## PWM STEP-DOWN DC/DC CONVERTER WITH SYNCHRONOUS RECTIFIER

NO.EA-129-130510

# OUTLINE

The R1232D Series are CMOS-based PWM step-down DC/DC converters with synchronous rectifier, low supply current. As an output capacitor, a 10μF or more ceramic capacitor can be used with the R1232D.

Each of these ICs consists of an oscillator, a PWM control circuit, a voltage reference unit, an error amplifier, a soft-start circuit, protection circuits, a protection against miss operation under low voltage (UVLO), a chip enable circuit, a synchronous rectifier, Nch. driver transistor, and so on. A low ripple, 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. (As for R1232D001x type, divider resistors are also necessary.) In terms of the output voltage, it is fixed internally in the R1232Dxx1x types. While in the R1232D001x types, the output voltage is adjustable with external divider resistors.

As protection circuits, current limit circuit which limits peak current of $L_X$ at each clock cycle, and latch type protection circuit exist. The latch protection works if the term of the over-current condition keeps on a certain time. Latch-type protection circuit works to latch an internal driver with keeping it disable. To release the condition of 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.

# FEATURES

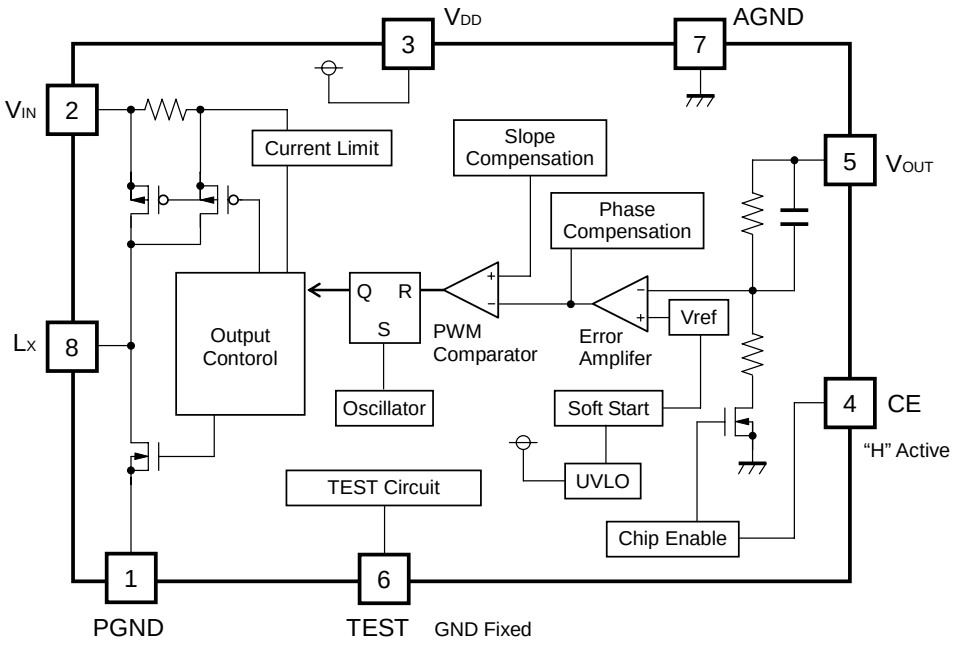
- Two choices of Oscillator Frequency ..... 1MHz, 2.25MHz
  (Small inductors can be used. 4.7μH for 1MHz/2.2μH for 2.25MHz)
- Built-in Driver ON Resistance ..... P-channel 0.2Ω (at $V_{IN}$=5.0V)
- Built-in Soft-start Function..... Typ. 1.0ms (fosc=1MHz type)
- Output Voltage ..... 0.9V to 3.3V (R1232Dxx1x Type)
  0.8V to $V_{IN}$ (R1232D001x Type)
- High Accuracy Output Voltage ..... ±2.0%
- Built-in Current Limit Circuit ..... Typ. 1.4A
- Package ..... SON-8 (t=0.9mm)

# APPLICATIONS

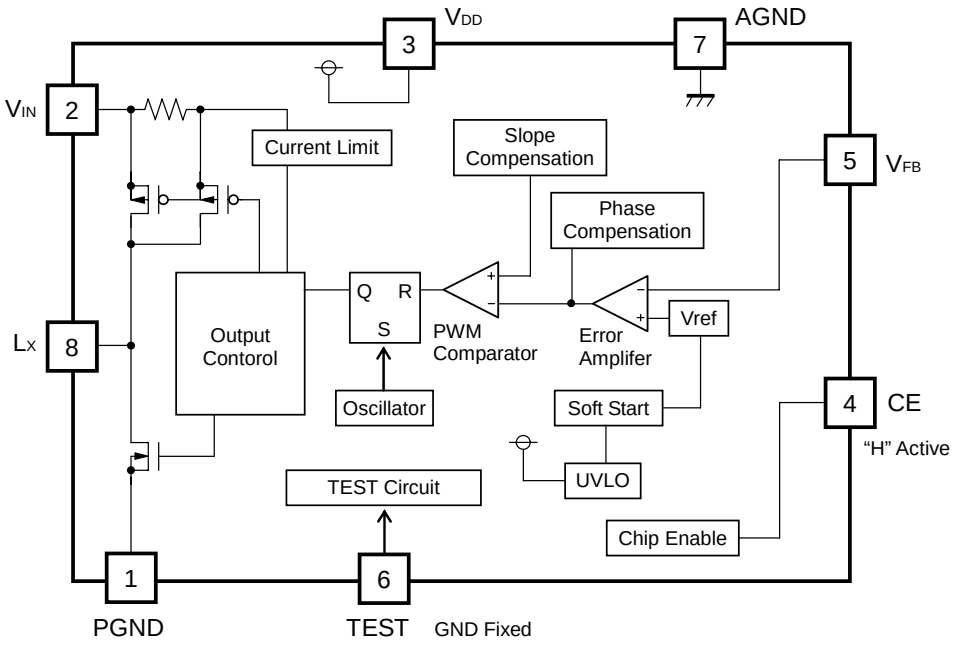
- Power source for portable equipment such as PDA, DSC, Notebook PC.
- Power source for HDD

# BLOCK DIAGRAMS

**R1232Dxx1A/B**




**R1232D001C/D**



# SELECTION GUIDE

In the R1232D Series, the output voltage, the oscillator frequency and the output voltage adjustment for the ICs can be selected at the user's request.

| Product Name | Package | Quantity per Reel | Pb Free | Halogen Free |
|---|---|---|---|---|
| R1232Dxx1∗-TR-FE | SON-8 | 3,000 pcs | Yes | Yes |

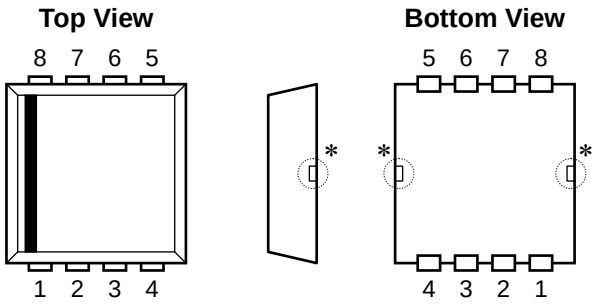
xx: The output voltage can be designated in the range from 0.9 V(09) to 3.3V(33) in 0.1V steps.
(For externally adjustable output voltage type, (00).)

∗ : The oscillator frequency and the output voltage adjustment are options as follows.

| Code | Oscillator frequency | Output voltage adjustment |
|---|---|---|
| A | 1MHz | No |
| B | 2.25MHz | No |
| C | 1MHz | Yes |
| D | 2.25MHz | Yes |

# PIN CONFIGURATION

**SON-8**




# PIN DESCRIPTIONS

| Pin No | Symbol | Pin Description |
|---|---|---|
| 1 | PGND | Ground Pin |
| 2 | $V_{IN}$ | Voltage Supply Pin |
| 3 | $V_{DD}$ | Voltage Supply Pin |
| 4 | CE | Chip Enable Pin (active with "H") |
| 5 | $V_{OUT}/V_{FB}$ | Output/Feedback Pin |
| 6 | TEST | Test Pin (Forced to the GND level.) |
| 7 | AGND | Ground Pin |
| 8 | $L_X$ | $L_X$ Switching Pin (CMOS Output) |

* Tab is GND level. (They are connected to the reverse side of this IC.) The tab is better to be connected to the GND, but leaving it open is also acceptable.

