# Hardware Wallet Power Architecture SPADE

## Setting

The hardware wallet we're building will need a power source in order to store funds and enable customers to access them. We've decided on wireless NFC as a communication standard intended for mobile smartphone interactions for easier use, which means we won't naturally have a tethered connection to a computer for power. We aim to target a level of functionality and consistency that prohibits relying exclusively on the power that can be harvested from the NFC field during signing, as some simpler RFID tag type devices do. In order to take advantage of the flexible, untethered experience offered by NFC, we think it is important to design out any dependence on a hard connection to another computer for the wallet hardware to work. This leaves us with a hard requirement for an on-device, self contained power source, most likely a replaceable or rechargeable battery.

We're designing the wallet using a technology called multisignature to enable a variety of use patterns, and we imagine that most people will keep our hardware in a safe place and avoid keeping it with them for the majority of its life, but it's challenging to predict the full range of use patterns in advance. With that in mind, we're trying to optimize for several different requirements all at once, including (broadly) Function, Product Experience, and Cost.

**Function** - The design needs to be able to meet the power requirements of the wallet hardware completely, predictably, and throughout its lifespan. This means supporting the range of features and functions of the hardware, including authentication with the wallet's owner, generating, storing, accessing, and signing with private keys, sending and receiving information with a paired smartphone, and communicating its status and activity visually to the wallet's owner.

- Reliability and Safety - While the wallet hardware might spend most of its life stored in a safe place, it also needs to reliably survive the stresses and shocks that come with its occasional use and transport. It's important to select a power solution that allows the device to be resilient to being dropped, sat on, kept in a hot car, or exposed to the grit or moisture in a pocket or a backpack.
- Current and Voltage - Power requirements of the processor and related components need to be met, including peak and continuous current at the appropriate voltage. While there is some variability here depending on complexity and feature richness, this is mostly a binary go/no-go criteria.

- Longevity - The wallet hardware is only one part of the multisig system protecting its owners money, but one that we expect to be in use for years. While the multisig system we're designing can reliably recover from hardware failures, device replacement is an inconvenience we want to minimize by ensuring a sufficient device lifespan.

**Product Experience** - We need the product not just to work, but to work **well**. This means being comfortable, convenient, and easy to understand, among many other variables. Some specific facets of the experience we're thinking about impacted by this decision:

- Industrial Design - The size, weight, and overall feel of the hardware is a qualitative metric, but an important one. Including external access for recharge or battery doors for battery replacement can constrain design space. A smaller, lighter power solution gives more flexibility to the design of the hardware.

- Frequency of battery replacement / recharge - Any onboard power source is going to need replenishment in the form of a swap of a dead battery or a recharge of an onboard one, and a design that allows this to happen less often will be a better one.

- Complexity (Hassle) of battery replacement / recharge - Replaceable batteries mean the wallet's owner sometimes needs to figure out what kind of battery needs replacing, keep some on hand or find out where/how to purchase it, and how to remove the old one from the device and replace it. On board rechargeable batteries mean the wallet's owner needs to make sure they have the appropriate cable or accessory handy, or find it if they don't, and find an available power plug and wait out sufficient recharge times. Any solution we implement will have tradeoffs, and so our goal should be to consider and minimize the 'hassle' of power maintenance.

**Costs** - To create a device that makes self custody accessible for a global audience, we need to be conscious of the all in costs for our wallet. The power architecture can impact these in a few different ways:

- Manufacturing/BOM costs - The cost of raw materials going into the device. This includes not just the power source, but all the supporting components needed to integrate it, and any in-box hardware that needs to be included for a first time setup.

- Maintenance and support costs - The costs incurred from ongoing maintenance, including replacement batteries, replacing lost accessories, or even the cost of power to recharge the device itself.

## People

This decision affects most aspects of the project, from the industrial design of the hardware, the engineering requirements to incorporate, manufacture, and test, as well as the assumptions built into the accompanying software, and so requires involvement from the entire hardware wallet team. Additionally as part of our mission to design in the open we're looking to share our thought processes with the community, both to solicit feedback and to build understanding of the product we're building.

