High Voltage High Current LED Driver Controller for Buck, Boost or Buck-Boost Topology

General Description
The RT8496 is a current-mode PWM controller designed to drive an external MOSFET for high current LED applications. With a current sense amplifier threshold of 315mV, the LED current is adjustable with one external current sense resistor. With the maximum operating input voltage of 36V and output voltage up to 150V, the RT8496 is ideal for Buck, Boost or Buck-Boost operation.

With the switching frequency programmable over 100kHz to 1MHz, the external inductor and capacitors can be small while maintaining high efficiency.

Dimming can be done by either analog or digital. The built-in clamping comparator and filter allow easy low noise analog dimming conversion from digital signal with only one external capacitor.

The RT8496 is available in the SOP-14 package.

Applications
- General Industrial High Power LED Lighting
- Desk Lights and Room Lighting
- Building and Street Lighting
- Industrial Display Backlight

Features
- High Voltage Capability : $V_{IN}$ Up to 36V, LED Sensing Threshold Common Mode Voltage Up to 150V
- Buck, Boost or Buck-Boost Operation
- Adjustable Switching Frequency
- Easy Dimming Control : Analog or Digital Converting to Analog with One External Capacitor
- Adjustable Soft-Start to Avoid Inrush Current
- Adjustable Over-Voltage Protection
- $V_{IN}$ Under-Voltage Lockout and Thermal Shutdown

Ordering Information
RT8496

Package Type
S : SOP-14

Lead Plating System
G : Green (Halogen Free and Pb Free)

Note:
Richtek products are:
- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

Simplified Application Circuit
## 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>RSET</td>
<td>Switching frequency setting. Connect a resistor from RSET to GND. $R_{RSET} = 30, \text{k}\Omega$ will set $f_{SW} = 360, \text{kHz}$.</td>
</tr>
<tr>
<td>2</td>
<td>ISW</td>
<td>Current sense for external MOSFET switch. Connect the current sense resistor between external N-MOSFET switch and the ground.</td>
</tr>
<tr>
<td>3</td>
<td>ISP</td>
<td>LED current sense amplifier positive input with common mode up to 150V.</td>
</tr>
<tr>
<td>4</td>
<td>ISN</td>
<td>LED current sense amplifier negative input. Voltage threshold between ISP and ISN is 315mV with common mode voltage up to 150V.</td>
</tr>
<tr>
<td>5</td>
<td>VC</td>
<td>Compensation node for PWM control loop.</td>
</tr>
<tr>
<td>6</td>
<td>ACTL</td>
<td>Analog dimming control. The effective programming voltage range of the pin is between 0.2V and 1.2V.</td>
</tr>
<tr>
<td>7</td>
<td>DCTL</td>
<td>Digital dimming control by adding a $0.47, \mu\text{F}$ filtering capacitor on ACTL pin, the PWM dimming signal on DCTL pin can be averaged and converted into analog dimming signal on the ACTL pin.</td>
</tr>
<tr>
<td>8</td>
<td>SS</td>
<td>Soft-start time setting. A capacitor of at least 10nF is required for proper soft-start.</td>
</tr>
<tr>
<td>9</td>
<td>SYNC</td>
<td>Switching frequency synchronization pin. In order to synchronize RT8496 switching frequency to external frequency, the SYNC pin must be fed with square wave with frequency higher than the set switching frequency of RT8496. The high level voltage of the square wave must be higher than 1.4V. The SW pin will be pulled low (turned off) on the rising edge (from low to high) of the SYNC pin signal to achieve frequency synchronization. Keep the SYNC pin floating if the switching frequency synchronization function is not used.</td>
</tr>
<tr>
<td>10</td>
<td>OVP</td>
<td>Over-voltage protection sense input. The PWM converter turns off when the voltage of the pin goes higher than 1.18V.</td>
</tr>
<tr>
<td>11</td>
<td>VCC</td>
<td>Power supply of the chip. For good bypass, a low ESR capacitor is required.</td>
</tr>
<tr>
<td>12</td>
<td>GND</td>
<td>Ground. The Exposed Pad must be Soldered to a Large PCB and Connected to GND for Maximum Power Dissipation.</td>
</tr>
<tr>
<td>13</td>
<td>GBIAS</td>
<td>Internal gate driver bias. A good bypass capacitor is required.</td>
</tr>
<tr>
<td>14</td>
<td>GATE</td>
<td>External MOSFET switch gate driver output.</td>
</tr>
</tbody>
</table>
Functional Block Diagram

