

### DESCRIPTION

The MP86933 is a monolithic, half-bridge driver with built-in, internal power MOSFETs and gate drivers. The MP86933 achieves 12A of continuous output current over a wide input supply range and can operate from 100kHz to 2MHz.

The integration of a driver and MOSFETs results in high efficiency due to an optimal dead time and parasitic inductance reduction.

The MP86933 works with tri-state output controllers and comes with a general-purpose current sense and temperature sense.

The MP86933 is ideal for server and telecom applications where efficiency and small size are a premium. The MP86933 is available in a small FC-TQFN-13 (3mmx3mm) package.

### FEATURES

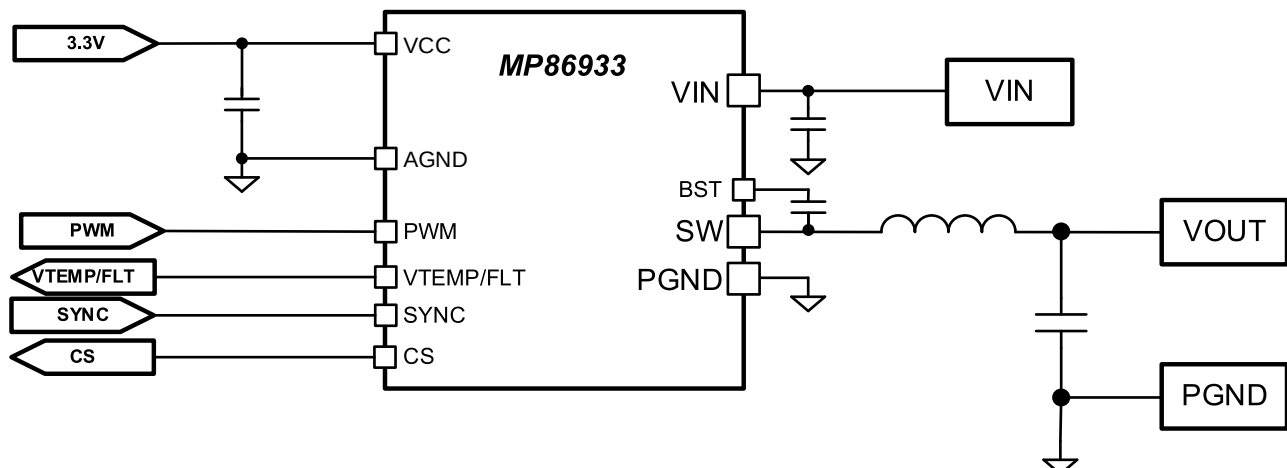
- Wide 4.5V to 16V Operating Input Range
- Compliant with Intel DrMOS V4.0 Spec
- 12A Output Current
- Accepts Tri-State PWM Signal
- Built-In Switch for Bootstrap
- Current Sense
- Temperature Sense
- Current-Limit Protection
- Over-Temperature Protection (OTP)
- Fault Reporting: Over-Current and Over-Temperature
- Used for Multi-Phase Operation
- Available in a TQFN-13 (3mmx3mm) Package

### APPLICATIONS

- Server and Telecom Voltage Regulators
- Graphic Card Core Regulators
- Power Modules

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### TYPICAL APPLICATION



## ORDERING INFORMATION

| Part Number* | Package           | Top Marking |
|--------------|-------------------|-------------|
| MP86933GQT   | TQFN-13 (3mmx3mm) | See Below   |

\* For Tape & Reel, add suffix -Z (e.g. MP86933GQT-Z)

