TB3301

Powering Solution from a Single Cell Li-Ion Battery Using the MCP16411 and a Battery Charger

Author: Elisa Goicea
Microchip Technology Inc.

INTRODUCTION

The newly-developed Internet of Things (IoT) devices are usually powered by using a battery that is directly related to the system power consumption. Two or three alkaline batteries or small Li-Ion coin cells are used for long runtime operation systems. For portable systems that need higher power ratings, a rechargeable Li-Ion battery type is preferred.

Many IoT devices require a standard 3.6V or 3.3V rail, therefore, the battery type used is often a Li-Ion cell. Sometimes, a full battery utilization is mandatory (from 4.2V to 2.8V), thus a Buck-Boost converter is suitable for this type of applications. However, these converters are costly and often too complex to be integrated into the system. The MCP16411 has a unique feature called Automatic Input-to-Output Bypass that, when the battery voltage is higher than what the system needs, allows the MCP16411 synchronous step-up switching regulator to fit perfectly for many requests. Other main features consist of the low quiescent current consumption, PFM/PWM mode of operation for high efficiency, Output Discharge feature in shutdown mode, as well as programmable Undervoltage Lockout (UVLO), and Low Battery Output (LBO). The Automatic Input-to-Output Voltage Bypass mode during operation helps to optimize the battery utilization and achieve high efficiency while the fresh batteries' nominal voltage is in the same range with the converter's output value.

On the other hand, the battery charging management is implemented using the MCP73830. This charge controller provides specific algorithms for single cell Li-Ion or Li-Polymer batteries to achieve optimal capacity and safety in the shortest charging time possible.

MCP1641X KEY FEATURES

- Input Voltage Range: 0.8V (after start-up) to 5.25V
- Low Device Quiescent Current: 5 µA (typically)
- Up to 96% Efficiency
- Programmable Low Battery Output (LBO)
- Programmable Undervoltage Lockout (UVLO)
- 1A Typical Peak Inductor Current Limit:
  - I_{OUT} > 170 mA @ 2V V_{OUT}, 1.2V V_{IN}
  - I_{OUT} > 200 mA @ 3.3V V_{OUT}, 1.5V V_{IN}
  - I_{OUT} > 600 mA @ 5.0V V_{OUT}, 3.6V V_{IN}
- Adjustable Output Voltage Range
- Automatic Input-to-Output Bypass Operation
- Automatic PFM/PWM Operation
- PWM Switching Frequency: 500 kHz (typically)
- Power Good and Die Overtemperature Output
- Inrush Current Limiting and Internal Soft Start
- Low Noise, Anti-Ringing Control
- Shutdown Current: 2.3 µA (typically)
- Selectable, Logic-Controlled, Shutdown States:
  - Output Discharge Option
  - Input-to-Output Bypass Option

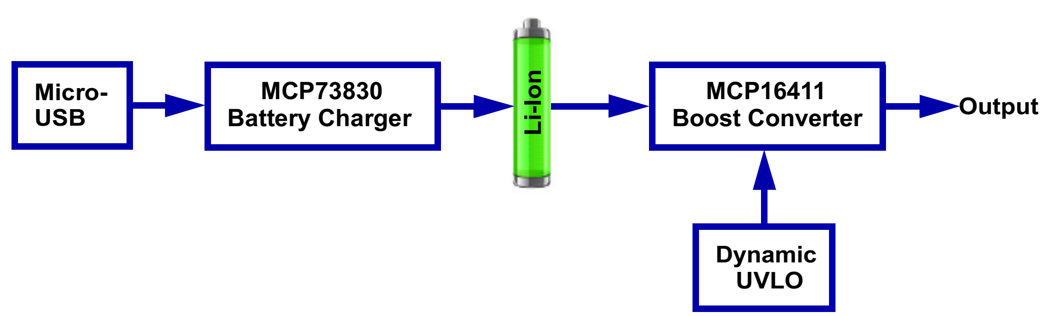

FIGURE 1: *MCP16411 – Boost Converter with Battery Charging Management Block Diagram.*

APPLICATION CIRCUIT DESCRIPTION

This application consists of several blocks, including a DC-DC boost converter with dynamic UVLO thresholds and the battery charger, as shown in Figure 1.

