



# MPQ8633B-H

## 16V, 20A, Configurable-Frequency, Synchronous Step-Down Converter with Adjustable Current Limit and Voltage Tracking

### DESCRIPTION

The MPQ8633B-H is a fully integrated, high-frequency, synchronous step-down converter. It offers a compact solution that can achieve up to 20A of output current ( $I_{OUT}$ ) across a wide input voltage ( $V_{IN}$ ) range, with excellent load and line regulation. The MPQ8633B-H operates at high efficiency across the entire  $I_{OUT}$  load range.

Internally compensated constant-on-time (COT) control provides fast transient response and eases loop stabilization.

The adjustable switching frequency ( $f_{SW}$ ) can be set to 600kHz, 800kHz, or 1000kHz by configuring the MODE pin. This maintains a constant  $f_{SW}$ , regardless of the output voltage ( $V_{OUT}$ ) or  $V_{IN}$ .

The  $V_{OUT}$  start-up ramp is controlled via an internal timer (1ms). For a longer internal timer, add a capacitor to the TRK/REF pin. An open-drain power good (PGOOD) signal indicates whether  $V_{OUT}$  is within its nominal voltage range. If the input supply fails to power the MPQ8633B-H, then PGOOD is clamped at about 0.7V via an external pull-up voltage.

Full protection features include over-current protection (OCP), over-voltage protection (OVP), under-voltage protection (UVP), and thermal shutdown.

The MPQ8633B-H requires a minimal number of readily available, standard external components, and is available in a QFN-21 (3mmx4mm) package.

### FEATURES

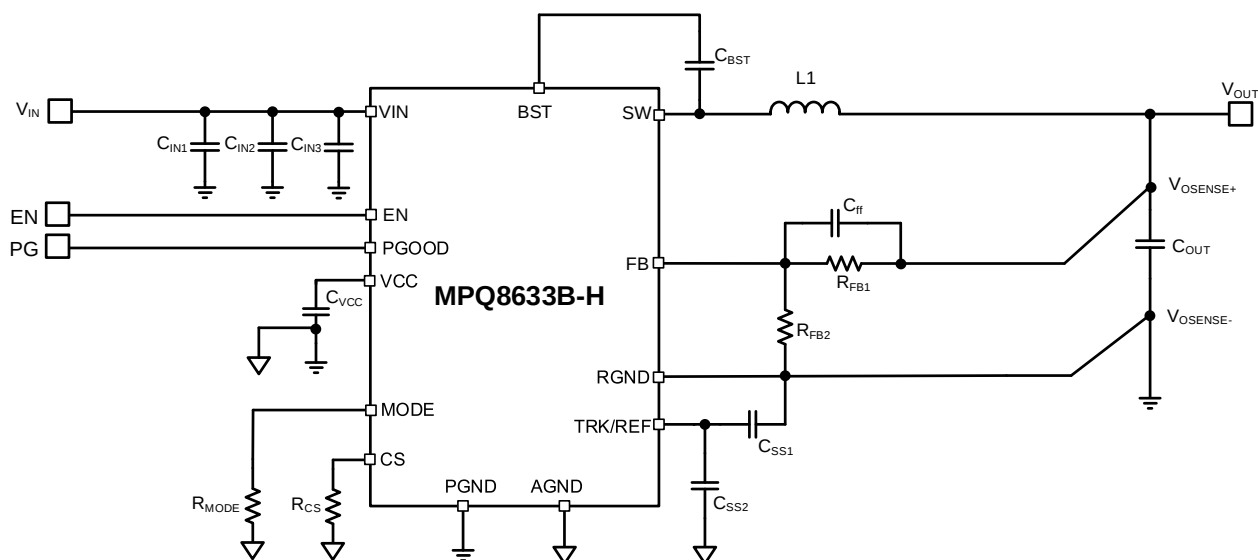
- Wide Input Voltage ( $V_{IN}$ ) Range
  - 2.7V to 16V  $V_{IN}$  Range with External 3.3V VCC Bias
  - 4V to 16V  $V_{IN}$  Range with Internal Bias or External 3.3V VCC Bias
- Differential  $V_{OUT}$  Remote Sense
- Configurable Accurate Current Limit
- 20A Output Current ( $I_{OUT}$ )
- Low  $R_{DS(ON)}$  Integrated Power MOSFETs
- Proprietary Switching Loss Reduction Technique
- Adaptive Constant-On-Time (COT) Control for Fast Transient Response
- Stable with Zero ESR Output Capacitor
- 0.5%  $V_{REF}$  for 0°C to 70°C  $T_J$  Range
- 1%  $V_{REF}$  for -40°C to +125°C  $T_J$  Range
- Selectable Pulse Skip Mode (PSM)/Forced Continuous Conduction Mode (FCCM)
- Excellent Load Regulation
- $V_{OUT}$  Tracking
- PGOOD Active Clamped Low during Power Failure
- Configurable Soft-Start Time ( $t_{SS}$ ) from 1ms
- Pre-Bias Start-Up
- 600kHz, 800kHz, or 1000kHz Selectable  $f_{SW}$
- Non-Latch OCP, OVP, UVP, UVLO, and Thermal Shutdown
- Adjustable Output between 0.6V and 90% of  $V_{IN}$ , with 5.5V Maximum
- Available in a QFN-21 (3mmx4mm) Package

### APPLICATIONS

- Telecommunication/Networking Systems
- Servers, Cloud-Computing, and Storage
- Base Stations
- General-Purpose POL Systems
- 12V Distribution Power Systems
- High-End Televisions
- Game Consoles and Graphic Cards

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# TYPICAL APPLICATION



## ORDERING INFORMATION

| Part Number    | Package          | Top Marking | MSL Rating |
|----------------|------------------|-------------|------------|
| MPQ8633B-HGLE* | QFN-21 (3mmx4mm) | See Below   | 1          |

\* For Tape & Reel, add suffix -Z (e.g. MPQ8633B-HGLE-Z).

## TOP MARKING

**MPYW**

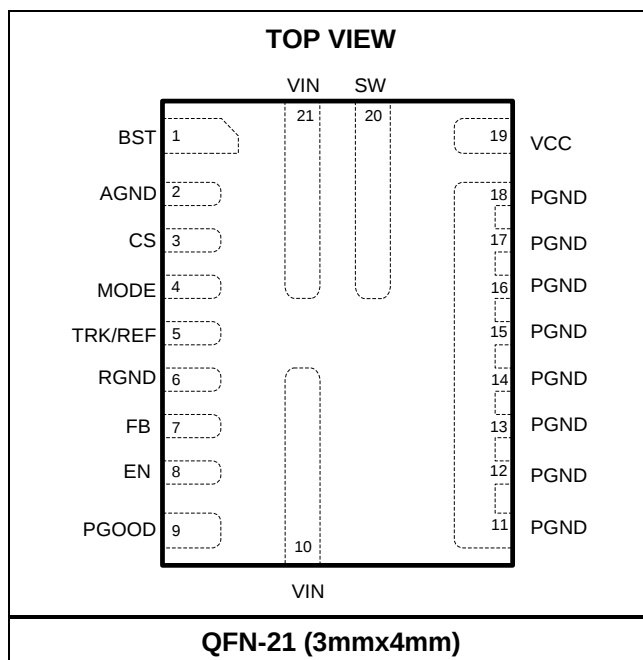
**8633**

**BLLL**

**EH**

MP: MPS prefix  
Y: Year code  
W: Week code  
8633B: First five digits of the part number  
LLL: Lot number  
E: Package prefix  
H: Non-latch OVP