## TOP MARKING

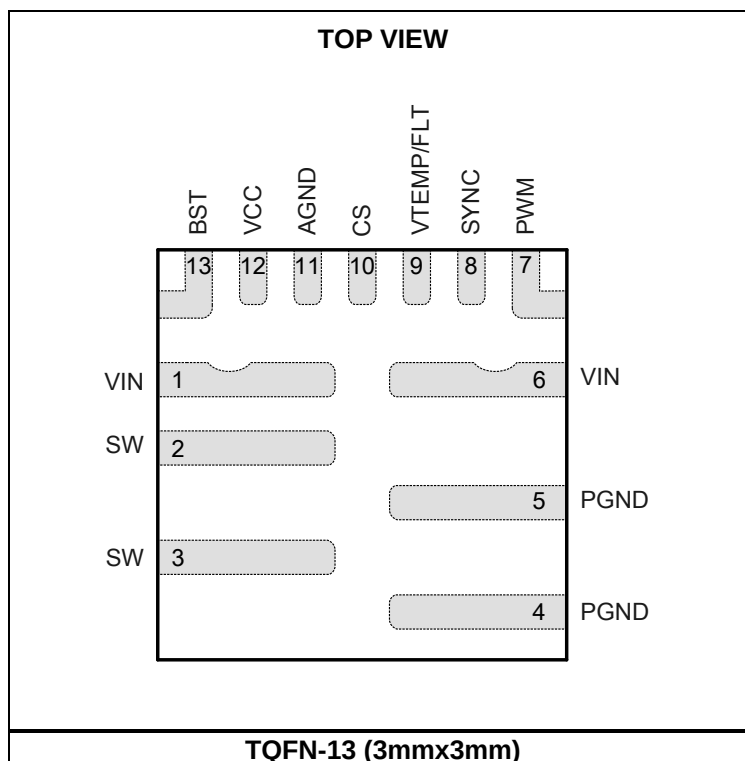
**AQLY**  
**LLL**

AQL: Product code of MP86933GQT

Y: Year code

LLL: Lot number

## PACKAGE REFERENCE



## ABSOLUTE MAXIMUM RATINGS <sup>(1)</sup>

|                                                |                      |
|------------------------------------------------|----------------------|
| Supply voltage (VIN) .....                     | 18V                  |
| V <sub>SW</sub> (DC) .....                     | -0.3V to VIN + 0.3V  |
| V <sub>SW</sub> (25ns).....                    | -3V to 25V           |
| VIN - V <sub>SW</sub> (10ns) .....             | -5V to 32V           |
| V <sub>BST</sub> - V <sub>SW</sub> (25ns)..... | 5V                   |
| V <sub>BST</sub> .....                         | V <sub>SW</sub> + 4V |
| All other pins .....                           | -0.3V to +4V         |
| Instantaneous current .....                    | 25A                  |
| Junction temperature .....                     | 150°C                |
| Lead temperature .....                         | 260°C                |
| Storage temperature .....                      | -65°C to +150°C      |

## Recommended Operating Conditions <sup>(2)</sup>

|                                               |                 |
|-----------------------------------------------|-----------------|
| Supply voltage (VIN) .....                    | 4.5V to 16V     |
| Driver voltage (VCC).....                     | 3.0V to 3.6V    |
| Operating junction temp. (T <sub>J</sub> )... | -40°C to +125°C |

|                                          |                                 |                                      |
|------------------------------------------|---------------------------------|--------------------------------------|
| <b>Thermal Resistance <sup>(3)</sup></b> | <b><math>\theta_{JB}</math></b> | <b><math>\theta_{JC\_TOP}</math></b> |
| TQFN-13 (3mmx3mm) .....                  | 5.2 .....                       | 42.9... °C/W                         |

### NOTES:

- 1) Exceeding these ratings may damage the device.
- 2) The device is not guaranteed to function outside of its operating conditions.
- 3)  $\theta_{JB}$  is the thermal resistance from the junction to the board around the PGND soldering point.  
 $\theta_{JC\_TOP}$  is the thermal resistance from junction to the top of the package.

## ELECTRICAL CHARACTERISTICS

VIN = 12V, VCC = 3.3V, TA = 25°C, unless otherwise noted.

| Parameter                                                  | Symbol        | Condition                                   | Min  | Typ  | Max  | Units |
|------------------------------------------------------------|---------------|---------------------------------------------|------|------|------|-------|
| VIN under voltage lockout threshold rising                 |               |                                             |      | 4.1  | 4.5  | V     |
| VIN under voltage lockout threshold hysteresis             |               |                                             |      | 380  |      | mV    |
| VIN quiescent current in standby mode                      | IIN Stby      | PWM = Hi-Z, SYNC = Hi-Z, VIN = 4.5V to 22V  |      |      | 1    | μA    |
| VCC quiescent current in active mode                       | ICC Quiescent | PWM = low, no switching, SYNC = high or low |      |      | 3    | mA    |
| VCC quiescent current in standby mode                      | ICC Stby      | SYNC = Hi-Z                                 |      |      | 30   | μA    |
| VCC voltage UVLO rising                                    |               |                                             | 2.5  | 2.7  | 2.9  | V     |
| VCC voltage UVLO hysteresis                                |               |                                             |      | 200  |      | mV    |
| High-side current limit                                    | ILIM_FLT      |                                             |      | 25   |      | A     |
| High-side current limit shutdown counter <sup>(4)</sup>    |               |                                             |      | 4    |      | Times |
| Low-side current limit <sup>(4)</sup>                      |               |                                             |      | -5   |      | A     |
| Low-side off time in negative current limit <sup>(4)</sup> |               |                                             |      | 40   |      | ns    |
| Dead-time rising <sup>(4)</sup>                            |               |                                             |      | 3    |      | ns    |
| Dead-time falling <sup>(4)</sup>                           |               | Positive inductor current                   |      | 8    |      | ns    |
|                                                            |               | Negative inductor current                   |      | 40   |      | ns    |
| SYNC logic high voltage                                    |               |                                             | 2.40 |      |      | V     |
| SYNC tri-state region                                      |               |                                             | 1.3  |      | 1.7  | V     |
| SYNC logic low voltage                                     |               |                                             |      |      | 0.70 | V     |
| PWM high to SW rising delay <sup>(4)</sup>                 | tRising       |                                             |      | 20   |      | ns    |
| PWM low to SW falling delay <sup>(4)</sup>                 | tFalling      |                                             |      | 20   |      | ns    |
| PWM tri-state to SW Hi-Z delay <sup>(54)</sup>             | tLo-HiZ       |                                             |      | 50   |      | ns    |
|                                                            | tHiZ-Lo       |                                             |      | 50   |      | ns    |
|                                                            | tHiZ-Hi       |                                             |      | 50   |      | ns    |
| Minimum SW pulse width <sup>(4)</sup>                      |               |                                             |      | 30   |      | ns    |
| Current sense gain accuracy                                |               | 5A ≤ ISW ≤ 15A                              | -3   | 0    | 3    | %     |
| Current sense gain                                         |               |                                             |      | 10   |      | μA/A  |
| Current sense offset                                       |               | IOUT = 0A                                   | -5   | 0    | 5    | μA    |
|                                                            |               | SW Hi-Z                                     | -2   | 0    | 2    | μA    |
| Current sense common mode voltage range                    | VCS_COM       |                                             | 0.8  |      | 2.0  | V     |
| Temperature sense gain <sup>(4)</sup>                      |               |                                             |      | 10   |      | mV/°C |
| Temperature sense offset <sup>(4)</sup>                    |               |                                             |      | -100 |      | mV    |
| Temperature sense voltage range <sup>(4)</sup>             |               | T = 150°C                                   |      | 1.4  |      | V     |
|                                                            |               | T = 100°C                                   |      | 0.90 |      | V     |
|                                                            |               | T = 25°C                                    |      | 0.15 |      | V     |