## ABSOLUTE MAXIMUM RATINGS

(AGND=PGND=0V)

| Symbol | Item | Rating | Unit |
|---|---|---|---|
| $V_{IN}$ | $V_{IN}$ Supply Voltage | −0.3 to 6.5 | V |
| $V_{DD}$ | $V_{DD}$ Pin Voltage | −0.3 to 6.5 | V |
| $V_{LX}$ | $L_X$ Pin Voltage | −0.3 to $V_{IN}$ + 0.3 | V |
| $V_{CE}$ | CE Pin Input Voltage | −0.3 to $V_{IN}$ + 0.3 | V |
| $V_{TEST}$ | TEST Pin Input Voltage | −0.3 to $V_{IN}$ + 0.3 | V |
| $V_{OUT}/V_{FB}$ | $V_{OUT}/V_{FB}$ Pin Input Voltage | −0.3 to $V_{IN}$ + 0.3 | V |
| $I_{LX}$ | $L_X$ Pin Output Current | ±1.5 | V |
| $P_D$ | Power Dissipation (SON-8)* | 480 | mW |
| Ta | Operating Temperature Range | −40 to 85 | °C |
| Tstg | 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

- **R1232DxxxA/C**

Ta=25°C

| Symbol | Item | Conditions | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Operating Input Voltage | | 2.6 | | 5.5 | V |
| $V_{OUT}$ | Step-down Output Voltage | $V_{IN}$=$V_{CE}$=5.0V, $I_{OUT}$=10mA | ×0.980 | | ×1.020 | V |
| $V_{FB}$ | Feedback Voltage | R1232D001C | 0.784 | 0.800 | 0.816 | V |
| $\Delta V_{OUT}/\Delta Ta$ | Step-down Output Voltage Temperature Coefficient | −40°C ≦ Ta ≦ 85°C | | ±150 | | ppm/°C |
| fosc | Oscillator Frequency | $V_{IN}$=$V_{CE}$ =$V_{SET}$ +1.5V | 0.75 | 1.00 | 1.25 | MHz |
| $I_{DD}$ | Supply Current | $V_{IN}$=$V_{CE}$ =5.5V, $V_{OUT(VFB)}$=5.5V | 70 | 140 | 190 | μA |
| Istandby | Standby Current | $V_{CE}$=$V_{OUT(VFB)}$=0V, $V_{IN}$= 5.5V | | 0.0 | 5.0 | μA |
| $I_{LXleak}$ | Lx Leakage Current | $V_{IN}$=5.5V,$V_{CE}$=0V $V_{LX}$=5.5V or 0V | −5.0 | 0.0 | 5.0 | μA |
| $R_{ONP}$ | ON Resistance of Pch Transistor | $V_{IN}$=5.0V, $I_{LX}$=200mA | | 0.20 | 0.35 | Ω |
| $R_{ONN}$ | ON Resistance of Nch Transistor | $V_{IN}$=5.0V, $I_{LX}$=200mA | | 0.20 | 0.35 | Ω |
| Maxduty | Oscillator Maximum Duty Cycle | | 100 | | | % |
| tstart | Soft-start Time | $V_{IN}$=$V_{CE}$ =5.0V, at no load | 0.5 | 1.0 | 1.4 | ms |
| tprot | Protection Delay Time | $V_{IN}$=$V_{CE}$ =5.0V | 0.1 | 2.0 | 10.0 | ms |
| $I_{LX}$limit | Lx Current Limit | $V_{IN}$=$V_{CE}$ =5.0V | 1.0 | 1.4 | | A |
| $V_{UVLO1}$ | UVLO Detector Threshold | $V_{IN}$=$V_{CE}$ =2.6V-> 1.5V | 2.10 | 2.25 | 2.40 | V |
| $V_{UVLO2}$ | UVLO Released Voltage | $V_{IN}$=$V_{CE}$ =1.5V-> 2.6V | 2.20 | $V_{UVLO1}$ +0.10 | 2.50 | V |
| $I_{CE}$ | CE Input Current | $V_{IN}$=5.5V, $V_{CE}$ =5.5V or 0V | −0.1 | 0.0 | 0.1 | μA |
| $I_{VOUT}$ ($I_{VFB}$) | $V_{OUT}$/$I_{VFB}$ Leakage Current | $V_{IN}$=5.5V, $V_{CE}$ =0V, $V_{OUT}$($I_{VFB}$)=5.5V or 0V | −0.1 | 0.0 | 0.1 | μA |
| $V_{CEH}$ | CE "H" Input Voltage | $V_{IN}$=5.5V | 1.5 | | | V |
| $V_{CEL}$ | CE "L" Input Voltage | $V_{IN}$=3.0V | | | 0.3 | V |

**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. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

- **R1232DxxxB/D**

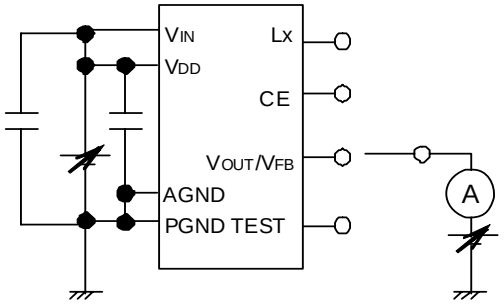
Ta=25°C

| Symbol | Item | Conditions | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Operating Input Voltage | | 2.6 | | 5.5 | V |
| $V_{OUT}$ | Step-down Output Voltage | $V_{IN}$=$V_{CE}$=5.0V,$I_{OUT}$=10mA | ×0.980 | | ×1.020 | V |
| $V_{FB}$ | Feedback Voltage | R1232D001D | 0.784 | 0.800 | 0.816 | V |
| $\Delta V_{OUT}/\Delta Ta$ | Step-down Output Voltage Temperature Coefficient | −40°C ≦ Ta ≦ 85°C | | ±150 | | ppm/°C |
| fosc | Oscillator Frequency | $V_{IN}$=$V_{CE}$=$V_{SET}$+1.5V | 1.91 | 2.25 | 2.58 | MHz |
| $I_{DD}$ | Supply Current | $V_{IN}$=$V_{CE}$ =5.5V, $V_{OUT(VFB)}$=5.5V | 170 | 240 | 310 | μA |
| Istandby | Standby Current | $V_{CE}$=$V_{OUT(VFB)}$=0V, $V_{IN}$= 5.5V | | 0.0 | 5.0 | μA |
| $I_{LXleak}$ | $L_X$ Leakage Current | $V_{IN}$=5.5V, $V_{CE}$=0V, $V_{LX}$=5.5V or 0V | −5.0 | 0.0 | 5.0 | μA |
| $R_{ONP}$ | ON Resistance of Pch Transistor | $V_{IN}$=5.0V, $I_{LX}$=200mA | | 0.20 | 0.35 | Ω |
| $R_{ONN}$ | ON Resistance of Nch Transistor | $V_{IN}$=5.0V, $I_{LX}$=200mA | | 0.20 | 0.35 | Ω |
| Maxduty | Oscillator Maximum Duty Cycle | | 100 | | | % |
| tstart | Soft-start Time | $V_{IN}$=$V_{CE}$=5.0V, at no load | 0.15 | 0.4 | 0.7 | ms |
| tprot | Protection Delay Time | $V_{IN}$=$V_{CE}$=5.0V | 0.1 | 2.0 | 10.0 | ms |
| $I_{LX}$limit | $L_X$ Current Limit | $V_{IN}$=$V_{CE}$=5.0V | 1.0 | 1.4 | | A |
| $V_{UVLO1}$ | UVLO Detector Threshold | $V_{IN}$=$V_{CE}$=2.6V -> 1.5V | 2.10 | 2.25 | 2.40 | V |
| $V_{UVLO2}$ | UVLO Released Voltage | $V_{IN}$=$V_{CE}$ =1.5V -> 2.6V | 2.20 | $V_{UVLO1}$ +0.10 | 2.50 | V |
| $I_{CE}$ | CE Input Current | $V_{IN}$=5.5V, $V_{CE}$ =5.5V/0V | −0.1 | 0.0 | 0.1 | μA |
| $I_{VOUT}$ ($I_{VFB}$) | $V_{OUT}$/$I_{VFB}$ Leakage Current | $V_{IN}$=5.5V, $V_{CE}$ =0V, $V_{OUT}$($I_{VFB}$)=5.5V or 0V | −0.1 | 0.0 | 0.1 | μA |
| $V_{CEH}$ | CE "H" Input Voltage | $V_{IN}$=5.5V | 1.5 | | | V |
| $V_{CEL}$ | CE "L" Input Voltage | $V_{IN}$=3.0V | | | 0.3 | V |

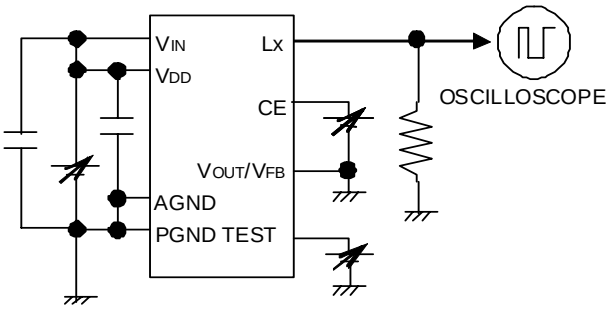
**RECOMMENDED OPERATING CONDITIONS (ELECTRICAL CHARACTERISTICS)**

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. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

