RICHTEK®

RT6575E

Dual-Channel Synchronous DC-DC Step-Down Controller with 5V/3.3V LDOs

1 General Description

The RT6575E is a dual-channel step-down controller generating supply voltages for battery-powered systems. It includes two Pulse-Width Modulation (PWM) controllers adjustable from 2V to 5.5V, and two fixed 5V/3.3V linear regulators. Each linear regulator provides up to 100mA output current and 3.3V linear regulator provides 1% accuracy under 35mA. The RT6575E features an oscillator output to drive the external charge pump application. Other features include on-board power-up sequencing, a power-good output, internal soft-start, and soft-discharge output that prevents negative voltage during shutdown.

A constant current ripple PWM control scheme operates without sense resistors and provides 100ns response to load transients. For maximizing power efficiency, the RT6575E automatically switches to the diode-emulation mode in light load applications. The RT6575E is available in the WQFN-20L 3x3 package. The recommended junction temperature range is –40°C to 125°C, and the ambient temperature range is –40°C to 85°C.

2 Ordering Information

RT6575E □□□

Pin 1 Orientation
Empty: Quadrant 1
(2): Quadrant 2, Follow EIA-481

Package Type(1)
QW: WQFN-20L 3x3 (W-Type)

Lead Plating System
G: Richtek Green Policy Compliant(2)

Note 1.

- Marked with (1) indicated: Compatible with the current requirements of IPC/JEDEC J-STD-020.
- Marked with (2) indicated: Richtek products are Richtek Green Policy compliant.

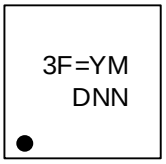
3 Features

- **Support Connected Standby Mode for Ultrabook**
- **CCRCOT Control with 100ns Load Step Response**
- **PWM Maximum Duty Ratio > 98%**
- **5V to 25V Input Voltage Range**
- **Dual Adjustable Output:**
  - **CH1: 2V to 5.5V**
  - **CH2: 2V to 4V**
- **5V/3.3V LDOs with 100mA Output Current**
- **1% Accuracy on 3.3V LDO Output**
- **Oscillator Driving Output for Charge Pump Application**
- **Internal Frequency Setting**
  - **300kHz/355kHz (CH1/CH2)**
- **Internal Soft-Start and Soft-Discharge**
- **4700ppm/°C $R_{DS(ON)}$ Current Sensing**
- **Independent Switcher Enable Control**
- **Built-In OVP/UVP/OCP/OTP**
- **Non-Latch UVLO**
- **Power-Good Indicator**

4 Applications

- Notebook and Sub-Notebook Computers
- System Power Supplies
- 3-Cell and 4-Cell Li + Battery-Powered Devices

5 Marking Information



3F= : Product Code
YMDNN : Date Code

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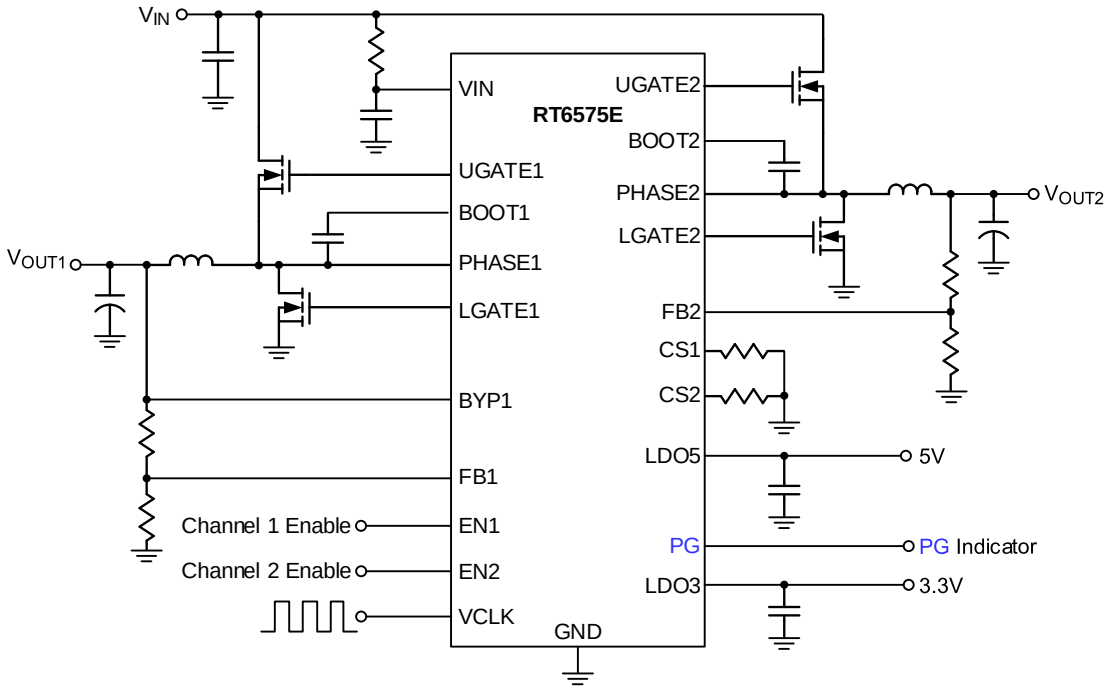
6 Simplified Application Circuit



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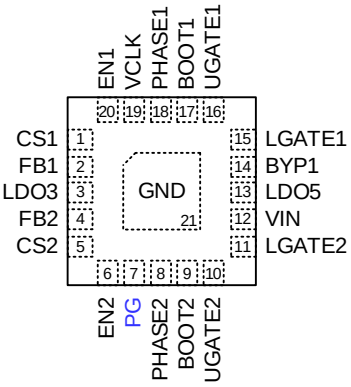
7 Pin Configuration

(TOP VIEW)



WQFN-20L 3x3

8 Functional Pin Description

Pin No.	Pin Name	Pin Function
1	CS1	Current limit setting. Connect a resistor to GND to set the threshold for channel 1 synchronous $R_{DS(ON)}$ sense. The GND-PHASE1 current-limit threshold is 1/8th of the voltage seen at CS1 over a 0.2V to 2V range. There is an internal 10μA current source from LDO5 to CS1.
2	FB1	Feedback voltage input for channel 1. Connect FB1 to a resistive voltage divider from VOUT1 to GND to adjust the output from 2V to 5.5V.
3	LDO3	3.3V Linear Regulator Output. It is always on when VIN is higher than the VINPOR threshold.
4	FB2	Feedback voltage input for channel 2. Connect FB2 to a resistive voltage divider from VOUT2 to GND to adjust the output from 2V to 4V.
5	CS2	Current limit setting. Connect a resistor to GND to set the threshold for channel 2 synchronous $R_{DS(ON)}$ sense. The GND-PHASE2 current-limit threshold is 1/8th of the voltage seen at CS2 over a 0.2V to 2V range. There is an internal 10μA current source from LDO5 to CS2.
6	EN2	Enable control input for channel 2.
7	PG	Power-good indicator output for channel 1 and channel 2 (Logical AND).
8	PHASE2	Switch node of channel 2 MOSFETs. PHASE2 is the internal lower supply rail for the UGATE2 high-side gate driver. PHASE2 is also the current-sense input for channel 2.
9	BOOT2	Bootstrap supply for channel 2 High-Side Gate Driver. Connect to an external capacitor according to the typical application circuits.
10	UGATE2	High-side gate driver output for channel 2. UGATE2 swings between PHASE2 and BOOT2.
11	LGATE2	Low-Side gate driver output for channel 2. LGATE2 swings between GND and LDO5.
12	VIN	Power input for 5V and 3.3V LDO regulators and buck controllers.
13	LDO5	5V linear regulator output. LDO5 is also the supply voltage for the low-side MOSFET and the analog supply voltage for the device.
14	BYP1	Switch-over source voltage input for LDO5.

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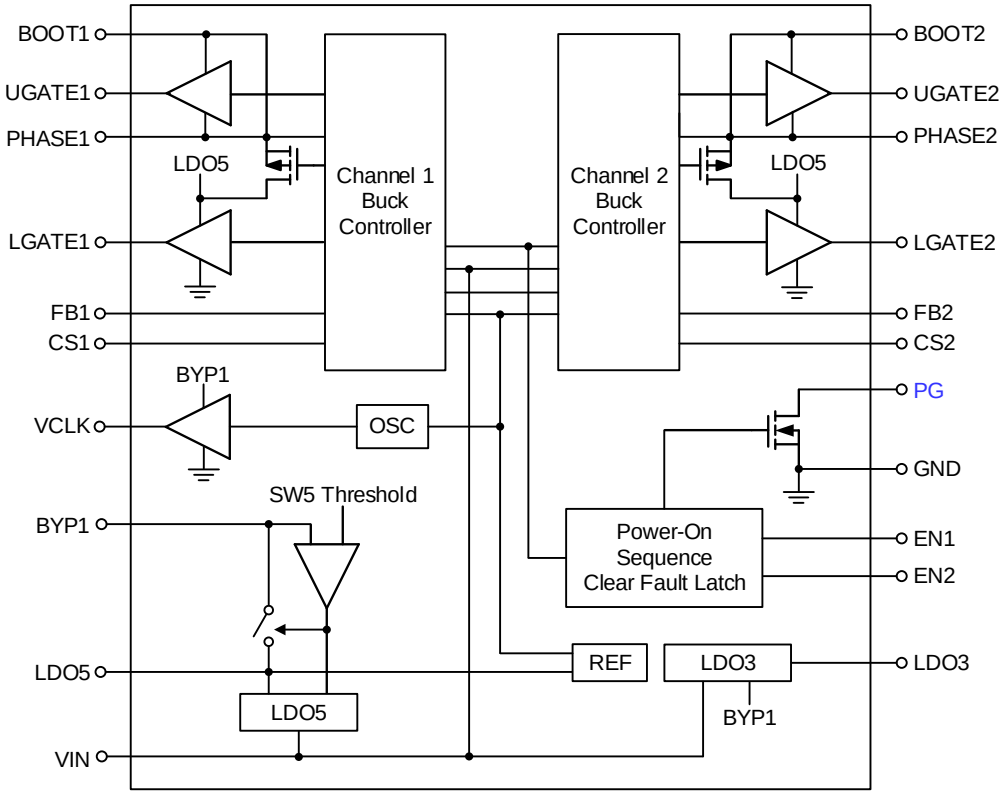
Pin No.	Pin Name	Pin Function
15	LGATE1	Low-side gate driver output for channel 1. LGATE1 swings between GND and LDO5.
16	UGATE1	High-side gate driver output for channel 1. UGATE1 swings between PHASE1 and BOOT1.
17	BOOT1	Bootstrap supply for the channel 1 High-Side Gate Driver. Connect to an external capacitor according to the typical application circuits.
18	PHASE1	Switch node of channel 1 MOSFETs. PHASE1 is the internal lower supply rail for the UGATE1 high-side gate driver. PHASE1 is also the current sense input for channel 1.
19	VCLK	Oscillator output for the charge pump.
20	EN1	Enable control input for channel 1.
21 (Exposed Pad)	GND	Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation.

