

600mA* Step-down DC/DC Converter with Synchronous Rectifier

NO.EA-155-111124

OUTLINE

The RP500x Series are CMOS-based 600mA* 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. 0.1V 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 WLCSP-6-P2, DFN1616-6, DFN(PLP)1820-6, SOT-23-6W, high density mounting on boards is possible.

*)This is an approximate value, because output current depends on conditions and external parts.

FEATURES

- Supply Current Typ. 400 μ A (at PWM mode)
Typ. 100 μ A (at VFM mode)
- Standby Current Max. 5 μ A
- Input Voltage Range 2.55V to 5.50V
- Output Voltage Range..... 1.1V to 3.3V (0.1V steps)
(For other voltages, please refer to MARK INFORMATIONS.)
- Output Voltage Accuracy..... $\pm 1.5\%$ ($V_{OUT} \geq 1.6V$), $\pm 24mV$ ($V_{OUT} < 1.6V$)
- Temperature-Drift Coefficient of Output Voltage ... Typ. $\pm 100ppm/^{\circ}C$
- Oscillator Frequency Typ. 1.2MHz
- Oscillator Maximum Duty Cycle Min. 100%
- Built-in Driver ON Resistance Typ. Pch. 0.3 Ω , Nch. 0.38 Ω ($V_{IN} = 3.6V$)
- UVLO Detector Threshold..... Typ. 2.2V
- Soft Start Time..... Typ. 120 μ s
- Lx Current Limit..... Typ. 900mA
- Latch type Protection Circuit Typ. 1.5ms
- Two choices of Switching Mode..... Automatic PWM/VFM mode change / PWM fixed
- Packages WLCSP-6-P2, DFN1616-6, DFN(PLP)1820-6, SOT-23-6W

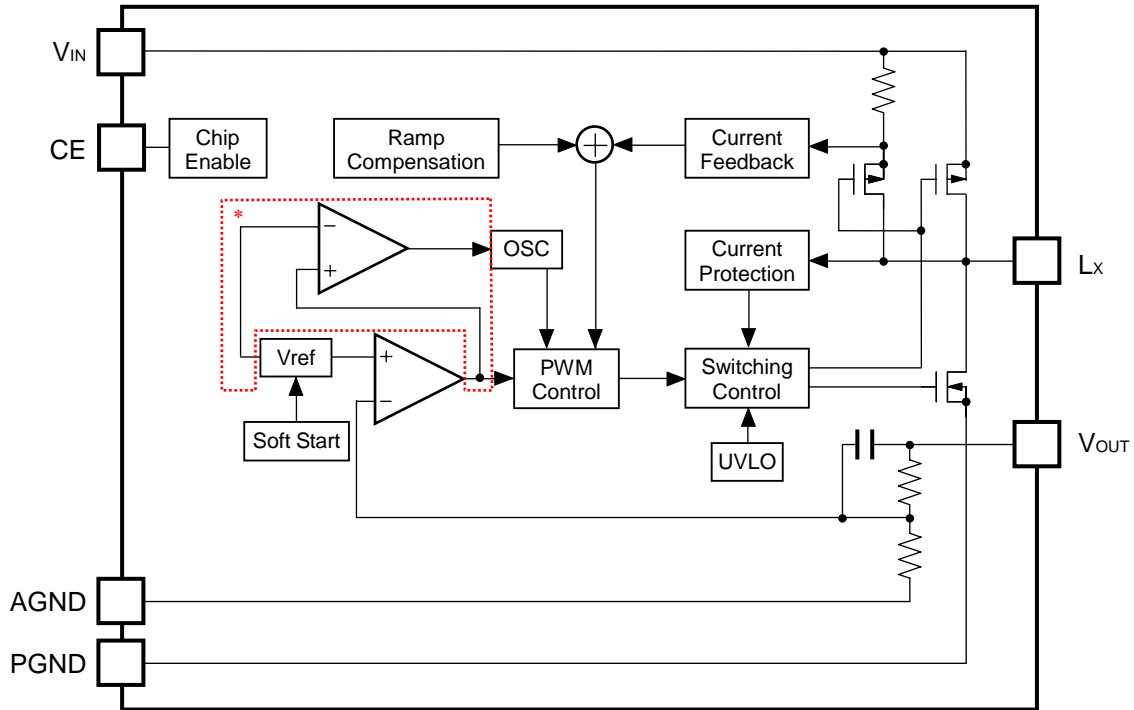
APPLICATIONS

- Power source for battery-powered equipment.
- Power source for hand-held communication equipment, cameras, VCRs, camcorders.
- Power source for HDD, portable equipment.

RP500x

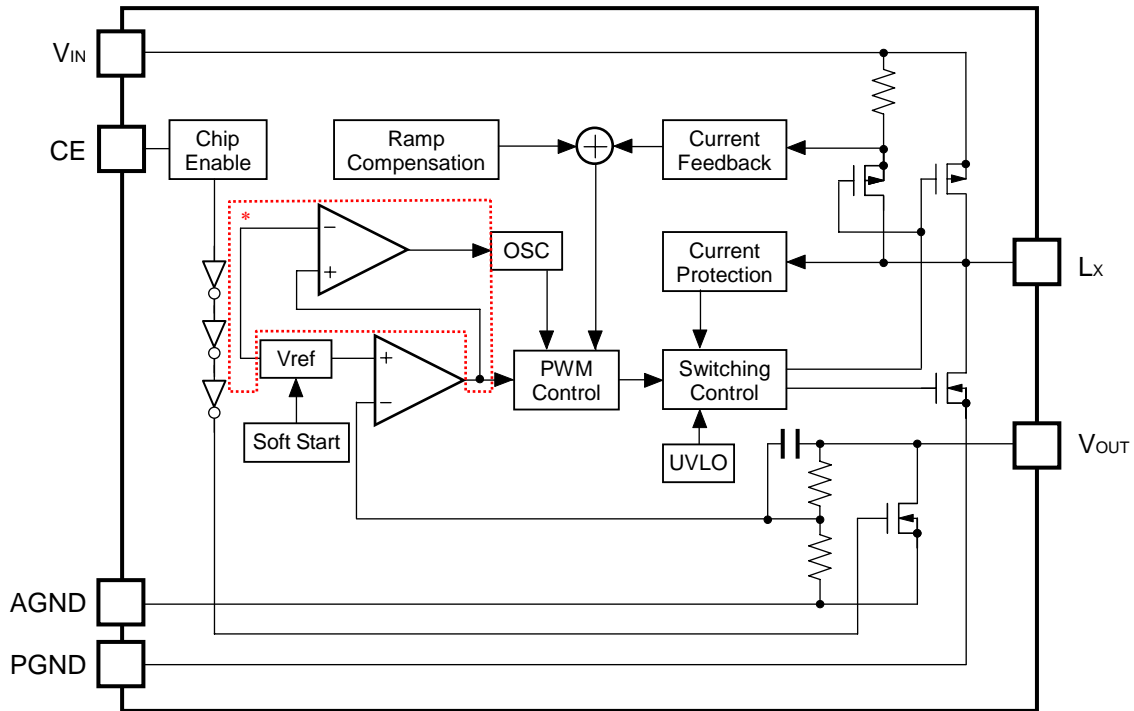
BLOCK DIAGRAMS

RP500xxx1A/2A



*) only RP500xxx1A for automatic PWM/VFM mode change

RP500xxx3A/4A



*) only RP500xxx3A for automatic PWM/VFM mode change

SELECTION GUIDE

The output voltage, switching mode, and auto discharge function for the ICs can be selected at the user's request.

Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
RP500Zxx*A-E2-F	WLCSP-6-P2	5,000 pcs	Yes	Yes
RP500Lxx*A-TR	DFN1616-6	5,000 pcs	Yes	Yes
RP500Kxx*A-TR	DFN(PLP)1820-6	5,000 pcs	Yes	Yes
RP500Nxx*A-TR-FE	SOT-23-6W	3,000 pcs	Yes	Yes

xx: The output voltage can be designated in the range from 1.1V(11) to 3.3V(33) in 0.1V steps^{*1}.
(For other voltages, please refer to MARK INFORMATIONS.)

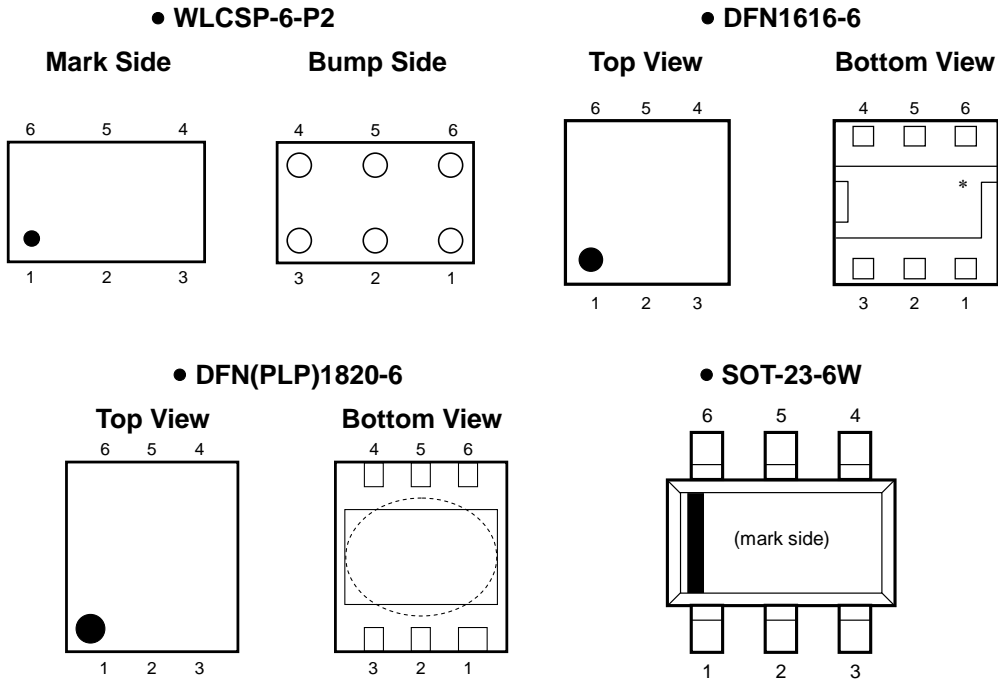
* : The switching mode, and auto discharge function can be designated.

