

## Triple-Channel Synchronous-Rectified Buck MOSFET Driver

### General Description

The RT9605B is a high frequency, triple-channel synchronous-rectified buck MOSFET driver specifically designed to drive six power N-MOSFETs. The part is promoted to pair with Richtek's multiphase buck PWM controller family for high-density power supply implementation. The output drivers of RT9605B can efficiently switch power MOSFETs at frequency 300kHz typically. Operating in higher frequency should consider the thermal dissipation carefully. Each driver of RT9605B is capable to drive a 3nF load in 30/40ns rising/falling time with little propagation delay from input transition to the gate of the power MOSFET. The device implements bootstrapping on the upper gate with only an external capacitor and a diode required. This reduces circuit complexity and allows the use of higher performance, cost effective N-MOSFETs. All drivers incorporate adaptive shoot-through protection to prevent upper and lower MOSFETs from conducting simultaneously and shorting the input supply. The RT9605B also detects the fault condition during initial start-up prior to the multi-phase PWM controller takes control. As a result, the input supply will latch into the shutdown state. The RT9605B comes to a small footprint package with VQFN-24L 4x4 package.

### Ordering Information

RT9605B□□

- Package Type  
QV : VQFN-24L 4x4 (V-Type)  
(Exposed Pad-Option 1)
- Lead Plating System  
P : Pb Free  
G : Green (Halogen Free and Pb Free)  
Z : ECO (Ecological Element with Halogen Free and Pb free)

Note :

Richtek products are :

- ▶ RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- ▶ Suitable for use in SnPb or Pb-free soldering processes.

### Features

- Drive Six N-MOSFETs for 3-Phase Buck PWM Control
- Adaptive Shoot-Through Protection
- Support High Switching Frequency
- Fast Output Rising/Falling Time
- Propagation Delay 40ns
- Tri-State Input for Bridge Shutdown
- Upper MOSFET Direct Short Protection
- Small 24-Lead VQFN Package
- RoHS Compliant and 100% Lead (Pb)-Free

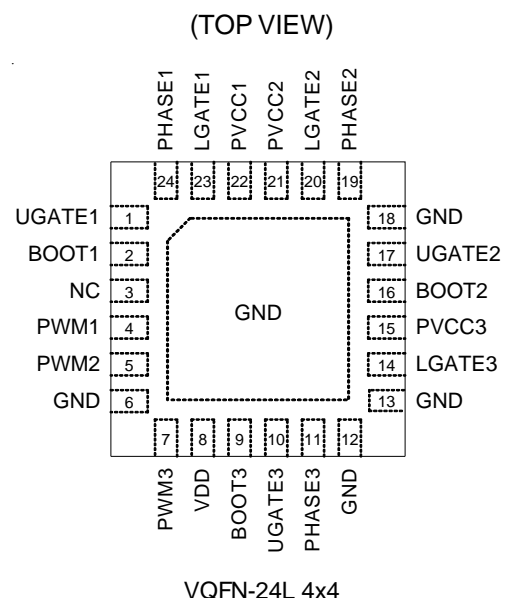
### Applications

- CPU Core Voltage Supplies on Motherboard
- High Frequency Low Profile DC/DC Converters
- High Current Low Voltage DC/DC Converters

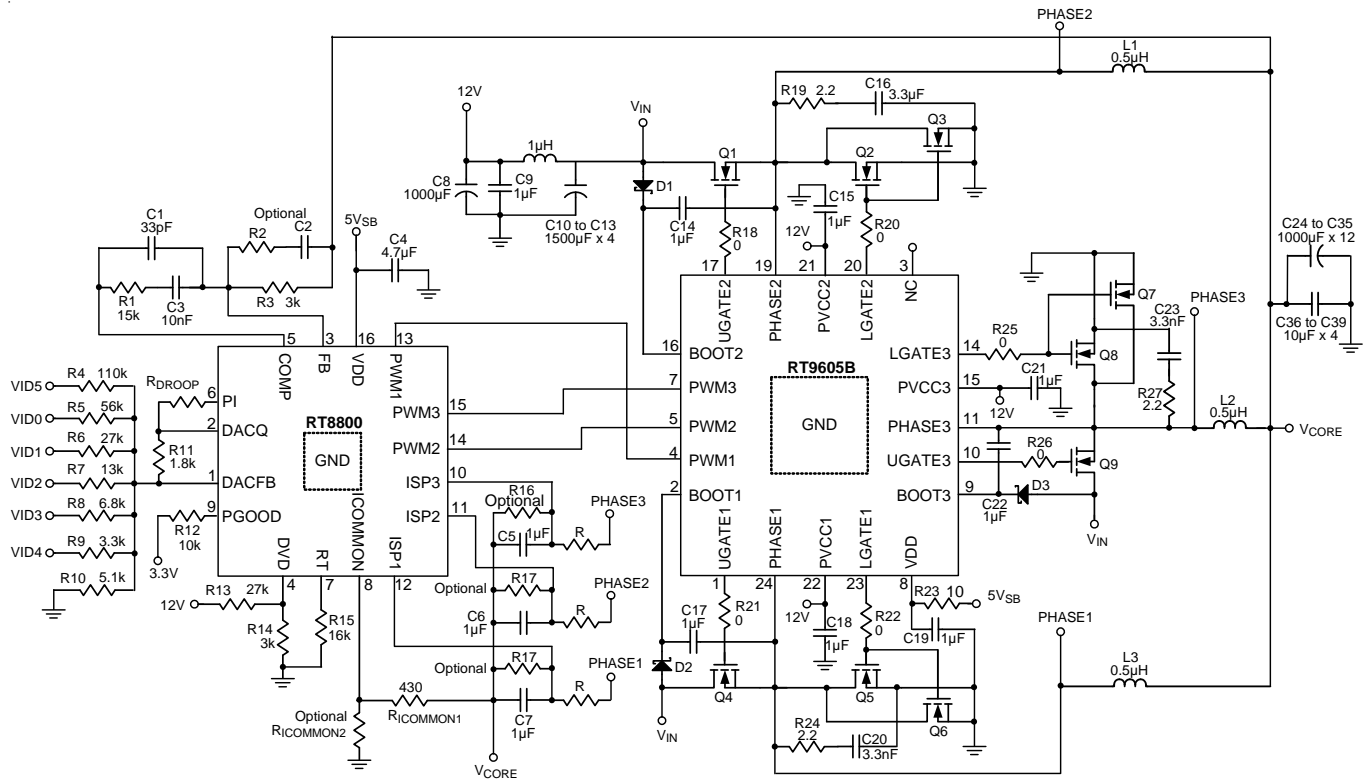
### Marking Information

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

### Pin Configurations



## Typical Application Circuit



## Functional Pin Description

### UGATE1 (Pin 1), UGATE2 (Pin 17), UGATE3 (Pin 10)

Upper Gate Drive Output. Should be connected to the upper MOSFET gate.

