

## 170- $\mu$ Vrms ZERO-RIPPLE SWITCHED CAP BUCK-BOOST CONVERTER FOR VCO SUPPLY

### FEATURES

- **Wide Input Voltage Range:**
  - 1.8 V To 5.5 V for 2.7-V, 3-V, 3.3-V Output (TPS60240/2/3)
  - 2.7 V To 5.5 V for 5-V Output (TPS60241)
- **170- $\mu$ Vrms Zero Ripple Output:**
  - at 20 Hz to 10 MHz Bandwidth
- **Minimum Number of External Components**
  - No Inductors
  - Only Small Ceramic Chip Capacitors
- **Up to 90% Efficiency**
- **Regulated 3.3-V (TPS60240), 5-V (TPS60241), 3-V (TPS60243), and 2.7-V (TPS60242) Output Voltage With  $\pm 2.5\%$  Accuracy Over Load**
- **Up to 25-mA Output Current**
- **Shutdown Mode: 0.1  $\mu$ A Typical**
- **Thermal Protection and Current Limit**
- **Microsmall 8-Pin MSOP Package**
- **EVM Available TPS60241EVM-194**

- **Digital Cameras**
- **MP3 Players**
- **SIM Modules**
- **Electronic Games**
- **Memory Backup**
- **Handheld Meters**
- **Bias Supplies**

### DESCRIPTION

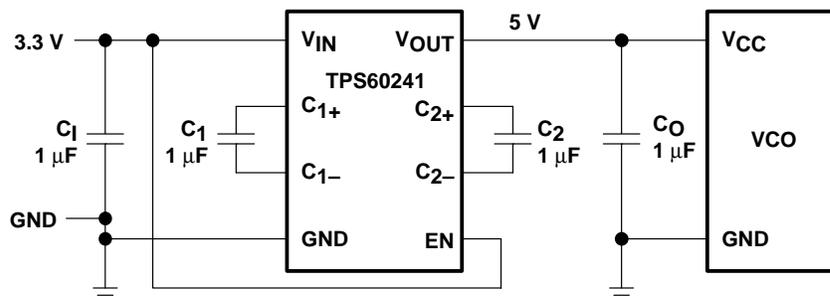
The TPS6024x is a switched capacitor voltage converter, ideally suited for VCO and PLL applications that require low noise and tight tolerances. Its dual-cap design uses four ceramic capacitors to provide ultralow output ripple yet high efficiency, while eliminating the need for inefficient linear regulators.

A wide input supply voltage range of 2.7 V to 5.5 V makes the TPS6024x ideal for lithium-based battery applications. The TPS60240/2/3 operates down to 1.8 V, supporting a 3.3-V, 2.7-V, 3-V output from two-cell, nickel- or alkaline-based chemistries. The devices work equally well for low EMI dc/dc step-up conversion without the need for an inductor. The high switching frequency (typical 160 kHz) promotes the use of small surface-mount capacitors, saving board space. The converter's shutdown mode conserves battery energy.

### APPLICATIONS

- **VCO and PLL Power for:**
  - PDA Phones
  - Cellular Phones
  - PCMCIA Modems
- **Smartcard Readers**

### typical application circuit



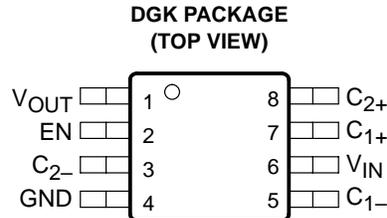
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

# TPS60240, TPS60241 TPS60242, TPS60243

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## description(continued)

The devices are thermally protected and current-limited for reliable operation even under persisting fault conditions. Normal quiescent current (ground pin current) is only 250  $\mu$ A, and typically 0.1  $\mu$ A in shutdown mode. The TPS6024x devices come in a thin, 8-pin MSOP (DGK) package with a component height of only 1,1 mm.

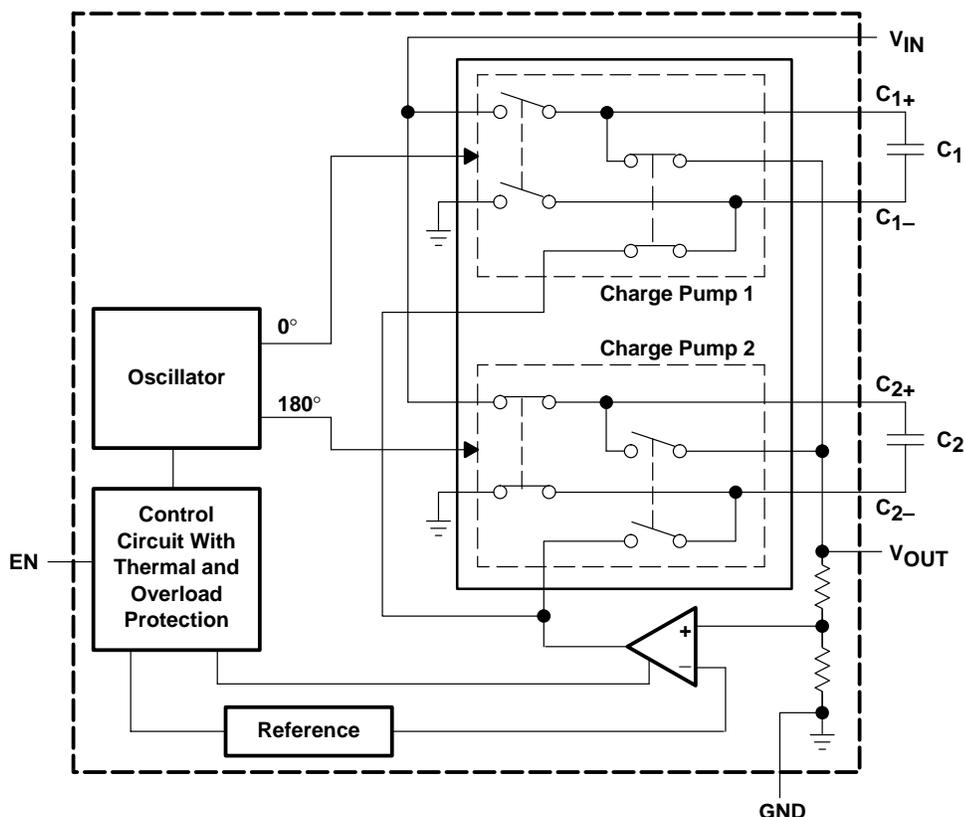


### AVAILABLE OPTIONS

$T_A$	PART NUMBER†	PACKAGE MARKING	PACKAGE	OUTPUT VOLTAGE (V)
–40°C to 85°C	TPS60241DGKR	AUB	DGK (8-pin MSOP)	5 V
–40°C to 85°C	TPS60240DGKR	ATM	DGK (8-pin MSOP)	3.3 V
	TPS60242DGKR	AYF	DGK (8-pin MSOP)	2.7 V
	TPS60243DGKR	AYG	DGK (8-pin MSOP)	3 V

† This package type is available taped and reeled only. Quantity is 2500 units per reel (e.g., TPS60241DGKR). The devices are also available on mini reel with 250 units per reel. To order this packaging option, replace the R with a T in the part number (e.g., TPS60261DGKT).

functional block diagram



Terminal Functions

TERMINAL NAME	NO.	I/O	DESCRIPTION
C1+	7		Positive terminal of the flying capacitor C <sub>1</sub>
C1-	5		Negative terminal of the flying capacitor C <sub>1</sub>
C2+	8		Positive terminal of the flying capacitor C <sub>2</sub>
C2-	3		Negative terminal of the flying capacitor C <sub>2</sub>
EN	2	I	Enable terminal, active high
GND	4		Ground
V <sub>IN</sub>	6	I	Supply voltage input TPS60241: 2.7 V to 5.5 V, TPS60240/2/3: 1.8 V to 5.5 V. Bypass V <sub>IN</sub> to GND with a 1-μF external capacitor (C <sub>I</sub> ).
V <sub>OUT</sub>	1	O	Regulated power output. Bypass V <sub>OUT</sub> to GND with a 1-μF external filter capacitor (C <sub>O</sub> ). TPS60241: regulated 5-V output, TPS60240: regulated 3.3-V output, TPS60242: regulated 2.7-V output, TPS60243: regulated 3-V output

**detailed description**

**operating principle**

The TPS6024x charge pump is a fixed-frequency, dual-phase charge pump that provides 25 mA of continuous supply current for low-noise applications such as VCOs used in cell phones and wireless appliances.

