

INSTRUCTION MANUAL: BATTERY PACK DESIGN, BUILD AND TESTING

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Prototypes building

Tools

- long nose pliers
- wire cutters
- insulating tape
- 5-mm nut driver for the Vruzend kit.
- 6-mm nut driver for the BatteryBloc kit.
- Screwdriver

Materials

Table 1: List of materials

Type	Item description
Cells	ICR18650-26J battery cells
Solderless battery kits	BatteryBlocs kit
	Vruzend kit
Wiring, monitoring, and switching accessories	Leads with built-in fuse holders 30A 24V
	Fuse, 100pcs set
	BMS <ul style="list-style-type: none"> • 3S 40A 12V Multi-Protectional BMS PCB Board with Balance Charging • 4S 30A 14.8V PCB BMS 18650 Li-ion Battery Protection Board with Balance • 7S 24V 20A Lithium Battery BMS Protection Board with Balancing Function
	40A 12-24VDC Circuit Breaker
	Battery Disconnect Switch 12-48V
	High Precision Watt-meter Analyzer
	Multimeter



Pack design

Essential information data sheets

Two important documents, namely the [Specification of Product](#) and [Safety Data Sheet](#) for the ICR18650-26J model are saved on the Google drive for fast access. They contain valuable information critical to the safe handling and proper use of the battery cell. These include nominal specifications, charge and discharge characteristics, hazards identification, first aid measures, firefighting measures.

For a single cell, Table 6 shows a voltage range from 2.75 to 4.2 V, a charging rate up to 2600mA (1C) and discharging rate up to 5200mA (2C). For multiple-cell packs, the guidelines for electrically designing a pack to be used as an energy storage system are reproduced below. The voltage ranges from 3 to 4 V instead of the wider range for single-cell applications.

Table 2: Electrical design guidelines for an ESS

Item	value
Standard charging voltage (4.20V cell)	4.00V
Charging method	CC-CV
Full-charging cut-off current	0.025C
Min. voltage of terminate discharging	3.00V
Min. voltage of over-discharging protection	2.50V
BMS shut-down voltage	2.00V
Max. consumption current of BMS after shutdown	10 μ A/cell
Do not charge	<1.00V
Pre-charging voltage range	1.0V - 3.0V
Current range of pre-charging	0.1C to 0.5C

Comparing Table 2 and Table 6 reveals that battery packs designed as per recommendations, individual cells will each store or drain less than the OEM rated capacity as the cycling is terminated a little earlier.

As for the mechanical design, the manufacturer recommends the following actions:

- install partitions between BMS and cells
- check if the pack is designed to be able to avoid thermal runaway
- analyze the battery pack's thermal distribution and its effect on the pack cycle
- use non-flammable case
- apply improved material (steel) to the case
- analyze the battery pack's structure, system, installation status and use environment

Pack Sizing

Considering the ratings of the BMS and battery cell (5200mA maximum discharge rate), we calculate the number of cells in parallel.

Table 3: battery pack size and nominal ratings

BMS	Model	Discharge current (A)	Pack configuration	Nominal Ratings
3S BMS	NLY-3C-V3.0	40	3s7p	18,200mAh, 10.89V
4S BMS	CF-4S30S-A	30	4s5p	13,000mAh, 14.52V
7S BMS	SHL1-7S-20A	20	7s3p	7,800mAh, 25.41V

Cycling Parameters

Using the settings recommended by the manufacturer's and listed in Table 2, the battery charging and discharging settings for each of the chosen configuration of 3s7p, 4s5p and 7s3p are as per Table 4 below.

