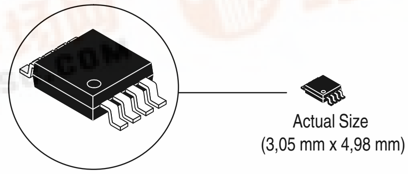
TEXAS INSTRUMENTS



SLVS372B – JUNE 2001 – REVISED JANUARY 2002

170-µVrms 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-µVrms 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 ±2.5% Accuracy Over Load**
- **Up to 25-mA Output Current**
- **Shutdown Mode: 0.1 µA Typical**
- **Thermal Protection and Current Limit**
- **Microsmall 8-Pin MSOP Package**
- **EVM Available TPS60241EVM-194**

APPLICATIONS

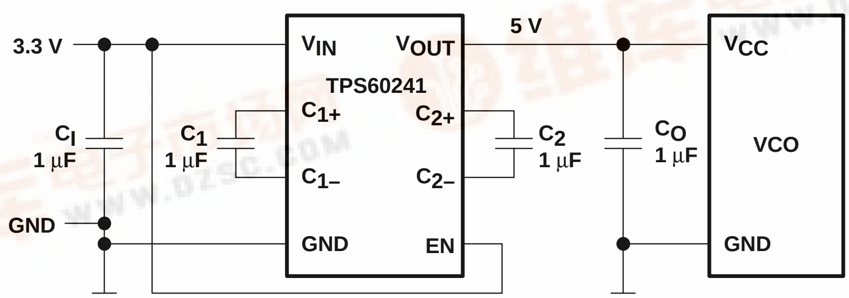
- **VCO and PLL Power for:**
  - **PDA Phones**
  - **Cellular Phones**
  - **PCMCIA Modems**
- **Smartcard Readers**
- **Digital Cameras**
- **MP3 Players**
- **SIM Modules**
- **Electronic Games**
- **Memory Backup**
- **Handheld Meters**
- **Bias Supplies**

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.

typical application circuit

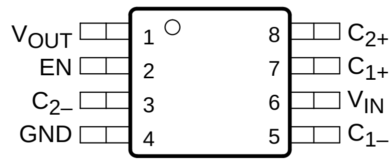


TEXAS INSTRUMENTS

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 µA, and typically 0.1 µA in shutdown mode. The TPS6024x devices come in a thin, 8-pin MSOP (DGK) package with a component height of only 1,1 mm.

DGK PACKAGE
(TOP VIEW)

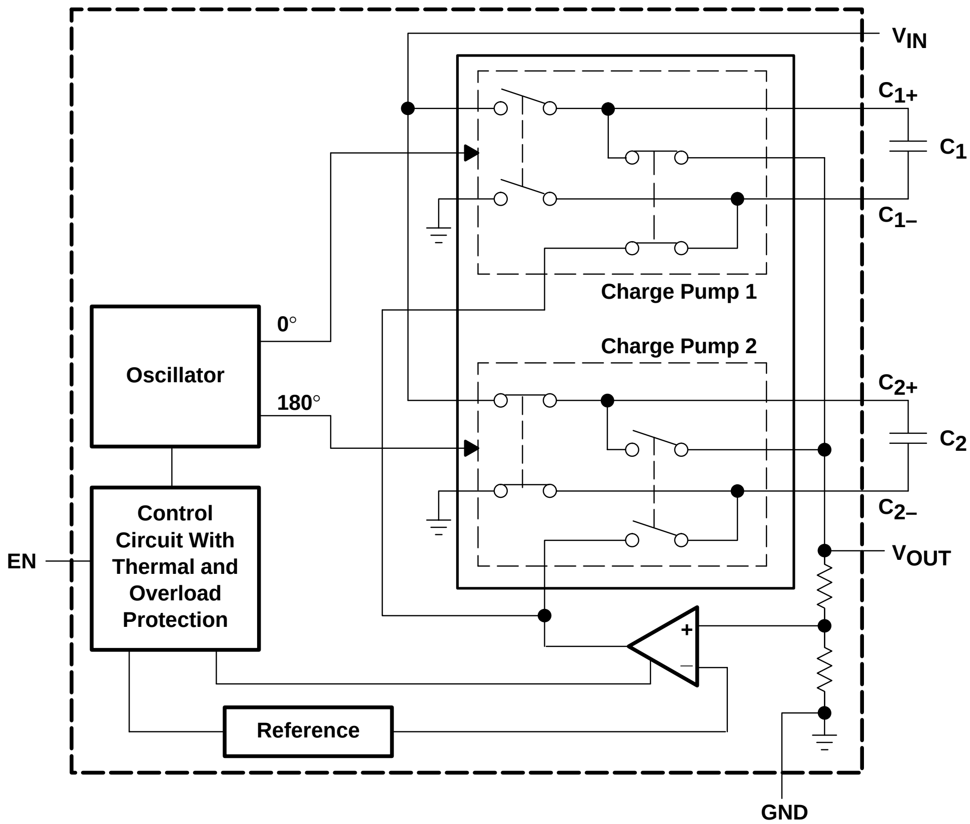


AVAILABLE OPTIONS

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	TERMINAL NO.	I/O	DESCRIPTION
C_{1+}	7		Positive terminal of the flying capacitor C_1
C_{1-}	5		Negative terminal of the flying capacitor C_1
C_{2+}	8		Positive terminal of the flying capacitor C_2
C_{2-}	3		Negative terminal of the flying capacitor C_2
EN	2	I	Enable terminal, active high
GND	4		Ground
V_{IN}	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_{IN} to GND with a 1-µF external capacitor (C_I).
V_{OUT}	1	O	Regulated power output. Bypass V_{OUT} to GND with a 1-µF external filter capacitor (C_O). 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_1 is charged to the supply voltage. Terminal C_{1+} is connected to V_{IN}, and C_{1-} is connected to GND. In the second phase, C_{1-} is connected to the output of the operational amplifier, and C_{1+} is connected to V_{OUT}. The operational amplifier then adjusts its output until the output V_{OUT} delivers the correct voltage to make the resistor divided feedback point equal to the reference voltage. During this second phase, C_2 is charged to supply voltage. Terminal C_{2-} is connected to GND, and C_{2+} is connected to V_{IN}. Phase one is then repeated with C_2, now acting to provide charge to the output in place of C_1, 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_O).

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_O delays the start-up time.

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

Supply voltage, V_{DD} . . . –0.3 V to 6 V
Power dissipation, P_D . . . Internally limited
Voltage EN . . . –0.3 V to 6 V
Voltage C_{2-}, C_{1-} . . . –0.3 V to V_I or 5.5 V, whichever is lowest
Voltage C_{2+}, C_{1+} . . . –0.3 V to V_I, V_O, or 5.5 V, whichever is lowest
Junction temperature, T_J . . . 125°C
Storage temperature, T_{stg} . . . –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	$T_A \leq 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ 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_{TH-JA} = 150°C/W.

