

# SM72441 Programmable Maximum Power Point Tracking Controller for Photovoltaic Solar Panels

Check for Samples: [SM72441](#)

## FEATURES

- Renewable Energy Grade
- Programmable Maximum Power Point Tracking
- Photovoltaic Solar Panel Voltage and Current Diagnostic
- Single Inductor Four Switch Buck-boost Converter Control
- VOUT Overvoltage Protection
- Over-Current Protection

## PACKAGE

- TSSOP-28

## Block Diagram

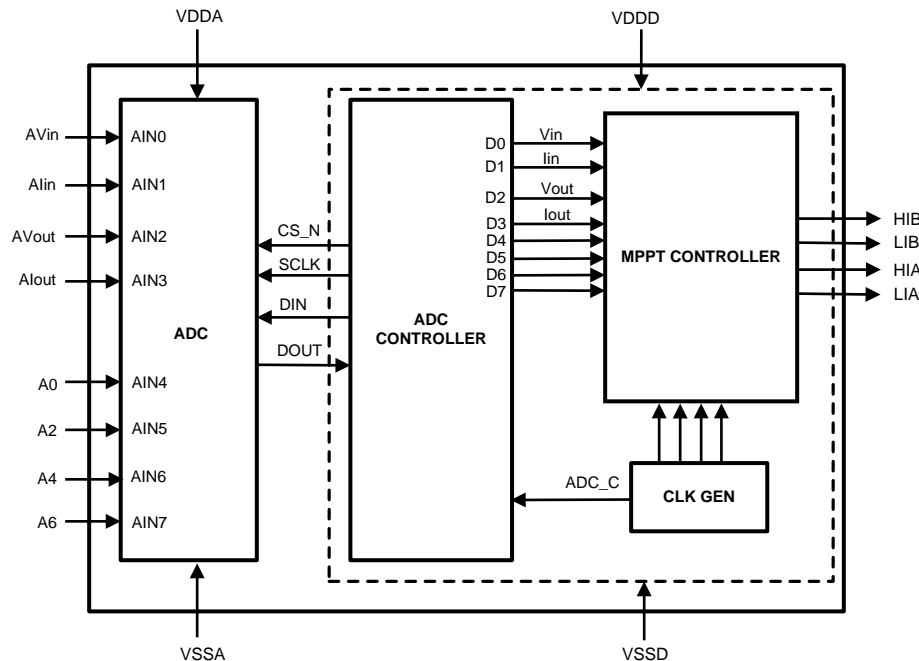


Figure 1. Block Diagram

## DESCRIPTION

The SM72441 is a programmable MPPT controller capable of controlling four PWM gate drive signals for a 4-switch buck-boost converter. Along with SM72295 (Photovoltaic Full Bridge Driver) it creates a solution for an MPPT configured DC-DC converter with efficiencies up to 98.5%. Integrated into the chip is an 8-channel, 12 bit A/D converter used to sense input and output voltage and current, as well as board configuration. Externally programmable values include maximum output voltage and current as well as different settings on slew rate, and soft-start.



