National Semiconductor

June 1, 2011

# SM72441

# Programmable Maximum Power Point Tracking Controller for Photovoltaic Solar Panels

## General 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.

## 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

SolarMagic™ by National Semiconductor

## Block Diagram

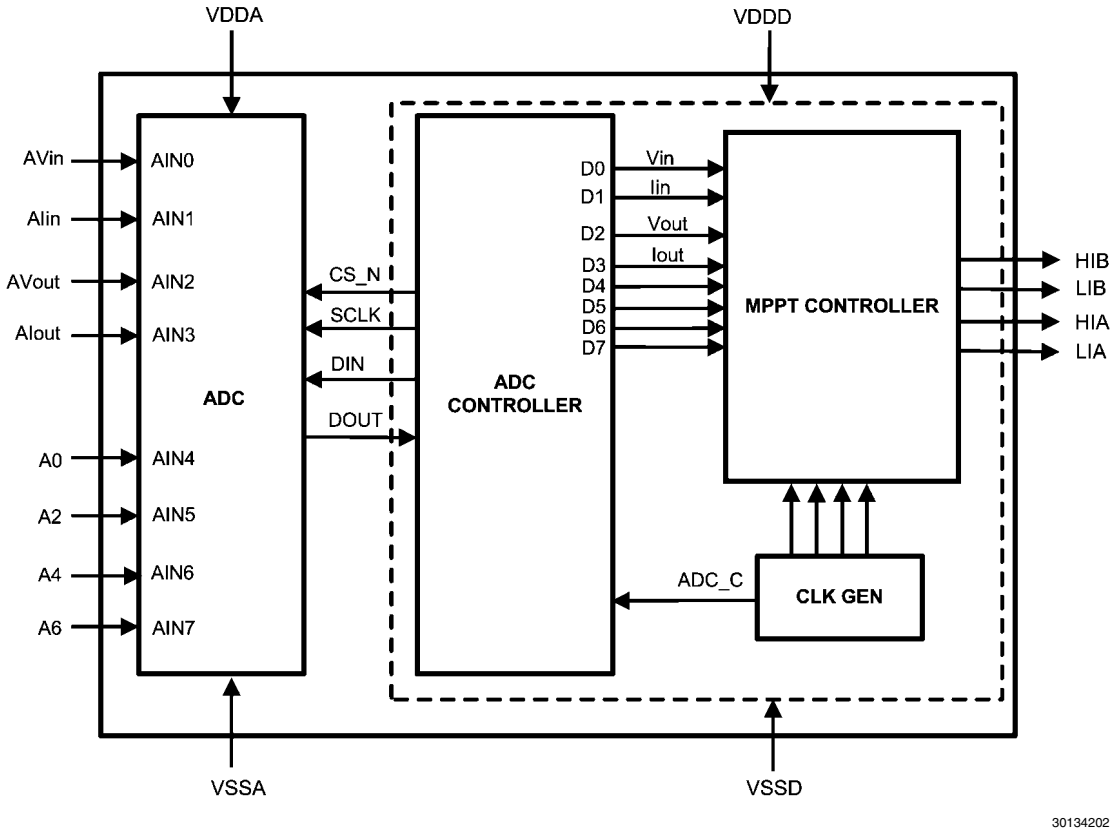



**FIGURE 1. Block Diagram**

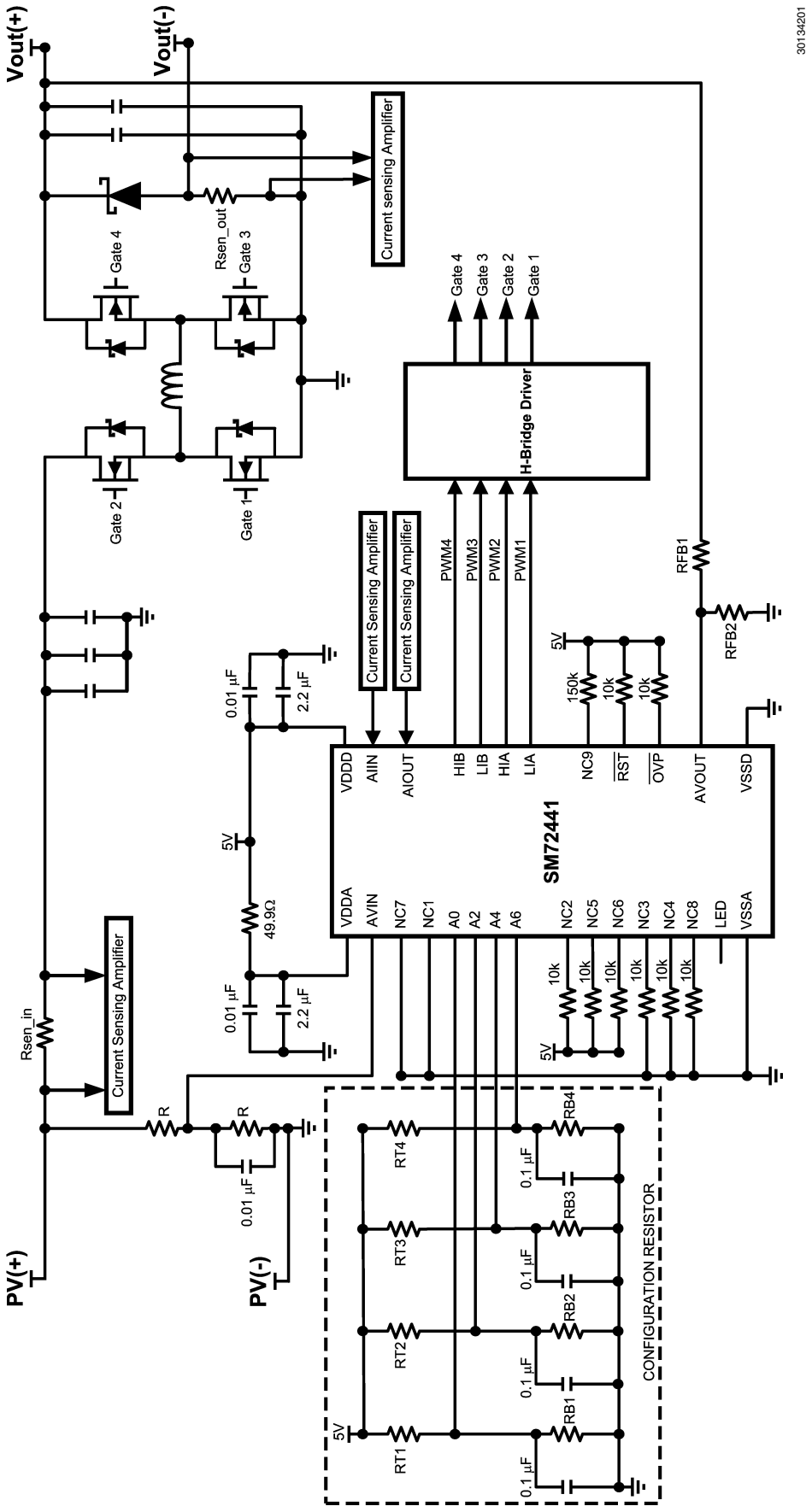
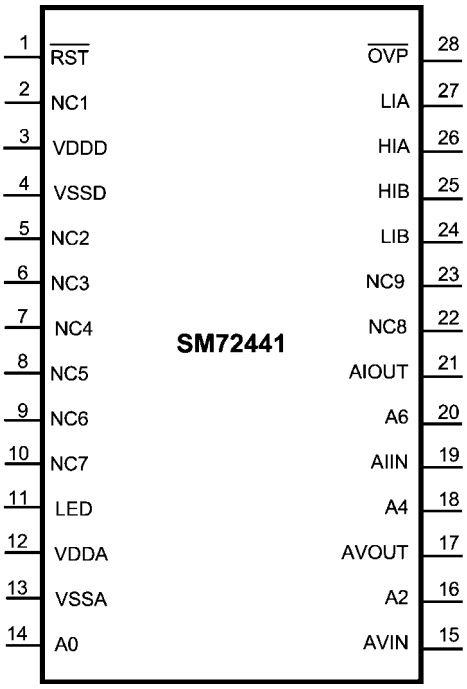