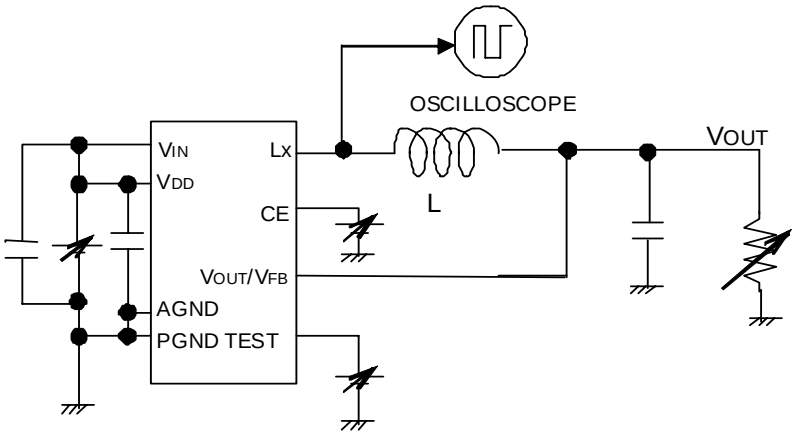
# TEST CIRCUIT



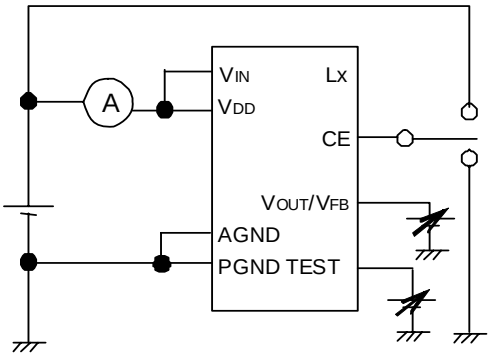

**Test Circuit for Input Current and Leakage Current**



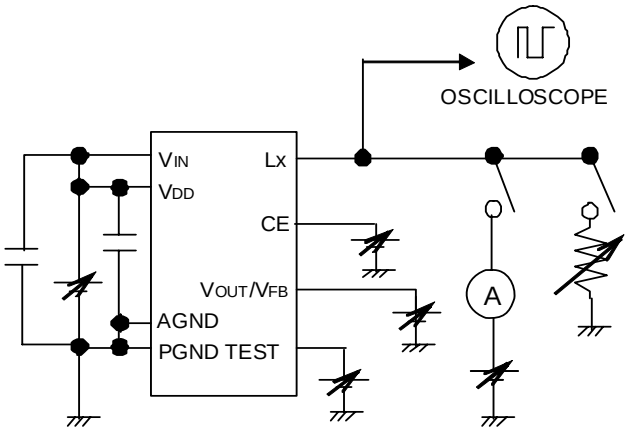

**Test Circuit for Input Voltage and UVLO voltage**




**Test Circuit for Output Voltage, Oscillator Frequency, Soft-Starting Time**



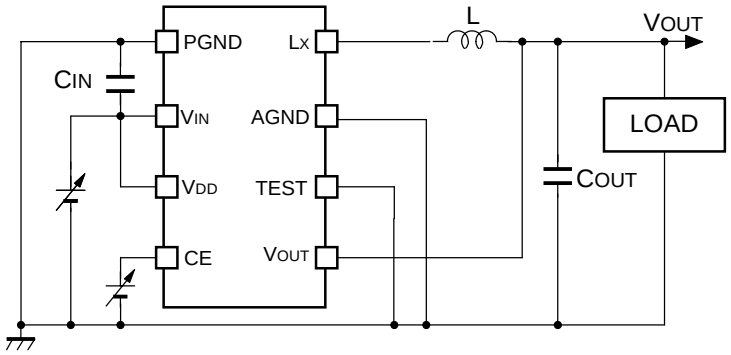

**Test Circuit for Supply Current and Standby Current**



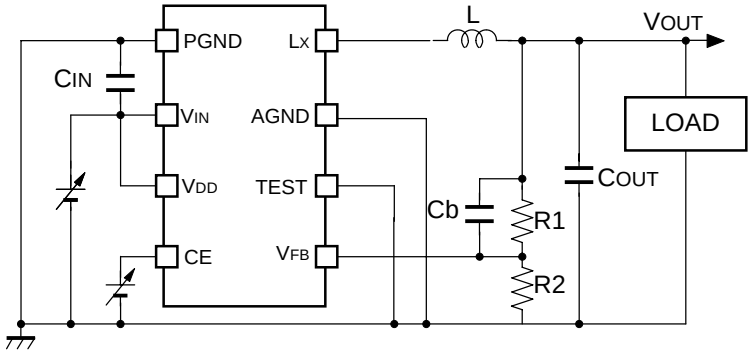

**Test Circuit for ON resistance of $L_X$, Limit Current, Delay Time of Protection Circuit**

# TYPICAL APPLICATION AND TECHNICAL NOTES

- **Fixed Output Voltage Type**




- **Adjustable Output Type**




| | |
|---|---|
| $C_{IN}$ | 10μF C2012JB0J106MT (TDK), 10μF CM21B106M06AB (Kyocera) |
| $C_{OUT}$ | 10μF C2012JB0J106MT (TDK), 10μF CM21B106M06AB (Kyocera) |
| L | 4.7μH/2.7μH VLP5610-4R7MR90, VLP5610-2R7M1R0 (TDK)<br>*2.2μH is also suitable for B/D version. |

In terms of setting R1, R2, Cb, refer to the technical notes.

When you use these ICs, consider the following issues;

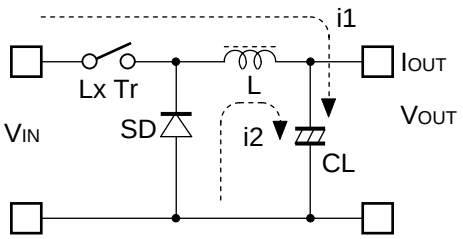
- Input the same voltage into power supply pins, $V_{IN}$ and $V_{DD}$. Set the same level as AGND and PGND.
- When you control the CE pin by another power supply, do not make its "H" level more than the voltage level of $V_{IN}$ / $V_{DD}$ pin.
- Set external components such as an inductor, $C_{IN}$, $C_{OUT}$ as close as possible to the IC, in particular, minimize the wiring to $V_{IN}$ pin and PGND pin.
- At stand by mode, (CE="L"), the LX output is Hi-Z, or both P-channel transistor and N-channel transistor of $L_X$ pin turn off.
- Set the "Test pin" to the GND. Do not make the test pin voltage as floating or other voltage.
- Reinforce the $V_{IN}$, PGND, and $V_{OUT}$ lines sufficiently. Large switching current may flow in these lines. If the impedance of $V_{IN}$ and PGND lines is too large, the internal voltage level in this IC may shift caused by the switching current, and the operation might be unstable.
- Over current protection circuit supervises the inductor peak current (the current flowing Pch transistor) at all each switching cycle, and if the current beyond the Lx current limit, Pch transistor is turned off. 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%, Pch transistor is latched in the OFF state and the operation of DC/DC converter stops.

The performance of power source circuits using these ICs extremely depends upon the peripheral circuits. Pay attention in the selection of the peripheral circuits. In particular, design the peripheral circuits in a way that the values such as voltage, current, and power of each component, PCB patterns and the IC do not exceed their respected rated values.

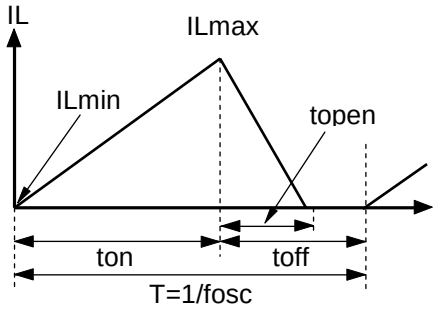
# OPERATION of step-down DC/DC converter and Output Current

The step-down DC/DC converter charges energy in the inductor when $L_X$ transistor is ON, and discharges the energy from the inductor when $L_X$ 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:

**<Basic Circuits>**




**<Current through L>**




Step 1: P-channel Tr. turns on and current IL (=i1) flows, and energy is charged into $C_L$. At this moment, IL increases from Ilmin (=0) to reach ILmax in proportion to the on-time period (ton) of P-channel Tr.

Step 2: When P-channel Tr. turns off, Synchronous rectifier N-channel Tr. turns on in order that L maintains IL at ILmax, and current IL (=i2) flows.

Step 3: IL (=i2) decreases gradually and reaches IL=ILmin=0 after a time period of topen, and N-channel Tr. Turns off. Provided that in the continuous mode, next cycle starts before IL becomes to 0 because toff time is not enough. In this case, IL value increases from this Ilmin (>0).

In the case of PWM control system, the output voltage is maintained by controlling the on-time period (ton), with the oscillator frequency (fosc) being maintained constant.

- **Continuous Conduction Mode**

The maximum value (ILmax) and the minimum value (ILmin) of the current flowing through the inductor are the same as those when P-channel Tr. turns on and off.

The difference between ILmax and ILmin, which is represented by ΔI;

$$\Delta I = ILmax - ILmin = V_{OUT} \times topen/L = (V_{IN} - V_{OUT}) \times ton/L \quad \text{..... Equation 1}$$

Where, $t = 1/fosc = ton + toff$

$duty\ (\%) = ton/t \times 100 = ton \times fosc \times 100$

$topen \leqq toff$

In Equation 1, $V_{OUT} \times topen/L$ and $(V_{IN} - V_{OUT}) \times ton/L$ are respectively shown the change of the current at ON, and the change of the current at OFF.