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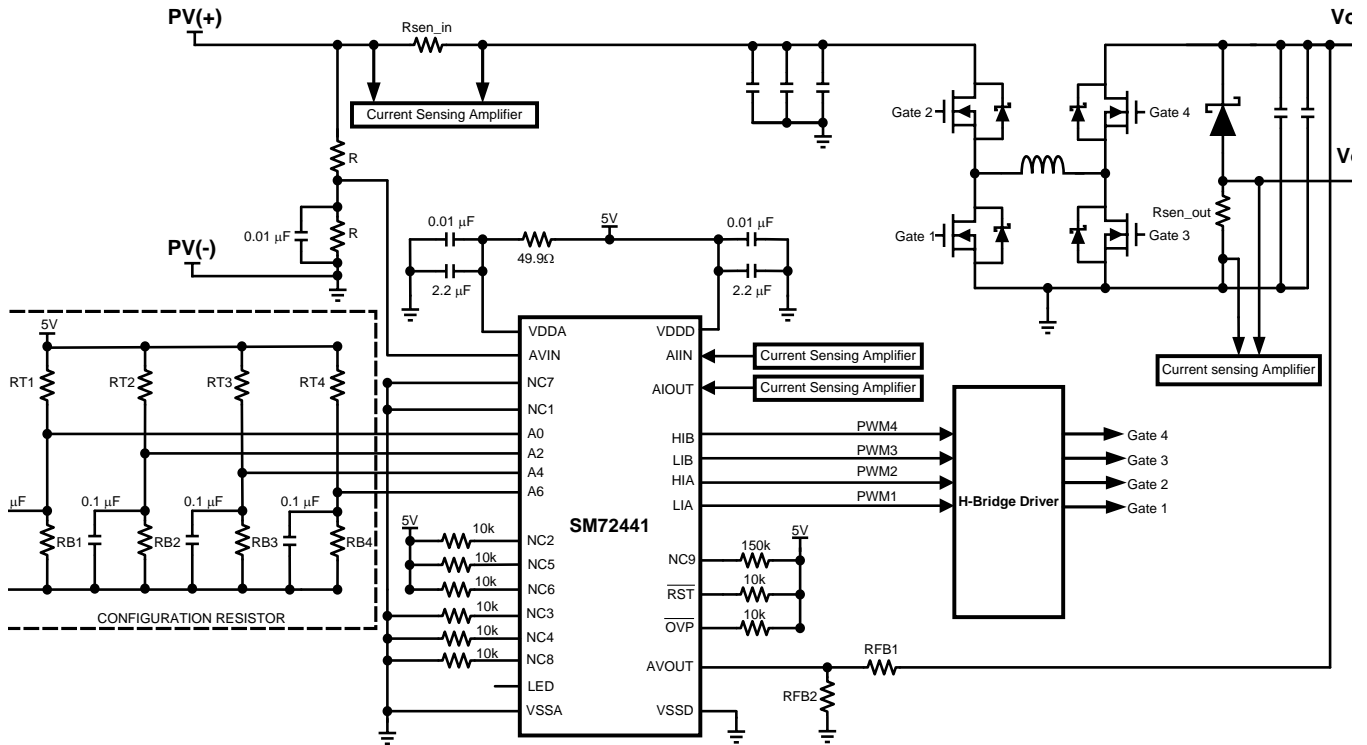
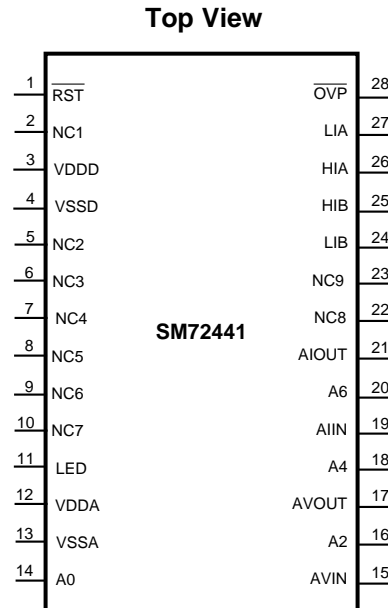


