2A, 18V, 500kHz, ACOT™ Step-Down Converter

General Description
The RT6212A/B is a high-efficiency, monolithic synchronous step-down DC-DC converter that can deliver up to 2A output current from a 4.5V to 18V input supply. The RT6212A/B adopts ACOT architecture to allow the transient response to be improved and keep in constant frequency. Cycle-by-cycle current limit provides protection against shorted outputs and soft-start eliminates input current surge during start-up. Fault conditions also include output under-voltage protection, output over-current protection, and thermal shutdown.

Ordering Information

<table>
<thead>
<tr>
<th>Package Type</th>
<th>Lead Plating System</th>
<th>Reference Voltage</th>
<th>UVP Option</th>
<th>PSM/PWM</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>J6F : TSOT-23-6 (FC)</td>
<td>G : Green (Halogen Free and Pb Free)</td>
<td>None : VREF = 0.8V</td>
<td>H : Hiccup</td>
<td>A : PSM/PWM</td>
<td>Richtek products are:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R : VREF = 0.765V</td>
<td></td>
<td>B : Force-PWM</td>
<td>- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Suitable for use in SnPb or Pb-free soldering processes.</td>
</tr>
</tbody>
</table>

Features
- Integrated 163mΩ/86mΩ MOSFETs
- 4.5V to 18V Supply Voltage Range
- 500kHz Switching Frequency
- ACOT Control
- Feedback Reference Voltage 0.8V ± 1.5%
- Feedback Reference Voltage 0.765V ± 1.5%
- Internal Start-Up into Pre-Biased Outputs
- Compact Package : TSOT-23-6 Pin
- Input Under-Voltage Lockout
- Over-Current Protection and Hiccup

Applications
- Set-Top Boxes
- Portable TVs
- Access Point Routers
- DSL Modems
- LCD TVs

Marking Information

2W= : Product Code
DNN : Date Code
RT6212AHRGJ6F

2V= : Product Code
DNN : Date Code
RT6212BHRGJ6F

0B= : Product Code
DNN : Date Code
RT6212AHGJ6F

0A= : Product Code
DNN : Date Code
RT6212BHGJ6F

Simplified Application Circuit

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**Functional Pin Description**

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Pin Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>System ground. Provides the ground return path for the control circuitry and low-side power MOSFET.</td>
</tr>
<tr>
<td>2</td>
<td>LX</td>
<td>Switch node. LX is the switching node that supplies power to the output and connect the output LC filter from LX to the output load.</td>
</tr>
<tr>
<td>3</td>
<td>VIN</td>
<td>Power input. Supplies the power switches of the device.</td>
</tr>
<tr>
<td>4</td>
<td>FB</td>
<td>Feedback voltage input. This pin is used to set the desired output voltage via an external resistive divider. The feedback voltage is 0.765V/0.8V typically.</td>
</tr>
<tr>
<td>5</td>
<td>EN</td>
<td>Enable control input. Floating this pin or connecting this pin to GND can disable the device and connecting this pin to logic high can enable the device.</td>
</tr>
<tr>
<td>6</td>
<td>BOOT</td>
<td>Bootstrap supply for high-side gate driver. Connect a 100nF or greater capacitor from LX to BOOT to power the high-side switch.</td>
</tr>
</tbody>
</table>

**Functional Block Diagram**

The diagram illustrates the power stage and dead-time control of the device, including the shutdown comparator, UV protection, ripple generator, comparator, control, power stage, and dead-time control. The diagram also shows the connections for VIN, GND, LX, FB, EN, and BOOT.

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DS6212A/B-08 August 2018
Operation
The RT6212A/B is a synchronous step-down converter with advanced constant on-time control mode. Using the ACOT™ control mode can reduce the output capacitance and provide fast transient response. It can minimize the component size without additional external compensation network.

Soft-Start (SS)
The RT6212A/B provides an internal soft-start feature for inrush control. At power up, the internal capacitor is charged by an internal current source \( I_{SS} \) to generate a soft-start ramp voltage as a reference voltage to the PWM comparator. The device will initiate switching and the output voltage will smoothly ramp up to its targeted regulation voltage only after this ramp voltage is greater than the feedback voltage \( V_{FB} \). The output voltage starts to rise in 85\( \mu \)s from EN rising, and the soft-start ramp-up time \( (V_{FB} \text{ from } 0V \text{ to } V_{REF}) \) is 1ms.

UVLO Protection
To protect the chip from operating at insufficient supply voltage, the UVLO is needed. When the input voltage of \( V_{IN} \) is lower than the UVLO falling threshold voltage, the device will be lockout.