**FIGURE 2. Typical Application Circuit**

## Connection Diagram

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**Top View**
**TSSOP-28**

## Ordering Information

| Order Number | Description | NSC Package Drawing | Supplied As | Package Top Mark |
|---|---|---|---|---|
| SM72441MTX | TSSOP-28 | MTC28 | 2500 Units in Tape and Reel | S72441 |
| SM72441MTE | TSSOP-28 | MTC28 | 250 Units in Tape and Reel | S72441 |
| SM72441MT | TSSOP-28 | MTC28 | 48 Units in rail | S72441 |

## Pin Descriptions

| Pin | Name | Description |
|---|---|---|
| 1 | $\overline{RST}$ | 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. |
| 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 | $\overline{OVP}$ | Overvoltage Protection Pin. Active Low. SM72441 will reset once voltage on this pin drops below its threshold voltage. |

## Absolute Maximum Ratings (*Note 1*)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| 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<br>max 6.0V |
| Voltage on Any Pin to GND | -0.3 to $V_A$ +0.3V |
| Input Current at Any Pin (Note 3) | ±10 mA |
| Package Input Current (Note 3) | ±20 mA |
| Storage Temperature Range | -65°C to +150°C |
| ESD Rating (*Note 2*) | |
| Human Body Model | 2 kV |

## 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 |

Specifications in standard typeface are for $T_J$ = 25°C, and those in boldface type apply over the full operating junction temperature range.(*Note 3*)

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

**Note 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 guaranteed. Operating Ratings indicate conditions for which the device is intended to be functional, but does not guarantee specific performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

**Note 2:** The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

**Note 3:** Min and Max limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. Limits are used to calculate National's Average Outgoing Quality Level (AOQL).

**Note 4:** Not tested. Guaranteed 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. The typical application circuit is shown in *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.

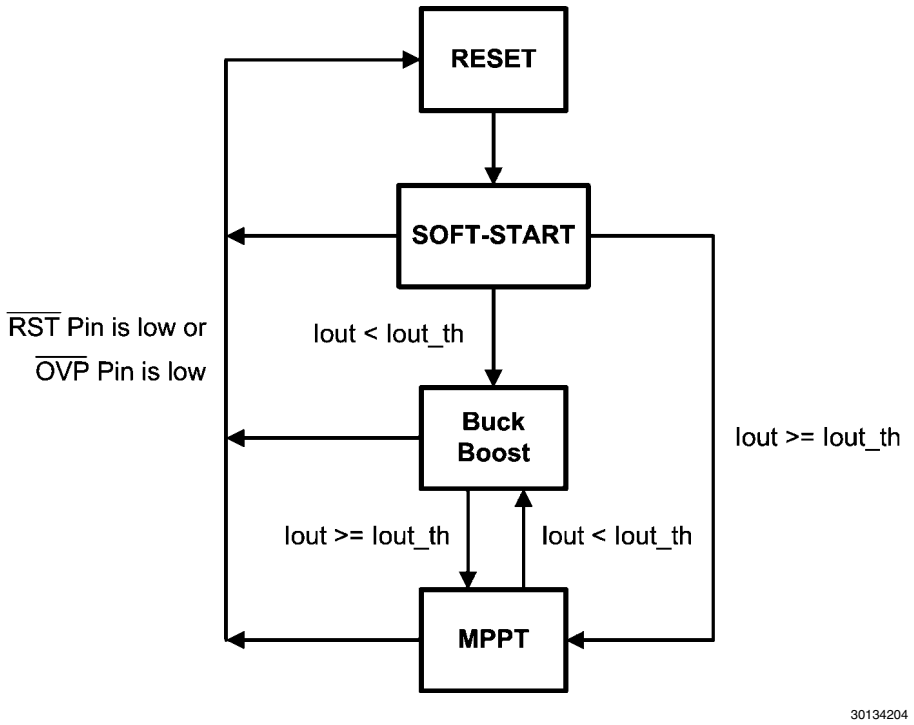



**FIGURE 3. High Level State Diagram for Startup**

## 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 3* 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 AIOUT pin. For an appropriate voltage level, refer to AIIN and AIOUT section of this datasheet.