Table 4: Cycling settings for the designed packs

Configuration Number of cells	Charging (1C) CC-CV (4V/cell, 0.025C cut-off)	Discharge (2C) (3V/cell termination)
3s7p 21 cells	12 V max (455 mA cut-off) 9,100 mA standard 18,200 mA max	9V cut-off 3,640 A standard 36,400 A max
4s5p 20 cells	16 V (325 mAh cut-off) 6,500 mA standard 13,000 mA max	12V cut-off 2,600 mA standard 26,000 mA maximum
7s3p 21 cells	28 V (195 mA cut-off) 3900 mA standard 7800 mA maximum	21V 1,560 A standard 15,600 A maximum

Instructions Steps

Instructions

1. Choose the pack series-parallel configuration according to your design needs
2. Select the right tools, materials, and equipment
3. Match the cells to combine in parallel/series with the [rePackr - 18650 pack builder](#) tool. This is done according to capacity and internal resistance to get the most similar values in each pack and thus have better balancing and longer overall life for the pack. Details of matched cells for the available BMS is presented in Table 7 to Table 9 in Appendix 2.
4. Insert the matched cells into the battery block as per chosen configuration of series-parallel cells. The battery building using solderless kits is detailed in Appendix 3: Battery assembly with solderless kits.
5. Include the necessary monitoring (switch, meter) and protection circuitry (fuse, BMS)
6. Test the pack performance by charging and discharging recording capacity, voltage, current and duration values.

Pack Testing and Results

Individual pack configuration ratings are listed in Table 7 to Table 9.

Table 5: Battery Pack Testing Parameters and Results

Pack Configuration	Test step	Settings	Start Conditions	End Conditions	Capacity (mAh)
4s5p – 13Ah 14.52V 12,516 mAh 50.6 mΩ	0.5 - 1C Charge	6500mA		16V, 325mA cut-off	
		0.25C			
	0.2C -2C Discharge	2600 mA		12V cut-off	
		0.1C			
7s3p – 7.8Ah 25.41V 7,507 mAh 147.3 mΩ	Charge (28V)	3900 mA		28V, 195 mA cut-off	
		0.25C			
	Discharge	1560 mA		21V cut-off	
		0.1C			
3s7p – 18.2Ah 10.98V 17,517 mAh 27.1 mΩ	Charge (12V)	9100 mA		455 mA cut-off	
		0.25C			
	1/5C Discharge	3640 mA		9V cut-off	
		0.1C			

Appendices

Appendix 1: Specifications

Cell OEM Datasheet Essentials

Table 6: Datasheet essentials

	
Brand	Samsung
Model	ICR18650-26J
Capacity	2600mAh Rated
Voltage	3.63V Nominal
Charging	4.20V Maximum 1300mA Standard ($\frac{1}{2}$ C) 2600mA Maximum
Discharging	2.75V Cutoff 520mA Standard ($\frac{1}{5}$ C) 5200mA Maximum
Description	Pink Cell Wrapper White Insulator Ring 18650 Form Factor

Appendix 2: Best matching for each configuration

Table 7: Example of matched cells for the 4s5p pack configuration

Cell Number	Tested Capacity (mAh)	IR (mΩ)	Branch	Module ratings	Pack ratings
-LM-0032004	2532.07	67	1	12,515 mAh 12.50 mΩ	12,516 mAh 50.6 mΩ
+LM-0038004	2507.87	63	1		
+LM-0014006	2493.21	62	1		
+LM-0007011	2491.53	61	1		
+LM-0007010	2490.35	60	1		
-LM-0032008	2525.47	65	2	12,518 mAh 12.60 mΩ	
-LM-0005008	2509.78	62	2		
+LM-0038008	2497.08	62	2		
+LM-0038006	2491.6	63	2		
+LM-0014010	2490.67	63	2		
-LM-0032006	2521.74	66	3	12,518 12.58 mΩ	
+LM-0038002	2512.08	62	3		
-LM-0032007	2503.98	65	3		
+LM-0007002	2490.91	62	3		
-LM-0005009	2489.31	60	3		
-LM-0032010	2518.18	65	4	12,515 12.95 mΩ	
-LM-0032009	2515.71	67	4		
-LM-0032005	2498.14	65	4		
+LM-0038003	2492.59	64	4		
+LM-0014008	2490.66	67	4		

