MICROCHIP

AN1337

Optimizing Battery Life in DC Boost Converters Using MCP1640

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INTRODUCTION

Microchip Technology Inc. has developed the MCP1640/B/C/D devices for battery-powered applications. These devices possess all the modern design features, such as high efficiency, low quiescent current, compact size, and low number of external components.

The MCP1640 is a synchronous step-up DC-DC converter that provides up to 96% efficiency and runs at 500 kHz frequency. The device offers easy-to-use power supply solutions for applications powered by one, two or three-cell alkaline, NiCd, NiMH, or single-cell Li-Ion/Li-Polymer batteries.

This application note details the practical considerations for more efficient use of the MCP1640 device in applications. It also gives ideas on how to increase battery life.

MCP1640/B/C/D FEATURES AND OPTIONS

The MCP1640/B/C/D features include:

- Low start-up voltage (typically 0.65V, at 1 mA load and 3.3V output) and continuous operating after start-up, until 0.35V input voltage is reached
- Output voltage range, from 2V to 5.5V
- PWM/PFM mode operation automatically selected (MCP1640/C)
- Low quiescent current (19 µA typical in PFM mode)
- Shutdown current less than 1 µA
- Integrated synchronous switch
- Internal compensation
- Low noise, anti-ring control
- Inrush current limit and soft start

The typical peak current limit is 800 mA. It delivers more than 100 mA load current at 1.2V input and 3.3V output, or more than 300 mA at 5.0V output, when supplied with 3.3V input. Detailed information will be presented in the following sections.

Microchip offers the MCP1640 in four options, which help users meet different system requirements. The devices and their available options are shown in Table 1.

TABLE 1: PART NUMBER SELECTION

Part Number	PWM/ PFM	PWM	True Output Disconnect	Bypass
MCP1640	X	—	X	—
MCP1640B	—	X	X	—
MCP1640C	X		—	X
MCP1640D	—	X	—	X

Choosing Between PWM/PFM and PWM-Only Mode

The MCP1640/B/C/D series operate in two modes:

- Pulse-Width Modulation (PWM, in continuous and discontinuous mode), or Pulse Frequency Modulation (PFM) – for MCP1640 and MCP1640C
- PWM only – for MCP1640B and MCP1640D

The PFM mode starts when the output current reduces below a predetermined threshold. During PFM mode, a high peak current is used to pump up the output to the threshold limit. If the output voltage reaches the maximum limit, the switching pulses will stop and the device enters in a low quiescent current, to minimize the current drawn from the power source (battery). The automatic switching from PWM to PFM mode is used for light load conditions to maximize the efficiency over a wide range of output current. PFM mode has one disadvantage: higher output voltage ripple. While working in PFM/PWM mode, the output voltage increases to approximately 50 mV. The PFM to PWM current threshold depends on the input voltage (see Figure 1).

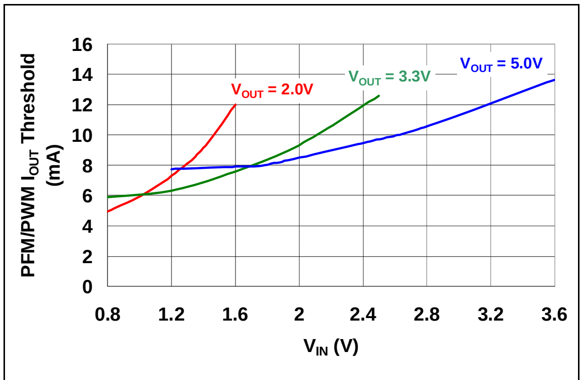

FIGURE 1: *PFM to PWM Output Threshold vs. Input Voltage.*

Figure 2 demonstrates the difference between the output voltage in PFM mode and PWM mode, which is approximately 50 mV at 1.2V input and 3.3V output. The load step is from 25 mA to 1 mA. As shown in Figure 1, the threshold between modes (from PWM to PFM) is approximately 6 mA.

MCP1640B/D devices operate at a constant 500 kHz switching frequency, lowering the output ripple voltage when compared to the MCP1640/C devices, which have the PWM/PFM mode option. Under light load conditions and a typical minimum duty cycle of 100 ns, the MCP1640B/D devices continue to switch at a constant frequency. At lighter loads (below few mA), the MCP1640B/D devices begin to skip pulses.

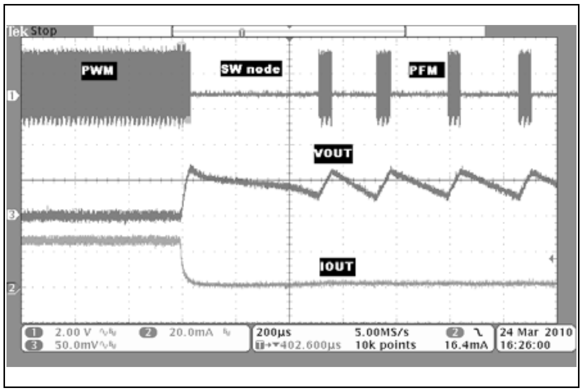

FIGURE 2: *Evaluation of the PWM and PFM Modes – Load Step from 25 mA to 1 mA.*

Figure 3 depicts the efficiency of the two modes: PFM/PWM mode and PWM-only mode. It shows the main disadvantage of not entering in PFM mode – lower efficiency for light loads.

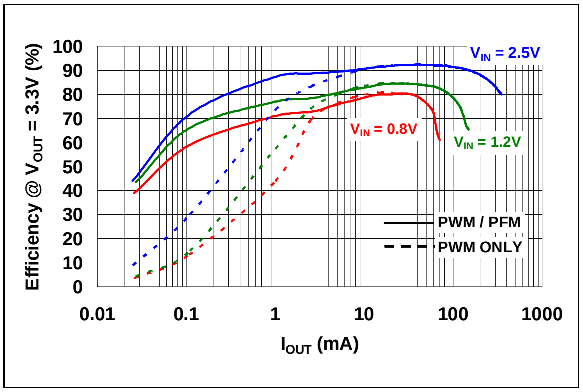

FIGURE 3: *Efficiency vs. Load Current (V_{OUT} = 3.3V).*

In conclusion, when the output ripple is not a primary design goal, but efficiency is a key feature of the project (especially for light loads), the MCP1640/C devices are strongly recommended, especially in battery-powered systems. They will help to increase the battery lifetime in portable applications.

Choosing Between True Output Disconnect and Input Bypass

When starting to design with the MCP1640 device, the engineer has to select a shutdown state. Depending on the selected shutdown option, the output is completely isolated from the input, or the input is bypassed to the output. The device will be in Shutdown mode if EN pin is low.

The MCP1640 and MCP1640B devices incorporate a True Output Disconnect feature. The output is disconnected from the input by turning off the integrated P-Channel switch (Figure 4) and removing the switch bulk diode connection (turning off the additional P-Channel transistor). During this mode, the current consumed from the input (battery) is less than 1 µA.

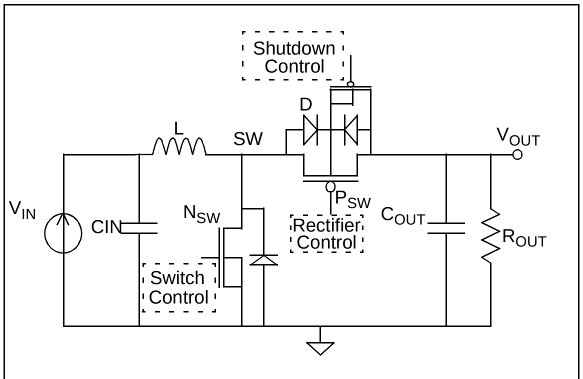

FIGURE 4: *Simplified Current Flow Schematic of MCP1640 Boost Converter.*

The output voltage is held up by the external C_{OUT} capacitor, because the True Output Disconnect feature does not discharge it.

