

High-Voltage 3.6A Integrated Switch PFM/PWM Boost Regulator

Features

- 36V, 100 mΩ Integrated Switch
- Up to 92% Efficiency
- Higher Current Compared to the Previous MCP166x Switchers Family
- Output Voltage Range: Up to 32V
- 3.6A Typical Peak Input Current Limit:
 - $I_{OUT} > 1\text{ A}$ at 5.0V V_{IN} , 12V V_{OUT}
 - $I_{OUT} > 700\text{ mA}$ at 3.3V V_{IN} , 12V V_{OUT}
 - $I_{OUT} > 400\text{ mA}$ at 4.2V V_{IN} , 24V V_{OUT}
- Input Voltage Range: 2.9V to 5V
- Input Undervoltage Lockout (UVLO):
 - UVLO at V_{IN} Rising: 2.9V, typical
 - UVLO at V_{IN} Falling: 2.7V, typical
- No Load Input Current: 250 μA Typically for Pulse-Frequency Modulation (PFM), 500 μA Typically for Pulse-Width Modulation (PWM)
- Shutdown Mode with 0.4 μA Typical Quiescent Current
- Automatically PFM/PWM or Selected by the MODE Pin, for High Efficiency
- 500 kHz PWM Operation with Skipping Mode Operation Selectable by Dedicated MODE Pin
- Feedback Voltage Reference: $V_{FB} = 1.2\text{V}$
- Cycle-by-Cycle Current Limiting
- Internal Compensation
- Inrush Current Limiting and Internal Soft Start
- Output Overvoltage Protection (OVP) and Open-Load Protection (OLP) for Constant Current Configuration
- Thermal Shutdown
- Easily Configurable for Single-ended Primary-inductor Converter (SEPIC), Cuk or Flyback Topologies
- Available Package: 10-Lead 2x2 mm VQFN

Applications

- Three-Cell Alkaline, Lithium and NiMH/NiCd Portable Products
- Single-Cell Li-Ion to 5V, 12V or 24V Converters
- LCD Bias Supply for Portable Applications
- Camera Phone Flash
- Flashlight
- Battery-Powered LEDs
- Lighting Applications

- Portable Medical Equipment
- Hand-Held Instruments

General Description

The MCP1665 device is a compact, high-efficiency, fixed-frequency, nonsynchronous step-up DC-DC converter that integrates a 36V, 100 mΩ NMOS switch. It provides a space-efficient high-voltage step-up power supply solution for applications powered by either three-cell alkaline, Ultimate Lithium, NiCd, NiMH, one-cell Li-Ion or Li-Polymer batteries.

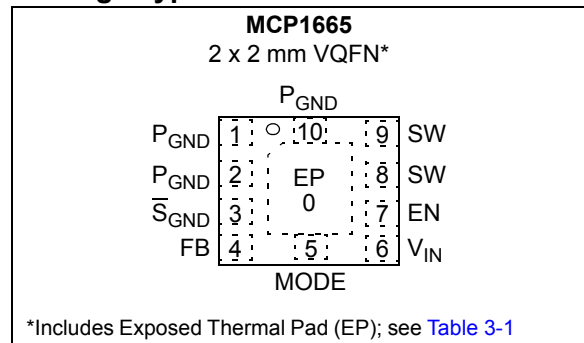
The integrated switch is protected by the typical 3.6A cycle-by-cycle inductor peak current limit operation. There is an output overvoltage protection and an open-load protection that turn off switching so that if the feedback resistors are accidentally disconnected, the feedback pin is short-circuited to GND or the output is exposed to excessive voltage.

Soft Start circuit allows the regulator to start-up without high inrush current or output voltage overshoot from a low-voltage input. The device features an UVLO which avoids start-up and operation with low inputs or discharged batteries for cell-powered applications. A PFM switching mode (used for power saving) is implemented and it is selectable by the dedicated MODE pin.

For standby applications (EN = GND), the device stops switching, enters Shutdown mode and consumes 0.4 μA of (typical) input current (feedback divider current not included).

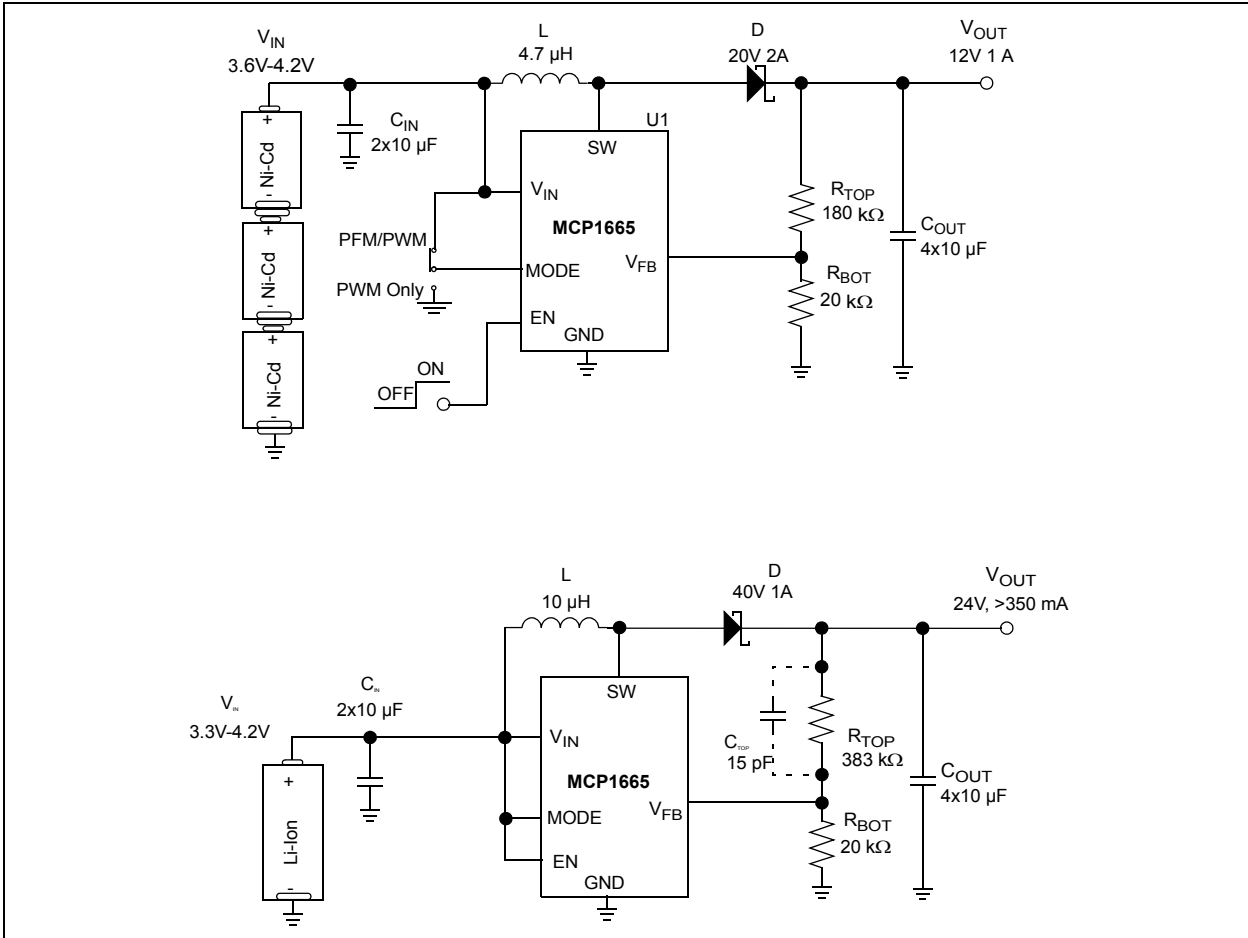
MCP1665 is easy to use and allows creating classic boost, SEPIC or flyback DC-DC converters within a small Printed Circuit Board (PCB) area. All compensation and protection circuitry are integrated to minimize the number of external components. Ceramic input and output capacitors are used.

Package Types

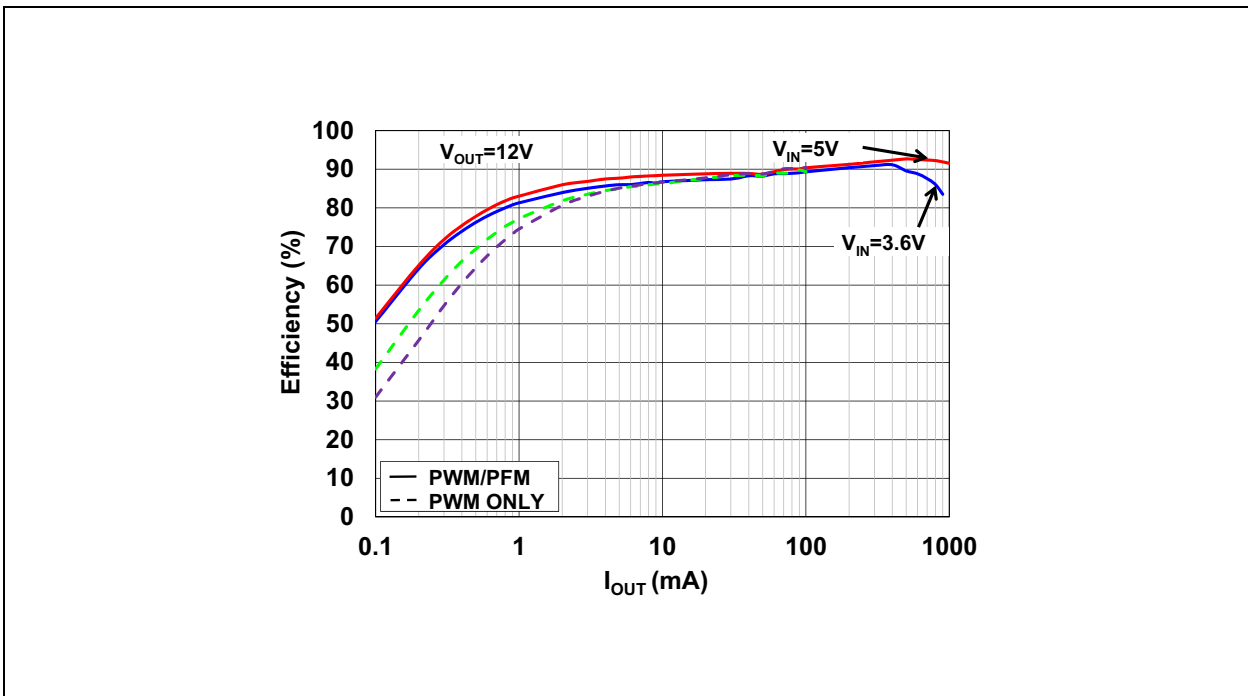


MCP1665

Typical Applications



Best Efficiency vs. I_{OUT}



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings

| | |
|---------------------------------------------|--------------------|
| EN, V _{IN} , V _{FB} – GND | +5.5V |
| V _{SW} – GND | +36V |
| Power Dissipation | Internally Limited |
| Storage Temperature | –65°C to +150°C |
| Ambient Temperature with Power Applied | –40°C to +125°C |
| Operating Junction Temperature | –40°C to +150°C |
| ESD Protection On All Pins: | |
| HBM | 4 kV |
| MM | 300V |

Note: Stresses above those listed under “Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect the device’s reliability.