- Responsible: Wallet Lead
- Approver: Hardware Lead
- Consulted:
    - Wallet Team: Product, Industrial Design, Product Design, Mechanical Engineering, Electrical Engineering, Embedded Software, Manufacturing Test Engineering, Engineering Program Mgmt, Software Lead
    - Hardware Team
    - Input via internal company slack and external channels including Twitter

## Alternatives

Once defining our criteria for function, user experience, and cost and considering several strategies we dug deep on three of the most straightforward implementation options:

1. Coin Cell - A single coin cell battery with a battery door on the back of the enclosure. Data in the table below is based on using a CR2450, which we chose as an example for its electrical properties and relative commonality.
2. Rechargeable LiPo - A custom LiPo pack with USB-C charging port. Would possibly include a USB-C charging cable and regionalized power brick.
3. Alkaline AAA - A single AAA battery with a battery door on the back of the enclosure.

The table below compares performance to our criteria across these three concepts and highlights areas of concern or risk. No one option is perfect so we need to weigh each criteria against our goals for the overall product experience in order to make a decision.

Note: many of the values listed below come from publicly available datasheets for specific battery options. These values can vary across different manufacturers, and especially with respect to load temperature, and usage patterns. They are best understood as approximations.

| | | Coin Cell | Rechargeable LiPo | Alkaline AAA |
|---|---|---|---|---|
| Implementation Summary | | Single CR2450 with battery door on back of enclosure for replacement | Custom LiPo pack with USB-C charging port. Includes possible USB-C cable and regionalized charging brick. | Single AAA battery with battery door on back of enclosure for replacement |
| Minimum Product Thickness | | • ~8mm | • Customizable pack design possible, in general LiPo is less energy dense than coin cells by volume, but more energy dense than alkaline | • ~14.5mm |
| Nominal Capacity | | • ~610mAh (dependent on load) @ 3.0V nominal | • Customizable pack design possible | • ~1000mAh (dependent on load) @ 1.5V nominal |
| Shelf Life | | • 5~10 years | • 3~5 years (*see shelf life section below table) | • 5~10 years |
| Years between recharge or replacement (Estimated based on early power models) | Low Use (use: once per month) | • 4~5 years | • 1.5~2 years | • 4~5 years |
| | Medium Use (use: twice per week) | • 2~3 years | •1~1.5 years | • 2~3 years |
| | High Use (use: twice per day) | • 0.5~1 year | • 0.5~1 year | • 0.5~1 year |
| Reliability and Safety | | • Low weight and many examples of reliable coin cell carrier design<br>• Bayonet style coin cell door easily lends itself to o-ring waterproof sealing | • Connector port increases reliability risk over designs with no connector<br>• Waterproofed port possible but more costly | • Long term storage battery corrosion risk<br>• Increased mass adds risk in drop testing<br>• Waterproof sealing strategy for battery door can be challenging |
| Replacement Availability | | • Coin cells unlikely to have readily on hand and sometimes challenging to find for purchase | • Charging cable and adapter is more commonly on hand than consumable battery supply, especially for users of mobile phones with the same standard.<br>• Can quickly charge for immediate use or use while wired (power path charger) | • AAA more likely to have on hand than Coin Cell |
| In-Box Considerations | | • none | • Posible USB-C charging cable and regionalized charging brick | • none |
| System Cost | | • Additional EE components to enable a workable solution, coin cell, battery carrier, waterproof battery door | • LiPo pack, USB-C connector, possible in box USB-C cable and power brick | • AAA, battery carrier, waterproof battery door |
| Max Continuous Current (minimum 100mA preferred) | | • 3mA<br>• Not sufficient to support EE architecture, would require a work around | • Customizable pack design possible | • Unspecified (likely 500mA+) |
| Max Pulse Current (1s) (minimum 100mA preferred) | | • 50mA | • Customizable pack design possible | • Unspecified (likely 500mA+) |
| Nominal Cell Voltage (Open Circuit) (minimum 1.5V preferred) | | • 3.0V | • 4.2V (may reduce to support greater battery longevity) | • 1.5V |
| Minimum Cell Voltage (closed circuit) (minimum 0.95V preferred) | | • 2.0V | • 2.9V | • 0.8V |
| Nominal Cell Impedance (at | | • 10Ω | • Varies (likely < 500mΩ) | • 150mΩ |