Even if the output current ($I_{OUT}$) is, topen < toff as illustrated in the above diagram is not realized with this IC. At least, topen is equal toff (topen=toff), and when $I_{OUT}$ is further increased, ILmin becomes larger than zero (ILmin>0). The mode is referred to as the continuous mode.

In the continuous mode, when Equation 1 is solved for ton and assumed that the solution is tonc

$$tonc = t \times V_{OUT} / V_{IN} \quad \text{Equation 2}$$

When the ton=tonc, the mode is the continuous mode.

# OUTPUT CURRENT AND SELECTION OF EXTERNAL COMPONENTS

When P-channel Tr. of $L_X$ is ON:

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

$$V_{IN} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times I_{RP} / ton \quad \text{Equation 3}$$

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

$$L \times I_{RP} / toff = V_F + V_{OUT} + R_{ONN} \times I_{OUT} \quad \text{Equation 4}$$

Put Equation 4 to Equation 3 and solve for ON duty of P-channel transistor, Don=ton/(toff+ton),

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

Ripple Current is as follows;

$$I_{RP} = (V_{IN} - V_{OUT} - R_{ONP} \times I_{OUT} - R_L \times I_{OUT}) \times D_{ON} / fosc / L \quad \text{Equation 6}$$

wherein, peak current that flows through L, and $L_X$ Tr. is as follows;

$$ILmax = I_{OUT} + I_{RP} / 2 \quad \text{Equation 7}$$

Consider ILmax, condition of input and output and select external components.

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

## How to Adjust Output Voltage and about Phase Compensation

As for Adjustable Output type, feedback pin ($V_{FB}$) voltage is controlled to maintain 0.8V.
Output Voltage, $V_{OUT}$ is as following equation;

$V_{OUT}$ R1+R2=$V_{FB}$:R2
$V_{OUT}=V_{FB}\times(R1+R2)/R2$

Thus, with changing the value of R1 and R2, output voltage can be set in the specified range.

In the DC/DC converter, with the load current and external components such as L and C, phase might be behind 180 degree. In this case, the phase margin of the system will be less and stability will be worse. To prevent this, phase margin should be secured with proceeding the phase. A pole is formed with external components L and $C_{OUT}$.

$$fpole \sim 1/2\pi\sqrt{LC_{OUT}}$$

A zero (signal back to zero) is formed with R1 and Cb.

$$\cong fzero \sim 1/(2p\times R1\times Cb)$$

First, choose the appropriate value of R1, R2 and Cb.
Set R1+R2 value 100kΩ or less.

For example, if L=4.7μH, $C_{OUT}$=10μF, the cut off frequency of the pole is approximately 23kHz.
To make the cut off frequency of the zero by R1, R2, and Cb be higher than 23kHz,
set R1=33kΩ and Cb=100pF.If $V_{OUT}$ is set at 2.0V, R2=22kΩ is appropriate.

# External Components

### 1.Inductor

Select an inductor that peak current does not exceed ILmax. If larger current than allowable current flows, magnetic saturation occurs and makes transform efficiency be worse.

Supposed that the load current is at the same, the smaller value of L is used, the larger the ripple current is.

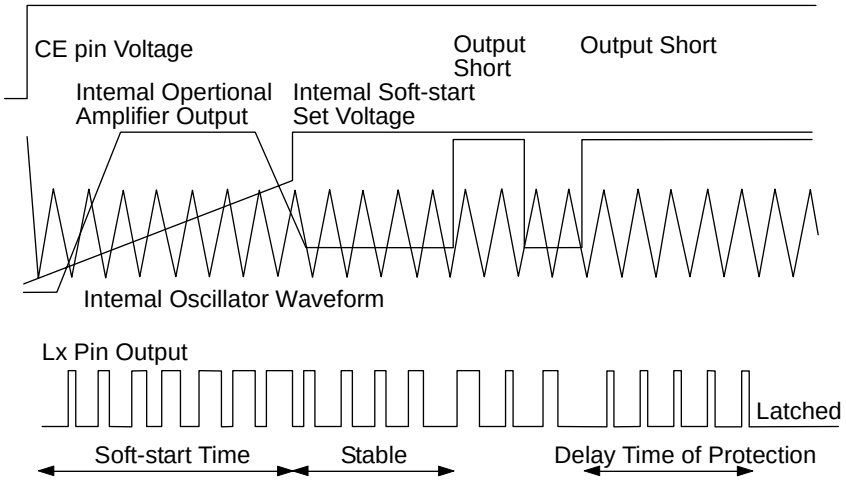
Provided that the allowable current is large in that case and DC current is small, therefore, for large output current, efficiency is better than using an inductor with a large value of L and vice versa.

### 2.Capacitor

As for $C_{IN}$, use a capacitor with low ESR (Equivalent Series Resistance) Ceramic type of a capacity at least 10μF for stable operation.

$C_{OUT}$ can reduce ripple of the output voltage, therefore as much as 10μF ceramic type is recommended.

# TIMING CHART




The timing chart as shown above describes the waveforms starting from the IC is enabled with CE and latched with protection. During the soft-start time, until the level is rising up to the internal soft-start set voltage, the duty cycle of $L_X$ is gradually wider and wider to prevent the over-shoot of the voltage. During the term, the output of amplifier is "H". After the output voltage reaches the set output voltage, they are balanced well. Herein, if the output pin would be short circuit, the output of amplifier would become "H" again, and the condition would continue for 2.0ms (Typ.), or the Lx limit current is exceeded even once when the driver operates by duty 100%, latch circuit would work and the output of $L_X$ would be latched with "OFF". (Output ="High-Z")

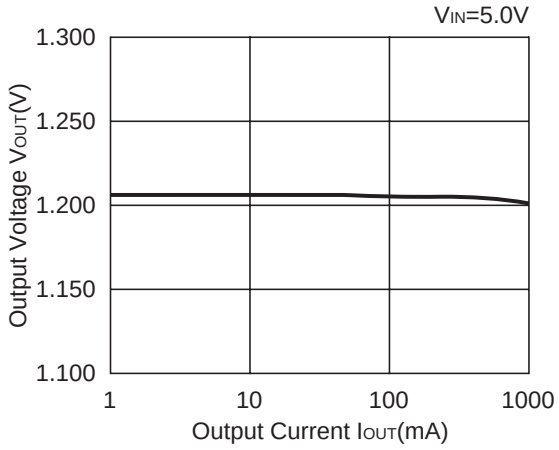
If the output short is released before the latch circuit works (within 2ms after output shorted), the output of amplifier is balanced in the stable state again.

Once the IC is latched, to release the protection, input "L" with CE pin, or make the supply voltage at UVLO level or less.

