1.5 A Buck-Boost DC/DC Converter with Synchronous Rectifier

NO. EA-353-150422

OUTLINE

The RP602Z is a CMOS-based 1.5 A*1 buck-boost DC/DC converter with synchronous rectifier. Internally, a single converter consists of an oscillator, a reference voltage unit, an error amplifier, a switching control circuit, a mode control circuit, a soft-start circuit, an undervoltage lockout (UVLO) circuit, an overvoltage protection (OVP) circuit, an overcurrent protection circuit, a thermal shutdown circuit and switching transistors.
The RP602Z offers two power controlling methods, forced PWM control type and PWM/VFM auto switching control type. The power controlling method can be selected 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 2.7 to 4.2 V in 0.1 V step. The output voltage accuracy is as high as ±1.5%. Protection circuits included in the RP602Z are overcurrent protection circuit and thermal shutdown circuit.
The RP602Z is offered in a 20-bump WLCSP package measuring 2.305 mm x 1.700 mm which can achieve the smallest possible footprint solution on board where area is limited.

*1 The output current can be affected by environmental conditions or external components. This is an approximate value.

FEATURES

- Input Voltage Range (Absolute Maximum Ratings) ....2.3 V to 5.5 V (6.5 V)
- Output Voltage Range ....2.7 V to 4.2 V, Adjustable in 0.1 V steps
- Output Voltage Accuracy ....±1.5%
- Line Regulation ....Typ. 0.5%, PWM Mode
- Load Regulation ....Typ. 0.1% at I_{OUT} = 0 mA to 500 mA, PWM Mode
- Maximum Output Current ....Typ. 1.5 A, PVIN = 3 V, VOUT = 3.3 V
- Maximum Burst Current..2.7 A, PV_{IN} = 3 V, V_{OUT} = 3.3 V, Duty = 10%, t = 2.0 ms
- Overcurrent Limit Protection ....Typ. 4.2 A
- Oscillator Frequency...Typ. 2.6 MHz
- Built-in Driver ON Resistance ....Typ. Pch. 80 mΩ, Nch. 80 mΩ, V_{IN} = 3.6 V
- Device Quiescent Current ....Typ. 27.5 µA, VFM mode, non-switching
- UVLO Detector Threshold ....Typ. 2.0 V
- Soft-start Time ....Typ. 1.0 ms
- Thermal Shutdown Temperature ....Typ. 150°C
- Inductor ....1.0 µH
- Package ....20-bump WLCSP, 2.305 mm x 1.700 mm

APPLICATIONS

- Power source for portable equipment such as laptops, PDAs, DSCs, cellular phones, and smartphones
- Power source for Li-ion battery-used equipment

SELECTION GUIDE

Selection Guide

Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
RP602Zxxx$-E2-F	WLCSP-20-P1	5,000 pcs	Yes	Yes

xxx: Specify the set output voltage (V_{SET}) within the range of 2.7 V to 4.2 V in 0.1 V[*1] steps

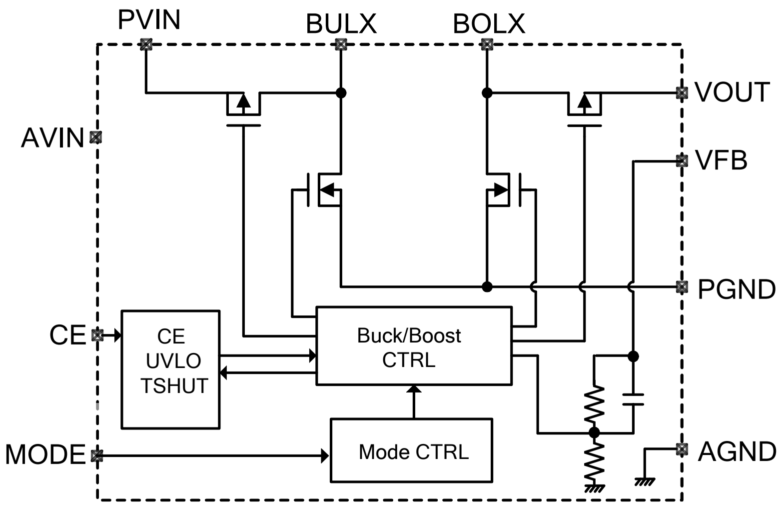
$: Specify the combination of the auto-discharge option and the protection function option.

Symbol	Auto-discharge Function	Latch-type Protection	Reset-type Protection	Short-circuit Protection
A[*2]	Yes	Yes	No	Yes
B[*2]	No	Yes	No	Yes
C	Yes	No	Yes	Yes
D[*2]	No	No	Yes	Yes
E[*2]	Yes	No	No	Yes
F[*2]	No	No	No	Yes

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

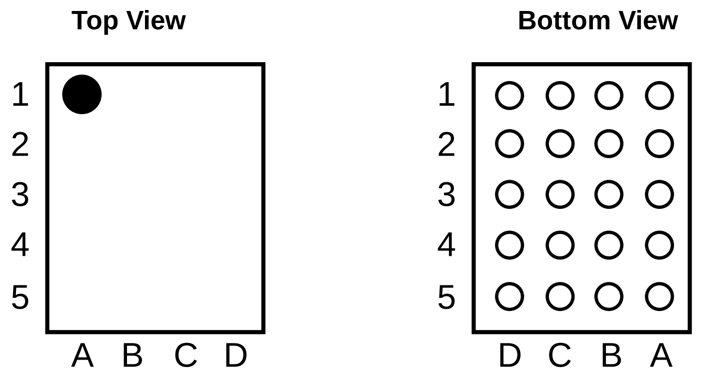
[*2] The mass production is scheduled.

BLOCK DIAGRAM



RP602Z Block Diagram

PIN DESCRIPTION



WLCSP-20 Pin Configuration

Pin Description

Pin No	Symbol	Pin Description
A5, B5, C5[*1]	VOUT	Output Voltage Pin
A4, B4, C4[*1]	BOLX	Boost Switching Output Pin
A3, B3, C3[*2]	PGND	Power GND Pin
A2, B2, C2[*1]	BULX	Buck Switching Output Pin
A1, B1, C1[*1]	PVIN	Power Input Voltage Pin
D1[*1]	AVIN	Analog Power Input Voltage Pin
D2	CE	Chip Enable Pin, Active-high
D3	MODE	Mode Control Pin, Forced PWM Control: L, PWM/VFM Auto Switching Control: H
D4[*2]	AGND	Analog GND Pin
D5	VFB	Output Voltage Feedback Pin

[*1] The pin numbers sharing the same pin symbol must be connected together: A4, B4, and C4 of the BOLX pin, A2, B2, and C2 of the BULX pin, A5, B5, and C5 of the VOUT pin. D1 of the AVIN pin and A1, B1, and C1 of the PVIN pin must be connected together.

[*2] D4 of the AGND pin and A3, B3, and C3 of the PGND pin must be connected to the ground.

Pin Truth Table

CE Pin	MODE Pin[*1]	Operation
"L"	-	OFF
"H"	"H"	PWM/ VFM Auto Switching Control Mode
	"L"	Forced PWM Control Mode

[*1] The logic to the MODE pin should not be changed while CE = "H".

ABSOLUTE MAXIMUM RATINGS

Absolute Maximum Ratings

Symbol	Item	Rating	Unit
V_{IN}	AVIN/ PVIN Pin Input Voltage	−0.3 to 6.5	V
V_{BULX}	BULX Pin Voltage	−0.3 to V_{IN} + 0.3	V
V_{BOLX}	BOLX Pin Voltage	−0.3 to V_{OUT} + 0.3	V
V_{CE}	CE Pin Input Voltage	−0.3 to 6.5	V
V_{MODE}	MODE Pin Input Voltage	−0.3 to 6.5	V
V_{OUT}	VOUT Pin Voltage	−0.3 to 6.5	V
V_{FB}	VFB Pin Voltage	−0.3 to 6.5	V
I_{LX}	BULX/ BOLX Pin Output Current	4.2	A
P_D	Power Dissipation (Standard Land Pattern)*1	1400	mW
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 are 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

Open-loop Measurement GND = 0 V, unless otherwise noted.