Code	Modulation method	Auto discharge function
1	PWM/VFM auto switching	No
2	PWM fixed	No
3	PWM/VFM auto switching	Yes
4	PWM fixed	Yes

(The RP500Kxx3A does not exist. Please use RP500Lxx3A.)

*1) 0.05V step is also available as a custom code.

PIN CONFIGURATIONS



PIN DESCRIPTIONS

• WLCSP-6-P2, SOT-23-6W

Pin No	Symbol	Pin Description
1	V_{OUT}	Output Pin
2	PGND	Ground Pin
3	Lx	Lx Switching Pin
4	V_{IN}	Input Pin
5	AGND	Ground Pin
6	CE	Chip Enable Pin ("H" Active)

• DFN1616-6, DFN(PLP)1820-6

Pin No	Symbol	Pin Description
1	CE	Chip Enable Pin ("H" Active)
2	AGND	Ground Pin
3	V_{IN}	Input Pin
4	Lx	Lx Switching Pin
5	PGND	Ground Pin
6	V_{OUT}	Output Pin

*) 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}	Input Voltage	-0.3 to 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 6.5	V
V_{OUT}	Output Voltage	-0.3 to 6.5	V
I_{Lx}	Lx Pin Output Current	800	mA
P_D	Power Dissipation (WLCSP-6-P2) *	650	mW
	Power Dissipation (DFN1616-6) *	640	
	Power Dissipation (DFN(PLP)1820-6) *	880	
	Power Dissipation (SOT-23-6W) *	430	
T_{opt}	Operating Temperature Range	-40 to 85	°C
T_{stg}	Storage Temperature Range	-55 to 125	°C

*) For Power Dissipation, please refer to PACKAGE INFORMATION.

ABSOLUTE MAXIMUM RATINGS

Electronic and mechanical stress momentarily exceeded absolute maximum ratings may cause the permanent damages and may degrade the life time and safety for both device and system using the device in the field. The functional operation at or over these absolute maximum ratings is not assured.

RP500x

ELECTRICAL CHARACTERISTICS

• RP500x

T_{opt}=25°C

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit	
V _{IN}	Operating Input Voltage		2.55		5.5	V	
V _{OUT}	Output Voltage	V _{IN} =V _{CE} =3.6V or Set V _{OUT} +1V	V _{OUT} ≥ 1.6V	×0.985	×1.015	V	
			V _{OUT} < 1.6V	-24	24	mV	
ΔV _{OUT} /ΔT _{opt}	Output Voltage Temperature Coefficient	-40°C ≤ T _{opt} ≤ 85°C		±100		ppm /°C	
f _{osc}	Oscillator Frequency	V _{IN} =V _{CE} =3.6V or Set V _{OUT} +1V	0.96	1.2	1.44	MHz	
I _{DD1}	Supply Current 1	V _{IN} =V _{CE} =5.5V, V _{OUT} =0V		400	500	μA	
I _{DD2}	Supply Current 2	V _{IN} =V _{CE} =V _{OUT} =5.5V	PWM/VFM		100	160	μA
			PWM fixed		400	500	
I _{standby}	Standby Current	V _{IN} =5.5V, V _{CE} =0V		0	5	μA	
R _{ONP}	ON Resistance of Pch Tr.	V _{IN} =3.6V, I _{LX} =-100mA		0.3		Ω	
R _{ONN}	ON Resistance of Nch Tr.	V _{IN} =3.6V, I _{LX} =-100mA		0.38		Ω	
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	
I _{VOUTH}	V _{OUT} "H" Input Current *1	V _{IN} =V _{OUT} =5.5V, V _{CE} =0V	-1	0	1	μA	
I _{VOU TL}	V _{OUT} "L" Input Current	V _{IN} =5.5V, V _{CE} =V _{OUT} =0V	-1	0	1	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	
V _{CEH}	CE Input Voltage "H"	V _{IN} =5.5V	1.0			V	
V _{CEL}	CE Input Voltage "L"	V _{IN} =5.5V			0.4	V	
Maxduty	Oscillator Maximum Duty Cycle		100			%	
t _{start}	Soft-start Time	V _{IN} =V _{CE} =3.6V or Set V _{OUT} +1V		120	150	μs	
I _{LXlim}	Lx Current Limit	V _{IN} =V _{CE} =3.6V or Set V _{OUT} +1V	600	900		mA	
t _{prot}	Protection Delay Time	V _{IN} =V _{CE} =3.6V or Set V _{OUT} +1V	0.5	1.5	5.0	ms	
V _{UVLO1}	UVLO Detector Threshold	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	
R _{LOW}	Low Output Nch Tr. ON Resistance *2	V _{IN} =3.6V, V _{CE} =0V		80		Ω	

Test circuit is "OPEN LOOP" and AGND=PGND=0V unless otherwise noted.

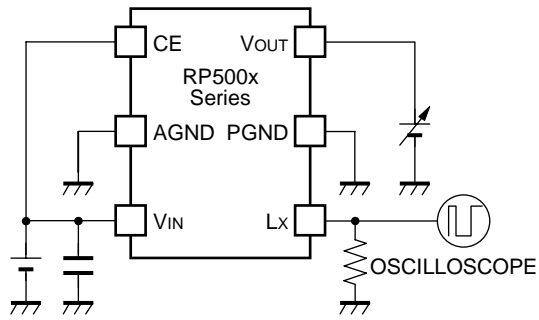
*1) without auto discharge version only

*2) with auto discharge version only

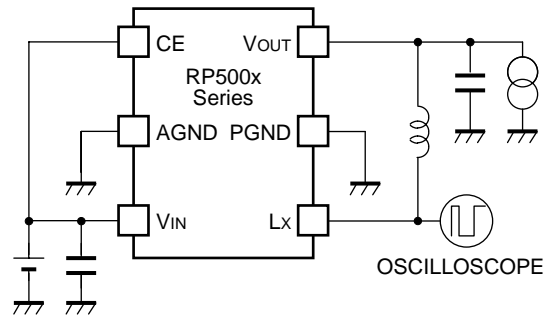
RECOMMENDED OPERATING CONDITIONS (ELECTRICAL CHARACTERISTICS)

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.

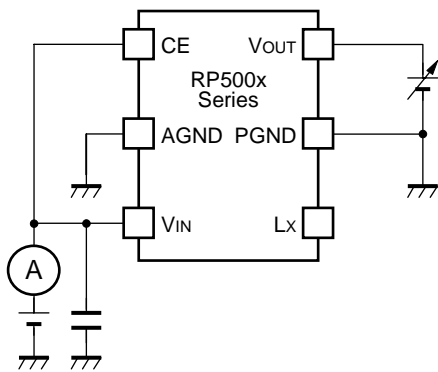
TEST CIRCUITS



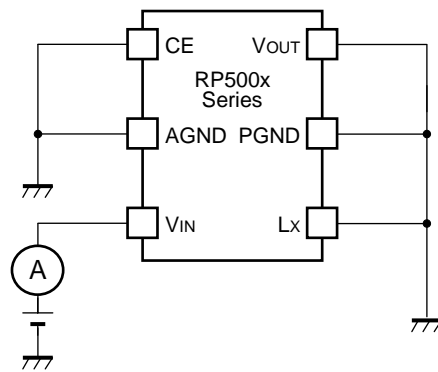
Output Voltage



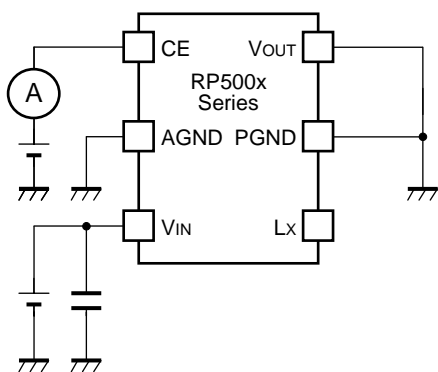
Oscillator Frequency



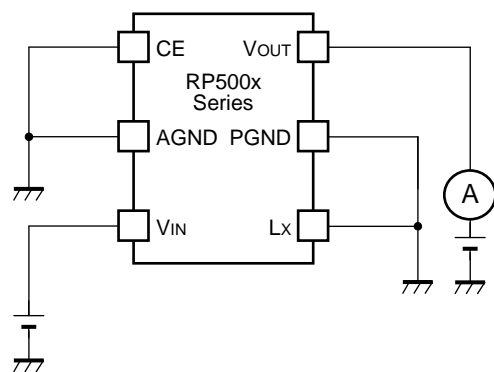
Supply Current 1,2



Standby Current



CE "H"/"L" Input Current



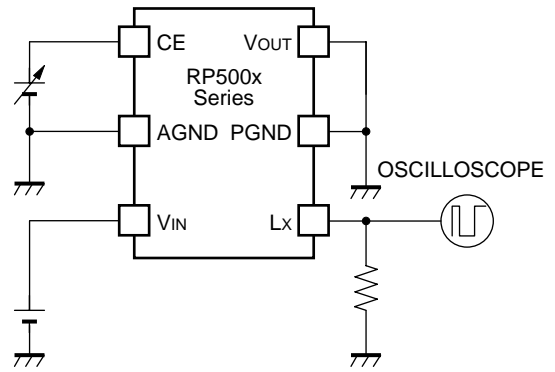
VOUT "H"/"L" Current

* RP500Z (WLCSP-6-P2) is the limited product. As of March in 2018.

