

step-down DC/DC Converters with synchronous rectifier

NO.EA-155-080522

OUTLINE

The RP500X Series are CMOS-based step-down DC/DC Converters with synchronous rectifier.

Each of these ICs consists of an oscillator, a switching control circuit, a reference voltage unit, an error amplifier, a soft-start circuit, protection circuits, UVLO circuit, switching transistors, and so on. A low ripple, high efficiency step-down DC/DC converter can be easily composed of this IC with only an inductor and capacitors. In terms of the output voltage, since the feedback resistances are built-in, the voltage is fixed internally. 50mV(custom-made) step output can be set by laser-trim and 1.5% or 24mV tolerance depending on the output voltage is guaranteed.

Mode alternative circuit works automatically for improving the efficiency. Considering fixed noise frequency, PWM fixed control type is also available. 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 exist. The latch-type protection circuit works to latch an internal driver with keeping it disable. To release the condition of the protection, after disabling 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.

Since packages are DFN(PLP)1820-6, SOT23-6, WLCSP-6 (0.16φ), high density mounting on boards is possible.

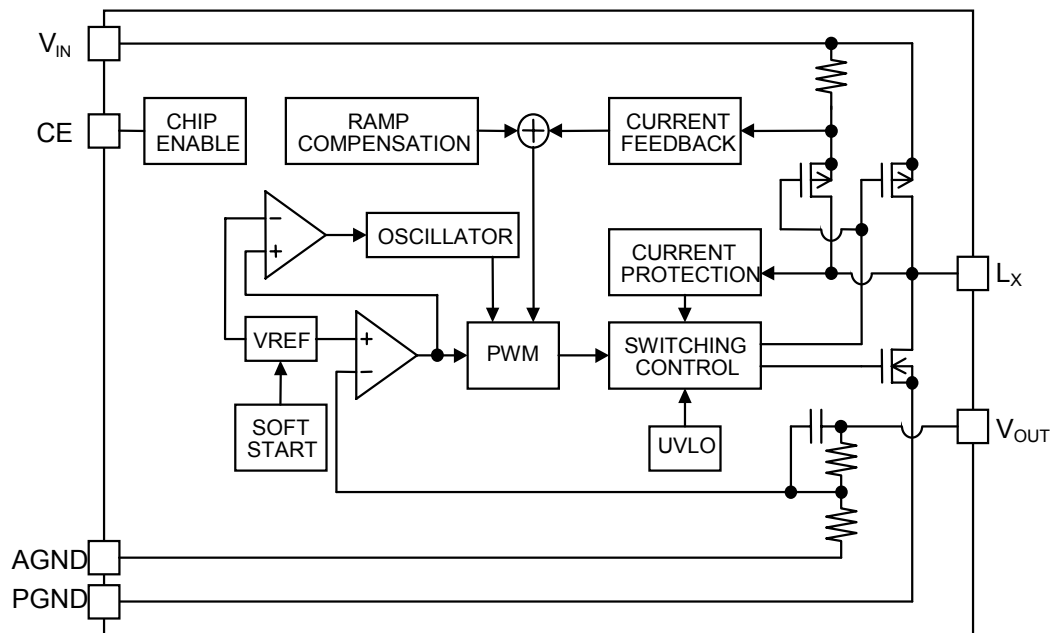
FEATURES

- Input Voltage Range..... 2.55V to 5.50V
- Output Voltage..... 1.1V to 3.3V
(It is possible in the range from 1.1V to 3.3V with a step 0.1V)
- High Accuracy Output Voltage $\pm 1.5\%$ ($V_{out} \geq 1.6V$)
 $\pm 24mV$ ($V_{out} < 1.6V$)
- Supply Current..... Typ. 400 μA (at PWM mode)
Typ. 100 μA (at PFM mode)
- Oscillator Frequency Typ. 1.2MHz
- Built-in Soft start Function Typ. 0.1ms
- Built-in Latch type Protection Typ. 1.5ms
- Built-in UVLO Function..... Typ. 2.2V
- Two choices of Switching Mode Automatic PWM/PFM mode change / PWM fixed
- Packages..... DFN(PLP)1820-6, SOT23-6W, WLCSP-6 (0.16φ)

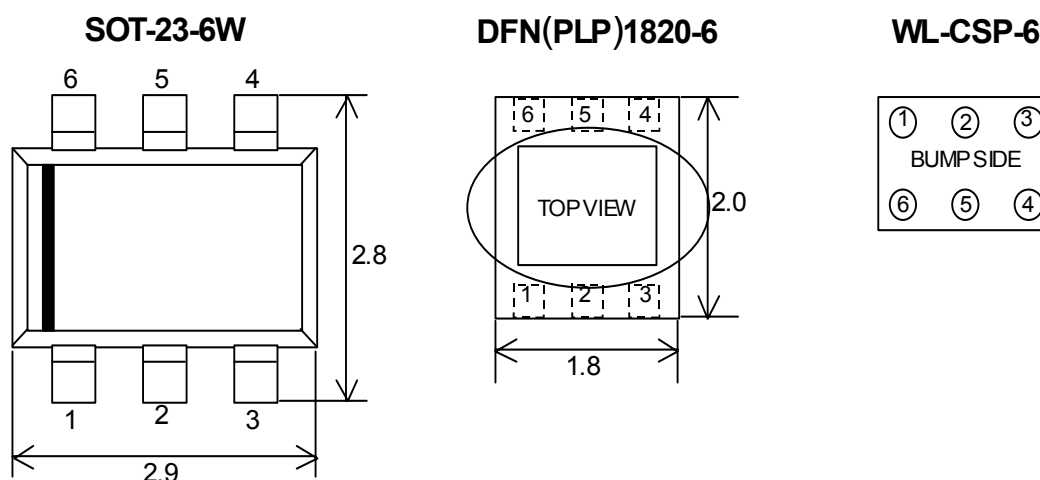
APPLICATIONS

- Power source for portable equipment such as cellular, PDA, DSC, Notebook PC
- Power source for HDD
- Power source for Li-ion battery-used equipment

BLOCK DIAGRAM



PIN CONFIGURATION



PIN DESCRIPTIONS

WLCSP-6 / SOT-23-6W

Pin No.	Symbol	Pin Description
1	VOUT	Output
2	PGND	Ground
3	LX	Lx Switching
4	VIN	Voltage Supply
5	AGND	Ground
6	CE	Chip Enable (High Active)

DFN(PLP)1820-6

Pin No.	Symbol	Pin Description
1	CE	Chip Enable (High Active)
2	AGND	Ground
3	VIN	Voltage Supply
4	LX	Lx Switching
5	PGND	Ground
6	VOUT	Output

* Tab in the  parts have GND level. (They are connected to the back side of this IC.)
Do not connect to other wires or land patterns

ABSOLUTE MAXIMUM RATINGS

AGND=PGND=0V

Symbol	Item	Rating	Unit
V_{IN}	V_{IN} Supply Voltage	6.5	V
V_{LX}	Lx 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_{OUT}	Vout Pin Voltage	-0.3 to $V_{IN}+0.3$	V
I_{LX}	Lx Pin Output Current	800	mA
P_D	Power Dissipation	DFN(PLP)	880
		SOT	430
		WLCSP	650
T_{opt}	Operating Temp. Range	-40 to 85	°C
T_{stg}	Storage Temp. Range	-55 to 125	°C

ABSOLUTE MAXIMUM RATINGS

Absolute Maximum ratings are threshold limit values that must not be exceeded ever for an instant under any conditions. Moreover, such values for any two items must not be reached simultaneously. Operation above these absolute maximum ratings may cause degradation or permanent damage to the device. These are stress ratings only and do not necessarily imply functional operation these limits.

SELECTION GUIDE

In the RP500 series, output voltage, function options, etc. can be designated with user's request. Part number can be designated as follows:

RP500X xx x x - xx ← Part Number

$\begin{matrix} \uparrow & \uparrow & \uparrow & \uparrow & \uparrow \\ a & b & c & d & e \end{matrix}$

Code	Contents
a	Designation of the package K: DFN(PLP)1820-6 N: SOT-23-6W Z: WL-CSP-6
b	Designation of output voltage Designation is possible in the range from 1.1V to 3.3V with a step of 0.1V
c	Designation of the function (with or without PWM/PFM Alternative function, auto discharge function) 1:with PWM/PFM alternative, without auto discharge 2:without PWM/PFM alternative, without auto discharge 4:without PWM/PFM alternative function, with auto discharge function
d	Frequency A: 1.2MHz
e	Designation of the taping type TR:SOT23-6W / DFN(PLP)1820-6 E2:WLCSP-6

*0.05V step is also available as a custom code.