### BOOT1 (Pin 2), BOOT2 (Pin 16), BOOT3 (Pin 9)

Floating bootstrap supply pin for the upper gate drive. Connect the bootstrap capacitor between this pin and the PHASE pin. The bootstrap capacitor provides the charge to turn on the upper MOSFET.

### NC (Pin 3)

No connected.

### PWM1 (Pin 4), PWM2 (Pin 5), PWM3 (Pin 7)

PWM input control signal. Connect this pin to the PWM output of the controller. If the PWM signal enters and remains within the shutdown window, are both UGATE and LGATE are driven low, disabling the output MOSFETs.

### GND (Pin 6, 12, 13, 18)

Chip power ground.

### VDD (Pin 8)

Supply Input. Connect to +5V stand-by power. Place a bypass capacitor between this pin and GND.

### PHASE1 (Pin 24), PHASE2 (Pin 19), PHASE3 (Pin 11)

Upper driver return. Should be connected to the common node of upper and lower MOSFETs. The PHASE voltage is monitored for adaptive shoot-through protection.

### LGATE1 (Pin 23), LGATE2 (Pin 20), LGATE3 (Pin 14)

Lower Gate Drive Output. Should be connected to the lower MOSFET gate.

### PVCC1 (Pin 22), PVCC2 (Pin 21), PVCC3 (Pin 15)

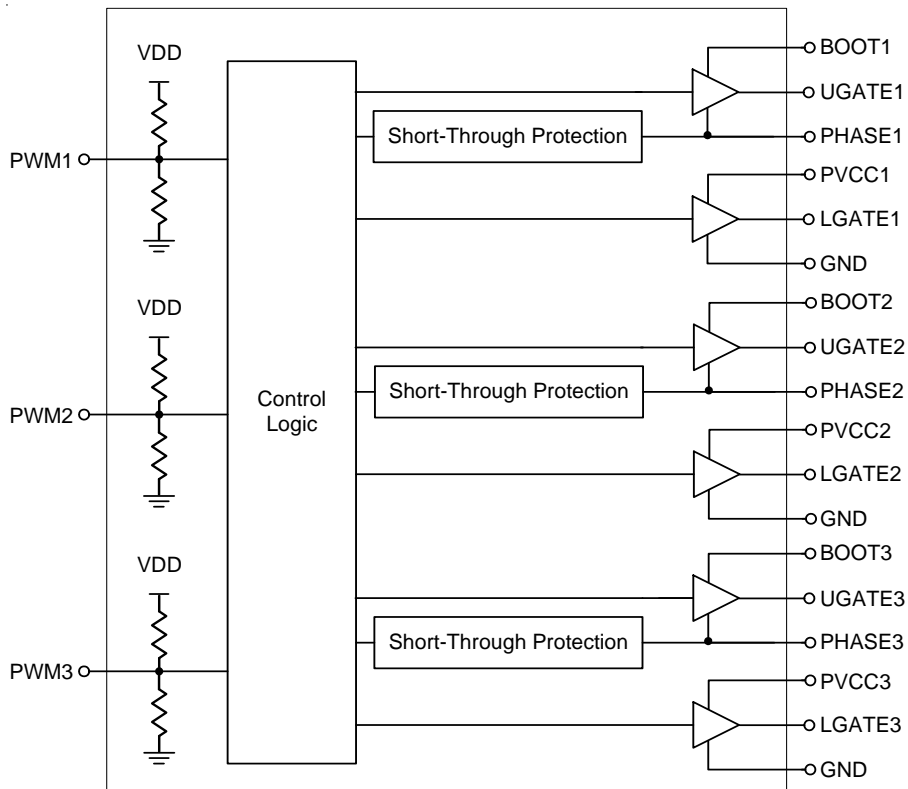
Supply Input. Connect to +12V supply. Place a bypass capacitor between this pin and PGND.

### Exposed Pad

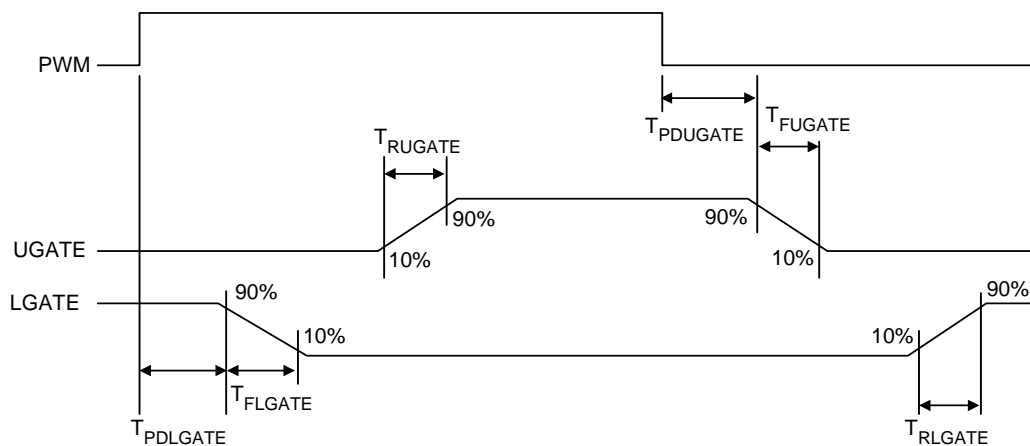
Exposed pad should be soldered to PCB board and connected to GND.

