to 24kΩ range, then calculate the value of \( R_1 \) as follows:

\[
R_1 = R_2 \times \left( \frac{I_{\text{OUT(MAX)}} \times \text{DCR}}{\Delta V_{\text{OUT(MAX)}}} \right)
\]

where \( I_{\text{OUT(MAX)}} \) is the maximum output current and \( \Delta V_{\text{OUT(MAX)}} \) is the maximum allowable droop in the output voltage at full load.
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To set the no-load output voltage (V_{OUT}), calculate the value of R3 as follows:

$$R3 = \left( \frac{V_{FB}}{V_{OUT} - V_{FB}} \right) \left( \frac{R1 \times R2}{R1 + R2} \right)$$

where V_{FB} is the feedback regulation voltage (0.6V when using the internal reference or V_{REFIN2} for external reference). If the desired output voltage is equal to the reference voltage (typical for tracking applications), R3 is not installed.

To achieve the lowest possible load regulation in applications where voltage positioning is not desired, R1 is not installed and R3 is calculated as follows:

$$R3 = \left( \frac{V_{FB}}{V_{OUT} - V_{FB}} \right) \times R2$$

Compensation

To ensure stable operation, connect a compensation capacitor (C_r) across the upper feedback resistor as shown in Figure 7. To find the value of this capacitor, follow the compensation design procedure below.

Choose a closed-loop bandwidth (f_c) that is less than 1/3 the switching frequency (f_s). Calculate the output double pole (f_o) as follows:

$$f_o = \frac{1}{2\pi \sqrt{L \times C_{OUT} \times R_{LOAD} + ESR}}$$

The FB peak-to-peak voltage ripple is:

$$V_{FB, RIPPLE} = \left( \frac{1}{1 + \frac{R2}{R1}} \right) \times \left( \frac{V_{OUT}}{1 + \frac{DCR}{R_{LOAD}} \times f_c} \right)$$

The output ripple voltage due to the ESR of the output capacitor, C_{OUT}, is:

$$V_{OUT, RIPPLE} = \frac{V_{OUT}}{V_{IN}} \left( \frac{V_{IN} - V_{OUT}}{L \times f_s} \right) \times \left( \frac{1}{ESR + \frac{1}{8 \times C_{0} \times f_s}} \right)$$

Target the feedback ripple in the 25mV to 60mV range. For high duty-cycle applications (> 70%), a feedback ripple of 25mV is recommended.

Finally, calculate the value of C_r as follows:

$$C_r = \frac{V_{OUT}}{V_{IN}} \left( \frac{V_{IN} - V_{OUT}}{R1 \times f_s \times \left( V_{FB, RIPPLE} - V_{OUT, RIPPLE} \right)} \right)$$

MOSFET Selection

Each output of the MAX8664 is capable of driving two to four external, logic-level, n-channel MOSFETs as the circuit switch elements. The key selection parameters are:

- On-resistance (R_{DS(ON)})—the lower, the better.
- Maximum Drain-to-Source Voltage (V_{DSS})—should be at least 20% higher than the input supply rail at the high-side MOSFET's drain.
- Gate charges (Q_g, Q_{gd}, Q_{gs})—the lower, the better.

For a 5V input application, choose MOSFETs with rated R_{DS(ON)} at V_{GS} ≤ 4.5V. With higher input voltages, the internal VL regulator provides 6.5V for gate drive in order to minimize the on-resistance for a wide range of MOSFETs.

For a good compromise between efficiency and cost, choose the high-side MOSFETs that have conduction losses equal to switching losses at nominal input voltage and output current. Low R_{DS(ON)} is preferred for low-side MOSFETs. Make sure that the low-side MOSFET(s) do not spuriously turn on due to dV/dt caused by the high-side MOSFET(s) turning on, as this would result in shoot-through current and degrade the efficiency. MOSFETs with a lower Q_{gd} / Q_{gs} ratio have higher immunity to dV/dt. For high-current applications, it is often preferable to parallel two MOSFETs rather than to use a single large MOSFET.