TABLE 1-1: DC AND AC CHARACTERISTICS

| Electrical Specifications: Unless otherwise specified, all limits apply for typical values at ambient temperature T _A = +25°C, V _{IN} = 3.6V, I _{OUT} = 25 mA, V _{OUT} = 12V, C _{IN} = 22 μF, C _{OUT} = 40 μF, X7R ceramic, L = 4.7 μH. | | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|---------------------|------|--------------|-------|---------------------------------------------------------------------------------|
| Boldface specifications apply over the controlled T _A range of –40°C to +125°C. | | | | | | |
| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
| Input Voltage Range | V _{IN} | 2.7 | — | 5 | V | Note 1 |
| Undervoltage Lockout (UVLO) | UVLO _{START} | 2.7 | 2.85 | 3 | V | V _{IN} rising, I _{OUT} = 25 mA resistive load |
| | UVLO _{STOP} | 2.5 | 2.65 | 2.8 | V | V _{IN} falling, I _{OUT} = 25 mA resistive load |
| Output Voltage Adjust Range | V _{OUT} | V _{IN} +1V | — | 32 | V | Note 1 |
| Maximum Output Current | I _{OUT} | — | 1000 | — | mA | 5.0V V _{IN} , 12V V _{OUT} 10% drop (Note 4) |
| | | — | 700 | — | mA | 3.3V V _{IN} , 12V V _{OUT} 10% drop (Note 4) |
| | | — | 400 | — | mA | 4.2V V _{IN} , 24V V _{OUT} 10% drop (Note 4) |
| Feedback Voltage | V _{FB} | 1.164 | 1.2 | 1.236 | V | — |
| V _{FB} Accuracy | — | -3 | — | 3 | % | — |
| Feedback Input Bias Current | I _{VFB} | — | 10 | — | nA | — |
| No Load Input Current (PFM) | I _{IN0} | — | 250 | — | μA | Device switching, no load, MODE = V _{IN} (Note 2, Note 4) |
| Shutdown Quiescent Current | I _{QSHDN} | — | 0.4 | 2.5 | μA | EN = GND, feedback divider current not included (Note 3) |
| Peak Switch Current Limit | I _{Lmax} | — | 3.6 | — | A | Note 4 |
| NMOS Switch Leakage | I _{NLK} | — | 0.3 | — | μA | V _{IN} = V _{SW} = 5V; V _{EN} = V _{FB} = GND |
| NMOS Switch ON Resistance | R _{DS(ON)} | — | 0.1 | — | Ω | V _{GS} = 3.6V, Peak Limit = 3.6A (Note 4) |
| Line Regulation | $ \frac{\Delta V_{FB}/V_{FB}}{\Delta V_{IN}} $ | — | 0.02 | 0.1 | %/V | V _{IN} = 3V to 5V, I _{OUT} = 150 mA |

- Note 1:** Minimum input voltage in the range of V_{IN} (V_{IN} ≤ 5V < V_{OUT}) depends on the maximum duty cycle (DC_{MAX}) and on the output voltage (V_{OUT}), according to the boost converter equation:
 $V_{INmin} = V_{OUT} \times (1 - DC_{MAX})$. (V_{OUT} – V_{IN}) > 1V is required for boost applications.
- 2:** I_{IN0} varies with input and output voltage and input capacitor leakage (Figure 2-8). I_{IN0} is measured on the V_{IN} pin when the device is switching (EN = V_{IN}), at no load, with R_{TOP} = 180 kΩ and R_{BOT} = 20 kΩ.
- 3:** I_{QSHDN} is measured on the V_{IN} pin when the device is not switching (EN = GND), at no load, with the feedback resistors (R_{TOP} + R_{BOT}) disconnected from V_{OUT}.
- 4:** Determined by characterization, not production tested.

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TABLE 1-1: DC AND AC CHARACTERISTICS (CONTINUED)

Electrical Specifications: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{ mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$.
Boldface specifications apply over the controlled T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|----------------------------------|--------------------------|------------|------|------------|------------------|------------------------------------------------------------------------------------|
| Load Regulation | $ \Delta V_{FB}/V_{FB} $ | — | 0.2 | — | % | $I_{OUT} = 50\text{ mA}$ to 600 mA , PWM only operation (Note 4) |
| Maximum Duty Cycle | DC_{MAX} | — | 90 | — | % | Note 4 |
| Switching Frequency | f_{SW} | 425 | 500 | 575 | kHz | $\pm 15\%$ |
| EN Input Logic High | V_{IH} | 70 | — | — | % of V_{IN} | $I_{OUT} = 1\text{ mA}$ |
| EN Input Logic Low | V_{IL} | — | — | 18 | % of V_{IN} | $I_{OUT} = 1\text{ mA}$ |
| EN Input Leakage Current | I_{ENLK} | — | 5 | — | nA | $V_{EN} = 5\text{V}$ |
| MODE Input Logic High | — | 54 | — | — | % of V_{IN} | $I_{OUT} = 10\text{ mA}$, Note 4 |
| MODE Input Logic Low | — | — | — | 27 | % of V_{IN} | $I_{OUT} = 10\text{ mA}$, Note 4 |
| MODE Input Leakage Current | — | — | 5 | — | nA | $V_{MODE} = 5\text{V}$ |
| Soft-Start Time | t_{SS} | — | 3.7 | — | ms | T_A , EN Low-to-High, 90% of V_{OUT} |
| Thermal Shutdown Die Temperature | T_{SD} | — | 150 | — | $^\circ\text{C}$ | Note 4 |
| Die Temperature Hysteresis | T_{SDHYS} | — | 15 | — | $^\circ\text{C}$ | Note 4 |

- Note 1:** Minimum input voltage in the range of V_{IN} ($V_{IN} \leq 5\text{V} < V_{OUT}$) depends on the maximum duty cycle (DC_{MAX}) and on the output voltage (V_{OUT}), according to the boost converter equation:
 $V_{INmin} = V_{OUT} \times (1 - DC_{MAX})$. ($V_{OUT} - V_{IN}$) $> 1\text{V}$ is required for boost applications.
- 2:** I_{IN0} varies with input and output voltage and input capacitor leakage (**Figure 2-8**). I_{IN0} is measured on the V_{IN} pin when the device is switching ($EN = V_{IN}$), at no load, with $R_{TOP} = 180\text{ k}\Omega$ and $R_{BOT} = 20\text{ k}\Omega$.
- 3:** I_{QSHDN} is measured on the V_{IN} pin when the device is not switching ($EN = \text{GND}$), at no load, with the feedback resistors ($R_{TOP} + R_{BOT}$) disconnected from V_{OUT} .
- 4:** Determined by characterization, not production tested.

TABLE 1-2: TEMPERATURE SPECIFICATIONS

Electrical Specifications: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{ mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.
Boldface specifications apply over the controlled T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--------------------------------------|---------------|------|------|------|---------------------------|--------------|
| Temperature Ranges | | | | | | |
| Operating Junction Temperature Range | T_J | -40 | — | +125 | $^\circ\text{C}$ | Steady State |
| Storage Temperature Range | T_A | -65 | — | +150 | $^\circ\text{C}$ | — |
| Maximum Junction Temperature | T_J | — | — | +150 | $^\circ\text{C}$ | Transient |
| Package Thermal Resistances | | | | | | |
| Thermal Resistance, 10LD-VQFN-2x2 mm | θ_{JA} | — | 48.3 | — | $^\circ\text{C}/\text{W}$ | — |

2.0 TYPICAL PERFORMANCE CURVES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (for example, outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{ mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.

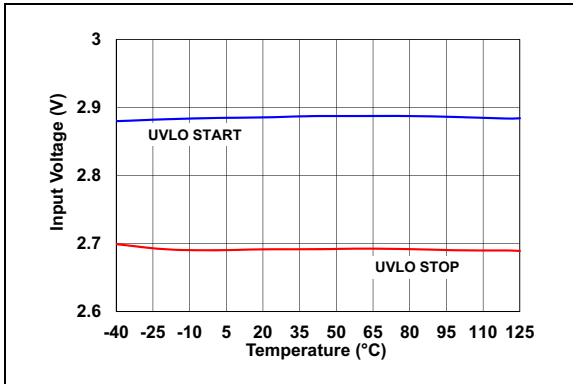


FIGURE 2-1: Undervoltage Lockout (UVLO) vs. Ambient Temperature.

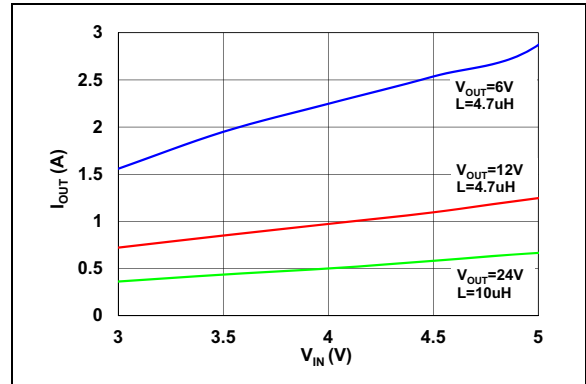


FIGURE 2-3: Maximum Output Current vs. V_{IN} (V_{OUT} in Regulation with Maximum 10% Drop).

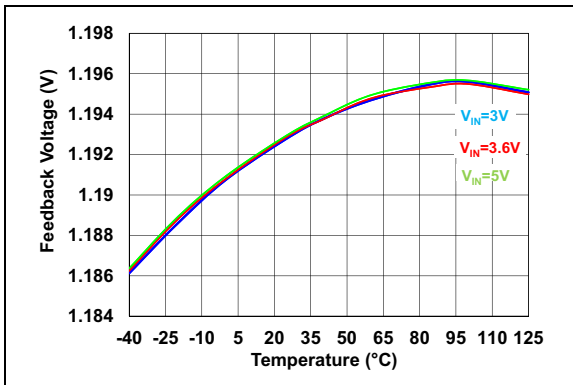


FIGURE 2-2: V_{FB} Voltage vs. Ambient Temperature and V_{IN} .

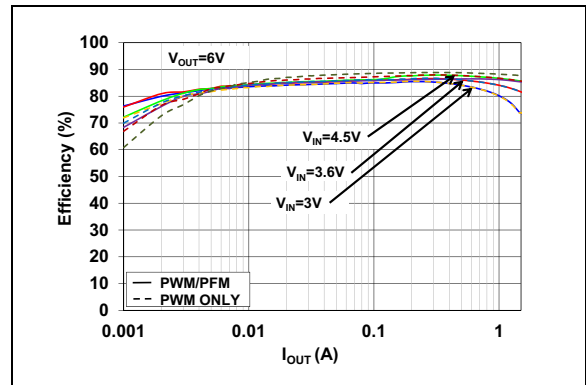


FIGURE 2-4: 6.0V V_{OUT} Efficiency vs. I_{OUT} .

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Note: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.

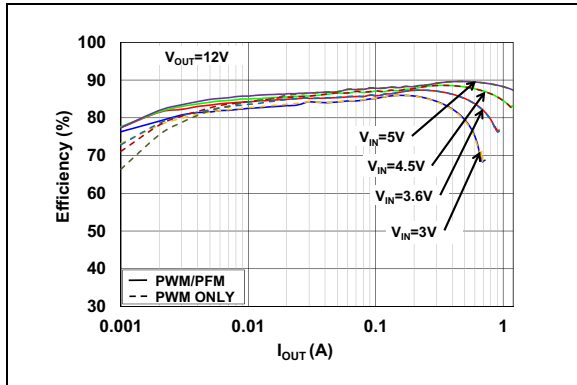


FIGURE 2-5: 12.0V V_{OUT} Efficiency vs. I_{OUT} .

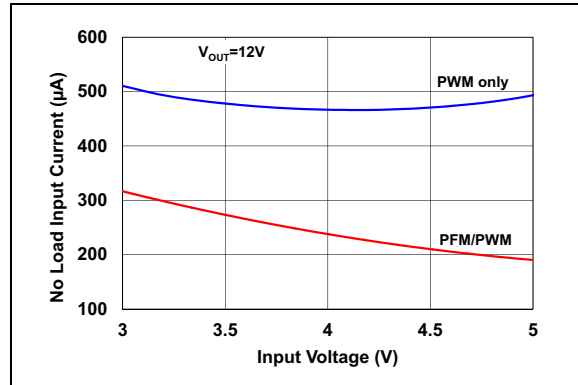


FIGURE 2-8: No Load Input Current, I_{IN0} vs. V_{IN} ($EN = V_{IN}$).