recommended operating conditions

			MIN	NOM	MAX	UNIT
V_I	Input voltage range	TPS60240, TPS60242, TPS60243	1.8		5.5	V
		TPS60241	2.7		5.5	
I_O	Output current range	All devices		25		mA
C_I	Input capacitor			1		µF
C_1, C_2	Flying capacitors			1		µF
C_O	Output capacitor			1		µF
T_A	Operating temperature range		–40		85	°C

electrical characteristics for TPS6024X at T_A = 25°C, C_I = C_O =1 µF, C_1 = C_2 = 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_I	Input voltage	TPS60240 Assured start-up		I_O ≤ 5 mA, R_L = 600 Ω	1.8		5.5	V
		TPS60241 Assured start-up		I_O ≤ 12 mA, R_L = 417 Ω	2.7		5.5	
		TPS60242 Assured start-up		I_O ≤ 12 mA, R_L = 225 Ω	1.8		5.5	
		TPS60243 Assured start-up		I_O ≤ 10 mA, R_L = 300 Ω	1.8		5.5	
V_O	Output voltage	TPS60240		1.8 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 5 mA	3.2175	3.3	3.3825	V
				2.4 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 25 mA				
		TPS60241		2.7 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 12 mA	4.875	5	5.125	
				3 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 25 mA				
		TPS60242		1.8 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 12 mA	2.6325	2.7	2.7675	
				2.3 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 25 mA				
		TPS60243		1.8 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 10 mA	2.925	3	3.075	
				2.3 V ≤ V_I ≤ 5.5 V, 0 mA ≤ I_O ≤ 25 mA				
I_O	Output current	TPS60240/2/3	Nominal	2 V ≤ V_I ≤ 5.5 V	12			mA
			Short circuit	V_I = 2 V			80	
		TPS60241	Nominal	2.7 V ≤ V_I ≤ 5.5 V	12			
			Short circuit	V_I = 3.25 V			80	
f_{OSC}		Internal clock source			100	160	220	kHz
V_n	Output noise voltage	TPS60240/2/3		V_I < 2.5 V, I_O = 5 mA, ESR < 0.1 Ω, measured over 20 Hz to 10 MHz, C_O = 4.7 µF		170		µV RMS
		TPS60241		V_I = 2.7 V, I_O = 5 mA, ESR < 0.1 Ω, measured over 20 Hz to 10 MHz, C_O = 4.7 µF		170		
$V_{I(H)}$	EN	Logic high input voltage V_{OH}			1.3		5.5	V
$V_{I(L)}$	EN	Logic low input voltage V_{OL}			–0.2		0.4	V
$I_{I(H)}$	EN	Logic high input current					100	nA
$I_{I(L)}$	EN	Logic low input current					100	nA
$t_{(EN)}$	EN	Start-up time		V_O > 90% of $V_{(NOM)}$ 0.1 mA ≤ I_O ≤ 10 mA, C_O = 1 µF		0.5		ms
η	Efficiency	TPS60240		I_O = 5 mA, V_I = 1.8 V		89.6%		
		TPS60241		I_O = 10 mA, V_I = 2.7 V		90.8%		
		TPS60242		I_O = 10 mA, V_I = 1.8 V		73%		
		TPS60243		I_O = 10 mA, V_I = 1.8 V		81%		

electrical characteristics for TPS6024X at T_A = 25°C, C_I = C_O =1 µF, C_1 = C_2 = 1 µF (unless otherwise noted), limits apply over the specified temperature range, –40°C to 85°C (continued)

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_Q	Quiescent current		I_O = 0 mA, V_I = 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
	Efficiency	vs Input voltage	1–4
		vs Output current	5–8
V_O	Output voltage	vs Input voltage	9–12
		vs Output current	13–16
		vs Free-air temperature	17
	Quiescent current	vs Input voltage	18
		vs Free-air temperature	19
$I_{L(sd)}$	Shutdown current	vs Free-air temperature	20
V_n	Output noise voltage	vs Output current	21
	Maximum output current	vs Input voltage	22–25
	Load transient response		26
	Start-up timing		27
	Line transient response		28
	Noise voltage spectrum		29
	Output voltage ripple	vs Time	30