Figure 4

\[ V_{ISP} - V_{ISN} \text{ (mV)} \]

\[ V_{VACTL} \text{ (V)} \]

315

0 0.2 1.2

\( V_{ACTL} \text{ (V)} \)

\( V_{VACTL} \text{ (V)} \)

Figure 4
Operation

The start up voltage of the RT8496 is around 4.5V. When VCC voltage is greater than 4.5V, the RT8496 starts operation and a regulated GBIAS supply voltage is generated by an internal LDO circuit. With VCC greater than 10V, the GBIAS supply will be regulated around 8.5V to supply the power for the internal GATE pin driver circuit.

The RT8496 is a constant switching frequency PWM controller. The OSC block generates an adjustable switching frequency set by an external resistor at RSET pin. The RT8496 is also equipped with switching frequency synchronization function. The switching frequency can be synchronized to the frequency of the signal feeding into the SYNC pin. On the rising edge of the SYNC pin signal toggled from low to high (the high level voltage must be higher than 1.4V), the switch will be turned off. In order to make the switching frequency synchronization function to work, the frequency of the signal feeding into the SYNC pin must be greater than the nominal switching frequency set by the resistor at the RSET pin.

As the system starts, the capacitor at the soft-start pin is slowly charged by an internal current source around 6μA. During soft-start period, the VC pin voltage follows the soft-start pin voltage up by one VBE and gradually ramps up. The slowly rising VC pin voltage allows the PWM duty to increase gradually to achieve soft-start function.

In normal operation, the GATE turns high when the oscillator (OSC) turns high. The ISW pin voltage is the triangular feedback signal of the sensed switch current (which equals inductor current ramp). The PWM comparator compares the ISW pin voltage to the VC pin voltage. When the ISW pin voltage exceeds the VC pin voltage, the PWM comparator resets the latch and turns off GATE. If the ISW pin voltage does not exceed the VC pin voltage by the end of the switching cycle, the GATE will be turned off by the OSC circuit for a minimum off time. The cycle repeats when the GATE is turned on at the beginning of the next OSC cycle.

The RT8496 features high voltage LED driver control. The common mode operation voltage of the ISP and ISN pins can be high up to 150V. The regulated (V_{ISP} - V_{ISN}) sense threshold voltage is around 315mV. If the sensed (V_{ISP} - V_{ISN}) voltage is lower than 315mV, the VC pin will be charged higher by the internal OP AMP in the PWM control loop and vice versa. By the PWM closed loop control, the (V_{ISP} - V_{ISN}) voltage is regulated to 315mV. The actual LED output current can be adjusted by the sense resistor between the ISP and ISN pins.

The dimming can be done by varying the ACTL/DCTL pin voltage signal. The internal sense threshold reference for (V_{ISP} - V_{ISN}) regulation follows the ACTL/DCTL signal to achieve dimming control.

The fault protection features of the RT8496 include (1) VCC Under-Voltage Lockout (UVLO) (2) VOUT Over-Voltage Protection (OVP) (3) switch Over-Current Protection (OCP) (4) Over-Temperature Protection (OTP).
Absolute Maximum Ratings  
(Note 1)
- Supply Input Voltage, VCC: -0.3V to 38V
- GBIAS, GATE: -0.3V to 10V
- ISW: -0.3V to 1V
- ISP, ISN: -0.3V to 180V
- DCTL, ACTL, OVP (Note 2): -0.3V to 8V
- SYNC: -0.3V to 20V
- SS, RSET, VC: -0.3V to 5V
- Power Dissipation, P_D @ T_A = 25°C: 0.87W
- Package Thermal Resistance (Note 3): 113.9°C/W
- Junction Temperature: 150°C
- Lead Temperature (Soldering, 10 sec.): 260°C
- Storage Temperature Range: -65°C to 150°C
- ESD Susceptibility (Note 4): 2kV (HBM, Human Body Model, except the HV pins ISP (500V) and ISN (500V)), 200V (MM, Machine Model)