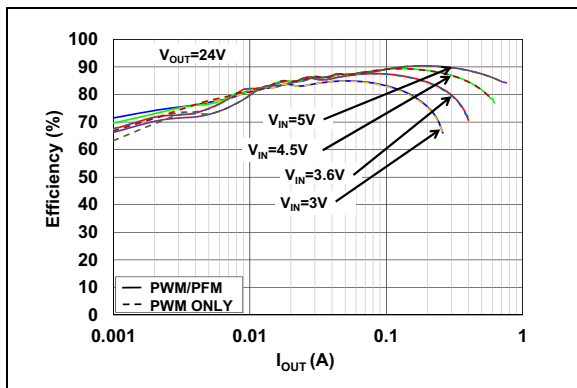


FIGURE 2-6: 24.0V V_{OUT} Efficiency vs. I_{OUT} .

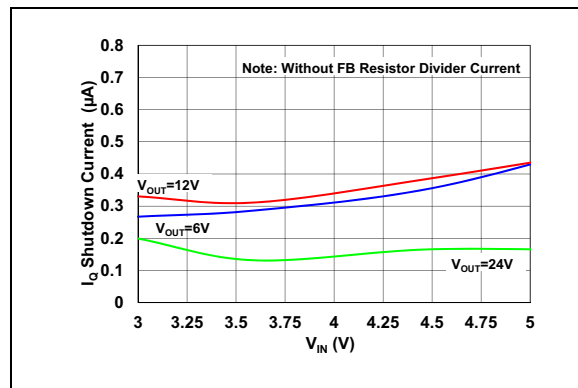


FIGURE 2-9: Shutdown Quiescent Current, I_{QSHDN} vs. V_{IN} ($EN = GND$).

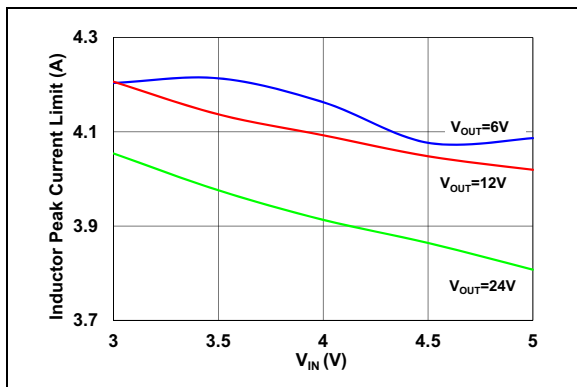


FIGURE 2-7: Inductor Peak Current Limit vs. Input Voltage.

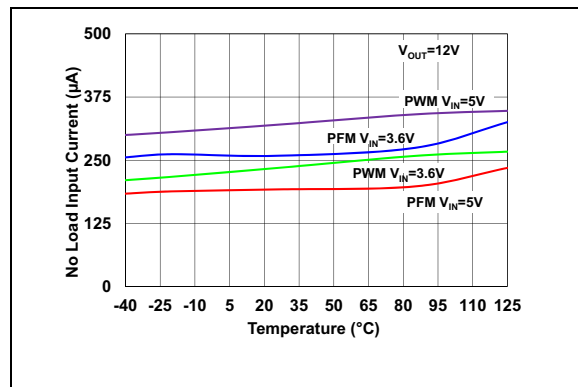


FIGURE 2-10: No Load Input Current, I_{IN0} vs. Ambient Temperature.

Note: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{ mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.

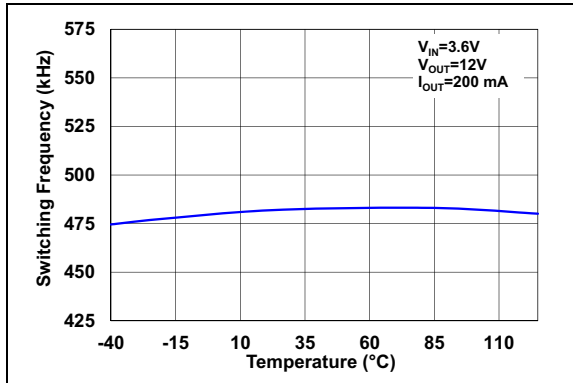


FIGURE 2-11: f_{SW} vs. Ambient Temperature.

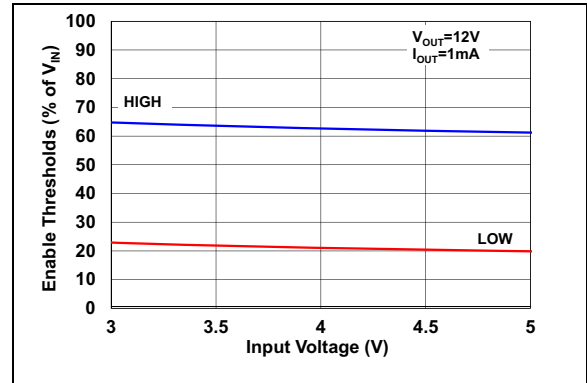


FIGURE 2-14: Enable Threshold vs. Input Voltage.

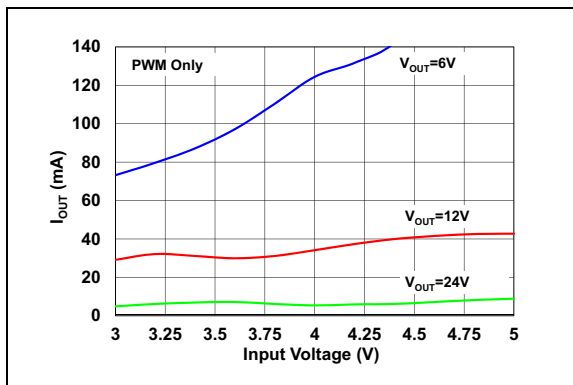


FIGURE 2-12: PWM Pulse Skipping Mode Threshold vs. V_{IN} .

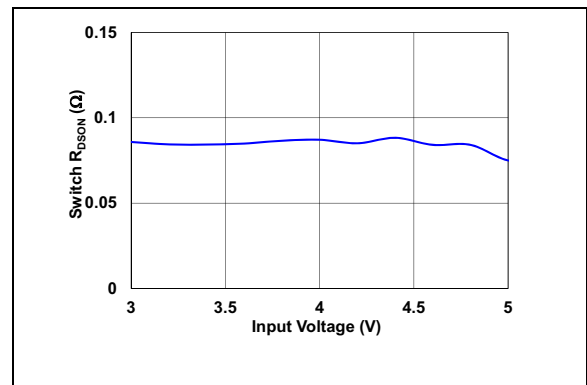


FIGURE 2-15: N-Channel Switch $R_{DS(on)}$ vs. V_{IN} .

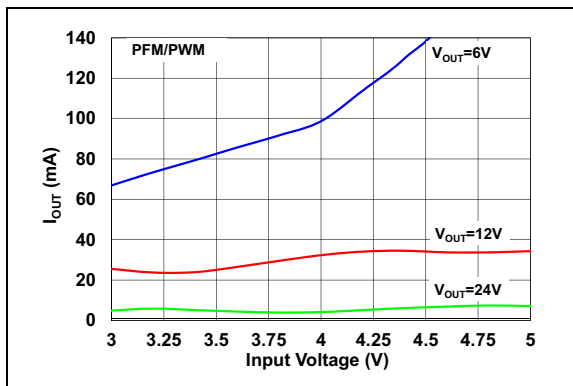


FIGURE 2-13: PFM/PWM Mode Threshold.

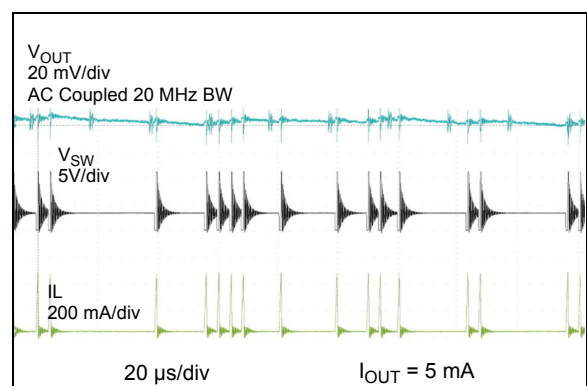


FIGURE 2-16: 12.0V V_{OUT} Light Load PWM Mode Waveforms.

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Note: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.

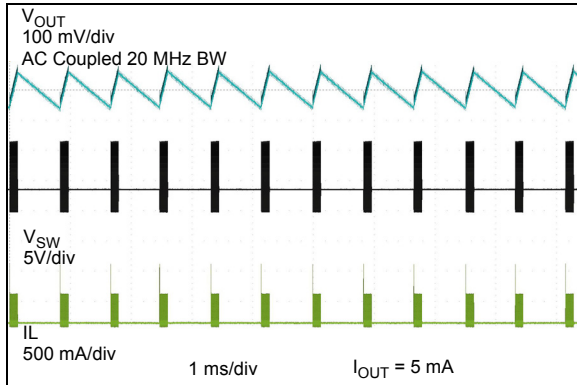


FIGURE 2-17: 12.0V V_{OUT} Light Load PFM Mode Waveforms.

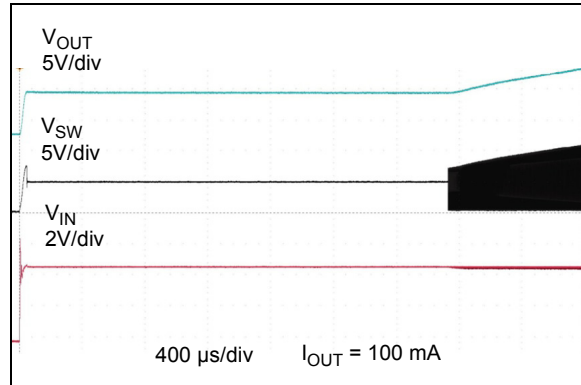


FIGURE 2-20: 12.0V Start-Up ($V_{IN} = V_{ENABLE}$).

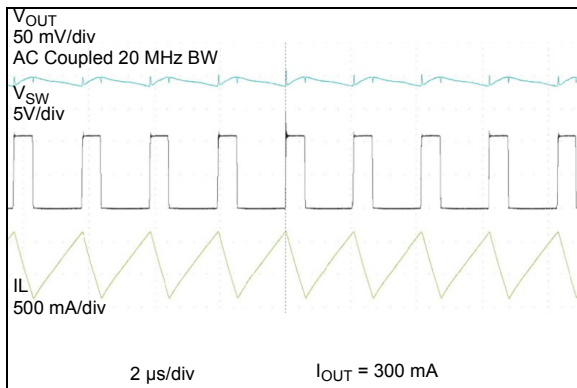


FIGURE 2-18: High-Load PWM Mode Waveforms.

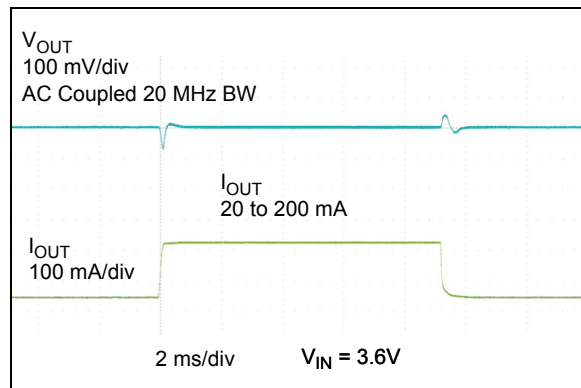


FIGURE 2-21: 12.0V V_{OUT} Load Transient Waveforms for PWM only ($\text{MODE} = \text{GND}$).

