



**THE DATASHEET OF  
LTC7060EMSE#PBF**



# 100V Half-Bridge Driver with Floating Grounds and Adjustable Dead-Time

## FEATURES

- **Unique Symmetric Floating Gate Driver Architecture**
- **High Noise Immunity, Tolerates ±10V Ground Difference between Input and Output Grounds**
- **100V Maximum Input Voltage Independent of IC Supply Voltage  $V_{CC}$**
- **6V to 14V  $V_{CC}$  Operating Voltage**
- **4V to 14V Gate Driver Voltage**
- **0.8Ω Pull-Down, 1.5Ω Pull-Up for Fast Turn-On/Off**
- **Adaptive Shoot-Through Protection**
- **Programmable Dead-Time**
- **Three-State PWM Input with Enable Pin**
- **$V_{CC}$  UVLO/OVLO and Floating Supplies UVLO**
- **Drives Dual N-Channel MOSFETs**
- **Open-Drain Fault Indicator**
- **Available in Thermally Enhanced 12-LEAD MSOP**
- **AEC-Q100 Qualified for Automotive Applications**

## APPLICATIONS

- Automotive and Industrial Power Systems
- Telecommunication Power Systems
- Half-Bridge and Full-Bridge Converters

## DESCRIPTION

The **LTC®7060** drives two N-Channel MOSFETs in a half-bridge configuration with supply voltages up to 100V. Both high-side and low-side drivers can drive the MOSFETs with a different ground reference, providing excellent noise and transient immunity.

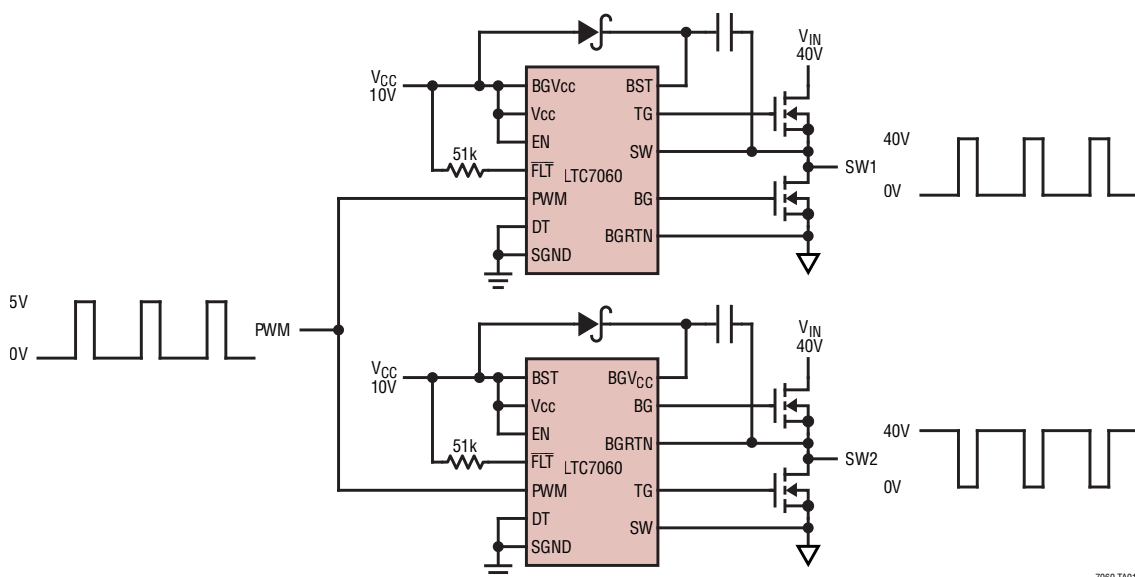
Its powerful 0.8Ω pull-down and 1.5Ω pull-up MOSFET drivers allows the use of large gate capacitance high voltage MOSFETs. Additional features include UVLO, Three-State PWM input, adjustable turn-on/-off delays and shoot-through protection.

See chart below for a similar driver in this product family.

PARAMETER	LTC7060	LTC7061	LTC7062	LTC7063
Input Signal	Three-State PWM	CMOS/TTL Logic	CMOS/TTL Logic	Three-State PWM
Shoot-Through Protection	Yes	Yes	No	Yes
Absolute Max Voltage	115V	115V	115V	155V
$V_{CC}$ Falling UVLO	5.3V	4.3V	4.3V	5.3V

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## TYPICAL APPLICATION



7060 TAD1

# LTC7060

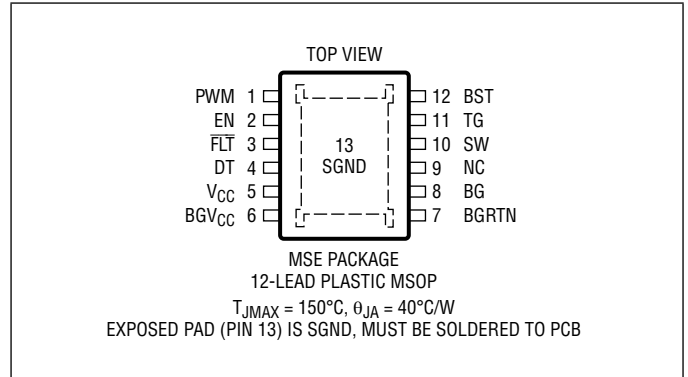
## ABSOLUTE MAXIMUM RATINGS

(Note 1)

$V_{CC}$ Supply Voltage	-0.3V to 15V
Top Side Driver Voltage (BST)	-0.3V to 115V
Bottom Side Driver Voltage ( $BGV_{CC}$ )	-0.3V to 115V
SW, BGRTN	-10V to 100V
(BST-SW)	-0.3V to 15V
( $BGV_{CC}$ -BGRTN)	-0.3V to 15V
EN, $\overline{FLT}$	-0.3V to 15V
DT, PWM	-0.3V to 6V
Driver Output TG (with Respect to SW)	-0.3V to 15V
Driver Output BG (with Respect to BGRTN)	-0.3V to 15V
Operating Junction Temperature Range (Note 2, 3)	-40°C to 150°C
Storage Temperature Range	-65°C to 150°C

Note: All voltages are referred to SGND unless otherwise noted.

## PIN CONFIGURATION



## ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LTC7060EMSE#PBF	LTC7060EMSE#TRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 125°C
LTC7060IMSE#PBF	LTC7060IMSE#TRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 125°C
LTC7060JMSE#PBF	LTC7060JMSE#TRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 150°C
LTC7060HMSE#PBF	LTC7060HMSE#TRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 150°C
<b>AUTOMOTIVE PRODUCTS**</b>				
LTC7060EMSE#WPBF	LTC7060EMSE#WTRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 125°C
LTC7060IMSE#WPBF	LTC7060IMSE#WTRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 125°C
LTC7060JMSE#WPBF	LTC7060JMSE#WTRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 150°C
LTC7060HMSE#WPBF	LTC7060HMSE#WTRPBF	LTC7060	12-Lead Plastic MSSOP	-40°C to 150°C

Contact the factory for parts specified with wider operating temperature ranges. \*The temperature grade is identified by a label on the shipping container.

**Tape and reel specifications.** Some packages are available in 500 unit reels through designated sales channels with #TRMPBF suffix.

\*\*Versions of this part are available with controlled manufacturing to support the quality and reliability requirements of automotive applications. These models are designated with a #W suffix. Only the automotive grade products shown are available for use in automotive applications. Contact your local Analog Devices account representative for specific product ordering information and to obtain the specific Automotive Reliability reports for these models.