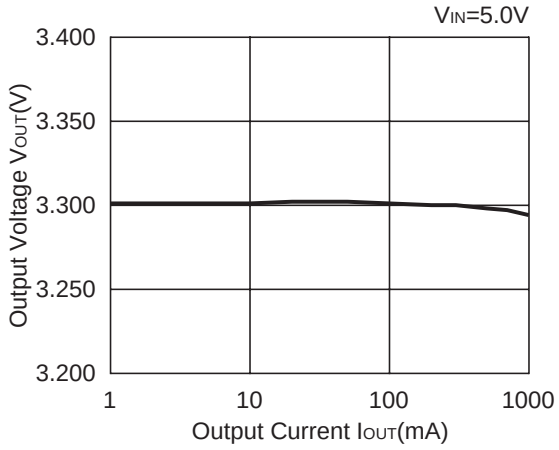
# TYPICAL CHARACTERISTICS

### 1) Output Voltage vs. Output Current ($C_{IN}$ = 10µF, $C_{OUT}$ = 10µF)

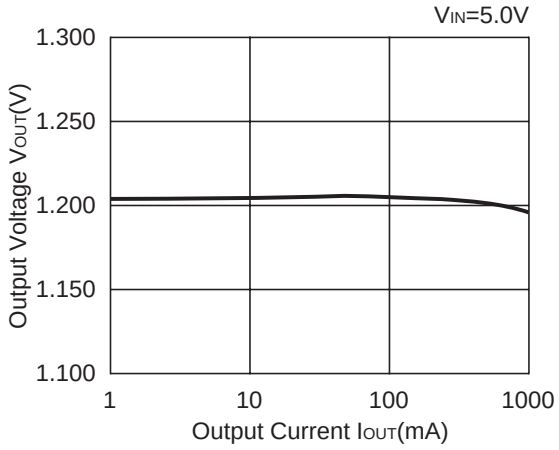
**R1232D121A**




**R1232D331A**




**R1232D121B**

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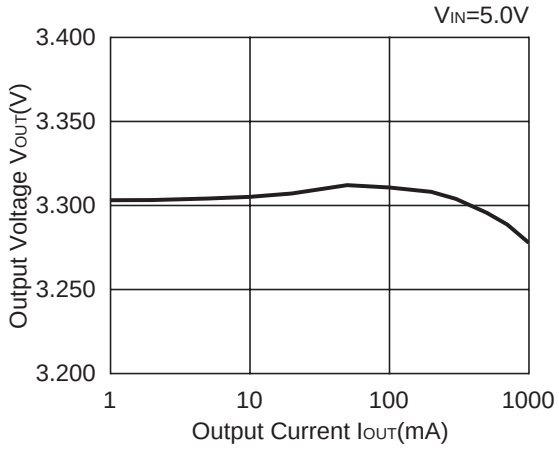
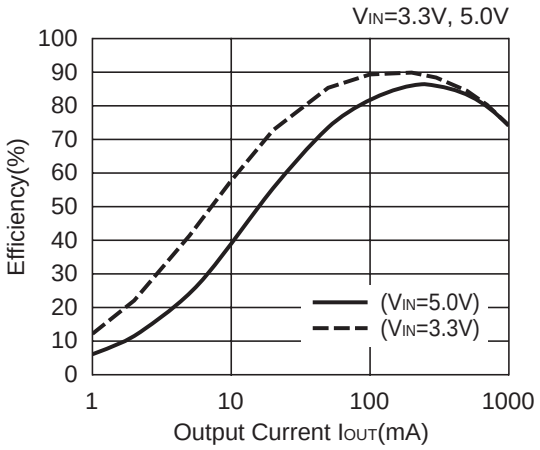



### 2) Efficiency vs. Output Current ($C_{IN}$ = 10µF, $C_{OUT}$ = 10µF)

**R1232D121A**

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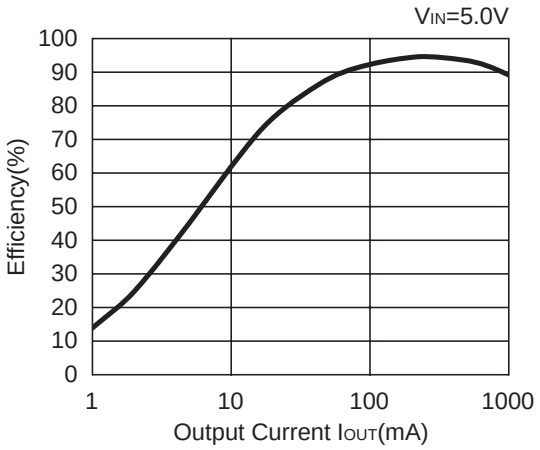

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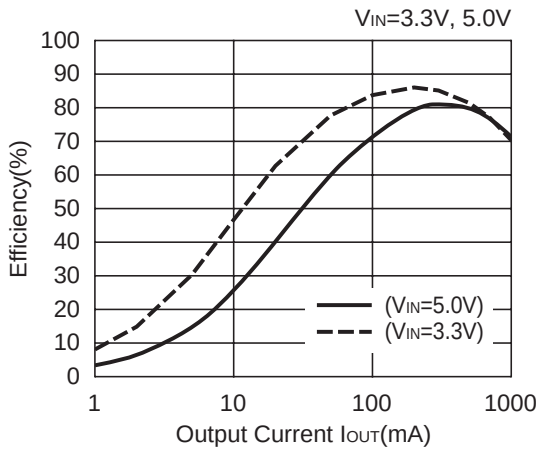


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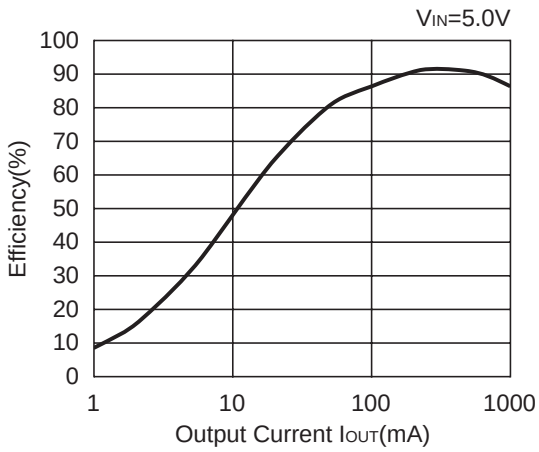
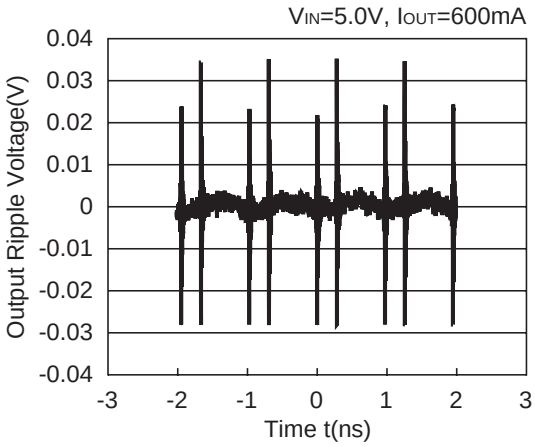



### 3) Output Waveform

**R1232D121A**

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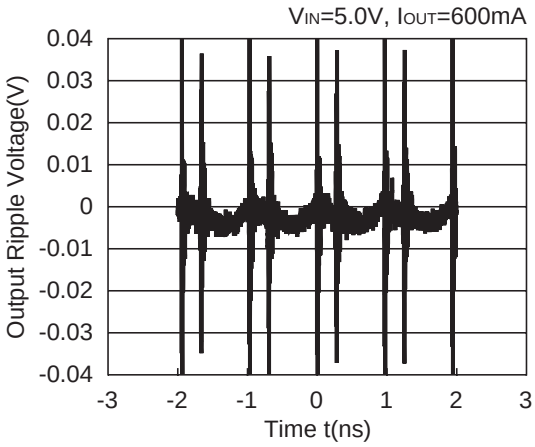
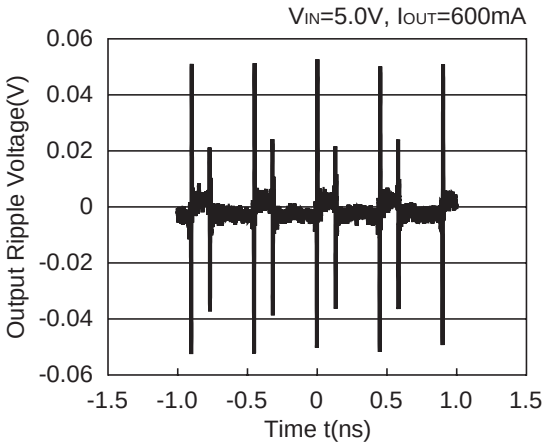



**R1232D121B**

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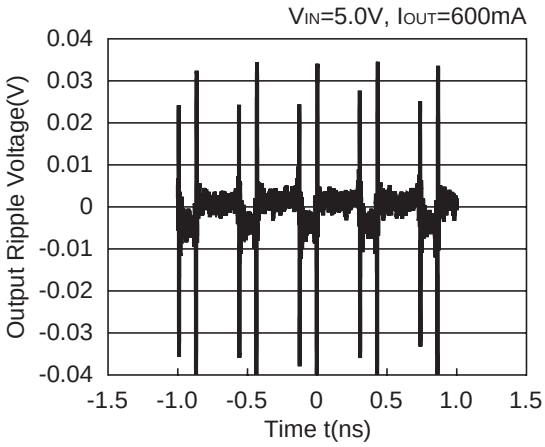
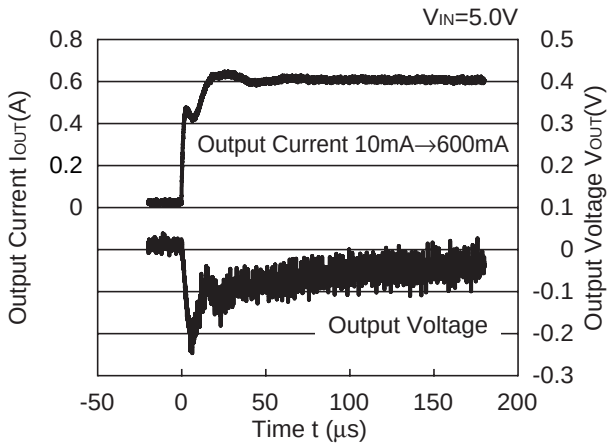


### 4) Load Transient Response

**R1232D121A**

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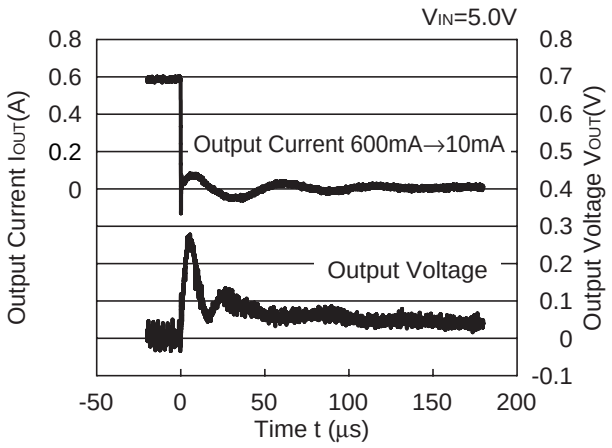


