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

OUTLINE

The RP550K001A is a CMOS-based 1A\(^1\) dual step-down DC/DC converter with synchronous rectifier. Internally, a single converter consists of oscillators, reference voltage units, error amplifiers, switching control circuits, soft-start circuit, latch type protection circuit, an under voltage lockout (UVLO) circuit, a thermal shutdown circuit and switching transistors.

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.

Latch type protection circuit latches the built-in driver to the OFF state during high load or if the output is short-circuited for a specified time (protection delay time). The latch protection circuit can be released by once setting the converter into the standby mode with the CE pin and then setting it back to the active mode, or, by turning the power off and back on. Setting the supply voltage lower than the UVLO detector threshold can also release the latch protection circuit. Thermal shutdown circuit detects overheating of the converter and stops the converter operation to protect it from damage if the junction temperature exceeds the specified temperature.

By inputting a signal to the MODE pin, the RP550K001A can choose PWM/VFM auto switching control or forced PWM control. In low output current, PWM/VFM auto switching control automatically switches from PWM mode to VFM mode in order to achieve high efficiency. Likewise, in low output current, forced PWM control switches at fixed frequency in order to reduce noise.

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

The RP550K001A is available in DFN(PLP)2730-12 package which achieves high-density mounting on boards.

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

FEATURES

- Supply Current ................................................................. Typ. 45\(\mu\)A (VFM mode with no load/ 1 channel)
- Standby Current .............................................................. Max. 10\(\mu\)A
- Input Voltage Range ...................................................... 2.3V to 5.5V (\(V_{SET} \geq 0.8V\))
- Output Voltage Range ...................................................... Adjustable from 0.6V (Recommended range is up to 3.3V)
- Feedback Voltage Accuracy .............................................. ±9mV (\(V_{FB}=0.6V\))
- Output Voltage Temperature Coefficient ............................. ±100ppm/°C
- Oscillator Frequency ....................................................... Typ. 2.25MHz
- Oscillator Maximum Duty ................................................ Min. 100%
- Built-in Driver ON Resistance ............................................ Typ. Pch. 0.25Ω, Nch. 0.21Ω (\(V_{IN}=3.6V\))
- UVLO Detector Threshold ............................................... Typ. 2.0V
- Soft Start Time ............................................................... Typ. 0.2ms
- Lx Current Limit Circuit .................................................. Typ. 1700mA/ channel
- Latch Type Protection Circuit ......................................... Typ. 1.5ms
- Package ................................................................. DFN(PLP)2730-12
APPLICATION

- Power source for battery-powered equipment
- Power source for hand-held communication equipment, cameras, and VCRs
- Power source for Wireless LAN terminals

BLOCK DIAGRAM

Figure 1. RP550K001A
SELECTION GUIDE

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Package</th>
<th>Quantity per Reel</th>
<th>Pb Free</th>
<th>Halogen Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP550K001A-TR</td>
<td>DFN(PLP)2730-12</td>
<td>5,000pcs</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Output voltage is adjustable with external divider resistors. Recommended output voltage range is from 0.6V to 3.3V.

PIN CONFIGURATIONS

- **DFN(PLP)-2730-12**

PIN DESCRIPTIONS

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$V_{FB2}$</td>
<td>Channel 2 Feedback Pin</td>
</tr>
<tr>
<td>2</td>
<td>MODE</td>
<td>Mode Control Pin (&quot;H&quot; forced PWM control, &quot;L&quot; PWM/VFM auto switching control)</td>
</tr>
<tr>
<td>3</td>
<td>$V_{IN}$</td>
<td>Input Pin$^2$</td>
</tr>
<tr>
<td>4</td>
<td>$V_{IN}$</td>
<td>Input Pin$^2$</td>
</tr>
<tr>
<td>5</td>
<td>AGND</td>
<td>Analog Ground Pin$^3$</td>
</tr>
<tr>
<td>6</td>
<td>$V_{FB1}$</td>
<td>Channel 1 Feedback Pin</td>
</tr>
<tr>
<td>7</td>
<td>CE1</td>
<td>Channel 1 Chip Enable Pin (&quot;H&quot; active)</td>
</tr>
<tr>
<td>8</td>
<td>$L_{X1}$</td>
<td>Channel 1 Lx Switching Pin</td>
</tr>
<tr>
<td>9</td>
<td>PGND1</td>
<td>Channel 1 Power Ground Pin$^3$</td>
</tr>
<tr>
<td>10</td>
<td>PGND2</td>
<td>Channel 2 Power Ground Pin$^3$</td>
</tr>
<tr>
<td>11</td>
<td>$L_{X2}$</td>
<td>Channel 2 Lx Switching Pin</td>
</tr>
<tr>
<td>12</td>
<td>CE2</td>
<td>Channel 2 Chip Enable Pin (&quot;H&quot; active)</td>
</tr>
</tbody>
</table>