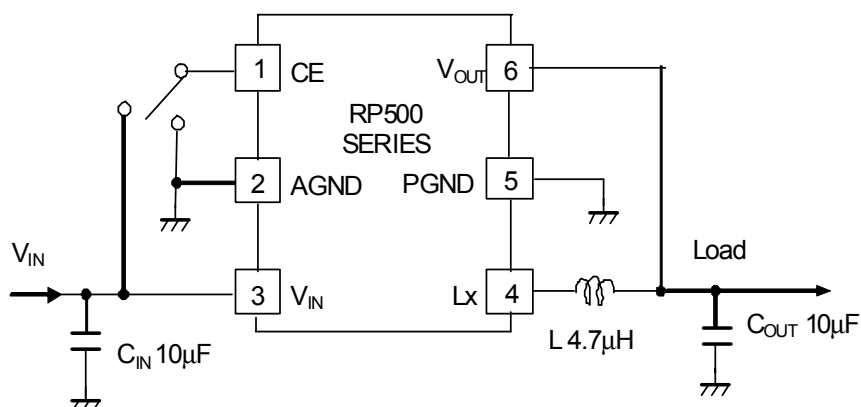
ELECTRICAL CHARACTERISTICS

T_{opt}=25°C

Symbol	Item	Condition	Min.	Typ.	Max.	Unit
V _{IN}	Operating Input Voltage		2.55		5.50	V
V _{OUT}	Step-down Output Voltage	V _{IN} =V _{CE} =3.6V or V _{SET} +1V V _{OUT} □1.6V V _{OUT} <1.6V	-1.5% -0.024		+1.5% 0.024	V
ΔV _{OUT} /ΔT	Step-down Output Voltage Temperature Coefficient	-40°C≤T _{OPT} ≤85°C		±100		ppm/°C
F _{OSC}	Oscillator Frequency	V _{IN} =V _{CE} =3.6V or V _{SET} +1V	-20%	1.2	+20%	MHz
I _{SS1}	Supply Current 1	V _{IN} =V _{CE} =5.5V, V _{OUT} =0		400	500	μA
I _{SS2}	Supply Current 2	V _{IN} =V _{CE} =5.5V, V _{OUT} =5.5V		100	160	μA
I _{STB}	Standby Current	V _{IN} =5.5V, V _{CE} =0V		0	5	μA
I _{CEH}	CE "H" Input Current	V _{IN} =V _{CE} =5.5V	-1	0	1	μA
I _{CEL}	CE "L" Input Current	V _{IN} =5.5V, V _{CE} =0V	-1	0	1	μA
I _{VOUTH}	V _{OUT} "H" Input Current	V _{IN} =V _{OUT} =5.5V, V _{CE} =0V	-1	0	1	μA
I _{VOUTL}	V _{OUT} "L" Input Current	V _{IN} =5.5V, V _{CE} =V _{OUT} =0V	-1	0	1	μA
I _{LXLEAKH}	Lx Leakage Current "H"	V _{IN} =V _{LX} =5.5V, V _{CE} =0V	-1	0	5	μA
I _{LXLEAKL}	Lx Leakage Current "L"	V _{IN} =5.5V, V _{CE} =V _{LX} =0V	-5	0	1	μA
V _{CEH}	CE "H" Input Voltage	V _{IN} =5.5V	1.0			V
V _{CEL}	CE "L" Input Voltage	V _{IN} =5.5V			0.4	V
R _{ONP}	On Resistance of Pch Tr.	I _{LX} =-100mA		0.3		Ω
R _{ONN}	On Resistance of Nch Tr.	I _{LX} =-100mA		0.38		Ω
Maxdty	Max Duty Ratio		100			%
T _{START}	Soft-start Time	V _{IN} =V _{CE} =3.6V or V _{SET} +1V		120	150	μs
I _{LXLIM}	Lx Current Limit	V _{IN} =V _{CE} =3.6V or V _{SET} +1V	600	900		mA
T _{PROT}	Protection Delay Time	V _{IN} =V _{CE} =3.6V or V _{SET} +1V	0.5	1.5	5.0	ms
V _{UVLO1}	UVLO Detector Voltage	V _{IN} =V _{CE}	2.1	2.2	2.3	V
V _{UVLO2}	UVLO Released Voltage	V _{IN} =V _{CE}	2.2	2.3	2.4	V

*) Test circuit is "OPEN LOOP" and V_{IN}=V_{CE}=3.6V or V_{SET}+1V, AGND=PGND=0V unless otherwise noted.

TYPICAL APPLICATION



Parts Recommendation

- L: 4.7µH VLF3010AT-4R7MR30 (TDK)
- COUT: 10µF Ceramic C2012JB0J106K (TDK)
- CIN: 10µF C2012JB0J106K (TDK)

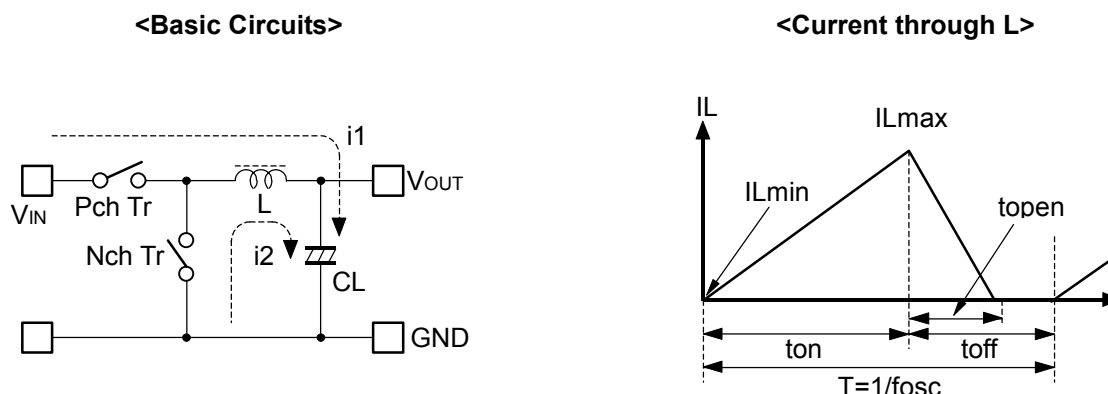
When you use these ICs, consider the following issues:

- Set the same level as AGND and PGND.
- Set external components such as an inductor, CIN, COUT as close as possible to the IC, in particular, minimize the wiring to VIN pin and PGND pin. The wiring between VOUT and load and between L and VOUT should be separated.
- Use an external capacitor CIN between VIN and GND, and COUT with a capacity of 10µF or more ceramic type.
- Choose an inductor with inductance range from 4.7µH to 10.0µH. The phase compensation has been made by these values with output capacitors. The recommendation characteristics of the inductor are low DC resistance, large enough permissible current, and strong against the magnetic saturation. Inductance value may shift depending on an inductor. If the inductance value at an actual load current is low, Lx peak current may increase and may overlap the Lx current limit. As a result, over current protection may work.
- Over current protection circuit may be affected by self-heating and heat radiation environment.
- Reinforce the VIN, PGND, and VOUT lines sufficiently. Large switching current may flow in these lines. If the impedance of VIN 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.

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.(such as the voltage, current, and power)

OPERATION OF THE BUCK CONVERTER AND THE OUTPUT CURRENT

The 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 ($=i1$) 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 ($=i2$) flows.
- Step 3: I_L ($=i2$) 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 ΔI :

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

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

OUTPUT CURRENT AND SELECTION OF EXTERNAL COMPONENTS

The relation between the output current and external components is as follows:

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.)

$$V_{IN} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times I_{RP} / t_{on} \dots\dots\dots \text{Equation 1}$$

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

$$L \times I_{RP} / t_{off} = R_{ONN} \times I_{OUT} + V_{OUT} + R_L \times I_{OUT} \dots\dots\dots \text{Equation 2}$$

Put Equation 2 to Equation 1 and solve for ON duty of P-channel transistor, $t_{on}/(t_{off} + t_{on}) = D_{ON}$,

$$D_{ON} = (V_{OUT} + R_{ONN} \times I_{OUT} + R_L \times I_{OUT}) / (V_{IN} + R_{ONN} \times I_{OUT} - R_{ONP} \times I_{OUT}) \dots\dots\dots \text{Equation 3}$$

Ripple Current is as follows:

$$I_{RP} = (V_{IN} - V_{OUT} - R_{ONP} \times I_{OUT} - R_L \times I_{OUT}) \times D_{ON} / f_{osc} / L \dots\dots\dots \text{Equation 4}$$

wherein, peak current that flows through L, and L_x Tr. is as follows:

$$I_{Lmax} = I_{OUT} + I_{RP} / 2 \dots\dots\dots \text{Equation 5}$$

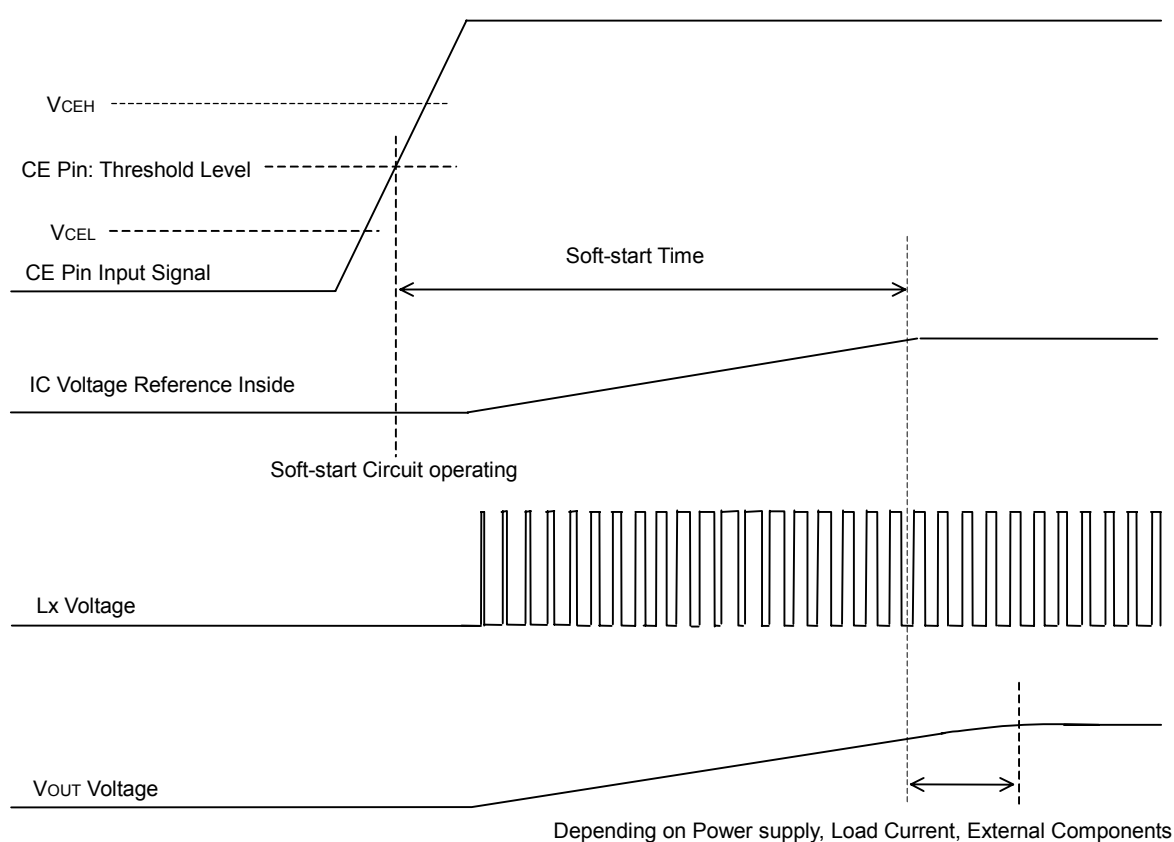
Consider I_{Lmax}, condition of input and output and select external components.

