RL78/I1A
IPD-less Digital Switching Power Circuit Using RL78/I1A

Introduction

This application note provides an example for achieving an IPD-less auxiliary power circuit using an AC/DC switching control IC RL78/I1A to reduce the cost of an AC/DC switching power circuit.

As an example, the following parts can be reduced by removing IPD from TPW-RL78I1A-2C.

<table>
<thead>
<tr>
<th>Increase/decrease in the number of parts after removing IPD from TPW-RL78I1A-2C</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC</td>
</tr>
<tr>
<td>One LYT0006D (Power Integrations) removed</td>
</tr>
<tr>
<td>Capacitor</td>
</tr>
<tr>
<td>4 capacitors removed</td>
</tr>
<tr>
<td>Diode</td>
</tr>
<tr>
<td>One diode removed</td>
</tr>
<tr>
<td>Inductor</td>
</tr>
<tr>
<td>One inductor removed</td>
</tr>
<tr>
<td>Resistor</td>
</tr>
<tr>
<td>3 resistors increased</td>
</tr>
</tbody>
</table>

Target Device

RL78/I1A

When applying the sample program covered in this application note to another microcomputer, modify the program according to the specifications for the target microcomputer and conduct an extensive evaluation of the modified program.
Contents

1. Introduction ................................................................................................................................ 3

2. Overview of Circuit .................................................................................................................... 4
  2.1 Overall Circuit ...................................................................................................................... 4

3. Details of Circuit ........................................................................................................................ 5
  3.1 Overall Configuration of Auxiliary Power Circuit ................................................................. 5
    3.1.1 Resistive Voltage Divider Circuit .................................................................................... 7
      3.1.1.1 Designing Resistance Values R1, R2, and R3 ............................................................. 8
    3.1.2 Capacitance C1 ................................................................................................................ 8
    3.1.2 LDO Operation Control .................................................................................................... 10
    3.1.3 Power Supply Circuit Using PFC Transformer Auxiliary Winding .................................. 11

4. Example of Circuit Constant Design for Application ............................................................. 14
  4.1 Design Example of Resistive Voltage Division Ratio and Capacitance (VDD current = 15 mA) ........................................................................................................................................ 14
  4.2 Notes ...................................................................................................................................... 15
    4.2.1 VCC Voltage Generated by Resistive Voltage Divider Circuit ........................................ 15
    4.2.2 Considerations for Commercial Voltage Phase .............................................................. 15
    4.2.3 Selection of LDO ............................................................................................................ 15

5. Reference Documents ............................................................................................................. 16

Revision History .......................................................................................................................... 17
1. Introduction
This application note provides an example of removing IPD from an LED power evaluation device (TPW-RL78I1A-2C) using RL78/I1A.
2. Overview of Circuit

2.1 Overall Circuit

A non-insulated step-up PFC control circuit is used in TPW-RL78I1A-2C. A gate driver power voltage \((V_{CC})\) is generated through IPD, and an MCU power voltage \((V_{DD})\) is generated through LDO from the main power circuit.

In this circuit, the IPD is replaced with a new circuit (consisting of a resistive voltage divider circuit and auxiliary winding) from TPW-RL78I1A-2C. In the new circuit, the AC input voltage after full-wave rectification goes through a resistive voltage divider circuit and is then smoothed by capacitors, generating an MCU power voltage through LDO. An auxiliary winding is added to the choke coil to supplement power from the auxiliary winding, in addition to the resistive voltage divider circuit, during PFC switching to minimize current flow in the resistive voltage divider circuit.

In TPW-RL78I1A-2C, an auxiliary winding for ZCD is provided for the choke coil. To simplify circuit design, however, another auxiliary winding is added in this circuit.

Note: The ZCD auxiliary winding and additional auxiliary winding can be used as one winding depending on conditions.
3. Details of Circuit

3.1 Overall Configuration of Auxiliary Power Circuit

Figure 3-1 shows the overall configuration of the auxiliary power circuit.

As shown in Figure 3-1, the new circuit mainly consists of a resistive voltage divider circuit, an LDO control circuit, and an auxiliary winding circuit. Details of each circuit are described in the following sections.

- Resistive voltage divider circuit: Section 3.1.1
- LDO control circuit: Section 3.1.2
- Auxiliary winding circuit: Section 3.1.3

Figure 3-1 Overall Configuration of Auxiliary Power Circuit

Vcc : Power supply for switching driver
VDD : Power supply for MCU
Figure 3 - 2 shows the current route before and after activating the MCU.