9 Functional Block Diagram



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10 Absolute Maximum Ratings

(Note 2)

- VIN to GND ---------- –0.3V to 30V
- BOOTx to GND
  - DC ---------- –0.3V to 36V
  - <100ns ---------- –5V to 42V
- BOOTx to PHASEx
  - DC ---------- –0.3V to 6V
  - <100ns ---------- –5V to 7.5V
- PHASEx to GND
  - DC ---------- –5V to 30V
  - <100ns ---------- –10V to 42V
- UGATEx to GND
  - DC ---------- –5V to 36V
  - <100ns ---------- –10V to 42V
- UGATEx to PHASEx
  - DC ---------- –0.3V to 6V
  - <100ns ---------- –5V to 7.5V
- LGATEx to GND
  - DC ---------- –0.3V to 6V
  - <100ns ---------- –5V to 7.5V
- Other Pins ---------- –0.3V to 6.5V
- Power Dissipation, P_D @ T_A = 25°C
  - WQFN-20L 3x3 ---------- 3.33W
- Package Thermal Resistance (Note 3)
  - WQFN-20L 3x3, θ_{JA} ---------- 30°C/W
  - WQFN-20L 3x3, θ_{JC} ---------- 7.5°C/W
- Junction Temperature ---------- 150°C
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 4)
  - HBM (Human Body Model) ---------- 2kV

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.

Note 3. θ_{JA} is measured under natural convection (still air) at T_A = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ_{JC} is measured at the bottom of the package.

Note 4. Devices are ESD sensitive. Handling precautions are recommended.

11 Recommended Operating Conditions

(Note 5)

- Supply Voltage, VIN ---------- 5V to 25V
- Junction Temperature Range ---------- –40°C to 125°C
- Ambient Temperature Range ---------- –40°C to 85°C

Note 5. The device is not guaranteed to function outside its operating conditions.

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12 Electrical Characteristics

(V_{IN} = 12V, V_{EN1} = V_{EN2} = 3.3V, VCS1 = V_{CS2} = 2V, No Load, T_A = 25°C, unless otherwise specified.)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Input Supply						
VIN Power-On Reset Rising Threshold	$V_{IN_POR_R}$	Rising Threshold	--	4.6	4.9	V
VIN Power-On Reset Falling Threshold	$V_{IN_POR_F}$	Falling Threshold	3.2	3.7	--	
VIN Standby Current	I_{VIN_STBY}	Both Buck Controllers Off, V_{EN1} = V_{EN2} = GND	--	80	100	μA
VIN Quiescent Current (Non-Switching)	I_{VIN_nsw}	Both Buck Controllers On, V_{FBx} = 2.05V, V_{BYP1} = 5.05V	--	15	25	μA
BYP1 Supply Current	I_{BYP1_nsw}	Both Buck Controllers On, V_{FBx} = 2.05V, V_{BYP1} = 5.05V	--	420	500	μA
Soft-Start						
Soft-Start Time	t_{SSx}	V_{OUT} ramp-up time	--	0.9	--	ms
Buck Controllers Output and FB Voltage						
FBx Feedback Voltage	V_{FBx}	CCM Operation	1.98	2	2.02	V
BYP1 Discharge Current	I_{DISCHG_BYP1}	V_{BYP1} = 0.5V	10	45	--	mA
PHASEx Discharge Current	I_{DISCHG_SWx}	V_{PHASEx} = 0.5V	5	8	--	mA
Switching Frequency						
Switching Frequency	f_{SWx}	V_{IN} = 20V, V_{OUT1} = 5V	240	300	360	kHz
		V_{IN} = 20V, V_{OUT2} = 3.33V	280	355	430	
Minimum Off-Time	t_{OFF_MIN}	V_{FBx} = 1.9V	--	200	275	ns
Current Sense						
CSx Source Current	I_{CSx}	V_{CSx} = 1V, V_{FBx} = 1.9V	9	10	11	μA
CSx Current Temperature Coefficient	T_{C_ICSx}	In Comparison with 25°C	--	4700	--	ppm/°C
Zero-Current Threshold 1	V_{ZC1_TH}	V_{FB1} = 2.05V, PHASE1 - GND	–8	–1	2	mV
Zero-Current Threshold 2	V_{ZC2_TH}	V_{FB2} = 2.05V, PHASE2 - GND	–8	–1	3.5	mV
Internal Regulator						
LDO5 Output Voltage	V_{OUT_LDO5}	V_{IN} = 12V, No Load	4.9	5	5.1	V
		V_{IN} > 7V, I_{LDO5} < 100mA	4.8	5	5.1	
		V_{IN} > 5.5V, I_{LDO5} < 35mA	4.8	5	5.1	
		V_{IN} > 5V, I_{LDO5} < 20mA	4.5	4.75	5.1	

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Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
LDO3 Output Voltage	V_{OUT_LDO3}	V_{IN} = 12V, No Load	3.267	3.3	3.333	V
		V_{IN} > 7V, I_{LDO3} < 100mA	3.217	3.3	3.383	
		V_{IN} > 5.5V, I_{LDO3} < 35mA	3.267	3.3	3.333	
		V_{IN} > 5V, I_{LDO3} < 20mA	3.217	3.3	3.383	
LDO5 Output Current	I_{LDO5}	V_{OUT_LDO5} = 4.5V, V_{BYP1} = GND, V_{IN} = 7.4V	100	175	--	mA
LDO3 Output Current	I_{LDO3}	V_{OUT_LDO3} = 3V, V_{IN} = 7.4V	100	175	--	mA
LDO5 Switch-Over Threshold to BYP1	V_{SWTH}	Rising Edge at BYP1 Regulation Point	--	4.66	--	V
LDO5 Switch-Over Equivalent Resistance	R_{SW}	LDO5 to BYP1, 10mA	--	1.5	3	Ω
VCLK Output						
VCLK On-Resistance	R_{VCLK}	Pull-up and Pull-down Resistance	--	10	--	Ω
VCLK Switching Frequency	f_{VCLK}		--	260	--	kHz
UVLO						
LDO5 UVLO Threshold	V_{UVLO5}	Rising Edge	--	4.3	4.6	V
		Falling Edge	3.7	3.9	4.1	
LDO3 UVLO Threshold	V_{UVLO3}	Channel x Off	--	2.5	--	V
Power-Good						
Power-Good Voltage Threshold	V_{PG}	PG Detect, V_{FBx} Rising Edge	84	88	92	%
Power-Good Voltage Hysteresis	V_{PG_HYS}	Hysteresis	--	8	--	
Power-Good Leakage Current		High state, V_{PG} = 5.5V	--	--	1	μA
Power-Good Output Low Voltage		I_{SINK} = 4mA	--	--	0.3	V
Fault Detection						
Output Overvoltage Protection Threshold	V_{OVP}	FBx with Respect to Internal Reference	109	113	117	%
OVP Propagation Delay			--	1	--	μs
Output Undervoltage Protection Threshold	V_{UVP}	UVP Detect, FBx Falling Edge	47	52	57	%
UVP Shutdown Blanking Time	t_{SHDN_UVP}	From ENx Enable	--	1.3	--	ms
Over-Temperature Protection						
Over-Temperature Protection Threshold	T_{OTP}		--	150	--	°C
Over-Temperature Protection Hysteresis	T_{OTP_HYS}		--	10	--	°C

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Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Logic Inputs						
ENx Input Voltage Rising Threshold	V_{ENx_R}	SMPS On	1.6	--	--	V
ENx Input Voltage Falling Threshold	V_{ENx_F}	SMPS Off	--	--	0.4	
Internal Boost Switch						
Internal Boost Switch On-Resistance	R_{BST}	LDO5 to BOOTx	--	80	--	Ω
Power MOSFET Drivers						
UGATEx On-Resistance	R_{UGATEx}	High State, $V_{BOOTx} - V_{UGATEx}$ = 0.25V, $V_{BOOTx} - V_{PHASEx}$ = 5V	--	3	--	Ω
		Low State, $V_{UGATEx} - V_{PAHSEx}$ = 0.25V, $V_{BOOTx} - V_{PHASEx}$ = 5V	--	2	--	
LGATEx On-Resistance	R_{LGATEx}	High State, $V_{LDO5} - V_{LGATEx}$ = 0.25V, V_{LDO5} = 5V	--	3	--	Ω
		Low State, V_{LGATEx} – GND = 0.25V	--	1	--	
Dead-Time	t_D	LGATEx Rising	--	20	--	ns
		UGATEx Rising	--	30	--	

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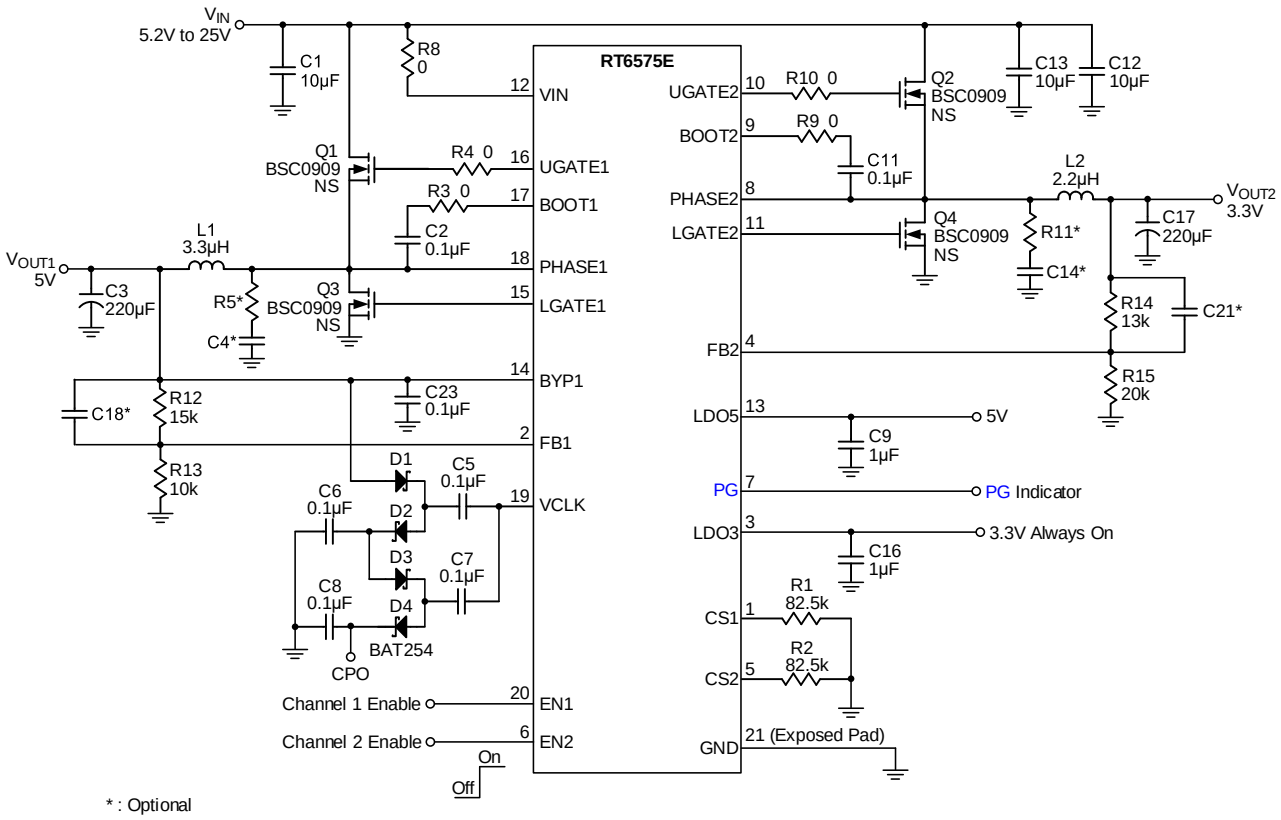
13 Typical Application Circuit



