600 mA PWM/VFM Step-Down DC/DC Converter with Synchronous Rectifier

NO.EA-259-150130

OUTLINE

The RP504x is a low supply current CMOS-based PWM/VFM step-down DC/DC converter with synchronous rectifier featuring 600 mA[*1] output current. Internally, a single converter consists of an oscillator, a reference voltage unit, an error amplifier, a switching control circuit, a mode control circuit (RP504xxx1A/D), a soft-start circuit, a Latch-type protection circuit, an under voltage lockout (UVLO) circuit a.nd switching transistors.

The RP504x is employing synchronous rectification for improving the efficiency of rectification by replacing diodes with built-in switching transistors. Using synchronous rectification not only increases circuit performance but also allows a design to reduce parts count.

Power controlling method can be selected from forced PWM control type or PWM/VFM auto switching control type by inputting a signal to the MODE pin. In low output current, forced PWM control switches at fixed frequency rate in order to reduce noise. Likewise, in low output current, PWM/VFM auto switching control automatically switches from PWM mode to VFM mode in order to achieve high efficiency.

Output voltage is internally fixed type which allows output voltages that range from 0.8 V to 3.3 V in 0.1 V step. The output voltage accuracy is as high as ±1.5% or ±18 mV.

Protection circuits included in the RP504x are overcurrent protection circuit and latch type protection circuit. Overcurrent protection circuit supervises the inductor peak current in each switching cycle, and if the current exceeds the L_X current limit (I_{LXLIM}), it turns off P-channel Tr. Latch type protection circuit latches the built-in driver to the OFF state and stops the operation of the step-down DC/DC converter if the overcurrent status continues or V_{OUT} continues being the half of the setting voltage for equal or longer than protection delay time (tprot). To cancel the latch type protection circuit, select the standby mode or the active mode with the CE pin, or drop the power supply voltage below the UVLO detector threshold.

The RP504x is offered in 6-pin DFN(PLP)1216-6F, 6-pin DFN1616-6B and 5-pin SOT-23-5 packages which achieve the smallest possible footprint solution on boards where area is limited.

[*1] This is an approximate value. The output current is dependent on conditions and external components.

FEATURES

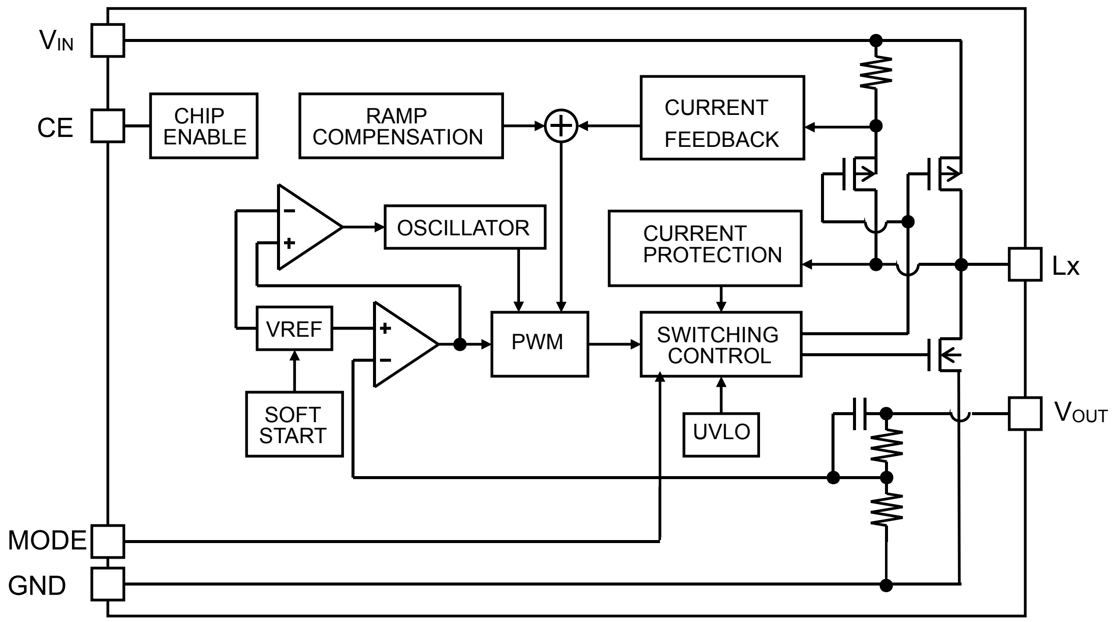
- Supply Current .... Typ. 25 μA in VFM mode without any load
- Standby Current.. Max. 5 μA
- Input Voltage Range .... 2.3 V to 5.5 V (V_{OUT} ≥ 1.0 V)
- Output Voltage Range... 0.8 V to 3.3 V in 0.1 V step
- Output Voltage Accuracy....................................... ±1.5% (V_{OUT} ≥ 1.2 V), ±18 mV (V_{OUT} < 1.2 V)
- Temperature-Drift Coefficient of Output Voltage ... Typ. ±40 ppm/°C
- Oscillator Frequency .... Typ. 2.25 MHz
- Oscillator Maximum Duty Cycle .... Min. 100%
- Built-in Driver ON Resistance .... Typ. Pch. 0.34 Ω, Nch. 0.43 Ω (V_{IN} = 3.6 V)
- UVLO Detector Threshold..................................... Typ. 2.0 V
- Soft Start Time .... Typ. 0.15 ms
- L_X Current Limit .... Typ. 900 mA
- Latch-type Protection Circuit................................. Typ. 1.5 ms
- Auto-discharge Function .... Only for RP504xxxxD
- Power Controlling Method..................................... forced PWM control or PWM/VFM auto switching control
- MODE Pin[*1] .... "H": forced PWM control,
  "L": PWM/VFM auto switching control
- Package[*1] .... DFN1616-6B, DFN(PLP)1216-6F, SOT-23-5

[*1] DFN(PLP)1216-6F, DFN1616-6B: forced PWM control by pulling MODE pin "H" or PWM/VFM auto switching control by pulling MODE pin "L"
SOT-23-5: forced PWM control for RP504xxxxC and PWM/VFM auto switching control for RP504xxxxB

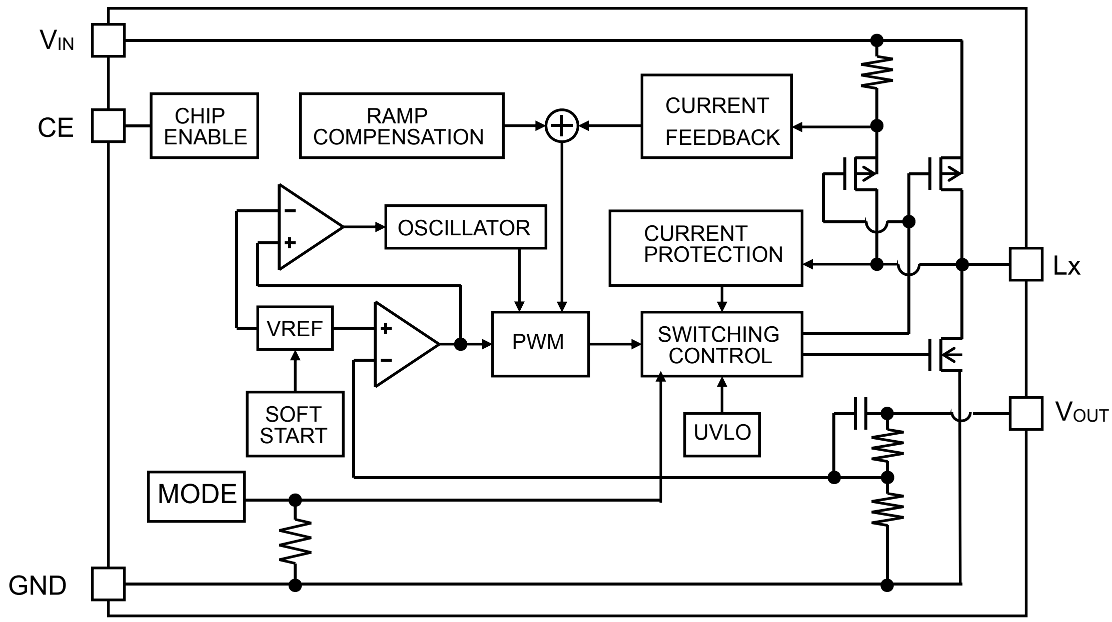
APPLICATIONS

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

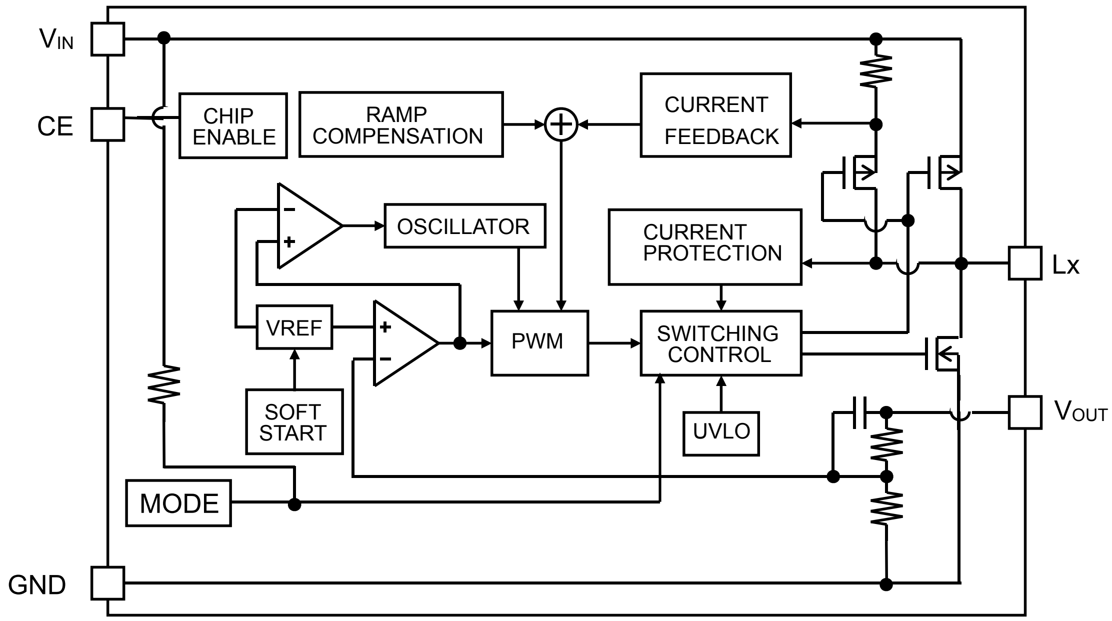
BLOCK DIAGRAMS



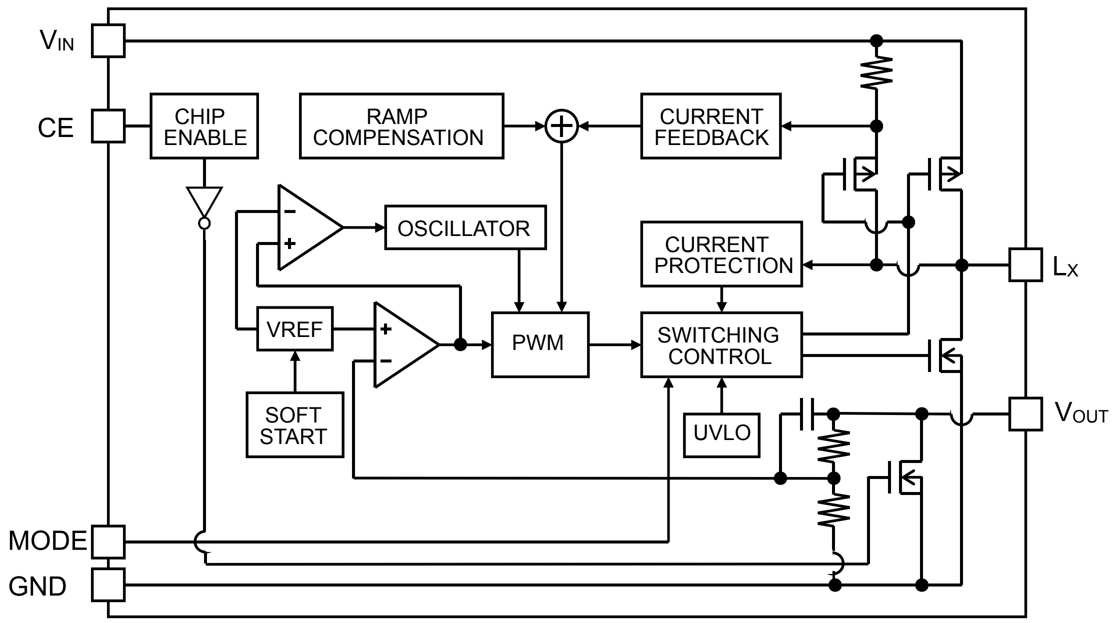
RP504xxxxA Block Diagram



RP504xxxxB Block Diagram



RP504xxxxC Block Diagram



RP504xxxxD Block Diagram

SELECTION GUIDE

The set output voltage, the package type, the MODE control pin function and the auto-discharge[*1] function are user-selectable options.

Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
RP504Kxx1$-E2	DFN(PLP)1216-6F	5,000 pcs	Yes	Yes
RP504Lxx1$-TR	DFN1616-6B	5,000 pcs	Yes	Yes
RP504Nxx1$-TR-FE	SOT-23-5	3,000 pcs	Yes	Yes

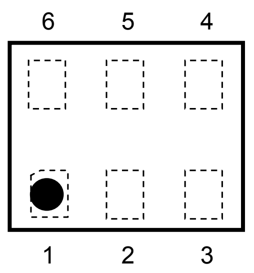
xx: Specify the set output voltage (V_{SET}) within the range of 0.8 V(08) to 3.3 V(33) in 0.1 V steps.
Refer to the section of *PACKAGE INFORMATION* for detailed information.

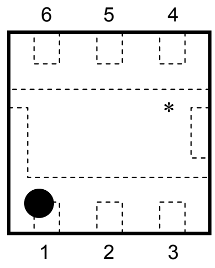
$: Specify the package type, the MODE control pin function and the auto-discharge function.

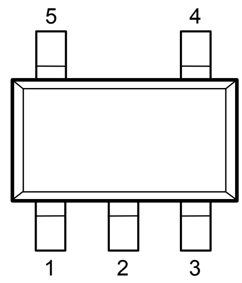
<table>
<tr><th rowspan="2">$</th><th rowspan="2">Package</th><th colspan="2">MODE Control Pin Function</th><th rowspan="2">Auto-discharge Function</th></tr>
<tr><th>MODE Pin</th><th>Power Controlling Method</th></tr>
<tr><td rowspan="2">A</td><td>DFN1616-6B</td><td rowspan="2">Yes</td><td rowspan="2">“H”: forced PWM
“L”: PWM/VFM auto switching control</td><td rowspan="2">No</td></tr>
<tr><td>DFN(PLP)1216-6F</td></tr>
<tr><td>B</td><td>SOT-23-5</td><td>No</td><td>PWM/VFM auto switching control</td><td>No</td></tr>
<tr><td>C</td><td>SOT-23-5</td><td>No</td><td>forced PWM control</td><td>No</td></tr>
<tr><td rowspan="2">D</td><td>DFN1616-6B</td><td rowspan="2">Yes</td><td rowspan="2">“H”: forced PWM control
“L”: PWM/VFM auto switching control</td><td rowspan="2">Yes</td></tr>
<tr><td>DFN(PLP)1216-6F</td></tr>
</table>

[*1] Auto-discharge function quickly lowers the output voltage to 0 V, when the chip enable signal is switched from the active mode to the standby mode, by releasing the electrical charge accumulated in the external capacitor.
[*2] 0.05 V step is also available as a custom code.

PIN DESCRIPTION







DFN(PLP)1216-6F Pin Configurations **DFN1616-6B Pin Configurations** **SOT-23-5 Pin Configurations**

RP504Kxx1A, RP504Kxx1D: DFN(PLP)1216-6F Pin Description

Pin No.	Symbol	Description
1	V_{IN}	Input Pin
2	MODE	Mode Control Pin ("H": forced PWM control, "L": PWM/VFM auto switching control)
3	CE	Chip Enable Pin (Active-high)
4	V_{OUT}	Output Pin
5	GND	Ground Pin
6	L_X	L_X Switching Pin

RP504Lxx1A, RP504Lxx1D: DFN1616-6B Pin Description

Pin No.	Symbol	Description
1	CE	Chip Enable Pin (Active-high)
2	MODE	Mode Control Pin ("H": forced PWM control, "L": PWM/VFM auto switching control)
3	V_{IN}	Input Pin
4	L_X	L_X Switching Pin
5	GND	Ground Pin
6	V_{OUT}	Output Pin

∗ The tab on the bottom of the package enhances thermal performance and is electrically connected to GND (substrate level). It is recommended that the tab be connected to the ground plane on the board. If not, the tab can be left open.