RP500x



Lx Leakage Current



CE Input Voltage



**Pch • Nch transistor ON resistance /
Output Delay for Protection / Lx Current limit**

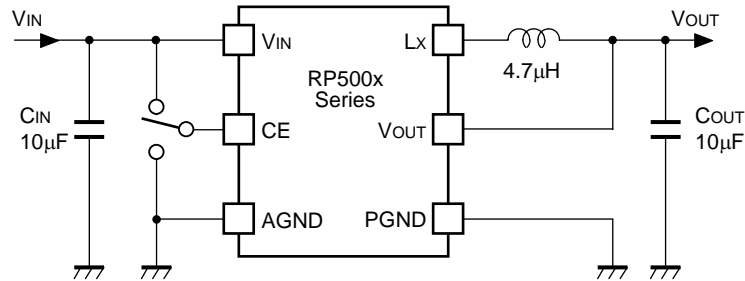


Soft-start Time



UVLO Detector Threshold • Released Voltage

TYPICAL APPLICATION



Symbol	Parts Recommendation		
C _{IN}	10µF	Ceramic	C2012JB0J106K (TDK)
C _{OUT}	10µF	Ceramic	C2012JB0J106K (TDK)
L	4.7µH	VLF3010AT-4R7MR30	

TECHNICAL NOTES

When using these ICs, consider the following points:

- Set the same level as AGND and PGND.
- 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. 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. The wiring between V_{OUT} and load and between L and V_{OUT} should be separated.
- Use an external capacitor C_{IN} between V_{IN} and GND, and C_{OUT} with a capacity of 10µF or more ceramic type.
- Choose an inductor with inductance range from 4.7µH to 10µH. 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, L_x peak current may increase and may overlap the L_x current limit. As a result, over current protection may work.
- Over current protection circuit may be affected by self-heating and heat radiation environment.

*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)

RP500x

Operation of step-down DC/DC converter and 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: Pch Tr. turns on and current IL (=i1) flows, and energy is charged into CL. At this moment, IL increases from ILmin (=0) to reach ILmax in proportion to the on-time period (ton) of Pch Tr.
- Step 2: When Pch Tr. turns off, Synchronous rectifier Nch 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 topon, and Nch 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.

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

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

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

wherein,

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

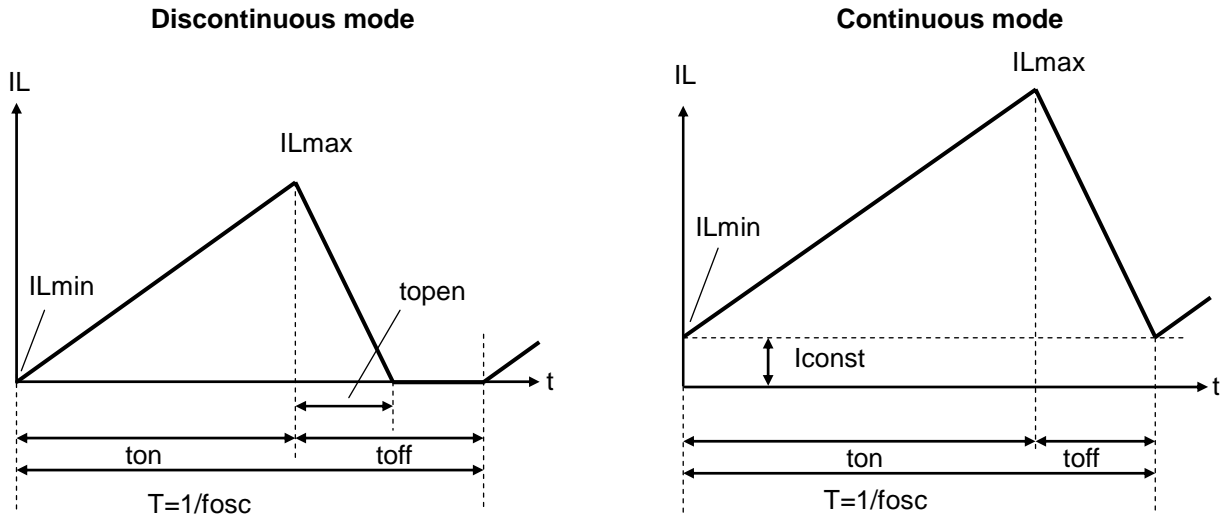
$$\text{duty (\%)} = t_{on} / T \times 100 = t_{on} \times f_{osc} \times 100$$

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

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

Discontinuous mode and Continuous mode

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



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

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

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

Output Current and selection of External components

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

When Pch Tr. of L_x is ON:

(Wherein, Ripple Current p-p value is described as I_{RP} , ON resistance of Pch Tr. and Nch 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 .)

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

When Pch Tr. of L_x is "OFF" (Nch Tr. is "ON"):

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

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

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

RP500x

Ripple Current is as follows:

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

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

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

Consider $I_{Lx\max}$, condition of input and output and select external components.

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

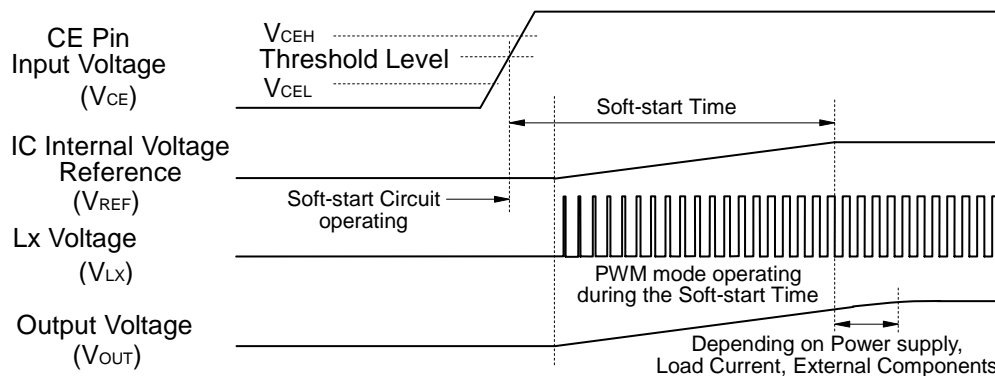
TIMING CHART

(1) Soft Start Time

- In the case of starting this IC with CE

In the case of starting this IC with CE, the operation can be as in the timing chart below.

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



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

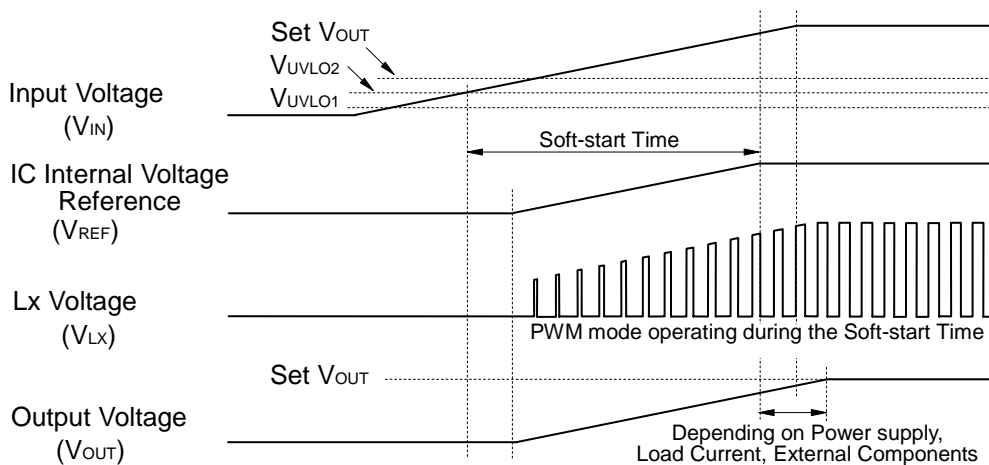
*Soft start time is not always equal to the turn-on speed of DC/DC converter.

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

- In the case of starting with power supply

In the case of starting with power supply, when the input voltage (V_{IN}) is larger than UVLO released voltage (V_{UVLO2}), soft start circuit operates, and after that, the same explanation above is applied to the operation.

