Microprocessor Power Management with Watchdog Timer for Automotive Application

NO.EC-136-161122

OUTLINE

The R5104V is a high voltage tolerance CMOS-based microprocessor power management IC with high accuracy output voltage and detector threshold and with ultra low supply current. The IC consists of a voltage regulator, a voltage detector and a watchdog timer. Thus, the R5104V has the function of a power management for microprocessor, a monitor of the voltage of a power source and a microprocessor supervisor.

The built-in voltage regulator with an external driver transistor can supply Min.1A current to a system. Therefore the IC is very suitable for various power supply systems for microprocessors. The built-in voltage detector monitors the output voltage, and has an output delay function and the delay time can be set by an external capacitor (C_D). The output voltage and the detector threshold voltage can be set individually for each IC by laser trimming.

Furthermore, when a microprocessor works incorrectly, the watchdog timer which checks over microprocessor generates reset signals intermittently to prevent a whole system from being malfunction.

The timeout periods for watchdog and reset can also be set individually by an external capacitor (C_{TW}).

There are two types of power down function: R5104VxxxA and R5104VxxxB. R5104VxxxA can turn off the monitoring of clock input for the watchdog timer, and R5104VxxxB can turn off all the circuits and realize the standby mode.

FEATURES

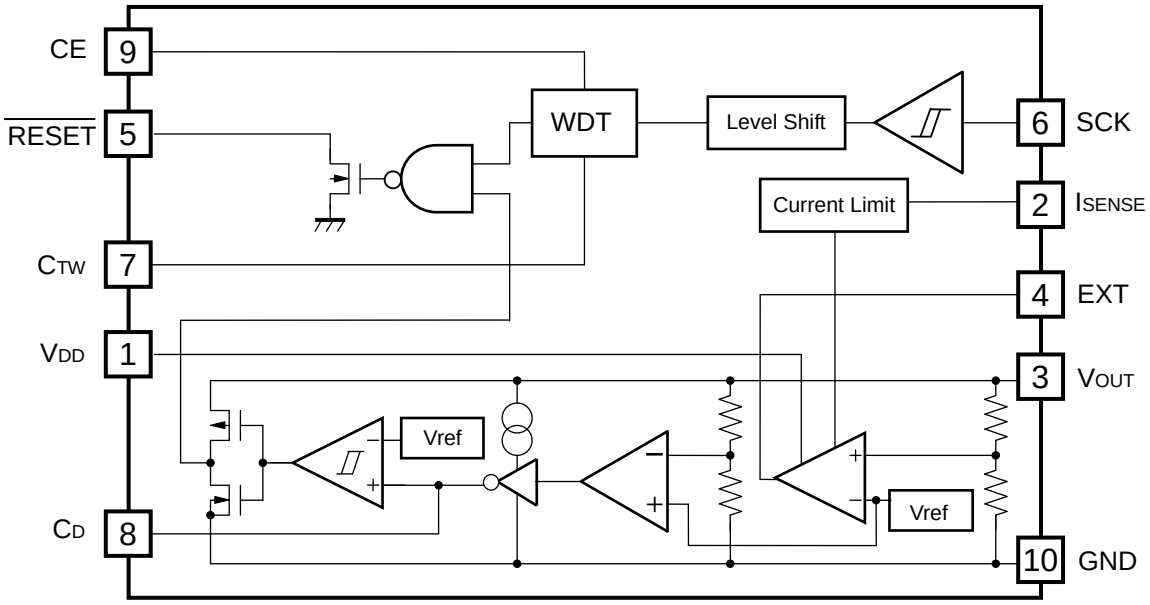
- Input Voltage Range (Maximum Rating) ·····Max.36.0V (50.0V)
- Operating Temperature Range ·····−40°C to 125°C
- Supply Current·····Typ. 60μA (I_{OUT}=0mA)
- Standby Current·····Typ. 0.1μA (R5104VxxxB)
- Output Voltage·····3.3V to 5.0V
- Detector Threshold Voltage ·····2.8V to 4.0V
- High Accuracy Output Voltage of Voltage Regulator and Detector Threshold ·····± 2.0%
- Output Voltage Temperature Coefficient ·····Typ. ±50 ppm/°C (−40°C to 125°C)
- Ripple Rejection·····Typ. 55dB
- Built-in Watchdog Timer
- Adjustable Timeout Period for Watchdog and Reset by External Capacitor
- Individual Control for Watchdog Timer by CE Pin
- Adjustable Power-on Reset Delay Time by External Capacitor
- Package·····SSOP-10

APPLICATION

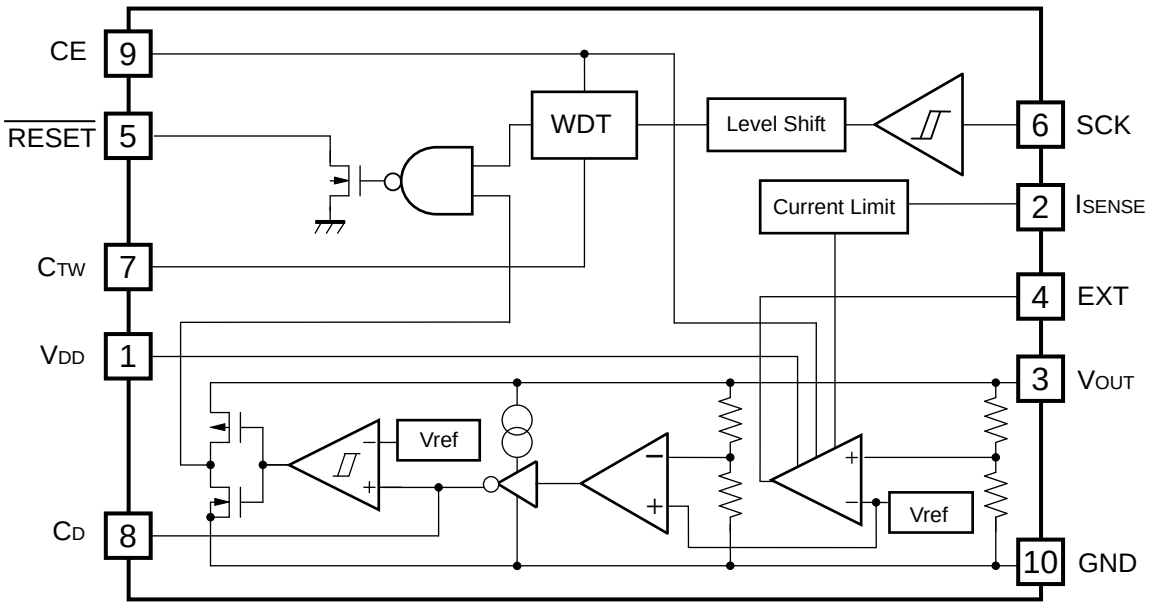
- Power source for control units including EV inverter and charge control.

BLOCK DIAGRAMS

R5104VxxxA



R5104VxxxB



SELECTION GUIDE

The output voltage, the detector threshold, and the operation of the CE pin for the ICs are selectable at the users' request.

Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
R5104Vxxx∗-E2-#G	SSOP-10	2,000 pcs	Yes	Yes

xxx : The combination of output voltage and detector threshold for each channel can be designated by serial numbers. (For details, please refer to MARK INFORMATIONS.)

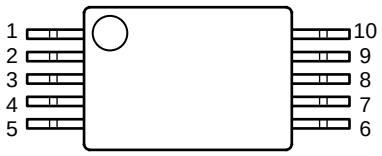
∗ : The options for the CE pin are as follows.
(A) Watchdog timer off
(B) Standby mode

: Specify the automotive class code.