# ELECTRICAL CHARACTERISTICS *(continued)*

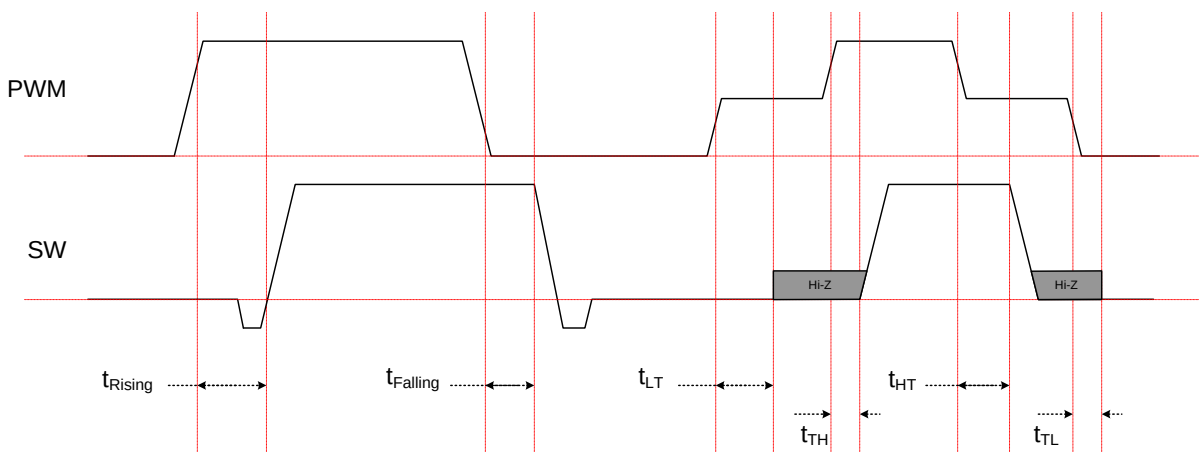
VIN = 12V, VCC = 3.3V, TA = 25°C, unless otherwise noted.

| Parameter                                | Symbol | Condition                   | Min  | Typ | Max | Units |
|------------------------------------------|--------|-----------------------------|------|-----|-----|-------|
| Over-temperature shutdown <sup>(4)</sup> |        |                             |      | 160 |     | °C    |
| OTP threshold hysteresis <sup>(4)</sup>  |        |                             |      | 20  |     | C     |
| VTEMP during fault <sup>(4)</sup>        |        |                             | 3.0  | 3.3 |     | V     |
| PWM resistor                             |        | Pull up, SYNC = low or high |      | 6   |     | kΩ    |
|                                          |        | Pull down                   |      | 5   |     | kΩ    |
| PWM logic high voltage                   |        |                             | 2.30 |     |     | V     |
| PWM tri-state region                     |        |                             | 1.1  |     | 1.9 | V     |
| PWM logic low voltage                    |        |                             |      |     | 0.7 | V     |