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



*Turn-on speed is affected by next conditions;

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

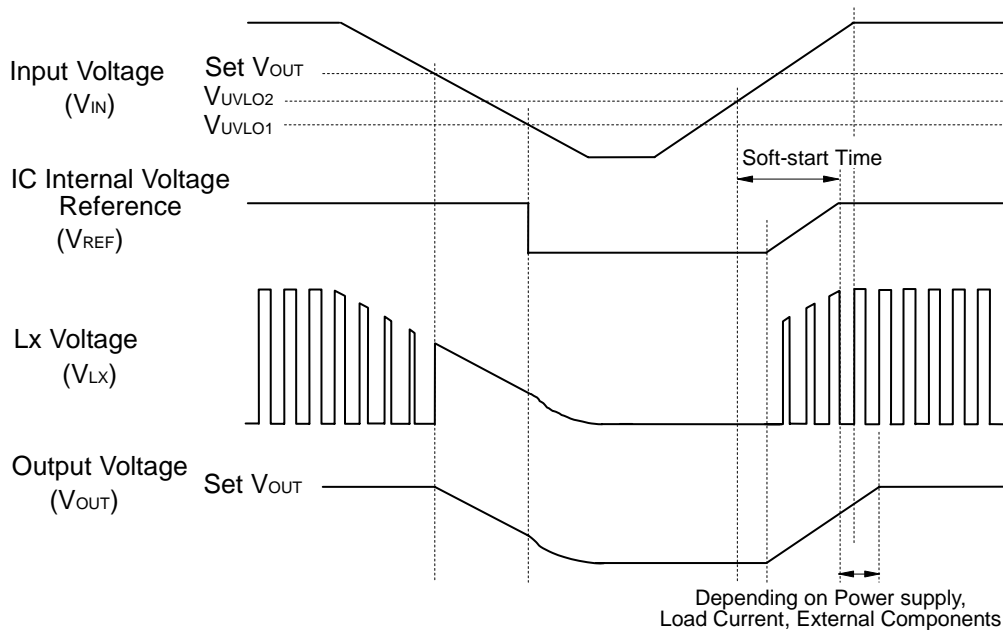
RP500x

(2) Under Voltage Lockout (UVLO) Circuit

The step-down DC/DC converter stops and ON duty becomes 100%, if input voltage (V_{IN}) becomes less than the set output voltage (Set V_{OUT}), the output voltage (V_{OUT}) gradually drops according to the input voltage (V_{IN}). If the input voltage drops more and becomes less than UVLO detector threshold (V_{UVLO1}), the under voltage lockout circuit (UVLO) operates, the IC internal reference voltage (V_{REF}) stops, switching transistors turn off and the output voltage drops according to the load and output capacitor C_{OUT} value.

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

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



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

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

Over current protection circuit supervises the coil peak current (the current flowing Pch transistor) at each switching cycle, and if the current beyond the Lx current limit (I_{Lxlim}), Pch transistor is turned off. the Lx current limit of RP500x is Typ.900mA.

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

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

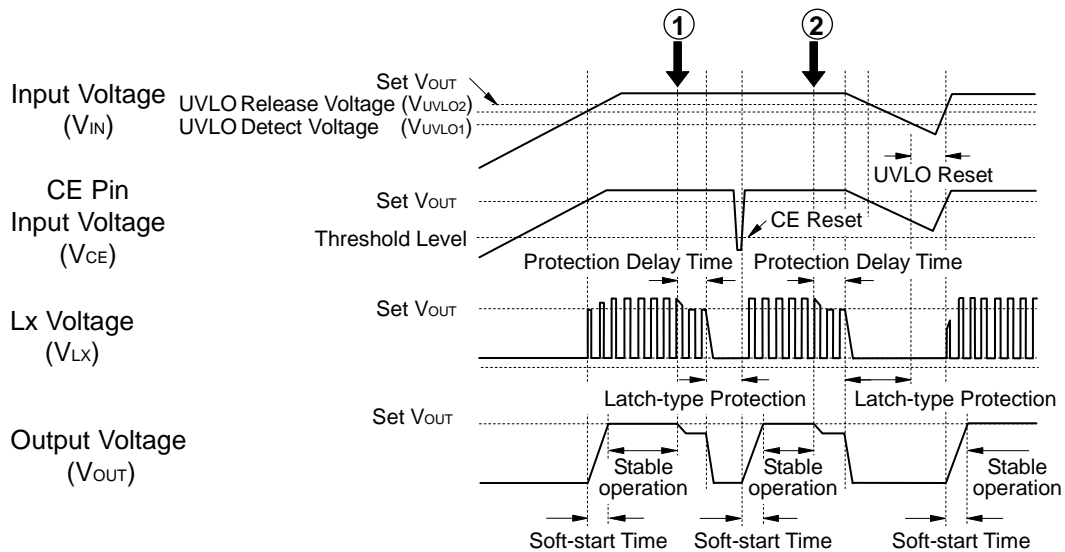


To release the condition of latch type protection, restart this IC by inputting "L" signal to CE pin, or restart this IC with power-on or make the supply voltage lower than UVLO detector threshold (V_{UVLO1}) level.

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

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

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

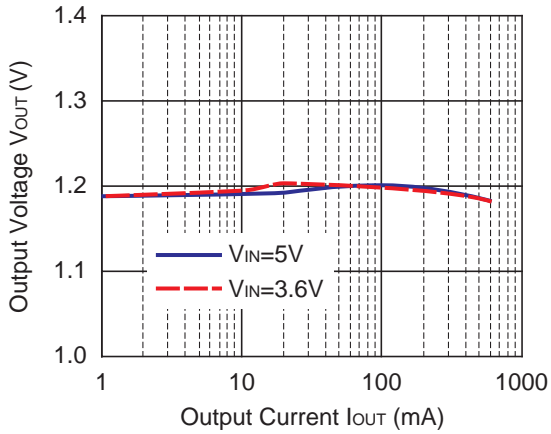


RP500x

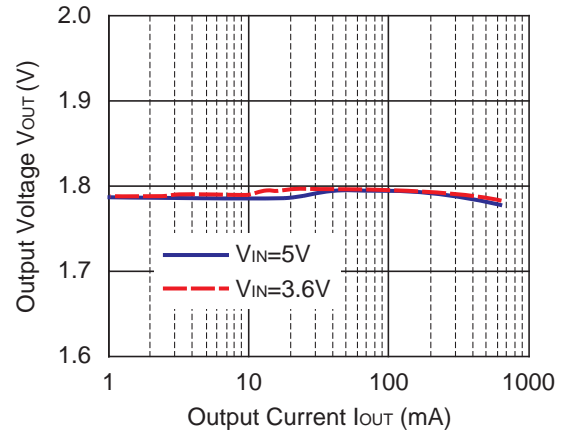
TYPICAL CHARACTERISTICS

1) Output Voltage vs. Output Current

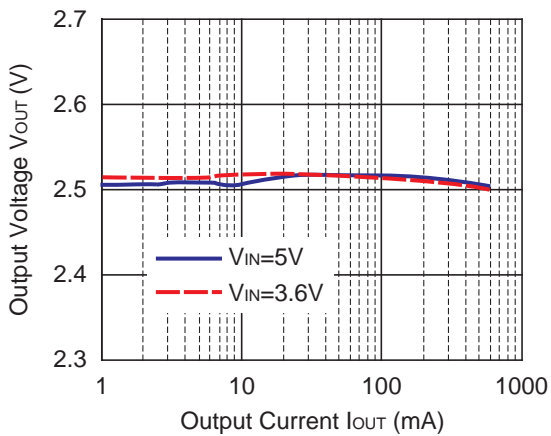
RP500x121A/123A



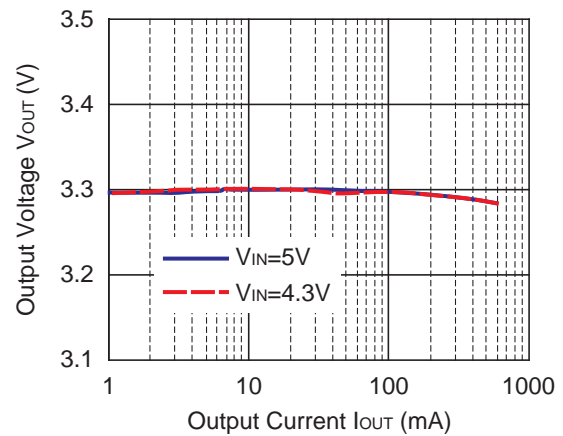
RP500x181A/183A



RP500x251A/253A



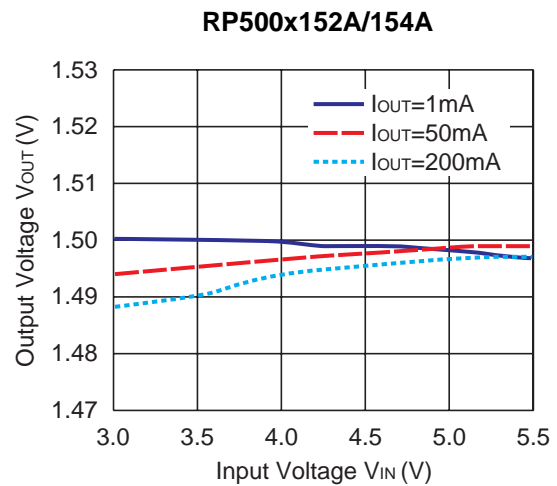
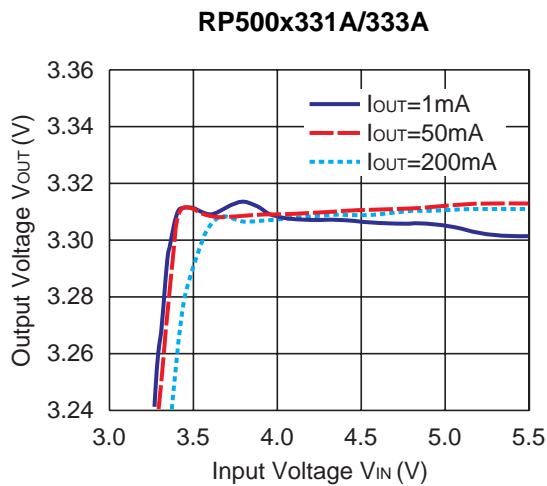
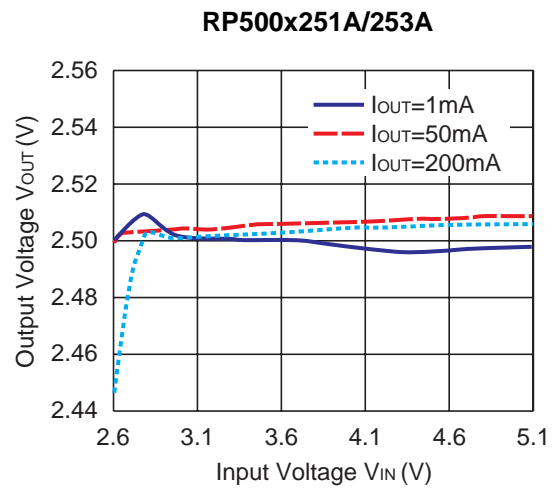
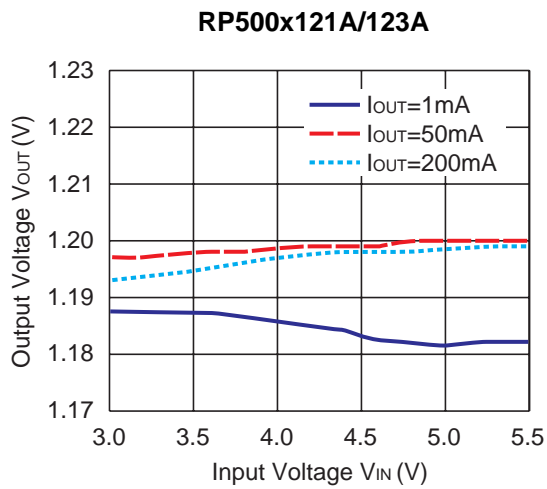
RP500x331A/333A



