

## PWM/PFM step-down DC/DC Converters with synchronous rectifier and Through mode

NO.EA-197-111124

### OUTLINE

The RP904 series are CMOS-based PWM/PFM step-down DC/DC Converters with synchronous rectifier, low supply current and through mode.

DC/DC converter of the RP904X consists of an oscillator, a PWM/PFM control circuit, a reference voltage unit, an error amplifier, a soft-start circuit, protection circuits, a protection against miss operation under low voltage (UVLO), PWM-DC to DC converter or bypass switch alternative circuit, a chip enable circuit, and a driver transistor. A high efficiency step-down DC/DC converter can be easily composed of this IC with only a few kinds of external components, or an inductor and capacitors.

The output voltage of the DC/DC converter has two kinds of output voltage, and alternative with the VSEL pin.

The RP904 series are PWM/PFM step-down DC/DC converter, thus, when the load current is small, the operation can be switching into the PFM operation from PWM control if the user chooses the VFM mode. As protection circuits, the current limit circuit which limits peak current of Lx at each clock cycle, and the latch type protection circuit which works if the term of the over-current condition keeps on a certain time in PWM mode. Latch-type protection circuit works to latch an internal driver with keeping it disable. To release the protection, after disable this IC with a chip enable circuit, enable it again, or restart this IC with power-on or make the supply voltage at UVLO detector threshold level or lower than UVLO.

The RP904 has also a bypass switch between  $V_{DD}$  and  $V_{OUT}$ .

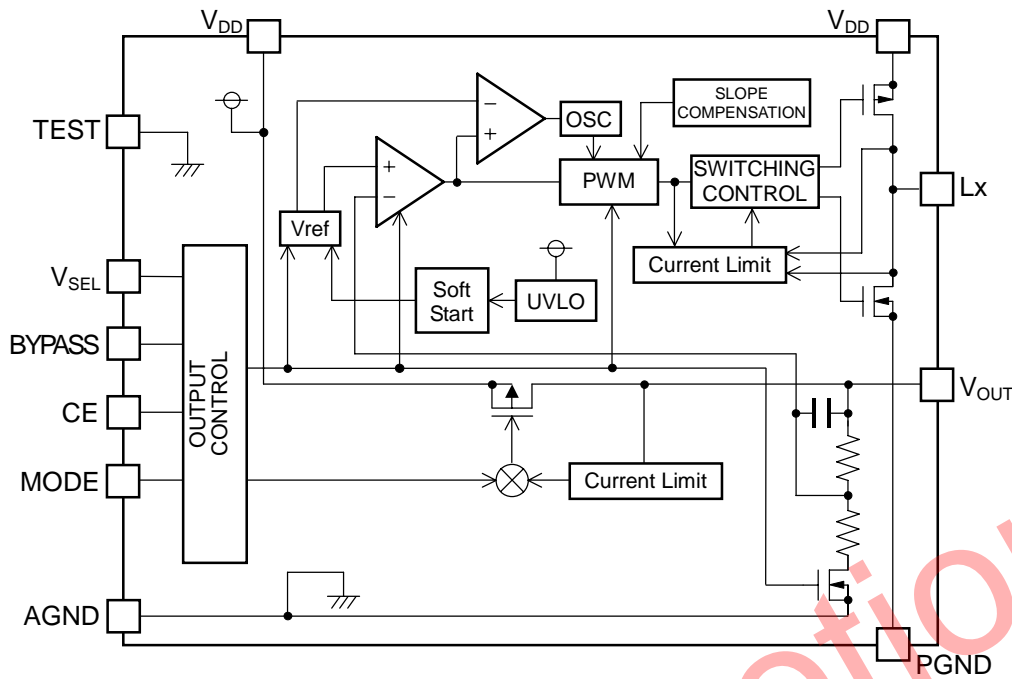
### FEATURES

|  |  |
|--|--|
| Built-in Driver ON Resistance.....   | Typ. Pch 0.25Ω, Nch 0.23Ω ( $V_{IN}=3.6V$ )  |
| Input Voltage.....   | 2.5V to 5.5V<br>(2.5V to 5.0V in case of $V_{SET2}<1.2V$ )   |
| Built-in Soft-start Function .....   | Typ. 0.135ms   |
| Latch-type Protection Function.....  | Typ. 0.8ms   |
| Standby Current.....   | Typ. 0.02μA  |
| Output Current.....  | Min. 1A(DC/DC in PWM mode), (switch)   |
| Oscillator Frequency.....  | Typ. 2MHz  |
| Bypass switch on resistance .....  | Typ. 68mΩ  |
| Operation select is possible among DC/DC mode, and through switch mode with BYPASS pin |  |
| Absolute Input Maximum Rating.....   | 6.5V   |
| Output Voltage.....  | Built-in Driver Stepwise Setting with a step of 0.1V in the range of 1.2V to 3.3V( $V_{SET1}$ ), 1.0V to 1.5V( $V_{SET2}$ )<br>$V_{SET2}+0.2V \leq V_{SET1}$ |
| Package.....   | WLCSP-11-P2  |

### APPLICATIONS

Power source for portable equipment such as DSC, DVC, and communication equipment

BLOCK DIAGRAM



RP904xxxxA: MODE pin= "H": PWM mode, MODE pin= "L" VFM mode

V<sub>SET</sub> pin = "H": V<sub>OUT</sub>=V<sub>SET1</sub> V<sub>SEL</sub> pin="L": V<sub>OUT</sub>=V<sub>SET2</sub>

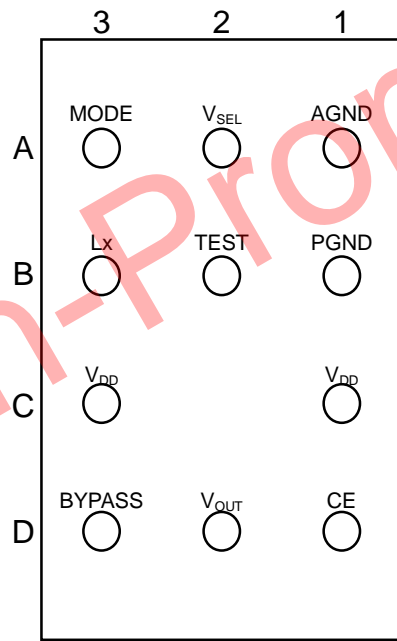
Bypass pin="H": DC/DC Mode, Bypass pin="L" Bypass Mode

| Pin name         | Pin state at off |
|------------------|------------------|
| CE               | Pull Down        |
| MODE             | Pull Down        |
| V <sub>SEL</sub> | Pull Down        |
| BYPASS           | Pull Down        |

**PIN DESCRIPTION**

| Pin No. | Symbol           | Description                                 |
|---------|------------------|---|
| 1A      | AGND             | Ground Pin                                  |
| 2A      | V <sub>SEL</sub> | Output Voltage Alternative Pin              |
| 3A      | MODE             | PWM/VFM alternative Pin                     |
| 1B      | PGND             | Ground Pin                                  |
| 2B      | TEST             | TEST Pin (Connect this pin to the GND)      |
| 3B      | Lx               | Lx Pin                                      |
| 1C, 3C  | V <sub>DD</sub>  | Voltage Supply Pin                          |
| 1D      | CE               | Chip Enable Pin (active with "H")           |
| 2D      | V <sub>OUT</sub> | Output Pin                                  |
| 3D      | BYPASS           | Bypass enable Pin (DC/DC or Bypass control) |

\*) All V<sub>DD</sub> terminals must be connected.



BOTTOM VIEW

## SELECTION GUIDE

In the RP904x Series, the output voltage, and the taping type for the ICs can be selected at the user's request.

| Product Name  | Package     | Quantity per Reel | Pb Free | Halogen Free |
|---|-------------|-------------------|---------|--------------|
| RP904Zxx1*-E2-F   | WLCSP-11-P2 | 4,000pcs          | Yes     | Yes          |
| xx : Setting Output Voltage ( $V_{OUT}$ ) combination, alphanumeric custom code.  |             |                   |         |              |
| * : Designation of chip enable and BYPASS pin polarities<br>(A) CE; "H" active, BYPASS pin; "H"=DC/DC converter mode, "L" = Bypass Mode |             |                   |         |              |

## ABSOLUTE MAXIMUM RATINGS

AGND=PGND=0V

| Symbol       | Item                         | Rating               | Unit |
|--------------|------------------------------|----------------------|------|
| $V_{DD}$     | $V_{DD}$ Supply Voltage      | -0.3 to 6.5          | V    |
| $V_{LX}$     | Lx Pin Voltage               | -0.3 to $V_{DD}+0.3$ | V    |
| $V_{CE}$     | CE Pin Input Voltage         | -0.3 to 6.5          | V    |
| $V_{MODE}$   | MODE Pin Input Voltage       | -0.3 to 6.5          | V    |
| $V_{BYPASS}$ | BYPASS Pin Input Voltage     | -0.3 to 6.5          | V    |
| $V_{SEL}$    | $V_{SEL}$ Pin Input Voltage  | -0.3 to 6.5          | V    |
| $V_{OUT}$    | $V_{OUT}$ Pin Voltage        | -0.3 to $V_{DD}+0.3$ | V    |
| $I_{LX}$     | Lx Pin Output Current        | 2000                 | mA   |
| $I_{OUT}$    | $V_{OUT}$ Pin Output Current | 1400                 | mA   |
| $P_D$        | Power Dissipation            | 1000                 | mW   |
| $T_a$        | Operating Temperature Range  | -40 to+85            | °C   |
| $T_{stg}$    | Storage Temperature Range    | -55 to+125           | °C   |

\*) For Power Dissipation, 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 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 is not assured.

**ELECTRICAL CHARACTERISTICS**

**RP904Zxx1A**

(Ta=25°C)

| Symbol           | Item                            | Conditions   | Min. | Typ. | Max. | Unit |
|------------------|---------------------------------|--|------|------|------|------|
| V <sub>DD</sub>  | Operating Input Voltage         | V <sub>DD</sub>  | 2.5  |      | 5.5  | V    |
| I <sub>DD1</sub> | Supply Current 1 (Standby mode) | V <sub>DD</sub> =5.5V, V <sub>CE</sub> =V <sub>BYPASS</sub> =0V  |      |      | 5.0  | μA   |
| I <sub>DD2</sub> | Supply Current 2 (Through mode) | V <sub>DD</sub> =V <sub>CE</sub> =V <sub>SEL</sub> =3.6V, V <sub>BYPASS</sub> =0V  | 350  |      | 850  | μA   |
| I <sub>DD3</sub> | Supply Current 3                | V <sub>DD</sub> =V <sub>CE</sub> =V <sub>BYPASS</sub> =V <sub>MODE</sub> =3.6V, V <sub>OUT</sub> =GND (No switching)           | 300  |      | 650  | μA   |
| I <sub>DD4</sub> | Supply Current 4                | V <sub>DD</sub> =V <sub>CE</sub> =V <sub>SEL</sub> =V <sub>MODE</sub> =0V, V <sub>OUT</sub> =V <sub>DD</sub> (No switching) *1 | 140  |      | 240  | μA   |

\*1) If V<sub>OUT</sub>>V<sub>SET</sub>, internal oscillation stops.

**DC/DC Part**

(Ta=25°C)

| Symbol                 | Item                                    | Conditions   | Min.  | Typ.  | Max.  | Unit.  |
|------------------------|---|--|-------|-------|-------|--------|
| V <sub>OUT</sub>       | Output Voltage                          | V <sub>DD</sub> =3.6V, V <sub>SET</sub> ≥ 1.6V                                     | x0.98 |       | x1.02 | V      |
|                        |   | Open Loop, V <sub>SET</sub> < 1.6V   | -0.03 |       | +0.03 |        |
| f <sub>osc</sub>       | Oscillator Frequency                    | V <sub>DD</sub> =3.6V  | 1.60  | 2.00  | 2.40  | MHz    |
| t <sub>START</sub>     | Soft-start Time                         | V <sub>DD</sub> =3.6V, Open Loop   |       | 0.135 | 0.170 | ms     |
| R <sub>ONP</sub> **    | ON Resistance of Pch Transistor *Note 1 | V <sub>DD</sub> =3.6V, I <sub>LX</sub> = -100mA                                    |       | 0.250 | 0.450 | Ω      |
| R <sub>ONN</sub> **    | ON Resistance of Nch Transistor *Note 1 | V <sub>DD</sub> =3.6V, I <sub>LX</sub> = -100mA                                    |       | 0.230 | 0.450 | Ω      |
| I <sub>LXLEAK</sub>    | Lx Leakage Current                      | V <sub>DD</sub> =5.5V, V <sub>CE</sub> =0V, Lx=5.5V/0V                             | -10.0 | 0.3   | 10.0  | μA     |
| I <sub>VOUT</sub>      | V <sub>OUT</sub> Leakage Current        | V <sub>DD</sub> =5.5V, V <sub>CE</sub> =0V, V <sub>OUT</sub> =5.5V                 | -1.0  | 0.002 | 1.0   | μA     |
| ΔV <sub>OUT</sub> /ΔTa | Output Voltage Temperature Coefficient  | -40°C ≤ Ta ≤ 85°C  |       | ±100  |       | ppm/°C |
| Maxduty                | Oscillator Maximum Duty Cycle           |  | 100   |       |       | %      |
| I <sub>LXLIM</sub> **  | Lx Current Limit *Note 1                | V <sub>DD</sub> =3.6V, Open Loop   | 1200  | 1600  | 2000  | mA     |
| t <sub>PROT</sub>      | Protection Delay Circuit                | V <sub>DD</sub> =3.6V  | 0.3   | 0.8   | 2.0   | ms     |
| t <sub>SETDC</sub> **  | DC/DC output settling time *Note 1      | setting signal receive->90% of V <sub>OUT</sub> , I <sub>OUT</sub> ≥ 100mA *Note 2 |       | 25    |       | μs     |
| V <sub>UVLO1</sub>     | UVLO Threshold Voltage                  | V <sub>DD</sub> =V <sub>CE</sub> , V <sub>BYPASS</sub> =V <sub>OUT</sub> =0V       | 2.15  | 2.25  | 2.35  | V      |
| V <sub>UVLO2</sub>     | UVLO Released Voltage                   | V <sub>DD</sub> =V <sub>CE</sub> , V <sub>BYPASS</sub> =V <sub>OUT</sub> =0V       | 2.25  | 2.35  | 2.45  | V      |
| I <sub>PDM</sub>       | MODE pull-down current                  | V <sub>DD</sub> =V <sub>MODE</sub> =3.6V   | 1.0   | 2.0   | 6.0   | μA     |
| V <sub>MODEH</sub>     | MODE "H" Input Voltage                  |  | 1.1   |       |       | V      |
| V <sub>MODEL</sub>     | MODE "L" Input Voltage                  |  | 0.0   |       | 0.45  | V      |
| I <sub>PDV</sub>       | V <sub>SEL</sub> pull-down current      | V <sub>DD</sub> =V <sub>SEL</sub> =3.6V  | 1.0   | 2.0   | 6.0   | μA     |
| V <sub>VSELH</sub>     | V <sub>SEL</sub> "H" Input Voltage      |  | 1.1   |       |       | V      |
| V <sub>VSELL</sub>     | V <sub>SEL</sub> "L" Input Voltage      |  | 0.0   |       | 0.45  | V      |

**Bypass Switch**

(Ta=25°C)

| Symbol                 | Item                                   | Conditions                                 | Min. | Typ. | Max. | Unit |
|------------------------|--|--|------|------|------|------|
| R <sub>ON</sub> **     | Bypass Switch On Resistance<br>*Note 1 | V <sub>DD</sub> =3.0V                      |      | 68   | 120  | mΩ   |
| I <sub>leak</sub>      | Switch Off leakage current             |  | 0.1  | 2.0  | 20.0 | μA   |
| I <sub>BYPLIM</sub> ** | Bypass Current Limit<br>*Note 1        | V <sub>DD</sub> =2.8V to 3.3V              | 1.02 | 1.40 | 1.80 | A    |
| I <sub>BYPPROT</sub>   | Bypass Protection Delay Circuit        |  | 0.3  | 0.8  | 2.0  | ms   |
| I <sub>PDB</sub>       | BYPASS pull-down current               | V <sub>DD</sub> =V <sub>BYPASS</sub> =3.6V | 1.0  | 2.0  | 6.0  | μA   |
| V <sub>BYPASSH</sub>   | BYPASS"H" Input Voltage                |  | 1.1  |      |      | V    |
| V <sub>BYPASSL</sub>   | BYPASS"L" Input Voltage                |  | 0.0  |      | 0.45 | V    |

**Others**

(Ta=25°C)

| Symbol                 | Item                                   | Conditions  | Min. | Typ. | Max. | Unit |
|------------------------|--|---|------|------|------|------|
| t <sub>SETBYP</sub> ** | BYPASS output settling time<br>*Note 1 | setting signal receive->90% of V <sub>DD</sub><br>*Note 3 |      | 25   |      | μs   |
| I <sub>PDC</sub>       | CE pull-down current                   | V <sub>DD</sub> =V <sub>CE</sub> =3.6V                    | 1.0  | 2.0  | 6.0  | μA   |
| V <sub>CEH</sub>       | CE "H" Input Voltage                   |   | 1.1  |      |      | V    |
| V <sub>CEL</sub>       | CE "L" Input Voltage                   |   | 0.00 |      | 0.45 | V    |

\*Note1) This item is guaranteed by design.