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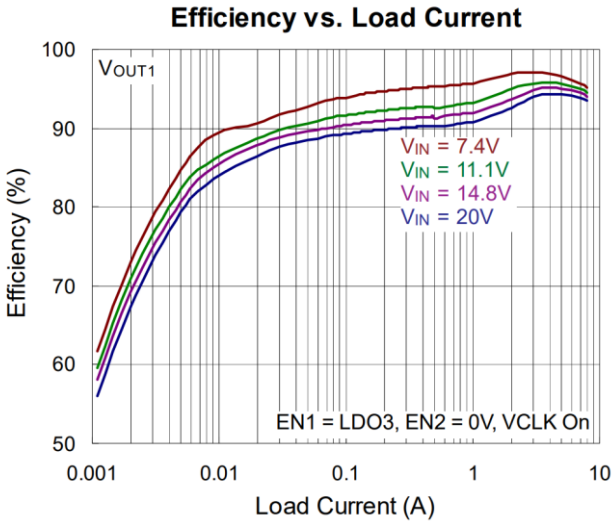
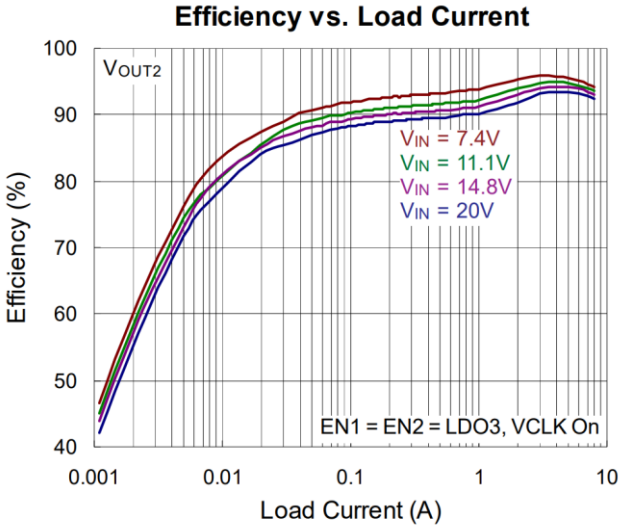
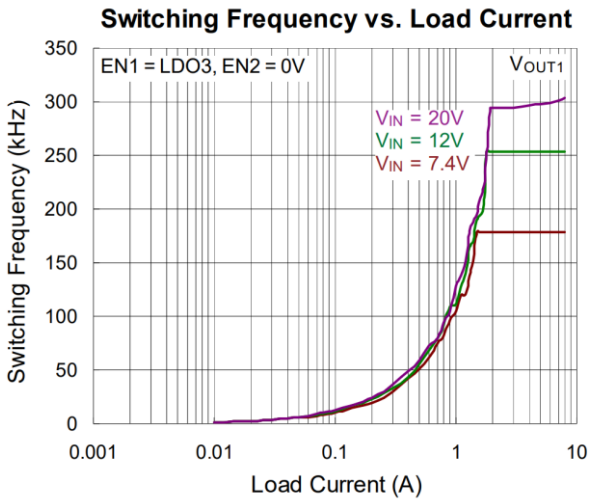
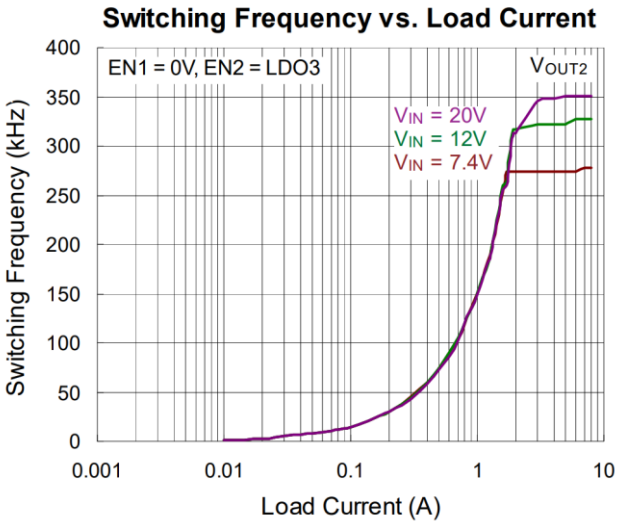
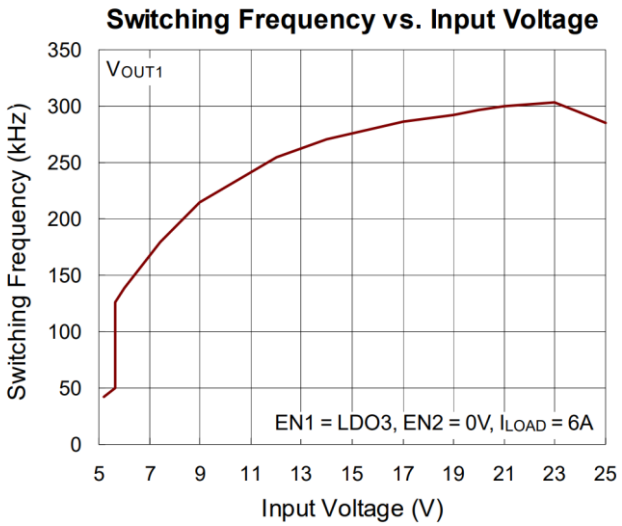
14 Typical Operating Characteristics

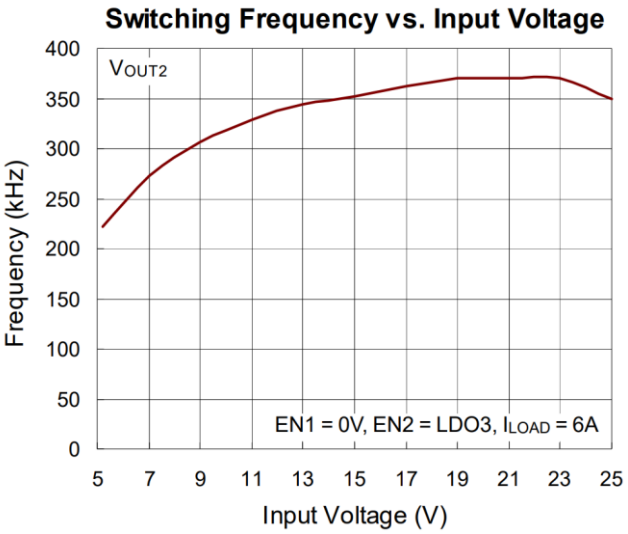












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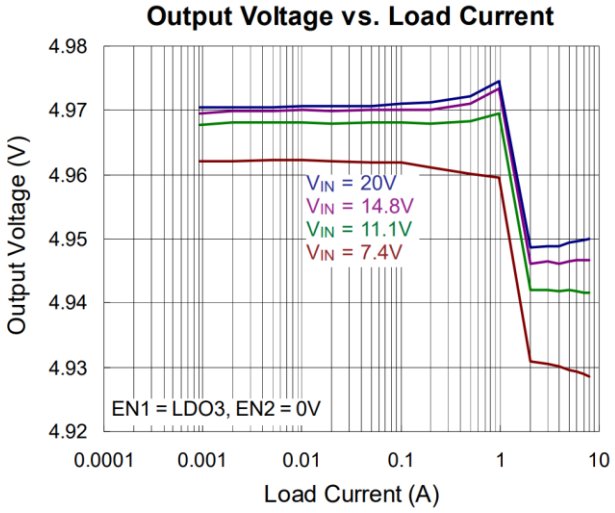

