

800-mA SYNCHRONOUS STEP-DOWN CONVERTER

FEATURES

- High-Efficiency Synchronous Step-Down Converter With up to 95% Efficiency
- 12- μ A Quiescent Current (Typ)
- 2.7-V to 10-V Operating Input Voltage Range
- Adjustable Output Voltage Range From 0.7 V to 6 V
- Fixed Output Voltage Options Available in 1.5 V, 1.8 V, and 3.3 V
- Synchronizable to External Clock Signal up to 1.2 MHz
- High Efficiency Over a Wide Load Current Range in Power-Save Mode
- 100% Maximum Duty Cycle for Lowest Dropout
- Low Noise Operation in Forced Fixed Frequency PWM Operation Mode
- Internal Softstart
- Overtemperature and Overcurrent Protected
- Available in 10-Pin Microsmall Outline Package MSOP

DESCRIPTION

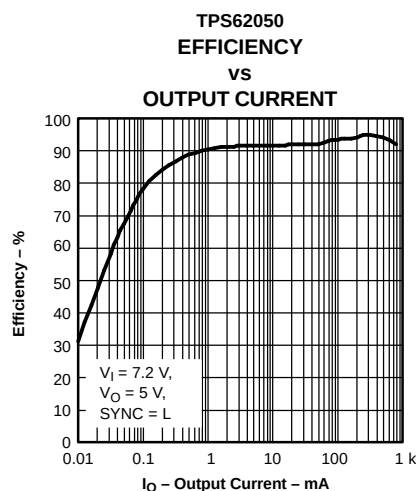
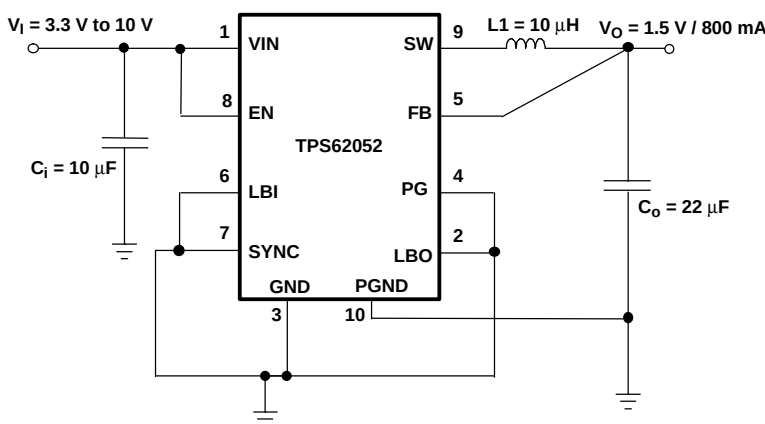
The TPS6205x devices are a family of high-efficiency synchronous step-down dc/dc converters ideally suited for systems powered from a 1-cell or 2-cell Li-Ion battery or from a 3-cell to 5-cell NiCd, NiMH, or alkaline battery.

The TPS62050 is a synchronous PWM converter with integrated N-channel and P-channel power MOSFET switches. Synchronous rectification increases efficiency and reduces external component count. To achieve highest efficiency over a wide load current range, the converter enters a power-saving pulse-frequency modulation (PFM) mode at light load currents. Operating frequency is typically 850 kHz, allowing the use of small inductor and capacitor values. The device can be synchronized to an external clock signal in the range of 600 kHz to 1.2 MHz. For low noise operation, the converter can be programmed into forced-fixed frequency in PWM mode. In shutdown mode, the current consumption is reduced to less than 2 μ A. The TPS6205x is available in the 10-pin (DGS) micro-small outline package (MSOP) and operates over an free air temperature range of -40°C to 85°C.

APPLICATIONS

- Cellular Phones
- Organizers, PDAs, and Handheld PCs
- Low Power DSP Supply
- Digital Cameras and Hard Disks

TYPICAL APPLICATION CIRCUIT



MATHECAD is a trademark of Mathsoft Incorporated.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Copyright © 2002–2003, Texas Instruments Incorporated



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION

PACKAGED DEVICES PLASTIC MSOP (1) (DGS)	OUTPUT VOLTAGE	LBI/LBO FUNCTIONALITY	PACKAGE MARKING
TPS62050DGS	Adjustable 0.7 V to 6 V	Standard	BFM
TPS62051DGS	Adjustable 0.7 V to 6 V	Enhanced	BGB
TPS62052DGS	1.5 V	Standard	BGC
TPS62054DGS	1.8 V	Standard	BGE
TPS62056DGS	3.3 V	Standard	BGG

- (1) The DGS packages are available taped and reeled. Add an R suffix to the device type (i.e., TPS62050DGSR) to order quantities of 2500 devices per reel.

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range unless otherwise noted (1)

	TPS6205x
Supply voltage, V_I	-0.3 V to 11 V
Voltage at EN, SYNC	-0.3 V to V_I
Voltage at LBI, FB, LBO, PG	-0.3 V to 7 V
Voltage at SW	-0.3 V to 11 V (2)
Output current, I_O	850 mA
Maximum junction temperature, T_J	150°C
Operating free-air temperature range, T_A	-40°C to 85°C
Storage temperature range, T_{stg}	-65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	300°C

- (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
- (2) The voltage at the SW pin is sampled in PFM mode 15 μ s after the PMOS has switched off. During this time the voltage at SW is limited to 7 V maximum. Therefore, the output voltage of the converter is limited to 7 V maximum.

PACKAGE DISSIPATION RATING

PACKAGE	$T_A \leq 25^\circ\text{C}$ POWER RATING	DERATING FACTOR $T_A \leq 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$ POWER RATING	$T_A = 85^\circ\text{C}$ POWER RATING
10-PIN MSOP (1)	555 mW	5.56 mW/°C	305 mW	221 mW

- (1) The thermal resistance junction to ambient soldered onto a PCB of the 10-pin MSOP is 180°C/W.

RECOMMENDED OPERATING CONDITIONS

	MIN	NOM	MAX	UNIT
Supply voltage at V_I	2.7		10	V
Voltage at PG, LBO			6	V
Maximum output current			800 (1)	mA
Operating junction temperature	-40		125	°C

- (1) Assuming no thermal limitation

ELECTRICAL CHARACTERISTICS

$V_I = 7.2\text{ V}$, $V_O = 3.3\text{ V}$, $I_O = 300\text{ mA}$, $EN = V_I$, $T_A = -40^\circ\text{C}$ to 85°C unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY CURRENT						
V_I	Input voltage range		2.7		10	V
$I_{(Q)}$	Operating quiescent current	$I_O = 0\text{ mA}$, $SYNC = \text{GND}$, $V_I = 7.2\text{ V}$		12	20	μA
$I_{(SD)}$	Shutdown current	$EN = \text{GND}$		1.5	5	μA
		$EN = \text{GND}$, $T_A = 25^\circ\text{C}$		1.5	3	
$I_{(Q,LBI)}$	Quiescent current with enhanced LBI comparator version.	$EN = V_I$, $LBI = \text{GND}$, TPS62051 only		5		μA
ENABLE						
V_{IH}	EN high level input voltage		1.3			V
V_{IL}	EN low level input voltage				0.3	V
	EN trip point hysteresis			100		mV
$I_{(kg)}$	EN input leakage current	$EN = \text{GND}$ or V_{IN} , $V_I = 7.2\text{ V}$		0.01	0.2	μA
$I_{(EN)}$	EN input current	$0.6\text{ V} \leq V_{(EN)} \leq 4\text{ V}$		2		μA
$V_{(UVLO)}$	Undervoltage lockout threshold			1.6		V
POWER SWITCH						
$r_{DS(on)}$	P-channel MOSFET on-resistance	$V_I \geq 5.4\text{ V}$; $I_O = 300\text{ mA}$		400	650	$\text{m}\Omega$
		$V_I = 2.7\text{ V}$; $I_O = 300\text{ mA}$		600	850	
	P-channel MOSFET leakage current	$V_{DS} = 10\text{ V}$			1	μA
	P-channel MOSFET current limit	$V_I = 7.2\text{ V}$, $V_O = 3.3\text{ V}$	1000	1200	1400	mA
$r_{DS(on)}$	N-channel MOSFET on-resistance	$V_I \geq 5.4\text{ V}$; $I_O = 300\text{ mA}$		300	450	$\text{m}\Omega$
		$V_I = 2.7\text{ V}$; $I_O = 300\text{ mA}$		450	550	
	N-channel MOSFET leakage current	$V_{DS} = 6\text{ V}$			1	μA
POWER GOOD OUTPUT, LBI, LBO						
$V_{(PG)}$	Power good trip voltage		$V_{ml} - 2\%$			V
	Power good delay time	V_O ramping positive		50		μs
		V_O ramping negative		200		
V_{OL}	PG, LBO output low voltage	$V_{(FB)} = 0.8 \times V_O$ nominal, $I_{(sink)} = 1\text{ mA}$			0.3	V
	PG, LBO output leakage current	$V_{(FB)} = V_O$ nominal, $V_{(LBI)} = V_I$		0.01	0.25	μA
	Minimum supply voltage for valid power good, LBO signal			2.3		V
$V_{(LBI)}$	Low battery input trip voltage	Input voltage falling		1.21		V
	Low battery input trip point accuracy				1.5%	
$V_{(LBI,HYS)}$	Low battery input hysteresis			15		mV
$I_{(kg,LBI)}$	LBI leakage current			0.01	0.1	μA
OSCILLATOR						
f_S	Oscillator frequency		600	850	1000	kHz
$f_{(SYNC)}$	Synchronization range		600		1200	kHz
V_{IH}	SYNC high level input voltage		1.5			V
V_{IL}	SYNC low level input voltage				0.3	V
$I_{(kg)}$	SYNC input leakage current	$SYNC = \text{GND}$ or V_{IN}		0.01	0.1	μA
	SYNC trip point hysteresis			100		mV
	Duty cycle of external clock signal		20%		90%	
OUTPUT						
V_O	Adjustable output voltage range	TPS62050, TPS62051	0.7		6.0	V
$V_{(FB)}$	Feedback voltage	TPS62050, TPS62051	0.5			V
	FB leakage current	TPS62050, TPS62051		0.02	0.1	μA