**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the specified operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$  (Note 2).  $V_{CC} = V_{BGVCC} = V_{BST} = 10\text{V}$ ,  $V_{BGRTN} = V_{SW} = 0\text{V}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	
<b>Input Supply and <math>V_{CC}</math> Supply</b>							
$V_{IN}$	Input Supply Operating Range				100	V	
$V_{CC}$	IC Supply Operating Range		6		14	V	
$I_{VCC}$	$V_{CC}$ Supply Current	$V_{EN} = V_{PWM} = 0\text{V}$ , $R_{DT} = 100\text{k}\Omega$		0.4		mA	
$V_{UVLO\_VCC}$	$V_{CC}$ Undervoltage Lockout Threshold	$V_{CC}$ Falling	5	5.3	5.6	V	
		Hysteresis		0.3		V	
$V_{OVLO\_VCC}$	$V_{CC}$ OVLO Threshold	$V_{CC}$ Rising		14.6		V	
		Hysteresis		0.8		V	
<b>BG Gate Driver Supply (<math>BGV_{CC}</math>-BGRTN)</b>							
$V_{BGVCC-BGRTN}$	BG Driver Supply Voltage Range (With Respect to BGRTN)		4		14	V	
$I_{BGVCC}$	Total $BGV_{CC}$ Current (Note 4)	BG = Low		8		$\mu\text{A}$	
		BG = High		100		$\mu\text{A}$	
$V_{UVLO\_BGVCC}$	Undervoltage Lockout Threshold	$BGV_{CC}$ Falling, With Respect to BGRTN		3.4		V	
		Hysteresis		0.3		V	
<b>TG Gate Driver Supply (BST-SW)</b>							
$V_{BST-SW}$	TG Driver Supply Voltage Range (With Respect to SW)		4		14	V	
$I_{BST}$	Total BST Current (Note 4)	TG = Low		8		$\mu\text{A}$	
		TG = High		100		$\mu\text{A}$	
$V_{UVLO\_BST}$	Undervoltage Lockout Threshold	BST Falling, With Respect to SW		3.4		V	
		Hysteresis		0.3		V	
<b>Input Signal (PWM, EN)</b>							
$V_{IH(TG)}$	TG Turn-On Input Threshold	PWM Rising	●	2.6	3.1	3.6	V
$V_{IL(TG)}$	TG Turn-Off Input Threshold	PWM Falling	●	2.45	2.95	3.45	V
$V_{IH(BG)}$	BG Turn-On Input Threshold	PWM Falling	●	0.5	1	1.5	V
$V_{IL(BG)}$	BG Turn-Off Input Threshold	PWM Rising	●	0.75	1.25	1.75	V
$V_{PWM\_TRI}$	PWM Input Three-State Float Voltage			1.9	2.1	2.3	V
$R_{UP\_PWM}$	PWM Internal Pull-Up Resistor	To Internal 4.5V Supply		48		$\text{k}\Omega$	
$R_{DOWN\_PWM}$	PWM Internal Pull-Down Resistor			42		$\text{k}\Omega$	
$V_{ENR}$	EN Pin Rising Threshold	EN Rising	●	1.1	1.2	1.3	V
$V_{ENF}$	EN Pin Falling Threshold	EN Falling		1.1		V	
$R_{EN}$	EN Pin Internal Pull-Down Resistor			2		$\text{M}\Omega$	
<b>Dead-Time and FAULT (DT, FLT)</b>							
$t_{PLH(BG)} / t_{PLH(TG)}$	BG/TG Low to TG/BG High Propagation Delay (Dead-Time)	$R_{DT} = 0\Omega$		32		ns	
		$R_{DT} = 24.9\text{k}\Omega$		43		ns	
		$R_{DT} = 64.9\text{k}\Omega$		62		ns	
		$R_{DT} = 100\text{k}\Omega$		76		ns	
		$R_{DT} = \text{Open}$		250		ns	
$R_{FLTb}$	Open Drain Pull-Down Resistance			60		$\Omega$	
$t_{FLTb}$	FLT Pin Release Delay	Low to High		100		$\mu\text{s}$	

**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the specified operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$  (Note 2).  $V_{CC} = V_{BGVCC} = V_{BST} = 10\text{V}$ ,  $V_{BGRTN} = V_{SW} = 0\text{V}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>Low Side Gate Driver Output (BG)</b>						
$V_{OH(BG)}$	BG High Output Voltage	$I_{BG} = -100\text{mA}$ , $V_{OH(BG)} = V_{BGVCC} - V_{BG}$		150		mV
$V_{OL(BG)}$	BG Low Output Voltage	$I_{BG} = 100\text{mA}$ , $V_{OL(BG)} = V_{BG} - V_{BGRTN}$		80		mV
$R_{UP(BG)}$	BG Pull-Up Resistance	$V_{BGVCC-BGRTN} = 10\text{V}$		1.5		$\Omega$
$R_{DOWN(BG)}$	BG Pull-Down Resistance	$V_{BGVCC-BGRTN} = 10\text{V}$		0.8		$\Omega$
<b>High Side Gate Driver Output (TG)</b>						
$V_{OH(TG)}$	TG High Output Voltage	$I_{TG} = -100\text{mA}$ , $V_{OH(TG)} = V_{BST} - V_{TG}$		150		mV
$V_{OL(TG)}$	TG Low Output Voltage	$I_{TG} = 100\text{mA}$ , $V_{OL(TG)} = V_{TG} - V_{SW}$		80		mV
$R_{UP(TG)}$	TG Pull-Up Resistance	$V_{BST-SW} = 10\text{V}$		1.5		$\Omega$
$R_{DOWN(TG)}$	TG Pull-Down Resistance	$V_{BST-SW} = 10\text{V}$		0.8		$\Omega$
<b>Switching Time</b>						
$t_{PHL(BG)}$	PWM High to BG Low Propagation Delay			17		ns
$t_{PHL(TG)}$	PWM Low to TG Low Propagation Delay			17		ns
$t_r(BG)$	BG Output Rise Time	$C_{LOAD} = 3.3\text{nF}$ (Note 5)		18		ns
$t_f(BG)$	BG Output Fall Time	$C_{LOAD} = 3.3\text{nF}$ (Note 5)		13		ns
$t_r(TG)$	TG Output Rise Time	$C_{LOAD} = 3.3\text{nF}$ (Note 5)		18		ns
$t_f(TG)$	TG Output Fall Time	$C_{LOAD} = 3.3\text{nF}$ (Note 5)		13		ns
$t_{PH(EN)}$	EN High to TG/BG High Propagation Delay			30		ns
$t_{PL(EN)}$	EN Low to TG/BG Low Propagation Delay			36		ns

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Ratings for extended periods may affect device reliability and lifetime.

**Note 2:** The LTC7060E is guaranteed to meet performance specifications from  $0^\circ\text{C}$  to  $85^\circ\text{C}$  junction temperature. Specifications over the  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  operating junction temperature range are assured by design, characterization and correlation with statistical process controls. The LTC7060I is guaranteed over the  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  operation junction temperature range. The LTC7060J is guaranteed over the  $-40^\circ\text{C}$  to  $150^\circ\text{C}$  operation junction temperature range. The LTC7060H is guaranteed over the  $-40^\circ\text{C}$  to  $150^\circ\text{C}$  operation junction temperature range. High junction temperature degrades operation lifetimes; operating lifetime is derated

for junction temperatures greater than  $125^\circ\text{C}$ . Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with board layout, the rated package thermal impedance and other environment factors.

**Note 3:**  $T_J$  is calculated from the ambient temperature  $T_A$  and power dissipation PD according to the following formula

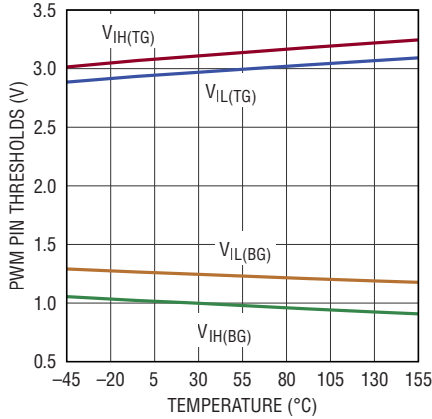
$T_J = T_A + (P_D \cdot 51^\circ\text{C/W})$  for LFCSP package;  $T_J = T_A + (P_D \cdot 40^\circ\text{C/W})$  for MSOP package.

**Note 4:** The total current includes both the current from  $BGV_{CC}/BST$  to  $BGRTN/SW$  and the current to  $SGND$ . Dynamic supply current is higher due to the gate charge being delivered at the switching frequency.

**Note 5:** Rise and fall times are measured using 10% and 90% levels.

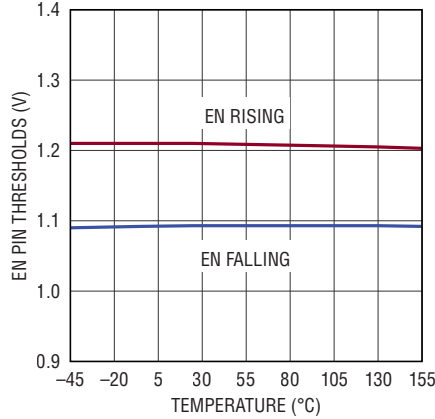
**TYPICAL PERFORMANCE CHARACTERISTICS**  $T_A = 25^\circ\text{C}$ , unless otherwise noted.

