RICHTEK®

RTQ2078-QF

Functional Safety PMIC for Automotive Camera Sensor/ Module

1 General Description

The RTQ2078-QF is a highly integrated PMIC designed for automotive camera applications. It includes three step-down converters, and one high PSRR low-dropout (LDO) regulator

The high-voltage step-down converter operates with an input voltage range of up to 24V and is capable of sustaining a 36V load dump. It is suitable for a direct connection to a 12V battery or Power Over Coax (PoC) connection.

The RTQ2078-QF offers overvoltage and undervoltage monitors, and fault status reported by I^2C for system fault reporting purpose.

The device offers system design flexibility with I^2C or factory-trimmed configurable functions, including adjustable output voltage for each channel, customizable power-on sequencing, and overvoltage (OV) or undervoltage (UV) monitor threshold voltage. The RTQ2078-QF is available in a WET-UQFN-16L 3x3 (FC) package with wettable flanks.

The recommended junction temperature range is –40°C to 125°C, and the ambient temperature range is –40°C to 125°C.

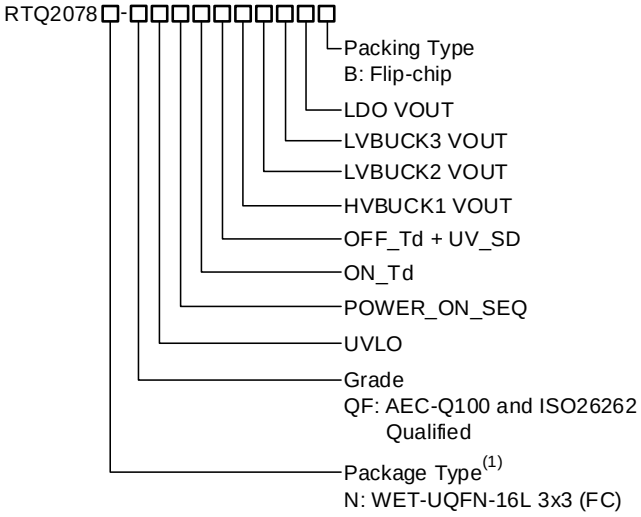
2 Applications

- Functional Safety Related Automotive Camera Modules
  - Surround View Camera
  - Front View Camera
  - Rear View Camera
  - Dash Cam DVR
  - Driver Monitoring System
  - Cabin Monitor

3 Features

- **AEC-Q100 Grade 1 Qualified**
- **Compliance with ISO 26262 ASIL B**
- **Power-On Built-In Self Test (BIST) for OV/UV Monitors, I^2C Cyclic Redundancy Check (CRC), and OTP Register CRC Protection**
  - **Three Step-Down Converters (HVBuck1, LVBuck2, and LVBuck3) with Peak-Current Mode PWM Operation and PSM Mode for Sentry Mode via I^2C Setting**
  - **Fixed Switching Frequency at 2.1MHz**
  - **EMI Reduction features including Spread Spectrum and Phase-Shift Operation**
  - **HVBuck1 Supports Input Voltage from 4V to 24V with Load Dump Protection (36V for ≤ 400ms Transient), Adjustable Output Voltage, and up to 1.5A Output Current**
  - **LVBuck2 and LVBuck3 Support Input Voltage from 2.7V to 5V, Adjustable Output Voltage and up 1.5A Output Current**
  - **Pins Related to LVBuck2/LVBuck3 Can Floating if the Channel is Unused**
- **Low Dropout Regulator (LDO)**
  - **LDO with 2.7V to 5V Input Voltage, Adjustable Output Voltage, up to 0.3A Output Current, and High PSRR with 0.1A Output Current (60dB at 100kHz, 40dB at 1MHz)**
- **Input and Output Functions**
  - **Power and Error Status Indication via PGOOD**
- **Small Form Factor Wettable WET-UQFN-16L 3x3 (FC) Package with Compact BOM**
- **Ambient Temperature Range: –40°C to 125°C**
- **Junction Temperature Range: –40°C to 125°C**

4 Ordering Information



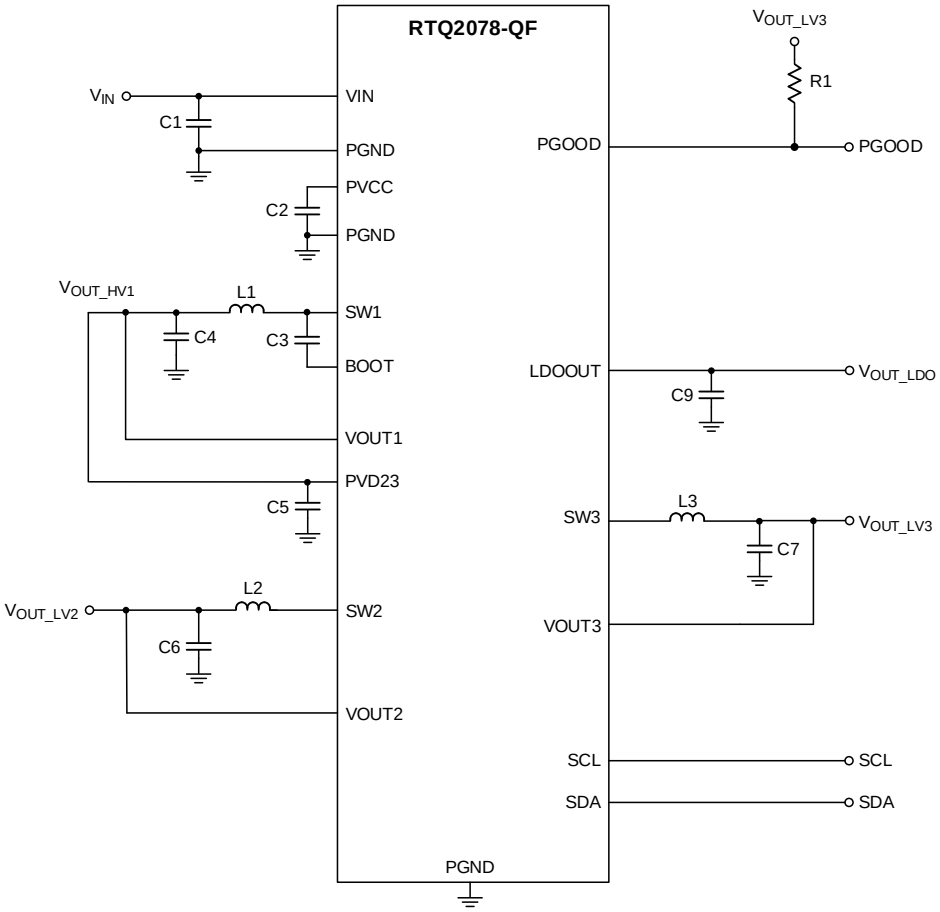
Note 1.

Richtek products are Richtek Green Policy compliant and marked with (1) indicates compatible with the current requirements of IPC/JEDEC J-STD-020.

5 Marking Information

For marking information, contact our sales representative directly or through a Richtek distributor located in your area.

6 Simplified Application Circuit



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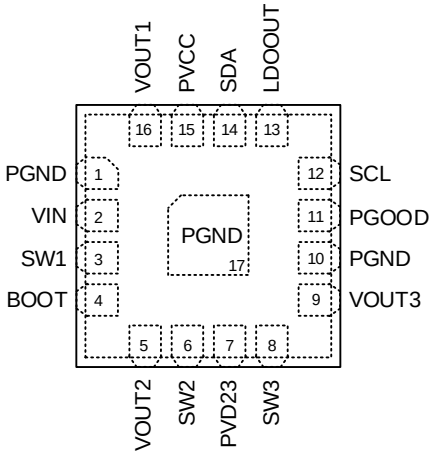
7 Pin Configuration

(TOP VIEW)



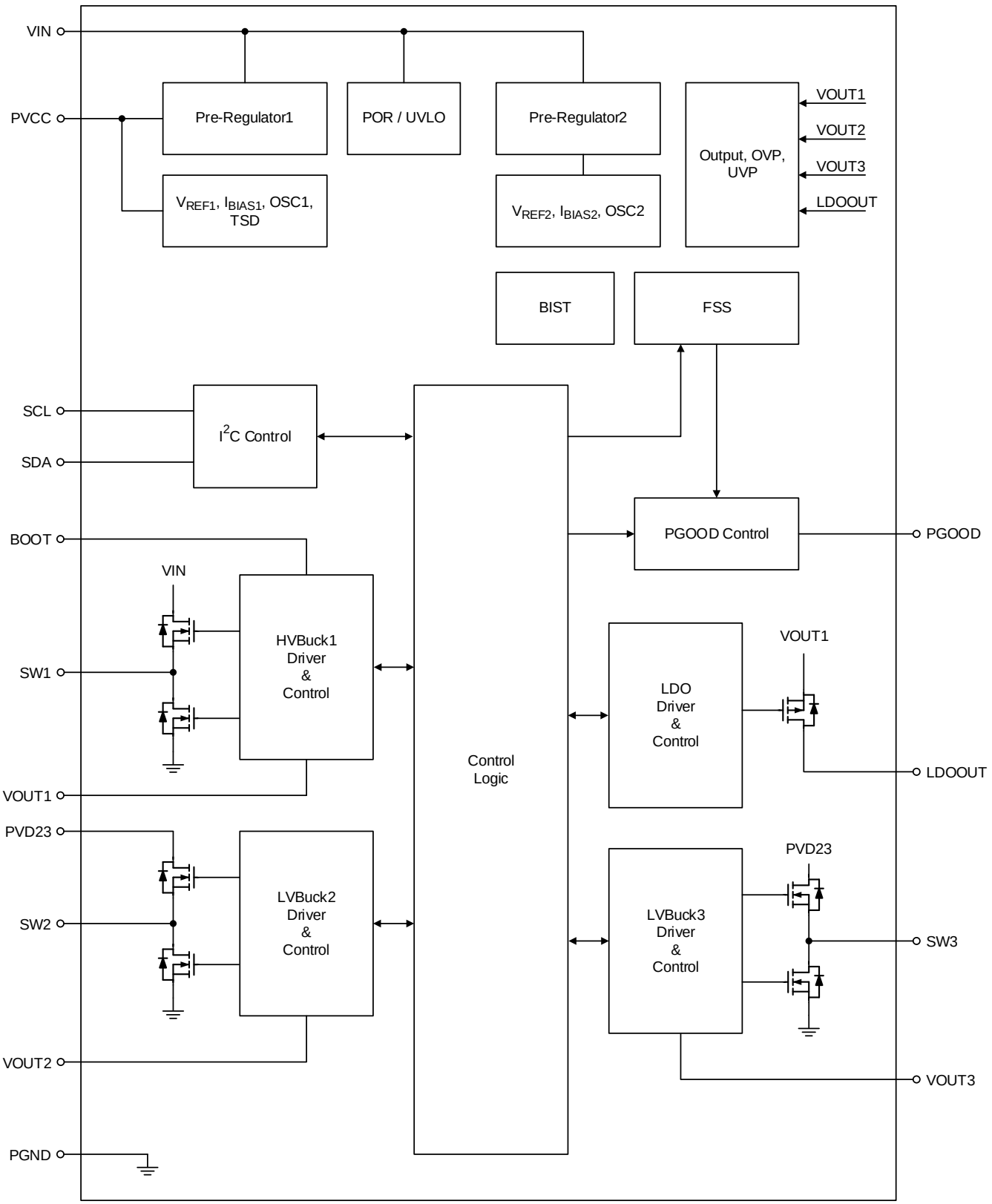
WET-UQFN-16L 3x3 (FC)

8 Functional Pin Description

Pin No.	Pin Name	Pin Function
1, 10, 17 (Exposed Pad)	PGND	IC thermal pad and power ground. It must be connected to the main ground plane for proper operation.
2	VIN	HVBuck1 and PMIC system input source power.
3	SW1	HVBuck1 switch node.
4	BOOT	HVBuck1 BOOT pin.
5	VOUT2	LVBuck2 output voltage feedback. It is recommended to directly connect the output capacitor node to this pin for better regulation.
6	SW2	LVBuck2 switch node.
7	PVD23	LVBuck2/3 input source power. Assume that PVD23 connects to the HVbuck1 output.
8	SW3	LVBuck3 switch node.
9	VOUT3	LVBuck3 output voltage feedback. It is recommended to directly connect the output capacitor node to this pin for better regulation.
11	PGOOD	Open-drain output, PMIC power status for indication. When PGOOD is in a high state, it indicates that all outputs are functioning normally.
12	SCL	I^2C interface serial clock input pin, open-drain. Connect to an external pull-up resistor is required.
13	LDOOUT	LDO output pin. It is recommended to directly connect the output capacitor node to this pin for better regulation.
14	SDA	I^2C interface serial data pin, open-drain. Connect to an external pull-up resistor is required.
15	PVCC	Internal analog power output. Connect a 1μF ceramic decouple capacitor between this pin and ground. Additional external loading to this pin is forbidden.

Pin No.	Pin Name	Pin Function
16	VOUT1	HVBuck1 output voltage feedback. It is recommended to directly connect the output capacitor node to this pin for better regulation. This pin is also the LDO input source power and transmits the power through the internal path.

9 Functional Block Diagram



10 Absolute Maximum Ratings

(Note 2)

- VIN, SW1 ---------- –0.3V to 36V
- BOOT ---------- –0.3V to 36V
- BOOT to SW1 ---------- –0.3V to 5V
- VOUT1, PVD23, VOUT2, SW2, SW3, VOUT3, LDOOUT, PVCC, PGOOD, SDA, SCL ---------- –0.3V to 6.5V
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature ---------- 150°C
- Storage Temperature Range ---------- –65°C to 150°C

Note 2. Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

11 ESD Rating

(Note 3)

- ESD Susceptibility

  HBM (Human Body Model) ---------- 2kV

Note 3. Devices are ESD sensitive. Handling precautions are recommended.

12 Recommended Operating Conditions

(Note 4)

- Supply Voltage, VIN ---------- 4V to 24V
- Supply Voltage, PVD23 ---------- 2.7V to 5V
- Ambient Temperature Range ---------- –40°C to 125°C
- Junction Temperature Range ---------- –40°C to 125°C

Note 4. The device is not guaranteed to function outside its operating conditions.

13 Thermal Information

(Note 5)

Thermal Parameter		WET-UQFN-16L 3x3	Unit
θ_{JA}	Junction-to-ambient thermal resistance (JEDEC standard)	54.87	°C/W
$\theta_{JC(Top)}$	Junction-to-case (top) thermal resistance	5.73	°C/W
$\theta_{JC(Bottom)}$	Junction-to-case (bottom) thermal resistance	12.4	°C/W
θ_{JB}	Junction-to-board thermal resistance	24	°C/W

Note 5. For more information about thermal parameter, see the Application and Definition of Thermal Resistances report, AN061.

