2.25-MHz 600-mA STEP-DOWN CONVERTERS

Check for Samples: TPS62260-Q1, TPS62261-Q1, TPS62262-Q1, TPS62263-Q1

FEATURES

- **Qualified for Automotive Applications**
- **High-Efficiency Step-Down Converter**
- **Output Current up to 600 mA**
- **Wide V_{IN} Range from 2-V to 6-V for Li-Ion Batteries with Extended Voltage Range**
- **2.25-MHz Fixed Frequency Operation**
- **Power Save Mode at Light Load Currents**
- **Output Voltage Accuracy in PWM Mode ±1.5%**
- **15-µA (Typ) Quiescent Current**
- **100% Duty Cycle for Lowest Dropout**
- **Soft Start**
- **Voltage Positioning at Light Loads**
- **Available in a Small 2×2×0,8-mm SON Package**
- **Allows <1-mm Solution Height**

APPLICATIONS

- **PDAs, Pocket PCs**
- **Low Power DSP Supply**
- **Portable Media Players**
- **POL applications**

DESCRIPTION

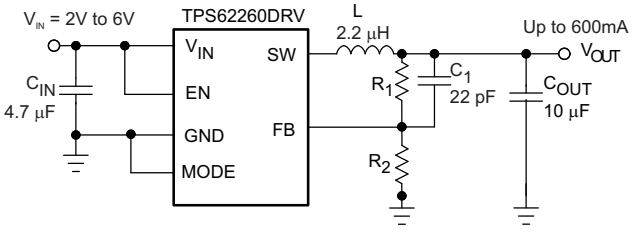
The TPS6226x devices are high-efficiency synchronous step-down dc-dc converters optimized for battery powered applications. It provides up to 600-mA output current from a single Li-Ion cell and is ideal to power mobile phones and other portable applications.

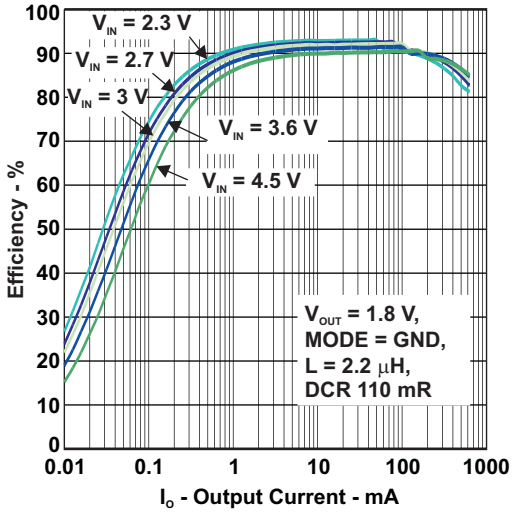
With an wide input voltage range of 2 V to 6 V, the device supports applications powered by Li-Ion batteries with extended voltage range, two and three cell alkaline batteries, 3.3-V and 5-V input voltage rails.

The TPS6226x operates at 2.25-MHz fixed switching frequency and enters Power Save Mode operation at light load currents to maintain high efficiency over the entire load current range.

The Power Save Mode is optimized for low output voltage ripple. For low noise applications, the device can be forced into fixed frequency PWM mode by pulling the MODE pin high. In the shutdown mode, the current consumption is reduced to less than 1 µA. TPS6226x allows the use of small inductors and capacitors to achieve a small solution size.

The TPS6226x is available in a very small 2×2mm 6-pin SON package.





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.

PowerPAD is a trademark of Texas Instruments.

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.

ORDERING INFORMATION(1)

T_A	OUTPUT VOLTAGE	PACKAGE(2)		ORDERABLE PART NUMBER	TOP-SIDE MARKING
–40°C to 85°C	Adjustable	SON – DRV	Reel of 3000	TPS62260IDRVRQ1	OEO
–40°C to 105°C	1.8 V			TPS62261TDRVRQ1	OFE
	1.2 V			TPS62262TDRVRQ1	OFF
	2.5 V			TPS62263TDRVRQ1	OFG
–40°C to 105°C	Adjustable			TPS62260TDRVRQ1	OEO

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

ABSOLUTE MAXIMUM RATINGS(1)

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

	Input voltage range(2)		–0.3 V to 7 V
	Voltage range at EN, MODE		–0.3 V to V_{IN} +0.3 V, ≤ 7 V
	Voltage on SW		–0.3 V to 7 V
	Peak output current		Internally limited
	ESD rating(3)	HBM, Human-body model	2000 V
		CDM, Charged-device model	1000 V
		MM, Machine model	200 V
T_J	Operating junction temperature		–40°C to 125°C
T_{stg}	Storage temperature range		–65°C to 150°C

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to network ground terminal.
(3) The human body model is a 100-pF capacitor discharged through a 1.5-kΩ resistor into each pin. The machine model is a 200-pF capacitor discharged directly into each pin.

DISSIPATION RATINGS

PACKAGE	$R_{\theta JA}$	POWER RATING FOR T_A ≤ 25°C	DERATING FACTOR ABOVE T_A = 25°C
DRV	76°C/W	1300 mW	13 mW/°C

RECOMMENDED OPERATING CONDITIONS

			MIN	NOM	MAX	UNIT
V_{IN}	Supply voltage		2		6	V
	Output voltage range for adjustable voltage		0.6		VIN	V
T_A	Operating ambient temperature	TPS62260IDRVRQ1	–40		85	°C
		TPS6226XTDRVRQ1	-40		105	
T_J	Operating junction temperature		–40		125	°C

ELECTRICAL CHARACTERISTICS

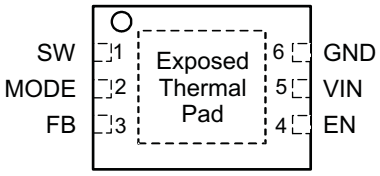
Over full operating ambient temperature range, typical values are at T_A = 25°C. Unless otherwise noted, specifications apply for condition V_{IN} = EN = 3.6V. External components C_{IN} = 4.7µF 0603, C_{OUT} = 10µF 0603, L = 2.2µH, see the parameter measurement information.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Supply							
V_{IN}	Input voltage range			2.3		6	V
I_{OUT}	Output current(1)	V_{IN} 2.5 V to 6 V				600	mA
		V_{IN} 2.3 V to 2.5 V				300	
		V_{IN} 2 V to 2.3 V				150	
I_Q	Operating quiescent current	I_{OUT} = 0 mA, PFM mode enabled (MODE = GND), device not switching			15		µA
		I_{OUT} = 0 mA, PFM mode(2) enabled (MODE = GND), device switching, V_{OUT} = 1.8 V			18.5		
		I_{OUT} = 0 mA, switching with no load (MODE = V_{IN}), PWM operation, V_{OUT} = 1.8 V, V_{IN} = 3 V			3.8		mA
I_{SD}	Shutdown current	EN = GND	T_A = 25°C		0.1	1	µA
			T_A = 105°C			2.5	
UVLO	Undervoltage lockout threshold	Falling			1.85		V
		Rising			1.95		
Enable, Mode							
V_{IH}	High level input voltage, EN, MODE	2 V ≤ V_{IN} ≤ 6 V		1		VIN	V
V_{IL}	Low level input voltage, EN, MODE	2 V ≤ V_{IN} ≤ 6 V		0		0.4	V
I_{IN}	Input bias current, EN, MODE	EN, MODE = GND or VIN			0.01	1	µA
Power Switch							
$R_{DS(on)}$	High-side MOSFET on-resistance	V_{IN} = V_{GS} = 3.6 V, T_A = 25°C			240	480	mΩ
	Low-side MOSFET on-resistance				185	380	
I_{LIMF}	Forward current limit MOSFET, high side and low side	V_{IN} = V_{GS} = 3.6 V, T_A = 25°C		0.8	1	1.3	A
T_{SD}	Thermal shutdown	Increasing junction temperature			140		°C
	Thermal shutdown hysteresis	Decreasing junction temperature			20		
Oscillator							
f_{SW}	Oscillator frequency	2 V ≤ V_{IN} ≤ 6 V		2	2.25	2.5	MHz
Output							
V_{OUT}	Adjustable output voltage range			0.6		V_{IN}	V
V_{ref}	Reference voltage				600		mV
V_{FB}	Feedback voltage PWM mode	MODE = V_{IN}, PWM operation, for fixed output voltage versions V_{FB} = V_{OUT}, 2.5 V ≤ V_{IN} ≤ 6 V, 0 mA ≤ I_{OUT} ≤ 600 mA (3)		–1.5%	0%	1.5%	
	Feedback voltage PFM mode	MODE = GND, device in PFM mode, voltage positioning active(2)			1%		
	Load regulation	PWM Mode			-0.5		%/A
$t_{Start\ Up}$	Start-up time	Time from active EN to reach 95% of V_{OUT} nominal			500		µs
t_{Ramp}	V_{OUT} ramp-up time	Time to ramp from 5% to 95% of V_{OUT}			250		µs
I_{lkg}	Leakage current into SW pin	V_{IN} = 3.6 V, V_{IN} = V_{OUT} = V_{SW}, EN = GND (4)			0.1	1	µA

(1) Not production tested
(2) In PFM mode, the internal reference voltage is set to typ. 1.01×V_{ref}. See the parameter measurement information.
(3) For V_{IN} = V_O + 0.6 V
(4) In fixed output voltage versions, the internal resistor divider network is disconnected from FB pin.

PIN ASSIGNMENTS

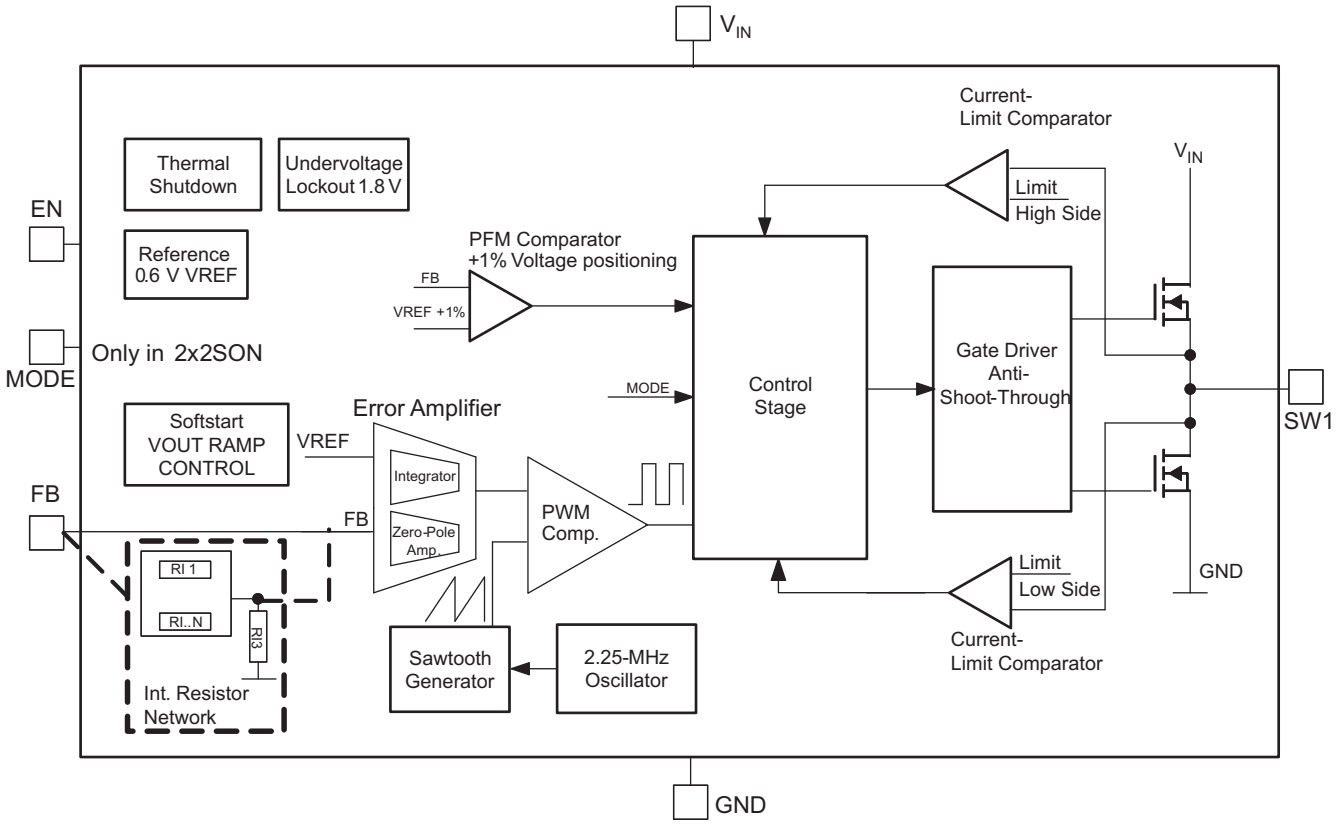
DRV PACKAGE
(TOP VIEW)



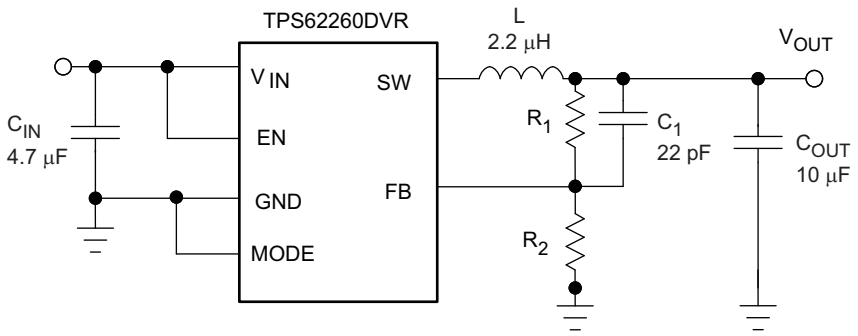
TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
SW	1	OUT	This is the switch pin and is connected to the internal MOSFET switches. Connect the external inductor between this terminal and the output capacitor.
MODE	2	I	This pin is only available at SON package option. MODE pin = high forces the device to operate in fixed frequency PWM mode. MODE pin = low enables the Power Save Mode with automatic transition from PFM mode to fixed frequency PWM mode.
FB	3	I	Feedback for the internal regulation loop. Connect the external resistor divider to this pin. In case of fixed output voltage option, connect this pin directly to the output capacitor.
EN	4	I	This is the enable pin of the device. Pulling this pin to low forces the device into shutdown mode. Pulling this pin to high enables the device. This pin must be terminated.
V_{IN}	5	PWR	Power supply
GND	6	PWR	Ground

