Optimizing Power Management for Portable Multimedia Devices

by
David Brown
Senior Manager of Applications Engineering
Advanced Analogic Technologies, Inc.

Designers of wireless handheld systems have always faced difficult challenges. They must build small, lightweight systems that are both easy to use and durable. At the same time, the success of the systems they design is directly impacted by how long they can run without recharge. Power conservation and optimization is a constant design theme.

Perhaps the greatest challenge these designers face today, however, is optimizing power management in a market that demands constantly evolving feature sets. When most developers design a portable device they center their design around a particular processor and chip set. A power management unit (PMU) is selected to provide power to the system. Typically, that PMU covers most of the power functions including charging the battery, powering the processor and chipsets.

But portable device designs rarely stay the same for long. Invariably first generation products do not provide all the functionality the market demands. More often than not, product developers must add new features to distinguish their product from the competition or customize some existing feature to attract new markets and support new applications. When they do that, the off-the-shelf PMU that accompanies the core chipset will not satisfy the power requirements for that added functionality. Instead, designers must add new power management technologies to build the most power efficient, cost-effective, and compact system the market demands.

But building new power management schemes into an existing design is an extremely costly and time-consuming process. The key to addressing these new power management challenges lies in planning early in the design flow. Today designers must anticipate how technology trends will drive changes in their design and understand the implications of those new feature sets on system power management. They must understand the unique power requirements of each subsystem in their design and understand how specific design techniques and power management components can meet those needs.

This technical article will begin that education process by describing the unique power management challenges the major subsystems in a portable design present. In particular, it will look at new developments in the core processor, RF communications, display backlighting, port power/protection, and accessory lighting subsystems, what power management technology options are available to designers, and which design approach offers the best solution.

Core Processor

Of all the subsystems in a portable multimedia device, few consume as much current as the core system processor. Accordingly, the core system processor plays a pivotal role in the system power budget. Designers must constantly minimize the power consumption of the processor through manipulation of sleep modes, reducing standby current, and other techniques (see Figure 1).

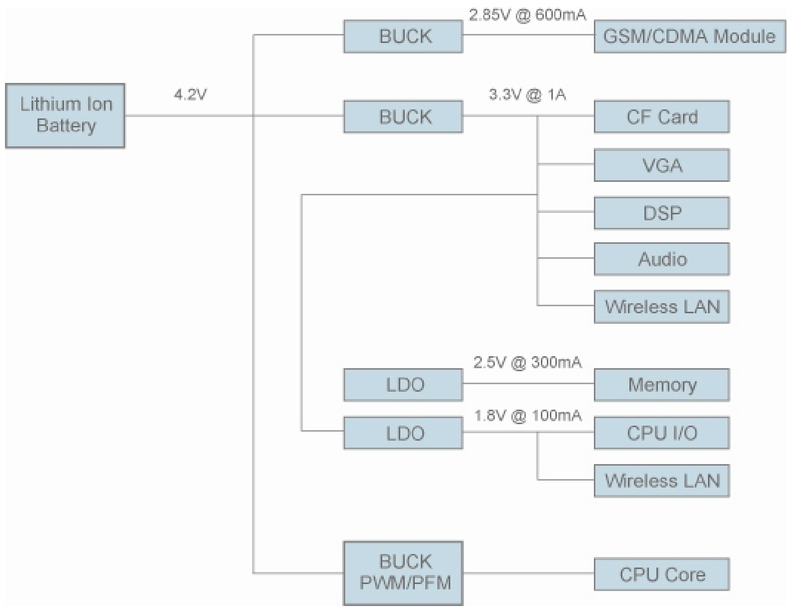

Figure 1.

Recently, as IC manufacturers have driven processor operating voltages lower and lower, that job has become increasingly complicated. Historically, designers have used simple linear regulators to support the core processor in their system. Linear regulators offer a number of advantages. They are relatively simple to implement and they require few external components. But they can be highly inefficient power conversion devices, especially as core voltages continue to decrease.

As an example, many portable systems use a Lithium-ion battery to supply a source of approximately 3.6V. At the same time, system designers are driving operating voltages down toward 1.2V to conserve power and extend battery life. If the system uses a linear regulator to deliver power to the core processor, the regulator will deliver less than 40 percent efficiency. Accordingly, over 60 percent of the power delivered to the processor will be lost in the form of heat. That inefficiency not only has a profound impact on the life of the battery, it also forces designers building the highly compact boards in the system to carefully consider the impact of thermal issues in their design.