Recommended Operating Conditions  
(Note 5)
- Supply Input Voltage Range, VCC: 4.5V to 36V
- ISP, ISN: 150V
- Junction Temperature Range: -40°C to 125°C

Electrical Characteristics
(VCC = 24V, No Load on any Output, T_A = 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>Overall</td>
<td>Supply Current</td>
<td>I_VCC</td>
<td>V_{VC} ≤ 0.4V (Switching off)</td>
<td>--</td>
<td>6</td>
<td>7.2</td>
</tr>
<tr>
<td>SYNC Input Voltage</td>
<td>Logic-High</td>
<td>V_SYNCH</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Logic-Low</td>
<td>V_SYNCL</td>
<td>--</td>
<td>--</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>SYNC Input Current</td>
<td>SYNC &gt; 2V</td>
<td>--</td>
<td>--</td>
<td>1.2</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>Current Sense Amplifier</td>
<td>Input Threshold (V_{ISP} – V_{ISN})</td>
<td>V_{ACTL} = 1.4V, 12V ≤ Common mode ≤ 150V</td>
<td>302</td>
<td>315</td>
<td>328</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>ISP Input Current</td>
<td>I_{ISP}</td>
<td>4.5V ≤ V_{ISP} ≤ 150V</td>
<td>--</td>
<td>140</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>ISN Input Current</td>
<td>I_{ISN}</td>
<td>4.5V ≤ V_{ISN} ≤ 150V</td>
<td>--</td>
<td>60</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>VC Output Current</td>
<td>I_{VC}</td>
<td>V_{ISP} – V_{ISN} = 315mV, 0.5V ≤ V_{VC} ≤ 2.4V</td>
<td>--</td>
<td>±20</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>VC Threshold for PWM Switch Off</td>
<td>--</td>
<td>0.7</td>
<td>--</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

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### LED Dimming

<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>Analog Dimming ACTL Pin Input Current</td>
<td>I&lt;sub&gt;ACTL&lt;/sub&gt;</td>
<td>V&lt;sub&gt;ACTL&lt;/sub&gt; = 1.2V</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>μA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V&lt;sub&gt;ACTL&lt;/sub&gt; = 0.2V</td>
<td>--</td>
<td>10</td>
<td>--</td>
<td>μA</td>
</tr>
<tr>
<td>Maximum LED Current On Threshold at ACTL</td>
<td>V&lt;sub&gt;ACTL_on&lt;/sub&gt;</td>
<td></td>
<td>--</td>
<td>1.2</td>
<td>1.5</td>
<td>V</td>
</tr>
<tr>
<td>LED Current Off Threshold at ACTL</td>
<td>V&lt;sub&gt;ACTL_off&lt;/sub&gt;</td>
<td></td>
<td>0.15</td>
<td>0.2</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>DCTL Input Current</td>
<td>I&lt;sub&gt;DCTL&lt;/sub&gt;</td>
<td>V&lt;sub&gt;DCTL&lt;/sub&gt; = 0.3V ≤ V&lt;sub&gt;DCTL&lt;/sub&gt; ≤ 6V</td>
<td>--</td>
<td>--</td>
<td>0.5</td>
<td>μA</td>
</tr>
<tr>
<td>DCTL Input Voltage</td>
<td>V&lt;sub&gt;DCTL_H&lt;/sub&gt; (Note 6)</td>
<td></td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;DCTL_L&lt;/sub&gt; (Note 6)</td>
<td></td>
<td>--</td>
<td>--</td>
<td>0.3</td>
<td>V</td>
</tr>
</tbody>
</table>

