Serial and Parallel Battery Configurations

Battery packs achieve the desired operating voltage by connecting several cells in series, with each cell adding to the total terminal voltage. Parallel connection attains higher capacity for increased current handling, as each cell adds to the total current handling. Some packs may have a combination of serial and parallel connections. Laptop batteries commonly have four 3.6V Li-ion cells in series to achieve 14.4V and two strings of these 4 cells in parallel (for a pack total of 8 cells) to boost the capacity from 2,400mAh to 4,800mAh. Such a configuration is called 4S2P, meaning 4 cells are in series and 2 strings of these in parallel. Insulating foil between the cells prevents the conductive metallic skin from causing an electrical short. The foil also shields against heat transfer should one cell get hot.

Most battery chemistries allow serial and parallel configuration. It is important to use the same battery type with equal capacity throughout and never mix different makes and sizes. A weaker cell causes an imbalance. This is especially critical in a serial configuration and a battery is only as strong as the weakest link.

Imagine a chain with strong and weak links. This chain can pull a small weight but when the tension rises, the weakest link will break. The same happens when connecting cells with different capacities in a battery. The weak cells may not quit immediately but get exhausted more quickly than the strong ones when in continued use. On charge, the low cells fill up before the strong ones and get hot; on discharge the weak are empty before the strong ones and they are getting stressed.

Single Cell Applications

The single-cell design is the simplest battery pack. A typical example of this configuration is the cellular phone battery with a 3.6V lithium-ion cell. Other uses of a single cell are wall clocks, which typically use a 1.5V alkaline cell, as well as wristwatches and memory backup.

The nominal cell voltage of nickel is 1.2V. There is no difference between the 1.2V and 1.25V cell; the marking is simply preference. Whereas consumer batteries use 1.2V/cell as the nominal rating, industrial, aviation and military batteries adhere to the original 1.25V. The alkaline delivers 1.5V, silver-oxide 1.6V, lead acid 2V, primary lithium 3V, Li-phosphate 3.3V and regular lithium-ion 3.6V. Li-manganese and other lithium-based systems sometimes use 3.7V. This has nothing to do with electrochemistry and these batteries can serve as 3.6V cells. Manufacturers like to use a higher voltage because low internal resistance causes less of a voltage drop with a load.

Serial Connection

Portable equipment needing higher voltages use battery packs with two or more cells connected in series. Figure 3-8 shows a battery pack with four 1.2V nickel-based cells in series to produce 4.8V. In comparison, a four-cell lead acid string with 2V/cell will generate 8V, and four Li-ion with 3.6V/cell will give 14.40V. If you need an odd voltage of, say, 9.5 volts, you can connect five lead acid, eight NiMH/NiCd), or three Li-ion in series. The end battery voltage does not need to be exact as long as it is higher than what the device specifies. A 12V supply should work; most battery-operated devices can tolerate some over-voltage.

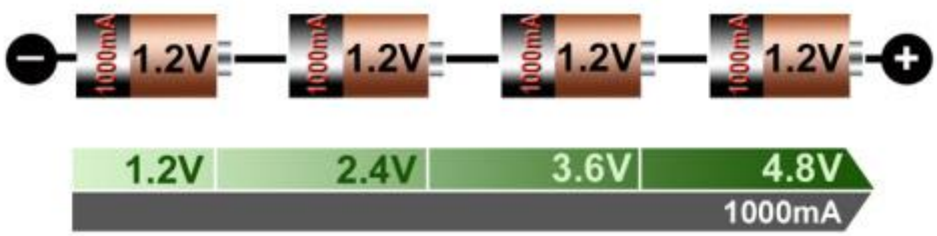

Figure 1: Serial connection of four NiCd or NiMH cells
Adding cells in a string increases the voltage; the current remains the same.
Courtesy of Cadex

A higher voltage has the advantage of keeping the conductor size small. Medium-priced cordless power tools run on 12V and 18V batteries; high-end power tools use 24V and 36V. The car industry talked about increasing the starter battery from 12V (14V) to 36V, better known as 42V, by placing 18 lead acid cells in series. Logistics of changing the electrical components and arcing problems on mechanical switches derailed the move. Early hybrid cars run on 148V batteries; newer models have batteries with 450–500V. Such a high-voltage battery requires 400 nickel-based cells in series. Li-ion cuts the cell count by three.