As shown in the left circuit diagram in Figure 3 - 2, the MCU current is supplied from the resistive voltage divider circuit after power is turned on before the MCU is activated. After the MCU is activated and switching starts, the MCU current is supplied from the auxiliary winding of the choke coil.

Figure 3 - 2 Main MCU Power Supply Route

Figure 3 - 3 shows the waveforms of voltages \( V_{CC} \) and \( V_{DD} \) after AC power is turned on until switching starts. An RC circuit is provided before the LDO. After power is turned on, capacitor C1 is gradually charged. When capacitor C1 is fully charged, the LDO is activated by controlling its CONTROL pin signal. However, current required for high-speed operation in the MCU cannot be supplied only by the resistive voltage divider circuit. Therefore, C1 is gradually discharged after the LDO is activated. For this reason, to prevent \( V_{CC} \) dropping below the specified voltage for input-output voltage of the LDO, the MCU enters standby mode (to reduce MCU current), or switches to supply current from the auxiliary winding to restore \( V_{CC} \).

In Figure 3 - 3, the MCU is activated and enters standby mode. Then switching is started by the external input signal.

Figure 3 - 3 Waveforms of Voltages \( V_{CC} \) and \( V_{DD} \)
3.1.1 Resistive Voltage Divider Circuit
This circuit is used to activate the MCU when AC power is turned on. Figure 3 - 4 shows the circuit diagram.

**Figure 3 - 4 resistive voltage divider circuit**

![Resistive Voltage Divider Circuit Diagram]

In the resistive voltage divider circuit, the full-wave-rectified AC input voltage is divided by resistors R1, R2, and R3, and then smoothed by capacitor C1. The smoothed AC voltage is stepped down to 5 VDC by the LDO, and is then supplied to the MCU.

The resistive voltage divider circuit is designed to reduce the current to the minimum necessary to mitigate resistor power loss. For this reason, the current required for activating the MCU system (assuming 5 mA current required for 10 ms in this circuit) is supplied from the resistive voltage divider circuit and charged capacitor C1.

Table 3-1 lists conditions to be considered for designing resistance values (R1, R2, and R3) and capacitance value (C1). An example of designing R1, R2, R3, and C1 values to meet a worst case scenario is described in sections 3.1.2 and 3.1.3.

**Table 3-1 Conditions to Be Considered for Determining Parameters (90 VAC – 260 VAC)**

<table>
<thead>
<tr>
<th>Related Parameters</th>
<th>Conditions to Be Considered</th>
<th>Worst Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2, R3</td>
<td>• The VCC voltage is not less than the pre-driver operating voltage.</td>
<td>90 VAC</td>
</tr>
<tr>
<td>R1, R2, R3</td>
<td>• The VCC voltage meets the withstand voltages of connected elements.</td>
<td>260 VAC</td>
</tr>
<tr>
<td></td>
<td>• The loss in each resistor (including derating) meets the ratings.</td>
<td></td>
</tr>
<tr>
<td>R1, R2, R3, C1</td>
<td>• Charges that can activate the MCU can be charged (depending on system).</td>
<td>90 VAC</td>
</tr>
<tr>
<td>LDO activation</td>
<td>• The startup time (C1 charging time at power-on) is within the allowable range.</td>
<td></td>
</tr>
</tbody>
</table>

Vcc: Pre-driver power voltage, Vdd: MCU power voltage (5 V)
3.1.1.1 Designing Resistance Values R1, R2, and R3

The VCC voltage that is output from the resistive voltage divider circuit is determined from the AC input voltage and the resistance values R1, R2, and R3.

Assuming that the Vcc voltage is obtained by dividing the average AC voltage, Vcc can be calculated as follows. (The LDO circuit is not taken into consideration for simplification.)

\[
V_{av} = \frac{2}{\pi} V_m = \frac{2}{\pi} \sqrt{2} V_{rms}
\]

\[
V_{cc} = \frac{R_3}{R_1 + R_2 + R_3} V_{av}
\]

V_{av}: Average AC voltage, V_m: Maximum AC voltage, V_{rms}: Effective value of AC voltage

According to the conditions listed in Table 3-1, it should be considered that Vcc is not more than the maximum operating voltage (260 VAC) and is not less than the minimum operating voltage (90 VAC) of the pre-driver, and power at 260 VAC with resistance R1 to R3 is less than the rated value. (Thus, use values for R1, R2, and R3 that allow for steady current flow.)