	Operating Temperature Range	Guaranteed Specs Temperature Range	Screening
K	-40°C to 125°C	25°C	High and low temperature

PIN DESCRIPTIONS

SSOP-10



Pin No	Symbol	Pin Description
1	V_{DD}	Power supply Pin Clock
2	I_{SENSE}	Sense Pin for Current Limit of VR. Monitoring the dropout voltage generated at an external resistor between pin 1 and pin 2, if the dropout exceeds 0.3V (Typ.), the current limit works.
3	V_{OUT}	Output Pin for Voltage Regulator
4	EXT	External Transistor Drive Pin
5	$\overline{\text{RESET}}$	Output Pin for Reset signal of Watchdog timer and Voltage Detector. (Output Type is Nch Open Drain, Output "L" at detecting Detector Threshold and Watchdog Timer Reset.)
6	SCK	Clock Input Pin from Microprocessor
7	C_{TW}	External Capacitor Pin for Setting Reset and Watchdog Timeout Periods
8	C_D	External Capacitor Pin for Setting Delay Time of Voltage Detector
9	CE	Control Switch Pin for halting Watchdog timer (A version), or Chip Enable Pin (B version)
10	GND	Ground Pin

ABSOLUTE MAXIMUM RATINGS

Symbol	Item		Rating	Unit
V_{DD}	Supply Voltage		-0.3 to 50	V
V_{PEAK}	Peak Input Voltage[*1]		60	V
V_{CD}	Output Voltage[*2]	Voltage of C_D Pin	V_{SS} −0.3 to 7.5	V
V_{CTW}		Voltage of C_{TW} Pin	V_{SS} −0.3 to 7.5	V
V_{OUT}		Voltage of V_{OUT} Pin	V_{SS} −0.3 to 7.5	V
V_{RESET}		Voltage of $\overline{RESET}$ Pin	V_{SS} −0.3 to 7.5	V
V_{CE}	Input Voltage	Voltage of CE Pin	V_{SS} −0.3 to V_{IN}+0.3	V
V_{ISENSE}		Voltage of I_{SENSE} Pin	V_{SS} −0.3 to V_{IN}+0.3	V
V_{SCK}		Voltage of SCK Pin	V_{SS} −0.3 to V_{IN}+0.3	V
I_{EXT}	Output Current	Current of EXT Pin	20	mA
I_{RESET}		Current of $\overline{RESET}$ Pin	10	mA
P_D	Power Dissipation (SSOP-10)[*3]	Standard Land Pattern	450	mW
Topt	Operating Temperature Range		-40 to 125	°C
Tstg	Storage Temperature Range		-55 to 140	°C

[*1] Within application time of 200ms
[*2] Don't force any voltage more than supply voltage to C_D, C_{TW}, V_{OUT}, and $\overline{RESET}$ pins.
[*3] Refer to the section of *Package Information* for details.

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 CONDITION

Symbol	Item	Operating Ratings	Unit
V_{IN}	Input Voltage	to 36.0	V
Ta	Operating Temperature Range	−40 to 125	°C

RECOMMENDED OPERATING CONDITION

All of electronic equipment should be designed that the mounted semiconductor devices operate within the recommended operating ratings. The semiconductor devices cannot operate normally over the recommended operating ratings, even if when they are used over such ratings by momentary electronic noise or surge. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating ratings.

ELECTRICAL CHARACTERISTICS

V_{IN}=CE=V_{ISENSE}=12V, I_{OUT}=100mA, C_{CTW}=0.1μF, C_D=0.01μF, unless otherwise noted.

● **R5104VxxxA** **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
I_{SS}	Supply Current	I_{OUT}=0mA		60	100	μA
Ioff	Supply Current (WDT inactive)	V_{IN}=12V, CE=0V		50	90	μA
V_{CEH}	CE Input Voltage "H"		2.0		V_{IN}+0.3	V
V_{CEL}	CE Input Voltage "L"		0		0.25	V

VR Part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
V_{OUT}	Output Voltage		×0.98		×1.02	V
I_{OUT}	Output Current *1	V_{IN}=12V	1.0			A
V_{DIF}	Dropout Voltage *1	I_{OUT}=300mA		50		mV
$\Delta V_{OUT}/\Delta I_{OUT}$	Load Regulation *1	V_{IN}=12V,1mA≤I_{OUT}≤1A		15	60	mV
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation *1	I_{OUT}=100mA V_{SET}+1V≤V_{IN}≤36V		0.05	0.10	%/V
I_{SINK1}	EXT Output Sink Current Limit	V_{IN}=12V, V_{OUT}=V_{SET}-0.2V	9	14	20	mA
I_{SINK2}	EXT Output Sink Current Limit (Output short)	V_{IN}=12V, V_{OUT}=0V	0.20	0.50	0.85	mA
V_{ISENSE}	Current Limit Detector Threshold		0.23	0.30	0.37	V

*1 Depending on the capability of an external PNP transistor. Use an h_{FE} with approximately 100 to 300. The output current does not always mean continuous current because of the limit of power dissipation of PNP transistor.

VD Part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
$-V_{DET}$	Detector Threshold		×0.98		×1.02	V
V_{HYS}	Hysteresis Range		($-V_{SET}$) ×0.01	($-V_{SET}$) ×0.02	($-V_{SET}$) ×0.03	V
V_{TCD}	C_D pin Detector Threshold		2.35	2.50	2.65	V
I_{CD}	Internal Current Value for Delay Time Setting		0.12	0.30	0.47	μA
V_{INL}	Minimum Operating Voltage	V_{OUT} pin voltage			2.0	V

WDT Part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
t_{WD}	Watchdog Timeout Period	C_{TW}=0.1μF	200	300	510	ms
t_{WR}	Reset Hold Time of WDT	C_{TW}=0.1μF	35	70	120	ms
V_{IHSCK}	SCK Input Voltage "H"		V_{SET}×0.8		V_{IN}+0.3	V
V_{ILSCK}	SCK Input Voltage "L"		0		0.1	V
T_{SCKW}	SCK Input Pulse Width	$-V_{SET}$≥3.0V	500			ns
		$-V_{SET}$≤2.9V	5000			

V_{IN}=CE=V_{ISENSE} =12V, I_{OUT}=100mA, C_{CTW}=0.1μF, C_D=0.01μF, unless otherwise noted.

● **R5104VxxxB** **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
I_{SS}	Supply Current	I_{OUT}=0mA		60	100	μA
Ioff	Supply Current (Standby)	V_{IN}=12V, CE=0V		0.1	0.5	μA
V_{CEH}	CE Input Voltage "H"		2.0		V_{IN}+0.3	V
V_{CEL}	CE Input Voltage "L"		0		0.25	V

VR part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
V_{OUT}	Output Voltage		×0.98		×1.02	V
I_{OUT}	Output Current *1	V_{IN}=12V	1.0			A
V_{DIF}	Dropout Voltage *1	I_{OUT}=300mA		50		mV
$\Delta V_{OUT}/\Delta I_{OUT}$	Load Regulation *1	V_{IN}=12V ,1mA≤I_{OUT}≤1A		15	60	mV
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation *1	I_{OUT}=100mA V_{SET}+1V≤V_{IN}≤36V		0.05	0.10	%/V
I_{SINK1}	EXT Output Sink Current Limit	V_{IN}=12V, V_{OUT}=V_{SET}-0.2V	9	14	20	mA
I_{SINK2}	EXT Output Sink Current Limit (Output Short)	V_{IN}=12V, V_{OUT}=0V	0.20	0.50	0.85	mA
V_{ISENSE}	Current Limit Detector Threshold		0.23	0.30	0.37	V

*1 Depending on the capability of an external PNP transistor. Use an h_{FE} with approximately 100 to 300. The output current does not always mean continuous current because of the limit of power dissipation of PNP transistor.

VD part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
-V_{DET}	Detector Threshold		×0.98		×1.02	V
V_{HYS}	Hysteresis Range		(-V_{SET}) ×0.01	(-V_{SET}) ×0.02	(-V_{SET}) ×0.03	V
V_{TCD}	C_D pin Detector Threshold		2.35	2.50	2.65	V
I_{CD}	Internal Current Value for Delay Time Setting		0.12	0.30	0.47	μA
V_{INL}	Minimum Operating Voltage	V_{OUT} pin Voltage			2.0	V

WDT part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
t_{WD}	Watchdog Timeout Period	C_{TW}=0.1μF	200	300	510	ms
t_{WR}	Reset Hold Time of WDT	C_{TW}=0.1μF	35	70	130	ms
V_{IHSCK}	SCK Input Voltage "H"		V_{SET}×0.8		V_{IN}+0.3	V
V_{ILSCK}	SCK Input Voltage "L"		0		0.1	V
T_{SCKW}	SCK Input Pulse Width	-V_{SET}≥3.0V	500			Ns
		-V_{SEET}≤2.9V	5000			

V_{IN}=CE=V_{ISENSE} =12V, I_{OUT}=100mA, C_{CTW}=0.1μF, C_D=0.01μF, unless otherwise noted.

