RP604x Series

Ultra-low Quiescent Current (I_Q = 0.3 μA), 300 mA, Buck-Boost DC/DC Converter

No. EA-415-190507

OVERVIEW

The RP604x is a buck-boost converter featuring a minimum supply current and a high efficiency at low-load. The device operates at the low operating quiescent current (I_Q = 0.3 μA) to make the most of battery life for the battery driver operated intermittently.

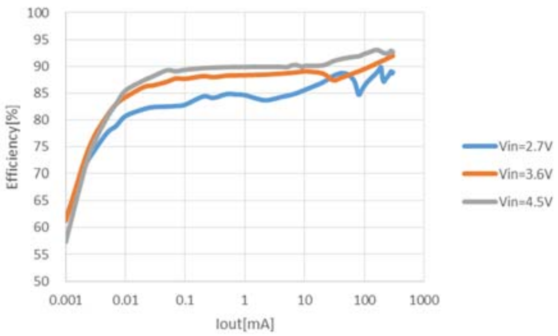
KEY BENEFITS

- The low supply current (I_Q = 0.3 μA) can achieve making battery life longer and battery's size-reduction.
- Wide range of input voltage (1.8 V to 5.5 V) can support for every batteries from a coin-type battery to a USB port.
- Selectable package: WLCSP-20-P2 or DFN(PLP)2730-12

KEY SPECIFICATIONS

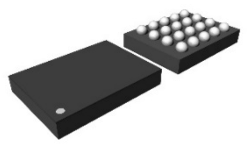
- Input Voltage: 1.8 V to 5.5 V
- Output Voltage: 1.6 V to 5.2 V, 0.1 V step
- Output Voltage Accuracy: ±1.5%
- Maximum Output Current: 300 mA at Buck
- Built-in Driver On-resistance (RP604Z, V_{IN} = 3.6 V): PMOS = Typ.0.12 Ω, NMOS = Typ. 0.12 Ω
- Operating Quiescent Current (I_Q): 0.3 μA
- Standby Current: 0.01 μA
- Protection Features: UVLO, OVP, LX Peak Current, and Thermal Shutdown

TYPICAL CHARACTERISTICS

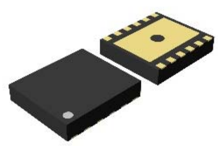


V_{OUT} = 3.3 V

PACKAGES



WLCSP-20-P2
1.71 x 2.315 x 0.40(1) mm
(1) maximum dimension



DFN(PLP)2730-12
2.70 x 3.00 x 0.6(1) mm
(1) maximum dimension

OPTIONAL FUNCTIONS

The auto-discharge function and the set output voltage (V_{SET}) are user-selectable options.

Product Name	Auto-discharge Function	V_{SET}
RP604xxx1A	Disable	1.6 V to 5.2 V (0.1 V step)
RP604xxx1B	Enable	

APPLICATIONS

- Wearable Appliances: SmartWatch, SmartBand, Healthcare
- Li-ion/Coin Battery-used Equipment
- Low-power Wireless Communication Equipment: *Bluetooth*® Low Energy, ZigBee, WiSunm, ANT
- Low-power Devices for CPU, Memory, Sensor Device, Energy Harvesting

SELECTION GUIDE

The set output voltage, the auto-discharge function(1) and the package are user-selectable options.

Selection Guide

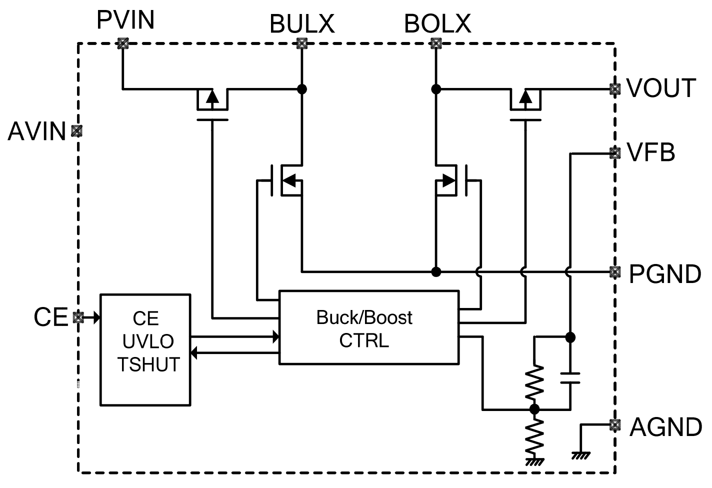
Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
RP604Zxx1$-E2-F	WLCSP−20−P2	5,000 pcs	Yes	Yes
RP604Kxx1$-TR	DFN(PLP)2730-12	5,000 pcs	Yes	Yes

xx: Specify the set output voltage (V_{SET}) within the range of 1.6 V (16) to 5.2 V (52) in 0.1 V steps.

$: Specify the auto-discharge function.

Version	Auto-discharge Function	V_{SET}
A	Disable	1.6 V to 5.2 V
B	Enable	

BLOCK DIAGRAM



RP604xxx1A/ RP604xxx1B Block Diagram

(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.

PIN DESCRIPTIONS

WLCSP-20-P2 Pin Configuration

WLCSP-20-P2 Pin Description

Pin No.	Pin Name	Description
A5, B5, C5	VOUT	Output Voltage Pin
A4, B4, C4	BOLX	Boost Switching Output Pin
A3, B3, C3, D3	PGND	Power GND Pin
A2, B2, C2	BULX	Buck Switching Output Pin
A1, B1, C1	PVIN	Power Input Voltage Pin
D1	AVIN	Analog Power Input Voltage Pin
D2	CE	Chip Enable Pin, Active-high
D4	AGND	Analog GND Pin
D5	VFB	Output Voltage Feedback Pin

DFN(PLP)2730-12 Pin Configuration

DFN(PLP)2730-12 Pin Description

Pin No.	Pin Name	Description
1	AVIN	Analog Power Input Voltage Pin
2	CE	Chip Enable Pin, Active-high
3	PGND	Power GND Pin
4	PGND	Power GND Pin
5	AGND	Analog GND Pin
6	VFB	Output Voltage Feedback Pin
7	VOUT	Output Voltage Pin
8	BOLX	Boost Switching Output Pin
9	PGND	Power GND Pin
10	PGND	Power GND Pin
11	BULX	Buck Switching Output Pin
12	PVIN	Power Input Voltage Pin

* The tab on the bottom of the package shown by blue circle is a substrate potential (GND). It is recommended that this tab be connected to the ground plane on the board but it is possible to leave the tab floating.