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

TIMING CHART

(1) Soft-start Time

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 is beyond the threshold level, the operation of the IC starts. The threshold voltage of CE pin is in between CE "H" input voltage and CE "L" input voltage described in the electrical characteristics table. Soft-start circuit operates, and after the certain time, the reference voltage inside the IC is rising gradually up to the constant value. Soft-start time is the time interval from CE 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.

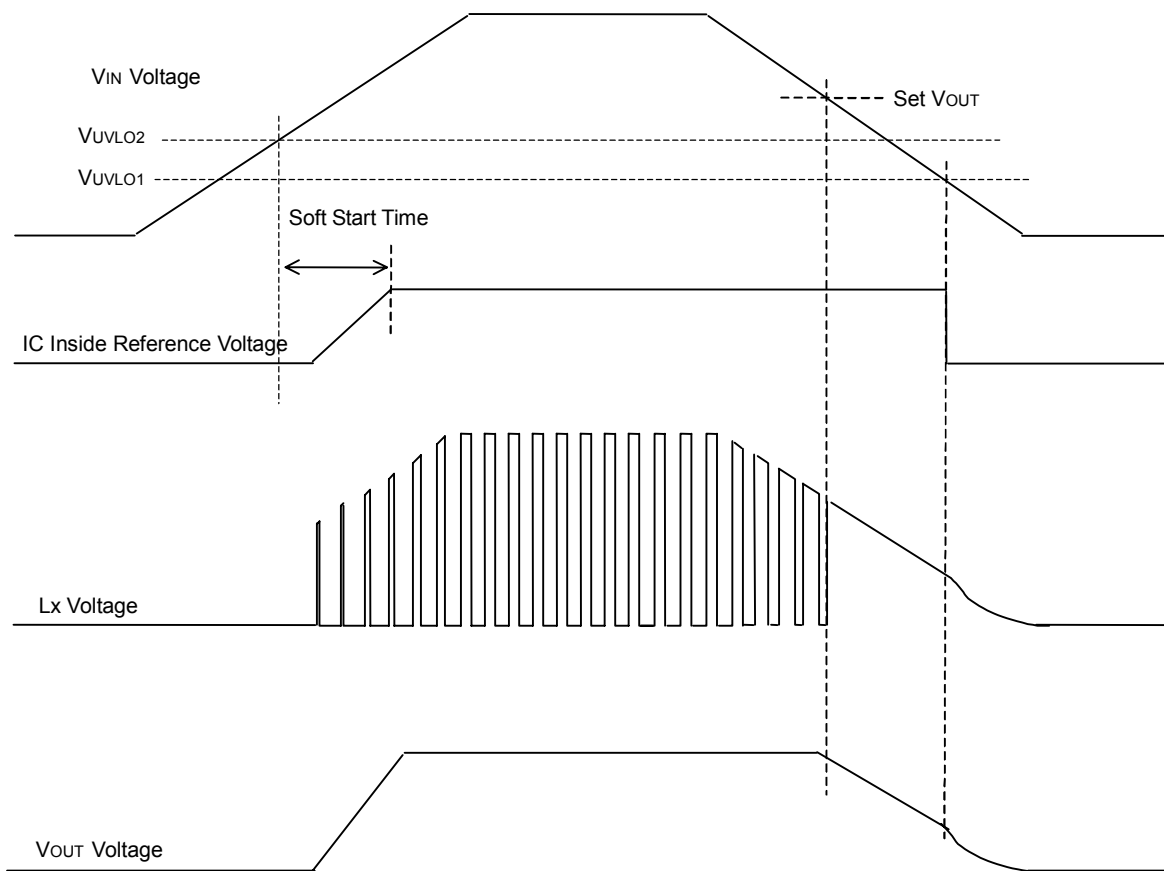


In the case of starting with power supply, when the input voltage for V_{IN} is larger than UVLO released voltage, soft start circuit operates, and after that, the same explanation above is applied to the operation. Turn-on speed is affected by next conditions;

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

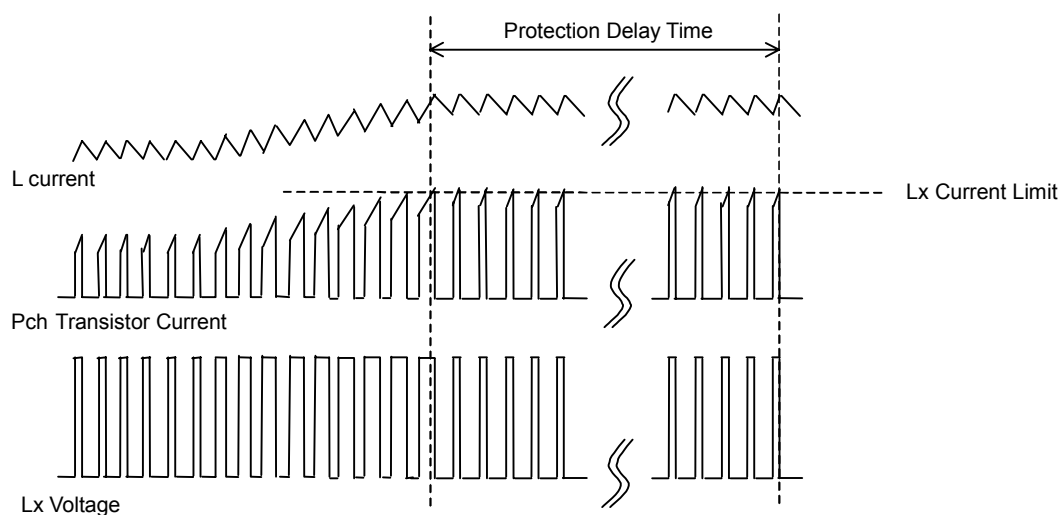
(2) Under Voltage Lockout (UVLO) Circuit

The under voltage lockout circuit (UVLO) stops the switching operation of DC/DC converter if V_{IN} voltage becomes less than UVLO detector threshold. To restart the normal operation, V_{IN} voltage must be more than UVLO released voltage. The timing chart below describes the operation with varying 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.



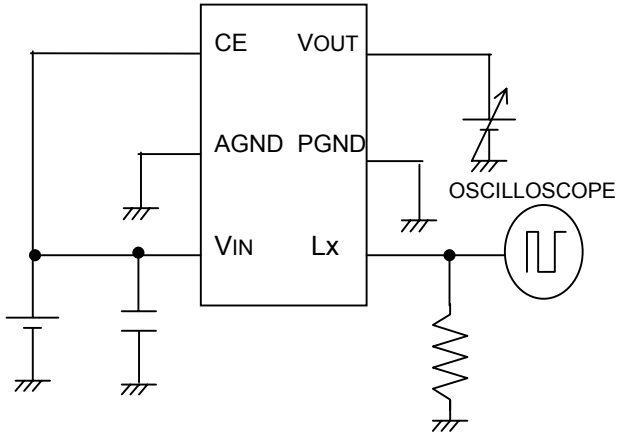
(3) Over Current Protection Circuit

Over current protection circuit supervises the current flowing Pch transistor at 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, the operation of DC/DC converter stops. Or, when the Lx limit current is exceeded even once when the driver operates by duty100%, the operation of DC/DC converter stops. To restart the operation, restart with power on or with CE pin control. Lx current limit and protection delay time is affected by self-heating and ambient environment. If the output is short and the input voltage VIN is drastically dropped or becomes unstable, the protection operation and delay time may vary.