## PACKAGE REFERENCE



## PIN FUNCTIONS

| Pin #                                | Name    | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                                    | BST     | <b>Bootstrap.</b> Connect a capacitor between the SW and BST pins to form a floating supply across the high-side MOSFET (HS-FET) driver.                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 2                                    | AGND    | <b>Analog ground.</b> Use the AGND pin as the control circuit reference point.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 3                                    | CS      | <b>Current limit setting.</b> Connect a resistor to AGND to set the current limit. See the Current Sense (CS) and Over-Current Protection (OCP) section on page 15 for more details.                                                                                                                                                                                                                                                                                                                                                                                  |
| 4                                    | MODE    | <b>Mode selection.</b> Configure the MODE pin to select forced continuous conduction mode (FCCM), pulse skip mode (PSM), or the operating switching frequency ( $f_{sw}$ ). See Table 1 on page 14 for more details.                                                                                                                                                                                                                                                                                                                                                  |
| 5                                    | TRK/REF | <b>External tracking voltage input.</b> The output voltage ( $V_{OUT}$ ) tracks the TRK/REF input signal. Use a ceramic decoupling capacitor placed as close to the TRK/REF pin as possible to decouple TRK/REF. Capacitors with X7R or X5R grade dielectrics are recommended due to their stable temperature characteristics. The soft-start time ( $t_{ss}$ ) determines the capacitance of the TRK/REF capacitor ( $C_{TRK/REF}$ ). The capacitance of this capacitor determines the soft-start time. See the Soft Start (SS) section on page 14 for more details. |
| 6                                    | RGND    | <b>Differential remote sense negative input.</b> Connect the RGND pin to the negative side of the voltage sense point. Short RGND to GND if not used.                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 8                                    | EN      | <b>Enable.</b> The EN pin is an input signal that turns the converter on and off. Pull EN high to turn the converter on; pull EN low to turn it off. For automatic start-up, use a pull-up resistor or a resistive voltage divider to connect the EN and VIN pins. Do not float EN.                                                                                                                                                                                                                                                                                   |
| 9                                    | PGOOD   | <b>Power good output.</b> The PGOOD pin is an open-drain signal. Use a pull-up resistor connected to a DC voltage for a logic high signal that indicates whether $V_{OUT}$ is within its regulation range. There is a delay (about 1ms) between when $V_{FB} \geq 92.5\%$ of the reference voltage ( $V_{REF}$ ) and when PGOOD is pulled high.                                                                                                                                                                                                                       |
| 10, 21                               | VIN     | <b>Input voltage.</b> The VIN pin supplies power for the internal MOSFET and the converter. Use decoupling input capacitors to decouple the input rail. Use wide PCB traces to make this connection.                                                                                                                                                                                                                                                                                                                                                                  |
| 11, 12, 13,<br>14, 15, 16,<br>17, 18 | PGND    | <b>System ground.</b> The PGND pin is the reference ground for the regulated $V_{OUT}$ . Therefore, care must be taken during PCB layout. Use wide PCB traces to make the connection.                                                                                                                                                                                                                                                                                                                                                                                 |
| 19                                   | VCC     | <b>Internal 3V LDO output.</b> The VCC pin supplies power for the driver and control circuits. Use a 1μF decoupling ceramic capacitor placed as close to the VCC pin as possible to decouple VCC. Capacitors with X7R or X5R grade dielectrics are recommended due to their stable temperature characteristics.                                                                                                                                                                                                                                                       |
| 20                                   | SW      | <b>Switch output.</b> Connect the SW pin to the inductor and bootstrap capacitor ( $C_{BST}$ ). SW is pulled up to VIN by the HS-FET during the pulse-width modulation (PWM) duty cycle on time ( $t_{ON}$ ). ( $I_L$ ) SW is pulled low by the inductor current during the PWM duty cycle off-time ( $t_{OFF}$ ). Use wide PCB traces to make this connection.                                                                                                                                                                                                       |

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

|                                |                 |
|--------------------------------|-----------------|
| Supply voltage ( $V_{IN}$ )    | 18V             |
| $V_{SW(DC)}$                   | -0.3V to +18.3V |
| $V_{SW}$ (25ns) <sup>(2)</sup> | -3V to +25V     |
| $V_{SW}$ (25ns)                | -5V to +25V     |
| $V_{BST}$                      | -0.3V to +22.3V |
| $V_{CC, EN}$                   | 4.5V            |
| All other pins                 | -0.3V to +4.3V  |
| Junction temperature           | 170°C           |
| Lead temperature               | 260°C           |
| Storage temperature            | -65°C to +170°C |

## ESD Ratings

|                            |           |
|----------------------------|-----------|
| Human body model (HBM)     | Class 2   |
| Charged device model (CDM) | Class C2B |

## Recommended Operating Conditions <sup>(3)</sup>

|                                                 |                          |
|-------------------------------------------------|--------------------------|
| Supply voltage ( $V_{IN}$ )                     | 4V to 16V                |
| $V_{IN(DC)} - V_{SW(DC)}$ <sup>(4)</sup>        | -0.3V to $V_{IN} + 0.3V$ |
| $V_{SW(DC)}$ <sup>(4)</sup>                     | -0.3V to $V_{IN} + 0.3V$ |
| Output voltage ( $V_{OUT}$ )                    | 0.6V to 5.5V             |
| External VCC bias ( $V_{CC\_EXT}$ )             | 3.12V to 3.6V            |
| Maximum output current ( $I_{OUT\_MAX}$ )       | 20A                      |
| Maximum output current limit ( $I_{OC\_MAX}$ )  | 24A                      |
| Maximum peak inductor current ( $I_{L\_PEAK}$ ) | 28A                      |
| EN voltage ( $V_{EN}$ )                         | 3.6V                     |
| Operating junction temp ( $T_J$ )               | -40°C to +125°C          |

| Thermal Resistance <sup>(5) (6)</sup> | $\theta_{JB}$ | $\theta_{JC\_TOP}$ |
|---------------------------------------|---------------|--------------------|
| QFN-21 (3mmx4mm)                      | 8             | 18                 |

### Notes:

- 1) Exceeding these ratings may damage the device.
- 2) Measured using a differential oscilloscope probe.
- 3) The device is not guaranteed to function outside of its operating conditions.
- 4) If the input voltage ( $V_{IN}$ ) is 16V and the switching period is  $\leq 25ns$  with a maximum repetition rate (1000kHz), then the voltage rating should be between -3V and +23V.
- 5)  $\theta_{JB}$  is the thermal resistance from the junction to the board near the PGND soldering point.
- 6)  $\theta_{JC\_TOP}$  is the thermal resistance from the junction to the top of the package.

## ELECTRICAL CHARACTERISTICS

$V_{IN} = 12V$ ,  $T_J = -40^{\circ}C$  to  $+125^{\circ}C$ , unless otherwise noted.

| Parameters                                    | Symbol                             | Condition                                                                | Min  | Typ  | Max  | Units                 |
|-----------------------------------------------|------------------------------------|--------------------------------------------------------------------------|------|------|------|-----------------------|
| Supply Current                                |                                    |                                                                          |      |      |      |                       |
| Shutdown current                              | I <sub>SD</sub>                    | V <sub>EN</sub> = 0V                                                     |      | 11   | 30   | μA                    |
| Quiescent current                             | I <sub>Q</sub>                     | V <sub>EN</sub> = 2V, V <sub>FB</sub> = 0.65V                            |      | 650  | 850  | μA                    |
| MOSFET                                        |                                    |                                                                          |      |      |      |                       |
| Switch leakage                                | I <sub>SWLKG_HS</sub>              | V <sub>EN</sub> = 0V, V <sub>SW</sub> = 0V                               |      | 0    | 10   | μA                    |
|                                               | I <sub>SWLKG_LS</sub>              | V <sub>EN</sub> = 0V, V <sub>SW</sub> = 12V                              |      | 0    | 30   |                       |
| Current Limit                                 |                                    |                                                                          |      |      |      |                       |
| Current limit threshold                       | V <sub>LIM</sub>                   |                                                                          | 1.15 | 1.2  | 1.25 | V                     |
| I <sub>CS</sub> to I <sub>OUT</sub> ratio     | I <sub>CS</sub> / I <sub>OUT</sub> | I <sub>OUT</sub> ≥ 2A                                                    | 9    | 10   | 11   | μA/A                  |
| Low-side negative current limit               | I <sub>LIMIT_NEG</sub>             |                                                                          |      | -18  |      | A                     |
| Negative current limit timeout <sup>(7)</sup> | t <sub>NCL</sub>                   |                                                                          |      | 200  |      | ns                    |
| Switching Frequency                           |                                    |                                                                          |      |      |      |                       |
| Switching frequency <sup>(8)</sup>            | f <sub>SW</sub>                    | MODE and GND are connected, I <sub>OUT</sub> = 0A, V <sub>OUT</sub> = 1V | 480  | 600  | 720  | kHz                   |
|                                               |                                    | MODE = 30.1kΩ, I <sub>OUT</sub> = 0A, V <sub>OUT</sub> = 1V              | 680  | 800  | 920  | kHz                   |
|                                               |                                    | MODE = 60.4 kΩ, I <sub>OUT</sub> = 0A, V <sub>OUT</sub> = 1V             | 850  | 1000 | 1150 | kHz                   |
| Minimum on time <sup>(7)</sup>                | t <sub>ON_MIN</sub>                | V <sub>FB</sub> = 500mV                                                  |      |      | 50   | ns                    |
| Minimum off time <sup>(7)</sup>               | t <sub>OFF_MIN</sub>               | V <sub>FB</sub> = 500mV                                                  |      |      | 180  | ns                    |
| Over-Voltage and Under-Voltage Protection     |                                    |                                                                          |      |      |      |                       |
| OVP threshold                                 | V <sub>OVP</sub>                   |                                                                          | 113  | 116  | 119  | % of V <sub>REF</sub> |
| UVP threshold                                 | V <sub>UVP</sub>                   |                                                                          | 77   | 80   | 83   | % of V <sub>REF</sub> |
| Feedback Voltage and Soft Start               |                                    |                                                                          |      |      |      |                       |
| Feedback voltage                              | V <sub>REF</sub>                   | T <sub>J</sub> = -40°C to +125°C                                         | 594  | 600  | 606  | mV                    |
|                                               |                                    | T <sub>J</sub> = 0°C to 70°C                                             | 597  | 600  | 603  | mV                    |
| TRK/REF source current                        | I <sub>TRK/REF_SOURCE</sub>        | V <sub>TRK/REF</sub> = 0V                                                |      | 42   |      | μA                    |
| TRK/REF sink current                          | I <sub>TRACK_SINK</sub>            | V <sub>TRK/REF</sub> = 1V                                                |      | 12   |      | μA                    |
| Soft-start time                               | t <sub>SS</sub>                    | C <sub>TRACK</sub> = 1nF, T <sub>J</sub> = 25°C                          | 0.75 | 1    | 1.25 | ms                    |
| Error Amplifier (EA)                          |                                    |                                                                          |      |      |      |                       |
| EA offset                                     | V <sub>OS</sub>                    |                                                                          | -3   | 0    | +3   | mV                    |
| Feedback (FB) current                         | I <sub>FB</sub>                    | V <sub>FB</sub> = V <sub>REF</sub>                                       |      | 50   | 100  | nA                    |
| Enable (EN) and Under-Voltage Lockout (UVLO)  |                                    |                                                                          |      |      |      |                       |
| EN input rising threshold                     | V <sub>EN_RISING</sub>             |                                                                          | 1.17 | 1.22 | 1.27 | V                     |
| EN hysteresis                                 | V <sub>EN_HYS</sub>                |                                                                          |      | 200  |      | mV                    |
| EN input current                              | I <sub>EN</sub>                    | V <sub>EN</sub> = 2V                                                     |      | 0    |      | μA                    |
| V <sub>IN</sub> UVLO                          |                                    |                                                                          |      |      |      |                       |
| V <sub>IN</sub> UVLO rising threshold         | V <sub>IN_UVLO_RISING</sub>        | V <sub>CC</sub> = 3.3V                                                   |      | 2.4  | 2.7  | V                     |
| V <sub>IN</sub> UVLO falling threshold        | V <sub>IN_UVLO_FALLING</sub>       | V <sub>CC</sub> = 3.3V                                                   |      | 1.85 | 2.15 | V                     |

