Battery Output Current Sense Protection IC

General Description
The RT9554A is designed for over-current detection. The current sense amplifier amplifies the voltage across resistor which is connected between CSP and CSN by 200. The amplified voltage is compared with the voltage of BAT_REF and check whether over-current happens or not. The RT9554A also provides a comparator with two input pins, AC_REAL and AC_REF for users. There is an output pin FLAG as an indicator which is a N-MOSFET in open-drain configuration. Users can connect one resistor between the FLAG pin and supply voltage. Either over-current condition occurs or the AC_REAL voltage is larger than the AC_REF voltage, the FLAG is pulled low. The RT9554A is a available in the WDFN-8L 2x2 package.

Features
- Common Mode Input Range up to 24V
- VCC Operating Current : 200μA
- VCC Shutdown Current : 5μA (under S3/S4/S5)
- Programmable Over-Current Level
- FLAG Signal goes Low when OCP
- RoHS Compliant and Halogen Free

Applications
- Notebooks

Pin Configurations (TOP VIEW)

Ordering Information
RT9554A

- Package Type
  QW : WDFN-8L 2x2 (W-Type)
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

Marking Information

2CW
W : Date Code

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>VCC</td>
<td>Power Supply Input. Connect this pin to 5V and place a minimum 0.1µF decoupling capacitor. The decoupling capacitor should be placed to this pin as close as possible.</td>
</tr>
<tr>
<td>2</td>
<td>EN</td>
<td>Enable Control Input.</td>
</tr>
<tr>
<td>3</td>
<td>FLAG</td>
<td>Open-Drain Output. Connected to an external resistor. When over-current occurs, this pin will be pulled low.</td>
</tr>
<tr>
<td>4</td>
<td>AC_REF</td>
<td>Comparator Inverting Input.</td>
</tr>
<tr>
<td>5</td>
<td>AC_REAL</td>
<td>Comparator Non-Inverting Input.</td>
</tr>
<tr>
<td>6</td>
<td>BAT_REF</td>
<td>Over-Current Threshold Setting. It is used to set over-current threshold from 0.4V to 2V.</td>
</tr>
<tr>
<td>7</td>
<td>CSN</td>
<td>Negative Current Sense Input.</td>
</tr>
<tr>
<td>8</td>
<td>CSP</td>
<td>Positive Current Sense Input.</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**

![Function Block Diagram](image)

**Operation**

The RT9554A consists of one current sensing amplifier and one comparator, and it provides the following functions: over-current protection and voltage comparison between AC_REAL and AC_REF. Users can connect one resistor between the FLAG pin and supply voltage. Either over-current condition or the occurs AC_REAL voltage is larger than AC_REF, the FLAG pin is pulled low.

**Over Current Protection**

With 1mΩ order of resistor shunts between CSP and CSN, the current sensing amplifier amplifies the voltage between CSP and CSN by 200 and compares the result with the BAT_REF voltage. If the output voltage of current sensing amplifier is larger than the BAT_REF voltage, the FLAG pin is pulled low.

**AC_REAL & AC_REF Comparison**

A comparator is designed for the voltage comparison between AC_REAL and AC_REF. If the voltage of AC_REAL is larger than AC_REF, the FLAG pin is pulled low.
Absolute Maximum Ratings  
(Note 1)
- CSP/CSN to GND: −0.3V to 26V
- VCC, BAT_REF, EN, AC_REAL, AC_REF, FLAG to GND: −0.3V to 6V
- Power Dissipation, $P_D @ T_A = 25°C$: 2.19W
- Package Thermal Resistance (Note 2)
  - WDFN-8L 2x2, $\theta_JA$: 45.5°C/W
  - WDFN-8L 2x2, $\theta_JC$: 11.5°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
  - MM (Machine Model): 200V

Recommended Operating Conditions  
(Note 4)
- High-Side Voltage, VCSP/VCSN: 4.5V to 24V
- Supply Voltage, VCC: 4.5V to 5.5V
- Junction Temperature Range: −40°C to 125°C
- Ambient Temperature Range: −40°C to 85°C