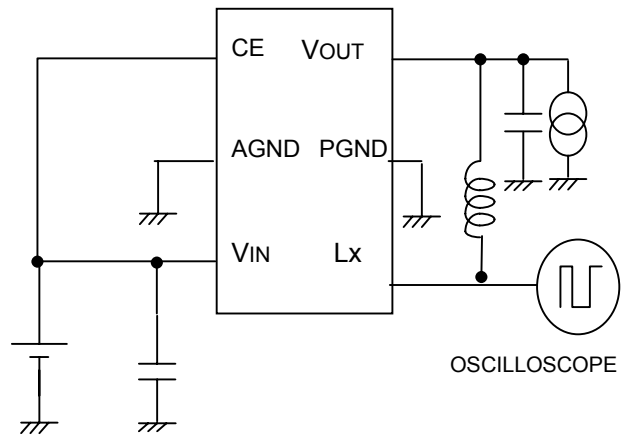


TEST CIRCUITS

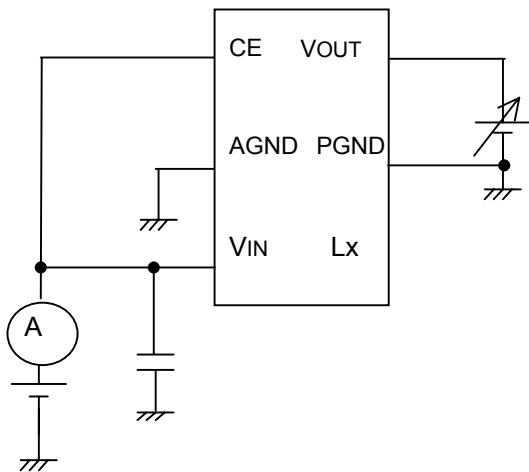
Output Voltage ss



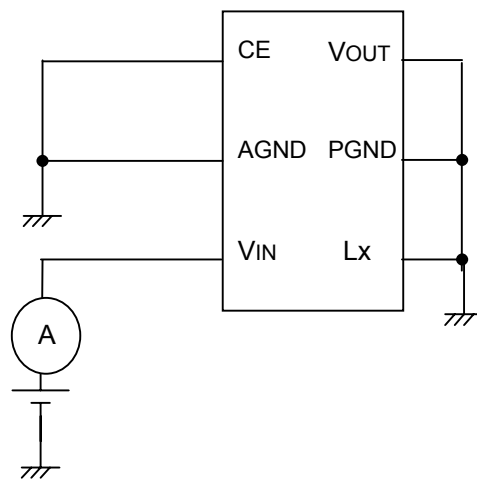
Oscillator Frequency



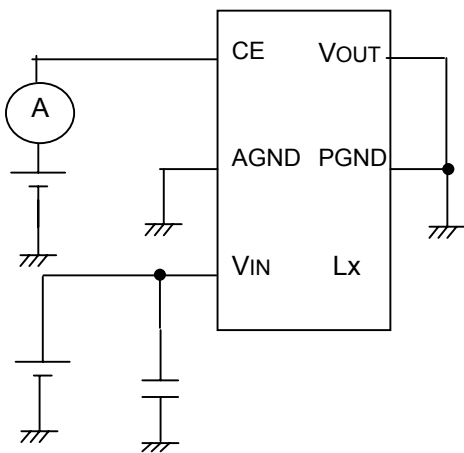
Supply Current 1,2



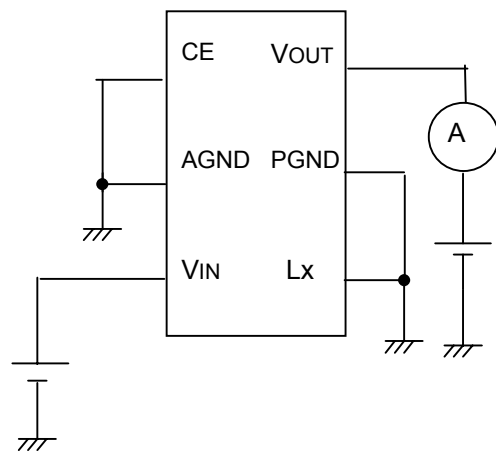
Standby Current



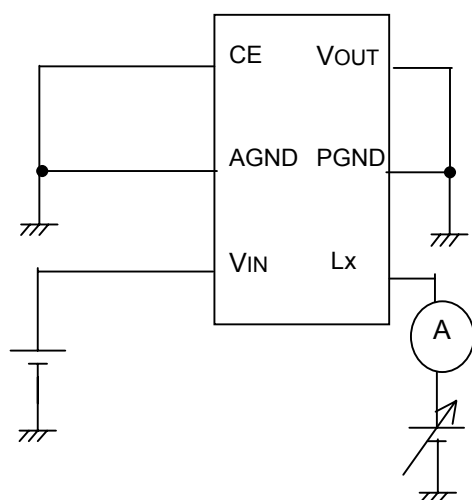
CE“H”/“L”Input Current



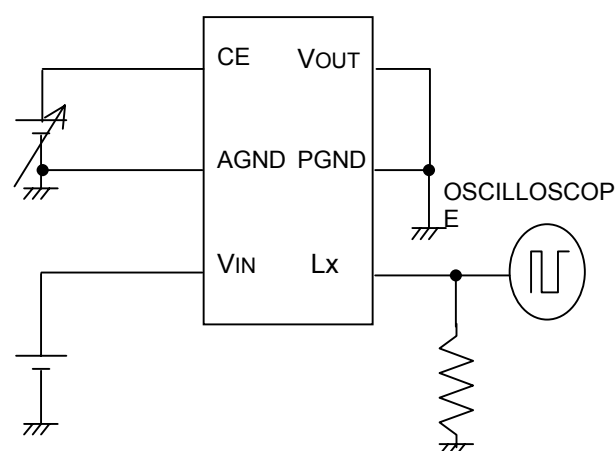
Vout“H”/“L”Current



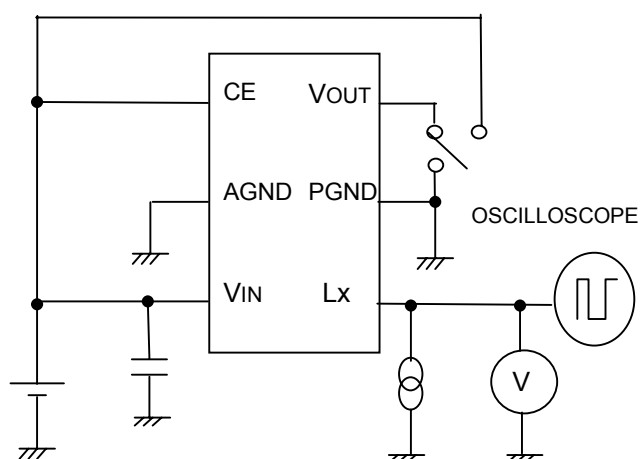
LX Leakage Current



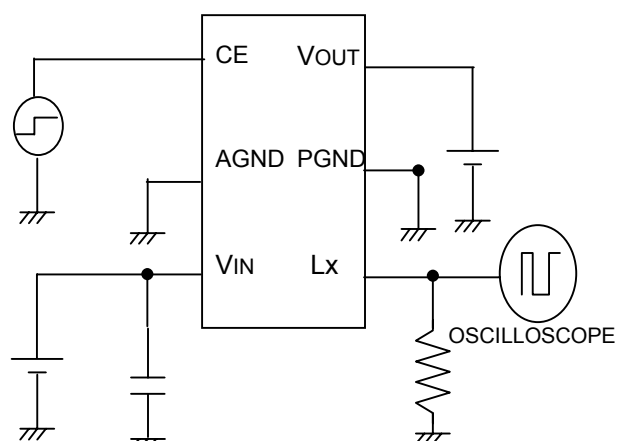
CE Input Voltage



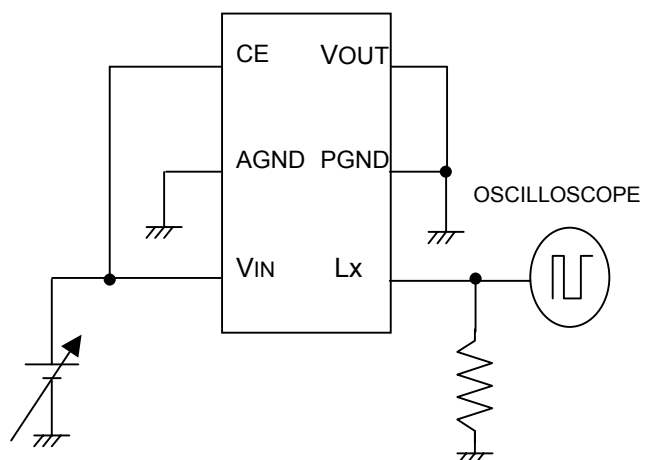
<Pch·Nch transistor ON resistance Output Delay for Protection·Lx Current Limit>



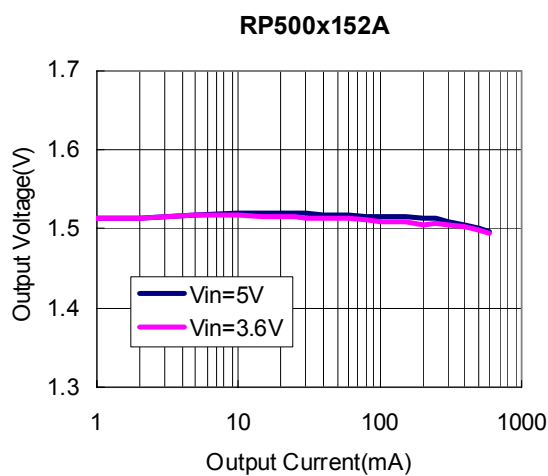
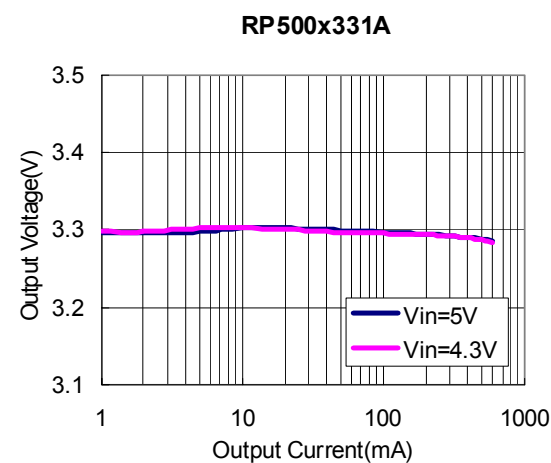
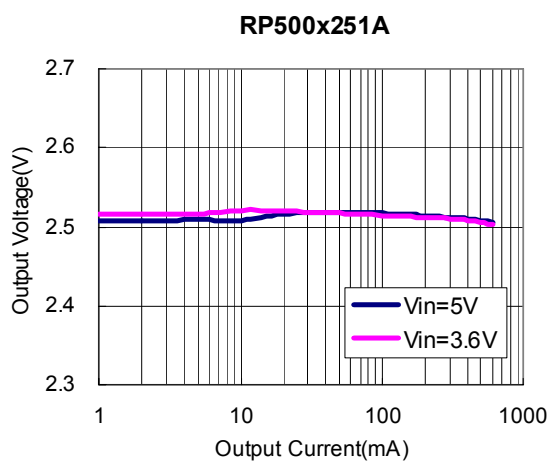
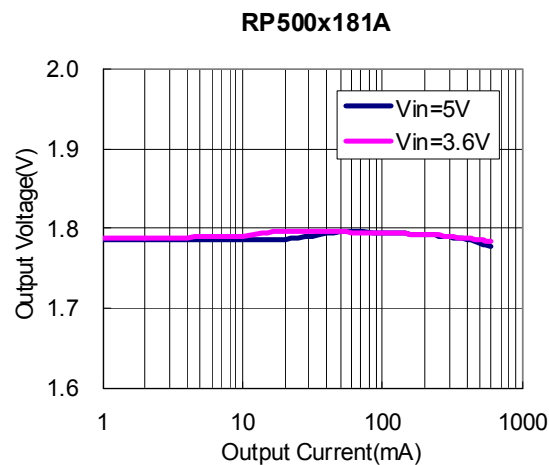
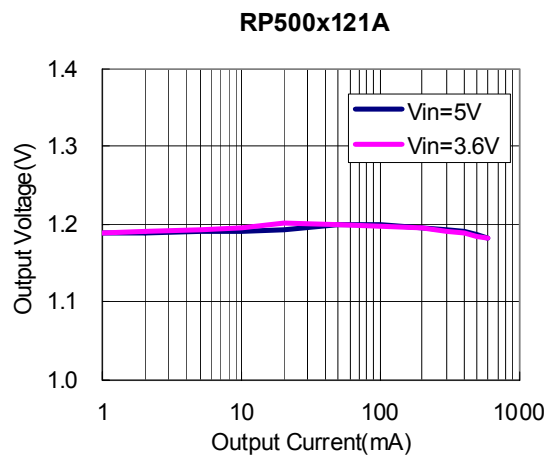
<Soft-start Time>



