# 28 VDC Battery Packs Using Nanophosphate Cells

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**Abstract**

The success of lithium ion chemistry in the consumer electronics industry has helped to generate interest in the chemistry for larger commercial and military applications, including batteries for satellites, aircraft, and ground vehicles where volume is often at a premium and reduced weight allows for extended usage or more payload capability. Lithium ion batteries have begun to receive attention in these arenas as the technology has matured to a point that it is able to demonstrate enhanced life and high reliability. Further, the safety characteristics of the iron phosphate chemistry, coupled with a robust, battery management system offers an additional layer of protection of the battery system. A123 has developed several battery configurations built around its Nanophosphate cell chemistry. The inherent safety of the A123 nanophosphate chemistry has generated interest from applications as diverse as commercial aviation to hybrid electric vehicles. This cell chemistry is also ideally suited for use in aerospace applications, as it has the weight advantages of lithium ion chemistry, coupled with improved safety. A123 has developed a family of 28 V batteries for a wide variety of applications from aircraft to ground vehicles as a replacement for lead acid starter batteries. Data presented will include charge discharge, cycling and engine start profile results.

**Introduction**

The success of lithium ion chemistry in the consumer electronics industry has helped to generate interest in the chemistry for larger commercial and military applications, including batteries for satellites, aircraft, and ground vehicles where volume is often at a premium and reduced weight allows for extended usage or more payload capability.

Lithium ion batteries have begun to receive attention in these arenas as the technology has matured to a point that it is able to demonstrate enhanced life and high reliability. Using small mass produced cells such as the A123Systems 26650 cell provides a means of creating light weight, highly reliable packs that are easily customizable to a variety of applications and volumes. Further, the safety characteristics of the iron phosphate chemistry, coupled with a robust, battery management system offers an additional layer of protection of the battery system.

**Description of ANR26650M1 Cells**

The A123Systems Nanophosphate® 26650 is a 3.3 V, 2.2 Ah (nominal) cell. An 11 mΩ internal resistance (1.0 s DC pulse) is typical. Mass is approximately 72 g. This cell is rated for 70 A continuous discharge and 120 A discharge under a 10 s pulse.

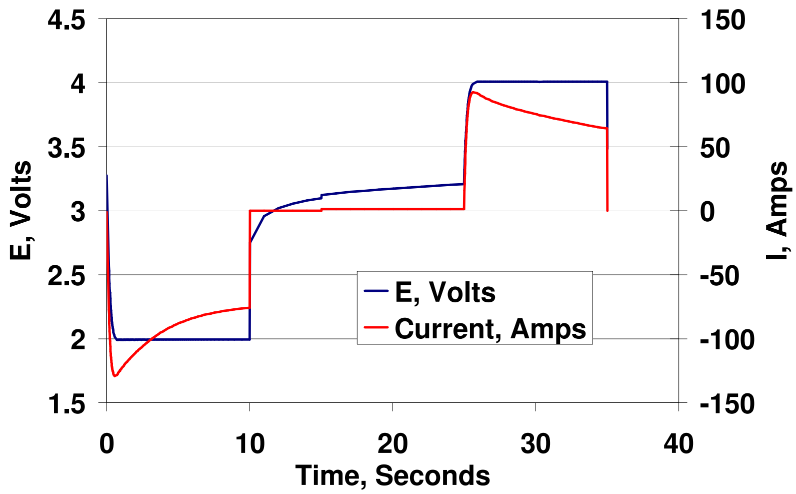


**Figure 1.** CV Transients for Peak Power Determination on an ANR26650M1 Cell.

**Results**

*Peak power test results:* The peak power response for ANR26650M1 cell is shown in Figure 4. (Note that the peak power curves demonstrate cell capabilities, but are not intended to suggest recommended operating conditions.) Both the regen curve and the load curve are quite flat from 10-90% SoC. For comparison, the peak power curves, in watts/liter of a high quality 26650 NCA cell are also included. Figure 3 shows the peak power curves for the ANR26650M1 cell over a temperature range of -20℃ to 60℃.

