RP550L001B-Y

1 A PWM/VFM Dual Step-down DC/DC Converter with Synchronous Rectifier for Industrial Applications

OUTLINE

The RP550L001B is a 1 A\(^{(1)}\) dual step-down DC/DC converter with synchronous rectifier. Replacing diodes with built-in switching transistors improves the efficiency of rectification. Therefore, by simply using two inductors, resistors and capacitors as the external components, a low ripple high efficiency synchronous rectifier step-down DC/DC converter can be easily configured.

Protection functions include a current limit function, a latch-off overcurrent protection function, a thermal shutdown function, and so on.

Output Voltage Control Methods have two operating modes: Forced PWM mode and PWM/VFM Auto-switching mode. By inputting a signal to the MODE pin, the RP550L001B can select from between two modes.

When the both converters are in PWM control, the converters operate with 180° turn-on phase shift of the switching transistors.

This is a high-reliability semiconductor device for industrial applications (-Y) that has passed both the screening at high temperature and the reliability test with extended hours.

FEATURES

- Input Voltage Range (Maximum Rating)
  
  \[0.6 \leq V_{\text{SET}} < 0.8 \text{ V} \quad \text{and} \quad 0.8 \leq V_{\text{SET}} \leq 2.3 \text{ V to } 5.5 \text{ V (6.5 V)}\]

- Operating Temperature Range
  
  \(-40^\circ\text{C to } 105^\circ\text{C}\)

- Supply Current
  
  Typ. 45 \(\mu\text{A}\) (VFM mode at no load per 1 channel)

- Standby Current
  
  Typ. 0 \(\mu\text{A}\)

- Adjustable Output Voltage Range\(^{(3)}\)
  
  0.6 \text{ V to } 3.3 \text{ V}

- Feedback Voltage Accuracy
  
  \(\pm 9 \text{ mV} (V_{\text{FB}} = 0.6 \text{ V})\)

- Output Voltage Temperature Coefficient
  
  \(\pm 100 \text{ ppm/}^\circ\text{C}\)

- Oscillator Frequency
  
  Typ. 2.3 MHz

- Oscillator Maximum Duty
  
  Min. 100%

- Built-in Driver ON Resistance
  
  Typ. Pch. 0.25 \(\Omega\), Nch. 0.21 \(\Omega\) (\(V_{\text{IN}} = 3.6 \text{ V}\))

- UVLO Detector Threshold
  
  Typ. 2.0 \text{ V}

- Soft Start Time
  
  Typ. 0.2 ms

- LX Current Limit Circuit
  
  Typ. 1900 mA/ channel

- Latch Type Protection Circuit
  
  Typ. 1.5 ms

- Package
  
  DFN3030-12 (3.0 mm x 3.0 mm)

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\(^{(1)}\) This is an approximate value, because output current depends on conditions and external components.

\(^{(2)}\) \(V_{\text{SET}}\): Set Output Voltage

\(^{(3)}\) Output voltage is settable by external resistor. Recommended range is up to 3.3 \text{ V}.\)
APPLICATIONS

- Industrial equipments such as FAs and smart meters
- Equipments used under high-temperature conditions such as surveillance camera and vending machine
- Equipments accompanied by self-heating such as motor and lighting

SELECTION GUIDE

Set output voltage \( (V_{SET}) \) is adjustable with external divider resistors. The recommended \( V_{SET} \) range is from 0.6 V to 3.3 V.
PIN DESCRIPTIONS

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VFB2</td>
<td>Channel 2 Feedback Pin</td>
</tr>
</tbody>
</table>
| 2       | MODE   | Mode Control Pin  
("H" forced PWM mode, "L" PWM/VFM auto switching mode) |
| 3       | VIN (<sup>(1)</sup>) | Input Pin |
| 4       | VIN (<sup>(1)</sup>) | Input Pin |
| 5       | AGND (<sup>(2)</sup>) | Analog Ground Pin |
| 6       | VFB1   | Channel 1 Feedback Pin |
| 7       | CE1    | Channel 1 Chip Enable Pin ("H" active) |
| 8       | LX1    | Channel 1 LX Switching Pin |
| 9       | PGND1 (<sup>(2)</sup>) | Channel 1 Power Ground Pin |
| 10      | PGND2 (<sup>(2)</sup>) | Channel 2 Power Ground Pin |
| 11      | LX2    | Channel 2 LX Switching Pin |
| 12      | CE2    | Channel 2 Chip Enable Pin ("H" active) |

* The exposed tab on the bottom of the package enhances thermal performance and is electrically connected to GND (substrate level). It is recommended that the exposed tab be connected to the ground plane on the board or otherwise be left open.