RP504Nxx1B, RP504Nxx1C: SOT-23-5 Pin Description

Pin No.	Symbol	Description
1	V_{OUT}	Output Pin
2	GND	Ground Pin
3	L_X	L_X Switching Pin
4	V_{IN}	Input Pin
5	CE	Chip Enable Pin (Active-high)

ABSOLUTE MAXIMUM RATINGS

Absolute Maximum Ratings (GND = 0 V)

Symbol	Item	Rating		Unit
V_{IN}	V_{IN} Input 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 6.5		V
V_{MODE}	Mode Control Pin Voltage	−0.3 to 6.5		V
V_{OUT}	V_{OUT} Pin Voltage	−0.3 to 6.5		V
I_{LX}	L_X Pin Output Current	900		mA
P_D	Power Dissipation (Standard Land Pattern)*1	DFN(PLP)1216-6F	385	mW
		DFN1616-6B	640	
		SOT-23-5	420	
Ta	Operating Temperature Range	−40 to 85		°C
Tstg	Storage Temperature Range	−55 to 125		°C

*1 Refer to *PACKAGE INFORMATION* for detailed 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.

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.

ELECTRICAL CHARACTERISTICS

RP504xxx1A, RP504xxx1D Electrical Characteristics (Ta = 25°C)

Symbol	Item	Conditions		Min.	Typ.	Max.	Unit
V_{IN}	Operating Input Voltage	V_{OUT} ≥ 1.0		2.3		5.5	V
		V_{OUT} < 1.0		2.3		4.5	
V_{OUT}	Output Voltage	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V	V_{OUT} ≥ 1.2 V	x0.985		x1.015	V
			V_{OUT} < 1.2 V	−0.018		+0.018	
$\Delta V_{OUT}/\Delta Ta$	Output Voltage Temperature Coefficient	−40°C ≤ Ta ≤ 85°C			±40		ppm/°C
fosc	Oscillator Frequency	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		1.95	2.25	2.55	MHz
I_{DD1}	Supply Current 1	V_{IN} = V_{CE} = 5.5 V, V_{OUT} = V_{SET} × 0.8			400	800	μA
I_{DD2}	Supply Current 2	V_{IN} = V_{CE} = V_{OUT} = 5.5 V	V_{MODE} = 0 V		25	40	μA
			V_{MODE} = 5.5 V		400	800	
Istandby	Standby Current	V_{IN} = 5.5 V, V_{CE} = 0 V			0	5	μA
I_{CEH}	CE "H" Input Voltage	V_{IN} = V_{CE} = 5.5 V		−1	0	1	μA
I_{CEL}	CE "L" Input Voltage	V_{IN} = 5.5 V, V_{CE} = 0 V		−1	0	1	μA
I_{MODEH}	Mode "H" Input Current	V_{IN} = V_{MODE} = 5.5 V		−1	0	1	μA
I_{MODEL}	Mode "L" Input Current	V_{IN} = 5.5 V, V_{MODE} = 0 V		−1	0	1	μA
I_{VOUTH}	V_{OUT} "H" Input Current[*1]	V_{IN} = V_{OUT} = 5.5 V, V_{CE} = 0 V		−1	0	1	μA
I_{VOUTL}	V_{OUT} "L" Input Current	V_{IN} = 5.5 V, V_{CE} = V_{OUT} = 0 V		−1	0	1	μA
$I_{LXLEAKH}$	L_X Leakage Current "H"	V_{IN} = V_{LX} = 5.5 V, V_{CE} = 0 V		−1	0	5	μA
$I_{LXLEAKL}$	L_X Leakage Current "L"	V_{IN} = 5.5 V, V_{CE} = V_{LX} = 0 V		−5	0	1	μA
V_{CEH}	CE "H" Input Voltage	V_{IN} = 5.5 V		1.0			V
V_{CEL}	CE "L" Input Voltage	V_{IN} = 2.3 V				0.4	V
V_{MODEH}	Mode "H" Input Voltage	V_{IN} = 5.5 V		1.0			V
V_{MODEL}	Mode "L" Input Voltage	V_{IN} = 2.3 V				0.4	V
R_{LOW}	Nch On Resistance[*2]	V_{IN} = 3.6 V, V_{CE} = 0 V			30		Ω
R_{ONP}	On Resistance of Pch Tr.	V_{IN} = 3.6 V, I_{LX} = −100 mA			0.34		Ω
R_{ONN}	On Resistance of Nch Tr.	V_{IN} = 3.6 V, I_{LX} = −100 mA			0.43		Ω
Maxduty	Oscillator Maximum Duty Cycle			100			%
tstart	Soft-start Time	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V			150	310	μs
I_{LXLIM}	Lx Current Limit	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		700	900		mA
tprot	Protection Delay Time	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		0.5	1.5	5	ms
V_{UVLO1}	UVLO Detector Threshold	V_{IN} = V_{CE}		1.9	2.0	2.1	V
V_{UVLO2}	UVLO Released Voltage	V_{IN} = V_{CE}		2.0	2.1	2.2	V

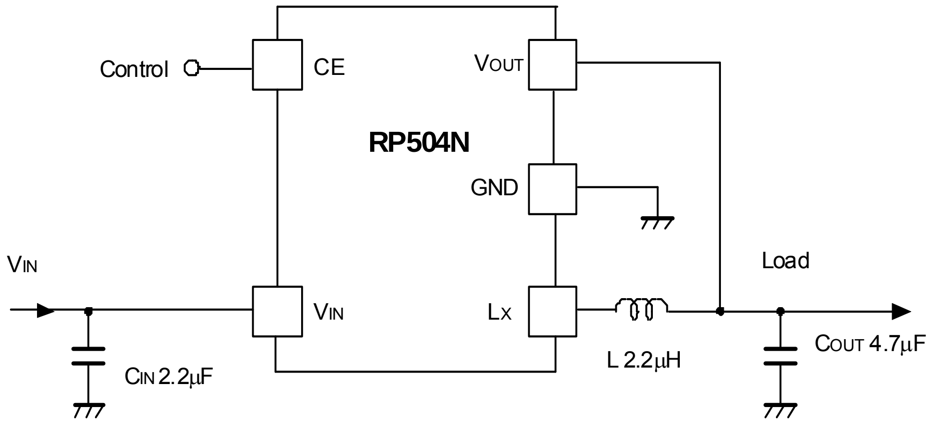
All test items listed under *ELECTRICAL CHARACTERISTICS* are done under the pulse load condition (Tj ≈ Ta = 25°C) except Output Voltage Temperature Coefficient.
Test circuit is "OPEN LOOP" and AGND = PGND = 0 V unless otherwise specified.
[*1] Only for RP504xxx1A/B/C with no auto-discharge
[*2] Only for RP504xxx1D with auto-discharge

RP504xxxxB, RP504xxxxC Electrical Characteristics (Ta = 25°C)

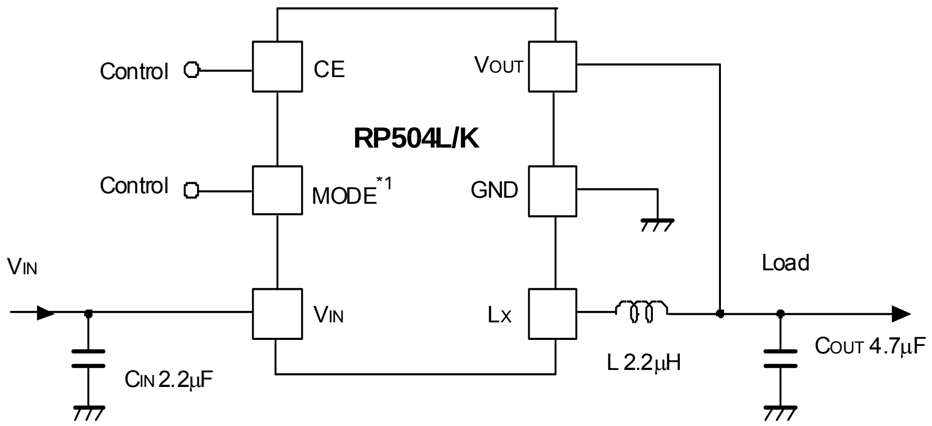
Symbol	Item	Conditions		Min.	Typ.	Max.	Unit
V_{IN}	Operating Input Voltage	V_{OUT} ≥ 1.0		2.3		5.5	V
		V_{OUT} < 1.0		2.3		4.5	
V_{OUT}	Output Voltage	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V	V_{OUT} ≥ 1.2 V	x0.985		x1.015	V
			V_{OUT} < 1.2 V	−0.018		+0.018	
$\Delta V_{OUT}/\Delta Ta$	Output Voltage Temperature Coefficient	−40°C ≤ Ta ≤ 85°C			±40		ppm/°C
fosc	Oscillator Frequency	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		1.95	2.25	2.55	MHz
I_{DD1}	Supply Current 1	V_{IN} = V_{CE} = 5.5 V, V_{OUT} = V_{SET} × 0.8			400	800	μA
I_{DD2}	Supply Current 2	V_{IN} = V_{CE} = V_{OUT} = 5.5 V	RP504xxx1B		25	40	μA
			RP504xxx1C		400	800	
Istandby	Standby Current	V_{IN} = 5.5 V, V_{CE} = 0 V			0	5	μA
I_{CEH}	CE "H" Input Voltage	V_{IN} = V_{CE} = 5.5 V		−1	0	1	μA
I_{CEL}	CE "L" Input Voltage	V_{IN} = 5.5 V, V_{CE} = 0 V		−1	0	1	μA
I_{VOUTH}	V_{OUT} "H" Input Current	V_{IN} = V_{OUT} = 5.5 V, V_{CE} = 0 V		−1	0	1	μA
I_{VOUTL}	V_{OUT} "L" Input Current	V_{IN} = 5.5 V, V_{CE} = V_{OUT} = 0 V		−1	0	1	μA
$I_{LXLEAKH}$	L_X Leakage Current "H"	V_{IN} = V_{LX} = 5.5 V, V_{CE} = 0 V		−1	0	5	μA
$I_{LXLEAKL}$	L_X Leakage Current "L"	V_{IN} = 5.5 V, V_{CE} = V_{LX} = 0 V		−5	0	1	μA
V_{CEH}	CE "H" Input Voltage	V_{IN} = 5.5 V		1.0			V
V_{CEL}	CE "L" Input Voltage	V_{IN} =2.3 V				0.4	V
R_{ONP}	On Resistance of Pch Tr.	V_{IN} =3.6 V, I_{LX} = −100 mA			0.34		Ω
R_{ONN}	On Resistance of Nch Tr.	V_{IN} =3.6 V, I_{LX} = −100 mA			0.43		Ω
Maxduty	Oscillator Maximum Duty Cycle			100			%
tstart	Soft-start Time	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V			150	310	μs
I_{LXLIM}	L_X Current Limit	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		700	900		mA
tprot	Protection Delay Time	V_{IN} = V_{CE} = 3.6 V or V_{SET} +1 V		0.5	1.5	5	ms
V_{UVLO1}	UVLO Detector Threshold	V_{IN} = V_{CE}		1.9	2.0	2.1	V
V_{UVLO2}	UVLO Released Voltage	V_{IN} = V_{CE}		2.0	2.1	2.2	V

All test items listed under *ELECTRICAL CHARACTERISTICS* are done under the pulse load condition (Tj ≈ Ta = 25°C) except Output Voltage Temperature Coefficient.
Test circuit is "OPEN LOOP" and AGND = PGND = 0 V unless otherwise specified.

TYPICAL APPLICATION



RP504N Typical Application: MODE Pin not included



RP504K/L Typical Application: MODE Pin included

*1 MODE = "H": forced PWM control, MODE = "L": PWM/VFM auto switching control

Recommended Components

Symbol	Capacitance	Type	Manufacturer
C_{IN}	2.2 µF	Ceramic Capacitor	C1608JB0J225K(TDK)
	2.2 µF x 2		C1005JB0J225K (TDK) JMK105BJ225MV (Taiyo Yuden)
	4.7 µF		C1005X5R0J475M (TDK) JMK105BJ475MV (Taiyo Yuden)
C_{OUT}	4.7 µF	Ceramic Capacitor	C1608JB0J475K (TDK) GRM188B30J475KE18 (Murata)
L	2.2 µH	Inductor	MIPSZ2520D2R2 (FDK) MIPS2520D2R2 (FDK) MLP2520S2R2M (TDK) VLS252010T-2R2M (TDK)

TECHNICAL NOTES

The performance of power supply circuits using this IC largely depends on the peripheral circuits. Please be very careful when setting the peripheral parts. When designing the peripheral circuits of each part, PCB patterns, and this IC, please do not exceed the rated values (Voltage, Current, Power).

- Ensure the V_{IN} and GND lines are sufficiently robust. A large switching current flows through the GND lines, the V_{DD} line, the V_{OUT} line, an inductor, and L_X. If their impedance is too high, noise pickup or unstable operation may result. Set the external components as close as possible to the IC and minimize the wiring between the components and the IC, especially between a capacitor (C_{IN}) and the V_{IN} pin. The wiring between V_{OUT} and load and between L and V_{OUT} should be separated.
- Choose a low ESR ceramic capacitor. The capacitance of C_{IN} should be more than or equal to 2.2 μF. The capacitance of a capacitor (C_{OUT}) should be between 4.7 μF to 10 μF.
- The Inductance value should be set within the range of 2.2 μH to 4.7 μH. However, the inductance value is limited by output voltage. Refer to the table below. The phase compensation of this IC is designed according to the C_{OUT} and L values. Choose an inductor that has small DC resistance, has enough allowable current and is hard to cause magnetic saturation. If the inductance value of an inductor is extremely small, the peak current of L_X may increase. The increased L_X peak current reaches “L_X limit current” to trigger overcurrent protection circuit even if the load current is less than 600 mA.
- Overcurrent protection circuit, Latch-type protection circuit may be affected by self-heating and heat radiation environment.

RICOH

OPERATION OF STEP-DOWN CONVERTER AND OUTPUT CURENT

The step-down DC/DC converter charges energy in the inductor when L_X Tr. turns “ON”, and discharges the energy from the inductor when L_X Tr. turns “OFF” and operates with less energy loss, so that a lower output voltage (V_{OUT}) than the input voltage (V_{IN}) can be obtained. The operation of the step-down DC/DC converter is explained in the following figures.

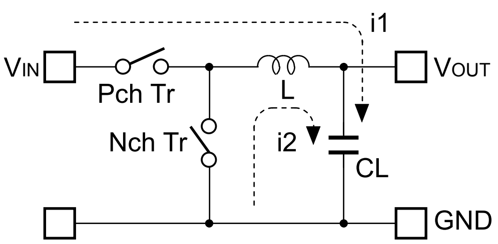


Figure 1. Basic Circuit

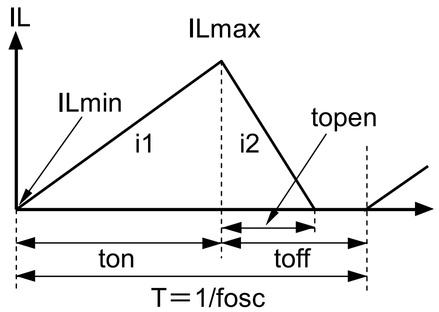


Figure 2. Inductor Current (IL) flowing through Inductor

Step1. P-channel Tr. turns “ON” and IL (i1) flows, L is charged with energy. At this moment, i1 increases from the minimum inductor current (ILmin), which is 0 A, and reaches the maximum inductor current (ILmax) in proportion to the on-time period (ton) of P-channel Tr.

Step2. When P-channel Tr. turns “OFF”, L tries to maintain IL at ILmax, so L turns N-channel Tr. “ON” and IL (i2) flows into L.

Step3. i2 decreases gradually and reaches ILmin after the open-time period (topen) of N-channel Tr., and then N-channel Tr. turns “OFF”. This is called discontinuous current mode.
As the output current (I_{OUT}) increases, the off-time period (toff) of P-channel Tr. runs out before IL reaches ILmin. The next cycle starts, and P-channel Tr. turns “ON” and N-channel Tr. turns “OFF”, which means IL starts increasing from ILmin. This is called continuous current mode.

In the case of PWM mode, V_{OUT} is maintained by controlling ton. During the PWM mode, the oscillator frequency (fosc) is constantly maintained.

As shown in Figure 2, when the step-down DC/DC operation is constant, ILmin and ILmax during ton of P-channel Tr. would be the same as ILmin and ILmax during toff of the P-channel Tr.

The current differential between ILmax and ILmin is described as ΔI.

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

However,

T = 1 / fosc = ton + toff
Duty (%) = ton / T × 100 = ton × fosc × 100
topen ≤ toff

In Equation 1, “V_{OUT} × topen / L” shows the amount of current change in “OFF” state. Also, “(V_{IN} − V_{OUT}) × ton / L” shows the amount of current change at “ON” state.

