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

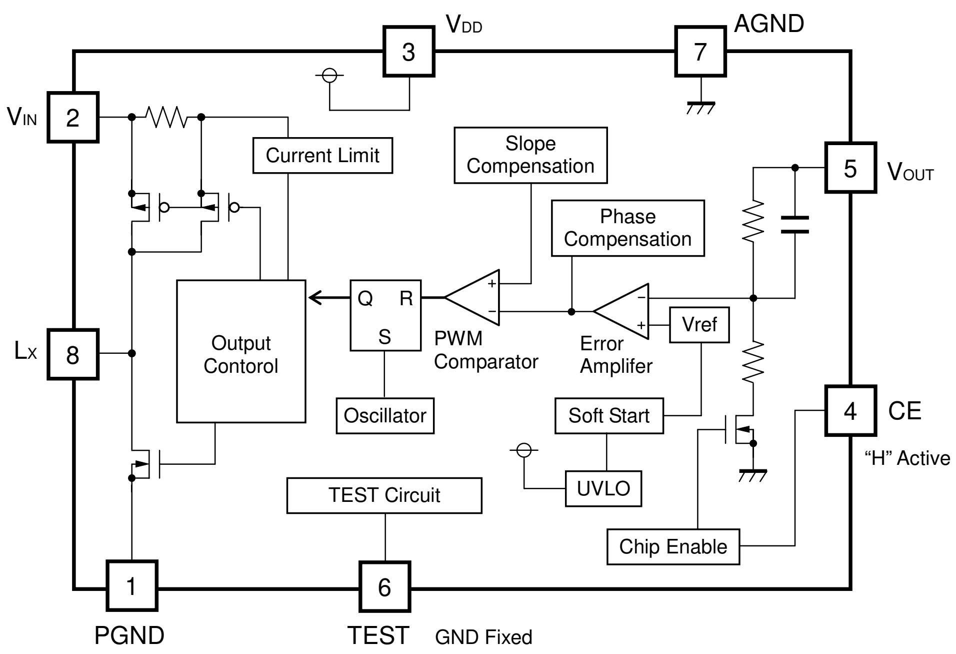
- Two choices of Oscillator Frequency 1MHz, 2.25MHz
  (Small inductors can be used. 4.7μH for 1MHz/2.2μH for 2.25MHz)
- Built-in Driver ON Resistance .... P-channel 0.2Ω (at V_{IN}=5.0V)
- Built-in Soft-start Function... Typ. 1.0ms (fosc=1MHz type)
- Output Voltage .... 0.9V to 3.3V (R1232Dxx1x Type)
  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

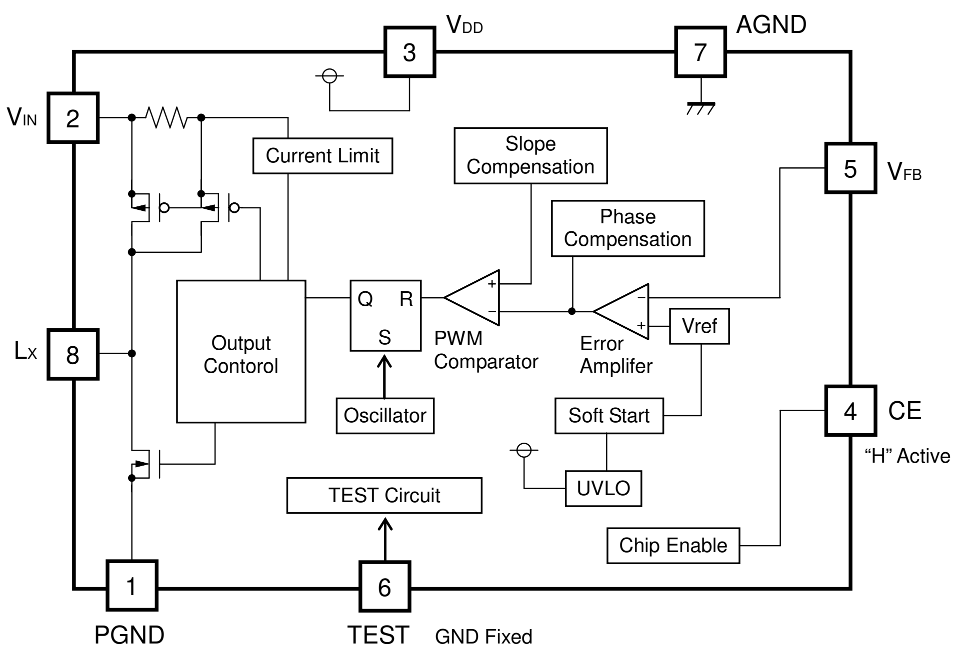
- Power source for portable equipment such as PDA, DSC, Notebook PC.
- Power source for HDD

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

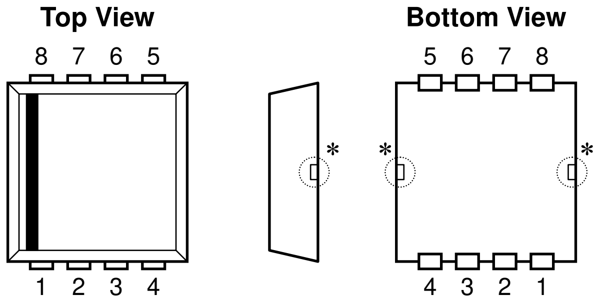
xx: The output voltage can be designated in the range from 0.9 V(09) to 3.3V(33) in 0.1V steps.
(For externally adjustable output voltage type, (00).)

∗ : 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}	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	0.5	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**

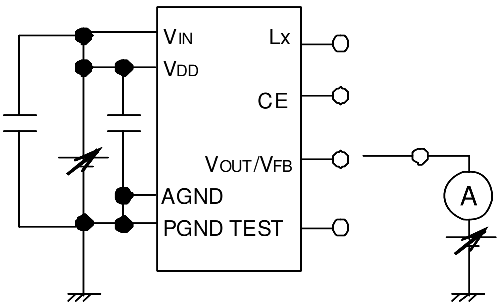
Ta=25°C

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	$-40°C \leqq Ta \leqq 85°C$		±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	$V_{IN}=V_{CE}=5.5V$, $V_{OUT}(V_{FB})=5.5V$	170	240	310	μA
Istandby	Standby Current	$V_{CE}=V_{OUT}(V_{FB})=0V$, $V_{IN}=5.5V$		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	0.15	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	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	$V_{IN}=5.5V$, $V_{CE}=5.5V/0V$	–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

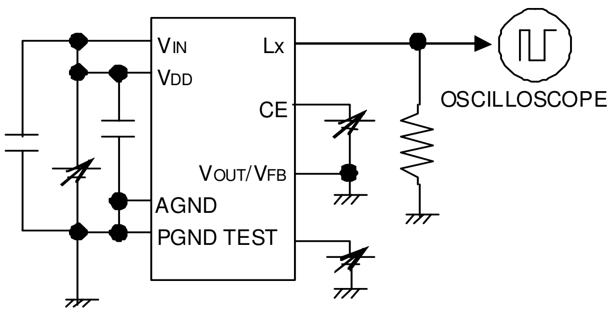
RECOMMENDED OPERATING CONDITIONS (ELECTRICAL CHARACTERISTICS)

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.