| | | | |
|---|---|---|---|
| 25°C) (maximum 0.5Ω preferred) | • Not sufficient to support EE architecture, would require a work around | | |
| Max Cell Impedance (at 25°C) (maximum 1Ω preferred) | • 20Ω+ | • Varies (likely < 1Ω) | • 300mΩ |
| Evaluation Summary | Coin Cell battery enables a smaller ID and has good reliability characteristics but capabilities are challenged to support EE architecture. Additional circuitry required to avoid brownout scenarios will add to complexity and cost. | A rechargeable system with a custom pack enables a more efficient EE architecture but comes with additional cost, reliability risks, and potentially a shorter device lifespan. | Alkaline AAA implementation would likely support the EE architecture well, but comes at the cost of a thicker, larger, and heavier product with reliability risks. |

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|---|---|---|---|
| L | Best / Low<br>• Expected to meet target with no anticipated risks | MH | Good / Med-High<br>• Potentially high risk to meet target with alternatives identified but requiring further investigation |
| M | Better / Medium<br>• Unlikely or minor risks identified to meet target | H | Blocker / High<br>• Does not meet target or is high risk without alternatives identified |

## Criteria and Color-Coding

**Recharge / Replacement 'Hassle'**

Not completely captured in the above table are some qualitative callouts worth keeping in mind when evaluating a whole solution.

- Coin cell - The pain points here come from being the least familiar power technology under consideration, as well as a battery type that comes in a wider variety of standards and specs that make the replacement process potentially confusing or frustrating. The proposed CR2450 cell type is one example, but there are many more. We expect a risk in shopping for, locating and installing may lead to purchases of the 'wrong' type of battery, replacement with battery chemistry our wallet design is not intended to support, or potentially wallet owners giving up on the use of the product in general.

- Rechargeable LiPo - The pain points with this solution stem mostly from dependence on an accessory which the wallet owner will need to have available, as well as requiring proximity to and time spent connected to a power outlet. A connector that seems relatively common today like USBc won't be common for everyone, especially as technology changes over the span of the device's lifetime. Even if it does remain prevalent as a connector standard, it still adds some mental overhead to maintaining the wallet hardware, especially if its storage location isn't in convenient range of an outlet / near other devices that regularly need recharging (like the phone used to interact with the wallet).

- Replaceable AAA - A globally common battery type, and less prone to confusion or availability challenges than a coin cell, but still one which requires a special purchase to replace, or keeping a stock of slowly aging batteries on hand for replacements. Additionally, such alkaline cells are prone to battery leaks / corrosion when kept in use or stored in a device over a number of years, leading to clean-up, possible device damage, and confusion and mistrust about continued safe operation.

**Minimum Product Thickness and Industrial Design**

"Minimum Product Thickness" is our most quantitative way to convey something that can be quite subjective - impact on industrial design. From the little white reader all the way to the all aluminum Square register, Block as a company has always prided itself on delivering products that are not just functional and simple to use, but also beautiful in form and something that sellers can be proud of. We're confident that the technical merits of the hardware wallet will appeal to many, and we want to give it a form that matches and accentuates its technical prowess. The components we pick have a big impact on how we can execute on the wallet's design, and the power story has the largest effect on how we can execute here. Thickness is not everything when it comes to design, but Z stack ends up mattering a lot when the engineering team gets down to trying to realize our industrial design visions. Just like our sellers appreciate the design of their Square products, we want Block's hardware wallet to be something that our future customers are proud to own and use.

**Reliability and Safety**

Our seller products see some of the harshest environments consumer electronics products are subjected to. Designing products that can survive those conditions for as long as possible takes a lot of upfront planning, testing, and iteration. When designing a new product like the hardware wallet, making smart decisions around reliability early pays dividends on the backend of product development. While we don't think we'd be putting ourselves at a significant disadvantage with any of our power choices, we think some options are likely to be inherently more reliable than others. For example, external connectors require a lot of consideration when it comes to reliability, as they can fail in more ways than one, and when they do, customers typically have to return their device. On the other hand, battery doors can introduce failure modes of their own, whether they be mechanical or ingress related. Since we know some choices may require more work for us to meet our high expectations for reliability, we want to make sure we factor this into our decision.

On the topic of safety, we test our products extensively to make sure that our products not only are reliable, but also safe for our customers to use. Out of the power choices here, lithium polymer batteries require a bit of special consideration around their design, both mechanically and electrically. It's something we're no stranger to, but we felt worth calling out for the purposes of this comparison.