Figure 2. Typical Application Circuit

## Connection Diagram



**Figure 3. TSSOP-28 Package**  
See Package Drawing PW0028A

### Pin Descriptions

Pin	Name	Description
1	$\overline{\text{RST}}$	Active low signal. External reset input signal to the digital circuit.
2	NC1	No Connect. This pin should be grounded.
3	VDDD	Digital supply voltage. This pin should be connected to a 5V supply, and bypassed to VSSD with a 0.1uF monolithic ceramic capacitor.
4	VSSD	Digital ground. The ground return for the digital supply and signals.
5	NC2	No Connect. This pin should be pulled up to the 5V supply using 10k resistor.
6	NC3	No Connect. This pin should be grounded using a 10k resistor.
7	NC4	No Connect. This pin should be grounded using a 10k resistor.
8	NC5	No Connect. This pin should be pulled up to 5V supply using 10k resistor.
9	NC6	No Connect. This pin should be pulled up to 5V supply using 10k resistor.
10	NC7	No Connect. This pin should be grounded.
11	LED	LED pin outputs a pulse during normal operation.
12	VDDA	Analog supply voltage. This voltage is also used as the reference voltage. This pin should be connected to a 5V supply, and bypassed to VSSA with a 1uF and 0.1uF monolithic ceramic capacitor.
13	VSSA	Analog ground. The ground return for the analog supply and signals.
14	A0	A/D Input Channel 0. Connect a resistor divider to 5V supply to set the maximum output voltage. Please refer to application section for more information on setting the resistor value.
15	AVIN	A/D Input to sense input voltage.
16	A2	A/D Input Channel 2. Connect a resistor divider to 5V supply to set MPPT update rate. Please refer to application section for more information on setting the resistor value.
17	AVOUT	A/D Input to sense the output voltage.
18	A4	A/D Input Channel 4. Connect a resistor divider to 5V supply to set the maximum output current. Please refer to application section for more information on setting the resistor value.
19	AIIN	A/D Input to sense input current.
20	A6	A/D Input Channel 6. Connect a resistor divider to 5V supply to set the maximum output voltage slew rate. Please refer to application section for more information on setting the resistor value.
21	AIOUT	A/D Input to sense the output current.

### Pin Descriptions (continued)

Pin	Name	Description
22	NC8	No Connect. This pin should be grounded using a 10k resistor.
23	NC9	No Connect. This pin should be connected with 150k pull-up resistor to 5V supply.
24	LIB	Low side boost PWM output.
25	HIB	High side boost PWM output.
26	HIA	High side buck PWM output.
27	LIA	Low side buck PWM output.
28	$\overline{\text{OVP}}$	Overvoltage Protection Pin. Active Low. SM72441 will reset once voltage on this pin drops below its threshold voltage.



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### Absolute Maximum Ratings<sup>(1)(2)</sup>

Analog Supply Voltage $V_A$ (VDDA -VSSA)		-0.3 to 6.0V
Analog Supply Voltage $V_D$ (VDDD -VSSD)		-0.3 to $V_A + 0.3V$ , max 6.0V
Voltage on Any Pin to GND		-0.3 to $V_A + 0.3V$
Input Current at Any Pin (Note 3)		$\pm 10$ mA
Package Input Current (Note 3)		$\pm 20$ mA
Storage Temperature Range		-65°C to +150°C
ESD Rating <sup>(3)</sup>	Human Body Model	2 kV

- (1) Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is ensured. Operating Ratings indicate conditions for which the device is intended to be functional, but does not ensure specific performance limits. For specified performance limits and associated test conditions, see the Electrical Characteristics tables.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
- (3) The human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin.

### Recommended Operating Conditions

Operating Temperature	-40°C to 105°C
$V_A$ Supply Voltage	+4.75V to +5.25V
$V_D$ Supply Voltage	+4.75V to $V_A$
Digital Input Voltage	0 to $V_A$
Analog Input Voltage	0 to $V_A$
Junction Temperature	-40°C to 125°C

## Electrical Characteristics

Specifications in standard typeface are for  $T_J = 25^\circ\text{C}$ , and those in boldface type apply over the full operating junction temperature range.<sup>(1)</sup>