TYPICAL CHARACTERISTICS

TPS60240
EFFICIENCY
vs
INPUT VOLTAGE

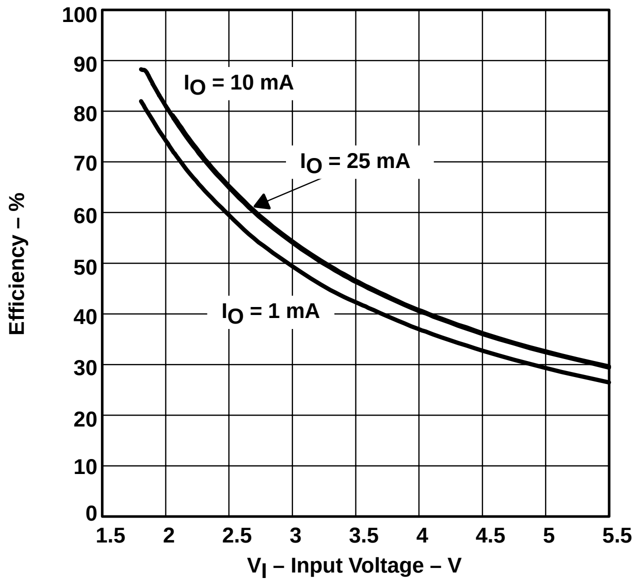


Figure 1

TPS60241
EFFICIENCY
vs
INPUT VOLTAGE

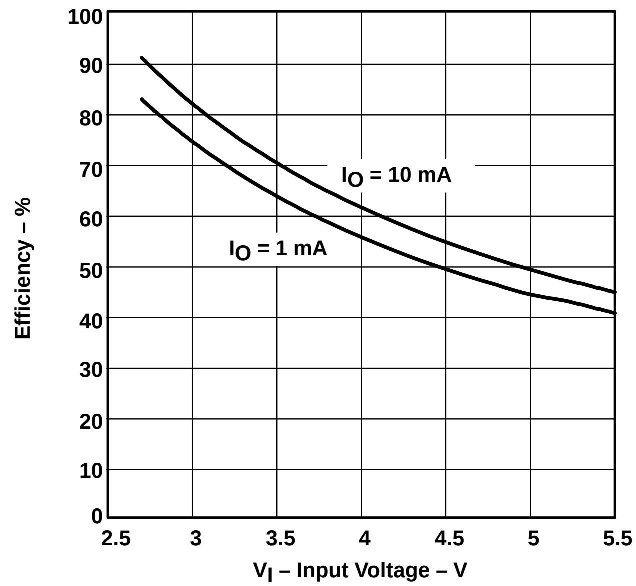


Figure 2

TPS60242
EFFICIENCY
vs
INPUT VOLTAGE

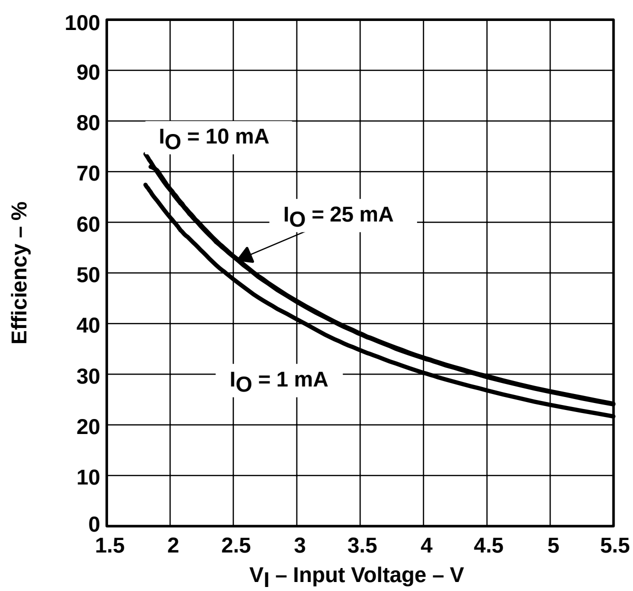


Figure 3

TPS60243
EFFICIENCY
vs
INPUT VOLTAGE

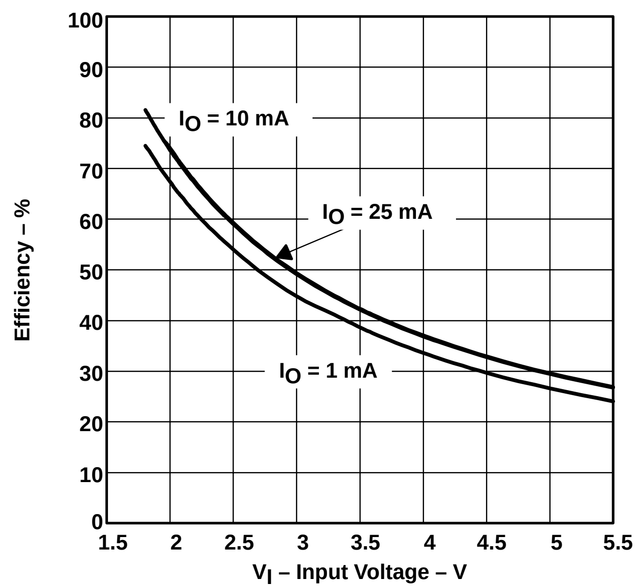


Figure 4

TYPICAL CHARACTERISTICS

TPS60240
EFFICIENCY
vs
OUTPUT CURRENT

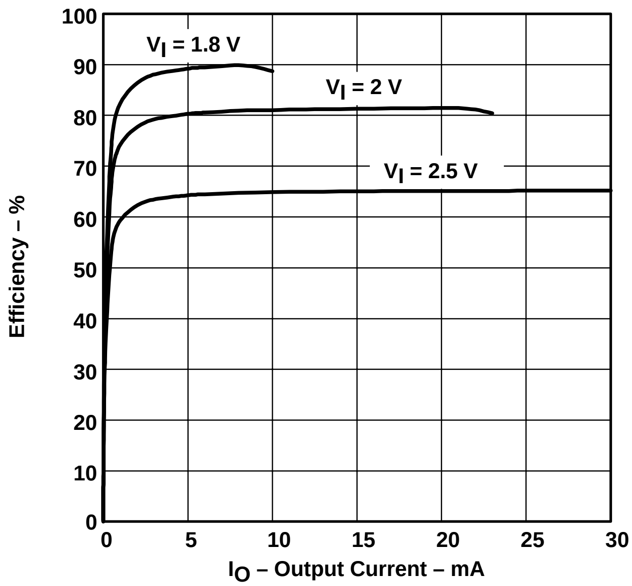


Figure 5

TPS60241
EFFICIENCY
vs
OUTPUT CURRENT

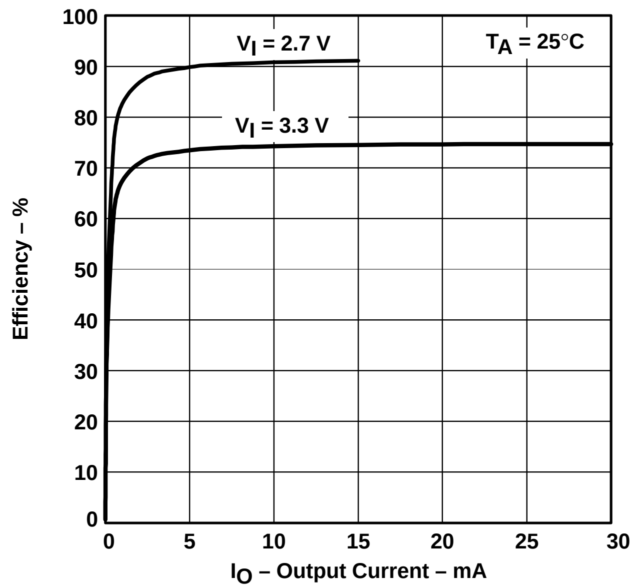


Figure 6

TPS60242
EFFICIENCY
vs
OUTPUT CURRENT

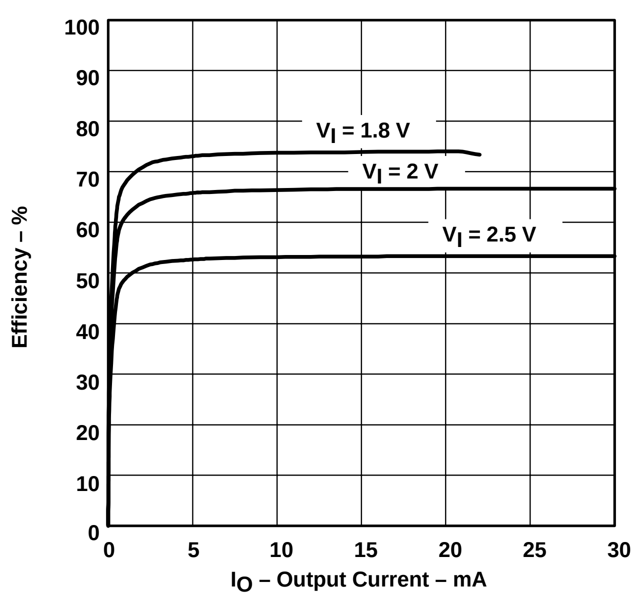


Figure 7

TPS60243
EFFICIENCY
vs
OUTPUT CURRENT

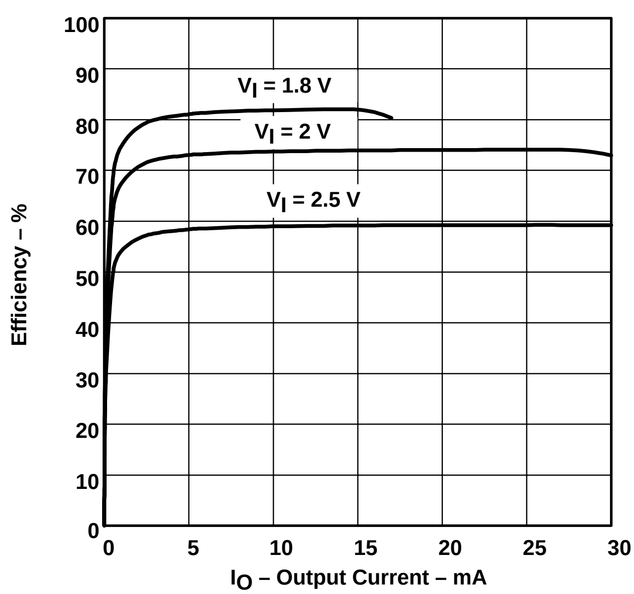