TPS62050, TPS62051
TPS62052, TPS62054, TPS62056

SLVS432D–SEPTEMBER 2002–REVISED OCTOBER 2003

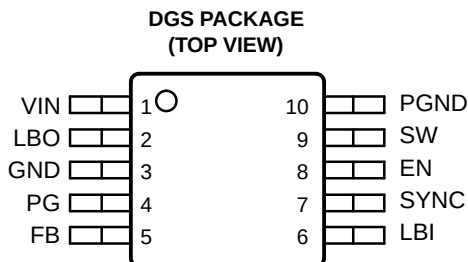
ELECTRICAL CHARACTERISTICS (continued)

$V_I = 7.2\text{ V}$, $V_O = 3.3\text{ V}$, $I_O = 300\text{ mA}$, $EN = V_I$, $T_A = -40^\circ\text{C}$ to 85°C unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Feedback voltage tolerance	TPS62050, TPS62051	V _I = 2.7 V to 10 V, 0 mA< I _O < 600 mA	-3%		3%	
Fixed output voltage tolerance (1)	TPS62052	V _I = 2.7 V to 10 V, 0 mA< I _O < 600 mA	-3%		3%	
	TPS62054	V _I = 2.7 V to 10 V, 0 mA< I _O < 600 mA	-3%		3%	
	TPS62056	V _I = 3.75 V to 10 V, 0 mA< I _O < 600 mA	-3%		3%	
Resistance of internal voltage divider forfixed-voltage versions			700	1000	1300	kΩ
Line regulation		V _O = 3.3 V, V _I = 5 V to 10 V, I _O = 600 mA		5.2		mV/V
Load regulation		V _I = 7.2 V; I _O = 10 mA to 600 mA		0.0045		%/mA
η	Efficiency	V _I = 5 V; V _O = 3.3 V; I _O = 300 mA		93%		
		V _I = 3.6 V; V _O = 2.5 V; I _O = 200 mA		93%		
Duty cycle range for main switches					100%	
Minimum t _{on} time for main switch				100		ns
Shutdown temperature				145		°C
Start-up time		I _O = 200 mA, V _I = 5 V, V _O = 3.3 V, C _O = 22 μF, L = 10 μH		1		ms

- (1) The worst case $r_{DS(on)}$ of the PMOS in 100% mode for an input voltage of 3.3 V is 0.75 Ω . This value can be used to determine the minimum input voltage if the output current is less than 600 mA with the TPS62056.

PIN ASSIGNMENTS



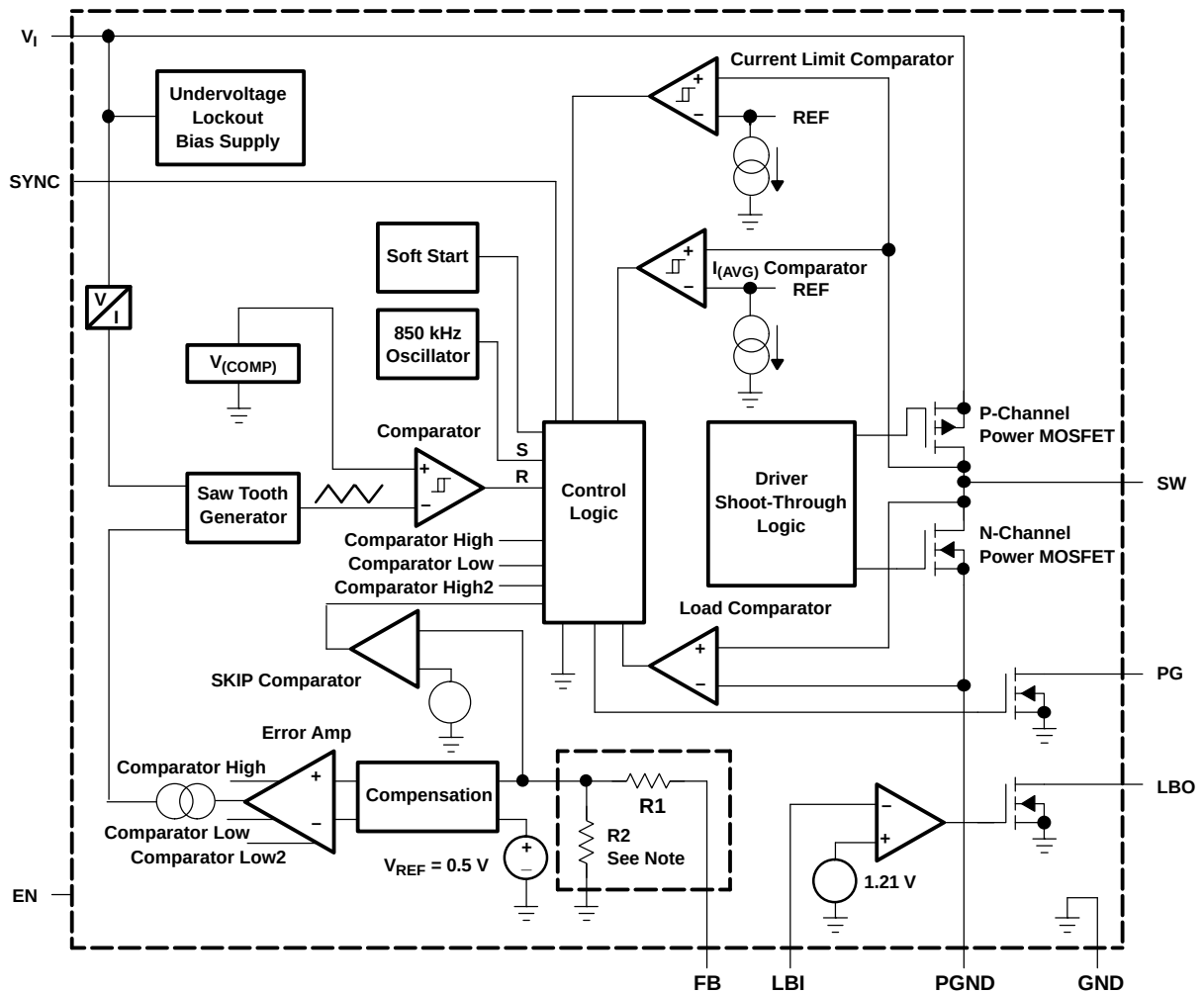
Terminal Functions

TERMINAL NAME	NO.	I/O	DESCRIPTION
EN	8	I	Enable. A logic high enables the converter, logic low forces the device into shutdown mode, reducing the supply current to less than 2 μ A.
FB	5	I	Feedback pin for the fixed output voltage option. For the adjustable version, an external resistive divider is connected to this pin. The internal voltage divider is disabled for the adjustable version.
GND	3	I	Ground
LBO	2	O	Open drain low battery output. Logic low signal indicates a low battery voltage.
LBI	6	I	Low battery input
PG	4	O	Power good comparator output. This is an open-drain output. A pullup resistor should be connected between PG and VOUT. The output goes active high when the output voltage is greater than 95% of the nominal value.
PGND	10	I	Power ground. Connect all power grounds to this pin.
SW	9	O	Connect the inductor to this pin. This pin is the switch pin and connected to the drain of the internal power MOSFETS.
SYNC	7	I	Input for synchronization to the external clock signal. This input can be connected to an external clock or pulled to GND or V_I . When an external clock signal is applied, the device synchronizes to this external clock and the device operates in fixed PWM mode. When the pin is pulled to either GND or V_I , the internal oscillator is used and the logic level determines if the device operates in fixed PWM or PWM/PFM mode. SYNC = HIGH: Low-noise mode enabled, fixed frequency PWM operation is forced SYNC = LOW (GND): Power-save mode enabled, PFM/PWM mode enabled.
VIN	1	I	Supply voltage input