RP602ZxxxC Electrical Characteristics (Ta = 25°C)

Symbol	Item	Conditions		Min.	Typ.	Max.	Unit
V_{IN}	Operating Input Voltage			2.3		5.5	V
I_{DD}	Quiescent Current	V_{IN} = 5.5 V, V_{OUT} = 4.2 V,	V_{MODE} = 5.5 V		27.5	60	µA
			V_{MODE} = 0 V		1000	1400	
Istandby	Standby Current	V_{IN} = 5.5 V, V_{CE} = 0 V			0.1	5.0	µA
V_{OUT}	Output Voltage	V_{IN} = 3.6 V		x0.985		x1.015	V
$\Delta V_{OUT}/\Delta Ta$	Output Voltage Temperature Coefficient	−40°C ≤ Ta ≤ 85°C			±50		ppm/°C
V_{OVP}	OVP Detector Threshold	V_{IN} = 3.6 V, Rising		4.5	5.0	5.5	V
	OVP Released Voltage	V_{IN} = 3.6 V, Falling		4.3	4.8	5.3	V
fosc	Switching Frequency	V_{IN} = 3.6 V		2.4	2.6	2.9	MHz
I_{LIMHS}	BULX Current Limit*1	V_{IN} = 3.6 V		3.7	4.2		A
R_{ON}	High & Low Switch On Resistance	V_{IN} = 3.6 V			80		mΩ
R_{DIS}	On Resistance of Discharge Tr. (RP602ZxxxA/C/E)	V_{IN} = 3.6 V, V_{CE} = 0 V			80		Ω
I_{FBH}	V_{FB} “H” Input Current	V_{IN} = 5.5 V, V_{CE} = 0 V V_{FB} = 5.5V				1	µA
I_{FBL}	V_{FB} “L” Input Current	V_{IN} = 5.5 V, V_{CE} = 0 V V_{FB} = 0 V				1	µA
V_H	CE, MODE & Input Voltage "H"	V_{IN} = 5.5 V		1.0			V
V_L	CE, MODE & Input Voltage "L"	V_{IN} = 2.3 V				0.4	V
I_H	CE, MODE & "H" Input Current	V_{IN} = V_{CE} = 5.5 V		−1	0	1	µA
I_L	CE, MODE & "L" Input Current	V_{IN} = 5.5 V, V_{CE} = 0 V		−1	0	1	µA
V_{UVLO1}	UVLO Detector Threshold	V_{IN} = Falling		1.83	2.00		V
V_{UVLO2}	UVLO Released Voltage	V_{IN} = Rising			2.05	2.25	V
T_{TSD}	Thermal Shutdown Threshold Temperature	Tj, Rising			150		°C
T_{TSR}		Tj, Falling			110		°C
tstart	Soft-start Time	V_{IN} = 3.6 V			1		ms
tprot	Protection Delay Time (RP602ZxxxA/B/C/D)	V_{IN} = 3.6 V			1.6		ms
trst	Delay Time for Reset Protection (RP602ZxxxC/D)	V_{IN} = 3.6 V			12		ms

All test items listed under *ELECTRICAL CHARACTERISTICS* are done under the pulse load condition (Tj ≈ Ta = 25°C).
*1 BULX Current Limit vary according to the switching duty ratio.

Product-specific Electrical Characteristics (Ta = 25°C)

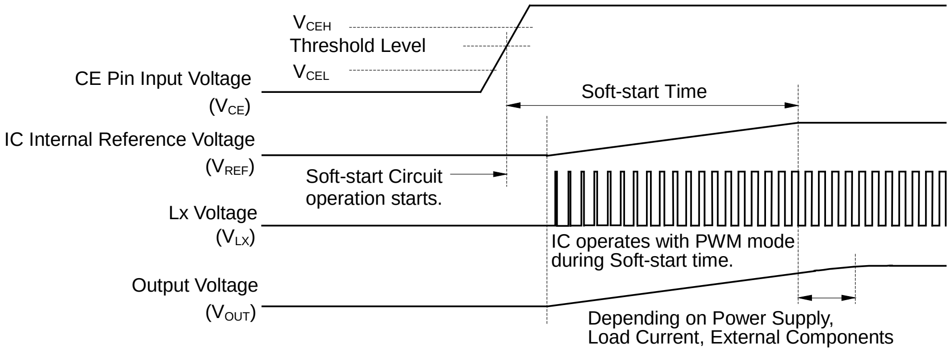
Product Name	V_{OUT} (V)		
	Min.	**Typ.**	**Max.**
RP602Z270x	2.660	2.700	2.740
RP602Z280x	2.758	2.800	2.842
RP602Z290x	2.857	2.900	2.943
RP602Z300x	2.955	3.000	3.045
RP602Z310x	3.054	3.100	3.146
RP602Z320x	3.152	3.200	3.248
RP602Z330x	3.251	3.300	3.349
RP602Z340x	3.349	3.400	3.451
RP602Z350x	3.448	3.500	3.552
RP602Z360x	3.546	3.600	3.654
RP602Z370x	3.645	3.700	3.755
RP602Z380x	3.743	3.800	3.857
RP602Z390x	3.842	3.900	3.958
RP602Z400x	3.940	4.000	4.060
RP602Z410x	4.039	4.100	4.161
RP602Z420x	4.137	4.200	4.263

THEORY OF OPERATION

Soft-start Time

Starting-up with CE Pin

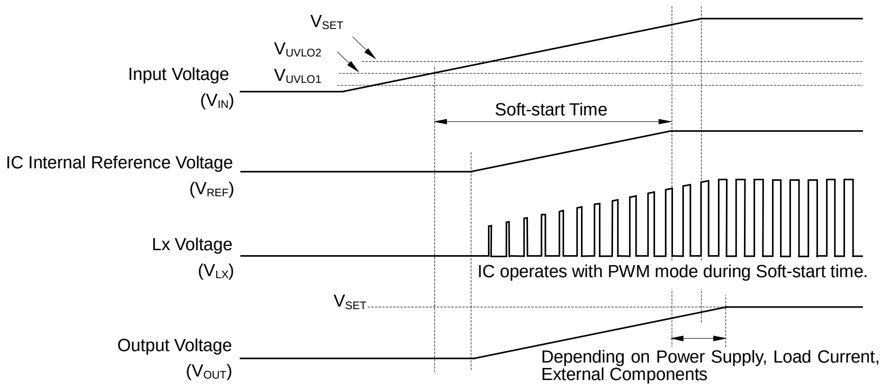
The IC starts to operate when the CE pin voltage (V_{CE}) exceeds the threshold voltage. The threshold voltage is preset between CE "H" input voltage (V_{CEH}) and CE "L" input voltage (V_{CEL}). After the start-up of the IC, soft-start circuit starts to operate. Then, after a certain period of time, the reference voltage (V_{REF}) in the IC gradually increases up to the specified value. Soft-start time (tstart) 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 DC/DC converter. 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.



Timing Chart: Starting-up with CE Pin

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. 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}.



Timing Chart: Starting-up with Power Supply

Undervoltage Lockout (UVLO) Circuit

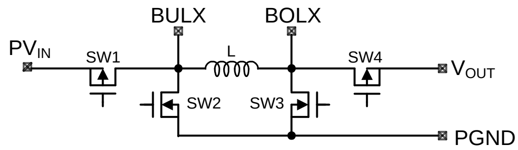
If the V_{IN} becomes lower than the UVLO detector threshold (V_{UVLO1}), the UVLO circuit starts to operate, V_{REF} stops, and P-channel and N-channel built-in switch transistors turn "OFF". As a result, V_{OUT} drops according to the C_{OUT} capacitance value and the load. To restart the operation, V_{IN} needs to be higher than V_{UVLO2}.

Overvoltage Protection (OVP) Circuit

If the V_{OUT} becomes higher than the OVP detector threshold (V_{OVP}), the OVP circuit starts to operate, 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.

