Using power solutions to extend battery life in MSP430 applications

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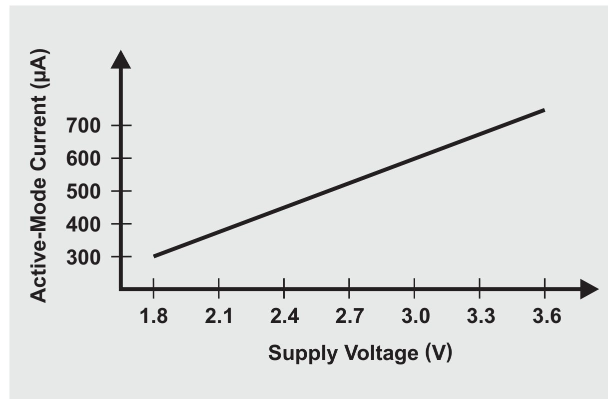
The MSP430 is the lowest-power microprocessor available in the market. Its inherently low-power operation is ideal for battery-powered applications where frequent battery replacement is undesirable. This article shows two simple but effective power solutions that further minimize MSP430 power consumption and extend battery life.

In an attempt to prolong battery life, software engineers go to great lengths to optimize code, minimize memory accesses, etc. Hardware engineers focus on ways to shut down unused circuitry, ensure that all quiescent currents and leakage paths are minimized, and maximize power-supply efficiency.

In most cases, engineers eliminate any DC/DC conversion altogether if the system's source voltage falls within the MSP430's input operating range. Many MSP430 designs do not need an input power supply because the MSP430 device family accepts extremely wide variations in input voltage. For example, the MSP430FG4618 operates with an input voltage of between 1.8 V and 3.6 V. Because of this wide input range, many MSP430 designs operate directly from a battery without additional power conversion. Examples of input sources that do not need power conversion are dual alkaline, nickel metal hydride, and nickel cadmium batteries, as well as primary lithium-ion coin cells.

An often overlooked technique for extending battery life is to add an input power supply, even if it is otherwise not needed. Adding a power supply between the input-voltage source and the MSP430 to increase battery life is contradictory to conventional thinking. This is because of two things that all power supplies have in common: They have quiescent current (I_q) at no load that sinks current from the battery to ground; and they have less than 100% efficiency, which dissipates power in the power supply. Even power supplies optimized for low-power and battery-powered applications have less than 100% efficiency, with quiescent currents that continually drain battery capacity. Typical power-supply efficiencies for an MSP430 application operating at 3.0 V from two AA batteries is 85 to 92%. Typical I_q values range from 15 to 50 µA. Conventional thinking says that removing this power supply and operating the application directly from the battery will extend battery life by an additional 8 to 15% because the effective efficiency will then be 100%.

Figure 1. MSP430FG4618's supply current versus its supply voltage



MSP430 supply current varies linearly with input voltage, so operating the system with lower voltages reduces both MSP430 input current and overall power consumption. Figure 1 shows the variation in the MSP430FG4618's 1-MHz active-mode supply current (I_{AM}) versus its supply voltage.

Operating at the lowest required input voltage minimizes battery current, but this requires the insertion of a power supply. Regardless of topology, this power supply will be less than 100% efficient. A common design scenario is an MSP430 operating from two series-connected AA alkaline batteries that supply 3.2 V when new and 1.8 V when discharged. The designer must choose between two power-system topologies. The first is to operate directly from the battery voltage, which results in a higher MSP430 input current. The second is to insert a power supply between the battery and the MSP430. After considering the power supply's efficiency and quiescent current, many designers quickly choose to operate directly from the input source. Few designers are aware that adding a power supply can actually provide significant improvements in battery life, even with efficiency and quiescent-current concerns.

Designers must deviate from conventional thinking that efficiency is the most important figure of merit in a power system. In a battery-powered system, battery current drain is the main concern. The examples in Figure 2 help make this point. System 1 in Figure 2a operates directly from two AA alkaline batteries. An equivalent power supply in this example has 100% efficiency and 0-µA quiescent current. All power delivered from the battery is available to the MSP430. For System 2 in Figure 2b, a TPS780xx LDO has been inserted. The LDO's efficiency is defined by V_{OUT}/V_{IN}, which averages to approximately 90% over the entire voltage range of the batteries. The LDO also draws 500 nA of quiescent current from the battery. When only efficiency and quiescent current are considered, System 1 clearly wins. However, System 2 draws less current from the batteries, which extends the system's operating time.

Figure 3 compares the two systems' battery currents. When the battery voltage is above 2.2 V, System 1 consumes more battery current because the MSP430 operating current is a linear function of input voltage. System 2 consumes a constant current because the LDO maintains a constant 2.2 V at the MSP430. As the battery voltage drops to 2.2 V and below, the two MSP430s consume the same current. System 2 consumes an additional 500 nA due to the TPS780xx's quiescent current (I_q). When the input voltage is above 2.2 V, System 2's reduced battery current results in longer system run time.

Two lab experiments were conducted with an MSP430FG4618 operating at 5 MHz while powered by two AAA alkaline batteries. These experiments were set up to correspond with the two systems in the previous example. In this second example, System 1, with the MSP430 powered directly from the batteries, operated for 223 hours before shutting down. System 2, which used a TPS780xx to drop the MSP430 operating voltage to 2.2 V, operated for 298 hours before shutting down. The addition of the TPS780xx LDO, which operates at 90% efficiency with these operating conditions, extended battery life by 30%.

