1925

My e-bike build

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My e-bike build story

This is a journey into getting what you want.   The following is a detailed story (or report, but that sounds too much like work) of how I modified a carbon mountain bike frame into a custom all-purpose e-bike. The text includes details of how I designed and built a unique lithium battery and the many lessons learned along the way. The battery design is probably patentable, but I would rather just put this out for the public to use rather than lock it up in propriety technology. This is a text publication because although YouTube videos are helpful for showing various techniques; they usually are lacking in details and it's like trying to put a puzzle together with numerous bits of information all over the place. This document includes some handy composite building technique I have developed over the years that are ideal for the DIY person.

I found these e-gravel bikes (Scott Addict RC eride) to be quite interesting; weighting below 30 pounds, and with a range of about 50 miles. The e-gravel bike with X20 Mahle hub motor setup looked awesome. Then I investigated the whole gravel bike scene, with lots of information out on the internet and social media. The trend there is wider tires, up to 50mm wide. Most of these gravel bikes are set-up with road dropper bars and maximum tire width of 32 mm. What I want is a light weight gravel bike with flat bars and mountain bike tires

That is my basic understanding and ideas of what a "gravel" bike should be or I as I define it an adventure bike. There is nothing like that on the market.

The hub motor for me had to be more of a plug and play kit, where the controller and motor were sold together.

After an exhaustive search for a through axial hub motor I only found a couple: Mahle X20, Promotion Truckrun, and Keyde. The Mahle x 20 is the idea hub motor, except it is un obtainable for the DIY er due to the proprietary setup with the manufacture and distributor. Mahle is basically forbidding the DIY er to use their motor. The Truckrun hub is kind of questionable, as it is advertised on AliExpress and indicates it is a thru axial design, but the photos show an axial. It is sold as a kit with clunky cable pull brake levers, cadence sensor, monitor, throttle, and controller.   All the stuff I did not want to hook up to my bike.   It is very inexpensive and sold as a kit or just the motor at about $210. This RN04 motor made my list but required a lot more information to commit to it and getting information from the manufacturer through AliExpress is hit or miss, with a big language barrier.

The Keyde s110 has an informative website with technical details, manuals, and design dimensions. The motor has a couple of configurations, but I am mainly going for the 36 volt and the standard 142 x 12mm rear axial configuration. The motor is not a true thru axial design like the Mahle, but still functions as one, as there are internal threads on the ends on the hub. Drive and non-drive side bolts goes through the frames through axial holes and into the internal threads of the hub, thus securing it to the frame. The hub has a pair left and right side of locking blocks that slots into the frame to restrict motor rotation. It was a bit odd and concerning that the power cord was on the drive side of the motor, but it turned out to be a non-issue. The cool design features of this hub, is that the controller and torque sensor are integral to the hub and that it has blue tooth connectivity to the monitor. It's an integrated kit, just plug and play very little setup required and no extra wiring from the motor to the monitor or the motors gear changing switch.

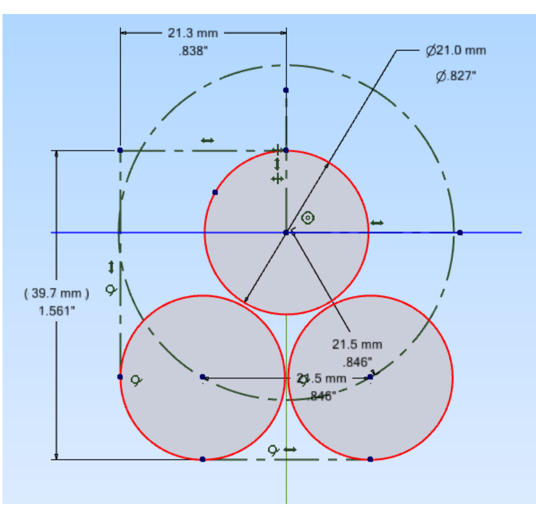
Battery

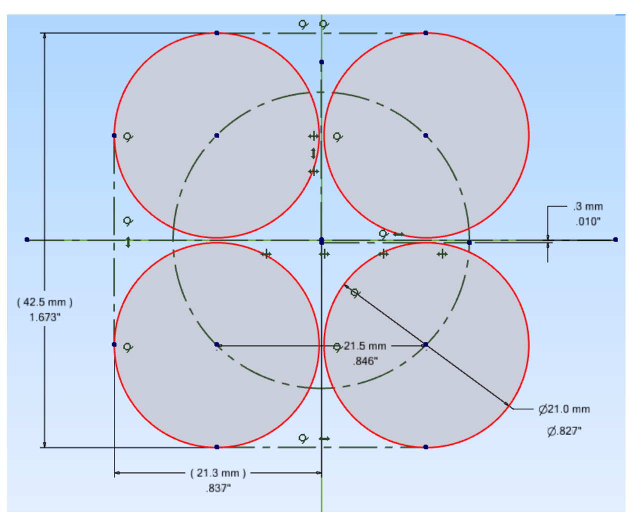
I went down a lot of rabbit holes on the quest to figure this technology out. Again, the baseline design is the Scott e-gravel bike and the x20 motor at 36 volts, 250 watts. The Mahle X20 system includes internal batteries (iX250 and iX350) with different dimensions and ratings. The iX250 battery measures approximately (469.5x 49.6x41.8) mm and is rated at 236 Wh and 36V about 1.5Kg (3lbs), while the iX350 is (469.5x 51x 52) mm with 350 Wh, and about2.3 kg (5 lbs) both batteries are 36 volts. The inner details of the ix250 and ix350 are not published, but with a little bit of reverse engineering you can kind of figure out what basically is in the battery, a side from the controller and BMS that are hidden inside the battery container.