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.

$^2$ No.3 pin and No.4 pin must be wired to the $V_{IN}$ plane when mounting on boards.

$^3$ No.5 pin, No.9 pin and No.10 pin be must wired to the GND plane when mounting on boards.
### ABSOLUTE MAXIMUM RATINGS

(AGND=PGND1=PGND2=0V)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$</td>
<td>$V_{IN}$ Input Pin Voltage</td>
<td>-0.3 to 6.5</td>
<td>V</td>
</tr>
<tr>
<td>$V_{LX1}, V_{LX2}$</td>
<td>$L_{X1}, L_{X2}$ Pin Voltage</td>
<td>-0.3 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 to 6.5</td>
<td>V</td>
</tr>
<tr>
<td>$V_{MODE}$</td>
<td>MODE Pin Voltage</td>
<td>-0.3 to 6.5</td>
<td>V</td>
</tr>
<tr>
<td>$V_{FB1}, V_{FB2}$</td>
<td>$V_{FB1}, V_{FB2}$ Pin Voltage</td>
<td>-0.3 to 6.5</td>
<td>V</td>
</tr>
<tr>
<td>$I_{LX1}, I_{LX2}$</td>
<td>$L_{X1}, L_{X2}$ Pin Output Current</td>
<td>1.7</td>
<td>A</td>
</tr>
<tr>
<td>$P_D$</td>
<td>Power Dissipation*4</td>
<td>1000</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>Standard Land Pattern*4</td>
<td>1950</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>High Wattage Land Pattern*4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_a$</td>
<td>Operating Temperature Range</td>
<td>-40 to +85</td>
<td>°C</td>
</tr>
<tr>
<td>$T_{stg}$</td>
<td>Storage Temperature Range</td>
<td>-55 to +125</td>
<td>°C</td>
</tr>
</tbody>
</table>

*For more information about Power Dissipation, Standard Land Pattern and High Wattage Land Pattern, please refer to PACKAGE INFORMATION.

### ABSOLUTE MAXIMUM RATINGS

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

### RECOMMENDED OPERATING CONDITIONS (ELECTRICAL CHARACTERISTICS)

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 conditions by momentary electronic noise or surge. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.
ELECTRICAL CHARACTERISTICS