(1) VIN pin (No.3 and No.4) must be wired to the VIN plane when mounting on boards.
(2) GND pin (No.5, No.9, and No.10) must be wired to the GND plane when mounting on boards.
# Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{IN})</td>
<td>VIN Pin Voltage</td>
<td>(-0.3 \text{ to } 6.5)</td>
<td>V</td>
</tr>
<tr>
<td>(V_{LX1}, V_{LX2})</td>
<td>LX1 / LX2 Pin Voltage</td>
<td>(-0.3 \text{ to } V_{IN} + 0.3)</td>
<td>V</td>
</tr>
<tr>
<td>(V_{CE1}, V_{CE2})</td>
<td>CE1 / CE2 Pin Voltage</td>
<td>(-0.3 \text{ to } 6.5)</td>
<td>V</td>
</tr>
<tr>
<td>(V_{MODE})</td>
<td>MODE Pin Voltage</td>
<td>(-0.3 \text{ to } 6.5)</td>
<td>V</td>
</tr>
<tr>
<td>(V_{FB1}, V_{FB2})</td>
<td>VFB1 / VFB2 Pin Voltage</td>
<td>(-0.3 \text{ to } 6.5)</td>
<td>V</td>
</tr>
<tr>
<td>(I_{LX1}, I_{LX2})</td>
<td>LX1 / LX2 Pin Output Current</td>
<td>1.9</td>
<td>A</td>
</tr>
<tr>
<td>(P_D)</td>
<td>Power Dissipation(^{(1)})</td>
<td>1250</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>(DFN3030-12) Standard Test Land Pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>JEDEC STD. 51-7 Test Land Pattern</td>
<td>2440</td>
</tr>
<tr>
<td>(T_J)</td>
<td>Junction Temperature Range</td>
<td>(-40 \text{ to } 150)</td>
<td>°C</td>
</tr>
<tr>
<td>(T_{stg})</td>
<td>Storage Temperature Range</td>
<td>(-55 \text{ to } 150)</td>
<td>°C</td>
</tr>
</tbody>
</table>

**ABSOLUTE MAXIMUM RATINGS**

Electronic and mechanical stress momentarily exceeded absolute maximum ratings may cause the permanent damages and may degrade the life time and safety for both device and system using the device in the field. The functional operation at or over these absolute maximum ratings are not assured.

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# Recommended Operating Conditions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{IN})</td>
<td>Input Voltage ((0.6 \text{ V} \leq V_{SET}^{(2)} &lt; 0.8 \text{ V}))</td>
<td>2.3 to 4.5</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Input Voltage ((0.8 \leq V_{SET}^{(2)}))</td>
<td>2.3 to 5.5</td>
<td>V</td>
</tr>
<tr>
<td>(T_a)</td>
<td>Operating Temperature Range</td>
<td>(-40 \text{ to } 105)</td>
<td>°C</td>
</tr>
</tbody>
</table>

**RECOMMENDED OPERATING CONDITIONS**

All of electronic equipment should be designed that the mounted semiconductor devices operate within the recommended operating conditions. The semiconductor devices cannot operate normally over the recommended operating conditions, even if they are used over such ratings by momentary electronic noise or surge. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

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\(^{(1)}\) Refer to **POWER DISSIPATION** for detailed information.

\(^{(2)}\) \(V_{SET}\): Set Output Voltage
**ELECTRICAL CHARACTERISTICS**

Test Circuit is “OPEN LOOP” and Test Condition is AGND = PGND1 = PGND2 = 0 V, unless otherwise noted. The specifications surrounded by [ ] are guaranteed by design engineering at -40°C ≤ Ta ≤ 105°C.