### PWM Control

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>f&lt;sub&gt;SW&lt;/sub&gt;</th>
<th>R&lt;sub&gt;RESET&lt;/sub&gt; = 30kΩ</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Off-Time</td>
<td>R&lt;sub&gt;RESET&lt;/sub&gt; = 30kΩ</td>
<td></td>
<td>--</td>
<td>250</td>
<td>--</td>
<td>ns</td>
</tr>
</tbody>
</table>

### Switch Gate Driver

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;GBIAS&lt;/sub&gt;</td>
<td>I&lt;sub&gt;GBIAS&lt;/sub&gt; = 20mA</td>
<td>7.8</td>
<td>8.5</td>
<td>9.2</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;GATE_H&lt;/sub&gt;</td>
<td>I&lt;sub&gt;GATE&lt;/sub&gt; = −50mA</td>
<td>--</td>
<td>7.2</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;GATE_L&lt;/sub&gt;</td>
<td>I&lt;sub&gt;GATE&lt;/sub&gt; = 100μA</td>
<td>--</td>
<td>7.8</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;GATE_H&lt;/sub&gt;</td>
<td>I&lt;sub&gt;GATE&lt;/sub&gt; = 50mA</td>
<td>--</td>
<td>0.25</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;GATE_L&lt;/sub&gt;</td>
<td>I&lt;sub&gt;GATE&lt;/sub&gt; = 100μA</td>
<td>--</td>
<td>0.1</td>
<td>--</td>
<td>V</td>
</tr>
</tbody>
</table>

### GATE Drive Rise and Fall Time

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1nF Load at GATE</td>
<td>2</td>
<td>15</td>
<td>300</td>
<td>ns</td>
</tr>
</tbody>
</table>

### PWM Switch Current Limit Threshold

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;C&lt;/sub&gt; = 1V</td>
<td>235</td>
<td>270</td>
<td>305</td>
<td>mV</td>
</tr>
</tbody>
</table>

### OVP and Soft-Start

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;OVP_th&lt;/sub&gt;</td>
<td></td>
<td>--</td>
<td>1.18</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>I&lt;sub&gt;OVP&lt;/sub&gt;</td>
<td>0.9V ≤ V&lt;sub&gt;OVP&lt;/sub&gt; ≤ 1.5V</td>
<td>--</td>
<td>--</td>
<td>0.5</td>
<td>μA</td>
</tr>
<tr>
<td>I&lt;sub&gt;SS&lt;/sub&gt;</td>
<td>V&lt;sub&gt;SS&lt;/sub&gt; ≤ 2V</td>
<td>--</td>
<td>6</td>
<td>--</td>
<td>μA</td>
</tr>
</tbody>
</table>

### Thermal Shutdown Threshold

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;SD&lt;/sub&gt;</td>
<td></td>
<td>--</td>
<td>145</td>
<td>--</td>
<td>°C</td>
</tr>
<tr>
<td>AT&lt;sub&gt;SD&lt;/sub&gt;</td>
<td></td>
<td>--</td>
<td>10</td>
<td>--</td>
<td>°C</td>
</tr>
</tbody>
</table>

**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.** If connected with a 20kΩ serial resistor, ACTL and DCTL can go up to 36V.

**Note 3.** 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. θ<sub>JC</sub> is measured at the exposed pad of the package.