<UVLO Detector Threshold·Release Voltage>

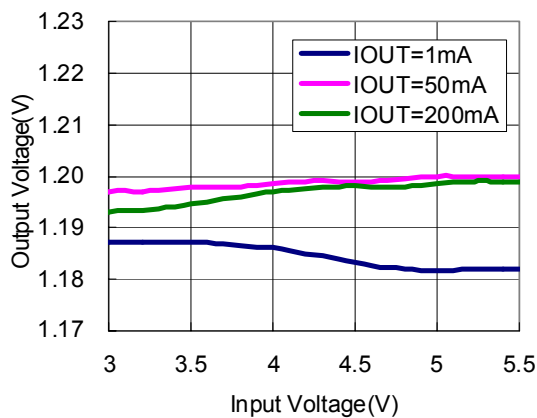


TYPICAL CHARACTERISTICS
1)Output Voltage VS. Output Current

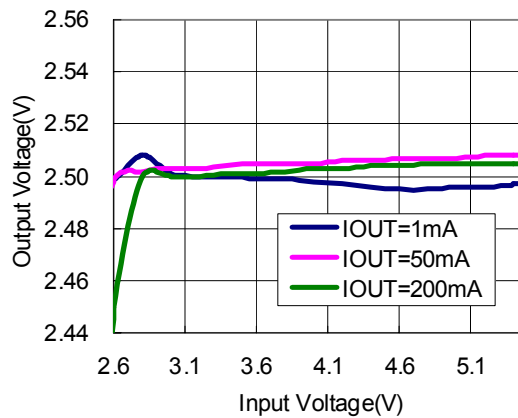


2) Output Voltage VS. Input Voltage

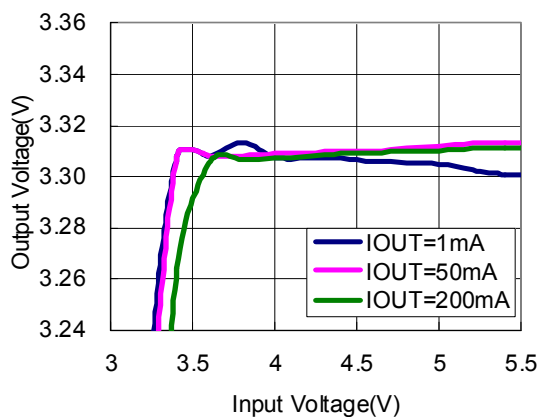
RP500x121A



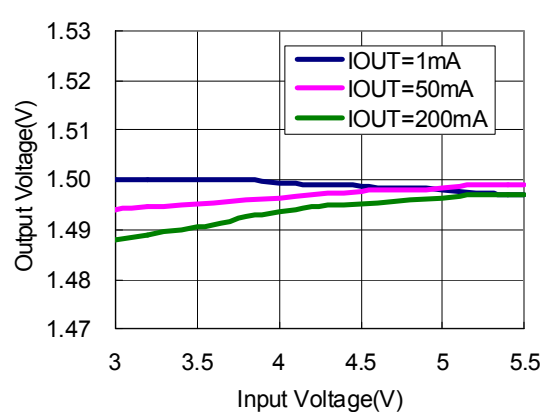
RP500x251A



RP500x331A

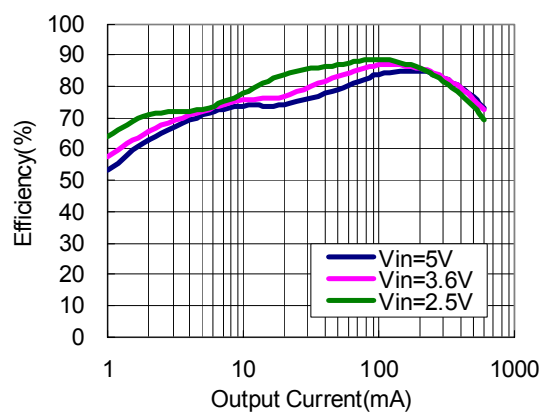


RP500x152A

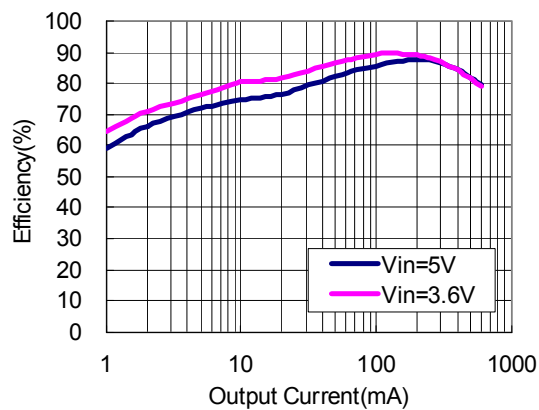


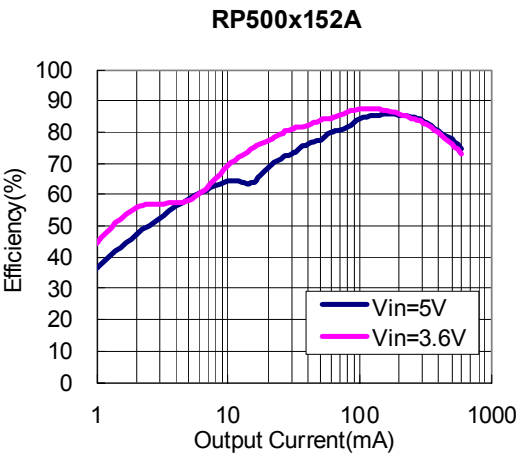
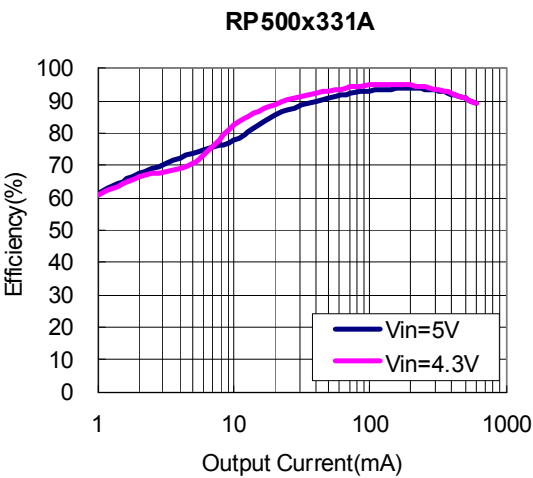
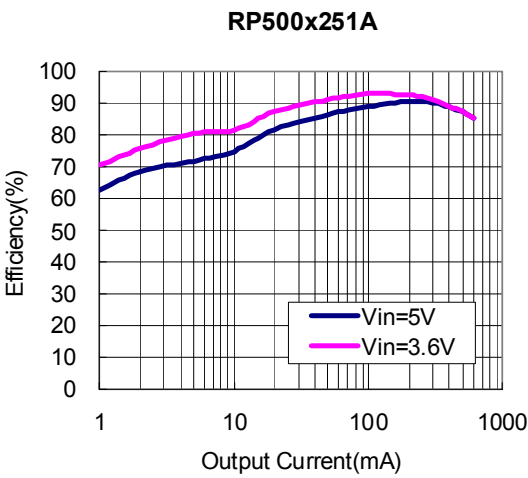
3) Efficiency VS. Output Current