FUNCTIONAL BLOCK DIAGRAM



PARAMETER MEASUREMENT INFORMATION



L: LPS3015 2.2 µH, 110 mΩ
C_{IN} GRM188R60J475K 4.7 µF Murata 0603 size
C_{OUT} GRM188R60J106M 10 µF Murata 0603 size

TYPICAL CHARACTERISTICS

Table 1. Table of Graphs

			FIGURE
η	Efficiency	Output Current V_{OUT} = 1.8 V, Power Save Mode, MODE = GND	Figure 1
		Output Current V_{OUT} = 1.8 V, PWM Mode, MODE = V_{IN}	Figure 2
		Output Current V_{OUT} = 3.3 V, PWM Mode, MODE = V_{IN}	Figure 3
		Output Current V_{OUT} = 3.3 V, Power Save Mode, MODE = GND	Figure 4
	Output Voltage Accuracy	Output Current	Figure 5
		at 25°C, V_{OUT} = 1.8 V, Power Save Mode, MODE = GND	Figure 6
		at –40°C, V_{OUT} = 1.8 V, Power Save Mode, MODE = GND	Figure 7
		at 85°C, V_{OUT} = 1.8 V, Power Save Mode, MODE = GND	Figure 8
		at 25°C, V_{OUT} = 1.8 V, PWM Mode, MODE = V_{IN}	Figure 9
		at –40°C, V_{OUT} = 1.8 V, PWM Mode, MODE = V_{IN}	Figure 10
		at 85°C, V_{OUT} = 1.8 V, PWM Mode, MODE = V_{IN}	Figure 11
	Typical Operation	PWM Mode, V_{OUT} = 1.8 V	Figure 12
	Mode Transition	MODE Pin Transition From PFM to Forced PWM Mode at light load	Figure 13
		MODE Pin Transition From Forced PWM to PFM Mode at light load	Figure 14
	Start-up Timing		Figure 15
	Load Transient	Forced PWM Mode , V_{OUT} = 1.5 V, 50 mA to 200 mA	Figure 16
		Forced PWM Mode , V_{OUT} = 1.5 V, 200 mA to 400 mA	Figure 17
		PFM Mode to PWM Mode, V_{OUT} = 1.5 V, 150 µA to 400 mA	Figure 18
		PWM Mode to PFM Mode, V_{OUT} = 1.5 V, 400 mA to 150 µA	Figure 19
		PFM Mode, V_{OUT} = 1.5 V, 1.5 mA to 50 mA	Figure 20
		PFM Mode, V_{OUT} = 1.5 V, 50 mA to 1.5 mA	Figure 21
		PFM Mode to PWM Mode, V_{OUT} = 1.8 V, 50 mA to 250 mA	Figure 22
		PFM Mode to PWM Mode, V_{OUT} = 1.5 V, 50 mA to 400 mA	Figure 23
		PWM Mode to PFM Mode, V_{OUT} = 1.5 V, 400 mA to 50 mA	Figure 24
	Line Transient	PFM Mode, V_{OUT} = 1.8 V, 50 mA	Figure 25
		PFM Mode, V_{OUT} = 1.8 V, 250 mA	Figure 26
	Typical Operation	PFM V_{OUT} Ripple, V_{OUT} = 1.8 V, 10 mA, L = 2.2µH, C_{OUT} = 10µF	Figure 27
		PFM V_{OUT} Ripple, V_{OUT} = 1.8 V, 10 mA, L = 4.7µH, C_{OUT} = 10µF	Figure 28
	Shutdown Current into VIN	vs Input Voltage, (T_A = 85°C, T_A = 25°C, T_A = -40°C)	Figure 29
	Quiescent Current	vs Input Voltage, (T_A = 85°C, T_A = 25°C, T_A = -40°C)	Figure 30
	Static Drain Source On-State Resistance	vs Input Voltage, (T_A = 85°C, T_A = 25°C, T_A = -40°C)	Figure 31
			Figure 32
			Figure 33

EFFICIENCY (Power Save Mode) vs OUTPUT CURRENT

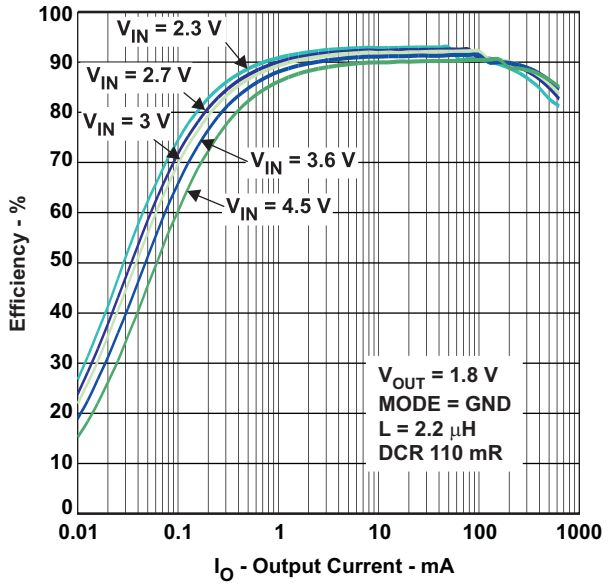


Figure 1.

EFFICIENCY (PWM Mode) vs OUTPUT CURRENT

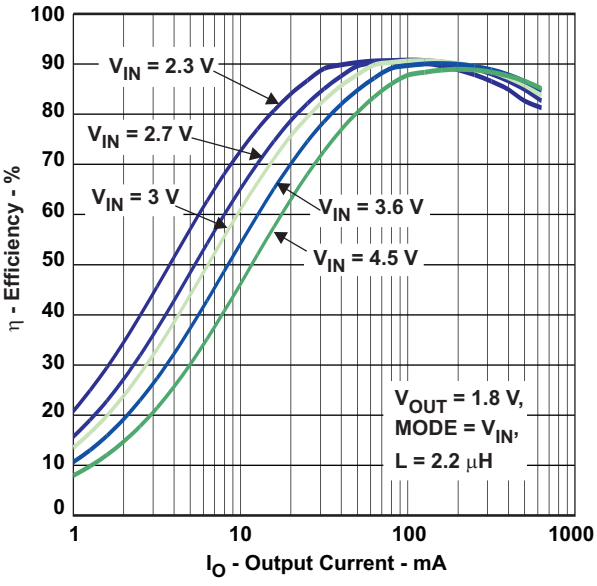


Figure 2.

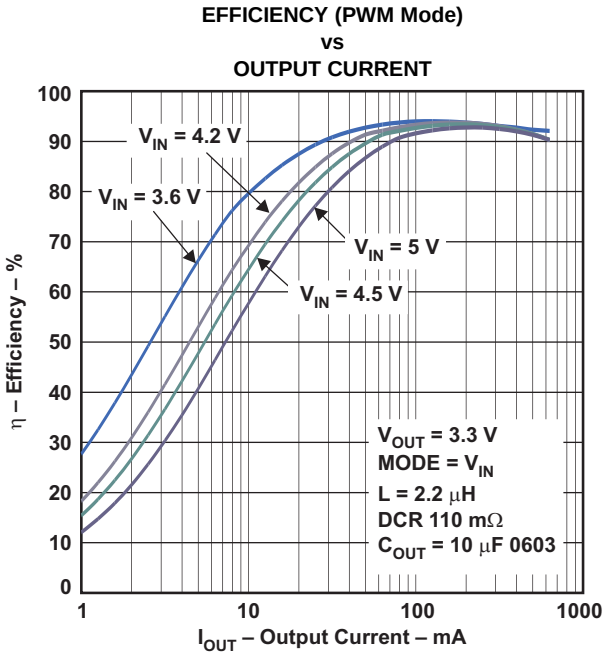


Figure 3.

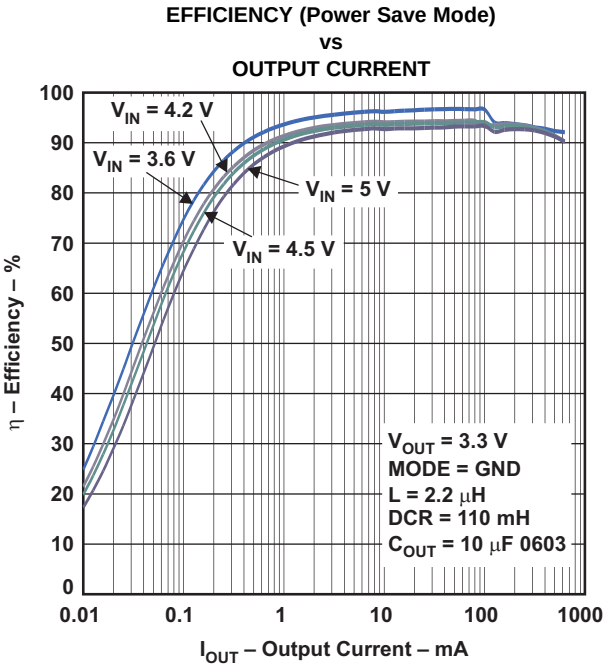


Figure 4.

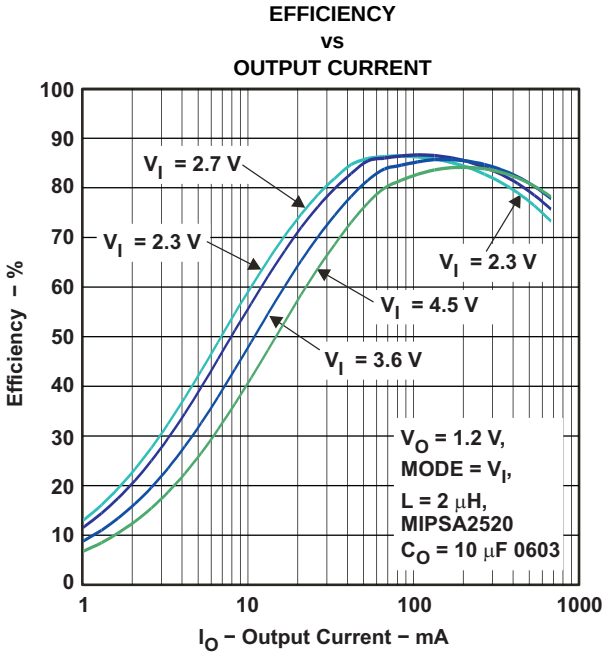


Figure 5.

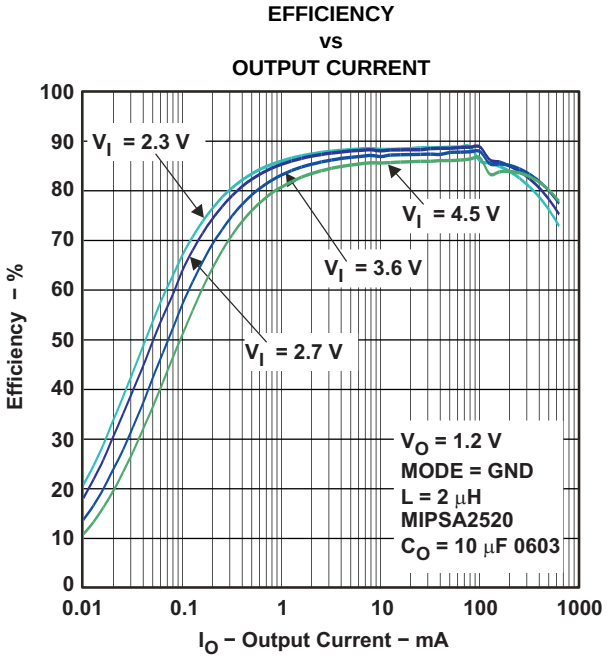


Figure 6.

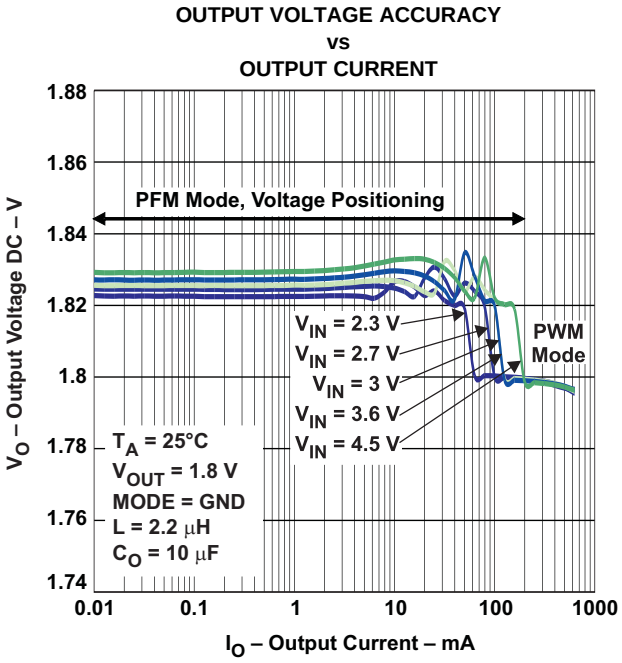
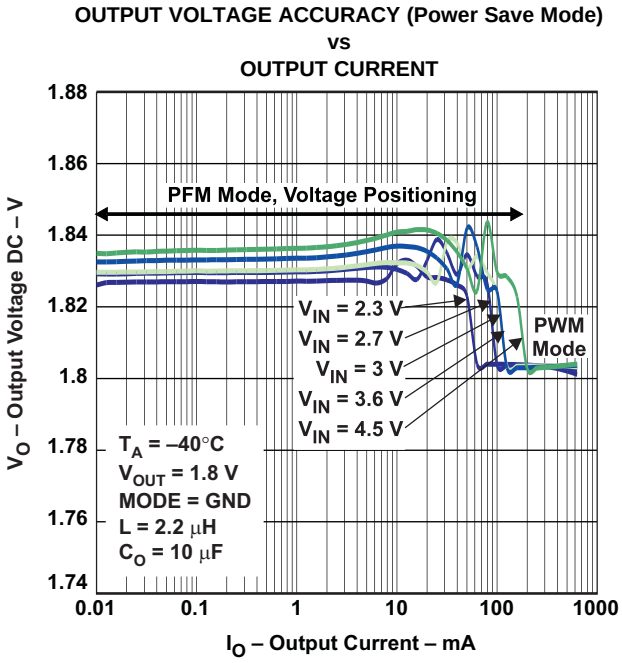


Figure 7.