**Note 4.** Devices are ESD sensitive. Handling precaution is recommended.

**Note 5.** The device is not guaranteed to function outside its operating conditions.

**Note 6.** Guaranteed by design, not subjected to production test.
Typical Application Circuit

Figure 1. Analog Dimming in Boost Configuration

Figure 2. Analog Dimming in Buck Configuration
Figure 3. Analog Dimming in Buck-Boost Configuration
Typical Operating Characteristics

Efficiency vs. Output Voltage

- **Boost**
  - $V_{IN} = 30V$, $V_{OUT} = 48V$ to $150V$, $I_{OUT} = 150mA$, $L = 68\mu H$

Efficiency vs. Input Voltage

- **Buck**
  - $V_{IN} = 130V$ to $265V$, $V_{OUT} = 120V$, $I_{OUT} = 150mA$, $L = 47\mu H$

Efficiency vs. Output Voltage

- **Boost**
  - $V_{IN} = 12V$ to $30V$, $V_{OUT} = 20V$, $I_{OUT} = 400mA$, $L = 47\mu H$

Efficiency vs. Input Voltage

- **Buck-Boost**
  - $V_{IN} = 12V$ to $30V$, $V_{OUT} = 20V$, $I_{OUT} = 400mA$, $L = 47\mu H$

Supply Current vs. VCC

- $R_{SET} = 30k\Omega$

Switching Frequency vs. VCC

- $R_{SET} = 30k\Omega$
DCTL Dimming on PWM Duty 80%

Power On form VCC Voltage

Power Off form VCC Voltage

DCTL Dimming on PWM Duty 80%

Power On form VCC Voltage

Power Off form VCC Voltage

I_{OUT} = 150mA, PWM Duty = 80%, L = 68\mu H

Time (5\mu s/Div)

V_{CC} (10V/Div)

GATE (10V/Div)

I_{OUT} (200mA/Div)

Time (10ms/Div)

I_{OUT} (100mA/Div)

I_{L} (2A/Div)

PWM (5V/Div)

I_{OUT} = 150mA, PWM Duty = 50%, L = 68\mu H

Time (10ms/Div)
Applications Information

The RT8496 is a current mode PWM controller designed to drive an external MOSFET for high current LED applications. The LED current can be programmed by an external resistor. The input voltage range of the RT8496 can be up to 36V and the output voltage can be up to 150V. The RT8496 provides analog and PWM dimming to achieve LED current control.

GBIAS Regulator and Bypass Capacitor

The GBIAS pin requires a capacitor for stable operation and to store the charge for the large GATE switching currents. Choose a 25V rated low ESR, X7R or X5R ceramic capacitor for best performance. The value of a 1μF capacitor will be adequate for many applications.

Place the capacitor close to the IC to minimize the trace length to the GBIAS pin and also to the IC ground. An internal current limit on the GBIAS output protects the RT8496 from excessive on-chip power dissipation.

The GBIAS pin has its own under-voltage disable (UVLO) set to 4.3V(typical) to protect the external FETs from excessive power dissipation caused by not being fully enhanced. If the input voltage, VIN, will not exceed 8V, then the GBIAS pin should be connected to the input supply. Be aware if GBIAS supply is used to drive extra circuits besides RT8496, typically the extra GBIAS load should be limited to less than 10mA.

Loop Compensation

An external resistor in series with a capacitor is connected from the VC pin to GND to provide a pole and a zero for proper loop compensation. The external inductor, output capacitor and the compensation resistor and capacitor determine the loop stability. The inductor and output capacitor are chosen based on performance, size and cost.

The compensation resistor and capacitor at VC are selected to optimize control loop response and stability. For typical LED applications, a 3.3nF compensation capacitor at VC is adequate, and a series resistor should always be used to increase the slew rate on the VC pin to maintain good regulation of LED current during fast transients on the input supply to the converter. The typical compensation for the RT8496 is 10kΩ and 3.3nF.

Soft-Start

The soft-start of the RT8496 can be achieved by connecting a capacitor from SS pin to GND. The built-in soft-start circuit reduces the start-up current spike and output voltage overshoot. The soft-start time is determined by the external capacitor charged by an internal 6μA constant charging current. The SS pin directly limits the rate of voltage rise on the VC pin, which in turn limits the peak switch current.

The soft-start interval is set by the soft-start capacitor selection according to the equation:

\[ t_{SS} = C_{SS} \times \frac{2.4V}{6\mu A} \]

A typical value for the soft-start capacitor is 0.1μF. The soft-start capacitor is discharged when VCC falls below its UVLO threshold, during an over temperature event or during an GBIAS under voltage event.