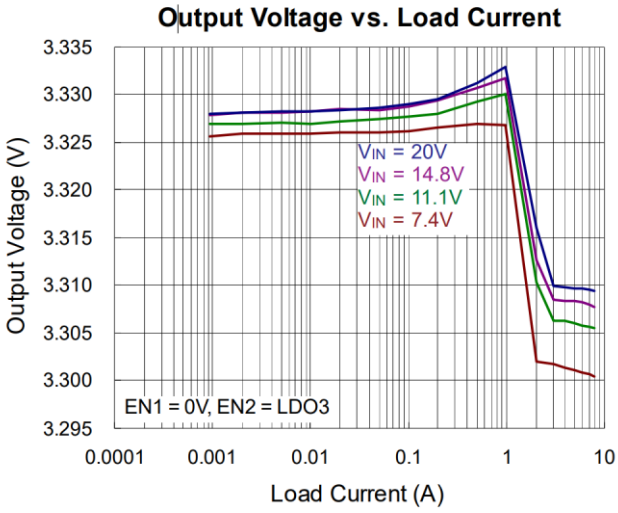

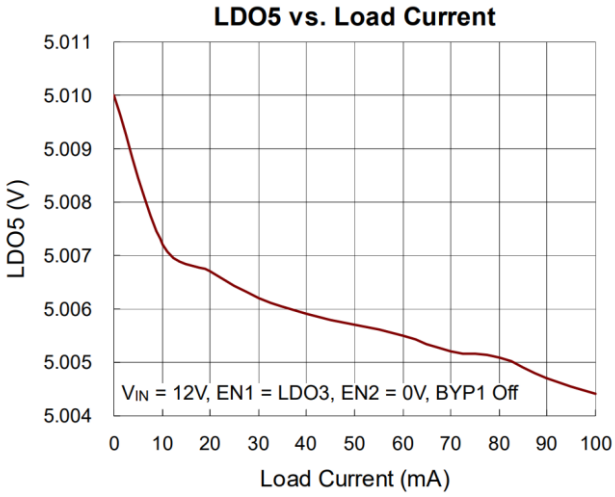

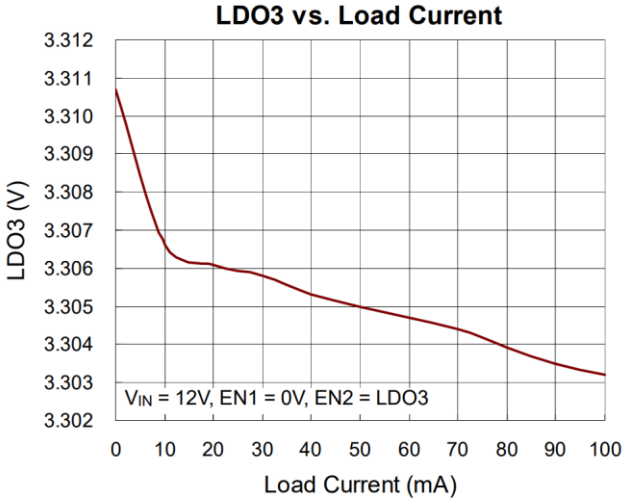

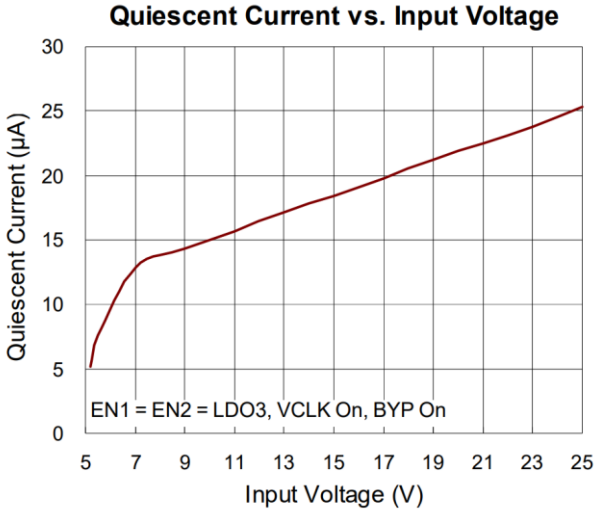

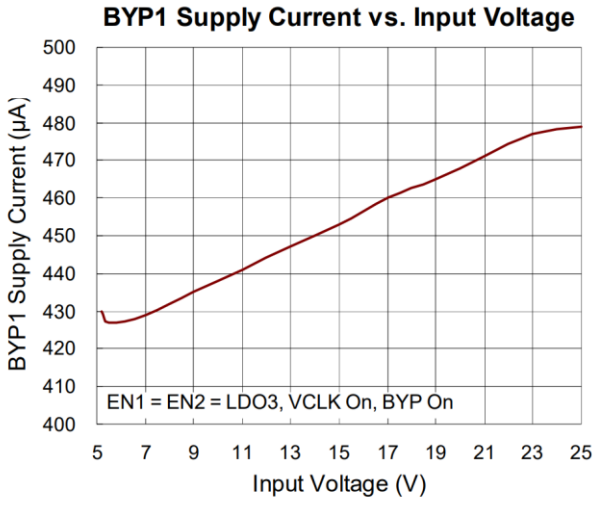

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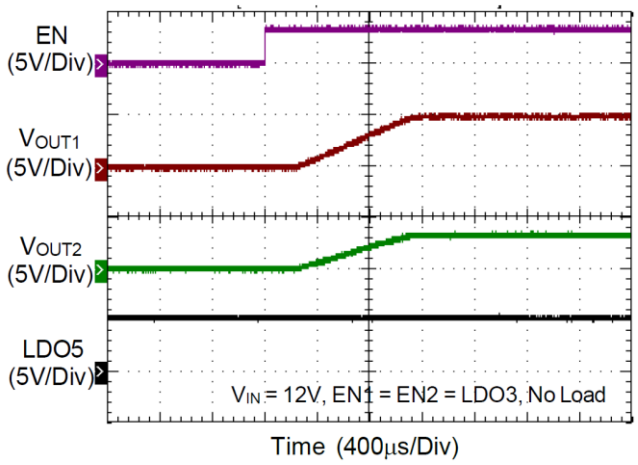
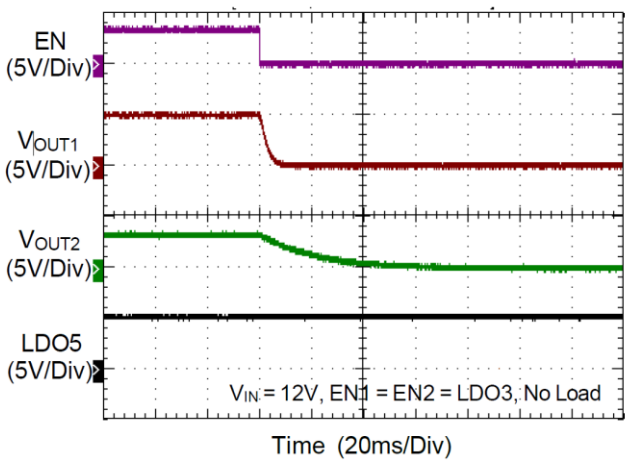
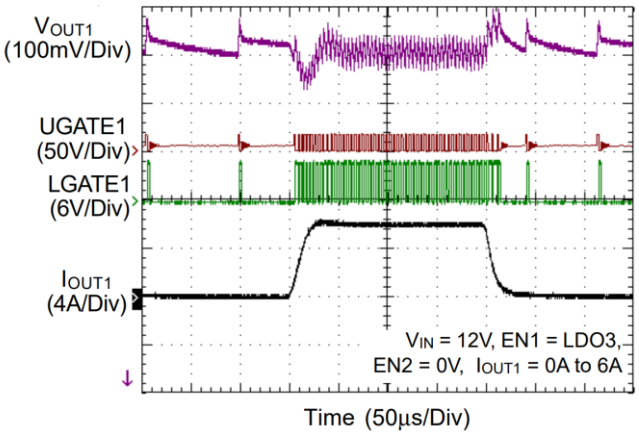
Power On from EN



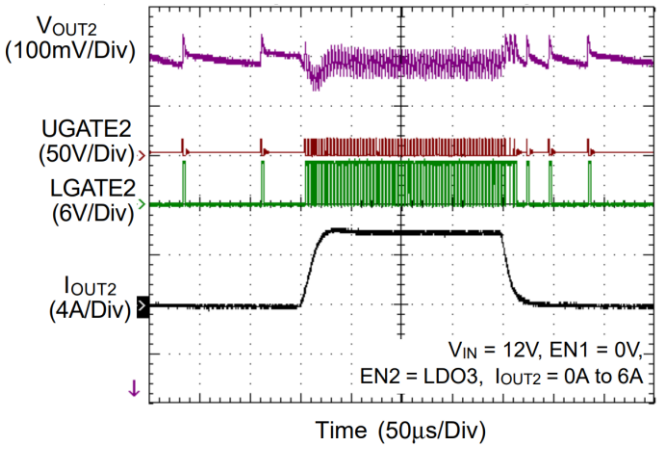
Power Off from EN



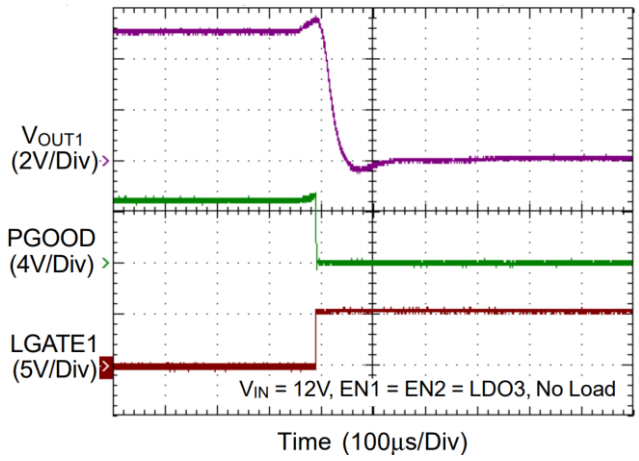
VOUT1 Load Transient Response



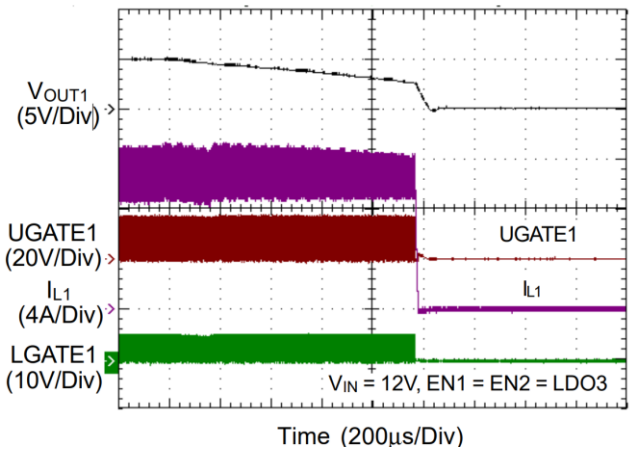
VOUT2 Load Transient Response



OVP



UVP



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15 Operation

The RT6575E includes two constant-on-time synchronous step-down controllers and two linear regulators.

15.1 Buck Controller

In normal operation, the high-side N-MOSFET is turned on when the output voltage is lower than VREF and is turned off after the internal one-shot timer expires. While the high-side N-MOSFET is turned off, the low-side N-MOSFET is turned on to conduct the inductor current until the next cycle begins.

15.2 Soft-Start

For the internal soft-start function, an internal current source charges an internal capacitor to develop the soft-start ramp voltage. The output voltage will track the internal ramp voltage during the soft-start interval. Refer to Soft-Start for details.

15.3 PG

The power-good output is an open-drain architecture. When the soft-start of the two channels is completed, the PG open-drain output will become high impedance. Refer to PG for details.

15.4 Overcurrent Protection (OCP)

The current limit circuit employs a unique “valley” current sensing algorithm. If the magnitude of the current sense signal at PHASE is above the current-limit threshold, the PWM is not allowed to initiate a new cycle. Thus, if the current to the load exceeds the average output inductor current, the output voltage falls and eventually crosses the undervoltage protection threshold, leading to IC shutdown. Refer to Overcurrent Protection (OCP) for details.

15.5 Overvoltage Protection (OVP) and Undervoltage Protection (UVP)

The two-channel output voltages are continuously monitored for overvoltage and undervoltage conditions. When the output voltage exceeds the overvoltage threshold (113% of VOUT), UGATE goes low and LGATE is forced high. When it is less than 52% of the reference voltage, undervoltage protection is triggered, and then both UGATE and LGATE gate drivers are forced low. The controller is latched until ENx is reset or LDO5 is re-supplied. Refer to Output Overvoltage Protection (OVP) and Output Undervoltage Protection (UVP) for details.