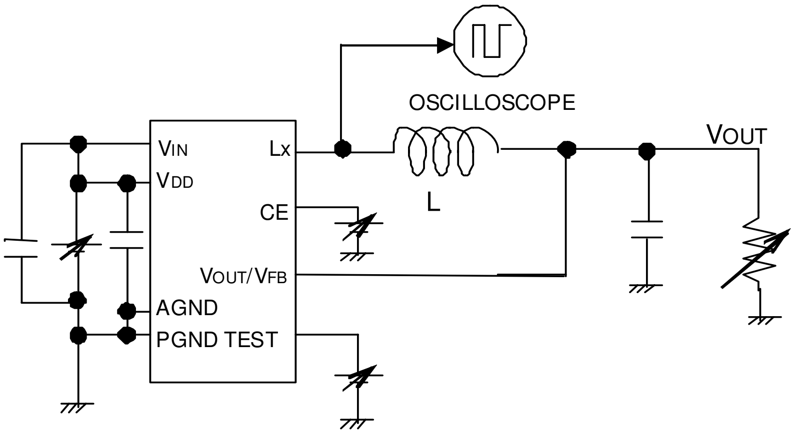
TEST CIRCUIT



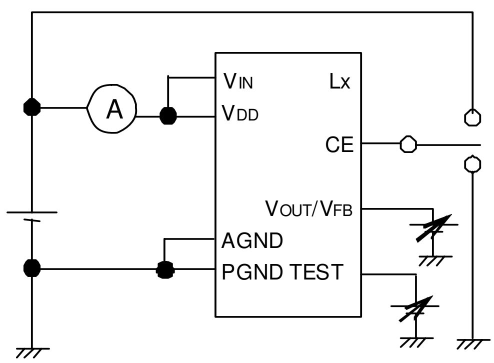
Test Circuit for Input Current and Leakage Current



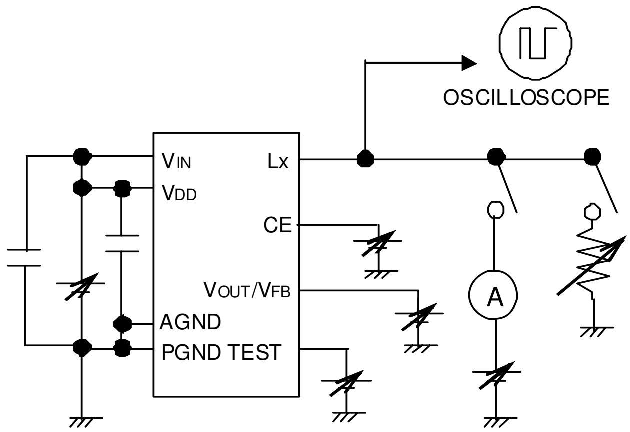
Test Circuit for Input Voltage and UVLO voltage



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



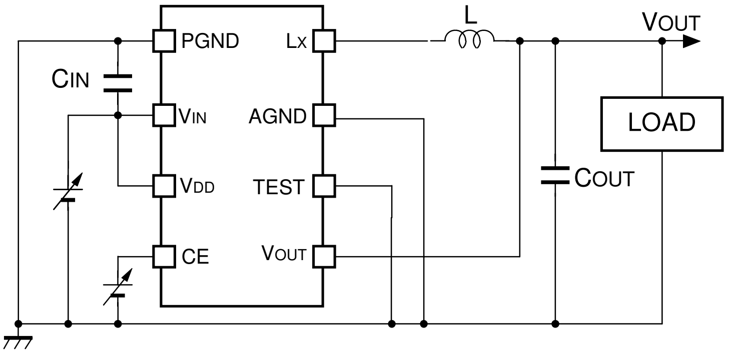
Test Circuit for Supply Current and Standby Current



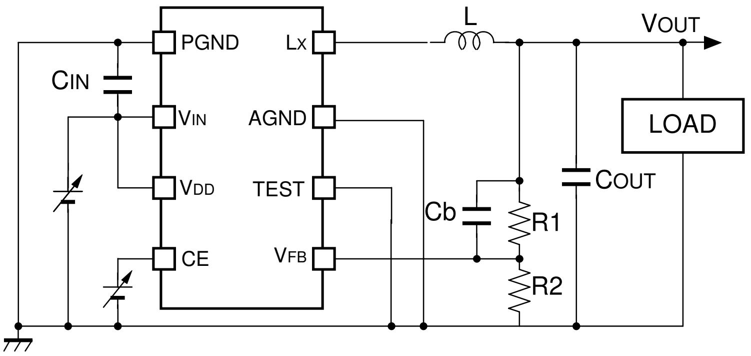
Test Circuit for ON resistance of L_X, Limit Current, Delay Time of Protection Circuit

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) *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;

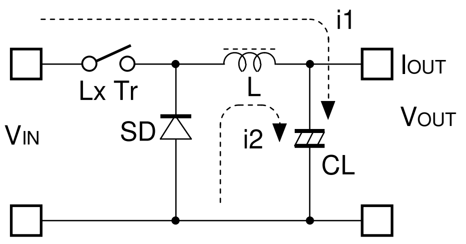
- Input the same voltage into power supply pins, V_{IN} and V_{DD}. Set the same level as AGND and PGND.
- When you control the CE pin by another power supply, do not make its "H" level more than the voltage level of V_{IN} / V_{DD} pin.
- Set external components such as an inductor, C_{IN}, C_{OUT} 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.

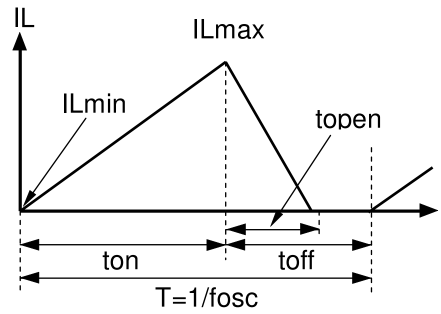
OPERATION of step-down DC/DC converter and Output Current

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

$tonc = t \times V_{OUT}/V_{IN}$ .... 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.)