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**Function Block Diagram**



**Timing Diagram**



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## Absolute Maximum Ratings (Note 1)

- Driver Supply Voltage, PVCC ----- -0.3V to 15V
- Core Supply Voltage, VDD ----- -0.3V to 7V
- BOOT to PHASE ----- -0.3V to 15V
- PHASE to GND
  - DC ----- -5V to 15V
  - < 20ns ----- -10V to 30V
- LGATE
  - DC ----- (GND - 0.3V) to (V<sub>PVCC</sub> + 0.3V)
  - < 20ns ----- -2V to (V<sub>PVCC</sub> + 0.3V)
- UGATE
  - DC ----- (V<sub>PHASE</sub> - 0.3V) to (V<sub>BOOT</sub> + 0.3V)
  - < 20ns ----- (V<sub>PHASE</sub> - 2V) to (V<sub>BOOT</sub> + 0.3V)
- PWM Input Voltage ----- (GND - 0.3V) to 7V
- Package Thermal Resistance (Note 2)
  - VQFN-24L 4x4,  $\theta_{JA}$  ----- 67°C/W
- Junction Temperature ----- 150°C
- Lead Temperature (Soldering, 10 sec.) ----- 260°C
- Storage Temperature Range ----- -65°C to 150°C
- ESD Susceptibility (Note 3)
  - HBM (Human Body Mode) ----- 2kV
  - MM (Machine Mode) ----- 150V

## Recommended Operating Conditions (Note 4)

- Driver Supply Voltage, PVCC ----- 12V  $\pm$ 10%
- Core Supply Voltage, VDD ----- 5V  $\pm$ 10%
- Junction Temperature Range ----- -40°C to 125°C
- Ambient Temperature Range ----- -40°C to 85°C

## Electrical Characteristics

(Recommended Operating Conditions, T<sub>A</sub> = 25°C unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
<b>VDD Supply Current</b>						
Operation Current	I <sub>VDD</sub>	Frequency = 250kHz	--	--	10	mA
<b>Power On Reset</b>						
PVCC POR Threshold		V <sub>PVCC</sub> Rising	7.2	8	8.8	V
PVCC Hysteresis			--	1.1	--	V
VDD Threshold		V <sub>DD</sub> Rising	3.7	4	4.3	V
<b>PWM Input</b>						
Input Current	I <sub>PWM</sub>	V <sub>PWM_IN</sub> = 0V	500	600	700	$\mu$ A
		V <sub>PWM_IN</sub> = 5V	200	350	500	
Floating Voltage	V <sub>PWMFL</sub>		1.4	1.8	2.2	V

*To be continued*

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Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
PWM Threshold	V <sub>PWMRTH</sub>	PWM_IN Rising	2.7	3.1	3.5	V
	V <sub>PWMFTH</sub>	PWM_IN Falling	0.8	1	1.3	V
<b>Output</b>						
UGATE Rise Time	t <sub>RUGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	80	--	ns
UGATE Fall Time	t <sub>FUGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	40	--	ns
LGATE Rise Time	t <sub>RLGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	40	--	ns
LGATE Fall Time	t <sub>FLGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	25	--	ns
UGATE Turn-Off Propagation Delay	t <sub>PDUGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	30	--	ns
LGATE Turn-Off Propagation Delay	t <sub>PDLGATE</sub>	PV <sub>CC</sub> = 12V, 3nF load	--	25	--	ns
Shutdown Window			0.8	--	3.5	V

**Note 1.** Stresses listed as the above “Absolute Maximum Ratings” may cause permanent damage to the device. These are for stress ratings. 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 for extended periods may remain possibility to affect device reliability.

**Note 2.**  $\theta_{JA}$  is measured in the natural convection at T<sub>A</sub> = 25°C on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

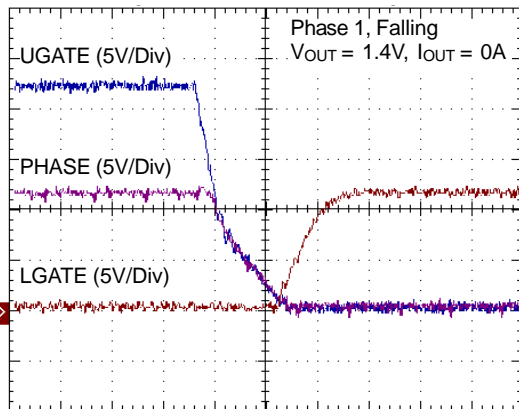
**Note 3.** Devices are ESD sensitive. Handling precaution recommended.

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

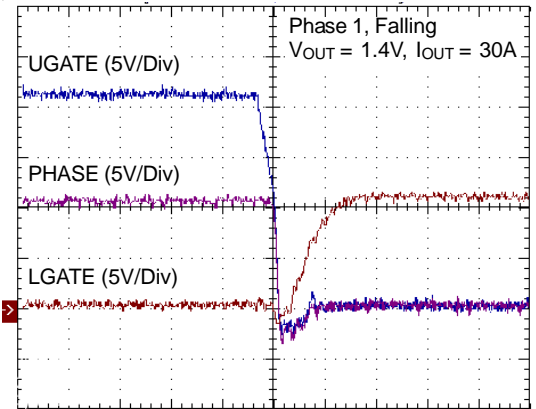
## Typical Operating Characteristics

$V_{IN} = 12V$ , unless otherwise specified.