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>ANALOG INPUT CHARACTERISTICS</b>						
$A_{Vin}$ , $A_{Lin}$ $A_{Vout}$ , $A_{Lout}$	Input Range		-	0 to $V_A$	-	V
$I_{DCL}$	DC Leakage Current		-	-	<b><math>\pm 1</math></b>	$\mu\text{A}$
$C_{INA}$	Input Capacitance <sup>(2)</sup>	Track Mode	-	33	-	pF
		Hold Mode	-	3	-	pF
$V_{ERR}$	DC Voltage Measurement Accuracy			0.1		%
<b>DIGITAL INPUT CHARACTERISTICS</b>						
$V_{IL}$	Input Low Voltage		-	-	<b>0.8</b>	V
$V_{IH}$	Input High Voltage		<b>2.8</b>	-	-	V
$C_{IND}$	Digital Input Capacitance <sup>(2)</sup>		-	2	<b>4</b>	pF
$I_{IN}$	Input Current		-	$\pm 0.01$	<b><math>\pm 1</math></b>	$\mu\text{A}$
<b>DIGITAL OUTPUT CHARACTERISTICS</b>						
$V_{OH}$	Output High Voltage	$I_{SOURCE} = 200 \mu\text{A}$ $V_A = V_D = 5\text{V}$	<b><math>V_D - 0.5</math></b>	-	-	V
$V_{OL}$	Output Low Voltage	$I_{SINK} = 200 \mu\text{A}$ to $1.0 \text{ mA}$ $V_A = V_D = 5\text{V}$	-	-	<b>0.4</b>	V
$I_{OZH}$ , $I_{OZL}$	Hi-Impedance Output Leakage Current	$V_A = V_D = 5\text{V}$			<b><math>\pm 1</math></b>	$\mu\text{A}$
$C_{OUT}$	Hi-Impedance Output Capacitance <sup>(2)</sup>			2	<b>4</b>	pF
<b>POWER SUPPLY CHARACTERISTICS (<math>C_L = 10 \text{ pF}</math>)</b>						
$V_A$ , $V_D$	Analog and Digital Supply Voltages	$V_A \geq V_D$	<b>4.75</b>	5	<b>5.25</b>	V
$I_A + I_D$	Total Supply Current	$V_A = V_D = 4.75\text{V}$ to $5.25\text{V}$	<b>7</b>	10	<b>15</b>	mA
$P_C$	Power Consumption	$V_A = V_D = 4.75\text{V}$ to $5.25\text{V}$		50	<b>78</b>	mW
<b>PWM OUTPUT CHARACTERISTICS</b>						
$f_{PWM}$	PWM switching frequency			210		kHz
$t_{DEAD}$	Dead time			38		ns

(1) Min and Max limits are 100% production tested at  $25^\circ\text{C}$ . Limits over the operating temperature range are specified through correlation using Statistical Quality Control (SQC) methods. Limits are used to calculate Texas Instrument's Average Outgoing Quality Level (AOQL).

(2) Not tested. Specified by design.

## OPERATION DESCRIPTION

### OVERVIEW

The SM72441 is a programmable MPPT controller capable of outputting four PWM gate drive signals for a 4-switch buck-boost converter. Refer to the Typical Application Circuit diagram (Figure 2).

The SM72441 uses an advanced digital controller to generate its PWM signals. A maximum power point tracking (MPPT) algorithm monitors the input current and voltage and controls the PWM duty cycle to maximize energy harvested from the photovoltaic module. MPPT performance is very fast. Convergence to the maximum power point of the module typically occurs within 0.01s. This enables the controller to maintain optimum performance under fast-changing irradiance conditions.

Transitions between buck, boost, and buck-boost modes are smoothed, and advanced digital PWM dithering techniques are employed to increase effective PWM resolution. Output voltage and current limiting functionality are integrated into the digital control logic. The controller is capable of handling both shorted and no-load conditions and will recover smoothly from both.