● **R5104V007A** **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
I_{SS}	Supply Current	I_{OUT}=0mA		45	80	μA
Ioff	Supply Current (WDT inactive)	V_{IN}=12V, CE=0V		45	80	μA
V_{CEH}	CE Input Voltage "H"		2.0		V_{IN}+0.3	V
V_{CEL}	CE Input Voltage "L"		0.00		0.25	V

VR part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
V_{OUT}	Output Voltage		×0.98		×1.02	V
I_{OUT}	Output Current *1	V_{IN}=12V	1.0			A
V_{DIF}	Dropout Voltage *1	I_{OUT}=300mA		50		mV
$\Delta V_{OUT}/\Delta I_{OUT}$	Load Regulation *1	V_{IN}=12V ,1mA≤I_{OUT}≤1A		15	60	mV
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation *1	I_{OUT}=100mA V_{SET}+1V≤V_{IN}≤36V		0.05	0.10	%/V
I_{SINK1}	EXT Output Sink Current Limit	V_{IN}=12V, V_{OUT}=V_{SET}-0.2V	9	14	20	mA
I_{SINK2}	EXT Output Sink Current Limit (Output short)	V_{IN}=12V, V_{OUT}=0V	0.20	0.50	0.85	mA
V_{ISENSE}	Current Limit Detector Threshold		0.23	0.30	0.37	V

*1 Depending on the capability of an external PNP transistor. Use an hFE with approximately 100 to 300. The output current does not always mean continuous current because of the limit of power dissipation of PNP transistor.

VD part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
$-V_{DET}$	Detector Threshold		×0.98		×1.02	V
V_{HYS}	Hysteresis Range		($-V_{SET}$) ×0.01	($-V_{SET}$) ×0.02	($-V_{SET}$) ×0.03	V
V_{TCD}	C_D pin detector threshold		2.35	2.50	2.65	V
I_{CD}	Internal Current value for Delay Time Setting		0.12	0.30	0.47	μA
V_{INL}	Minimum Operating Voltage	V_{OUT} pin Voltage			2.0	V

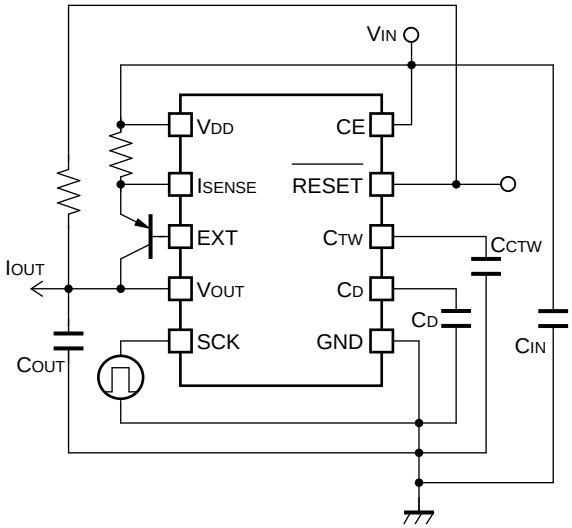
WDT part **(Ta = 25°C)**

Symbol	Item	Conditions	Min.	Typ.	Max.	Unit
t_{WD}	Watchdog Timeout Period	C_{TW}=0.1μF	200	300	510	ms
t_{WR}	Reset Hold Time of WDT	C_{TW}=0.1μF	35	70	130	ms
V_{IHSCK}	SCK Input Voltage "H"		V_{SET}×0.8		V_{IN}+0.3	V
V_{ILSCK}	SCK Input Voltage "L"		0.0		0.1	V
T_{SCKW}	SCK Input Pulse Width	$-V_{SET}$≥3.0V	500			ns
		$-V_{SET}$≤2.9V	5000			

- **Product-specific Electrical Characteristics**

Product Name	V_{OUT} [V]			$-V_{DET}$ [V]			V_{HYS} [V]		
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.
R5104V002x	4.900	5.000	5.100	3.332	3.400	3.468	0.034	0.068	0.102
R5104V003x	3.234	3.300	3.366	2.940	3.000	3.060	0.030	0.060	0.090
R5104V004x	4.900	5.000	5.100	3.626	3.700	3.774	0.037	0.074	0.111
R5104V007x	3.332	3.400	3.468	3.038	3.100	3.162	0.031	0.062	0.093
R5104V008x	3.332	3.400	3.468	2.940	3.000	3.060	0.030	0.060	0.090

TYPICAL APPLICATION



TECHNICAL NOTES

The phase compensation is made with the phase compensation circuit in the IC and the ESR of the output capacitor to make the operation stable. Therefore connect a 10μF or more value capacitor between V_{OUT} and GND. The ESR range of the output capacitor should be approximately 1Ω to 10Ω.

The fluctuation and the noise of the supply voltage, or a drastic change of the output voltage by the load transition of the regulator might be the reason of the mis-operation of the watchdog timer. If the SCK input pulse frequency is beyond 10kHz, or if the capacitance value of C_{TW} pin is large, the watchdog timer is easily affected by the fluctuation or noise of the supply voltage, or the fluctuation of the regulator output voltage, and it may cause an unstable operation.

If V_{IN} (supply voltage) may swing momentary, the regulator output is also swings. If the output of the voltage regulator becomes lower than detector voltage threshold, the built-in detector may generate the reset signal.

Built-in over-current limit works as monitoring the sink current of EXT pin and limits the current. Considering the over-current of the corrector current caused by short of EXT pin and GND externally, set a resistor between EXT pin and the base of the external driver transistor to limit the base current.

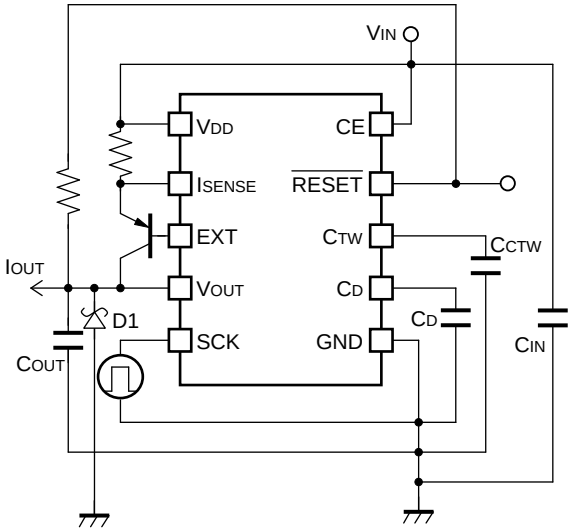
Use a 100pF or more value capacitor for C_{TW} pin.

Use a 10pF or more capacitor for C_D pin. A capacitor must be connected to C_D pin to use R5104VxxxA.

To avoid the mis-operation, during watchdog timer monitoring time, there is some ignoring time against clock pulse. Therefore, during the ignoring time, input clock pulse (rising edge trigger) is ignored. The ignoring time $V_{REF}2H$ is approximately as follows:

The time interval for C_{TW} pin voltage from $V_{REF}2H$ to $V_{REF}2H-(V_{REF}2H-V_{REF}2L)/4$