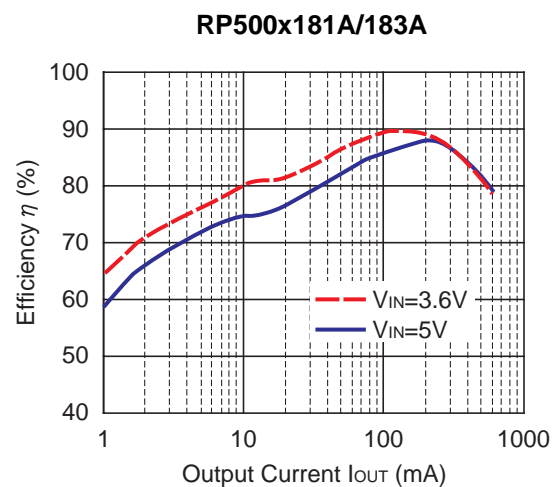
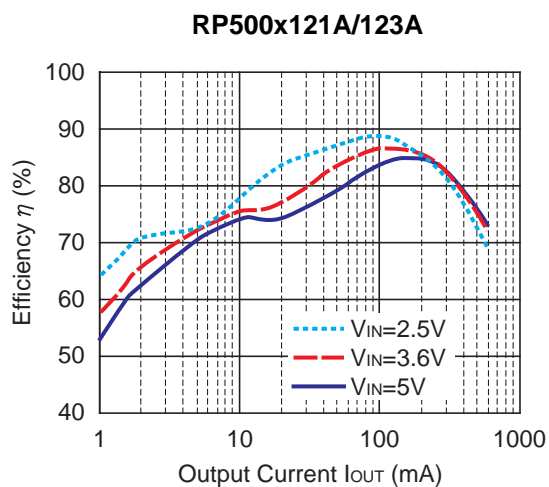
RP500x152A/154A



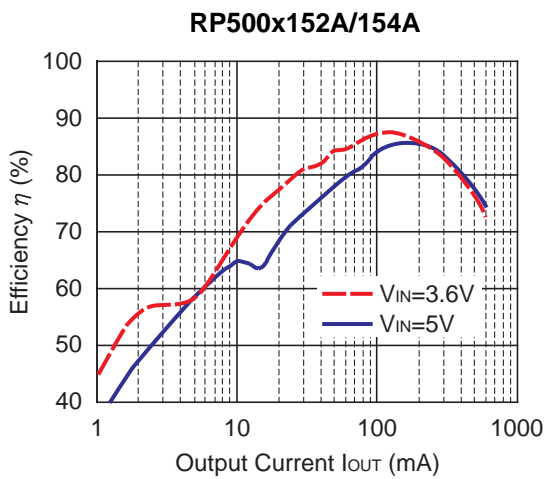
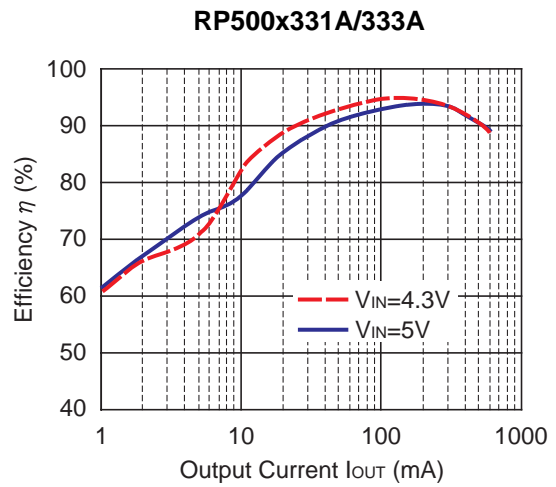
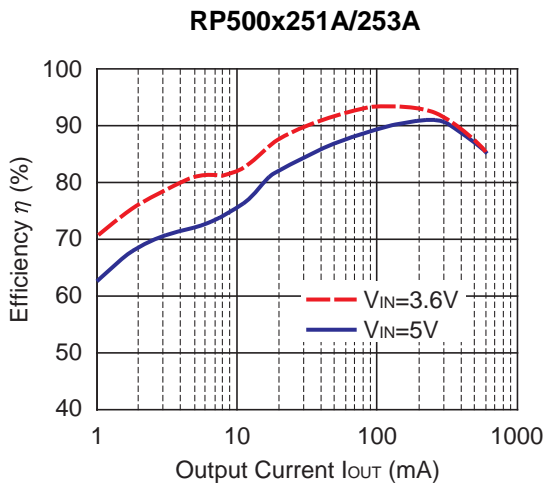
2) Output Voltage vs. Input Voltage



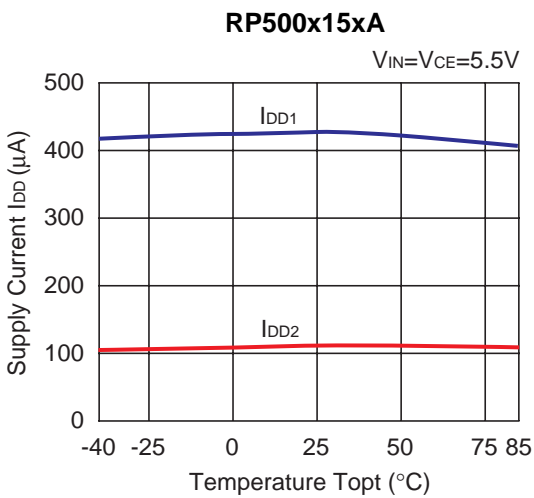
3) Efficiency vs. Output Current



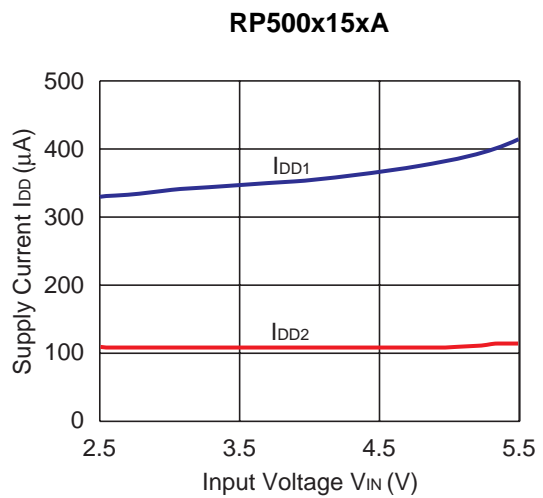
RP500x



4) Supply Current 1, 2 vs. Temperature

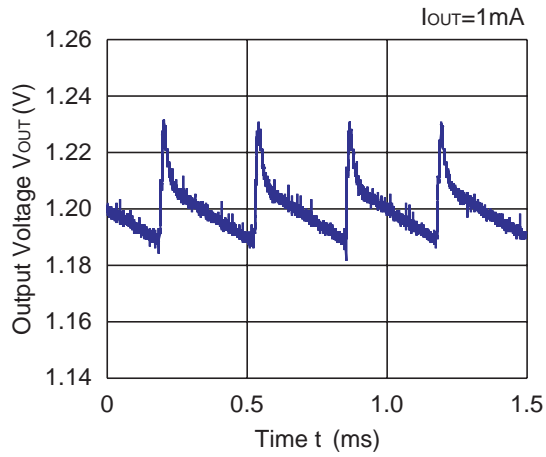


5) Supply Current 1, 2 vs. Input Voltage

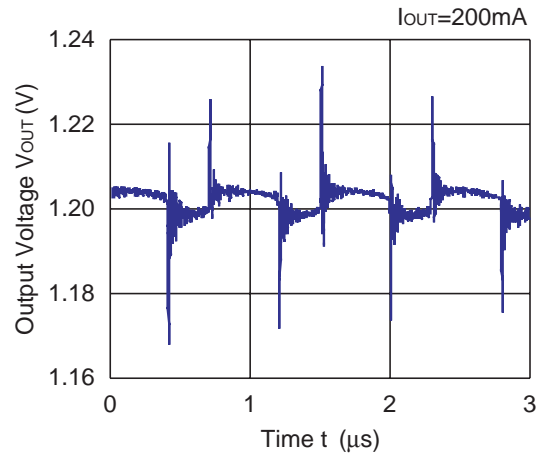


6) DC/DC Output Waveform ($C_{IN}=C_{OUT}=10\mu F$, $L=4.7\mu H$)