Low-noise operation results from using a proprietary dual-phase charge pump topology that relies on an operational amplifier in the feedback loop to reduce ripple. During the first phase, C<sub>1</sub> is charged to the supply voltage. Terminal C<sub>1+</sub> is connected to V<sub>IN</sub>, and C<sub>1-</sub> is connected to GND. In the second phase, C<sub>1-</sub> is connected to the output of the operational amplifier, and C<sub>1+</sub> is connected to V<sub>OUT</sub>. The operational amplifier then adjusts its output until the output V<sub>OUT</sub> delivers the correct voltage to make the resistor divided feedback point equal to the reference voltage. During this second phase, C<sub>2</sub> is charged to supply voltage. Terminal C<sub>2-</sub> is connected to GND, and C<sub>2+</sub> is connected to V<sub>IN</sub>. Phase one is then repeated with C<sub>2</sub>, now acting to provide charge to the output in place of C<sub>1</sub>, which is connected to the supply. The dual-phase operation lowers the output ripple voltage significantly compared to a standard single-phase charge pump. In addition, the linear feedback of the operational amplifier eliminates the ripple during discharge of the output capacitor (C<sub>O</sub>).

**shutdown**

Driving EN low disables the converter. This disables the internal circuits and reduces input current to typically 0.1 μA. In this mode, the load is disconnected from the supply voltage. The device exits shutdown once EN is set to a high level.

**start-up procedure**

The converter is enabled when EN is set from logic low to high. The start-up time to reach 90% of the nominal output voltage is typically 0.5 ms at load currents lower than 10 mA and with an output capacitor of 1 μF. Increasing the values of C<sub>O</sub> delays the start-up time.

**absolute maximum ratings over operating free-air temperature (unless otherwise noted)†**

Supply voltage, V <sub>DD</sub> .....	-0.3 V to 6 V
Power dissipation, P <sub>D</sub> .....	Internally limited
Voltage EN .....	-0.3 V to 6 V
Voltage C <sub>2-</sub> , C <sub>1-</sub> .....	-0.3 V to V <sub>I</sub> or 5.5 V, whichever is lowest
Voltage C <sub>2+</sub> , C <sub>1+</sub> .....	-0.3 V to V <sub>I</sub> , V <sub>O</sub> , or 5.5 V, whichever is lowest
Junction temperature, T <sub>J</sub> .....	125°C
Storage temperature, T <sub>stg</sub> .....	-65°C to 150°C
Shortcircuit output current .....	80 mA maximum

† 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.

**DISSIPATION RATING TABLE**

PACKAGE	T <sub>A</sub> ≤ 25°C POWER RATING	DERATING FACTOR ABOVE T <sub>A</sub> = 25°C	T <sub>A</sub> = 70°C POWER RATING	T <sub>A</sub> = 85°C POWER RATING
DGK	376 mW	3.76 mW/°C	207 mW	150 mW

NOTE: The thermal resistance junction to ambient of the DGK package is R<sub>TH-JA</sub> = 150°C/W.

recommended operating conditions

		MIN	NOM	MAX	UNIT	
V <sub>I</sub>	Input voltage range	TPS60240, TPS60242, TPS60243		1.8	5.5	V
		TPS60241		2.7	5.5	
I <sub>O</sub>	Output current range	All devices			25	mA
C <sub>I</sub>	Input capacitor				1	μF
C <sub>1</sub> , C <sub>2</sub>	Flying capacitors				1	μF
C <sub>O</sub>	Output capacitor				1	μF
T <sub>A</sub>	Operating temperature range	-40		85	°C	

electrical characteristics for TPS6024X at T<sub>A</sub> = 25°C, C<sub>I</sub> = C<sub>O</sub> = 1 μF, C<sub>1</sub> = C<sub>2</sub> = 1 μF (unless otherwise noted), limits apply over the specified temperature range, -40°C to 85°C

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT	
V <sub>I</sub>	Input voltage	TPS60240 Assured start-up		I <sub>O</sub> ≤ 5 mA, R <sub>L</sub> = 600 Ω		1.8	5.5	V
		TPS60241 Assured start-up		I <sub>O</sub> ≤ 12 mA, R <sub>L</sub> = 417 Ω		2.7	5.5	
		TPS60242 Assured start-up		I <sub>O</sub> ≤ 12 mA, R <sub>L</sub> = 225 Ω		1.8	5.5	
		TPS60243 Assured start-up		I <sub>O</sub> ≤ 10 mA, R <sub>L</sub> = 300 Ω		1.8	5.5	
V <sub>O</sub>	Output voltage	TPS60240		1.8 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 5 mA		3.2175	3.3	3.3825
				2.4 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 25 mA				
		TPS60241		2.7 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 12 mA		4.875	5	5.125
				3 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 25 mA				
		TPS60242		1.8 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 12 mA		2.6325	2.7	2.7675
				2.3 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 25 mA				
		TPS60243		1.8 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 10 mA		2.925	3	3.075
				2.3 V ≤ V <sub>I</sub> ≤ 5.5 V, 0 mA ≤ I <sub>O</sub> ≤ 25 mA				
I <sub>O</sub>	Output current	TPS60240/2/3	Nominal	2 V ≤ V <sub>I</sub> ≤ 5.5 V		12		
			Short circuit	V <sub>I</sub> = 2 V		80		
		TPS60241	Nominal	2.7 V ≤ V <sub>I</sub> ≤ 5.5 V		12		
			Short circuit	V <sub>I</sub> = 3.25 V		80		
f <sub>OSC</sub>	Internal clock source		100	160	220	kHz		
V <sub>n</sub>	Output noise voltage	TPS60240/2/3		V <sub>I</sub> < 2.5 V, I <sub>O</sub> = 5 mA, ESR < 0.1 Ω, measured over 20 Hz to 10 MHz, C <sub>O</sub> = 4.7 μF		170		
		TPS60241		V <sub>I</sub> = 2.7 V, I <sub>O</sub> = 5 mA, ESR < 0.1 Ω, measured over 20 Hz to 10 MHz, C <sub>O</sub> = 4.7 μF		170		
V <sub>I(H)</sub>	EN	Logic high input voltage V <sub>OH</sub>		1.3		5.5	V	
V <sub>I(L)</sub>	EN	Logic low input voltage V <sub>OL</sub>		-0.2		0.4	V	
I <sub>I(H)</sub>	EN	Logic high input current				100	nA	
I <sub>I(L)</sub>	EN	Logic low input current				100	nA	
t <sub>(EN)</sub>	EN	Start-up time		V <sub>O</sub> > 90% of V <sub>(NOM)</sub> 0.1 mA ≤ I <sub>O</sub> ≤ 10 mA, C <sub>O</sub> = 1 μF		0.5		
η	Efficiency	TPS60240		I <sub>O</sub> = 5 mA, V <sub>I</sub> = 1.8 V		89.6%		
		TPS60241		I <sub>O</sub> = 10 mA, V <sub>I</sub> = 2.7 V		90.8%		
		TPS60242		I <sub>O</sub> = 10 mA, V <sub>I</sub> = 1.8 V		73%		
		TPS60243		I <sub>O</sub> = 10 mA, V <sub>I</sub> = 1.8 V		81%		

**TPS60240, TPS60241  
TPS60242, TPS60243**

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**electrical characteristics for TPS6024X at  $T_A = 25^\circ\text{C}$ ,  $C_1 = C_O = 1 \mu\text{F}$ ,  $C_1 = C_2 = 1 \mu\text{F}$  (unless otherwise noted), limits apply over the specified temperature range,  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  (continued)**

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I <sub>Q</sub>	Quiescent current	I <sub>O</sub> = 0 mA, V <sub>I</sub> = 3 V		250	325	μA
		In shutdown mode		0.1	1	
Thermal shutdown	Temperature activated			160		°C
	Temperature deactivated			140		

**TYPICAL CHARACTERISTICS**

**Table of Graphs**

		FIGURE
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	vs Output current	5–8
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Quiescent current	vs Input voltage	18
	vs Free-air temperature	19
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Load transient response		26
Start-up timing		27
Line transient response		28
Noise voltage spectrum		29
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TYPICAL CHARACTERISTICS