High-voltage batteries require careful cell matching, especially when drawing heavy loads or when operating in cold temperatures. With so many cells in series, the possibility of one failing is real. One open cell would break the circuit and a shorted one would lower the overall voltage.

Serial and Parallel Battery Configurations

Cell matching has always been a challenge when replacing a faulty cell in an aging pack. A new cell has a higher capacity than the others, causing an imbalance. Welded construction adds to the complexity of repair and for these reasons, battery packs are commonly replaced as a unit when one cell fails. High-voltage hybrid batteries, in which a full replacement would be prohibitive, divide the pack into blocks, each consisting of a specific number of cells. If one cell fails, the affected block is replaced.

Figure 2 illustrates a battery pack in which “cell 3” produces only 0.6V instead of the full 1.2V. With depressed operating voltage, this battery reaches the end-of-discharge point sooner than a normal pack and the runtime will be severely shortened. The remaining three cells are unable to deliver their stored energy when the equipment cuts off due to low voltage. The cause of cell failure can be a partial short cell that consumes its own charge from within through elevated self-discharge, or a dry-out in which the cell has lost electrolyte by a leak or through inappropriate usage.

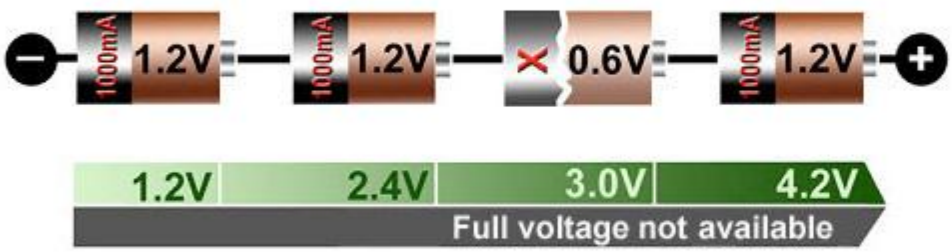

Figure 2: Serial connection with one faulty cell
Faulty “cell 3” lowers the overall voltage from 4.8V to 4.2V, causing the equipment to cut off prematurely. The remaining good cells can no longer deliver the energy.
Courtesy of Cadex

Parallel Connection

If higher currents are needed and larger cells with increased ampere-hour (Ah) ratings are not available or the design has constraints, one or more cells are connected in parallel. Most chemistry allows parallel configurations with little side effect. Figure 3 illustrates four cells connected in parallel. The voltage of the illustrated pack remains at 1.2V, but the current handling and runtime are increased fourfold.

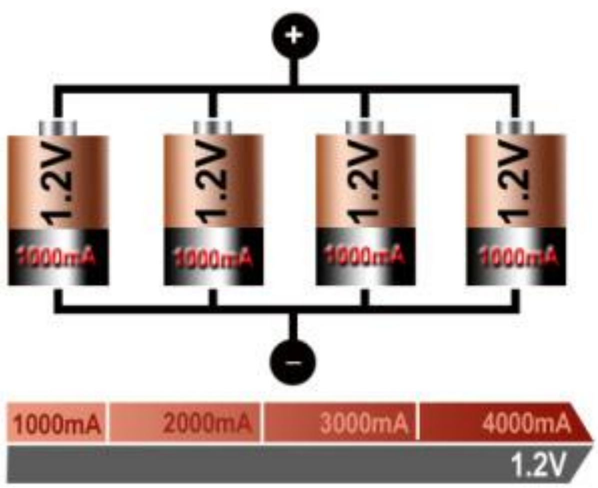

Figure 3: Parallel connection of four cells
With parallel cells, the current handling and runtime increases while voltage stays the same.
Courtesy of Cadex

A high-resistance cell, or one that is open, is less critical in a parallel circuit than in serial configuration, however, a weak cell reduces the total load capability. It’s like an engine that fires on only three cylinders instead of all four. An electrical short, on the other hand, could be devastating because the faulty cell would drain energy from the other cells, causing a fire hazard. Most so-called shorts are of mild nature and manifest themselves in elevated self-discharge. Figure 4 illustrates a parallel configuration with one faulty cell.