An often underutilized method to extend battery life is dynamic voltage scaling (DVS). With DVS, the input supply is reduced if the MSP430 is operated at a lower clock speed or placed into a low-power mode. The examples presented earlier demonstrated that operating with lower input voltages reduces current consumption and extends battery life. For example, an MSP430 system operating with a 7-MHz maximum clock frequency may require the input voltage to be 3.3 V. If the clock speed is reduced to 4.6 MHz, the MSP430 requires only a 2.0-V input voltage. If the MSP430 is placed into low-power mode, the required input voltage is only 1.8 V.

Figure 2. Two alkaline-system configurations

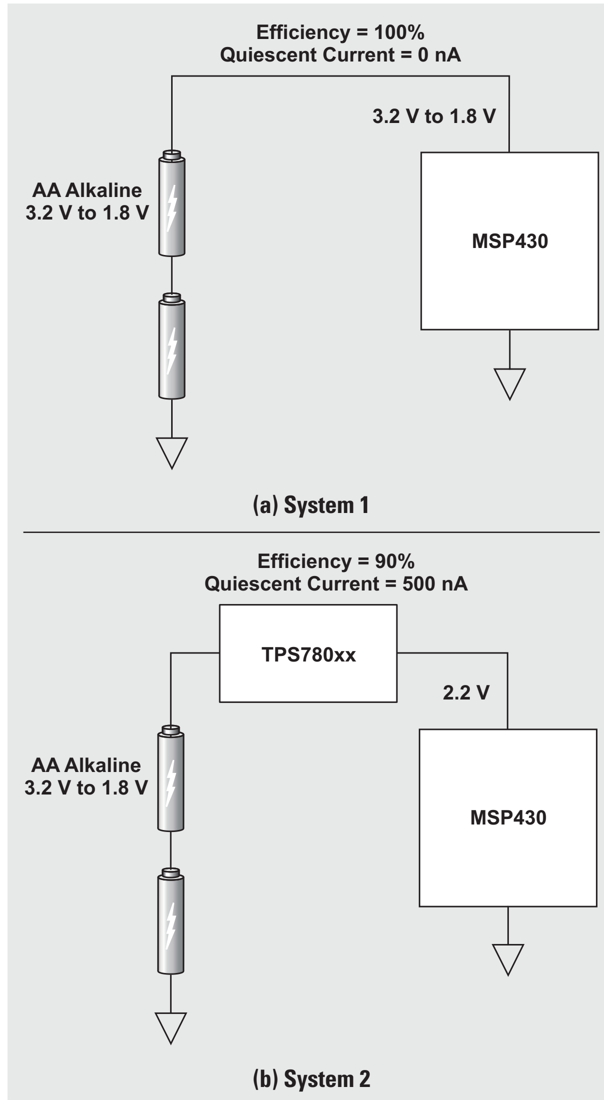


Figure 3. MSP430's operating current versus battery voltage

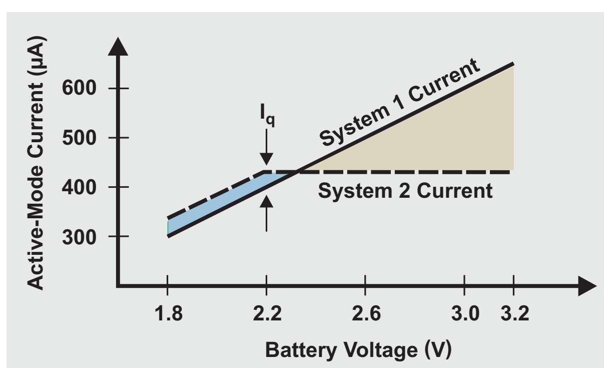


Figure 4 shows a battery-powered system that uses the TPS780xx to implement DVS to save battery power. The TPS780xx, which is an LDO with an ultralow quiescent current of 500 nA, contains a digital input (V_{SET}) that connects directly to the MSP430. The MSP430 pulls this pin high to set V_{OUT} at 2.2 V and pulls it low to set V_{OUT} at 3.3 V. This configuration allows the MSP430 to adjust its input voltage as its operating conditions change.

Even if the MSP430 is operated only at 7 MHz when active and placed into low-power mode when not active, DVS can significantly extend battery life. In low-power mode 3 (LPM3), the MSP430FG4618's operating currents at inputs of 3.3 V and 2.2 V are 2.13 µA and 1.3 µA, respectively. With the TPS780xx's 0.5-µA quiescent current added, the battery currents are 2.63 µA and 1.8 µA, respectively. DVS reduces battery current by 26% under these conditions. This reduction of LPM3 battery current is critical for systems that spend a significant amount of time in sleep mode.

When designing an MSP430 power system, an engineer should pay close attention to selecting the proper operating voltage. Minimizing the nominal operating voltage and implementing DVS when possible will provide significant improvements in a system's run time.

Related Web sites

power.ti.com
www.ti.com/msp430
www.ti.com/sc/device/MSP430FG4618
www.ti.com/sc/device/TPS78001

Figure 4. MSP430 with DVS implemented