The MCP1641X is a low-voltage step-up switching regulator with battery monitoring features, delivering high efficiency over a wide range of inputs.

This family of devices features low quiescent current, a programmable start-up voltage (Undervoltage Lockout – UVLO), Low Battery Indication (LBI/LBO), adjustable output voltage and dual mode of operation: PFM/PWM and PWM Only. It also features an integrated synchronous switch, internal compensation, low noise anti-ringing control, inrush current limit and soft start.

The Undervoltage Lockout (UVLO) prevents faulty operation below 0.8V ($UVLO_{STOP}$) and allows the boost converter to start in normal operation, by default, at 0.85V ($UVLO_{START}$). The programmable $UVLO_{START}$ threshold can be set through an external resistive divider, but it cannot be lower than 0.85V. Additionally, a low battery indicator circuit is implemented with an LBO warning pin, which triggers when the battery's voltage is below the UVLO's trip point.

An additional safety feature used when powering a device from batteries is the monitoring of the internal device's temperature. The Power Good and Die Overtemperature (PGT) pin provides an error signal if the output voltage drops below 10% of its nominal value or the temperature of the integrated circuit die exceeds +75°C, typically. This threshold can be programmed by customer request, from +55°C to +85°C, with +10°C increments.

Furthermore, the step-up converter family provides either Output Discharge or Input-to-Output Bypass features, while the device is in Shutdown when pulling the Enable pin to GND. During this mode of operation, a low quiescent current of 2.3 µA (typically) is consumed from the input.

When analyzing Figure 2, which depicts the schematic of the entire circuitry, it should be noted that the MCP16411 was chosen due to the Automatic PFM/PWM Operation. This operation maintains the efficiency high even at light loads, as well as a lower quiescent current, compared to the PWM only options. The device also features a PGT open drain output pin; it shows the state of the output voltage and the device's temperature: it triggers whenever V_{OUT} < 90% of the nominal output voltage or when the die's temperature is higher than +75°C. Moreover, the MCP16411 has the Output Discharge feature in Shutdown mode; this will automatically discharge the output capacitor when the device is disabled.

For this application, the board was designed with the output voltage set to 3.3V. If a different output voltage is desired, the resistive divider consisting of R_T and R_B can be calculated using Equation 1.

EQUATION 1: FEEDBACK RESISTIVE DIVIDER FOR ADJUSTABLE V_{OUT}

$$R_T = R_B\left(\frac{V_{OUT}}{V_{FB}} - 1\right)$$

Where V_{FB} is typically 0.97V.

The circuitry that is framed with green color (Figure 2) represents the dynamic changing circuitry for the LBO/UVLO thresholds; the LBO, $UVLO_{START}$ and $UVLO_{STOP}$ thresholds can be programmed independently by adding supplementary components. The MCP16411 allows a start-up voltage which can be easily programmed by the means of a resistive divider connected to the UVLO pin; this feature is used to increase the $UVLO_{START}$ threshold.

The additional components are helping on the UVLO falling threshold setup. When the $UVLO_{STOP}$ threshold is changed dynamically to the desired value and the battery voltage reaches that value, the boost converter will be disabled and the load will be disconnected. This function is very important for Li-Ion batteries, as discharging them below the cut-off voltage may cause leakage or irreversible damage.

Equation 2 can be used for calculating the programmed value of the $UVLO_{START}$ threshold, where V_{REF_UVLO} is the Internal Voltage Reference (485 mV) from the UVLO comparator block, while R_H and R_L are the external network resistors. Therefore, R_H is connected to V_{IN}, R_L is connected to GND and both R_H and R_L are connected to the UVLO input pin.

EQUATION 2: UVLO RESISTIVE DIVIDER FOR PROGRAMMABLE START-UP VOLTAGE

$$R_H = R_L\left(\frac{UVLO_{START}}{V_{REF\_UVLO}} - 1\right)$$

The value of the $UVLO_{START}$ threshold that is implemented in this application was set to 3.0V.

The boost converter will start switching when the battery voltage is 3.0V or higher than 3.0V and it will regulate the output voltage at 3.3V. After start-up, the R_{H1} resistor and the N-Channel MOSFET become an active part of the circuit. The PGT signal will then turn on the

N-MOS switch and will connect R_H in parallel with R_{H1}. Therefore, the UVLO threshold will be dynamically changed to 2.8V.