TPS62050, TPS62051 TPS62052, TPS62054, TPS62056

SLVS432D–SEPTEMBER 2002–REVISED OCTOBER 2003

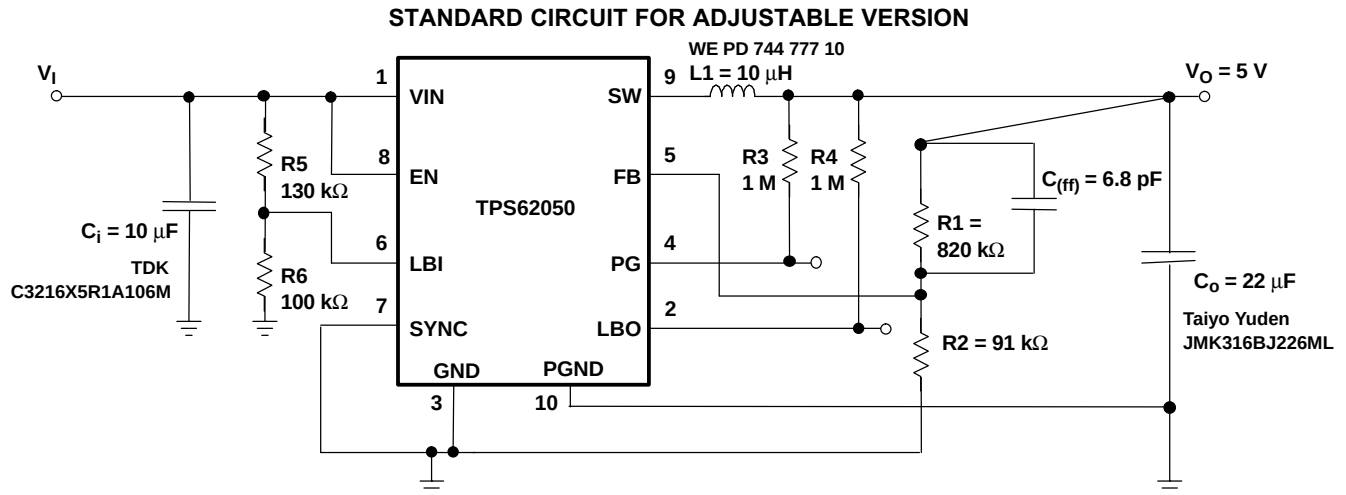
FUNCTIONAL BLOCK DIAGRAM



NOTE: For the adjustable versions (TPS62050, TPS62051), the internal feedback driver is disabled and the FB pin is directly connected to the GM amplifier.

PARAMETER MEASUREMENT INFORMATION

All graphs were generated using the circuit as shown unless otherwise noted. For output voltages other than 5 V, the fixed voltage versions are used. The resistors R1, R2, and the feedforward capacitor (Cff) are removed and the feedback pin is directly connected to the output.

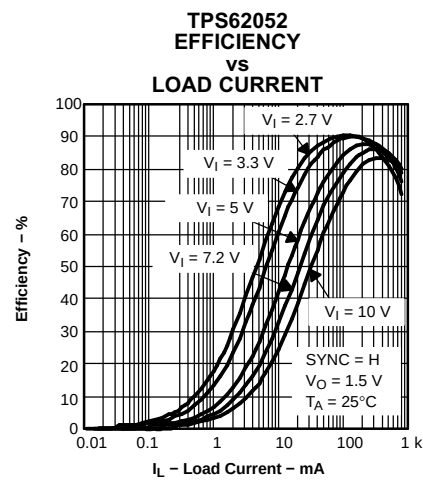
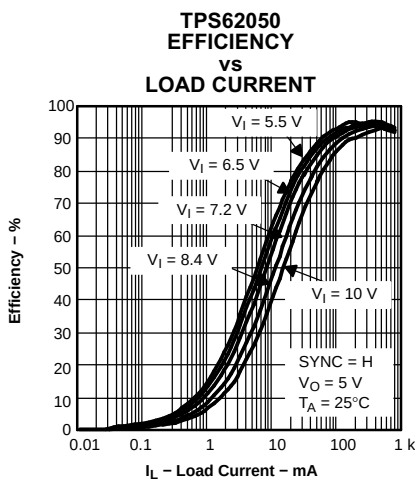
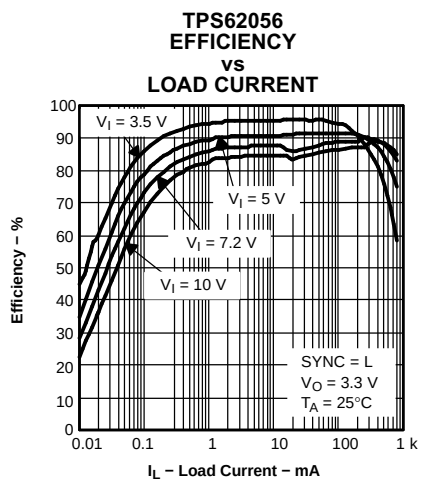
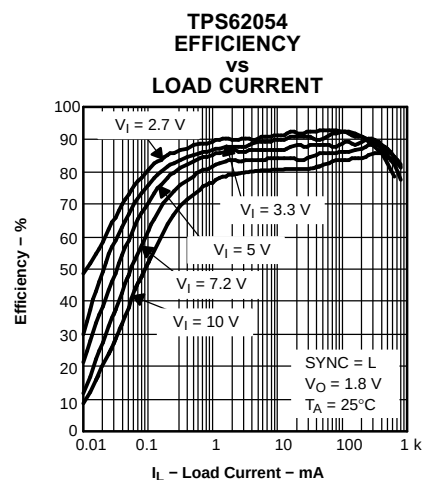
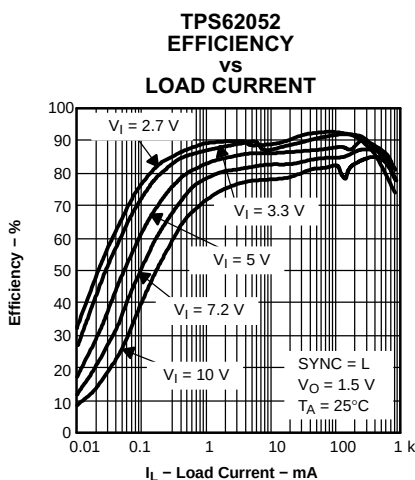
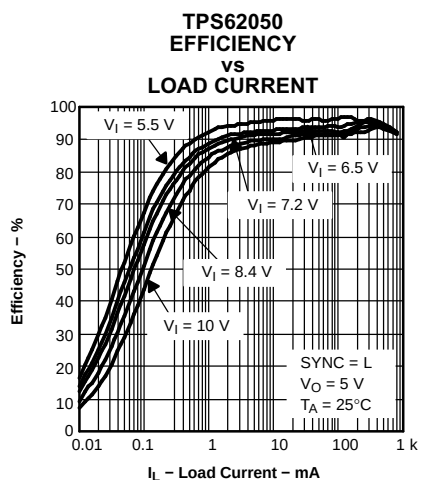


Quiescent Current Measurements and Efficiency Were Taken
With: R5 = Open, R4 = Open, LBI Connected to GND.