LED Current Setting

The LED current is adjustable by placing an appropriate value current sense resistor between the ISP and ISN pins. Typically, sensing of the current should be done at the top of the LED string. The ACTL pin should be tied to a voltage higher than 1.2V to get the full-scale 315mV (typical) threshold across the sense resistor. The ACTL pin can also be used to dim the LED current to zero, although relative accuracy decreases with the decreasing voltage sense threshold. When the ACTL pin voltage is less than 1.2V, the LED current is:

\[ I_{LED} = \frac{(V_{ACTL} - 0.2) \times 0.315}{R_{SENSE}} \]

Where,

\[ R_{SENSE} \] is the resistor between ISP and ISN.

When the voltage of ACTL is higher than 1.2V, the LED current is regulated to:

\[ I_{LED(MAX)} = \frac{315mV}{R_{SENSE}} \]

The ACTL pin can also be used in conjunction with a thermistor to provide over-temperature protection for the LED load, or with a voltage divider to VIN to reduce output
power and switching current when $V_{IN}$ is low. The presence of a time varying differential voltage signal (ripple) across ISP and ISN at the switching frequency is expected.

The amplitude of this signal is increased by high LED load current, low switching frequency and/or a smaller value output filter capacitor. The compensation capacitor on the VC pin filters the signal so the average difference between ISP and ISN is regulated on the user-programmed value.

**Switching Frequency Setting**
The RSET frequency adjust pin allows the user to adjust the switching frequency from 100kHz to 1MHz for optimized efficiency and performance or external component size. Higher frequency operation allows smaller component size but increases switching losses and gate driving current, and may not allow sufficient high or low duty cycle operation. Lower frequency operation gives better performance but with larger external component size. For an appropriate $R_{\text{RSET}}$ resistor value see Table 1 or Figure 4. An external resistor from the RSET pin to GND is required and do not leave this pin open.

**Table 1. Switching Frequency vs. $R_{\text{RSET}}$ Value (1% Resistor)**

<table>
<thead>
<tr>
<th>$f_{\text{OSC}}$ (kHz)</th>
<th>$R_{\text{RSET}}$ (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>8</td>
</tr>
<tr>
<td>800</td>
<td>10</td>
</tr>
<tr>
<td>600</td>
<td>15</td>
</tr>
<tr>
<td>500</td>
<td>19</td>
</tr>
<tr>
<td>300</td>
<td>35</td>
</tr>
<tr>
<td>200</td>
<td>55</td>
</tr>
<tr>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>

**Output Over Voltage Setting**
The RT8496 is equipped with Over-Voltage Protection (OVP) function. When the voltage at OVP pin exceeds a threshold of approximately 1.18V, the power switch is turned off. The power switch can be turned on again once the voltage at OVP pin drops below 1.18V. For the Boost and Buck-Boost application, the output voltage could be clamped at a certain voltage level. The OVP voltage can be set by the following equation:

$$V_{\text{OUT, OVP}} = 1.18 \times \left(1 + \frac{R_1}{R_2}\right)$$

Where,

$R_1$ and $R_2$ are the voltage dividers from $V_{\text{OUT}}$ to GND with the divider center node connected to OVP pin.

**Over-Temperature Protection**
The RT8496 has Over-Temperature Protection (OTP) function to prevent the excessive power dissipation from overheating. The OTP function will shut down switching operation when the die junction temperature exceeds 145°C. The chip will automatically start to switch again when the die junction temperature cools off.
**Inductor Selection**

The converter operates in discontinuous conduction mode when the inductance value is less than the value $L_{BCM}$. With an inductance greater than $L_{BCM}$, the converter operates in Continuous Conduction Mode (CCM). The inductance $L_{BCM}$ is determined by the following equations.

