Safe battery charging in wearables and other small systems

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The Internet of Things is all set to enhance almost every aspect of modern life. By collecting and analyzing vast amounts of data, it will allow us to manage our own health, reduce energy consumption at home and work, monitor and improve our local environment and much, much more.

While the potential applications of the Internet of Things are many and varied, they do share some key characteristics. The devices that collect the data need to be small, easy to use and available almost all the time. These requirements are perhaps most readily apparent in the wearable devices that are already used by millions of people around the world to track their activity, monitor their fitness and improve their wellbeing.

To collect the necessary data, wearables need to be worn almost constantly. Hence they need to be small and comfortable and they need to be capable of operating continuously for long periods. Smart home sensor nodes and other Internet of Things applications face similar demands.

That raises the question of how to power these devices. Ideally, they would draw energy direct from their environment so that they would always have power. While great strides are being made in reducing power consumption and improving energy harvesting, this ideal remains some distance off. For the foreseeable future, we will need to rely on batteries as the primary power source. In particular, to minimize waste from the billions of devices, rechargeable batteries are likely to be the power source of choice for some years.

The natural choice for wearables

Wearables are severely size constrained, and the need for comfort when wearing them for extended periods means they must be light too. So batteries must be as small as possible. What's more, repeated studies by IDC and GMI have shown that battery lifetimes are the number one purchase driver for consumers buying battery-powered portable products. Thus high battery capacity is essential for a successful product.

Meeting both these at the same time takes the challenge for batteries to the next level. Thankfully, Li-ion batteries boast a number of characteristics that allow them to address this challenge, making them the ideal choice for wearable applications.

Firstly, they offer high energy densities, allowing system designers to opt for smaller, lighter batteries while delivering longer operating times. At the same time, Li-ion batteries typically operate at 3.7 V compared to 1.2 V for NiMH or NiCd. This means fewer cells are required, which again helps enable smaller, lighter systems. Furthermore, they have much slower self-discharge rates than nickel-based batteries: around 2% per month compared to up to 5% per day for NiMH and NiCd. So fewer recharges are required and the batteries are more likely to be ready to use after long periods of inactivity – making systems more user friendly.

Of course, all technologies have their downsides too. For example, Li-ion batteries are more complex to manufacture than nickel-based rechargeables, making them more expensive. However, as a high volume product, the usual economies of scale – along with ongoing technical developments – are rapidly bringing down costs.

As recent news headlines highlight, Li-ion batteries also pose higher potential safety risks. They use a flammable electrolyte, and if the charging voltage becomes too high or too low it can cause the battery to catch fire or explode. Most Li-ion batteries have internal protection circuits that to some extent guard against over- or under-voltage. However, Li-ion batteries still need a more sophisticated charging process than their nickel-based counterparts.

Li-ion batteries: enabling comfortable and convenient wearables

- High energy density for small batteries with long lifetimes
- Higher operating voltage means fewer cells and smaller systems
- Slower self-discharge: fewer recharges and also ready to go

The challenge of charging

To avoid such safety issues, Li-ion batteries require a constant current (CC), constant voltage (CV) charging process. In this process, the battery is initially charged at a fixed current until it reaches a set voltage. Then the charging circuitry switches over to a constant voltage mode, providing the necessary current to maintain the set voltage.

The choice of the current and voltage levels needs to be carefully balanced for best results. Charging at higher voltages increases the capacity of the battery, but going too high can stress or overcharge the battery leading to permanent damage, instability and danger. Similarly, a higher charging current can speed up charging but at the expense of the battery's capacity: reducing the charging current by 30% can increase the charge the battery stores by as much as 10%.

Typically, then, the charging current is set to half the battery's capacity (the maximum current the battery can deliver for one hour) and the voltage to 4.2 V per cell. However, it has been shown that using slightly lower values for the current and voltage can reduce the aging of the battery, allowing it to maintain a higher charge capacity over more charging cycles.

Ensuring safety

Due to this complexity, the charging solution must be capable closely monitoring the charging current and voltage, and providing stable control loops for maintaining them at the appropriate values at the appropriate point in the charging cycle (i.e. keeping the current constant in the first stage and the voltage constant in the second phase).

The charging solution also needs to be thoroughly tested according to stringent standards. These standards cover a broader range of test conditions than required for charging nickel-based batteries and also feature additional battery-specific tests.

JEITA specification

The Japan Electronics and Information Technology Industries Association has developed a specification that describes the use and charging of Li-ion batteries. Although this specification is just a guideline and not strict standard from a certification body, it is widely regarded in the industry as helping to ensure that Li-ion batteries are used safely.

The JEITA specification defines a minimum temperature (T1), a maximum temperature (T4) and three temperature regions in between (low, medium and high) for safe charging. See figure 1.