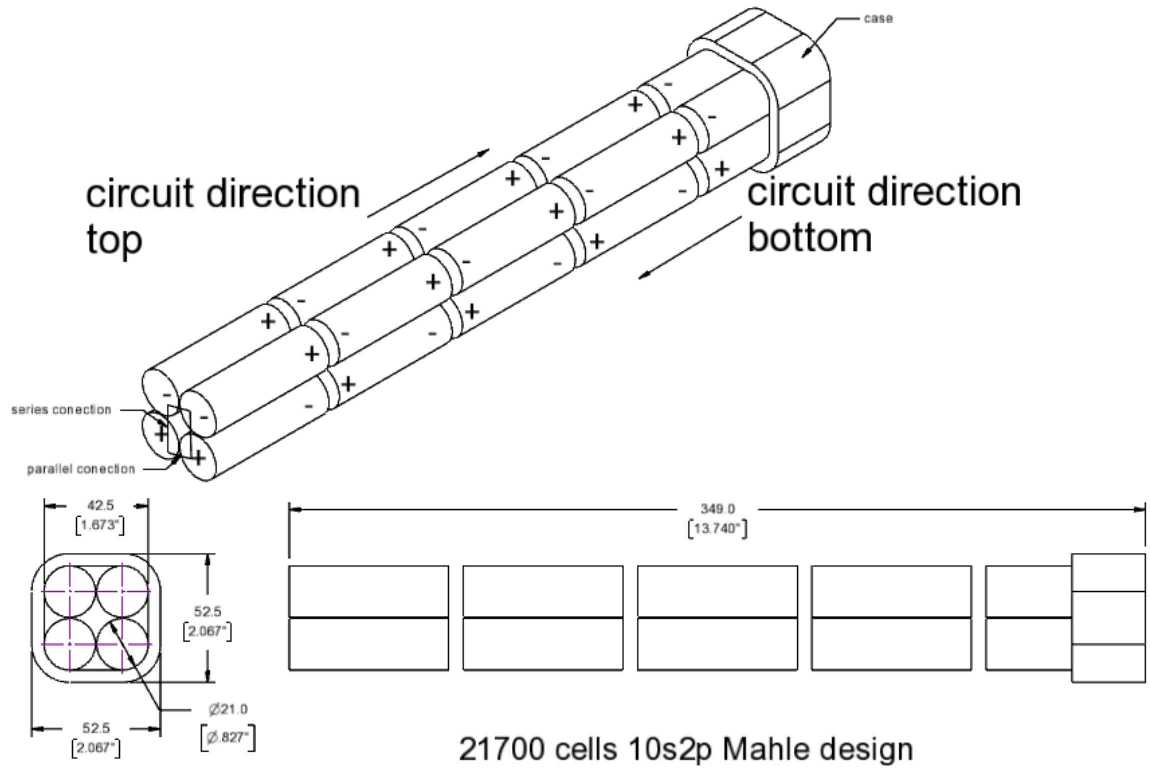
Mahle iX3 battery

There are basically two types of lithium battery cells used for e-bike batteries, the 18650 and the 21700 series cells. The cell nomenclature is the first two numbers denote the cell dimeter and the last three numbers the length in millimeters. The 18650 is 18mm diameter by 65.0mm long, a typical weight for this cell is about 45 to 50 grams. The 21700 weights about 60 to 70 grams. Looking at the iX250 cross section of 50x 42mm, two 18650 cell side by side with about 2 mm clearance around them yields about 42mm, then stacking 2 more on top would be roughly a 42x 42 square. The 21700 cells tightly packed would yield a 42x42 mm square pack as well. But that is excluding the container design and those unknown wires and electronics.

The ix350 battery pack is a square; I have sketched out a 10s2p battery configuration which I think Mahle is doing. Battery nomenclature; 10s2p, means 10 cells in series connection, yielding a 37 voltage, the 2 p means two of these cells are connected in parallel, which does not change the voltage, but increases the amperage capacity by 2. For example, two 12V, 100 Ah batteries wired in parallel will result in a 12V system with a 200 Ah capacity. The watt-hour formula is Wh=voltage x battery amp hours (wh=v x ah). Knowing the reported Wh for each battery we can back out, or verify the battery configuration. iX250 battery @ 250wh/37v=6.8ah, divide that by 2 for 2 cells in parallel yields 3.3ah/cell which is about right for a typical 18650 cell. Doing the same math for the iX350 battery @ 350wh/37v=9.5ah/2 = 4.7ah/cell which is again typical for a 21700 cell. This makes sense as a 10s2p battery configuration with a stack of 4 cells is relativity simple to make the cell-to-cell connections. The two cells on the bottom side by side are in parallel, then as an example the positive terminal of these two cells contact the negative terminals of 2 parallel cells in front of it. That continues for 5 cells, then at the far end the positive to negative connection goes up to the pair of cells stacked on top of the last two to connect them in series. The series connection on the top pair continues back to the starting point, thus completing the circuit for the 10s2p battery configuration.



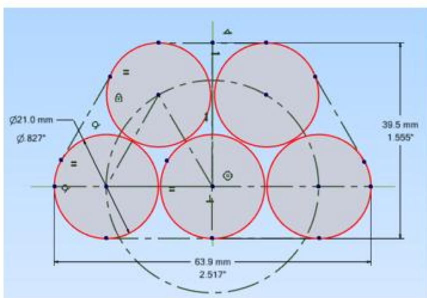




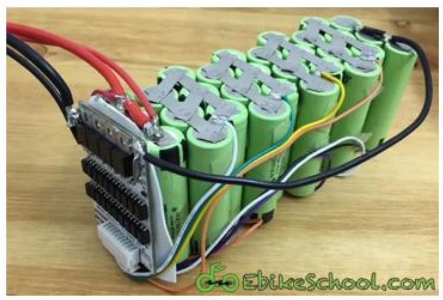
We now have a pretty good idea of what is powering these Mahle systems. It is also interesting to note that reported max estimated ranges for the iX250 and iX350 are 100 km (62 miles) and 140 km (87 miles) respectfully. I have no idea how those range numbers were arrived, as a typical bike ride is not some standard track loop, but has a lot of natural elements, hills, wind, temperature, and rider fitness. Looks like they are using a generalized energy to milage rate of 2.5wh/ km (4wh/mi). To do a powered 160 km (100 mile) ride, theatrically we'd need at least a 400wh battery. We'd need more watt hours than a Mahle battery

DIY battery design

After numerous sketches of battery stack layouts, I zeroed in on a 5-cell stack, repeated 6 times, for about rough profile of 475 x 40 x 64mm, compared to iX350 at 470 x 51 x 52mm. The 5 stack 21700 cell cross section is slightly lower profile at 40mm and 12mm wider than the ix350 battery. Also remember the Keyde controller is packaged into the hub, so we don't need extra space for that. However, making the 10s3p in a 5cell stack makes the cell connections complicated. Most YouTube DIY battery builds are with the cells in a vertical position as shown in the ebikeschool.com information. There is a lot of good information about building your own lithium battery pack on that website. A very interesting design that helps one break from the vertical cell battery pack design is this article electric bike review forum by Lawrence Eaden for an in-tube down tube and seat tube battery pack design. The cell-to-cell connections get a bit tricky for the horizontal stack deign. The closest application for horizontally stacked cells I found is from the e-skate board battery designs YouTube video, by RB E-Motion. There are some clever design approaches on how to connect the cells together without actually soldering directly onto the terminals. I have incorporated these extended nickel tab connection designs into my battery build and when a bit farther with it to avoid solder directly to the cells.