TYPICAL APPLICATION FOR IC CHIP BREAKDOWN PREVENTION



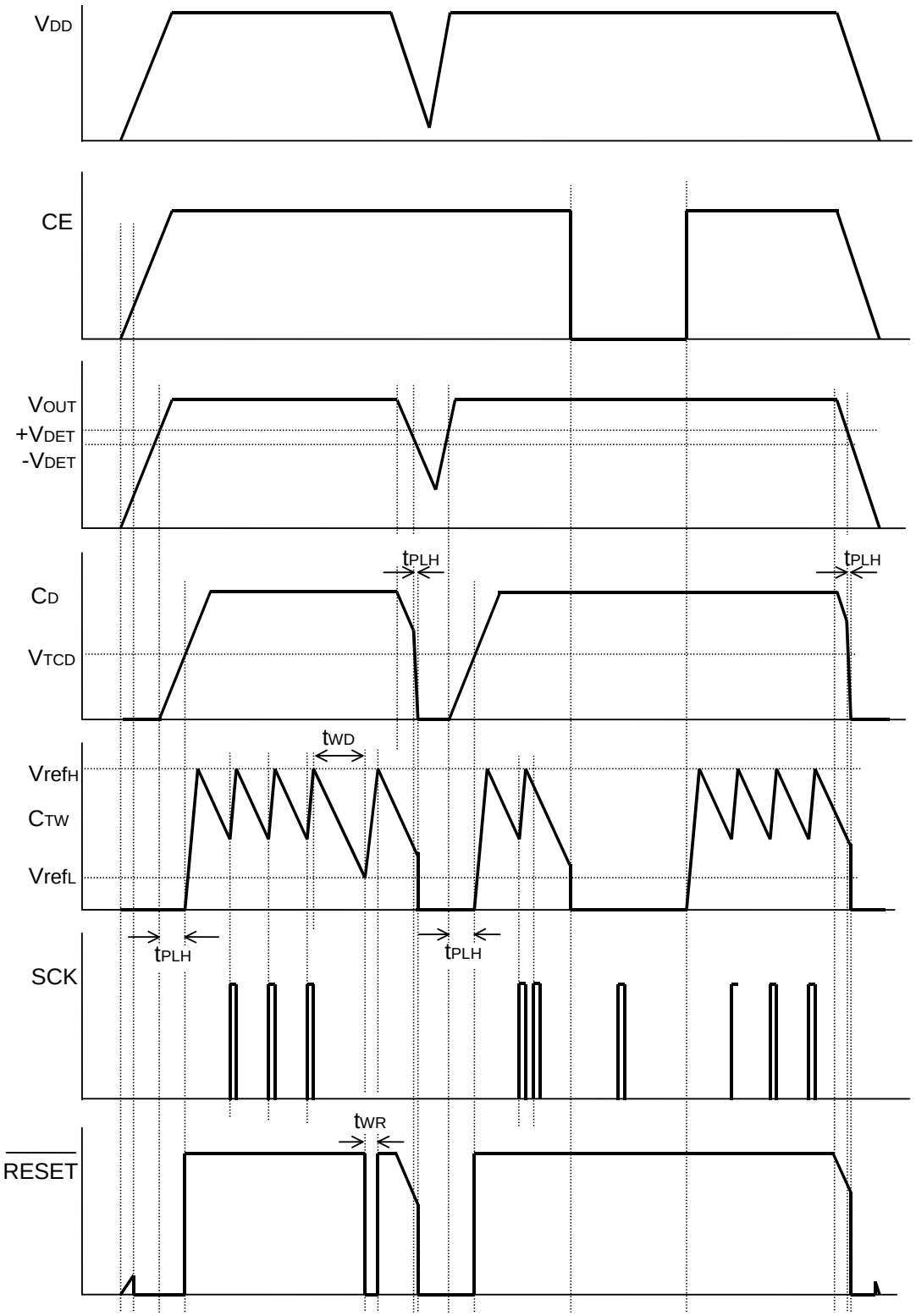
R5104Vxxxx Typical Application

When a sudden surge of electrical current travels along the V_{OUT} pin and GND due to a short-circuit, electrical resonance of a circuit involving an output capacitor (C2) and a short circuit inductor generates a negative voltage and may damage the device or the load devices. Connecting a schottky diode (D1) between the V_{OUT} pin and GND has the effect of preventing damage to them.

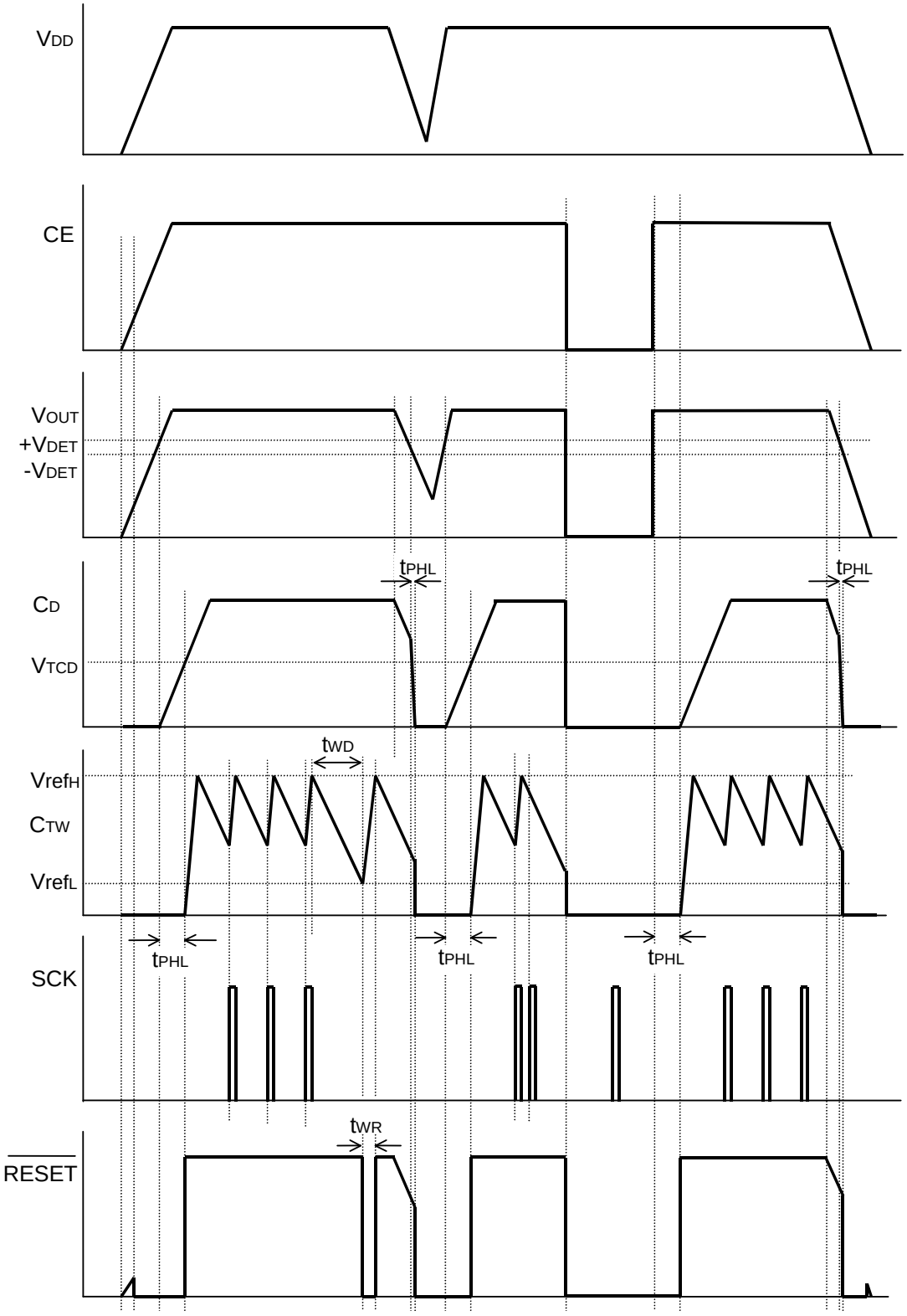
OPERATION DESCRIPTION

● TIMING CHART

R5104VxxxA



R5104VxxxB


VDD
CE
VOUT
+VDET
-VDET
tPHL
tPHL
CD
VTCD
tWD
VrefH
CTW
VrefL
tPHL
tPHL
tPHL
SCK
tWR
RESET

● **R5104VxxxA (Watchdog Timer On/Off type)**

The R5104VxxxA have the function that turns off the clock input of the watchdog timer. When the watchdog timer is enabled (CE="H"), the output of the internal regulator and SCK input pulse are supervised, while the watchdog timer is disabled (CE="L"), only the regulator is supervised.

● **R5104VxxxB (Standby Function)**

Since the standby function is included in the R5104VxxxB, the consumption current of the system can be reduced. The supply current at the standby mode is very small, typically 0.1μA.

● **Output Delay Time Setting of the built-in voltage detector**

The released delay time from reset of the voltage detector (t_{PLH}) can be calculated with the external capacitor value C_D and the next formula.

$$t_{PLH} = V_{TCD} \times C_D / I_{CD} \ (S)$$

On the other hand, output delay time for detecting voltage (t_{PHL}) is not specified, the time depends on the capacitance value of C_D.

PACKAGE INFORMATION

Power Dissipation (SSOP-10)

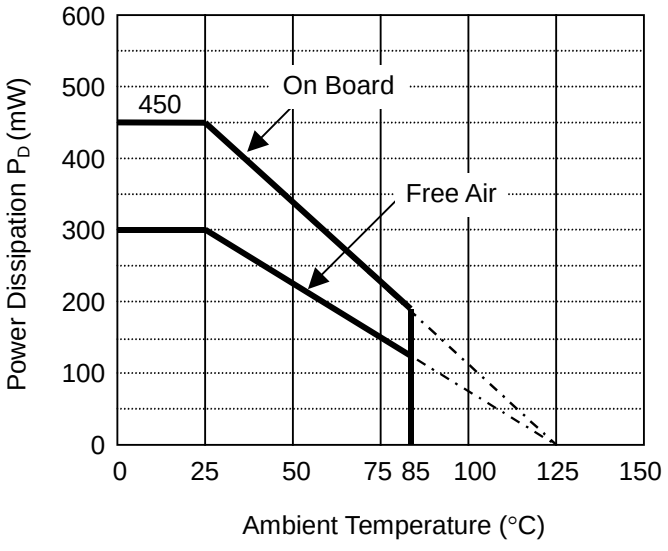
Power Dissipation (P_D) depends on conditions of mounting on board. This specification is based on the measurement at the condition below:

Measurement Conditions

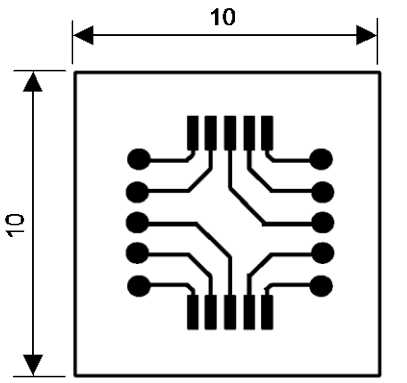
	Standard Test Land Pattern
Environment	Mounting on Board (Wind velocity=0m/s)
Board Material	Glass cloth epoxy plastic (Single sided)
Board Dimensions	10mm x 10mm x 1.6mm
Copper Ratio	Approx. 10%
Through-holes	—

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

	Standard Test Land Pattern	Free Air
Power Dissipation	450mW	300mW
Thermal Resistance	θja = (125-25°C)/0.45W = 222°C/W	333°C/W



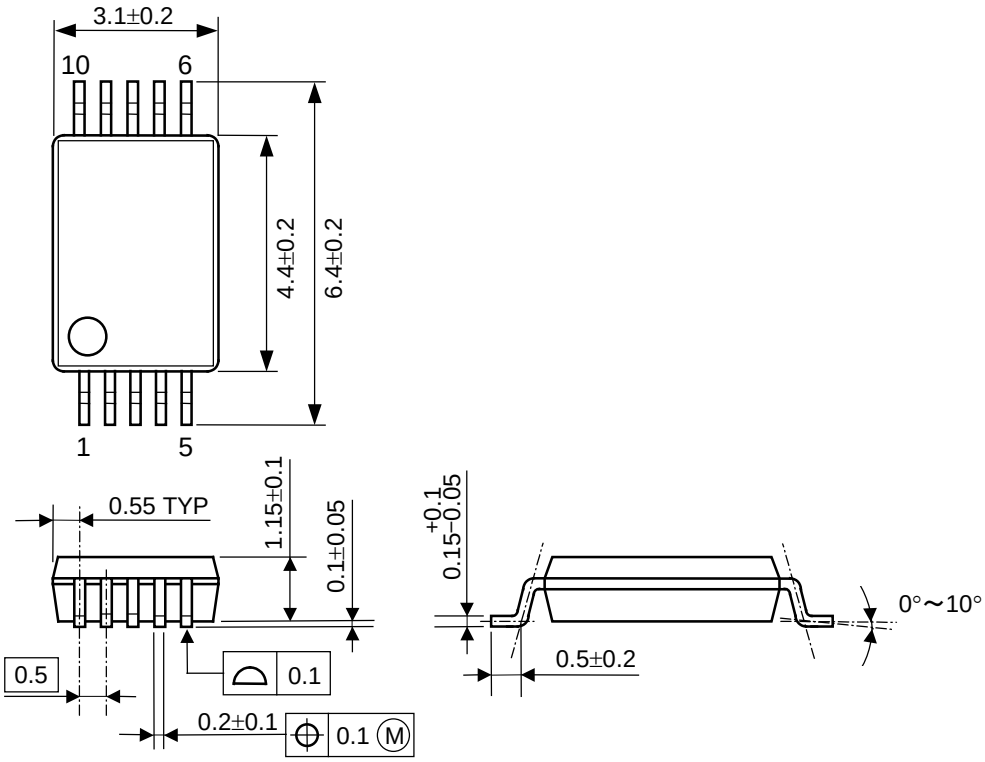
Power Dissipation



Measurement Board Pattern

IC Mount Area (Unit: mm)

Package Dimension (SSOP-10)



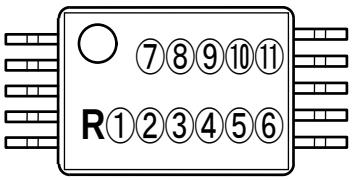
Unit: mm

Mark Specification (SSOP-10)

①②③④⑤⑥⑦ : Product Code ・・・ Refer to "*Mark Specification Table*"

⑧⑨⑩ : Lot Number ・・・ Alphanumeric Serial Number

⑪ : Lot Sub Number ・・・ Alphanumeric Serial Number

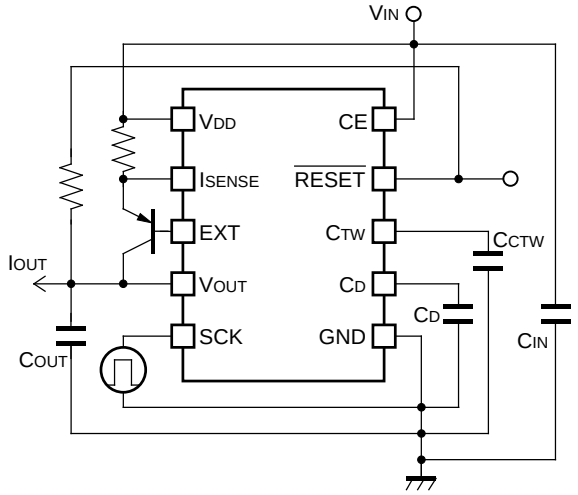


R5104V Mark Specification Table (SSOP-10)

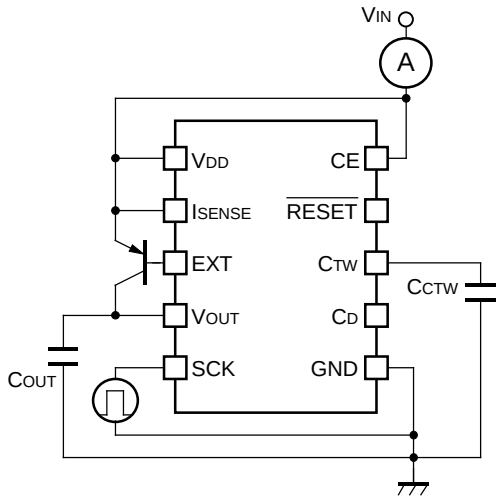
Product Name	①②③④⑤⑥⑦	VR	VD
R5104V002A	5 1 0 4 0 2 A	5.0V	3.4V
R5104V002B	5 1 0 4 0 2 B	5.0V	3.4V
R5104V003A	5 1 0 4 0 3 A	3.3V	3.0V
R5104V003B	5 1 0 4 0 3 B	3.3V	3.0V
R5104V004A	5 1 0 4 0 4 A	5.0V	3.7V
R5104V004B	5 1 0 4 0 4 B	5.0V	3.7V
R5104V007A	5 1 0 4 0 7 A	3.4V	3.1V
R5104V007B	5 1 0 4 0 7 B	3.4V	3.1V
R5104V008A	5 1 0 4 0 8 A	3.4V	3.0V
R5104V008B	5 1 0 4 0 8 B	3.4V	3.0V