Thermal Shutdown
When the junction temperature exceeds the OTP threshold value, the IC will shut down the switching operation. Once the junction temperature cools down and is lower than the OTP lower threshold, the converter will automatically resume switching.

Output Under-Voltage Protection and Hiccup Mode
The RT6212A/B includes output under-voltage protection (UVP) against over-load or short-circuited condition by constantly monitoring the feedback voltage \( V_{FB} \). If \( V_{FB} \) drops below the under-voltage protection trip threshold (typically 50% of the internal feedback reference voltage), the UV comparator will go high to turn off both the internal high-side and low-side MOSFET switches.

If the output under-voltage condition continues for a period of time, the RT6212A/B will enter output under-voltage protection with hiccup mode. During hiccup mode, the IC will shut down for \( t_{HICCUP\_OFF} \) (3.6ms), and then attempt to recover automatically for \( t_{HICCUP\_ON} \) (1.2ms). Upon completion of the soft-start sequence, if the fault condition is removed, the converter will resume normal operation; otherwise, such cycle for auto-recovery will be repeated until the fault condition is cleared. Hiccup mode allows the circuit to operate safely with low input current and power dissipation, and then resume normal operation as soon as the over-load or short-circuit condition is removed.
Absolute Maximum Ratings  (Note 1)
- Supply Input Voltage ........................................... –0.3V to 20V
- Switch Node Voltage, LX ........................................ –0.3V to (VIN + 0.3V)
  < 50ns .................................................. –6V to 25V
- BOOT Pin Voltage ................................................ (VLX – 0.3V) to (VIN + 6.3V)
- Other Pins ........................................................ –0.3V to 6V
- Power Dissipation, PD @ TA = 25°C
  TSOT-23-6 (FC) ............................................... 1.667W
- Package Thermal Resistance  (Note 2)
  TSOT-23-6 (FC), θJA .................................................. 60°C/W
  TSOT-23-6 (FC), θJC .................................................. 8°C/W
- Lead Temperature (Soldering, 10 sec.) ......................... 260°C
- Junction Temperature ............................................ 150°C
- Storage Temperature Range ................................. –65°C to 150°C
- ESD Susceptibility  (Note 3)
  HBM (Human Body Model) ........................................... 2kV

Recommended Operating Conditions  (Note 4)
- Supply Input Voltage ........................................... 4.5V to 18V
- Ambient Temperature Range ................................... –40°C to 85°C
- Junction Temperature Range .................................. –40°C to 125°C

Electrical Characteristics
(VIN = 12V, TA = 25°C, unless otherwise specified)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>VIN</td>
<td>VIN Supply Input Operating Voltage</td>
<td>4.5</td>
<td>--</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Under-Voltage Lockout Threshold</td>
<td>UVLO</td>
<td>RT6212A/BHGJ6F</td>
<td>3.6</td>
<td>3.9</td>
<td>4.2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RT6212A/BHRGJ6F</td>
<td>3.45</td>
<td>3.75</td>
<td>4.05</td>
<td>V</td>
</tr>
<tr>
<td>Under-Voltage Lockout Threshold Hysteresis</td>
<td>ΔUVLO</td>
<td>--</td>
<td>340</td>
<td>--</td>
<td>mV</td>
<td></td>
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<tr>
<td>Shutdown Current</td>
<td>ISHDN</td>
<td>VEN = 0V</td>
<td>--</td>
<td>--</td>
<td>5</td>
<td>μA</td>
</tr>
<tr>
<td>Quiescent Current</td>
<td>IQ</td>
<td>VEN = 2V, VFB = 0.85V</td>
<td>--</td>
<td>0.5</td>
<td>--</td>
<td>mA</td>
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<tr>
<td>Soft-Start</td>
<td></td>
<td></td>
<td>--</td>
<td>1000</td>
<td>--</td>
<td>μs</td>
</tr>
<tr>
<td>Enable Voltage</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Enable Voltage Threshold</td>
<td>VEN_R</td>
<td>VEN rising, RT6212A/BHGJ6F</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>V</td>
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<tr>
<td></td>
<td>VEN_F</td>
<td>VEN falling, RT6212A/BHGJ6F</td>
<td>1.18</td>
<td>1.28</td>
<td>1.38</td>
<td>V</td>
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<tr>
<td></td>
<td>VEN_R</td>
<td>VEN rising, RT6212A/BHRGJ6F</td>
<td>1.33</td>
<td>1.43</td>
<td>1.53</td>
<td>V</td>
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<tr>
<td>Parameter</td>
<td>Symbol</td>
<td>Test Conditions</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Unit</td>
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<td>---------------------------------</td>
<td>--------------</td>
<td>------------------------------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Feedback Voltage</td>
<td>V&lt;sub&gt;EN_F&lt;/sub&gt;</td>
<td>V&lt;sub&gt;EN&lt;/sub&gt; falling, RT6212A/BHRGJ6F</td>
<td>1.11</td>
<td>1.21</td>
<td>1.31</td>
<td></td>
</tr>
</tbody>
</table>