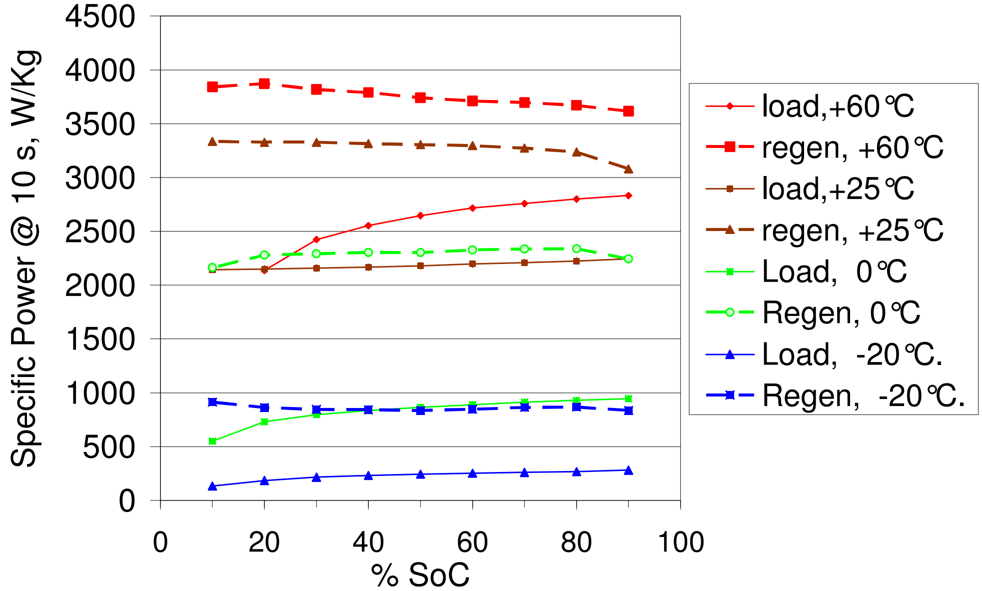


**Figure 3.** Peak Power Curves for ANR26650M1 Cell at Different Temperatures.

The load power at -20℃ is about 250 Watts/Kg and at 60℃ it has increased to 2500-2800 Watts/Kg. Again, the power curves are relatively flat across a wide SoC range.

**Battery Description**

The battery is nominally 26 Vdc, consisting of eight cells in series twelve series strings are arranged in parallel to provide a nominally 26 Ah battery. The external dimensions of the battery case are 7.8"L x 8.25"W x. 8.0"H. At 25 lbs, it is approximately half the weight of a comparably sized Nickel Cadmium battery. Listed below are the functional characteristics of the battery.

*Description of Peak Power Protocol:* The peak power protocol is intended to reflect the capability of the battery to respond to loads with durations of seconds or less. These loads may be vehicle acceleration or regenerative braking, or shorter loads such as weapons systems. The load profile for peak power tests is shown in Figure 4. The C/2 discharge current prior to the load pulse is not shown. After the load pulse, a 5 second rest occurs and then a 10 second C/2 charge is applied prior to the 4.0 Volt regeneration pulse. Peak power calculations are made by taking the product of the current and voltage at the end of the 10 second pulse and dividing this value by the cell weight in kilograms to produce watts/kg, or, alternatively, by the cell volume to provide watts/liter. The peak power protocol was applied over a wide range of temperatures and states of charge.

**Figure 4.** 28 V, 26 Ah battery

- Nominal Voltage 26.0V
- Capacity 26 Ah
- Charge Voltage 28.8 V
- Charge Current 120 A
- Discharge Current 1000 A (max pulse, 10 sec @50% SOC)
- Operating Temperature -30°C to +60°C

Kapton film heaters are installed in the battery to enable operation down to -30°C. The cell used in the battery pack is A123Systems 26650 nanophosphate cell, which offers the benefit of high power capability, long life, and safety characteristics inherent to iron phosphate chemistries.

**Battery Management System**

Each battery has an on board battery management system that monitors and reports on state of charge, state of health, voltage, current, heater status and battery temperature. The function of the battery management system is described below.

- **Equalization:** The BMS is capable of detecting and maintaining better than 3% inequality in internal state of charge. The BMS shall be sized to be able to correct 3% inequality between any two cells or cell blocks (group of parallel connected cells). This shall be accomplished over a single discharge and charge cycle wherein 80% of the capacity is withdrawn and the battery is recharged at a voltage limit anywhere in the range of to a taper charge of C/50.