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

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

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

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

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

Ripple Current is as follows;

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

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

$ILmax = I_{OUT} + I_{RP}/2$ .... 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.

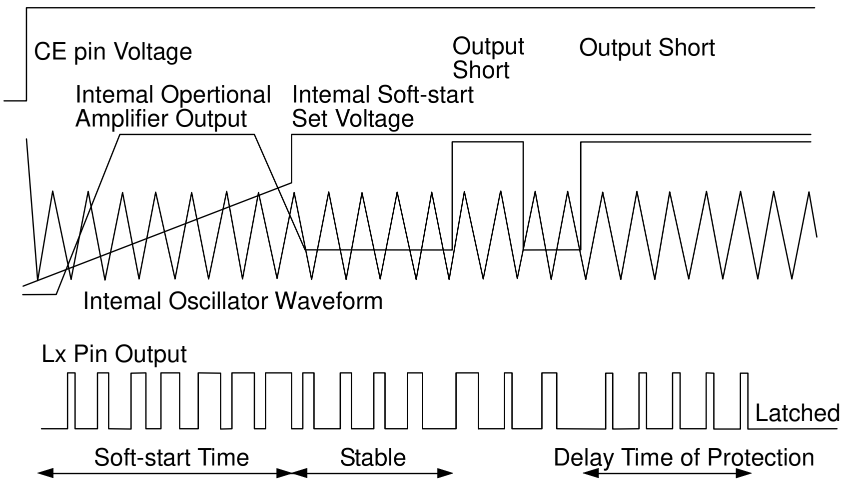
Provided that the allowable current is large in that case and DC current is small, therefore, for large output current, efficiency is better than using an inductor with a large value of L and vice versa.

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")

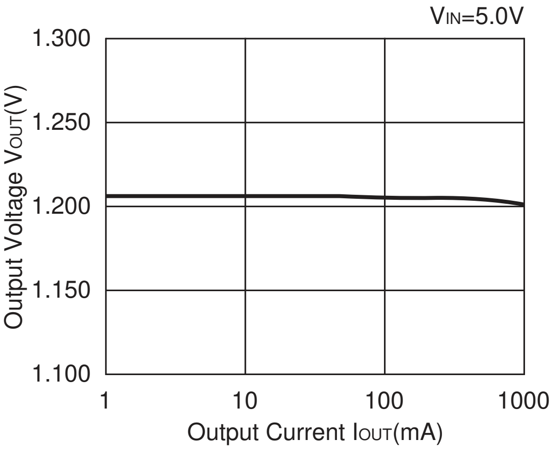
If the output short is released before the latch circuit works (within 2ms after output shorted), the output of amplifier is balanced in the stable state again.

