GPIO Pins Power Signal Chain in Personal Electronics Running on Li-Ion Batteries

Chuck Sins, Analog Signal Chain

TEXAS INSTRUMENTS

Introduction

With the popularity of lithium-ion batteries in personal electronics (PE) growing, it has become important for integrated circuit manufacturers to make sure that their devices are compatible with their voltage range. For example, if you were to do a tear-down on a cell phone, you would find that much if not all of the electronics on the circuit board operate directly from the lithium ion battery or from a voltage that is available from one of the application specific integrated circuits (ASICs) on the board. Because PE devices such as cell phones are incorporating more and more functionality, this requirement to operate without the need of an external voltage regulator applies to both analog and digital circuitry.

Two common applications of an analog signal chain that exist in many PE devices are precision battery current and voltage monitoring. To select proper devices to satisfy this requirement, it is important to study the resources available in the system and understand the metrics for the signals you need to monitor.

Resources Available in PE Devices

Let's look at the resources available in the system first. As mentioned previously, many PE devices such as cell phones are powered from a lithium ion battery. As shown in Figure 1, most lithium ion batteries are fully charged to approximately 4.2V. Likewise, they usually need to be recharged when they reach 3V.

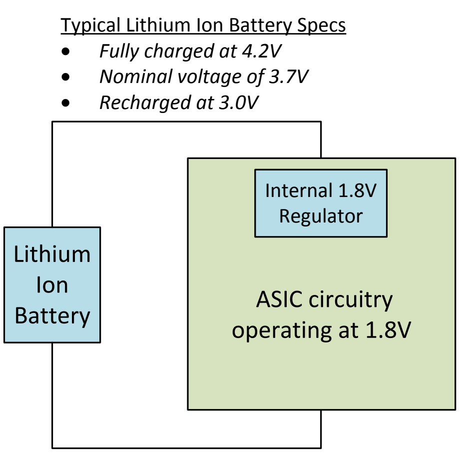

Figure 1. PE Device Resources

Until recently, many devices had operating voltage ranges that extended from 2.7V to 5V which sounds perfect for operating from a lithium ion battery. If price and power consumption were no concern, discrete signal chain devices such as amplifiers, comparators, and analog-to-digital converters would continue to meet these same voltage range requirements. However, price and power consumption are ever increasing in importance along with printed circuit board space. To integrated circuit manufacturers across the industry, this means making smaller, lower power, and cost-sensitive analog signal chain components.

One way to reduce size, power, and cost is to create devices that operate at low supply voltages but have limited high voltage operation. By doing this, IC designers can reduce the physical size of their designs and fit in smaller packages. One such example is the LPV821, a nano-power zero-drift amplifier that is well suited to monitor system current being extracted from the lithium ion battery. The LPV821 has an operating voltage range of 1.7V to 3.6V. On the surface, it appears that such a device would not be applicable in a lithium-ion powered system. Fortunately, that is not the case in systems that have microcontrollers and highly integrated ASICs. Because designers of these integrated devices also seek to reduce physical die size, power, and cost, they dedicate a small portion of their silicon to regulate the lithium-ion battery voltage down to a lower voltage such as 1.8V. By limiting the operating voltage for most of the circuitry inside their ASIC, the designer can greatly reduce the physical die area. The benefit to an external, low-power, analog signal chain device such as the LPV821 is that the device can be powered directly from general purpose input/output pins that are available on the device. These pins, better known as GPIO pins, are capable of sinking and sourcing mA's of current and because they are generated by a circuitry that is running from an internal regulator, the voltage that they output is well within the operating voltage range of devices such as the LPV821. This technique of using GPIO pins to power devices is only possible with low power devices. With a quiescent current of 650nA's, the LPV821 is seen as a minimal load to the GPIO pin.

System Current Monitoring

A recommended circuit diagram where the LPV821 is used to monitor system current is shown in Figure 2. This application circuit is referred to as low-side current sensing. The term low-side refers to the fact that the current is being sensed across a shunt resistor that is connected on the ground side (anode) of the lithium ion battery. The value of this shunt resistor is typically in the milli-ohm range. The value is very small compared to the kilo and Mega ohm range that is commonly seen in many analog circuits because the system designer wishes to minimize the voltage drop across the resistor. The more voltage drop across the resistor, the less voltage range the PE device has to operate. Unfortunately, using a mΩ shunt resistor comes at a price to the amplifier that is trying to monitor the voltage drop across it. Assuming that the PE device is normally consuming milli-amps of current, the voltage drop that the amplifier is trying to detect can be in the 10's to 100's of micro-volts. Amplifiers with mV's of offset cannot be used in this application because the signal of interest falls within the minimum and maximum offset limits. Fortunately, the LPV821 is a zero-drift (chopper) amplifier which means that the LPV821 has very low offset voltage relative to other types of amplifiers and the offset does not change over temperature and time. In the case of the LPV821, it has a typical offset voltage error of 1.5uV. So monitoring a small voltage drop across the shunt resistor is not a problem. In the circuit of Figure 2, the amplifier has a voltage gain of approximately – (R_2/R_1). Looking at the amplifier circuit more closely, you will notice that the amplifier is configured as an inverting amplifier where the non-inverting terminal is referenced to ground and the inverting terminal is connected to a voltage that goes slightly below ground