14 Electrical Characteristics

(T_A = T_J = –40°C to 125°C, V_{IN} = 6V, V_{OUT_HV1} = 3.6V, V_{OUT_LV2} = 1.1V, V_{OUT_LV3}= 1.8V, V_{OUT_LDO} = 3.3V, unless otherwise specified.)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
System						
VIN Undervoltage Lock-out Falling	V_{UVLO_F}		3.135	3.3	3.465	V
VIN Undervoltage Lock-out Rising	V_{UVLO_R}		3.61	3.8	3.99	V
VIN Overvoltage Rising Protection	V_{OVP_VIN}		24.735	25.5	26.265	V
VIN Overvoltage Hysteresis	$V_{OVP\_HYS\_VIN}$		5	6	7	V
Pre-Regulator (Note 6)						
PVCC Voltage Range	V_{PVCC}		4.4	4.65	4.9	V
CH1_HVBuck1						
Input Voltage Range	V_{IN_HV1}	V_{IN_HV1} = VIN	4	--	24	V
Output Voltage Range	V_{OUT_HV1}	V_{IN_HV1} = 4V to 24V	2.7	--	5	V
Output Voltage Accuracy	$V_{OUT\_ACC\_HV1\_FPWM}$	V_{OUT_HV1} = 2.7V to 5V, V_{IN_HV1} = 6V, 9V, 12V, I_{OUT_HV1} = 0 to 1.5A, FPWM	–1.5	--	1.5	%
Soft-Start Time	t_{SS_HV1}	Time from V_{OUT_HV1} to rise from 10% to 90% of target value, no load	500	1000	1500	µs
Switching Frequency	f_{SW_HV1}		1.89	2.1	2.31	MHz
Spread Spectrum Range	f_{SSP}		--	12	--	%
High-Side MOSFET On-Resistance	$R_{ON\_UG\_HV1}$		--	210	--	mΩ
Low-Side MOSFET On-Resistance	$R_{ON\_LG\_HV1}$		--	120	--	mΩ
Minimum On-Time	$t_{MIN\_ON\_HV1}$		--	--	40	ns
Minimum Off-Time	$t_{MIN\_OFF\_HV1}$		--	--	50	ns
Positive Inductor Peak Current Limit	$I_{CL\_PK\_HV1}$		1.9	2.5	3.1	A
Positive Inductor Valley Current Limit	$I_{CL\_VALLEY\_HV1}$		--	1.6	--	A
Negative Inductor Peak Current Limit	$I_{CL\_N\_PK\_HV1}$	HVBuck1 in FPWM	1.3	1.8	2.3	A

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Discharge Resistor	R_{DIS_HV1}		20	50	80	Ω
HVBuck1 Output Undervoltage Falling Threshold Detection	V_{UVP_HV1}		--	80	--	%
HVBuck1 Output Undervoltage Falling Threshold Detection Accuracy	$V_{UVP\_ACC\_HV1}$		–1.3	--	1.3	%
HVBuck1 Output Overvoltage Rising Threshold Detection	V_{OVP_HV1}		--	110	--	%
HVBuck1 Output Overvoltage Rising Threshold Detection Accuracy	$V_{OVP\_ACC\_HV1}$		–1.3	--	1.3	%
CH2_LVBuck2						
Input Voltage Range	V_{IN_LV2}		2.7	--	5	V
Output Voltage Range	V_{OUT_LV2}		0.6	1.1	1.9	V
Output Voltage Accuracy	$V_{OUT\_ACC\_LV2\_FPWM}$	V_{OUT_LV2} = 0.6V to 1.9V, V_{IN_LV2} = 3.6V, I_{OUT_LV2} = 0A to 1.5A, FPWM	–1.5	--	1.5	%
Soft-Start Time	t_{SS_LV2}	Time for V_{OUT_LV2} to rise from 10% to 90% of target value, no load	600	1200	1800	μs
Switching Frequency	f_{SW_LV2}		1.89	2.1	2.31	MHz
Spread Spectrum Range	f_{SSP}		--	12	--	%
Hide-Side MOSFET On-Resistance	$R_{ON\_UG\_LV2}$		--	56	--	mΩ
Low-Side MOSFET On-Resistance	$R_{ON\_LG\_LV2}$		--	34	--	mΩ
Minimum On-Time	$t_{MIN\_ON\_LV2}$		--	--	44	ns
Positive Inductor Peak Current Limit	$I_{CL\_PK\_LV2}$		2.1	2.5	2.9	A
Positive Inductor Valley Current Limit	$I_{CL\_VALLEY\_LV2}$		--	1.8	--	A
Negative Inductor Peak Current Limit	$I_{CL\_N\_PK\_LV2}$	LVBuck2 in FPWM	0.7	1.7	2.9	A

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Discharge Resistor	R_{DIS_LV2}		6	9	14	Ω
LVBuck2 Output Undervoltage Falling Threshold Detection	V_{UVP_LV2}		--	95	--	%
LVBuck2 Output Undervoltage Falling Threshold Detection Accuracy	$V_{UVP\_ACC\_LV2}$		–1.3	--	1.3	%
LVBuck2 Output Overvoltage Rising Threshold Detection	V_{OVP_LV2}		--	105	--	%
LVBuck2 Output Overvoltage Rising Threshold Detection Accuracy	$V_{OVP\_ACC\_LV2}$		–1.3	--	1.3	%
PVD23 Overvoltage Rising Protection	V_{OVP_PVD23}		5.35	5.8	6.25	V
PVD23 Overvoltage Hysteresis	$V_{OVP\_HYS\_PVD23}$		--	580	--	mV
CH3_LVBuck3						
Input Voltage Range	V_{IN_LV3}		2.7	--	5	V
Output Voltage Range	V_{OUT_LV3}		0.6	1.8	1.9	V
Output Voltage Accuracy	$V_{OUT\_ACC\_LV3\_FPWM}$	V_{OUT_LV3} = 0.6V to 1.9V, V_{IN_LV3} = 3.6V, I_{OUT_LV3} = 0A to 1.5A, FPWM	–1.5	--	1.5	%
Soft-Start Time	t_{SS_LV3}	Time from V_{OUT_LV3} to rise from 10% to 90% of target value, no load	600	1200	1800	μs
Switching Frequency	f_{SW_LV3}		1.89	2.1	2.31	MHz
Spread-Spectrum Range	f_{SSP}		--	12	--	%
High-Side MOSFET On-Resistance	$R_{ON\_UG\_LV3}$		--	56	--	mΩ
Low-Side MOSFET On-Resistance	$R_{ON\_LG\_LV3}$		--	34	--	mΩ
Minimum On-Time	$t_{MIN\_ON\_LV3}$		--	--	44	ns
Positive Inductor Peak Current Limit	$I_{CL\_PK\_LV3}$		2.1	2.5	2.9	A

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Positive Inductor Valley Current Limit	$I_{CL\_VALLEY\_LV3}$		--	1.8	--	A
Negative Inductor Peak Current Limit	$I_{CL\_N\_PK\_LV3}$	LVBuck3 in FPWM	0.7	1.7	2.9	A
Output Discharge Resistor	R_{DIS_LV3}		6	9	14	Ω
LVBuck3 Output Undervoltage Falling Threshold Detection	V_{UVP_LV3}		--	95	--	%
LVBuck3 Output Undervoltage Falling Threshold Detection Accuracy	$V_{UVP\_ACC\_LV3}$		–1.3	--	1.3	%
LVBuck3 Output Overvoltage Rising Threshold Detection	V_{OVP_LV3}		--	105	--	%
LVBuck3 Output Overvoltage Rising Threshold Detection Accuracy	$V_{OVP\_ACC\_LV3}$		–1.3	--	1.3	%
PVD23 Overvoltage Rising Protection	V_{OVP_PVD23}		5.35	5.8	6.25	V
PVD23 Overvoltage Hysteresis	$V_{OVP\_HYS\_PVD23}$		--	580	--	mV
CH4_LDO						
Input Voltage Range	V_{IN_LDO}		2.7	--	5	V
Output Voltage Range	V_{OUT_LDO}		1.8	3.3	3.5	V
Output Voltage Accuracy	$V_{OUT\_ACC\_LDO}$	V_{OUT_LDO} = 1.8V to 3.5V, (V_{IN_LDO} - V_{OUT_LDO}) ≥ 0.3V, I_{OUT_LDO} = 0mA to 300mA	–1.5	--	1.5	%
Soft-Start Time	t_{SS_LDO}	Time for V_{OUT_LDO} to rise from 10% to 90% of target value, no load.	200	700	1100	μs
Dropout Voltage (Note 7)	$V_{DROP\_300\_LDO}$	I_{OUT_LDO} = 300mA	--	--	300	mV
	$V_{DROP\_150\_LDO}$	I_{OUT_LDO} = 150mA	--	--	150	
Maximum Output Current	$I_{OUT\_MAX\_LDO}$		300	--	--	mA
Output Current Limit	I_{CL_LDO}		345	450	555	mA

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Discharge Resistor	R_{DIS_LDO}		48	76	104	Ω
LDO Output Undervoltage Falling Threshold Detection	V_{UVP_LDO}		--	95	--	%
LDO Output Undervoltage Falling Threshold Detection Accuracy	$V_{UVP\_ACC\_LDO}$		–1.3	--	1.3	%
LDO Output Overvoltage Rising Threshold Detection	V_{OVP_LDO}		--	105	--	%
LDO Output Overvoltage Rising Threshold Detection Accuracy	$V_{OVP\_ACC\_LDO}$		–1.3	--	1.3	%
I/O Control						
PGOOD Low-Level Output Voltage	V_{OL_PGOOD}	Current into the PGOOD pin is equal to 5mA	--	--	200	mV
PGOOD Input Leakage Current	I_{LEAK_PGOOD}	1.8V is applied on the PGOOD pin	--	--	1	μA
PGOOD Delay Time	t_{PGOOD_DLY}	Time interval between the completion of the soft-start process for the last channel and the subsequent assertion of the PGOOD signal	9	10	11	ms

Note 6. PVCC is the pre-regulator output voltage only for internal circuitry. External loading on the PVCC pin is forbidden.

Note 7. Dropout voltage is the voltage difference between the input and the output at which the output voltage drops to 100mV below its nominal value.

14.1 System Characteristics

The following specifications are guaranteed by design and are not performed in production testing. (T_A = T_J = –40°C to 125°C, V_{IN} = 6V, V_{OUT_HV1} = 3.6V, V_{OUT_LV2} = 1.1V, V_{OUT_LV3} = 1.8V, V_{OUT_LDO} = 3.3V, unless otherwise specified.)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
System						
Quiescent Current of VIN	I_{Q_ON}	EN = H, $V_{UVLO\_R} \le V_{IN} \le$ 24V, V_{OUT_HV1} ties to PVD23 and PVD45, all channels are ON, no load.	--	20	--	mA
Quiescent Current of VIN	I_{Q_OFF}	EN = H, $V_{UVLO\_R} \le V_{IN} \le$ 24V, V_{OUT_HV1} ties to PVD23 and PVD45, all channels are OFF.	--	3	--	mA
Over-Temperature Protection	T_{TSD}		--	170	--	°C
Over-Temperature Protection Hysteresis	T_{TSD_HYS}		--	20	--	°C
CH1_HVBuck1						
Maximum Output Current	$I_{OUT\_MAX\_HV1}$	Depends on the input voltage and the output voltage	1.5	--	--	A
Load Transient	$V_{LOAD\_TRAN\_HV1\_FPWM}$	V_{OUT_HV1} = 3.6V, V_{IN_HV1} = 6V/9V/12V, I_{OUT_HV1} = 10mA to 0.5A to 10mA, 1μs, FPWM	–150	--	150	mV
Line Transient	$V_{LINE\_TRAN\_HV1\_FPWM}$	V_{OUT_HV1} = 3.6V, V_{IN_HV1} = 5V to 18.5V to 5V, 100μs, I_{OUT_HV1} = 0.5A, FPWM	–50	--	50	mV
Load Regulation	$V_{LOAD\_REG\_HV1}$	V_{OUT_HV1} = 3.6V, V_{IN_HV1} = 6V/9V/12V, ΔI_{OUT_BK1} = 1.5A, FPWM	--	--	0.1	%
Line Regulation	$V_{LINE\_REG\_HV1}$	V_{OUT_HV1} = 3.6V, V_{IN_HV1} = 5V to 18.5V, I_{OUT_HV1} = 1.5A	--	--	1	%
Output Ripple Voltage	$V_{RIPPLE\_HV1\_FPWM}$	Peak to peak in one switching cycle, FPWM, SSP_EN bit = 0	--	--	20	mVpp
CH2_LVBuck2						
Maximum Output Current	$I_{OUT\_MAX\_LV2}$		1.5	--	--	A
Load Transient	$V_{LOAD\_TRAN\_LV2\_FPWM}$	V_{OUT_LV2} = 1.1V, V_{IN_LV2} = 3.6V, I_{OUT_LV2} = 100mA to 0.5A to 100mA, 1μs, FPWM	–50	--	50	mV

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Line Transient	$V_{LINE\_TRAN\_LV2\_FPWM}$	V_{OUT_LV2} = 1.1V, V_{IN_LV2} = 3V to 5V to 3V, 50μs, I_{OUT_LV2} = 10mA/0.75A/1.5A, FPWM	–50	--	50	mV
Load Regulation	$V_{LOAD\_REG\_LV2}$	V_{OUT_LV2} = 1.1V, V_{IN_LV2} = 3.6V, ΔI_{OUT_BK2} = 1.5A, FPWM	--	--	0.15	%
Line Regulation	$V_{LINE\_REG\_LV2}$	V_{OUT_LV2} = 1.1V, V_{IN_LV2} = 2.7V to 5V, I_{OUT_LV2} = 1.5A	--	--	1	%
Output Ripple Voltage	$V_{RIPPLE\_LV2\_FPWM}$	Peak to peak in one switching cycle, FPWM, SSP_EN bit = 0	--	--	10	mVpp
CH3_LVBuck3						
Maximum Output Current	$I_{OUT\_MAX\_LV3}$		1.5	--	--	A
Load Transient	$V_{LOAD\_TRAN\_LV3\_FPWM}$	V_{OUT_LV3} = 1.8V, V_{IN_LV3} = 3.6V, I_{OUT_LV3} = 100mA to 0.5A to 100mA, 1μs, FPWM	–50	--	50	mV
Line Transient	$V_{LINE\_TRAN\_LV3\_FPWM}$	V_{OUT_LV3} = 1.8V, V_{IN_LV3} = 3V to 5V to 3V, 50μs, I_{OUT_LV3} = 10mA/0.75A/1.5A, FPWM	–50	--	50	mV
Load Regulation	$V_{LOAD\_REG\_LV3}$	V_{OUT_LV3} = 1.8V, V_{IN_LV3} = 3.6V, ΔI_{OUT_BK3} = 1.5A, FPWM	--	--	0.15	%
Line Regulation	$V_{LINE\_REG\_LV3}$	V_{OUT_LV3} = 1.8V, V_{IN_LV3} = 2.7V to 5V, I_{OUT_LV3} = 1.5A	--	--	1	%
Output Ripple Voltage	$V_{RIPPLE\_LV3\_FPWM}$	Peak to peak in one switching cycle, FPWM, SSP_EN bit = 0	--	--	10	mVpp
CH4_LDO						
Power Supply Rejection Ratio	PSRR	V_{OUT_LDO} = 3.3V, V_{IN_LDO} ≥ 3.6V, I_{OUT_LDO} = 100mA, f = 100kHz Disturbing signal = 100mV	--	60	--	dB
		V_{OUT_LDO} = 3.3V, V_{IN_LDO} ≥ 3.6V, I_{OUT_LDO} = 100mA, f = 100kHz to 1MHz Disturbing signal = 100mV	--	40	--	dB
Load Transient	$V_{LOAD\_TRAN\_LDO}$	V_{OUT_LDO} = 3.3V, V_{IN_LDO} = 3.6V, I_{OUT_LDO} = 10mA to 0.2A to 10mA, 1μs, C_{O_LDO} = 2.2μF	–25	--	25	mV
Line Transient	$V_{LINE\_TRAN\_LDO}$	V_{OUT_LDO} = 3.3V, V_{IN_LDO} step 600mV, 10μs, the LDO is not in dropout condition, I_{OUT_LDO} = 1mA/0.3A	–25	--	25	mV

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
I²C						
SCL, SDA High-Level Input Threshold Voltage	V_{IH_I2C}		1.2	--	--	V
SCL, SDA Low-Level Input Threshold Voltage	V_{IL_I2C}		--	--	0.4	V
SCL Clock Frequency	f_{SCL}		--	--	1000	kHz
(Repeated) Start Hold Time	$t_{HD;STA}$	Hold time (repeated) start condition. After this period, the first clock pulse is generated.	0.26	--	--	µs
SCL Clock Low Time	t_{LOW}		0.5	--	--	µs
SCL Clock High Time	t_{HIGH}		0.26	--	--	µs
(Repeated) Start Setup Time	$t_{SU;STA}$	Set-up time for a repeated START condition	0.26	--	--	µs
SDA Data Hold Time	$t_{HD;DAT}$		0	--	--	ns
SDA Set-up Time	$t_{SU;DAT}$		50	--	--	ns
STOP Condition Setup Time	$t_{SU;STO}$		0.26	--	--	µs
Bus Free Time between Stop and Start Condition	t_{BUF}		0.5	--	--	µs
Rising Time of Both SDA and SCL Signals	t_R		--	--	120	ns
Falling Time of Both SDA and SCL Signals	t_F		--	--	120	ns
SDA Output Low Sink Current	I_{OL_I2C}	SDA voltage = 0.4V	2	--	--	mA
Protection Time Deglitch						
HVBuck1 Output UVP Deglitch Time	$t_{UVP\_DEG\_HV1}$		--	50	--	µs
LVBuck2 Output UVP Deglitch Time	$t_{UVP\_DEG\_LV2}$		--	50	--	µs

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
LVBuck3 Output UVP Deglitch Time	$t_{UVP\_DEG\_LV3}$		--	50	--	μs
LDO Output UVP Deglitch Time	$t_{UVP\_DEG\_LDO}$		--	50	--	μs
HVBuck1 Output OVP Deglitch Time	$t_{OVP\_DEG\_HV1}$		--	50	--	μs
LVBuck2 Output OVP Deglitch Time	$t_{OVP\_DEG\_LV2}$		--	50	--	μs
LVBuck3 Output OVP Deglitch Time	$t_{OVP\_DEG\_LV3}$		--	50	--	μs
LDO Output OVP Deglitch Time	$t_{OVP\_DEG\_LDO}$		--	50	--	μs
PVD23 OVP Rising Deglitch Time	$t_{OVP\_R\_DEG\_PVD23}$	ΔV = 700mV	--	5	6	μs
PVD23 OVP Falling Deglitch Time	$t_{OVP\_F\_DEG\_PVD23}$	ΔV = 700mV	--	5	6	μs
HVBuck1 OCP Deglitch Time	$t_{OCP\_DEG\_HV1}$		--	1	--	ms
LVBuck2 OCP Deglitch Time	$t_{OCP\_DEG\_LV2}$		--	1	--	ms
LVBuck3 OCP Deglitch Time	$t_{OCP\_DEG\_LV3}$		--	1	--	ms
LDO OCP Deglitch Time	$t_{OCP\_DEG\_LDO}$		--	1	--	ms
Component Constraint (Note 4)						
Effective Output Inductance	L_{HV1}		1	1.5	2	μH
	L_{LV2}		0.68	1	1.2	
	L_{LV3}		0.68	1	1.2	
Effective Boot Capacitance	C_{BOOT}		0.07	0.1	0.13	μF
Effective PVCC Capacitance	C_{PVCC}		0.3	1	1.4	μF
Effective Input Capacitance	C_{IN_HV1}		1.5	4.7	10	μF
	C_{IN_PVD23}		1.5	4.7	10	
	C_{IN_VOUT1}	For LDO input	0.7	2.2	4	