For Buck application:

$$L_{BCM} = \frac{V_{OUT}}{2 \times I_{OUT} \times f} \times \left( \frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

For Boost application:

$$L_{BCM} = \frac{V_{IN}^2}{2 \times I_{OUT} \times f} \times \left( \frac{V_{OUT} - V_{IN}}{V_{OUT}^2} \right)$$

For Buck-Boost application:

$$L_{BCM} = \frac{V_{IN}^2}{2 \times I_{OUT} \times f} \times \left( \frac{V_{OUT} - V_{IN}}{V_{OUT}^2 + V_{IN}^2} \right)$$

where

$V_{OUT}$ = output voltage.

$V_{IN}$ = input voltage.

$f$ = operating frequency.

$I_{OUT}$ = LED current.

Choose an inductance based on the operating frequency, input voltage and output voltage to provide a current mode ramp signal during the MOSFET on period for PWM control loop regulation. The inductance also determines the inductor ripple current. Operating the converter in CCM is recommended, which will have the smaller inductor ripple current and hence the less conduction losses from all converter components.

As a design example, to design the peak to peak inductor ripple to be ±30% of the output current, the following equations can be used to estimate the size of the needed inductance:

For Buck application:

$$L = \frac{V_{OUT}}{2 \times 0.3 \times I_{OUT} \times f} \times \left( \frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

For Boost application:

$$L = \frac{V_{IN}^2}{2 \times 0.3 \times I_{OUT} \times f} \times \left( \frac{V_{OUT} - V_{IN}}{V_{OUT}^2} \right)$$

For Buck-Boost application:

$$L = \frac{V_{IN}^2}{2 \times 0.3 \times I_{OUT} \times f} \times \left( \frac{V_{OUT} - V_{IN}}{V_{OUT}^2 + V_{IN}^2} \right)$$

The inductor must also be selected with a saturation current rating greater than the maximum inductor current during normal operation. The maximum inductor current can be calculated by the following equations.

For Buck application:

$$I_{PEAK} = \frac{I_{OUT} \times V_{OUT}}{2 \times L \times f} \times \left( \frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

For Boost application:

$$I_{PEAK} = \frac{V_{OUT} \times I_{OUT} \times V_{OUT}}{V_{IN} \times \eta} \times \left( \frac{V_{IN} - V_{OUT}}{V_{OUT}^2} \right)$$

For Buck-Boost application:

$$I_{PEAK} = \frac{V_{OUT} \times I_{OUT} \times V_{OUT}}{V_{IN} \times \eta} \times \left( \frac{V_{IN} - V_{OUT}}{V_{OUT}^2} \right)$$

where

$\eta$ is the efficiency of the power converter.

**Power MOSFET Selection**

For applications operating at high input or output voltages, the power N-MOSFET switch is typically chosen for drain voltage $VDS$ rating and low gate charge. Consideration of switch on-resistance, $R_{DS(ON)}$, is usually secondary because switching losses dominate power loss. The $GBIAS$ regulator on the RT8496 has a fixed current limit to protect the IC from excessive power dissipation at high $VIN$, so the N-MOSFET should be chosen so that the product of $Qg$ at 5V and switching frequency does not exceed the $GBIAS$ current limit.

**ISW Sense Resistor Selection**

The resistor, $R_{SW}$, between the Source of the external N-MOSFET and GND should be selected to provide adequate switch current to drive the application without exceeding the current limit threshold set by the ISW pin sense threshold of RT8496. The ISW sense resistor value can be calculated according to the formula below:

$$R_{SW} = \frac{\text{Current Limit Threshold Minimum Value}}{\text{I}_{OCP}}$$

where $I_{OCP}$ is about 1.33 to 1.5 times of inductor peak current $I_{PEAK}$. 

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The placement of RSW should be close to the source of the N-MOSFET and the IC GND of the RT8496. The ISW pin input to RT8496 should be a Kelvin sense connection to the positive terminal of R_SW.

