Battery Design Guide for Portable Electronics

An Approach in Simple Terms

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Today's world is becoming more and more portable. The wireless and cordless revolution in the electronics industry has increased the demands and requirements for portable power at an incredible rate. One does not walk into a room often without seeing a portable appliance of some type, whether it is a cellular phone, cordless power tool, PDA or notebook computer.

To this end, the needs of battery design within complex systems are more important than ever. Often an afterthought, the battery is a large piece of a system design.

Batteries are "electrochemical" devices, which means that energy is stored in chemical form that is then converted into electrical energy. As many have experienced in basic chemistry class, chemical reactions are strongly influenced by environmental factors. Many reactions speed up tenfold or higher by applying heat to the reaction via a burner or a hot plate, and slow considerably when placed in ice. These same reactions and environmental influences effect batteries in a similar manner, and can affect the design of a finished system dramatically.

System Approach

When first designing a system, usually only the overall system performance is targeted. What the system needs to accomplish and how the system needs to interact with a user are usually well known in concept. How the system gets powered usually becomes an afterthought. Interactions the battery may have to system performance may become critical after a design has been completed on the bench top using a power supply to develop.

Power is a key part of every portable system design success.

There are many battery systems available in the world today, each with advantages and disadvantages. Some offer superior energy density in terms of power per unit of weight and space such as Lithium Ion secondary (rechargeable) or Lithium metal primary (single use disposable) systems. Some offer good power density in terms of supplying extremely high currents for short cycle times such as Lead Acid Systems. Others have superior power density when it comes to supplying high currents required by power tools such as Nickel Cadmium systems. The battery system that is used for each application is dependent on many factors. All of these factors need to be considered to accomplish the end goal of performing well in the system.

Design Parameters / Voltage Requirements

The first requirement for successful battery design is definition of the key electrical parameters. These parameters are very important in choosing the correct chemistry and safety devices within the battery design. Operating voltage is a key component of this step. What are the upper and lower operating voltages desired to operate the device? Are there key components in the system design that will begin to fail to operate at certain voltage thresholds?

Portable electronics for the most part operate utilizing a constant power type discharge, this means that the current required will increase as the battery discharges to maintain the constant power (P=V*I). This effect in most battery systems will mean a quicker and faster rate of voltage decay as the battery discharges. This can affect the system runtime and ability to react in adequate time to inform the user of power loss. Since the electrochemical system is a chemical system first, the environmental effects will influence this performance.

The battery will be less able to respond to higher currents in lower temperatures, since the rates of reaction are slowed. This is usually seen as depressed voltage due to higher internal resistance at lower temperatures.

Current Requirements

The setup of an oscilloscope and a shunt to monitor current requirements of a device.

The second key parameter needed for adequate battery design is the maximum current requirement. This is an important factor and will influence the battery designer's choice of protection circuitry, chemistry, wire and trace sizes and battery capacity. It is important to remember that the current used to design a system on a bench top using a power supply may be different than the current required from a battery. As discussed earlier, important parameters such as temperature, internal resistance of the battery, and the constant power discharge of a battery will often dictate higher currents at end of battery life. It is important to characterize the current requirement of the system over the entire usable voltage range. Current should always be measured using an oscilloscope and the voltage drop across a low resistance shunt (0.1W or 0.01W works well) of appropriate power rating, as a digital voltmeter will not allow the engineer to evaluate transient pulses correctly.

Important parameters not to be overlooked are startup currents and surges, or intermittent transient pulses. Current drain from a device can be variable and influenced by a number of factors. Often when the battery is first connected or the system is powered on, there are extremely high current requirements for a short duration of time, such as the high current required to initially charge capacitors. The factors that affect the current requirement mentioned above will influence the startup current as well. The battery designer needs to know these requirements. Protection circuitry used in many sophisticated battery packs limit currents by very fast acting circuitry. This circuitry will often engage during these startup pulses if not properly defined ahead of time, causing a system shutdown. It is very important to define the startup pulses throughout the usable system voltage range as current requirements may differ throughout, and will probably vary with temperature fluctuations. Characterization of the transients within the device discharge voltage range is important as well, as currents may increase toward end of life causing protection circuits to engage and stop the discharge.