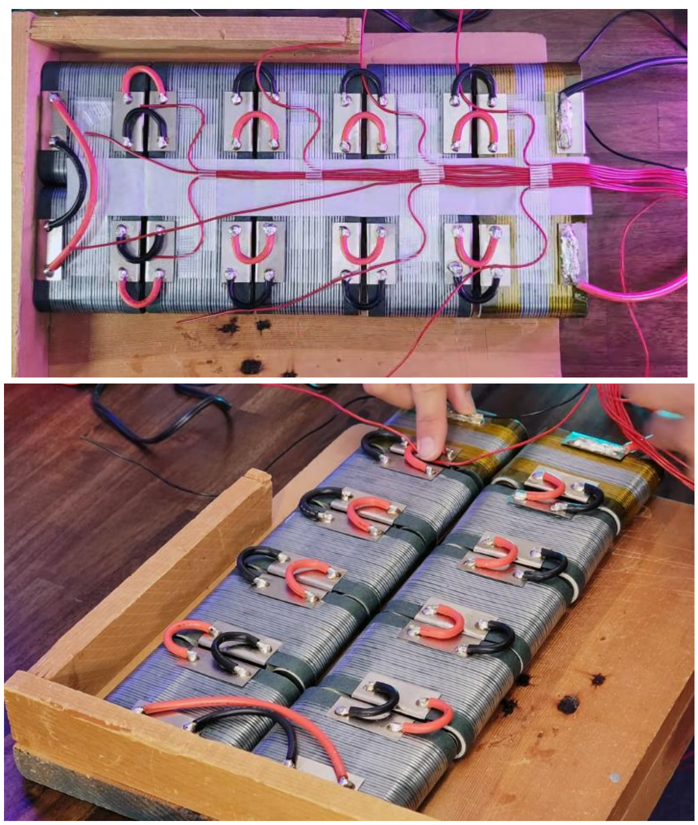


5 cell stack

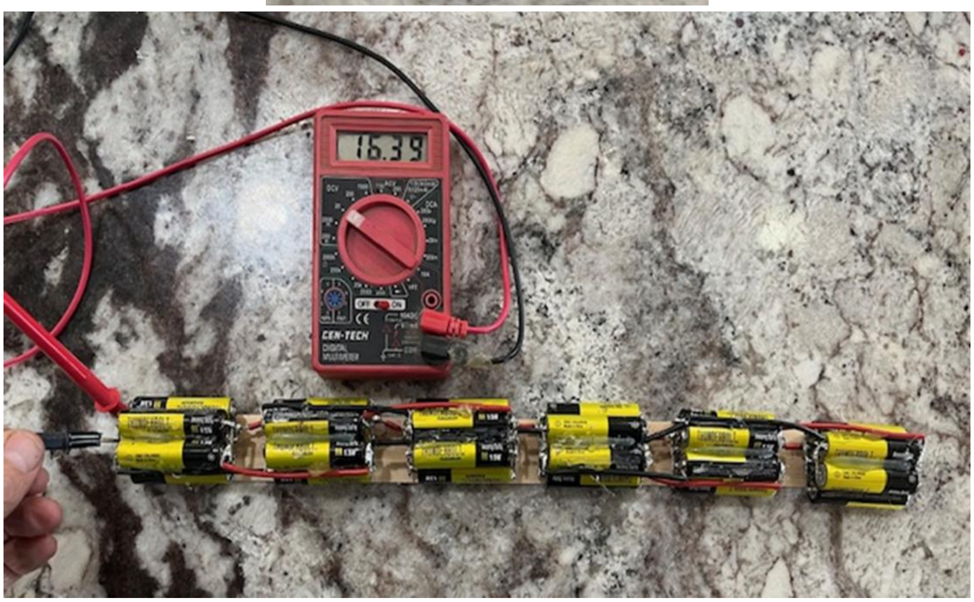


vertical stack cells


single horizontal stack, battery



Skate board horizontal cell stack, 10s4p 21700



Prototype 10s3p battery with AA cell, 16.5 volts

Before completely committing to building the lithium battery pack, I decided to make a quick protype to understand the connections better and to see if it would work. I brought a pack of 1.5 volt AA alkaline batteries from harbor freight. I figured using the smaller 1.5v AA batteries to build the prototype, I'd be less likely to blow something up and start a fire. I soldered the connections together and used wire to make the longer connections. This was a good exercise as with my skill level of soldering demonstrated that there was no way I could solder lithium cells together without destroying them and possibly creating a fire. The next step was the design phase of the project. 1. Figure out a process friendly method to connect the lithium cells in a 10s3p configuration. 2. Figure out how this battery pack was going to fit in/on and existing mountain bike frame.

Nickle strips and BMS

The general list of building materials are lithium 21700 cells, nickel strips .2 & .15, insulating rings, 2" wide Kapton tape, fish tape, fiber glass rods, fiber glass cloth & epoxy resin, spot welder, cell tester- charger, battery charger, 1mm thick EVA foam, 10AWG wire and soldering supplies.

The design is a 5-stack x 6 places in a 10s3p configuration. I selected the Samsung 50E, 21700, 5000mAh, 9.8A cells, to go with a name brand cell. The 5ah per cell is pretty impressive at about $4 to $8 per cell. Spot welding on nickel strips seemed like the way to go, but then there are different thickness of nickel strips, which basically determines how much current you can run across them to design a safe battery. There are also inferior nickel strips which are not pure nickel but nickel coated steel, which can rust and do not have the reduced conductive properties of pure nickel. I used .15 and .2 mm thick "pure" nickel strips in 50mm wide rolls from AliExpress.

A common engineering rule of thumb for battery pack building is to size pure nickel strips for approximately 10 Amps per square millimeter (A/mm^2) of continuous current draw. A good source for explaining the nickel strap amperage capacity and helping with sizing your electrical requirements can be found from Qiolor.   In general, for the 10s3p design with 5ah per cell in a 3p configuration will yield about 15ah. For Max amperage we multiple that by the 3 cells in parallel giving a max amperage of 45 amps. For my build I used .2mm thick strip in the series sections and was about 50mm wide; .2 x 50mm = 10mm^2 and extrapolating from the genderized table; should be good for 50 amps. For my process-oriented design, I have a few double layers of nickel strips.

Strip Dimensions (Thickness x Width)	Cross-Sectional Area (mm2)	Continuous Ampacity (Amps)
0.1mm x 7mm	0.7	~3.0 A to ~4.5 A
0.15mm x 8mm	1.2	~7 A
0.15mm x 10mm	1.5	~10 A
0.2mm x 8mm	1.6	~9 A
0.2mm x 10mm	2.0	~12-14 A

A BMS works by monitoring a battery's voltage, current, and temperature to ensure it operates safely and efficiently. It prevents overcharging, over-discharging, and overheating by calculating the battery's state of charge and health, and then it can shut down the system or regulate power flow if it detects unsafe conditions. The BMS also balances the individual cells within the pack to ensure they all charge and discharge evenly, which prolongs the battery's lifespan.

Selecting the BMS is based on your continuous current rating with a safety factor of 2; Motor watt rating/voltage) x 2. My system would be rated for a BMS at about 14-15amps minimal. Under sizing the BMS is not recommended as the BMS could be damaged trying to handle the higher loads. I selected a smart 30amp BMS from JIABAIDA for my system, I saw a few good review on these BMS. The nice features of this BMS is that it has a blue tooth capability to your phone to both set BMS parameters and monitor the status of all the cells in your battery