Overcurrent Protection Circuit

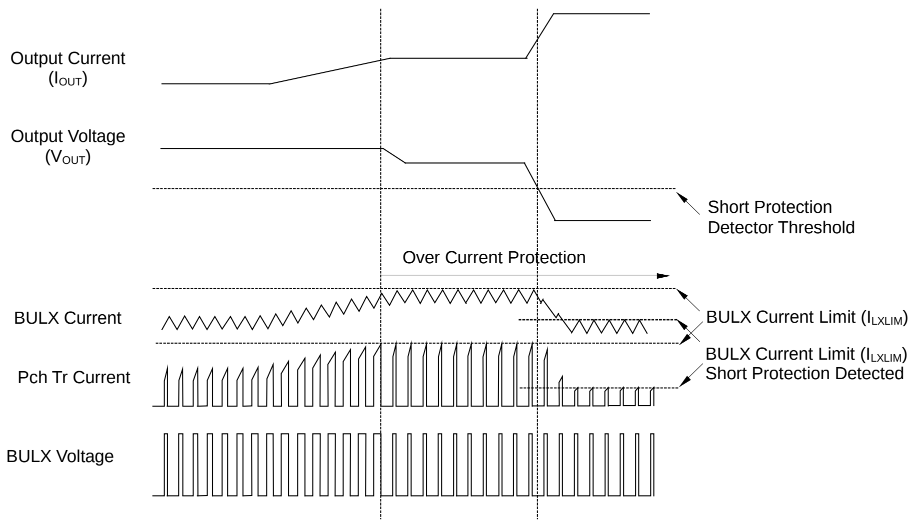
Overcurrent protection circuit supervises the inductor peak current (the peak current flowing through Pch Tr (SW1) in each switching cycle, and if the current exceeds the BULX current limit (I_{LXLIM}), it turns off Pch Tr (SW1). I_{LXLIM} of the RP602Z is set to Typ.4200 mA.



Simplified Diagram of Output Switches

Short Protection Circuit

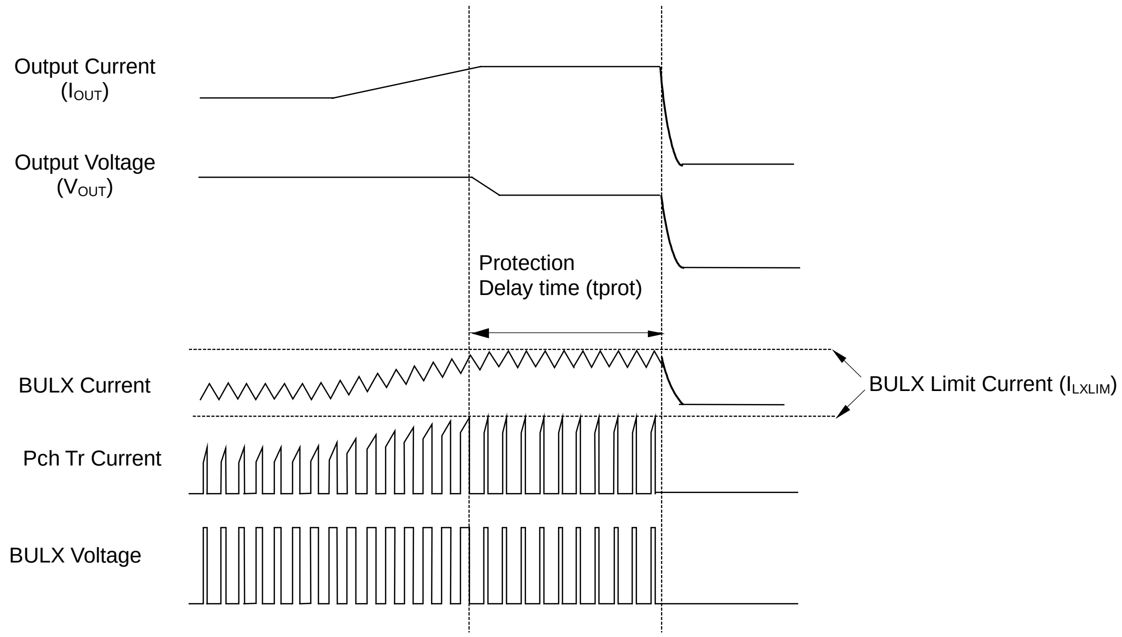
If the V_{OUT} becomes lower than a certain threshold, the BULX current limit is reduced.



Timing Chart: Overcurrent Protection Circuit & Short Protection Circuit

Latch Type Protection Circuit: RP602ZxxxA/B

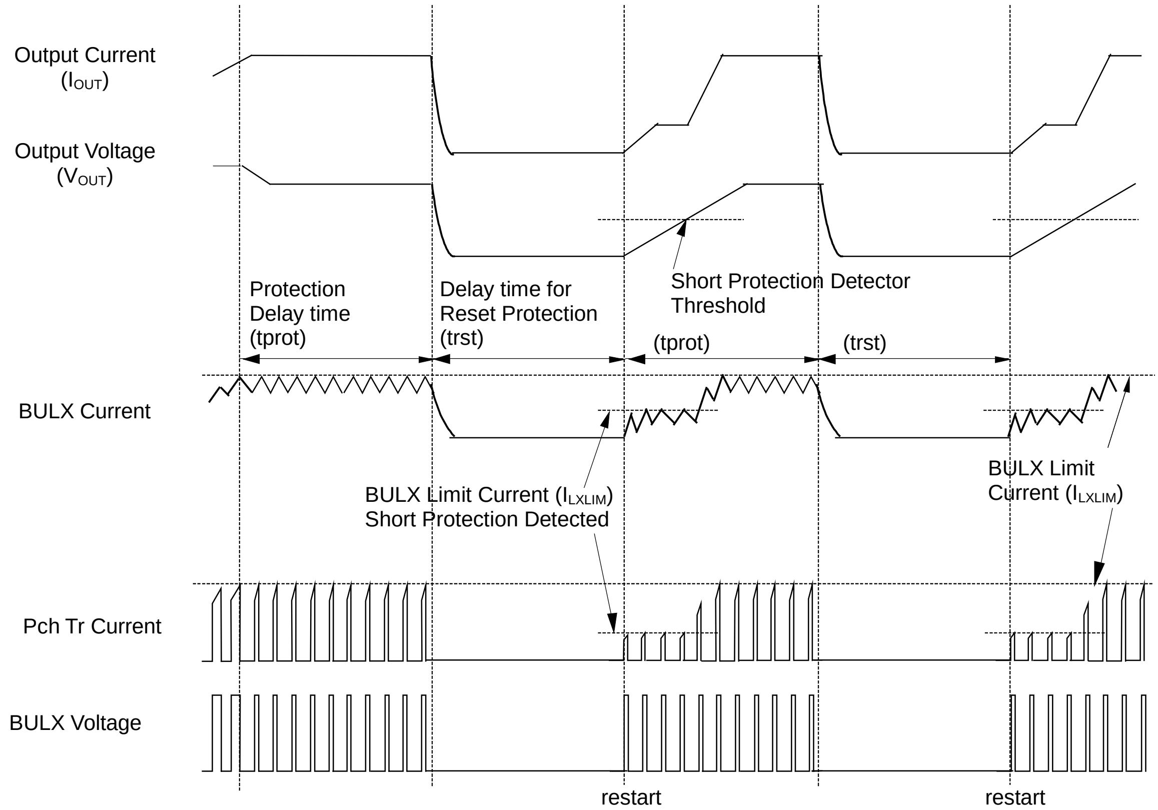
The latch type protection circuit latches the built-in drivers of SW1, SW2, SW3 and SW4 off to stop the operation of the device if the overcurrent state continues more than the protection delay time (tprot).
To release the latch-type protection, switch the CE pin from high to low to reset the device or make the input voltage (V_{IN}) lower than the UVLO detector threshold (V_{UVLO1}).