ABSOLUTE MAXIMUM RATINGS

Absolute Maximum Ratings (GND = 0 V)

Symbol	Parameter			Rating	Unit
V_{IN}	A/PVIN Pin 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 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			900	mA
P_D	Power Dissipation(1)	WLCSP-20-P2	JEDEC STD. 51-9	1490	mW
		DFN(PLP)2730-12	JEDEC STD. 51-7	3100	mW
Tj	Junction Temperature Range			−40 to 125	°C
Tstg	Storage Temperature Range			−55 to 125	°C

ABSOLUTE MAXIMUM RATINGS
Electronic and mechanical stress momentarily exceeded absolute maximum ratings may cause permanent damage 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

Recommended Operating Conditions

Symbol	Parameter	Rating	Unit
V_{IN}	Input Voltage	1.8 to 5.5	V
Ta	Operating Temperature Range	−40 to 85	°C

RECOMMENDED OPERATING CONDITIONS
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 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.

(1) Refer to *POWER DISSIPATION* for detailed information.

ELECTRICAL CHARACTERISTICS

The specifications surrounded by [ ] are guaranteed by design engineering at −40°C ≤ Ta ≤ 85°C.

RP604Z/K Electrical Characteristics (Ta = 25°C)

Symbol	Parameter	Test Conditions/Comments		Min.	Typ.	Max.	Unit
V_{OUT}	Output Voltage	V_{IN} = V_{CE} = 3.6 V		x 0.985		x 1.015	V
I_Q	Operating Quiescent Current	V_{IN} = V_{CE} = V_{OUT} = 3.6 V, V_{SET} = 3.3V at rest			0.3		µA
$I_{STANDBY}$	Standby Current	V_{IN} = 5.5 V, V_{CE} = 0 V			0.01	1	µA
I_{CEH}	CE Pin Input Current, High	V_{IN} = V_{CE} = 5.5 V		[−0.025]	0	[0.025]	µA
I_{CEL}	CE Pin Input Current, Low	V_{IN} = 5.5 V, V_{CE} = 0 V		[−0.025]	0	[0.025]	µA
I_{VOUTH}	VFB Pin Input Current, High	V_{IN} = V_{FB} = 5.5 V, V_{CE} = 0 V		[−0.025]	0	[0.025]	µA
I_{VOUTL}	VFB Pin Input Current, Low	V_{IN} = 5.5 V, V_{CE} = V_{FB} = 0 V		[−0.025]	0	[0.025]	µA
V_{OVP}	OVP Threshold Voltage	V_{IN} = 3.6 V, rising (detection)			6.0		V
		V_{IN} = 3.6 V, falling (release)			5.5		V
R_{DISN}	Auto-discharge NMOS On-resistance[(1)]	V_{IN} = 3.6 V, V_{CE} = 0 V			100		Ω
V_{CEH}	CE Pin Input Voltage, High	V_{IN} = 5.5 V		[1.0]			V
V_{CEL}	CE Pin Input Voltage, Low	V_{IN} = 2.0 V				[0.4]	V
R_{ONP}	PMOS On-resistance	RP604Z	V_{IN} = 3.6 V, I_{LX} = −100 mA		0.12		Ω
		RP604K	V_{IN} = 3.6 V, I_{LX} = −100 mA		0.15		Ω
R_{ONN}	NMOS On-resistance	RP604Z	V_{IN} = 3.6 V, I_{LX} = −100 mA		0.12		Ω
		RP604K	V_{IN} = 3.6 V, I_{LX} = −100 mA		0.15		Ω
T_{TSD}	Thermal Shutdown Threshold Temperature	Tj, rising (detection)			140		°C
T_{TSR}		Tj, falling (release)			100		°C
t_{START}	Soft-start Time	V_{IN} = V_{CE} = 3.6 V			20		ms
I_{LXLIM}	LX Current Limit	V_{IN} = V_{CE} = 3.6 V		[600]	900		mA
V_{UVLOF}	UVLO Threshold Voltage	V_{IN} = V_{CE}, falling (detection)		[1.40]	1.50	[1.65]	V
V_{UVLOR}		V_{IN} = V_{CE}, rising (release)		[1.55]	1.65	[1.80]	V

All test items listed under Electrical Characteristics are done under the pulse load condition (Tj ≈ Ta = 25°C). Unless otherwise noted, the test runs with “Open-loop Control” (GND = 0 V).

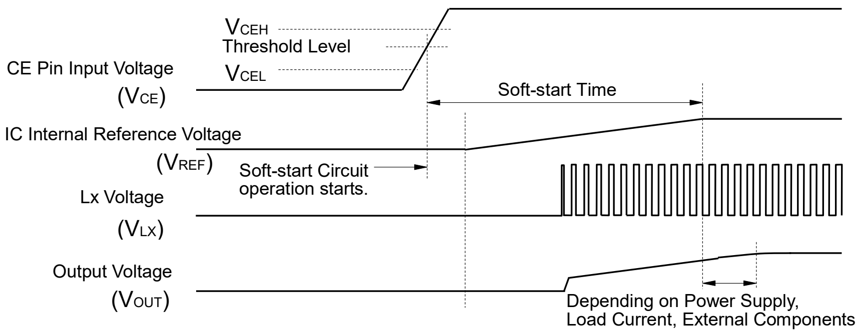
(1) RP604xxx1B only

THEORY OF OPERATION

Soft-start Time

Starting-up with CE Pin

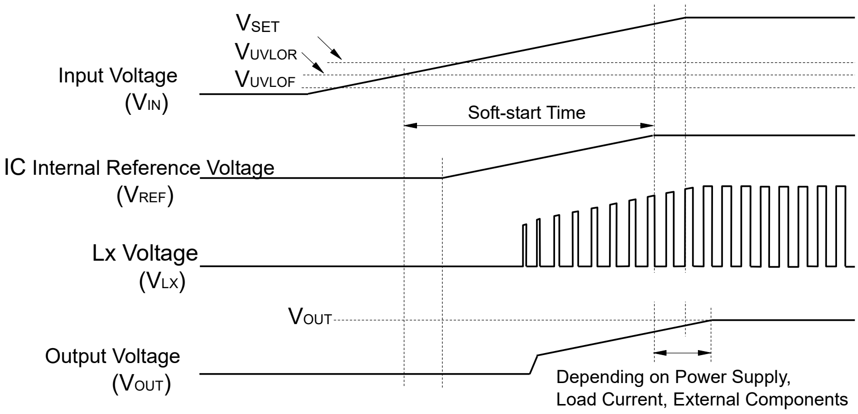
The IC starts to operate when the CE pin voltage (V_{CE}) exceeds the threshold voltage. The threshold voltage is preset between CE "H" input voltage (V_{CEH}) and CE "L" input voltage (V_{CEL}). After the start-up of the IC, soft-start circuit starts to operate. Then, after a certain period of time, the reference voltage (V_{REF}) in the IC gradually increases up to the specified value. Switching starts when V_{REF} reaches the preset voltage, and after that the output voltage rises accompanying V_{REF}'s increase. Soft-start time (t_{START}) 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_{UVLOR}), 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. Switching starts when V_{REF} reaches the preset voltage, and after that the output voltage rises accompanying V_{REF}'s increase. 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