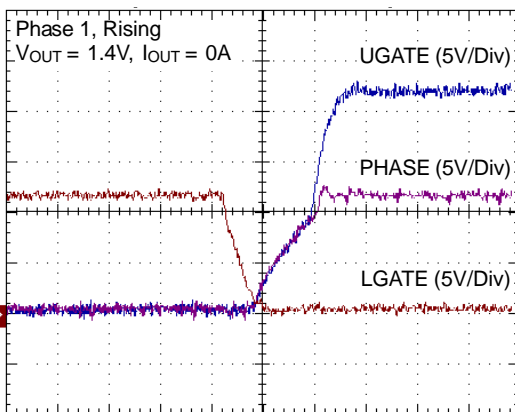
### Dead Time



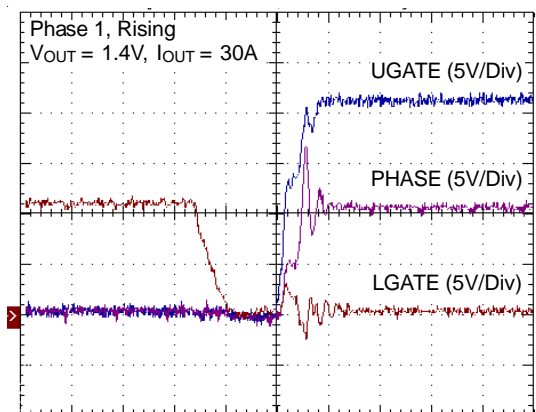
### Dead Time



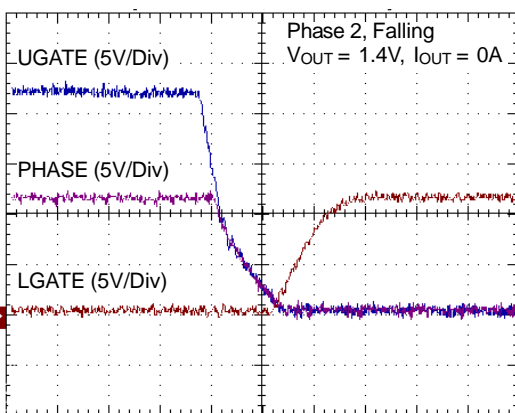
### Dead Time



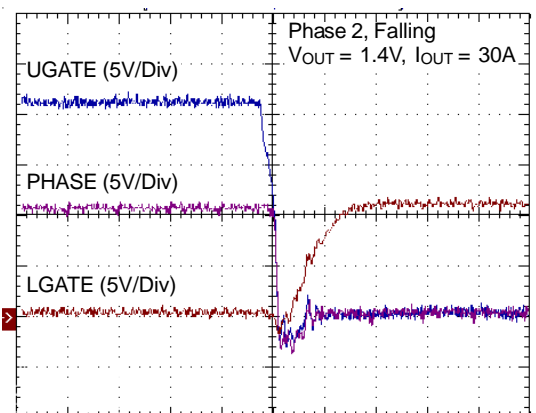
### Dead Time



### Dead Time

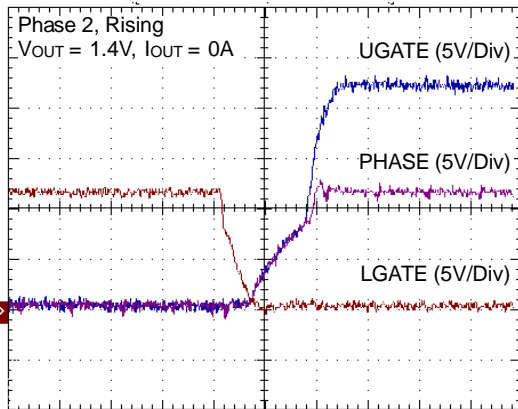


### Dead Time



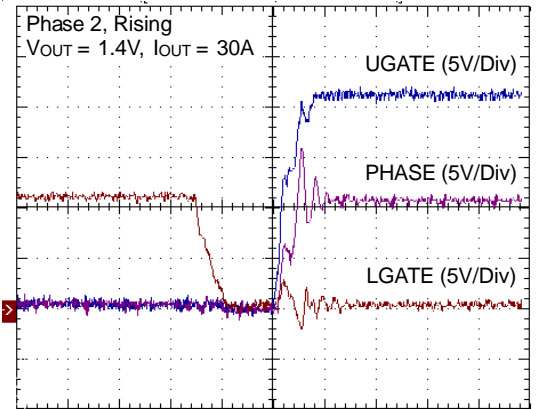
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**Dead Time**



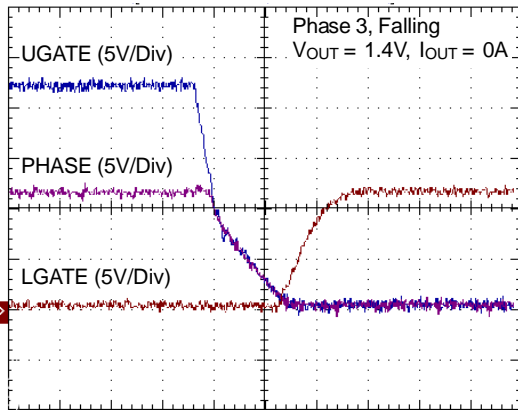
Time (50ns/Div)

**Dead Time**



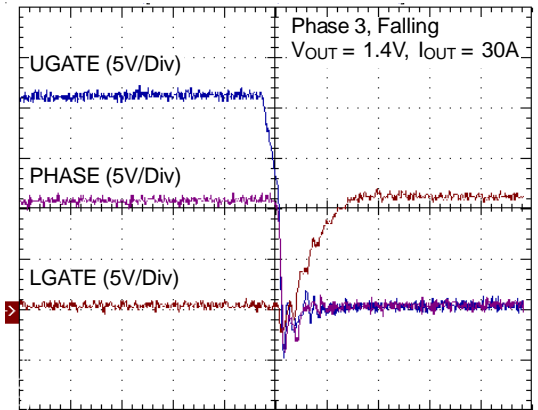
Time (50ns/Div)