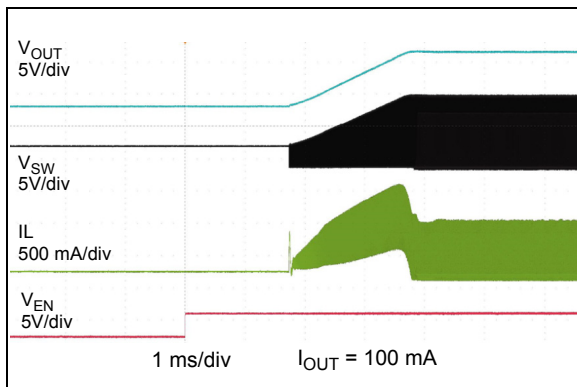


FIGURE 2-19: 12.0V Start-Up from Enable.

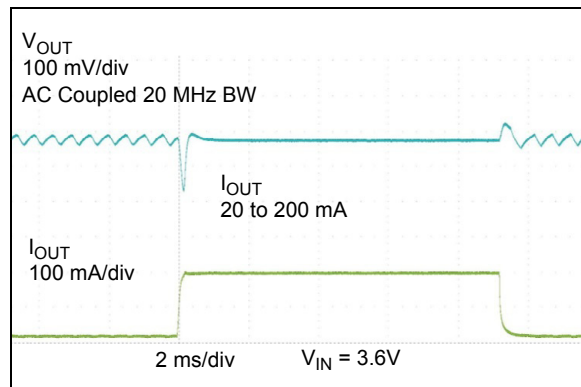


FIGURE 2-22: 12.0V V_{OUT} Load Transient Waveforms for PFM/PWM ($\text{MODE} = V_{IN}$).

Note: Unless otherwise specified, all limits apply for typical values at ambient temperature $T_A = +25^\circ\text{C}$, $V_{IN} = 3.6\text{V}$, $I_{OUT} = 25\text{mA}$, $V_{OUT} = 12\text{V}$, $C_{IN} = 22\ \mu\text{F}$, $C_{OUT} = 40\ \mu\text{F}$, X7R ceramic, $L = 4.7\ \mu\text{H}$ and 10-Lead 2x2 mm VQFN package.

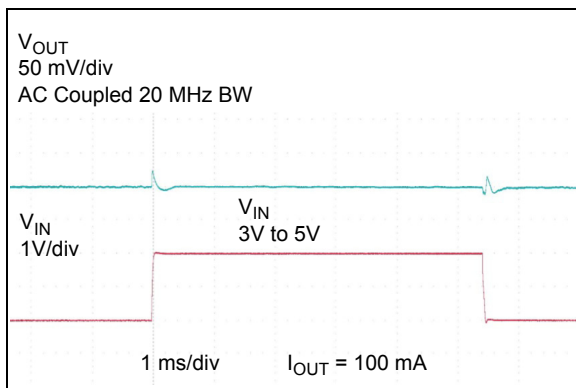


FIGURE 2-23: 12.0V V_{OUT} Line Transient Waveforms.

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NOTES:

3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in [Table 3-1](#)

TABLE 3-1: PIN FUNCTION TABLE

| MCP1665 10Lead 2X2 mm VQFN | Symbol | Description |
|----------------------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| 1 | P _{GND} | Power Ground Pin |
| 2 | P _{GND} | Power Ground Pin |
| 3 | S _{GND} | Signal Ground Pin |
| 4 | V _{FB} | Feedback Voltage Pin |
| 5 | MODE | MODE select pin MODE = GND: device is switching in PWM only MODE = V _{IN} : device is switching in PFM for light load |
| 6 | V _{IN} | Input Voltage Pin |
| 7 | EN | Enable Control Input Pin EN = GND: device is in shutdown EN = V _{IN} : device switching |
| 8 | SW | Switch Node, Boost Inductor Input Pin |
| 9 | SW | Switch Node, Boost Inductor Input Pin |
| 10 | P _{GND} | Power Ground Pin |
| 0 | EP | Exposed Thermal Pad (EP); must be connected to Ground. |

3.1 Power Ground Pin (P_{GND})

The power ground pin is used as a return for the high-current N-Channel switch. The signal ground and power ground must be connected externally in one point.

3.2 Signal Ground Pin (S_{GND})

The signal ground pin is used as a return for the integrated reference voltage and error amplifier. The signal ground and power ground must be connected externally in one point.

3.3 Feedback Voltage Pin (V_{FB})

The V_{FB} pin is used to provide output voltage regulation by using a resistor divider. The V_{FB} voltage is 1.2V typical.

3.4 MODE Select Pin

This pin selects the power saving mode between PFM/PWM (MODE = V_{IN}) and PWM only (MODE = GND).

3.5 Power Supply Input Voltage Pin (V_{IN})

Connect the input voltage source to V_{IN}. The input source must be decoupled with a 22 μF (minimum) capacitor to GND.

3.6 Enable Pin (EN)

The EN pin is a logic-level input used to enable or disable device switching and to lower the quiescent current while disabled. A logic high will enable regulator's output. A logic low will ensure that the regulator is disabled.

3.7 Switch Node Pin (SW)

Connect the inductor from the input voltage to the SW pin. The SW pin carries inductor current, which is 3.6A peak (typical). The integrated N-Channel switch drain is internally connected to the SW node.

3.8 Exposed Thermal Pad (EP)

There is no internal electrical connection between the Exposed Thermal Pad (EP) and the S_{GND} and P_{GND} pins. PGND, SGND and EP must be connected together in one low-impedance ground point. A separate ground plane is recommended.

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NOTES:

4.0 DETAILED DESCRIPTION

4.1 Device Overview

MCP1665 is a constant frequency PFM/PWM boost (step-up) converter, based on a peak current mode control architecture, which delivers high efficiency over a wide load range, from three-cell Alkaline, Ultimate Lithium, NiMH, NiCd and single-cell Li-Ion battery inputs. A high level of integration lowers the total system cost, eases implementation and reduces board area.

The device features controlled start-up voltage (UVLO), adjustable output voltage, 500 kHz switching frequency, PFM/PWM mode or PWM/skipping selectable by the dedicated MODE pin, 36V integrated switch, internal compensation, inrush current limit, soft start and overvoltage/open load protections (in case the V_{FB} connection is lost).

The typical 100 m Ω , 36V integrated switch is protected by the 3.6A (typical) cycle-by-cycle peak inductor current limit. When the ENABLE pin is pulled to ground (EN = GND), the device stops switching, enters in Shutdown mode and consumes approximately 0.4 μ A of input current (feedback current is not included).

MCP1665 can be used to design classic boost, SEPIC or flyback DC-DC converters.

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4.2 Functional Description

The MCP1665 device is a compact, high-efficiency, fixed-frequency, step-up DC-DC converter, that provides an easy-to-use high-output power supply solution for applications powered by either three-cell Alkaline or Lithium Energizer, three-cell NiCd or NiMH, one-cell Li-Ion or Li-Polymer, or two-cell lead-acid batteries.

Figure 4-1 depicts the functional block diagram of the MCP1665 device. It incorporates a current-mode control scheme, in which the PWM ramp signal is derived from the NMOS power switch current (V_{SENSE}). This ramp signal adds slope ramp compensation signal (V_{RAMP}) and is compared to the output of the error amplifier (V_{ERROR}) to control the on-time of the power switch.

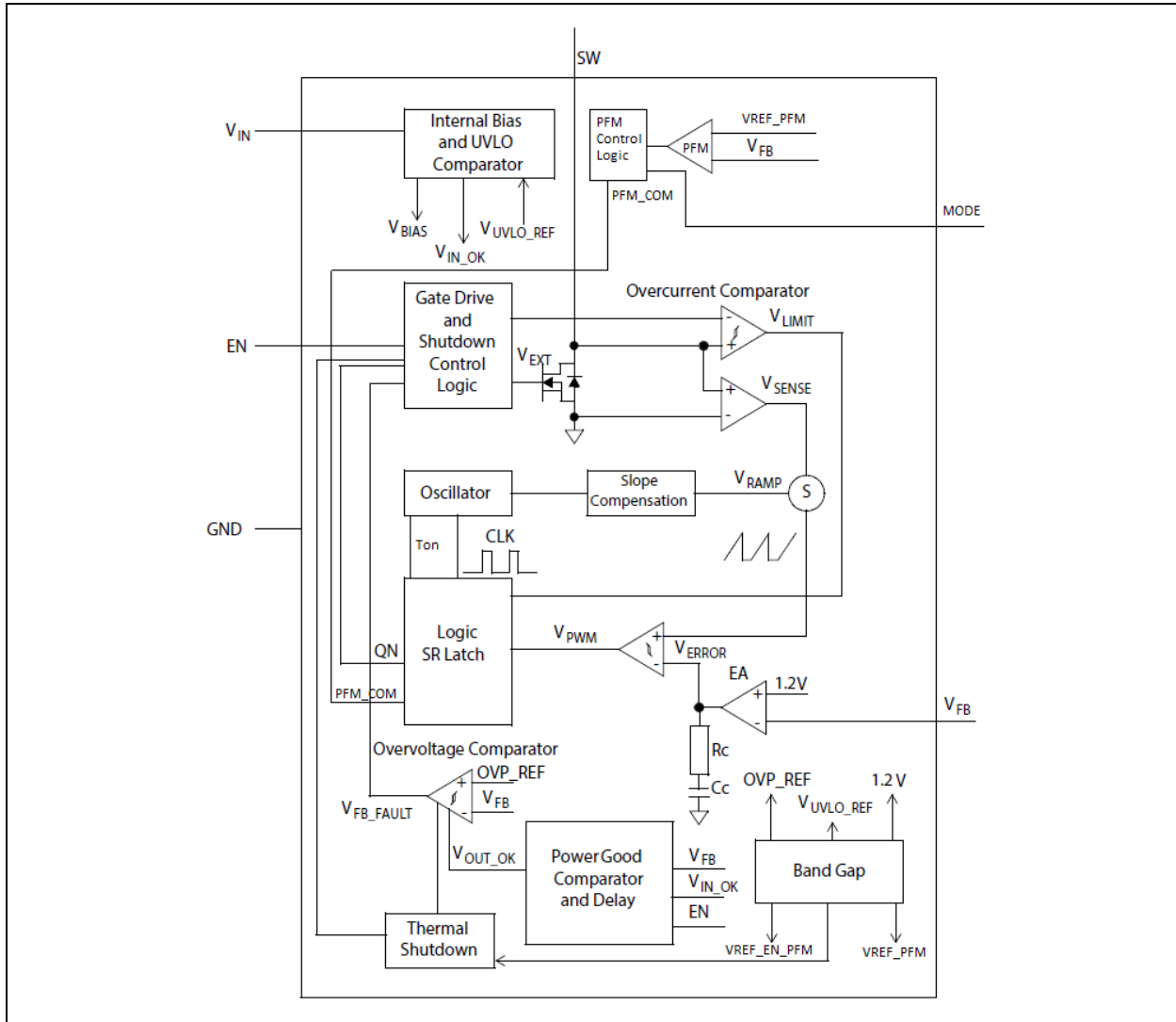


FIGURE 4-1: MCP1665 Simplified Block Diagram.

4.2.1 INTERNAL BIAS

The MCP1665 device gets its bias from the V_{IN} pin. The V_{IN} bias is used to power the device and drive circuits over the entire operating range. The maximum V_{IN} is 5V. If a higher input voltage is required, the V_{IN} pin should be separately powered within its specified voltage range. An example is available in Figure 6-3. Other examples can be found in AN2085 “Designing Applications with MCP166X High Output Voltage Boost Converter Family.”