**PWM Pin Thresholds vs Temperature**



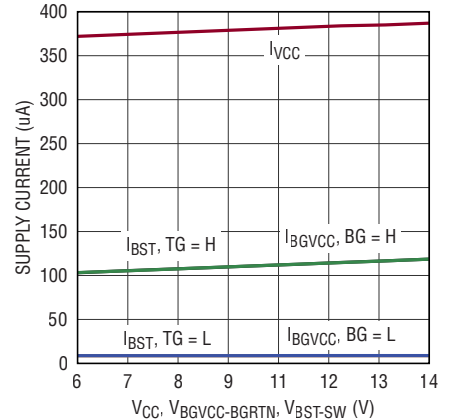
7060 G01

**EN Pin Thresholds vs Temperature**



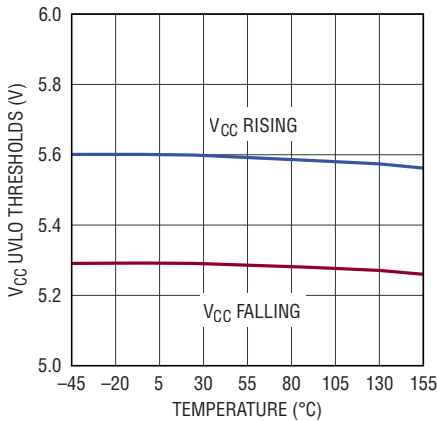
7060 G02

**Quiescent Supply Current vs Supply Voltage**



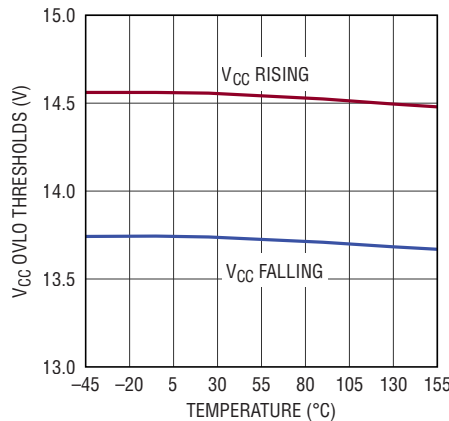
7060 G03

**$V_{CC}$  Undervoltage Lockout Thresholds vs Temperature**



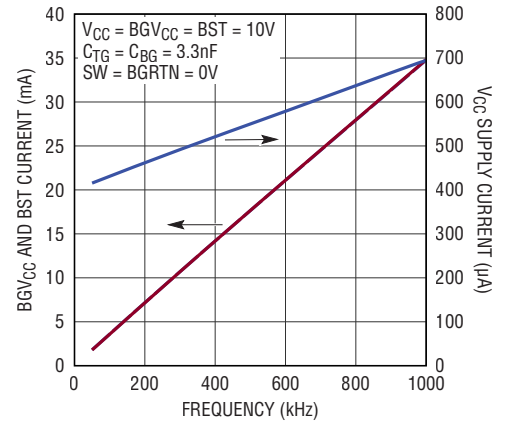
7060 G04

**$V_{CC}$  Overvoltage Lockout Thresholds vs Temperature**



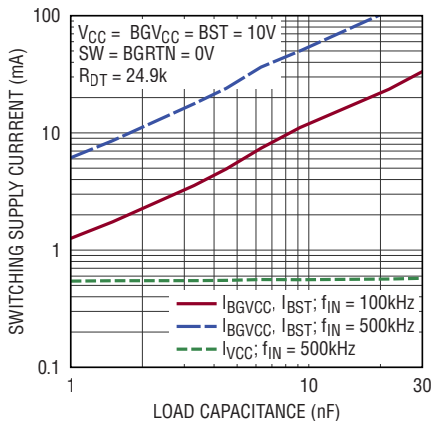
7060 G05

**Supply Current vs Input Frequency**



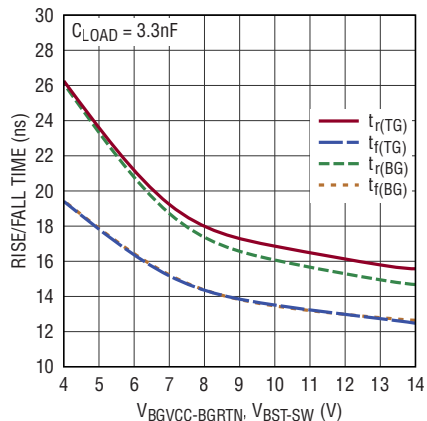
7060 G06

**Switching Supply Current vs Load Capacitance**



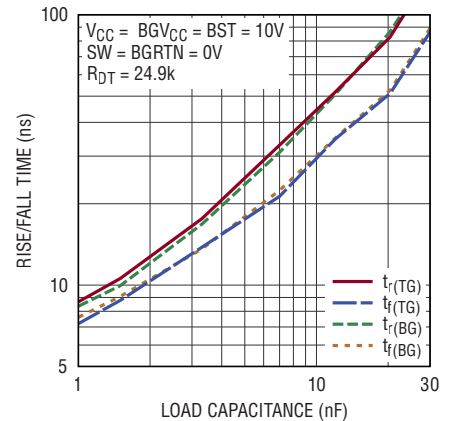
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**Rise and Fall Time vs Floating Supply Voltage**



7060 G08

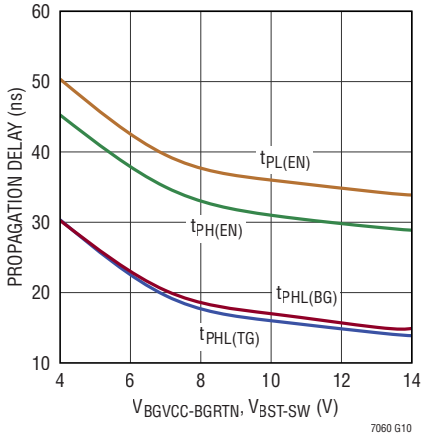
**Rise and Fall Time vs Load Capacitance**



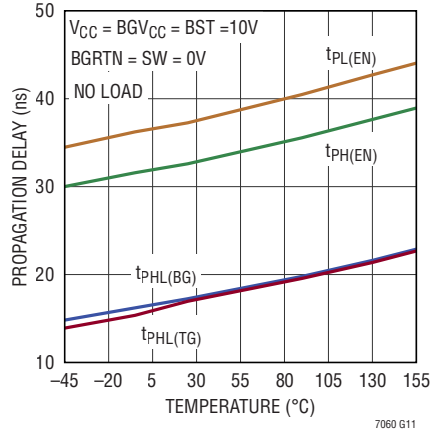
7060 G09

**TYPICAL PERFORMANCE CHARACTERISTICS**  $T_A = 25^\circ\text{C}$ , unless otherwise noted.

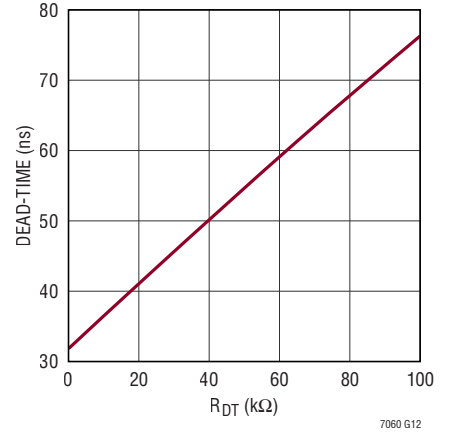
**Propagation Delay vs Floating Supply Voltage**