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Effective Output Capacitance	C_{O_HV1}		3.3	10	14	µF
	C_{O_LV2}		4.5	10	14	
	C_{O_LV3}		4.5	10	14	
	C_{O_LDO}		0.7	2.2	33	
Output Capacitance ESR for HVBuck1, LVBuck2, LVBuck3, and LDO	C_{O_ESR}		--	10	20	mΩ

15 Typical Application Circuit

15.1 General CIS Application

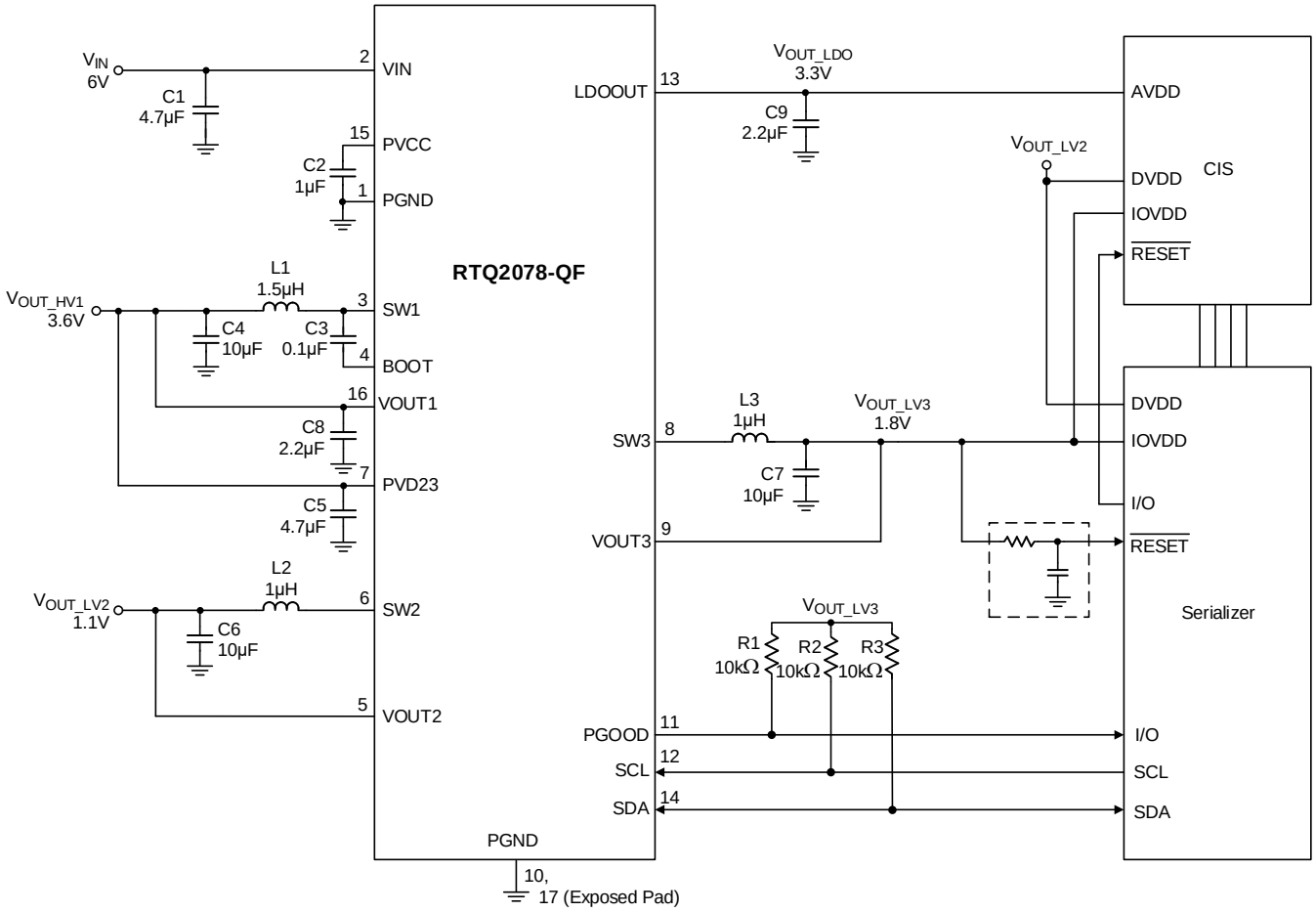
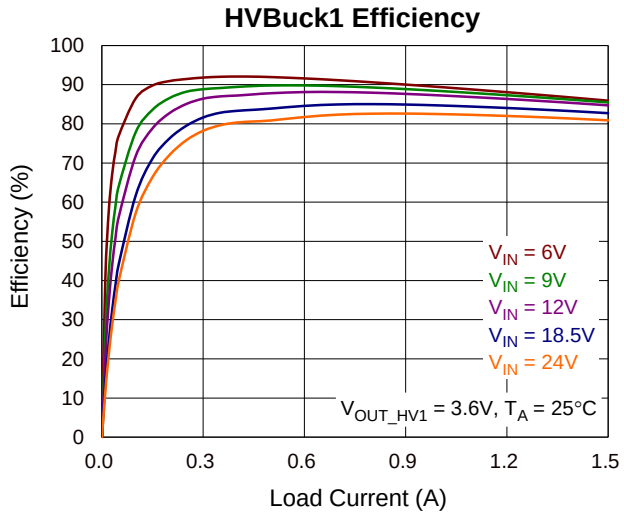
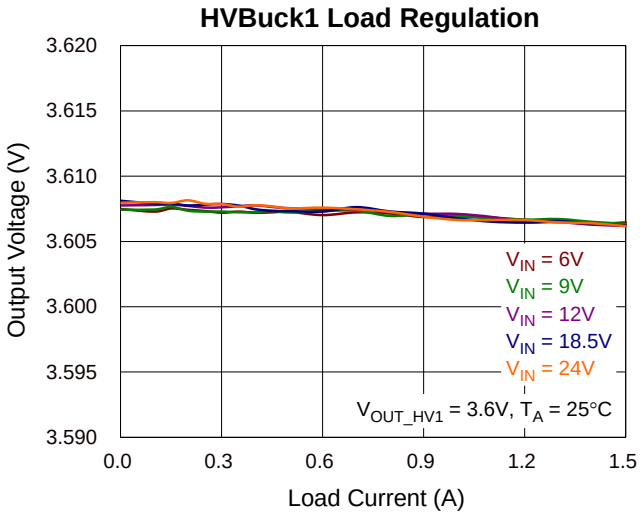


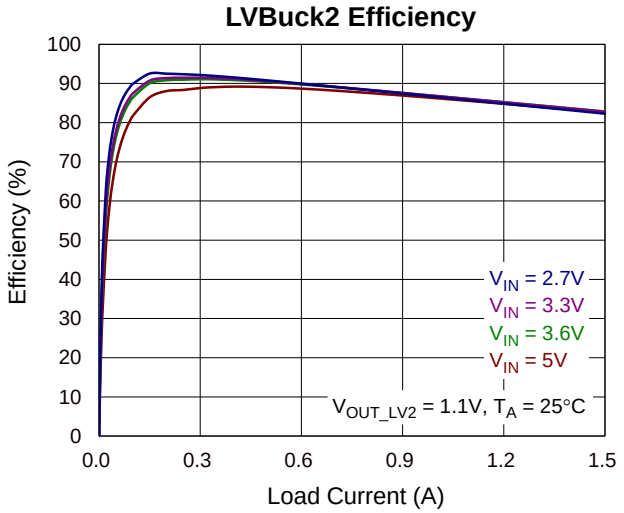
Table 1. Recommended Component List for Evaluation Board

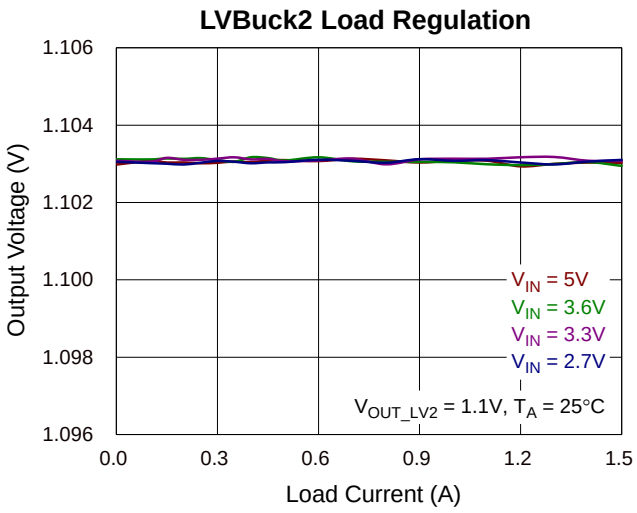
Reference	Qty	Part Number	Description	Package	Manufacturer
C1	1	GCJ31CC71H475KA01	4.7µF/50V/X7S	1206	MURATA
C2	1	GRT155C81A105KE01	1µF/10V/X6S	0402	MURATA
C3	1	GRT155R71C104KE01	0.1µF/16V/X7R	0402	MURATA
C4, C6, C7	3	GRT188C81A106ME13	10µF/10V/X6S	0603	MURATA
C5	1	GRT188C81C475KE13	4.7µF/16V/X6S	0603	MURATA
C8, C9	2	GRT155C81A225KE13	2.2µF/10V/X6S	0402	MURATA
L1	1	TFM201610ALMA1R5MTAA	1.5µH/3.1A/85mΩ	0806	TDK
L2, L3	2	TFM201610ALMA1R0MTAA	1µH/3.7A/50mΩ	0806	TDK
R1	1	MR02X1002FAL	10kΩ/1%	0201	WALSIN

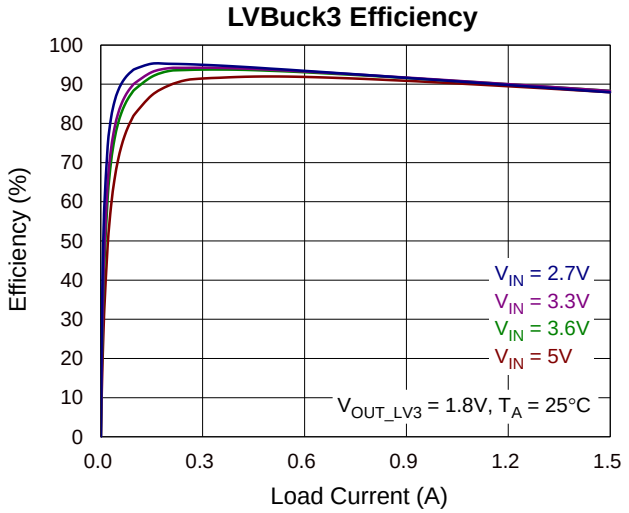
16 Typical Operating Characteristics

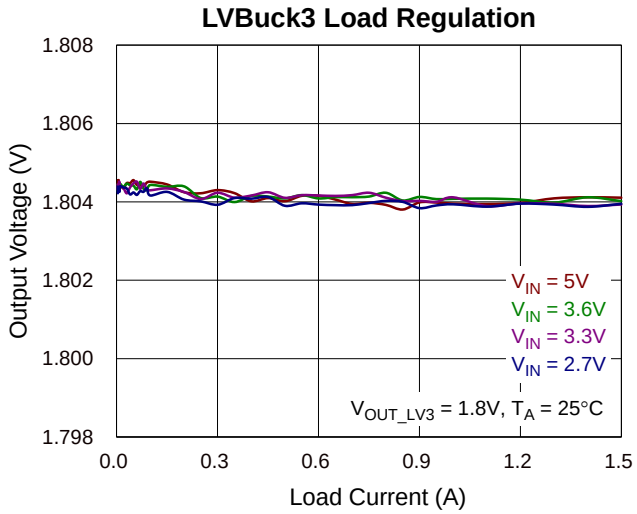




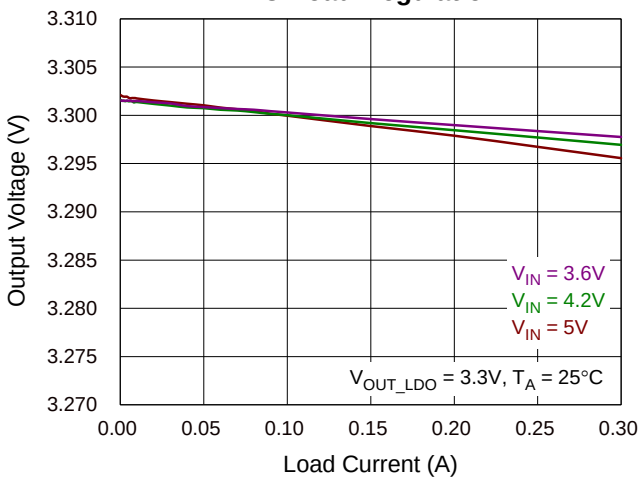




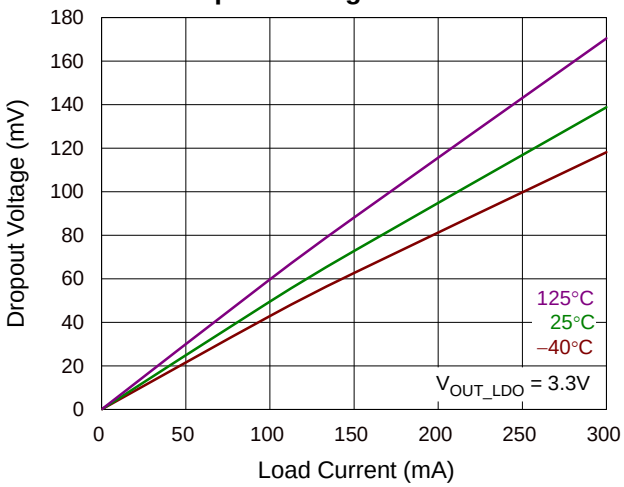




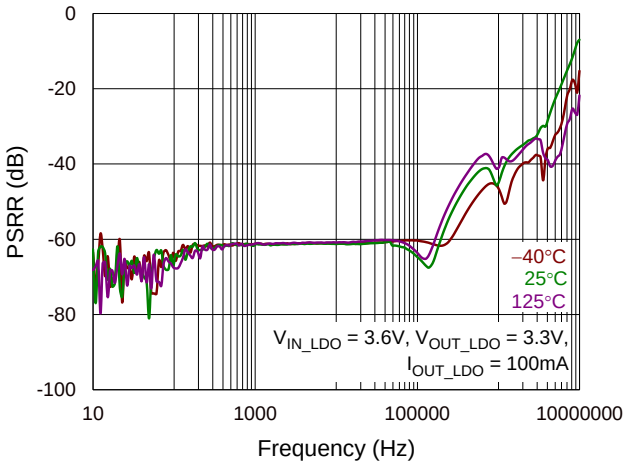
LDO Load Regulation



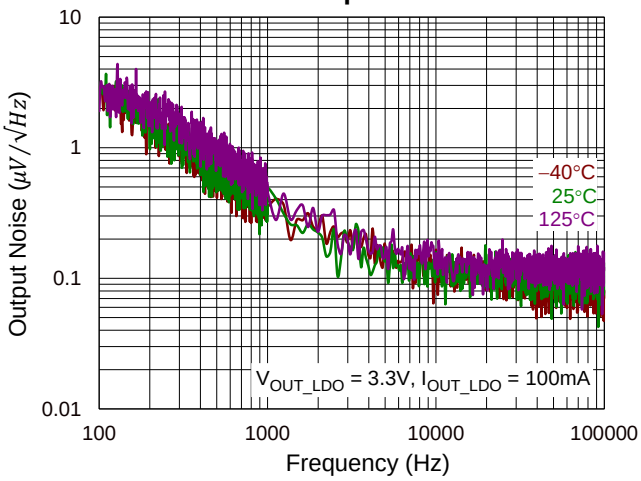
LDO Dropout Voltage vs. Load Current



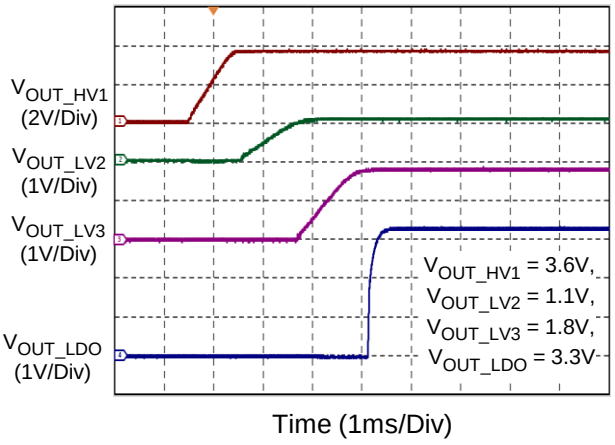
LDO PSRR



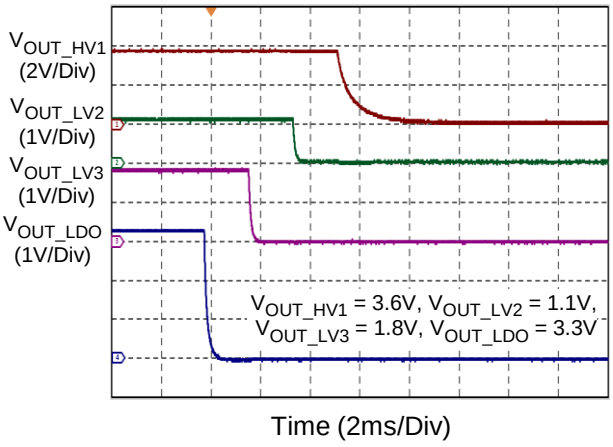
LDO Output Noise



SEQ0 Power-On



SEQ0 Power-Off



17 Operation

The RTQ2078-QF is a highly integrated power management integrated circuit (PMIC) for automotive camera system. It includes three step-down converters (HVBuck1, LVBuck2, and LVBuck3) and one generic LDO.