DC/DC buck converters offer much more efficient power conversion. Efficiency varies from device to device depending on several factors, including switching frequency, the resistance of the switches or MOSFETs inside the IC, and the resistance of the external inductor used with the converter. In general, however, DC/DC buck converters offer efficiency in the 80 to 90 percent range. That higher efficiency will result in longer battery life and fewer thermal issues on the printed circuit board.

Of course, those advantages do not come free. The DC/DC buck converter requires more external components than a linear regulator, including at least one inductor, several capacitors and resistors, and depending on the type of converter sometimes an external diode. That results in a higher bill of materials, a more complex supply chain, and requires more PCB space to implement the design. Moreover, designing a DC/DC buck converter into a PCB layout is a more complex process and usually requires some board design experience to develop a successful and efficient board layout.

A second issue portable system designers must carefully consider is light load efficiency. In most systems, the core processor is in sleep mode much of the time. Switching converters are inherently less efficient in light load environments because their MOSFET gate charge losses and quiescent current losses become more dominant than the MOSFET conduction losses. Some switching converters consume as much power as the core processor itself in stand-by state. Therefore, it is essential that designers build systems which operate at very low quiescent current and select switching converters which have excellent light load efficiency.

RF Section

A second key subsystem in any portable system design today is the RF communications link. These circuits can range from relatively slow local data links using Bluetooth® technology to significantly more complex 802.11 Ethernet wireless LAN or 3G cellular systems.

The key point for designers to remember is that the power requirements for the RF circuit are completely separate and different than those for the core microprocessor. While the most important design issue from a power standpoint for the core system processor is to maximize power efficiency, the key priority for the RF circuit is reducing noise. RF circuits are inherently sensitive. Receiver performance is typically judged by the range of the unit. However, the performance of the receiver is directly affected by internal system noise. The power that is applied to the RF circuit from the digital portions of the design must be clean and free of noise.

Secondly, RF transmitters must meet very specific FCC regulations. One way to make sure the transmitter in a design stays within those specified limits is to provide a clean power supply. Otherwise, the performance transmitter may wander and violate federal regulations.

Third, RF circuits typically operate at higher voltages than the core processor in a portable system. Most RF circuits operate from a 3V or 3.3V supply. Accordingly, the system does not usually have to step-down the voltage from the battery supply as much as the core processor. At the same time, current consumption of RF circuits usually runs much lower than the core processor. Since the circuit is not consuming as much power, power efficiency is a less important issue in RF circuit design.

Given the need for a low noise supply and the reduced emphasis on efficiency, linear regulators offer the better option for RF applications. Switching power supplies such as DC/DC buck converters are inherently noisy. Linear regulators provide much lower noise and provide input-to-output isolation.

Moreover, the distinct features of a linear regulator can help designers meet the specific requirements of different wireless technologies. For example, a device using TDMA technology as a wireless link is constantly switching on and off. The constant switching of the load on and off places a high premium on the use of a linear regulator with very fast transient response capable of stabilizing the voltage going out to the circuit. The constantly switching of the power on and off will cause a voltage drop on the main distribution bus of the voltage coming from the battery. A linear regulator capable of providing excellent isolation from this load can help ensure other areas of the system are not disrupted by the power supply drop.

On the other hand a portable multimedia device using CDMA technology for the RF link needs a linear regulator with different characteristics. CDMA transmitters are constantly active so they do not incur a load transient problem. Fast transient response is not a high priority. Low noise is a more important issue with CDMA technology.

Designers may also want to select linear regulators with key features to support a particular application. For example, some linear regulators provide power-OK flags. In most designs, if the power supply to the regulator drops, the outputs supply will drop out of regulation and the RF transmitter will not perform within specifications. Some systems compensate for that event by turning the transmitter off when its performance does not meet specified limits. A power-OK flag serves as a voltage-monitoring tool. It senses that the transmitter is out of spec and instructs the system to shut it down to meet government regulations.

Display Backlighting

Over the last two years, one of the most exciting changes in portable handheld devices has been the move from monochrome to color displays. Capable of dramatically improving the user experience, these new color displays are being used to support a variety of new multimedia applications including location service, gaming, and video capture and playback.

The recent move to color displays is having a profound impact on power requirements for portable devices. The most common display technology in use today is the color TFT LCD. Typically, these displays are illuminated by white light from a backlighting source. To provide a pure white source needed for a true color-correct display, designers can employ a variety of methods. Some use an electro-luminescent technology, which is quite effective, but it is also relatively complex and expensive to implement. The most cost-efficient source of backlighting and the most common implemented today is white LEDs.