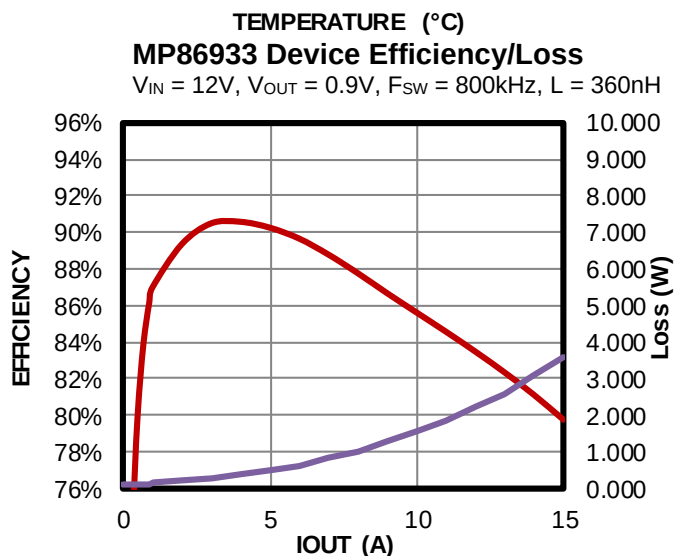
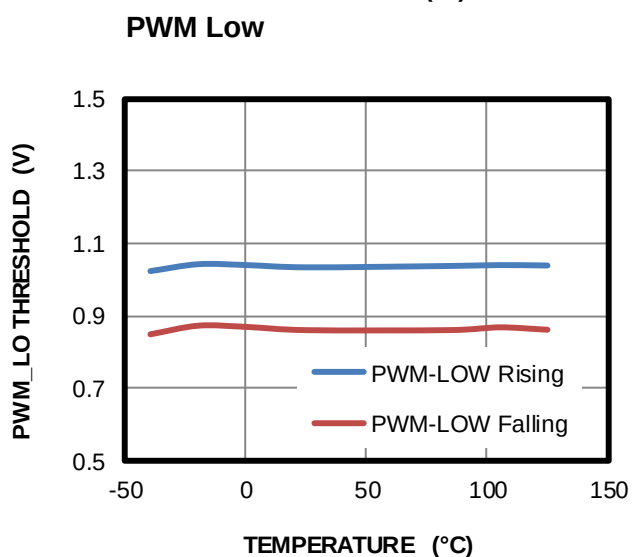
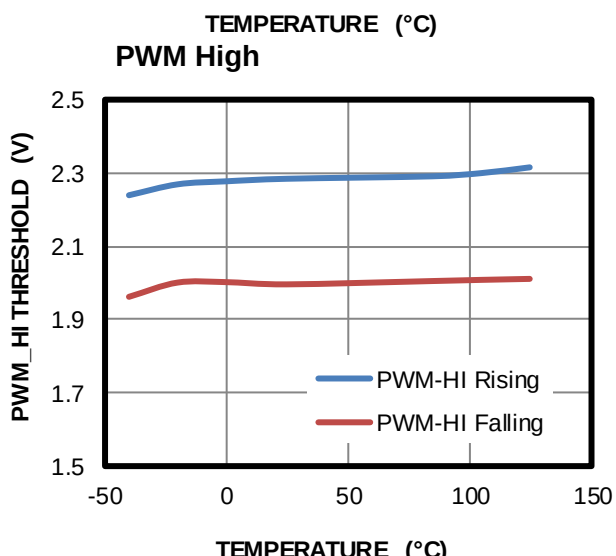
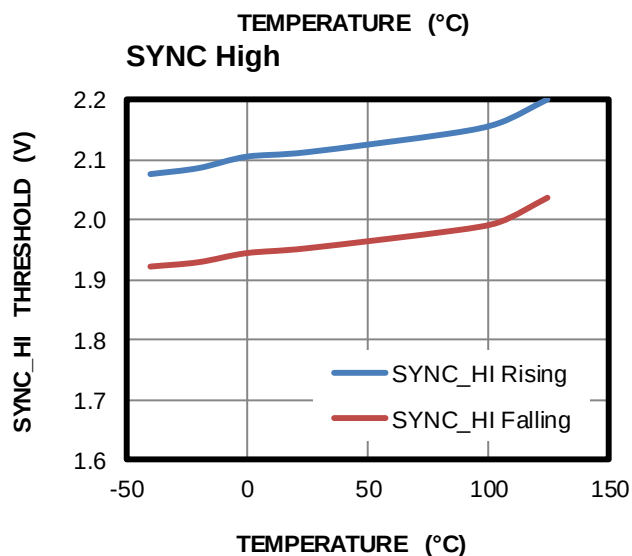
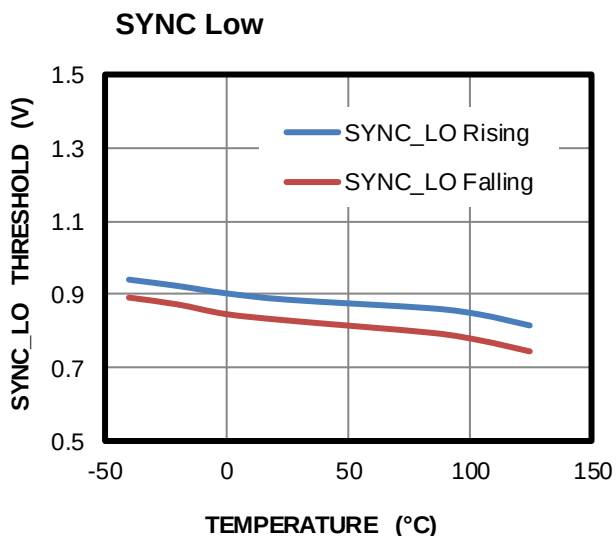
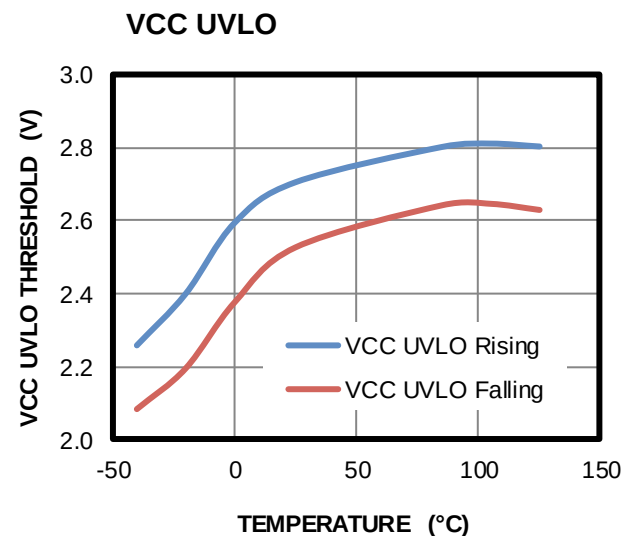
## NOTE:

4) Guaranteed by design, not tested in production. The parameter is tested during parameters characterization.