17.1 System Undervoltage and Overvoltage Protection

The RTQ2078-QF disables all channels if the VIN voltage falls below the Undervoltage Lock-Out level (V_{UVLO_F}) and the duration time is longer than 32μs. The device initializes in its default state after the VIN voltage recovers from V_{UVLO_R}.

When the VIN voltage reaches the overvoltage protection level ($V_{OVP\_R\_VIN}$), the step-down converters and LDO are disabled immediately. Then the IC enters the “Regulator Off” state, and PGOOD changes from "H" to "L" to indicate the IC is in a fault status. When V_{IN} falls below 19.5V and the duration time is longer than 5μs, then the RTQ2078-QF resumes operation automatically.

If the VIN voltage exceeds 20V, ensure the start-up rise slope is below 80mV/μs. This cannot be controlled by the SEQ_CTRL bit 0x00[0] for power on/off sequences to guarantee correct execution of the overvoltage protection function.

17.2 Over-Temperature Protection

The RTQ2078-QF features thermal shutdown (TSD) protection. When the junction temperature exceeds the typical threshold of 170°C, the TSD function is activated, resulting in the disabling all outputs as the device enters the “Regulator Off” state. Meanwhile, the PGOOD status also changes from "H" to "L" state to indicate the IC is in a fault status. The RTQ2078-QF will automatically resume normal operation once the junction temperature falls below the TSD threshold with a 20°C hysteresis band and VIN is below 19.5V.

17.3 Pre-Regulator

The device integrates a 4.58V linear regulator (PVCC) supplied by VIN to provide power to the internal circuitry. The PVCC is “NOT” allowed to power any other device or circuitry. A 1μF decoupling capacitor must be connected between PVCC and PGND to filter noise, and it needs to be placed as close as possible to the PVCC pin.

17.4 Peak Current Mode Control

The three step-down converters utilize peak current mode control. At the beginning of each clock cycle, the internal high-side MOSFET turns on, allowing the current to ramp up in the inductor. By comparing the inductor peak current signal with the internal compensation signal derived from the feedback voltage, the turn-on time of high-side and low-side MOSFETs in every switching cycle are determined. In other words, the inductor current is used to control the duty-cycle and output voltage regulation of the converter.

17.5 Spread Spectrum Operation

Due to the periodicity of the switching signal, energy tends to concentrate at the fundamental frequency and its N-order harmonics. This concentration of energy can result in radiation that may cause the EMI issues. To address this, the RTQ2078-QF is equipped with a spread spectrum function designed to reduce EMI and ensure compliance with automotive EMC standards (CISPR 25). The spread spectrum function employs a pseudo-random sequence to modulate the switching frequency, allowing it to vary randomly within a range of 0% to 12%. For example, with a 2.1MHz typical switching frequency, the actual frequency will randomly oscillate between 2.1MHz and 2.352MHz. As a result, the RTQ2078-QF effectively prevents the switching frequency from interfering with the 1.8MHz AM band, which is a critical requirement of CISPR 25.

17.6 Phase-Shift Operation

The RTQ2078-QF supports phase-shift operation to prevent all step-down converters from switching simultaneously, further reducing the radiation quantity of energy. The phase-shift difference in the clock between each step-down converter automatically changes based on the numbers of enabled channels. For example, when two step-down converters are in use, the initial turn-on time between two high-side MOSFETs has a 180-degree phase difference. Likewise, there is a 120-degree phase difference when three step-down converters are in use.

17.7 Channel Floating Allowable

To save PCB layout space and reduce material costs, the unused low-voltage step-down converters (CH2/CH3) can be left with floating pins, eliminating the need for inductors and output capacitors. The RTQ2078-QF automatically detects the pin status during the power-on procedure to determine whether the channel is used or not. After that, any malfunction in an unused channel will not impact the device operation.

17.8 Reboot Operation

The RTQ2078-QF features a reboot function applicable when VIN does not exceed 20V.

If the register bit 0x00[1] is set to 1, the device will disable all channels upon detecting a fault event. It will then exit the Fail-safe state and reboot, while preserve the record of the fault event. Conversely, if the register bit at 0x00[1] is set to 0, the IC remains in the Fail-safe state.

17.9 Power-Good and Error Indication

The RTQ2078-QF features an open-drain output pin named PGOOD (Power-Good) to indicate both the output voltage status of all channels and errors. Connect a pull-up resistor from the PGOOD pin to an external voltage. When the last channel in the power-on sequence reaches 90% of its target output voltage, the PGOOD signal will be pulled high to indicate a “Power-Good” status after a 10ms delay.

Table 2. Unused Channel Pin Considerations

Unused Channel	Unused Pin Number	Unused Pin Name	Pin Configuration
LVBuck2	5	VOUT2	Floating
	6	SW2	Floating
	7	PVD23	Connect to a stable voltage
LVBuck3	7	PVD23	Connect to a stable voltage
	8	SW3	Floating
	9	VOUT3	Floating
LDO	13	LDOOUT	Floating with minimum effective output capacitance
PGOOD	11	PGOOD	Floating
I^2C	12	SCL	Connect to ground
	14	SDA	Connect to ground

18 Application Information

(Note 8)

18.1 Device and Channel Enable Control

When the supply voltage V_{IN} reaches the power-on reset level 2.7V (typical), the device is enabled and ready to receive I^2C commands for configuration. When V_{IN} exceeds the UVLO rising voltage and the SEQ_CTRL register at 0x00[0] = 1, the power-on sequence gets started. The channels are sequenced power-off if the SEQ_CTRL register at 0x00[0] = 0. All channels shut down immediately without any sequence once V_{IN} falls below UVLO falling voltage.

18.2 Device Register Configuration Control

Write access to the registers or bits marked as ”CFG_LOCK (Configured Lock)” is restricted via the TM_PASS_CODE registers at 0x20 and 0x21. Before the configuration of the registers can be changed, the correct password must be written to enter Guest Mode to unlock the control registers. To exit Guest Mode and lock the control registers, thereby preventing unexpected operations, an incorrect password must be entered once changes are finalized.

18.3 Device State Machine

There are seven main states listed in the Table 3.

Table 3. Device State

State	Description	Entry	Exit
Power-Off	The device is in non-operation state.	• $V_{IN} \leq$ 2.5V (typical)	• $V_{IN} \geq$ 2.7V (typical)
Regulator Off	The device loads OTP for the default setting and passes OTP CRC checksum value comparison. All channels are still disabled and the PGOOD signal are driven at a low state.	From Power-Off • Pass OTP CRC checksum value comparison From Standby/Power-On • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) • RESET behavior (RESET bit) From Active/Alarm • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) • RESET behavior (RESET bit) • SEQ_CTRL_bit 0x00[0] = 0 From Fail-Safe • $V_{IN} \leq V_{UVLO\_F}$ • RESET behavior (RESET bit) • REBOOT_ACT 0x00[1] = 1	To Power-Off • $V_{IN} \leq$ 2.5V (typical) To BIST • $V_{IN} \geq V_{UVLO\_R}$ and no fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) and no RESET behavior (RESET bit)

State	Description	Entry	Exit
Standby	The device passes built-in self-test (BIST) and waits for an I^2C command to enable all channels.	BIST pass	<u>To Regulator Off</u> • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) <u>To Power-On</u> • SEQ_CTRL 0x00[0] = 1 AND No RESET behavior (RESET bit)
Power-On	Channel power-on procedure gets started.	<u>From Standby</u> • SEQ_CTRL 0x00[0] = 1 AND No RESET behavior (RESET bit)	<u>To Regulator Off</u> • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) <u>To Active</u> • The output voltages of all enabled channels rise to 90% of target values <u>To Fail-Safe</u> • Fault event (CH V_O UVP, CH V_O OVP) if the register 0x0F = 1Fh, 0x10 = 1Fh • Fault event (CH OCP)
Active	The output voltages of all enabled channels rise to 90% of target values. The PGOOD signal changes to high state to indicate the power status and any fault events.	<u>From Power-On</u> • All enabled channels output voltages rise to 90% of target values <u>From Alarm</u> • All fault registers (0x11, 0x13, 0x14, 0x15) event = 0	<u>To Regulator Off</u> • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) • RESET behavior (RESET bit) • SEQ_CTRL 0x00[0] = 0 <u>To Alarm</u> • Fault event (CH V_O UVP, CH V_O OVP) if register 0x0F = 00h, 0x10 = 00h • Any fault register (0x11 to 0x15, except 0x12[6]) event = 1 <u>To Fail-Safe</u> • Fault event (CH V_O UVP, CH V_O OVP) if register 0x0F = 1Fh, 0x10 = 1Fh • Fault event (CH OCP)

State	Description	Entry	Exit
Alarm	When a fault event is detected but the channel is not turned off, the PGOOD signal changes to low state to indicate power status and fault event.	From Active • Fault event (CH V_O UVP, CH V_O OVP) if register 0x0F = 00h, 0x10 = 00h • Any fault register (0x11, 0x13, 0x14, 0x15) event = 1	To Regulator Off • $V_{IN} \leq V_{UVLO\_F}$ • Fault event (V_{IN} OVP, V_{PVD23} OVP, TSD) • RESET behavior (RESET bit) • SEQ_CTRL 0x00[0] = 0 To Active • All fault registers (0x11, 0x13, 0x14, 0x15) event = 0 To Fail-Safe • Fault event (CH VO UVP, CH VO OVP) if register 0x0F = 1Fh, 0x10 = 1Fh • Fault event (CH OCP)
Fail-safe	When a fault event is detected and all channels are turned off, the PGOOD signal changes to a low state to indicate the power status and fault event.	• BIST fail • Fault event (CH V_O UVP, CH V_O OVP) if register 0x0F = 1Fh, 0x10 = 1Fh • Fault event (CH OCP)	To Regulator Off • $V_{IN} \leq V_{UVLO\_F}$ • RESET behavior (RESET bit) • REBOOT_ACT 0x00[1] = 1

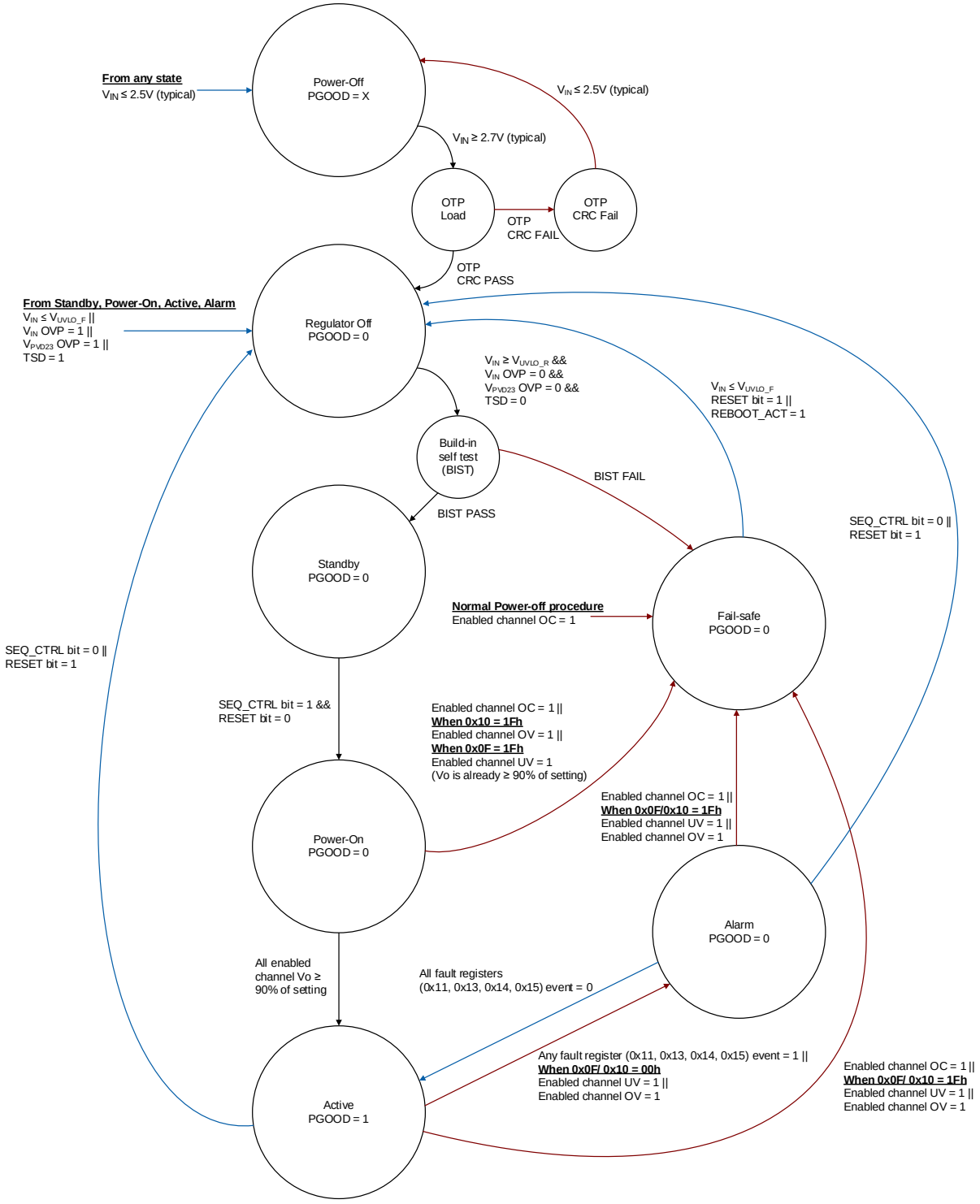


Figure 1. State Diagram

18.4 Power Sequence and Interval Time Setting

The RTQ2078-QF supports four power-on sequences, as shown in Table 4. Only when the SEQ_CTRL register at 0x00[0] = 0, the power sequence register at 0x02[2:0] and the interval time register at 0x02[6:3] between adjacent channels can be configured by I^2C. The new settings will be applied at the next power-up. The RTQ2078-QF is also equipped with the OTP36 register at 0xE4[6:0] to provide OTP (One-Time Programmable) settings of power sequence and interval time to establish factory default settings.

Table 4. Power-On Sequence

SEQ No.	Sequence			
SEQ0	CH1	CH2	CH3	CH4
SEQ1	CH1	CH4	CH3	CH2
SEQ2	CH1	CH3	CH4	CH2
SEQ3	CH1	CH2, CH3, CH4		

18.5 Power-On/Off Control

There are methods using V_{UVLO}, the SEQ_CTRL register bit at 0x00[0] or the RESET register bit at 0x0D[4] to flexibly control the RTQ2078-QF power sequence for different requirements and applications. The power-off sequence is the reverse order of the power-on sequence.