**Dead Time**



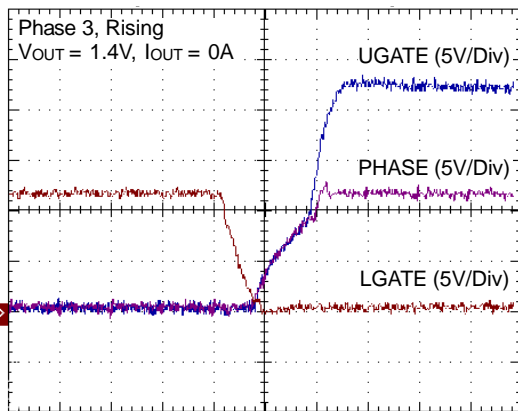
Time (50ns/Div)

**Dead Time**



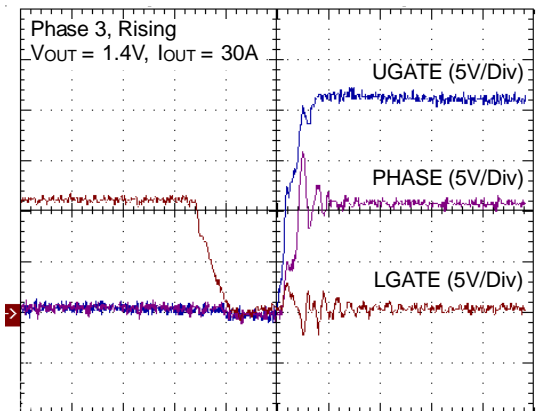
Time (50ns/Div)

**Dead Time**



Time (50ns/Div)

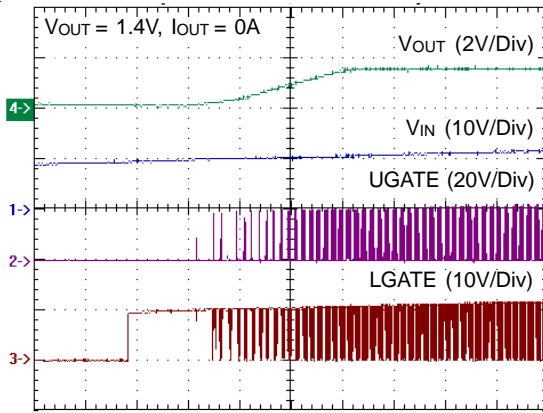
**Dead Time**



Time (50ns/Div)

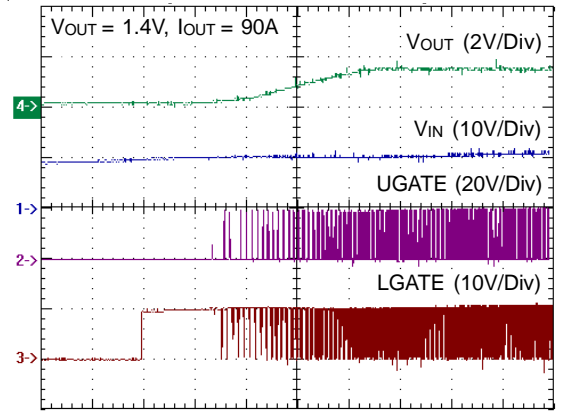
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**Power On**



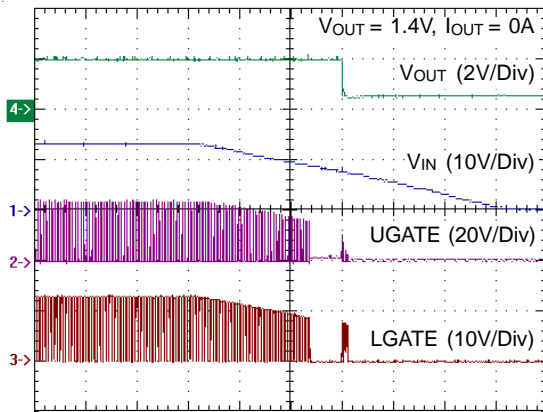
Time (2.5ms/Div)

**Power On**



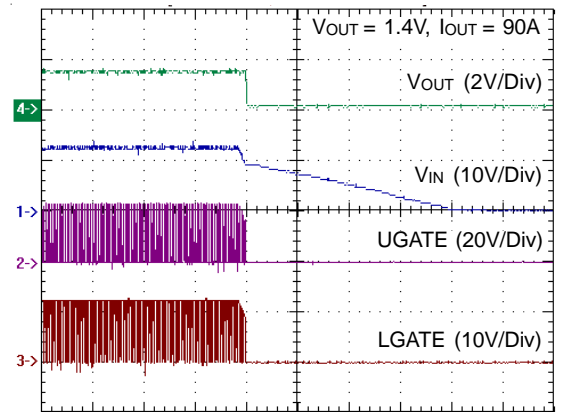
Time (2.5ms/Div)

**Power Off**



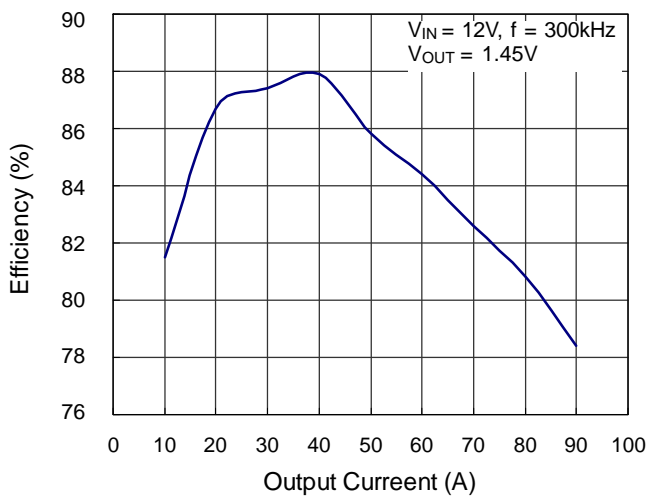
Time (25ms/Div)

**Power Off**



Time (25ms/Div)

**Efficiency vs. Output Current**



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**Application Information**

The RT9605B is designed to drive three sets of both high side and low side N-MOSFET through externally input PWM control signal. It has power-on protection function which held UGATE and LGATE low before PV<sub>CC</sub> rising across the threshold voltage. After the initialization, the PWM signal takes the control. The rising PWM signal first forces the LGATE turns low then UGATE is allowed to go high just after a non-overlapping time to avoid shoot-through. The falling of PWM signal first forces UGATE to go low. When UGATE and PHASE reach a predetermined low level, LGATE is allowed to turn high. The non-overlapping function is also presented between UGATE and LGATE signal transient.