Timing Chart: RP602ZxxxA/B Latch Protection Circuit

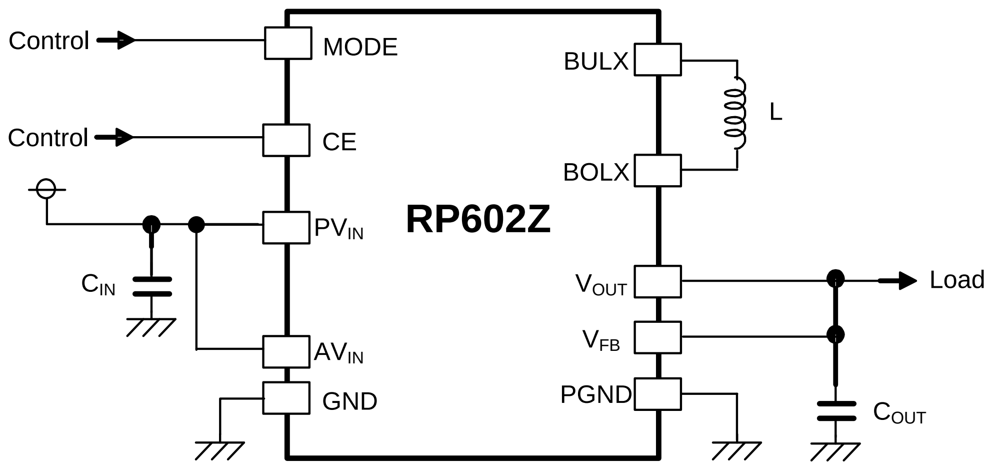
Reset Type Protection Circuit: RP602ZxxxC/D

When the overcurrent state continues more than the protection delay time (tprot), Reset type protection circuit operates and switching stops and the built-in drivers of SW1, SW2, SW3 and SW4 turn off and restarts after delay time for reset protection (trst). When the overcurrent state is released, the operation is automatically released and returns to normal operation.



Timing Chart: RP602ZxxxC/D Reset Protection Circuit

APPLICATION INFORMATION



RP602ZxxxC/D Typical Application Circuit

Recommended External Components

Symbol	Description
C_{IN}*1	10 µF, Ceramic, GRM188R60J106ME47, Murata
C_{OUT}*2	22 µF x 2, Ceramic, GRM188R60J226MEA0, Murata
L	1.0 µH, Inductor, DFE201610P- 1R0M, TOKO 1.0 µH, Inductor, XAL4020- 102ME, Coilcraft

*1 Place C_{IN} as close as possible to the PV_{IN} pin.

*2 Place C_{OUT} as close as possible to the V_{OUT} pin.

Technical Notes on External Components Selection

- Use ceramic capacitors having a low equivalent series resistance (ESR). C_{OUT} should be paralleled with another C_{OUT}. When selecting the capacitors, consider the bias characteristics and input/ output voltage.
- When the built-in switches are turned off, the inductor may generate a spike-shaped high voltage. Use the high-breakdown voltage capacitor (C_{OUT}) which output voltage is 1.5 times or more than the set output voltage.
- Use an inductor that has a low DC resistance, has an enough tolerable current and is less likely to cause magnetic saturation. If the inductance value is extremely small, the peak current of L_X may increase. When the peak current of L_X reaches to the L_X limit current (I_{LXLIM}), overcurrent protection circuit starts to operate. When selecting the inductor, consider the maximum output current of Lx pin (I_{LXMAX}). Refer to *Calculation Method of Maximum Output Current of Lx Pin (I_{LXMAX}) in Continuous Mode* for details.

Calculation Method of Maximum Output Current of Lx Pin (I_{LXMAX}) in Continuous Mode

The maximum output current of Lx pin (I_{LXMAX}) can be calculated as follows, in the case of an ideal converter operating in steady conditions, using the components listed in *Recommended External Components* of *APPLICATION INFORMATION*.

Ripple Current P-P value is described as I_{RP}, ON resistance of Pch Tr. is described as R_{ONP}, ON resistance of Nch Tr. is described as R_{ONN}, and DC resistor of the inductor is described as R_L.

First, when Pch Tr. is “ON”, the following equation is satisfied.

$V_{IN} = V_{OUT} + (R_{ONP} + R_L) \times I_{OUT} + L \times I_{RP} / ton$ .... Equation 1

Second, when Pch Tr. is "OFF" (Nch 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 2

Put Equation 2 into Equation 1 to solve ON duty of Pch 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 3

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 4

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

$IL_Xmax = I_{OUT} + I_{RP} / 2$ .... Equation 5

TECHNICAL NOTES

The performance of a power source circuit using this device is highly dependent on a peripheral circuit. A peripheral component or the device mounted on PCB should not exceed a rated voltage, a rated current or a rated power. When designing a peripheral circuit, please be fully aware of the following points.

- Place the bypass capacitor (C_{INP}) between the V_{INP} pin and the GND pin with shortest-distance wiring.
- Place the output capacitor (C_{OUT}) between the V_{OUT} pin and the GND pin with shortest-distance wiring. Connect GND of C_{OUT} to the GND pin with shortest-distance wiring.
- Make the GND plane wide.
- Ensure the V_{INP} and GND lines are firmly connected. A large switching current flows through the V_{INP}, GND, inductor, BOLX, BULX and V_{OUT} lines. If their impedance is too high, noise pickup or unstable operation may result.
- Connect the BOLX pin and the inductor and the BULX pin with shortest-distance wiring.

PACKAGE INFORMATION

POWER DISSIPATION (WLCSP-20-P1)

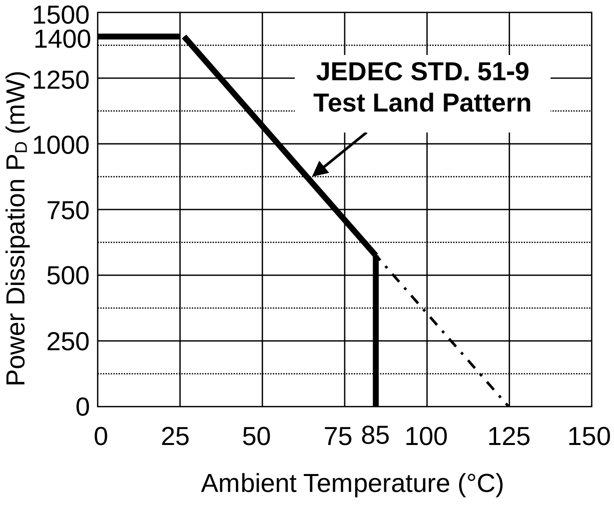
Power Dissipation (P_D) of the package is dependent on PCB material, layout, and environmental conditions. The following conditions are used in this measurement.

Measurement Conditions

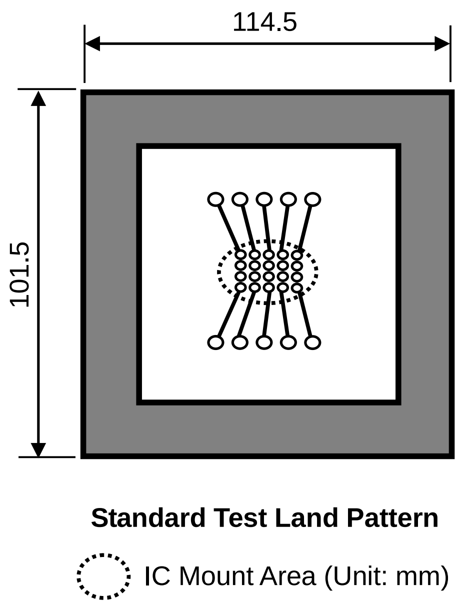
	JEDEC STD. 51-9 Test Land Pattern
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (4-Layer)
Board Dimensions	101.5 mm x 114.5 mm x 1.6 mm
Copper Ratio	Top-side, Back-side: Approx.60% 2nd, 3rd Layer: Approx. 100%

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

	JEDEC STD. 51-9 Test Land Pattern
Power Dissipation	1400 mW
Thermal Resistance	θja = (125 − 25°C) / 1.4 W = 71°C/W