## ELECTRICAL CHARACTERISTICS (continued)

$V_{IN} = 12V$ ,  $T_J = -40^{\circ}C$  to  $+125^{\circ}C$ , unless otherwise noted.

| Parameters                                   | Symbol                    | Condition                                                                                        | Min  | Typ  | Max  | Units          |
|----------------------------------------------|---------------------------|--------------------------------------------------------------------------------------------------|------|------|------|----------------|
| <b>VCC Regulator</b>                         |                           |                                                                                                  |      |      |      |                |
| VCC UVLO rising threshold                    | $V_{CC\_UVLO\_RISING}$    |                                                                                                  | 2.65 | 2.8  | 2.95 | V              |
| VCC UVLO falling threshold                   | $V_{CC\_UVLO\_FALLING}$   |                                                                                                  | 2.35 | 2.5  | 2.65 | V              |
| VCC regulator                                | $V_{CC}$                  |                                                                                                  | 2.88 | 3    | 3.12 | V              |
| VCC load regulation                          |                           | $I_{CC} = 25mA$                                                                                  |      | 0.5  |      | %              |
| <b>Power Good (PGOOD)</b>                    |                           |                                                                                                  |      |      |      |                |
| PGOOD high rising threshold                  | $V_{PGOOD\_HIGH\_RISING}$ | FB from low to high                                                                              | 89.5 | 92.5 | 95.5 | % of $V_{REF}$ |
| PGOOD low rising threshold                   | $V_{PGOOD\_LOW\_RISING}$  | FB from low to high                                                                              | 113  | 116  | 119  | % of $V_{REF}$ |
| PGOOD low falling threshold                  | $V_{PGOOD\_LOW\_FALLING}$ | FB from high to low                                                                              | 77   | 80   | 83   | % of $V_{REF}$ |
| PGOOD low to high delay                      | $t_{DELAY\_PGOOD}$        | $T_J = 25^{\circ}C$                                                                              | 0.63 | 0.9  | 1.17 | ms             |
| PGOOD sink current capability                | $V_{PGOOD\_SINK}$         | $I_{PG} = 10mA$                                                                                  |      |      | 0.5  | V              |
| PGOOD leakage current                        | $I_{PGOOD\_LEAK}$         | $V_{PG} = 3.3V$                                                                                  |      |      | 3    | $\mu A$        |
| PGOOD low-level output voltage ( $V_{OUT}$ ) | $V_{PGOOD\_LOW\_100}$     | $V_{IN} = 0V$ , $T_J = 25^{\circ}C$ , pull PGOOD up to 3.3V via a 100k $\Omega$ pull-up resistor |      | 650  | 800  | mV             |
|                                              | $V_{PGOOD\_LOW\_10}$      | $V_{IN} = 0V$ , $T_J = 25^{\circ}C$ , pull PGOOD up to 3.3V via a 10k $\Omega$ pull-up resistor  |      | 750  | 900  | mV             |
| <b>Thermal Protection</b>                    |                           |                                                                                                  |      |      |      |                |
| Thermal shutdown <sup>(7)</sup>              | $T_{SD}$                  |                                                                                                  |      | 160  |      | $^{\circ}C$    |
| Thermal shutdown hysteresis <sup>(7)</sup>   |                           |                                                                                                  |      | 30   |      | $^{\circ}C$    |

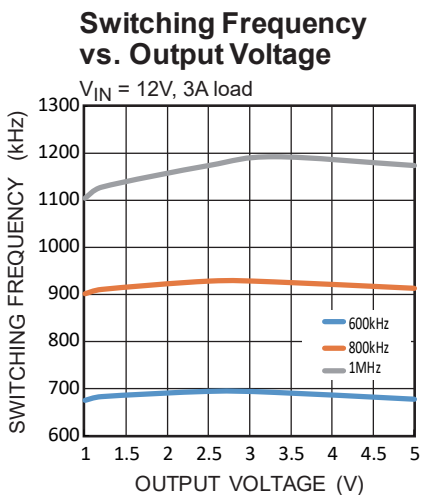
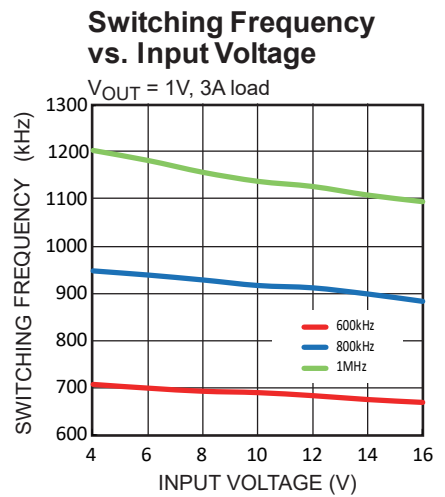
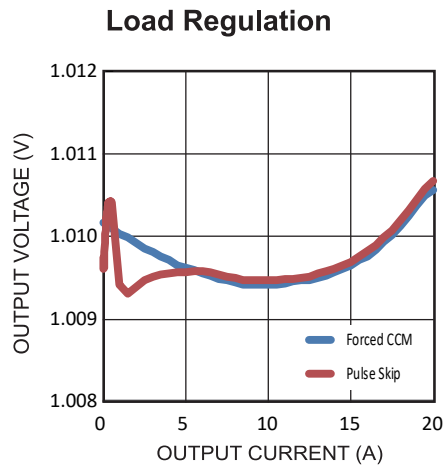
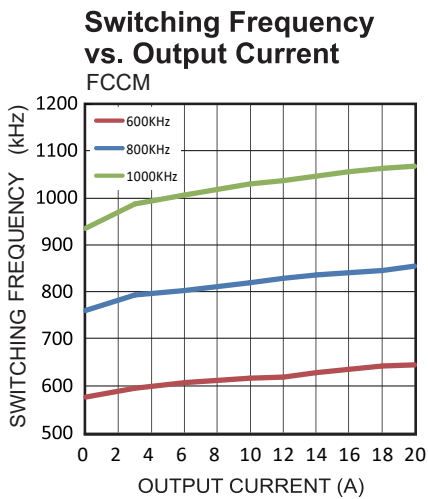
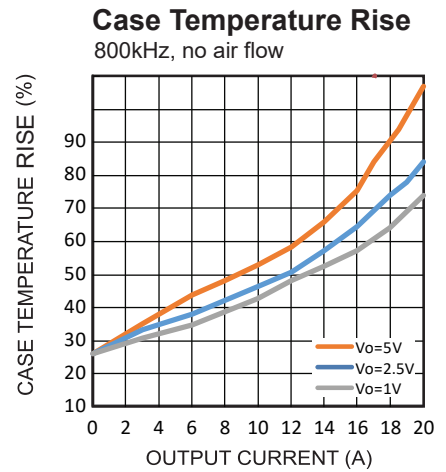
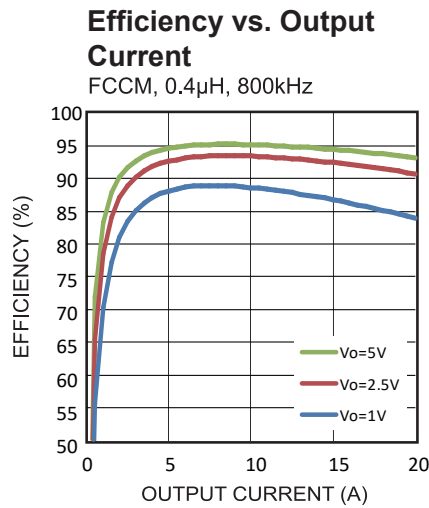
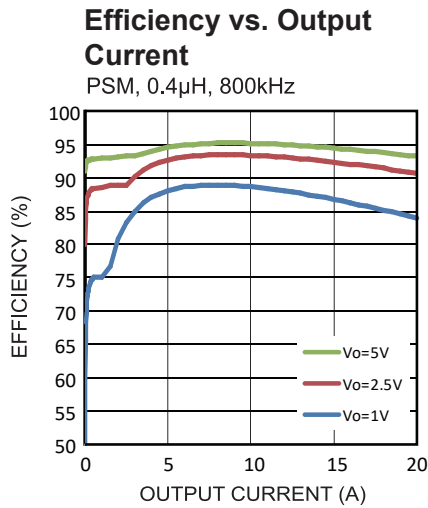
### Notes:

7) Guaranteed by design.