### Years Between Recharge / Replacement

*What is a 'use'?* - As we roughly define it here for estimating power use, a single instance of a wallet owner waking their device, authenticating with it, tapping to receive transaction data from a paired smartphone via NFC, signing the relevant transaction and passing it back, with a bit of idle time on either side. It's worth noting that users shouldn't require the wallet hardware for every transaction, as wallet owners may end up choosing to rely on only their Mobile Key + Backend key to make small, spontaneous transactions. Use patterns are likely to vary, but we're reasonably confident that up until we see much higher use frequency, battery drain remains relatively modest, and on order of passive discharge any battery experiences even in idle storage.

#### Max Current, Cell Internal Resistance, and Shelf Life

In the table above, several electrical parameters have been assigned color-coded ratings based on a preferred value. These values were obtained from early power modeling of the electrical system. The product and engineering team members first worked to define device states based on features and use cases. Typical and worst case current consumption numbers for each of the key consumers in the system (microcontroller, NFC front-end, power supplies, etc.) were then pulled from their respective datasheets and adjusted to account for voltage level and expected efficiency of the switching power supplies. While this modeling is not a substitute for measurements of real devices, it is extremely important for determining electrical requirements for batteries. In cases where the expected current consumption exceeds the max continuous discharge specs for extended periods, we have assigned a higher risk rating as extra design complexity is required to manage this scenario. Max current values are closely related to cell internal resistance, which limits the max current that can reliably be drawn from a cell without substantial voltage drop – this is important for us to consider as getting this wrong can result in 'brownouts' under certain conditions, which may manifest to customers as a reboot loop or other inscrutable failures. The power modeling also factored in expected shelf-life and self-discharge characteristics of each option, allowing the team to approximate expected battery replacement intervals.

Regarding shelf-life of rechargeable lithium batteries, self-discharge is much higher than it is for the other chemistries shown. Left untouched, a rechargeable battery will deplete on its own, and can eventually deplete to levels where it is unable to be recharged or used. This can be prevented by periodic charging, and is not representative of how long a product with such a battery would last. How long it will last is dependent on factors such as system design, peak charging voltage, cycle count, and environmental conditions (e.g. temperature). The number of battery cycles is expected to be low in most use cases, so a rechargeable battery will likely last longer than the quoted shelf-life spec, provided it is treated with care.

### Why not consider multiple batteries?

Aside from the options presented above, we considered hybrid solutions containing multiple types of batteries (rechargeable and coin cell, for example), as well as multiple coin cells (series or parallel configurations). While the hybrid solutions appear to offer a way to workaround non-ideal characteristics of each battery, they cannot be guaranteed to have both batteries charged at all times, and therefore have similar constraints to the options above while adding more cost and complexity to the product. As for multiple coin cells in series or parallel configurations, there are certain benefits to each approach, but they also introduce additional complications. A parallel configuration will divide the internal resistance but is subject to back-charging if the cells are unbalanced or a short-circuit if accidentally installed with opposing polarities. Extra protection is required to mitigate this, such as an ideal ‘diode-or’ circuit. Additional parts add increased BOM cost and supply-chain risk, especially given the industry-wide IC shortage. A series configuration will offer a higher voltage and therefore reduced current for the system’s switching supplies, but will also double the internal resistance, leading to similar voltage drop at half the current. While this drop is more tolerable at a higher voltage, transients in the system need to be carefully managed (PSRR of power supplies). Additionally, the higher nominal voltage from two cells in series exceeds the input range (5.5V max) of some of the most attractive, low-power switching supply options. These supplies are critical for managing reducing quiescent current and increasing time between replacement. In both configurations, unbalanced cells may reduce performance to that of one cell at best, and in some cases cause additional problems (such as higher internal resistance than a single cell). This increases the number of corner-cases that need to be managed and can contribute to confusion for the end customer.

## Decide

Our next steps are to gather input, discuss and weigh the alternatives, and decide on a design direction as a preferred path - which we’ll document in this section.

## Explain

Once we’ve decided, we’ll share rationale behind the decision, including some value judgements on the different tradeoffs and a callout of any investigations or mitigations planned to address the identified risks with our selected power direction.