The MCP1640C and MCP1640D devices incorporate the Input Bypass shutdown option. If the device is shut down, the output will be connected to the input through the internal P-Channel MOSFET. In this mode, the current drawn from the input is also less than 1 µA. During shutdown, additional current flow is consumed by the external resistor divider. The loss of the feedback (FB) current is avoided by disconnecting the feedback resistors during shutdown. The regulated feedback loop is not used during Shutdown mode. It is recommended to use high value resistors (of approximately hundred kohms) in the feedback voltage sense network, to keep the biasing current low (this does not influence the frequency response).

The Input Bypass mode is used when the input voltage is almost equal with the necessary output voltage, or is high enough for the load to operate in Sleep or low quiescent current mode. When regulated output voltage is necessary, the shutdown control will enable the boost converter.

THE MCP1640 APPLICATIONS

This section describes the practical aspects and considerations when working with the MCP1640. An example of a 3.3V @ 100 mA application schematic is shown in Figure 5.

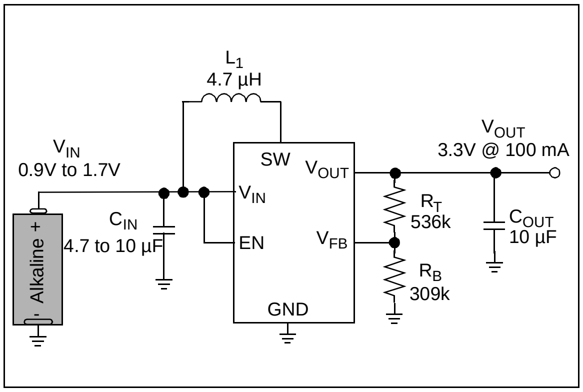

FIGURE 5: 3.3V @ 100 mA Application Schematic.

Maximum Output Current and Voltage Range

The MCP1640 converter starts from 0.65V input, and will continuously operate down to 0.35V. The maximum output voltage is 5.5V and the minimum is 2.0V, with $V_{IN} < V_{OUT}$. For alkaline battery-powered applications, it is recommended that the battery discharge is terminated at 0.6V to 0.7V, to prevent the rupturing of the cell. For rechargeable chemistries, follow the manufacturers' recommended cutoff voltage.

The MCP1640 can also operate below 2.0V output voltage, with some limitations. Detailed information for applications with V_{OUT} = 1.8V can be found in AN1311 [2].

The maximum device output current is dependent upon the input and output voltage. For example, to ensure a 100 mA load current for V_{OUT} = 3.3V, a minimum of 0.9V input voltage (V_{IN}) is necessary. If an application is powered by one Li-Ion battery (V_{IN} from 3.0V to 4.2V), the maximum load current the MCP1640 can deliver is 300 mA.

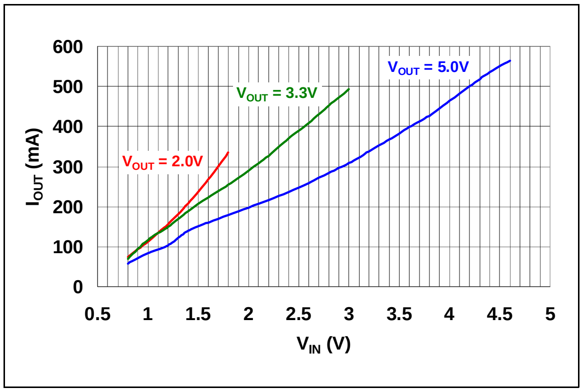

FIGURE 6: Maximum Output Current vs. Input Voltage.

Figure 7 illustrates the No Load Input Current for both modulation options: MCP1640/C (PWM/PFM) and MCP1640B/D (PWM-only). This parameter depends on the input voltage, and is much lower in PWM/PFM mode. By pulling the EN pin low, the current drawn from the input source will be less than 1 µA (in Shutdown mode). This helps to increase battery lifetime.

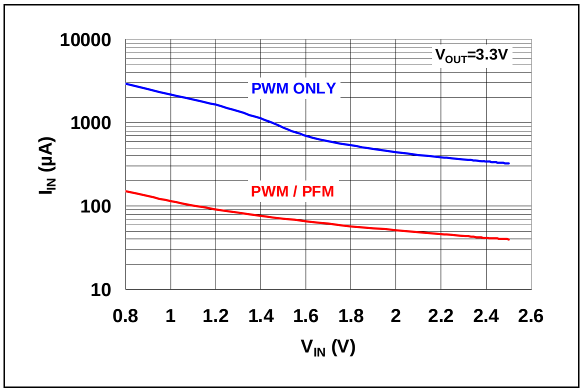

FIGURE 7: No Load Input Current vs. Input Voltage.

Components – Input and Output Capacitors, Boost Inductor and Feedback Resistors

This section describes the recommended components to use with MCP1640 devices.

The typical input capacitance is 4.7 µF. If the device is located far from the input source (battery), additional capacitance can be added. For higher output current battery powered applications, a 10 µF input capacitor is recommended. For low output current applications that operate in PWM mode only (MCP1640B/D), lower input capacitance can be used. Figures 8, 9 and 10 demonstrate how the MCP1640B device works with a 0.1 µF input capacitor for different load currents (no load, 5 mA and 15 mA). The input ripple is large, but the system is stable. This low-cost solution can be used for low duty cycle (short on time) applications.

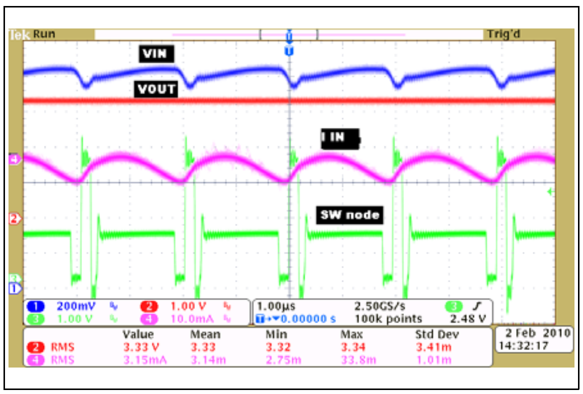

FIGURE 8: *MCP1640B Working with 0.1 µF Input Capacitor, No Load and V_{IN} = 1.2V.*

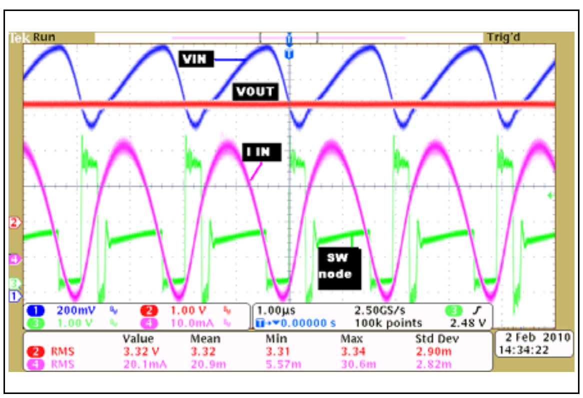

FIGURE 9: *MCP1640B Working with 0.1 µF Input Capacitor, I_{OUT} = 5 mA.*

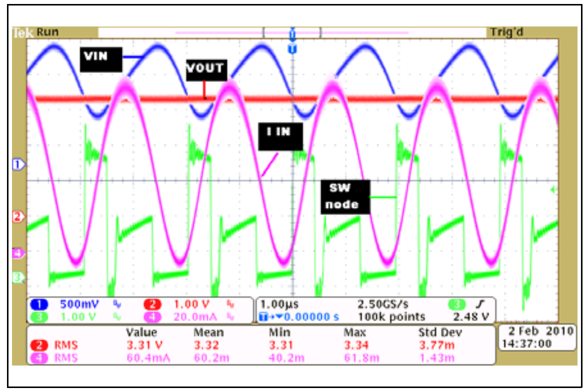

FIGURE 10: *MCP1640B Working with 0.1 µF Input Capacitor, I_{OUT} = 15 mA.*

A 10 µF output capacitor is recommended for most applications. To avoid instability, ceramic output capacitors with 4.7 µF can be used with some restrictions. The output voltage ripple will also be affected by the reduction of the output capacitance. AN1311 [2] describes the system stability using a 4.7 µF output capacitor, and also includes additional information on the boost inductance and output capacitance limits used with MCP1640.