15.6 LDO5 and LDO3

When the VIN voltage exceeds the POR rising threshold, LDO3 and LDO5 will default to turn on. The linear regulators LDO5 and LDO3 provide 5V and 3.3V regulated outputs, respectively.

15.7 Switching Over

The BYP1 is connected to the channel 1 output. After the channel 1 output voltage exceeds the set threshold (4.66V), the output will be bypassed to the LDO5 output to maximize efficiency.

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16 Application Information

(Note 6)

The RT6575E is a dual-channel, low-quiescent, Mach Response™ DRVTM mode synchronous buck controller targeted for Ultrabook system power supply solutions. Richtek's Mach Response™ technology provides fast response to load steps. The topology solves the poor load transient response timing problems of fixed-frequency current mode PWMs and avoids the problems caused by widely varying switching frequencies in CCR (constant current ripple) constant on-time and constant off-time PWM schemes. A special adaptive on-time control trades off the performance and efficiency over a wide input voltage range. The RT6575E includes 5V (LDO5) and 3.3V (LDO3) linear regulators. The LDO5 linear regulator steps down the battery voltage to supply both internal circuitry and gate drivers. The synchronous switch gate drivers are directly powered by LDO5. When VOUT1 rises above 4.66V, an automatic circuit disconnects the linear regulator and allows the device to be powered by VOUT1 via the BYP1 pin.

16.1 PWM Operation

The Mach Response™ DRVTM mode controller relies on the output filter capacitor's Effective Series Resistance (ESR) to act as a current sense resistor, so that the output ripple voltage provides the PWM ramp signal. Referring to the RT6575E's Function Block Diagram, the synchronous high-side MOSFET is turned on at the beginning of each cycle. After the internal one-shot timer expires, the MOSFET will be turned off. The pulse width of this one-shot is determined by the converter's input and output voltages to keep the frequency fairly constant over the entire input voltage range. Another one-shot sets a minimum off-time (200ns typical). The on-time one-shot will be triggered if the error comparator is high, the low-side switch current is below the current-limit threshold, and the minimum off-time one-shot has timed out.

16.2 PWM Frequency and On-Time Control

For each specific input voltage range, the Mach Response™ control architecture operates with pseudo-constant frequency by feedforwarding the input and output voltage into the on-time one-shot timer. The high-side switch on-time is inversely proportional to the input voltage as measured by VIN and proportional to the output voltage. The inductor ripple current operating point remains relatively constant, resulting in an easy design methodology and predictable output voltage ripple. The frequency of the 3V output controller is set higher than the frequency of the 5V output controller. This is done to prevent audio frequency “beating” between the two sides, which switch asynchronously for each side.

The RT6575E adaptively changes the operation frequency according to the input voltage. Higher input voltage usually comes from an external adapter, so the RT6575E operates with a higher frequency to achieve better performance. Lower input voltage usually comes from a battery, so the RT6575E operates with a lower switching frequency for reduced switching losses. For a specific input voltage range, the switching cycle period is given by:

For 5V VOUT,

$$\text{Period } (\mu\text{sec.}) = \frac{V_{IN} \times 2.7}{V_{IN} - 3.79}$$

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For 3V VOUT,

$$\text{Period } (\mu\text{sec.}) = \frac{V_{IN} \times 2.45}{V_{IN} - 2.59}$$

where the VIN is in volts.

The on-time guaranteed in the Electrical Characteristics table is influenced by switching delays in the external high-side power MOSFET.

16.3 Diode Emulation Mode

In diode emulation mode, the RT6575E automatically reduces switching frequency at light load conditions to maintain high efficiency. This reduction of frequency is achieved smoothly. As the output current decreases from a heavy load condition, the inductor current also reduces and eventually reaches the point where its current valley touches zero, making the boundary between continuous conduction and discontinuous conduction modes. To emulate the behavior of diodes, the low-side MOSFET allows only partial negative current to flow when the inductor freewheeling current becomes negative. As the load current further decreases, it takes longer to discharge the output capacitor to the level that requires the next “ON” cycle. The on-time is kept the same as in the heavy load condition. Conversely, when the output current increases from light load to heavy load, the switching frequency increases to the preset value as the inductor current reaches the continuous conduction. The transition load point to the light load operation is shown in Figure 1 and can be calculated as follows:

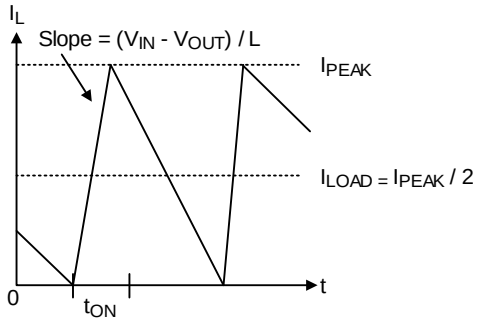

Figure 1. Boundary Condition of CCM/DEM

$$I_{LOAD(SKIP)} \approx \frac{(V_{IN} - V_{OUT})}{2L} \times t_{ON}$$

where t_{ON} is the on-time.

The switching waveforms may appear noisy and asynchronous when a light load causes diode emulation operation. This is normal and results in high efficiency. Trade-offs in PFM noise versus light load efficiency are made by varying the inductor value. Generally, low inductor values produce a broader efficiency versus load curve, while higher values result in higher full load efficiency (assuming that the coil resistance remains fixed) and less output voltage ripple. Penalties for using higher inductor values include a larger physical size and degraded load transient response (especially at low input voltage levels).

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16.4 Linear Regulators (LDOx)

The RT6575E includes 5V (LDO5) and 3.3V (LDO3) linear regulators. The regulators can supply up to 100mA for external loads. Bypass LDOx with a 1μF to 4.7μF capacitor, with the recommended value being a 1μF ceramic capacitor. When VOUT1 is higher than the switch-over threshold (4.66V), an internal 1.5Ω P-MOSFET switch connects BYP1 to the LDO5 pin while simultaneously disconnecting the internal linear regulator.

16.5 Overcurrent Protection (OCP)

The RT6575E has cycle-by-cycle current limit control. The current limit circuit employs a unique “valley” current sensing algorithm. If the magnitude of the current sense signal at PHASEx is above the current-limit threshold, the PWM is not allowed to initiate a new cycle (Figure 2). The actual peak current is greater than the current-limit threshold by an amount equal to the inductor ripple current. Therefore, the exact current limit characteristic and maximum load capability are functions of the sense resistance, inductor value, battery, and output voltage.

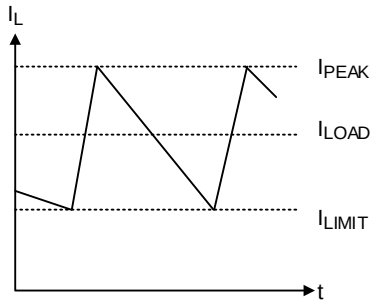

Figure 2. “Valley” Current Limit

The RT6575E uses the on-resistance of the synchronous rectifier as the current sense element and supports temperature-compensated MOSFET $R_{DS(ON)}$ sensing. The R_{ILIM} resistor between the CSx pin and GND sets the current-limit threshold. The resistor R_{ILIM} is connected to a current source from CSx, which is 10μA (typical) at room temperature. The current source has a 4700ppm/°C temperature slope to compensate for the temperature dependency of the $R_{DS(ON)}$. When the voltage drop across the sense resistor or low-side MOSFET equals 1/8 of the voltage across the R_{ILIM} resistor, positive current limit will be activated. The high-side MOSFET will not be turned on until the voltage drop across the MOSFET falls below 1/8 of the voltage across the R_{ILIM} resistor.
Choose a current limit resistor according to the following equation:

$V_{LIMIT} = (R_{LIMIT} \times 10\mu A - 35mV)/8 = I_{LIMIT} \times R_{DS(ON)}$

$R_{LIMIT} = ((I_{LIMIT} \times R_{DS(ON)}) \times 8 + 35mV)/10\mu A$

Carefully observe the PCB layout guidelines to ensure that noise and DC errors do not corrupt the current sense signal at PHASEx and GND. Mount or place the IC close to the low-side MOSFET.

16.6 VCLK for Charge Pump

A 260kHz VCLK signal can be used for the external charge pump circuit. The VCLK signal becomes available when EN1 enters the ON state. The VCLK driver circuit is driven by the BYP1 voltage.

The external 14V charge pump is driven by VCLK. As shown in Figure 3, when VCLK is low, C1 will be charged by VOUT1 through D1. The C1 voltage is equal to V_{OUT1} minus the diode drop. When VCLK becomes high, C1 transfers the charge to C2 through D2 and charges C2 to V_{VCLK} plus C1. As VCLK transitions low in the next cycle, C3 is charged to C2 minus a diode drop through D3. Finally, C3 charges C4 through D4 when VCLK switches high. Thus, the total charge pump voltage, V_{CP}, is:

$V_{CP} = VOUT1 + 2 \times V_{VCLK} - 4 \times V_D$

where V_{VCLK} is the peak voltage of the VCLK driver, which is equal to LDO5, and V_D is the forward voltage drop across the Schottky diode.

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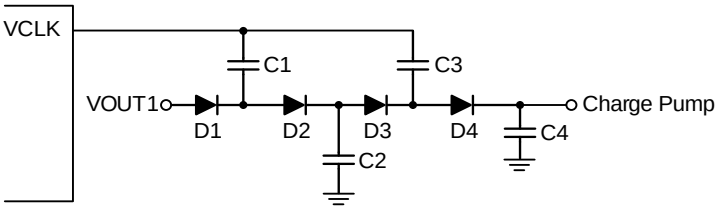

Figure 3. Charge Pump Circuit Connected to VCLK

16.7 MOSFET Gate Driver (UGATEx, LGATEx)

The high-side driver is designed to drive high-current, low $R_{DS(ON)}$ N-MOSFET(s). When configured as a floating driver, 5V bias voltage is delivered from the LDO5 supply. The average drive current is also calculated by the gate charge at VGS = 5V times the switching frequency. The instantaneous drive current is supplied by the flying capacitor between the BOOTx and PHASEx pins. A dead-time to prevent shoot-through is internally generated from high-side MOSFET off to low-side MOSFET on and low-side MOSFET off to high-side MOSFET on.

The low-side driver is designed to drive high-current, low $R_{DS(ON)}$ N-MOSFET(s). The internal pull-down transistor that drives LGATEx low is robust, with a typical on-resistance of 1Ω. A 5V bias voltage is delivered from the LDO5 supply. The instantaneous drive current is supplied by an input capacitor connected between LDO5 and GND.

For high-current applications, some combinations of high and low-side MOSFETs may cause excessive gate-drain coupling, which leads to efficiency killing, EMI production, and shoot-through currents. This is often remedied by adding a resistor in series with BOOTx, which increases the turn-on time of the high-side MOSFET without degrading the turn-off time. See Figure 4.