TEST CIRCUITS

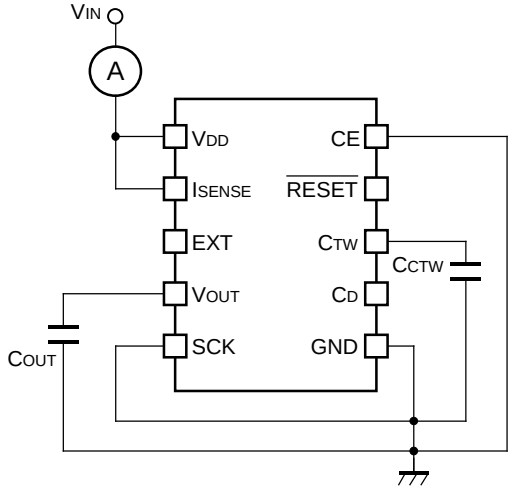
Standard Test Circuit



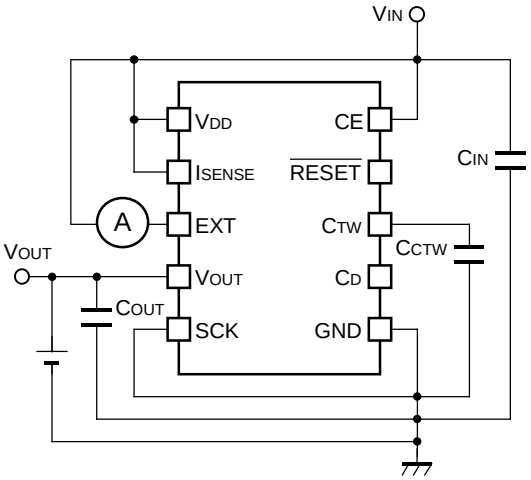
Supply Current Test Circuit



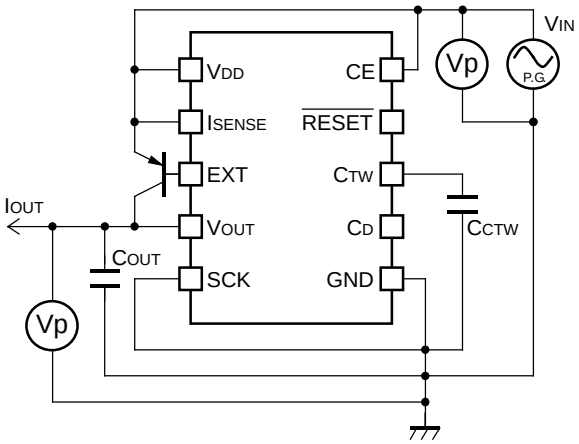
Standby Current Test Circuit



EXT Sink Current Test Circuit



Ripple Rejection Test Circuit

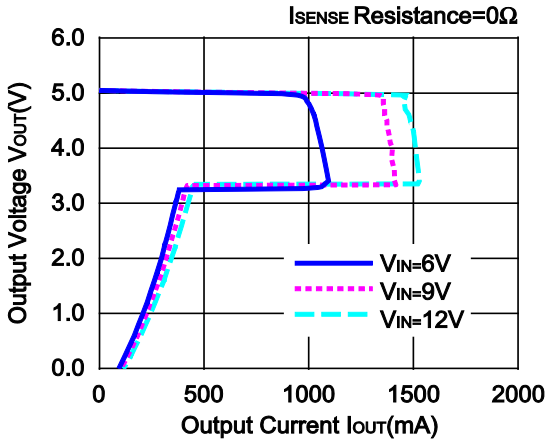


TYPICAL CHARACTERISTICS

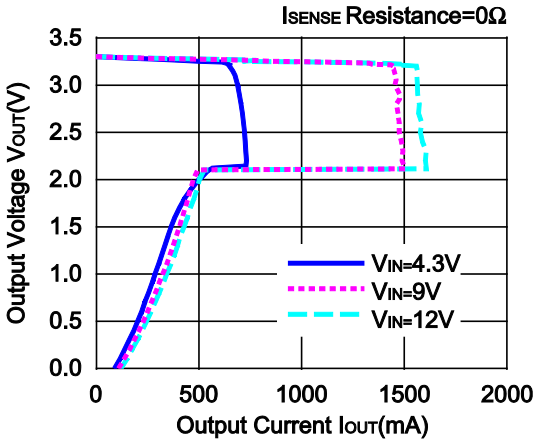
Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