8) Guaranteed by over-temperature correlation.

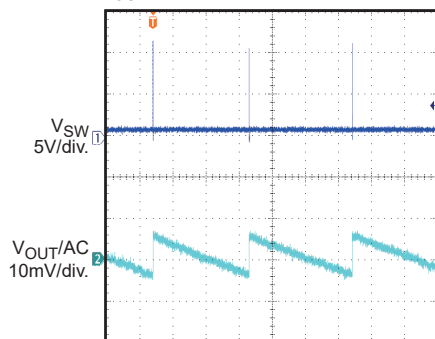
# TYPICAL PERFORMANCE CHARACTERISTICS

$V_{IN} = 12V$ ,  $T_A = 25^\circ C$ ,  $V_{OUT} = 1.2V$ ,  $f_{SW} = 800kHz$ , unless otherwise noted.

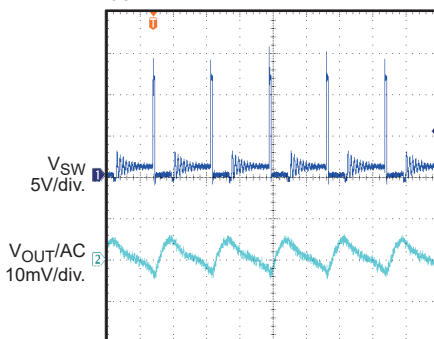


# TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

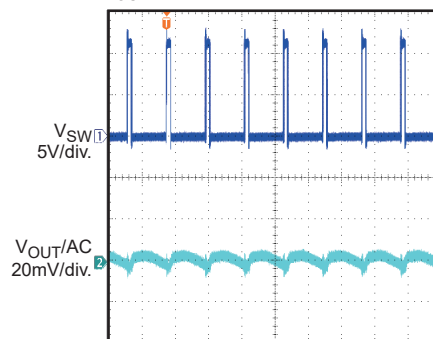
$V_{IN} = 12V$ ,  $T_A = 25^{\circ}C$ ,  $V_{OUT} = 1.2V$ ,  $f_{SW} = 800kHz$ , unless otherwise noted.

**Steady State**
 $I_{OUT} = 0A$ , PSM


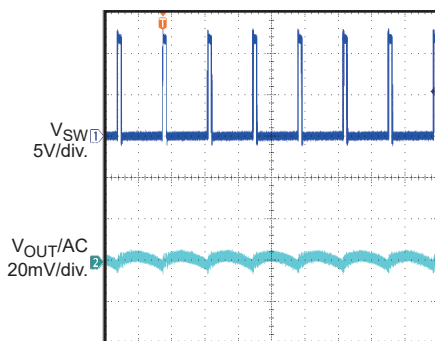
200µs/div.

**Steady State**
 $I_{OUT} = 0.5A$ , PSM


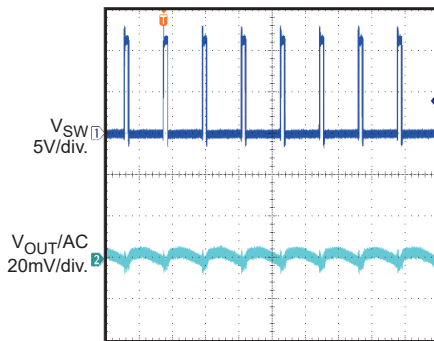
2µs/div.

**Steady State**
 $I_{OUT} = 20A$ , PSM


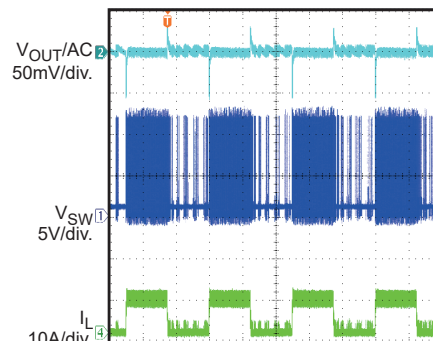
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**Steady State**
 $I_{OUT} = 0A$ , FCCM


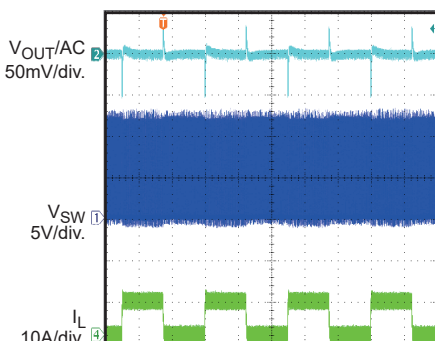
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**Steady State**
 $I_{OUT} = 20A$ , FCCM


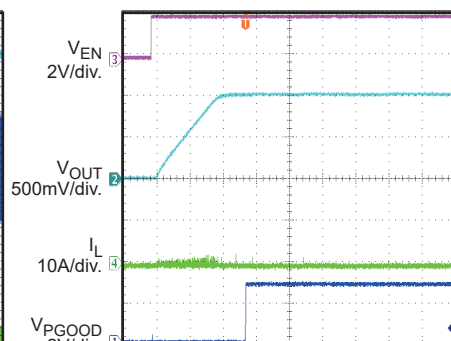
1µs/div.

**Load Transient**
 $I_{OUT} = 0A$  to 8A, PSM


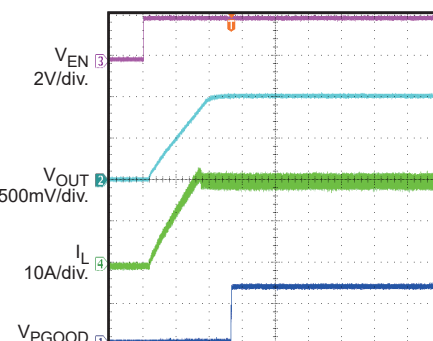
400µs/div.

**Load Transient**
 $I_{OUT} = 0A$  to 8A, FCCM


400µs/div.

**Power Up through EN**
 $I_{OUT} = 0A$ , PSM


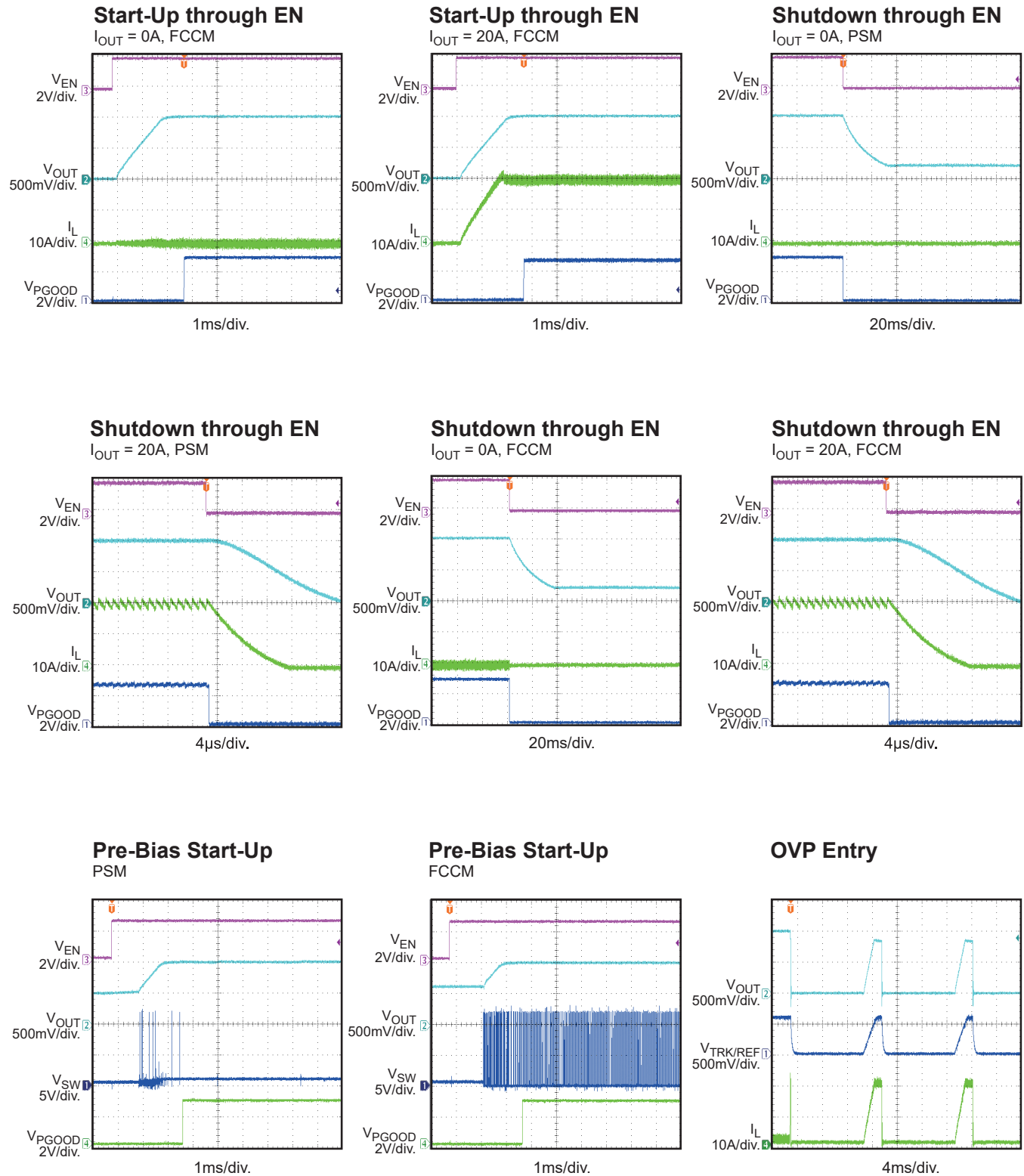
1ms/div.