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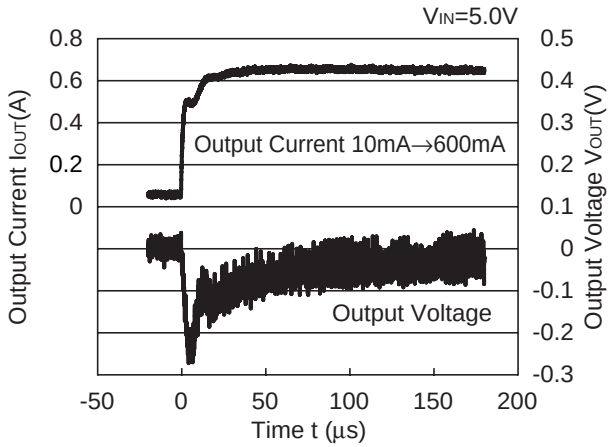


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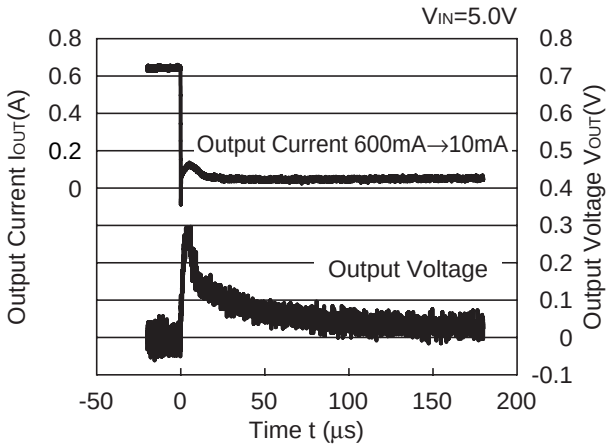
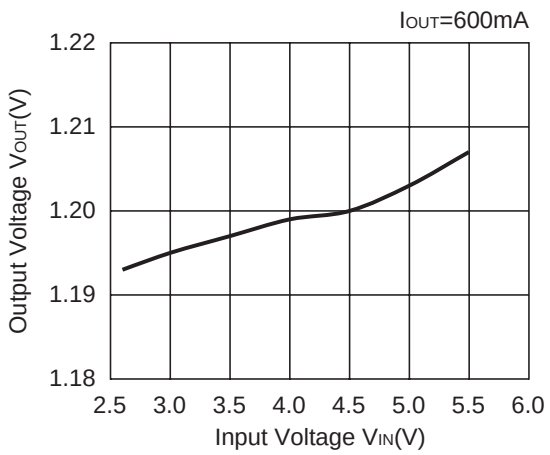



### 5) Output Voltage vs. Input Voltage

**R1232D121A**

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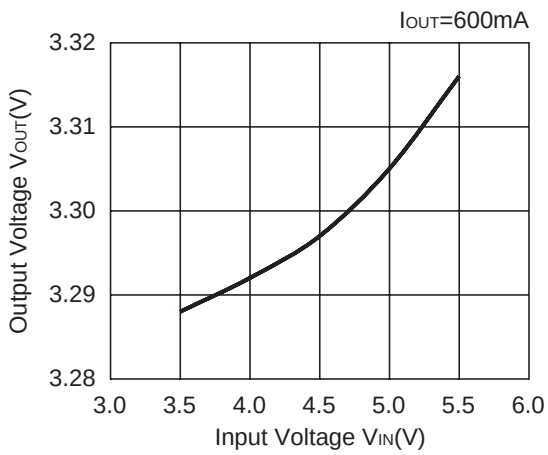
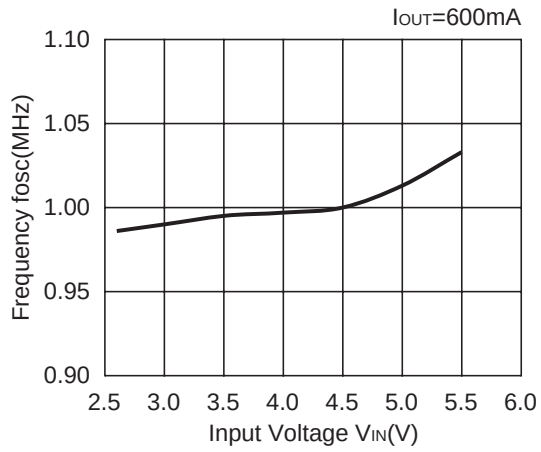


### 6) Oscillator Frequency vs. Input Voltage

**R1232D121A**

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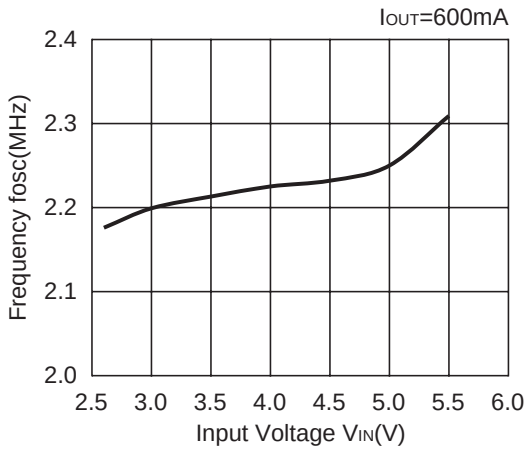
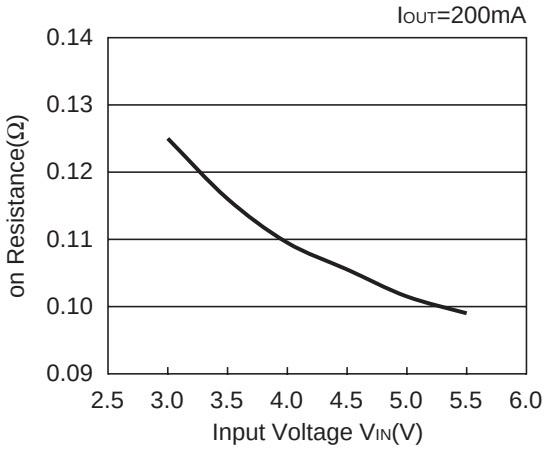
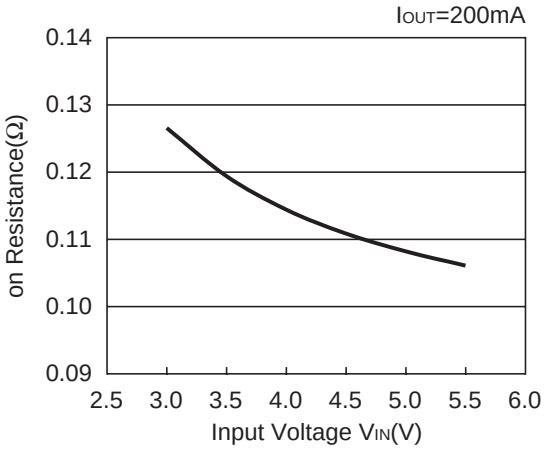



### 7) Lx Transistor On Resistance vs. Input Voltage

**Switching Tr. Pch on Resistance**

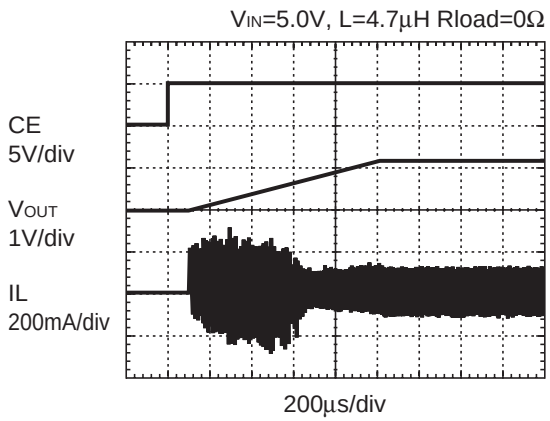



**Synchronous Rectifier Tr. Nch on Resistance**




### 8) Turn-on speed by CE pin

**R1232D121A**

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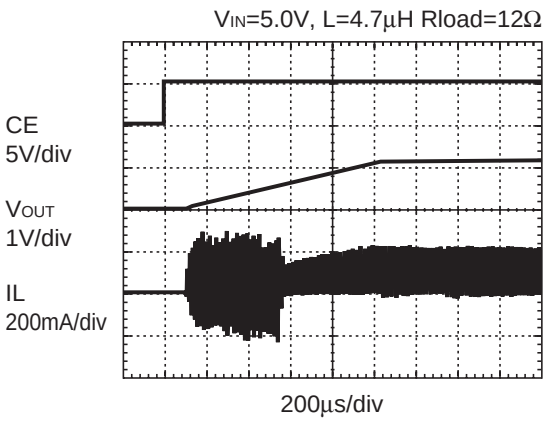

