System Developers' Aid for Battery Powered Systems

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1. Scope

This document provides an overview of selecting a battery and properly integrating the battery into a system's design. It is a collection of general information, best practices, and lessons learned; but should not be viewed as an exhaustive authority on system development. Specific measurements, values, and limits are not discussed here as they vary from battery to battery. The reader is encouraged to do their due diligence in researching the chosen battery and assuring the system meets all safety, performance, logistical, and interoperability requirements. Additional information is located on https://battery.army.mil

2. Choosing a battery

Battery selection is based on meeting system requirements for size, weight, voltage, and runtime. Rechargeable batteries reduce life cycle costs, eliminate resupply logistics, but require tactical environment recharging. Primary (throwaway) batteries can provide longer runtimes and power in tactical environments where recharging is not possible. Some batteries (form, fit, function) are available in both rechargeable and non-rechargeable versions.

It is strongly recommended that the battery and charger selection/design process begin early in the end item development to avoid complications in integrating the battery into the end item or getting approvals for use.

2.1. Preferred battery

As of the date of publication of this document, the Army is undergoing a review and update of its Preferred Battery List and the waiver process for using a non-preferred power source. For updates, please see battery.army.mil.

3. Battery characteristics

Batteries have unique physical, environmental, and electrical parameters to consider when selecting the battery configuration. It is worth noting that a given configuration may contain multiple technologies/chemistries with differing performance. To understand the characteristics and limitations of a given battery, developers should reference the source documentation and specifications for each battery considered.

4. Battery specifications

4.1. 'Base Specifications' and 'Slash Sheets'

Army standard batteries are specified by a combination of documents compromising a Military Performance (MIL-PRF) specification. The main document, often referred to as the 'base specification' or 'base spec' contains the characteristics that multiple different battery form factors share based on the same technology(ies) they have in common. Commonalities include such characteristics as environmental and safety. Base specifications also contain optional characteristics that are still common but not present in all form factors. An example of this would be what communication protocol (if any) the battery uses or how deep of immersion the battery is expected to survive.

Unique characteristics of each battery are defined in the 'slash sheets'. (Slash sheets get their name because they share the same specification number with their base specification followed by a slash '/' and then a number indicating their order of publication.) The slash sheet will contain the battery's form, fit, and function characteristics, battery-configuration-specific performance requirements, and specify which optional characteristics are applicable. It will also contain detailed pass/fail criteria to ensure specification compliance. Multiple chemistries having the same form factor may be on the same slash sheet.

4.2. Specification paragraphs

Military Performance specifications contain 6 sections:

1. Scope
2. Applicable Documents
3. Requirements
4. Verification
5. Packaging
6. Notes

While most of these sections are self-explanatory, sections 3 and 4 contain the main technical information for the battery. Section 3, requirements, contains all technical attributes that a battery must achieve in terms of threshold values with strict pass/fail criteria. Section 4, verification, prescribes the methodology and test parameters used to verify the requirements of section 3.

4.3. Design to the specification (not the hardware)

System developers should design their hardware to accommodate all specification tolerances to include dimensional and electrical. They should avoid designing to a particular physical battery representation (i.e. a manufactured product), regardless of whether it complies to the specification. Batteries are built to performance specifications and are not built to print**.** Any battery characteristics outside of specified requirements cannot be relied upon.

Specifications and drawings contain minor dimensional tolerances to allow for flexibility of design for manufacturability. This means that two vendors producing the same battery may have *slightly* different sizes (i.e. differences measured in thousandths of inch). These variances can even be within the same vendor's battery following an update to their design. **The end item battery compartment design should accommodate the specified dimensional tolerances.**

Performance (capacity, rate capability, temperature range, cycle life, etc) parameters of specifications are often in the terms of threshold values. For example, a battery may be required to maintain a 10A load. This means that if a battery can carry a 20A load, it meets the requirement. This does not guarantee that other vendors' batteries can meet the 20A load nor does it guarantee that same vendor's future products will as well. **The end item design should only rely on the specified performance of a battery.**

4.4. Inspections

Military performance specifications contain multiple levels of inspections for batteries. During the initial qualification of batteries, called First Article Inspection (testing associated with this inspection is known as First Article Test (FAT)), sufficient batteries are produced and tested such that all requirements will be verified. During on-going production, all batteries receive acceptance inspection. Additionally, samples are selected from every production lot for quality control testing.

4.5. Configuration control

Batteries procured to Military Performance Specifications are subject to strict configuration control. After passing FAT, the design, processes, and procedures to produce a battery are frozen to ensure batteries do not deviate from the established requirements. **Procuring approved batteries only through the standard supply system will ensure batteries meet specification requirements and undergo all required inspections.**

5. Environmental characteristics

5.1. Physical

Military batteries are designed to be reliable and safe when subjected to the rigors of a combat environment, but not all batteries are required to meet the same levels of durability. For example, batteries to be used inside a protective battery compartment may be less durable than ones designed mounted externally to an end item. Generally, non-rechargeable batteries are less rugged than their rechargeable counterparts as they only need to survive a single mission. For example, a rechargeable battery may be required to be fully operation following an immersion, whereas its non-rechargeable counterpart may just be required to not pose any hazard to the user following an immersion. System developers should review the requirements for all variants of a chosen form factor.