4.2.2 START-UP VOLTAGE AND SOFT START

The MCP1665 device starts at input voltages that are higher than or equal to a predefined set UVLO value. MCP1665 starts switching at 2.85V (typical) for a 12V output (25 mA load). Once started, the device will continue to operate under normal load conditions, down to 2.7V (typical). A soft-start feature is present and it provides a way to limit the inrush current drawn from the input (batteries) during start-up. The soft start

has an important role in applications where the switch voltage will reach 32V. During start-up, excessively high switch current, together with the presence of high voltage, can overstress the NMOS switch.

When the device is powered ($EN = V_{IN}$ and V_{IN} rises from zero to its nominal value), the output capacitor charges to a value close to the input voltage (or V_{IN} minus a Schottky diode voltage drop). The overshoot on output is limited by slowly increasing the reference of the error amplifier. There is an internal reference voltage circuit that charges an internal capacitor with a weak current source. The voltage on this capacitor slowly ramps the reference voltage. The soft-start capacitor is completely discharged in the event of a commanded shutdown or a thermal shutdown.

Due to the direct path from input to output, in the case of start-up by enable (EN voltage switches from low-to-high), the output capacitor is already charged and the output starts from a value close to the input voltage (Figure 2-19).

The internal oscillator has a delayed start in order to let the output capacitor completely charge to the input voltage value.

4.2.3 UNDERVOLTAGE LOCKOUT (UVLO)

MCP1665 features an UVLO that prevents fault operation below 2.7V, which corresponds to the value of three discharged primary cells. The device starts its normal operation at 2.85V (typical) input. The upper limit is set to avoid any input transients (temporary V_{IN} drop), which might trigger the $UVLO_{STOP}$ threshold and restart the device. Usually, these voltage transients (overshoots and undershoots) have up to a few hundreds mV.

MCP1665 is a nonsynchronous boost regulator. Due to this fact, there is a direct path from V_{IN} to V_{OUT} through the inductor and the diode. This means that, while the device is not switching (V_{IN} below $UVLO_{STOP}$ threshold, when $EN = GND$ and during thermal shutdown), V_{OUT} is not zero, but equal to $V_{IN} - V_F$ (where V_F is the voltage drop on the rectifying diode).

See [Section 2.0 “Typical Performance Curves”](#) for more information.

4.2.4 PWM AND PFM MODE OPERATION

MCP1665 operates as a fixed-frequency, nonsynchronous converter. The switching frequency is maintained at 500 kHz with a precision oscillator.

Lossless current sensing converts the peak current signal to a voltage (V_{SENSE}) and adds it to the internal slope compensation (V_{RAMP}). This summed signal is compared to the voltage error amplifier output (V_{ERROR}) to provide a peak current control signal (V_{PWM}) for the PWM control block. The slope compensation signal depends on the input voltage. Therefore, the converter

provides the proper amount of slope compensation to ensure stability. The inductor peak current limit is set to 3.6A typical.

4.2.5 MODE PIN FUNCTIONALITY

1. MODE = GND

The MCP1665 device will operate in PWM mode, even during light-load operation, by skipping pulses to keep the output regulation. By operating in PWM mode, the output ripple is low and the frequency is constant.

2. MODE = V_{IN}

The MCP1665 device will operate in PFM mode at light-load currents, resulting in a low-quiescent current consumption. During the sleep period between two consecutive bursts of switching cycles, MCP1665 consumes less than 30 μ A (typical) from the supply, for its internal circuitry. The switching pulse bursts represent a small percentage of the total running cycle, so the overall average current drawn from the battery is reduced. The PFM mode shows higher output ripple voltage than the PWM mode and variable PFM mode frequency. The PFM to PWM mode threshold is a function of the input voltage, output voltage and load current.

Note: If a high-load current is required during the sleep time between two switching bursts of PFM ($MODE = V_{IN}$), the output voltage drops more, compared to the PWM only ($MODE = GND$), before the output recovers. The reason is that during sleep mode, most of the internal circuitry of the switcher is turned off, in order to save input power. When steep load changes are expected and the output voltage ripple has to be always low, it is recommended to use the switcher in PWM only $MODE = GND$.

4.2.6 ADJUSTABLE OUTPUT VOLTAGE

The MCP1665 output voltage is adjustable with a resistor divider network from $V_{IN} + 1V$ to 32V. High value resistors are recommended to minimize power loss and keep the efficiency high at light loads. The device integrates a transconductance type error amplifier and the values of the feedback resistors do not influence the stability of the system.

4.2.7 MINIMUM INPUT VOLTAGE FOR A SPECIFIED OUTPUT CURRENT

The maximum output current for which the device can regulate the output voltage depends on the input and the output voltage.

The minimum input voltage necessary to reach the value of the desired voltage output depends on the maximum duty cycle, in accordance with the mathematical relationship $V_{OUT} = V_{INmin}/(1 - D_{MAX})$.

MCP1665

As there is a typical 3.6A inductor peak current limit, V_{OUT} can go out of regulation before reaching the maximum duty cycle.

For example, to ensure a 800 mA load current for $V_{OUT} = 12.0V$, a minimum of 3.6V input voltage is necessary. If an application is powered by one Li-Ion battery (V_{IN} from 3.3V to 4.2V), the minimum load current the MCP1665 device can deliver is close to 350 mA at 24.0V output (see [Figure 2-3](#)).

4.2.8 ENABLE PIN

The MCP1665 device is enabled when the EN pin is set high. The device is set into Shutdown mode when the EN pin is set low. To enable the boost converter, the EN voltage level must be greater than 70% of the V_{IN} voltage. To disable the boost converter, the EN voltage must be less than 18% of the V_{IN} voltage.

In Shutdown mode, the MCP1665 device stops switching and all internal control circuitry is switched off. MCP1665's internal circuitry will consume in this state 0.4 μA (typical). In boost configuration, the input voltage will be bypassed to output through the inductor and the Schottky diode.

4.2.9 INTERNAL COMPENSATION

The error amplifier, with its associated compensation network, completes the closed-loop system by comparing a fraction of the output voltage to a reference at the input of the error amplifier and by feeding the amplified and inverted error voltage to the control input of the inner current loop. The compensation network provides phase leads and lags at appropriate frequencies to cancel excessive phase lags and leads of the power circuit. All necessary compensation components and slope compensation are integrated.

4.2.10 OPEN LOAD PROTECTION (OLP)

An internal V_{FB} fault signal turns off the PWM signal (V_{EXT}) and MCP1665 stops switching in the event of:

- short circuit of the feedback pin to GND
- disconnection of the feedback divider from V_{OUT}

For a regular boost converter without any protection implemented, if the V_{FB} voltage drops to ground potential, its N-Channel transistor is forced to switch at full duty cycle. As a result, V_{OUT} rises and the SW pin's voltage exceeds the maximum rating and damages the boost regulator IC, the external components and the load. Because a lower feedback voltage can cause an output voltage overshoot, a feedback undervoltage comparator can be used to protect the circuit.

The MCP1665 has implemented a protection which turns off PWM switching when the V_{FB} pin's voltage drops to ground level. An additional comparator uses a 80 mV (approximate) reference, monitors the V_{FB} voltage and generates an internal V_{FB_FAULT} signal for control logic circuits, if the voltage decreases under this

reference. Using an undervoltage feedback comparator, in addition to an UVLO input circuit, it acts as a permanently Low Battery device turning off.

The OLP comparator is disabled during the start-up sequence and during a thermal shutdown event.

4.2.11 OVERVOLTAGE PROTECTION (OVP)

A dedicated comparator monitors V_{FB} and if the voltage increases by 5% (typical) above the nominal value, the part stops switching until the voltage on the feedback pin drops to the nominal value. When proper feedback voltage is detected, the switching resumes. This is meant to protect the device against excessive output voltage or high overshoots during load steps.

4.2.12 INPUT OVER-CURRENT LIMIT

The MCP1665 device uses a 3.6A (typical) cycle-by-cycle inductor peak current limit to protect the N-channel switch. There is an over-current comparator which resets the driving latch when the peak of the inductor current reaches the limit. In current limitation, the output voltage starts dropping.

4.2.13 OUTPUT SHORT CIRCUIT CONDITION

Like all nonsynchronous boost converters, MCP1665's inductor current will increase excessively during a short-circuit at the converter's output. Short circuit at the output will cause the rectifying diode to fail and the inductor's temperature to rise. When the diode fails, the SW pin becomes a high-impedance node, it remains connected only to the inductor and the excessive resulted ringing will damage the MCP1665 device.

4.2.14 OVERTEMPERATURE PROTECTION

Overtemperature protection circuitry is integrated into the MCP1665 device. This circuitry monitors the device's junction temperature and shuts down the device if the junction temperature exceeds the typical 150°C threshold. If this threshold is exceeded, the device will automatically restart when the junction temperature drops by approximately 15°C. The output open load protection (OLP) is reset during an overtemperature condition to allow the resuming of the operation.

5.0 APPLICATION INFORMATION

5.1 Typical Applications

The MCP1665 nonsynchronous boost regulator operates over a wide output voltage range, up to 32V. The input voltage ranges from 2.9V to 5V. The device operates down to 2.7V input, with limited specification. The UVLO thresholds are set to 2.85V, when V_{IN} is ramping and to 2.7V, when V_{IN} is falling. The power efficiency conversion is high for several decades of load range. Output current capability increases with the input voltage and decreases with the increasing output voltage. The maximum output current is based on an N-channel switch peak current limit set to 3.6A, and on a maximum duty cycle of 90%. Typical characterization curves in this data sheet are presented to display the typical output current capability.

5.2 Adjustable Output Voltage Calculations

To calculate the resistor divider values for the MCP1665, Equation 5-1 can be used, where R_{TOP} is connected to V_{OUT} , R_{BOT} is connected to GND and both are connected to the V_{FB} input pin.

EQUATION 5-1:

$$R_{TOP} = R_{BOT} \times \left(\frac{V_{OUT}}{V_{FB}} - 1 \right)$$

EXAMPLE 5-1:

$$\begin{aligned} V_{OUT} &= 12.0V \\ V_{FB} &= 1.2V \\ R_{BOT} &= 20 \text{ k}\Omega \\ R_{TOP} &= 180 \text{ k}\Omega \end{aligned}$$

EXAMPLE 5-2:

$$\begin{aligned} V_{OUT} &= 24.0V \\ V_{FB} &= 1.2V \\ R_{BOT} &= 20 \text{ k}\Omega \\ R_{TOP} &= 380 \text{ k}\Omega \text{ (} V_{OUT} = 24.18V \text{ with a standard} \\ &\text{value of } 383 \text{ k}\Omega \text{)} \end{aligned}$$

The values of the two resistors, R_{TOP} and R_{BOT} , affect the no load input current and quiescent current. In Shutdown mode ($EN = GND$), the device consumes 0.4 μA (typical). With 400 $K\Omega$ feedback divider for 24V output, the current that the divider drains from the input is 9 μA . This value is higher than the current consumption of the device itself. Keeping R_{TOP} and R_{BOT} high will optimize efficiency conversion at very light loads.

There are some potential issues with higher value resistors, as in the case of small surface mount resistors: environment contamination can create leakage paths on the PCB that significantly change the divider ratio, so it may affect the output voltage tolerance.

5.2.1 OPEN LOAD PROTECTION

The MCP1665 device features an output open-load protection (OLP) in case R_{TOP} is disconnected from the V_{OUT} line. An 80 mV (approximate) OVP reference is compared to the V_{FB} voltage. If the voltage on the V_{FB} pin drops below the reference value, the device stops switching and prevents V_{OUT} from rising up to a dangerous value.

OLP is not enabled during start-up and thermal shutdown events.