# PWM TIMING CHART

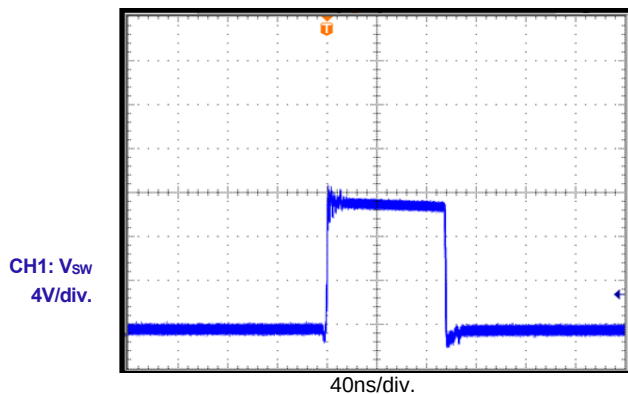


# TYPICAL PERFORMANCE CHARACTERISTICS

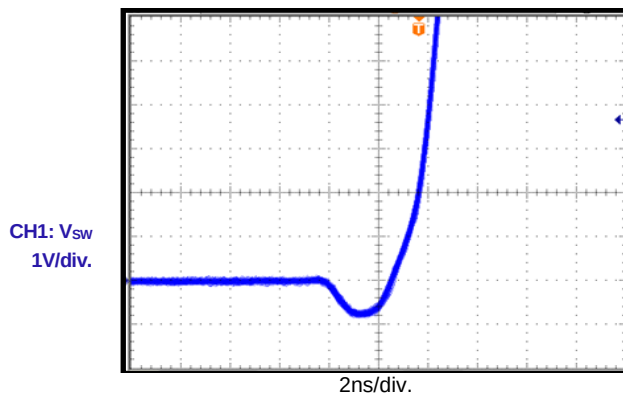


# TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

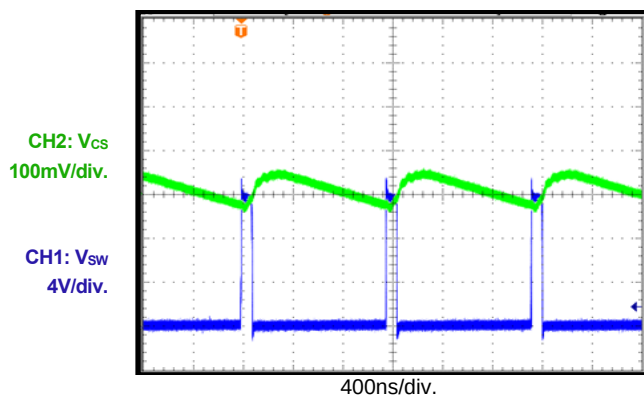
## Switching Waveform

 $V_{IN} = 12A$ ,  $L = 150nH$ ,  $I_{OUT} = 6A$ 


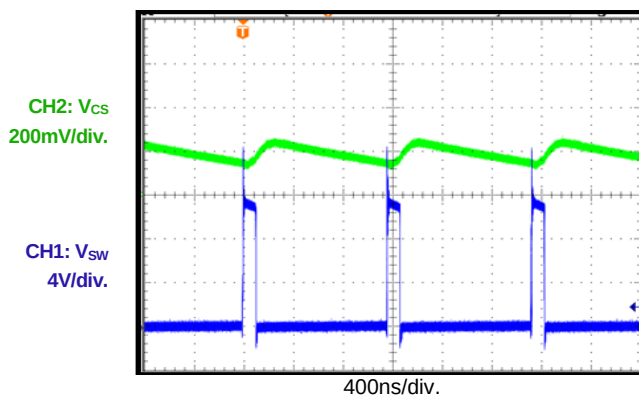
## Dead Time @ SW Rising

 $I_{OUT} = 10A$ 


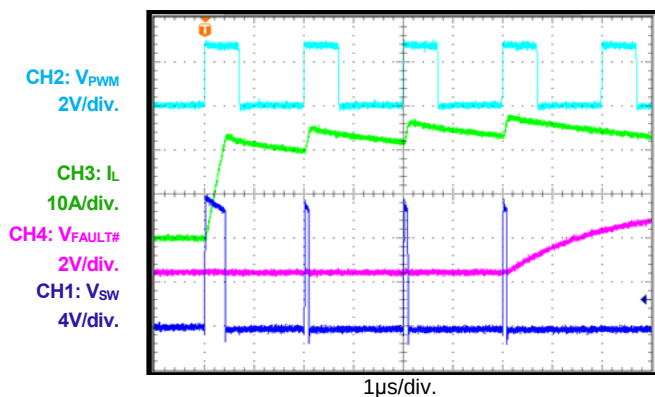
## CS Output Waveform

 $I_{OUT} = 0A$ 


## CS Output Waveform

 $I_{OUT} = 12A$ 


## HS Current Limit



## PIN FUNCTIONS

| Pin # | Name      | Description                                                                                                                                                                                                                                 |
|-------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1, 6  | VIN       | <b>Supply voltage.</b> Place a capacitor ( $C_{IN}$ ) close to the device to support the switching current reducing voltage spikes at the input.                                                                                            |
| 2, 3  | SW        | <b>Switch output.</b>                                                                                                                                                                                                                       |
| 4, 5  | PGND      | <b>Power ground.</b> Place multiple vias on the inner solid ground layers to minimize parasitic impedance and thermal resistance.                                                                                                           |
| 7     | PWM       | <b>Pulse-width modulation input.</b> Leave PWM floating or drive PWM to middle-state to enable diode emulation mode.                                                                                                                        |
| 8     | SYNC      | <b>Diode emulation mode and standby mode selection.</b> Leave SYNC floating or drive SYNC to middle-state to enter standby mode. Pull SYNC high for normal operation. Pull SYNC low to enable diode emulation mode.                         |
| 9     | VTEMP/FLT | <b>Single pin temperature sense and fault reporting.</b>                                                                                                                                                                                    |
| 10    | CS        | <b>Current sense output.</b>                                                                                                                                                                                                                |
| 11    | AGND      | <b>Analog ground.</b> Connect AGND to the PGND plane at the VCC decoupling capacitor.                                                                                                                                                       |
| 12    | VCC       | <b>3.3V supply input for internal circuitry and gate driver.</b> Decouple VCC with a ceramic capacitor ( $1\mu\text{F}$ or higher) to AGND.                                                                                                 |
| 13    | BST       | <b>Bootstrap.</b> BST requires a $0.1\mu\text{F}$ to $1\mu\text{F}$ capacitor to drive the power switch's gate above the supply voltage. Connect the capacitor between SW and BST to form a floating supply across the power switch driver. |