RICOH

DISCONTINUOUS MODE AND CONTINUOUS MODE

As illustrated in Figure 3., when I_{OUT} is relatively small, topen < toff. In this case, the energy charged into L during ton will be completely discharged during toff, as a result, I_{LMIN} = 0. This is called discontinuous mode.

When I_{OUT} is gradually increased, eventually topen = toff and when I_{OUT} is increased further, eventually I_{LMIN} > 0. This is called continuous mode.

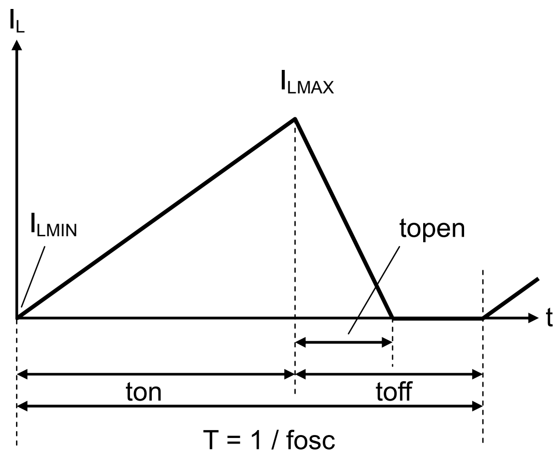


Figure 3. Discontinuous Mode

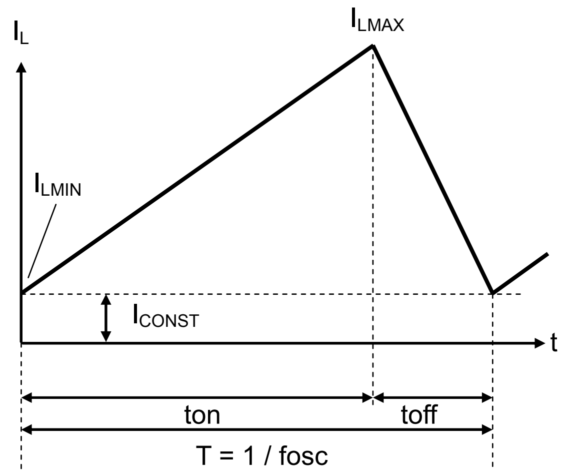


Figure 4. Continuous Mode

In the continuous mode, the solution of Equation 1 is described as tonc.

tonc = T × V_{OUT} / V_{IN} .... Equation 2

When ton < tonc, it indicates discontinuous mode, and when ton = tonc, it indicates continuous mode.

OUTPUT CURRENT AND SELECTION OF EXTERNAL COMPONENTS

The following equations explain the relationship between output current and peripheral components used in the diagrams in *TYPICAL APPLICATIONS*.

Ripple Current P-P value is described as I_{RP}, ON resistance of P-channel Tr. is described as R_{ONP}, ON resistance of N-channel Tr. is described as R_{ONN}, and 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

Second, when P-channel Tr. is "OFF" (N-channel Tr. Is "ON"), the following equation is satisfied.

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

Put Equation 4 into Equation 3 to solve ON duty of P-channel Tr. (D_{ON} = 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 described 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

Peak current that flows through L, and L_X Tr. is described as follows:

$I_{LXMAX} = I_{OUT} + I_{RP} / 2$ .... Equation 7

Consider I_{LXMAX} when setting conditions of input and output, as well as selecting the external components.
The above calculation formulas are based on the ideal operation of the I_{CS} in continuous mode.

RICOH

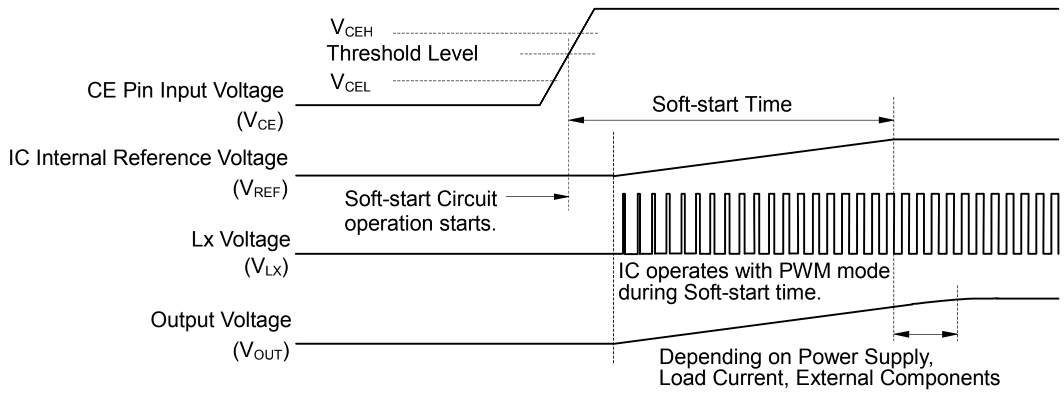
TIMING CHART

SOFT-START TIME

Starting-up with CE Pin

The IC starts to operate when the CE pin voltage (V_{CE}) exceeds the threshold voltage. The threshold voltage is preset between CE "H" input voltage (V_{CEH}) and CE "L" input voltage (V_{CEL}).

After the start-up of the IC, soft-start circuit starts to operate. Then, after a certain period of time, the reference voltage (V_{REF}) in the IC gradually increases up to the specified value.

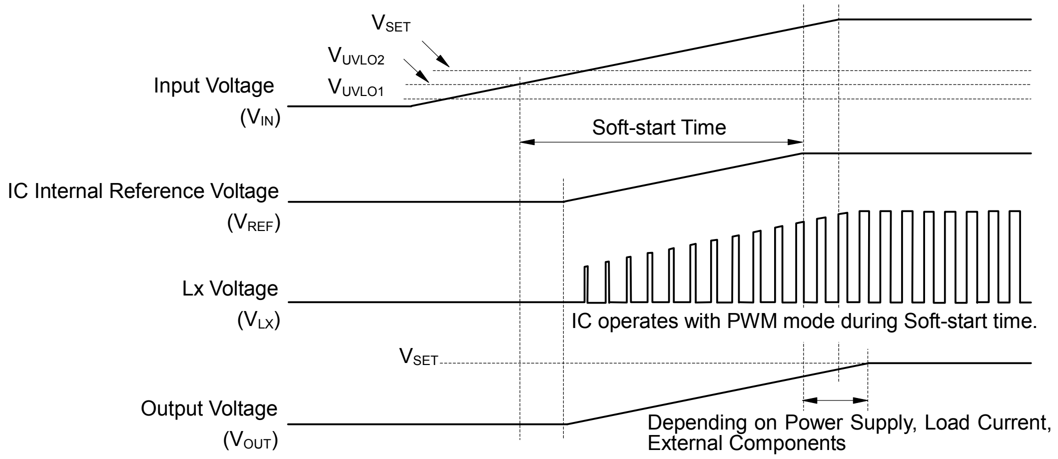


Soft-start time starts when soft-start circuit is activated, and ends when the reference voltage reaches the specified voltage.

Soft start time is not always equal to the turn-on speed of the step-down DC/DC converter. Please note that the turn-on speed could be affected by the power supply capacity, the output current, the inductance value and the C_{OUT} value.

Starting-up with Power Supply

After the power-on, when V_{IN} exceeds the UVLO released voltage (V_{UVLO2}), the IC starts to operate. Then, soft-start circuit starts to operate and after a certain period of time, V_{REF} gradually increases up to the specified value. Soft-start time starts when soft-start circuit is activated, and ends when V_{REF} reaches the specified voltage.



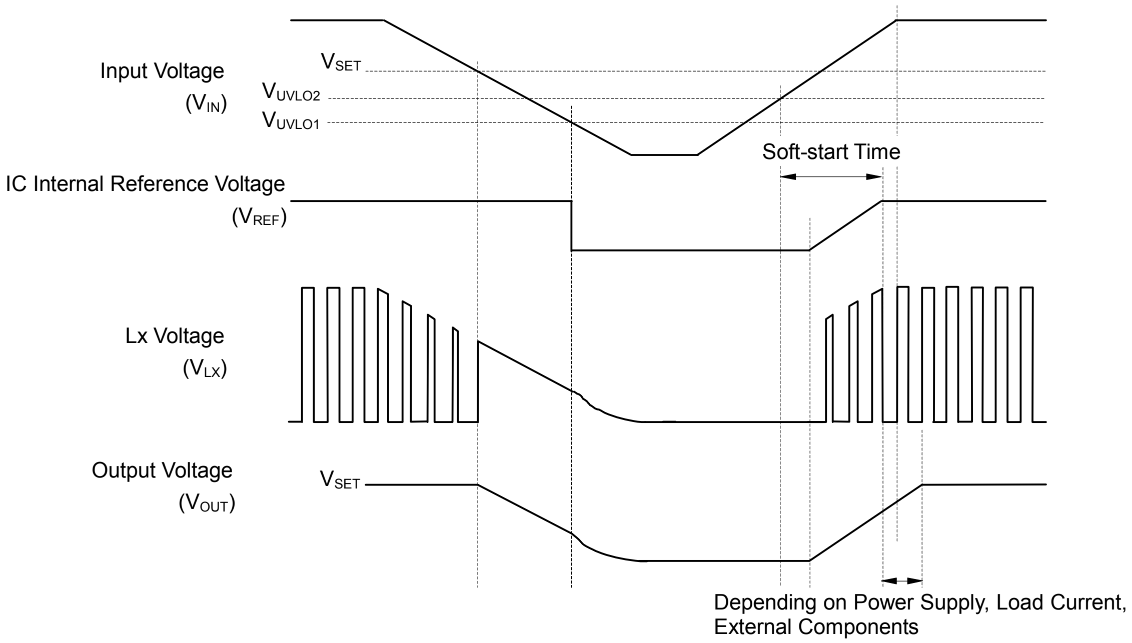
Please note that the turn-on speed of V_{OUT} could be affected by the power supply capacity, the output current, the inductance value, the C_{OUT} value and the turn-on speed of V_{IN} determined by C_{IN}.

Under Voltage Lockout (UVLO) Circuit

If V_{IN} becomes lower than V_{SET}, the step-down DC/DC converter stops the switching operation and ON duty becomes 100%, and then V_{OUT} gradually drops according to V_{IN}.

If the V_{IN} becomes lower than the UVLO detector threshold (V_{UVLO1}), the UVLO circuit starts to operate, V_{REF} stops, and P-channel and N-channel built-in switch transistors turn "OFF". As a result, V_{OUT} drops according to the C_{OUT} capacitance value and the load.

To restart the operation, V_{IN} needs to be higher than V_{UVLO2}. The timing chart below shows the voltage shifts of V_{REF}, V_{LX} and V_{OUT} when V_{IN} value is varied.



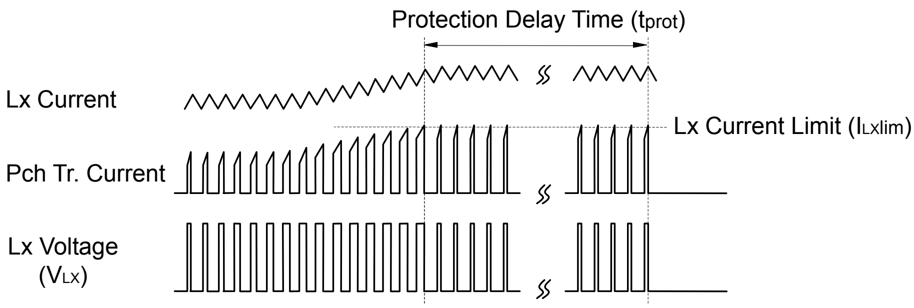
Falling edge (operating) and rising edge (releasing) waveforms of V_{OUT} could be affected by the initial voltage of C_{OUT} and the output current of V_{OUT}.

Overcurrent Protection Circuit, Latch Type Protection Circuit

Overcurrent protection circuit supervises the inductor peak current (the peak current flowing through Pch Tr.) in each switching cycle, and if the current exceeds the Lx current limit (I_{LXLIM}), it turns off Pch Tr. I_{LXLIM} of the RP504x is set to Typ.900 mA.

Latch type protection circuit latches the built-in driver to the OFF state and stops the operation of the step-down DC/DC converter if the overcurrent status continues or V_{OUT} continues being the half of the setting voltage for equal or longer than protection delay time (tprot).

Please note that I_{LXLIM} and tprot could be easily affected by self-heating or ambient environment. If the V_{IN} drops dramatically or becomes unstable due to short-circuit, protection operation and tprot could be affected.



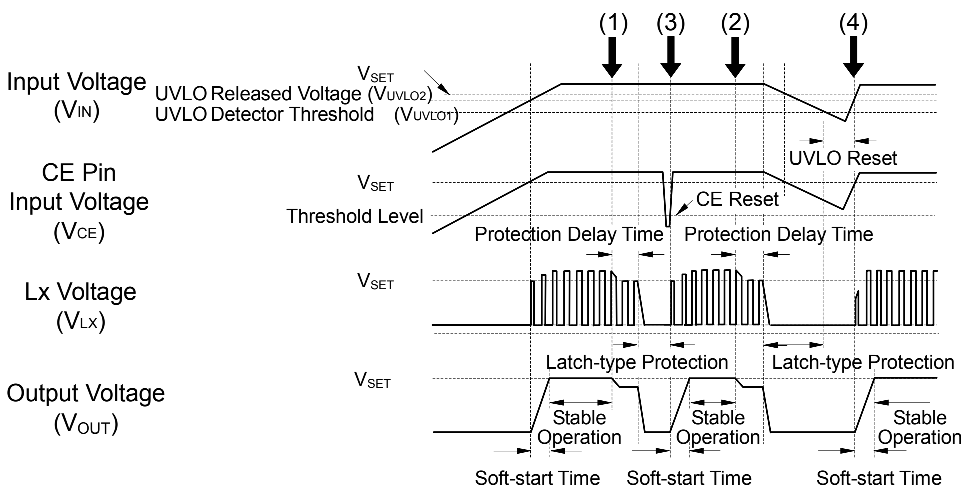
To release the latch type protection circuit, restart the IC by inputting "L" signal to the CE pin, or restart the IC with power-on or make the supply voltage lower than V_{UVLO1}.

The timing chart below shows the voltage shift of V_{CE}, V_{LX} and V_{OUT} when the IC status is changed by the following orders: V_{IN} rising → stable operation → high load → CE reset → stable operation → V_{IN} falling → V_{IN} recovering (UVLO reset) → stable operation.

(1)(2) If the large current flows through the circuit or if the IC goes into low V_{OUT} condition due to short-circuit or other reasons, the latch type protection circuit latches the built-in driver to "OFF" state after tprot. Then, V_{LX} becomes "L" and V_{OUT} turns "OFF".

(3) The latch type protection circuit is released by CE reset, which puts the IC into "L" once with the CE pin and back into "H".

(4) The latch type protection circuit is released by UVLO reset, which makes V_{IN} lower than V_{UVLO1}.



PACKAGE INFORMATION

POWER DISSIPATION (DFN(PLP)1216-6F)

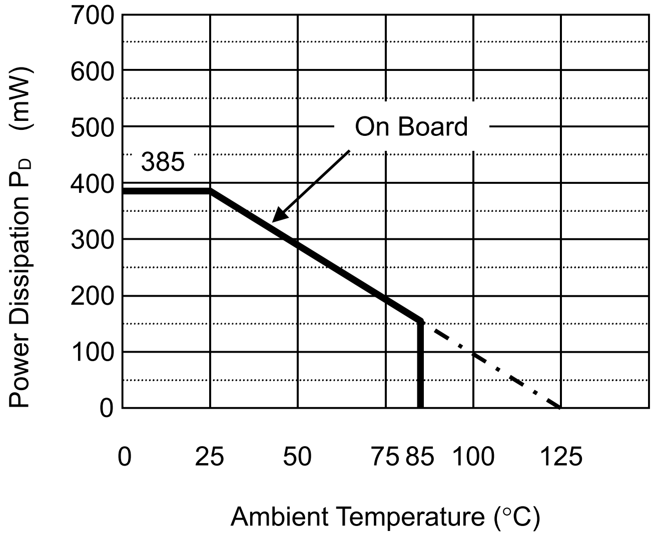
Power Dissipation (P_D) of the package is dependent on PCB material, layout, and environmental conditions. The following conditions are used in this measurement.