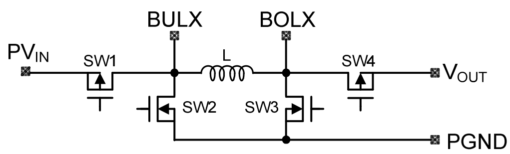
If the V_{IN} becomes lower than the UVLO detector threshold (V_{UVLOF}), the UVLO circuit starts to operate, V_{REF} stops, and P-channel and N-channel built-in switch transistors turn “OFF”. As a result, V_{OUT} drops according to the C_{OUT} capacitance value and the load. To restart the operation,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

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.

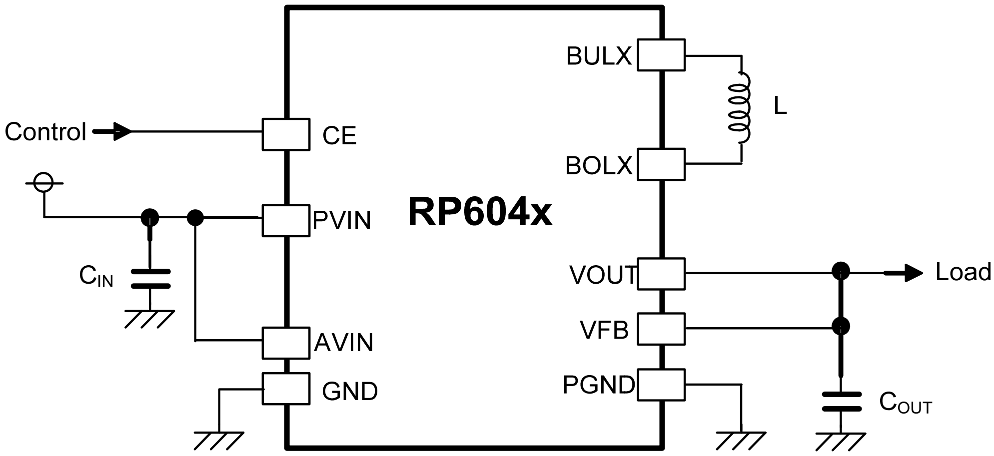
Overcurrent Protection Circuit

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 RP604x is set to Typ. 0.9 A.



Simplified Diagram of Output Switches

APPLICATION INFORMATION



RP604x Typical Application Circuit

Recommended External Components

Symbol	Description
C_{IN}	10 µF or more, Ceramic Capacitor
C_{OUT}	22 µF, Ceramic Capacitor
L	2.2 µH, Inductor

Calculation Method of Peak Current of LX Pin (I_{LXMAX}) in Continuous Mode

The peak current of Lx pin (I_{LXMAX}) can be calculated as follows, in the case of an ideal buck 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.

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

Second, when Pch Tr. is "OFF" (Nch Tr. is "ON"), the following equation is satisfied.

$L \times I_{RP} / t_{OFF} = R_{ONN} \times I_{OUT} + V_{OUT} + R_L \times I_{OUT}$ ··· Equation 2

Put Equation 2 into Equation 1 to solve ON duty of Pch Tr. ($D_{ON} = t_{ON} / (t_{OFF} + t_{ON})$):

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

The peak current of LX pin (I_{LXMAX}) can be calculated as follows, in the case of an ideal boost 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}, Average inductor current is described as I_{LX}, ON resistance of Pch. Tr. and ON resistance of Nch. Tr. is described as R_{ONP} and R_{ONN} respectively, and DC resistor of the inductor is described as R_L.

First, when Nch. Tr. is "ON", the following equation is satisfied.

$$L \times I_{RP} / t_{ON} = V_{IN} - (R_L + R_{ONN}) \times I_{LX} \quad \cdots \text{Equation 6}$$

Second, when Nch. Tr. is "OFF" (Pch. Tr. is "ON"), the following equation is satisfied.

$$L \times I_{RP} / t_{OFF} = V_{OUT} + (R_L + R_{ONP}) \times I_{LX} - V_{IN} \quad \cdots \text{Equation 7}$$

Put Equation 7 into Equation 6 to solve ON duty of Nch. Tr. ($D_{ON} = t_{ON} / (t_{OFF} + t_{ON})$):

$$D_{ON} = (V_{OUT} - V_{IN} + R_L \times I_{LX} + R_{ONP} \times I_{LX}) / (V_{OUT} + R_{ONP} \times I_{LX} - R_{ONN} \times I_{LX}) \quad \cdots \text{Equation 8}$$

Ripple Current is described as follows:

$$I_{RP} = (V_{IN} - R_L \times I_{LX} - R_{ONN} \times I_{LX}) \times D_{ON} / f_{OSC} / L \quad \cdots \text{Equation 9}$$

Peak current that flows through L (I_{LMAX}), and LX Tr. is described as follows:

$$I_{LXMAX} = I_{LX} + I_{RP} / 2 \quad \cdots \text{Equation 10}$$

Also, the average peak current (I_{OUT} and D_{ON}) in the boost circuit is described as follows:

$$I_{LX} = I_{OUT} / (1 - D_{ON}) \quad \cdots \text{Equation 11}$$

TECHNICAL NOTES

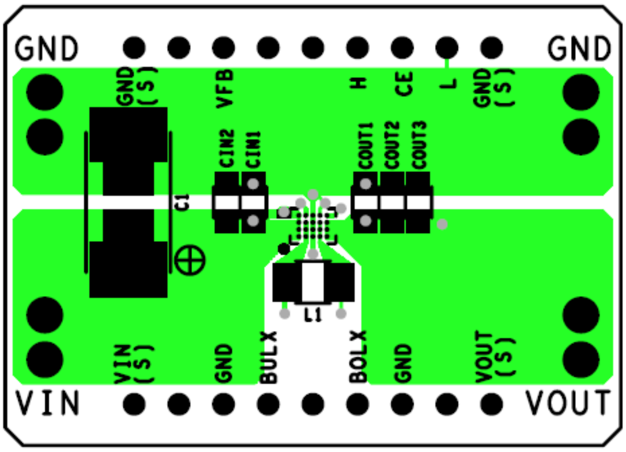
The performance of a power source circuit using this device is highly dependent on a peripheral circuit. A peripheral component or the device mounted on PCB should not exceed a rated voltage, a rated current or a rated power. When designing a peripheral circuit, please be fully aware of the following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