\*Note2) This item describes the transition time from V<sub>SEL</sub>="L" to "H" or "H" to "L" at V<sub>MODE</sub>="H" and V<sub>BYPASS</sub>="H" or at V<sub>MODE</sub>="H" and V<sub>BYPASS</sub>="L" or V<sub>BYPASS</sub>="L" to "H" at V<sub>MODE</sub>="H", V<sub>SEL</sub>="H".

\*Note3) This item describes the transition time from V<sub>BYPASS</sub>="H" to "L" at V<sub>MODE</sub>="H" and V<sub>SEL</sub>="H".

**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 when they are used over such conditions by momentary electronic noise or surge. The semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

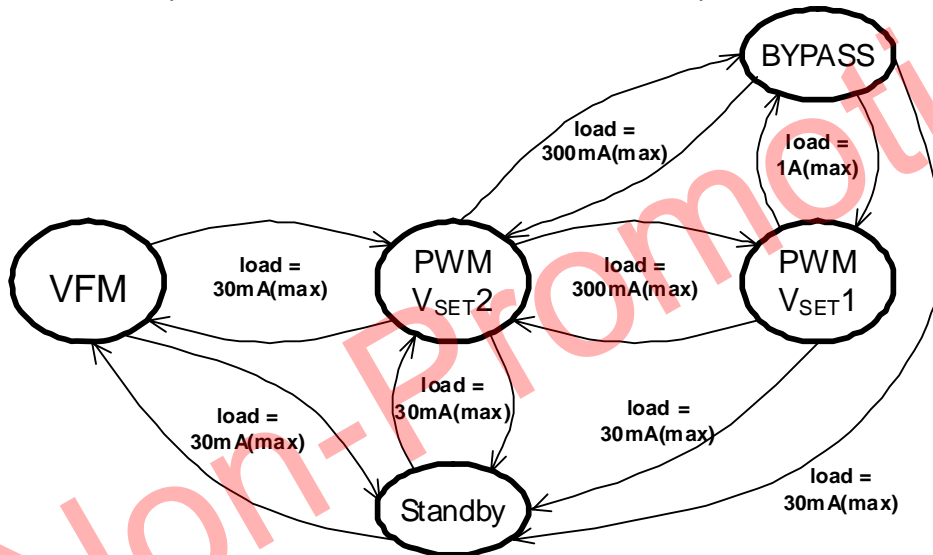
**LOGIC TABLE**

|                  |         |     |                         |        |                         |
|------------------|---------|-----|-------------------------|--------|-------------------------|
| CE               | 0       | 1   | 1                       | 1      | 1                       |
| V <sub>SEL</sub> | 0/1     | 0   | 0                       | 1      | 1                       |
| BYPASS           | 0/1     | 0/1 | 0/1                     | 0      | 1                       |
| MODE             | 0/1     | 0   | 1                       | 0/1    | 0/1                     |
| <b>STATE</b>     | Standby | VFM | PWM(V <sub>SET2</sub> ) | BYPASS | PWM(V <sub>SET1</sub> ) |

- \* Note 1) If V<sub>SET1</sub> is not necessary, by fixing the logic of BYPASS at "L" and MODE at "H", DC/DC mode (V<sub>SET2</sub>) and the bypass mode can be switched over with VSEL pin. (V<sub>SEL</sub>="H": Bypass mode)
- \* Note 2) If V<sub>SET2</sub> is not necessary, by fixing the logic of VSEL at "H", DC/DC mode (V<sub>SET1</sub>) and the bypass mode can be switched over with BYPASS pin. (BYPASS="L": Bypass mode)

**OUTPUT CURRENT LIMIT CONDITION at MODE TRANSIENT**

In terms of the operation of mode transient, the maximum output current at mode transient is as follows:



Note 1) At the start-up, if the first mode is VFM or PWM of V<sub>SET2</sub>, at first, power on, and the secondly, forced the enable signal to CE pin.

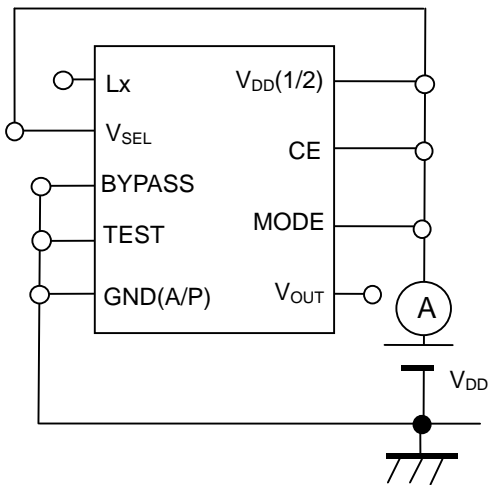
Note 2) In the actual application, if a magnet or similar to magnet is put very close to the IC, the IC itself is not affected, however, the inductor may be affected and the inductance value may shift, as a result, the inductance value could be not enough for the operation of the RP904Z.

In our simulation, if the inductance value decreases to 0.5μH or less, the peak of the ripple current increases and detected at start-up and the operation may stop. In this case, gain shifts lower and the operation could be unstable against the input and load variation.

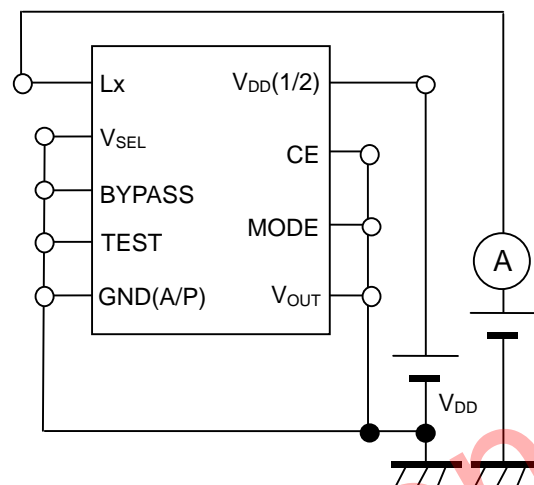
At the operation, at least 1μH inductance value is necessary.  
As an initial value, the nominal inductance value should be 2.2μF or more.

## TEST CIRCUITS

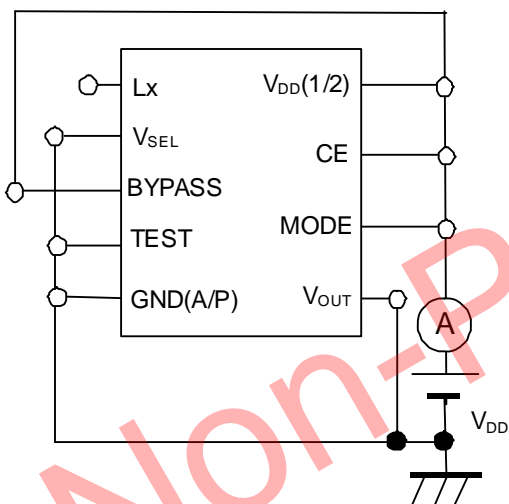
Supply Current 2



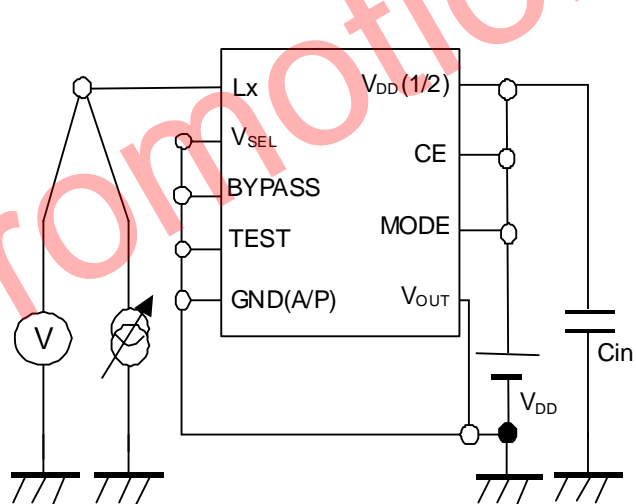
Lx Leakage Current



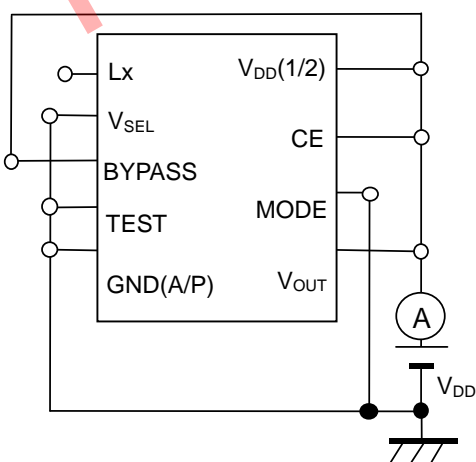
Supply Current 3



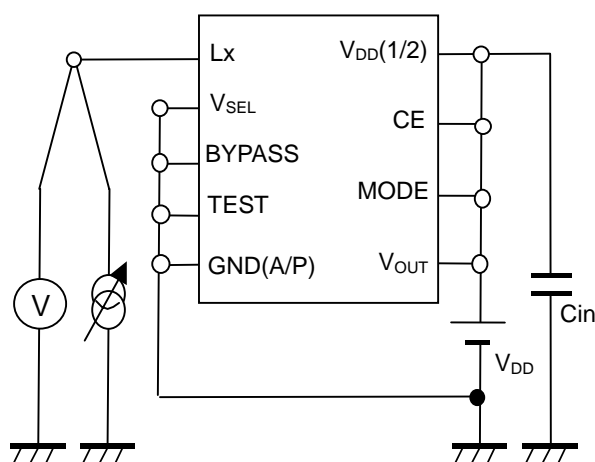
Lx On resistance (Pch)



Supply Current 4

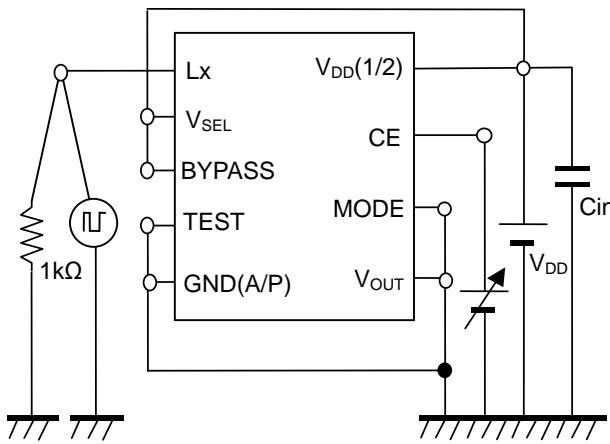


Lx On resistance (Nch)

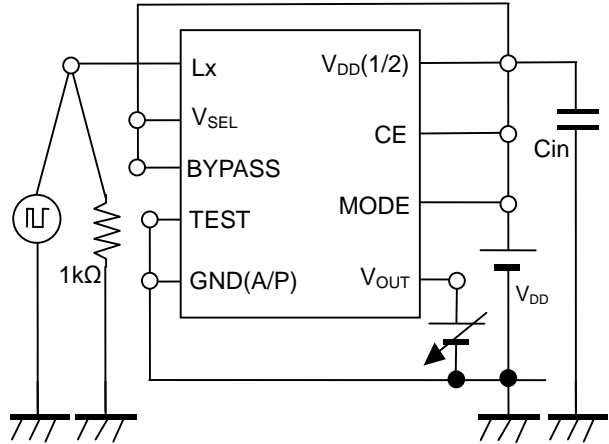




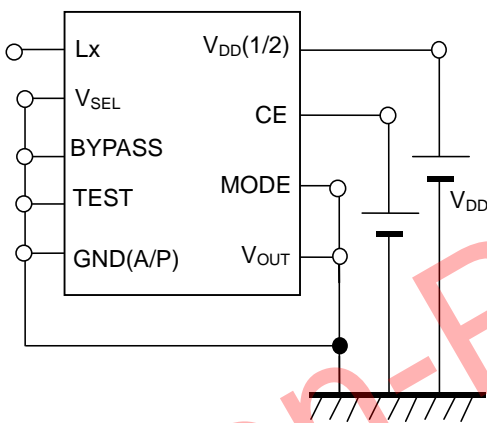
CE Input Voltage



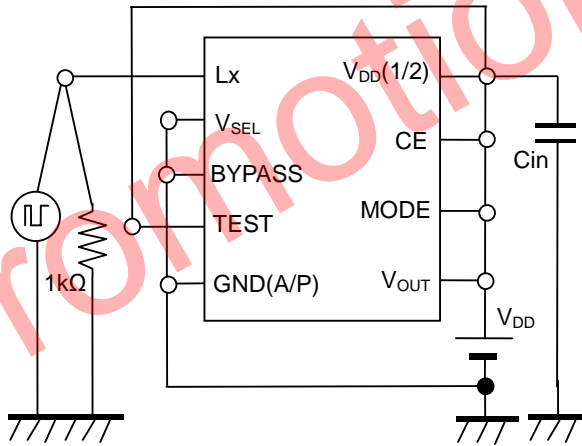
Output Voltage



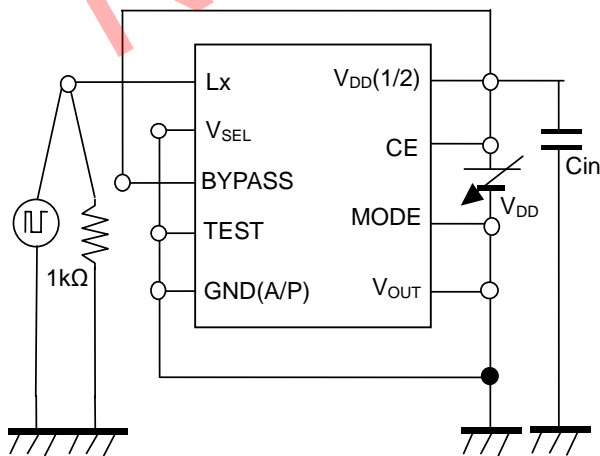
CE Input Current



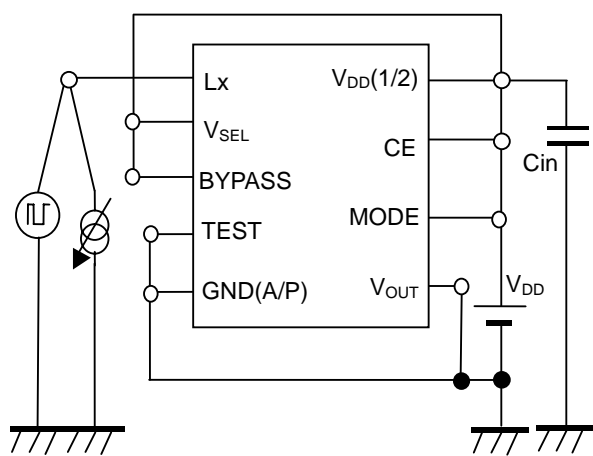
Oscillator Frequency



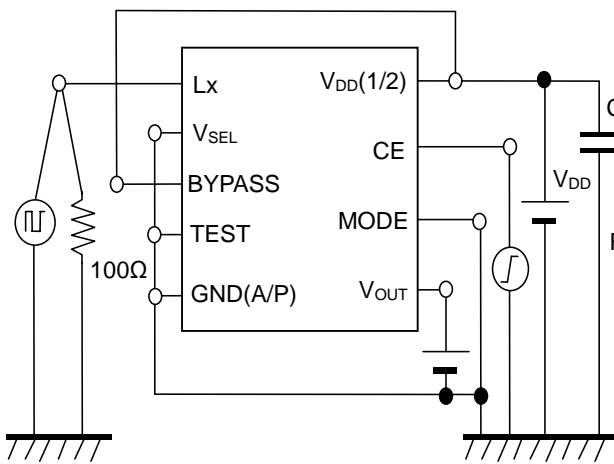
UVLO Detector Threshold/Released Voltage Hysteresis



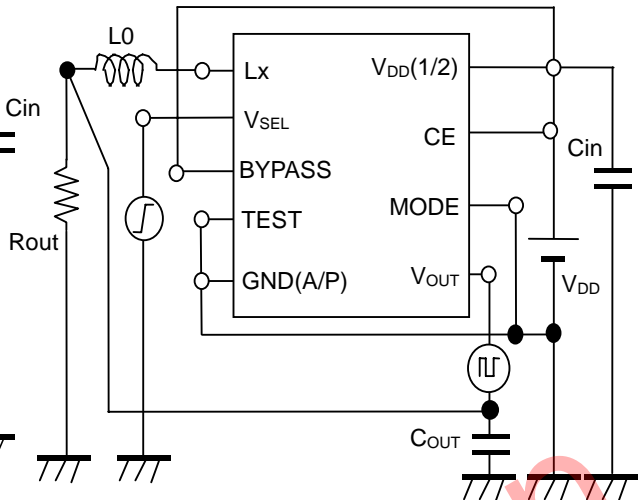
Lx Current Limit "H"