Measurement Conditions

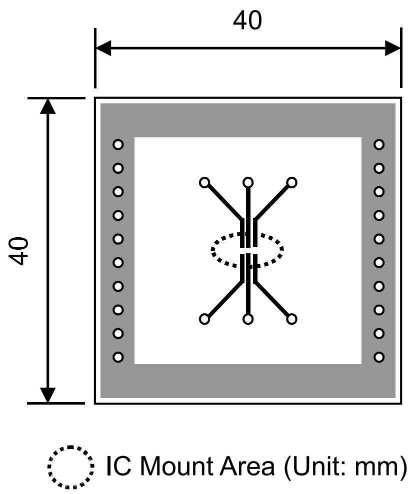
	Standard Land Pattern
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (Double-sided)
Board Dimensions	40 mm x 40 mm x 1.6 mm
Copper Ratio	Topside: Approx. 50%, Backside: Approx. 50%
Through-holes	ϕ 0.3 mm x 26 pcs

Measurement Result (Ta = 25°C, Tjmax = 125°C)

	Standard Land Pattern
Power Dissipation	385 mW
Thermal Resistance	θja = (125 − 25 °C) / 0.385W = 260 °C/W
	θjc = 30°C/W



Power Dissipation vs. Ambient Temperature



Measurement Board Pattern

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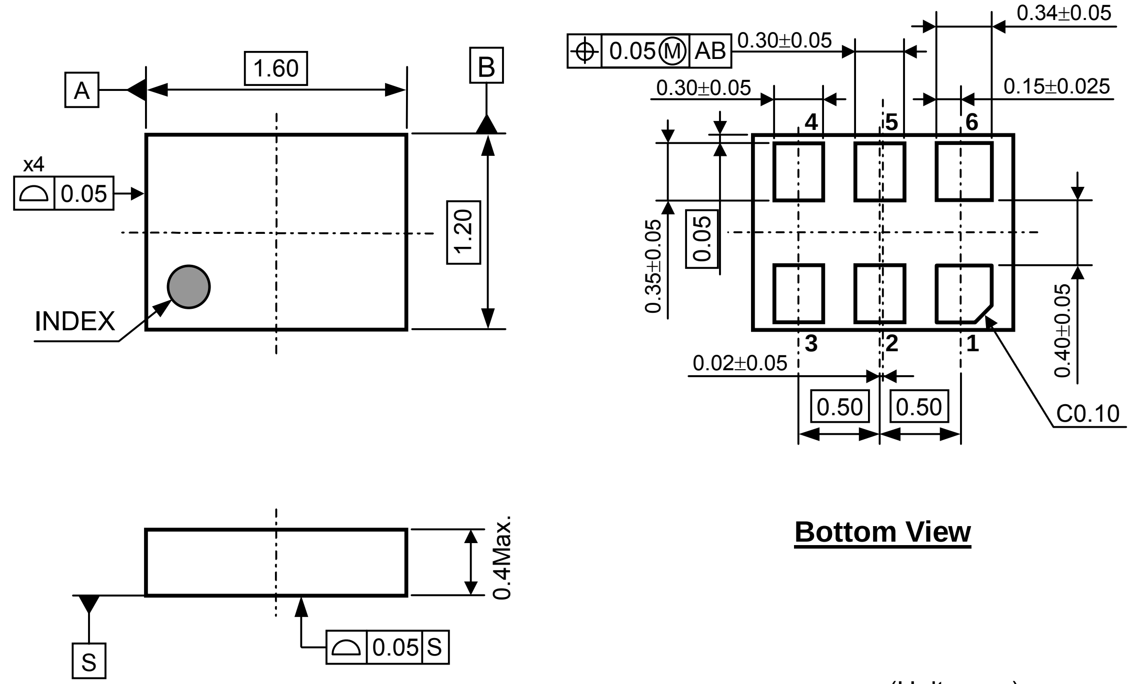
PACKAGE DIMENSIONS (DFN(PLP)1216-6F)



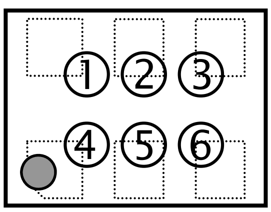
(Unit : mm)

DFN(PLP)1216-6F Package Dimensions

MARK SPECIFICATION (DFN(PLP)1216-6F)

①②③④: Product Code … **Refer to *MARK SPECIFICATION TABLE (DFN(PLP)1216-6F).***

⑤⑥: Lot Number … Alphanumeric Serial Number



DFN(PLP)1216-6F Mark Specification

MARK SPECIFICATION TABLE (DFN(PLP)1216-6F)

RP504K

Product Name	①②③④
RP504K081A	**D A 0 8**
RP504K091A	**D A 0 9**
RP504K101A	**D A 1 0**
RP504K111A	**D A 1 1**
RP504K121A	**D A 1 2**
RP504K131A	**D A 1 3**
RP504K141A	**D A 1 4**
RP504K151A	**D A 1 5**
RP504K161A	**D A 1 6**
RP504K171A	**D A 1 7**
RP504K181A	**D A 1 8**
RP504K191A	**D A 1 9**
RP504K201A	**D A 2 0**
RP504K211A	**D A 2 1**
RP504K221A	**D A 2 2**
RP504K231A	**D A 2 3**
RP504K241A	**D A 2 4**
RP504K251A	**D A 2 5**
RP504K261A	**D A 2 6**
RP504K271A	**D A 2 7**
RP504K281A	**D A 2 8**
RP504K291A	**D A 2 9**
RP504K301A	**D A 3 0**
RP504K311A	**D A 3 1**
RP504K321A	**D A 3 2**
RP504K331A	**D A 3 3**
RP504K121A5	**D A 0 1**
RP504K131A5	**D A 0 2**
RP504K121A2	**D A 0 3**
RP504K101A5	**D A 0 4**

Product Name	①②③④
RP504K081D	**D B 0 8**
RP504K091D	**D B 0 9**
RP504K101D	**D B 1 0**
RP504K111D	**D B 1 1**
RP504K121D	**D B 1 2**
RP504K131D	**D B 1 3**
RP504K141D	**D B 1 4**
RP504K151D	**D B 1 5**
RP504K161D	**D B 1 6**
RP504K171D	**D B 1 7**
RP504K181D	**D B 1 8**
RP504K191D	**D B 1 9**
RP504K201D	**D B 2 0**
RP504K211D	**D B 2 1**
RP504K221D	**D B 2 2**
RP504K231D	**D B 2 3**
RP504K241D	**D B 2 4**
RP504K251D	**D B 2 5**
RP504K261D	**D B 2 6**
RP504K271D	**D B 2 7**
RP504K281D	**D B 2 8**
RP504K291D	**D B 2 9**
RP504K301D	**D B 3 0**
RP504K311D	**D B 3 1**
RP504K321D	**D B 3 2**
RP504K331D	**D B 3 3**
RP504K121D5	**D B 0 1**
RP504K131D5	**D B 0 2**
RP504K121D2	**D B 0 3**
RP504K101D5	**D B 0 4**

POWER DISSIPATION (DFN1616-6B)

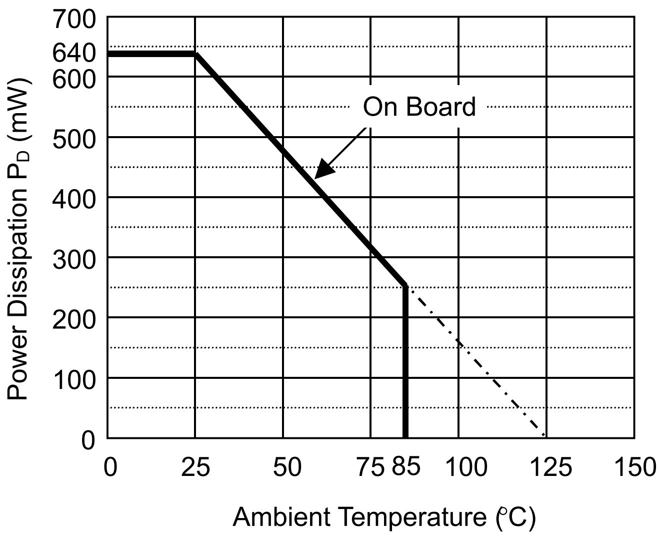
Power Dissipation (P_D) of the package is dependent on PCB material, layout, and environmental conditions. The following conditions are used in this measurement.

Measurement Conditions

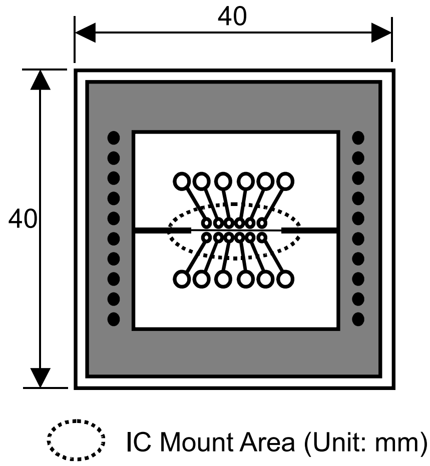
	Standard Land Pattern
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (Double-sided)
Board Dimensions	40 mm x 40 mm x 1.6 mm
Copper Ratio	Topside: Approx. 50%, Backside: Approx. 50%
Through-holes	ϕ 0.5 mm x 32 pcs

Measurement Result (Ta = 25°C, Tjmax = 125°C)

	Standard Land Pattern
Power Dissipation	640 mW
Thermal Resistance	θja = (125 − 25°C) / 0.64 W = 156°C/W
	θjc = 23 °C/W

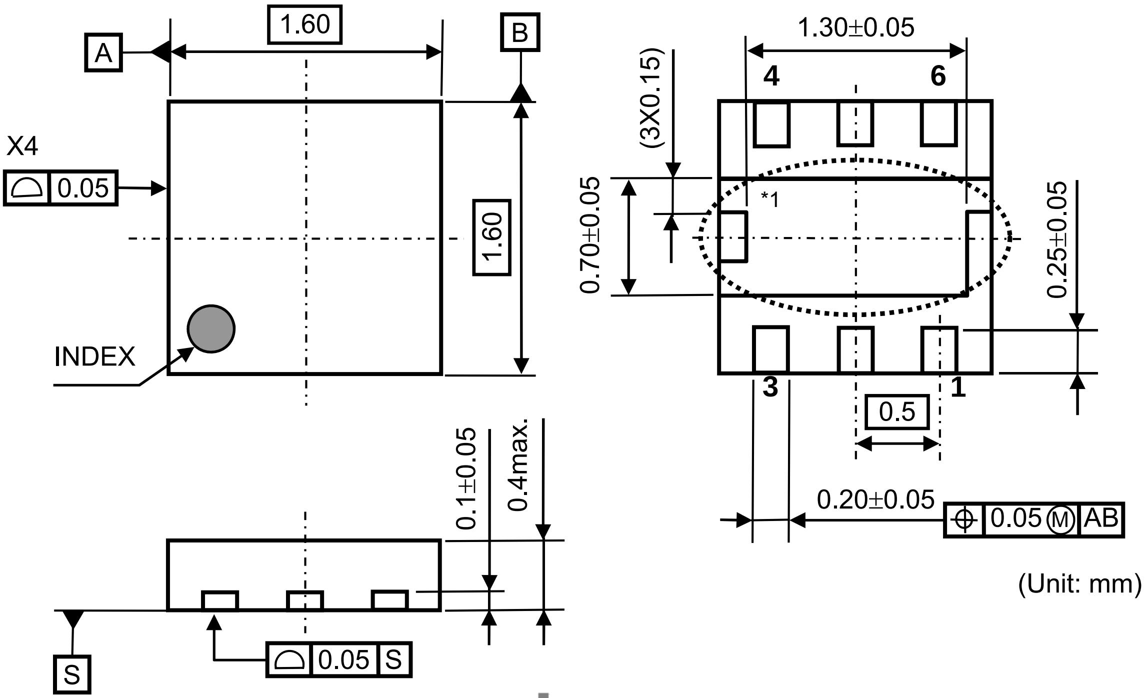


Power Dissipation vs. Ambient Temperature



Measurement Board Pattern

PACKAGE DIMENSIONS (DFN1616-6B)



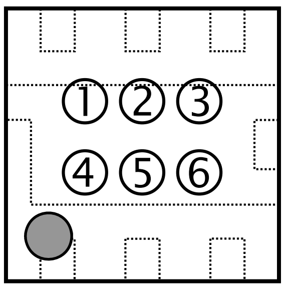
*1 The tab on the bottom of the package enhances thermal performance and is electrically connected to GND (substrate level). It is recommended that the tab be connected to the ground plane on the board. If not, the tab can be left open.

DFN1616-6B Package Dimensions

MARK SPECIFICATION (DFN1616-6B)

①②③④: Product Code … **Refer to *MARK SPECIFICATION TABLE (DFN1616-6B).***

⑤⑥: Lot Number … Alphanumeric Serial Number



DFN1616-6B Mark Specification

RICOH

MARK SPECIFICATION TABLE (DFN1616-6B)

RP504L

Product Name	①②③④
RP504L081A	**A Z 0 8**
RP504L091A	**A Z 0 9**
RP504L101A	**A Z 1 0**
RP504L111A	**A Z 1 1**
RP504L121A	**A Z 1 2**
RP504L131A	**A Z 1 3**
RP504L141A	**A Z 1 4**
RP504L151A	**A Z 1 5**
RP504L161A	**A Z 1 6**
RP504L171A	**A Z 1 7**
RP504L181A	**A Z 1 8**
RP504L191A	**A Z 1 9**
RP504L201A	**A Z 2 0**
RP504L211A	**A Z 2 1**
RP504L221A	**A Z 2 2**
RP504L231A	**A Z 2 3**
RP504L241A	**A Z 2 4**
RP504L251A	**A Z 2 5**
RP504L261A	**A Z 2 6**
RP504L271A	**A Z 2 7**
RP504L281A	**A Z 2 8**
RP504L291A	**A Z 2 9**
RP504L301A	**A Z 3 0**
RP504L311A	**A Z 3 1**
RP504L321A	**A Z 3 2**
RP504L331A	**A Z 3 3**
RP504L121A5	**A Z 0 1**
RP504L131A5	**A Z 0 2**
RP504L121A2	**A Z 0 3**
RP504L101A5	**A Z 0 4**

Product Name	①②③④
RP504L081D	**C Z 0 8**
RP504L091D	**C Z 0 9**
RP504L101D	**C Z 1 0**
RP504L111D	**C Z 1 1**
RP504L121D	**C Z 1 2**
RP504L131D	**C Z 1 3**
RP504L141D	**C Z 1 4**
RP504L151D	**C Z 1 5**
RP504L161D	**C Z 1 6**
RP504L171D	**C Z 1 7**
RP504L181D	**C Z 1 8**
RP504L191D	**C Z 1 9**
RP504L201D	**C Z 2 0**
RP504L211D	**C Z 2 1**
RP504L221D	**C Z 2 2**
RP504L231D	**C Z 2 3**
RP504L241D	**C Z 2 4**
RP504L251D	**C Z 2 5**
RP504L261D	**C Z 2 6**
RP504L271D	**C Z 2 7**
RP504L281D	**C Z 2 8**
RP504L291D	**C Z 2 9**
RP504L301D	**C Z 3 0**
RP504L311D	**C Z 3 1**
RP504L321D	**C Z 3 2**
RP504L331D	**C Z 3 3**
RP504L121D5	**C Z 0 1**
RP504L131D5	**C Z 0 2**
RP504L121D2	**C Z 0 3**
RP504L101D5	**C Z 0 4**

POWER DISSIPATION (SOT-23-5)

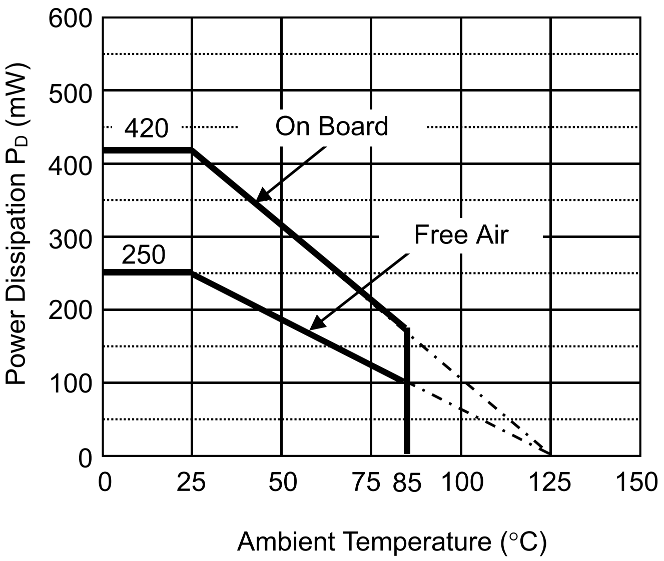
Power Dissipation (P_D) of the package is dependent on PCB material, layout, and environmental conditions. The following conditions are used in this measurement. This data is taken from SOT-23-6.