Figure 8

TYPICAL CHARACTERISTICS

TPS60240
OUTPUT VOLTAGE
vs
INPUT VOLTAGE

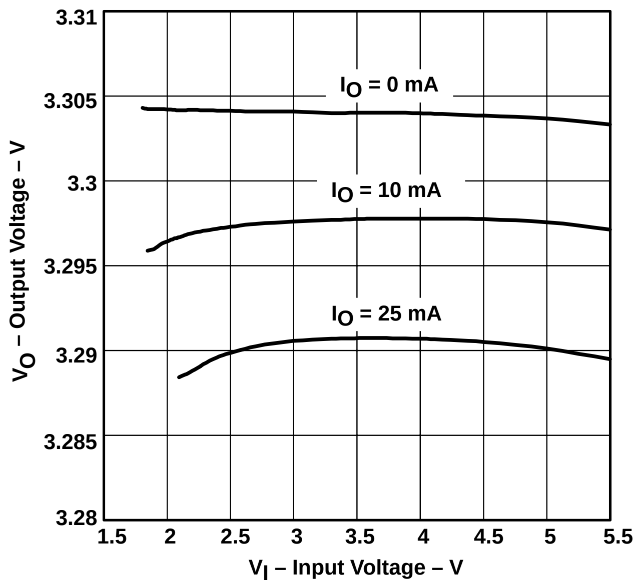


Figure 9

TPS60241
OUTPUT VOLTAGE
vs
INPUT VOLTAGE

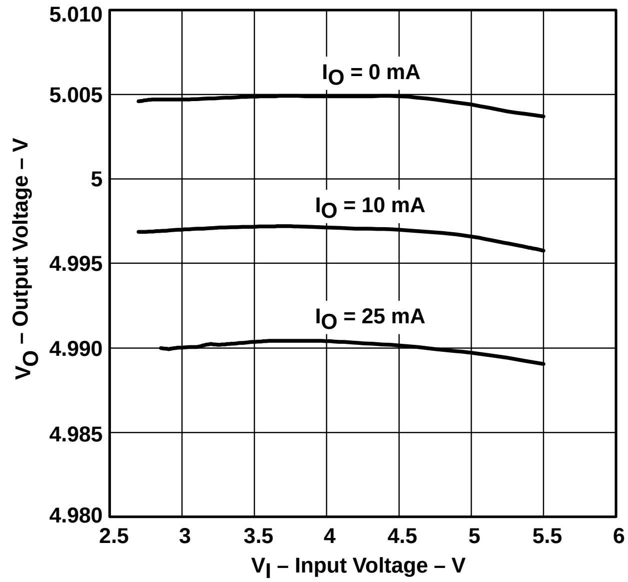


Figure 10

TPS60242
OUTPUT VOLTAGE
vs
INPUT VOLTAGE

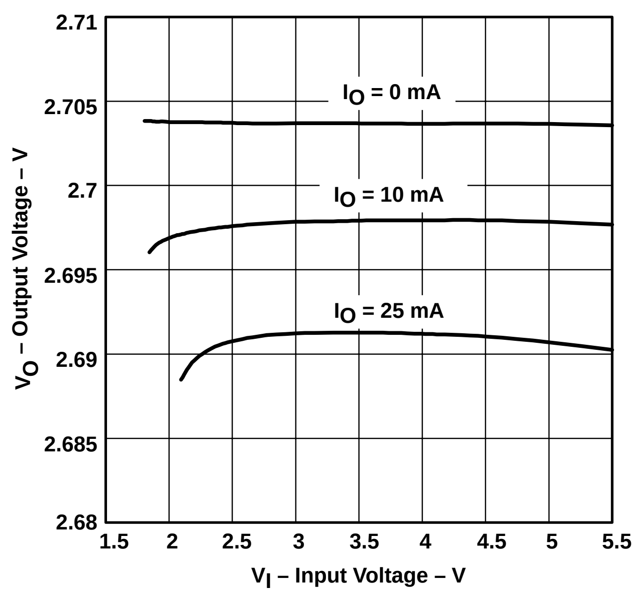


Figure 11

TPS60243
OUTPUT VOLTAGE
vs
INPUT VOLTAGE

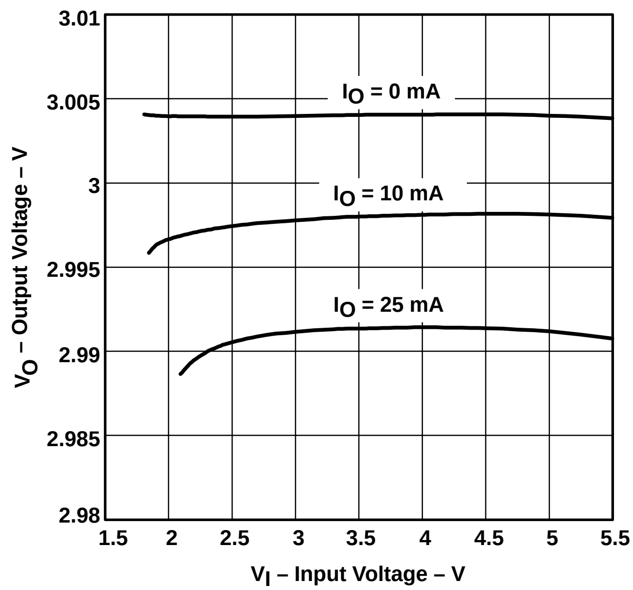


Figure 12

TYPICAL CHARACTERISTICS

TPS60240
OUTPUT VOLTAGE
vs
OUTPUT CURRENT

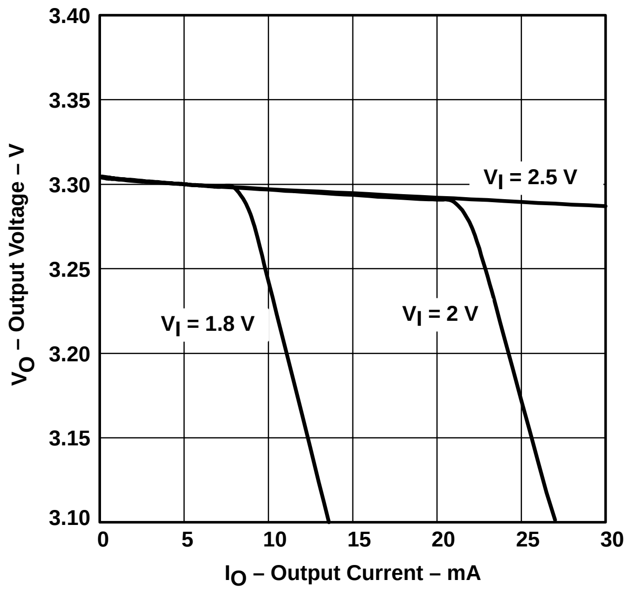


Figure 13

TPS60241
OUTPUT VOLTAGE
vs
OUTPUT CURRENT

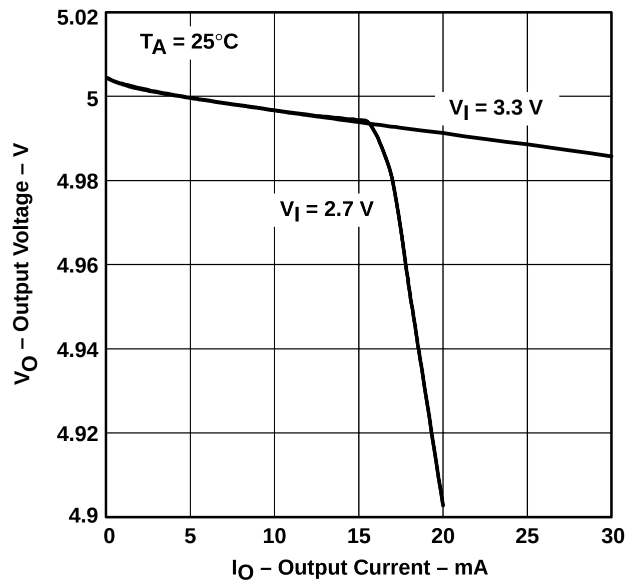


Figure 14

TPS60242
OUTPUT VOLTAGE
vs
OUTPUT CURRENT

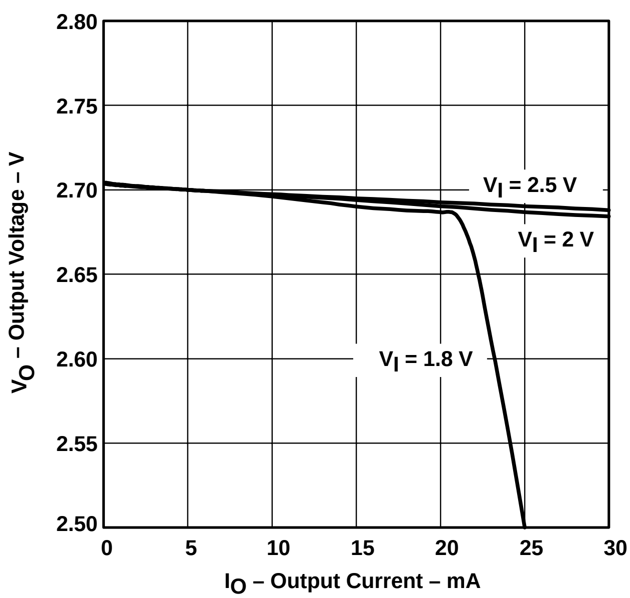


Figure 15

TPS60243
OUTPUT VOLTAGE
vs