The operating voltage of the pre-driver (IXYS602PI produced by IXYS Integrated Circuits Division) used in this circuit is 4.5 V to 35 V. Therefore, R1, R2 = 68 kΩ and R3 = 15 kΩ were set as a result of designed resistance values R1, R2, and R3 based on the conditions mentioned above.

<table>
<thead>
<tr>
<th>AC (V)</th>
<th>Vav (V)</th>
<th>R1, R2 (kΩ)</th>
<th>R3 (kΩ)</th>
<th>Vcc (V)</th>
<th>R1, R2 Power (W)</th>
<th>R3 Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>81.1</td>
<td>68</td>
<td>15</td>
<td>8.04</td>
<td>0.020</td>
<td>0.0023</td>
</tr>
<tr>
<td>260</td>
<td>234.1</td>
<td>68</td>
<td>15</td>
<td>23.25</td>
<td>0.163</td>
<td>0.0360</td>
</tr>
</tbody>
</table>

3.1.1.2 Capacitance C1

Assuming that 5 mA current is required for activating the MCU for 10 ms and the LDO is activated by a Vcc voltage of approximately 7 V, capacitance C1 is calculated based on the condition that the voltage drop in capacitor C1 is 1.5 V or less.

The quantity of electric charge Q and capacitance C of capacitor C1, voltage V, current i, and time t are in the following relationship.

\[
Q = CV = it
\]

When the above conditions are assigned to this equation,

\[
C = \frac{it}{V} = \frac{0.005 \times 0.01}{1.5} = 33 \times 10^{-6}
\]

Thus, capacitance C is 33 µF.

Here, C1 capacitance is set to 47 µF with a margin.

Figure 3 - 5 shows the result of evaluation based on the above design using an actual device. At 90 VAC, where the current supply ability of the resistive voltage divider circuit is lowest, the interval from AC power on to LDO activation is approximately 2.6 s, and the VDD = 5 V hold time with a load of 5 mA connected is approximately 15 ms.
Figure 3 - 5 $V_{CC}/V_{DD}$ Voltage Waveforms (R1, R2 = 68 k$\Omega$, R3 = 15 k$\Omega$, C1 = 47 $\mu$F, 5 mA Load Connected to $V_{DD}$)

The result in Figure 3 - 5 verifies that the resistive voltage divider circuit can provide the current required to activate RL78/I1A (5 mA for 10 ms). However, high-speed operation in the MCU is not enabled only with the current supplied from the resistive voltage divider circuit.

For this reason, a circuit that supplies power from the auxiliary winding of a PFC transformer for constant power supply to the MCU is described in the following section.
3.1.2 LDO Operation Control

An LDO with an enable control (CONTROL) function is used in this circuit.

After AC power is turned on, capacitor C1 is gradually charged. After the VCC voltage becomes constant, the CONTROL pin is controlled to activate the LDO.

The LDO (NJW4104U2-05B produced by Nissinbo Micro Devices Inc.) used in this circuit is activated when the CONTROL pin voltage (V_{CONT(on)}) is 1.2 V. For this reason, this circuit is designed to divide the VCC voltage so that the LDO is activated at 7.2 V.

After the LDO is activated, the output voltage is input to the CONTROL pin to have hysteresis for continuous LDO operation even if VCC drops.

Table 3-3 LDO Control Waveform

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{CONT(on)}</td>
<td>V_{CONT} = (V_{CC} + 15) / 6 [V]</td>
</tr>
<tr>
<td>0 V</td>
<td>LDO ON</td>
</tr>
</tbody>
</table>

![LDO Control Waveform Diagram]
3.1.3 Power Supply Circuit Using PFC Transformer Auxiliary Winding

After the MCU is activated and switching starts, the auxiliary winding on the choke coil provides power by utilizing voltage fluctuations caused by switching.

Figure 3 - 7 shows the voltage waveform between both ends of the choke coil during switching. This voltage is divided by the turns ratio of the transformer, and the VCC waveform is rectified by the diode and capacitor C1.

In TPW-RL78I1A-2C, an auxiliary winding on the choke coil detects the zero current signal. Therefore, a 6-turn winding is added to this auxiliary winding, forming a transformer (primary side: 106 turns, secondary side: 6 turns). The power supply circuit is designed to supply power from the added winding after PFC switching starts by connecting the transformer to the bottom end of resistor R2 in the resistive voltage divider circuit after rectification by the diode. When the turns ratio is 106:6, this circuit can generate a voltage of approximately 12 V (at 260 V) to 20 V (at 90 V). (Figure 3 - 8, Figure 3 - 9)

Determine the optimum turns ratio according to the circuit to be used so that the auxiliary winding output does not exceed the withstand voltage of each element.