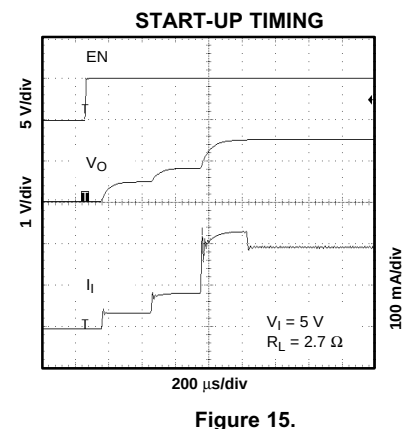
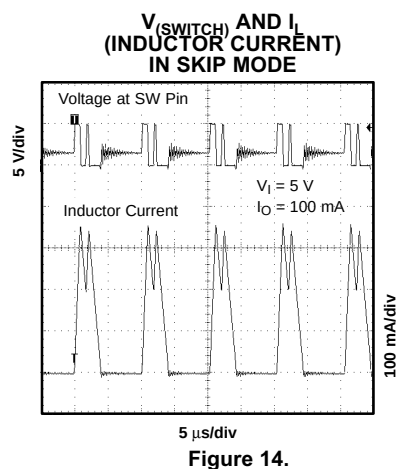
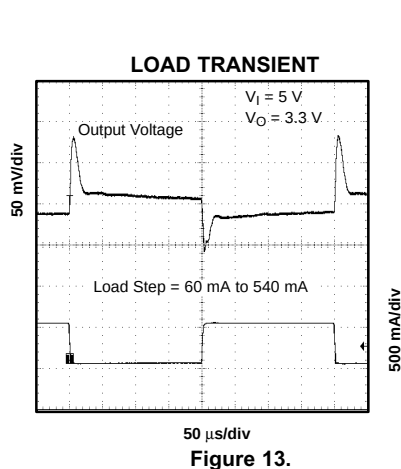
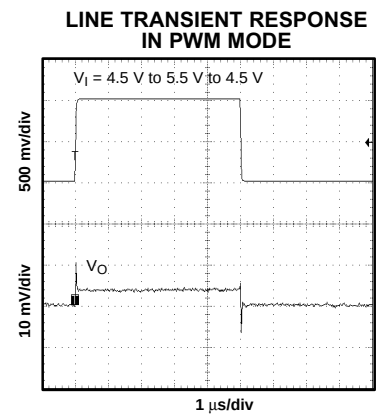
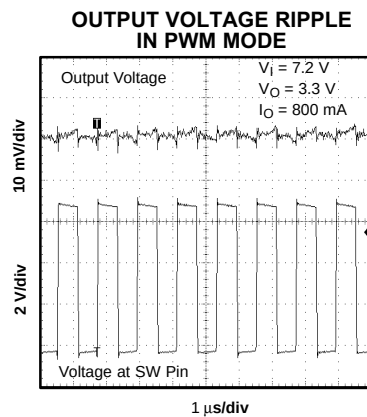
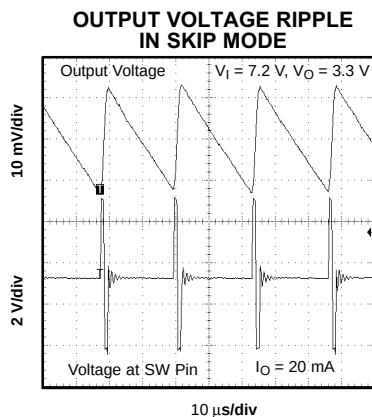
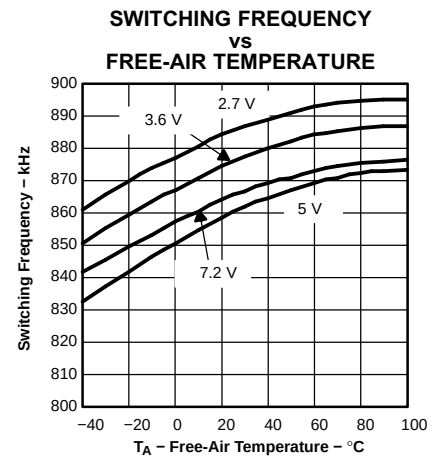
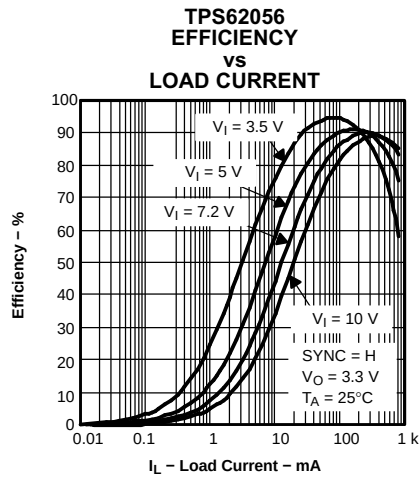
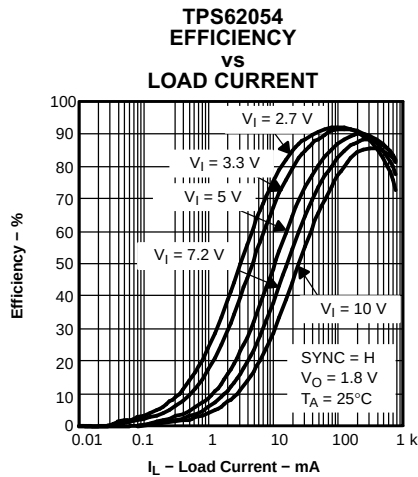
TYPICAL CHARACTERISTICS

TABLE OF GRAPHS

	FIGURE
Efficiency vs load current	1 - 8
Switching frequency vs temperature	9
Output voltage ripple in SKIP mode	10
Output voltage ripple in PWM mode	11
Line transient response in PWM mode	12
Load transient	13
$V_{(switch)}$ and I_L (inductor current) in skip mode	14
Start-up timing	15



TYPICAL CHARACTERISTICS (continued)



APPLICATION INFORMATION

Operation

The TPS6205x is a synchronous step-down converter that operates with a 850-kHz fixed frequency pulse width modulation (PWM) at moderate to heavy load currents and enters the power-save mode at light load current.

During PWM operation the converter uses a unique fast response voltage mode control scheme with input voltage feed forward to achieve good line and load regulation with the use of small ceramic input and output capacitors. At the beginning of each clock cycle initiated by the clock signal (S), the P-channel MOSFET switch is turned on and the inductor current ramps up until the voltage-comparator trips and the control logic turns the switch off. Also the switch is turned off by the current limit comparator in case the current limit of the P-channel switch is exceeded. After the dead time preventing current shoot through, the N-channel MOSFET rectifier is turned on and the inductor current ramps down. The next cycle is initiated by the clock signal again, turning off the N-channel rectifier and turning on the P-channel switch.

The error amplifier as well as the input voltage determines the rise time of the saw tooth generator; therefore, any change in input voltage or output voltage directly controls the duty cycle of the converter giving a very good line and load transient regulation.

Constant Frequency Mode Operation (SYNC = HIGH)

In the constant frequency mode, the output voltage is regulated by varying the duty cycle of the PWM signal in the range of 100% to 10%. Connecting the SYNC pin to a voltage greater than 1.5 V forces the converter to operate permanently in the PWM mode even at light or no load currents. The advantage is the converter operates with a fixed switching frequency that allows simple filtering of the switching frequency for noise sensitive applications. In this mode, the efficiency is lower compared to the power-save mode during light loads (see Figure 16). The N-MOSFET of the devices stays on even when the current into the output drops to zero. This prevents the device from going into discontinuous mode. The device transfers unused energy back to the input. Therefore, there is no ringing at the output that usually occurs in the discontinuous mode. The duty cycle range in constant frequency mode is 100% to 10%.

It is possible to switch from forced PWM mode to the power-save mode during operation by pulling the SYNC pin low. The flexible configuration of the SYNC pin during operation of the device allows efficient power management by adjusting the operation of the TPS6205x to the specific system requirements.

Power-Save Mode Operation (SYNC = LOW)

As the load current decreases, the converter enters the power-save mode operation. During power-save mode the converter operates with reduced switching frequency in PFM and with a minimum quiescent current to maintain high efficiency. Whenever the average output current goes below the skip threshold, the converter enters the power-save mode. The average current depends on the input voltage. It is 100 mA at low input voltages and up to 200 mA with maximum input voltage. The average output current must be below the threshold for at least 32 clock cycles (t_{cy}) to enter the power-save mode. During the power-save mode the output voltage is monitored with a comparator. When the output voltage falls below the comp low threshold set to 0.8% above V_O nominal, the P-channel switch turns on. The P-channel switch turns off as the peak switch current of typically 200 mA is reached. The N-channel rectifier turns on and the inductor current ramps down. As the inductor current approaches zero, the N-channel rectifier is turned off and the switch is turned on starting the next pulse. When the output voltage can not be reached with a single pulse, the device continues to switch with its normal operating frequency, until the comparator detects the output voltage to be 1.6% above the nominal output voltage. The converter wakes up again when the output voltage falls below the comp low threshold. This control method reduces the quiescent current to typically to 12 μ A and the switching frequency to a minimum achieving the highest converter efficiency. Having these skip current thresholds 0.8% and 1.6% above the nominal output voltage gives a lower absolute voltage drop during a load transient as anticipated with a standard converter operating in this mode.

APPLICATION INFORMATION (continued)

Feedforward Capacitor

The feedforward capacitor, $C_{(ff)}$ shown in Figure 20, improves the performance in SKIP mode. The comparator is faster, therefore, there is less voltage ripple at the output in SKIP mode. Use the values listed in Table 1. Larger values decrease stability in fixed frequency PWM mode. If the TPS6205x is only operated in fixed frequency PWM mode, the feedforward capacitor is not needed.

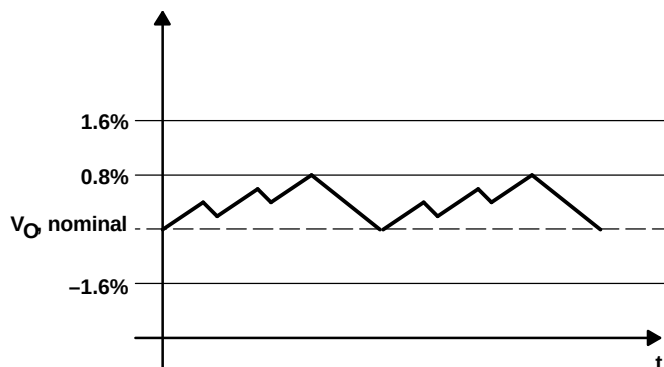


Figure 16. Power-Save Mode Output Voltage Thresholds

The converter enters the fixed frequency PWM mode again as soon as the output voltage falls below the comp low 2 threshold set to 1.6% below V_O , nominal.