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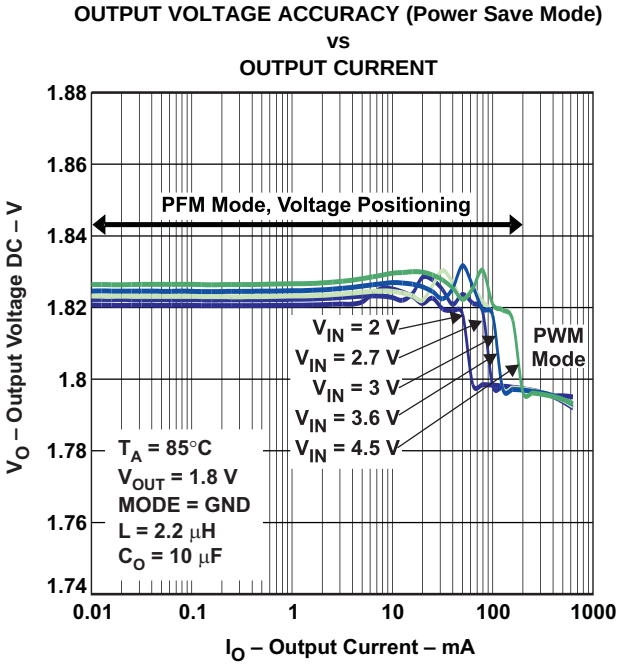

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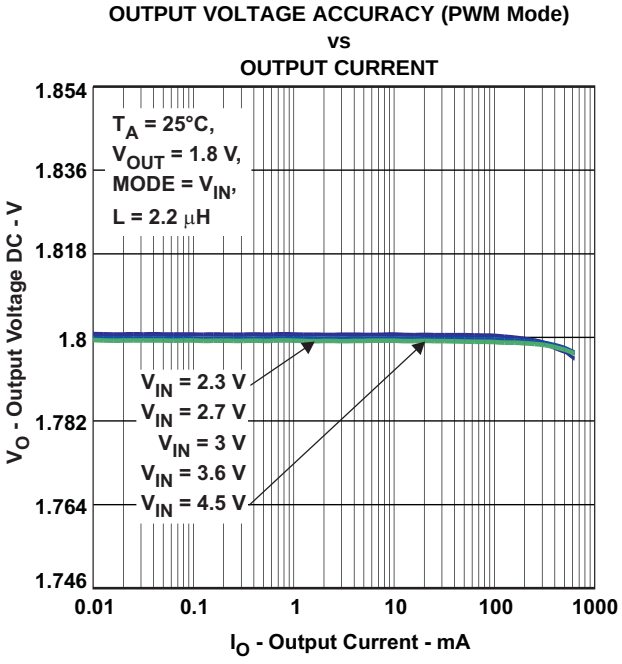


Figure 10.

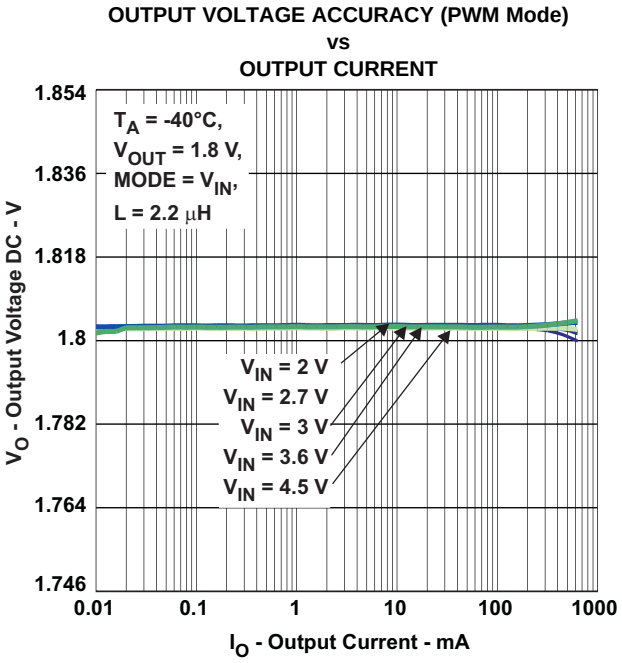


Figure 11.

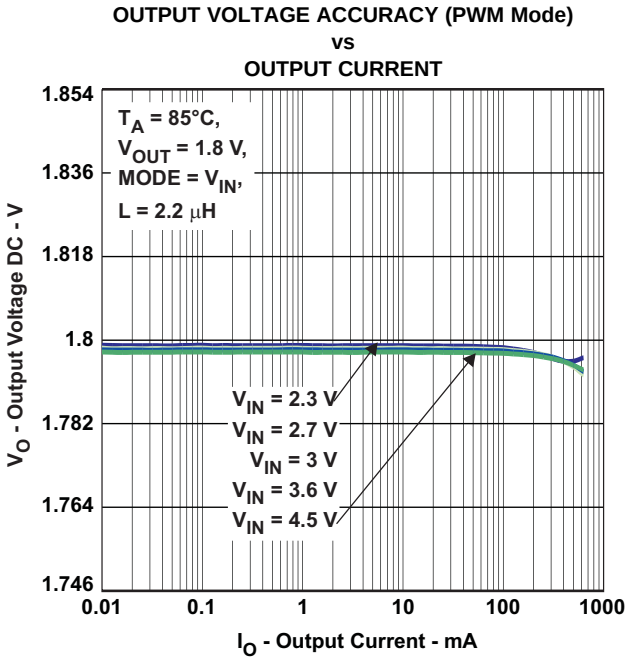


Figure 12.

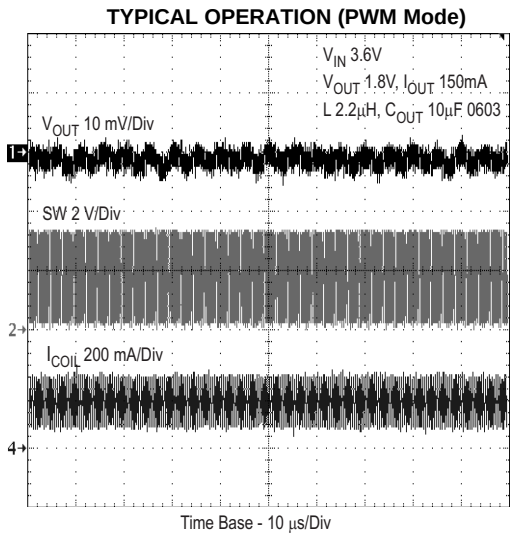


Figure 13.

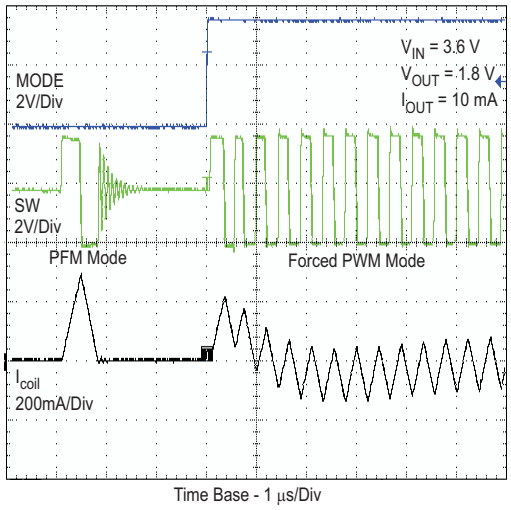


Figure 14.

MODE PIN TRANSITION FROM PWM TO PFM MODE AT LIGHT LOAD

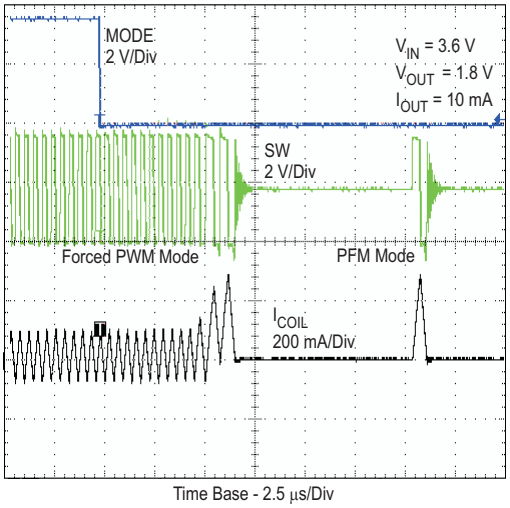


Figure 15.

START-UP TIMING

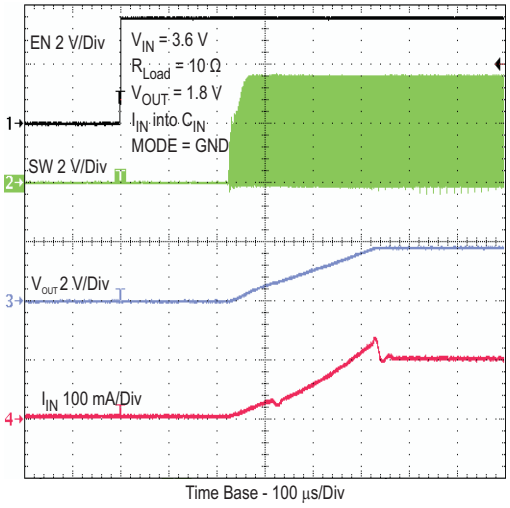


Figure 16.

LOAD TRANSIENT (Forced PWM Mode)

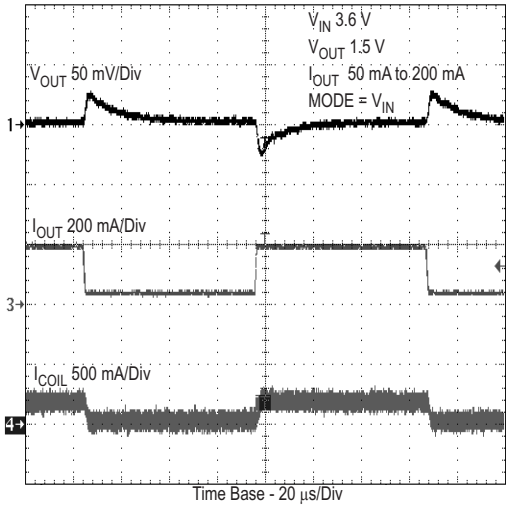


Figure 17.

LOAD TRANSIENT (Forced PWM Mode)

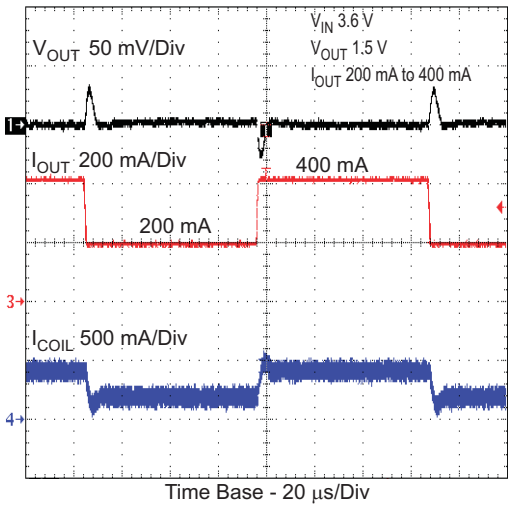


Figure 18.

LOAD TRANSIENT
(Forced PFM Mode To PWM Mode)

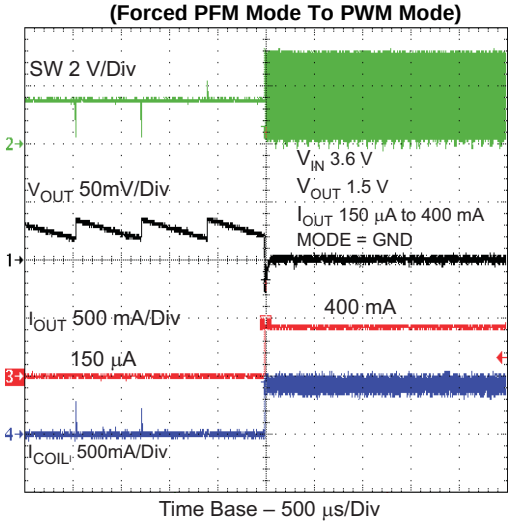


Figure 19.

LOAD TRANSIENT
(Forced PWM Mode To PFM Mode)

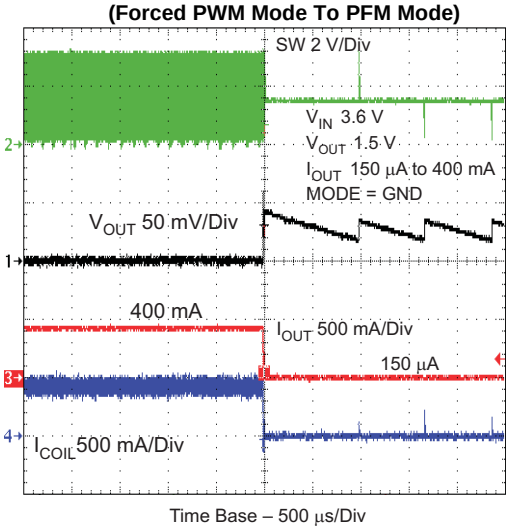


Figure 20.