- Use ceramic capacitors with a low equivalent series resistance (ESR), considering 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 peak current of LX pin (I_{LXMAX}). Refer to *Calculation Method of Peak Current of Lx Pin (I_{LXMAX}) in Continuous Mode* for details.
- When an intermediate voltage other than V_{IN} or GND is input to the CE pin, a supply current may be increased with a through current of a logic circuit in the IC. The CE pin is neither pulled up nor pulled down, therefore an operation is not stable at open.

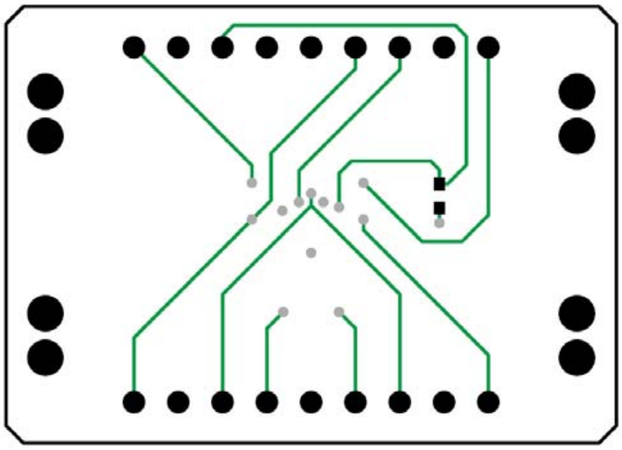
PCB Layout

RP604Z (Package: WLCSP-20-P2) PCB Layout

Topside

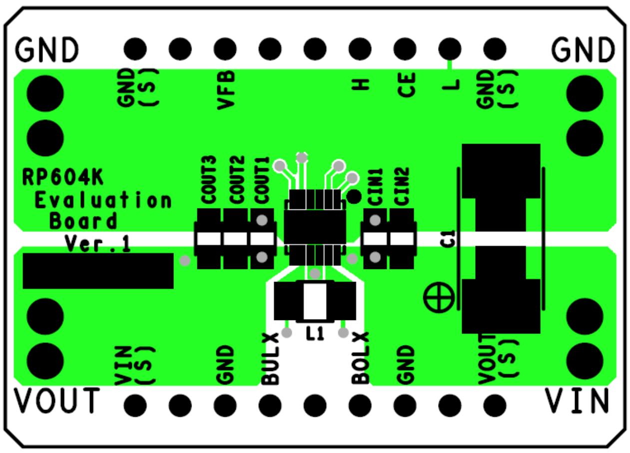


Backside

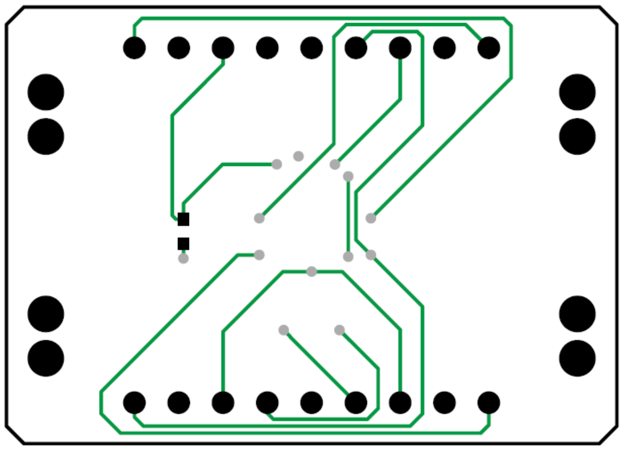


RP604K (Package: DFN(PLP)2730-12) PCB Layout

Topside



Backside

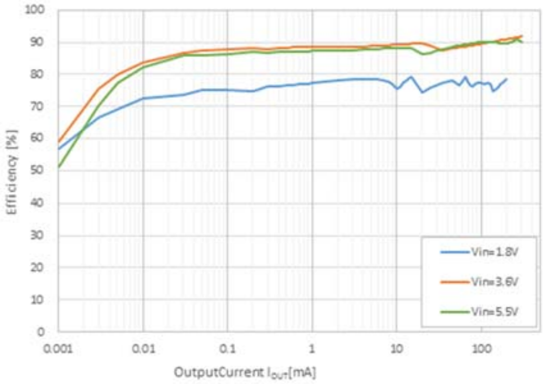


TYPICAL CHARACTERISTICS

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

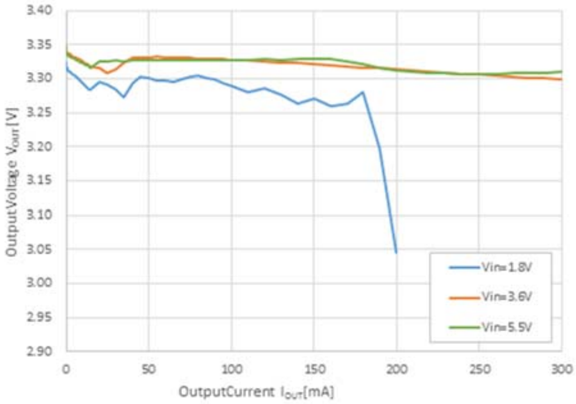
1) Output Current vs. Efficiency with Different Input Voltages

RP604Z331x



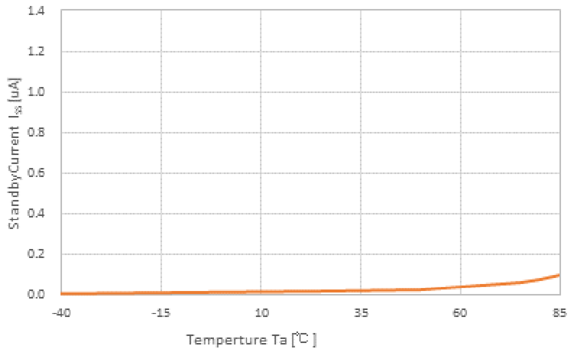
2) Output Current vs. Output Voltage with Different Input Voltages