Soft-Start

The TPS6205x has an internal soft-start circuit that limits the inrush current during start-up. This prevents possible voltage drops of the input voltage if a battery or a high impedance power source is connected to the input of the TPS6205x.

The soft-start is implemented as a digital circuit increasing the switch current in steps of 200 mA, 400 mA, 800 mA and then the typical switch current limit of 1.2 A. Therefore the start-up time mainly depends on the output capacitor and load current. Typical start-up time with a 22- μ F output capacitor and a 200-mA load current is 1 ms.

100% Duty Cycle Low Dropout Operation

The TPS6205x offers the lowest possible input to output voltage difference while still maintaining operation with the use of the 100% duty cycle mode. In this mode, the P-channel switch is constantly turned on. This is particularly useful in battery powered applications to achieve longest operation time by taking full advantage of the whole battery voltage range, i.e. The minimum input voltage to maintain regulation depends on the load current and output voltage and can be calculated as:

APPLICATION INFORMATION (continued)

$$V_I(\min) = V_O(\max) + I_O(\max) \times (r_{DS(on)}(\max) + R_L)$$

$I_O(\max)$ = Maximum output current plus inductor ripple current

$r_{DS(on)}(\max)$ = Maximum P-Channel switch $r_{DS(on)}$

R_L = DC resistance of the inductor

$V_O(\max)$ = Nominal output voltage plus maximum output voltage tolerance

Enable and Overtemperature Protection

Logic low on EN forces the TPS6205x into shutdown. In shutdown, the power switch, drivers, voltage reference, oscillator, and all other functions are turned off. The supply current is reduced to less than 2 μA in the shutdown mode. When the device is in thermal shutdown, the bandgap is forced to stay on even if the device is set into shutdown by pulling EN to GND. As soon as the temperature drops below the threshold, the device automatically starts again.

If an output voltage is present when the device is disabled, which could be an external voltage source or super cap, the reverse leakage current is specified under electrical characteristics. Pulling the enable pin high starts up the TPS6205x with the soft-start as described under the paragraph soft-start. If the EN pin is connected to any voltage other than V_I or GND, an increased leakage current of typically 10 μA and up to 20 μA can occur.

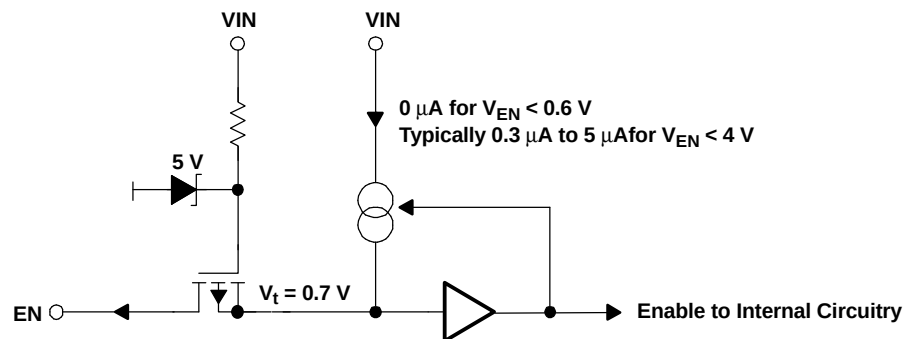


Figure 17. Internal Circuit of the ENABLE Pin

The EN pin can be used in a pushbutton configuration as shown in Figure 18. The external resistor to GND must be capable of sinking 0.3 μA with a minimum voltage drop of 1.3 V to keep the system enabled when both switches are open. When the ON-button is pressed, the device is enabled and the current through the external resistor keeps the voltage level high to ensure that the device stays on when the ON-button is released. When the OFF-button is pressed, the device is switched off and the current through the external resistor is zero. The device therefore stays off even when the OFF-button is released.

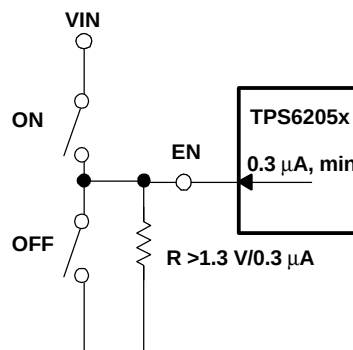


Figure 18. Pushbutton Configuration for the EN-Pin

APPLICATION INFORMATION (continued)

Undervoltage Lockout

The undervoltage lockout circuit prevents the device from misoperation at low input voltages. It prevents the converter from turning on the switch or rectifier MOSFET under undefined conditions.

Synchronization

If no clock signal is applied, the converter operates with a typical switching frequency of 850 kHz. It is possible to synchronize the converter to an external clock within a frequency range from 600 kHz to 1200 kHz. The device automatically detects the rising edge of the first clock and synchronizes to the external clock. If the clock signal is stopped, the converter automatically switches back to the internal clock and continues operation. The switchover is initiated if no rising edge on the SYNC pin is detected for a duration of four clock cycles. Therefore, the maximum delay time can be 8.3 μ s if the internal clock has its minimum frequency of 600 kHz. During this time, there is no clock signal available. The device stops switching until the internal circuitry is switched to the internal clock source.

When the device is switched between internal synchronization and external synchronization during operation, the output voltage may show transient over/undershoot during switchover. The voltage transients are minimized by using 850 kHz as an initial external frequency, and changing the frequency slowly (>1 ms) to the value desired. The voltage drop at the output when the device is switched from external synchronization to internal synchronization can be reduced by increasing the output capacitor value.

If the device is synchronized to an external clock, the power-save mode is disabled and the device stays in forced PWM mode.

Connecting the SYNC pin to the GND pin enables the power-save mode. The converter operates in the PWM mode at moderate to heavy loads and in the PFM mode during light loads maintaining high efficiency over a wide load current range.

Power Good Comparator

The power good (PG) comparator has an open drain output capable of sinking typically 1 mA. The PG function is only active when the device is enabled (EN = high). When the device is disabled (EN = low), the PG pin is pulled to GND.

The PG output is only valid after a 250 μ s delay after the device is enabled and the supply voltage is greater than 2.7 V. Power good is low during the first 250 μ s after shutdown and in shutdown.

The PG pin becomes active high when the output voltage exceeds typically 98.5% of its nominal value. Leave the PG pin unconnected, or connect to GND when not used.

Low-Battery Detector (Standard Version)

The low-battery output (LBO) is an open drain type which goes low when the voltage at the low battery input (LBI) falls below the trip point of $1.21\text{ V} \pm 1.5\%$. The voltage at which the low-battery warning is issued is adjusted with a resistive divider as shown in Figure 20. The sum of the resistors R1 and R2 is recommended to be in the 100-k Ω to 1-M Ω range for high efficiency at low output current. An external pullup resistor at LBO can either be connected to OUT, or any other voltage rail in the voltage range of 0 V to 6 V. During start-up, the LBO output signal is invalid for the first 500 μ s. LBO is high impedance when the device is disabled. If the low-battery comparator function is not used, connect LBI to ground. The low-battery detector is disabled when the device is disabled. Leave the LBO pin unconnected, or connect to GND when not used.

APPLICATION INFORMATION (continued)

ENABLE/Low-Battery Detector (Enhanced Version) TPS62051 Only

The TPS62051 offers an enhanced LBI functionality to provide a precise, user programmable undervoltage shutdown. No additional supply voltage supervisor (SVS) is needed to provide this function.

When the enable (EN) pin is pulled high, only the internal bandgap voltage reference is switched on to provide a reference source for the LBI comparator. As long as the voltage at LBI is less than the LBI trip point, all other internal circuits are shut down, reducing the supply current to 5 μ A. As soon as input voltage at LBI rises above the LBI trip point of 1.21 V, the device is completely enabled and starts switching.

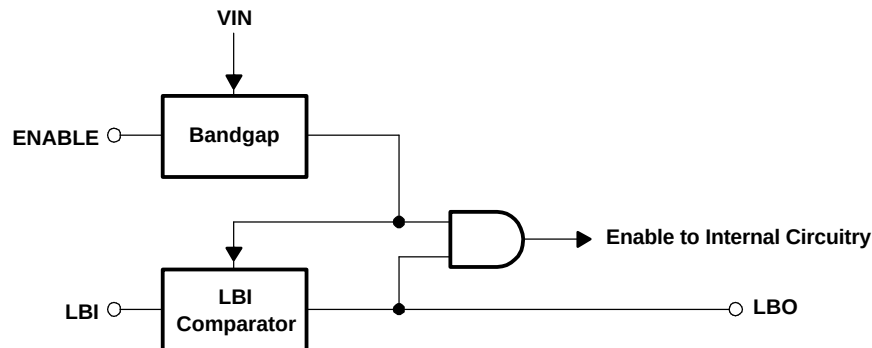


Figure 19. Block Diagram of ENABLE/LBI Functionality for TPS62051

The logic level of the LBO pin is not defined for the first 500 μ s after EN is pulled high.

When the enhanced LBI is used to supervise the battery voltage and shut down the TPS62051 at low input voltages, the battery voltage rises again when the current drops to zero. The implemented hysteresis on the LBI pin may not be sufficient for all types of batteries. Figure 20 shows how an additional external hysteresis can be implemented.