The PWM signal is acted as "High" if above the rising threshold and acted as "Low" if below the falling threshold. Any signal level remaining within the shutdown window is considered as "tri-state", the output drivers are disabled and both MOSFET gates are pulled and held low. If the PWM signal floating, the pin will be kept at 2.1V by the internal divider and provide the PWM controller with a recognizable level.

The RT9605B typically operates at frequency of 200kHz to 300kHz. It shall be noted that to place a 1N4148 or schottky diode between the PV<sub>CC</sub> and BOOT pin as shown in the typical application circuit.

**Driving Power MOSFETs**

The DC input impedance of the power MOSFET is extremely high. When V<sub>gs</sub> at 12V, the gate draws the current only few nano-amperes. Thus once the gate has been driven up to "ON" level, the current could be negligible.

However, the capacitance at the gate to source terminal should be considered. It requires relatively large current to source and sink the gate rapidly. It also needs to switch drain current on and off with high speed. The required gate drive currents are calculated as follows.

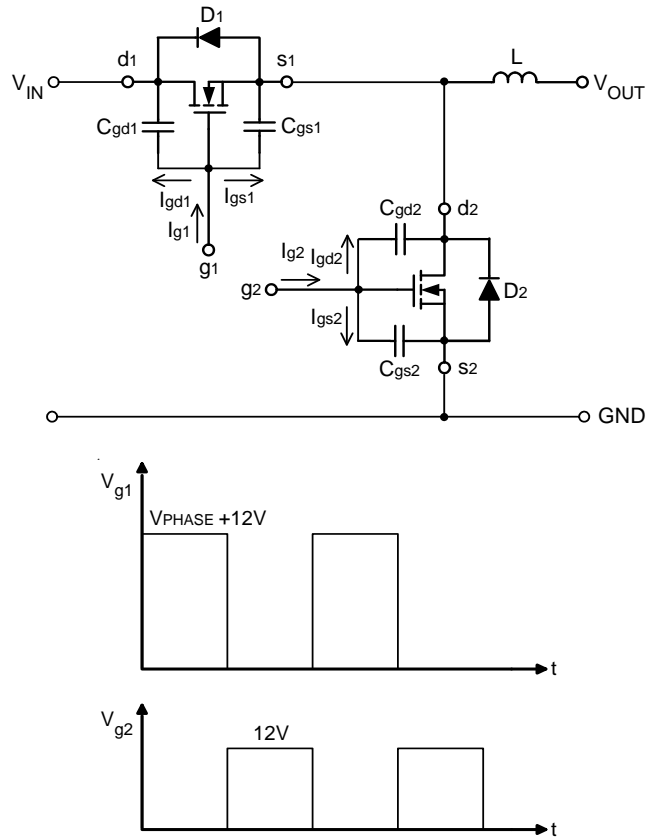


Figure 1. Equivalent Circuit and Associated Waveforms

In Figure 1, the current I<sub>g1</sub> and I<sub>g2</sub> are required to move the gate up to 12V. The operation consists of charging C<sub>gd</sub> and C<sub>gs</sub>. C<sub>gs1</sub> and C<sub>gs2</sub> are the capacitances from gate to source of the high side and the low side power MOSFETs, respectively. In general data sheets, the C<sub>gs</sub> is referred as "C<sub>iss</sub>" which is the input capacitance. C<sub>gd1</sub> and C<sub>gd2</sub> are the capacitances from gate to drain of the high side and the low side power MOSFETs, respectively and referred to the data sheets as "C<sub>riss</sub>" the reverse transfer capacitance. For example, t<sub>r1</sub> and t<sub>r2</sub> are the rising time of the high side and the low side power MOSFETs respectively, the required current I<sub>gs1</sub> and I<sub>gs2</sub> are showed below :

$$I_{gs1} = C_{gs1} \frac{dV_{g1}}{dt} = \frac{C_{gs1} \times 12}{t_{r1}} \tag{1}$$

$$I_{gs2} = C_{gs2} \frac{dV_{g2}}{dt} = \frac{C_{gs2} \times 12}{t_{r2}} \tag{2}$$

Before driving the gate of the high side MOSFET up to 12V (or 5V), the low side MOSFET has to be off; and the high side MOSFET is turned off before the low side is turned on. From Figure 1, the body diode "D<sub>2</sub>" had been turned on before high side MOSFETs turned on.

$$I_{gd1} = C_{gd1} \frac{dV}{dt} = C_{gd1} \frac{12V}{t_{r1}} \quad (3)$$

Before the low side MOSFET is turned on, the C<sub>gd2</sub> have been charged to V<sub>IN</sub>. Thus, as C<sub>gd2</sub> reverses its polarity and g<sub>2</sub> is charged up to 12V, the required current is

$$I_{gd2} = C_{gd2} \frac{dV}{dt} = C_{gd2} \frac{V_{IN} \times 12}{t_{r2}} \quad (4)$$