Test Circuit is “OPEN LOOP” and Test Condition is AGND=PGND1=PGND2=0V, unless otherwise noted.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Conditions</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\text{IN}</td>
<td>Operating Input Voltage</td>
<td>0.8V ≤ V\text{SET}^6</td>
<td>0.6V ≤ V\text{SET} &lt; 0.8V</td>
<td>2.3</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\text{FB}</td>
<td>Feedback Voltage</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 0.6V</td>
<td>0.591</td>
<td>0.600</td>
<td>0.609</td>
<td>V</td>
</tr>
<tr>
<td>ΔV\text{FB}/ΔT\text{a}</td>
<td>Output Voltage Temperature Coefficient</td>
<td>-40°C ≤ T\text{a} ≤ 85°C</td>
<td></td>
<td>±100</td>
<td>ppm</td>
<td>°/C</td>
<td></td>
</tr>
<tr>
<td>f\text{osc}</td>
<td>Oscillator Frequency</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td></td>
<td>2.00</td>
<td>2.25</td>
<td>2.50</td>
<td>MHz</td>
</tr>
<tr>
<td>I\text{DD1}</td>
<td>Supply Current 1\text{a}</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td></td>
<td>800</td>
<td>1100</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>I\text{DD2}</td>
<td>Supply Current 2\text{a}</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 5.5V, V\text{FB1} = V\text{FB2} = 0.45V, V\text{MODE} = 0V</td>
<td></td>
<td>45</td>
<td>60</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>I\text{DD3}</td>
<td>Supply Current 3\text{a}</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 5.5V, V\text{FB1} = V\text{FB2} = 0.75V, V\text{MODE} = 5.5V</td>
<td></td>
<td>800</td>
<td>1100</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>I\text{standby}</td>
<td>Standby Current \text{a}</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>0</td>
<td>10</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>I\text{CEH}</td>
<td>CE “H” Input Current</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 5.5V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{CEL}</td>
<td>CE “L” Input Current</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{MODEH}</td>
<td>MODE “H” Input Current</td>
<td>V\text{IN} = V\text{MODE} = 5.5V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{MODEL}</td>
<td>MODE “L” Input Current</td>
<td>V\text{IN} = 5.5V, V\text{MODE} = 0V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{FBH}</td>
<td>V\text{FB “H” Input Current}</td>
<td>V\text{IN} = 5.5V, V\text{FB1} = V\text{FB2} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{FBL}</td>
<td>V\text{FB “L” Input Current}</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{LXLEAKH}</td>
<td>L\text{X Leakage Current “H”}\text{a}</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>-1</td>
<td>0</td>
<td>5</td>
<td>μA</td>
</tr>
<tr>
<td>I\text{LXLEAKL}</td>
<td>L\text{X Leakage Current “L”}\text{a}</td>
<td>V\text{IN} = 5.5V, V\text{CE1} = V\text{CE2} = 0V</td>
<td></td>
<td>-5</td>
<td>0</td>
<td>1</td>
<td>μA</td>
</tr>
<tr>
<td>V\text{CEH}</td>
<td>CE “H” Input Voltage</td>
<td>V\text{IN} = 5.5V</td>
<td></td>
<td>1.0</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\text{CEL}</td>
<td>CE “L” Input Voltage</td>
<td>V\text{IN} = 2.3V</td>
<td></td>
<td>0.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\text{MODEH}</td>
<td>MODE “H” Input Voltage</td>
<td>V\text{IN} = 5.5V</td>
<td></td>
<td>1.0</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\text{MODEL}</td>
<td>MODE “L” Input Voltage</td>
<td>V\text{IN} = 2.3V</td>
<td></td>
<td>0.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>R\text{OPN}</td>
<td>Pch Transistor ON Resistance</td>
<td>V\text{IN} = 3.6V, I\text{LX1} = I\text{LX2} = -100mA</td>
<td></td>
<td>0.25</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>R\text{ONN}</td>
<td>Nch Transistor ON Resistance</td>
<td>V\text{IN} = 3.6V, I\text{LX1} = I\text{LX2} = -100mA</td>
<td></td>
<td>0.21</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>Maxduty</td>
<td>Oscillator Maximum Duty Cycle</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>t\text{start}</td>
<td>Soft-start Time</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td></td>
<td>200</td>
<td>300</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td>I\text{LXlim}</td>
<td>L\text{X Limit Current}</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td></td>
<td>1400</td>
<td>1700</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>t\text{prot}</td>
<td>Protection Delay Time</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2} = 3.6V</td>
<td></td>
<td>0.5</td>
<td>1.5</td>
<td>5</td>
<td>ms</td>
</tr>
<tr>
<td>V\text{UVLO1}</td>
<td>UVLO Detector Threshold</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2}</td>
<td></td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>V</td>
</tr>
<tr>
<td>V\text{UVLO2}</td>
<td>UVLO Released Voltage</td>
<td>V\text{IN} = V\text{CE1} = V\text{CE2}</td>
<td></td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>V</td>
</tr>
<tr>
<td>Symbol</td>
<td>Item</td>
<td>Conditions</td>
<td>Min.</td>
<td>Typ.</td>
<td>Max.</td>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------</td>
<td>---------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>$T_{TSD}$</td>
<td>Thermal Shutdown Temperature</td>
<td>Junction Temperature</td>
<td>140</td>
<td></td>
<td></td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>$T_{TSR}$</td>
<td>Thermal Shutdown Released Temperature</td>
<td>Junction Temperature</td>
<td>100</td>
<td></td>
<td></td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