### RP550L001B Electrical Characteristics

(Ta = 25°C)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VFB</strong></td>
<td>Feedback Voltage</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 3.6 \text{ V} )</td>
<td>0.591</td>
<td>0.600</td>
<td>0.609</td>
<td>V</td>
</tr>
<tr>
<td><strong>fosc</strong></td>
<td>Oscillator Frequency</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 3.6 \text{ V} )</td>
<td>2.05</td>
<td>2.30</td>
<td>2.55</td>
<td>MHz</td>
</tr>
<tr>
<td><strong>IDD1</strong></td>
<td>Supply Current 1 (1)</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 5.5 \text{ V}, V_{FB1} = V_{FB2} = 0.45 \text{ V}, V_{MODE} = 0 \text{ V} )</td>
<td>800</td>
<td>(1100)</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IDD2</strong></td>
<td>Supply Current 2 (1)</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 5.5 \text{ V}, V_{FB1} = V_{FB2} = 0.75 \text{ V}, V_{MODE} = 0 \text{ V} )</td>
<td>45</td>
<td>(60)</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IDD3</strong></td>
<td>Supply Current 3 (1)</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 5.5 \text{ V}, V_{FB1} = V_{FB2} = 0.75 \text{ V}, V_{MODE} = 5.5 \text{ V} )</td>
<td>800</td>
<td>(1100)</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>Istandby</strong></td>
<td>Standby Current (2)</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = 0 \text{ V} )</td>
<td>0</td>
<td>(1)</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>ICEH</strong></td>
<td>CE “High” Input Current (1)</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = 5.5 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>ICEL</strong></td>
<td>CE “Low” Input Current (1)</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IMODEH</strong></td>
<td>MODE “H” Input Current</td>
<td>( V_{IN} = V_{MODE} = 5.5 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IMODEL</strong></td>
<td>MODE “L” Input Current</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{MODE} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IFBH</strong></td>
<td>VFB “High” Input Current (1)</td>
<td>( V_{IN} = V_{FB1} = V_{FB2} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>IFBL</strong></td>
<td>VFB “Low” Input Current (1)</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = V_{FB1} = V_{FB2} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>ILXLEAKH</strong></td>
<td>LX Leakage Current “High” (1)</td>
<td>( V_{IN} = V_{IL1} = V_{IL2} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>ILXLEAKL</strong></td>
<td>LX Leakage Current “Low” (1)</td>
<td>( V_{IN} = 5.5 \text{ V}, V_{CE1} = V_{CE2} = V_{IL1} = V_{IL2} = 0 \text{ V} )</td>
<td>1</td>
<td>0</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td><strong>VCEH</strong></td>
<td>CE “H” Input Voltage</td>
<td>( V_{IN} = 5.5 \text{ V} )</td>
<td>1.0</td>
<td>1.0</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td><strong>VCEL</strong></td>
<td>CE “L” Input Voltage</td>
<td>( V_{IN} = 2.3 \text{ V} )</td>
<td>0.4</td>
<td>0.4</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td><strong>VMODEH</strong></td>
<td>MODE “High” Input Voltage</td>
<td>( V_{IN} = 5.5 \text{ V} )</td>
<td>1.0</td>
<td>1.0</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td><strong>VMODEL</strong></td>
<td>MODE “Low” Input Voltage</td>
<td>( V_{IN} = 2.3 \text{ V} )</td>
<td>0.4</td>
<td>0.4</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td><strong>RONP</strong></td>
<td>Pch.Transistor ON Resistance</td>
<td>( V_{IN} = 3.6 \text{ V}, I_{LX1} = I_{LX2} = -100 \text{ mA} )</td>
<td>0.25</td>
<td>0.21</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td><strong>RONN</strong></td>
<td>Nch.Transistor ON Resistance</td>
<td>( V_{IN} = 3.6 \text{ V}, I_{LX1} = I_{LX2} = -100 \text{ mA} )</td>
<td>0.25</td>
<td>0.21</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td><strong>Tstart</strong></td>
<td>Soft-start Time</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 3.6 \text{ V} )</td>
<td>200</td>
<td>(500)</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td><strong>ILXLM</strong></td>
<td>LX Limit Current</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 3.6 \text{ V} )</td>
<td>(1400)</td>
<td>1900</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td><strong>IPROT</strong></td>
<td>Protection Delay Time</td>
<td>( V_{IN} = V_{CE1} = V_{CE2} = 3.6 \text{ V} )</td>
<td>0.5</td>
<td>1.5</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td><strong>VVUL01</strong></td>
<td>UVLO Threshold Voltage</td>
<td>( V_{IN} = V_{CE1} = V_{CE2}, \text{ Falling} )</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>V</td>
</tr>
<tr>
<td><strong>VVUL02</strong></td>
<td>UVLO Threshold Voltage</td>
<td>( V_{IN} = V_{CE1} = V_{CE2}, \text{ Rising} )</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>V</td>
</tr>
<tr>
<td><strong>TTS0D</strong></td>
<td>Thermal Shutdown Threshold Temperature</td>
<td>Tj, Rising</td>
<td>165</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TTSR</strong></td>
<td>Thermal Shutdown Threshold Temperature</td>
<td>Tj, Falling</td>
<td>125</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Either Channel 1 value or Channel 2 value is indicated.
(2) The sum of Channel 1 and Channel 2 is indicated.
THEORY OF OPERATION

Soft-start
Starting-up with CE Pin
RP550L starts to operate when the CE pin voltage \( V_{CE} \) exceeds the threshold voltage. The threshold voltage is preset between CE “High” input voltage \( V_{CEH} \) and CE “Low” input voltage \( V_{CEL} \). The soft-start circuit also starts to operate after the device start-up. Then, after a certain period of time, the reference voltage \( V_{REF} \) in the device gradually increases up to the specified value.

Notes: Soft start time \( t_{START} \) might not be always equal to an actual turn-on speed of the step-down DC/DC converter. Please note that the turn-on speed could be affected by the power supply capacity, the output current, the inductance value, and the \( C_{OUT} \) value.

Starting-up with Power Supply
After the power-on, the device starts to operate when \( V_{IN} \) exceeds the UVLO released voltage \( V_{UVLO2} \). The soft-start circuit also starts to operate. Then after a certain period of time, \( V_{REF} \) gradually increases up to the specified value.

Notes: Please note that the turn-on speed of \( V_{OUT} \) could be affected by the following conditions.

1. Power supply capacity and Turn-on speed of \( V_{IN} \) determined by \( C_{IN} \)
2. Output current and Output capacity of \( C_{OUT} \)

\( t_{START} \) indicates the duration until the reference voltage \( V_{REF} \) reaches the specified voltage after soft-start circuit’s activation.
Under Voltage Lockout (UVLO)

If \( V_{IN} \) becomes lower than \( V_{SET} \), the step-down DC/DC converter stops the switching operation and ON duty becomes 100%, and then \( V_{OUT} \) gradually drops according to \( V_{IN} \).