RP604Z331x



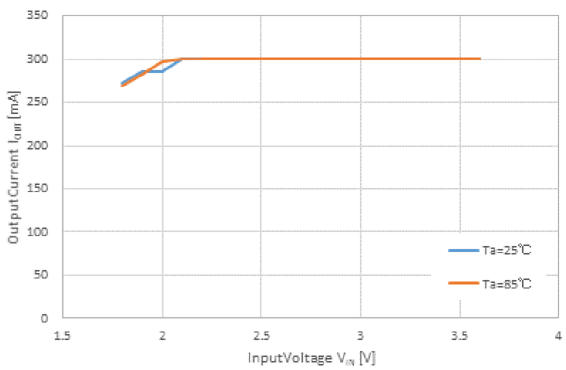
3) Temperature vs. Standby Current

RP604Z331x,V_{IN} = 5.5 V

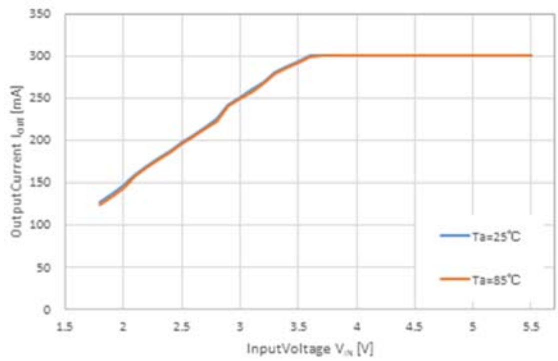


4) Input Voltage vs. Output Current

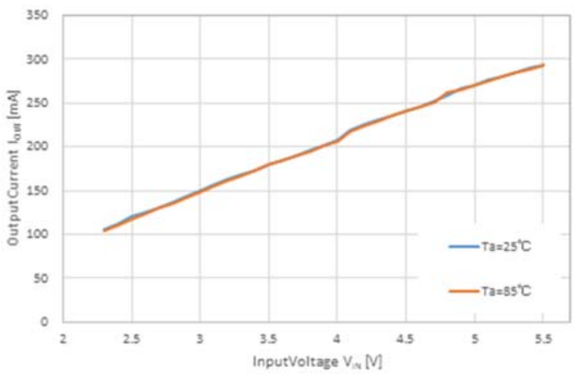
RP604Z161x, I_{OUT} = (I_{IN} = 300 mA)



RP604Z331x, I_{OUT} = (I_{IN} = 300 mA)

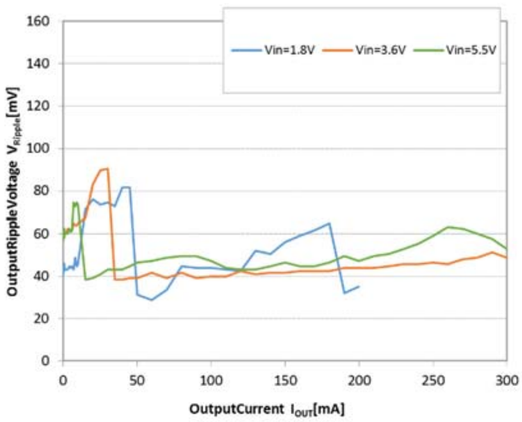


RP604Z521x, I_{OUT} = (I_{IN} = 300 mA)