The Lithium-ion battery used to provide power in most portable devices supplies 4.2V at full charge. When it is depleted, that supply can drop to anywhere from 2.8V to 3.2V. White LEDs have a typical forward voltage of approximately 3.5V at 20mA. Therefore, when the Lithium-ion battery is fully charged, the system must provide a step-down regulator to reduce the operating voltage to 3.5V. In most cases, a traditional linear regulator can serve this function. When the Lithium-ion battery is depleted, however, and the supply voltage drops below the 3.5V required for the white LEDs, the system must provide a mechanism to step up the voltage in a highly efficient and low-cost manner.

Designers supplying power to white LEDs must consider a number of factors before selecting the best components for their system. The best solution involves a complex interplay of power efficiency, LED brightness consistency, footprint, design complexity, and cost.

White LED drivers vary significantly in design. Some manufacturers use DC/DC boost converters to provide power to a series of white LEDs connected in series. One advantage to this approach is that it provides all of the LEDs connected in series with the same current ensuring equal brightness. These inductive boost converters help minimize power consumption by offering high voltage conversion efficiency. But they also require the use of a number of costly components including Schottky diodes, capacitors, resistors, and inductors. Moreover, the inductors usually have a high profile which often conflicts with the low profile requirements of portable displays. Finally, these devices also produce a high degree of noise which, when combined with their high external component count, can significantly complicate board design.

Other manufacturers use charge pumps and connect the LEDs in parallel. Typically, charge pumps operate in a voltage doubling fashion or as a fractional charge pump. Some of these devices use a constant voltage output. These devices offer a simpler board design and lower cost than white LED drivers built around inductive boost converters, but under certain input voltage conditions they also provide lower efficiency.

More recently, manufacturers have developed white LED drivers based on constant current source output or current output charge pumps (see Figure 2). These devices offer lower noise because the constant current circuit topology minimizes line noise with excellent output-to-input isolation. Second, the use of independent current source outputs provides more uniform LED brightness. Within the last two years, some manufacturers of constant current charge pumps have begin developing dual-mode topologies which transition between 1.5x fractional charge pump and a 1x load switch mode to optimize efficiency.

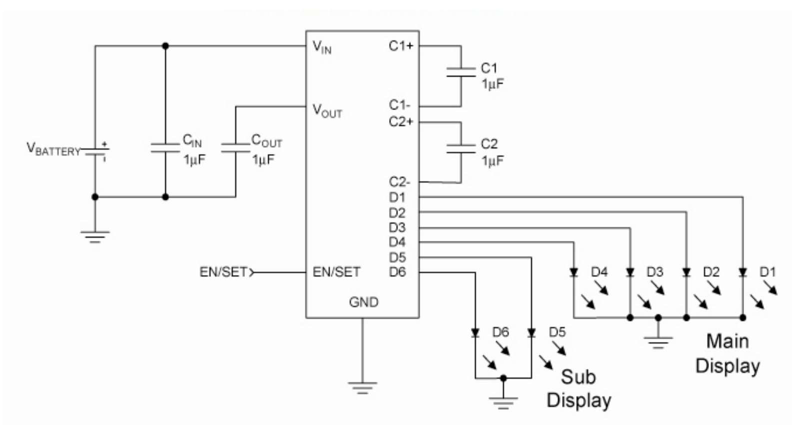

Figure 2: Dual Display White LED Driver.

Another highly useful feature found on some of these new white LED drivers is a simple single-wire digital interface to supply 32-level logarithmic scale LED brightness control. Controlling the brightness of the white LEDs is crucial to maximizing battery life. When the portable system is plugged into the wall, for example, the display can operate at full brightness. But when the user unplugs the device and operates off the battery, the system must manage the brightness of the display to conserve power.

Most white LED drivers using inductive boost converters and some using charge pumps control the brightness of each LED by switching the converter off at a very high frequency using a PWM control signal. The PWM control signals must be generated by the system controller which requires constant use of system resources. PWM signals also vary over a wide range and can potentially interfere with audio signals. This approach also requires a digital-to-analog converter (DAC) to control this function. A few white LED driver manufacturers now offer constant current source output charge pump devices with a single-wire digital interface. In comparison, a digital interface just requires a simple GPIO pin and a few lines of software to provide far more efficient and precise control of LED brightness.