It is helpful to calculate these currents in a typical case. Assume a synchronous rectified buck converter, input voltage V<sub>IN</sub> = 12V, V<sub>g1</sub> = V<sub>g2</sub> = 12V. The high side MOSFET is PHB83N03LT whose C<sub>iss</sub> = 1660pF, C<sub>rss</sub> = 380pF, and t<sub>r</sub> = 14ns. The low side MOSFET is PHB95N03LT whose C<sub>iss</sub> = 2200pF, C<sub>rss</sub> = 500pF and t<sub>r</sub> = 30ns, from the equation (1) and (2) we can obtain

$$I_{gs1} = \frac{1660 \times 10^{-12} \times 12}{14 \times 10^{-9}} = 1.428 \text{ (A)} \quad (5)$$

$$I_{gs2} = \frac{2200 \times 10^{-12} \times 12}{30 \times 10^{-9}} = 0.88 \text{ (A)} \quad (6)$$

from equation. (3) and (4)

$$I_{gd1} = \frac{380 \times 10^{-12} \times 12}{14 \times 10^{-9}} = 0.326 \text{ (A)} \quad (7)$$

$$I_{gd2} = \frac{500 \times 10^{-12} \times (12 + 12)}{30 \times 10^{-9}} = 0.4 \text{ (A)} \quad (8)$$

the total current required from the gate driving source is

$$I_{g1} = I_{gs1} + I_{gd1} = (1.428 + 0.326) = 1.745 \text{ (A)} \quad (9)$$

$$I_{g2} = I_{gs2} + I_{gd2} = (0.88 + 0.4) = 1.28 \text{ (A)} \quad (10)$$

By a similar calculation, we can also get the sink current required from the turned off MOSFET.

## Select the Bootstrap Capacitor

Figure 2 shows part of the bootstrap circuit of RT9605B. The V<sub>CB</sub> (the voltage difference between BOOT and PHASE pins provides a voltage to the gate of the high side power MOSFET. This supply needs to be ensured that the MOSFET can be driven. For this, the capacitance C<sub>B</sub> has to be selected properly. It is determined by following constraints.

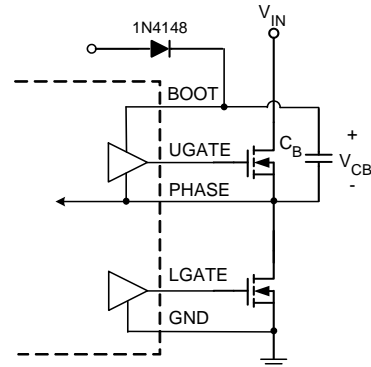


Figure 2. Part of Bootstrap Circuit of RT9605B

In practice, a low value capacitor C<sub>B</sub> will lead the overcharging that could damage the IC. Therefore to minimize the risk of overcharging and reducing the ripple on V<sub>CB</sub>, the bootstrap capacitor should not be smaller than 0.1μF, and the larger the better. In general design, using 1μF can provide better performance. At least one low-ESR capacitor should be used to provide good local de-coupling. Here, to adopt either a ceramic or tantalum capacitor is suitable.

## Power Dissipation

For not exceeding the maximum allowable power dissipation to drive the IC beyond the maximum recommended operating junction temperature of 125°C, it is necessary to calculate power dissipation appropriately. This dissipation is a function of switching frequency and total gate charge of the selected MOSFET. Figure 3 shows the power dissipation test circuit. C<sub>L</sub> and C<sub>U</sub> are the UGATE and LGATE load capacitors, respectively. The bootstrap capacitor value is 1μF.

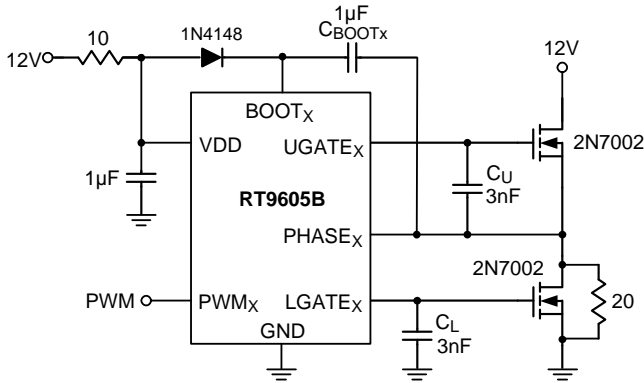


Figure 3. Test Circuit (One Phase is Shown)

Figure 4 shows the power dissipation of the RT9605B as a function of frequency and load capacitance. The value of the  $C_U$  and  $C_L$  are the same and the frequency is varied from 100kHz to 1MHz.

The operating junction temperature can be calculated from the power dissipation curves (Figure 4). Assume  $V_{DD} = 12V$ , operating frequency is 200kHz and the  $C_U=C_L=1nF$  which emulate the input capacitances of the high side and low side power MOSFETs. From Figure 4, the power dissipation is 100mW. For RT9605B, the package thermal resistance  $\theta_{JA}$  is  $67^\circ C/W$ , the operating junction temperature is calculated as :

$$T_J = (67^\circ C/W \times 100mW) + 25^\circ C = 31.7^\circ C \quad (11)$$

where the ambient temperature is  $25^\circ C$ .

The method to improve the thermal transfer is to increase the PC board copper area around the RT9605B firstly. Then, adding a ground pad under IC to transfer the heat to the peripheral of the board.

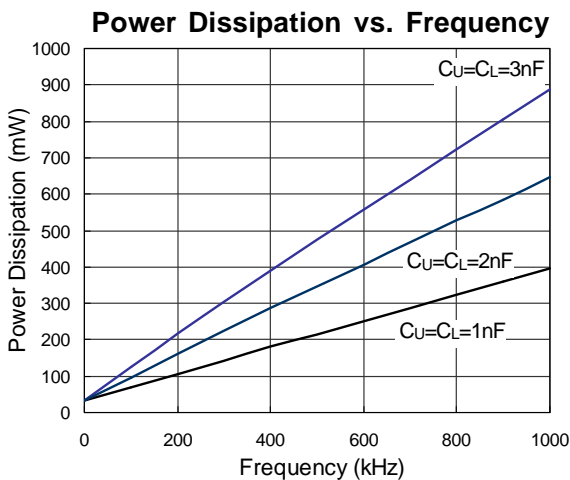


Figure 4. Power Dissipation vs. Frequency

### Over Voltage Protection Function at Power On

An unique feature of the RT9605B is the addition of over voltage protection in the event of upper MOSFET direct shorted before power on. The RT9605B detects the fault condition during initial start-up, the internal power on OVP sense circuitry will rapidly drive the low side MOSFET on before the multi-phase PWM controller takes control.

Figure 5 shows the measured waveforms with the high side MOSFET directly shorted to 12V.