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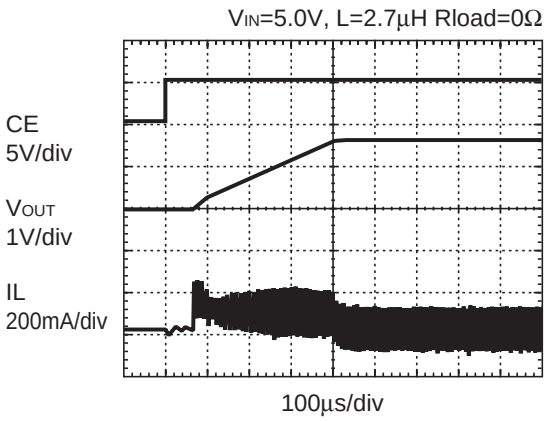


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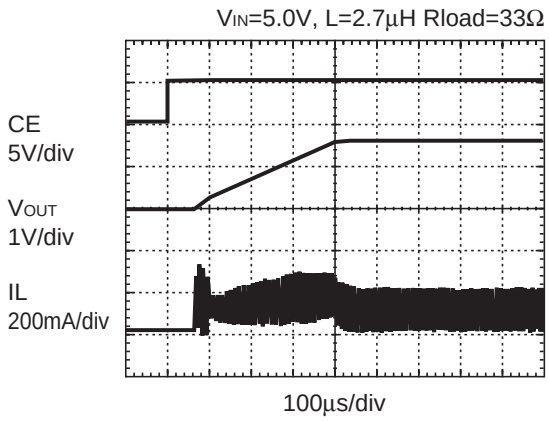
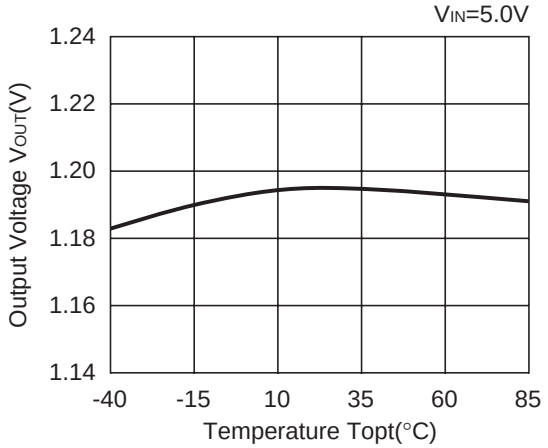
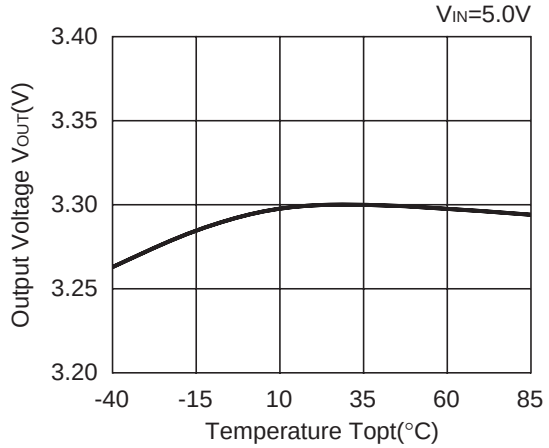



## 9) Output Voltage vs. Temperature

**R1232D121A**

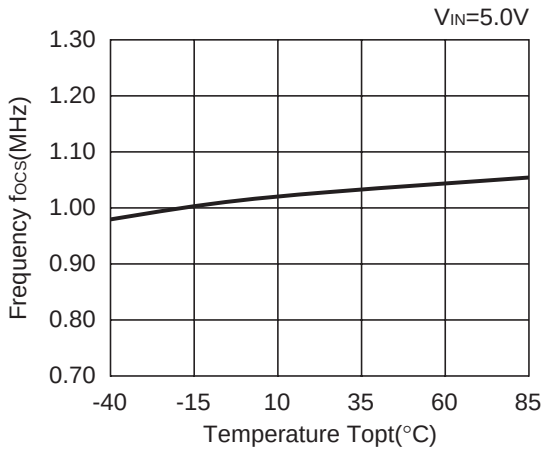



**R1232D331A**

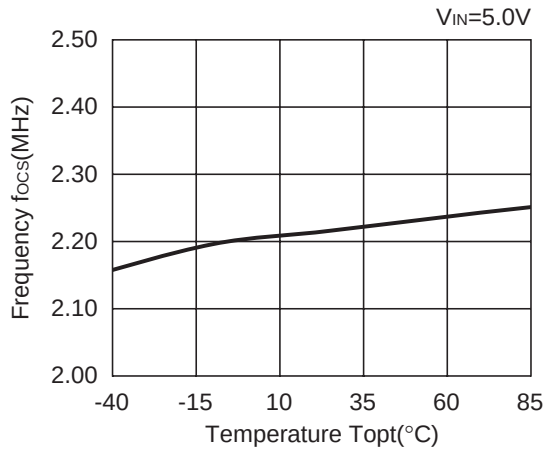



## 10) Oscillator Frequency vs. Temperature

**R1232D121A**

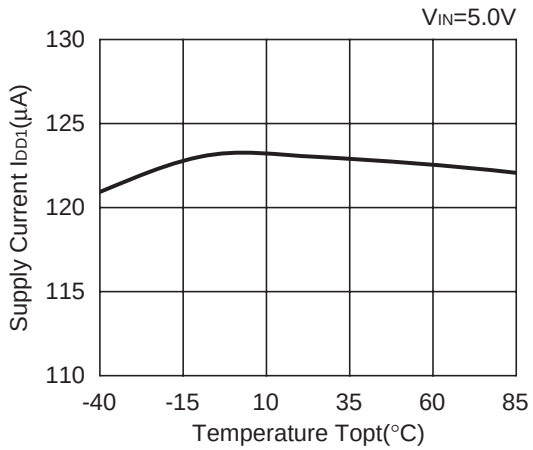



**R1232D331B**



### 11) Supply Current vs. Temperature

**R1232D121A**

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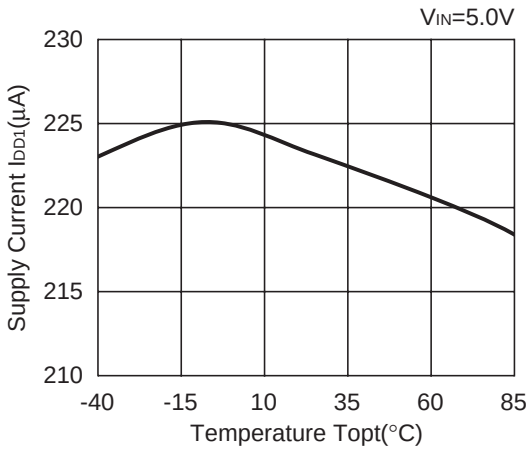
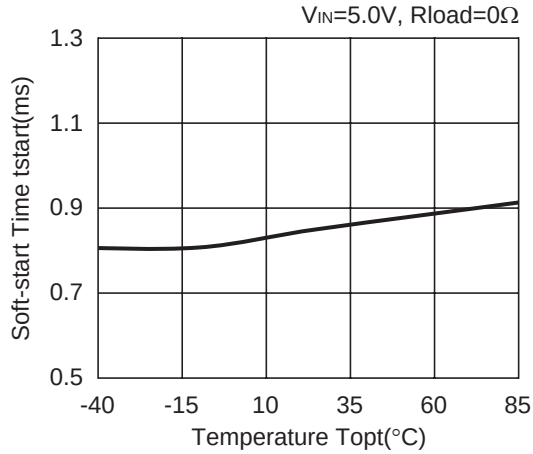
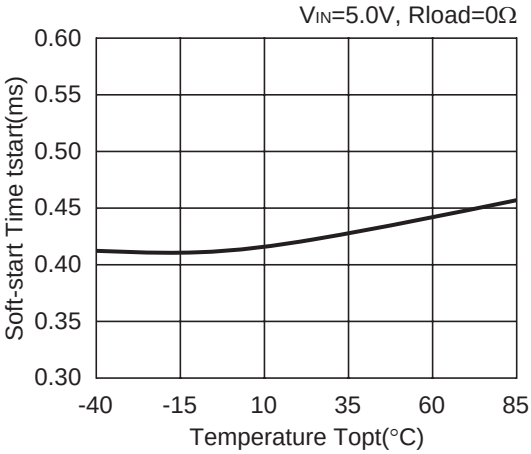