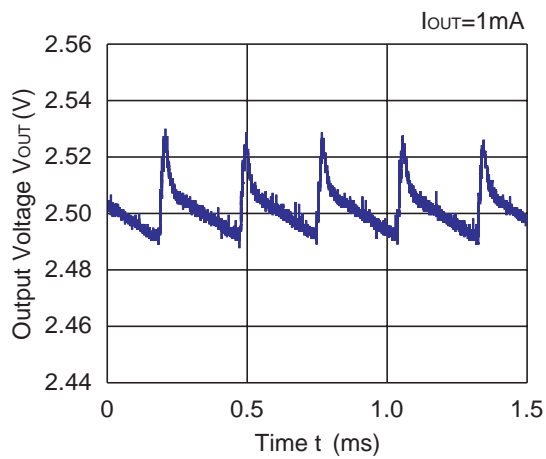
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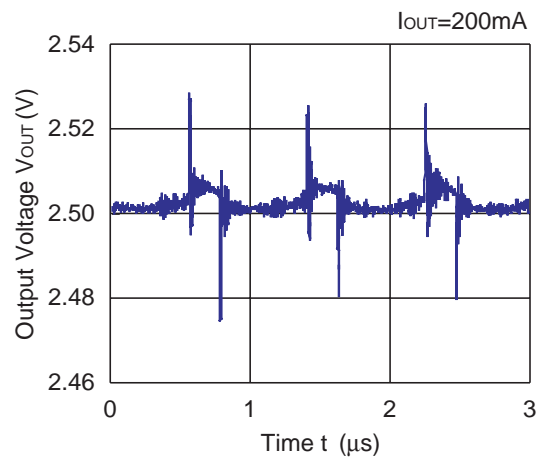
RP500x12xA



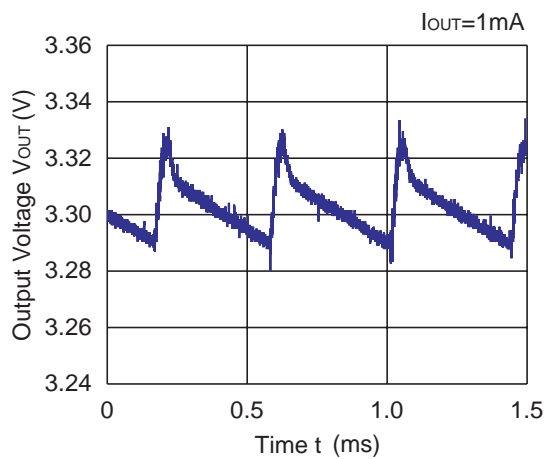
RP500x251A/253A



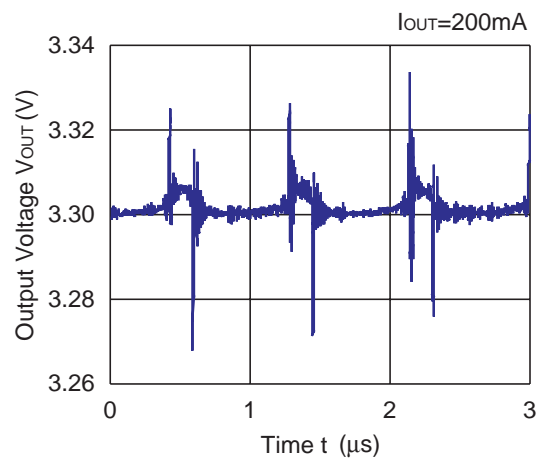
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RP500x331A/333A



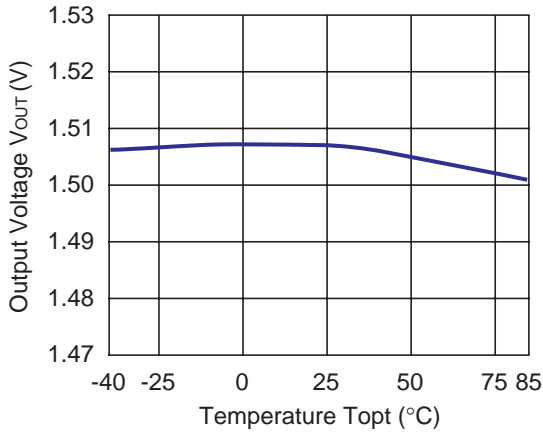
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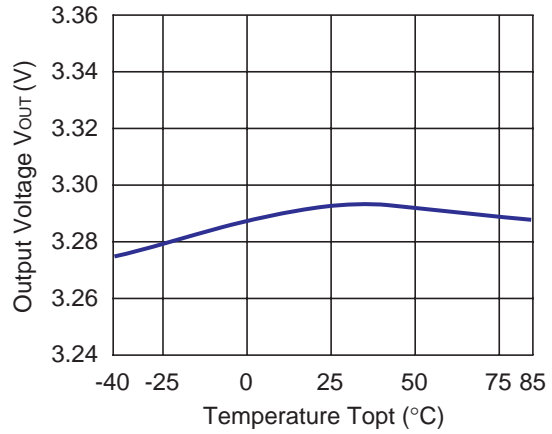
RP500x

7) Output Voltage vs. Temperature

RP500x15xA

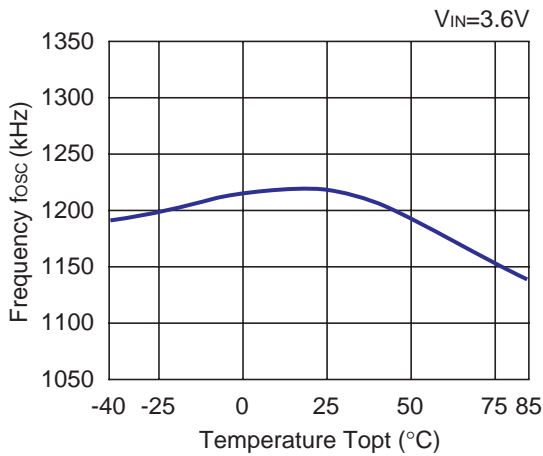


RP500x33xA



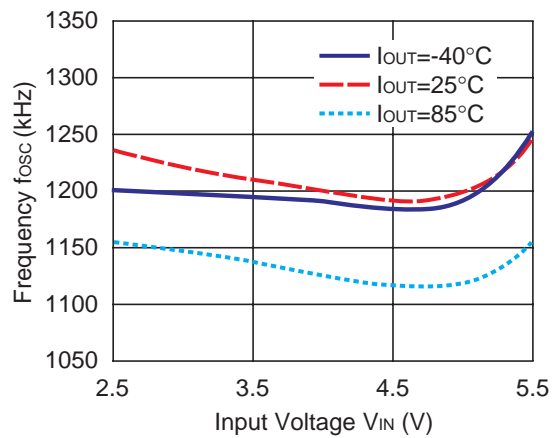
8) Oscillator Frequency vs. Temperature

RP500x15xA



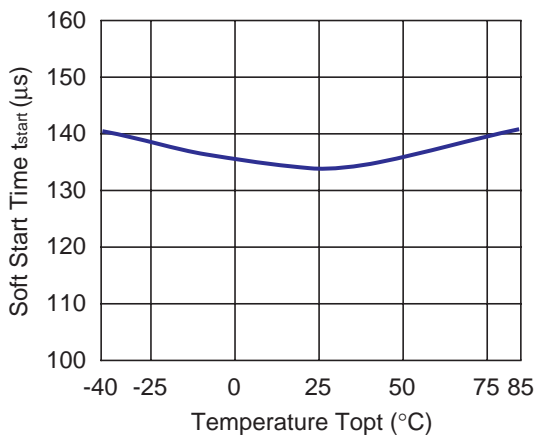
9) Oscillator Frequency vs. Input Voltage