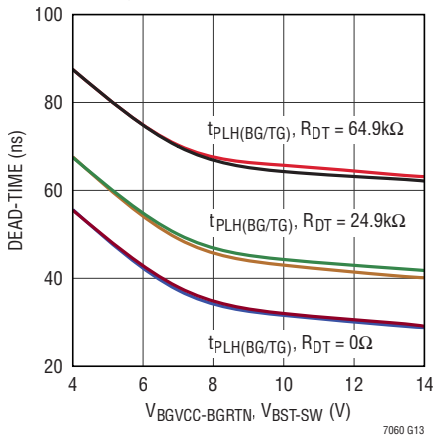
**Propagation Delay vs Temperature**



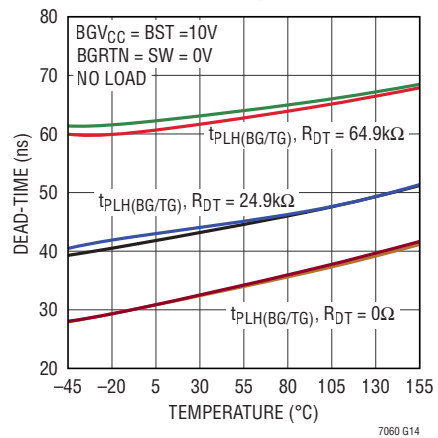
**Dead-Time vs  $R_{DT}$**



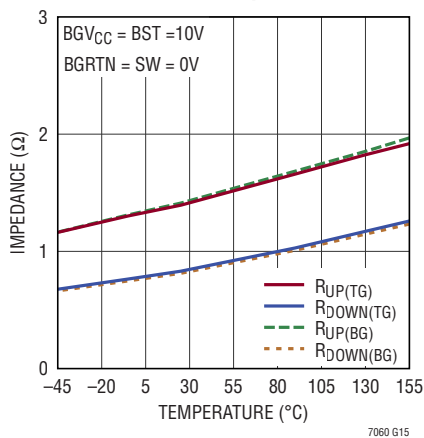
**Dead-Time vs Floating Supply Voltage**



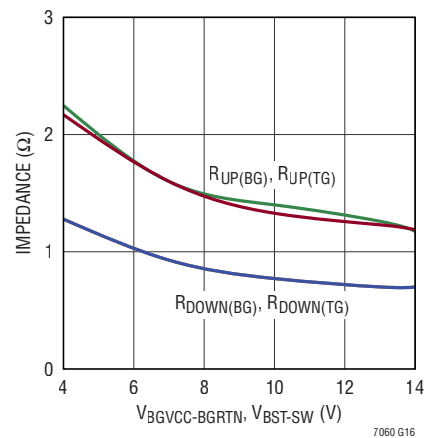
**Dead-Time vs Temperature**



**TG/BG Pull-Up and Pull-Down Resistance vs Temperature**



**TG/BG Pull-Up and Pull-Down Resistance vs Floating Supply Voltage**



## PIN FUNCTIONS

**V<sub>CC</sub>**: V<sub>CC</sub> Supply. IC bias supply referred to the SGND pin. An internal 4.5V supply is generated from the V<sub>CC</sub> supply to bias most of the internal circuitry. A bypass capacitor with a minimum value of 0.1 $\mu$ F should be tied between this pin and the SGND pin.

**BGV<sub>CC</sub>**: Bottom MOSFET Driver Supply. The bottom MOSFET gate driver is biased between this pin and the BGRTN pin. An external capacitor should be tied between this pin and BGRTN and placed close to the IC.

**BGRTN**: Bottom MOSFET Driver Return. The bottom gate driver is biased between BGV<sub>CC</sub> and BGRTN. Kelvin connect BGRTN to the bottom MOSFET source pin for high noise immunity. The voltage difference between the BGRTN pin and the SGND can be  $-10\text{V}$  to  $100\text{V}$ .

**BG**: Bottom MOSFET Gate Driver Output. This pin drives the gate of the N-channel MOSFET between BGRTN and BGV<sub>CC</sub>.

**BST**: Top MOSFET Driver Supply. The top MOSFET gate driver is biased between this pin and the SW pin. An external capacitor should be tied between this pin and the SW pin and placed close to the IC.

**SW**: Top MOSFET Driver Return. The top gate driver is biased between BST and SW. Kelvin connect SW to the top MOSFET source pin for high noise immunity. The voltage difference between the SW pin and SGND can be  $-10\text{V}$  to  $100\text{V}$ .

**TG**: Top MOSFET Gate Driver Output. This pin drives the gate of the N-channel MOSFET between SW and BST.

**DT**: Dead-Time Program Pin Referred to the SGND Pin. A single resistor from this pin to SGND sets the BG/TG low to TG/BG high propagation delay. See the operation section for details.

**PWM**: Three-State Gate Driver Input Signal Referred to the SGND Pin. The TG/BG state is determined by the voltage at this pin. If this pin is floating, an internal resistor divider triggers the High-Z mode in which both BG and TG are turned off. Trace capacitance on this pin should be minimized.

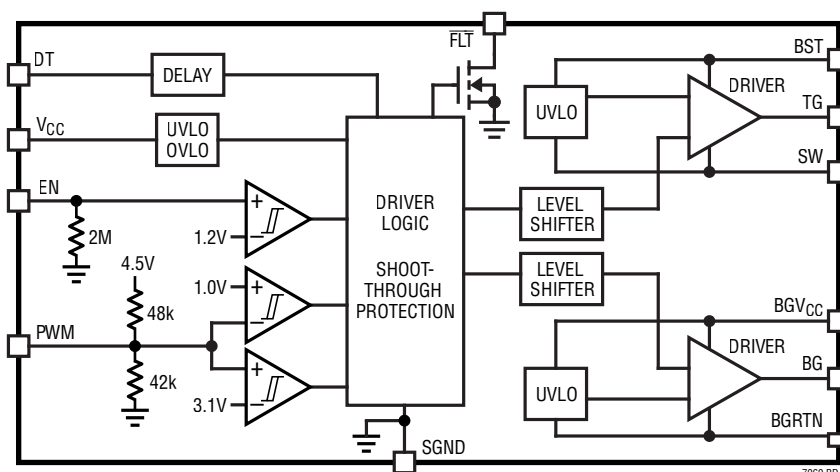
**EN**: Enable Control Input Pin Referred to the SGND Pin. A voltage on this pin above 1.2V enables the gate drivers. The TG and BG pins are both in the low state if this pin is logic low.

**FLT**: Open Drain Fault Output Pin Referred to the SGND Pin. Open-drain output that pulls to SGND during V<sub>CC</sub> UVLO/OVLO and floating supplies UVLO condition. The typical pull-down resistance is 60 $\Omega$ .

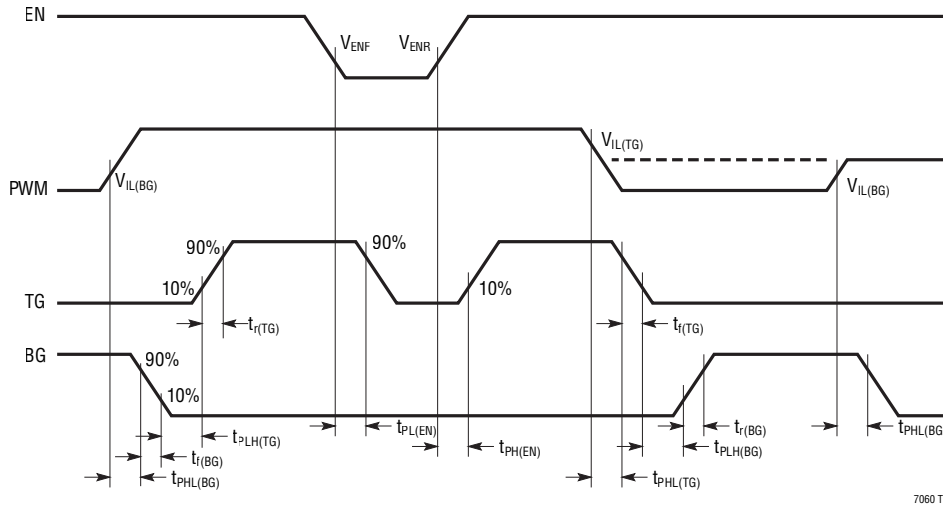
**NC**: No Internal Connection. Always keep this pin floating. It is intentionally skipped to isolate adjacent high voltage pins.

**SGND**: Chip Ground. The exposed pad must be soldered to the PCB ground for electrical contact and for rated thermal performance.

## BLOCK DIAGRAM



**TIMING DIAGRAM**



7060 TD

**OPERATION**

**OVERVIEW**

The LTC7060 receives a ground-referenced, low voltage digital PWM signal to drive two N-channel power MOSFETs in a half-bridge configuration. The gate of the low side MOSFET is driven high or low, swinging between  $BGV_{CC}$  and  $BGRTN$ , depending on the state of the PWM pin. Similarly, the gate of the high side MOSFET is driven complimentary to the low side MOSFET, swinging between  $BST$  and  $SW$ .

Both the low side and high side drivers are floating gate drivers. The unique double floating architecture makes the gate driver outputs robust and less sensitive to ground noise. The symmetric design allows the half-bridge output to be inverting or non-inverting of the input logic.