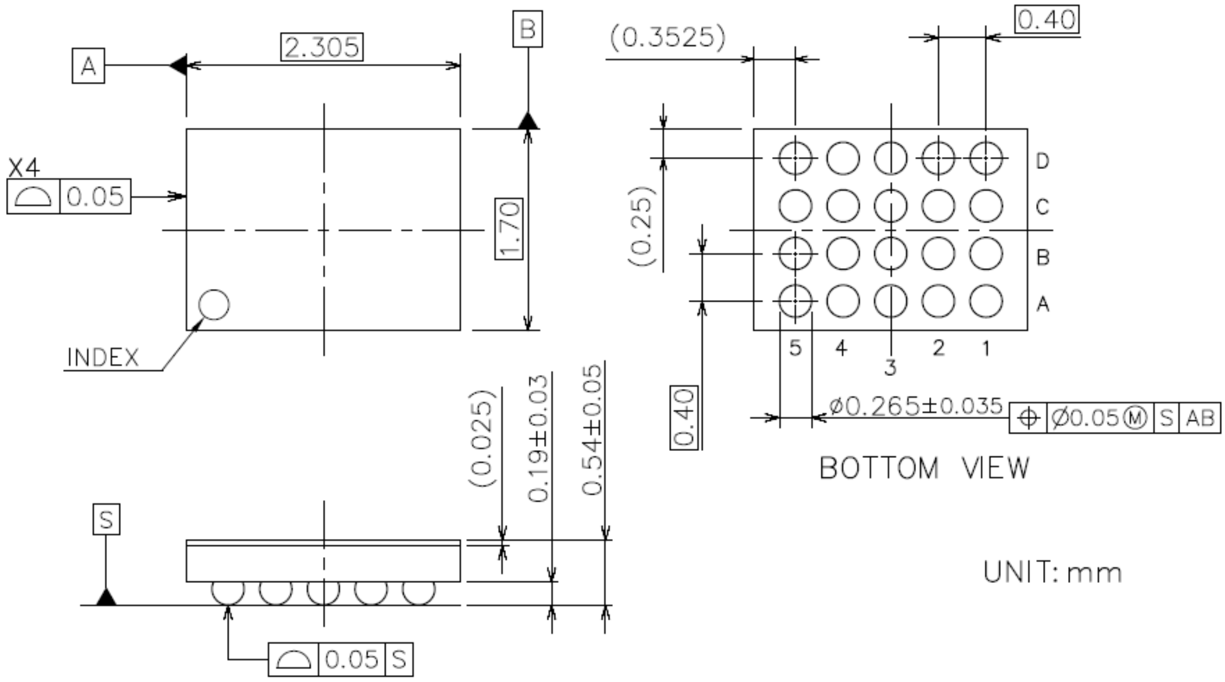


Ambient Temperature vs. Power Dissipation



Measurement Board Pattern

PACKAGE DIMENSIONS (WLCSP-20-P1)



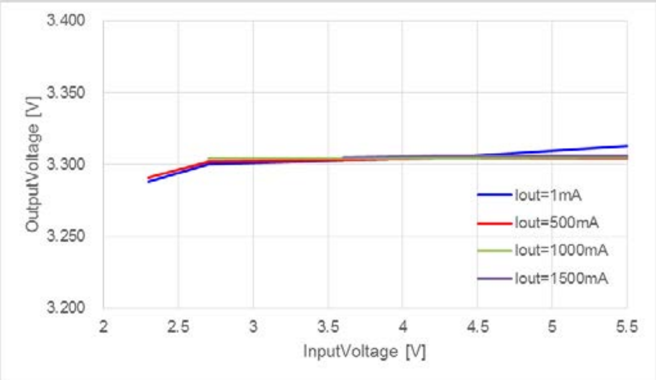
WLCSP-20-P1 Package Dimensions

TYPICAL CHARACTERISTICS

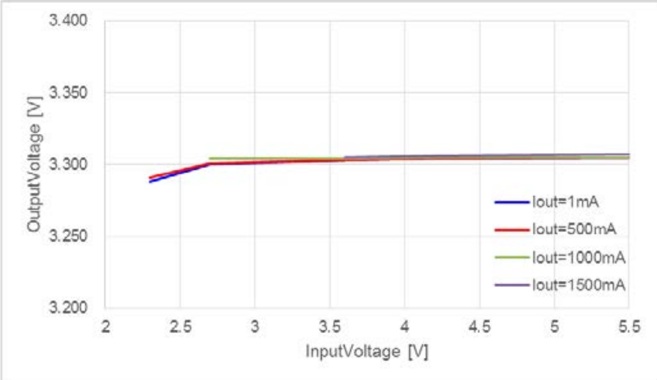
Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

1) Input Voltage vs. Output Voltage

RP602Z330x, MODE = H

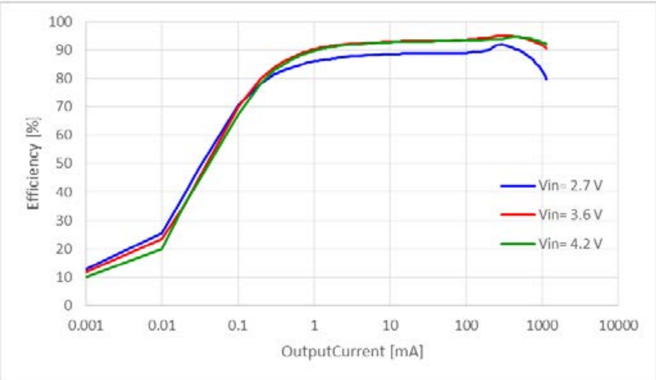


RP602Z330x, MODE = L

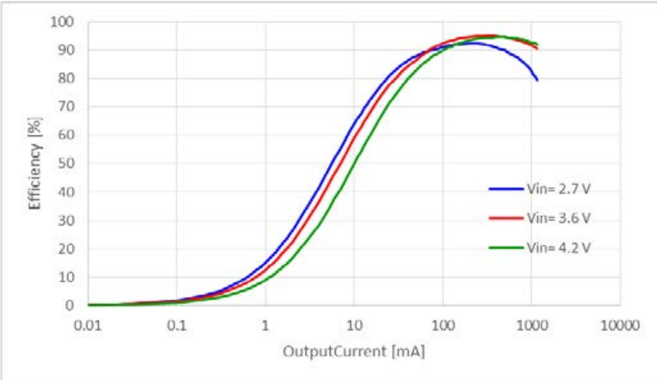


2) Output Current vs. Efficiency (for Different Input Voltages)