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

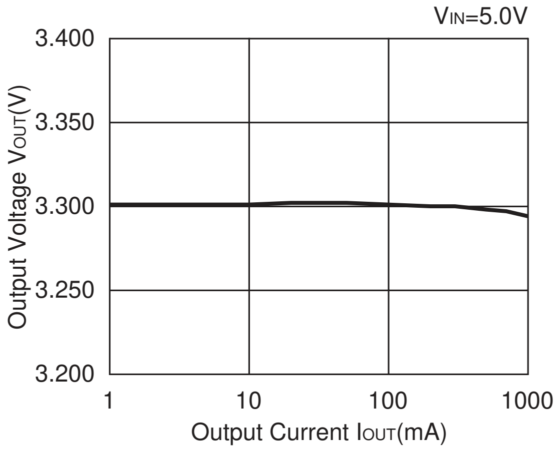
TYPICAL CHARACTERISTICS

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

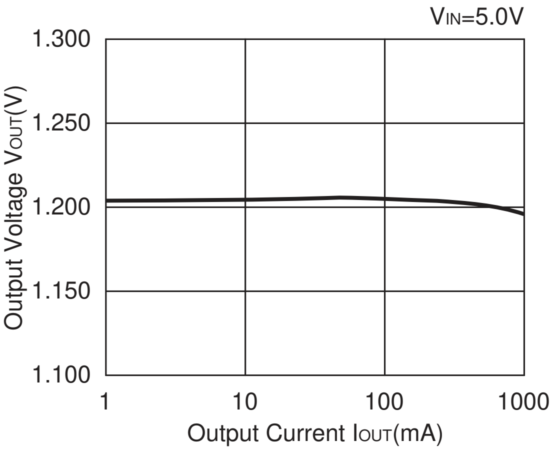
R1232D121A



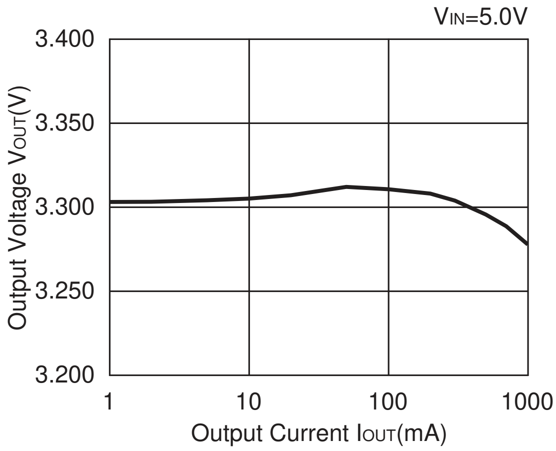
R1232D331A



R1232D121B

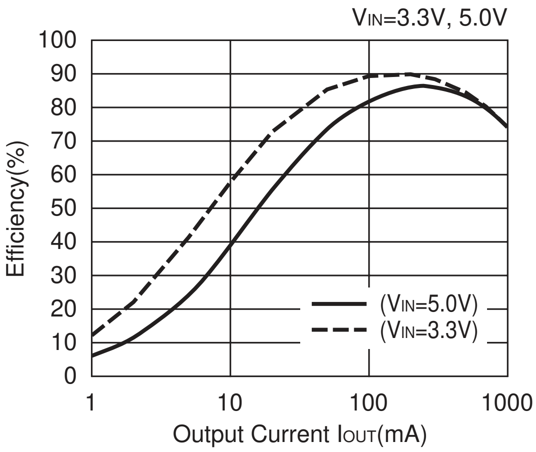


R1232D331B



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

R1232D121A



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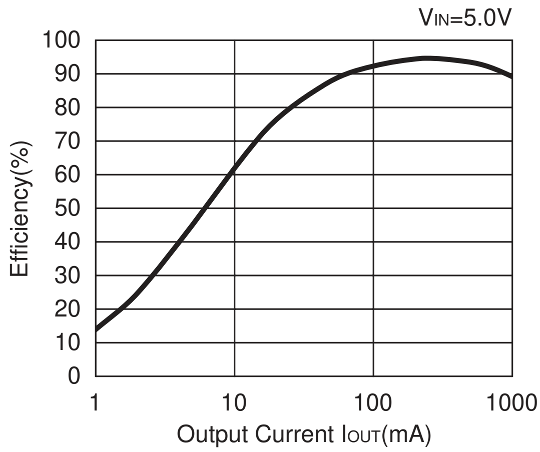
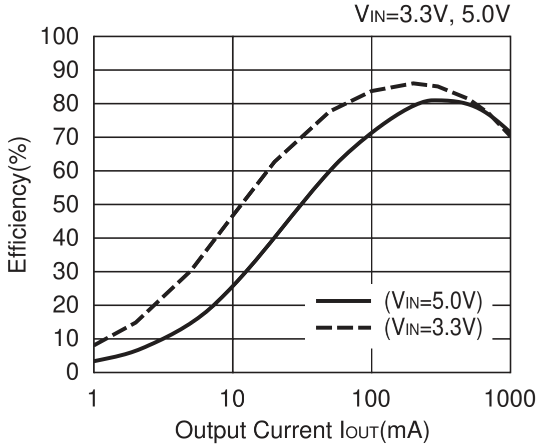


R1232D121B



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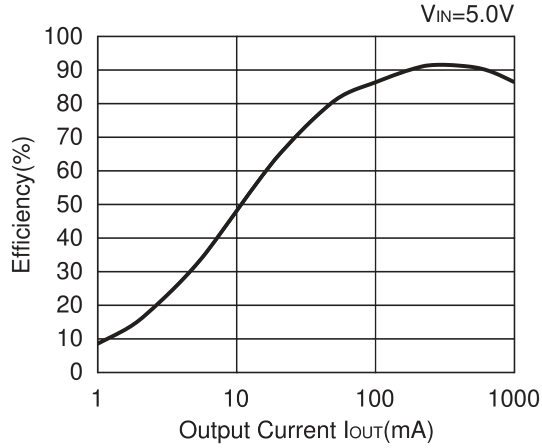
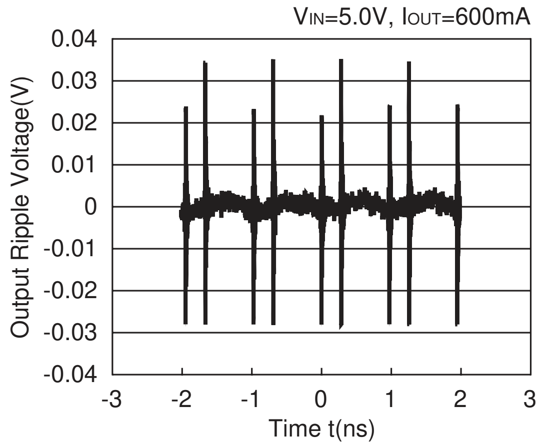


3) Output Waveform

R1232D121A



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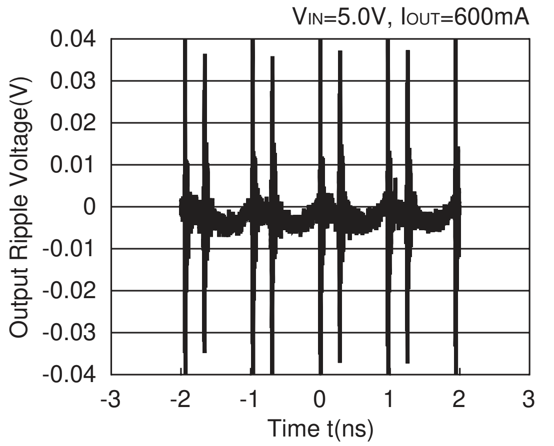

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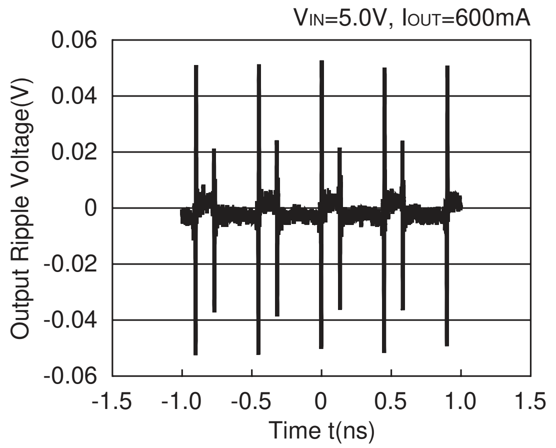

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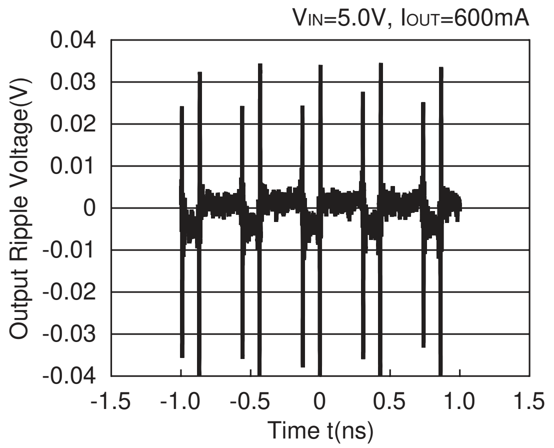
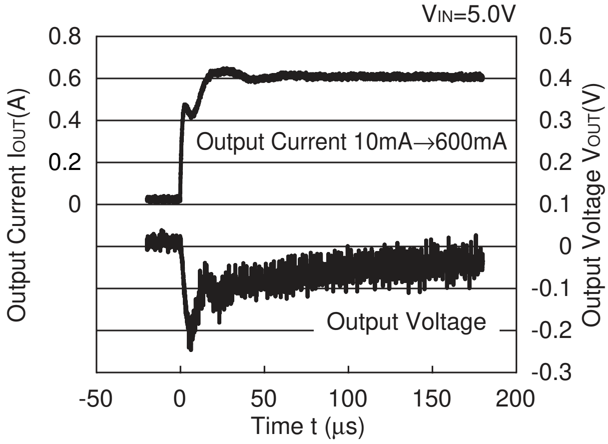