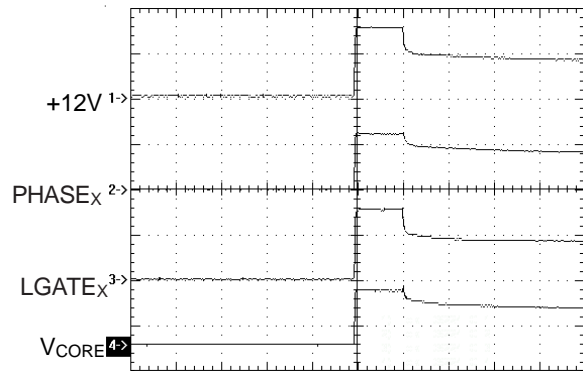


Figure 5. Waveforms at High Side MOSFET Shorted

Please note that the +12V trigger point to RT9605B is at 3V, and the clamped level on PHASE pin is at about 2.4V. Obviously since the PHASE pin voltage increases during initial start-up, the  $V_{CORE}$  increases correspondingly, but it would quickly drop-off following the voltage in LGATE and +12V.

### Layout Consideration

Figure 6 shows the schematic circuit of a two-phase synchronous buck converter to implement the either phase of RT9605B. The converter operates at  $V_{IN} 12V$ .

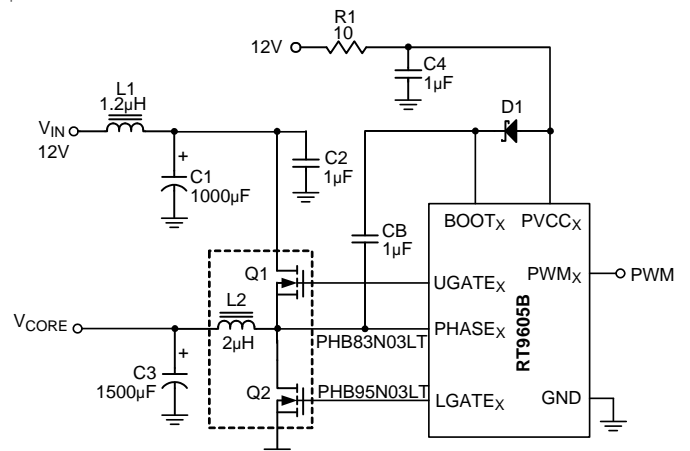
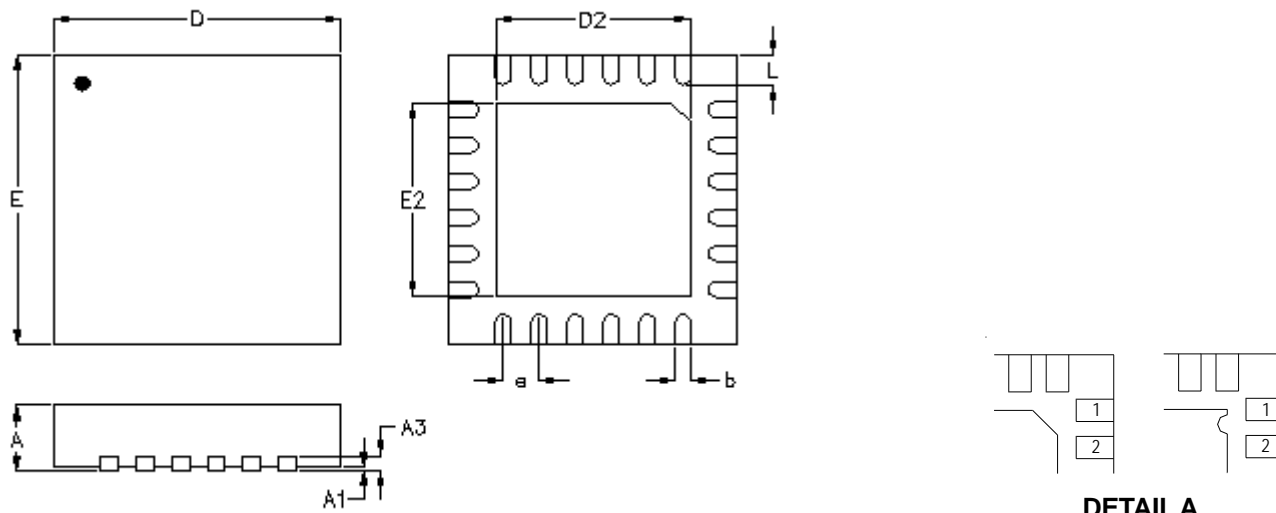


Figure 6. Sync. Buck Converter Circuit

When layout the PC board, it should be very careful. The power-circuit section is the most critical one. If not configured properly, it will generate a large amount of EMI. The junction of Q1, Q2, L2 should be very close.

Next, the trace from UGATE, and LGATE to the gates of MOSFET should also be short to decrease the noise of the driver output signals. The bypass capacitor C4 should be connected to GND directly. Furthermore, the bootstrap capacitors ( $C_B$ ) should always be placed as close to the pins of the IC as possible. The trace from PHASE to the common node of the two MOSFETs should be kept wide since it usually carries large current.

**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	0.800	1.000	0.031	0.039	
A1	0.000	0.050	0.000	0.002	
A3	0.175	0.250	0.007	0.010	
b	0.180	0.300	0.007	0.012	
D	3.950	4.050	0.156	0.159	
D2	Option 1	2.400	2.500	0.094	0.098
	Option 2	2.650	2.750	0.104	0.108
E	3.950	4.050	0.156	0.159	
E2	Option 1	2.400	2.500	0.094	0.098
	Option 2	2.650	2.750	0.104	0.108
e	0.500		0.020		
L	0.350	0.450	0.014	0.018	

**V-Type 24L QFN 4x4 Package**

**Richtek Technology Corporation**

14F, No. 8, Tai Yuen 1<sup>st</sup> Street, Chupei City  
 Hsinchu, Taiwan, R.O.C.  
 Tel: (8863)5526789

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