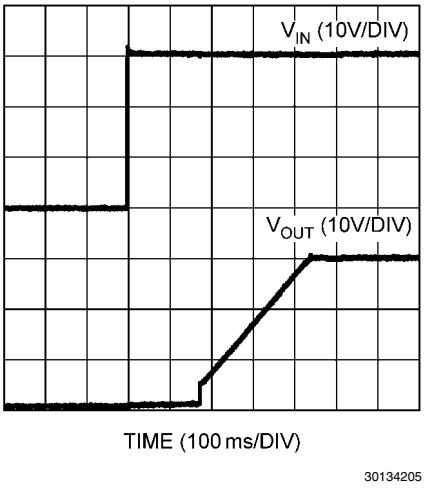



**FIGURE 4. Start-Up Waveforms of Controlled Output**

## 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).

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

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.

## AIIN 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) AIIN 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) AIIN 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) + ΔI or if the voltage on AIOUT is less than 0.488 V (rising) and 0.293 (falling) + ΔI. 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 AIOUT 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 kΩ.

**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 < VADC2 < Vfs/16 | 1.2 ms | Disabled | Disabled | N/A | N/A |
| 1Vfs/16 < VADC2 <2Vfs/16 | 38 ms | Disabled | Disabled | N/A | N/A |
| 2Vfs/16 < VADC2 <3Vfs/16 | 77 ms | Disabled | Disabled | N/A | N/A |
| 3Vfs/16 < VADC2 <4Vfs/16 | 38 ms | Enabled | Disabled | N/A | N/A |
| 4Vfs/16 < VADC2 <5Vfs/16 | 38 ms | Enabled | Enabled | 1.15 | 60 (0.3 A) |
| 5Vfs/16 < VADC2 <6Vfs/16 | 38 ms | Enabled | Enabled | 1.15 | 90 (0.45 A) |
| 6Vfs/16 < VADC2 <7Vfs/16 | 38 ms | Enabled | Enabled | 1.15 | 120(0.6 A) |
| 7Vfs/16 < VADC2 <8Vfs/16 | 38 ms | Enabled | Enabled | 1.25 | 60 |
| 8Vfs/16 < VADC2 <9Vfs/16 | 38 ms | Enabled | Enabled | 1.25 | 90 |
| 9Vfs/16 < VADC2 <10Vfs/16 | 38 ms | Enabled | Enabled | 1.25 | 120 |
| 10Vfs/16 < VADC2 <11Vfs/16 | 77 ms | Enabled | Enabled | 1.15 | 60 |
| 11Vfs/16 < VADC2 <12Vfs/16 | 77 ms | Enabled | Enabled | 1.15 | 90 |
| 12Vfs/16 < VADC2 <13Vfs/16 | 77 ms | Enabled | Enabled | 1.15 | 120 |
| 13Vfs/16 < VADC2 <14Vfs/16 | 77 ms | Enabled | Enabled | 1.25 | 60 |
| 14Vfs/16 < VADC2 <15Vfs/16 | 77 ms | Enabled | Enabled | 1.25 | 90 |
| 15Vfs/16 < VADC2 <16Vfs/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.

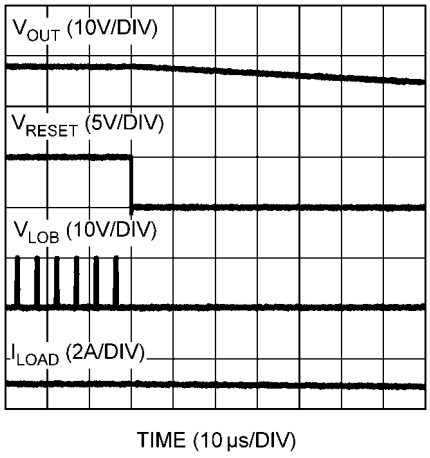



**FIGURE 5. Reset Operational Behavior**

As seen in *Figure 5*, 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 6*. 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 6* 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; itis 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.