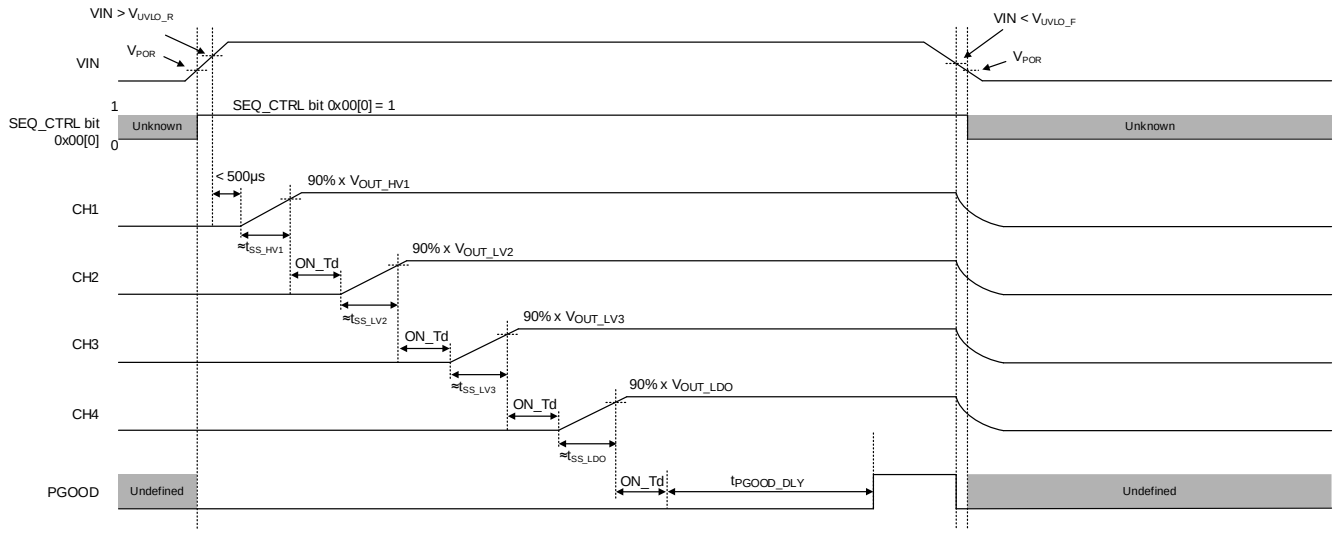


Figure 2. Example of SEQ0 Power Sequence Triggered by V_{UVLO}

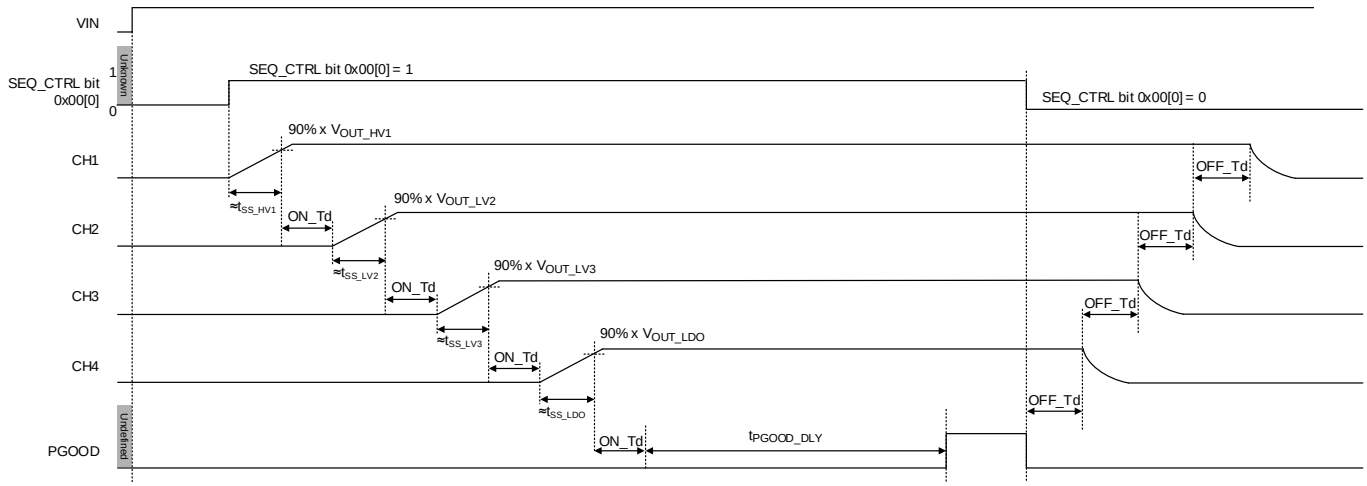


Figure 3. Example 1 of SEQ0 Power Sequence Triggered by SEQ_CTRL

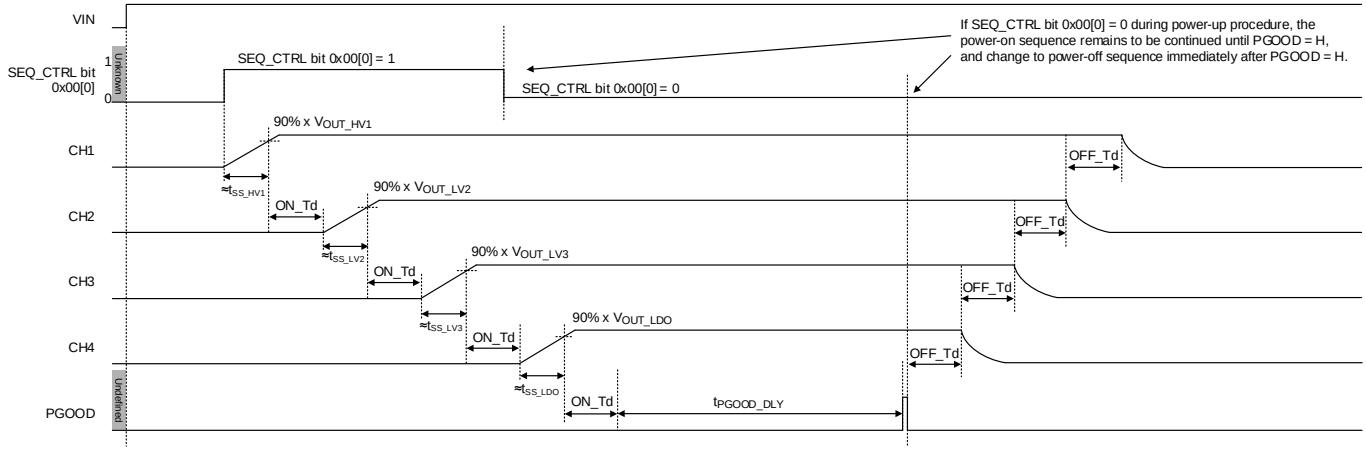


Figure 4. Example 2 of SEQ0 Power Sequence Triggered by SEQ_CTRL

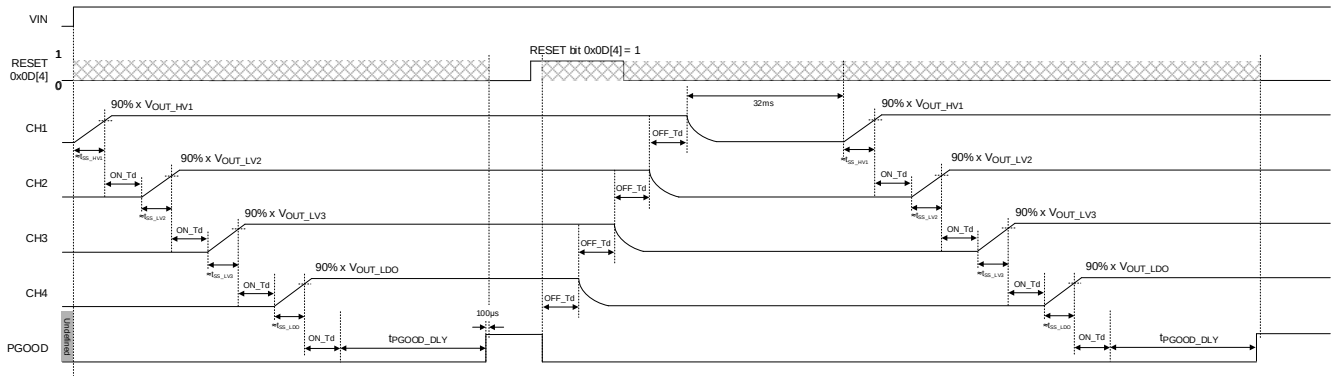


Figure 5. Example of SEQ0 Power Sequence Triggered by the RESET bit

18.6 Output Voltage Setting

The output voltage settings of all rails are controlled through I^2C by configuring the relevant registers. The RTQ2078-QF also equipped with OTP37 to OTP38 registers, ranging from 0xE5 to 0xE6, to enable one-time programmable settings for corresponding output voltages, establishing them as the factory default settings.

18.6.1 HVBuck1, LVBuck2 and LVBuck3

HVBuck1 output voltage can be set via the register at 0x03[3:0] from 2.7V to 5V, and the default voltage is 3.6V.

LVBuck2 output voltage can be set via the register at 0x04[4:0] from 0.6V to 1.9V, and the default voltage is 1.1V.

LVBuck3 output voltage can be set via the register at 0x05[4:0] from 0.6V to 1.9V, and the default voltage is 1.8V.

18.6.2 LDO

LDO output voltage can be set via the register at 0x06[4:0] from 1.8V to 3.5V. The default voltage is set at 3.3V.

18.7 Reset Function

The RTQ2078-QF is equipped with a RESET register at 0x0D[4] to reset the device when VIN does not exceed 20V. The device activates the RESET function 100μs after the PGOOD signal asserts high.

The RESET_ACT register bit at 0x0D[3] offers two configuration options:

- If register bit 0x0D[3] = 0, all registers, except for the sequence control related registers at 0x02[4:0] and fault event indication registers at 0x11, 0x13, 0x14, 0x15 are reset to their default values. The device follows the sequence settings to disable output rails. The fault event log remains stored in the corresponding registers and can be accessed by the ECU after the reset.
- If register bit 0x0D[3] = 1, all registers, except for the sequence control related register at 0x02[4:0] are reset to their default values. The device follows the sequence settings to disable output rails.

18.8 Protection Features

The RTQ2078-QF is equipped with multiple protections to safeguard the device from damage caused by abnormal operations or fault conditions, including overload, short-circuit, soldering issues, and more.

18.8.1 Channel Output Undervoltage Protection (UVP)

There are four configurable UVP thresholds via the registers at 0x08. The output UVP deglitch time is adjustable through the registers at 0x09[3:0]. When any of the bits at 0x0F[4:1] is configured to 1, the device disables all channels simultaneously and enters a Fail-safe State once an UV fault is detected on any channel. Conversely, if all bits at 0x0F[4:1] are configured to 0 when an UV fault is detected, the device does not disable any channels but enters an Alarm State instead. The registers at 0x13[4:1] indicate that an UV fault event occurred on the corresponding channel, independent of the setting at 0x0F[4:1]. The RTQ2078-QF also includes OTP35 at registers 0xE3[1], providing one-time programmable settings of the channel output UVP behavior to be set as the factory default. Based on various states, there are different methods to reset the device, as shown in Table 3.

18.8.2 Channel Output Overvoltage Protection (OVP)

There are four configurable OVP thresholds via the registers at 0x0A. The output OVP deglitch time is adjustable through the registers at 0x0B[3:0]. When any of the bits at 0x10[4:1] is configured to 1, the device disables all channels simultaneously and enters a Fail-safe State once an OV fault is detected on any channel. Conversely, if all bits at 0x10[4:1] are configured to 0 when an OV fault is detected, the device does not disable any channels but enters an Alarm State instead. The registers at 0x14[4:1] indicate that the OV fault event occurred on the

corresponding channel, independent of the setting at 0x10[4:1]. The RTQ2078-QF also includes OTP35 at registers 0xE3[2], providing one-time programmable settings of the channel output OVP behavior to be set as the factory default. Based on various states, there are different methods to reset the device, as shown in Table 3.

18.8.3 Channel Overcurrent Protection (OCP)

This section describes overcurrent protection function of HVBuck1, LVBuck2, and LVBuck3 and LDO.

18.8.3.1 HVBuck1, LVBuck2, and LVBuck3

The step-down converter includes a cycle-by-cycle peak current-limit protection for the high-side MOSFET, safeguarding against abnormal increases in inductor current, including those beyond the inductor's saturation current rating. In the event of an overcurrent, the controller immediately turns off the high-side MOSFET and turns on the low-side MOSFET to keep the inductor current within the peak current limit. After the inductor current decreases to below the valley current limit, the high-side MOSFET resumes switching. If an overcurrent fault is continuously detected for a duration longer than the deglitch time, the device disables all channels simultaneously and enters a Fail-safe State. There are different methods to reset the device, as shown in Table 3.

18.8.3.2 LDO

When the load reaches the current-limit threshold, the output current is regulated to maintain the current limit level. If an overcurrent fault persists beyond the deglitch time, the device simultaneously disables all channels and enters a Fail-safe State. There are different methods to reset the device, as shown in Table 3.

18.8.4 Channel Input Overvoltage Protection (OVP)

If the input voltage of step-down converters (LVBUCK2 and LVBUCK3), and LDO reaches the overvoltage protection threshold, the device disables all channels simultaneously and enters a Regulator Off State. The device then automatically restarts and powers back on once the input voltage falls below the overvoltage threshold minus the hysteresis value.

18.8.5 Built-In Self Test Protection

The RTQ2078-QF features a Built-in Self Test (BIST) to ensure design integrity and enhance reliability. It conducts internal circuit tests before starting the rail power-on procedure The device enters a Fail-safe State without activating the rails if the BIST fails, and the BIST_FAULT_EVT register at 0x11[6] is set to 1 to indicate a BIST failure.

18.8.6 OTP Register CRC (Cyclic Redundancy Check) Protection

When the supply voltage V_{IN} exceeds the power-on reset level of 2.7V (typical), the device loads OTP data to reset all registers to default values, and the CRC controller begins to perform a CRC to verify the integrity of the OTP registers. The CRC controller calculates the checksum value of the OTP registers and compares this value against the stored checksum value in OTP40. If a checksum error is detected, the device remains in the Power Off State and sets the OTP_CRC_EVT register at 0x11[5] to 1 as an indication.

18.8.7 Device Configuration Register CRC Protection

When the ECU changes registers to apply new settings, the CRC controller executes a CRC check to validate the integrity of the affected registers. If a checksum mismatch occurs, the device remains the current settings without reconfiguration. The CRC controller uses the standard CRC-8 polynomial, $X^8 + X^2 + X+1$, to calculate the checksum, and it evaluates the CRC across an 8-bit string.

Table 5. Protection List

Channel	Type	Threshold (Typ.)	Deglitch Time (Typ.)	Channels Behavior	Reset and Threshold (Typ.)
Base	BIST	NA	NA	All channels stay disabled	Refer to Table 3. (Fail-safe State)
	OTP CRC	NA	NA	All channels stay disabled	$V_{IN} \leq 2.5V$ or EN = L
System	UVLO	$V_{IN} \leq 3.3V$ (after IC operation)	32µs	Disable all channels	$V_{IN} \geq 3.8V$
	OVP	$V_{IN} \geq 25.5V$	5µs	Disable all channels	$V_{IN} \leq 19.5V$, Auto-recovery
	TSD	$T_J \geq 170°C$	5µs	Disable all channels	$T_J \leq 150°C$, Auto-recovery
	I^2C CRC	NA	NA	Keep all channels in operation	NA
CH1 HVBuck1	UVP	$V_{OUT\_HV1} \leq V_{OUT\_HV1}$ x 80%	50µs	If 0x0F[4] = 0, keep all channels in operation	If 0x0F[4] = 0, refer to Table 3. (Alarm State)
				If 0x0F[4] = 1, disable all channels and latch-off	If 0x0F[4] = 1, refer to Table 3. (Fail-safe State)
	OVP	$V_{OUT\_HV1} \geq V_{OUT\_HV1}$ x 110%	50µs	If 0x10[4] = 0, keep all channels in operation	If 0x10[4] = 0, refer to Table 3. (Alarm State)
				If 0x10[4] = 1, disable all channels and latch-off	If 0x10[4] = 1, refer to Table 3. (Fail-safe State)
	OCP	$I_{L1\_peak} \geq 2.5A$	1ms	Cycle-by-cycle detection If keeps for 1ms, disable all channels and latch-off	Refer to Table 3. (Fail-safe State)
CH2 LVBuck2	UVP	$V_{OUT\_LV2} \leq V_{OUT\_LV2}$ x 95%	50µs	If 0x0F[3] = 0, keep all channels in operation	If 0x0F[3] = 0, refer to Table 3. (Alarm State)
				If 0x0F[3] = 1, disable all channels and latch-off	If 0x0F[3] = 1, refer to Table 3. (Fail-safe State)
	OVP	$V_{OUT\_LV2} \geq V_{OUT\_LV2}$ x 105%	50µs	If 0x10[3] = 0, keep all channels in operation	If 0x10[3] = 0, refer to Table 3. (Alarm State)
				If 0x10[3] = 1, disable all channels and latch-off	If 0x10[3] = 1, refer to Table 3. (Fail-safe State)
	OCP	$I_{L2\_peak} \geq 2.5A$	1ms	Cycle-by-cycle detection If keeps for 1ms, disable all channels and latch-off	Refer to Table 3. (Fail-safe State)