Port Power and Protection

Another important power issue in portable device design is port protection. Every portable device has some type of physical interface to input or output data. The most common example is the widely adopted USB standard which defines a host/peripheral relationship. USB 2.0 specifies that 5V must be supplied to the port. One of the primary requirements for portable devices is to protect the internal system if any failure occurs at the port. Failures could range from a short caused by some object jammed into the port to the connection of a defective peripheral device. To ensure system reliability and user safety, the system must provide protection to the internal power bus.

A variety of manufacturers offer port protection switches. Typically, they are comprised of a high-side P-channel MOSFET with embedded intelligence to support current limiting and over-temperature protection. Once a short circuit occurs, these devices protect the motherboard of the portable device by denying access.

One of the newest areas in port power and protection is power devices designed to support the emerging USB-on-the-go (OTG) standard. An addendum to the USB 2.0 standard, USB OTG was developed to support the direct interconnection of two portable devices. While USB 2.0 defines a relationship between a host PC and peripherals that plug into it, the standard does not define the relationship between two portable devices such as PDAs, cell phones, and digital cameras when there is no PC host.

Under USB OTG, the two devices automatically negotiate between themselves which device will be the host (so-called A-devices) and which will be the peripheral (so-called B-devices). This new technology promises to open up a wide range of new applications for mobile devices, such as allowing camera users to link directly to a printer. But it also opens up a variety of new power management challenges.

To maintain compatibility with the existing USB standard, an OTG A-device must provide at least 8mA between 4.4V and 5.25V to power the Vbus. Voltage rise time must be less than 100ms in case the peripheral draws more current than can be supplied by the A-device. In that case the A-device must turn off Vbus and terminate the session.

When the Vbus is not powered up, the A-device must have only 40kohm to 100 kohm resistance on the Vbus and voltage due to leakage on the Vbus must be less than 0.2V. The OTG-device's Vbus decoupling capacitance must also fall between 1uF and 6.5uF. The standard USB host must meet a minimum of 96uF.

USB OTG minimizes power consumption by turning off the Vbus when there is no active session. If the A-device turns off the Vbus, but the B-device wants to use the bus, the B-device can request that the A-device turn on Vbus. This request is called Session Request Protocol (SRP) and is performed by data-line pulsing and Vbus pulsing. The OTG spec also defines four important Vbus voltage thresholds that the system must monitor to ensure OTG-device compatibility. To meet this requirement the system must monitor four voltage ranges: >4.4V, 0.8 to 4.0V, 0.8 to 2.0V, and 0.2 to 0.8V.

While power issues with the traditional USB 2.0 spec are mostly confined to keeping track of voltage drops across current-limiting ICs, connectors, and PCB traces, the new OTG spec opens up a variety of power management problems. Meeting Vbus power supply requirements is one issue. A power management system for an OTG device must provide a 4.4V to 5.25V output with at least 8mA of current. Most portable devices operate from a Lithium-ion battery which supplies between 3.0V and 4.2V depending on the state of the charge. Accordingly, to comply with the USB-OTG specification, portable devices must step-up their 3.0V to 4.2V supply to 4.4V to 5.25V.

At the same time, the USB-OTG standard calls for at least 8mA and allows negotiation to higher currents if the peripheral needs more power. While the standard allows OTG devices to provide up to 500mA, that is hardly realistic in a battery-powered portable device. But many applications may require up to 100mA.

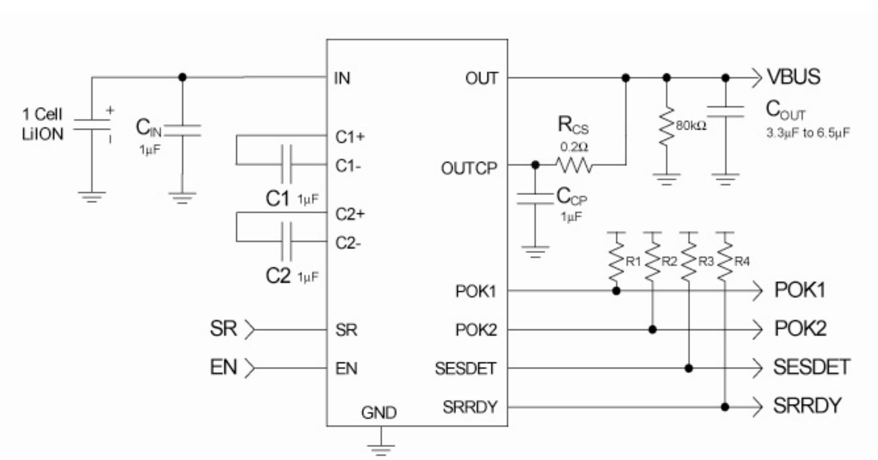

Figure 3: USB OTG Power Management IC.