## BLOCK DIAGRAM

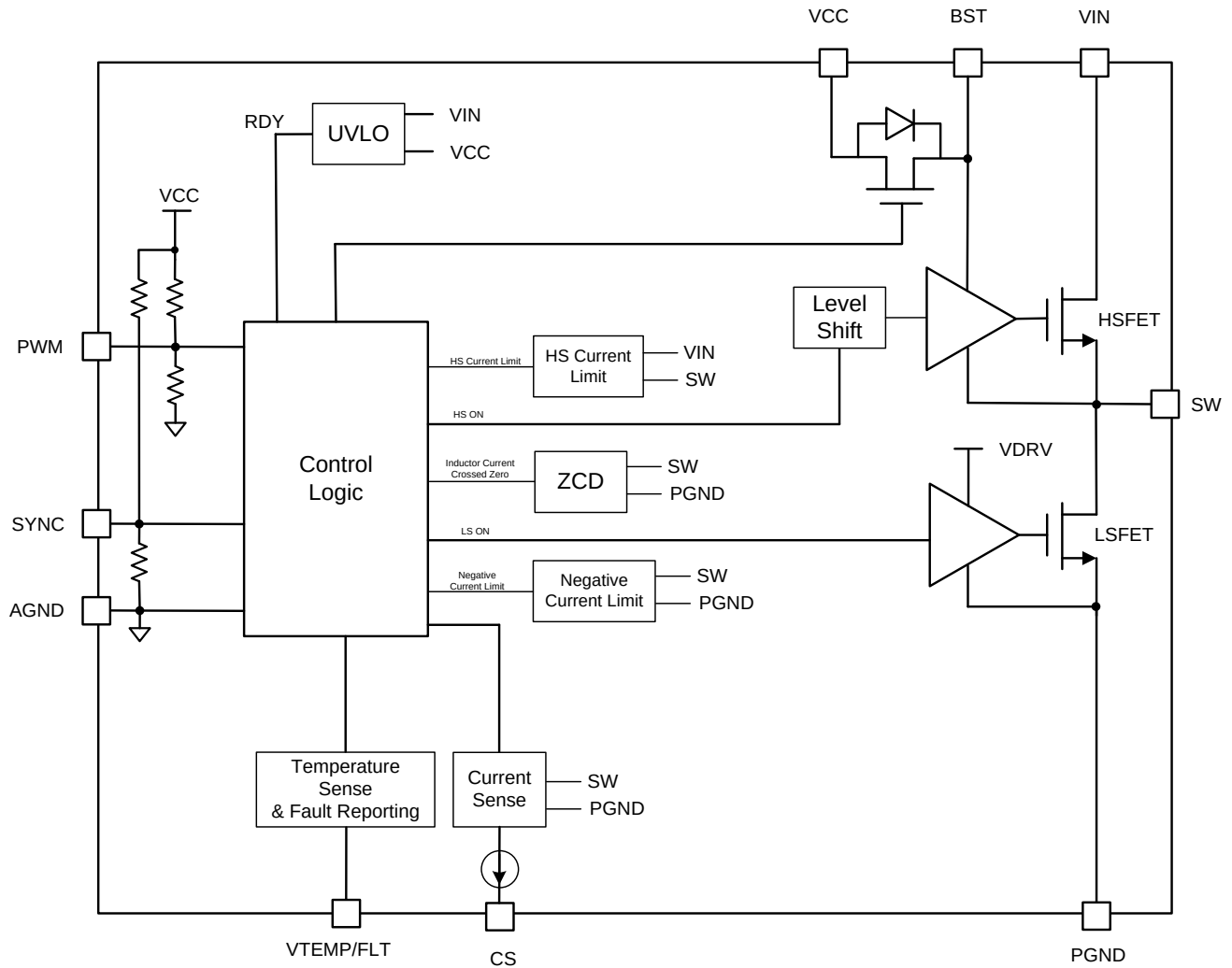


Figure 1: Functional Block Diagram

## OPERATION

The MP86933 is a 12A, monolithic, half-bridge driver with MOSFETs ideally suited for multi-phase buck regulators.

Operation begins when VIN, VCC, and V<sub>BST</sub> signals are sufficiently high.

### Pulse-Width Modulation (PWM)

The PWM input pin is capable of tri-state input. When the PWM input signal is within the tri-state threshold window for 50ns, typically ( $T_{HT}$  or  $T_{LT}$ ), the high-side MOSFET (HS-FET) is turned off immediately, and the low-side MOSFET (LS-FET) is in diode emulation mode, which is on until zero-current detection. The tri-state PWM input can be from a forced middle voltage PWM signal or made by floating the PWM input, and the internal current source charges the signal to a middle voltage. Please refer to the PWM timing diagram for the propagation delay definition from PWM to the SW node.

### Standby Mode

When SYNC is floating or forced to a middle-state voltage for 2 $\mu$ s, the MP86933 enters standby mode. In standby mode, the part shuts down, and both the CS and VTEMP/FLT outputs are disabled. The fault latch cannot be reset by entering standby mode.

### Diode Emulation Mode

In diode emulation mode, when PWM is either low or in a tri-state input, the LS-FET is turned on whenever the inductor current is positive. The LS-FET is off if the inductor current crosses the zero current. Diode emulation mode can be enabled by pulling SYNC low, driving PWM to middle state, or floating PWM.

### Positive and Negative Inductor Current Limit

When HS-FET over-current is detected for four consecutive cycles, the HS-FET latches off, VTEMP/FLT is pulled to 3.3V, and the LS-FET turns on until zero-current detection. Recycle VIN/VCC or toggle EN to release the latch and restart the device.