OUTPUT CURRENT

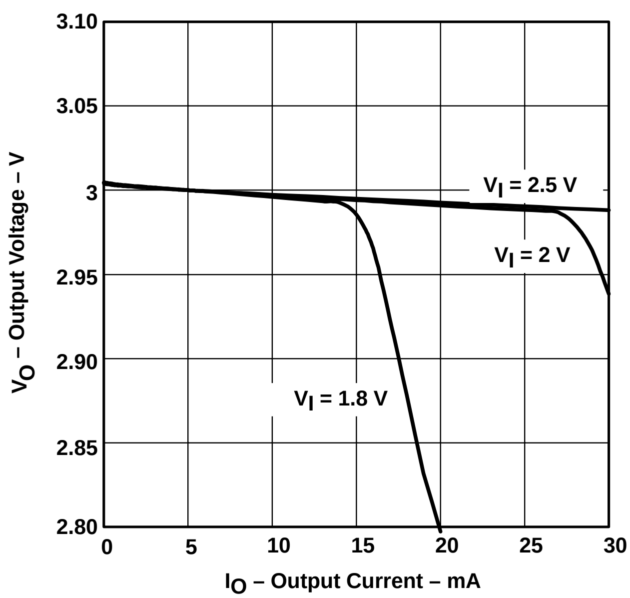


Figure 16

TYPICAL CHARACTERISTICS

TPS60241
OUTPUT VOLTAGE
vs
FREE-AIR TEMPERATURE

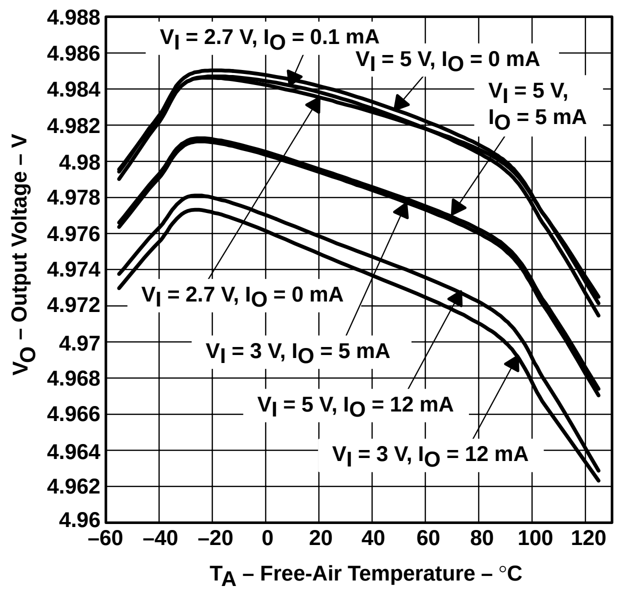


Figure 17

TPS60241
QUIESCENT CURRENT
vs
INPUT VOLTAGE

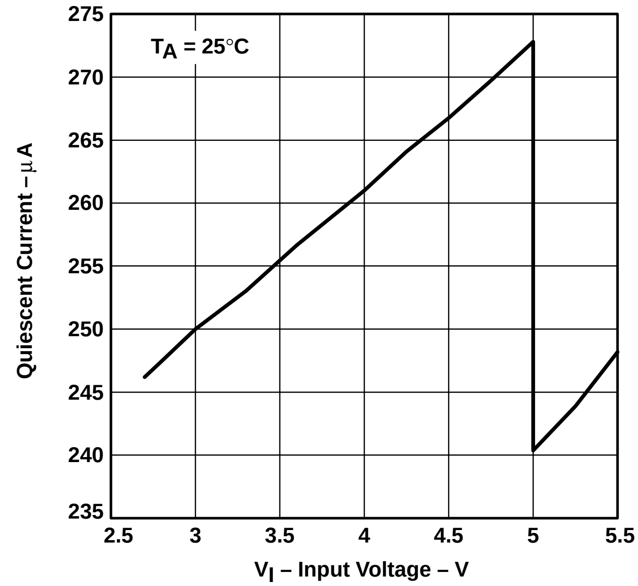


Figure 18

TPS60241
QUIESCENT CURRENT
vs
FREE-AIR TEMPERATURE

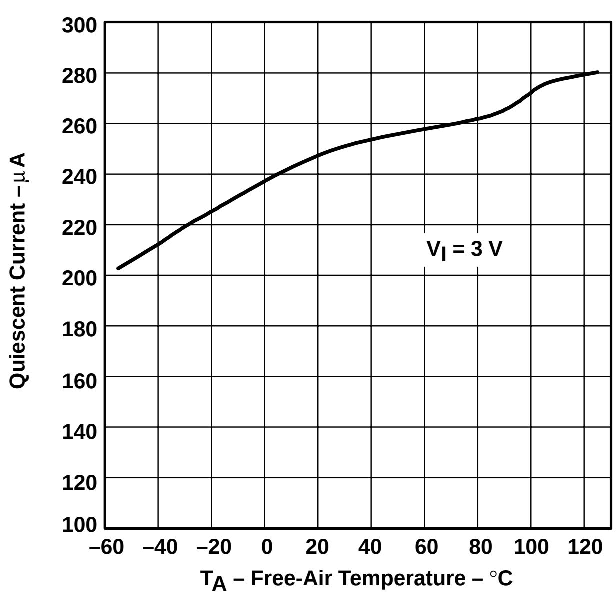


Figure 19

TPS60241
SHUTDOWN CURRENT
vs
FREE-AIR TEMPERATURE

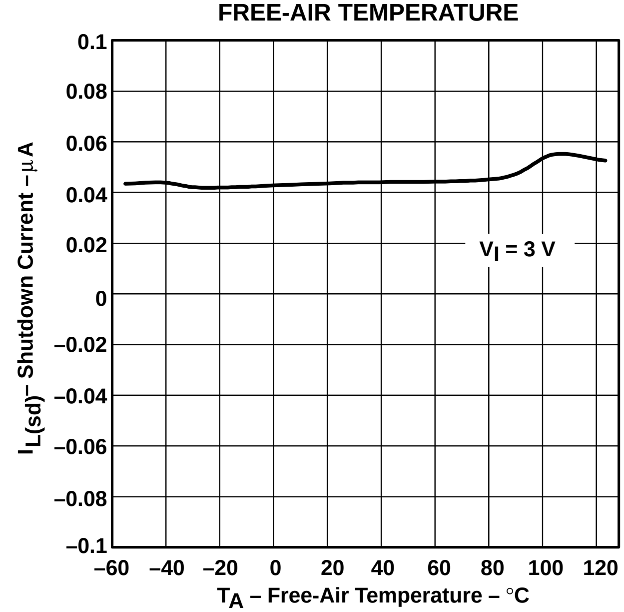


Figure 20

TYPICAL CHARACTERISTICS

TPS60241
OUTPUT NOISE VOLTAGE
vs
OUTPUT CURRENT

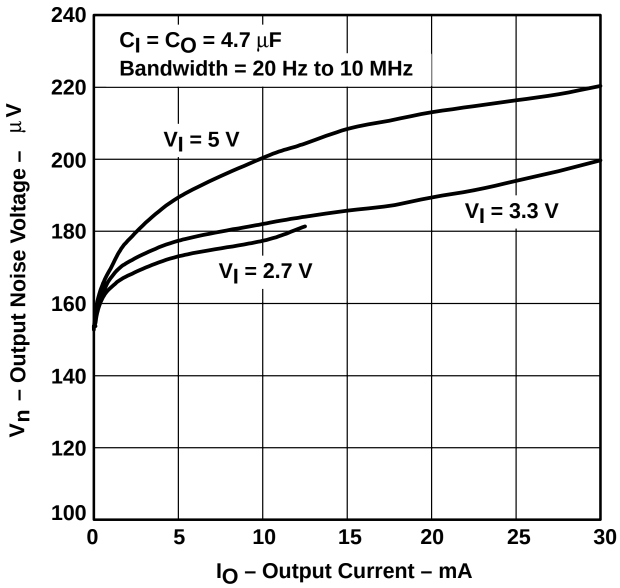


Figure 21

TPS60240
MAXIMUM OUTPUT CURRENT
vs
INPUT VOLTAGE

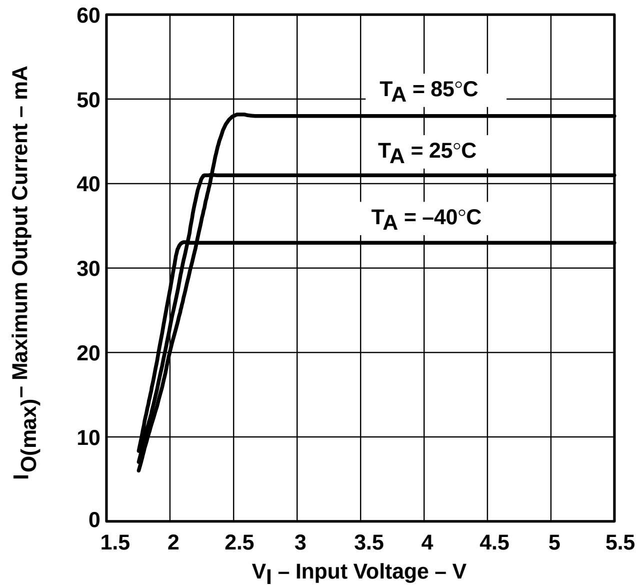


Figure 22

TPS60241
MAXIMUM OUTPUT CURRENT