1) Output Voltage vs. Output Current

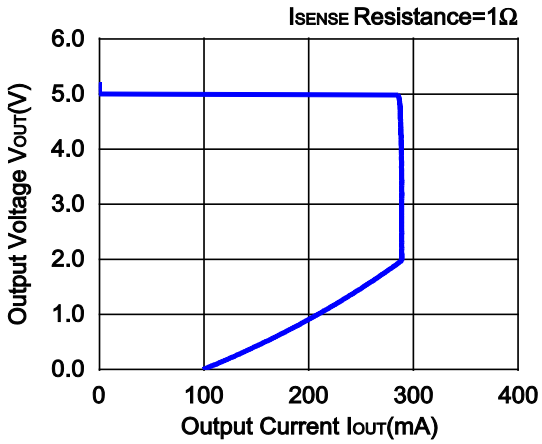
5.0V



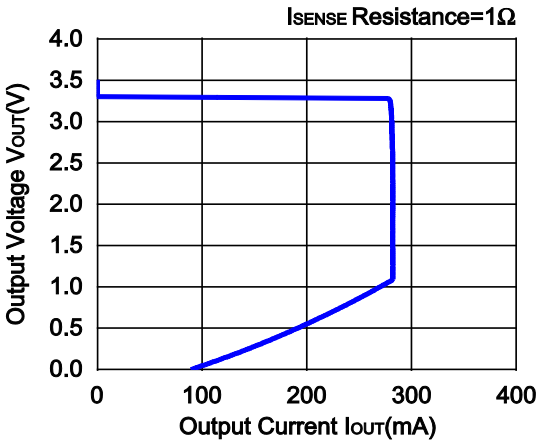
3.3V



5.0V

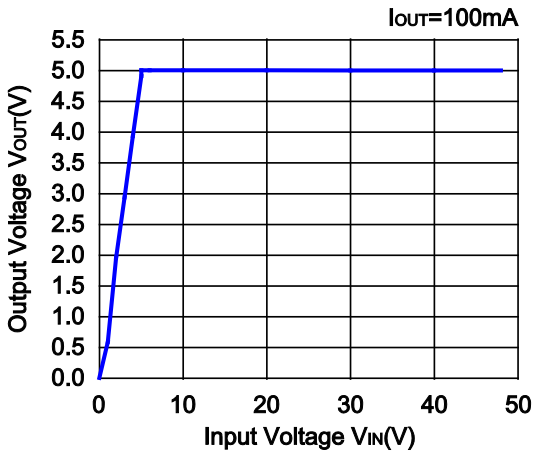


3.3V

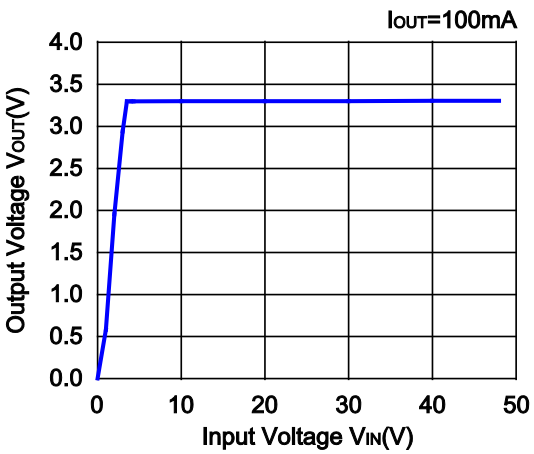


2) Output Voltage vs. Input Voltage

5.0V

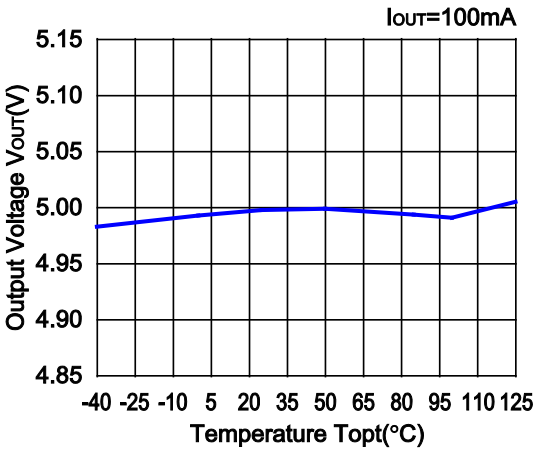


3.3V

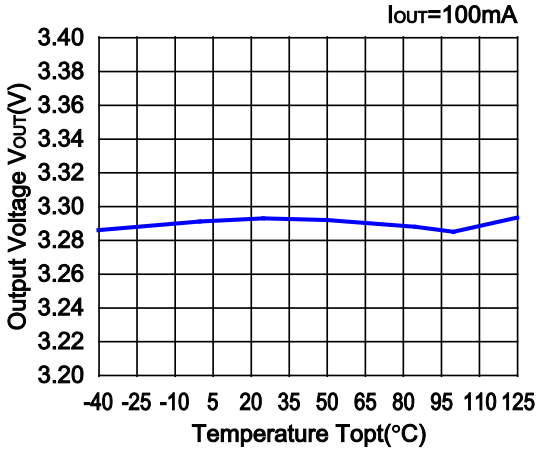


3) Output Voltage vs. Temperature

5.0V

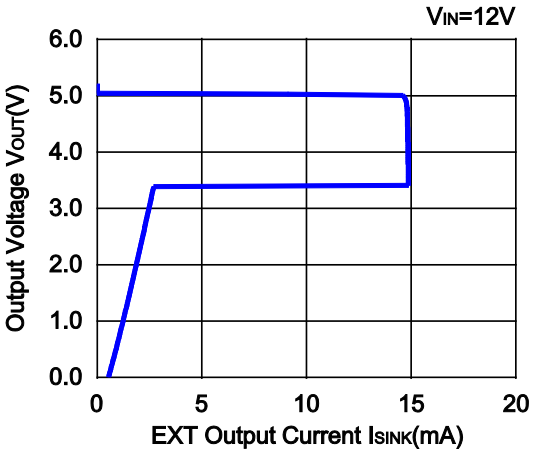


3.3V

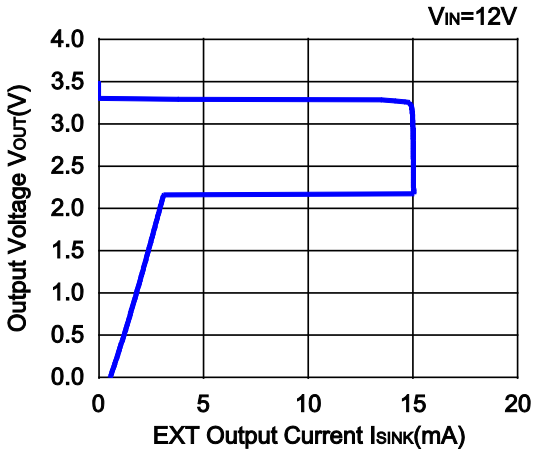


4) Base Current Limit vs. Output Voltage

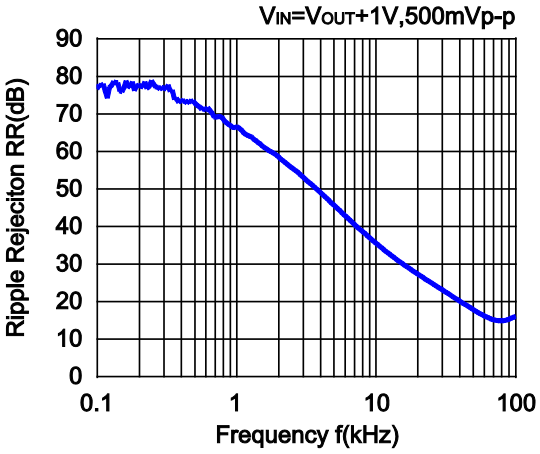
5.0V



3.3V

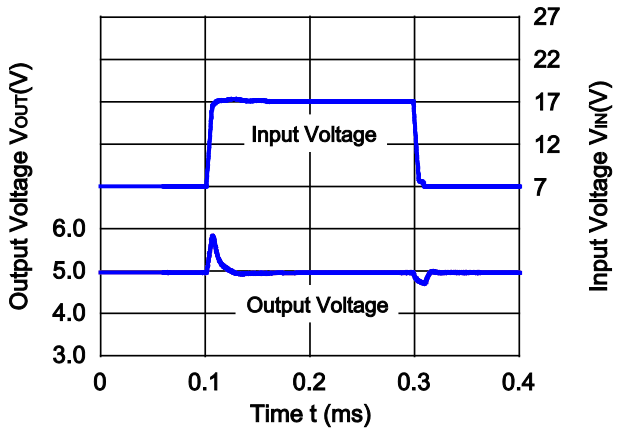


5) Ripple Rejection vs. Frequency

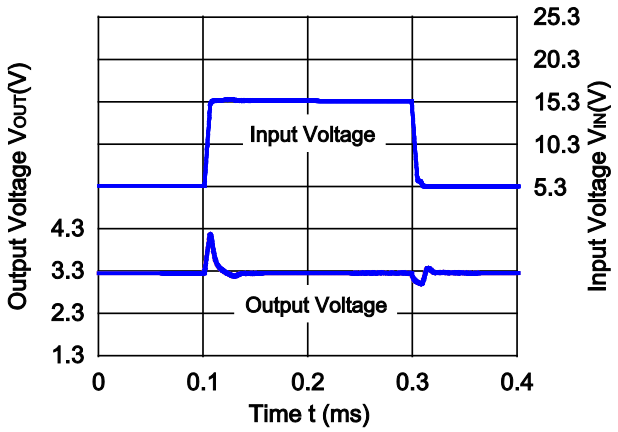


6) Input Transient Response

5.0V

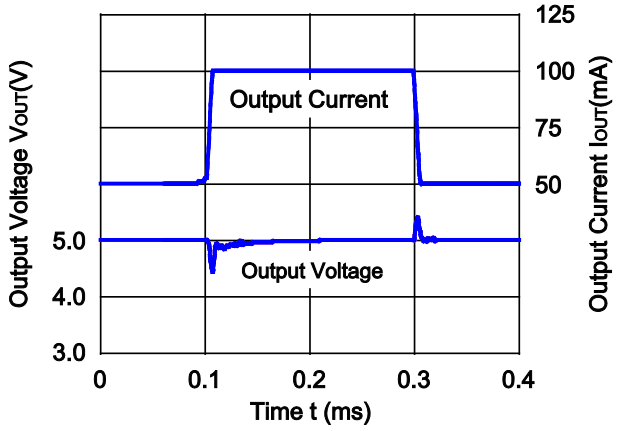


3.3V

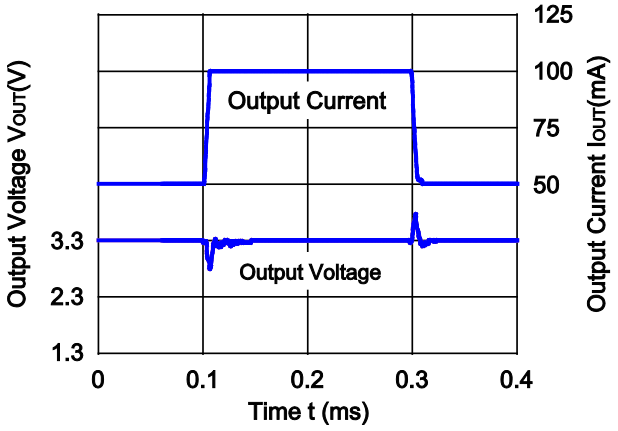


7) Load Transient Response

5.0V

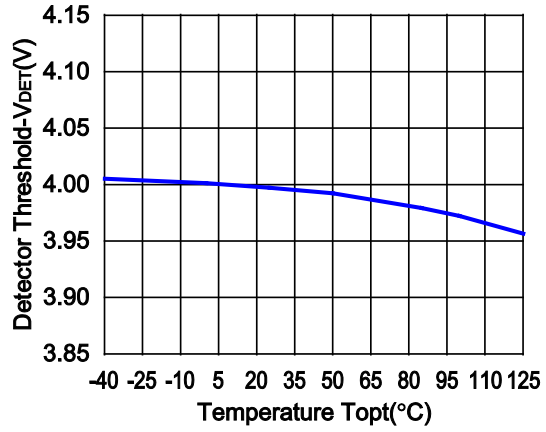


3.3V

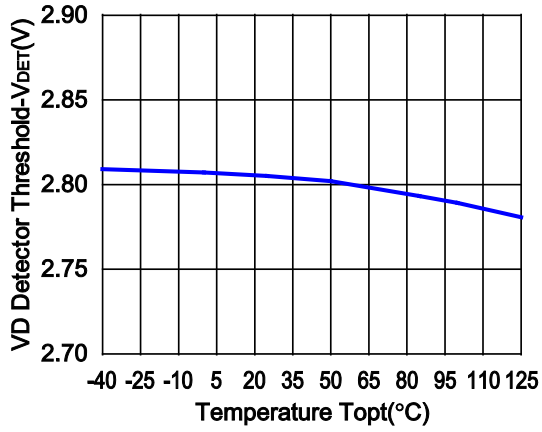


8) Detector Threshold vs. Temperature