For proper thermal management, the power dissipation must be calculated at the desired maximum operating junction temperature, maximum output current, and worst-case input voltage. For the low-side MOSFET(s), the worst-case power dissipation occurs at the highest duty cycle (V_{IN(MAX)}). The low-side MOSFET(s) operate as zero voltage switches; therefore, major losses are the channel conduction loss (P_{LSCC}) and the body diode conduction loss (P_{LSDC}):

$$P_{LSCC(MAX)} = \left( 1 - \frac{V_{OUT}}{V_{IN(MAX)}} \right) \times I_{LOAD(MAX)} \times R_{DS(ON)}$$

Use R_{DS(ON)} at T_{J(MAX)}:

$$P_{LSDC(MAX)} = 2 \times I_{LOAD(MAX)} \times V_F \times t_D \times f_s$$

where V_F is the body diode forward-voltage drop, t_D is the dead time between high-side and low-side switching transitions (25ns typical), and f_s is the switching frequency.
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The high-side MOSFET(s) operate as duty-cycle control switches and have the following major losses: the channel conduction loss ($P_{HSCC}$), the overlapping switching loss ($P_{HSSW}$), and the drive loss ($P_{HSDR}$). The maximum power dissipation could occur either at $V_{IN(MAX)}$ or $V_{IN(MIN)}$:

$$P_{HSCC(MAX)} = \frac{V_{OUT}}{V_{IN(MIN)}} \times I_{LOAD(MAX)} \times R_{DS(ON)}$$

Use $R_{DS(ON)}$ at $T_{J(MAX)}$:

$$P_{HSSW(MAX)} = V_{IN(MAX)} \times I_{LOAD(MAX)} \times \frac{Q_{GD}}{I_{GATE}} \times f_{S}$$

where $I_{GATE}$ is the average DH driver output-current capability determined by:

$$I_{GATE} = \frac{0.5 \times V_{IL}}{R_{DS(ON)(DR)} + R_{GATE}}$$

where $R_{DS(ON)(DR)}$ is the DH driver’s on-resistance (see the Electrical Characteristics) and $R_{GATE}$ is the internal gate resistance of the MOSFET (~ 2Ω):

$$P_{HSDR} = Q_{G} \times V_{GS} \times f_{S} \times \frac{R_{GATE}}{R_{GATE} + R_{DS(ON)(DR)}}$$

where $V_{GS} \approx V_{VL}$.

The high-side MOSFET(s) do not have body diode conduction loss, unless the converter is sinking current. When sinking current, calculate this loss as $P_{HSDC(MAX)} = I_{LOAD(MAX)} \times V_{F} \times (2 \times t_{DT} + t_{WD}) \times f_{S}$, where $t_{WD}$ is about 130ns.

Allow an additional 20% for losses due to MOSFET output capacitances and low-side MOSFET body diode reverse-recovery charge dissipated in the high-side MOSFET(s). Refer to the MOSFET data sheet for thermal resistance specifications to calculate the PCB area needed to maintain the desired maximum operating junction temperature with the above calculated power dissipations.

**MOSFET Snubber Circuit**

Fast switching transitions cause ringing because of resonating circuit parasitic inductance and capacitance at the switching nodes. This high-frequency ringing occurs at LX’s rising and falling transitions and can interfere with circuit performance and generate EMI. To dampen this ringing, a series RC snubber circuit is added across each low-side switch. Below is the procedure for selecting the value of the series RC circuit.

Connect a scope probe to measure $V_{LX_\_}$ to GND and observe the ringing frequency, $f_{R}$.

Find the capacitor value (connected from $LX_\_$ to GND) that reduces the ringing frequency by half.

The circuit parasitic capacitance ($C_{PAR}$) at $LX_\_$ is then equal to 1/3 the value of the added capacitance above. The circuit parasitic inductance ($L_{PAR}$) is calculated by:

$$L_{PAR} = \frac{1}{\left(2 \pi f_{R}\right)^2} \times C_{PAR}$$

The resistor for critical dampening ($R_{SNUB}$) is equal to $2 \pi \times f_{R} \times L_{PAR}$. Adjust the resistor value up or down to tailor the desired damping and the peak-voltage excursion.