If the \( V_{IN} \) drops more and becomes lower than the UVLO detector threshold (\( V_{UVLO1} \)), the UVLO circuit starts to operate, \( V_{REF} \) stops, and Pch. and Nch. built-in transistors become the OFF state. As a result, \( V_{OUT} \) drops according to the \( C_{OUT} \) capacitance value and the load.

To restart the operation, \( V_{IN} \) is required to be higher than \( V_{UVLO2} \). The timing chart below shows the voltage shifts of \( V_{REF}, V_{LX} \) and \( V_{OUT} \) in response to variation of the \( V_{IN} \) value.

Notes: Falling edge (operating) and rising edge (releasing) waveforms of \( V_{OUT} \) might be affected by the initial voltage of \( C_{OUT} \) and the output current of \( V_{OUT} \).
**Current limit Function**

Current limit circuit supervises the inductor peak current (the current flowing through Pch. transistor) in each switching cycle, and if the current exceeds the LX current limit ($i_{LXLIM}$), Pch. transistor is turned off. $i_{LXLIM}$ of the RP550L001B is Typ. 1.9 A.

**Latch Type Protection**

Latch type protection circuit latches the built-in driver in the OFF state and stops the operation of the step-down DC/DC converter, if the over current status or $V_{OUT}$ being dropped to the half of the setting voltage due to shorting continues for the protection delay time ($t_{PROT}$).

To release the latch type protection circuit, restart the device by inputting "L" signal to the CE pin or making the supply voltage lower than $V_{UVLO1}$.

Notes: $i_{LXLIM}$ and $t_{PROT}$ could be easily affected by self-heating or ambient environment. If the $V_{IN}$ drops dramatically or becomes unstable due to short-circuit, protection operation and $t_{PROT}$ could be affected.
The timing chart below shows the voltage shift of $V_{CE}$, $V_{LX}$ and $V_{OUT}$ when the device status is changed by the following orders: $V_{IN}$ rising $\rightarrow$ stable operation $\rightarrow$ high load $\rightarrow$ CE reset $\rightarrow$ stable operation $\rightarrow$ $V_{IN}$ falling $\rightarrow$ $V_{IN}$ recovering (UVLO reset) $\rightarrow$ stable operation.

(1)(2) If the large current flows through the circuit or the device goes into low $V_{OUT}$ condition due to short-circuit or other reasons, the latch type protection circuit latches the built-in driver to “OFF” state after $t_{PROT}$. Then, $V_{LX}$ becomes "L" and $V_{OUT}$ turns “OFF”.

(3) The latch type protection circuit is released by CE reset, which puts the device into "L" once with the CE pin and back into "H".

(4) The latch type protection circuit is released by UVLO reset, which makes $V_{IN}$ lower than $V_{UVLO1}$.
**Operation of Step-down DC/DC Converter and Output Current**

The step-down DC/DC converter charges energy in the inductor when LX transistor turns “ON”, and discharges the energy from the inductor when LX transistor turns “OFF” and controls with less energy loss, so that a lower output voltage ($V_{OUT}$) than the input voltage ($V_{IN}$) can be obtained. The operation of the step-down DC/DC converter is explained in the following figures.

**Basic Circuit**

- Step1. Pch. transistor turns “ON” and $I_L$ ($i_1$) flows, $L$ is charged with energy. At this moment, $i_1$ increases from the minimum inductor current ($I_{L\text{MIN}}$), which is 0 A, and reaches the maximum inductor current ($I_{L\text{MAX}}$) in proportion to the on-time period ($t_{ON}$) of Pch. transistor.

- Step2. When Pch. transistor turns “OFF”, $L$ tries to maintain $I_L$ at $I_{L\text{MAX}}$, so $L$ turns Nch. transistor “ON” and $I_L$ ($i_2$) flows into $L$.

- Step3. $i_2$ decreases gradually and reaches $I_{L\text{MIN}}$ after the open-time period ($t_{OPEN}$) of NMOS transistor, and then Nch. transistor turns “OFF”. This is called discontinuous current mode. As the output current ($I_{OUT}$) increases, the off-time period ($t_{OFF}$) of Pch. transistor runs out before $I_L$ reaches $I_{L\text{MIN}}$. The next cycle starts, and Pch. transistor turns “ON” and Nch. transistor turns “OFF”, which means $I_L$ starts increasing from $I_{L\text{MIN}}$. This is called continuous current mode.

In PWM mode, $V_{OUT}$ is maintained by controlling $t_{ON}$. The oscillator frequency ($f_{OSC}$) is maintained constant during PWM mode.