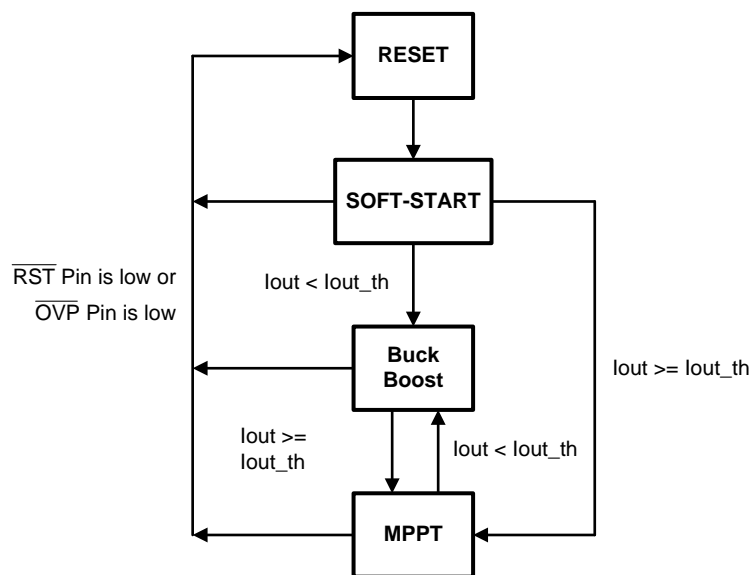
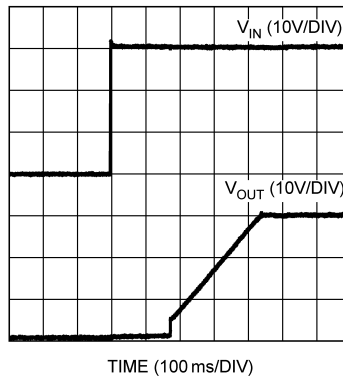


Figure 4. High Level State Diagram for Startup

### STARTUP

SM72441 has a soft start feature that will ramp its output voltage for a fixed time of 250ms. MPPT mode will be entered during soft start if the load current exceeded the minimum current threshold. Otherwise, buck-boost operation is entered after soft-start is finished where the ratio between input and output voltage is 1:1. Refer to Figure 4 for a high level state diagram of startup. The current threshold to transition between MPPT to standby (buck-boost) mode and vice versa can be set by feeding the output of current sensing amplifier (Figure 2) to the AIIN and AIOU pin. For an appropriate voltage level, refer to the **AIIN AND AIOU PIN** section of this datasheet.



**Figure 5. Start-Up Waveforms of Controlled Output**

## MAXIMUM OUTPUT VOLTAGE

Maximum output voltage on the SM72441 is set by resistor divider ratio on pin A0. (Please refer to [Figure 2](#) Typical Application Circuit).

$$V_{OUT\_MAX} = 5 \times \frac{RB1}{RT1 + RB1} \times \frac{(RFB1 + RFB2)}{RFB2} \quad (1)$$

Where RT1 and RB1 are the resistor divider on the ADC pin A0 and RFB1 and RFB2 are the output voltage feedback resistors. A typical value for RFB2 is about 2 kΩ.

## CURRENT LIMIT SETTING

Maximum output current can be set by changing the resistor divider on A4 (pin 18). (Refer to [Figure 2](#) ). Overcurrent at the output is detected when the voltage on AIOUT (pin 21) equals to the voltage on A4 (pin 18). The voltage on A4 can be set by a resistor divider connected to 5V whereas a current sense amplifier output can be used to set the voltage on AIOUT.

## AIIIN AND AIOUT PIN

These two pins are used to set current threshold from standby (buck-boost mode) to MPPT mode and from MPPT mode into standby mode.

In order to transition from standby to MPPT mode, the following conditions have to be satisfied:

- 1) AIIIN and AIOUT voltage > 0.488V
- 2) Iout < Iout\_max

On the other hand, in order to transition from MPPT to standby mode, the following condition have to be satisfied:

- 1) AIIIN and AIOUT voltage < 0.293V
- 2) Iout < Iout\_max

Current limit is triggered when AIOUT (pin 21) voltage is equal to A4 (pin 18).

## AVIN PIN

AVIN pin is an A/D input to sense the input voltage of SM72441. A resistor divider can be used to scale the max voltage to about 4V, which is 80% of the full scale of the A/D input.