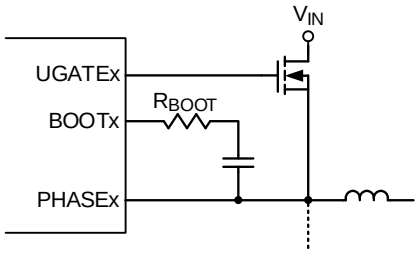

Figure 4. Increasing the UGATEx Rise Time

16.8 Soft-Start

The RT6575E provides an internal soft-start function to prevent large inrush current and output voltage overshoot when the converter starts up. The soft-start (SS) automatically begins once the device is enabled. During soft-start, it clamps the ramping of the internal reference voltage, which is compared with the FBx signal. The typical soft-start duration is 0.9ms. A unique PWM duty limit control is designed specifically for FBx floating to prevent output overvoltage during the soft-start period.

16.9 UVLO Protection

The RT6575E has LDO5 undervoltage-lockout protection (UVLO). When the LDO5 voltage is lower than 3.9V (typical) and the LDO3 voltage is lower than 2.5V (typical), both switch power supplies are shut off. This is a non-latch protection.

16.10 PG

PG is an open-drain output and requires a pull-up resistor. PG is actively held low during soft-start, standby, and shutdown. For the RT6575E, PG is released when both output voltages are above 88% of nominal regulation point. The PG signal goes low if either output turns off or is 20% below or 13% over its nominal regulation point.

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16.11 Output Overvoltage Protection (OVP)

The output voltage can be continuously monitored for overvoltage conditions. If the output voltage exceeds 13% of its set voltage threshold, the overvoltage protection is triggered, and the LGATEx low-side gate drivers are forced high. This activates the low-side MOSFET switch, which rapidly discharges the output capacitor and pulls the output voltage downward.

The RT6575E latches once OVP is triggered and can only be released by either toggling ENx or cycling VIN. There is a 1μs delay built into the overvoltage protection circuit to prevent false transitions.

Note that latching LGATEx high will cause the output voltage to dip slightly negative due to previously stored energy in the LC tank circuit. For loads that cannot tolerate a negative voltage, place a power Schottky diode across the output to act as a reverse polarity clamp.

If the overvoltage condition is caused by a short in the high-side switch, turning the low-side MOSFET on 100% will create an electrical short circuit between the battery and GND to blow the fuse and disconnect the battery from the output.

16.12 Output Undervoltage Protection (UVP)

The output voltage can be continuously monitored for undervoltage conditions. If the output voltage is less than 52% (typical) of its set voltage threshold, the undervoltage protection will be triggered, and then both UGATEx and LGATEx gate drivers will be forced low. The UVP is ignored for at least 1.3ms (typical) after a start-up or a rising edge on ENx. Toggle ENx or cycle VIN to reset the UVP fault latch and restart the controller.

16.13 Over-Temperature Protection (OTP)

The RT6575E features thermal shutdown to prevent damage from excessive heat dissipation. Thermal shutdown occurs when the die temperature exceeds 150°C. All internal circuitry is turned off during thermal shutdown. The RT6575E triggers thermal shutdown if LDO5 is not supplied from V_{OUT1}, while the input voltage on VIN and the current drawn from LDO5 are too high. Nevertheless, even if LDO5 is supplied from VOUT1, overloading LDO5 can cause large power dissipation on automatic switches, which may still result in thermal shutdown.

16.14 Discharge Mode (Soft Discharge)

When ENx is low and the output undervoltage fault latch is set, the output discharge mode will be triggered. During discharge mode, an internal switch creates a path for discharging the output capacitors' residual charge to GND.

16.15 Standby Mode

When VIN exceeds the POR threshold and ENx is < 0.4V, the RT6575E operates in standby mode, and CH1 and CH2 are in the OFF state. For the RT6575E, LDO5 and LDO3 are in the ON state, consuming approximately 35uA while in standby mode.

16.16 Power-Up Sequencing and On/Off Controls (ENx)

EN1 and EN2 control the power-up sequencing of the two channels of the buck converter. The 0.4V falling edge threshold on ENx can be used to detect a specific analog voltage level and to shut down the device. Once in shutdown, the 1.6V rising edge threshold activates, providing sufficient hysteresis for most applications.

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Table 1. Operation Mode Truth Table

Mode	Condition	Comment
LDO Overcurrent Protection	LDOx < UVLO threshold	Transitions to discharge mode after VIN POR. LDO5 and LDO3 remain active.
Run	ENx = high, V_{OUT1} or V_{OUT2} are enabled	Normal Operation.
Overvoltage Protection	Either output >113% of the nominal level.	LGATEx is forced high. LDO3 and LDO5 are active. Exit by VIN POR or by toggling ENx.
Undervoltage Protection	Either output < 52% of the nominal level after 1.3ms time-out expires and output is enabled	Both UGATEx and LGATEx are forced low and enter discharge mode. LDO3 and LDO5 are active. Exit by VIN POR or by toggling ENx.
Discharge	Either output is still high in standby mode	During discharge mode, there is one path to discharge the output capacitors' residual charge to GND via an internal switch.
Standby	VIN > POR ENx < 0.4V	LDO3 and LDO5 are active
Over-Temperature Protection	T_J > 150°C	All circuitries are off. Exit by VIN POR.

Table 2. Enabling/PG State

EN1	EN2	LDO5	LDO3	CH1 (5VOUT)	CH2 (3.3VOUT)	VCLK	PG
OFF	OFF	ON	ON	OFF	OFF	OFF	Low
ON	OFF	ON	ON	ON	OFF	ON	Low
OFF	ON	ON	ON	OFF	ON	OFF	Low
ON	ON	ON	ON	ON	ON	ON	High

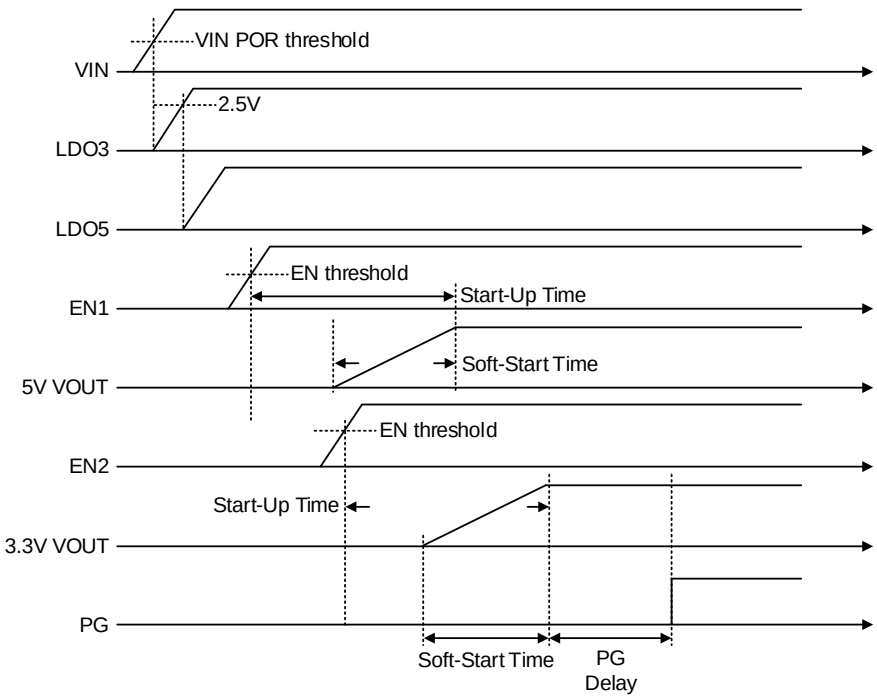

Figure 5. RT6575E Timing

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16.17 Output Voltage Setting (FBx)

Connect a resistive voltage divider at the FBx pin between V_{OUTx} and GND to adjust the output voltage from 2V to 5.5V for CH1 and 2V to 4V for CH2, as shown in Figure 6. The recommended R2 value is between 10kΩ and 20kΩ. Solve for R1 using the following equation:

$$V_{OUT(Valley)} = V_{FBx} \times \left(1 + \left(\frac{R1}{R2}\right)\right)$$

where V_{FBx} is 2V (typical)

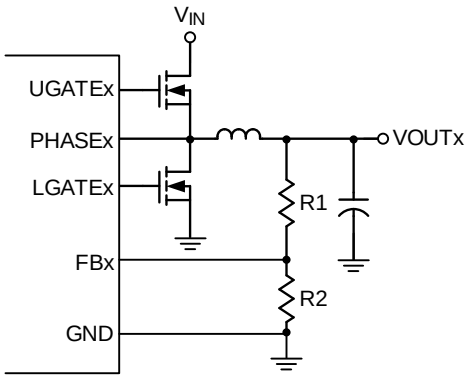

Figure 6. Setting V_{OUTx} with A Resistive Voltage Divider

16.18 Output Inductor Selection

The switching frequency (on-time) and operating point (% ripple or LIR) determine the inductor value as shown below:

$$L = \frac{t_{ON} \times (V_{IN} - V_{OUTx})}{LIR \times I_{LOAD(MAX)}}$$

where LIR is the ratio of the peak-to-peak ripple current to the average inductor current.

Find a low-loss inductor with the lowest possible DC resistance that fits within the given dimensions. Ferrite cores are often the best choice, although powdered iron is inexpensive and can work well at 200kHz. The core must be large enough to avoid saturation at the peak inductor current I_{PEAK}.

$I_{PEAK} = I_{LOAD(MAX)} + [\,(LIR/2) \times I_{LOAD(MAX)}\,]$

The calculation above serves as a general reference. To further improve transient response, the output inductance can be reduced. Of course, besides the inductor, the output capacitor should also be considered when improving transient response.

16.19 Output Capacitor Selection

The capacitor value and ESR determine the amount of the output voltage ripple and load transient response. Thus, the capacitor value must be greater than the largest value calculated using the following equations:

$$V_{SAG} = \frac{(\Delta I_{LOAD})^2 \times L \times (t_{ON} + t_{OFF(MIN)})}{2 \times C_{OUT} \times \left[V_{IN} \times t_{ON} - V_{OUTx}(t_{ON} + t_{OFF(MIN)})\right]}$$

$$V_{SOAR} = \frac{(\Delta I_{LOAD})^2 \times L}{2 \times C_{OUT} \times V_{OUTx}}$$

$$V_{P-P} = LIR \times I_{LOAD(MAX)} \times \left(ESR + \frac{1}{8 \times C_{OUT} \times f}\right)$$

where V_{SAG} and V_{SOAR} are the allowable amounts of undershoot and overshoot voltage during load transient, V_{p-p} is the output ripple voltage, and $t_{OFF(MIN)}$ is the minimum off-time.