All test items listed under Electrical Characteristics (P.5, P.6) are done under the pulse load condition ($T_j=T_a=25^\circ C$) except Output Voltage Temperature Coefficient and Oscillator Maximum Duty Cycle.

*5 For Standby Current, the sum of Channel 1 and Channel 2 is indicated.

As for the following currents, either Channel 1 value or Channel 2 value is indicated.
- Supply Current 1 to Supply Current 3
- CE “H” Input Current
- CE “L” Input Current
- $V_{FB}$ “H” Input Current
- $V_{FB}$ “L” Input Current
- $I_{LX}$ Leakage Current “H”
- $I_{LX}$ Leakage Current “L”

*6 $V_{SET}$= Set Output Voltage
TYPICAL APPLICATION

Figure 2. RP550K001A

Note: MODE="H" forced PWM control
MODE="L" PWM/VFM auto switching control

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Components</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIN</td>
<td>10μF</td>
<td>Ceramic Capacitor</td>
<td>C1608JB0J106M(TDK)</td>
</tr>
<tr>
<td>COUT</td>
<td>10μF</td>
<td>Ceramic Capacitor</td>
<td>C1608JB0J106M(TDK)</td>
</tr>
<tr>
<td>L</td>
<td>2.2μH</td>
<td>Inductor</td>
<td>MIPSA2520D2R2(FDK)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Components</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIN</td>
<td>10μF</td>
<td>Ceramic Capacitor</td>
<td>C1608JB0J106M(TDK)</td>
</tr>
<tr>
<td>COUT</td>
<td>10μF x 2</td>
<td>Ceramic Capacitor</td>
<td>C1608JB0J106M(TDK)</td>
</tr>
<tr>
<td>L</td>
<td>1.5μH</td>
<td>Inductor</td>
<td>MIPSA2520D1R5(FDK)</td>
</tr>
</tbody>
</table>
**TECHNICAL NOTES**

When using the RP550K001A, please consider the following points.

- AGND, PGND1 and PGND2 must be wired to the GND plane when mounting on boards.
- The VDD 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 IC and minimize the wiring between the components and the IC, especially between a capacitor and the VIN pin. The wiring between VFB and load and between L and VOUT should be separated.
- Choose a low ESR ceramic capacitor. The ceramic capacitance of a capacitor (CIN) connected between VIN and GND should be more than or equal to 10µF. The ceramic capacitance of a capacitor (COUT) connected between VOUT and GND should be 10µF to 20µF. Please be aware of the characteristics of bias dependence and temperature fluctuation of ceramic capacitor.
- The phase compensation of this IC is designed according to the above COUT values and L values. For stable operation, a ceramic capacitance value and an inductance value have to be selected within these values. Choose an inductor that has small DC resistance, has enough allowable current and is hard to cause magnetic saturation. If the inductance value of an inductor is extremely small, 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".
- Over current protection circuit and latch type protection circuit may be affected by self-heating or power dissipation environment.
- The output voltages (VOUT1, VOUT2) are adjustable by changing the values of R11, R12, R21, and R22 as follows.