The boost converter efficiency depends on the input/output voltage and load current. The majority of losses come from the internal switch resistance. For low input/output voltage applications, the efficiency is lower than in high input/output voltage applications. The boost inductor resistance also impacts the efficiency. Larger size inductors have lower resistance, resulting in higher efficiency. This implies a trade-off between size, cost and performance. The inductor represents a decisive factor in the application design.

Figure 11 demonstrates the influence of size and R_{DC} (DC series resistance of inductors) in the design, for two inductor types:

- 4.7 µH, R_{DC} = 0.04Ω, I_{SAT} = 1.8A, 6x6x3 mm
- 4.7 µH, R_{DC} = 0.256Ω, I_{SAT} = 0.7A, 3x3x1 mm

The lower the inductor R_{DC}, the higher the efficiency.

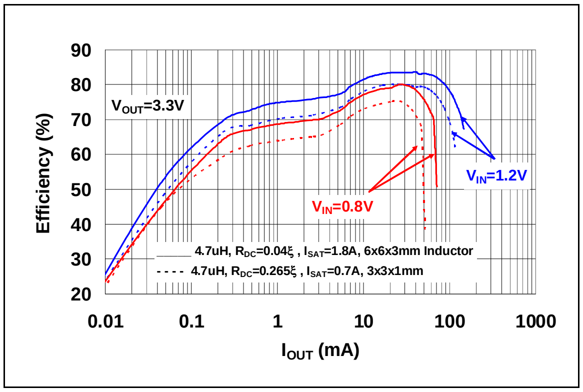

FIGURE 11: *Efficiency @ V_{OUT} = 3.3V vs. Output Current for Two Inductor Types (with Different R_{DC} and I_{SAT}).*

The boost inductor value can vary from 2.2 µH to 10 µH. An inductance value of 4.7 µH is recommended to achieve a good balance between inductor size, converter load transient response and noise. The MCP1640 Data Sheet [1] describes several inductors that can be used (see Section 5 in the Data Sheet). Application Note AN1311 [2] also describes several conditions, where inductors smaller or larger than 4.7 µH are used. Note that for boost converters, the inductor's current can be much higher than the output current. When choosing the inductor current, look for the saturation current parameter to be higher than the peak input current. Saturation current typically specifies a point where the inductance decreases a percentage of the rated value. This percentage is between 10% to 40%. As inductance decreases, the inductor ripple current increases. Reaching the current peak limit should be avoided.

The output capacitor does not affect only the output voltage ripple. Efficiency is also affected by the capacitor's equivalent series resistance. The resistive loss depends on the selected capacitor type (ceramic, aluminum or tantalum dielectric). The best choice is the ceramic capacitor, which has the lower DC equivalent resistance, ESR (less than 10 mΩ). Aluminum types have a few ohms of resistance. Figure 12 illustrates how the efficiency and the maximum output current are affected by different output capacitor types, when V_{OUT} = 3.3V and V_{IN} = 1.2V.

Using high ESR capacitor types result in poor efficiency. When running with a 10 µF ceramic output capacitor, the MCP1640 generates a maximum of 150 mA at 3.3V output and 1.2V input. If the ceramic capacitor is replaced with a 10 µF aluminum capacitor, the maximum output current reached by the MCP1640 is approximately 65 mA. Figure 12 also shows a 15 µF low ESR tantalum capacitor that performs with similar efficiency to a 10 µF ceramic capacitor.

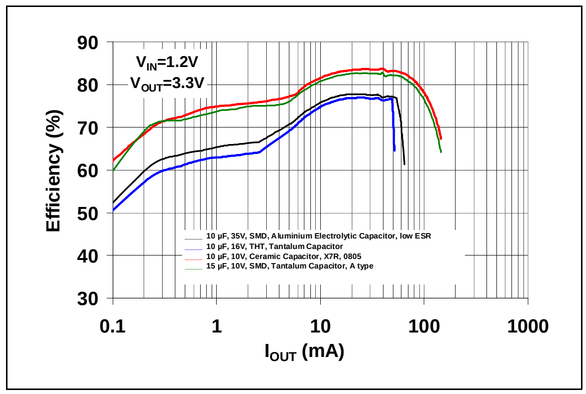

FIGURE 12: *Efficiency @ V_{OUT} = 3.3V vs. Output Current for Different Output Capacitors Types.*

As mentioned previously, the output voltage range for the MCP1640 is from 2.0V to 5.5V. The output voltage is a function of the feedback voltage, derived from R_{TOP} and R_{BOT} resistors, as shown in Figure 13. The resistors' values can be higher than indicated in Figure 13. A potential issue with higher value resistors is environmental contamination, which can create a leakage current path on the PCB. This will affect the feedback voltage and the output voltage regulation. Designers should use resistors that are larger than 1 MΩ with precaution. In normal humidity conditions, the FB input leakage is very low and the resistors' values will not affect the stability of the system. The internal Error Amplifier is a trans-conductance type; gain is not related to the resistors' values. To calculate the resistor values, the following equation can be used:

EQUATION 1:

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

where V_{FB} voltage for MCP1640 is 1.21V.