**V<sub>CC</sub> SUPPLY**

$V_{CC}$  is the power supply for the LTC7060's internal circuitry. An internal 4.5V supply is generated from the  $V_{CC}$  supply to bias most of the internal circuits referred to  $SGND$ . The  $V_{CC}$  pin may be tied to the  $BGV_{CC}$  pin if  $SGND$  and  $BGRTN$  are at the same potential.  $V_{CC}$  is independent of  $V_{IN}$ .

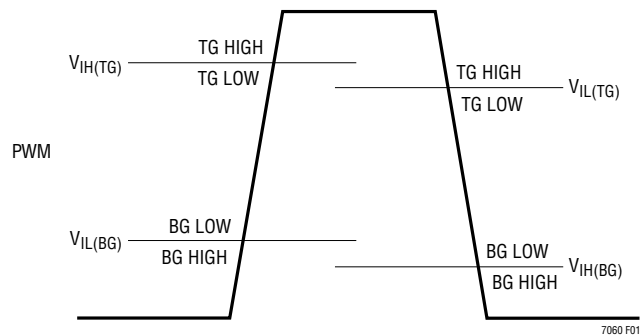
**INPUT STAGE (PWM, EN)**

The LTC7060 employs a three-state PWM input with fixed transition thresholds. The relationship between

the transition thresholds and three input states of the LTC7060 is illustrated in Figure 1. When the voltage on PWM is greater than the threshold  $V_{IH(TG)}$ , TG is pulled up to  $BST$ , turning the high side MOSFET on. This MOSFET will stay on until PWM falls below  $V_{IL(TG)}$ . Similarly, when PWM is less than  $V_{IH(BG)}$ , BG is pulled up to  $BGV_{CC}$ , turning the low side MOSFET on. BG will stay high until PWM increases above the threshold  $V_{IL(BG)}$ .

The hysteresis between the corresponding  $V_{IH}$  and  $V_{IL}$  voltage levels eliminates false triggering due to the noise during switch transitions. However, care should be taken to keep noise from coupling into the PWM pin, particularly in high frequency, high voltage applications.

The thresholds are positioned to allow for a region in which both BG and TG are low. An internal resistor divider



7060 F01

**Figure 1. Three-State PWM Operation**

## OPERATION

sets the PWM pin voltage into this region if the signal driving the PWM pin goes into a high impedance state.

The EN pin can also be used to keep both BG and TG low if the high impedance state is not available from the PWM driving signal. Driving the EN pin low keeps both TG and BG off, and driving the EN pin high enables TG and BG switching based on the PWM input. There is an internal  $2\text{M}\Omega$  pull-down resistor from the EN pin to SGND, keeping the EN default state low if its input is not driven.

Both three-state PWM and EN pin can be used by the controller IC to perform the Discontinuous Conduction Mode (DCM) in switching regulator applications.

## OUTPUT STAGE

A simplified version of the LTC7060's output stage is shown in Figure 2. The BG and TG design are symmetric and they both have floating gate driver outputs. The pull-up device is a PMOS with a typical  $1.5\Omega$   $R_{DS(ON)}$  and the pull-down device is a NMOS with a typical  $0.8\Omega$   $R_{DS(ON)}$ . The wide driver supply voltage ranging from 4V to 14V enables the driving of different power MOSFETs, such as logic level or higher threshold MOSFETs. However, the LTC7060 is optimized for higher threshold MOSFETs (e.g.  $BST-SW = 10\text{V}$  and  $BGV_{CC}-BGRTN = 10\text{V}$ ). The driver

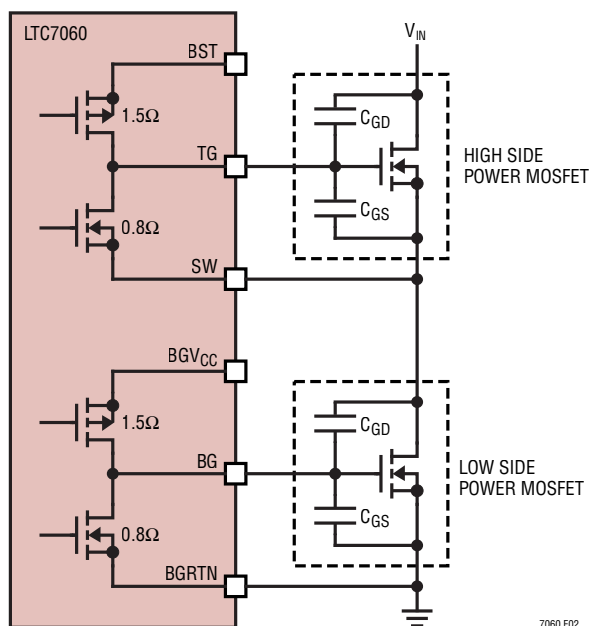


Figure 2. Simplified Output Stage in Half-Bridge Configuration

output pull-up and pull-down resistance may increase with lower driver supply voltage.

Since the power MOSFETs generally account for the majority of the power loss in a converter, it is important to turn them on and off quickly, thereby minimizing the transition time and power loss. The LTC7060's typical  $1.5\Omega$  pull-up resistance and  $0.8\Omega$  pull-down resistance are equivalent to 3A peak pull-up current and 6A peak pull down current at a 10V driver supply. Both BG and TG can produce a rapid turn-on transition for the MOSFETs with capability of driving a  $3.3\text{nF}$  load with 18ns rise time.

Furthermore, a strong pull-down on the driver outputs prevents cross-conduction current. For example, in the half-bridge configuration shown in Figure 2, when BG turns the low side power MOSFET off and TG turns the high side power MOSFET on, the voltage on the SW pin could rise to  $V_{IN}$  very rapidly. This high frequency positive voltage transient will couple through the  $C_{GD}$  capacitance of the low side power MOSFET to the BG pin. If the BG pin is not held down sufficiently, the voltage on the BG pin could rise above the threshold voltage of the low side power MOSFET, momentarily turning it back on. As a result, both the high side and low side MOSFETs would be conducting, which would cause significant cross-conduction current to flow through the MOSFETs from  $V_{IN}$  to ground, thereby incurring substantial power loss and potentially damaging the MOSFETs. For this reason, short PCB traces for the BG and TG pins, which minimize the parasitic inductances, are recommended.

## PROTECTION CIRCUITRY

When using the LTC7060, care must be taken not to exceed any of the ratings specified in the Absolute Maximum Ratings section. As an added safeguard, the LTC7060 incorporates overtemperature shutdown feature. If the junction temperature reaches approximately  $180^\circ\text{C}$ , the LTC7060 will enter thermal shutdown mode and BG will be pulled to BGRTN; TG will be pulled to SW. Normal operation will resume when the junction temperature cools down below  $165^\circ\text{C}$ . The overtemperature level is not production tested. The LTC7060 is guaranteed to operate below  $150^\circ\text{C}$ .

## OPERATION

The LTC7060 contains both undervoltage and overvoltage lockout detectors that monitor the  $V_{CC}$  supply. When  $V_{CC}$  falls below 5.3V or rises above 14.6V, BG and TG pins are pulled to BGRTN and SW, respectively, turning off both the external MOSFETs. When  $V_{CC}$  has adequate supply voltage but less than the overvoltage threshold, normal operation will resume.

Additional undervoltage lockout circuitry is included in each floating driver supply. The BG will be pulled down to BGRTN when the floating voltage from  $BGV_{CC}$  to BGRTN falls below 3.3V. Similarly, the TG will be pulled down to SW when the floating voltage from BST to SW is less than 3.3V.

The normal operation and undervoltage/overvoltage logic table is shown in Table 1.

**Table 1. Normal Operation and Undervoltage/Overvoltage Logic**

PWM	EN	$V_{CC}$ UVLO or OVLO	(BST-SW) UVLO	( $BGV_{CC}$ - BGRTN) UVLO	TG	BG
X	L	X	X	X	L	L
X	X	Y	X	X	L	L
L	H	N	X	N	L	H
L	H	N	X	Y	L	L
H	H	N	N	X	H	L
H	H	N	Y	X	L	L
HIGH-Z	H	X	X	X	L	L

Note: "X" means "Don't Care"

### ADAPTIVE SHOOT-THROUGH PROTECTION

Internal adaptive shoot-through protection circuitry monitors the external MOSFETs to ensure that they do not conduct simultaneously. The LTC7060 does not allow the bottom MOSFET to turn on until the gate-source voltage on the top MOSFET is sufficiently low, and vice-versa. This feature improves efficiency and reliability by eliminating potential shoot-through current through the MOSFETs during switching transitions.