4) Load Transient Response

R1232D121A



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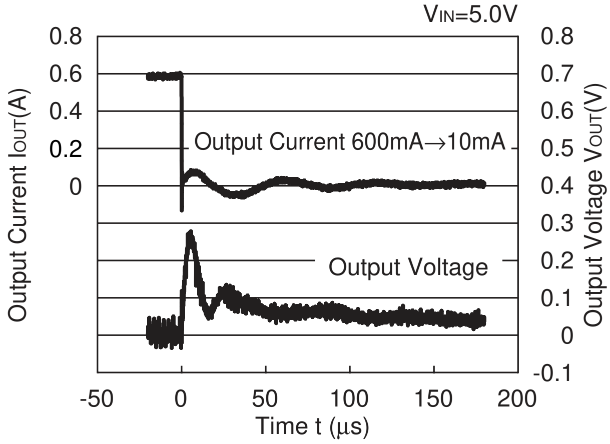

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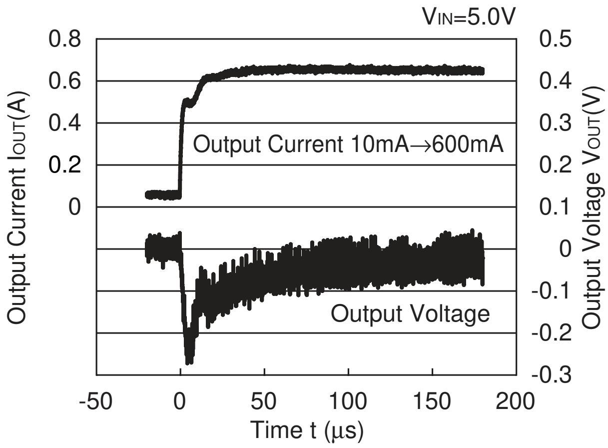

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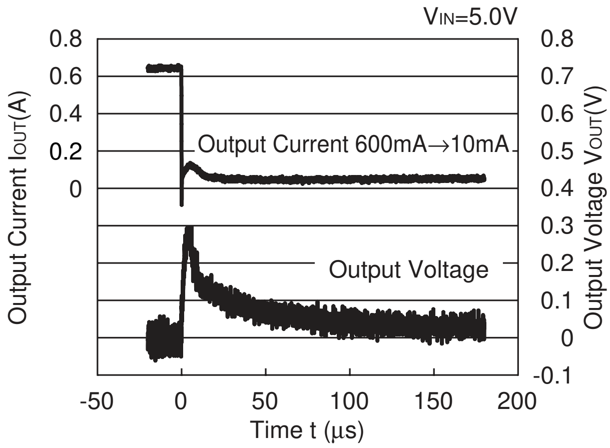
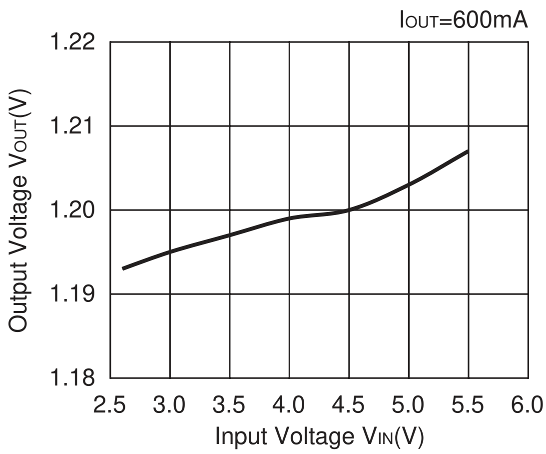


5) Output Voltage vs. Input Voltage

R1232D121A



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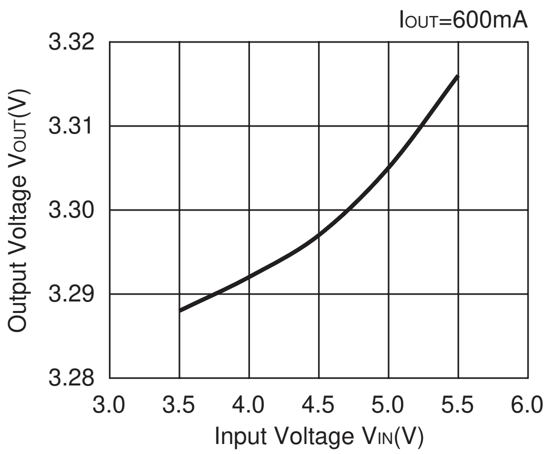
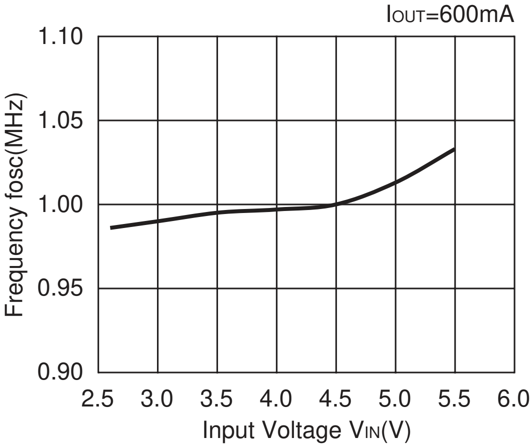


6) Oscillator Frequency vs. Input Voltage

R1232D121A



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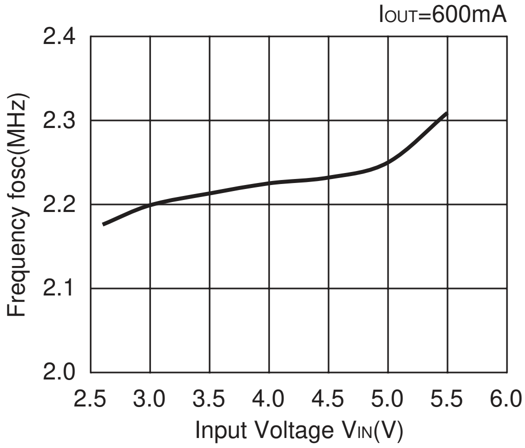
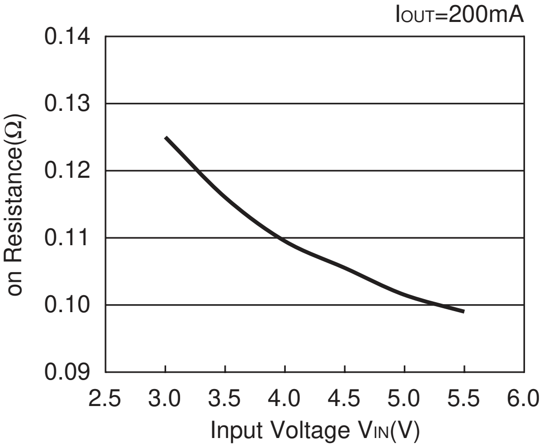
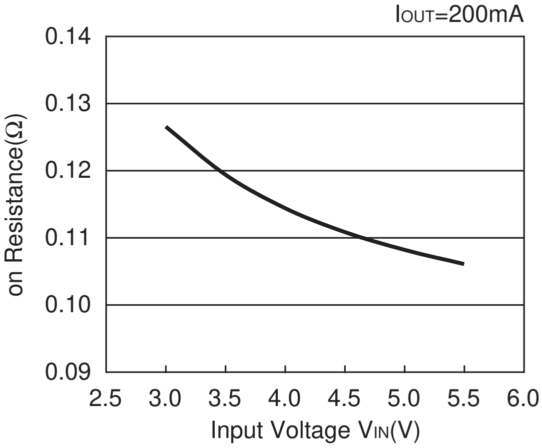