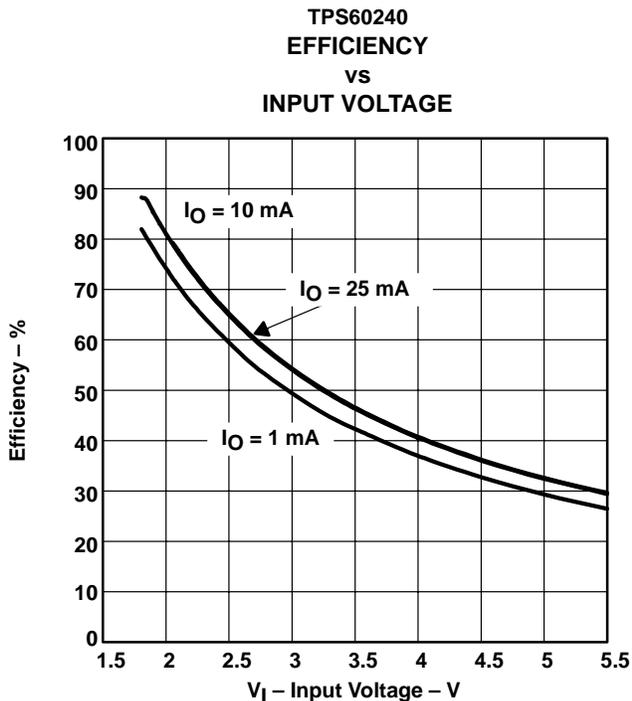


Figure 1

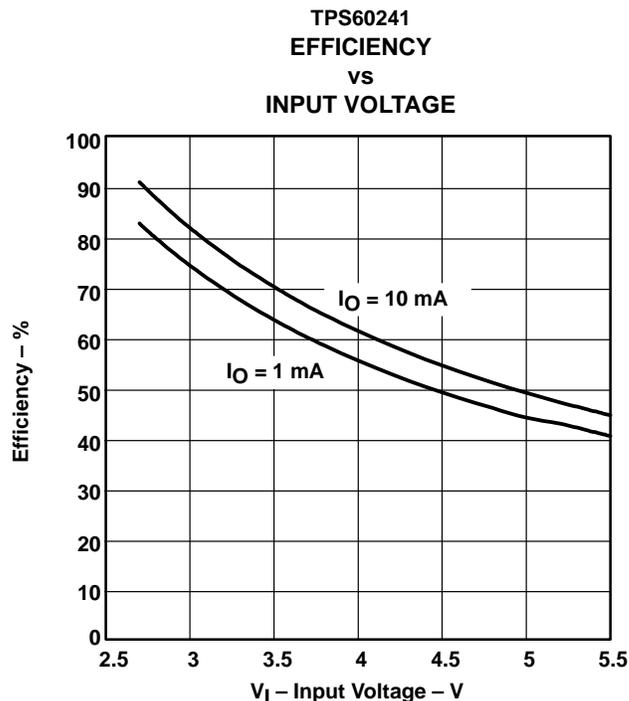


Figure 2

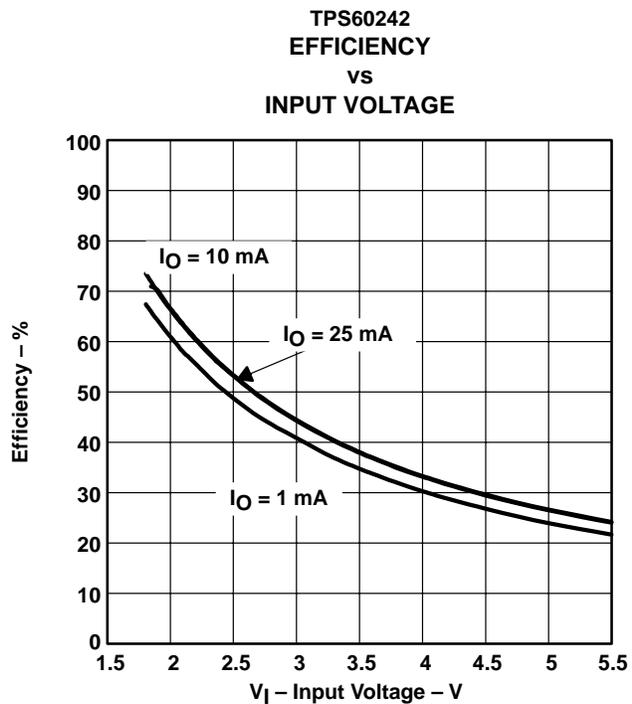


Figure 3

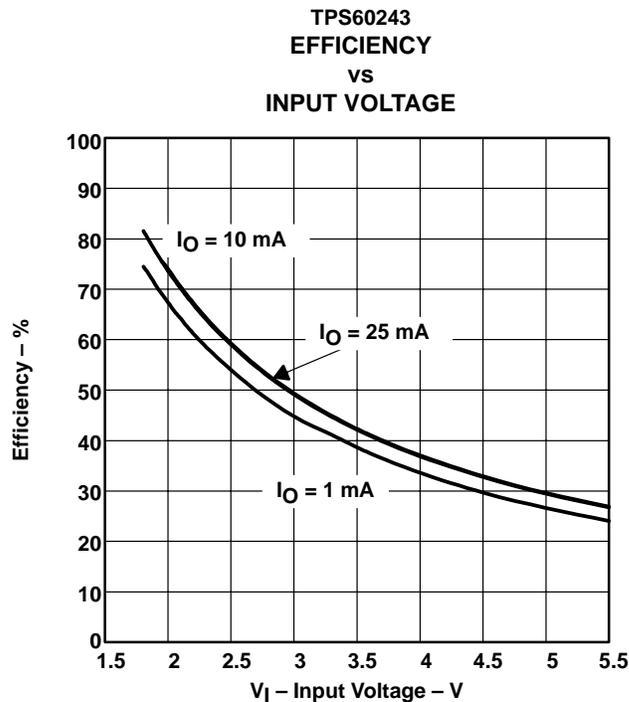


Figure 4

TYPICAL CHARACTERISTICS

TPS60240  
 EFFICIENCY  
 VS  
 OUTPUT CURRENT

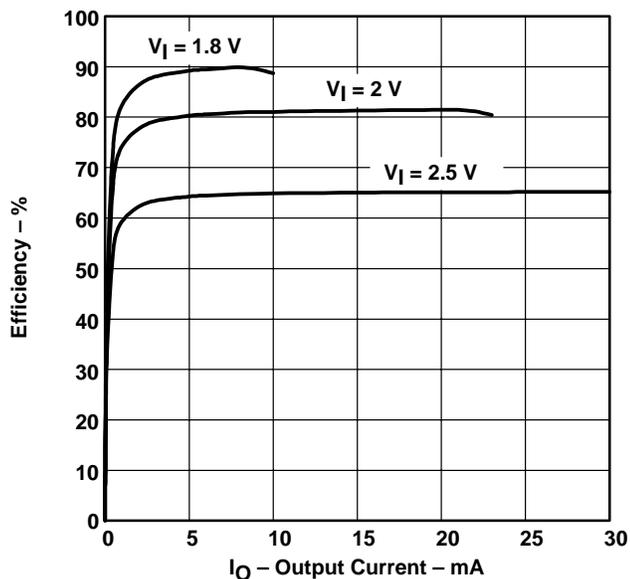


Figure 5

TPS60241  
 EFFICIENCY  
 VS  
 OUTPUT CURRENT

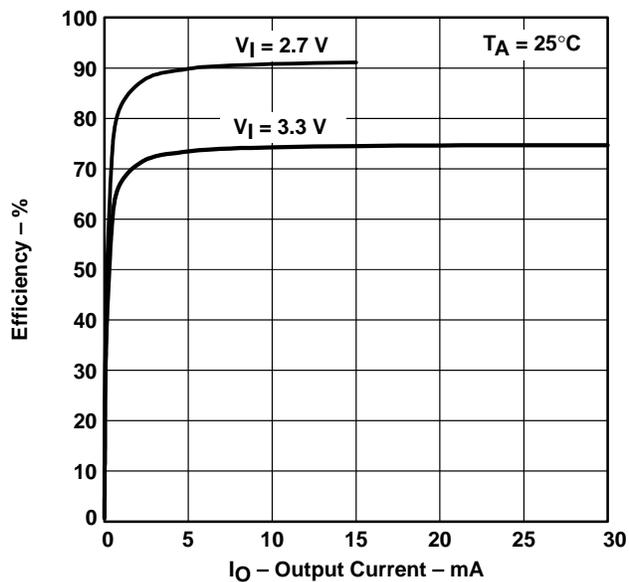


Figure 6

TPS60242  
 EFFICIENCY  
 VS  
 OUTPUT CURRENT