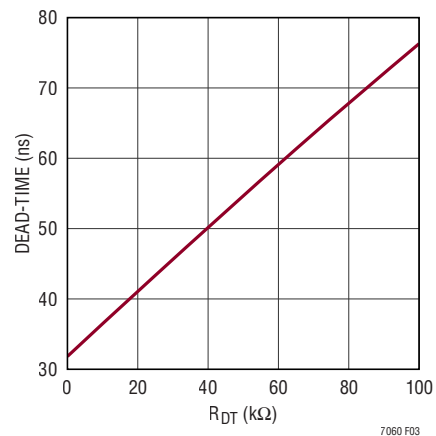
### PROGRAMMABLE DEAD-TIME

To ensure robust shoot-through protection in high voltage half-bridge configuration and switched capacitor converter

applications, the LTC7060 provides a DT pin which can be used to program the propagation delay during BG/TG low to TG/BG high transition (Dead-Time). An external resistor ( $R_{DT}$ ) from the DT pin to the SGND equally sets both the BG low to TG high propagation delay and the TG low to BG high propagation delay. Their relationship can be seen in Figure 3. The Dead-Time can be estimated by the following equation when the  $R_{DT}$  is less than 100k $\Omega$ :

$$\text{Dead-Time} = R_{DT} \cdot 0.44\text{ns/k}\Omega + 32\text{ns}$$

If the DT pin is shorted to SGND, the Dead-Time is 32ns. If the DT Pin is floating, the Dead-Time is around 250ns.



**Figure 3. Dead-Time vs  $R_{DT}$**

### FAULT FLAG

The  $\overline{\text{FLT}}$  pin is connected to the open-drain of an internal N-channel MOSFET. It needs a pull-up resistor (e.g. 51k) tied to a supply such as  $V_{CC}$  or any other bias voltage up to 15V. The  $\overline{\text{FLT}}$  pin is pulled low to SGND immediately if any of these conditions are met:

- The  $V_{CC}$  is below its UVLO threshold or above its OVLO threshold.
- ( $BGV_{CC}$ -BGRTN) is below its UVLO threshold.
- (BST-SW) is below its UVLO threshold.
- The junction temperature reaches approximately 180°C.

When all the faults are cleared, the  $\overline{\text{FLT}}$  pin is pulled up by the external resistor after a built-in 100 $\mu$ s delay.

## APPLICATIONS INFORMATION

### BOOTSTRAPPED SUPPLY (BGV<sub>CC</sub>-BGRTN, BST-SW)

Either or both of the BGV<sub>CC</sub>-BGRTN and BST-SW supplies can be bootstrapped supplies. An external boost capacitor, C<sub>B</sub>, connected between BGV<sub>CC</sub> and BGRTN, or between BST and SW, supplies the gate driver voltage for its respective MOSFET driver. When the external MOSFET is turned on, the driver places the C<sub>B</sub> voltage across the gate-source of the MOSFET. This enhances the MOSFET and turns it on.

The charge to turn on the external MOSFET is referred to gate charge, Q<sub>G</sub>, and is typically specified in the external MOSFET data sheet. The boost capacitor, C<sub>B</sub>, needs to have at least 10 times the gate capacitance to turn on the external MOSFET fully. Gate charge can range from 5nC to hundreds of nC and is influenced by the gate drive level and type of external MOSFET used. For most applications, a capacitor value of 0.1uF for C<sub>B</sub> will be sufficient. However, if multiple MOSFETs are paralleled and driven by the LTC7060, C<sub>B</sub> capacitance needs to be increased correspondingly.

An external supply, typically V<sub>CC</sub> connected through a Schottky diode, is required to keep the C<sub>B</sub> charged. The LTC7060 does not charge the C<sub>B</sub> and always discharges the C<sub>B</sub>. When the BG/TG is high, the total current from BGV<sub>CC</sub>/BST to BGRTN/SW and SGND is typically 100μA; when the BG/TG is low, the total current from BGV<sub>CC</sub>/BST is typically 8μA.

### POWER DISSIPATION

To ensure proper operation and long-term reliability, the LTC7060 must not operate beyond its maximum temperature rating. Package junction temperature can be calculated by:

$$T_J = T_A + (P_D)(\theta_{JA})$$

where:

T<sub>J</sub> = junction temperature

T<sub>A</sub> = ambient temperature

P<sub>D</sub> = power dissipation

θ<sub>JA</sub> = junction-to-ambient thermal resistance

Power dissipation consists of standby, switching and capacitive load power losses:

$$P_D = P_{DC} + P_{AC} + P_{QG}$$

where:

P<sub>DC</sub> = quiescent power loss

P<sub>AC</sub> = internal switching loss at input frequency f<sub>IN</sub>

P<sub>QG</sub> = loss due to turning on and off external MOSFET with gate charge Q<sub>G</sub> at frequency f<sub>IN</sub>

The LTC7060 consumes very little quiescent current. The DC power loss at V<sub>CC</sub> = 10V is only (10V)(0.4mA) = 4mW.

At a particular switching frequency, the internal power loss increases due to both AC currents required to charge and discharge internal nodal capacitances and cross-conduction currents in the internal logic gates. The sum of the quiescent current and internal switching current with no load are shown in the Typical Performance Characteristics plot of Switching Supply Current vs Input Frequency.

The gate charge losses are primarily due to the large AC currents required to charge and discharge the capacitance of the external MOSFETs during switching. For identical pure capacitive loads C<sub>LOAD</sub> on BG and TG at switching frequency f<sub>IN</sub>, the load losses would be:

$$P_{CLOAD} = (C_{LOAD})(f_{IN})[(V_{BST-SW})^2 + (V_{BGVCC-BGRTN})^2]$$

In a typical synchronous buck configuration, the V<sub>CC</sub> is connected to the power for the bottom MOSFET driver, BGV<sub>CC</sub>. V<sub>BST-SW</sub> is equal to V<sub>CC</sub> - V<sub>D</sub>, where V<sub>D</sub> is the forward voltage drop of the external Schottky diode between V<sub>CC</sub> and BST. If this drop is small relative to V<sub>CC</sub>, the load losses can be approximated as:

$$P_{CLOAD} \approx 2(C_{LOAD})(f_{IN})(V_{CC})^2$$

Unlike a pure capacitive load, a power MOSFET's gate capacitance seen by the driver output varies with its V<sub>GS</sub> voltage level during switching. A MOSFET's capacitive load power dissipation can be calculated using its gate charge, Q<sub>G</sub>. The Q<sub>G</sub> value corresponding to the MOSFET's V<sub>GS</sub> value (V<sub>CC</sub> in this case) can be readily obtained from the manufacturer's Q<sub>G</sub> vs V<sub>GS</sub> curves. For identical MOSFETs on BG and TG:

$$P_{QG} \approx 2(Q_G)(f_{IN})(V_{CC})$$

## APPLICATIONS INFORMATION

### BYPASSING AND GROUNDING

The LTC7060 requires proper bypassing on the  $V_{CC}$ ,  $V_{BST-SW}$ , and  $V_{BGVCC-BGRTN}$  supplies due to its high speed switching (nanoseconds) and large AC currents (amperes). Careless component placement and PCB trace routing may cause excessive ringing and under/overshoot.