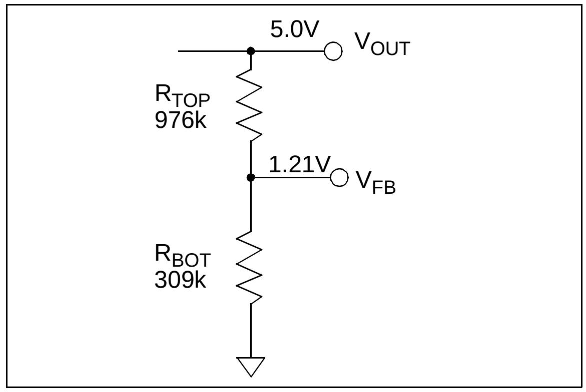

FIGURE 13: *Feedback Resistors Divider Values for 5.0V Output Voltage.*

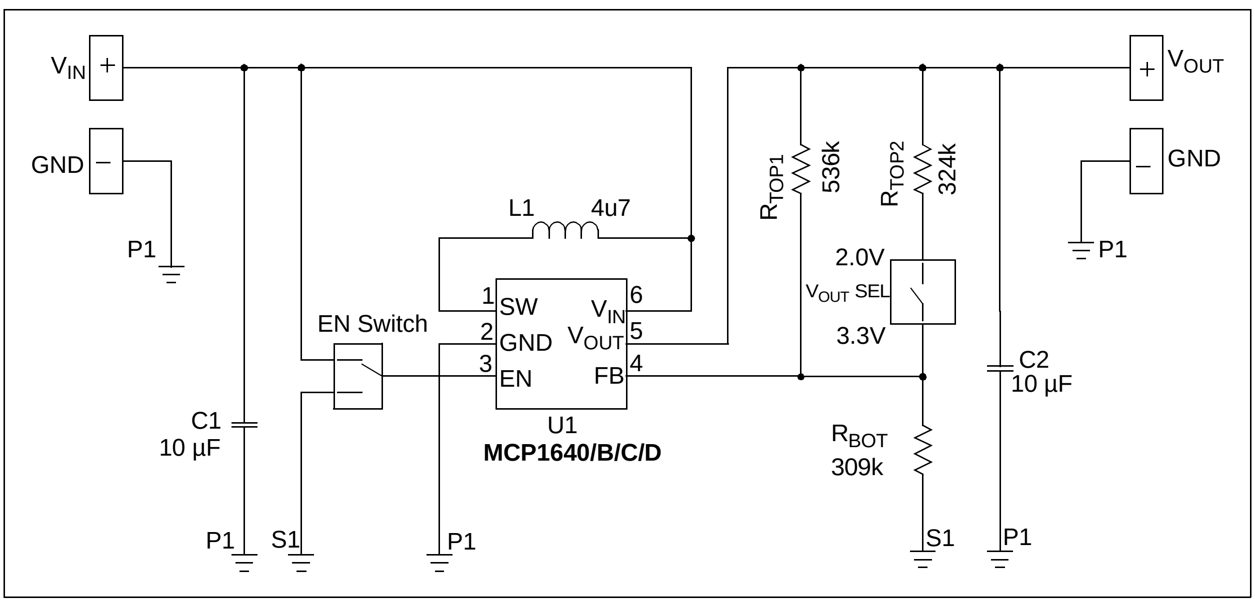

FIGURE 14: *MCP1640/B/C/D - SOT23, Two Output Voltages Options (2.0V and 3.3V) Using a Switch to Connect R_{TOP} Resistors in Parallel.*

As an example, for V_{OUT} = 3.3V, the boost application resistor values are:

R_{TOP} = 536 kΩ and R_{BOT} = 309 kΩ,

or

R_{TOP} = 6.8 MΩ and R_{BOT} = 3.9 MΩ.

Manually-selected multiple output voltages can be designed using jumpers or miniature switches. For boost converters, the removal of the feedback resistors when using jumpers, must be avoided. If the feedback loop is opened, the output voltage will increase above the absolute maximum output limits of the MCP1640 and damages the device. To solve this problem, connect resistors in parallel with the switches, as shown in Figure 14 (2.0V and 3.3V output application). When switch V_{OUT} SEL is open, the output is 3.3V, because only the R_{TOP1} is connected. If the switch is closed, the output is 2.0V, while R_{TOP1} and R_{TOP2} are connected in parallel (the equivalent resistance is approximately 202 kΩ).

R_{TOP2} is calculated by using the resistance value for V_{OUT1} = 3.3V and the equivalent resistance (R_{EQ}), for V_{OUT2} = 2.0V.

EQUATION 2:

$$R_{TOP1} = R_{BOT} \times \left(\frac{V_{OUT1}}{V_{FB}} - 1\right)$$

where: R_{BOT} is user's choice.

EQUATION 3:

$$R_{EQ} = R_{BOT} \times \left(\frac{V_{OUT2}}{V_{FB}} - 1\right)$$

where: $R_{EQ} = R_{TOP1} \, II \, R_{TOP2}$

With R_{BOT} selected and R_{EQ}, we can calculate R_{TOP2}:

EQUATION 4:

$$R_{TOP2} = \frac{(R_{TOP1} \times R_{EQ})}{(R_{TOP1} - R_{EQ})}$$

TIPS ON HOW TO INCREASE BATTERY LIFE

MCP1640 was developed to increase battery lifetime. Low input voltage operation, PFM/PWM mode, up to 96% efficiency, low quiescent current, True Output Disconnect and Input-to-Output Bypass shutdown options are only a few of the features that help extend the battery life.

How to Estimate the Battery Service Time

The primary battery capacity (expressed in terms of mAh) is an indication of the battery life for a specific drain rate, at a specific cutoff voltage. For an alkaline battery, the discharge curve (Battery Voltage vs. Service Time) is given for a constant discharge current and a specified cutoff voltage. Using this curve, the available capacity can be obtained by multiplying the drain current (mA) with time (hours) at the cutoff voltage required. Figure 15 shows a typical 100 mA constant current discharge curve at room temperature for an AA/LR6 alkaline battery, that can be found in the manufacturer's battery data sheet. For example, this battery would have a capacity of 100 mA x 25h = 2500 mAh under 100 mA drain, with a 0.8V cutoff. The same battery, at 1.2V cutoff and with the same 100 mA drain current, would be 100 mA x 15h = 1500 mAh.

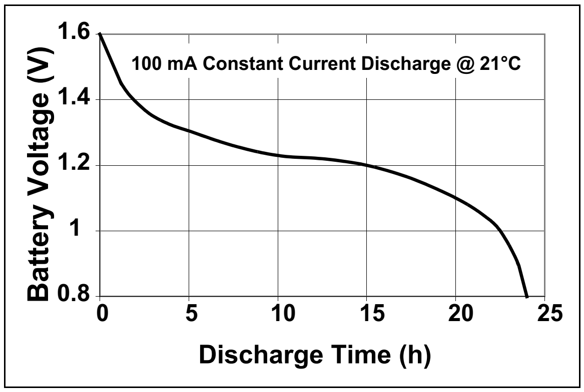

FIGURE 15: *Typical AA/LR6 Alkaline Battery Discharge Curve @ 100 mA to 0.8V cutoff.*

In conclusion, the service time of the alkaline batteries is dependent upon the discharge current and the cutoff voltage. The primary battery is more efficient at lower discharge currents, as shown in Figure 17. The cutoff voltage will impact the battery run time. Generally, if the battery is discharged to 0.8V, approximately 95% of the battery capacity is used.

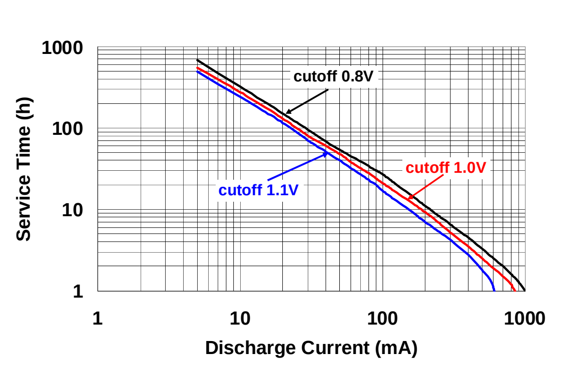

FIGURE 16: *Typical Constant Current Discharge Characteristics @ 21°C to Different Cutoff Voltages, for an AA/LR6 Alkaline Battery.*

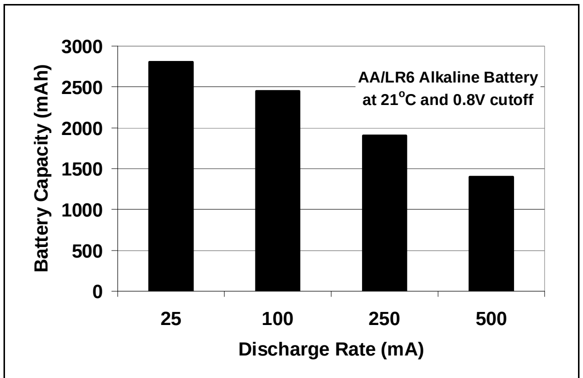

FIGURE 17: *Battery Capacity vs. Drain Current Chart @ 21°C to 0.8V Cutoff.*

If the load does not require permanent constant current, and the application is pulsed on and off, the operating on-time can impact battery service time. The amount of additional service time depends on the load current and the on/off time of the load. In this case, there is no simple equation to calculate the battery life.