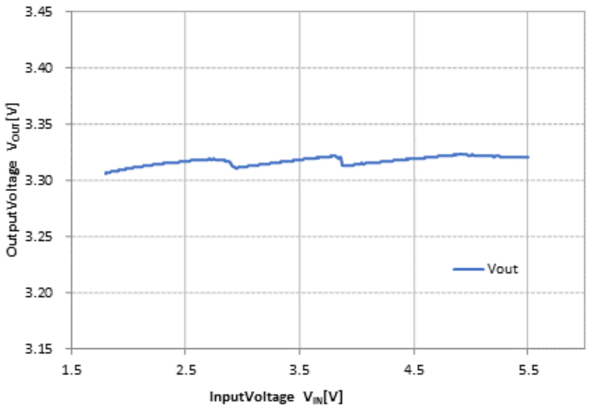
5) Output Ripple vs. Output Current

RP604Z331x

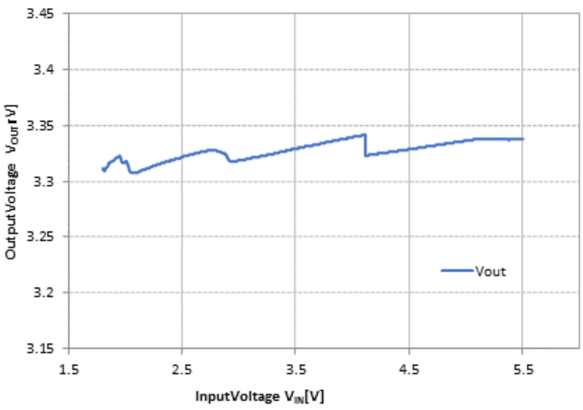


6) Input Voltage vs. Output Voltage

RP604Z331X, I_{OUT} = 1 mA

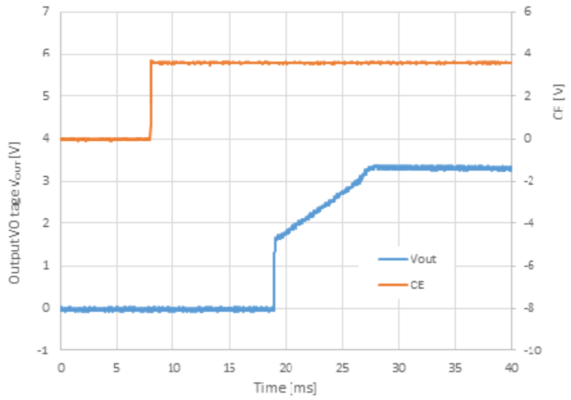


RP604Z331X, I_{OUT} = 100 mA

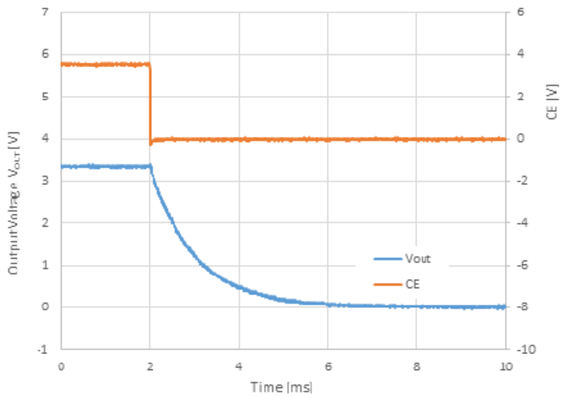


7) Starting-up/ Shutting-down Waveform with CE Pin

RP604Z331x, I_{OUT} = 0 mA

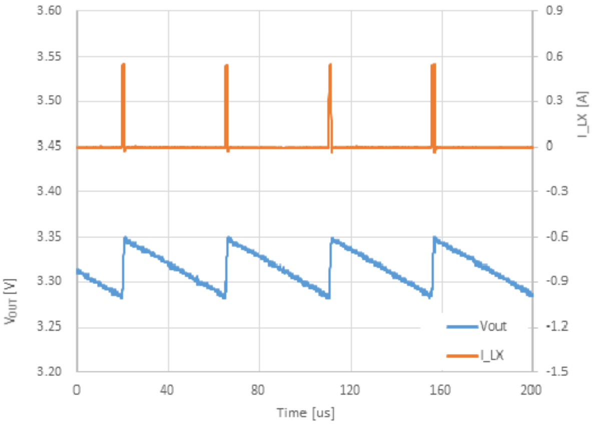


RP604Z331x, I_{OUT} = 0 mA

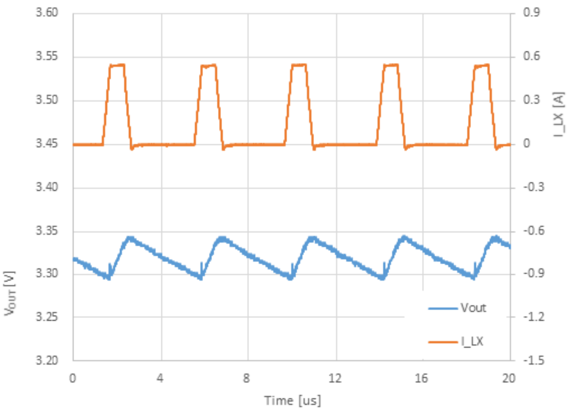


8) V_{OUT} Waveform

RP604Z331x, V_{IN} = 3.6 V, I_{OUT} = 10 mA

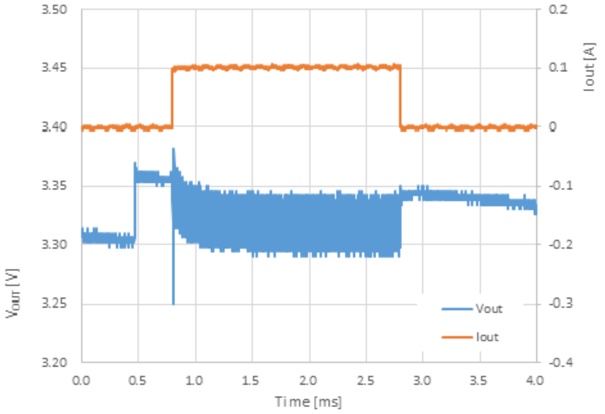


RP604Z331x, V_{IN} = 3.6 V, I_{OUT} = 100 mA



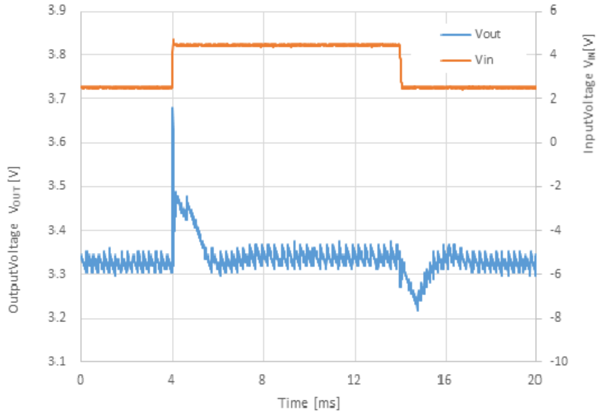
9) Load Transient Response

RP604Z331x, V_{IN} = 3.6 V, I_{OUT} = 0.01 mA ←→ 100 mA

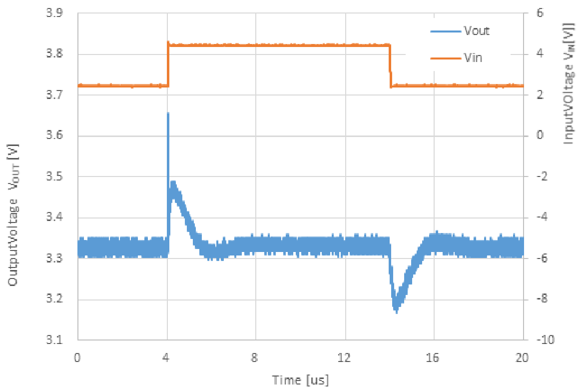


10) Input Transient Response

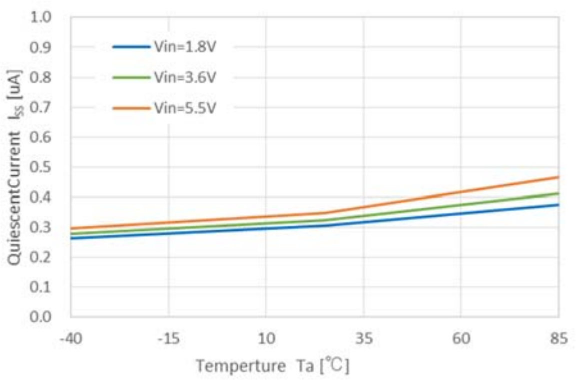
RP604Z331x, V_{IN} = 2.5 V ←→ 4.5 V, I_{OUT} = 1 mA



RP604Z331x, V_{IN} = 2.5 V ←→ 4.5 V, I_{OUT} = 100 mA



11) Temperature vs. Supply Current



The power dissipation of the package is dependent on PCB material, layout, and environmental conditions. The following measurement conditions are based on JEDEC STD. 51-9.