When the battery gets discharged below 2.8V, the LBO pin switches to low level and will warn the user to replace or to recharge the battery. When the LBO signal warns the low battery event, it pulls the emitter of the NPN transistor (Q_1) to low level, turning it on. As a result, the NPN transistor asserts to low the enable input pin of the switching regulator, which shuts down the output of the converter.

This simple method for increasing the $UVLO_{STOP}$ threshold (in order to shut down the device at 2.8V input) protects the Li-Ion Battery from over-discharging.

The dynamically changing threshold for the UVLO can be calculated using Equation 3, where V_{REF_UVLO} is 485 mV, LBO_{HYST} is a hysteresis of 20 mV, typically (between the $UVLO_{START}$ and LBO thresholds), and R_{H1} sets the value for the desired $UVLO_{STOP}$ threshold.

For safety reasons, the 18650 Li-Ion battery's manufacturers do not recommend using the cells below their specified Function End Point (FEP) or Cut-Off Voltage since they do not have a fair amount of energy available anymore; the FEP for 18650 Li-Ion batteries is around 2.8V or 2.7V.

This proposed application was designed to turn off the output of the converter if the input voltage decreases below 2.8V, which will prevent discharging the battery below its FEP. The dynamic LBO/UVLO thresholds decrease the risk of battery leakage because this phenomenon might be able to produce serious damage to the applications or to the battery casing.

EQUATION 3: DYNAMIC UVLO/LBO

$$UVLO_{DYNAMIC} = \left(\frac{R_H \| R_{H1}}{R_L} + 1\right)(V_{REF\_UVLO} - LBO_{HYST})$$

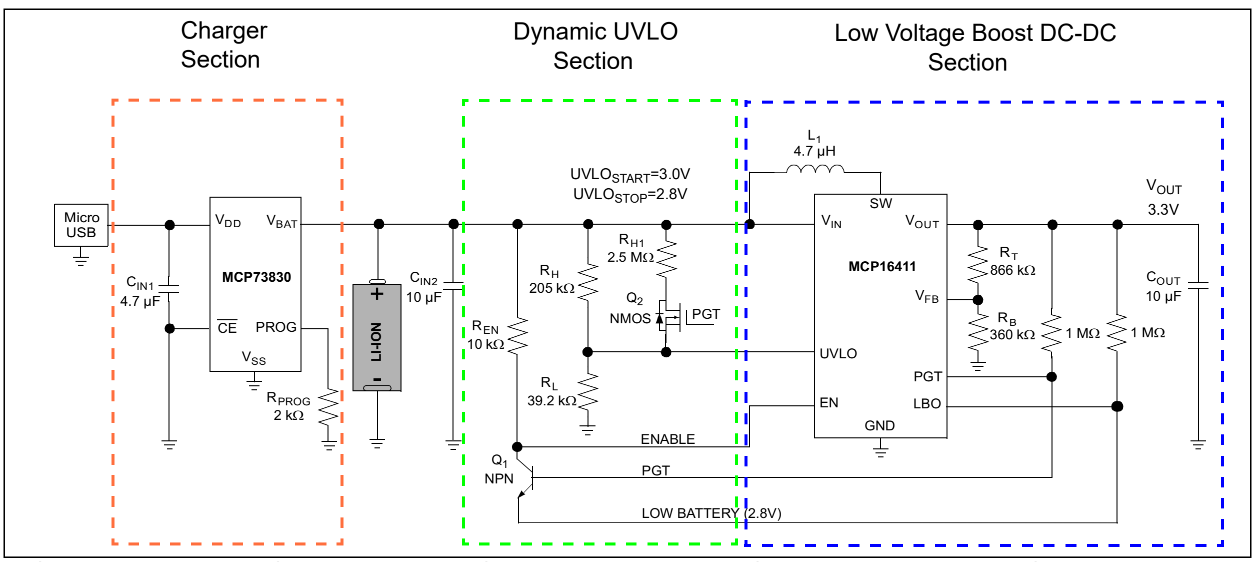

FIGURE 2: *MCP16411 - Boost Converter with Battery Charging Management Circuit Diagram.*

The proposed application is used to provide 3.3V regulated output voltage from an input that varies from a minimum of 2.8V to a maximum 4.2V (e.g., the voltage range of a fresh 18650 cylindrical Li-Ion battery). Figure 3 reveals the maximum output current that can be obtained by the MCP16411 switching regulator for different battery voltages.