When the LS-FET detects a -5A current, the MP86933 turns off the LS-FET for 40ns to limit the negative current. The LS-FET's negative current limit will not trigger a fault report.

### Over-Temperature Protection (OTP)

When the junction temperature reaches the over-temperature threshold, the HS-FET latches off, VTEMP/FLT is pulled to 3.3V, and the LS-FET turns on until zero-current detection.

### Temperature Sense Output with Fault Indicator (VTEMP/FLT)

VTEMP/FLT is a pin with dual functions.

- 1) Junction Temperature Sense: VTEMP/FLT is a voltage output proportional to the junction temperature whenever VCC is higher than its UVLO and is in active mode. The gain is 10mV/°C with a -100mV offset at 25°C (i.e.: 0V @  $T_J < 10^\circ\text{C}$ , 0.15V @  $T_J = 25^\circ\text{C}$  and 0.9V @  $T_J = 100^\circ\text{C}$ ).
- 2) Fault Function: When any fault occurs, VTEMP/FLT is pulled to 3.3V, typically (3.0V minimum) regardless of the temperature to report the fault event. VTEMP/FLT monitors three fault events.
  - i. Over-Current Limit: To trip the over-current fault, the current limit must be exceeded four consecutive times. Once the fault occurs, the MP86933 latches off to turn the HS-FET off. The LS-FET is turned off when the inductor current reaches zero.
  - ii. Over-Temperature Fault at  $T_J > 160^\circ\text{C}$ : Once the fault occurs, the MP86933 latches off to turn the HS-FET off. The LS-FET is turned off when the inductor current reaches zero.
  - iii. SW to PGND Short: Once the fault occurs, the MP86933 latches off to turn the HS-FET off.

The fault latch cannot be reset by entering standby mode. The fault latch can be released by recycling either VIN or VCC.

### Current Sense Output (CS)

CS is a bidirectional current source proportional to the inductor current. The current sensing gain is 10μA/A. A resistor is used to program the voltage gain proportional to the inductor current if needed.

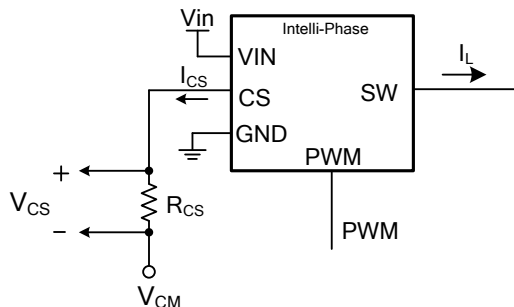
The CS output has two states (see Table 1). In standby mode, the CS circuit is disabled and needs 20μs to wake up and enter active mode if needed.

**Table 1: CS Output States**

| PWM | SYNC             | CS      |
|-----|------------------|---------|
| PWM | High             | Active  |
| PWM | High             | Active  |
| PWM | Low              | Active  |
| x   | Hi-Z (or middle) | Standby |

The CS voltage range of 0.7V to 2.1V is required to obtain an accurate CS current output up to +500μA/-200μA (i.e.: +50A/-12A). Generally, there is a resistor ( $R_{CS}$ ) connected from CS to an external voltage which is capable of sinking small currents to provide enough of a voltage level to meet the required operating voltage range.

Figure 2 shows the typical circuit diagram of the CS connection to achieve a differential voltage source reflected in the inductor current.



**Figure 2: Typical Circuit Diagram for CS Connection**

To keep  $V_{CS}$  within the operating range, design  $R_{CS}$  with Equation (1) and Equation (2):

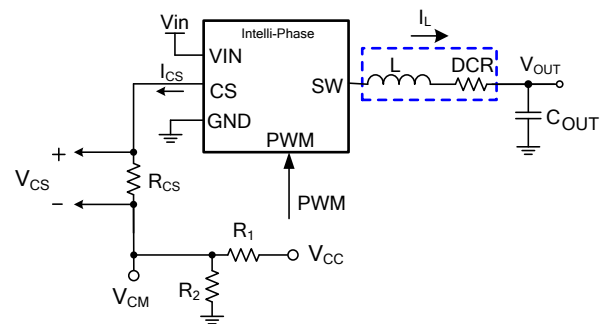
$$0.7V < I_{CS} \times R_{CS} + V_{CM} < 2.1V \quad (1)$$

$$I_{CS} = I_L \times G_{CS} \quad (2)$$

Where  $V_{CM}$  is the reference voltage connected to  $R_{CS}$ .

$V_{CM}$  can be from a voltage divider from 3.3V (i.e.: VCC) (see Figure 3).

Make  $R_{CS}$  much larger than  $R_1$  parallel to  $R_2$  to minimize  $V_{CM}$  variation over  $I_{CS}$ .