Table 8: Example of matched cells for the 7s3p pack configuration

Cell Number	Tested Capacity (mAh)	IR (Ω)	Module	Module ratings	Pack ratings
-LM-0032004	2532	67	1	7,512 mAh	7,507 mAh 147.3 m Ω
+LM-0038006	2492	63	1	21.07 m Ω	
+LM-0008005	2489	60	1		
-LM-0032008	2525	65	2	7,507 mAh	
+LM-0038003	2493	64	2	20.97 m Ω	
-LM-0005009	2489	60	2		
-LM-0032006	2522	66	3	7,506 mAh	
+LM-0014006	2493	62	3	21.09 m Ω	
+LM-0007002	2491	62	3		
-LM-0032010	2518	65	4	7,506 mAh	
+LM-0038008	2497	62	4	21.10 m Ω	
+LM-0014010	2491	63	4		
-LM-0032009	2516	67	5	7,505 mAh	
-LM-0032005	2498	65	5	21.41 m Ω	
+LM-0007011	2492	61	5		
+LM-0038002	2512	62	6	7,507 mAh	
-LM-0032007	2504	65	6	21.10 m Ω	
+LM-0014008	2491	63	6		
-LM-0005008	2510	62	7	7,508 mAh	
+LM-0038004	2508	63	7	20.55 m Ω	
+LM-0007010	2490	60	7		

Table 9: matched cells for the 3s7p pack configuration

Cell Number	Tested Capacity (mAh)	IR (mΩ)	Module	Module ratings	Pack ratings
-LM-0032004	2532.07	67	1	17,517 mAh 9.03 mΩ	17,517 mAh 27.1 mΩ
+LM-0038002	2512.08	62	1		
-LM-0032007	2503.98	65	1		
-LM-0032005	2498.14	65	1		
+LM-0007011	2491.53	61	1		
+LM-0014008	2490.66	63	1		
+LM-0008005	2488.51	60	1		
-LM-0032008	2525.47	65	2	17,518 mAh 9.03 mΩ	
-LM-0032009	2515.71	67	2		
+LM-0038004	2507.87	63	2		
+LM-0038008	2497.08	62	2		
+LM-0038006	2491.6	63	2		
+LM-0014010	2490.67	63	2		
-LM-0005009	2489.31	60	2		
-LM-0032006	2521.74	66	3	17,517 mAh 8.99 mΩ	
-LM-0032010	2518.18	65	3		
-LM-0005008	2509.78	62	3		
+LM-0014006	2493.21	62	3		
+LM-0038003	2492.59	64	3		
+LM-0007002	2490.91	62	3		
+LM-0007010	2490.35	60	3		

Appendix 3: Battery assembly with solderless kits

BatteryBlocs

BatteryBlocs use 3D-printed holders that keep together cells connected through magnets and steel strips. They come in even-numbered parallel cells starting from 1s4p that can hold 4 cells in parallel.



Figure 1: "BatteryBloc" kit

Magnet retainer: base/cover for the galvanized steel strip
block holder
Parallel plate, galvanized steel strip 30x35 mm
Parallel plate, galvanized steel strip, 65x35 mm
Cable lug, small
Cable lug, big
Nylon bolts & nuts
Magnets, pair
Nylon washer, big
Nylon washer, small

Assembly instructions for the simplest 1s4p BatteryBlocs are as per the instruction [4P Assembly - YouTube](#):



Vruzend kits

Vruzend kits enable to make battery packs in all imaginable sizes. They come in 2 versions that are compared in table below:

Features	V1.6	V2.1
Number of cells	52 cells	30 cells
Rating	3.5A continuous per cell	20A continuous per cell
Price	\$37.99	\$41.99

The version V2.1 that Hinckley has in stock has the following items:

Description	
 <p>V2.1 kit - What's in the box?</p> <ul style="list-style-type: none"> 60 terminal caps 60 nickel-plated copper alloy nuts 4 nickel-plated copper wire clamps 8 barrel bolts 80 nickel-plated pure-copper bus bars 	<ul style="list-style-type: none"> • 60 cell terminal blocks with nickel coated copper alloy spring contacts • 60 screw terminals and nuts • 80 pure copper bus bars coated in pure nickel for corrosion resistance and high conductivity • 4 main wire clamps (for charge/discharge wires) • 4 cable tie straps for securing the pack

Assembly instructions for the V2.1 version are as per the video instruction at [New & improved Vruzend V2.1 no-weld 18650 kit - YouTube](#)