RP500x121A

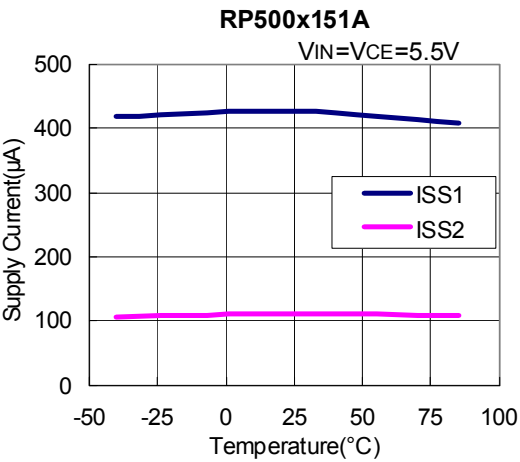


RP500x181A

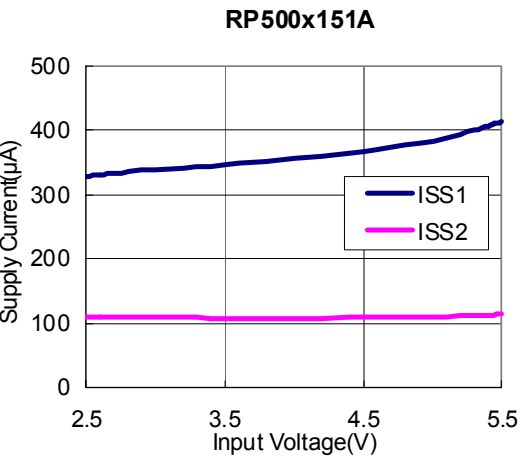




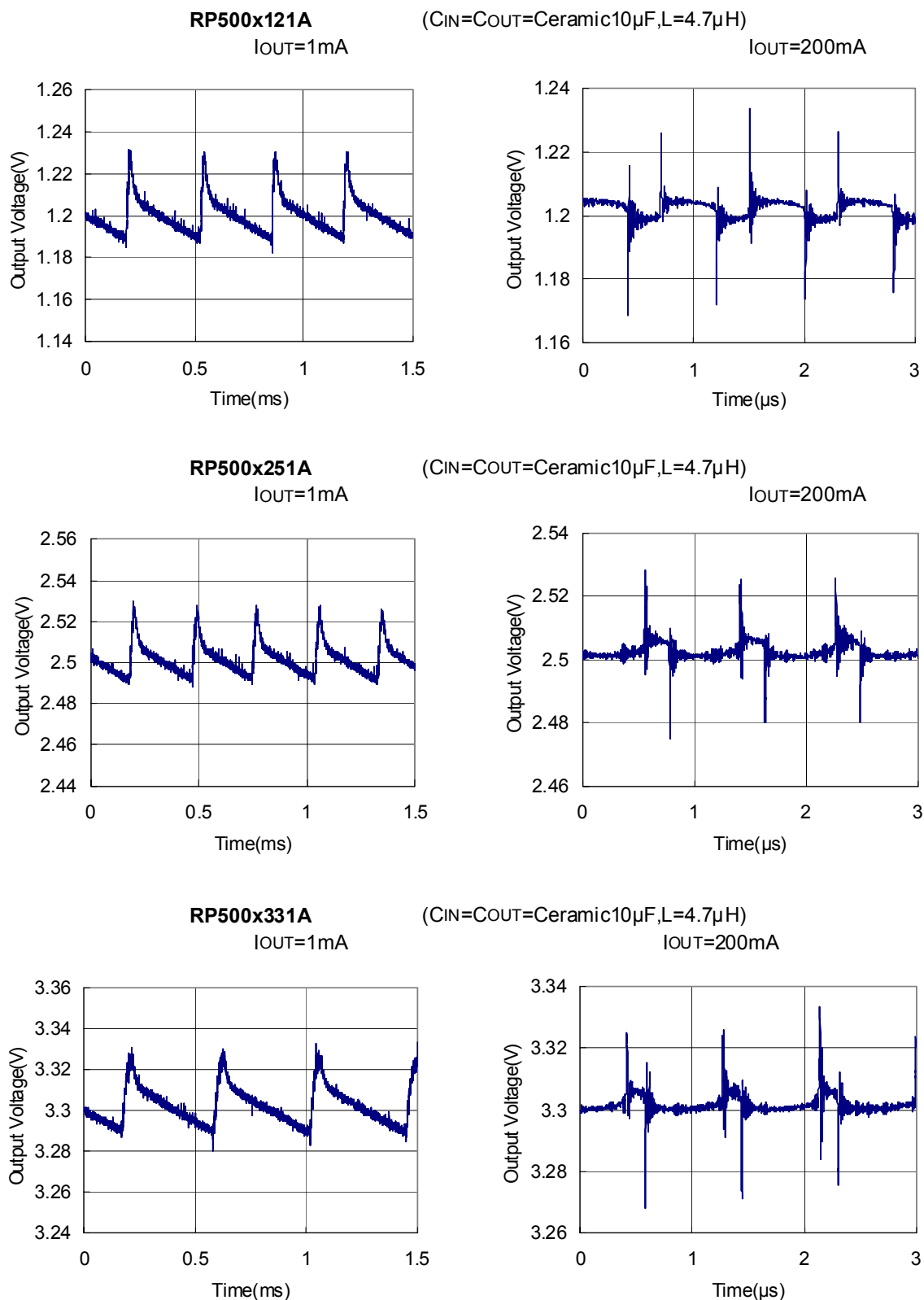
4)Supply Current 1,2 VS. Temperature



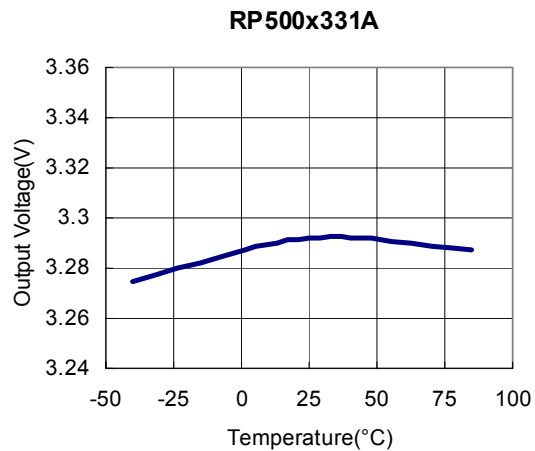
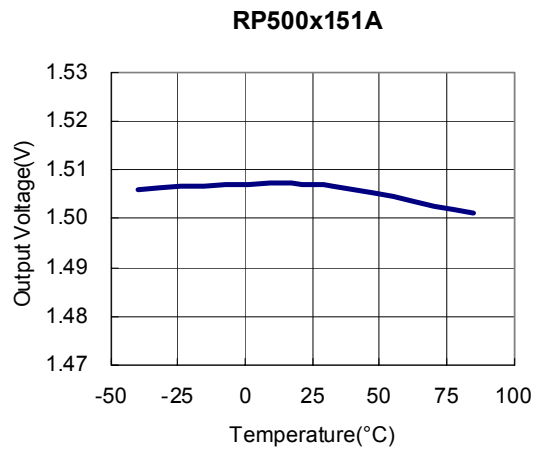
5)Supply Current 1,2 VS. Input Voltage



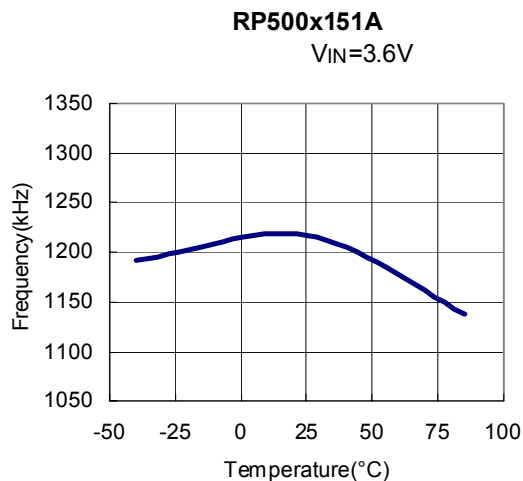
6)DC/DC Output Waveform



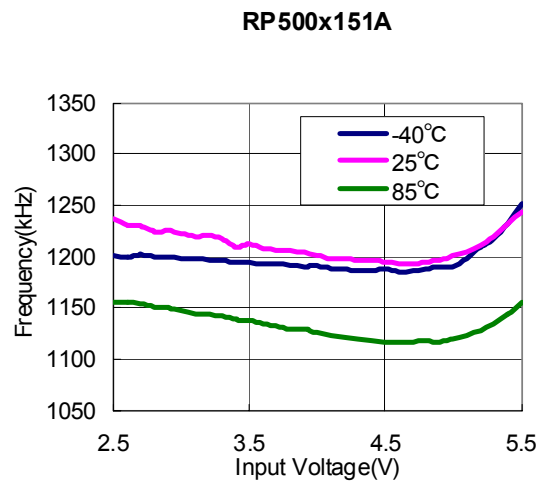
7) Output Voltage VS. Temperature



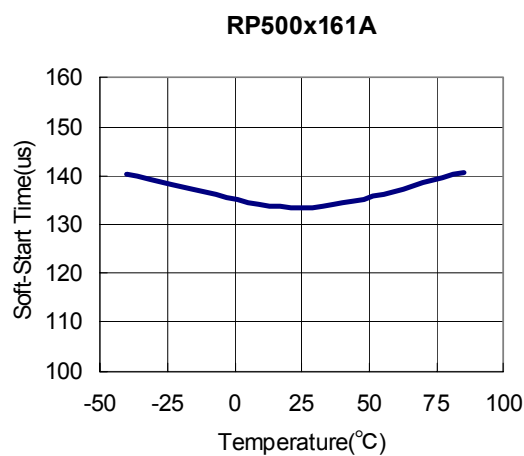
8) Osillator Frequency VS. Temperature



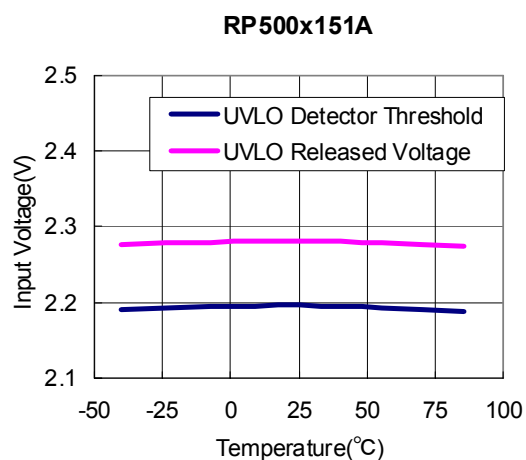
9) Osillator Frequency VS. Input Voltage



