High Voltage Multiple-Topology LED Driver with Open Detection

General Description
The RT8474A is a current-mode LED driver supporting wide input voltage range from 4.5V to 50V in multiple topologies.
With the internal 500kHz operating frequency, the size of the external PWM inductor and input/output capacitors can be minimized. High efficiency is achieved by a 100mV current sensing control. LED dimming control can be done from either analog or PWM signal. The RT8474A provides an internal soft-start function to avoid inrush current and thermal shutdown to prevent the device from overheat.
The RT8474A is available in the SOP-8 (Exposed pad) package.

Features
- High Voltage : $V_{\text{IN}}$ Up to 50V, $V_{\text{OUT}}$ Up to 50V
- Support Multiple-Topologies (Buck / Boost / Buck-Boost)
- Built-In 2A Power Switch
- Current-Mode PWM Control
- 500kHz Fixed Switching Frequency
- Analog or PWM Control Signal for LED Dimming
- Internal Soft-Start to Avoid Inrush Current
- OVP Pin for Adjustable OVP Level Protection (for Buck Only)
- Under-Voltage Lockout
- Thermal Shutdown
- RoHS Compliant and Halogen Free

Ordering Information
RT8474A
- Package Type
  - SP : SOP-8 (Exposed-Option 2)
- 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.

Applications
- Desk Lights and Room Lighting
- Industrial Display Backlight

Marking Information
RT8474AGSP : Product Number
GSPYMDNN : Date Code

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>VCC</td>
<td>Supply Voltage Input. For good bypass, connect a low ESR capacitor between this pin and GND.</td>
</tr>
<tr>
<td>2</td>
<td>ISP</td>
<td>Positive Current Sense Input.</td>
</tr>
<tr>
<td>3</td>
<td>ISN</td>
<td>Negative Current Sense Input. Voltage threshold between ISP and ISN is 100mV.</td>
</tr>
<tr>
<td>4</td>
<td>OVP</td>
<td>Over-Voltage Protection Sense Input. OVP pin is used for OVP protection function in buck topology only. The OVP pin must be tied to ISP pin in boost and buck-boost topologies.</td>
</tr>
<tr>
<td>5</td>
<td>VC</td>
<td>Compensation Node for Current Loop.</td>
</tr>
<tr>
<td>6</td>
<td>CTL</td>
<td>Analog Dimming Control Input. Effective programming range is 0.2V to 1.2V.</td>
</tr>
<tr>
<td>7</td>
<td>SW</td>
<td>Switch Node of the PWM Converter.</td>
</tr>
<tr>
<td>8</td>
<td>CREG</td>
<td>Regulator Output for Internal Circuit. Place a 1μF capacitor to stabilize the 5V output regulator.</td>
</tr>
<tr>
<td>9 (Exposed Pad)</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>
</tbody>
</table>
Function Block Diagram

**Operation**

The RT8474A can be used in multiple topologies. In Buck converter applications, an OVP pin is specially designed to be used for an over voltage protection function.

RT8474A uses a fixed frequency, current-mode control scheme to provide excellent line and load regulation. The control loop has a current sense amplifier which senses the voltage between the ISP and ISN pins and provides an output voltage at the VC pin. A PWM comparator then turns off the internal power switch when the sensed power switch current exceeds the compensated VC pin voltage. The power switch will not be reset by the oscillator clock in each cycle. If the comparator does not turn off the switch in a cycle, the power switch will be on for more than a full switching period until the comparator is tripped. In this manner, the programmed voltage across the sense resistor is regulated by the control loop.

The current through the sense resistor is set by the programmed voltage and the sense resistance. The voltage across the sense resistor can be programmed by the analog or digital signal at the CTL pin. The RT8474A provides protection functions which include over-temperature, and switch current limit to prevent abnormal situations.
### Absolute Maximum Ratings  (Note 1)
- Supply Input Voltage, VCC: −0.3V to 60V
- SW Pin Voltage at Switching off, ISP, ISN, OVP: −0.3V to 60V
- CREG Voltage: −0.3V to 6V
- CTL Voltage (Note 2): −0.3V to 20V
- Power Dissipation, P_D @ T_A = 25°C
  SOP-8 (Exposed Pad): 3.44W
- Package Thermal Resistance (Note 3)
  SOP-8 (Exposed Pad), θ_JA: 29°C/W
  SOP-8 (Exposed Pad), θ_JC: 2°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)
  HBM (Human Body Model): 2kV
  MM (Machine Model): 200V

### Recommended Operating Conditions  (Note 5)
- Supply Input Voltage: 4.5V to 50V
- Junction Temperature Range: −40°C to 125°C
- Ambient Temperature Range: −40°C to 85°C