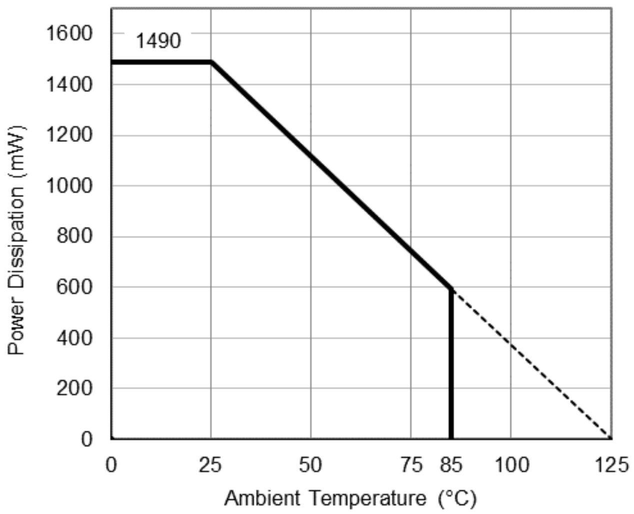
Measurement Conditions

Item	Measurement Conditions
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (Four-Layer Board)
Board Dimensions	101.5 mm x 114.5 mm x 1.6 mm
Copper Ratio	Outer Layers (First and Fourth Layers): 60% Inner Layers (Second and Third Layers): 100%

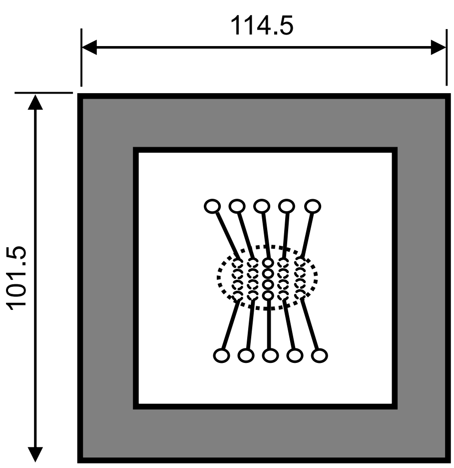
Measurement Result (Ta = 25°C, Tjmax = 125°C)

Item	Measurement Result
Power Dissipation	1490 mW
Thermal Resistance (θja)	θja = 67 °C/W

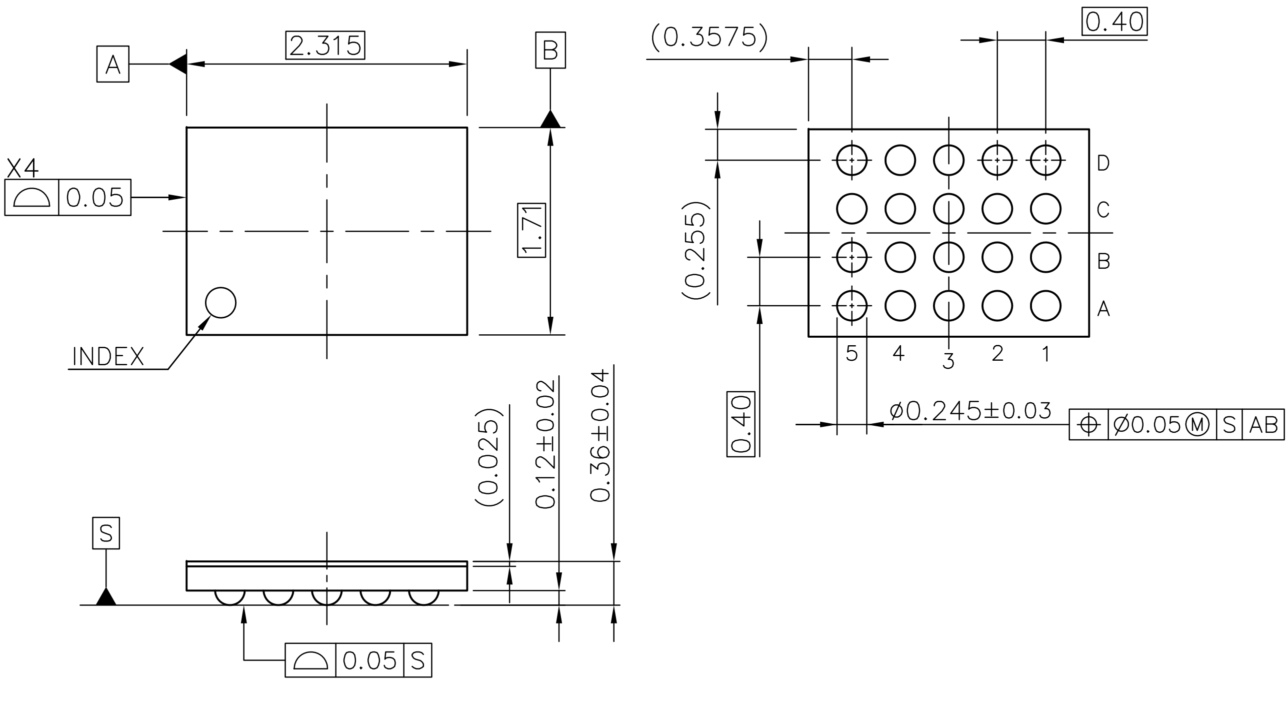
θja: Junction-to-Ambient Thermal Resistance



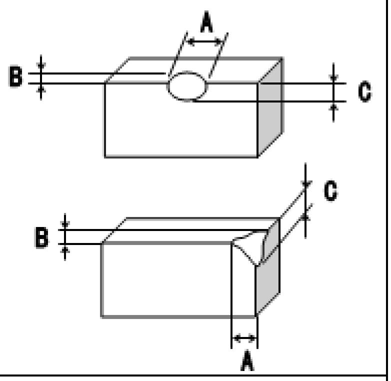
Power Dissipation vs. Ambient Temperature



Measurement Board Pattern



WLCSP-20-P2 Package Dimensions (Unit: mm)

No.	Inspection Items	Inspection Criteria	Figure
1	Package chipping	A≥0.2mm is rejected B≥0.2mm is rejected C≥0.2mm is rejected And, Package chipping to Si surface and to bump is rejected.	
2	Si surface chipping	A≥0.2mm is rejected B≥0.2mm is rejected C≥0.2mm is rejected But, even if A≥0.2mm, B≤0.1mm is acceptable.	
3	No bump	No bump is rejected.	
4	Marking miss	To reject incorrect marking, such as another product name marking or another lot No. marking.	
5	No marking	To reject no marking on the package.	
6	Reverse direction of marking	To reject reverse direction of marking character.	
7	Defective marking	To reject unreadable marking. (Microscope: X15/ White LED/ Viewed from vertical direction)	
8	Scratch	To reject unreadable marking character by scratch. (Microscope: X15/ White LED/ Viewed from vertical direction)	
9	Stain and Foreign material	To reject unreadable marking character by stain and foreign material. (Microscope: X15/ White LED/ Viewed from vertical direction)	

The power dissipation of the package is dependent on PCB material, layout, and environmental conditions. The following measurement conditions are based on JEDEC STD. 51-7.