The MCP16411 device features the Automatic PFM/PWM function, which allows the converter to operate in PFM (Pulse Frequency Modulation) Mode at light loads, to achieve the maximum efficiency. Figure 4 represents the efficiency versus load current graph.

The circuitry that is framed with orange color in Figure 2 represents the charging circuitry for the battery. Therefore, a Total System Solution (TSS) that can be powered from a Li-Ion battery is completed by adding to the main circuit a Linear Battery Charger IC.

The MCP73830 is a charge management controller that provides specific charge algorithms for single-cell Li-Ion/Li-Polymer batteries. This device was designed to achieve optimal capacity and it allows up to 1000 mA constant current for applications that require fast charging. The fast-charging current allows the battery to be charged up to 80% or 100% in a short period of time.

This linear battery charger has an internal 4 Hour Fixed Elapsed Timer. If this timer expires before the recharge threshold is reached, the charge cycle will be stopped. The MCP73830 device remains in this condition until the battery is reinserted or the input power or CE pin is cycled.

MCP73830 KEY FEATURES

- Complete Linear Charge Management Controller:
  - Integrated Pass Transistor
  - Integrated Current Sense
  - Integrated Reverse Discharge Protection
- Constant-Current/Constant-Voltage Operation
- Programmable Charge Current: 100 mA – 1000 mA
- Soft-Start to avoid Inrush Current
- Fixed Elapsed Timer: 4 Hours
- Automatic End-of-Charge (EOC) Control Termination: 7.5% and 10%
- Automatic Power-Down when Input Power Removed
- Undervoltage Lockout (UVLO)
- Chip/Charge Enable Pin (CE)
- Available Package: 6-lead 2 mm x 2 mm TDFN

The user can program the charging current by using an on-board resistor; Equation 4 shows how the programming resistor can be calculated.

As a result, the MCP73830 can charge a single-cell 18650 Cylindrical Li-Ion battery from a Micro-USB port for the proposed circuit.

EQUATION 4: PROGRAMMING CHARGE CURRENT

$$I_{REG} = \frac{1000}{R_{PROG}}$$

Where R_{PROG} is the current programming resistor.

Due to the fact that the load is directly connected to the battery, a protection circuit is required to prevent overvoltage during the charging cycle of the Li-Ion batteries.

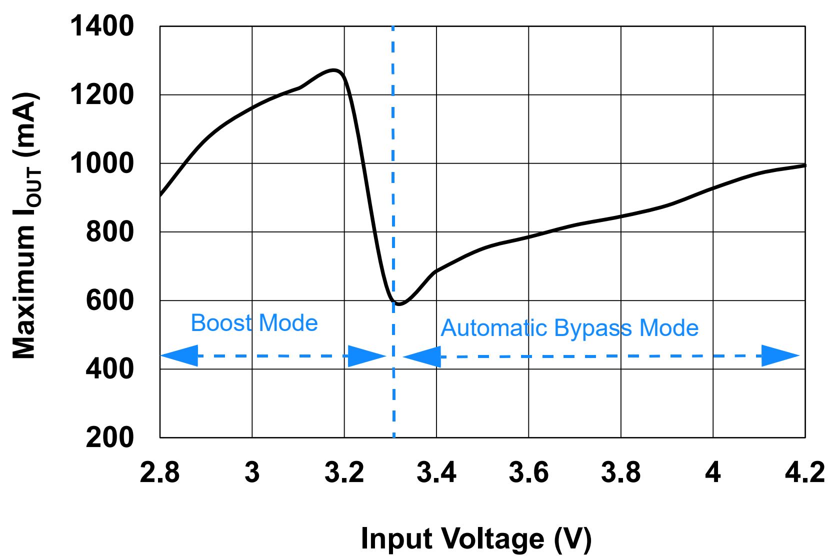

FIGURE 3: MCP16411 - Maximum I_{OUT} vs. V_{IN}, after Start-up, $V_{OUT} \leq$ 5% below the Regulation Point.