### Electrical Characteristics
(V CC = 5V, C IN = 1μF, 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>
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<tr>
<td>Overall</td>
<td></td>
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<tr>
<td>Regulator Output Voltage</td>
<td>V_CREG</td>
<td>I_CREG = 20mA</td>
<td>4.5</td>
<td>5</td>
<td>5.5</td>
<td>V</td>
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<tr>
<td>Supply Current</td>
<td>I_VCC</td>
<td>VC ≤ 0.4V</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>mA</td>
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<tr>
<td>VIN Under-Voltage Lockout Threshold</td>
<td>V_UVLO</td>
<td>VIN Rising</td>
<td>--</td>
<td>4.2</td>
<td>4.5</td>
<td>V</td>
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<tr>
<td></td>
<td></td>
<td>VIN Falling</td>
<td>3.9</td>
<td>4.1</td>
<td>--</td>
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<tr>
<td>Current Sense Amplifier</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Input Threshold (V_ISP − V_ISN)</td>
<td>V_CTL ≥ 1.25V</td>
<td></td>
<td>97</td>
<td>100</td>
<td>103</td>
<td>mV</td>
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<tr>
<td>Input Current</td>
<td>I_ISP</td>
<td>V_ISP = 24V</td>
<td>--</td>
<td>200</td>
<td>--</td>
<td>μA</td>
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<td></td>
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<td>--</td>
<td>20</td>
<td>--</td>
<td>μA</td>
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<tr>
<td>Output Current</td>
<td>I_VC</td>
<td>2.4V &gt; VC &gt; 0.3V</td>
<td>--</td>
<td>±10</td>
<td>--</td>
<td>μA</td>
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<td>VC Threshold for CTL Switch Off</td>
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<td>--</td>
<td>0.4</td>
<td>--</td>
<td>V</td>
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<td>LED Dimming</td>
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<tr>
<td>Input Current of CTL Pin</td>
<td>I_CTL</td>
<td>0.2V ≤ V_CTL ≤ 1.2V</td>
<td>--</td>
<td>1</td>
<td>2</td>
<td>μA</td>
</tr>
<tr>
<td>LED Current Off Threshold at CTL</td>
<td>V_CTL_OFF</td>
<td></td>
<td>0.15</td>
<td>0.2</td>
<td>0.25</td>
<td>V</td>
</tr>
<tr>
<td>LED Current On Threshold at CTL</td>
<td>V_CTL_ON</td>
<td></td>
<td>--</td>
<td>1.2</td>
<td>1.5</td>
<td>V</td>
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<table>
<thead>
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<th>Parameter</th>
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<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
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<td>Switch Frequency</td>
<td>$f_{SW}$</td>
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<td>440</td>
<td>500</td>
<td>540</td>
<td>kHz</td>
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<tr>
<td>Maximum Duty Cycle</td>
<td>$D_{MAX}$</td>
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<td>--</td>
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<td>100</td>
<td>%</td>
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<td>Minimum On-Time</td>
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<td></td>
<td>--</td>
<td>100</td>
<td>200</td>
<td>ns</td>
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<td>SW $R_{DS(ON)}$</td>
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<td></td>
<td>--</td>
<td>--</td>
<td>0.15</td>
<td>Ω</td>
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<tr>
<td>SW Current Limit</td>
<td>$I_{LIM_SW}$</td>
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<td>2</td>
<td>2.5</td>
<td>--</td>
<td>A</td>
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<td>OVP Threshold</td>
<td>$V_{OVP}$</td>
<td>$V_{ISP} - V_{OVP}$</td>
<td>1.15</td>
<td>1.2</td>
<td>1.25</td>
<td>V</td>
</tr>
<tr>
<td>OVP Recovery</td>
<td></td>
<td>$V_{OVP} = 1.2V$</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>OVP Input Current</td>
<td>$I_{OVP}$</td>
<td>$V_{OVP} \leq 1.5V$</td>
<td>--</td>
<td>30</td>
<td>--</td>
<td>μA</td>
</tr>
<tr>
<td>Soft-Start Time</td>
<td></td>
<td>(Note 6)</td>
<td>--</td>
<td>5.7</td>
<td>--</td>
<td>ms</td>
</tr>
<tr>
<td><strong>Over-Temperature Protection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Shutdown Threshold</td>
<td>$T_{SD}$</td>
<td></td>
<td>--</td>
<td>150</td>
<td>--</td>
<td>°C</td>
</tr>
<tr>
<td>Thermal Shutdown Hysteresis</td>
<td>$\Delta T_{SD}$</td>
<td></td>
<td>--</td>
<td>20</td>
<td>--</td>
<td>°C</td>
</tr>
</tbody>
</table>