RP500x15xA



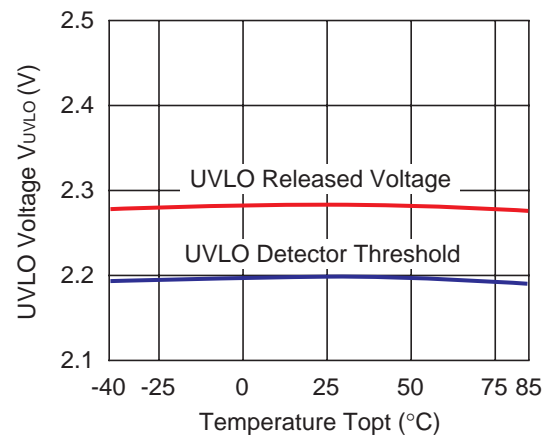
10) Soft-start Time vs. Temperature

RP500x16xA

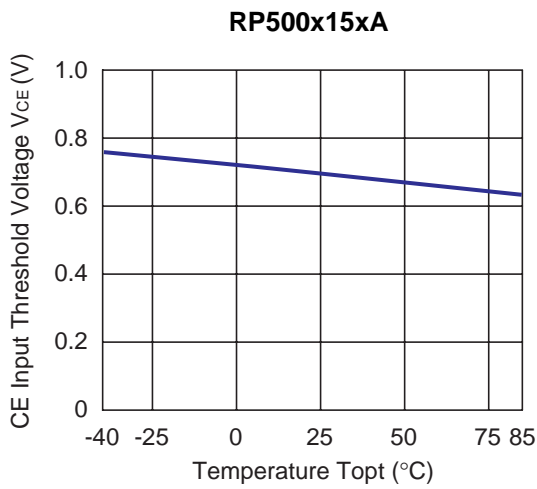


11) UVLO Detector Threshold/ Released Voltage vs. Temperature

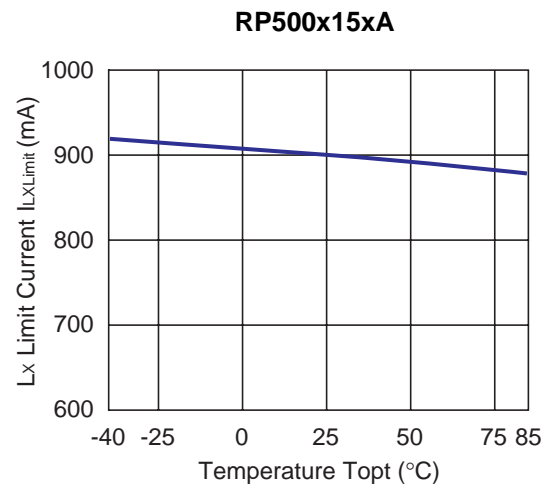
RP500x15xA



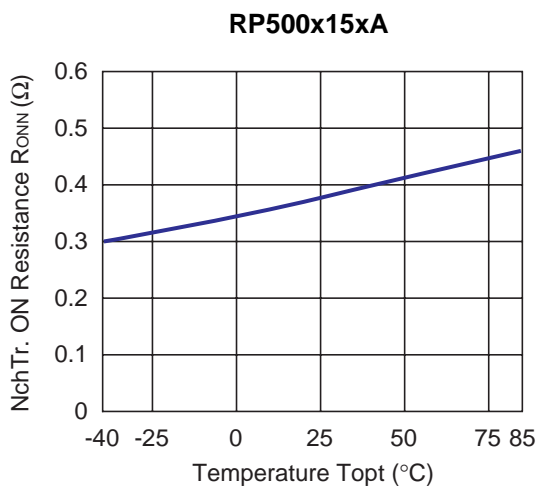
12) CE Input vs. Temperature



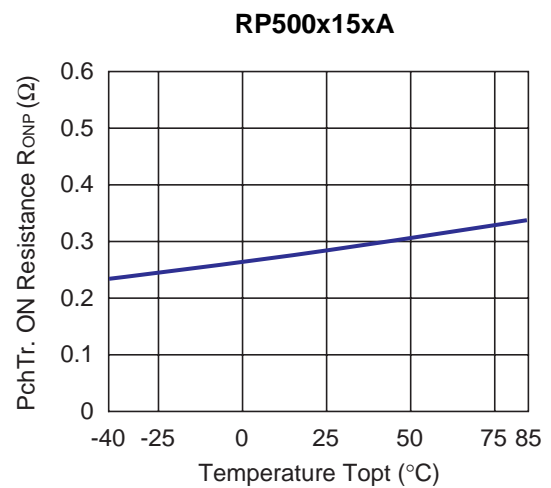
13) Lx Current Limit vs. Temperature



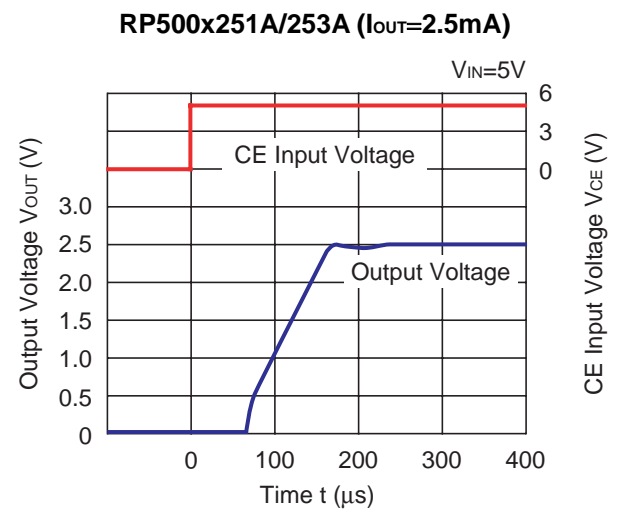
14) Nch Tr. ON Resistance vs. Temperature



15) Pch Tr. ON Resistance vs. Temperature

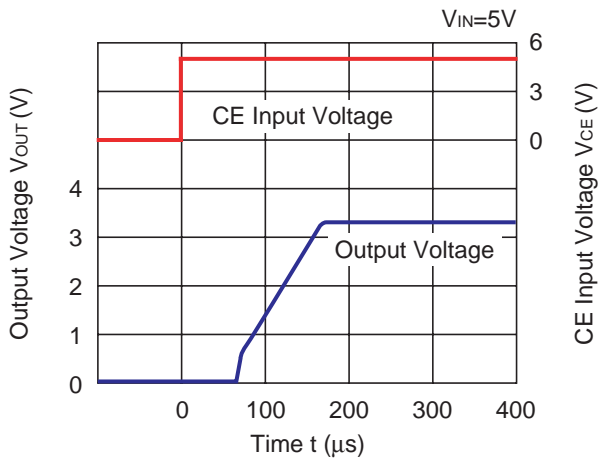


16) Turn on speed with CE pin (C_{IN}=C_{OUT}=Ceramic 10μF, L=4.7μH)

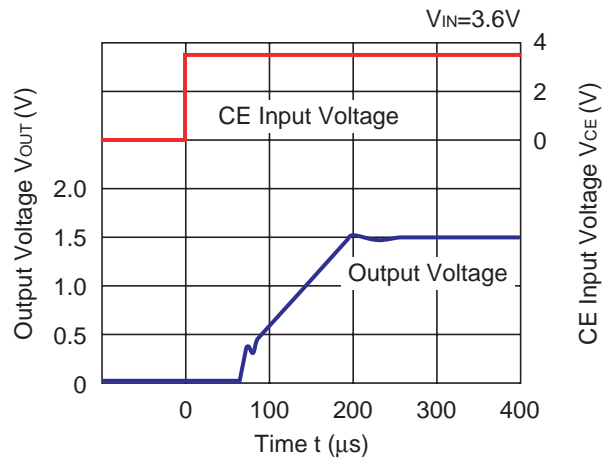


RP500x

RP500x331A/333A ($I_{OUT}=3.3mA$)

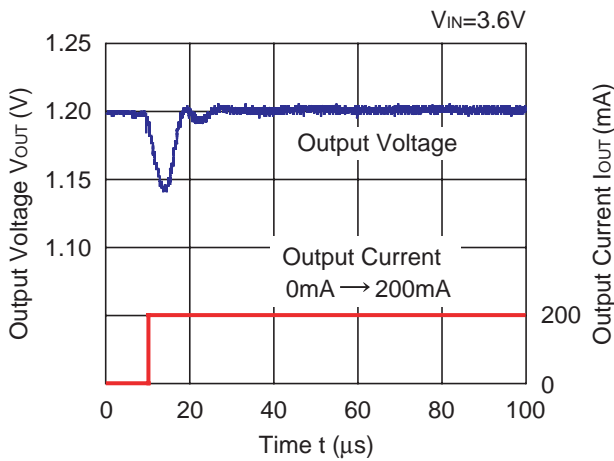


RP500x152A/154A ($I_{OUT}=1.5mA$)

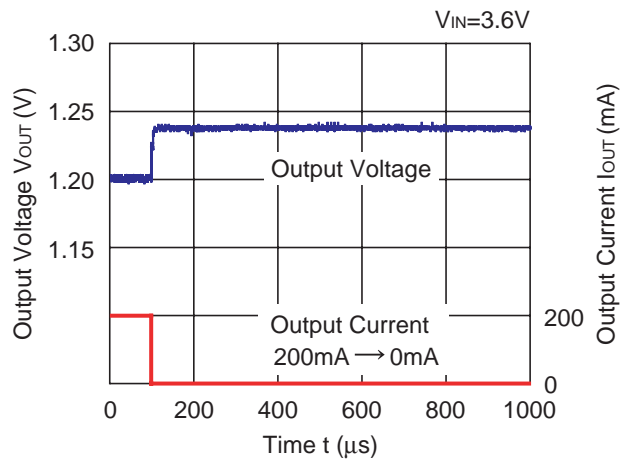


17) Load Transient Response ($C_{IN}=C_{OUT}=\text{Ceramic } 10\mu F, L=4.7\mu H$)