Spot Welding

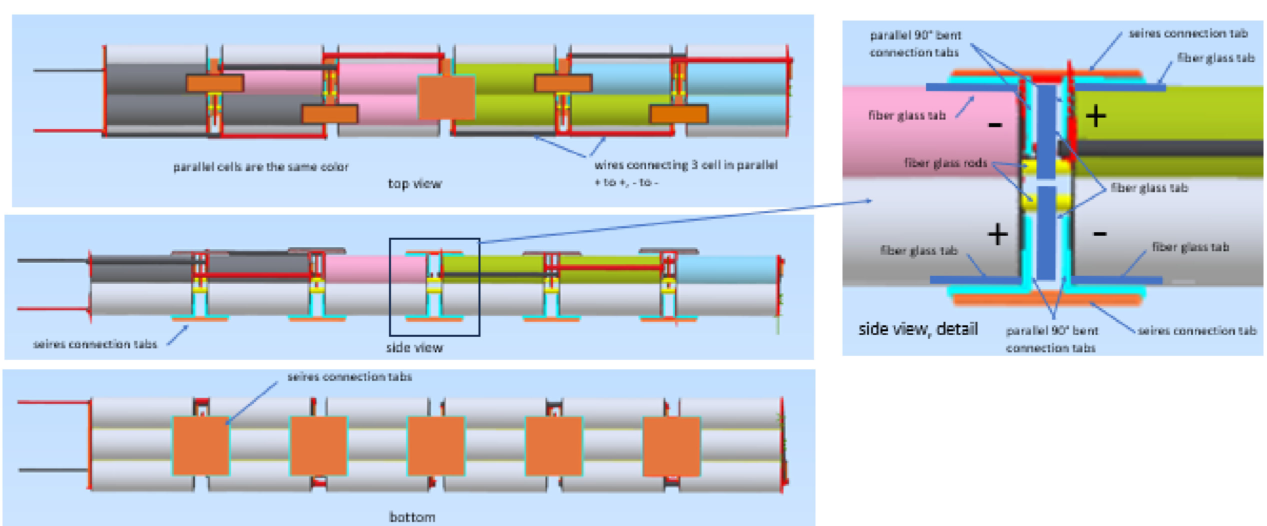
There is an abundance of commercially available spot-welding products on the internet. I brought and returned 4 of them from Amazon before I found one that actually could produce a descent .2 mm thick nickel spot weld. Then there are the DIY microwave transformer spot welders. The micro wave transformer spot welders probably work pretty well, but this is like reinventing a spot welder.

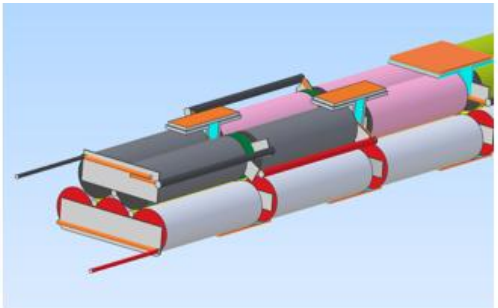
The spot welder I did find that made acceptable welds was a Farad Capacitor Spot Welder double pulse welding machine on eBay for about $100. You can also find these on AliExpress for less, but the shipping time was pretty long. I highly suggest reading the reviews to try to figure out which ones are junk, because there are a lot of these this to choose from. As this is mainly a one-off project I didn't want to spend too much on a one-use tool, but if you're going to make a few of these batteries you'd probably want a higher end unit. The main thing you want is something that can spot weld 0.2 and thicker nickel. I recommend the units with probes as opposed to fixed electrodes. The probe spot welders are more geometry flexible for this type of battery build configuration.

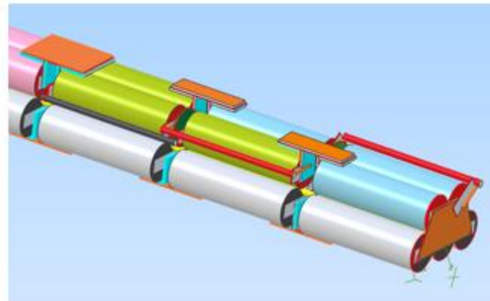
I made some test welds using a strip of sheet metal and 0.15 and 0.2mm thick nickel strips, to figure out the setting, and how to produce an acceptable spot weld. I see some people test welding directly on to batteries, which doesn't seem like a good idea as you can ruin the cell if it's too hot, and will probably have to rip the test tab off the cell potentially damage it. I pulled on the test tabs and they held, so I proceeded to assemble my battery.

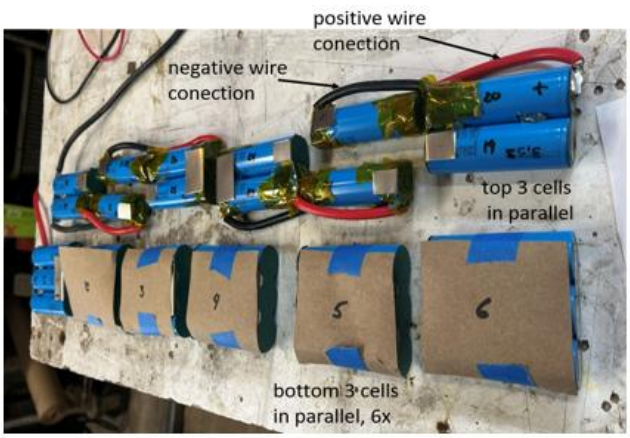
10s3p design

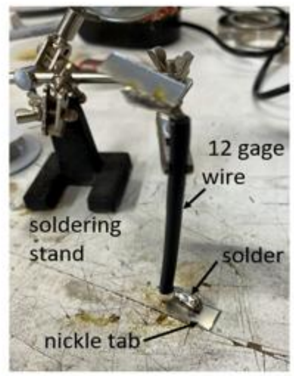
Below is a 3d model of the 10s3p battery design. The 3d model was very helpful to visualize the construction and make detail drawings of the nickel tabs and wires need to make the assembly. This design incorporates the skate board technique of moving the weld connection to the outside of the cell by spot welding on a 90-degree bent tab to the cells. The bent tab was spot welded to the terminals and the bent tab would go up and over the side of the cells for further spot welding a connection.   The insulating fiber glass strips were added to separate the cells during assembly and to insulate the side of the cells from shorting out when the external tab is spot welded. The fiber glass laminate under the tabs are important. When I was spot welding, the weld went through the nickel tab and shorted out the cell on the cell's exterior. The cells started smoking and I ripped the bottom 3 parallel cells out of the pack and put them far out in the drive way till the chemical reaction stopped. It wasn't obvious to me that the cells exterior has a fine insulating coat on it that is not very heat resistant. The whole exterior of the cell is negatively connected to the cell. Scrape off the insulation coating and the cell can easily be short circuited and cause a fire.



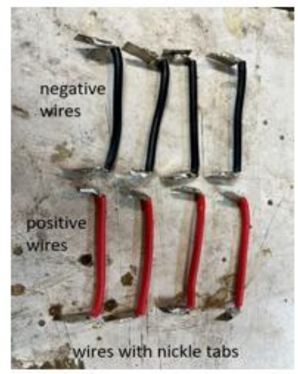








wire soldering set up



The 3 cells in the foreground are the bottom 3 cells in parallel. The 1 x 2 cells are the cells that go on top of the bottom 3. The top 1x2 cells are connected in parallel with wires with nickel tabs spot welded to the cell's terminals. I made a few wooden jigs to hold the cells for assembly as you have to work on both the top and bottom of the pack. I hot glued the cells together using the wooden jigs to hold them in position. You have to be careful not to overheat the cells went applying the hot glue. 1/8 inch diameter fiberglass rods were hot glued between the cells to given the pack some strength and to limit flex, which could damage the connections.