**Power Up through EN**
 $I_{OUT} = 20A$ , PSM


1ms/div.

# TYPICAL PERFORMANCE CHARACTERISTICS (continued)

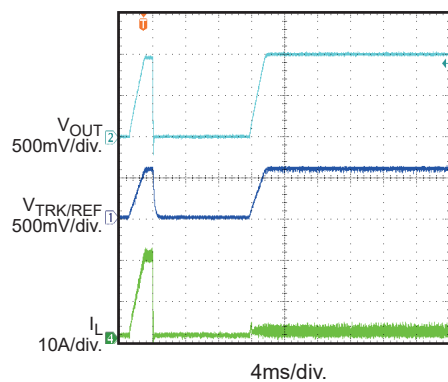
$V_{IN} = 12V$ ,  $T_A = 25^{\circ}C$ ,  $V_{OUT} = 1.2V$ ,  $f_{SW} = 800kHz$ , unless otherwise noted.



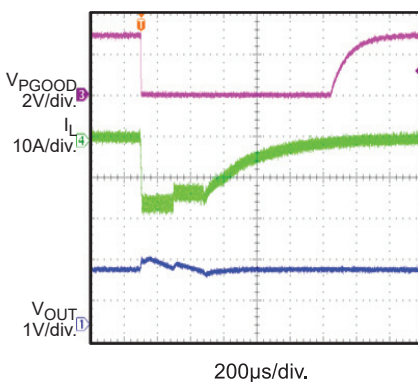
# TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

$V_{IN} = 12V$ ,  $T_A = 25^{\circ}C$ ,  $V_{OUT} = 1.2V$ ,  $f_{SW} = 800kHz$ , unless otherwise noted.

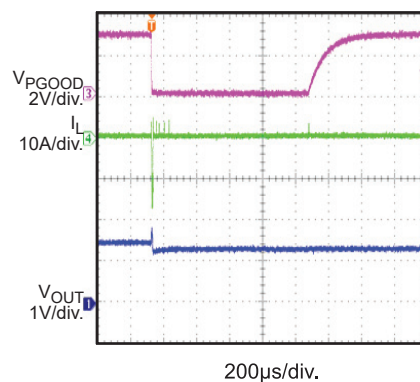
## OCP Entry



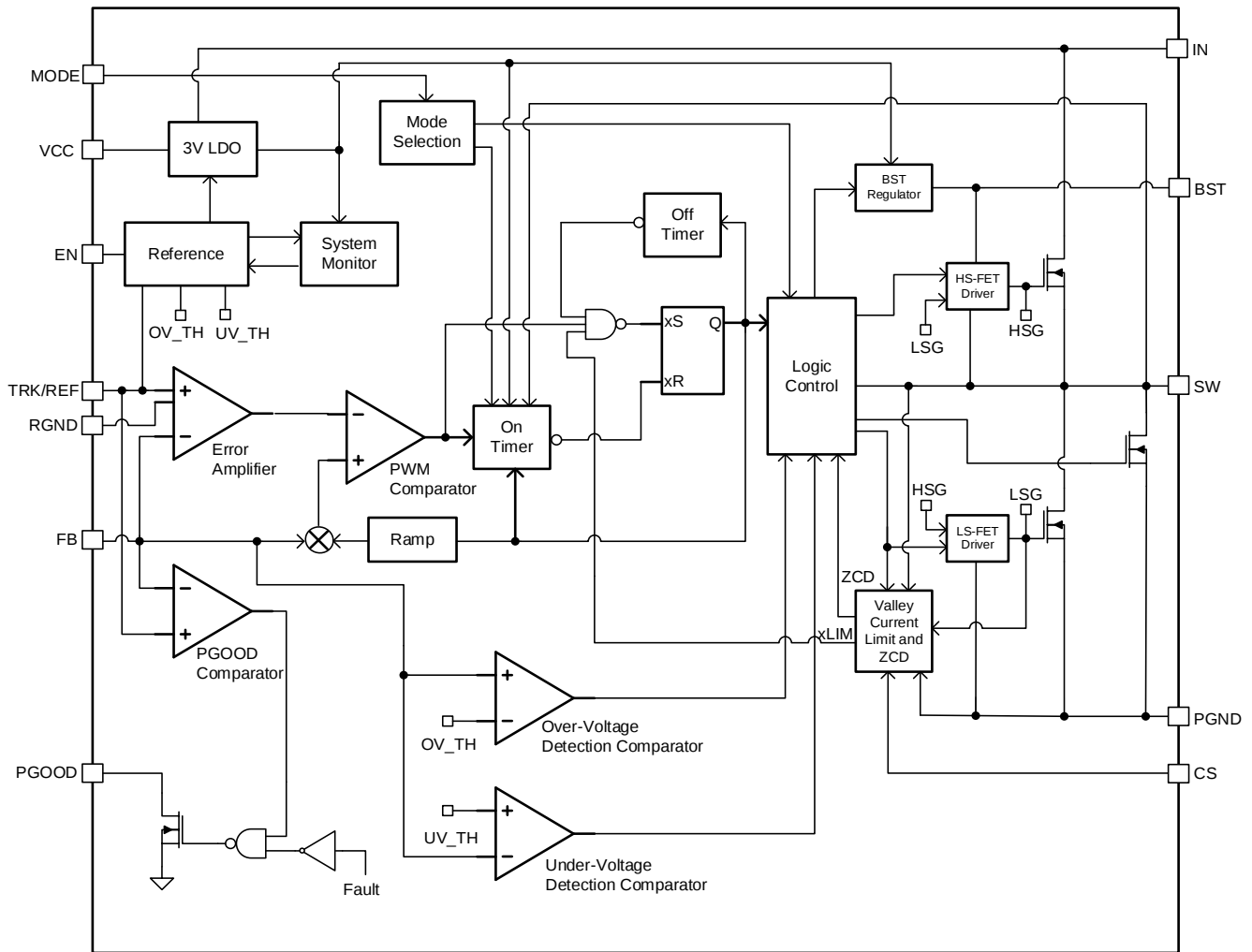
## Over-Voltage Protection FCCM



## Over-Voltage Protection PSM



# FUNCTIONAL BLOCK DIAGRAM



**Figure 1: Functional Block Diagram**

## OPERATION

### Constant-On-Time (COT) Control

The MPQ8633B-H employs constant-on-time (COT) control to achieve fast load transient response. Figure 2 shows the COT control stage.

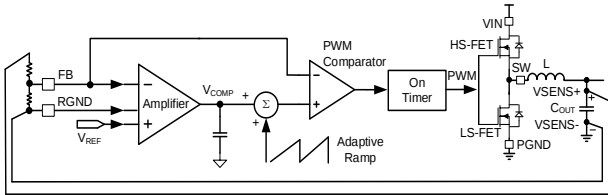


Figure 2: COT Control

The operational amplifier corrects error voltages between  $V_{FB}$  and  $V_{REF}$ . The MPQ8633B-H also uses the amplifier to provide excellent load regulation across the entire load range in both forced continuous conduction mode (FCCM) and pulse skip mode (PSM).

The RGND pin provides the differential output voltage ( $V_{OUT}$ ) remote sense function. For best performance, the pair of the remote sense traces should be kept in low impedance state.

The MPQ8633B-H has internal ramp compensation to support a low ESR, MLCC output capacitor ( $C_{OUT}$ ) solution. The adaptive internal ramp provides stable operation across the entire operating input voltage ( $V_{IN}$ ) range and  $V_{OUT}$  range, with a proper design of the output L/C filter.

### Pulse-Width Modulation (PWM) Mode

The operation amplifier corrects any error between  $V_{FB}$  and  $V_{REF}$ , and generates a fairly smooth DC voltage comp voltage ( $V_{COMP}$ ). The internal ramp is superimposed onto  $V_{COMP}$ , which is compared to the  $V_{FB}$ . If  $V_{FB}$  drops below  $V_{COMP}$ , then the high-side MOSFET (HS-FET) turns on. The HS-FET remains on for a fixed on time ( $t_{ON}$ ).  $t_{ON}$  is determined by  $V_{IN}$ ,  $V_{OUT}$ , and the selected switching frequency ( $f_{SW}$ ). After  $t_{ON}$  has elapsed, the HS-FET turns off. It turns on again once  $V_{FB}$  drops below  $V_{COMP}$ . The MPQ8633B-H regulates  $V_{OUT}$  by repeating this operation. The low-side MOSFET (LS-FET) turns on once the HS-FET is off to minimize conduction loss. If both the HS-FET and the LS-FET turn on at the same time, then a dead short occurs between the VIN and PGND pins.

This is called shoot-through. To avoid shoot-through, a dead time (DT) is generated internally between the HS-FET off time ( $t_{OFF}$ ) and the LS-FET  $t_{ON}$ , and vice versa. Figure 3 shows PWM mode under heavy-load conditions.