LOAD TRANSIENT (PFM Mode)

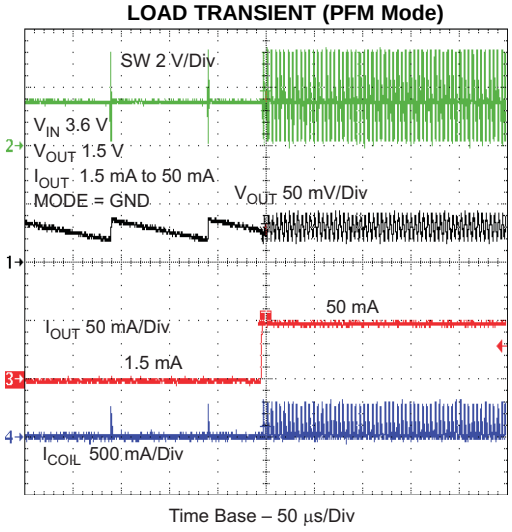


Figure 21.

LOAD TRANSIENT (PFM Mode)

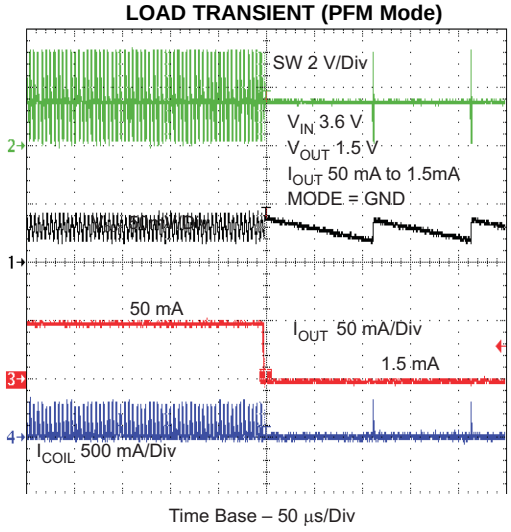


Figure 22.

LOAD TRANSIENT
(PFM Mode To PWM Mode)

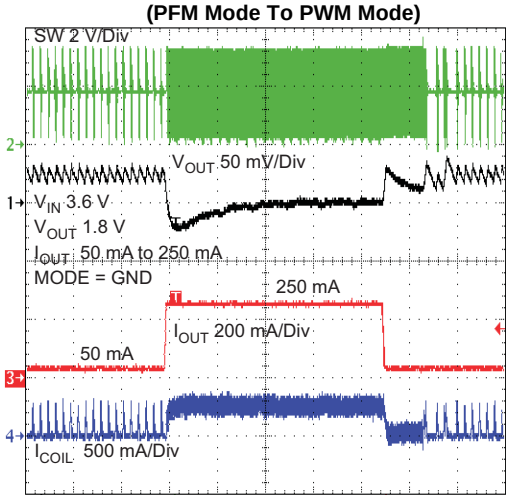


Figure 23.

LOAD TRANSIENT
(PFM Mode To PWM Mode)

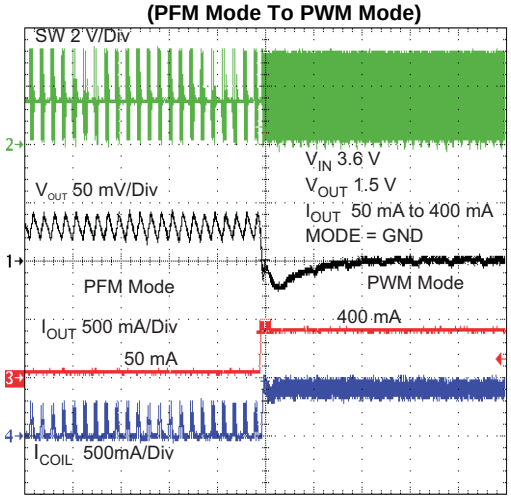


Figure 24.

LOAD TRANSIENT
(PWM Mode To PFM Mode)

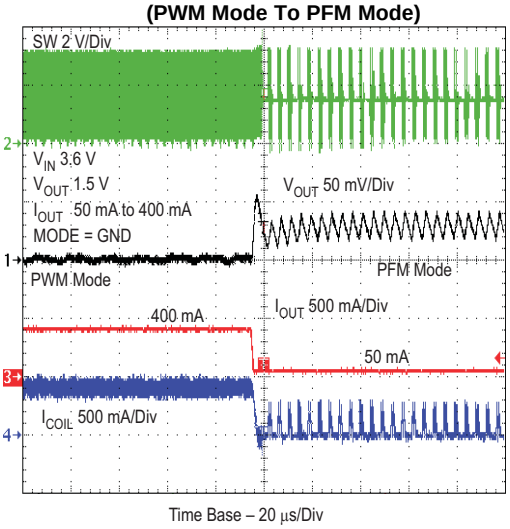


Figure 25.

LINE TRANSIENT (PFM Mode)

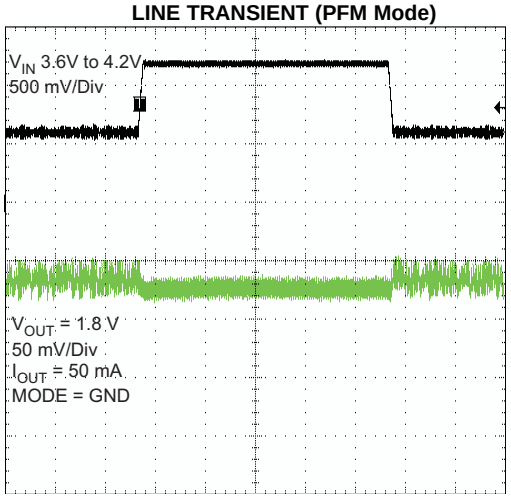


Figure 26.

LINE TRANSIENT (PWM Mode)

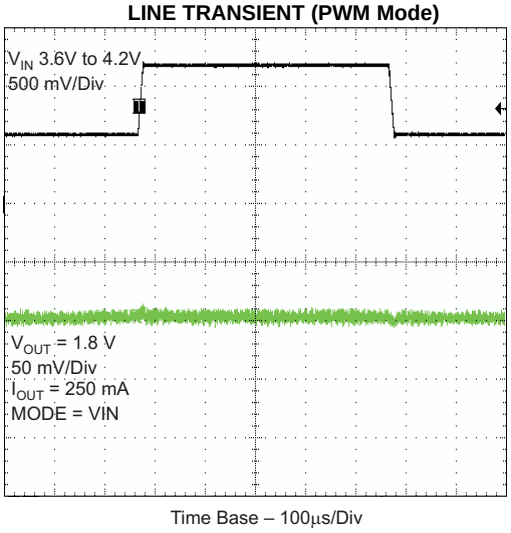


Figure 27.

TYPICAL OPERATION (PFM Mode)

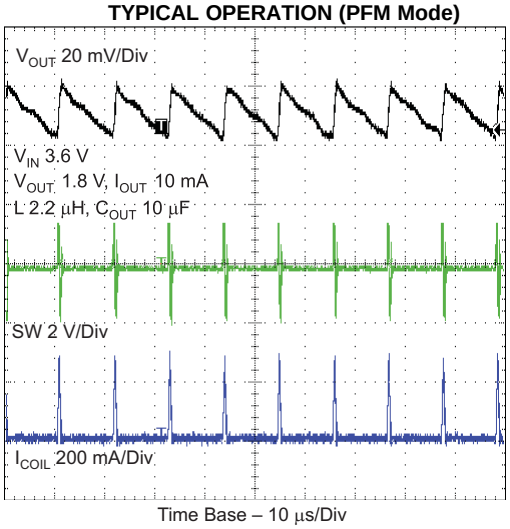


Figure 28.

TYPICAL OPERATION (PFM Mode)

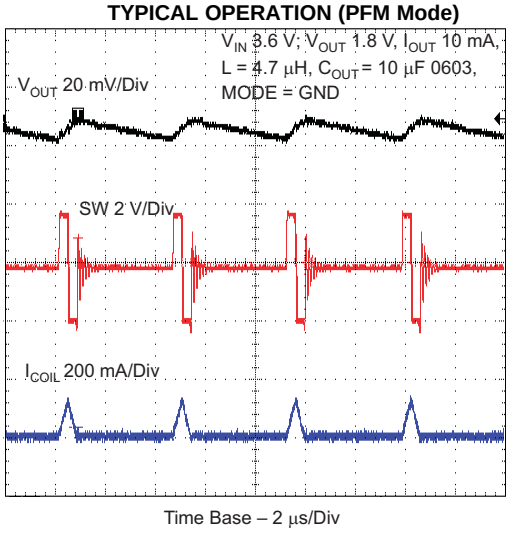


Figure 29.

SHUTDOWN CURRENT INTO VIN vs INPUT VOLTAGE

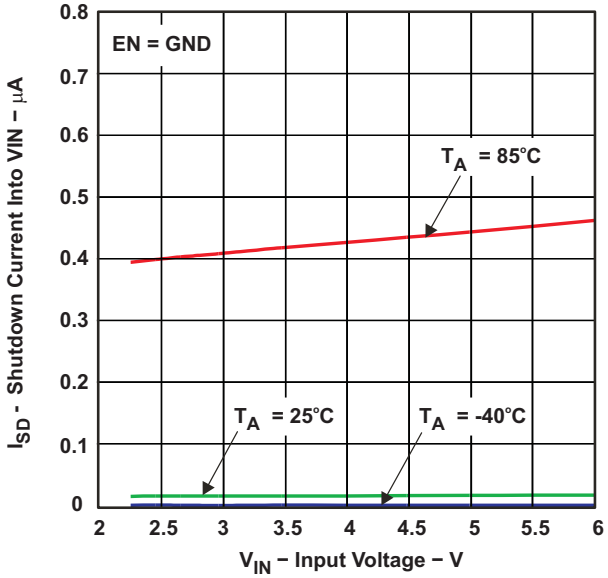


Figure 30.

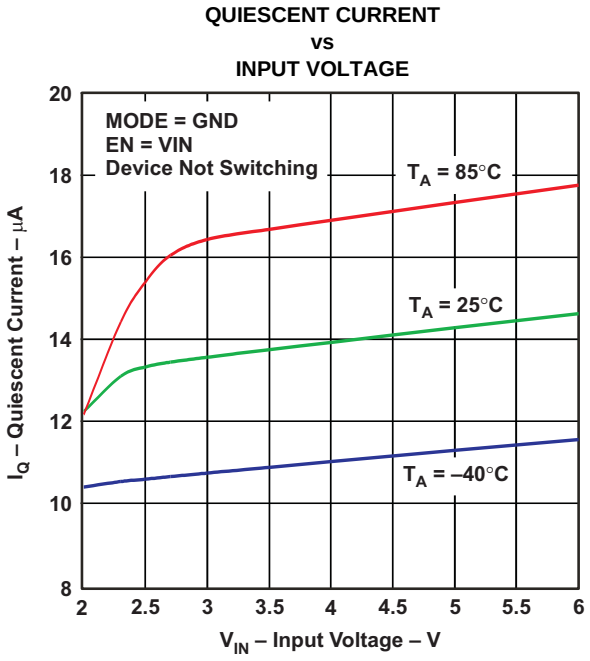


Figure 31.

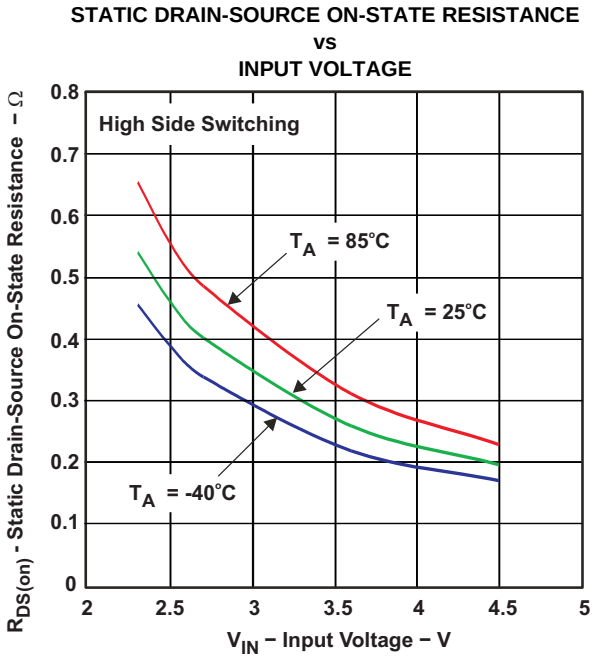


Figure 32.

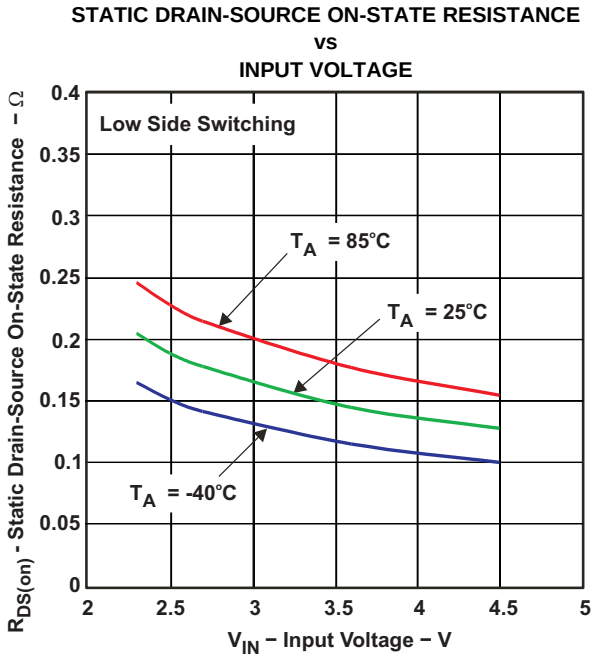


Figure 33.