Wood jigs for holding cells in position

3 top cells, connecting in parallel

Bottom of top cells with fiber glass rod

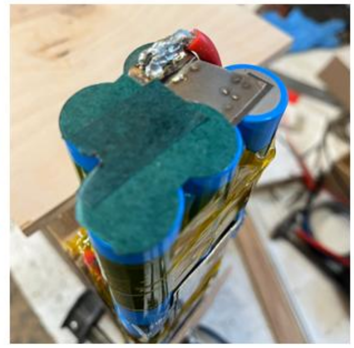
top of top cells, completed

main (+,-) cable connection

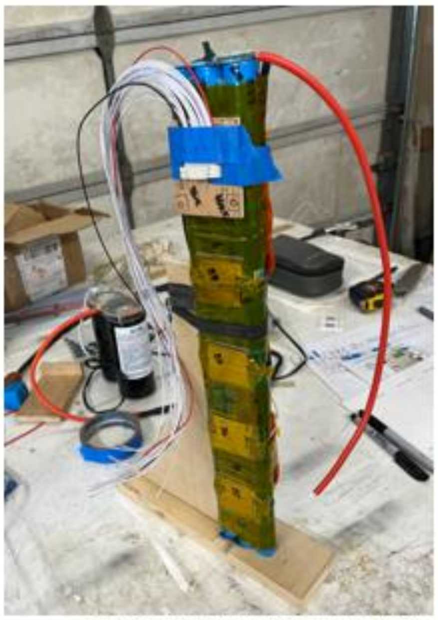
battery pack in vertical positon to connect the bottom to the top

bottom to top serial connection
.2 thick nickle tab

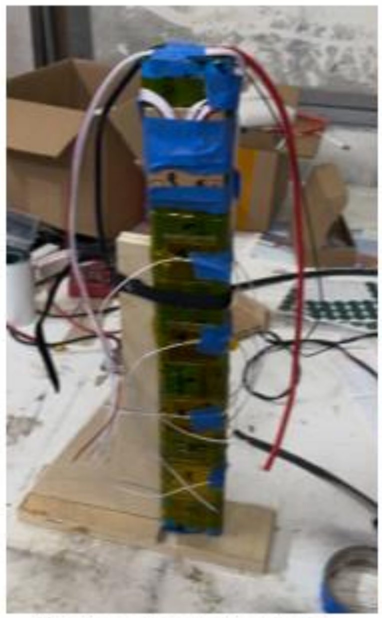
bottom to top serial connection
spot weld



bottom to top serial connection
felt insulation covering

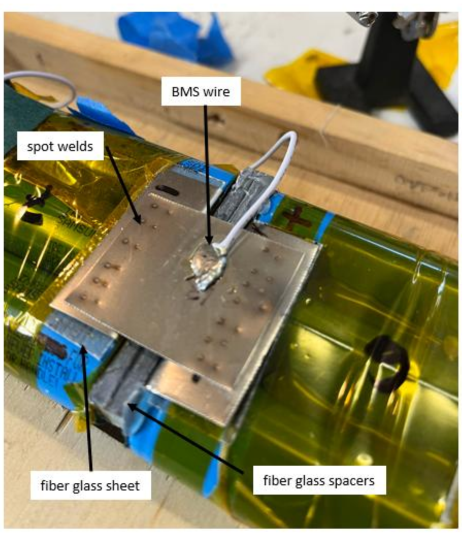


BMS wire layout, with wood bms space holder

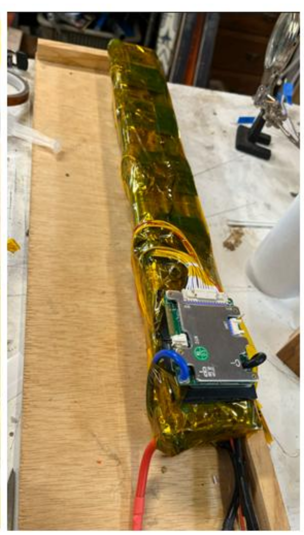


BMS wires on the bottom 3 parallel cells

BMS wires on the top cell, & wire routing



connecting bottom 3 parallel cells
BMS wire soldered, at series connector nickle strip



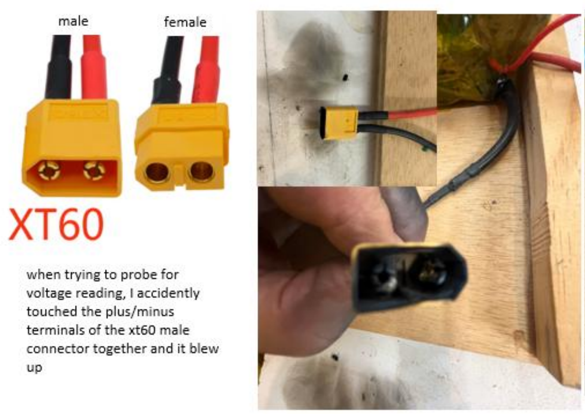
battery pack, wrapped in kapton tape with BMS

BMS detail

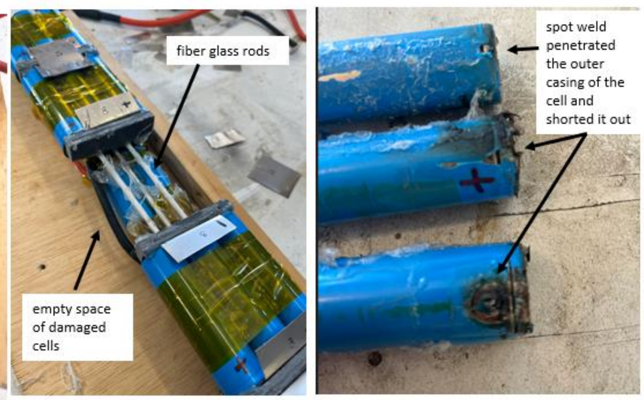
Lessons learned

I wasn't too familiar with the XT60, XT30 connector design and mistaken the male connector for the female. It is generally a good idea to put the female side of a connector on the hot side of the circuit to avoid shorting out the terminals. It is a lot harder to accidently connect two female terminals together.