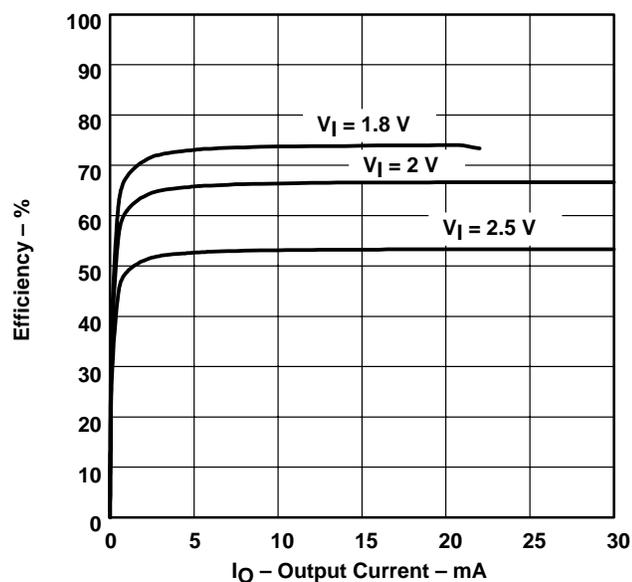


Figure 7

TPS60243  
 EFFICIENCY  
 VS  
 OUTPUT CURRENT

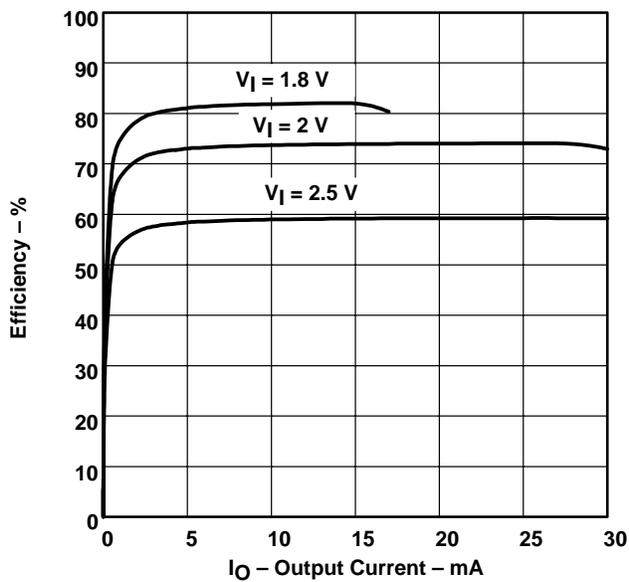


Figure 8

TYPICAL CHARACTERISTICS

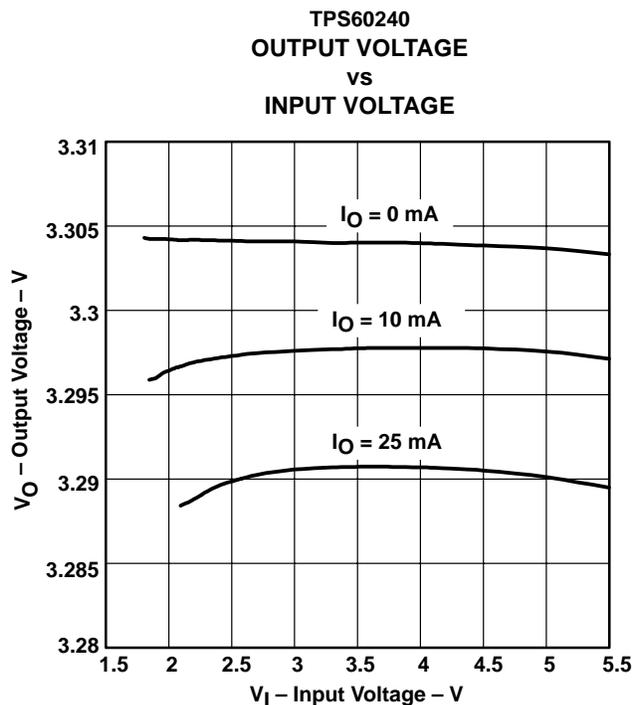


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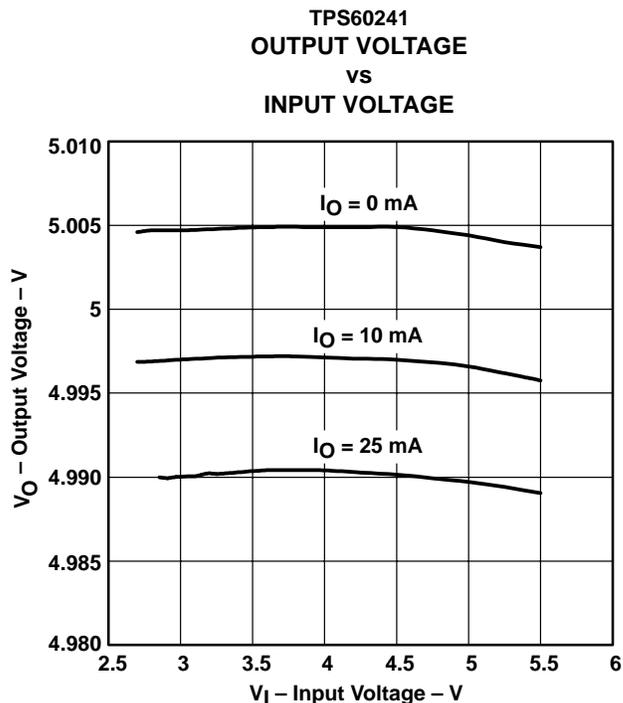


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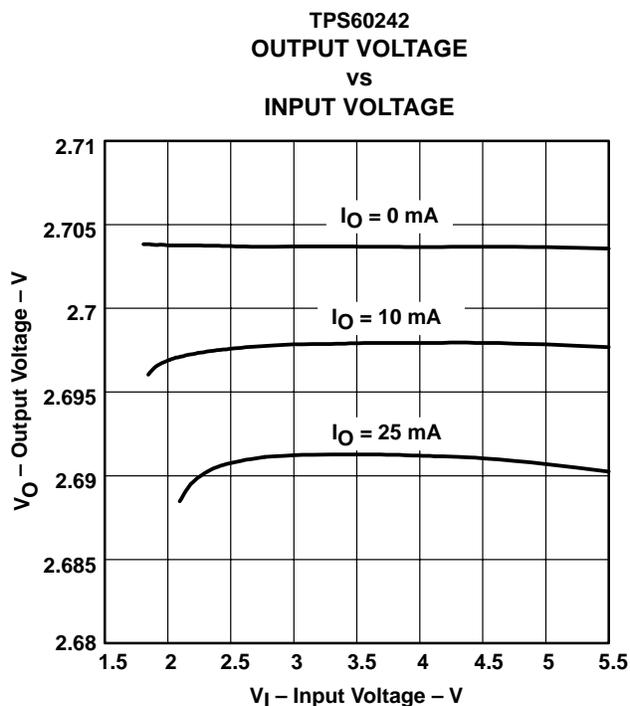


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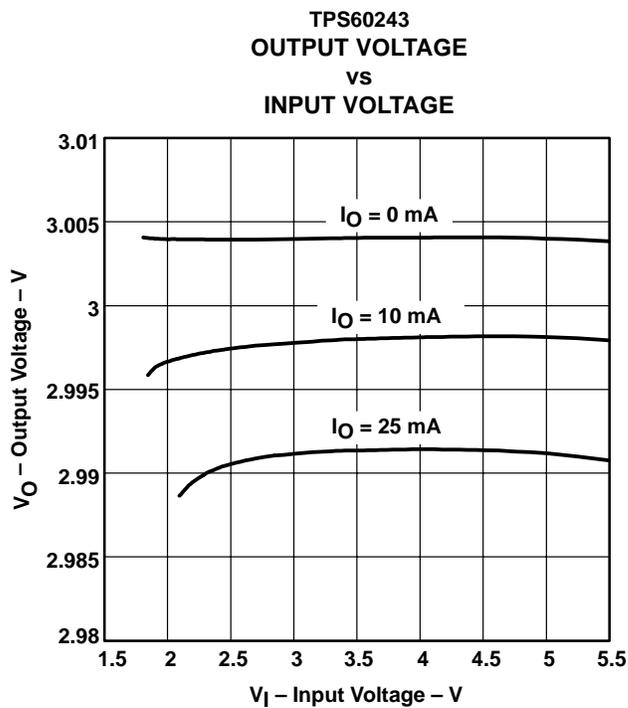