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

- If R11, R12, R21, and R22 are too large, the impedances of VFB1 and VFB2 also become large, as a result, the IC 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.

\[
\begin{align*}
C_{11} &= 2.2 \times 10^6 / R12 \quad \text{[F]} \quad (0.6V \leq V_{\text{OUT1}} \leq 3.3V) \\
C_{21} &= 2.2 \times 10^6 / R22 \quad \text{[F]} \quad (0.6V \leq V_{\text{OUT2}} \leq 3.3V)
\end{align*}
\]

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

<table>
<thead>
<tr>
<th>Output Voltage VOUT1, VOUT2 [V]</th>
<th>Resistor [kΩ]</th>
<th>Capacitor [pF]</th>
</tr>
</thead>
<tbody>
<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>

- The performance of power source circuits using this IC largely depends on the peripheral circuits. When selecting the peripheral components, please consider the conditions of use. Do not allow each component, PCB pattern and the IC to exceed their respected rated values (voltage, current, and power) when designing the peripheral circuits.
OPERATION OF STEP-DOWN DC/DC CONVERTER AND OUTPUT CURRENT

The step-down DC/DC converter charges energy in the inductor when $L_x$ Tr. turns “ON”, and discharges the energy from the inductor when $L_x$ Tr. 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.

**Figure 3. Basic Circuit**

**Figure 4. Inductor Current (IL) flowing through Inductor**

**Step 1:** Pch Tr. is “ON” and current $I_L=i_1$ flows, and energy is charged into $CL$. At this moment, in proportion to the time while Pch Tr. is “ON” ($t_{ON}$), $I_L=i_1$ increases from $I_L=I_{LMIN}=0$, and reaches $I_LMAX$.

**Step 2:** While Pch Tr. is “OFF” and synchronous rectifier Nch Tr. is “ON”, $L$ tries to maintain $I_L=I_{LMAX}$, so $I_L=i_2$ flows into $L$.

**Step 3:** $I_L=i_2$ decreases gradually and reaches $I_L=I_{LMIN}=0$ after the time while Pch Tr. is “OFF” ($t_{OFF}$). Then, synchronous rectifier Nch Tr. turns “OFF”. Provided that in the continuous mode, next cycle starts before $I_L=I_{LMIN}=0$ because the time while Pch Tr. is “OFF” ($t_{OFF}$) is not enough. In this case, $I_L$ value increases from this $I_{LMIN}>0$.

In the case of PWM mode, $V_{OUT}$ is maintained by controlling $t_{ON}$. During PWM mode, the oscillator frequency ($f_{OSC}$) is being maintained constant.

As shown in Figure 4, while the step-down operation is constant, the minimum inductor current ($I_{LMIN}$) and the maximum inductor current ($I_{LMAX}$) when Pch Tr. is “ON” would be same as the maximum and the minimum inductor currents when Pch Tr. is “OFF”.

The current differential between $I_{LMAX}$ and $I_{LMIN}$ is described as $\Delta I$.

$$\Delta I = I_{LMAX} - I_{LMIN} = V_{OUT} \times t_{OPEN} / L = (V_{IN} - V_{OUT}) \times t_{ON} / L.$$  \hspace{1cm} \text{Equation 1}

However,

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

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

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

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

As illustrated in Figure 5, when the output current \( I_{\text{OUT}} \) is relatively small, \( t_{\text{OPEN}} < t_{\text{OFF}} \). In this case, the energy charged into the inductor during \( t_{\text{ON}} \) will be completely discharged during \( t_{\text{OFF}} \), as a result, \( I_{\text{MIN}} = 0 \). This is called discontinuous mode.

When \( I_{\text{OUT}} \) is gradually increased, eventually \( t_{\text{OPEN}} = t_{\text{OFF}} \) and when \( I_{\text{OUT}} \) is increased further, eventually \( I_{\text{MIN}} > 0 \). This is called continuous mode.

\[
\text{In the continuous mode, the solution of Equation 1 is } t_{\text{ONC}}.
\]

\[
t_{\text{ONC}} = T \times \frac{V_{\text{OUT}}}{V_{\text{IN}}} \quad \text{Equation 2}
\]

When \( t_{\text{ON}} < t_{\text{ONC}} \), it is discontinuous mode, and when \( t_{\text{ON}} = t_{\text{ONC}} \), it is continuous mode.
Forced PWM Mode and VFM Mode

By setting the MODE pin to “H”, the IC switches the frequency at the fixed rate to reduce noise even when the output load is light. Therefore, when $I_{\text{OUT}}$ is $\Delta I/2$ or less, $I_{\text{MIN}}$ becomes less than 0. That is, the accumulated electricity in $CL$ is discharged through the IC side while $IL$ is increasing from $I_{\text{MIN}}$ to 0 during $t_{\text{ON}}$ time, and also while $IL$ is decreasing from 0 to $I_{\text{MIN}}$ during $t_{\text{OFF}}$ time.