**Feedback Reference Voltage**

<table>
<thead>
<tr>
<th></th>
<th>V&lt;sub&gt;REF&lt;/sub&gt;</th>
<th>4.5V ≤ V&lt;sub&gt;IN&lt;/sub&gt; ≤ 18V, RT6212A/BHRGJ6F</th>
<th>0.788</th>
<th>0.8</th>
<th>0.812</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4.5V ≤ V&lt;sub&gt;IN&lt;/sub&gt; ≤ 18V, RT6212A/BHRGJ6F</td>
<td>0.753</td>
<td>0.765</td>
<td>0.777</td>
<td></td>
</tr>
</tbody>
</table>

**Internal MOSFET**

**High-Side On-Resistance**

| R<sub>DS(ON)_H</sub> | VBOOT − V<sub>LX</sub> = 4.8V | -- | 163 | -- | mΩ |

**Low-Side On-Resistance**

| R<sub>DS(ON)_L</sub> | -- | 86 | -- |      |

**Current Limit**

**High-Side Switch Current Limit**

| I<sub>LIM_H</sub> | -- | 5.8 | -- | A |

**Low-Side Switch Valley Current Limit**

| I<sub>LIM_L</sub> | 2.6 | 3.3 | -- |      |

**Switching Frequency**

| f<sub>SW</sub> | 400 | 500 | 640 | kHz |

**On-Time Timer Control**

**Minimum On-Time**

| t<sub>ON_MIN</sub> | 35 | 60 | 85 | ns |

**Minimum Off-Time**

| t<sub>OFF_MIN</sub> | 185 | 240 | 315 |    |

**Output Under-Voltage and Over-Voltage Protections**

**OVP Trip Threshold**

| OVP detect | -- | 125 | -- | % |

**OVP Propagation Delay**

| -- | 10 | -- | µs |

**UVP Trip Threshold**

| UVP detect | 45 | 50 | 55 | % |

| Hysteresis | -- | 10 | -- |    |

**UVP Propagation Delay**

| -- | 5 | -- | µs |

**Thermal Shutdown**

**Thermal Shutdown Threshold**

| T<sub>SD</sub> | -- | 150 | -- | °C |

**Thermal Shutdown Hysteresis**

| ΔT<sub>SD</sub> | -- | 20 | -- |    |

**Note 1.** 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 may affect device reliability.

**Note 2.** θ<sub>JA</sub> is measured under natural convection (still air) at T<sub>A</sub> = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. The first layer is filled with copper. θ<sub>JA</sub> is measured at the lead of the package.

**Note 3.** Devices are ESD sensitive. Handling precaution recommended.

**Note 4.** The device is not guaranteed to function outside its operating conditions.
Table 1. Recommended Components Selection (RT6212A/BHGJ6F)

<table>
<thead>
<tr>
<th>V&lt;sub&gt;OUT&lt;/sub&gt; (V)</th>
<th>R1 (kΩ)</th>
<th>R2 (kΩ)</th>
<th>C&lt;sub&gt;FF&lt;/sub&gt; (pF)</th>
<th>L (μH)</th>
<th>C&lt;sub&gt;OUT&lt;/sub&gt; (μF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>126</td>
<td>24</td>
<td>10 to 22</td>
<td>4.7</td>
<td>22</td>
</tr>
<tr>
<td>3.3</td>
<td>75</td>
<td>24</td>
<td>10 to 22</td>
<td>3.6</td>
<td>22</td>
</tr>
<tr>
<td>2.5</td>
<td>51</td>
<td>24</td>
<td>10 to 22</td>
<td>3.6</td>
<td>22</td>
</tr>
<tr>
<td>1.8</td>
<td>30</td>
<td>24</td>
<td>10 to 22</td>
<td>2.2</td>
<td>22</td>
</tr>
<tr>
<td>1.5</td>
<td>21</td>
<td>24</td>
<td>--</td>
<td>2.2</td>
<td>22</td>
</tr>
<tr>
<td>1.2</td>
<td>12</td>
<td>24</td>
<td>--</td>
<td>2.2</td>
<td>22</td>
</tr>
<tr>
<td>1.0</td>
<td>6</td>
<td>24</td>
<td>--</td>
<td>2.2</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 2. Recommended Components Selection (RT6212A/BHRGJ6F)