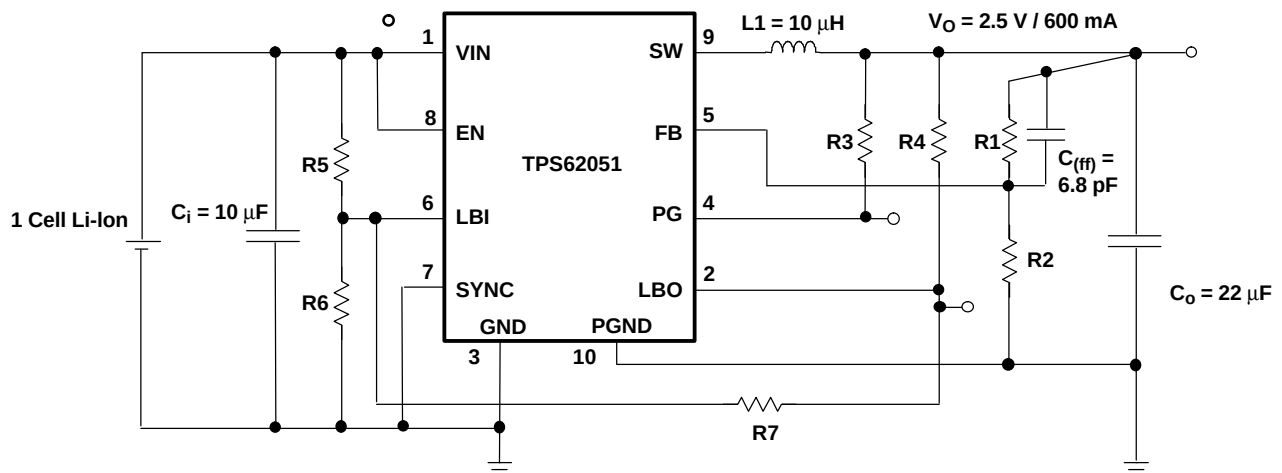


Figure 20. Enhanced LBI With Increased Hysteresis

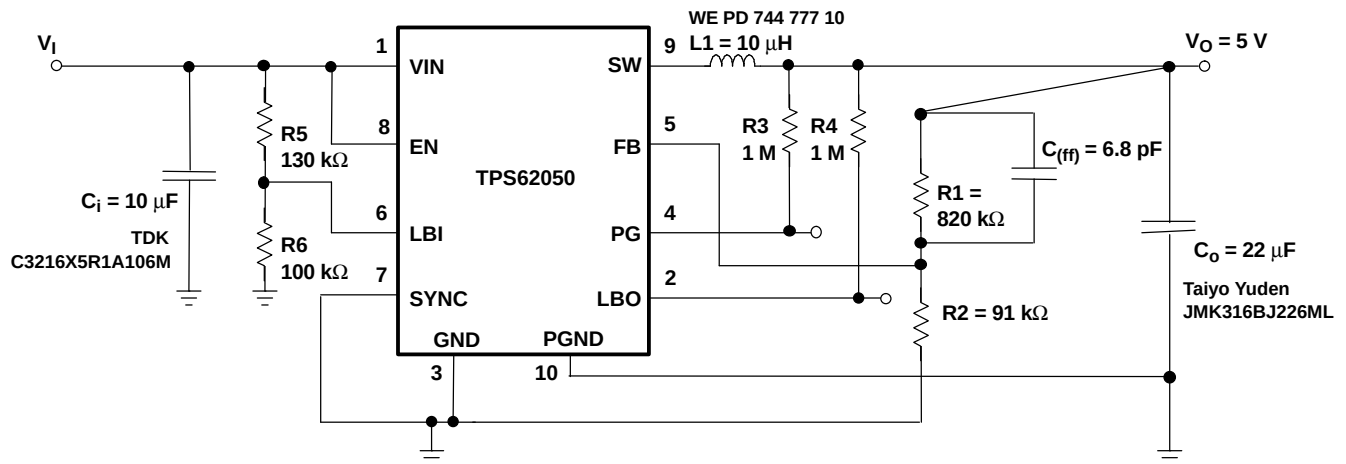
A MATHCAD™ file to calculate R7 can be downloaded from the product folder on the TI web.

APPLICATION INFORMATION (continued)

No Load Operation

If the converter operates in the forced PWM mode and there is no load connected to the output, the converter regulates the output voltage by allowing the inductor current to reverse for a short period of time.

STANDARD CIRCUIT FOR ADJUSTABLE VERSION



Quiescent Current Measurements and Efficiency Were Taken
With: R5 = Open, R4 = Open, LBI Connected to GND.

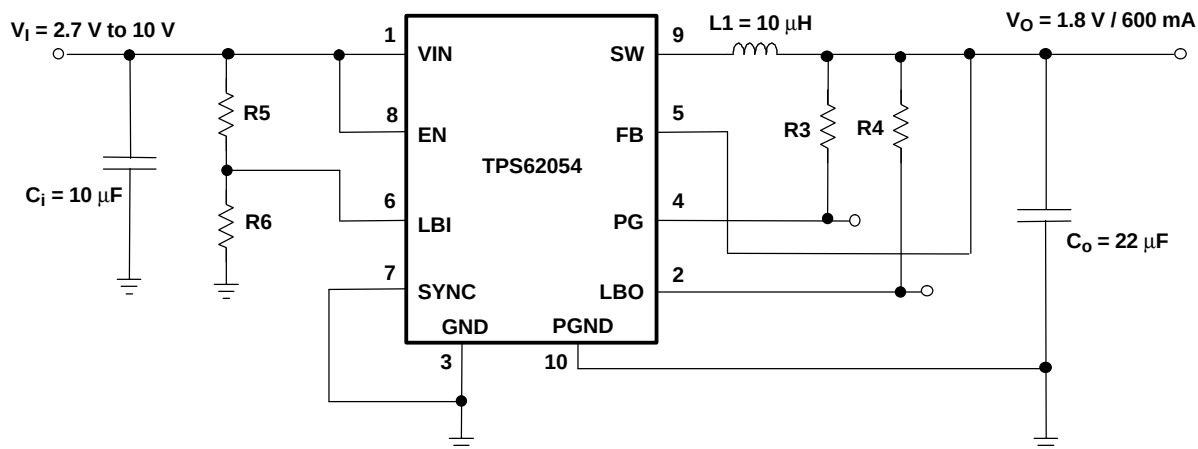
$$V_O = V_{FB} \times \frac{R1 + R2}{R2} \quad R1 = R2 \times \left(\frac{V_O}{V_{FB}} \right) - R2 \quad V_{FB} = 0.5V$$

Table 1. Values

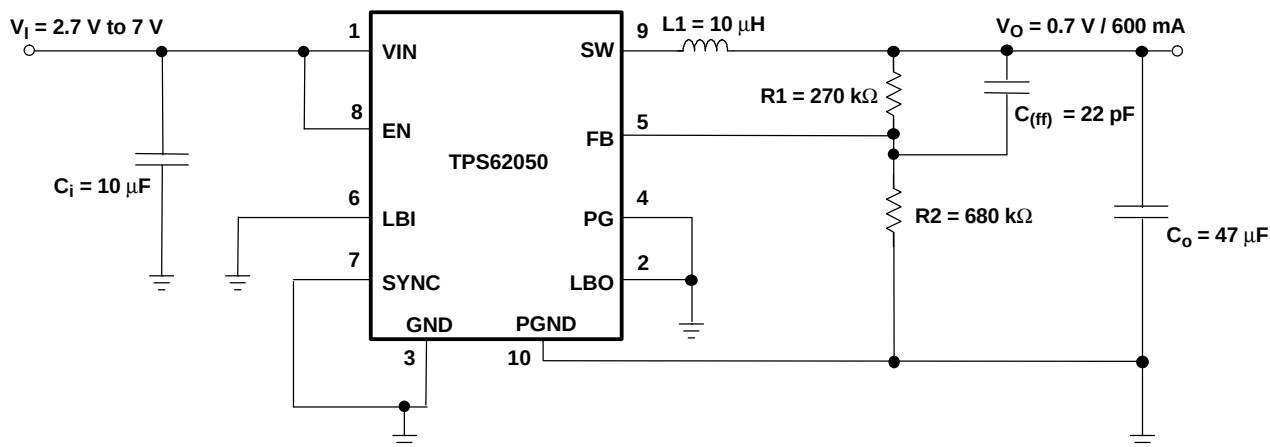
NOMINAL OUTPUT VOLTAGE	EQUATION	POSSIBLE RESISTOR COMBINATION	TYPICAL FEEDBACK CAPACITOR
0.7 V	$R1 = 0.4 \times R2$	$R1 = 270 \text{ k}, R2 = 680 \text{ k}$	$C_{(ff)} = 22 \text{ pF}$
1.2 V	$R1 = 1.4 \times R2$	$R1 = 510 \text{ k}, R2 = 360 \text{ k} (1.21 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$
1.5 V	$R1 = 2 \times R2$	$R1 = 300 \text{ k}, R2 = 150 \text{ k} (1.50 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$
1.8 V	$R1 = 2.6 \times R2$	$R1 = 390 \text{ k}, R2 = 150 \text{ k} (1.80 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$
2.5 V	$R1 = 4 \times R2$	$R1 = 680 \text{ k}, R2 = 169 \text{ k} (2.51 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$
3.3 V	$R1 = 5.6 \times R2$	$R1 = 560 \text{ k}, R2 = 100 \text{ k} (3.30 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$
5 V	$R1 = 9 \times R2$	$R1 = 820 \text{ k}, R2 = 91 \text{ k} (5.0 \text{ V})$	$C_{(ff)} = 6.8 \text{ pF}$

APPLICATION INFORMATION (continued)

STANDARD CIRCUIT FOR FIXED VOLTAGE VERSION



CONVERTER FOR 0.7-V OUTPUT VOLTAGE



The TPS62050 is used to generate output voltages as low as 0.7 V. With such low output voltages, the inductor discharges very slowly. This leads to a high output voltage ripple in power-save mode (SYNC = GND). It is therefore recommended to use a larger output capacitor to keep the output ripple low. With an output capacitor of 47 μF , the output voltage ripple is less than 40 mV_{pp}.