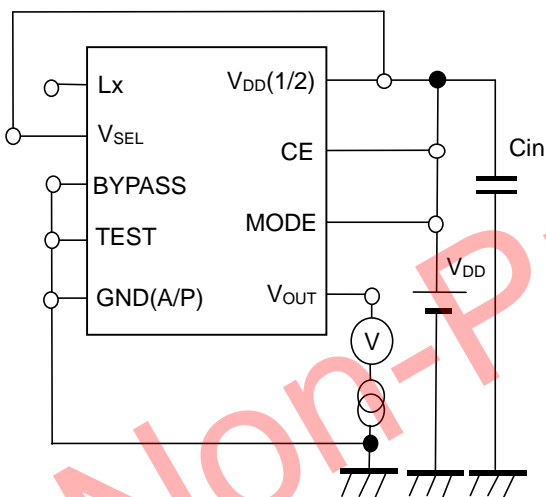
**Soft Start Time**



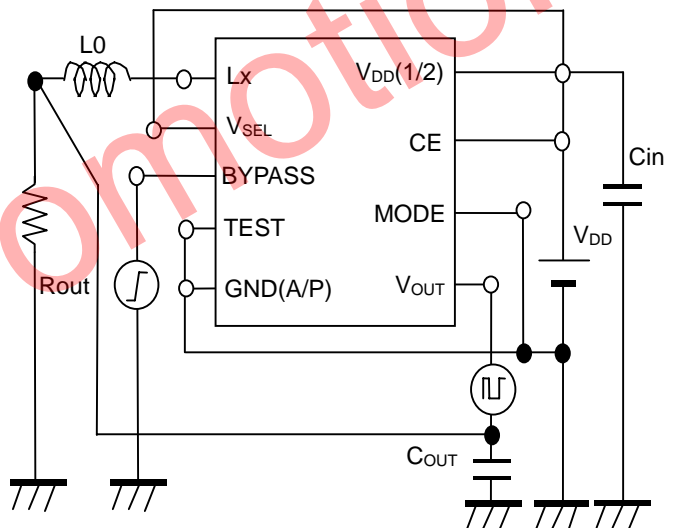
**Output Settling Time 1**



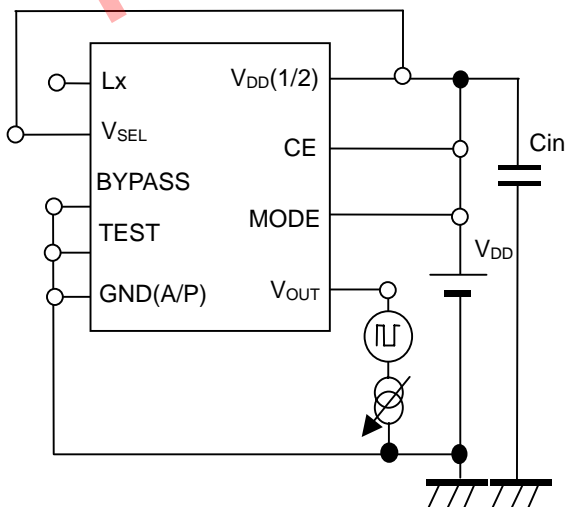
**BYPASS ON resistance**



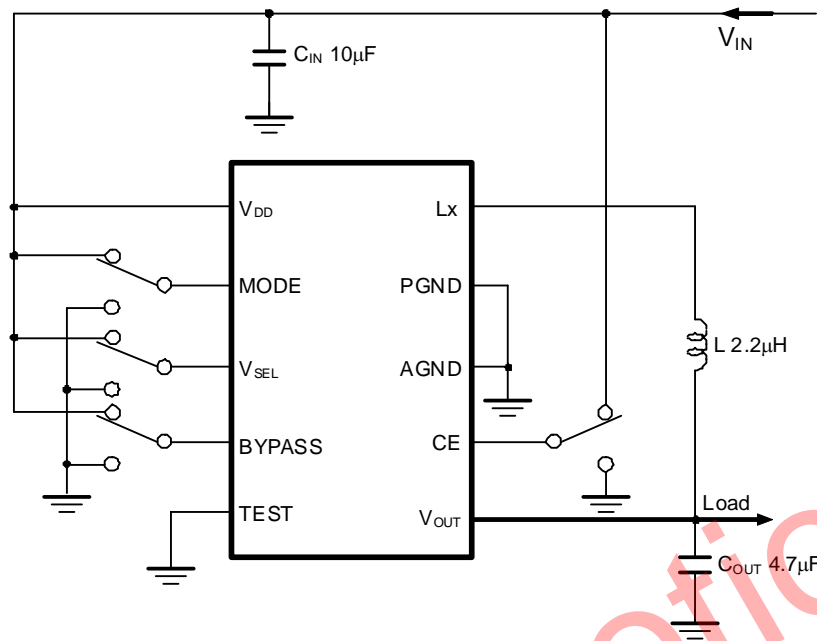
**Output Settling Time 2**



**BYPASS Current Limit**



TYPICAL APPLICATION



Parts Recommendation

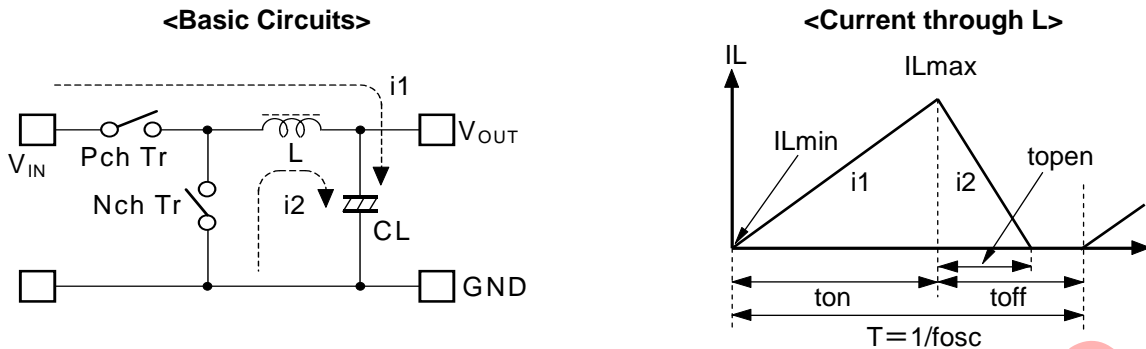
|           |  |
|-----------|--|
| $C_{IN}$  | 10µF Ceramic type (C2012JB0J106K: TDK)                                 |
| $C_{OUT}$ | 4.7µF Ceramic type (C2012JB1A475K: TDK)<br>(JMK107BJ475MA: TaiyoYuden) |
| L         | 2.2µH(CKP2520: Taiyo Yuden) (NR3010: Taiyo Yuden)<br>(MIPS2520: FDK)   |

External Components

- If PGND pin and AGND pin are connected in common, put the input capacitor  $C_{IN}$  as 10µF or more at the nearest connect point.
- If an input capacitor  $C_{IN}$  is set to the PGND pin and AGND pin respectively, set 10µF or more capacitor to PGND pin.
- Connect the TEST pin to the GND. Connect TEST pin can be in common with PGND pin and AGND pin.

## OPERATION of step-down DC/DC converter and Output Current

The step-down DC/DC converter charges energy in the inductor when Lx transistor is ON, and discharges the energy from the inductor when Lx transistor is OFF and controls with less energy loss, so that a lower output voltage than the input voltage is obtained. The operation will be explained with reference to the following diagrams:



- Step 1: P-channel Tr. turns on and current  $I_L (=i_1)$  flows, and energy is charged into CL. At this moment,  $I_L$  increases from  $I_{Lmin} (=0)$  to reach  $I_{Lmax}$  in proportion to the on-time period ( $t_{on}$ ) of P-channel Tr.
- Step 2: When P-channel Tr. turns off, Synchronous rectifier N-channel Tr. turns on in order that L maintains  $I_L$  at  $I_{Lmax}$ , and current  $I_L (=i_2)$  flows.
- Step 3:  $I_L (=i_2)$  decreases gradually and reaches  $I_L = I_{Lmin} = 0$  after a time period of  $t_{open}$ , and N-channel Tr. Turns off. Provided that in the continuous mode, next cycle starts before  $I_L$  becomes to 0 because  $t_{off}$  time is not enough. In this case,  $I_L$  value increases from this  $I_{Lmin} (>0)$ .

In the case of PWM control system, the output voltage is maintained by controlling the on-time period ( $t_{on}$ ), with the oscillator frequency ( $f_{osc}$ ) being maintained constant.

The maximum value ( $I_{Lmax}$ ) and the minimum value ( $I_{Lmin}$ ) of the current flowing through the inductor are the same as those when P-channel Tr. turns on and off.

The difference between  $I_{Lmax}$  and  $I_{Lmin}$ , which is represented by  $\Delta I$ ;

$$\Delta I = I_{Lmax} - I_{Lmin} = V_{OUT} \times t_{open} / L = (V_{DD} - V_{OUT}) \times t_{on} / L \dots \dots \dots \text{Equation 1}$$

Wherein,  $T = 1/f_{osc} = t_{on} + t_{off}$

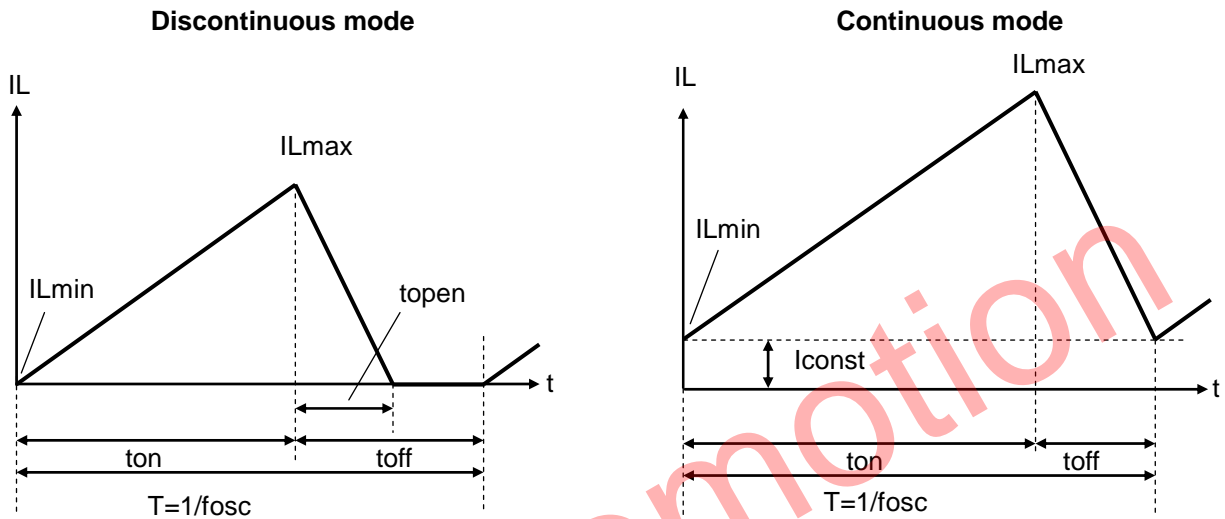
$$\text{duty (\%)} = t_{on} / T \times 100 = t_{on} \times f_{osc} \times 100$$

$$t_{open} \leq t_{off}$$

In Equation 1,  $V_{OUT} \times t_{open} / L$  and  $(V_{DD} - V_{OUT}) \times t_{on} / L$  respectively show the change of the current at "ON", and the change of the current at "OFF".

### Discontinuous mode and Continuous mode

When the output current ( $I_{OUT}$ ) is relatively small,  $t_{open} < t_{off}$  as illustrated in the following diagram. In this case, the energy is charged in the inductor during the time period of  $t_{on}$  and is discharged in its entirety during the time period of  $t_{off}$ , therefore  $I_{Lmin}$  becomes to zero ( $I_{Lmin}=0$ ). When  $I_{OUT}$  is gradually increased, eventually,  $t_{open}$  becomes to  $t_{off}$  ( $t_{open}=t_{off}$ ), and when  $I_{OUT}$  is further increased,  $I_{Lmin}$  becomes larger than zero ( $I_{Lmin}>0$ ). The former mode is referred to as the discontinuous mode and the latter mode is referred to as continuous mode.



In the continuous mode, when Equation 1 is solved for  $t_{on}$  and assumed that the solution is  $t_{onc}$ ,

$$t_{onc} = T \times V_{OUT} / V_{IN} \dots \dots \dots \text{Equation 2}$$

When  $t_{on} < t_{onc}$ , the mode is the discontinuous mode, and when  $t_{on} = t_{onc}$ , the mode is the continuous mode.

## OUTPUT CURRENT AND SELECTION OF EXTERNAL COMPONENTS

When P-channel Tr. of Lx is ON:

(Wherein, Ripple Current P-P value is described as  $I_{RP}$ , ON resistance of P-channel Tr. and N-channel Tr. of Lx are respectively described as  $R_{ONP}$  and  $R_{ONN}$ , and the DC resistor of the inductor is described as  $R_L$ .)

$$V_{DD} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times I_{RP} / t_{on} \dots\dots\dots \text{Equation 3}$$

When P-channel Tr. of Lx is "OFF"(N-channel Tr. is "ON"):

$$L \times I_{RP} / t_{off} = R_L \times I_{OUT} + V_{OUT} + R_{ONN} \times I_{OUT} \dots\dots\dots \text{Equation 4}$$

Put Equation 4 to Equation 3 and solve for ON duty of P-channel transistor,  $t_{on} / (t_{off} + t_{on}) = D_{ON}$ ,

$$D_{ON} = (V_{OUT} - R_{ONN} \times I_{OUT} + R_L \times I_{OUT}) / (V_{DD} + R_{ONN} \times I_{OUT} - R_{ONP} \times I_{OUT}) \dots\dots\dots \text{Equation 5}$$

Ripple Current is as follows;

$$I_{RP} = (V_{DD} - V_{OUT} - R_{ONP} \times I_{OUT} - R_L \times I_{OUT}) \times D_{ON} / f / L \dots\dots\dots \text{Equation 6}$$

Wherein, peak current that flows through L, and Lx Tr. is as follows;

$$I_{Lmax} = I_{OUT} + I_{RP} / 2 \dots\dots\dots \text{Equation 7}$$

Consider  $I_{Lmax}$ , condition of input and output and select external components.

\* The above explanation is directed to the calculation in an ideal case in continuous mode.

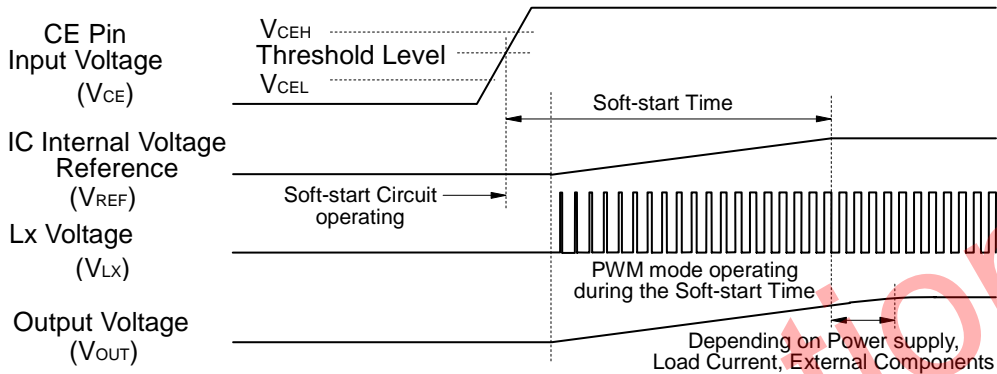
If CE pin input signal is forced earlier than the supply voltage,  $V_{OUT}$  rises up with keeping its voltage difference between the input and the output fixed by the input voltage against  $V_{DD}$ .

## TIMING CHART

### (1) Soft Start Time

#### In the case of starting this IC with CE

In the case of starting this IC with CE, the operation can be as in the timing chart below. When the voltage of CE pin ( $V_{CE}$ ) is beyond the threshold level, the operation of the IC starts. The threshold voltage of CE pin is in between CE "H" input voltage ( $V_{CEH}$ ) and CE "L" input voltage ( $V_{CEL}$ ) described in the electrical characteristics table. Soft-start circuit operates, and after the certain time, the reference voltage inside the IC ( $V_{REF}$ ) is rising gradually up to the constant value.