The capacitor ($C_{SNUB}$) should be at least 2 to 4 times the value of the $C_{PAR}$ to be effective. The power loss of the snubber circuit is dissipated in the resistor ($P_{RSNUB}$) and can be calculated as:

$$P_{RSNUB} = C_{SNUB} \times (V_{IN})^2 \times f_{SW}$$

where $V_{IN}$ is the input voltage and $f_{SW}$ is the switching frequency. Choose an $R_{SNUB}$ power rating that meets the specific application’s derating rule for the power dissipation calculated.

**Setting the Overcurrent Threshold**

Connect a resistor from $ILIM_\_$ to the drain of the high-side MOSFET(s) to set the overcurrent protection threshold. $ILIM_\_$ sinks 50µA (typ) through this resistor. When the drain-source voltage exceeds the voltage drop across this resistor during the high-side MOSFET(s) on-time, overcurrent protection is triggered. To set the output current level where overcurrent protection is triggered ($ILIMIT$), calculate the value of the $ILIM_\_$ resistor as follows:

$$R_{ILIM_\_} = \frac{R_{DS(ON)HS} \times ILIMIT}{50 \mu A}$$

where $R_{DS(ON)HS}$ is the maximum on-resistance of the high-side MOSFET(s) at +25°C. At higher temperatures, the $ILIM_\_$ current increases to compensate for the temperature coefficient of the high-side MOSFET(s).
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**Input Capacitor**

The input filter capacitors reduce peak currents drawn from the power source and reduce noise and voltage ripple on the input caused by the circuit’s switching. The input capacitors must meet the ripple current requirement (I_{RMS}) imposed by the switching currents. The ripple current requirement can be estimated by the following equation:

\[
I_{\text{RMS}} = \frac{1}{\text{Vin}} \sqrt{(V_{\text{OUT1}})^2 \times (V_{\text{IN}} - V_{\text{OUT1}})^2 + (V_{\text{OUT2}})^2 \times (V_{\text{IN}} - V_{\text{OUT2}})^2}
\]

Choose a capacitor that exhibits less than 10°C temperature rise at the maximum operating RMS current for optimum long-term reliability.

**Applications Information**

**PCB Layout Guidelines**

Careful PCB layout is an important factor in achieving low switching losses and clean, stable operation. The switching power stage requires particular attention. Follow these guidelines for good PCB layout:

1) A multilayer PCB is recommended.

2) Place IC decoupling capacitors as close as possible to the IC pins. Keep separate power ground and signal ground planes. Place the low-side MOSFETs near the PGND pin. Arrange the high-side MOSFETs and low-side MOSFETs in such a way that the high-side MOSFET’s drain is close and near the low-side MOSFET’s source. This allows the input ceramic decoupling capacitor to be placed directly across and as close as possible to the high-MOSFET’s drain and the low-side MOSFET’s source. This helps contain the high switching current within this small loop.

3) Pour an analog ground plane in the second layer underneath the IC to minimize noise coupling.

4) Connect input, output, and VL capacitors to the power ground plane; connect all other capacitors to the signal ground plane.

5) Place the MOSFETs as close as possible to the IC to minimize trace inductance of the gate drive loop. If parallel MOSFETs are used, keep the trace lengths to both gates equal and short.

6) Connect the drain leads of the power MOSFET to a large copper area to help cool the device. Refer to the power MOSFET data sheet for recommended copper area.

7) Place the feedback network components as close as possible to the IC pins.

8) The current-limit setting RC should be Kelvin connected to the high-side MOSFETs’ drain. Refer to the MAX8664 evaluation kit for an example layout.
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

**Pin Configuration**

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<thead>
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<td>FB1 19</td>
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<td>PWRGD 18</td>
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<td>VCC 17</td>
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**Chip Information**

PROCESS: BiCMOS
Low-Cost, Dual-Output, Step-Down Controller with Fast Transient Response

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.)

- DRAWING NOT TO SCALE -

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