<table>
<thead>
<tr>
<th>V&lt;sub&gt;OUT&lt;/sub&gt; (V)</th>
<th>R1 (kΩ)</th>
<th>R2 (kΩ)</th>
<th>C&lt;sub&gt;FF&lt;/sub&gt; (pF)</th>
<th>L (μH)</th>
<th>C&lt;sub&gt;OUT&lt;/sub&gt; (μF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>133</td>
<td>24</td>
<td>10 to 22</td>
<td>4.7</td>
<td>22</td>
</tr>
<tr>
<td>3.3</td>
<td>80.6</td>
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<td>10 to 22</td>
<td>3.6</td>
<td>22</td>
</tr>
<tr>
<td>2.5</td>
<td>54.9</td>
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<td>3.6</td>
<td>22</td>
</tr>
<tr>
<td>1.8</td>
<td>32.5</td>
<td>24</td>
<td>10 to 22</td>
<td>2.2</td>
<td>22</td>
</tr>
<tr>
<td>1.5</td>
<td>23.2</td>
<td>24</td>
<td>--</td>
<td>2.2</td>
<td>22</td>
</tr>
<tr>
<td>1.2</td>
<td>13.7</td>
<td>24</td>
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<td>2.2</td>
<td>22</td>
</tr>
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<td>1.0</td>
<td>7.5</td>
<td>24</td>
<td>--</td>
<td>2.2</td>
<td>22</td>
</tr>
</tbody>
</table>
Typical Operating Characteristics

**Efficiency vs. Output Current**

- **RT6212A**, $V_{OUT} = 1.2V$
  - $V_{IN} = 4.5V$
  - $V_{IN} = 12V$
  - $V_{IN} = 18V$

- **RT6212B**, $V_{OUT} = 1.2V$
  - $V_{IN} = 4.5V$
  - $V_{IN} = 12V$
  - $V_{IN} = 18V$

**Efficiency vs. Output Current**

- **RT6212A**, $V_{IN} = 12V$
  - $V_{OUT} = 5V$
  - $V_{OUT} = 3.3V$
  - $V_{OUT} = 1.2V$

- **RT6212B**, $V_{IN} = 12V$
  - $V_{OUT} = 5V$
  - $V_{OUT} = 3.3V$
  - $V_{OUT} = 1.2V$

**Output Voltage vs. Output Current**

- **RT6212A**
  - $V_{IN} = 12V$, $V_{OUT} = 1.2V$

- **RT6212B**
  - $V_{IN} = 12V$, $V_{OUT} = 1.2V$

**Output Voltage vs. Input Voltage**

- **$I_{OUT} = 1A$**
  - $V_{OUT} = 1.23V$

- **$I_{OUT} = 2A$**
  - $V_{OUT} = 1.22V$
  - $V_{OUT} = 1.20V$
  - $V_{OUT} = 1.19V$
Switching Frequency vs. Output Current

Switching Frequency vs. Temperature

Feedback Voltage vs. Input Voltage

Feedback Voltage vs. Temperature
Inductor Valley Current Limit vs. Input Voltage

Inductor Valley Current Limit vs. Temperature

Shutdown Current vs. Input Voltage

Shutdown Current vs. Temperature

Quiescent Current vs. Input Voltage

Quiescent Current vs. Temperature
**Input UVLO vs. Temperature**

- **RT6212A/BHGJ6F**
- **Rising**
- **Falling**

**Enable Threshold vs. Temperature**

- **RT6212A/BHGJ6F**
- **Rising**
- **Falling**

**Input UVLO vs. Temperature**

- **RT6212A/BHRGJ6F**
- **Rising**
- **Falling**

**Enable Threshold vs. Temperature**

- **RT6212A/BHRGJ6F**
- **Rising**
- **Falling**

**Load Transient Response**

- **RT6212A**
- **RT6212B**

Input and output specifications:

- **VIN = 12V, VOUT = 1.2V, IOUT = 0 to 2A**
- **VOUT (100mV/Div)**
- **IOUT (1A/Div)**
- **Time (100μs/Div)**
VIN = 12V, VOUT = 1.2V, IOUT = 1A
Voltage Ripple
Time (1μs/Div)

VIN = 12V, VOUT = 1.2V, IOUT = 2A
Voltage Ripple
Time (1μs/Div)