RP602Z330x, MODE = H

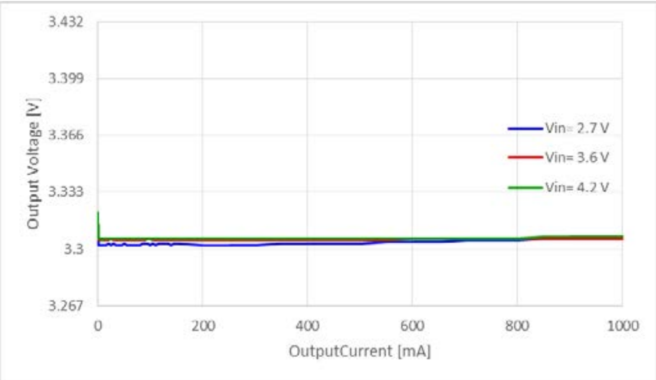


RP602Z330x, MODE = L

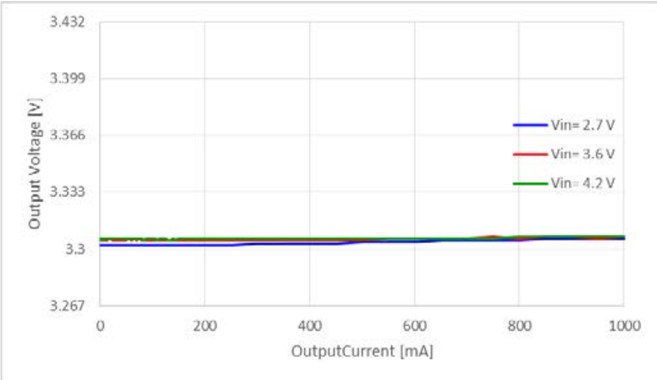


3) Output Current vs. Output Voltage

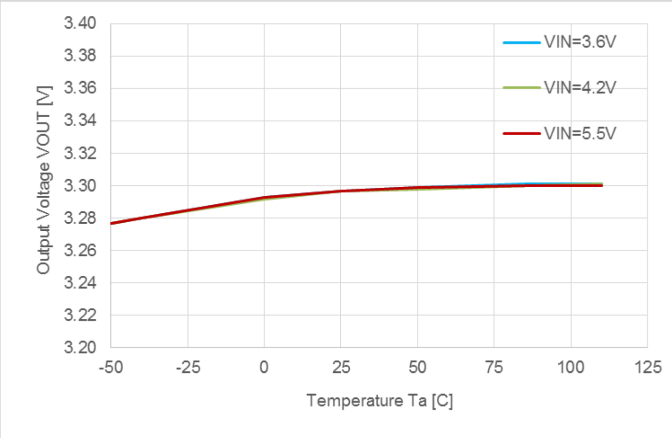
RP602Z330x, MODE = H



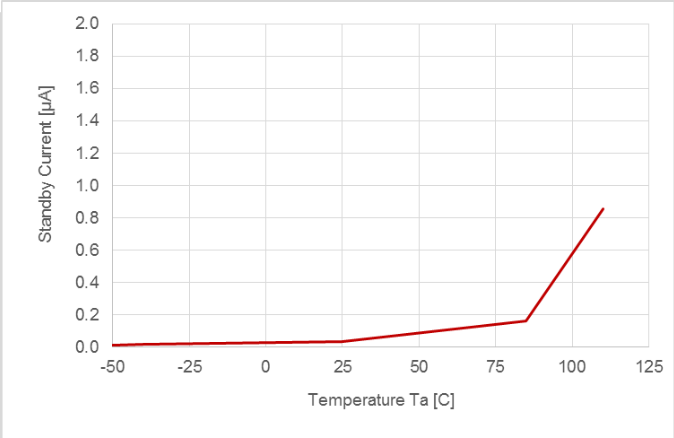
RP602Z330x, MODE = L



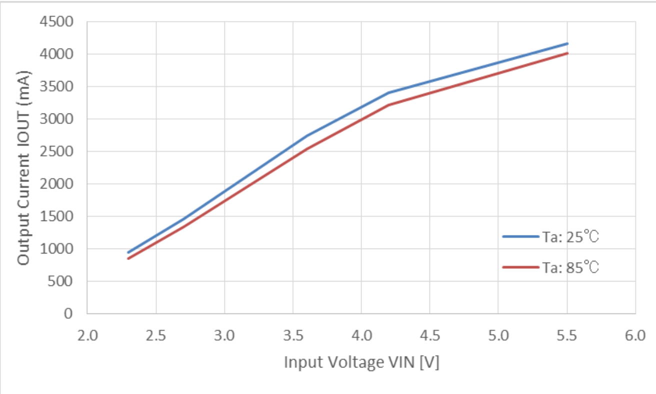
4) Temperature vs. Output Voltage
RP602Z330x



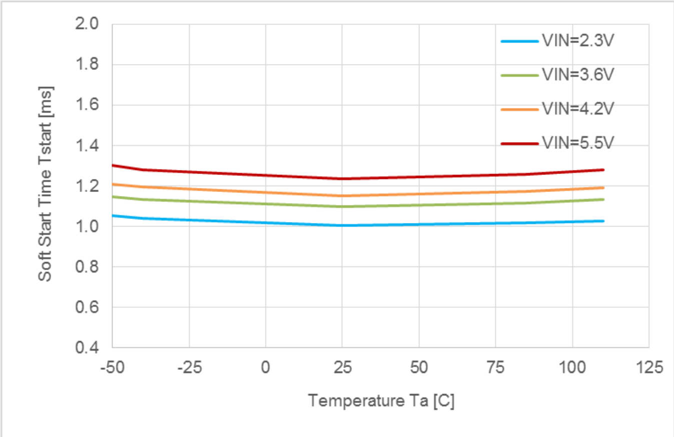
5) Temperature vs. Standby Current
RP602Z330x, V_{IN} = 5.5 V



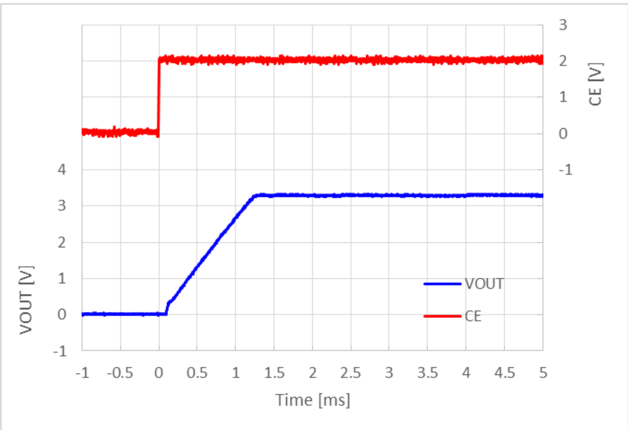
6) Input Voltage vs. Output Current
RP602Z330x, MODE = L



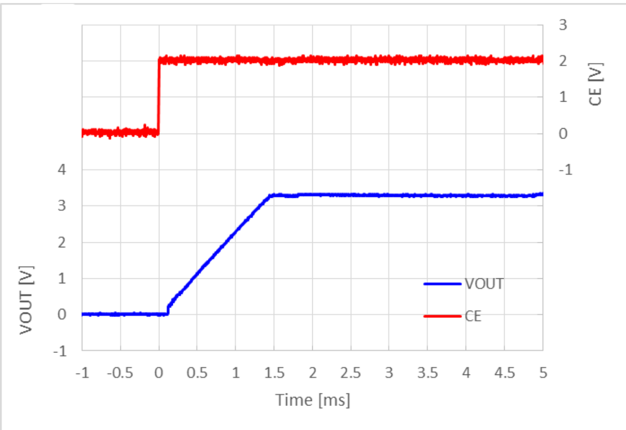
7) Temperature vs. Soft-start Time
RP602Z330x



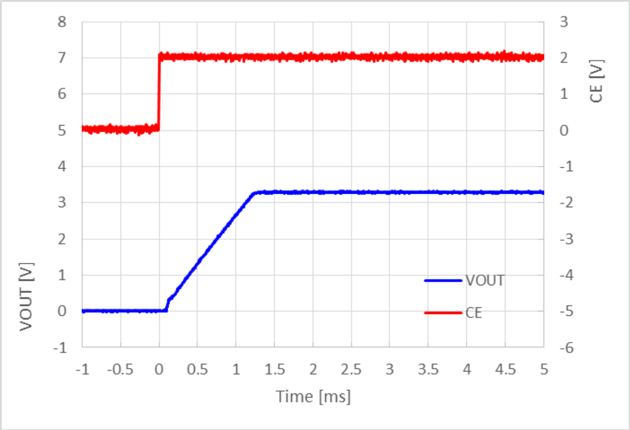
8) CE Start-up Waveform
RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 0 mA



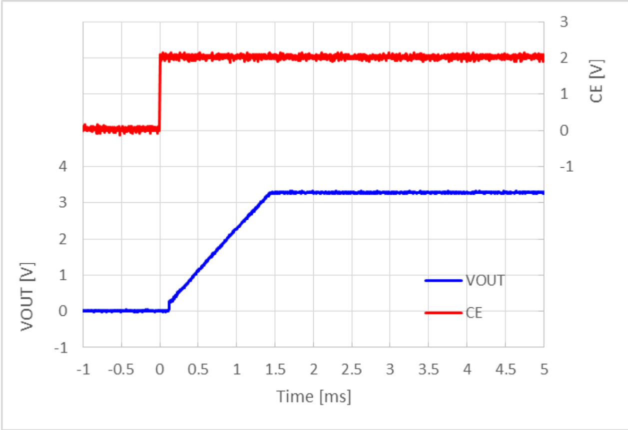
RP602Z330x, V_{IN} = 5.5 V, MODE = H
I_{OUT} = 0 mA



RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 0 mA

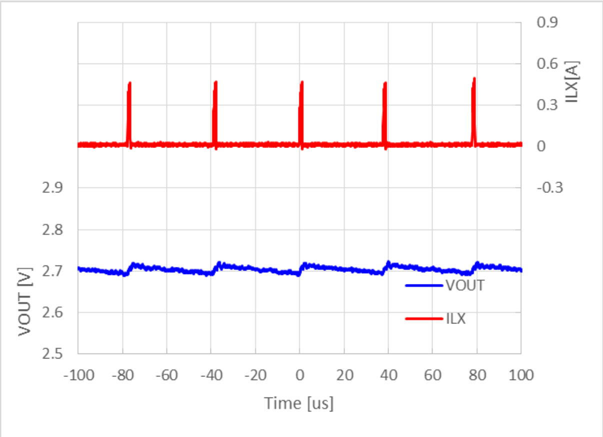


RP602Z330x, V_{IN} = 5.5 V, MODE = L
I_{OUT} = 0 mA

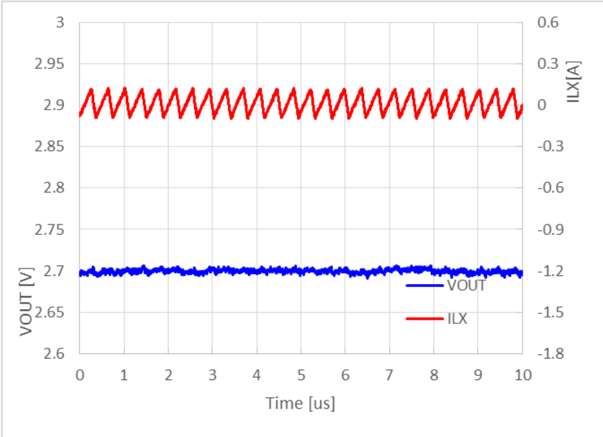


9) V_{OUT} Waveform

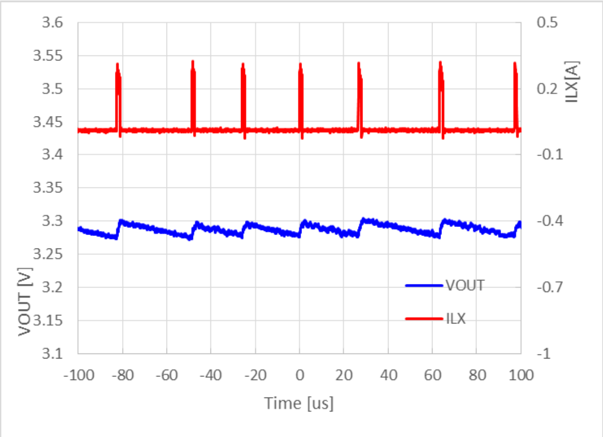
RP602Z270x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 10 mA



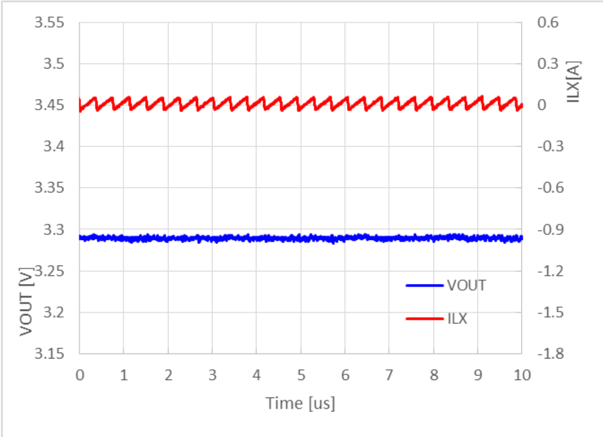
RP602Z270x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 0 mA



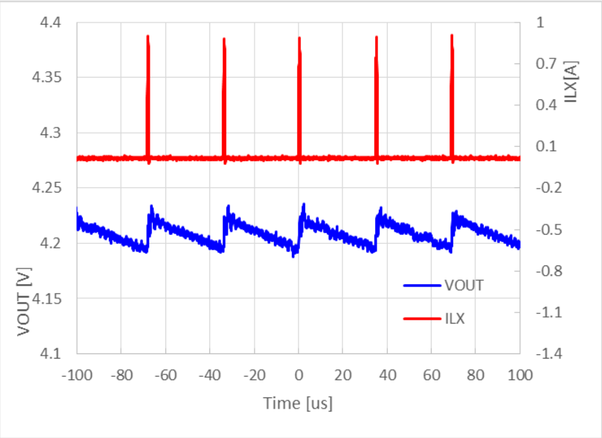
RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 10 mA



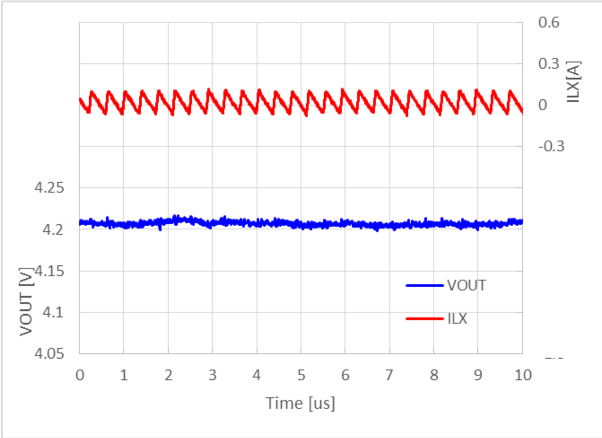
RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 0 mA



RP602Z420x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 10 mA

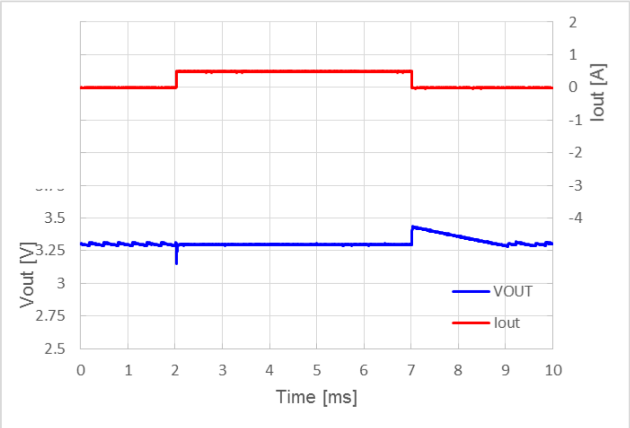


RP602Z420x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 0 mA

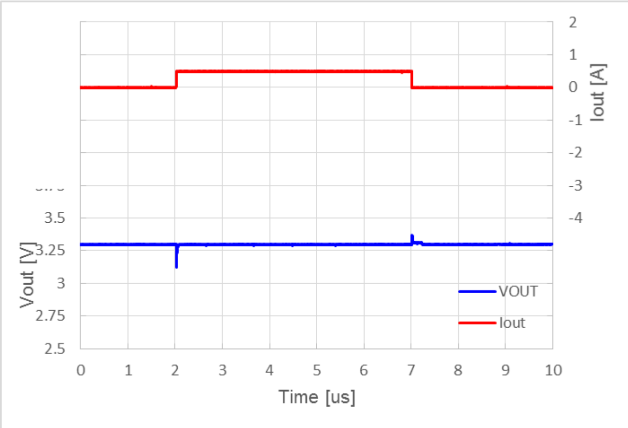


10) Load Transient Response Waveform

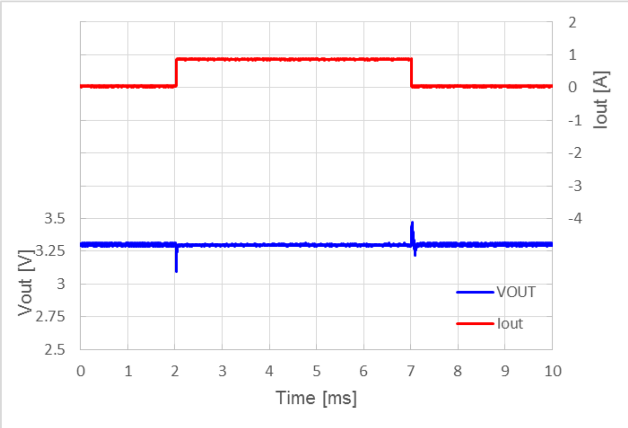
RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 1 mA ←→ 500 mA