DETAILED DESCRIPTION

OPERATION

The TPS6226x step down converter operates with typically 2.25 MHz fixed frequency pulse width modulation (PWM) at moderate to heavy load currents. At light load currents the converter can automatically enter Power Save Mode and operates then in PFM mode.

During PWM operation the converter use a unique fast response voltage mode control scheme with input voltage feed-forward to achieve good line and load regulation allowing the use of small ceramic input and output capacitors. At the beginning of each clock cycle initiated by the clock signal, the High Side MOSFET switch is turned on. The current flows now from the input capacitor via the High Side MOSFET switch through the inductor to the output capacitor and load. During this phase, the current ramps up until the PWM comparator trips and the control logic will turn off the switch. The current limit comparator will also turn off the switch in case the current limit of the High Side MOSFET switch is exceeded. After a dead time preventing shoot through current, the Low Side MOSFET rectifier is turned on and the inductor current will ramp down. The current flows now from the inductor to the output capacitor and to the load. It returns back to the inductor through the Low Side MOSFET rectifier.

The next cycle will be initiated by the clock signal again turning off the Low Side MOSFET rectifier and turning on the on the High Side MOSFET switch.

POWER SAVE MODE

The Power Save Mode is enabled with MODE Pin set to low level. If the load current decreases, the converter will enter Power Save Mode operation automatically. During Power Save Mode the converter skips switching and operates with reduced frequency in PFM mode with a minimum quiescent current to maintain high efficiency. The converter will position the output voltage typically +1% above the nominal output voltage. This voltage positioning feature minimizes voltage drops caused by a sudden load step.

The transition from PWM mode to PFM mode occurs once the inductor current in the Low Side MOSFET switch becomes zero, which indicates discontinuous conduction mode.

During the Power Save Mode the output voltage is monitored with a PFM comparator. As the output voltage falls below the PFM comparator threshold of V_{OUT} nominal +1%, the device starts a PFM current pulse. The High Side MOSFET switch will turn on, and the inductor current ramps up. After the On-time expires, the switch is turned off and the Low Side MOSFET switch is turned on until the inductor current becomes zero.

The converter effectively delivers a current to the output capacitor and the load. If the load is below the delivered current, the output voltage will rise. If the output voltage is equal or higher than the PFM comparator threshold, the device stops switching and enters a sleep mode with typical 15µA current consumption.

If the output voltage is still below the PFM comparator threshold, a sequence of further PFM current pulses are generated until the PFM comparator threshold is reached. The converter starts switching again once the output voltage drops below the PFM comparator threshold.

With a fast single threshold comparator, the output voltage ripple during PFM mode operation can be kept small. The PFM Pulse is time controlled, which allows to modify the charge transferred to the output capacitor by the value of the inductor. The resulting PFM output voltage ripple and PFM frequency depend in first order on the size of the output capacitor and the inductor value. Increasing output capacitor values and inductor values will minimize the output ripple. The PFM frequency decreases with smaller inductor values and increases with larger values.

The PFM mode is left and PWM mode entered in case the output current can not longer be supported in PFM mode. The Power Save Mode can be disabled through the MODE pin set to high. The converter will then operate in fixed frequency PWM mode.

Dynamic Voltage Positioning

This feature reduces the voltage under/overshoots at load steps from light to heavy load and vice versa. It is active in Power Save Mode and regulates the output voltage 1% higher than the nominal value. This provides more headroom for both the voltage drop at a load step, and the voltage increase at a load throw-off.

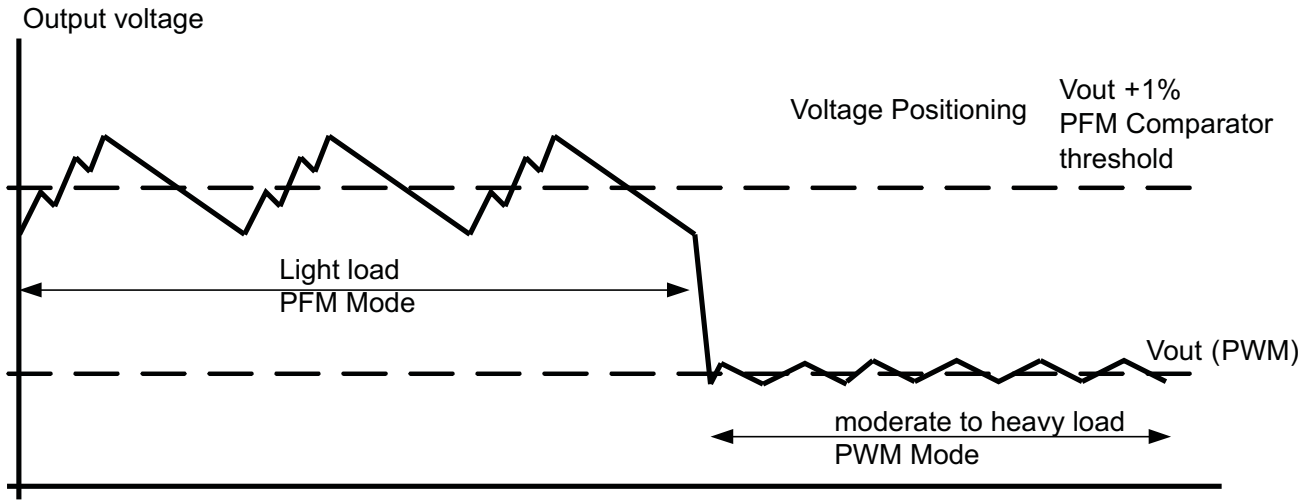


Figure 34. Power Save Mode Operation with automatic Mode transition

100% Duty Cycle Low Dropout Operation

The device starts to enter 100% duty cycle mode once the input voltage comes close to the nominal output voltage. In order to maintain the output voltage, the High Side MOSFET switch is turned on 100% for one or more cycles.

With further decreasing VIN the High Side MOSFET switch is turned on completely. In this case the converter offers a low input-to-output voltage difference. This is particularly useful in battery-powered applications to achieve longest operation time by taking full advantage of the whole battery voltage range.

The minimum input voltage to maintain regulation depends on the load current and output voltage, and can be calculated as:

$$V_{IN}min = V_O max + I_O max \times (R_{DS(on)} max + R_L)$$

With:

$I_O$max = maximum output current plus inductor ripple current

$R_{DS(on)}$max = maximum P-channel switch RDSon.

R_L = DC resistance of the inductor

$V_O$max = nominal output voltage plus maximum output voltage tolerance

Undervoltage Lockout

The undervoltage lockout circuit prevents the device from malfunctioning at low input voltages and from excessive discharge of the battery and disables the output stage of the converter. The undervoltage lockout threshold is typically 1.85V with falling V_{IN}.

MODE SELECTION

The MODE pin allows mode selection between forced PWM mode and Power Save Mode.

Connecting this pin to GND enables the Power Save Mode with automatic transition between PWM and PFM mode. Pulling the MODE pin high forces the converter to operate in fixed frequency PWM mode even at light load currents. This 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.

The condition of the MODE pin can be changed during operation and allows efficient power management by adjusting the operation mode of the converter to the specific system requirements.

ENABLE

The device is enabled setting EN pin to high. During the start up time $t_{Start\ Up}$ the internal circuits are settled and the soft start circuit is activated. The EN input can be used to control power sequencing in a system with various DC/DC converters. The EN pin can be connected to the output of another converter, to drive the EN pin high and getting a sequencing of supply rails. With EN = GND, the device enters shutdown mode in which all internal circuits are disabled. In fixed output voltage versions, the internal resistor divider network is then disconnected from FB pin.

SOFT START

The TPS6226x has an internal soft start circuit that controls the ramp up of the output voltage. The output voltage ramps up from 5% to 95% of its nominal value within typical 250µs. This limits the inrush current in the converter during ramp up and prevents possible input voltage drops when a battery or high impedance power source is used. The soft start circuit is enabled within the start up time $t_{Start\ Up}$.

SHORT-CIRCUIT PROTECTION

The High Side and Low Side MOSFET switches are short-circuit protected with maximum switch current = I_{LIMF}. The current in the switches is monitored by current limit comparators. Once the current in the High Side MOSFET switch exceeds the threshold of it's current limit comparator, it turns off and the Low Side MOSFET switch is activated to ramp down the current in the inductor and High Side MOSFET switch. The High Side MOSFET switch can only turn on again, once the current in the Low Side MOSFET switch has decreased below the threshold of its current limit comparator.

THERMAL SHUTDOWN

As soon as the junction temperature, T_J, exceeds 140°C (typical) the device goes into thermal shutdown. In this mode, the High Side and Low Side MOSFETs are turned-off. The device continues its operation when the junction temperature falls below the thermal shutdown hysteresis.

APPLICATION INFORMATION

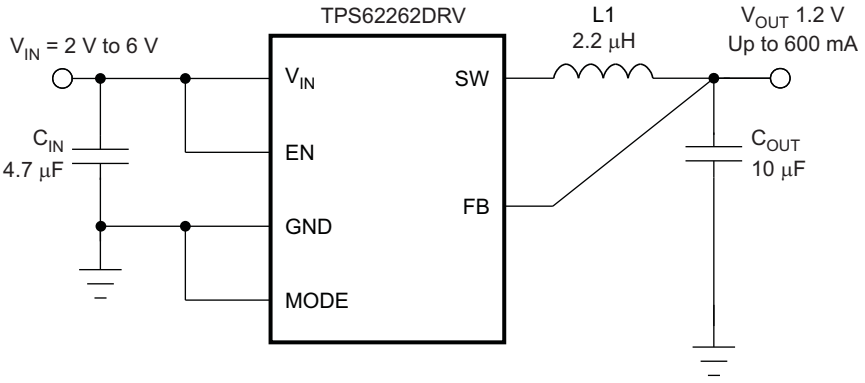


Figure 35. Fixed 1.2-V Output

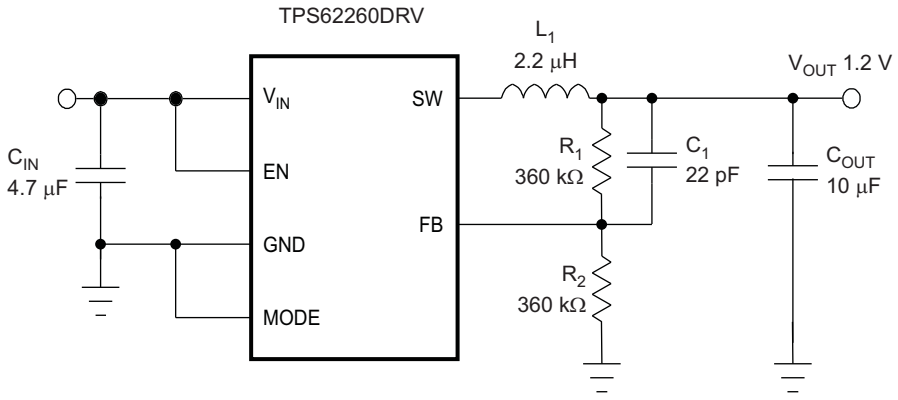


Figure 36. Adjustable 1.2-V Output

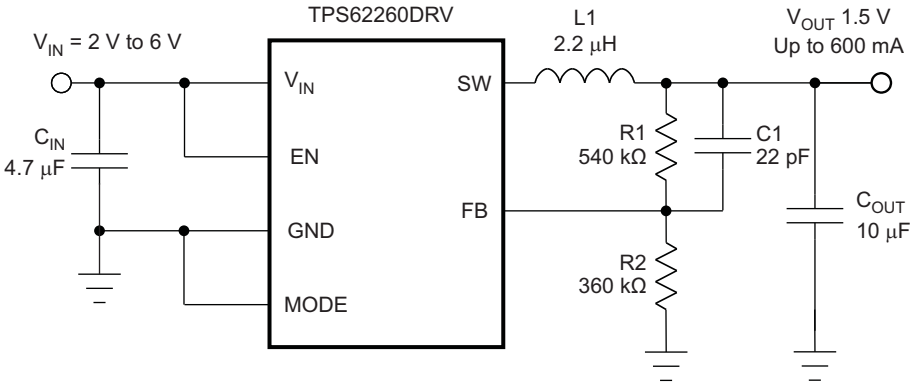


Figure 37. Adjustable 1.5-V Output

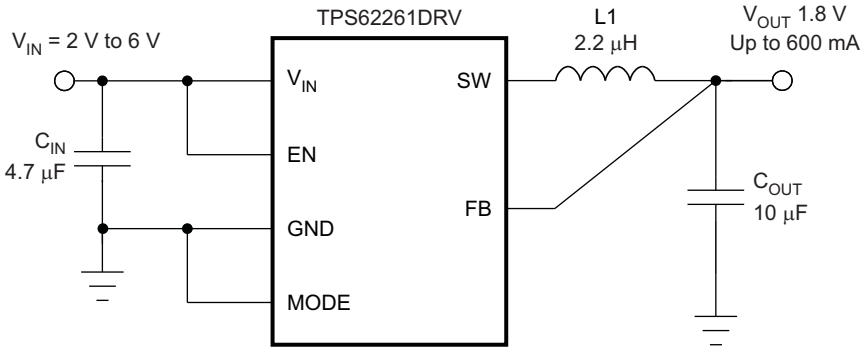


Figure 38. Fixed 1.8-V Output

OUTPUT VOLTAGE SETTING

The output voltage can be calculated to:

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R_1}{R_2}\right)$$ with an internal reference voltage V_{REF} typical 0.6V.

To minimize the current through the feedback divider network, R_2 should be 180 kΩ or 360 kΩ. The sum of R_1 and R_2 should not exceed ~1MΩ, to keep the network robust against noise. An external feed forward capacitor C_1 is required for optimum load transient response. The value of C_1 should be in the range between 22pF and 33pF.