Figure 12

TYPICAL CHARACTERISTICS

TPS60240  
 OUTPUT VOLTAGE  
 VS  
 OUTPUT CURRENT

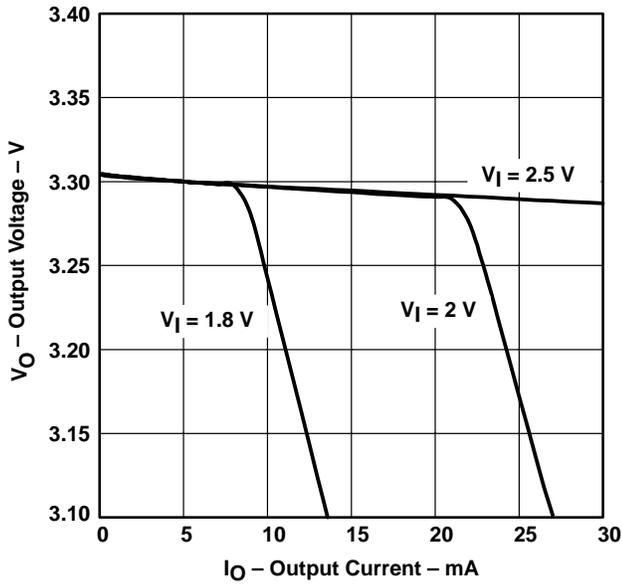


Figure 13

TPS60241  
 OUTPUT VOLTAGE  
 VS  
 OUTPUT CURRENT

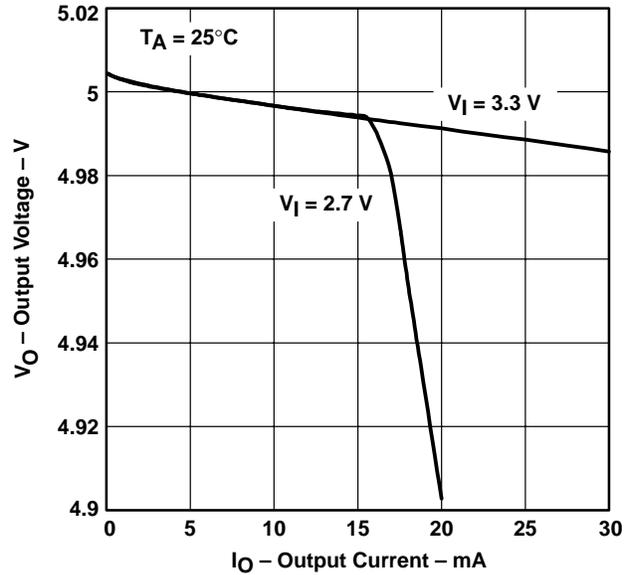


Figure 14

TPS60242  
 OUTPUT VOLTAGE  
 VS  
 OUTPUT CURRENT

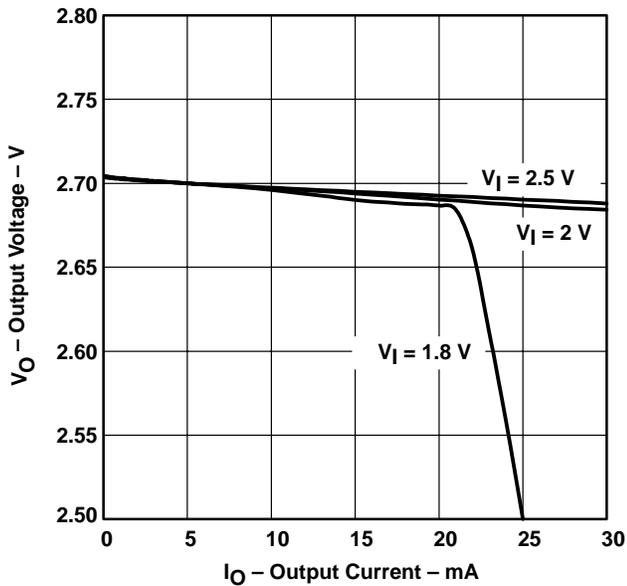


Figure 15

TPS60243  
 OUTPUT VOLTAGE  
 VS  
 OUTPUT CURRENT

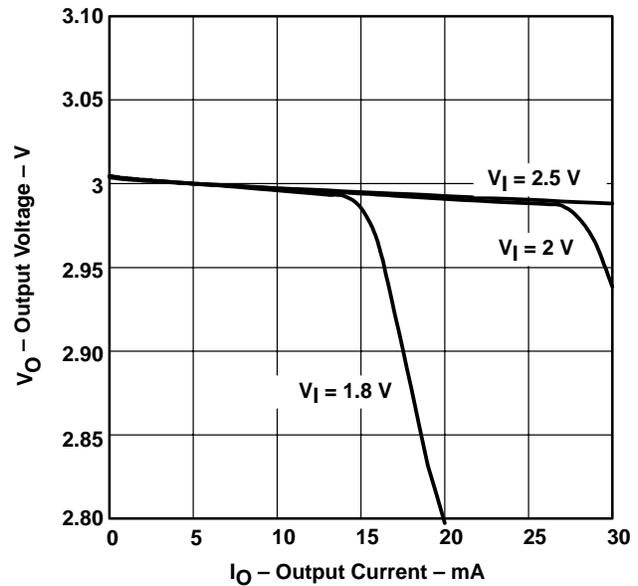
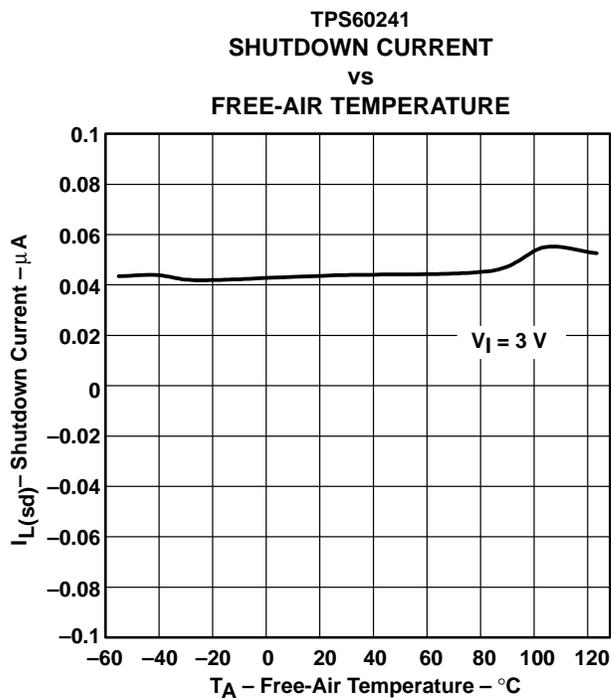
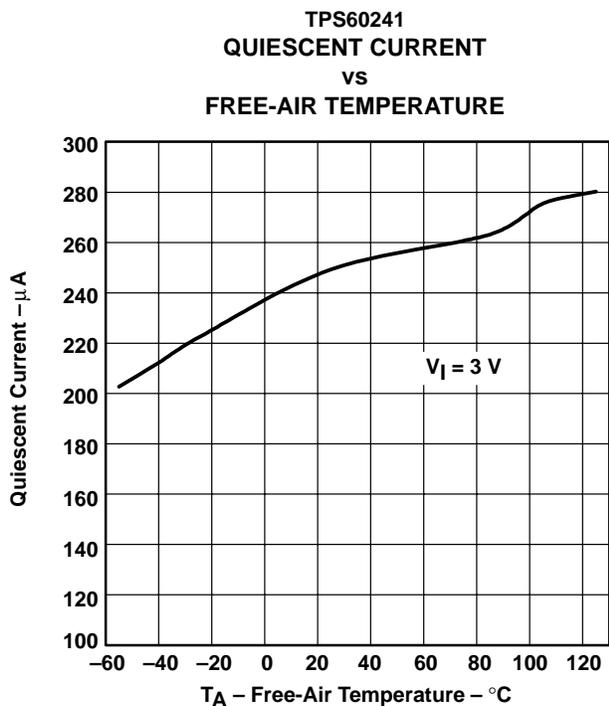
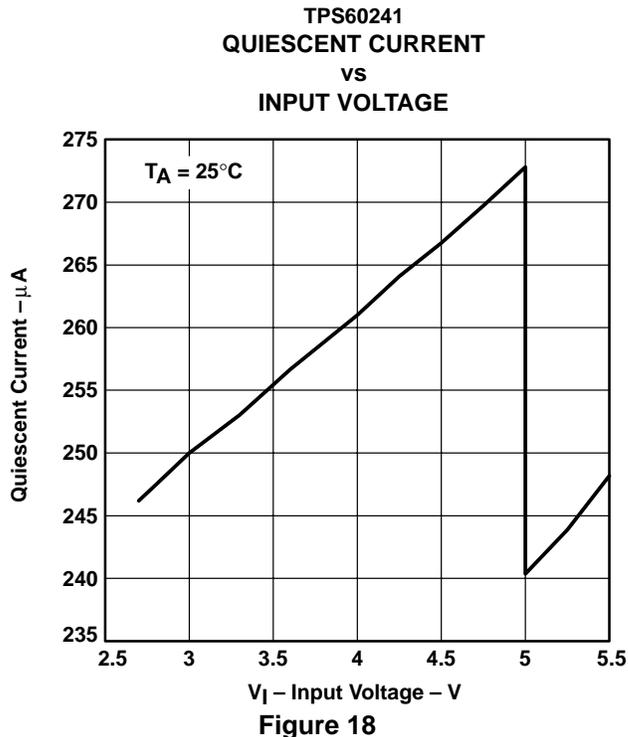
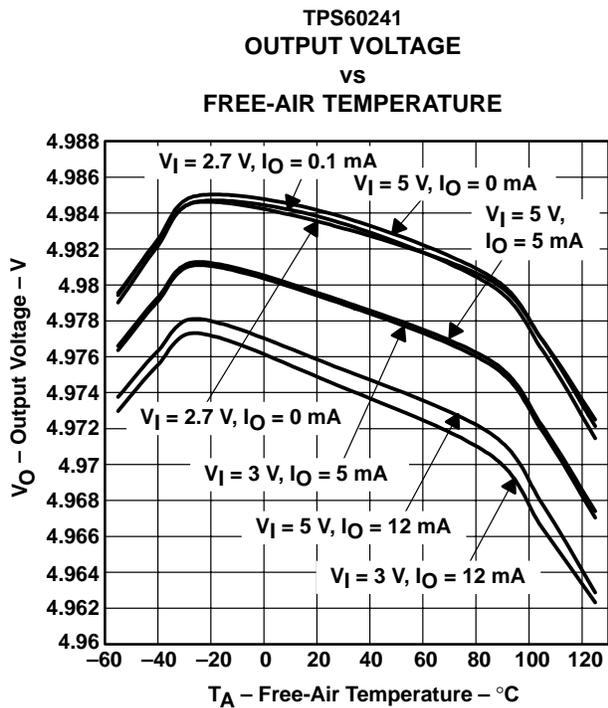