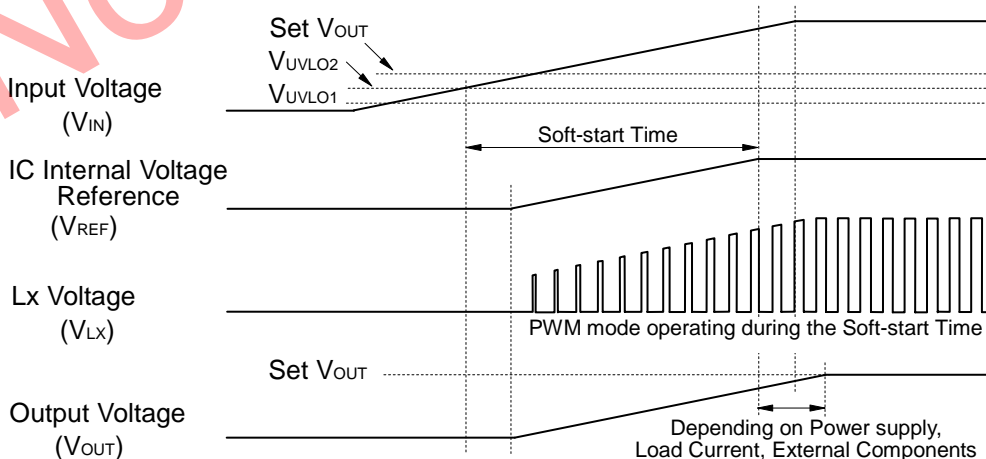
Soft-start time is the time interval from soft start circuit starting point to the reference voltage level reaching point up to this constant level.

\*Soft start time is not always equal to the turn-on speed of DC/DC converter.

The power supply capacity for this IC, load current, inductance and capacitance values affect the turn-on speed.

#### In the case of starting with power supply

In the case of starting with power supply, when the input voltage ( $V_{IN}$ ) is larger than UVLO released voltage ( $V_{UVLO2}$ ), soft start circuit operates, and after that, the same explanation above is applied to the operation. Soft-start time is the time interval from soft start circuit starting point to the reference voltage level reaching point up to this constant level.



\*Turn-on speed is affected by next conditions;

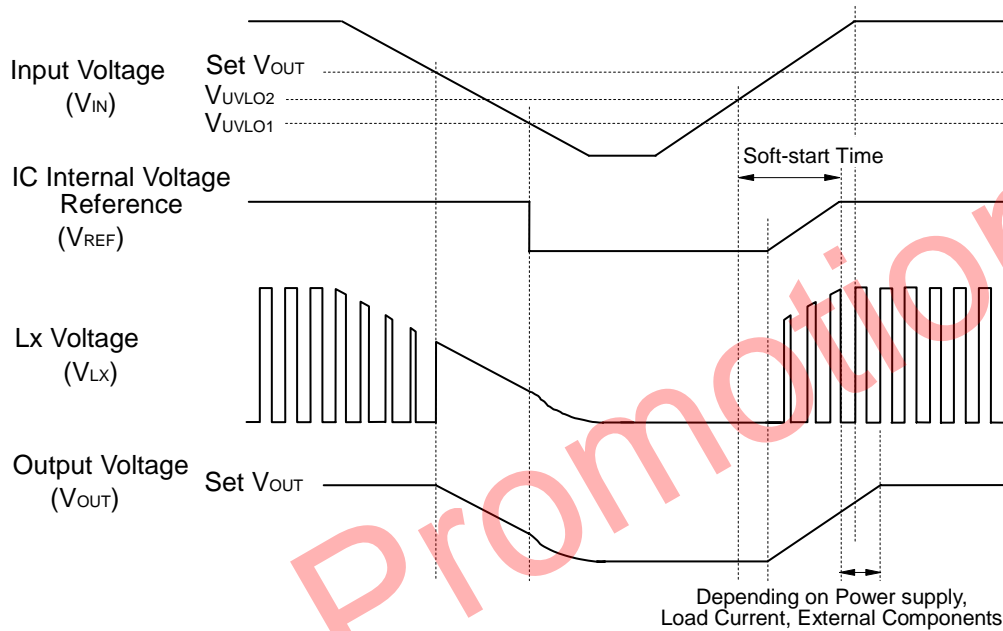
- (a) Input Voltage ( $V_{IN}$ ) rising speed depending on the power supplier to the IC and input capacitor  $C_{IN}$ .
- (b) Output Capacitor  $C_{OUT}$  value and load current value.

• (2) Under Voltage Lockout (UVLO) Circuit

The step-down DC/DC converter stops switching if input voltage ( $V_{IN}$ ) becomes less than the set output voltage (Set  $V_{OUT}$ ), the output voltage ( $V_{OUT}$ ) gradually drops according to the input voltage ( $V_{IN}$ ). If the input voltage drops more and becomes less than UVLO detector threshold ( $V_{UVLO1}$ ), the under voltage lockout circuit (UVLO) operates, the IC internal reference voltage ( $V_{REF}$ ) stops and the output voltage drops according to the load.

To restart the normal operation, the input voltage ( $V_{IN}$ ) must be more than the UVLO released voltage ( $V_{UVLO2}$ ).

The timing chart below describes the operation with varying the input voltage ( $V_{IN}$ ).



\*Actually, the waveform of  $V_{OUT}$  at UVLO working and releasing varies depending on the initial voltage of  $C_{OUT}$  and load current situation.

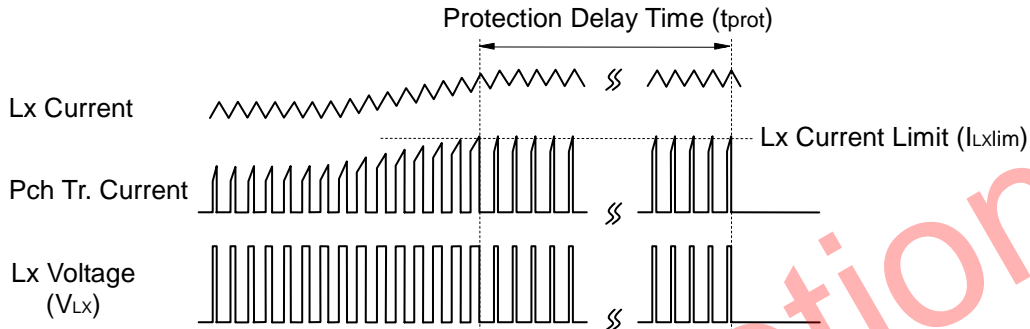


**(3) Over Current Protection Circuit, Latch Type Protection Circuit**

Over current protection circuit supervises the coil peak current (the current flowing Pch transistor) at each switching cycle, and if the current beyond the Lx current limit ( $I_{Lxlim}$ ), Pch transistor is turned off. the Lx current limit of RP904K is Typ.1.6A.

Further, if the over current status continues equal or longer than protection delay time, or, when the Lx limit current is exceeded even once when the driver operates by duty 100%, a built-in driver is latched in the OFF state and the operation of DC/DC converter stops.

\*Lx current limit and protection delay time is affected by self-heating and ambient environment. If the output is short and the input voltage ( $V_{IN}$ ) is drastically dropped or becomes unstable, the protection operation and delay time may vary.

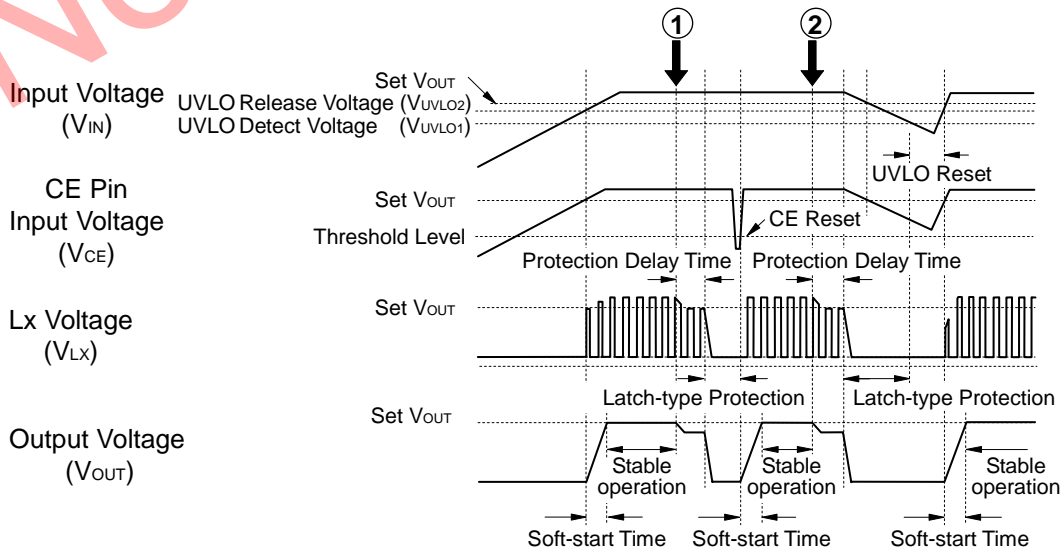


To release the condition of latch type protection, restart this IC by inputting "L" signal to CE pin, or restart this IC with power-on or make the supply voltage lower than UVLO detector threshold ( $V_{UVLO1}$ ) level.

The timing chart shown below describes the changing process of input voltage rising, stable operating, operating with large current, reset with CE pin, stable operating, input voltage falling, input voltage recovering, and stable operating.

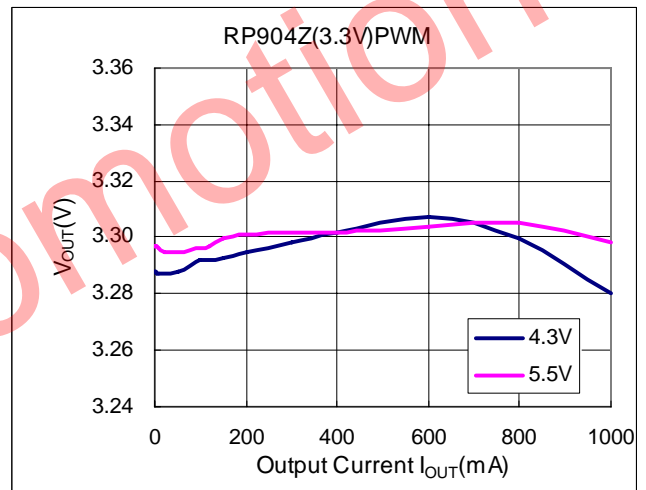
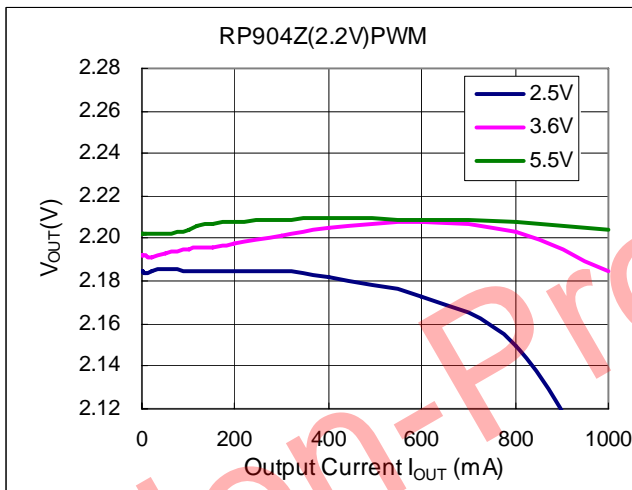
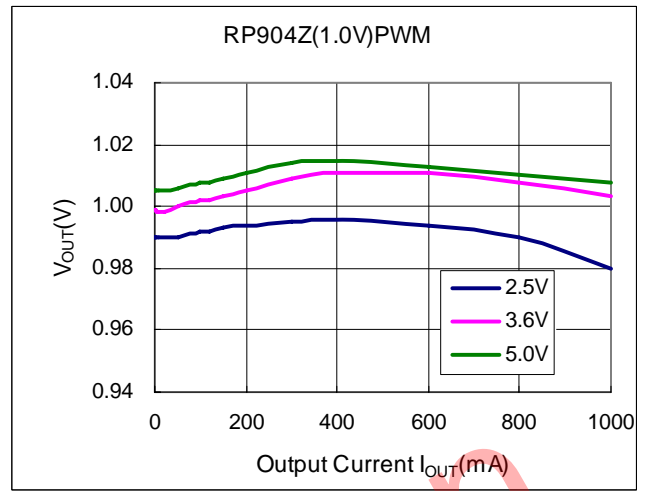
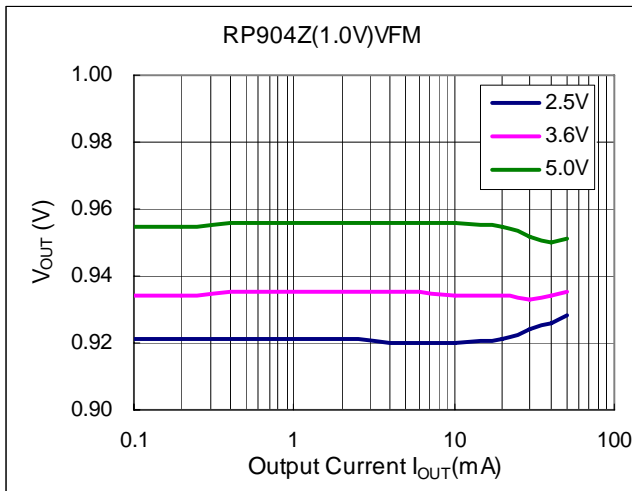
If too large current flows through the circuit because of short or other reasons, after the delay time of latch type protection a built-in driver is latched in the OFF state and  $V_{Lx}$  signal will be "L", then output will turn off. At the point ①, release the latch type protection is realized with CE reset as changed CE signal from "L" to "H".

At the point ②, release the latch type protection is realized with UVLO reset as make the supply voltage lower than UVLO detector threshold ( $V_{UVLO1}$ ) level.

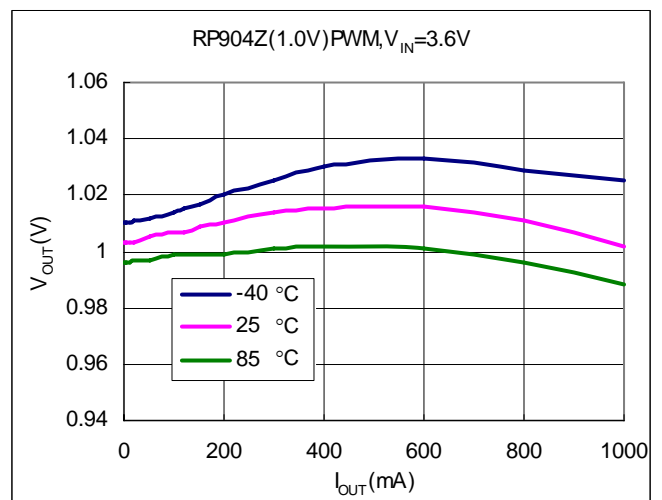
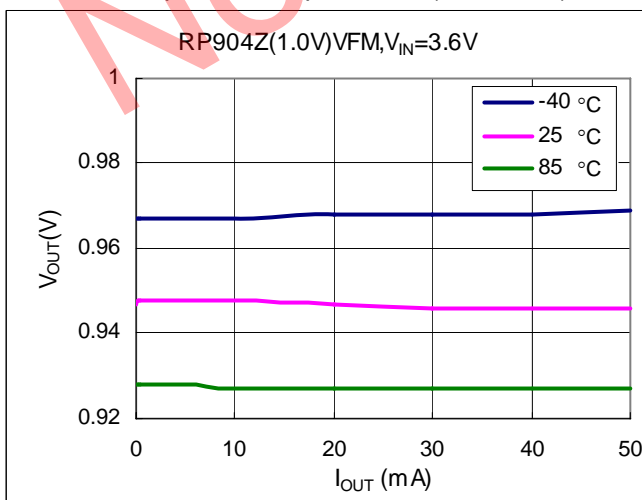


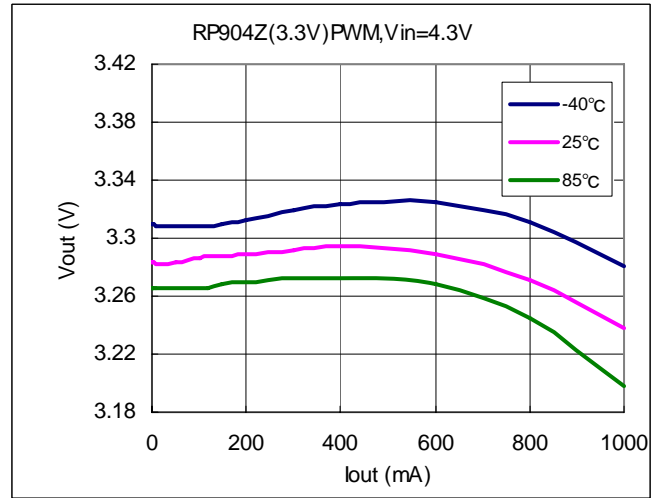
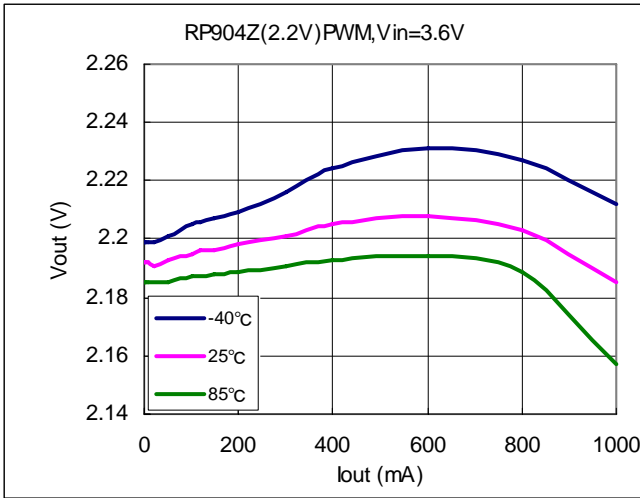
TYPICAL CHARACTERISTICS