Route the FB line away from noise sources, such as the inductor or the SW line.

OUTPUT FILTER DESIGN (INDUCTOR AND OUTPUT CAPACITOR)

The TPS6226x is designed to operate with inductors in the range of 1.5µH to 4.7µH and with output capacitors in the range of 4.7µF to 22µF. The part is optimized for operation with a 2.2µH inductor and 10µF output capacitor.

Larger or smaller inductor values can be used to optimize the performance of the device for specific operation conditions. For stable operation, the L and C values of the output filter may not fall below 1µH effective inductance and 3.5µF effective capacitance.

Inductor Selection

The inductor value has a direct effect on the ripple current. The selected inductor has to be rated for its dc resistance and saturation current. The inductor ripple current (ΔI_L) decreases with higher inductance and increases with higher V_I or V_O.

The inductor selection has also impact on the output voltage ripple in PFM mode. Higher inductor values will lead to lower output voltage ripple and higher PFM frequency, lower inductor values will lead to a higher output voltage ripple but lower PFM frequency.

Equation 1 calculates the maximum inductor current in PWM mode under static load conditions. The saturation current of the inductor should be rated higher than the maximum inductor current as calculated with Equation 2. This is recommended because during heavy load transient the inductor current will rise above the calculated value.

$$\Delta I_L = V_{OUT} \times \frac{1 - \frac{V_{OUT}}{V_{IN}}}{L \times f} \quad (1)$$

$$I_L\,max = I_{out}\,max + \frac{\Delta I_L}{2} \quad (2)$$

With:

f = Switching Frequency (2.25MHz typical)

L = Inductor Value

ΔI_L = Peak to Peak inductor ripple current

I_{Lmax} = Maximum Inductor current

A more conservative approach is to select the inductor current rating just for the switch current limit I_{LIMF} of the converter.

Accepting larger values of ripple current allows the use of lower inductance values, but results in higher output voltage ripple, greater core losses, and lower output current capability.

The total losses of the coil have a strong impact on the efficiency of the DC/DC conversion and consist of both the losses in the dc resistance ($R_{(DC)}$) and the following frequency-dependent components:

- The losses in the core material (magnetic hysteresis loss, especially at high switching frequencies)
- Additional losses in the conductor from the skin effect (current displacement at high frequencies)
- Magnetic field losses of the neighboring windings (proximity effect)
- Radiation losses

Table 2. List of Inductors

DIMENSIONS [mm³]	Inductance µH	INDUCTOR TYPE	SUPPLIER
2.5x2.0x1.0max	2.0	MIPS2520D2R2	FDK
2.5x2.0x1.2max	2.0	MIPSA2520D2R2	FDK
2.5x2.0x1.0max	2.2	KSLI-252010AG2R2	Htachi Metals
2.5x2.0x1.2max	2.2	LQM2HPN2R2MJ0L	Murata
3x3x1.5max	2.2	LPS3015 2R2	Coilcraft

Output Capacitor Selection

The advanced fast-response voltage mode control scheme of the TPS6226x allows the use of tiny ceramic capacitors. Ceramic capacitors with low ESR values have the lowest output voltage ripple and are recommended. The output capacitor requires either an X7R or X5R dielectric. Y5V and Z5U dielectric capacitors, aside from their wide variation in capacitance over temperature, become resistive at high frequencies.

At nominal load current, the device operates in PWM mode and the RMS ripple current is calculated as:

$$I_{RMSC_{OUT}} = V_{OUT} \times \frac{1 - \frac{V_{OUT}}{V_{IN}}}{L \times f} \times \frac{1}{2 \times \sqrt{3}} \quad (3)$$

At nominal load current, the device operates in PWM mode and the overall output voltage ripple is the sum of the voltage spike caused by the output capacitor ESR plus the voltage ripple caused by charging and discharging the output capacitor:

$$\Delta V_{OUT} = V_{OUT} \times \frac{1 - \frac{V_{OUT}}{V_{IN}}}{L \times f} \times \left(\frac{1}{8 \times Cout \times f} + ESR \right) \quad (4)$$

At light load currents, the converter operates in Power Save Mode and the output voltage ripple is dependent on the output capacitor and inductor value. Larger output capacitor and inductor values minimize the voltage ripple in PFM mode and tighten DC output accuracy in PFM mode.

Input Capacitor Selection

An input capacitor is required for best input voltage filtering, and minimizing the interference with other circuits caused by high input voltage spikes. For most applications, a 4.7µF to 10µF ceramic capacitor is recommended. Because ceramic capacitor loses up to 80% of its initial capacitance at 5 V, it is recommended that 10µF input capacitors be used for input voltages > 4.5V. The input capacitor can be increased without any limit for better input voltage filtering. Take care when using only small ceramic input capacitors. When a ceramic capacitor is used at the input and the power is being supplied through long wires, such as from a wall adapter, a load step at the output or VIN step on the input can induce ringing at the VIN pin. This ringing can couple to the output and be mistaken as loop instability or could even damage the part by exceeding the maximum ratings.

Table 3. List of Capacitors

CAPACITANCE	TYPE	SIZE	SUPPLIER
4.7 µF	GRM188R60J475K	0603 1.6x0.8x0.8mm³	Murata
10 µF	GRM188R60J106M69D	0603 1.6x0.8x0.8mm³	Murata

LAYOUT CONSIDERATIONS

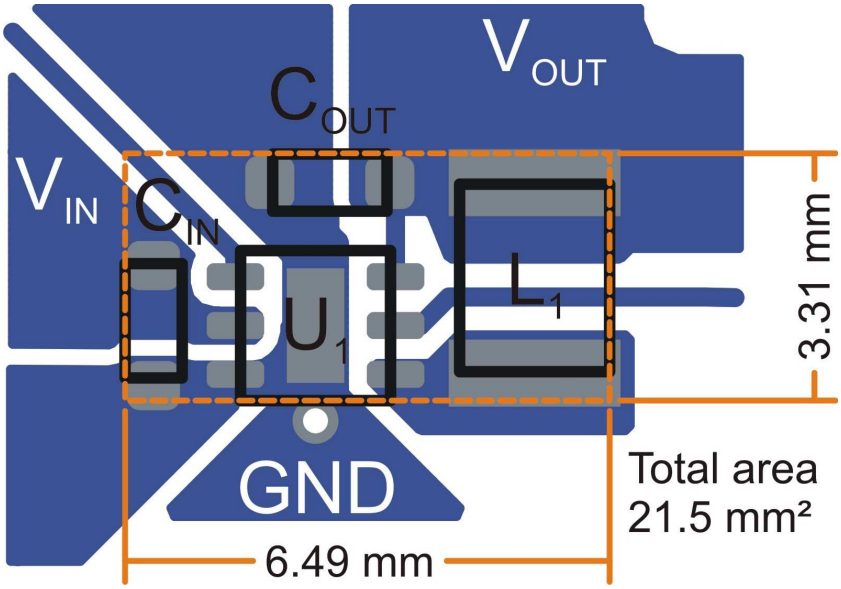


Figure 39. Suggested Layout for Fixed Output Voltage Options

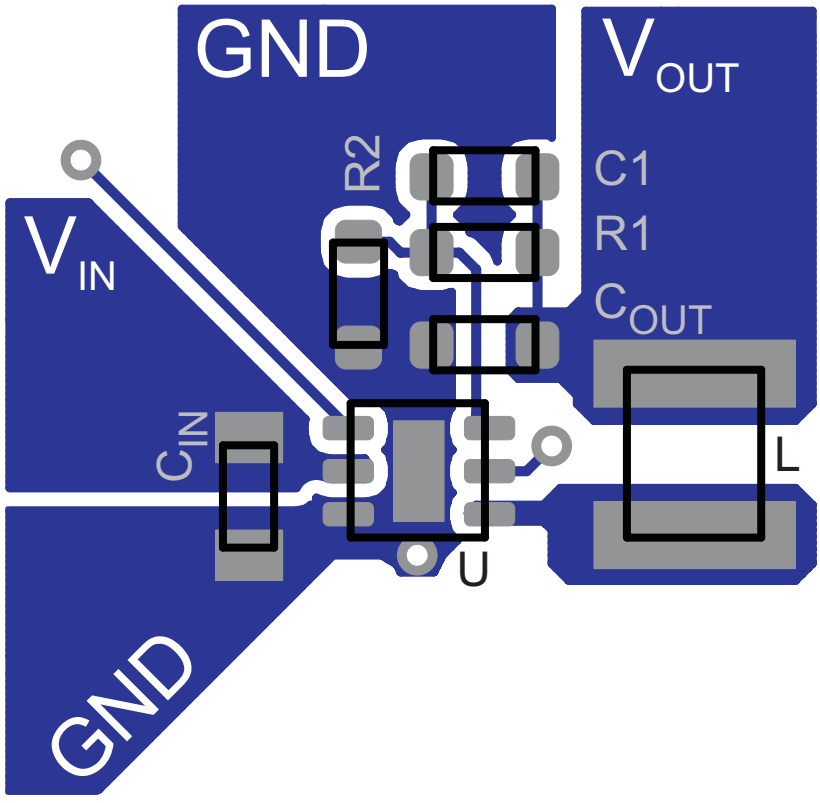


Figure 40. Suggested Layout for Adjustable Output Voltage Version

As for all switching power supplies, the layout is an important step in the design. Proper function of the device demands careful attention to PCB layout. Care must be taken in board layout to get the specified performance. If the layout is not carefully done, the regulator could show poor line and/or load regulation, stability issues as well as EMI problems. It is critical to provide a low inductance, impedance ground path. Therefore, use wide and short traces for the main current paths. The input capacitor should be placed as close as possible to the IC pins as well as the inductor and output capacitor.

Connect the GND Pin of the device to the PowerPAD™ land of the PCB and use this pad as a star point. Use a common Power GND node and a different node for the Signal GND to minimize the effects of ground noise. Connect these ground nodes together to the PowerPAD land (star point) underneath the IC. Keep the common path to the GND PIN, which returns the small signal components and the high current of the output capacitors as short as possible to avoid ground noise. The FB line should be connected right to the output capacitor and routed away from noisy components and traces (e.g., SW line).

REVISION HISTORY

Changes from Revision B (February, 2011) to Revision C	Page
• Added extra row in ordering information table.	2

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS62260IDRVRQ1	ACTIVE	WSON	DRV	6	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 85	OEO	Samples
TPS62260TDDCRQ1	ACTIVE	SOT-23-THIN	DDC	5	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	SJZ	Samples
TPS62260TDRVRQ1	ACTIVE	WSON	DRV	6	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	OEO	Samples
TPS62261TDRVRQ1	ACTIVE	WSON	DRV	6	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	OFE	Samples
TPS62262TDRVRQ1	ACTIVE	WSON	DRV	6	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	OFF	Samples
TPS62263TDRVRQ1	ACTIVE	WSON	DRV	6	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	OFG	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

OTHER QUALIFIED VERSIONS OF TPS62260-Q1, TPS62261-Q1, TPS62262-Q1, TPS62263-Q1 :

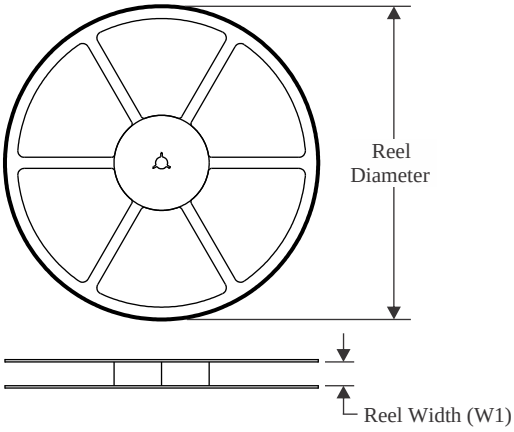
- Catalog: TPS62260, TPS62261, TPS62262, TPS62263

NOTE: Qualified Version Definitions:

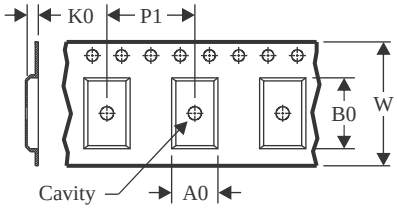
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

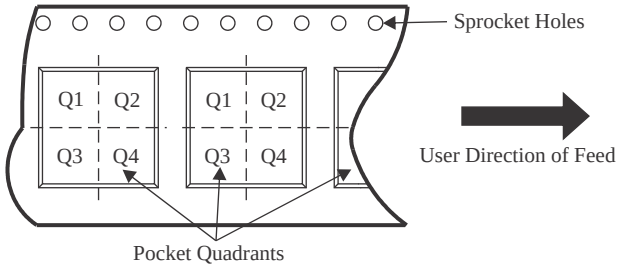


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

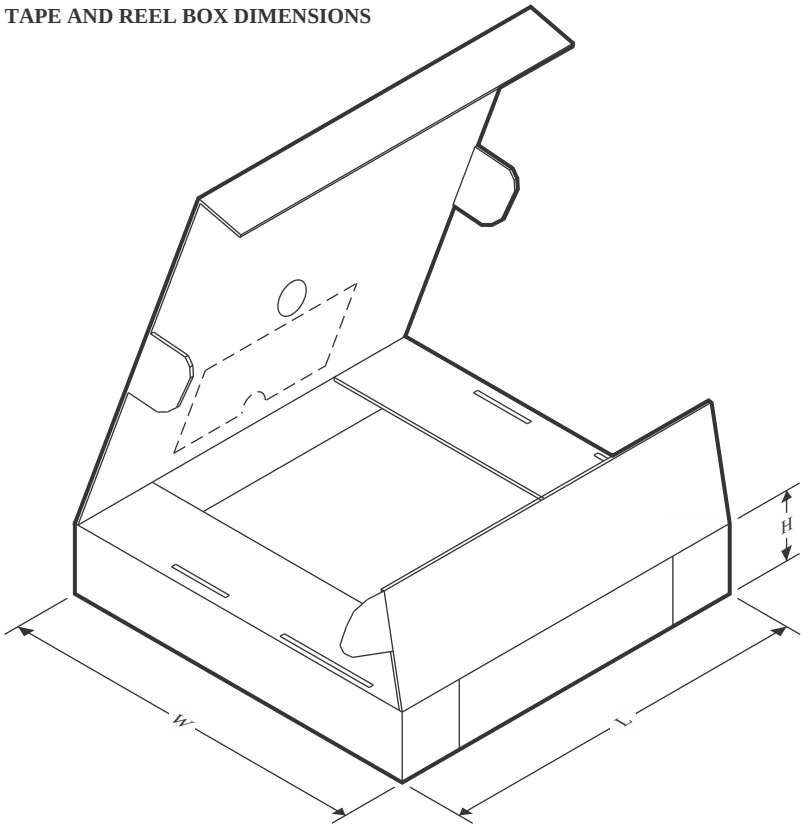
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TPS62260IDRVRQ1	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TPS62260TDDCRQ1	SOT-23-THIN	DDC	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS62260TDRVRQ1	WSON	DRV	6	3000	179.0	8.4	2.2	2.2	1.2	4.0	8.0	Q2
TPS62260TDRVRQ1	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TPS62261TDRVRQ1	WSON	DRV	6	3000	179.0	8.4	2.2	2.2	1.2	4.0	8.0	Q2
TPS62262TDRVRQ1	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TPS62263TDRVRQ1	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2