## CONFIGURABLE SETTINGS

The voltage on A0 sets the max output voltage; whereas the voltage on A2 enables MPPT update rate and limits the max boost ratio when output current is below the standby threshold. Output current limit is set by the voltage on A4 and output voltage slew rate limit is set on A6. In order to set a slew rate limit of 125V/sec, the ratio of the two resistors in A6 should be 9:1.

The low current condition is detected if the voltage on AIIN is less than 0.488V (rising) and 0.293 (falling) +  $\Delta I$  or if the voltage on AIOU is less than 0.488 V (rising) and 0.293 (falling) +  $\Delta I$ . If low current is detected, the converter operates in standby mode and limit the maximum duty cycle to either a 1 (buck-boost), 1.15 (boost) or 1.25 (boost) conversion ratio (programmable). In this case no MPPT will be performed.

The actual value of current will depend on the gain of the current sensing amplifier circuitry that feeds the AIIN and AIOU pins.

For more complete information on the various settings based on the voltage level of A2, please refer to [Table 1](#) below. Vfs denotes the full scale voltage of the ADC which is equal to VDDA where VDDA is a reference voltage to analog ground.

A typical value for top configuration resistors (RT1 to RT4) should be 20 k $\Omega$ .

**Table 1. List of Configurable Modes on ADC Channel 2**

ADC Channel 2	MPPT Update Time	Slew Rate Detection	Low Current Detection	Initial Boost Ratio	Delta I
$0 < V_{ADC2} < V_{fs}/16$	1.2 ms	Disabled	Disabled	N/A	N/A
$1V_{fs}/16 < V_{ADC2} < 2V_{fs}/16$	38 ms	Disabled	Disabled	N/A	N/A
$2V_{fs}/16 < V_{ADC2} < 3V_{fs}/16$	77 ms	Disabled	Disabled	N/A	N/A
$3V_{fs}/16 < V_{ADC2} < 4V_{fs}/16$	38 ms	Enabled	Disabled	N/A	N/A
$4V_{fs}/16 < V_{ADC2} < 5V_{fs}/16$	38 ms	Enabled	Enabled	1.15	60 (0.3 A)
$5V_{fs}/16 < V_{ADC2} < 6V_{fs}/16$	38 ms	Enabled	Enabled	1.15	90 (0.45 A)
$6V_{fs}/16 < V_{ADC2} < 7V_{fs}/16$	38 ms	Enabled	Enabled	1.15	120(0.6 A)
$7V_{fs}/16 < V_{ADC2} < 8V_{fs}/16$	38 ms	Enabled	Enabled	1.25	60
$8V_{fs}/16 < V_{ADC2} < 9V_{fs}/16$	38 ms	Enabled	Enabled	1.25	90
$9V_{fs}/16 < V_{ADC2} < 10V_{fs}/16$	38 ms	Enabled	Enabled	1.25	120
$10V_{fs}/16 < V_{ADC2} < 11V_{fs}/16$	77 ms	Enabled	Enabled	1.15	60
$11V_{fs}/16 < V_{ADC2} < 12V_{fs}/16$	77 ms	Enabled	Enabled	1.15	90
$12V_{fs}/16 < V_{ADC2} < 13V_{fs}/16$	77 ms	Enabled	Enabled	1.15	120
$13V_{fs}/16 < V_{ADC2} < 14V_{fs}/16$	77 ms	Enabled	Enabled	1.25	60
$14V_{fs}/16 < V_{ADC2} < 15V_{fs}/16$	77 ms	Enabled	Enabled	1.25	90
$15V_{fs}/16 < V_{ADC2} < 16V_{fs}/16$	77 ms	Enabled	Enabled	1.25	120



## RESET PIN

When the reset pin is pulled low, the chip will cease its normal operation and turn-off all of its PWM outputs. Below is an oscilloscope capture of a forced reset condition.