Figure 16

TYPICAL CHARACTERISTICS



TYPICAL CHARACTERISTICS

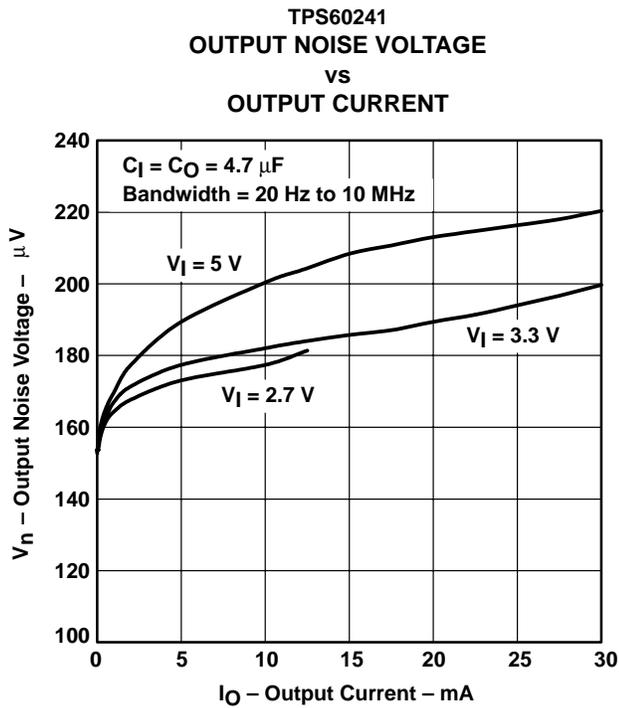


Figure 21

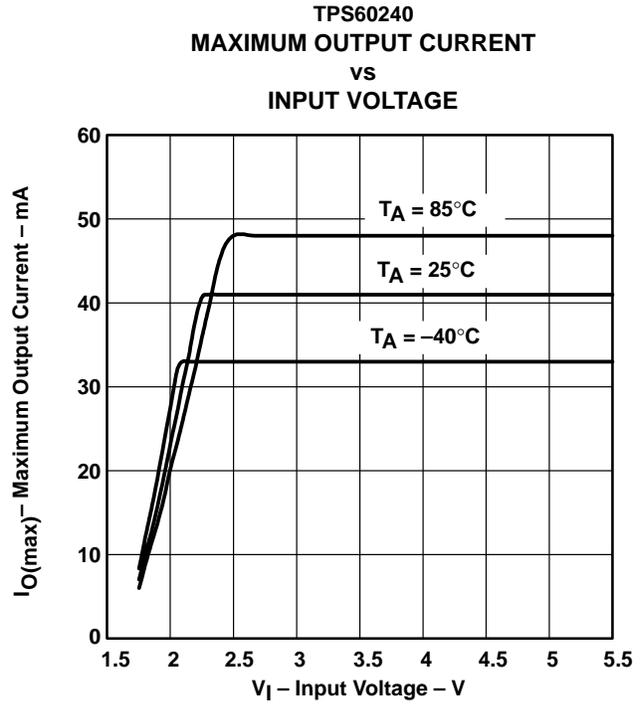


Figure 22

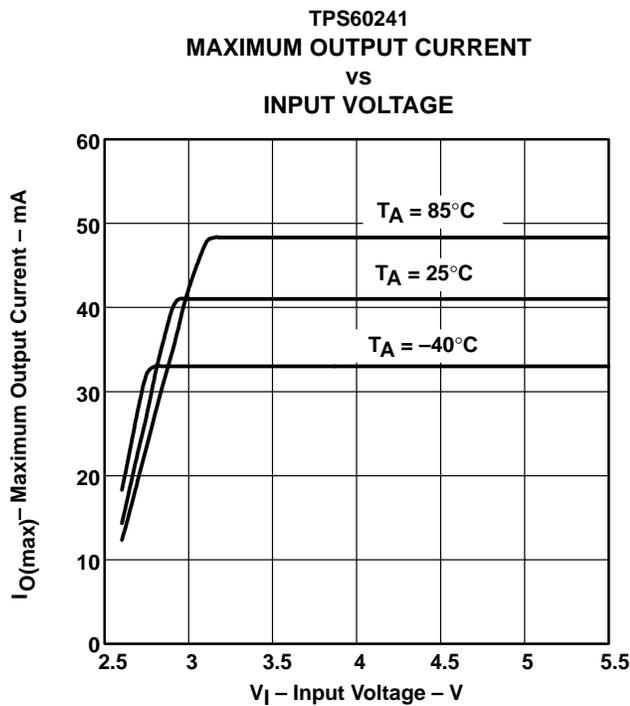


Figure 23

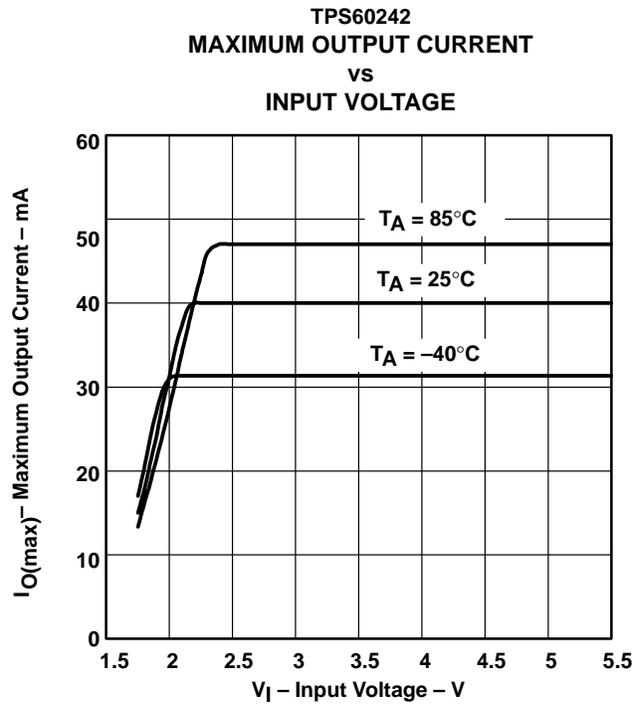


Figure 24

TYPICAL CHARACTERISTICS

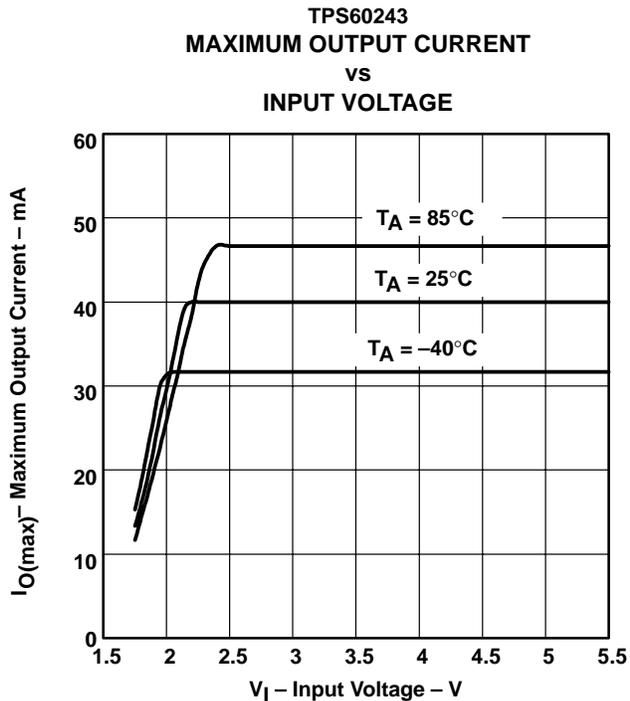


Figure 25

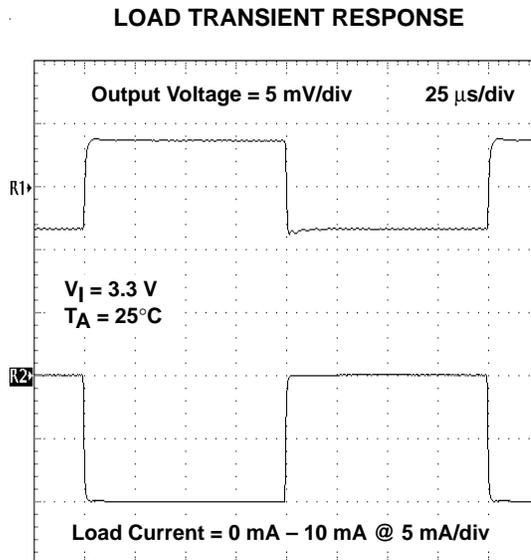


Figure 26

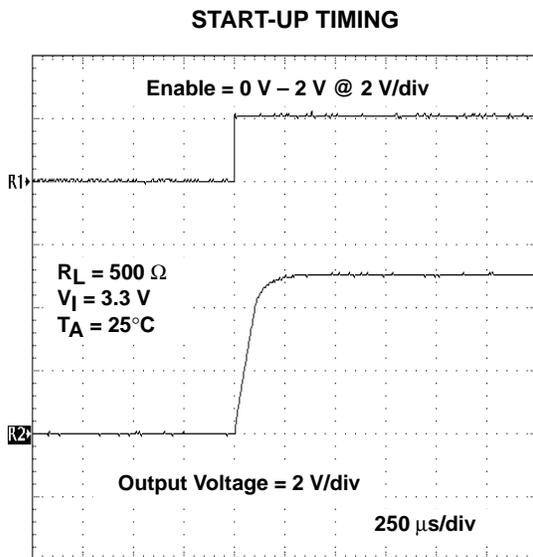


Figure 27

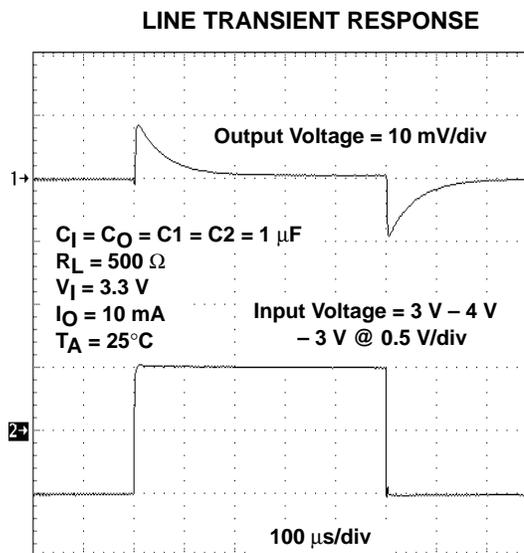
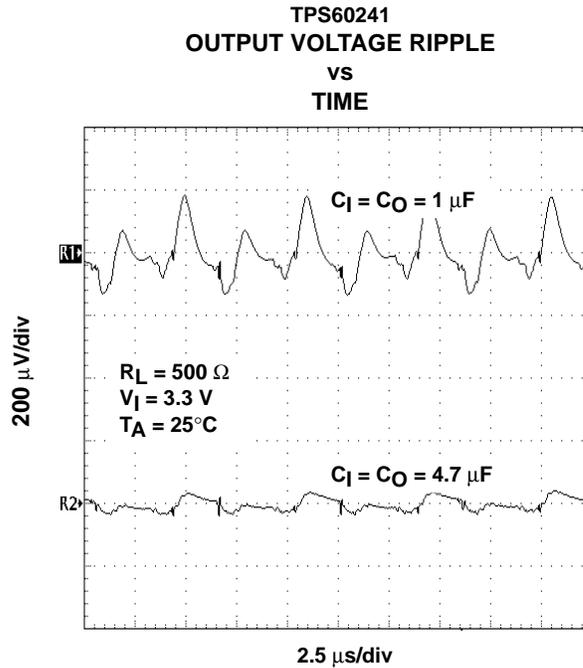
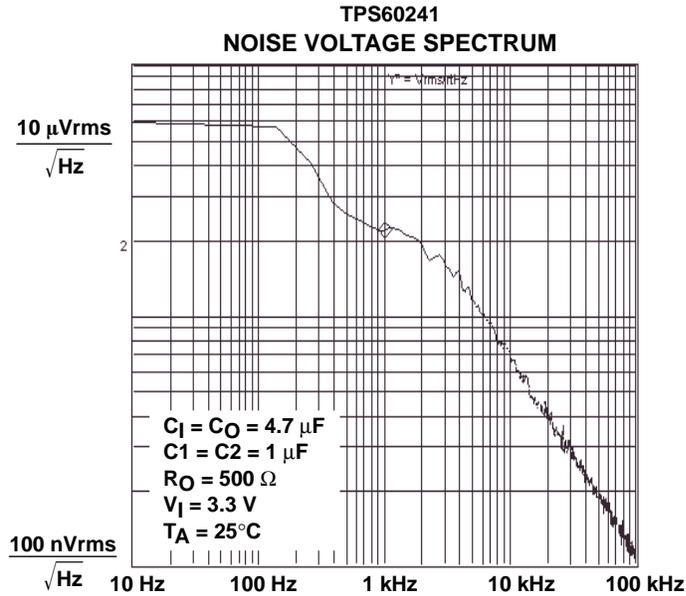


Figure 28

TYPICAL CHARACTERISTICS



NOTE: Scope triggered by voltage at flying capacitors, noise removed by averaging function and bandwidth limit 20 MHz.

APPLICATION INFORMATION

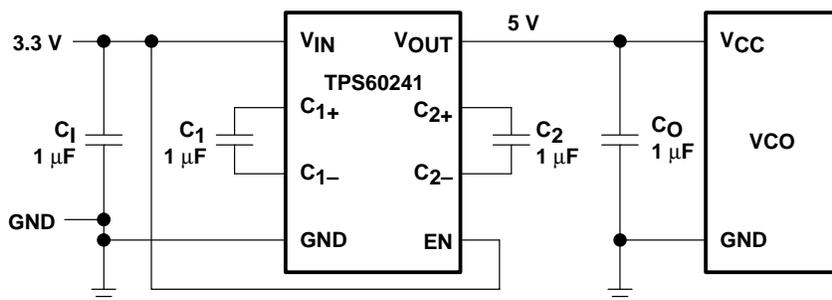


Figure 31. 5-V Low-Noise VCO Supply From 3.3-V Input