When the step-down DC/DC operation is constant, $I_{L\text{MIN}}$ and $I_{L\text{MAX}}$ during $t_{ON}$ of Pch. transistor would be same as during $t_{OFF}$ of Pch. transistor. The current differential between $I_{L\text{MAX}}$ and $I_{L\text{MIN}}$ is described as $\Delta I$, as the following equation 1.

$$\Delta I = I_{L\text{MAX}} - I_{L\text{MIN}} = V_{OUT} \times t_{OPEN} / L = (V_{IN} - V_{OUT}) \times t_{ON} / L \quad \cdots \quad \text{Equation 1}$$

The above equation is predicated on the following requirements.

$$T = 1 / f_{OSC} = t_{ON} + t_{OFF}$$

$$\text{duty (\%)} = t_{ON} / T \times 100 = t_{ON} \times f_{OSC} \times 100$$

$$t_{OPEN} \leq t_{OFF}$$

In Equation 1, “$V_{OUT} \times t_{OPEN} / L$” shows the amount of current change in "OFF" state. Also, “$(V_{IN} - V_{OUT}) \times t_{ON} / L$” shows the amount of current change at "ON" state.
Discontinuous Mode and Continuous Mode

As illustrated in Figure A., when $I_{OUT}$ is relatively small, $t_{OPEN} < t_{OFF}$. In this case, the energy charged into $L$ during $t_{ON}$ will be completely discharged during $t_{OFF}$, as a result, $I_{LMIN} = 0$. This is called discontinuous mode. When $I_{OUT}$ is gradually increased, eventually $t_{OPEN} = t_{OFF}$ and when $I_{OUT}$ is increased further, eventually $I_{LMIN} > 0$ as illustrated in Figure B. This is called continuous mode.

Forced PWM Mode and VFM Mode

Operating mode to control the output voltage is selectable between a forced PWM mode and a PWM/VFM auto-switching mode, and can be set by the MODE pin. The forced PWM control switches at fixed frequency rate in order to reduce noise in low output current. The PWM/VFM auto-switching control automatically switches from PWM mode to VFM mode in order to achieve high efficiency in low output current.

Forced PWM Mode

By setting the MODE pin to “H”, the device switches the frequency at the fixed rate to reduce noise even when the output load is light. Therefore, when $I_{OUT}$ is $\Delta I/2$ or less, $I_{LMIN}$ becomes less than “0”. That is, the accumulated charge in $C_{OUT}$ is discharged through the internal transistor while $I_L$ is increasing from $I_{LMIN}$ to “0” during $t_{ON}$, and also while $I_L$ is decreasing from “0” to $I_{LMIN}$ during $t_{OFF}$.
VFM Mode

By setting the MODE pin to “L”, in low output current, the device automatically switches into VFM mode in order to achieve high efficiency. In VFM mode, $t_{ON}$ is forced to end when the inductor current reaches the pre-set $I_{MAX}$. In the VFM mode, $I_{MAX}$ is typically set to 280 mA for the RP550L001B. When $t_{ON}$ reaches 1.5 times of $T = 1 / f_{OSC}$, $t_{ON}$ will be forced to end even if the inductor current is not reached $I_{MAX}$.

![VFM Mode Diagram](image)

Forced PWM Mode

VFM Mode
APPLICATION INFORMATION

Typical Application Circuit

Notes: MODE = “H” forced PWM mode, MODE = “L” PWM/VFM auto switching mode

Recommended External Components

Table 1. Recommended External Components: 0.8 V ≤ VSET ≤ 3.3 V

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Components</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIN</td>
<td>10 µF</td>
<td>Ceramic Capacitor</td>
<td>CGA4J1X7R0J106K125AC (TDK)</td>
</tr>
<tr>
<td>COUT</td>
<td>10 µF</td>
<td>Ceramic Capacitor</td>
<td>CGA4J1X7R0J106K125AC (TDK)</td>
</tr>
<tr>
<td>L</td>
<td>2.2 µH</td>
<td>Inductor</td>
<td>VLS3012ET-2R2M-CA (TDK)</td>
</tr>
</tbody>
</table>

Table 2. Recommended External Components: 0.6 V ≤ VSET < 0.8 V

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Components</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIN</td>
<td>10 µF</td>
<td>Ceramic Capacitor</td>
<td>CGA4J1X7R0J106K125AC (TDK)</td>
</tr>
<tr>
<td>COUT</td>
<td>10 µF x 2</td>
<td>Ceramic Capacitor</td>
<td>CGA4J1X7R0J106K125AC (TDK)</td>
</tr>
<tr>
<td>L</td>
<td>1.5 µH</td>
<td>Inductor</td>
<td>VLS3012ET-1R5N-CA (TDK)</td>
</tr>
</tbody>
</table>
Cautions in selecting external parts

- Choose a low ESR ceramic capacitor. The ceramic capacitance of a capacitor (C\text{IN}) connected between VIN and GND should be more than or equal to 10 µF. The ceramic capacitance of a capacitor (C\text{OUT}) connected between VOUT and GND should be 10 µF to 20 µF. Please be aware of the characteristics of bias dependence and temperature fluctuation of ceramic capacitor.