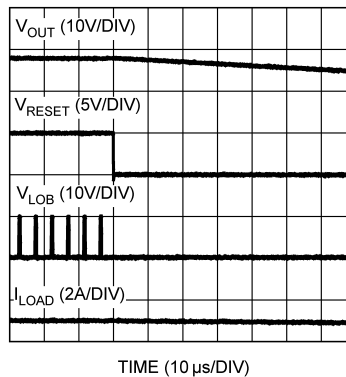


Figure 6. Reset Operational Behavior

As seen in Figure 6, the initial value for output voltage and load current are 28V and 1A respectively. After the reset pin is grounded, both the output voltage and load current decreases immediately. MOSFET switching on the buck-boost converter also stops immediately.  $V_{LOB}$  indicates the low side boost output from the SM72295.

## ANALOG INPUT

An equivalent circuit for one of the ADC input channels is shown in Figure 7. Diode D1 and D2 provide ESD protection for the analog inputs. The operating range for the analog inputs is 0V to  $V_A$ . Going beyond this range will cause the ESD diodes to conduct and result in erratic operation.

The capacitor C1 in Figure 7 has a typical value of 3 pF and is mainly the package pin capacitance. Resistor R1 is the on resistance of the multiplexer and track / hold switch; it is typically 500Ω. Capacitor C2 is the ADC sampling capacitor; it is typically 30 pF. The ADC will deliver best performance when driven by a low-impedance source (less than 100Ω). This is especially important when sampling dynamic signals. Also important when sampling dynamic signals is a band-pass or low-pass filter which reduces harmonic and noise in the input. These filters are often referred to as anti-aliasing filters.

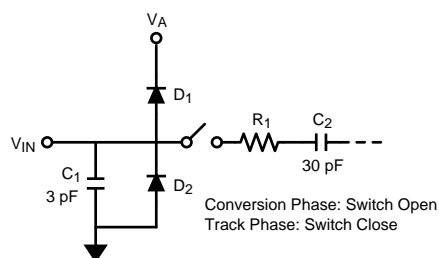


Figure 7. Equivalent Input Circuit

## DIGITAL INPUTS AND OUTPUTS

The digital input signals have an operating range of 0V to  $V_A$ , where  $V_A = V_{DDA} - V_{SSA}$ . They are not prone to latch-up and may be asserted before the digital supply  $V_D$ , where  $V_D = V_{DDD} - V_{SSD}$ , without any risk. The digital output signals operating range is controlled by  $V_D$ . The output high voltage is  $V_D - 0.5V$  (min) while the output low voltage is 0.4V (max).

## REVISION HISTORY

Changes from Revision F (April 2013) to Revision G	Page
• Changed layout of National Data Sheet to TI format .....	<a href="#">9</a>

## PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
SM72441MT/NOPB	ACTIVE	TSSOP	PW	28	48	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR		S72441	<a href="#">Samples</a>
SM72441MTE/NOPB	ACTIVE	TSSOP	PW	28	250	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR		S72441	<a href="#">Samples</a>
SM72441MTX/NOPB	ACTIVE	TSSOP	PW	28	2500	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR		S72441	<a href="#">Samples</a>

(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.

(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side 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 Top-Side Marking for that device.

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## TAPE AND REEL INFORMATION



### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
SM72441MTE/NOPB	TSSOP	PW	28	250	178.0	16.4	6.8	10.2	1.6	8.0	16.0	Q1
SM72441MTX/NOPB	TSSOP	PW	28	2500	330.0	16.4	6.8	10.2	1.6	8.0	16.0	Q1