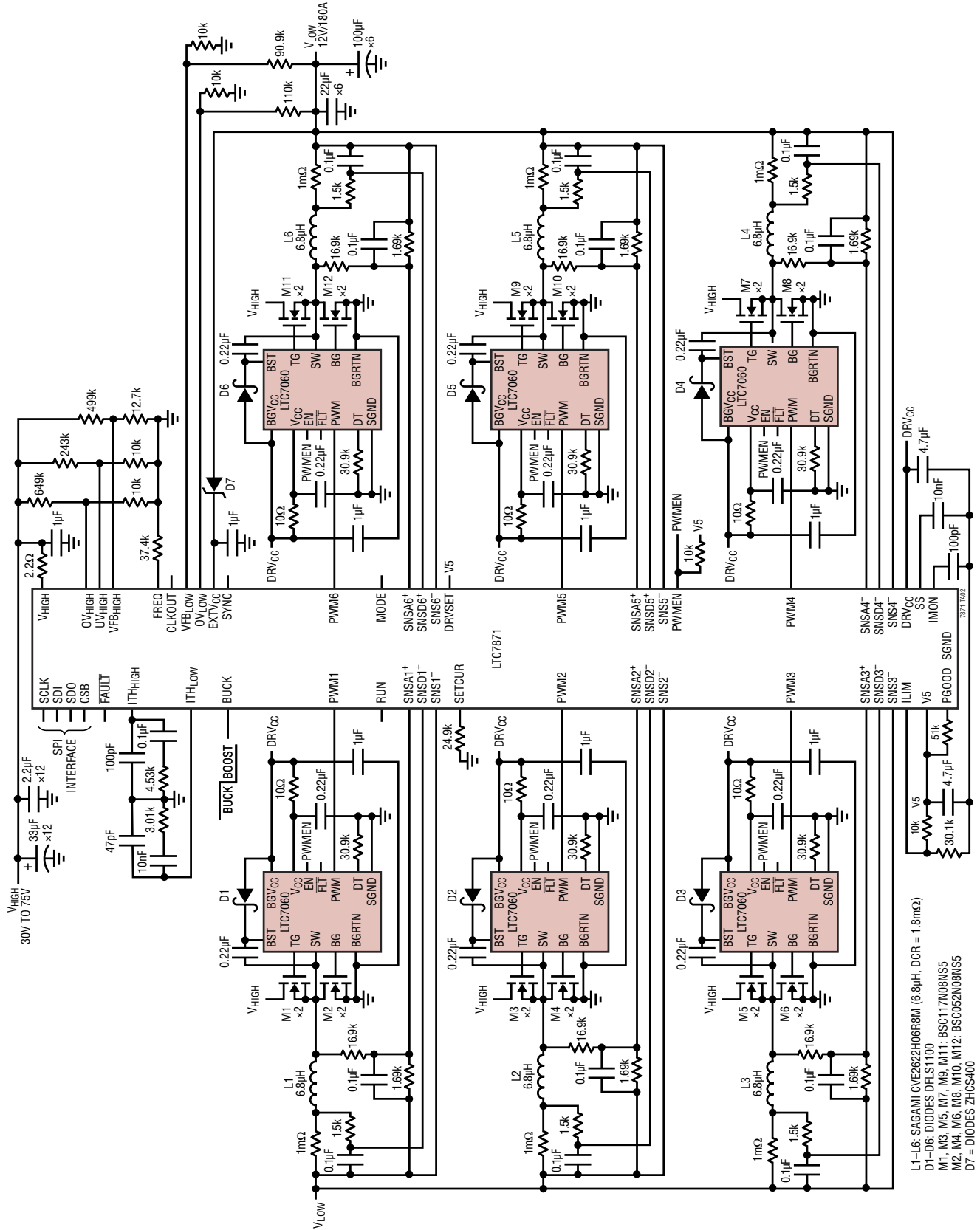
To obtain the optimum performance from the LTC7060:

- Mount the bypass capacitors as close as possible between the  $V_{CC}$  and SGND pins, the  $BGV_{CC}$  and BGRTN pins, and the BST and SW pins. The leads should be shortened as much as possible to reduce lead inductance.
- Use a low inductance, low impedance ground plane to reduce any ground drop and stray capacitance. Remember that the LTC7060 switches greater than 5A peak currents and any significant ground drop will degrade signal integrity.
- Plan the power/ground routing carefully. Know where the large load switching current is coming from and going to. Maintain separate ground return paths for the input pin and the output power stage.
- Kelvin connect the TG pin to the top MOSFET gate and SW pin to the top MOSFET source. Kelvin connect the BG pin to the bottom MOSFET gate and BGRTN to the bottom MOSFET source. Keep the copper trace between the driver output pin and load short and wide.
- Be sure to solder the Exposed Pad on the back side of the LTC7060 packages to the board. Failure to make good thermal contact between the exposed back side and the copper board will result in thermal resistances far greater than specified for the packages.



TYPICAL APPLICATIONS

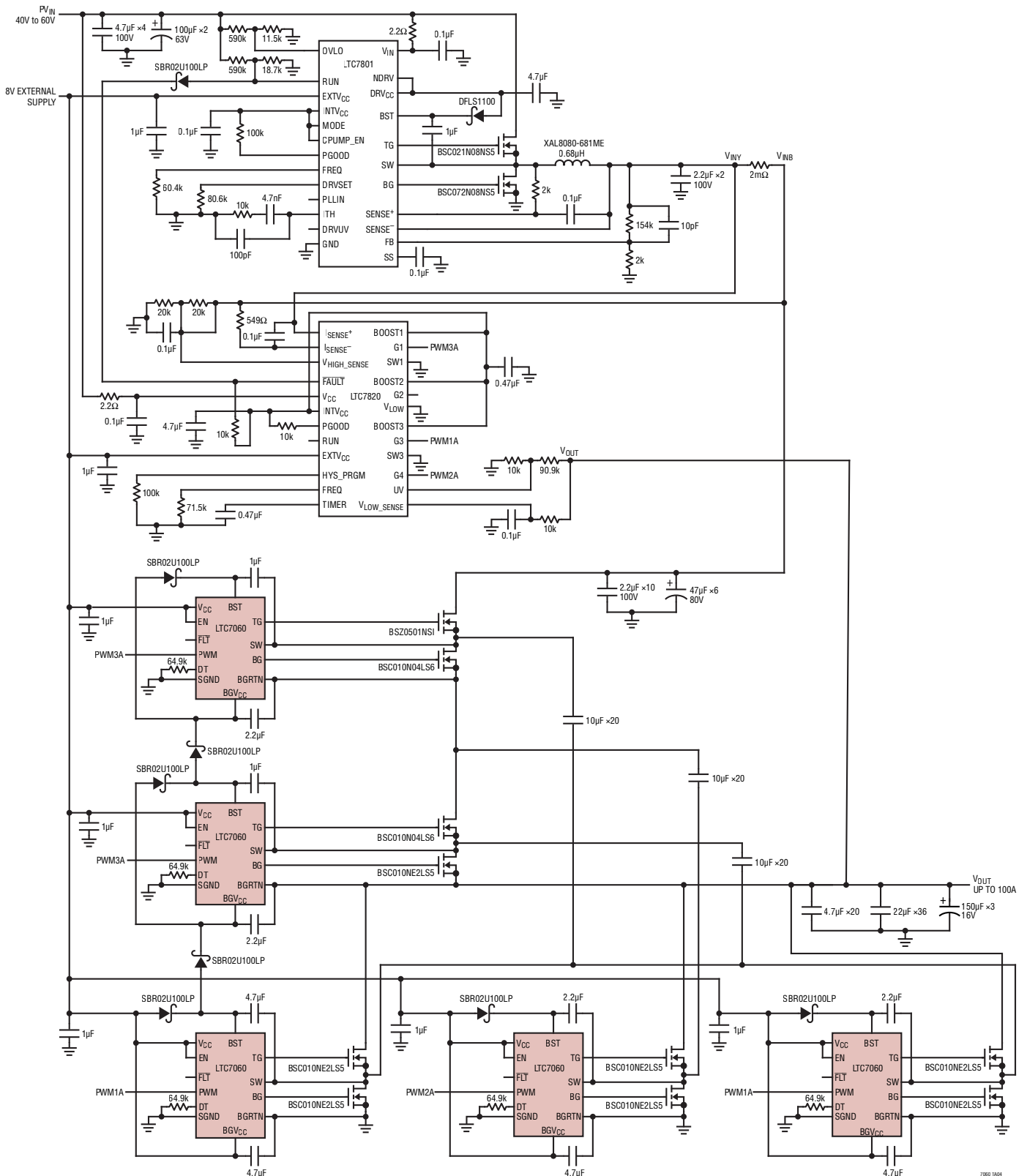
High Efficiency 6-Phase, 12V, 180A Supply



- L1-L6: SAGAMI CVE2622H06R8M (6.8µH, DCR = 1.8mΩ)
- D1-D6: DIODES DFLS1100
- M1, M3, M5, M7, M9, M11: BSC117N08NS5
- M2, M4, M6, M8, M10, M12: BSC052N08NS5
- D7 = DIODES ZHCS400