For a boost convertor working at a constant output current, the output power is also constant, therefore the efficiency of the system must be considered (which is high for MCP1640), to calculate the input current. Because the current consumption increases as the battery voltage drops, the input power can be considered quasi-constant in low power applications, if the efficiency is high. For such applications, the lifetime estimation can be within an acceptable tolerance on the curves presented in Figure 16, considering the average power consumed.

For rechargeable cells, a good start to approximate the service time is Peukert's Law, elaborated by the German scientist W. Peukert in 1897, which expressed the capacity of a lead-acid battery in terms of the rate at which the battery is discharged.

EQUATION 5:

$$t = \frac{C}{I^k}$$

Where:

t	=	time of discharge (h)
C	=	capacity of cell (Ah)
I	=	discharge current (A)
k	=	Peukert constant

For a lead-acid battery, the value of *k* is typically between 1.1 and 1.3. However, for an ideal battery, the constant *k* equals 1. In this case, the actual capacity is independent of the drain current.

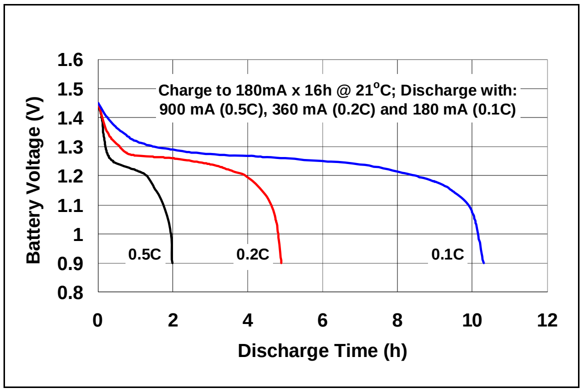

FIGURE 18: *Typical Discharge Time vs. Battery Voltage Graphs at Different Discharge Rate, for 1800 mAh NiMh Battery.*

This is a simple way to estimate the lifetime of a rechargeable battery. Figure 18 shows a typical discharge curve for a 1800 mAh NiMh cell. Battery lifetime depends on the charge current, discharge current and cutoff voltage. If the 0.9V cutoff is used, the estimated service time will be approximately:

EQUATION 6:

$$t = \frac{1800mAh}{900mA} = 2h$$

when discharging with 0.5 C, or:

EQUATION 7:

$$t = \frac{1800mAh}{360mA} = 5h$$

when discharging at 0.2 C.

Depending on the battery state – number of charging/discharging cycles or charging algorithms, ambient temperature – the lifetime decreases, in contrast with the calculated value.

Regardless of the selected battery type, when powering a boost DC-DC application, a boost device with a lower input shutdown voltage and lower start-up voltage, such as MCP1640, becomes important (down to 0.35V).

Increasing Battery Service Time Using MCP1640 – Tips and Tricks

The key features of the MCP1640 that help increase the life of the battery are:

- Up to 96% efficiency
- PFM mode for lighter load (see Figures 3 and 7)
- Low input start-up voltage, typically 0.65V at 1 mA load
- Low shutdown voltage (MCP1640/B/C/D devices continuously operating down to 0.35V)
- True output disconnect EN option, preventing leakage current from input to output by removing the P-Channel MOS bulk diode (less than 1 µA is consumed from the battery in this mode)
- 19 µA quiescent current

For applications powered by non-rechargeable batteries, such as alkaline, that consume a few mA, the MCP1640 device can operate to the minimum input voltage necessary to completely remove all the energy from the battery. As shown in Figure 19, the MCP1640 will start with 1 mA load from a minimum input of 0.65V, and will continuously regulate the output voltage as the input voltage drops to 0.35V. It is important to know the minimum operating voltage of the MCP1640 device, to estimate the life of the battery below the cutoff value (0.8V).

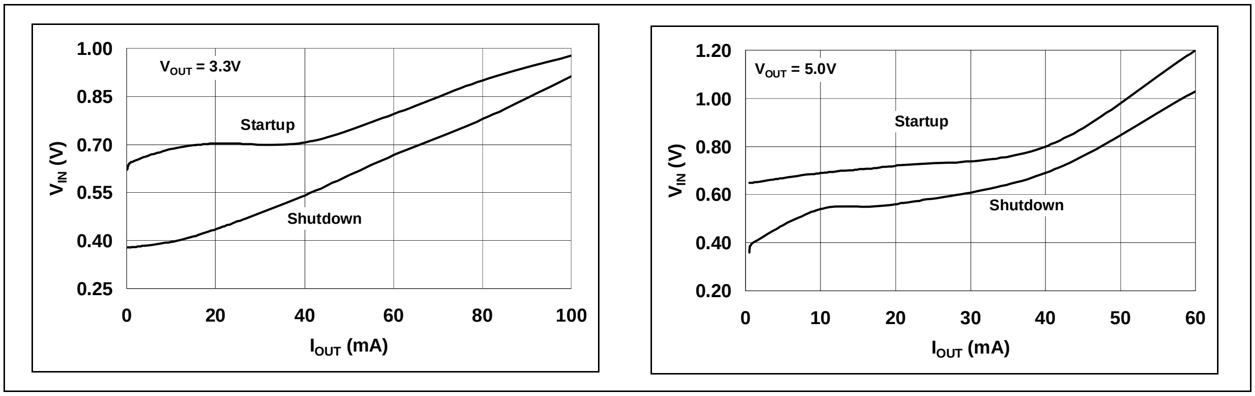

FIGURE 19: *Minimum Start-up and Shutdown V_{IN} into Resistive Load vs. I_{OUT}.*

Depending on the design considerations (size, cost, etc.) and load requirements, here are a few tips to improve battery life:

- Choose an inductor with lower DC series resistance (see Figure 11)
- Choose input and output ceramic capacitors (with lower DC series resistance)
- Increase output capacitor up to 100 µF (see Figure 12)
- Increase the input capacitor to reduce the input voltage ripple and lower the source impedance
- Increase feedback resistors (in terms of MΩ)
- Pulse EN pin to turn on and off the device, accepting a larger output ripple voltage to reduce the average input current. In microcontroller applications, this method can reduce no load standby current.

INCREASING THE VALUE OF FEEDBACK RESISTORS

The feedback resistor network (connected between V_{OUT} and GND) that biases the FB pin (R_{TOP} and R_{BOT} in Figures 13 and 14) can be increased. Larger value resistors will not affect MCP1640's stability. If the environmental conditions permit (no excessive humidity), the megohm resistors can be used, without affecting stability.

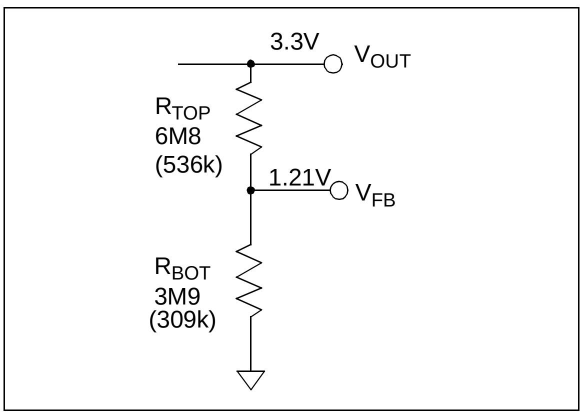

FIGURE 20: *Increase of the Feedback Resistors Value for a 3.3V Output.*

Through Hole Technology (THT) resistors can be used to avoid potential issues with environmental contamination. Smaller package-sized resistors 0805 and 0603, with megohm values, can create a leakage current path on PCB that will change the V_{FB} voltage. Tests with THT resistors have favorable results, for example with R_{TOP} = 6.8 MΩ and R_{BOT} = 3.9 MΩ.