Measurement Conditions

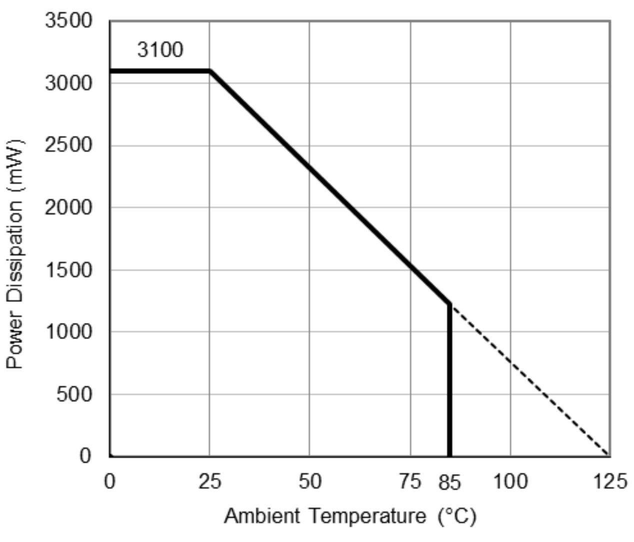
Item	Measurement Conditions
Environment	Mounting on Board (Wind Velocity = 0 m/s)
Board Material	Glass Cloth Epoxy Plastic (Four-Layer Board)
Board Dimensions	76.2 mm × 114.3 mm × 0.8 mm
Copper Ratio	Outer Layer (First Layer): Less than 95% of 50 mm Square Inner Layers (Second and Third Layers): Approx. 100% of 50 mm Square Outer Layer (Fourth Layer): Approx. 100% of 50 mm Square
Through-holes	ϕ 0.3 mm × 23 pcs

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

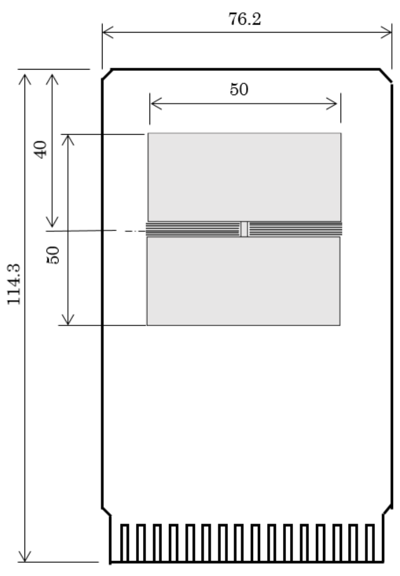
Item	Measurement Result
Power Dissipation	3100 mW
Thermal Resistance (θja)	θja = 32°C/W
Thermal Characterization Parameter (ψjt)	ψjt = 8°C/W

θja: Junction-to-Ambient Thermal Resistance

ψjt: Junction-to-Top Thermal Characterization Parameter



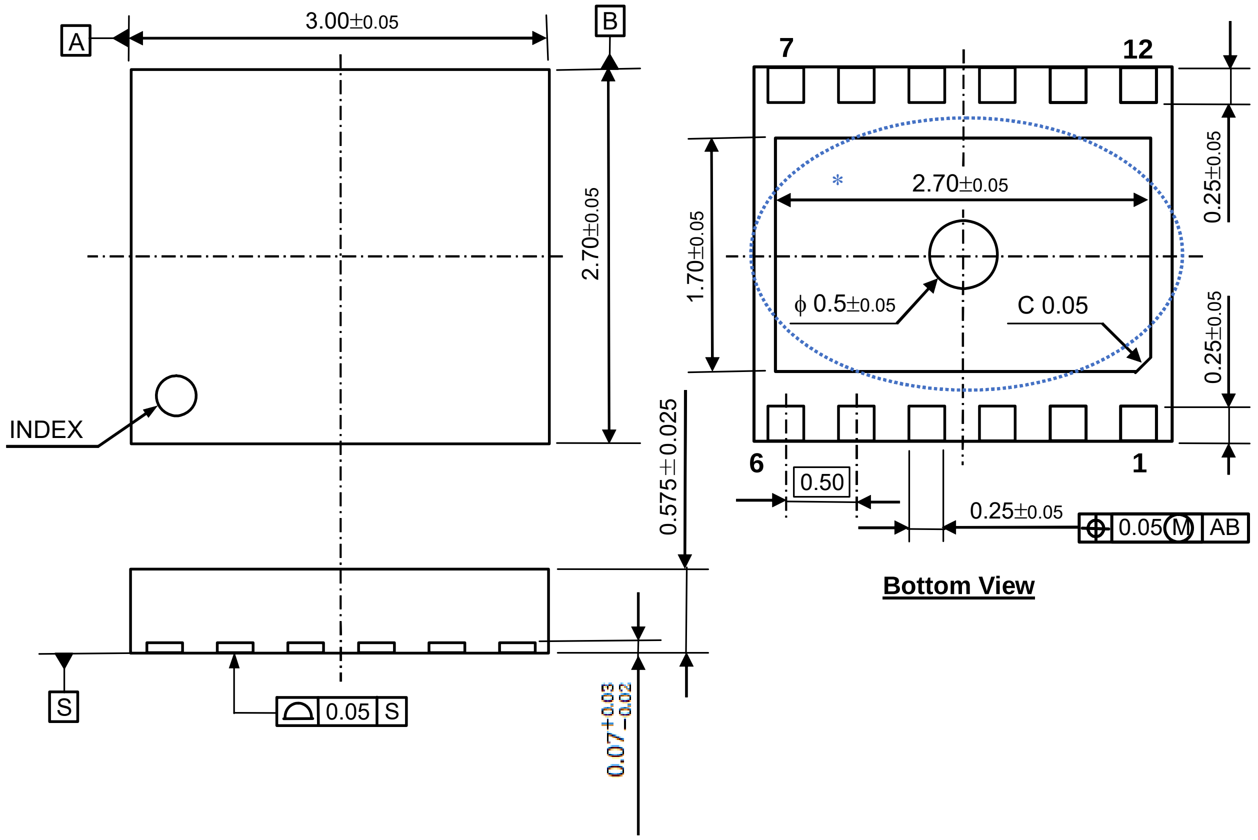
Power Dissipation vs. Ambient Temperature



Measurement Board Pattern

RICOH

Ver. A



DFN(PLP)2730-12 Package Dimensions (Unit: mm)

*The tab on the bottom of the package shown by blue circle is a substrate potential (GND). It is recommended that this tab be connected to the ground plane on the board but it is possible to leave the tab floating.

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