- **Voltage Limiting:** The BMS is capable of bypassing charge current around a cell or cell block that reaches a pre-set voltage limit so as to maintain the cell voltage at the limit. At least 1A of bypass capability shall be provided

- **Telemetry:** The BMS includes the capability to transmit telemetry in a serial word. Telemetry shall be updated at a nominal rate of once per second. The telemetry message shall include the following parameters:
    - Battery voltage
    - Battery cell and electronics temperatures
    - Fault detection status
    - Battery connection status (if a connect switch is required inside of the battery)
    - Depth of discharge
    - Battery current
- **Fault Management:** The battery monitors key parameters and flags the following faults:
    - **Cell Over-Voltage:** an Over-Voltage (OV) fault will be declared if any cell reaches an over-voltage limit.
    - **Cell Under-Voltage:** an Under-Voltage (UV) fault will be declared if any cell drops below an under-voltage limit. The limit shall be adaptive in response to the rate of discharge such that it does not false-trigger during current pulses when at an intermediate state of charge.
    - **Cell Over-Temperature:** a cell Over-Temperature (OT) fault will be declared if any temperature sensor monitoring the battery cells exceeds a fault limit for more than one second.
    - **Electronics Over-Temperature:** an Electronics Over-Temperature (EOT) fault will be declared if any temperature sensor monitoring the battery management electronics exceeds a fault limit for more than one second.
    - **Battery Charge Over-Current.** The BMS shall include the option to detect excessive rate of charge.

**Test Data**
Figure shows an engine start profile that the battery was tested to. The red line indicated on the graph shows the current draw used to start the engine. The blue line indicates the battery voltage. Further testing was performed on the pack to verify that the battery was capable of performing three successive engine starts as shown in Figure
Additional safety of flight testing has been performed on this battery, with the battery successfully completing the following tests per RTCA-DO-160E

- Ground survival low temperature test and short-time operating low temperature test per DO-160E para 4.5.1
- Operating low temperature per DO-160E para 4.5.2
- Ground survival high temperature test and short term operating high temperature test per DO-160E para 4.5.3
- Operating high temperature per DO-160E para 4.5.4
- Altitude test
- Temperature variation, temperature variation testing will be performed per RTCA DO-160E per section 5, category C
- Vibration; vibration testing will be performed per RTCA DO-160E per section 8, category S, zone 1 curve C, standard vibration for fixed wing aircraft.
- Operational shock and crash safety; Operational shock and crash safety testing will be performed per RTCA DO-160E per section 7, category B.

## Conclusion

The 28 V battery originally designed for aircraft applications, has generated interest across a wider range of applications. Test data shows excellent life characteristics, and improved safety over other systems. The initial safety of flight testing has demonstrated the capability of the design to meet the environmental requirements of an aircraft application. This battery is currently available for prototype testing.