USING THE INPUT-TO-OUTPUT BYPASS OPTION (MCP1640C/D) FOR LONGER SLEEP MODE LOADS

When the EN pin is low, the MCP1640C and MCP1640D enter in an Input-to-Output Bypass Shutdown mode. During Shutdown, the internal P-Channel MOS transistor is turned on and input voltage is bypassed through the P-Channel to the output. This option reduces the quiescent current, in applications that operate in Sleep mode directly from the source, but require a higher voltage for the normal operating mode. In Shutdown mode, MCP1640C/D consumes less than 1 µA from the battery. A part of the current is also consumed by the feedback resistors.

DISABLING FEEDBACK RESISTORS DURING SHUTDOWN FOR MCP1640C/D

Depending on the values of the R_{TOP} and R_{BOT} , and on the range of V_{OUT}, the current consumed by the feedback network can be several µA, which is more than the MCP1640 consumes in Shutdown mode. Analyzing Figure 13, when two batteries are in series (V_{IN} = 2.4 V typical), the current consumed by the feedback resistors with the EN pin low can be approximated using Equation 8:

EQUATION 8:

$$I = \frac{(2.4V)}{(976k + 309k)} = 1.87\mu A$$

Note: Voltage on inductor or P-Channel is not considered.

By increasing the R_{TOP} and R_{BOT} at 6.8 MΩ and 3.9 MΩ, the consumed current will be lower, as demonstrated in the following equation:

EQUATION 9:

$$I = \frac{(2.4V)}{(6.8M\Omega + 3.9M\Omega)} = 0.23\mu A$$

One solution could be the removal of the feedback resistors during shutdown by using an N-Channel MOSFET to eliminate the FB divider current path, as shown in Figure 21. The transistor's gate is controlled by the EN pin. When EN is high and MCP1640C/D is operating in Boost mode, the N-Channel FET is turned on, and the feedback network is closed. When the EN pin is low, the transistor is off, removing the feedback current path. It is recommended to use an N-Channel with a low V_{GSth}. A good choice would be FDN337N, with a gate threshold below 2V. Using the FDN337N for the feedback divider, the input current for the MCP1640C is reduced to 0.75 µA in Standby mode by using the Input-to-Output bypass option.

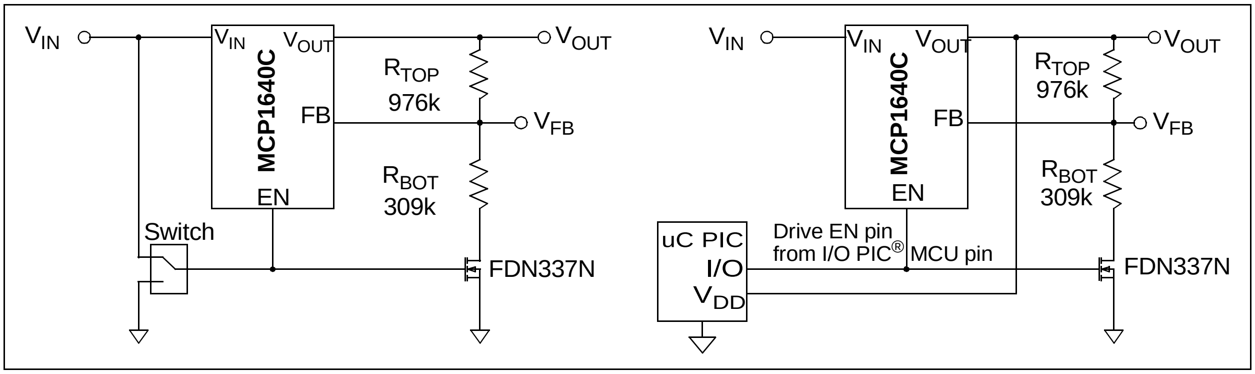

FIGURE 21: *Removing Feedback Resistors when EN is Low for MCP1640C, with Input-to-Output Bypass Option.*

REDUCING STANDBY – NO LOAD INPUT CURRENT IN MICROCONTROLLER APPLICATIONS

When an application is powered by a single alkaline or NiCd/NiMh battery (V_{IN} = 1.2V), and the application operates for a long period in Standby mode (remote controls, electronic torch, etc.), the block diagram described in Figure 21 is not applicable, because the microcontroller requires a minimum of 2V to operate. In Sleep mode, the microcontroller consumes very few µA. The input current measured for a typical application similar to Figure 7 is 40 µA to 100 µA. The MCP1640 operating in PFM mode can be used in True Output Disconnect mode, to lower the input current consumed from the battery by using the microcontroller in Sleep mode.

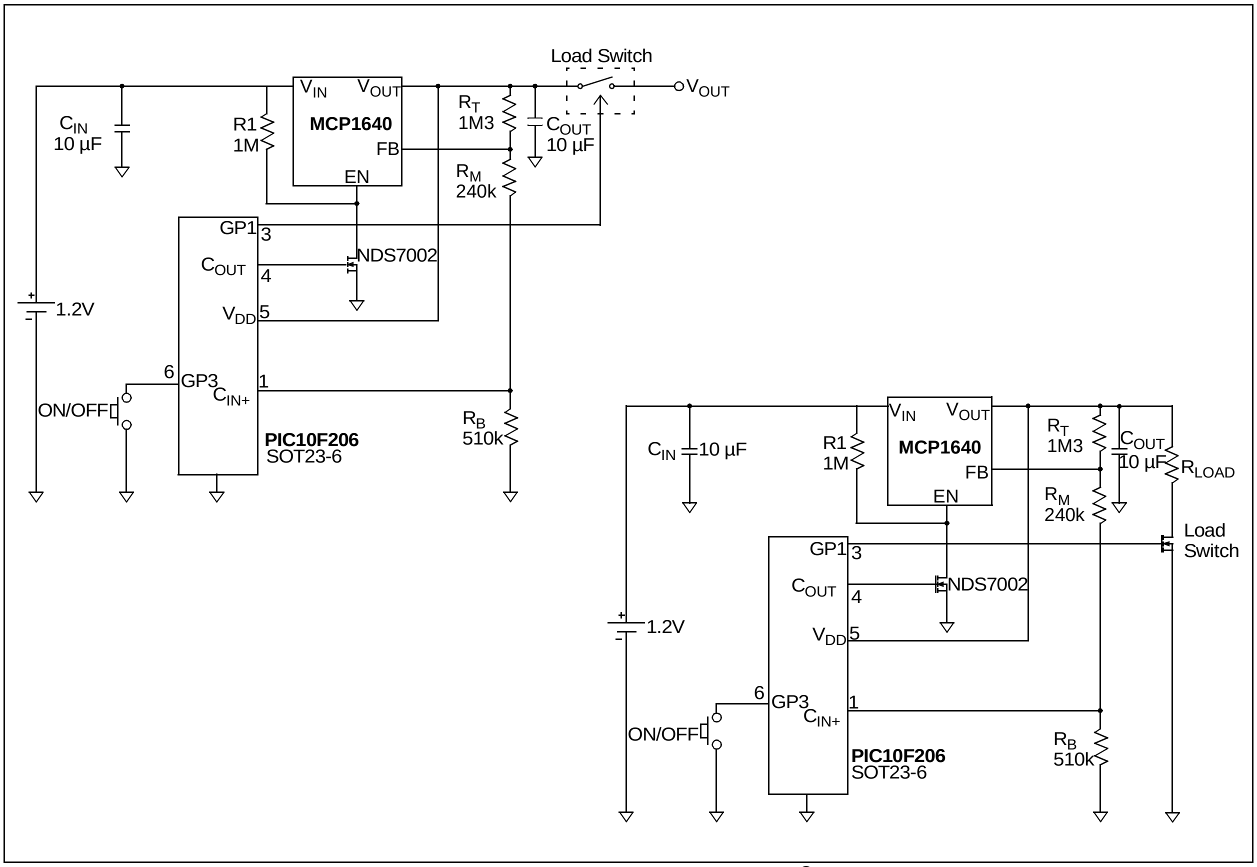

FIGURE 22: Typical Applications Using MCP1640C with PIC® Microcontroller Attached – Reducing Standby No Load Current.