VIN = 12V, VOUT = 1.2V, IOUT = 2A
Power On from Input Voltage
Time (2.5ms/Div)

VIN = 12V, VOUT = 1.2V, IOUT = 2A
Power Off from Input Voltage
Time (25ms/Div)

VIN = 12V, VOUT = 1.2V, IOUT = 2A
Power On from Enable
Time (2.5ms/Div)

VIN = 12V, VOUT = 1.2V, IOUT = 2A
Power Off from Enable
Time (2.5ms/Div)
Application Information

Inductor Selection

Selecting an inductor involves specifying its inductance and also its required peak current. The exact inductor value is generally flexible and is ultimately chosen to obtain the best mix of cost, physical size, and circuit efficiency. Lower inductor values benefit from reduced size and cost and they can improve the circuit's transient response, but they increase the inductor ripple current and output voltage ripple and reduce the efficiency due to the resulting higher peak currents. Conversely, higher inductor values increase efficiency, but the inductor will either be physically larger or have higher resistance since more turns of wire are required and transient response will be slower since more time is required to change current (up or down) in the inductor. A good compromise between size, efficiency, and transient response is to use a ripple current (ΔIL) about 30% of the desired full output load current. Calculate the approximate inductor value by selecting the input and output voltages, the switching frequency (fSW), the maximum output current (IOUT(MAX)) and estimating a ΔIL as some percentage of that current.

\[
L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_{SW} \times \Delta I_L}
\]

Once an inductor value is chosen, the ripple current (ΔIL) is calculated to determine the required peak inductor current.

\[
\Delta I_L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_{SW} \times L} \quad \text{and} \quad I_{L(PEAK)} = I_{OUT(MAX)} + \frac{\Delta I_L}{2}
\]

To guarantee the required output current, the inductor needs a saturation current rating and a thermal rating that exceeds I_{L(PEAK)}. These are minimum requirements. To maintain control of inductor current in overload and short circuit conditions, some applications may desire current ratings up to the current limit value. However, the IC's output under-voltage shutdown feature make this unnecessary for most applications.

I_{L(PEAK)} should not exceed the minimum value of IC's upper current limit level or the IC may not be able to meet the desired output current. If needed, reduce the inductor ripple current (ΔIL) to increase the average inductor current (and the output current) while ensuring that I_{L(PEAK)} does not exceed the upper current limit level.

For best efficiency, choose an inductor with a low DC resistance that meets the cost and size requirements. For low inductor core losses some type of ferrite core is usually best and a shielded core type, although possibly larger or more expensive, will probably give fewer EMI and other noise problems.

Considering the Typical Operating Circuit for 1.2V output at 2A and an input voltage of 12V, using an inductor ripple of 1A (50%), the calculated inductance value is:

\[
L = \frac{1.2 \times (12 - 1.2)}{12 \times 500kHz \times 1A} = 2.16\mu H
\]

The ripple current was selected at 1A and, as long as we use the calculated 2.16μH inductance, that should be the actual ripple current amount. The ripple current and required peak current as below:

\[
\Delta I_L = \frac{1.2 \times (12 - 1.2)}{12 \times 500kHz \times 2.16\mu H} = 1A
\]

and \(I_{L(PEAK)} = 2A + \frac{1A}{2} = 2.5A\)

For the 2.16μH value, the inductor's saturation and thermal rating should exceed at least 2.5A. For more conservative, the rating for inductor saturation current must be equal to or greater than switch current limit of the device rather than the inductor peak current.

Input Capacitor Selection

The input filter capacitors are needed to smooth out the switched current drawn from the input power source and to reduce voltage ripple on the input. The actual capacitance value is less important than the RMS current rating (and voltage rating, of course). The RMS input ripple current (IRMS) is a function of the input voltage, output voltage, and load current:

\[
I_{RMS} = I_{OUT(MAX)} \times \frac{V_{OUT}}{V_{IN}} \sqrt{\frac{V_{IN}}{V_{OUT}} - 1}
\]
Ceramic capacitors are most often used because of their low cost, small size, high RMS current ratings, and robust surge current capabilities. However, take care when these capacitors are used at the input of circuits supplied by a wall adapter or other supply connected through long, thin wires. Current surges through the inductive wires can induce ringing at the RT6212A/B input which could potentially cause large, damaging voltage spikes at VIN. If this phenomenon is observed, some bulk input capacitance may be required. Ceramic capacitors (to meet the RMS current requirement) can be placed in parallel with other types such as tantalum, electrolytic, or polymer (to reduce ringing and overshoot).