Measurement Conditions

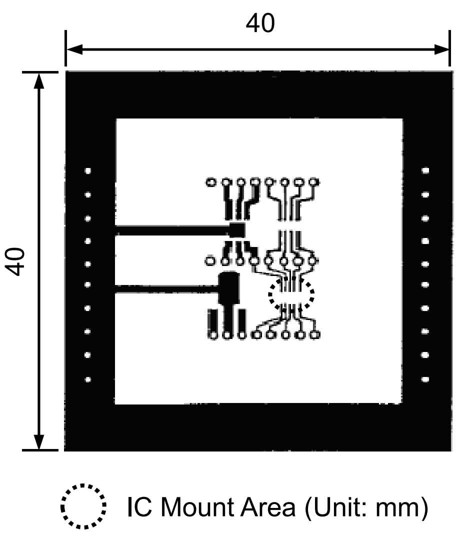
	Standard Land Pattern
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (Double-sided)
Board Dimensions	40 mm x 40 mm x 1.6 mm
Copper Ratio	Top side: Approx. 50%, Back side: Approx. 50%
Through-holes	ϕ 0.5 mm x 44 pcs

Measurement Result (Ta = 25°C, Tjmax = 125°C)

	Standard Land Pattern	Free Air
Power Dissipation	420 mW	250 mW
Thermal Resistance	θja = (125 − 25°C) / 0.42 W = 238°C/W	400°C/W

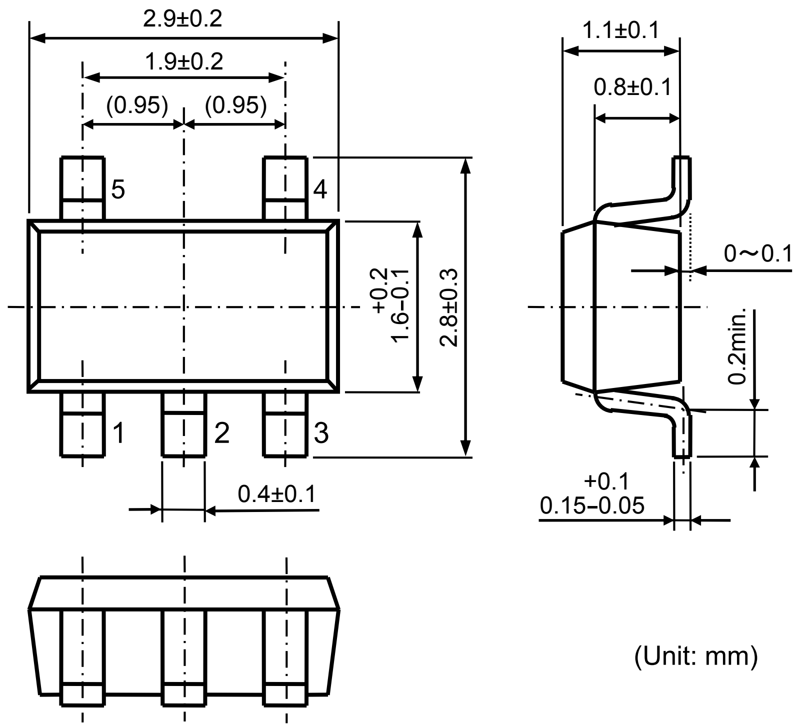


Power Dissipation vs. Ambient Temperature



Measurement Board Pattern

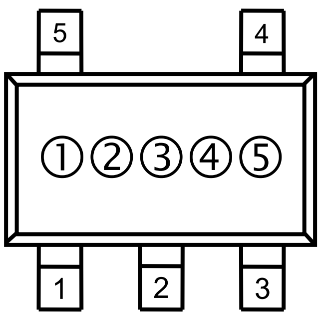
PACKAGE DIMENSIONS (SOT-23-5)



SOT-23-5 Package Dimensions

MARK SPECIFICATION (SOT-23-5)

①②③: Product Code … **Refer to *MARK SPECIFICATION TABLE (SOT-23-5).***
④⑤: Lot Number … Alphanumeric Serial Number



SOT-23-5 Mark Specification

MARK SPECIFICATION TABLE (SOT-23-5)

RP504N

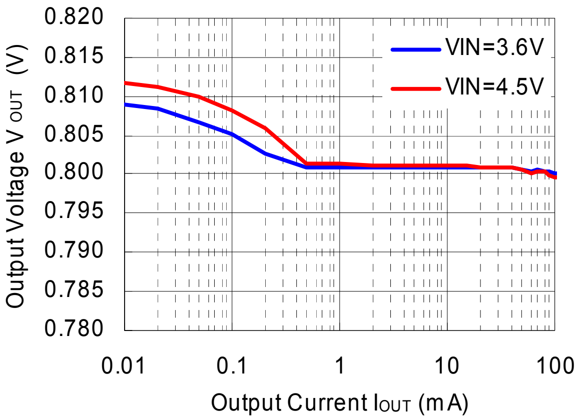
Product Name	①②③	Product Name	①②③
RP504N081B	**M 0 8**	RP504N081C	**N 0 8**
RP504N091B	**M 0 9**	RP504N091C	**N 0 9**
RP504N101B	**M 1 0**	RP504N101C	**N 1 0**
RP504N111B	**M 1 1**	RP504N111C	**N 1 1**
RP504N121B	**M 1 2**	RP504N121C	**N 1 2**
RP504N131B	**M 1 3**	RP504N131C	**N 1 3**
RP504N141B	**M 1 4**	RP504N141C	**N 1 4**
RP504N151B	**M 1 5**	RP504N151C	**N 1 5**
RP504N161B	**M 1 6**	RP504N161C	**N 1 6**
RP504N171B	**M 1 7**	RP504N171C	**N 1 7**
RP504N181B	**M 1 8**	RP504N181C	**N 1 8**
RP504N191B	**M 1 9**	RP504N191C	**N 1 9**
RP504N201B	**M 2 0**	RP504N201C	**N 2 0**
RP504N211B	**M 2 1**	RP504N211C	**N 2 1**
RP504N221B	**M 2 2**	RP504N221C	**N 2 2**
RP504N231B	**M 2 3**	RP504N231C	**N 2 3**
RP504N241B	**M 2 4**	RP504N241C	**N 2 4**
RP504N251B	**M 2 5**	RP504N251C	**N 2 5**
RP504N261B	**M 2 6**	RP504N261C	**N 2 6**
RP504N271B	**M 2 7**	RP504N271C	**N 2 7**
RP504N281B	**M 2 8**	RP504N281C	**N 2 8**
RP504N291B	**M 2 9**	RP504N291C	**N 2 9**
RP504N301B	**M 3 0**	RP504N301C	**N 3 0**
RP504N311B	**M 3 1**	RP504N311C	**N 3 1**
RP504N321B	**M 3 2**	RP504N321C	**N 3 2**
RP504N331B	**M 3 3**	RP504N331C	**N 3 3**
RP504N121B5	**M 0 1**	RP504N121C5	**N 0 1**
RP504N131B5	**M 0 2**	RP504N131C5	**N 0 2**

TYPICAL CHARACTERISTICS

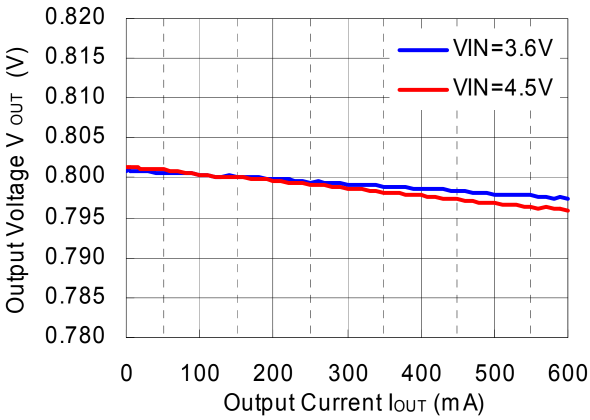
Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

1) Output Voltage vs. Output Current

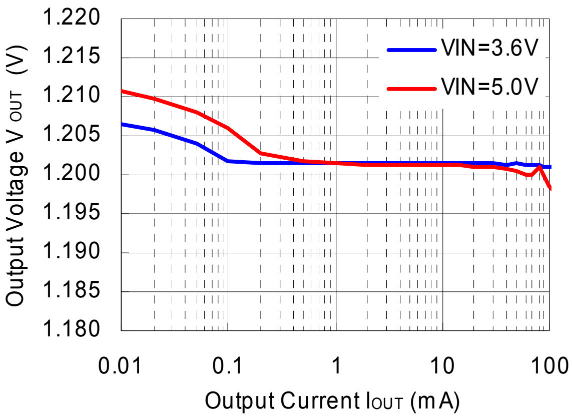
RP504x V_{OUT} = 0.8 V
MODE = "L"PWM/VFM Auto Switching Control



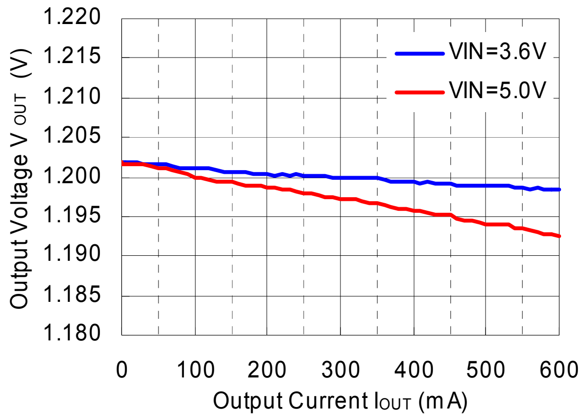
RP504x V_{OUT} = 0.8 V
MODE = "H" Forced PWM Control



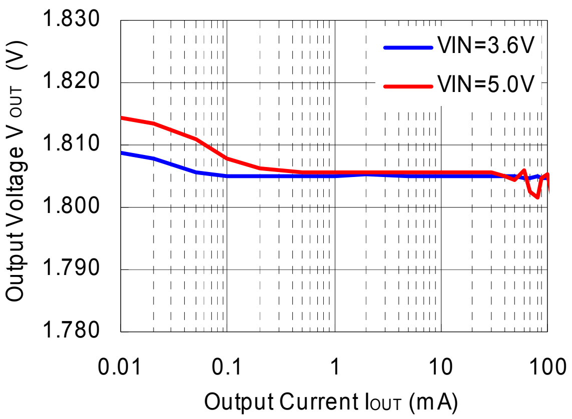
RP504x V_{OUT} = 1.2 V
MODE = "L"PWM/VFM Auto Switching Control



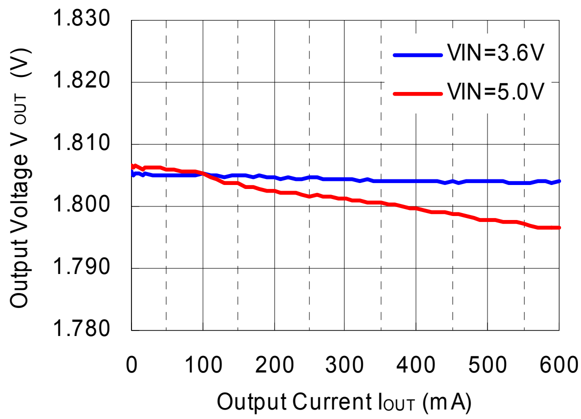
RP504x V_{OUT} = 1.2 V
MODE = "H" Forced PWM Control



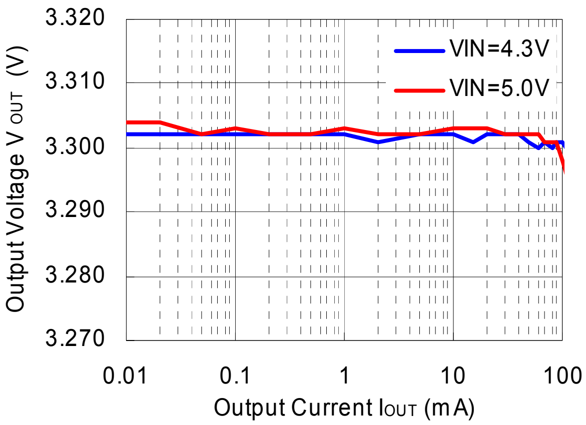
RP504x V_{OUT} = 1.8 V
MODE = "L"PWM/VFM Auto Switching Control



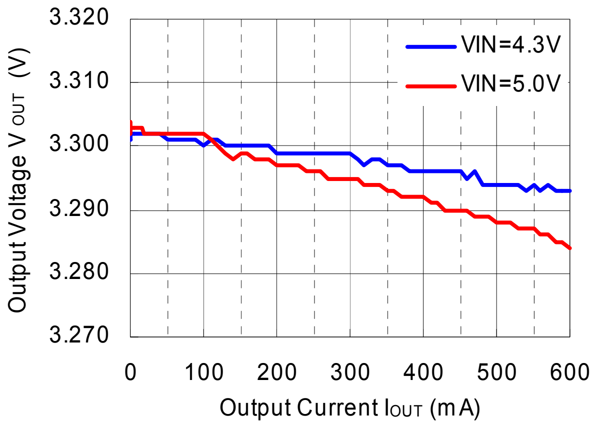
RP504x V_{OUT} = 1.8 V
MODE = "H" Forced PWM Control



RP504x VOUT = 3.3 V
MODE = "L"PWM/VFM Auto Switching Control

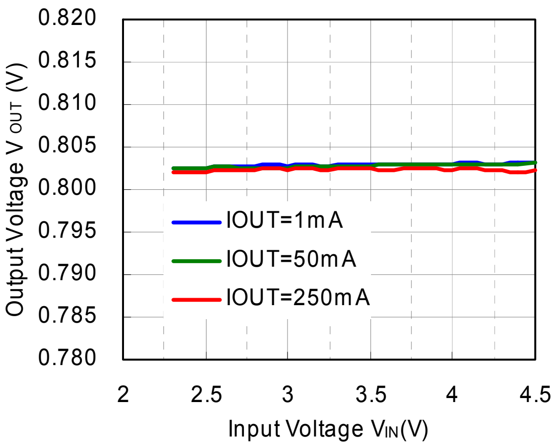


RP504x VOUT = 3.3 V
MODE = "H" Forced PWM Control

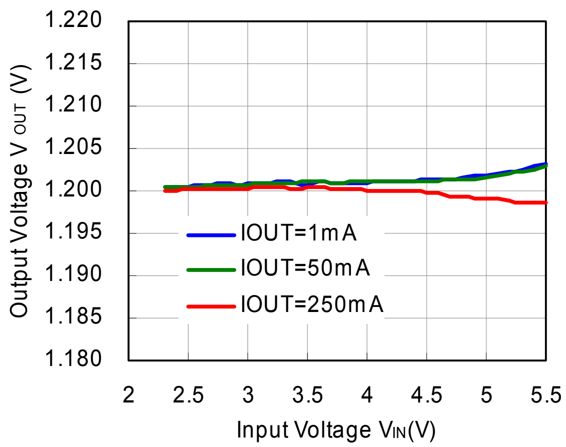


2) Output Voltage vs. Input Voltage

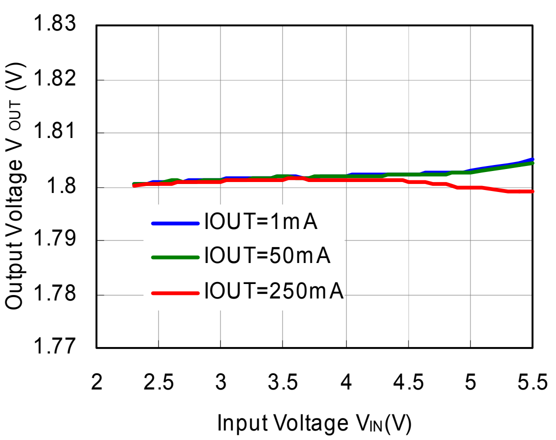
RP504x VOUT = 0.8 V
MODE = "H" Forced PWM Control



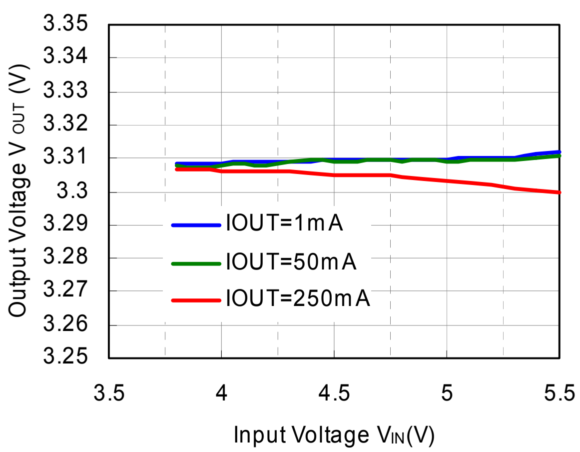
RP504x VOUT = 1.2 V
MODE = "H" Forced PWM Control



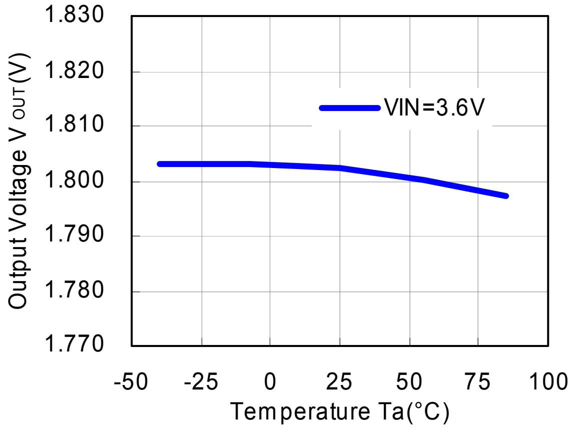
RP504x VOUT = 1.8 V
MODE = "H" Forced PWM Control