\[
\begin{align*}
&\text{Figure 7. Forced PWM Mode} \\
&\text{VFM Mode} \\
&\text{By setting the MODE pin to “L”, in low output current, the IC automatically switches into VFM mode in order to achieve high efficiency. In VFM mode, ton is forced to end when the inductor current reaches the pre-set ILMAX. With the RP550K001A, ILMAX in the VFM mode is typically set to 280mA. When } t_{\text{ON}} \text{ reaches 1.5 times of } T=1/f_{\text{OSC}}, t_{\text{ON}} \text{ will be forced to end even if the inductor current is not reached ILMAX.}
\end{align*}
\]
Output Current and Selection of External Components

The following equations explain the relationship between output current and peripheral components used in Figure 2 in Typical Applications (P.7).

Ripple Current P-P value is described as \( I_{RP} \), ON resistance of Pch Tr. is described as \( R_{ONP} \), ON resistance of Nch Tr. is described as \( R_{ONN} \), and DC resistor of the inductor is described as \( R_L \).

First, when Pch Tr. is "ON", the following equation is satisfied.

\[
V_{IN} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times I_{RP} \times t_{ON} \quad \text{Equation 3}
\]

Second, when Pch Tr. is "OFF" (Nch Tr. is "ON"), the following equation is satisfied.

\[
L \times I_{RP} \times t_{OFF} = R_{ONN} \times I_{OUT} + V_{OUT} + R_L \times I_{OUT} \quad \text{Equation 4}
\]

Put Equation 4 into Equation 3 to solve ON duty of Pch Tr. (\( D_{ON} = t_{ON} / (t_{OFF} + t_{ON}) \)):

\[
D_{ON} = \frac{V_{OUT} + R_{ONN} \times I_{OUT} + R_L \times I_{OUT}}{(V_{IN} + R_{ONN} \times I_{OUT} - R_{ONP} \times I_{OUT})} \quad \text{Equation 5}
\]

Ripple Current is described as follows:

\[
I_{RP} = \frac{(V_{IN} - V_{OUT} - R_{ONP} \times I_{OUT} - R_L \times I_{OUT}) \times D_{ON}}{f_{osc} \times L} \quad \text{Equation 6}
\]

Peak current that flows through \( L \) and \( L_X \) Tr. is described as follows:

\[
I_{L_{MAX}} = I_{OUT} + I_{RP} / 2 \quad \text{Equation 7}
\]

- Please consider \( I_{L_{MAX}} \) when setting conditions of input and output, as well as selecting the external components.
- The above calculation formulas are based on the ideal operation of the ICs in continuous mode.
TIMING CHART

(1) Soft Start Time

Starting-up with CE Pin

The IC starts to operate when the CE pin voltage \( V_{CE} \) exceed the threshold voltage. The threshold voltage is preset between CE “H” input voltage \( V_{CEH} \) and CE “L” input voltage \( V_{CEL} \).

After the start-up of the IC, soft-start circuit starts to operate. Then, after a certain period of time, the reference voltage \( V_{REF} \) in the IC gradually increases up to the specified value.

![Figure 9. Timing Chart](image)

Soft-start time starts when soft-start circuit activates, and ends when the reference voltage reaches the specified voltage.

- Soft start time is not always equal to the 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 IC starts to operate when \( V_{IN} \) exceed the UVLO released voltage \( V_{UVLO2} \). Soft-start circuit starts to operate and then after a certain period of time, \( V_{REF} \) in the IC gradually increases up to the specified value. Soft-start time starts when soft-start circuit activates, and ends when \( V_{REF} \) reaches the specified voltage.

![Figure 10. Timing Chart](image)

Soft-start time starts when soft-start circuit activates, and ends when the reference voltage reaches the specified voltage.