Choose capacitors rated at higher temperatures than required. Several ceramic capacitors may be paralleled to meet the RMS current, size, and height requirements of the application. The typical operating circuit uses 22μF and 0.1μF low ESR ceramic capacitors on the input.

Output Capacitor Selection

The RT6212A/B are optimized for ceramic output capacitors and best performance will be obtained using them. The total output capacitance value is usually determined by the desired output voltage ripple level and transient response requirements for sag (undershoot on positive load steps) and soar (overshoot on negative load steps).

Output Ripple

Output ripple at the switching frequency is caused by the inductor current ripple and its effect on the output capacitor’s ESR and stored charge. These two ripple components are called ESR ripple and capacitive ripple. Since ceramic capacitors have extremely low ESR and relatively little capacitance, both components are similar in amplitude and both should be considered if ripple is critical.

\[ V_{\text{RIPPLE}} = V_{\text{RIPPLE(ESR)}} + V_{\text{RIPPLE(C)}} \]
\[ V_{\text{RIPPLE(ESR)}} = \Delta I \times \text{ESR} \]
\[ V_{\text{RIPPLE(C)}} = \frac{\Delta I}{8 \times C_{\text{OUT}} \times f_{\text{SW}}} \]

For the Typical Operating Circuit for 1.2V output and an inductor ripple of 1A, with 1 x 22μF output capacitance each with about 5mΩ ESR including PCB trace resistance, the output voltage ripple components are:

\[ V_{\text{RIPPLE(ESR)}} = 1A \times 5\text{mΩ} = 5\text{mV} \]
\[ V_{\text{RIPPLE(C)}} = \frac{1A}{8 \times 22\mu\text{F} \times 500\text{kHz}} = 11.4\text{mV} \]
\[ V_{\text{RIPPLE}} = 5\text{mV} + 11.4\text{mV} = 16.4\text{mV} \]

Output Transient Undershoot and Overshoot

In addition to voltage ripple at the switching frequency, the output capacitor and its ESR also affect the voltage sag (undershoot) and soar (overshoot) when the load steps up and down abruptly. The ACOT transient response is very quick and output transients are usually small.

However, the combination of small ceramic output capacitors (with little capacitance), low output voltages (with little stored charge in the output capacitors), and low duty cycle applications (which require high inductance to get reasonable ripple currents with high input voltages) increases the size of voltage variations in response to very quick load changes. Typically, load changes occur slowly with respect to the IC’s 500kHz switching frequency.

But some modern digital loads can exhibit nearly instantaneous load changes and the following section shows how to calculate the worst-case voltage swings in response to very fast load steps.

The output voltage transient undershoot and overshoot each have two components: the voltage steps caused by the output capacitor’s ESR, and the voltage sag and soar due to the finite output capacitance and the inductor current slew rate. Use the following formulas to check if the ESR is low enough (typically not a problem with ceramic capacitors) and the output capacitance is large enough to prevent excessive sag and soar on very fast load step edges, with the chosen inductor value.

\[ V_{\text{RIPPLE(ESR)}} = \Delta I \times \text{ESR} \]
\[ V_{\text{RIPPLE(C)}} = \frac{\Delta I}{8 \times C_{\text{OUT}} \times f_{\text{SW}}} \]

\[ V_{\text{TOTAL}} = V_{\text{ESR}} + V_{\text{C}} \]

\[ V_{\text{ESR}} = \frac{\Delta I}{\text{ESR}} \]
\[ V_{\text{C}} = \frac{\Delta I}{8 \times C \times f_{\text{SW}}} \]
The amplitude of the ESR step up or down is a function of the load step and the ESR of the output capacitor:

\[ V_{\text{ESR \_STEP}} = \Delta I_{\text{OUT}} \times R_{\text{ESR}} \]

The amplitude of the capacitive sag is a function of the load step, the output capacitor value, the inductor value, the input-to-output voltage differential, and the maximum duty cycle. The maximum duty cycle during a fast transient is a function of the on-time and the minimum off-time since the ACOT™ control scheme will ramp the current using on-times spaced apart with minimum off-times, which is as fast as allowed. Calculate the approximate on-time (neglecting parasites) and maximum duty cycle for a given input and output voltage as:

\[ t_{\text{ON}} = \frac{V_{\text{OUT}}}{V_{\text{IN}} \times f_{\text{SW}}} \quad \text{and} \quad D_{\text{MAX}} = \frac{t_{\text{ON}}}{t_{\text{ON}} + t_{\text{OFF \_MIN}}} \]