Figure 3 - 6 Power Supply Circuit Using Auxiliary Winding

Figure 3 - 7 Voltage Waveform at Both Ends of Choke Coil in Steady State (Switching cycle and duty cycle differ from actual values)
Figure 3 - 8 Auxiliary Winding Output Voltage (at 90 VAC, Upper Waveform: Auxiliary Winding Voltage, Lower Waveform: Vcc)

Figure 3 - 9 Auxiliary Winding Output Voltage (at 260 VAC, Upper Waveform: Auxiliary Winding Voltage, Lower Waveform: Vcc)
Figure 3 - 10 shows the V_{CC} waveform at the beginning of switching.

Because the PFC output voltage gradually rises after switching starts, the voltage difference between both ends of the choke coil is small immediately after switching starts at 90 VAC in particular, which prevents an output voltage higher than V_{CC} (supplied from the resistive voltage divider circuit) from being generated. After that, when the PFC output voltage rises and the auxiliary winding output voltage exceeds V_{CC}, current supply from the auxiliary winding starts.

In Figure 3 - 10, the auxiliary winding output voltage exceeds V_{CC} after 20 ms and current supply from the auxiliary winding starts.

If suppression of V_{CC} voltage drop is required, MCU current should be decreased.

**Figure 3 - 10 Auxiliary Winding Output Voltage (at 90 VAC)**

![Figure 3 - 10 Auxiliary Winding Output Voltage (at 90 VAC)](image)
4. Example of Circuit Constant Design for Application

4.1 Design Example of Resistive Voltage Division Ratio and Capacitance ($V_{DD}$ current = 15 mA)

In 3.1.1 Resistive Voltage Divider Circuit, a $V_{DD}$ current of 5 mA is estimated. Table 4-1 shows a parameter design example when 15 mA $V_{DD}$ current is required.

When mounting elements in an actual circuit or changing parameters, adequate evaluation is required to verify that the conditions listed in Table 3-1 are met.

Table 4-1 Parameter Design Example ($V_{DD}$ current = 15 mA)

<table>
<thead>
<tr>
<th>$V_{DD}$ Current</th>
<th>R1, R2</th>
<th>R3</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mA</td>
<td>68 kΩ</td>
<td>15 kΩ</td>
<td>57 µF</td>
</tr>
<tr>
<td>15 mA</td>
<td>33 kΩ</td>
<td>8.2 kΩ</td>
<td>100 µF</td>
</tr>
</tbody>
</table>
4.2 Notes

4.2.1 V<sub>CC</sub> Voltage Generated by Resistive Voltage Divider Circuit
In 3.1.1 Resistive Voltage Divider Circuit, it is assumed that the PFC circuit is not considered and V<sub>CC</sub> is generated by dividing the average AC voltage. In the actual circuit (TPW-RL78I1A-2C), however, a rectification diode and a capacitor are connected (as a PFC circuit) after the rectification bridge circuit. Because the voltage shown in Figure 4 - 1 is input to the resistive voltage divider circuit before switching starts, V<sub>CC</sub> is obtained by dividing approximately 120 VDC by resistors R1, R2, and R3 at 90 VAC.

Figure 4 - 1 Resistive Voltage Divider Circuit Input Voltage (at 90 VAC)

4.2.2 Considerations for Commercial Voltage Phase
The startup time at the beginning of switching varies with the phase of commercial power voltage. When using a commercial power supply in your system, evaluate the system adequately considering the phase of the commercial power voltage.

4.2.3 Selection of LDO
The input/output potential difference of the LDO affects the limit current at the beginning of switching. Select devices with a small input/output potential difference. In NJW4104U2-05B used in this circuit, the input/output phase difference is 0.25 V (Max.).
5. Reference Documents

RL78/I1A User’s Manual: Hardware (R01UH0169)
RL78 family user's manual software (R01US0015)
The latest versions can be downloaded from the Renesas Electronics website.

Technical update
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<th>Description</th>
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<tr>
<td>1.00</td>
<td>2022.12.27</td>
<td>—</td>
<td>—</td>
<td>First Edition</td>
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