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16.20 Selection Guide of MOSFET $R_{DS(ON)}$ for ZCD Function

Through the ZCD (Zero Current Detection) function, the IC can effectively reduce the switching frequency in DEM (Discontinuous Emission Mode), thereby improving power conversion efficiency. When ZCD is triggered, the device cuts off the low-side MOSFET, causing both the high-side and low-side MOSFETs to be in an off state. The working principle of ZCD is as follows: when the low-side MOSFET conducts, and the inductor current (IL) passing through the $R_{DS(ON)}$ of the low-side MOSFET generates a voltage drop (VPHASE) that falls below the ZC threshold of the IC's internal comparator, ZCD is triggered. The device then turns off the low-side MOSFET and enters DEM mode. The related waveforms can be seen in Figure 7.

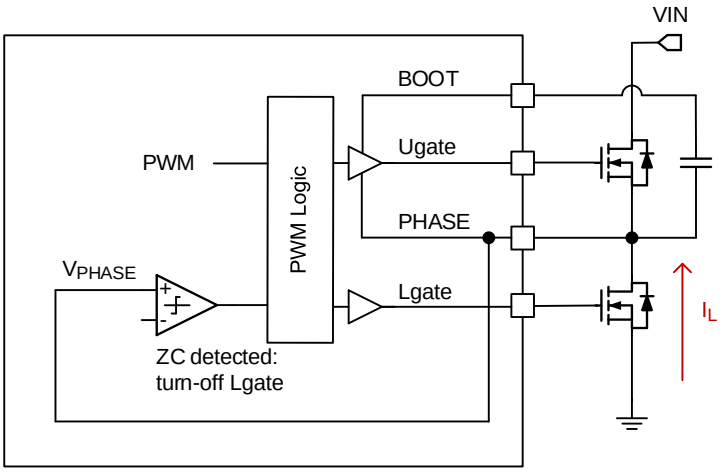

Figure 7. Functional Block Diagram for ZCD

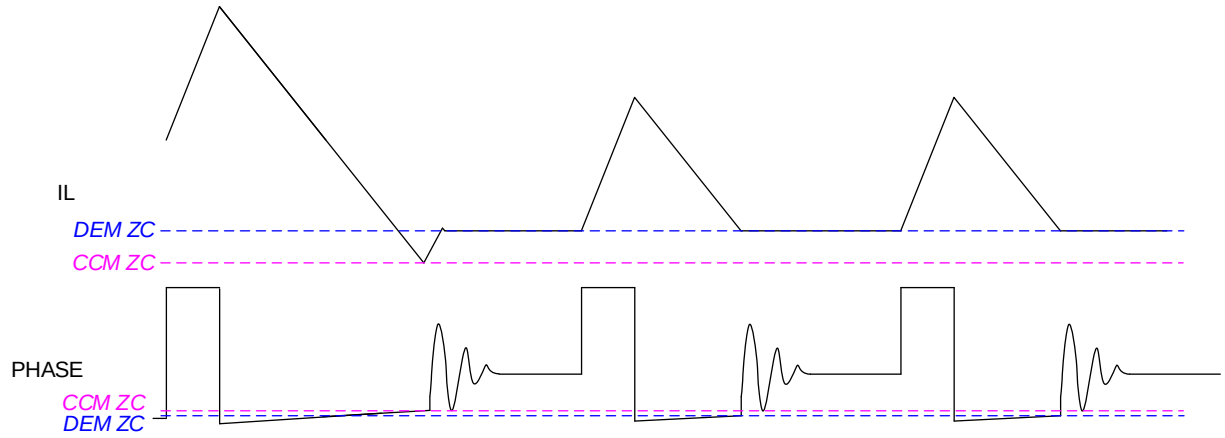

Figure 8. DEM Operation Diagram

To optimize the transition between DEM and CCM and to prevent unstable output voltage due to frequent switching, the ZCD current thresholds for CCM and DEM are designed with hysteresis. In CCM mode, the ZCD threshold is lowered to reduce the likelihood of triggering ZCD. Once in DEM, the ZCD current threshold is raised, making it easier to trigger ZCD in DEM mode. As shown in Figure 9, when the inductor current is high and the device is in CCM mode, the ZCD maintains a lower current threshold (CCM_ZC). After the inductor current decreases and triggers ZCD to enter DEM, the device adjusts the ZCD current threshold upwards to DEM_ZC, which helps the device to operate stably in the DEM state.

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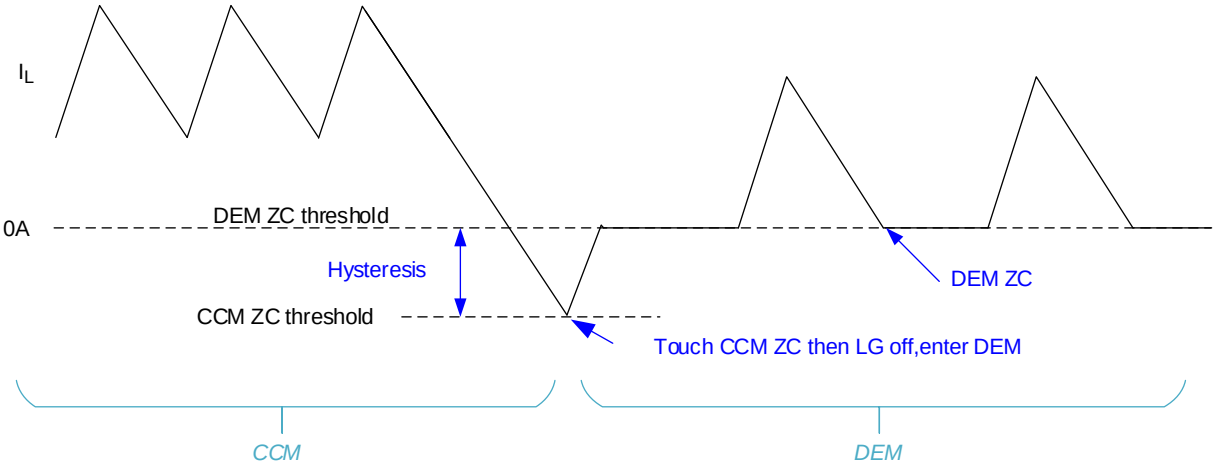

Figure 9. DEM Operation Diagram

The accuracy of ZCD is not only related to the internal design parameters of the device but also to the external inductor current and the selected MOSFET's $R_{DS(ON)}$. To ensure that the device operates correctly in DEM mode, the relationship between the external MOSFET and the inductor current must be considered.

$$R_{DS(ON),min} > \frac{|V_{ZC_TH_MAX}|}{\Delta I_L / 2}$$

$$\Delta I_L = \frac{V_{IN} - V_{OUT}}{L} \times \frac{V_{OUT}}{V_{IN}} \times \frac{1}{F_{sw}}$$

where the $V_{ZC_TH_MAX}$ is the maximum ZCD threshold value in CCM mode, and it is important to note that this ZCD threshold is the maximum value of (PHASEx – GND), as shown in the Electrical Characteristics. When evaluating the ZCD function, it is necessary to consider the operating conditions of the IC as well as the variance in external component parameters.

16.21 Thermal Considerations

For continuous operation, do not exceed absolute maximum junction temperature. The maximum power dissipation depends on the thermal resistance of the IC package, PCB layout, rate of surrounding airflow, and difference between junction and ambient temperature. 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 recommended operating condition specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, θ_{JA}, is layout dependent. For the WQFN-20L 3x3 package, the thermal resistance, θ_{JA}, is 30°C/W on a standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at T_A = 25°C can be calculated using the following formula:

$P_{D(MAX)}$ = (125°C – 25°C) / (30°C /W) = 3.33W for a WQFN-20L 3x3 package.

The maximum power dissipation depends on the operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance, θ_{JA}. The derating curve in Figure 10 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

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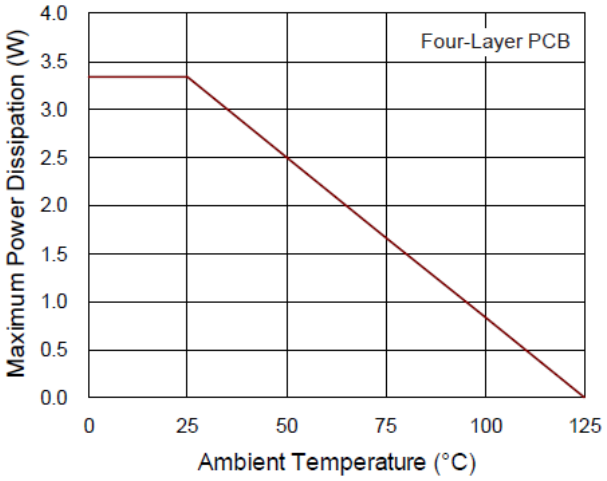

Figure 10. Derating Curve of Maximum Power Dissipation

16.22 Layout Considerations

Layout is very important in high-frequency switching converter design. Improper PCB layout can radiate excessive noise and contribute to the converter's instability. Certain points must be considered before starting a layout with the RT6575E.

- Place the filter capacitor close to the device, within 12mm (0.5 inch) if possible.
- Keep the current limit setting network as close as possible to the device. Routing of the network should avoid coupling to high-voltage switching nodes.
- Connections from the drivers to the respective gate of the high-side or the low-side MOSFET should be as short as possible to reduce stray inductance. Use 0.65mm (25 mils) or wider traces.
- All sensitive analog traces and components, such as FBx, PG, should be placed away from high-voltage switching nodes, such as PHASEx, LGATEx, UGATEx, or BOOTx nodes to avoid coupling. Use internal layer(s) as ground plane(s) and shield the feedback trace from power traces and components.
- Place the ground terminals of VIN capacitor(s), VOUTx capacitor(s), and the source of low-side MOSFETs as close to each other as possible. The PCB trace of PHASEx node, which connects to the source of the high-side MOSFET, the drain of the low-side MOSFET, and the high-voltage side of the inductor, should be as short and wide as possible.

Note 6. 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.