- Choose an inductor that has small DC resistance, has enough permissible current and is hard to cause magnetic saturation. If the inductance value of the inductor becomes extremely small under the load conditions, the peak current of LX may increase along with the load current. As a result, over current protection circuit may start to operate when the peak current of LX reaches to LX limit current. Therefore, choose an inductor with consideration for the value of IL\text{MAX}.

- The output voltage (V\text{OUT1}, V\text{OUT2}) is adjustable by changing the resistance values of resistors (R11 and R12, R21 and R22) as follows.

\[
\begin{align*}
V\text{OUT1} &= 0.6 \times \frac{(R11 + R12)}{R12} \quad (\text{Recommended rage: } 0.6 \text{ V} \leq V\text{OUT1} \leq 3.3 \text{ V}) \\
V\text{OUT2} &= 0.6 \times \frac{(R21 + R22)}{R22} \quad (\text{Recommended rage: } 0.6 \text{ V} \leq V\text{OUT2} \leq 3.3 \text{ V})
\end{align*}
\]

If R11, R12, R21, and R22 are too large, the impedances of VFB1 and VFB2 also become large, as a result, the device could be easily affected by noise. For this reason, R12 and R22 should be 100kΩ or less. If the operation becomes unstable due to the high impedances, the impedances should be decreased.

C11 and C21 can be calculated by the following equations. Please use the value close to the calculation result.

\[
\begin{align*}
C11 &= 2.2 \times 10^{-6} / R12 \quad \text{[F]} \quad (0.6 \text{ V} \leq V\text{OUT1} \leq 3.3 \text{ V}) \\
C21 &= 2.2 \times 10^{-6} / R22 \quad \text{[F]} \quad (0.6 \text{ V} \leq V\text{OUT2} \leq 3.3 \text{ V})
\end{align*}
\]

The recommended resistance values for R11, R12, R21, R22, C11, and C21 are as follows.

<table>
<thead>
<tr>
<th>Output Voltage V\text{OUT1}, V\text{OUT2} [V]</th>
<th>Resistor [kΩ]</th>
<th>Capacitor [pF]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11, R21</td>
<td>R12, R22</td>
<td>C11, C21</td>
</tr>
<tr>
<td>0.6</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0.7</td>
<td>16.7</td>
<td>100</td>
</tr>
<tr>
<td>0.8</td>
<td>33.3</td>
<td>100</td>
</tr>
<tr>
<td>1.2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1.8</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>2.5</td>
<td>317</td>
<td>100</td>
</tr>
<tr>
<td>3.3</td>
<td>450</td>
<td>100</td>
</tr>
</tbody>
</table>
Calculation Conditions of LX Pin Maximum Output Current (IL\textsubscript{LMAX})

The following equations explain the relationship to determine IL\textsubscript{LMAX} at the ideal operation of the device in continuous mode.

- \(I_{RP}\) : Ripple Current P-P value
- \(\frac{R_{ONP}}{R_{ONN}}\) : ON resistance of Pch. / Nch. transistor
- \(R_L\) : DC resistor of the inductor

First, when the Pch. transistor is “ON”, Equation 1 is satisfied.

\[
V_{IN} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times \frac{I_{RP}}{t_{ON}} \quad \text{Equation 1}
\]

Second, when the Pch. transistor is “OFF” (the Nch. transistor is "ON"), Equation 2 is satisfied.

\[
L \times \frac{I_{RP}}{t_{OFF}} = R_{ONN} \times I_{OUT} + V_{OUT} + R_L \times I_{OUT} \quad \text{Equation 2}
\]

Put Equation 2 into Equation 1 to solve ON duty of the Pch. transistor (\(D_{ON} = \frac{t_{ON}}{t_{OFF} + t_{ON}}\)).

\[
D_{ON} = \frac{(V_{OUT} + R_{ONN} \times I_{OUT} + R_L \times I_{OUT})}{(V_{IN} + R_{ONN} \times I_{OUT} - R_{ONP} \times I_{OUT})} \quad \text{Equation 3}
\]

Ripple Current is described as follows:

\[
I_{RP} = (V_{IN} - V_{OUT} - R_{ONP} \times I_{OUT} - R_L \times I_{OUT}) \times D_{ON} / f_{OSC} / L \quad \text{Equation 4}
\]

Peak current that flows through L, and LX transistor is described as follows:

\[
I_{L\text{LMAX}} = I_{OUT} + \frac{I_{RP}}{2} \quad \text{Equation 5}
\]
TECHNICAL NOTES

The performance of a power source circuit using this device is highly dependent on a peripheral circuit. A peripheral component or the device mounted on PCB should not exceed a rated voltage, a rated current or a rated power. When designing a peripheral circuit, please be fully aware of the following points.

- AGND, PGND1 and PGND2 must be wired to the GND plane when mounting on boards.

- The VIN pins must be wired to the VIN plane when mounting on boards.

- Ensure the VIN and GND lines are sufficiently robust. A large switching current flows through the GND line, the VDD line, the VOUT line, an inductor, and LX. If their impedance is too high, noise pickup or unstable operation may result. Set external components as close as possible to the device and minimize the wiring between the components and the device, especially between a capacitor and the VIN pin. The wiring between VFB and load and between L and VOUT should be separated.