5.3 Input Capacitor Selection

The boost input current is smoothed by the boost inductor, reducing the amount of filtering necessary at the input. Some capacitance is recommended to provide decoupling from the input source. Due to the fact that MCP1665 is rated to work up to +125°C ambient temperature, low ESR X7R ceramic capacitors are well suited, since they have a low temperature coefficient and are small-sized.

For limited temperature range use, at up to +85°C, an X5R ceramic capacitor can be used. For light-load applications, 22 μF of capacitance is sufficient at the input.

Please note that if MCP1665's power supply impedance cannot be kept as low as needed in order to maintain the input voltage permanently above the UVLO threshold, it is recommended to connect an electrolyte or a tantalum capacitor in parallel with the ceramic mentioned above. Otherwise, unwanted behaviors (such as restarts, oscillation or bus-pumping) may be noticed while under high load.

For high-power applications that have high source impedance or long leads (wires), using a 220-470 μF input capacitor, is recommended to sustain the high input boost currents. Additional input capacitance can also be added, to provide a stable input voltage during high load step-ups.

Table 5-1 contains the recommended range for the input capacitor value.

MCP1665

5.4 Output Capacitor Selection

The output capacitor helps provide a stable output voltage during sudden load transients and reduces the output voltage ripple. As with the input capacitor, an X7R ceramic capacitor is recommended for this application. Using other capacitor types (aluminum or tantalum) with large ESR has an effect on the converter's efficiency, maximum output power and stability. For limited temperature range (up to 85°C), X5R ceramic capacitors can be used. The DC rating of the output capacitor should be greater than the V_{OUT} value. Generally, ceramic capacitors lose much of their capacity when the voltage applied is close to their maximum DC rating. Choosing a capacitor with a safe higher DC rating or placing more capacitors in parallel assure enough capacity to correctly filter the output voltage.

The MCP1665 device is internally compensated, so output capacitance range is limited. See [Table 5-1](#) for the recommended output capacitor range.

An output capacitance higher than 40 μF adds a better load step response and high-frequency noise attenuation, especially while stepping from light to heavy load currents.

While the N-Channel switch is on, the output current is supplied by the output capacitor C_{OUT} . The amount of output capacitance and equivalent series resistance will have a significant effect on the output

voltage ripple. While C_{OUT} provides load current, a voltage drop also appears across its internal ESR that results in voltage ripple. A trade-off between load step behavior and loop's dynamic response speed should be done before increasing the C_{OUT} very much.

Peak-to-peak output ripple voltage also depends on the equivalent series inductance (ESL) of the output capacitor. There are ceramic capacitors with special internal architecture that minimize the ESL. For output voltages that require low-ripple for high-frequency components, capacitors with low ESL (for instance, reverse geometries) are recommended. Consult the ceramic capacitor's manufacturer portfolio for more information.

TABLE 5-1: CAPACITOR VALUE RANGE

| | C_{IN} | C_{OUT} |
|---------|------------------|------------------|
| Minimum | 22 μF | 40 μF |
| Maximum | — | 80 μF |

5.5 Inductor Selection

The MCP1665 device is designed to be used with small surface mount inductors; the inductance value can range from 4.7 μH to 10 μH . An inductance value of 4.7 μH is recommended for output voltages below 15V. For higher output voltages, up to 32V, an inductance value of 10 μH is optimum.

TABLE 5-2: MCP1665 RECOMMENDED INDUCTORS FOR BOOST CONVERTERS

| Part Number | Value (μH) | DCR Ω (typ.) | I_{SAT} (A) | Size WxLxH (mm) |
|---------------------------------------------|-------------------------|---------------------|---------------|-----------------|
| Coilcraft | | | | |
| MSS1048-472 | 4.7 | 11.4 | 4.36 | 10.2x10x4.8 |
| MSS1038-103 | 10 | 35 | 3.9 | 10.2x10x3.8 |
| XAL5030-472ME | 4.7 | 36 | 6.7 | 5.28x5.48x3.1 |
| Würth Elektronik | | | | |
| 744778004 | 4.7 | 42 | 4.2 | 7.3x7.3x3.2 |
| 7447714047 | 4.7 | 10.4 | 8 | 10x10x5 |
| 7443340470 | 4.7 | 12.7 | 8 | 8.4x7.9x7.2 |
| 7447714100 | 10 | 23 | 5 | 10x10x5 |
| 74437368100 | 10 | 27 | 5.2 | 10x10x3.8 |
| Various | | | | |
| Bourns [®] , Inc. RLB0913-4r7k | 4.7 | 20 | 4.3 | 8.5x12.5 |
| Bourns, Inc. SRN6045-4R7Y | 4.7 | 37.6 | 4 | 6x4.5 |
| Panasonic [®] - ECG ELL8TP4R7NB | 4.7 | 14 | 4 | 8x8x4.7 |

Several parameters are used to select the appropriate inductor: maximum-rated current, saturation current and copper resistance (DCR). For boost converters, the inductor current is much higher than the output current. The average inductor current is equal to the

input current. The inductor's peak current is 30-40% higher than the average. The lower the inductor DCR is, the higher the efficiency of the converter: a common trade-off is size versus efficiency.

The saturation current typically specifies a point at which the inductance has rolled off a percentage of the rated value. This can range from a 20% to 40% reduction in inductance. As inductance rolls off, the inductor ripple current increases, as does the peak switch current. It is important to keep the inductance from rolling off too much, causing switch current to reach the peak limit and affecting output voltage regulation.

5.6 Rectifying Diode Selection

Schottky diodes are used to reduce losses. The diode's average forward current rating must be equal or higher than the maximum output current. The diode's peak repetitive forward current rating has to be equal or higher than the inductor peak current. The diode's reverse breakdown voltage must be higher than the internal switch rating voltage of 36V.

The converter's efficiency will be improved if the voltage drop across the diode is lower. The average forward voltage rating is forward-current dependent, which is equal in particular to the load current.

At high temperature operation the diode's leakage current can also have a significant effect on the converter's operational efficiency.

For high currents and high ambient temperatures, use a diode with good thermal characteristics.

See [Table 5-3](#) for recommended diodes.

TABLE 5-3: RECOMMENDED SCHOTTKY DIODES

| Type | V _{OUTmax} | Max T _A |
|------------|---------------------|--------------------|
| STPS2L40 | 32V | <85°C |
| DFLS2100-7 | 32V | <125°C |

5.7 Thermal Calculations

The MCP1665 device is available in a 10-lead 2x2 mm VQFN package. The junction temperature can be estimated by calculating the power dissipation and applying the package thermal resistance (θ_{JA}). The maximum continuous junction temperature rating for the MCP1665 device is +125°C.

To quickly estimate the internal power dissipation for the switching boost regulator, an empirical calculation using measured efficiency can be used. Being given the measured efficiency, the internal power dissipation is estimated by [Equation 5-2](#).

EQUATION 5-2:

$$\left(\frac{V_{OUT} \times I_{OUT}}{\text{Efficiency}} \right) - (V_{OUT} \times I_{OUT}) = P_{Dis}$$

The difference between the first term, input power, and the second term, power delivered, is the power dissipated when using the MCP1665 device. This is an estimate, assuming that most of the power lost is internal to the MCP1665 and not by C_{IN}, C_{OUT}, the diode and the inductor. There is some percentage of power lost in the boost inductor and rectifying diode, with very little loss in the input and output capacitors. For a more accurate estimation of the internal power dissipation, also subtract the I_{INRMS}² × L_{DCR} and I_{OUT} × V_F power dissipation (where I_{INRMS} is the average input current, L_{DCR} is the inductor series resistance and V_F is the diode voltage drop).

5.8 PCB Layout Information

Good printed circuit board layout techniques are important to any switching circuitry, and switching power supplies are no different. When wiring the switching high-current paths, short and wide traces should be used. Therefore, it is important that the input and output capacitors are placed as close as possible to the MCP1665 device, in order to minimize the loop area.

The feedback resistors and feedback signal should be routed away from the switching node and the switching current loop. When possible, ground planes and traces should be used to help shield the feedback signal and minimize noise and magnetic interference.

The Exposed Thermal Pad should be soldered to thermal vias going through PCB down to the ground plane, in order to properly dissipate the heat generated inside and to avoid thermal shutdown. PGND, SGND and EP should be connected together in one low-impedance ground point.

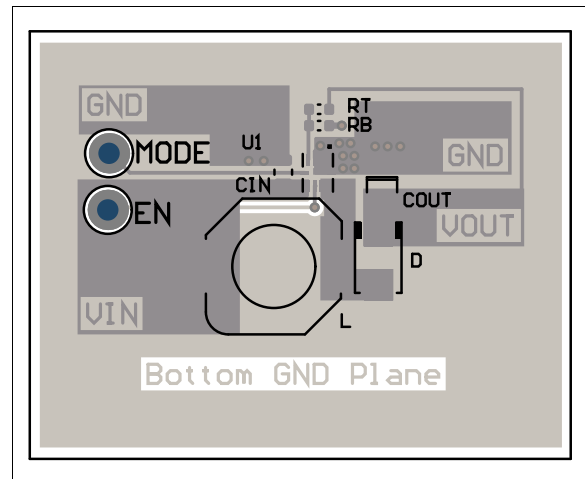


FIGURE 5-1: 10-Lead 2x2 mm VQFN Recommended Layout.

MCP1665

NOTES:

6.0 TYPICAL APPLICATION CIRCUITS

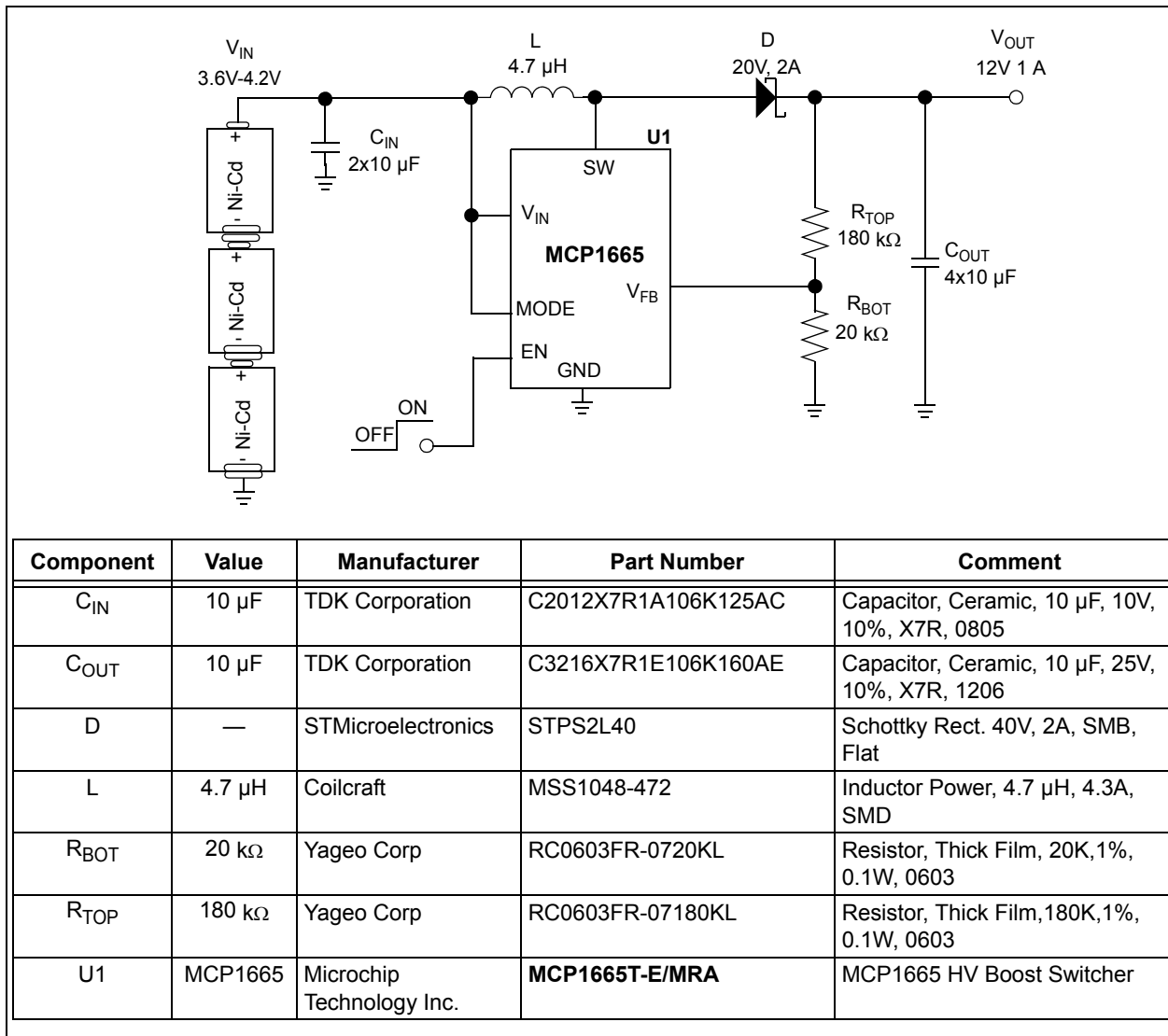


FIGURE 6-1: Three Ni-Cd Cells to 12V Boost Converter.