Channel	Type	Threshold (Typ.)	Deglitch Time (Typ.)	Channels Behavior	Reset and Threshold (Typ.)
	Input OVP	$V_{IN\_LV2} \geq 5.8V$	5µs	Disable all channels	$V_{IN\_LV2} \leq 5.22V$, Auto-recovery
CH3 LVBuck3	UVP	$V_{OUT\_LV3} \leq V_{OUT\_LV3}$ x 95%	50µs	If 0x0F[2] = 0, keep all channels in operation	If 0x0F[2] = 0, refer to Table 3. (Alarm State)
				If 0x0F[2] = 1, disable all channels and latch-off	If 0x0F[2] = 1, refer to Table 3. (Fail-safe State)
	OVP	$V_{OUT\_LV3} \geq V_{OUT\_LV3}$ x 105%	50µs	If 0x10[2] = 0, keep all channels in operation	If 0x10[2] = 0, refer to Table 3. (Alarm State)
				If 0x10[2] = 1, disable all channels and latch-off	If 0x10[2] = 1, refer to Table 3. (Fail-safe State)
	OCP	$I_{L3\_peak} \geq 2.5A$	1ms	Cycle-by-cycle detection If keeps for 1ms, disable all channels and latch-off	Refer to Table 3. (Fail-safe State)
	Input OVP	$V_{IN\_LV3} \geq 5.8V$	5µs	Disable all channels	$V_{IN\_LV3} \leq 5.22V$, Auto-recovery
CH4 LDO	UVP	$V_{OUT\_LDO} \leq V_{OUT\_LDO}$ x 95%	50µs	If 0x0F[1] = 0, keep all channels in operation	If 0x0F[1] = 0, refer to Table 3. (Alarm State)
				If 0x0F[1] = 1, disable all channels and latch-off	If 0x0F[1] = 1, refer to Table 3. (Fail-safe State)
	OVP	$V_{OUT\_LDO} \geq V_{OUT\_LDO}$ x 105%	50µs	If 0x10[1] = 0, keep all channels in operation	If 0x10[1] = 0, refer to Table 3. (Alarm State)
				If 0x10[1] = 1, disable all channels and latch-off	If 0x10[1] = 1, refer to Table 3. (Fail-safe State)
	OCP	$I_{OUT\_LDO} \geq 450mA$	1ms	Disable all channels and latch-off	Refer to Table 3. (Fail-safe State)

Table 6. Fault Status and Event Log

Channel	Type	PGOOD	Event
Base	BIST	L	BIST_FAULT_EVT (0x11[6] = 1)
	OTP CRC	L	OTP_CRC_EVT (0x11[5] = 1)
System	UVLO	L	NA
	OVP	L	VIN_OV_EVT (0x11[2] = 1)
	TSD	L	TSD_EVT (0x11[3] = 1)
	I^2C CRC	L	NA
CH1 HVBuck1	UVP	L	HVBUCK1_UV_EVT (0x13[4] = 1)
	OVP	L	HVBUCK1_OV_EVT (0x14[4] = 1)
	OCP	L	HVBUCK1_OC_EVT (0x15[4] = 1)
CH2 LVBuck2	UVP	L	LVBUCK2_UV_EVT (0x13[3] = 1)
	OVP	L	LVBUCK2_OV_EVT (0x14[3] = 1)
	OCP	L	LVBUCK2_OC_EVT (0x15[3] = 1)
	Input OVP	L	PVD23_OV_EVT (0x11[1] = 1)
CH3 LVBuck3	UVP	L	LVBUCK3_UV_EVT (0x13[2] = 1)
	OVP	L	LVBUCK3_OV_EVT (0x14[2] = 1)
	OCP	L	LVBUCK3_OC_EVT (0x15[2] = 1)
	Input OVP	L	PVD23_OV_EVT (0x11[1] = 1)
CH4 LDO	UVP	L	LDO_UV_EVT (0x13[1] = 1)
	OVP	L	LDO_OV_EVT (0x14[1] = 1)
	OCP	L	LDO_OC_EVT (0x15[1] = 1)

18.9 Inductor Selection

18.9.1 HVBuck1, LVBuck2, and LVBuck3

Based on the following equations, the maximum inductor current for various load conditions can be determined. It is recommended that the inductor's saturation current rating exceed the calculated maximum current. To achieve optimal performance and efficiency, an inductor with a low Direct Current Resistance (DCR) should be chosen. The recommended nominal inductance is 1.5μH for HVBuck1 and 1μH for LVBuck2/LVBuck3.

$$\Delta I_L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_{SW} \times L}$$

$$I_{L\_peak} = I_{OUT} + \frac{1}{2} \times \Delta I_L$$

18.10 Input and Output Capacitor Selection

18.10.1 HVBuck1, LVBuck2, and LVBuck3

It is recommended to use at least a 4.7μF input capacitor with a 10μF output capacitor for step-down converters. The ripple voltage is an important parameter when choosing output capacitor. This portion consists of two parts. One is the product of the ripple current and the ESR of the output capacitor; the other is generated by the charging and discharging cycles of the output capacitor. The output ripple voltage can be calculated using the following formula:

$$\Delta V_{OUTRipple} = \Delta V_{ESR} + \Delta V_{OUT} = \Delta V_{ESR} + \frac{\Delta I_L}{8 \times C_{OUT} \times f_{SW}}$$

where $\Delta V_{ESR} = I_{Crms} \times R_{CESR}$

18.10.2 LDO

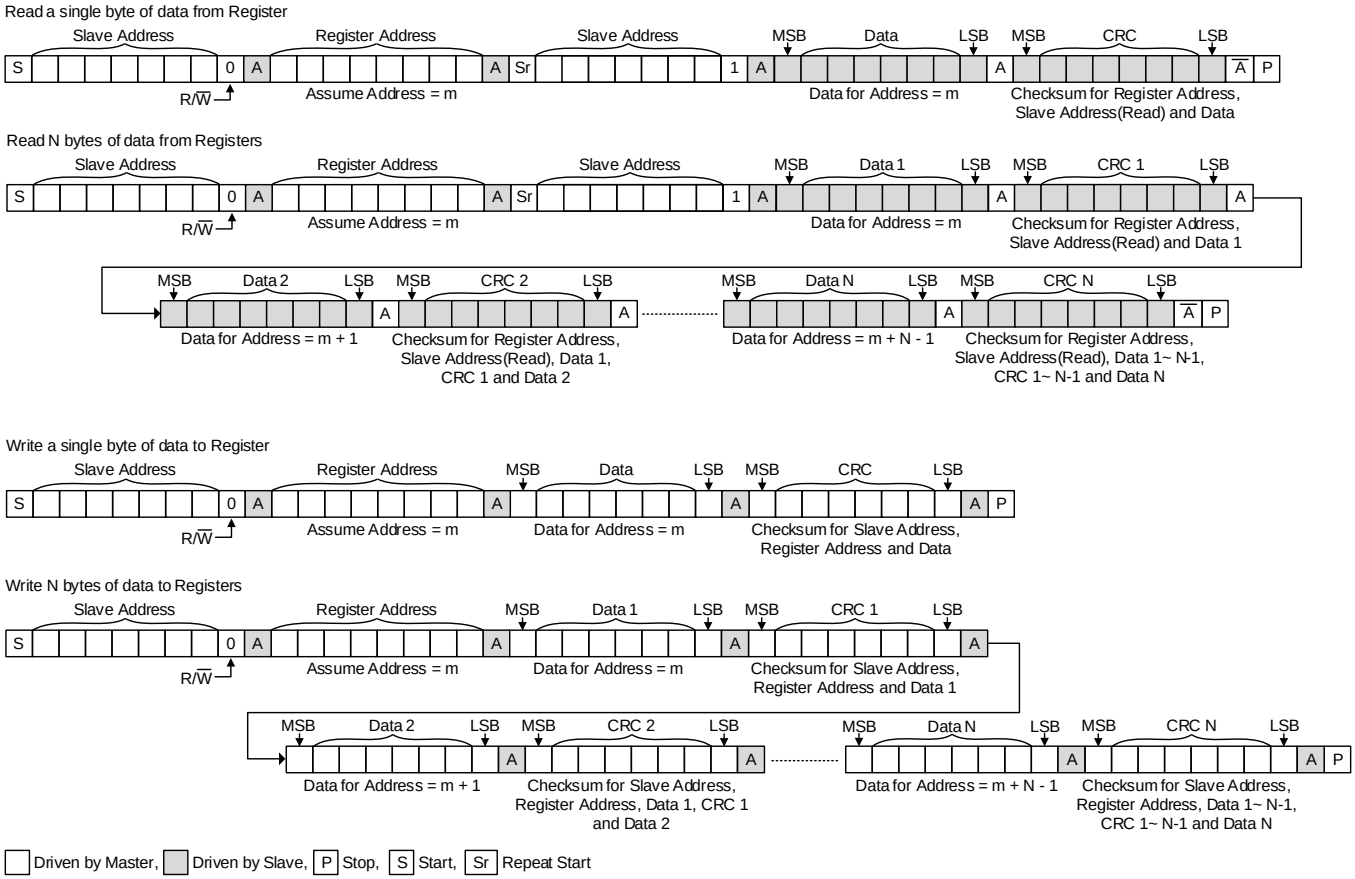
Proper selection of external capacitors is crucial for stability and performance of any LDO. A 2.2μF capacitor is generally suitable for both input and output of the LDO. Additional capacitors in parallel on the output can enhance noise suppression, it may also result in increased inrush current during the LDO's power-up sequence. This potential trade-off should be carefully evaluated.

18.11 I²C Interface

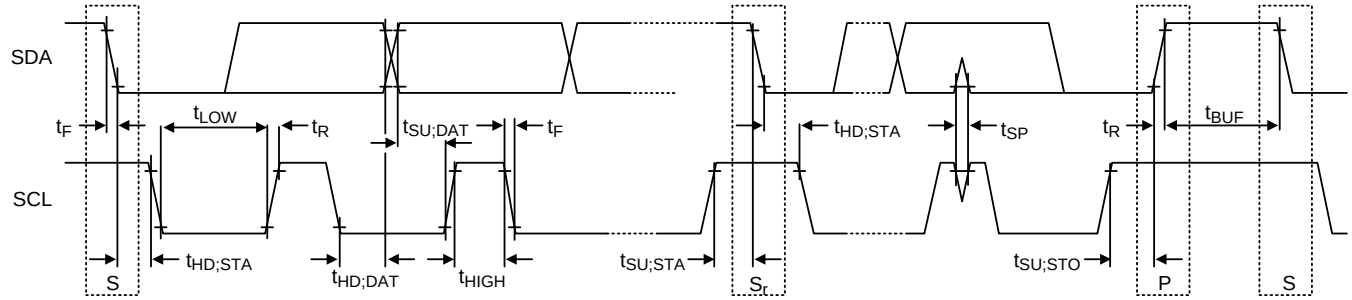
18.11.1 Slave Address

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 = LSB
1	1	1	0	1	0	1	R/$\overline{W}$

18.11.2 Read and Write Function



18.11.3 I^2C Waveform Information



18.12 Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula:

$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$

where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, θ_{JA}, is highly package dependent. For WET-UQFN-16L 3x3 (FC) package, the thermal resistance, θ_{JA}, is 54.87°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at T_A = 25°C can be calculated by the following formula:

$P_{D(MAX)}$ = (125°C – 25°C) / (54.87°C/W) = 1.82W for a WET-UQFN-16L 3x3 (FC) package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, θ_{JA}. The derating curve in Figure 6 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

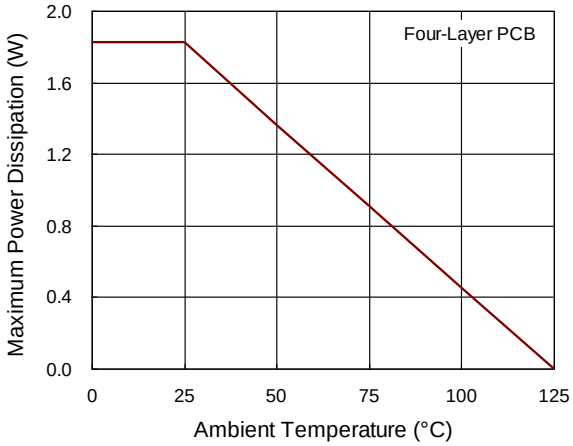


Figure 6. Derating Curve of Maximum Power Dissipation

18.13 Layout Considerations

The PCB layout is an important factor in maintaining the high performance of the RTQ2078-QF. Special attention must be given to the high current paths and fast-switching nodes in the PCB layout to ensure the robustness of the RTQ2078-QF. An improper layout can result in issues such as poor line or load regulation, shifts in ground and output voltage, stability problems, unsatisfactory EMI performance, or reduced efficiency. To optimize the performance of the RTQ2078-QF, the following PCB layout guidelines must be strictly followed:

- The trace from the switching node to the inductor should be kept as short as possible to minimize the switching loop, which will help to improve EMI characteristics.
- Place the input and output capacitors as close as possible to their respective pins to ensure effective filtering.
- Keep the main power traces as wide and short as possible.
- Connect the AGND and PGND to a solid ground plane to enhance thermal dissipation and provide noise immunity.
- Directly connect the step-sown converter’s output capacitor to the feedback network to avoid voltage deviations caused by parasitic resistance and inductance in the PCB traces.

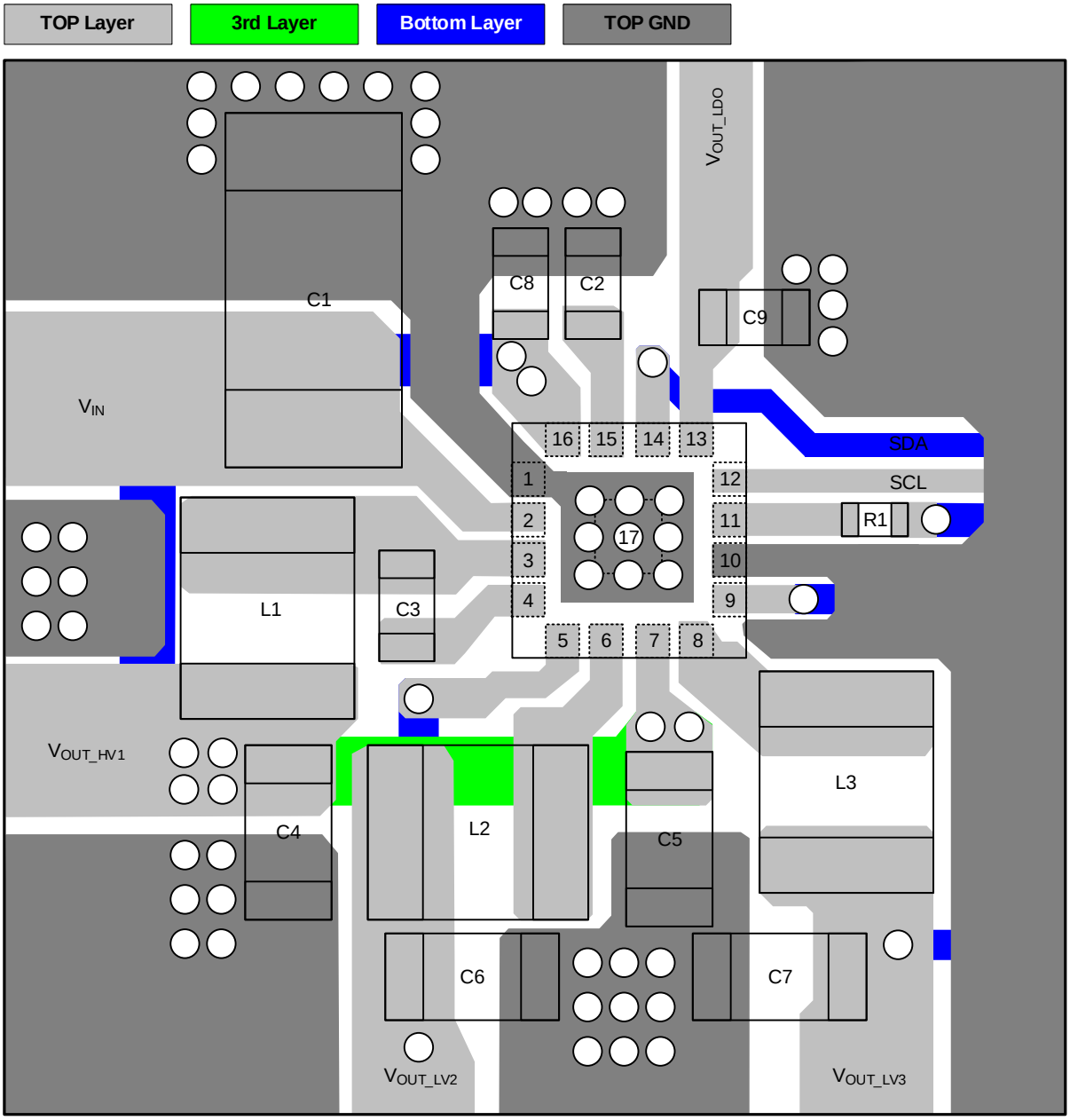


Figure 7. PCB Layout Guide

Note 8. The information provided in this section is for reference only. The customer is solely responsible for the designing, validating, and testing your product incorporating Richtek's product and ensure such product meets applicable standards and any safety, security, or other requirements.