5.2. Thermal

Batteries are optimal when stored and operated at moderate temperature conditions; temperature extremes can be detrimental to the available capacity and/or cycle life.

5.2.1. High temperature

Storage at high temperatures can permanently damage batteries and affect their capacity and performance. During operation, in addition to ambient conditions, batteries create their own heat due to internal impedances. This effect is called ‘self-heating’ and is proportional to the load applied.

Charging or operating at too high a temperature can pose safety concerns, and because of this, all batteries feature thermal cutoffs to protect the battery. These may be temporary thermal switches and/or permanent thermal fuses. **These thermal protections are in place for user safety to prevent cell ventings, and should not be relied upon as an active form of protection. The end item should self-limit its load on the battery to ensure safe operating conditions.** Smart batteries can communicate their operating temperature to the system being powered (see 7.5).

5.2.2. Low temperature

Storage at low temperatures will not damage batteries. Operating at low temperatures will decrease the battery capacity available (runtime) and lower the operating voltage. At extreme temperatures, the battery’s cells may cease to be functional. Low temperature performance is based on battery chemistry and the size of the battery. System developers should understand the low temperature performance of their system battery. Low temperature charging of lithium-ion batteries is dangerous. **When operating at *extreme* cold temperatures, the electronic components in the battery may malfunction leading to erratic and/or unsafe operating conditions.**

6. Electrical characteristics

The electrical characteristics of a battery are determined by the cell technology, the series and parallel cell configuration, safety components (thermal and electrical fuses, diodes, etc.), the current (amperage) rating of the connector, and other design choices. Batteries are rated with nominal voltages which represent the average battery voltage under a “medium” load. Batteries do not have a constant output voltage unless there is a voltage regulator integrated into the battery (which is rare). End items should be designed to use the entire operating voltage range of the battery as outlined in the battery specification.

A cell's chemistry determines the voltage of an individual cell, while its power output is a function of both the technology and design choices made.

These cells are then packaged together to create a battery. Because the chemistry determines the voltage, battery voltages are limited to multiples of cell voltages (unless there are regulating electronics on the output). If a target voltage of 10V is desired, and the cell were to have a 3V output, a battery would have to be either 9V or 12V but could not be 10V. This is why battery form factors that are available in multiple chemistries have slightly different voltages. Systems should be designed, at a minimum, to accept output voltages of all battery chemistries available for the chosen form factor. Additional leeway should be designed into the system to accept wider voltages and accommodate future technologies.

6.1. Open-Circuit Voltage (OCV)

Open-circuit voltage (OCV) is the difference in electrical potential between two battery terminals when disconnected from any circuit and there in no current flowing.

The cell chemistry and internal cell configuration drives the battery OCV. Normally, OCV is the highest voltage produced by a battery, and end item input circuitry should be designed accordingly.

6.2. Closed-Circuit Voltage (CCV)

Closed-circuit voltage (CCV) is the difference of electrical potential between two battery terminals when discharging through a specified load circuit.

The cell chemistry and internal cell configuration drive the CCV. While the CCV is specified for a given load, it can be taken as an approximation of the highest operating voltage for a given battery. As the battery's capacity is consumed, the operating voltage of the battery will continue to decrease until the cutoff voltage (see 6.3)

6.3. Cutoff Voltage

The cutoff voltage for a battery is used for capacity and initial voltage delay (see 6.7) measurements of batteries.

Capacity tests generally terminate when the battery voltage falls below this threshold. Because batteries are described by performance specifications, a battery's behavior below cutoff voltage is often not specified and cannot be relied upon to be consistent across vendors or even different iterations of the same vendor's product. **Some load condition/battery chemistry combinations of discharging a battery beyond its cutoff voltage can be abusive and result in a safety event. Batteries should not be operated below their cutoff voltage.**

6.4. Nominal Voltage

The nominal voltage of a battery is the average voltage of a battery discharged under a specified load.

While nominal voltage is useful to describe a particular battery, it does mean that the battery will maintain a single voltage throughout its discharge. In reality, the voltage will follow a particular curve following an overall downward trend from CCV (see 6.2) to cutoff voltage (see 6.3). The precise shape of the curve will depend on the battery technology.

6.5. Regulated voltage output

Some batteries may contain voltage-regulating electronics on their outputs. These allow the battery to behave more like a power supply than a battery that can provide a fixed voltage output regardless of the state of charge of the internal cells (while capacity is available) thereby separating the end item from the OCV, CCV, and cutoff voltages of the internal cells. The battery's specification will describe the characteristics and/or reference documentation for the output characteristics and protocol for batteries with a regulation voltage output.