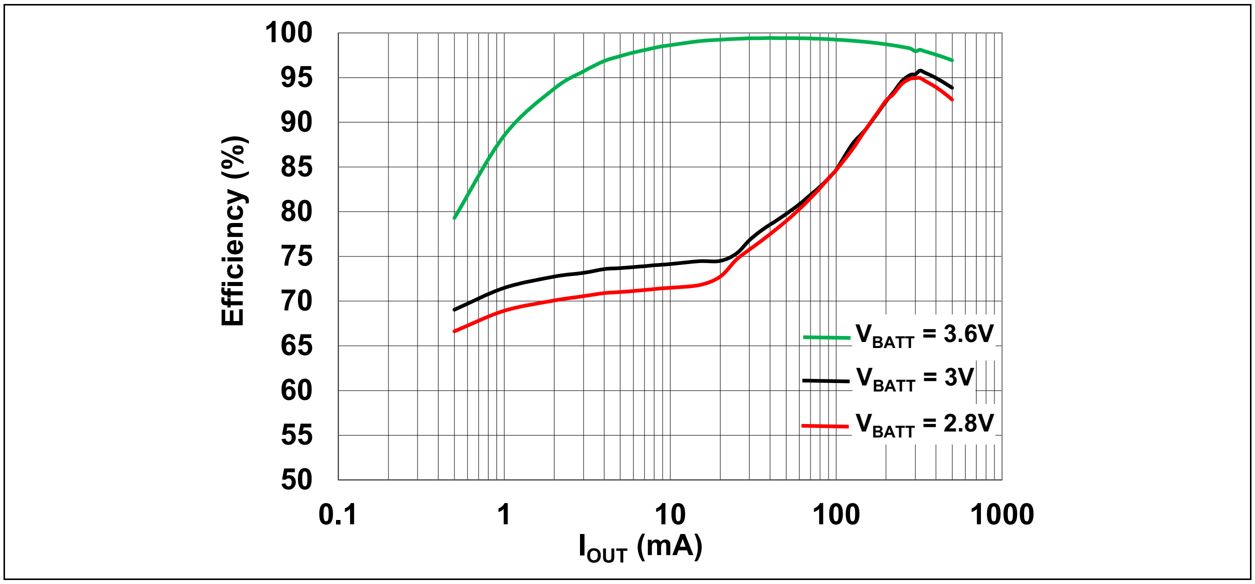

FIGURE 4: *MCP16411 - Efficiency vs. I_{OUT} for V_{OUT} = 3.3V.*

Figure 5 shows the working principle of the MCP16411 with dynamic UVLO thresholds application. A power supply was used to feed the converter, therefore, the input voltage (the purple signal) is ramping up/down from 2.0V to 4.2V (which represents the voltage of a fresh Li-Ion battery). When the input voltage is 3.0V (cursor "a"), the UVLO start-up trip point is reached, so the V_{OUT} goes up to the desired value (3.3V) and the LBO signal gets high.

When the input voltage decreases and the $UVLO_{STOP}$ value is reached (2.8V – cursor "b"), the Enable input is asserted to low, turning off the output of the converter. Consequently, the LBO switches to low level, with 150 µs response time, which will trigger (indicate) the low battery warning.