MCP1665

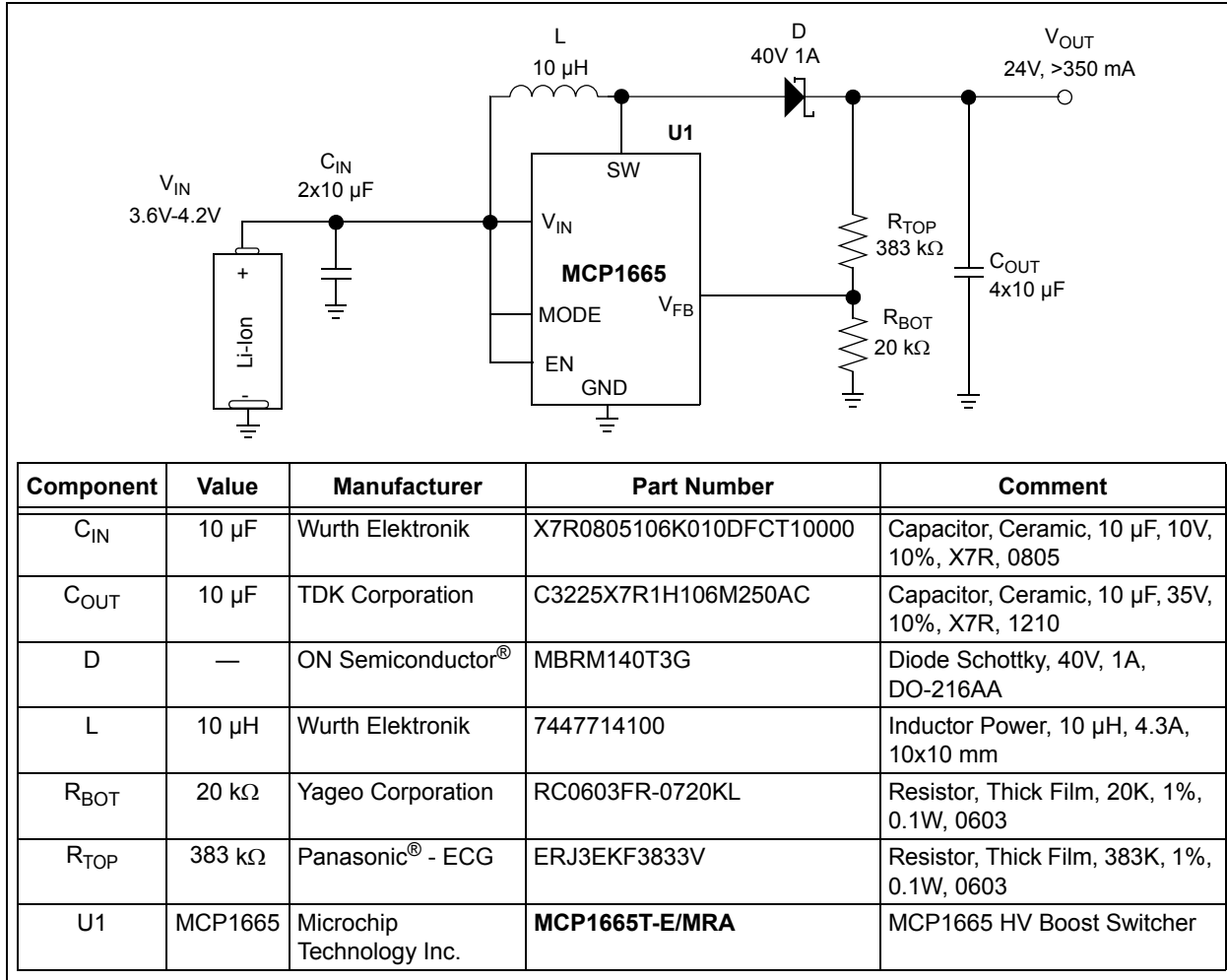


FIGURE 6-2: Single Li-Ion Cell to 24V Output Boost Converter.

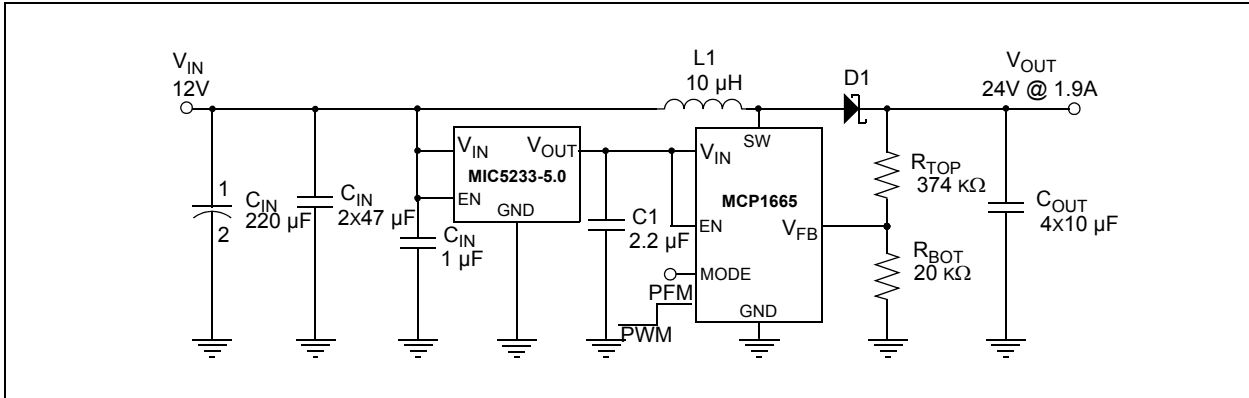


FIGURE 6-3: MCP1665 High-Voltage Input 12V to 24V Output Boost Converter.

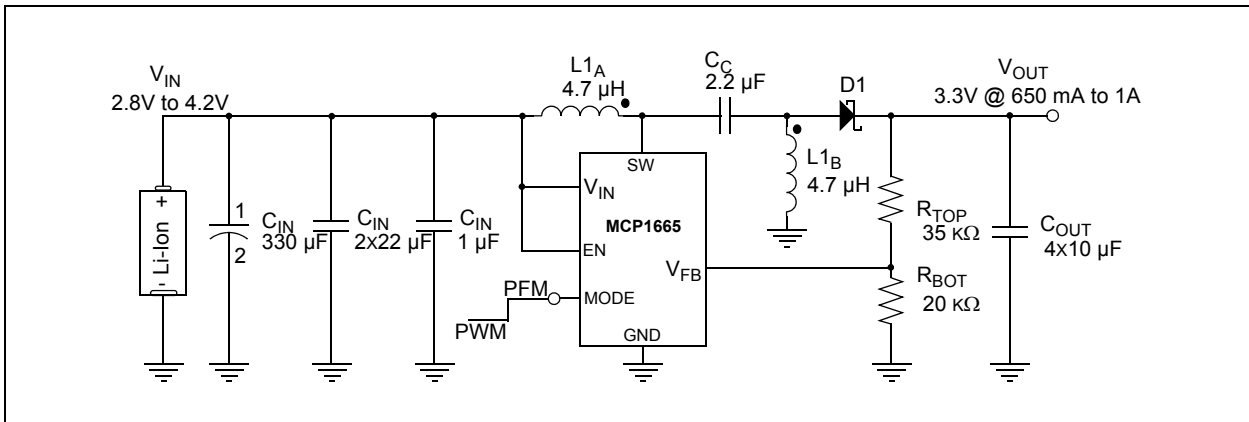


FIGURE 6-4: MCP1665 Single Li-Ion Cell SEPIC Converter.

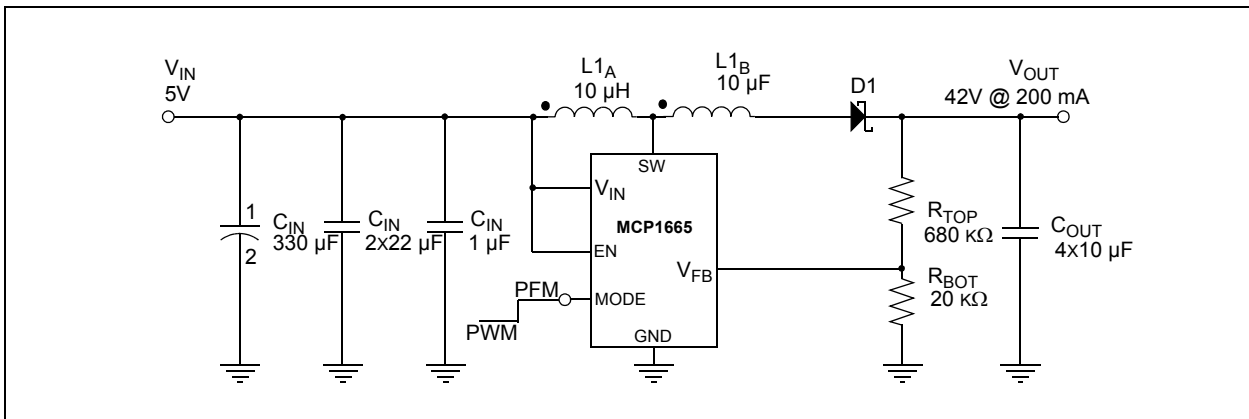


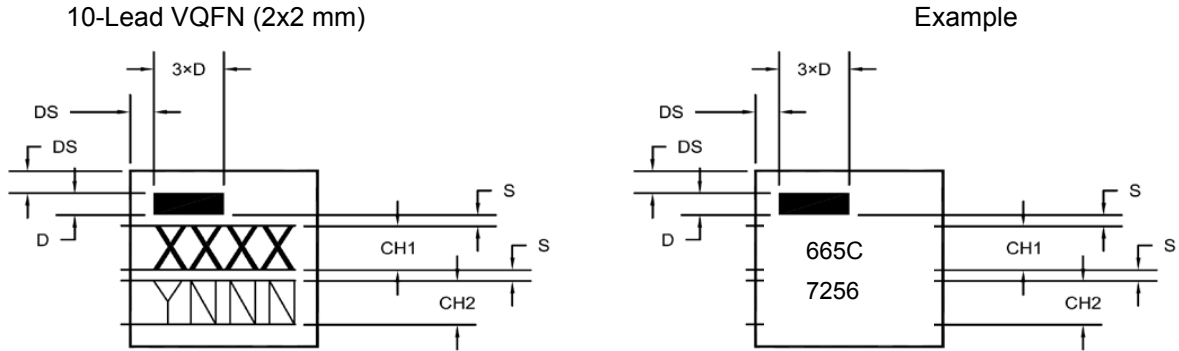
FIGURE 6-5: MCP1665 Coupled-Inductors Boost Converter.