Spot welding on the outside of the cells appears to be a good design/process improvement for assembling the cells, but an insulating layer needs to be under the tab that is spot welded. I found this out the hard way and almost blew up the battery pack.



always put the female connector side on the hot side of the circuit



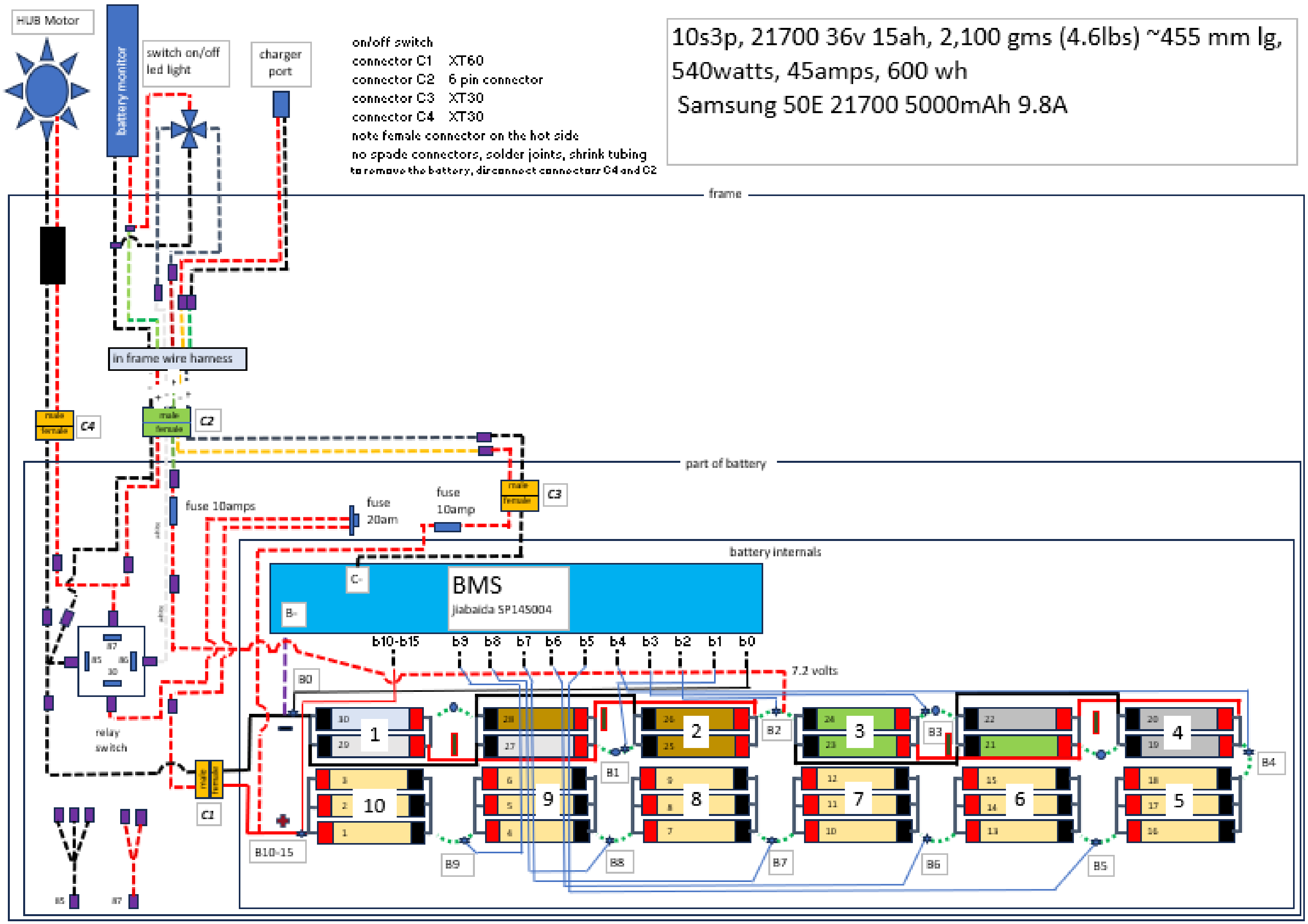
damaged cells from spot weld going trough the nickel strip
put fiber glass sheets under all the tabs after this happened

Battery pack container

The next step for the battery pack is to build an enclosure to protect the cells, BMS and wiring from the elements and glue on a mounting bar. I measure the completed battery pack and made a 3d model of it, then made a wooden mandrel of the model slight oversized by a couple of millimeters in the x,y,z planes. A 4-layer fiber glass cloth layup was generated for the shells. Fiber glass is used because it is non-conductive and the battery pack is going into a carbon fiber frame which is conductive. The fiberglass battery pack shell will isolate the battery from the carbon frame. The shells were made in two steps, one for the top and one for the bottom using the same mandrel. The sides of the top and bottom shell were extended about an inch for later assembly and gluing. These shells were made by wetting out the dry fiberglass cloth with ambient curing epoxy resin and then vacuum bagging the mandrel and wet layup. The shells were removed from the mandrel and rough edges were trimmed up. The shrink-wrapped battery pack was placed in the fiber glass shells and top, bottom and the end was glued in place. If needed the glued seam could be broken apart to repair the battery pack, but I don't except to be doing that very much. The outer shell is mainly a function part and buried inside the bicycle frame so the cosmetics of it do not matter. A simple 1/8 inch 1x1inch aluminum bar with two pressed in threaded rivet nuts was bonded to the bottom of the battery shell so the battery could be fastened to the bike frame.

Electrical Circuit

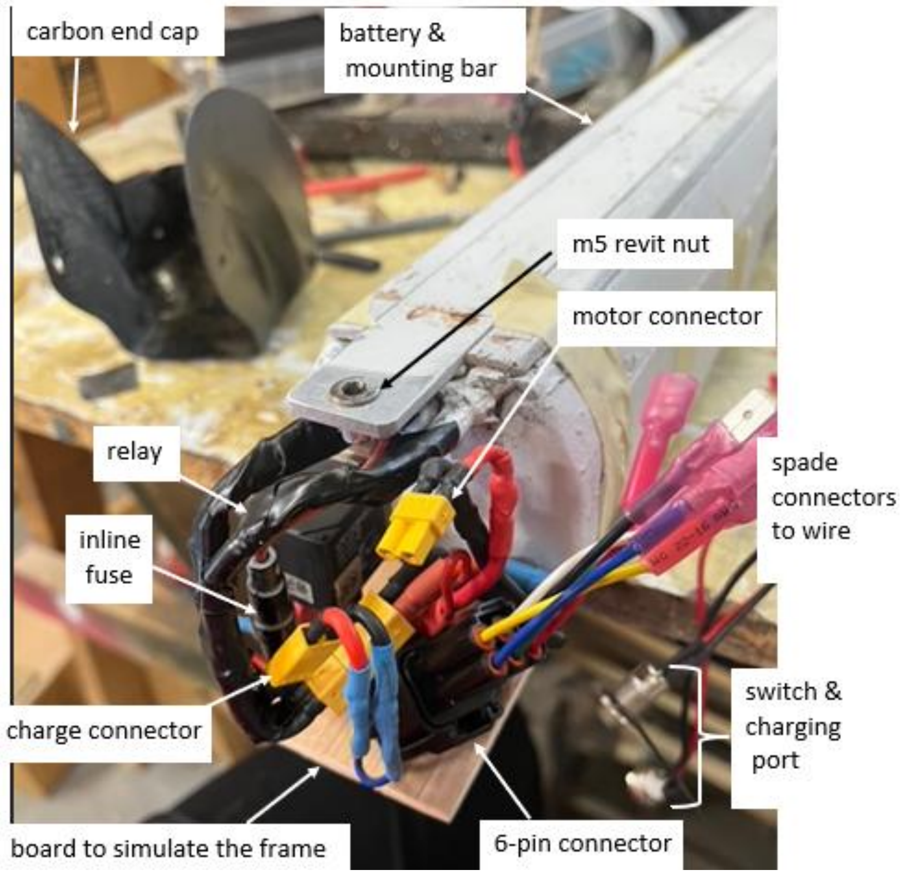
The Keyde hub motor/e-bike was quite simple given that the torque sensor and controller are housed in the hub. The hub's blue tooth connects to a remote monitor and power selection switch (1 to 5 "hub gears"). The circuit was dry tested outside of the bike by connecting the power output to some 100-watt light bulbs to make sure it worked as intended. I consulted with my brother-in-law who is an electric engineer for advice. The circuit is what worked for my application and may not work for your application**. I claim no responsibility** for someone using this circuit for their DIY project. As I am not an electric engineer, my schematic is more of a cartoon to visualize how everything is connected.