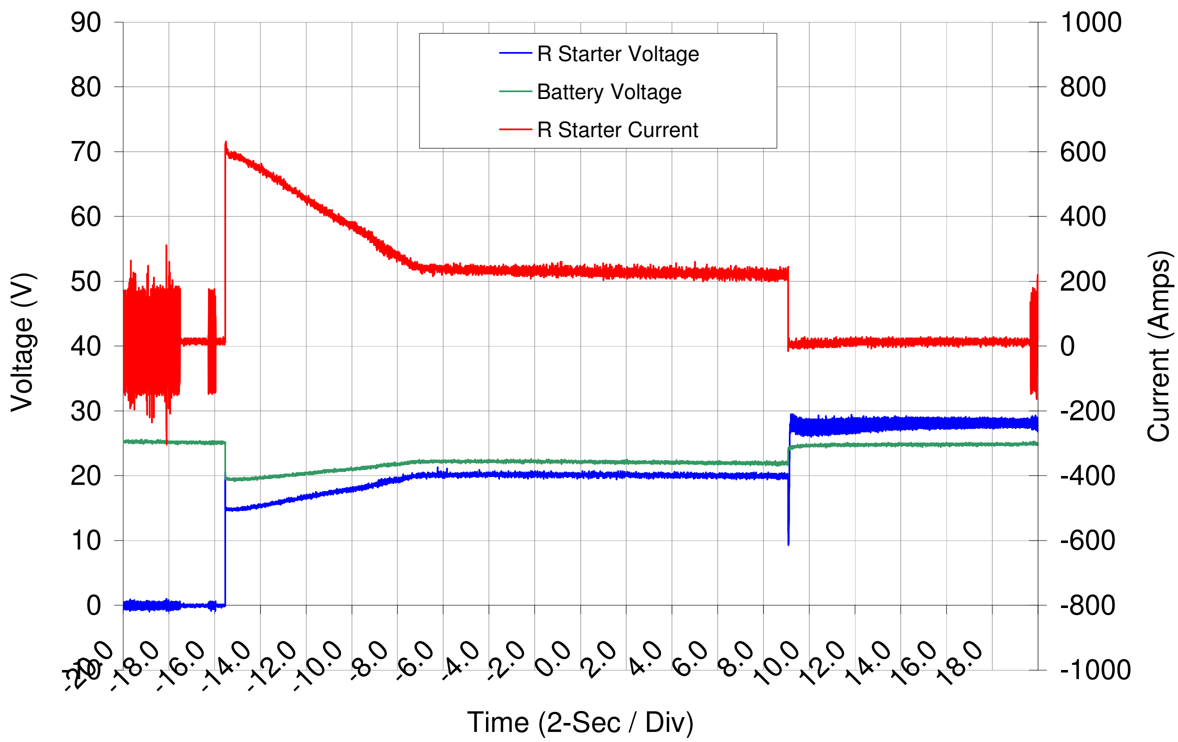


**Figure 5.** Engine Start Pulse.

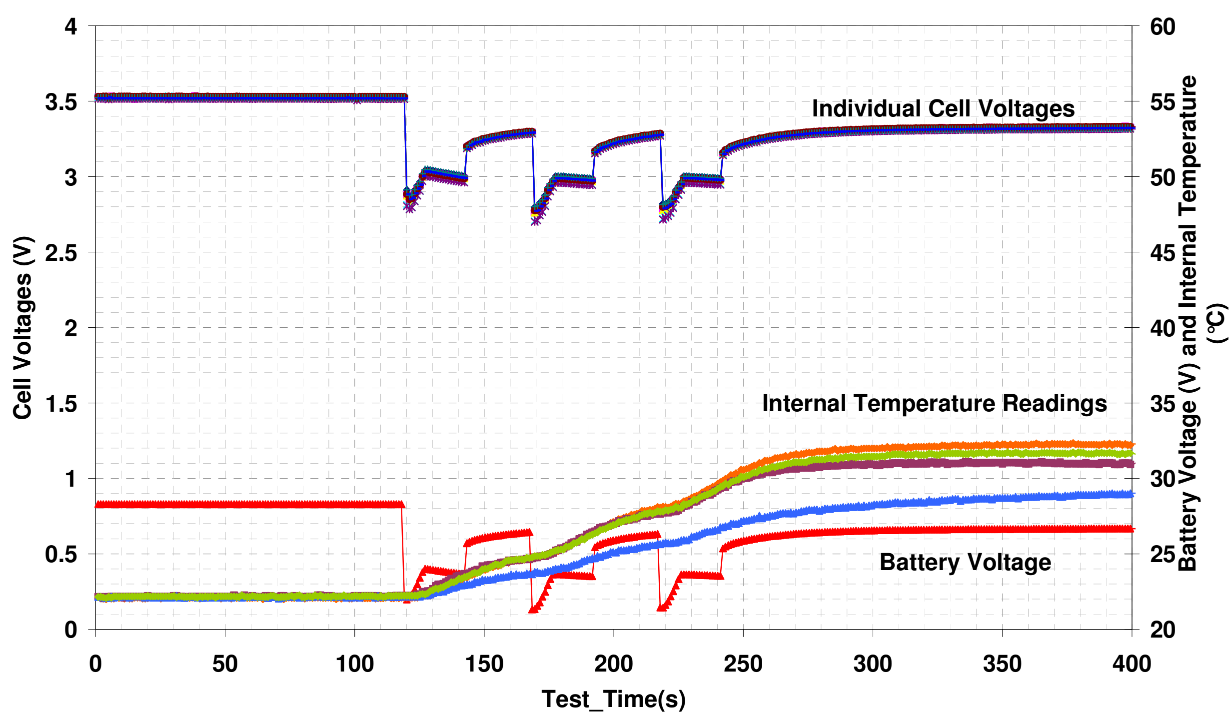


**Figure 6.** Battery Pulse Capability