7) Lx Transistor On Resistance vs. Input Voltage

Switching Tr. Pch on Resistance

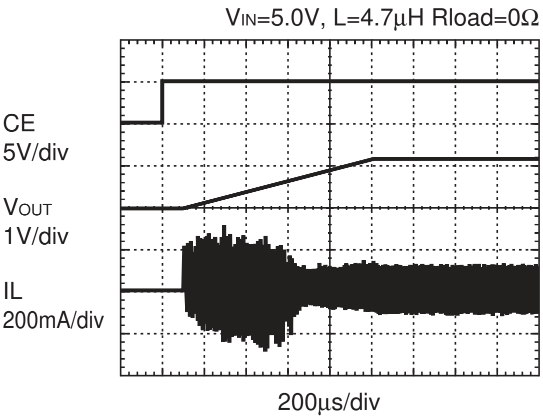


Synchronous Rectifier Tr. Nch on Resistance



8) Turn-on speed by CE pin

R1232D121A



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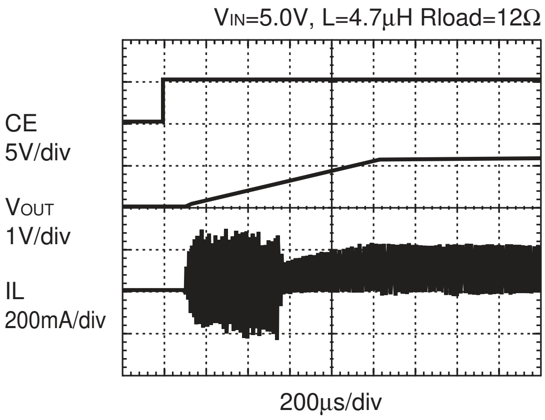

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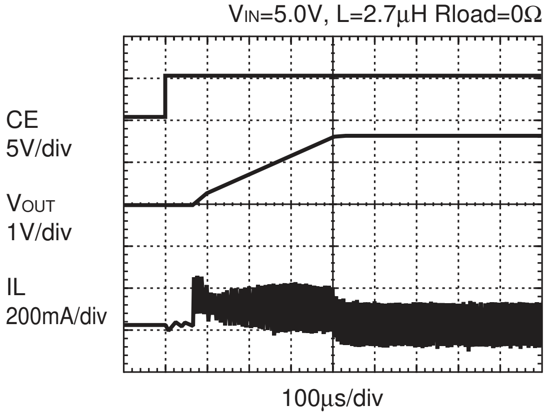

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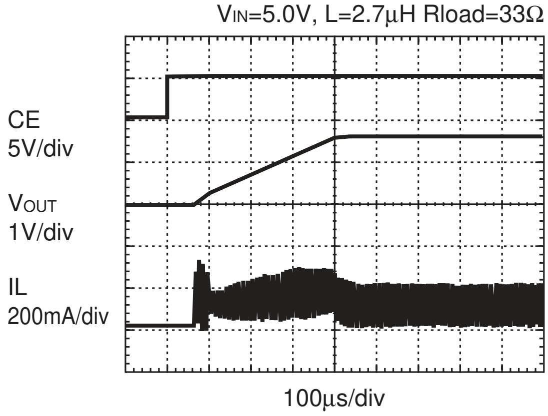
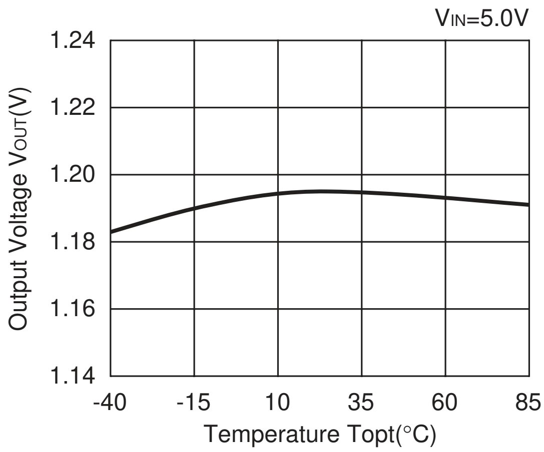


9) Output Voltage vs. Temperature

R1232D121A



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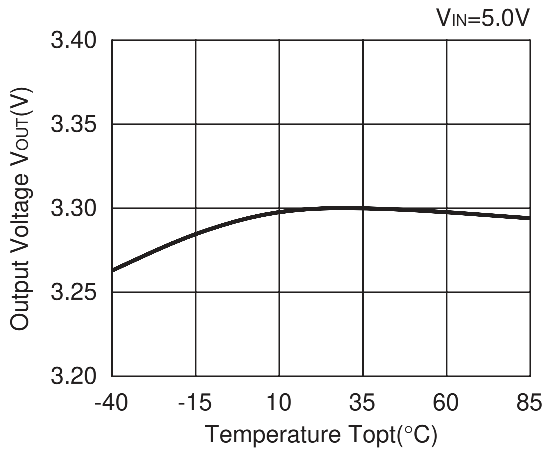
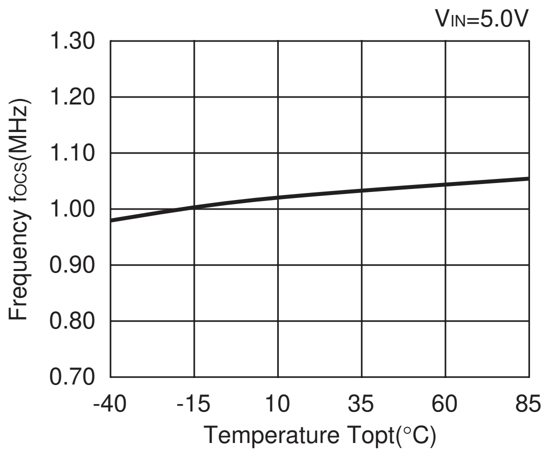