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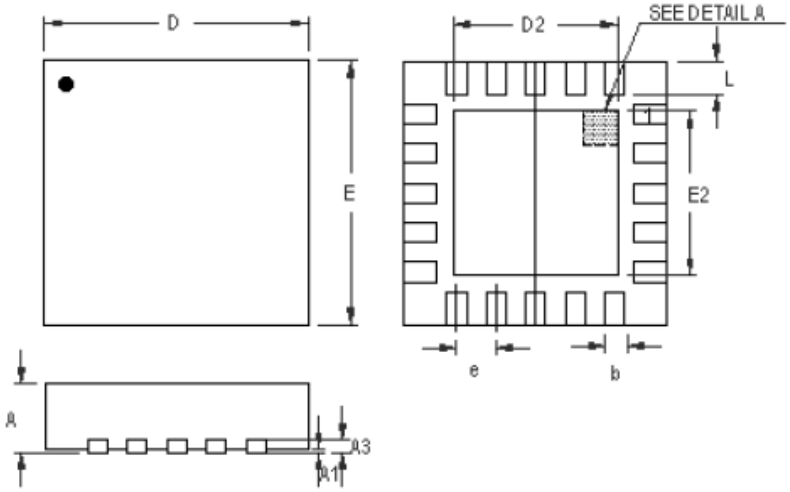
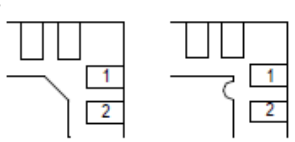
17 Outline Dimension





DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.150	0.250	0.006	0.010
D	2.900	3.100	0.114	0.122
D2	1.650	1.750	0.065	0.069
E	2.900	3.100	0.114	0.122
E2	1.650	1.750	0.065	0.069
e	0.400		0.016	
L	0.350	0.450	0.014	0.018

W-Type 20L QFN 3x3 Package

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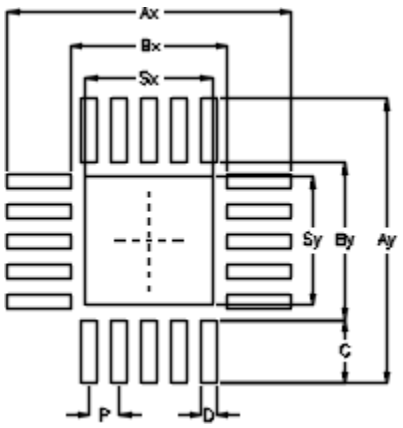
18 Footprint Information



Package	Number of Pin	Footprint Dimension (mm)									Tolerance
		P	Ax	Ay	Bx	By	C	D	Sx	Sy	
V/W/U/XQFN3*3-20	20	0.40	3.80	3.80	2.10	2.10	0.85	0.20	1.70	1.70	±0.05

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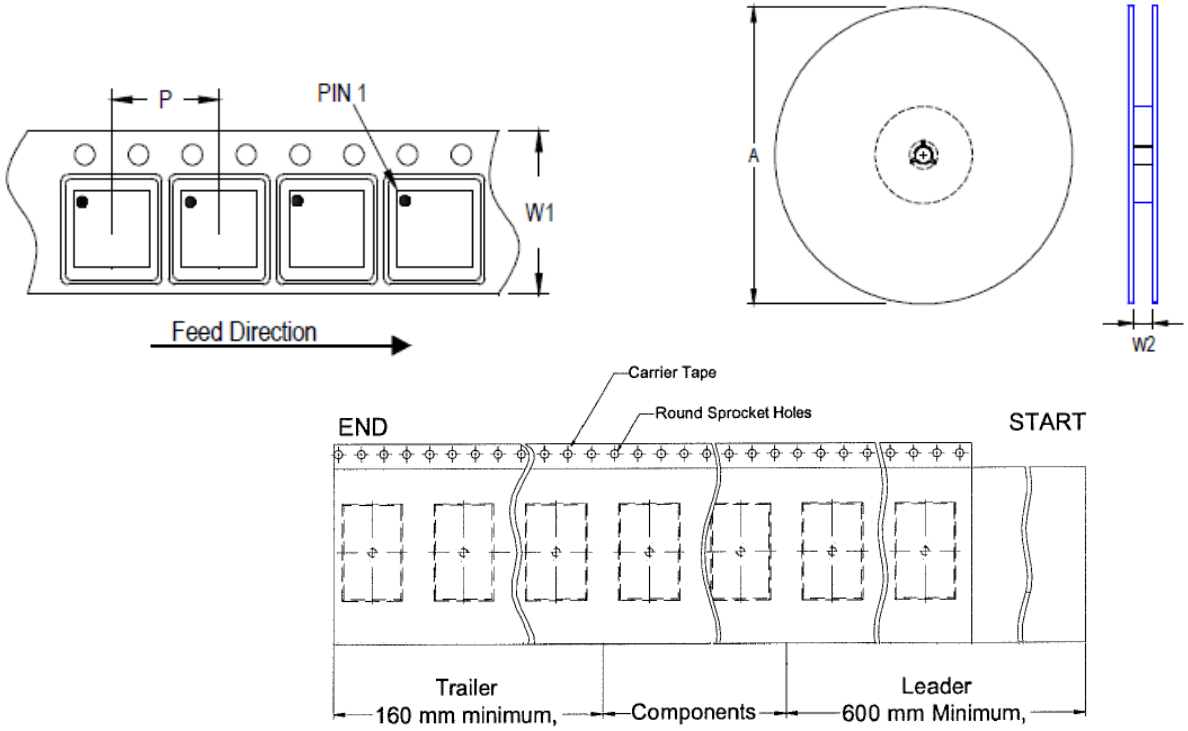
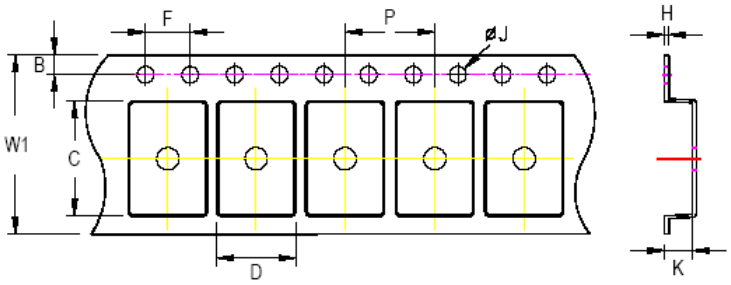
19 Packing Information

19.1 Quadrant 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	12	8	180	7	1,500	160	600	12.4/14.4



C, D, and K are determined by component size. The clearance between the components and the cavity is as follows:
- For 12mm carrier tape: 0.5mm max.

Tape Size	W1	P		B		F		ØJ		H
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Max.
12mm	12.3mm	7.9mm	8.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	0.6mm

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19.2 Quadrant 1 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”	1,500	Box A	3	4,500	Carton A	12	54,000
			Box E	1	1,500	For Combined or Partial Reel.		

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19.3 Quadrant 1 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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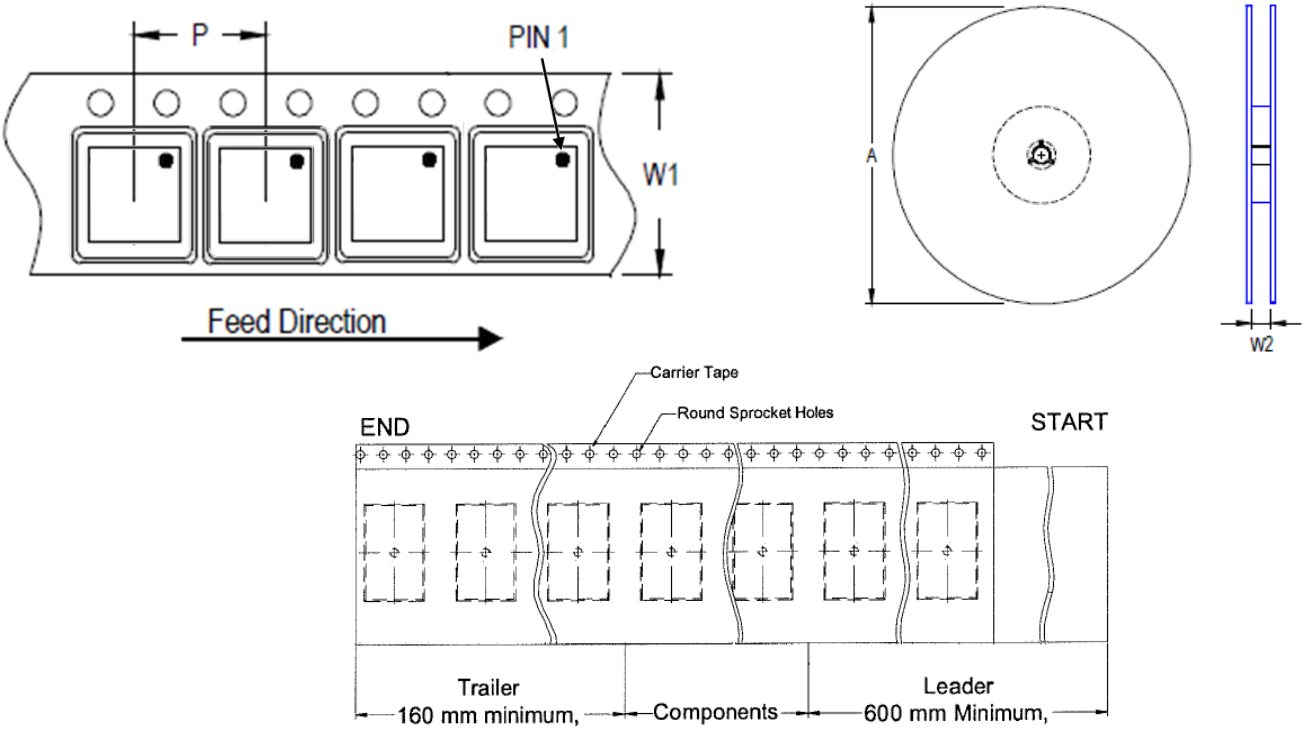
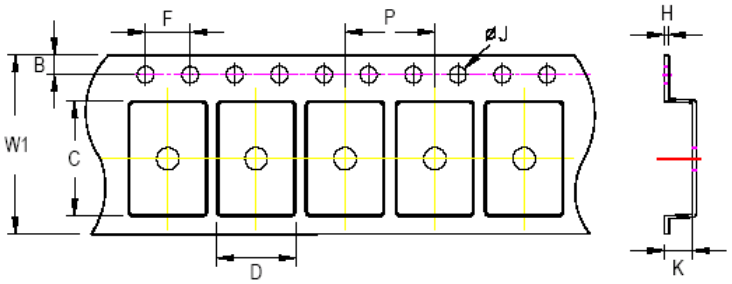
19.4 Quadrant 2 Tape and Reel Data



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	12	8	180	7	1,500	160	600	12.4/14.4



C, D, and K are determined by component size. The clearance between the components and the cavity is as follows:
- For 12mm carrier tape: 0.5mm max.

Tape Size	W1	P		B		F		ØJ		H
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Max.
12mm	12.3mm	7.9mm	8.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	0.6mm

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19.5 Quadrant 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”	1,500	Box A	3	4,500	Carton A	12	54,000
			Box E	1	1,500	For Combined or Partial Reel.		

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19.6 Quadrant 2 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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20 Datasheet Revision History

Version	Date	Description	Item
02	2024/9/25	Modify	*Changed the name of pin 7 to PG* *General Description on page 1* *Features on page 1* *Ordering Information on page 1* *Electrical Characteristics on page 7* *Application Information on page 15 to 25* *Footprint Information on page 27* - Added Footprint Information *Packing Information on page 28 to 33* - Added packing information

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