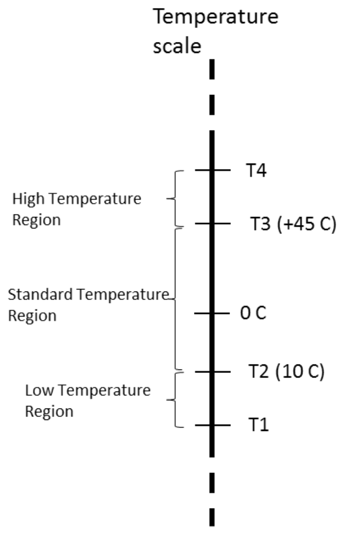

Figure 1: JEITA specification temperature regions for safe charging of Li-ion batteries

A maximum safe current is defined for each temperature region.

- Low temperature region: maximum current is 50% of battery capacity
- Standard temperature region: maximum current is 70% of battery capacity
- Low temperature region: the maximum current is 60% of battery capacity

These safe currents are shown in figure 2, with the corresponding safe voltage zones.

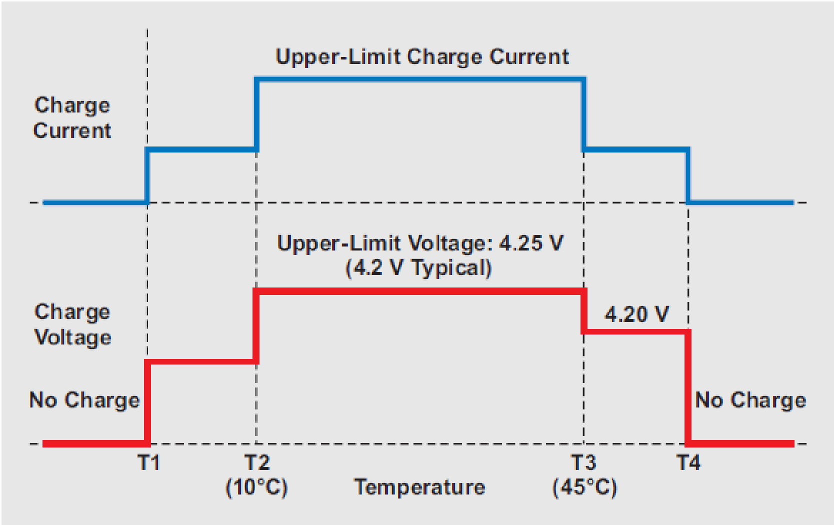

Figure 2: safe currents and voltages for charging Li-ion batteries according to the JEITA specification

Safe charging with the DA1468x family

Wearables and many other Internet of Things devices are extremely constrained in their size and weight. To help ensure safe battery charging while adhering to these form factor requirements, Dialog's SmartBond™ DA1468x family SoCs feature integrated battery management functionality that (with some external components and connections) fully supports the JEITA specification.

Central to this functionality is a flexible CC/CV charging algorithm. Supporting currents from 200 µA to 400 mA, the algorithm allows for the charging of batteries with a range of capacities. Figure 3 shows how the DA1468x SoCs connect to the battery to enable charging

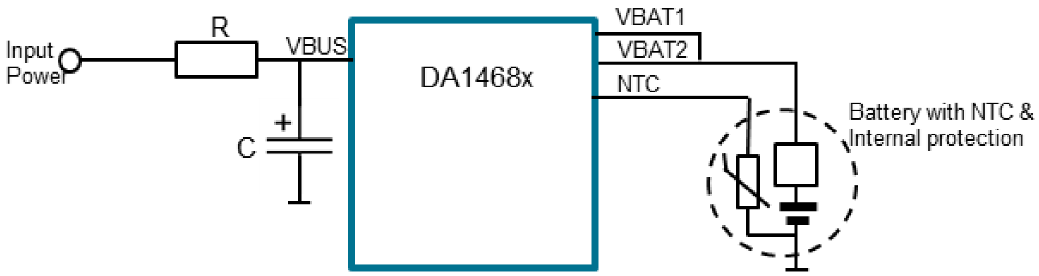

Figure 3: example circuit for charging Li-ion batteries with the Dialog DA14680 or DA14681

The algorithm identifies four distinct charging phases: pre-charging, constant current, constant voltage and voltage monitoring.

The charging cycle

Charging begins as soon as an input voltage is detected. If the battery is severely depleted (e.g. so that its voltage is less than 3 V), the algorithm triggers the pre-charging phase. Here the battery is “pre-charged” with a low current (around 10% of the battery’s capacity) until the battery is ready to accept the full charging current. This prevents overheating.