The question for portable system designers is how they can meet those power requirements as efficiently as possible to limit impact on battery run time. Some of the first power management devices to meet the USB-OTG standard use a high frequency fractional (1.5x) charge pump to meet those specifications.

Why? One reason is to meet required output capacitance (see Figure 3). A high frequency switched capacitor regulator can use small capacitors on the output to easily comply with the USB-OTG standard's maximum 6.5uF requirement. Power management solutions using inductor-based DC/DC boost converters can experience stability problems with small capacitors.

Fractional charge pumps also offer a highly efficient voltage conversion solution compared to a standard regulated voltage doubler. As an example, if the Lithium-ion battery's voltage is 3.6V, a 5V output regulated voltage doubler's theoretical efficiency would be 69 percent. Under the same input and output conditions, a 1.5x fractional charge pump would achieve 93 percent efficiency.

To monitor the four voltage thresholds defined in the spec, the system must provide voltage detectors with extremely low quiescent current in order to maximize power savings. This is especially true for the 2.0V voltage detector because it must remain enabled even when the A-device turns off the bus so it can recognize an SRP event. Moreover, when the OTG-device is acting as a B-device, the maximum allowed unconfigured current is 150uA.

USB-OTG power management devices must also support the ability of a B-device to wake up the Vbus when it is turned off to save power. This device performs this task with data-line pulsing and Vbus pulsing to initiate an SRP. Therefore, the power management system must be able to drive the Vbus and monitor voltage and timing simultaneously.

Accessory Lighting

One feature that has grown increasingly common in today's portable devices is accessory lighting. Many devices now add color LEDs to alert the user that a function is enabled. Examples include a light indicating the battery is charging or the wireless link is in service. Sometimes designers use multi-color LEDs to indicate the different status of a function such as a battery in standby versus charging mode. LEDs are also used as fashion accessories which can be programmed by the user to indicate, for example, on a cell phone when a particular caller is calling (see Figure 4). In addition, LEDs are often integrated into portable devices such as digital cameras to provide light to illuminate a subject or to provide a photoflash capability. Typically, designers use an array of white LEDs to support this function.

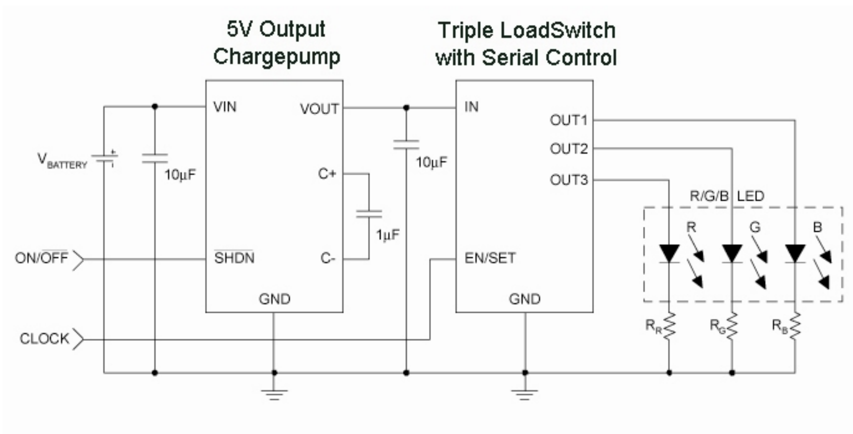

Figure 4.

In many of these applications, the power management system must step up the voltage to the 3.5 to 4.5V range for a short duration. Power efficiency is naturally the key challenge in all of these applications. But at the same time any power management solution for accessory lighting must be extremely low cost and compact.

The most efficient and low cost solutions for these applications use a charge pump topology. These devices can supply a high amount of current for a very short period of time. They are ideally suited to applications like a photoflash where the system must supply 200 to 400mA for 100msec. In addition, simple voltage doubling charge pump devices only require three external ceramic capacitors to perform this task. That keeps cost low and requires little PCB real estate.

Conclusion

Today's portable multimedia products are constantly evolving. New trends in wireless communications, display backlighting, wire interfaces and accessory lighting present entirely new challenges for designers facing the arduous task of minimizing power consumption while adding new capabilities.

The key to addressing these new challenges is to consider power management issues early in the development process. Before the market forces them to add new features and functions, designers must understand the unique power requirements of each functional block in their system, what design options are available and which technologies and components will offer them the best strategy for minimizing power consumption and extending battery life.