1) Output Voltage vs. Output Current  
1-1 Input Voltage Dependence

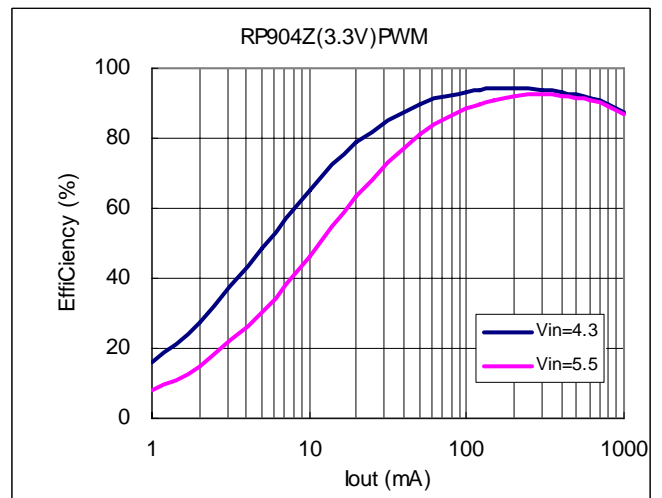
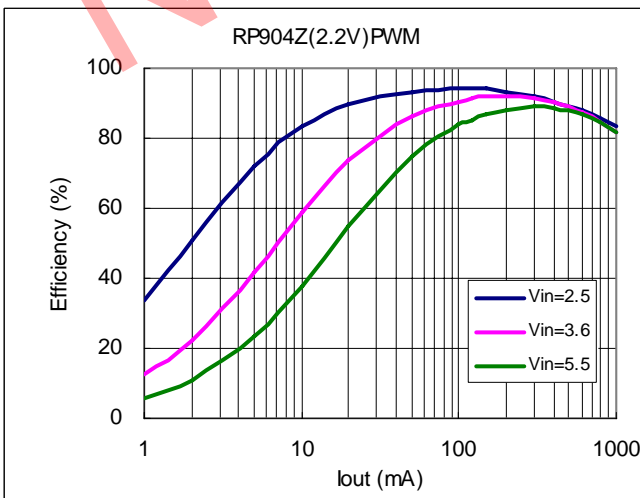
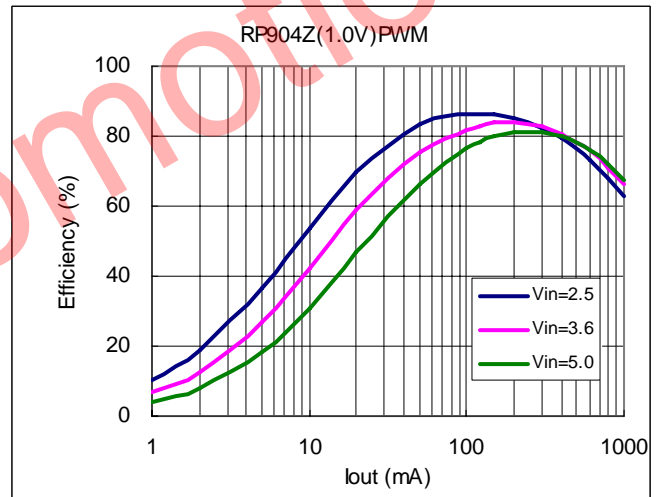
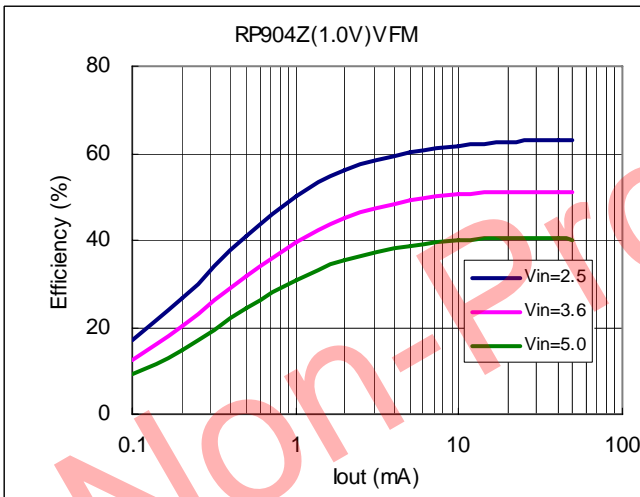


1-2 Temperature Dependence ( $V_{SET}=2.9V$ )

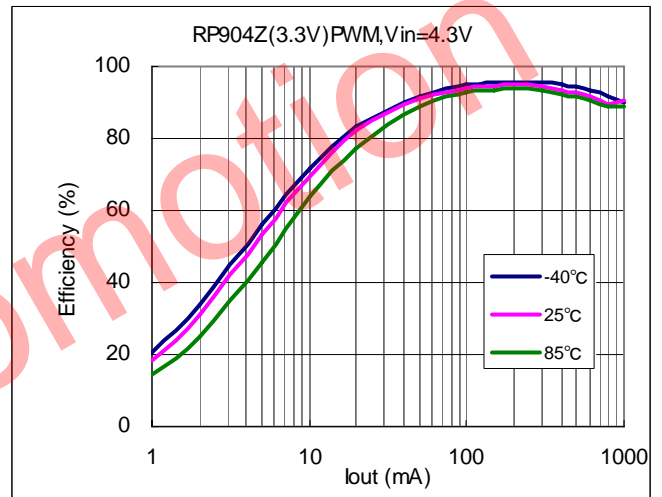
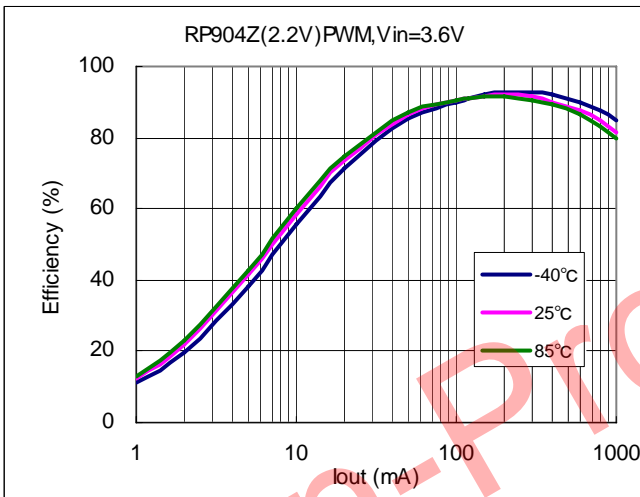
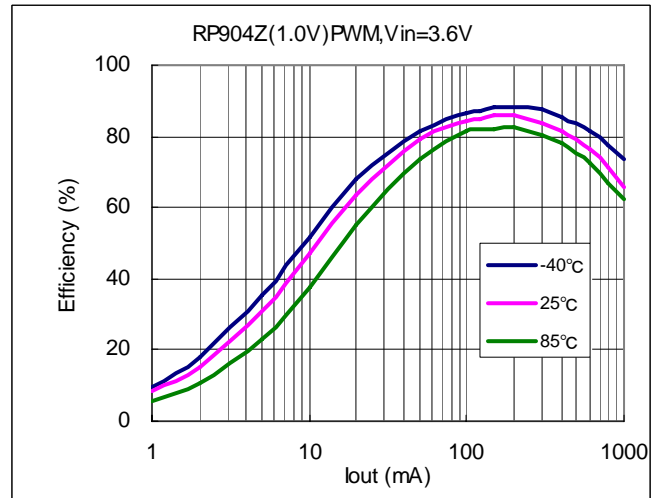
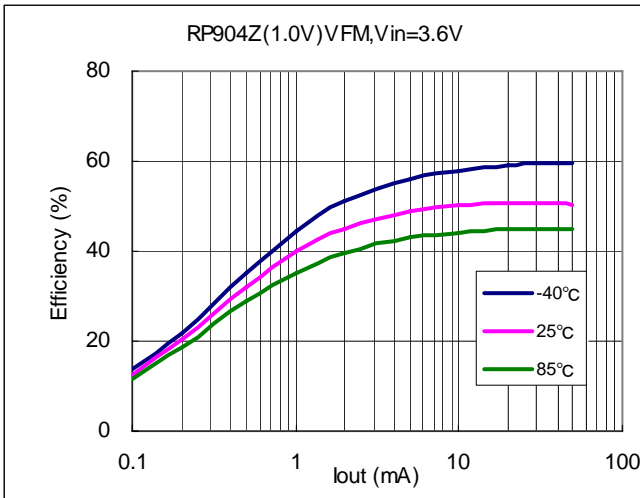




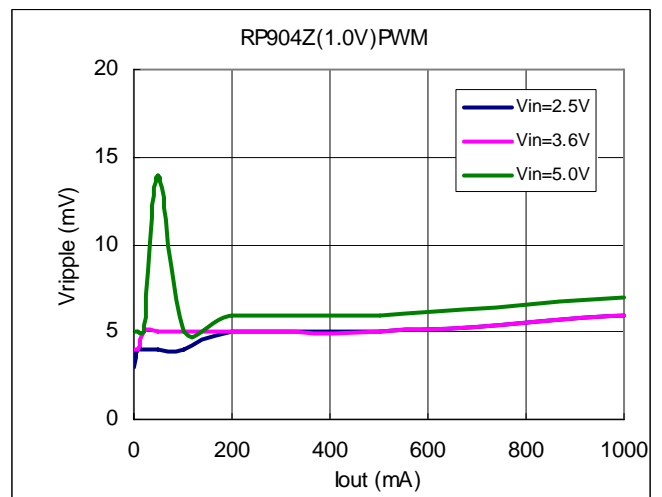
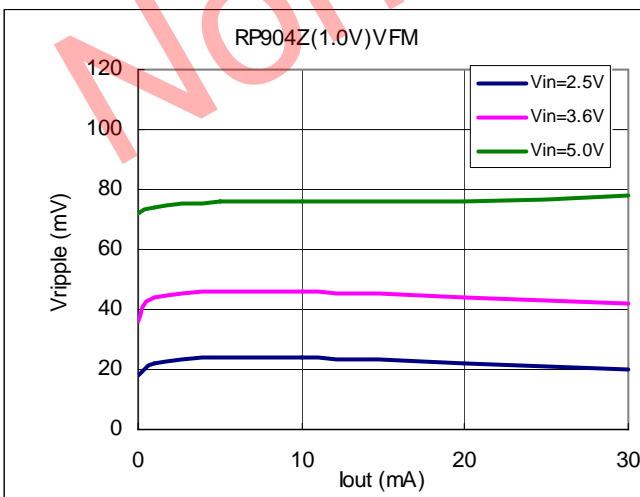
2) Efficiency vs. Output Current  
2-1 Input Voltage Dependence

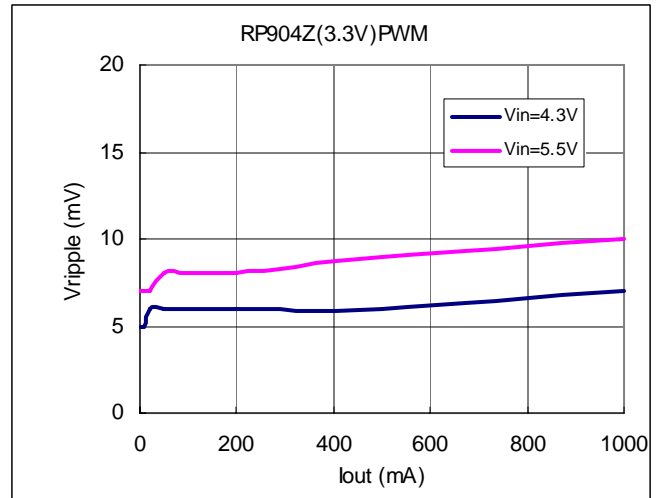
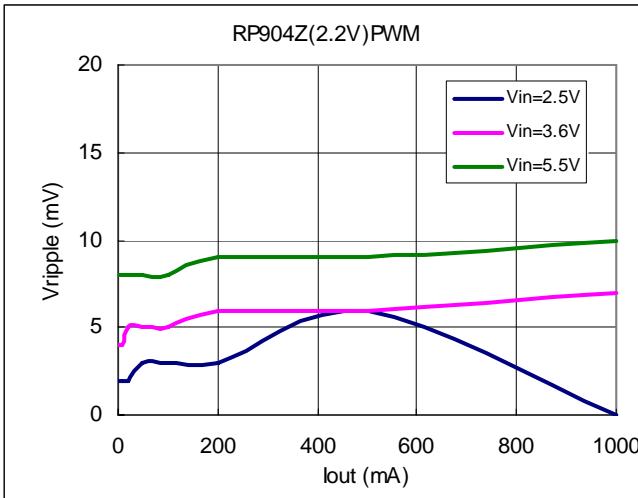


2-2. Temperature Dependence

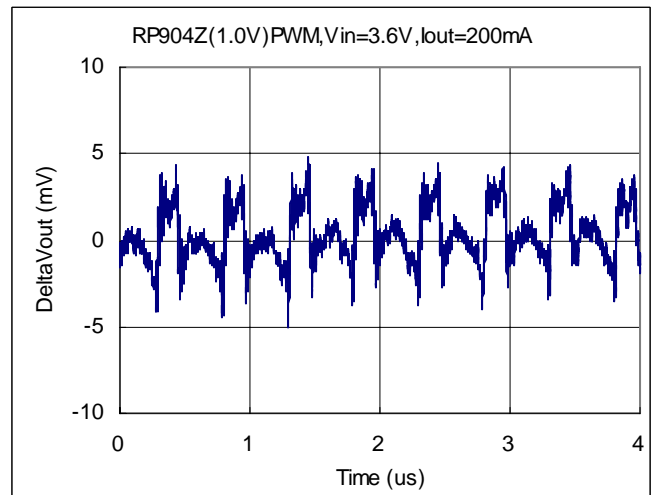
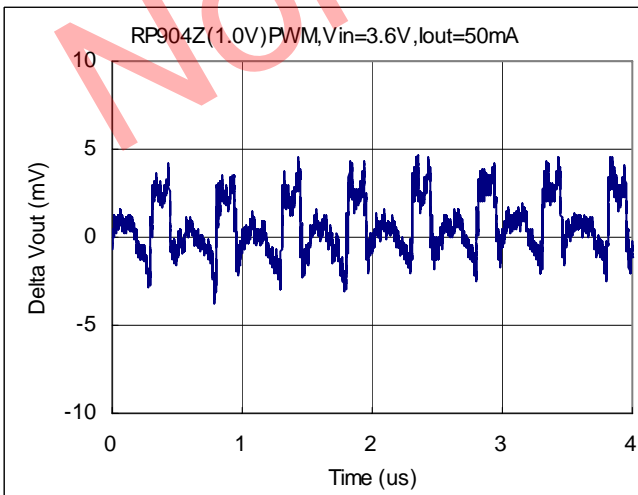
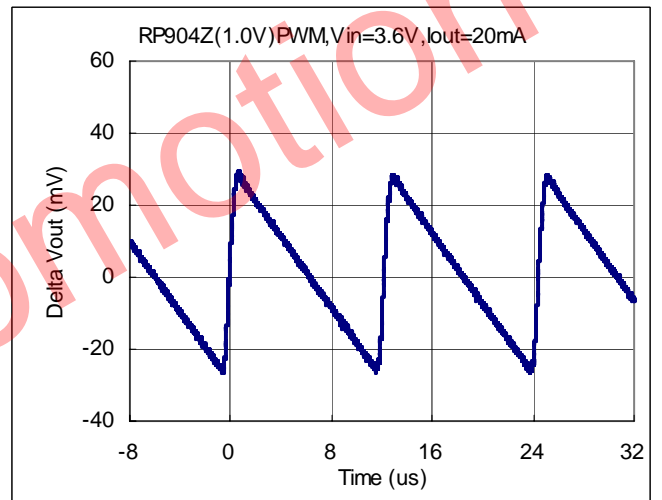
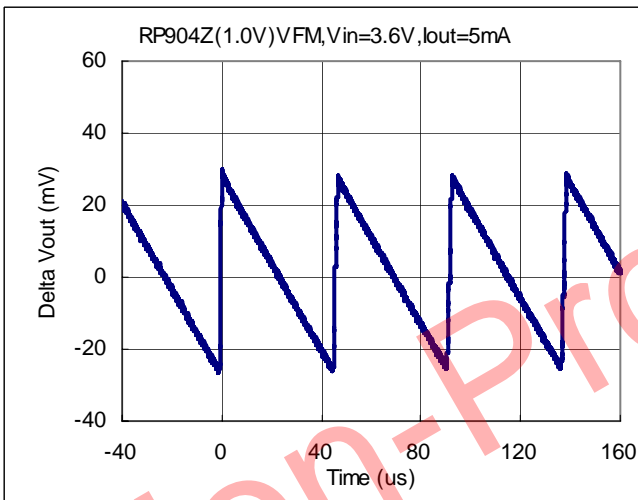