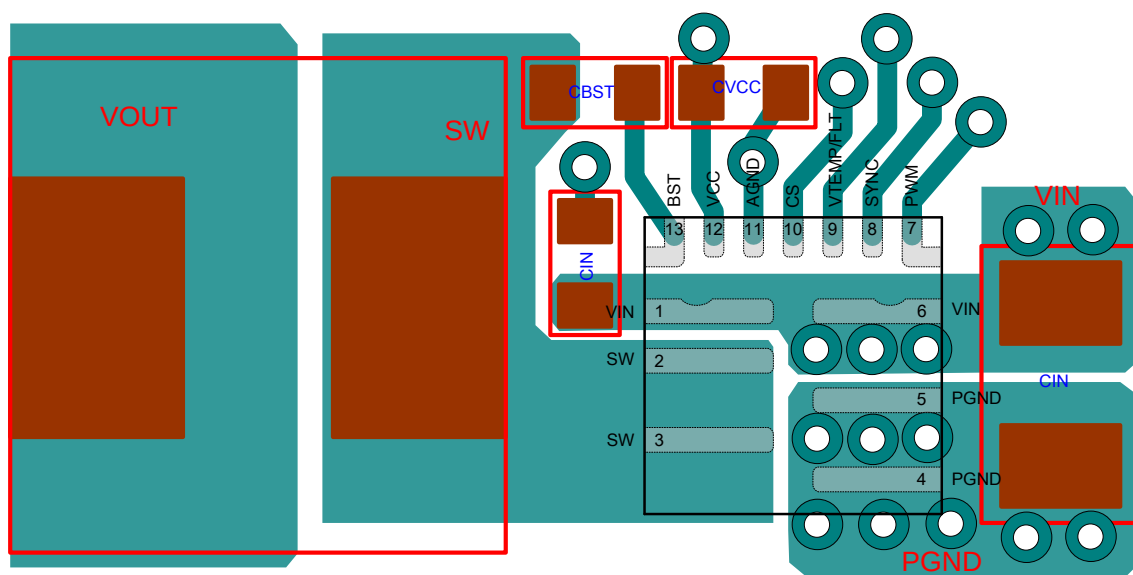
**Figure 3: Use VCC to Generate  $V_{CM}$  for CS Signal**

## APPLICATION INFORMATION

### PCB Layout Guidelines

Efficient PCB layout is critical for stable operation. For best performance, refer to Figure 4 and follow the guidelines below.

1. Place the input MLCC capacitors as close to VIN and PGND as possible.
2. Place the major MLCC capacitors on the same layer as the MP86933.
3. Maximize the VIN and PGND copper plane to minimize the parasitic impedance.
4. Place as many PGND vias as possible close to PGND to minimize both parasitic impedance and thermal resistance.
5. Place the VCC decoupling capacitor close to the device.
6. Connect AGND and PGND at the point of the VCC capacitor's ground connection.
7. Place the BST capacitor as close to BST and SW as possible.
8. Route the path with trace widths 20 mils or higher.
9. Use 0.1μF to 1μF bootstrap capacitors.
10. Keep the CS signal trace away from high-current paths like SW and PWM.



**Figure 4: Example of PCB Layout (Placement & Top Layer PCB)**

Input Capacitor: 0805 & 0402 package

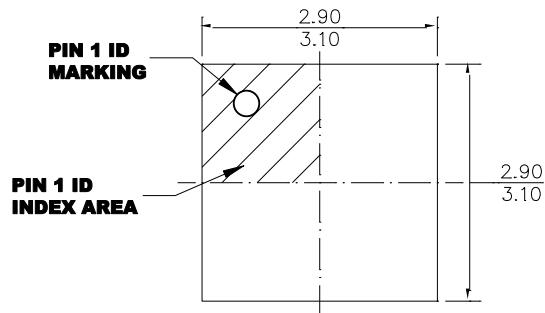
Inductor: 6.5 x 6.5 (mm)

VCC/BST capacitor: 0402 package

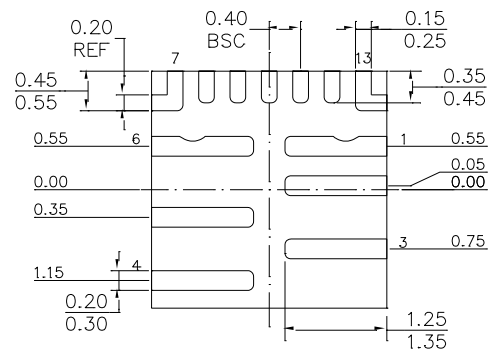
Via size: 20/10 mils

# PACKAGE INFORMATION

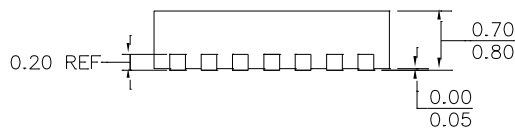
## TQFN-13 (3mmx3mm)



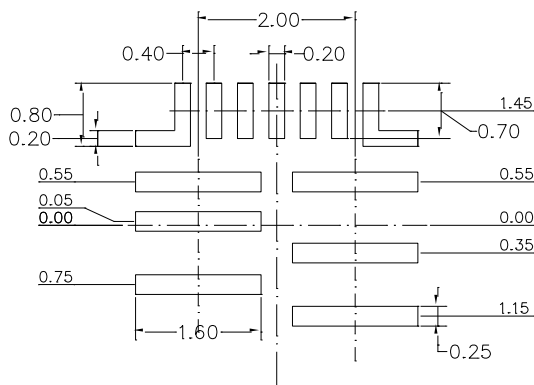
**TOP VIEW**



**BOTTOM VIEW**



**SIDE VIEW**



**RECOMMENDED LAND PATTERN**

### NOTE:

- 1) ALL DIMENSIONS ARE IN MILLIMETERS.
- 2) EXPOSED PADDLE SIZE DOES NOT INCLUDE MOLD FLASH.
- 3) LEAD COPLANARITY SHALL BE 0.10 MILLIMETERS MAX.
- 4) JEDEC REFERENCE IS MO-220.
- 5) DRAWING IS NOT TO SCALE.

## REVISION HISTORY

| Revision # | Revision Date | Description                                                         | Pages Updated |
|------------|---------------|---------------------------------------------------------------------|---------------|
| r1.1       | 5/19/2020     | Correct/add the “Vin-Vsw (10ns) ..... -5V to 32V” on absMax rating. | Page 3        |
| r1.2       | 5/26/2021     | Update the thermal impedance.                                       | Page 3        |

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