10) Oscillator Frequency vs. Temperature

R1232D121A



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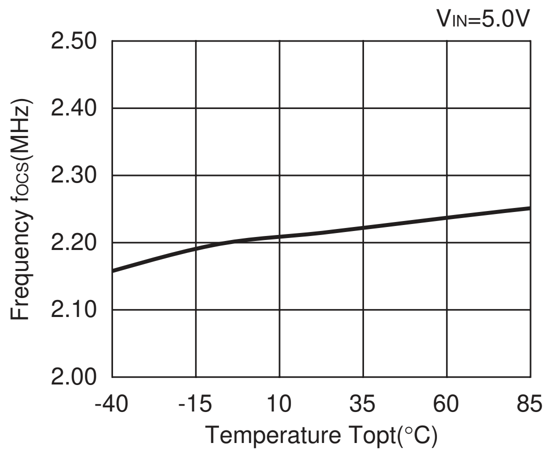
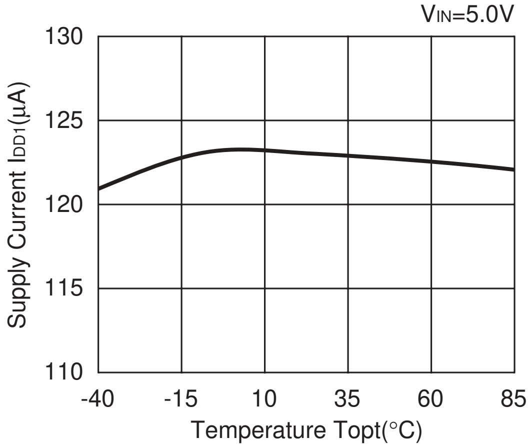


11) Supply Current vs. Temperature

R1232D121A



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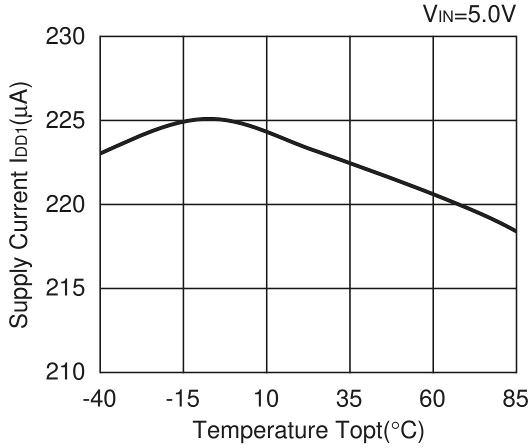
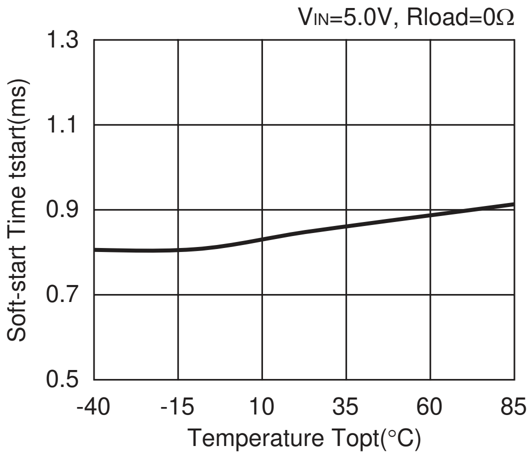


12) Soft-start time vs. Temperature

R1232D121A



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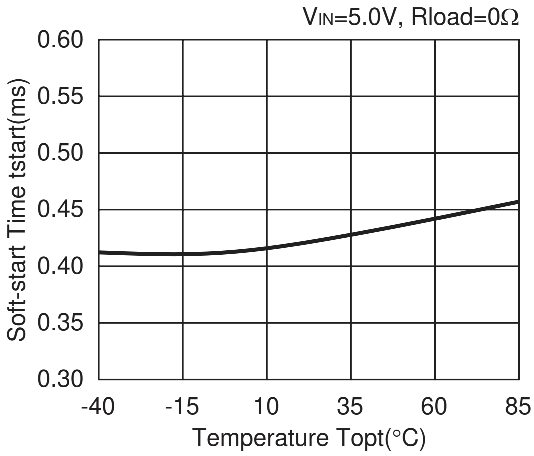
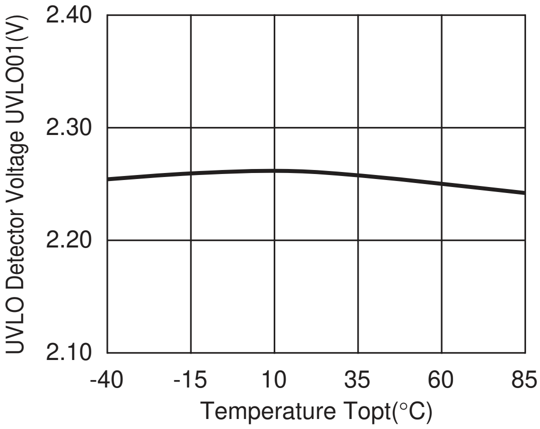


13) UVLO Voltage vs. Temperature

R1232D121A



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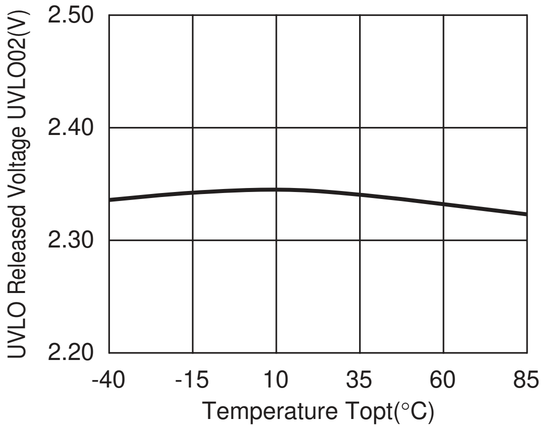
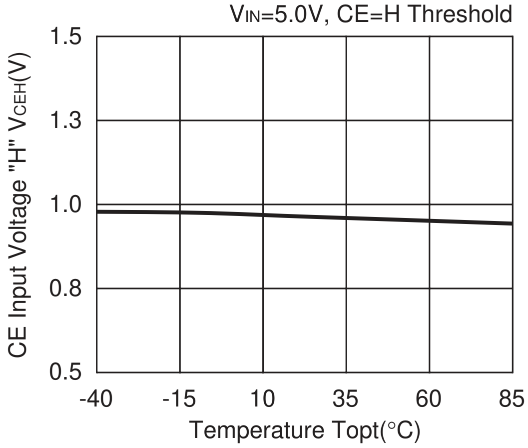