# TYPICAL APPLICATIONS

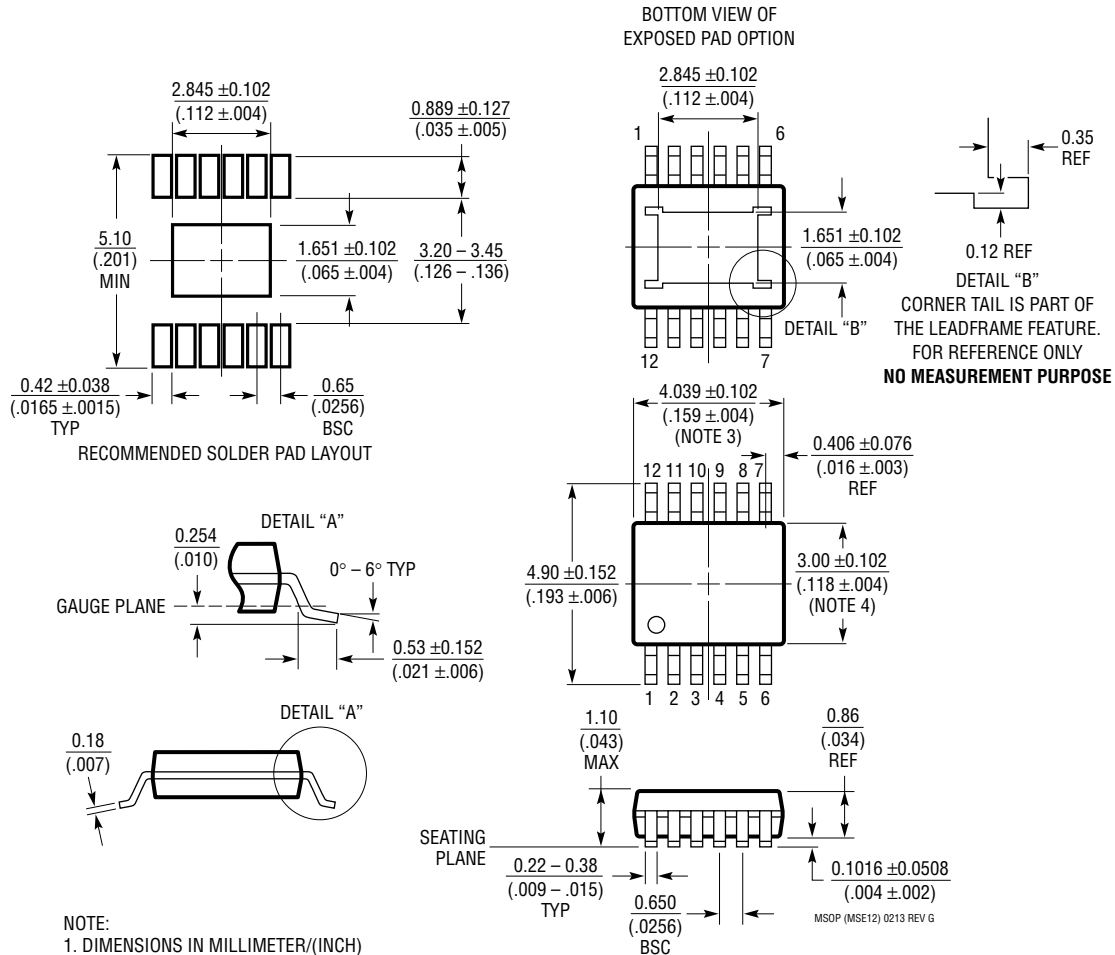
## Up to 100A High Efficiency 4 to 1 Switched Capacitor Converter



7180 1004

**PACKAGE DESCRIPTION**

**MSE Package**  
**12-Lead Plastic MSOP, Exposed Die Pad**  
 (Reference LTC DWG # 05-08-1666 Rev G)

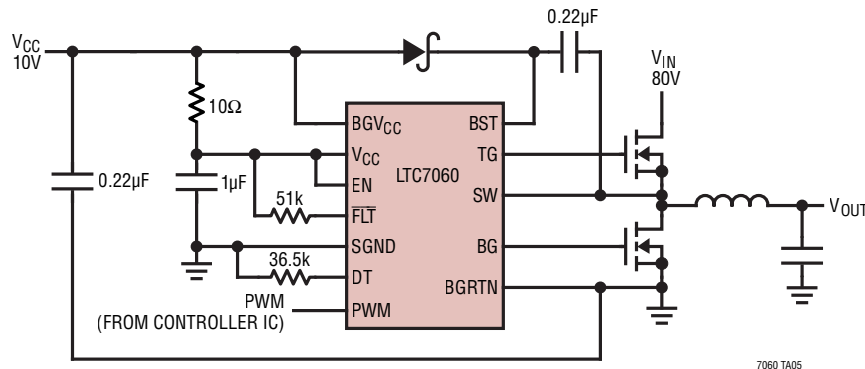


## REVISION HISTORY

REV	DATE	DESCRIPTION	PAGE NUMBER
A	04/20	Updated Order Information.	2
		R <sub>DT</sub> changed from 64.9kΩ to 100kΩ in I <sub>VCC</sub> row.	3
B	02/22	Updated AEC-Q100 statement to qualified.	1

## TYPICAL APPLICATION

### High Input Voltage Buck Converter





## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
<a href="#">LTC4449</a>	High Speed Synchronous N-Channel MOSFET Driver	Up to 38V Supply Voltage, $4V \leq V_{CC} \leq 6.5V$ , 3.2A Peak Pull-Up/4.5A Peak Pull-Down
<a href="#">LTC4442/</a> <a href="#">LTC4442-1</a>	High Speed Synchronous N-Channel MOSFET Driver	Up to 38V Supply Voltage, $6V \leq V_{CC} \leq 9.5V$ , 2.4A Peak Pull-Up/5A Peak Pull-Down
<a href="#">LTC4446</a>	High Voltage Synchronous N-Channel MOSFET Driver without Shoot-Through Protection	Up to 100V Supply Voltage, $7.2V \leq V_{CC} \leq 13.5V$ , 2.5A Peak Pull-Up/3A Peak Pull-Down
<a href="#">LTC4444/</a> <a href="#">LTC4444-5</a>	High Voltage Synchronous N-Channel MOSFET Driver with Shoot-Through Protection	Up to 100V Supply Voltage, $4.5V/7.2V \leq V_{CC} \leq 13.5V$ , 2.5A Peak Pull-Up/3A Peak Pull-Down
<a href="#">LTC3774</a>	Dual, Multiphase Current Mode Synchronous Step-Down DC/DC Controller for Sub-Milliohm DCR Sensing	Operates with DrMOS, Power Blocks or External Drivers/MOSFETs, $4.5V \leq V_{IN} \leq 38V$ , $0.6V \leq V_{OUT} \leq 3.5V$
<a href="#">LTC3861</a>	Dual, Multiphase Step-Down Voltage Mode DC/DC Controller with Accurate Current Sharing	Operates with Power Blocks, DrMOS or External MOSFETs, $3V \leq V_{IN} \leq 24V$
<a href="#">LTC7851</a>	Quad Output, Multiphase Step-Down Voltage Mode DC/DC Controller with Accurate Current Sharing	Operates with DrMOS, Power Blocks or External Drivers/MOSFETs, $V_{IN}$ Range Depends on External Components, $3V \leq V_{CC} \leq 5.5V$ , $0.6V \leq V_{OUT} \leq V_{CC} - 0.5V$
<a href="#">LTC7820</a>	Fixed Ratio High Power Inductorless (Charge Pump) DC/DC Controller	$6V \leq V_{IN} \leq 72V$ , 2:1 Voltage Divider, 1:2 Voltage Doubler, 1:1 Voltage Inverter, Low Noise Soft Switching, 4mm × 5mm QFN-28
<a href="#">LTC7821</a>	Hybrid Step-Down Synchronous Controller	$10V \leq V_{IN} \leq 72V$ , $0.9V \leq V_{OUT} \leq 20V$ , Low Noise Soft Switching, 5mm × 5mm QFN-32
<a href="#">LTC7871</a>	Six-Phase, Synchronous Bidirectional Buck or Boost Controller	$V_{HIGH}$ up to 100V, $V_{LOW}$ up to 60V, SPI Interface, 64-Lead LQFP
<a href="#">LTC7801</a>	150V Low $I_Q$ , Synchronous Step-Down DC/DC Controller, 100% Duty Cycle Capability, Adjustable 5V to 10V Gate Drive	$4V \leq V_{IN} \leq 140V$ , $150V_{PK}$ , $0.8V \leq V_{OUT} \leq 60V$ , $I_Q = 40\mu A$ , PLL Fixed Frequency 50kHz to 900kHz

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