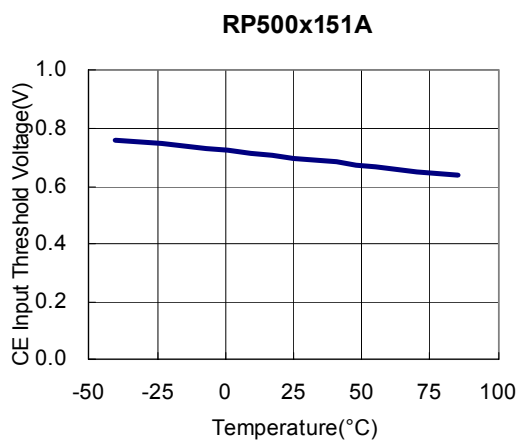
10) Soft-start Time VS. Temperature



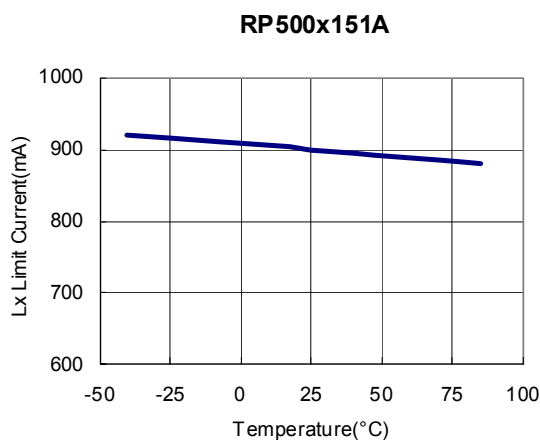
11) UVLO Detector Threshold / Released Voltage



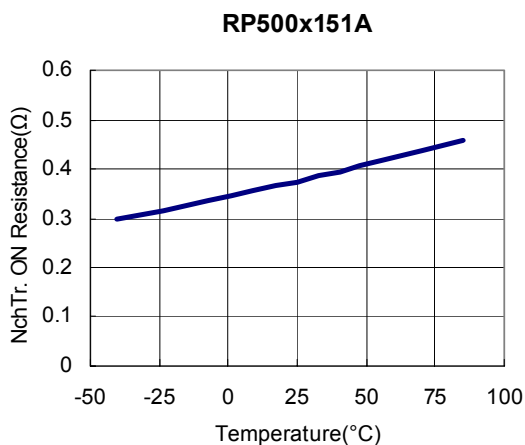
12)CE Input Voltage VS. Temperature



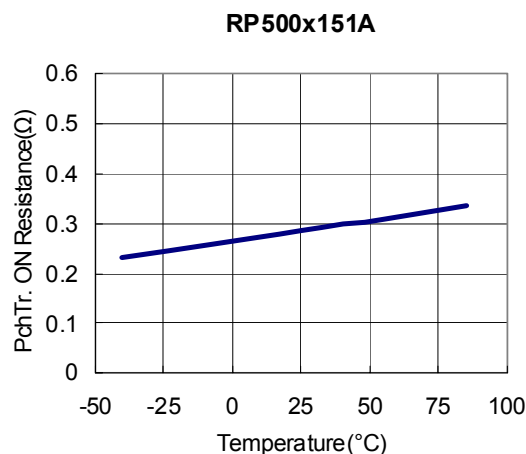
13)Lx Limit Current VS. Temperature



14)Nch Tr.ON Resistance VS. Temperature

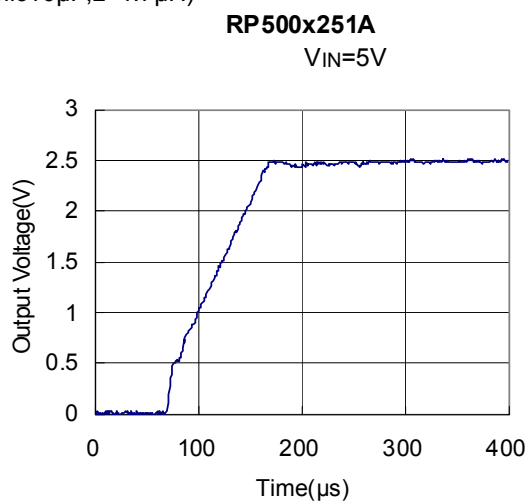
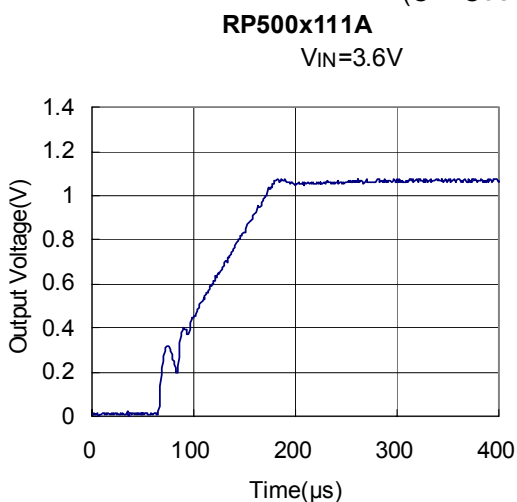


15)Pch Tr. ON Resistance VS. Temperature

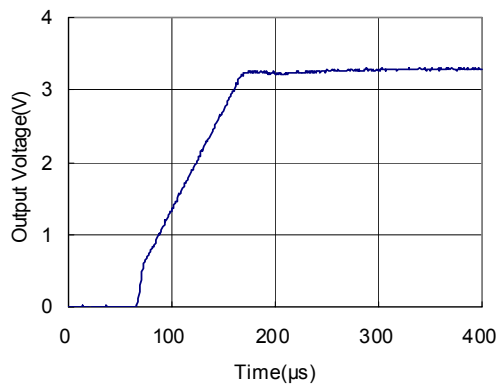


16)Start-Up Waveform

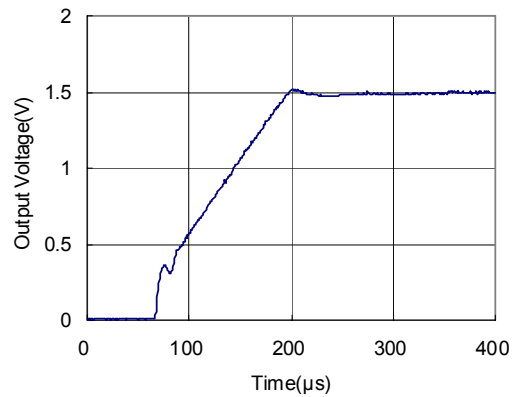
(C_{IN}=C_{OUT}=Ceramic10μF,L=4.7μH)



RP500x331A
VIN=5V

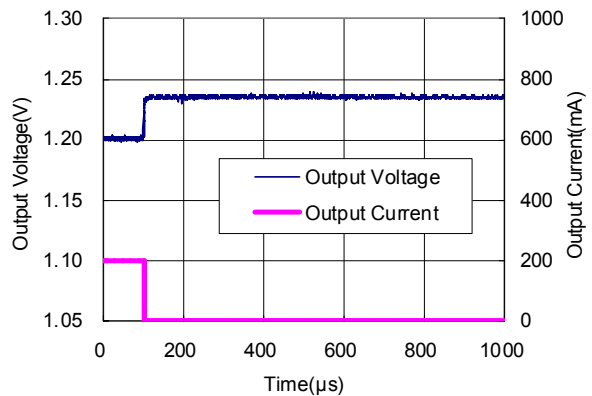
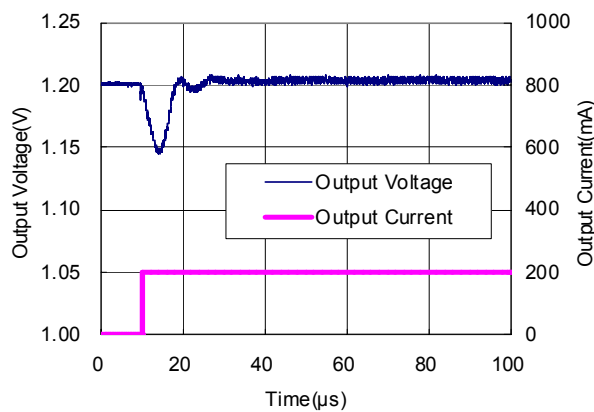


RP500x152A
VIN=3.6V

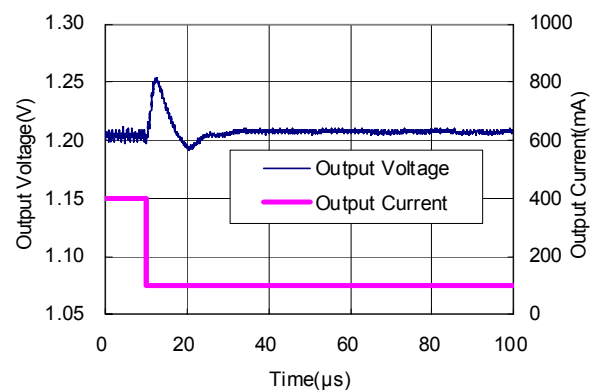
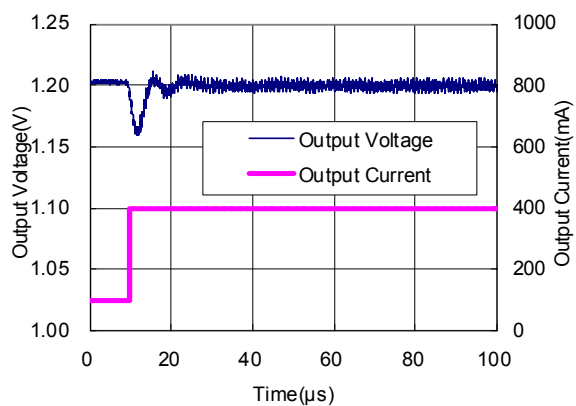


17) Load Transient Response

RP500x121A (CIN=COUT=Ceramic10μF,L=4.7μH,VIN=3.6V)
IOUT=0mA to 200mA IOUT=200mA to 0mA