The actual on-time will be slightly longer as the IC compensates for voltage drops in the circuit, but we can neglect both of these since the on-time increase compensates for the voltage losses. Calculate the output voltage sag as:

\[ V_{\text{SAG}} = \frac{L \times (\Delta I_{\text{OUT}})^2}{2 \times C_{\text{OUT}} \times (V_{\text{IN}}(\text{MIN}) \times D_{\text{MAX}} - V_{\text{OUT}})} \]

The amplitude of the capacitive soar is a function of the load step, the output capacitor value, the inductor value and the output voltage:

\[ V_{\text{SOAR}} = \frac{L \times (\Delta I_{\text{OUT}})^2}{2 \times C_{\text{OUT}} \times V_{\text{OUT}}} \]

For the Typical Operating Circuit for 1.2V output, the circuit has an inductor 2.16μH and 1 x 22μF output capacitance with 5mΩ ESR each. The ESR step is 2A x 5mΩ = 10mV which is small, as expected. The output voltage sag and soar in response to full 0A-2A-0A instantaneous transients are:

\[ V_{\text{SAG}} = \frac{2.16\mu H \times (2A)^2}{2 \times 22\mu F \times (12V \times 0.455 - 1.2V)} = 46.1mV \]

\[ V_{\text{SOAR}} = \frac{2.16\mu H \times (2A)^2}{2 \times 22\mu F \times 1.2V} = 163.6mV \]

The sag is about 3.84% of the output voltage and the soar is a full 13.6% of the output voltage. The ESR step is negligible here but it does partially add to the soar, so keep that in mind whenever using higher-ESR output capacitors.

The soar is typically much worse than the sag in high input, low-output step-down converters because the high input voltage demands a large inductor value which stores lots of energy that is all transferred into the output if the load stops drawing current. Also, for a given inductor, the soar for a low output voltage is a greater voltage change and an even greater percentage of the output voltage.

Any sag is always short-lived, since the circuit quickly sources current to regain regulation in only a few switching cycles. With the RT6212B, any overshoot transient is typically also short-lived since the converter will sink current, reversing the inductor current sharply until the output reaches regulation again. The RT6212A discontinuous operation at light loads prevents sinking current so, for that IC, the output voltage will soar until load current or leakage brings the voltage down to normal.

Most applications never experience instantaneous full load steps and the RT6212A/B high switching frequency and fast transient response can easily control voltage regulation at all times. Also, since the sag and soar both are proportional to the square of the load change, if load steps were reduced to 1A (from the 2A examples preceding) the voltage changes would be reduced by a factor of almost ten. For these reasons sag and soar are seldom an issue except in very low-voltage CPU core or DDR memory supply applications, particularly for devices with high clock frequencies and quick changes into and out of sleep modes. In such applications, simply increasing the amount of ceramic output capacitor (sag and soar are directly proportional to capacitance) or adding extra bulk capacitance can easily eliminate any excessive voltage transients.
In any application with large quick transients, always calculate soar to make sure that over-voltage protection will not be triggered. Under-voltage is not likely since the threshold is very low (50%), that function has a long delay (5μs), and the IC will quickly return the output to regulation. Over-voltage protection has a minimum threshold of 125% and short delay of 10μs and can actually be triggered by incorrect component choices, particularly for the RT6212A which does not sink current.

Feed-Forward Capacitor (CFF)
The RT6212A/B are optimized for ceramic output capacitors and for low duty cycle applications. However for high-output voltages, with high feedback attenuation, the circuit’s response becomes over-damped and transient response can be slowed. In high-output voltage circuits (VOUT > 1.8V) transient response is improved by adding a small “feed-forward” capacitor (CFF) across the upper FB divider resistor (Figure 1), to increase the circuit's Q and reduce damping to speed up the transient response without affecting the steady-state stability of the circuit. Choose a suitable capacitor value that following below step.

1. Get the BW the quickest method to do transient response from 30% load to 60% load. Confirm the damping frequency. The damping frequency is BW.

2. CFF can be calculated base on below equation:

\[
C_{FF} = \frac{1}{2 \times 3.1412 \times R_1 \times BW \times 0.8}
\]

\[
C_{FF} = \frac{1}{2 \times 3.1412 \times R_1 \times BW \times 0.765}
\]

Enable Operation (EN)
For automatic start-up the low-voltage EN pin can be connected to VIN through a 100kΩ resistor. Its large hysteresis band makes EN useful for simple delay and timing circuits. EN can be externally pulled to VIN by adding a resistor-capacitor delay (REN and CEN in Figure 2). Calculate the delay time using EN's internal threshold where switching operation begins (1.5V/1.43V, typical).