Electrical Characteristics  
($V_{CC} = 5V$, $T_A = 25°C$, 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>CSN CSP Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage Range</td>
<td>$V_{CSP}, V_{CSN}$</td>
<td>EN = High</td>
<td>5</td>
<td>--</td>
<td>24</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>$I_{CSN} + I_{CSP}$</td>
<td>EN = Low</td>
<td>--</td>
<td>50</td>
<td>--</td>
<td>$\mu$A</td>
</tr>
<tr>
<td>VCC Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCC Operating Current</td>
<td>$I_{VCC}$</td>
<td>$V_{CC} &gt; \text{POR}, EN = \text{High}$</td>
<td>--</td>
<td>200</td>
<td>--</td>
<td>$\mu$A</td>
</tr>
<tr>
<td>VCC Shutdown Current</td>
<td>$I_{VCC}_{\text{shd}}$</td>
<td>$V_{CC} &gt; \text{POR}, EN = \text{Low}$</td>
<td>--</td>
<td>2</td>
<td>5</td>
<td>$\mu$A</td>
</tr>
<tr>
<td>VCC POR Rising Voltage</td>
<td>$V_{IN}_{\text{POR}}$</td>
<td>Rising</td>
<td>2.8</td>
<td>--</td>
<td>3.7</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hysteresis</td>
<td>--</td>
<td>400</td>
<td>--</td>
<td>$\text{mV}$</td>
</tr>
</tbody>
</table>

Enable
| Enable Input Voltage | Logic-High $V_{IH}$ | 0.7 | --  | --  | V    |
|                     | Logic-Low $V_{IL}$  | --  | --  | 0.3 | V    |

Current Sense Circuit
| System Response Time | $OC_{\text{delay}}$ | OCP triggered | --  | 50  | --  | $\mu$s |
| OP Gain | $A_V$ | $V_{CSP} = V_{CSN} = 12V$ | --  | 200 | --  | V/V  |
### Absolute Maximum Ratings

<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>FLAG Pull Low Voltage</td>
<td>$I_{\text{SINK}} \geq 10\text{mA}$</td>
<td>--</td>
<td>--</td>
<td>0.1</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Input Current Sensing Accuracy</td>
<td>$V_{\text{BAT,REF}} = 0.4\text{V}$</td>
<td>--</td>
<td>--</td>
<td>15</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{\text{BAT,REF}} = 0.8\text{V}$</td>
<td>--</td>
<td>--</td>
<td>10</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{\text{BAT,REF}} = 2\text{V}$</td>
<td>--</td>
<td>--</td>
<td>5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>FLAG Leakage Current</td>
<td>$I_{\text{leak,FLAG}}$</td>
<td>EN LOW</td>
<td>--</td>
<td>--</td>
<td>5</td>
<td>$\mu\text{A}$</td>
</tr>
</tbody>
</table>

### Notes

**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.** $\theta_{JA}$ is measured at $T_A = 25^\circ\text{C}$ 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 3.** Devices are ESD sensitive. Handling precaution is recommended.

**Note 4.** The device is not guaranteed to function outside its operating conditions.

<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>OCSET Comparator</td>
<td>$I_{\text{leak,BAT,REF}}$</td>
<td>EN LOW</td>
<td>--</td>
<td>--</td>
<td>5</td>
<td>$\mu\text{A}$</td>
</tr>
<tr>
<td>BAT,REF Leakage Current</td>
<td>$V_{\text{BAT,REF}}$</td>
<td>0.4</td>
<td>--</td>
<td>2</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

### AC_REAL & AC_REF Comparator

<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>Comparator Offset</td>
<td>$V_{\text{AC,REAL}}$</td>
<td>$V_{\text{AC,REAL}} = 0.3\text{V}$ to $2\text{V}$</td>
<td>--</td>
<td>--</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>AC_REAL Input Range</td>
<td>$V_{\text{AC,REAL}}$</td>
<td>0.3</td>
<td>--</td>
<td>2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>AC_REF Input Range</td>
<td>$V_{\text{AC,REF}}$</td>
<td>0.3</td>
<td>--</td>
<td>2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Comparator Response Time</td>
<td>$V_{\text{AC,REAL}} &gt; V_{\text{AC,REF}}$</td>
<td>$\text{FLAG go low}$</td>
<td>--</td>
<td>--</td>
<td>200</td>
<td>ns</td>
</tr>
</tbody>
</table>
Typical Application Circuit
Typical Operating Characteristics

**AC REF = 1V, AC_REAL from 0 to 5V**

- AC REF (1V/Div)
- AC REAL (2V/Div)
- FLAG (1V/Div)

**Time (10μs/Div)**

**AC REF = 1V, AC_REAL from 5 to 0V**

- AC REF (1V/Div)
- AC REAL (2V/Div)
- FLAG (1V/Div)

**Time (40μs/Div)**

**ILOAD (5A/Div)**

**BAT_REF = 1V, ILOAD = 0A to 6A**

- BAT_REF (500mV/Div)
- FLAG (1V/Div)