Once the battery voltage reaches an appropriate level, the algorithm switches to the constant current phase. The battery is charged at a higher current (up to the battery’s capacity) until voltage reaches 4.2 V (nominal value). At this point, the charger moves into the constant voltage phase to avoid the risk of overcharging. Here, the voltage is held at 4.2 V and the current drops to around 10% of the battery’s capacity. The transition from constant current to constant voltage is made gradually and smoothly to avoid damaging the battery.

At this point the battery is fully charged. If it is left connected, the charger moves into the voltage monitoring phase, providing a periodic top up charge to counteract the battery’s self-discharge. This is typically done when the battery’s open circuit voltage drops below 4.0 V.

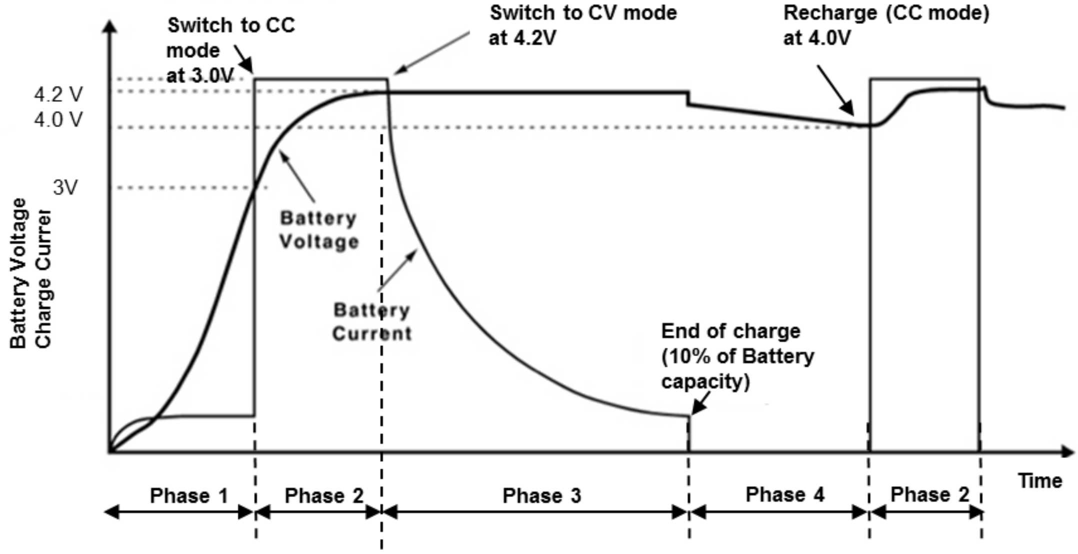

Figure 4: the charging cycle for the Dialog DA14680 and DA14681

Within this basic cycle, system designers can adjust a number of parameters to customize the charging process. These include:

- Pre-charge current (should be set to 10%[1] - i.e. between 1 and 15 mA)
- Pre-charge voltage V_{pcv} (should be set to 3.05 V)
- Pre-charge timer (default value = 15 mins)
- Constant charging current I_{cc} (should be set to 70%[1])
- Charging voltage V_{float} (range 4.2 – 4.6 V)
- Constant current (CC) timer (default value = 180 mins)
- Constant voltage (CV) timer (default value = 360 mins)

[1] Current are given as percentages of the battery capacity – i.e. the maximum current a battery can deliver for 1 hour

Building in protection

Helping to ensure safety, the DA14680 and DA14681 offer a number of built in protection features to guard against problems caused by non-standard charging conditions. These include protection against:

- Under voltage discharging
- Over voltage charging
- Over current charging
- Timeouts in pre-charging, constant current and constant voltage phases
- Low and high battery temperatures (with an external NTC and connection)

It is highly recommended that the battery has its own internal protection against over voltage charging, under voltage discharging and over current (dis)charging. In addition, the battery must have an internal Negative Temperature Coefficient (NTC) sensor which should be connected to the NTC pin of the DA14680 or DA14681. This pin should also be connected to an analog-digital converter (ADC) input (e.g. ADC5).

Safe, convenient and reliable wearables

The wearables sector is growing fast – and will continue to grow for some years to come. Progress is being made in both the power consumption of systems and the potential for energy harvesting. But the wearable that charges itself from the environment remains a distant goal. Hence, powering wearables – and other highly featured Internet of Things applications – remains the job of rechargeable batteries.

Li-ion technologies enable smaller, lighter batteries with greater capacities, helping system designers meet form factor constraints and deliver long battery lifetimes that will delight consumers. Their higher operating voltage means fewer cells are required, further reducing system size and improving design flexibility.

But these batteries need more sophisticated charging solutions to ensure safe and efficient charging. Dialog's DA1468x family offers integrated battery management functionality including a JEITA-compliant charging algorithm and internal protection features. Delivering all this on one chip helps further reduce system size while maximizing design flexibility and simplifying the design process. So designers can deliver feature-rich, comfortable and visually appealing wearables faster.