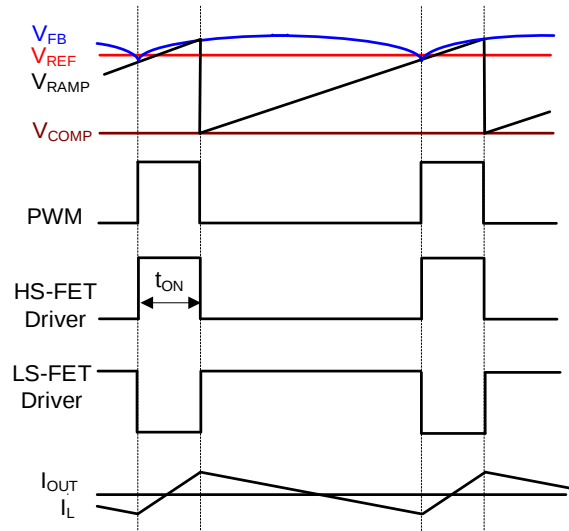


Figure 3: CCM during Heavy-Load Operation

### Continuous Conduction Mode (CCM)

If the output current ( $I_{OUT}$ ) is high and the inductor current ( $I_L$ ) is above 0A, then the part operates in continuous conduction mode (CCM) (see Figure 3). The MPQ8633B-H can also be configured to operate in forced continuous conduction mode (FCCM) when the  $I_{OUT}$  is low. See the Mode Selection section on page 14 for more details.

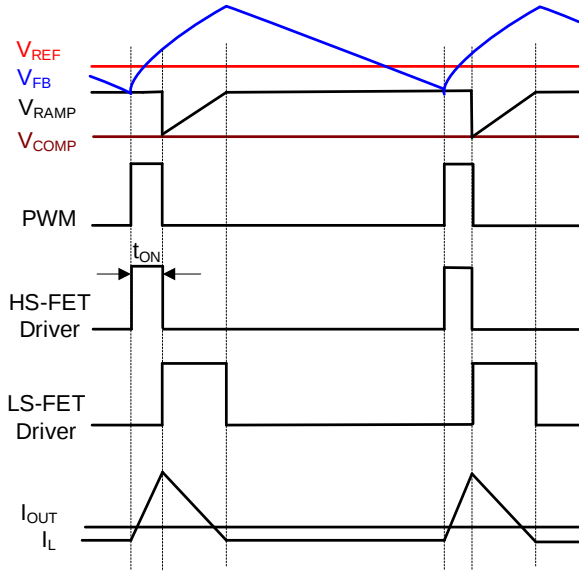
$f_{SW}$  remains fairly constant in CCM (PWM mode), which maintains a constant output voltage ripple ( $\Delta V_{OUT}$ ) throughout the entire load range.

### Pulse-Skip Mode (PSM)

The MPQ8633B-H can be configured to operate in pulse-skip mode (PSM) at light loads to improve efficiency.  $I_L$  decreases as the load decreases. Once  $I_L$  reaches 0A, the device enters PSM. See the Mode Selection section on page 14 for more details.

If  $V_{FB}$  drops below  $V_{COMP}$ , then the HS-FET turns on for a fixed interval. Once the HS-FET turns off, the LS-FET turns on until  $I_L$  reaches 0A. In PSM,  $V_{FB}$  should not reach  $V_{COMP}$  while  $I_L$

approaches 0A. The LS-FET driver turns on and enters a high impedance (Hi-Z) state once  $I_L$  reaches 0A. A current modulator takes control of the LS-FET and limits  $I_L$  to below -1mA. The output capacitors discharge slowly to PGND via the LS-FET. In PSM at light loads, the HS-FET does not turn on as frequently as in FCCM. As a result, PSM has higher efficiency compared to that in FCCM. Figure 4 shows PSM under light-load conditions.



**Figure 4: PSM during Light-Load Operation**

As  $I_{OUT}$  increases from light load, the time period regulated by the current modulator decreases. The HS-FET turns on more frequently, and  $f_{SW}$  increases accordingly.  $I_{OUT}$  reaches its critical level once the current modulator time is 0s. The critical level of the  $I_{OUT}$  can be calculated with Equation (1):

$$I_{OUT} = \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{2 \times L \times F_{SW} \times V_{IN}} \quad (1)$$

The device enters CCM once  $I_{OUT}$  exceeds its critical level. After  $I_{OUT}$  has exceeded its critical level,  $f_{SW}$  remains fairly constant across the entire  $I_{OUT}$  range.

The MPQ8633B-H can be configured to operate in FCCM, even under light-load conditions (see Table 1).

### Mode Selection

The MPQ8633B-H provides both FCCM and

PSM for light-load operation. It also has three selectable  $f_{SW}$  options. The operation mode and  $f_{SW}$  is set by the resistor connected between MODE and AGND or MODE and VCC. Choose a resistance to select the desired mode and  $f_{SW}$ . (see Table 1).

**Table 1: Mode Selection**

| MODE Resistor Value   | Mode at Light Loads | Switching Frequency |
|-----------------------|---------------------|---------------------|
| VCC                   | PSM                 | 600kHz              |
| 243kΩ (±20%) to AGND  | PSM                 | 800kHz              |
| 121kΩ (±20%) to AGND  | PSM                 | 1000kHz             |
| AGND                  | FCCM                | 600kHz              |
| 30.1kΩ (±20%) to AGND | FCCM                | 800kHz              |
| 60.4kΩ (±20%) to AGND | FCCM                | 1000kHz             |

### Soft Start (SS)

The MPQ8633B-H has a 1ms minimum soft-start time ( $t_{SS}$ ). Connect a soft-start capacitor ( $C_{SS}$ ) between the TRK/REF and RGND pins to increase  $t_{SS}$ .

The total soft-start capacitance ( $C_{SS}$ ) can be calculated with Equation (2):

$$C_{SS}(\text{nF}) = \frac{t_{SS}(\text{ms}) \times 36\mu\text{A}}{0.6(\text{V})} \quad (2)$$

$C_{SS}$  can also be calculated with Equation (3):

$$C_{SS} = C_{SS1} + C_{SS2} \quad (3)$$

Where  $C_{SS2}$  is  $\geq 22\text{nF}$ .

### Output Voltage Tracking and Reference

The MPQ8633B-H provides an analog input pin (TRK/REF) to track a second power supply or accept an external reference. If an external voltage is connected to TRK/REF, then it acts as the reference voltage ( $V_{REF}$ ) for  $V_{OUT}$ .  $V_{FB}$  also follows this external voltage signal, and the soft-start settings are ignored. The TRK/REF input signal can be between 0.3V and 1.4V. During start-up, the TRK/REF should exceed 600mV to ensure proper operation. After that, TRK/REF can be set to any value between 0.3V and 1.4V.

### Pre-Biased Start-Up

The MPQ8633B-H is designed for monotonic start-up into a pre-biased load. If  $V_{OUT}$  is pre-biased to a certain voltage during start-up, then the HS-FET and LS-FET turn off until the on the TRK/REF voltage ( $V_{TRK/REF}$ ) exceeds the  $V_{FB}$ . Before the TRK/REF voltage reaches the pre-biased FB level, If the BST capacitor ( $C_{BST}$ ) between the BST to SW pins is below 2.3V, and  $V_{TRK/REF}$  has not reached the pre-biased FB level, then the LS-FET turns on to allow VCC to charge  $C_{BST}$ . The LS-FET turns on for short pulses, so the drop in the pre-biased voltage is negligible.

### Current Sense (CS) and Over-Current Protection (OCP)

The MPQ8633B-H features an on-die current sense and a configurable positive current limit ( $I_{LIMIT}$ ) threshold.

$I_{LIMIT}$  is active while the IC is on. During the LS-FET on state,  $I_L$  (the SW current) is sensed and mirrored to the CS pin with the current-sense gain ( $G_{CS}$ ) ratio. Connect a resistor ( $R_{CS}$ ) between the CS and AGND pins to make the CS voltage ( $V_{CS}$ ) proportional to  $I_L$  cycle-by-cycle. The HS-FET can only turn on once  $V_{CS}$  is below the internal over-current protection (OCP) threshold ( $V_{OCP}$ ) while the LS-FET is on to limit the SW valley current cycle-by-cycle.

The current limit threshold ( $R_{CS}$ ) can be calculated with Equation (4):

$$R_{CS}(\Omega) = \frac{V_{OCP}}{G_{CS} \times (I_{LIMIT} - \frac{(V_{IN} - V_{OUT}) \times V_{OOUT}}{V_{IN}} \times \frac{1}{2 \times L \times f_{SW}})} \quad (4)$$

Where  $V_{OCP}$  is 1.2V,  $G_{CS}$  is 10 $\mu$ A/A, and  $I_{LIMIT}$  is the desired current limit in amps.

After the MPQ8633B-H starts up, there is a delay time ( $t_{DELAY}$ ) (3ms) before OCP and hiccup mode are active. If the IC detects an over-current (OC) condition for 31 consecutive cycles, or if  $V_{FB}$  drops below the under-voltage protection (UVP) threshold, the part enters hiccup mode. In hiccup mode, the HS-FET turns off, and the LS-FET turns on after zero current detection (ZCD). The TRK/REF capacitor ( $V_{TRK/REF}$ ) is also discharged during hiccup mode. After about 11ms, the MPQ8633B-H initiates a soft start to resume normal operation. If the OC condition remains

after 3ms, then the device repeats this operation until the OC condition is removed and  $V_{OUT}$  reaches its regulation voltage level.