LAYOUT AND BOARD SPACE

All capacitors should be soldered as close as possible to the IC.

For information on the PCB layout see the user's guide SLVU081.

Keep the feedback track as short as possible. Any coupling to the FB pin may cause additional output voltage ripple.

APPLICATION INFORMATION (continued)

INDUCTOR SELECTION

A 10-μH minimum inductor should be used with the TPS6205x. Values larger than 22 μH or smaller than 10 μH may cause stability problems due to the internal compensation of the regulator. After choosing the inductor value of typically 10 μH, two additional inductor parameter should be considered: the current rating of the inductor and the dc resistance. The dc resistance of the inductance directly influences the efficiency of the converter. Therefore, an inductor with lowest dc resistance should be selected for highest efficiency. In order to avoid saturation of the inductor, the inductor should be rated at least for the maximum output current plus half the inductor ripple current which is calculated as:

$$\Delta I_L = V_O \times \frac{1 - \frac{V_O}{V_I}}{L \times f} \quad I_L(\text{max}) = I_O(\text{max}) + \frac{\Delta I_L}{2}$$

f = Switching frequency (850 kHz typical)

L = Inductor value

ΔIL = Peak-to-peak inductor ripple current

I_L(max) = Maximum inductor current

The highest inductor current occurs at maximum VIN . A more conservative approach is to select the inductor current rating just for the maximum switch current of the TPS6205x which is 1.4 A maximum. See Table 2 for inductors that have been tested for operation with the TPS6205x.

Table 2. Inductors

MANUFACTURER	TYPE	INDUCTANCE	DC RESISTANCE	SATURATION CURRENT
TDK	SLF7032T- 100M1R4SLF7032T- 220M96SLF7045T- 100M1R3SLF7045T- 100MR90	10 μH ±20%22 μH ±20%10 μH ±20%22 μH ±20%	53 mΩ±20%110 mΩ±20%36 mΩ±20%61 mΩ±20%	1.4 A0.96 A1.3 A0.9 A
Sumida	CDR74B	10 μH	70 mΩ	1.65 A
	CDR74B	22 μH	130 mΩ	1.12 A
	CDH74	10 μH	49 mΩ	1.8 A
	CDH74	22 μH	110 mΩ	1.23 A
	CDR63B	10 μH	140 mΩ	1 A
	CDRH4D28	10 μH	128 mΩ	1 A
	CDRH5D28	10 μH	48 mΩ	1.3 A
	CDRH5D18	10 μH	92 mΩ	1.2 A
Coilcraft	DT3316P-153	15 μH	60 mΩ	1.8 A
	DT3316P-223	22 μH	84 mΩ	1.5 A
Wuerth	WE-PD 744 778 10	10 μH	72 mΩ	1.68 A
	WE-PD 744 777 10	10 μH	49 mΩ	1.84 A
	WE-PD 744 778 122	22 μH	190 mΩ	1.07A
	WE-PD 744 777 122	22 μH	110 mΩ	1.23 A

APPLICATION INFORMATION (continued)

OUTPUT CAPACITOR SELECTION

The output capacitor should have a minimum value of 22µF. For best performance, a low ESR ceramic output capacitor is needed.

For completeness, the RMS ripple current is calculated as:

$$I_{RMS(CO)} = V_O \times \frac{1 - \frac{V_O}{V_I}}{L \times f} \times \frac{1}{2 \times \sqrt{3}}$$

The overall output ripple voltage is the sum of the voltage spike caused by the output capacitor ESR plus the voltage ripple caused by charge and discharging the output capacitor:

$$\Delta V_O = V_O \times \frac{1 - \frac{V_O}{V_I}}{L \times f} \times \left(\frac{1}{8 \times C_O \times f} + R_{ESR} \right)$$

The highest output voltage ripple occurs at the highest input voltage V_I .

INPUT CAPACITOR SELECTION

Because the buck converter has a pulsating input current, a low ESR input capacitor is required for best input voltage filtering and minimizing the interference with other circuits caused by high input voltage spikes. The input capacitor should have a minimum value of 10 µF and can be increased without any limit for better input voltage filtering. The input capacitor should be rated for the maximum input ripple current calculated as:

$$I_{RMS} = I_O(\max) \times \sqrt{\frac{V_O}{V_I} \times \left(1 - \frac{V_O}{V_I} \right)}$$

The worst case RMS ripple current occurs at $D = 0.5$ and is calculated as: $I_{RMS} = I_O/2$. Ceramic capacitors have a good performance because of their low ESR value and they are less sensitive to voltage transients compared to tantalum capacitors. Place the input capacitor as close as possible to the input pin of the IC for best performance.

Table 3. Capacitors

MANUFACTURER	PART NUMBER	SIZE	VOLTAGE	CAPACITANCE	TYPE
Taiyo Yuden	JMK212BJ106MG	0805	6.3 V	10 µF	Ceramic
	JMK316BJ106ML	1206	6.3 V	10 µF	Ceramic
	JMK316BJ226ML	1206	6.3 V	22 µF	Ceramic
	LMK316BJ475ML	1206	10 V	4.7 µF (1)	Ceramic
	EMK316BJ475ML	1206	16 V	4.7 µF (1)	Ceramic
	EMK325BJ106KN-T	1210	16 V	10 µF	Ceramic
Kemet	C1206C106M9PAC	1206	6.3 V	10 µF	Ceramic
TDK	C2012X5R0J106M	0805	6.3 V	10 µF	Ceramic
	C3216X5R0J226M	1206	6.3 V	22 µF	Ceramic
	C3216X5R1A106M	1206	10 V	10 µF	Ceramic

(1) Connect two in parallel.

APPLICATION INFORMATION (continued)

Table 4. Capacitor Manufacturers

MANUFACTURER	CAPACITOR TYPE	INTERNET
Taiyo Yuden	X7R/X5R ceramic	www.t-yuden.com
TDK	X7R/X5R ceramic	www.component.tdk.com
Vishay	X7R/X5R ceramic	www.vishay.com
Kemet	X7R/X5R ceramic	www.kemet.com

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/Ball Finish	MSL Peak Temp ⁽³⁾
TPS62050DGS	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62050DGSG4	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62050DGSR	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62050DGSRG4	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62051DGS	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62051DGSG4	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62051DGSR	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62051DGSRG4	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62052DGS	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62052DGSG4	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62052DGSR	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62052DGSRG4	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62054DGS	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62054DGSG4	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62054DGSR	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62054DGSRG4	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62056DGS	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62056DGSG4	ACTIVE	MSOP	DGS	10	80	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62056DGSR	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS62056DGSRG4	ACTIVE	MSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM

⁽¹⁾ The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBsolete: TI has discontinued the production of the device.