RP504x VOUT = 3.3 V
MODE = "H" Forced PWM Control

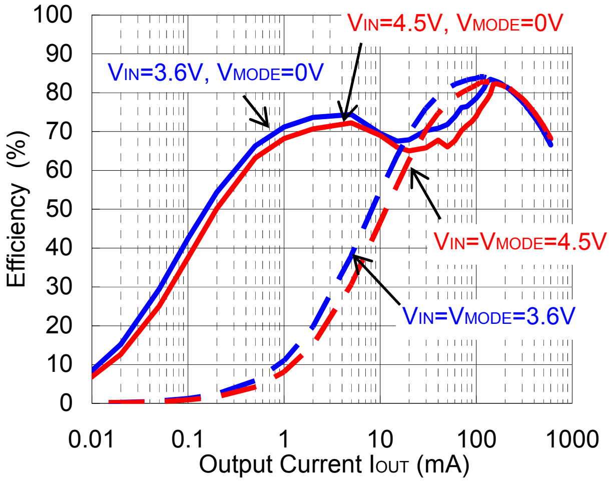


3) Output Voltage vs. Temperature

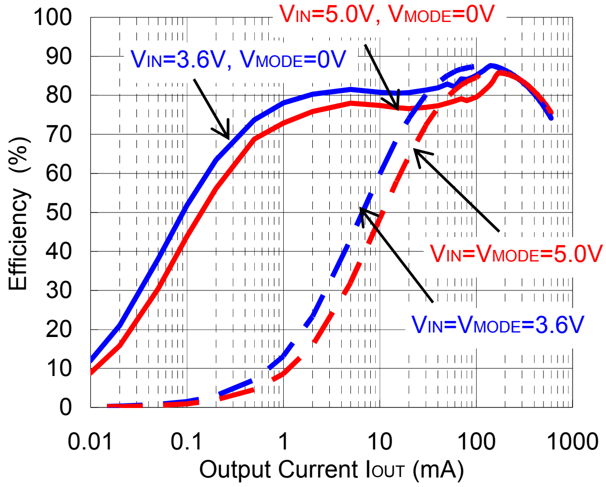


4) Efficiency vs. Output Current

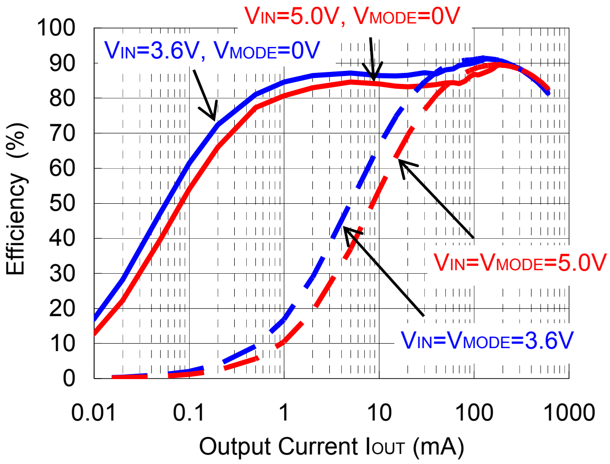
RP504x VOUT = 0.8 V



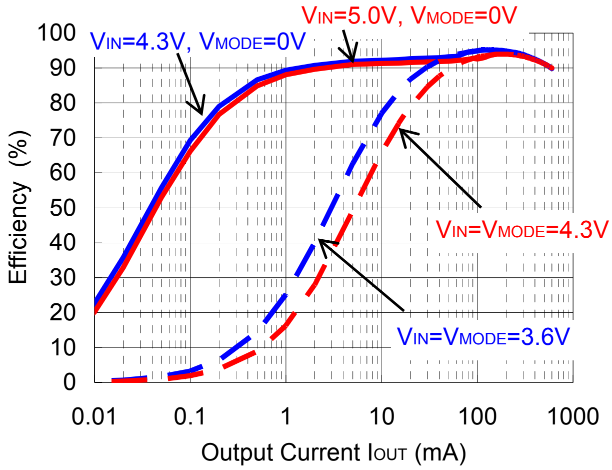
RP504x VOUT = 1.2 V



RP504x VOUT = 1.8 V



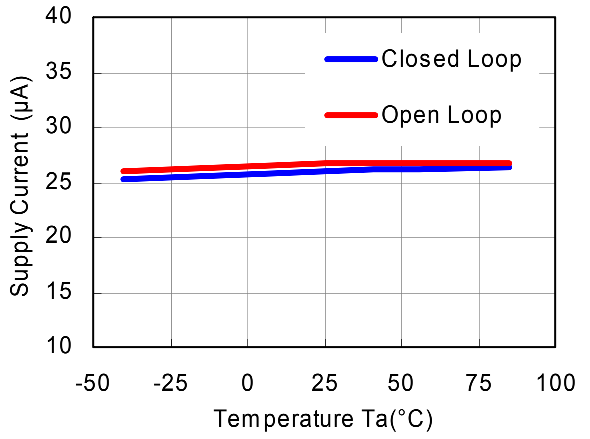
RP504x VOUT = 3.3 V



RICOH

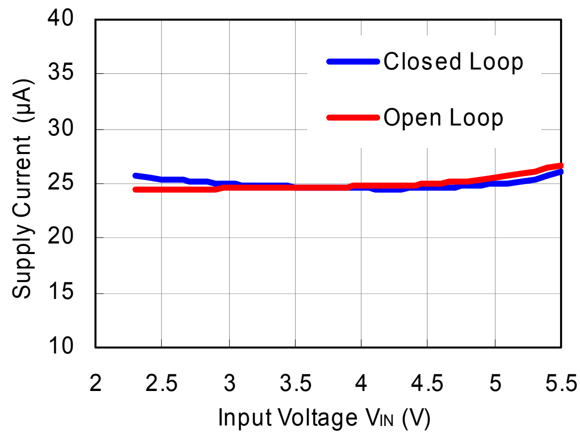
5) Supply Current vs. Temperature

RP504x V_{OUT} = 1.8 V (V_{IN} = 5.5 V)
MODE = "L"PWM/VFM Auto Switching Control



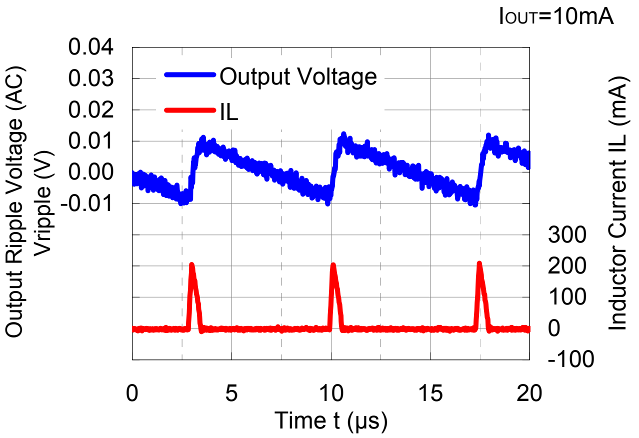
6) Supply Current vs. Input Voltage

RP504x V_{OUT} = 1.8 V
MODE = "L"PWM/VFM Auto Switching Control

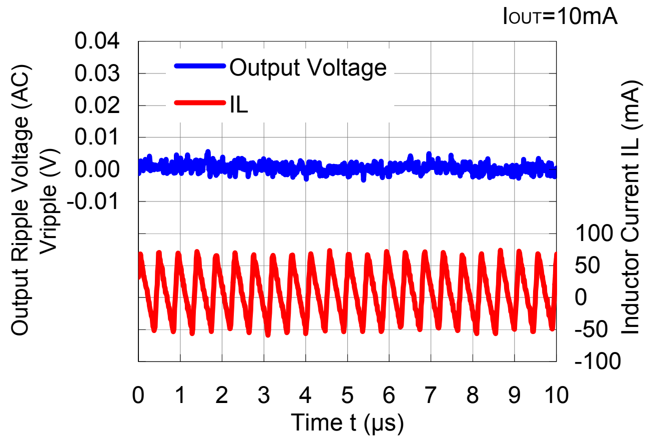


7) Output Voltage Waveform

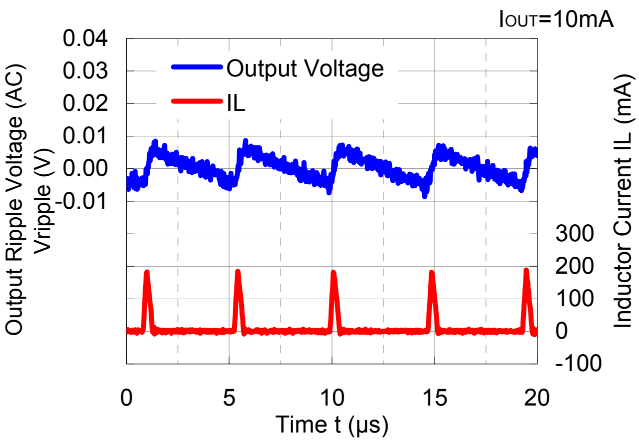
RP504x V_{OUT} = 0.8 V (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



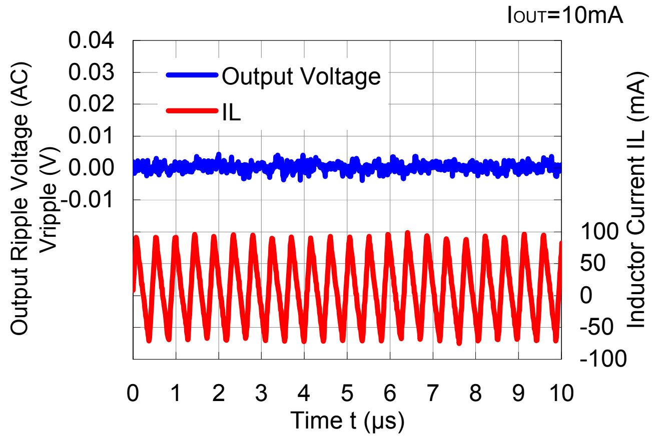
RP504x V_{OUT} = 0.8 V (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



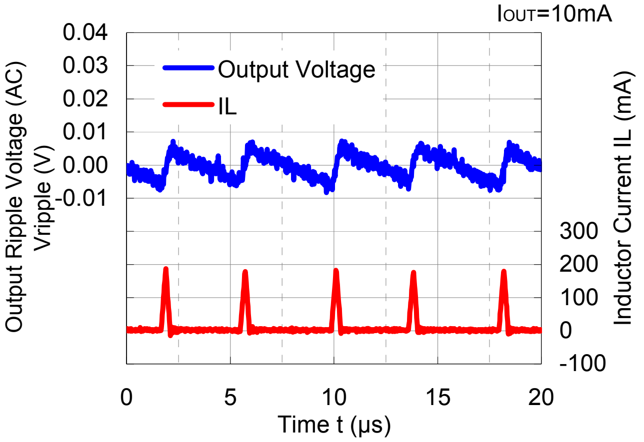
RP504x V_{OUT} = 1.2V (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



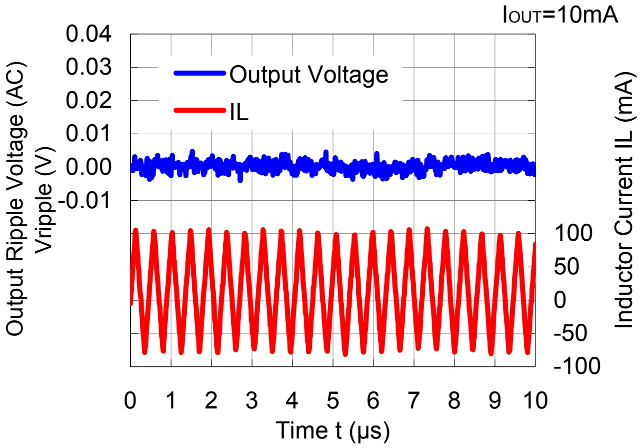
RP504x V_{OUT} = 1.2 V (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



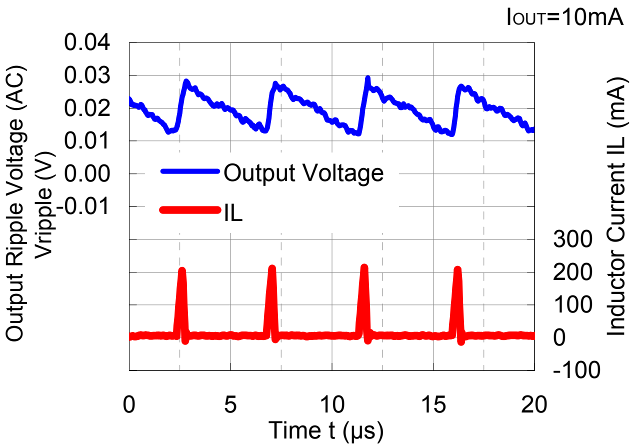
RP504x V_{OUT} = 1.8 V (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



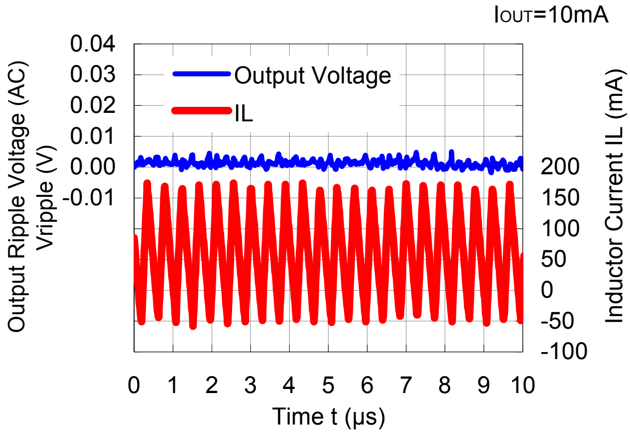
RP504x V_{OUT} = 1.8 V (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



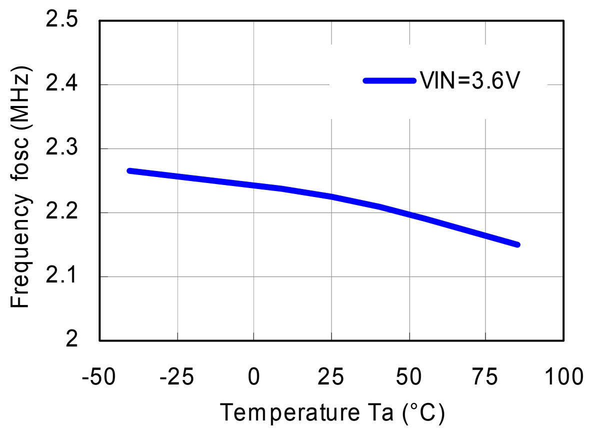
RP504x V_{OUT} = 3.3 V (V_{IN} = 5.0 V)
MODE = "L"PWM/VFM Auto Switching Control



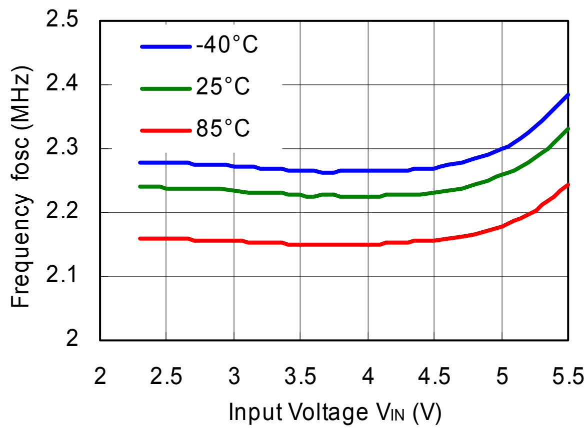
RP504x V_{OUT} = 3.3 V (V_{IN} = 5.0 V)
MODE = "H" Forced PWM Control