The next parameter to cover is the quiescent (background) current drain of the device. Devices, even when powered down, require small amounts of current to power memory, switches and component leakage. This number is very important when designing a system that will use a primary battery that cannot be recharged, as one does not want the battery to fully discharge while the system is off. This value becomes critical when defining the shelf life storage characteristics of a battery when installed in a device and specifying battery recharge requirements.

Capacity and Runtime Requirements

The next step is to calculate the desired battery capacity based on the above requirements and the device runtime requirements. This will allow the proper size battery to be designed for the application. Remember that rechargeable systems will lose capacity as cycles of use accumulate.

The desired runtime near the end of the useful life of a device should be considered and the battery appropriately sized to deliver the proper capacity at the later stages of device life.

Physical Requirements

Notice there has been no mention of physical size of the battery as a requirement. This is purposeful. Without the battery parameters properly defined as mentioned above, it is impossible to define the size of the battery required. Often it is done in the reverse order, since engineers and designers have a defined space to work with, and the battery gets what is left. This is not the best practice but unfortunately it is the one often used. It is possible to design a battery to fit in a space, even create custom cell sizes to accommodate space requirements, but it will often add cost and lead-time to a battery design, which usually is not a desired option. Materials such as cases, contacts, circuitry, wiring and even labels can quickly consume

Many of the materials that consume valuable space within a battery pack, but which are of utmost necessity for a successful design.

available space beyond what the actual cells occupy.

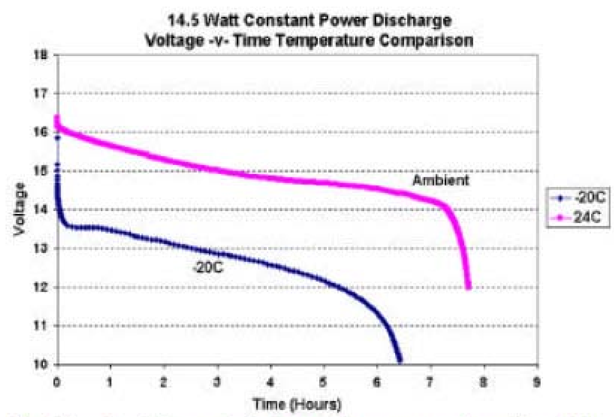
If the proper space is not available for the battery, runtimes can be dramatically reduced to unacceptable levels and require redesign of the system.

The important thing to remember is that battery technologies evolve slowly, and with the elements that are electrochemically active on the periodic table well known, the battery technologies will continue to be evolutionary more than revolutionary.

In thinking about your design, consider the end goals and power needs. Lithium is the choice battery material in terms of energy density per unit volume and weight. Rechargeable lithium ion systems have cell energy densities approaching 200 Wh/Kg and 450 Wh/L. When turned into a battery pack, especially a removable pack or a small pack size, energy density overall drops to 60 percent or less of these values (typically 100 Wh/Kg, 225 Wh/L). Primary lithium systems have roughly double the energy density of rechargeable lithium ion systems. Using these values will help to define the required space and weight of a battery based on a lithium system during initial design.

Temperature Requirements

Further important parameters required for proper battery pack design are the temperature requirements for the pack. This includes the storage ambient temperatures expected during the life of the battery pack, the operational ambient temperatures, and the internal device operational temperatures. Storage temperatures of the pack will affect its long-term life, usually with lower temperatures (<30°C for most battery systems) resulting in optimum life expectancy, and high temperatures (>60°C) are usually most detrimental. This is related to the enhanced chemical reactions that typically occur as temperature is increased. Operational temperatures behave similarly to storage temperatures, with rate of charge and discharge coupled with temperature causing more variation in expected performance. Many of the materials that consume valuable space within a battery pack, but which are of utmost necessity for a successful design.



The internal resistance of a battery pack suppresses the voltage during discharge at low temperature (-20C) when compared to ambient (24C), resulting in reduced runtime.

Do not overlook the fact that a battery will be a source of heat during use, especially during charge, and it is important to design the device to allow for dissipation of the extra heat generation.