For Sleep mode or light load applications, the MCP1640's enable input is pulsed at a slow rate to reduce the average input current. The EN pin drive frequency depends on the MCP1640 output capacitor value and microcontroller sleep current. The microcontroller will wake-up only to turn on the MCP1640 for a short period of time to pump-up the output voltage. The typical time to charge the output capacitor voltage to 3.3V is 750 ns, with a load less than 10 µA.

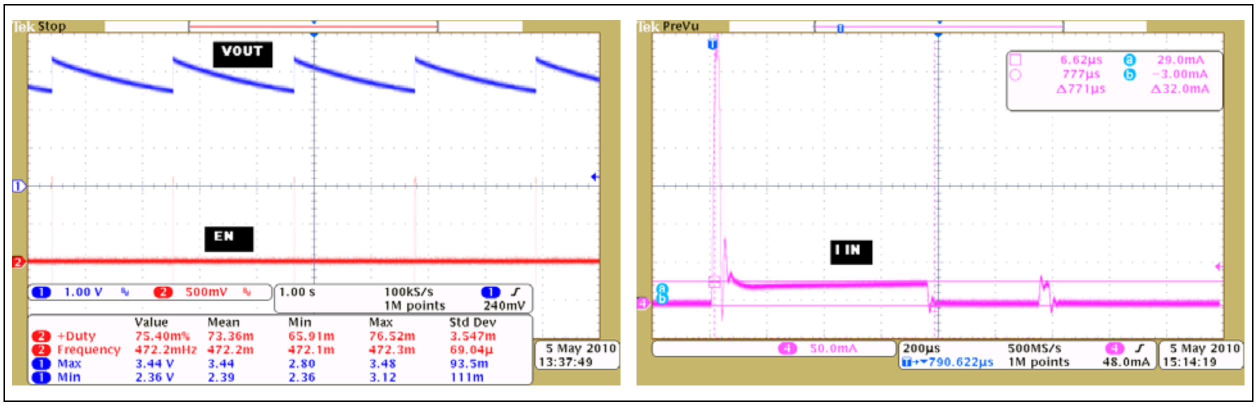

FIGURE 23: Experimental Results – Output Voltage and Drive Signal (Left) and Short Pulse Input Current (Right) Using Switching Method for EN Pin (also see Figures 22 and 25).

There are different hardware and software methods to determine the output voltage level of the MCP1640/C device and/or the frequency of the EN signal used to enable and disable the MCP1640.

For example, Figure 22 shows two low-cost and low-component applications that use a PIC10F206 to perform the main goal: reduce the input current in Standby when load is disconnected. When MCP1640 is in Shutdown, it typically consumes 0.75 µA, but with the analog comparator enabled, the PIC10F206 consumes more than 100 µA. To reduce this current, the microcontroller operates in Sleep mode most of the time. The comparator is periodically enabled (using the internal timer of the microcontroller) to verify the output voltage of the MCP1640. On the schematic in Figure 22, the PIC10F206 consumes approximately 10 µA for a short period of time (when EN signal is high), and about 2 µA when in Sleep mode.

To avoid losing power on the passive components, the application also uses MCP1640's feedback network as an input to the PIC MCU comparator (C_{IN+} comparator input). The inverter input, C_{IN-}, is connected to a 0.6V internal PIC MCU reference. For this application, the threshold of the comparator is around 2.3V. The positive duty cycle is less than 1%, and the frequency of the EN signal is ~0.5 Hz (see Figure 23). The microcontroller periodically enables the MCP1640 to keep its bias at a minimum of 2.0V. Figure 24 demonstrates that the input current with no load is reduced by approximately 87%, from 90 µA to 11 µA. Using the push button as a wake-up feature, the EN signal goes high permanently, powering the microcontroller with a regulated 3.3V.

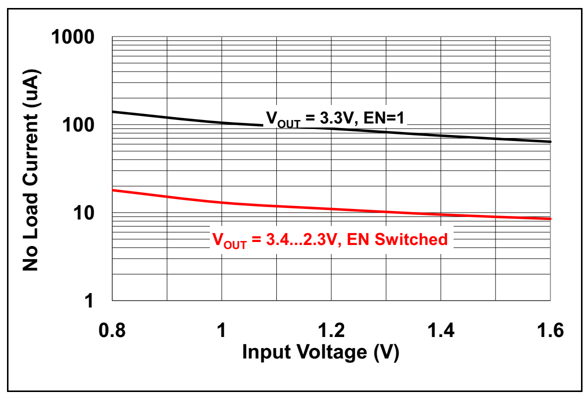

FIGURE 24: No Load Current Reduced with 87% Using EN Switched Method.

Because PIC10F206 is powered from the MCP1640's output, the application starts with EN high for a short period. An N-Channel MOS transistor is used to drive the EN pin.