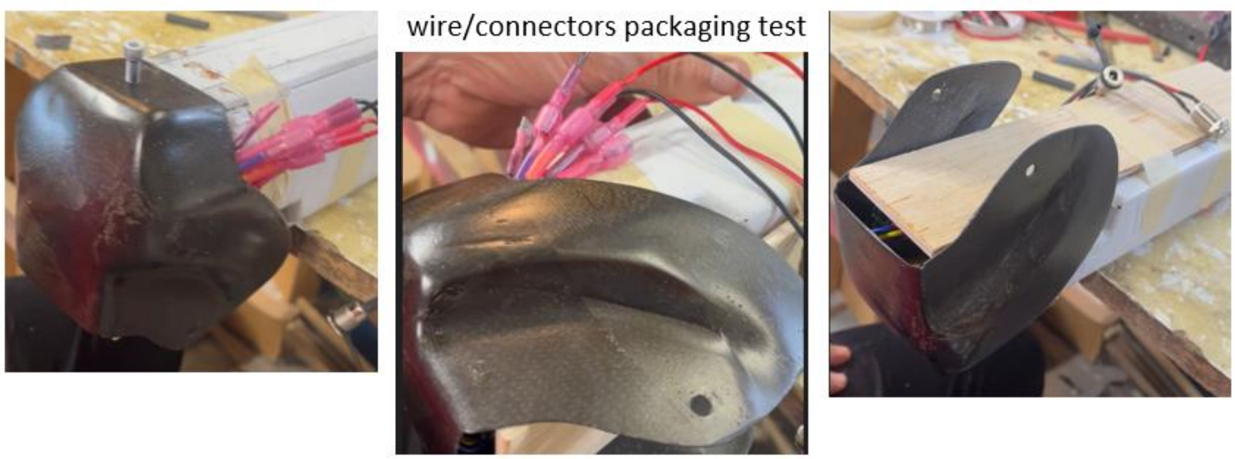
10s3p, 21700 36v 15ah, 2,100 gms (4.6lbs) ~455 mm lg,
540watts, 45amps, 600 wh
Samsung 50E 21700 5000mAh 9.8A
on/off switch
connector C1 XT60
connector C2 6 pin connector
connector C3 XT30
connector C4 XT30
note female connector on the hot side
no spade connectors, solder joints, shrink tubing
to remove the battery, disconnect connectors C4 and C2
HUB Motor
battery monitor
switch on/off led light
charger port
frame
in frame wire harness
C4
C2
C3
C1
male
female
part of battery
fuse 10amps
fuse 20am
fuse 10amp
battery internals
BMS
Jiabaida SP145004
B-
C-
b10-b15
b9
b8
b7
b6
b5
b4
b3
b2
b1
b0
7.2 volts
relay switch
B0
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10-15
1
2
3
4
5
6
7
8
9
10

There are 3 distinct regions of the circuit, inside the battery pack, part of the battery, and inside of the bicycle frame. It is helpful to look at the circuit in this manner, as least for me; so, I know what stays with the battery if removed and what is attached to the frame. The outer frame electrical parts are removable if needed, but most of the electrical joints are soldered together. Initially, I was going to use spade connectors for everything, but as it turned out the spade connectors are bulky and there wasn't enough available space to pack it all into the available space.

The wire connection schematic shows that there are wires bundles which need to run both internal and external to the frame and to the motor. External to the frame are a charging port (5.5x2.1 mm DC Power Supply Jack Socket Female), luminated switch (12mm Latching Push Button Switch High Round Head Stainless Steel) and a battery voltage monitor. These devices required drilling 13mm holes into the frame, during frame modification these areas were reinforced with addition carbon fiber fabric to reduce the stress risers from the holes. The lighted switch and voltage monitor are quite helpful in both getting a visual the motor is activated and the voltage state of the battery. The monitor is quite cheap and is simply double back taped to the frame, so it's easy to replace if needed. The hub motors power cable runs external to the frame, so custom carbon fiber channels were made so that the wire is not exposed to the trail debris (rocks).