**Schottky Diode Selection**
The Schottky diode, with their low forward voltage drop and fast switching speed, is necessary for the RT8496 applications. In addition, power dissipation, reverse voltage rating and pulsating peak current are the important parameters for the Schottky diode selection. Choose a suitable Schottky diode whose reverse voltage rating is greater than maximum output voltage. The diode's average current rating must exceed the average output current. The diode conducts current only when the power switch is turned off (typically less than 50% duty cycle). If using the PWM feature for dimming, it is important to consider diode leakage, which increases with the temperature, from the output during the PWM low interval. Therefore, choose the Schottky diode with sufficiently low leakage current.

**Capacitor Selection**
The input capacitor reduces current spikes from the input supply and minimizes noise injection to the converter. For most of the RT8496 applications, a 10μF ceramic capacitor is sufficient. A value higher or lower may be used depending on the noise level from the input supply and the input current to the converter.

In Boost application, the output capacitor is typically a ceramic capacitor and is selected based on the output voltage ripple requirements. The minimum value of the output capacitor \( C_{OUT} \) is approximately given by the following equation:

\[
C_{OUT} = \frac{I_{OUT} \times V_{OUT}}{V_{IN} \times V_{RIPPLE} \times f_{SW}}
\]

For LED applications, the equivalent resistance of the LED is typically low and the output filter capacitor should be sized to attenuate the current ripple. Use of X7R type ceramic capacitors is recommended. Lower operating frequencies will require proportionately higher capacitor values.

**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 SOP-14, the thermal resistance, \( \theta_{JA} \), is 113.9°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at \( T_A = 25°C \) can be calculated as below:

\[
P_{D(MAX)} = \frac{(125°C - 25°C)}{(113.9°C/W)} = 0.87W
\]

The maximum power dissipation depends on the operating ambient temperature for the fixed \( T_{J(MAX)} \) and the thermal resistance, \( \theta_{JA} \). The derating curves in Figure 5 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

**Figure 5. Derating Curve of Maximum Power Dissipation**

\[\text{Maximum Power Dissipation (W)}\]

<table>
<thead>
<tr>
<th>Ambient Temperature (°C)</th>
<th>Maximum Power Dissipation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>25</td>
<td>1.4</td>
</tr>
<tr>
<td>50</td>
<td>1.2</td>
</tr>
<tr>
<td>75</td>
<td>1.0</td>
</tr>
<tr>
<td>100</td>
<td>0.8</td>
</tr>
<tr>
<td>125</td>
<td>0.6</td>
</tr>
<tr>
<td>150</td>
<td>0.4</td>
</tr>
<tr>
<td>175</td>
<td>0.2</td>
</tr>
<tr>
<td>200</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Four-Layer PCB
Layout Consideration

PCB layout is very important to design power switching converter circuits. The layout guidelines are suggested as follows:

- The power components L1, D1, Cin, M1 and Cout must be placed as close to each other as possible to reduce the ac current loop area. The PCB trace between power components must be as short and wide as possible due to large current flow through these traces during operation.

- The input capacitor CVCC must be placed as close to VCC pin as possible.

- Place the compensation components to VC pin as close as possible to avoid noise pick up.

- Connect GND pin and Exposed Pad to a large ground plane for maximum power dissipation and noise reduction.

![PCB Layout Guide](image.png)

Figure 6. PCB Layout Guide
Outline Dimension

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Dimensions In Millimeters</th>
<th>Dimensions In Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A</td>
<td>8.534</td>
<td>8.738</td>
</tr>
<tr>
<td>B</td>
<td>3.810</td>
<td>3.988</td>
</tr>
<tr>
<td>C</td>
<td>1.346</td>
<td>1.753</td>
</tr>
<tr>
<td>D</td>
<td>0.330</td>
<td>0.508</td>
</tr>
<tr>
<td>F</td>
<td>1.194</td>
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<tr>
<td>H</td>
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<td>I</td>
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<td>0.254</td>
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<tr>
<td>J</td>
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<td>6.198</td>
</tr>
<tr>
<td>M</td>
<td>0.406</td>
<td>1.270</td>
</tr>
</tbody>
</table>

14-Lead SOP Plastic Package

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