An external MOSFET can be added to implement digital control of EN when no system voltage above 2V is available (Figure 3). In this case, a 100kΩ pull-up resistor, REN, is connected between VIN and the EN pin. MOSFET Q1 will be under logic control to pull down the EN pin. To prevent enabling circuit when VIN is smaller than the VOUT target value or some other desired voltage level, a resistive voltage divider can be placed between the input voltage and ground and connected to EN to create an additional input under voltage lockout threshold (Figure 4).
Output Voltage Setting

Set the desired output voltage using a resistive divider from the output to ground with the midpoint connected to FB. The output voltage is set according to the following equations:

\[ V_{OUT} = 0.8V \times (1 + \frac{R1}{R2}) \]
\[ V_{OUT} = 0.765V \times (1 + \frac{R1}{R2}) \]

Place the FB resistors within 5mm of the FB pin. Choose \( R2 \) between 10k\( \Omega \) and 100k\( \Omega \) to minimize power consumption without excessive noise pick-up and calculate \( R1 \) as follows:

\[ R1 = \frac{R2 \times (V_{OUT} - V_{REF})}{V_{REF}} \]

For output voltage accuracy, use divider resistors with 1% or better tolerance.

External BOOT Bootstrap Diode

When the input voltage is lower than 5.5V it is recommended to add an external bootstrap diode between VIN (or VINR) and the BOOT pin to improve enhancement of the internal MOSFET switch and improve efficiency. The bootstrap diode can be a low cost one such as 1N4148 or BAT54.

External BOOT Capacitor Series Resistance

The internal power MOSFET switch gate driver is optimized to turn the switch on fast enough for low power loss and good efficiency, but also slow enough to reduce EMI. Switch turn-on is when most EMI occurs since \( V_{LX} \) rises rapidly. During switch turn-off, \( LX \) is discharged relatively slowly by the inductor current during the dead time between high-side and low-side switch on-times. In some cases it is desirable to reduce EMI further, at the expense of some additional power dissipation. The switch turn-on can be slowed by placing a small (<47\( \Omega \)) resistance between BOOT and the external bootstrap capacitor. This will slow the high-side switch turn-on and \( V_{LX} \)’s rise. To remove the resistor from the capacitor charging path (avoiding poor enhancement due to undercharging the BOOT capacitor), use the external diode shown in Figure 6 to charge the BOOT capacitor and place the resistance between BOOT and the capacitor/diode connection.

Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature \( T_{J(MAX)} \), listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula:

\[ P_{D(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JA}} \]

where \( T_{J(MAX)} \) is the maximum junction temperature, \( T_A \) is the ambient temperature, and \( \theta_{JA} \) is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, \( \theta_{JA} \), is highly package dependent. For a TSOT-23-6 (FC) package, the thermal resistance, \( \theta_{JA} \), is 60°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The
maximum power dissipation at $T_A = 25^\circ C$ can be calculated as below:

$$P_{D\,(MAX)} = \frac{(125^\circ C - 25^\circ C)}{(60^\circ C/W)} = 1.667\,W$$

for a TSOT-23-6 (FC) package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J\,(MAX)}$ and the thermal resistance, $\theta_{JA}$. The derating curve in Figure 7 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

**Layout Considerations**

Follow the PCB layout guidelines for optimal performance of the device.

- Keep the high-current paths short, especially at the ground terminals. This practice is essential for stable, jitter-free operation. The high current path comprising of input capacitor, high-side FET, inductor, and the output capacitor should be as short as possible. This practice is essential for high efficiency.

- Place the input MLCC capacitors as close to the VIN and GND pins as possible. The major MLCC capacitors should be placed on the same layer as the RT6212A/B.

- LX node is with high frequency voltage swing and should be kept at small area. Keep analog components away from the LX node to prevent stray capacitive noise pickup.

- Connect feedback network behind the output capacitors. Place the feedback components next to the FB pin.

- For better thermal performance, to design a wide and thick plane for GND pin or to add a lot of vias to GND plane.

An example of PCB layout guide is shown from Figure 8.
Keep the LX node at small area and keep analog components away from the LX node to prevent stray capacitive noise pickup.

The VIN trace should have enough width, and use several vias to shunt the high input current.

Connect feedback network behind the output.

Put the input MLCC capacitors as close to VIN pin and GND pins as possible.

Add extra vias for thermal dissipation.

Place the feedback components next to the FB pin.

Figure 8. PCB Layout Guide
### Outline Dimension

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<th>Symbol</th>
<th>Dimensions In Millimeters</th>
<th>Dimensions In Inches</th>
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TSOT-23-6 (FC) Surface Mount Package

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