14) CE Input Voltage vs. Temperature

R1232D121A



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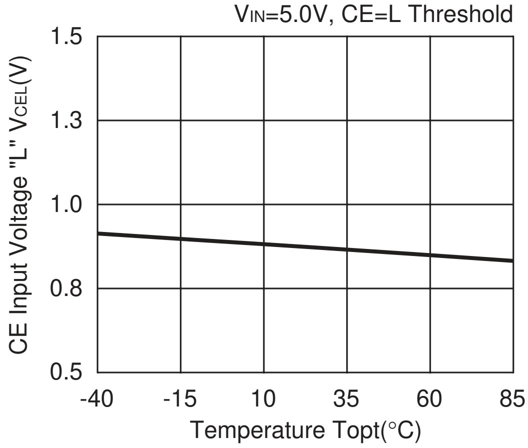
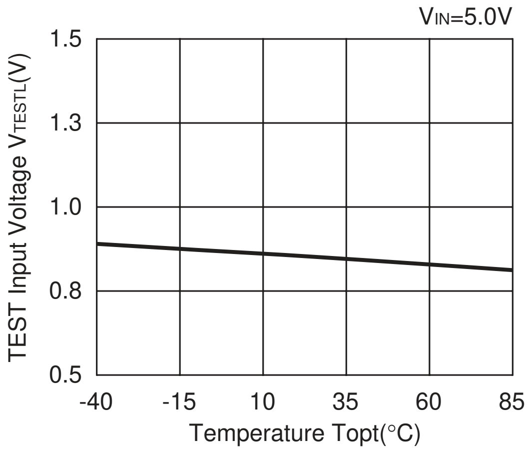


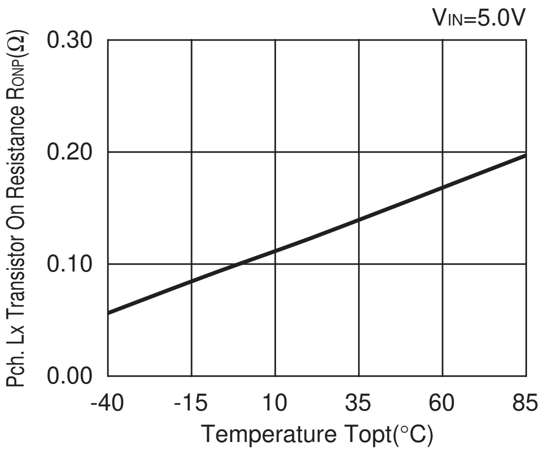
15) TEST Input Voltage vs. Temperature

R1232D121A

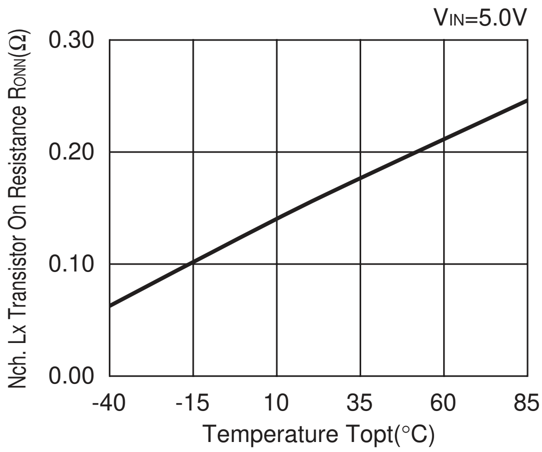


16) Lx Transistor On Resistance vs. Temperature

Driver Tr. Pch ON Resistance

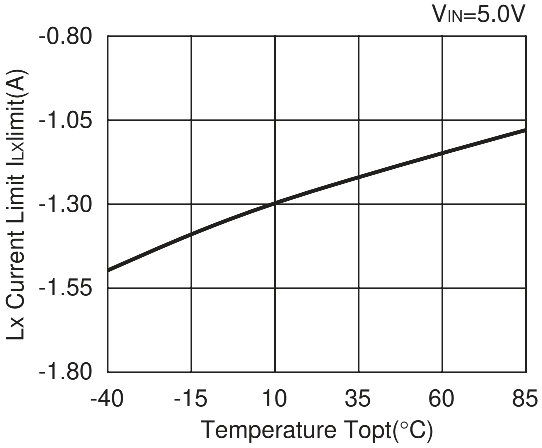


Rectifier Tr.Nch ON Resistance



17) Current Limit vs. Temperature

R1232D121A



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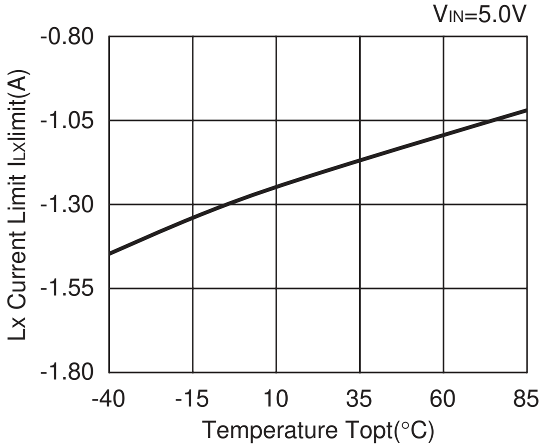
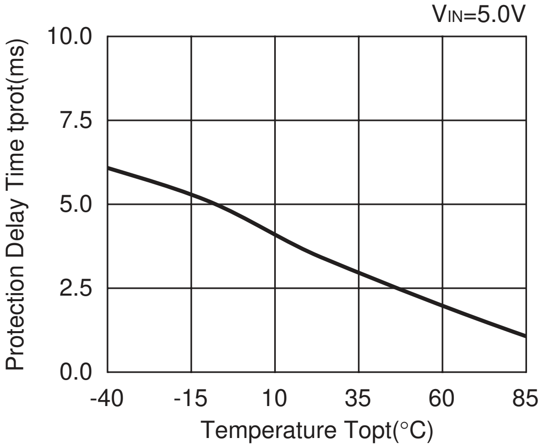


18) Protection Delay Time vs. Temperatures

R1232D121A



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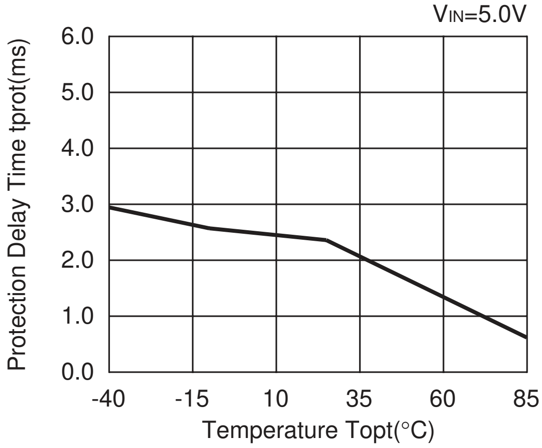

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