Serial and Parallel Battery Configurations

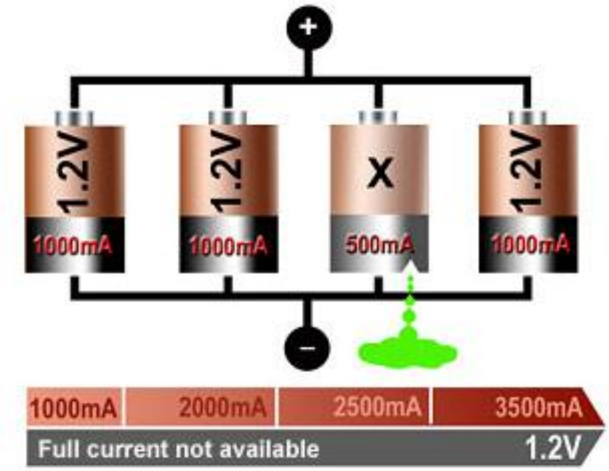

Figure 4: Parallel/connection with one faulty cell
A weak cell will not affect the voltage but will provide a low runtime due to reduced current handling. A shorted cell could cause excessive heat and become a fire hazard.
Courtesy of Cadex

Serial/Parallel Connection

The serial/parallel configuration shown in Figure 5 allows superior design flexibility and achieves the wanted voltage and current ratings with a standard cell size. The total power is the product of voltage times current, and the four 1.2V/1000mAh cells produce 4.8Wh. Serial/parallel connections are common with lithium-ion, especially for laptop batteries, and the built-in protection circuit must monitor each cell individually. Integrated circuits (ICs) designed for various cell combinations simplify the pack design.

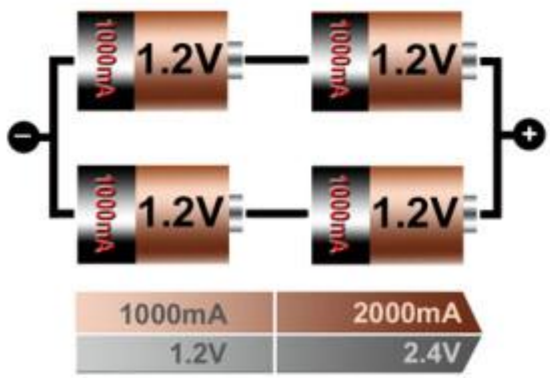

Figure 5: Serial/ parallel connection of four cells
This configuration provides maximum design flexibility.
Courtesy of Cadex

Simple Guidelines for Using Household Primary Batteries

- Keep the battery contacts clean. A four-cell configuration has eight contacts (cell to holder and holder to next cell); each contact adds resistance.
- Never mix batteries; replace all cells when weak. The overall performance is only as good as the weakest link in the chain.
- Observe polarity. A reversed cell subtracts rather than adds to the cell voltage.
- Remove batteries from the equipment when no longer in use to prevent leakage and corrosion. While spent alkaline normally do not leak, spent carbon-zinc discharge corrosive acid that can destroy the device.
- Don’t store loose cells in a metal box. Place individual cells in small plastic bags to prevent an electrical short. Don’t carry loose cells in your pockets.
- Keep batteries away from small children. If swallowed, the current flow of the battery can ulcerate the stomach wall. The battery can also rupture and cause poisoning.
- Do not recharge non-rechargeable batteries; hydrogen buildup can lead to an explosion. Perform experimental charging only under supervision.

Simple Guidelines for Using Household Secondary Batteries

- Observe polarity when charging a secondary cell. Reversed polarity can cause an electrical short that can lead to heat and fire if left unattended.
- Remove fully charged batteries from the charger. A consumer charger may not apply the optimal trickle charge and the cell could be stressed with overcharge.