- Over current protection circuit and latch type protection circuit may be affected by self-heating or power dissipation environment.
TYPICAL CHARACTERISTICS

Typical Characteristics are intended to be used as reference data, they are not guaranteed.

1) Output Voltage vs. Output Current

**RP550L001B**

**V\text{OUT} = 0.6 \text{ V}**

**MODE = “L”, PWM/VFM Auto-Switching Control**

**RP550L001B**

**V\text{OUT} = 0.8 \text{ V}**

**MODE = “L”, PWM/VFM Auto-Switching Control**

**RP550L001B**

**V\text{OUT} = 1.2 \text{ V}**

**MODE = “L”, PWM/VFM Auto-Switching Control**

**RP550L001B**

**V\text{OUT} = 0.6 \text{ V}**

**MODE = “H”, Forced PWM Control**

**RP550L001B**

**V\text{OUT} = 0.8 \text{ V}**

**MODE = “H”, Forced PWM Control**

**RP550L001B**

**V\text{OUT} = 1.2 \text{ V}**

**MODE = “H”, Forced PWM Control**
2) Output Voltage vs. Input Voltage

**RP550L001B V<sub>OUT</sub> = 0.8 V**

MODE = “H”, Forced PWM Control

**RP550L001B V<sub>OUT</sub> = 1.2 V**

MODE = “H”, Forced PWM Control
RP550L001B-Y

NO. EY-285170518

3) Feedback Voltage vs. Ambient Temperature

4) Efficiency vs. Output Current
5) Supply Current vs. Ambient Temperature
RP550L001B  \( V_{OUT} = 1.8 \) V \((V_{IN} = 5.5 \) V\)
MODE = "L", PWM/VFM Auto-Switching Control

6) Supply Current vs. Input Voltage
RP550L001B  \( V_{OUT} = 1.8 \) V
MODE = "L", PWM/VFM Auto-Switching Control
7) Output Voltage Waveform

RP550L001B  \( V_{\text{OUT}} = 0.6 \, \text{V} \) (\( V_{\text{IN}} = 3.6 \, \text{V} \))

MODE = “L”, PWM/VFM Auto-Switching Control

- \( V_{\text{OUT}} = 0.6 \, \text{V} \) (\( V_{\text{IN}} = 3.6 \, \text{V} \))

MODE = “L”, PWM/VFM Auto-Switching Control

RP550L001B  \( V_{\text{OUT}} = 0.8 \, \text{V} \) (\( V_{\text{IN}} = 3.6 \, \text{V} \))

MODE = “L”, PWM/VFM Auto-Switching Control

- \( V_{\text{OUT}} = 0.8 \, \text{V} \) (\( V_{\text{IN}} = 3.6 \, \text{V} \))

MODE = “H”, Forced PWM Control

RP550L001B  \( V_{\text{OUT}} = 0.8 \, \text{V} \) (\( V_{\text{IN}} = 3.6 \, \text{V} \))

MODE = “H”, Forced PWM Control
RP550L001B  \( V_{OUT} = 1.2 \text{ V (} V_{IN} = 3.6 \text{ V)} \)
MODE = “L”, Auto-Switching Control

RP550L001B  \( V_{OUT} = 1.2 \text{ V (} V_{IN} = 3.6 \text{ V)} \)
MODE = “H”, Forced PWM Control

RP550L001B  \( V_{OUT} = 1.8 \text{ V (} V_{IN} = 3.6 \text{ V)} \)
MODE = “L”, PWM/VFM Auto-Switching Control

RP550L001B  \( V_{OUT} = 1.8 \text{ V (} V_{IN} = 3.6 \text{ V)} \)
MODE = “H”, Forced PWM Control
RP550L001B  \( V_{\text{OUT}} = 3.3 \, \text{V} \) (\( V_{\text{IN}} = 4.3 \, \text{V} \))
MODE = “L”, PWM/VFM Auto-Switching Control

RP550L001B  \( V_{\text{OUT}} = 3.3 \, \text{V} \) (\( V_{\text{IN}} = 4.3 \, \text{V} \))
MODE = “H”, Forced PWM Control

8) Oscillator Frequency vs. Ambient Temperature

9) Oscillator Frequency vs. Input Voltage

10) Soft-start Time vs. Ambient Temperature
11) UVLO Detector/Released Threshold vs. Ambient Temperature

**UVLO Detector Threshold**

![Graph of UVLO Detector Threshold vs. Temperature](image1)

**UVLO Released Threshold**

![Graph of UVLO Released Threshold vs. Temperature](image2)

12) CE Input Voltage vs. Ambient Temperature

**CE "H" Input Voltage (V_in = 5.5 V)**

![Graph of CE "H" Input Voltage vs. Temperature](image3)

**CE "L" Input Voltage (V_in = 2.3 V)**

![Graph of CE "L" Input Voltage vs. Temperature](image4)

13) LX Limit Current vs. Ambient Temperature

![Graph of LX Limit Current vs. Temperature](image5)
14) Nch. Transistor ON Resistance vs. Ambient Temperature