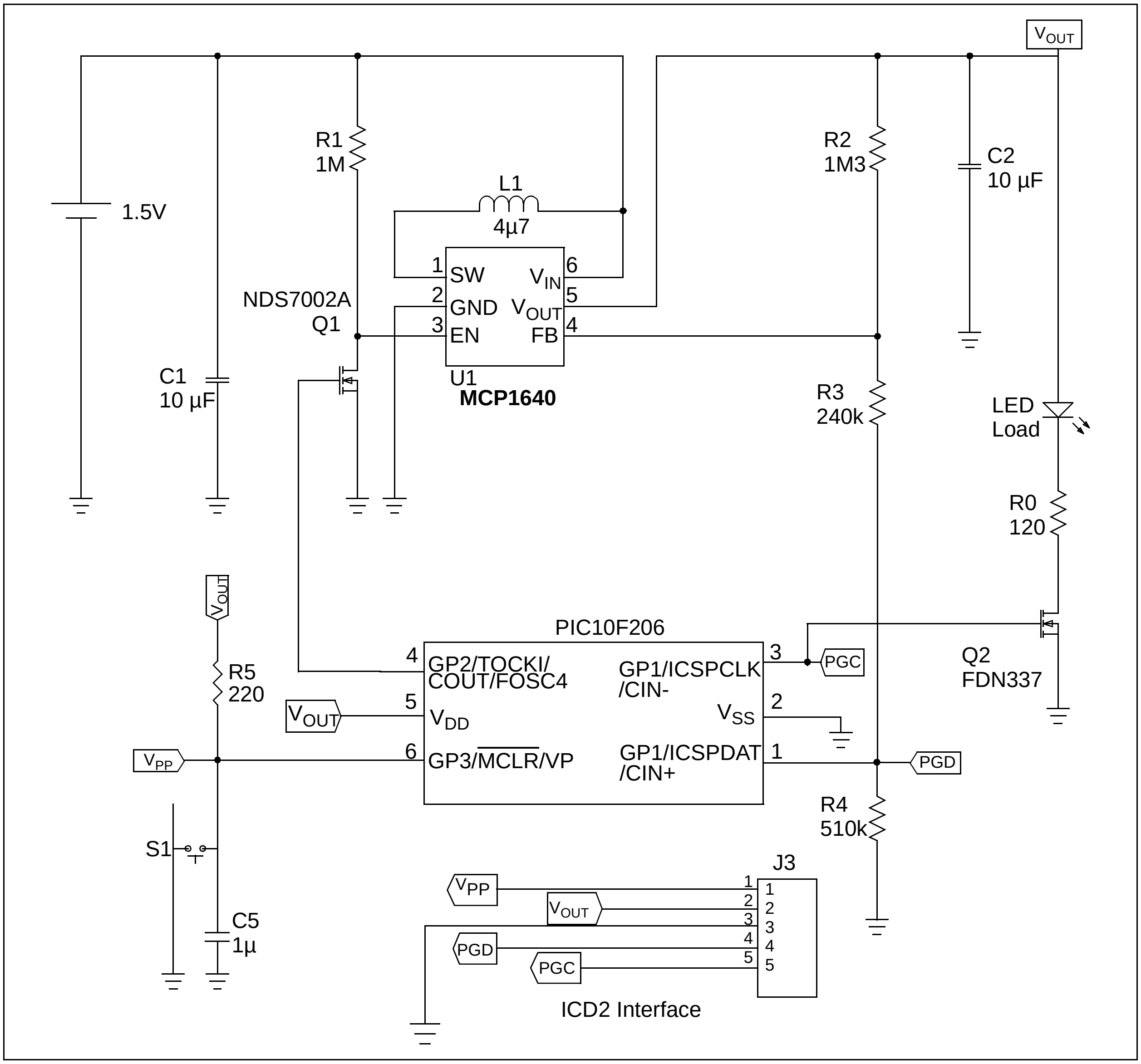

FIGURE 25: *Application Example – MCP1640 and PIC10F206, to Reduce Standby Current.*

The source code for MPLAB® IDE with HI-TECH C compiler, used in the application illustrated in Figure 25, is listed in **Appendix A: "Source Code Example"**. The code can be easily modified to use with any PIC microcontroller with compatible peripherals. The Watchdog Timer enables the PIC MCU periodically. Its internal comparator is enabled for a short period of time to verify MCP1640's output voltage level. If V_{OUT} is lower than the 2.3 V threshold voltage, fixed by R2, R3 and R4 resistors, a short low-level signal will drive the gate of NDS7002 transistor low, enabling the MCP1640. The output capacitor holds the output above 2.3V for more than two seconds.

This solution demonstrates a method that can be used for any PIC MCU application that runs in Sleep mode for extended periods of time. By implementing this method, battery life can be extended up to 10 times.

CONCLUSIONS

In the low voltage boost applications that are powered by batteries, the MCP1640 offers flexible options to help increase the battery lifetime. The MCP1640 device can easily be attached to a microcontroller and used in applications that work for extended periods of time in Standby mode, because they consume less µA of current than one-cell battery applications. Battery life is extended by using the MCP1640 family, due to its low operating voltage capability.

REFERENCES

[1] MCP1640/B/C/D Data Sheet, *"0.65V Start-up Synchronous Boost Regulator with True Output Disconnect or Input/Output Bypass Option"*, (DS22234)

[2] AN1311, *"Single Cell Input Boost Converter Design"*, (DS01311)

[3] *"Alkaline Manganese Dioxide – Handbook and Application Manual"*, Energizer Battery Manufacturing Inc.

[4] Energizer E91 Product Data Sheet, Energizer Holdings, Inc.

[5] "Alkaline Manganese Dioxide Battery, MN1500_US_CT, AA (LR6), Zn/MnO_2 battery Product Data Sheet", Duracell®

[6] GP180AAH Product Data Sheet, GP Batteries

APPENDIX A: SOURCE CODE EXAMPLE

```
//----------------------------------------------------------------------------
// This software example is the property of Microchip Technology Incorporated
// Program:   MCP1640EV-LSBC.c
// Author:    Sergiu Oprea & Valentin C. Constantin (Microchip)
//
// PIC Processor: PIC10F206
// Description:
//           Demonstrated reducing no load current for MCP1640
//           in PIC attach application using HI-TECH C compiler
//
// Modifications: -
//
//----------------------------------------------------------------------------

#include <htc.h>

__CONFIG (WDTEN & MCLRDIS & UNPROTECT); // start with GP3 as input pin & WDT enabled

//----------------------------------------------------------------------------
// Section:  Processor I/O Definitions
//----------------------------------------------------------------------------
#define EN  GP2   //DRIVE MCP1640 EN PIN FROM GP2 WITH INVERTED SIGNAL
#define LED GP1   //DRIVE LED LOAD FROM GP1
#define button GP3  //INPUT BUTTON ON PORT GP3

//----------------------------------------------------------------------------
// Section:  COMPARATOR SETUP
//----------------------------------------------------------------------------
#define COMP_SETUP_1 0b01111011; //comparator enabled
#define COMP_SETUP_2 0b01110011; //comparator disabled

//----------------------------------------------------------------------------
// Section:  WORKING VARIABILE
```

```
//----------------------------------------------------------------------------
unsigned char temp = 0x00;
bit  button_state; // STAE OF PUSH-BUTTON
bit  LED_STATE;    // STAE OF LOAD-LED

//----------------------------------------------------------------------------
// Code Segment
//----------------------------------------------------------------------------
/*****************************************************************************
  Function:
    void main (void)
  Summary:
    Main program entry point.
  Description:
    Main program entry point.  The system will initialize the PIC processor
    and peripherals and then loop forever while monitoring the MCP1640 state.
  Returns:
    None
  ***************************************************************************/
void main(void)
{
 OPTION = 0b11011011;    //GP2 is set as output
 TRIS = 0b11111001;      //GP2, GP1 direction is output
 CMCON0 = COMP_SETUP_2;  //Comparator is disabled

 if((STATUS & 0xF8) == 0x18) //Power On Reset?
 {
  EN = 0;                //On Power On Reset starts MCP1640 switching
 }

 LED = 0;               //Turn-off the load - LED
 button_state = 0;//if push-button hold-on set the button state to low,
 temp = 0;
 LED_STATE = 0;         //and LED state to low

/* main forever loop */
  while(1)
 {
   if(!button)         //if push-button is pressed,
   {
        CLRWDT();
        temp++;        //wait
        if(temp == 20)
        {
```

```
        temp = 0;
        if(!button_state)     //and button state is low,
          {
            if(LED==0)             //and LED off
            {
             EN = 0;               //turn ON the MCP1640 output,
             for(temp=0;temp<100;temp++) NOP();
             LED_STATE = 1;
             LED = 1;              //and turn ON the LED
            }
            else { LED_STATE = 0; LED = 0; }
             button_state = 1;    //else keep the LED OFF
          }
         }
     }   else button_state = 0;
//if no push button pushed detected and LED is OFF:
   if ((LED_STATE==0)&&(button))
   {
   CLRWDT();
   CMCON0 = COMP_SETUP_1; //Enable comparator; 0.6V internal reference
   for(temp=0;temp<10;temp++) NOP();      //delay for stable comp output
   if(CMCON0&0x80)                        //check comparator output and
    {
      CMCON0 = COMP_SETUP_2;             //disable it,
      EN = 1;                            //stop switching MCP1640
      temp = GPIO;     //read the output latch to avoid false interrupt on PIN Change
      SLEEP();                           //and go to SLEEP Mode
    }
   else
    {
      CMCON0 = COMP_SETUP_2;             //else keep disable it,
      EN = 0;                            //start MCP1640
      for(temp=0;temp<150;temp++) NOP(); //for short period
      EN = 1;                            //and stop it.
      temp = GPIO; //read the output latch to avoid false interrupt on PIN Change
     SLEEP();                            //and go to SLEEP Mode
    }
   }
    else
   {
     CLRWDT();                           //reset the internal timer
   }
  }
}
```

NOTES:

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