MCP1665

NOTES:

7.0 PACKAGING INFORMATION

7.1 Package Marking Information



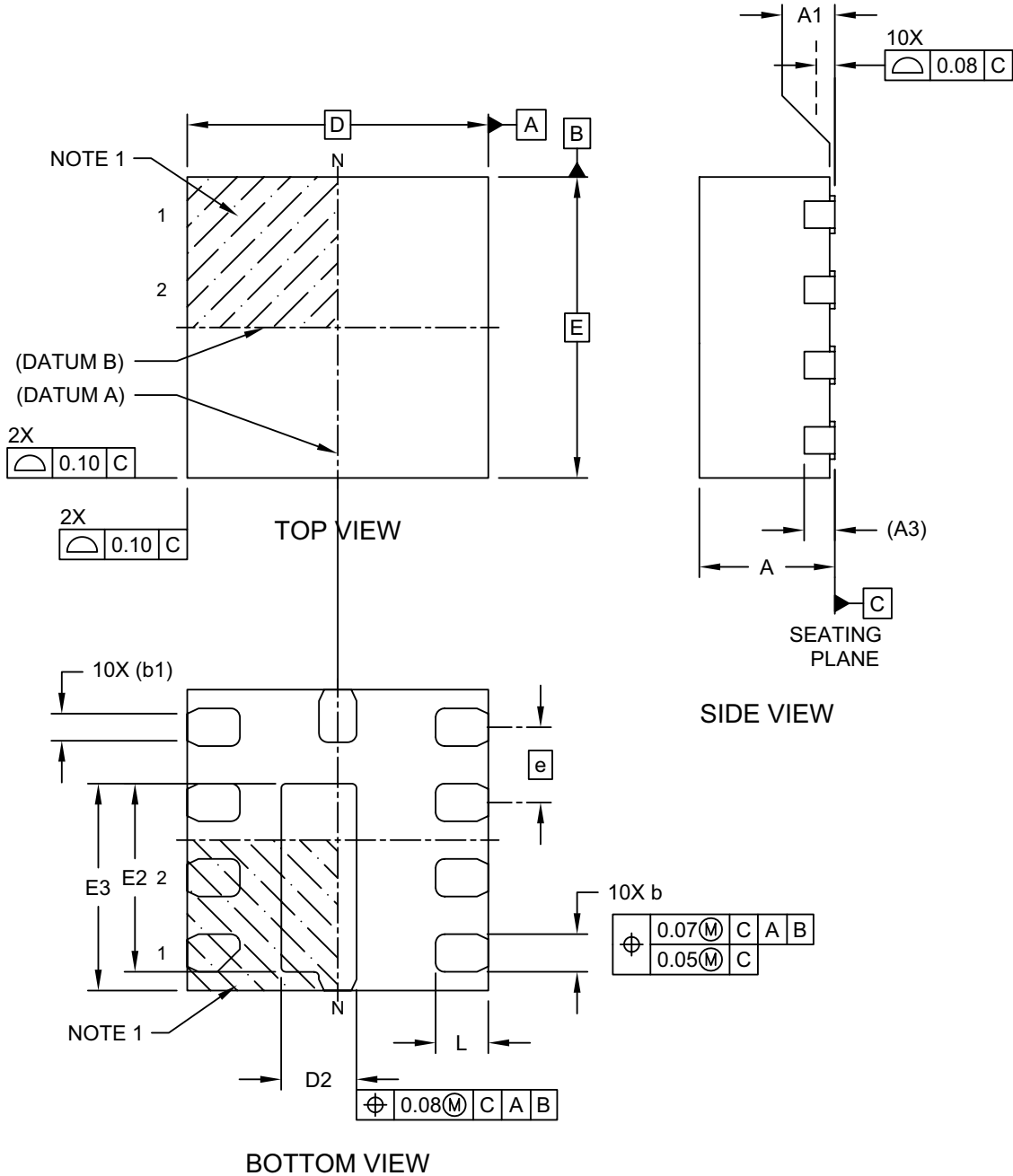
| | | |
|----------------|--------|------------------------------------------------------------------------------------------------------------------|
| Legend: | XX...X | Customer-specific information |
| | Y | Year code (last digit of calendar year) |
| | YY | Year code (last 2 digits of calendar year) |
| | WW | Week code (week of January 1 is week '01') |
| | NNN | Alphanumeric traceability code |
| | (e3) | Pb-free JEDEC® designator for Matte Tin (Sn) |
| | * | This package is Pb-free. The Pb-free JEDEC designator (e3) can be found on the outer packaging for this package. |

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

MCP1665

10-Lead Very Thin Plastic Quad Flat, No Lead Package (MRA) - 2x2 mm Body [VQFN] With Fused Exposed Pad

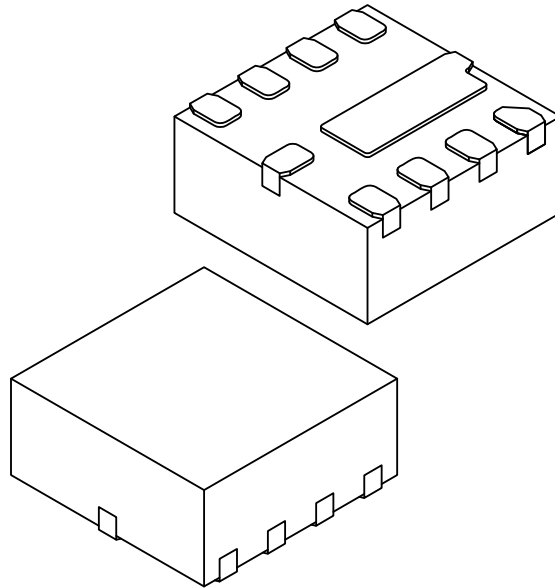
Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Microchip Technology Drawing C04-1208C Sheet 1 of 2

10-Lead Very Thin Plastic Quad Flat, No Lead Package (MRA) - 2x2 mm Body [VQFN] With Fused Exposed Pad

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



| Dimension Limits | Units | MILLIMETERS | | |
|---------------------|-------|-------------|------|-------|
| | | MIN | NOM | MAX |
| Number of Terminals | N | 10 | | |
| Pitch | e | 0.50 BSC | | |
| Overall Height | A | 0.80 | 0.85 | 0.90 |
| Standoff | A1 | 0.00 | 0.02 | 0.05 |
| Terminal Thickness | A3 | 0.203 REF | | |
| Overall Length | D | 2.00 BSC | | |
| Exposed Pad Length | D2 | 0.45 | 0.50 | 0.55 |
| Overall Width | E | 2.00 BSC | | |
| Exposed Pad Width | E2 | 1.20 | 1.25 | 1.30 |
| Exposed Pad Width | E3 | 1.325 | 1.37 | 1.425 |
| Terminal Width | b | 0.20 | 0.25 | 0.30 |
| Terminal Width | b1 | 0.18 REF | | |
| Terminal Length | L | 0.30 | 0.35 | 0.40 |

Notes:

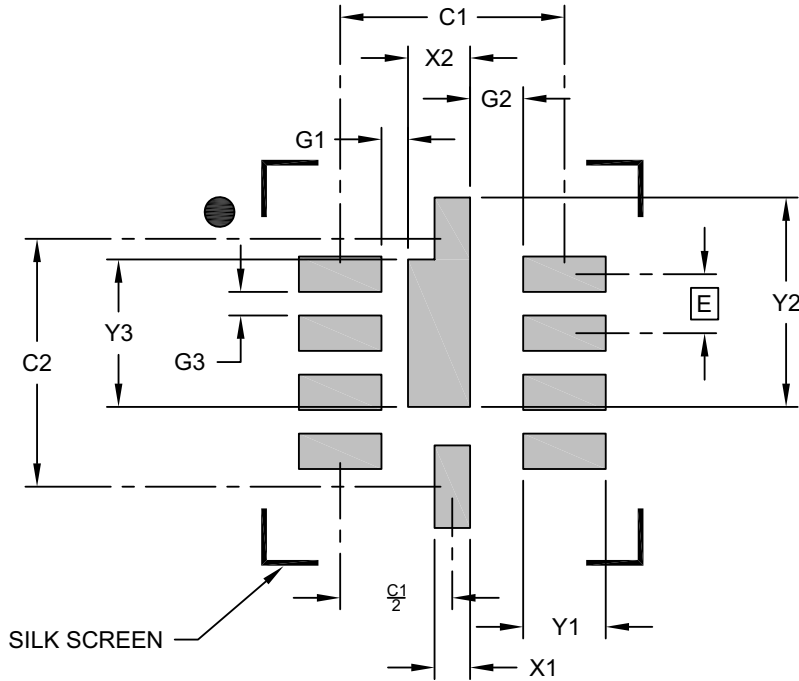
- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Package is saw singulated
- Dimensioning and tolerancing per ASME Y14.5M
 - BSC: Basic Dimension. Theoretically exact value shown without tolerances.
 - REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-1208C Sheet 2 of 2

MCP1665

10-Lead Very Thin Plastic Quad Flat, No Lead Package (MRA) - 2x2 mm Body [VQFN] With Fused Exposed Pad

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



RECOMMENDED LAND PATTERN

| Dimension | Units | MILLIMETERS | | |
|---------------------------------|-------|-------------|------|------|
| | | MIN | NOM | MAX |
| Contact Pitch | E | 0.50 BSC | | |
| Center Pad Width | X2 | | | 0.53 |
| Center Pad Length | Y2 | | | 1.77 |
| Center Pad Length | Y3 | | | 1.25 |
| Contact Pad Spacing | C1 | | 1.90 | |
| Contact Pad Spacing | C2 | | 2.10 | |
| Contact Pad Width (X10) | X1 | | | 0.30 |
| Contact Pad Length (X10) | Y1 | | | 0.70 |
| Contact Pad to Center Pad (X3) | G1 | 0.22 | | |
| Contact Pad to Center Pad (X4) | G2 | 0.45 | | |
| Contact Pad to Contact Pad (X6) | G3 | 0.20 | | |

Notes:

- Dimensioning and tolerancing per ASME Y14.5M
BSC: Basic Dimension. Theoretically exact value shown without tolerances.
- For best soldering results, thermal vias, if used, should be filled or tented to avoid solder loss during reflow process

Microchip Technology Drawing C04-3208B

APPENDIX A: REVISION HISTORY

Revision A (October 2017)

- Original Release of this Document.

MCP1665

NOTES:

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

| <u>PART NO.</u> | <u>XI</u> ⁽¹⁾ | - | <u>X</u> | <u>XX</u> |
|------------------------|---------------------------------------------------------------|---|----------------------------------------------------------|----------------------------------------------------------|
| Device | Tape and Reel Option | | Temperature Range | Package |
| Device: MCP1665 | Tape and Reel Option: T = Tape and Reel ⁽¹⁾ | | Temperature Range: E = -40°C to +125°C (Extended) | Package: MRA = VQFN (Very Thin Plastic Quad Flat) |

Examples:

a) MCP1665T-E/MRA = Tape and Reel, Extended temperature, 10LD VQFN 2x2 package.

Note 1: Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option.

MCP1665

NOTES:

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Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
<http://www.microchip.com/support>
Web Address:
www.microchip.com

Atlanta
Duluth, GA
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ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon

Hong Kong
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Fax: 852-2401-3431

Australia - Sydney
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Fax: 44-118-921-5820