wire/connectors packaging test

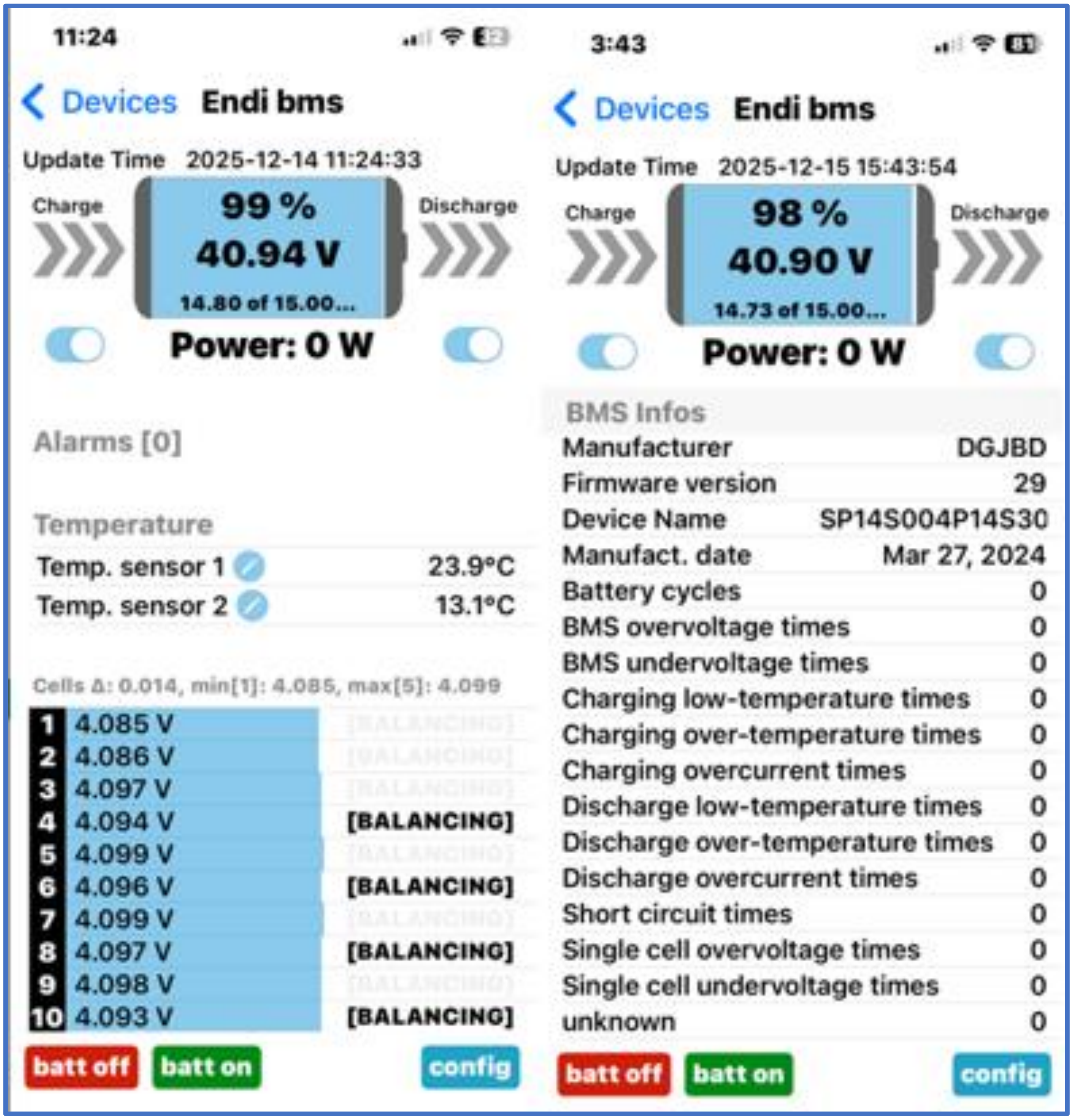


The battery attachment deign is such that the battery can be removed from the frame relatively easily because it does not interfere with the bottom bracket and crankset There are 8 wires which connect to battery and the external hardware. To facilitate an easy method of disconnecting the battery a 6-pin connector and xt30 connector were incorporated. Removing the battery entails unscrewing to M5 bolts on the bottom side of the down tube and disconnecting the 6-pin and xt30 connectors, then the battery just slides out of its enclosure.

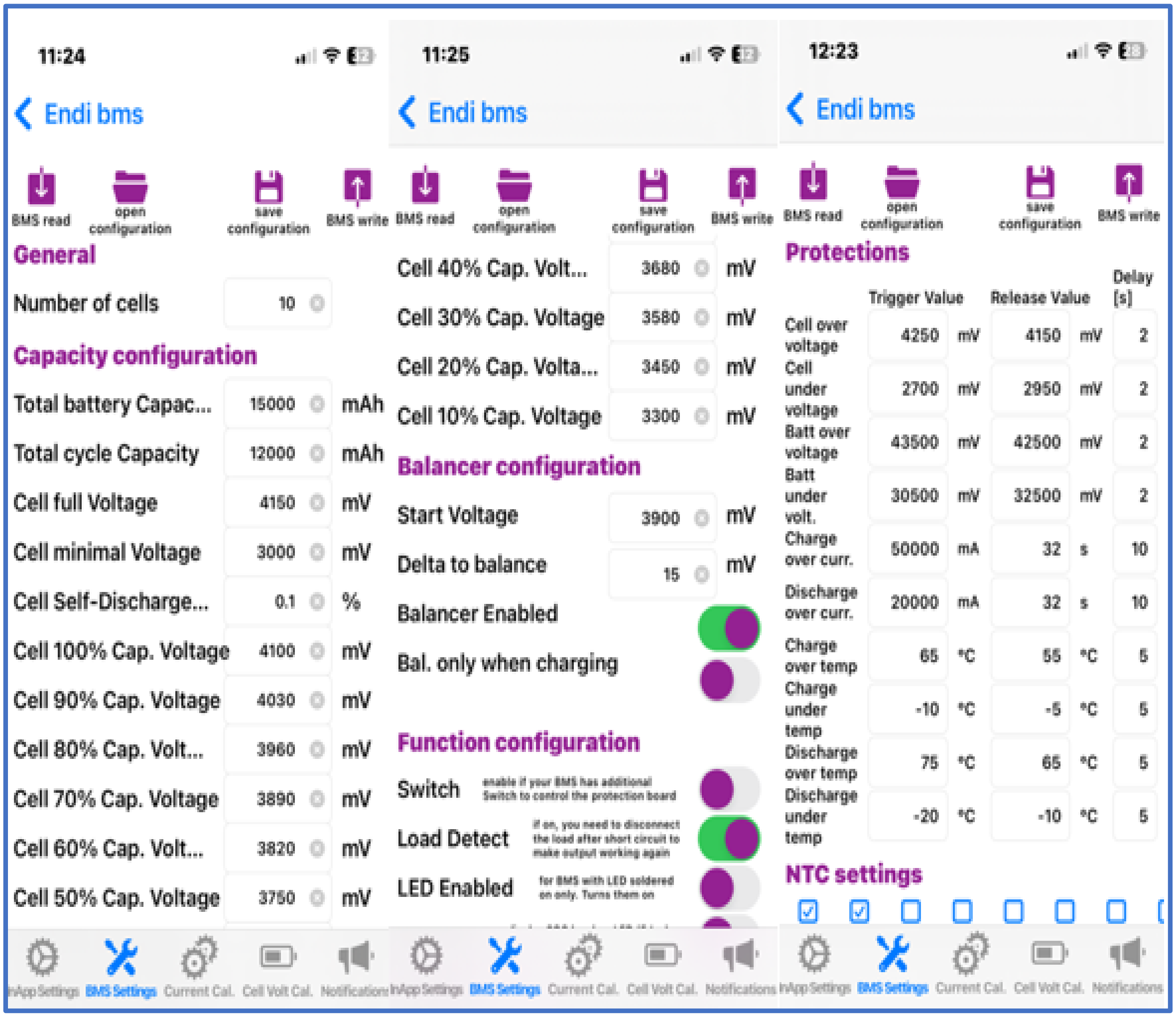
Attached to the outside of the battery pack is a rely switch (36v, 15 amp relay : 2449-A2M1CSQ6VDC1.6-ND , 40 amp 75 v switching 6v switch, coil). The relay is needed because the on/off latch switch is only rated for 12 volts. The on/off switch is powered by the series of cells 1,2,3, resulting in a 9-12volt power source. The relay switch is bolted to the batteries case end, as there is a 5mm rivet nut installed to the end cap. There are 3 fuses in the circuit, a main one for the battery (20 amps), one for the switch (10amps) and one for the charger (10amps). These fuses are accessible with the battery still installed in the frame, by removing the enclosure's BB carbon fiber end cap.

Setting the BMS parameters is kind of complicated given that I really don't understand how it works and it is from China with little to no documentation. My web search and use of Gemini gives you just enough information to probably safety set it up, but not exact sure of that. If you're building your own battery, I highly recommend using a smart BMS, which has blue tooth to your phone capabilities. The blue tooth to your phone allows you to communicate with the BMS and see what it is doing. This also allows one to set the electrical parameters protections of the BMS to monitor your battery pack.

The configuration page of the BMS is where the setting data is. These settings have to be manually input into the BMS via your phone's blue tooth. Shown below are the most important setting, capacity, balancer, and protections for my 10s3p battery. The protections (for me) are not straight forward and there's isn't much information on the internet on how to set these trigger and release values for over/ under voltage for both the cell and complete battery and over/under battery charge (amps). Again, **I am not response** for these settings not working for your build.



Main BMS page



BMS configuration page