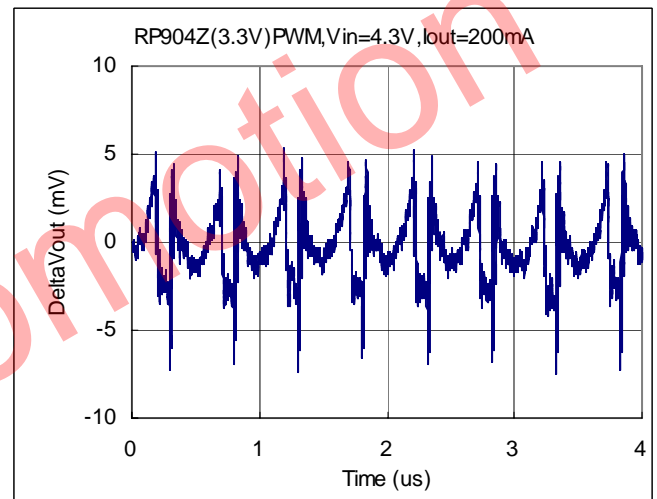
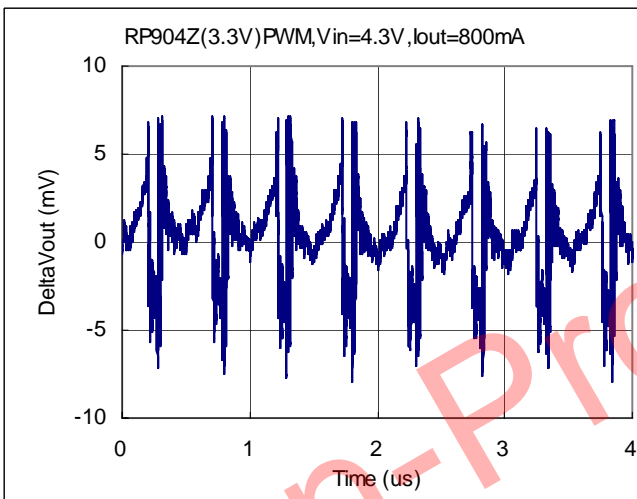
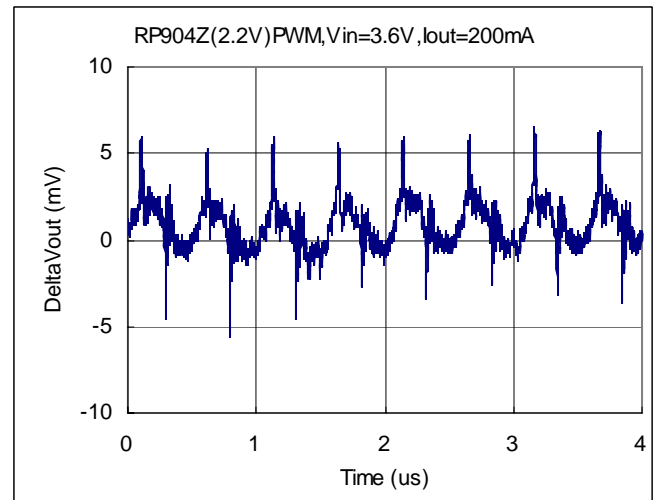
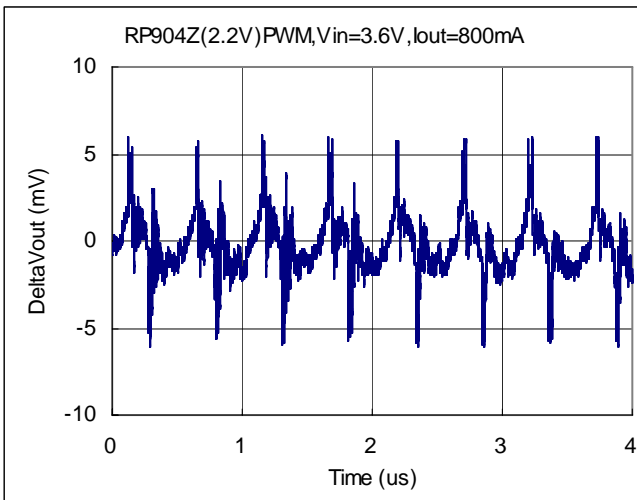
3) Output Ripple Voltage vs. Output Current



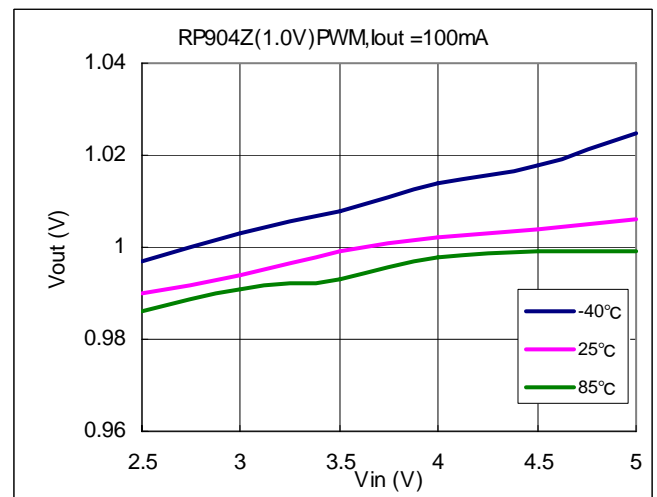
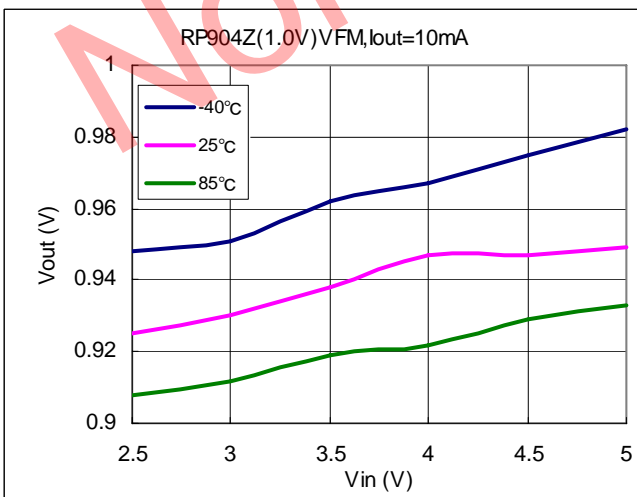


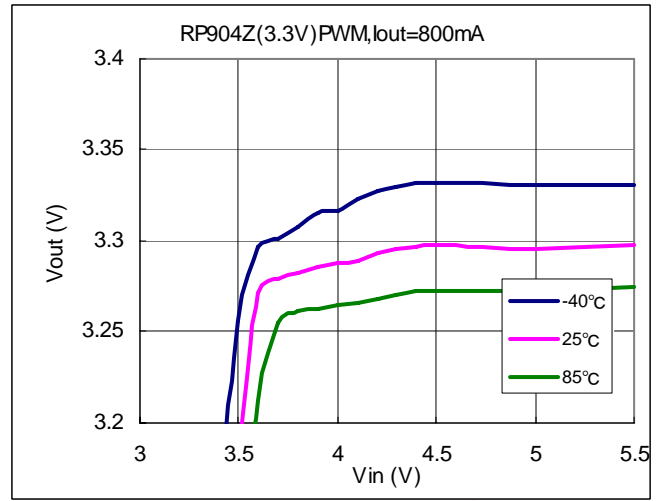
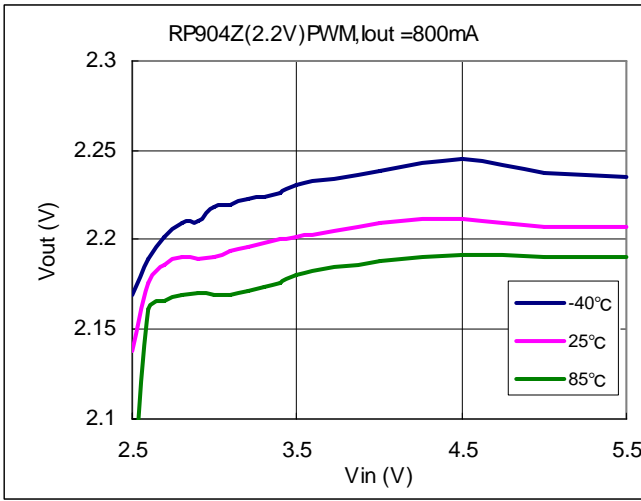
4) Output Waveform



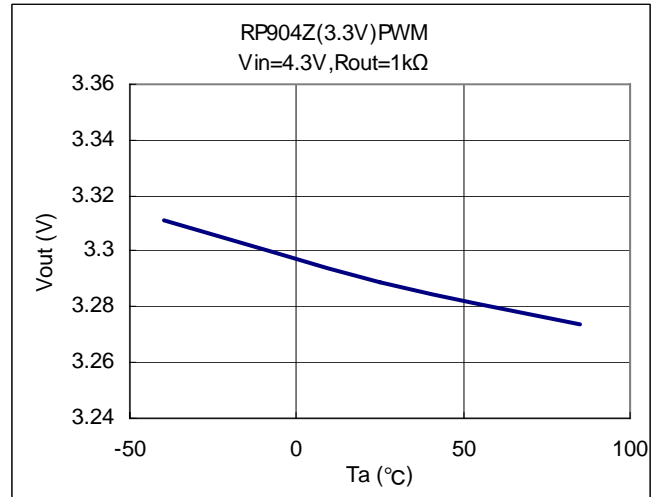
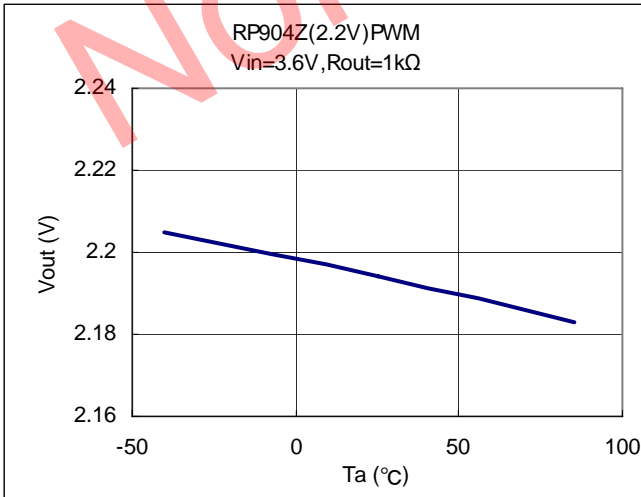
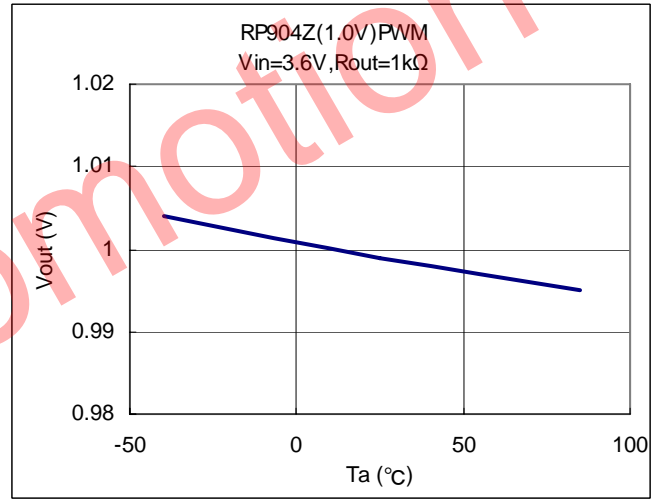
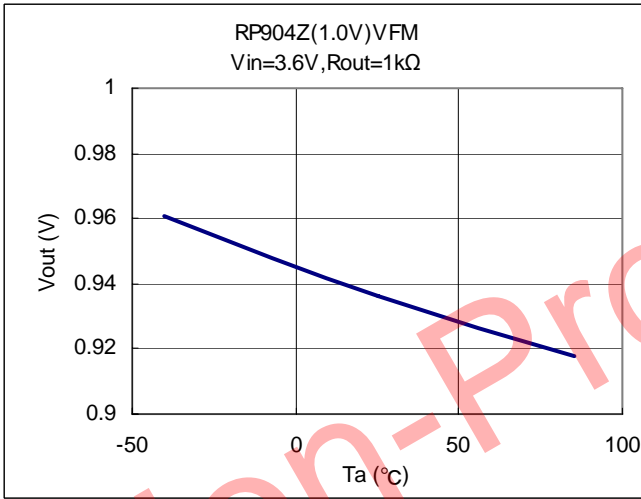


5) Output Voltage vs. Input Voltage

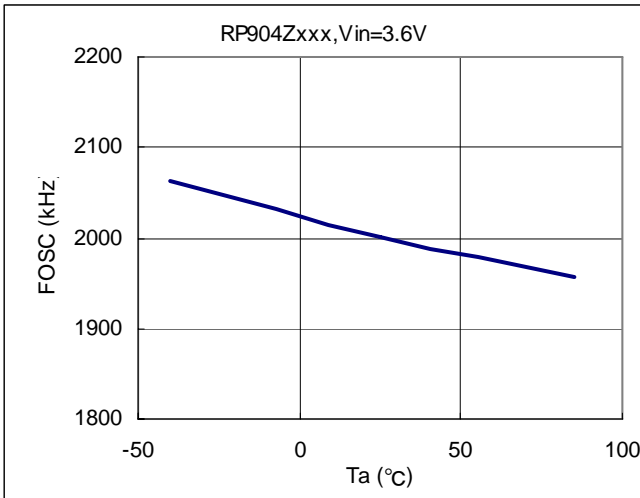




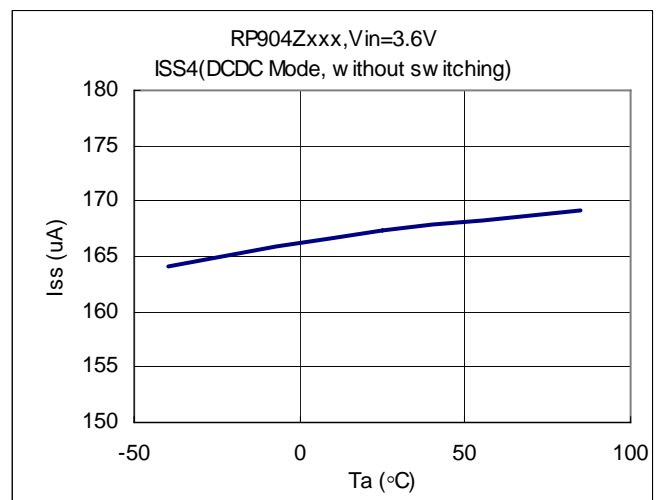
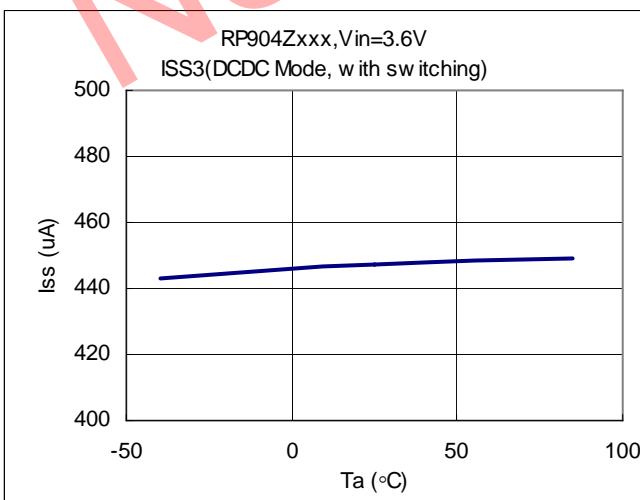
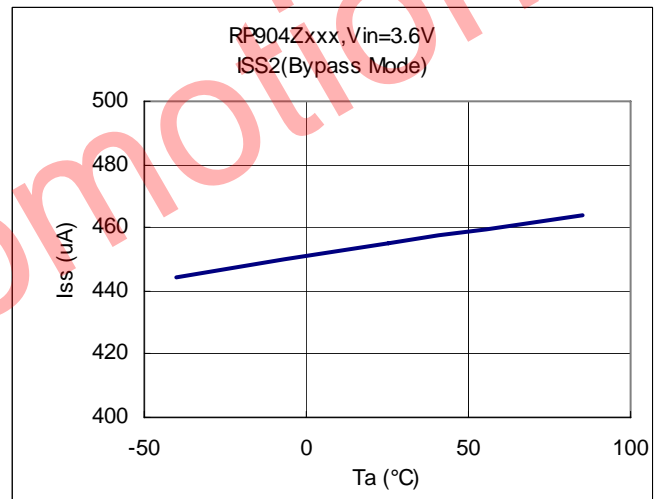
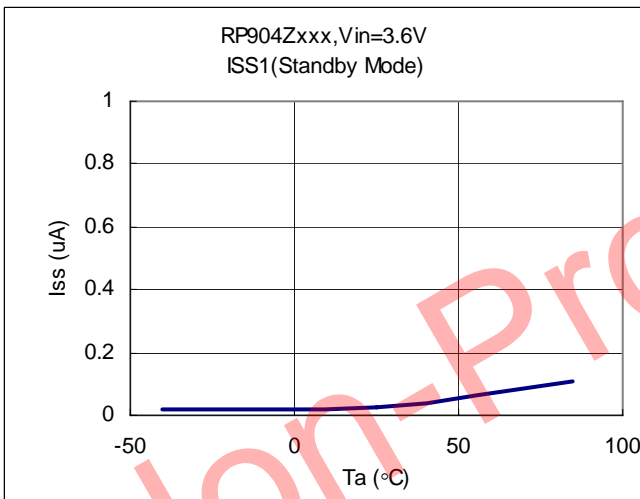
6) Output Voltage vs. Temperature