TAPE AND REEL BOX DIMENSIONS

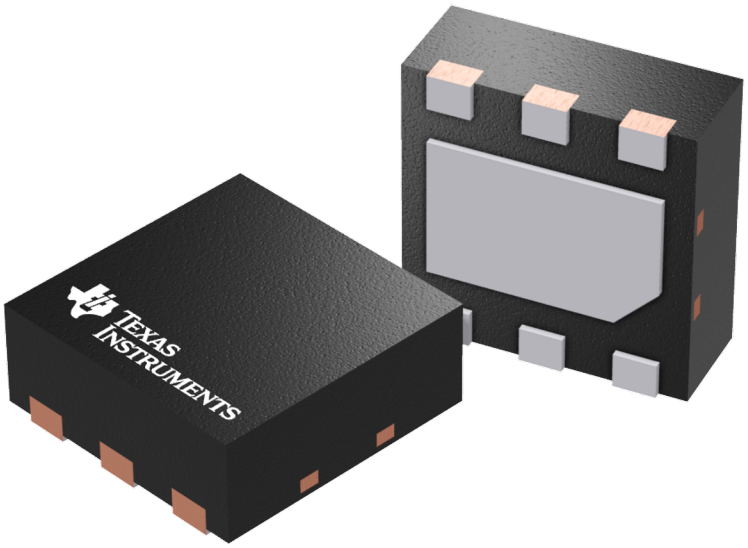


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS62260IDRVRQ1	WSON	DRV	6	3000	210.0	185.0	35.0
TPS62260TDDCRQ1	SOT-23-THIN	DDC	5	3000	213.0	191.0	35.0
TPS62260TDRVRQ1	WSON	DRV	6	3000	213.0	191.0	35.0
TPS62260TDRVRQ1	WSON	DRV	6	3000	210.0	185.0	35.0
TPS62261TDRVRQ1	WSON	DRV	6	3000	213.0	191.0	35.0
TPS62262TDRVRQ1	WSON	DRV	6	3000	210.0	185.0	35.0
TPS62263TDRVRQ1	WSON	DRV	6	3000	210.0	185.0	35.0

DRV 6 WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



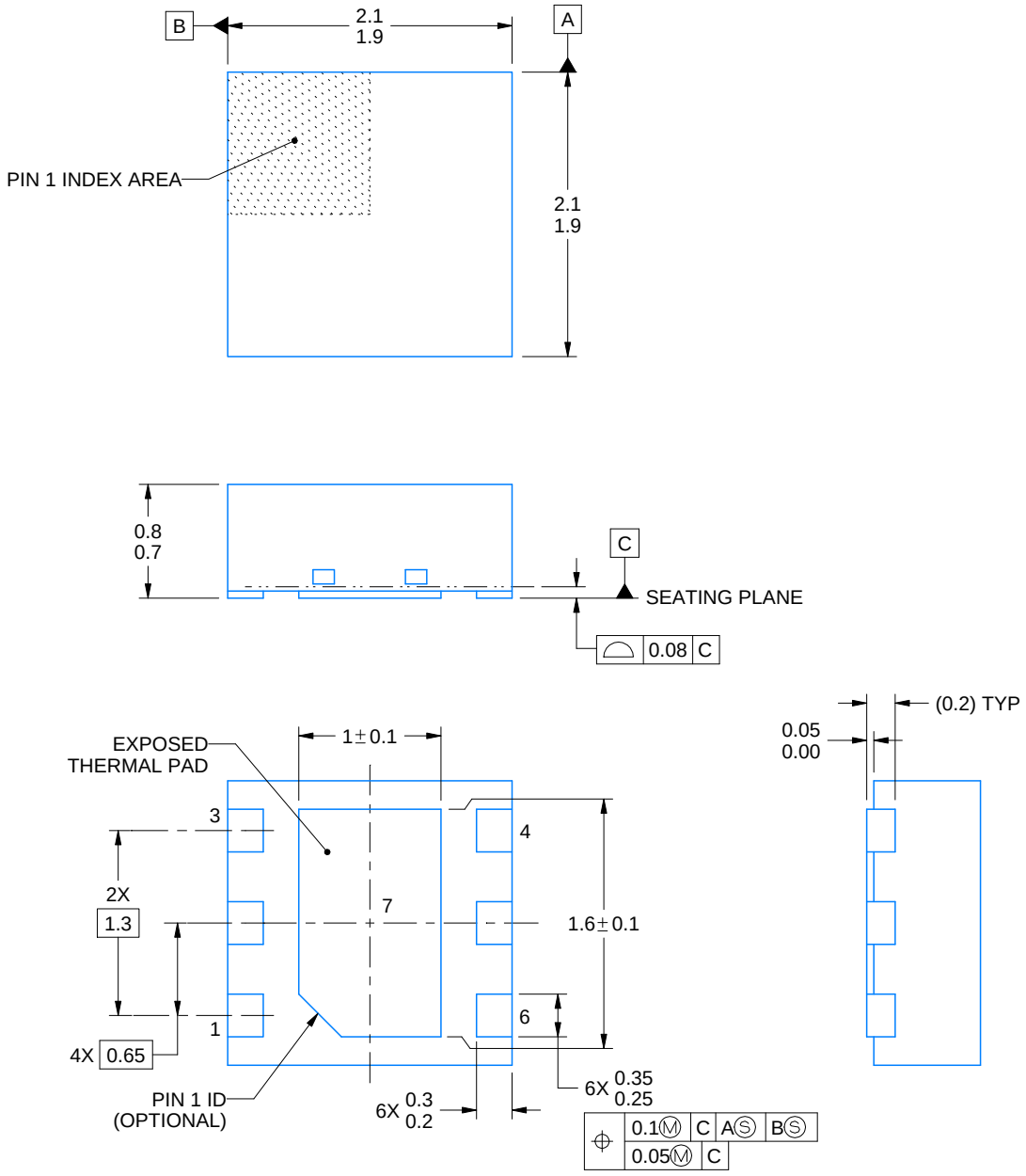
Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

PACKAGE OUTLINE

DRV0006A

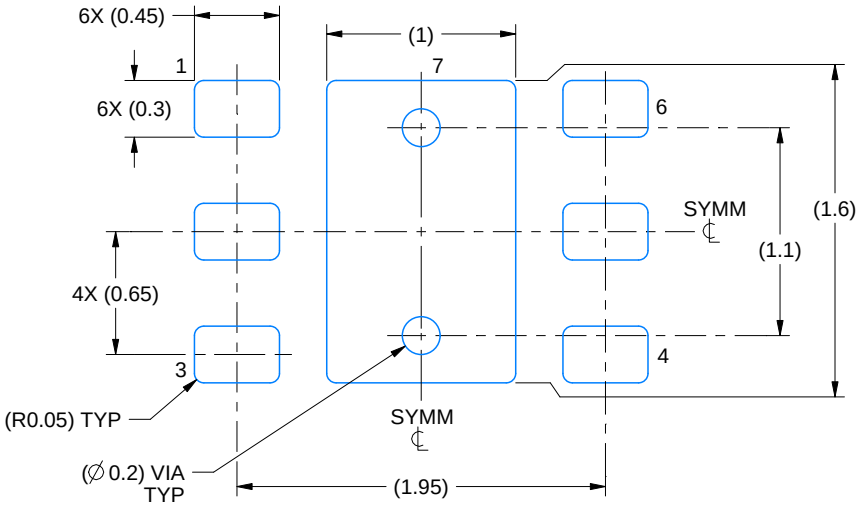
WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

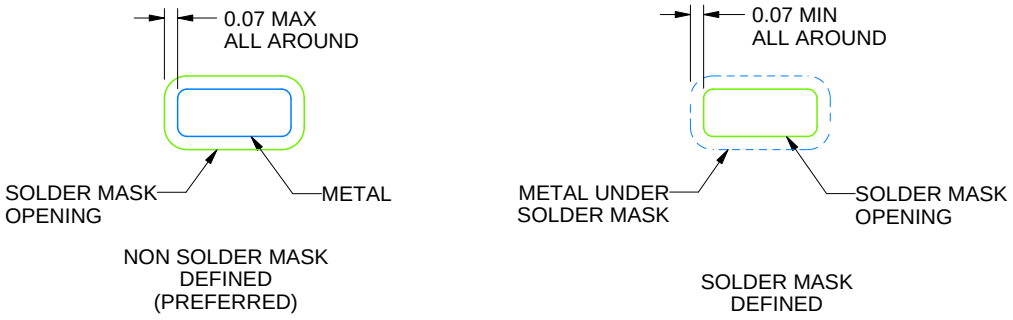


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE
SCALE:25X



SOLDER MASK DETAILS

4222173/B 04/2018

NOTES: (continued)

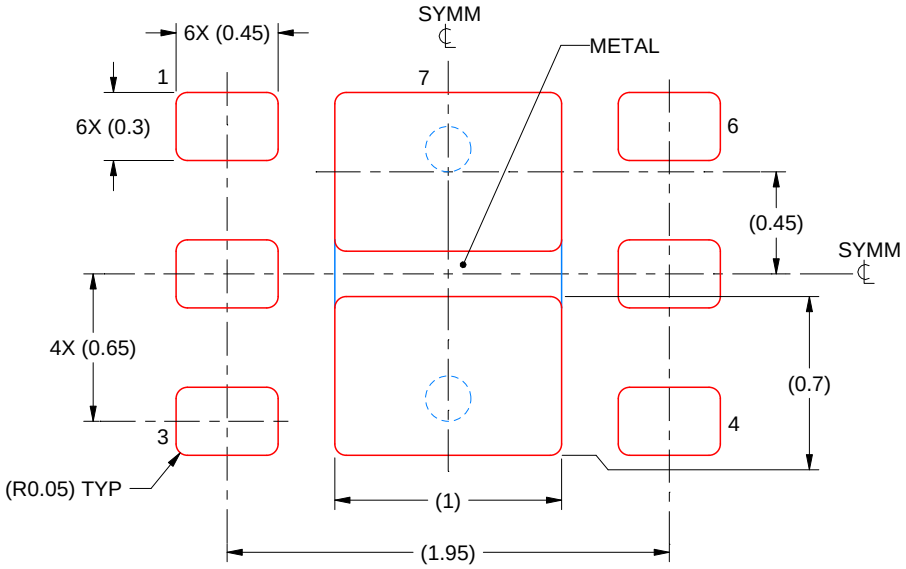
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If some or all are implemented, recommended via locations are shown.