**Note 1.** Stresses beyond those listed "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, PWM can go up to 40V.

**Note 3.** $\theta_{JA}$ is measured at $T_A = 25°C$ on a high effective thermal conductivity four-layer test board per JEDEC 51-7. $\theta_{JC}$ 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.** Guarantee by design, not subject to production testing.
Typical Application Circuit

Buck Configuration

Boost Configuration

Note:
1. VIN, VSW, VIN, VISP, VISN < 50V
2. VLED : the voltage across the LED string
3. Vz : Zener diode breakdown voltage
Buck-Boost Configuration

Note:
1. \( V_{SW} < 50V, V_{IN} + V_{LED} < 50V \)
2. \( V_{LED} \): the voltage across the LED string
3. \( V_z \): Zener diode breakdown voltage
Typical Operating Characteristics

Efficiency vs. Input Voltage

LED Current vs. VCTL

Supply Current vs. VCC

ISP-ISN Threshold vs. Temperature

SW R_{DS(ON)} vs. VCC

SW R_{DS(ON)} vs. Temperature
OVP Voltage vs. Temperature

- Voltage vs. Temperature graph showing OVP Voltage (VOVP) and OVP Recovery vs. Temperature (°C) at VCC = 24V.

Frequency vs. VCC

- Frequency vs. VCC graph showing Frequency (kHz) vs. VCC (V) with data points for VIN = 24V, IOUT = 340mA, L = 47μH, LED = 6pcs.

Power On from VCC

- Power On from VCC graph showing VIN, VOUT, and IOUT vs. Time (25ms/Div).

Power Off from VCC

- Power Off from VCC graph showing VIN, VOUT, and IOUT vs. Time (50ms/Div).

OVP Turn On when LED Take Off and Restore

- OVP Turn On when LED Take Off and Restore graph showing VIN, VOUT, IOUT, VOVP vs. Time (250ms/Div).

Switching

- Switching graph showing SW, VIN, VOUT, IOUT vs. Time (2.5μs/Div).
Application Information

The RT8474A can be used in multiple topologies. In Buck converter applications, an OVP pin is specially designed to be used for an over voltage protection function.

RT8474A uses a fixed frequency, current-mode control scheme to provide excellent line and load regulation. The control loop has a current sense amplifier which senses the voltage between the ISP and ISN pins and provides an output voltage at the VC pin. A PWM comparator then turns off the internal power switch when the sensed power switch current exceeds the compensated VC pin voltage. The power switch will not be reset by the oscillator clock in each cycle. If the comparator does not turn off the switch in a cycle, the power switch will be on for more than a full switching period until the comparator is tripped. In this manner, the programmed voltage across the sense resistor is regulated by the control loop.

Frequency Compensation

The RT8474A has an external compensation pin, allowing the loop response to be optimized for specific applications. 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 typical value for the RT8474A is 10k and 3.3nF.

LED Current Setting

The LED current can be calculated by the following equation:

\[ I_{\text{LED(MAX)}} = \left( \frac{V_{\text{ISP}} - V_{\text{ISN}}} {R_{\text{SENSE}}} \right) \]

where \((V_{\text{ISP}} - V_{\text{ISN}})\) is the voltage between the ISP and ISN pins (100mV typ. if CTL dimming is not applied) and \(R_{\text{SENSE}}\) is the resistor between the ISP and ISN pins.

Current Limit

The RT8474A can limit the peak switch current with its internal over-current protection feature. In normal operation, the power switch is turned off when the switch current hits the loop-set value. The over-current protection function will turn off the power switch independent of the loop control when the peak switch current reaches around 2A.

Output Over-Voltage Setting

The RT8474A OVP pin provides the Over-Voltage Protection (OVP) function for buck topology only. The OVP sense threshold is referenced to the top side of the LED string with hysteresis. When the voltage difference between the ISP pin and the OVP pin exceeds a threshold of approximately 1.2V, the power switch will be turned off. The power switch can be turned on again once the voltage difference between the ISP pin and OVP pin drops below 1V. The OVP protection voltage level can be set by the resistor divider R3 and R4 across the output capacitor C4 between ISP pin and the bottom end of the LED string, with the center node of the resistor divider tied to the OVP pin. Typically, set \(R4 = 10k\Omega\) is suggested.

Over-Temperature Protection

The RT8474A 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 150°C. The chip will automatically start to switch again when the die junction temperature cools off.