7) Oscillator Frequency vs. Temperature

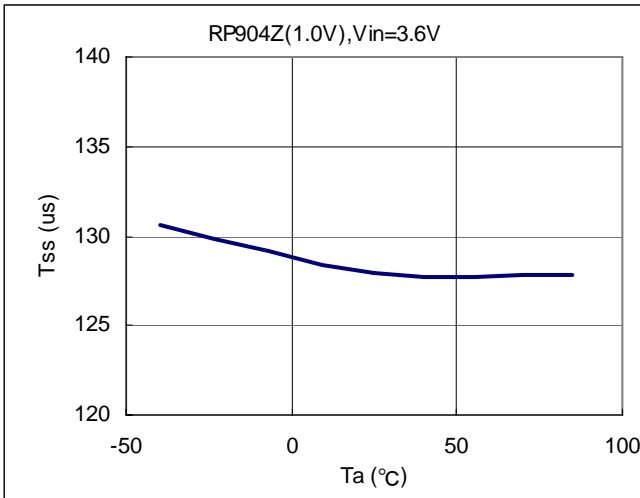


8) Supply Current vs. Temperature

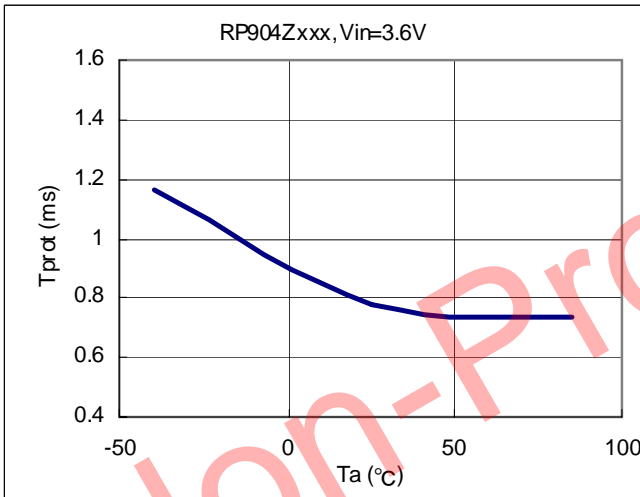




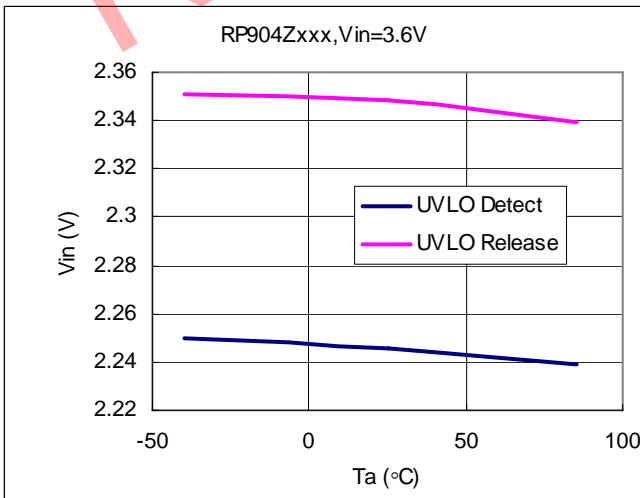
9) Soft-start Time vs. Temperature



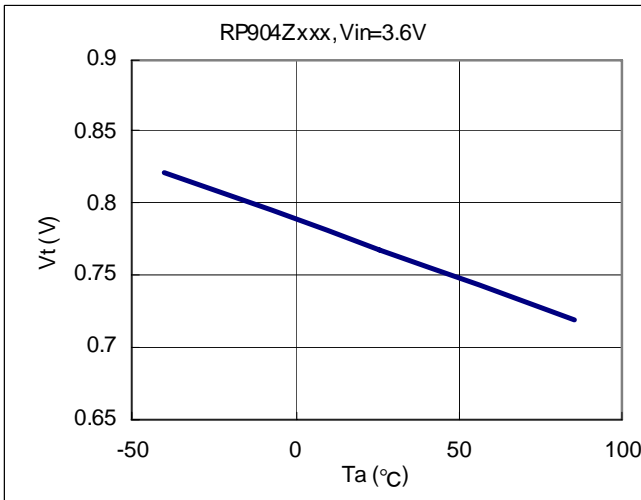
10) Protection Delay Time vs. Temperature



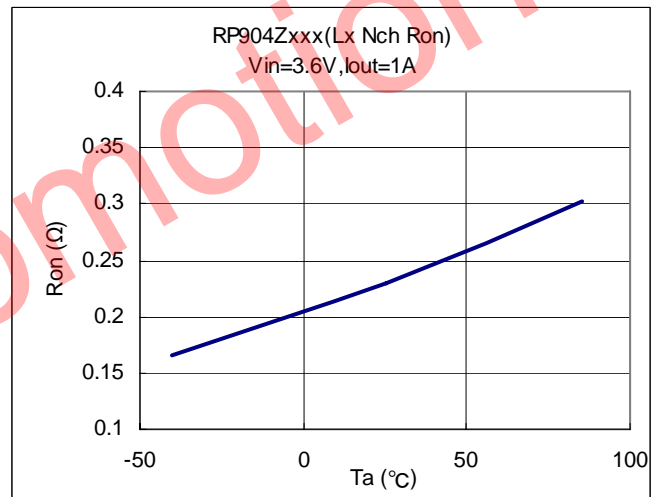
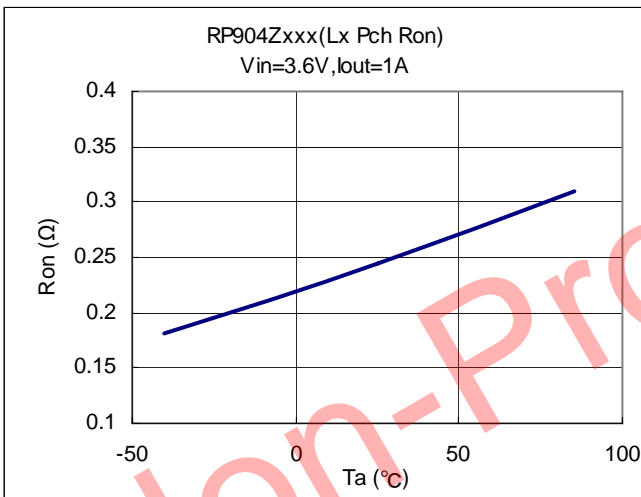
11) UVLO Detector Threshold / Released Voltage vs. Temperature



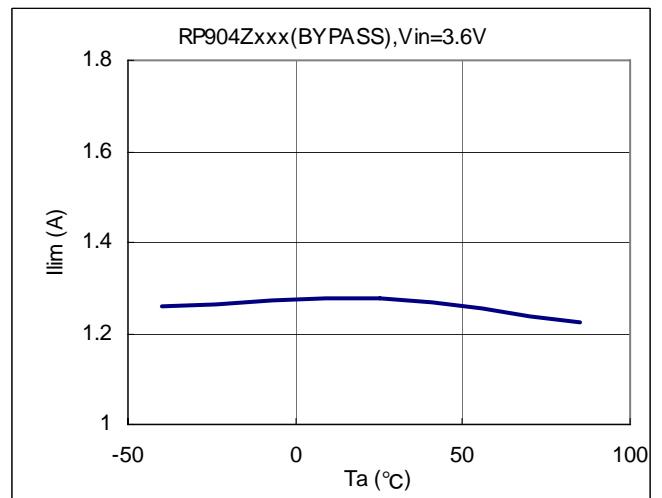
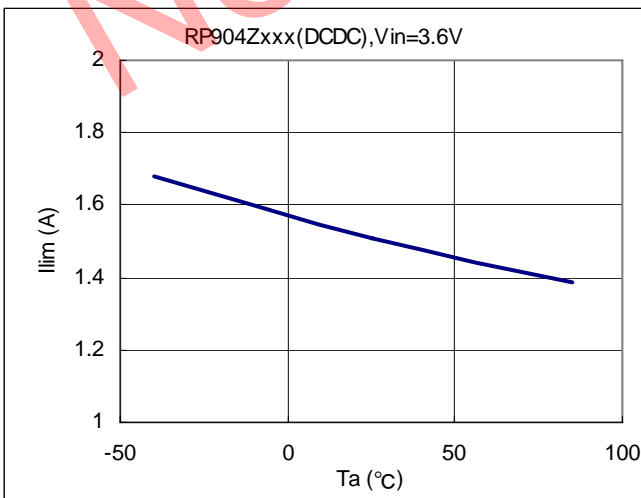
12) CE Input Threshold Voltage vs. Temperature



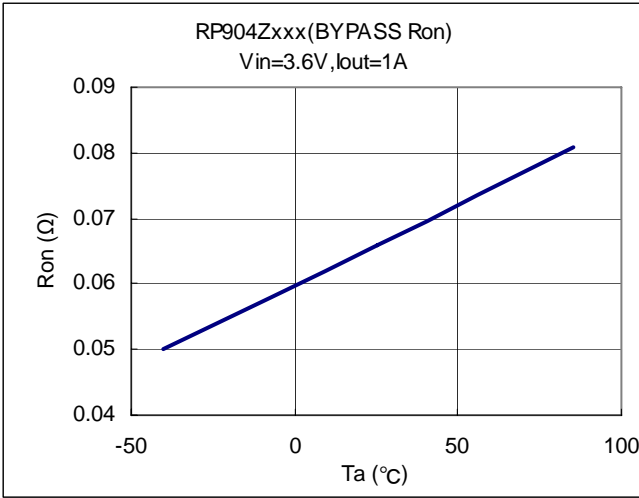
13) L<sub>x</sub> Transistor ON Resistance vs. Temperature



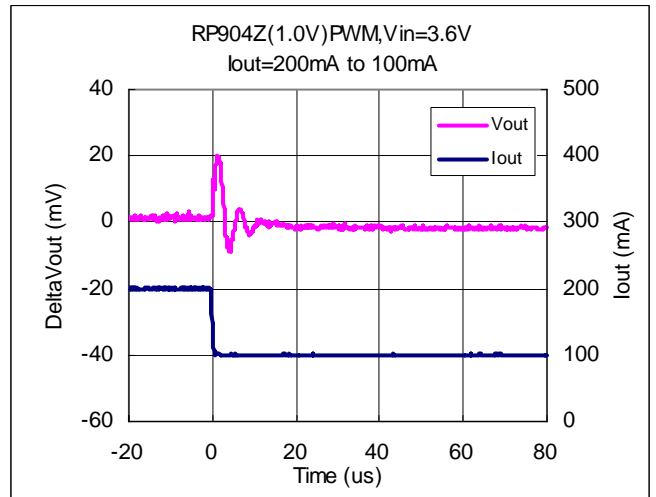
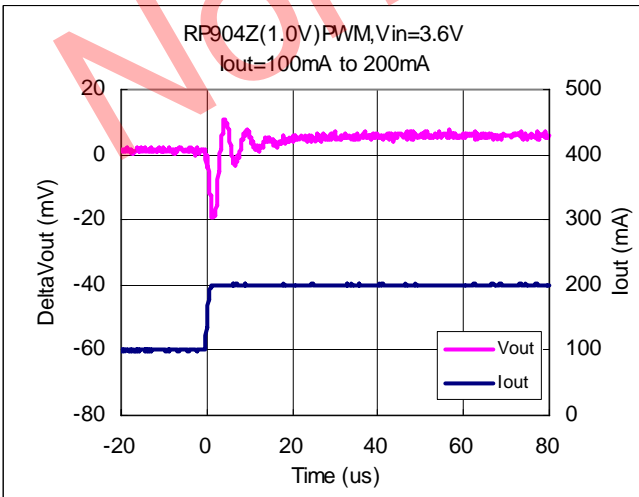
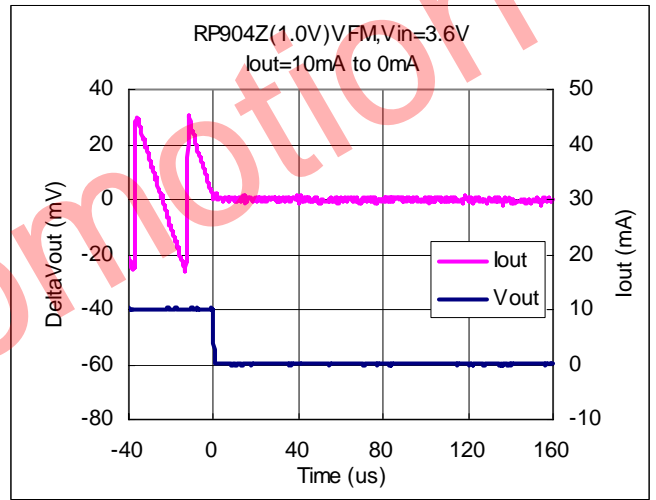
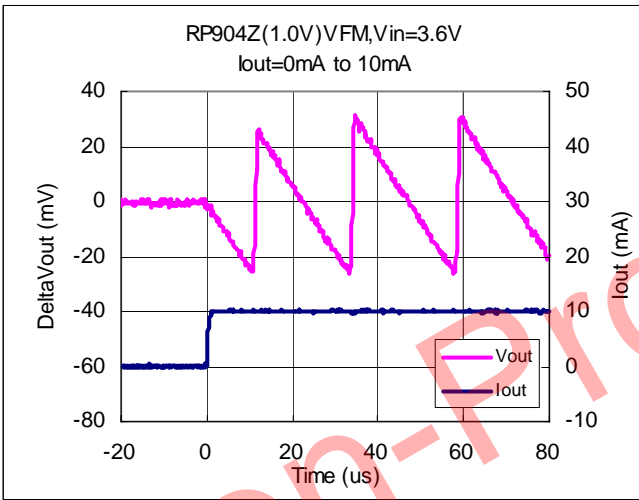
14) Current Limit vs. Temperature

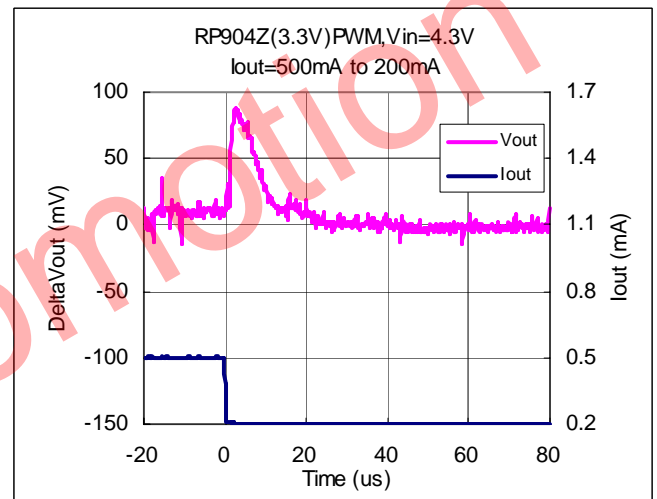
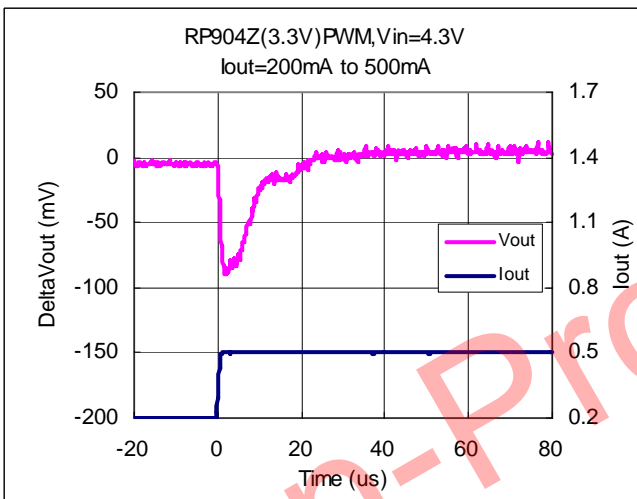
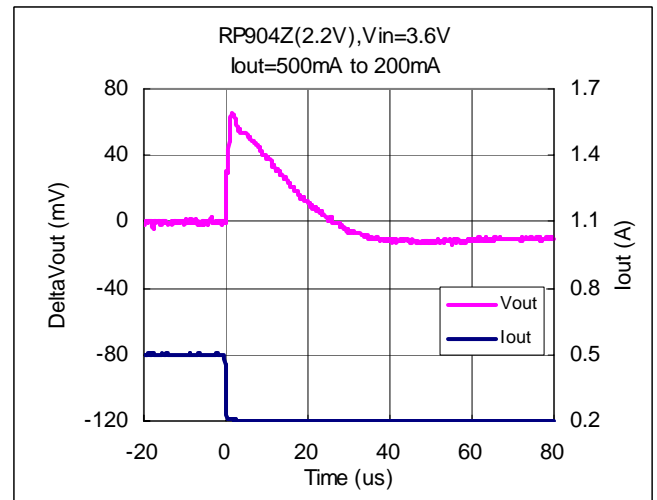
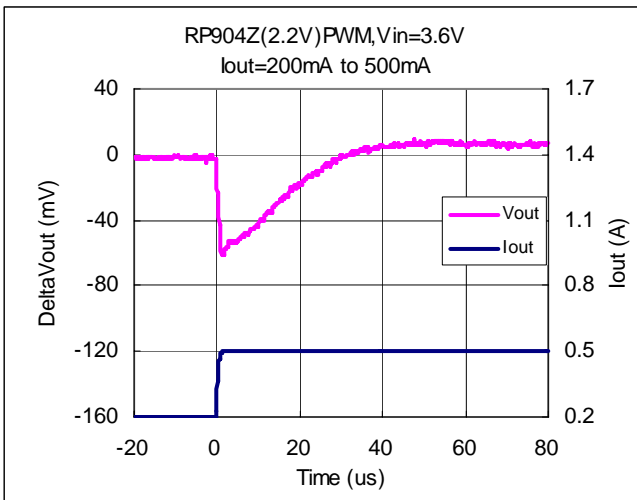