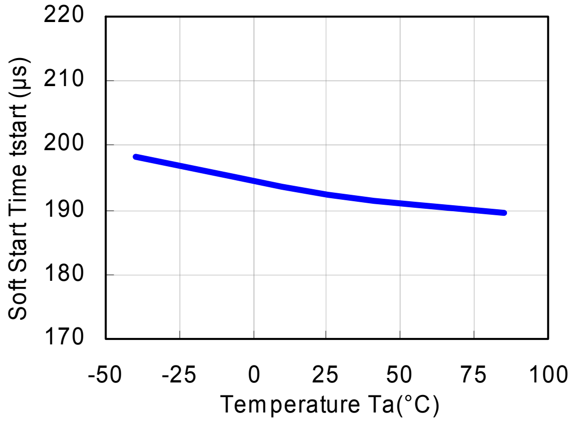
8) Frequency vs. Temperature



9) Frequency vs. Input Voltage

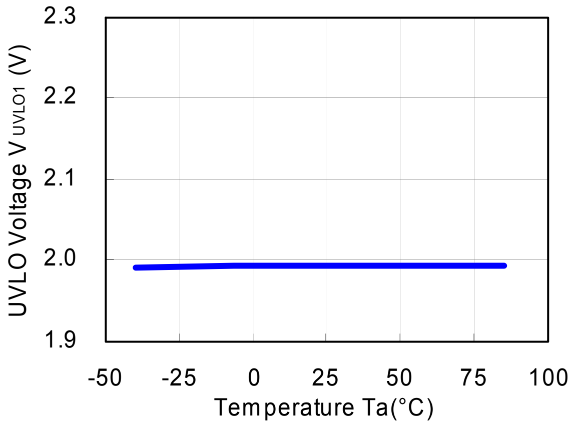


10) Soft Start Time vs. Temperature

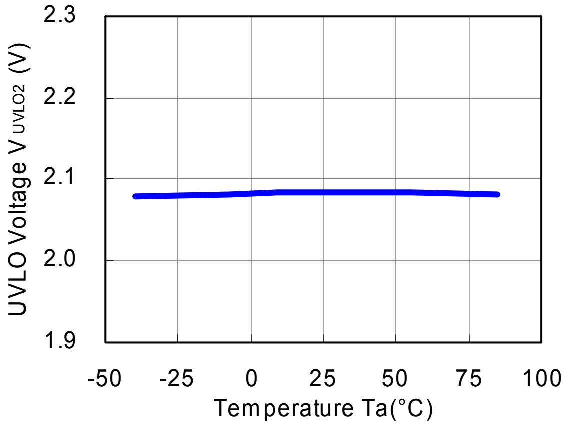


11) UVLO Detector Threshold / Released Voltage vs. Temperature

UVLO Detector Threshold Voltage

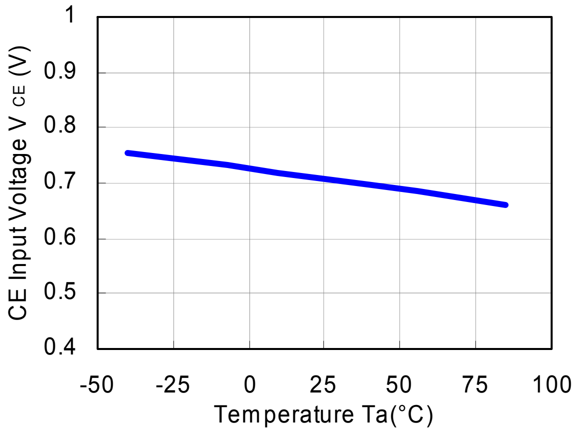


UVLO Released Voltage

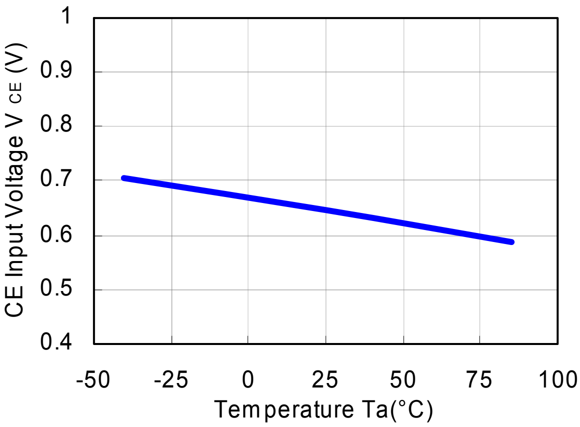


12) CE Input Voltage vs. Temperature

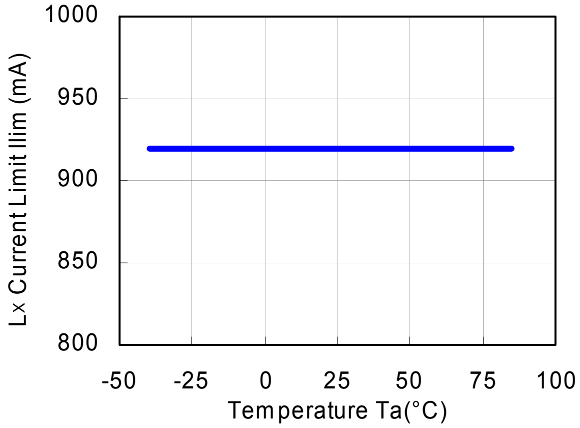
CE "H" Input Voltage (V_{IN} = 5.5 V)



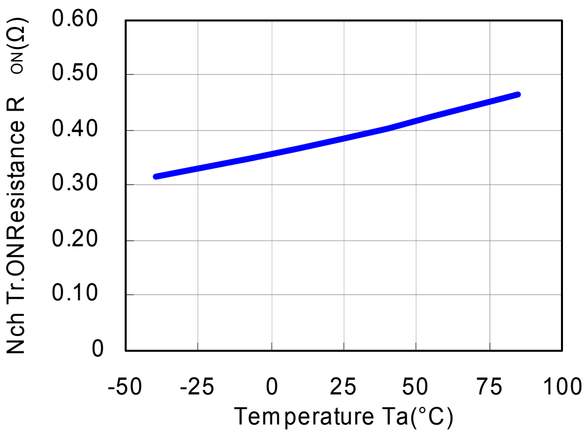
CE "H" Input Voltage (V_{IN} = 2.3 V)



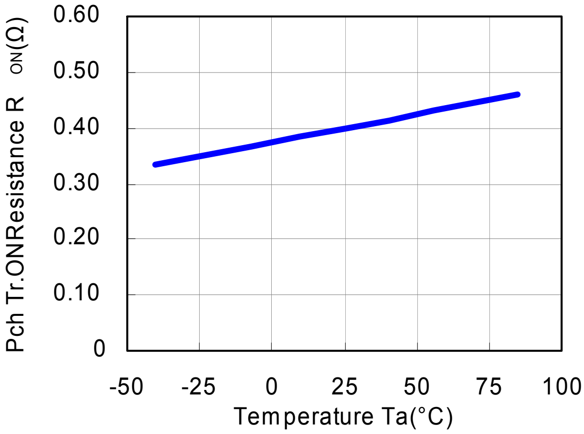
13) L_X Current Limit vs. Temperature



14) Nch Tr. ON Resistance vs. Temperature

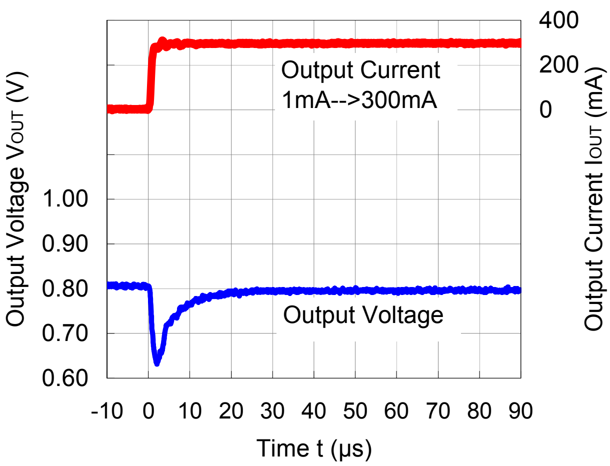


15) Pch Tr. ON Resistance vs. Temperature

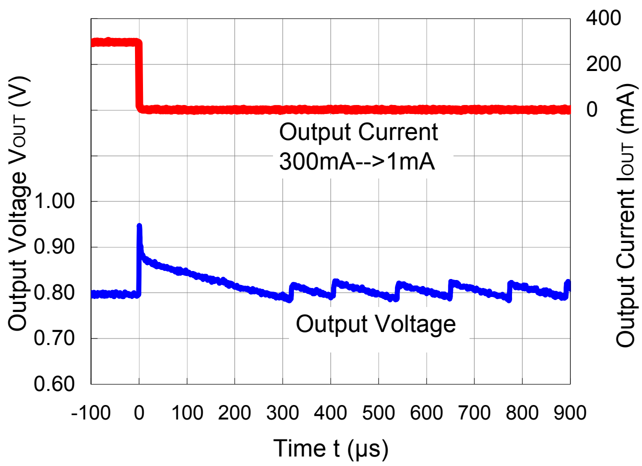


16) Load Transient Response

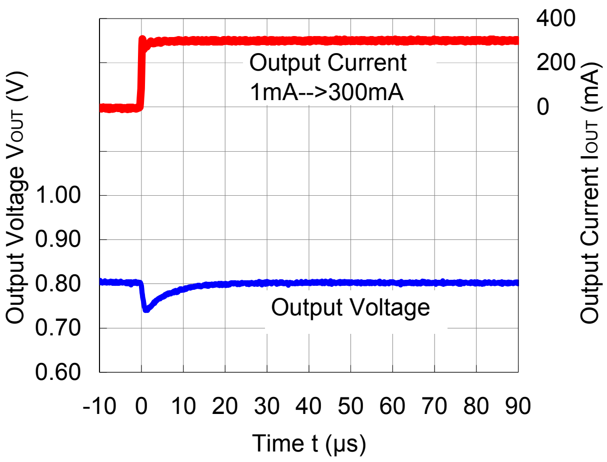
RP504x081x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



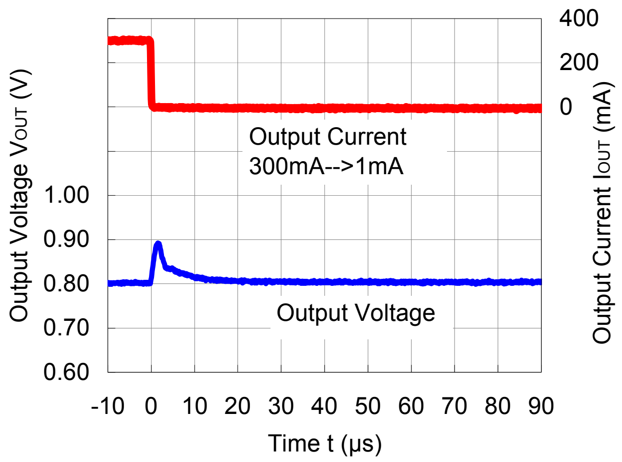
RP504x081x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



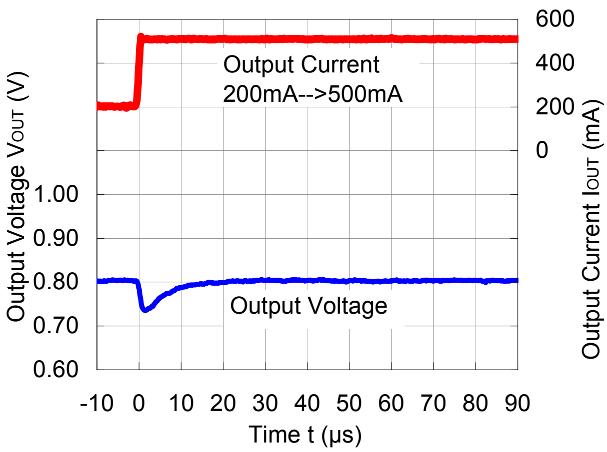
RP504x081x (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



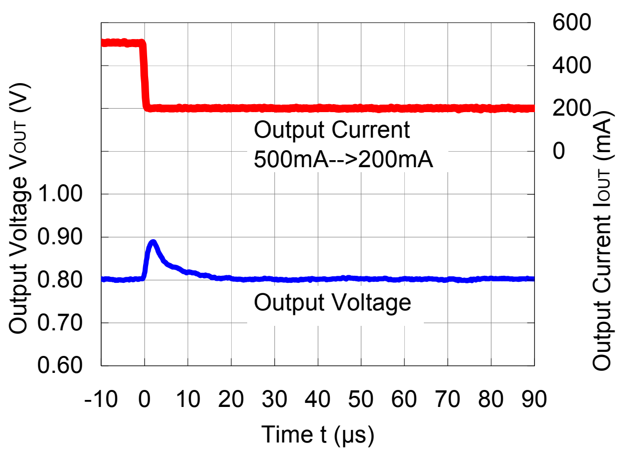
RP504x081x (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



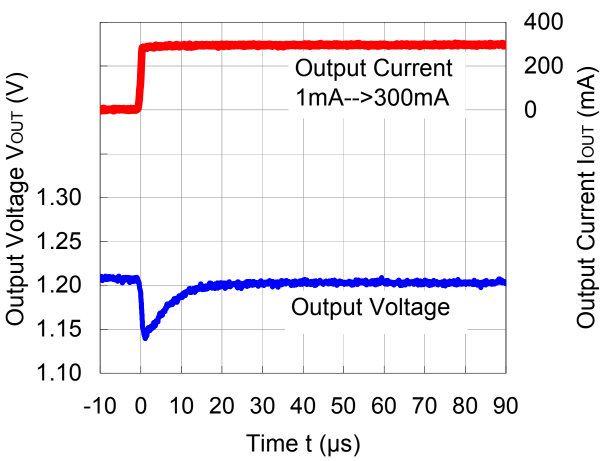
RP504x081x (V_{IN} = 3.6 V)



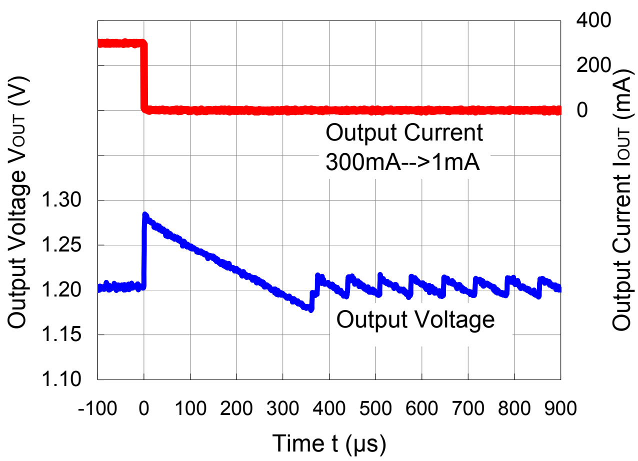
RP504x081x (V_{IN} = 3.6 V)



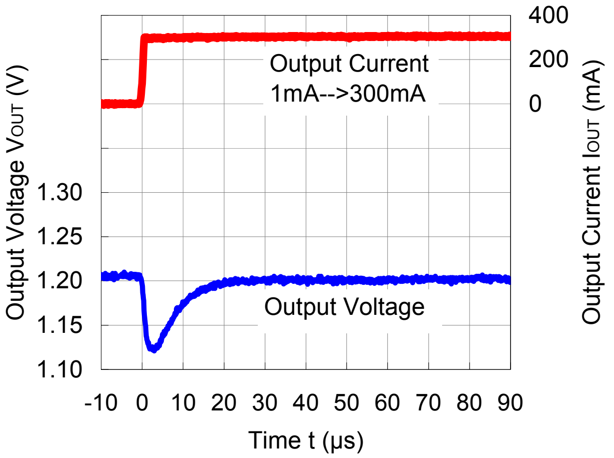
RP504x121x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



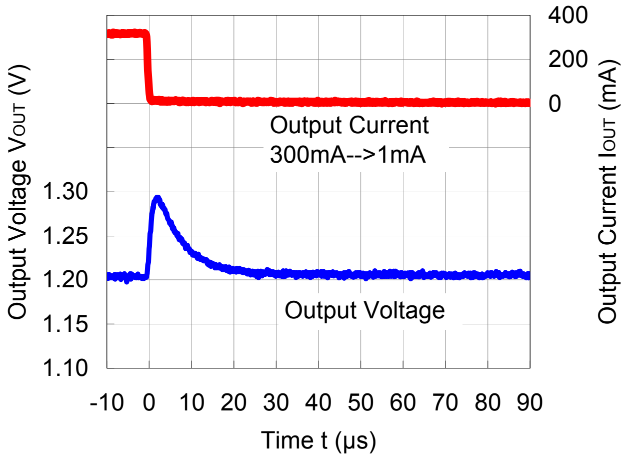
RP504x121x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



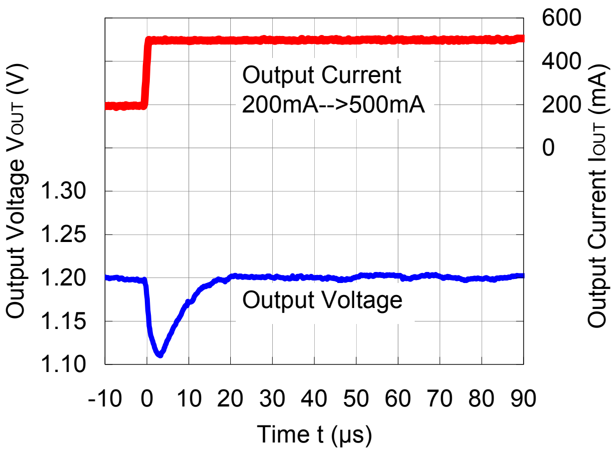
RP504x121x (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