### Negative Inductor Current Limit

If the LS-FET detects a -18A current, then the LS-FET turns off for 200ns to limit the negative current.

### Over-Voltage Protection (OVP)

The MPQ8633B-H monitors  $V_{OUT}$  continuously. The FB pin is connected to the tap of the feedback resistor divider to detect whether an over-voltage (OV) condition has occurred. This provides over-voltage protection (OVP) with hiccup mode for the device.

If  $V_{FB}$  exceeds 116% of  $V_{REF}$ , then OVP is triggered. The power good (PGOOD) pin is pulled down until it reaches the low-side negative current limit ( $I_{LIMIT\_NEG}$ ). Once the PGOOD current ( $I_{PGOOD}$ ) reaches  $I_{LIMIT\_NEG}$ , the LS-FET turns off for 200ns and the HS-FET turns on for 200ns. After 200ns, the LS-FET turns on again. The MPQ8633AH repeats this operation to discharge the OV condition on the output. Once  $V_{FB}$  drops below 105% of  $V_{REF}$ , the IC exits OVP discharge mode.

### Thermal Shutdown

Thermal shutdown protects the IC from operating at exceedingly high temperatures by internally monitoring the junction temperature ( $T_J$ ). If  $T_J$  exceeds the thermal shutdown threshold (typically 160°C), then the converter shuts down and discharges the TRK/REF capacitors. Once  $T_J$  drops below 130°C, then the converter initiates a SS to resume normal operation. There is a hysteresis of about 30°C. Thermal shutdown is a non-latch protection.

### Output Voltage Setting and Remote Output Voltage Sensing

Choose a value for  $R_{FB1}$ . Then  $R_{FB2}$  can be calculated with Equation (5):

$$R_{FB2}(k\Omega) = \frac{V_{REF}}{V_{OUT} - V_{REF}} \times R_{FB1}(k\Omega) \quad (5)$$

For the best load transient response, place a feed-forward capacitor ( $C_{FF}$ ) in parallel to  $R_{FB1}$ .  $R_{FB1}$  and  $C_{FF}$  add an extra zero to the system,

which improves loop response.  $R_{FB1}$  and  $C_{FF}$  are selected so that the zero is between 20kHz and 60kHz. This zero can be calculated with Equation (6):

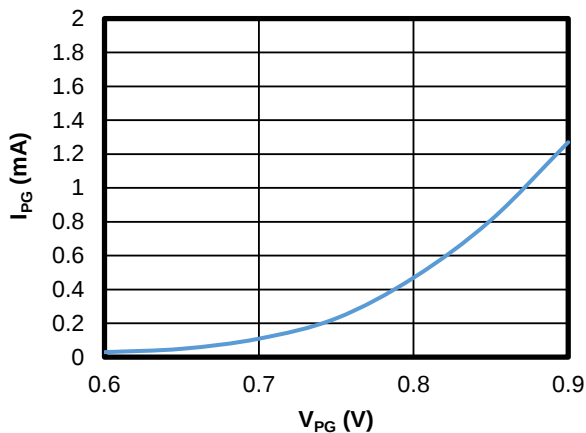
$$f_z = \frac{1}{2\pi \times R_{FB1} \times C_{FF}} \quad (6)$$

### Power Good (PGOOD)

The MPQ8633B-H has a power good (PGOOD) output pin. PGOOD is the open-drain of a MOSFET. Connect PGOOD to  $V_{CC}$  or another external voltage source below 3.6V via a pull-up resistor (10k $\Omega$ ). Once  $V_{IN}$  is applied, the MOSFET turns on and PGOOD is pulled down low before TRK/REF is ready. Once  $V_{FB}$  reaches 92.5% of  $V_{REF}$ , PGOOD is pulled high after a 0.8ms delay.

If  $V_{FB}$  drops to 80% of  $V_{REF}$  or exceeds 116% of the nominal  $V_{REF}$ , then PGOOD is pulled low. PGOOD can only be pulled high again after a SS is initiated.

If the input supply fails to power the IC, then PGOOD is pulled low, even when it is tied to an external DC source via a pull-up resistor. The relationship between the PGOOD voltage ( $V_{PGOOD}$ ) and the pull-up current is shown in Figure 5.



**Figure 5: Pull-Up Current vs. PGOOD Voltage**

### Enable (EN) Configuration

The enable (EN) pin turns the converter on and off. Pull EN high to turn the converter on; pull EN low to turn it off. Do not float EN. EN can be driven by an analog or a digital control logic signal to enable and disable the part. The MPQ8633B-H provides accurate EN thresholds, which allows a resistor divider connected between the  $V_{IN}$  and AGND pins can be used to configured  $V_{IN}$  to enable the part. This is highly recommended for applications with no dedicated EN control logic signals to avoid  $V_{EN}$  dropping below or exceeding the under-voltage lockout (UVLO) threshold during start-up and shutdown. The resistor divider values ( $R_{UP}$  +  $R_{DOWN}$ ) can be calculated with Equation (7):

$$V_{IN\_START}(V) = V_{EN\_RISING} \times \frac{R_{UP} + R_{DOWN}}{R_{DOWN}} \quad (7)$$

Where  $V_{EN\_RISING}$  is 1.22V.

Choose  $R_{UP}$  and  $R_{DOWN}$  so that that  $V_{EN}$  does not exceed 3.6V as  $V_{IN}$  reaches its maximum value.

EN can also be connected to  $V_{IN}$  via a pull-up resistor ( $R_{UP}$ ). Choose  $R_{UP}$  so that the maximum EN current is 50 $\mu$ A.  $R_{UP}$  can be calculated with Equation (8):

$$R_{UP}(k\Omega) = \frac{V_{IN\_MAX}(V)}{0.05(mA)} \quad (8)$$

## APPLICATION INFORMATION

### Selecting the Input Capacitor ( $C_{IN}$ )

The step-down converter has a discontinuous input current ( $I_{IN}$ ) and requires a capacitor to supply AC current to the step-down converter while maintaining the DC  $V_{IN}$ . Use ceramic capacitors for the best performance. Place the input capacitors as close to the VIN pin as possible.

The capacitance can vary significantly with the temperature. Capacitors with X5R and X7R dielectrics are recommended due to their stable temperature characteristics and low ESR.

The input capacitors should have a ripple current rating that exceeds the converter's maximum input ripple current. The input ripple current ( $I_{CIN}$ ) can be estimated with Equation (9):

$$I_{CIN} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)} \quad (9)$$

The worst case condition occurs at  $V_{IN} = 2 \times V_{OUT}$ , which can be calculated with Equation (10):

$$I_{CIN} = \frac{I_{OUT}}{2} \quad (10)$$

For simplification, choose an input capacitor ( $C_{IN}$ ) with an RMS current rating that exceeds half the maximum load current ( $I_{LOAD\_MAX}$ ).  $C_{IN}$  determines the converter's input voltage ripple ( $\Delta V_{IN}$ ). If there is a  $\Delta V_{IN}$  requirement in the system, then select  $C_{IN}$  to meet the system's specification.

$\Delta V_{IN}$  can be calculated with Equation (11):

$$\Delta V_{IN} = \frac{I_{OUT}}{f_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (11)$$

The worst-case condition occurs at  $V_{IN} = 2 \times V_{OUT}$ , which can be calculated with Equation (12):

$$\Delta V_{IN} = \frac{1}{4} \times \frac{I_{OUT}}{f_{SW} \times C_{IN}} \quad (12)$$

### Selecting the Output Capacitor ( $C_{OUT}$ )

The output capacitor ( $C_{OUT}$ ) maintains the DC  $V_{OUT}$ . Use POSCAP or ceramic capacitors for the best performance. The output voltage ripple ( $\Delta V_{OUT}$ ) can be estimated with Equation (13):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_{SW} \times C_{OUT}}\right) \quad (13)$$

When using ceramic capacitors, the capacitance dominates the impedance at  $f_{SW}$ . For simplification,  $\Delta V_{OUT}$  can be calculated with Equation (14):

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_{SW}^2 \times L \times C_{OUT}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (14)$$

The capacitance also dominates the  $\Delta V_{OUT}$ . For simplification,  $\Delta V_{OUT}$  can be estimated with Equation (15):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times R_{ESR} \quad (15)$$

### Selecting the Inductor

The inductor supplies a constant current to the output load while being driven by the switching  $V_{IN}$ . A larger inductor results in less ripple current and lower  $\Delta V_{OUT}$ ; however, a larger inductor has a larger size, a higher series resistance, and a lower saturation current. Choose an inductor so that the peak-to-peak inductor ripple current ( $\Delta I_L$ ) is between 30% and 40% of the maximum switch  $I_{LIMIT}$ . The peak inductor current ( $I_{L\_PEAK}$ ) should be below the maximum switch  $I_{LIMIT}$ . The inductance ( $L$ ) can be calculated with Equation (16):

$$L = \frac{V_{OUT}}{f_{SW} \times \Delta I_L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (16)$$

Choose an inductor that will not saturate under the maximum  $I_{L\_PEAK}$ .  $I_{L\_PEAK}$  can be calculated with Equation (17):

$$I_{L\_PEAK} = I_{OUT} + \frac{V_{OUT}}{2 \times f_{SW} \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (17)$$

## PCB Layout Guidelines

Efficient PCB layout is critical for stable operation. For the best performance, refer to Figure 6 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 IC.
3. Ensure that both the VIN and PGND copper planes are large enough to minimize parasitic impedance.
4. Place as multiple PGND vias as close to PGND as possible 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 VCC capacitor's ground connection.
7. Place the BST capacitor ( $C_{\text{BST}}$ ) as close to the BST and SW pins as possible using  $\geq 20$  mil traces. It is recommended to have  $C_{\text{BST}}$  be between 0.1 $\mu\text{F}$  and 1 $\mu\text{F}$ .
8. Place the REF capacitor ( $C_{\text{REF}}$ ) close to TRK/REF and RGND.
9. Place a via on the PGOOD pad as close to the IC as possible, and at least 10mm away from the positive side of the first input decoupling capacitor.
10. Place the VOSENSE capacitor between the output sensing traces, and close to the FB components.