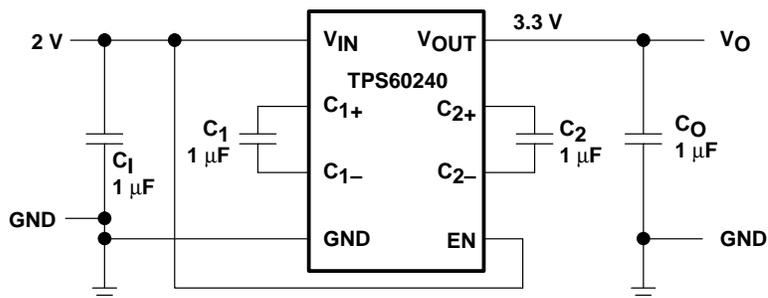


Figure 32. 2-V to 3.3-V Low-Noise Converter

output voltage ripple

The output voltage ripple depends on the capacitors used. Table 1 illustrates the dependence between output voltage ripple and capacitor selection.

Table 1. Output Voltage Ripple and Capacitor Selection

C <sub>1</sub>	C <sub>O</sub>	C <sub>1</sub>	C <sub>2</sub>	OUTPUT VOLTAGE RIPPLE [μVrms]
1 μF	1 μF	1 μF	1 μF	288
2.2 μF	2.2 μF	1 μF	1 μF	212
4.7 μF	4.7 μF	1 μF	1 μF	183
4.7 μF	1 μF	1 μF	1 μF	272
1 μF	4.7 μF	1 μF	1 μF	185

NOTE: V<sub>I</sub> = 3.3 V, V<sub>O</sub> = 5 V, R<sub>L</sub> = 500 Ω, T<sub>A</sub> = 25°C

**APPLICATION INFORMATION**

**components**

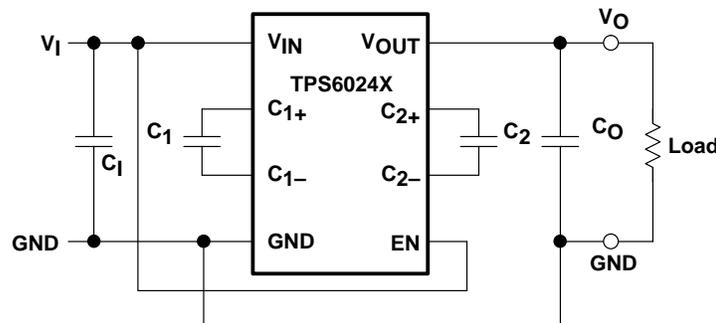
For the best output ripple performance, low-ESR ceramic capacitors are recommended (see Table 2).