vs
INPUT VOLTAGE

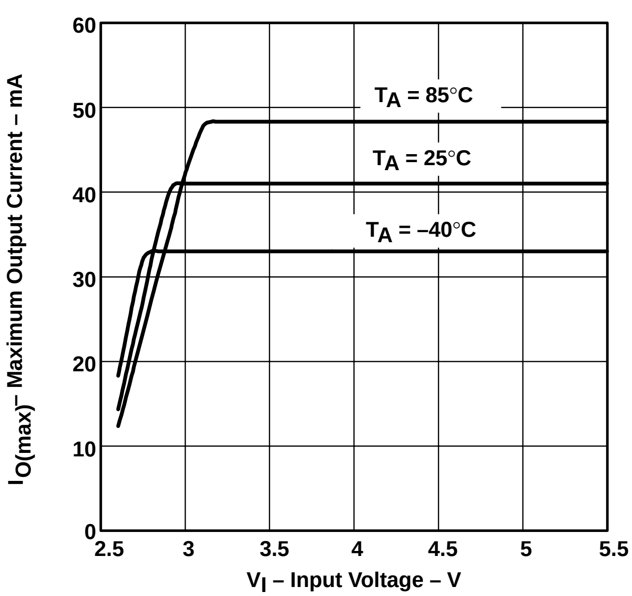


Figure 23

TPS60242
MAXIMUM OUTPUT CURRENT
vs
INPUT VOLTAGE

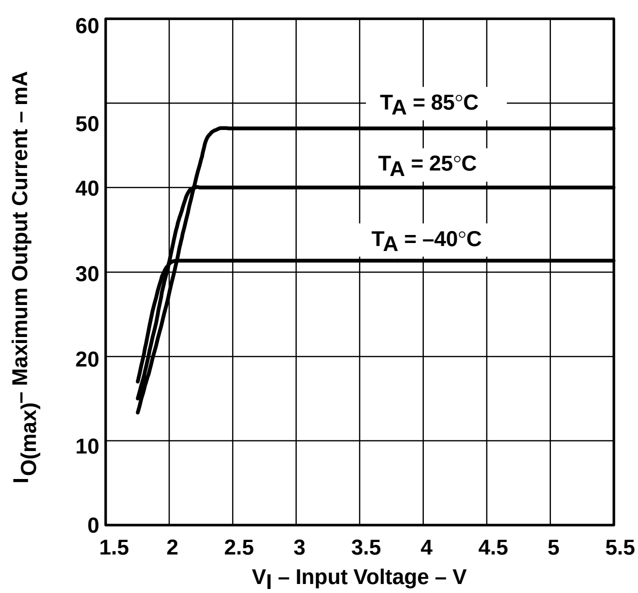


Figure 24

TYPICAL CHARACTERISTICS

TPS60243
MAXIMUM OUTPUT CURRENT
vs
INPUT VOLTAGE

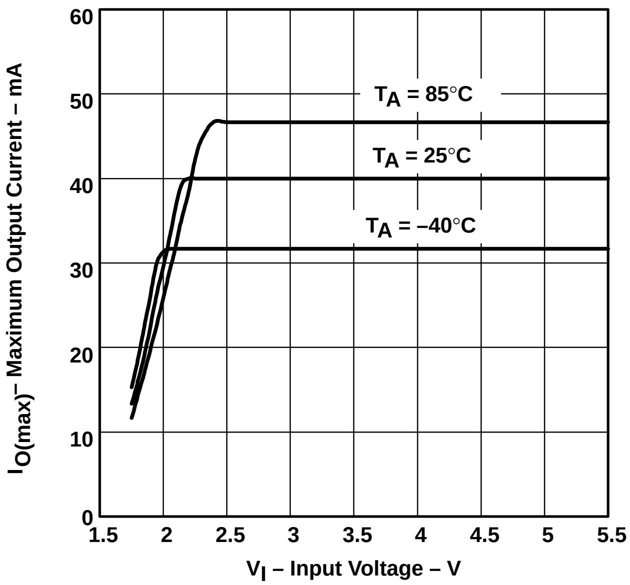


Figure 25

LOAD TRANSIENT RESPONSE

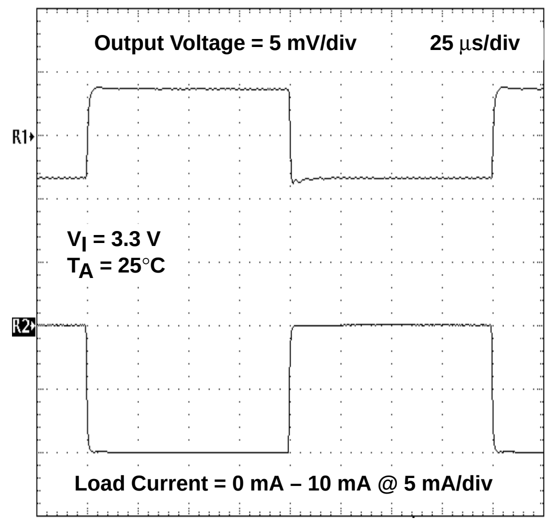


Figure 26

START-UP TIMING

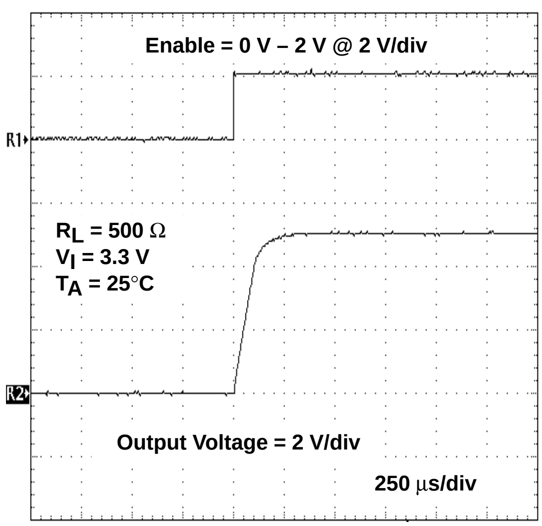


Figure 27

LINE TRANSIENT RESPONSE

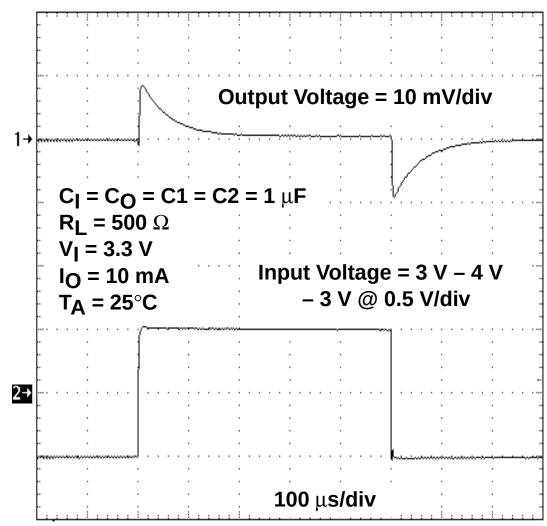


Figure 28

TYPICAL CHARACTERISTICS

TPS60241
NOISE VOLTAGE SPECTRUM

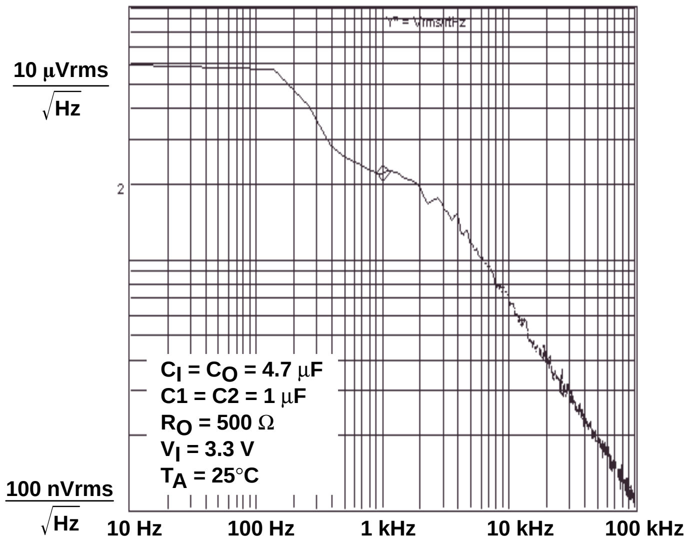
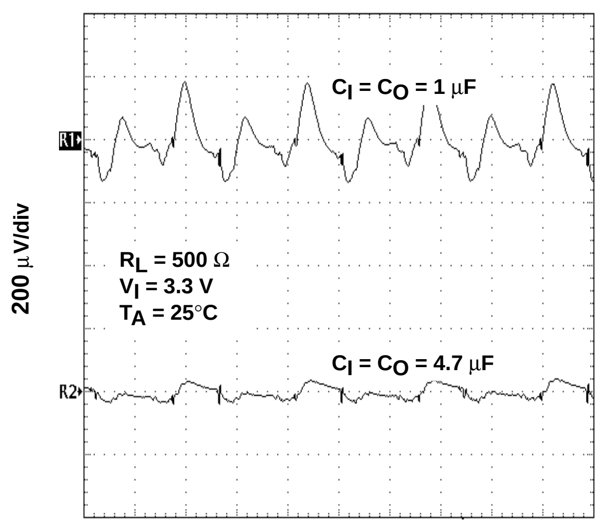


Figure 29

TPS60241
OUTPUT VOLTAGE RIPPLE
vs
TIME



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