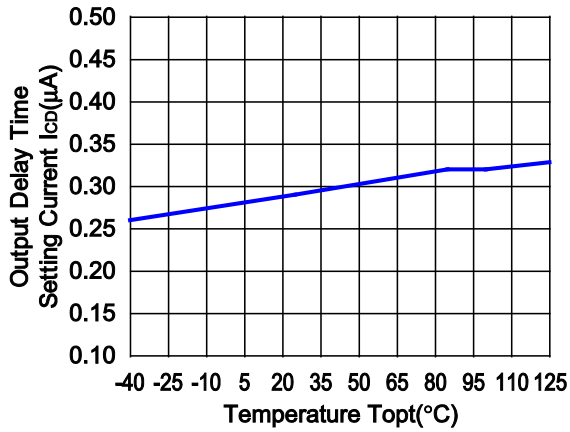
4.0V



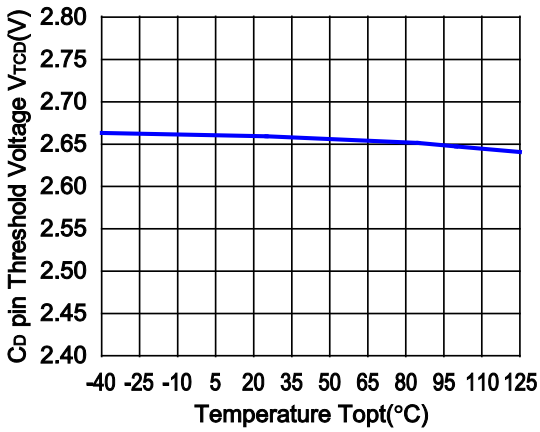
2.8V



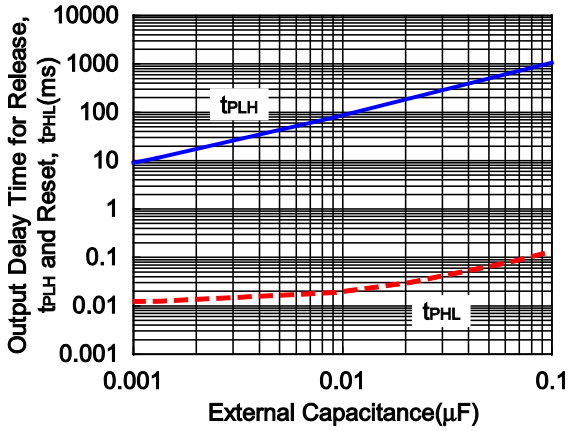
9) Output Voltage vs. Output Current



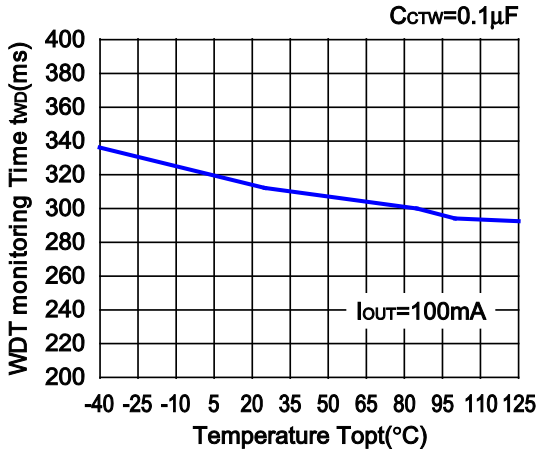
10) C_D Pin Threshold vs. Temperature



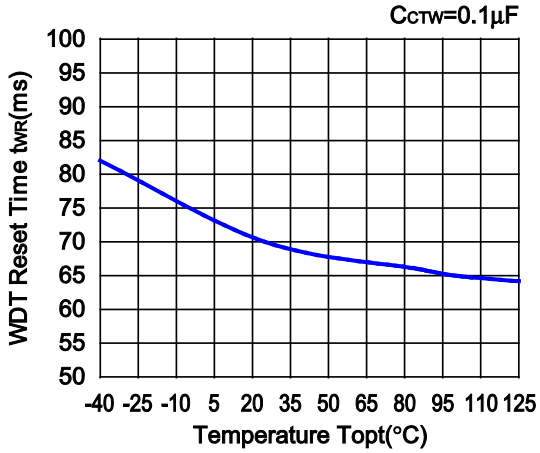
11) C_D Pin External Capacitance vs. Delay Time



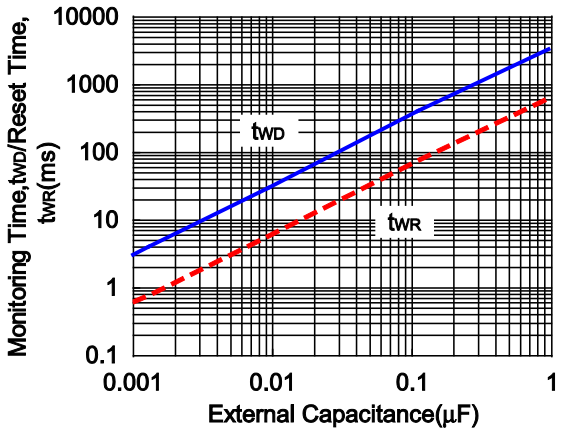
12) WDT monitoring Time vs. Temperature



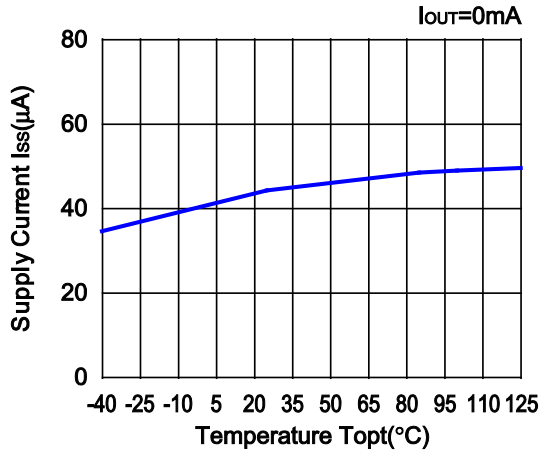
13) WDT Reset Time vs. Temperature



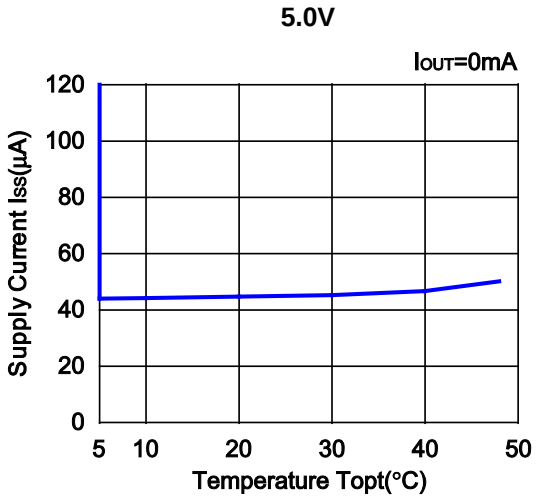
14) External Capacitance vs. WDT monitoring/Reset Time



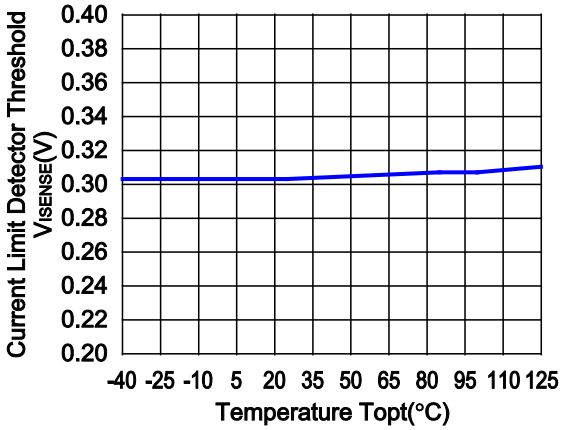
15) Supply Current vs. Temperature



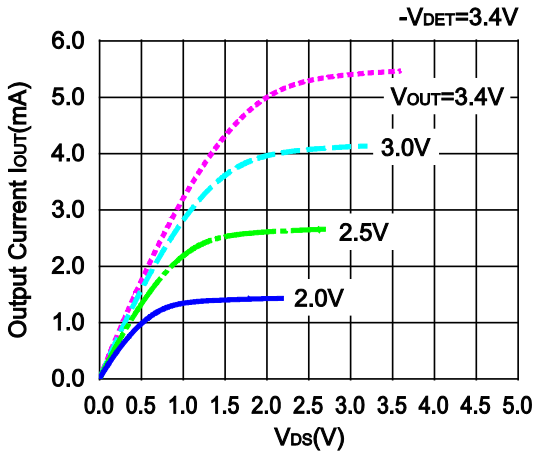
16) Supply Current vs. Input Voltage



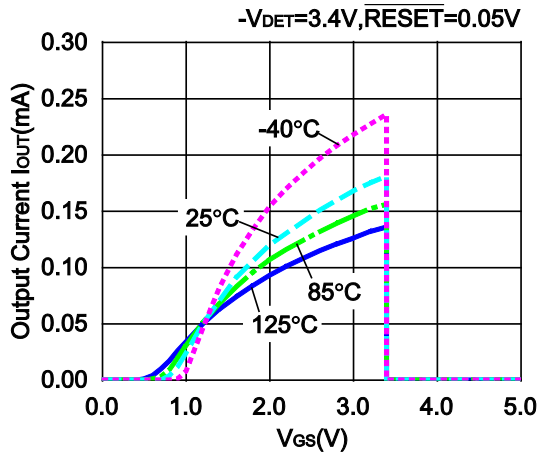
17) Current limit detector threshold vs. Temperature



18) Nch Driver Output Current vs. V_{DS}



19) Nch Driver Output Current vs. V_{GS}



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