**Table 2. Recommended Capacitors**

PART	MANUFACTURER	PART NUMBER	VALUE	TOLERANCE	DIELECTRIC MATERIAL	PACKAGE	RATED VOLTAGE
C <sub>I</sub>	Taiyo Yuden	LMK212BJ105KG-T	1 μF	10%	X7R	0805	10
	TDK	C2012X5R0J475K	4.7 μF	10%	X5R	0805	6.3
C <sub>O</sub>	Taiyo Yuden	LMK212BJ105KG-T	1 μF	10%	X7R	0805	10
	TDK	C2012X5R0J475K	4.7 μF	10%	X5R	0805	6.3
C <sub>1</sub> , C <sub>2</sub>	Taiyo Yuden	LMK212BJ105KG-T	1 μF	10%	X7R	0805	10
C <sub>F</sub>	Taiyo Yuden	LMK212BJ105KG-T	1 μF	10%	X7R	0805	10

**layout consideration**

In order to get optimal noise behavior, keep the power lines to the capacitors and load as short as possible. Use of power planes is recommended.



**Figure 33. Layout Diagram**

APPLICATION INFORMATION

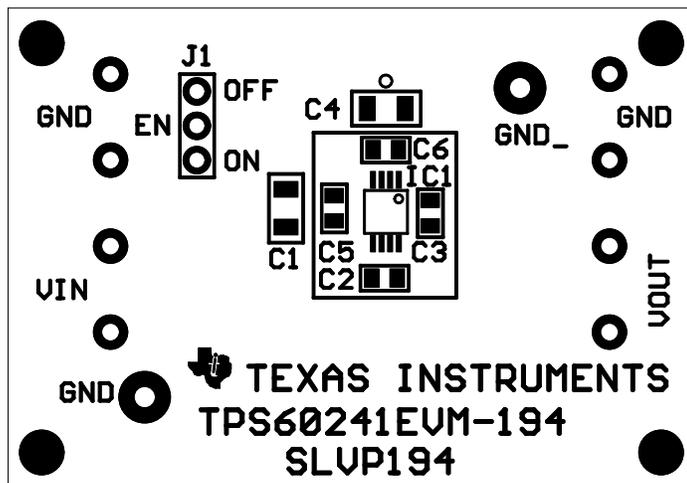


Figure 34. Top Silkscreen

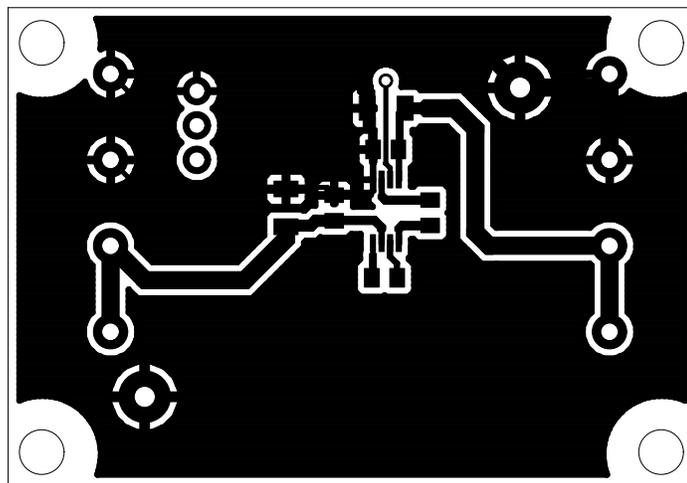


Figure 35. Top Layer

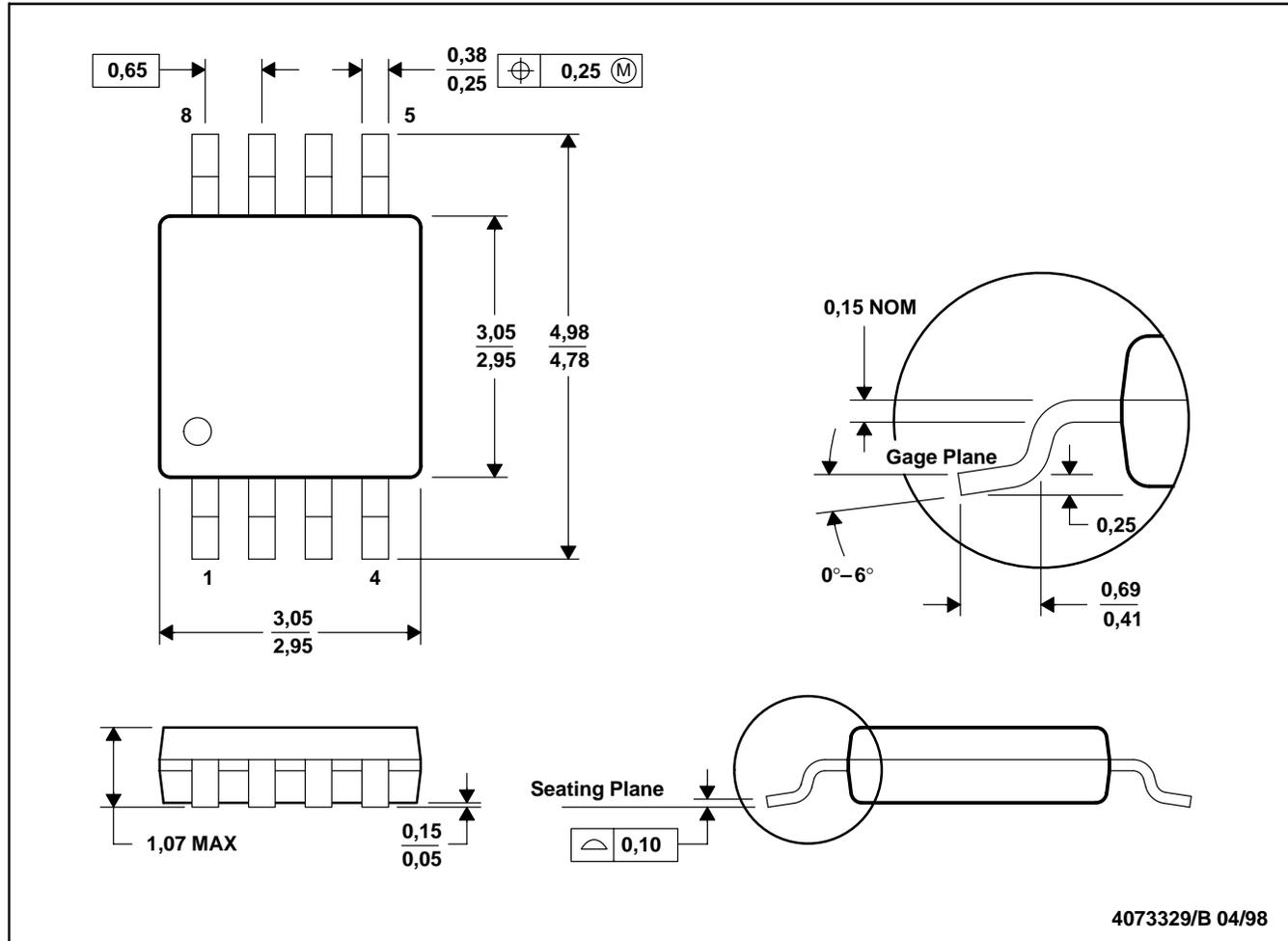
device family products

PART NUMBER	DESCRIPTION
REG710	30-mA switched cap dc/dc converter
REG711	50-mA switched cap dc/dc converter
TPS60110	Regulated 5-V, 300-mA low-noise charge pump dc/dc converter
TPS60111	Regulated 5-V, 150-mA low-noise charge pump dc/dc converter

MECHANICAL DATA

DGK (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



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

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
TPS60240DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60240DGKR	ACTIVE	MSOP	DGK	8	2500	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60240DGKT	ACTIVE	MSOP	DGK	8	250	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60241DGKR	ACTIVE	MSOP	DGK	8	2500	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60241DGKT	ACTIVE	MSOP	DGK	8	250	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60242DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60242DGKR	ACTIVE	MSOP	DGK	8	2500	TBD	CU NIPDAU	Level-3-235C-168 HR
TPS60242DGKT	ACTIVE	MSOP	DGK	8	250	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60243DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60243DGKR	ACTIVE	MSOP	DGK	8	2500	TBD	CU NIPDAU	Level-2-240C-1 YEAR
TPS60243DGKT	ACTIVE	MSOP	DGK	8	250	TBD	CU NIPDAU	Level-2-240C-1 YEAR

<sup>(1)</sup> 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.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS) 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.

**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)

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

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Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
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