6.6. Maximum load

The maximum load a battery can maintain is a function of many factors including the battery chemistry, cell construction, ambient temperature, whether the load is dynamic or static, and safety electronics. Different batteries of the same form factor may have different maximum loads they can maintain. The Battery Slash Sheets contain the maximum loads the battery can provide. End items should be designed to accept the maximum number of battery technologies for a given form factor without overloading a battery. If this is not possible, the end item should contain a method to only operate with acceptable battery types, such as communicating with the battery (see 7.5) or via a keyed connector (see 7.2).

Many batteries contain current-limiting circuitry and/or fuses. **These are in place as a safety device and should not be relied upon as an active form of over-current protection. The end item should not exceed the maximum current of the battery as described in the battery specification.**

6.7. Voltage delay

Voltage delay is the time allowed for the battery voltage under load to recover above the specified cutoff voltage (see 6.3) A voltage delay is a short delay a resting battery may exhibit after a load is applied until it reaches its proper closed-circuit voltage (see 6.2). This effect may be more pronounced when the battery is cold. Maintaining a load on the battery may help it recover its operating voltage.

Note: systems should be designed to not repeatedly attempt to recover a battery that exhibits a voltage delay, as a battery discharged beyond cutoff may exhibit similar voltage characteristics to a battery with a voltage delay (see 6.3).

7. Battery configuration

7.1. Battery compartment requirements

All non-rechargeable and rechargeable lithium batteries can vent (emit smoke, flame, or even a violent rupture) when exposed to abusive conditions. If the end item requires that the battery be contained within the item, the battery compartments need to be designed in such a way to safely release the pressure if a cell venting occurs. For more information on battery compartment design, see TB 43-6135.

7.2. Battery output connector

All batteries will have some form of connector to interface with the end item and charger (if applicable). Connectors can be as simple as flat contact points for the battery positive (+) and negative (-) or more complex such as a cable connector with immersion penetration ratings, extra pins for communication (see 7.5), EMI shielding, physical keying, strain-relief ratings, etc.

Variants of the same connector may be present across different batteries of the same form factor. An example is a keying mechanism preventing non-rechargeable batteries from being placed on a charger but still allowing rechargeable and non-rechargeable batteries to be used on an end item. Connectors may also be shared across different battery form factors that share similar electrical characteristics. This can allow for flexible end-item design, allowing for multiple battery options, thereby allowing the user to make weight, volume, and runtime tradeoffs on a per-mission basis. System developers should research all variants and applications of batteries and connectors when designing a system.

7.3. State of Charge Indicator (SOCI)

Some batteries may contain a State of Charge Indicator (SOCI), allowing the user to determine the remaining capacity. This device may be user-activated or always on and may either be a passive display or light-emitting display. Generally, the presence of a SOCI should not make a large impact on system design. Still some things to be cognizant of are the avoidance of inadvertent activation and the ability for the user to view the display while the battery is installed (if possible).

7.4. Complete Discharge Device (CDD)

Some non-rechargeable batteries contain a Complete Discharge Device (CDD). The CDD is designed to consume any remaining lithium in a battery and is used when the battery is processed for disposal. The presence of a CDD will have minimal impact on a system's hardware design, but care should be taken not to inadvertently activate it. The CDD does, however, have an effect on overall system logistics as it affects the disposal process for batteries. For more information on the CDD and battery disposal, please see TB 43-0134.

7.5. 'Smart' batteries

Many batteries today are considered 'Smart,' meaning they contain a data interface for the battery to report its information and status to its charger and/or end item. Some examples of available data fields are battery chemistry, date of manufacture, voltage, temperature, and remaining capacity. Enabling a smart interface on an end item can allow for much more robust battery management. Battery specifications will reference the relevant communication protocols needed to communicate with the battery.

8. Logistics

8.1. Shelf-life and service-life

Batteries are perishable items with limited time which they can be kept in storage before use, called shelf-life. A shelf-life code is assigned to batteries with National Stock Numbers (NSNs) and is determined by estimating that a battery stored in temperate climactic conditions will have at least 85% of its original performance. Shelf-life codes will also indicate whether or not the shelf-life has the potential to be extended. Most non-rechargeable batteries are eligible for shelf-life extensions following an inspection process. Rechargeable batteries can have their shelf-life extended through maintenance (see 8.2). **Pre-packaging batteries with end items will impose shelf-life limits on the end items as well.**

After a battery is placed in service for the first time, it exits its shelf-life period and enters its service-life. There is no formal time period regulating the service-life of batteries, but batteries will continue to age after being placed in service. Repeated cycling of rechargeable batteries will put additional wear on the battery, necessitating replacement sooner.

8.2. Storage and maintenance

Due to shelf-life constraints, batteries should be stored by rotating stock on a first-in-first-out basis; this minimizes the chances of batteries expiring while still in storage. The amount of time rechargeable batteries can be kept in storage can be extended by periodically providing a maintenance charge.

8.3. Transportation

Batteries, particularly lithium and lithium-ion, are subject to various legal and carrier-imposed shipping restrictions, rules, and regulations. Batteries should only be packaged and shipped by properly trained and certified individuals.