Figure 30

APPLICATION INFORMATION

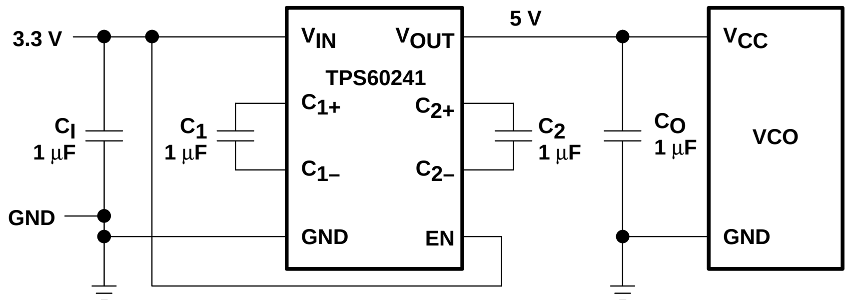


Figure 31. 5-V Low-Noise VCO Supply From 3.3-V Input

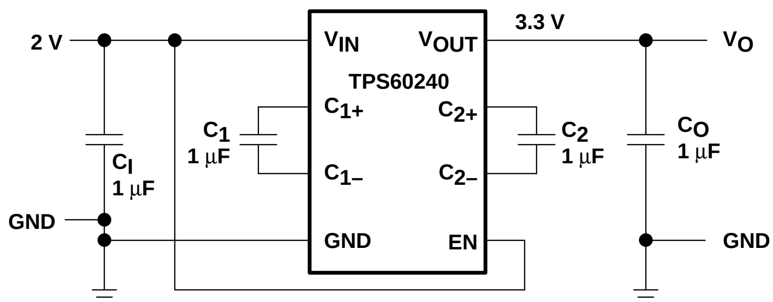


Figure 32. 2-V to 3.3-V Low-Noise Converter

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_I	C_O	C_1	C_2	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_I = 3.3 V, V_O = 5 V, R_L = 500 Ω, T_A = 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_I	Taiyo Yuden	LMK212BJ105KG–T	1 µF	10%	X7R	0805	10
	TDK	C2012X5R0J475K	4.7 µF	10%	X5R	0805	6.3
C_O	Taiyo Yuden	LMK212BJ105KG–T	1 µF	10%	X7R	0805	10
	TDK	C2012X5R0J475K	4.7 µF	10%	X5R	0805	6.3
C_1, C_2	Taiyo Yuden	LMK212BJ105KG–T	1 µF	10%	X7R	0805	10
C_F	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.