⁽²⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

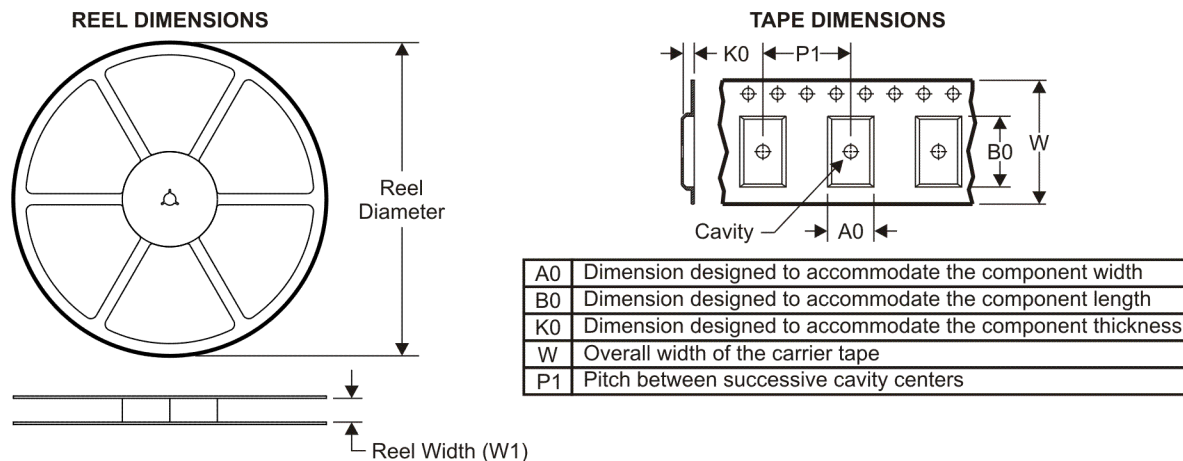
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

⁽³⁾ MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

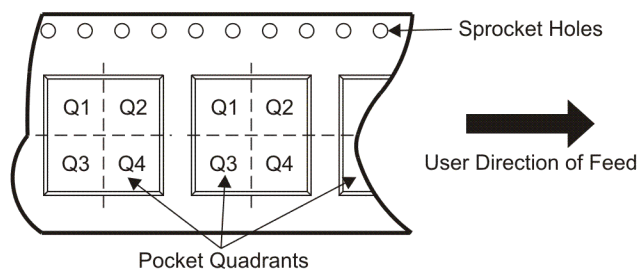
Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION



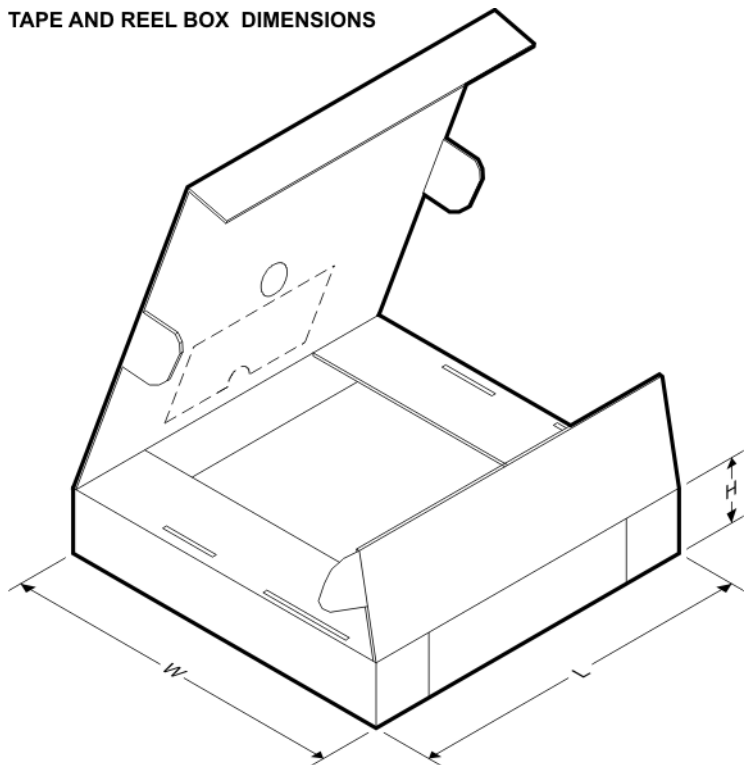
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS62050DGSR	MSOP	DGS	10	2500	330.0	12.4	5.2	3.3	1.6	8.0	12.0	Q1
TPS62051DGSR	MSOP	DGS	10	2500	330.0	12.4	5.2	3.3	1.6	8.0	12.0	Q1
TPS62052DGSR	MSOP	DGS	10	2500	330.0	12.4	5.2	3.3	1.6	8.0	12.0	Q1
TPS62054DGSR	MSOP	DGS	10	2500	330.0	12.4	5.2	3.3	1.6	8.0	12.0	Q1
TPS62056DGSR	MSOP	DGS	10	2500	330.0	12.4	5.2	3.3	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS

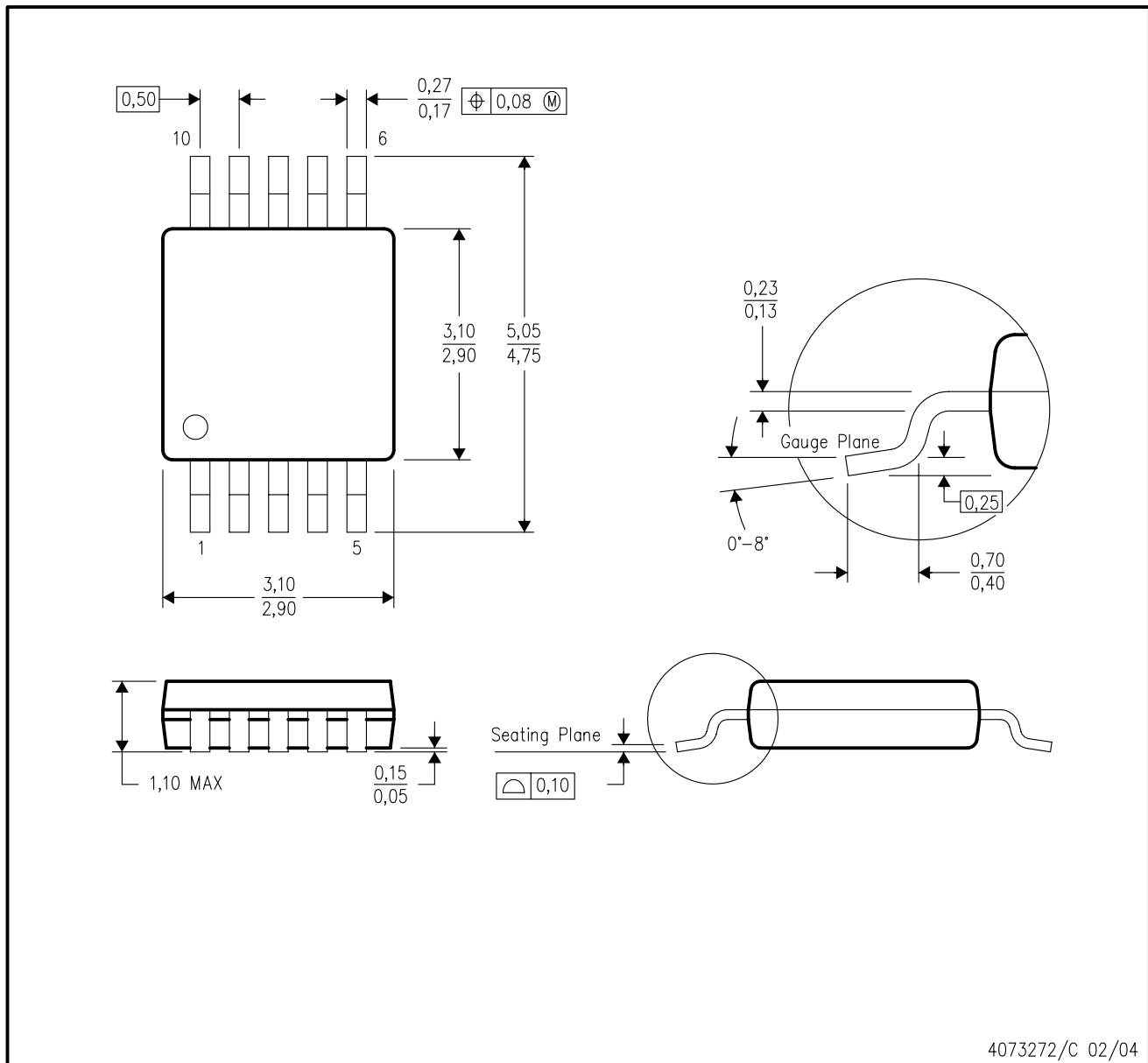


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS62050DGSR	MSOP	DGS	10	2500	338.1	340.5	21.1
TPS62051DGSR	MSOP	DGS	10	2500	338.1	340.5	21.1
TPS62052DGSR	MSOP	DGS	10	2500	338.1	340.5	21.1
TPS62054DGSR	MSOP	DGS	10	2500	338.1	340.5	21.1
TPS62056DGSR	MSOP	DGS	10	2500	338.1	340.5	21.1

DGS (S-PDSO-G10)

PLASTIC SMALL-OUTLINE PACKAGE



4073272/C 02/04

- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Body dimensions do not include mold flash or protrusion.
 - Falls within JEDEC MO-187 variation BA.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products

Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
RF/IF and ZigBee® Solutions	www.ti.com/lprf

Applications

Audio	www.ti.com/audio
Automotive	www.ti.com/automotive
Broadband	www.ti.com/broadband
Digital Control	www.ti.com/digitalcontrol
Medical	www.ti.com/medical
Military	www.ti.com/military
Optical Networking	www.ti.com/opticalnetwork
Security	www.ti.com/security
Telephony	www.ti.com/telephony
Video & Imaging	www.ti.com/video
Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2009, Texas Instruments Incorporated