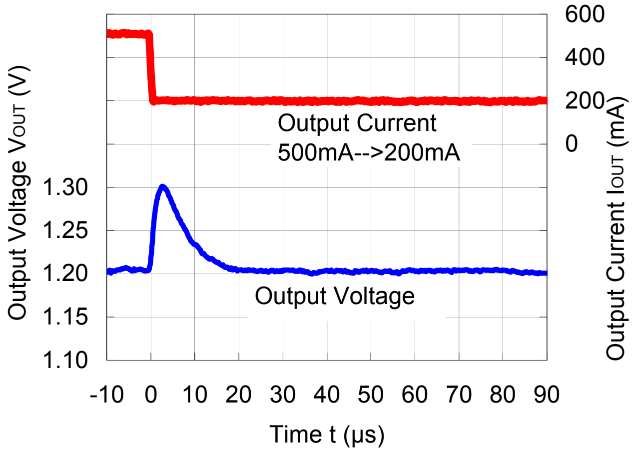
RP504x121x (V_{IN} = 3.6 V)
MODE = "H" Forced PWM Control



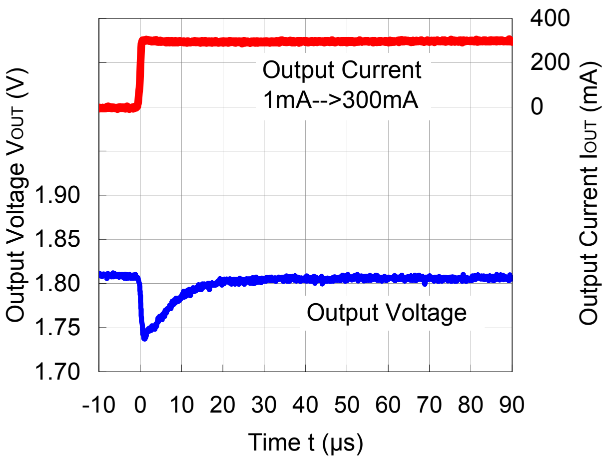
RP504x121x (V_{IN} = 3.6 V)



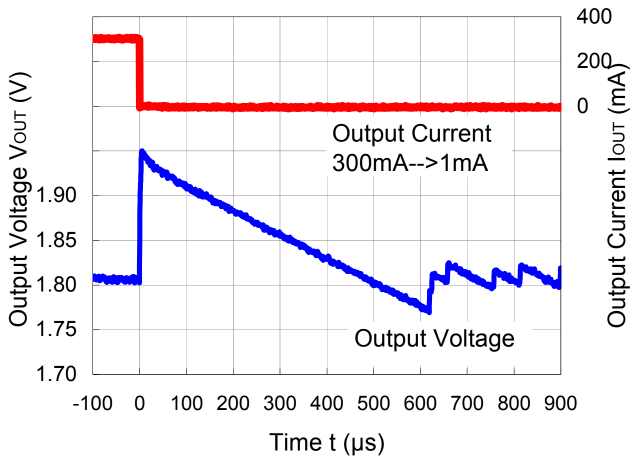
RP504x121x (V_{IN} = 3.6 V)



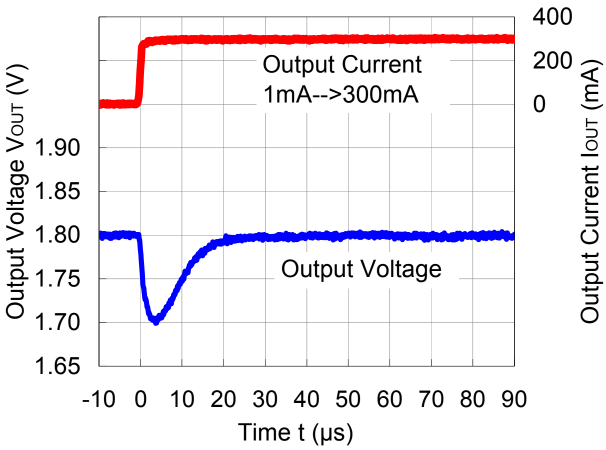
RP504x181x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



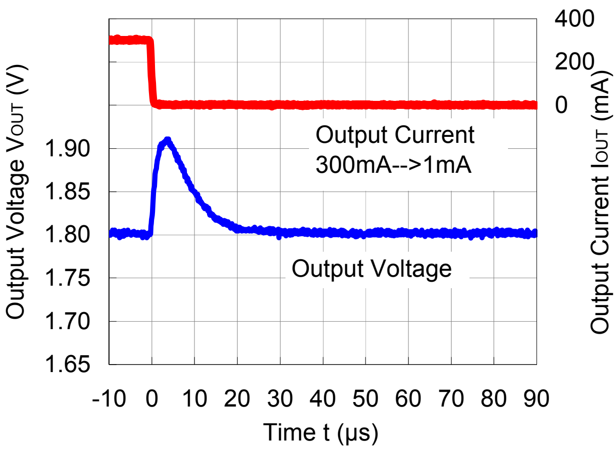
RP504x181x (V_{IN} = 3.6 V)
MODE = "L"PWM/VFM Auto Switching Control



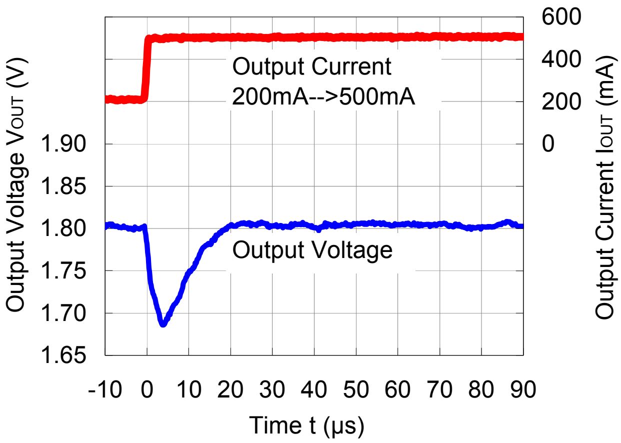
RP504x181x (V_{IN} = 3.6 V)
MODE = “H” Forced PWM Control



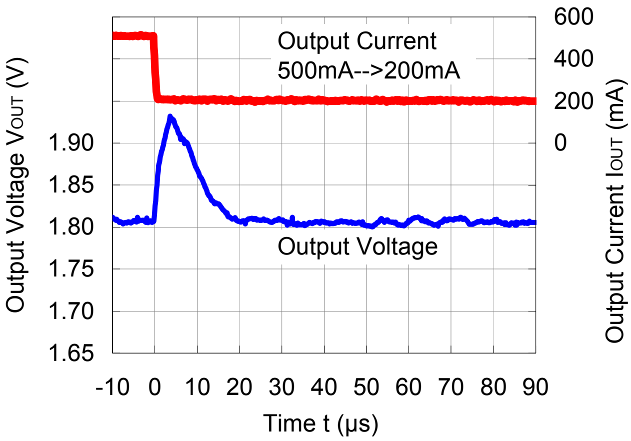
RP504x181x (V_{IN} = 3.6 V)
MODE = “H” Forced PWM Control



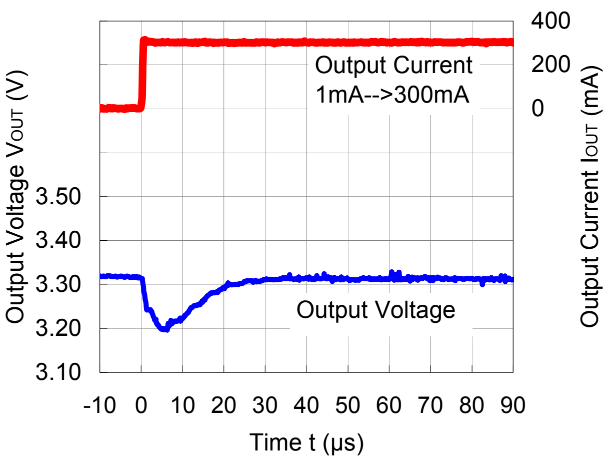
RP504x181x (V_{IN} = 3.6 V)



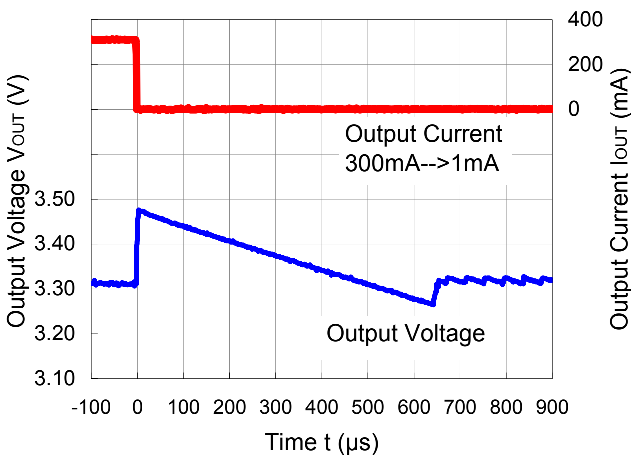
RP504x181x (V_{IN} = 3.6 V)



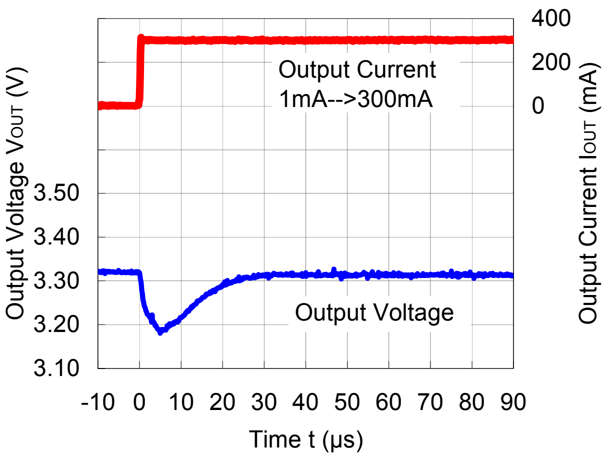
RP504x331x (V_{IN} = 5.0 V)
MODE = “L”PWM/VFM Auto Switching Control



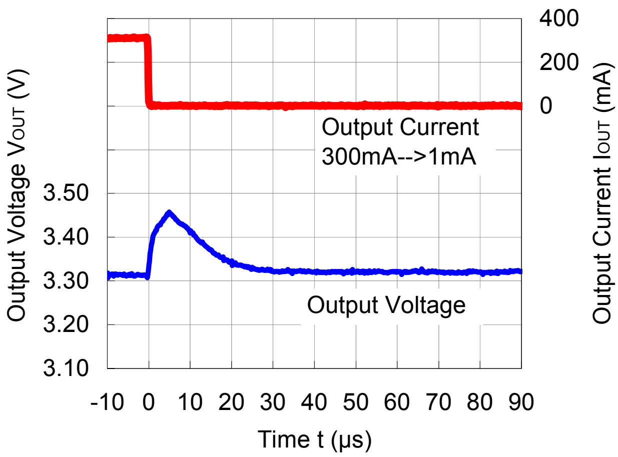
RP504x331x (V_{IN} = 5.0 V)
MODE = “L”PWM/VFM Auto Switching Control



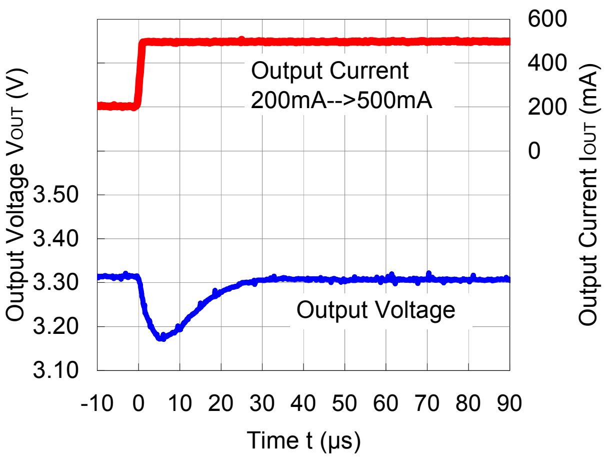
RP504x331x (V_{IN} = 5.0 V)
MODE = "H" Forced PWM Control



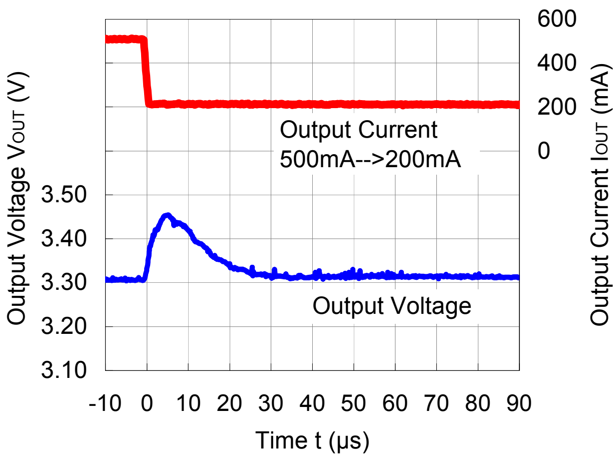
RP504x331x (V_{IN} = 5.0 V)
MODE = "H" Forced PWM Control



RP504x331x (V_{IN} = 5.0 V)

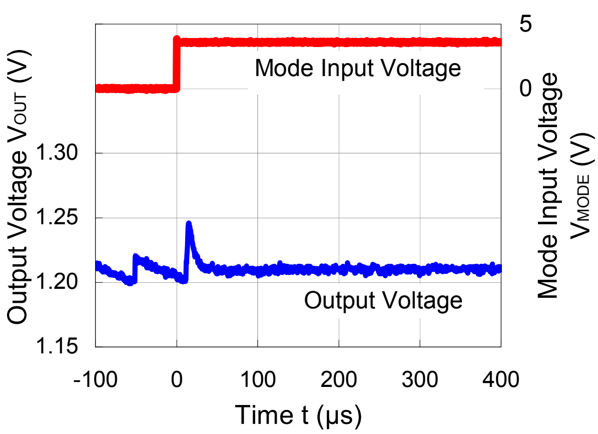


RP504x331x (V_{IN} = 5.0 V)

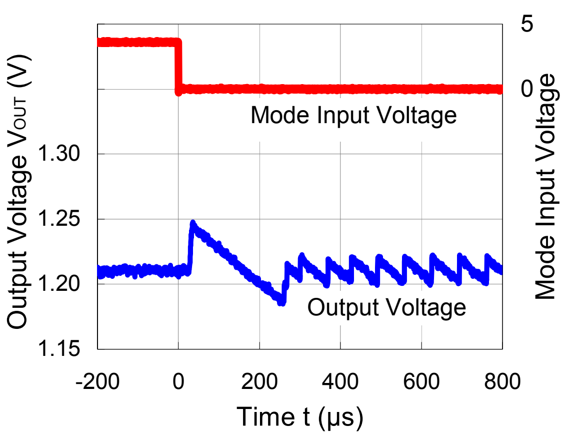


17) Mode Switching Waveform

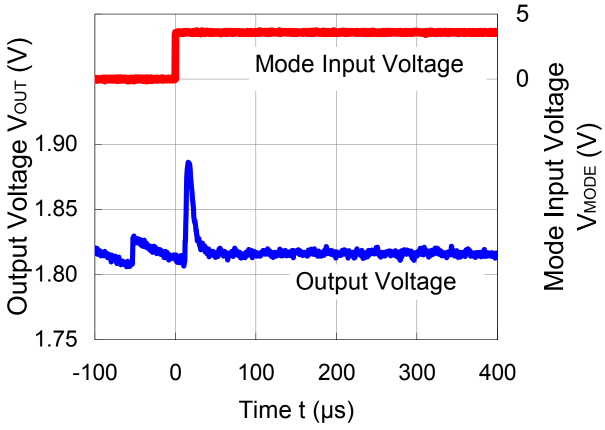
RP504x (V_{OUT} = 1.2 V, I_{OUT} = 1 mA)
MODE = "L" --> MODE = "H"



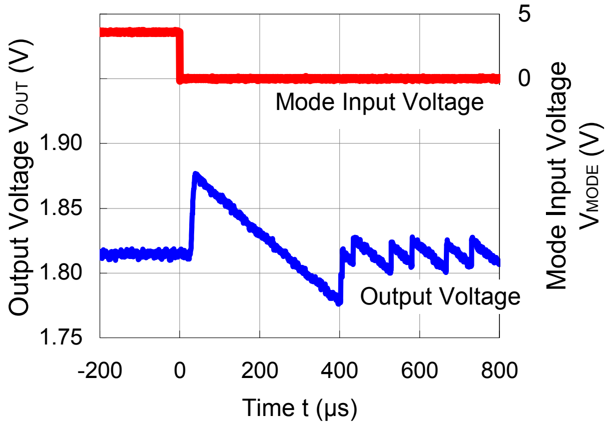
RP504x (V_{OUT} = 1.2 V, I_{OUT} = 1 mA)
MODE = "H" --> MODE = "L"



RP504x (V_{OUT} = 1.8 V, I_{OUT} = 1 mA)
MODE = "L" --> MODE = "H"



RP504x (V_{OUT} = 1.8 V, I_{OUT} = 1 mA)
MODE = "H" --> MODE = "L"



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