EXAMPLE STENCIL DESIGN

DRV0006A

WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD #7
88% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:30X

4222173/B 04/2018

NOTES: (continued)

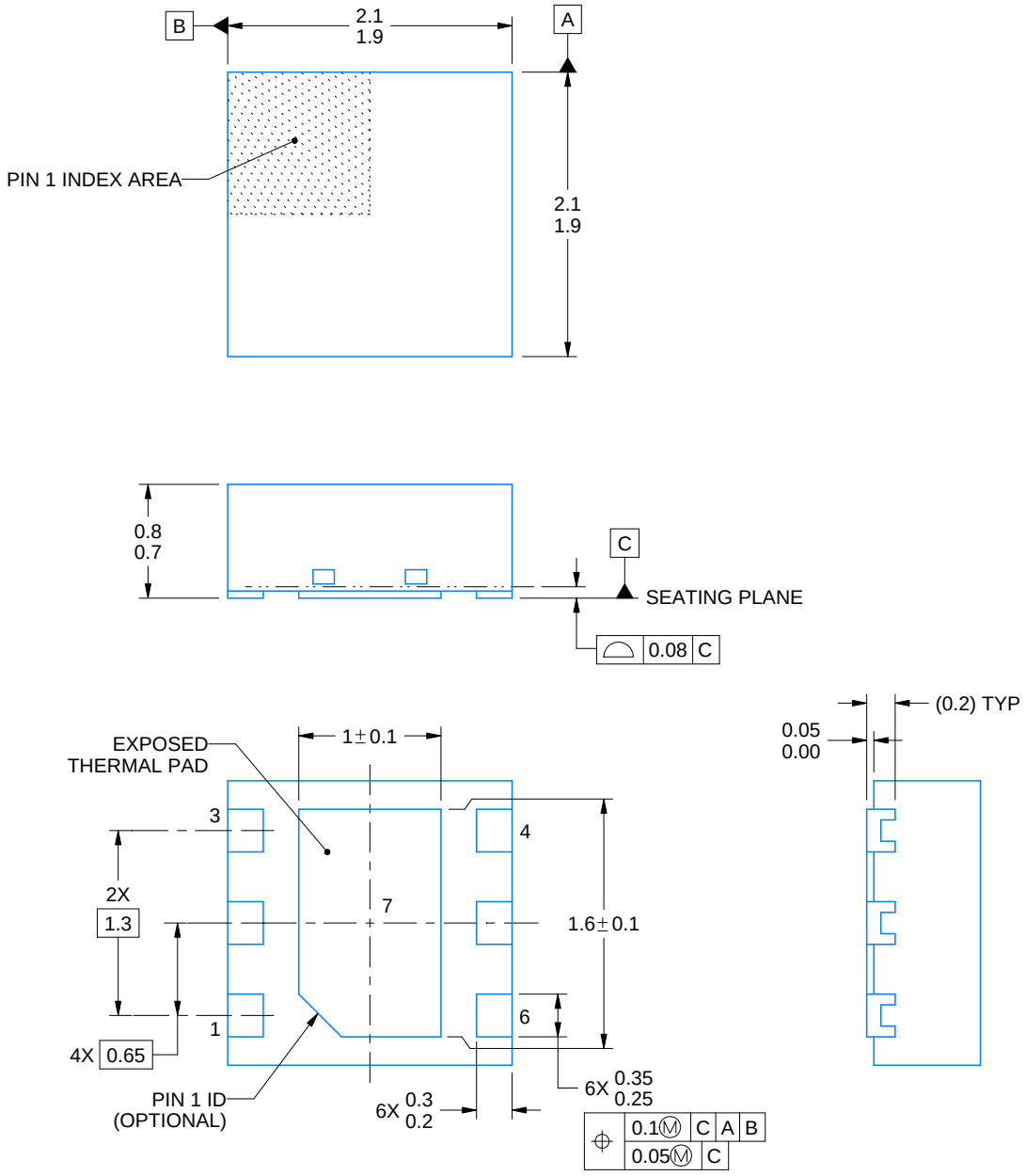
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

DRV0006D

PACKAGE OUTLINE

WSON - 0.8 mm max height

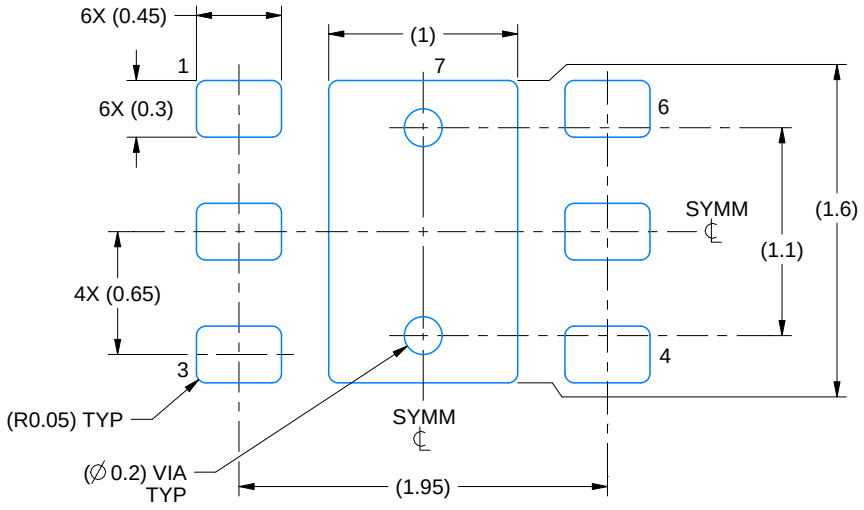
PLASTIC SMALL OUTLINE - NO LEAD



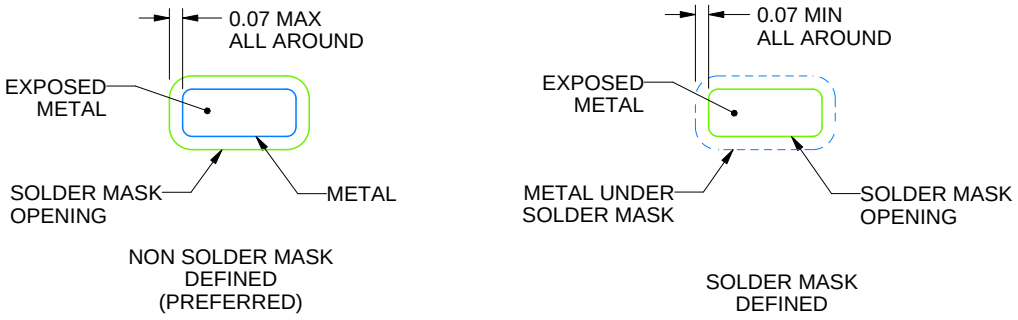
4225563/A 12/2019

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:25X

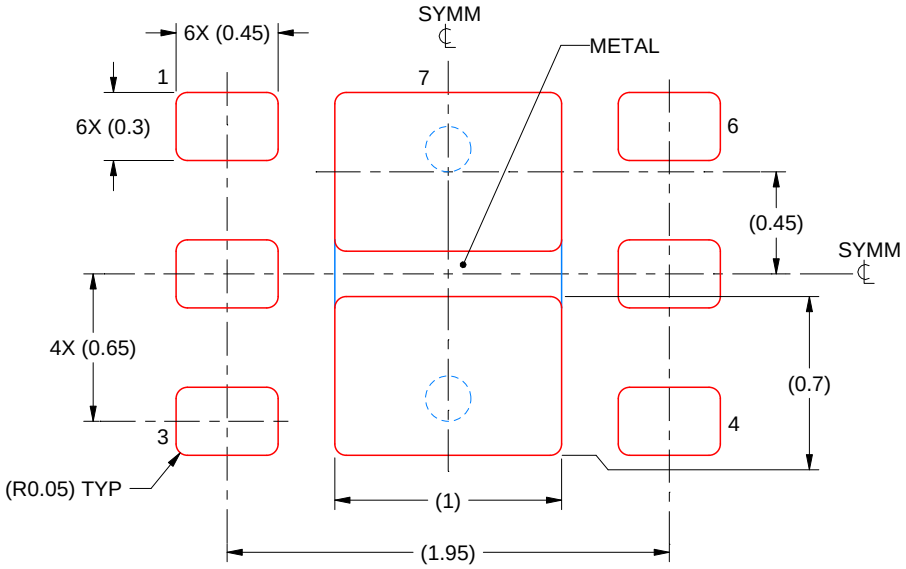


SOLDER MASK DETAILS

4225563/A 12/2019

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If some or all are implemented, recommended via locations are shown.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD #7
88% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:30X

4225563/A 12/2019

NOTES: (continued)

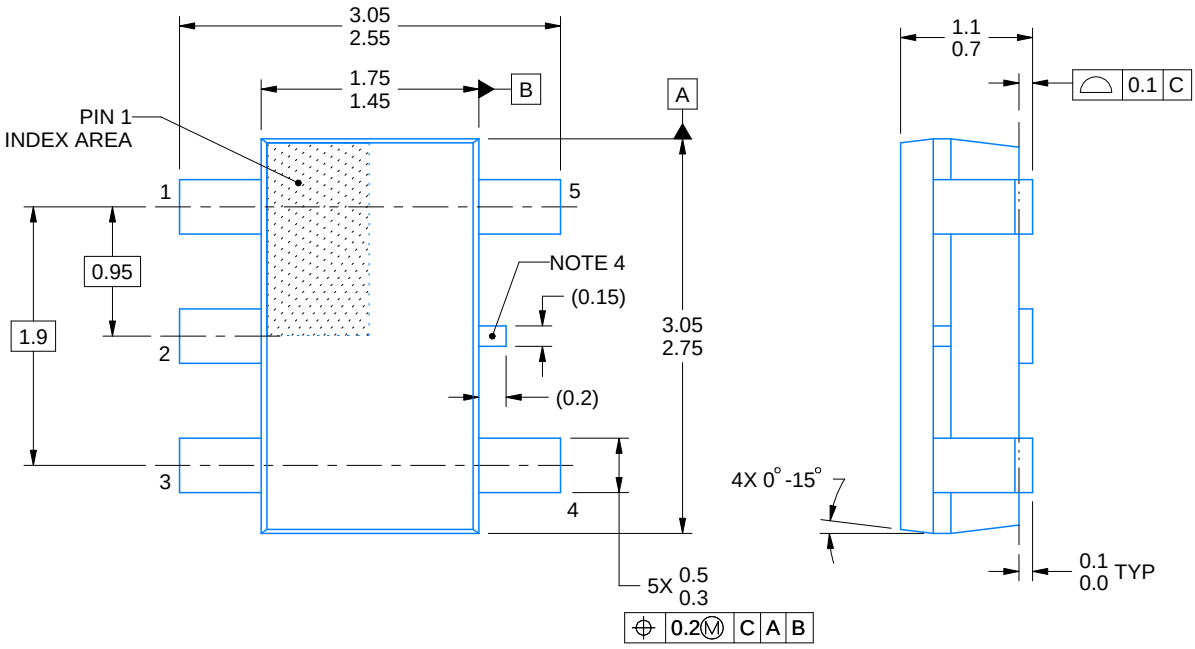
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

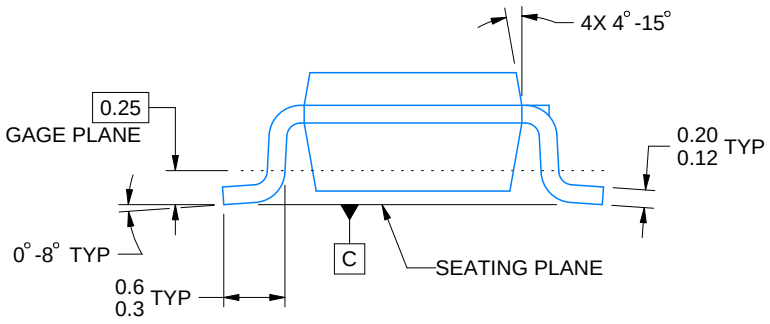
PACKAGE OUTLINE

DDC0005A

SOT-23 - 1.1 max height

SMALL OUTLINE TRANSISTOR

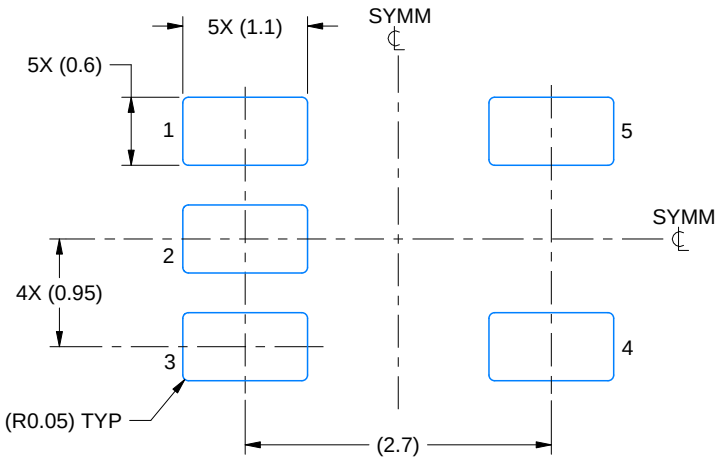




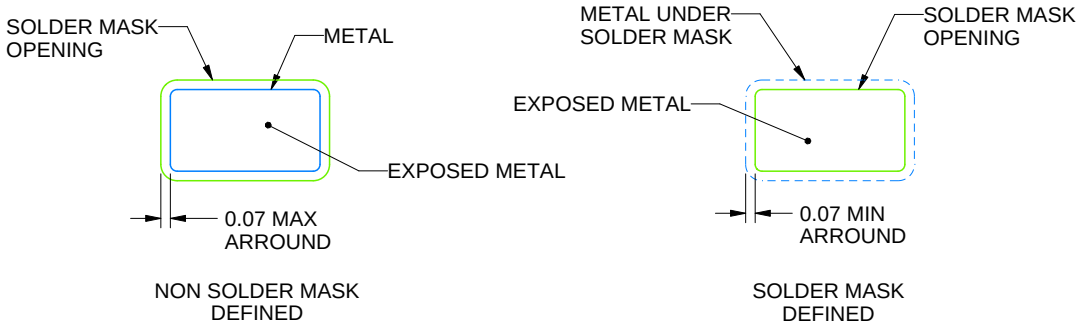
4220752/C 08/2024

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-193.
4. Support pin may differ or may not be present.



LAND PATTERN EXAMPLE
EXPLOSED METAL SHOWN
SCALE:15X

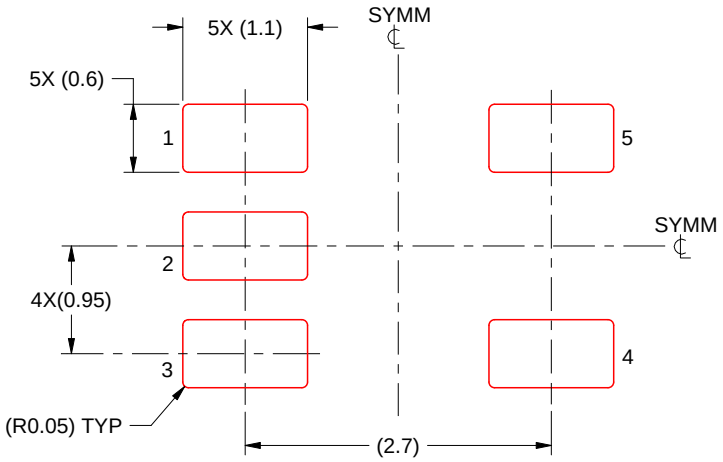


SOLDERMASK DETAILS

4220752/C 08/2024

NOTES: (continued)

4. Publication IPC-7351 may have alternate designs.
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
BASED ON 0.125 THICK STENCIL
SCALE:15X

4220752/C 08/2024

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
7. Board assembly site may have different recommendations for stencil design.

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