- Please note that the turn-on speed of \( V_{OUT} \) could be affected by the power supply capacity, the output current, the inductance value, the \( C_{OUT} \) value and the turn-on speed of \( V_{IN} \) determined by \( C_{IN} \).
(2) Under Voltage Lockout (UVLO) Circuit

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

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

To restart the operation, $V_{\text{IN}}$ needs to be higher than $V_{\text{UVLO2}}$. The timing chart below shows the voltage shifts of $V_{\text{REF}}$, $V_{\text{LX}}$ and $V_{\text{OUT}}$ when $V_{\text{IN}}$ value is varied.

Figure 11. Timing Chart

- Falling edge (operating) and rising edge (releasing) waveforms of $V_{\text{OUT}}$ could be affected by the initial voltage of $C_{\text{OUT}}$ and the output current of $V_{\text{OUT}}$. 
(3) Over Current Protection Circuit, Latch Type Protection Circuit

Over current protection circuit supervises the inductor peak current (the peak current flowing through Pch Tr.) in each switching cycle, and if the current exceeds the \( I_{LX} \) current limit \( (I_{LXLIM}) \), it turns off Pch Tr. \( I_{LXLIM} \) of the RP550K001A is set to Typ.1700mA.

Latch type protection circuit latches the built-in driver to the OFF state and stops the operation of the step-down DC/DC converter if the over current status continues or \( V_{OUT} \) continues being the half of the setting voltage for equal or longer than protection delay time \( (tprot) \).

Note: \( I_{LXLIM} \) and \( tprot \) 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 \( tprot \) could be affected.

![Diagram](image-url)

**Figure 12. Protection Delay Time**

To release the latch type protection circuit, restart the IC by inputting "L" signal to the CE pin, or restart the IC with power-on or make the supply voltage lower than \( V_{UVLO1} \).

The timing chart below shows the voltage shifts of \( V_{LX} \) and \( V_{OUT} \) when the IC status is changed by the following orders: \( V_{IN} \) and \( V_{CE} \) rising → stable operation → high load → CE reset → stable operation → high load → \( V_{IN} \) falling → \( V_{IN} \) recovering (UVLO reset) → stable operation.

(1)(2) If the large current flows through the circuit or the IC 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 \( tprot \). Then, \( V_{LX} \) becomes "L" and \( V_{OUT} \) turns “OFF”.

(3) The latch type protection circuit is released by CE reset, which puts the IC 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 \( V_{UVLO1} \).

![Diagram](image-url)

**Figure 13. Timing Chart**
CHARACTERISTICS

1) Output Voltage vs. Output Current

**RP550K001A** V_{out}=0.6V
MODE="L" PWM/VFM Auto Switching Control

**RP550K001A** V_{out}=0.6V
MODE="H" Forced PWM Control

**RP550K001A** V_{out}=0.8V
MODE="L" PWM/VFM Auto Switching Control

**RP550K001A** V_{out}=0.8V
MODE="H" Forced PWM Control

**RP550K001A** V_{out}=1.2V
MODE="L" PWM/VFM Auto Switching Control

**RP550K001A** V_{out}=1.2V
MODE="H" Forced PWM Control
2) Output Voltage vs. Input Voltage

**RP550K001A V_{OUT}=0.8V**

**MODE=“H” Forc3d PWM Control**

**RP550K001A V_{OUT}=1.2V**

**MODE=“H” Forc3d PWM Control**

---

**RP550K001A V_{OUT}=1.8V**

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

**RP550K001A V_{OUT}=1.8V**

**MODE=“H” Forced PWM Control**

---

**RP550K001A V_{OUT}=3.3V**

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

**RP550K001A V_{OUT}=3.3V**

**MODE=“H” Forced PWM Control**

---

**Output Voltage vs. Input Voltage**

**RP550K001A V_{OUT}=0.8V**

**MODE=“H” Forced PWM Control**

**RP550K001A V_{OUT}=1.2V**

**MODE=“H” Forced PWM Control**
3) Feedback Voltage vs. Ambient Temperature

4) Efficiency vs. Output Current
5) Supply Current vs. Ambient Temperature
RP550K001A  V_{OUT}=1.8V(V_{IN}=5.5V)
MODE="L"PWM/VFM Auto Switching Control