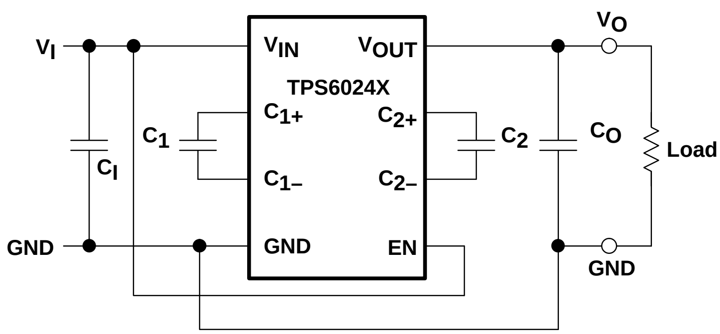


Figure 33. Layout Diagram

APPLICATION INFORMATION

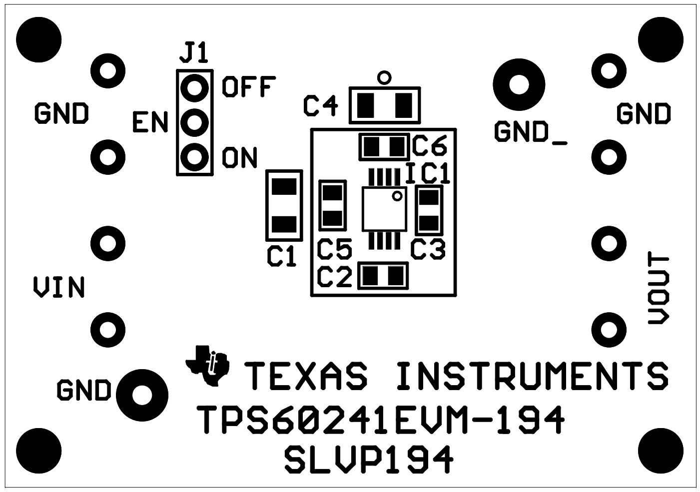


Figure 34. Top Silkscreen

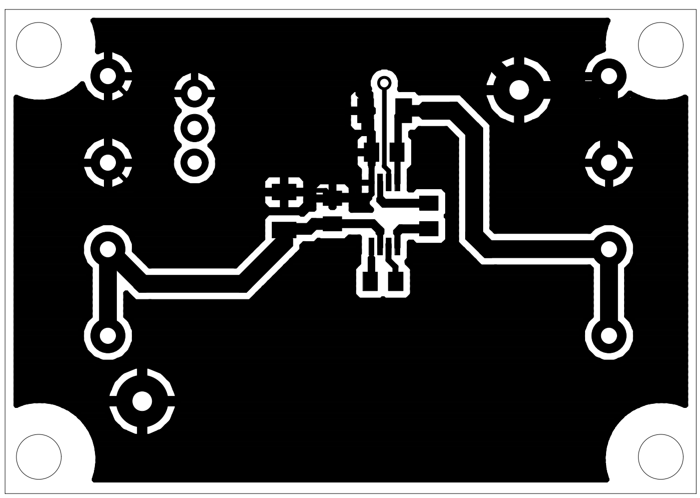


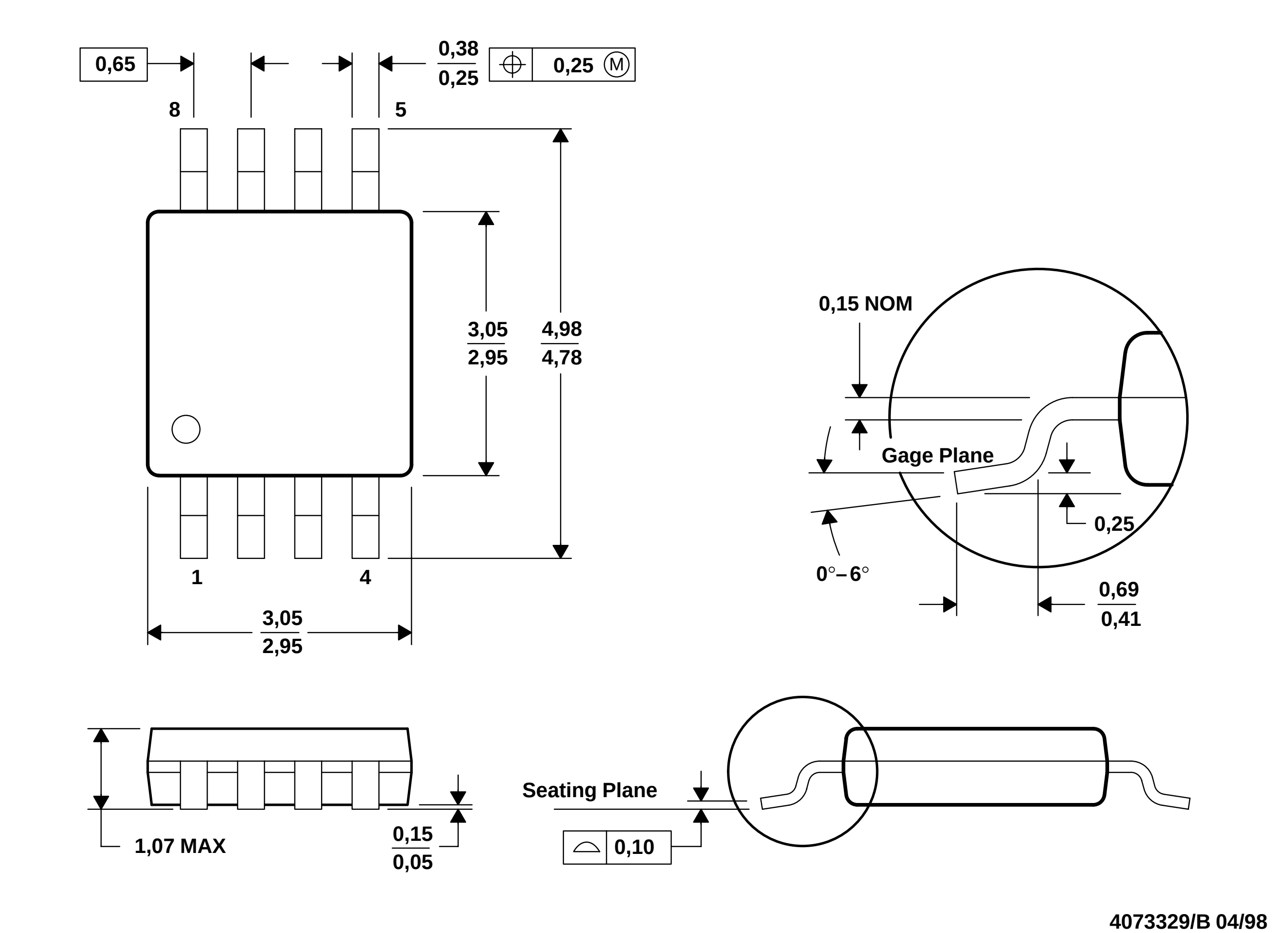
Figure 35. Top Layer

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 [(1)]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [(2)]	Lead/Ball Finish	MSL Peak Temp [(3)]
TPS60240DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60240DGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60240DGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60240DGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60241DGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60241DGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60241DGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60241DGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60242DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60242DGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60242DGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60242DGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60242DGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60243DGK	ACTIVE	MSOP	DGK	8		TBD	Call TI	Call TI
TPS60243DGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS60243DGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

(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.

PACKAGE OPTION ADDENDUM

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