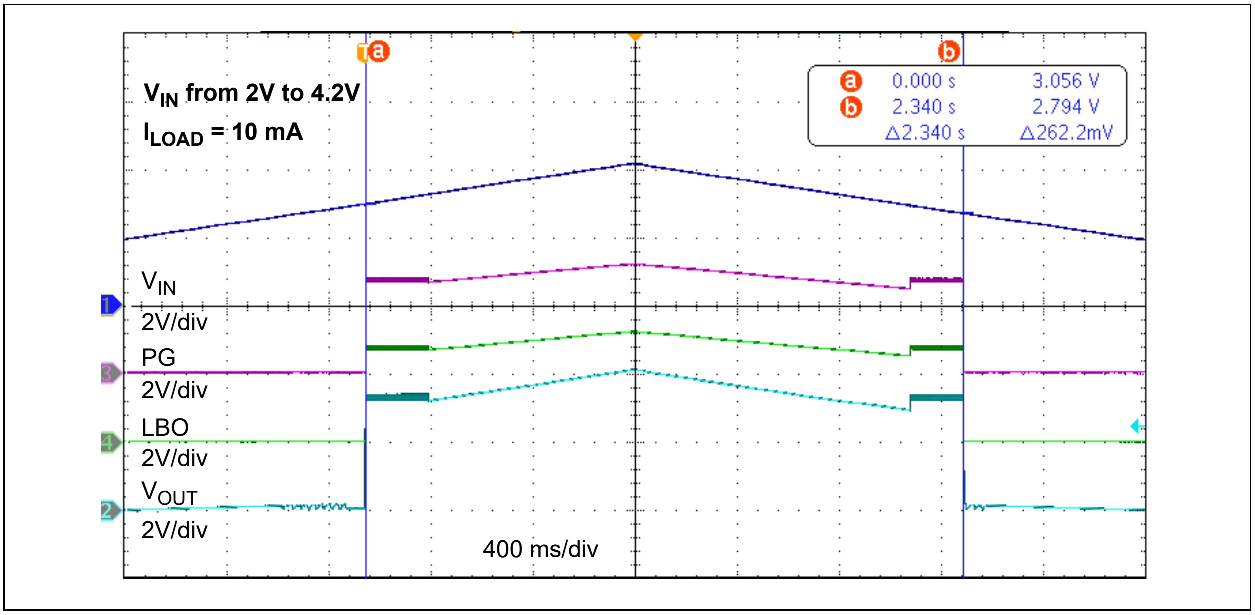

FIGURE 5: *MCP16411 Using Dynamic UVLO Thresholds – Show Proofing Waveforms.*

The proposed solution was designed using a form factor for the PCB, which is compatible with a holder for a single cell 18650 cylindrical Li-Ion battery, as shown in Figure 6.

To complete this Total System Solution, a few external components were added.

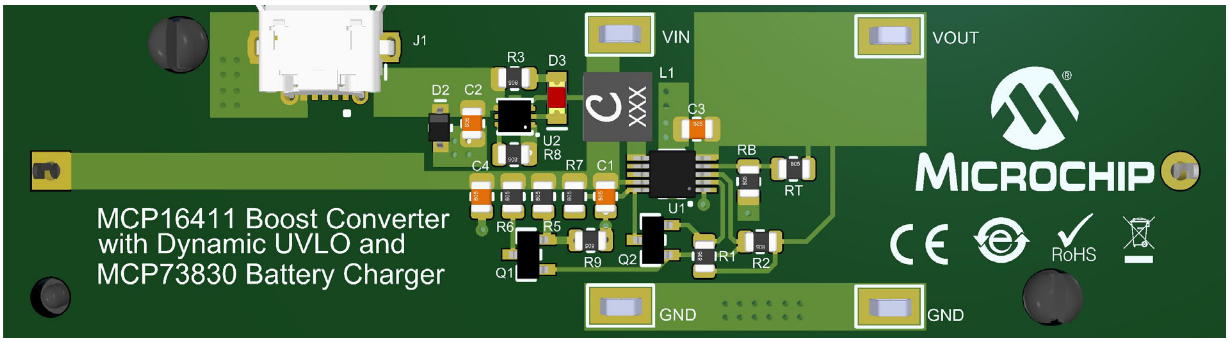

FIGURE 6: *MCP16411 Boost Converter and MCP73830 Battery Charger: Practical Implementation.*

CONCLUSIONS

Nowadays, the portable and wearable technologies are evolving more and more. Therefore, the proposed solution was designed to be powered from a single cell Li-Ion battery. Some of these applications may be represented by electric toothbrushes or shavers, which can be designed using full analog electronic components.

The main advantage of this TSS is represented by the utilization of the MCP16411 step-up DC-DC converter, due to its high efficiency, low quiescent current and safety features, as the indicators for Power Good and Die Overtemperature. Moreover, the battery-friendly features are represented by the Automatic Input-to-Output Bypass during operation and Programmable UVLO thresholds; all these benefits are translated into a maximum battery capacity utilization.

In addition, the proposed TSS provides easy implementation and requires a minimum number of extra components, which reduces the BOM, the total system cost, as well as the board area.