15) BYPASS Switch ON Resistance VS. Temperature

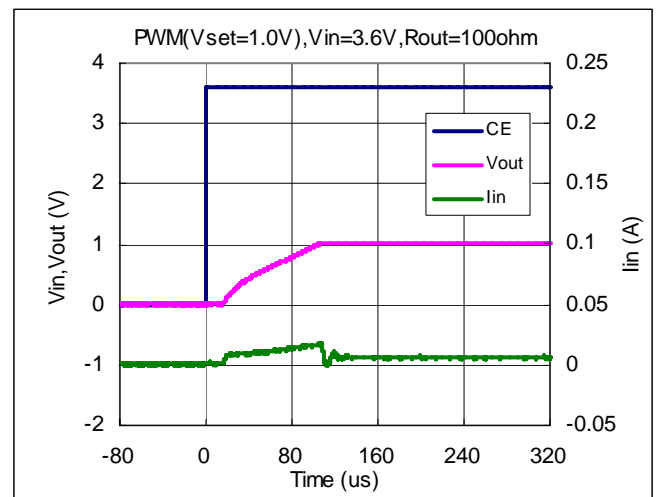
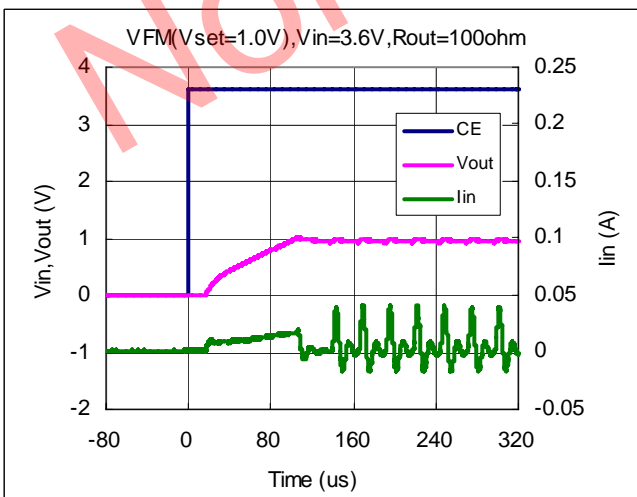


16) Load Transient Response



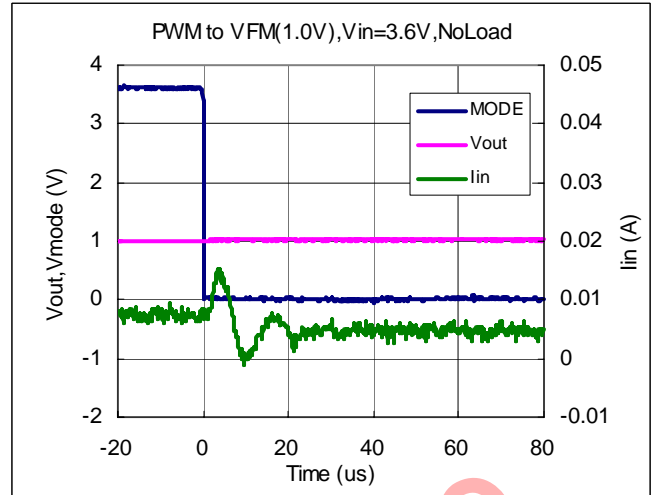
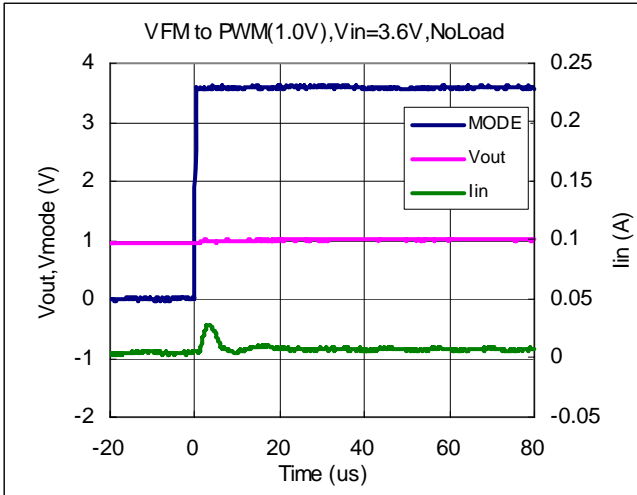


17) Start-Up Waveform

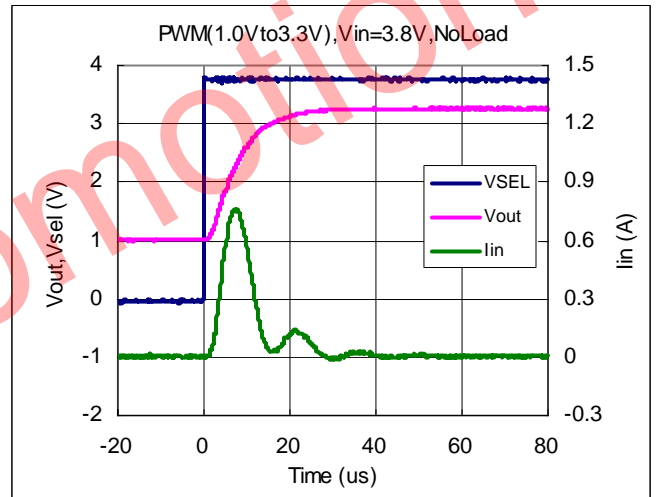
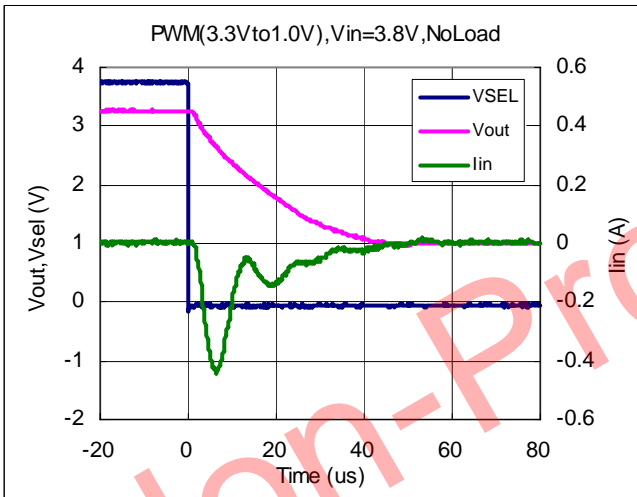


18) Transition Waveform

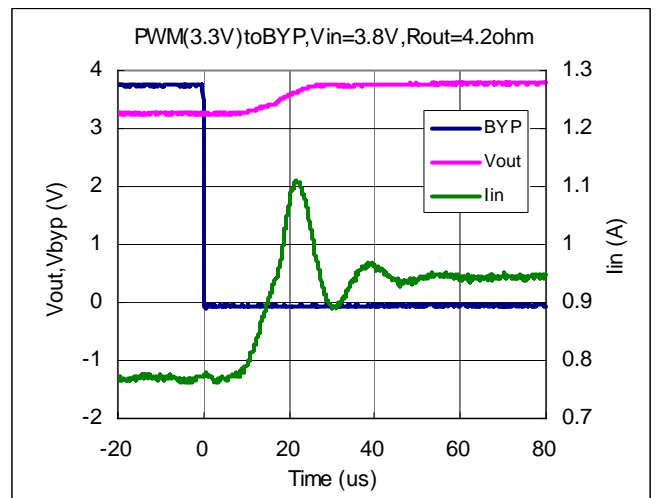
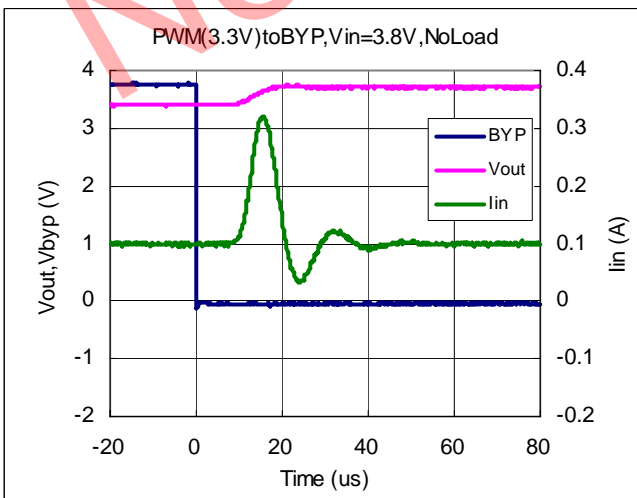
18-1 Transition between VFM-PWM2

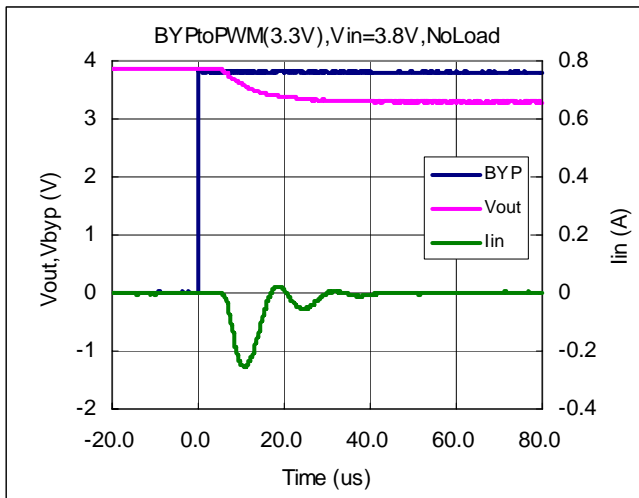


18-2 Transition between PWM1-PWM2

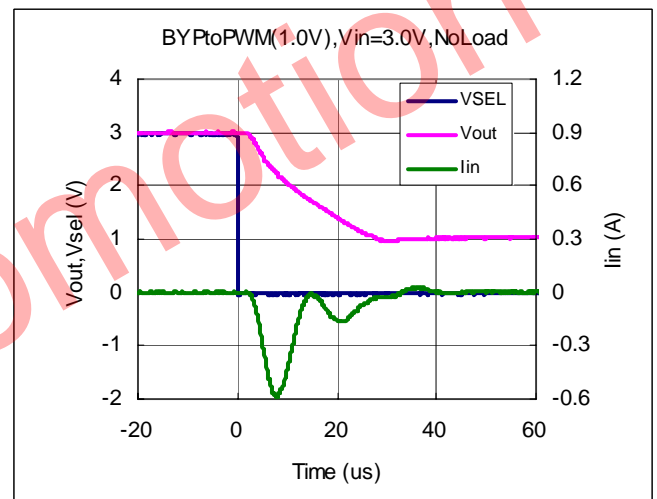
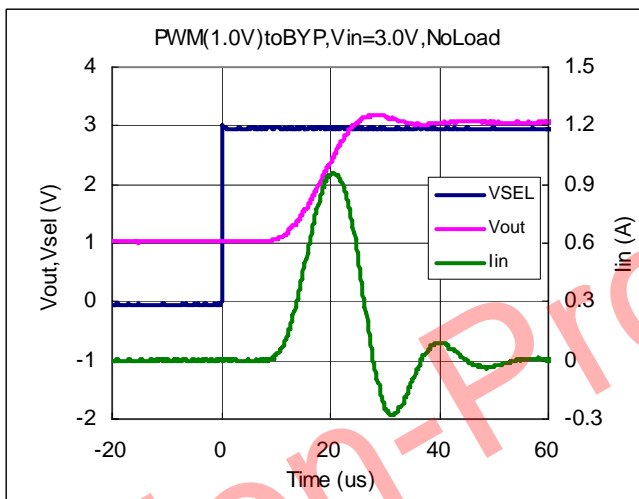


18-3 Transition between PWM1-BYPASS





18-4 Transition between PWM2-BYPASS



\*External Components for the measurement of typical characteristics

$C_{IN}$ : 10 $\mu$ F (C2012JB0J106K: TDK)

$C_{OUT}$ : 4.7 $\mu$ F (JMK107BJ475MA: Taiyo Yuden)

L: 2.2 $\mu$ H(CKP2520: Taiyo Yuden)



1. The products and the product specifications described in this document are subject to change or discontinuation of production without notice for reasons such as improvement. Therefore, before deciding to use the products, please refer to Ricoh sales representatives for the latest information thereon.
2. The materials in this document may not be copied or otherwise reproduced in whole or in part without prior written consent of Ricoh.
3. Please be sure to take any necessary formalities under relevant laws or regulations before exporting or otherwise taking out of your country the products or the technical information described herein.
4. The technical information described in this document shows typical characteristics of and example application circuits for the products. The release of such information is not to be construed as a warranty of or a grant of license under Ricoh's or any third party's intellectual property rights or any other rights.
5. The products listed in this document are intended and designed for use as general electronic components in standard applications (office equipment, telecommunication equipment, measuring instruments, consumer electronic products, amusement equipment etc.). Those customers intending to use a product in an application requiring extreme quality and reliability, for example, in a highly specific application where the failure or misoperation of the product could result in human injury or death (aircraft, spacevehicle, nuclear reactor control system, traffic control system, automotive and transportation equipment, combustion equipment, safety devices, life support system etc.) should first contact us.
6. We are making our continuous effort to improve the quality and reliability of our products, but semiconductor products are likely to fail with certain probability. In order to prevent any injury to persons or damages to property resulting from such failure, customers should be careful enough to incorporate safety measures in their design, such as redundancy feature, fire containment feature and fail-safe feature. We do not assume any liability or responsibility for any loss or damage arising from misuse or inappropriate use of the products.
7. Anti-radiation design is not implemented in the products described in this document.
8. Please contact Ricoh sales representatives should you have any questions or comments concerning the products or the technical information.



**Ricoh is committed to reducing the environmental loading materials in electrical devices with a view to contributing to the protection of human health and the environment.**

Ricoh has been providing RoHS compliant products since April 1, 2006 and Halogen-free products since April 1, 2012.

**RICOH** RICOH ELECTRONIC DEVICES CO., LTD.

<http://www.e-devices.ricoh.co.jp/en/>

#### Sales & Support Offices

##### **RICOH ELECTRONIC DEVICES CO., LTD.**

**Higashi-Shinagawa Office (International Sales)**  
3-32-3, Higashi-Shinagawa, Shinagawa-ku, Tokyo 140-8655, Japan  
Phone: +81-3-5479-2857 Fax: +81-3-5479-0502

##### **RICOH EUROPE (NETHERLANDS) B.V.**

**Semiconductor Support Centre**  
Prof. W.H. Keesomlaan 1, 1183 DJ Amstelveen, The Netherlands  
Phone: +31-20-5474-309

##### **RICOH ELECTRONIC DEVICES KOREA CO., LTD.**

3F, Haesung Bldg. 504, Teheran-ro, Gangnam-gu, Seoul, 135-725, Korea  
Phone: +82-2-2135-5700 Fax: +82-2-2051-5713

##### **RICOH ELECTRONIC DEVICES SHANGHAI CO., LTD.**

Room 403, No.2 Building, No.690 Bilbo Road, Pu Dong New District, Shanghai 201203,  
People's Republic of China  
Phone: +86-21-5027-3200 Fax: +86-21-5027-3299

##### **RICOH ELECTRONIC DEVICES CO., LTD.**

**Taipei office**  
Room 109, 10F-1, No.51, Hengyang Rd., Taipei City, Taiwan (R.O.C.)  
Phone: +886-2-2313-1621/1622 Fax: +886-2-2313-1623