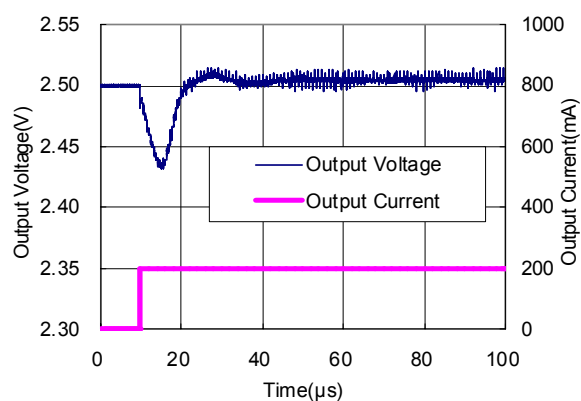


RP500x121A (CIN=COUT=Ceramic10μF,L=4.7μH,VIN=3.6V)
IOUT=100mA to 400mA IOUT=400mA to 100mA

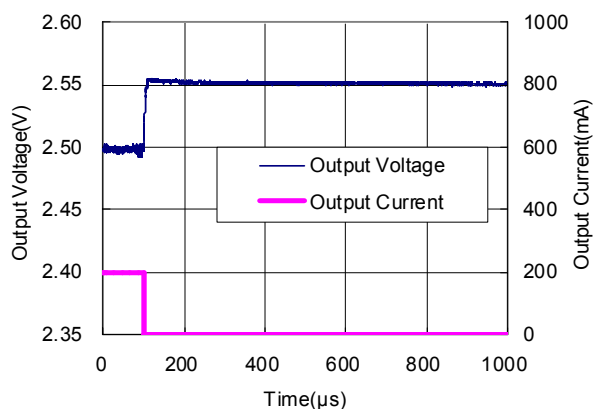


RP500x251A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=5.0\text{V}$)

$I_{OUT}=0\text{mA}$ to 200mA

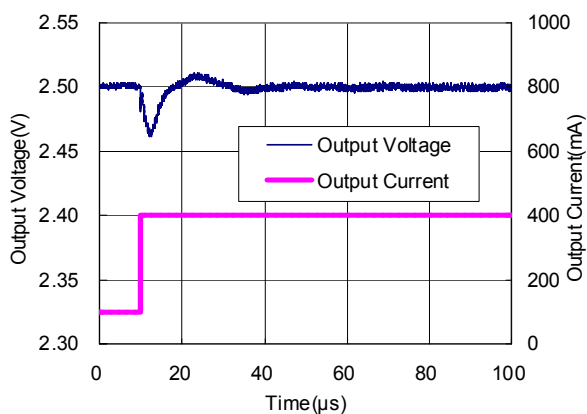


$I_{OUT}=200\text{mA}$ to 0mA

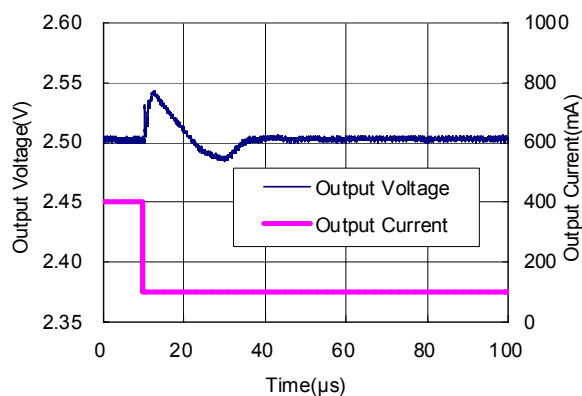


RP500x251A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=5.0\text{V}$)

$I_{OUT}=100\text{mA}$ to 400mA

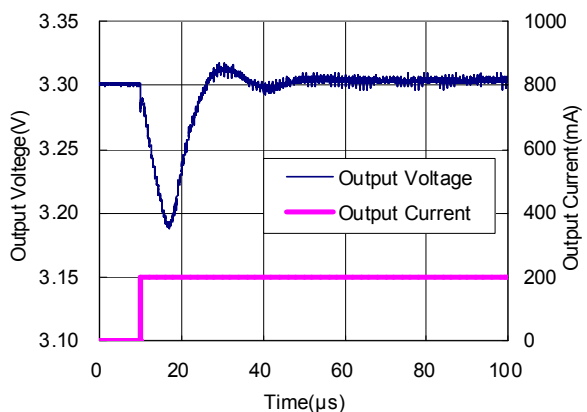


$I_{OUT}=400\text{mA}$ to 100mA

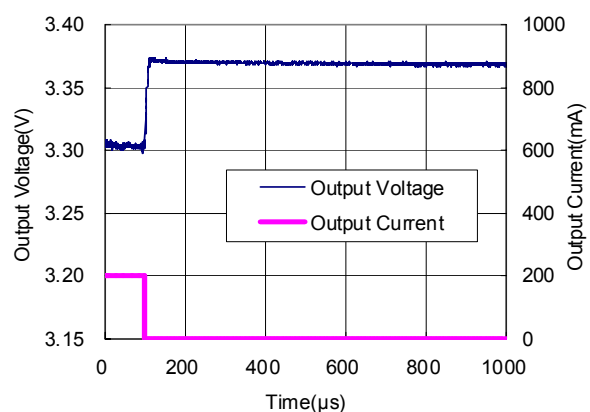


RP500x331A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=5.0\text{V}$)

$I_{OUT}=0\text{mA}$ to 200mA

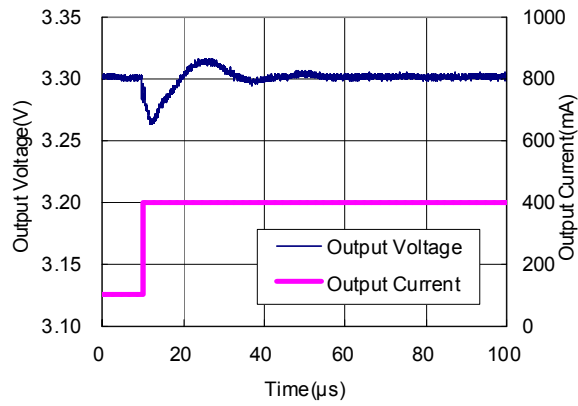


$I_{OUT}=200\text{mA}$ to 0mA

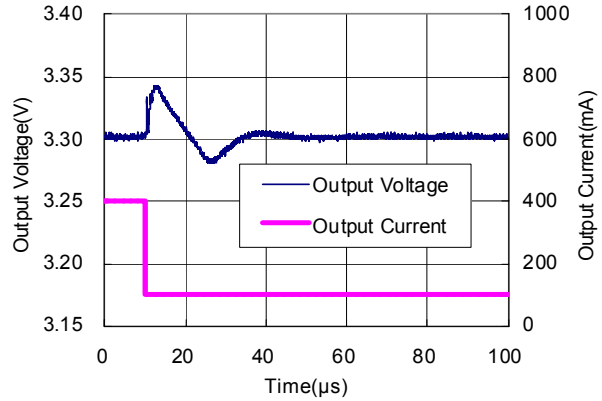


RP500x331A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=5.0\text{V}$)

$I_{OUT}=100\text{mA}$ to 400mA

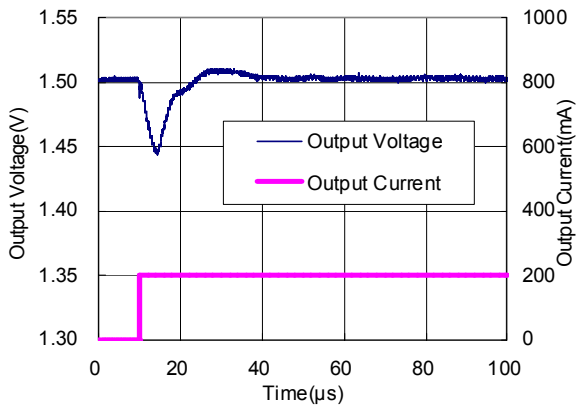


$I_{OUT}=400\text{mA}$ to 100mA

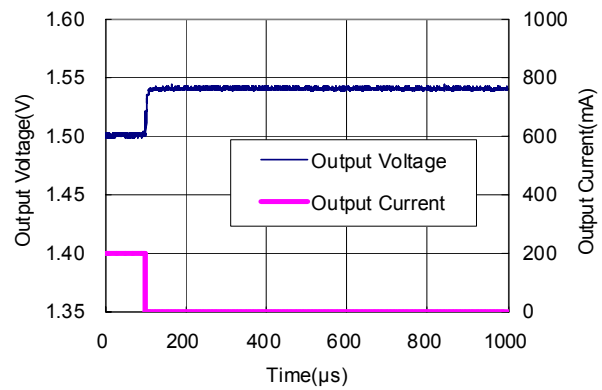


RP500x152A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=3.6\text{V}$)

$I_{OUT}=0\text{mA}$ to 200mA

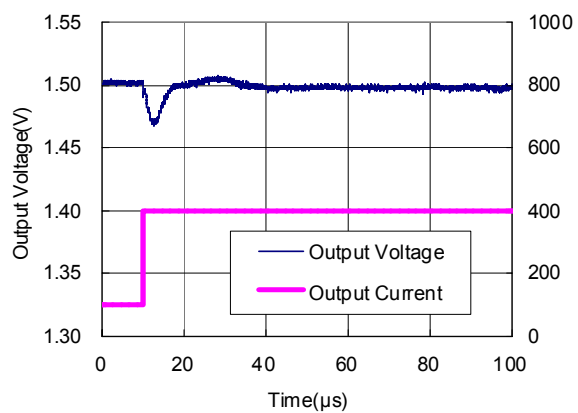


$I_{OUT}=200\text{mA}$ to 100mA



RP500x152A ($C_{IN}=C_{OUT}=\text{Ceramic}10\mu\text{F}, L=4.7\mu\text{H}, V_{IN}=3.6\text{V}$)

$I_{OUT}=100\text{mA}$ to 400mA



$I_{OUT}=400\text{mA}$ to 100mA