**Time (10μs/Div)**

**Power On Mask Time**

- ILOAD (5A/Div)
- FLAG (2V/Div)
- BAT_REF (500mV/Div)
- EN (5V/Div)

**Time (1ms/Div)**

**Power Off from EN**

- ILOAD (5A/Div)
- FLAG (2V/Div)
- BAT_REF (900mV/Div)
- EN (5V/Div)

**Time (500μs/Div)**
OCP Accuracy Curve

VIN = 12V, Rs = 1mΩ
Application Information

The RT9554A provides battery OCP protection functions with FLAG indicator to informs system. It can operate with minimized external components of switching power supply systems to achieve OCP protection. The over-current is detected by monitoring the differential voltage of input current sense resistor. The RT9554A provides a 50μs system response time for FLAG and there is a 3ms mask time after EN rising edge. Also, the RT9554A provides a comparator with two pins, AC_REAL and AC_REF for users.

**FLAG**

The FLAG is an open-drain output and requires a pull-up resistor. When over-current is detected, FLAG is pulled low within 50μs and maintain until OCP status releases.

**Over Current Protection (OCP)**

As an industry standard, high accuracy current sense amplifier is used to monitor the input current that flow through current sense resistor. The RT9554A detects CSP-CSN differential voltage across the current sense resistor to monitor input current from battery. The OCP trigger point equation is shown as below:

\[
\text{BAT\_REF} = 3.3V \times \frac{R2}{R1+R2} \\
(I_{\text{SENSE}} \times 0.001) \times 200 = \text{BAT\_REF}
\]

200 is the internal error amp AV.

We suggest R1+R2 = 100kΩ to avoid power consumption. Isense is over-current protection trigger point.

For the overall timing sequence, please refer to Figure 1.

![Figure 1. Timing Sequence](image)

**Filter capacitor**

A 0.1μF capacitor between CSP and CSN for differential mode filtering is recommended. A 0.1μF capacitor between CSN and ground is for common mode filtering, and an optional 0.1μF capacitor between CSP and ground is for common mode filtering.

The CSP and CSN pins are used to sense Rsense with default value of 1mΩ. However, resistors of other values can also be used. Using a larger sense resistor, can have higher regulation accuracy, but, it comes with higher conduction loss.

**Thermal Considerations**

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

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

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

For recommended operating condition specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, \(\theta_{JA}\), is layout dependent. For WDFN-8L 2x2 package, the thermal resistance, \(\theta_{JA}\), is 45.5°C/W on a standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at \(T_A = 25°C\) can be calculated by the following formula:

\[
P_{D(\text{MAX})} = \frac{(125°C - 25°C)}{45.5°C/W} = 2.19W \text{ for WDFN-8L 2x2 package}
\]

The maximum power dissipation depends on the operating ambient temperature for fixed \(T_{J(\text{MAX})}\) and thermal resistance, \(\theta_{JA}\). The derating curve in Figure 2 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.
Layout Considerations

Layout is very important for the RT9554A. If designed improperly, the PCB may radiate excessive noise. Certain points must be considered before starting a layout for the RT9554A.

- Connect an RC low pass filter to VCC, 0.1μF, and 2.2Ω are recommended. Connect a RC low pass filter to EN, 0.1μF, and 1kΩ are recommended. Place the filter capacitor close to the IC.
- Current sense connections must always be made using Kelvin connections to ensure an accurate signal with the current limit resistor located at the device.
- All sensitive analog traces and components such as CSP, CSN, VCC, EN and FLAG, should be placed away from high voltage switching nodes to avoid coupling.

Figure 2. Derating Curve of Maximum Power Dissipation
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>0.700</td>
<td>0.800</td>
</tr>
<tr>
<td>A1</td>
<td>0.000</td>
<td>0.050</td>
</tr>
<tr>
<td>A3</td>
<td>0.175</td>
<td>0.250</td>
</tr>
<tr>
<td>b</td>
<td>0.200</td>
<td>0.300</td>
</tr>
<tr>
<td>D</td>
<td>1.950</td>
<td>2.050</td>
</tr>
<tr>
<td>D2</td>
<td>1.000</td>
<td>1.250</td>
</tr>
<tr>
<td>E</td>
<td>1.950</td>
<td>2.050</td>
</tr>
<tr>
<td>E2</td>
<td>0.400</td>
<td>0.650</td>
</tr>
<tr>
<td>e</td>
<td></td>
<td>0.500</td>
</tr>
<tr>
<td>L</td>
<td>0.300</td>
<td>0.400</td>
</tr>
</tbody>
</table>

W-Type 8L DFN 2x2 Package

Note: The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

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