### 12) Soft-start time vs. Temperature

**R1232D121A**

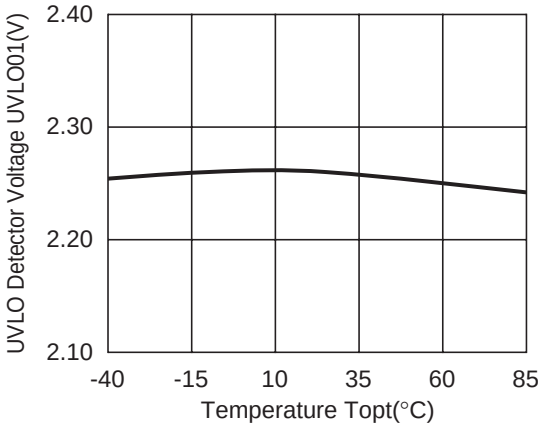



**R1232D331B**

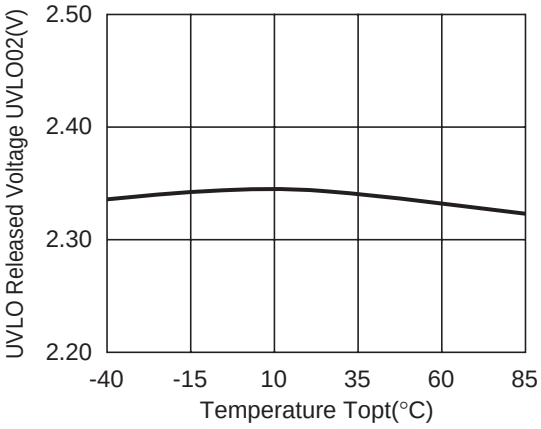



### 13) UVLO Voltage vs. Temperature

**R1232D121A**

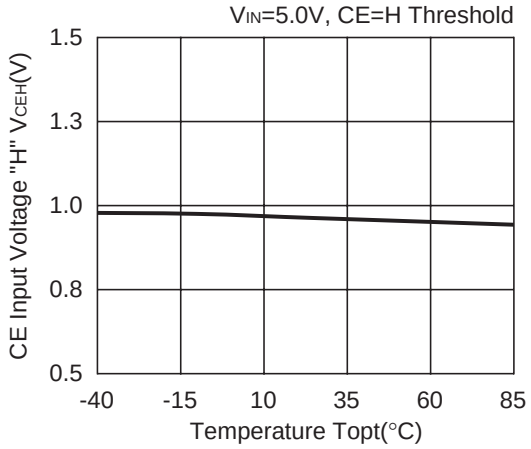



**R1232D121A**

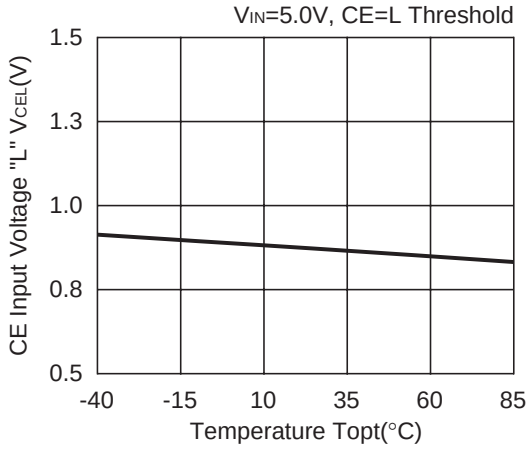


### 14) CE Input Voltage vs. Temperature

**R1232D121A**

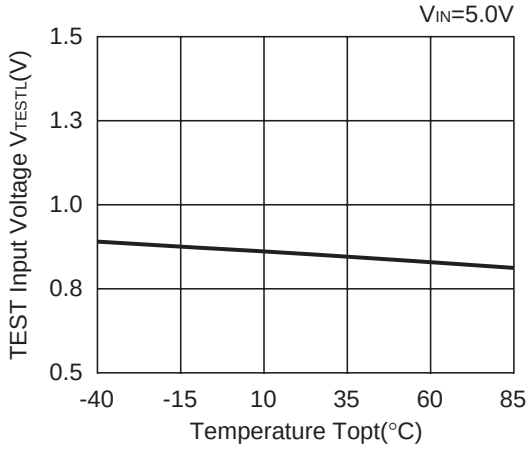



**R1232D121A**



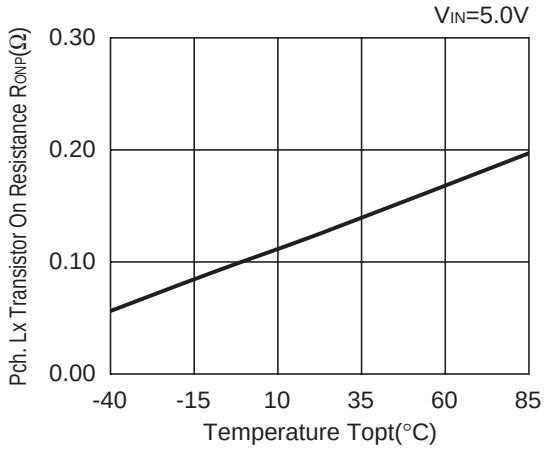

### 15) TEST Input Voltage vs. Temperature

**R1232D121A**

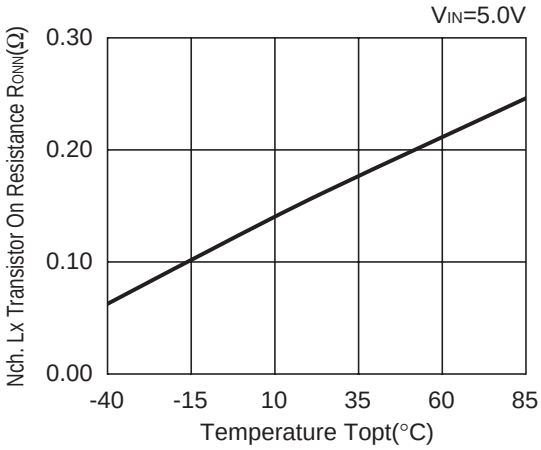



### 16) Lx Transistor On Resistance vs. Temperature

**Driver Tr. Pch ON Resistance**

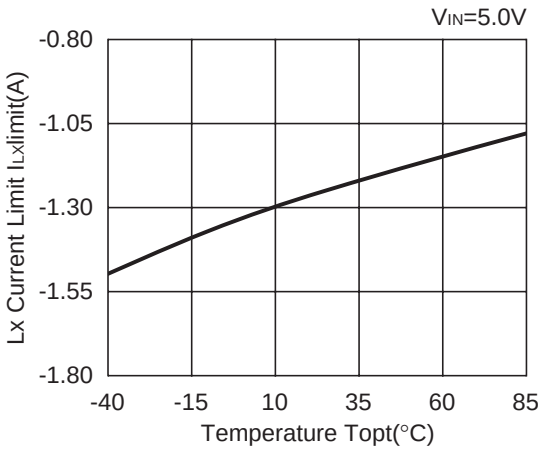



**Rectifier Tr.Nch ON Resistance**

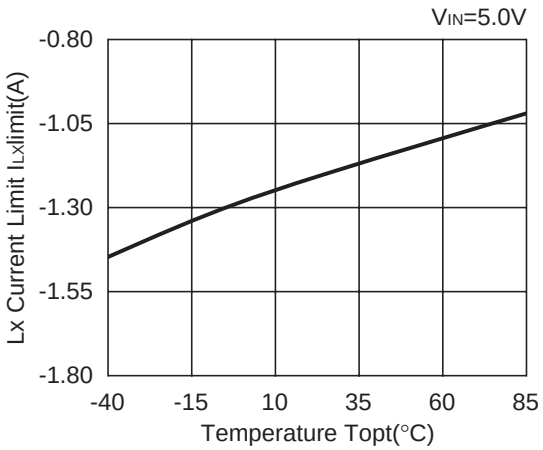


### 17) Current Limit vs. Temperature

**R1232D121A**

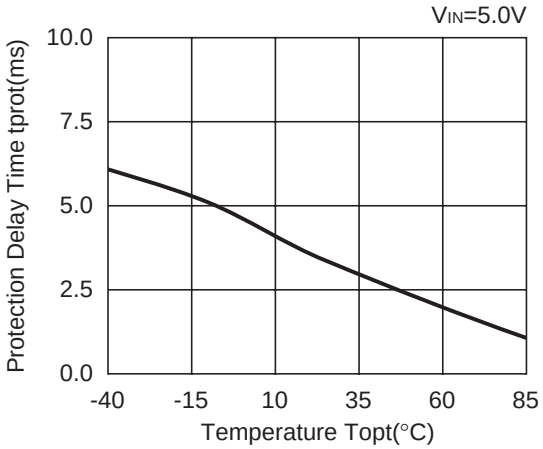



**R1232D331B**

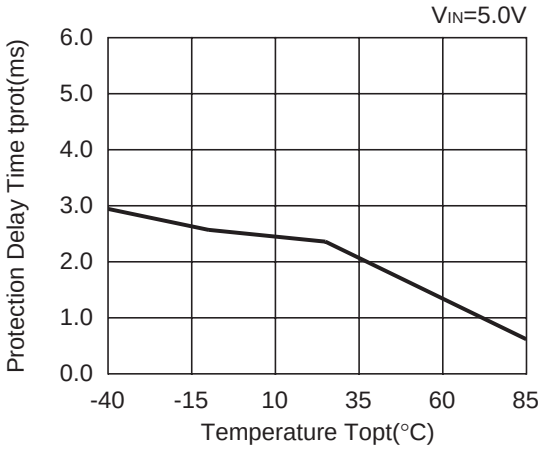



### 18) Protection Delay Time vs. Temperatures

**R1232D121A**




**R1232D331B**



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11. Please contact our sales representatives should you have any questions or comments concerning the products or the technical information.

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