6) Supply Current vs. Input Voltage
RP550K001A  V_{OUT}=1.8V
MODE="L"PWM/VFM Auto Switching Control

7) Output Voltage Waveform
RP550K001A  V_{OUT}=0.6V(V_{IN}=3.6V)
MODE="L"PWM/VFM Auto Switching Control

RP550K001A  V_{OUT}=0.6V(V_{IN}=3.6V)
MODE="H" Forc PWM Control
RP550K001A  $V_{OUT}=0.8\text{V}(V_{IN}=3.6\text{V})$  
MODE="L" PWM/VFM Auto Switching Control

![Diagram of output voltage and inductor current for MODE="L"PWM/VFM Auto Switching Control with $I_{OUT}=10\text{mA}$](image1)

RP550K001A  $V_{OUT}=1.2\text{V}(V_{IN}=3.6\text{V})$  
MODE="L" PWM/VFM Auto Switching Control

![Diagram of output voltage and inductor current for MODE="L"PWM/VFM Auto Switching Control with $I_{OUT}=10\text{mA}$](image2)

RP550K001A  $V_{OUT}=0.8\text{V}(V_{IN}=3.6\text{V})$  
MODE="H" Forced PWM Control

![Diagram of output voltage and inductor current for MODE="H" Forced PWM Control with $I_{OUT}=10\text{mA}$](image3)

RP550K001A  $V_{OUT}=1.2\text{V}(V_{IN}=3.6\text{V})$  
MODE="H" Forced PWM Control

![Diagram of output voltage and inductor current for MODE="H" Forced PWM Control with $I_{OUT}=10\text{mA}$](image4)
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
12) CE Input Voltage vs. Ambient Temperature

CE “H” Input Voltage (V_{IN}=5.5V)

CE “L” Input Voltage (V_{IN}=2.3V)

13) Lx Limit Current vs. Ambient Temperature

14) Nch Transistor ON Resistance vs. Ambient Temperature

15) Pch Transistor ON Resistance vs. Ambient Temperature
16) Load Transient Response

**RP550K001A (VIN=3.6V, VOUT=0.6V)**

MODE="L" PWM/VFM Auto Switching Control

![Graph 1](image1)

MODE="H" Forced PWM Control

![Graph 2](image2)

![Graph 3](image3)

![Graph 4](image4)
RP550K001A (Vin=3.6V, Vout=1.8V)  
MODE="L" PWM/VFM Auto Switching Control

Output Voltage V_{OUT} (V)  
Output Current I_{OUT} (mA)

 modes

RP550K001A (Vin=3.6V, Vout=1.8V)  
MODE="H" Forced PWM Control

Output Voltage V_{OUT} (V)  
Output Current I_{OUT} (mA)

 modes

RP550K001A (Vin=3.6V, Vout=1.8V)

Output Voltage V_{OUT} (V)  
Output Current I_{OUT} (mA)
17) Mode Switching Waveform

RP550K001A (Vin=3.6V, Vout=1.2V, Iout=1mA)
MODE="L" --> MODE="H"

Time t (μs)

Output Voltage Vout (V)

Mode Input Voltage V MODE (V)

Output Voltage

Mode Input Voltage

RP550K001A (Vin=3.6V, Vout=1.8V, Iout=1mA)
MODE="L" --> MODE="H"

Time t (μs)

Output Voltage Vout (V)

Mode Input Voltage V MODE (V)

Output Voltage

Mode Input Voltage

RP550K001A (Vin=3.6V, Vout=1.2V, Iout=1mA)
MODE="H" --> MODE="L"

Time t (μs)

Output Voltage Vout (V)

Mode Input Voltage V MODE (V)

Output Voltage

Mode Input Voltage

RP550K001A (Vin=3.6V, Vout=1.8V, Iout=1mA)
MODE="H" --> MODE="L"

Time t (μs)

Output Voltage Vout (V)

Mode Input Voltage V MODE (V)

Output Voltage

Mode Input Voltage
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