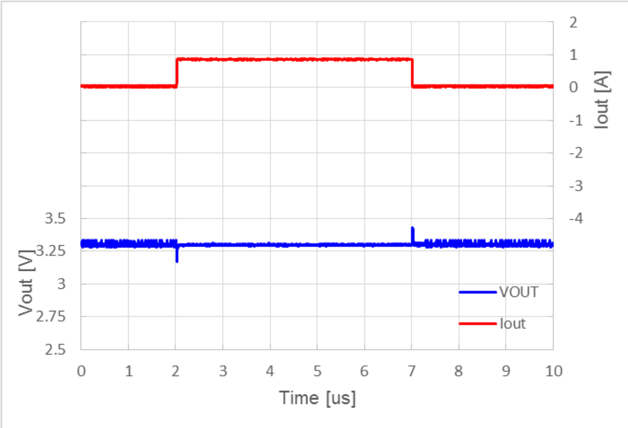
RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 1 mA ←→ 500 mA



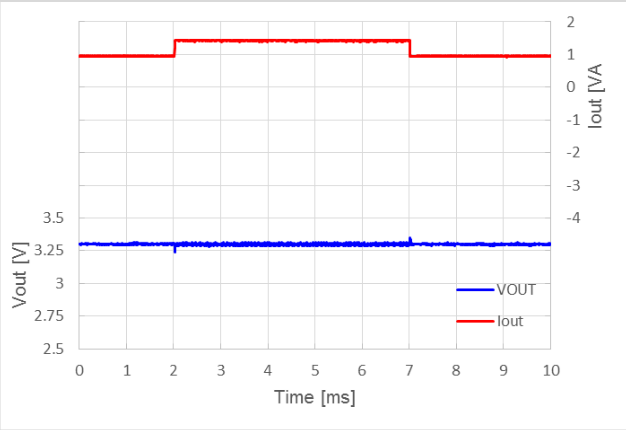
RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 50 mA ←→ 900 mA



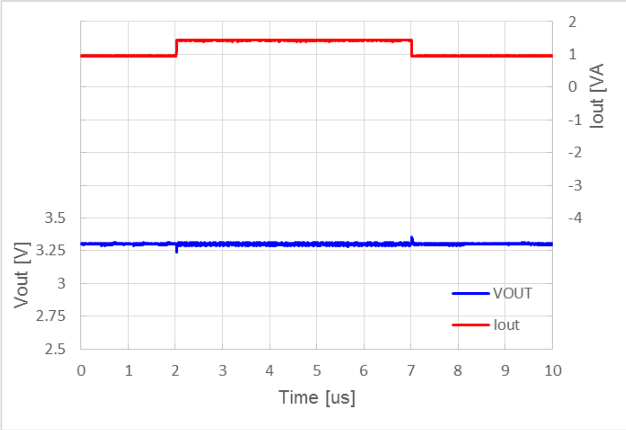
RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 50 mA ←→ 900 mA



RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 1000 mA ←→ 1500 mA

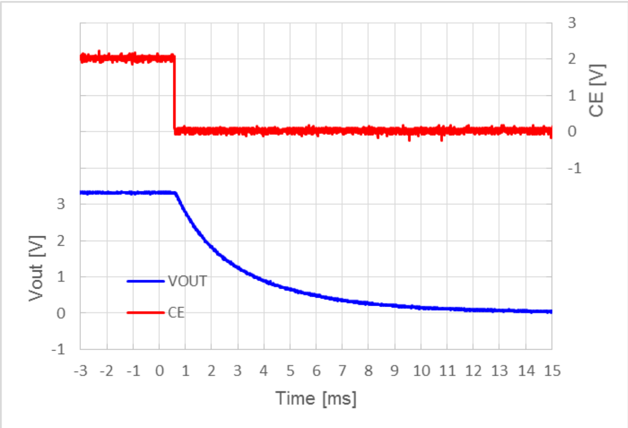


RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 1000 mA ←→ 1500 mA

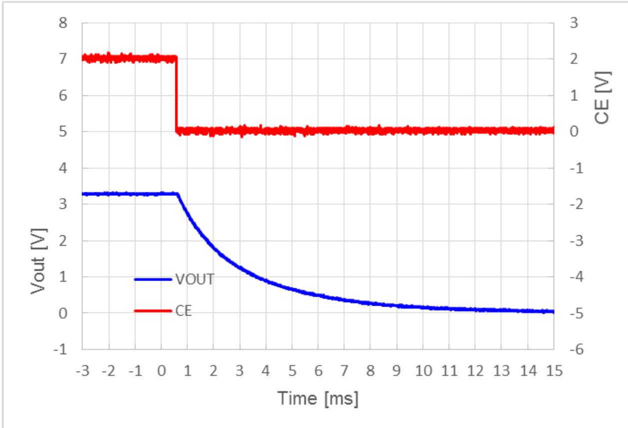


11) CE Turn off Waveform

RP602Z330x, V_{IN} = 3.6 V, MODE = H
I_{OUT} = 0 mA

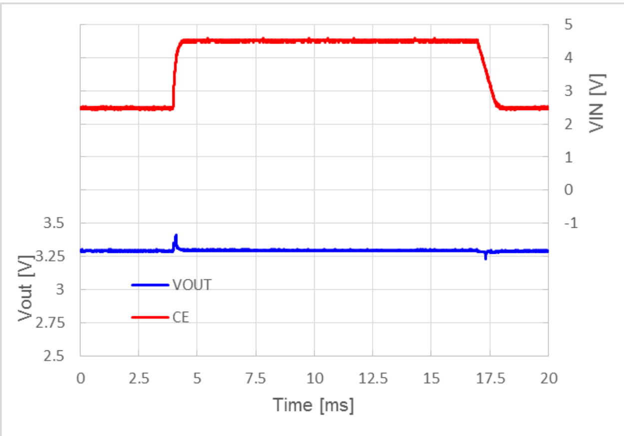


RP602Z330x, V_{IN} = 3.6 V, MODE = L
I_{OUT} = 0 mA

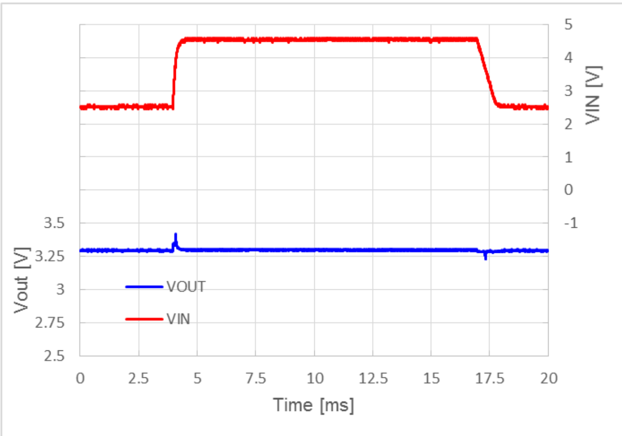


12) Input Transient Response Waveform

RP602Z330x, MODE = H
I_{OUT} = 500 mA, V_{IN} = 2.5 V ←→ 4.5 V



RP602Z330x, MODE = L
I_{OUT} = 500 mA, V_{IN} = 2.5 V ←→ 4.5 V



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