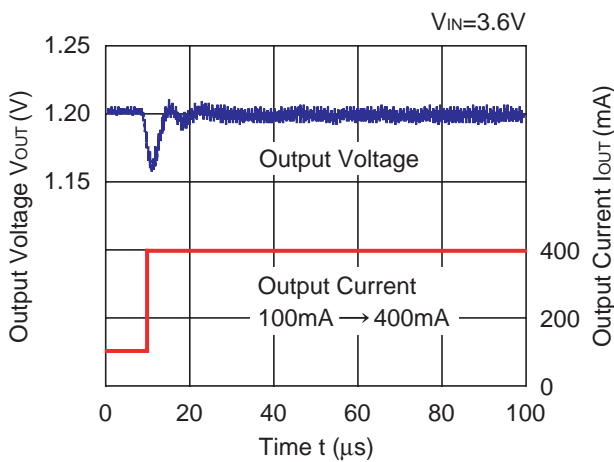
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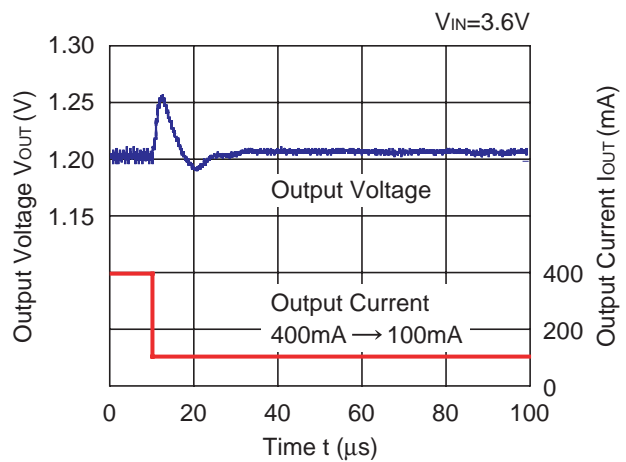
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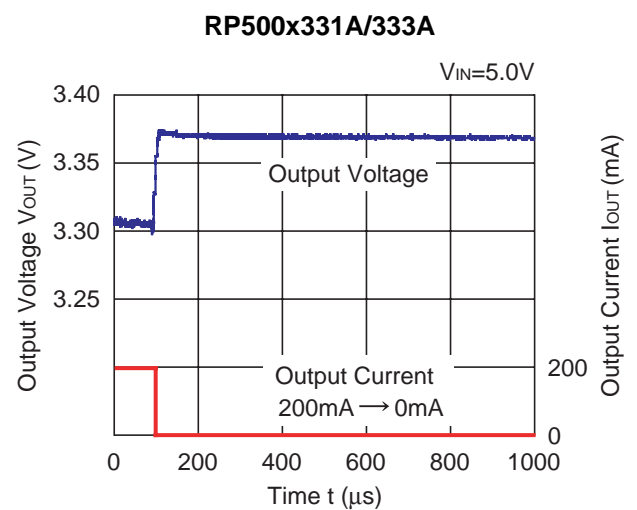
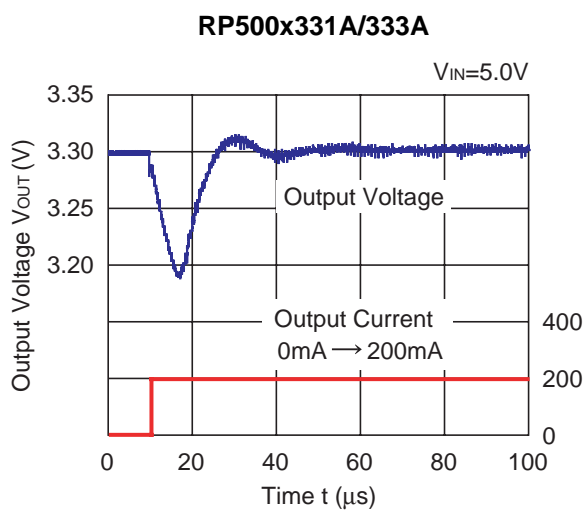
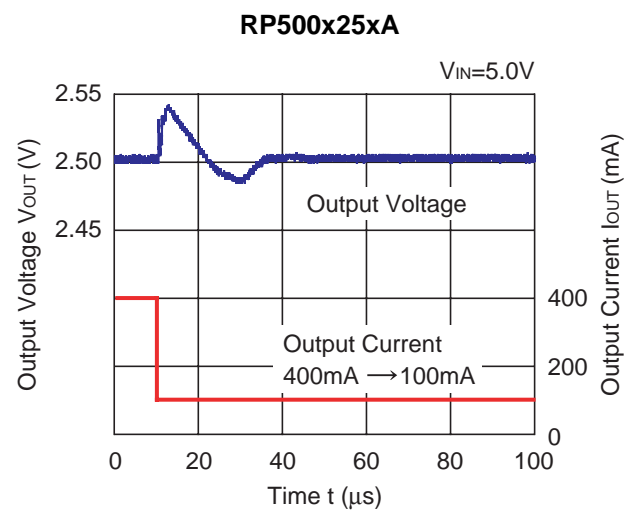
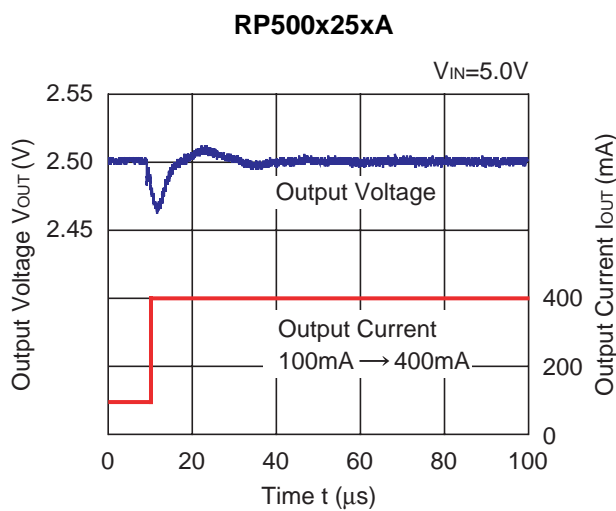
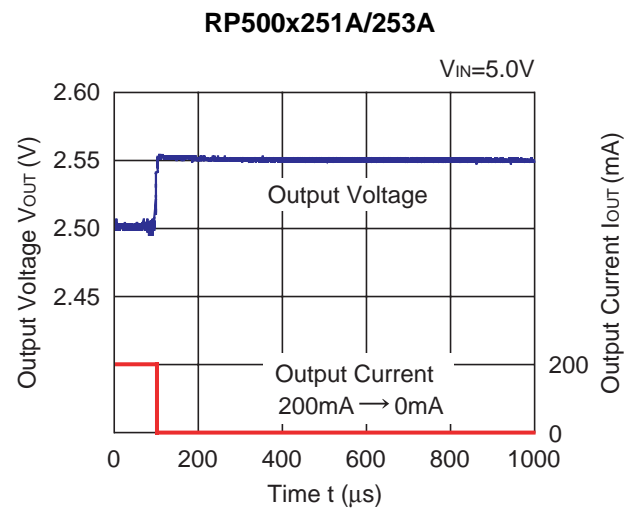
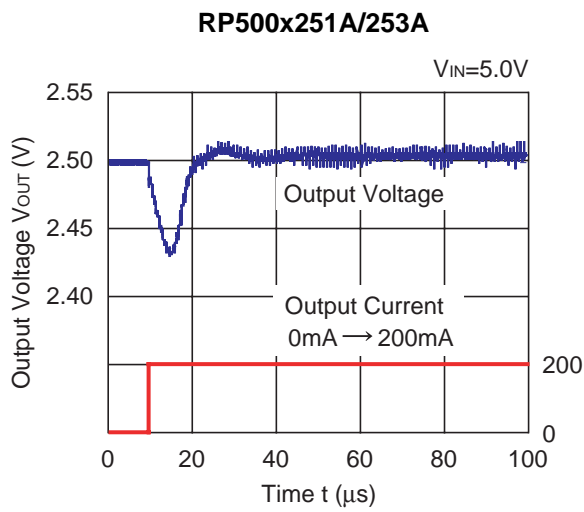


RP500x12xA



RP500x12xA



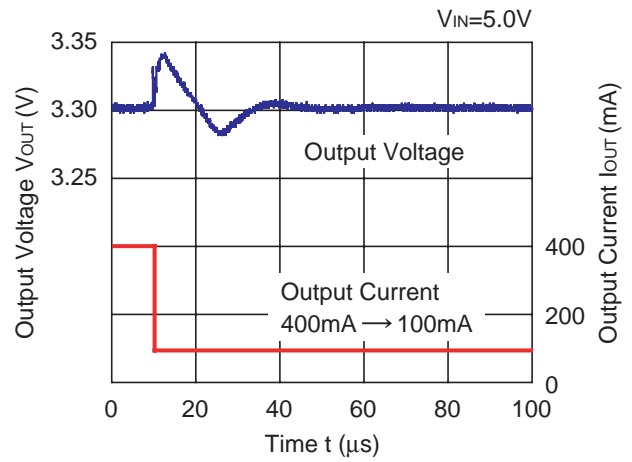


RP500x

RP500x33xA



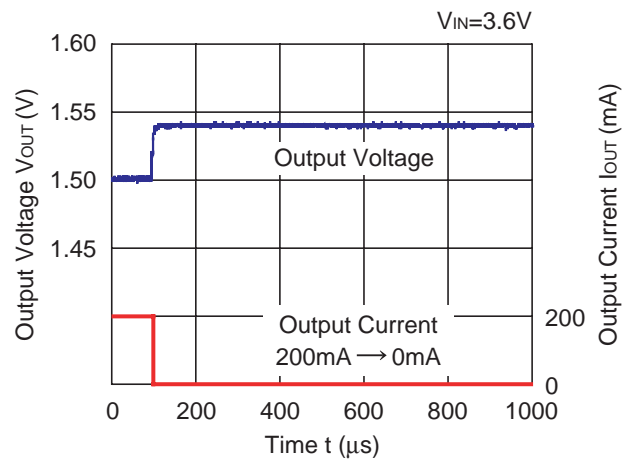
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RP500x152A/154A



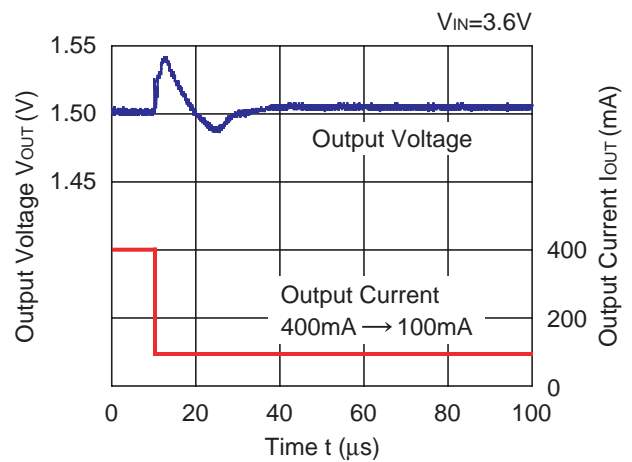
RP500x152A/154A



RP500x15xA



RP500x15xA





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