![Graph showing Nch. Transistor ON Resistance vs. Temperature]

15) Pch. Transistor ON Resistance vs. Ambient Temperature

![Graph showing Pch. Transistor ON Resistance vs. Temperature]

16) Load Transient Response
RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 0.6 V)
MODE = "L", PWM/VFM Auto-Switching Control

![Graph showing Load Transient Response for Nch. Transistor]

RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 0.6 V)
MODE = "L", PWM/VFM Auto-Switching Control

![Graph showing Load Transient Response for Pch. Transistor]
RP550L001B (V\text{IN} = 3.6 \text{ V}, V\text{OUT} = 0.6 \text{ V})

MODE = "L", PWM/VFM Auto-Switching Control

RP550L001B (V\text{IN} = 3.6 \text{ V}, V\text{OUT} = 0.8 \text{ V})

MODE = "H", Forced PWM Control

RP550L001B (V\text{IN} = 3.6 \text{ V}, V\text{OUT} = 0.6 \text{ V})

RP550L001B (V\text{IN} = 3.6 \text{ V}, V\text{OUT} = 0.8 \text{ V})

MODE = "L", PWM/VFM Auto-Switching Control
RP550L001B (VIN = 3.6 V, VOUT = 0.8 V)

MODE = “L”, PWM/VFM Auto-Switching Control

MODE = “L”, Forced PWM Control

RP550L001B (VIN = 3.6 V, VOUT = 1.2 V)

MODE = “H”, PWM/VFM Auto-Switching Control

MODE = “H”, Forced PWM Control
RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 1.2 V)

MODE = "L", PWM/VFM Auto-Switching Control

RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 1.8 V)

MODE = "H", Forced PWM Control
RP550L001B (VIN = 3.6 V, VOUT = 1.8 V)

MODE = "L", PWM/VFM Auto-Switching Control

RP550L001B (VIN = 5.0 V, VOUT = 3.3 V)

MODE = "H", Forced PWM Control

RP550L001B (VIN = 5.0 V, VOUT = 3.3 V)

MODE = "H", Forced PWM Control
17) Mode Switching
RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 1.2 V, I_{OUT} = 1 mA)
MODE = "L" → MODE = "H"

RP550L001B (V_{IN} = 3.6 V, V_{OUT} = 1.2 V, I_{OUT} = 1 mA)
MODE = "H" → MODE = "L"
The power dissipation of the package is dependent on PCB material, layout, and environmental conditions. The following conditions are used in this measurement.

### Measurement Conditions

<table>
<thead>
<tr>
<th></th>
<th>Standard Test Land Pattern</th>
<th>JEDEC STD.51-7 Test Land Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Mounting on Board</td>
<td>Mounting on Board</td>
</tr>
<tr>
<td></td>
<td>(Wind Velocity=0m/s)</td>
<td>(Wind Velocity = 0 m/s)</td>
</tr>
<tr>
<td>Board Material</td>
<td>Glass cloth epoxy plastic</td>
<td>Glass Cloth Epoxy Plastic</td>
</tr>
<tr>
<td></td>
<td>(Double sided)</td>
<td>(Four-Layer Board)</td>
</tr>
<tr>
<td>Board Dimensions</td>
<td>40mm x 40mm x 1.6mm</td>
<td>76.2 mm × 114.3 mm × 1.6 mm</td>
</tr>
<tr>
<td>Copper Ratio</td>
<td>Top side: Approx. 50%,</td>
<td>Outer Layers (First and Fourth Layers):</td>
</tr>
<tr>
<td></td>
<td>Back side: Approx. 50%</td>
<td>Less than 10% of 60 mm Square</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inner Layers (Second and Third Layers):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100% of 74.2 mm Square</td>
</tr>
<tr>
<td>Through-holes</td>
<td>φ 0.54mm x 32pcs</td>
<td>φ 0.85 mm × 64 pcs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* The land pattern of Tab (Heat spreader), the inner layers and the backside pattern are connected by 0.3mm through-hole.</td>
</tr>
</tbody>
</table>

### Measurement Result

(Ta = 25°C, Tjmax = 150°C)

<table>
<thead>
<tr>
<th></th>
<th>Standard Test Land Pattern</th>
<th>JEDEC STD.51-7 Test Land Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>1250mW</td>
<td>2440 mW</td>
</tr>
<tr>
<td>Thermal Resistance</td>
<td>( \theta ja = (150-25°C)/1.25W = 100°C/W )</td>
<td>( \theta ja = (150 - 25°C) / 2.44 W = 51.2°C/W )</td>
</tr>
<tr>
<td></td>
<td>( \theta jc = 18°C/W )</td>
<td>( \theta jc = 5.9°C/W )</td>
</tr>
</tbody>
</table>

![Graph of Power Dissipation vs. Ambient Temperature](image)

![Measurement Board Pattern](image)

IC Mount Area (mm)
The tab on the bottom of the package is substrate level (GND). It is recommended that the tab be connected to the ground plane on the board, or otherwise be left floating.
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