19 Functional Register Description

R: Read Only

R/W: Read and Write

W1C: Write Clear (Write "1" then automatic clears to "0" after procedure finish)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
TOP_CFG	0x00	Meaning	Reserved	Reserved	Reserved	UVLO		UVLO_DEG	REBOOT_ACT	SEQ_CTRL
		Default	0	0	0	0	0	0	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

UVLO (CFG_LOCK)	VIN UVLO (Falling/Rising) voltage setting
	00: 3.3V/3.8V (Default) 01: 3.8V/4.5V 10: 4.3V/5.0V 11: 6.8V/7.3V
UVLO_DEG (CFG_LOCK)	UVLO falling deglitch time setting
	0: 32μs (Default) 1: 64μs
REBOOT_ACT (CFG_LOCK)	IC auto-reboot behavior selection when the PMIC enters a Fail-safe State
	0: Auto-reboot is disabled (Default) 1: Auto-reboot is enabled (Register keep)
SEQ_CTRL	Sequence ON and OFF control
	0: Sequence OFF 1: Sequence ON (Default)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_ CFG	0x01	Meaning	PGOOD_DLY		BUCK_ MODE	HVBUCK 1_DIS	LVBUCK 2_DIS	LVBUCK 3_DIS	LDO_ DIS	Reserved
		Default	0	1	1	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

PGOOD_DLY (CFG_LOCK)	Time interval between the completion of the soft-start process for the last channel and the announcement of the Power-Good status
	00: 5ms 01: 10ms (Default) 10: 15ms 11: 20ms
BUCK_MODE (CFG_LOCK)	LVBuck2 and LVBuck3 operation mode
	0: PSM 1: FPWM (Default)
HVBUCK1_DIS (CFG_LOCK)	HVBuck1 active output discharge
	0: Enable (Default) 1: Disable
LVBUCK2_DIS (CFG_LOCK)	LVBuck2 active output discharge
	0: Enable (Default) 1: Disable
LVBUCK3_DIS (CFG_LOCK)	LVBuck3 active output discharge
	0: Enable (Default) 1: Disable
LDO_DIS (CFG_LOCK)	LDO active output discharge
	0: Enable (Default) 1: Disable

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
SEQ_ ON_ CFG	0x02	Meaning	Reserved	ON_Td		OFF_Td		Reserved	POWER_ON_SEQ	
		Default	0	0	0	1	0	0	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
ON_Td (CFG_LOCK)			Delay time between power-on channel and its next channel							
			00: 0ms (Default) 01: 0.5ms 10: 1ms 11: 2ms							
OFF_Td (CFG_LOCK)			Delay time between power-off channel and its next channel							
			00: 1ms 01: 1.5ms 10: 2ms (Default) 11: 3ms							
POWER_ON_SEQ (CFG_LOCK)			Power-ON sequence settings							
			00: SEQ0 01: SEQ1 (Default) 10: SEQ2 11: SEQ3							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
HVBUCK1_OUT_CFG	0x03	Meaning	Reserved	Reserved	Reserved	Reserved	HVBUCK1_VOUT			
		Default	0	0	0	0	1	0	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_VOUT (CFG_LOCK)			HVBuck1 output voltage can be set from 2.7V to 4V (100mV/step), 4.5V, and 5.0V							
			0000: 2.7V 0001: 2.8V 0010: 2.9V 0011: 3.0V 0100: 3.1V 0101: 3.2V 0110: 3.3V 0111: 3.4V 1000: 3.5V 1001: 3.6V (Default) 1010: 3.7V 1011: 3.8V 1100: 3.9V 1101: 4.0V 1110: 4.5V 1111: 5.0V							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
LVBUCK2_OUT_CFG	0x04	Meaning	Reserved	Reserved	Reserved	LVBUCK2_VOUT				
		Default	0	0	0	0	1	0	1	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
LVBUCK2_VOUT (CFG_LOCK)			LVBuck2 output voltage can be set from 0.6V to 1.4V (50mV/step) and 1.4V to 1.9V (100mV/step)							
			00000: 0.60V 00001: 0.65V 00010: 0.70V 00011: 0.75V 00100: 0.80V 00101: 0.85V 00110: 0.90V 00111: 0.95V 01000: 1.00V 01001: 1.05V 01010: 1.10V (Default) 01011: 1.15V 01100: 1.20V 01101: 1.25V 01110: 1.30V 01111: 1.35V 10000: 1.40V 10001: 1.50V 10010: 1.60V 10011: 1.70V 10100: 1.80V 10101: 1.90V 10110: 1.90V 10111: 1.90V 11000: 1.90V 11001: 1.90V 11010: 1.90V 11011: 1.90V 11100: 1.90V 11101: 1.90V 11110: 1.90V 11111: 1.90V							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
LVBUCK3_OUT_CFG	0x05	Meaning	Reserved	Reserved	Reserved	LVBUCK3_VOUT				
		Default	0	0	0	1	0	1	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
LVBUCK3_VOUT (CFG_LOCK)			LVBuck3 output voltage can be set from 0.6V to 1.4V (50mV/step) and 1.4V to 1.9V (100mV/step)							
			00000: 0.60V 00001: 0.65V 00010: 0.70V 00011: 0.75V 00100: 0.80V 00101: 0.85V 00110: 0.90V 00111: 0.95V 01000: 1.00V 01001: 1.05V 01010: 1.10V 01011: 1.15V 01100: 1.20V 01101: 1.25V 01110: 1.30V 01111: 1.35V 10000: 1.40V 10001: 1.50V 10010: 1.60V 10011: 1.70V 10100: 1.80V (Default) 10101: 1.90V 10110: 1.90V 10111: 1.90V 11000: 1.90V 11001: 1.90V 11010: 1.90V 11011: 1.90V 11100: 1.90V 11101: 1.90V 11110: 1.90V 11111: 1.90V							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
LDO_OUT_CFG	0x06	Meaning	Reserved	Reserved	Reserved	LDO_VOUT				
		Default	0	1	1	1	0	0	1	1
		Read/Write	R/W	R	R	R/W	R/W	R/W	R/W	R/W
LDO_VOUT (CFG_LOCK)			LDO output voltage can be set from 1.8V to 1.9V (50mV/step) and 2.5V to 3.5V (50mV/step)							
			00000: 1.80V 00001: 1.85V 00010: 1.90V 00011: 2.50V 00100: 2.55V 00101: 2.60V 00110: 2.65V 00111: 2.70V 01000: 2.75V 01001: 2.80V 01010: 2.85V 01011: 2.90V 01100: 2.95V 01101: 3.00V 01110: 3.05V 01111: 3.10V 10000: 3.15V 10001: 3.20V 10010: 3.25V 10011: 3.30V (Default) 10100: 3.35V 10101: 3.40V 10110: 3.45V 10111: 3.50V					

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_ UVP1_ CFG	0x08	Meaning	HVBUCK1_UV		LVBUCK2_UV		LVBUCK3_UV		LDO_UV	
		Default	1	1	0	1	0	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_UV (CFG_LOCK)			HVBuck1 UV detection threshold with respect to the target voltage							
			00: 95% 01: 90% 10: 85% 11: 80% (Default)							
LVBUCK2_UV (CFG_LOCK)			LVBuck2 UV detection threshold with respect to the target voltage							
			00: 96.5% 01: 95% (Default) 10: 94% 11: 90%							
LVBUCK3_UV (CFG_LOCK)			LVBuck3 UV detection threshold with respect to the target voltage							
			00: 96.5% 01: 95% (Default) 10: 94% 11: 90%							
LDO_UV (CFG_LOCK)			LDO UV detection threshold with respect to the target voltage							
			00: 96.5% 01: 95% (Default) 10: 94% 11: 90%							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_ UVP2_ CFG	0x09	Meaning	Reserved	Reserved	Reserved	Reserved	HVBUCK1_UV_ DEG		LVCH_UV_DEG	
		Default	0	0	0	1	0	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_UV_DEG (CFG_LOCK)			HVBuck1 UV detection deglitch time selection							
			00: Reserved 01: 50µs (Default) 10: 75µs 11: 100µs							
LVCH_UV_DEG (CFG_LOCK)			LVBuck2, LVBuck3, and LDO UV detection deglitch time selection							
			00: Reserved 01: 50µs (Default) 10: 75µs 11: 100µs							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_ OVP1_ CFG	0x0A	Meaning	HVBUCK1_OV		LVBUCK2_OV		LVBUCK3_OV		LDO_OV	
		Default	0	1	0	1	0	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_OV (CFG_LOCK)			HVBuck1 OV detection threshold with respect to the target voltage							
			00: 105% 01: 110% (Default) 10: 115% 11: 120%							
LVBUCK2_OV (CFG_LOCK)			LVBuck2 OV detection threshold with respect to the target voltage							
			00: 103.5% 01: 105% (Default) 10: 106% 11: 110%							
LVBUCK3_OV (CFG_LOCK)			LVBuck3 OV detection threshold with respect to the target voltage							
			00: 103.5% 01: 105% (Default) 10: 106% 11: 110%							
LDO_OV (CFG_LOCK)			LDO OV detection threshold with respect to the target voltage							
			00: 103.5% 01: 105% (Default) 10: 106% 11: 110%							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_ OVP2_ CFG	0x0B	Meaning	Reserved	Reserved	Reserved	Reserved	HVBUCK1_OV_ DEG		LVCH_OV_DEG	
		Default	0	0	0	1	0	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_OV_DEG (CFG_LOCK)			HVBuck1 OV detection deglitch time selection							
			00: Reserved 01: 50µs (Default) 10: 75µs 11: 100µs							
LVCH_OV_DEG (CFG_LOCK)			LVBuck2, LVBuck3, and LDO OV detection deglitch time selection							
			00: Reserved 01: 50µs (Default) 10: 75µs 11: 100µs							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
FUNC1_CFG	0x0D	Meaning	Reserved	Reserved	Reserved	RESET	RESET_ACT	FAULT_MASK	PHASE_EN	SSP_EN
		Default	0	0	0	0	0	0	1	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

RESET	SW reset and reset behavior follows 0x0D[3], RESET_ACT
	0: None (Default) 1: SW Reset
RESET_ACT (CFG_LOCK)	RESET triggered registers behavior selection
	0: Reset all registers to default value , with the exception of the fault event registers (default) 1: Reset all registers to default value
FAULT_MASK (CFG_LOCK)	All faults event mask
	0: Unmask (Default) 1: Mask
PHASE_EN (CFG_LOCK)	Bucks' switching phase shift function
	0: Disable 1: Enable (Default)
SSP_EN (CFG_LOCK)	Bucks' switching frequency spread spectrum function
	0: Disable 1: Enable (Default)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
PROTEC1_CFG	0x0F	Meaning	Reserved	Reserved	Reserved	HVBUCK1_UV_SD	LVBUCK2_UV_SD	LVBUCK3_UV_SD	LDO_UV_SD	Reserved
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

HVBUCK1_UV_SD (CFG_LOCK)	HVBuck1 undervoltage protection behavior selection
	0: Only inform ECU of fault events (Default) 1: Channel latch-off and inform ECU of fault events
LVBUCK2_UV_SD (CFG_LOCK)	LVBuck2 undervoltage protection behavior selection
	0: Only inform ECU of fault events (Default) 1: Channel latch-off and inform ECU of fault events
LVBUCK3_UV_SD (CFG_LOCK)	LVBuck3 undervoltage protection behavior selection
	0: Only inform ECU of fault events (Default) 1: Channel latch-off and inform ECU of fault events
LDO_UV_SD (CFG_LOCK)	LDO undervoltage protection behavior selection
	0: Only inform ECU of fault events (Default) 1: Channel latch-off and inform ECU of fault events

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
PROTEC2_CFG	0x10	Meaning	Reserved	Reserved	Reserved	HVBUCK1_OV_SD	LVBUCK2_OV_SD	LVBUCK3_OV_SD	LDO_OV_SD	Reserved
		Default	0	0	0	1	1	1	1	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

HVBUCK1_OV_SD (CFG_LOCK)	HVBuck1 overvoltage protection behavior selection
	0: Only inform ECU of fault events 1: Channel latch-off and inform ECU of fault events (Default)
LVBUCK2_OV_SD (CFG_LOCK)	LVBuck2 overvoltage protection behavior selection
	0: Only inform ECU of fault events 1: Channel latch-off and inform ECU of fault events (Default)
LVBUCK3_OV_SD (CFG_LOCK)	LVBuck3 overvoltage protection behavior selection
	0: Only inform ECU of fault events 1: Channel latch-off and inform ECU of fault events (Default)
LDO_OV_SD (CFG_LOCK)	LDO overvoltage protection behavior selection
	0: Only inform ECU of fault events 1: Channel latch-off and inform ECU of fault events (Default)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
BASE1_EVT	0x11	Meaning	Reserved	BIST_FAULT_EVT	OTP_CRC_EVT	Reserved	TSD_EVT	VIN_OV_EVT	PVD23_OV_EVT	Reserved
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	W1C	W1C	W1C	W1C	W1C	W1C	W1C

BIST_FAULT_EVT	BIST fault acknowledgement
	0: No fault are detected, or faults are masked (Default) 1: Fault is detected
OTP_CRC_EVT	Internal OTP CRC checking fault acknowledgement
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
TSD_EVT	Thermal shutdown event acknowledgement
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
VIN_OV_EVT	VIN overvoltage threshold event acknowledgement
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
PVD23_OV_EVT	PVD23 overvoltage threshold event acknowledgement
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_UV_EVT	0x13	Meaning	Reserved	Reserved	Reserved	HVBUCK1_UV_EVT	LVBUCK2_UV_EVT	LVBUCK3_UV_EVT	LDO_UV_EVT	Reserved
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	W1C	W1C	W1C	W1C	W1C
HVBUCK1_UV_EVT			HVBuck1 undervoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault is detected							
LVBUCK2_UV_EVT			LVBuck2 undervoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault ever is detected							
LVBUCK3_UV_EVT			LVBuck3 undervoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault ever is detected							
LDO_UV_EVT			LDO undervoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault ever is detected							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_OV_EVT	0x14	Meaning	Reserved	Reserved	Reserved	HVBUCK1_OV_EVT	LVBUCK2_OV_EVT	LVBUCK3_OV_EVT	LDO_OV_EVT	Reserved
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	W1C	W1C	W1C	W1C	W1C
HVBUCK1_OV_EVT			HVBuck1 overvoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault is detected							
LVBUCK2_OV_EVT			LVBuck2 overvoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault is detected							
LVBUCK3_OV_EVT			LVBuck3 overvoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault is detected							
LDO_OV_EVT			LDO overvoltage fault event							
			0: No faults are detected, or faults are masked (Default) 1: Fault is detected							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CH_OC_EVT	0x15	Meaning	Reserved	Reserved	Reserved	HVBUCK1_OC_EVT	LVBUCK2_OC_EVT	LVBUCK3_OC_EVT	LDO_OC_EVT	Reserved
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	W1C	W1C	W1C	W1C	W1C

HVBUCK1_OC_EVT	HVBuck1 overcurrent fault event
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
LVBUCK2_OC_EVT	LVBuck2 overcurrent fault event
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
LVBUCK3_OC_EVT	LVBuck3 overcurrent fault event
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected
LDO_OC_EVT	LDO overcurrent fault event
	0: No faults are detected, or faults are masked (Default) 1: Fault is detected

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
DEV_STAT	0x16	Meaning	Reserved	Reserved	Reserved	Reserved	Reserved	DEV_STATE		
		Default	0	0	0	0	0	0	0	0
		Read/Write	R	R	R	R	R	R	R	R

DEV_STATE	Indicates the PMIC present state
	000: Regulator OFF State or BIST State (Default) 001: Standby State 010: Power-On State 011: Active State 100: Alarm State 101: Fail-Safe State 110: Reserved 111: Reserved

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP_CRC_1	0x18	Meaning	CRC_START	CRC_FAIL	CRC_DONE	CRC_EN	Reserved	Reserved	Reserved	Reserved
		Default	0	0	0	1	0	0	0	0
		Read/Write	R/W	R	R	R/W	R/W	R/W	R/W	R/W

CRC_START	For OTP CRC value calculation, the calculated value is displayed at 0x19
	0: None (Default) 1: Enable
CRC_FAIL	OTP CRC comparison result
	0: None or CRC pass (Default) 1: CRC fail
CRC_DONE	OTP CRC calculation process
	0: None or calculating (Default) 1: Calculation completed
CRC_EN	OTP CRC function
	0: Disable 1: Enable (Default)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP_CRC_2	0x19	Meaning	OTP_CRC_RESULT							
		Default	0	0	0	0	0	0	0	0
		Read/Write	R	R	R	R	R	R	R	R
OTP_CRC_RESULT		OTP CRC calculation value								