**TAPE AND REEL BOX DIMENSIONS**

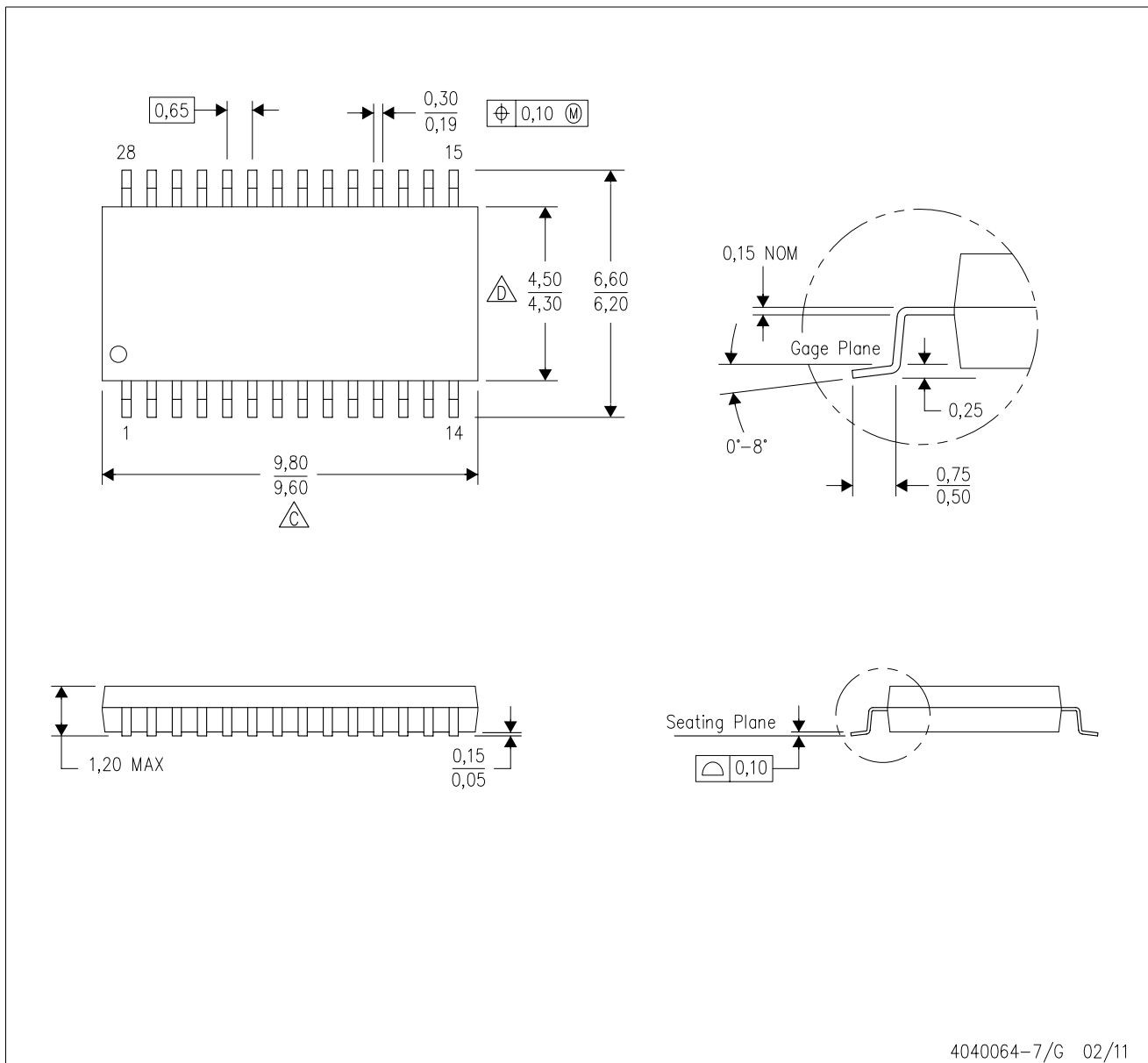

\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
SM72441MTE/NOPB	TSSOP	PW	28	250	213.0	191.0	55.0
SM72441MTX/NOPB	TSSOP	PW	28	2500	367.0	367.0	38.0



# MECHANICAL DATA

PW (R-PDSO-G28)

PLASTIC SMALL OUTLINE



4040064-7/G 02/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - B. This drawing is subject to change without notice.
  -  C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
  -  D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
  - E. Falls within JEDEC MO-153

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Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
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