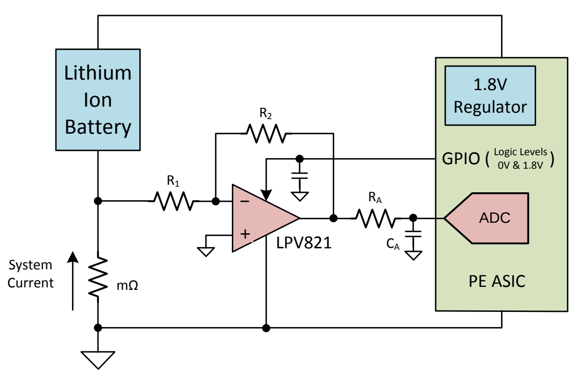

Figure 2. Precision Current Monitoring

Figure 3 shows a simulation of this circuit with a gain of 200V/V. The current being monitored has a peak current level of 20mA. Due to the extremely low offset voltage of the LPV821, it is very effective at monitoring the low level of system current. As mentioned previously, another benefit of the LPV821 is the extremely low quiescent current of the device. With a quiescent current of 650nA, the GPIO pin has no problem powering the amplifier and maximizes the battery life of the device.

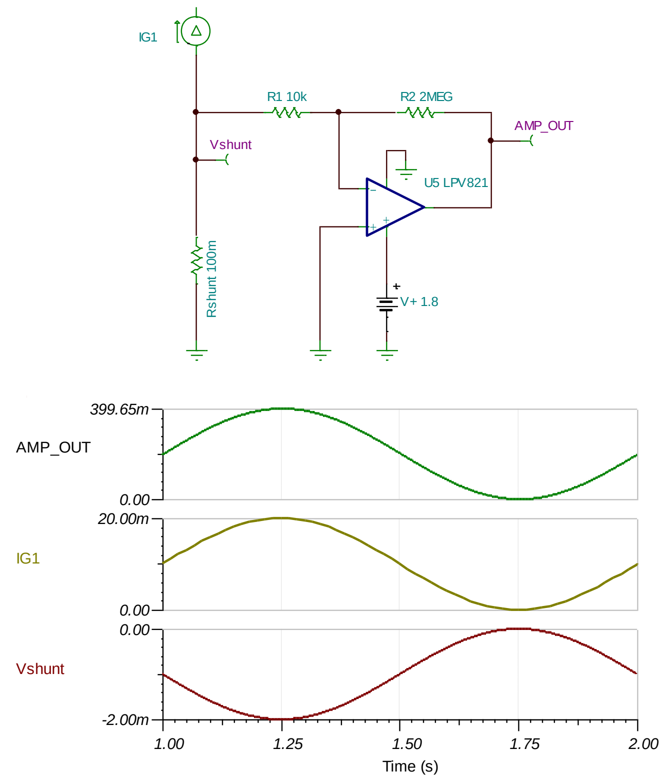

Figure 3. Precision Current Monitoring Simulation

Battery Voltage Monitoring

A recommended circuit diagram for monitoring battery voltage is shown in Figure 4. Similar to the application circuit for monitoring the system current, the nano-power comparator, TLV7081, is being powered directly from a GPIO pin. Because most systems are mainly interested when the system battery drops below a specified value, a single comparator which alerts of an under voltage condition is sufficient. The TLV7081 is well-suited for this PE application due to its low quiescent current of 370nA and small form factor. The comparator has only four leads and occupies a board space of 0.7 × 0.7 mm^2. As shown in the diagram, the TLV7081 has only four leads because the inverting input to the comparator is internally connected to the supply pin. In this sort of configuration, the regulated GPIO output pin serves as the supply voltage and the voltage reference for the circuit. Resistor divider pair R_1 and R_2 divide-down the lithium ion battery voltage such that the comparator output will transition from high to low when the battery voltage drops below 3V. Because the supply voltage is serving as the reference voltage, the TLV7081 has a unique design architecture on the non-inverting input pin that allows the common-mode voltage range to extend beyond the power supply. Most analog devices are limited to the supply range but the TLV7081 incorporates an input structure that is expected to operate above and below the supply voltage. This is specifically valuable in applications where the comparator is not powered immediately by the GPIO pin but the battery is still connected to the comparator input. Furthermore, because the input to the TLV7081 extends beyond the supply, the comparator can be used in circuits where power supply sequencing is a concern.