Safety

Safety features are sometimes an afterthought, and special precautions are used to protect battery packs, especially in lithium ion systems. Protection circuitry is usually designed into any lithium ion battery pack to prevent the cells in the battery from over charge and over discharge conditions and high currents or short circuits. Some circuitry goes further than the standard parameters and guards against high temperature charge and discharge, as well as high charge rates at low temperatures. The circuit usually consists of a protection IC, several FET devices, and sense resistors. These circuits add cost and space to the battery pack requirements and careful placement is required in physical layouts. The active circuits in lithium ion batteries continually draw power causing the battery to constantly discharge slowly, although usually in the micro amp current range. Other rechargeable battery chemistries may not need the elaborate protection of an active circuit as lithium ion does, but some protection devices are still used.

These devices can be resettable such as PPTC (polymeric positive temperature coefficient) devices, which grow in resistance as temperature rises until the current is cut off or bimetallic switches that disconnect at high temperatures. Other devices are one time non-resettable and permanently cause the pack to be disabled, such as current fuses or thermal fuses. Primary batteries usually incorporate a diode to prevent charging a non-rechargeable battery pack; this adds a voltage drop to the final battery and can reduce the usable capacity from the battery.

Remember that to make the battery safe and robust a variety of components, potting and encapsulating materials and other devices may be required, and will consume valuable space within the pack. Safety certifications such as Underwriters Laboratories recognition should be specified prior to battery pack design.

EMI / ESD Protection

Often overlooked in some designs are the effects of Electromagnetic Interference (EMI) or protection from Electrostatic Discharge. EMI comes in a few forms, radiated and conducted. Either form can occur throughout the electromagnetic spectrum. The primary problem with the occurrence of EMI is disruption or reduction of performance of electronics. This can be severely damaging when working with wireless communication designs, where EMI can cause attenuation losses in signal strength and noise during transmission. Typically battery packs act as radiated sources of EMI.

Often the system is designed with EMI protection but the connection to the battery pack is overlooked, therefore EMI signals are sent back through the battery connection and out of the battery causing interference. Some system designs are so critical that the battery pack needs to be shielded. The most cost-effective way to combat these circumstances is to place the battery pack in a shielded compartment of the system. To place shielding inside the battery pack is usually not cost effective, especially in applications where primary batteries are to be used. Adding shielding to the battery pack can increase the pack's weight and physical size.

A battery for the military land warrior system utilizes a push button LED fuel gauge.

Electrostatic discharge is especially damaging to critical electronics components, and occurs when a high voltage static charge reacts directly with or in close proximity to the battery terminals. If the battery pack being designed has sophisticated electronic controls, it should be designed to withstand and be protected from ESD. A battery for the military land warrior system utilizes a push button LED fuel gauge.

Smart Batteries

Smart batteries are becoming more popular in the rechargeable battery pack arena. A smart battery has critical battery information stored within the battery and can monitor and prevent unsafe conditions. The smart battery will communicate with the host device through a connector to provide information about remaining capacity, battery voltage, error conditions, cycles completed, internal temperature, current, and several other factors. The smart battery can request a conditioning cycle, which will fully discharge a battery pack and then recharge it to allow the internal remaining capacity value to be accurately calibrated. Smart batteries often have an LED or LCD display that will allow the user to check the state of charge of a battery prior to use.

Lithium Ion smart batteries typically use coulomb counting to determine capacity, which means the circuit monitors the capacity in and out of the battery by measuring voltage across a sense resistor. Smart batteries are usually rechargeable due to the increased cost of the circuitry, although special applications utilizing primary batteries will occasionally use smart battery technology (aerospace, military and medical).

Shipping

A final important parameter to remember is battery shipment. There have been new transportation regulations imposed and under review concerning lithium and lithium ion batteries. Increased testing is required on certain battery packs to allow shipment as non-hazardous material and some batteries even require special testing to ship at all. There are also regulations in place that require special labeling for shipment of certain battery packs or equipment containing battery packs. Be certain to check with the appropriate national and international agencies (such as the US Department of Transportation) for the latest transportation regulations.

In Conclusion

Many factors influence the proper design of a battery pack. Some of the factors are more commonly overlooked such as available space, transient currents and EMI protection. When designing a battery, serious thought must be given to defining key electrical parameters, desired capacity and runtime, physical characteristics, safety and cost. This guide should bring many of these important design considerations to light and allow issues to be identified early in the design life cycle of the system, resulting in on-time power source fulfillment of your next project.

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