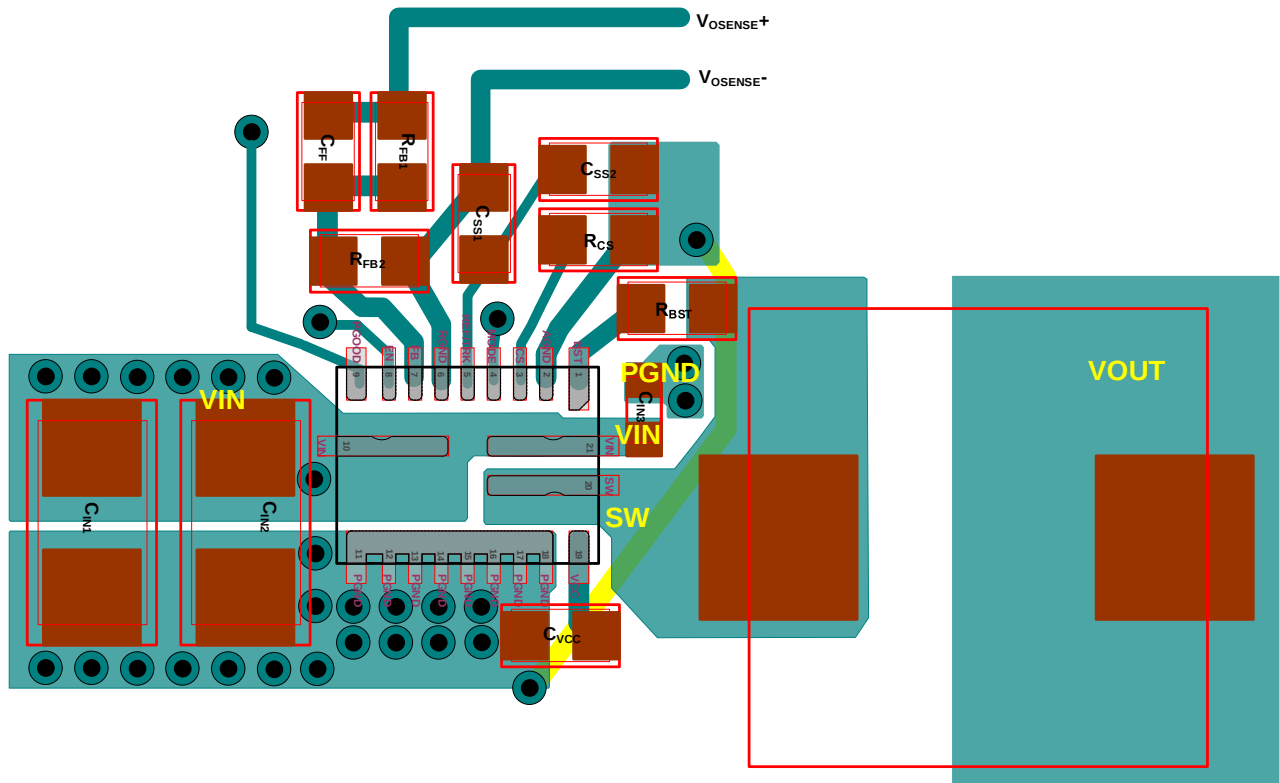
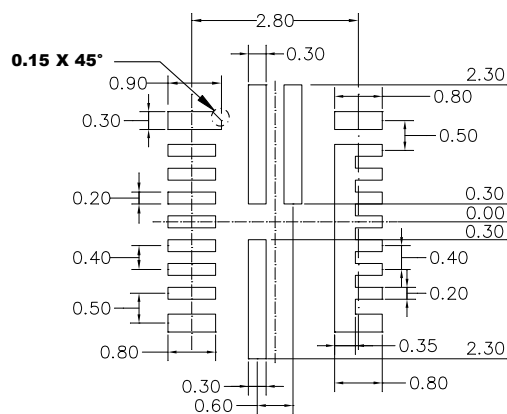
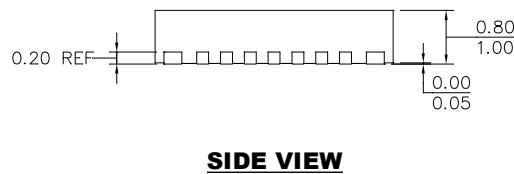
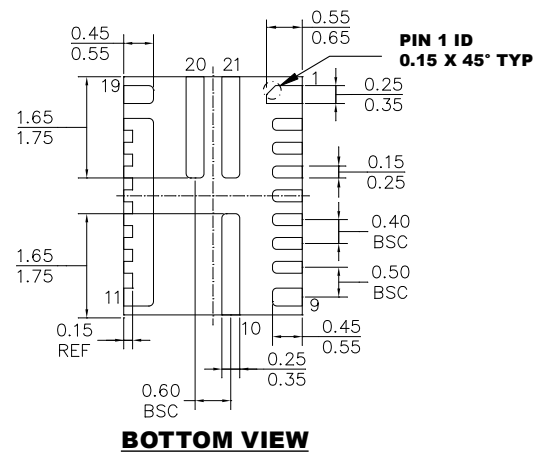
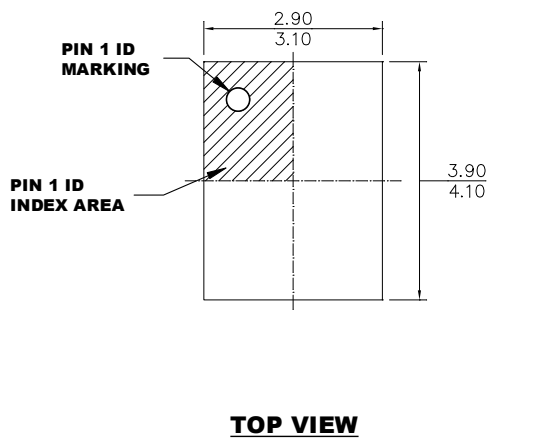


Figure 6: Recommended PCB Layout

## PACKAGE INFORMATION

### QFN-21 (3mmx4mm)

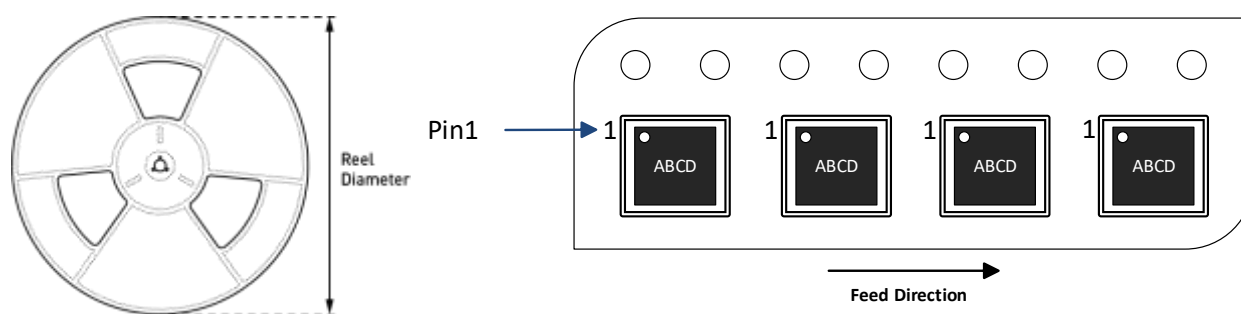


## **RECOMMENDED LAND PATTERN**

**NOTE:**

- 1) THE LAND PATTERNS OF PINS 1, 9, 10, 11, 19, 20, AND 21 ARE THE SAME WIDTH.
- 2) ALL DIMENSIONS ARE IN MILLIMETERS.
- 3) EXPOSED PADDLE SIZE DOES NOT INCLUDE MOLD FLASH.
- 4) LEAD COPLANARITIES SHALL BE 0.1 MILLIMETERS MAX.
- 5) JEDEC REFERENCE IS MO-220.
- 6) DRAWING IS NOT TO SCALE.

# CARRIER INFORMATION



| Part Number     | Package Description | Quantity/ Reel | Quantity/ Tube | Quantity/ Tray | Reel Diameter | Carrier Tape Width | Carrier Tape Pitch |
|-----------------|---------------------|----------------|----------------|----------------|---------------|--------------------|--------------------|
| MPQ8633B-HGLE-Z | QFN-21 (3mmx4mm)    | 5000           | N/A            | N/A            | 13in          | 12mm               | 8mm                |

## REVISION HISTORY

| Revision # | Revision Date | Description     | Pages Updated |
|------------|---------------|-----------------|---------------|
| 1.0        | 2/25/2022     | Initial Release | -             |

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