Inductor Selection

Choose an inductor that can handle the necessary peak current without saturating and ensure that the inductor has a low DCR (copper-wire resistance) to minimize \(I^2R\) power losses. A 4.7μH to 22μH inductor will meet the demand of most of the RT8474A applications. Inductor manufacturers specify the maximum current rating as the current where the inductance falls to certain percentage of its nominal value, typically 65%. In Multiple-Topology application where the transition between discontinuous and continuous modes occurs, the value of the required output inductor, \(L\), can be approximated by the following equation:

For Buck application:

\[ L = \frac{V_{\text{OUT}}} {f \times \Delta L} \times \left( 1 - \frac{V_{\text{OUT}}} {V_{\text{IN(MAX)}}} \right) \]
The ripple current $\Delta I_L$ and peak current $I_{PEAK}$ can be calculated:

$$\Delta I_L = \left(\frac{V_{OUT}}{f \times L}\right) \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

$$I_{PEAK} = I_{OUT} + \frac{\Delta I_L}{2}$$

For Boost application:

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

The ripple current $\Delta I_L$ and peak current $I_{PEAK}$ can be calculated:

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

$$I_{PEAK} = \left(\frac{I_{OUT} \times V_{OUT}}{\eta \times V_{IN}}\right) + \frac{\Delta I_L}{2}$$

For Buck-Boost application:

$$L = \frac{V_{OUT} \times \left(\frac{V_{IN}}{V_{IN} + V_{OUT}}\right)}{f \times \Delta I_L}$$

The ripple current $\Delta I_L$ and peak current $I_{PEAK}$ can be calculated:

$$\Delta I_L = \frac{V_{OUT} \times \left(\frac{V_{IN}}{V_{IN} + V_{OUT}}\right)^2}{f \times L}$$

$$I_{PEAK} = \frac{V_{OUT} + V_{IN} \times \eta \times I_{OUT}}{V_{IN} \times \eta} + \frac{\Delta I_L}{2}$$

where,

$V_{OUT}$ = output voltage.

$V_{IN}$ = input voltage.

$I_{OUT}$ = LED current.

$f$ = switching frequency.

$\eta$ = efficiency.

**Schottky Diode Selection**

The Schottky diode, with their low forward voltage drop and fast switching speed, is necessary for RT8474A applications. In addition, power dissipation, reverse voltage rating and pulsating peak current are important parameters of the Schottky diode that must be considered. 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).

**Capacitor Selection**

The input capacitor reduces current spikes from the input supply and minimizes noise injection to the converter. For most RT8474A applications, a 4.7$\mu$F 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 Buck application, the output capacitor is typically ceramic and selection is mainly based on the output voltage ripple requirements. The output ripple, $\Delta V_{OUT}$, is determined by the following equation:

$$\Delta V_{OUT} \leq \Delta I_L \times [ESR + \frac{1}{8 \times f \times C_{OUT}}]$$

**Thermal Considerations**

For continuous operation, do not exceed the maximum operation junction temperature 125°C. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula:

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_JA$$

where $T_{J(MAX)}$ is the maximum operation junction temperature, $T_A$ is the ambient temperature and $\theta_JA$ is the junction to ambient thermal resistance.

For recommended operating conditions specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, $\theta_{JA}$, is layout dependent. For SOP-8 (Exposed Pad) package, the thermal resistance $\theta_{JA}$ is 29°C/W on the standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at $T_A = 25°C$ can be calculated by following formula:

$$P_{D(MAX)} = (125°C - 25°C) / (29°C/W) = 3.44W$$

for SOP-8 (Exposed Pad) package.

The maximum power dissipation depends on operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance $\theta_{JA}$. The deration curve in Figure 1 allows the designer to see the effect of rising ambient temperature on the maximum power allowed.
Layout Considerations

PCB layout is very important when designing power switching converter circuits. Some recommended layout guidelines are as follows:

- The power components L1, D1 and C4 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.
- Place L1 and D1 as close to each other as possible. The trace should be as short and wide as possible.
- The input capacitor C5 must be placed as close to the VCC pin as possible.
- Place the compensation components to the VC pin as close as possible to avoid noise pickup.

![Figure 2. PCB Layout Guide](image-url)

Figure 1. Derating Curve of Maximum Power Dissipation

![Figure 1. Derating Curve of Maximum Power Dissipation](image-url)
Outline Dimension

8-Lead SOP (Exposed Pad) Plastic Package

<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>4.801</td>
<td>5.004</td>
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<tr>
<td>B</td>
<td>3.810</td>
<td>4.000</td>
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<tr>
<td>C</td>
<td>1.346</td>
<td>1.753</td>
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<td>D</td>
<td>0.330</td>
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<td>F</td>
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