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
TM_PASS_CODE1	0x20	Meaning	TM_PASS_CODE1							
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
TM_PASS_CODE1		To enter Guest Mode, set 0x20 = 8'h69 and 0x21 = 8'h96 sequentially To leave Guest Mode, set 0x20 ≠ 8'h69 or 0x21 ≠ 8'h96								

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
TM_PASS_CODE2	0x21	Meaning	TM_PASS_CODE2							
		Default	0	0	0	0	0	0	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
TM_PASS_CODE2		To enter Guest Mode, set 0x20 = 8'h69 and 0x21 = 8'h96 sequentially To leave Guest Mode, set 0x20 ≠ 8'h69 or 0x21 ≠ 8'h96								

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP34	0XE2	Meaning	UV_LVCH		OV_LVCH		UV_DEG_LVCH		OV_DEG_LVCH	
		Default	0	1	0	1	0	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
UV_LVCH (Not in RTK P/N Options)			LVBuck2, LVBuck3, and LDO UV detection threshold with respect to target voltage							
			00: 96.5% 01: 95% (Default) 10: 94% 11: 90%							
OV_LVCH (Not in RTK P/N Options)			LVBuck2, LVBuck3, and LDO OV detection threshold with respect to target voltage							
			00: 103.5% 01: 105% (Default) 10: 106% 11: 110%							
UV_DEG_LVCH (Not in RTK P/N Options)			LVBuck2, LVBuck3, and LDO UV detection deglitch time selection							
			00: Reserved 01: 50μs (Default) 10: 75μs 11: 100μs							
OV_DEG_LVCH (Not in RTK P/N Options)			LVBuck2, LVBuck3, and LDO OV detection deglitch time selection							
			00: Reserved 01: 50μs (Default) 10: 75μs 11: 100μs							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP35	0XE3	Meaning	OV_HVCH		UVLO		UVLO_DEG	CH_OV_SD	CH_UV_SD	REBOOT
		Default	0	1	0	0	0	1	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

OV_HVCH (Not in RTK P/N Options)	HVBuck1 OV detection threshold with respect to the target voltage
	00: 105% 01: 110% (Default) 10: 115% 11: 120%
UVLO	VIN UVLO (Falling/Rising) voltage setting
	00: 3.3V/3.8V (Default) 01: 3.8V/4.5V 10: 4.3V/5.0V 11: 6.8V/7.3V
UVLO_DEG (Not in RTK P/N Options)	UVLO falling deglitch time setting
	0: 32μs (Default) 1: 64μs
CH_OV_SD (Not in RTK P/N Options)	HVBuck1, LVBuck2, LVBuck3, and LDO overvoltage protection behavior selection
	0: Only inform ECU of fault events 1: Channel latch-off and inform ECU of fault events (Default)
CH_UV_SD	HVBuck1, LVBuck2, LVBuck3, and LDO undervoltage protection behavior selection
	0: Only inform ECU of fault events (Default) 1: Channel latch-off and inform ECU of fault events
REBOOT (Not in RTK P/N Options)	IC auto-reboot behavior selection when the PMIC enters a Fail-safe State
	0: Auto-reboot is disabled (Default) 1: Auto-reboot is enabled (Register keep)

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP36	0XE4	Meaning	SEQ_CTRL	ON_Td		OFF_Td		Reserved	POWER_ON_SEQ	
		Default	1	0	0	1	0	0	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

SEQ_CTRL (Not in RTK P/N Options)	Sequence ON and OFF control
	0: Sequence OFF 1: Sequence ON (Default)
ON_Td	Delay time between power-on channel and its next channel
	00: 0ms (Default) 01: 0.5ms 10: 1ms 11: 2ms
OFF_Td	Delay time between power-off channel and its next channel
	00: 1ms 01: 1.5ms 10: 2ms (Default) 11: 3ms
POWER_ON_SEQ	Power-ON sequence settings
	00: SEQ0 01: SEQ1 (Default) 10: SEQ2 11: SEQ3

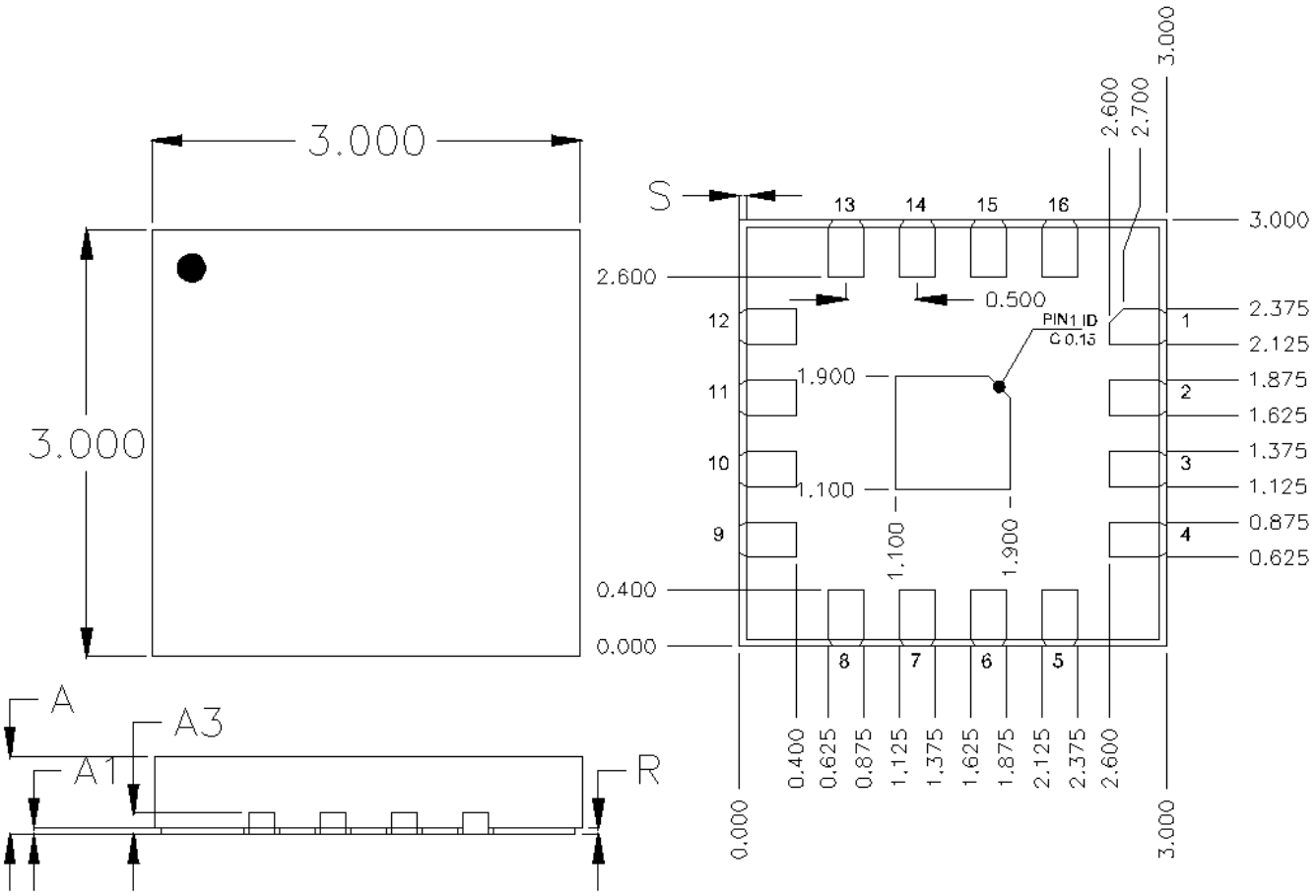
Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP37	0XE5	Meaning	HVBUCK1_VOUT				LVBUCK2_VOUT			
		Default	1	0	0	1	0	1	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
HVBUCK1_VOUT			HVBuck1 output voltage can be set from 2.7V to 4V (100mV/step), 4.5V, and 5.0V							
			0000: 2.7V 0001: 2.8V 0010: 2.9V 0011: 3.0V 0100: 3.1V 0101: 3.2V 0110: 3.3V 0111: 3.4V 1000: 3.5V 1001: 3.6V (Default) 1010: 3.7V 1011: 3.8V 1100: 3.9V 1101: 4.0V 1110: 4.5V 1111: 5.0V							
LVBUCK2_VOUT			LVBuck2 output voltage can be set from 0.9V to 1.4V (50mV/step) and 1.4V to 1.9V (100mV/step)							
			0000: 0.90V 0001: 0.95V 0010: 1.00V 0011: 1.05V 0100: 1.10V (Default) 0101: 1.15V 0110: 1.20V 0111: 1.25V 1000: 1.30V 1001: 1.35V 1010: 1.40V 1011: 1.50V 1100: 1.60V 1101: 1.70V 1110: 1.80V 1111: 1.90V							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP38	0XE6	Meaning	LVBUCK3_VOUT				LDO_VOUT			
		Default	1	1	1	0	1	1	0	1
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
LVBUCK3_VOUT			LVBuck3 output voltage can be set from 0.9V to 1.4V (50mV/step) and 1.4V to 1.9V (100mV/step)							
			0000: 0.90V 0001: 0.95V 0010: 1.00V 0011: 1.05V 0100: 1.10V 0101: 1.15V 0110: 1.20V 0111: 1.25V 1000: 1.30V 1001: 1.35V 1010: 1.40V 1011: 1.50V 1100: 1.60V 1101: 1.70V 1110: 1.80V (Default) 1111: 1.90V							
LDO_VOUT			LDO output voltage can be set from 1.8V and 2.7V to 3.4V (50mV/step)							
			0000: 1.80V 0001: 2.70V 0010: 2.75V 0011: 2.80V 0100: 2.85V 0101: 2.90V 0110: 2.95V 0111: 3.00V 1000: 3.05V 1001: 3.10V 1010: 3.15V 1011: 3.20V 1100: 3.25V 1101: 3.30V (Default) 1110: 3.35V 1111: 3.40V							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP39	0XE7	Meaning	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	ADR
		Default	0	0	1	1	0	1	0	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
ADR (Not in RTK P/N Options)			PMIC slave address							
			0: 75h (7bit) (Default) 1: 76h (7bit)							

Address Name	Register Address	Description	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OTP40	0XE8	Meaning	CRC_B7	CRC_B6	CRC_B5	CRC_B4	CRC_B3	CRC_B2	CRC_B1	CRC_B0
		Default	0	1	0	0	0	1	1	0
		Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
CRC_CODE			After modifying the settings of OTP34 to OTP40, write the register 0x18[7] = 1. This action triggers the PMIC to automatically calculate a new CRC which is shown in the register 0x19. Enter the new CRC value into OTP40 to complete the PMIC BIST process successfully.							

20 Outline Dimension

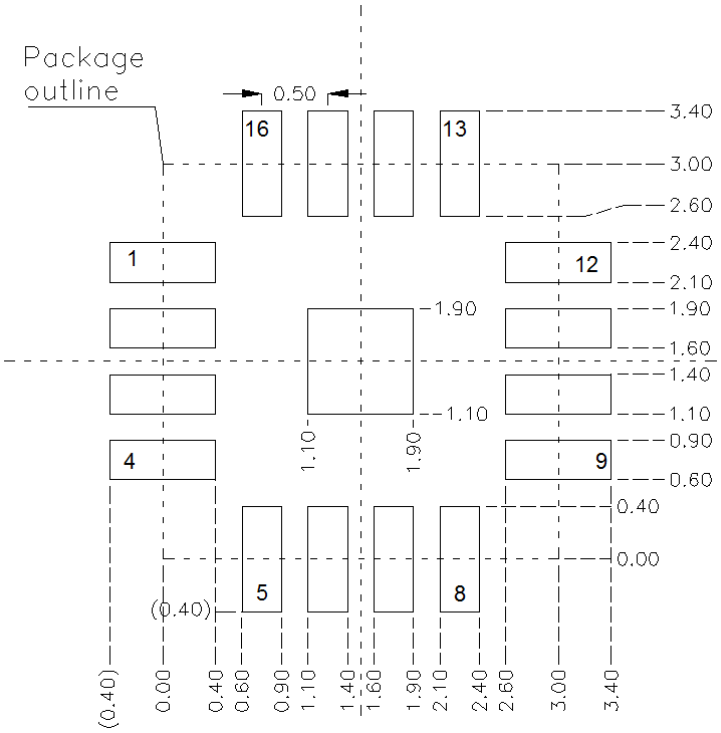


Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.500	0.600	0.020	0.024
A1	0.000	0.050	0.000	0.002
A3	0.100	0.200	0.004	0.008
R	0.050	0.150	0.002	0.006
S	0.001	0.090	0.000	0.004

Tolerance
±0.050

WET U-Type 16L QFN 3x3 Package (FC)

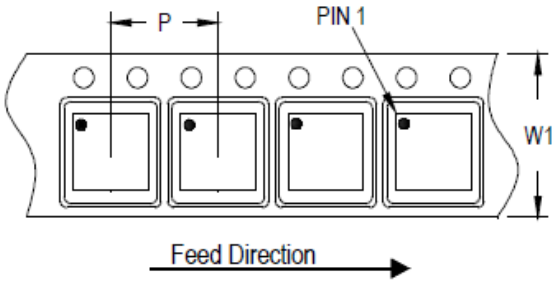
21 Footprint Information

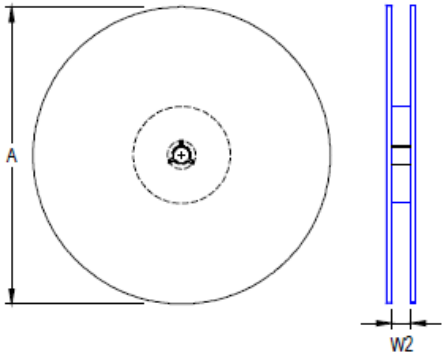


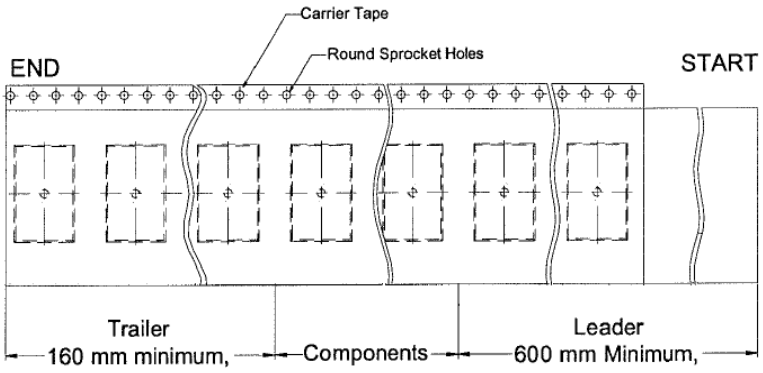
Package	Number of Pin	Tolerance
WET-UQFN3x3-16(FC)	16	±0.05 mm

22 Packing Information

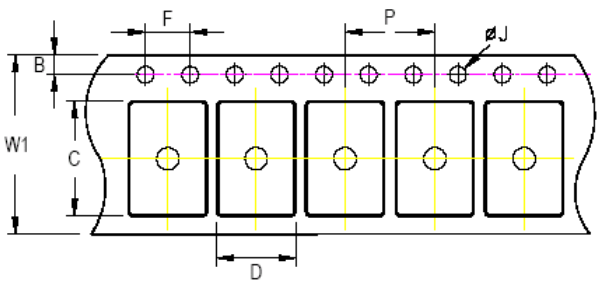
22.1 Tape and Reel Data







Package Type	Tape Size (W1) (mm)	Pocket Pitch (P) (mm)	Reel Size (A)		Units per Reel	Trailer (mm)	Leader (mm)	Reel Width (W2) Min./Max. (mm)
			(mm)	(in)				
QFN/DFN 3x3	8	4	180	7	3,000	160	600	8.4/9.9



C, D, and K are determined by component size. The clearance between the components and the cavity is as follows:

- For 8mm carrier tape: 0.5mm max.

Tape Size	W1	P		B		F		ØJ		H
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Max.
8mm	8.3mm	3.9mm	4.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	0.6mm

22.2 Tape and Reel Packing

Step	Photo/Description	Step	Photo/Description
1	 Reel 7”	4	 3 reels per inner box **Box A**
2	 HIC & Desiccant (1 Unit) inside	5	 12 inner boxes per outer box
3	 Caution label is on backside of Al bag	6	 Outer box **Carton A**

Container / Package	Reel		Box			Carton		
	Size	Units	Item	Reels	Units	Item	Boxes	Unit
QFN & DFN 3x3	7”	3,000	Box A	3	9,000	Carton A	12	108,000
			Box E	1	3,000	For Combined or Partial Reel.		

22.3 Packing Material Anti-ESD Property

Surface Resistance	Aluminum Bag	Reel	Cover tape	Carrier tape	Tube	Protection Band
Ω/cm^2	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**

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23 Datasheet Revision History

Version	Date	Description	Item
00	2024/5/24	Final	Applications on P1