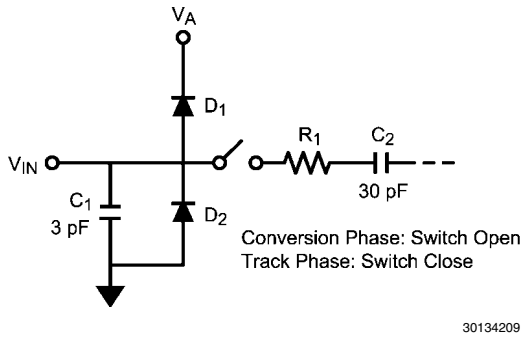
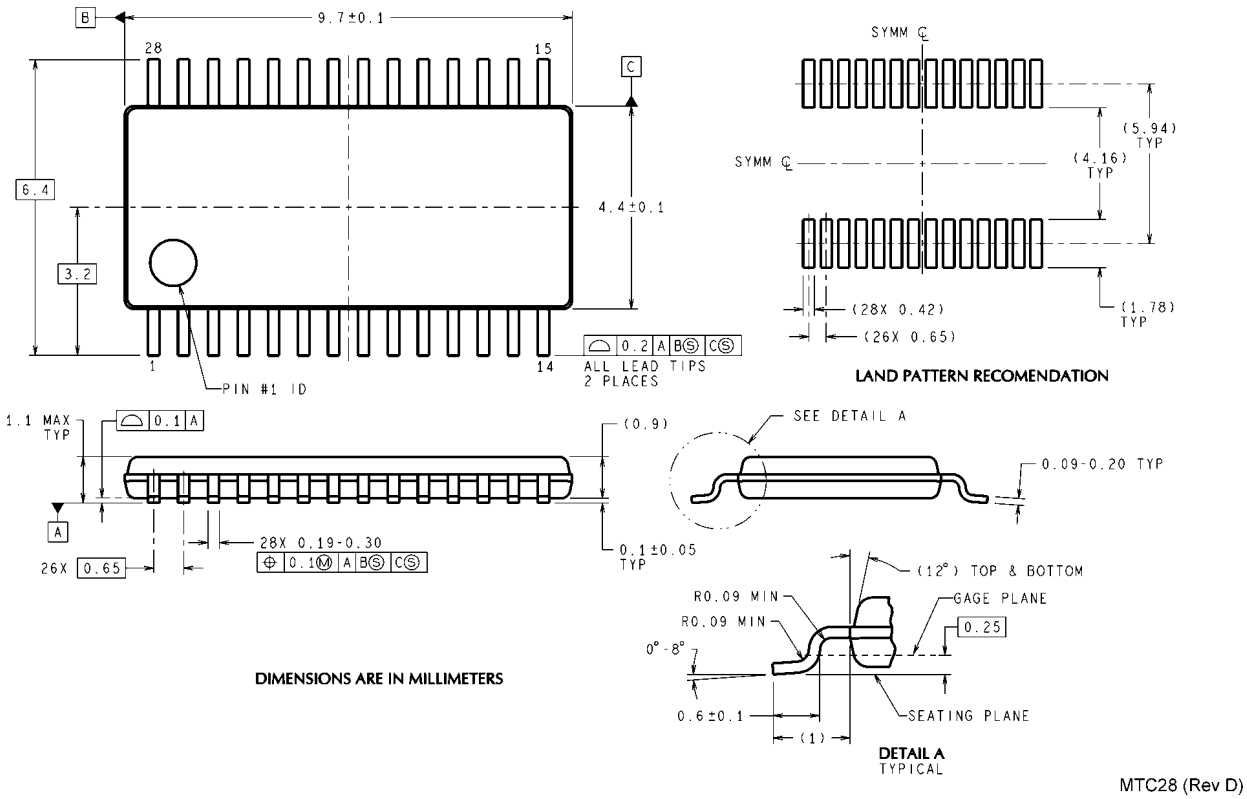



**FIGURE 6. Equivalent Input Circuit**

## DIGITAL INPUTS and OUTPUTS

The digital input signals have an operating range of 0V to $V_A$, where $V_A$ = VDDA - VSSA. They are not prone to latch-up and may be asserted before the digital supply $V_D$, where $V_D$ = VDDD - VSSD, 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).

## Physical Dimensions inches (millimeters) unless otherwise noted




MTC28 (Rev D)

**NS Package Drawing MTC28**

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