REFERENCES

1. MCP73830/L Datasheet, "*Single-Cell Li-Ion/Li-Polymer Battery Charge Management Controllers in 2x2 TDFN*", DS20005049, Microchip Technology Inc., 2011/2019.

2. MCP1641X Datasheet, "*Low IQ Boost Converter with Programmable Low Battery, UVLO and Automatic Input-to-Output Bypass Operation*", DS20006394, Microchip Technology Inc., 2020.

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specifications contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is secure when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods being used in attempts to breach the code protection features of the Microchip devices. We believe that these methods require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Attempts to breach these code protection features, most likely, cannot be accomplished without violating Microchip's intellectual property rights.
- Microchip is willing to work with any customer who is concerned about the integrity of its code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of its code. Code protection does not mean that we are guaranteeing the product is "unbreakable." Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

For information regarding Microchip's Quality Management Systems, please visit www.microchip.com/quality.

Trademarks

ISBN: 978-1-5224-8133-1

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
Tel: 678-957-9614
Fax: 678-957-1455

Austin, TX
Tel: 512-257-3370

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453
Tel: 317-536-2380

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608
Tel: 951-273-7800

Raleigh, NC
Tel: 919-844-7510

New York, NY
Tel: 631-435-6000

San Jose, CA
Tel: 408-735-9110
Tel: 408-436-4270

Canada - Toronto
Tel: 905-695-1980
Fax: 905-695-2078

ASIA/PACIFIC

Australia - Sydney
Tel: 61-2-9868-6733

China - Beijing
Tel: 86-10-8569-7000

China - Chengdu
Tel: 86-28-8665-5511

China - Chongqing
Tel: 86-23-8980-9588

China - Dongguan
Tel: 86-769-8702-9880

China - Guangzhou
Tel: 86-20-8755-8029

China - Hangzhou
Tel: 86-571-8792-8115

China - Hong Kong SAR
Tel: 852-2943-5100

China - Nanjing
Tel: 86-25-8473-2460

China - Qingdao
Tel: 86-532-8502-7355

China - Shanghai
Tel: 86-21-3326-8000

China - Shenyang
Tel: 86-24-2334-2829

China - Shenzhen
Tel: 86-755-8864-2200

China - Suzhou
Tel: 86-186-6233-1526

China - Wuhan
Tel: 86-27-5980-5300

China - Xian
Tel: 86-29-8833-7252

China - Xiamen
Tel: 86-592-2388138

China - Zhuhai
Tel: 86-756-3210040

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444

India - New Delhi
Tel: 91-11-4160-8631

India - Pune
Tel: 91-20-4121-0141

Japan - Osaka
Tel: 81-6-6152-7160

Japan - Tokyo
Tel: 81-3-6880- 3770

Korea - Daegu
Tel: 82-53-744-4301

Korea - Seoul
Tel: 82-2-554-7200

Malaysia - Kuala Lumpur
Tel: 60-3-7651-7906

Malaysia - Penang
Tel: 60-4-227-8870

Philippines - Manila
Tel: 63-2-634-9065

Singapore
Tel: 65-6334-8870

Taiwan - Hsin Chu
Tel: 886-3-577-8366

Taiwan - Kaohsiung
Tel: 886-7-213-7830

Taiwan - Taipei
Tel: 886-2-2508-8600

Thailand - Bangkok
Tel: 66-2-694-1351

Vietnam - Ho Chi Minh
Tel: 84-28-5448-2100

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4485-5910
Fax: 45-4485-2829

Finland - Espoo
Tel: 358-9-4520-820

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Garching
Tel: 49-8931-9700

Germany - Haan
Tel: 49-2129-3766400

Germany - Heilbronn
Tel: 49-7131-72400

Germany - Karlsruhe
Tel: 49-721-625370

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Germany - Rosenheim
Tel: 49-8031-354-560

Israel - Ra'anana
Tel: 972-9-744-7705

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Italy - Padova
Tel: 39-049-7625286

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Norway - Trondheim
Tel: 47-7288-4388

Poland - Warsaw
Tel: 48-22-3325737

Romania - Bucharest
Tel: 40-21-407-87-50

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

Sweden - Gothenberg
Tel: 46-31-704-60-40

Sweden - Stockholm
Tel: 46-8-5090-4654

UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820

02/28/20