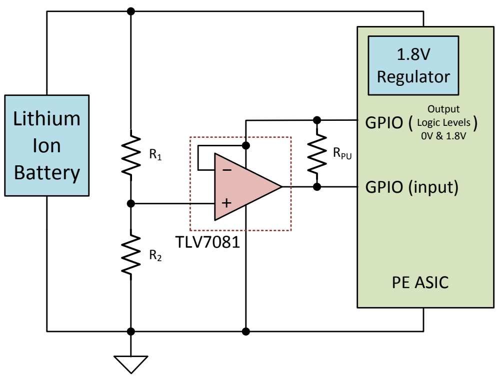

Figure 4. Precision Voltage Monitoring

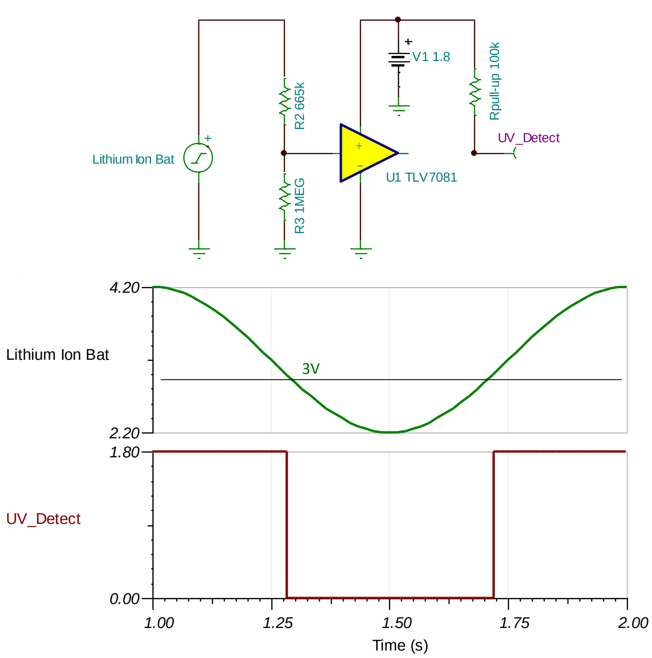

Figure 5. Precision Voltage Monitoring Simulation

Figure 5 shows a simulation of the TLV7081 monitoring the battery voltage as it slowly drops from 4.2V at full charge to 3V when the battery will need to be recharged.

Conclusion

The demands for low power, small size, and low cost will continue to drive the PE market as companies simultaneously increase their device's capabilities. As shown in this Tech Note, the voltage range of lithium ion batteries in PE devices does not tell the entire story for what operating voltages are acceptable in the system. With PE devices getting smaller and adding more features, it is important to leverage all available resources including the use of GPIO pins on ASICs and microcontrollers to power analog signal chain devices. Low power devices such as the LPV821 and the TLV7081 are just a couple examples of devices within the low power amplifier and comparator portfolio of Texas Instruments that are well-suited for this application.

Listed below are other low power amplifiers and comparators that can be powered from GPIO pins or directly from batteries. Many of these devices also have the added benefit of being offered in both leaded and space-saving leadless packages.

Table 1. Low-Power, Micro-Package Comparators

Family	Package	IQ	t_{PD}	Output
TLV7081	WCSP-4	370 nA	4 us	OD
TLV7011	X2SON, SC70-5	5 uA	260 ns	PP
TLV7021	X2SON, SC70-5	5 uA	260 ns	OD
TLV7031	X2SON, SC70-5	335 nA	3 us	PP
TLV7041	X2SON, SC70-5	335 nA	3 us	OD
TLV3691	X2SON, SC70-6	75 nA	24 us	PP

Table 2. Nano-Power, Micro-Package Amplifiers

Family	Package	# of Ch	IQ	VOS
LPV821	SOT23-5	Single	650 nA	1.5 uV
TLV8541	SOT23-5	Single	550 nA	500 uV
TLV8542	X2QFN, VSSOP-8	Dual	550 nA	500 uV
TLV8544	TSSOP, SOIC-14	Quad	500 nA	500 uV
LPV811	SOT23-5	Single	450 nA	60 uV
LPV812	SOT23-5	Dual	425 nA	55 uV